THE INTEGRAL VIEW OF THE SOFT GAMMA-RAY REPEATER SGR 1806-20

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ABSTRACT

We present the results obtained by INTEGRAL on the Soft-Gamma Ray Repeater SGR 1806–20. In particular we report on the temporal and spectral properties of the bursts detected during a moderately active period of the source in September and October 2003 and on the search for quiescent emission.

Key words: Gamma Rays : bursts; 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 et al. (2000) for a review of this class of objects). Occasionally, SGRs also emit giant bursts that last up to a few hundred seconds and exhibit remarkable pulsations that reveal their spin periods (e.g. Mazets et al. (1973), Hurley et al. (1999)).

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 (see e.g. Duncan & Thompson (1992), Paczyński (1992), Thompson & Duncan (1995)), as caused by a highly magnetized ($B \sim 10^{15}$ G) slowly rotating ($P \sim 5$-$8$ s) neutron star. In this model magnetic dissipation causes the neutron star crust to fracture. These fractures generate sudden shifts in the magnetospheric footpoints, which trigger the generation of Alfvén pulses, which in turn accelerate electrons above the pair-production threshold, resulting quickly in an optically thick pair-photon plasma. The cooling of this plasma generates the typical short bursts of soft γ-ray radiation. The longer bursts are powered by magnetic reconnection, and involve the entire neutron star magnetosphere.

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 September and October 2003 during a period of moderate bursting activity (Mereghetti & Götz 2003b, Götz et al. 2003a, Hurley et al. 2003a, Mereghetti et al. 2003b, Götz et al. 2003b). These
data have two advantages compared to previous observations in the soft \(\gamma\)-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. BURSTING ACTIVITY

2.1. Detection and Localization

In July 2003 a new active period of SGR 1806–20 was detected by the IPN (see e.g. Hurley et al. 2003). The source remained active throughout the month of August and so an INTEGRAL Target of Opportunity Observation (TOO) was triggered. INTEGRAL observed it for 240 ks starting on September 3 2003, and 3 faint bursts were detected. Afterwards the monitoring of the source continued during the Galactic Center Deep Exposure (GDCE) as part of INTEGRAL Core Program observations (yielding an additional exposure of about \(~1\) Ms on the source), during which 21 bursts have been detected. All the bursts have been detected and localized in near real time by the INTEGRAL Burst Alert System (IBAS; Mereghetti et al. 2003), using IBIS data in the 15-200 keV range. The burst detection rate vs. time is shown in Fig. 1. 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. 2 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 burst positions in instrumental coordinates are plotted in Fig. 3 (see also Tab. 1). As can be seen most of the bursts are located in the partially coded field of view of IBIS. A few bursts fall within the JEM-X field of view, but unfortunately they are the faintest ones. The only burst for which a simultaneous IBIS/JEM-X detection has been obtained (see Fig. 4), is the one with instrumental coordinates \(Y=-0.97^\circ\) and \(Z=-2.22^\circ\) (burst number 8). This burst has a rather small fluence: \(2.2\times10^{-8}\) erg cm\(^{-2}\) (15-100 keV).

2.2. Data Analysis

We have analyzed only ISGRI data, since PICsIT in its standard operation mode does not have the combined time resolution and sensitivity to study such short bursts. The background subtracted IBIS/ISGRI light curves of the bursts, binned at 10 ms, are shown in Fig. 4. 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 15-200 keV energy range (most of the bursts had little or no signal at higher energy).
None of the bursts has been found in a preliminary analysis of SPI (Vedrenne et al. 2003) data, but further analysis is underway. Only one burst fell into the OMC (Mas-Hesse et al. 2003) field of view, but the large extinction towards the object ($A_v \sim 30$ mag) prevents the detection of any optical emission (see also Castro-Tirado et al. 1998).

The light curves shown in Fig. 2 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, reported in Tab. 1, range typically from $\sim 0.1$ to $\sim 0.2$ s for single peaked bursts and can be as long as $\sim 0.6$ s for double peaked bursts.

