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Searching for optical flares on the X-ray transient EXO 040830-7134.7

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ABSTRACT

This paper provides a brief overview of the research on EXO 040830-7134.7 since the discovery of the X-ray transient. The data of its observations in the X-ray and optical ranges of the spectrum are analyzed. As a result of processing the light curves and through visual control, more than 30 significant flares have been detected. The maximum flare energy is recorded at 10^{34} erg. Images with the most typical flares are presented in this publication.

Key words: X-ray transient, red dwarf, optical flares

1 Introduction

The X-ray source EXO 040830-7134.7 was first reported in van der Woerd et al. (1989). Using the low-energy telescope of the European Space Agency's X-ray observatory EXOSAT, 30 observations of this source were carried out over two years; at that time these were the longest X-ray observations of a single star of spectral type dMe. During two observations, EXO 040830-7134.7 was almost three times brighter than the average X-ray luminosity. In addition, during one observation, it was found that the source was seven times brighter than the average value for at least two hours. Assuming that the increase in luminosity is associated with a flare on the star, EXO 040830-7134.7 turned out to be the brightest in the X-ray range among the previously studied red dwarfs.

Our interest in EXO 040830-7134.7 is due to the presence of this object in the catalog of flaring stars of the UV Cet type and related objects in the solar neighborhood (Gershberg et al., 1999) with subsequent inclusion into the catalog of stars with solar-type activity GTSh10 (Gershberg et al., 2011).

1.1 X-ray emission from EXO 040830-7134.7

Analyzing the all-sky X-ray survey performed in 1990–1992 using the WATCH monitors on board the Granat observatory, Castro-Tirado et al. (1999) confirmed that EXO 040830-7134.7 demonstrates the brightest flare among the previously recorded events in peculiar stars.

In subsequent years, EXO 040830-7134.7 was observed in the X-ray range by the ROSAT (Voges et al., 1994), BeppoSAX (Giommi et al., 2000), and XMM-Newton (Della et al., 2004) observatories.

The longest series of observations in the X-ray range (Fig. 1) was obtained at the ROSAT observatory. According to the data from the second ROSAT source catalog (Boller et al., 2016), EXO 040830-7134.7 is associated with the X-ray source 2RXS J040808.2-712703 and exhibits weak variability. Nevertheless, some episodes on the light curve in X-rays, when the background radiation level tends to zero, can be considered a manifestation of flare activity.

2 Observations in the optical range

In 1991, EXO 040830-7134.7 was included into the catalog of flaring stars in the solar neighborhood (Pettersen, 1991). In the same year, this object was included in the summary list of X-ray observations of emission red dwarfs, active spectroscopic binary systems, and young stars (Linsky, 1991). This work also provides a comparison of the parameters of stellar and solar flares.

Photometric and spectroscopic studies of EXO 040830-7134.7 were published in Cutispoto et al. (1996). In this paper, the object is designated as EXO 040829-7134.7. In one of the observing seasons presented in this work, some evidence of optical variability with a period of about 5.2 ± 0.20 days was obtained. However, this brightness variability is not confirmed by observations carried out in another period. The assumed spectral type of the star determined by Cutispoto et al., M0 Ve, is in good agreement with that given earlier (van der Woerd et al., 1989).

When searching for X-ray observations of EXO 040830-7134.7, our attention was drawn to the data obtained using the Optical Monitoring Camera (OMC) on board the INTEGRAL[1] orbital observatory. Figure 2 presents the ob-

