# Discovery of MeV emission from Magnetar, AXP 1E1547.0−5408, with *Suzaku* Wide-band All-sky Monitor


T. Yasuda[1], W. Iwakiri[1], Y. Terada[1], M. S. Tashiro[1], T. Enoto[2], A. Bamba[3,4], S. Shibata[5], Y. E. Nakagawa[6], K. Makishima[7] and The Suzaku-WAM team

[1] Saitama University, 255 Shimo-Okubo, Sakawa, Saitama, 338-8570, Japan
[2] KIPAC, Stanford University, Stanford, CA 94305, USA
[3] School of Cosmic Physics, Dublin Institute for Advanced Studies 31 Fitzwilliam Place, Dublin 2, Republic of Ireland
[4] ISAS/JAXA, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210, Japan
[5] Department of Physics, Yamagata University, Kojirakawa, Yamagata, 990-8560, Japan
[6] RIKEN, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan
[7] University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo, 113-0033, Japan
*E-mail(TY): yasuda@crystal.heal.phy.saitama-u.ac.jp*



Abstract

Magnetars are considered to be neutron stars with strong magnetic fields of $10^{13}$-$10^{15}$ Gauss. Although many high energy observations are performed on magnetars, their radiation process is still a mystery. Here, we report an observational hint of the detection of a MeV emission from a magnetar, AXP 1E1547.0−5408, with the Wide-band All-sky Monitor (WAM) onboard *Suzaku* satellite, which has a large effective area of around 400 $\mathrm{cm}^2$ at 1 MeV photon. The detection of the MeV photons from magnetar's short bursts are quite rare and have an important implication of its emission process, sincce the high energy photons have not yet been observed above the MeV range from their persistent emission. In 2009 January 22, the object became active and the WAM detected $\sim$ 250 bursts in a day and successfully detected the X-ray emissions up to 1 MeV range from one of these bursts. This possible detection is the first evidence of MeV emission from magnetar bursts. The X-ray spectra obtained with the WAM were well reproduced by a power law model with a photon index of $\sim$ 2.7 plus a soft black body component. The data did not require any cut-off or a break in the 200 keV to 1.1 MeV range.



Key words: stars: magnetars - X-rays: individual(AXP 1E1547.0−5408) - X-rays: bursts


## 1. Introduction

The magnetars are considered to be isolated neutron stars with strong magnetic fields of $10^{13}$-$10^{15}$ Gauss. They are observed as "Anomalous X-ray Pulsars (AXPs)" or "Soft Gamma-ray Repeaters (SGRs)". They have relatively slow spin periods of 2-12 s among pulsars, but with high spin down rates $\sim 10^{-13}$ - $10^{-11}$ s $\mathrm{s}^{-1}$.

One of the prominent features of several objects are the repeated short bursts in the soft gamma-ray band, whose brightness exceeds the eddington luminosity up to $\sim 10^{42}$ erg $\mathrm{s}^{-1}$. Such a burst emission is thought to be powered by magnetic energy. However, the detail of radiation process still have not been well understood, although the data were obtained by many observatories so far.

Another feature is the persistent-hard non-thermal X-ray component up to $\sim$ 100 keV have been discovered (Kuiper et al. 2004, 2006; Götz et al. 2006; den Hartog et al 2008; Rea et al 2009; Enoto et al. 2010a). Since there are no detection from magnetar in GeV band with *Fermi*-LAT (Abdo et al. 2010) nor in MeV band with *COMPTEL* (den Hartog et al. 2006; Kuiper et al. 2006), the hard X-ray components should have a cut-off feature in MeV band. However, there is no report of successful firm detection around $\sim$ MeV energy range. This feature is common both in persistent emission and short bursts (Abdo et al. 2010). The *Suzaku* satellite has been also performed a systematic study of the broadband spectroscopy of magnetars (Enoto et al 2010b).

