Astron. Astrophys. 348, 1–7 (1999)

ASTRONOMY
AND
ASTROPHYSICS

Flat Friedmann-Robertson-Walker cosmologies with adiabatic matter creation: kinematic tests

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Received 28 September 1998 / Accepted 1 February 1999

Abstract. We investigate observational consequences of a cosmological scenario driven by adiabatic matter creation. Exact expressions for the lookback time, age of the universe, luminosity distance, angular diameter, and galaxy number counts versus redshift are derived and their meaning discussed in detail. The expressions of the conventional FRW models are significantly modified and provide a powerful method to limit the parameters of the models.

Key words: cosmology: theory

Nowadays, the increasing difficulties with standard Friedmann-Robertson-Walker (FRW) cosmologies compel the investigation of alternative big-bang models. One of the main motivations is the conflict between the expanding age of the universe, as inferred from recent measurements of the Hubble parameter (Friedmann 1998), and the age of the oldest stars in globular clusters (Bolte & Hogan 1995, Pont et al. 1998). The corresponding uncertainties related to such determinations are now believed to be considerably small, thereby ruling out large regions in the space parameter of the standard cosmology even for open models (Bagla et al. 1996). Such restrictions may be even more efficient near future, first, from better data analysis with consequent reduction in incertainities, and second, due to improved experiments as well as new observational facts. For instance, the recent discovery of a $3.5 \mathrm{Gyrs}$ old galaxy at $z = 1.554$ (Dunlop et al. 1996) has been proved to be incompatible with ages estimates for a flat universe unless the Hubble parameter is less than $45 \mathrm{kms}^{-1}\mathrm{Mpc}^{-1}$. Such a constraint is more stringent than globular cluster age constraints (Krausss 1997). This "age problem" is not an isolated difficulty of the FRW model since it also affects others basic features of the standard cosmology, like the structure formation through gravitational amplification of small primeval density perturbations (Jeans' Instability). Indeed, with the exception of a very low Hubble constant variant this galaxy formation scenario seems to be inconsistent with the estimated age of the universe. For open universes, where the "age problem" is less acute, this happens because of the growth of perturbations since recombination is relatively suppressed in low density models (Kofmann et al. 1993, White & Bunn 1995).

On the other hand, recent measurements of the deceleration parameter using Type Ia supernovae (Garnavich et al. 1998, Perlmutter et al. 1998) indicate that the universe may be accelerating today, or equivalently, that the deceleration parameter may be negative. These measurements pose a big problem for the standard model (for any of its variants) since their predictions are $q_o > 0$, whatever the sign adopted for curvature. More recently still, improved observations from a sample of 16 supernovae type Ia plus 34 nearby novae, were used to place constraints on $H_o, \Omega_m, \Omega_\Lambda$ and q_o (Riess et al. 1998). These authors concluded that the standard flat model ($\Omega_m = 1, \Omega_\Lambda = 0, q_o > 0$) is ruled out and that several effects, among them extinction, evolution, sample selection bias, and local flows, are not enough to reconcile the data with the predictions of this model. In such a state of affairs, it seems more prudent to follow the tradition in cosmology by considering alternative big-bang scenarios. As a matter of fact, the positive evidences in favor to standard model, although not negligible, are not at all abundant, and are presently under investigation.

Some years ago, a thermodynamic description of gravitational creation of matter and radiation was proposed in the literature (Prigogine et al. 1989; Lima et al. 1991; Calvão et al. 1992; Lima & Germano 1992). The crucial ingredient of this formulation is the explicit use of a balance equation for the number density of the created particles in addition to Einstein field equations (EFE). In this framework, the thermodynamic second law leads naturally to a reinterpretation of the energy momentum tensor (EMT) corresponding to an additional stress term (creation pressure), which in turn depends on the matter creation rate, and may considerably alter several predictions of the standard big-bang cosmology. The compatibility between this approach and the kinetic theory of a relativistic gas has also been addressed (Triginer et al. 1996, Zimdahl et al. 1996). Studies envolving matter creation and early universe physics include the singularity problem (Prigogine et al. 1989; Abramo & Lima 1996), reheating during the inflationary epoch (Zimdahl & Pavón 1994), the age of the universe problem (Lima et al. 1999), the entropy problem (Lima & Abramo 1996; Brevik & Stokkan 1996) and the amplification of gravitational waves (Maia et al. 1997; Tavares & Maia 1998). Of special interest to

