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Wide-band spectra of magnetar burst and persistent emission

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Abstract. We studied wide-band spectra of magnetar bursts and persistent emission using *Suzaku* and HETE-2 data. Small burst spectra of SGR 0501+4516 consist of a two blackbody function and a hard power-law which are the same components during persistent emission. In addition, the bright burst spectra of SGR 1806−20 observed by HETE-2 also consist of the same components. Luminosities of two components for both bursts and persistent emission show a correlation over five orders of magnitude. These results suggest a common emission mechanism between burst and persistent emission, further leading to a possibility that the persistent emission may consist of numerous micro bursts. A ToO observation of AXP 4U0142+614 with *Suzaku* on 7 September 2011 suggests that the persistent emission spectrum in the active phase might be harder than that in the quiet phase.

Key words. Stars: magnetars – Stars: pulsars: individual(SGR 0501+4516) – Stars: pulsars: individual(SGR 1806−20) – Stars: pulsars: individual(AXP 4U 0142+614)

1. Introduction

Astrophysical interest in magnetars, strongly magnetized neutron stars with surface fields up

Send offprint requests to: Y.E. Nakagawa to ~ 10^{15} G (Duncan, & Thompson 1992), has been growing for the last decade. They emit X-ray photons through magnetic field dissipation. Magnetars are unique objects to study interactions between magnetic fields and photons.

Soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs) are phenomenologically defined to be magnetars. They exhibit X-ray persistent emission (~ 10^{-11} erg cm^{-2} s^{-1} in 2-10 keV) and super-Eddington burst activity (~ 10^{-6} erg cm^{-2} s^{-1} in 2-100 keV). These energetic phenomena are presumably related to electron-positron plasmas in the magnetosphere. Since there are several common characteristics between the SGRs and the AXPs such as spectra and rotation periods of 2-12 s, they are thought to be the same class of objects. However the emission mechanisms of the burst and persistent emission remain unknown. The spectra of the X-ray persistent emission below 10 keV are well modeled by a photoelectrically absorbed two blackbody function (2BB) or blackbody plus a power law (BB+PL). Recent studies using INTEGRAL (e.g., Kuiper, Hermsen, & Mendez 2004) and *Suzaku* (e.g., Enoto et al. 2010), found a hard X-ray component above 10 keV in the spectra of the persistent emission which is well described by PL with very hard photon indices of about −1. The most acceptable spectral model of SGR short bursts detected by the High Energy Transient Explorer 2 (HETE-2; Ricker et al. 2003) is a 2BB model (Nakagawa et al. 2007).

Given that the bursts and persistent emission are both energized by the magnetic fields which are thought to be a promising energy source, there could be very similar physical processes between them. Consequently, their spectra could emerge alike. The spectra of both the bursts and persistent emission show a strong linear correlation between the lower and higher temperatures of 2BB (Nakagawa et al. 2009). This correlation suggests common emission mechanisms between the bursts and persistent emission (Nakagawa et al. 2009). If this is the case, the burst spectra may also display the hard X-ray component which has only been found in the spectra of the persistent emission so far.

2. Hard power-law component in bursts and persistent emissions

We present spectral studies of burst emission of SGR 0501+4516 and SGR 1806−20, and persistent emission of AXP 4U 0142+614. All quoted errors are 90% confidence levels.

2.1. *Suzaku* observations of small bursts from SGR 0501+4516

SGR 0501+4516 was discovered by *Swift* on 22 August 2008. Since it was undergoing intense burst activity, a *Suzaku* ToO observation was performed on 26 August 2008 with the *Suzaku* narrow field instruments; the X-ray imaging spectrometer (XIS; 0.2-12 keV energy band; Koyama et al. 2007), and the hard X-ray detector (HXD; 10-700 keV energy band; Takahashi et al. 2007). *Suzaku* detected the X–ray persistent emission, and 32 bursts during a ~20 ks observation (Enoto et al. 2009). An analysis of a large burst was reported in Enoto et al. (2009). Then we analyzed 31 short bursts with low fluences which were not affected by pile-up. Since there was not enough statistics in each short burst, we summed their spectra. The photoelectric absorption was fixed to 8.9×10^{21} cm^{-2} (Enoto et al. 2009).

