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Long-Term Variation of the Spin Period of a Magnetic Cataclysmic Variable, MU Camelopardalis

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Results of an analysis of 11 nights of R-filter CCD photometry data of an intermediate polar MU Camelopardalis (MU Cam) obtained at the Korean 1.0 m telescope at Mt. Lemmon are reported. After checking the spin period with our data, $P_{spin}=0.^{d}01373801(59)$, we compiled the reported data of maxima timing and an O-C diagram analysis has been carried out to understand the spin period variation. A significant spin period variation was detected, and fitting the O-C points to a cubic parabola led to an ephemeris of $BJD_{\max} = 2453682.4178(94) + 0.0137380(13)E - 2.07(55)\times10^{-11}E^2 + 2.28(52)\times10^{-15}E^3$. The torque experienced by the magnetic compact star accreting in a disk is estimated as $\tau \approx 1.815\times10^{35} g\,cm^2/s^2$ in a simple approximation in order to show how important monitoring the period variation is. Thus we conclude that monitoring the long-term spin period variation will help to understand the physical condition of magnetic compact stars.

Keywords: cataclysmic variables, intermediate polar, period variation, O-C diagram

1. INTRODUCTION

MU Camelopardalis (MU Cam) was first observed by the ROSAT All-Sky Survey (RASS) as an X-ray source, 1RXS J062518.2+733433, and later it has identified as an optical counterpart of this X-ray source by Kazarovets et al. (2006). Wei et al. (1999) classified this object as a cataclysmic variable with the spin period of $0.^{d}01374127(5)$ and the orbital period of $0.^{d}19661(27)$. Even though no definite characteristics about the eclipse have been reported yet, the optical pulse profile represents a sinusoidal single peak. Staude et al. (2003) reported a relativly strong HeII emission line which shows the existence of photons able to ionize the atoms. This characteristic has been discussed by other authors (Araujo-Betancor et al. 2003, Staude et al. 2003, 2008, Kim et al. 2005a, Kozhevnikov et al. 2006). These observational characteristics led to the classification of this object as an intermediate polar or DQ Her type magnetic cataclysmic variable.

The spin period of intermediate polars generally vary in the course of time (Warner 1986, 1995, Patterson 1994, Hellier 2001). Many corrections of the MU Cam spin period have been reported by several authors (Araujo-Betancor et al. 2003, Staude et al. 2003, Kim et al. 2005a). In order to study the rotational evolution of magnetic white dwarfs in intermediate polars, a long time-base monitoring of the spin period variation is definitely needed. This object has been included in the list of key targets of the inter-longitude astronomy (ILA) project (Andronov et al. 2003). As results of this project, deceleration and acceleration of the spin in the intermediate polars have already been detected: deceleration in BG CMi by Kim et al. (2005b) and alternatively, acceleration in FO Aqr (Andronov et al. 2005).

In this paper, we present results based on 11 nights of R charge-coupled device (CCD)-photometry obtained in 2005-2006 with a 1 m telescope of the Korean Astronomy Observatory at Mt. Lemmon in the USA.

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2. OBSERVATION AND ANALYSIS

MU Cam was observed with a 2 K by 2 K CCD camera mounted on the 1 m telescope at Mt. Lemmon Optical Astronomy Observatory during the 2005 and 2006 season. Given the CCD plate scale of 0.64 arcsec/pixel at f/7.5 Cassegrain focus, the image field of view was 22.2 arcmin by 22.2 arcmin. We obtained R-filter CCD photometry data from 11 nights from November 2005 to April 2006. The observational log is presented in Table 1 with exposure time and total observation points. A total of 907 points of observation were used for this study.

To determine the instrumental magnitudes of stars in the field of MU Cam, the IRAF/DAOPHOT package (Massey & Davis 1992) has been used. For the final determination of magnitudes, the computer program multicolumn view by Andronov & Baklanov (2004) has been used, which uses the method of multiple comparison stars (Kim et al. 2004).

In the method of multiple comparison stars, an independent R brightness estimate of 7 bright stars in the vicinity of the MU Cam was made based on the method described in Kim et al. (2005a). The standardized R light curve has been obtained by using an artificial star which made it possible to increase accuracy estimates. The R magnitude of MU Cam varied from 15.5 mag to 14.7 mag in the 2005-2006 season as shown in Fig. 1. A bright state and a faint state are not shown in this season, which is clearly seen by Kim et al. (2005a).

The spin period of MU Cam has been found from the power spectrum analysis (Lenz et al. 2005) using the usual Fourier transformation as following:

$$f(t) = Z + \sum_i A_i \sin\left(2\pi(\Omega_i t + \Phi_i)\right) \quad (1)$$

Here Z is a zero point of f(t), A_i, Ω_i, Φ_i are the amplitude at the frequency i, the peak frequency and the phase in the power spectrum, respectively. With the found spin period of $0.^d01373801(59)$, we constructed a spin folded light curve for MU Cam in the 2005-2006 season as shown in Fig. 1.