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us is the particular case termed “adiabatic” matter creation. Under “adiabatic” conditions, particles (and consequently entropy) are continuously generated, however, the specific entropy per particle of each component remains constant during the whole process (Calvão et al. 1992; Lima & Germano 1992). For photon creation, this means that equilibrium relations are preserved ($n \sim T^3$, $\rho \sim T^4$) and also that the photon spectrum may be compatible with the isotropy of the CMBR (Lima 1996, 1997). In addition to the papers already cited, several authors have also used such a formulation in the last few years to study different dynamical aspects of cosmological models (Zimdhall & Pavón 1993, Brevik & Stokkan 1996). The advantages of this new thermodynamic approach over the old bulk viscosity description for matter creation (Zeldovich 1970) have been discussed both in the context of the first order nonequilibrium thermodynamics (Lima & Germano 1992) and causal formulation (Gariel & Le Denmat 1995). These studies clearly revealed that matter creation cannot consistently be modeled by the bulk viscosity mechanism even considering that both are scalar processes.

An overview of the literature show, however, that the dynamical properties of cosmological models with “adiabatic” matter creation have been more carefully investigated than their observational consequences in the present matter dominated phase. This is an important point, because the viability of big-bang models with matter creation could partially be answered by deriving expressions for the classical cosmological tests, thereby analysing the influence of this mechanism on the well known predictions of the standard FRW model.

In order to fill this gap, we focus here on the quantities of interest to the present dust like stage. In Sect. 1, we set up the cosmological equations with adiabatic matter creation, reviewing briefly some basic features of such an approach. In Sect. 2, by adopting a creation scenario recently proposed by Lima et al. (1996), we derive new expressions for the observable quantities and analyse some of their properties. The data are then used to limit the unique free quantity (creation parameter) of the model. We conclude with a discussion of the main results.

1. Flat FRW equations with “adiabatic” matter creation

Let us now consider the flat FRW line element $(c = 1)$

$$ds^2 = dt^2 - R^2(t)(dr^2 + r^2 d\theta^2 + r^2 sin^2\theta d\phi^2) \quad , \tag{1}$$

where r, θ, and ϕ are dimensionless comoving coordinates and R is the scale factor.

In that background, the nontrivial EFE for a fluid endowed with “adiabatic” matter creation and the balance equation for the particle number density can be written as (Prigogine et al. 1989; Calvão et al. 1992)

$$8\pi G\rho = 3\frac{\dot{R}^2}{R^2} \quad , \tag{2}$$

$$8\pi G(p + p_c) = -2\frac{\ddot{R}}{R} - \frac{\dot{R}^2}{R^2} \quad , \tag{3}$$

$$\frac{\dot{n}}{n} + 3\frac{\dot{R}}{R} = \frac{\psi}{n} \quad , \tag{4}$$

where an overdot means time derivative and ρ, p, n and ψ are the energy density, thermostatic pressure, particle number density and matter creation rate, respectively. The creation pressure p_c depends on the matter creation rate, and for “adiabatic” matter creation, it assumes the following form (Calvão et al. 1992; Lima & Germano 1992)

$$p_c = -\frac{\rho + p}{3nH}\psi \quad , \tag{5}$$

where $H = \dot{R}/R$ is the Hubble parameter.

As usual in cosmology, the cosmic fluid obeys the “gamma-law” equation of state

$$p = (\gamma - 1)\rho \quad , \tag{6}$$

where the constant γ lies on the interval [0,2].

