Is the present cosmic expansion decelerating?

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Abstract

We probe the recent cosmic expansion by directly reconstructing the deceleration parameter $q(z)$ at recent times with a linear expansion at $z = 0$ using the low redshift SNIa and BAO data. Our results show that the observations seem to favor a slowing down of the present cosmic acceleration. Using only very low redshift SNIa data, for example, those within $z < 0.1$ or 0.2, we find that our Universe may have already entered a decelerating expansion era since a positive $q(0)$ seems to be favored. This result is further supported by a different approach which aims to reconstruct $q(z)$ in the whole redshift region. So, the accelerating cosmic expansion may be just a transient phenomenon.

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I. INTRODUCTION

The fact that our Universe entered a phase of accelerating expansion at redshift $z$ less than $\sim 0.5$ is well established by several data sets \cite{1-3}, and most analysis seem to suggest that this cosmic acceleration is increasing with time. However, recently, Shafieloo et al. \cite{4} found, by using the Constitution type Ia supernova data (SNIa) \cite{5} and data from the baryon acoustic oscillation (BAO) distance ratio of the distance measurements obtained at $z = 0.2$ and $z = 0.35$ in the galaxy power spectrum \cite{6, 7}, and the CPL parametrization \cite{8} for the equation of state for dark energy, that the acceleration of the cosmic expansion is probably slowing down. At the same time, they also found that this result is dependent both on the data and the parametrization used. For example, they showed that observations still favor an increasing cosmic acceleration when BAO and SNIa is combined with the cosmic microwave background radiation (CMB) data from WMAP7 \cite{9}. However, if a different parametrization or a subsample (SNLS+ESSENCE+CfA) of the Constitution SNIa is used, both SNIa+BAO and SNIa+BAO+CMB favor that the cosmic acceleration is slowing down. Thus, two different, even opposite, results have been obtained. The discrepancy may arise because of either the systematics in some data or that the CPL parametrization is not versatile-enough to accommodate the evolution of dark energy implied by the data. The same issue was also studied, recently, by Gong et al. \cite{10} and Li et al. \cite{11, 12}. They found that the systematics in data sets, the parametrization of dark energy as well as the system error in SNIa all affect outcome for the reconstructed cosmic expansion history. So, up to now, we can not answer for sure the question as to whether the current cosmic acceleration is slowing down or speeding up. One of the main difficulties is that the evolutionary properties of dark energy is still unknown.

In the present paper, we take a different approach by directly reconstructing the evolutionary behavior of the deceleration parameter $q(z)$ at recent times using observational data without any assumption on the cause of the dynamical evolution of the Universe, whether it be dark energy or modified gravity. Since we are only interested in the property of the current cosmic evolution, we use a linear expansion for $q(z)$, i.e., we let $q(z) = q_0 + q_1 z^1$,

\footnote{1 This was firstly proposed in Ref. \cite{13} to probe the cosmic evolution from the SNIa data.}
which should be a very reasonable approximation in the low redshift regions, for example, 
$z < 0.2$. Because the linear expansion may only be valid in the low redshifts, we only 
use the low redshift data, such as the SNIa data points in the low redshift regions and 
BAO, to determine the parameters $q_0$ and $q_1$ to obtain the evolutionary behavior of $q(z)$ 
at $z \sim 0$, which may give a qualitative result for the present cosmic acceleration.

II. DATA AND RESULTS

The data sets used here include the SNIa and BAO. For SNIa, the latest Union2 compi-
lation released by the Supernova Cosmology Project (SCP) collaboration recently [14] 
is considered since it is the currently largest published SNIa sample. This Union2 consists 
of 557 data points in the range $0.015 < z < 1.4$. But we only select data points at low 
redshifts. To give a comparison of different cases, we consider four kinds of low redshift 
regions, i.e., $z \leq 0.1$, $z \leq 0.2$, $z \leq 0.35$ and $z \leq 0.5$. For $z \leq 0.1$, 0.2, 0.35 and 0.50, there 
are 166, 220, 318, and 402 data points, respectively.

For BAO data, as in Refs. [4, 10, 11], we use the distance ratio obtained at $z = 0.20$ and 
z = 0.35 from the joint analysis of the 2dF Galaxy Redshift Survey and SDSS data [7]. 
So, only in the cases of $z \leq 0.35$ and $z \leq 0.5$, we can combine the SNIa and BAO to 
probe the evolutionary behavior of $q(z)$.

The results are shown in Fig. (1). The upper left, upper right, down left and down right 
panels show the results from the SNIa with $z \leq 0.10$, 0.20, 0.35 and 0.50, respectively. 
The regions between red dashed lines represent the allowed evolutionary behavior from the 
Union2 SNIa data at the $1\sigma$ confidence level, while the green regions are the results from 
SNIa+BAO. Apparently, for all cases, the Union2 SNIa seems to favor that the present 
cosmic acceleration is slowing down since the best fit line of the deceleration parameter 
is increasing with the decreasing of $z$, although at $1\sigma$ confidence level the case of an 
increasing cosmic acceleration cannot be ruled out. With the addition of BAO data, the 
decreasing trend of the cosmic acceleration becomes more evident. For the cases $z \leq 0.10$ 
and 0.2, the observations not only favor a slowing down of the cosmic acceleration, but 
also seems to indicate that the Universe has probably entered a decelerating expansion at
the present since $q(0)$ is largely in the positive region. This behavior is more evident when data points within $z < 0.1$ are used to reconstruct $q(z)$ than that within $z < 0.2$. So, our result seems to suggest that the accelerating expansion of our Universe might be just a transient phenomenon. It is interesting to note that a similar result was also obtained in Ref. [18] with a cosmographic method.

