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Flares activity of selected stars from GTSh10 catalog by CRTS data

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Based on the database of photometric observations of the CRTS project over an interval of more than 9 years, the activity of red dwarfs from the GTSh10 catalog was analyzed. The total number of analyzed objects, a list of stars with detected flares, amplitudes and moments of recorded events are presented. For the most interesting objects, from the point of view of the analysis of flare activity, the light curves are plotted on the investigated time interval.

Keywords: Variable stars: general

1 Introduction

The article presents information on the continuation of the study of flare activity in red dwarfs from the GTSh10 catalog (Gershberg et al. 2011) based on the photometric observations database of the CRTS project (Drake et al. 2009). Previously, for 2032 stars from catalog GTSh10 analysis was conducted photometric observation series in band V for the period from MJD 2453464.15625 to MJD 2456591.367188 and by 360593 estimates of the brightness of 868 stars detected 2222 flares. However, further studies have shown the need for a more detailed study of the CRTS project data. Some of the discovered features of CRTS data and their correct accounting are considered in this article.

2 Catalog GTSh10

In 2010, a catalog of stars with solar-type activity was prepared, which was designated GTSh10. It included dwarf stars with various manifestations of solar type activity:

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objects with dark spots, with hydrogen and calcium chromospheric emission, with transient flares in different wavelength ranges, with radio and X-ray radiation of star coronas (the catalog is available at http://craocrimea.ru/∼aas/CATALOGUEs/G+2010/eCat/G+2010.html).

The creation of this catalog was preceded by a lot of work done in the late 1990's in the CrAO to compile the most complete database at that time about flaring stars and related objects.

Based on this database, which included 462 objects, a paper was compiled and published entitled "Catalog and Bibliography of flare stars of UV Cet-type and their related objects in the solar neighborhood" (Gershberg et al. 1999). The catalog was given in the form of an electronic supplement to the journal publication and was later printed in the monograph of R.E. Gershberg "Solar-type activity in the main sequence stars" (Gershberg 2005) and in the SIMBAD database (Wenger et al. 2006) it received the designation GKL99. Currently, a new version of the Catalog of Stars with the activity of the solar type is being prepared.

3 The Catalina Surveys projects and data release 2

The Catalina Surveys consist of the Catalina Sky Survey (CSS) and the Catalina Real-time Transient Survey (CRTS) NASA-funded research on observing objects near the Earth. The surveys involve three telescopes: the Mt. Lemmon Survey 1.5-m Cassegrain, Catalina Sky Survey 0.7-m Schmidt and Siding Springs Survey 0.5-m Schmidt.

CSDR2 (Catalina Surveys Data Release 2) is the second presentation of data from CRTS surveys. This data release encompasses the photometry for 500 million objects (40 billion measurements) with V magnitudes between 11.5 and 21.5 from an area of 33,000 square degrees. Catalina photometry covers objects in the range $-75^\circ < \mathrm{Dec} < 70^\circ$ and $|b| > 15^\circ$ (more info: http://nesssi.cacr.caltech.edu/DataRelease/).

4 Selection of stars for the development of processing techniques

An analysis of the literature on the stars included in the GTSh10 catalog showed that for some of them there is, at best, one or two articles on the presence of flare activity. Based on this data, the objects were included in the catalogs of variable stars GCVS (Samus et al. 2017) and VSX (Watson et al. 2015). To confirm flare activity and refine the procedure, we performed an investigation of the light curves of selected objects through the photometric survey CRTS.

As a result of the analysis of 8 stars, 97 flares events were detected. We describe a method for data processing, a list of objects examined, the number of flares detected, their amplitudes and the time of registration.

Table 1 contains a list of the objects investigated. The first and second columns indicate the name of the object in the GTSh10 catalog and the SIMBAD database (Wenger et al. 2000, 2006). The third and fourth columns contain the coordinates of the object at the epoch of 2000.0. In the fifth and sixth columns – the value of

Table 1

GTSh10	SIMBAD	R.A. (2000.0)	Decl. (2000.0)	CSDR2	Gaia DR2	T, day	Epochs	Note
1	2	3	4	5	6	7	8	9
1062	QR Tau	03:47:09.01	+22:17:32.3	17.98	18.29	3011	393	–
0972	V1008 Tau	03:45:30.83	+22:33:27.8	15.02	15.26	3011	406	–
0754	V599 Tau	03:39:56.67	+22:28:24.3	15.41	15.61	3011	472	–
0773	KM Tau	03:39:08.12	+24:46:14.6	14.53	16.32	2976	346	–
1582	V0697 Tau	04:33:23.79	+23:59:26.9	11.15	11.40	3121	360	1*
3085	RY Sex	10:36:01.22	+05:07:12.8	11.32	11.37	3127	391	–
3718	IZ Boo	14:20:04.68	+39:03:01.4	11.28	11.26	2984	248	–
5367	BD Psc	23:02:02.98	-02:11:39.9	18.05	18.19	3061	350	–

*According to the Gaia DR2 catalog, the object is a tight pair at a distance of less than 2 arc seconds with stellar magnitudes in the band G $12^m.0498$ and $12^m.2719$. The table shows the total magnitude of both components.

