# ☆ Search for correlations within the GRB-SN connection

## SN luminosity standardizations for cosmology

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**Long γ-ray bursts (GRBs) have been found in association with core-collapse supernovae (SNe) since the emblematic case of the GRB 980425/SN 1998bw. They are thought to be the final fate of some massive stars with main-sequence masses > 15 $M_\odot$. The GRB emission can be detected up to very high redshifts ($z \sim 9$) and their SN counterpart has been observed up to redshift of ~ 1. We managed to reduced the dispersion in the luminosities of GRB-SNe by using the SN light-curve stretch factor and the GRB spectral peak energy for a sample of 15 events in the redshift range of $0.01 < z < 0.68$. While SNe Ia and II deliver distances as precise as 7% (Hamuy et al. 1996) and 10% (Olivares E. et al. 2010), respectively, we show that GRB-SNe can determine distances with 13% precision. This results unfolds new opportunities to exploit GRB-SNe to probe the cosmic expansion of the Universe.**

## Motivation

**Previous attempts** at standardizing the luminosity of GRB-SN events:

- Using the γ-ray emission (Amati et al. 2007)
- Using the SN similarly to type Ia SNe (Cano 2014)

The **advantages of using GRB-SNe as distance indicators** are:

- GRBs are accompanied by over-luminous type Ic SNe, which are as bright as SN Ia.
- No SN search is required, since the γ-ray emission signals the event.

**However**,

- Available data are from diverse telescopes and filters.
- Sources are faint and rare.
- To build a large sample, many years has to pass.