1E 1547.0−5408 was suggested as a magnetar candidate, which is associated with a young supernova remnant (Galfand & Gaensler. 2007). The discovery in radio observation of a spin period ($\sim$ 2.07 s) and a spin down rate ($\sim 2.3 \times 10^{-11}$ s $\mathrm{s}^{-1}$) derived an estimate of dipole surface field at $\sim 2.2 \times 10^{14}$ Gauss. In 2009 January 22, the object became active and showed a large number of short bursts, which are detected by several satellites, *Swift* (Gronwall et al, 2009) , *Fermi* (von Kienlin

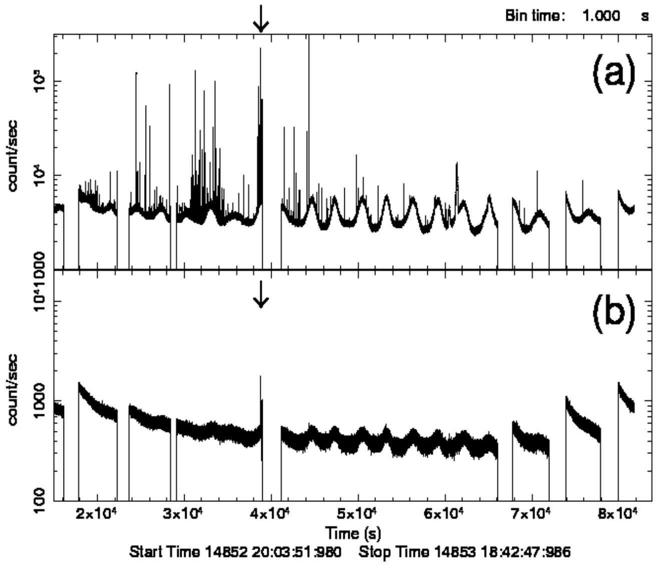


Fig. 1. The one day light curves in 2009 Jan 22, both of which are obtained by *Suzaku*-WAM. The energy ranges are (a) 29-587 keV and (b) 587-887 keV. The data gaps are due to passages through the south atlantic anomaly, and the data fluctuation in a long time scale are due to a variation of flux densuty of charged particles which depends on geomagnetic cut-off-rigidity.

& Connaughton, 2009), *INTEGRAL* (Savchenko et al, 2009), *Wind* (Golenetskii et al, 2009), *RHESSI* (Bellm et al, 2009), and also *Suzaku* (Terada et al, 2009). Here, we present results from *Suzaku*-WAM data.

## 2. Observation

The *Suzaku* Wide-band All-sky Monitor (WAM) is designed to monitor high energy transient activities such as gamma-ray bursts, solar flares and short bursts from magnetar (Yamaoka et al. 2009). It has a capability to monitor whole the sky in the 2 $\pi$ steradian, with a wide energy range of 50 keV - 5 MeV and a large effective area reaching $\sim$ 400 cm$^2$ at 1 MeV photon. This effective area is the largest among current gamma-ray detectors in the energy range 300 keV - 5 MeV. Thanks to these features, in 2009 January 22, the WAM successfully detected about 250 short bursts from the direction of AXP 1E1547.0−54008 in a day (Terada et al., 2009). The obtained light curves are shown in Figure 1. The time binning is 1 s.

## 3. Analysis and Result

We have detected 124 bursts during 2009 January 22 01:09:59-17:02:56 UT with 28 $\sigma$ detection in the 72-115 keV. We first checked the hardness ratio between the 115-286 keV count rate to the 72-115 keV count rate. Figure 2 shows the derived hardness-count rate diagram of the bursts. Then we checked the light curve in the 587 - 887 keV energy band (Figure 1), in order to find the

