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Photometric activity of the unique X-ray transient CI Camelopardalis (XTE J0421+560)

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Abstract

We present an analysis of the photometric observations of the peculiar X-ray binary and X-ray transient CI Cam (XTE J0421+560), mostly covering the interval following its 1998 outburst. We show that the most prominent variations are observed in the *I* band, with the amplitude decreasing toward the *V* (and *U*) passband. We find that CI Cam displays complicated shifts in the colour diagrams and show that the variations of the continuum play a significant role in the colour changes. We also resolve the signatures of the variations of the very strong Hα emission with respect to the combination of the continuum and other lines in the colours. On the basis of the shifts in the colour diagrams and of the spectral energy distribution determined from the photometry we propose that the division of the dominant contributions of the superimposed spectral components (free–free emission (Clark, J.S., Miroshnichenko, A.S., Larionov, V.M., et al., 2000, A&A, 356, 50) and the (pseudo)photospheric emission) occurs near $\lambda = 550$ nm. We make use of this division for an explanation of the decoupling of the variations of *U–B* and *B–V* from those in *V–R*, *R–I* and *V–I*. We observed two maxima of brightness (the second one only in *R* and *I*) separated by 1350 d in which the (pseudo)photospheric emission, f–f/f–b and Hα emission appear to be involved in a complicated way. We find some indications that the variations of the source of the optical light can be related to those of the X-ray source in quiescence, particularly in an event which we interpret as a density enhancement in the matter exchange. We explain the huge changes of the absorption of the X-ray spectrum, N_H, not reflected in the colour variations in the optical region, in terms of the variations of N_H confined to the region hotter than the temperature of the condensation of the dust, maybe related to the filling of the disk embedding the compact object. We argue that the dominant part of the X-ray emission comes from the close vicinity of the compact object, not from the donor. Very low-amplitude (~0.02 mag) intranight optical variations can be present in four nights of our observations in the post-outburst period; they have the form of bumps on the time-scale of about an hour, but without any coherent component. We also point out the similarities in the situation of CI Cam and the microquasar LS 5039/RX J1826–1450, as regards the variations of brightness coming from the vicinity of the compact object.

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1. Introduction

CI Cam (MWC 84) is the optical counterpart of the X-ray transient XTE J0421+560, discovered on March 31, 1998 (Smith et al., 1998). It presented some characteristics that made it quite atypical among the X-ray transients

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(e.g. Frontera et al., 1998; Orr et al., 1998; Revnivtsev et al., 1999; Clark et al., 2000; Hynes et al., 2002). The X-ray outburst was accompanied by a strong brightening in the optical and radio. It was considerably shorter than the outbursts in typical soft X-ray transients (SXTs) (e.g. Chen et al., 1997). Mioduszewski and Rupen (2004) suggested that the jets were smothered early on by the unusually dense circumstellar medium. This outburst is usually interpreted either as a periastron passage of the compact object (Hynes et al., 2002) or as a disc instability (Robinson et al., 2002), although a thermonuclear runaway on a white dwarf (nova explosion) was also proposed by Frontera et al. (1998), Orlandini et al. (2000) and Ishida et al. (2004). Recently, Šimon et al. (2006) discussed several possible scenarios and presented the arguments for the disc instability using the King and Ritter (1998) formalism.

The outburst occurred in an unusual system because the optical spectrum of CI Cam is classified as B[e] (e.g. Lamers et al., 1998; Clark et al., 2000). Miroshnichenko et al. (2002) argued that its distance is less than or equal to 3 kpc, while Robinson et al. (2002) argued that it is at least 5 kpc. The outburst influenced both the photometric and spectroscopic properties of the system (e.g. Clark et al., 2000; Hynes et al., 2002; Barsukova et al., 2002). The compact object is most likely either a black hole (BH) or a neutron star (NS) (e.g. Robinson et al., 2002; Belloni et al., 1999; Hynes et al., 2002; Mioduszewski and Rupen, 2004), but a white dwarf was also proposed (e.g. Ishida et al., 2004). The orbital period P_{orb} remains uncertain, although fluctuations of brightness before (Bergner et al., 1995; Miroshnichenko, 1995) and after the outburst (Barsukova et al., 2002; Barsukova et al., 2005a; Barsukova et al., 2005b) were reported. Barsukova et al. (2005a) and Barsukova et al. (2005b) claimed that the period of 19.41 ± 0.02 d, accompanied by the variations of the radial velocity in He II 4686 emission line, is P_{orb}.

