Anisotropic Universe Models with Positive Cosmological Constant

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Abstract Following the recognition of a positive value for the vacuum energy density and the realization that a simple Kantowski-Sachs model might fit the classical tests of cosmology, we study the qualitative behavior of three anisotropic and homogeneous models: Kantowski-Sachs, Bianchi type-I and Bianchi type-III universes, with dust and a cosmological constant, in order to find out which are physically permitted. We find that these models undergo isotropization up to the point that the observations will not be able to distinguish between them and the standard model, except for the Kantowski-Sachs model ($\Omega_{k0} < 0$) and for the Bianchi type-III ($\Omega_{k0} > 0$) with $\Omega_{k0}$ smaller than some critical value $\Omega_{k0}^{\text{crit}}$. Even if one imposes that the Universe should be nearly isotropic since the last scattering epoch ($z \approx 1000$), meaning that the Universe should have approximately the same Hubble parameter in all directions (considering the COBE 4-Year data), there is still a large range for the matter density parameter compatible with Kantowsky-Sachs and Bianchi type-III for $\Omega_k + \Omega_{\Lambda_0} - 1 \leq \delta$, for a very small $\delta$. The Bianchi type-I model becomes exactly isotropic owing to our restrictions and we have $\Omega_k + \Omega_{\Lambda_0} = 1$ in this case. Of course, all these models approach locally an exponential expanding state provided the cosmological constant $\Omega \Lambda > \Omega_{\Lambda_0}^{\text{crit}}$.

Keywords Cosmological Constant, Kantowsky-Sachs Model, Bianchi Models, Vacuum Energy Density, Isotropization, Hubble Parameter

1 Introduction

Over the last decade, the issue of whether or not there is a nonzero value for the vacuum energy density, or cosmological constant, has been raised quite often. Indeed, the possibility of a nonzero cosmological constant $\Lambda$ has been entertained several times in the past for theoretical and observational reasons (the early history of $\Lambda$ as a parameter in General Relativity has been reviewed by [1], [2], and [3]). Recent supernovae results [4], [5] strongly support a positive and possibly quite large cosmological constant. Even taking the Hubble constant to be in the range 60-75 km/s/Mpc it is possible to show [6] that the standard model of flat space with vanishing cosmological constant is ruled out. In a very nice review [7] it is argued that postulating an $\Omega_{\Lambda}$-dominated model seems to solve a lot of problems at once. And again, in a quite recent review on the physics and cosmology of the cosmological constant, it is added that “recent years have provided the best evidence yet that this elusive quantity does play an important dynamical role in the universe” [8].

On the other hand, if the classical tests of cosmology are applied to a simple Kantowski-Sachs metric and the results compared with those obtained for the standard model, the observations will not be able to distinguish between these models if the Hubble parameters along the orthogonal directions are assumed to be approximately equal [9]. Indeed, as [10] points out, the number of cosmological solutions which demonstrate exact isotropy well after the big bang origin of the Universe is a small fraction of the set of allowable solutions of the cosmological equations. It is therefore prudent to take seriously the possibility that the Universe is expanding anisotropically. Note also that some shear free anisotropic models display a FLRW-like behavior, as it is shown in [11].

2 The Global Behavior of the $\Lambda \neq 0$ Models

Taking all this into consideration, we discuss the behavior of some homogeneous but anisotropic models with axial symmetry, filled with a pressureless perfect fluid (dust) and a non vanishing cosmological constant. For this, we will restrict our study to the the metric forms

$$ds^2 = -c^2 dt^2 + a^2(t)dr^2 + b^2(t)(d\theta^2 + f_k^2(\theta)d\phi^2), \quad (1)$$

with the two scale factors $a(t)$ and $b(t)$; $k$ is the curvature index of the 2-dimensional surface $d\theta^2 + f_k^2(\theta)d\phi^2$ and can take the values $+1, 0, -1$ implying $f_k(\theta)$ equal $\sin(\theta)$, $\theta$, $\sinh(\theta)$, respectively, giving the following three
different metrics: Kantowski-Sachs, Bianchi type-I, and Bianchi type-III [12], [13].

