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CCD Photometry of the Intermediate Polar BG Canis Minoris

by

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ABSTRACT

CCD optical photometry of the intermediate polar BG CMi is reported. New times of maxima give evidence for further decrease of the 15-min period. The decrease is sufficiently well described with a quadratic ephemeris and does not require including a cubic term at the moment. The obtained times of the orbital minima confirm the stability of the orbital period.

Key words: *Stars: individual: BG CMi – binaries: close – novae, cataclysmic variables*

1. Introduction

BG Canis Minoris is a well known intermediate polar, whose optical counterpart, a blue cataclysmic variable of about 15^{th} mag, was identified with the hard X-ray source 3A 0729+103 by McHardy *et al.* (1984). It is known as the first of three intermediate polars with positively detected circular polarization in the optical and infrared (Penning *et al.* 1986, West *et al.* 1987), providing evidence for a strong ($\sim$ 4 MG) magnetic field of the white dwarf in the system. The most striking photometric feature of the star is its 15-min (913-s) modulation with optical amplitude of about 0.3 mag. This modulation observed also in X-rays and in the infrared (McHardy *et al.* 1987, Penning *et al.* 1986) is commonly believed to be a direct manifestation of the white dwarf rotation.

The orbital period equal to $3\overset{h}{.}2$ is also clearly seen in optical photometry, X-rays and spectroscopy (McHardy *et al.* 1984, 1987; Penning 1985) with its photometric amplitude equal to a few tenth of magnitude.

BG CMi belongs to a group of seven intermediate polars whose rotational periods of their white dwarfs are known to be changing (Patterson 1994, Warner 1995). A decrease of the period has been observed for four of these objects, and an increase for two of them. For one object (FO Aqr) the sign of the spin period

derivative has apparently changed, *i.e.*, an initially observed spinning-down seems to be followed now by a spinning-up (Osborne and Mukai 1989, Kruszewski and Semeniuk 1993).

BG CMi is an object with decreasing rotation period, what has been first shown by Patterson (1990) and Augusteijn *et al.* (1991). Recently Garlick *et al.* (1994) claimed that the cubic ephemeris describes the behavior of the 15-min period of BG CMi marginally better than the quadratic one, what would suggest a possible change of the time derivative of the spin period.

In 1994 we have included BG CMi to the Warsaw (Ostrowik) program of tracking spin period changes of intermediate polars. In the present paper we report on first results obtained for the star.

2. Observations

The present observations of BG CMi were carried out at the Ostrowik station of the Warsaw University Observatory with TK512 CCD at the Cassegrain focus of the 0.6 m telescope. The used CCD camera has been described by Udalski and Pych (1992). A journal of observations is given in Table 1. The exposure times were 30 or 50 seconds, depending on the atmospheric conditions, and a dead time between the frames was 10 or 20 seconds for different runs. We have monitored the star mainly in the V filter. Only during the last two runs of March, 1996 we measured the star in the Cousins R filter.

T a b l e 1

Journal of the Ostrowik CCD observations of BG CMi

Date	Time of start JD 2449000. +	Length of run (hours)	Filter
1994 Feb 16	400.246	5.9	V
Mar 15	427.332	1.4	V
Mar 21	433.380	1.0	V
Oct 11	637.625	0.8	V
1994 Nov 2	659.592	1.4	V
1995 Mar 10	787.245	1.9	V
1995 Oct 24	1015.513	3.8	V
1996 Mar 20	1163.285	3.1	R
1996 Mar 21	1164.238	3.4	R

All the data reductions have been performed with our procedure based on the IRAF package. The profile photometry has been done with the DAOphotII package.

Relative magnitudes ΔV and ΔR of BG CMi were obtained as the difference of magnitude of the variable and the magnitude corresponding to the sum of intensities

of five comparison stars. The comparison stars are marked in the chart displayed in Fig. 1.

