GRB CORRELATIONS AND THEIR COSMOLOGICAL APPLICATIONS

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Notwithstanding the variety of GRB's different peculiarities, some common features may be identified looking at their light curves.

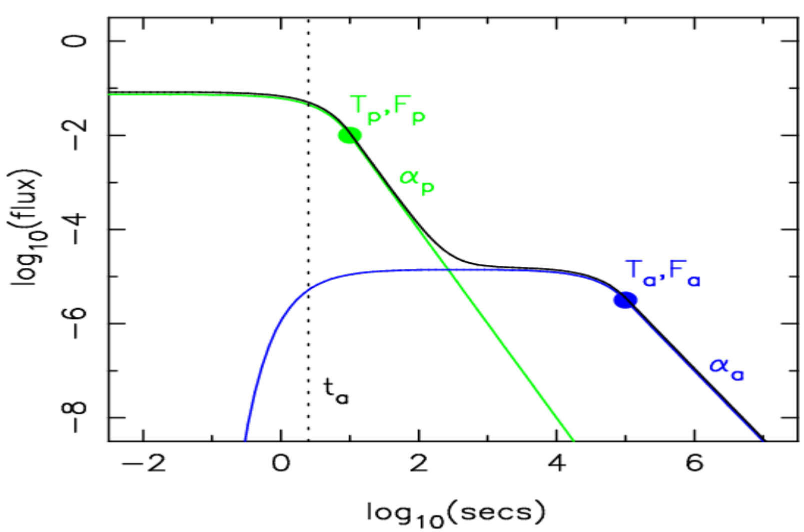
A breakthrough :

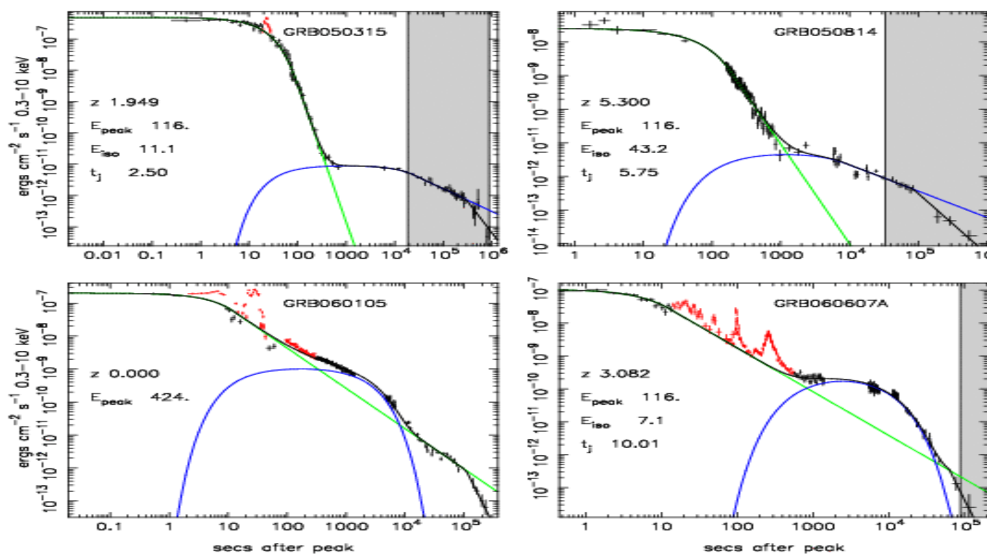
- a more complex behavior of the light curves, different from the broken power-law assumed in the past (Obrien et al. 2006,Sakamoto et al. 2007). A plateau phase has been discovered.

Phenomenological model with SWIFT lightcurves

A significant step forward in determining common features in the afterglow

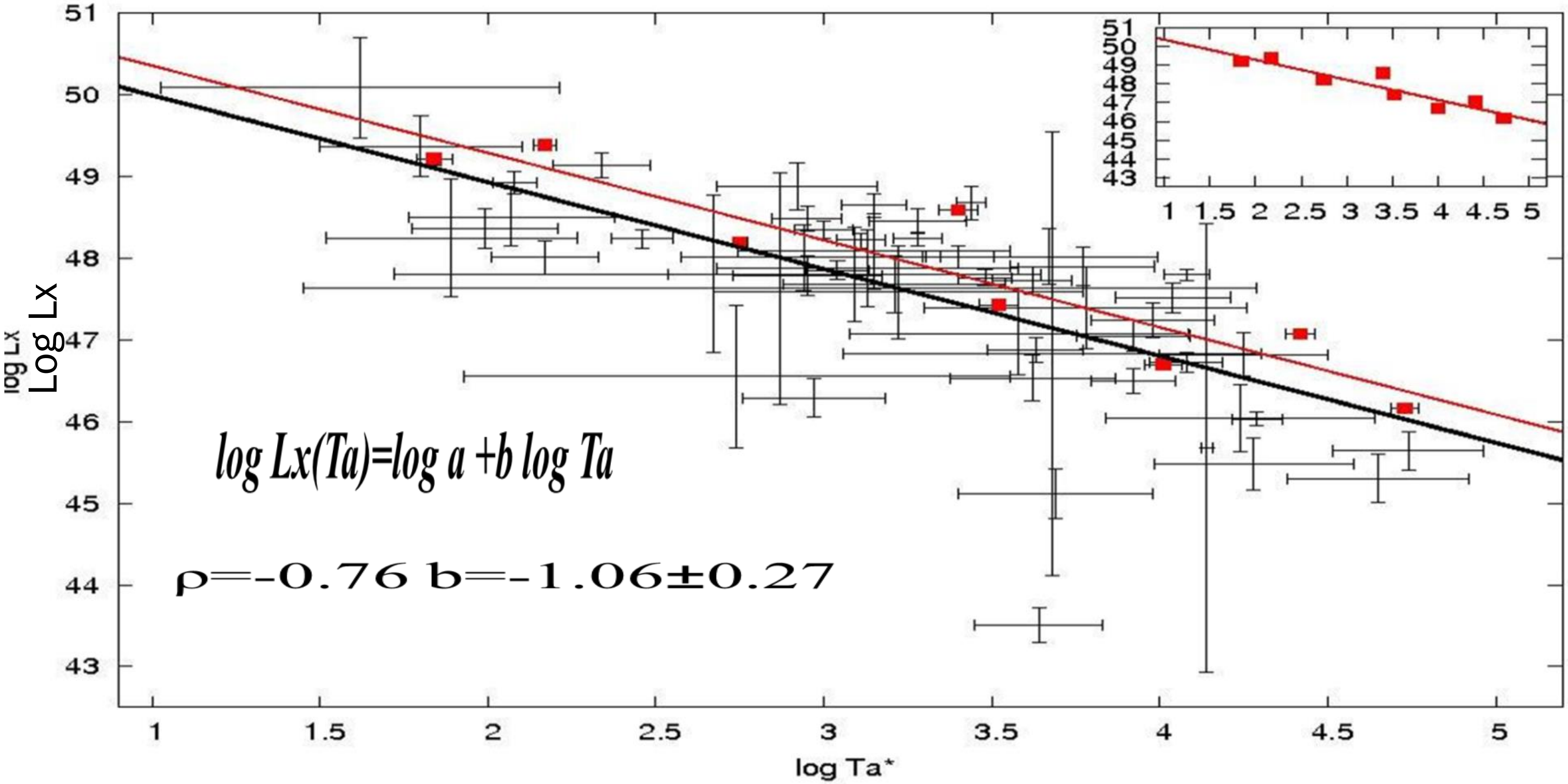
- X-ray afterglow light curves of the full sample of Swift GRBs shows that they may be fitted by the same analytical expression (Willingale et al. 2007)





Willingale et al. 2010 improved this model with the high latitude emission ones, afterglow fitting of W2010 and W2007 are compatible