Einstein equations for the metric (1), for which the matter content is in the form of a perfect fluid and a cosmological term, $\Lambda$, are then as follows [12], [13]:

\[
2 \frac{\ddot{a}}{a} + \frac{\dot{b}^2}{b^2} + \frac{k c^2}{b^2} = 8\pi G \rho + \Lambda c^2, \tag{2}
\]
\[
2 \frac{\ddot{b}}{b} + \frac{\dot{b}^2}{b^2} + \frac{k c^2}{b^2} = -8\pi G \frac{p}{c} + \Lambda c^2, \tag{3}
\]
\[
\frac{\ddot{a}}{a} + \frac{\dot{b}}{b} + \frac{\dot{a}}{a} \frac{\dot{b}}{b} = -8\pi G \frac{c^2}{c} + \Lambda c^2, \tag{4}
\]

where $\rho$ is the matter density and $p$ is the (isotropic) pressure of the fluid. Here $G$ is the Newton’s gravitational constant and $c$ is the speed of light. If we consider a vanishing pressure ($p = 0$), which is compatible with the present conditions for the Universe, the last two equations take the form

\[
2 \frac{\ddot{b}}{b} + \frac{\dot{b}^2}{b^2} + \frac{k c^2}{b^2} = \Lambda c^2, \tag{5}
\]
\[
\frac{\ddot{a}}{a} + \frac{\dot{b}}{b} + \frac{\dot{a}}{a} \frac{\dot{b}}{b} = \Lambda c^2, \tag{6}
\]

and equation (5) can easily be integrated to give

\[
\frac{\dot{b}^2}{b^2} = M_1 \frac{b^3}{b^3} - \frac{k c^2}{b^2} + \frac{\Lambda}{3} c^2, \tag{7}
\]

where $M_1$ is a constant of integration.

The Hubble parameters corresponding to the scale factors $a(t)$ and $b(t)$ are defined by

\[
H_a \equiv \frac{\dot{a}}{a} \quad \text{and} \quad H_b \equiv \frac{\dot{b}}{b}. \tag{8}
\]

Using them to introduce the following dimensionless parameters, in analogy with which it is usually done in the Friedmann-Lemaître-Robertson-Walker (FLRW) universes, let us define

\[
M_1 \frac{b^3}{b^3} H_b^2 \equiv \Omega_M, \tag{9}
\]

\[
\frac{k c^2}{b^2} \equiv \Omega_k, \tag{10}
\]

\[
\frac{\Lambda c^2}{3H_b^2} \equiv \Omega_\Lambda. \tag{11}
\]

The conservation equation (7) can now be rewritten as

\[
\Omega_M + \Omega_k + \Omega_\Lambda = 1. \tag{12}
\]

Now defining the dimensionless variable $y = b/b_0$ where $b_0 = b(t_0)$ is the angular scale factor for the present age of the Universe, and using equation (11) (taken for $t = t_0$), one may rewrite equation (7) as

\[
\dot{y} = \pm H_{b_0} \sqrt{\Omega_{M_0} \left( \frac{1}{y} - 1 \right) + \Omega_{\Lambda_0} (y^2 - 1) + 1}, \tag{13}
\]

where the density parameters defined previously and $H_{b_0}$ with the zero subscript, denote as before these quantities at the present time $t_0$. In this way, the number of independent parameters has been reduced. Substituting equation (7) into equation (2) gives

\[
\dot{a} = \frac{M_\rho - M_1 \frac{k}{3} + \frac{2}{3} \Lambda c^2 ab}{2 \sqrt{M_1 b - k c^2 b^2 + \frac{\Lambda}{3} c^2 b^4}}, \tag{14}
\]

where $M_\rho$ is a constant proportional to the matter in the Universe,

\[
M_\rho = 8\pi G \rho a b. \tag{15}
\]

