Constraints on Cardassian universe from Gamma ray bursts

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Abstract

Constraints on the original Cardassian model and the modified polytropic Cardassian model are examined from the recently derived 42 gamma-ray bursts (GRBs) data calibrated with the method avoiding the circularity problem. The results show that GRBs can be an optional observation to constrain on the Cardassian models. Combining the GRBs data with the newly derived size of baryonic acoustic oscillation peak from the Sloan Digital Sky Survey (SDSS), and the position of first acoustic peak of the Cosmic Microwave Background radiation (CMB) from Wilkinson Microwave Anisotropy Probe (WMAP), we find $\Omega_m^0 = 0.27^{+0.02}_{-0.02}$, $n = 0.06^{+0.07}_{-0.08}$ (1σ) for the original Cardassian model, and $\Omega_m^0 = 0.27^{+0.03}_{-0.02}$, $n = -0.09^{+0.23}_{-1.91}$, $\beta = 0.82^{+2.10}_{-0.62}$ (1σ) for the modified polytropic Cardassian model.

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I. INTRODUCTION

The astrophysical observations of recent years, including Type Ia supernovae (SNe Ia; [1, 2, 3, 4, 5, 6, 7]), the size of the baryonic acoustic oscillation (BAO) peak detected in the large-scale correlation functions of luminous red galaxies from the Sloan Digital Sky Survey (SDSS; [8]), and cosmic microwave background radiation (CMB; [9, 10, 11, 12, 13, 14]), support that the present expansion of our universe is accelerating. This is important to help us understand our universe, but its nature still remains as an open question today. A large number of cosmological models have been proposed by cosmologists, in order to explain the accelerating expansion of the universe. There are two main categories of proposals. The first ones (dark energy models) are proposed by assuming an energy component with negative pressure (the dark energy) in the universe, this dark energy dominates the total energy density of the universe and drives its acceleration of expansion at recent times. The other proposals suggest that the general relativity fails in the present cosmic time space scale, and the extra geometric effect is the reason of the acceleration. The Cardassian models which investigate the acceleration of the universe by a modification to the Friedmann-Robertson-Walker (FRW) equation [15] belongs to this categorie.

Here we focus on the Cardassian models, including both of the original Cardassian model and the modified polytropic Cardassian model. The original Cardassian model is based on the modified Friedmann equation and has two parameters $\Omega_{m0}$ and $n$. It predicts the same distance-redshift relation as generic quintessence models, although their physical principles are totally different from each other. The modified polytropic Cardassian model can be obtained by introducing an additional parameter $\beta$ into the original Cardassian model which reduces to the original model when $\beta = 1$. The luminosity distance-redshift relation of the modified polytropic Cardassian model can be very different from generic quintessence models.

As we know, many observational constraints have been placed on Cardassian models, including those from the angular size of high redshift compact radio sources [16], the distance modula of SNe Ia [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27], the shift parameter of the CMB [18, 23, 27, 28], the baryon acoustic peak from the SDSS [18, 28], the gravitational lensing [29], the x-ray gas mass fraction of clusters [24, 30], the large scale structure [27, 31, 32], the Hubble parameter versus redshift data [28], and the combined analysis of different
Recently, the gamma-ray bursts (GRBs) have been regarded as the standard candles since several empirical GRB luminosity relations were proposed as distance indicators to be a complementary probe to the universe \cite{34, 35, 36, 37, 38}. However, an important point related to the use of GRBs for cosmology is the dependence on the cosmological model in the calibration of GRB relations. The relations of GRBs presented above have been calibrated by assuming a particular cosmological model for the difficulty to calibrate the relations with a low-redshift sample. Therefore the circularity problem can not be avoided easily \cite{34}. A new method in a completely cosmology independent manner to calibrate GRBs by interpolating directly from SNe Ia has been proposed \cite{39, 40}, and the circularity problem can be solved. Following the SNe Ia interpolation method, the distance modulus of 42 calibrated GRBs at $z > 1.4$ are derived. Now, one may use them to constrain cosmological models without circularity problem \cite{41}.

The main purpose of this work is to give out constraints on Cardassian models with the newly derived 42 GRBs’ data, which have avoided the circularity problem by new method \cite{39, 40}, along with the size of baryonic acoustic oscillation peak from SDSS \cite{8}, and the position of first acoustic peak of CMB from WMAP \cite{14}. As a result, we find that stronger constraints can be given out with this combined data set than most of the former results, such as the results with SNe Ia data \cite{21, 22, 23}, and the results with other combined data set \cite{24, 33}.

This paper is organized as follows: In section 2, we give out the basic equations of Cardassian models. In section 3, we describe the analysis method for the GRBs data and present the constraint results. In section 4, we describe the analysis method for the combined data set including GRBs, BAO and CMB, and present their constraint results. In section 5, we give out the conclusions and some discussions.

