SIGRAV Cosmology School - Firenze

Cosmography by Gamma Ray Bursts : GRB as distance indicators ?

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Outlines

- Brief Introduction
- GRB Relations used in this work and their calibration
- Building a GRB–Sn Ia Hubble diagram
- Data fitting
- Results and Discussions
- Conclusions

Introduction

- ✓ One of the most important question in cosmology

- ✓ **How old is the Universe ???**

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

But the Friedmann equation tells us that this question is related with another question...

What is the thermal history of the Universe ???

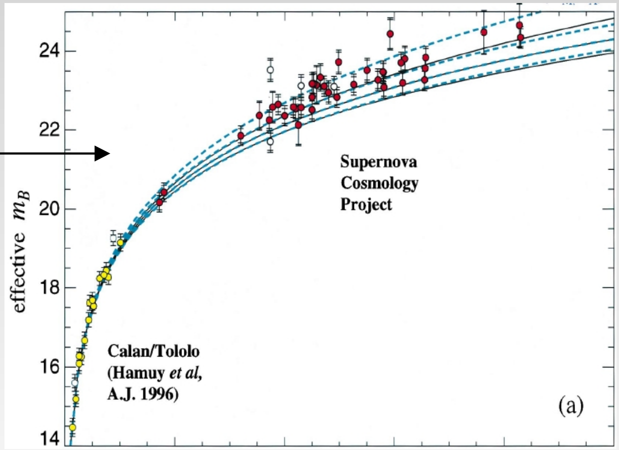
The traditional way of presenting the solution to these problems is the use of the *cosmological distance ladder*

We start from a very accurate standard candle

- ***Supernovae Ia***
  - hardly detectable at z > 1.7
  - need of indicators at higher redshift

SCP - UNION

Kowalski et al. (2008)

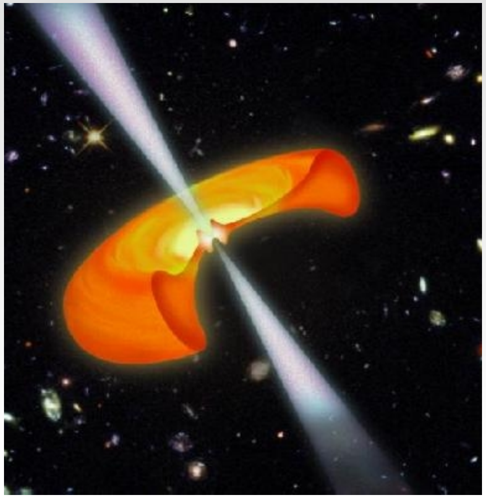


Possible solution : GRB

- Most powerful explosions in the Universe
- Originated from the black hole formation
- Observed at considerable distances

...frame them into the standard of **cosmological distance ladder** ?

- Several detailed models give account for the GRB formation, e.g. (Meszaros 2006, Ruffini et al 2008)...
- ...but none of them is intrinsically capable of connecting all the observable quantities !!!

