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TESS and ground-based photometry of magnetic CVs

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I summarize recent work on magnetic CVs (mCVs). Observations were carried out using the McDonald Observatory 2,1-m telescope obtaining high-speed (1-5 sec cadence) photometry, analyzed in coordination with photometry from the Transiting Exoplanet Survey Satellite (TESS), with 120-s cadence. Asynchronous Polars (APs) and the possibly related new class of slowly rotating Intermediate Polars (IPs) are the focus of this work. An Interactive Magnetic Value Model was developed and proposed to explain mass transfer variations in APs. In this model, the strong magnetic field of the white dwarf interacts with the moderately strong magnetic field of the rapidly spinning donor star. The superposition of the magnetic fields of both stars at the inner Lagrangian point (L1) may either inhibit or enhance mass transfer through L1, depending on the orientation of the resultant field. Rapid changes in the accretion rate are observed in polars, initiating high or low accretion states, and in some IPs, and may be explained by rapid changes in the composite magnetic field at L1 affecting the mass transfer rate.

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1. Introduction

I'd like to thank Franco Giovannelli for allowing me this opportunity. First, I will review a few things concerning recent results on magnetic cataclysmic variables (mCVs). Then I will discuss other recent work on the magnetic field interactions of Asynchronous Polars (APs) and Intermediate Polars (IPs), especially the Interactive Magnetic Valve Model. The observations presented here were mostly done using TESS photometry, an example is shown in Figure 1, combined with McDonald Observatory 2.1-m telescope high-speed photometry, with an example shown in Figure 2. For many more examples see the original papers summarized here.

2. Asynchronous Polars or Slowly Rotating Intermediate Polars?

Briefly stated (Asynchronous Polars (APs) are just like ordinary polars except that there is up to about 15% percent difference between the spin period of the white dwarf and the orbital period. See Table 1 of Littlefield et al. [1], for a list of APs and slowly rotating Intermediate Polars (IPs). In all but one of these binaries, the white dwarf spins a bit faster than the binary orbit. APs cannot be identified as such from a single observation of a few hours. They appear as an ordinary synchronous polar on short time scales, depending on the degree of asynchronism. However, when observed on longer time scales the light curve changes because the accretion flow is continuously redirected as the binary progresses through its spin-orbit beat cycle. Switching between accretion regions, also known as pole switching occurs and results in accretion geometry changes as evidenced by light curve differences as a function of beat phase. The difference between an AP and a synchronous polar can be determined from photometry by measuring the beat period between the white dwarf spin and the binary orbit. Spectroscopic observations often unambiguously track the orbital period in APs [e. g. 2] just as they do for normal polars.

The magnetic field of the accreting white dwarf in a mCV will cause synchronization of the rotation of the white dwarf to the binary orbital period if the field strength is above ∼10 MG. The APs have such strong fields that some of them have already been determined to be synchronizing on short time scales [3,4,5]. For example, Nova Cygni 1975, also known as the polar V1500 Cygni, is undergoing post-nova synchronization on a time scale of a few hundred years [5]. It was also found that the white dwarf in V1500 Cygni is still cooling 40 years after the nova. So it is clear that the nova eruption caused V1500 Cygni to become an asynchronous polar; however, we do not know for sure if was synchronous before the eruption. But the time scale of a few hundred years suggests that it probably was synchronous before the nova. The original APs, V1500 Cygni [5] and BY Cam [2] are each about 1% asynchronous, although V1500 Cygni was about 2% asynchronous after the 1975 nova was discovered to be an AP in 1991 [6].

Based on TESS observations of CD Ind, which is also about 1% asynchronous an argument that CD Ind is a short-period analog to BY Cam was made because of the similarity between their long-term power spectra and accretion pole switching characteristics [7,8], also see Hakala et al. [9]. In addition, it was hypothesized that a hidden pole accretes material during part of the 7.3-day beat cycle in CD Ind.

