ACCRETION IN MAGNETIC CATACLYSMIC VARIABLES

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ABSTRACT. We discuss the arguments in favour of the suggestion that polars (AM Her systems) and intermediate polars (IP's) have magnetic fields of the same order of magnitude, and form one single class of objects. The period distribution of magnetic cataclysmic variables is well explained if they evolve the same way as non magnetic systems, IP's becoming AM Her systems after crossing the gap. We discuss some consequences of the limited magnetic moment distribution ($10^{33} \leqslant \mu \leqslant 10^{34}$ G cm^{-3}) in magnetic CV's, in particular for the existence of accretion discs in those systems.

1. INTRODUCTION

Cataclysmic variables (CV's) in which the white dwarf is strongly magnetic form a distinct subgroup of these accreting binaries. This subgroup can be naturally divided into the AM Herculis (polar) systems, in which the white dwarf spins effectively synchronously with the orbit, and the

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intermediate polars (DQ Herculis systems) in which the spin is more rapid. The fact that phase-dependent polarization is found in AM Her systems, but until recently not in the intermediate polars, together with the lack of synchronism, has led to suggestions that the fields in the latter are systematically weaker (see e.g. Lamb and Patterson, 1983); as we shall see, this idea has to face serious difficulties.

It is well known that in low mass systems such as CV's, the orbit (and hence the period P) must decrease under the influence of angular momentum losses in order to maintain the mass transfer. Since all but three AM Her systems have periods shorter than 2 hours and all but two polars have periods greater than 3 hr (see Fig. 1), two questions arise : first, what are the progenitors of AM Her's and second what is the evolutionary fate of IP's. As the sum of both distributions is similar to that of non magnetic CV's, a straightforward interpretation of the period histogram is that most magnetic CV's are intermediate polars at long periods, and evolve into AM Her systems when their period (and hence separation) becomes small enough for the interaction with the secondary star to bringabout synchronization of the white dwarf spin to the orbit (Chanmugam and Ray, 1984; King *et al.*, 1985). A necessary consequence is however that the magnetic field distributions in the two classes cannot be distinct. Other interpretations of the period histogram based on the hypothesis that the magnetic fields of the IP's are systematically weaker than that of the AM Hers have been proposed. Since the period distribution of IP's is consistent with that of non magnetic systems (probability ~ 44%, assuming a binomial distribution, see Schmidt and Liebert, 1986), but that of AM Hers is not ($P \sim 8 \times 10^{-4}$), Schmidt, *et al.* (1986) have suggested that IP's evolve as normal CV's, while the AM Her distribution is distorted by the fact that they evolve much faster than normal systems above the gap. We shall see below that any attempt to increase the mass transfer rate (and hence to decrease the lifetime) above the gap results in a very

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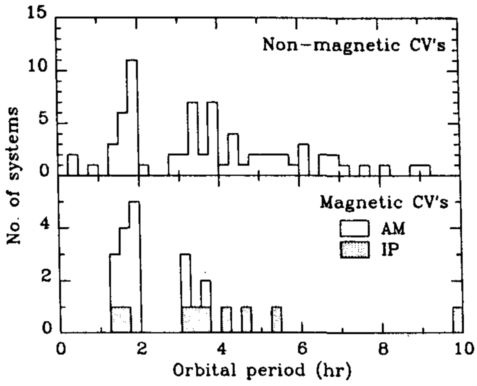

Figure 1 : period histogram of cataclysmic variables

significant broadening of the gap as compared to non magnetic systems, which is excluded by the observations. *This conclusion holds quite independently of the precise nature of the mechanism causing the period gap*, provided that CV's evolve through the gap as detached systems.

2. EVOLUTION OF MAGNETIC CV's

Mass transfer in short period (P $\leqslant$ 10 hr) CV's results from angular momentum losses which shrink the orbit, and hence maintain the secondary in contact with its Roche lobe. For P < 2 hr, the observed $\dot{M}$ is rather low, and the corresponding angular momentum losses are almost certainly due to gravitational radiation. Above 3 hr, some additional mechanism must be at work to explain the observed $\dot{M}$, and the cessation of this mechanism produces the period gap (Rappaport *et al.*, 1983; Spruit and Ritter, 1983). The reason for that is quite simple : as the companion star looses matterat a rate faster than the rate at which its thermal structure can follow ($M_2/\dot{M}$ < Kelvin Helmholtz time, M_2 = secondary mass), its radius is greater than what it should be for its mass, and the greater the mass loss rate, the greater the excess over the main sequence radius (see e.g. Ritter, 1985a). When the braking mechanism is switched off, mass transfer ceases, and the secondary is able to

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relax towards its main sequence size. Mass transfer resumes only when gravitational radiation brings the star back into contact. The duration of the gap therefore increases with the departure from main sequence, and hence with increasing accretion rate above the gap.