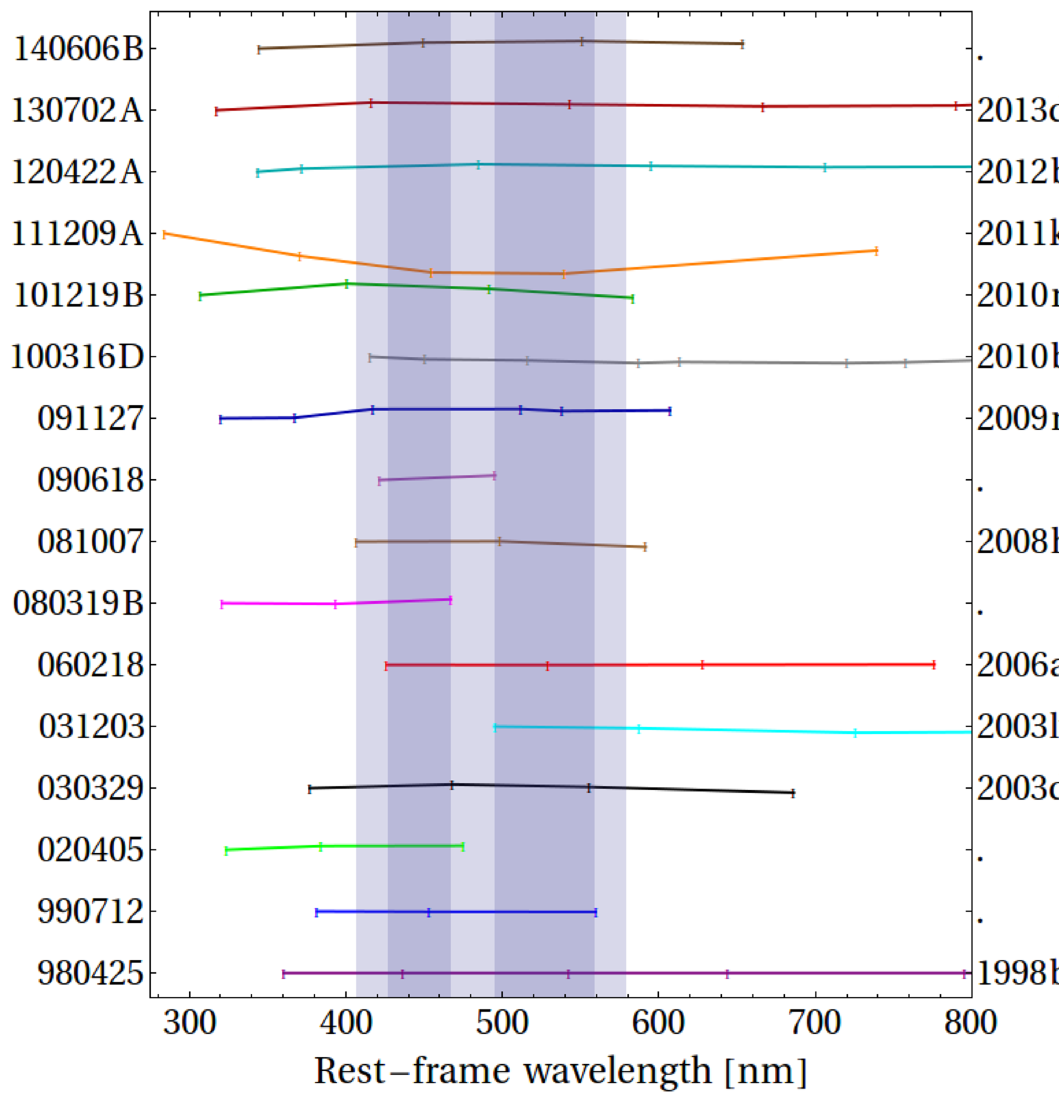
## Sample Selection

Out of a total of more than 30 events, we selected **16 GRB-SNe with detections in at least two filters** in order to:

- increase the wavelength overlap at their corresponding rest frames and, therefore,
- bypass the K-correction due to the wide range of redshifts.

The rest-frame wavelength ranges that maximize the sample size are the dark shaded regions in the figure below:

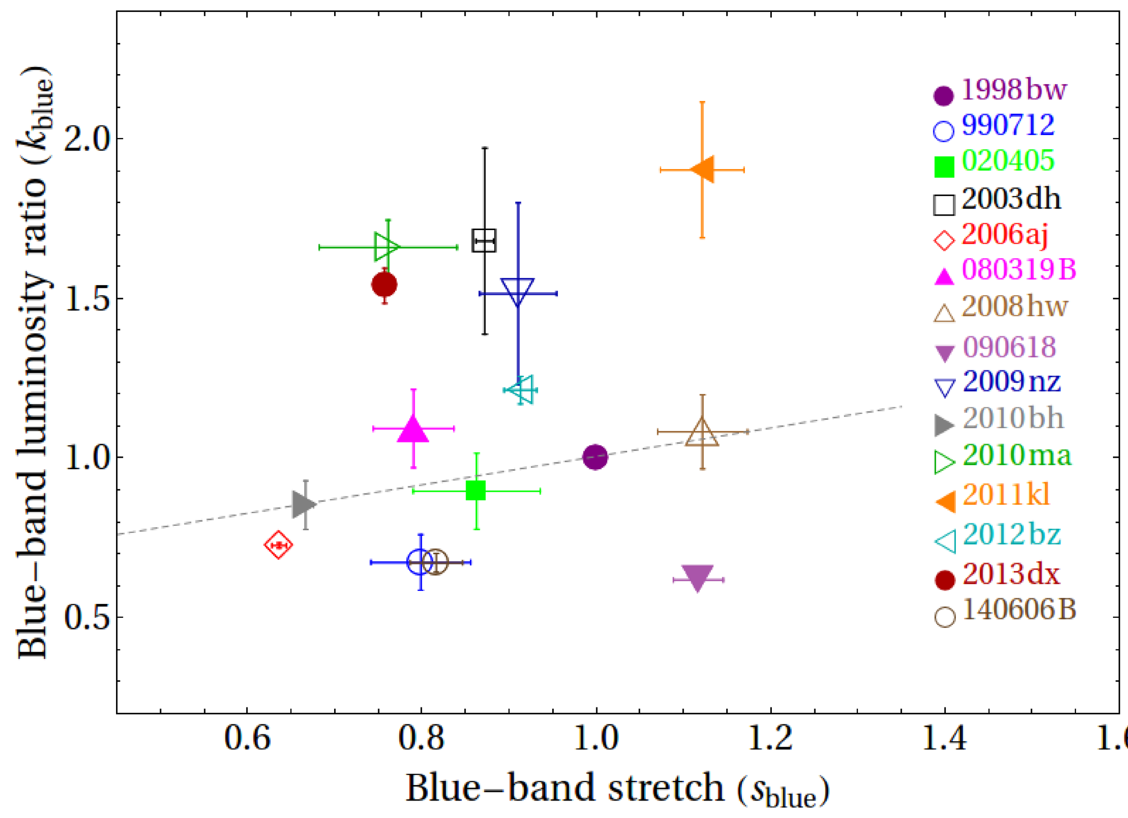
- the *blue* band (427-467 nm) with 15 events and
- the *green* band (495-559 nm) with 13 events.



