THE PERIOD AND MAGNETIC FIELD DISTRIBUTIONS OF CATACLYSMIC VARIABLES: IMPLICATIONS FOR THEIR EVOLUTION

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ABSTRACT. Comparison of the period distributions of various classes of CVs confirms an extreme bias of the synchronous AM Her systems toward short orbital periods, while the DQ Her systems do not differ significantly from the distribution of non-magnetic systems. This suggests either strong selection effects or enhanced evolution of the AM Her systems. There is as yet no obvious bimodality in either the magnetic field distributions of isolated white dwarfs or of CV primaries. However, clear differences between the two exist: the strongest being that magnetic primaries are overrepresented among short period CVs by more than an order of magnitude in comparison to the field white dwarfs.

1. INTRODUCTION

The presence of a magnetic field on the primary star of a cataclysmic variable (CV) may have an important influence on the secular evolution of the system. Recently, King et al. (1985) and Schmidt, Stockman and Grandi (1986) have developed somewhat orthogonal ideas on how the evolution of magnetic CVs might proceed. In this report, we reassess the distributions of binary periods and the likely magnetic fields for different CV groups, compare the latter with the distribution of magnetic fields in single (isolated) magnetic white dwarfs, and explore implications for the evolution of the magnetic systems.

2. THE PERIOD DISTRIBUTIONS OF MAGNETIC AND NON-MAGNETIC CVS

For the purpose of this discussion, we divide the CVs into three groups--(1) the synchronously-rotating AM Her systems (AMs), (2) the asynchronous DQ Her systems (DQs), including some which are sometimes called 'intermediate polars' (these have a demonstrated, stable photometric periodicity attributable to the rotation of the white

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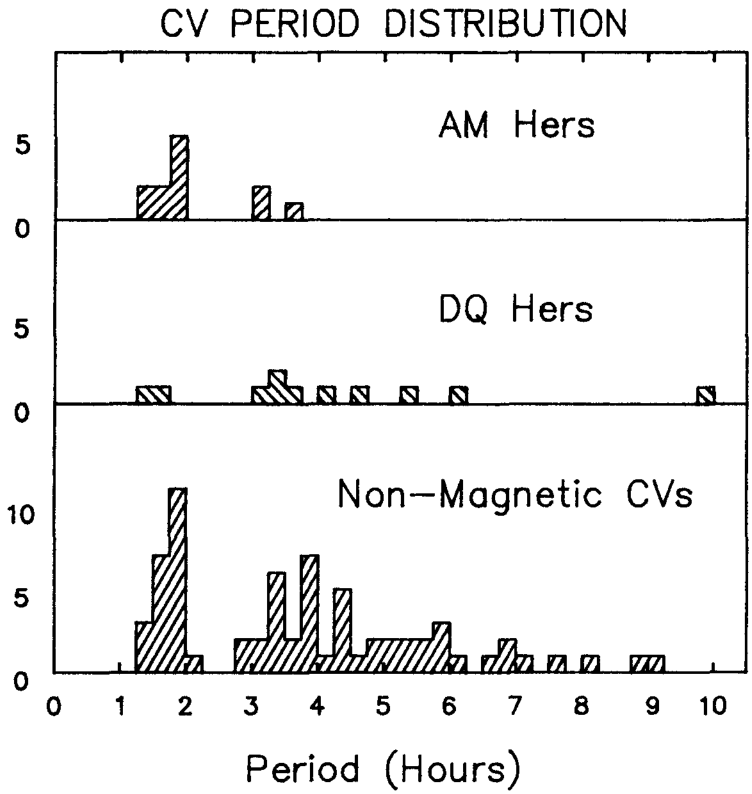

Figure 1. Orbital period distributions for the spin-orbit locked AM Her systems, the asynchronous DQ Her systems, and the presumably Non-Magnetic CVs, as drawn from the catalog of Ritter (1986).

dwarf); and (3) the "non-magnetic" CVs (Non-Ms) for which there is no direct evidence of a magnetic field on the primary star. We show in Figure 1 the histograms of CVs in these three categories with known orbital periods up to 10 hours, using data taken from Ritter's (1986) catalogue. The reader is referred to Morris et al. (1987) for details.

First, we argue that the period distributions of DQs and Non-Ms are not significantly different. A Kolmogorov-Smirnov (K-S) comparison of the two finds that if both were drawn from the same parent distribution, 95% of the 'draws' would result in distributions which differ by at least as much as that observed. Since DQs with sufficiently strong magnetic fields will eventually lock up and become AMs after their periods decrease (King et al. 1985), some bias of the DQs toward long periods would be expected. This bias is greatest if one adopts the idea that DQs and AMs have the same magnetic field

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distribution. We discuss this issue in the following Section.

On the other hand, it is clear that the period distributions of the AMs and Non-M CVs are significantly different. The AMs, with 9 of 12 known objects below the period gap, would be drawn from a distribution like that of the Non-Ms less than 0.1% of the time. As King et al. point out, at least part of this difference is likely to be due to the fact that for each AM field value, there is a maximum period above which it will not be locked and would instead appear as a DQ.

