High-Cadence B-Band Search for Optical Flares on CR Draconis

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Received November 22, 2016; revised December 16, 2016, January 12, 2017; accepted January 12, 2017

Abstract The high-cadence search at 50 samples/sec of CR Dra revealed one B-band flare of 560 ± 30 seconds' duration, and 30-mmag peak above the mean. Three additional potential low-level flares could not be confirmed. The search for fast sub-second flares was conducted with negative results. The study collected 1.15×10^7 photometric measurements over 64.16 hours on 27 nights from May 6, 2016, through October 25, 2016. This represents a flare rate of 0.016 flare/hour. The CR Dra binary has resolved orbital components with established orbital elements. From this flare and historical flare events, any correlation between the system components' calculated linear separation and flare activity level could not be confirmed.

1. Introduction

CR Draconis is one of approximately 100 nearby flare stars within 25 pc, a short period young Me dwarf binary type M5.6V (Simbad 2016), B-magnitude 10.92, HIP 79796. The flaring of the young Me dwarf star systems is related to their stage of evolution. That is, almost all dwarf stars possess the ability to flare during an early portion of their evolution and some of low luminosity can stay in this stage for 10^{10} years or longer (Mirzoyan 1990). Factors influencing this evolutionary process are still under study, with stellar rotation, magnetic fields, total mass, and potentially their component separation being contributors. Tamazian *et al.* (2008) presents a good summary of the current theories for flaring of these systems. One recent study area is the relationship between flares and the rapid changes in their stellar magnetic field configuration and coronal mass ejections (CME). Manchester *et al.* (2005) describes a model whereby the CME drives "fast-mode" shock from the stellar surface to distances of approximately 1 AU with consequent plasma and magnetic field changes, which may affect flare activity. This theory has researchers looking for nearby binaries with short periods and known orbits to look for correlation between component separation within ~ 2 AU or less and increased flare rates or flux energy levels. For this reason alone, the short period binary CR Dra is of interest in understanding the relationship, if any, between flaring and magnetic field interaction of close partners.

CR Dra is one of a small number of nearby flare stars less than 25 pc distant with the potential for resolving the individual bodies and calculating orbit and dynamical mass. Tamazian *et al.* (2008) used speckle measurements to refine the previous work of Blazit *et al.* (1987) to resolve the two-body system. These data revealed a highest probability mass sum of 1.00 Ms, a dynamical parallax of 58.43 mas or 17.4 pc, an orbital period of 4.040 ± 0.005 years, and orbital elements with ephemeris for the years 2008–2013. With these data the correlation between the bodies' orbital separation and flaring were studied as proposed by Manchester *et al.* (2005). The very limited historical flare data (Table 1) were superimposed on the calculated orbital positions (Tamazian *et al.* 2008), and revealed "no plausible correlation between flaring activity and linear distance between components."

The objective of this search was to conduct a high-cadence photometric study to capture conventional longer flares and also any solo or short duration sub-second flares preceeding, during, or following the main outburst. Such data should improve the granularity of knowledge of an outburst event and potentially capture very fast solo events missed by conventional long integration photometry (Vander Haagen 2013, 2015). These data will also be resampled for longer flare analysis. In addition, any flare data will be correlated with the component orbital position.

2. Optical system, data collection, and analysis tools

The optical system consisted of a 43-cm corrected Dall-Kirkham scope, a high-speed silicon photomultiplier (SPM), and a data acquisition system capable of sub-millisecond data collection times. The SPM was chosen for this application

Table 1. The historical data for CR Dra flares show the observation time span, detection results, linear separation distance (d) in AU, and flare rates. Flare rates were generally not cited (—) or total observing time was not provided to enable calculation.

