Testing DE models by GRBs: new distance indicators?

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Outline

- Cosmography at high redshift
- Improving the Hubble diagram
- GRBs and their calibration
- Building a GRBs-Hubble diagram
- GRB data fitting
- Results
- Conclusions and Perspectives

Introduction

- ✓ The most important question in cosmology
- ✓ **How measure the Universe ?**

Several answers to this question in the literature
(one for all Rowan-Robinson 1985)

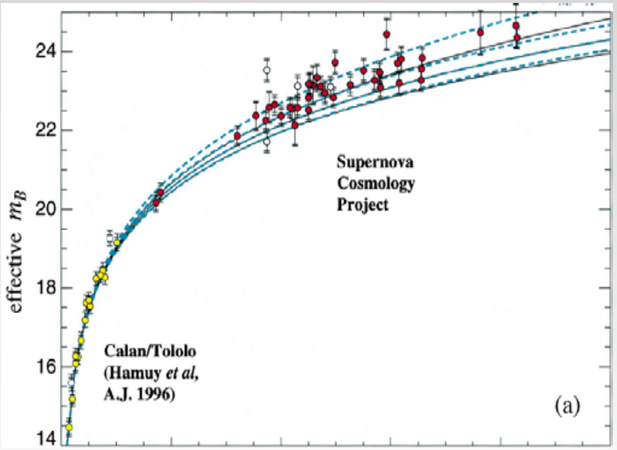
But the Friedmann equations tells us that this question is related to another question...

Are there standard rulers, rods and clocks?

The traditional way to search for solutions to these problems is the use of *cosmological distance ladder*

SNela are the powerful standard candles

SCP, HZT 1998 →



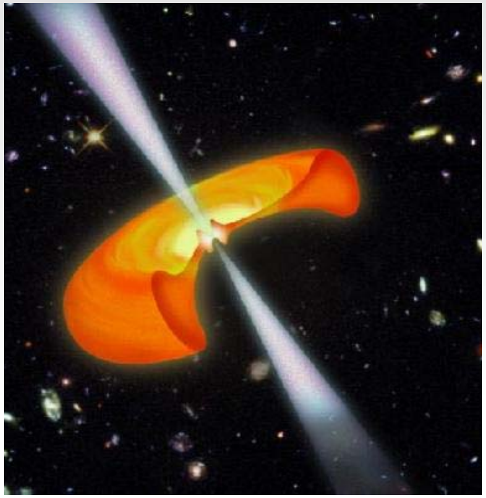
- hardly detectable at z > 1.7
- degeneration in DE models
- need of indicators at higher redshift

Possible solution : GRBs

- Most powerful explosions in the Universe
- Originated by BH formations?
- Observed at considerable distances

Open issue: to frame them into the standard of **cosmological distance ladder**!

- Several detailed models give account for the GRB formation (e.g. Meszaros 2006)...
- ...but none of them is intrinsically capable of connecting all the observable quantities !!!



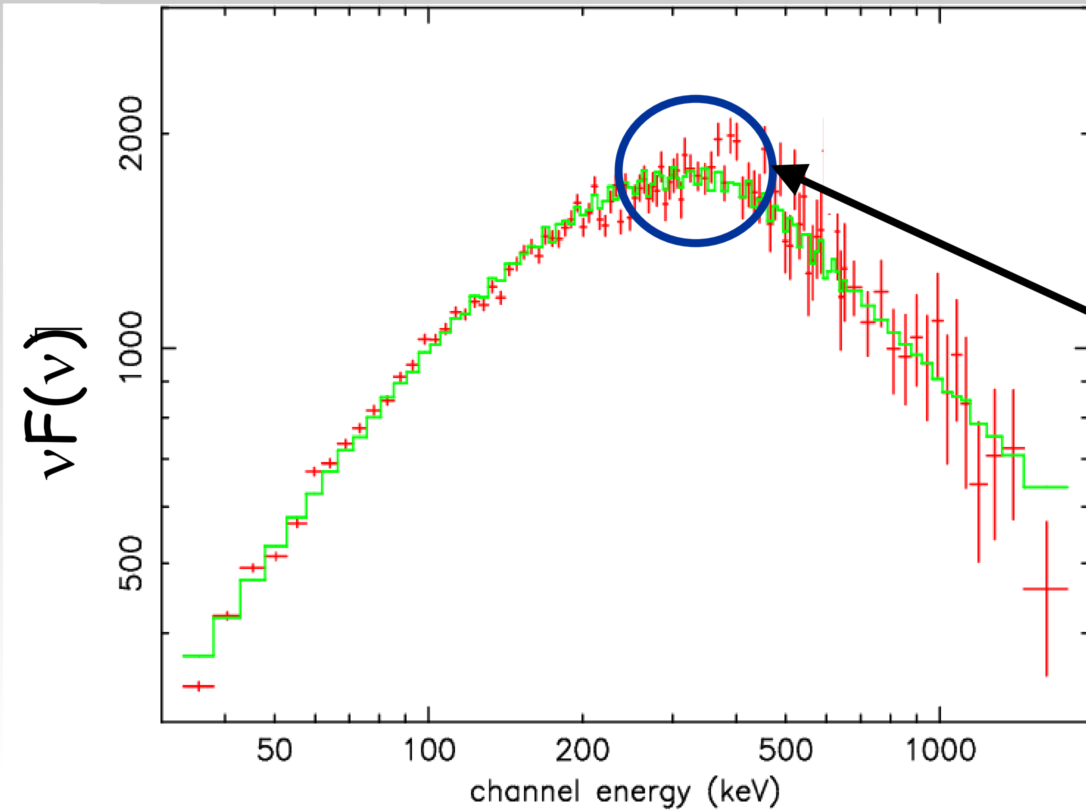
currently GRBs cannot be properly used as standard candles since GRB standard model is questionable

(S. Basilakos & L. Perivolaropoulos 2008)

... but ...

