Red Flares on Stars: Optical Observations and Possible Interpretation

M. A. Ibrahimov

Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia
mansur@inasan.ru

Abstract. Compiled optical observations of new phenomenon, red flares on stars (RFs), are presented and discussed in paper. Generally, in optic RFs look like "slow" flares who demonstrate unusual "3-redness": "red" maxima, "red" distribution of flare amplitudes (opposite to that observed for flares of typical UV Cet type stars), and "red" optical colors. Available statistics and observed optical features of RFs are analysed. RF features are suggested to explain in light of impacting exobodies. In that picture, small bodies in some exoplanet system impact to each other or/and impact to exoplanets/exomoons themselves producing slow and powerful flares in optic with unusual "3-redness" characteristics.

Keywords: stars: flare

DOI:10.26119/978-5-6045062-0-2_2020_288

1 Introduction

Well-known and well-studied flares on typical UV Cet type stars demonstrate "blue" maxima (normally in optical U band), "blue" distribution of flare amplitudes (which normally drops from blue to red/IR bands), and "blue" optical colors (so called "blueing" during the flare). However, there are some flares who demonstrate right opposite characteristics. In this paper such flares are suggested to term as "red flares" (RFs). RFs are new and previously non-attracted attention phenomenon. Available RF statistics includes 3 objects and 5 RFs observed on them. These are UU CrB (1 RF in 1980), FF Ori (2 RFs in 1991 and 1992), and IX Oph (2 RFs in 1992 and 1993). Compiled RF optical observations are presented and analysed in paper. RFs demonstrate the following features in optic: "slow" flares with "red" maxima, "red" distribution of flare amplitudes (opposite to that observed for typical UV Cet type stars), and "red" optical colors. RFs markedly differ from typical flares observed for UV Cet type stars. Main differs are: i) RFs happened in systems hosted F-K type stars, ii) RFs appeared to be powerful flares or superflares (estimated powers ranged in 10^{36}-10^{39} erg), iii) RFs are "slow" flares (all well-observed RFs had a duration more than 30 min), iv) RFs flare energy distribution notably differs from that of UV Cet type flares (so called "3-redness" of RFs: red maxima, red amplitude distribution, and red colors). Another one possible (possible because of small event statistics) differ is: RFs seem to be recurrent flares (2 of 3 objects demonstrated recurrent flares).

2 Red Flare Statistics and Observed Optical Features

All so far observed optical data for RFs is summarized in Table 1. Chronologically, the first RF was observed on May 21, 1980 on F8V star UU CrB (Olson 1980). Flare duration was more than 40 min. The inverse ("red") distribution of flare amplitudes was $\Delta I_K{:}\Delta V = 0.30 : 0.05$. However, the flare colors seemed to be difficult to analyse and compare with that of other RFs (observations had been done in specific photometric system using combination of Stromgren-Crawford and Kron $uvby + I_K$ filters).

Table 1. Red flare statistics and observed optical features

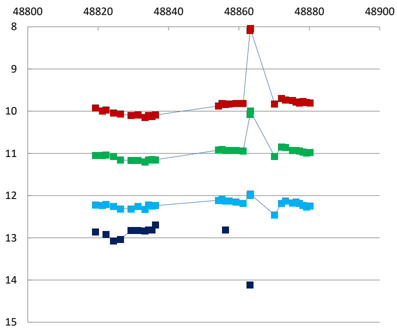
No.	Star name	Flare date	Duration ($\gtrsim$ *min*)	Red maxima ΔR (*mag*)	Red amplitude distributions $\Delta R{:}\Delta V{:}\Delta B{:}\Delta U$ (*mag*)	Red colors $(UB){:}(BV){:}(VR)$ (*mag*)
1	UU CrB	1980 May 21	40	0.3(ΔI_K)	$\Delta I_K{:}\Delta V = 0.30 : 0.05$	*no*
2	FF Ori	1991 Oct 26	2	0.1	0.1 : 0.0 : 0.0 : *no*	0.06 (V-R)
3	FF Ori	1992 Oct 22	60	0.1	0.1 : 0.0 : 0.0 : *no*	0.06 (V-R)
4	IX Oph	1992 Aug 28	70	1.8	1.8 : 1.0 : 0.2 : -1.3	2.12 : 1.94 : 1.98
5	IX Oph	1993 Jul 27	2	1.8	1.8 : 0.9 : 0.3 : *no*	*no* : 1.94 : 2.01

Remarks to Table 1:

UU CrB (Olson 1980): F8V star; observed in 5 color Stromgren-Crawford and Kron $uvby + I_K$ system; Johnson ΔV system magnitude from original paper; estimated flare power $\approx 7 \times 10^{35}$ erg.

FF Ori (Zakirov 1993, 1996): eclipsing binary system with B8V + F0 IV-III stars and $P = 1.8105$ day; observed in $UBVR$ system; recurrent RFs with a time lag of 12 months between the flares; both flares happened in $MinI$ at phases 0.001–0.025P (63 minutes); estimated flare power 10^{36} erg.

IX Oph (Ibrahimov 2019): $SB1$ spectral binary system with invisible primary and visible K1-3 III secondary components; observed in $UBVR$ system; brightness variations with amplitude $\sim 1^m$, possible period ~ 150 day, and UV-excess of -0.3^m with 15-20 day long "plateau" in U-curve were detected by Ibrahimov & Grankin (2019); recurrent RFs with a time lag of 11 months between the flares; estimated flare power $\gtrsim 10^{39}$ erg.



