FREGATE observation of a strong burst from SGR1900+14

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Abstract.
After a long period of quiescence, the soft gamma repeater SGR1900+14 was suddenly reactivated on April 2001. On July 2nd 2001, a bright flare emitted by this source triggered the WXM and FREGATE instruments onboard the HETE-2 satellite. Unlike typical short (< 0.1 s) and spiky SGRs recurrent bursts, this event features a 4.1 s long main peak, with a sharp rise (~ 50 ms) and a slower cutoff (~ 250 ms). This main peak is followed by a ~ 2 sec decreasing tail. We found no evidence of any precursor or any extended ‘afterglow’ tail to this burst. We present the preliminary spectral fits of the total emission of this flare as observed by the FREGATE instrument between 7 and 150 keV. The best fit is obtained with a model consisting of two blackbody components of temperatures 4.15 keV and 10.4 keV. A thermal bremsstrahlung can not be fitted to this spectrum. We compare these features and the burst energetics with the other strong or giant flares from SGR1900+14.

INTRODUCTION

With only four (maybe five) objects known, the Soft Gamma Repeaters (SGRs, see [7] for a review) are rare sources. They undergo repeated, unpredictable periods of intense activity during which they emit few hundreds of brief (~ 0.1 s) and intense (~ 10^5 – 10^4 L_Edd) bursts of soft γ-rays. Besides these classic bursts, very rarely, SGRs emit giant flares[^1], which are extremely energetic (typically ~ 10^{44} erg) and much longer events, lasting for several minutes. The SGR active phases usually last only from a few weeks to a few months. They are separated by long periods (from years to decades) of quiescence during which the SGRs are detected as persistent soft X-ray sources associated with supernova remnants.

Among the few Soft Gamma Repeaters, SGR1900+14 is a kind of prototype. This source was first detected in 1979 ([20]) when it burst 3 times in 2 days. Its activity resumed in 1992 ([14]) and afterwards in May 1998 ([5], [6]) and April 2001 ([5], [10], [11]). During the quiescence state, ASCA and RXTE observations revealed a low luminosity (~ 3 × 10^{34} ergs s^-1) soft X-ray source with a periodicity of 5.16 s and a high value of period derivative[^2] (~ 6 × 10^{-11} s^-1, [3], [7], [12]). SGR1900+14 lies just outside G42.8+0.6, a 10^4-year-old galactic supernova remnant. It is plausible that the SGR is a young neutron star, born in this supernova. If the spindown of the neutron star is due to magnetic braking, assuming purely dipole radiation, the inferred magnetic field is found to be B ~ 8 × 10^{14} G. All these indices support the hypothesis formulated in 1992 that SGR are strongly magnetized young neutron stars (i.e. magnetars [3]). In a magnetar, the energy of the bursts are drawn from the magnetic field energy which dominates all other sources of energy including the neutron star rotation ([25]).

The 2001 reactivation period of SGR1900+14 started with a burst detected by Ulysses on April 17 ([11]) and a strong ~ 40 s flare detected by BeppoSax the day after ([5], [11]). In June-July 2001, SGR1900+14 was very active and entered the antisolar field-of-view of the HETE instruments. Many short classic bursts were detected at that time and are reported elsewhere. At 03:34:06.53 UTC on 2 July, the HETE-2 FREGATE and WXM instruments detected and localized a strong burst lasting 4.1 s from SGR1900+14 ([24]). In this paper, we report on the preliminary timing and spectral analysis of

[^1]: So far, only two such giant flares have been detected: the famous events of March 5 1979 from SGR0526-66 and August 27 1998 from SGR1900+14.
[^2]: A similar spin period and rapid spindown is also measured for SGR 1806-20 ([18]).
FIGURE 1. The FREGATE 6–80 keV time history centered on the trigger time. The peak is cut off on the linear plot.

this strong burst as observed with FREGATE. The WXM data on this burst are also presented in these proceedings ([26]).

The FREGATE observations

Large scale timing analysis

The four identical units of X/γ-ray detectors onboard HETE-2, named FREGATE, are sensitive to photons between 6 and 400 keV (see [1] for a full description of the experiment and operating modes). Using the continuous time history data (resolution 0.16 s in 4 energy bands) we have searched indices for the SGR activity before (i.e. precursors) and after (i.e. extended tail or ‘afterglows’) the main peak for which the instruments triggered. For that purpose, we have built light curves in various energy bands and with various time resolutions. We didn’t find any such features. As an exemple, Figure 1 shows the FREGATE 6–80 keV time history centered on the trigger time. On the large scale plot (more than 10 minutes with 4 s resolution), we see that the count rate goes back to the background level immediatly after the 4.1 s flare (labelled ‘SGR’ on the plot). Three other features to note: 170 s after the trigger the very soft (i.e. no photons above 30 keV) and short (\(\sim 5\) s) excess labelled ‘XRB’ on the plot is probably due to a galactic X-ray burster. Unfortunatly this burst was outside the WXM field-of-view and was not localized. About four minutes after the trigger, the large step visible in this light curve is due to an Earth occultation of Cyg X-1. Finally, about 20 s after the SGR peak, the slight increase in the count rate (marginally significant) is possibly due to the variability of Cyg X-1 or to a background fluctuation.

