A new interpretation of the cosmic acceleration

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Recent data from the high-z supernovae search projects are re-analyzed using the apparent magnitudes of distant objects vs. redshift, with an excellent fit, based on the exact solution provided by the bimetric Janus cosmological model.

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THE SUCCESSIVE MODELINGS

Astrophysics and cosmology experienced successive paradigmatic transitions. By early XX^th century, the geometrical view of A.Einstein converted Newton''s dynamics into an approximation of solutions based on a field equation. Friedmann's time-dependent solutions gave some hope to get a definite deep understanding of cosmic dynamics. Decades ago, cosmologists believed that the last step was to make a choice between three solutions, corresponding to $(-1, 0, +1)$ values of the curvature index k. and were convinced that the cosmologic constant was zero, or close to zero. But a lot of discrepancies arose, year after year. Fritz Zwicky found that the random velocities of the galaxies in clusters was too large. V.Rubin [1] deduced in 1979 that the mass of galaxies, as derived from photometric observations, could not balance the centifugal force for gazeous particles orbiting them. Observations of strong gravitational lensing effects could not be explained by visible matter action. At the end of the eighties the primeval universe, revealed by CMB appeared strongly homogeneous, which could not be explained by Friedmann''s model. Icing on the cake : by the late 1990''s data on distant supernovae did reveal that the cosmic expansion is accelerating instead of slowing [2] [3]. Such evidence gave the 2011 Nobel Price to S.Perlmutter, Brian P.Schmidt and Adam G.Riess.

THE EXTRA-COMPONENTS OPTION

Over the last decades, necessary improvements to the models, either in astrophysics or in cosmology, consisted to add new components: the primeval Universe homogeneity has been accounted for by assuming a new particle, the inflaton; at galactic scales, halos of dark matter were introduced so as to fit the observed rotation velocities; at larger scales, studies of the weak lensing provided a new way for mapping the invisible. Finally, by the late years 90 the cosmological model itself had to be deeply improved by adding a new component called the dark energy. So as the model presently favored by cosmologists is the so-called concordance or ΛCDM model.
In this context, the magnitudes observed for high-redshift supernovae [3] have allowed to put constraints about non-relativistic aspects of this model, i.e. the present Universe with a null pressure, and more exactly concerning the distribution between dark matter and dark energy, Ω_M and Ω_Λ. With the ΛCDM model, the apparent magnitude may be written such as :

$$m(z) = cst + 5\,Log_{10}\left[\frac{1+z}{\sqrt{|\kappa|}}\;+\;S\left(\sqrt{|\kappa|}\,F(z)\right)\right] \tag{1}$$

where
$F(z) = \int\limits_0^z \left((1+z')^2\,(1+\Omega_M z')\;-z'(2+z')\,\Omega_\Lambda\right)^{-\frac{1}{2}}\,dz'$

and with 3 possibilities for S :

$\Omega_M + \Omega_\Lambda < 1 : S(x) = sh(x)\,and\,\kappa = 1-(\Omega_M+\Omega_\Lambda)$
$\Omega_M + \Omega_\Lambda = 1 : S(x) = x\,and\,\kappa = 1$
$\Omega_M + \Omega_\Lambda > 1 : S(x) = sin(x)\,and\,\kappa = 1-(\Omega_M+\Omega_\Lambda)$

Assuming a flat Universe ($\Omega_M + \Omega_\Lambda = 1$), fits to observed magnitudes resulted into (cf. joint light curve analysis with statistical errors in ref.[4]) :

$$\Omega_M = 0.289 \pm 0.018 \qquad (\Omega_\Lambda = 1-\Omega_M = 0.711)$$

Theses values are obtained with 740 points and 5 free parameters. Best fit gives $\chi^2/d.o.f. = 717/735$.

OUR BIMETRIC OPTION

By early 1950s, cosmologists like H.Bondi [5] had assumed that the Universe might consist of both positive and negative masses. However, his attempts to include this new view in Einstein's model immediately led him facing an unmanageable problem : positive masses were attracting everything, while negative ones were repelling everything. Hence the so-called runaway phenomenon : when two masses with opposite signs were interacting, the positive one was running away followed by the negative one... And both particles were experiencing a uniform acceleration, with a constant system energy because of their opposite signs... This problem has precluded any interest for particles with

negative mass and energy for half a century at least.
In 2014-2015, a bimetric model is put forward [6] [7] in which a $g^{(+)}_{\mu\nu}$ metric is associated with massive particles of positive energy, and positive mass if they own, and another $g^{(-)}_{\mu\nu}$ metric for massive particles of negative energy, and negative mass if they own. Both metrics form joint solutions to a system of coupled field equations [8][6] derived from a lagrangian derivation [9]. Then, the Newtonian approximation leads to a totally different model :

- masses of same sign attract them according to Newton's law
- masses of opposite sign repel them according to anti-Newton.

