Very Short-Duration UV–B Optical Flares in RS CVn-type Star Systems

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Abstract Very short-duration UV–B optical flares were observed during a high-cadence search for conventional flares on three RS CVn type stars: AR Lac, II Peg, and UX Ari. A statistical criterion was developed for isolating these short-duration optical flares from random photon events. Five flares, ranging in duration from 30 to 85ms with peaks 0.29–0.51 mag. above the mean, were detected within the 132 hours of monitoring time. The time resolution of the observations was 5ms for AR Lac and 10ms for II Peg and UX Ari.

1. Introduction

A flare survey was conducted of known RS CVn-type flare stars AR Lac, II Peg, and UX Ari from August 15, 2012, through December 28, 2012. The optical system consisted of a 43cm 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 the remote controlled application because it has comparable sensitivity to a standard single channel vacuum photomultiplier yet a more robust mechanical and electrical design with the disadvantage of higher dark counts (Vander Haagen 2012).

The optical train is shown in Figures 1 and 2. The incoming beam is split approximately 80/5 with the reflected portion passing through the UV–B 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. These photon pulses are sent to a PC-based data acquisition system where they are gated and counted based upon the collection rate. A 10ms gate was used for most of the measurements, generating a 100Hz data collection rate or 100 samples/second (100s/sec). The balance of the incoming beam passes straight through to a conventional CCD camera used for initial alignment and guiding. The SPM is mounted within the housing on a miniature X-Y stage for precise alignment to the center of the CCD camera. This allows automated flips and realignment to the small field of view SPM.

Each data set was also time-stamped at one-second intervals using a GPS time signal. Data sets can be timed between the 1-second intervals using synchronized tics provided by the data acquisition system. Each of the acquisition system files consists of one million data sets. Files of this size are too large for spreadsheet analysis but are easily analyzed using signal processing software such as SIGVIEW (SignalLab 2013). The files can be reviewed and processed using a variety of filters, time domain transforms, and statistical tools.

2. Flare search

The search's initial objective was collection of rapid cadence data on three known flare stars for profiling of the rise and fall structure and possible oscillation detection during the flare sequences (Mathioudakis *et al.* 2003). However, when reviewing over 476Ksec of data another unusual phenomenon became apparent. Very short flares of 10 to 100ms duration were observed unconnected with conventional flaring activity. These very short flares generally had a build up of one or more points at 3σ or higher with a peak at 4–10σ. A similar 50ms-duration flare was reported for EV Lac in the UV–B band by Zhilyaev *et al.* (1990).

A criterion was developed to isolate these short-duration flares in the database of 6.6×10^7 data sets: 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 400, 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 2013). This process is similar in direction to that followed by flare searches (Byrne *et al.* 1994). The probability of this sequence being a random event can be represented by Equation (1), where N is the number of photons gated each measurement and σ is for the positive events only.

$$\Pi_{3,3,5\sigma} = P_r(3\sigma)^2 5\sigma = (1.35 \times 10^{-3})^2 \times (2.9 \times 10^{-7})\, N = 5.2 \times 10^{-13}\, N \qquad (1)$$

With N ranging from 400 to 2000 the probability of the event sequence being random ranges from approximately 2×10^{-10} to 10^{-9}. This criterion was used for each of the data sets to isolate potential short-duration flares.

3. AR Lac

AR Lac is a RS CVn-type eclipsing binary system with flaring reported from the X-ray to the optical region (Kovari and Pagano 2000). AR Lac was observed in the B band. The total monitoring time was179Ksec, or 49.7 hours. Sampling occurred at 200s/sec (5ms gating period) with two short-duration flares observed that meet the detection criterion, or 0.04 flares/hour. Figure 3 shows a flare that occurred on September 5, 2012. This flare had strong leading intensity points with maxima at 6σ, approximately 85ms in duration with peak 0.42 mag. above mean. The Figure 4 flare occurred on September 15, 2012, with duration of 30ms and 0.32 mag. above mean.