Dainotti et al. correlation $L_X - T^*_a$

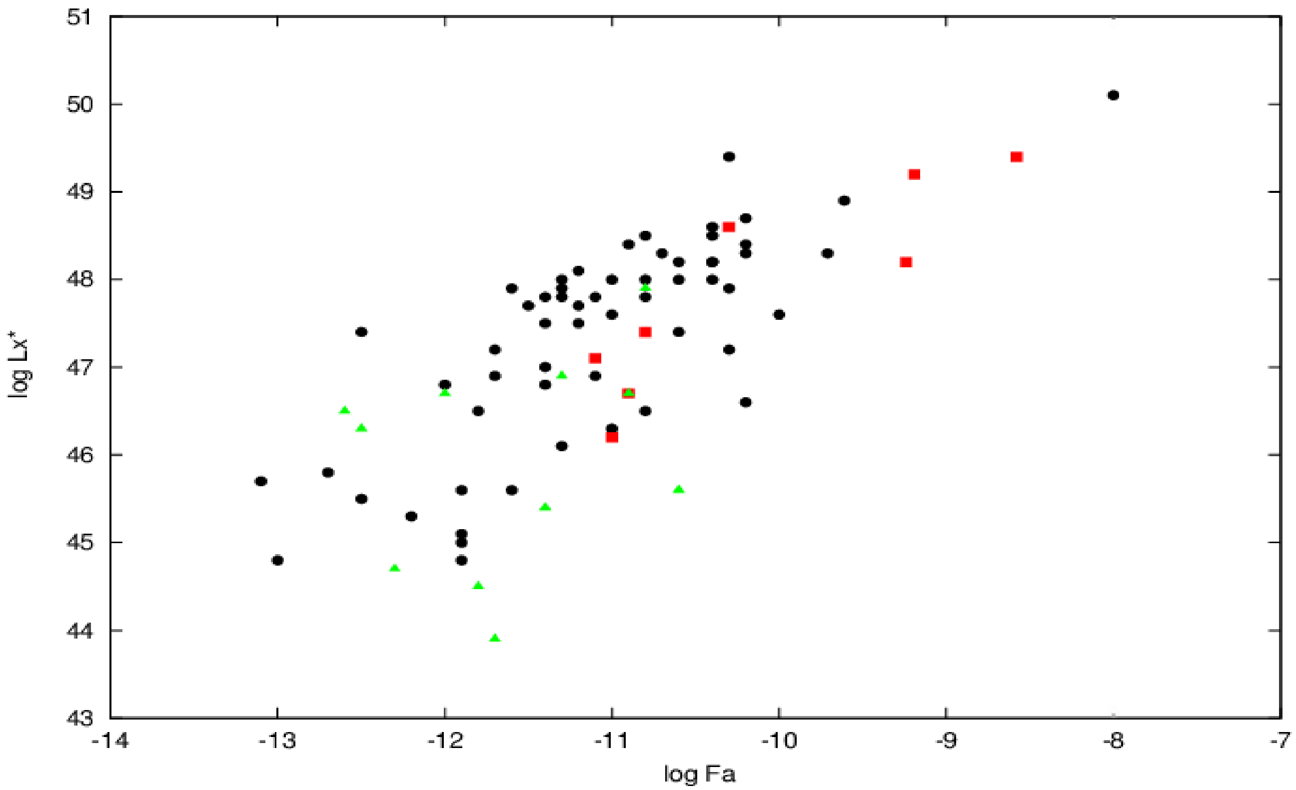


Firstly discovered in 2008 by Dainotti, Cardone, & Capozziello MNRAS, 391, L 79D (2008)

Later updated by Dainotti, Willingale, Cardone, Capozziello & Ostrowski ApJL, 722, L 215 (2010)

Lx(T*a) vs T*a distribution for the sample of 62 long afterglows

IS THE TIGHT CORRELATION DUE TO BIAS SELECTION EFFECTS?



If we had had a selection effect we would have observed the red points only for the higher value of fluxes.

The green triangles are XRFs, red points are the low error bar GRBs

PROMPT – AFTERGLOW CORRELATIONS

Dainotti et al., MNRAS, 418,2202, 2011

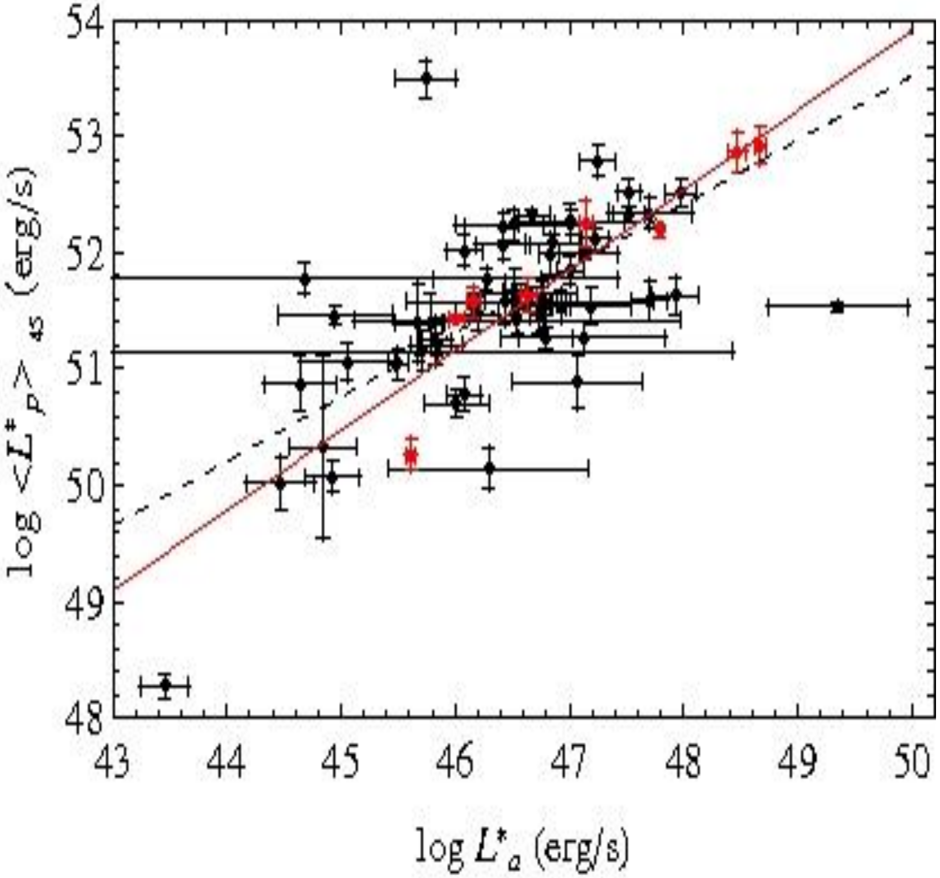
A search for possible physical relations between the afterglow characteristic luminosity $L^*_a \equiv L_x(T_a)$

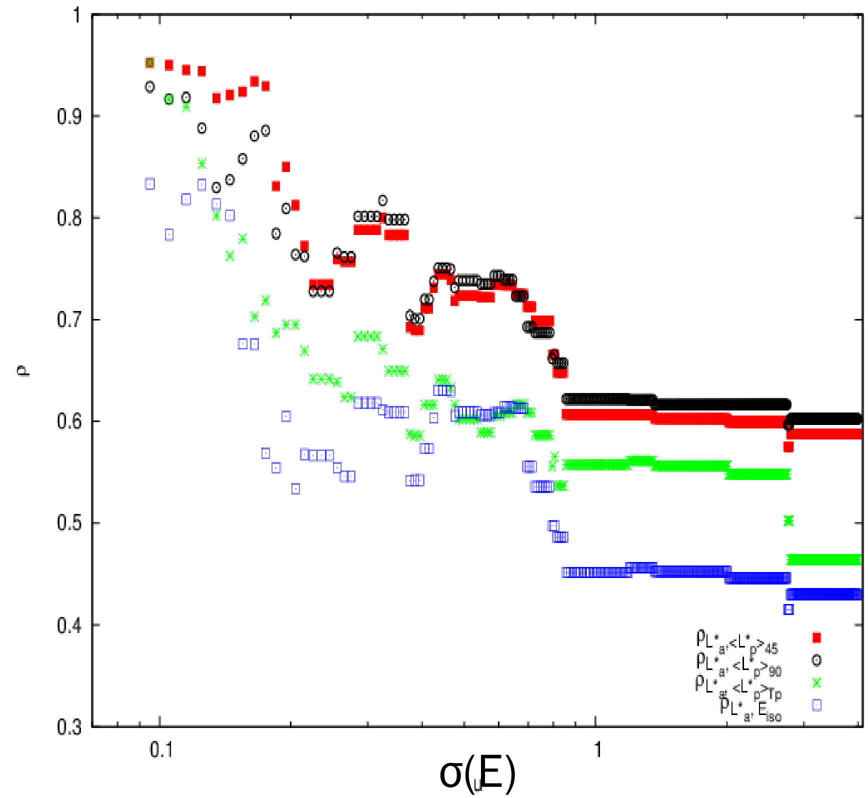
and

the prompt emission quantities:

1.) the mean luminosity derived as $\langle L^*_p \rangle_{45} = E_{iso}/T^*_{45}$
2.) $\langle L^*_p \rangle_{90} = E_{iso}/T^*_{90}$
3.) $\langle L^*_p \rangle_{T_p} = E_{iso}/T^*_p$
4.) the isotropic energy E_{iso}

For the theoretical interpretation of these correlations see Daigne's talk





Correlation coefficients ρ for for the long GRB subsamples with the varying error parameter σ(E)

L*a vs. <L*p>45 for 62 long GRBs (the **σ(E)** ≤ 4 subsample).

(L*A, <L*P>45) - RED

(L*A, <L*P>90) - BLACK

(L*A, <L*P>TP) - GREEN

(L*A, EISO) - BLUE

$$\sigma(E) = (\sigma_{Lx}^2 + \sigma_{Ta}^2)^{1/2}$$

Conclusion I

GRBs with well fitted afterglow light curves

obey tight physical scalings, both in their afterglow properties and in the prompt-afterglow relations.

