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THE DENSITY OF INTERGALACTIC DUST: AN UPPER LIMIT*

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ABSTRACT

Recently reported values of the magnitude and redshift of distant galaxies are used to set a limit on the total absorption by intergalactic dust. We then show that the density of such dust is likely to be well below the cosmologically critical density of 1.8×10^{-29} g cm^{-3}.

A crucial and unanswered question in cosmology is the mean density of mass-energy in the Universe. It is well known (Oort 1958; Kiang 1961) that the luminous matter present in galaxies contributes only $\sim 5 \times 10^{-31}$ g cm^{-3}. This value should be compared with 1.8×10^{-29} g cm^{-3}, a characteristic value for the density required to close the Universe in cosmologies with the cosmological constant Λ equal to zero. Frequent attempts have been made to find the "missing matter" in the form of intergalactic hydrogen (Gunn and Peterson 1965; Penzias and Wilson 1969), intergalactic stars (Roach and Smith 1968; Peebles and Partridge 1967), or electromagnetic radiation (Peebles 1969), with no success. In this Note we estimate the possible contribution by uniformly distributed intergalactic dust. We do so by finding the total absorption produced by such matter in the light from distant galaxies.

Such a calculation was performed 22 years ago by Eigenson (1949). When his value for the total absorption is corrected to a current value for the Hubble constant, H = 100 km s^{-1} Mpc^{-1}, it becomes[1] $\alpha = 0.0046$ mag Mpc^{-1}. He based his calculation on the work of Stebbins and Whitford (1948) and Shapley and Ames (1929) which has now been superseded. Dufay (1957), by analyzing counts of galaxies, obtained a rough upper limit of 0.0011 mag Mpc^{-1}. Using newer data obtained by Sandage and tabulated by Peach (1969), we obtain a smaller upper limit for α, and thus a smaller upper limit on the possible density of intergalactic dust, ρ_d.

Sandage's data are in the form of magnitude and redshift measurements for the first brightest galaxy in thirty-eight clusters. To these data we fit the expression, adapted from Humason, Mayall, and Sandage (1956),

$$M = m - 5 \log (cz/Hd) - 2.5 \log [\exp (1 - q_0)z] + Az \qquad (1)$$

for various values of q_0, the deceleration parameter. In this equation, M is the absolute magnitude of each galaxy, assumed to be the same for all, and m is the observed magnitude of each; z is its redshift corrected for solar motion; d is a normalizing factor, 10^{-5} Mpc; and A is the intergalactic absorption per unit redshift interval. We have assumed that the cosmological constant is zero. For small redshifts ($z \lesssim 0.2$ for this study), we may reexpress A in terms of magnitudes of absorption per Mpc using the simple relation $zc = HR$, where the distances R are measured in Mpc and we again take H = 100 km s^{-1} Mpc^{-1}. Thus the absorption coefficient per Mpc is $\alpha = HA/c$.

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[1] He actually gives $\alpha = 0.025$ mag per Mpc for $H \approx 550$ km s^{-1} Mpc^{-1}.

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The values of α so obtained for various values of q_0 appear in Table 1. Note that the estimated standard deviation of the mean in α exceeds α for values of $q_0 \geq 0.5$ ("closed" models).

Now let us estimate the maximum density of intergalactic dust consistent with these values of α. We shall work with the value for $q_0 = 0.02$ since it gives the largest value of α. In the calculations which follow, we will take as an upper limit on absorption the value of α plus 1 standard deviation, i.e., 4.5×10^{-4} mag Mpc^{-1}. For the moment, we shall assume that the dust is uniformly distributed.

First, in the somewhat unlikely event that intergalactic dust resembles ordinary interstellar dust, for which the total absorption coefficient in the visible is thought to be about 1.6 mag kpc^{-1} and $\rho_i \sim 1.3 \times 10^{-26}$ g cm^{-3}, we find $\rho_d \lesssim 4 \times 10^{-33}$ g cm^{-3}, several orders of magnitude below the critical density. However, as the characteristic particle radii become very large or very small, the absorption *per gram* of the material decreases. Let us first consider large particles. How large must they be to permit ρ_d to be as large as 1.8×10^{-29} g cm^{-3}, and yet have $\alpha \lesssim 4.5 \times 10^{-4}$ mag Mpc^{-1}? The extinction cross-section of a solid particle which is large compared with the wavelength of light is twice its geometrical cross-section. Hence

$$(3 \times 10^{24}) 2\pi r^2 n \leq 4.5 \times 10^{-4} \text{ mag Mpc}^{-1} , \tag{2}$$

where the large numerical factor is to convert to Mpc^{-1} and n is the number density of particles, given by

$$n = \frac{\rho_d}{4\pi r^3 \rho/3} \tag{3}$$

with ρ_d taken as 1.8×10^{-29} g cm^{-3}. We shall assume that ρ, the density of the material involved, is unity. Substituting equation (3) in equation (2), we find $r \gtrsim 2$ mm to satisfy the inequality. It is difficult to see how particles of this size could be produced and distributed through intergalactic space. On the other hand, the present argument does not rule out the presence of "missing matter" in the form of dead stars or collapsed objects since their radii, for reasonable assumptions about their masses, will exceed 2 mm by at least six orders of magnitude.

For particles much smaller than the wavelength of light (here, $\lambda = 5500$ Å) the extinction coefficient is (van de Hulst 1957):

$$Q = \frac{8}{3}\left(\frac{2\pi r}{\lambda}\right)^4 \left|\frac{m^2 - 1}{m^2 + 2}\right|^2 , \tag{4}$$

TABLE 1

VALUES OF THE ABSORPTION COEFFICIENT PER MEGAPARSEC FOR VARIOUS VALUES OF q_0 FOUND BY FITTING EQUATION (1) TO SANDAGE'S OBSERVATIONAL DATA

Deceleration Parameter q_0	Absorption, α per Mpc	Standard Deviation in α
0.02	2.4×10^{-4}	2.1×10^{-4}
0.1	2.3×10^{-4}	2.1×10^{-4}
0.5	1.9×10^{-4}	2.1×10^{-4}
1.0	1.0×10^{-4}	2.2×10^{-4}

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so that the extinction cross-section is

$$\sigma = \frac{128\pi^5 r^6}{3\lambda^4}\left|\frac{m^2-1}{m^2+2}\right|^2 . \tag{5}$$

In equations (4) and (5), m^2 is the square of the refractive index of the material of which the dust is formed, which is of course unknown. We adopt $m^2 = 2$, a value that allows for the possibility that the refractive index may have a nonzero imaginary part. Combining equation (3) with equation (5) and again requiring that the total absorption per Mpc be less than 4.5×10^{-4} mag, we find that r must be less than 70 Å. This value is about an order of magnitude smaller than representative figures for the size of interstellar grains. Clearly, if m^2 is less than 2, the limit on r is larger.

These rough calculations indicate that uniformly distributed dust particles having characteristic radii in the range

$$7 \times 10^{-7}\ \text{cm} < r < 0.2\ \text{cm}$$

cannot contribute as much as 1.8×10^{-29} g cm^{-3} to the mean density of the Universe, and therefore cannot serve to close the Universe.

The dynamics of clusters of galaxies, however, suggest that much of the "missing matter" may be concentrated in clusters. If so, our analysis, made on the assumption of uniform distribution, is no longer valid. The effect of intracluster dust would be to alter m in equation (1) and not to contribute a term linear in z.

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