Combining Eqs. (2) and (3) with (5) and (6) it is readily seen that the scale factor satisfies the generalized FRW differential equation

$$R\ddot{R} + (\frac{3\gamma_* - 2}{2})\dot{R}^2 = 0 \quad , \tag{7}$$

where γ_* is an effective “adiabatic index” given by

$$\gamma_* = \gamma(1 - \frac{\psi}{3nH}) \quad . \tag{8}$$

To proceed further it is necessary to assume a physically reasonable expression to the matter creation rate ψ. As can be seen from (4), the dimensionless parameter $\frac{\psi}{3nH}$ is the ratio between the two relevant rates envolved in the process. When this ratio is very small, the creation process can be neglected; and if it is much bigger than unity, we see from (5) that p_c becomes meaningless, because it will be much greather than the energy density. A reasonable upper limit of this ratio should be unity ($\psi = 3nH$), since in this case ψ has exactly the value that compensates for the dilution of particles due to expansion. In this work we confine our attention to the simple phenomenological expression (Lima et al. 1996)

$$\psi = 3\beta nH \quad , \tag{9}$$

where β is smaller than unity, and presumably given by some particular quantum mechanical model for gravitational matter creation. In general, β must be a function of the cosmic era, or equivalently, of the γ parameter, which specifies if the universe is dominated by vacuum ($\gamma = 0$), radiation ($\gamma = \frac{4}{3}$) or dust ($\gamma = 1$). However, for the sake of brevity we denote all of them generically by β, assumed here to be a constant at each phase.

With this choice, the FRW equation for $R(t)$ given by (7) can be rewritten as

$$R\ddot{R} + \Delta\dot{R}^2 = 0 \quad , \tag{10}$$

the first integral of which is

$$\dot{R}^2 = \frac{A}{R^{2\Delta}} \quad , \tag{11}$$

where $\Delta = \frac{3\gamma(1-\beta)-2}{2}$, and from (2) A is a positive constant, which must be determined in terms of the present quantities. It is worth noting that for $\beta \geq 1 - \frac{2}{3\gamma}$, or equivalently, $\Delta \leq 0$, the above equations imply that $\ddot{R} \geq 0$, thereby leading to power law inflation. In particular, for $\Delta = 0$, these universes expand with constant velocity, and are new examples of coasting cosmologies whose dynamic behavior is driven by matter creation. The observational consequences of "coasting cosmologies" generated by exotic "K-matter", like cosmic strings, have been studied in detail (Gott & Rees 1987; Kolb 1989). All of them are characterized by energy density $\rho \sim R^{-2}$ and total pressure $P_t = -\frac{1}{3}\rho$ (see Eqs. (12) and (15)).

Using Eq. (11), it is straightforward to obtain the energy density, the pressures (p and p_c) and the particle number density as functions solely of the scale factor R and of the β parameter. These quantities are given by:

$$\rho = \rho_o (\frac{R_o}{R})^{3\gamma(1-\beta)} \quad , \tag{12}$$

$$p_c = -\beta\gamma\rho_o (\frac{R_o}{R})^{3\gamma(1-\beta)} \quad , \tag{13}$$

$$n = n_o (\frac{R_o}{R})^{3(1-\beta)} \quad , \tag{14}$$

$$P_t = (\gamma_* - 1)\rho = [\gamma(1-\beta) - 1]\rho_o (\frac{R_o}{R})^{3\gamma(1-\beta)} \quad , \tag{15}$$

In the above expressions the subscript "o" refers to the present values of the parameters, and the total pressure is $P_t = p + p_c$. As expected, for $\beta = 0$, Eqs. (12)-(15) reduce to those of the standard FRW flat model for all values of the γ parameter (Kolb & Turner 1990).

The solution of (11) for all values of γ and β can be written as

$$R = R_o [1 + \frac{3\gamma(1-\beta)}{2} H_o (t - t_o)]^{\frac{2}{3\gamma(1-\beta)}} \quad . \tag{16}$$

Note also that for $\gamma > 0$, we can choose $t_o = 2H_o^{-1}/3\gamma(1-\beta)$, with the above equation assuming a more familiar form, namely:

$$R(t) = R_o [\frac{3\gamma(1-\beta)}{2} H_o t]^{\frac{2}{3\gamma(1-\beta)}} \quad . \tag{17}$$

In particular, for a "coasting cosmology" driven by matter creation one finds $R \sim t$, as it should be. Note also that in the limit $\beta = 0$, Eqs. (16) and (17) reduce to the well known expressions of the FRW flat model.

