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Long-term activity and outburst of the microquasar CI Cam (XTE J0421+560)

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We present an analysis of the long-term activity of CI Cam (XTE J0421+560). It includes the 1998 outburst, its impact on the activity of the system in the following years, and a comparison with the activity detected on the archival Bamberg photographic plates (1928–1939). We argue that the outburst can be explained by the thermal instability of the accretion disk embedding the black hole, analogous to the outbursts of soft X-ray transients. We show a line of evidence that, in quiescence, the dominant part of the X-ray emission in CI Cam comes from the close vicinity of the compact, mass accreting object, not from the supergiant donor component. In quiescence, the optical/IR activity is caused by the contributions of several superimposed spectral components; this is true also for the proposed 1300 d cycle. We explain the large variations of the absorption in the X-ray spectrum, not reflected in the brightness and color variations in the optical region, in terms of the changes in the hot disk embedding the black hole.

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1. Introduction

CI Cam (MWC 84) is the optical counterpart of the X-ray transient XTE J0421+560 [22]. Characteristics of the 1998 outburst are quite atypical among X-ray transients (e.g. [9, 15]). The X-ray outburst was accompanied by a strong brightening in the optical and radio. Jets launched during the outburst were probably smothered early on by the unusually dense circumstellar medium [12]. The outburst occurred in an unusual system, because the optical spectrum is classified as B[e] (e.g. [11, 7]). This event influenced both the photometric and spectroscopic properties of the system (e.g. [7]). The compact object is most likely a black hole (BH) or a neutron star (e.g. [18, 12]). The distance d is less than 3 kpc according to [14], but more than 5 kpc according to [18]. The orbital period $P_{\rm orb}$ is uncertain. [2, 3] claimed that the photometric period of 19.41 ± 0.02 d, accompanied by the variations of the radial velocity in He II 4686, is $P_{\rm orb}$.

2. Data analysis

The long-term activity of CI Cam was analyzed using the photoelectric and CCD observations obtained in 1989–2004 using the data from [4, 21]. In order to extend the coverage to the past, the measurements on the photographic plates from the archive of the Bamberg Observatory were included (Figure 1a). The points are connected by line in densely covered segments. These plates were blue-band sensitive, which is similar to the B filter. The exposure time was 60 min (Figure 1b). These observations covered the years 1928–1939, with the typical uncertainty of 0.05 mag. An example of the time evolution of the I band magnitude in quiescence after the 1998 outburst can be seen in Figure 1c. The variation of the color indices over the same time interval as in Figure 1c is displayed in Figure 1d. More details can be found in [20, 21]. In order to compare the peak magnitude of the 1998 outburst with that of soft X-ray transients (SXTs), the relation of the absolute V magnitude $M_{\rm V}$ of SXTs at the outburst maximum vs. $P_{\rm orb}$ was investigated (Figure 1e).

3. Results

We present an analysis of the optical activity of CI Cam on the timescales of years and decades.

The comparison of the activity of CI Cam in the optical passband in 1928–1939 and 1989–1994 shows mutually similar characters of the brightness variations in these two intervals that precede the 1998 outburst. The fluctuations on the timescale of days with the mean magnitude almost constant can be readily seen. The variations in the photographic blue band refer to the dominant variations of the (pseudo)photospheric layers (see [21]). We detect no waves like those observed after the 1998 outburst. The mean blue magnitude in 1928–1939 appears to be plausibly consistent with that in 1989–1994, which means no significant secular variations on the timescale of decades. The smooth waves in the optical light curve appeared immediately after the 1998 outburst [21]. This suggests a change of the activity after this outburst. We interpret this as the impact of this outburst on the behavior of the system in the following years. These findings indicate that the outbursts like that in 1998 are quite rare in CI Cam, with their recurrence time longer than a decade.

