Discovery of another AM Her variable in the period gap

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ABSTRACT

Recently, Buckley et al. drew attention to a new AM Her variable, RE1938 – 4612, discovered by the ROSAT survey with a period of 2.33 h which places it in the middle of the usual 2–3 h period gap for cataclysmic variables. Here, we report the discovery of yet another AM Her variable, V2009 – 65.5, with a period of 2.66 h, also within the period gap. We argue that the anomalously high proportion of AM Hers within the period gap indicates that the canonical magnetic braking mechanism used to explain the orbital evolution of other CVs may not be applicable to the AM Hers. Possible alternative models are discussed.

Key words: accretion, accretion discs – binaries: close – stars: individual: V2009 – 65.5 – stars: magnetic fields – novae, cataclysmic variables.

1 INTRODUCTION

Cataclysmic variables (CVs) are low-mass close binaries in which a white dwarf primary accretes matter from a Roche-lobe-filling M dwarf secondary. One of the striking characteristics of the CVs is the existence of the ‘period gap’ between 2 and 3 h, within which there is a dramatic drop in the observed number of systems. This observation has been successfully explained in terms of the magnetic braking (MB) model for CV evolution (Rappaport, Verbunt & Joss 1983). The essential feature of the MB model is that, for periods greater than 3 h, the late-type star is magnetically active and loses angular momentum through magnetic braking due to a stellar wind. The loss of angular momentum is transferred to the binary through tidal coupling. According to this theory, near $P \approx 3$ h the M star becomes fully convective and magnetic braking ceases to be effective due to the loss of the magnetic field. The M star is out of thermal equilibrium at this point due to the prior rapid mass loss, and it recedes within its Roche lobe as it regains thermal equilibrium (Rappaport et al. 1983). The orbital evolution for $P < 3$ h is driven mainly by gravitational radiation (GR). The lower limit of the period gap ($\approx 2$ h) is the point at which the M star again comes into contact with its Roche lobe.

Until recently, observations appeared to indicate that the AM Her-type variables also follow a similar evolutionary scenario. Thus of the 17 previously known systems only one, namely UZ For, was within the period gap, while five were above the period gap. Recently, a ROSAT source, RE1938 – 4612, was discovered by Buckley et al. (1993) to be a polarized CV with a period of 2.33 h. Two other ROSAT sources, RE2107 – 05 and RE0531 – 462, have subsequently been reported as AM Hers with periods of 125 min (Hakala et al. 1993; Schwake, Thomas & Beuermann 1993) and 140 min (Buckley, private communication) respectively, which also place them within the period gap.

In this paper, we present detailed observations of yet another new AM Her-type variable, V2009 – 65.5, which lies within the period gap. Unlike the other new AM Hers, this system was discovered as a variable by optical observations, as a part of a survey of high Galactic latitude variable objects in overlapping regions of UK Schmidt plates.

A preliminary account of these observations was reported by Drissen et al. (1992).

2 OBSERVATIONS

V2009 – 65.5 was discovered during a survey for highly variable objects detected in the overlapping regions of the digitized UK Schmidt J plates of the southern hemisphere (Drissen & Shara, in preparation). This survey aims to build unbiased samples of new cataclysmic variables and variable quasars. Briefly, aperture photometry (DAOPHOT: Stetson

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1987) is used to determine instrumental magnitudes of each star in a pair of plates. Every object that varies significantly (by more than 0.5 mag) is then singled out and examined by eye in order to reject spurious detections such as plate defects. The object in question changed in magnitude by \( \Delta m = 1 \) mag between the two epochs (Drissen et al., in preparation). A finding chart is given in Fig. 1.

A discovery spectrum of V2009 - 65.5 obtained with the Anglo-Australian Telescope (AAT) on 1992 May 29 is shown in Fig. 2. The data show a characteristic AM Her-type spectrum with broad Balmer and He I lines in emission, and high-excitation lines such as He II at 4686 Å and the C-N blend at 4650 Å also in emission. These characteristics, combined with the evidence of long-term high and low states, strongly suggested that V2009 - 65.5 is probably a member of the AM Her class. The discovery spectrum also shows a flat continuum and a large Balmer decrement, with the flux at He II (4686 Å) being roughly half that at H\( \beta \).

In order to confirm the binary nature of V2009 - 65.5, broad-band \( V \) and \( R \) photometric observations were obtained using the Australian National University (ANU) 2.3-m telescope at Siding Spring Observatory for a period of 8 h on 1992 June 20. The data showed that the intensity in both bands is modulated with a period of approximately 2.66 h.

