New Results on Stellar Flares Monitored with MAXI/GSC

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Abstract

Monitor of All-Sky X-ray Image (MAXI) started its operation in 2009 August. Owing to its unprecedentedly high sensitivity as an all-sky X-ray monitor, and to its capability of real-time data transfer, MAXI is able not only to make a continuous monitor of X-ray sources, but also to catch quickly various transient X-ray events, like flares on stars. Making use of this capability, we have searched stellar flares, and have detected fourteen flares from six RS CVns and one flare from a Young Stellar Objects. These flares are on the high-end as flares from stars. In this review, we will report preliminary results on the X-ray flares from the stellar sources.

Key words: flare — RS CVn — YSO — stars: (II Peg, HR1099, AR Lac, UX Ari, VY Ari, SZ Psc, TWA-7) — X-rays: stars

1. Introduction

Cool stars, which have spectral type of F, G, K, and M, are known to have flares which radiate in all wavelengths, from radio to γ-rays (e.g., Favata & Micela 2003; Güdel 2004). The flares are characterized by fast-rise and slow-decay light curves, which last from tens of minutes up to one day. They are understood to originate with release of energy accumulated in magnetic fields. RS Cvn systems and Young Stellar Objects (YSOs), however, are especially active among them.

RS CVn systems are short period binaries in which the components are tidally locked. One of the components is a late-type, evolved (spectral type $\sim$K) star. YSOs are classes of a star in its early stage of evolution prior to main-sequence phase. RS CVn systems and YSOs show a preponderance of phenomena associated with magnetic activity in stars, such as, starspots, variability, flares, strong coronal and transition region emission lines, and coronal forbidden lines.

These systems have been intensively studied at optical, X-ray, and radio wavelengths (e.g. Ayres et al. 2001; Osten et al. 2003). However, since there had been no X-ray monitoring system which has good sensitivity enough to detect stellar flares, it had been difficult to catch large flares.

As the astronomical mission on the Explored Facility of the Japanese Experiment Module "Kibo", attached to the International Space Station (ISS), Monitor of All-Sky X-ray Image (MAXI; Matsuoka et al. 2009) started its operation in 2009 August. Owing to its unprecedentedly high sensitivity as an all-sky X-ray monitor, and to its capability of real-time data transfer, MAXI is able not only to make a continuous monitor of X-ray sources, but also to catch quickly various transient X-ray events, like flares on stars. Making use of this capability, we have searched stellar flares, and have detected fourteen flares from RS CVns and a Young Stellar Objects. In this review, we will report preliminary results on the characteristics of X-ray flares from the sources.

2. Observation 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. 2010). Here, we report the results with only the GSC, which offer a larger sky coverage and effective area than those of the SSC. The GSC consists of twelve one-dimensional position-sensitive proportional counters operated in the 2–20 keV range. The GSC observes two different directions (horizontal and zenithal direction) with an instantaneous field of view of $3^\circ \times 160^\circ$ 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. See Matsuoka et al. (2009) for more details of the MAXI.

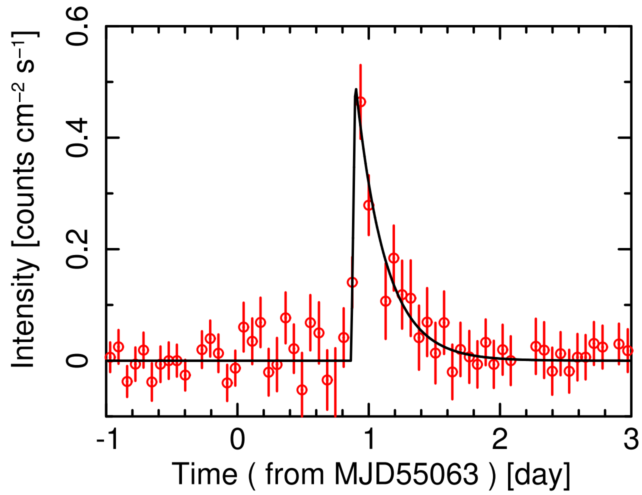

Fig. 1. Light curve of the flare from II Peg detected on 2009 August 20–21 in 2–10 keV band

