Supernova constraints on alternative models to dark energy

Yungui Gong* and Chang-Kui Duan†

Institute of Applied Physics and College of Electronic Engineering, Chongqing University of Posts and Communications, Chongqing 400065, China

16 October 2004

ABSTRACT
The recent observations of type Ia supernovae suggest that the universe is accelerating now and decelerated in the recent past. This may be the evidence of the breakdown of the standard Friedmann equation. The Friedmann equation \( H^2 = \rho \) modified to be a general form \( H^2 = g(\rho) \). Three models with particular form of \( g(\rho) \) are considered in detail. The supernova data published by Tonry et al. (2003) and Knop et al. (2003) are used to analyze the models. After the best fit parameters are obtained, we then find out the transition redshift \( z_T \) when the universe switched from the deceleration phase to the acceleration phase.

Key words: cosmological parameters–cosmology: theory–distance scale–supernovae: type Ia–radio galaxies: general

1 INTRODUCTION
The type Ia supernova observations suggest that the expansion of the universe is speeding up rather than slowing down (Perlmutter et al. 1998; Garnavich et al. 1998; Riess et al. 1998; Tonry et al. 2003; Knop et al. 2003). The measurements of the anisotropy of the cosmic microwave background favor a flat universe (de Bernardis et al. 2000; Hanany et al. 2000; Bennett et al. 2003; Spergel et al. 2003). The observation of type Ia supernova SN 1997ff at \( z \sim 1.7 \) also supports that the universe was in the deceleration phase in the recent past (Riess 2001). The transition from the deceleration phase to the acceleration phase happened around the redshift \( z_T \sim 0.5 \) (Turner & Riess 2002; Daly & Diergowski 2003). A form of matter with negative pressure widely referred as dark energy is usually introduced to explain the accelerating expansion. The simplest form of dark energy is the cosmological constant with the equation of state \( p = -\rho \). The cosmological constant model can be easily generalized to dynamical cosmological constant models, such as the dark energy model with the equation of state \( p = p_0 - \rho \), the generalized Chaplygin gas model with the equation of state \( p = -A/\rho^\alpha \), the tachyon field (Armendariz-Picon, Damour & Mukhanov 1999; Amendola et al. 2003; Cunha, Alcaniz & Lima 2004). In general, a scalar field \( Q \) that slowly evolves down its potential \( V(Q) \) takes the role of a dynamical cosmological constant (Caldwell, Dave & Steinhardt 1998; Zlatev, Wang & Steinhardt 1999; Ferreira & Joyce 1997; Sahni & Starobinsky 2000; Rubano & Barrow 2001; Johri 2002; Sen & Sethi 2002; Dvali, Gabadadze & Porrati 2002; Amendola et al. 2003; Bagla, Jassal & Padmanabhan 2003; Padmanabhan & Choudhury 2000; Sen & Sethi 2002; Dvali & Turner 2003; Chung & Freese 1999).

Although dark energy models are consistent with current observations, the nature of dark energy is still a mystery. Therefore it is possible that the observations show a sign of the breakdown of the standard cosmology. Some alternative models to dark energy models were proposed along this line of reasoning. These models are motivated by brane cosmology (Dvali, Gabadadze & Porrati 2002). In this scenario, our universe is a three-brane embedded in a five dimensional spacetime. The five dimensional action is

\[
S_5 = -\frac{1}{2\kappa_5} \int d^5x \sqrt{G} R + S_{\text{orb}} + S_{\text{boundary}} + S_{\text{GH}},
\]

where \( R \) is the curvature scalar, \( G \) is the determinant of the metric, \( \kappa_5 \) is the five dimensional gravitational constant, \( S_{\text{orb}} \) is the brane energy density, \( S_{\text{boundary}} \) is the brane tension, and \( S_{\text{GH}} \) is the Gauss-Bonnet term.

