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Letter to the Editor

The orbital period of the cataclysmic variable WX Ceti ⋆

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Summary. We present the results of optical photometry of the dwarf nova WX Cet, which recently went into outburst, possibly for the first time since 1963. Our data, which were obtained during quiescence, show a periodic modulation of the optical brightness of WX Cet, with a period of 6.98 ± 0.04 hours. Based on the observation of high-amplitude (~8 mag) outbursts from a system with a 7 hour orbital period we argue that either the secondary star is not a normal main-sequence star, or that the outbursts are not due to an accretion instability similar to that in dwarf novae.

Key words: close binary stars; cataclysmic variables

1. Introduction

WX Cet is a cataclysmic variable for which an outburst was first detected in 1963 by Strohmeier (1964). Using Harvard plate archival data Gaposchkin (1976) found that three more outbursts had occurred between 1939 and 1945; he suggested that WX Cet is a dwarf nova of the U Gem subtype, with an average time interval between outbursts of ~450 days. However, this cycle length was not confirmed by Meinunger (1977), who did not detect any outbursts using plate material that covered about half a century. The large amplitude of the outbursts and the long intervals between them are properties which WX Cet shares with WZ Sge, and it has therefore been suggested that these systems are similar (Bailey 1979). This suggestion found some support in the results of a comparison of the quiescent optical spectra of WX Cet and WZ Sge by Downes and Margon (1981). Recently, WX Cet has gone into outburst, probably for the first time since 1963 (McNaught and Hurst 1989; Margon et al. 1989).

We report here the results of photometric observations of WX Cet, made during quiescence, which show that the quiescent optical brightness of this system is variable. These variations appear to be periodic (likely reflecting the orbital period). Our best estimate for the period is 6.98 ± 0.04 hours.

2. Observations

The observations were made during five nights between 1987 July 31 and August 5, with the CCD camera (RCA SID 501 EX chip, 320 x 500 pixels, pixel size 30 m) on the 1.5 m Danish telescope at the European Southern Observatory, La Silla. A total of 236 frames (V band) were collected, with integration times of 300 s. Photometric information was extracted from the frames using aperture photometry software, based on the IHAP image processing package. The sky-corrected magnitude of WX Cet was determined relative to those of three local comparison stars on the same frame.

3. Results

The results of our observations are summarized in Fig. 1, which shows the relative magnitude of WX Cet as a function of time for each of the five nights separately. The average V magnitude of WX Cet (obtained from a comparison of our results with CCD measurements of stars with known UBV photometry) is ~ 17.5, with an estimated accuracy (in the zero point of the photometry) of ± 0.2 mag. From Figure 1 it is clear that the V magnitude of WX Cet is variable, with a total amplitude of ~0.4 magnitude. The variations consist of rather rapid (time scale less than an hour) fluctuations of ~0.1 magnitude, superposed on a much slower variation (time scale several hours).

To search for possible periodicity in these brightness variations we have used the phase-dispersion minimization method of Stellingwerf (1978); since the light curves indicate that the time scale of the variations is comparable to (or longer than) the length of the individual nightly runs, we searched the period interval from ~3.5 to 12 hours, in frequency steps of 0.01 day^{-1}. The results of our search are displayed in a periodogram (see Fig. 2). The dips in this periodogram indicate the presence of periodicity in the brightness variations of WX Cet . Since the six deepest dips correspond to either harmonics, or to 1-day aliases, of other frequencies, we suspect that these dips reflect the presence of only one period. The width of the peaks is consistent with the hypothesis of a strictly periodic (as opposed to a quasi-periodic) signal.

Our nightly data stretches are less than five hours long, which is insufficient to make an unambiguous choice between the dips in the periodogram. However, the fact that during all five nights the brightness varied substantially (either upward or downward) during intervals of less than ~ 3 hours, suggests that the period is unlikely to be as long as 10 hours (unless the light curve is double-peaked, as in the case of ellipsoidal variations). Of the periods below 10 hours the one at 6.98 hours corresponds to the deepest dip, and therefore also to the largest amplitude of the folded average light curve (0.22 ± 0.02 magnitudes; see Fig. 3). For this reason we favour the 6.98 ± 0.04 hours as the best candidate period; as mentioned above we consider it unlikely that the period is smaller than the 1-day alias at 5.4 hours (see Fig. 2).

