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Discovery of a New X-Ray Transient Source in the Scutum Region with Suzaku

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Abstract

During an observation of the Galactic plane in the Scutum region with the Suzaku satellite, we discovered a new X-ray transient source, designated Suzaku J1844−0404. Compared with previous Chandra observations of the same field, four Chandra X-ray sources exist within the current positional uncertainty of Suzaku J1844−0404. A firm identification is not possible. From the beginning of the observation, the X-ray intensity was significant at $\sim 5 \times 10^{-14}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ (2–10 keV), which may be a possible precursor. Later, the source exhibited a flare with a peak flux of $\sim 10^{-12}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ (2–10 keV). A strong and narrow emission line at ~ 6.66 keV was observed during the flare, most likely the He-like Fe line. The spectrum in 1–10 keV is consistent with a heavily absorbed ($N_{\mathrm{H}} \sim 3 \times 10^{22}\,\mathrm{H\,cm^{-2}}$) thin thermal emission with kT as high as ~ 7 keV. A single short flare, as observed, is rather unlikely for a cataclysmic variable. The source is probably an active binary star or a young stellar object.

Key words: stars: flare — stars: individual (Suzaku J1844−0404) — X-rays: spectra — X-rays: stars — X-rays: transients

1. Introduction

We conducted a long observation on the Galactic plane in the Scutum region with the Suzaku satellite (Mitsuda et al. 2006). This region had been observed previously with ASCA and Chandra, in which no bright point source was known to exist. The main purpose of the present observation was to investigate the long-standing issue of the origin of the unresolved Galactic ridge X-ray emission (GRXE) (e.g., Worrall et al. 1982; Warwick et al. 1985; Koyama et al. 1986; Yamauchi et al. 1996; Kaneda et al. 1997; Ebisawa et al. 2001, 2005; Tanaka 2002; Revnivtsev et al. 2006) with better spectral resolution, a wider energy band, and lower background of Suzaku than the previous observations.

In the course of the present Suzaku observation, we detected a transient flare of a new source. During the flare, the source showed a strong emission line at ~ 6.7 keV, most probably the He-like iron line, such as seen in the GRXE spectrum. Also, the continuum is similarly hard to that of the GRXE.

Since these features might have relevance to the GRXE problem, we report here the results of an analysis of this transient source. The results concerning the GRXE observation will be presented separately.

2. Observation and Data Reduction

A Suzaku observation of the Scutum region on the Galactic plane was carried out on 2005 October 28–30 for 100 ks. Suzaku has 4 X-ray CCD camera systems (XIS: Koyama et al. 2007) placed at the focal planes of four thin foil X-Ray Telescope (XRT: Serlemitsos et al. 2007) modules and the co-aligned non-imaging Hard X-ray Detector (HXD: Takahashi et al. 2007; Kokubun et al. 2007). The day-averaged background level of the HXD-PIN detector was