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the average stellar magnitude according to CSDR2 in the V and Gaia DR2 (Gaia collaboration 2018) band in the G band. The seventh column contains information on the duration of observations in days (T, day) and the eighth column indicates the number of epochs of observations (Epochs). In the last column – comments.

Using the Gaia DR2 database (Riello et al. 2018), comparison stars were selected for each of the investigated objects by the following criteria: the brightness of comparison stars is comparable with the brightness of the object and the color indices of the object and comparison stars are close in value.

Also, for each object and comparison stars from the CSDR2 database, series of photometric observational data were obtained. When analyzed, data was used for comparison stars that coincide in time with the data for the object.

Given that the filling of the CSDR2 database occurs on the basis of observations made on 3 telescopes, as well as during the implementation of this project, the recording equipment was repeatedly replaced, so the photometric material is non-uniform. As a result, there is a displacement of zero point in the calibration of stellar magnitudes. Figure 1 illustrates the light curve of one of the comparison stars in the V1012 Tau region. The graph shows that for the same object, the stellar magnitudes determined on different instruments are shown with an offset, marked with different markers (cross and circle), this is due to the processing of observational material obtained on different instruments.

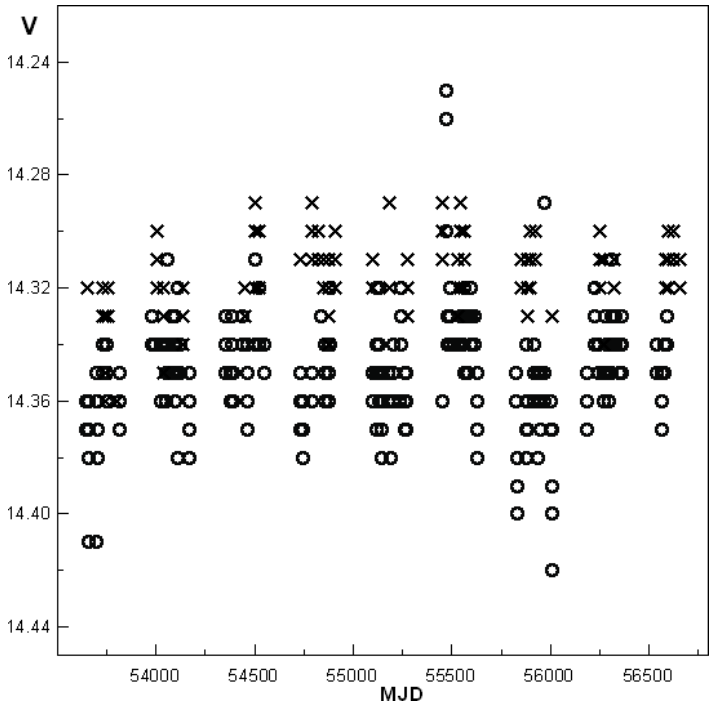


Figure 1 Photometric series of observations obtained on different instruments in the instrumental band V.

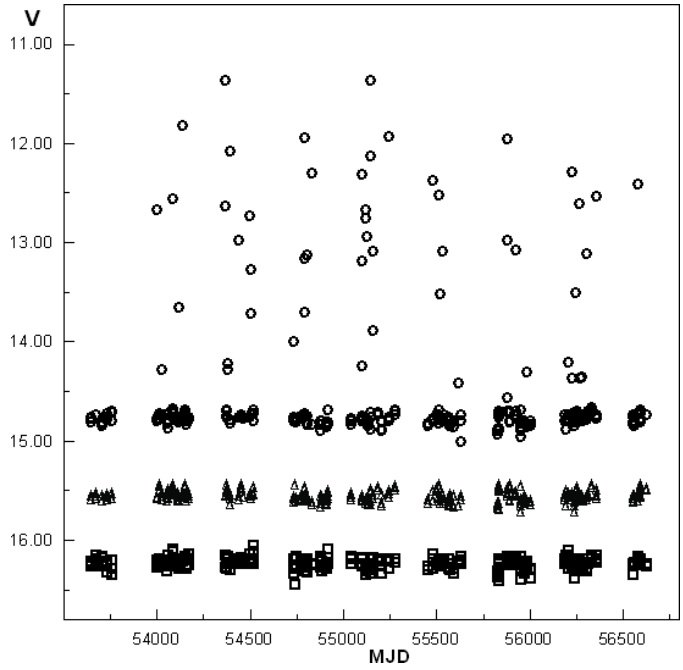


Figure 2 The light curves KM Tau and comparison stars after processing.