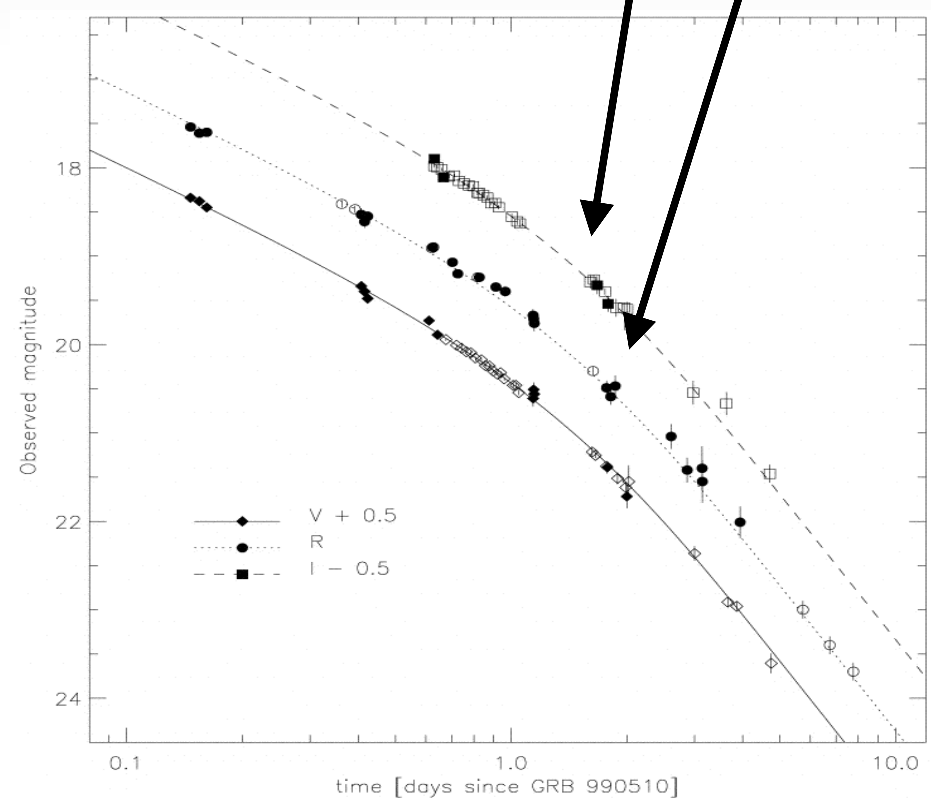
there are several observational correlations among the photometric and spectral properties of GRBs: they can be used, in principle, as **distance indicators**

Properties of GRBs



Peak Energy of the spectrum

Optical t-break



✓ **E-iso** is the isotropic energy emitted in the burst, while **E-gamma** is the collimated **E-iso**

✓ The collimation angle is related to the optical **t-break**

Two relations are particularly useful

- Liang-Zhang relation (Liang & Zhang 2005) :

$$\log E_{iso} = a + b_1 \log \frac{E_p(1+z)}{300keV} + b_2 \log \frac{t_b}{(1+z)1day}$$

- Ghirlanda relation (Ghirlanda et al 2004) :

$$\log E_\gamma = a + b \log \frac{E_p}{300keV}$$

where

$$E_\gamma = (1 - \cos\theta_{jet})E_{iso} \qquad \theta_{jet} = 0.163\left(\frac{t_b}{1+z}\right)^{3/8}\left(\frac{n_0\eta_\gamma}{E_{iso,52}}\right)^{1/8}$$

Calibration

- It is necessary to avoid the circularity problem...
- Calibration by SNeIa (Liang et al 2008) :

Working hypotheses:

1. The above relations work at any z
2. At the same z , GRBs and SNeIa should have the same luminosity distance

Relation	a	b
$E_{\gamma} - E_p$	52.26 ± 0.09	1.69 ± 0.11
$E_{iso} - E_p - t_b$	52.83 ± 0.10	2.28 ± 0.30
		-1.07 ± 0.21

Building the Hubble diagram

Let us calculate d_l for each GRB → $d_l = \left(\frac{E_{iso}}{4\pi S'_{bolo}}\right)^{\frac{1}{2}}$

Where $S'_{bolo} = S_{bolo}/(1+z)$

so we obtain

1) $$d_l = \left[\frac{10^a \left(\frac{E_p(1+z)}{300keV}\right)^{b_1} \left(\frac{t_b}{(1+z)1day}\right)^{b_2}}{4\pi S'_{bolo}}\right]^{1/2}$$