The smooth waves with a possible cycle-length of about 1300 d are typical for the post-outburst activity of CI Cam in $UBVRI$ in 1999–2004. Cycles of a comparable length are observed in some

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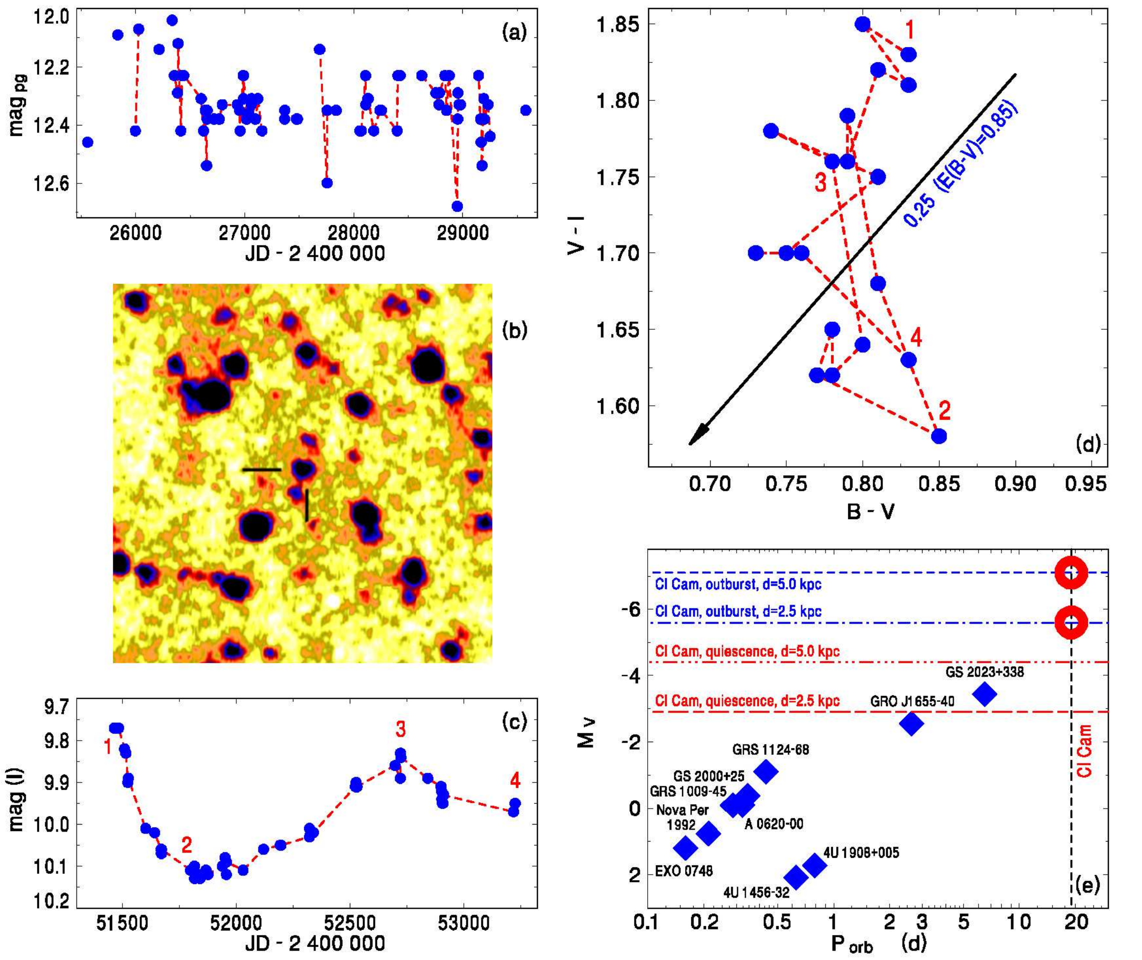

Figure 1: (a) The long-term activity of CI Cam on the archival, blue-band sensitive photographic plates. (b) Example of the plate (Sept 13, 1936). North is up, east to the left. Field size shown here is 36×36 arcmin. (c) Example of the time evolution of the I band magnitude in quiescence after the 1998 outburst. (d) $B-V$ vs. $V-I$ diagram for CI Cam after the outburst. The line connecting the points denotes the time evolution. The numbers at some points enable a comparison with Figure 1c. The color indices are not corrected for the reddening. The vector denotes the reddening of CI Cam $E_{\rm B-V} = 0.85$ mag [18]. (e) The absolute V band magnitude $M_{\rm V}$ of SXTs at the outburst maximum vs. $P_{\rm orb}$ (filled diamonds). $M_{\rm V}$ of CI Cam in the 1998 outburst and in quiescence for two values of d is given. The parameters of 10 SXTs are from [19]. Because of incomplete coverage of the optical lightcurve, the magnitude of CI Cam is given for $t - T_{\rm max} = 1$ d, where $T_{\rm max}$ refers to the time of the peak X-ray luminosity. Large circles mark CI Cam for $P_{\rm orb}$ proposed by [2].

