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Accretion Curtains And Funnels

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Eclipsing AM Herculis Binaries

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Abstract. AM Herculis Binaries (or Polars) are a subclass of the Cataclysmic Variables in which the accreting white dwarf has a strong magnetic field giving rise to highly polarized cyclotron radiation from the shock heated accretion region. A number of AM Herculis binaries are now known in which the white dwarf is eclipsed by the companion star. High time resolution observations of these eclipses allow a particularly detailed study of the process of accretion onto the magnetic white dwarf. Results on a number of systems will be presented and used to derive information on the accretion structure as well as on the fundamental properties of the binaries.

1. Introduction

The magnetic cataclysmic variables form a subclass of the cataclysmic variables (CVs) in which the white dwarf has a strong magnetic field. Magnetic CVs are further subdivided into two classes. The synchronous systems (also known as Polars or AM Herculis Binaries) are those systems in which the magnetic field causes the white dwarf rotation to be synchronized with the orbital period. Accretion is channeled along the field lines and no accretion disk is formed. The magnetic fields of the white dwarfs in these systems are typically in the range 10 to 60 MG.

The asynchronous systems (known as Intermediate Polars or DQ Herculis Binaries) are systems in which the white dwarf rotation is faster than the orbital period. There are no direct magnetic field measurements for any of these systems but the fields are probably lower than those of Polars (maybe in the range 0.1 to 5 MG). In these systems the accretion is probably via an accretion disk which is disrupted in its inner regions by the magnetic field. In some cases accretion may be directly from the stream (e.g. RX J1712.6−2414, Buckley et al. 1995).

AM Her itself was the first magnetic CV to be recognized, when Tapia (1977) discovered its large circular polarization varying around the binary cycle. The circular polarization results from optical cyclotron radiation which is one of the defining characteristics of these systems. While a few more AM Her systems have been discovered by purely optical techniques, the majority are originally detected as X-ray sources. Recently many new systems have been found as a result of the all-sky survey by the ROSAT satellite. The number of AM Her systems now stands at over 50.

In AM Her systems accretion is channeled along the field lines and hits the white dwarf on one or two regions near its magnetic poles. These regions are shock heated to temperatures $\sim 10^8$ K and radiate in the hard X-ray by thermal bremsstrahlung. The magnetic fields are in the range 10 to 60 MG, putting the fundamental cyclotron frequency in the infrared at around 2 to 10 μm. The polarized cyclotron radiation observed in the optical and near IR is cyclotron harmonic emission in harmonics up to about 10. The strong soft X-ray emission in AM Her systems is black body radiation from a heated area of the white dwarf photosphere with T $\sim 10^5$ K.

The magnetic field of the white dwarf can be measured by a number of methods. Zeeman features can be seen either in the white dwarf photosphere or in cool halo gas seen in absorption againt the cyclotron region. Many systems show a series of very broad emission features due to different cyclotron harmonics the spacing of which is a measure of the field. Results from the different techniques generally agree well. A summary of magnetic field measurements is given by Bailey (1995).

2. Eclipsing Systems

The first AM Her system observed to show eclipses was DP Leo (Biermann et al. 1985). More recently several more eclipsing systems have been found (as listed in table 1), and several of these are bright enough (15th to 16th magnitude) for detailed study.

Table 1. Eclipsing AM Herculis Binaries

Name	Max V	Period
HU Aqr (RE J2107−05)	15.3	125min
UZ For	16	126min
RX J0515+01	16	8 hours
1H 1752+08	16.4	112min
RX J0929−24	17	3 hours
EP Dra (H1907+690)	18	104min
DP Leo	18	90min
WW Hor	18	115min

The light curves of eclipsing AM Her systems are very distinctive. Since most of the radiation comes from close to the white dwarf the eclipses are deep, usually with a flat bottom at which only the secondary is visible.

Probably the best studied eclipsing system is UZ For. Bailey and Cropper (1991) obtained high time resolution light curves during the faint state (like most AM Her systems, UZ For shows long term light variations between a bright and faint state — presumably as a result of changes in accretion rate). The ingress and egress light curves showed two stages, one lasting about 40 seconds which was identified with the photosphere of the white dwarf, and one lasting only a few seconds which is identified with the cyclotron emitting spot, on the surface of the white dwarf.

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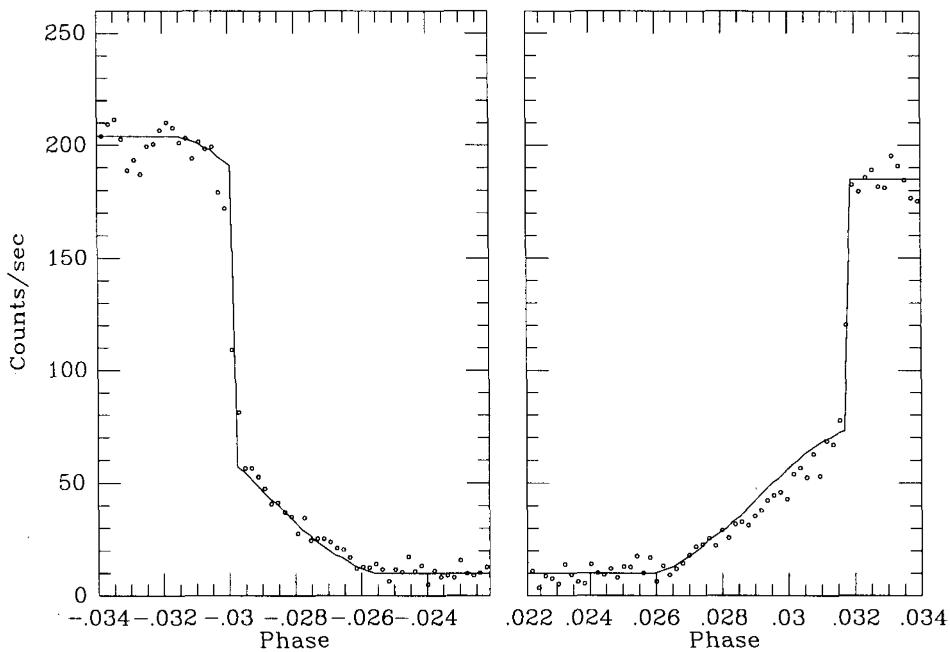