Figure 2. IBIS/ISGRI background subtracted light curves of the SGR 1806-20 bursts in the 15-100 keV range. Each panel corresponds to a time interval of one second and the time bins are of 10 ms. Units of the axes are time in seconds and vignetting-corrected counts per bin. Time=0 corresponds to the starting time of the $T_{90}$ computation and is reported on top of each panel (month - day - UT time) together with the total number of net counts.
Table 1. Fluences (15-100 keV), Peak Fluxes (over 10 ms, 15-100 keV), $T_{90}$ durations, net counts (background subtracted, but not corrected for vignetting) and instrumental coordinates for all the bursts.

| Burst Number | Fluence 10$^{-8}$ erg cm$^{-2}$ | Peak Flux 10$^{-7}$ erg cm$^{-2}$ s$^{-1}$ | $T_{90}$ ms | Net Counts | Off-Axis Angle Y degrees | Off Axis Angle Z degrees |
|--------------|---------------------------------|---------------------------------------------|-------------|------------|--------------------------|--------------------------|
| 1            | 1.65 ± 0.16                     | 3.74 ± 0.75                                | 437         | 109        | -3.89                    | -1.86                    |
| 2            | 1.84 ± 0.17                     | 4.26 ± 0.80                                | 69          | 122        | -3.96                    | 0.15                     |
| 3            | 1.97 ± 0.17                     | 2.15 ± 0.57                                | 579         | 131        | 4.05                     | 0.17                     |
| 4            | 4.92 ± 0.27                     | 14.77 ± 1.49                               | 109         | 85         | 10.26                    | 8.21                     |
| 5            | 65.35 ± 0.09                    | 60.73 ± 3.02                               | 179         | 770        | 3.36                     | -12.96                   |
| 6            | 46.58 ± 0.84                    | 50.42 ± 2.75                               | 199         | 562        | 3.35                     | -12.92                   |
| 7            | 5.49 ± 0.28                     | 15.73 ± 1.53                               | 99          | 250        | 3.64                     | -7.56                    |
| 8            | 2.21 ± 0.18                     | 3.67 ± 0.74                                | 160         | 147        | -0.97                    | -2.22                    |
| 9            | 6.15 ± 0.30                     | 12.71 ± 1.38                               | 89          | 302        | -6.32                    | -4.49                    |
| 10           | 2.89 ± 0.21                     | 5.27 ± 0.89                                | 139         | 162        | -5.61                    | 0.77                     |
| 11           | 20.99 ± 0.56                    | 36.40 ± 2.34                               | 169         | 777        | -0.71                    | 8.87                     |
| 12           | 3.17 ± 0.22                     | 9.18 ± 1.17                                | 129         | 210        | -3.69                    | 3.77                     |
| 13           | 3.06 ± 0.21                     | 4.83 ± 0.85                                | 89          | 203        | -3.69                    | 3.73                     |
| 14           | 3.89 ± 0.24                     | 4.86 ± 0.85                                | 489         | 259        | -3.69                    | 3.78                     |
| 15           | 3.94 ± 0.24                     | 15.62 ± 1.53                               | 69          | 114        | -10.03                   | -3.26                    |
| 16           | 3.50 ± 0.23                     | 7.95 ± 1.09                                | 99          | 131        | -8.63                    | -1.40                    |
| 17           | 2.72 ± 0.20                     | 7.21 ± 1.04                                | 189         | 124        | -7.29                    | 0.50                     |
| 18           | 3.62 ± 0.23                     | 9.45 ± 1.19                                | 89          | 195        | -5.95                    | 2.44                     |
| 19           | 2.50 ± 0.19                     | 8.49 ± 1.13                                | 119         | 151        | -4.66                    | 4.42                     |
| 20           | 3.71 ± 0.24                     | 14.33 ± 1.47                               | 159         | 193        | -3.45                    | 6.41                     |
| 21           | 7.88 ± 0.34                     | 8.15 ± 1.11                                | 475         | 409        | -3.46                    | 6.42                     |
| 22           | 27.21 ± 0.64                    | 43.71 ± 2.56                               | 188         | 1145       | -3.87                    | 8.10                     |
| 23           | 25.17 ± 0.61                    | 54.80 ± 2.87                               | 288         | 561        | -11.12                   | -2.48                    |
| 24           | 4.29 ± 0.25                     | 4.24 ± 0.80                                | 159         | 212        | -5.67                    | 5.12                     |

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

We have verified that there is no correlation between...
Figure 7. 15-40 keV light curve (Top Panels), 40-100 keV light curve (Middle Panels), and time resolved hardness ratio (Bottom Panels) for four bursts with good statistics. The time resolved hardness ratio for bursts number 11, 22, 9 is inconsistent with a constant value at \( \sim 3.5 \sigma \) level (Götz et al., 2004a).

