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# FITTING THE LUMINOSITY DATA FROM TYPE Ia SUPERNOVAE IN THE FRAME OF THE COSMIC DEFECT THEORY

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The cosmic defect (CD) theory is reviewed and used to fit the data for the accelerated expansion of the universe, obtained from the apparent luminosity of 192 SnIa's. The fit from the CD theory is compared with the one obtained by means of ΛCDM. The results from the two theories are in good agreement and the fits are satisfactory. The correspondence between the two approaches is discussed and interpreted.

*Keywords*:

## 1. Introduction

As is well known, an extremely important finding of the last decade has been the accelerated expansion of the universe. This was rather a surprise, mainly based on the observation of luminosity distance of type Ia supernovae (SnIa).[1,2] Nowadays, the picture which seems to emerge from the data is that of a universe which has undergone a transition from a decelerated to an accelerated phase, with a relatively recent turning point located at $z_{\text{tr}} \simeq 0.46$.[3] This framework seems to be confirmed by cross-comparison with other pieces of evidence.[4–7] The discovery gave rise to an active search for an explanation on the theoretical side, within and outside general relativity (GR). An immediate effect was to revive the old cosmological constant, Λ.[8] Afterward, a number of evolutionary sons of Λ or new exotic fields were elaborated, mostly based on the idea of "dark energy."[9–17] Also various possibilities of alternative, modified or extended versions of GR have actively been explored.[18–22]

Here, our purpose is to review the existing observational data and some proposed fits, comparing them one with another and with the results of a recently introduced four-vector theory, which we shall call the "cosmic defect" theory, CD for short.[23,24]

The CD theory, which also has correspondences in the group of the so-called vector "ether" theories,[25] will also be revised and recast in the following.

Whenever a theory is contrasted with the data from experience (here, from observation), one has to face a number of different problems. First of all, there is the reliability and cleanness of the data: we shall not elaborate on this, assuming the discussion to have been effectively conducted in the literature.[26–28] A second, subtle issue is that, even in presenting apparently raw data, underlying assumptions often exist, originating in one or another theoretical view: as far as possible, we shall try to express the existing information in a model-independent way. Finally, any theory usually has (a number of) free parameters to adjust, in order to fit the experiment; of course, the more parameters you have, the more you will be able to reproduce a given empirical trend, but any choice must be checked for consistency in as many different physical situations as possible.

As we shall see, the CD theory gives a reasonably good fit for the SnIa data, making use of a limited number of parameters and, at the same time, offers an interpretation paradigm based on correspondences with known physical phenomena without calling for new dark entities.

## 2. Luminosity Distance, Magnitude and Redshift

In the framework of the supernova observations, a key role is played by the concept of luminosity distance, $d_l$, which is defined as

$$d_l \doteq \sqrt{\frac{L_{\text{obs}}}{4\pi\Phi}}, \tag{1}$$

where $L_{\text{obs}}$ is the absolute luminosity of the source (released energy per unit time) corresponding to the $z$ value measured by the observer, and $\Phi$ is the energy flux density (energy per unit time and surface) measured at the observer's site. In an expanding universe both energy and time are affected by the expansion so that the effective luminosity for the observer, in terms of the absolute luminosity at the source, is[29]

$$L_{\text{obs}} = \frac{L_S}{(1+z)^2}.$$

In a universe endowed with the typical Robertson–Walker (RW) symmetries, (1) becomes

$$d_l = a_0 r_S (1+z),$$

where $a_0$ is the scale parameter at the observer, and $r_S$ is the coordinate distance of the source from the observer. The latter, written in terms of the distance traveled by a light ray, is in turn

$$r_S = c\int_{t_S}^{t_0} \frac{dt}{a(t)},$$

where of course $t$ is the cosmic time. In terms of the redshift and the scale factor we may also write

$$cdt = c\frac{da}{\dot{a}} = -\frac{cdz}{(1+z)H(z)}, \tag{2}$$

where the dot denotes the derivative with respect to $t$, and $H = \dot{a}/a$ is the Hubble parameter.