In our paper, we analyse the photometric observations and colour indices, covering the interval from JD 2451103 to JD 2453383 following the 1998 outburst. We also compare the colour behaviour in quiescence and in outburst. We resolve the contribution of the continuum and Hα in the colour changes. We present the spectral energy distributions determined from the photometry and demonstrate their differences between quiescence and outburst. We search for a relation between the optical and X-ray variations in quiescence. We also bring new fast photometry.

2. Observations and data collection

The Johnson *V* and Kron–Cousins *R* and *I* CCD images were obtained by the Maksutov telescope $D = 180$ mm, focal ratio *f*:5.55, and the SBIG ST-6 camera in the Astronomical Institute in Ondřejov in 1999–2004. The $D = 400$ mm, f:4.25 telescope equipped with the SBIG ST-7 camera and the *VRI* filters was used at the Brno Observatory in 1999–2000. Sets of one to five frames in each filter were usually obtained each night. Typical exposure times were 60–90 s. In addition, searches for the intranight variations in VRI were carried out at several occasions. In all cases, the individual observations were grouped into the night bins and the mean magnitudes in the individual nights were calculated. They are listed in Table 1.

The basic comparison star GSC 3723.54 with $V = 10.40$ (Barsukova et al., 2002) was used in the Ondřejov and Brno observations. The brightness of this star in the *R* and *I* passbands was obtained from the stars GSC 3723.104 and GSC 3723.80 which were measured on the Ondřejov and Brno CCD frames as the check stars calibrated by Henden (2002). The resulting magnitudes of GSC 3723.54 are $R = 9.97$ and $I = 9.59$.

We added to our data those obtained by Barsukova et al. (2002), Barsukova et al. (2005b) and Henden and Sumner (submitted).

The fast photoelectric photometry was performed in Loiano at the Ritchey–Chretien *f*:8 focus of the 152 cm 'G.D. Cassini' telescope, where two heads work in contiguous stellar fields with a separation spanning from 13′ to 21′ in right ascension and from −6.5′ to 6.5′ in declination. The acquisition clock is the same for the two measure channels. The measure system has an internal cash to allow for asynchronous communication with the computer while the acquisition is synchronous with the clock (Piccioni et al., 2002). The typical seeing at Loiano was 2.5″. We report a selection of the best observation runs. The details of the observations are listed in Table 2.

3. Data analysis

The whole photometric history of CI Cam, based on the *V* band CCD and photoelectric observations, is displayed in Fig. 1. The observations span over the years 1989–2004 but the coverage is far from being uniform. The largest gap in the data occurs between 1994 and 1998. The

Table 1
Journal of the photometric *VRI* observations, based on the Ondřejov (O) and Brno (B) CCD data sets

JD_{hel}	V	σ_V	N_{oV}	R	σ_R	N_{oR}	I	σ_I	N_{oI}	Obs.
51483.445	11.62	0.02	19	10.59		1	9.77		1	*O*
51498.512	11.65	0.02	123							*B*
51509.337	11.63	0.02	4	10.63	0.01	3	9.82	0.01	3	*B*

The heliocentric Julian Date (JD 2400000) of the middle of the series is listed. The daily means are given for each filter, including their standard deviation, σ, and the number of observations in a series, N_o. Typical exposure time was 90 or 60 s. (The full table is available in the electronic issue of the journal).