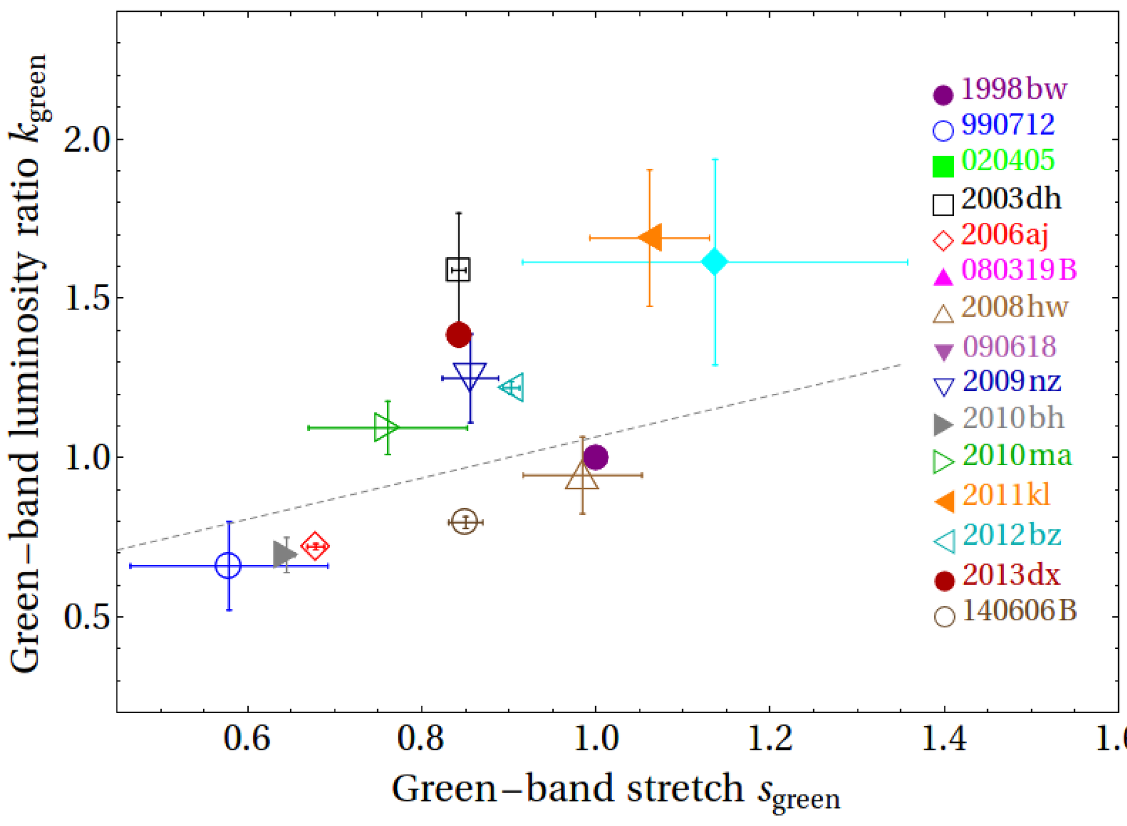

The figure shows the SEDs of the GRB-SNe with respect to the luminosity of SN 1998bw, offset for clarity. This is known as the ***k*** **luminosity factors** (Zeh et al. 2004). Similarly, the **stretch factor *s*** is defined as a measure of the light-curve width. Consequently, $k = 1$ and $s = 1$ represent the light curves of SN 1998bw. The data is taken from Kann et al. (2016), Olivares E. et al. (2015), and Olivares E. et al. (2012). Finally, by integrating the relative SEDs in the blue and green ranges and dividing by Δλ, **we compute average *k* and *s* values for both sub-samples.**

