Part 2
Magnetic Fields
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Magnetic Field Evolution in Accreting White Dwarfs

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Abstract. I discuss the effect of accretion on the magnetic field of an accreting white dwarf. Whereas the magnetic fields of isolated white dwarfs are not expected to change significantly with time, I show that if an accreting white dwarf increases in mass at a rate $> 1\text{–}5 \times 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$, accretion overcomes ohmic diffusion and has a significant effect on the field structure. I discuss the implications of this result for observed systems. In particular, accretion induced field evolution may provide the missing evolutionary link between the strong field, slowly accreting AM Her systems and the weak field, more rapidly accreting intermediate polars.

1. Introduction

The number of known magnetic white dwarfs is steadily increasing, with interesting differences emerging between isolated and accreting white dwarfs. Table 1 summarizes properties of the two populations (also see Wickramasinghe & Ferrario 2000 for a comprehensive recent review). The field strengths of the isolated white dwarfs extend to higher values than the accreting white dwarfs, $\sim 10^9$ G for isolated white dwarfs as opposed to 2×10^8 G for the most magnetic accretor. Magnetism seems to be more common amongst accreting white dwarfs, although this may be due to selection effects. The mean mass of isolated magnetic white dwarfs is high, $\gtrsim 1\ M_\odot$, in contrast to the usual white dwarf mass of $0.6\ M_\odot$, and consistent with the old idea that magnetic white dwarfs evolve from the magnetic Ap stars (Kawka et al. 2002 give a recent discussion). Accreting magnetic white dwarfs, however, do not seem to have significantly different masses from the usual CV average $\approx 0.7\ M_\odot$. Finally, a striking *similarity* between isolated and accreting stars is that their fields are usually complex (i.e. non-dipolar).

Theoretical calculations of ohmic decay in an isolated, cooling white dwarf show that the magnetic field changes little over its lifetime (Chanmugam & Gabriel 1972; Fontaine, Thomas, & van Horn 1973; Wendell, van Horn, & Sargent 1987, hereafter WVS). In addition, no dependence of field strength on age is observed (except perhaps that the incidence of magnetism might increase with age, Liebert et al. 2002). Our "intuition" is therefore that white dwarf magnetic fields are constant with time. An accreting white dwarf on the other hand has a very different history, raising the question of whether its magnetic field might evolve in a different way. Here, I describe calculations which show that the field structure may be substantially affected by accretion if the accretion is rapid

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enough, $\dot{M} > \dot{M}_c \approx (1\text{–}5) \times 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$ (Cumming 2002, hereafter C02). At lower accretion rates, ohmic diffusion allows the field to "keep up" with the accretion flow. This critical accretion rate lies in the middle of observed rates, with interesting implications for observations.

I start by discussing the physical processes which lead to field evolution in §2. I briefly review the physics that sets the ohmic decay time, and go on to present calculations of the evolution of the magnetic field under the action of accretion and ohmic diffusion. In §3, I discuss the implications for observed systems of allowing the white dwarf field to change with time, and conclude in §4.

Table 1. Properties of Magnetic White Dwarfs

	Isolated	Accreting
Number	≈ 65	≈ 90
Magnetic Field	3×10^4–10^9 G	7×10^6–3×10^8 G (AM Hers) $\sim 10^5$–10^7 G (IPs)
Fraction	$\approx 5\%$	$\approx 25\%$
Mean mass	$> 0.95\ M_\odot$	$\approx 0.7\ M_\odot$
Complexity?	yes	yes

2. Field Evolution in an Accreting White Dwarf

2.1. Ohmic decay

Magnetic fields undergo ohmic decay as the currents which support the field dissipate. Calculations of ohmic decay in isolated, cooling white dwarfs show that the ohmic time is longer than the cooling time (Chanmugam & Gabriel 1972; Fontaine, Thomas, & van Horn 1973; WVS). Here, I briefly review the physics which sets the conductivity of the white dwarf interior, and point out an important feature of accreting white dwarfs, that the decay time is almost independent of core temperature or mass (C02).