3. CONSTRAINTS ON THE MAGNETIC FIELD DISTRIBUTIONS FOR WHITE DWARFS AND CV PRIMARY STARS

Recent discoveries have increased the number of known field white dwarfs with detected magnetic fields to about 20. As depicted in Figure 2, these include stars with field strengths spanning the range 10^6 to nearly 10^9 gauss (1-1000 MG). Several new stars have been found with field strengths close to 1 MG. These discoveries required the use of accurate spectrophotometry or spectropolarimetry, observations available for only a small fraction of the known white dwarf sample. Thus, it is likely that other magnetic white dwarfs have escaped detection, especially with fields in the 1-10 MG range. Upper limits of 10^4-10^5 G are available for ~ 10% of the brightest white dwarfs. A complete list of known magnetic degenerates is given in Schmidt (1986).

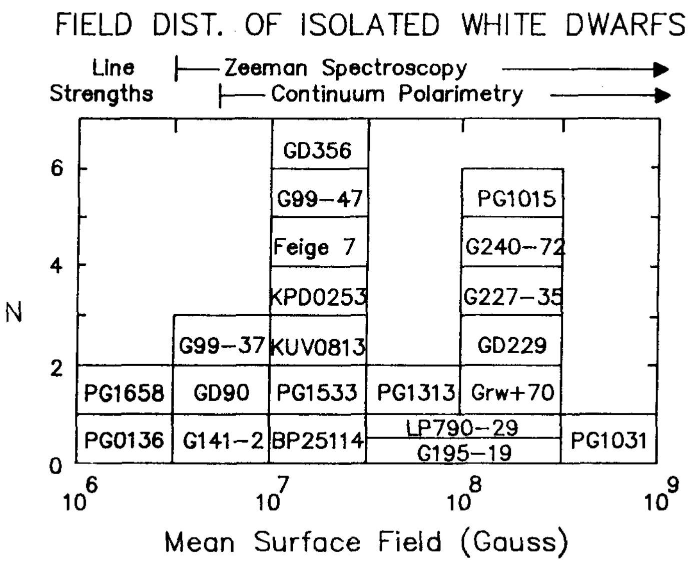

Figure 2. The current magnetic field distribution of single magnetic white dwarfs. See Schmidt (1986) for details.

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The available data are consistent with the simple hypothesis that the distribution of magnetic field strengths is "flat" between ~ 1 and 1000 MG. Yet, the known magnetic degenerates constitute only about 2% of the total sample of spectroscopically identified white dwarfs (i.e. McCook and Sion 1984). Thus, it is possible that an equal fraction of stars--about 1/2 of 1%--occupy each decade of field strength from 10^6 to 10^9 gauss, as previously suggested by Angel, Borra and Landstreet (1981). Below this are the remaining ~ 95% of white dwarfs. Given the modest fractions of stars which have been properly surveyed for low fields, it is also possible that steadily increasing fractions of stars occupy the field decades spanning 10^7 down to 10^4 gauss.

The simplest statement encompassing these possibilities is that the detected magnetic white dwarfs form the high-field tail of a currently unknown overall distribution of magnetism in white dwarfs. There is no observational evidence that the isolated white dwarf distribution is bimodal. This conclusion is of interest in view of the theoretical arguments of King (1985) and vis-a-vis the distribution of magnetic field strengths for CV primaries.

Likewise, it is not at all clear that the distribution of magnetic fields among CV primary stars is bimodal. Fields may often be directly measured for the AMs, i.e. from Zeeman or cyclotron features. However, they must be inferred for the DQs from their "equilibrium" spin periods (Lamb and Patterson 1983; King et al. 1985). It is very likely that these inferences are not always correct, and that there is considerable uncertainty in the field distribution of the DQs.

The assumption involved is that the magnetic white dwarf will always rotate near the speed required for a balance between centrifigual and gravitational forces on the matter being carried by field lines at the magnetospheric radius. The magnetic field strength required to achieve this balance may be expressed as a function of the orbital period, the spin period, the primary and secondary masses, and the accretion rate.

Yet, there is evidence in individual cases that this assumption may be violated. The best example may be the nearly locked system TT Ari (P_{orb}=3.31 hr, P_{rot}=3.19 hr), for which the prescription implies a surface field > 20 MG (Chanmugam and Ray 1984; King et al. 1985). Yet, during a recent state of low accretion, Shafter et al. (1985) observed the absorption spectrum of the white dwarf primary, usually hidden by a disk, at optical wavelengths. The hydrogen absorption lines appeared unperturbed (by Zeeman splitting), setting an upper limit of ~ 4 MG on any photospheric field. It is possible that the assumption of an equilibrium rotation rate may be true on average, but large discrepancies can exist for individual objects at any moment in evolutionary time!