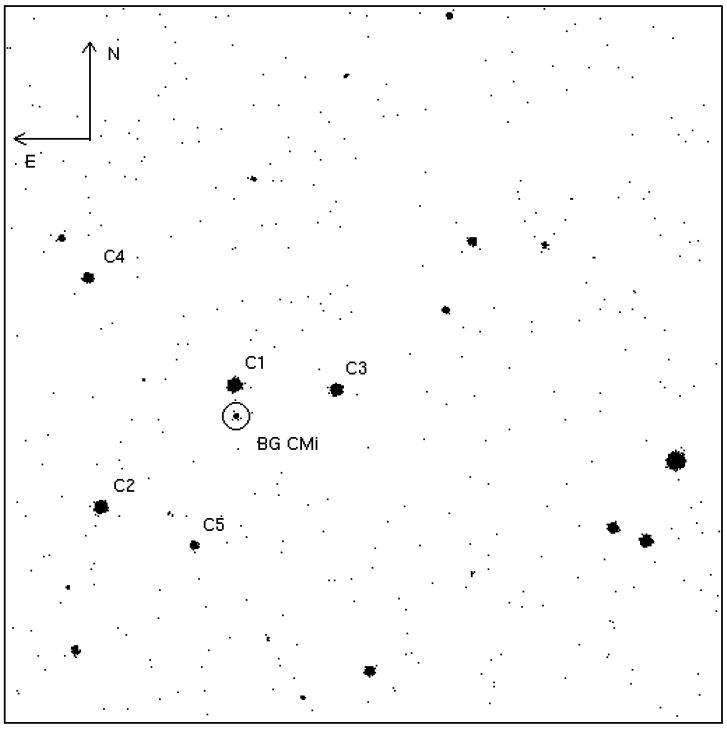

Fig. 1. A CCD finding chart for BG CMi and comparison stars. The chart covers a region 6.5 × 6.5 arcminutes.

Two observational runs of Table 1, the first and the last ones, are displayed in Fig. 2. The 15-min modulation is present in all our runs with the average peak-to-peak amplitude of about 0.3 mag.

3. The 15-min Periodicity

Table 2 gives the pulse maximum times, obtained from our observations, together with their mean errors σ. A single time of maximum is given for each night. Such time of maximum was obtained by calculating deviations from an ephemeris for all well defined maxima in an observing run and by adding the average of such deviations to the time predicted by the ephemeris for a chosen maximum observed approximately in the middle of a particular observing run. An exception is the shortest run of Table 1, when only one well defined pulse maximum was observed. We decided to place its time in Table 2 as we obtained an identical value by fitting a sinusoid with the fixed period 0.01057283 days to this run. The cycle numbers E in Table 2 relate to the ephemeris (1)

To investigate period behavior of the 15-min periodicity we have combined the times of pulse maxima of Table 2 with those previously published. The main bulk of the earlier published data are 68 times of maxima collected by Patterson