The timescale for ohmic decay is $t_{\rm ohm} = 4\pi\sigma L^2/c^2$, where σ is the electrical conductivity, and L the lengthscale over which the magnetic field changes. For a fluid interior, the conductivity is set by collisions between the current-carrying electrons and the ions. The energy scale for these collisions is the Fermi energy of the degenerate electrons, which is temperature-independent. The resulting conductivity is $\sigma \approx 10^{21}\ \mathrm{s}^{-1}\ x^3/(1 + x^2)$ (Yakovlev & Urpin 1980), where $x \approx (\rho_6/\mu_e)^{1/3}$ measures the electron Fermi momentum. For a solid core, the conductivity is set by collisions with phonons, whose density and spectrum depends on temperature. The conductivity in this case is $\sigma \approx 6 \times 10^{21}\ \mathrm{s}^{-1}\ (\rho_6/T_6)(1 + 0.24\rho_6/T_6^2)^{1/2}$ (the last term is important for temperatures below the Debye temperature of the crystal) (Baiko & Yakovlev 1995). The transition from solid to liquid occurs at $T_{\rm melt} \approx 3 \times 10^6\ \mathrm{K}\ \rho_6^{1/3}$, when the ratio of Couloumb energy to thermal energy $\Gamma = (Ze)^2/kTa \approx 173$ (a is the interion spacing). When calculating conductivities, WVS and C02 adopt different schemes to interpolate between the non-degenerate and degenerate regimes. However, it is worth noting for future work that recent calculations by Potekhin (1999) and Potekhin et al. (1999) treat the regime of intermediate degeneracy[1].

Table 2. Ohmic decay timescales for liquid white dwarfs (10^9 years, as a function of l and n for the mode)

	$M = 0.6\ M_\odot$			$M = 1.0\ M_\odot$		
	$n=1$	$n=2$	$n=3$	$n=1$	$n=2$	$n=3$
$l=1$	7.6	2.5	1.2	12	4.1	2.0
$l=2$	3.5	1.6	0.87	5.7	2.5	1.4
$l=3$	2.0	1.1	0.66	3.3	1.7	1.1

As an isolated white dwarf cools, the conductivity is at first constant with time while the core is liquid, but then increases with time once a solid core forms after $\approx 10^9$ yrs (see Figure 2 of WVS). The simplification that occurs for accreting white dwarfs is that the core temperature in most cases is expected to be $\gtrsim 10^7$ K because of compressional heating (Nomoto 1982; Townsley & Bildsten 2002), high enough to prevent crystallization. The evolution under ohmic decay can be resolved into eigenmodes, which account for the variation in conductivity and lengthscale L throughout the star. To estimate the lowest order decay time, I take a rough average over the star. I assume $\sigma \propto \rho$ throughout most of the star, use the liquid conductivity, and a typical lengthscale $L \approx R/2$, giving

$$\tau \approx 10^{10}\ \mathrm{yrs}\ \left(\frac{\rho_c}{3\times 10^6\ \mathrm{g\ cm^{-3}}}\right)^{1/3}\left(\frac{R}{10^9\ \mathrm{cm}}\right)^2\left(\frac{10\left<\rho\right>}{\rho_c}\right), \tag{1}$$

where $\rho_c/\left<\rho\right>$ is the ratio of the central density to the mean density (6 for an $n = 3/2$ polytrope; 54 for $n = 3$). Note that as well as being temperature independent, $t_{\rm ohm}$ is also independent of mass: the standard mass-radius relation $R \propto M^{-1/3}$ gives $\rho^{1/3}R^2 \approx$ constant. This estimate agrees well with detailed calculations of the ohmic decay modes. Table 2 gives ohmic decay times associated with different poloidal modes (l and n are angular and radial quantum numbers) for zero-temperature white dwarfs with liquid conductivity (C02, following the mode calculations of WVS). Figure 1 shows the radius R, central density, central conductivity σ_c, and central ohmic time $t_{\rm ohm} = 4\pi\sigma_c R^2/c^2$ for zero-temperature white dwarf models. The lowest order decay mode is $\tau \approx t_{\rm ohm}/40$ (compared with $t_{\rm ohm}/\pi^2$ for a constant density star, for which the eigenvalues can be obtained analytically; WVS). The lowest order ohmic decay mode has a decay time that varies by a factor of 2 over mass, τ = 7–12 billion years.

