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Testing the DGP model with gravitational lensing statistics

Zong-Hong Zhu[1,2] and M. Sereno[3]

[1] Department of Astronomy, Beijing Normal University, Beijing 100875, PR China
e-mail: `zhuzh@bnu.edu.cn`
[2] Institut d'Astrophysique Spatiale (IAS), CNRS & Univ. Paris-Sud, Bâtiment 121, 91405 Orsay, France
[3] Institut für Theoretische Physik, Universität Zürich, Winterthurerstrasse 190, 8057 Zürich, Switzerland
e-mail: `sereno@physik.unizh.ch`

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ABSTRACT

Aims. The self-accelerating braneworld model (DGP) appears to provide a simple alternative to the standard ΛCDM cosmology to explain the current cosmic acceleration, which is strongly indicated by measurements of type Ia supernovae, as well as other concordant observations.

Methods. We investigate observational constraints on this scenario provided by gravitational-lensing statistics using the Cosmic Lens All-Sky Survey (CLASS) lensing sample.

Results. We show that a substantial part of the parameter space of the DGP model agrees well with that of radio source gravitational lensing sample.

Conclusions. In the flat case, $\Omega_{\rm K} = 0$, the likelihood is maximized, $\mathcal{L} = \mathcal{L}_{\rm max}$, for $\Omega_{\rm M} = 0.30^{+0.19}_{-0.11}$. If we relax the prior on $\Omega_{\rm K}$, the likelihood peaks at $\{\Omega_{\rm M}, \Omega_{r_c}\} \simeq \{0.29, 0.12\}$, slightly in the region of open models. The confidence contours are, however, elongated such that we are unable to discard any of the close, flat or open models.

Key words. cosmological parameters – cosmology: theory – gravitational lensing – quasars: general

1. Introduction

The accelerating expansion of our universe was first discovered by the measurements of distant type Ia supernovae (SNe Ia; Riess et al. 1998; Perlmutter et al. 1999), and was confirmed by the observations of the cosmic microwave background anisotropies (WMAP: Bennett et al. 2003), and the large-scale structure in the distribution of galaxies (SDSS: Tegmark et al. 2004a,b). By assuming General Relativity, a dark-energy component has been invoked as the most feasible mechanism for the acceleration. However, although fundamental to our understanding of the Universe, its nature (as well as the nature of dark matter) remains a completely open question.

Among the several alternatives to dark energy, the models that use branes and extra dimensions to obtain an accelerating universe are particularly interesting (Randall & Sundrum 1999a,b). The general principle behind such models is that our 4-dimensional universe would be a brane embedded into a higher dimensional spacetime bulk on which gravity can propagate. One famous brane world model is proposed by Dvali et al. (2000), which is widely referred to as the DGP model. This scenario describes a self-accelerating, 5-dimensional, brane world model with a noncompact, infinite-volume, extra dimension in which the dynamics of gravitational interaction is governed by a competition between a 4-dimensional, Ricci scalar term, induced on the brane, and an ordinary 5-dimensional, Einstein-Hilbert action. For scales below a crossover radius $r_{\rm c}$ (where the induced 4-dimensional, Ricci scalar dominates), the gravitational force experienced by two punctual sources is the usual 4-dimensional $1/r^2$ force, whereas for distance scales larger than $r_{\rm c}$ the gravitational force follows the 5-dimensional $1/r^3$ behavior. The Friedmann equation is modified as follows

$$H^2 = H_0^2\left[\Omega_{\rm K}(1+z)^2 + \left(\sqrt{\Omega_{r_c}} + \sqrt{\Omega_{r_c} + \Omega_{\rm M}(1+z)^3}\right)^2\right] \qquad (1)$$

where H is the Hubble parameter as a function of redshift z (H_0 is its value at the present), $\Omega_{\rm K}$, Ω_{r_c} and $\Omega_{\rm M}$ represent the fractional contribution of curvature, the bulk-induced term and the matter (both baryonic and nonbaryonic), respectively. Ω_{r_c} is defined to be $\Omega_{r_c} \equiv 1/4r_c^2H_0^2$. From Eq. (1), the DGP model is a testable scenario with the same number of parameters as the standard ΛCDM model.