⋆ Based on observations made at the European Southern Observatory

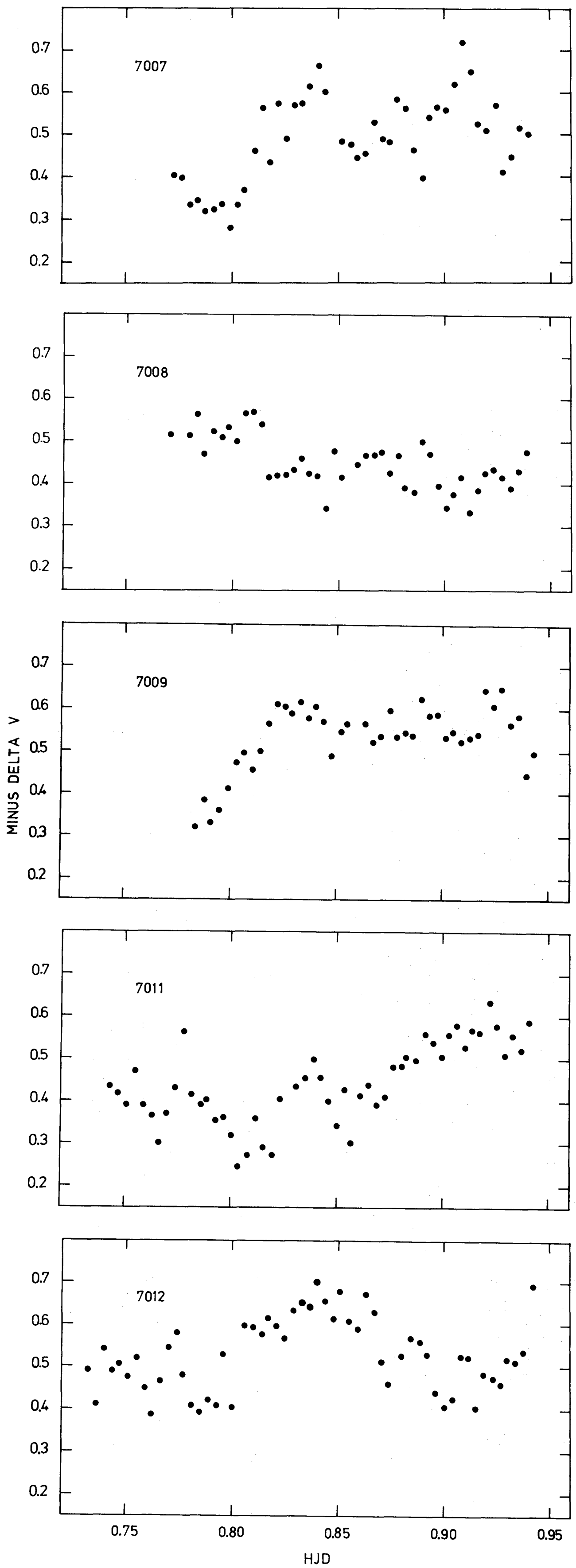

Fig. 1. *Light curves of WX Cet, as observed during five nights between July 31 and August 5, 1987. The relative V magnitude of WX Cet (with respect to the average magnitude of three local comparison stars on the same CCD frame) is plotted as a function of fractional HJD. The integer part of the HJD (minus 2440000) is indicated by the number in each panel.*

The non-random brightness variations on a time scale of an hour and less, which give rise to night-to-night variations of the shape of the light curve, make it difficult to formally assign a level of confidence to the detection of the periodic variations. If we apply the expression given by Stellingwerf (1978), in which it is presumed that the deviations from the average light curve are purely statistical, we find that the depth of the dip near P = 6.98 hours has a probability of less than $3\ 10^{-6}$ to occur by chance coincidence (this takes into account the number of trial periods).