[1] INTEGRAL – https://www.cosmos.esa.int/web/integral/home

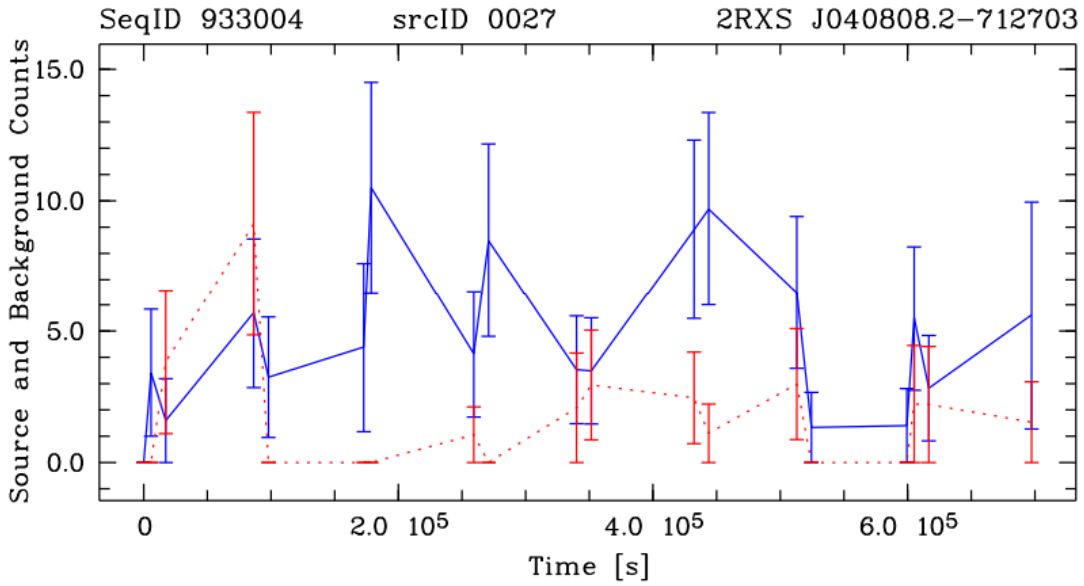

Fig. 1. Light curve of the object 2RXS J040808.2-712703 = EXO 040830-7134.7 in the X-ray spectral range. The axes show time from the beginning of observations in seconds and detector counts for the source (blue curve) and background (red curve). Measurement errors are indicated.

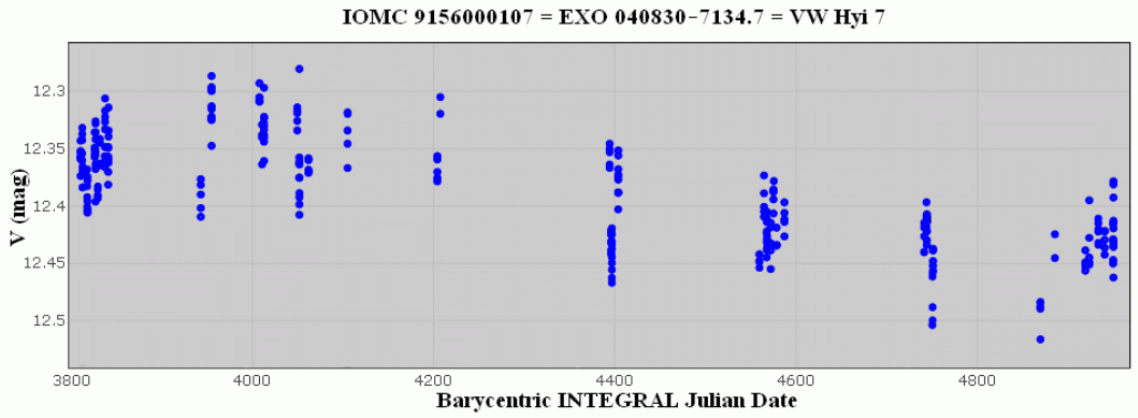

Fig. 2. Light curve of EXO 040830-7134.7 obtained with the OMC instrument on board the INTEGRAL observatory.

