A giant flare from a weak–lined T Tauri Star TWA–7 detected with MAXI/GSC

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Abstract

We present a gigantic X-ray flare from TWA-7 detected with the Gas Slit Camera (GSC) aboard the Monitor of All-sky X-ray Image (MAXI) on the International Space Station. The flare was observed on 2010 September 7th at the scan transit starting at UT 2010-09-07 18:24:30, and the flux decayed with an e-folding time of $\leq$2 hours. At the flux maximum, X-ray luminosity reached 1×10^{33} ergs s^{-1}, which ranks the brightest level for flares in T Tauri stars. Since MAXI/GSC can monitor a target only once ($\sim$1 min) per 92 min orbit, the real X-ray peak might be missed. In that case, the X-ray luminosity we obtained gives only the lower limit as the flare peak. Since TWA-7 has neither accreting disk nor binary companion, TWA-7 is an example to indicate that neither accretion nor binarity might be essential to originate gigantic flares.

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, TWA 7A) is a weak-lined T Tauri star identified as part of the TW Hydrae Association (TWA; Kastner et al. 1997) by Webb et al. (1999) based on the proper-motion studies in conjunction with youth indicators such as high lithium abundance, X-ray activity, and evidence of strong chromospheric activity. Based on the width of the Li 6707 line, Neuhäuser et al. (2000) deduced that TWA-7 is a pre-main-sequence star. TWA-7 was not detected by Hipparcos, but its membership in the TWA sets its distance to be 55±16 pc (Neuhäuser et al. 2000; Weinberger et al. 2004; Low et al. 2005). Its spectral type is M1 based on LRIS (Low Resolution Imaging Spectrograph) spectra (Webb et al. 1999). Based on existing photometry, evolutionary tracks, and isochrone fitting, Neuhäuser et al. (2000) derived an age of 1–6 Myr and a mass of 0.55±0.15 $M_{\odot}$, although the age of the association is generally taken to be 8–10 Myr (Stauffer et al. 1995; Zuckerman & Song 2004) assuming that planet formation is ongoing and disk dissipation is occurring.

TWA 7 has infrared (IR) excess emission which indicates the presence of a disk. The first notation was made in submillimeter observations by Webb (2000), and then successive IR detections have been reported by Low et al. (2005) and Matthews et al. (2007). Using SCUBA on the JCMT, Matthews derived the mass of the debris disk to be 18 M_{lunar} assuming a mass opacity of 1.7 cm^2 g^{-1} with a temperature of 45 K. Neuhäuser et al. (2000) detected a possible planetary companion to TWA-7 using HST NICMOS. However, they noted that the position angles and separations are slightly more consistent with a background object than with a companion. A further search with the HST NICMOS (Lowrance et al. 2005) revealed the nearby point source is identified as a background object, from the inconsistency in proper motion.

X-rays from TWA-7 was discovered with the ROSAT all-sky survey in 1996 June (RASS; Voges et al. 1999), and TWA-7 is named as 1RXS J104230.3-334014 in the ROSAT All-Sky Bright Source Catalogue. The X-ray luminosity is about 1×10^{30} ergs s^{-1} in ROSAT band in accordance with Webb et al. (1999) and Neuhäuser et al. (2000). XMM-Newton detected TWA-7 through the XMM-Newton Slew Survey in 2010 January, and derived flux of 6×10^{-12} ergs cm^{-2} s^{-1} in 0.2-12 keV band, which corresponds to 2×10^{30} ergs s^{-1} in the same band. This is not inconsistent with that derived with RASS.

From TWA-7, we detected a gigantic X-ray flare on 2010 September 7th, through the X-ray monitoring observation with MAXI/GSC. The maximum X-ray luminosity is nearly three orders of magnitude higher than the previously observed ones, and ranks the brightest level for flares in T Tauri stars.

2. Observations and Results

The MAXI carries two scientific instruments: the Gas Slit Camera (GSC) (Nakahira et al. 2009) and the Solid State Camera (SSC) (Tomida et al. 2010). The GSC consists of twelve one-dimensional position-sensitive proportional counters operated in the 2–20 keV range, while the SSC is composed of 32 X-ray CCD cameras with an energy range of 0.5–12 keV. The GSC observes two different directions (horizontal and zenithal direction) with an instantaneous field of view of 3°×160° each covered by six cameras. It covers 70 percent of the whole sky in every orbit, while ISS orbits the earth 16 times per day. Both instruments have been working properly in orbit, but at the time the gigantic flare from TWA-7 was observed (on 2010 September 7th), four out of the twelve GSC cameras were off due to discharges in the proportional counters. See Matsuoka et al. (2009) for more details of the MAXI. In this paper, we report the results with only the GSC, which offer larger effective area than those of the SSC.