The newly discovered AP, SDSS J084617.11+2453-44.1, has a conspicuous 6.77-day beat cycle resulting from a 4.64-hour orbital period from a 2.8% asynchronism [10]. The latter is in line with

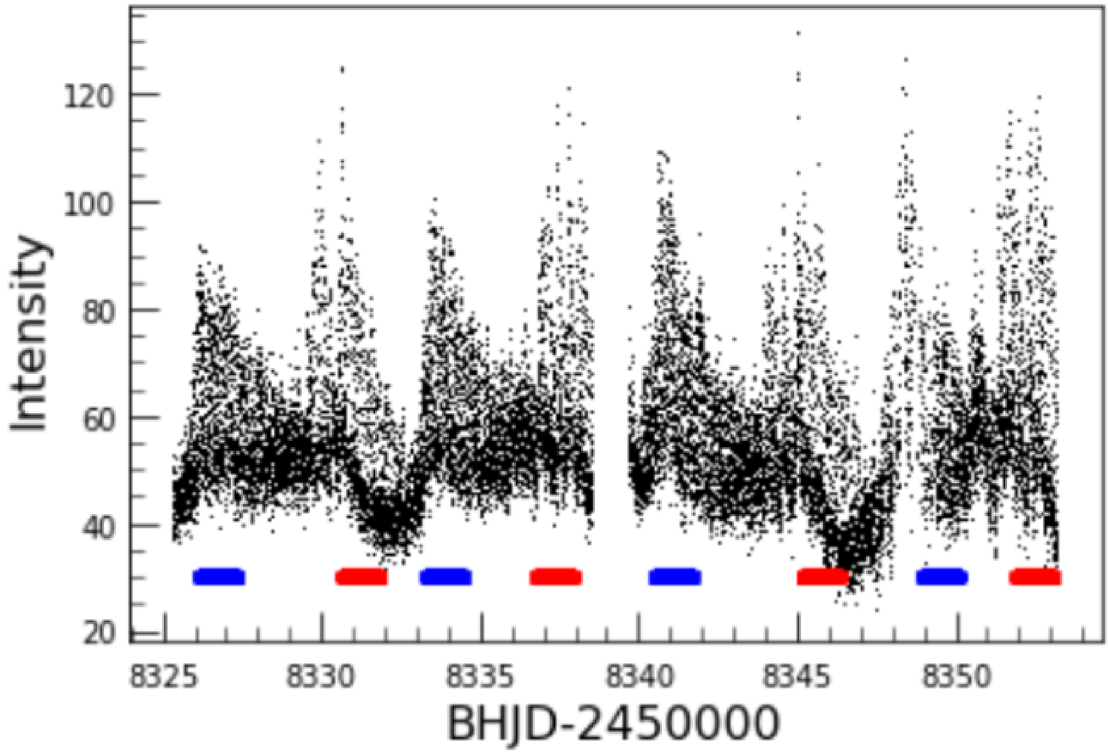

Figure 1: The nearly continuous TESS light curve of CD Ind. The time resolution is 2-min and the data span about 28 days. Four beat cycles are clearly seen. While details cannot be resolved on this scale, notice that the individual spin pulses are superimposed on a continuous brightness variation (seen as a dark band) modulated at the beat cycle. The red and blue lines point to data subsets examined in more detail in what follows. Credit: Mason et al. (2020) [8].

the previously discovered polars IGR J19552+0044 at 2.8%, and IRSX J083842.1-282723 which is about 4% asynchronous. An outlier is the AP V1432 Aql which is over synchronous with a white dwarf spin period that is 0.2% longer than the orbital period.

Asynchronous polars blur the line between APs and slowly rotating IPs. The term slowly rotating IPs should be reserved for those IPs that are either maintaining asynchronism or becoming synchronous for the first time. While APs are previous polars that have been knocked out of synchronism by, for example, one or more novae. It is possible that a synchronous polar could have had a nova eruption before fully re-synchronizing from a prior nova eruption, thereby pushing it further away from synchronism with each nova.

An interesting case is Paloma [10] usually classified as an AP, which is about 13% asynchronous. TESS observations resolve the ambiguity in the white dwarf spin period. Using TESS we find a white dwarf spin period of 2.27 hr. Paloma has a short 0.7-day beat period compared to other APs because of its high degree of asynchronism.

The difference between APs and slowly rotating IPs is further blurred with the help of a new asynchronous polar J13441.83+204408.3 [1]. Is just less than 10% asynchronous. J1344 in particular, challenges conventional theory concerning asynchronism. It seems to be too asynchronous to