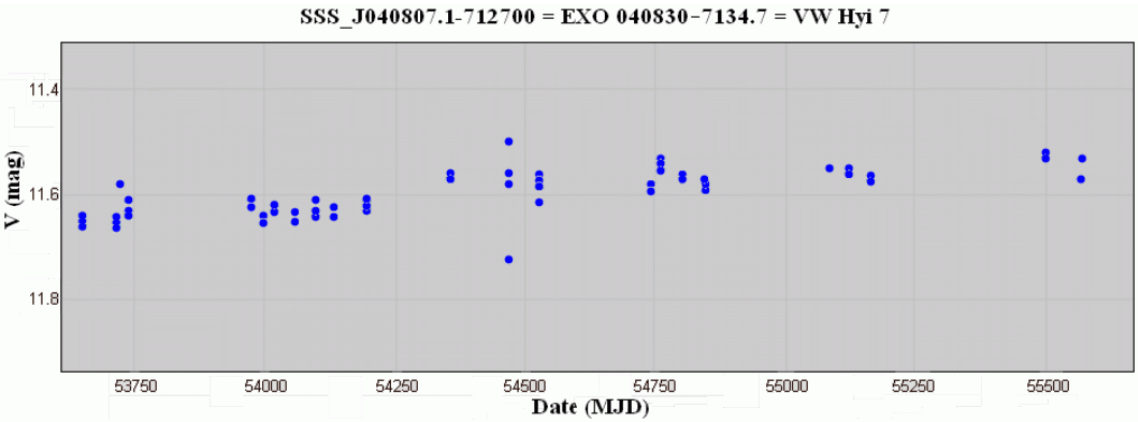

Fig. 3. Light curve of EXO 040830-7134.7 obtained by SSS within the CSS project.

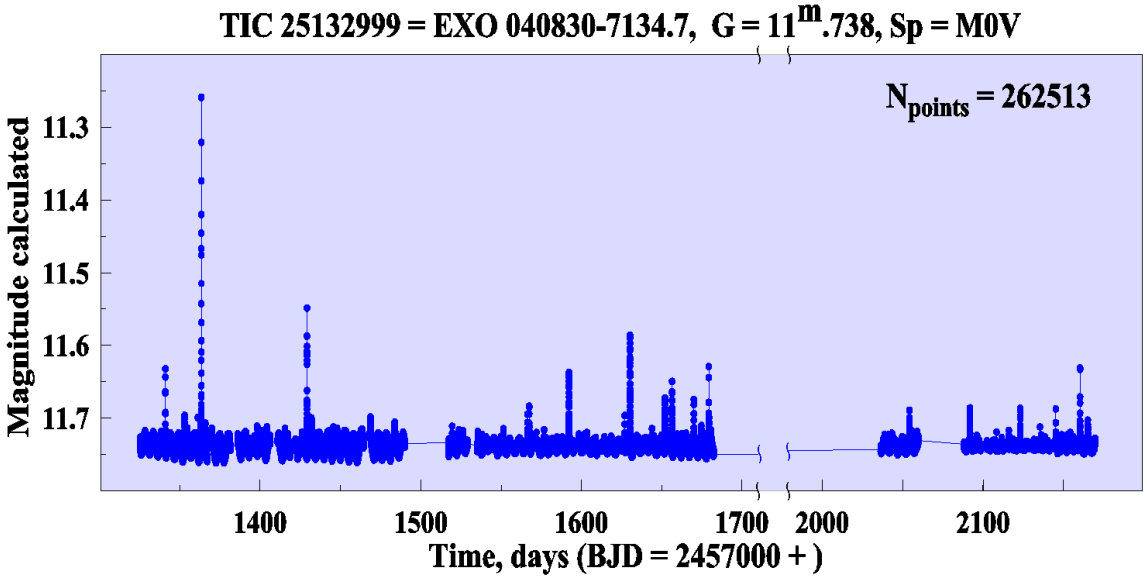

Fig. 4. Light curve of EXO 040830-7134.7 constructed from TESS observation data.

ject's light curve in the V band, obtained based on data from the OMC Archive at CAB (INTA-CSIC), preliminarily processed by ISDC[2].

The observation series of more than three years demonstrates a wave-like trend with an amplitude of about $0^m.2$ and a half-period of about 2.7 years. It is possible that the activity cycle for this object is a period close to 5.4 years. The average error of the presented observations is $0^m.02$. Intraseasonal brightness variations with an amplitude of $\sim 0^m.1$ are visible, which may be associated with the star's rotation period.

Figure 3 shows the light curve of EXO 040830-7134.7 obtained as a result of processing observations from the 500-mm Schmidt telescope (a field of $6° \times 6°$, $11^m < V < 19^m$; Siding Springs Survey (SSS) is one of the services of the Catalina Sky Survey[3] (CSS) project). The average error of the observations is $0^m.05$, $V_{max} = 11^m.5$, $V_{min} = 11^m.72$.