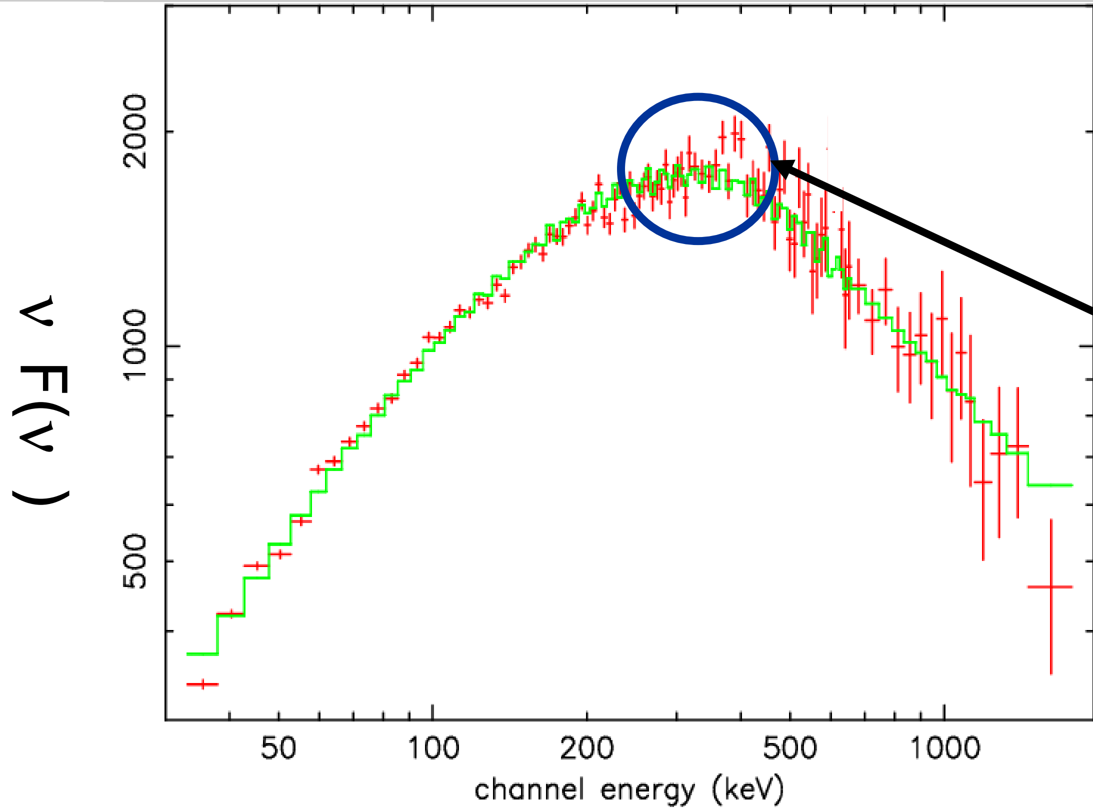


currently GRB cannot be used as standard candles

...but...

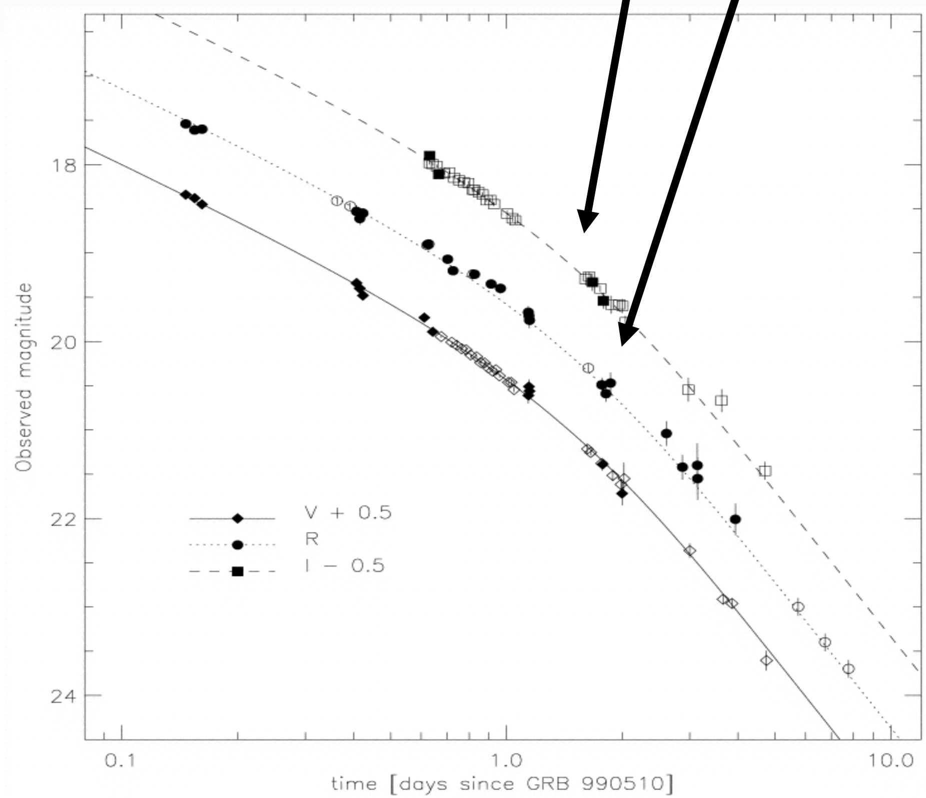
there are several observational correlations among the photometric and spectral properties of GRBs which features them to be used as **distance indicators**

