THE EFFECT OF INTERGALACTIC DUST ON THE MEASUREMENT OF THE COSMOLOGICAL DECELERATION PARAMETER q_0

S. M. CHITRE and J. V. NARLIKAR
Tata Institute of Fundamental Research, Bombay, India

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Abstract. In a recent attempt to explain the cosmic microwave background without the big bang, a thermalization mechanism involving intergalactic whisker grains of graphite was proposed. The effect of absorption by the intergalactic medium in general, and of the above type in particular, on the measurement of the deceleration parameter q_0 of the expanding universe is discussed. Its effect is shown to be comparable in magnitude but opposite to that of the luminosity evolution in galaxies. A consequential selection effect is also discussed.

1. Introduction

Recent work in observational cosmology indicates that the earlier estimate of the cosmological deceleration parameter $q_0 \approx 1$ (Sandage, 1961, 1972) was somewhat higher than the present ones which lie between $q_0 \approx +0.33$ and $q_0 \approx -1.27$ under different sets of assumptions (Gunn and Oke, 1975). From consideration of ages of globular clusters Sandage and Tamman (1975) have also revised the value of q_0 down to $q_0 \approx 0$. Thus the possibility of an accelerating universe, somewhat embarrassing for classical general relativity, cannot be disregarded off hand (Gunn and Tinsley, 1975).

We wish to investigate the effect that an absorbing intergalactic medium would have on the measured value of q_0. That a systematic intergalactic absorption would imply a positive correction to the measured value of q_0, is well known. However, a lack of specific details about the intergalactic medium has prevented theoreticians from making concrete estimates. De Vaucouleurs *et al.* (1972) have presented evidence for reddening in the local supercluster possibly due to intergalactic dust. A scenario involving intergalactic dust grains has been presented by Layzer and Hively (1973) who find an appreciable extinction at large redshifts $z \gtrsim 3$. Here we make some estimates based on a somewhat different dust model invoked recently to account for the cosmic microwave background *without* the big bang (Wickramasinghe *et al.*, 1975; Narlikar *et al.*, 1975 referred to, respectively, as I and II).

Basically this model requires an intergalactic medium containing needle-shaped grains such as whiskers of graphite. Such whiskers can grow to lengths in the range $\sim 100\,\mu$–1 mm and then act as thermalizers of ambient radiation from galaxies, QSOs, etc. The graphite whiskers of such lengths with cross-sectional radii $\sim 10^{-5}$ cm have large absorption cross sections for photons peaking over a wavelength range

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around $\lambda \gtrsim 0.3$ mm. The resulting black-body curve could peak at a wavelength $\lambda \sim 1$ mm. The limitations of this model and some possible observational checks on it have been discussed in II.

The purpose of the present calculation is two-fold. The first one is to investigate whether such model involves appreciable corrections to q_0, which may have some bearing on choosing the correct cosmological model. The second purpose is to check whether the effects are so large as to make the above model untenable on observational grounds. Although the presence of intergalactic dust in I was invoked to account for the microwave background without a big bang, the astrophysical processes responsible for such an intergalactic dust could operate in Friedmann models as well as in the steady-state model. For this reason we investigate the observational consequence of the dust in both types of models.

2. Intergalactic Absorption and q_0

We first calculate the change Δm in the apparent magnitude of a galaxy with a redshift z_0, produced by intergalactic absorption. Thus if m_0 is the apparent magnitude the galaxy would have had in the absence of any intergalactic absorption, and m the observed apparent magnitude,

$$m = m_0 + \Delta m. \tag{1}$$

We calculate Δm in the case of (i) the steady-state model (denoted briefly by SS) and (ii) the Friedmann models with pressureless matter and a given q_0. Three cases in this latter class will be specifically calculated. These are the empty Friedmann model (EF in brief), the Einstein-de Sitter model (E-dS) and the model earlier favoured by Sandage with $q \approx +1$ (ES).

If $\exp[-\tau(z_0, \lambda_0)]$ is the attenuation in the observed intensity in a band around the wavelength λ_0, we have

$$\Delta m = 2.5(\log_{10} e)\tau(z_0, \lambda_0). \tag{2}$$

We assume that the present density of intergalactic matter is ϱ_0 and H is the Hubble constant. Let $K(\lambda)$ denote the absorption cross section per unit mass of the intergalactic dust at wavelength λ. Then in the steady-state model we have

$$\tau_{SS}(z_0, \lambda_0) = \frac{c\varrho_0}{H} \int_0^{z_0} K\left(\frac{\lambda_0}{1+z}\right) \frac{dz}{1+z}, \tag{3}$$

where c is the velocity of light.

For the Friedmann model with a given q_0 the corresponding result is

$$\tau(z_0, \lambda_0, q_0) = \frac{c\varrho_0}{H} \int_0^{z_0} K\left(\frac{\lambda_0}{1+z}\right) \frac{1+z}{(1+2q_0 z)^{1/2}}\, dz. \tag{4}$$

The three specific cases EF, E-dS and ES are given, respectively, by $q_0 = 0$, $q_0 = \frac{1}{2}$ and $q_0 = 1$.

To calculate the numerical corrections it is necessary to know $K(\lambda)$ and ϱ_0; and it is here that we use the model mentioned above. For graphite whisker grains the mass absorption coefficient is

$$K(\lambda) = \frac{2Q(\lambda)}{\pi a s}, \tag{5}$$

where $Q(\lambda)$ is the mean efficiency factor for absorption at wavelength λ for randomly oriented infinite cylinders, a = cross-sectional radius of the cylinder and s = mass density of the grain material. Taking values from Narlikar *et al.* (1975) we set $a \approx 10^{-5}$ cm, $s = 2\text{g cm}^{-3}$, $\lambda = 3200$ Å $= \Lambda$ (say), $Q = 0.64$ and get $K(\Lambda) \simeq 2 \times 10^4 \text{ cm}^2 \text{ g}^{-1}$.

