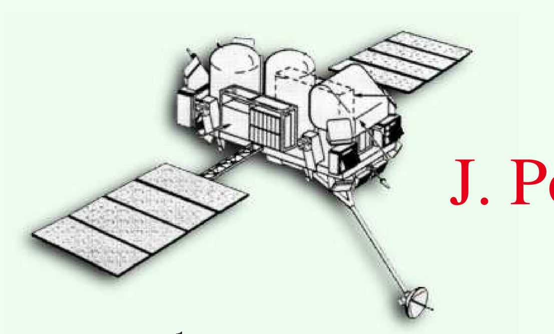
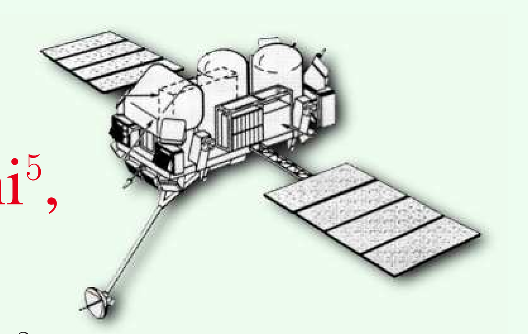


Search for Correlations Between BATSE Gamma-Ray Bursts and Supernovae



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Abstract

We report on complex statistical research of space-time correlated supernovae and CGRO-BATSE gamma-ray bursts. We show that there exists a significantly higher abundance of core-collapse supernovae among the correlated supernovae, but the subset of all correlated objects does not seem to be physically different from the whole set.

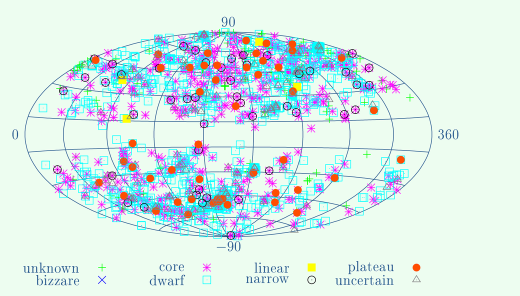
Introduction

The origin and source of gamma-ray bursts (GRBs) still remain a puzzle. This tremendous energy could be released on a short time-scale during a collapse of a massive star in a supernova-like explosion. There are several pieces of observational evidence supporting the connection between GRBs and supernovae (SNe): some GRBs reveal an underlying SN in an optical afterglow lightcurve (e.g. GRB980326), sometimes supported by spectral and colour signatures (e.g. GRB030329 and SN2003dh), and there are a few objects with space-time coincidence (e.g. GRB980425 and SN1998bw).

We have used the current CGRO-BATSE GRB catalogue (up to date version to April 2004) [2] and combined data from Asiago Padova [4], Harvard [3] and Sternberg [1] catalogues of SNe.

Pseudotypes

There is a wide range of the SN types existing in the input data. For easier manipulation we have divided all the SNe into several types, called *pseudotypes*. Note that the division is not disjunct. The abundance of the pseudotypes is listed in Figure 1. For the purposes of our study it is useful to simplify this division into three pseudotypes only: the `dwarf`, the `core` and the `unknown` SNe.



pseudotype	catalogue identification
unknown	'NULL', '?'
core	'ib', 'ib?', 'ic', 'ic?', 'ic', 'ib/c', 'ic-p', 'ii', 'ii?', 'iib', 'iib?', 'iic', 'iic?', 'ii-n', 'ii-n?', 'ii-l', 'ii-p', 'ii-p?', 'iipec'
dwarf	'ia' ,'ia?', 'ia-p', 'ia-p?', 'i', 'i?', 'i-p', 'i-l'
type1	'i', 'i?', 'i-l', 'ia', 'ia?', 'ia-p', 'ia-p?', 'ib', 'ib?', 'ic', 'ic?', 'ib/c', 'ic-p'
type2	'ii', 'ii-l', 'ii?', 'iib', 'iib?', 'iic', 'iic?', 'ii-l', 'iipec'
plateau	'ia-p', 'ia-p?', 'ic-p', 'ii-p', 'ii-p?', 'i-p'
linear	'i-l', 'ii-l'
narrow	'ii-n', 'ii-n?'
bizzare	'iipec'
uncertain	'/[^\?]\?/'

Figure 1: Definition of used SNe pseudotypes.