The advantages of the DGP model has triggered interest to constrain its model parameters using cosmological observations, such as the magnitude-redshift relation of supernovae of type Ia (Avelino & Martins 2002; Deffayet et al. 2002; Zhu & Alcaniz 2005; Maartens & Majerotto 2006; Barger et al. 2007; Movahed et al. 2007), the cosmic microwave background shift parameter from WMAP and the baryon acoustic oscillation peak from SDSS (Guo et al. 2006; Lazkoz et al. 2006; Rydbeck et al. 2007; He et al. 2007), the angular size – redshift data of compact radio sources (Alcaniz 2002), the age measurements of high-z objects (Alcaniz et al. 2002), the lookback time to galaxy clusters (Pires et al. 2006), the optical gravitational-lensing surveys (Jain et al. 2002), the observed Hubble parameter $H(z)$ data (Wan et al.), and large-scale structure (Multamäki et al. 2003; Lue et al. 2004; Koyama & Maartens 2006; Song et al. 2007). For a recent review on the DGP phenomenology, see Lue (2006).

In this paper, we consider the observational constraints on the parameters of the DGP model introduced by the Cosmic

Lens All-Sky Survey (CLASS) lensing data set. Our results are in agreement with other recent analyses, which provides a complementary test to the DGP model.

Gravitational lensing has been becoming a useful tool for modern astrophysics. It provides cosmological tests in several ways, such as gravitational-lensing statistics (Kochanek 1996; Zhu 1998; Cooray & Huterer 1999; Chiba & Yoshii 1999; Chae et al. 2002; Sereno 2005), weak-lensing surveys (Benabed & Bernardeau 2001), Einstein rings in galaxy-quasar systems (Yamamoto & Futamase 2001), clusters of galaxies acting as lenses on background high-redshift galaxies (Sereno 2002; Sereno & Longo 2004; Sereno 2007), and gravitational lens time-delay measurements (Schechter 2004). Results from techniques based on gravitational lensing are complementary to other methods and can provide restrictive limits on the acceleration mechanism. The aim of the current paper is to check the validity of the DGP model with radio-selected gravitational-lensing statistics. We adopt the Cosmic Lens All-Sky Survey (CLASS) statistical data, which consists of 8958 radio sources out of which 13 sources are multiply imaged (Browne et al. 2003; Chae et al. 2002). We analyse only multiply-imaged sources whose image-splittings are known to be caused by single early-type galaxies, which reduces the total number of lenses to 10. We show that a large parameter space of the DGP model is in good agreement with this radio-source gravitational lensing sample. The maximum likelihood occurs for $\{\Omega_{\rm M}, \Omega_{r_c}\} \simeq \{0.29, 0.12\}$, slightly in the region of open models.

The paper is organized as follows. In Sect. 2, the basics of gravitational-lensing statistics is introduced. Properties of the CLASS sample and its statistical analysis are illustrated in Sect. 3. Finally, we present our conclusions and discussion in Sect. 4.

2. Basics of gravitational lensing statistics

A realistic statistical analysis of gravitational lenses can be performed based on simple assumptions (Kochanek 1996; Chae 2003; Sereno 2005, and references therein). The standard approach is based on the observed number count of galaxies, and on the simple, singular isothermal sphere (SIS) model for lens galaxies.

The differential probability that a background source is lensed by a background galaxy of velocity dispersion between σ and $\sigma + {\rm d}\sigma$, and in the redshift interval from $z_{\rm d}$ to $z_{\rm d} + {\rm d}z_{\rm d}$, is

$$\frac{{\rm d}^2\tau}{{\rm d}z_{\rm d}{\rm d}\sigma} = \frac{{\rm d}n_{\rm G}}{{\rm d}\sigma}(z_{\rm d}, \sigma) s_{\rm cr}(\sigma) \frac{c{\rm d}t}{{\rm d}z_{\rm d}}, \tag{2}$$

where $s_{\rm cr}$ is the cross section for the lensing event, and $\frac{{\rm d}n_{\rm G}}{{\rm d}\sigma}$ is the differential number density of the lens population. For a conserved, comoving number density of lenses, $n_{\rm G}(z) = n_0(1+z)^3$.

The lens distribution can be modeled using a modified Schechter function of the form (Sheth et al. 2003)

$$\frac{{\rm d}n_0}{{\rm d}\sigma} = n_* \left(\frac{\sigma}{\sigma_*}\right)^{\alpha} \exp\left[-\left(\frac{\sigma}{\sigma_*}\right)^{\beta}\right] \frac{\beta}{\Gamma(\alpha/\beta)} \frac{1}{\sigma}, \tag{3}$$

where α is the faint-end slope, β the high-velocity cut-off, and n_* and σ_* are the characteristic number density and velocity dispersion, respectively. Early-type or late-type populations contribute to the lensing statistics in different ways and type-specific galaxy distributions are required. As a conservative approach, we do not consider lensing by spiral galaxies. The description of the late-type galaxy population is plagued by large uncertainties and they contribute no more than 20–30% of the total lensing optical depth. A proper modeling of the distribution of the lensing galaxies is central to the lensing statistics. In our analysis, we use the results of Choi et al. (2007) who analyzed data from the the SDSS Data Release 5 to derive the velocity dispersion distribution function of early-type galaxies. They found $n_* = 8.0 \times 10^{-3}\ h^3\ {\rm Mpc}^{-3}$, where h is H_0 in units of 100 km s^{-1} Mpc^{-1}, $\sigma_* = 144 \pm 5$ km s^{-1}, $\alpha = 2.49 \pm 0.10$, and $\beta = 2.29 \pm 0.07$.