In any case, blind application of the equilibrium spin-magnetic field equation (King et al. 1985, eqn. 2.11), assuming a primary mass of $1M_{\odot}$, yields a field distribution for DQs shown in Figure 3. Also shown for comparison is the AM distribution. The result is that the field distribution of the DQs is much broader and includes much lower field strengths than the AMs. This conclusion is in agreement with that of Lamb and Patterson (1983), but not with King et al. (1985).

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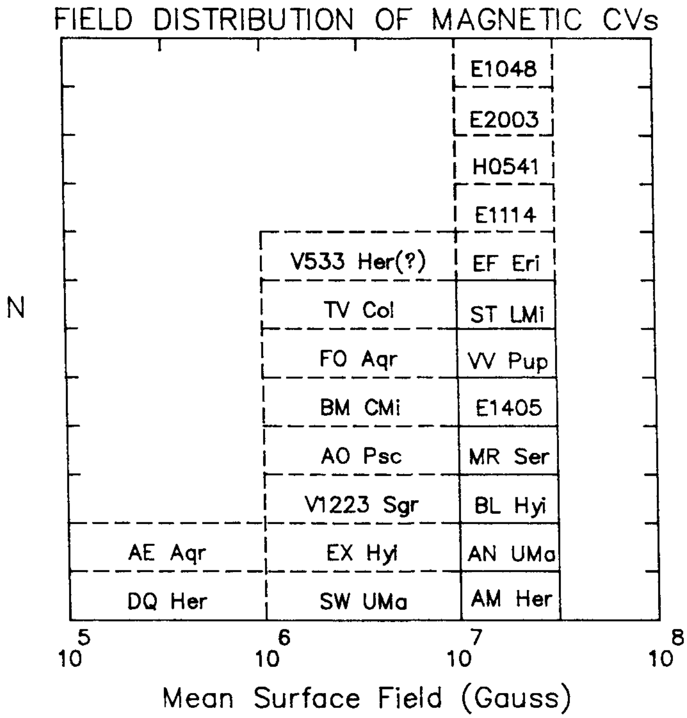

Figure 3. The field distribution of magnetic CVs. Objects with measured field strengths are denoted by solid boxes; dashed boxes represent values inferred from the energy spectra (AMs) or from the assumption of equilibrium spin periods (DQs).

For the Non-M CVs, no reasonable field strength estimates are possible, though there is an expectation that the fields should be generally lower. Indeed, there may be overlap among the Non-Ms and DQs near 10^5 gauss, and bimodality in the total distribution has not been demonstrated.

It is nonetheless clear that the distributions of the known CV primaries and isolated white dwarfs differ in the following respects:

(1) a large relative number of CVs (at least all of the AMs) have fields in the narrow interval 20-40 MG;

(2) there are no known cases of CV primaries with $B > 40$ MG;

(3) a much larger fraction of known CV primaries than isolated white dwarfs have detected fields (~ 20% vs. 2%). The magnetic CV fraction is even higher among those systems with $P < 2$ hours. If this preponderance of magnetic systems is due to selection (i.e. X-rays), then > 10 times as many non-magnetic CVs remain to be discovered in a given volume of space.

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4. IMPLICATIONS FOR CV EVOLUTION

At sufficiently long orbital periods, all CVs (magnetic or not) have accretion disks and spin/orbit locking cannot occur. For these, some form of angular momentum loss other than gravitational radiation is required. Magnetic braking via a stellar wind caught in the secondary's magnetic field is plausible and currently fashionable (Verbunt and Zwaan 1981).

As systems evolve to shorter periods, those with ~ 20-40 MG primaries eventually disrupt the shrinking disks, lock up, and accrete via a funnel. These become the AMs. Once locked, further angular momentum decay may be aided by magnetic braking in the field of the primary (Schmidt, Stockman and Grandi 1986). Accelerated evolution, plus a lack of long period disk-less systems, would then account for the observed very biased period distribution of AMs.

At typical CV accretion rates, disks exist around <10 MG primaries at all periods, and they will never lock up. EX Hyi and the new DQ Her system SW UMa (Shafter et al. 1986) are almost certainly in this class, plus some of the long orbital period DQs (especially those with rapidly-rotating primaries: DQ Her, AE Aqr).

CVs with > 40 MG primaries suffer greatly enhanced angular momentum loss through magnetic braking centered on the primary, and are likely to be either very short-lived or unrecognizable as magnetic systems (Schmidt et al. 1986; King 1985).

5. CONCLUDING REMARKS

While the ideas in the previous section contribute toward explaining the differing magnetic field distributions of observed CV primaries and of field white dwarfs, we are still left with the question as to why the former have an order of magnitude larger fraction of detected magnetic white dwarfs than the latter. One may suspect that the common envelope stage favors formation of a close binary (i.e. rapid decrease of the orbital period) when the degenerate core is strongly magnetic. If this were so, the number of long period CVs may be severely underestimated, as argued for different reasons by Ritter and Burkert (1986).

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