Using the procedure above, equation (13) can be rewritten in the form

\[
\Omega_\rho - \Omega_M + 2 \Omega_\Lambda = 2 \frac{H_a}{H_b}, \tag{16}
\]

where

\[
\Omega_\rho = \frac{M_\rho}{a b^2 H_b^2}. \tag{17}
\]

From equation (2) one may define a matter density parameter. For this, we introduce the notion of mean Hubble factor $H$ such that $3H = H_a + 2H_b$. Also, for these models, the shear scalar $\sigma$ [13] is given by

\[
\sigma = \frac{1}{\sqrt{3}} (H_a - H_b). \tag{18}
\]

Thus, equation (2) may be rewritten [12] as

\[
3H^2 + \frac{k c^2}{b^2} = 8\pi G \rho + \sigma^2 + \Lambda c^2. \tag{19}
\]

As in FLRW we call critical matter density $\rho_c$ when $k = 0$ and $\Lambda = 0$

\[
\rho_c = \frac{3H^2 - \sigma^2}{8\pi G}. \tag{20}
\]

The matter density is generally defined as $\Omega = \rho / \rho_c$, then

\[
\Omega = \frac{8\pi G \rho}{3H^2 - \sigma^2} \equiv \frac{8\pi G \rho}{2H_a H_b + H_b^2}. \tag{21}
\]

just like in FLRW models, and such that $\Omega = 1$ when $k = 0$ and $\Lambda = 0$, and which is related to $\Omega_\rho$ by

\[
\Omega = \frac{\Omega_\rho}{1 + \frac{2H_a}{H_b}}, \tag{22}
\]

Although $\Omega_M$ is not the matter density parameter, it performs the same important role. We emphasize the fact that if for one particular time $H_a = H_b$ and $\Omega_\Lambda = 1$, then, by equations (11), (15) and (21), $3\Omega = \Omega_\rho = \Omega_M - \Omega_k$; and if $0 < \Omega_\Lambda \ll 1$ and $\Omega_M = 1$, then, $-\Omega_k = \Omega_\Lambda$ and $\Omega \approx 1$.

Introducing another dimensionless variable $x = a/a_0$, equation (13) takes the form

\[
x = H_{b_0} \frac{\Omega_{M_0} \left( \frac{1}{y} - 1 \right) + \Omega_{\Lambda_0} (y^2 - 1) + 1}{y \sqrt{\Omega_{M_0} \left( \frac{1}{y} - 1 \right) + \Omega_{\Lambda_0} (y^2 - 1) + 1}}, \tag{23}
\]

and its number of independent parameters was also reduced, now at the expense of equation (15) taken for the present time $t = t_0$.

Now, we want to find the time dependence of $b(t)$ in a qualitative way, starting from equation (12). Since the
model universe will be defined only where \( y^2 \geq 0 \), as was previously done by [14] for FLRW models, the problem is reduced to find out the zeros of \( \dot{y} \), with \( y \neq 0 \).

There are two \( \Omega_A \) values which characterize two zones of distinct behavior for the scale factor \( b \). Starting with condition \( \dot{y} = 0 \) one may obtain

\[
\Omega_{\lambda_0} = \frac{(\Omega_{M_0} - 1)y - \Omega_{M_0}}{y^3 - y}
\]