[1]Details and computer codes to calculate these conductivities can be found at http::/www.ioffe.rssi.ru/astro/conduct/

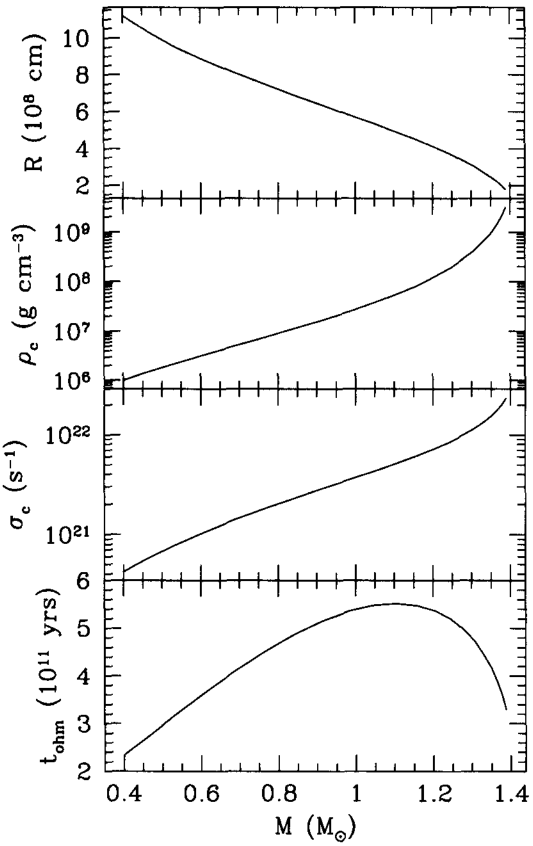

Figure 1. Properties of zero-temperature liquid white dwarfs. Shown are the radius R, central density, central conductivity σ_c, and the central ohmic time $t_{\rm ohm} = 4\pi\sigma_c R^2/c^2$. The lowest order ohmic mode has a decay time $\tau \approx t_{\rm ohm}/40$.

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2.2. The Effect of Accretion

An accreting white dwarf accretes a significant mass on a timescale shorter than the ohmic decay time, raising the question of what happens to its magnetic field. The answer depends on the accretion rate. The field structure may be substantially affected by accretion if the accretion is rapid enough, $\dot{M} > \dot{M}_c \approx (1\text{–}5) \times 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$, whereas at lower accretion rates, ohmic diffusion allows the field to "keep up" with the accretion flow (C02).

Timescales The simplest way to understand this critical accretion rate is to note that the time to accrete the whole star at $10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$ is comparable to the ohmic time $\sim 10^{10}$ years. Of course, what matters is the ratio of local timescales at each point in the star. Following Cumming, Zweibel, & Bildsten (2001) (who applied these ideas to accreting neutron stars), I define the local timescales $t_{\mathrm{accr}} = \Delta M/\dot{M}$, and $t_{\mathrm{diff}} = 4\pi\sigma H^2/c^2$, where ΔM is the mass above that depth, and H is the local pressure scale height. Figure 2 shows t_{accr} and t_{diff} in the envelope of a 0.6 $M_\odot$ white dwarf accreting at $\dot{M} = 10^{-10}$ and $10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$. The ohmic times for the two models agree in the interior where the conductivity is temperature independent, but differ in the outer layers where the conductivity $\sigma \propto T^{3/2}$. The jumps in the ohmic time are due to changes in composition (we assume a C/O core with a pure He layer and a layer of accreted solar composition material). Figure 2 shows that the ratio $t_{\mathrm{diff}}/t_{\mathrm{accr}}$ is insensitive to depth, and is unity for $\dot{M} = (1\text{–}5) \times 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$. Simple analytic estimates give the same result.

Time-dependent models To follow the magnetic field structure over time under the joint action of accretion and ohmic diffusion, I make some simplifying assumptions. The first is that the field is axisymmetric and poloidal, $\boldsymbol{B}(r,\theta,t) = B_r(r,\theta,t)\hat{e}_r + B_\theta(r,\theta,t)\hat{e}_\theta$, in which case it is described by a single component of the vector potential, $\boldsymbol{B} = \boldsymbol{\nabla}\times A_\phi(r,\theta,t)\hat{e}_\phi$, which may be expanded in terms of spherical harmonics

$$A_\phi(r,\theta,t) = \sum_l \frac{R_l(r,t)}{r} P_l^1(\cos\theta), \tag{2}$$

(P_l^1 is the associated Legendre function of order 1). The second is that the accretion is spherically-symmetric. In that case, each spherical harmonic l evolves independently (e.g. a dipole remains a dipole under spherical accretion), giving the following 1D advection-diffusion equation,

$$\frac{\partial R_l}{\partial t} = -v_r \frac{\partial R_l}{\partial r} + \eta \left[\frac{\partial^2 R_l}{\partial r^2} - \frac{l(l+1)R_l}{r^2} \right], \tag{3}$$

which is straightforward to evolve numerically.