4. Discussion

From our optical photometry of WX Cet we have found that the brightness of this system shows an approximately sinusoidal modulation with an amplitude of 0.2 magnitudes. Such light curves, which are not uncommon amongst cataclysmic variables, are likely the result of the changing visibility of a "bright spot" at the outer edge of the disk, where the stream of matter from the secondary hits the disk (see e.g. Robinson 1976). Applicability of this model to the light curve of WX Cet implies that the accretion process accounts for a sizeable, if not dominating, fraction of the total optical luminosity of the system.

The observed splitting of the emission lines in the quiescent spectrum of WX Cet led Downes and Margon (1981) to predict that eclipses may occur in the optical light curve. The average light curve (Fig. 3) shows no clear evidence for eclipses, and it appears that if they are present their depth is probably limited to about a tenth of a magnitude.

The ~7 h period which we have found for WX Cet is much larger than that of WZ Sge (80 min; Krzeminski 1962), and one could question whether the similarity of these systems with respect to the very large amplitude of their outbursts and the long intervals between them (Bailey 1979; Downes and Margon 1981) has any deeper significance. We note that other systems are known which have long inter-outburst intervals and very large outburst amplitudes (see e.g. Richter 1986), and whose orbital periods are also much longer than that of WZ Sge, e.g. VY Aqr and DO Dra, with orbital periods of 5.3 and 4.0 hours, respectively (Ritter, 1988). Based on the (Kukarkin-Parenago) relation between the amplitude of dwarf-nova outbursts and the intervals between them (see e.g. Richter 1986), it has been suggested that the very large amplitudes amplitudes of the outbursts of systems such as WZ Sge and WX Cet may be related to a very low value of the mass accretion rate in these systems (Van Paradijs 1985; Warner 1987).

According to the "standard model" of cataclysmic variables (see e.g. Robinson 1976, and Patterson 1984) the secondary star in these systems is a Roche-lobe filling low-mass star near the main sequence. The mass transfer in these systems is driven by steady loss of orbital angular momentum by gravitational radiation and magnetic braking of a main-sequence secondary star (see e.g., Rappaport, Verbunt & Joss 1983). For such secondary stars there is an approximately linear relation between