We propose these GRBs as good candidates for

the standard Gamma Ray Burst

to be used both

- in constructing the GRB physical models and
- in cosmological applications
- (Cardone, V.F., Capozziello, S. and Dainotti, M.G 2009, MNRAS, 400, 775C
- Cardone, V.F., Dainotti, M.G., Capozziello, S., and Willingale, R. 2010, MNRAS, 408, 1181C)

LET'S GO ONE STEP BACK

BEFORE

proceeding with any further application to cosmology

or using the luminosity-time correlation as discriminant among theoretical models for the plateau emission

We need to answer the following question:

Is what we observe a truly representation of the events or there might be selection effect or biases?

Is the LT correlation intrinsic to GRBs, or is it only an apparent one, induced by observational limitations and by redshift induced correlations?

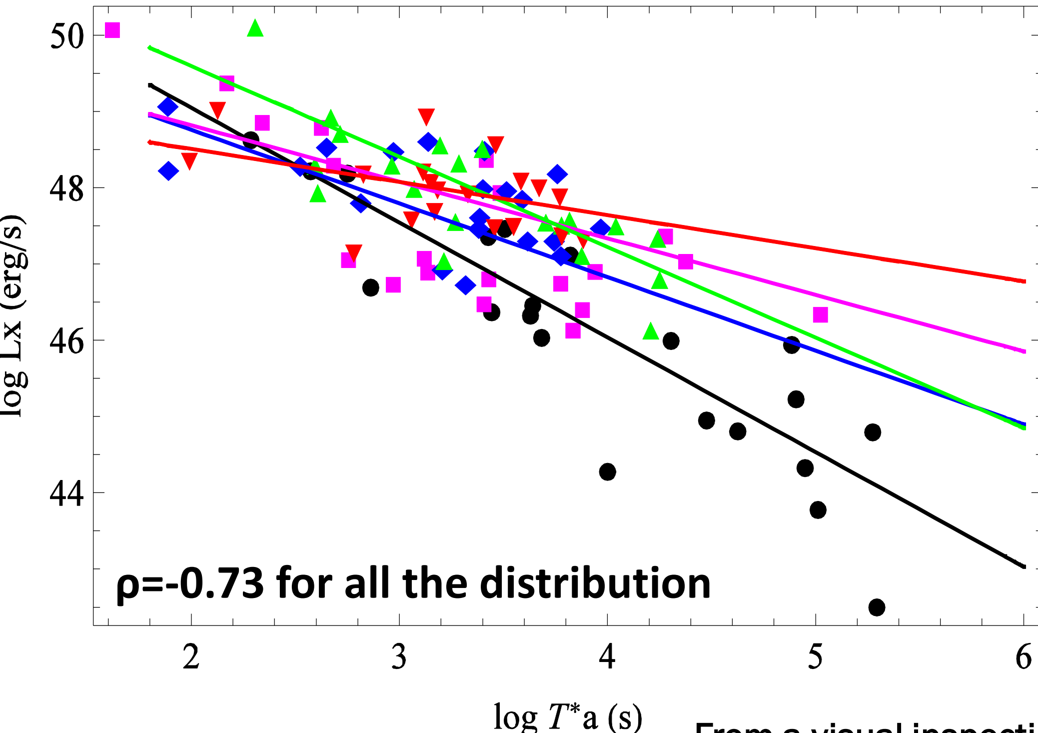
THEREFORE,

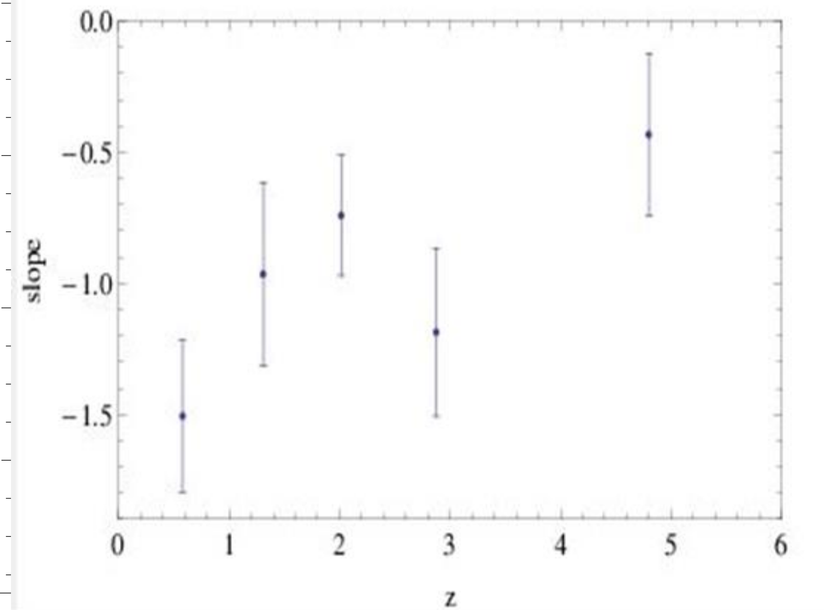
at first one should determine the true correlations among the variables

Importance of selection effects has been discussed in previous talks, see Graham, Hunt, Sakamoto.

DIVISION IN REDSHIFT BINS FOR THE UPDATED SAMPLE OF 100 GRBS (WITH FIRM REDSHIFT AND PLATEAU EMISSION)

Dainotti et al. 2013, ApJ, 774, 157D





black for $z < 0.89$,
magenta for $0.89 \leq z \leq 1.68$,
blue for $1.68 < z \leq 2.45$
Green $2.45 < z \leq 3.45$
red for $z \geq 3.45$.

From a visual inspection it is hard to evaluate if there is a redshift induced correlation. Therefore, we have applied the test of Dainotti et al. 2011, ApJ, 730, 135D to check that the slope of every redshift bin is consistent with every other.

BUT It is not enough to answer definitely the question.

The slope of each redshift bin are compatible in 2 sigma from the first to the last, while in 1 sigma the contiguous ones.

THEREFORE, FOR A MORE RIGOROUS UNDERSTANDING WE APPLY:

The Efron & Petrosian method (EP) (ApJ, 399, 345,1992)

to obtain unbiased correlations, distributions, and evolution with redshift from a data set truncated due to observational biases.

corrects for instrumental threshold selection effect and redshift induced correlation

has been already successfully applied to GRBs (Lloyd,N., & Petrosian, V. ApJ, 1999)

The technique we applied

Investigates whether the variables of the distributions, L^*_X and T^*_a are correlated with redshift or are statistically independent.

do we have luminosity vs. redshift evolution? $g(z)$

do we have plateau duration vs. redshift evolution? $f(z)$

If yes

how to accomodate the evolution results in the analysis?

By defining new independent variables!

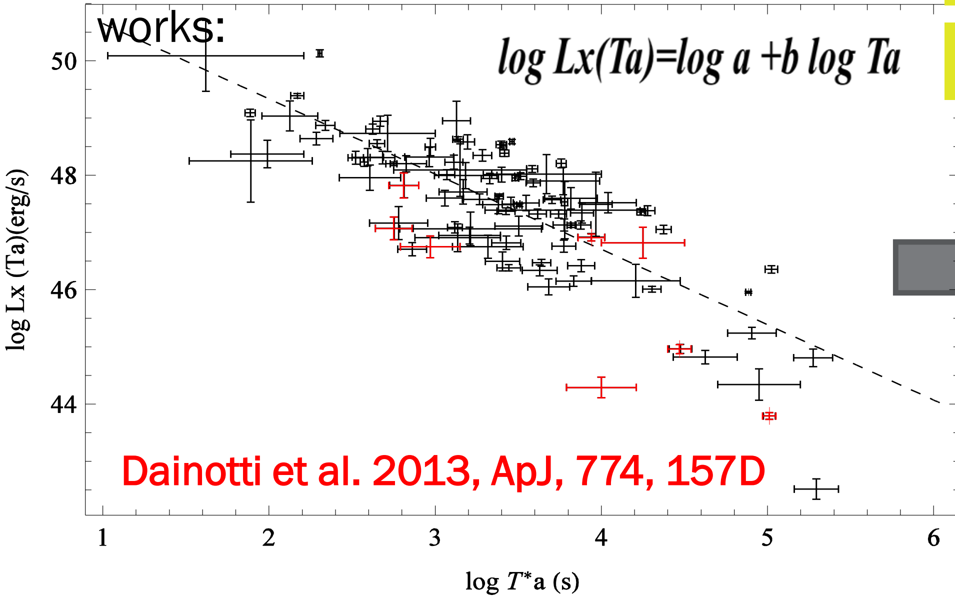
→

LUMINOSITY-TIME CORRELATION IN X-RAY AFTERGLOWS

This is the last update of previous works:

Dainotti, et al. MNRAS, 391, L 79D (2008)

Dainotti et al. ApJL, 722, L 215 (2010)

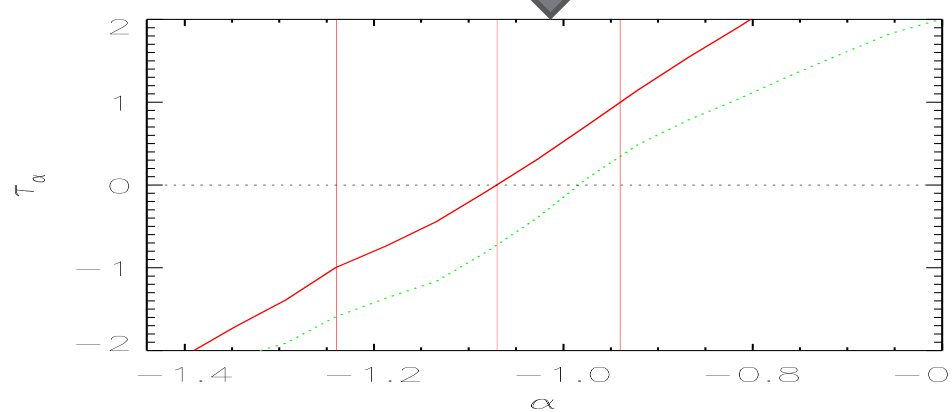


The observed correlation slope vs the intrinsic one

-1.07 ± 0.14

The observed slope b=-1.27 ± 0.15

After correction of luminosity and time evolution , and luminosity detection bias through the Efron & Petrosian (1999) technique one obtains the intrinsic correlation



(Dainotti et al. 2013, ApJ, 774, 157D)

CONCLUSIONS - PART II

The correlation La-Ta exists !!!

