Spectral evolution of weak bursts from SGR 1806–20 observed with INTEGRAL

D. Götz1,2, S. Mereghetti1, I. F. Mirabel3,4, and K. Hurley5

1 Istituto di Astrofisica Spaziale e Fisica Cosmica – CNR, Sezione di Milano “G. Occhialini”, via Bassini 15, 20133 Milano, Italy
2 Dipartimento di Fisica, Università degli Studi di Milano Bicocca, P.zza della Scienza 3, 20126 Milano, Italy
3 Service d’Astrophysique, CEA/Saclay, Orme des Merisiers, Bât. 709, 91191 Gif-sur-Yvette, France
4 Instituto de Astronomía y Fisica del Espacio / CONICET, cc67, suc 28, 1428 Buenos Aires, Argentina
5 UC Berkeley Space Sciences Laboratory, Berkeley CA 94720-7450, USA

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Abstract. We report on bursts from the Soft Gamma-Ray Repeater SGR 1806–20 detected with INTEGRAL in October 2003, during a period of moderate activity of the source. The spectral and temporal properties of 21 short bursts are consistent with those found in previous observations, even if these bursts are among the faintest observed in the 15–200 keV range from this source. During some of the bursts a clear spectral evolution is visible. The data also show, for the first time, evidence for a hardness-intensity anti-correlation within SGR 1806–20 bursts.

Key words. gamma rays: bursts – gamma rays: observations – pulsars: general – stars: individual: SGR 1806-20

1. Introduction

Soft Gamma-ray Repeaters (SGRs) are a class of peculiar high-energy sources discovered through their recurrent emission of soft γ-ray bursts. These bursts have typical durations of ~0.1 s and luminosities in the range $10^{39}$–$10^{42}$ ergs s$^{-1}$ (see Hurley 2000 for a review of this class of objects). The bursting activity and the persistent emission observed in the ~0.5–10 keV energy range are generally explained in the framework of the “Magnetar” model (e.g. Duncan & Thompson 1992; Thompson & Duncan 1995), as caused by a highly magnetized ($B \sim 10^{15}$ G) slowly rotating ($P \sim 5$–8 s) neutron star.

SGR 1806–20 is one of the most active Soft Gamma-ray Repeaters. Here we report new observations of this source obtained with the INTEGRAL satellite in October 2003 during a period of bursting activity (Götz et al. 2003a; Hurley et al. 2003; Mereghetti et al. 2003b; Götz et al. 2003b). These data have two advantages compared to previous observations in the soft γ-ray energy range of bursts from this source. First, they have been obtained with an imaging instrument, thus we can exclude that the bursts originate from a different source in the field. Second, they have a good sensitivity and time resolution which allows us to study the spectral evolution of relatively faint bursts.

2. Observations and data analysis

The region of SGR 1806–20 was observed by INTEGRAL (Winkler et al. 2003) between October 8 and 15 2003 as part of the Core Program deep observation of the Galactic Centre, yielding an exposure of about ~480 ks on the source. Several bursts from the direction of SGR 1806–20 were detected in near real time by the INTEGRAL Burst Alert System (IBAS, Mereghetti et al. 2003a), using data from the IBIS instrument (Ubertini et al. 2003). IBIS, a coded mask telescope with a large field of view ($29^\circ \times 29^\circ$), comprises two detector layers: ISGRI (15 keV–1 MeV, Lebrun et al. 2003) and PICsIT (170 keV–10 MeV, Labanti et al. 2003). Only ISGRI data are relevant here, since PICsIT does not have enough time resolution for the study such short bursts.

In total, 21 bursts were detected by the IBAS programs. By means of images accumulated over the time intervals corresponding to the individual bursts, we can be confident that all of them originated from SGR 1806–20. In fact, the derived coordinates are all within ~2′ from the well known position of SGR 1806–20 (Kaplan et al. 2002), while the 90% confidence error circle is typically of the order of ~2.5′. In particular, the bursts positions are not consistent with the possible SGR 1808–20 (Lamb et al. 2003) recently discovered at 15′ from SGR 1806–20.

Send offprint requests to: D. Götz, e-mail: diego@mi.iasf.cnr.it

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The background subtracted light curves of the bursts, binned at 10 ms, are shown in Fig. 1. In order to increase the signal-to-noise-ratio, they were extracted from ISGRI pixels illuminated by the source for at least half of their surface and selecting counts in the 15–100 keV energy range (most of the bursts had little or no signal at higher energy). The bursts were detected at various off-axis angles, ranging from 2.5 to 13.3 degrees, corresponding to a variation of 80% in the instrument effective area. The light curves shown in Fig. 1 have been corrected for this vignetting effect. The total number of net counts actually recorded for each burst is indicated in the corresponding panel.