The third assumption is that the white dwarf keeps the mass it accretes. I ignore the major uncertainty of whether the white dwarf mass increases or decreases with time because of mass loss in classical novae (e.g. Livio & Truran 1992). Novae occur for accretion rates $\lesssim 10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$ for which the accreted hydrogen and helium burns unstably (Fujimoto 1982; MacDonald 1983). For

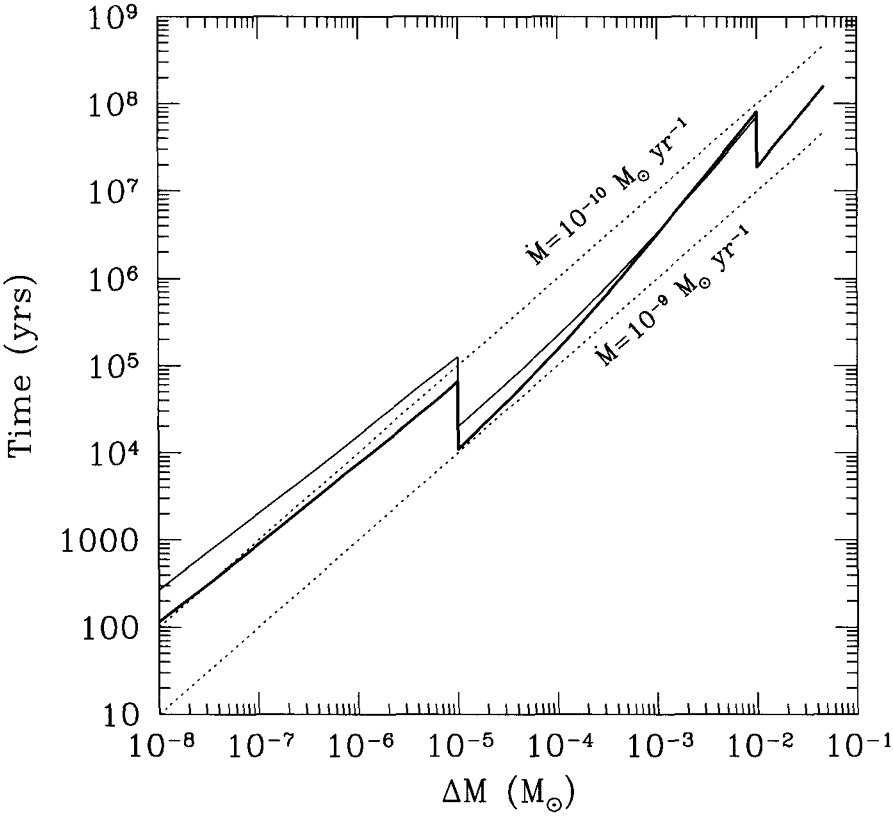

Figure 2. Ohmic diffusion time (solid lines) and accretion time (dotted lines) in the white dwarf envelope for $\dot{M} = 10^{-10}$ and 10^{-9} $M_{\odot}$ yr^{-1}. The accretion time (dotted lines) is labelled with the appropriate accretion rate (the accretion time is smaller for a higher accretion rate). The diffusion time (solid lines) is independent of accretion rate in the degenerate layers (the conductivity depends only on density); but is longer for higher accretion rates in the non-degenerate layers (the conductivity increases with temperature).

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$\dot{M} \lesssim 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$, the hydrodynamic simulations of Prialnik & Kovetz (1995) showed that the white dwarf mass decreased, with an uncertain middle ground between 10^{-9} and $10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$. The accretion rates of IPs are estimated to be $10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$, whereas AM Hers have lower rates $\approx 5 \times 10^{-11}\ M_\odot\ \mathrm{yr}^{-1}$, so that there may be a range of behavior for the observed magnetic CVs. For these calculations, I ignore this issue and assume that all the mass is accreted.