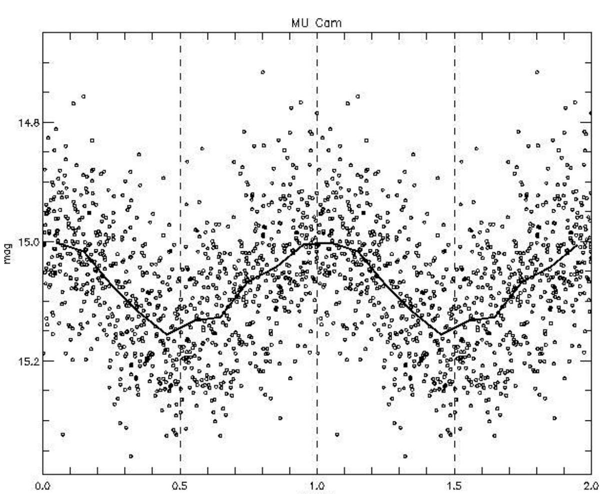

Fig. 1. Spin folded light curve of MU Cam in 2005-2006 season. The used spin period is $0.^d01373801(59)$, and the line is the connection of mean magnitude at each spin phase. The Y-axis represents the standardized magnitude and the X-axis the spin phase of MU Cam. The pulse phase has been repeated over two cycles.

Table 1. Observational log of MU Cam.

Date	Filter	Exposure time (s)	Observation points (Nr.)
20051117	R	50	
20051119	R	50	
20051120	R	50~60	587
20051121	R	50	
20051122	R	50	
20060117	R	120~140	
20060118	R	120	
20060119	R	120	322
20060412	R	200	
20060413	R	200	
20060416	R	200	

MU Cam: MU Camelopardalis.

Table 2. Times of maxima using Gaussian fitting.

Peak point	Time (BJD-400000)	Gaussian sigma	Constant	Sigma	Perror
-0.12335	53692.01039	0.00303	0.08579	0.02999	1.04864
-0.1395	53693.74225	0.00279	0.1546	0.03055	1.02215
-0.13511	53693.92037	0.0026	0.1433	0.02638	1.01185
-0.09437	53693.93412	0.00256	0.13279	0.01581	1.01312
-0.08724	53693.96171	0.00219	0.02859	0.02006	1.04077
-0.12535	53693.9897	0.00333	0.11157	0.01711	1.06711
-0.10892	53694.91026	0.00253	0.07696	0.03293	1.0792
-0.11778	53695.92699	0.00269	0.11807	0.0176	1.10199
-0.11679	53696.71004	0.002	0.06095	0.03219	1.07343
-0.11388	53696.71011	0.00215	0.07052	0.03024	1.04544
-0.10199	53696.72389	0.00184	0.06651	0.02519	1.09493
-0.10105	53696.72388	0.00191	0.07091	0.02043	1.08505
-0.13258	53696.87464	0.00264	0.1429	0.02614	1.01186
-0.13397	53696.87465	0.00254	0.13292	0.03167	1.01374
-0.10676	53696.91559	0.00219	0.13578	0.02274	1.04102
-0.04308	53752.62434	0.00246	0.04527	0.01968	1.01309
-0.04491	53752.6245	0.00206	0.03204	0.02776	1.04758
-0.13918	53752.70506	0.00271	0.09123	0.02662	1.04345
-0.16183	53753.59907	0.00287	0.09698	0.03053	0.99665
-0.16831	53753.59914	0.00244	0.06393	0.03114	0.95539
-0.13405	53753.65339	0.00184	0.04601	0.02957	1.03459
-0.13264	53754.69772	0.00315	0.12035	0.01893	1.09837
-0.14524	53754.71168	0.00324	0.11148	0.02342	1.07492

Peak point, time and Gaussian sigma are A(0), A(1) and A(2) in Eq. (2). Constant is the constant value of fitted Gaussian curve. Sigma and perror are values in the best fitted Gaussian curve.

MU Cam is a faint object (R magnitude~15.5-14.7 in the 2005-2006 season) and has a relatively short spin period, which leads to very small points of observation near the extremes. The exact estimation of times of extreme needs a very complicated numerical analysis. Such analysis will be presented separately elsewhere. In this paper, we want to check the general behaviour of the spin period in the time series. For this purpose a simple Gausian fitting has been adapted. The fitting equation is

$$A(0)\times\exp\left\{-0.5\times\left[\left(x-A(1)\right)/A(2)\right]^2\right\}, \quad (2)$$

where $A(0)$, $A(1)$ and $A(2)$ are the peak value, the position at peak center and the Gausian width respectively. A total of 56 times of extremes have been found in our data, and 23 maximum timing data are used for the O-C analysis. These times of maxima obtained by Gaussian fitting are listed in Table 2.

3. RESULTS AND DISCUSSION

The found spin period of MU Cam, $0.^d01373801(59)$, seems to be the same value as Staude et al. (2003) and Kim et al. (2005a) in the error interval. But it is necessary to check for the possible period variations, $\dot{P}$, which are usually seen in intermediate polars.