The data processing procedure, according to which the light curves for OMC and SSS were constructed, included downloading observations using the links specified in footnotes 2 and 3. After extracting the information, the data were checked for the presence of bad pixels and PSF profiles, for the discrepancy between the centroid of the obtained star image and its coordinates, for the presence of significant errors in determining stellar magnitudes. As a result, estimates of the brightness of EXO 040830-7134.7 were obtained, and erroneous values were excluded from them. Based on these data, the light curves presented in Figs. 2 and 3 were constructed. Analysis of the light curves, taking into account the low temporal resolution of the observed series, did not show significant flare activity of EXO 040830-7134.7 in the optical spectral range.

3 Flare activity according to TESS data

Cross-identification of GTSh10[4] objects with data from the TESS[5] observatory (Ricker et al., 2014) showed that at the beginning of 2021, there were 16 sets of registration of this object containing 262 513 individual observations. During a visual analysis of the light curves of EXO 040830-7134.7, a significant number of high-amplitude flares in the optical spectral range were detected (Fig. 4).

In Gorbachev, Shlyapnikov (2021) we conducted a detailed study of the observational data obtained at the TESS observatory. In particular, using all registration sets of EXO 040830-7134.7, the average rotation period of the star was independently determined, which amounted to 5.18 ± 0.06 days, which is in good agreement with the period of 5.2 ± 0.20 days published in Cutispoto et al. (1996).

Analysis of the distribution of flares by the phase of the light curve of EXO 040830-7134.7 showed that low-amplitude flares are distributed fairly uniformly, while flares with higher energies occur during the rise and decay of the object's brightness. Most of the 88 flares for which the energy was calculated do not exceed the threshold of 10^{34} erg. Seventeen flares have an energy of more than 10^{34} erg and can be considered as superflares.

The paper separately considers the issue of the rise and decay time of flares. It is shown that there is a clear correlation between the decay time and the energy of flares.

Figure 5 shows the profiles of the most characteristic flares identified from the TESS observation data. The time of the flare maximum (t_{max}), flare energy (E_{flare}), and flare duration (Δt) are indicated. The calculation of the flare energy was carried out according to the method described in Günther

[2] The OMC Archive – https://sdc.cab.inta-csic.es/omc/index.jsp
[3] Catalina Sky Survey – https://catalina.lpl.arizona.edu/
[4] GTSh10 catalog – http://www.crao.ru/~aas/CATALOGUEs/G+2010/eCat/G+2010.html
[5] TESS Exoplanet Mission – https://www.nasa.gov/tess-transiting-exoplanet-survey-satellite