It is further assumed that particles of negative mass, even bearing an electric charge, interact with particles of positive mass only through this anti-gravitational force, and not through electromagnetic, electroweak or strong interactions. In such conditions any encounter between both species becomes impossible, as well as any electromagnetic detection, including the optical range.

The nature of negative matter is explicated in [6], section 6. Such cohabitation for particles with opposite energies is considered impossible in the context of QFT, but this only results from the arbitrary choice imposed to time-inversion operator T, fixed as anti-linear and anti-unitary, very exactly for excluding negative energy states [10].

One cannot invoke some void instability, due to $(+m\,,\,-m)$ pair creations : there is no definite quantum theory which gives a description of such phenomenon.

In reference [6] a time-dependent solution is built, based on isotropy and homogeneity hypothesis, i.e. FLRW metrics, which provides exact joint solutions giving the scale factors $(a^{(+)}\,,\,a^{(-)})$.

The solution for positive species corresponds to $k = -1$ and :

$$\begin{aligned} a^{(+)}(u) &= \alpha^2\, ch^2(u) \\ t^{(+)}(u) &= \tfrac{\alpha^2}{c}\left(1 + \tfrac{sh(2u)}{2} + u\right) \end{aligned} \tag{2}$$

Where we can see than $\ddot{a}^{(+)} > 0$ which qualitatively fits observation.
In the following we will develop this solution, which owns no free parameters, to derive the values of apparent magnitude, versus redshift.For sake of simplicity, we will now write $a^{(+)} \equiv a$.
The deceleration parameter q is :

$$q \equiv -\frac{a\,\ddot{a}}{\dot{a}^2} = -\frac{1}{2\,sh^2(u)} < 0 \tag{3}$$

And the Hubble constant is :

$$H \equiv \frac{\dot{a}}{a} \tag{4}$$

We can show (see annex A) the relation for the bolometric magnitude with respect to the redshift z :

$$m_{bol} = 5Log_{10}\left[z + \frac{z^2(1-q_0)}{1 + q_0 z + \sqrt{1+2q_0 z}}\right] + cst \tag{5}$$

where $q_0 < 0$ and $1 + 2q_0 z > 0$. Fitting q_0 and cst to recent available observational data from [4], gives :

$$q_0 = -0.087 \pm 0.015$$

Results presented bleow, show the standardized distance modulus $\mu = 5log_{10}(d_L/10pc)$, linked to experimental parameters through the relation :

$$\mu = m^*_B - M_B + \alpha X_1 - \beta C \tag{6}$$

where m_B^* is the observed peak magnitude in rest frame B band, X_1 is the time stretching of the light curve and C the supernova color at maximum brightness.
Both M_B, α and β are nuisance parameters in the distance estimate.
We took the values given in ref.[4] corresponding to the best fit of the whole set of combined data (740 supernovae) with ΛCDM model.