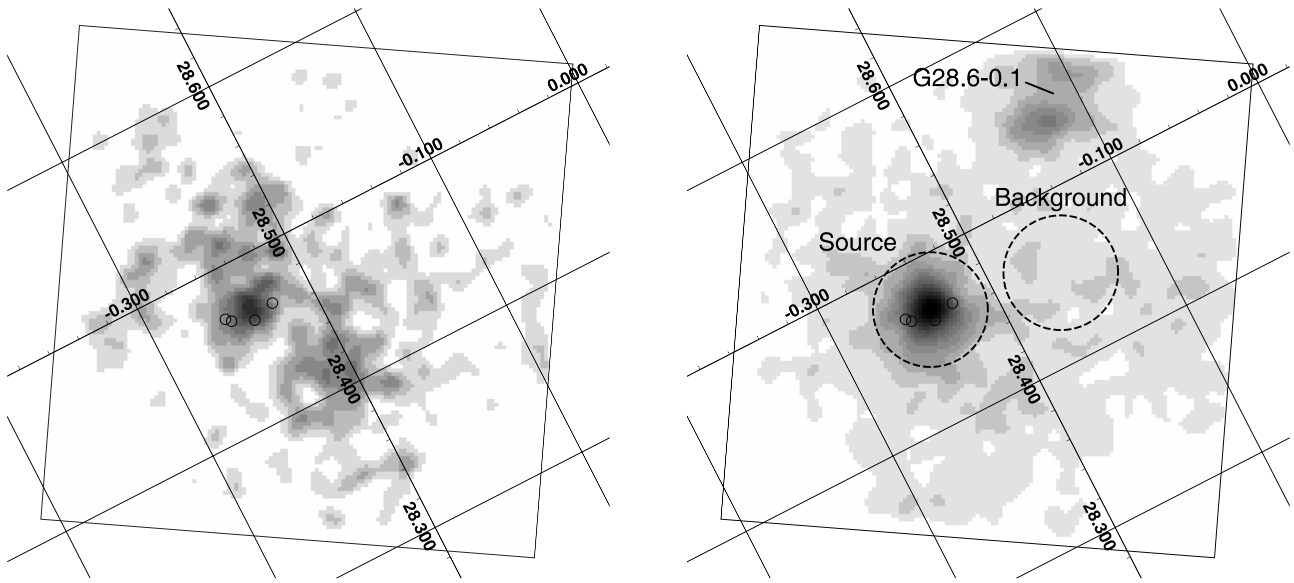

Fig. 1. X-ray images in the 0.7–2.0 (left) and 2.0–10.0 keV (right) energy bands obtained with the Suzaku XIS taken during the source flare. Data obtained with 4 XIS detectors were combined. The images were smoothed with a Gaussian distribution of $\sigma = 0\overset{\prime}{.}28$. The scales are logarithmic and the coordinates are Galactic. The square shows the XIS FOV and the small circles show the positions of Chandra sources listed in table 1. The dashed circles in the right panel show the source and the background regions for the timing and spectral analysis.

about 10 mCrab (Kokubun et al. 2007), and the current reproducibility of the in-orbit background was $\sim 3\%$ in the best case. Since the flux of the transient source was ~ 0.05 mCrab at its flare peak (see section 3), it is difficult to analyze such a faint source with the current accuracy of the non X-ray background estimation. Therefore, we concentrate on the XIS data analysis in this paper.

XIS sensor-1 (XIS 1) has a back-illuminated (BI) CCD, while the other three XIS sensors (XIS 0, 2, and 3) have front-illuminated (FI) CCDs. The XIS was operated in the normal clocking mode. The field center was $(l, b) = (28\overset{\circ}{.}46, -0\overset{\circ}{.}20)$. This region had already been observed with ASCA (Yamauchi et al. 1996; Kaneda et al. 1997) and Chandra (Ebisawa et al. 2001, 2005), and no persistent X-ray sources brighter than $\sim 10^{-12}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ have been found in the field. The XIS field of view (FOV) is $18' \times 18'$, which is comparable to that of the Chandra ACIS, and hence Suzaku observed almost the same region as Chandra.

The data reduction and analysis were made using the HEADAS software version 6.0.6. The XIS pulse-height data for each X-ray event were converted to Pulse Invariant (PI) channels using the xispi software version 2006-12-26 and the calibration database version 2006-05-22. We excluded the data obtained at the South Atlantic Anomaly, during Earth occultation, and at low elevation angles from Earth rim of $< 5^\circ$ (night Earth) and $< 20^\circ$ (day Earth). We also removed hot and flickering pixels. The resultant exposure time was 92 ks.

We checked the energy scale of the XIS using the calibration source (^{55}Fe) line, and confirmed that the Kα and Kβ line energies were in agreement with the expected values within the current calibration accuracy ($\sim 0.2\%$: Koyama et al. 2007).

3. Results

Figure 1 shows X-ray images obtained in the 0.7–2.0 and 2.0–10.0 keV energy bands taken during the source flare. In the hard X-ray band, one diffuse and another point-like X-ray sources are clearly seen, whereas they are very weak in the soft X-ray band, which shows that these are hard X-ray sources. The extended source in the north is a supernova remnant candidate G28.6$-$0.1 (Bamba et al. 2001; Ueno et al. 2003). The other near to the center of the FOV is the new transient source [the signal-to-noise ratio (S/N) = 29 in the 1–10 keV]. We compared the XIS profile of this transient source with that of a point source 3A 1742$-$294, and found that its profile is consistent with a point source. The peak position was determined to be $(\mathrm{RA, Dec})_{\mathrm{J2000}} = (18^{\mathrm{h}}44^{\mathrm{m}}08\overset{\mathrm{s}}{.}3, -4^\circ04'50'')$, where the positional accuracy is about $1'$ at present (Serlemitsos et al. 2007). This source is designated as Suzaku J1844$-$0404. We note that Suzaku J1844$-$0404 was also detected at the S/N = 5 level before the flare.