It can be useful as model discriminator **among several models that predict the Lx-Ta anti-correlation**:

energy injetion model from a spinning-down magnetar at the center of the fireball *Dall' Osso et al. (2010), Xu & Huang (2011), Rowlinson & Obrien (2011), Rowlinson et al. (2014). In this last paper the intrinsic correlation has been taken into account.*

Accretion model onto the central engine as the long term powerhouse for the X-ray flux *Cannizzo & Gerhels (2009), Cannizzo et al. 2010*

Prior emission model for the X-ray plateau *Yamazaki (2009) (see Sakamoto's talk)*

DOES THE LX-TA CORRELATION EXIST FOR LAT GRBS?

(SEE THE PREVIOUS TALK OF PIRON AND TAVANI)

First step: we can determine the existence of the plateaus ?

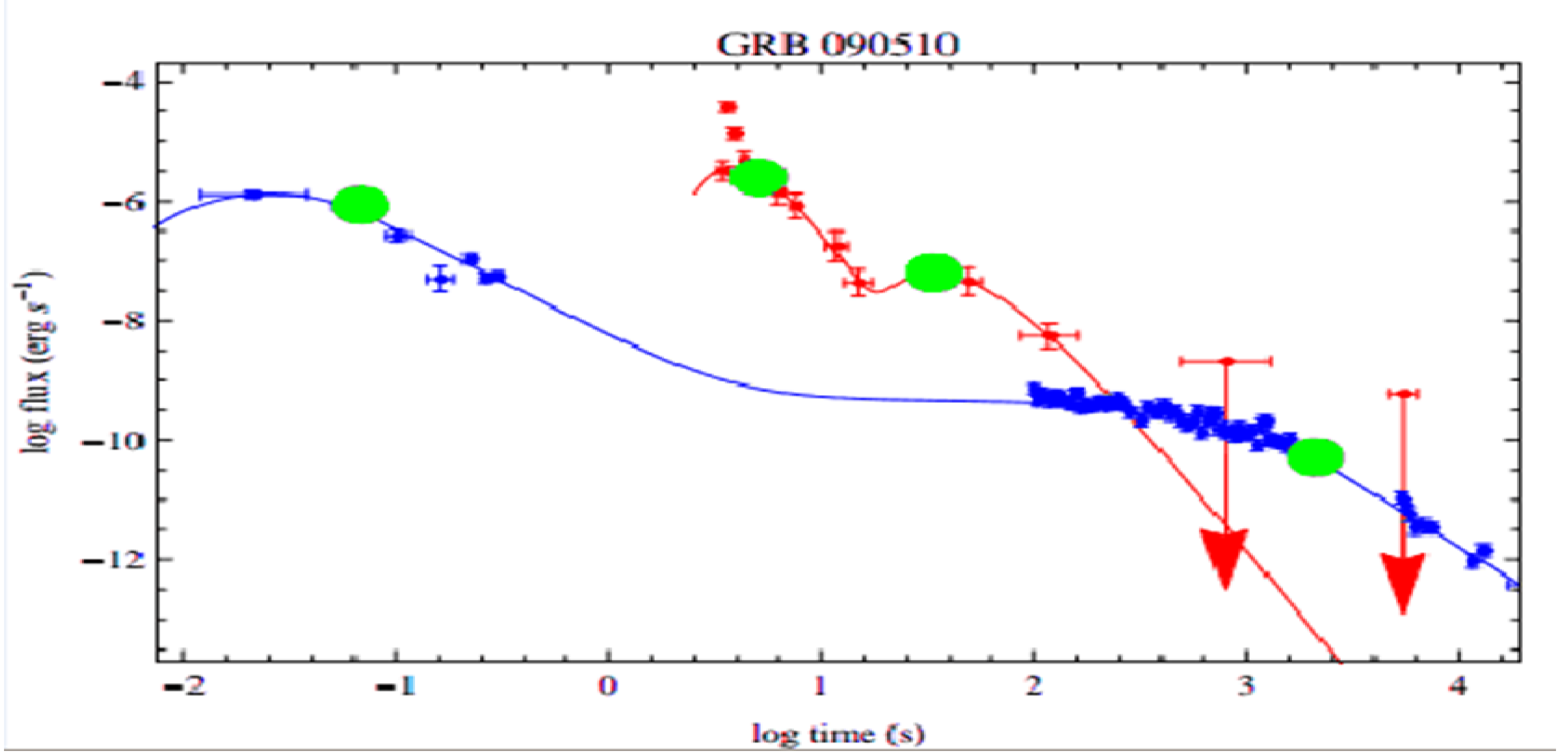
If exists does it depend on a forward shock emission?

From a sample of 35 GRBs (Ackerman et al. 2013, the First Fermi-LAT GRB catalog) we can safely select only 4 GRBs with firm redshift if we consider the fits without upper limits only.

What is the most appropriate method to deal with X-ray and LAT data together?

We show simultaneously the X-ray and LAT light curves.

GRB 090510 SHORT HARD - A SPECTROSCOPIC REDSHIFT Z=0.903±0.003 (RAU ET AL. 2009)



The only case with an overlap between LAT data and XRT at 100 s.

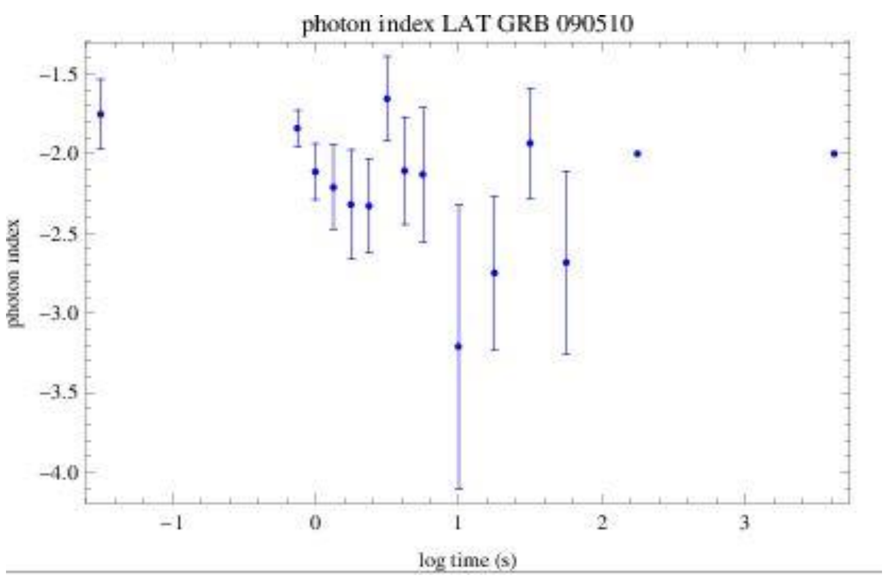
Fit: Fp=-3.5,alp=6.34,Tp=0.66,tp=0, Fa=-5.34, ala=4.35, Ta=1.51,ta=20
reduced χ^2 power law: $\chi^2 = 0.09$ P=0.02, reduced χ^2 plateau: =0.61 P=0.99

