Suzaku observation of AXP 1E 1841-045 and the future observation in the MAXI era

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Abstract

We report results of the Suzaku observation of the anomalous X-ray pulsar (AXP) 1E 1841−045. We obtained the spectrum from 0.4 keV to ∼70 keV simultaneously. The model consisting of a blackbody and two power-law functions could simulate the spectrum well. We also found that the power-law function at the higher energy can be replaced with a thermal bremsstrahlung. The fact that the hard X-ray emission can be interpreted as a thermal bremsstrahlung would support the theoretical emission model proposed by Thompson & Beloborodov (2005). Emission mechanism of the hard X-ray component can be understood by detecting the variability of the photon index and cutoff energy. In this reason, the MAXI monitoring for magnetars (AXPs and SGRs) are extremely important. The monitoring of the pulse frequency and pulse profiles of magnetars are also important as well as that of the flux. MAXI can detect transient phenomena and trigger the multi-wavelength observation. Especially, near-infrared monitoring observation and correlation study would be able to elucidate the mysterious infrared emission mechanism of magnetars. We estimated the detectability of the magnetars and their pulsation by MAXI using the MAXI simulator.

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1. Introduction

Anomalous X-ray pulsars (AXPs) and soft gamma repeaters (SGRs) are thought to be magnetars, which are strongly magnetized neutron stars with emission powered by the dissipation of magnetic energy (see Woods & Thompson (2006) for a recent review). So far, 10 AXPs (including 3 transient AXPs) and 6 SGRs have been found. They distribute along with the Galactic plane and the Large and Small Magellanic Clouds. Their characteristics are as follows: (1) Their spin periods concentrate in a narrow range (2 – 12 s). Spin periods and spin-down rates imply the strong dipole magnetic fields of 10^{14} – 10^{15} G. (2) Their X-ray luminosities ($L_X \sim 10^{34}$–10^{36} ergs s^{-1}) exceeding the spin-down energy loss rate of neutron stars suggests that AXPs and SGRs are not rotation-powered pulsars. (3) They are radio quiet with exceptions of XTE J1810−197 (Camilo et al. 2006) and 1E 1547.0−5408 (Camilo et al. 2007). (4) They showed spiky short bursts with durations $\Delta t \sim 0.1$ s, and sometimes showed giant flare. (5) Their X-ray spectra are simulated by a compound of a blackbody and power-law function with rather steep photon index ($\Gamma \sim 2$ - 4) or two temperature blackbodies. Above ∼ 10 keV, there is another hard X-ray component extending to ∼ 150 keV. (6) They shows various time variability like flux variation, pulse profile change, timing noise of pulse period, and glitch of pulse period. (7) They have infrared/optical counterparts and these fluxes are variable. Owing to the last two characteristics, magnetars are thought to be good target of MAXI.

In this paper, we at first show the results of Suzaku observation of the AXP 1E 1841-045 (Morii et al. 2008), and secondly we show science of magnetars achieved by MAXI.

2. Suzaku observation of AXP 1E 1841-045

1E 1841−045 is one of prototypes of AXPs. It locates on the center of the supernova remnant (SNR) Kes 73 with a diameter of about $4'$ (Morii et al. 2003). By using a Chandra data (0.6 – 7.0 keV) Morii et al. (2003) showed that the spectrum was simulated well with a model consisting of the blackbody ($kT = 0.44 \pm 0.02$ keV) and the power-law function ($\Gamma = 2.0 \pm 0.3$). Kuiper, Hermsen & Mendez (2004) discovered a very hard (photon index: 0.94 ± 0.16) pulsed hard X-ray emission up to ∼ 150 keV, using the RXTE/PCA (1.8 – 23.8 keV) and the RXTE/HEXTE (15 – 250 keV). this hard X-ray component is thought to amount substantial fraction in the energy range below ∼ 10 keV. Therefore, the Suzaku wide band spectroscopy is important to determine the spectrum.

