INTERMEDIATE POLARS IN LOW STATES

Brian Warner

Department of Astronomy, University of Cape Town, Rondebosch 7700, South Africa
warner@physci.uct.ac.za

Abstract

Although no intermediate polar (IP) has been observed in recent years to descend into a state of low rate of mass transfer, there are candidate stars that appear to be already in intermediate and low states. V709 Cas is probably an intermediate state IP; NSV 2872 appears to be a low state IP, and will probably resemble the long orbital period IP V1072 Tau if it returns to a high state. The enigmatic star V407 Vul, which has had many interpretations as an ultra-short period binary, has many resemblances to the pre-cataclysmic variable V471 Tau, and may therefore be an IP precursor of quite long orbital period, and not yet a fully fledged cataclysmic variable.

Keywords: techniques: photometric - binaries: close - stars: cataclysmic variables

Introduction

The two principal classes of magnetic cataclysmic variable (mCV) are the synchronous rotators and the asynchronous rotators. The former, known as polars, possess white dwarf primaries with fields strong enough to interact with the secondary star and effect synchronous rotation of the primary with the orbital motion of the secondary. In the latter, known as intermediate polars (IPs) the primary is less strongly magnetized so the primary rotates with a period different from $P_{\text{orb}}$.

The polars are well known for having unstable mass transfer from the secondary to the primary – with resulting high and low states of accretion luminosity. Although relatively low states of IPs are known from studies of archived plates (Garnavich & Szkody 1988), and V1223 Sgr in particular has had extensive low states, it is a curious, and often regretted, fact that since they were recognized in the early 1980s, none of the well-studied IPs has entered into a low state. There would be obvious advantages to studying IPs in low states, particularly if the rate of mass transfer $\dot{M}$ were to shut off completely – the spectrum of the white dwarf would then be visible uncontaminated by accretion emission.
and the possibility of measuring field strengths via the Zeeman effect, as is done during polar low states, would appear.

**V709 Cas**

A first move in this direction has been made possible by V709 Cas, which has $P_{\text{orb}} = 5.34$ h and $P_{\text{rot}} = 5.22$ min. The optical spectrum of this system shows the presence of broad absorption lines of the white dwarf primary, on which are superimposed the continuum and emission lines from the accretion disc and accretion curtains (Bonnet-Bidaud et al. 2001). Only an upper limit $B < 10$ MG is so far possible for the field strength, but variable X-Ray flux on time scales of months to years show that V709 Cas has unstable $\dot{M}$ which may at some time fall low enough for the white dwarf spectrum to be more clearly studied. Both Bonnet-Bidaud (2001) and De Martino et al. (2001), from different approaches, find $\dot{M} \sim 1 \times 10^{16}$ g s$^{-1}$, which is a factor of 4–10 lower than the values for $\dot{M}$ deduced for more normal IPs (see Table 7.4 of Warner 1995).

Thus V709 Cas appears to be an IP in an intermediate state of $\dot{M}$, which is compatible with the weakly visible spectrum of the primary. Its present brightness is $m \sim 14$, so a reconstruction of its historic light curve from archived plates is both feasible and desirable – if it attains a normal high state it could reach 12th magnitude.

**V1072 Tau and NSV 2872**

As a second step we might wonder whether there are in fact IPs in long-lived low states, already known but not properly recognized as such. As an example we can consider the IP V1072 Tau and ask what it would look like if it were to descend to a state of low $\dot{M}$.

V1072 Tau is a long period IP, with $P_{\text{orb}} = 9.95$ h and $P_{\text{rot}} = 62.0$ min (Remillard et al. 1994). Its optical spectrum is that of a late K star with superimposed emission lines and continuum from the accretion process. The K spectral type of the secondary is appropriate for a Roche lobe filling star in long period orbit. If the system were in a low state the spectrum would be dominated by the K star absorption spectrum, but there would be a contribution at short wavelengths (the U band, and shorter wavelengths), with the flux modulated at 62 min period either from the low level of Roche lobe overflow, or from magnetically channeled wind from the secondary (as in V471 Tau, which we discuss below).

Such an object might be quite difficult to discover (but would certainly be found eventually in any wide field survey like the Sloan Digital Sky Survey). It could, however, be readily found if the long-term light curve shows higher states of $\dot{M}$.
The object described here sounds very like the recently recognized low state CV known as NSV 2872. This star was first found to be variable by Ruegemer (1933), and a more complete light curve was provided by Zinner (1932) and Florja & Kukarkin (1935). It has a brightness range of $m_{pg} = 11.4 - 14.5$ and was classified in the GCVS as a suspected nova-like or dwarf nova. A spectrum obtained near the lower end of its brightness range showed only the absorption lines of an early K star, with no emission lines, and was consequently thought not to be a CV (Liu & Hu 2000). However, Kozhevnikov (2003) has made extensive photometric observations near minimum brightness (at $B \sim 14.4$: Kozhevnikov, private communication) and concludes that it (a) has very low level rapid flickering, characteristic of a CV in a low state of $\dot{M}$ and (b) has a coherent periodicity at 87.850 min of low and variable amplitude (3 – 8 mmag).

NSV 2872 therefore looks very much what we would expect of an IP in a long orbital period, accreting at a very low rate. The already recognized range of brightness of $\sim 3$ mag shows that it can have high states. This is another system for which a more complete historical light curve would be very useful – and one that should be monitored regularly in order to detect the occurrence of a high state, where it could take on the appearance of V1072 Tau. A far UV study of the hot component is also obviously of some interest.