4. II Peg

A second RS CVn-type eclipsing binary system, II Peg, was studied with UV–B optical flaring reported by Henry and Newsom (1996). II Peg and UX Ari were observed in the UV–B band using an Edmund 500nm short pass filter. When combined with the response of the SPM the resultant band pass is approximately 380 to 500nm. Sampling was at 100s/sec (10ms gating period) for a total of 205Ksec, or 69.4 hours. Two short flares were recorded, or 0.03 flare/hour. The Figure 5 flare occurred on November 6, 2012, with duration of 50ms and 0.36 mag. above mean. The periodicity produced by peaks 2, 3, and 4 of Figure 5 generate a strong 6.3–7+ Hz component on the power spectral density spectrum (PSD) of Figure 6. Figure 7 shows the November 8, 2012, flare with duration of approximately 70ms and 0.51 mag. above mean.

5. UX Ari

The third target was UX Ari, a member of a subset of RS CVn stars with flares reported by Henry and Newsom (1996). Sampling was at 100s/sec (10ms gating period) for a total of 92Ksec, or 25.6 hours. With one detected flare the resultant rate was 0.04 flare/hour. Figure 8 shows the December 13, 2012, flare with duration of 60ms and peak 0.29 mag. above mean.

6. Discussion and conclusions

The potential for atmospheric scintillation as source or inducer of the short duration peaks was investigated. There was no simultaneous secondary reference to rule out this contribution. Fourier PSD transforms were made of each data set. A wide range of noise amplitude and cutoff frequencies were present across the data sets. Where short-duration peaking occurred, digital band pass filters were employed to isolate the frequency domain signature of the event. No signature that was narrow or consistent enough could be identified. Such a signature might allow correlation with the frequency domain noise spectra to give indication of possible contribution to the peaking events. This area of investigation did not prove fruitful.

In conclusion, very short optical flares were observed during a high cadence search for conventional flares on three RS CVn type stars. A statistical criterion was developed for isolating these short optical flares from random photon events in the 6.6×10^7 data sets. Five flares, ranging in duration from 30 to 85ms with peaks 0.29–0.51 mag. above the mean, were detected within the 476Ksec, or 132 hours, of monitoring time. Whether the criterion is too restrictive or permits occasional random events to be classified as flares will require additional collaboration. With collaborative support a theoretical analysis of the short flare events could be developed.

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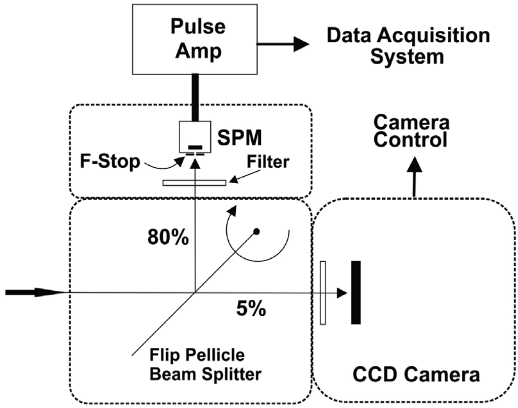

Figure 1. Optical train showing pellicle beam splitter with reflective and pass-through beams. Reflected path passes through the narrow band filter, aperture, and onto the silicon photomultiplier. The pellicle can be flipped to allow 100% light transmission for initial target alignment using the CCD 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.

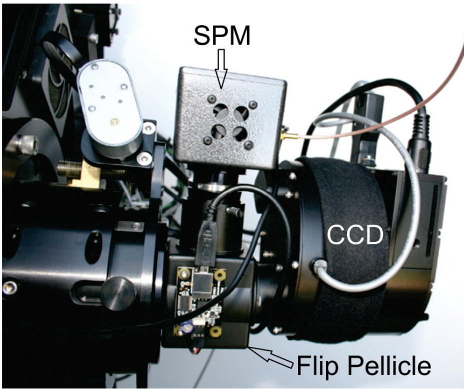

Figure 2. The optical train photo shows the SPM detector assembly mounted top center with SBIG CCD camera to the right in the same relative positions as the Figure 1 diagram. The flip pellicle is automated with its housing and motor controller visible directly below the SPM.