## Luminosity versus stretch

What has been found for SN Ia (Phillips et al. 1993) and recently for a joint sample of broad-lined type Ic SNe and GRB-SNe (Cano 2014) is that the higher the luminosity the slower is evolves. Using a larger sample of GRB-SNe, we will put to test the findings by Cano (2014) and assess whether GRB-SNe could deliver precise distances. The next figure shows the *k*-*s* plane for 15 GRB-SNe in our blue band.




The correlation above is poor ($R^2$=0.1, *P*-value=0.22, $\sigma_k$=0.35). **For our green-band data, we find a better correlation** as shown in the following figure ($R^2$=0.2, *P*-value=0.17, $\sigma_k$=0.25) with a lower scatter.

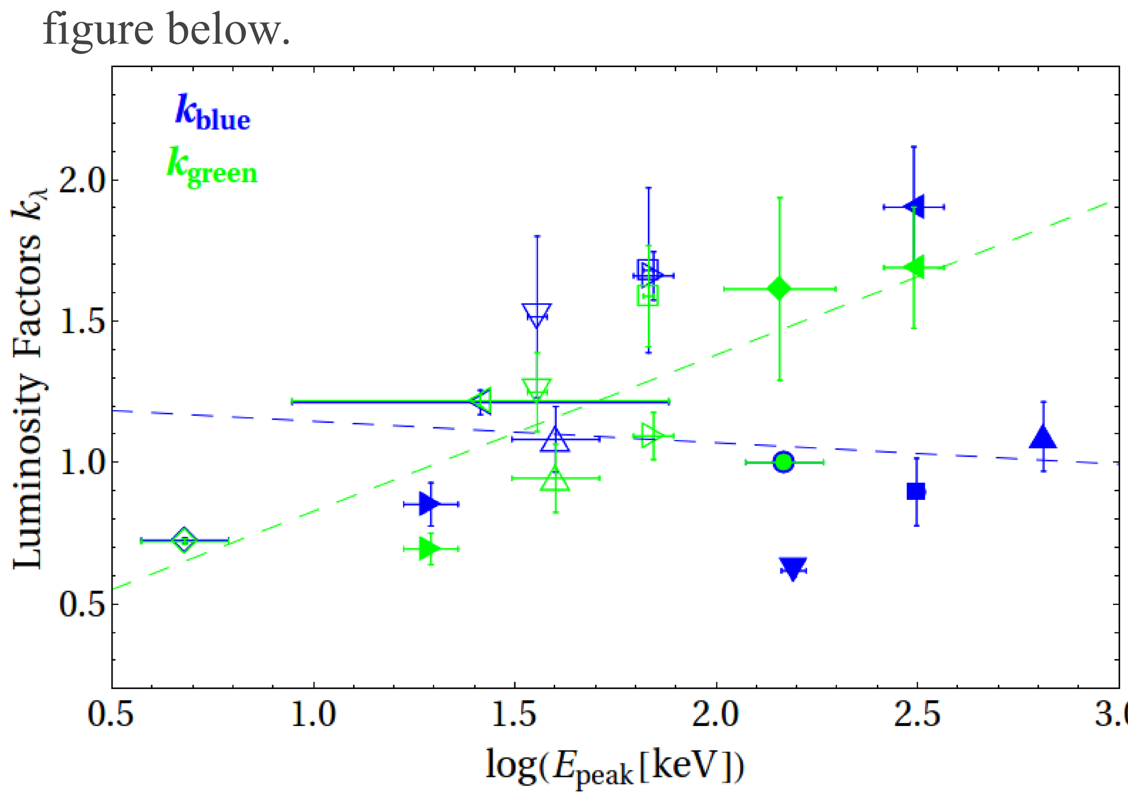



Thus using the green-band *k*-*s* relation **we can determine GRB-SN luminosities with 25% precision.**

