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Measurements with the resonant gravitational wave detector EXPLORER during the gamma-ray burst 980425

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Abstract. We report on the operation of the resonant gravitational wave (g.w.) detector **Explorer** of the Rome group ($M = 2300$ kg, $T = 2.6$ K, located at CERN) at the time of the gamma-ray burst GRB 980425 (April 25.90915 UT, 1998), which is probably associated with the supernova **SN 1998bw**. We present the data of the detector (with sensitivity $h_{\rm c} = 8\ 10^{-19}$ for a 1 ms pulse), and use the **BeppoSAX** data to estimate the initial time of the GRB: a basic parameter for any correlation analysis.

The g.w. data exhibit no significant time signature around the GRB 980425. We wish to remark the importance to make use, in spite of the present low sensitivity, of the data collected with g.w. detectors, that can be regarded as active observatories, in coincidence with the **BeppoSAX** data.

Key words: gravitational waves — gamma-ray bursts

1. Introduction

In spite of the breakthrough obtained with BeppoSAX for the comprehension of the Gamma-Ray Burst (GRB) phenomenon, an exhaustive explanation is still lacking. Possible mechanisms have been conceived to explain GRBs, all of them involving compact objects and some suggesting an associated g.w. flux, although below the sensitivity of the presently operating g.w. detectors (Thorne 1992). However, due to the complete novelty of this phenomenon we consider certainly worthwhile to search whether a correlation between the GRBs and the data collected with g.w. detectors exists. The discovery of the supernova **SN 1998bw**, probably associated with the GRB 980425, prompted us to analyse the data of the **Explorer** detector around the time of GRB 980425. This unusual supernova was observed later (Galama et al. 1998) within the error box of GRB 980425 (Soffitta et al. 1998). The optical and radio light curves (Galama et al. 1998; Kulkarni et al. 1998b) imply that the supernova explosion probably occurred sometimes during the period 24-27 April 1998, consistent with the hypothesis that the SN 1998bw and the GRB 980425 occur simultaneously.

2. BeppoSAX gamma-ray burst monitor data

The Gamma Ray Burst Monitor (GBRM), on board the BeppoSAX satellite, consists of the 4 anticoincidence CsI (Na) shields of the Phoswich Detection System (Frontera et al. 1997) with dedicated electronics and data storage. Two of the four GRBM units (1 and 3) are co-aligned with the Wide Field Cameras. The GRBM operates in the energy range $40-700$ keV and the counts from each shield are used to reveal the Gamma-Ray Burst event. If the counting rate averaged on a short integration time (actually 1 s) exceeds simultaneously in two shields the background (estimated on a long integration time, actually 32 s) of $n\sigma$ (actually 4) then the GRBM logic is triggered and 3 different files are stored with high time resolution binning, containing the light curve from 10 s before trigger until 88 s after the trigger. In-flight data show, after proper setting of the thresholds, a stable and poissonian background, except for a few, well detected, spikes from highly charged particles (Feroci et al. 1997).

3. The EXPLORER data

The **Explorer** detector, located at CERN, is a 2300 kg cylinder of aluminum alloy with primary quadrupole resonance close to 900 Hz equipped with a resonant capacitive transducer matched to a d.c. SQUID amplifier