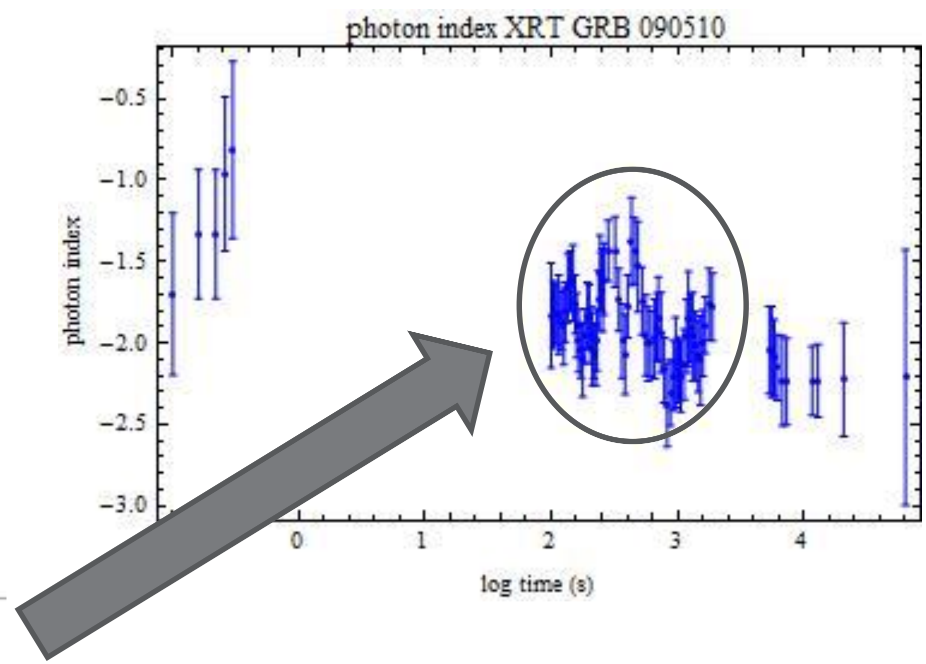
THE CONVERSION FACTOR

$$\frac{\int_{0.3\ keV}^{10\ KeV} E E^{-\beta} dE}{\int_{10^5\ keV}^{10^7\ KeV} E E^{-\beta} dE}$$ = Conversion factor from LAT to XRT.

The XRT Swift energy band 0.3-10 KeV; LAT band is 100 MeV -1 GeV

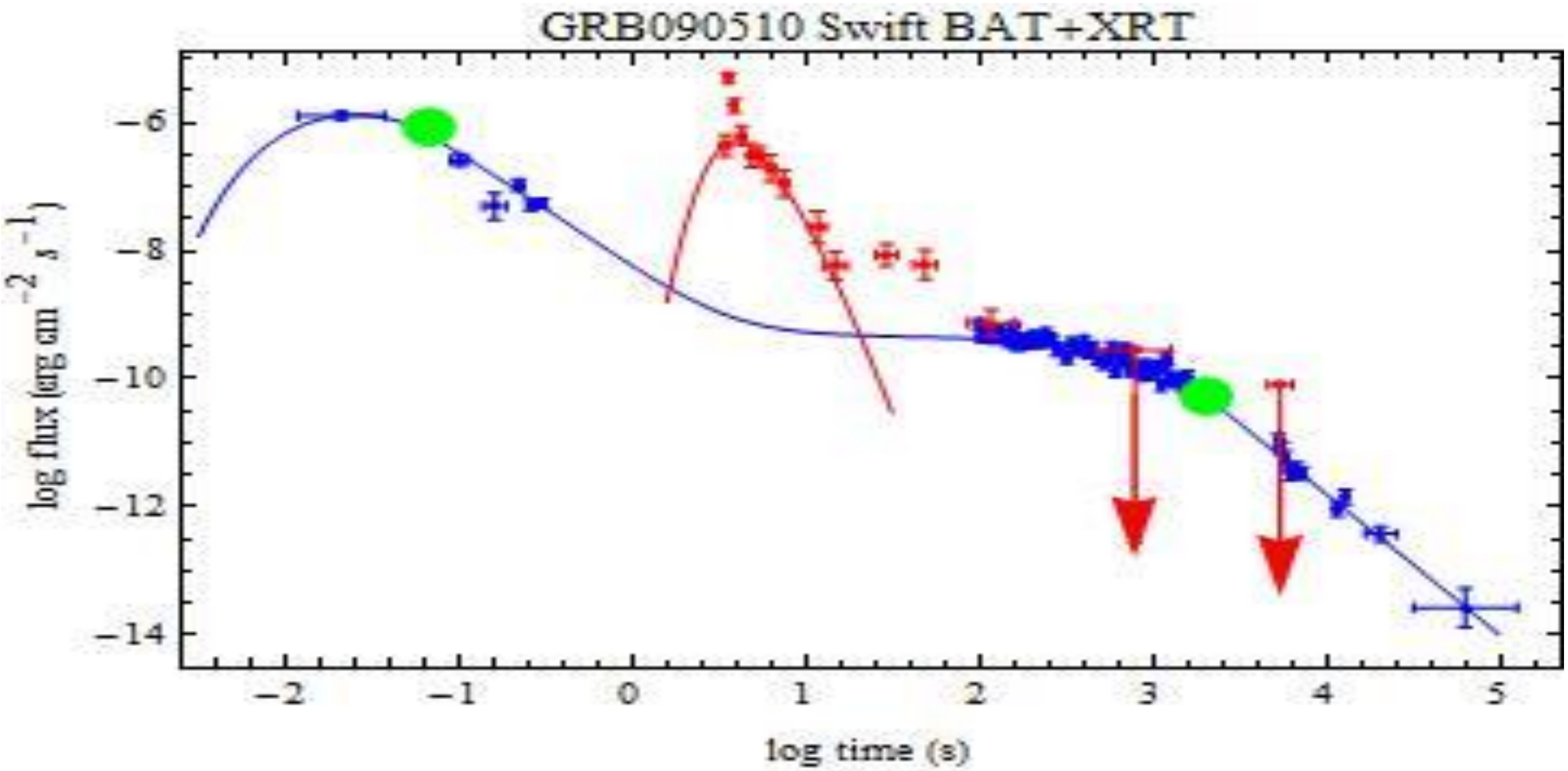
Every single point of LAT is multiplied by Conversion factor, where β is the best spectral fit value in the integrated spectrum





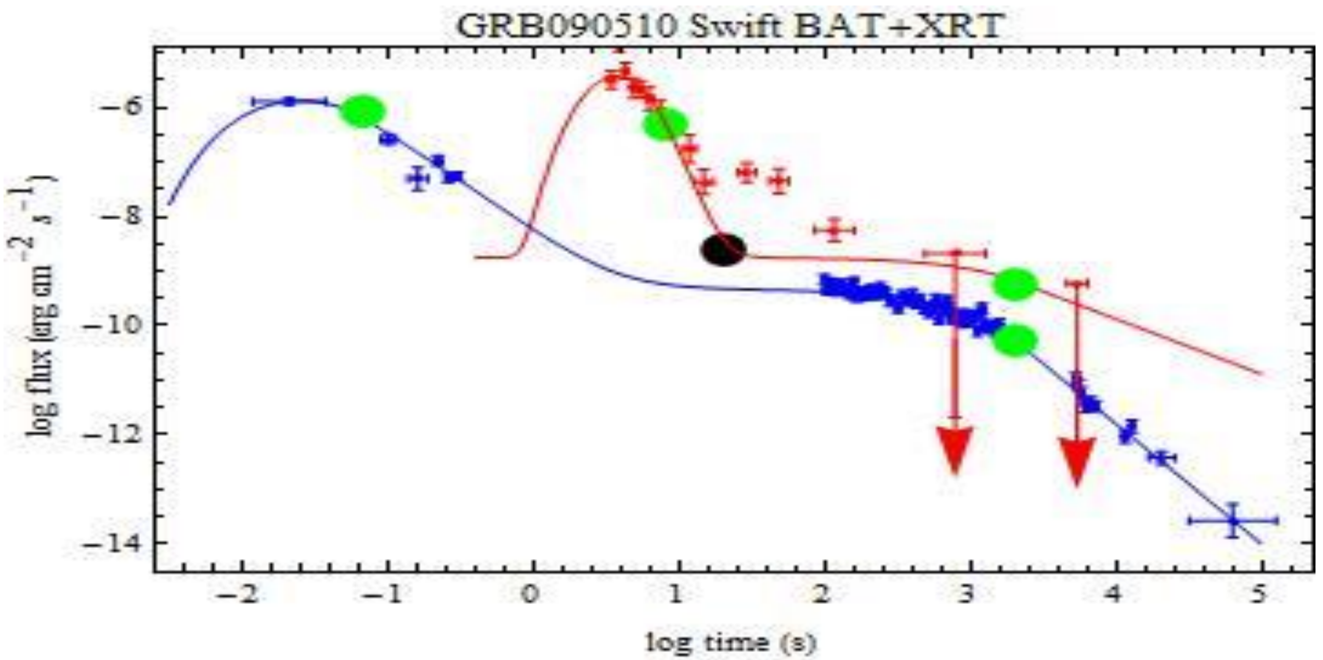
We averaged the spectral parameters in the time interval 100-1000, βmean= -1.87.
If we vary the spectral parameter in the indicated circular region (-2.0,-1.5) contemporaneously with the fit parameters of the W07 model we found that the best fit sets of parameters are the ones with the value of βmean.

RESCALING OF THE SPECTRUM



In this case we have perfect coverage of the data allowing for a good determination of the end time of the plateau emission

IF WE CONSIDER FLARING ACTIVITY IN LAT



Then we have possibility to note indication that the evaluated Ta is consistent both for high energy emission and XRT emission. In order to make this indication stronger one can rescale the energy spectra.