2) $$d_l = 7.575 \frac{(1+z)a^{2/3}[E_p(1+z)/100\,\mathrm{keV}]^{2b/3}}{(S_{bolo}t_b)^{1/2}(n_0\eta_\gamma)^{1/6}} \mathrm{Mpc}.$$

The Hubble series

Connect the previous results with the Hubble series:

$$d_L(z) = \frac{cz}{H_0}\left\{1 + \frac{1}{2}[1-q_0]z - \frac{1}{6}\left[1 - q_0 - 3q_0^2 + j_0 + \frac{kc^2}{H_0^2a_0^2}\right]z^2 + \frac{1}{24}\left[2 - 2q_0 - 15q_0^2 - 15q_0^3 + 5j_0 + 10q_0j_0 + s_0 + \frac{2kc^2(1+3q_0)}{H_0^2a_0^2}\right]z^3 + O(z^4)\right\}.$$

Where we have the cosmographic parameters (SC et al PRD2008)

$$H(t) = +\frac{1}{a}\frac{da}{dt},$$

$$q(t) = -\frac{1}{a}\frac{d^2a}{dt^2}\left[\frac{1}{a}\frac{da}{dt}\right]^{-2}$$

$$j(t) = +\frac{1}{a}\frac{d^3a}{dt^3}\left[\frac{1}{a}\frac{da}{dt}\right]^{-3}$$

$$s(t) = +\frac{1}{a}\frac{d^4a}{dt^4}\left[\frac{1}{a}\frac{da}{dt}\right]^{-4}$$

These parameters can be expressed in terms of the dark energy density and EoS...

$$w = p/\rho$$

CPL parametrization : $w(z)_{DE} = w_0 + w_a z\left(\frac{1}{1+z}\right)$

$$E^2(z) = \Omega_M(1+z)^3 + \Omega_X(1+z)^{3(1+w_0+w_a)}e^{-\frac{3w_a z}{1+z}},$$

$$E(z) = H/H_0$$

So we can evaluate the cosmographic parameters:

$$q_0 = \frac{1}{2} + \frac{3}{2}(1-\Omega_M)w_0\,,$$

$$j_0 = 1 + \frac{3}{2}(1-\Omega_M)\left[3w_0(1+w_0)+w_a\right]$$

$$\begin{aligned} s_0 = & -\frac{7}{2} - \frac{33}{4}(1-\Omega_M)w_a \\ & - \frac{9}{4}(1-\Omega_M)\left[9+(7-\Omega_M)w_a\right]w_0 \\ & - \frac{9}{4}(1-\Omega_M)(16-3\Omega_M)w_0^2 \\ & - \frac{27}{4}(1-\Omega_M)(3-\Omega_M)w_0^3\,. \end{aligned}$$

Log version of luminosity distance

- If we consider the distance modulus

$$\mu = 25 + \frac{5}{ln(10)} ln[d_l/(1Mpc)] + 25$$

- and substitute the luminosity distance

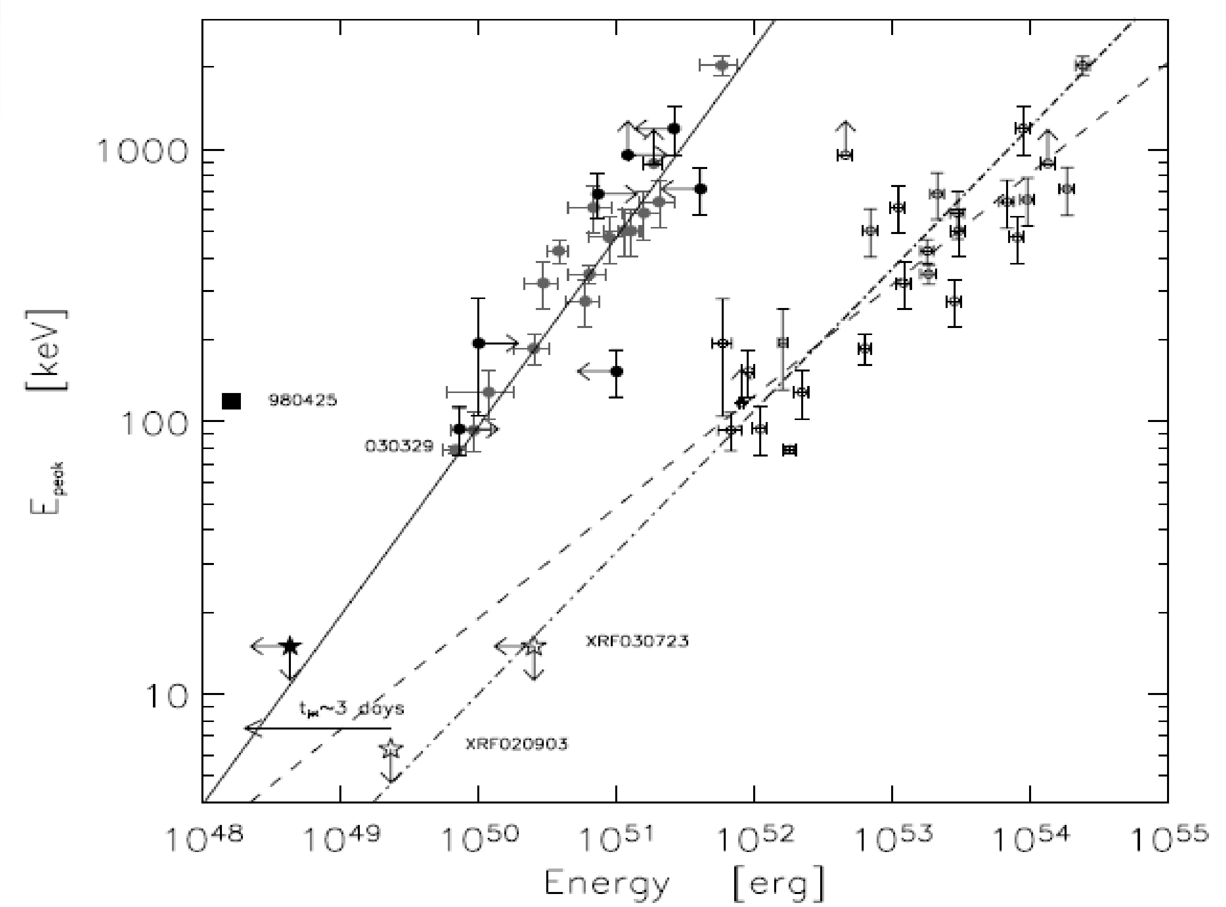
$$\begin{aligned}\ln[d_l/(zMpc)] = \ln(d_H/Mpc) - \frac{1}{2}[-1 + q_0]z \\ + \frac{1}{24}[-3 + 10q_0 + 9q_0^2 - 4(j_0 + 1 + \frac{kd_H^2}{a_0^2})]z^2 \\ + \frac{1}{24}[4q_0(j_0 + 1 + kd_H^2 a_0^2) + 5 - 9q_0 - 16q_0^2 - 10q_0^3 \\ + j_0(7 + 4q_0) + s_0]z^3 + O(z^4)\,.\end{aligned}$$