It is then easily seen that the luminosity distance is

$$d_l = c(1+z)\int_0^z (1+\zeta)\frac{da(\zeta)}{\dot{a}(\zeta)} = c(1+z)\int_0^z \frac{d\zeta}{H(\zeta)}.$$

Usually, astronomical objects are classified in terms of their magnitude $m$, rather than their luminosity. By definition, the bolometric magnitude (integrated over all frequencies) depends logarithmically on the luminosity distance, according to the formula

$$\begin{aligned} m - M_S = 25 + 5\log d_l &= 25 + 5\log\left(a_0 c\,(1+z)\int_{t_S}^{t_0}\frac{dt}{a}\right) \\ &= 25 + 5\log\left(c\,(1+z)\int_0^z \frac{d\zeta}{H(\zeta)}\right) \\ &= 25 + 5\log\left(c\frac{(1+z)}{H_0}\int_0^z \frac{d\zeta}{E(\zeta)}\right), \end{aligned} \tag{3}$$

where distances are expressed in Mpc and it is $H_0 = H(0)$ and $E(z) = H(z)/H_0$; $m - M_S$ is usually called the "distance modulus."

The integral in (3) depends of course on the model which one uses to describe the cosmic expansion. For a dust-filled universe in a typical Friedman–Robertson–Walker (FRW) scenario, it is indeed

$$a(t) = a_0\sqrt[3]{6\pi G\rho_{m0}}\,t^{2/3}, \tag{4}$$

$\rho_{m0}$ being the present matter energy density and $G$ the gravitation constant.

As a consequence one expects that

$$(m - M_S)_{\mathrm{FRW}} = 25 + 5\log\left[\frac{3c}{\sqrt{6\pi G\rho_{m0}}}(1 + z - \sqrt{1+z})\right]. \tag{5}$$

If one considers a $\Lambda$-cold-dark-matter universe ($\Lambda$CDM), i.e. an FRW universe with a cosmological constant $\Lambda$, it is

$$E(z) = \sqrt{\Omega_m(1+z)^3 + 1 - \Omega_m}, \tag{6}$$

where $\Omega_m = \rho_m/\rho_c$ represents the ratio between the matter density and the critical density (ensuring the flatness of space). The difference $\Omega_\Lambda = 1 - \Omega_m$ allows for the effect of the cosmological constant.

The formula (6) is a special case of the more general

$$E(z) = \sqrt{\sum_i \Omega_i (1+z)^{3(1+w_i)}},$$

allowing for any number of components of the content of the universe, with different equations of state.

## 3. The Cosmic Defect Theory

The CD theory is based on the presence of a cosmic (four-)vector field in the universe. This vector field is interpreted as the strain flux density in a continuum with a pointlike defect.[a] Actually we start from a universe which, at the large scale, is considered to be isotropic, homogeneous and globally expanding. Our idea, which is explained in more detail in Refs. 23 and 24, is that the global symmetry of the universe, including the expansion, is a consequence of the presence of a texture defect in the four-dimensional space–time, and of its symmetry. A defect like this, as is the case for any material continuum, is not, per se, a dynamical feature (it is there or not); however it induces a strained state in the medium which shows up as a non flat intrinsic metric tensor. Of course, we are referring to the full space–time curvature and not to the simple space curvature; in what follows we shall indeed consider a spatially flat RW universe. A strained state in a continuum may indeed be represented by means of a vectorial displacement field. The defect is described as a singular event (or a singular spacelike hypersurface); if now the strain tensor is projected, at each event, onto a direction orthogonal to the spacelike defect (single event or hyperplane, in the case of a flat-space global RW symmetry), a vector field is obtained, whose flow lines materially diverge only at the defect and nowhere else: any intersection would act as a "source," i.e. as an additional defect, but, since the observation of the universe at large suggests so, we assume that there is only one defect at the origin of cosmic time. From this picture two features of the vector field naturally emerge: (a) it is timelike; (b) it is divergenceless everywhere except at the defect. These constraints and conditions, in an RW universe, lead to a unique solution for the norm of the vector, $\gamma$ (coinciding with the absolute value of its time component), namely

$$\gamma = \frac{Q^3}{a^3}, \tag{7}$$

where $Q$ is a constant and $a$ is the scale factor of the RW metric. We stress the fact that $\gamma$ is not a dynamical quantity, which means that, as for any defect in a solid, its form is not the consequence of the application of a variational principle: it depends on extrinsic conditions. In a solid we would have, for example, impurities or dislocations along the domain walls formed at the moment of some phase transition, or other kinds of defects. Of course, the dynamical properties of the material will depend on the presence of the defects, but the latter will not be the result of any internal extremization of anything. In practice, as we shall see, we will not vary with respect to $\gamma$: (7) is a consequence of the symmetry of the defect.