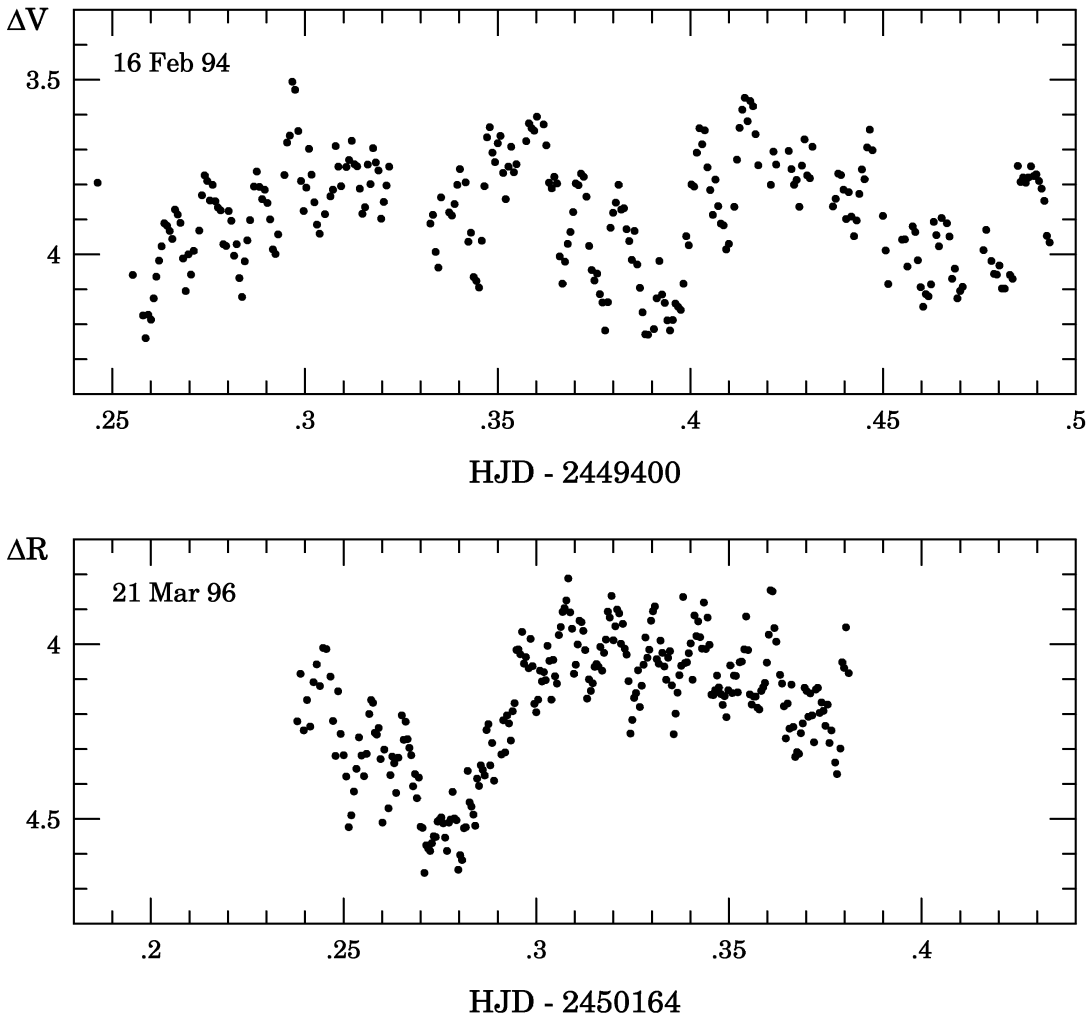

Fig. 2. Two selected light curves of BG CMi obtained during the present observations.

and Thomas (1993). We have rejected from their list the time corresponding to $E = 36833$, as it must be somehow erroneous. Besides we have used 6 maxima of Singh *et al.* (1991) and the maximum of Augusteijn *et al.* (1991) corresponding to HJD 2445406.56395, which were omitted by Patterson and Thomas, and 3 maxima of Garlick *et al.* (1994).

Based on all these data, *i.e.*, 87 times of maxima, we obtained the following quadratic ephemeris:

$$\begin{aligned} \mathrm{HJD}_{\mathrm{Max}} = 2445020.2800 &+ 0.010572992\,E - 3.83\times10^{-13}E^2 \\ &\pm 0.0002 \pm 0.000000002 \quad \pm 0.04 \end{aligned} \tag{1}$$

Fig. 3 displays the $O-C$ deviations calculated using the linear ephemeris $\mathrm{HJD}_{\mathrm{Max}} = 2445020.2800 + 0.010572992E$. The solid line in the figure presents the fit corresponding to the quadratic ephemeris (1).

Table 2

New times of maxima of the 15-min periodicity

Cycle E	HJD 2449000.+	σ
414278	400.3711	.0003
416831	427.3642	.0004
417402	433.4002	.0003
436719	637.6350	$\leq$.0018
438798	659.6133	.0009
450874	787.2906	.0005
472468	1015.5939	.0004
486440	1163.3153	.0004
486535	1164.3197	.0004

