Stellar flares detected with MAXI for the past 7 years

Yohko Tsuboi[1], Ryo Sasaki[1], Yumiko Nakamura[1], Ken Yabuki[1], Atsushi Kawagoe[1], Soichiro Kaneto[1], Yasuharu Sugawara[2], Hitoshi Negoro[3], and the MAXI Team

[1] Department of Physics, Faculty of Science and Engineering, Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo 112-8551, Japan
[2] ISAS, JAXA, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 229-8510, Japan
[3] Department of Physics, Nihon University, 1-8 Kanda-Surugadai, Chiyoda-ku, Tokyo 101-8308, Japan
E-mail(YT): tsuboi@phys.chuo-u.ac.jp

Abstract

Since the launch in 2009 August, with the unprecedentedly high sensitivity as an all-sky X-ray monitor, MAXI has caught more than a hundred of huge flares from stars. Most of them are from low-mass, active stars (RS CVn systems, an Algol system, dMe systems, a dKe system, Young Stellar Objects). With the total radiative energy of 10^{34-39} ergs, the MAXI detections have broken the record of the largest flaring magnitudes in each stellar categories (e.g. "RS CVn" and so on). The enlarged sample of intense flares has enabled us to do systematic studies in various viewpoints. One of the studies is our discovery of a universal correlation between the flare duration and the intrinsic X-ray luminosity, which holds for 5 and 12 orders of magnitude in the duration and $L_{\rm X}$, respectively (Tsuboi et al. 2016).

Besides low-mass stars, a historically brightest X-ray flare has been detected with MAXI from the massive star system, Eta Carinae (Negoro et al. 2014).

In this review, we introduce the studies of stellar flares obtained in 7.25-year monitoring with MAXI.

Key words: stars: activity — stars: flare — stars: late-type — stars: rotation — stars: variables: general

1. Introduction

Stellar flares are thought to be a resultant of magnetic reconnection on a stellar surface. The closest stellar flares to us are solar flares. The typical total energy of a solar flare ranges from 10^{29} to 10^{32} erg (e.g., Shibata & Yokoyama 2002), and the duration is several minutes to several hours (e.g., Shimizu 1995). Despite the long history of the observation of the solar flares, the high energy cut-off of the solar flares in the occurrence rate (dN/dE) versus flare energy (E) has not yet been reported. Whereas, in 2012, Maehara and his co-workers discovered 365 flares with the total energy of 10^{33}–10^{36} erg, in the range of so called "super-flare" (Schaefer et al. 2000), on 148 G-type dwarfs which includes 10 Sun-like stars (Maehara et al. 2012). This frightens us, because our civilization would suffer from much more severe damages, if superflares were really to occur on the Sun.

Even if we are apart from the solar flares, generally, we cannot answer the following fundamental questions; how large flares can a star have, and how is such a flare? The best way to answer such questions would be to use MAXI, which has the unprecedentedly high sensitivity for an all-sky X-ray monitor. Here, we report the results with the gas proportional counters (GSC) of MAXI obtained in the first 7.25-year operation from 2009 August to 2016 November.

2. Results

2.1. Flare sample

We detected 106 flares on twenty-seven low-mass stars; fourteen RS CVn systems, one Algol system (Algol), nine dMe stars, one dKe star, one Young Stellar Object (TWA-7) and one K-type variable star. The detection of the flare from TWA-7 and the results from the first two-year monitoring with MAXI have been already reported in Uzawa et al. (2011) and Tsuboi et al. (2016), respectively. Most of the categories are classified as active binaries, which consist of the pair of a sub-giant and a main sequence, and a pair of a giants and main-sequence, and a pair of two main-sequence stars. The distance between each stellar component are 1–2 times of their own stellar sizes. We should note that our sample contains single active stars, although they are minor (Uzawa et al. 2011 and Tsuboi et al. 2016).

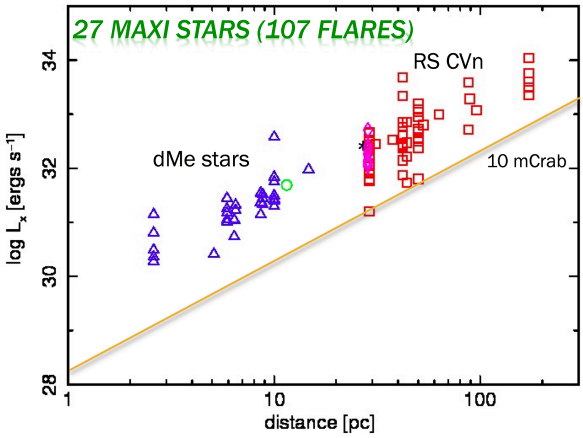

Fig. 1. Log-log plot of X-ray luminosity in the 2–20 keV band of flares vs. distance from stars detected with MAXI/GSC. The squares, triangles, circle, diamond, and star show RS-CVn type stars, dMe stars, dKe star, Algol, and TWA-7, respectively. The detection limit appears to be roughly 10 mCrab in the 2–20 keV band.