For the correct analysis of the flare activity of the investigated stars, the data were reduced to one zero point. This procedure was performed as follows:

- for each instrument, the mean value and the quadratic deviation were calculated;
- for the purpose of increasing accuracy when data is reduced to one zero point, data with large own errors and exceeding level 3 σ were excluded from the photometric series;
- star with instrumental stellar magnitude, which is close to the catalog was selected as the zero point;
- for the photometric data series obtained on other instruments, the difference between their average value and the mean value of the star selected as the zero point was calculated;
- the obtained values of the difference were added to the corresponding series of measurements.

From the above described procedure for reduction the photometric series provided the possibility of a homogeneous analysis of data obtained on different instruments.

From the consideration, time-correlated events with a gloss variation exceeding level 3 σ were eliminated, since they cannot be observed simultaneously at several objects. We believe this to be due to instrumental errors of the observational series.

Figure 2 shows the results of observations of the KM Tau star (circle) and its comparison stars (triangles and squares) after the treatment described above.

To take into account the emerging trend, one of the comparison stars was selected as the reference, and all the photometric data series were reduced to a change in the brightness of this star.

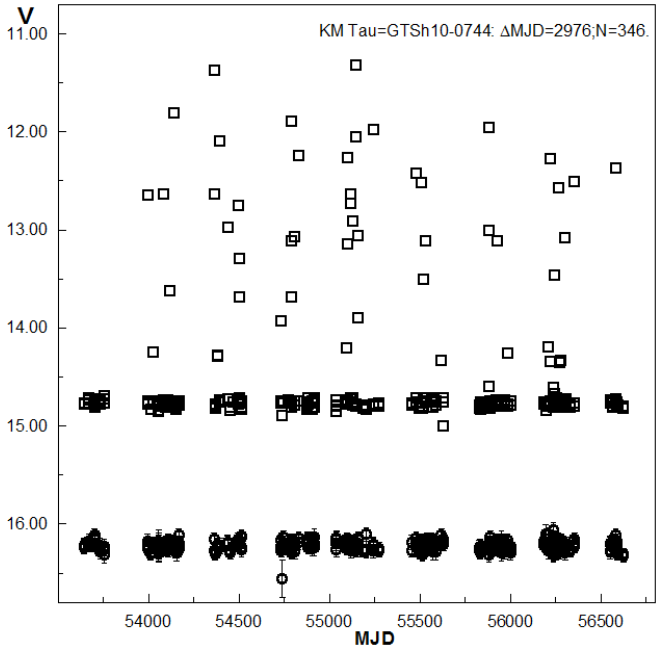


Figure 3 The light curves of KM Tau and the comparison star (explanations in the text).

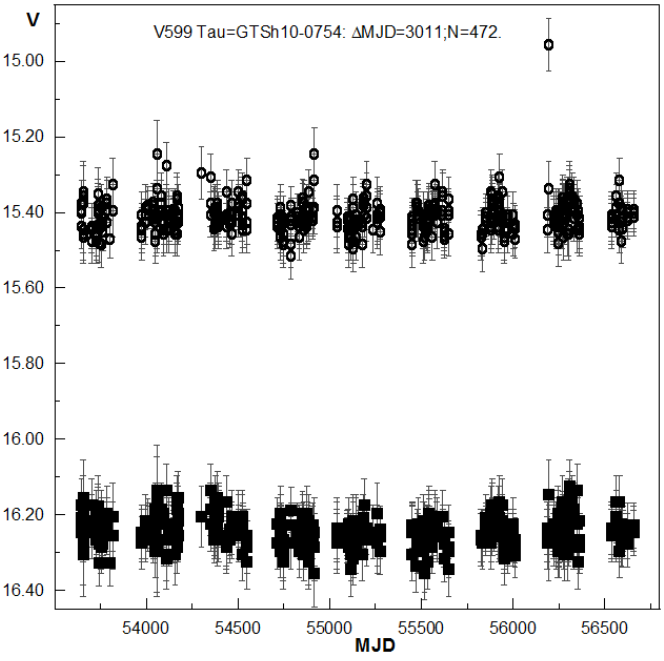


Figure 4 The light curves of the object V599 Tau (circle) and the comparison star (squares).