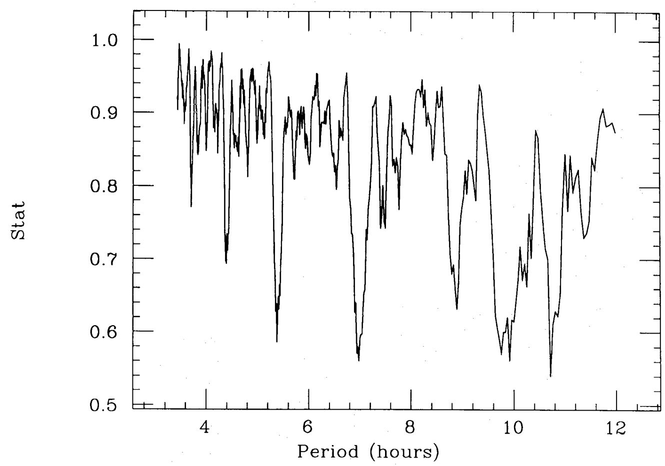

Fig. 2. *Periodogram of the brightness variations of WX Cet.*

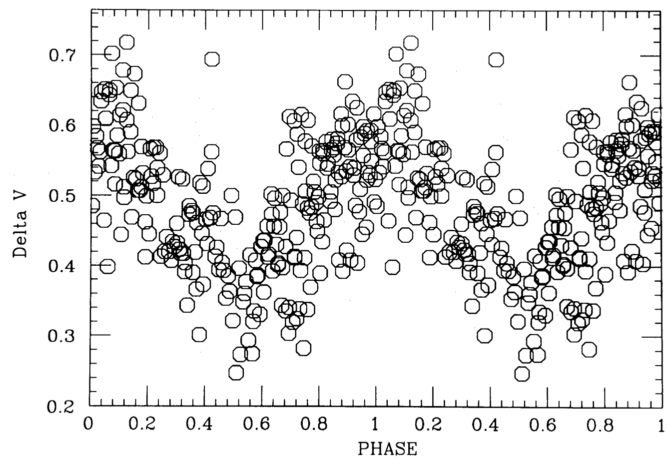

Fig. 3. *V band light curve of WX Cet, folded at a period of 6.98 hours.*

their mass and the orbital period (Warner 1976). The mass transfer rate is expected to scale approximately as the cube of the period.

In case the secondary in WX Cet is such a Roche lobe filling main-sequence star, the orbital period of 7 hours corresponds to a secondary mass of ~0.75 $M_\odot$, a spectral type near K0, and a corresponding absolute magnitude M_V ~ +6.0 (the system may be brighter due to a contribution from the accretion disk). One expects that a K0 secondary star is visible through its absorption lines in the combined optical spectrum of the binary (see e.g. Stover et al. 1981); however, the spectrum published by Downes and Margon (1981) is a bit too noisy to establish the presence of (diluted) K-type features. With an outburst amplitude of ~ 8 magnitudes the absolute magnitude of WX Cet at outburst maximum would then be ~ - 2. This is at least a factor 100 brighter than the peak brightness of dwarf novae during outbursts, which is a well defined function of the orbital period with quite small scatter [Warner (1987); see also Vogt (1981); for an orbital period of 7 h the results of Warner (1987) show that the average peak magnitude during dwarf-nova outbursts is +4.0 ± 0.4 (s.d.)]. This very large difference in absolute magnitudes indicates that if the above assumptions about the secondary of WX Cet are correct, the outbursts are unlikely to be caused by an accretion instability similar to those in "normal" dwarf novae.

If, on the other hand, the outbursts of WX Cet are similar to those observed in other dwarf novae, the secondary has an absolute magnitude M_V ~ +11. The reason why the secondary could be so very much fainter than expected for a Roche lobe filling main-sequence star could be either that it underfills its Roche lobe during quiescence by a large factor, or because it is not a normal main-sequence star. The first possible explanation leads to the problem of accounting for the large outbursts. Current mechanisms for dwarf novae outbursts are sudden Roche lobe overflows of the secondary (e.g. Bath 1975), or an instability in the accretion disk which in quiescence is continually fed by a stream of mass transfer from the scondary (Osaki 1974). In both cases the outburst mechanism is hard to reconcile with a secondary which underfills its Roche lobe by a large factor. If the second of the above mentioned possible explanations is correct, the secondary of WX Cet might be similar to that in Cen X-4, for which Chevalier et al. (1989) have argued that it is a highly evolved star which has lost most of its hydrogen envelope due to previous mass transfer.

With such a very faint (M_V ~ +11) secondary accretion may provide a sizeable contribution to the total luminosity of the system (as required by the above interpretation of the light curve as a "bright spot" hump), and yet occur at a rate which is sufficiently low to account for the large interval between the outbursts (as required by the above-mentioned interpretation of the Kukarkin-Parenago relation). This may fit the quiescent infra-red colour of WX Cet observed by Szkody and Feinskog (1988), which indicates that its continuum energy distribution is somewhat bluer than that corresponding to a K-type dwarf (Frogel et al. 1978).

The possibility that some of the secondaries of cataclysmic variables can have an internal structure that deviates strongly from that of a main-sequence star (see e.g. Pylyser and Savonije 1988) may partly explain the large range in mass accretion rates observed at a given value of the orbital period. This explanation may apply independent of the "hibernation" model proposed by Shara et al. (1986), of which it is independent. In the latter model long-term cyclic variations of the mass transfer rate occur, due to the detachment of the secondary from its Roche lobe following (classical) nova outbursts and the subsequent shrinking of the orbit (due to gravitatinal radiation and magnetic braking).

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