Early-type galaxies can be well approximated as singular isothermal spheres. As shown in Maoz & Rix (1993) and Kochanek (1996), radial mass distribution, ellipticity and core radius of the lens galaxy are unimportant in altering the cosmological limits. Assuming a flat model of universe, a typical axial ratio of 0.5, for a mixed population of oblate and prolate spheroids, would induce a shift of $\sim$0.04 in the estimation of $\Omega_{\rm M}$ (Mitchell et al. 2005), well below statistical uncertainties. Since departures from spherical symmetry induce a relatively small effect on lens statistics and the distribution of mass ellipticities is highly uncertain, spherically-symmetric models supply a viable approximation. The cross section of a SIS is

$$s_{\rm cr} = 16\pi^3 \left(\frac{\sigma}{c}\right)^4 \left(\frac{D_{\rm d} D_{\rm ds}}{D_{\rm s}}\right)^2, \tag{4}$$

where $D_{\rm d}$, $D_{\rm ds}$ and $D_{\rm s}$ are the angular diameter distances between the observer and the deflector, the deflector and the source, and the observer and the source, respectively. The two multiple images will form at an angular separation

$$\Delta\theta = 8\pi \left(\frac{\sigma}{c}\right)^2 \frac{D_{\rm ds}}{D_{\rm s}}, \tag{5}$$

which relates the image separation to the velocity dispersion of the lens galaxy. The total optical depth for multiple imaging of a compact source, τ, the probability that a SIS forms multiple images of a background source with angular separation $\Delta\theta$, ${\rm d}\tau/{\rm d}\Delta\theta$, and the probability of lensing by a deflector at $z_{\rm d}$, ${\rm d}\tau/{\rm d}z_{\rm d}$, can be obtained by integrating the differential probability in Eq. (2).

Lensing probabilities must be corrected for the magnification bias B, i.e. the tendency of gravitationally-lensed sources to be preferentially included in flux-limited samples due to their increased apparent brightness (Turner 1990; Fukugita & Turner 1991; Fukugita et al. 1992; Kochanek 1993). The bias factor for a source at redshift $z_{\rm s}$ with apparent magnitude m is given by

$$\begin{aligned} \boldsymbol{B}(m, z, M_0) &= \left(\frac{{\rm d}N_{\rm s}}{{\rm d}m}\right)^{-1} \\ &\times \int_{M_0}^{+\infty} \frac{{\rm d}N_{\rm s}}{{\rm d}m}(m + 2.5 \log M, z) P(M) {\rm d}M, \end{aligned} \tag{6}$$

M_0 being the minimum magnification of a multiply-imaged source, with value $M_0 = 2$; $P(M){\rm d}M = 2M_0^2 M^{-3}{\rm d}M$ is the probability that a multiple image-lensing event causes a total flux increase by a factor of M (Kochanek 1993). The function ${\rm d}N_{\rm s}/{\rm d}m$ is the differential source number count in magnitude bins ${\rm d}m$. Furthermore, since observations have finite resolution and dynamic range, lens discovery rates are affected by the ability to resolve multiple-source images (Kochanek 1993). Lensing probabilities must then account for the resolution limit of the survey. For the SIS model, selection effects can be characterized by the maximum magnitude difference that can be detected for two images separated by $\Delta\theta$, $\Delta m(\Delta\theta)$, which determines a minimum total magnification $M_f = M_0(f+1)/(f-1)$, where $2.5 \log f \equiv \Delta m$ (Kochanek 1993).

Finally, the likelihood function can be written as (Kochanek 1993; Chae et al. 2002)

$$\mathcal{L} = \prod_{i=1}^{N_{\rm U}} (1 - p_i) \prod_{j=1}^{N_{\rm L}} p_{l,j}, \tag{7}$$

where $N_{\rm L}$ is the number of multiple-imaged sources and $N_{\rm U}$ is the number of unlensed sources. $p_{\rm l}$ is a probability that takes into account all of the data available for each lens system, i.e. the lens redshift and/or the image separation (Chae et al. 2002; Mitchell et al. 2005). Probabilities are corrected for bias and selection effects.