II. THE BASIC EQUATIONS OF CARDASSIAN MODELS

In 2002, Freese and Lewis \cite{15} proposed Cardassian model as a possible explanation for the acceleration by modifying the FRW equation without introducing the dark energy. The basic FRW equation can be written as

$$H^2 = \frac{8\pi G}{3}\rho$$

(1)
where $G$ is the Newton gravitation constant and $\rho$ is the density of summation of both matter and vacuum energy. For the Cardassian model, which is modified by adding a term on the right side of Eq.(1), the FRW equation is shown as below

$$H^2 = \frac{8\pi G}{3} \rho_m + B\rho_m^n$$

(2)

The latter term, which is so called Cardassian term, may show that our observable universe as a 3 + 1 dimensional brane is embedded in extra dimensions. Here $n$ is assumed to satisfy $n < 2/3$, and $\rho_m$ only represents the matter term without considering the radiation for simplification. The first term in Eq.(2) dominates initially, so the equation becomes to the usual Friedmann equation in the early history of the universe. At a redshift $z \sim O(1)$, the two terms on the right side of the equation become equal, and thereafter the second term begins to dominate, and drives the universe to accelerate. If $B = 0$, it becomes the usual FRW equation, but with only the density of matter. If $n = 0$, it is the same as the cosmological constant universe. By using

$$\rho_m = \rho_{m0}(1 + z)^3 = \Omega_{m0}\rho_c(1 + z)^3$$

(3)

we obtain

$$E^2 = \frac{H^2}{H_0^2} = \Omega_{m0}(1 + z)^3 + (1 - \Omega_{m0})(1 + z)^{3n}$$

(4)

where $z$ is the redshift, $\rho_{m0}$ is the present value of $\rho_m$ and $\rho_c = 3H_0^2/8\pi G$ represents the present critical density of the universe. Obviously, this model predicts the same distance-redshift relation as the quiessence with $\omega_Q = n - 1$, but with totally different intrinsic nature.

The luminosity distance of this model is

$$d_L = cH_0^{-1}(1 + z)\int_0^z dz[\Omega_{m0}(1 + z)^3 + (1 - \Omega_{m0})(1 + z)^{3n}]^{-1/2}$$

(5)

where $c$ is the velocity of light.

The modified polytropic Cardassian universe is obtained by introducing an additional parameter $\beta$ into the original Cardassian model, which reduces to the original model if $\beta = 1$,

$$H^2 = H_0^2[\Omega_{m0}(1 + z)^3 + (1 - \Omega_{m0})f_X(z)]$$

(6)
where

$$f_X(z) = \frac{\Omega_m}{1-\Omega_m}[(1+z)^3(1+\Omega^{-\beta}_m-1)]^{1/\beta}-1$$

(7)

Here if the $\beta = 1$ and $n = 1$, then $f_X(z) = 1$, and this model just corresponds to $\Lambda$CDM.

The corresponding luminosity distance of Eq. (6) is

$$d_L = cH_0^{-1}(1+z)\int_0^z dz[\Omega_m(1+z)^3(1 + \Omega^{-\beta}_m - 1)]^{1/\beta}-1/2$$

(8)

III. CONSTRAINTS FROM GRBS

The distance modulus of the 42 GRBs ($z > 1.4$) we use here are newly obtained by the interpolating method [39] which compiled in Table 2 of ref. [40]. The main idea is the cosmic distance ladder. Similar to the case of calibrating SNe Ia as the standard candles by using Cepheid variables, we can also calibrate GRBs as standard candles with a large amount of SNe Ia. These distance modulus are so far the most independent GRBs’ result on prior cosmological models, and their method avoids the circularity problem more clearly than previous cosmology-dependent calibration methods. Although the number of GRBs is small and the systematic and statistical errors are relatively large so that their contribution to the constraints would be not so significant, this is still a beneficial exploration. So far, this data set has never been used to constrain the Cardassian models, here for the first time, we introduce them into the constraining process. Constraints from GRBs can be obtained by fitting the distance modulus $\mu(z)$

$$\mu(z) = 5 \log_{10} d_L + M$$

(9)

Here $M$ being the absolute magnitude of the object, which is 42.38, and we set $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ [42].

In order to place limits on model parameters ($\Omega_m, n, \beta$) with the observation data, we make use of the maximum likelihood method, that is, the best fit values for these parameters can be determined by minimizing

$$\chi^2_{GRBs} = \sum_i \frac{[\mu_{obs}(z_i) - \mu(z_i)]^2}{\sigma_i^2}$$

(10)

where the $\sigma_i$ represent the uncertainty of GRBs data.
With the 42 GRBs data set, by minimizing the corresponding $\chi^2_{GRBs}$ in Eq. (10), we get the constraints results as Fig.1 shows. This result is consistent with the former result of SNe Ia small sample [20]. Fig.2 shows the result for the modified polytropic Cardassian model with the GRBs data set only.