We first searched the SIMBAD database, but found no corresponding source. Using source catalogs of the Two Micron All Sky Survey and ESO/NTT near-infrared (NIR) observation by Ebisawa et al. (2005), we found many (> 100) sources within the positional uncertainty of Suzaku J1844$-$0404. Comparing the source position with those obtained with Chandra by Ebisawa et al. (2005), we found four X-ray sources within $1'$ radius of Suzaku J1844$-$0404: CXOGPE J18440505$-$0404369, CXOGPE J18440760$-$0405141, CXOGPE J18441098$-$0405168, and CXOGPE J18441189$-$0405126, as listed in table 1. The new transient source could be one of the Chandra sources, but no firm identification is possible.

For constructing the light curve of Suzaku J1844$-$0404, the source counts were extracted from a circle of a $2'$ radius,

Table 1. Chandra sources within 1′ from Suzaku J1844−0404.

Source name CXOGPE	$\Delta\theta^*$ (arcmin)	$HR^\dagger$	Flux‡ (erg s^{-1} cm^{-2})	NIR§
18440505−0404369	0.84	0.03 ± 0.13	2.0×10^{-14}	Yes
18440760−0405141	0.44	0.74 ± 0.17	8.4×10^{-15}	No
18441098−0405168	0.80	0.31 ± 0.19	7.1×10^{-15}	Yes
18441189−0405126	0.97	0.60 ± 0.14	1.7×10^{-14}	No

* Separation angle from Suzaku J1844−0404.
† Hardness ratio defined as $HR \equiv (H - S)/(H + S)$, where H and S are the count rates in the 3–8 keV and the 0.5–3 keV, respectively (Ebisawa et al. 2005).
‡ Observed flux in the 2–10 keV (Ebisawa et al. 2005).
§ Presence of near-infrared (NIR) counterparts (Ebisawa et al. 2005).

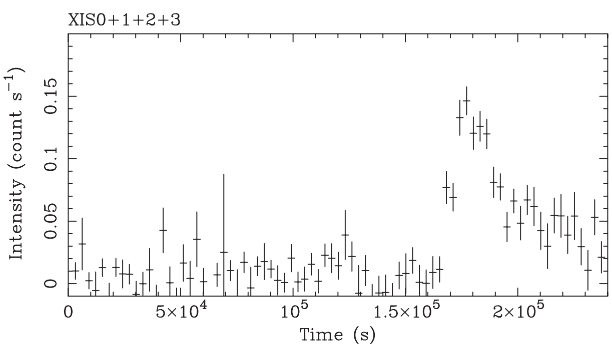

Fig. 2. Background-subtracted light curve of a transient source in the 1–10 keV energy band. Data obtained from 4 XIS detectors were added. Each bin width is 3000 s. Time is referenced to 3:00 UT on 2005 October 28.

while the background counts were extracted from the blank region in the same FOV with the same region size (see figure 1 right). To increase photon statistics, data obtained with the 4 XIS detectors were combined. We confirmed that the background level did not change during the observation. The background rate in each time bin of 6000 s ($\approx$ an orbital period of Suzaku) was found to be constant within the statistical errors (the reduced χ^2 value = 0.73 for the degrees of freedom of 39).

Figure 2 shows the background-subtracted X-ray light curve obtained in the 1–10 keV energy band. At the beginning of the observation, the source was very faint. However, a significant flux (possible precursor) was noticeable.

On 2005 October 30, it turned into an active phase. The flare started between 1^h and 2^h (UT), and the flux reached a peak at around 4^h (UT). After the peak, the intensity decayed with a time constant of roughly 2×10^4 s. The active phase lasted until the end of the observation.

In order to search for coherent pulsation, we carried out a Fourier analysis using the data during the flare. However, no coherent pulsation was found over the range from 16 s to 4096 s.

Figure 3 shows the time-averaged spectra of Suzaku J1844−0404 during the flare. The source and the background spectra were extracted from the same regions as used for the light curve. For maximizing the photon statistics, the data obtained with the three FI detectors (XIS 0, 2, and 3) were combined. The source counts in the 1–10 keV energy band were 2540 and 1160 for XIS 0+2+3 and XIS 1, respectively. The background counts in the same energy band and the same exposure time were 1077 and 553 for XIS 0+2+3 and XIS 1, respectively.