If we consider \( \Omega_{\lambda_0} = \Omega_{\lambda_0}(y) \), as a function of \( y \), then this function presents a relative minimum and a maximum, that we will denote by \( \Omega_{\lambda_L} \) and \( \Omega_{\lambda_M} \), respectively. The relative minimum depends on \( \Omega_{M_0} \) in the following way [14]: For \( \Omega_{M_0} < 1/2 \) we have

\[
\Omega_{\lambda_c} = \frac{3\Omega_{M_0}}{2} \left\{ \left[ \frac{(\Omega_{M_0} - 1)^2}{\Omega_{M_0}^2} - 1 + \frac{1}{\Omega_{M_0}} \right]^{1/3} + \frac{1}{\sqrt{(\Omega_{M_0} - 1)^2/\Omega_{M_0}^2 - 1 + (1 - \Omega_{M_0})/\Omega_{M_0}}} \right\}^{1/3}
\]

for \( \Omega_{M_0} \geq 1/2 \) the expression is

\[
\Omega_{\lambda_c} = -3\Omega_{M_0} \cos \left( \frac{\theta + 2\pi}{3} \right) - (\Omega_{M_0} - 1). \tag{25}
\]

The relative maximum is done by

\[
\Omega_{\lambda_M} = -3\Omega_{M_0} \cos \left( \frac{\theta + 4\pi}{3} \right) - (\Omega_{M_0} - 1), \tag{26}
\]

where \( \theta = \cos^{-1} \left( \frac{\Omega_{M_0} - 1}{\Omega_{M_0}} \right) \). These expressions are limiting zones of the \((\Omega_{\lambda_0}, \Omega_{M_0})\) plane, where \( \dot{y} = 0 \) has three or one solutions (for details see [14]). The \( \Omega_{\lambda_M} \) expression is also defined for \( \Omega_{M_0} > 1/2 \), but it has the meaning of a maximum only for \( \Omega_{M_0} > 1 \). The \( \Omega_{\lambda_0} \) less or equal to \( \Omega_{\lambda_M} \) imposes the recollapse of scale factor \( b \), while greater values produces inflexional behaviors for \( b \). The \( \Omega_{\lambda_0} \) values greater or equal to \( \Omega_{\lambda_M} \) are physically “forbidden” because they don’t reproduce the present Universe (see [14]). Obviously, \( \Omega_{\lambda_M} < \Omega_{\lambda_0} \) always.

Although we are considering anisotropic models, the equation (12) for \( \dot{y} \) as a function of \( \Omega_{M_0} \) is mathematically the same as equation (2) obtained by [14] for the homogeneous and isotropic FLRW models. From equations (12) and (22) one obtains the differential equation

\[
\frac{dx}{dy} = \frac{\Omega_{M_0} \left( 1 - \frac{x}{y} \right) + \Omega_{\lambda_0} ((-1 + x)y^2 - \frac{H_{\infty}}{\Omega_{M_0}})}{\Omega_{M_0} (1 - y) + \Omega_{\lambda_0} (y^2 - y) + y}. \tag{27}
\]

This equation automatically complies with the two conservation equations (11) and (15) evaluated at \( t_0 \). There are some particular values of the parameters \((\Omega_{M_0}, \Omega_{\lambda_0})\) for which this equation has exact solutions. However, for the majority of the values of the parameters, the solution has only been obtained by numerical integration.

We may admit that at a certain moment of time, which we can take as the present time \( t_0 \), the Hubble parameters along the orthogonal directions may be assumed to be approximately equal, \( H_a \approx H_b \), even though we started with an anisotropic geometry. This hypothesis has been considered in [9] for the case of a Kantowski-Sachs (KS) model. From this study we derived the conclusion that the classical tests of cosmology are not at present sufficiently accurate to distinguish between a FLRW model and the KS defined in that paper, with \((H_{\infty} \approx H_{b_0})\), except for small values of \( b_0 \).

Taking \( H_{\infty} = H_{b_0} \) for simplicity, one can then integrate equation (27) and find three different solutions, one for each \( k \) value. Figure 1 and Figure 2 shows the three kinds of behaviors as a result of integration.