Space and time correlation

The situation is easy in the space domain, A GRB and a SN make a pair if the location of the SN falls into the GRB errorbox which yield 3σ error.

In the time domain it is not a priori theoretically clear what is the time delay between the SN and an eventual gamma emission. For our purposes we postulated the time of the optical emission to be the time of the maximum $T_{\max}$ of the optical lightcurve of the SN. Unfortunately only a fraction of the SNe provides an information about the date of $T_{\max}$. We solved the problem statistically and we assumed the time delay between $T_{\max}$ and the time of the discovery T_{disc} to be the median $M_{\max} = -4$ days. We get it from the distribution (Figure 2) of all known time delays. Thus for the SNe which have the time of the maximum missing we computed it as

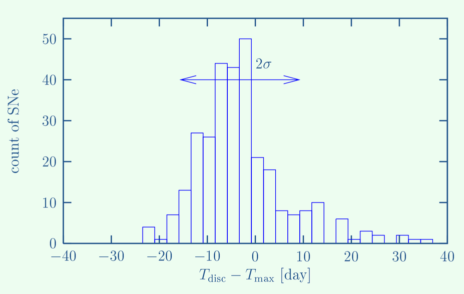


Figure 2: $T_{\text{dist}} - T_{\max}$ delay.

$$T_{\max} = T_{\text{disc}} + M_{\max}.$$

The time delay T_δ between the possible prompt gamma emission T_γ of the SN and its optical emission $T_{\max}$ may depend on the type of the SN. We respect it by the division into the pseudotypes. We represent the time delay by the shift in time T_δ which is the mean μ_γ of the Gaussian distribution function and by the half-width of the time window T_{error} which is $3\sigma_\gamma$ error in the term of the Gaussian. Generally it could be written as

$$T_\gamma = (T_{\max} + \mu_\gamma) \pm 3\sigma_\gamma.$$

We tried to make the best possible estimate. The typical time delay T_δ can be estimated for the dwarf SN as a relatively narrow time interval $+20 \pm 7$ days [5]. For the `core`-collapse SNe we choose the typical values of the time delay to be 0 ± 30 days.

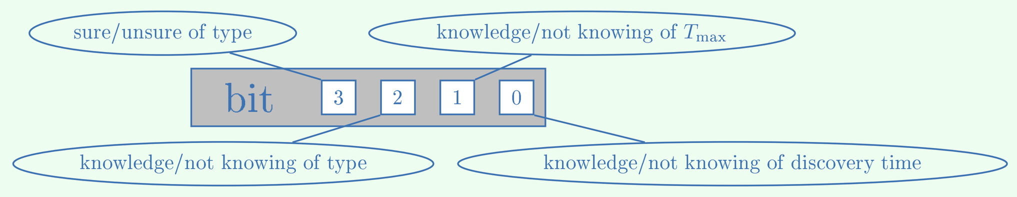


Figure 3: Sense of bits of magic_χ value.

For the SNe of unknow or uncertain type we used a statistical estimation of the time-shift and the width of the time error. Other uncertainty is the method in the $T_{\max}$ estimate. It is described by the magic_χ number (Figure 3). The larger uncertainty enlarges the time window.