Observable Properties of the 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 t–break, as we can see in the next slide…

The relations used

- 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

- Necessary to avoiding the circularity problem…
- Calibration with Supernovae Ia (Liang et al 2008):

Work hypothesis

- Our relations work at any z
- At the same z GRB and Sn Ia 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 a Hubble diagram

- 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:

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

(Visser 2004 CQG)

Where we have the cosmographic parameters

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

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

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

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

These parameters can be expressed in terms of the dark energy density and EoS... $w = p/\rho$

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

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

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

(Capozziello et al 2008 PhysRevD)

So we can evaluate the C–parameters

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

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

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

Last step...

- If we consider the distance modulus

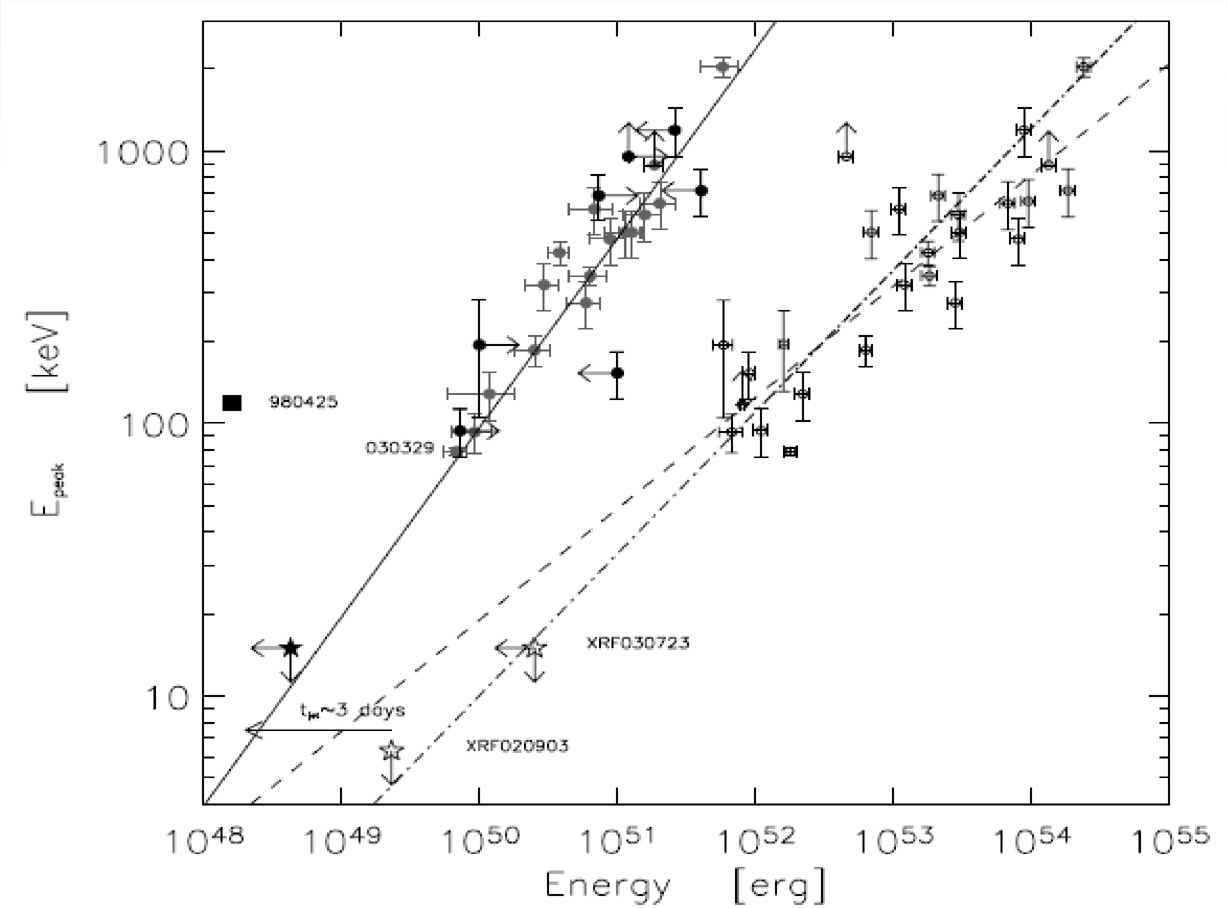
$$\mu = 25 + \frac{5}{ln(10)} ln[d_l/(1Mpc)] + 25$$

- and substituting the luminosity distance defined previously, then...