[a] Actually the defect could correspond to any singular hypersurface.

The other relevant feature of the CD theory is in the choice of the Lagrangian for the space–time containing the defect. This choice is inspired by the correspondence between the (bidimensional) phase space of an RW universe and that of a point particle moving through a viscous fluid.[23,24] Including the presence of matter (i.e. whatever is not accounted for by space–time), the action integral is

$$S = \int (\kappa e^{-g_{\mu\nu}\gamma^{\mu}\gamma^{\nu}} R + \mathcal{L}_{\mathrm{matter}})\sqrt{-g}d^4x, \tag{8}$$

with $\kappa \equiv c^4/16\pi G$ and $d^4x = dtdrd\theta d\varphi$. Explicitly introducing the RW symmetry and considering matter in terms of scalar functions, the Lagrangian read out of (8) is

$$\mathcal{L}_0 = -\mathcal{V}_k[6\kappa e^{-\gamma^2}(a^2\ddot{a} + a\dot{a}^2) + \kappa_0 f a^3 \dot{a}^2 + \varpi h a^3], \tag{9}$$

where $\mathcal{V}_k$ is the part of the Lagrangian which is not affected by any variation with respect to the metric, and, in the flat $k = 0$ case (polar coordinates), equals $r^2 \sin\theta$. The presence of matter is represented by two scalar functions, $f$ and $h$, coupling with space–time through the constants $\kappa_0$ and $\varpi$. The function $h$ represents a matter-energy density of a perfect fluid: the $f$ function accounts for a possible coupling with the rate of expansion of the universe, $\dot{a}$, representing a kind of "drag" by the expanding space–time. Actually $f$ has been included just for the sake of generality, but it will indeed be dropped soon.

The second derivative of $a$ with respect to $t$, appearing in (9), is easily eliminated, once the action is integrated by parts, thus giving a final effective Lagrangian of the universe:

$$\mathcal{L} = -\mathcal{V}_k\left[-6\kappa e^{-\gamma^2}\left(\frac{6}{a^5} + a\right)\dot{a}^2 + \kappa_0 f a^3 \dot{a}^2 + \varpi h a^3\right]. \tag{10}$$

From (10) the Hamiltonian function is readily obtained:

$$\mathcal{H} \doteq \dot{a}\frac{\partial \mathcal{L}}{\partial \dot{a}} - \mathcal{L} = -\mathcal{V}_k\left\{\left[\kappa_0 f a^3 - 6\kappa e^{-\gamma^2}\left(\frac{6}{a^5} + a\right)\right]\dot{a}^2 - \varpi h a^3\right\}. \tag{11}$$

As usual, $\mathcal{H}$ can be interpreted as the energy content of the system described by the effective Lagrangian (10), so that in our case it represents the energy content of the universe. The Hamiltonian of an isolated system is a conserved quantity, since it is identically

$$\frac{d\mathcal{H}}{dt} = \ddot{a}\frac{\partial \mathcal{L}}{\partial \dot{a}} + \dot{a}\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{a}} - \frac{\partial \mathcal{L}}{\partial a}\dot{a} - \frac{\partial \mathcal{L}}{\partial \dot{a}}\ddot{a} \equiv 0. \tag{12}$$

From now on use will be made of $\alpha = a/Q$, so we write

$$\left[\kappa_0 f \alpha^3 - 6\kappa e^{-\gamma^2}\left(\frac{6}{\alpha^5} + \alpha\right)\right]\dot{\alpha}^2 - \varpi h \alpha^3 = \mathcal{W} = \mathrm{const}. \tag{13}$$

From (13) one directly gets the expansion rate equation:

$$\dot{\alpha}^2 = \frac{\mathcal{W} + \varpi h \alpha^3}{\kappa_0 f \alpha^3 - 6\kappa e^{-\gamma^2}\left(\dfrac{6}{\alpha^5} + \alpha\right)}.$$