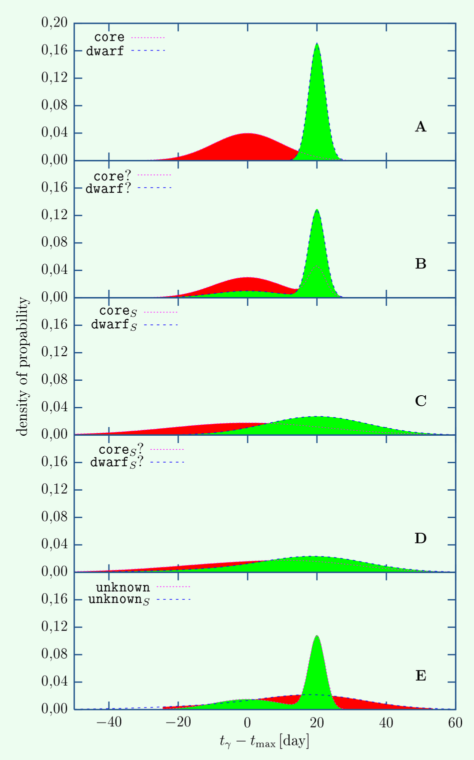


Figure 4: T_γ window size.

For each pseudotype we assume the Gaussian distribution of the time delays $T_\gamma - T_{\max}$. We calculated the weighted average of the particular densities of the probability for every configuration of the magic_χ with respect to the level of uncertainty we had. For the match we used the best Gaussian fit of the density of the probability (Figure 4). The matching process itself reflects the effect of the selection of the SNe into the pseudotypes, it results into the different size of the time error used for each pseudotype. The larger time-errorbox of the particular pseudotype we have the greater number of matched pairs of this kind we expect. To compare this effect it is useful to do the matching separately for two different sets of settings: $\mathbb{A}$ for the one which is dependent on the pseudotype of the SN and $\mathbb{B}$ for which is not (Figure 5).

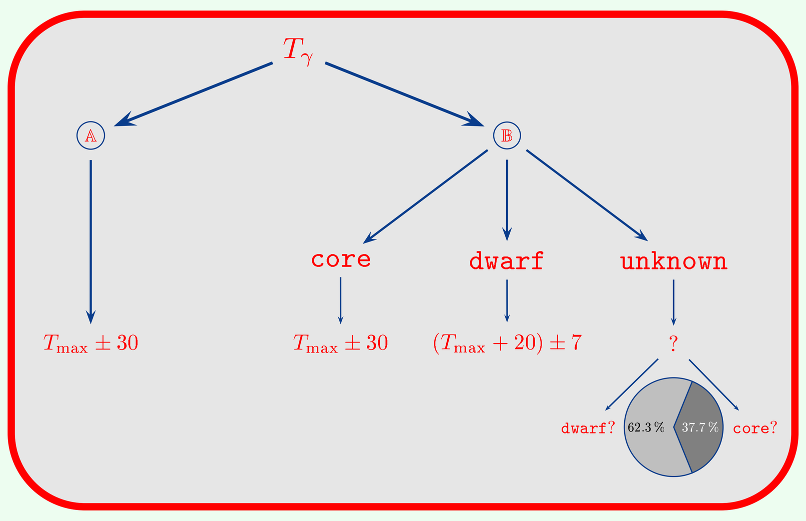


Figure 5: Description of the two approaches of getting T_γ window.

Results of the matching

We obtained 92 of possibly correlated pairs in the case $\mathbb{A}$ and 127 in the case $\mathbb{B}$. The sky maps illustrating the results are plotted in Figure 6.

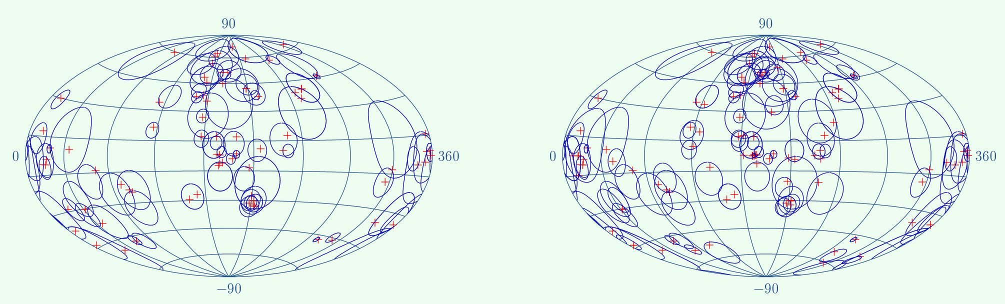


Figure 6: Matched pairs. Set $\mathbb{A}$ on the left.