* E-mail: gongyg@cqupt.edu.cn
† E-mail: duanck@cqupt.edu.cn
where $R$ is the Ricci scalar in five dimensions, $G$ is the five dimensional metric determinant, $\kappa_5$ is the five dimensional Newton's constant, $S_{orb}$ is the orbifold action, $S_{\text{boundary}}$ represents the boundary action and $S_{\text{GH}}$ is the Gibbons-Hawking boundary terms. In these models, the usual Friedmann equation $H^2 = \frac{8\pi G}{3} \rho$ is modified to a general form $H^2 = g(\rho)$ and the universe is composed of the ordinary matter only \citep{Freese_2002, Freese_2003, Gondolo_2003, Sen_2003a, Sen_2003b, Zhu_2003a, Zhu_2003b, Zhu_2003c, Zhu_2004, Wang_2003, multama_2003, Multamaki_2004, Dev_2003, Alcaniz_2003, Frith_2004, Gong_2004, Gong_2003, Gong_2003a, Gong_2003b, Gong_2003c, Gong_2004a, Gong_2004b, Gong_2004c}. One particular example is the brane cosmology with $g(\rho) \sim \rho + \rho^2$. In order to retain the success of the standard cosmology at early times, we require that the modified cosmology recovers the standard cosmology at early times. So $g(\rho)$ must satisfy $g(\rho) \sim \rho$ when $\rho \gg \rho_0$, where $\rho_0$ is the current matter energy density.

For a spatially flat, isotropic and homogeneous universe with both an ordinary pressureless dust matter and a minimally coupled scalar field $Q$ sources, the Friedmann equations are

$$H^2 = \left(\frac{a}{a_0}\right)^2 = \frac{8\pi G}{3} \rho_m (\rho + \rho_Q),$$

$$\ddot{a} = \frac{8\pi G}{3} (\rho_m + \rho_Q + 3p_Q),$$

where dot means derivative with respect to time, $\rho_m = \rho_{\text{m0}}(a_0/a)^3$ is the matter energy density, a subscript 0 means the value of the variable at present time, $p_Q = Q^2/2 + V(Q)$, $\rho_Q = Q^2/2 - V(Q)$ and $V(Q)$ is the potential of the quintessence field. The modified Friedmann equations for a spatially flat universe are

$$H^2 = H_0^2 g(x),$$

$$\ddot{a} + H_0^2 g(x) = \frac{3H_0^2 x}{2} g(x) \left(\frac{\rho + p}{\rho}\right),$$

$$\dot{\rho} + 3H(\rho + p) = 0,$$

where $x = 8\pi G \rho p / 3H_0^2 = x_0 (1+z)^3$ during the matter dominated epoch, $z = z_0 / a_0 / a$ is the redshift parameter, $g(x) = x + \cdots$ is a general function of $x$ and $g'(x) = dq / dx$. Note that the universe did not start to accelerate when the other nonlinear terms in $g(x)$ started to dominate. To recover the standard cosmology at early times, we require that $g(x) \approx x$ when $x \gg x_0$. For the matter dominated flat universe, $\rho = \rho_m$ and $p = \rho_m$. Let $\Omega_{m0} = 8\pi G \rho_{m0} / 3H_0^2$, then $x_0 = \Omega_{m0}$, $g(x_0) = 1$ and $x = \Omega_{m0}(1+z)^3$ during the matter dominated era.

The luminosity distance $d_L$ is defined as

$$d_L(z) = a_0 (1+z) \int_0^{t_0} \frac{dt'}{a(t')} = \frac{1+z}{H_0} \int_0^z g^{-1/2} \Omega_{m0}(1+u)^3 du.$$

The apparent magnitude redshift relation is

$$m(z) = M + 5 \log_{10} d_L(z) + 25 = M + 5 \log_{10} D_L(z) = M + 5 \log_{10} \left(1+z \int_0^z g^{-1/2} \Omega_{m0}(1+u)^3 du\right),$$

where $D_L(z) = H_0 d_L(z)$ is the “Hubble-constant-free” luminosity distance, $M$ is the absolute peak magnitude and $M = M + 5 \log_{10} H_0 + 25$. $M$ can be determined from the low redshift limit at where $D_L(z) = z$. The parameters in our model are determined by minimizing