The GSC detected a short transient X-ray emission at the position of (R.A., Dec) = (+160.86 deg, -33.68 deg) = (10 43 27, -33 40 53) (J2000) at the scan transit starting at UT 2010-09-07 18:22:45. Figure 1 shows the error region (90 % confidence level) which is a summation of our derived statistical error box and a systematic uncertainty of 0.2°. In the error region, only TWA-7 exists as a source in ROSAT bright source catalog, with a separation of about 0.2° from the best-fit position (see Figure 1).

The source was not detected at this location in the previous scanning (92 min before the detection) at more than a 3-σ level. Figure 2 shows the contour maps with a

Table 1. General properties of TWA–7

Parameter	Value	Ref.
Spectral Type	M2 Ve	Torres et al. 2006
Age (Myr)	8	Matthews et al. 2007
P_{rot} (days)	5.05	Lawson & Crause 2005
$v^{\dagger}$ (km s^{-1})	19.2	Yang et al. 2008
i (degree)	28	Yang et al. 2008
M ($M_{\odot}$)	0.92	Yang et al. 2008
R ($R_{\odot}$)	1.89	Yang et al. 2008
Distance (pc)	55	Low et al. 2005

† : Rotation velocity is derived from inclination angle and v sin i.

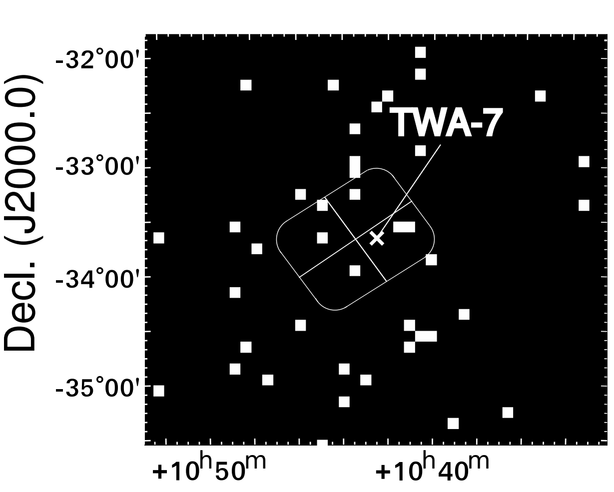

Fig. 1. This figure shows position err of a short X-ray transient at the position of (R.A., Dec)= (+160.86 deg, -33.68 deg)(J2000). A rectangular error box with the following corners:(R.A., Dec) = (+161.09deg, -34.13 deg), (+160.23deg, -33.68 deg), (+160.63deg, -33.23 deg), (+161.49deg, -33.68 deg)(J2000).
This error box indicates statistical error with 90 percent confidence level, and there is additional systematic uncertainty of 0.2°(90% containment radius). Only one X-ray source is present in the ROSAT bright catalog in this error region with a separation of about 0.2° from the best-fit position. The source is a T Tauri star TWA-7.

