THE ASTRONOMICAL JOURNAL, 119:2583–2588, 2000 June

POSSIBLE INTERPRETATIONS OF THE MAGNITUDE-REDSHIFT RELATION FOR SUPERNOVAE OF TYPE IA

S. K. BANERJEE,[1] J. V NARLIKAR,[1] N. C. WICKRAMASINGHE,[2] F. HOYLE,[3] AND G. BURBIDGE[4]
Received 2000 January 1; accepted 2000 March 1

ABSTRACT

It has been shown by Riess et al. and Perlmutter et al. that the observed redshift-magnitude relation for supernovae of type Ia, which suggests that the deceleration parameter q_0 is negative, can be explained in a Friedmann model with a positive cosmological constant. We show that a quasi–steady state cosmology (QSSC) model can also fit the supernova data. Since most of the emphasis and publicity have been concentrated on explanations involving the Friedmann model, we show how a good fit can be obtained to the observations in the framework of the QSSC. Using this model, we show that absorption due to intergalactic dust may play an important role. This may explain why a few of the supernovae observed show large deviations from the curve determined by the majority of the data.
Key words: cosmology: observations — cosmology: theory — dust, extinction — supernovae: general

1. INTRODUCTION

For the standard cosmological model, we have the Robertson-Walker line element

$$ds^2 = c^2\,dt^2 - S^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta\,d\phi^2)\right]. \tag{1}$$

In terms of the scale factor $S(t)$, the Hubble constant and the so-called deceleration parameter $q(t)$ are defined at any cosmic epoch t by

$$H(t) = \dot{S}(t)/S(t)\ ; \quad q(t) = -(1/H^2)[\ddot{S}(t)/S(t)]\ . \tag{2}$$

The history of measurement of q_0, the value $q(t)$ at the present epoch t_0, is briefly as follows. Sandage (1961a, 1961b) pointed out that the different Friedmann models without the cosmological constant have definite predictions for this parameter, with $q_0 = \frac{1}{2}$ for the simplest model, $k = 0$, while $q_0 > \frac{1}{2}$ for models with $k = 1$, and $q_0 < \frac{1}{2}$ for models with $k = -1$. *In all cases*, however, q_0 is *expected to be positive*, and Sandage outlined a program for determining the value of this parameter by measuring apparent magnitudes m of "standard candle" sources at progressively higher redshifts z with the help of the 200 inch (5 m) Hale Telescope. Subsequent measurements of the m-z relation, during the 1960s and the 1970s, always yielded a positive range of values of q_0, except in one case where, while highlighting the role of the aperture correction, Gunn & Oke (1975) widened the error bars to allow the possibility of a negative q_0, which in turn implied an *accelerating universe.*

If the observations clearly show that q_0 is negative, there are two different cosmological scenarios that can explain it. The first is to insert a positive cosmological constant into the usual Friedmann models. The second is to remember that in the classical steady state cosmology, $q_0 = -1$ (Hoyle 1948; Bondi & Gold 1948), and in the quasi–steady state cosmology (QSSC), q_0 will also be negative. The actual value of q_0 in the QSSC depends on the details of the creation process (Hoyle, Burbidge, & Narlikar 1993, 1994a, 1994b).

In recent years, a new observational approach has been taken to the determination of q_0. This is to use supernovae (SNe) of type Ia as "standard candles" to derive an m-z relation to high enough values of z so that q_0 can be determined. An extensive observational program of this type is being carried out by two groups, Riess et al. (1998) and Perlmutter et al. (1999). They have observed more than 60 supernovae Ia out to $z \simeq 1$. While there may be questions concerning the use of these supernovae as standard candles, we shall assume in what follows that the observed m-z relation obtained from these data suggests that q_0 is negative.

Even though these are observational studies and not primarily theoretical analyses, the authors of these papers have immediately interpreted their results only in terms of Friedmann models with a positive cosmological constant. In this paper, we describe an alternative way in which the results can be interpreted.

In § 2, we briefly discuss the situation if the results are interpreted in terms of the standard hot big bang model. In § 3, we discuss the theoretical m-z relation in the framework of the quasi–steady state model.