## GRB versus SN properties

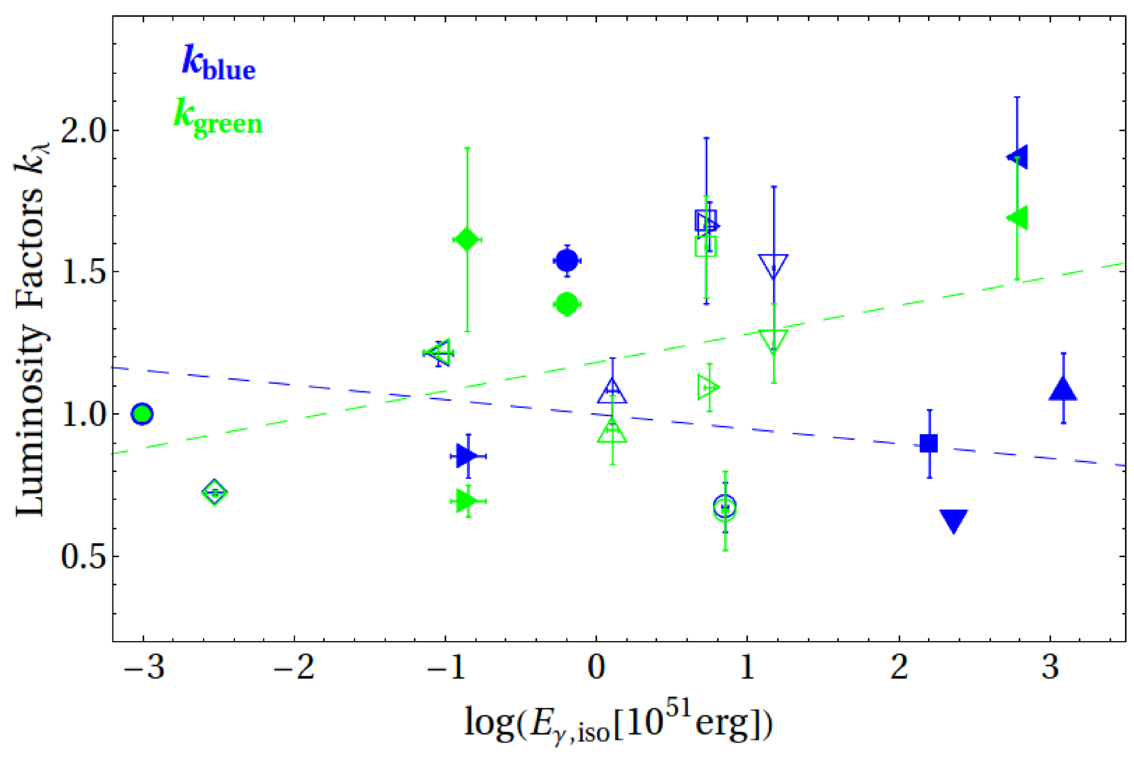
Given that GRB and SN are observational events that are both produce by the same core collapse, we investigate whether the SN luminosity can be related either to the spectral peak energy ($E_{\rm peak}$) or to the isotropic energy release ($E_{\gamma,\rm iso}$) of the GRB.

A correlation between **$E_{\rm peak}$ and *k*** has already been proposed by Li (2008), however, using only 3 GRB-SNe and one XRF-SN. We recover the correlation in the figure below.




For the green-band data, we demonstrate that **the correlation above is more significant than the *k*-*s* relation** ($R^2$=0.44, *P*-value=0.04, $\sigma_k$=0.25), although using less objects (N=10). For the blue band, there is a strong outlier (GRB 090618), which coincidently has no green-band data and does not support a correlation (*P*-value=0.8). The symbols represent the same objects as in previous figures.