I solve equation (3) numerically, using the lowest order dipole ohmic decay mode as an initial condition. Figure 3 shows the initial and final field configurations after accreting 0.1 $M_\odot$ onto a 0.6 $M_\odot$ white dwarf at three different rates. For $\dot{M} \leq 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$, the field structure is unaffected by accretion, but the number density of field lines decreases due to ohmic decay. For $\dot{M} = 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$, however, the field structure is substantially changed as magnetic flux is advected inwards by accretion.

Open issues and future work Accretion is obviously not spherically symmetric in magnetic CVs. However, in C02, I argued that because gas pressure overwhelms magnetic pressure for an accreted mass $\Delta M \lesssim 10^{-10}\ M_\odot B_7^2$, the accreted matter should spread in a thin layer near the surface, and that deeper in the star spherical accretion is a good approximation. The interior solutions are not sensitive to the boundary condition at the surface, as also found by Choudhuri & Konar (2002) in their simulations of accretion onto neutron stars. One critical difference in the neutron star case is that the field is anchored at the top of the neutron star crust, so that as matter piles up on the pole, the field kinks at the boundary between the solid crust and overlying thin fluid atmosphere. Litwin et al. (2001) propose that ballooning instabilities operating at this kink lead to spreading of matter away from the polar cap at the atmosphere/crust interface. However, in the accreting white dwarf case there is no solid crust: the star is completely fluid. Instabilities may be less important in the spreading of material in this case, since disturbances in the field can propagate rapidly throughout the star (at the Alfven speed) and dissipate. This may allow for a straightforward 2D simulation of accretion at the polar cap, and the subsequent distortion of the dipole field.

Magnetic buoyancy instabilities might be expected to allow the field to reemerge, in which case the critical accretion rate would be set by a competition with transport by instabilities rather than ohmic diffusion. However, for the neutron star case, Cumming et al. (2001) showed that the strong stratification prevents these instabilities, at least for the simplified geometry considered there (plane-parallel, horizontal magnetic field). A similar stabilization is expected in the white dwarf case. The basic argument is that, apart from the very outermost layers of the star, gas pressure completely overwhelms magnetic pressure. The buoyancy effects induced by the magnetic field are then easily overcome by the stratification. There are instabilities with essentially horizontal displacements that bypass the stratification (but are then ineffective at vertical/radial mixing). A purely poloidal field such as the one we have considered here undergoes a kink-type instability near its neutral point (see summary in Mestel 1999), unless a stabilizing toroidal field is present. The joint evolution of mixed poloidal and toroidal fields would be interesting to consider further.