In § 4, we shall consider the possibility that the observed m-z relation is due to the presence of intergalactic absorbing dust grains. This suggestion has been already made by Aguirre (1999), who has argued that dust in the form of intergalactic whiskers first proposed by Wickramasinghe et al. (1975) and later by Hoyle & Wickramasinghe (1988) and Wickramasinghe & Wallis (1996) is involved. Aguirre (1999) has shown that the corrections to the theoretical magnitudes in the standard model because of intergalactic absorption by dust of this type do result in satisfactory agreement with the supernova data without having to invoke a cosmological constant. In this context, it is worth recalling the earlier work by Chitre & Narlikar (1976), where these authors had used the same dust grains to compute their effect on the observed deceleration parameter and showed that the effect is toward making q_0 negative.

The type of dust proposed by Wickramasinghe et al. (1975) was meant to act as a thermalizer for starlight, the argument being that a large fraction of starlight (say, ~ 10

[1] Inter-University Centre for Astronomy and Astrophysics, Pune, India.
[2] School of Mathematics, University of Wales, Cardiff, Senghennydd, Cardiff, Wales, UK.
[3] 102 Admirals Walk, West Cliff, Bournemouth, Dorset, England, UK.
[4] Center for Astrophysics and Space Sciences and Department of Physics, University of California, San Diego, La Jolla, CA 92093.

times more than what is actually observed) has been thermalized and seen as the microwave background. Lately this has been proposed by Hoyle et al. (1994a, 1994b) to explain the spectrum and anisotropy of the cosmic microwave background within the framework of the quasi–steady state cosmology. Although this cosmology provides a motivation for whisker-shaped grains, it was shown by Narlikar et al. (1997) that, regardless of cosmological considerations, there are other astrophysical scenarios where such grains play a crucial role.

While Aguirre (1999) has interpreted the observations in terms of intergalactic absorption in the standard model, we shall discuss dust absorption using the QSSC. Finally, we compare the different possible explanations.

2. THE OBSERVED *m-z* RELATION USING THE STANDARD MODEL

Perlmutter et al. (1999) based their analysis on 60 data points from supernova observations, 18 of them being low-redshift supernovae from Hamuy et al. (1996), used to set the zero point. The remaining 42 in the set are high-redshift supernovae from the Supernova Cosmology Project. These authors fitted the *m-z* observations of the 42 + 18 supernovae with cosmological models ranging from the simple Friedmann ones with $\lambda = 0$ to those with a nonzero cosmological constant. Apart from providing fits to the data, these authors have also drawn contours of different confidence levels in the Ω_m-Ω_Λ plane to show the permissible ranges in the parameter space. Their conclusion is that a *nonzero* cosmological constant is required to understand the dimming of the distant supernovae. These data have also recently been analyzed together with the data on the microwave background anisotropies to set similar limits (Efstathiou et al. 1999). Garnavich et al. (1998) and White (1998) have also shown that the "cosmic microwave background (CMB) + SN Ia gives a flat universe with a cosmological constant.

What is required of the model if the cosmological constant is nonzero? In standard cosmology, there is a strong theoretical opinion that seeks to relate the present state of the universe to a very early era in the universe, when it was $\sim 10^{-36}$ s old, when as a result of a phase transition caused by the symmetry breaking of the Grand Unified Theory (GUT) there was a brief inflationary phase, which reset many of the physical conditions of the universe. The inflationary phase is like the de Sitter universe, driven by a vacuum-induced cosmological constant. This constant was, however, very high (greater by some 108 orders of magnitude) compared with its presently observed value. In models in which λ is zero, the assumption is that after the inflationary phase was over the constant driving it became zero, a natural enough conclusion since the constant arose because of the difference between the true and false vacua, a difference that disappeared at the close of inflation. However, if λ is nonzero, it must be assumed that a tiny relic was left over to survive to the present epoch. In his review of the cosmological constant, Weinberg (1989) has pointed out that such an assumption involves a fine-tuning of the order of one part in 10^{108}. Ironically, one of the claimed merits of inflation was that it does away with fine-tuning of cosmological parameters. While considerable cosmological significance has been attached to this claim for a nonzero λ by Perlmutter et al. (1999), it is only fair to point out that these results suggest a conventional model that is not very attractive, however much any alternatives are disliked, or are not even considered.

3. THE OBSERVED *m-z* RELATION INTERPRETED IN THE QUASI–STEADY STATE MODEL

We first show how the theoretical *m-z* relation is obtained in the QSSC. The theory has been discussed in several papers by three of us (F. H., G. B., and J. V. N.; Hoyle et al. 1993, 1994a, 1994b; Hoyle, Burbidge, & Narlikar 1995).