B[e] stars, so CI Cam would not be unique in this respect. Cycles with the typical lengths of $\sim$130 to $\sim$1600 days, sometimes present only in some color bands, were reported for several such objects (see [13] for a review). Significant variations of the continuum light play a large role in CI Cam, because otherwise we would observe rather independent variations of the individual color indices (Figure 1d, see [21] for details). We interpret them in terms of several superposed spectral components, with the division of their dominant contributions near $\lambda = 550$ nm: free-free emission from the wind and/or envelope (in the red and near IR spectral region; [7]), and another component in the blue region: a (pseudo)photospheric emission.

We interpret the 1998 outburst in terms of the thermal instability of the accretion disk embedding the BH. The very fast rise in X-rays observed e.g. by [9] can be explained by the evaporated inner disc region prior to the outburst using the model [8]. This event is of the type FRED, hence we applied the model of [10], in which the irradiation by X-rays is strong enough to ionize all of the disk out to its outer edge. The luminosity at the outburst peak is $L_{\rm peak} \approx 3 \times 10^{38}$ erg/s (0.8 $L_{\rm Edd}$) ($d = 5$ kpc), the disk mass being $M_{\rm h}(0) \approx 1.5 \times 10^{23}$ g and the disk radius being $R_{\rm h}(0) \approx 2.5 \times 10^{10}$ cm. This is consistent with the disks of soft X-ray transients (SXTs) (see [20] for more). The small $M_{\rm h}(0)$ and $R_{\rm h}(0)$ speak in favor of a small, wind-fed disk [23]. A comparison of the absolute magnitude of CI Cam with those of SXTs puts an important constraint on the emission mechanism. The absolute peak magnitude of outburst, $M_{\rm V}$, of SXTs tends to brighten with $P_{\rm orb}$ [19]. A very large disk radius that would be needed if it were the site of luminosity in outburst of CI Cam is in contradiction with the small $R_{\rm h}(0)$ inferred from the model of [10] and the rapid outburst decline. Most luminosity thus comes from a different site, which is also supported by the reddening of the colors in outburst ($\Delta(B-V) \approx 0.33$ mag, $\Delta(V-R) \approx 0.45$ mag from the observations of [1]) and the very bright $M_{\rm V}$ in outburst. This can be caused by heating up an extended envelope by a small disk and/or jet formation.

A comparison of the outburst in CI Cam with the ensemble of SXTs shows that $L_{\rm peak} \approx 0.8 L_{\rm Edd}$ ($d = 5$ kpc) of this event is typical for the outbursts of SXTs in [6]. The rise timescale $\tau_{\rm r} \approx 0.3$ d and decay timescale $\tau_{\rm d} \approx 0.8$ d are the shortest ones among SXTs. The total outburst energy $E_{\rm tot} \approx 2 \times 10^{43}$ ergs ($d = 5$ kpc) sorts this event to the least energetic third of outbursts of SXTs on a logarithmic scale of $E_{\rm tot}$.

Huge changes observed in the X-ray absorption of CI Cam in quiescence after the outburst by [16, 5], with $N_{\rm H}$ variable from 6×10^{21} to 4×10^{23} atom/cm^2, are accompanied neither by the brightness nor color variations, if the relation of [17] is applied. The variations of $N_{\rm H}$ are thus confined to the region hotter than the temperature of the dust condensation. This provides us with an important information on the site of the increasing density of the medium. We thus conclude that the dominant part of the X-ray emission originates from the compact object, not from the donor. The increase of the X-ray absorption can be caused by re-filling of the disk embedding the BH.

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