Uniting Burst and Quiescent Emission Mechanisms of Magnetars

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Abstract

Spectral studies of both quiescent emission ($\sim 10^{-11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ in 2-10 keV) and bursts ($\sim 10^{-6}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ in 2-100 keV) are presented for 11 magnetar candidates using HETE-2, *Suzaku*, XMM-*Newton*, *Chandra* and *Swift* data. Spectra of the quiescent emission and the bursts for most magnetar candidates are reproduced by a photoelectrically absorbed two blackbody function (2BB). There is a strong linear correlation between lower and higher temperatures of 2BB, irrespective of objects and/or emission types (i.e., the quiescent emission and the bursts). In addition, a hard X-ray tail is discovered in a summed spectrum of the small bursts from SGR 0501+4516 detected by *Suzaku*, which is discovered only in the quiescent emission spectra so far. These results could suggest a possible evidence of common emission mechanisms between the quiescent emission and the bursts of magnetar candidates. The quiescent emission could consist of numerous micro-bursts. If this is the case, total released energy of small fluence ($< 10^{-8}\,\mathrm{erg\,cm^{-2}}$ in 2-100 keV) bursts of a cumulative number-intensity distribution can be comparable to a released energy of the quiescent emission. It has arised that the total released energy can easily maintain the quiescent emission energy.

Key words: stars: neutron

1. Introduction

Magnetars are one of the unusual neutron stars with super strong magnetic fields up to $\sim 10^{15}$ G (e.g., Duncan & Thompson 1992). They emit X-ray, gamma-ray photons through magnetic field dissipations. The magnetars are unique objects to study interactions between magnetic fields and photons.

Two apparent classes are known as magnetar candidates, a soft gamma repeater (SGR) and an anomalous X-ray pulsar (AXP). They exhibit X-, and gamma-ray quiescent emission ($F \sim 10^{-11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ in 2-10 keV) and super-Eddington, sporadic, repetitive burst activities. Since there are several common characteristics between the SGR and the AXP such as rotation periods of P =2-12 s, they are thought to be same class of objects.

The X-ray quiescent emission spectra below 10 keV are well modeled by a photoelectrically absorbed two blackbody function (2BB) or blackbody plus a power law (BB+PL). A hard X-ray tail above 10 keV discovered by INTEGRAL (e.g., Kuiper et al. 2004), is well described by a power law (PL) with very hard indeces of $\Gamma <$ 1-2 ($N \propto E^{-\Gamma}$). Some more physical models are suggested for the X-ray quiescent emission spectra (e.g., Rea et al. 2008). The most acceptable spectral model of SGR short bursts detected by High Energy Transient Explorer 2 (HETE-2) is 2BB (Nakagawa et al. 2007).

Given that the quiescent emission and the burst are energized by the magnetic fields which is thought to be prospective, there would be a very similar physical process between them. Consequently, their spectra could emerge alike. We claim that the most acceptable spectral model of the SGR short bursts detected by HETE-2 is 2BB even if it should be considered just as an empirical model (Nakagawa et al. 2007). If the SGR and the AXP are same class of objects, it would also be preferred that the quiescent emission spectra are reproduced by 2BB rather than BB+PL. In addition, the burst spectra may also have the hard X-ray tail reproduced by PL which is found only in the quiescent emission spectra heretofore. In this paper, we present spectral studies of both the quiescent emission and the burst of the magnetar candidates.

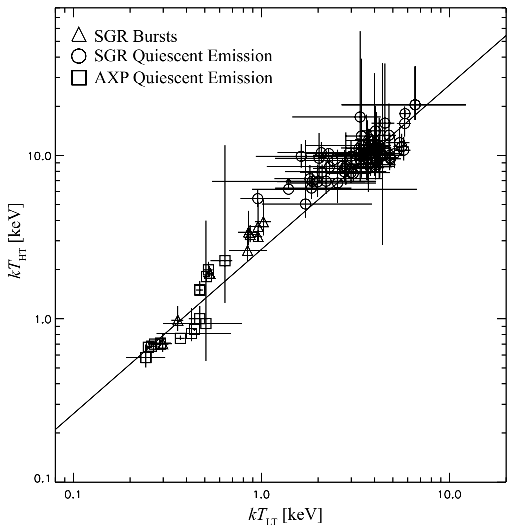

Fig. 1. A correlation between lower and higher temperatures of 2BB ($kT_{\rm LT}$ and $kT_{\rm HT}$).