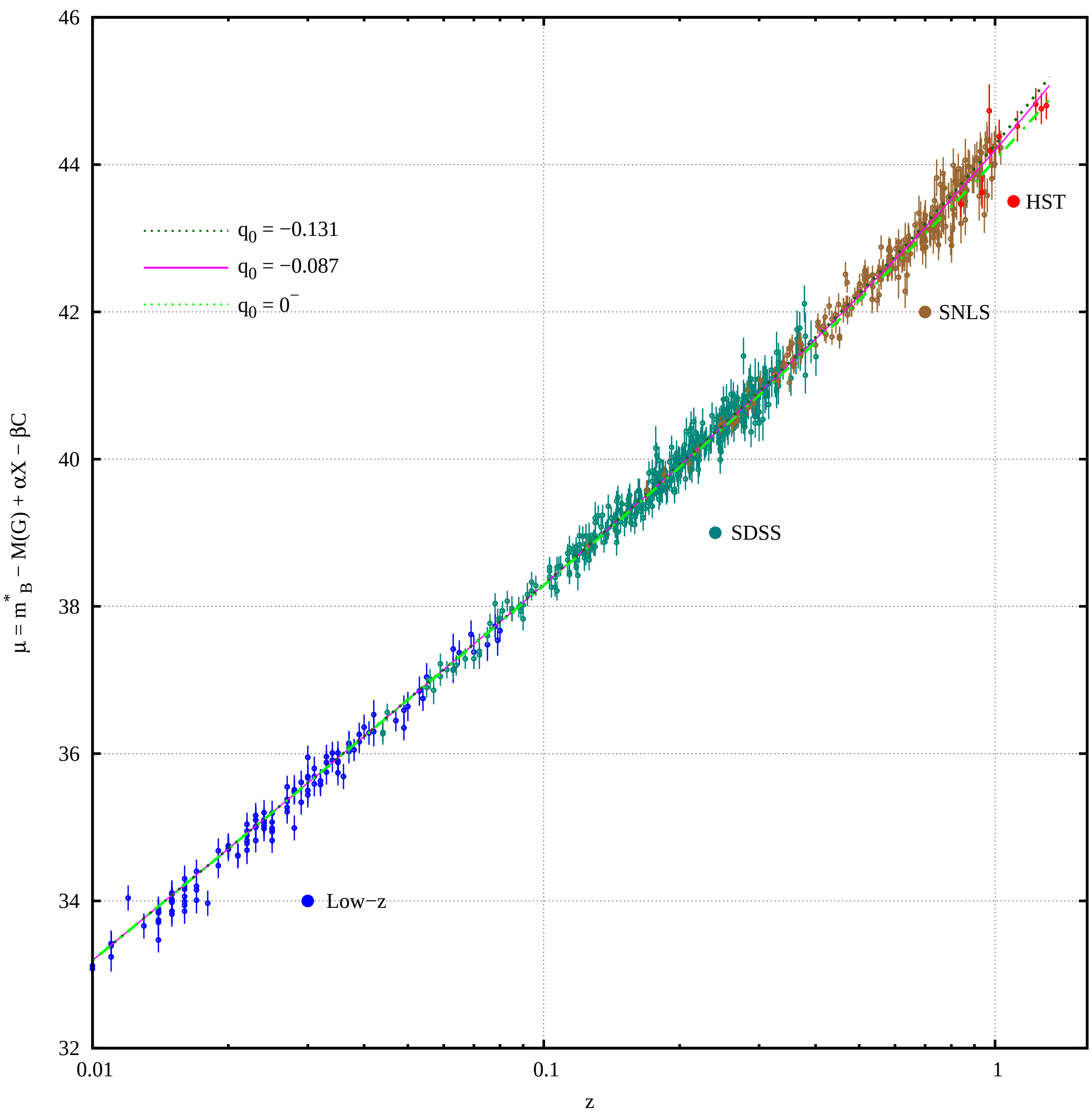

FIG. 1. Hubble diagram of the combined sample (log redshift scale)

With the best fit we get $\chi^2/d.o.f. = 657/738$ (740 points and 2 parameters). The corresponding curves are shown in fig. 1, 2, 3, 4, in excellent agreement with the experimental data. The comparison with both model best fits are shown in fig. 5.
We can derive the age of the universe (see annex B) with respect to q_0 and H_0 and some numerical values, for different (q_0, H_0)values, are given in table I. For our best fit, we get $T_0 = \frac{1.07}{H_0} = 15.0 Gyr$.

