Two photometric periods in the AM CVn system CP Eridani

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Accepted 2011 December 29. Received 2011 December 28; in original form 2011 November 7

ABSTRACT

We report photometric periodicities in the AM CVn system CP Eridani (CP Eri) of 1716.2 ± 0.2 and 1701.4 ± 0.2 s, obtained while the system was in quiescence. From a second observation obtained during superoutburst, we interpret the 1716-s signal as a superhump period (Psh) and the 1701-s signal as the orbital period (Porb) of the binary. The derived fractional superhump period excess ε adds CP Eri to a small collection of AM CVn stars with ε measured via time-series photometry of superhump and orbital periods. Plotting ε(Porb) for these systems, we find that AM CVn systems may, as expected, be evolving towards longer Porb. We discuss a technique of using ε to determine the degree of degeneracy of the donor star in a contact binary, and we show that for the AM CVn systems, the donor stars are well described by mass–radius relations of partially-degenerate objects.

Key words: accretion, accretion discs – binaries: close – stars: individual: CP Eridani – novae, cataclysmic variables – white dwarfs.

1 INTRODUCTION

“One of these men is genius to the other: And so of these, which is the natural man, And which the spirit? Who deciphers them?”

“The Comedy of Errors” (5.1.334-36) – William Shakespeare

CP Eridani (CP Eri) was identified as a blue variable object by Luyten & Haro (1959), who reported it at $V = 17$, ~2.5 mag brighter than it appears on the POSS plates. Szkody et al. (1989) observed it at $V ~ 17.8$ and later at 19.7, at which time they detected a periodicity around 28 min (Howell et al. 1991). Abbott et al. (1992) resolved the periodicity photometrically as 28.73 min (1724 ± 4 s). They also obtained two spectra separated in time by 2 months, showing weak He i emission and He ii absorption; neither of them showed hydrogen. The spectral data and short period together place CP Eri in the AM CVn family of cataclysmic variables (CVs); interacting binary white dwarfs with helium-rich and hydrogen-depleted donor stars that are likely to be at least partially degenerate. CP Eri has since been observed in high and low states, with corresponding helium lines in absorption or emission, respectively. This alternating behaviour is characteristic of AM CVn systems in the period range of 20–40 min. Further spectroscopy has been conducted by Groot et al. (2001) and Sion et al. (2006).

Estimates of Porb and Psh for CVs are important because they are directly measurable parameters and can narrate evolutionary history. We chose CP Eri for detailed photometry because of its episodic high-state behaviour and hence likelihood of displaying superhumps. A preliminary report by Patterson (2001) cites periodicities around 1701 and 1716 s; this paper contains the full report.

2 OBSERVATIONS

We observed CP Eri three times, several months apart, in 1998 with the 1.3-m McGraw–Hill telescope at the MDM Observatory at Kitt Peak, using a $1024 \times 1024$ pixel CCD chip with a pixel length of 24 μm. The full unbinned chip yields a 0.28 arcsec pixel−1 field of view. To minimize the readout time, we used a quarter of the chip area binned 2 × 2. The resulting deadtime between images was around 5 s. Exposure times were generally 5–20 s. We performed data reduction during observations via standard UNIX and IRAF scripts. The resulting light curve is a plot of differential magnitude with respect to a comparison star on the field.

For CP Eri, we used a filter of bandpass 3500–8000 Å to maximize the count rate, and a comparison star of $V = 15.54$ (the effective wavelength for a blue star is in the V band). Observing runs consisted of ~4.5 h windows with ~19.5 h gaps. Table 1 is an observing log of the three runs. The log for the third run is condensed for brevity, because it is long (22 d) and we did not use it for period determination.

During the 11-night run, CP Eri was highly stable and near quiescence. The average magnitude was $V ~ 19.9$, with a trend of decreasing brightness of 3 per cent. Fig. 1 (top left-hand panel) shows the mean-subtracted light curve of one representative night.

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Table 1. CP Eri observations with the 1.3-m McGraw-Hill telescope at the MDM Observatory, 1998.