We observed AXP 1E 1841-045 by Suzaku (Mitsuda et al. 2007) on April 19-22, 2006 as a target of AO-1. We used XIS and HXD/PIN detectors to cover the energy range of 0.4 – 10 keV and 12 – about 70 keV, respectively. HXD/GSO was used for the upper limit at around 100 keV. The exposure of the observation was 100 ks. We followed the standard method to analyze the data (Morii et al. 2008). The pulse phase-averaged spectrum was well fitted by three component consisting of a blackbody, power-law function, and another power-law function. Interestingly, the photon index of the power-law of the higher energy part was ~1.6. This value can also be explained by thermal bremsstrahlung. Here, the Gaunt factor and the exponential cut-off around 100 keV can change the photon index of bremsstrahlung of 1 (Rybicki & Lightman 1979) to ~1.6 in the energy range of PIN (10 – 50 keV). Then we also fitted the phase-averaged spectrum by a compound of a blackbody, power-law function, and thermal bremsstrahlung (figure 1). This model also fitted the spectrum well, with a bremsstrahlung temperature of $kT = 51.7^{+14.1}_{-8.8}(\mathrm{stat})^{+68.0}_{-22.1}(\mathrm{syst})$ keV.

Interpretation for a hard X-ray by a thermal bremsstrahlung is interesting, because one of theoretical model of emission mechanism predicted the similar spectrum of a thermal bremsstrahlung (Beloborodov & Thompson 2007). Moreover, we checked a self-consistency for the thermal bremsstrahlung emission. For this emission to be valid, the emission region must be optically thin. Assuming that the Thomson cross-section, optical depth must be $l > 3.4 \times 10^9$ cm. It is too large value in comparison with the radius of neutron stars ($\sim$ 10 km). Nevertheless, in the ultra strong magnetic field, the cross-section of the Thomson scattering is suppressed by $7.6 \times 10^{-5}(kT/10\mathrm{keV})^2(B/10B_{\mathrm{QED}})^{-2}$, where the $B_{\mathrm{QED}} = 4.4 \times 10^{13}$ G is the quantum critical magnetic field (Thompson & Duncan 1995). Then, $l > 2.9 \times 10^4$ cm for $B = 7.1 \times 10^{14}$ G and $kT = 100$ keV, where the B is the dipole magnetic field at the surface of this AXP estimated by $3.2 \times 10^{19}(P\dot{P})^{1/2}$ G. So, the l become a reasonable size. It can be said that optically thin emission like thermal bremsstrahlung itself is an expression of the ultra strong magnetic field of magnetars.

2.1. Comparison of spectra between Suzaku and Integral

By comparing the Suzaku and Integral spectra (figure 2), we found that the flux at around 20 – 70 keV is consistent between them. However, the spectrum of Integral is slight harder than that of Suzaku. The photon indices of Suzaku and Integral are +0.38 ±0.05(stat)±0.16(syst) and +0.68 ± 0.11, respectively. The significance of the difference is 1.5 sigma level. There are the following possibilities: 1) just a systematic difference between the Suzaku and Integral. 2) time variation of the hard X-ray component. The spectrum of Integral was obtained by long span of 1.7 years, while that of Suzaku was obtained by only 3 days. and 3) An effect of a comptonized hump, which is expected in the spectrum come from the region with intermediate optical thickness. The detailed calculation was shown in Miyamoto (1978) and Sunyaev & Titarchuk (1980). If this possibility is true, the shape of the hump may be sensitive to the structure of the magnetosphere of magnetars. Therefore, the time variability of hard X-ray spectrum is interesting, and hence the detection of magnetar flare using MAXI is important.

3. Magnetar observation by MAXI

3.1. magnetar science by MAXI

Magnetars shows transient phenomena as shown in the introduction. Interestingly, new magnetars have been discovered as transient sources. Recent examples are XTE J1810-197 (Ibrahim et al. 2004), CXOU J164710.2-455216 (Naik et al. 2008), and SGR 0501+4516 (Barthelmy et al. 2008). MAXI will discover new magnetars. Even for the known magnetars, they shows flares in the time scales from days to months (Kaspi et al. 2003, Gotthelf & Halpern 2006). MAXI can detect such flares and broadcast this occurrence quickly. We can trigger the multi-wavelength observation. Especially, follow-up observations in hard X-ray, infrared/optical and radio bands are quite interesting, because their emission mechanisms are still open question. The multi-wavelength flux monitoring and correlation study is a key to elucidate the emission mechanism.