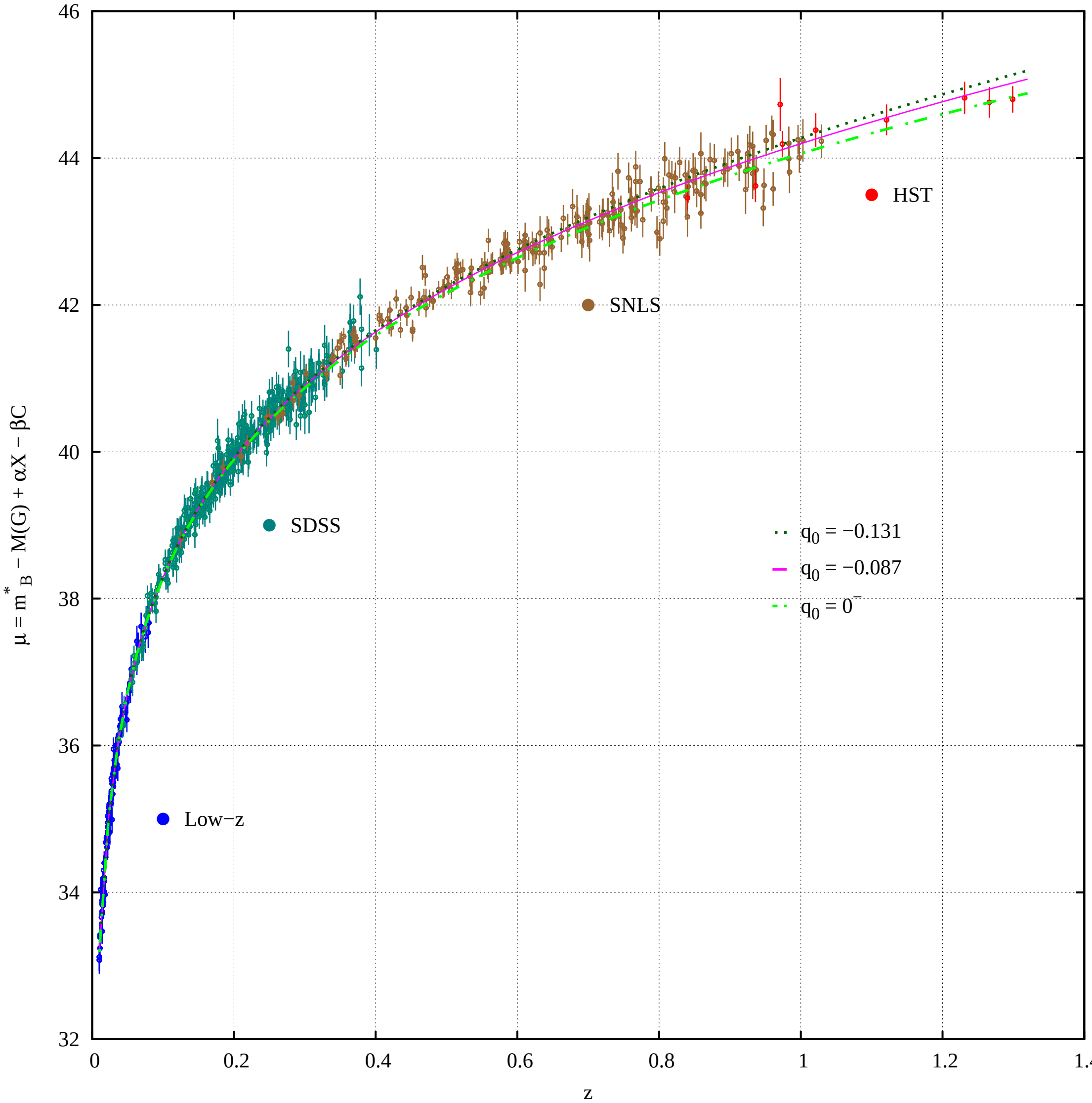

FIG. 2. Hubble diagram of the combined sample (linear redshift scale)

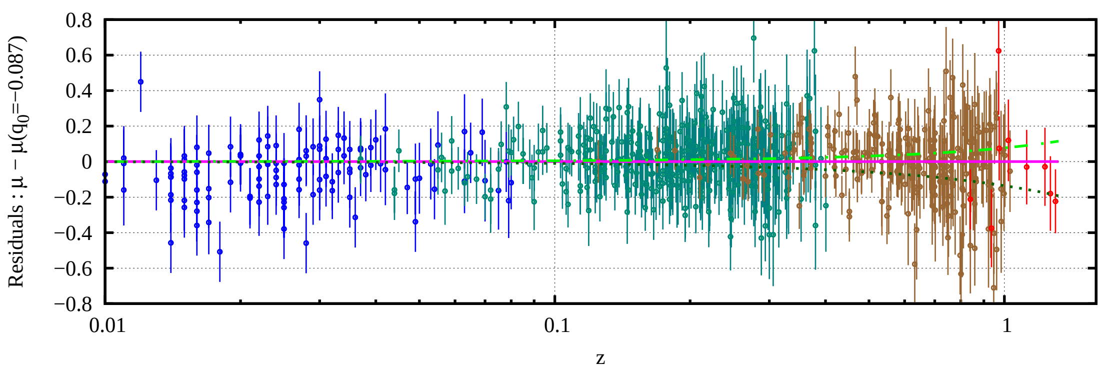

FIG. 3. Residuals of the combined sample (log redshift scale)