Actually, if we want to recover the usual meaning of the matter term in a comoving reference frame, we must choose

$$\kappa_0 = 0,$$

so that the expansion rate can be rewritten as

$$\dot{\alpha}^2 = -\frac{\mathcal{W} + \varpi h \alpha^3}{6\kappa e^{-1/\alpha^6}\left(\dfrac{6}{\alpha^5} + \alpha\right)}. \tag{14}$$

In the absence of a defect we should recover the classical FRW model; for this reason, it should be

$$\frac{\dot{a}^2}{a^2} = \frac{8\pi G}{3}\rho = \frac{1}{6\kappa}\rho c^4, \tag{15}$$

where $\rho c^2$ is the energy density of matter. However, under the same condition ($Q = \gamma = 0$) Eq. (14) gives

$$\frac{\dot{a}^2}{a^2} = -\frac{\mathcal{W}Q^3 + \varpi h a^3}{\kappa a^3} = -\frac{\varpi}{\kappa} h. \tag{16}$$

Consistency between (15) and (16) then requires that

$$\varpi = -\frac{1}{6},$$
$$h = \rho c^4.$$

The final formula for the expansion rate of the universe is

$$\dot{\alpha}^2 = -\frac{\mathcal{W} - \rho c^4 \alpha^3}{6\kappa e^{-1/\alpha^6}\left(\dfrac{6}{\alpha^5} + \alpha\right)}. \tag{17}$$

Let us now suppose that the cosmic fluid is made up of a number of different noninteracting components, each with its equation of state in the form

$$p_i = w_i \rho_i c^2,$$

where $w_i$ are real positive numbers ($w_i \geq 0$) and $p_i$ is the partial pressure of the $i$th component.

The conservation laws imply that

$$\rho_i = \rho_{i0}\frac{\alpha_0^{3(1+w_i)}}{\alpha^{3(1+w_i)}}.$$

Introducing this relation into (17) we have

$$\dot{\alpha}^2 = -\frac{\mathcal{W} - c^4 \sum_i \rho_{i0}\dfrac{\alpha_0^{3(1+w_i)}}{\alpha^{3w_i}}}{6\kappa e^{-1/\alpha^6}\left(\dfrac{6}{\alpha^5} + \alpha\right)}. \tag{18}$$

The corresponding Hubble parameter is

$$H = \frac{\dot{a}}{a} = \frac{\dot{\alpha}}{\alpha} = \frac{1}{\alpha}\sqrt{\frac{c^4 \sum_i \rho_{i0} \frac{\alpha_0^{3(1+w_i)}}{\alpha^{3w_i}} - \mathcal{W}}{6\kappa e^{-1/\alpha^6}\left(\frac{6}{\alpha^5} + \alpha\right)}}$$

$$= \frac{c^2}{\sqrt{6\kappa}}(1+z)^{3/2}\sqrt{\frac{\sum_i \rho_{i0}(1+z)^{3w_i} - \mathfrak{w}}{e^{-(1+z)^6/\alpha_0^6}[1 + 6(1+z)^6/\alpha_0^6]}}, \quad (19)$$

with $\mathfrak{w} = \mathcal{W}/(c^4\alpha_0^3)$.

In the case of dust ($w = 0$) and radiation ($w = 1/3$) it is

$$H(z) = (1+z)^{3/2}\sqrt{\frac{c^4}{6\kappa}\rho_{m0}}\sqrt{\frac{1 + \varepsilon_0(1+z) - b}{e^{-(1+z)^6/\alpha_0^6}[1 + 6(1+z)^6/\alpha_0^6]}}. \quad (20)$$

The adimensional quantity $\varepsilon_0 = \rho_{r0}/\rho_{m0}$ is the present ratio between the radiation and the matter energy density in the universe. $b$ is $\mathfrak{w}/\rho_{m0}$.

## 4. Observations Versus Theory

In order to compare theory and observation we make reference to the same set of data used recently by Davis *et al.*[30] and incorporating supernovae analyzed in four different groups: 60 from the ESSENCE (Equation of State: SupErNovae trace Cosmic Expansion) project,[31,32] 57 from SNLS (SuperNova Legacy Survey),[33] 45 nearby supernovae, and 30 detected by the Hubble Space Telescope and qualified as "golden" supernovae by Riess *et al.*[34] As mentioned in the introduction, we shall not enter into a discussion on the elaboration of the data, but assume them exactly the way they are published or anyway accessible, considering them as the best available at the moment.