Staude et al. (2003) presented a precise ephemeris,

$$BJD_{\max} = 2452682.4181(5) + 0.^d01374127(5)\cdot E \quad (3)$$

using a compilation of their own maxima timings and maxima timings obtained from the photometric data of Arajo-Betancor et al. (2003). With this basic ephemeris, Kim et al. (2005a) tried to fit a cubic parabola to the O-C diagram with their timing in the season of 2004-2005 as well as the data of Staude et al. (2003), because the parabolic fit did not deviate significantly from the line. They found statistically significant variation in an ephemeris:

$$BJD_{\max} = 2453682.41810(24) + 0.013741329(61)E - 7.1(2.9)\times10^{-12}E^2 + 7.8(3.0)\times10^{-17}E^3 \quad (4)$$

Adding our maxima timings of 2005-2006 to this O-C diagram and fitting to a cubic parabola leads to an ephemeris

$$BJD_{\max} = 2453682.4178(94) + 0.0137380(13)E - 2.07(55)\times10^{-11}E^2 + 2.28(52)\times10^{-15}E^3 \quad (5)$$

which exhibits a possible trend to spin up. The fitting result is shown in Fig. 2. Even if we see a clear variation of the spin period of MU Cam, it is unclear whether the spin period will become slower or faster in the future. Staude et al. (2008) suggested that MU Cam has different accretion states which causes to the significant change in brightness and also the change of the spin period. In order to study this problem in more detail, we need further monitoring of this interesting intermediate polar.

Recently, a deceleration of the spin period ($\dot{P}_{spin} > 0$ in BG CMi, Kim et al. 2005b) and an acceleration of the spin period ($\dot{P}_{spin} < 0$ in FO Aqr, Andronov et al. 2005) have been detected. This situation assumes that magnetic compact stars accreting in a disk should experience a torque more complex than the simple and easily calculated matter torque that Ghosh & Lamb (1979) explained theoretically. However, Patterson (1994) shows that the magnetic moment controls the spin rate of intermediate polars. The variation of accretion rate can cause the change of the magnetic moment of the compact star and the spin rate. On the observational point of view, monitoring the variation of the spin period of intermediate polars is very important for studies of the rotational evolution of magnetic white dwarfs in intermediate polars. Therefore, a long time-base monitoring is highly needed for these objects.

Even if a more complicated treatment is needed for understanding the angular momentum from the disk in the magnetic compact star, we can estimate the torque of MU Cam by using a simple consideration in order to

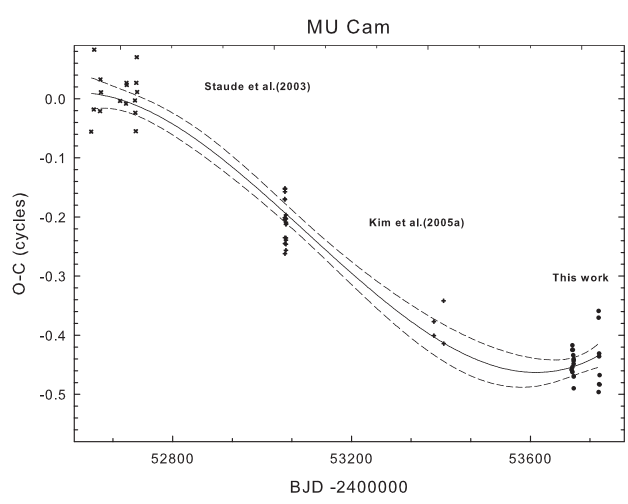

Fig. 2. O-C values for times of spin maxima calculated with the linear ephemeris Eq. (3). The data published by Staude et al. (2003) are marked as x, the data published by Kim et al. (2005a) are marked as +, and our data are marked as ·. The curved line and dashed lines show the cubic ephemeris Eq. (5) and the corresponding 1σ error corridor.

show how important monitoring the period variation is.

The torque (τ) is a variation of the angular momentum (L) per unit of time. By using $L = I\omega$ and $\omega = \frac{2\pi}{P}$, we obtain

$$\tau = -2\pi I \frac{\dot{P}}{P^2}, \quad (6)$$

where I is the moment of inertia (and ω is the angular velocity given by the spin period (P) of the star $\left(\omega = \frac{2\pi}{P}\right)$. With results of this paper ($\dot{P} \approx -4.07 \times 10^{-8} s/s$ and P = 0.^{d}013738008) as well as using the moment of inertia ($I \sim 10^{50}\, g\, cm^2$, Frank et al. 2002), we obtain a torque of $\approx 1.815 \times 10^{35} g cm^2/s^2$. It is also important to mention that the distance of MU Cam is unknown, so that a further estimate of the physical situation of this system in comparison with other intermediate polars is not possible. However, we conclude that monitoring the long-term spin period variation will help to understand the physical condition in magnetic compact stars. A detailed consideration of the accretion torque in magnetic compact stars will be published elsewhere.

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