$$\chi^2 = \sum_i \frac{(m_{\text{obs}}(z_i) - m(z_i))^2}{\sigma_i^2},$$

where $\sigma_i$ is the total uncertainty in the observations. The $\chi^2$ minimization procedure is based on MINUIT code. We use the 54 supernova data with both the stretch correction and the host-galaxy extinction correction, i.e., the fit 3 supernova data by \cite{Knop_2003}, the 20 radio galaxy and 78 supernova data by \cite{Daly_2003}, and the supernova data by \cite{Tonry_2003} to find the best fit parameters. In the fit, the range of parameter space for $M$ is $M = [-3.9, 3.2]$, the range of parameter space for $\Omega_{m0}$ is $\Omega_{m0} = [0, 4]$. The transition from deceleration to acceleration happens when the deceleration parameter $q = -\ddot{a} / a H^2 = 0$. From equations (4) and (6), we have

$$g[\Omega_{m0}(1+z)^3] = \frac{3}{2} \Omega_{m0}(1+z)^3 g'[\Omega_{m0}(1+z)^3],$$

$$q_0 = \frac{3}{2} \Omega_{m0} g'[\Omega_{m0}] - 1.$$

To compare the modified model with the dark energy model, we make the following identification

$$\omega_Q = \frac{xg'(x) - g(x)}{g(x) - x}.$$

2 Chaplygin gas model

The Chaplygin gas model $p = -A / \rho^\alpha$ in the framework of alternative model to dark energy is

$$g(x) = x + \Omega_{Q0}[A_s + (1 - A_s)(x / \Omega_{Q0})^{\beta}]^{1/\beta},$$

where $\Omega_{Q0} = 1 - \Omega_{m0}$, $\beta = 1 + \alpha$ and $A_s = (8\pi G / 3H_0^2 \Omega_{Q0})^\alpha A$. The $\alpha = 1$ model is motivated by a d-brane in $d+2$ spacetime. Since $g'(x) = 1 + \Omega_{Q0}(1-A_s) / [A_s + (1-A_s) (x / \Omega_{Q0})^{\beta}]^{2/\beta-1} / (x / \Omega_{Q0})^{\beta}$, so

$$\Omega_{m0} \Omega_{Q0} / (1+z_0)^3 = [A_s + (1-A_s)(1+z_0)^{3\beta}]^{1-1/\beta}$

$$= A_s - 1/2 (1-A_s)(1+z_0)^{3\beta},$$

$$q_0 = 1/2 - \frac{3}{2} A_s (1 - \Omega_{m0}).$$

$q_0 < 0$ gives that $A_s > (1 - \Omega_{m0})^{-1}/3$. To retain the success of the standard model at early epochs, we require $g(x) \approx x$ when $x \gg 1$. In other words, we require $A_s \sim 1$. Therefore, we have the following constraints

$$(1 - \Omega_{m0})^{-1}/3 < A_s < 1,$$

$$A_s \sim 1.$$

The best fits to the 54 supernovae by \cite{Knop_2003} are $\Omega_{m0} = [0, 0.44]$ centered at almost zero, $A_s = [0.99, 1]$ centered at almost one and $\beta = [1, 3.23]$ centered at 22.0 with $\chi^2 = 43.9$. The best fits to the 98 radio galaxy and supernova data compiled by \cite{Daly_2003} are
Supernova constraints on alternative models to dark energy

3 GENERALIZED CARDASSIAN MODEL

The model is
\[ g(x) = x[1 + Bx^{\alpha(n-1)}]^{1/\alpha}, \]
where \( B = (\Omega_{\text{mo}}^{\alpha} - 1)/\Omega_{\text{mo}}^{\alpha(n-1)}, \) \( \alpha > 0 \) and \( n < 1 - 1/3(1 - \Omega_{\text{mo}}^{\alpha}) \). When \( n = 0 \), \( g(x) = B^{1/\alpha}(1 + x^n/B)^{1/\alpha} \) which is the case studied by Freese [2003]. For the special case \( \alpha = 1 \) and \( n = 0 \), \( g(x) = x + B \) which is the standard cosmology with a cosmological constant. From a purely phenomenological point of view we may think that gravity is modified in such a way that acceleration kicks in when the energy density approaches a certain value [Carroll 2003]. The model is motivated from a three-brane located at the \( Z_2 \) symmetry fixed plane of a five dimensional spacetime. Chung and Freese showed that if one parametrizes the Hubble rate in terms of the brane energy density, then Cardassian model is derived with suitable choice of the five dimensional energy momentum tensor [Chung & Freese 1999]. The generalized Cardassian model gives
\[ g'(x) = [1 + Bx^{\alpha(n-1)}]^{1/\alpha} + (n-1)Bx^{\alpha(n-1)}[1 + Bx^{\alpha(n-1)}]^{1/\alpha-1}, \]
(17)
Combining equation (17) with equations (10) and (11), we get
\[ 1 + z_T = [(\Omega_{\text{mo}}^{\alpha} - 1)(2 - 3n)]^{1/3(1-n)}, \]
(18)
\[ q_0 = \frac{1}{2} + \frac{3}{2}(n-1)(1 - \Omega_{\text{mo}}^{\alpha}). \]
(19)
If we think the generalized Cardassian model as ordinary Friedmann universe composed of matter and dark energy, we can identify the following relationship for the parameters in the Cardassian and quintessence models
\[ \omega_0 = \frac{n-1}{1 - \Omega_{\text{mo}}^{\alpha}}. \]