![Figure 1](image1.png)

**Figure 1.** Scale factors relation, that is, the \( x - y \) dependence for the three models Kantowski-Sachs \((k = 1)\), Bianchi type-I \((k = 0)\) and Bianchi type-III \((k = -1)\). We show the behaviour of \( x(y) \) when \( \Omega_{\lambda_M} < \Omega_{\lambda_0} \). Concretely we have for Kantowski-Sachs \( \Omega_{M_0} = 9 \) and \( \Omega_{\lambda_0} = 1.5 \); for Bianchi type-I \( \Omega_{M_0} = 2 \) and \( \Omega_{\lambda_0} = -1 \); for Bianchi type-III \( \Omega_{M_0} = 1 \) and \( \Omega_{\lambda_0} = -1 \).

![Figure 2](image2.png)

**Figure 2.** Scale factors relation, that is, the \( x - y \) dependence for the three models Kantowski-Sachs \((k = 1)\), Bianchi type-I \((k = 0)\) and Bianchi type-III \((k = -1)\). We show the behaviour of \( x(y) \) when \( \Omega_{\lambda_M} < \Omega_{\lambda_0} \). The particular values for the plotting are, for Kantowski-Sachs \( \Omega_{M_0} = 2 \) and \( \Omega_{\lambda_0} = 1.5 \); for Bianchi type-I \( \Omega_{M_0} = 0.5 \) and \( \Omega_{\lambda_0} = 0.5 \); for Bianchi type-III \( \Omega_{M_0} = 0.2 \) and \( \Omega_{\lambda_0} = 0.4 \).

The behavior for the Kantowski-Sachs and Bianchi type-III cases depends on the \( \Omega_{\lambda_0} \) value. If \( \Omega_{\lambda_0} \leq \Omega_{\lambda_M} \), there will be a maximum value for \( y \), \( (y_m) \), and since then \( \dot{y}(y_m) = 0 \), the slope of the curve \( x = x(y) \) will be infinite at that point. Specifically, we have \( \dot{x}(y_m) = +\infty \) for Kantowski-Sachs, and \( \dot{x}(y_m) = -\infty \) for Bianchi type-III, even though \( x(y_m) \) is finite. When \( \Omega_{\lambda_M} < \Omega_{\lambda_0} < \Omega_{\lambda_0} \), after \( x = y = 1 \) is reached we find an almost linear
relation between the two scale factors $x$ and $y$ for the
two models. While for Bianchi type-I model we have
$x = y$ for the present restrictions. So, we see that for
the KS model, the scale factor $a(t)$ starts from infinity
if $b(t)$ starts from zero. For the Bianchi type-I model,
the scale factors are always proportional or even equal.
In this situation we don’t have an anisotropic model;
in fact, we can easily prove that this model is isotropic
by a properly reparametrization of the coordinates. For
the Bianchi type-III model, the scale factor $b(t)$ never
starts from zero, but has an initial value different from
zero when $a$ is null. The following plot shows the zones
in the 2-dimensional parameter space $(Ω_0, Ω_Λ)$ where
each model is allowed (Figure 3).

![Figure 3](image)

**Figure 3.** The Kantowski-Sachs model corresponds to the region above the straight line $(Ω_0 < 0)$; the Bianchi type-III model corresponds to the region below the straight line; $(Ω_0 > 0)$; the straight line represents the region for the Bianchi type-I model $(Ω_0 = 0)$. The grey zone is physically forbidden because do not reproduce the actual situation of the Universe. This zone is delimited by the equations $x = 0$, (24) and (25).

Taking into account the analysis given in [14], we may
easily derive the qualitative behavior of $y(t)$, since our
equation (12) is mathematically equivalent to his equa-
tion (3). Now, going back to Figure 1 and Figure 2, one
can then determine the $x(t)$. The plotting below sum-
marizes the several possibilities for the three models:
Kantowski-Sachs, Bianchi type-I and Bianchi type-III
models, respectively.