3.2. MAXI simulation for magnetars

To check the detectability of magnetars by MAXI, we simulated four bright magnetars, 4U 0142+61, 1E 2259+586, 1RXS J170849.0-400910, and XTE J1810-197 by using MAXI GSC simulator. The last XTE J1810-197 is a transient AXP, which once became bright on 2003 July (Ibrahim et al. 2004). We used peak flux for this AXP (Gotthelf & Halpern 2006). For sources other than last one, we used the spectra consisting of a blackbody and power-law function. The spectral parameters are obtained by the analysis of the Chandra archival data. For the last one, we used two temperature blackbodies (Gotthelf & Halpern 2006). The table 1 shows the parameters inputed for the MAXI GSC simulator. For GSC simulator, we set the status of all 12 counters working and backgrounds of CXB and NXB were taken into consideration. The detectability for these sources are shown in figure 3 and table 2. For all of them, the persistent flux monitoring can be possible within a time scale of a week. Such a frequent monitoring was not possible by RXTE/PCA pointing observation. For 1RXS J170849.0-400910, pulse period monitoring is possible. Interestingly, this source showed glitches (Kaspi & Gavriil 2003), which is a key

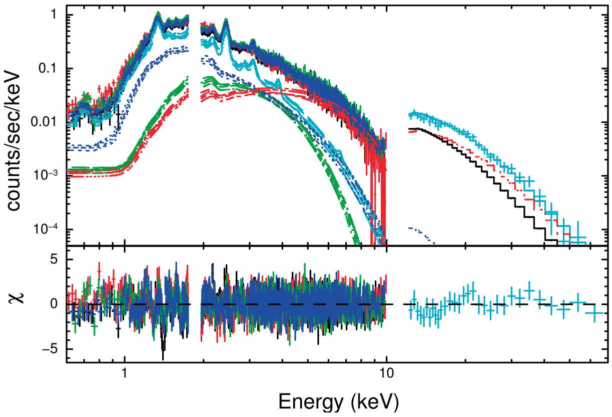

Fig. 1. Spectrum of AXP 1E 1841−045 obtained by Suzaku observation. It is fitted with a combination of the SNR Kes 73 and the AXP spectra. Here, the SNR spectrum was determined by the spectrum analysis for Chandra data. The AXP spectrum was three component model consisting of a blackbody(green), power-law(blue) and thermal bremsstrahlung(red). Black histogram in PIN region is the component of the cosmic X-ray background and Galactic ridge X-ray emission. This figure is extracted from Morii et al. (2008).

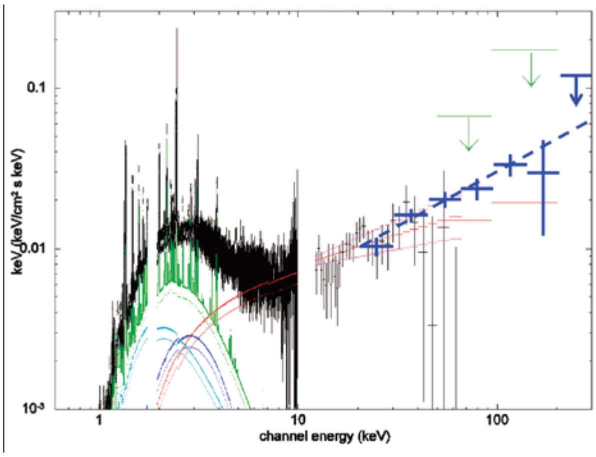

Fig. 2. νF_ν plot of AXP 1E 1841-045 obtained by Suzaku observation compared with Integral spectrum (Kuiper et al. 2006). Black data crosses below and above 10 keV shows Suzaku XIS and PIN data, respectively. The red histogram shows power-law component of the AXP. The Magenta histogram shows the systematic uncertainty range caused by the 3% uncertainty of the non X-ray background of PIN. Green upper limit shows GSO upper limit. Blue crosses shows Integral spectrum extracted from Kuiper et al. (2006).

to understand the internal structure of magnetars. Transient sources like XTE J1810-197 can be monitored very frequently. Pulse profile change and pulse period change (glitch) could be monitored, when the source was bright. Fortunately, XTE J1810-197 was bright for a few hundred days.

3.3. transient AXPs

A transient AXP XTE 1810-197 is a good example to simulate how MAXI will detect the flares of magnetars and monitor them. This object was serendipitously discovered within the field of view of the RXTE/PCA, when RXTE performed a pointing observation for nearby SGR 1806-20 (Ibrahim et al. 2004). In addition, this object could not be found by RXTE/ASM, then there are about 100 day blank of observation around the initial flare-up duration, as shown in Gotthelf & Halpern (2006). MAXI would detect this source only in 0.4 days in 5 sigma level, and pulsation can be detected in 3 days exposures. Therefore, MAXI would broadcast the appearance of this type of objects so quickly. MAXI can also monitor the declining light curve so frequently.