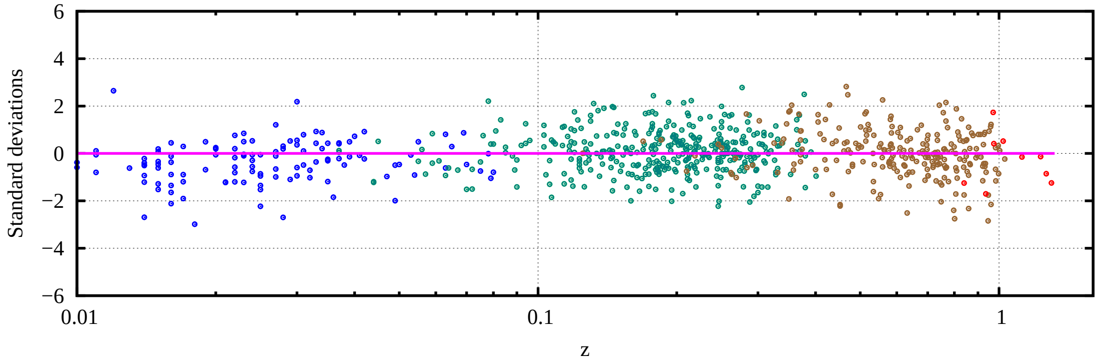

FIG. 4. Standard deviations of the combined sample (log redshift scale)