2. Expressions for the observational quantities

In what follows we assume that the present material content of the Universe is dominated by a pressureless nonrelativistic gas (dust). Following standard lines we also define the physical parameters $q_o = -\frac{R\ddot{R}}{\dot{R}^2}|_{t=t_o}$ (deceleration parameter) and $H_o = \frac{\dot{R}}{R}|_{t=t_o}$ (Hubble parameter). From (10) it is readily seen that

$$q_o = \frac{1 - 3\beta}{2} \quad . \tag{18}$$

Therefore, for a given value of β, the deceleration parameter q_o with matter creation is always smaller than the corresponding one of the FRW flat model. The critical case ($\beta = \frac{1}{3}, q_o = 0$), describes a "coasting cosmology". Curiously, instead of being supported by "K-matter" (Kolb 1989), this kind of model is obtained in the present context for a dust filled universe, for which even negative values of q_o are allowed, since the constraint $q_o < 0$ can always be satisfied provided $\beta > 1/3$. These results are in line with recent measurements of the deceleration parameter q_o using Type Ia supernovae (Perlmutter et al. 1998, Garnavich et al. 1998, Riess et al. 1998). Such observations indicate that the universe may be accelerating today ($q_o < 0$), which corresponds dynamically to a negative pressure term in the EFE. This would also indicate that the universe is much older than a flat model with the usual deceleration parameter $q_o = 0.5$, and would reconcile other recent results (Freedman 1998), pointing to a Hubble parameter H_o larger than $50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (see discussion below Eq. (21)). To date, only models with a cosmological constant, or the so-called "quintessence" (of which Λ is a special case), or a second dark matter component with repulsive self-interaction have been invoked as being capable of explaining these results (Caldwell et al. 1998, Cornish & Starkman 1998). In the present context, these prescriptions for alternative cosmologies are replaced by a flat model endowed with an "adiabatic" matter creation process. Before continuing, we need to express the constant A in terms of R_o and H_o. From (8) one finds

$$A = H_o^2 R_o^{3(1-\beta)} \quad . \tag{19}$$

The kinematical relation distances must be compared with the observations in order to put limits on the free parameter of the models.

a) Lookback Time-Redshift. For a given redshift z, the scale function $R(t_z)$ is related to R_o by $1 + z = \frac{R_o}{R}$. The lookback time is exactly the time interval required by the universe to evolve between these two values of the scale factor. Inserting the value of A given above in the first integral (11), the lookback time-redshift relation can be easily derived and it is given by

$$t_o - t(z) = \frac{2H_o^{-1}}{3(1-\beta)} \left[1 - \frac{1}{(1+z)^{\frac{3(1-\beta)}{2}}} \right] \quad , \tag{20}$$

which generalizes the standard FRW flat result (Sandage 1988). In Fig. 1 we plot the lookback time as a function of the redshift for selected values of β.

Taking the limit $z \to \infty$ in (20) the present age of the universe (the extrapolated time back to the bang) is

$$t_o = \frac{2H_o^{-1}}{3(1-\beta)} \quad , \tag{21}$$

which for $\beta = 0$ reduces to the same expression of the standard dust model (Kolb & Turner, 1990).