→ we can estimate also the snap parameter

→ there is no need to transform the uncertainties on the distance modulus (Schaefer 2007)

GRB data sample

- We used 27 GRBs from the Schaefer sample
- The errors come only from the photometry
- We assume $\eta_\gamma = 0.2$ and $\sigma_\eta = 0$



Ghirlanda et al. (2004)

GRB data fitting

- Estimates of the deceleration, jerk and snap parameters
- Degeneration on jerk $j_0 + 1 + \frac{kd_H^2}{a_0^2}$ removed by k = 0
- Two different fits :

Flat Universe

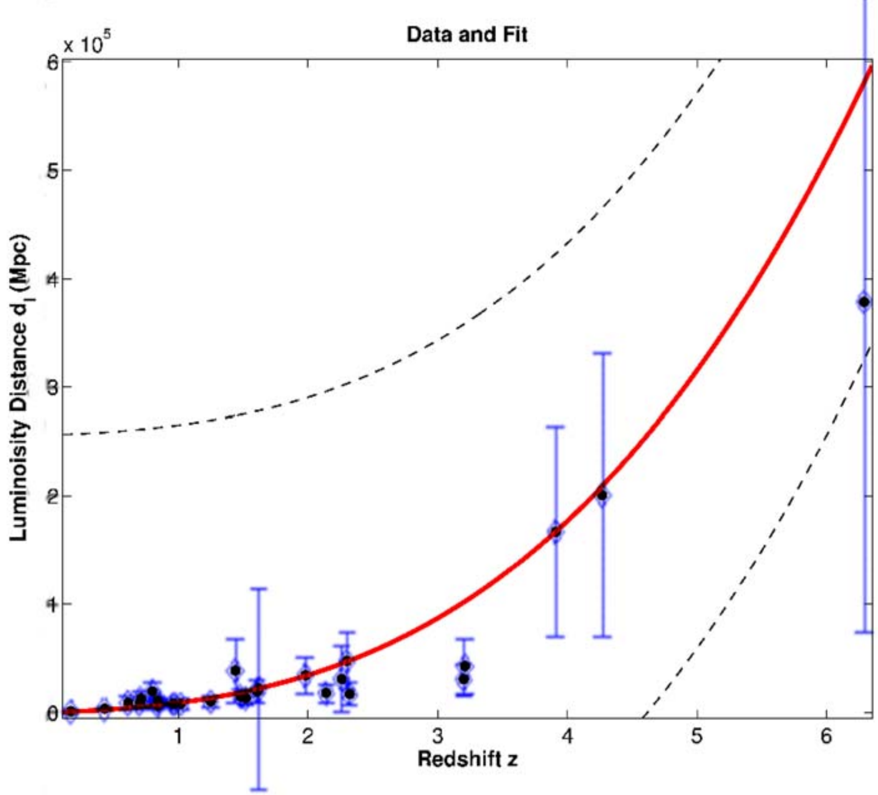
1) $$d(z) = \sum_{i=1}^{3} a_i z^i$$

2) $$\ln[d(z)/(zMpc)] = \sum_{i=1}^{3} b_i z^i$$

Constraint:
(Komatsu et al 2008)
Simplest assumption:

