A Large X-Ray Flare from a Single Weak-Lined T Tauri Star TWA-7 Detected with MAXI GSC

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Abstract

We present a large X-ray flare from a nearby weak-lined T Tauri star TWA-7 detected with the Gas Slit Camera (GSC) on the Monitor of All-sky X-ray Image (MAXI). The GSC captured X-ray flaring from TWA-7 with a flux of $3 \times 10^{-9}$ erg cm$^{-2}$ s$^{-1}$ in 2-20 keV band during the scan transit starting at 2010-09-07 18:24:30 (UT). The estimated X-ray luminosity at the scan in the energy band is $3 \times 10^{28}$ erg s$^{-1}$, indicating that the event is among the largest X-ray flares from T Tauri stars. Since MAXI GSC monitors a target only during a scan transit of about a minute per 92 min orbital cycle, the luminosity at the flare peak might have been higher than that detected. At the scan transit, we observed a high X-ray-to-bolometric luminosity ratio, log $L_X/L_{bol} = -0.1^{+0.3}_{-0.2}$; i.e., the X-ray luminosity is comparable to the bolometric luminosity. Since TWA-7 has neither an accreting disk nor a binary companion, the observed event implies that none of those are essential to generate such big flares in T Tauri stars.

Key words: stars: flare — stars: individual (1RXS J104230.3−334014, TWA−7) — stars: late-type — stars: pre–main-sequence — X-rays: stars

1. Introduction

TWA-7 (2MASS J10423011−3340162) is a weak-lined T Tauri star first recognized with a follow-up observation of unidentified ROSAT X-ray sources (Voges et al. 1999; Webb et al. 1999; Neuhäuser et al. 2000). It is a member of the nearby association of young stars, TW Hydrae Association (TWA: Kastner et al. 1997). The distance to the source is estimated to be 27 ± 2 pc by Mamajek (2005) from the moving cluster method (e.g., Atanasijevic 1971; de Bruijne 1999). We use this value as the distance throughout this paper, although in the past literature, $d = 55 \pm 16$ pc had been usually adopted from the apparent extent of TWA and the mean Hipparcos distance derived from four members of TWA (Neuhäuser et al. 2000). TWA-7 has the spectral type of M1 and youth indicators of high lithium abundance, X-ray activity, and strong
chromospheric activity (Webb et al. 1999; Neuhäuser et al. 2000). The bolometric luminosity at 27 pc is re-calculated to be $\log L_{bol}/L_\odot \sim -1.0$ from the value obtained by Neuhäuser et al. (2000) who assumed that $d = 55$ pc. The excess emission detected with infrared (24 $\mu$m and 70 $\mu$m: Low et al. 2005) and submillimeter bands (Webb 2000; Matthews et al. 2007) indicates the presence of a debris disk without ongoing accretion. The mass of the disk is estimated to be 4.3 $M_{\text{Jupiter}}$, if the distance is 27 pc.

Owing to the close proximity, the multiplicity of TW A-7 has been well studied with imaging observations. Neuhäuser et al. (2000) argued the possibility of direct imaging detection of extra-solar planets with ground-based telescopes, and raised the evidence for a possible planetary companion to TW A-7 using HST NICMOS. Assuming the distance of 55 pc, they estimated the mass of 3 $M_{\text{Jupiter}}$ for the faint object. A further search with the HST NICMOS revealed that the faint possible companion is a background object from the inconsistency in proper motions (Lowrance et al. 2005), but the above studies indicate that any possible companion of TW A-7 must have a very low mass, possibly planetary mass.

In the ROSAT All-Sky Survey catalog (Voges et al. 1999), TW A-7 is named as 1RXS J104230.3–334014. An X-ray flux of $3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ is derived in the ROSAT band ($\sim$0.1–2 keV) by Webb et al. (1999) and Stelzer and Neuhäuser (2000). TW A-7 is also detected through the XMM-Newton Slew Survey in 2010 January at 1.9 counts s$^{-1}$ (0.2–12 keV) and 1.6 counts s$^{-1}$ (0.2–2 keV) (Saxton et al. 2008). The hardness ratio obtained by dividing the count rate in 2–12 keV by that in 0.2–2 keV band is 0.19. If we assume a thin thermal spectrum (apec model in XSPEC: Smith et al. 2001) with metal abundance of 0.3 solar and negligible absorbing column, a temperature of $kT = 2$ keV is consistent with the observed hardness ratio. This model gives the flux of $4 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ (0.2–2 keV), and $2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ (2–12 keV). The flux in the 0.2–2 keV band is almost equal to that obtained with ROSAT, and we can be confident that these fluxes correspond to the quiescent level.