Estimates of the Hubble expansion parameter from a variety of methods are now converging to $h \equiv$

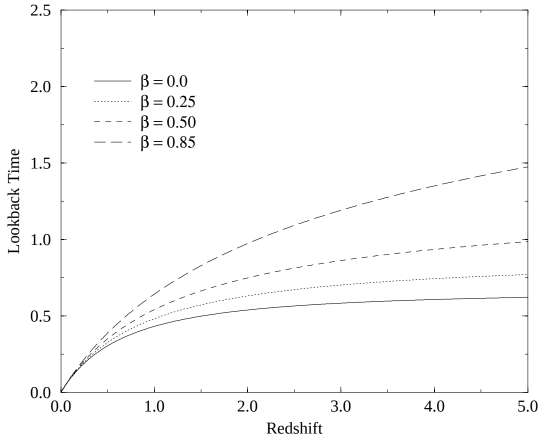

Fig. 1. Lookback time as a function of the redshift for some selected values of Ω_o and β. The solid curve is the FRW flat universe with no matter creation ($\beta = 0$). The lookback time increases for higher values of β, i.e., models with larger matter creation rate are older.

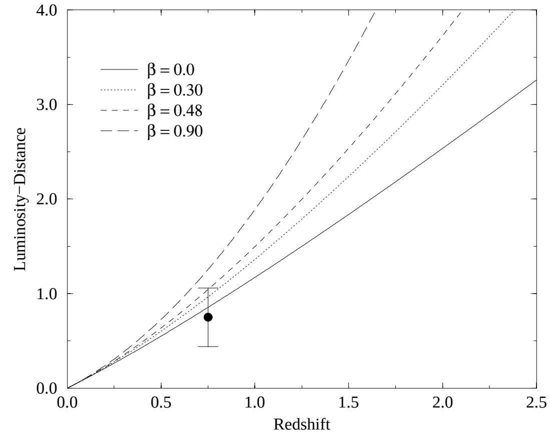

Fig. 2. Luminosity distance as a function of the redshift for flat models with adiabatic matter creation. The solid curve is the Einstein-de Sitter model ($\beta = 0$). The selected values of β are shown in the picture. Here the typical error bar and data point are taken from Kristian et al.

$(H_o/100\mathrm{km/sec/Mpc}) = 0.7 \pm 0.1$ (Freedman 1998). Assuming no matter creation ($\beta = 0$), the lower and upper limits of this value imply that the expansion age of a dust-filled flat universe, which is theoretically favored by inflation, would be either 10.8×10^9 years or 8.2×10^9 years. These results are in direct contrast to the measured ages of some stars and stellar systems, believed to be at least $(12 - 16) \times 10^9$ years old or even older if one adds a realistic incubation time (Bolte & Hogan 1995, Pont et al. 1998). As can easily be seen from (21), the matter creation process helps because for a given Hubble parameter H_o the expansion age t_o is always larger than $\frac{2}{3}H_o^{-1}$, which is the age of the universe for the FRW flat model. It is exactly H_o^{-1} for a coasting cosmology ($\beta = \frac{1}{3}$), and greater than H_o^{-1} for $\beta > \frac{1}{3}$. In this way, one may conclude that the matter creation ansatz (9) changes the predictions of standard cosmology, thereby alleviating the problem of reconciling observations with the inflationary scenario. It is interesting that matter creation increases the dimensionless parameter $H_o t_o$ while preserving the overall expanding FRW behavior.

b) Luminosity Distance-Redshift. The luminosity distance of a light source is defined as $d_l^2 = \frac{L}{4\pi l}$, where L and l are the absolute and apparent luminosities, respectively. In the standard FRW metric (1) it takes the form (Sandage 1961; Weinberg 1972)

$$d_l = R_o r(z)(1+z) \quad , \tag{22}$$

where $r(z)$ is the radial coordinate distance of the object at light emission. Starting from (1), this quantity can be easily derived as follows: since a light signal satisfies the geodesic equation of motion $ds^2 = 0$ and geodesics intersecting $r_o = 0$ are lines of constant θ and ϕ, the geodesics equation can be written as

$$\int_o^r dr = \int_{R(t)}^{R_o} \frac{dR(t')}{\dot{R}(t')R(t')} \quad . \tag{23}$$

