Part 8

Stellar Components

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White Dwarfs in Magnetic Cataclysmic Variables

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Abstract. An attempt has been made here to seek the origin of the magnetic white dwarfs in Cataclysmic Variables. Following the suggestion made in the case of isolated white dwarfs, we look at the possibility of binaries with magnetic A type stars known as chemically peculiar stars as progenitors of MCVs. The evolution of the binary is discussed and compared with the available statistics.

1. Introduction

The magnetic cataclysmic variables (MCVs) are grouped into polars and intermediate polars (IPs). The magnetic field associated with the white dwarf (WD) is higher in case of the polars. The white dwarfs in MCVs provide an excellent opportunity to understand the evolution of a binary in the presence of magnetic field. The evolution is influenced by the interaction of the components, the stellar wind, the accretion on to the WD, evolution of the secondary as well as the continuous adjustment of the orbital parameters.

It is very well known that a significant fraction of the MS stars in the spectral range B - A are chemically peculiar stars. These are classified in to CP1 (metallic line stars, earlier designation Am, with overabundances of metals), CP2 (overabundance of Si, Sr. etc., earlier designation Ap stars) and CP3 (overabundance of Hg, Mn etc.). Among these it is known that CP2 have substantial magnetic fields ranging from 1000 to 100000 G (Lanz, 1992). A significant fraction of these are established to be binaries (Seggeweiss, 1992). As a consequence the continuum energy distributions also are modifed (Shylaja & Ashok, 2002).

Here we consider the evolution of these binaries as probable progenitors of MCVs. The argument proceeds along the following lines

1. The evolution of the orbital parameters.
2. Effect of the magnetic field and
3. Statistics of CP binaries and MCVs.

Angel, Borra, & Landstreet (1981) have proposed that these CP stars are progenitors of MWDs based on the space density considerations. This is confined to the isolated WDs only.

2. Parameters of the Binary

One of the primary requirements of the progenitors is that the mass ratio of the components be small. This allows the more massive evolve into a WD within a small fraction of the nuclear time scale of the less massive one. The massive component as a CP star is in the mass range 3 - 5 $M_\odot$ as derived from their position on the HR diagram. A higher mass range has been observed for a significant fraction (Babu and Shylaja, 1982); however, we do not consider them for the present context keeping in mind the unlikely event of those evolving in to WDs. The mass ration q may be small $0.3 \lesssim q \lesssim 0,2$, so that the other component is of spectral type G.

We follow the technique used by Bethe & Brown (1998) for the evolution of compact binaries that merge and modify it for the present context.

Let us consider a typical binary with massive component A and where the less massive B is solar type. The orbital period is decided by the initial separation. There can be a range of values for a, the semi major axis. We consider the case when it is sufficiently large so that initially the evolution of A, the massive component is not influenced by the companion. Let us see how the orbit evolves into a smaller period to allow the interaction of components.

The star A evolves into a giant in time τ_{ns}. During the Roche lobe overflow (RLOF) matter is transferred to B continuously. The fraction of the mass thus transferred to B is given by Vracken et al.(1991) as

$$\beta = (M_{B0}/M_{A0})^{1.84} = q^{1.84}.$$

Here subscript 0 denotes the initial mass. Thus at the end of RLOF, star B has a mass given by

$$M_{B1} = M_{A1} f(q).$$

The subscript 1 denotes the final masses. The mass of A will be approximately reduced by 30%. The value of $f(q)$ is less than 1 for $q \lesssim 0.68$. Hence there is a net gain in the mass of B. However this will not be substantial to change its τ_{ns}. The mass loss rates of Ap stars have been measured to be in the range of $10^{-8} M_\odot$/year (Willson, Bowen, & Struck - Marcell, 1987). This is a crucial parameter to decide the mass of the core left behind after the RLOF. For example, consider a star of mass 3.6 $M_\odot$ with $\tau_{ns} = 1.2 \text{ x } 10^8$ years (Taylor, 1970). If the mass loss rate is $10^{-8} M_\odot$/year, the final mass of the core would be 2.4 $M_\odot$. If the mass loss rate is $2 \text{ x } 10^{-8} M_\odot$/year, the final mass would be 1.2 $M_\odot$.

The distribution of the masses of WDs in CVs have been studied (Sion,1999) and it is apparent that a peak occurs at about 0.8 - 0.9 $M_\odot$. Compiling the data on MCVs (Cherepaschchuk et al. 1996) the distribution for MWDs is depicted in Figure 1 from which two points are immediately apparent: (1) the masses of WDs in IPs are marginally higher than in polars; (2) the average mass is 0.8 –0.9 $M_\odot$ as in case of nonmagnetic CVs.

Although the selection effect plays a role, the number of WDs with mass higher than $0.9 M_\odot$ cannot be ignored.