➔ we start to make the data fitting
➔ moreover we can estimate also the snap parameter
➔ there is no need to transform the uncertainties on the distance modulus (Schaefer 2007)

GRB data sample

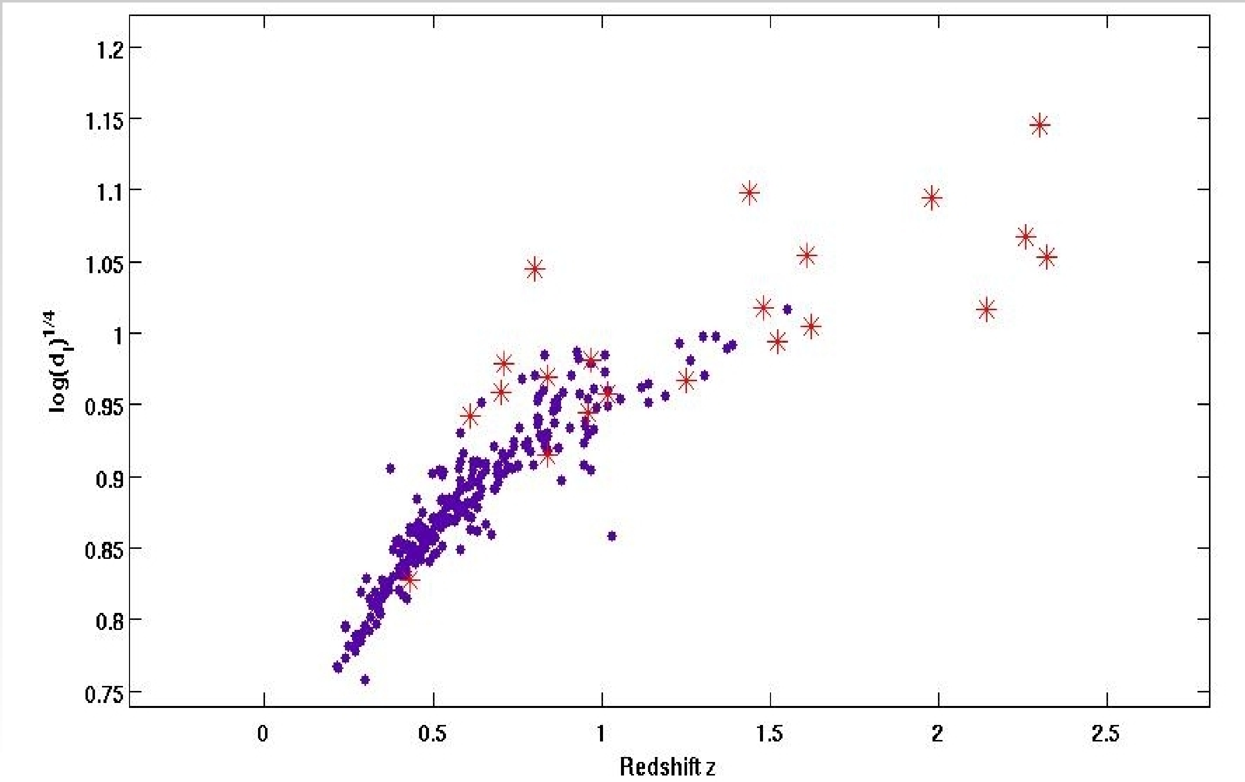
- 27 GRBs from the (Schaefer 2007) sample
- The error data are only of a photometric nature
- We assume $\eta_\gamma = 0.2$ and $\sigma_\eta = 0$



Courtesy
Ghirlanda et al.
(2004)

Data fitting

wider sample :
27 GRB
+
307 UNION SnIa



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

→ ***Flat Universe***

Constraints: → $H_0 \simeq 70 \pm 2$ km/sec/Mpc (Komatsu et al 2008)