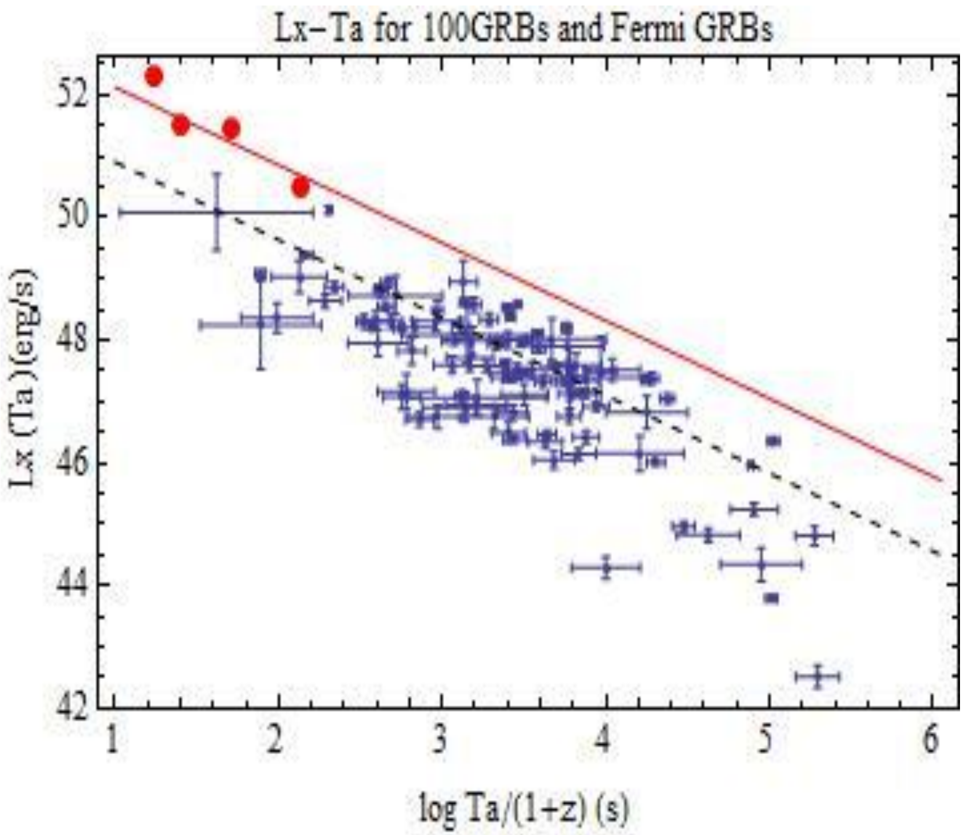
FROM THE ANALYSIS OF THE BURSTS WE HAVE COMPUTED THE VALUES OF THE TEMPORAL INDEX, A, AND COMBINING THEM WITH THE SPECTRAL INDEX B WE COMPUTE THE CLOSURE RELATION, $A = (3B - 1)/2$, FOR THE PLATEAU PHASE.

WE SHOW IN WHICH CASES THE CLOSURE RELATIONSHIP ARE FULFILLED. WHEN THEY ARE FULFILLED THERE IS COMPATIBILITY WITH THE EXTERNAL SHOCK SCENARIO.

GRB name	α	β	$\alpha = (3\beta - 1)/2$
GRB 090926	1.02	1.13	Yes
GRB 090902B	1.26	1.3	Yes
GRB 090510	4.35	1.35	No
GRB 080916C	2.60	1.0	No

While GRB 090902B is compatible with the explanation of Kumar & Duran 2010, GRB 080916C and GRB 090510 show that the closure relations are not fulfilled.

CONCLUSION: LUMINOSITY-TIME RELATIONS FOR HIGH ENERGY GRBS



Even as the paucity of the data restrains us from drawing any definite conclusion we note similar fitted slopes for L-T correlation, but with different normalizations.

L-T correlation seems not to depend on particular energy range:

a physical scaling for GRB afterglows both in X-rays and in γ-rays.

Normalizations: **log a=52.17 in X-rays and 53.40 in γ-rays**

UPDATING THE GRB HUBBLE DIAGRAM
WITH THE DAINOTTI ET AL. CORRELATION

Allows to increase both the GRBs sample (83 GRBs vs 69) in Schaefer et al. 2006

reduce the uncertainty on the distance moduli μ*(z) of the 14%*
Cardone, V.F., Capozziello, S. and Dainotti, M.G 2009, MNRAS, 400, 775C

The use of the HD with the only Dainotti et al. correlation alone or in combination with other data shows that the use of GRBs leads to constraints in agreement with previous results in literature.

A larger sample of high-luminosity GRBs can provide a valuable information in the search for the correct cosmological model (Cardone, V.F., Dainotti, M.G et al. 2010, MNRAS, 408, 1181)

HOW SELECTION EFFECTS CAN INFLUENCE CORRELATION AND COSMOLOGY AND WHAT IS THE CIRCULARITY PROBLEM?

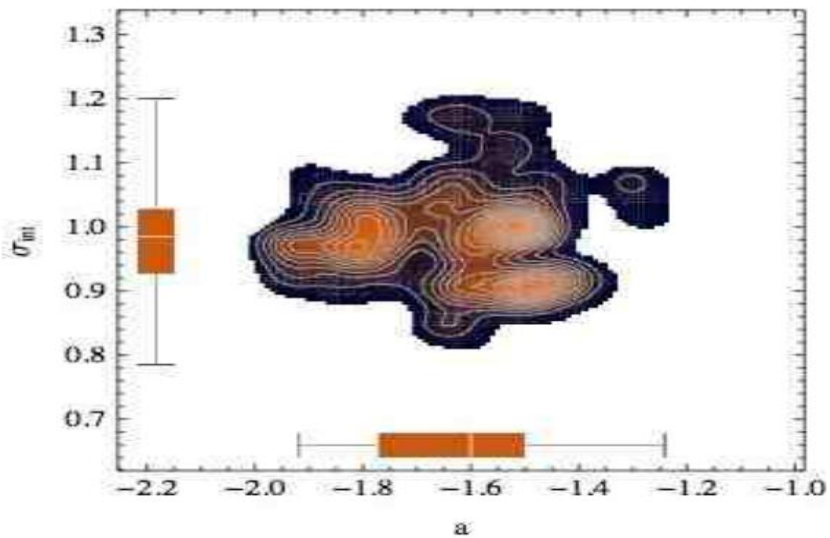
In Dainotti et al. 2013b MNRAS, 436, 82D we show how the change of the slope of the correlation can affect the cosmological parameters.

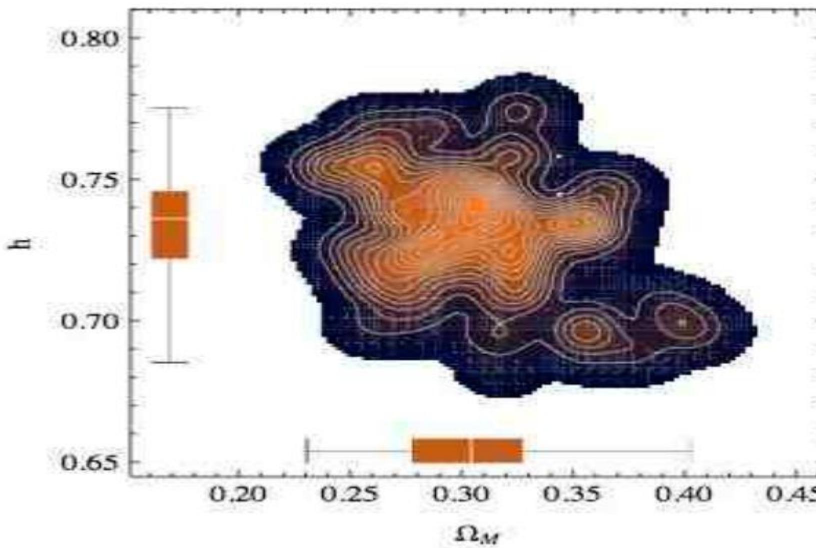
With a simulated data set of 101 GRBs with a central value of the correlation slope that differs on the intrinsic one by a 5σ factor.

The circularity problem derive from the fact that the parameters a and b depend on a given cosmology.