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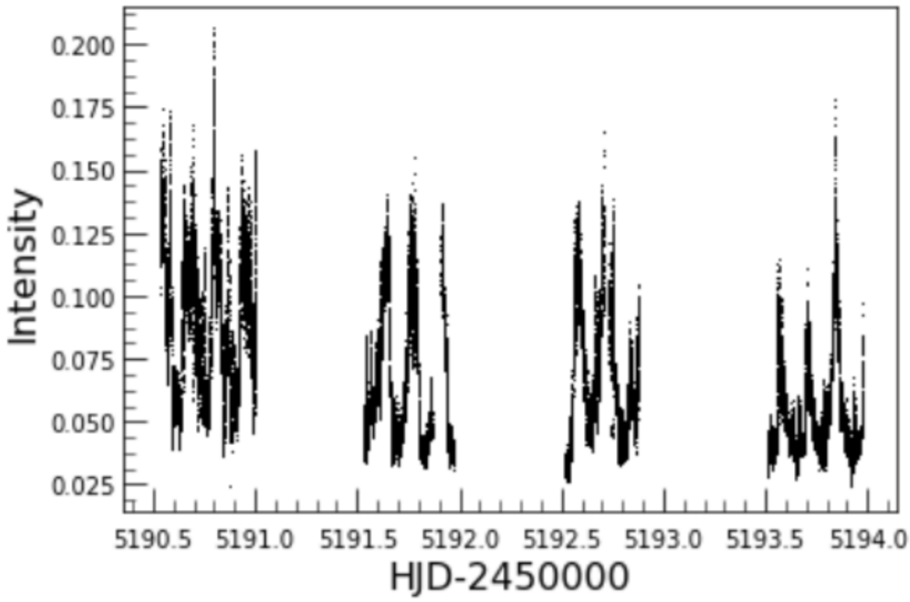

Figure 2: BY Cam (R-band) light curves from four nights in 2009 December using the McDonald Observatory 2.1-m telescope. Notice that observation times were nearly 12 hours. The pulse structure varies significantly from night to night and often within a single night. Pulses are seen superimposed on an overall nightly brightness variation that repeats on the beat cycle, like CD Ind (recall Figure 1). Credit: Mason et al. (2020) [8].

have had synchronism disrupted by a single nova and because it has such a short period, likely P = 102 min, and a strong magnetic field of B = 56 MG, the expected time scale for synchronization of J1344 to become a polar must be quite short. Its origin is a bit mysterious and will require follow-up observations to determine the synchronization time scale. One possibility is that the white dwarf in J1344 has a high mass [1]. It is important to note that the synchronization time scale for an IP to become a polar is significantly increased for a high-mass white dwarf, because of the small white dwarf radius associated with the high mass [1].

3. Interactive Magnetic Valve Model

An Interactive Magnetic Valve Model for mass transfer in polars, capable of modulating mass transfer over the beat cycle in the typical AP, BY Cam, was proposed [11]. Essentially the same model was applied to synchronous polars to explain their high and low accretion states [12] and to the low-field polar AM Her and the canonical high-field polar AR UMa in a joint study of TESS observations [13]. AR UMa was also observed in its rare High state using the McDonald Observatory 2.1-m telescope [13]. At much lower magnetic field strength of IPs, accretion rarely if ever stops as it does frequently in most polars [14]. The IP, YY Dra often known as DO Dra, was found to undergo occasional and very brief low accretion states due to a cessation of mass transfer [15]. The Interactive Magnetic Valve Model may also explain these short-term events. The Interactive Magnetic Valve Model argues that the interaction between the, 10-235 MG, magnetic field of the white dwarf interacts with the few kG magnetic field of the donor star to either cut off or