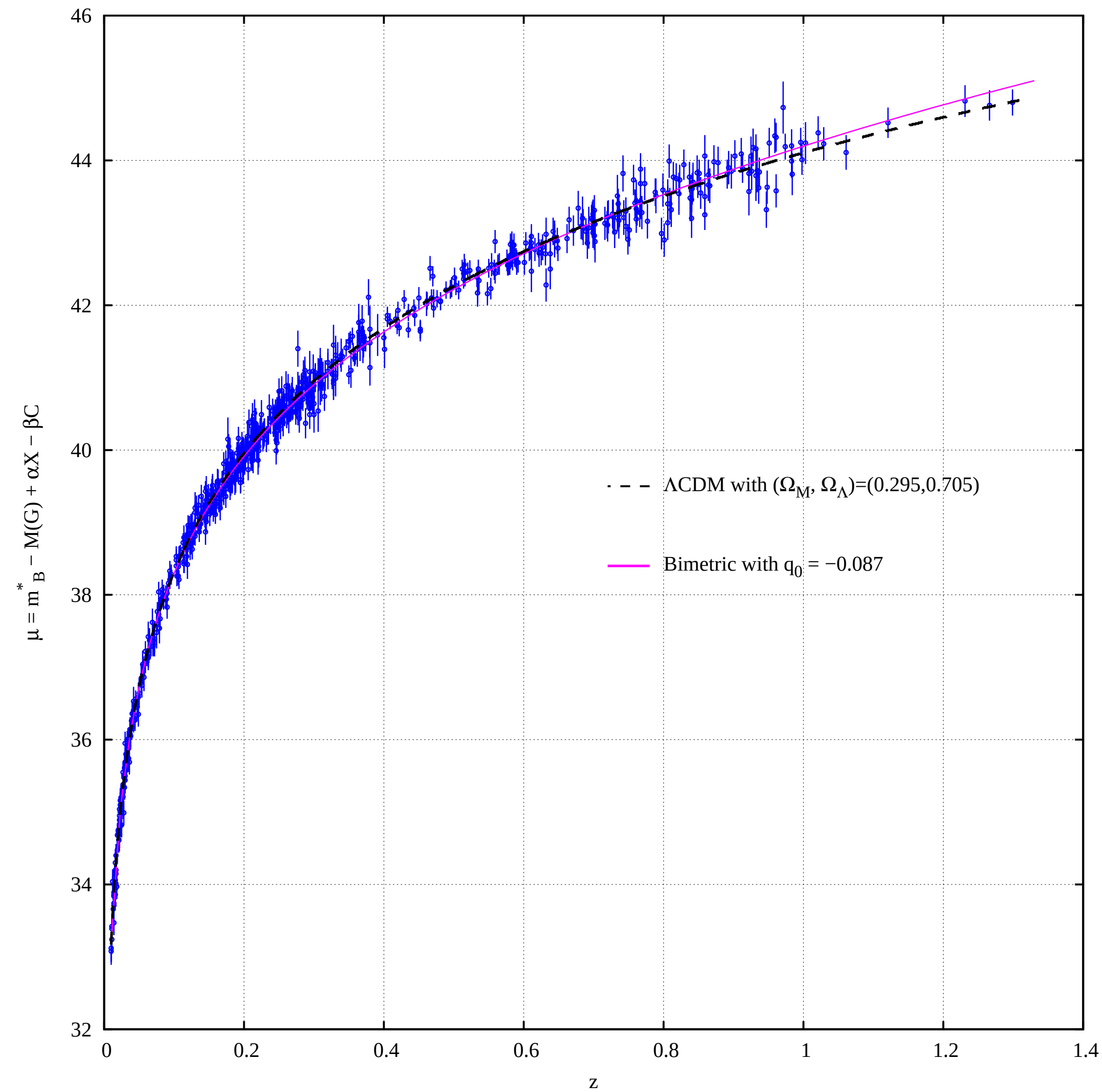

FIG. 5. Hubble diagram compared with the 2 models (linear redshift scale)

TABLE I. T_0 values with respect to q_0 and H_0

T_0 (Gyr)		q_0 **0.000**	**-0.045**	**-0.087**	**-0.102**	**-0.117**	**-0.132**
H_0	**70**	14.0	15.0	15.0	14.9	14.9	14.86
	73	13.4	14.4	14.4	14.3	14.3	14.2

CONCLUSION

We have reviewed the interpretation of the SNle data based on ΛCDM model, by introducing a new analysis based on our Janus bimetric cosmological model. Although resulting charts are comparable , they rely on a fundamentally different approach. The ΛCDM model is based on an description of the universe, where unknown components have been added (first : dark matter, and today : dark energy) with free parameters adjustment to fit the observations, while our model is self-consistent and based on a geometrical theory including a Lagrangian derivation giving an excellent fit to the observational data, magnitude versus redshift.
The deceleration parameter q_0 is found to be small and there is no need in our model to introduce a non zero cosmological constant to fit the so far available data.

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Annex A : Bolometric magnitude

Starting from the cosmological equations corresponding to positive species and neglectible pressure (dust universe) establish in ref. [6] :

$$a^{(+)\,2}\,\ddot{a}^{(+)} + \frac{8\pi G}{3}E = 0 \tag{7}$$

with $E \equiv a^{(+)\,3}\rho^{(+)} + a^{(-)\,3}\rho^{(-)} = constant < 0$.
For the sake of simplicity we will write $a \equiv a^{(+)}$ in the following. A parametric solution of Eq. (7) can be written as :

$$a(u) = \alpha^2\,ch^2(u) \qquad t(u) = \frac{\alpha^2}{c}\left(1 + \frac{sh(2u)}{2} + u\right) \tag{8}$$

with

$$\alpha^2 = -\frac{8\pi G}{3\,c^2}\,E \tag{9}$$

This solution imposes $k = -1$.
Writing the definitions: $q \equiv -\frac{a\ddot{a}}{\dot{a}^2}$ and $H \equiv \frac{\dot{a}}{a}$ we can write :

$$q = -\frac{1}{2\,sh^2(u)} = -\frac{4\pi G}{3}\,\frac{|E|}{a^3\,H^2} \tag{10}$$

and also

$$(1-2\,q)\;=\;\frac{c^2}{a^2\,H^2} \tag{11}$$

In terms of the time t used in the FRLW metric, the light emitted by G_e at time t_e is observed on G_0 at a time t_0 ($t_e > t_0$) and the distance l travelled by photons ($ds^2 = 0$) is related to the time difference t and then to the u parameter through the relation :

$$l = \int_{t_e}^{t_0} \frac{c\,dt}{a(t)} \;=\int_{u_e}^{u_0} \frac{(1+ch(2\,u)}{ch^2(u)}du \;= 2\,u_0\;-\;2\,u_e \tag{12}$$