Observation Date	*Flares Detected*	*Distance (d) AU*	*Flare Rate*	*Reference*
1968 May 28–July 14	none	2.59–2.34	0	Cristaldi and Rodono (1970)
1970 May 11–June 18	1 flare	2.45–2.52	—	Cristaldi and Longhitano (1979)
1971 July 1	1 flare	2.95	—	Cristaldi and Rodono (1973)
1974 June 7	1 flare	2.47	0.025 flares/hour	Kareklidis *et al.* (1977)
1974 June	low activity	2.47	—	Mahmoud (1991)
1975 June–August	none	2.96–2.93	0 flares, 46.9 hours	Mahmoud *et al.* (1980)
1978 May 10–17	1 flare	2.41	—	Anderson (1979)
1980 July 19–20	none (Einstein)	2.41	0	Ambruster *et al.* (1987)
1991 June	none (ROSAT)	2.95	0	Tsikoudi and Kellett (1997)
2007 March–July	none	2.78–2.93	0	Tamazian *et al.* (2008)
2007 April–July	20 flares	2.83–2.92	—	Dal (2012)

because it has sensitivity comparable to a standard single channel vacuum photomultiplier yet a more robust mechanical and electrical design with the disadvantage of higher dark counts (Vander Haagen 2011).

The optical system is shown in Figure 1. The incoming beam is split approximately 85/4 with the reflected portion passing through the optical filter, an f-stop yielding a 57 arc-second field, and onto the SPM detector. A wide bandwidth pulse amplifier amplifies the SPM signal, producing a 2–3 volt pulse of approximately 50ns for each converted photon. The photon pulses are sent to a PC-based data acquisition system where they are gated and counted based upon the collection rate. A 20-ms gate was used for measurements, generating a 50 Hz data collection rate or 50 samples/second. The balance of the incoming beam passes through the beam splitter to a conventional CCD camera used for initial alignment, guiding, and measurement of both the guide star flux and background flux. The target flux counts along with GPS 1-second time stamps are recorded in the DAQ Log File by the data acquisition system (Vander Haagen and Owings 2014). The CCD Data and Control stream consists of reference and background flux values plus pixel counts for each guide star sample, typically every 5 seconds. These values are stored in the AG (auto-guider) Tracker Log file.

Upon completion of the night's search the DAQ Log File and the CCD's AG Tracker Log File are merged and parsed so every target data point is matched to the time Tracker data with the target counts corrected for the SPM dark counts and sky background in a quadrature calculation, and each sample GPS time-stamped. This parsing operation results in an integrated file with all constituents ready for analysis, with each file containing up to one million sample lines each containing target, reference, and background data. Files of this size are too large for spreadsheet analysis but are easily analyzed using signal processing software such as SIGVIEW (SignalLab 2016). The files are reviewed and can be processed using a variety of filters,

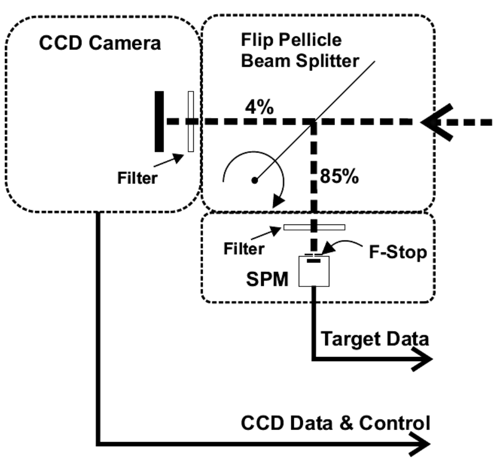

Figure 1. The optical train pictorial shows the pellicle beam splitter with both reflected and pass-through beams. The reflected beam passes through the narrow band filter, aperture, and onto the silicon photomultiplier (SPM). The pellicle can be flipped to allow 100% light transmission for initial target alignment using the CCD camera. The SPM is mounted on a X-Y stage for precise centering of detector to the centerline of the CCD camera. Guiding is provided with pellicle in position shown.

time domain transforms, and statistical tools. After reviewing the high speed data for fast flares the data were resampled using SIGVIEW to 2-second bins for the longer flare search. The same reference star is used for each run. Since the prime flare attributes for analysis are the ratio of peak flux to mean flux, duration, and the flare profile, the data are not corrected for air mass.