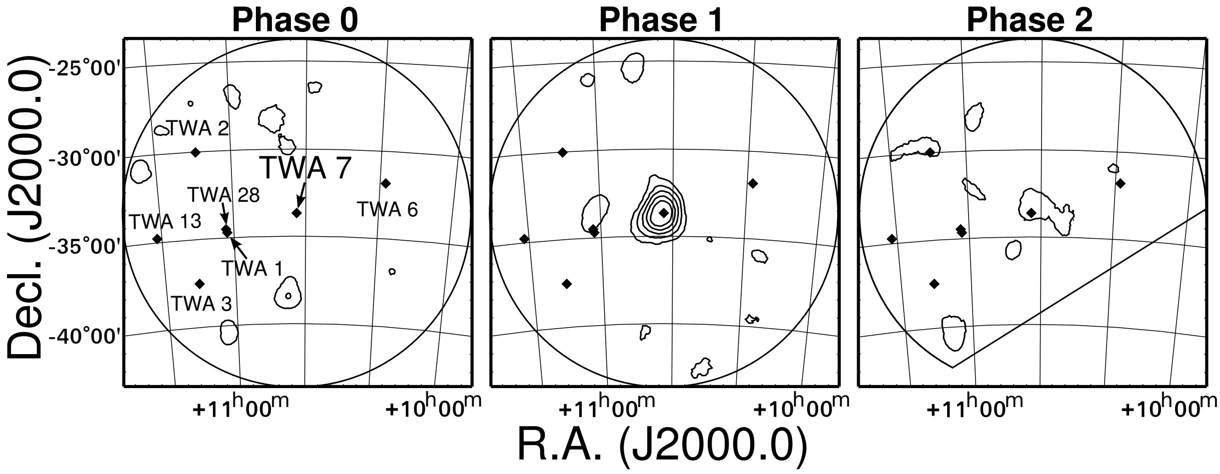

Fig. 2. Time-partitioned MAXI/GSC images around TWA-7 with a radius of 10°. The images were smoothed with a Gaussian distribution of σ=0.65°. *Left panel*, Phase0;*middle panel*, Phase1; *right panel*,Phase2. The contour levels, in unit of counts pixel^{-1}, are: 0.040, 0.055, 0.070, 0.085, 0.100, for all figures. The diamonds show the position of TWA(Webb et al. 1999;Sterzik et al. 1999;Mamajek & Feigelson 2001;Lawson & Crause 2005;Reid 2003;Song et al. 2003;Mamajek 2005). The sky coordinates are J2000.0.

radius of 10° centered on TWA-7 in the 2–20 keV band, showing pre-flare phase (Phase 0), the flare phase (Phase 1), and the flare-decay phase (Phase 2). At the scan of Phase 1, X-ray emission from TWA-7 appeared suddenly with source significance of 14 σ, and at the Phase 2, it has been already decayed to 4-σ level.

Figure 3 shows the background-subtracted X-ray light curve in 2–20 keV band. The data were extracted from an ellipse with 1.8° of semi-major axis and 2.5° of semi-minor axis, centered on TWA-7. This region was selected to maximize S/N ratio. The background region is made from a 10° radius circle centered on TWA-7, removing the source regions. We fitted the light curve with a burst model(*BURS* model in *QDP*; linear rise followed by an exponential decay). The upper limit of the linear rising time is derived as 1.6 hours from the time-span between Phase 0 and 1, and the e-folding time for decay phase (Phase 1 and 2) is obtained to be $\leq$2.1 hours (90% confidence range) by fitting. These values are not inconsistent with the stellar flares reported in the literatures.

Figure 4 shows the background-subtracted X-ray spectrum at the flare phase (Phase 1). The source region and the background region are common to those for light curve. We fitted the spectrum with an optically-thin thermal plasma model (*APEC* model in XSPEC; Smith et al. 2001) in which all the metal abundances were fixed at 0.3 of solar values, which is generally obtained in various star forming region. Since the interstellar absorption toward TWA-7 is negligible, we fixed the absorbing columns to be 0. The best-fit values are summarized in Table 2, while the best-fit model is shown as a solid line in Figure 4. The derived emission measure is extremely large, 9.6 (2.5–18) $\times 10^{55}$ cm^{-3}, and then X-ray luminosity is 1.2 (0.8–1.5) $\times 10^{33}$ ergs s^{-1} (errors are 90% confidence range). We further tried a fitting with a power-law model, and obtain the best-fit values showing in Table 3. These results indicate that this flare is one of the brightest flares in those of T Tauri stars.

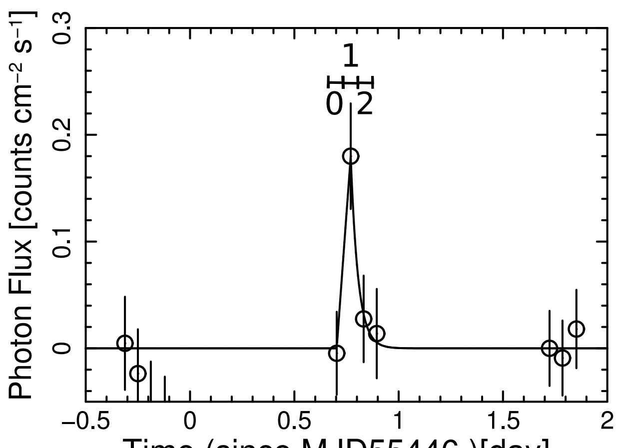

Fig. 3. MAXI/GSC light curve of TWA-7 in the 2-20 keV band. The solid line shows the best-fit model(BURS). For the analysis of the flare the observations are divided into 3 parts as indicated in the figure. Phase0:2010-9-7 (UT)16:51:01-16:56:36. Phase1:2010-9-7 (UT)18:22:45-18:28:04. Phase2:2010-9-7 (UT)19:55:32-19:59:48.