A way to overcome this problem is to change contemporaneously the fit parameters and the cosmology

FULL SAMPLE : GRB+SNE +H(Z)

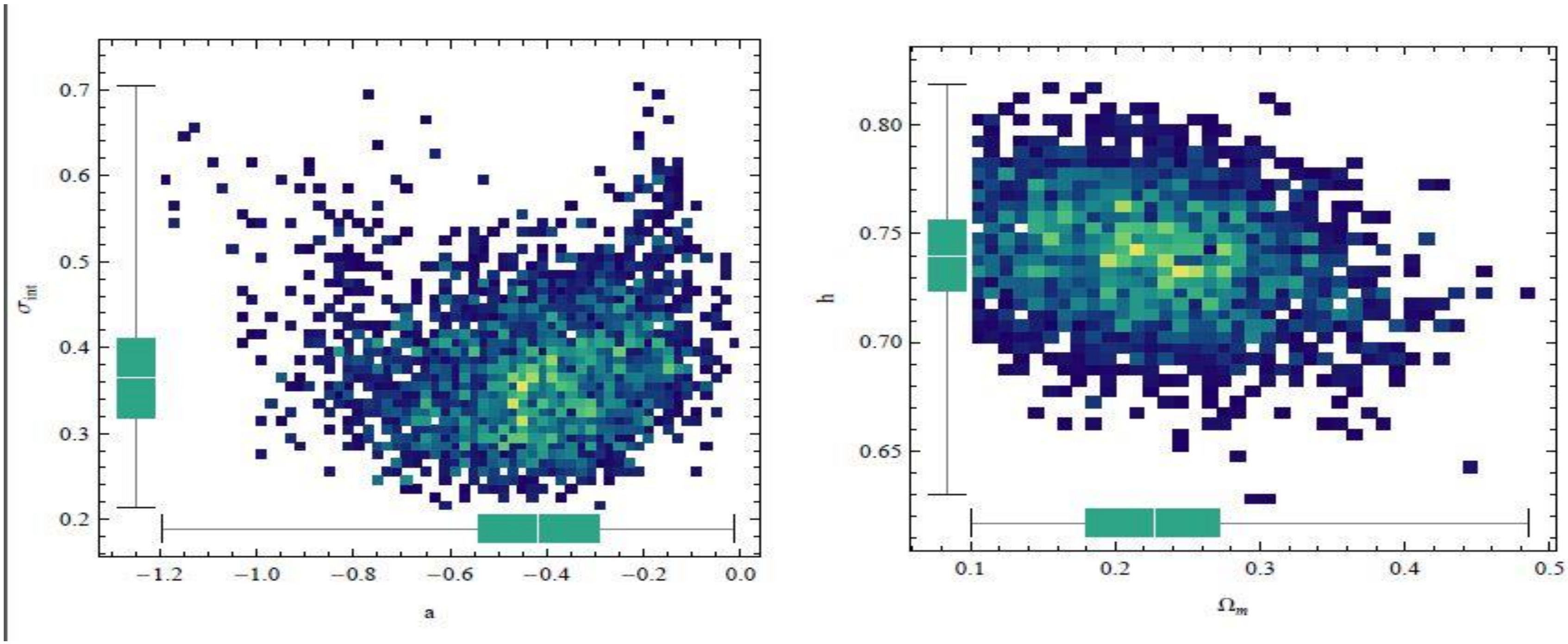




Parameters for non flat/flat models are not distinguishable: Overestimated of the 13% in Ω_M, compared to the Ia SNe (Ω_M , σ_M) = (0.27, 0.034), while the H_0, best-fitting value is compatible in 1σ compared to other probes.

We show that this compatibility of H_0 is due to the large intrinsic scatter associated with the simulated sample.

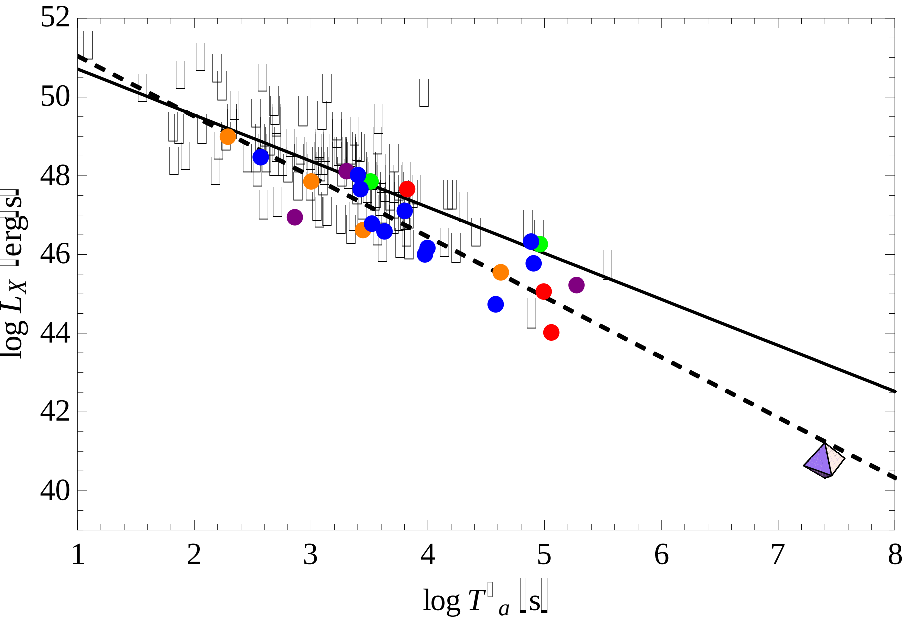
HIGH LUMINOUS SAMPLE: GRBS ONLY



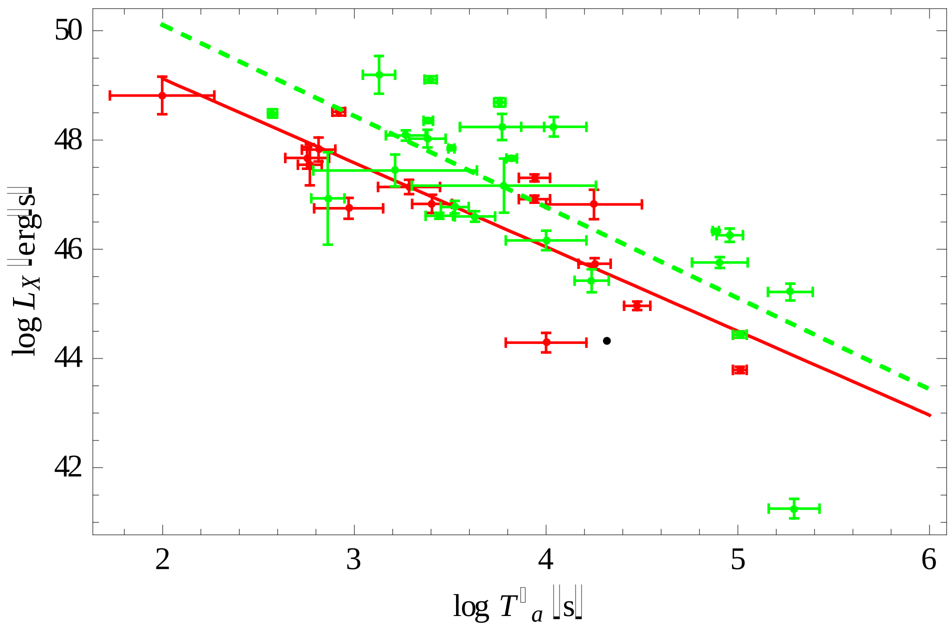
Threshold value $(\log L*X)_{th}$ = 48.7, we are far well enough to the point in which the corrected luminosity function departs from the observed value Lx=47.

HighL sample differs of 5% in the value of H_0 computed in Peterson et al. 2010, while the scatter in Ω_M is underestimated by the 13%.

Looking for a more homogeneous sample for a "Standard GRB set" both for cosmology and for a more precise redshift estimator

