Recent Outbursts of the High Mass X-Ray Binary CI Camelopardalis

Abstract

CI Camelopardalis (CI Cam) is a High Mass X-Ray Binary (HMXB) that was discovered by the All Sky Monitor (ASM) on board the Rossi X-Ray Timing Explorer (RXTE) when it underwent an outburst in 1998. CI Cam, also known as XTE J0421+560, peaked first in X-rays followed by optical and radio wavelengths(2.25, 8.3, and 15 GHz). Several soft X-ray flares were observed after the initial flare. The optical flux was observed to quickly return to quiescent levels, while the radio flare was of much longer duration. The outburst was also detected by the X-ray satellite BeppoSax and the Burst and Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory. The optical counterpart, CI Cam, is a B0-2 blue supergiant Be star and, assuming a compact object as an accretion companion (black hole, neutron star, white dwarf), the system can be designated an HMXB. Additionally, there is a pulsating third companion with periods of 0.41521 and 0.26647 days. While the initial outburst occurred in 1998, there is photometric evidence that there have been several later outbursts of similar magnitude to the original 1998 event. This paper will discuss these later outburst events as well as the identified pulsation modes.

1.0 Introduction

There are two classes of X-Ray binaries, Low Mass X-Ray Binaries (LMXBs) and High Mass X-Ray Binaries (HMXBs). LMXBs consist of a white dwarf and a dim main sequence M or K star orbiting in a binary pair, with the white dwarf accreting matter from the companion star. HMXBs consist of a black hole, neutron star, or white dwarf accreting matter from young, massive, bright O or B spectral type companion stars. There are two broad classes of HMXBs, short period ones (a few days) with O or B supergiant companions (SG/X-ray binary) and longer period ones (weeks to years) with B-type companions (specifically a rapidly rotating Be star, where the “e” refers to emission spectrum, producing a Be/X-ray binary). The majority of known High Mass X-Ray Binaries are Be/X-ray systems. Matter is transferred from the ordinary star to the black hole, white dwarf, or neutron star, thereby producing X-rays and optical light as the gravitational energy of the accreting material is converted into electromagnetic radiation. The X-ray radiation is produced by the accretion disk and accretion layer of the neutron star while the optical energy comes from the O or B star (these are referred to as the “optical counterparts” of the X-ray/optical binary system). The SG/X-ray binary fills or nearly fills its Roche lobe and transfers mass via an accretion disk to the orbiting compact companion. In the Be/X-ray binary, the compact object follows an eccentric orbit, spending little time in close proximity to the Be companion. Additionally, the Be star is rapidly rotating and transfers mass to the compact companion through stellar wind and a centrifugally produced equatorial disk. CI Cam is one of five HMXBs being continually observed by AARI using the AAVSOnet system of robotic telescopes. While the photometry of most HMXB objects tends to vary over a relatively small range (less than one magnitude), CI Cam exhibits a significantly larger range and has a complex structure. This structure will be examined in this paper.

2.0 Methods

The photometry data for CI Cam was obtained from the AAVSO VSX (American Association of Variable Star Observers; Variable Star Index) (Kloppenborg 2021) database. Specifically, the data was in the Johnson-Cousins BVRI photometric magnitude ranges (Johnson B; 400-500 nm, Johnson V; 500-700 nm, Cousins R; 550-800 nm, and Cousins I; 700-900 nm) and pure visual data. Additional data was obtained from the ASAS-SN (All-Sky Automated Survey for SuperNova) (Kochanek, et al. 2017) global network of robotic telescopes. The ASAS-SN photometric magnitude range is Sloan g (402.5-551.5 nm). An ASAS-SN light curve was computed for 2000 days, combined with the visual and Johnson-Cousins BVRI data, and analyzed with the AAVSO VStar (Benn, D. 2012, Algorithms + Observations = VStar, JAAVSO, v40, n2, pp.852-866) software. The total span for all photometry was April 4, 1998 to March 4, 2024. The composite light curve (BVRI, Visual, Sloan g) is shown in Figure 1.

