RXTE Observations of Soft Gamma Repeater Bursts

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The spectra of short soft gamma repeater (SGR) bursts at photon energies above ∼15 keV are often well described by an optically thin thermal bremsstrahlung model (i.e., F(E) $\propto$ E^{-1} $e^{(-E/kT)}$) with kT=20−40 keV. However, the spectral shape burst continuum at lower photon energies (down to ∼2 keV) is not well established. It is important to better understand the SGR burst spectral properties at lower energies since inadequate description of the burst spectral continuum could lead to incorrect conclusions, such as existence of spectral lines. Here, we present detailed spectral investigations (in 2-200 keV) of 163 bursts from SGR 1806-20, all detected with Rossi X-ray Timing Explorer during the 2004 active episode that included the giant flare on 27 December 2004. We find that the great majority of burst spectra are well represented by the combination of a blackbody plus a OTTB models.

§1. Introduction

Soft Gamma Repeaters (SGRs) form a small group of neutron stars which are characterized by their emission of repetitive bursts of hard X-rays and soft γ-rays. These bursts are short duration (typically ∼0.1 s) but very intense events (peak luminosities $\lesssim 10^{41}$ ergs s^{-1}). The burst recurrence times are sporadic, varying from seconds to years. On extremely rare occasions, SGRs also emit so-called giant flares. These are the three brightest high-energy transients ever detected, the March 5^{th}, 1979 flare from SGR $0526-66$, the August 27^{th}, 1998 flare from SGR $1900+14$ and the December 27 th, 2004 flare from SGR $1806-20$. The peak luminosities of giant flares are much higher, ranging $\sim 10^{44}$ to $\gtrsim 10^{47}$ ergs s^{-1} (in case of the December 27 giant flare).

All SGRs are also persistent X-ray sources with X-ray (2−10 keV) luminosities $\sim 10^{33-35}$ ergs s^{-1}. Spin periods of three sources are rather slow (5−8 s) and they exhibit very very large spin-down rates ($\sim 10^{-10}$ s s^{-1}). The rotation power in these sources are orders of magnitudes less than the observed energy output. Therefore, when coherent pulsations and rapid spindown were discovered from SGR 1806−20[4] interpreted as due to magnetic braking of a strongly magnetized neutron star (or magnetar, $B_{\rm dipole} \approx 10^{15}$ G).

In magnetar model, these objects are neutron stars with super-strong magnetic fields ($10^{14} - 10^{15}$ G).[1] It is the decay of this magnetic field which powers both the burst and persistent emission. The short duration SGR bursts are believed to be triggered by either starquakes induced by magnetic stresses in the neutron star crust,[7] or magnetic reconnection events occurring within a twisted magnetosphere.[5] The giant flares likely involve a more profound restructuring of the crust and magnetic field on a global scale.[7] Persistent magnetospheric currents, driven by twists in the evolving magnetic field, contribute to the quiescent (non-burst) flux from SGRs.[8] Also, the decaying magnetic field heats the neutron star interior and this heat is conducted to the surface, resulting in thermal X-ray emission[20,22].

SGR burst spectra at photon energies above ∼15 keV are well described by an optically thin thermal bremsstrahlung (i.e., $F(E) \propto E^{-1}\, e^{(-E/kT)}$) with kT = 20−40. However, the burst spectral properties at lower photon energies (down to ∼2 keV) is not well established. Recent studies of typical SGR burst spectra over a broader energy range (2− few hundred keV) revealed that the sum of two blackbody functions with temperatures of 3 keV and ∼10 keV provides an adequate fit to data,[6].[2] Ibrahim et al. (2003) used a power law model to fit the 2−20 keV band burst spectral continuum and deduced large residuals around 5 keV which were then interpreted as absorption lines due to proton cyclotron resonance.[3] It is important to note that description of the SGR burst spectral data with inadequate continuum models could lead to incorrect conclusions.

Here, we present detailed spectral investigations (in 2-200 keV) of 163 bursts from SGR 1806-20, all detected with Rossi X-ray Timing Explorer during the 2004 active episode that included the giant flare on 27 December 2004.

§2. RXTE Observations and Data Analysis

SGR 1806−20 was monitored with RXTE in 98 pointed observations between 22 January and 22 November 2004. The duration of pointed observations varied between ∼0.9 and 16.4 ks, with a total exposure time of ∼622 ks. For each pointing, we have searched the Proportional Counter Array data in 2−60 keV range for SGR bursts. We have found 1640 events that can be identified as short bursts. In Figure 1 we show the 2004 activity history of SGR 1806−20 as observed within RXTE pointings.

Out of SGR 1806−20 bursts, we have selected 163 events which contained at least 600 burst counts with the PCA. For very bright events, we have excluded the time bins with counts rates larger than 18000 counts s^{-1} PCU^{-1} to avoid the effects of the instrumental deadtime. We accumulated background spectra from a total of 120 s intervals (two 60 s intervals prior to and following the event). We have accumulated HEXTE (15−200 keV) burst and background spectra for each event from the same accumulation intervals as those for PCA data. We then fit the joint PCA-HEXTE spectra (2.5−200 keV) simultaneously with the following continuum models: power law, blackbody, optically thin thermal bremsstrahlung (OTTB), thermal bremsstrahlung, blackbody + blackbody and blackbody + OTTB. In spectral fitting we fixed the interstellar hydrogen column density at 6.8×10^{22} cm^{-2} (obtained from Chandra and XMM-Newton observations[9]) due to the fact that the PCA is not sensitive to photon energies below 2.5 keV and, therefore, could not accurately constrain the column density.