There are four parameters in the fits: the mass density \( \Omega_{\text{mo}} \), the parameters \( n \) and \( \alpha \), as well as the nuisance parameter \( \mathcal{M} \). The range of parameter space explored is: \( n = [-10, 0.66] \) and \( \alpha = (0, 10^7] \). The best fits to the supernova data [Daly & Döring 2003; Tonry et al. 2003; Knop et al. 2003] generally give very large \( \alpha > 100 \), so \( B \approx \Omega_{\text{mo}}^{\alpha} \) and the transition redshift is weakly dependent on \( \alpha \). Furthermore, \( \chi^2 \) changes very little when \( \alpha \) changes over a fairly large range. In other words, the generalized Cardassian model differs little from the Cardassian gas model tends to be the \( \Lambda \) model.

\[ \omega_0 = \begin{cases} 0, & \text{if } \alpha = 1 \end{cases} \]
So we will discuss the Cardassian model in more detail below.

3.1 Cardassian Model

The Cardassian model is the special case \( \alpha = 1 \) of the generalized Cardassian model. This model is equivalent to the dark energy model with a constant equation of state \( p_0 = \omega_0 \rho_0 \) in the sense of dynamical evolution. The equivalence is provided by \( n = 1 + \omega_0 \) and the equivalent dark energy potential is \( V(Q) = A[\sinh(Q/\alpha + C)]^{-\alpha} \) with \( \alpha = \frac{1}{2} - 2/(n-1) \). The best fits to the 54 supernovae by Knop et al. [2003] are \( \Omega_{\text{mo}} = 0.56^{+0.09}_{-0.12}, n = -3.0^{+2.2}_{-3.4} \) and \( \chi^2 = 43.73 \). The \( \Omega_{\text{mo}} \) and \( n \) contour plot is shown in figure [1].

The best fits to the 98 radio galaxy and supernova data compiled by Daly & Döring [2003] are \( \Omega_{\text{mo}} = 0.14^{+0.32}_{-0.14}, n = 0.26^{+0.21}_{-0.16} \) and \( \chi^2 = 87.45 \). The contour plot is shown in figure [2].

The best fits to the 172 supernovae with redshift \( z > 0.01 \) and \( A_v < 0.5 \) mag [Tonry et al. 2003] are \( \Omega_{\text{mo}} = 0.48^{+0.18}_{-0.18}, n = -1.2^{+1.6}_{-1.2} \) and \( \chi^2 = 171.4 \). The best fits to the 194 supernovae by Tonry et al. [2003] and Barris et al. [2004] are \( \Omega_{\text{mo}} = 0.51^{+0.08}_{-0.16}, n = -1.2^{+1.9}_{-1.2} \) and \( \chi^2 = 196.7 \). The contour plot is shown in figure [3]. The plot agrees well with the figure 13 in Tonry et al. [2004] and the figure 6 in Frith [2004].