Figure 1. Eclipse light curve and fitted model for UZ For (from Bailey and Cropper 1991)

A model has been fitted to these light curves which is based on the assumption of a Roche lobe filling secondary eclipsing a spherical white dwarf, with a bright accretion spot placed on it. This geometrical model has five parameters, the binary mass ratio ($q = M_2/M_1$), the inclination (i), the radius of the white dwarf as a fraction of the binary separation (R_2/a) and the longitude and latitude of the spot. If a value for q is assumed the light curve fit can be used to determine all the other parameters, and also to determine the masses of both components if a standard white dwark mass-radius relation is assumed. The results for UZ For are shown in table 2, and an example of the light curve fit is shown in figure 1.

Table 2. Model Parameters for UZ For

q	i (deg)	colat(deg)	R_1/a	M_1	M_2
0.12	84.3	169	0.020	0.50	0.06
0.15	82.8	161	0.017	0.61	0.09
0.2	81.0	150	0.014	0.71	0.14
0.3	78.6	138	0.012	0.79	0.24
0.5	75.6	126	0.0108	0.83	0.42

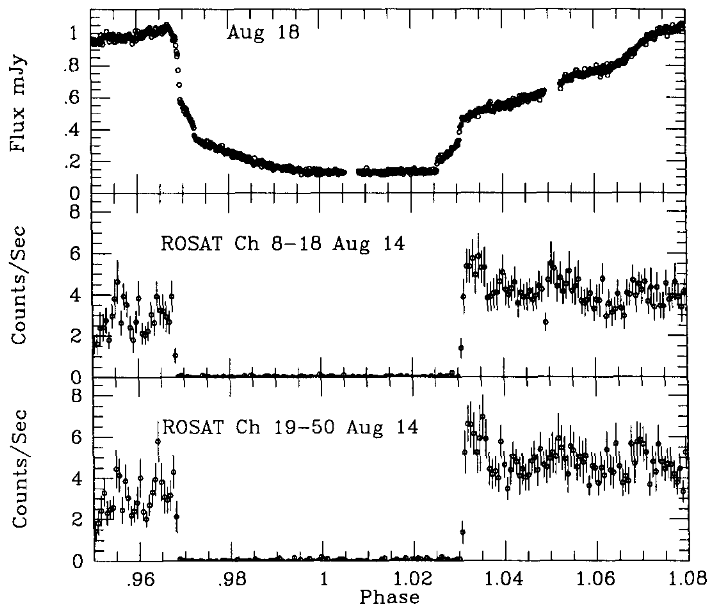

Figure 2. Optical (Unfiltered GaAs) and ROSAT PSPC light curves of the eclipses of UZ For

If we constrain the secondary mass to have the value required for a main sequence star which fills its Roche lobe we can obtain a unique model which then determined the mass of the white dwarf giving a value of $0.71M_{\odot}$ with an allowable range of 0.61 to $0.79M_{\odot}$.

Figure 2 shows the UZ For eclipse light curve on 1991 Aug 18 taken with the auxiliary photometer on the 3.9m Anglo-Australian Telescope during the bright state. The data were taken within a few days of a ROSAT PSPC observation of the source which is also shown. The bright state eclipse shows additional features. There are now two sharp steps in the egress and ingress. We interpret these as being due to two accretion regions close to the two poles of the white dwarf. One of these is at the same phase as that seen in the faint state, and coincides with the main step in the X-ray eclipse. This is therefore the main accretion region. The second step is attributed to a secondary accretion region near the opposite pole which receives a small fraction of the accretion flow. No significant X-ray emission can be seen from this region.

The bright state observations can be fitted with the same geometrical model as that obtained by Bailey and Cropper (1991) for the faint state with the addition of a second accretion spot at a longitude of 0° and a colatitude of 5°.

Another feature of the bright state light curves is the slow rise lasting several minutes after the white dwarf egress which is attributed to the reappearance of the accretion stream. The corresponding ingress occurs around, and just after, the ingress of the white dwarf. Similar structure is found in the light curves of

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the other eclipsing systems such as RE J2107-05 (Hakala et al. 1993, Glen et al. 1994).

Observations such as these provide a particularly direct confirmation of the basic model of AM Her systems, and enable a detailed model of the system to be obtained from largely geometrical considerations, without the necessity to model the complex physics occurring in the accretion process. Similar analyses are possible for other systems. Bailey et al. (1993) have obtained similar models for the light curves of the fainter eclipsing system DP Leo, again allowing the white dwarf mass to be determined (see also Stockman et al. 1994 for HST eclipse observations of this system).

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