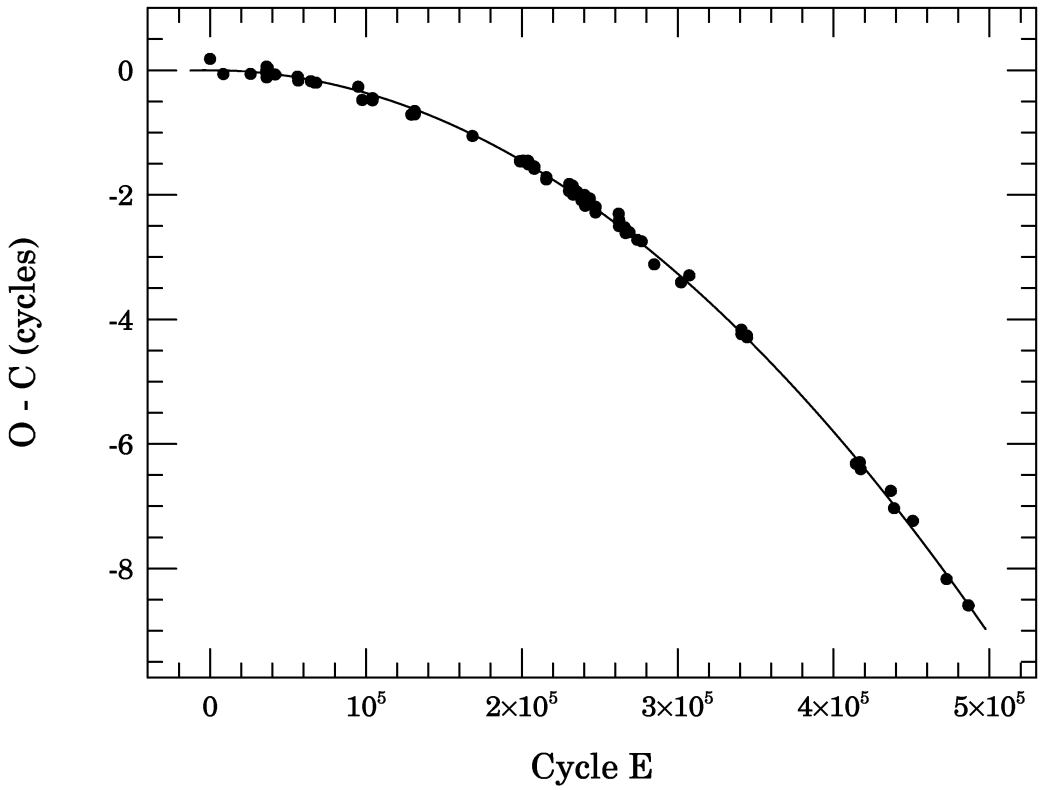

Fig. 3. $O-C$ values for times of maxima of the 15-min periodicity calculated with the linear ephemeris $\mathrm{HJD_{Max}} = 2445020.2800 + 0.010572992E$. The last nine maxima are from the present paper. The solid line is a fit corresponding to the quadratic ephemeris (1).

The cubic ephemeris obtained for the data gives no better fit. Therefore we conclude that at the moment there is no reason for claiming that $\dot{P}$ for the 15-min periodicity is changing.

4. The Orbital Minima

From our observations we have determined five times of minima of the orbital modulation of BG CMi. They are listed in Table 3.

Table 3

New times of the orbital minima

Cycle E	HJD 2449000.+	$O-C$
32505	400.3888	.0016
32750	433.4069	.0063
37071	1015.6494	.0000
38167	1163.3397	.0059
38174	1164.2757	–.0014

The least-squares solution obtained for the times of orbital minima collected by Patterson and Thomas (1993) and supplemented with the values of Table 3 confirmed the stability of the orbital period. The cycle numbers E and the $O-C$ residuals in Table 3 are calculated using the orbital ephemeris of Patterson and Thomas (1993):

$$\mathrm{HJD}_{\mathrm{Min}} = 2445020.384 + 0.1347486\ E$$

The mean amplitude of the orbital modulation observed in the time interval of our observations is 0.44 mag in V and 0.55 mag in R bands.

5. Summary

Based on nine observational runs obtained between February 14, 1994 and March 21, 1996 we have determined 9 times of pulse maxima of the 15-min periodicity and five orbital minima of the intermediate polar BG CMi. Analysis of all available times of pulse maxima give evidence for further decrease of the 15-min period. The $O-C$ residuals are satisfactorily well described with a quadratic ephemeris and do not require including a cubic term at the moment.

The obtained times of the orbital minima confirm the stability of the orbital period as determined by Patterson and Thomas (1993).

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