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PHYSICAL INTERPRETATION OF DWARF NOVA PRIMARY EFFECTIVE TEMPERATURES

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RESUMEN

Hemos llevado a cabo un estudio teórico del impacto de las envolventes acumulativas sobre el estado térmico de la enana blanca subyacente (WD). Esto nos permitió encontrar las temperaturas de equilibrio del núcleo de la WD, las masas de ignición de la nova clásica y las luminosidades térmicas de WDs que llevan a cabo acreción con tasas de $10^{-11} - 10^{-8} M_{\odot}$ yr^{-1}. Estas tasas de acreción son las más apropiadas para WDs en variables cataclísmicas (CVs) de ($P_{\rm orb} \lesssim 7$ hr), muchas de las cuales llevan a cabo acreción de manera esporádica como Novas Enanas. Fueron observadas más de veinte Novas Enanas en reposo, cuando la tasa de acreción es baja siendo posible detectar la fotosfera de la WD y medir la temperatura $T_{\rm eff}$. Comparando nuestro trabajo teórico con estas observaciones podemos restringir la masa de la WD y la tasa de acreción promediada en el tiempo, $\langle \dot{M} \rangle$. Si $\langle \dot{M} \rangle$ es la dada solamente mediante pérdidas de radiación gravitacional entonces las masas de WD son $> 0.8 M_{\odot}$. Una conclusión alterna es que las masas se encuentran más cerca de $0.6 M_{\odot}$ y ($\langle \dot{M} \rangle$) es 3 - 4 veces mayor que la esperada en base a pérdidas de radiación gravitacional.

ABSTRACT

We have undertaken a theoretical study of the impact of the accumulating envelopes on the thermal state of the underlying white dwarf (WD). This has allowed us to find the equilibrium WD core temperatures, the classical nova ignition masses and the thermal luminosities for WDs accreting at rates of $10^{-11} - 10^{-8} M_{\odot}$ yr^{-1}. These accretion rates are most appropriate to WDs in cataclysmic variables (CVs) of ($P_{\rm orb} \lesssim 7$ hr), many of which accrete sporadically as Dwarf Novae. Over twenty Dwarf Novae have been observed in quiescence, when the accretion rate is low and the WD photosphere is detected and $T_{\rm eff}$ measured. Comparing our theoretical work to these observations allows us to constrain the WD mass and the time averaged accretion rate, $\langle \dot{M} \rangle$. If $\langle \dot{M} \rangle$ is that given by gravitational radiation losses alone, then the WD masses are $> 0.8 M_{\odot}$. An alternative conclusion is that the masses are closer to $0.6 M_{\odot}$ and $\langle \dot{M} \rangle$ is 3-4 times larger than that expected from gravitational radiation losses.

Key Words: **BINARIES: CLOSE — NOVAE, CATACLYSMIC VARIABLES — STARS: DWARF NOVAE — WHITE DWARFS**

Dwarf Novae (DN) are the subset of Cataclysmic Variables (CVs) with low time-averaged accretion rates $\langle \dot{M} \rangle < 10^{-9} M_{\odot}$ yr^{-1} and thermally unstable accretion disks. The transfer of matter onto the WD occurs in outbursts that last a few days to a week once every month to year (or even longer in some systems). Most DN have orbital periods $P_{\rm orb} < 2$ hours, below the "period gap", with fewer above the gap (see Shafter 1992). During accretion disk quiescence, the $\dot{M}$ onto the WD is often low enough that the system's UV (and sometimes optical) emission is dominated by light from the WD surface, allowing for a measurement of the WD $T_{\rm eff}$, nearly all of which exceed $10,000$ K (Sion 1999). Thus, the WD is hotter than expected for its age, providing evidence of the thermal impact of prolonged accretion on the WD (Sion 1995). Townsley & Bildsten (2004) have calculated $T_{\rm eff}$ and its dependence on $\langle \dot{M} \rangle$, the WD mass, M, and core temperature, T_c. Here we summarize the the results of using this work to infer $\langle \dot{m} \rangle = \langle \dot{M} \rangle / 4\pi R^2$, where R is the WD radius, from measured $T_{\rm eff}$'s. See Townsley & Bildsten (2003) (hereafter TB03) for a more complete discussion. Since L is approximately linear in $\langle \dot{M} \rangle$, the physical quantity best constrained by $T_{\rm eff}$, which represents the flux per stellar surface area, is $\langle \dot{m} \rangle$ (TB03). Figure 1 shows the $\langle \dot{m} \rangle$'s inferred from the measured $T_{\rm eff}$'s tabulated by Winter & Sion (2003) with some small additions and modifications (TB). This observational $\langle \dot{m} \rangle$-$P_{\rm orb}$ relation shows clear evidence for a drop in $\langle \dot{m} \rangle$ below the period gap. The expectations from "standard" CV