The SGR flare

The inset in Figure 1 shows a zoom with a logarithmic scale on the peak of the burst, with 0.49 s time resolution. With the exception of the main peak, the only noticeable
feature is a short \( \sim 2 - 3 \) s tail rapidly decreasing to the background level after the peak.

A zoom on the first part of the burst is shown in Figure 2 (left). This light curve has been constructed with the ‘Burst Data’ of FREGATE (256k photons tagged in time with a resolution of 6.4 \( \mu \)s and in 256 energy channels for each detector). The dashed line represents the linear interpolation of the background level taken for times less than 2 s before and greater than 10 s after the trigger time. Several important features can be seen in this plot. First, no short precursors are detected during the few seconds before the main peak. The rise of the burst is quasi-linear in time and is fully resolved (\( \sim 50 \) ms). This sharp rise is followed by a short (\( \sim 20 \) ms) spike occurring at the peak of the flare. Then the intensity starts to decrease in a complex way. A zoom on the last part of the burst is shown in Figure 2 (right). The main peak terminates with a second short spike (lasting \( \sim 100 \) ms) immediately followed by a rapid decrease of the intensity lasting for \( \sim 0.35 \) s. After the main peak, a short spiky tail lasting for \( \sim 2 \) s is visible.

The spectrum and energetics of the flare

As a first spectral analysis, we have built the spectrum of the whole main peak (4.05 s duration) and a background spectrum for 10 s of data before the burst using the ‘Burst Data’ of FREGATE. The deconvolution matrices and the energy-to-channel relations for that date have been computed using the method validated with the Crab observations of FREGATE ([21]). A 2 % systematic error has been added to the statistical errors to account for the calibration uncertainties affecting this high-level spectrum. We have tried with XSPEC to fit the 7-150 keV FREGATE spectrum with several simple spectral models widely used for such bursts.

During these trials, the spectrum readily appeared to feature two main characteristics: (I) it is strongly curved below 20 keV, (II) it extends up to 150 keV. None of the single component models (thermal bremsstrahlung OTTB, powerlaw PL, blackbody BB, broken powerlaw, powerlaw with an exponential cutoff, etc...) provides an acceptable fit over the whole FREGATE range. As an example, we show in Figure 3 (right) the unfolded spectrum derived with an OTTB model for energies above 25 keV. If the fit is marginally acceptable (\( kT_{br} = 24.8 \) keV, \( \chi^2 = 1.49 \) for 47 dof), the model totally fails to reproduce the low energy part of the spectrum below 15 keV and the situation is even worse with the other simple models.

Among the composite models that we have tried (OTTB+BB, BB+PL, etc...) only the sum of two blackbody components (2BB) produces a good fit (\( \chi^2 = 1.127 \) for 66 dof) over the full energy range (see Figure 3, left). The temperatures we derived are \( kT_1 = 4.15 \pm 0.1 \) keV and \( kT_2 = 10.4 \pm 0.4 \) keV.

The flux of the burst was computed by extrapolating and integrating the fitted 2BB model in the energy band > 25 keV. We have computed the luminosity and the total energy for both spectral components and the total emission assuming an isotropic emission at a source distance of 10 kpc. All these results are reported in Table 1 and compared to those of 3 major bursts from the source in the same energy range.
FIGURE 3. The unfolded total emission spectrum of the July 2 2001 burst from SGR1900+14 seen by FREGATE. Right: a thermal bremsstrahlung above 25 keV can roughly reproduce the data but totally fails below $\sim 15$ keV. Left: using the best fit composite model with 2 blackbody in the extended range 7–150 keV

DISCUSSION AND CONCLUSIONS

On August 27, 1998 Konus-Wind, Ulysses, and BeppoSAX detected a giant flare from SGR1900+14 ([8], [9], [19]). Its luminosity of $1.41 \times 10^{41}$ ergs s$^{-1}$ (above 25 keV) and exceptional duration ($\sim 6$ min) made this event the most intense burst ever detected at Earth, thousands of times more energetic than the other bursts of this source. The pulsations at 5.16 s were clearly detected during the burst.