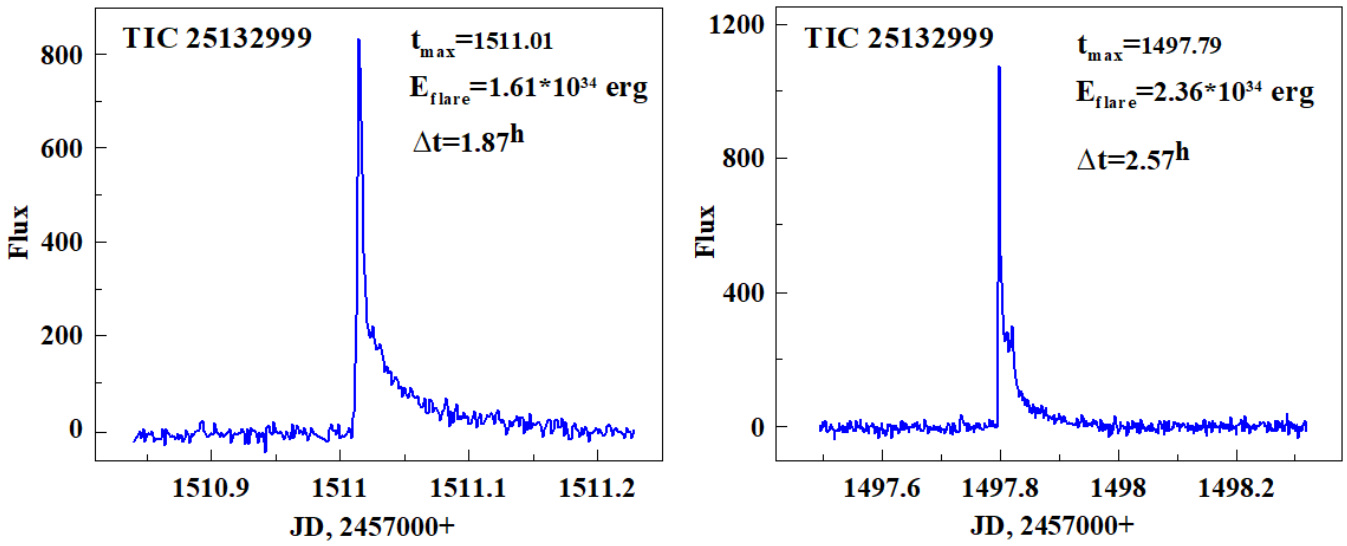

Fig. 5. Profiles of the most characteristic flares (Gorbachev, Shlyapnikov, 2021).

et al. (2020). The results considered in this work became the basis for conducting deeper studies published in Gorbachev, Shlyapnikov (2021).

4 Conclusions

A brief review of observations of the transient EXO 040830-7134.7 since its discovery in the X-ray range using the low-energy telescope of the EXOSAT observatory showed that the source is seven times brighter than the average flux value for at least two hours. At the time of detection, the object turned out to be the brightest in the X-ray range among the previously studied red dwarfs.

Analysis of the longest series of observations in the X-ray range performed at the ROSAT observatory showed weak variability. Some episodes on the light curve in X-rays, when the background radiation level tends to zero, can be interpreted as insignificant flare activity.

Two light curves in the optical range, obtained by the OMC camera on board the INTEGRAL observatory and with the Schmidt telescope within the CSS project, show weak variability with an amplitude of about $0^m.2$. According to the OMC data, a wave-like trend with a half-period of about 2.7 years is visually observed, possibly associated with the cyclic activity of the star. The most productive was the search for optical flares on EXO 040830-7134.7 based on observational data from the TESS observatory. As a result of processing the light curves and through visual control, more than 80 significant flares were detected. The maximum flare energy of more than 10^{34} erg was recorded.

An independent analysis found the axial rotation period, which amounted to 5.18 ± 0.06 days, which corresponds to the previously obtained result of 5.2 ± 0.20 days (Cutispoto et al., 1996).

A more detailed analysis, including the dependence of the star's flare activity on the phase of its rotation and the distribution of the number of detected flares on their energy, is presented by the authors in Gorbachev, Shlyapnikov (2021).

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References

Gorbachev M.A., Shlyapnikov A.A., 2021. 25th All-Russian Annual Conference on Solar Physics, Proceedings, SPb, pp. 97–100. (In Russ.)

Boller Th., Freyberg M.J., Trümper J. et al., 2016. Astron. Astrophys., vol. 588, id. A103.

Castro-Tirado A.J., Brandt S., Lund N., 1999. Astron. Astrophys., vol. 347, p. 927.

Cutispoto G., Tagliaferri G., Pallavicini R., et al., 1996. Astron. Astrophys. Sup., vol. 115, p. 41.

Della C.R., Maccacaro T., Caccianiga A., et al., 2004. Astron. Astrophys., vol. 428, p. 383.

Gershberg R.E., Katsova M.M., Lovkaya M.N., et al., 1999. Astron. Astrophys. Sup., vol. 139, p. 555.

Gershberg R.E., Terebizh A.V., Shlyapnikov A.A., 2011. Bull. Crim. Astrophys. Observ., vol. 107, iss. 1, p. 11.

Giommi P., Perri M., Fiore F., 2000. Astron. Astrophys., vol. 362, p. 799.

Günther M., Zhan Z., Seager S., et al., 2020. Astron. J., vol. 159, p. 60.

Linsky J.L., 1991. Memorie della Societa Astronomica Italiana, vol. 62, p. 307.

Pettersen B.R., 1991. Memorie della Societa Astronomica Italiana, vol. 62, p. 217.

Ricker G.R., Winn J.N., Vanderspek R., et al., 2014. Proceed. of the SPIE, vol. 9143, id. 914320, p. 20.

van der Woerd H., Tagliaferri G., Thomas H.C., et al., 1989. Astron. Astrophys., vol. 220, p. 221.

Voges W., Gruber R., Haberl F., et al., 1994. ROSAT Source Catalog. Available at: https://vizier.cds.unistra.fr/viz-bin/VizieR?-source=IX/11 (Accessed: 05 November 2021).