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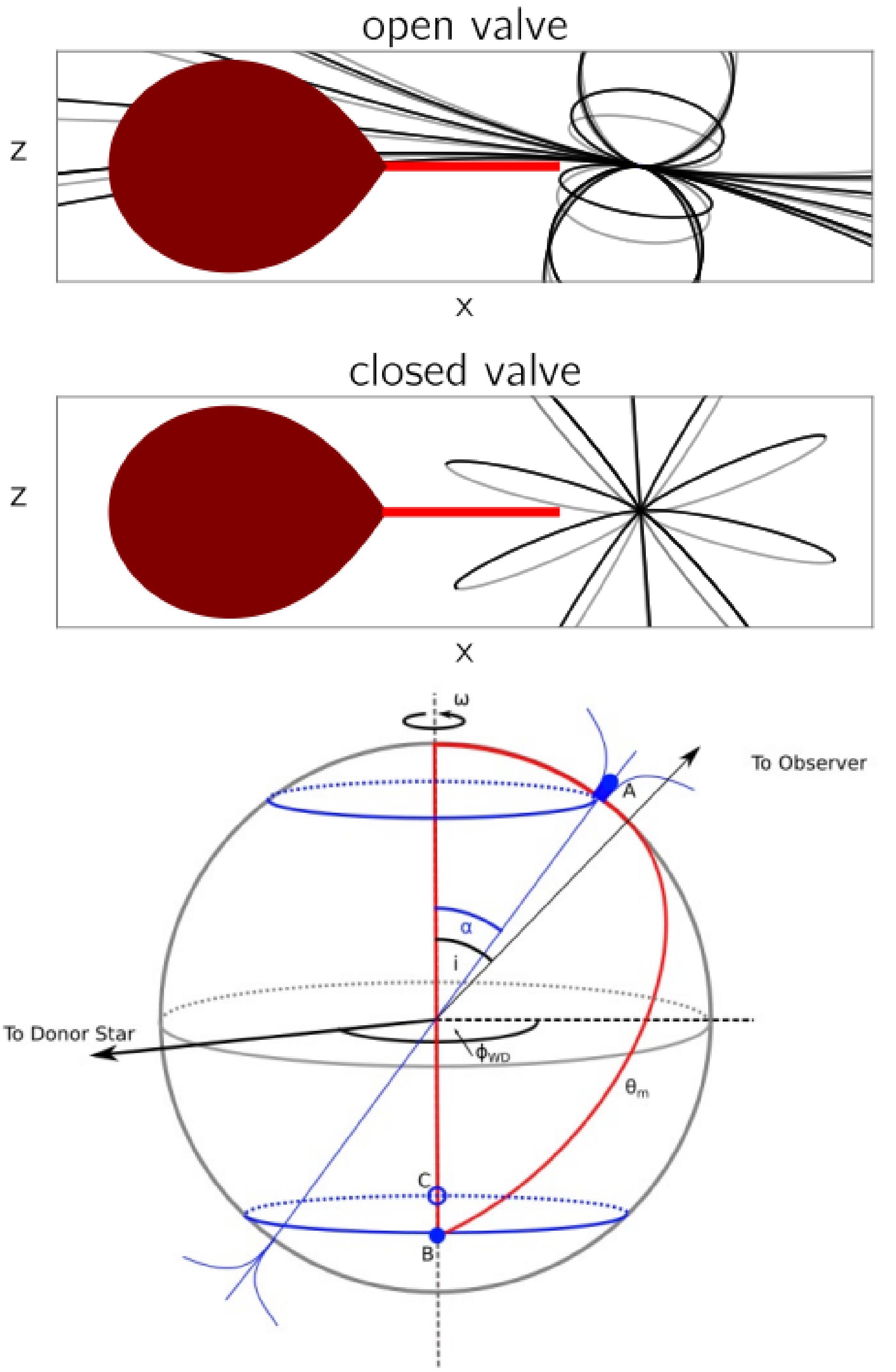

Figure 3: An Interactive Magnetic Valve model for polars. **Top:** The system is viewed at orbital phase 0.75 with two snapshots separated by 0.25 beat cycles. The WD magnetic field allows the flow when parallel **(top)** and is a barrier to mass transfer through L1 when the flow is perpendicular **(middle)** to the magnetic field. **Bottom:** Schematic diagram showing the best-effort determination of spot positions for BY Cam [11]. Accretion region A, at the upper magnetic pole, remains in view as the WD spins. Regions B and C are self-eclipsing and alternate in activity around the beat cycle. These spot positions compare favorably with MHD calculations [20,21]. Credit: Mason et al. (2022) [11].

enhance the plasma flow from the inner Lagrangian point on the donor [11, 12, 13]. A high-speed photometric flickering analysis of TESS observations of polars [16] and magnetic gating reported in the IP, TX Col [17], are likely both indicative of magnetically influenced accretion flows as is the presence of occasionally accreting polars in the 2-3 hr CV period gap [18].

In an extensive observing campaign [19] ASASSN-18fk was determined to be a WZ Sge-type dwarf nova. It underwent multiple rebrightenings and displays an 86.4-min superhump period over all stages of the superoutburst. A 22-min modulation is interpreted as the white dwarf spin period and suggests that ASASSN-18fk is a good IP candidate. More observations are encouraged.

4. Conclusions

A key science problem for APs is the origin of their asynchronism and to differentiate between true APs and slowly rotating IPs. The discovery of several new mCVs that blur the line between APs and IPs is providing constraints for which synchronization theory in the realm of magnetically channeled flows by accreting white dwarfs may be tested and further developed.

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