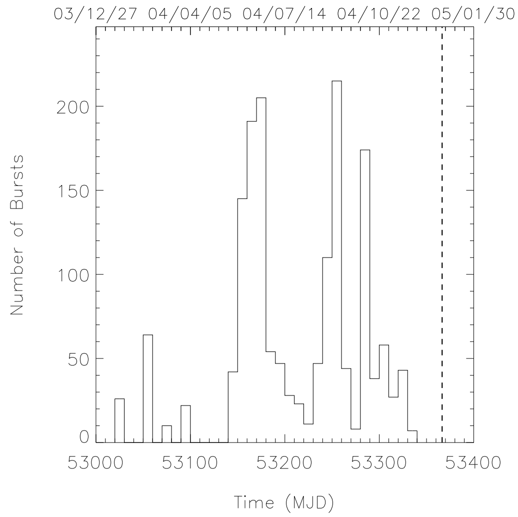

Fig. 1. Burst activity history of SGR 1806−20 within RXTE pointings. The dashed vertical line denotes the time of the giant flare on 27 December 2004.

§3. Results

We present the results of our broadband burst spectral analysis in Table I. We find that the sum of a blackbody and an OTTB models fits the largest fraction of burst spectra well, providing the best fit results for 63.2% of all selected burst spectra. The average blackbody temperatures is found to be 3.9±0.8 keV and the OTTB at 54.7±4.8 keV. The sum of two blackbodies is favored for 28.2% of event spectra at average temperatures of 2.3±0.1 and 11.5±1.1 keV. Power law and single blackbody models are clearly inadequate to model SGR 1806−20 bursts, providing the best fit to 0.6% and none of event spectra, respectively. Thermal bremsstrahlung model provides the best fit to only 2 events. OTTB model performs slightly better, fitting 11 out of 163 burst spectra well. A complete description of our SGR burst spectral study will be presented in Göğüş et al. (2007, in preparation).

Table I. Spectral fit results.

	Power Law	Blackbody	Thermal Brems.	OTTB	Blackbody+ Blackbody	Blackbody+ OTTB
Best %	0.6	0	1.2	6.8	28.2	63.2
kT/Γ	1.0(0.2)	-	118.4	53.0	2.3(0.1)	3.9(0.8)
(keV/)		-	(9.4)	(3.9)	11.5(1.1)	54.7(4.8)
$< \chi^2_\nu >$	2.63	4.47	1.94	1.46	1.25	1.09

We have also investigated the SGR 1806−20 bursts, detected in 1996, that were reported to exhibit absorption like features near 5 keV (Ibrahim et al. 2004). Ibrahim et al. used only the PCA data and modeled the continuum spectra with a power law model. In Figure 2, we present the combined PCA and HEXTE spectrum of this event, modeled with a single power law. There is, in deed, a signature of absorption line around the reported photon energy. Note that the column density must be exceptionally large (2.3×10^{23} cm^{-2}) for a power law to fit the data. On the other hand, the sum of a blackbody and an OTTB models provide a significantly better fit to the same spectrum in the entire broad range (Figure 3) and the evidence for absorption signature is nothing more than statistical fluctuations.

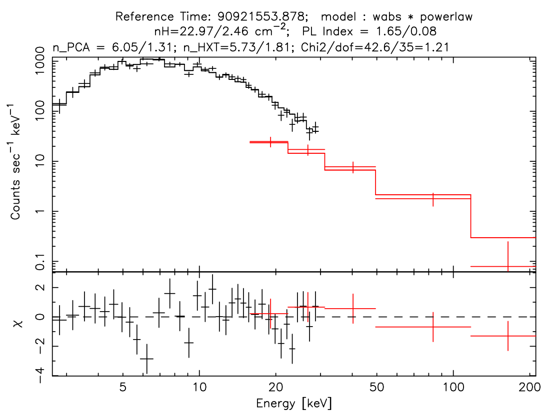

Fig. 2. Spectrum of an SGR 1806−20 burst, detected in 1996, modeled with a power law.

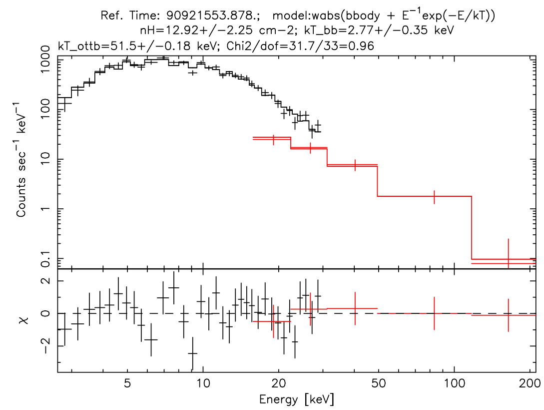

Fig. 3. Spectrum of the same burst as in Figure 2 modeled with the sum of a blackbody and an OTTB models.

§4. Summary and Discussion

We find that the great majority of SGR 1806−20 burst spectra in the 2.5−200 keV range are well represented by the combination of a blackbody plus a OTTB models. The blackbody component dominates in the energy range below about 15 keV. Our results, therefore, is consistent with earlier results that an OTTB model describes the burst spectra at photon energies larger than ∼15 keV.

We clearly rule out the power law model to represent SGR burst spectra. We believe that the absorption lines reported earlier (and interpreted as due to proton cyclotron resonance) is a result of an inadequate choice of the continuum model employed.

Nevertheless, proton cyclotron lines may be present in the burst or persistent emission spectra of a magnetar. The detection of such spectral features will be much more conclusive if it is done with a better suited instruments such as those on board Chandra, XMM-Newton or Suzaku.

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