An emission line is clearly seen at an energy of

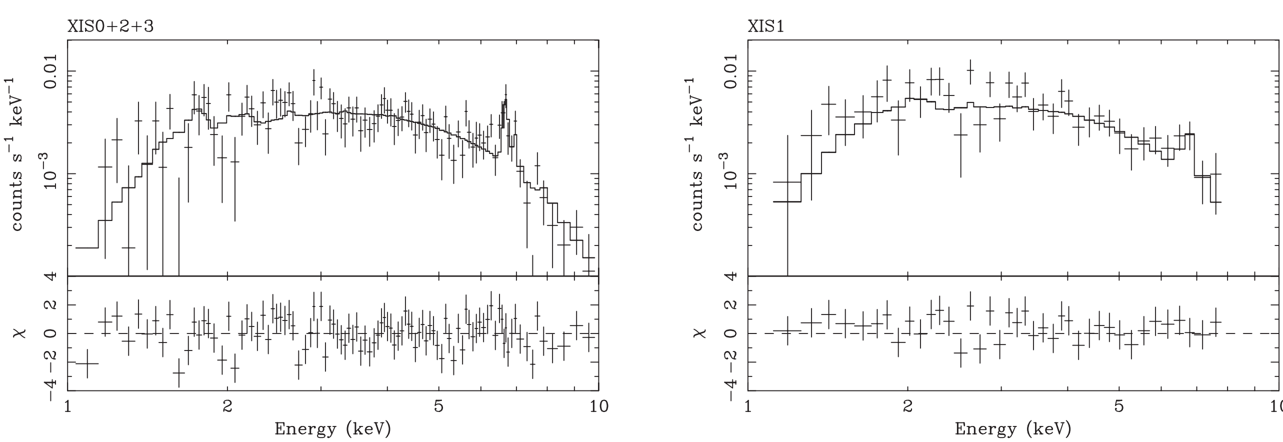

Fig. 3. Background-subtracted spectra of a transient source in the flare-phase obtained with XIS 0+2+3 (left) and XIS 1 (right). The histograms show the best-fit MEKAL model (see text and table 2).

Table 2. Results of a spectral analysis for the time-averaged spectra during the flare.*

Parameter	Values
Model: (power-law + emission line) $\times$ absorption	
$N_{\rm H}$ ($\times 10^{22}$ H cm^{-2})	$3.7^{+0.8}_{-0.7}$
Photon index	2.0 ± 0.3
Line energy (keV)	$6.66^{+0.03}_{-0.05}$
Line width (keV)	0 (fixed)
Equivalent width (eV)	470 ± 160
χ^2(d.o.f.)	153 (133)
Observed flux† ($\times 10^{-13}$ erg s^{-1} cm^{-2})	6.8
$N_{\rm H}$-corrected flux† ($\times 10^{-13}$ erg s^{-1} cm^{-2})	9.1
Model: (thermal bremsstrahlung + emission line) $\times$ absorption	
$N_{\rm H}$ ($\times 10^{22}$ H cm^{-2})	$3.1^{+0.6}_{-0.5}$
Temperature (keV)	$8.1^{+4.7}_{-2.4}$
Line energy (keV)	$6.66^{+0.03}_{-0.05}$
Line width (keV)	0 (fixed)
Equivalent width (eV)	470 ± 160
χ^2(d.o.f.)	153 (133)
Observed flux† ($\times 10^{-13}$ erg s^{-1} cm^{-2})	6.7
$N_{\rm H}$-corrected flux† ($\times 10^{-13}$ erg s^{-1} cm^{-2})	8.4
Model: MEKAL $\times$ absorption	
$N_{\rm H}$ ($\times 10^{22}$ H cm^{-2})	$3.1^{+0.6}_{-0.4}$
Temperature (keV)	$7.0^{+2.0}_{-1.6}$
Metal abundance‡ (solar)	$0.64^{+0.30}_{-0.22}$
χ^2(d.o.f.)	145 (134)
Observed flux† ($\times 10^{-13}$ erg s^{-1} cm^{-2})	6.7
$N_{\rm H}$-corrected flux† ($\times 10^{-13}$ erg s^{-1} cm^{-2})	8.6

* Errors indicate the single-parameter 90% confidence level.
† Energy flux in the 2–10 keV energy band.
‡ Relative to the solar value of Anders and Grevesse (1989).