The above results are summarized in table [1]. Combining the above results, we find that \( \Omega_{\text{mo}} = [0.6] \) centered at 0.45 and \( n = [-3.1, 0.5] \) centered at 0.6 at 99% confidence level. The 99% contour plot is shown in figure [4]. Take \( \Omega_{\text{mo}} = 0.3 \), we get \( z_T = 0.35, q_0 = -3.1 \) and \( \omega_0 = -3.44 \) when \( n = -2.44 \). \( z_T = 0.57, q_0 = -0.24 \) and \( \omega_0 = -0.7 \) when \( n = 0.3 \). These results are consistent with those obtained by Zhu & Fujimoto [2003a,b,c]. Zhu, Fujimoto & He [2003] and Sen & Set [2003].
4 MODEL 3

The last model we would like to consider is \(g(x) = (a + \sqrt{a^2 + x^2})^2\) \cite{Dvali:2003}, where \(a = (1 - \Omega_m)/2\). This model arises from the brane world theory by \cite{Dvali:2000}, in which gravity appears four dimensional at short distances while modified at large distances. For this model, we find that the equivalent dark energy equation of state parameter \(\omega_Q\), \(q_0\) and the transition redshift \(z_T\) from decelerated expansion to accelerated expansion are

\[
\omega_Q = -1/(1 + \Omega_m), \quad q_0 = 2\Omega_m - 1, \quad 1 + z_T = \left[2(1 - \Omega_m)^2/\Omega_m\right]^{1/3}.
\] (22)

Applying the 54 supernova data with host-galaxy extinction correction \cite{Knop:2003}, we find that \(\Omega_m = 0.19_{-0.07}^{+0.08}\) and \(\chi^2 = 45.71\). The 20 radio galaxy and the 78 supernovae compiled by Daly & Djorgovski \cite{Daly:2000} give the best fit \(\Omega_m = 0.18 \pm 0.03\) and \(\chi^2 = 87.6\). The best fit from the 172 supernovae with redshift \(z > 0.01\) and \(A_v < 0.5\) mag listed in Tonry et al. \cite{Tonry:2003} is \(\Omega_m = 0.17_{-0.05}^{+0.04}\) and \(\chi^2 = 175.2\). If we use the 194 supernovae given by \cite{Tonry:2003} and \cite{Barris:2004}, we find that \(\Omega_m = 0.22_{-0.03}^{+0.04}\) and \(\chi^2 = 200.6\). The above results are summarized in table 2.

Combining the above results, we get \(\Omega_m = 0.20 \pm 0.02\) at 1σ level or \(\Omega_m = 0.20_{-0.06}^{+0.07}\) at 3σ level. If we take \(\Omega_m = 0.15\), then we have \(q_0 = -0.61\) and \(z_T = 1.13\). If we take \(\Omega_m = 0.21\), then we have \(q_0 = -0.48\) and \(z_T = 0.81\). If we take \(\Omega_m = 0.28\), then we have \(q_0 = -0.34\) and \(z_T = 0.55\). These results are consistent with those obtained by \cite{Dvali:2000}.

### Table 1. Best fits to Cardassian model

| Fit # | \(\Omega_m\) 70% | 99% | \(n\) 70% | 99% | \(\chi^2\) |
|-------|------------------|-----|-------------|-----|---------|
| 1     | 0.56_{-0.12}^{+0.17} | -3.6_{-3.4}^{+2.2} | -3.6_{-3.4}^{+2.2} | 43.73 |
| 2     | 0.14_{-0.14}^{+0.48} | 0.26_{-0.21}^{+0.21} | 0.26_{-0.21}^{+0.21} | 87.45 |
| 3     | 0.48_{-0.48}^{+0.15} | -1.2_{-1.9}^{+1.1} | -1.2_{-1.9}^{+1.1} | 171.4 |
| 4     | 0.51_{-0.51}^{+0.14} | -1.2_{-1.9}^{+1.1} | -1.2_{-1.9}^{+1.1} | 196.7 |
| 5     | 0.45_{-0.45}^{+0.15} | -0.6_{-1.1}^{+0.7} | -0.6_{-1.1}^{+0.7} | 332.0 |

**Figure 2.** The 70% and 99% confidence contours of \(\Omega_m\) and \(n\) in Cardassian model from 20 radio galaxies and 78 supernovae compiled by Daly & Djorgovski \cite{Daly:2000}

**Figure 3.** The 70%, 95% and 99% confidence contours of \(\Omega_m\) and \(n\) in Cardassian model from the 172 supernovae with \(z > 0.01\) and \(A_v < 0.5\) mag listed in Tonry et al. \cite{Tonry:2003}