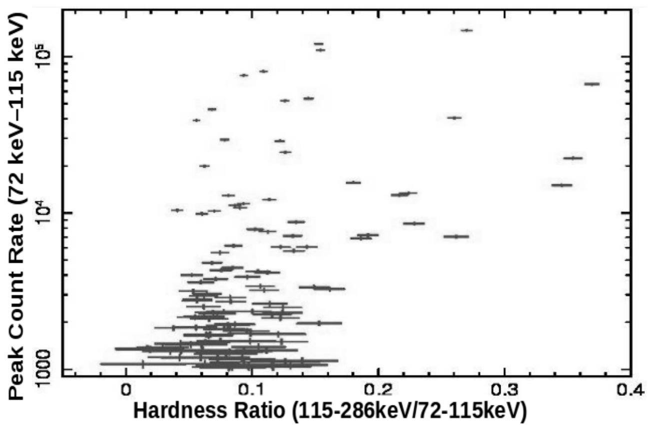


Fig. 2. The peak count rate in 72-115 keV energy band against the hardness ratio between the 115-286 keV count rate to the 72-115 keV count rate

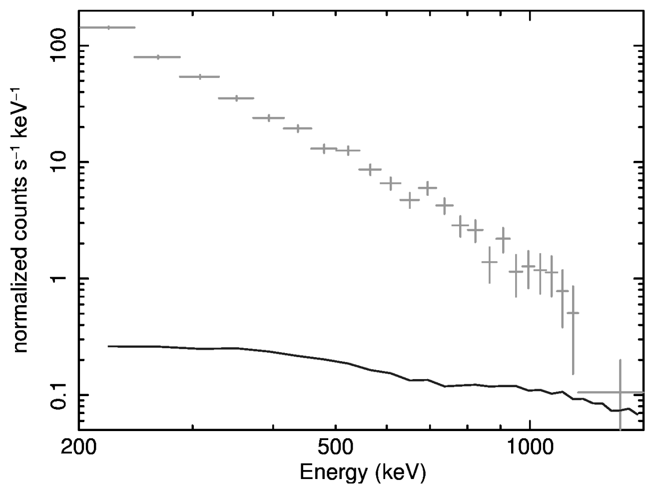


Fig. 3. The spectrum of the hardest emission burst. Cross points and line shows observed spectrum and 8 % of the background uncertainty, respectively.

hardest short burst. As a result, we selected this short burst occurs at 06:45:13, which is the highest hardness ratio and the brightest in 587 - 887 keV band. Hereafter we analyzed the spectrum of this short burst, to confirm whether the spectrum has cut-off or not.

We estimated the background uncertainty as following, which is the largest systematic error. We estimated the background by using Cut-Off Rigidity method to subtract the non X-ray background (Endo et al. 2010). The reproducibility of this method is reported to be typically $\sim$ 7 - 8 %. Figure 3 shows the spectrum of the hardest short burst after the background subtraction. The 8 % of the background uncertainty is also plotted in the figure 2. The count rate around 1 MeV is significant at 3.2 $\sigma$ confidence level above the background uncertainty.

We then performed the spectral fittings with a blackbody plus a power law model, with two different param-