3. Flare search

The study objective was capturing high time-resolution flaring activity connected with longer duration conventional flares and short duration solo flares. Very short flares of 10 to 100 ms duration have been observed unconnected with conventional flaring activity. These very short flares generally consisted of one or more points at 3σ or higher with a peak at 4–10σ. A 50ms duration flare was reported for EV Lac in the U–B band by Zhilyaev and Romanjuk (1990) and simultaneous U and B-band flares on BY Dra (Zalinian and Tovmassian 1987). Vander Haagen (2013) also reported very short duration flares on AR Lac, II Peg, and UX Ari of 30 to 85 ms duration with peaks 0.29–0.51 magnitude above the mean.

A criterion was developed to isolate these short duration flares in very large sample sizes: flares must consist of a minimum of three consecutive data points, two at or above 3σ and one at or above 5σ. Since the minimum number of photons per gate was always 100 or more, normal distribution statistics were used to compute the standard deviation. Statistics were collected 600 seconds prior to the event where possible using digital signal processing software (SignalLab 2016). This process is similar in direction to that followed by flare searches (Byrne *et al.* 1994) and as described by Vander Haagen (2015). The probability of this sequence being a random event is 5.2×10^{-13} N, where N is the number of integrations or samples taken during the observing interval and σ is for the positive events only. With N ranging from 1 to 2×10^6 samples during an observing interval the probability of the event sequence being random is appropriately small. This criterion was used for each of the data sets to isolate potential short duration flares.

The search for slower or longer flares with small flux change was best served by resampling to a longer gating period of two seconds. Searching for such signals in the 100 mmag or lower range with durations of minutes or longer at low S/N ratios is difficult amidst all high frequency noise. All the data groups were reviewed at both the 50 s/sec and the resampled 0.5 s/sec rates.

4. CR Dra data collection and results

Data collection was conducted over 27 nights from May 6, 2016, through October 25, 2016 (Figure 2). The total data collection time was 64.16 hours, or 231 Ksec at 50 samples/sec. Using a 500-nm low pass filter combined with the SPM response the resultant band pass approximates standard B-band. B-band was chosen since CR Dra emits greater flare energy at shorter wavelengths (Cristaldi and Longhitano 1979). The U-band would have been the best choice for low-level flare detection but the SPM detector has very little response in that region.

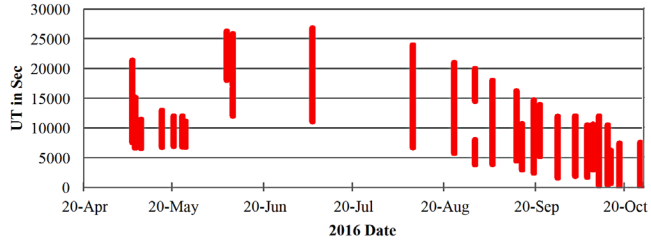

Figure 2. CR Dra data collection span of 27 nights from May 6 through October 25, 2106. The y-axis is in UT (seconds) for the date specified, showing the nightly time span when data were acquired, e.g., 7201 sec UT = 02:00:01 UT.

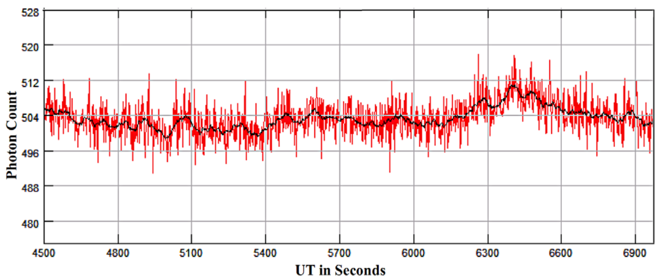

Figure 3. 2016-09-27, CR Dra data resampled at 0.5 s/sec (2 sec gating period) showing 30 mmag, 560 ± 30 seconds duration flare with 503 mean and 517 peak (4.1σ). The solid black line is a 20-sample running-average plot. CR Dra is a steady 10.92 B-mag star under non-flaring conditions. The time axis is in UT (seconds) for the date specified, e.g., 7201 sec UT = 02:00:01 UT.