**V471 Tau**

The eclipsing binary V471 Tau is a member of the Hyades cluster and is a detached pair consisting of a 35 000 K white dwarf in orbit around a dwarf K2 secondary with $P_{\text{orb}} = 12.5$ h. What makes it more interesting is that it shows a 9.25 min modulation in the U band with an amplitude of 9.5 mmag (Clemens et al. 1992) that is 180° out of phase with pulsed soft X-Rays at the same period. From the known contribution of the white dwarf to the U band we can estimate that the true amplitude of the 9.25 min modulation is $\sim 30$ mmag.

The explanation of the modulation is that the white dwarf has a magnetic field sufficiently strong to capture and channel part of the stellar wind from the secondary (Clemens et al. 1992). Thus V471 Tau is really a pre-IP, which will become an IP as soon as the secondary begins to overflow its Roche lobe.

The optical spectrum of V471 Tau shows the continuum and absorption lines of a K2 dwarf, currently with no emission lines (though in past years there has been Hα in emission, around phase 0.5 of the orbit) –
Rottler et al. (1998). In the UV, of course, a continuum contribution from the white dwarf is present.

There are strong similarities between V471 Tau and NSV 2872 – the difference being that the former does not have the low level flickering that is probably the signature of Roche lobe overflow.

**V407 Vul**

V407 Vul has had a roller coaster career. Discovered initially as an X-Ray source, RX J1919.4+2456, modulated at 569 s period and thought to belong to the class of soft X-Ray IPs (Haberl & Motch 1995; Motch et al. 1996), it was later suggested that it could be a strongly magnetic He-transferring system (i.e., an AM CVn polar) where the observed period would be orbital (Cropper et al. 1998). The optical component was later identified, at \( I \sim 18.6 \), and was found to be modulated at the 9.5 min period, being in antiphase with the X-Ray variation (Ramsay et al. 2000). The X-Ray flux was found to vary by an order of magnitude on a time scale of a year. Later observations (Ramsay et al. 2002) showed modulation in the \( R \) and \( V \) bands, the latter with an amplitude of \( \sim 65 \) mmag, and a spectral flux distribution like that of a reddened K star, with no emission lines.

Alternate models were proposed for V407 Vul, to account for the lack of emission lines and absence of polarization. Marsh & Steeghs (2002) suggested that the inter-star stream of gas impacts directly onto the primary, as in an Algol system, thus preventing an accretion disc from being formed. A unipolar-inductor model, as in the Jupiter-Io system, was proposed by Wu et al. (2002).

With the acquisition of a higher quality spectrum of V407 Vul it is now known that the spectrum is simply that of an apparently normal reddened K star, with the addition of a featureless pulsed component at the shortest wavelengths (Steeghs 2003). There are no emission lines and there is no helium present.

The similarities of the spectrum, X-Ray and pulsation period of V407 Vul and V471 Tau are quite striking. There are parallels, too, with the properties of NSV 2872.

**Conclusions**

Although no recognized IP has entered a low state since this class of mCV was identified, there appear to be low \( M \) IPs available for study. V709 Cas has the signature of an IP in an intermediate state, and will repay study if it moves up or down from that state. NSV 2872 has features that would be expected of a long orbital period IP in a low
state – in particular, if it returns to a high state it should resemble the high \( M \) IP V1072 Tau.

The enigmatic object V407 Vul, which has had many interpretations, has a strong resemblance to V471 Tau and so strictly is probably not a CV at all – it may be a long period pre-CV which will become an IP. Such systems may be relatively common – they are not easy to detect optically because they are dominated by the K star flux, yet the brightest is as close as the Hyades cluster. Lower mass systems, with M spectral type companions, will be easier to find as White Dwarf/M dwarf pairs, but will require appropriate extended photometry to detect rotationally modulated flux. Similarly, new detections through discovery of periodically modulated X-Ray flux will require extended pointed observations.

**Acknowledgments**

I thank Dayal Wickramasinghe for helpful discussions. My research is funded by the University of Cape Town.

**References**

Bonnet-Bidaud, J.M., Mouchet, M., de Martino, D., Matt, G. & Motch, C. (2001). A&A, 374, 1003

Clemens, J.C., et al. (1992). ApJ, 391, 773

Cropper, M., et al. (1998). MNRAS, 293, 57L

de Martino, D., et al. (2001). A&A, 377, 499

Florja, N.F. & Kukarkin, B.V. (1935). Perem. Zvezdy, 5, 19

Garnavich, P. & Szkody, P. (1988). PASP, 100, 1522

Haberl, F. & Motch, C. (1995). A&A, 307, L37

Kozhevnikov, V.P. (2003). A&A, 398, 267

Liu, W. & Hu, J.Y. (2000). ApJS, 128, 387

Marsh, T.R. & Steeghs, D. (2002). MNRAS, 331, 7L

Motch, C., et al. (1996). A&A, 307, 459

Ramsay, G., Cropper, M., Wu, K., Mason. K.O. & Hakala, P. (2000). MNRAS, 311, 75

Ramsay, G., et al. (2002). MNRAS, 333, 575

Remillard, R.A., et al. (1994). ApJ, 428, 785

Rottler, L., Batalha, C., Young, A. & Vogt, S. (1998). BAAS, 192, 6720

Ruegamer, H. (1933). AN, 248, 410

Steeghs, D. (2003). Workshop on Ultracompact Binaries, Santa Barbara.

See [http://online.kitp.ucsb.edu/online/ultra_c03/steeghs/](http://online.kitp.ucsb.edu/online/ultra_c03/steeghs/)

Warner, B. (1995). Cataclysmic Variable Stars. Cambridge University Press

Wu, K., Cropper, M., Ramsay, G. & Sekiguchi, K. (2002). MNRAS, 331, 221

Zinner, E. (1932). AN, 246, 17