In order to make this qualitative approach more quantitative, we used a double polytrope evolution code following the method of Rappaport *et al.* (1983). We first used the usual magnetic braking law (Verbunt and Zwaan, 1981), which gives the observed accretion rates of normal CV's above the gap, and assumed that magnetic braking ceases when the radiative core of the secondary disappears. We found a period gap between 2 and 3 hours, as observed. We then increased the accretion rates above the gap by a factor 2; this resulted in a period gap between 3.4 and 1.8 hr, removing 7 out of the 13 known AM Her systems. Of course, since the exact mechanism driving mass transfer is not known, one could argue that this modelling is not necessarily relevant. We therefore considered a case in which it was postulated that the braking mechanism ceases at 3 hr, as shown by observations. This results in systems so much out of thermal equilibrium that the period gap extends down to 83 mn, i.e. close to the minimum period (see Fig. 2). This would exclude all AM Her systems below the gap.

We therefore conclude that it is impossible to increase by more than a factor 2 the efficiency of the braking mechanism (and accelerate the evolution) without grossly affecting the observed (and very well defined) period gap for magnetic CV's; a factor 2 seems already too large to be compatible with observations. In the following we shall examine the consequences of similar magnetic field strengths in AM Her systems and in IP's (magnetic moment $\mu \sim 10^{33} - 10^{34}$ Gcm^3).

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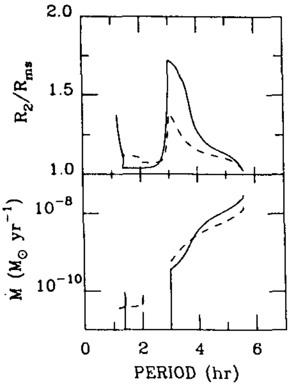

Figure 2 : Evolution of a binary system with M_1 = 1 $M_\odot$ in 2 cases : normal braking (dashed line) and braking increased by a factor 2 up to 3 hr (solid line)

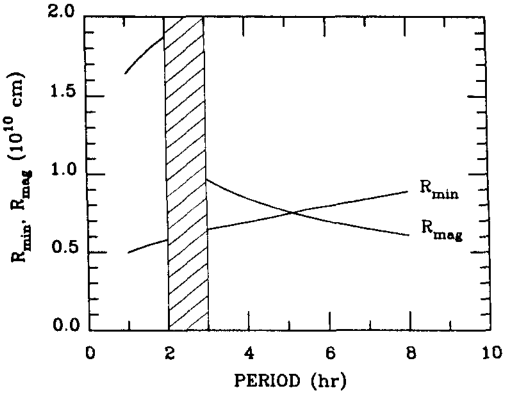

Figure 3 : Comparison between the magnetospheric radius R_{mag} and R_{min}

3. FORMATION OF A DISC

It is generally accepted that AM Her systems do not posess accretion discs, since the magnetospheric radius of the white dwarf (computed assuming spherical symmetry inflow)

$$r_\mu = 2.7 \times 10^{10} \mu_{33}^{4/7} \dot{M}_{16}^{-2/7} M_1^{-1/7} \text{ cm} \qquad (1)$$

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(where $\mu_{33} = \mu/10^{33}$ Gcm^3, $\dot{M}_{16} = \dot{M}/10^{16}$ gs^{-1} and M_1 is the primary mass in solar units) is of the same order as the orbital separation

$$a = 3.53 \times 10^{10} \, (M_1 + M_2)^{1/3} \, P_{hr}^{2/3} \text{ cm} \tag{2}$$

On the other hand, one has to reexamine the case of IP's, for which the existence of an accretion disc has been assumed in view of the supposedly lower magnetic fields.