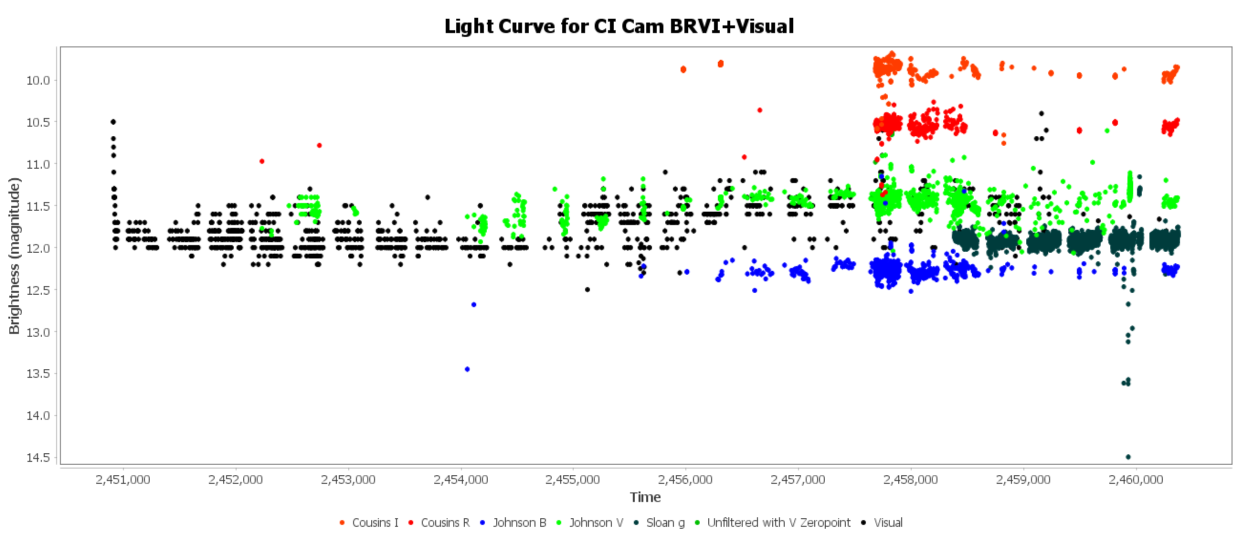

Figure 1: Composite Light Curve for CI Cam

3.0 Analysis and Results

The photometry bands mentioned above include the latest observations in the bands indicated, including the observations by AARI using the AAVSOnet system. The ASAS-SN Sloan g data, shown in Figure 2, was used to compute the orbital period of the two primary members of the system, yielding 19.374092 days as shown in Figure 3, which is consistent with previous measurements of the period of CI Cam.