It has been pointed out that the SNIa data obtained from different light curve fitting methods, such as SALT-II and MLCS2k2, may give different results on the property of dark energy [12, 15, 16]. Since the present Union2 SNIa set is only analyzed with the SALT2 light curve fitter, we now carry out a discussion of other SNIa sets, such as Constitution [17] and SDSS-II [16], and consider the effect of the different light curve fitters. The best fit results are shown in Tab.(1) for a linear expansion, $q(z) = q_0 + q_1 z$, using the SNIa data points within $z \leq 0.2$. It is easy to see that, except for the case of SDSS-II with the MCLS2k2 fitter, all other data sets seem to favor a slowing down of the cosmic acceleration because $q_1 < 0$ and a present decelerating cosmic expansion since $q_0 > 0$.

TABLE I: Summary of the best fit values for $q(z) = q_0 + q_1 z$ from the Constitution and SDSS-II SNIa data sets with $z \leq 0.2$.

|                    | $q_0$ | $q_1$  |
|--------------------|-------|--------|
| **SDSS − II(MCLS2k2)** | −1.23 | 11.76  |
| **SDSS − II(SALT2)**   | 0.389 | −15.25 |
| **Constitution(MLCS2k2)** | 1.556 | −48.21 |
| **Constitution(SALT2)** | 1.107 | −39.94 |

Finally, to get more complete picture for the evolution of the cosmic acceleration, let us try another different approach, which aims to reconstruct $q(z)$ with observational data in all redshifts. Now, we divide the whole redshift region into five segments, as shown below, and assume that the value of the deceleration parameter is a constant in each segment:

$$z : \quad 0 − 0.05 \quad 0.05 − 0.2 \quad 0.2 − 0.5 \quad 0.5 − 1.0 \quad 1.0 − (1)$$

$$q : \quad q_0 \quad q_1 \quad q_2 \quad q_3 \quad q_4$$
We then use the observational data to constrain these five free parameters. Besides the Union2 SNIa and BAO data, the CMB shift parameter from WMAP7 is also added in our analysis. The results are shown in Fig. (2). In this figure, the blue solid, green solid and red dashed lines represent the best fit results obtained from SNIa, SNIa+BAO and SNIa+BAO+CMB, respectively. The yellow region is the 1σ confidence level from SNIa+BAO+CMB. The best fit results show that all the observational data favor that the cosmic expansion is decelerating in both the high and very low redshift regions, which means that the accelerating cosmic expansion is possibly a transient phenomenon, although at the 1σ confidence level the observations still allow the possibility of a currently accelerating cosmic expansion. In addition, we find that the SNIa+BAO and SNIa+BAO+CMB give the consistent results. So, the tension between low redshift data (SNIa and BAO) and high redshift one (CMB) found in Refs. [4, 11, 19] disappears.

III. CONCLUSION

In summary, we have probed the recent cosmic expansion by reconstructing the deceleration parameter \( q(z) \) with a linear expansion at \( z = 0 \) using the low redshift Union2 SNIa data and BAO data. We find that the observations seem to favor a slowing down of the present cosmic acceleration. Using only very low redshift SNIa data, for example, those in \( z < 0.1 \) and \( 0.2 \), we obtain that our Universe may have already entered a decelerating expansion era at the present since a positive \( q(0) \) seems to be favored. This means that the accelerating cosmic expansion is probably a transient phenomenon. To see the effect of light curve fitting method on our results, we also consider the Constitution and SDSS-II SNIa datasets with the SALT2 and MLCS2k2 light curve fitters, respectively. The best fit result shows that except for the SDSS-II (MLCS2k2), all other data favor that the cosmic acceleration is possibly slowing down and the present cosmic expansion may be decelerating. Furthermore, we also tackled the issue by dividing the whole redshifts into five segments, assuming \( q(z) \) be a constant in each segment and then fitting the data from SNIa+BAO+CMB, and found that a transient accelerating cosmic expansion is plausible. Finally, we must point out that a currently accelerating cosmic expansion
cannot be ruled out at the 1σ confidence level although the best fit results do not favor it. To obtain a clearer answer, we still need to wait for more data.

FIG. 1: The evolutionary behavior of $q(z)$ with $q(z) = q_0 + q_1 z$. The red dashed lines are the results form the Union2 SNIa and the green regions are that from SNIa+BAO at the 1σ confidence level. The upper left, upper right, down left and down right panels correspond to the SNIa with $z \leq 0.1, 0.2, 0.35$ and 0.5, respectively.

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FIG. 2: The evolutionary behavior of $q(z)$ for model given in Eq. (1). The blue solid, green solid and red dashed lines represent the best fit results form Union2 SNIa, SNIa+BAO and SNIa+BAO+CMB, respectively. The yellow regions are the $1\sigma$ confidence level from SNIa+BAO+CMB.

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