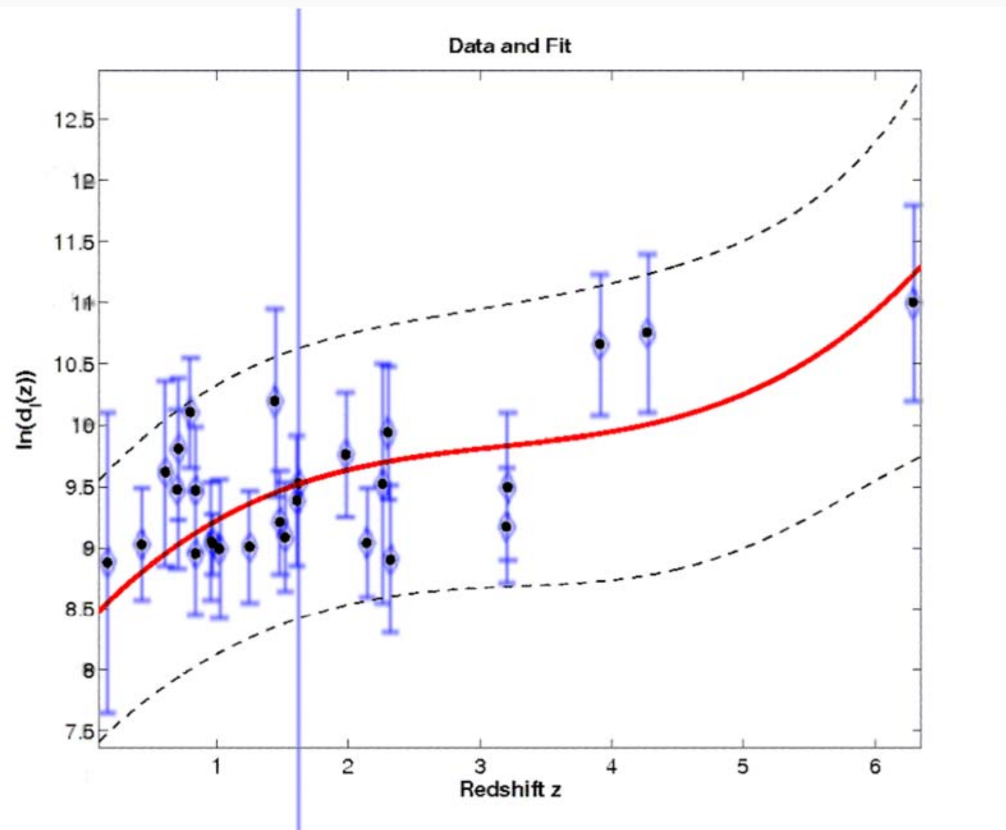
$$H_0 \simeq 70 \pm 2 \text{ km/sec/Mpc}$$