Altogether we use the luminosity data from 192 SnIa,[35–37] which we try to fit with theoretical models. For the optimization as well as for the determination of the uncertainty of the values of the parameters, we use a multidimensional nonlinear minimization by means of the MINUIT engine.[38,b] The optimization is made minimizing the reduced $\chi^2$ of the fit, where

$$\chi^2(\mathbf{p}) = \frac{\sum_i^N (f(x_i, \mathbf{p}) - e_i)^2}{\sigma_i^2}.$$

[b] The open source routine we used (due to G. Allodi of the University of Parma), named fminuit, is called from within MATLAB, and may be retrieved from ftp://ftp.fis.unipr.it/pub/matlab/fminuit.mex

Here **p** is the vector of free parameters being fitted (in our case they are usually two in number and $\sigma_i^2$ are the uncertainties in the individual measurements $e_i$; of course, $f$ is the function to be fitted and $x_i$ is the redshift parameter for the $i$th supernova. Therefore, the reduced $\chi^2$ is defined as $\chi^2$/d.o.f., where d.o.f. is the number of data minus the number of parameters we want to fit.

In what follows, the values of the parameters we get from the fit are given with a one-standard-deviation error, which corresponds to a 68.3% confidence level.

First, we use (5) and obtain the result shown in Fig. 1. Direct inspection of the graph shows that the data correspond to systematically lower luminosities than the ones given by the FRW model, whence the accelerated expansion interpretation comes.

The next step will be to test on the data the ΛCDM model in its simplest version. For that purpose we use (3) and (6). In practice

$$m - M_S = \mu + 5\log(1+z) + 5\log\int_0^z \frac{d\zeta}{\sqrt{\Omega_m(1+\zeta)^3 + 1 - \Omega_m}}. \tag{21}$$

The result, as is well known, is better than before, since the reduced $\chi^2$ is now $\chi^2 = 1.0295$ with a best-fitting $\mu = 43.30 \pm 0.03$, which corresponds to $H_0 = 65.6 \pm 0.9$ km/s×Mpc, and $\Omega_m = 0.27 \pm 0.03$, i.e. 27% of ordinary and dark matter plus 73% of dark energy (cosmological constant) in a spatially flat universe.

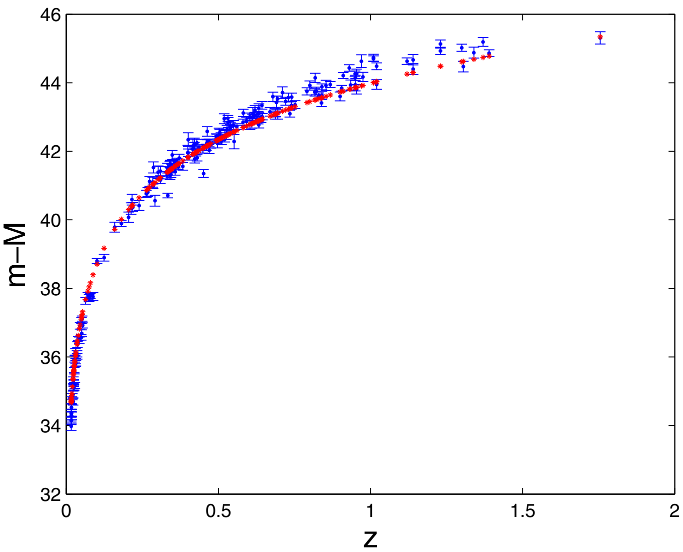


Fig. 1. Fit of distance modulus observations using a standard dust-filled Friedman–Robertson–Walker universe. The data are from 192 SnIa's, as explained in the text. Vertical bars represent the experimental uncertainties ($2\sigma$). The uncertainty on the redshift parameter $z$ would be imperceptible at the scale of the graph. The reduced $\chi^2$ is 2.1276.