We have searched flares from stars using the alert system "nova search" (Negoro et al. 2010). For further check, we have made X-ray movies with the field of view of 10 degree radius circle, setting one day observing time as one shot, using 2–10 keV band. All the sky is covered with about 200 field of views. The movies cover the span from 2009 August 15 to 2010 November 31. As the result, we confirmed fourteen flares from seven RS Cvn systems and one flare from a YSO in the span. Four out of seven sources showed more than one flares.

We made light curves of the flares in 2–10 keV band subtracting background, and fitted them with a burst model (linear rize followed by an exponential decay). In Figure 1, we show an example obtained from an RS CVn star, II Peg. We also made the spectra of the flare sources. We first fit the spectra with an absorbed thin thermal plasma model (wabs*mekal). Abundances are fixed to the cosmic value, and absorbing column densities are to the values reported with pointing observations (Osten et al. 2007; Piskunov et al. 1997; Rodono et al. 1999; Franciosini et al. 2001; Dupree et al. 1996; and Mitrou et al. 1997). From II Peg, we detected the biggest flare among stellar flares with the X-ray luminosity of 5 (3–9)$\times 10^{33}$ erg s^{-1} in 2–20 keV on 2009 August 20–21 (error is 90% confidence). The spectrum is quite hard, and only lower limits was obtained for the plasma temperature ($kT > 8.0$ keV). Then next we examined the fitting with an absorbed power law model (wabs*powerlaw). On the biggest flare on II Peg, the best-fit value of power-law index is obtained to be 0.77 (0.1–1.4) (error is 90% confidence).

3. Discussion

We caught dozens of big flares from RS CVns and a YSO with MAXI/GSC. In Figure 2, we show a log-log plot of

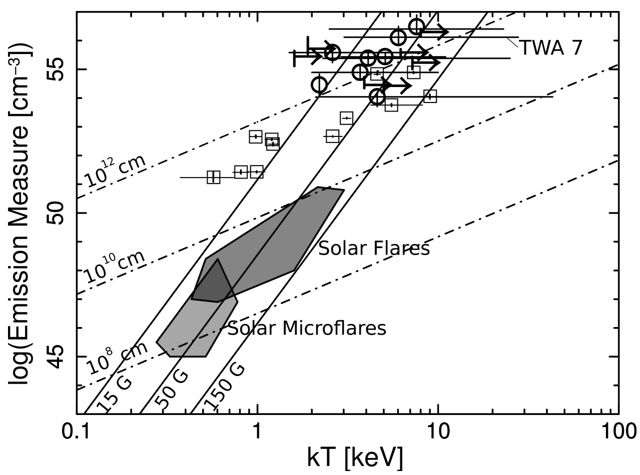

Fig. 2. Log-log plot of plasma temperture (kT) vs. emission measure (EM) for stellar flares. The MAXI-detected RS CVns and a YSO, TWA-7, are shown with open circles, and those but with only lower limit for kT are shown with arrows. The flares from RS CVns obtained with pointing observations (van den Oord et al. 1988, Pandey & Singh 2008, Mewe et al. 1996, Gudel et al. 1999, and Tsuru et al. 1989) are also plotted with open squares as well as solar flares (Feldman et al. 1995) and solar microflares (Shimizu 1995). The EM–T relation curves based on equation [$EM \propto B^{-5}T^{17/2}$: Shibata & Yokoyama 1999] are plotted together for B = 15, 50, and 150 Gauss.