Now, substituting (11) with the value of A given by (19) in the above equation, the radial coordinate distance as function of redshift is given by

$$r(z) = \frac{2}{(1-3\beta)R_o H_o}\left[1 - (1+z)^{\frac{3\beta-1}{2}}\right] \quad , \tag{24}$$

and therefore, the luminosity distance-redshift relation is written as

$$H_o d_l = \frac{2}{(1-3\beta)}\left[(1+z) - (1+z)^{\frac{1+3\beta}{2}}\right] \quad . \tag{25}$$

As one may check, when $\beta = 0$, the above expression reduces to

$$H_o d_l = 2\left[(1+z) - (1+z)^{\frac{1}{2}}\right] \quad , \tag{26}$$

which is the usual FRW result (Weinberg 1972). On the other hand, expanding (25) for small redshifts after some algebra one finds

$$H_o d_l = z + \frac{1}{2}(1 - \frac{1-3\beta}{2})z^2 + ... \quad , \tag{27}$$

which depends explicitly on the matter creation β parameter. However, inserting (18) we recover the usual FRW expansion for small redshifts, which depends only on the effective deceleration parameter q_o (Weinberg 1972; Kolb & Turner 1990). The luminosity distance as a function of the redshift is shown in Fig. 2. As expected, in these diagrams different models have the same behavior at $z << 1$ (Hubble law), and the possible discrimination among different models comes from observations at large redshifts ($z \geq 1$). However, it is usually believed that at such scales evolutionary effects cannot be neglected. The range of possible data at the limiting z for which evolutionary effects are not important are indicated by the data point and error bar (Kristian et al. 1978).

c) Angular Diameter-Redshift. The angular size θ of an object is an extremely sensitive function of the cosmic dynamics. In particular, the apparent continuity of the $\theta(z)$ relation for galaxies and quasars is also believed to be a strong support for the cosmological nature of the redshifts (Kapahi 1987). Here we are interested in angular diameters of light sources described as rigid rods and not as isophotal diameters. These quantities are naturally different, because in an expanding world the surface brightness varies with the distance (for more details see Sandage 1988).

Let D be the intrinsic size of a source located at $r(z)$, assumed independent of the redshift and perpendicular to the line of sight. If it emits photons at time t_1 that at time t_o reach an observer located at $r = 0$, its angular size at the moment of reception is defined by (Sandage 1961)

$$\theta = \frac{D(1+z)}{R_o r(z)} \quad . \tag{28}$$

Inserting the expression (24) for $r(z)$ into (28) we find

$$\theta = \frac{DH_o(1-3\beta)(1+z)^{\frac{3(1-\beta)}{2}}}{2\left[(1+z)^{\frac{1-3\beta}{2}} - 1\right]} \quad . \tag{29}$$

A log-log plot of angular size versus redshift is shown in Fig. 3 for selected values of β.

For all models, the angular size initially decreases with increasing z, reaches its minimum value at a given z_c, and eventually begins to increase for fainter magnitudes. This generic behavior for an expanding universe was predicted long ago in the context of the standard model (Hoyle 1959). It may be understood qualitatively in terms of an expanding space: the light observed today from a source at high z was emitted when the object was closer. How this effect depends on the β parameter? As can be seen from (29) the minimal value of which occur at $z_c(\beta) = [\frac{3(1-\beta)}{2}]^{\frac{2}{1-3\beta}} - 1$. As a result, the minimum persists in the presence of adiabatic matter creation, and is pushed to the right direction, that is, it is displaced to higher redshifts as the β parameter is increased. As expected, for $\beta = 0$ one finds $z_c = \frac{5}{4}$, which is the standard result for a dust filled FRW flat universe. It is also convenient to consider the limit of small redshifts in order to clarify the role played by β. Expanding (29) we have z

$$\theta = \frac{DH_o}{z}\left[1 + \frac{1}{2}(3 + \frac{1-3\beta}{2})z + ...\right] \quad . \tag{30}$$

Hence, "adiabatic" matter creation as modelled here also requires an angular size decreasing as the inverse of the redshift for small z. However, the second order term is a function of the β parameter. Its overall effect on the angular size distinguishes it from the Euclidean behavior ($\theta \approx z^{-1}$) more slowly than in the corresponding FRW model (see Fig. 3). In terms of q_o, inserting (18) into (30) gives

$$\theta = \frac{DH_o}{z}\left[1 + \frac{1}{2}(3 + q_o)z + ...\right] \quad , \tag{31}$$

which is formally the same FRW result for small redshifts (Sandage 1988). Note that even at this limit, constraints on the deceleration parameter from the data are equivalent to place limits on the values of β (see (18)).

