Super flare candidates detected by XMM-Newton

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Abstract

While superflare surveys on main-sequence stars have been well performed with Kepler satellite in the optical band (e.g. Maehara et al. 2012), there are few reports in the X-ray band. Hence necessity of statistical studies in the X-ray band has been enhanced recently. We found 23 objects which have the light curves like those of stellar flares in 2XMMi-DR3 catalog (Watson et al. 2009). Among them, we have identified 22 objects with the stars listed in available optical and infrared catalogs. We made SEDs from optical and infrared data, and derived temperatures and spectral types (M-type: 18, K-type: 3, F-type: 1). Temperatures of nine objects are lower than 3000 K. These nine stars are candidates of brown dwarf. To determine distance and age, we compared proper motion of our objects with those of near–earth moving group members. One M-type object is concluded to be a new member of AB Dor moving group (distance: 7–77 pc, age: 50–120 Myr, Malo et al. 2012), from the coordinate and proper motion. According to observation of Gaia, distances of two objects (K-type: 1, F-type: 1) are 210 (198–222) pc, 833 (189–1477) pc. Then we estimated absolute magnitude from the distances. Absolute magnitude of the K-type star is brighter than main-sequence K-type stars, while the F-type star has possibility of being a main-sequence star. Assuming that other objects (K-type: 2, M-type: 8 [Temperature > 3000 K]) are in the main sequence phase, we calculated their lower limits of distances from apparent magnitude and the temperature. The lower limits of distances of them are ranging also 10–200 pc. We calculated X-ray luminosities of thirteen objects from distances. Six of the thirteen objects have luminosities at least 10^{29} erg s^{-1}, well in the superflare class, suggesting that they are super flare star candidates. Furthermore, there is a possibility that four objects (F-type: 1, K-type: 2, M-type: 1) of the six superflare stars are main-sequence stars. We were able to detect four super flare star candidates in main-sequence phases.

Key words: Stars: flares

1. Introduction

Flares ten times more energetic than the largest solar flares are called super flare. Generally, superflares have been observed on binaries and YSOs in X-rays. Whereas superflare surveys for main-sequence stars have been performed actively in optical (e.g. Maehara et al. 2012), statistical studies in X-rays are still scarce.

2. No bias flare search

Our sample was selected from 2XMMi-DR3 produced by the XMM Survey Science Centre (Watson et al. 2009). In order to search for highly variable objects, we performed chi-square tests with a null hypothesis that the objects have constant fluxes. These probabilities were calculated from the time series in 0.2–12 keV by using the Science Analysis System (SAS) task ekstest excluding high background flaring times. We selected sources satisfying the following conditions: (1) the probability calculated by using EPIC-pn data $< 10^{-5}$, (2) the count rate for EPIC-pn in 0.2–12 keV > 0.03 counts s^{-1}, and (3) Galactic latitude $|b|$ >10, where all of these parameters are listed in 2XMMi-DR3. 1100 sources fulfilled these criteria. We applied further filtering conditions to construct our sample. We discarded sources in the fields of star forming regions, Small Magellanic Clouds, or Large Magellanic Clouds. Sources with object types Galaxy, X-ray source, or unidentified shown in the NASA/IPAC Extragalactic Database (NED) or the SIMBAD were regarded as AGN candidates. We selected stars which have the light curves resemble those of stellar flares (Abrupt

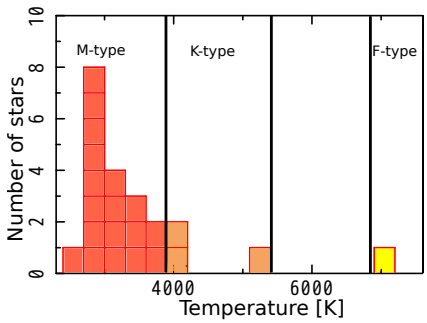

Fig. 1. Distribution of temperatures (M-type:18, K-type:3, F-type:1)