The summed spectrum of the 31 short bursts cannot be reproduced by a 2BB model, despite the fact that this model is known as the most acceptable model for the SGR short bursts (Nakagawa et al. 2007). There is an excess above ~20 keV. The excess is well reproduced by PL with an index of $-1.0^{+0.4}_{-0.3}$ which is comparable to the indices of the hard X-ray component in the persistent emission spectra. Therefore we have discovered hard X-ray component in a burst spectrum which was found only in the persistent emission spectra so far.

2.2. HETE-2 observations of bright bursts from SGR 1806−20

The hard X-ray component was not seen in bright bursts (~10^{-7}–10^{-6} erg cm^{-2} s^{-1}). In order to examine effects of the hard X-ray component on bright bursts spectra, we re-analyzed 50 bright bursts from SGR 1806−20 detected

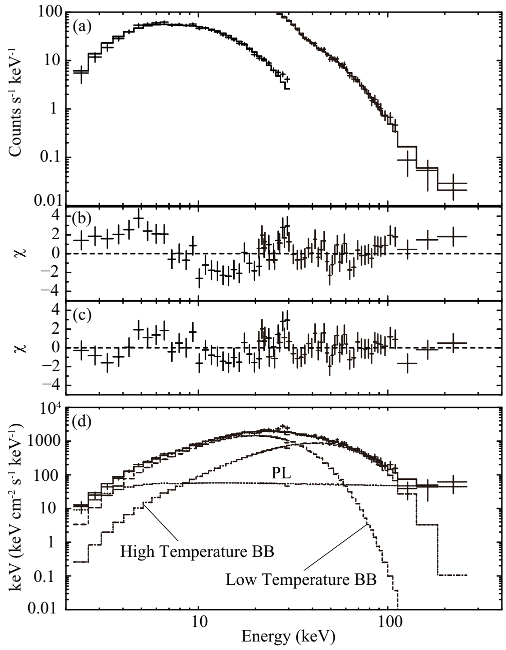

Fig. 1. Spectra of the bright bursts in the group with fluxes of (2.82-7.98)$\times 10^{-6}$ erg cm^{-2} s^{-1} from SGR 1806−20 observed by HETE-2. Panel (a) is spectra, panels (b)-(c) are residuals using 2BB and 2BB+PL, while panel (d) is the same as panel (a), but in the νF_ν form.

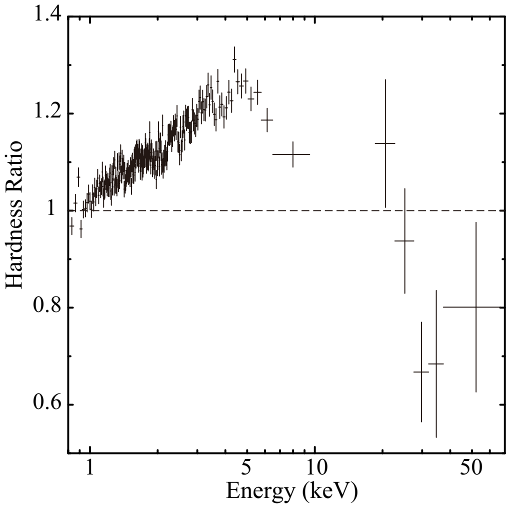

Fig. 2. A hardness ratio between a spectrum in the active phase and that in the quiet phase.

by the Wide-Field X-ray Monitor (WXM; 2-25 keV energy band; Shirasaki et al. 2003) and French Gamma Telescope (FREGATE; 6-400 keV energy band; Atteia et al. 2003) on-board HETE-2 (Nakagawa et al. 2007). Since temperatures of the 2BB models show almost constant values with ~4 keV and ~11 keV, we divided 50 bursts into 6 groups based on fluxes; 0.32-0.75, 0.75-1.03, 1.03-1.32, 1.32-1.58, 1.68-2.53, and 2.82-7.98 in unist of 10^{-6} erg cm^{-2} s^{-1}. The spectra in all groups are well fitted by a 2BB+PL model.