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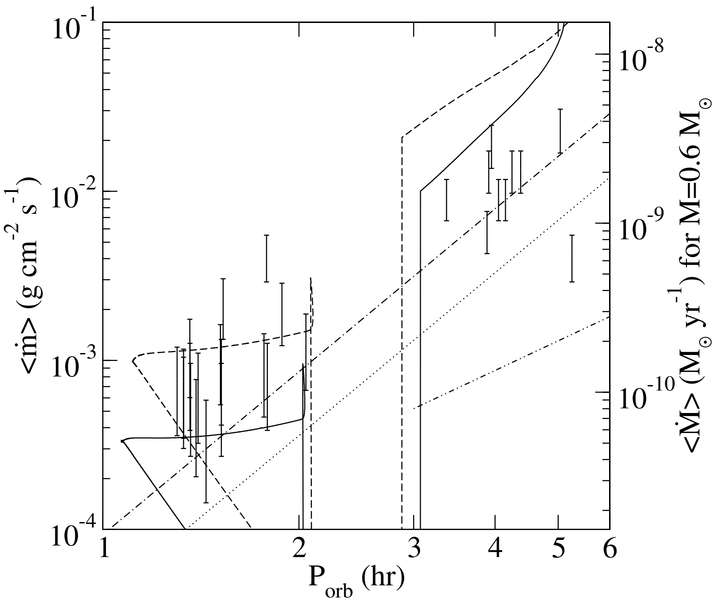

Fig. 1. Values for the time averaged accretion rate per WD surface area, $\langle\dot{m}\rangle \equiv \langle\dot{M}\rangle/4\pi R^2$, derived from the $T_{\rm eff}$ measurements in the table appearing in Winter & Sion (2003). The ranges indicated for each measurement are those allowed for $0.05M_{\rm ign} < M_{\rm acc} < 0.95M_{\rm ign}$ and $0.6M_\odot < M < 1.2M_\odot$. The curves show the $\langle\dot{m}\rangle$ predicted by Howell, Nelson, & Rappaport (2001) for $M = 0.7M_\odot$ (solid line) and $M = 1.1M_\odot$ (dashed line), Andronov et al. (2003) (dot-dot-dashed line), and Patterson's (1984) relation deduced from CV observations for $M = 0.6M_\odot$ (dotted line) and $1.0M_\odot$ (dashed line). The right hand scale gives $\langle\dot{M}\rangle_{0.6}$, the corresponding accretion rate if R is that for $M = 0.6M_\odot$. At the same $\langle\dot{m}\rangle$, $\langle\dot{M}\rangle_{1.0} = 0.4\langle\dot{M}\rangle_{0.6}$.

evolution (Howell et al. 2001) for $M = 0.7M_\odot$ (solid line) and $1.1M_\odot$ (dashed line) are shown in Figure 1. In this disrupted magnetic braking scenario, $\langle\dot{M}\rangle$ is set by magnetic braking above the period gap and by gravitational radiation below the period gap. Our deduced $\langle\dot{m}\rangle$'s are lower than the expected values above the period gap. It is important that we are inferring the long-term $\langle\dot{M}\rangle$, averaged over the thermal time of the radiative (nondegenerate) layer $\sim c_P T_c M_{\rm nd}/L \approx 10^4(\langle\dot{M}\rangle/10^{-10}M_\odot\ {\rm yr}^{-1})^{-0.75}$ years for $M = 0.8M_\odot$ (Townsley & Bildsten 2004), so that this discrepancy cannot be from temporarily low $\dot{M}$. The most recently improved calibration of the magnetic braking law, using spin-down of open cluster stars (Andronov et al. 2003; dot-dot-dashed line), yielded $\langle\dot{M}\rangle$'s above the period gap at least a factor of ten lower than Howell et al. (2001), falling below our inferences, so that braking in CVs must be enhanced over that responsible for the spin down of noninteracting low mass stars. Also shown is Patterson's (1984) deduction from observations, $\langle\dot{M}\rangle \approx 5.1\times10^{-10}(P_{\rm orb}/4\ {\rm hr}){\rm M}_\odot\ {\rm yr}^{-1}$, for $M = 0.6M_\odot$ (dotted line) and $1.0M_\odot$ (dot-dashed line). Our points are consistent with Patterson (1984) above the period gap, within the uncertainty in his estimates. Below the gap, however, our measurements are roughly a factor of 3 above his. The Patterson (1984) estimates also suffer from the absence of reliable distances, but in a more direct way than ours, making systematic errors difficult to quantify.

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