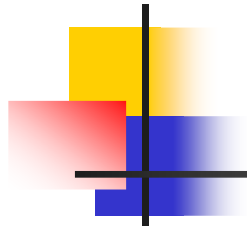


Distant indicators for GRBs

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Outline

Spectroscopic & photometric redshifts

GRB luminosity indicators : a bit of history

Accuracy, Calibration, Outliers

Are GRB luminosity indicators useful ?

Summary & perspectives



Spectroscopic redshifts

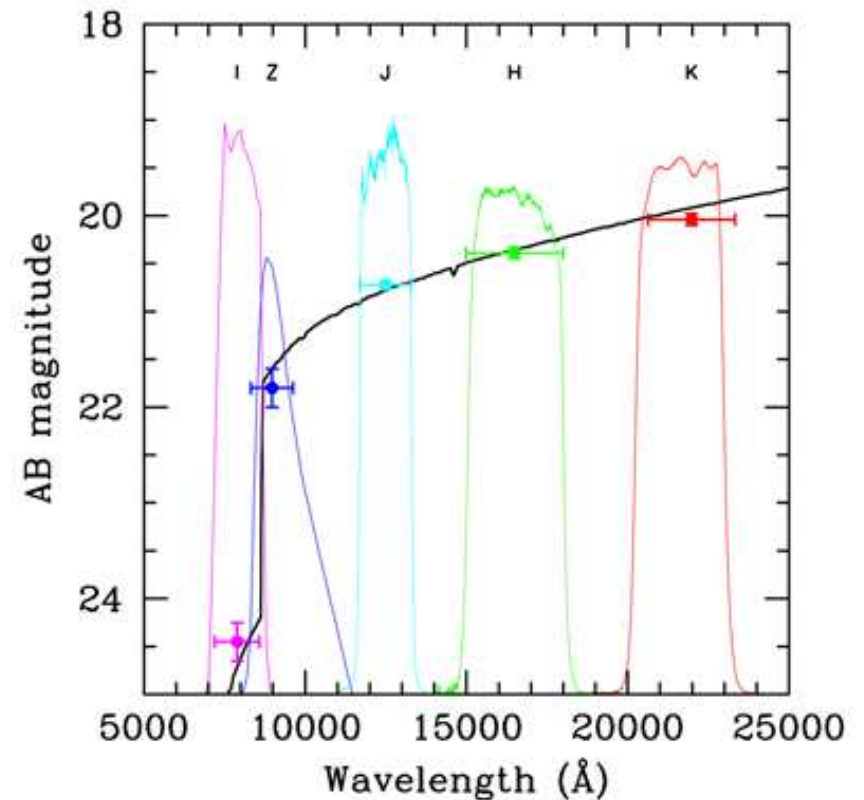
- They are the best distance indicators !

But...

- Out of 181 GRBs detected and localized by SWIFT, 51 have a redshift (from <http://www.mpe.mpg.de/~jcg/grbgen.html>)
 - Spectroscopic redshifts often require long observations with large telescopes
 - There are selection effects, e.g. dark bursts
- Additional distance indicators can be **very** helpful

‘Photometric redshifts’

- Based on the identification of the Lyman alpha cutoff in the optical spectrum of the afterglow (@1216Å at the source)
- Useful to point GRB 050904 as a possible GRB at high redshift
- Complicated by the temporal and spectral evolution of the afterglow
- Require simultaneous observations in several wavelengths