Since $\tau \ll 1$, the likelihood can be approximated as (Mitchell et al. 2004)

$$\mathcal{L} \simeq \exp\left[- \int N_z(z_{\rm s}) p(z_{\rm s}) {\rm d}z_{\rm s} \right] \prod_{j=1}^{N_{\rm L}} p_{l,j}, \tag{8}$$

where $N_z(z_{\rm s})$ is the redshift distribution of the sources. We use a uniform distribution for the priors on the cosmological parameters, so that, apart from an overall normalization factor, the likelihood can be identified with the posterior probability.

3. Data analysis

In this section, we discuss the radio-survey used for our lensing statistics and present the constraints on the parameters of the DGP model.

3.1. Data set

The most reliable data set suitable for a robust statistical analysis is that of 8958 flat-spectrum radio sources with 13 lenses from the Cosmic Lens All-Sky Survey (CLASS; Browne et al. 2003; Myers et al. 2003). Data of interest are listed in Table 1 of (Chae 2005). We limit our analysis to the early-type lens galaxies. Ten systems in the CLASS sample (0445+123, 0631+519, 0712+472, 1152+199, 1359+154, 1422+231, 1608+656, 1933+503, 2114+022 and 2319+051) are assumed to be early-type lenses (Chae 2005). We do not consider the information on the image separation in 1359+154, 1608+656 and 2114+022 whose splittings are strongly affected by galaxy companions close to the main lens.

The final CLASS statistical sample was selected such that, for doubly-imaged systems, the flux ratio was less than or equal to 10, and independent of the angular separation. According to the selection criteria, the compact radio-core images have separations greater than $\Delta\theta_{\rm min} = 0.3$ arcsec. The probabilities that enter the likelihood must be considered as the probabilities of producing image systems with separations $\geq \Delta\theta_{\rm min}$. Taking into account the CLASS observational selection function, Chae (2007) found a magnification bias of $B \simeq 3.36$ for the SIS.

Redshift measurements are only available for a restricted CLASS subsample. Following Sereno (2005), we model the redshift distribution $N_z(z_{\rm s})$ of the sources using a kernel empirical estimator. For the unmeasured lensed source redshifts, we set $z_{\rm s}$ to be the mean redshift of the sources lensed by early-type galaxies with measured redshift, $\langle z_{\rm s} \rangle_{\rm lensed} = 2.2$.

3.2. Statistical analysis

We perform a statistical analysis of our selected data subsample. As a first step, we fix the galactic parameters to their central values. We consider the related uncertainty at a later stage. In the flat case, $\Omega_{\rm K} = 0$, the likelihood is maximized, $\mathcal{L} = \mathcal{L}_{\rm max}$, for $\Omega_{\rm M} = 0.30^{+0.19}_{-0.11}$: see Fig. 1. Uncertainties denote the statistical 68.3% confidence limit for one parameter, calculated to be $\mathcal{L}/\mathcal{L}_{\rm max} = \exp(-1/2)$.

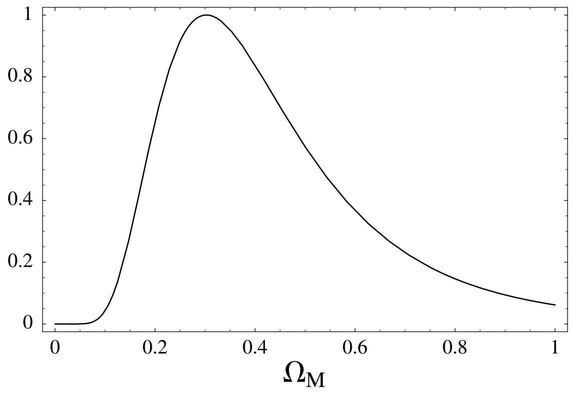

Fig. 1. Normalized likelihood, $\mathcal{L}/\mathcal{L}_{\rm max}$, as a function of $\Omega_{\rm M}$ for a flat geometry, $\Omega_{\rm K} = 0$.