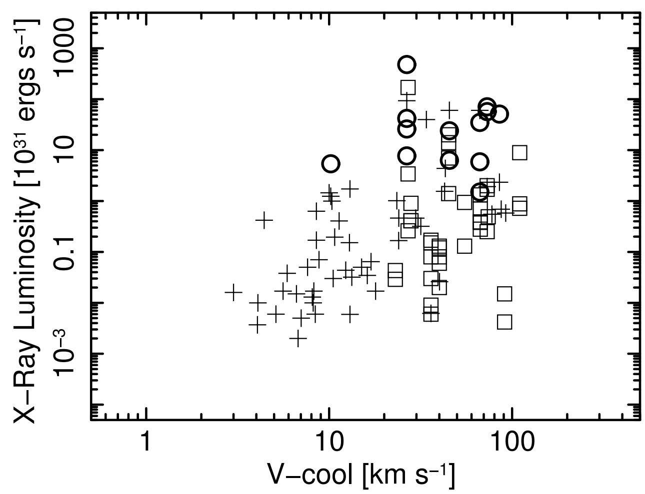

Fig. 3. The spin velocities of the cool component (late-type, evolved stars) in the RS CVn binaries vs. X-ray luminosities of them, together with those in active stars. The open circles show the values for RS CVns detected with MAXI/GSC, while the open squares indicate those for RS CVns detected with pointing observations (e.g. van den Oord et al. 1988, Mewe et al. 1996, Gudel et al. 1999, and Tsuru et al. 1989). The plusses show the catalogued values for active stars given in Eker et al. 2008 and therein.

plasma temperature (kT) vs. emission measure (EM) for stellar flares. The MAXI/GSC sources are shown with open circles (best-fit values and errors) and arrows (best-fit values and errors for EM, and the lower limit for kT). The flares from solar flares (Feldman et al. 1995), solar microflares (Shimizu 1995) are also plotted together. The open squares indicate the values for RS CVns which have been obtained with pointing observations (van den Oord et al. 1988, Pandey & Singh 2008, Mewe et al. 1996, Gudel et al. 1999, and Tsuru et al. 1989). Our samples are located at the high-end of the universal correlation.

From an RS CVn system, II Peg, we detected the biggest flare in stellar flares with the X-ray luminosity of 5×10^{33} ergs s $^{-1}$ in 2–20 keV band with quite hard spectrum. The luminosity in the band exceed that of the "super flare" from the same II Peg but detected with Swift on 2005 December 16 (Osten et al. 2007), since the peak X-ray luminosity of the "super flare" in the 2–20 keV band is calculated to be 2×10^{33} ergs s $^{-1}$, if we use their best-fit model (Orbit 1; 2T+G+NT model; see Osten et al. 2007). Having the peak luminosities of 10^{33} ergs s $^{-1}$, we can say that II Peg would be magnetically active in special among stars. With MAXI/GSC, the flares from II Peg were detected totally four times from 2009 August 15 to 2010 November 31, which is also indicating the extreme activity. Even if we apart from II Peg, the MAXI sources show flares repeatedly; the number of the sources are quite limited, but the number of the detected flares are not small. This means that only a limited number of stars have extreme flaring activities.

In order to search which physical parameters control the X-ray activities in stellar sources, we plot the spin velocities of the cool component (late-type, evolved stars) in the RS CVn binaries vs. X-ray luminosities of them in Figure 3. The open circles show the values for RS CVns detected with MAXI/GSC, while the open squares indicate those for RS CVns detected with pointing observations (e.g. van den Oord et al. 1988, Mewe et al. 1996, Gudel et al. 1999, and Tsuru et al. 1989). The plusses show the catalogued values for active stars given in Eker et al. 2008 and therein. Although it is not statistically significant, the plot seems to indicate a hint of a correlation between spin velocities and X-ray luminosities. We also made the same plot but for the spin velocities of the hot component (main-sequence stars) in the RS CVn binaries vs. X-ray luminosities. However, the plot distribute at random, and no hint of correlation was obtained. This may indicate that the cool component is a dominant source for big flares in RS CVn binaries. Since the cool component in RS CVns and YSOs have both deep convection layers, the depth of the convection layer might be another key for flaring activities on stellar sources. If MAXI/GSC can monitor stellar flares for a several years more, we would be able to obtain a statistically significant results for the speculations.

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