Spectral Energy Distribution of GRB050904



A bit of history

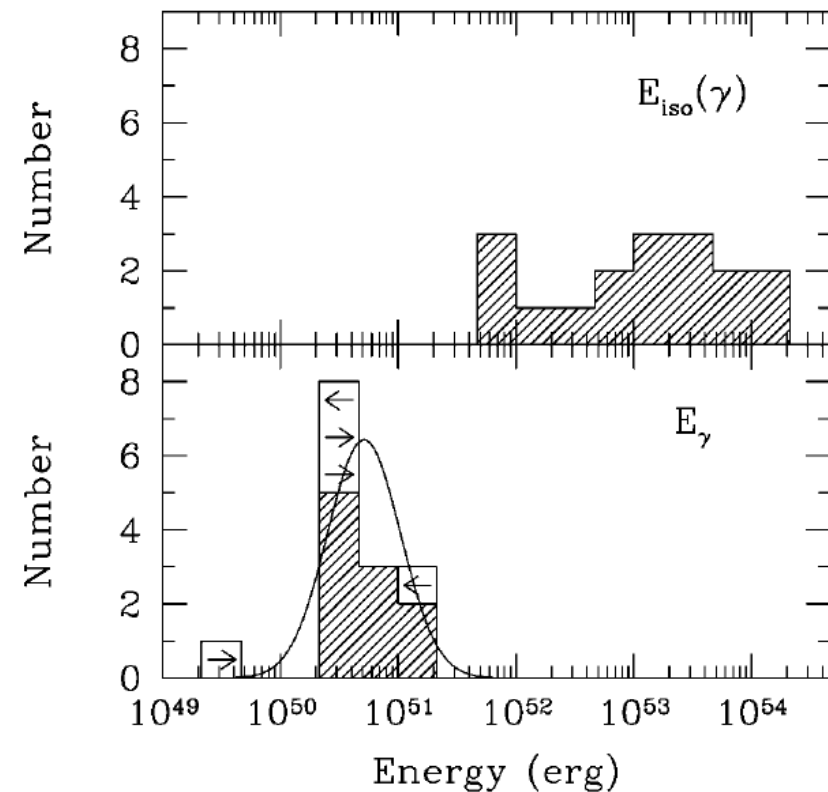
- In 1997 the first measures of GRB distances indicate a broad dispersion of GRB luminosities
- After 2000 many correlations are discovered (or re-discovered), allowing the ‘standardization’ of GRBs
 - Correlation Lag - Luminosity (Norris et al. 2000)
 - Correlation Variability – Luminosity (Reichart et al. 2001)
 - Evidence for a standard energy reservoir in GRBs (Frail et al. 2001)
 - Discovery of the $E_{\text{peak}} - E_{\text{iso}}$ relation (Amati et al. 2002)
 - The $E_{\text{peak}} - L_{\text{iso}}$ relation (Yonetoku et al. 2004)
 - The $E_{\text{peak}} - E_{\gamma}$ relation (Ghirlanda et al. 2004)
 - Multi-variable GRB luminosity indicator (Liang & Zhang 2005)
 - A tight correlation among the prompt emission properties of long GRBs (Firmani et al. 2006)

The standard energy reservoir

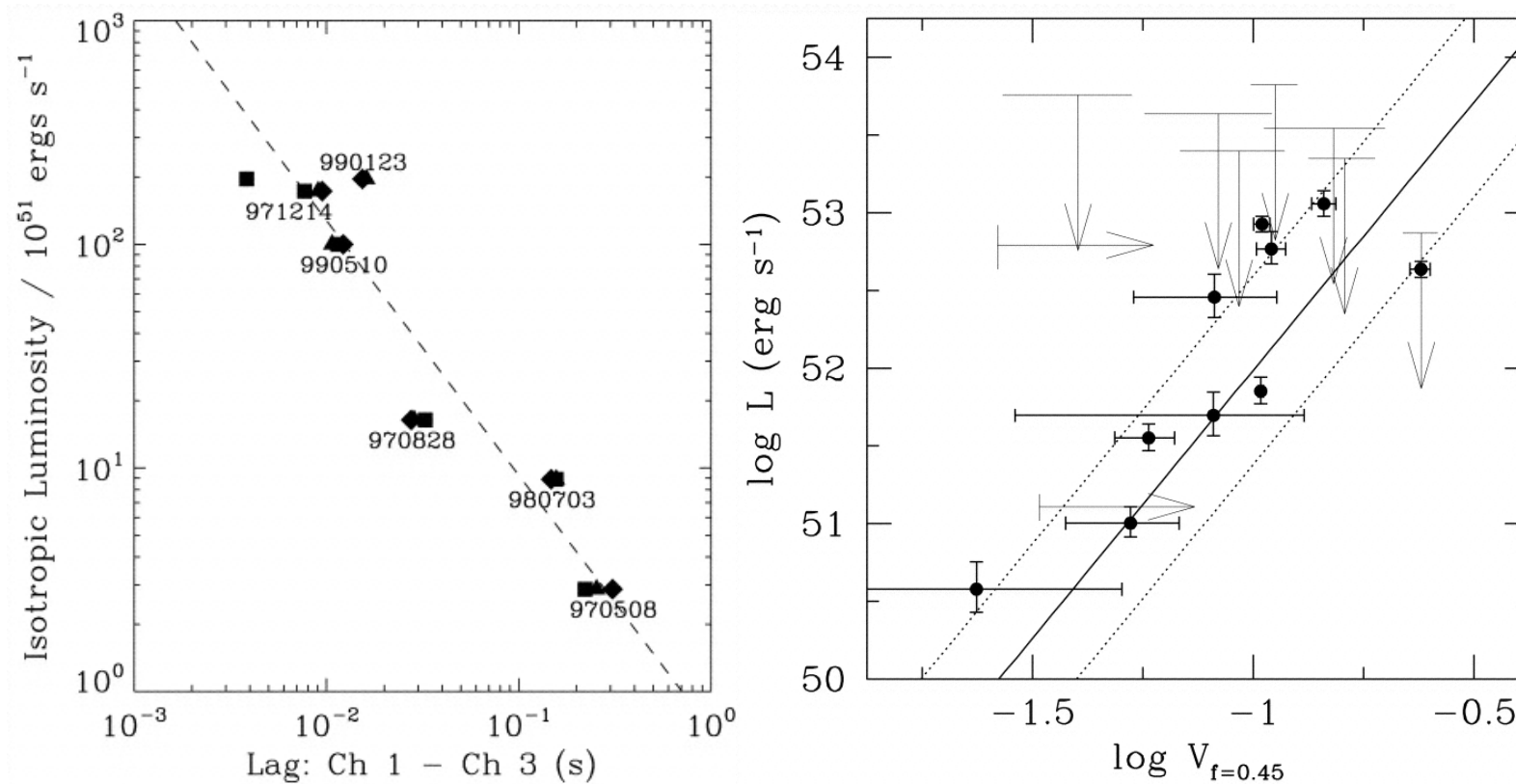
In 2001, Frail et al. computed the ‘true’ energy output of 17 GRBs.