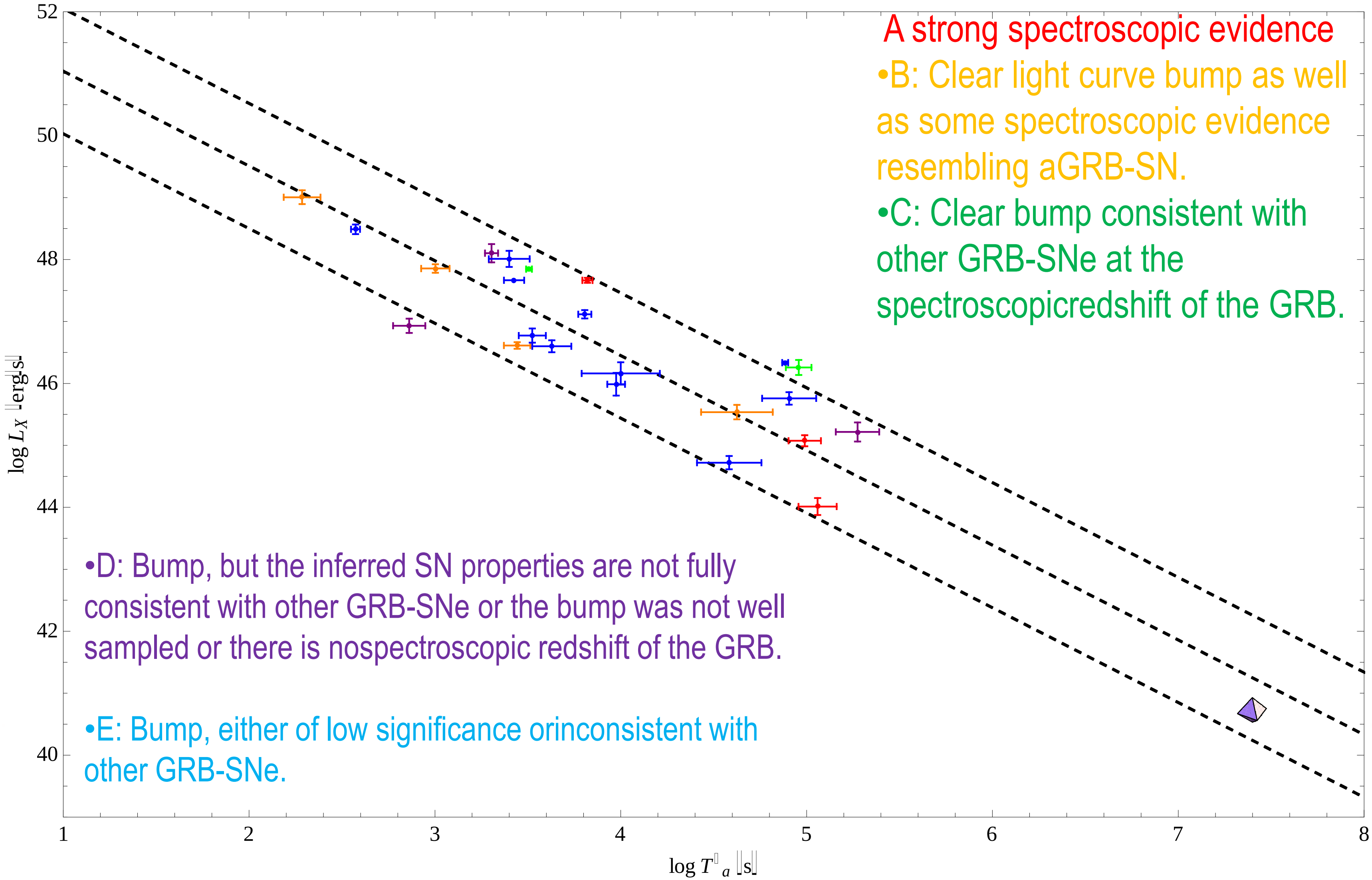


LONG SAMPLE AND GRB-SNE ASSOCIATED SAMPLE.



XRF and Short GRBs

The two dotted lines are the representation of 1 σ error around the best fitted slope. All the data points are within 1 σ. A+B category show ρ= -0.96 with P=1.4*10^3



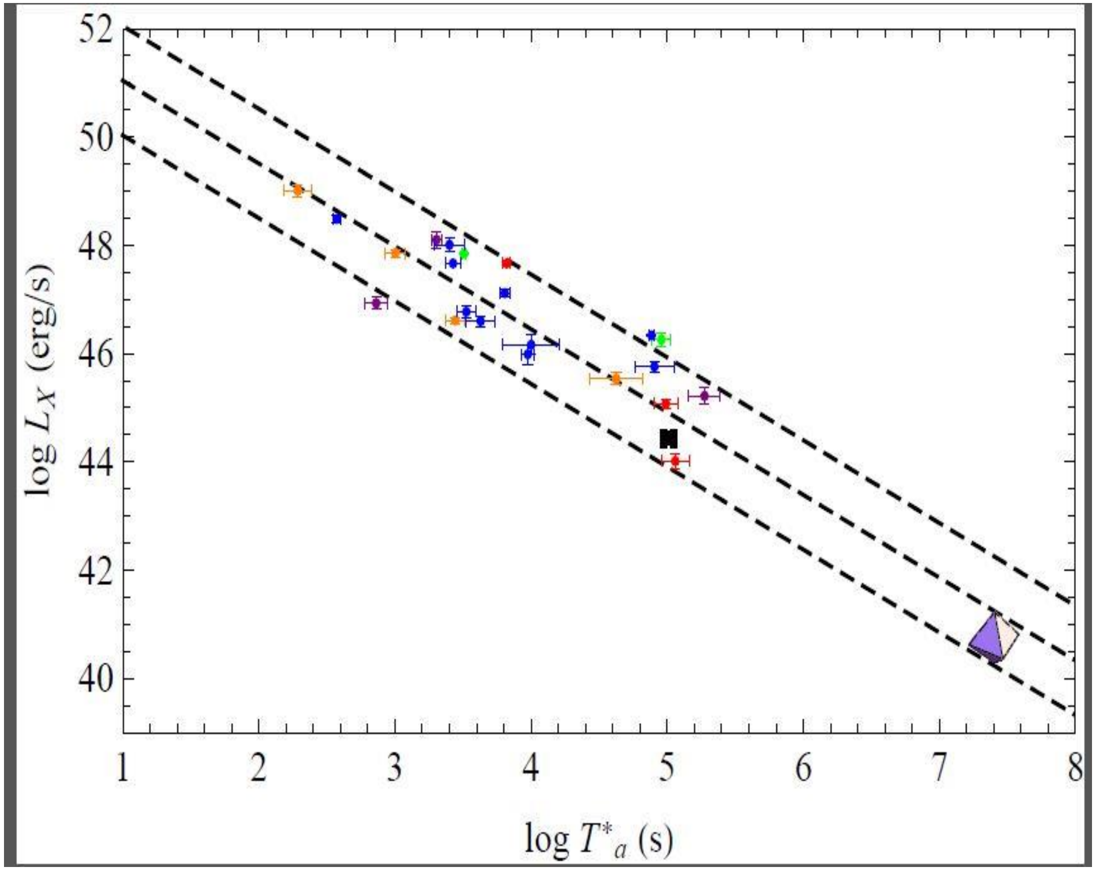
COMPARISON WITH CORRELATION COEFFICIENTS AND SLOPES

Table 1: GRB division in subsamples, the number of GRB in each category, N, the slope of the correlation, a, the normalization, b, the Spearman correlation coefficient, ρ, the Kendall τ statistics and the Probability, P, that an uncorrelared distribution can be drawn by chance. The first 4 categories are based on literature classification, while the last three categories are based on morphology of the lightcurves as described earlier.

GRB category	N of GRBs	a	b	ρ	τ	P
GRB-SNe	23	-1.45 $\pm$0.26	51.54 $\pm$1.02	-0.92	-0.74	$5.62 * 10^{-10}$
GRB-SNe (A+B category)	9	-1.89 $\pm$0.37	53.84 $\pm$1.69	-0.96	-0.78	$1.4 * 10^{-3}$
Short	17	-1.37 $\pm$0.53	51.24 $\pm$1.99	-0.87	-0.70	$1.57 * 10^{-6}$
Long	122	-1.22 $\pm$0.14	52.10 $\pm$0.45	-0.70	-0.52	$3.79 * 10^{-21}$
XRF	25	-1.66 $\pm$0.42	53.44 $\pm$1.63	-0.72	-0.54	$1.64 * 10^{-6}$

There is overlapping within 2 σ between GRB-SNe and long in the slope of the correlation, therefore from this fact we can’t draw conclusion about similarities or differences (Payne 2003)
The bidimensional KS=1.4 10^(-6) for the two Lx,Ta distributions thus demonstrating that the GRB-SNe is not drawn by the same distribution.

POSSIBLE EXPLANATION OF WHY THE CORRELATION IS STRONGER



if we regard SN 1998bw and 2006aj as two extremes defining the GRB-SNe, these three GRBs (B category) are still somewhere between A category. 081007/2008hw could be an outlier in the (naively-developed through a small sample) relation between peak magnitude and light curve speed (faster, the fainter), but one might need to do the fit to the data to see it is statistically justified.

GRB 060614 is within 1 σ thus it seems to suggest the hypothesis that for this event the SNe associated was too faint to be detected

CONCLUSIONS III AND FUTURE PERSPECTIVES:

This new subsample of GRBs could be as a test for cosmology together with type Ia SNe, because it is at small redshift range.

Investigation on why the GRB-Sne correlation is much tigher than the long normal Sne is still ongoing

We extended study of DE EoS up to redshift 9 using tight observational correlation in subclass of GRBs (Postnikov, S., Dainotti et al. 2014)

Resulting EoS band is consistent with cosmological constant (-1) and show small tendency for variations, although leaving it open for more data to come.

Current GRB events number and their luminosity distance estimation errors are consistent with what predicted by extrapolation from SNeIa and BAO. More (100 per $\Delta z=1$) and better quality (error/10) GRB data needed to narrow DE EoS at higher redshifts (Dainotti et al. 2011 suggests it is within reach).

Future work is to repeat the method changing the a and b parameters of the correlation together with the cosmological setting in order to have available all the GRB numbers

CORRELATION COEFFICIENT OF **LOG E_{ISO} - LOG E^*_{PEAK}**

The Spearman Correlation Coefficient ρ for Epeak vs Eiso in the GRB-SNe sample is ρ=0.45, while for the Epeak Eiso correlation for the total sample ρ=0.95. The difference in percentage is of 52.63 %

The slope for the TOTAL SAMPLE correlation is logEpeak=0.5*(LogEiso)+2*10^52,

while for GRB SNe associated LogEpeak=0.99*(LogEiso)+2*10^52

T 2