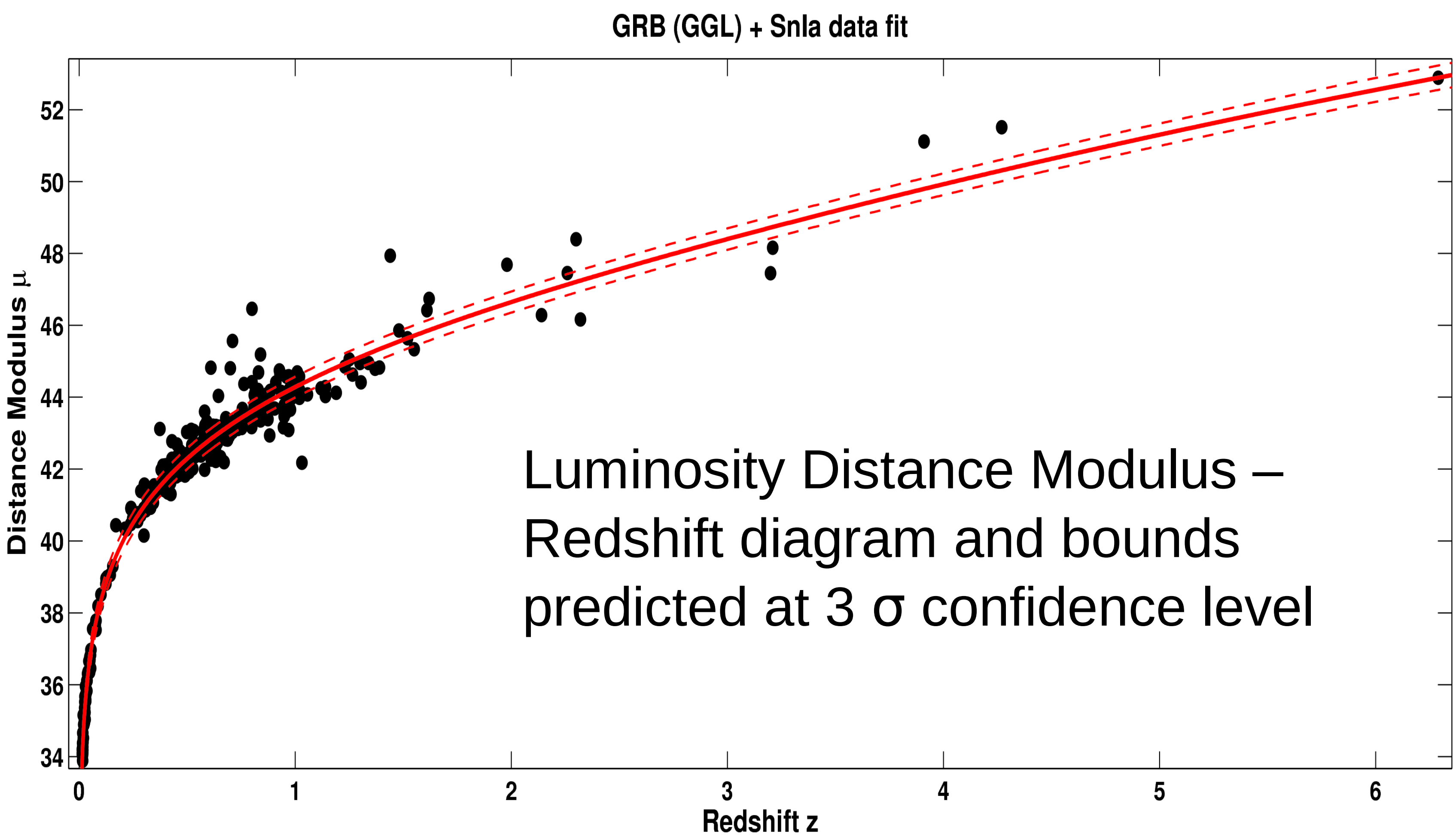
→ Constant EoS $(w_0, w_a) = (-1, 0)$

Non Linear Least Squares – Least Absolute Residual : $\frac{1}{N}\sum_{i=0}^{N-1} w_i \left| f_i - y_i \right|$

q_0	$j_0 + \Omega$	s_0
-0.68 ± 0.30	0.021 ± 1.07	3.39 ± 17.13
-0.78 ± 0.20	0.62 ± 0.86	8.32 ± 12.16

→

Ω_M	Ω_Λ
0.37 ± 0.31	0.63 ± 1.13
0.28 ± 0.30	0.72 ± 1.09



Testing the EoS parameters

- Knowing also the snap parameter it is possible to estimate the CPL parameters
- In this case we relax previous EoS constraint :

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

Results

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

That within the errors agree with the ΛCDM model but it doesn't agree with the epoch of the transition acceleration–deceleration : $\boxed{z > 10}$

But this estimate does not agree very well with the *real* value of the EoS...