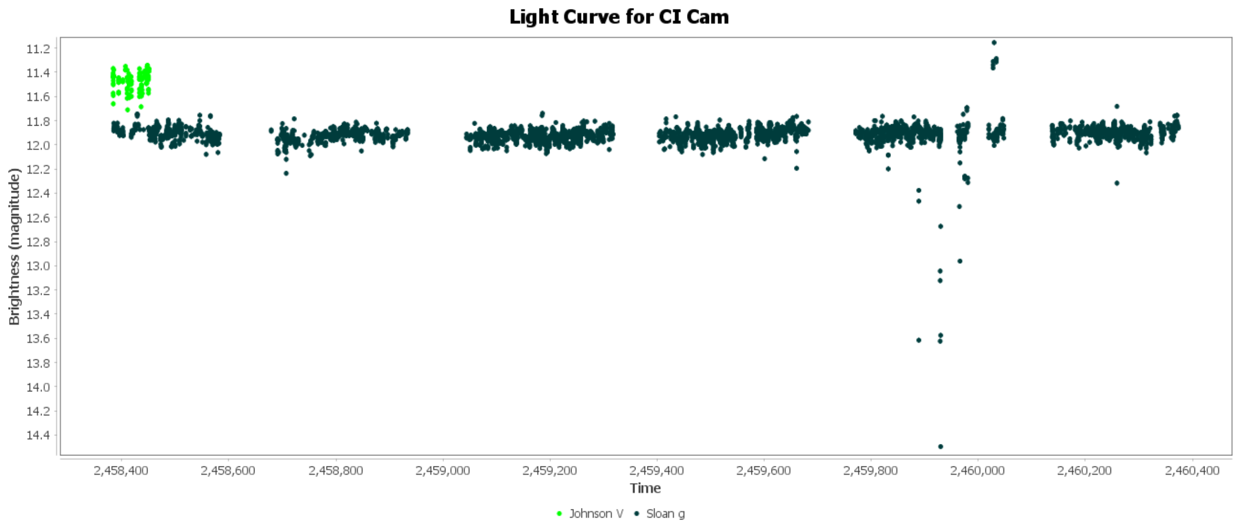

Figure 2: ASAS-SN (Sloan g) Photometry

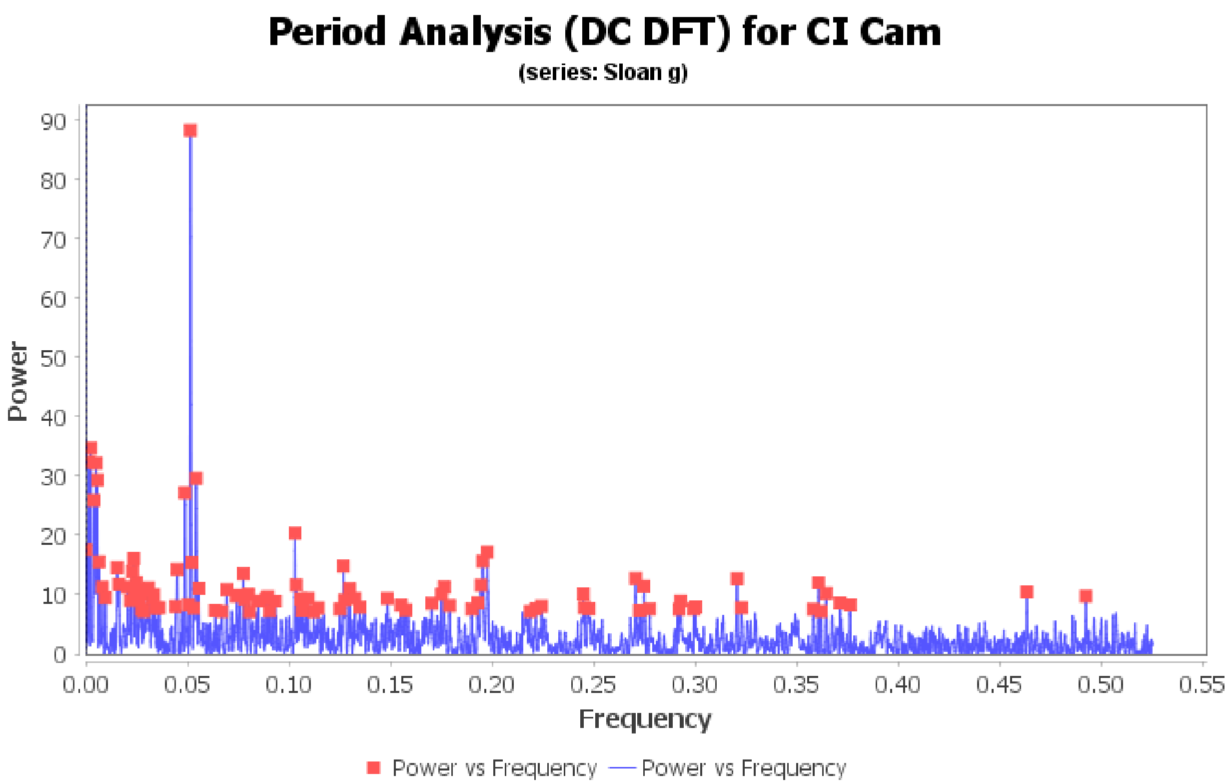

Figure 3: ASAS-SN (Sloan g) Periodogram

The Johnson-Cousins BVRI data, shown in Figure 4, indicated significant fluctuation of over one magnitude but with no discernible periodicity. However, there is a pulsating third companion with periods of 0.41521 and 0.26647 days, as described in Goranskij, V.P. and Barsukova, E.A, 2009, due to the pulsations of a B4 III-V type component. Additionally, Goranskij, V.P. and Barsukova, E.A, 2018 in ATel 12097 indicate that CI Cam began pulsation in a single mode of 0.4062 days. Evidently, the original pulsations in the secondary mode disappeared, suggesting that the pulsations are radial and the secondary mode was excited earlier due to a resonance. The BVRI fluctuations mentioned above may be due to the third component orbit and pulsations.

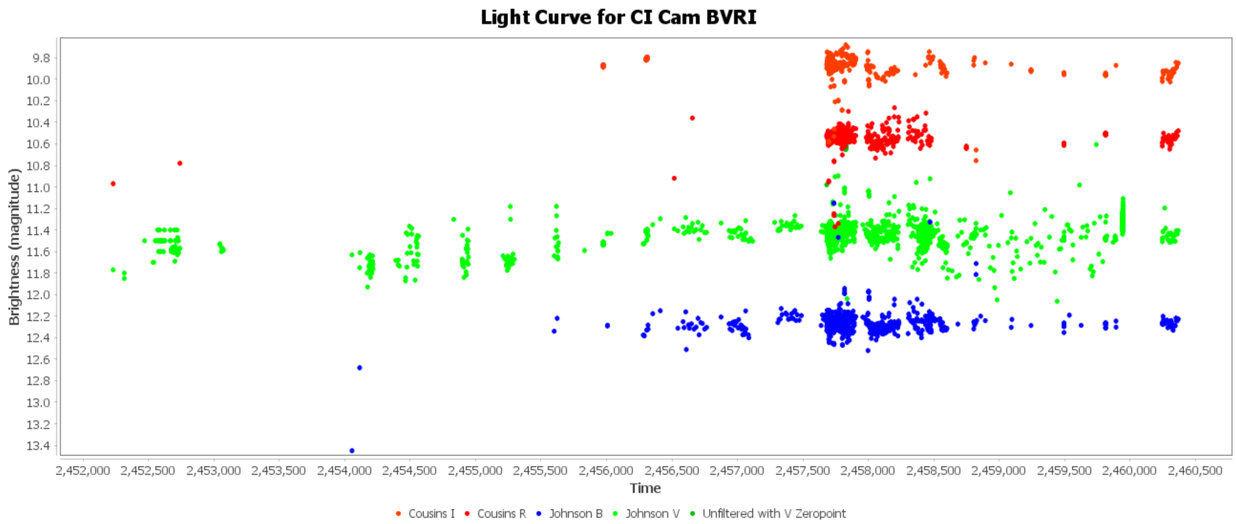

Figure 4: Johnson-Cousins BVRI Photometry

It has been suggested that the third component may be an FS CMa-type object (CI Cam-Remark 2). FS CMa objects are Be-type stars (spectral types ranging from O9 to A2) that exhibit much stronger hydrogen emission lines than those seen in classical Be stars and also exhibit forbidden (low excitation) lines of FeII, [FeII], [NII], [OI] and strong IR excesses, which are indicative of compact dust envelopes. They are also not fast rotators like the Be stars. They are most likely binary systems that currently are undergoing or have recently undergone a phase of a rapid mass exchange, associated with dust formation. Modeling of circumstellar dust formation is discussed in Clark, J.S., Miroshnichenko, A.S., Larionov, V.M., et al. 2000. The secondaries are typically 2-3 magnitudes fainter than their primaries. The complex structure of the circumstellar environments significantly veils the underlying stars and requires multi-technique investigation. They are located outside star formation regions and are probably main sequence stars (not supergiants). Their light curves show irregular long-term variations with long term (years) mean magnitude changes up to 2 magnitudes in V. Again, this could account for the rapid fluctuation seen in the BVRI photometry.