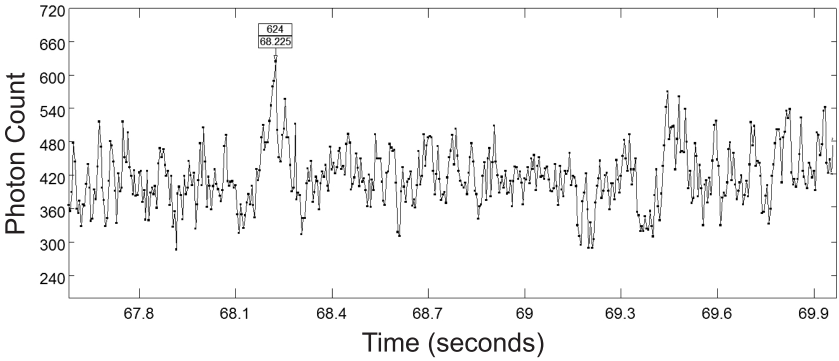

Figure 3. September 5, 2012, AR Lac sampled at 200 s/sec (5ms gating period) mean 424, σ 33, data leading to maxima 545, 579, 589, and 624 (6σ). A 3σ peak was 0.23 mag. above the mean. Flare length was 85ms with peak 0.42 mag. above mean. X-axis is seconds from start of data collection run. Annotation box on graph shows peak count (upper value) and time at peak (lower value).

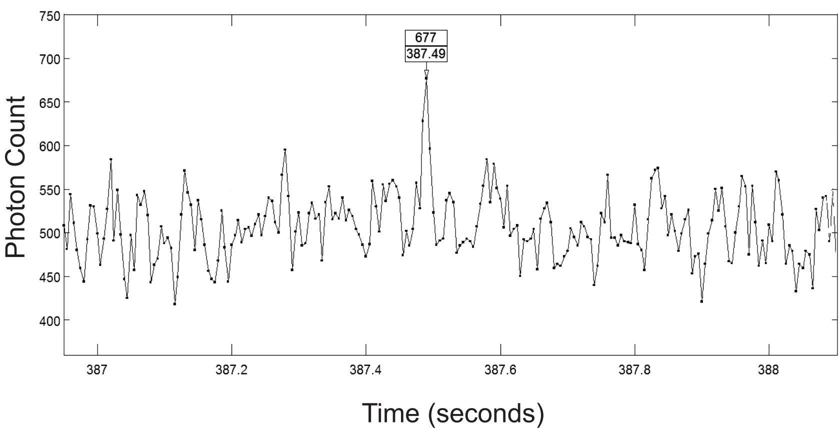

Figure 4. September 15, 2012, AR Lac sampled at 200s/sec, mean 502, σ 31, data points 628, 677 (5.6σ), 596. A 3σ peak was 0.18 mag. above the mean. Flare duration 30ms with peak 0.32 mag. above mean. Annotation box on graph shows peak count (upper value) and time at peak (lower value).

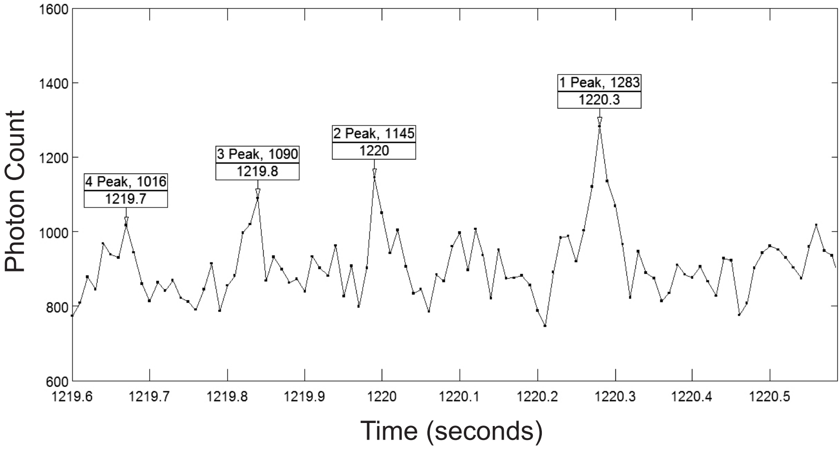

Figure 5. November 6, 2012, II Peg sampled at 100s/sec (10ms gating period), mean 921, σ 35, data point sequence on peak one 1121, 1283 (10.3σ), 1135, 1068. A 3σ peak was 0.12 mag above the mean. Peak 1 flare duration 50ms with peak 0.36 mag. above mean. Note periodicity of peaks 2, 3, and 4. Annotation box on graph shows peak count (upper value) and time at peak (lower value).