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

→ **We need a new method !!!**

(Capaccioli, Capozziello, Covone and Izzo 2008 submitted)

Starting from Friedmann...

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

with some calculation...

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

And if we consider a flat Universe as the observations of mission like WMAP and the Supernova data say...

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

…and the equality $\frac{a_0}{a} = 1 + z$ we have $H^2(z) = H_0^2 (1+z)^{3(w+1)}$

and if we insert the CPL parametrization for the EoS, we obtain finally

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

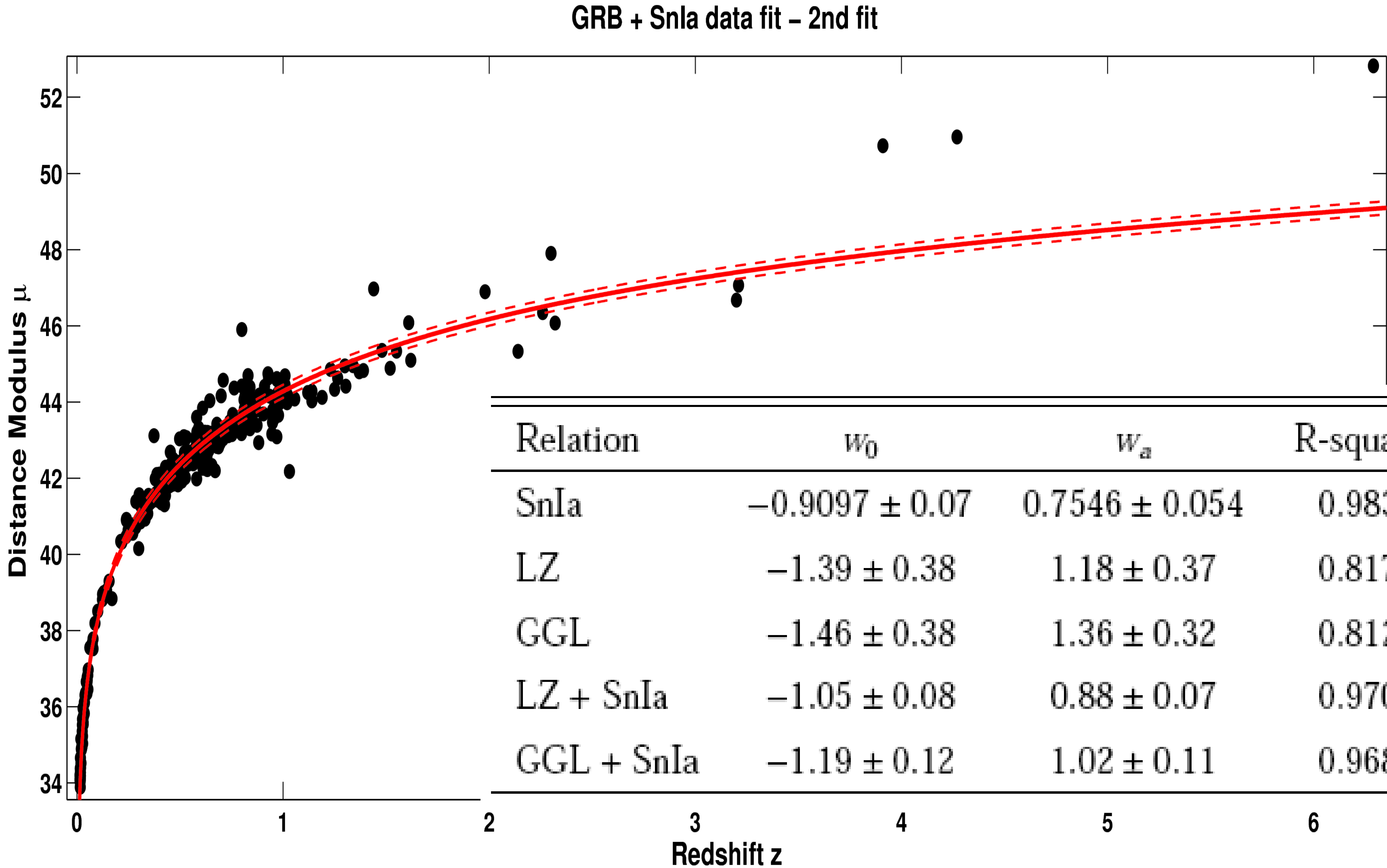
…which directly enters in the expression of the distance modulus…