The light curves shown in Fig. 1 have shapes typical for SGR bursts. From the light curves we determined the $T_{90}$ duration of each burst (i.e. the time during which 90% of the total burst counts are accumulated). The $T_{90}$ values range typically from $\sim 0.1$ to $\sim 0.2$ s for single peaked bursts and can be as long as $\sim 0.6$ seconds for double peaked bursts. In fact the $T_{90}$ values of these bursts include the “interpulse” period. Some bursts are preceded by a small precursor.
The peak flux and fluence for each burst were first derived in counts units from the light curves of Fig. 1, and then converted to physical units adopting a constant conversion factor derived from the spectral analysis of the brightest bursts (see next section). The resulting 15–100 keV peak fluxes and fluences are respectively in the range $(4–50) \times 10^{-7}$ erg cm$^{-2}$ s$^{-1}$ ($\Delta t = 10$ ms) and $(2–60) \times 10^{-8}$ erg cm$^{-2}$. Within the large uncertainties, the fluence distribution is consistent with the power law slope found by Göğüş et al. (2000). Many of these bursts are among the faintest ever detected from SGRs at these energies.

### 2.1. Spectral properties

For the bursts with more than 500 net counts we could perform a detailed spectral analysis. The 15–200 keV spectra, integrated over the whole duration of each burst, were well fitted by an Optically Thin Thermal Bremsstrahlung (OTTB) model, yielding temperatures in the range from 32 to 42 keV. We tried other models, like a power law or a black body, but they were clearly ruled out.

Adopting a temperature $kT = 38$ keV (consistent with the average spectra of the brightest bursts) we derived a conversion factor of $1 \text{ count s}^{-1} = 1.5 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ (15–100 keV), which we adopted for all the bursts.

To investigate the time evolution of the burst spectra we computed hardness ratios, defined as $HR = (H - S)/(H + S)$, based on the background subtracted counts in the ranges 40–100 keV ($H$) and 15–40 keV ($S$). The time resolved $HR$ values were computed for all the bursts with more than 200 net counts (i.e. for 12 bursts of our sample). The duration of the individual time bins were chosen in order to have at least 80 net counts in the total ($H + S$) band.

Some bursts show a significant spectral evolution, while others, particularly those with a “flat topped” profile, do not. Some examples are given in Fig. 2. While several bursts show a soft-to-hard evolution (e.g. number 6), others show a more complex evolution (e.g. number 19).

We investigated the variation of the hardness ratio versus intensity ($I$). Considering all the time bins of all the bursts (see Fig. 3), we find a hardness-intensity anti-correlation. The linear correlation coefficient of the data plotted in Fig. 3 has a chance probability $P$ smaller than $10^{-3}$ of being due to uncorrelated data. According to an F-test, the data are significantly ($\sim 5.2\sigma$) better described by a linear fit ($HR = 0.45 - 0.22 \times \log(I)$) than by a constant value. The exclusion of the three “flat topped” bursts from the fit does not affect the statistical significance of the anti-correlation.

We also find an hardness-fluence anti-correlation over the entire fluence range of our bursts, although with a smaller statistical significance ($P = 5 \times 10^{-3}$), which is consistent with our hardness-intensity anti-correlation and also with the results obtained with RXTE data at lower energies (Göğüş et al. 2001).

### 3. Discussion

Previous studies indicated weak or no spectral evolution for SGR bursts (e.g. Fenimore et al. 1994; Kouveliotou et al. 1987). Up to now indication for a hard-to-soft evolution has been reported only for a single burst from SGR 1806–20 (Strohmayer & Ibrahim 1998) and for a precursor to a long burst (3.5 s) from SGR 1900+14 (Ibrahim et al. 2001). The same kind of spectral evolution has also been reported for a ~9 s long burst from SGR 0526–66

![Fig. 2. 15–40 keV light curve (top panels), 40–100 keV light curve (middle panels), time resolved hardness ratio (bottom panels) for four bursts with good statistics. The time resolved hardness ratio for bursts number 8, 19, 6 is inconsistent with a constant value at ~3.5σ level.](image-url)
The hardness-intensity anti-correlation (which in many bursts manifests itself as a soft-to-hard time evolution) is present in bursts from SGR 1806–20 which are not particularly long, nor spectrally hard and not at all very energetic. It is interesting to note that this correlation is opposite to what found for the bursts emitted from 1E 2259+586 (Gavril et al. 2004), which although have lower fluences than the ones we measure.

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