They corrected the ‘isotropic equivalent energy’ E_{iso} by the opening angle of the jet, derived from the time of the ‘jet break’ in the optical afterglow.

They obtained E_γ with a much smaller dispersion than E_{iso} .

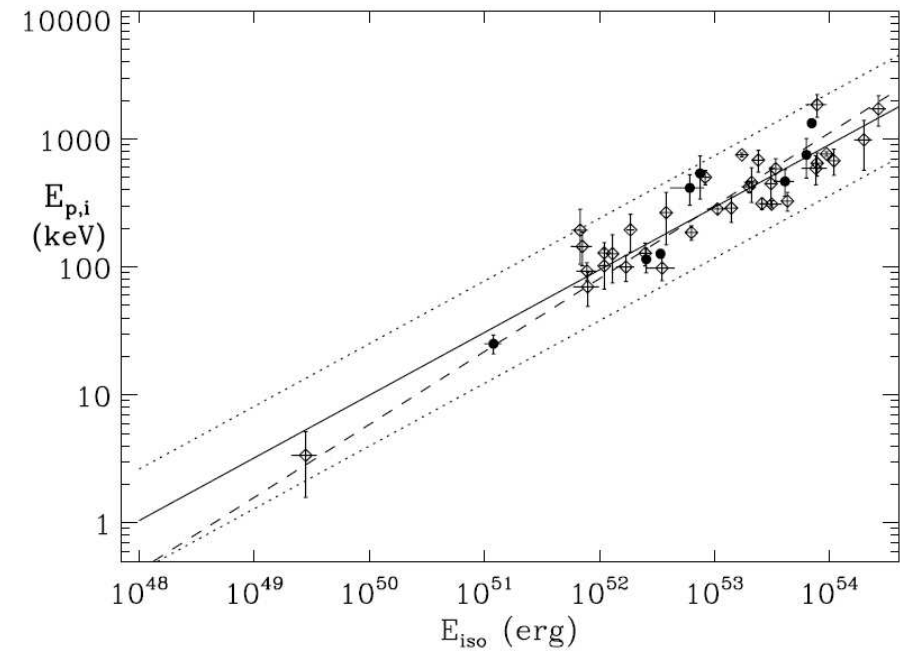
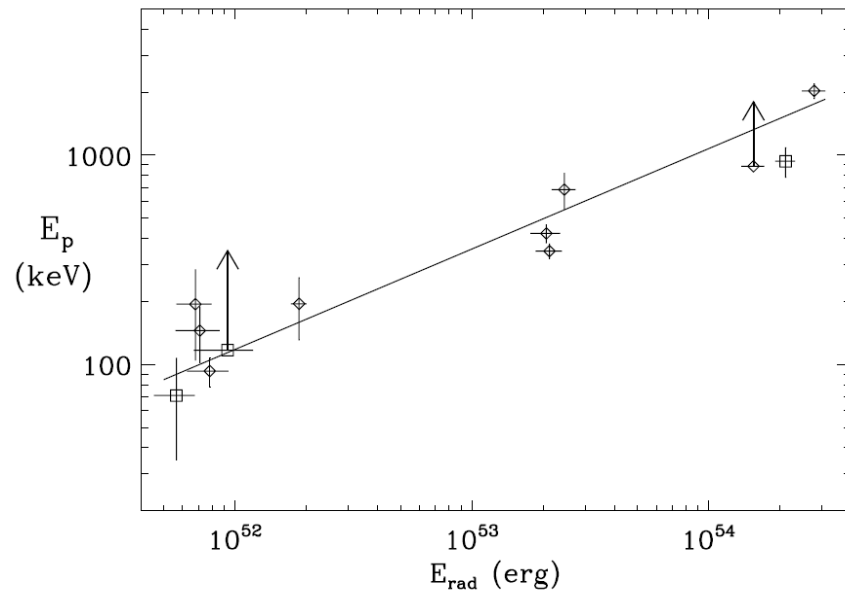