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

- Hubble function independent from the density parameters
- We don't use the CPL parameters only for the DE contribute, but for the total energy–matter density of the Universe
- Test for the CPL parametrization

Fit with the data : GRB + UNION Sn Ia

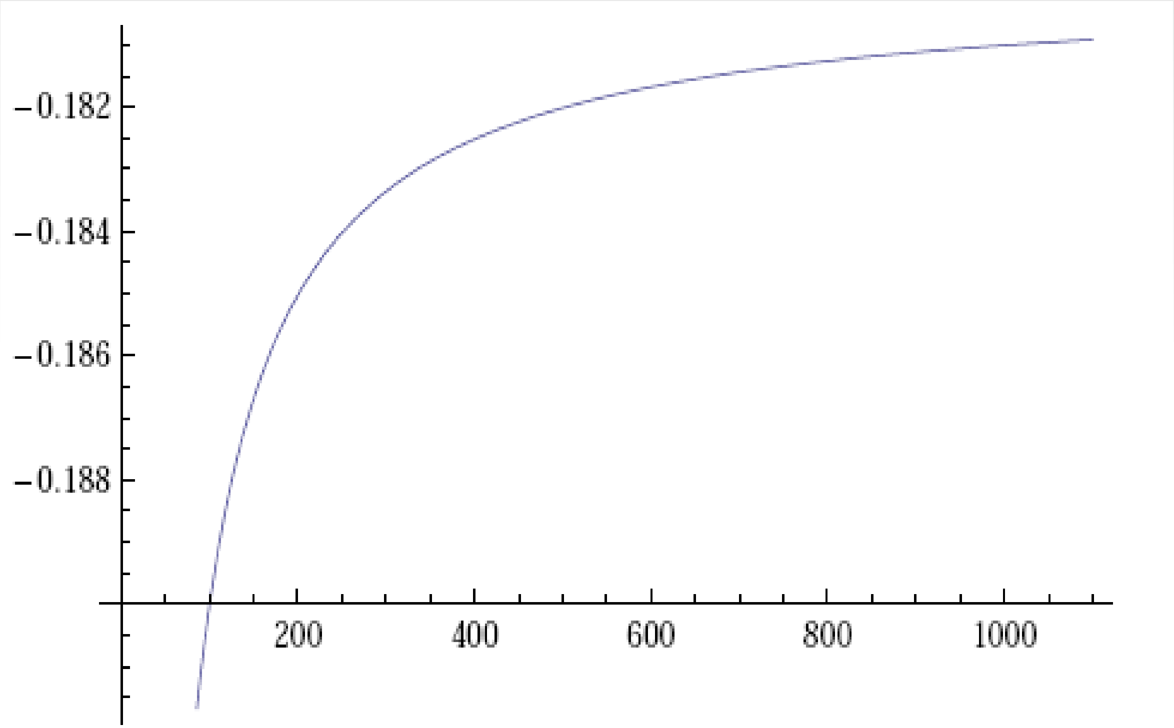
Non Linear Least Squares – Least Absolute Residual