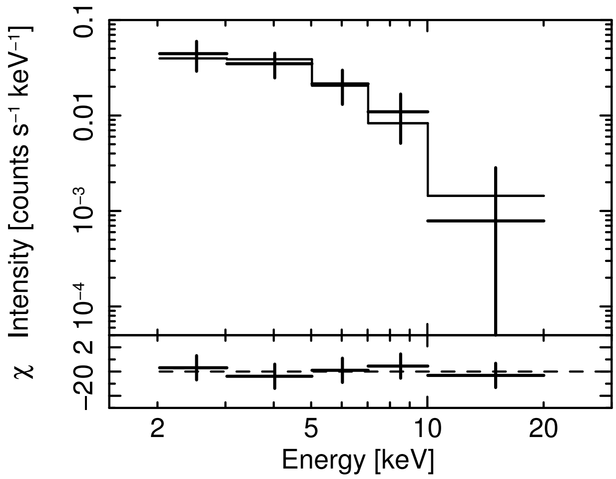

Fig. 4. MAXI/GSC spectrum of TWA-7 at Phase1. The solid line shows the best-fit model(apec). Lower panel shows the residuals from best-fit model.

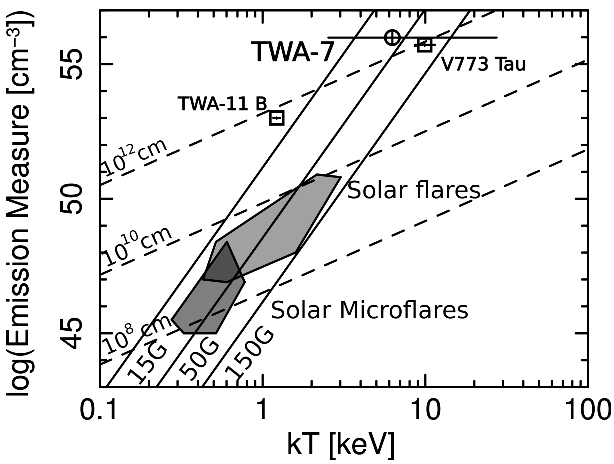

Fig. 5. log-log plot of emission measure (EM) vs. plasma temperture (kT) of X-ray flares of T Tauri stars(V773 Tau: the biggest T Tauri star flare occurred; Tsuboi et al. 1998. TWA-11 B: only observed an X-ray flare from TWA; López-Santiago et al. 2010) overlaid with solar flares (from Feldman et al. 1995), and solar microflares (from Shimizu 1995).
The EM–T relation curves based on equation [$EM \propto B^{-5}T^{17/2}$: Shibata & Yokoyama 1999] are also plotted for B = 15, 50, and 150 Gauss.

3. Discussion

The flare we detected from TWA-7 is among the brightest in those from T Tauri stars. Similar level of flare has been detected on a weak-lined T Tauri star, V773 Tau (Tsuboi et al. 1998). This source is a binary star, while TWA-7 is a single star. So, binary might be not the essential factor to originate strong flares.

TWA-7 has debris disks. We calculated several parameter of the flare (see Table 4), and we obtain the volume of the flare plasma $V \leq 4.0 \times 10^{33}$ cm^3. If the volume is in the shape of a loop similar to solar loops (i.e., aspect ratio a≡loop length/loop diameter = 0.1;van den Oord et al. 1988) and the loop cross section is constant, then the loop size is $\leq 8.0\times10^{11}$ cm ($\leq$0.053 AU). Low et al. (2005) determine that the dust orbiting TWA-7 exists at radii $\geq$7 AU from the star and has a temerature of 80K. Later, Matthews et al. (2007) determine that dust radius 100 AU and has a temperature of 21–65 K. It is impossible to connect the magnetic reconnection between the star and debris disks, because of debris disks are too far from the star.