<table>
<thead>
<tr>
<th>Run #</th>
<th>Date</th>
<th>Hours</th>
<th>Average $m_V$</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>January 1</td>
<td>3.05</td>
<td>16.5</td>
<td>Superoutburst</td>
</tr>
<tr>
<td></td>
<td>January 2</td>
<td>4.49</td>
<td>16.6</td>
<td>Superoutburst</td>
</tr>
<tr>
<td></td>
<td>January 6</td>
<td>4.21</td>
<td>18.7–18.3</td>
<td>Superoutburst (rising)</td>
</tr>
<tr>
<td></td>
<td>January 7</td>
<td>5.22</td>
<td>18.0–17.7</td>
<td>Superoutburst (rising)</td>
</tr>
<tr>
<td>2</td>
<td>September 17</td>
<td>1.58</td>
<td>19.5</td>
<td>Quiescence</td>
</tr>
<tr>
<td></td>
<td>September 18</td>
<td>4.62</td>
<td>19.7</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>September 19</td>
<td>4.53</td>
<td>19.8</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>September 20</td>
<td>4.96</td>
<td>19.9–19.8</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>September 24</td>
<td>4.27</td>
<td>20.1</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>September 25</td>
<td>4.44</td>
<td>20.0</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>September 26</td>
<td>4.97</td>
<td>20.0</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>September 27</td>
<td>3.65</td>
<td>20.1</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>December 10–31</td>
<td>100.24</td>
<td>N/A</td>
<td>Varying (see Fig. 3)</td>
</tr>
</tbody>
</table>

A second observation caught CP Eri in decline from superoutburst. Fig. 2 (top panel) is the light curve from January 2; it shows the sawtooth-shaped modulation that characterizes a superhump. Differential extinction is the likely cause of the slight decrease in brightness towards the end of the night. The first two nights of superoutburst data look like this, with $V \sim 16.5$. On the last two nights, the system was fainter and brightening ($V = 18.5$ and 17.8, respectively).

Finally, a 22-night December run caught CP Eri displaying widely varying behaviour that vexes attempts at characterization. Fig. 3 shows the full light curve. Due to the large variation in behaviour from night to night, this observation was minimally useful in period analysis (see Section 4: Discussion).

3 ANALYSIS

3.1 Estimating periods via the quiescent data

We derive period estimates from our observations of CP Eri in quiescence, because these data comprise the longest baseline in time and are most stable in magnitude.

After subtracting the mean magnitude from each night’s observations, we created a spliced light curve of the full 11-d baseline, in order to maximize frequency resolution. We then computed the power spectrum based on the discrete Fourier transform of the spliced light curve. Fig. 1 (bottom left-hand panel) shows the power spectrum with the following peaks noted: a strong signal around 50.34 cycles d$^{-1}$ and a weaker feature around 101.57 cycles d$^{-1}$. A synchronous summation at a frequency of 50.344 cycles d$^{-1}$ yields the waveform of Fig. 4 (top panel), which shows a relatively clear sinusoidal modulation, and which also attains the best signal subtraction. The period is 1716.2 ± 0.2 s, where the error is determined from the width of the peak.

We subtracted the main signal from the time-series, which resulted in the power spectrum of Fig. 1 (bottom right-hand panel). It

Figure 1. Top left-hand panel: Light curve of CP Eri in $V$ light on 1998 September 24. The $m_V$ of the comparison star is 15.54. The error in translating from our 3500–8000 Å bandpass to $V$ mag is <0.3 mag. Bottom left-hand panel: power spectrum with a baseline of 11 d, formed by splicing eight nights, each with ~5 h time-series. Significant features are marked with frequencies in cycles d$^{-1}$. Inset: magnification of the main signal. Top right-hand panel: spectral window of the main signal, for comparison. The magnification suggests that a second independent signal may be buried in the main signal. Bottom right-hand panel: power spectrum of the full 11-night baseline, with the main signal subtracted.
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Figure 2. Top panel: light curve of CP Eri in $V$ light on 1998 January 2. The $m_V$ of the comparison star is 15.54. The fading towards the end of the night is likely due to differential extinction. The error in translating from our 3500–8000 Å bandpass to $V$ mag is $<0.3$ mag. Bottom panel: nightly power spectrum, formed by splicing two consecutive nights with $\sim 5$ h time-series. Significant features are marked with frequencies in cycles d$^{-1}$. Inset: magnification of the main signal.

