# PREDICTIONS FOR SUPERNOVAE TYPE IA OBSERVATIONS

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In this work the predictions for the apparent magnitude of the light coming from supernovae type I-a are considered in the context of models of the Universe in which the coupling between the quintessence field and the background fluid can be minimal or non-minimal. The comparisons are made in some cases with the predictions of the standard lambda cosmology and in other cases with the observational data. A brief estimation of the usefulness of these observations is done.

## 1 Introduction

Recent observation of Type Ia Supernovae have provided indirect evidence that the Universe is accelerating, indicating the existence of a nearly uniform dark energy component with negative effective pressure[1,2].

By measuring 60 supernovae out to redshift near z =1, the Supernovae Cosmological Project (SCP) and the High-z Survey Project have accumulated strong evidence that the Universe is accelerating and that the equation of state of the dark energy component is negative

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## 2 The Models

We analyze two different models:

- Model I: Einstein's gravity with minimal coupling between the quintessence field and the background fluid.

  For this model we have analyzed the following cases:

- Case 1: the self-interaction potential is fixed from the outset to be a single exponential potential[3].
- Case 2: the single exponential potential is fixed from the outset to be a single exponential potential plus a negative cosmological constant[4].
- Case 3: no a priori assumption is made about the self-interaction potential. The relationship $\dot{\phi} = \frac{H}{k}$ is used instead[5].

• Model II: gravity with non-minimal coupling between the quintessence field and the background fluid, in particular: Brans-Dicke theory with a self-interacting scalar field.

For this model we have analyzed just one case:

- Case 4: no a priori assumption about the form of the self-interaction potential; the relationship $\dot{\phi} = \frac{H}{k}$ is used[6].

In all cases we reduced the cosmological parameters up to two free parameters. A computing code is used to constrain the space of parameters: to achieve this goal, we used some observational constraints that are more or less well established. The main observational facts we have consider are the following[7].

• At present ($z = 0$) the expansion is accelerated ($q(0) < 0$).

• The accelerated expansion is a relatively recent phenomenon. Observations point to a decelerated phase of the cosmic evolution at redshift $z = 1.7$. There is agreement that transition from decelerated into accelerated expansion occurred at $z \approx 0.5$ [8].

• The equation of state for the scalar field at present gives $\omega_\phi(\omega_\varphi) \sim -1$ (it behaves like a cosmological constant), with a 95% confidence limit $\omega < -0.6$ (see Ref.[9]).

• Although, at present, both the scalar (quintessence) field and ordinary matter have similar contributions in the energy content of the Universe ($\Omega_m(0) = 1/3 \Rightarrow \Omega_\phi(0) = 2/3$), in the past, ordinary matter dominated the cosmic evolution, [a]; meanwhile, in the future, the quintessence field will dominate (it already dominates) and will, consequently, determine the destiny of the cosmic evolution.

[a] A sufficiently long matter dominated decelerated phase is needed for the observed structure to develop from the density inhomogeneities [10].

Now we proceed to "observationally" test the solutions found in the cases studied in the former sections.

## 3 Observational Testing of the Models

The published data of supernovae consist of 60 SNe Ia [1]. The data analysis and the determination of cosmological parameters can be considered in two steps:

1. we compare the predictions of the theoretical models studied in each situation with the predictions of the standard lambda cosmology;

2. we perform a more refined analysis of the SNIa observational data.

### *3.1 First Step*

The measurement of the Hubble parameter for close supernovae[11], to be compared with the absolute magnitude M of the supernovae SN Ia.

The definitions of luminosity distance (in Mpc)

$$d_L = 3000(1+z)\int_0^z \frac{dz'}{H(z')} \tag{1}$$

and distance modulus

$$\delta \equiv m - M = 5\, log_{10}\, d_L(z) + 25\,. \tag{2}$$

We have thus to compare this last quantity in the case when $H(z)$ is taken from an usual model with $\Lambda$, that is,

$$H(z) = H_0\sqrt{(1+z)^2(1+\Omega_{m0}z) - z(2+z)(1-\Omega_{m0})}\,. \tag{3}$$

In Fig. 1 we show the behavior of the modulus distance vs redshift; for case 2 a relative deviations is about 1 % and for case 1 it is about 0.5 %. We appreciate that cases 3 and 4 almost take the same values that the lambda cold dark matter. We fixed the free parameters of the models to get the best possible fit.