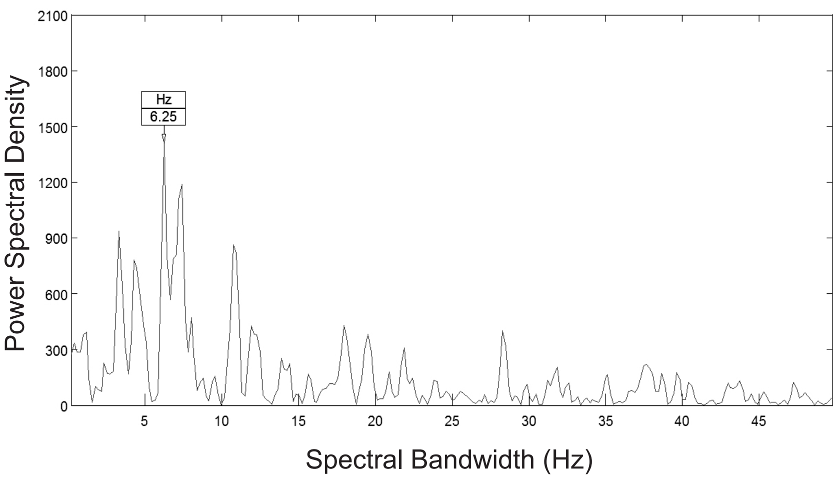

Figure 6. Power spectral density (PSD) curve of II Peg, November 6, 2012. Note 6.25–7+ Hz signal produced by peaks 2, 3, and 4 of Figure 5 data. The spectral bandwidth is 50 Hz as dictated by a sampling rate of 100 Hz.

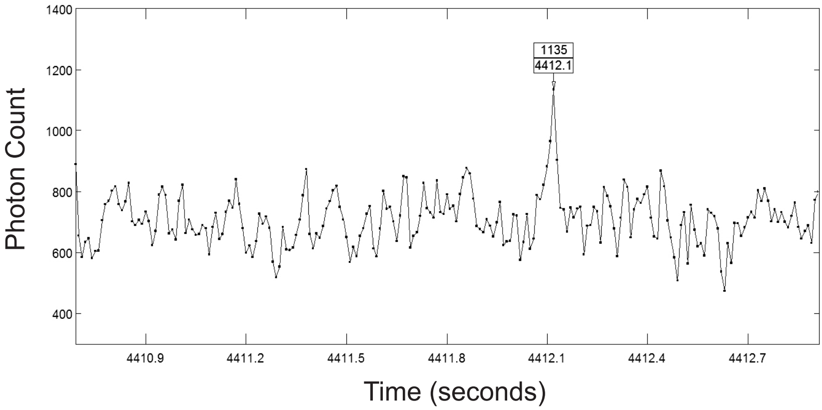

Figure 7. November 8, 2012, II Peg sampled at 100 s/sec, mean 710, σ 68, data point sequence 882, 964, 1135 (6.3σ), 903. A 3σ peak was 0.27 mag. above the mean. Flare duration 70 ms with peak 0.51 mag. above mean. Annotation box on graph shows peak count (upper value) and time at peak (lower value).

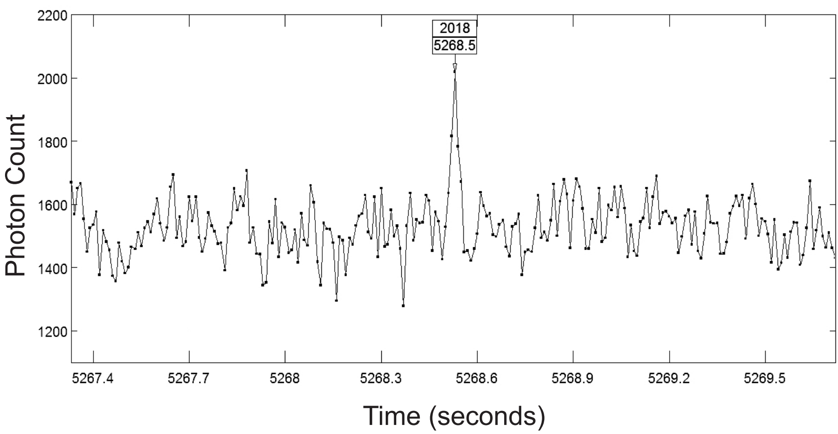

Figure 8. December 13, 2012, UX Ari sampled at 100s/sec, mean 1542, σ 80, data point sequence 1815, 2018 (6σ), 1783. A 3σ peak was 0.16 mag. above the mean. Flare duration 60 ms with peak 0.29 mag. above mean. Annotation box on graph shows peak count (upper value) and time at peak (lowervalue).