Light curves



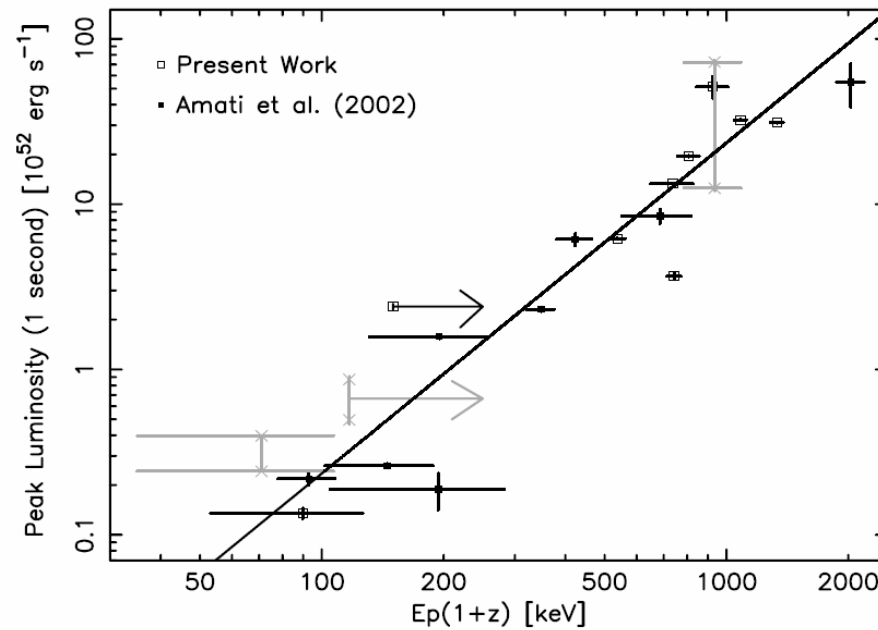
- Left: Spectral lags (Norris et al. 2000)
- Right: Variability (Reichart et al. 2001)

Spectra - 1



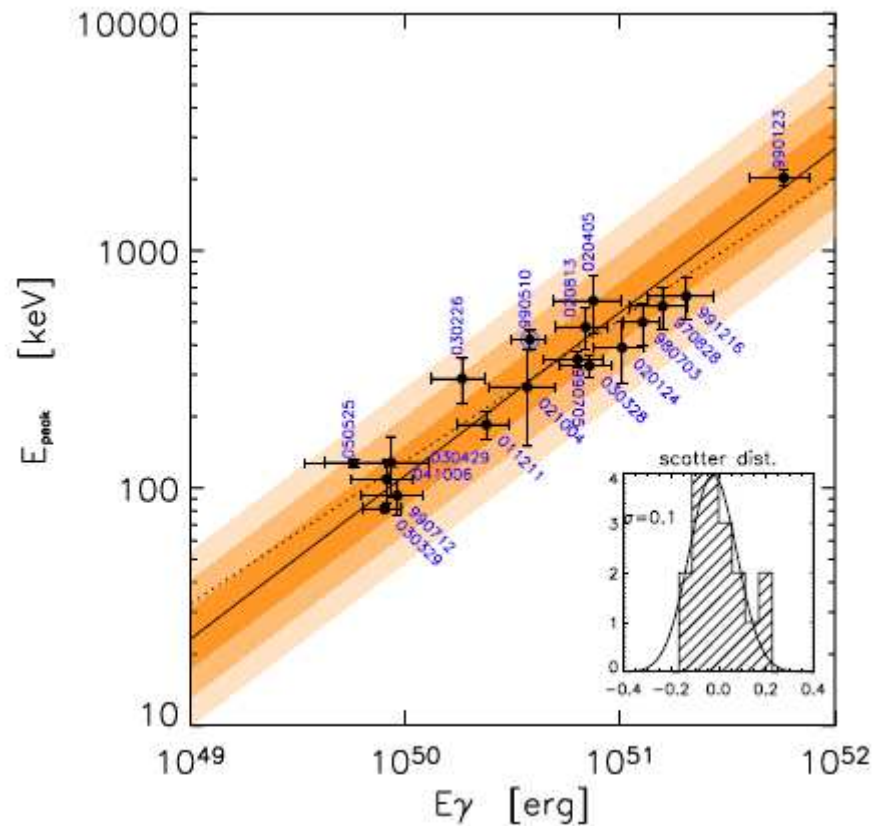
- The $E_{\text{peak}} - E_{\text{iso}}$ relation by Amati et al. (2001 & 2006)