Interestingly, the visual data, shown in Figure 5, and some of the Johnson V data obtained (April 4, 1998 to February 27, 2024; JD 2350908.29-JD 2460266.3944) indicates the presence of seven outbursts; the original from April 1998 and six additional outbursts of similar magnitude to the original. These six later outbursts seem to have not been discussed in current literature. A literature search indicated that there was very little information available beyond the early 2000's other than the publications concerning the pulsation modes described above. The seven outbursts indicated from the CI Cam visual and Johnson V data, shown in Figure 6, are:

1. April 4, 1998/JD 2450908.29; 10.5 magnitude/visual-original outburst
2. December 22, 2016/JD 2457745.3, 10.6 magnitude/visual
3. March 14, 2017/JD 2457826.52542, 10.476 magnitude/Johnson V
4. November 4, 2020/JD 2459158.4, 10.4 magnitude/visual
5. December 16, 2020/JD 2459200.3, 10.6 magnitude/visual
6. October 6, 2021/JD 2459494.4, 10.6 magnitude/visual
7. June 11, 2022/JD 2459741.5638, 10.606 magnitude/Johnson V

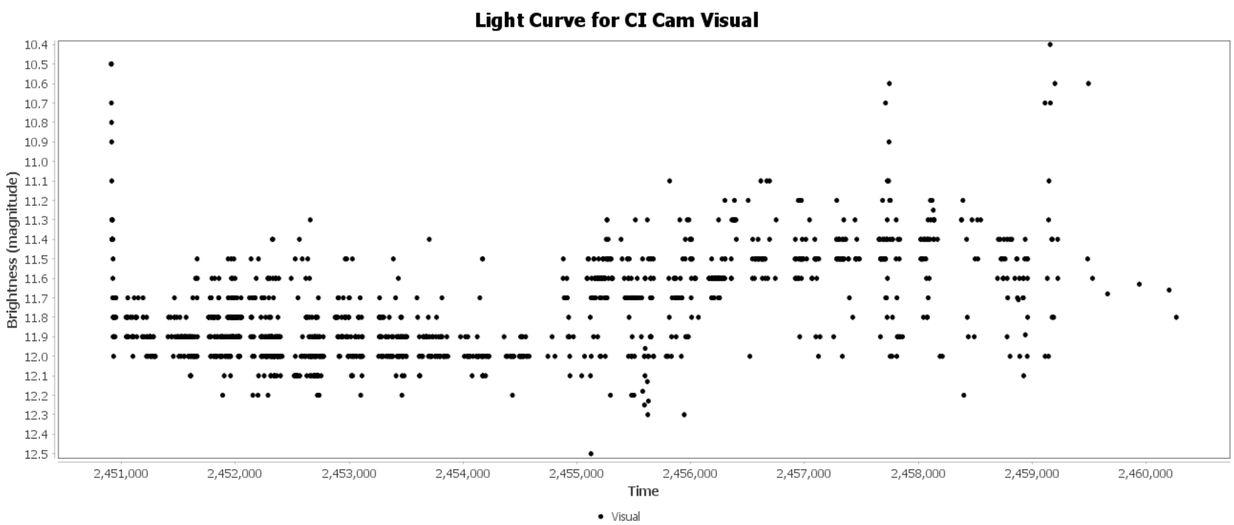

Figure 5: Visual Photometry

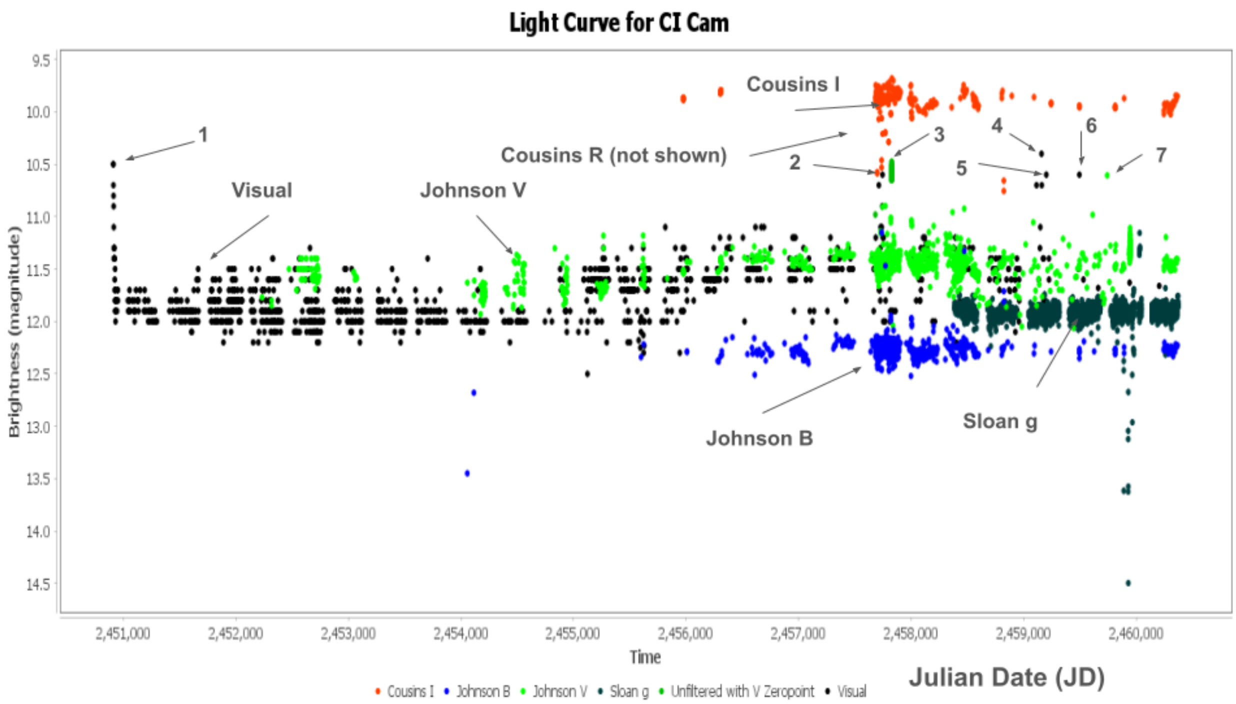

Figure 6: Composite Light Curve HMXB CI Cam Showing Outbursts

These outbursts, while quite obvious in the visual photometry, are not at all obvious in the BVRI bands. As can be seen in Figure 6, the Johnson V does correlate with visual for two observation dates, but does not generally track with the visual. The BRI data has little if any correlation, but does show the rapid fluctuation indicated above. This may also be due, at least in part, to irregular observations of CI Cam in BVRI, but this is not clear. It should be noted that the Cousins R data is not shown in Figure 6 because it obscures several important peak magnitudes in the visual photometry.

4.0 Conclusions

As can be seen from the simple analysis of HMXB CI Cam, determination of periods and other variations as well as potential physical mechanisms that may account for these variations is a complex process. CI Cam has been shown to exhibit orbital periodicity, multiple outbursts, and varying pulsation phenomena. This provides for a fruitful area of research, observation, and analysis. AARI is observing CI Cam, along with several other HMXB stars, with the AAVSOnet network of robotic telescopes and will continue to observe this object indefinitely.

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