Number of matched pairs

We rotated the SN catalogue around arbitrary axes. The histogram of the result of 295 different rotation both for $\mathbb{A}$ and $\mathbb{B}$ set of the parameters is shown in Figure 7. In both cases we found that the number of matched pairs is less than the average number of matched pairs as they were derived from the rotations but in both cases $\mathbb{A}$ and $\mathbb{B}$ within 1σ error.

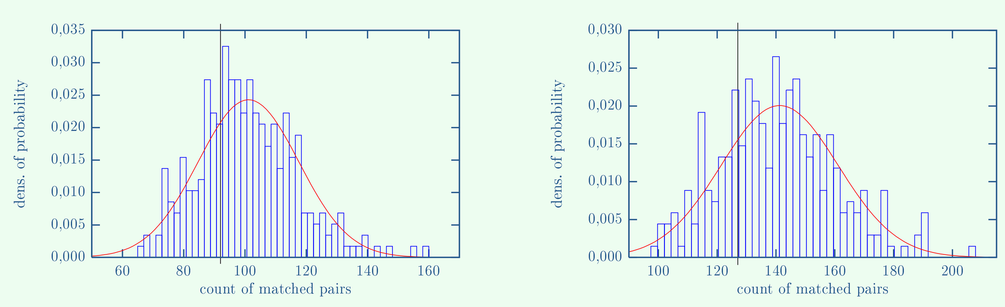


Figure 7: Distribution of count of matched pairs in rotation test. Vertical lines show count of real pairs. Set $\mathbb{A}$ on the left.

Physical coincidence limits

If there exists an additional physical correlation apart from the random one, the number of matched pairs will be higher when the real data set is used. The question is how small the correlation factor f could be to be detectable by us.

We created artificial data set for the testing procedure. We generated the set of GRBs, each with coordinates taken according to the isotropic distribution. The errorbox is taken a) randomly from the distribution of the real GRB errorboxes b) to be the median of the distribution.

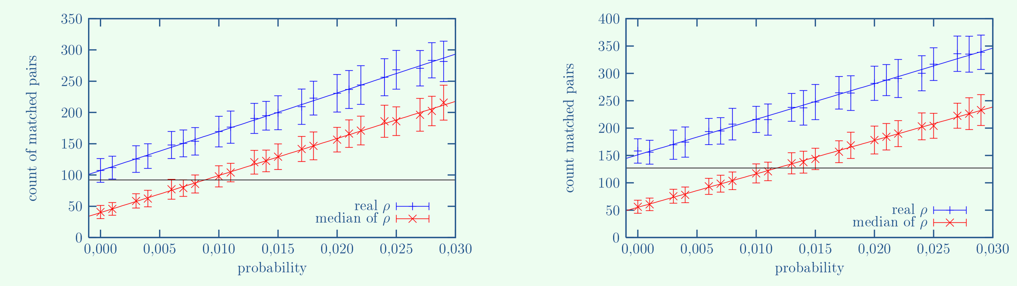


Figure 8: Counts of matched pairs with artificial correlation.

Then a fraction p of GRBs is set to be artificially correlated to a randomly chosen (but unique) SN in the meaning of the spatial and time condition used in the real matches $\mathbb{A}$ and $\mathbb{B}$. The values of p ran from $p = 0$ (no correlation) to $p = 0.14$.

The detailed view in the Figure 8 shows that in the case a) for the random size of the GRB errorbox if there is any correlation it is close to $p \sim 0$ both for $\mathbb{A}$ and $\mathbb{B}$ in the meaning of 1σ. If we enlarged the errorboxes to 3σ we got the maximal value of the fraction of the physically correlated pairs $p \sim 0.008$ both for $\mathbb{A}$ and $\mathbb{B}$.