Figure 3 illustrates the light curves of the KM Tau star (squares) and the comparison star (circle), taking into account the trend and indicating errors in the definition of stellar magnitudes according to the CSDR2 data. The axes indicate the moments of observations of stars, expressed in Julian dates and stellar magnitude.

In Fig. 4, the light curves of V599 Tau and comparison stars are presented as an example of the analysis of registered low-amplitude flares.

Table 2 presents flares of 8 stars from the GTSh10 Catalog obtained from the CSDR-2 database analysis. In the first column, the flares index number is indicated, the second and third columns display the star name in the GTSh10 Catalog and the SIMBAD database. The fourth and fifth columns indicate the mean value of the stellar magnitude in the V band and at the time of the flare. The sixth column shows the amplitude of the flare (ΔV), expressed in stellar magnitude. The seventh column indicates the moments of flares, expressed in Julian dates.

Table 2

No	GTSh10	SIMBAD	Vmid	Vmax	ΔV	MJD 2400000+
1	2	3	4	5	6	7
1	3085	RY Sex	11.344	10.710	0.634	53797.30798
2	3085	RY Sex	11.344	10.720	0.624	53797.30822
3	3085	RY Sex	11.344	10.730	0.614	53797.30869
4	3085	RY Sex	11.344	10.740	0.604	53797.30845
5	3085	RY Sex	11.344	10.800	0.544	55513.53513
6	3085	RY Sex	11.344	10.870	0.474	55618.43452
7	3085	RY Sex	11.344	10.880	0.464	55513.53831
8	3085	RY Sex	11.344	10.900	0.444	55513.53974
9	3085	RY Sex	11.344	10.970	0.374	54448.48841
10	0754	V599 Tau	15.410	15.246	0.164	54057.37771
11	0754	V599 Tau	15.410	15.276	0.134	54109.23623
12	0754	V599 Tau	15.410	15.296	0.114	54300.46913
13	0754	V599 Tau	15.410	15.306	0.104	54351.45268
14	0754	V599 Tau	15.410	15.316	0.094	54549.14331
15	0754	V599 Tau	15.410	15.246	0.164	54916.10929
16	0754	V599 Tau	15.410	15.246	0.164	54916.10929
17	0754	V599 Tau	15.410	15.316	0.094	54916.11216
18	0754	V599 Tau	15.410	15.306	0.104	55927.11119
19	0754	V599 Tau	15.410	14.956	0.454	56194.43174
20	0754	V599 Tau	15.410	15.316	0.094	56581.34108
21	0972	V1008 Tau	15.014	14.826	0.188	56302.11516
22	0972	V1008 Tau	15.014	14.796	0.218	56308.13098
23	1062	QR Tau	17.932	16.979	0.953	54109.22345
24	1062	QR Tau	17.932	17.199	0.733	54109.23011
25	1062	QR Tau	17.932	17.199	0.733	56308.16108
26	1062	QR Tau	17.932	17.139	0.793	56308.17374
27	5367	BD Psc	18.048	17.026	1.023	55563.10186
28	0773	KM Tau	14.757	12.669	2.089	53996.44652
29	0773	KM Tau	14.757	14.279	0.479	54027.36780
30	0773	KM Tau	14.757	12.559	2.199	54081.35915
31	0773	KM Tau	14.757	13.649	1.109	54116.26542