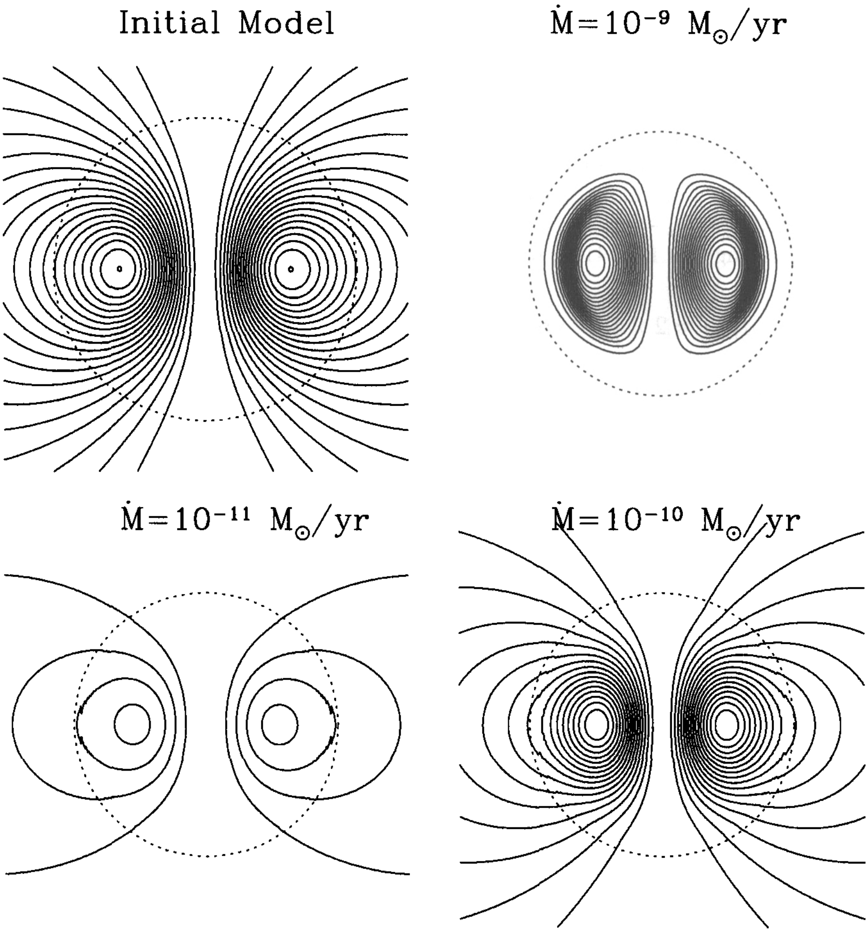

Figure 3. Magnetic field lines before and after accretion of 0.1 $M_\odot$ onto a 0.6 $M_\odot$ white dwarf at three different rates, $\dot{M} = 10^{-11}, 10^{-10}$, and 10^{-9} $M_\odot$ yr^{-1}. For $\dot{M} \leq 10^{-10}$ $M_\odot$ yr^{-1}, the number density of field lines decreases due to ohmic decay. For $\dot{M} = 10^{-9}$ $M_\odot$ yr^{-1}, magnetic flux is advected into the interior, dramatically reducing the surface field.

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2.3. Other processes

I briefly discuss two other processes that could lead to field evolution.

The Hall effect The observed complexity of white dwarf magnetic fields motivated Muslimov, van Horn, & Wood (1995) to suggest that the Hall effect might operate in white dwarfs. This effect, studied extensively in neutron stars (in particular by Goldreich & Reisenegger 1992), arises when the conducting electrons move in a fixed background of ions, and is described by the Hall term in Ohm's law, $\boldsymbol{E} = -(\boldsymbol{v_e}/c)\times\boldsymbol{B}$, where $\boldsymbol{v_e} = \boldsymbol{J}/n_e ec$ is the electron velocity. Physically, the field moves with the electrons, so that for example an initial poloidal field spontaneously twists under the action of its toroidal current (e.g., see Cumming & Arras 2003). The relevant timescale is the shearing time of the electron flow $\approx L/v_e$, giving $t_{\rm Hall} \approx n_e ecL/J \approx 4\pi n_e eL^2/cB$ (Goldreich & Reisenegger 1992).

Evaluating the Hall time for a white dwarf gives

$$t_{\rm Hall} \approx 2\times10^{10}\ {\rm yrs}\ \left(\frac{B}{10^9\ {\rm G}}\right)^{-1}\left(\frac{\langle\rho\rangle}{3\times10^5\ {\rm g\ cm^{-3}}}\right)R_9^2, \tag{4}$$

where I take $L \approx R/2$, and insert a mean density $\langle\rho\rangle$. This timescale depends only on density, and is independent of temperature. The magnetic field here is the interior field, which could be greater than the surface field (by an order of magnitude for the lowest order ohmic decay mode). As noted by MVW, if the interior field is 10^9 G, the ratio of Hall time to ohmic time is ≈ 10 for a liquid interior, and ≈ 1 for a solid interior (note that the timescale found by MVW is shorter than equation (4) predicts, perhaps due to a different choice of initial current distribution – see discussion in C02).

The Hall effect is probably not very important for accreting white dwarfs. First of all, even the most magnetic accreting white dwarfs observed have Hall times $\gtrsim 10^{10}$ years. However, more important is the fact that the interior is fluid rather than solid. In a fluid, the ions are free to respond to changes in the magnetic field on an Alfven crossing time ($\approx$ hours), most likely washing out Hall effects. Therefore calculations of Hall evolution such as those of Muslimov et al. (1995) may be inapplicable to fluid stars (see Cumming & Arras 2003 for a discussion of this issue).