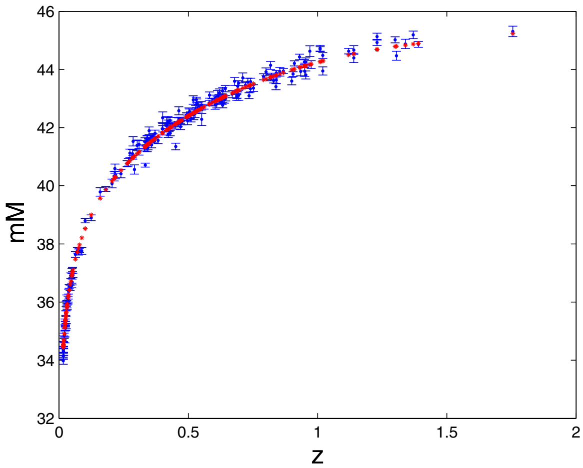


Fig. 2. Fit of distance modulus observations using the CD theory with two free parameters. Radiation is overlooked with respect to dust. The symbols are as in (1). The reduced chi square is $\chi^2 = 1.092$.

Finally, we test the CD theory. Use is made of (3) and (20) considering dust and radiation, so that

$$m - M_S = \mu + 5\log(1+z) + 5\log\int_0^z \sqrt{\frac{e^{-(1+\zeta)^6/\alpha_0^6}\left[1+6\,(1+\zeta)^6/\alpha_0^6\right]}{(1+\zeta)^3\,(1+\varepsilon_0\,(1+\zeta)-b)}}d\zeta. \tag{22}$$

We could treat $\mu$, $\alpha_0$ and $b$ as optimization parameters; however, the value to be introduced for $\varepsilon_0$ is the one currently agreed upon, excluding any dark contribution: $\varepsilon_0 \sim 10^{-4}$. Of course, as long as $z$ is in the order of a few units (as is the case for SnIa's), the radiation term in the denominator of the integrand is negligible, so that the contribution of $b$ may also be embedded in $\mu$ and the free parameters remain $\mu$ and $\alpha_0$ only. The result of the optimization process is $\mu = 43.26 \pm 0.03$ and $\alpha_0 = 1.79 \pm 0.04$; the reduced $\chi^2$ is $\chi^2 = 1.092$, almost as good as for $\Lambda$CDM. The graph is shown in Fig. 2.

We summarize the results of the three cases (FRW, $\Lambda$CDM, CD) in the following table:

| Model | $\chi^2$/d.o.f. | Parameters |
|---|---|---|
| FRW | 2.1276 | $\mu = 25 + 5\log\frac{3c}{\sqrt{6\pi G\rho_0}} = 45.14 \pm 0.01$ |
| LCDM | 1.0295 | $\mu = 25 + 5\log\frac{c}{H_0} = 43.30 \pm 0.03$ |
| | | $\Omega_m = 0.27 \pm 0.03$ |
| CD | 1.092 | $\mu = 43.26 \pm 0.03$ |
| | | $\alpha_0 = 1.79 \pm 0.04$ |

The parameters are the ones which are found and described in the text.

## 5. The Hubble Parameter and the Age of the Universe

Reconsidering now the explicit spelling-out of the parameters appearing in the CD theory used to draw Fig. 2, we see that it is

$$\mu = 25 - 5\log c + \frac{5}{2}\log\frac{6\kappa}{\rho_{m0}\,(1-b)},$$

where

$$\begin{aligned}\rho_{m0}(1-b) &= \frac{6\kappa}{c^2}10^{-\frac{2}{5}(\mu-25)} \\ &= (8.5 \mp 0.2)\times 10^{-27}\mathrm{kg/m^3}.\end{aligned} \quad (23)$$

The "visible" matter density in the universe is commonly assumed to be around $\sim 10^{-27}$–$10^{-28}$ kg/m$^3$, which means that $b$ must be $\sim -10$.

Then, introducing (23) into (20) and evaluating for $z = 0$, we obtain

$$\begin{aligned}H_0 &= \sqrt{\frac{c^4}{6\kappa}\frac{\rho_{m0}(1+\varepsilon_0-b)}{e^{-1/\alpha_0^6}(1+6/\alpha_0^6)}} \\ &= 62.8 \mp 1.7\ \mathrm{km/(s\times Mpc)},\end{aligned}$$

which is an acceptable result ($\varepsilon_0$ has been neglected with respect to $b$). The corresponding Hubble time is 15.6 Gy.