Only two days later (August 29), a strong bright burst was detected simultaneously by BATSE and RXTE (named, after [13], the unusual burst). This event exhibits a 3.5 s burst peak preceded by complex ($\sim 1$ s) precursor and followed by a long ($\sim 10^3$ s) tail modulated at the 5.16 s pulsation period. Its luminosity of $6.43 \times 10^{40}$ ergs s$^{-1}$ is a factor of only 2 less than the giant August 27 burst. Nevertheless, due to its shorter duration, the total energy carried by this burst is much less by a factor $\sim 200$.

On April 18, 2001 BeppoSAX was triggered by an intense X-ray burst from SGR1900+14 ([5], [10]). The event, also detected by Ulysses, lasted $\sim 40$ s and was modulated with the 5.16 s period. Unfortunately, no spectral data are available for this burst. Nevertheless, assuming an optically thin thermal bremsstrahlung spectral model with $kT \sim 30$ keV ([14]) the inferred $25-100$ keV fluence is $\sim 6.5 \times 10^{-6}$ ergs s$^{-1}$ cm$^{-2}$ ($\sim 7.8 \times 10^{40}$ ergs s$^{-1}$ at 10 kpc) that is similar to the previous burst. Nevertheless, considering its energetics and unusual duration,
Alternatively a PL+BB model also gives a good fit with kT \sim 2.4 - 2.5 keV and \gamma \sim 1.2 - 1.6.

### TABLE 1. Summary for the energetics of the SGR1900+14 July 2nd flare using the best spectral model (a sum of two blackbodies) in the range > 25 keV. For the calculations of the luminosity and total energy E_{tot} we assume a source distance of 10 kpc. These parameters are compared to those of 3 major bursts from the source in the same energy range.

| Burst               | Component | Flux \(10^{-6} \text{ ergs s}^{-1} \text{ cm}^{-2}\) | Luminosity \(10^{40} \text{ ergs s}^{-1}\) | E_{tot} \(10^{49} \text{ erg}\) |
|---------------------|-----------|---------------------------------|----------------|----------------|
| Jul. 2nd 2001 flare | 4.15 keV BB | 0.30                            | 0.36           | 1.45           |
|                     | 10.4 keV BB | 1.10                            | 1.33           | 5.40           |
|                     | 4.05 s total burst | 1.40                            | 1.69           | 6.85           |
| August 27, 1998 (giant) | ~ 370 s burst |                                    | 14.1           | 5200           |
| August 29, 1998 (unusual) | ~ 3.5 s burst |                                    | 6.43           | 22.5           |
| April 18, 2001 (intermediate) | ~ 40 s burst |                                    | 7.8            | 313            |

The morphology of the July 2nd, 2001 flare as observed with FREGATE resembles the August 29, 1998 unusual flare. Its duration is similar and the total energy carried by the burst above 25 keV is a factor of only 3–4 less. It is not surprising that we did not detect any precursor or pulsed afterglow at the level reported with RXTE ([13]). If we scale down these features by a factor of \(4 \times \text{FREGATE}/\text{RXTE} \sim 160\), they are undetectable against the somewhat large FREGATE background due to its extended field-of-view.

The main difference between the two bursts resides in the energy spectrum of the main peak. The unusual burst was so bright that the RXTE-PCA detectors was saturated during the majority of the peak. Nevertheless, the burst rise and burst falloff spectra could be fitted with a classical OTTB model with temperatures of \(17.2 \pm 2\) keV and \(15.4 \pm 2.5\) keV respectively. The BATSE spectrum of this burst could also be fitted above 25 keV by an OTTB model with \(kT = 20.6 \pm 0.3\) keV. Both analyses combined suggest a nonvarying spectrum for the unusual burst ([3]). The spectrum presented here can also be fitted by an OTTB model above 25 keV but it is much more curved than this model at lower energies. There is no doubt that such a feature would have been detected with RXTE if present for the unusual burst. Tentatively we have tried to fit our spectrum with a composite model consisting of two blackbodies with temperatures \(kT_1 = 4.15 \pm 0.1\) keV and \(kT_2 = 10.4 \pm 0.4\) keV. The equivalent radii for an isotropic emission are 25 and 3.5 km respectively (at 10 kpc). These values are suggestive of emission regions close to the stellar surface but our modelling is probably too crude to draw any definite conclusion. Many effects, such as the anisotropy of the heat flow through an ultramagnetized neutron star envelope, the reprocessing by a light element atmosphere and the general relativity correction can modify a thermal spectrum near a magnetar surface leading to different values of temperatures and radii ([23]).

A detailed discussion of the FREGATE observations of this burst in the framework of the magnetar model is in preparation and will be published in the near future ([23]).

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