Spectra - 2

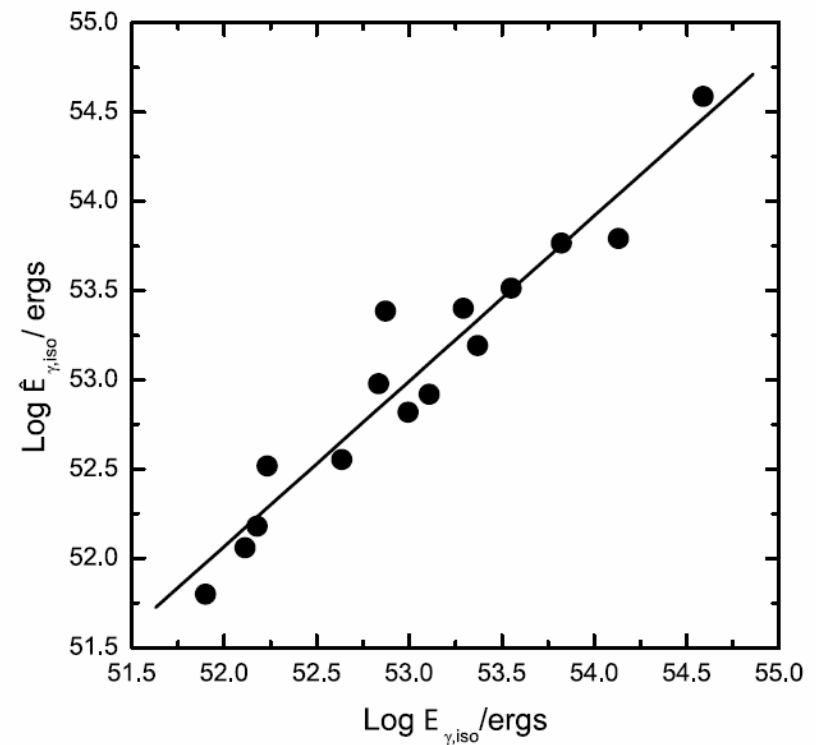


- The $E_{\text{peak}} - L_{\text{iso}}$ relation, by Yonetoku et al. (2004)

and the afterglow...

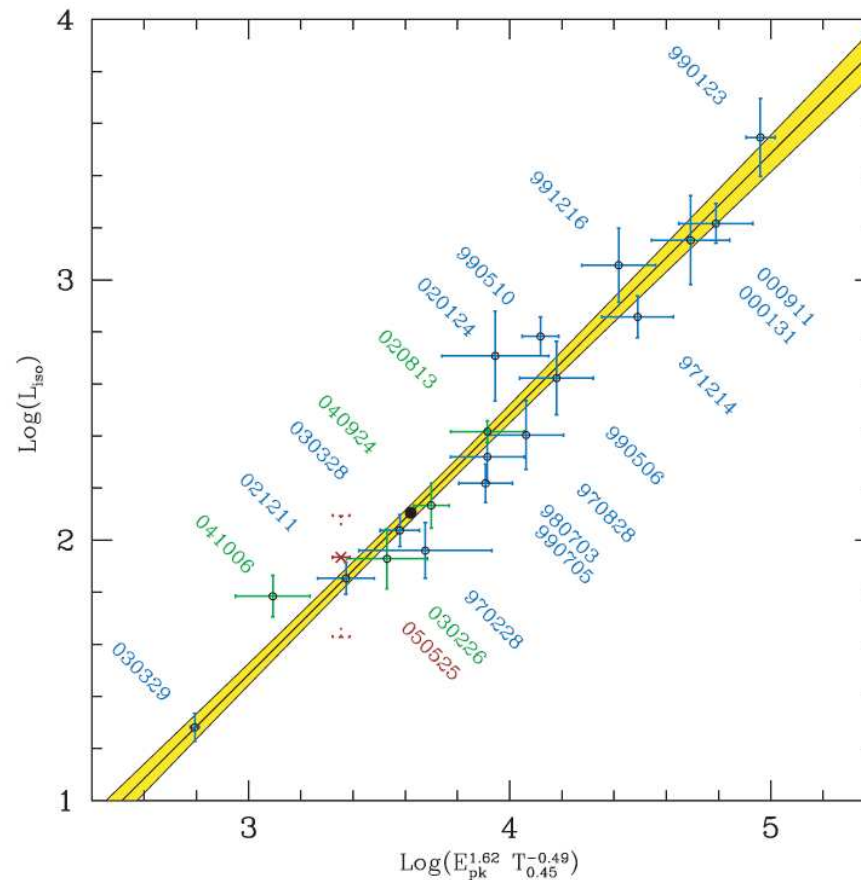


- $E_{\text{peak}} - E_{\gamma}$ relation (Ghirlanda et al. 2006)



- Liang & Zhang Correlation ($E_p - E_{\text{iso}} - t_b$), 2004

back to the prompt emission...