Table 2 continued

No	GTSh10	SIMBAD	Vmid	Vmax	ΔV	MJD 2400000+
1	2	3	4	5	6	7
32	0773	KM Tau	14.757	11.819	2.939	54140.16229
33	0773	KM Tau	14.757	11.359	3.399	54363.45136
34	0773	KM Tau	14.757	12.629	2.129	54363.47274
35	0773	KM Tau	14.757	14.219	0.539	54381.34290
36	0773	KM Tau	14.757	14.279	0.479	54381.38109
37	0773	KM Tau	14.757	12.079	2.679	54394.37463
38	0773	KM Tau	14.757	12.969	1.789	54438.23584
39	0773	KM Tau	14.757	12.729	2.029	54495.16531
40	0773	KM Tau	14.757	13.269	1.489	54502.13092
41	0773	KM Tau	14.757	13.709	1.049	54502.13705
42	0773	KM Tau	14.757	13.989	0.769	54732.38765
43	0773	KM Tau	14.757	11.939	2.819	54788.21439
44	0773	KM Tau	14.757	13.699	1.059	54788.22806
45	0773	KM Tau	14.757	13.159	1.599	54788.23492
46	0773	KM Tau	14.757	13.119	1.639	54807.21603
47	0773	KM Tau	14.757	12.299	2.459	54830.20827
48	0773	KM Tau	14.757	14.239	0.519	55096.39098
49	0773	KM Tau	14.757	13.179	1.579	55102.34871
50	0773	KM Tau	14.757	12.309	2.449	55102.36709
51	0773	KM Tau	14.757	12.669	2.089	55118.33675
52	0773	KM Tau	14.757	12.759	1.999	55118.36076
53	0773	KM Tau	14.757	12.939	1.819	55126.39566
54	0773	KM Tau	14.757	12.129	2.629	55143.26520
55	0773	KM Tau	14.757	11.369	3.389	55143.27242
56	0773	KM Tau	14.757	13.079	1.679	55157.27134
57	0773	KM Tau	14.757	13.879	0.879	55157.28573
58	0773	KM Tau	14.757	11.929	2.829	55241.14066
59	0773	KM Tau	14.757	12.369	2.389	55478.46743
60	0773	KM Tau	14.757	12.519	2.239	55510.31512
61	0773	KM Tau	14.757	13.519	1.239	55517.22801
62	0773	KM Tau	14.757	13.089	1.669	55532.40637
63	0773	KM Tau	14.757	14.419	0.339	55617.15120
64	0773	KM Tau	14.757	12.979	1.779	55880.37507
65	0773	KM Tau	14.757	11.959	2.799	55880.38595
66	0773	KM Tau	14.757	13.069	1.689	55927.09747
67	0773	KM Tau	14.757	14.309	0.449	55983.13490
68	0773	KM Tau	14.757	14.199	0.559	56208.48385
69	0773	KM Tau	14.757	14.369	0.389	56221.46453
70	0773	KM Tau	14.757	12.279	2.479	56221.47067
71	0773	KM Tau	14.757	13.499	1.259	56243.43473
72	0773	KM Tau	14.757	12.609	2.149	56263.28487
73	0773	KM Tau	14.757	14.369	0.389	56268.35601
74	0773	KM Tau	14.757	14.349	0.409	56274.20623
75	0773	KM Tau	14.757	13.109	1.649	56300.19817
76	0773	KM Tau	14.757	12.529	2.229	56353.14334
77	0773	KM Tau	14.757	12.409	2.349	56581.32540
78	1582	V0697 Tau	11.063	10.473	0.590	55063.46941

Table 2 continued

No	GTSh10	SIMBAD	Vmid	Vmax	ΔV	MJD 2400000+
1	2	3	4	5	6	7
79	1582	V0697 Tau	11.063	10.313	0.750	55094.51045
80	1582	V0697 Tau	11.063	10.333	0.730	55094.51097
81	1582	V0697 Tau	11.063	10.333	0.730	55094.51185
82	1582	V0697 Tau	11.063	10.353	0.710	55094.51264
83	1582	V0697 Tau	11.063	10.363	0.700	55094.51350
84	3718	IZ Boo	11.296	10.581	0.715	53900.33781
85	3718	IZ Boo	11.296	10.611	0.685	53900.33892
86	3718	IZ Boo	11.296	10.611	0.685	53900.34002
87	3718	IZ Boo	11.296	10.571	0.725	53900.34108
88	3718	IZ Boo	11.296	11.011	0.285	54593.46905
89	3718	IZ Boo	11.296	10.981	0.315	55330.33782
90	3718	IZ Boo	11.296	10.861	0.435	55330.34532
91	3718	IZ Boo	11.296	11.001	0.295	55330.35286
92	3718	IZ Boo	11.296	10.841	0.455	55636.30455
93	3718	IZ Boo	11.296	10.931	0.365	55636.31100
94	3718	IZ Boo	11.296	10.851	0.445	55636.31741
95	3718	IZ Boo	11.296	10.911	0.385	55636.32391
96	3718	IZ Boo	11.296	11.031	0.265	56371.43804
97	3718	IZ Boo	11.296	11.031	0.265	56371.44197

Conclusions

In the course of studying the flare activity of 8 stars from the GTSh10 catalog, a technique was developed and 2966 events were analyzed for more than 9 years of observations of these objects according to the Catalina Sky Survey project and 97 events are regarded by us as flares. The minimum fixed flare amplitude is $0^m.1$ of the star magnitude for V599 Tau, the maximum is $3^m.4$ for KM Tau. Given that for some of the stars investigated there was only one mention in the literature of the detection of the flares, this work confirms the presence of flare activity in these objects.

When analyzing the V0697 Tau state from the data of the Gaia DR2 catalog, it was found that the object is a close pair at a distance of less than 2 arc seconds with stellar magnitudes in the band G $12^m.0498$ and $12^m.2719$.

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