Figure 3. Light curve of CP Eri in $V$ light on 1998 December 10–31.

shows peaks at 50.78 and 101.57 cycles d$^{-1}$. A comparison with the spectral window of the main signal, Fig. 1 (top right-hand panel), indicates that these two peaks are independent of the main signal’s alias structure. We interpret the latter as the second harmonic (first overtone) of the former. The waveform of the 50.78 cycles d$^{-1}$ signal, Fig. 4 (middle panel), is not a sinusoid, which indicates that there is significant power in harmonic structure. The period is 1701.4 ± 0.2 s.

3.2 Interpreting periods via the superoutburst data

For the superoutburst data, our most informative power spectrum hails from a splice of just the first two nights of observation; at this time, CP Eri was brightest and most stable ($V \sim 16.5$). Fig. 2 (bottom panel) shows a main signal at 50.30 cycles d$^{-1}$, a small peak around 100 cycles d$^{-1}$, and none near 50.8 cycles d$^{-1}$. Fig. 4 (bottom panel) is the waveform obtained by folding the light curve over a 50.303 cycles d$^{-1}$ frequency (1717.7 ± 1.2 s). A strong sawtooth-shaped modulation, characteristic of superhumps, is present. Subtraction of this main signal reveals no significant secondary features. The presence of this 50.30 cycles d$^{-1}$ signal and absence of the 50.78 cycles d$^{-1}$ signal lead us to interpret the former as the superhump ($P_{\text{sh}}$) and latter as the orbital period ($P_{\text{orb}}$) of CP Eri (see Section 4: Discussion). Table 2 summarizes results for the quiescent and superoutburst runs.
Having identified $P_{\text{sh}}$, we returned to our 11-night baseline of quiescent data to study superhump drift via the nightly timings of minimum light of the superhump waveform. We did not find a coherent trend in the rate of change of the period.

### 3.3 CP Eri’s rapidly varying magnitude

Finally, during the 22-d observing run, CP Eri exhibited volatile behaviour, sharply rising and falling multiple times between $m_V \sim 16.6$ and 19.5 (Fig. 3). Our most informative power spectrum derives from a slice of seven nights near the end of the run. It shows a poorly resolved peak near 50.3 cycles d$^{-1}$ and a possible feature around 102 cycles d$^{-1}$ – demonstrating the likelihood that the main periodicity found in the quiescent data persists during these volatile episodes. The most pertinent use of these data is as a record of CP Eri’s proclivity towards this type of behaviour, which appears to be a characteristic of AM CVn systems in the period range of 20–40 min. CR Boo and V803 Cen share this behaviour (Kato et al. 2000 and Patterson et al. 2000, respectively), and most of the other AM CVn systems in this period range have been observed in both high and low states (Solheim 2010).

### 4 DISCUSSION

#### 4.1 Justifying our interpretations

The superoutburst of a CV is a rapid rise in brightness by 2–8 mag which persists for days to weeks. At the onset of superoutburst, a CV develops a second period in slight excess of $P_{\text{orb}}$ which occasionally persists into quiescence. This ‘superhump’ period is interpreted as a beat due to the resonance between $P_{\text{sh}}$ and the orbits in the outer disc, where the disc has gone elliptical due to the gravitational perturbation of the secondary. The resonance causes the disc to precess, and tidal stresses on the disc material periodically dissipate energy, which produces the observable modulation (Whitehurst 1988; Osaki 1989). For AM CVn systems, superhumps (and all high-state behaviours) are unique to systems with $P_{\text{orb}} < 40$ min (e.g. Solheim 2010).