- The $L_{\text{iso}} - E_{\text{p}} - T_{0.45}$ correlation (Firmani et al. 2006)



To summarize

- Various tight correlations allow to infer the intrinsic energetics (L_{iso} or E_{iso}) of GRBs from a few observables
- Each correlation gives a luminosity indicator
- The observed correlations depend on the cosmology and, for some of them, on the assumed physics of the afterglow (e.g. the Ghirlanda relation)



An excellent summary ...

New Journal of Physics

The open-access journal for physics

Gamma-ray bursts as standard candles to constrain the cosmological parameters

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New Journal of Physics **8** (2006) 123

Received 18 April 2006

Published 31 July 2006

Online at <http://www.njp.org/>

doi:10.1088/1367-2630/8/7/123



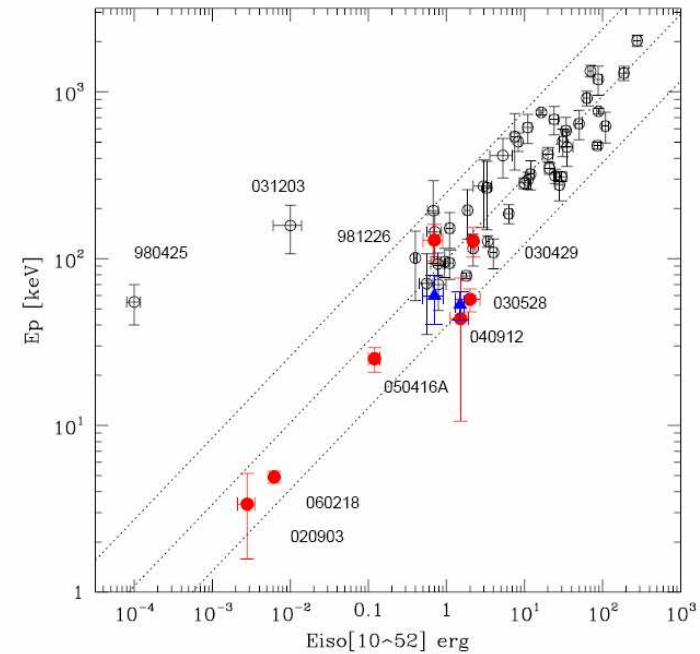
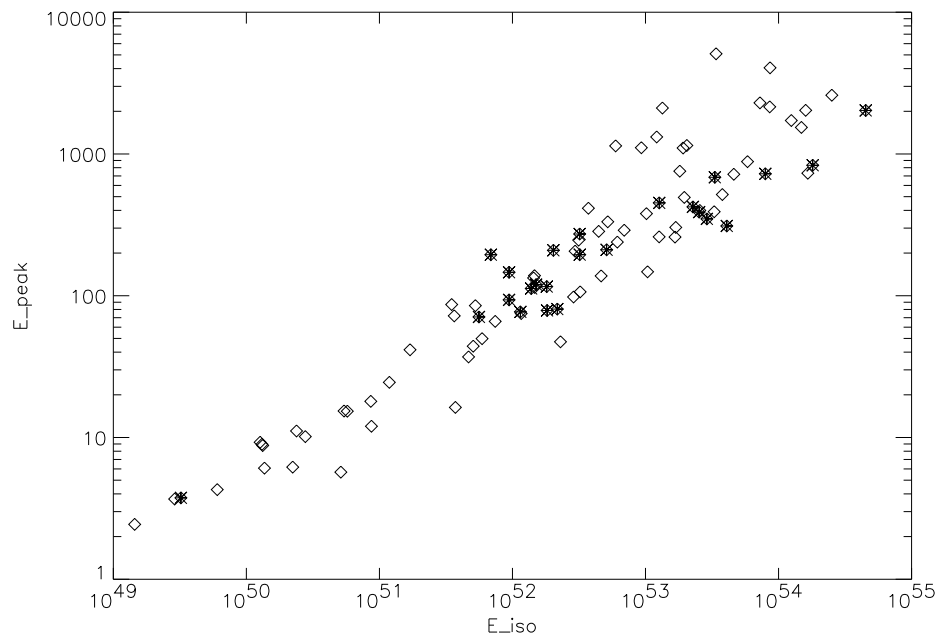
Accuracy

- The dispersion (standard deviation) of the bursts around the empirical relations is usually small. It varies from $\sigma \approx 0.06$ dex (15%) to $\sigma \approx 0.15$ dex (40%), depending on the correlation.
-
- The tighter correlations are $[L_{\text{iso}} - E_p - T_{0.45}]$, $[E_{\text{iso}} - E_{\text{peak}} - t_{\text{break}}]$, and $[E_p - E_\gamma]$.

But...