3.4. Monitoring in near-infrared band

Near-infrared (NIR) counterparts are found for about a half of magnetars (Woods & Thompson 2006). The emission mechanism is open question. Mainly two models are proposed: magnetospheric origin (Kern & Martin 2002, Eichler, Gedalin & Lyubarsky 2002, Lu & Zhang 2004) or dust disk around a magnetar (Wang, Chakrabarty & Kaplan 2006). If dust disk model is correct, the strong flux correlation between X-ray and NIR bands are expected as shown in figure 2 of Ertan, Göğüş & Alpar (2006). In this figure, light curves of 1E 2259+586

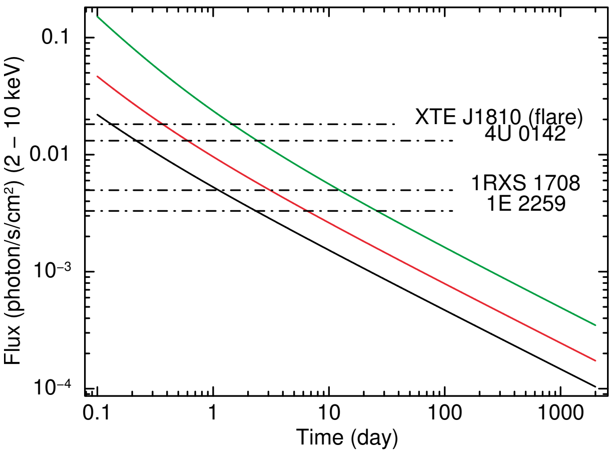

Fig. 3. Detectability for the four bright magnetars. The horizontal and vertical axes show exposure time (day) and flux (photon/s/cm^2) in 2 – 10 keV. The black, red and green curves show detection lines with 3, 5, and 10 sigma level.

in X-ray and near-infrared bands are shown, when 1E 2259+586 showed activities (spiky bursts, flare-up of the persistent emission) and the decay of the persistent flux in a time scale of a week. According to the disk model developed by Ertan, Göğüş & Alpar (2006), strong correlation was expected. Then, if this source flare again in MAXI era, we will be able to follow the X-ray light curve of 1E 2259+586 and also detect the flare and trigger ToO observations of infrared band. By this type of follow-up observation, mystery of the infrared emission mechanism of magnetars will be solved. Other type of observation like regular monitoring of the NIR flux can also be used to take a correlation between X-ray obtained by MAXI.

4. Summary

Scientific goals for magnetar observation by MAXI are as follows:

(1) MAXI will detect flares of known magnetars with time scales of day to month. MAXI will also discover new transient magnetars like XTE J1810-197, CXOU J164710.2-455216, and SGR 0501+4516.

(2) MAXI will monitor the pulse profile and pulse period change. Glitch detection is important to study for the internal structure of magnetars.

(3) MAXI will broadcast the appearance of magnetar activities, and trigger quick follow-up observations in multi-wavelength.

(4) Infrared emission mechanism of magnetars are controversial: Magnetospheric or dust disk around magnetars. Dust disk model predict strong flux correlation between X-ray and NIR. Then, MAXI and NIR collaboration is important. The NIR follow-up observation after magnetar-flare is decisive for the infrared emission mechanism.

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Table 1. Parameters for the GSC simulator to simulate for bright magnetars.

Objects	absorbed flux erg/s/cm^2 (2 - 10 keV)	N_H cm^{-2}	photon index	temperature keV
4U 0142+61	6.4×10^{-11}	0.93×10^{22}	3.4	0.47
1E 2259+586	1.5×10^{-11}	0.97×10^{22}	3.6	0.41
1RXS J170849.0-400910	2.8×10^{-11}	1.5×10^{22}	2.4	0.43
XTE J1810-197 (flare peak)	9×10^{-11}	0.65×10^{22}	–	0.25 / 0.68

Table 2. Detectability of bright magnetars

Objects	absorbed flux erg/s/cm^2 (2 - 10 keV)	source detection 5 sigma level	pulse fraction (%)	pulse detection 3 sigma level
4U 0142+61	6.4×10^{-11}	0.6 day	4 %	1 year
1E 2259+586	1.5×10^{-11}	7 day	23 %	$>$ 1 year
1RXS J170849.0-400910	2.8×10^{-11}	3 day	21 %	40 day
XTE J1810-197 (flare peak)	9×10^{-11}	0.4 day	43 %	3 day