Our primary justification for our period interpretations, then, hails from our short superoutburst observation. Superhumps characteristically have a repeatable waveform of fast rise and slow decay, with a modulation of $\sim 0.2$–$0.3$ mag – an apparent feature of the superoutburst light curve we obtained of CP Eri. The one period present in the corresponding power spectrum is 1717.7 s. Therefore, this observation confers extra credentials on the 1717-s signal for a superhump interpretation. Furthermore, the superoutburst data do not show the $\sim 1701$-s period that was observed during quiescence. It is common during superoutburst for the superhump to overpower any orbital signal (Warner 1995).

Why the disparity between the previous observation of CP Eri and one main periodicity of 1724 ± 4 s (Abbott et al. 1992)? We attribute it largely to the difference in CP Eri’s stability between our respective runs. Since Abbott et al. detected just one period, it is likely that they observed the system closer to superoutburst – that is, while $P_{\text{sh}}$ was obscured by the superhump luminosity.

Not that we expect future observations to confirm our value of $P_{\text{sh}}$ to within our derived errors. On the contrary, longer time-series observations should detect superhump drift. Furthermore, we did not catch any portion of CP Eri’s rise to superoutburst and thus cannot reference a time of maximum light.

#### 4.2 $\epsilon(P_{\text{orb}})$ as a proxy of AM CVn evolution

Estimates of $P_{\text{orb}}$ and $P_{\text{sh}}$ are valuable tools because they yield a proxy for the mass ratio $q$ – which is notoriously difficult to infer for non-eclipsing systems. Within the family of AM CVn systems, a trend in $q$ may indicate their direction of evolution. Thus, a proxy for $q$ allows us to probe evolutionary history. In a series of papers beginning in 1998 (e.g. Patterson et al. 2002, 2005), the authors define this proxy as the fractional superhump period excess $\epsilon$:

$$\epsilon = (P_{\text{sh}} - P_{\text{orb}})/P_{\text{orb}}.$$ 

Here is how we use $\epsilon$. For any contact binary, Kepler’s law combined with the requirement for Roche lobe overflow gives

$$P_{\text{orb}} (h) = 8.75 \left( \frac{M_2}{R_2^2} \right)^{1/2} \text{ (Faulkner & Flannery 1972)}.$$ (1)

with $M_2$ and $R_2$ in solar units.

Next we expect a mass–radius relation for the secondary that falls somewhere between two limits: $M(R)$ for a zero-temperature helium white dwarf of low mass (a fully-degenerate object),

$$R_2 = 0.0155 M_2^{0.212},$$

and $M(R)$ for a partially-degenerate helium star,

$$R_2 = 0.029 M_2^{0.19} \text{ (Savonije, de Kool & van den Heuven 1986)}.$$ (3)

Equations (1) and (2) yield

$$M_2 = 0.0069 P_{\text{orb}}^{-1.22} \text{ for the fully-degenerate case;}$$ (4)

and

$$M_2 = 0.018 P_{\text{orb}}^{-1.27} \text{ for the partially-degenerate helium star case.}$$ (5)

Meanwhile, from an empirical calibration that uses $q$ values from eclipsing H-rich CVs

$$\epsilon = 0.18q + 0.29q^2 \text{ (Patterson et al. 2005).}$$ (6)

We emphasize the utility of the final three equations. Equation (6) tells us that $\epsilon$ is, to first approximation, a proxy for $q$, and for superhumping systems, we can measure $\epsilon$ directly. Coupling equation (6) with equations (4) and (5), we get $\epsilon(P_{\text{orb}})$ for each case. A plot of $\epsilon(P_{\text{orb}})$ can concisely illustrate several interrelated properties of these systems.

Fig. 5 shows $\epsilon$ versus $P_{\text{orb}}$ for 10 AM CVn systems, including CP Eri. It is an update of fig. 6 from Patterson et al. (2002). Table 3 contains the relevant data. Eight of these 10 points were found via our period-finding technique. The two rightmost points were plotted via spectroscopic determinations of $q$ (Marsh 1999 and Ruiz et al. 2001, respectively) and an $\epsilon$ determination according to equation (6). The solid curves at the bottom and top represent the mass–radius relations of, respectively, a fully-degenerate secondary (equation 2)
and a partially-degenerate He-star secondary (equation 3), assuming $M_1 = 0.75 \, M_\odot$. The shaded region over each solid line represents, for each model, the range $0.6 < M_1 < M_\odot$.