3.1. *The Field Equations*

In the paper by Hoyle et al. (1995, hereafter Paper I) a detailed theoretical framework on which the QSSC models are based was given. The simplest models using the Robertson-Walker line element (eq. [1]) were discussed *in extenso* by Sachs, Narlikar, & Hoyle (1996,) hereafter Paper II, and we use here the approach of that paper.

Starting from a Machian theory of gravitation, which allows matter creation to be included through broken worldlines of particles, the following basic field equations emerge:

$$R_{ik} - \tfrac{1}{2}g_{ik}R + \lambda g_{ik} = -8\pi G[T_{ik} - f(c_i c_k - \tfrac{1}{4}g_{ik}c^l c_l)] \ . \quad (3)$$

Here the speed of light is taken as unity, and the scalar function $c(x^i)$ of the spacetime coordinates x^i represents the scalar creation field having its sources in the ends of particle worldlines. Both the creation field and the cosmological constant λ are determined by the large-scale distribution of matter in the universe, as is also the gravitational constant G. Note that G is positive, while f, the coupling constant of the c field, and also the cosmological constant λ are negative. Like their magnitudes, the signs of these constants are also determined by the large-scale structure of the universe, as to be expected in a theory motivated by Mach's principle (cf. Paper I).

In a dust medium, these field equations take the following form in a Robertson-Walker spacetime:

$$\frac{2\ddot{S}}{S} + \frac{\dot{S}^2 + k}{S^2} = \lambda + 2\pi G f \dot{c}^2 \ , \quad (4)$$

$$\frac{3(\dot{S}^2 + k)}{S^2} = \lambda + 8\pi G_\rho - 6\pi G f \dot{c}^2 \ . \quad (5)$$

The general conservation equation in this case is given by

$$T^{ik}_{;k} = f\{c^i c^k_{;k} + \tfrac{1}{2}c^i_{;k}c^k\} \ . \quad (6)$$

This equation represents two different modes of evolution: the *noncreative* mode, when both sides of the equation have the zero value, and the *creative* mode, when both sides are equal and *nonzero*. Sachs et al. (1996) have discussed both of the modes separately. The long-term expansion with the characteristic timescale P is driven by the creative mode, while the noncreative mode is responsible for oscillations with period Q around this solution. The timescale P is large compared with Q, implying that there may be a large number (20–25, say) of oscillations during one *e*-folding time of the long-term expansion. Here we are going to be concerned with only the noncreative mode of the model, as the data are expected to relate to the past history of the present oscillatory cycle alone. In this case, we have

$$T^{ik}_{;k} = 0 \ , \quad (7)$$

$$c^i c^k_{;k} + \tfrac{1}{2}c^i_{;k}c^k = 0 \ . \quad (8)$$

The above equations, with the help of the field equations (4) and (5), lead to

$$\frac{\dot{S}^2 + k}{S^2} = \frac{\lambda}{3} + \frac{A}{S^3} - \frac{B}{S^4} . \tag{9}$$

The constants A and B are positive since the matter density is positive and the c-field energy density is negative. Notice that with a negative λ, the expansion turns to contraction at a large enough S, while a bounce occurs at a small enough S as the constant B is positive. Thus, for all values of k, the solution is oscillatory.

The creation process works on the basis of the ambient c-field energy attaining a minimum threshold. When this reaches the rest mass energy of the Planck particle of mass $(c\hbar/G)^{1/2}$, creation of such particles takes place. Below this threshold, no creation is possible. As seen above, the energy density of the c field rises and falls during an oscillation in proportion to S^{-4}. Thus the strength is maximum at the minimum value of the scale factor $S_{\rm min}$. In the QSSC as it has been developed so far, creation takes place close to this minimum epoch only. This is because it is assumed that the strength of the c field can be maintained at and above the creation threshold only in a narrow time span ($\ll Q$) at each oscillatory minimum.

A more complete theory using a quantized c field would tell us how the creation rate is to be determined from environmental conditions. In the absence of such a theory, we have adopted an empirical and phenomenological approach, that of assuming that the creation occurs in the above discrete manner, and in the present paper we will use the standard QSSC picture arising from it.