The hardness ratios of the individual bursts and the off-axis angle at which they have been detected. In addition we have verified that the vignetting correction procedure used in Götz et al. (2004a) is consistent with the values of the flux of the Crab Nebula measured in different positions in the field of view of IBIS.

3. PERSISTENT EMISSION

Persistent (quiescent) emission from SGR 1806–20 has been discovered at X-ray (<10 keV) energies (Murakami et al., 1994). Up to now no detection at higher energies has been reported for any of the SGRs. We have analyzed IBIS, JEM-X and SPI data of the TOO (240 ksec), but we did not find convincing evidence of quiescent emission.

On the other hand analyzing IBIS/ISGRI Core Program data (\( \sim 1 \) Msec of exposure on SGR 1806–20), we detect the source at \( \sim 6 \sigma \) level in IBIS/ISGRI (see Fig. 4) in the 20-40 keV band. The flux is \( \sim 3 \) mCrab, consistent with an extrapolation of the spectrum measured at lower energies (Mereghetti et al., 2000). Although a detection with such a relatively small significance is also compatible with background systematic noise in the significance maps, the positional coincidence with the X-ray counterpart strengthens the detection.

Also SPI data have been searched for quiescent emission. 482 pointings around the position of SGR 1806–20 (Core Program and TOO data) have been used, yielding a total exposure of \( \sim 0.798 \) Ms. For the SPIROS (Skinner & Connell, 2003) analysis tool the catalogue of the sources detected by IBIS/ISGRI has been used as an input. A significance map was generated in the energy range between 28 and 48 keV. The measured flux is \( 0.69 \pm 0.15 \times 10^{-3} \) photons cm\(^{-2}\) s\(^{-1}\). This flux (\( \sim 10 \) mCrab) is slightly higher than the one measured by IBIS, but considering that the SPI detection level is just \( \sim 4.4 \sigma \), and that systematic errors are still present at this stage in the analysis of both instruments, we can consider the two results as consistent with each other.

Further GCDE observations during INTEGRAL
AO-2 will surely help to further assess the detection and the source flux.

Concerning JEM-X Core Program data, the analysis has still to be completed and will surely be helpful in order to better assess the possible IBIS and SPI detection.

The detection of pulsed emission is at the moment below our sensitivity.

4. CONCLUSIONS

We can summarize our results as follows:

• For the first time good evidence for spectral evolution of weak SGR bursts is presented and a hardness-intensity anti-correlation within the bursts has been found (Gotz et al., 2004a). This results represent a new challenge for the Magnetar model, which predicts that the effective temperature of the burst should vary weakly during the bursts, while we detect large spectral variations whitin the bursts as for number 9 and 22.

• We report for the first time the possible detection, in IBIS and SPI data, of the quiescent emission above 10 keV.

• IBIS is a very sensitive detector for SGR bursts, with fluences down to $\sim 10^{-8}$ erg cm$^{-2}$ in imaging mode. In fact in just 1.5 months it detected twice as many bursts from this source as BATSE.
Figure 8. Hardness-Intensity plot of the time-resolved hardness ratios of the 12 bursts with the best statistics. The hardness ratio is defined as \( \frac{H - S}{H + S} \), where \( H \) and \( S \) are the background subtracted counts in the ranges 40-100 keV and 15-40 keV respectively. The count rates are corrected for the vignetting and refer to the 15-100 keV range \( \text{[Götz et al., 2004a]} \).

During its whole lifetime \( \text{[Gögiš et al., 2000]} \).

- The search of pulsed emission is at the moment below the sensitivity threshold for our data.
- SGR 1806–20 will be observed again during INTEGRAL AO-2 allowing to study this source more deeply.

We finally note that since January 2004 the INTEGRAL Burst Alert System\(^1\) (IBAS) is distributing alerts also for SGR Bursts. Two examples are a \( \sim 0.2 \) s long burst from SGR 1806–20 detected at 10:24:08.35 UT on March 9 2004 \( \text{[Götz et al.]} \) and the \( \sim 0.5 \) s long faint burst detected at 13:02:06.33 UT on March 16 (IBAS Alert n. 1677). The alert messages have been distributed just \( \sim 20 \) seconds after the bursts, allowing for prompt follow-up observations at other wavelengths. This feature will be particularly useful in case of major bursts like the ones from SGR 1900+14 or SGR 0526-66.

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