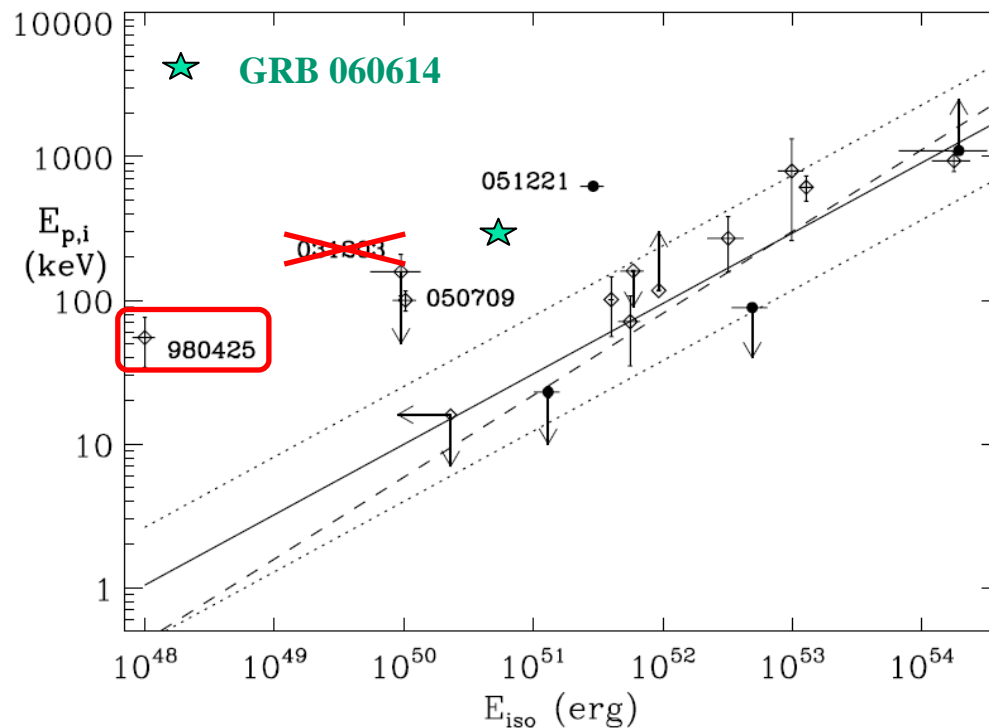
- The number of bursts used to calibrate these relations is small (15 – 20)
- To be used in the calibration of luminosity indicators GRBs must have a complete light-curve ($T_{0.45}$, lags, variability), a spectrum measured over a broad spectral range (E_{peak}), a dense follow-up of its optical afterglow (E_γ), and a redshift.

Are GRB luminosity indicators universal ?



- No outlier in 19 HETE GRBs with a redshift and an E_{peak}

Outliers to the Amati relation ?



- GRBs and XRFs : OK, except ...

- GRB 980425: clear outlier (too hard)
- GRB 031203: unclear

GRB 060614: Short GRB ??

GRB 060927: only GRB with E_p from SWIFT

- Short GRBs are clear outliers



Are GRB luminosity indicators useful ?

- GRB luminosity indicators have some advantages:
 - Luminosity indicators based on the prompt emission only can be **available for a large number of GRBs**, and can be used to provide pseudo-redshifts as surrogate of the redshift in **statistical studies**: redshift distribution, evolution of the Star Formation Rate (e.g. Schaefer et al. 2001, Lloyd-Ronning et al. 2002, Yonetoku et al. 2004), GRB classification...
 - Luminosity indicators based on the prompt emission can be **available quickly**, they can be used for the **quick identification of high-z GRBs**
 - **Accurate luminosity indicators** can be used to **measure the cosmological parameters**



Quick identification of high- z GRBs

- Identifying high- z GRBs ($z > 6-7$) is difficult
 - Afterglow identification requires highly sensitive NIR and/or X-ray observations
 - The measure of the redshift must be based on the afterglow because the spectroscopy of the host galaxy is likely to be impossible (or very difficult)
 - In short, they require a *huge observational effort*

→ A quick, reliable redshift indicator may be very helpful to sort out high- z GRB candidates

→ Luminosity indicators provide ‘standard candles’, which can be used to compute pseudo-redshifts (cf. talk by Alexandre Pelangeon)

but...