We detected a large X-ray flare from TW A-7 with the Gas Slit Camera (GSC) on the Monitor of All-sky X-ray Image (MAXI) deployed on the International Space Station (ATel #2836: Morii et al. 2010). The X-ray flux is three orders of magnitude higher than that in the quiescent level, and the X-ray luminosity indicates this event is among the largest X-ray flares from T Tauri stars.

## 2. Observations and Results

The MAXI carries two scientific instruments: the Gas Slit Camera (GSC) (Mihara et al. 2011) and the Solid State Camera (SSC) (Tomida et al. 2011). Both the GSC and the SSC consist of two identical modules aimed at different directions (horizontal and zenithal directions). The instantaneous field of view for one direction is $3^\circ \times 160^\prime$ (GSC) and $1^\circ 5 \times 90^\prime$ (SSC), if all the cameras are active. It means that they can cover 98% (GSC) and 70% (SSC) of the whole sky at the maximum every orbit, if there is no down time on the detectors. The MAXI surveys the sky 16 times per day. The GSC consists of twelve one-dimensional position-sensitive proportional counters operating in the 2–30 keV range, while the SSC is composed of 32 X-ray CCD cameras covering the energy range of 0.5–12 keV. The GSC offers larger effective area (5350 cm$^2$) than that of the SSC (200 cm$^2$). See Matsuoka et al. (2009) for more details about the MAXI. On 2010 September 7, two GSC cameras, covering the direction of TW A-7, caught an intense flare, while no data were obtained for the same direction with SSC.

The transient X-ray emission was observed at the position of $(\text{RA}, \text{Dec}) = (10^\text{h}43^\text{m}27^\text{s}, -33^\circ 40\arcmin 53^\arcsec)$ (J2000) during the scan transit of 40 seconds starting at 2010-09-07 18:22:45 (UT). The error region (90% confidence level) can be estimated with a combination of the statistical error box and the calibration uncertainty on the alignment (0.2 at the 90% limit: Sugizaki et al. 2011). The statistical error box is a rectangle with the long side of $0.885$ and the short side of $0.565$. The corners are $(\text{RA}, \text{Dec}) = (10^\text{h}44^\text{m}22^\text{s}, -34^\circ 07\arcmin 49^\arcsec)$, $(10^\text{h}40^\text{m}55^\text{s}, -33^\circ 40\arcmin 54^\arcsec)$, $(10^\text{h}42^\text{m}32^\text{s}, -33^\circ 13\arcmin 44^\arcsec)$, and $(10^\text{h}45^\text{m}58^\text{s}, -33^\circ 40\arcmin 36^\arcsec)$ (J2000). Within the error region, only TW A-7 was found in the ROSAT bright source catalog (Voges et al. 1999). In order to test the significance of the transient event, we counted the numbers of events in the 2–20 keV band in 18 circles with 1.5 radius around the transient event. Here, the radius 1.5 corresponds to the HWHM (Half-Width Half Maximum) of the PSF (Point Spread Function) of MAXI GSC. We adopted the standard deviation of these 18 measurements for the 1-sigma background fluctuation. We extracted the counts in the same X-ray band in the circle with the same radius centered at the transient event, and subtracted the average of the background counts. Then we confirmed that the transient event is detected with 12-$\sigma$ level, and at the previous and the following scan transits (92 min before and after the detection), no significant X-ray emission was detected at more than 3-$\sigma$ level. We, hereafter, call each of the above transits Phase 0 (pre-flare), Phase 1 (flare), and Phase 2 (post-flare), respectively.

Figure 1 shows the background-subtracted X-ray light curve
in the 2–20 keV band. The time span for one bin is about 1 minute, which corresponds to one scan transit. The data were extracted from an ellipse with 1.8 semi-major axis and 2.5 semi-minor axis, centered on TW A-7. This region was selected to maximize the S/N ratio. The background was extracted from a circle with radius of 10° centered on TW A-7, by removing the source region. In figure 1, the error bar indicates 1-σ error of the background-subtracted events, which is derived from $\sqrt{S^2 + B^2}$ ($S$ is the counts in the source region and $B$ is background counts which is expected to enter the source region). We fitted the light curve with a burst model which shows a linear rise followed by an exponential decay. The upper limit of the rising time is derived as 1.6 hours from which shows a linear rise followed by an exponential decay.

The upper limit of the rising time is derived as 1.6 hours from which shows a linear rise followed by an exponential decay. We fitted the light curve with a burst model in the 2–20 keV band. The time span for one bin is about 1.6 hours from the time-span between Phases 0 and 1, and the e-folding time is derived to be $\leq 2.1$ hr (90% confidence range) by fitting from Phase 1 to the last bin in figure 1. These values are not inconsistent with the stellar flares reported in the literature (e.g., Stelzer & Neuhauser 2000; Imanishi et al. 2003; Pandey & Singh 2008).