However, the possibility exists that the creation may not be limited to discrete epochs close to the oscillatory minima only but might continue for a while even after the minimum scale epoch is crossed, provided that even though the strength of the c field continues to fall it still stays above the creation threshold for part of the cycle. In this case, the creation rate will fall off from a peak at the oscillatory minimum and continue significantly for part of the cycle. If we had assumed that the creation rate stays constant at all epochs, we would be back with the old steady state theory of Bondi & Gold (1948) and Hoyle (1948). This situation therefore falls in between the strict steady cosmology and the QSSC. We shall refer to this as contemporary creation and explore its effects on the theoretical m-z relation in a later paper.

3.2. *Oscillatory Solutions*

For any appropriate choice of the constants A and B, the above equation yields an exact solution as

$$S = \bar{S}[1 + \eta \cos \psi(t)] , \tag{10}$$

$\bar{S}$ being constant and η a parameter varying between 0 and 1. $\psi(t)$ is given by the following expression:

$$\dot{\psi}^2 = (1 + \eta \cos \psi)^{-2}\left\{\frac{k}{\bar{S}^2} - \frac{\lambda}{3}[6 + 4\eta \cos \psi + \eta^2(1 + \cos^2 \psi)]\right\} , \tag{11}$$

with

$$A = 2k\bar{S} - \frac{4\lambda}{3}\bar{S}^3(1 + \eta^2) , \tag{12}$$

$$B = k\bar{S}^2(1 - \eta^2) - \frac{\lambda}{3}\bar{S}^4(1 - \eta^2)(3 + \eta^2) . \tag{13}$$

The model oscillates between the finite-scale limits

$$S_{\rm min} \equiv \bar{S}(1 - \eta) \le S \le \bar{S}(1 + \eta) \equiv S_{\rm max} . \tag{14}$$

The period of oscillation is given by

$$Q = \int_0^{2\pi} \times \frac{(1 + \eta \cos \psi)d\psi}{\{(k/\bar{S}^2) - (\lambda/3)[6 + 4\eta \cos \psi + \eta^2(1 + \cos^2 \psi)]\}^{1/2}} . \tag{15}$$

Notice that the cosmological constant λ has to be negative for the above solution to be possible. The basic theory of QSSC guarantees this. The present epoch in the oscillation may be denoted by t_0, with the last minimum occuring at $t_{\rm min}$, when $\psi = \pi$. The form of equation (10) for expressing the oscillatory solution was chosen for reasons of simplicity. First, the function $\psi(t)$ is almost linear in t for most of the period and differs significantly from it only near the minima of the function S (see Sachs et al. 1996). Second, the parameter η (which lies between 0 and 1) indicates how close to zero the minimum scale factor can be, which in turn can be related to the maximum redshift of any object belonging to the present cycle.

3.3. *The Dimensionless Parameters of the QSSC*

In order to compare the QSSC with the standard cosmology, it is convenient to recast some of the above formulae in terms of the various dimensionless parameters for density, cosmological constant, creation field energy, and space curvature, as was done by Banerjee & Narlikar (1999). We begin by defining the following parameters for the c field:

$$\rho_c = \tfrac{3}{4} f\dot{c}^2 , \quad p_c = -\tfrac{1}{4} f\dot{c}^2 . \tag{16}$$

Note that although the pressure and energy density are both negative, they follow the equation of state for disordered radiation, viz., $p = \rho/3$. This is hardly surprising when we note that the trace of the energy momentum tensor of the c field has zero trace. For this reason, we also find that the dependence of ρ_c on S is the same as for radiation, namely, $\rho_c \propto S^{-4}$. In the QSSC, the universe is never radiation dominated, and so the radiation term is dominated by the c field term. Thus, although in principle it is possible to imagine a universe in which the radiation term dominates over the c field term, thereby producing a spacetime singularity as in the standard models, there is no such possibility here.

We further define the dimensionless parameters by the following formulae:

$$\text{density parameter, } \Omega_0 = \frac{8\pi G\rho_0}{3H_0^2} ;$$

$$\text{cosmological constant parameter, } \Lambda_0 = \frac{\lambda}{3H_0^2} ;$$

$$\text{creation density parameter, } \Omega_{c,0} = \frac{8\pi G\rho_{c,0}}{3H_0^2} ;$$

$$\text{curvature parameter, } K_0 = \frac{k}{H_0^2 S_0^2} ; \tag{17}$$

where, to avoid confusion, we have set the velocity of light equal to unity. The subscript zero indicates that the quantity is evaluated at the present epoch. Note that the present value of the scale factor S_0 need not be equal to the scale parameter $\bar{S}$. We define the ratio

$$x_0 = S_0/\bar{S} . \quad (18)$$

In view of the field equations (4) and (5), we have the following relations between these parameters:

$$\Omega_0 = 2K_0 x_0^{-1} - 4\Lambda_0 x_0^{-3}(1 + \eta^2) ,$$
$$\Omega_{c,0} = -K_0 x_0^{-2}(1 - \eta^2) + \Lambda_0 x_0^{-4}(1 - \eta^2)(3 + \eta^2) . \quad (19)$$