In the case b) for the constant size of the GRB errorbox (set to be the median of the errorbox distribution) we got the limits $p \sim 0.011$ resp. $p \sim 0.015$ for $\mathbb{A}$ resp. $\mathbb{B}$ in the meaning of 1σ. We got $p \sim 0.018$ resp. $p \sim 0.022$ for $\mathbb{A}$ resp. $\mathbb{B}$.

Relative abundance of pseudotypes

We studied the spectrum of SN pseudotypes in the set of possibly correlated SNe with respect to all SNe. We test if the relative abundance of the core SNe differs from the whole SN catalogue.

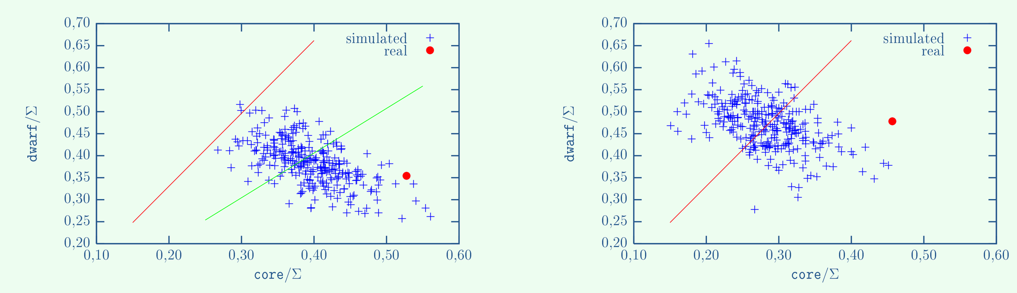


Figure 9: Fraction of `core` and `dwarf` pseudotypes.

To exclude the various possible selection effect and to prove the higher number of the core SNe among the coinciding pairs we compare the results of the real match with artificial random SN and GRB distribution we can generate using the rotation method.

In the case of artificially build catalogues we see a significant difference between the $\mathbb{A}$ and $\mathbb{B}$ sets of parameters (Figure 9). It is due to the different size of the time window.

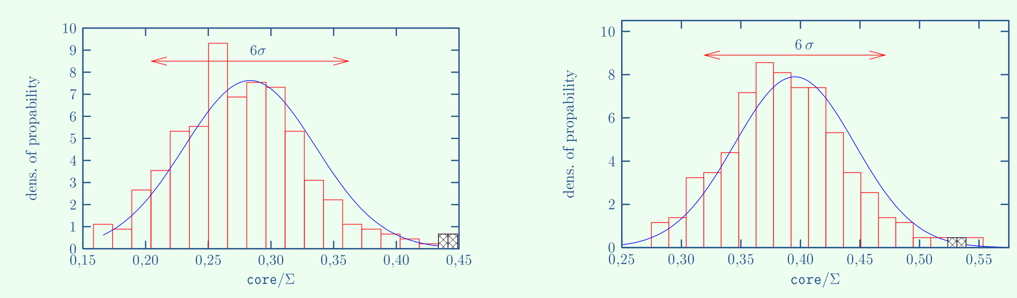


Figure 10: Fraction of pseudotype `core` of SNe.

However the relative abundance of the core SNe in the real match still remains different from the distribution of the relative abundances in the random cases. The distribution (Figure 10) of the abundances of the core SNe in the artificial data set is Gaussian up to 97.8% in the meaning of Kolmogorov–Smirnov test and the relative abundance of the core SNe in the real match is out of 3σ interval.

Conclusion

We have carried out a complex analysis of space-time correlated SNe and CGRO-BATSE GBRs. We have compared count of matched possible correlated pairs SN-GRB with a random one and have estimated the detectable fraction of physically and random correlated pairs. There exists a significantly higher abundance of core-collapse supernovae among the correlated supernovae, but the subset of all correlated objects does not seem to be physically different from the whole set.

Acknowledge

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