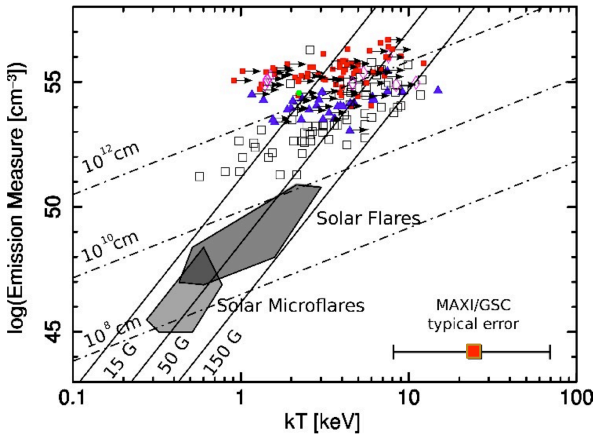

Fig. 2. Log-log plot of emission measure vs. plasma temperature (kT) for the MAXI X-ray flares (filled symbols), along with stellar flares from RS-CVn type, Algol, dMe stars and YSOs, solar flares, and solar microflares. The arrows indicate the lower limits for individual MAXI/GSC sources. EM-kT relations, for B= 15, 50, and 150 Gauss and for the loop-sizes of $10^8, 10^{10}$, 10^{12}, and 10^{14} cm, from Shibata & Yokoyama (1999) are also indicated.

Figure 1 shows the X-ray luminosity vs. distance to the source. This shows that the MAXI sources are within about 200 pc, and our detection limit is roughly 10 mCrab. The largest flares that we detected in seven-year monitoring have the luminosity of 10^{34} ergs s^{-1}. Thanks to the improvement of the alert system "nova search" (Negoro et al. 2016) during 7.25 years, all dMe stars within 10 pc distance have been detected with MAXI. On the other hand, the detected sample of active binaries are only the tip of the iceberg; within 100 pc distance, 256 active binaries are known to exist, but only 1/10 are detected. Moreover, none of the solar type stars has been detected, despite that within 20 pc distances, there are 15 such stars.

The total energies of the detected flares range from 10^{34} to 10^{39} erg in the 2-20 keV band, i.e. at least, more than two orders of magnitude larger than the maximum solar flare (10^{32} erg). The detail is reported in Sasaki et al. (2017).

2.2. Universal correlations

Figure 2 shows the plot of emission measure vs. plasma temperature. It had been known that there is a universal correlation which holds through many orders of magnitudes in emission measure (Shibata & Yokoyama 1999). MAXI sources lie on the high-end of the correlation. The large emission measures in the MAXI sources indicate that the radiative volume, and then the loop size, are larger than those in the solar flares by many orders of magnitudes, and the magnetic field, which is indicative of the plasma temperature, is on the other hand not so different from those in solar flares. In some flares, the loop size should be more than 10 times larger than even the distance between each binary component.

Recently, Tsuboi et al. (2016) discovered another universal correlation between the intrinsic X-ray luminosity in the 0.1–100 keV band and the duration of flares. Figure 3 shows the correlation which holds from solar micro flares to the large flares detected with MAXI/GSC. The MAXI flares are on the high-end of the positive correlation.

2.3. Serendipitous flares from HD347929

We have detected the flares from HD347929 in 2013 serendipitously and also have recognized that the source had another flare in 2010. Since we had possessed almost no information of this source, we conducted a spectroscopic observation in the optical band with Gumma observatory, and obtained a hint for the nature; it seems to be a young stellar object with a rich Li abundance. The detail will be reported elsewhere (Tsuboi et al. 2017).

2.4. The historically brightest X-ray flare on the massive star system, Eta Carinae

MAXI detected not only the flares on the low-mass stars but also those on a massive stellar system, Eta Carinae. Eta Carinae is a mystery source with surrounding dust nebulae. The dust erupted from Eta Carinae itself in the 19th century. There is also an X-ray emitting nebula, surrounding Eta Carinae, which is located outside of the dust nebulae. Then the nature of the central source has been little known, except for the information that it seems to be a stellar system containing at least two

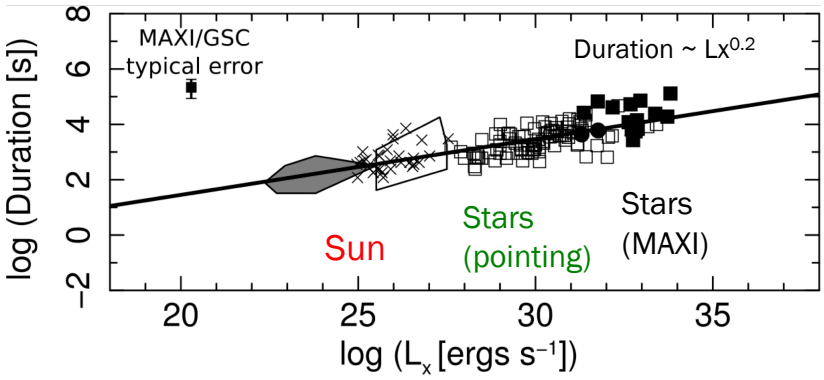

Fig. 3. Log-log plot of duration of flares vs. X-ray luminosity in the 0.1–100 keV band. The best-fit model is inserted with a broad solid line (Tsuboi et al. 2016).

massive stars. This is indicated from the periodic X-ray variation with 5.54 year period. Such variation is widely observed in wind colliding binaries, with the elliptical orbit and the enormous stellar winds from both stellar components. The X-ray intensities become maximum at the periastron.

At the last periastron of Eta Carinae in 2014 June, MAXI caught the highest X-ray flare among those ever recorded (Negoro et al. 2014). The long X-ray monitoring with MAXI toward the next periastron is highly deserved.

3. Summary

- 107 flares from 27 low-mass stars were detected.
- dMe stars within 10 pc were all detected.
- No flare has been detected from G type main sequence stars within 20 pc, so far.
- A universal correlation was obtained in the duration of flares vs. the bolometric X-ray luminosity.
- Serendipitously, huge flares were detected from one un-classified stellar source.
- The highest X-ray flare ever recorded was detected from Eta Carinae.

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