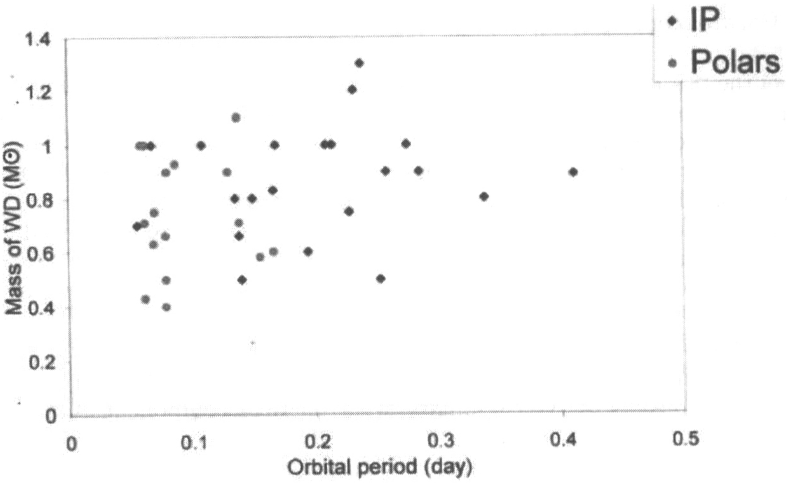

Figure 1. The distribution of masses of white dwarfs in MCVs

3. Evolution of the magnetic field

Post main-sequence evolution of a star with a primordial magnetic field has been dealt with extensively by Stepien (2000). Based on angular momentum considerations, the net torque on the star can be calculated as a consequence of the interaction with the environment. The net torque will be contributed by the disc, the wind and the accretion as well. In the present context of the binary with the orbital separation small enough to allow interaction, the accretion needs to be necessarily included.

$$T_{wind} = \frac{-WR^{7/5}\phi^{4/5}\dot{M}^{3/5}}{3(2GM)^{1/5}}$$

where $\dot{M}$ is the mass loss rate.

Thus it is clear that the mass loss plays a very important role in the PMS evolution. Li & Wickramasinghe (1998) have shown that magnetic fields reduce the wind zones. Consequently there is a magnetic braking and reduction in mass loss rate. This influences the future evolution of the orbit.

4. Evolution of the orbit

Let us now consider the evolution of the orbit itself. As mentioned earler, the initial masses M_{A0} and M_{B0} will change to M_{A1} andM_{B1}. The corresponding change in the orbital period from T_0 to T_1 may also be calculated as

$$T_1^2 = \frac{G(M_{A0} - M_{A1}f(q))(M_{B2} + \tau_{ns}\dot{M}_{A2})}{4\pi^2 a_1^3}$$

where a_1 is the final value of the semimajor axis. The evolution from T_0 to T_1 is gradual with a time scale of about $0.1\tau_{ns}$ (which may be few million years).

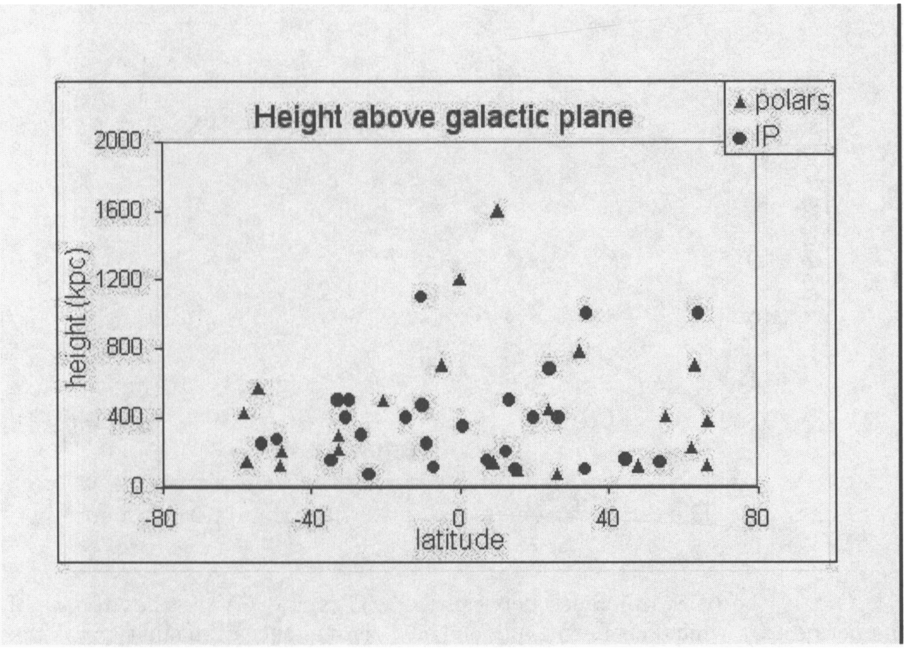

Figure 2. The distribution of MCVs above the Galactic Plane

In the typical example chosen earlier, with stars of $3.6 M_{\odot}$ and 1 $M_{\odot}$ if the initial orbital period was about 100 days, at the end of AGB phase it would reduce to about 10 days.

