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Autocorrelation analysis of GRBM–Beppo-SAX burst data(*)

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Summary. — An autocorrelation function (ACF) analysis was performed on 17 gamma-ray bursts with known redshift, using data from the GRBM on board Beppo-SAX. When corrected from the cosmic time dilation effect, the ACFs show a bimodal distribution at about half-maximum, in agreement with a previous study based on BATSE and Konus burst data. Although the results show more dispersion, the separation between the two classes is highly significant.

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1. – Introduction

The study of time scales is essential for the physical understanding of any astronomical phenomena. For gamma-ray bursts (GRBs) though, no characteristic time has been clearly identified, aside from the time duration of the events in the observed energy band. Individual power density spectra (PDS) are in general very diverse, but the average PDS of many bursts showed a power-law behaviour over two frequency decades, suggesting the absence of any preferred time scale [1]. However, since long bursts are at cosmological distances, it is likely that some temporal features might be *blurred* by time dilation effects. In a recent analysis of 16 long GRBs with known redshift z, that were detected by the BATSE and Konus experiments, it was shown that when corrected for cosmic time dilation the autocorrelation function (ACF) exhibits a clear bimodal distribution [2]. Taking as a measure the half-width at half-maximum, there is a highly significant *gap* between a *narrow* and a *broad* width class, the separation in standard deviations being $> 7\sigma$. The average widths (relative dispersions) are 1.6 s (32%) and 7.5 s (4%) for the narrow and broad classes, respectively. The results in [2] were based on a small number of observations, and therefore need to be confirmed by a larger statistical sample. In this paper we present preliminary results of an extension of that work using GRB data from

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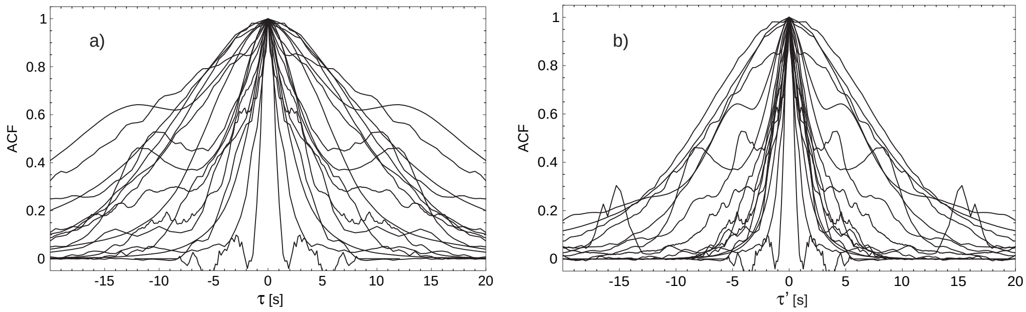

Fig. 1. – a) Observed autocorrelation functions of 17 GRBM bursts. b) Local ACFs where the time dilation effect has been corrected, with $\tau' = \tau/(1+z)$. Although not as clearly as with BATSE data, two width classes are noticeable at half-maximum. The *gap* separation represents a 3.1σ deviation with a chance probability $p < 0.0008$.

the Gamma Ray Burst Monitor (GRBM) on the Beppo-SAX satellite. The drawback of mixing data from different instruments is that this in itself might introduce more dispersion, that could in fact outweigh the benefits of an increased sample. For this reason we will consider separately the GRBM burst sample and evaluate its suitability for our ACF analysis.

2. – Data and methods

The ACF width shows a dependency with the energy band [3] and, like the pulse structure, it broadens at lower energies. We use the lower energy channel data of the GRBM that, being in the 40–700 keV energy range, roughly matches the BATSE (50–320 keV) and Konus (50–200 keV) ranges of the previous ACF study [2]. Note that since the ACF is a quadratic function of the number of counts, and there are more counts at lower energies, it is more important the agreement between the lower-end energy limits.

The standard high resolution 7.8125 ms data was binned up into a time resolution of 62.5 ms to improve the signal-to-noise ratio (S/N). This has no significant consequence for the measurement of the time scales that concerned us here, and reduces some noise artifacts in the ACF. In addition, it better matches the standard BATSE 64 ms temporal resolution for later comparison. In one case (GRB990510), because the on-board logic was not triggered by the burst, only 1 s data are available. A total of 17 GRBs were included in our sample. The light curves were corrected for dead-time and background subtracted.

To derive the ACF from the GRB light curves we followed the methods described in [2]. From a uniformly sampled count history with ΔT time resolution and N time bins, let m_i be the total observed counts at bin i. Also let b_i be the corresponding background level and $c_i = m_i - b_i$ the net counts. The discrete ACF as a function of the time lag $\tau = k\Delta T$ is

$$A(\tau) = \sum_{i=0}^{N-1} \frac{c_i c_{i+k}}{A_0}, \quad k = 1, \ldots, N-1 \tag{1}$$

and $A(0) = 1$ for $k = 0$. Here the periodic boundary conditions ($c_i = c_{i+N}$) are assumed.