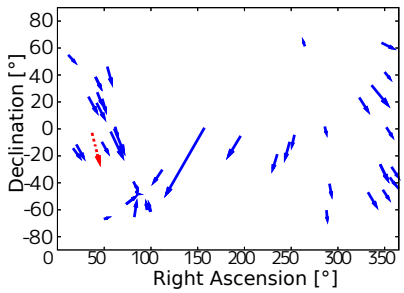

Fig. 2. Proper motions of AB Dor Moving group and our object. Solid line and dotted line show proper motion of AB Dor moving group and our object.

Fig. 3. Lower limits of distances of the ten samples.

rise of flux followed by exponential decay). After all screening, 23 sources were finally selected. Of these, 22 objects are found to have counterparts in optical (USNO-B1,GSC2.3.2) and infrared (2MASS, WISE) catalogs.

3. Discussion

3.1. Temperature

We made SEDs from optical and infrared data. Then we determined temperatures and spectral type (M-type: 18, K-type: 3, F-type: 1, shown in Fig 1). Temperatures of nine objects are cooler than 3000 K. We consider these objects to be brown dwarf candidates, judging from the temperatures (Thackrah et al. 1997). It should be noted that they may be members of a rare class of old brown dwarfs that show flares in the X-ray band (e.g. Rutledge et al. 2000, Age: 500 Myr). Main-sequence stars with intermediate spectral types are considered intrinsically X-ray inactive. A detailed investigation on the F-type object is necessary.

3.2. Comparison with near-earth moving group

We compared proper motions of our objects with proper motion of near–earth moving group to determine distances and age. One of our objects has proper motion resembling those of AB Dor moving group (Distance: 7–77 pc, Age: 50–120 Myr ; malo et al. 2012). From this reason, we concluded that the object is a new member of AB Dor moving group. Proper motion of AB Dor Moving group and our sample are shown in Fig 2. AB Dor Moving is in YSO phase. YSOs produce flares frequently (e.g. Imanishi et al. 2003). The young age of AB Dor moving group also supports the membership.

3.3. Distance

We determined distance of two objects (K-type: 210 [198–222] pc, F-type: 833 [189–1477] pc) based on parallaxes measured with Gaia, and we estimated absolute magnitude. Absolute magnitude of the K-type star is brighter than main-sequence K-type stars, while F-type star has possibility of being a main-sequence star. Assuming that other nine objects (Temperature > 3000 K) are in the main sequence phase, we determined lower limits of distances from apparent magnitude and the temperatures. We used V-band magnitude listed in GSC2.3.2 catalog as apparent magnitude, while, for objects not listed in that catalog, we estimated V-band magnitude from SED. We show lower limits of distances in Fig 3.

3.4. X-ray Luminosity

We calculated X-ray luminosities of our objects from distances (A member of AB Dor moving group: 1, With Gaia: 2, lower limits: 10). Luminosities were shown in Fig 4. Six flares have X-ray luminosities at least 10^{29} ergs s^{-1}, well in super flare class.

In conclusion, we succeeded in detecting six super flare stars. Furthermore, there is a possibility that four objects (F-type: 1, K-type: 2, M-type: 1) of the six super-flare stars are main-sequence stars. We were able to detect super flare star candidates in main-sequence phases.

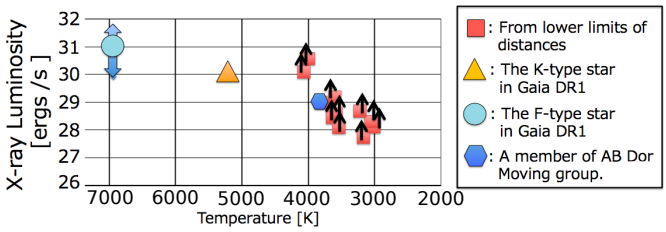

Fig. 4. X-ray luminosities of our objects.

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