$$\Lambda\text{CDM-universe} \quad (w_0, w_a) = (-1, 0)$$

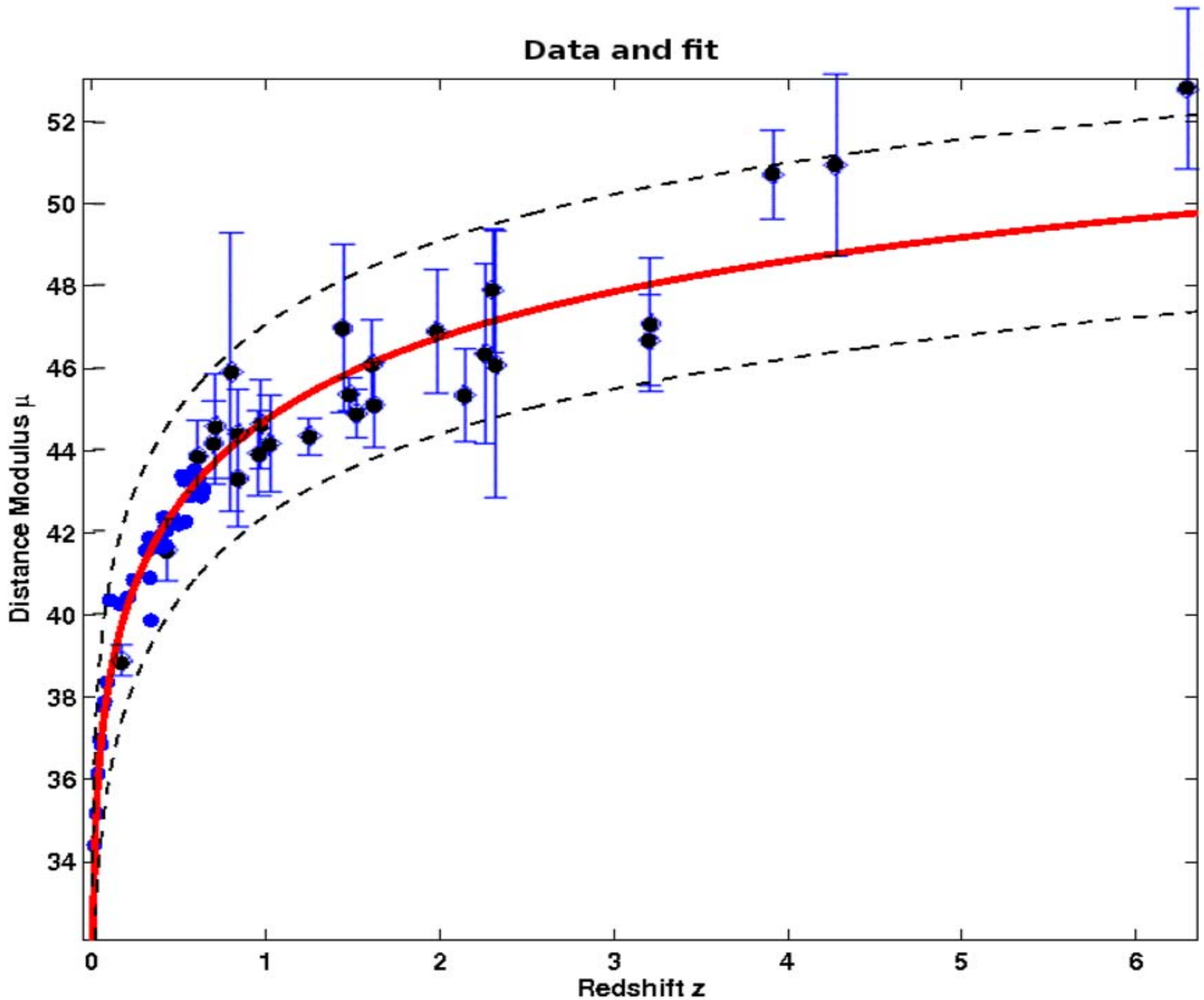


Luminosity distance vs Redshift diagram and bounds predicted at 68 % confidence level

Logarithmic version of the luminosity distance vs Redshift diagram and bounds predicted at 95 % confidence level



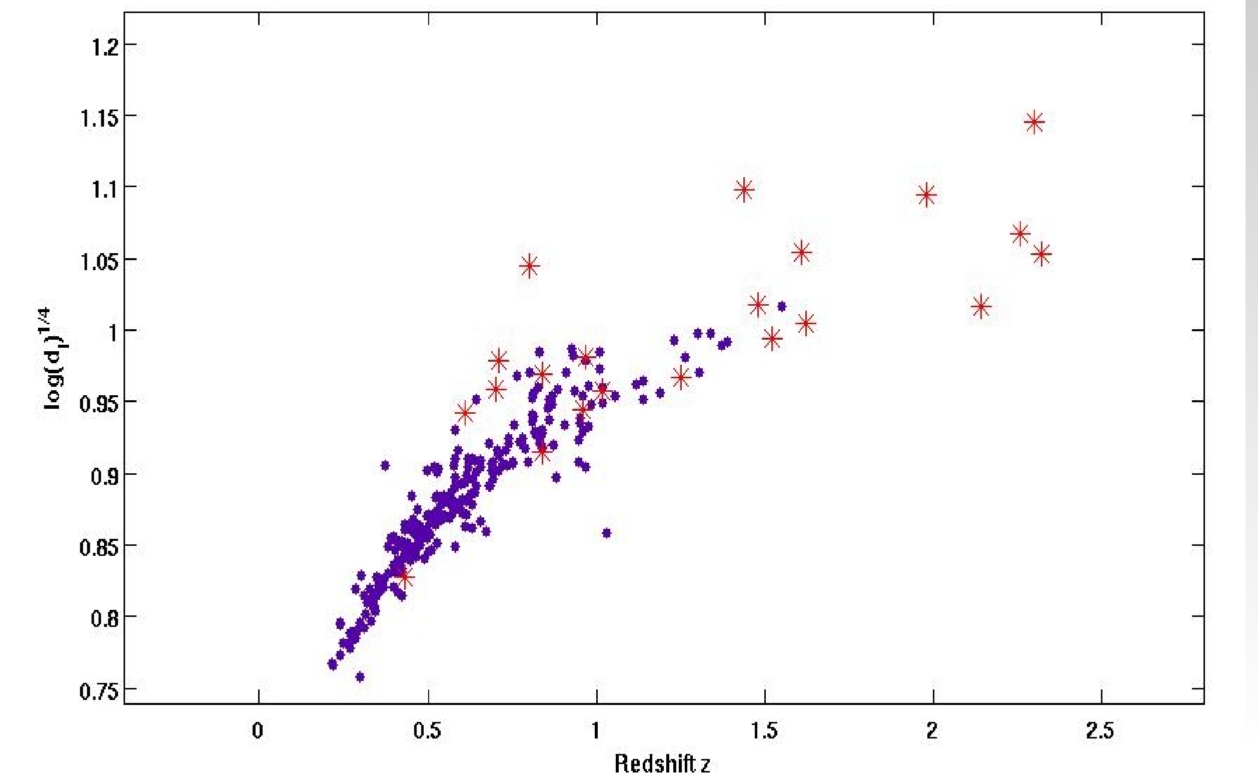
Fit with the data : GRB sample + 42 SNeIa



Relation	w_0	w_a	R-square
LZ	-1.19 ± 0.18	1.01 ± 0.18	0.936
GGL	-1.44 ± 0.11	1.30 ± 0.20	0.944

Improving SNeIa

wider sample :
27 GRB
+
307 UNION SNeIa



- Estimate of the deceleration, jerk and snap parameters
- Degeneration on jerk $j_0 + 1 + \frac{kd_H^2}{a_0^2}$ removed by k = 0