An observational constraint on the QSSC model is provided by the maximum redshift observable in the present cycle. Denoting it by z_{max}, we may use equations (14) and (18) to derive the following relation:

$$x_0 = (1 - \eta)(1 + z_{max}) . \quad (20)$$

These relations show that the parameter η, which describes the oscillatory part of the solution, is related to the relative physical magnitudes of the three controlling agencies—matter, the c field, and the cosmological constant. In particular, if $\eta \to 1$, the model tends to have a singular state as in the big bang. The above relation shows that in this limit the c field term ceases to be effective in causing a bounce.

Corresponding to the relations in the standard cosmology, those connecting these dimensionless quantities in the QSSC are

$$1 + K_0 = \Lambda_0 + \Omega_0 + \Omega_{c,0} , \quad (21)$$

$$\Omega_0 = 2[q_0 + \Lambda_0 - \Omega_{c,0}] . \quad (22)$$

From the definitions given in equation (17), we see that $K_0 = 0$ for $k = 0$, whereas K_0 is negative for $k = -1$. At the maximum redshift ($z = z_{max}$), we have the relation

$$0 = \Lambda_0 - K_0(1 + z_{max})^2 + \Omega_0(1 + z_{max})^3 + \Omega_{c,0}(1 + z_{max})^4, \quad (23)$$

which is satisfied identically for all values of the parameters η and K_0.

3.4. *The Theoretical m-z Relation*

We now use these results to derive the theoretical m-z relation in the QSSC as follows. Suppose the observer is at $r = 0$, $t = t_0$, when the light from a source at radial coordinate $r(z)$, redshift z, and luminosity L arrives there. Then, the apparent magnitude is given by

$$m(z) = -2.5 \log L + 5 \log [r(z)(1 + z)] + \text{constant} , \quad (24)$$

where the constant is determined by scaling to actual distances using $S(t_0)$ as the value of the length scale at the present epoch. For $k = 0$ the coordinate radius $r(z)$ is calculated using the expression

$$r(z) = \int_{S(t_0)/(1+z)}^{S(t_0)} \frac{dS}{S\dot{S}} . \quad (25)$$

We shall work with the simplest of the family of QSSC models described in the previous section and take $k = 0$. In the case of the exact solution of equation (9), we then have

$$r(z) = \int_{S(t_0)/(1+z)}^{S(t_0)} \frac{dS}{[(\lambda/3)S^4 + AS - B]^{1/2}} . \quad (26)$$

Alternatively, we can use the dimensionless parameters defined in equation (17) to replace the constants λ, A, and B in the above equation. It is convenient to do this if we are to make a comparison with the work of standard cosmology. We define $y = S_0/S$. Equation (26) then takes the form

$$r(z) = \frac{1}{H_0 S_0} \int_1^{1+z} \frac{dy}{(\Lambda_0 + \Omega_0 y^3 + \Omega_{c,0} y^4)^{1/2}} . \quad (27)$$

It now remains to put in the values of the relevant parameters and work out the function $m(z)$, from equation (24), for the various values of z. However, if there is significant absorption by intergalactic dust, we have to add an additional redshift-dependent term $\Delta m(z)$ to the magnitudes computed above. We next discuss the effect of dust.

4. THE EFFECT OF INTERGALACTIC DUST

We shall suppose that the dust is present in the form of metallic needles condensed from metallic vapors produced and ejected following production of heavy elements in supernovae. Laboratory experiments have shown that the condensates are not spherical but shaped like whiskers, with lengths in the range of 0.5–1 mm, and cross-sectional radii of the order of 10^{-6} cm. It has been argued by Hoyle, Burbidge, & Narlikar (2000) that the whiskers will be mainly of carbon and iron, the latter dominating close to the oscillatory minima of the QSSC. While the iron whiskers will dominate at longer wavelengths, the main absorption in the optical waveband will be due to carbon. We will therefore assume that carbon whiskers are the principal absorbers of optical radiation in intergalactic space.