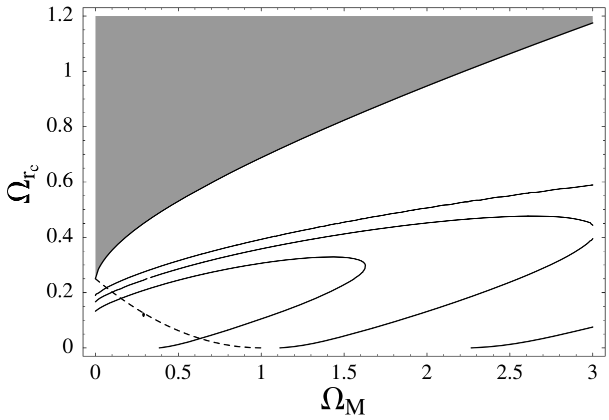

Fig. 2. Normalized likelihood, $\mathcal{L}/\mathcal{L}_{\rm max}$, in the $\Omega_{\rm M} - \Omega_{r_c}$ plane. The dot shows the best fit model and the contours denote the 68.3%, 95.4% and 99.7% confidence limits for two parameters. The dashed line represents the locus of flat models of universe ($\Omega_{\rm K} = 0$); bouncing models in the upper-left shaded region do not have big bang.

Even if we relax the prior on $\Omega_{\rm K}$, the likelihood peaks for nearly flat models. In fact, the likelihood is a maximum for $\{\Omega_{\rm M}, \Omega_{r_c}\} \simeq \{0.29, 0.12\}$, almost in the region of open models (see Fig. 2). The three contours in the figure correspond to the 68.3%, 95.4% and 99.7% confidence limits for two parameters, namely $\mathcal{L}/\mathcal{L}_{\rm max} = \exp(-2.30/2)$, $\exp(-6.17/2)$ and $\exp(-11.8/2)$, respectively. However, the contours are rather elongated, and are unable to rule out close, flat or open models.

Uncertainties in the redshift distribution of the sources can induce additional errors in the estimates of the cosmological parameters. A source of error is the finite size of the data set of measured source redshifts (only 27 source redshifts are known), which induces an error in the estimated redshift distribution. Using a bootstrap-resampling procedure, we creat a set of simulated distributions, which are used to create a new kernel estimator for the redshift distribution. It can be shown that the finite size of the data set induces a dispersion of ~0.08 on $\Omega_{\rm M}$ (Sereno 2005). On the other hand, the cosmological constraints are almost insensitive to the functional form used when modeling the redshift distribution. Conclusions are unaffected if a Gaussian distribution is used instead of the kernel estimator. Our results change in a negligible way if we use different values of z_s for the lensed sources with unknown redshift.

The main uncertainty in the estimation of cosmological parameters arises from errors in the assumed parameters of the velocity-dispersion distribution function, which describes the lens population. To estimate the source of this error, we simulated 100 sets of galactic parameters, by extracting values from normal distributions centered on the estimated parameter value and of a standard deviation given by the associated measurement uncertainty. The likelihood analysis was then repeated for each set of galactic parameters. Assuming flat cosmological models, the resulting distribution of the maximum likelihood estimates has a scatter of $\sim$0.09, which provides a similar uncertainty in the determination of $\Omega_{\rm M}$.

Finally a theoretically-important systematic uncertainty caused by small-scale inhomogeneities on large-scale observations. Matter distribution is locally inhomogeneous and affects light propagation and the related cosmological distances (Sereno et al. 2001, 2002, and references therein). However, the effect on the total lensing statistics is small, because the universe is globally homogeneous (Covone et al. 2005).

4. Conclusion and discussion

Since the discovery of the accelerating expansion of the universe, a large number scenarios, in addition to the standard ΛCDM cosmological model, have been proposed to describe the acceleration mechanism (for a recent review, see: Sahni & Starobinsky 2000; Padmanabhan 2003; Lima 2004; Copeland et al. 2006; Alcaniz 2006). Examples include the so-called "X-matter" (Turner & White 1997; Zhu et al. 2001; Alcaniz et al. 2003b; Dai et al. 2004; Rupetti et al. 2007; Wang et al. 2007), a decaying vacuum energy density or a time varying Λ-term (Ozer & Taha 1987; Vishwakarma 2001), an evolving scalar field, dubbed quintessence (Ratra & Peebles 1988; Caldwell et al. 1988; Wang & Lovelace 2001; Gong 2002; Chen & Ratra 2004; Choudhury & Padmanabhan 2005; Ichikawa et al. 2006), the phantom energy, in which the sum of the pressure and energy density is negative (Caldwell 2002; Dabrowski et al. 2003; Wang et al. 2004; Wu & Yu 2005, 2006; Chang et al. 2007), the Chaplygin gas (Kamenshchik et al. 2001; Bento et al. 2002; Alam et al. 2003; Alcaniz et al. 2003a; Dev et al. 2003; Silva & Bertolami 2003; Makler et al. 2003; Zhu 2004; Zhang & Zhu 2006), the quintom model (Feng et al. 2005; Guo et al. 2005; Zhao et al. 2005; Xia et al. 2006; Wei & Zhang 2007), the holographic dark energy (Li 2004; Zhang & Wu 2005; Chang et al. 2006), the Cardassion model (Freese & Lewis 2002; Zhu & Fujimoto 2002, 2003; Sen & Sen 2003; Wang et al. 2003; Gong & Duan 2004a,b; Wang 2005; Bento et al. 2006; Reboul & Cordoni 2006; Yi & Zhang 2007) and the Casimir force (Szydlowski & Godlowski 2007; Godlowski et al. 2007). All of these acceleration mechanisms should be tested using astronomical observations.