The present technology allows us to “see” the epoch
of last scattering of radiation at a redshift of about
1000, i.e., we can actually observe the most distant in-
formation that the Universe provides. The high level
of isotropy observed from the Cosmic Microwave Back-
ground Radiation (CMBR) [15] from this epoch to our
days imposes that the two Hubble factors $H_a$ and $H_b
must remain approximately equal from this epoch to
the present. In other words, we must impose a high
isotropy level from the last scattering onwards, in our
expressions, i.e.,

$$\frac{ΔH}{H_a} = \frac{H_a - H_b}{H_a},$$

such that $|ΔH/H_a| ≪ 1$. From COBE 4-Year data [16],
[17], we have $(σ/π)_0 \sim 10^{-9}$ and for last scattering epoch $(σ/π)_ls \sim 10^{-6}$. At the last scattering we may still con-
sider $H_a \simeq H_b \simeq H$ ($H$ defined above).

We computed several numerical integrations, with
equation (27), by the following way: we gave values to
$Ω_{M_0}$ and $Ω_Λ$ and integrated back in time, from now
to the last scattering epoch. These $Ω_{M_0}$ and $Ω_Λ$ values
were chosen such that, at last scattering we had $|ΔH/H|_ls = 1.7 \times 10^{-6}$ or $(dx/dy)_ls = 1 \pm 1.7 \times 10^{-6}$. To make this we implemented a 8 order
Runge-Kutta method [18].

We concluded that the sum $Ω_{M_0} + Ω_Λ$ must be close
to the unity from above for Kantowski-Sachs and from
below for Bianchi type-III models.

We summarized in the table below the result of imposing $|ΔH/H|_ls \sim 1.7 \times 10^{-6}$ for Kantowski-Sachs and Bianchi type-III models,
supposing $H_{in} = H_{ls}$ (because $(σ/π)_ls \sim 10^{-9}$).

From the table above we concluded that all combina-
tions of $Ω_0 + Ω_Λ$ near the unity are equally acceptable
for reproducing a small anisotropy ($σ/H)_ls \sim 10^{-6}$
at the last scattering. Nevertheless we paid special
attention to the values of $Ω_0 \sim 0.3$ and $Ω_Λ \sim 0.7,$
since they reproduce the better fit to recent observa-
tions [19]. We have in this scenario $|ΔH/H|_ls < 2 \times 10^{-6}$
for Kantowski-Sachs and Bianchi type-III universes. All
these models approach locally an exponential expand-
ing state [20] provided the cosmological constant if we
consider $Ω_Λ > Ω_{M_0}$.

### 3 Conclusions

For the Kantowski-Sachs model $(Ω_0 < 0)$ (see Figures
4 and 5), we conclude that if the scale factor $b(t)$ starts
from zero, then the scale factor $a(t)$ will start from in-
finity and decreases afterwards. When $Ω_Λ < Ω_{M_0}, b(t)$
reaches the maximum value recollapsing after that. So,
$a(t)$ will reach a relative maximum, when $b(t)$ is max-
imum, (see Figure 4). After that, when $b(t) = 0, a(t)$ goes
to infinity again. When $Ω_{M_0} < Ω_{M_Λ}$, the scale
factor $b(t)$ grows indefinitely, giving place to an infan-
tionary scenario. Then, $a(t)$ decreases reaching a
minimum value, and growing after that indefinitely, and
becoming proportional to $b(t)$ (see Figure 5). The initial
singularity is of a “cigar” type.

![Figure 4](image)

**Figure 4.** The scale factors $x$ and $y$ for the Kantowski-Sachs model $(Ω_0 = 0)$ when $Ω_Λ < Ω_{M_Λ}$. For the plotting we put $Ω_{M_0} = 9$ and $Ω_Λ = 1.5$.

1It is obvious that for Bianchi type-I model $(Ω_{M_0} + Ω_Λ = 1)$, with our restrictions, we have always $ΔH/H_a = 0$.  