IV. CONSTRAINTS FROM COMBINING GRBS, BAO AND CMB

In 2005, Eisenstein et al. [8] successfully found the size of baryonic acoustic oscillation peak by using a large spectroscopic sample of luminous red galaxy from the SDSS and obtained a parameter $A$, which is independent of dark energy models and for a flat universe can be expressed as

$$A = \frac{\sqrt{\Omega_{m0}}}{E(z_1)^{1/3}} \left[ \frac{1}{z_1} \int_0^{z_1} \frac{dz}{E(z)} \right]^{2/3}$$

(11)

where $z_1 = 0.35$ and the corresponding $A$ is measured to be $A = 0.469 \pm 0.017$. Using parameter $A$ we can obtain the constraint on Cardassian models from the SDSS.

The shift parameter $R$ of the CMB data can be used to constrain the Cardassian models and it can be expressed as

$$R = \sqrt{\Omega_{m0}} \int_0^{z_r} \frac{dz}{E(z)}$$

(12)

here $z_r = 1089$ for a flat universe. From the five-year WMAP result [44], the shift parameter is constrained to be $R = 1.700 \pm 0.019$ [14].

The best fit values for model parameters can be determined by minimizing

$$\chi^2 = \sum_i \left[ \frac{\mu_{obs}(z_i) - \mu(z_i)}{\sigma^2_i} \right]^2 + \frac{(A - 0.0469)^2}{0.017^2} + \frac{(R - 1.700)^2}{0.019^2}.$$  

(13)

With the GRBs + BAO + CMB data set, we find $\Omega_{m0} = 0.27^{+0.02}_{-0.02}, n = 0.06^{+0.07}_{-0.08}$ for the original Cardassian model at 1$\sigma$ confidence level. Details for constraints are shown in Fig. 3. We find that combining these observational data can tighten these model parameters significantly comparing to the results from former academic papers [17, 28, 45, 46].

For the modified polytropic Cardassian model, we obtain $\Omega_{m0} = 0.27^{+0.03}_{-0.02}, n = -0.09^{+0.23}_{-1.91}, \beta = 0.82^{+2.10}_{-0.62}$ at the 1$\sigma$ confidence level. Details for constraints are shown in Fig. 4.

From the Figs. 3 and 4 we find the flat $\Lambda$CDM cosmology is consistent with observations since the Cardassian model reduces to the flat $\Lambda$CDM when $n = 0$ and the modified polytropic Cardassian model is $\beta = 1, n = 0$.  

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V. CONCLUSIONS

From our data analysis results (Fig. 1 and Fig. 2), we can conclude that the 42 newly derived GRBs data can be used to set constraints on the Cardassian models. On the other hand, with GRBs + BAO + CMB jointly analysis, we obtain $\Omega_{m0} = 0.27^{+0.02}_{-0.02}$, $n = 0.06^{+0.07}_{-0.08}$ for the original Cardassian model, and $\Omega_{m0} = 0.27^{+0.03}_{-0.02}$, $n = -0.09^{+0.23}_{-0.02}$, $\beta = 0.82^{+2.10}_{-0.02}$ for the modified polytropic Cardassian model at 1$\sigma$ confidence level.

It is worth noticing that GRBs are important potential probes for cosmic history up to $z > 6$. Due to the lack of enough low red-shift GRBs to calibrate the luminosity relation, GRBs can not be used reliably and extensively in cosmology for now, but ref. \cite{39} has made an important improvement to this. Hereafter, along with more observed GRBs, like these 42 GRBs data, whose distance modulus are calibrated with the method excluding the circularity problem, GRBs could be used as an optional choice to set tighter constraints on parameters of Cardassian models and even other cosmographic model parameters.

Recently, some authors point out that there is observational selection bias in GRB relations\cite{47, 48} and possible evolution effects in GRB relations have been dicussed\cite{49, 50}. However, Ghirlanda et al. \cite{51} found that no sign of evolution with redshift of one GRB relation (the Amati relation), and the instrumental selection effects do not dominate for GRBs detected before the launch of the Swift satellite. More recently, ref. \cite{52} indicate that another GRB relation (the $E_p - L_{iso}$ relation) is not the result of instrumental selection effects. Nevertheless, for considering GRBs as standard candles for cosmological use, further examinations of possible evolution effects and selection bias should be required.

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FIG. 1: Constraints on $\Omega_{m0}$ and $n$ from $1\sigma$ to $3\sigma$ are obtained from 42 GRBs data for the original Cardassian model.

FIG. 2: Constraints on parameters of the modified polytropic Cardassian model by setting the best fit value over $\Omega_{m0}, \beta$ respectively from $1\sigma$ to $3\sigma$ are obtained from 42 GRBs data.
FIG. 3: Constraints on $\Omega_{m0}$ and $n$ from $1\sigma$ to $3\sigma$ are obtained from combined data set (including GRBs+BAO+CMB) for the original Cardassian model.

FIG. 4: Constraints on parameters of the modified polytropic Cardassian model by setting the best fit value over $\Omega_{m0}, \beta$ respectively from $1\sigma$ to $3\sigma$ are obtained from combined data set.
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