Flat Universe

Same hypotheses:
(Komatsu et al 2008)

$$H_0 \simeq 70 \pm 2 \text{ km/sec/Mpc}$$

ΛCDM $(w_0, w_a) = (-1, 0)$

Numerical results

Correspondence fit parameters – cosmographic parameters

Fit	q_0	$j_0 + \Omega$	s_0
$d_l(z)$ LZ	-0.94 ± 0.30	2.71 ± 1.1	
$d_l(z)$ GGL	-0.39 ± 0.11	2.52 ± 1.33	
$\ln[d_l/z]$ LZ	-0.68 ± 0.30	0.021 ± 1.07	3.39 ± 17.13
$\ln[d_l/z]$ GGL	-0.78 ± 0.20	0.62 ± 0.86	8.32 ± 12.16

Fit	Ω_M	Ω_Λ
$d_l(z)$ LZ	0.04 ± 0.03	0.65 ± 0.73
$d_l(z)$ GGL	0.46 ± 0.43	0.54 ± 2.82
$\ln[d_l/zMpc]$ LZ	0.37 ± 0.31	0.63 ± 1.13
$\ln[d_l/zMpc]$ GGL	0.28 ± 0.30	0.72 ± 1.09

Goodness of the fits

Fit	R-square
$d_l(z)$ LZ	0.9909
$d_l(z)$ GGL	0.9977
$\ln[d_l/zMpc]$ LZ	0.4005
$\ln[d_l/zMpc]$ GGL	0.2929

(SC & Izzo A&A 2008)

Testing the EoS parameters

- Knowing also the snap parameter it is possible to estimate the CPL parameters
- In this case we do not consider ΛCDM-universe

$$(w_0, w_a) \neq (-1, 0)$$

Results

$$w_0 = -0.53 \pm 0.64 \qquad w_a = 0.59 \pm 0.77$$

Within the errors, we have agreement with ΛCDM but it does not agree with the epoch of the transition deceleration-acceleration : $\boxed{z > 10}$ ..too large!!

This estimate could not agree with the *true* EoS...

- ✓ This is because the method used here works very well only at z < 1

⇒ **We need an improved cosmography at higer redshifts!!!**

(Izzo, SC, & Capaccioli, 2009)

Starting from Friedmann eqs...

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

$$H^2 = H_0^2\left[\Omega_0\left(\frac{a_0}{a}\right)^{3(w+1)} - (\Omega_0 - 1)\left(\frac{a_0}{a}\right)^2\right]$$

We assume a flat universe as standard

$k = 0$ $\Omega_0 \simeq 1$

…using the relations $$\frac{a_0}{a} = 1 + z$$ $$H^2(z) = H_0^2 (1 + z)^{3(w+1)}$$

and inserting the CPL parameterization for the EoS, we finally obtain

$$H(z) = H_0 \left[(1 + z)^{\frac{3}{2}(w_0+w_a+1)} \exp\left(\frac{-3 w_a z}{2(1 + z)} \right) \right]$$

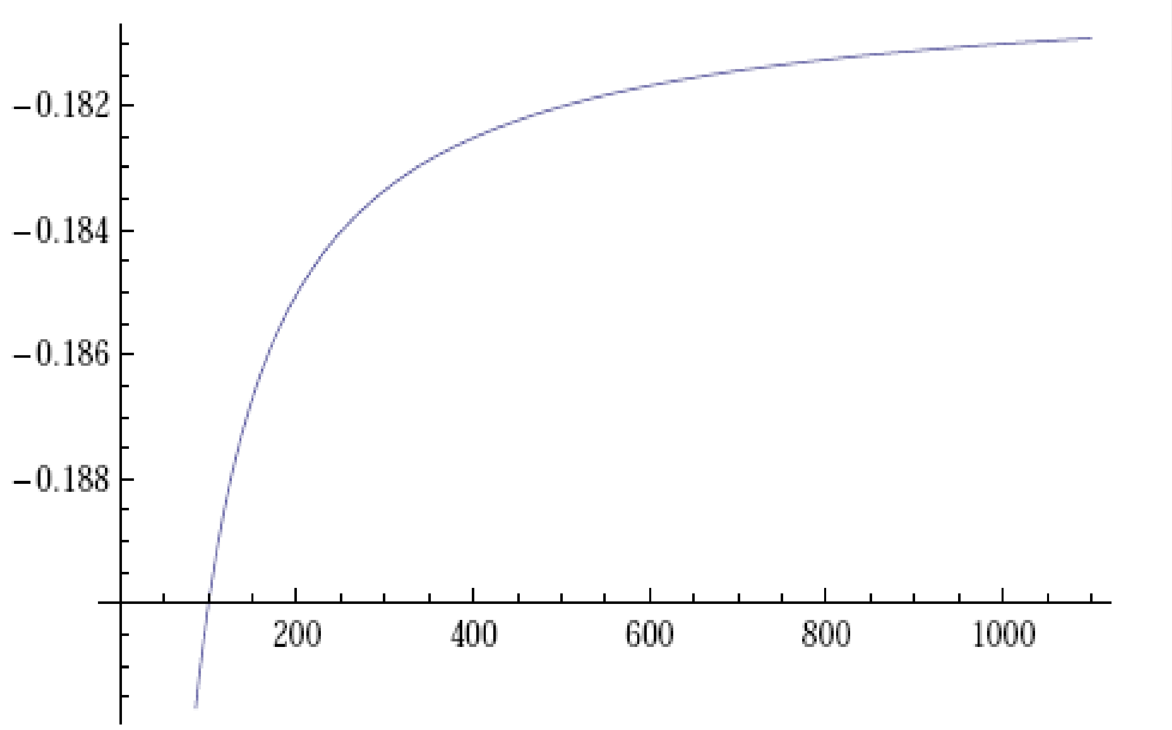
...which directly enters the expression for the distance modulus...