The mean mass extinction in this process is calculated using the formula

$$\Delta m(z) = 2.5 \log e \int_0^{l(z)} \kappa \rho \, dl , \quad (28)$$

where κ is the mass absorption coefficient, $\rho = \rho_g$ is the whisker grain density, and $l(z)$ is the distance traversed through the intergalactic medium up to redshift z. For the flat Robertson-Walker model, the above equation reduces to the form

$$\Delta m(z) = \int_{S(t_0)/(1+z)}^{S(t_0)} \frac{\kappa \rho_{g,0} S_0(1 + z)^2}{S\dot{S}} dS , \quad (29)$$

S being the scale factor and $\rho_{g,0}$ being the whisker grain density at the present epoch. Using the equations (25), (26), and (27) for the flat QSSC model, $\Delta m(z)$ is given by

$$\Delta m(z) = \frac{\kappa \rho_{g,0}}{H_0} \int_1^{1+z} \frac{dy}{(\Lambda_0 + \Omega_0 y^3 + \Omega_{c,0} y^4)^{1/2}} . \quad (30)$$

Normally κ depends on the wavelength and hence on z. However, as has been discussed by Wickramasinghe & Wallis (1996), it is effectively constant over a wide range of wavelengths, including those relevant here. This is why κ lies outside the integral.

The density of carbon grains is estimated to lie in the range 3–5 $\times 10^{-34}$ g cm^{-3}. However, we will use it as a parameter to be fitted to the m-z observations and determine its value by obtaining the best fit to the data. We take a specific QSSC model in which we assume the following parameters:

$$z_{\max} = 5 ,$$
$$\eta = 0.811 ,$$
$$\Lambda_0 = -0.358 .$$

We also put $H_0 = 65$ km s^{-1} Mpc^{-1}.

When fitting the theoretical magnitudes to the observed ones, the constant on the right-hand side of equation (24) and the density $\rho_{g,0}$ mentioned earlier appearing in $\Delta m(z)$ can be adjusted to get a minimum value of the χ^2 statistic.

Figure 1 shows the best-fit curve for the QSSC model together with the best-fit curve for the standard model ($k = 0$, $\lambda = 0$) in the big bang cosmology. Visually it is obvious that the former gives a better fit to the data. The minimum χ^2 values for the two cases confirm this visual impression. Omitting six out of the 60 points where the difference between theory and observations is excessive, the values for 54 points are 55.64 for the QSSC model and 69.27 for the standard model. The dust grain density for the best-fit QSSC model is $\rho_{g,0} = 3.3 \times 10^{-34}$ g cm^3, which is in good agreement with the density estimated elsewhere for the dust (Hoyle et al. 2000).

The magnitudes given in Figure 1 are "effective magnitudes" after including the effect of intergalactic dust in the theoretical computations of magnitudes predicted by a model. In the standard model, there is no intergalactic dust, and the result is simply based on the geometrical attenuation of flux from a redshifted source in an expanding universe. The QSSC model requires intergalactic dust to thermalize the relic starlight into a microwave background, and so it affects the magnitudes computed as per equation (28). We also clarify that Figure 1 does not show the result of optimizing the QSSC models with respect to its parameters. The parameters chosen above are typical, being in the range used in previous QSSC papers (Hoyle et al. 1994a, 1994b, 1995; Sachs et al. 1996; Narlikar et al. 1997; Banerjee & Narlikar 1999). As pointed out there, the model is robust with respect to its parameters in fitting the various cosmological data such as the CMB, ages of galaxies, radio source counts, and angular-size flux density relation.

We just pointed out that there are six observed supernovae that show large departures from the best-fit *m-z* curve. This may indicate that the physical properties of these supernovae are different from the others; i.e., it may cast doubt on the use of supernovae as standard candles.