The end of the AGB phase of star A is marked by a PN episode. This event can modify the orbital parameters to some extent. Drastic changes in the orbital parameters are to be expected. Energy and angular momentum conservation leads to shrinking of the orbit to an orbital period of one day or less. Following the technique used to test the disruption of a binary in a supernova event in a binary, we may find if there is an impact on the space velocity of the system. The dynamical interactions cannot be verified directly due to uncertainties in every parameter. Indirectly, we may search for the effect of a "kick" experienced, by the space velocity dispersion. The Galactic distribution of MCVs provides a clue. Figure 2 shows the distribution of MCVs above the Galactic plane. It is apparent that they are restricted to the disc of the Galaxy and are not endowed with abnormal high space velocities. Hence the transition from the CP binary into MCV can taken to be peaceful.

5. Evolutionary link among the polars and IP

Since the MCVs are not included in to "high space velocity" stars, we may look for alternative clues on the peaceful evolution of orbits. In this context, it is interesting to note that IPs have systematically higher orbital periods than polars. We may consider if there is an evolutionary link between the two.

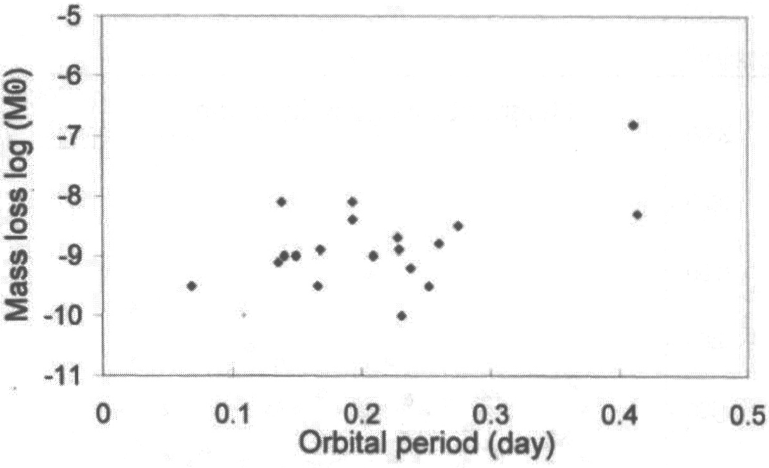

Figure 3. The variation of mass loss rates with orbital periods among MCVs

One of the basic difference between the MCVs and CVs is the absence of the period gap, which has been explained as a consequence of magnetic braking. Further, the magnetic field has been found to be effective in the increase of accretion rates as well (Warner, 1995) There is no accretion disc associated with polars. Thus as the circularisation of the orbit proceeds after the formation of the WD, it is continuously subject to the mass flow from the inner Lagrangian point L1. The condition that the semimajor axis be less than the magnetospheric radius is verified for a small number of stars by calculating the magnetospheric radius as

$$R_{mag} = 6.8 \times 10^9 \left(\frac{\mu}{10^{32}}\right)^{4/7} \left(\frac{\dot{M}}{10^{17}}\right)^{-2/7} \left(\frac{M}{M_\odot}\right)^{-1/7}$$

following King and Lasota (1993), taking $\mu = 10^{32}$. As the secondary evolves further, the circularisation of the orbit also continues, effectively reducing the orbital period. Hence we may expect to see a decrease in observed mass loss rates from the evolved systems. Figure 3 depicts the variation of the mass loss rates with orbital periods. A decreasing trend is noticeble, as a direct consequence of the magnetic field.

The secondaries are known to have an emperical relation with orbital period (Patterson, 1984)

$$M_2 = 0.38\left(\frac{P}{4}\right)^{1.22} M_\odot.$$

Thus the orbital evolution proceeds to create shorter period binaries with a steady decrease in the mass loss rate as well. This agrees with the possibility of IPs evolving into polars. As in the above emperical relation, the masses of secondaries also decrease with orbital period. The time scale of evolution here needs to investigated in greater detail.

Based on space density considerations, Angel et al. (1981) have argued that CP stars are progenitors of MWDs. They have not specifically considered the binaries. However, the argument can be safely extended to the binaries because of the following statistical figures. Among the CP stars, CP2 have high magnetic fields. There have been difficulties in measuring the magnetic fields of the other subgroups (Lanz, 1992). The percentage of binaries is also reasonably high, 55% for CP1, 5% for CP2 (Seggewiss, 1992).

The statistics of the MWDs as isolated stars and in MCVs is about 50% as derived from the compilation of Wickramasinghe & Ferrario (2000). Thus it is possible that all CPs evolve into MWDs both isolated and in MCVs.

The statistics available for verification of these aspects suffers from selection effect. Thus there is a need to search MCVs with longer orbital period, especially in age limited samples like the clusters. The single positive result from a cluster has been reported recently (Kanaan, Claver, & Liebert, 1999).

Conclusions

The possibility of the CP star binaries evolving in to MCVs is evaluated based on the effect of magnetic field, evolution of the orbital parameters and available statistics. The mass loss during the AGB phase appears to be a very crucial parameter. It is likely that the IPs evolve into polars. Detailed calculations on specific systems are needed to establish the criterion.

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