# Statistical research of hyper X-ray flares detected with MAXI

## – a correlation between the quiescent luminosity and the largest flare energy –


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Abstract

MAXI started its operation in 2009 August. Thanks to its unprecedentedly high sensitivity as an all-sky X-ray monitor and to its capability of real-time data transfer, we have detected 106 strong flares from twenty-seven active stars (fourteen RS CVn systems, one Algol systems, nine dMe stars, one dKe star, one Young Stellar Object and one K-type variable star). X-ray energies of these flares were $6 \times 10^{33}$–$9 \times 10^{38}$ erg in the 2–20 keV band. These flares can be high ends of their own categories (Tsuboi et al. 2016). Quiescent state X-ray emissions is thought to originate from the magnetic activity as well as stellar flares. In response to this, we compared the largest X-ray flare energy in 7.25 years (running period of MAXI until 2016 November) for each object ($\mathrm{E_{tot,max}}$) with quiescent state X-ray luminosity ($\mathrm{L_{x,q}}$). Each $\mathrm{L_{x,q}}$ was extracted from ROSAT All-Sky Survey Bright Source Catalogue (Voges et al.1999). As a result, we discovered a correlation of $\mathrm{E_{tot,max}} \propto \mathrm{L_{x,q}^{1.26}}$, for the first time. With this correlation, we can predict the highest flare energy in 7.25 years from $\mathrm{L_{x,q}}$ for all stars.



Key words: stars:flares — stars:RS-CVn type — stars:dMe


## 1. Introduction

Stellar flares are caused by magnetic reconnection which is speculated by numerous preceding solar studies. Flares often accelerate electrons and protons over MeV and GeV, respectively. The particles precipitate along the magnetic fields into the chromosphere, suddenly heating the plasma at the bottom of the magnetic loop up to very high temperatures.

A large number of solar and stellar flares were detected so far. MAXI detected many stellar flares. These flares are located at the high ends in correlation for both the duration time ($\tau$) vs. X-ray luminosity ($\mathrm{L_x}$) and the emission measure vs. temperature (Tsuboi et al. 2016).

Preceding works have discovered that a distribution of stellar flare energy can be approximated by a power-low

$$\frac{\mathrm{N}}{\tau_{\mathrm{obs}}}(\mathrm{E} > \mathrm{E_{tot}}) = \mathrm{A}\ \mathrm{E_{tot}^{-\alpha}} \quad \mathrm{year^{-1}}, \tag{1}$$

where $\mathrm{N(E > E_{tot})}$ and $\tau_{\mathrm{obs}}$ are the number of events with energy larger than the flare energy ($\mathrm{E_{tot}}$) and observed years, respectively. The index $\alpha$ is 0.6 on RS CVn system (Osten and Brown 1999), 0.52 and 0.7 on M dwarfs (Collura et al. 1988 and Pallavicini et al. 1990).

Quiescent state X-ray emissions is thought to originate from the magnetic activity as well as stellar flares. In response to this, the distribution of stellar flare, which ought to be typified by the largest flare energy in a certain period of time, can be considered to be related with quiescent X-ray emissions. To resolve the relevance, we focused on the largest flare energy which detected with MAXI in the running period of MAXI.

## 2. Result

MAXI has been observing the all sky in 7.25 years which is from 2009 August to 2016 November. MAXI has detected 106 strong flares from twenty-seven active stars (fourteen RS CVn systems, one Algol system, nine dMe stars, one dKe star, one Young Stellar Object and one K-type variable star). The locations of these stars on all-sky map are shown in Figure 1. The energies of these flares range from $6 \times 10^{33}$ to $9 \times 10^{38}$ erg in the 2–20 keV band, as shown in Figure 2. The flare energies detected with MAXI are more than two orders of magnitude larger

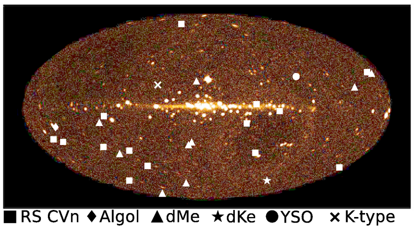


Fig. 1. Location of flare stars detected with MAXI on all-sky map

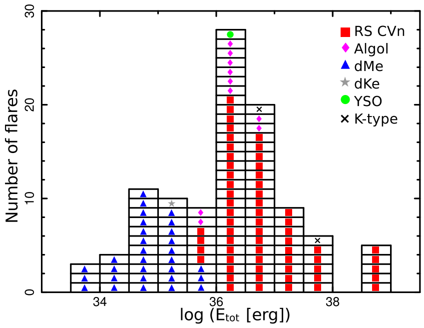


Fig. 2. The flare energy histgram detected with MAXI

than the maximum solar flare ($\approx 10^{32}$ erg).