4. Summary

We have analyzed MAXI/GSC observations of an intense X-ray flare detected in the weak line T Tauri star TWA-7. Our analysis of the GSC images, light curves, and X-ray spectra and a comparison with V773 Tau can be summarized as follows:

1. We detected an X-ray flare from TWA-7 for the first time.
2. Tha peak luminosity reached $\sim10^{33}$ ergs s^{-1}. Therefore, a gigantic flare occurs not only a binary star.
3. The loop length of the flare is $\leq$0.053 AU, debris disks are too far from the star to connect the flare loop between the star and debris disks.

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Table 2. Best fit parameters in the fitting with a thin thermal plasma model (apec).Error range refer to 90 % confidence intervals.

$N_{\rm H}$ (10^{22} cm^{-2})	kT (keV)	Z (solar abundance)	$\int n_e n_{\rm H} dV$ (10^{55} cm^{-3})	Flux† (10^{-9}ergs cm^{-2} s^{-1})	$L_{\rm X}^{\ddagger}$ (10^{33}ergs s^{-1})	χ^2_ν (d.o.f)
0 (fixed)	6.3	0.3 (fixed)	9.6	3.2	1.2	0.16 (3)
	(2.5–27)		(5.8–18)	(2.3–4.2)	(0.8–1.5)	

† : Flux in 2-20 keV band, the best-fit parameter kT is fixed and the error is obtained.
‡ : $L_{\rm X}$ in 2-20 keV, the value is obtained the best-fit parameter Flux. Distance in Table 1 is used.

Table 3. Best fit parameters in the fitting with an absorbed power law model (wabs*powerlaw).Error range refer to 90 % confidence intervals

$N_{\rm H}$ (10^{22} cm^{-2})	Γ	Flux† (10^{-9}ergs cm^{-2} s^{-1})	$L_{\rm X}^{\ddagger}$ (10^{33}ergs s^{-1})	χ^2_ν (d.o.f)
0 (fixed)	2.1	3.6	1.3	0.28 (3)
	(1.5–3.0)	(2.5–4.6)	(0.9–1.7)	

† : Flux in 2-20 keV band, the best-fit parameter Γ is fixed and the error is obtained.
‡ : $L_{\rm X}$ in 2-20 keV band, the value is obtained the best-fit parameter Flux. Distance in Table 1 is used.

Table 4. Parameters derived for flares

τ_d (ks)	τ_r (ks)	T_{max} (10^8K)	n_e (10^{11}cm^{-3})	p ($10^4 dyne$ cm^{-2})	V (10^{33}cm^3)	L (10^{11}cm)	B ($Gauss$)	$E_{\rm tot}$ (10^{37}ergs)
$\leq$7.6	$\leq$5.8	2.0	$\geq$1.2	$\geq$2.3	$\leq$4.0	$\leq$8.0	$\geq$760	$\leq$1.2
		(0.7–11)						

(1)τ_d is flare e-folding time.
(2)τ_r is flare linear riseing time.
(3)T_{max} is the temperature at the flare peak. (see equation (1))
(4)n_e is the electron density in the loop at the flare peak. (see equation (2))
(5)p is the maximum pressure in the loop at the flare peak. (see equation (3))
(6)V is volume of flaring plasma. (see equation (4))
(7)L is length of flaring loop. (see equation (5))
(8)B is minimum magnetic field necessary for confinement. (see equation (6))
(9)$E_{\rm tot}$ is total X-ray energy emitted during the flare. (see equation (7))

$$T_{obs} = 1.16 \times 10^7 kT$$
$$T_{max} = 0.13 T_{obs}^{1.16} \quad (1)$$
$$n_e = 4.4 \times 10^{10}\mathrm{cm}^{-3} (\tau_d/10ks)^{-1} \times (kT/keV)^{3/4}, \; for\ kT > 2keV \quad (2)$$
$$p = 2 n_e k T_{max} \quad (3)$$
$$V = EM/n_e^2 \quad (4)$$
$$L = (400V/\pi)^{1/3} \quad (5)$$
$$B = \sqrt{8\pi p} \quad (6)$$
$$E_{\rm tot} = L\mathrm{x} \times \tau_d \quad (7)$$

Equation (2) is quoted from van den Oord & Mewe(1989), (5) is quoted van den Oord et al. (1988), and others quoted from Pandey & Singh(2008).

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