![Figure 5](https://academic.oup.com/mnras/article-abstract/421/3/2310/1077812) Fractional superhump period excess $\varepsilon$ versus $P_{\text{orb}}$ for 10 AM CVn stars. Table 3 contains the relevant data. Eight of these 10 points were found via our period-finding technique. The two rightmost points were plotted via spectroscopic determinations of $q$ (Marsh 1999 and Ruiz et al. 2001, respectively) and an $\varepsilon$ determination according to equation (6). The solid curves at the bottom and top represent the mass–radius relations of, respectively, a fully-degenerate secondary (equation 2) and a partially-degenerate He-star secondary (equation 3), assuming $M_1 = 0.75 \, M_\odot$. The shaded region over each solid line represents, for each model, the range $0.6 < M_1 < M_\odot$.

We stress two points regarding this figure. First, nine out of 10 stars fall within the shaded region, which indicates that the donors can be modelled as partially-degenerate objects. Secondly, the points trace a decreasing slope, indicating evolution towards longer $P_{\text{orb}}$, as expected: a partially-degenerate object will expand upon mass loss, as will the Roche geometry of the binary.

Three minor points regarding the figure concern specific stars. For AM CVn systems, the spectroscopically determined value of $q$ differs significantly from the value derived from the empirical $\varepsilon(q)$ relation for H CV systems. Is this worrisome? Well, indeed the $\varepsilon(q)$ relation was established using H-rich systems only. Pearson (2007), for example, has raised concern that the relation may not be valid for He discs because of the significant role of pressure forces. However, this $\varepsilon(q)$ relation is likely to be at least a valuable estimate for He-rich systems: the gravitational perturbation of the secondary is the primary cause of disc ellipticity, and effects of gravity are not likely to depend sensitively on disc material. Tsugawa & Osaki (1997) modelled thermal and tidal instabilities for a He disc, which is essentially the same as for H discs (Osaki 1989), only shifted to higher temperature. Using this model, they successfully reproduced the observed cycling state of CR Boo (again, these CR Boo observations are akin to our third observation of CP Eri in this paper). Still, further data are needed to determine the validity of the empirical $\varepsilon(q)$ relation for He discs. Since AM CVn is just one data point, however, at this stage an interpretation of the discrepancy between the two $q$ values would be speculative.

Secondly, for SDSS J092638.71+362402.4 we note the good agreement between $q$ from $\varepsilon(q)$ and $q$ from eclipse timing. Finally, KL Dra merits a mention. KL Dra is the one outlier in $\varepsilon(P_{\text{orb}})$ space, falling far outside the distribution for a system with a partially-degenerate secondary. At the same time, KL Dra possesses the best-constrained value of $\varepsilon$ of all the superhumping AM CVn systems. This juxtaposition seems surprising enough to merit a follow-up observation.

We emphasize the utility of an $\varepsilon(P_{\text{orb}})$ plot for AM CVn theory. Finding $\varepsilon(P_{\text{orb}})$ for more AM CVn systems may help us to distinguish, for each binary, among the three proposed channels to formation (Nelemans et al. 2010). Thus, the distribution of AM CVn systems on $\varepsilon(P_{\text{orb}})$ space may indicate the fractional contribution of each channel to the observed population.

### 4.3 CP Eri in $\varepsilon(P_{\text{orb}})$ space

We calculated $\varepsilon$ twice for CP Eri: once using the value of $P_{\text{sh}}$ from the quiescent run, and again using the value of $P_{\text{sh}}$ from $P_{\text{orb}}$. We stress two points regarding this figure. First, nine out of 10 stars fall within the shaded region, which indicates that the donors can be modelled as partially-degenerate objects. Secondly, the points trace a decreasing slope, indicating evolution towards longer $P_{\text{orb}}$, as expected: a partially-degenerate object will expand upon mass loss, as will the Roche geometry of the binary.