We can also relate the distance l to the distance marker r by (using Friedman's metric with $k=-1$) :

$$l = \int_{t_e}^{t_0} \frac{c\,dt}{a(t)} \;=\int_0^r \frac{dr'}{\sqrt{1+r'^2}} = argsh(r) \tag{13}$$

So we can write :

$$r\;=\;sh(2\,u_0 - 2\,u_e)\;=\;2\,sh(u_0-u_e)\,ch(u_0-u_e) \tag{14}$$

We need now to link u_e and u_0 to observable quantities q_0, H_0, z. From Eq. (8) we get :

$$u\;=\;argch\left(\sqrt{\frac{a}{\alpha^2}}\right) \tag{15}$$

Eq. (12) gives the usual redshift expression :

$$a_e = \frac{a_0}{1+z} \tag{16}$$

From Eq. (10) and (15) we get :

$$u_0\;=\;argch\sqrt{\frac{2q_0-1}{2q_0}}\;=\;argsh\sqrt{-\frac{1}{2q_0}} \tag{17}$$

From Eq. (10), (15)) and (16)) we get :

$$u_e\;=\;argch\sqrt{\frac{2q_0-1}{2q_0(1+z)}}\;=\;argsh\sqrt{-\frac{1+2q_0z}{2q_0(1+z)}} \tag{18}$$

Inserting Eq. (17) and (18) into Eq. (14), after a 'few' technical manipulations, using at the end Eq.(11) and considering the constraint that $1+2q_0z > 0$, we get :

$$r = \frac{c}{a_0H_0}\,\frac{q_0z + (1-q_0)\left(1-\sqrt{1+2q_0z}\right)}{q_0^2(1+z)} \tag{19}$$

Which is similar to Mattig's work [11] with usual Friedmann solutions where $q_0 > 0$, here we have always $q_0 < 0$.

The total energy received per unit area and unit time interval measured by bolometers is related to the luminosity :

$$E_{bol}\;=\;\frac{L}{4\pi a_0^2 r^2 (1+z)^2} \tag{20}$$

Using Eq. (19), the bolometric magnitude can therefore be written as :

$$m_{bol} = 5Log_{10}\left(\frac{q_0z + (1-q_0)\left(1-\sqrt{1+2q_0z}\right)}{q_0^2}\right) + cst \tag{21}$$

This relation rewrites as [12]:

$$m_{bol} = 5Log_{10}\left[z + \frac{z^2(1-q_0)}{1+q_0z+\sqrt{1+2q_0z}}\right] + cst \tag{22}$$

valid for $q_0 = 0$.

Annex B : Age of the universe

Below we will establish the relation between the age of the universe T_0 with q_0 and H_0. This age is defined by :

$$T_0 \; = \; \frac{\alpha^2}{c} \left(\frac{sh(2u_0)}{2} + u_0 \right) \tag{23}$$

From Eq. (9), (10), (11) we get :

$$\frac{\alpha^2}{c} \; = \; -\frac{2q}{H} \, (1-2q)^{-\frac{3}{2}} \; = \; \frac{2q_0}{H_0} \, (1-2q_0)^{-\frac{3}{2}} \tag{24}$$

and so :

$$T_0. = -2q_0 \, (1-2q_0)^{-\frac{3}{2}} \left(\frac{sh(2u_0)}{2} + u_0 \right) \frac{1}{H_0} \tag{25}$$

Inserting Eq. (17) in Eq. (25) we finally get :

$$T_0.H_0 = 2q_0 \, (1-2q_0)^{-\frac{3}{2}} \left(argsh\sqrt{\frac{-1}{2q_0}} - \frac{\sqrt{1-2q_0}}{2q_0} \right) \tag{26}$$

This relation is shown in fig. 6.

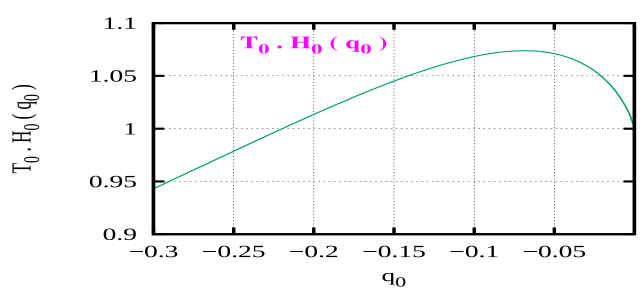

FIG. 6. Age of the universe time Hubble's constant versus q_0