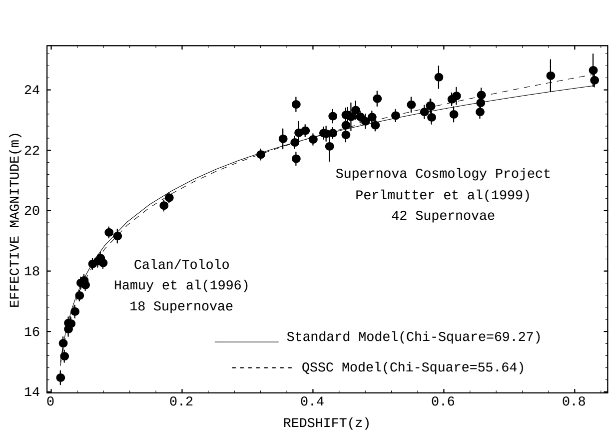

FIG. 1.—The *m-z* curves for two cosmological models drawn through data points. The continuous curve describes the best-fit standard Einstein–de Sitter model; the dotted line represents the best-fit QSSC model *together with intergalactic absorption.*

However, within the framework of the QSSC cosmology in which dust plays an important role in thermalizing stellar radiation to produce the microwave background, the large scatter in a few of these cases has a natural explanation. It simply means that a larger degree of absorption is present in a few localized regions than in the general field. This is expected since the dust grains are produced by events in discrete sources—individual galaxies and clusters of galaxies.

As the data on supernovae accumulate, it may be possible to test the dust hypothesis by plotting all of the supernovae in the sample on the sky in a three-dimensional plot (using redshifts) and identify those that show excess magnitudes. Then we may look for any nonrandomness in the distribution of such supernovae vis-à-vis the whole population. If such "nonrandom" regions stand out, these may well be the regions of excess dust.

It has been argued by Simonsen & Hannestad (1999) that whenever such whiskers (included in the term *gray dust* by these authors) are emitted from high-redshift galaxies, standard—i.e., spherical, reddening—dust would also be emitted that would have been visible in the spectra proposed by Aguirre (1999). The following calculation, however, shows that this criticism does not apply to the whisker model considered here.

Dust grains originating in the central disk of a galaxy would be acted on by radiation pressure from an anisotropic radiation field and would drift outward with average speeds of $\sim 10^5$ cm s^{-1}. The grains (whiskers or spheres) would inevitably carry a net electric charge and so would tend to be tied to magnetic field lines within a galactic disk (Chiao & Wickramasinghe 1972). Radiation pressure effects would, however, lead to the initiation of Parker-type instabilities, which permit a large-scale escape of grains once they reach the outer regions of a galaxy. Grains thus reaching the outskirts of a dusty galaxy would not only be acted on by radiation pressure from direct starlight but also from infrared radiation of dust in the inner region.

If $\kappa(a, l, \lambda)$ denotes the mass absorption coefficient of graphite whiskers of radius a and length l in random orientation as a function of wavelength λ, the ratio of radiation pressure to gravity is given by

$$\frac{p_r}{p_g} = 1.04 \times 10^{-4} \langle \kappa(a, l) \rangle \frac{L/L_0}{M/M_0} , \tag{31}$$

where

$$\langle \kappa(a, l) \rangle = \frac{\int_0^\infty \kappa(a, l, \lambda) F_\lambda \, d\lambda}{\int_0^\infty F_\lambda \, d\lambda} , \tag{32}$$

F_λ being the anisotropic radiation flux incident on the grains. Numerical calculations of $\kappa(a, l, \lambda)$ according to procedures discussed by Wickramasinghe & Wallis (1996) are given in Table 1 for the case of a whisker with a cross-sectional radius $a = 0.01$ μm.

Many dusty galaxies, including Seyfert and starburst galaxies, are known to have flux curves that peak near a wavelength of 100 μm, with total fluxes at such wavelengths exceeding optical and near-infrared fluxes by as much as a factor of 30. Schematically modeling such a flux curve as comprised of monochromatic radiation at 1.24 and 124.0

TABLE 1

MASS ABSORPTION FOR WHISKERS OF VARIOUS LENGTHS $a = 0.01\ \mu$m

λ (μm)	$l = 0.03\ \mu$m ($cm^2\ g^{-1}$)	$l = 0.50\ \mu$m ($cm^2\ g^{-1}$)	$l = 1.0\ \mu$m ($cm^1\ g^{-1}$)	$l = 10.0\ \mu$m ($cm^2\ g^{-1}$)
0.35	3.17E4	1.74E5	1.74E5	1.74E5
0.50	2.23E4	1.26E5	1.29E5	1.31E5
1.24	8.06E3	9.99E4	1.02E5	1.03E5
12.4	4.04E2	5.68E4	6.01E4	6.01E4
124.0......	9.45E2	2.63E2	3.73E3	6.01E4

μm with an intensity ratio of 1:30, we obtain $\langle \kappa(l) \rangle$ values for carbon whiskers of radii 0.01 μm Table 2.