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### Table 3. Orbital and superhump periods in AM CVn systems.

<table>
<thead>
<tr>
<th>Star</th>
<th>$P_{\text{orb}}$</th>
<th>$P_{\text{sh}}$</th>
<th>$\varepsilon$</th>
<th>$q$ from $\varepsilon$</th>
<th>$q$ (other)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM CVn</td>
<td>1028.7332 (3)</td>
<td>1051.2 (2)</td>
<td>0.0218 (2)</td>
<td>0.1038 (8)</td>
<td>0.18 (1)</td>
<td>2, 3</td>
</tr>
<tr>
<td>HP Lib</td>
<td>1102.70 (6)</td>
<td>1119.0 (2)</td>
<td>0.0148 (2)</td>
<td>0.0735 (9)</td>
<td>–</td>
<td>4, 5</td>
</tr>
<tr>
<td>CR Boo</td>
<td>1471.30 (5)</td>
<td>1487.29 (2)</td>
<td>0.01087 (5)</td>
<td>0.0554 (2)</td>
<td>–</td>
<td>6, 7</td>
</tr>
<tr>
<td>KL Dra</td>
<td>1501.8 (1)</td>
<td>1530.852 (6)</td>
<td>0.01934 (2)</td>
<td>0.0939 (9)</td>
<td>–</td>
<td>8, 9</td>
</tr>
<tr>
<td>V803 Cen</td>
<td>1596.4 (12)</td>
<td>1614.5 (35)</td>
<td>0.011 (3)</td>
<td>0.06 (1)</td>
<td>–</td>
<td>5, 10</td>
</tr>
<tr>
<td>SDSS J092638.71+362402.4</td>
<td>1698.6 (6)</td>
<td>1713.4 (1)</td>
<td>0.0087 (4)</td>
<td>0.045 (2)</td>
<td>0.041 (2)</td>
<td>11, 12</td>
</tr>
<tr>
<td>CP Eri</td>
<td>1701.4 (2)</td>
<td>1716.2 (2)</td>
<td>0.0091 (5)</td>
<td>0.047 (2)</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td>V406 Hya</td>
<td>2027.8 (5)</td>
<td>2041.5 (3)</td>
<td>0.0068 (4)</td>
<td>0.035 (2)</td>
<td>–</td>
<td>13, 14</td>
</tr>
<tr>
<td>GP Com</td>
<td>2794.05 (20)</td>
<td>None</td>
<td>–</td>
<td>–</td>
<td>&lt;0.02</td>
<td>15, 16</td>
</tr>
<tr>
<td>CE 315</td>
<td>3906 (42)</td>
<td>None</td>
<td>–</td>
<td>–</td>
<td>&lt;0.02</td>
<td>17</td>
</tr>
</tbody>
</table>

*“Other $q$” for AM CVn comes from Doppler tomography (Roelofs et al. 2006b).

*“Other $q$” for SDSS J092638.71+362402.4 comes from eclipse timing (Copperwheat et al. 2011).

*Value of $\varepsilon$ for CP Eri was calculated as described in this paper, and not from tabulated $P_{\text{orb}}$ and $P_{\text{sh}}$.

References. (1) This paper; (2) Skillman et al. (1999); (3) Provencal et al. (1995); (4) Patterson et al. (2002); (5) Roelofs et al. (2007a); (6) Patterson et al. (1997); (7) Provencal et al. (1997); (8) Wood et al. (2002); (9) Ramsay et al. (2010); (10) Patterson et al. (2000); (11) Copperwheat et al. (2011); (12) Anderson (2005); (13) Woudt & Warner (2003); (14) Roelofs et al. (2006a); (15) Nather et al. (1981); (16) Marsh (1999); (17) Ruiz et al. (2001).
superoutburst. These yield, respectively, \( \varepsilon = 0.0087 \pm 0.0002 \) and 0.0095 \( \pm 0.0008 \).