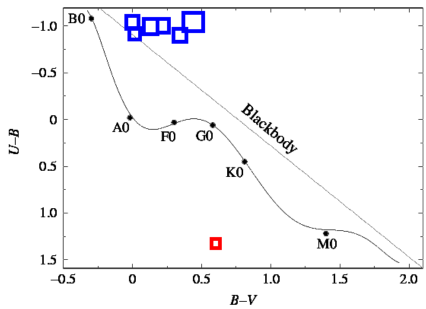


Fig. 1. *Left panel:* 1992 light curves of IX Oph in (top to bottom) R, V, B, and U bands. Scales in *mag* and $JD2400000+$ units. Red flare is seen in all curves with its red maximum in R and red amplitude distribution from flare in R to anti-flare (eclipse) in U. *Right panel:* (U-B)-(B-V) diagram in *mag* for intrinsic flare radiation. Typical UV Cet type flare radiation are plotted as blue squares, while red square is that for red flare of IX Oph.

The next two RFs were observed in FF Ori eclipsing binary during its $UBVR$ monitor (Zakirov 1993, 1996). System includes B8V + F0 IV-III stars with $P =$ 1.8105 day. The first RF had been observed on October 26, 1991 (1 observation), the second one on October 22, 1992 (8 observations). The both RFs happened near the primary minimum at phase interval 0.001–0.025P (63 min). RFs were observed in R-band only. No synchronous brightness variations were found in other bands. Maximal flare amplitude detected was $\Delta R \approx 0.1^m$. During the both RFs, $(V - R)$ color reddening was observed. At the primary minimum $(V - R) \approx 0.25^m$, while during RFs the average color was $(V - R) \approx 0.31^m$ (see Tables 3 and 5 in Zakirov (1996)). So, during the both flares the $(V - R)$ reddening was 0.06^m.

Two more RFs were detected by Ibrahimov (2019) in IX Oph during its $UBVR$ monitor. The star is $SB1$-type spectral binary system. Binaries was concluded from a joint analysis of IX Oph spectra obtained in 2004 using Keck/HIRES (Herbig 2005) and its 22-yr optic photometry (Ibrahimov & Grankin 2019). Primary component is appeared to be an invisible object with a strong UV radiation. Secondary one is a normal K1-3 giant. The first RF was observed on August 28, 1992 (observations lasted more than 70 minutes, three BVR and one U brightness estimates were obtained). The second RF was observed on July 27, 1993 (observation was about 2 minutes, one BVR- and no U-band brightness estimates were made). 1992 $UBVR$ light curve of IX Oph is shown in Fig. 1 (left panel). Accuracies of brightness estimates were 0.01–0.03^m for BVR and 0.05–0.07^m for U bands. 1992 RF of IX Oph (perhaps the most spectacular ever observed RF) is also shown in the panel. RF appears itself as characteristic "jumps" in all bands compared to generally smooth brightness variations. BVR jumps happened upward (flare), while U jump happened downward (anti-flare or eclipse). RF shown in Fig. 1 is the best example to demonstrate so called "3-redness": red maximum, red distribution of amplitudes and extremely red colors (see also Table 1 for exact numbers).

3 Possible Interpretation: Exoimpacts

Two-color (U-B)-(B-V) diagram for intrinsic flare radiation is shown in Fig. 1 (right panel). Data to plot such a radiation for flares of typical UV Cet type stars is taken from the recent monograph of Gershberg (2015) [Gershberg R.E., Solar-Type Stellar Activity of the Main Sequence Stars, Simferopol: Antikva Ltd., 2015, p.299] and shown as blue squares in the diagram. That for red flares observed on IX Oph calculated using Ibrahimov (2019) and plotted as red square.

Principal difference between two type of flares is clearly seen in the diagram. "Blue" flares locate above the line of non-redden colors. This generally implies a star nature of UV Cet type flares. "Red" flares locate beneath the line. This could be considered as a non-star nature of RFs. There are two general mechanisms to produce non-star radiation: i) disk accretion and ii) small body impacts. The latter seems to be reasonable to use as a possible interpretation of RF nature. If so, RF features (their long duration, unusual 3-redness, and recurrence) could naturally be explained in light of impacting exobodies. In that picture, small bodies in some exoplanet system impact to each other or/and impact to exoplanets/exomoons themselves producing (perhaps recurrently) slow and powerful flares in optic with unusual "3-redness" characteristics.

The first (and unique so far) direct observations of a half-year aftermath of a possible exoimpact had been observed in 2013 in NGC2547-ID8 system using IR *Spitzer* space telescope (Meng et al. 2014). Follow-up ground-based VI_C optical photometry of the system had also been done and no red flares detected within the system optical variations of order 0.05^m. The lack of RF type events could simply be explained by missing of them due to about 150 day long system non-visibility because of the Sun. If so, appropriate optical RFs would be happened in the system at the very beginning or before than the first successful IR-detection of exoimpact aftermath had been done. In any way, the both intensive and simultaneous optical and IR monitor are needed to verify exoimpact nature of the red flares.

Bibliography

Herbig, G. H. 2005, AJ, 130, 815
Ibrahimov, M. A. 2019, INASAN Science Reports, 4, 199
Ibrahimov, M. A. & Grankin, K. N. 2019, INASAN Science Reports, 4, 192
Meng, H. Y. A., Su, K. Y. L., Rieke, G. H., et al. 2014, Science, 345, 1032
Olson, E. C. 1980, Information Bulletin on Variable Stars, 1825
Zakirov, M. M. 1993, Information Bulletin on Variable Stars, 3925
Zakirov, M. M. 1996, Astronomy Letters, 22, 593