Rotation Whereas isolated white dwarfs rotate slowly, accreting white dwarfs may be spun up to rapid rates by accretion of angular momentum. King (1985), applying the equilibrium models of Moss (1979) to accreting white dwarfs, suggested that meridional currents could be responsible for the submergence of magnetic flux in the outer layers of rotating magnetic white dwarfs. The aim was to explain the narrow range of field strengths in AM Hers. In degenerate objects, the Eddington-Sweet argument follows through except the cooling time rather than Kelvin-Helmholtz time sets the circulation time, $t_{\rm circ} \approx t_{\rm cool}(\Omega_B/\Omega)^2$, where Ω is the rotation rate and $\Omega_B = GM/R^3$ the break up spin frequency (Kippenhahn & Möllenhoff 1974). This timescale becomes short in the outer layers of the star, perhaps allowing time for meridional circulations to act. One complication is that the presence of a magnetic field prevents spin up to rapid rates at which these circulations would be more effective. Detailed calculations of this process remain to be carried out.

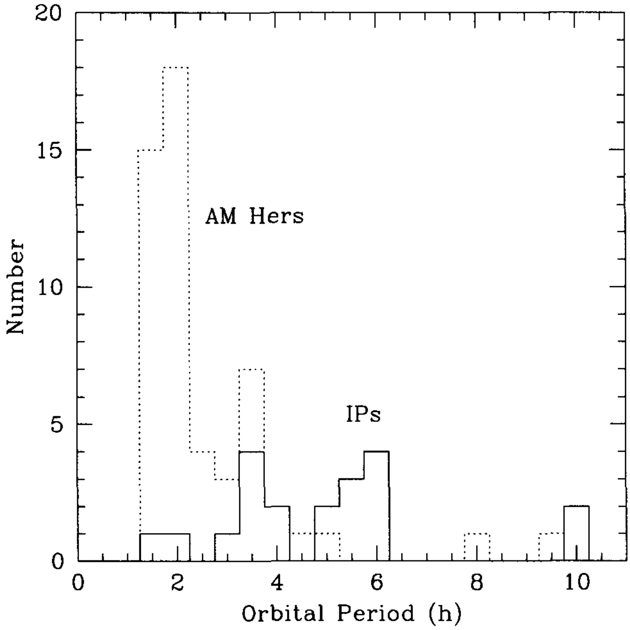

Figure 4. Orbital period distribution for 53 AM Her systems from Wickramasinghe & Ferrario (2000) and for 20 intermediate polars from the catalogue of Ritter & Kolb (1998).

3. Implications for Observed Systems

We have seen that accretion can have a significant effect on the magnetic field of an accreting white dwarf, if the accretion is rapid enough, $\dot{M} \gtrsim \dot{M}_c \approx (1\text{–}5) \times 10^{-10}\ M_\odot\ \mathrm{yr}^{-1}$. This contrasts with the usual assumption that white dwarf fields are constant in time. I now discuss the implications of this result for the observed magnetic systems.

3.1. An evolutionary connection between AM Hers and intermediate polars?

The orbital period distributions of AM Hers and IPs are very different (Figure 4). Most AM Hers have orbital periods $P_{\mathrm{orb}} \lesssim 3$ hours, while most IPs are found with $P_{\mathrm{orb}} \gtrsim 3$ hours. This led to suggestions of an evolutionary connection between AM Hers and IPs, that the IPs are the asynchronous progenitors of the AM Hers. A synchronization period of ≈ 3 h is plausible for a $\sim 10^7$ G white dwarf, explaining the two orbital period distributions (Chanmugam & Ray 1984; King, Frank, & Ritter 1985; Hameury et al. 1987). However, the

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evolution of these systems cannot be so simple, since the magnetic fields of the IPs are believed to be systematically lower than those of AM Hers. If IPs do have high fields, the optical polarization must somehow be suppressed in those systems, while if IPs have weaker fields, there is a whole class of asynchronous AM Her progenitors as yet undetected (King & Lasota 1991).