A general criterion for disc formation is that the initial gas stream from the mass donating star can orbit freely the accreting star, and interact with itself, building up a disc by spreading via viscosity. We may express this condition as the requirement that the stream's distance of closest approach R_{min} to the white dwarf should exceed the radius R_{mag} at which magnetic effects overcome the stream ram pressure. R_{mag} is not exactly equal to r_μ, because of geometrical effects; Hameury, King and Lasota (1986, hereafter HKL) find $R_{mag} = 0.37 \ R_\mu$. Values of R_{min} for any binary geometry are found in tables of Lubow and Shu (1975). Figure 3 shows the comparison between R_{min} and R_{mag}. From it, we must conclude that at least the simplest condition for disc formation is not met in short period ($P \leq 5$ hr) magnetic CV's. One must therefore consider how the gas stream interacts with the white dwarf magnetic field and penetrates the magnetosphere. This problem has been studied in detail in the case of X-ray pulsars (see Burnard *et al.*, 1983, and references therein).

Assuming that the gas stream's kinetic energy is largely dissipated at R_{mag} in form of a strong shock implies postshock temperatures $T \sim 4 \times 10^7$ K and densities $\rho \sim 2 \times 10^{-10}$ g cm^{-3}; the total energy radiated in the shock is about one tenth of the total accretion luminosity, and should be emitted in X-rays. Due to thermal instabilities, the shocked gas forms condensations of temperature $\sim 2 \times 10^4$ K. These blobs penetrate the magnetosphere via the

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Schwarzschild-Kruskal instability; their fate is largely determined by the strength of the magnetic drag forces acting on them, together with the growth rate of the Kelvin-Helmholtz instability. The latter results in a rain of small droplets, easily permeated by the magnetic field, and thus constrained to follow the magnetic field lines down to the surface of the white dwarf. One can estimate the time scales of those two effects and compare them with the orbital time of the blobs; one finds:

$$\frac{t_{drag}}{t_{orb}} = 0.68\ \mu_{33}^{-9/7}\ (r/R_{mag})^{-13/7}\ \dot{M}_{16}^{1/7} \tag{3}$$

$$\frac{t_{K-H}}{t_{orb}} = 0.4\ (\epsilon/0.1)^{-1}\ \mu_{33}^{-1}\ (r/R_{mag})^{23/12} \tag{4}$$

where $\epsilon \leqslant 0.1$ is the efficiency of the Kelvin-Helmholtz instability. One therefore expects roughly radial inflow (in a reference frame corotating with the field pattern) until $r/R_{mag} \sim 0.5$, where $t_{drag} > t_{orb}$. If ϵ is small, the blobs will follow a ballistic orbit that intersects the white dwarf surface, and cover a large fraction ($f_{cap} \sim 0.1$) of the star. If on the other hand ϵ is large enough, the blobs will be rapidly disrupted, and the matter will fall along magnetic fieldlines, resulting in $f_{cap} \sim 0.05$. In both cases, a disc does not form, and f_{cap} is relatively large, as implied by observations (King and Shaviv, 1984). It must be noted that (3) and (4) are estimates that suffer from our limited understanding of plasma instabilities; one should not therefore definitely reject that, at least in some cases, both t_{drag} and t_{K-H} are greater than t_{orb}, and hence that a disc forms.

Finally, the doubled emissions lines, which are frequently taken as indications that accretion discs are present in IP's, in our model arise from optically thin material stripped off from the accretion stream (before magnetospheric impact) by Kelvin-Helmholtz instabilities and forced to corotate with the magnetic field.

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4. CONCLUSION

We conclude that magnetic moments in magnetic CV's lie in the range 10^{33}-10^{34} G cm^3; this appears at first sight to be in contradition with Lamb and Patterson's (1983) claim that centrifugal limits on the spin period of IP's require systematically weaker fields than in AM Hers. HKL examine this problem, and show that the uncertainties in the lever arm of the accreting matter, and in how close to the centrifugal limit is the white dwarf assumed to spin (the 'fastness parameter', see Gosh and Lamb, 1979) allows magnetic moments at least a factor 6 larger than estmated by Lamb and Patterson. Note also that Ritter (1985) pointed out an inconsistency in the calculation of Lamb and Patterson.

This in turn implies that discs may not be present in IP's; HKL then predict that three types of orbital effects would be possible: (i) eclipse of the magnetospheric impact region by the secondary; (ii) broad photoelectric absorption of this region when viewed through the accretion stream; (iii) if the Kelvin-Helmholtz instability is inefficient inside R_{mag}, a considerable fraction of matter can drift across field lines and hit the white dwarf surface at a fixed position in the *orbital* frame, resulting in orbital modulation. Effects (i) to (iii) are observed in EX Hya and AO Psc (see HKL for a detailed discussion of observations).

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