6–7 keV in the spectrum. We made simultaneous fits of the FIs (XIS 0+2+3) and BI (XIS 1) spectra employing two models: a power-law + emission line model and a thermal bremsstrahlung + emission line model. The cross sections of photoelectric absorption were taken from Morrison and McCammon (1983). The center energy of the emission line was well determined to be $6.66^{+0.03}_{-0.05}$ keV, which is attributable to the Kα-line from He-like iron. Therefore, the X-ray emission is thought to be thermal emission from a high-temperature plasma. Next, we applied a thin thermal emission model (MEKAL model in XSPEC: Mewe et al. 1995). The abundance tables were taken from Anders and Grevesse (1989). The observed X-ray spectra were found to be well represented by the MEKAL model with a temperature of ~ 7 keV. The metallicity was determined to be ~ 0.6 solar, mainly from the equivalent width of the iron K-line. The absorption column $N_{\rm H}$ is $\sim 3 \times 10^{22}$ H cm^{-2}. The mean observed and the $N_{\rm H}$-corrected fluxes were estimated to be 6.7×10^{-13} erg s^{-1} cm^{-2} and 8.6×10^{-13} erg s^{-1} cm^{-2} in the 2–10 keV band, respectively. The best-fit parameters are listed in table 2, while the best-fit MEKAL model is plotted in figure 3. We also fitted the spectra to another thin thermal emission model (APEC model in XSPEC), and found that the results are essentially the same.

In order to examine the spectral variation, we made X-ray spectra for four consecutive time intervals: (1) the faint pre-flare phase, (2) the flare peak, (3) the first part of the decay phase, and (4) the later part of the decay phase. We determined for each phase the X-ray flux, temperature, and metal abundance employing the MEKAL model. Here, we used the FIs data only, since the FIs have better sensitivity than the BI around the iron K-line. $N_{\rm H}$ is fixed to the best-fit value ($N_{\rm H} = 3.1 \times 10^{22}$ H cm^{-2}) obtained for the spectrum of the entire flare. The results are shown in figure 4.

The temperature was low, ~ 2 keV, in the pre-flare phase. It jumped to ~ 8 keV at the flare peak, and then gradually decreased to ~ 4 keV. The observed flux in the 2–10 keV was $\sim 5 \times 10^{-14}$ erg s^{-1} cm^{-2} in the pre-flare phase, and reached

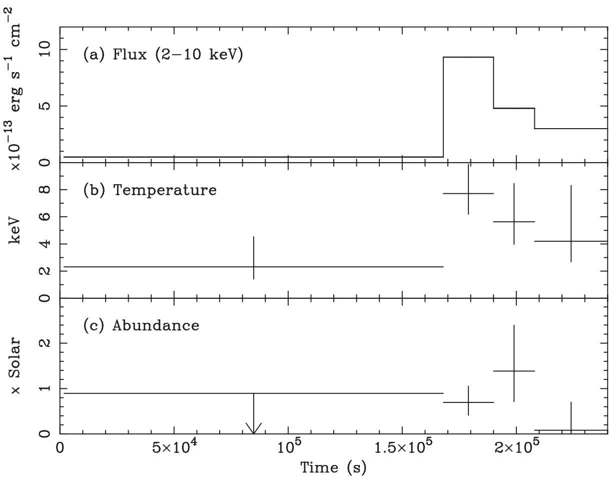

Fig. 4. Time variation of the observed X-ray flux in the 2–10 keV energy band (a), temperature of the thermal emission (b), and the metal abundance constrained primarily from a Fe-K line emission (c). Errors correspond to the 90% confidence level.

$\sim 10^{-12}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$ at the flare peak. We note that the flux level in the pre-flare phase is equivalent to the total flux of the 4 Chandra sources within the positional uncertainty (see table 1).