The technique of Patterson et al. takes a single value of \( P_{\text{orb}} \) as representative of a given CV. However, since \( P_{\text{orb}} \) tends to drift (e.g. Warner 1975), Patterson et al. consistently use \( P_{\text{orb}} \) at 4 d after maximum superoutburst light: after the most unstable magnitude variation has passed, but before most of the energy driving the superhump has radiated away. For CP Eri, neither of our values references a time of superoutburst maximum. In this situation, we generally prefer the value obtained during superoutburst to the value obtained during quiescence. However, in this case, our quiescent run was longer by a factor of three and hence yielded a better error. Thus, we shall take their average: \( \varepsilon = 0.0091 \pm 0.0005 \). Obviously, this is a coarse estimate. However, it will suffice for now because, for reasons just stated, a meaningful correction will come not from an appropriately weighted average, but rather from further observations of CP Eri. Our main finding is that both values of \( \varepsilon \) place CP Eri in \( \varepsilon(P_{\text{orb}}) \) space within the region bordered by a fully-degenerate white dwarf donor and a partially-degenerate helium star donor (fourth point from the left-hand side, within the shaded region).

From the \( \varepsilon(q) \) relation, we obtain \( q = 0.047 \) for CP Eri. Taking \( (M_1) = 0.75 \text{M}_\odot \) (Smith & Dhillon 1998; Knigge 2006), we estimate \( M_2 = 0.035 \text{M}_\odot \).

5 SUMMARY

5.1 CP Eri

An 11-night baseline of photometry on CP Eri in quiescence reveals periods of 1716.2 \( \pm 0.2 \) and 1701.4 \( \pm 0.2 \) s. From a shorter superoutburst observation, we interpret the former as \( P_{\text{sh}} \) and the latter as \( P_{\text{orb}} \). CP Eri is one of eight AM CVn systems with \( P_{\text{sh}} \) and \( P_{\text{orb}} \) measured to this precision. The fractional period excess \( \varepsilon \) plotted as a function of \( P_{\text{orb}} \) indicates that the donor star in CP Eri is partially degenerate, and it enhances a tentative pattern that AM CVn systems are evolving towards longer \( P_{\text{orb}} \). A separate observing run illustrates that CP Eri can change states multiple times on the order of days. This type of behaviour has been exhibited by two other AM CVn systems, both also in the period range of 20–40 min.

5.2 Recommendation

Only an observation of a complete superoutburst cycle can yield an informative picture of the superhump phenomenon for a particular CV. Our observations of CP Eri did not include a time of maximum superoutburst light, nor are they sufficiently powerful to determine superhump drift. Thus, further monitoring is desirable.

More generally, it will inform AM CVn system evolution to find an \( \varepsilon(P_{\text{orb}}) \) relation that is analogous to the work done by Patterson et al. for hydrogen CVs. A promising method of achieving this goal involves precise estimates of \( P_{\text{sh}} \) and \( P_{\text{orb}} \) for more helium rich CVs. The few systems discovered since 2008 have not been studied with the intensity necessary for a superhump determination to be made. Of particular interest are those likely to exhibit high-state behaviour: those with He absorption spectra and \( P_{\text{sh}} \) shorter than 40 min. To complement such work, it is desirable to obtain values of \( q \) from geometrical constraints, such as eclipses. Only one of the known helium CVs is an eclipser. However, surveys such as the Kepler mission, largely uncombed for new helium CV candidates, may reveal more eclipsing systems.

ACKNOWLEDGMENTS

This research was funded by the National Science Foundation (AST-0908363) and the Mt Cuba Astronomical Foundation. We also thank an anonymous referee for meticulous editing that caught oversights in the original manuscript.

REFERENCES

Luyten W. J., Haro G., 1959, PAST, 71, 469
Patterson J. et al., 1997, PASP, 109, 1100
Patterson J. et al., 2002, PASP, 114, 65
Patterson J. et al., 2005, PASP, 117, 1204

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