TABLE I. – *Sample of* 17 *GRBs detected by GRBM with known redshift. The first six columns give the burst name, the measured redshift z and the corresponding reference, the width class (n: narrow, b: broad), the ACF half-width at half-maximum τ_0, and the corresponding width corrected for time dilation $\tau_0' = \tau_0/(1+z)$. The last two columns give, when available for comparison, the width estimation done based on BATSE data τ_0^B* [2], *and the relative difference $\Delta\tau_0/\bar{\tau}_0$ with respect to the average value $\bar{\tau}_0$.*

GRB	z	Ref.	Class	τ_0(s)	τ_0'(s)	τ_0^B(s)	$\Delta\tau_0/\bar{\tau}_0$(%)
970228	0.695	[4]	n	1.20	0.71		
970508	0.835	[5]	n	3.92	2.14	2.70	37.1
971214	3.418	[6]	n	8.65	1.96	8.02	8.4
980326	1.2	[7]	n	2.44	1.11		
980329	3 ± 1	[8]	n	6.14	1.53	5.96	3.0
980425	0.0085	[9]	b	8.88	8.81	7.62	15.2
990123	1.6	[10]	b	17.43	6.70	19.81	−12.8
990506	1.3066	[11]	n	3.51	1.52	3.83	−8.6
990510	1.619	[12]	n	3.28	1.25	2.54	25.5
990705	0.86	[13]	b	14.28	7.67		
990712	0.434	[14]	n	4.08	2.84		
991216	1.02	[15]	n	3.33	1.65	3.80	−13.2
000210	0.846	[16]	n	1.91	1.04		
000214	0.47	[17]	n	2.53	1.72		
010222	1.477	[18]	n	5.42	2.19		
010921	0.45	[19]	b	9.81	6.77		
011121	0.362	[20]	b	10.91	8.01		

The normalisation constant A_0 is defined as

$$A_0 = \sum_{i=0}^{N-1} (c_i^2 - m_i). \tag{2}$$

The normalisation makes the ACF of each burst fluence independent. The term m_i in eq. (2) subtracts the contribution of the uncorrelated noise assuming that it follows Poisson statistics.

3. – Results and discussion

In fig. 1a we show the *observed* ACFs of all our GRB sample, and in fig. 1b the *local* ACFs where the cosmic time dilation effect has been removed, with $\tau' = \tau/(1+z)$ being the corrected time lag. Though not as evident as when using BATSE data, still two classes given by the local width at half-maximum can be recognised. We focus on the central part of the ACF. In some bursts where the light curve presents a few well separated pulses of similar intensity the ACF shows strong secondary features, while in most cases these secondary peaks are negligible. Our measurements are summarised in table I. Note that although GRB980329 redshift is only known to be in the $z = 2.0$–3.9 range [8], in any case its ACF would lie within the other narrow width bursts. In fig. 1b we used an average value of $z = 3$.

We obtained a mean value of ${\tau'}_0^{(\mathrm{n})} = (1.6 \pm 0.2)\,\mathrm{s}$ and ${\tau'}_0^{(\mathrm{b})} = (7.6 \pm 0.5)\,\mathrm{s}$, and a sample standard deviation of $\sigma^{(\mathrm{n})} = 0.7\,\mathrm{s}$ and $\sigma^{(\mathrm{b})} = 1.2\,\mathrm{s}$ for the narrow and broad sets, respectively. The *gap* separation between the two sets represents a 3.1σ deviation. The probability p of a random occurrence of such a gap was estimated using a Monte Carlo simulation, assuming that there are no characteristic time scales. I was found that $p < 0.0008$. The results are fully consistent with [2], as expected if width errors are larger but stochastic, since only 6 GRBs in this paper were not considered before. The main observed difference is the larger dispersion of the second class ($\sim 16\%$), while the first has about the same spread ($\sim 43\%$).

Table I shows in its last two columns a comparison of the ACFs widths of bursts detected by both GRBM and BATSE. The widths are not systematically broader in the first case (positive differences), therefore the discrepancies can not only be attributed to the different energy range. A better S/N and a more uniform directional response in the BATSE case, our reference instrument, might also be significant factors. The average percentile width difference at half-maximum is $\sim 15\%$. Therefore the dispersion increment in each class width can be explained taken into account the qualitative difference of the GRBM data.

4. – Conclusions

In this comparative study we found that the ACFs and their derived measurements based on GRBM data are consistent with the previous analysis using BATSE/Konus data. The observed dispersion is larger, but mean values of the characteristic time scales for each width class are equal to within the estimated uncertainties. Consequently, at least for this analysis, we can assume that the errors introduced by the instrument were mainly stochastic. Furthermore, despite the increased spread we were still able to identify two separated classes with a very high confidence level ($p < 0.0008$).

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