- Luminosity indicators have not been calibrated beyond $z \sim 4$
- GRB evolution with redshift may affect GRB correlations at high z
- Gravitational lensing can perturbate GRB correlations at high z

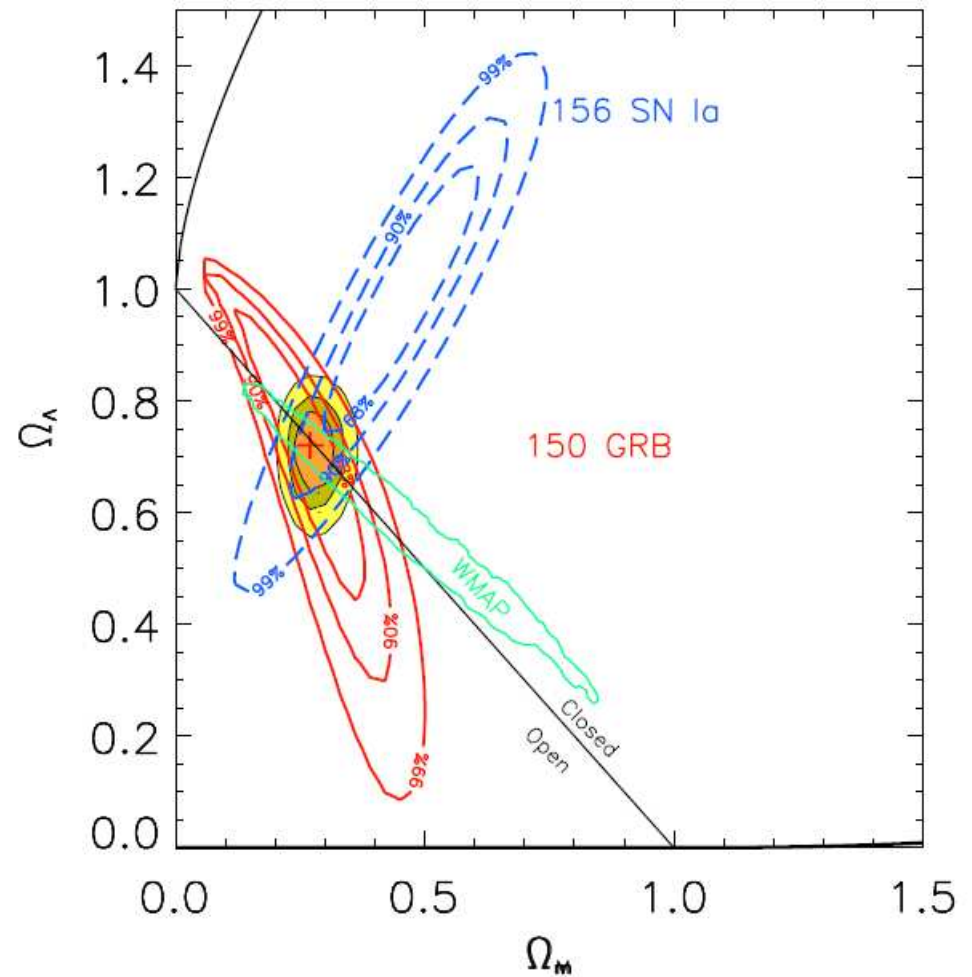


GRBs & Cosmology

Towards the 'standardization' of GRBs

- The accuracy of the best luminosity indicators opens the possibility to use them like standard candles for cosmological applications.
- The relation between the redshift and the luminosity distance depends on the cosmological parameters. Measuring the redshift AND the intrinsic luminosity allows in principle the determination of the cosmological parameters.
- Problem of circularity: the correlations are established within a given cosmology: we need a few events at $z \sim 0.1$.
- All accurate luminosity indicators need E_{peak}
- Cf. review by Ghirlanda et al. 2006

GRBs and Cosmology



Ghirlanda et al. 2006



Perspectives (observational)

- SWIFT (\rightarrow 2010):
 - Accurate light-curves,
 - Excellent X-ray follow-up
 - No E_{peak} (unless seen by KONUS)
 - 28% GRBs with a redshift
- INTEGRAL (\rightarrow 2008+):
 - Light-curves,
 - Good optical follow-up
 - Few E_{peak}
 - Few % GRBs with a redshift
- GLAST (2008 \rightarrow):
 - Accurate light-curves
 - E_{peak}
 - Little follow-up
 - Few redshifts
- SVOM (2011 \rightarrow):
 - Accurate light-curves,
 - Excellent optical follow-up
 - E_{peak}
 - TBD % GRBs with a redshift
 - High-z GRBs...

On mid-term the launch of GLAST will increase the fraction of SWIFT GRBs with E_{peak}

On the long term, SVOM has the potential to open a new era for GRB luminosity indicators

On the short term, wait for GRB with a pseudo-redshift of 10 !



Conclusions

- Luminosity indicators provide reliable luminosities for long GRBs ($\sigma \leq 0.1$ dex)
- They (already) offer interesting potentialities for statistical studies and quick redshift estimation.
- On the longer term, they may become a valuable tool for cosmological studies if new instruments permit the accurate measure of **all** the parameters which they need
- Present day uncertainties include
 - Calibration of luminosity indicators
 - Existence of outliers
 - Validity of indicators for high- z GRBs ?
 - Theoretical insight ?
- Luminosity indicators for Short/Hard GRBs ?
 - Do they span a sufficient range of redshifts ?
 - Do they follow Amati-like relations ?