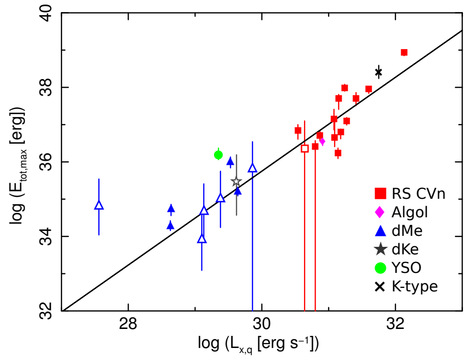


Fig. 3. The correlation between $\mathrm{E_{tot,max}}$ and $\mathrm{L_{x,q}}$.

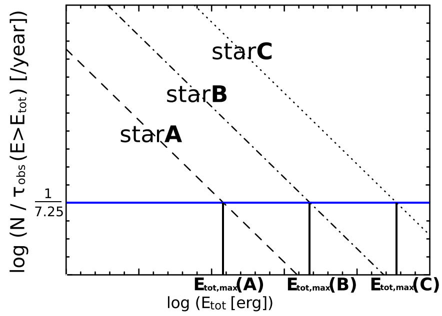


Fig. 4. The difference of the flare energy distribution of each star. Star A, B, C are arranged in order from a smaller $\mathrm{E_{tot,max}}$.

## 3. Discussion

### 3.1. The maximum flare energy prediction

The obtained flares can be high ends of their own categories (Tsuboi et al. 2016). We compared the maximum flare energy in running period of MAXI for each object ($\mathrm{E_{tot,max}}$) with quiescent X-ray luminosities ($\mathrm{L_{x,q}}$). Flare energies are derived by multiplying $\mathrm{L_x}$ by $\tau$. The value of $\tau$ were not measured for seven stars. For these flares, we used a correlation of $\tau \propto \mathrm{L_x^{0.2}}$ that was discovered in Tsuboi et al. (2016). We plotted the seven stars by open mark. On the other hand, each $\mathrm{L_{x,q}}$ was extracted from ROSAT All-Sky Bright Source Catalogue (Voges et al. 1999). We fitted all the data in Figure 3 by a power-law model and obtained the best-fit function of

$$\mathrm{E_{tot,max}} = 10^{-2.04\pm1.12}\ \mathrm{L_{x,q}^{1.26\pm0.04}} \quad \mathrm{erg}. \tag{2}$$

The error of the coefficient and the power are 1–$\sigma$ confidence level. The best-fit model is shown in Figure 3. With this correlation, we are able to predict the maximum X-ray flare energy of individual stars during the observing span of 7.25 years from their $\mathrm{L_{x,q}}$.

### 3.2. Flare energy distribution

The equation 2 implies that flare mechanisms among the all stellar systems are intrinsically the same. Assuming that all stellar flare systems obey the same index "$\alpha$" of equation 1, we fixed the index to 0.6. The N is 1, because $\mathrm{E_{tot,max}}$ occurred once in $\tau_{\mathrm{obs}}$ (7.25 years). The schematic view of this idea is shown in Figure 4. The equation of the number of flares is

$$\frac{1}{7.25\ \mathrm{years}}(\mathrm{E} \geq \mathrm{E_{tot,max}}) = \mathrm{A}\ \mathrm{E_{tot,max}^{-0.6}} \quad \mathrm{year^{-1}}. \tag{3}$$

$\mathrm{E_{tot,max}}$ With the equation 2, we were able to derive the normalization "A".

$$\mathrm{A} = 1.38 \times 10^{19.38} \times \left(\frac{\mathrm{L_{x,q}}}{10^{30}\ \mathrm{erg\ s^{-1}}}\right)^{0.72} \tag{4}$$

In this way, we also succeeded in predicting the number of flares in 7.25 years of each star from the quiescent state X-ray luminosity.

## References


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