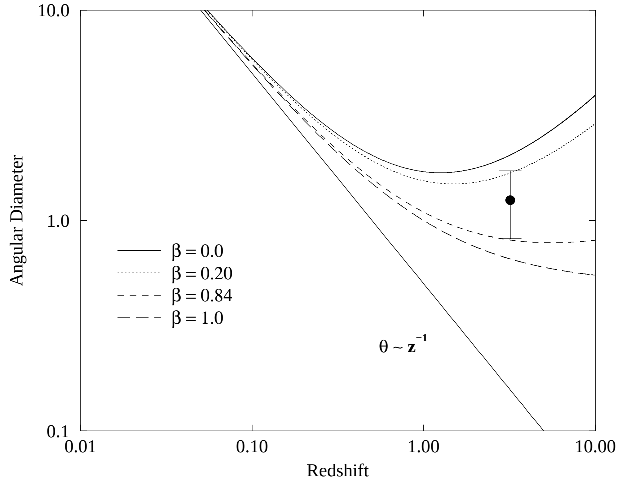

Fig. 3. Angular diameter versus redshift in flat models with adiabatic matter creation and selected values of β. The solid curve is the standard model ($\beta = 0$). The angular size reaches a minimum at a given z_c and increases for fainter magnitudes. The minimum is displaced for higher z as the β parameter is increased. The typical error bar and data point are taken from Gurvits (1994).

d) Number Counts. Let us now derive the galaxy number per redshift interval in the presence of adiabatic matter creation. We first notice that although modifying the evolution equation driving the amplification of small perturbations, and so the usual adiabatic treatment for galaxy formation, the created matter is smeared out and does not change the total number of sources present in the nonlinear regime. In other words, the number of galaxies already formed scales with R^{-3}.

Let $n_g(z,L)dL$ be the proper concentration of sources at redshift z with absolute luminosity between L and $L+dL$. The total number of galaxies $N_g(z)$ is proportional to the comoving volume

$$dN_g(z) = n_g dL dV_c = 4\pi n_g r^2 dr dL \quad . \tag{32}$$

Now, by using $\frac{dt}{R(t)} = \frac{dR}{R\dot{R}} = -dr$, we find that

$$\frac{dN_g}{4\pi n_g dz dL} = \frac{(R_o H_o)^{-1} r(z)^2}{\left[(1+z)^{3(1-\beta)/2}\right]} \quad , \tag{33}$$

where $n_g(z,L) = n_o(L)(1+z)^3$.

On the other hand, since the radial coordinate r(z) is given by Eq. (24) it follows that the expression for number-counts can be written as

$$\frac{(H_o R_o)^3 dN_g}{4\pi n_o z^2 dz dL} = \frac{\delta^2\left[1 - (1+z)^{-\frac{(1-3\beta)}{2}}\right]^2}{z^2(1+z)^{\frac{3(1-\beta)}{2}}} \quad , \tag{34}$$

where $\delta = \frac{2}{(1-3\beta)}$. For small redshifts, we have

$$\frac{(H_o R_o)^3 dN_g}{4\pi n_o z^2 dz dL} = 1 - 2\left[\frac{(1-3\beta)}{2} + 1\right]z + ... \quad . \tag{35}$$

The number count-redshift diagram for a dust-filled model with "adiabatic" matter creation is shown in Fig. 4, for the indicated values of β. Table 1 summarizes the limits to β obtained from each kinematic test.