$$\mu(z) = -5 + 5 \log d_l(z) \longleftarrow d_l(z) = c(1 + z) \int_0^z \frac{d\xi}{H(\xi)}$$

- the Hubble function is independent of density parameters
- We use the CPL parameters for the total matter-energy density, including DE
- This could be a new test for the CPL parameterization

preliminary results using CPL and full H(z)

w = w0 + wa z/(1+z)



- w < 0
- In agreement with the observed phantom - quintessence regime at present epoch
- The epoch for the transition acceleration - deceleration at z= 4.47909 ± 0.133

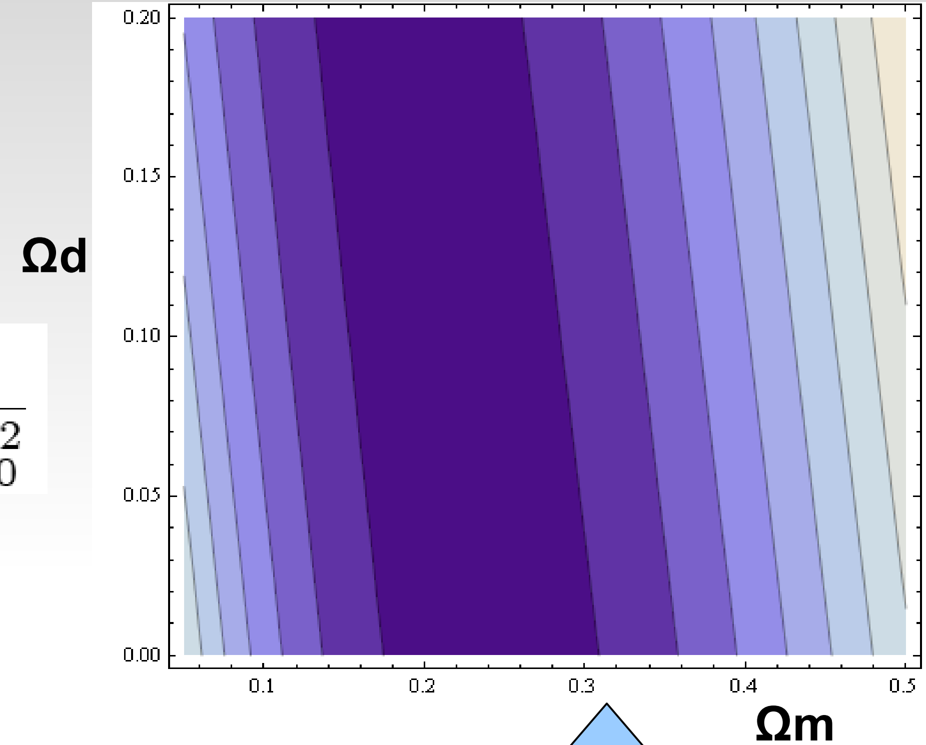
Quasar formation epoch ???

...work in progress...

Further applications

Application to constrain:

- Braneworld Models



$$\Omega_\Lambda = \frac{\Lambda}{3H_0^2}, \quad \Omega_\rho = \frac{\kappa^2 \rho_0}{3H_0^2}, \quad \Omega_d = \frac{2m_0}{a_0^{4-\alpha} H_0^2}$$

and $$\Omega_\rho + \Omega_d + \Omega_\Lambda = 1$$

$$H^2 = H_0^2 \left[\Omega_\Lambda + \Omega_\rho (1+z)^3 + \Omega_d (1+z)^{4-\alpha} \right]$$

α = 3

(Benini, Capozziello, Izzo & Gergely 2009 in preparation)

- Works in progress for f(R) theories

...preliminary results...

Results

- CPL parameterization works for the total matter-energy density
- Results agree with the ΛCDM model at low red shift
- Transition epoch for deceleration- acceleration ($z \approx 5$)
- Presence of a phantom regime at present epoch ($z << 1$)
- Need for a new EoS- parameterization more general than CPL?
- Need for wide GRB-samples, in particular GRBs at high redshift ($z \geq 6$)
- Relations among photometric and spectroscopic quantities as hints towards a GRB standard model?

Conclusions and Perspectives

- Cosmography suggests that GRBs are distance rulers (it is premature the statement "distance indicators" as for SNeIa).
- Matching with other distance indicators like SNeIa, clusters, giant elliptical galaxies and CMBR, one could achieve a robust cosmic distance ladder at any redshift.
- Improving the relation between GRBs observables to understand physical mechanisms (indication for GRB's "physical model" from cosmology??)
- H(z) is a powerful tool to discriminate among different standard candles and then among degenerate DE cosmological models...

Work in progress

References

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