With mass-to-light ratios of unity being applicable to dusty IR galaxies, we note from equation (31) and Table 2 that whiskers with lengths of the order of a few microns or greater have p_r/p_g ratios that are unequivocally greater than unity and are therefore expelled. Much shorter whiskers and spherical carbon grains will be retained within galaxies. The above considerations would dispose of the arguments, such as those advanced by Simonsen & Hannestad (1999), seeking to limit the density of whiskers injected into intergalactic space. Their analysis does not take account of the redistribution of starlight energy within the galaxy through which it is expelled, and their assumption of a color temperature of close to 10,000 K for the radiation incident on grains near the edge of a galaxy is clearly in error.

TABLE 2

PROPERTIES OF WHISKERS

l (μm)	$\langle \kappa(l) \rangle$
0.03	269
0.50	3593
1.0	7130
10	63533

5. CONCLUSIONS

The form of the observed m-z relation for supernovae of type Ia may be explained in the hot big bang cosmology provided that a nonzero cosmological constant is invoked. While this explanation has been widely publicized, the underlying theoretical problems have not been stressed.

An alternative explanation can be given by arguing that we live in a quasi–steady state universe, which will naturally have a negative value of q_0 corresponding to the creation of matter. Also in such a universe, dust is an important constituent. We have shown here that the observed m-z relation can be well fitted using this model and some absorption due to dust. It is possible that the supernovae that give the greatest scatter about the best-fit m-z curve already provide evidence that patchy absorption due to dust is present. Observations of the m-z relation for $z > 1$ will enable us to distinguish between the standard model and the quasi–steady state model.

J. V. N. and S. K. B. thank the Department of Atomic Energy, India, for support under the Homi Bhabha Professorship program.

REFERENCES

Aguirre, A. N. 1999, ApJ, 512, L19
Banerjee, S. K., & Narlikar, J. V. 1999, MNRAS, 307, 73
Bondi, H., & Gold, T. 1948, MNRAS, 108, 252
Chiao, R. Y., & Wickramasinghe, N. C. 1972, MNRAS, 159, 361
Chitre, S. M., & Narlikar, J. V. 1976, Ap&SS, 44, 101
Efstathiou, G., Bridle, S. L., Lasenby, A., Hobson, M., & Ellis, R. 1999, MNRAS, 303, L47
Garnavich, P., et al. 1998, ApJ, 509, 74
Gunn, J., & Oke, J. B. 1975, ApJ, 195, 255
Hamuy, M., Phillips, M. M., Schommer, R. A., Suntzeff, N. B., Maza, J., & Avilés, R. 1996, AJ, 112, 2391
Hoyle, F. 1948, MNRAS, 108, 372
Hoyle, F., Burbidge, G., & Narlikar, J. V. 1993, ApJ, 410, 437
———. 1994a, MNRAS, 267, 1007
———. 1994b, A&A, 289, 729
———. 1995, Proc. R. Soc. London A, 448, 191 (Paper I)
Hoyle, F., & Wickramasinghe, N. C. 1988, Ap&SS, 147, 245
Hoyle, F., Burbidge, G., & Narlikar, J. V. 2000. A Different Approach to Cosmology, (Cambridge: Cambridge Univ. Press)
Narlikar, J. V., Wickramasinghe, N. C., Sachs, R., & Hoyle, F. 1997, Int. J. Mod. Phys., 6, 125
Perlmutter, S., et al. 1999, ApJ, 517, 565
Riess, A., et al. 1998, AJ, 116, 1009
Sachs, R., Narlikar, J. V., & Hoyle, F. 1996, A&A, 313, 703 (Paper II)
Sandage, A. 1961a, ApJ, 133, 355
———. 1961b, ApJ, 134, 916
Simonsen, J. T., & Hannestad, S. 1999, A&A, 351, 1
Weinberg, S. 1989, Rev. Mod. Phys., 66, 1
White, S. D. M. 1998, ApJ, 506, 495
Wickramasinghe, N. C., Edmunds, M. G., Chitre, S. M., Narlikar, J. V., & Ramadurai, S. 1975, Ap&SS, 35, L9
Wickramasinghe, N. C., & Wallis, D. H. 1996, Ap&SS, 240, 157