2.3. Suzaku observations of persistent emissions of AXP 4U 0142+614

The *Swift* team reported that AXP 4U 0142+614 exhibited burst activities on 29 July 2011 and presented more than 10 bursts (Oates et al. 2011). We performed monitoring observations of AXP 4U 0142+614 using the X-ray Telescope (XRT; Burrows et al. 2005) on-board *Swift* (Gehrels et al. 2004). These observations show that the object maintained 20-30% increase in luminosities for more than a month. In the past decade, a variability of the luminosity is less than ±10% (Gonzalez et al. 2010). Then we performed a ToO observation of AXP 4U 0142+614 with *Suzaku* on 7 September 2011 because we expected that the object was in a rare active phase. There are no significant bursts during the ~41 ks observation.

To compare a spectrum of this ToO observation in an active phase with a spectrum of the observation in a quiet phase (Enoto et al. 2011) in a model-independent manner, we directly divided the former spectrum by the latter spectrum using the data of the XIS and HXD instruments. A hardness ratio is shown in figure 2. The spectra are clearly hard in about 1-10 keV in the active phase.

Spectral analyses of persistent emission with a 2BB+PL model imply a 2BB luminosity of (4.52±0.12)$\times 10^{35}$ erg s^{-1} and a PL luminosity in 2-70 keV of (10.2±0.7)$\times 10^{34}$ erg s^{-1}. These luminosities are 5% and 19% higher than the luminosities in the quiet phase (Enoto et al. 2011) of (4.31±0.01)$\times 10^{35}$ erg s^{-1} and

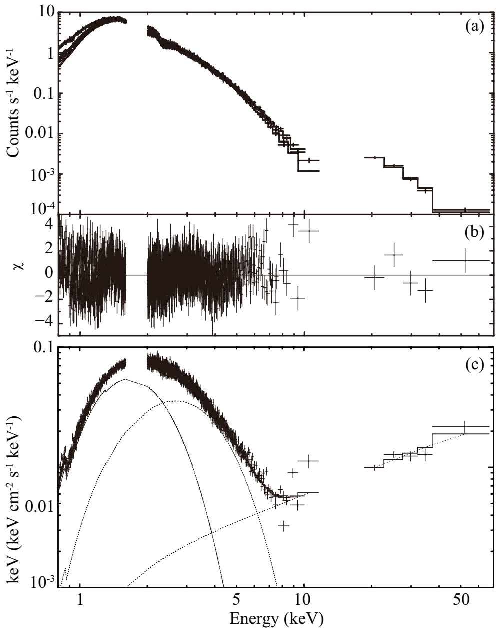

Fig. 3. Wide-band spectra of the persistent emission of AXP 4U 0142+614 observed by Suzaku. Panel (a) is spectra, panels (b) is residuals using 2BB+PL, while panel (c) is the same as panel (a), but in the νF_ν form.

$(8.6\pm0.9)\times10^{34}$ erg s^{-1}, respectively. This result implies that the persistent emission spectrum in the active phase might be harder than that in the quiet phase.

3. Conclusions

The bursts and persistent emission are similar, comprising not only the soft 2BB component, but also the hard PL component. Figure 4 presents a correlation between bolometric luminosities of the 2BB component and the luminosities of PL component which were derived from the *Suzaku* and HETE-2 data. The luminosities for AXP 1E 1547.0−5408 (Enoto et al. 2012) are also presented. There is a clear correlation over five orders of magnitude. These results suggest a common emission mechanisms between bursts and persistent emission. The persistent emission could be formed as a result of numerous micro bursts. The spectra of the

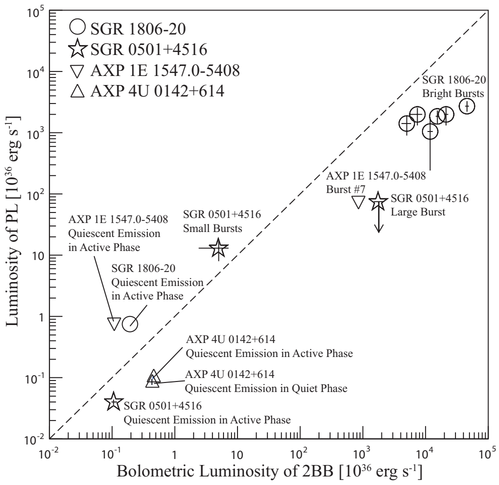

Fig. 4. A correlation between bolometric luminosities of 2BB and luminosities of PL.

persistent emission in the active phase might be harder than those in the quiet phase.

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