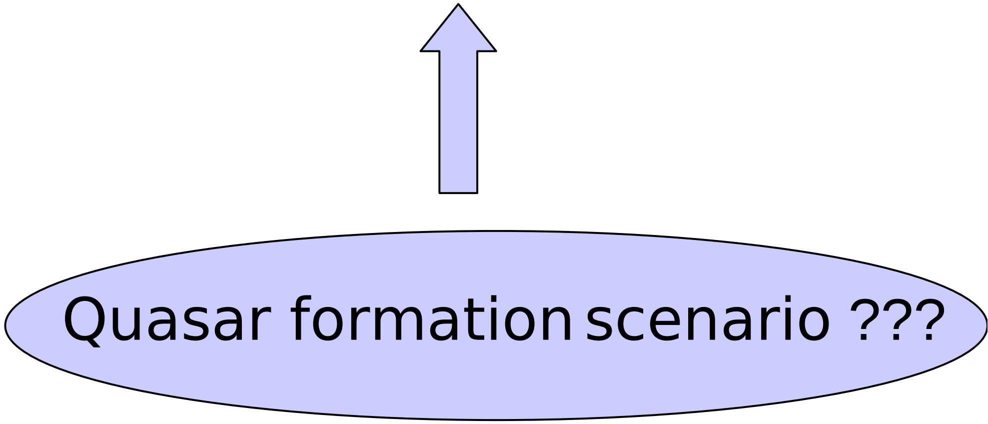
Relation	w_0	w_a	R-square
SnIa	-0.9097 ± 0.07	0.7546 ± 0.054	0.983
LZ	-1.39 ± 0.38	1.18 ± 0.37	0.817
GGL	-1.46 ± 0.38	1.36 ± 0.32	0.812
LZ + SnIa	-1.05 ± 0.08	0.88 ± 0.07	0.970
GGL + SnIa	-1.19 ± 0.12	1.02 ± 0.11	0.968

Constructing EOS(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
  $z = 4.47909 \pm 0.133$



...work in progress...

Coming soon

Tomographic representations and 4–order gravity

$$\Psi(x) = \frac{1}{2\pi|\Psi(0)|}\int \mathcal{W}(y,\mu,x)e^{i(y-\mu x/2)}dy\,d\mu$$

(Capozziello, Izzo & Luongo in preparation)

Noether simmetry

$$L_X\mathcal{L} = 0 \rightarrow X\mathcal{L} = 0\,,$$

A set of partial differential eqs whose results can be translated in tomographic representations...

$$\mathcal{W}(a,z) \sim \frac{-w_a}{1+z}.$$

$$\mathcal{W}(a,z) \propto \frac{w_a}{z(9w_1+18)+1}$$

Application to constraining
- Braneworld (RS type II)
- f(R) theories

(Izzo, Benini et al. 2009 in revision)

...preliminary results...

Discussions and Results

- CPL parameters applied to the total energy–matter density
- Results agree with the ΛCDM model
- Epoch of the transition acceleration–deceleration $(z \approx 5)$
- Presence of a phantom regime in our epoch $(z << 1)$
- Need of a new parametrization for the EoS ???
- Need of a wider sample of GRBs, in particular GRBs with higher redshift $(z > 6)$

Conclusions and Perspectives

- Cosmography results suggest that GRBs can be used as distance indicators
- Matching with other distance indicators like clusters, red galaxies and the CMB
- Improving the relation between GRBs observables, maybe with new relations...
- $H(z)$ obtained is a powerful tool to discriminate the other standard candles and also the several cosmological models (ΛCDM, Braneworld RS, $f(R)$)...

References

- Meszaros 2006 Rept Prog Phys 69, 2259
- Capozziello & Izzo 2008 A&A accepted
- Capozziello et al. 2008 Phys Rev D
- Kowalski et al. ApJ 2008
- Ruffini et al. *Proceedings of the XI Marcel Grossmann 2008*
- Liang et al. 2008 ApJ
- Liang & Zhang 2005 ApJ
- Visser 2004 CQG 21, 2603
- Schaefer 2007 ApJ 660, 16
- Ghirlanda et al. 2004 ApJ 616, 331

Some formula

$$R-square = 1 - \frac{SSE}{SST},$$

$$SSE = \sum_{i=1}^{n} w_i (y_i - \hat{y}_i)$$

$$SST = \sum_{i=1}^{n} w_i (y_i - \bar{y}_i)^2,$$

Gamma function

$$D_l(z) = \left(\frac{3w_a}{2}\right)^{-\frac{1+3w_0+3w_a}{2}} \exp\left(\frac{3w_a}{2}\right) \Gamma\left[\frac{1+3w_0+3w_a}{2}, \frac{3w_a}{2(1+\xi)}\right]\Bigg|_{\xi=0}^{\xi=z}$$