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(Astone et al. 1993). The signal from the transducer is fed into a band-pass amplifier, sampled with a sampling time $\Delta t = 4.5$ ms, and analysed off-line with an adaptive Fast Matched (FM) filter (Astone et al. 1997). The squared output E of the filter is expressed in kelvin; its average value is called *effective noise temperature* $T_{\rm eff}$ and represents the energy sensitivity of the detector for pulse detection, in the sense, that it gives the smallest energy variation that can be measured with $SNR = 1$. After the filtering, *events* were extracted with an adaptive threshold of $E_{\rm thr} \geq 19.5\, T_{\rm eff}$ (Frasca 1997). The relation between the $T_{\rm eff}$ and the strain sensitivity $h_{\rm c}$ of the Explorer antenna, for a 1 ms conventional g.w. burst, is (Pizzella 1975; Bonifazi 1990): $h_{\rm c} = 8.1\ 10^{-18} \cdot \sqrt{\frac{T_{\rm eff}}{\sin^4(\theta)}}$ where θ is the angle between the direction of the g.w. burst source and the antenna axis. The value of $\sin^4(\theta)$ was close to 1 over a period of 12 hours around the time of GRB 980425. The operation of the **Explorer** detector considering three days around the time of the burst, starting from day 114 UT, 1998 (April 24), was stationary. The average $T_{\rm eff}$ was of 10 mK, corresponding to an $h_{\rm c}$ (for best orientation) of $8\ 10^{-19}$. The mean rate was of 5.7 events per hour and no events were observed, at this SNR level close, within a few minutes, to the GRB time. In a time interval of $\pm$ 5 min around the GRB 980425 trigger time, we found no events above threshold, with the largest peak (144 mK) occurring 33.31 s before (21.49.10.90847 UT) (see for example Kochanek & Piran 1993). In Fig. 1 we report the **BeppoSAX** GRBM data in the $40-700$ keV band and the filtered Explorer data in $h_{\rm c}$ units. The difference between the *initial time*, obtained by fitting the light curve, and the *trigger time*, for this GRB, is of about 10 seconds.

4. Conclusions

If a source of g.w. bursts located at a distance R produces g.w. with total energy $M_{\rm gw}c^2$ (emitted uniformly over the solid angle 4 π, and in a bandwidth $\Delta\nu = 1/\tau$ where τ is the duration of the emission process) the corresponding $h_{\rm c}$ is given by (for the best orientation and at the resonant frequency $\frac{\omega_0}{2\pi}$) $h_{\rm c} = \sqrt{\frac{2GM_{\rm gw}}{cR^2{\omega^2}_0\tau}}$. For the SN 1998bw, using the known source location (RA = 19 h 35 min 03.34 s, dec. $= -52^\circ\ 50'\ 44.8''$), an estimated distance R from the Earth of 38 Mpc (Kulkarni et al. 1998b; Galama et al. 1998), and $M_{\rm gw} = 1\, M_\odot$, we have $h_{\rm c} = 8\ 10^{-21}$, while the sensitivity of **Explorer** detector is $8\ 10^{-19}$ (with SNR = 1), two orders of magnitude lower (The noise peak of 144 mK would correspond to an emission in g.w. of $\sim 1600\, M_\odot$). During that period two other g.w. detectors were in operation with a strain sensitivity close to Explorer within a factor 1.5: **Auriga** (Cerdonio et al. 1995) and **Allegro** (Mauceli et al. 1996). We are planning to do a concidence analysis between the three antennas, both for a short period, and for four days around the GRB 980425. This analysis will allow to give an upper limit for a g.w. pulse in the hypothesis that the SN 1998bw and the GRB 980425 occur simultaneously or not.

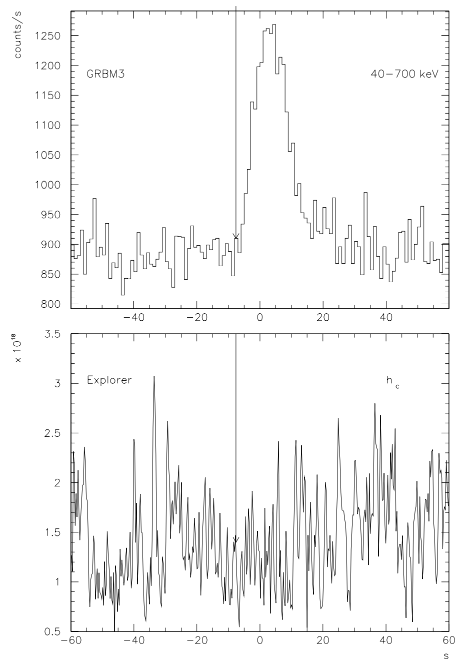

Fig. 1. BeppoSAX GRBM data in the $40 - 700$ keV band and filtered **Explorer** data in $h_{\rm c}$ units, (local maxima in time bins of 0.29 s). The arrows indicate the *initial time* of the GRB, obtained fitting the light curve

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