The next figure shows that there is a weak correlation between $E_{\gamma,\rm iso}$ and $k_{\rm green}$ ($R^2$=0.27, *P*-value=0.05, $\sigma_k$=0.38), although the dispersion is large.

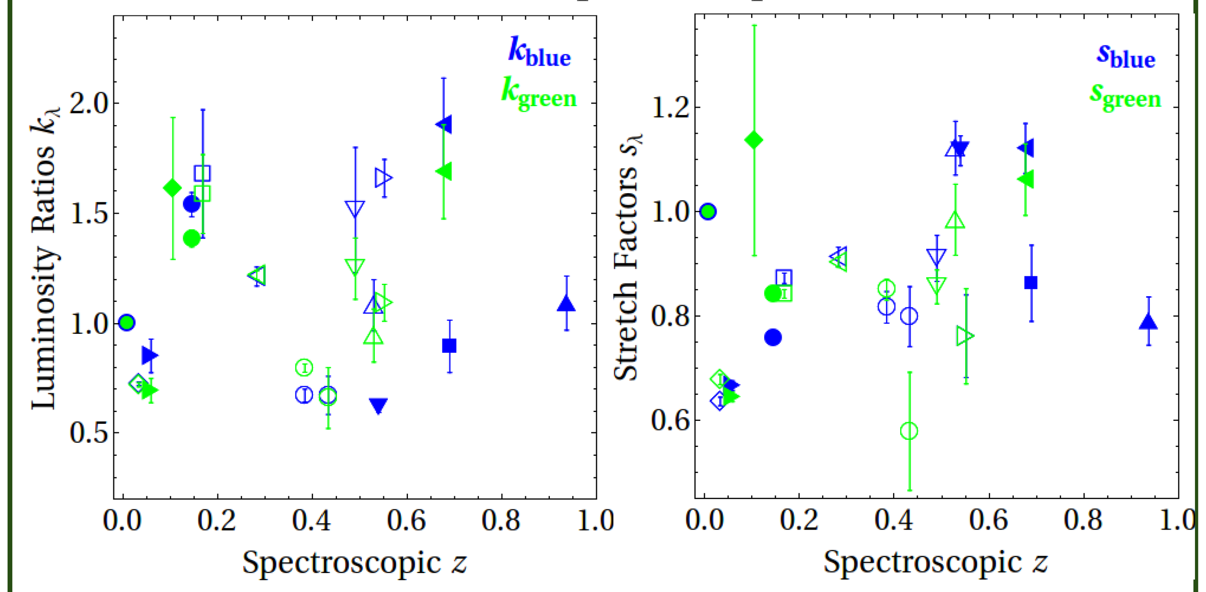



The physical motivation for the correlation above is that **if the GRB accretion-disk wind powers the SN**, stronger GRB jet implies stronger disk and more nickel would be synthesized.

The GRB data in this section has been taken from the literature (Sakamoto et al. 2005; Ulanov et al. 2005; Campana et al. 2006; and GCN circulars).

## Cosmic evolution

Using the redshift and the *k* and *s* light-curve parameters, we assess whether there is a significant evolutionary trend affecting the correlation presented above. The two figures below show that **there is no significant bias in either sample due to the cosmic evolution.** The symbols have been kept the same to label GRB-SNe like in the previous plots.




## Conclusions

☆ It seems that our strongest outlier and the reason for weaker correlations using the blue band is GRB 090618.

☆ We show that using both **the *k*-*s* and the *k*-$E_{peak}$ correlations** in the green band our method can **reduce the luminosity dispersion from 36% to 25%**.

☆ The latter translates into a **precision in distance of 13%**, which compared to the popular SN methods to determine distances (SN Ia, $\sigma_d$ ~ 7%; SN II, $\sigma_d$ ~ 10%) is **very promising for cosmology**.

☆ In the future, with a larger sample GRB-SNe we will be able to measure cosmological distances up to $z > 1$ and will be able to **test the findings from SN Ia observations.**

## REFERENCES

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