Figure 1. We show the relation of modulus distance vs redshift. The results correspond to cases 1, 2, 3 and 4, as indicated in the figure. The dotted curve corresponds to the ΛCDM model.

### *3.2 Second Step*

We realized the comparison of the high redshift supernovae with the theoretical prediction of bolometric distance

$$m = 5log(D_b) + m_0\,; \tag{4}$$

here, $D_b$ is the "Hubble free" bolometric distance

$$D_b = H_0(1+z)\int_0^z \frac{dz'}{H(z')} \tag{5}$$

and $m_0$ is a parameter connected to the absolute magnitude and the Hubble parameter.

In the data presented in Ref.[1] there are several values for the corrected apparent magnitude. Authors consider $m_B^{peak}$ and stretch luminosity in the corrected effective B-band magnitude $m_B^{eff}$. For the analysis of the cosmological parameters only $m_B^{eff}$ is used, together with its errors $\sigma_{m_B^{eff}}$.

There are several methods for SN Ia data analysis. Two of then are used in Ref.[2]. The first one is the Multicolor Light Curve Shape (MLCS) method and the second one is a template fitting method. In Ref.[1] another method is used. The data of both groups have the statistical errors given approximately as $\sigma_m \sim 0.25$.

We follow the authors of Ref.[1] to analyze the models described before. First of all, as a check of the procedure, we add to the flat cosmological model a $\Lambda$-term to fit the data. The standard $\chi^2$ algorithm of data analysis reveals a good agreement of our analysis with the published statistical values[1]. We use the complete set of data of 60 SNe Ia.

The analysis is performed by minimizing the value of weighted $\chi^2$:

$$\chi^2 = \sum \omega_i (m_i - m_i^{model})^2 \tag{6}$$

where $\omega_i$ is the weight of the i-th SN Ia, $m_i$ is its B-band effective apparent magnitude, and $m_i^{model}$ is its magnitude as predicted with the models introduced before and thoroughly before.

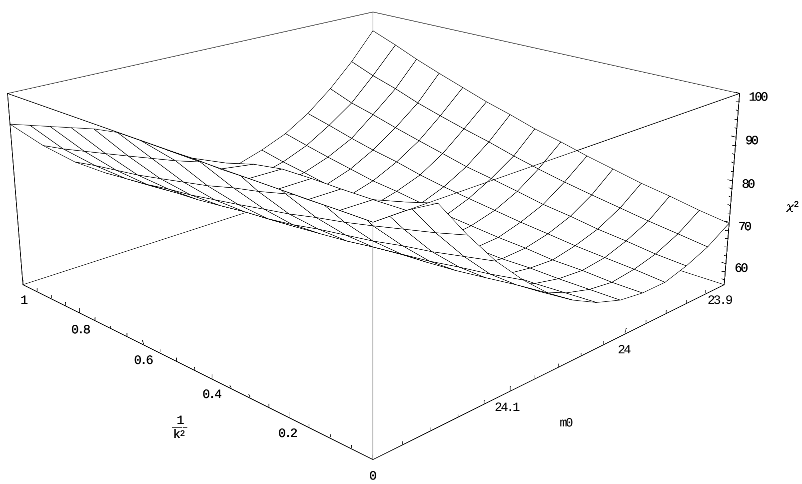


Figure 2. The function $\chi^2$ is plotted as a function of the free parameters $k$ and $m_0$ (we chose $\varepsilon = 0.01$). As seen, $k$ could have any value in the physically meaningful range so, SNIa luminosity observations do not allow for further constrain of the parameter space. Other observations could be considered for this purpose.

In Fig. 2 we show the three dimensional graphics for the relation between the two free parameters and $\chi^2$. From this plot we see that $\chi^2$ is quite insensitive to the value of $\frac{1}{k^2}$, while there is a minimum for a given value of the parameter $m_0 = 23.9$.

With this values of $m_0$ we have obtained the relation of the bolometric distance vs redshift shown in Fig. 3. We fixed the free parameters ($k$) of the models to get the best possible fit.

Figure 3. $\chi^2$ is plotted as a function of the free parameters $k$ and $m_0$ (we show the relation of bolometric distance vs redshift). The black line is for a case 3 and the dots are the experimental values.

## 4 Conclusions

We conclude that the observations of supernovae are not sufficient to constrain the values of important cosmological parameters in these models, such as $\Omega_{m0}$, $q_0$. We think it is because the logarithmic and integral relations in the expressions for the magnitudes smooth the differences between the models. There are works in progress to test these models with the CMB and density perturbations observations.

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