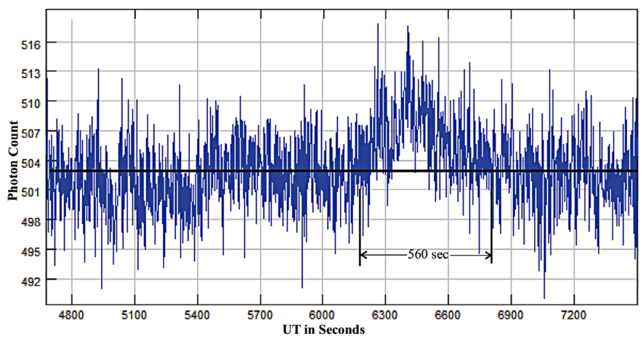

Figure 4. 2016-09-27 CR Dra axis expanded to show greater flare detail and the duration measurement. Sample rate is 50s/sec. Duration is measured between the approximate points where flux exits and returns to the mean value of 503 counts (horizontal line) or 560 ± 30 sec. The time axis is in UT (seconds) for the date specified, e.g., 7201 sec UT = 02:00:01 UT.

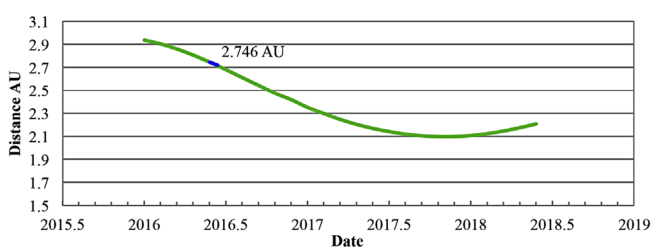

Figure 5, binary component linear separation calculated using the orbital elements from Tamazian *et al.* (2008). Highlight shows orbital position of 2016-09-27 flare at 2.75 AU.

No short duration flares were detected using the statistical criteria over the full 1.15×10^7 measurement data set.

All data sets were resampled using two-second gating, 0.5 s/sec, and reviewed for flare activity. Figure 3 shows a 2016-09-27 flare of 30 mmag, 4.1σ, and 560 ± 30 seconds' duration. The graph scale is expanded in Figure 4 to show greater instantaneous detail and the flare duration as measured at the mean quiescent flux crossing line. The flare occurred at the two-body linear separation of 2.75 AU as shown in the orbital plot (Figure 5). There were three other potential low level flares, two on 2016-10-09 and one on 2016-08-23, that could not be confirmed due to unstable atmospheric conditions and the poor S/N of the target and reference data.

5. Conclusions

In conclusion, a statistical criterion was used to isolate short duration optical flares from random photon events. No short duration flares were detected over the 64.16-hour observing period. One 560-second duration flare was detected with peak 30 mmag above the mean yielding a flare rate of 0.016 flare/hour. The flare rate is the prime indicator of activity and there are insufficient data for statistical analysis. However, the flare rate and magnitude are consistent with those reported by Kareklidis *et al.* (1977) at 2.47 AU linear separation, but likely a substantially lower rate than Dal (2012) at 2.83–2.92 AU, should the rate been provided.

The 0.016 flare/hour does not confirm or disapprove the conclusion of Tamazian *et al.* 2008 that there is no correlation between activity level and component separation. The activity level from the Dal (2012) search in which 20 flares were detected at 2.83-2.92 AU does help the argument. However, until a search is conducted close to the minimum body separation of 2.1 AU, where flare rates and/or flux increases are theorized, a firm conclusion seems premature. There will be an opportunity early in the fall of 2017 when the binary is at minimum linear separation to test the fast-mode shock hypothesis.

6. Acknowledgements

Thanks are expressed to L. E. Owings for his collaboration on the data pipeline and writing of the two software programs necessary for data reduction.

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