Rigorous cylinder formulae (Wickramasinghe, 1973) for $Q(\lambda)$ suggest a dependence on λ of the form λ^x, $x \sim 1$–2 in the visual and ultraviolet range of λ. For the present calculation we take $Q(\lambda) \propto K(\lambda) \propto \lambda^{-1}$ and write

$$K(\lambda) = \left(\frac{\Lambda}{\lambda}\right) 2 \times 10^4 \text{ cm}^2 \text{ g}^{-1}. \tag{6}$$

Also, in the above model ϱ_0 was taken to be such that in the steady-state model the optical depth at $\lambda = \Lambda = 3200$ Å was unity – i.e.,

$$\varrho_0 \simeq 2.45 \times 10^{-33} \text{ g cm}^{-3}. \tag{7}$$

As will be seen later, such a value for ϱ_0 does not produce excessive intergalactic absorption. How ϱ_0 of this order can arise has been discussed in I. With these details we compute (3) and (4) and get

$$\begin{aligned}
\tau_{\text{SS}} &= \left(\frac{\Lambda}{\lambda_0}\right) z_0, \\
\tau_{\text{EF}} &= \tfrac{1}{3} z_0 (z_0^2 + 3z_0 + 3) \left(\frac{\Lambda}{\lambda_0}\right), \\
\tau_{\text{EdS}} &= \tfrac{2}{5}[(1 + z_0)^{5/2} - 1] \left(\frac{\Lambda}{\lambda_0}\right), \\
\tau_{\text{ES}} &= [\tfrac{1}{15}(1 + 2z_0)^{1/2}(3z_0^2 + 8z_0 + 7) - \tfrac{7}{15}] \left(\frac{\Lambda}{\lambda_0}\right).
\end{aligned} \tag{8}$$

3. Numerical Results

In Table I are given the values of Δm for the above models at $z_0 = 0.3$, $z_0 = 0.6$ and $z_0 = 1.0$ at an observed wavelength of $\lambda_0 = 6400$ Å.

These numbers may be compared with the differences in m for different cosmologies at the same redshifts, given in Table II. The differences are stated in the form of departure from the straight-line Hubble plot which is followed by the ES model.

TABLE I

Magnitude corrections due to intergalactic absorption

Model	$z_0=0.3$	$z_0=0.6$	$z_0=1$
SS	0.16	0.32	0.54
EF	0.22	0.56	1.27
E-dS	0.20	0.49	1.01
ES	0.19	0.44	0.87

TABLE II

Theoretical magnitude differences between cosmological models

Model	$z_0=0.3$	$z_0=0.6$	$z_0=1$
SS	0.57	1.02	1.50
EF	0.30	0.57	0.88
E-dS	0.14	0.24	0.34
ES	0	0	0

Finally, we give in Table III the corrections required if the luminosity evolution is taken into account, according to the formulae given by Tinsley (1972a, b).

The numbers in Tables I–III can be interpreted as follows. If the observed magnitude of a galaxy at $z_0=0.3$ is m, then the magnitude corrected for intergalactic absorption for E-dS model is $m-0.20$. The magnitude according to this corrected for both intergalactic absorption and luminosity evolution is $m-0.20+0.43=m+0.23$. The same two corrections applied according to the E-F model lead to a corrected magnitude of $m-0.22+0.28=m+0.06$. Having made such corrections the new redshift magnitude plot may be compared with the theoretical prediction of the cosmological model made without including these two effects. Table II reflects the magnitude differences of theoretical predictions of the four selected models.

TABLE III

Magnitude corrections due to luminosity evolution

Model	$z_0=0.3$	$z_0=0.6$	$z_0=1$
SS	–	–	–
EF	−0.28	−0.50	−0.75
E-dS	−0.43	−0.75	−1.13
ES	−0.48	−0.85	−1.24

4. Discussion

It is evident from the Tables that the effect of intergalactic absorption on the observed Hubble diagram is to increase the value of q_0. The estimates mentioned earlier may have to be revised upwards if the absorption due to possible presence of intergalactic dust is taken into account. It is worth noting that these corrections are opposite to those based on the luminosity evolution of galaxies, and are roughly of comparable magnitude at $z_0 \sim 0.3$–0.6. Of course there is no luminosity evolution effect in the steady-state model, except through a selection effect which is briefly discussed below.

At larger redshifts, ($z_0 \gtrsim 0.5$) when the galaxies are being observed at magnitudes close to the plate-limits, it is natural for the observer to pick out the brightest galaxies. This selection effect is evidently enhanced with intergalactic absorption, for close to the plate-limits, a moderately bright galaxy may not be visible at all whereas a very bright galaxy will still form part of the sample. The result of including exceptionally bright galaxies in a sample leads to a bias which results in enhancing the value of q_0 as was apparent from the analysis of Gunn and Oke (1975) in the case of 3C 295. Thus a selection effect arising from intergalactic absorption will lead to an apparent value of q_0 in excess of the true value, i.e. in opposite direction to the effect of the absorption itself. We feel that these effects will be important in future attempts to determine q_0 by going to fainter magnitudes using a large space telescope. Such measurements will be useful in checking the validity of the dust model proposed in I. As the above calculations indicate, the steady-state model is still consistent with the present observations of q_0 (Gunn and Oke, 1975) even when there is an increase in the apparent magnitude resulting from the intergalactic obscuration proposed in I.

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