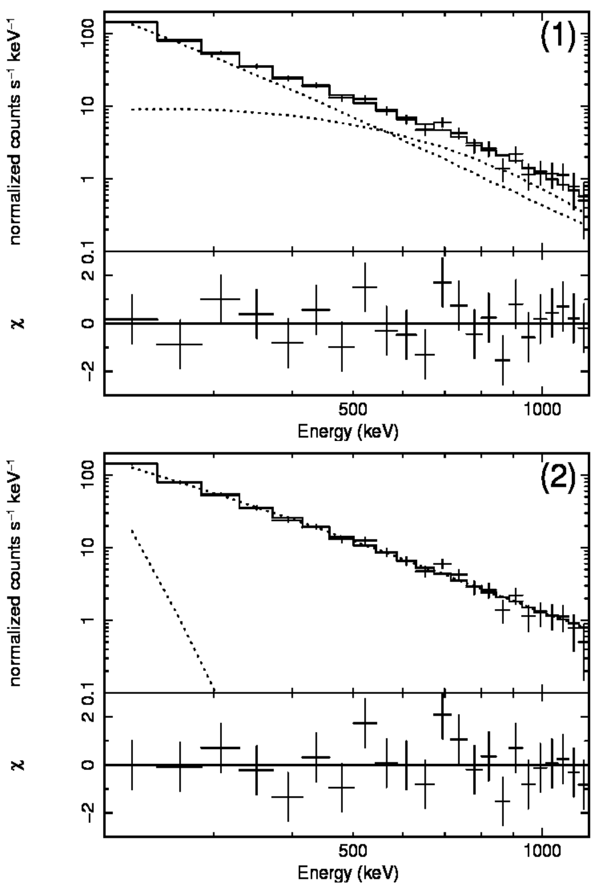


Fig. 4. The spectra of the hardest emission burst modeled by a power law plus a black body. (1) high temparature model, (2) low tempersature model.

eter sets, (1) high temperature or (2) low temperature (Figure 4). Each result is (1) blackbody temperature kT = 163.6 $^{+27.4}_{-19.9}$ keV, photon index $\Gamma$ = 3.6 $^{+0.2}_{-0.2}$, the estimate flux is 1.7.$^{+0.0}_{-1.5}$ $\times$ $10^{-5}$ ergs s$^{-1}$ cm$^{-2}$ in 200 keV - 1.2 MeV (blackbody flux is 5.8 $\times$ $10^{-6}$ ergs s$^{-1}$ cm$^{-2}$) (Figure 5) and (2) blackbody temperature kT = 9.7 $^{+21.6}_{-6.8}$ keV, photon index $\Gamma$ = 2.7 $^{+0.1}_{-0.2}$, the estimate flux is 1.7$^{+0.0}_{-0.7}$ $\times$ $10^{-5}$ ergs s$^{-1}$ cm$^{-2}$ in 200 keV - 1.2 MeV. In either case, high blackbody temperature and no break of power law in 200 keV to 1.2 MeV range, are required.

## 4. Discussion and Conclusion

We observed $\sim$ 250 short bursts from 1E 1547.0$-$5408 on 2009 Janurary 22 (UT)with *Suzaku*-WAM. We examined the hardest burst among them and succeeded in detecting high energy photons up to $\sim$ 1 MeV with 3.2 $\sigma$ confidence level. The derived spectrum requires a high temperature blackbody with a power-law component in the 200 keV to 1.2 MeV range, under the current calibration status. In case of the "high tempreture model",

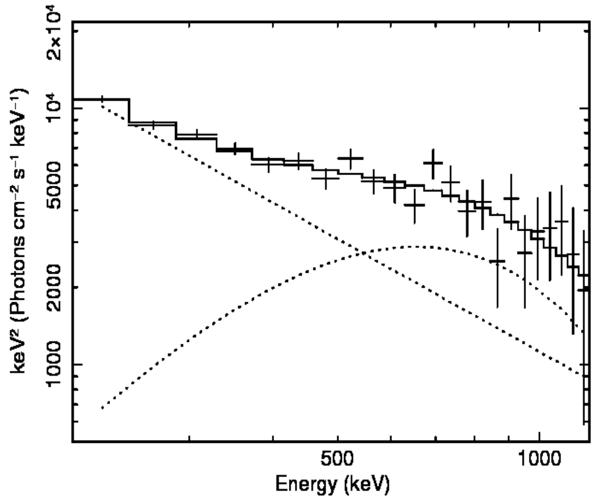


Fig. 5. The $\nu F_\nu$ spectrum of the high temparature model.

the radiation area ($S$) is estimated as,

$$S = \frac{L}{4\sigma T^4} = 590 \left(\frac{D}{5\mathrm{kpc}}\right)^2 \mathrm{m}^2,$$

where $L$, $T$ and $D$ denote the luminosity, blackbody temprature in keV and the distance of the source (Tiengo et al. 2009), respectively. This is the smallest "hot spot" or magnetically confined plasma near the neutron star surfce ever measured for a magnetor.

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