**Figure 4.** The 99% confidence contours of \(\Omega_m\) and \(n\) in Cardassian model from the sample data in Tonry et al. \cite{Tonry:2003}, Daly & Djorgovski \cite{Daly:2000} and Knop et al. \cite{Knop:2003}
Table 2. Best fits to model 3

| Data source | #  | $\Omega_{\text{tot}}$ | $\chi^2$ | $z_T$ | $\omega_Q$ |
|-------------|----|-------------------|--------|------|--------|
|            |    | 1$\sigma$ | 3$\sigma$ |        |        |
| Knop        | 54 | $0.19^{+0.07}_{-0.05}$ | $0.19^{+0.12}_{-0.12}$ | 45.71 | 0.90   | -0.84  |
| Daly        | 98 | 0.18 ± 0.03     | 0.18$^{+0.07}_{-0.07}$ | 87.6   | 0.95   | -0.85  |
| Tonry       | 172| $0.17^{+0.04}_{-0.03}$ | $0.17^{+0.14}_{-0.09}$ | 175.2  | 1.0    | -0.85  |
| Barris      | 194| $0.22^{+0.04}_{-0.03}$ | $0.22^{+0.13}_{-0.09}$ | 206.6  | 0.77   | -0.82  |
| Combined    | 346| 0.20 ± 0.02     | 0.20$^{+0.07}_{-0.06}$ | 334.6  | 0.86   | -0.83  |

5 DISCUSSIONS AND CONCLUSIONS

A general function $g(x)$ of the ordinary matter density was used to explain the current accelerating expansion of the universe. In this model, no exotic matter form is needed. This approach is equivalent to dark energy model building approach in the sense of dynamical evolution of the universe because we can map the modified part of energy density to dark energy. The function $g(x)$ satisfies the following conditions: (1) $g(x_0) = 1$; (2) $g(x) \approx x$ when $z \gg 1$; (3) $g(x_0) > 2\Omega_m g'(x_0)/2$, where $x = \Omega_m(1+z)^3 + \Omega_r(1+z)^4$. The generalized Chaplygin gas model tends to take the form of the dark energy model with a cosmological constant. Therefore the generalized Chaplygin gas model is disfavored in the framework of alternative models although it is a viable dark energy model. Unlike the gravitational lensing constraint, the supernova data do not provide tight constraint on the generalized Cardassian model. A fairly large range of parameters from the generalized Cardassian model are consistent with the supernova data. For the Cardassian model, the supernova data give $\Omega_m = [0.02, 0.62]$ and $n = [-3.11, 0.3]$ at the 99% confidence level. If we have better constraint on the transition redshift $z_T$, then we will be able to distinguish the Cardassian model from the $\Lambda$ model because the $\Lambda$ model is the special case $n = 0$. For the model 3, we find that $\Omega_m = [0.12, 0.28]$ with 99.7% confidence. Only the upper limit gives $z_T \sim 0.5$.

ACKNOWLEDGMENTS

The author Gong would like to thank Tonry for pointing out the program he used to compute $\chi^2$ in his webpage, the author Gong is also grateful to the discussion with Frith. The work is supported by Chongqing University of Post and Telecommunication under grants A2003-54 and A2004-05.