Figure 2 shows the background-subtracted X-ray spectrum during the flare phase (Phase 1). The source region and the background region are the same as those used to make the light curve. We fitted the spectrum with the optically-thin thermal plasma model (apec model) in which all the metal abundances were fixed to 0.3 of solar values (Anders & Grevesse 1989), which is generally obtained in various star forming regions (e.g., Imanishi et al. 2001; Scelsi et al. 2007). Since the interstellar absorption toward TW A-7 is negligible, we fixed the absorbing column to zero. The best-fit values are summarized in table 1, while the best-fit model is shown as the solid line in figure 2. We obtained $3 \times 10^{-9}$ erg s$^{-1}$ cm$^{-2}$ for the flux in the 2–12 keV band. It is three orders of magnitude larger than the quiescent level ($\sim 2 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, see section 1). The derived emission measure and X-ray luminosity in the 2–20 keV band are $2 (1–4) \times 10^{55}$ cm$^{-3}$ and $3 (2–4) \times 10^{32}$ erg s$^{-1}$, respectively (errors are 90% confidence range).

We also investigated the previous and following X-ray activity of this source using the entire MAXI GSC data record for about 1.5 years since the operation started in 2009 August 15, but found no significant flux except for the time span that this flare occurred on 2010 September 7. The upper limit is $1 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$ in the 4–10 keV band with a detection significance ($S/N$) of 7 (Hiroi et al. 2011). The detection limit of MAXI GSC is not sensitive enough to detect the quiescent X-ray flux of TW A-7 that one expects on the basis of previous measurements with different X-ray satellites. One might suspect that the MAXI GSC band, which extends to 20 keV, can constrain the presence of a non-thermal component, but with the poor statistics, the spectrum does not provide evidence for the component.

### 3. Discussion and Conclusion

We have detected an X-ray flare from TW A-7 for the first time. The X-ray luminosity in the 2–20 keV band reached up to $3 \times 10^{32}$ erg s$^{-1}$, which is relatively large in flares from T Tauri stars. This luminosity, however, gives only the lower limit on the flare peak, because MAXI GSC can monitor a target only once (~1 min) per 92 min orbital cycle. During Phase 1, which would not be the real peak, $\log L_X/L_{bol} = -0.1_{-0.3}^{+0.2}$ is obtained; i.e., the X-ray luminosity is comparable to the bolometric luminosity of $4 \times 10^{32}$ erg s$^{-1}$ at the phase. In various star-forming regions, the log $L_X/L_{bol}$ during flares from T Tauri stars range from $-2$ to $-4$ (e.g., $\rho$ Oph: Imanishi et al. 2001; Orion Trapezium at COUP project: Wolk et al. 2005). Even during the big flare from V773 Tau (Tsuboi et al. 1998), $\log L_X/L_{bol} = -1.3$, which is still one order of magnitude smaller than that of TW A-7. Thus the most striking result obtained from the flare is the high X-ray-to-bolometric luminosity ratio.

What makes TW A-7 special? TW A-7 is known to have neither a stellar mass companion nor an accretion disk (see section 1). This implies that neither binary (e.g., Getman et al. 2011) nor accretion (e.g., Kastner et al. 2002; Argiroffi et al. 2011), nor star–disk interaction (e.g., Hayashi et al. 1996; Shu et al. 1997; Montmerle et al. 2000) is essential to cause strong flares, but stellar magnetic activity alone can
drive such energetic flare events. An X-ray flare such as the one described herein with a large X-ray-to-bolometric ratio, \( \log \frac{L_X}{L_{bol}} \sim 0 \), has not been reported before from a T Tauri star, but has been reported in other stellar categories. Pye and McHardy (1983) and Rao and Vahia (1987) observed X-ray flares from RS CVn systems and dMe stars with the Sky Survey Instrument (SSI) on Ariel V, which scanned the sky once per ~100 min with sensitivity in the 2–18 keV band. The observed \( \log \frac{L_X}{L_{bol}} \) ranges from −2.9 to −0.1. With a trigger by the all sky monitor Swift BAT, Swift XRT also observed such a flare from the dMe star EV Lac with a \( \log \frac{L_X}{L_{bol}} \) of 0.49 in the 0.3–10 keV band. Stellar flare events with \( \log \frac{L_X}{L_{bol}} \) of about 0 have only been found with all-sky surveys. This means that such giant flares are too rare to be detected with pointing observations.

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