Accretion-induced magnetic field changes may allow a connection between the two populations. The $\dot{M}$ estimates of Warner (1995) show that AM Hers accrete at low rates, $\dot{M} \approx 5 \times 10^{-11}\ M_{\odot}\ \mathrm{yr}^{-1}$, whereas the IPs accrete more rapidly, $\dot{M} \approx (0.2\text{–}4) \times 10^{-9}\ M_{\odot}\ \mathrm{yr}^{-1}$. Interestingly, the critical rate $\dot{M}_c$ lies between these two values, suggesting the possibility that the magnetic fields in IPs have been reduced by accretion. The accretion rate in IPs may be high enough to avoid mass loss by classical novae, so that the white dwarf mass increases at a sufficient rate for this to occur. A drop in $\dot{M}$, e.g. at $P_{\mathrm{orb}} \approx$ 3–4h would allow the magnetic field to reemerge, on a timescale $\approx 3 \times 10^8$ yr $(\Delta M/0.1\ M_{\odot})^{7/5}$ (ΔM is the amount of accreted mass), similar to the time for a non-magnetic CV to cross the period gap. The picture is probably more complicated than this: for example, no correlation is seen between B and orbital period within AM Her systems (Wickramasinghe & Ferrario 2000). However, the fact that the magnetic field may change with time is a new ingredient to throw into the evolutionary models.

3.2. Rapidly accreting systems ("Type Ia progenitors")

The supersoft X-ray sources and symbiotic systems have $\dot{M} \gg \dot{M}_c$, and are believed to be stably burning the accreted matter, increasing the white dwarf mass. As well as a dramatic reduction in surface field strength, amplification of the internal field is also expected (flux conservation gives $B \propto \rho^{2/3}$). Unfortunately, we know little about the magnetic fields of these white dwarfs. Pulsations are seen in the symbiotic Z And (Sokoloski & Bildsten 1999), and a supersoft source in M31 (Osborne et al. 2001; King, Osborne, & Schenker 2002). If due to magnetic accretion, then a rough estimate gives $B \approx 10^7$ G in each case. We expect accretion to have a substantial effect on the magnetic field, so these are interesting systems to consider further.

3.3. Where are the 10^9 G accreting white dwarfs?

Whereas isolated white dwarf fields extend up to 10^9 G, most AM Hers have $B < 10^8$ G, with the highest being 2.8×10^8 G (AM Uma). This may be due to selection effects against finding high field accretors (Wickramasinghe & Ferrario 2000). Another possibility is that high field objects come into synchronization at wider separation (Wickramasinghe & Wu 1994), suppressing magnetic braking and not having time to come into contact. From our results, some difference is to be expected from the different ohmic decay properties — accreting white dwarfs are liquid and have shorter decay times. This could account for a factor of 2 difference over a Hubble time.

3.4. Complexity from accretion?

The ohmic decay time for the quadrupole component of the field is $\approx (4\text{–}6) \times 10^9$ years, allowing for the complex field structure seen in accreting white dwarfs to be fossil (perhaps consistent with complex fields seen in Ap stars). Another possibility is that the accretion flow directly leads to complexity of the field. The spreading of material away from the polar cap could induce higher order components of the surface field. An interesting observation is that the magnetic pole undergoing most accretion in AM Her systems is the pole with the weaker magnetic field in all cases with magnetic field measurements for both poles (Wickramasinghe & Ferrario 2000). Wickramasinghe & Wu (1991) suggest that this is a result of the role of the quadrupole component during synchronisation. An alternative suggested by our results is that after synchronisation occurs, the pole pointing towards the companion undergoes more rapid accretion which reduces the field strength at that pole, giving rise to the observed asymmetry. Even though the global rate for AM Hers is $< \dot{M}_c$, the local accretion rate in the layers for which the accreted material is still confined to the polar cap will be greater than the critical rate. Detailed models of the spreading of material away from the polar cap are required to investigate this further.

4. Conclusion

The differences in properties that are emerging between isolated magnetic white dwarfs and those accreting in binaries raise the question of whether there are differences in the magnetic field evolution in these two populations. Understanding this evolution is an important part of learning about the origin and evolution of white dwarf magnetism.

As I have shown here, the magnetic field of an accreting white dwarf can be directly affected by the accretion process, if it is rapid enough. The idea that white dwarf fields might change in these systems (contrary to our intuition from isolated white dwarfs) has interesting implications for observed systems, in particular the evolutionary connection between AM Hers and IPs. Rapidly accreting systems such as supersoft sources should show a reduced incidence of magnetism (or at least different properties) if these ideas are correct. From a theoretical standpoint, many interesting questions remain. In particular, the spreading of the accreted material away from the polar cap and its effect on the field structure is an important problem, with potential for direct comparisons between theory and observations.

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