4. Discussion

The transient X-ray source, Suzaku J1844−0404, found in the Scutum region is most likely to be a Galactic object based on an absorption argument: the Galactic H I column density towards the observed field was measured to be $N_{\mathrm{H\,I}} \sim 2\times10^{22}\,\mathrm{cm^{-2}}$ (Dickey, Lockman 1990; Kalberla et al. 2005), while the molecular hydrogen column density was estimated to be $N_{\mathrm{H_2}} \sim 2\times10^{22}\,\mathrm{cm^{-2}}$ from the CO survey (Dame et al. 2001). The N_{H} value ($3\times10^{22}\,\mathrm{cm^{-2}}$) observed for the transient source is lower than the total hydrogen column density, $N_{\mathrm{H\,I}} + 2N_{\mathrm{H_2}} \sim 6\times10^{22}\,\mathrm{cm^{-2}}$, which makes the source to be located within the Galaxy.

While X-ray properties alone give limited constraints, we discuss below possible candidates of the transient source. The X-ray spectrum during flaring is characterized by a strong Fe XXV line at around 6.7 keV, which most likely rules out a black hole binary and a neutron star binary as a possible source, since it is not usually found in the spectra of those classes of objects, regardless the source states (e.g., Nagase 1989; Tanaka, Lewin 1995; Asai et al. 2000). The temperature of the flare spectrum, when fitted with the thermal emission model, is $kT \sim 7\,\mathrm{keV}$. Possible sources that could show such a high-temperature thermal spectrum are cataclysmic variables (CVs), flaring stars (e.g., Algol type, RS CVn type, and dM dwarfs), and young stellar objects (YSOs: T Tauri stars and embedded proto stars). A fluorescent Fe Kα emission at 6.4 keV, which is usually present in the spectra of CVs (e.g., Ezuka, Ishida 1999), was not detected. However, our current upper limit on the equivalent width (EW) for a 6.4 keV line (EW $\leq 80\,\mathrm{eV}$) is not tight enough to rule out the possibility of a CV. Although the spectral argument leaves a CV as a viable option, the observed flare profile of a single peak does not seem to be typical of those seen in CV flaring, but resembles more those of flaring stars, or YSOs. The *e*-folding time of the flare of Suzaku J1844−0404 is $\sim 2\times10^4\,\mathrm{s}$, which is well within the range of flaring stars and YSOs (e.g., Tsuru et al. 1989; Stern et al. 1992; Koyama et al. 1996; Tsuboi et al. 1998). The temperature inferred from the flare spectrum is on the higher end of the temperature distribution of flares in active stars and YSOs, but $kT \sim 7\,\mathrm{keV}$ is not exceptional, because their flares can reach up to 10 keV in temperature at the peaks (e.g., Tsuboi et al. 1998). These types of objects sometimes show an increase of metallicity during the flares (Stern et al. 1992; Tsuboi et al. 1998; Güdel et al. 1999; Favata et al. 2000), a hint of which is seen in our Suzaku data, based on the Fe line measurements (figure 4).

In an attempt to estimate the source distance, if the mean density is assumed to be $1\,\mathrm{H\,cm^{-3}}$, the observed absorbing column density, $N_{\mathrm{H}} \sim 3\times10^{22}\,\mathrm{H\,cm^{-2}}$, gives a distance of $d \sim 10\,\mathrm{kpc}$. The 2–10 keV luminosity of Suzaku J1844−0404 is then estimated to be $\sim 10^{34}(d/10\,\mathrm{kpc})\,\mathrm{erg\,s^{-1}}$, which is at least an order of magnitude higher than the luminosity of flares observed in CVs, active stars, and YSOs (10^{31}–$10^{33}\,\mathrm{erg\,s^{-1}}$). A plausible explanation could be that the source is actually located closer to us, e.g., $d < 3\,\mathrm{kpc}$, and there is either intervening dense molecular clouds or absorbing matter intrinsic to the source that would provide extra absorption to account for the observed column density. Unfortunately, no useful information to check this hypothesis, e.g., a detailed map of molecular cloud distribution or star-forming regions, is available. If the absorption was intrinsic to the source, an embedded YSO would give a natural explanation.

5. Summary

Suzaku discovered a new X-ray transient source in the Scutum region on the Galactic plane. At the beginning of the observation, it was very faint, but then turned into an active phase. The X-ray spectrum exhibited an emission line from a highly ionized iron, and was well represented by a heavily absorbed ($N_{\mathrm{H}} \sim 3\times10^{22}\,\mathrm{H\,cm^{-2}}$) thin thermal-emission model with a temperature of $\sim 7\,\mathrm{keV}$. The spectral and temporal properties indicate that the source is probably an active binary star or a young stellar object.

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