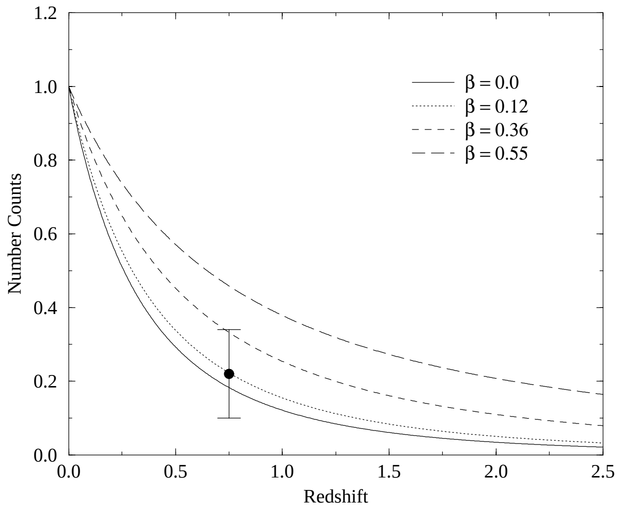

Fig. 4. Number counts as a function of the redshift for flat models with adiabatic matter creation. The solid curve is the standard Einstein-de Sitter model. The selected values of β are shown in the picture. Typical error bar and data point are taken from Loh & Spillar (1986).

3. Conclusion

The cosmological principle (homogeneity and isotropy of space) defines the shape of the line element up to a spatial scale function, which must be time dependent from the cosmological nature of the redshifts. As discussed here, the expanding "postulate" and its main consequences may also be compatible with a cosmic fluid endowed with adiabatic matter creation. The similarities and differences among universe models with matter creation, as described in the new thermodynamic approach, and the conventional matter conserved FRW model have been analysed from both formal and observational viewpoints. The rather slight changes introduced by the matter creation process, which is quantified by the β parameter, provides a reasonable fit of some cosmological data. Kinematic tests like luminosity distance, angular diameter and number-counts versus redshift relations perceptively constrain the matter creation parameter (see Table 1). For flat models with $\beta \neq 0$, the age of the universe is always greater than the corresponding FRW model ($\beta = 0$). More important still, the deceleration parameter q_o may be negative as suggested by recent type Ia supernovae observations. Related to this, the models studied here are alternatives to universes dominated by a cosmological constant or "quintessence".

The angular size versus redshift curves have the minimum displaced for higher values of z, thereby alleviating the problem in reconciling the angular size data from galaxies and quasars at intermediate and large redshifts. It is also interesting that all the theoretical and observational results previously obtained within a scenario driven by K-matter (Kolb 1989) are reproduced for a dust-filled universe with $\beta = \frac{1}{3}$.

In spite of these important physical consequences, the present matter creation rate, $\psi_o = 3n_oH_o \approx 10^{-16}$ nucleons $cm^{-3}yr^{-1}$, is nearly the same rate predicted by the steady-state universe (Hoyle et al. 1993). This matter creation rate is presently far below detectable limits.

Table 1. Limits to β

Test	β
Luminosity distance-redshift	$\beta \leq 0.48$
Angular size-redshift	$0.20 \leq \beta \leq 0.84$
Number counts-redshift	$\beta \leq 0.36$

The constraints on the β parameter should be compared with corresponding ones using the predictions of light element abundances from primordial nucleosynthesis. In fact, the important observational quantity for nucleosynthesis is the baryon-to-entropy ratio. In these models the temperature scale-factor relationship and entropy density are modified; therefore one may expect sensitive implications to the nucleosynthesis scenario.

Finally, it is not so difficult to widen the scope of the kinematic results derived here to include curvature effects, as well as a non-zero cosmological constant. In particular, concerning the "age problem", even closed universes seem to be compatible with the ages of the oldest globular clusters, when the value of the creation parameter is sufficiently high. Further details about kinematic tests in closed and opened universes with matter creation will be published elsewhere (Alcaniz & Lima 1999).

Acknowledgements. One of the authors (JASL) is grateful to Raul Abramo for helpful discussions. This work was partially supported by the project Pronex/FINEP (No. 41.96.0908.00) and Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (Brazilian Research Agency).

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