Of course, we should determine the age of the universe using the CD model; this can be done by means of (18), through integration:

$$\begin{aligned}t_0 &= \frac{1}{c^2}\sqrt{\frac{6\kappa}{\rho_{m0}\alpha_0^3}}\int_0^{\alpha_0}\sqrt{\frac{(6+\xi^6)\,e^{-\frac{1}{\xi^6}}}{\xi^4\left[(1-b)\,\xi+\varepsilon_0\alpha_0\right]}}d\xi \\ &= 9.0 \pm 0.2\mathrm{Gy}.\end{aligned}$$

The final numerical result has been obtained neglecting $\varepsilon_0\alpha_0$ with respect to the other terms in the denominator of the integrand. The value falls rather short as compared to the age of globular clusters, which fact may probably be interpreted as an inadequacy of the model at very early cosmic times.

## 6. Conclusion and Discussion

We have fitted the apparent luminosity data from SnIa's with the values predicted by the ΛCDM and the CD theories, comparing both with a traditional FRW universe. The result is of course partly known, but we see now that CD also improves with respect to FRW and gives a fit comparable with that of ΛCDM. Using the same data and the same number of parameters, we obtained similar values of the reduced $\chi^2$'s, suggesting the idea that CD is also a viable theory. It is, however, true that the apparently small difference in the reduced $\chi^2$'s of the fits corresponds to a rather big difference in the full $\chi^2$ which, when analyzed in the light of statistical information criteria, such as the Akaike information criterion (AIC)[39] and the Bayesian information criterion (BIC),[40] enhances the distance between the two theories in favor of ΛCDM. At the same time it is also true that both reduced values of $\chi^2$ are bigger than 1; furthermore, the $H_0$ values obtained from observation using different methods are systematically higher than those of the two-parameter best fits above. The most recent data from WMAP[41] yield $H_0 = 73.2^{+3.1}_{-3.2}$ km/s× Mpc, which is consistent with a number of other results produced by different methods and indicators (like SnI, SnII, Cepheids in nearby galaxies, Sunyaev–Zeldovitch effect, X-rays from clusters, and gravitationally lensed systems), all quoted in Ref. 41. The central values from these different observations range from 72 to 76 km/s×Mpc and in general the historical evolution of the estimated values of the Hubble constant seems to progressively converge toward something around 75 km/s×Mpc,[c] which is ∼15% more than the results got by means of the fits in this paper. If the "experimental" value of $H_0$ were used in the fits (so reduced to one-parameter ones), the agreement with the data would consistently worsen both for ΛCDM and for CD. In practice there is something missing beyond the details of the theories and their interpretation, which deserves investigation and insight.

ΛCDM is indeed different from CD: the former assumes in the universe the presence of a cosmological constant corresponding to a sort of uniformly and homogeneously distributed dark energy; the latter interprets space–time as a continuum with a cosmic defect inducing a strained state containing both the symmetry and the nonuniform expansion rate. Besides this, we know that ΛCDM requires also that the matter content in the universe be one order of magnitude bigger than what is expected from baryonic particles only. In the case of CD, instead, we saw that the ordinary matter density is combined with the effect induced by the defect via the $b$ parameter [see (23)], so that, in a sense, it gives rise to an effective matter/energy density one order of magnitude bigger than the actual one. Adding the fact that one can interpret the strained state induced by the cosmic defect as being the equivalent of a nonuniform (in time) dark energy, we see that in fact the principal difference between ΛCDM and CD could not be that deep. However, CD produces, somehow unexpectedly, one additional result, which is an inflationary phase in the initial life of the universe, with no need for an ad hoc field.[23,24] This is not the case with ΛCDM. The latter is of course mathematically simple and practically working, but it is not that simple on the side of the interpretation of what Λ actually is; furthermore it apparently implies a never-ending acceleration of the expansion. Our theory, instead, leads back to a final decelerated phase, which we think is a good feature. On the formal side we may also remark that CD has already proved to correspond to vector theories developed with different motivations and within a different scenario.[25] Of course, there are many observational facts against which to test the theory. We have started with the most well-known and considered one, i.e. SnIa luminosity, with no pretence that this is the end of the story. In this test the range of $z$ values is limited, and the poor result obtained for the age of the universe

[c]Look for instance at http://cfa-www.harvard.edu/~huchra/hubble

seems to indicate an inadequacy of the theory at high redshift values, where probably a better treatment of the matter content is in order. However, result with the type Ia supernovae, summed with the other features of the theory, is encouraging.

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