In this paper, we focused our attention on the DGP model. We analyzed the scenario using the Cosmic Lens All-Sky Survey sample (Browne et al. 2003; Myers et al. 2003) to obtain the 68.3%, 95.4% and 99.7% confidence regions on its parameters. It is shown that a large parameter space of the DGP model is consistent with this radio-source gravitational-lensing data set. In the flat case, $\Omega_{\rm K} = 0$, the likelihood is maximized, $\mathcal{L} = \mathcal{L}_{\rm max}$, for $\Omega_{\rm M} = 0.30^{+0.19}_{-0.11}$. If we relax the prior on $\Omega_{\rm K}$, the likelihood peaks at $\{\Omega_{\rm M}, \Omega_{r_c}\} \simeq \{0.29, 0.12\}$, slightly in agreement with open models. The obtained confidence regions of Fig. 2 are in good agreement with results from analyzing data of type Ia supernovae (Zhu & Alcaniz 2005), which implies that gravitational-lensing statistics provides an independent and complementary constraint on the DGP model. However, as for the data of type Ia supernovae, the confidence contours are rather elongated and we are unable to rule out close, flat or open models, using the CLASS data set. Using the *gold* sample of type Ia supernovae (SNeIa), the first year data from the Supernova Legacy Survey (SNLS) and the baryon acoustic oscillation (BAO) peak found in the Sloan Digital Sky Survey (SDSS), Guo et al. (2006) obtained, at a 99.73% confidence level, $\Omega_{\rm m} = 0.270^{+0.018}_{-0.017}$ and $\Omega_{r_c} = 0.216^{+0.012}_{-0.013}$ (hence a spatially-closed universe with $\Omega_{\rm k} = -0.350^{+0.080}_{-0.083}$), which appears to be in contradiction with the most recent WMAP results indicating a flat universe. Based on this result, the authors estimated that the transition redshift, at which the universe switches from deceleration to acceleration, is $0.70 < z_{q=0} < 1.01$, at 2σ confidence level. Therefore, the approach of combining observational data sets provides much stronger constraint on the DGP model, than any single data set. In the future, it should be possible to obtain yet stronger constraints on DGP model parameters, using larger gravitational-lensing data sets and a joint investigation with other astronomical observations.

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References

Alam, U., Sahni, V., Saini, T. D., & Starobinsky, A. A. 2003, MNRAS, 334, 1057
Alcaniz, J. S. 2002, Phys. Rev. D, 65, 123514
Alcaniz, J. S. 2006, Braz. J. Phys., 36, 1109
Alcaniz, J. S., Jain, D., & Dev, A. 2002, Phys. Rev. D, 66, 067301
Alcaniz, J. S., Jain, D., & Dev, A. 2003a, Phys. Rev. D, 67, 043514
Alcaniz, J. S., Lima, J. A. S., & Cunha, J. V. 2003b, MNRAS, 340, L39
Avelino, P. P., & Martins, C. J. A. P. 2002, ApJ, 565, 661
Barger, V., Gao, Y., & Marfatia, D. 2007, Phys. Lett. B, 648, 127
Benabed, K., & Bernardeau, F. 2001, Phys. Rev. D, 64, 083501
Bennett, C. L., Halpern, M., Hinshaw, G., et al. 2003, ApJS, 148, 1
Bento, M. C., Bertolami, O., & Sen, A. A. 2002, Phys. Rev. D, 66, 043507
Bento, M. C., Bertolami, O., Reboucas, M. J., & Santos, N. M. C. 2006, Phys. Rev. D, 73, 103521
Browne, I. W. A., Wilkinson, P. N., Jackson, N. J. F., et al. 2003, MNRAS, 341, 13
Caldwell, R. 2002, Phys. Lett. B, 545, 23
Caldwell, R., Dave, R., & Steinhardt, P. J. 1998, Phys. Rev. Lett., 80, 1582
Chae, K.-H. 2003, MNRAS, 346, 746
Chae, K.-H. 2005, ApJ, 630, 764
Chae, K.-H. 2007, ApJ, 658, L71
Chae, K.-H., Biggs, A. D., Blandford, R. D., et al. 2002, Phys. Rev. Lett., 89, 151301
Chang, Z., Wu, F.-Q., & Zhang, X. 2006, Phys. Lett. B, 633, 14
Chang, B., Liu, H., Xu, L., Zhang, C., & Ping, Y. 2007, JCAP, 0701, 016
Chen, G., & Ratra, B. 2004, ApJ, 612, L1
Chiba, M., & Yoshii, Y. 1999, ApJ, 510, 42
Choi, Y.-Y., Park, C., & Vogeley, M. S. 2007, ApJ, 658, 884
Choudhury, T. R., & Padmanabhan, T. 2005, A&A, 429, 807
Cooray, A. R., & Huterer, D. 1999, ApJ, 513, L95
Copeland, E. J., Sami, M., & Tsujikawa, S. 2006, Int. J. Mod. Phys. D, 15, 1753
Covone, G., Sereno, M., & de Ritis, R. 2005, MNRAS, 357, 773
Dabrowski, M. P., Stochowiak, T., & Szydlowski, M. 2003, Phys. Rev. D, 68, 103519
Dai, Z., Liang, E. W., & Xu, D. 2004, ApJ, in press [`arXiv:astro-ph/0407497`]
Deffayet, C., Landau, S. J., Raux, J., Zaldarriaga, M., & Astier, P. 2002, Phys. Rev. D, 66, 024019