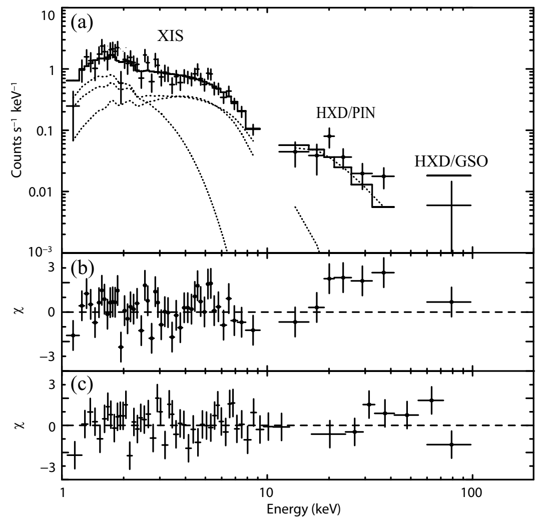

Fig. 2. Panel (a): a summed spectrum of 31 small bursts detected by *Suzaku* fitted with 2BB+PL. Panel (b) and (c): residuals using 2BB and 2BB+PL.

2. Observations and Data Analysis

The quiescent emission spectra of the 10 magnetar candidates using XMM-*Newton*, *Chanra* and *Swift* are analyzed in our study. The spectra of most magnetar candidates are represented by 2BB, while three AXPs seem to have an excess above ~7 keV. The excess is well modeled by PL with spectral parameteres of the hard X-ray tail measured by INTEGRAL. Thus the excess could be related to the hard X-ray tail. In figure 1, there is a strong linear correlation between lower and higher temperatures of 2BB ($kT_{\rm LT}$ and $kT_{\rm HT}$), irrespective of the quiescent emission and the bursts (Nakagawa et al. 2009).

SGR 0501+4516 was discovered by Swift on 22 Augst 2008. Since it was undergoing intense burst activity, a *Suzaku* ToO observation was performed on 26 August 2008. *Suzaku* detected the X- and gamma-ray quiescent emission and 32 bursts during a 20 ks observation. A spectra study of a main burst is reported in Enoto et al. 2009, and therefore we will focus on remaining 31 small bursts hereafter. A summed spectrum of the 31 small bursts cannot be reproduced by 2BB, despite 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 which is shown in figure 2 (b). The excess is well reproduced by PL with an index of $\Gamma = 1.0^{+0.3}_{-0.4}$ which is comparable to the indeces of the hard X-ray tail in the quiescent emission spectra. Therefore we discovered a hard X-ray tail in the burst spectrum which was found only in the quiescent emission spectra so far.

From what has been discussed above, we can conclude that the quiescent emission and the bursts are similar, comprising not only a soft X-ray 2BB spectrum, but also a hard X-ray PL spectrum.

3. Discussions and Conclusions

We found the strong linear correlation between the lower and higher temperatures of 2BB, irrespective of the quiescent emission and the bursts. The summed spectrum of the SGR 0501+4516 small bursts shows the hard X-ray tail which is found only in the quiescent emission spectra so far. There are similarities between the quiescent emission and the bursts which are not only a soft X-ray 2BB spectrum but also a hard X-ray PL spectrum. If there are common emission mechanisms between the quiescent emission and the bursts, the quiescent emission could be formed as a result of numerous micro-bursts. The energy released in low fluence ($<10^{-8}$ erg cm^{-2} in 2-100 keV) bursts estimated from a cumulative number-intensity distribution (Nakagawa et al. 2007) can be comparable to the released energy of the quiescent emission.

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