During 1992 July we carried out a series of observations of V2009 - 65.5, again using the AAT, but this time looking specifically for circular polarization, the defining characteristics for an AM Her-type system. Phase-resolved spectra were obtained around the orbit with a spectral resolution of 10 Å and a phase resolution of approximately 0.1 period with the AAO spectropolarimeter on July 25. The spectra showed strong negative circular polarization (up to 10 per cent) over the entire observed waveband (4400–7200 Å), and a spectral energy distribution that rises towards the red. The phase-averaged polarization and intensity spectra,

Figure 1. Finding chart for V2009 - 65.5 [RA 20°08′55.8″, Dec. −65°27′43″ (epoch 2000)], reproduced from a STScI digitized UK Schmidt J plate. The panel is 3.5 arcmin on a side. North is at the top, east to the left.

Figure 2. Discovery spectrum of V2009 - 65.5 obtained with the AAT on 1992 May 29. The most prominent lines are identified.
appropriately binned in wavelength, are shown in Fig. 3. The data show no clear evidence of resolvable cyclotron humps or atomic Zeeman lines, so a field determination is not possible [see Wickramasinghe (1990) for a recent review of Zeeman and cyclotron lines in AM Hers]. The overall slope of the polarized energy distribution and comparisons with other AM Hers, however, suggest that V2009 − 65.5 is probably a low-field (B ≈ 20 MG) system similar to EF Eri or AM Herculis itself.

The phase-dependent spectra were used to measure radial velocities of the Hα emission line, and the results are shown in Fig. 4. The velocity curve shows a large variation with a full amplitude of 600 km s⁻¹, again typical of AM Herculis-type systems in which the velocities reflect mainly the infall motion towards the white dwarf surface. The asymmetric nature of the velocity curves is probably caused by the presence of two such infall streams in this particular system (see below).

To investigate the nature of V2009 − 65.5 further, we obtained simultaneous phase-dependent circular polarization and intensity observations covering five wavebands, using the Hatfield Polarimeter on 1992 June 27, 28 and 29. These data are shown in Figs 5 and 6. From the Hatfield Polarimeter data we have derived the following ephemeris, where zero phase corresponds to the mid-point of the rapid rise in intensity which was the feature that could be most accurately timed:

\[ T = \text{HJD} 244,883.118 \pm 0.003 + 0.1109E. \]

The period is not sufficiently accurate to link these observations to the earlier 2.3-m ANU photometry.

The Hatfield data clearly show that V2009 − 65.5 is a ‘two-pole’ system. We note that the light curves show the presence of two maxima per orbital period. The strong maximum which lasts for 0.5 period is centred at 0.15 period and is seen in all wavebands. However, there is also a secondary maximum centred at 0.55 period which is absent, or only weakly present, in the bluest (3400–4800 Å) waveband, but is clearly seen in the redder wavebands. The radiation from the first component is negatively circularly polarized, while that from the second component is positively circularly polarized. These two components can be attributed to cyclotron emission from two accretion shocks (the main and secondary poles) located in two separate regions of opposite field polarity on the white dwarf surface, as we shall now show.

3 A TWO-POLE MODEL FOR V2009 − 65.5

The phase dependence of broad-band intensity and polarization can be modelled with different degrees of sophistication, depending on the nature of the data (linear or circular polarisation or both) and other information, such as field strengths, available (Ferrario & Wickramasinghe 1990; Wickramasinghe et al. 1991a). In the present case, we have no knowledge of field strength, nor do we have information on linear polarization or on the variation of polarization angle with phase. We are therefore not in a position to construct a definitive model for the system. Our aim is to present a model that explains most of the essential features in the observations presently at hand, although clearly the model will need to be refined when further constraints become available.

Our modelling procedure and notation have been discussed in detail in Wickramasinghe et al. (1991a) and Ferrario & Wickramasinghe (1990), and will not be repeated here. The best-fitting centred dipole model for the data in the 4900–5700 Å band is shown in Fig. 7. The model has an

![Figure 3](https://example.com/figure3.png)

Figure 3. Phase-averaged AAT spectra of V2009-65.5 obtained on 1992 July 25. Upper panel: polarization spectrum. Lower panel: intensity spectrum.
orbital inclination \( i = 40^\circ \) and a dipole inclination \( \theta_d = 170^\circ \). The main emission region is located below the orbital plane between magnetic colatitudes \( \theta_1 = 128^\circ \) and \( \theta_2 = 130^\circ \), and extends in magnetic longitude from \( \psi_1 = -60^\circ \) to \( \psi_2 = 55^\circ \). The second emission region extends in magnetic colatitude from \( \psi_1 = 20^\circ \) to \( \psi_2 = 22^\circ \), and in magnetic longitude from \( \psi_1 = -40^\circ \) to \( \psi_2 = 30^\circ \). The main and the secondary regions

**Figure 4.** Radial velocity curve of the H\( \alpha \) emission line, obtained from the spectroscopic data acquired on 1992 July 25.