Dev, A., Jain, D., & Alcaniz, J. S. 2003, Phys. Rev. D, 67, 023515

Dvali, G., Gabadadze, G., & Porrati, M. 2000, Phys. Lett. B, 485, 208

Feng, B., Wang, X., & Zhang, X. 2005, Phys. Lett. B, 607, 35

Freese, K., & Lewis, M. 2002, Phys. Lett. B, 540, 1

Fukugita, M., & Turner, E. L. 1991, MNRAS, 253, 99

Fukugita, M., Futamase, T., Kasai, M., & Turner, E. L. 1992, ApJ, 393, 3

Gong, Y. 2002, Class. Quan. Grav., 19, 4537

Gong, Y., & Duan, C. K. 2004a, Class. Quan. Grav., 21, 3655

Gong, Y., & Duan, C. K. 2004b, MNRAS, 352, 847

Guo, Z.-K., Piao, Y.-S., Zhang, X., & Zhang, Y.-Z. 2005, Phys. Lett. B, 608, 177

Guo, Z.-K., Zhu, Z.-H., Alcaniz, J. S., & Zhang, Y.-Z. 2006, ApJ, 646, 1

He, J.-H., Wang, B., & Papantonopoulos, E. 2007 [gr-qc/07071180]

Ichikawa, K., Kawasaki, M., Sekiguchi, T., & Takahashi, T. 2006, JCAP, 0612, 005

Jain, D., Dev, A., & Alcaniz, J. S. 2002, Phys. Rev. D, 66, 083511

Kamenshchik, A., Moschella, U., & Pasquier, V. 2001, Phys. Lett. B, 511, 265

Kochanek, C. S. 1993, ApJ, 419, 12

Kochanek, C. S. 1996, ApJ, 473, 595

Koyama, K., & Maartens, R. 2006, JCAP, 0601, 016

Lazkoz, R., Maartens, R., & Majerotto, E. 2006, Phys. Rev. D, 74, 083510

Lima, J. A. S. 2004, Braz. J. Phys., 34, 194

Lue, A. 2006, Phys. Rep., 423, 1

Lue, A., Scoccimarro, R., & Starkman, G. D. 2004, Phys. Rev. D, 69, 124015

Maartens, R., & Majerotto, E. 2006, Phys. Rev. D, 74, 023004

Makler, M., Oliveira, S. Q., & Waga, I. 2003, Phys. Rev. D, 68, 123521

Maoz, D., & Rix, H.-W. 1993, ApJ, 416, 425

Mitchell, J. L., Keeton, C. R., Frieman, J. A., & Sheth, R. K. 2005, ApJ, 622, 81

Movahed, M. S., Farhang, M., & Rahvar, S. 2007 [arXiv:astro-ph/0701339]

Multamäki, T., Gaztanaga, E., & Manera, M. 2003, MNRAS, 344, 761

Myers, S. T., Jackson, N. J., Browne, I. W. A., et al. 2003, MNRAS, 341, 1

Ozer, M., & Taha, O. 1987, Nucl. Phys. B, 287, 776

Padmanabhan, T. 2003, Phys. Rept., 380, 235 [hep-th/0212290]

Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ, 517, 565 [arXiv:astro-ph/9812133]

Pires, N., Zhu, Z.-H., & Alcaniz, J. S. 2006, Phys. Rev. D, 73, 123530

Randall, L., & Sundrum, R. 1999a, Phys. Rev. Lett., 83, 3370

Randall, L., & Sundrum, R. 1999b, Phys. Rev. Lett., 83, 4690

Ratra, B., & Peebles, P. J. E. 1988, Phys. Rev. D, 37, 3406

Reboul, H., & Cordoni, J.-P. 2006 [arXiv:astro-ph/0601703]

Riess, A. G., Filippenko, A. V., Challis, P., et al. 1998, AJ, 116, 1009

Rupetti, D., Allen, S. W., Amin, M. A., & Blandford, R. D. 2007, MNRAS, 375, 1510

Rydbeck, S., Fairbain, M., & Goobar, A. 2007, JCAP, 0705, 003

Sahni, V., & Starobinsky, A. 2000, Int. J. Mod. Phys. D, 9, 373

Schechter, P. 2004 [arXiv:astro-ph/0408338]

Sen, A. A., & Sen, S. 2003, ApJ, 588, 1

Sereno, M. 2002, A&A, 393, 757

Sereno, M. 2005, MNRAS, 356, 937

Sereno, M. 2007, MNRAS, 377, 229

Sereno, M., & Longo, G. 2004, MNRAS, 354, 1255

Sereno, M., Covone, G., Piedipalumbo, E., & de Ritis, R. 2001, MNRAS, 327, 517

Sereno, M., Piedipalumbo, E., & Sazhin, M. V. 2002, MNRAS, 335, 1061

Sheth, R. K., Bernardi, M., Schechter, P. L., et al. 2003, ApJ, 594, 225

Silva, P. T., & Bertolami, O. 2003, ApJ, 599, 829

Song, Y.-S., Sawicki, I., & Hu, W. 2007, Phys. Rev. D, 75, 064003

Tegmark, M., Strauss, M. A., Blanton, M. R., et al. 2004a, Phys. Rev. D, 69, 103501

Tegmark, M., Blanton, M. R., Strauss, M. A., et al. 2004b, ApJ, 606, 702

Turner, E. L. 1990, ApJ, 365, L43

Turner, M. S., & White, M. 1997, Phys. Rev. D, 56, R4439

Vishwakarma, R. G. 2001, Class. Quan. Grav., 18, 1159

Wan, H.-Y., Yi, Z.-L., & Zhang, T.-J. 2007, Phys. Lett. B, 651, 352

Wang, P. 2005, Phys. Rev. D, 72, 024030

Wang, Y., & Lovelace, G. 2001, ApJ, 562, L115

Wang, B., Gong, Y., & Su, R.-K. 2004 [hep-th/0408032]

Wang, F. Y., Dai, Z. G., & Zhu, Z.-H. 2007, ApJ, in press [arXiv:astro-ph/07060938]

Wei, H., & Zhang, S. N. 2007, Phys. Rev. D, 76, 063005

Wu, P., & Yu, H. 2005, Nucl. Phys. B, 727, 355

Wu, P., & Yu, H. 2006, Phys. Lett. B, 643, 315

Xia, J.-Q., Zhao, G.-B., Feng, B., & Zhang, X. 2006, Phys. Rev. D, 73, 063521

Yamamoto, K., & Futamase, T. 2001, Prog. Theor. Phys., 105, 707

Yi, Z.-L., & Zhang, T.-J. 2007, Phys. Rev. D, 75, 083515

Zhang, X., & Wu, F.-Q. 2005, Phys. Rev. D, 72, 043524

Zhang, H., & Zhu, Z.-H. 2006, Phys. Rev. D, 73, 043518

Zhao, G.-B., Xia, J.-Q., Li, H., et al. 2007, Phys. Lett. B, in press [arXiv:astro-ph/0612728]

Zhao, G.-B., Xia, J.-Q., Li, M., Feng, B., & Zhang, X. 2005, Phys. Rev. D, 72, 123515

Zhu, Z.-H. 1998, A&A, 338, 777

Zhu, Z.-H. 2004, A&A, 423, 421

Zhu, Z.-H., & Fujimoto, M.-K. 2002, ApJ, 581, 1

Zhu, Z.-H., & Fujimoto, M.-K. 2003, ApJ, 585, 52

Zhu, Z.-H., & Alcaniz, J. S. 2005, ApJ, 620, 7

Zhu, Z.-H., Fujimoto, M.-K., & Tatsumi, D. 2001, A&A, 372, 377