Table 1. Density parameters and relative difference between $H_a$ and $H_b$ for Kantowsky-Sachs and Bianchi type-III models.

| $\Omega_{M_0}$ | $\Omega_{b_0}$ | $\Delta M_0$ | $\Delta b_0$ | $\Delta b_0 / M_0$ |
|----------------|----------------|-------------|-------------|------------------|
| K-S            | $1$            | $\lesssim 1.7 \times 10^{-4}$ | $1$         | $-1.6 \times 10^{-4}$ |
| K-S            | $\lesssim 10^{-15}$ | $1$         | $-1.4 \times 10^{-6}$ |
| K-S            | $\lesssim 0.3 + 0.7 \times 10^{-9}$ | $0.7$       | $-1.7 \times 10^{-6}$ |
| K-S            | $0.3$          | $\lesssim 0.6 + 0.7 \times 10^{-9}$ | $-1.7 \times 10^{-6}$ |
| B III          | $1 - 10^{-10}$ | $\lesssim 9.9 \times 10^{-11}$ | $+1.3 \times 10^{-6}$ |
| B III          | $\lesssim 9.8 \times 10^{-14}$ | $1 - 10^{-13}$ | $+1.3 \times 10^{-6}$ |
| B III          | $\lesssim 0.3 - 10^{-11}$ | $0.7$       | $+1.8 \times 10^{-6}$ |
| B III          | $0.3$          | $\lesssim 0.7 - 10^{-11}$       | $+1.8 \times 10^{-6}$ |

For the Bianchi type-I model ($\Omega_{b_0} = 0$) (see Figures 6 and 7), the scale factors $a(t)$ and $b(t)$ are proportional or even equal. Thus, this model turns out to be an isotropic one (owing to our restrictions) and $\Omega_0 + \Omega_{b_0} = 1$. However, when $\Omega_{A_0} < \Omega_{A_M}$, $a(t)$ and $b(t)$ reach the maximum and recollapse after that. And when $\Omega_{A_M} < \Omega_{A_0} < \Omega_{A_0}$, $a(t)$ and $b(t)$ grow indefinitely after an inflection.

For the Bianchi type-III model ($\Omega_{b_0} > 0$) (see Figures 8 and 9), when $\Omega_{A_0} < \Omega_{A_M}$, $b(t)$ starts from an initial non vanishing value ($b(t = 0) = b_0 > 0$), reaching a maximum and recollapsing after that until reaches the same value for $t = 0$. Also, $a(t)$ has a similar behavior, but starts from zero and recollapses to zero, nevertheless, $a(t)$ exhibits a relative minimum when $b(t)$ is maximum. When $\Omega_{A_M} < \Omega_{A_0} < \Omega_{A_0}$, $b(t)$ starts again from a non vanishing value ($b(t > 0)$, growing indefinitely with an inflection. In this case, $a(t)$ starts from zero and grows indefinitely becoming approximately proportional to $b(t)$. So, the initial singularity is of a “pancake” type.

In conclusion, these models undergo isotropization becoming an asymptotically FLRW, except for the Kantowski-Sachs model ($\Omega_{b_0} < 0$) with $\Omega_{A_0} < \Omega_{A_M}$ and for the Bianchi type-III ($\Omega_{b_0} > 0$) with $\Omega_{A_0} < \Omega_{A_M}$. Taking into account the accuracy of the measurements of anisotropy on one hand and the fact that we can always adjust the density parameters such that $|\Omega_0 + \Omega_{A_0} - 1| = \delta$, with $\delta \sim 10^{-9}$ on the other, we conclude that these...
The scale factors $x$ and $y$ for the Bianchi type-III model ($\Omega_k > 0$) when $\Omega_{M0} < \Omega_{\Lambda0} < \Omega_{\Lambda c}$. For the plotting we put $\Omega_{M0} = 0.2$ and $\Omega_{\Lambda0} = 0.4$.

models can still stand as good candidates to describe the observed Universe.

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