REFERENCES

Alcaniz J S 2003 Preprint [astro-ph/0312424]
Amendola L et al. 2003 J. Cosmology Astroparticle Phys. 0307 005
Armendariz-Picon C, Damour T and Mukhanov V 1999 Phys. Lett. B 458 209
Avelino P P et al. 2003 Phys. Rev. D 67 023511 (Preprint astro-ph/0208528)
Bagnoli G, Mazzotta P, Vagnozzi L and Pagliaroli C 2003 J. Phys. Conden. Matter 15 725
Bagla J S, Jassal H K and Padmanabhan T 2003 Phys. Rev. D 67 063504
Barris B J et al. 2004 Astrophys. J. 602 571 (Preprint astro-ph/0310843)
Bennett C L et al. 2003 Astrophys. J. Supp. 148 1
Bento M C, Bertolami O and Sen A A 2002 Phys. Rev. D 66, 043507
Bilic N, Tupper G G and Vioillier R D 2002 Phys. Lett. B 535 17
Caldwell R R 2002 Phys. Lett. B 545 23
Caldwell R R, Dave R and Steinhardt P J 1998 Phys. Rev. Lett. 80 1582
Carroll S M 2003 Preprint [astro-ph/0310314]
Carturan D and Finelli F 2003 Phys. Rev. D 68 103501
Chimento L P 2003 Preprint [astro-ph/0311613]
Chung D J and Freese K 1999 Phys. Rev. D 61 023511
Cunha J V, Alcaniz J S and Lima J A S 2004 Phys. Rev. D 69 033001 (Preprint astro-ph/03106319)
Daly R A and Djorgovski S G 2003 Astrophys. J. 597 9
De Bernardis P et al. 2000 Nature 404 955
Deffayet C et al. 2002 Phys. Rev. D 66 024019
Dev A, Alcaniz J S and Jain D 2003 Preprint astro-ph/0305068
Di Pietro E and Demaret J 2001 Int. J. Mod. Phys. D 10 231
Dvali G, Gabadadze G & Porrati M 2000 Phys. Lett. B 485 208
Dvali G R and Turner M 2003 Preprint [astro-ph/03041510]
Ferreira P G and Joyce M 1997 Phys. Rev. Lett. 79 4740
Ferreira P G and Joyce M 1998 Phys. Rev. D 58 023503
Freese K 2003 Nucl. Phys. Suppl. 124 50
Freese K and Lewis M 2002 Phys. Lett. B 540 1
Frits W J 2004 Mon. Not. Roy. Astron. Soc. 348 916 (Preprint astro-ph/0311211)
Garnavich P M et al. 1998 Astrophys. J. 493 L53
Gondolo P and Freese K 2003 Phys. Rev. D 68 063509
Gong Y 2002 Class. Quantum Grav. 19 4537
Gong Y 2004 Preprint astro-ph/0404202
Gong Y and Duan C K 2003 Preprint gr-qc/0311060
Gong Y, Chen X M and Duan C K 2004 will appear in Mod. Phy. Lett. A (Preprint astro-ph/0404202)
Hanany S et al. 2000 Astrophys. J. 545 L5
Johri B V 2002 Class. Quantum Grav. 19 5959
Kamenshchik A, Moschella U and Pasquier V 2001 Phys. Lett. B 511 265
Kaplinghat M and Bridle S 2003 Preprint astro-ph/0312430
Knop R A et al. 2003 Preprint astro-ph/0309368
Multamaki T, Gaztanaga E and Manera M 2003 Mon. Not. Roy. Astron. Soc. 344 761
Padmanabhan T 2003 Phys. Rep. 380 235
Padmanabhan T and Choudhury T R 2002 Phys. Rev. D 66 081301
Padmanabhan T and Choudhury T R 2003 Mon. Not. Roy. Astron. Soc. 344 823
Perlmuter S, Turner M S and White M 1999 Phys. Rev. Lett. 83 670
Perlmuter S et al. 1998 Nature 391 51
Perlmuter S et al. 1999 Astrophys. J. 517 565
Ratra B and Peebles P J E 1988 Phys. Rev. D 37 3406
Riess A G 2001 Astrophys. J. 560 49
Riess A G et al. 1998 Astron. J. 116 1009
Rubano C and Barrow J D 2001 Phys. Rev. D 64 127301
Sahni V and Starobinsky A A 2000 Int. J. Mod. Phys. D 9 373
Sen S and Sen A A 2003a Astrophys. J. 588 1
Sen A A and Sen S 2003b Phys. Rev. D 68 023513
Sen A A and Sethi S 2002 Phys. Lett. B 532 159
Spergel D N et al. 2003 Astrophys. J. Supp. 148 175
Tonry J L et al. 2003 Astrophys. J. 594 1 (Preprint astro-ph/0305008)
Turner M S and Riess A G 2002 Astrophys. J. 569 18
Ureña-López L A and Matos T 2000 Phys. Rev. D 62 081302
Wang Y et al. 2003 Astrophys. J. 594 25
Zhu Z H and Fujimoto M 2003a Astrophys. J. 581 1
Zhu Z and Fujimoto M 2003b Astrophys. J. 585 52
Zhu Z H and Fujimoto M 2003c Astrophys. J. 602 12 (Preprint astro-ph/0312022)
Zhu Z H, Fujimoto M and He X T 2003 Astrophys. J. 603 365
Zlatev I, Wang L and Steinhardt P J 1999 Phys. Rev. Lett. 82 896