**Figure 5.** AAT broad-band circular polarization observations of V2009 \(-65.5\), obtained with the Hatfield Polarimeter on 1992 July 27, 28 and 29.

**Figure 6.** AAT broad-band intensity curves of V2009 \(-65.5\), obtained with the Hatfield Polarimeter on 1992 July 27, 28 and 29.

**Figure 7.** The solid line is our best-fitting model of the data in the 4900 - 5700 Å band. The model has an orbital inclination \( i = 40^\circ \) and a dipole inclination \( \theta_d = 170^\circ \) (see text).

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have electron shock temperatures $T = 10$ and $7 \text{ keV}$ respectively, and optical depth parameters $\Lambda = 3 \times 10^5$ and $4.5 \times 10^4$ respectively.

The main emission region is located below the orbital plane, is visible for approximately half of the orbital period, and is responsible for the negatively polarized intensity maximum. The secondary emission region is above the orbital plane, lies close to the rotational pole, and is visible at all phases. The two emission regions are located in regions of different field strength, and the specific and total accretion rates on to these regions are different, so that they have different optical depth parameters. The intensity from each region therefore peaks at a different frequency, and each region contributes a different relative amount to the total intensity at a given frequency. In our model, the main emission region has a weaker field in comparison to the secondary region. Its contribution to the total intensity, however, peaks at shorter wavelengths as a result of its higher accretion rate. Our multiwaveband observations show a systematic increase in the relative contribution from the secondary region with increase in wavelength. These observations, together with our model, suggest that the secondary emission region will dominate over the primary emission region at still longer wavelengths.

The picture that we have deduced for the location of the two emission regions relative to the orbital plane and the spin axis is very similar to that found for Grus VI (Wickramasinghe et al. 1991b).

4 DISCUSSION AND CONCLUSIONS

The results and model presented in this paper clearly identify V2009 − 65.5 as a new AM Herculis-type system in which two poles were active at the time of observation. The system is particularly interesting, since it lies in the period gap and was discovered independently of the ROSAT survey (Beuermann & Thomas 1993).

As noted in the Introduction, if we consider only the confirmed AM Hers, there are now five within the 2–3 h period range (UZ For, RE1938 − 4612, RE21017 − 0518, RE0531 − 462 and V2009-6). There are four new sources confirmed to be AM Hers from polarization studies with periods greater than 180 min [RE2316 − 05, RX1007 − 20, RX0203 + 29 and RX1313 − 32 (Buckley, private communication)], bringing the total above the period gap to nine. There are also four new confirmed sources (RE0453 − 42, RE1844 − 74, RE1149 + 28 and RE1307 + 53) below the gap. A plot of the number of systems against period now shows a nearly uniform distribution between 2 and 4 h, with no clear evidence for a period gap. In order to quantify this impression we need to compare the AM Her distribution with that of other CVs, as recently done by Ritter & Kolb (1992) for the pre-ROSAT sample of AM Hers. In their paper, the period gap for the non-AM Her-type CVs was defined to be between 125 and 190 min. If we use this as the definition of the period gap, RE2107 − 0518 is no longer in the gap while AM Her is inside the gap. The ratio of the number of systems in the period gap to the number above the period gap in a period bin of equal length (190–255 min) is 0.6 for the AM Hers and 0.1 for other CVs, suggesting that the gap is of less significance for the AM Hers.

We have carried out a statistical study of the two groups by dividing them into three period bins: bin 1 (1 < 125 min), bin 2 (125–90 min) and bin 3 (90–255 min). For the AM Hers we have used only the sources that have been confirmed as magnetic from polarization studies. A $\chi^2$ test of the resulting multinomial distributions shows that there is 7 per cent chance that the differences between the two groups arise due to sampling. If a fourth bin (255–320 min) is included, the differences between the two groups are statistically even more marked, with the probability that the differences occur by chance being 0.5 per cent.

Systems within the period gap are usually explained on the hypothesis that they do not evolve from longer periods but are born within the gap. With the increasing evidence for an anomalously larger proportion of AM Hers within the gap, however, alternative possibilities should be investigated. We feel that the most likely explanation is that the magnetic field has a direct influence on the orbital evolution. An interesting possibility has recently been discussed by Wickramasinghe & Wu (1993) (see also Wu & Wickramasinghe 1993). They argue that, in systems where the magnetic field is strong enough to lock the white dwarf into synchronous rotation with the orbit, there is a marked reduction in the magnetic flux in open field lines. The efficiency of magnetic braking may therefore be severely curtailed, and it is even possible that gravitational radiation may be the dominant source of orbital evolution, at least in the most strongly magnetized AM Herculis-type systems. Under these circumstances, there will be no rapid orbital evolution and, as a consequence, no period gap. Although the details of this model still need to be worked out, the 'no magnetic braking' model or some variant of it appears to be required to explain the present observations.

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