Long Term Variation of Quiescent Effective Temperatures of CV White Dwarfs

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Outline

- Compressional heat release and the quiescent $T_{\text{eff}}$
- Long-term accretion variation and $T_{\text{eff}}$
- Quiescent $T_{\text{eff}}$ in magnetics
- Comparing wind braking, magnetics and non-magnetics
- Testing improved wind braking laws
Heat Sources

Heat liberated by compression is transferred out to surface and in to core. Often called “compressional heating”.

Heat sources:
- Accretion light: only very near surface while actively accreting
- Compression: throughout star, mostly in light-element layer (really gravitational potential energy)
- Nuclear “simmering”: fusion near base of accreted layer (eventually becomes fast and triggers classical nova)
- Core heat capacity
Quasi-static Profile

Local thermal time short compared to accretion

\[ t_{\text{th}} \equiv \frac{c_P T}{\left( \frac{4 \alpha c T^4}{3 \kappa y^2} \right)} < t_{\text{acc}} \equiv \frac{\Delta M}{\langle \dot{M} \rangle} \]

\[ y = \frac{\Delta M}{4\pi R^2} \approx \frac{P}{g} \] is column depth.

Thermal state set by flux from deeper layers rather than from fluid element’s history.

Heat equation near surface:

\[ c_P \frac{\partial T}{\partial t} = \frac{\partial F}{\partial y} + c_P \dot{m} \frac{T}{y} \left[ \frac{\partial \ln T}{\partial \ln y} - \left( \frac{\partial \ln T}{\partial \ln P} \right)_{\text{ad}} \right] \]

where \( \dot{m} = \frac{\dot{M}}{4\pi R^2} \) is the instantaneous accretion rate. In steady-state, flux equals compressionally liberated energy

\[ L \approx \frac{k T_c}{\mu m_p} \langle \dot{M} \rangle \]

Energy release related to heat content of compressed material.
Quiescent $T_{\text{eff}}$

In steady state, under constant $\dot{M} = \langle \dot{M} \rangle$, quiescent surface has

$$T_{\text{eff}} = 1.7 \times 10^4 \text{K} \left( \frac{\langle \dot{M} \rangle}{10^{-10} M_\odot \text{ yr}^{-1}} \right)^{1/4} \left( \frac{M}{0.9 M_\odot} \right)$$

Can be inverted for $\langle \dot{M} \rangle$, but there is a nasty $M$ dependence.

More directly useful for comparing evolutionary expectations to data

Important question: how robust is $T_{\text{eff}}$ as indicator of actual average $\dot{M}$?
Effects of changing $\dot{M}$

Evolution of thermal profile

$\dot{M}$ alternating between $1$ and $9 \times 10^{-11} M_\odot \text{ yr}^{-1}$ on two different timescales

$10^3 \text{ yr}$

$10^5 \text{ yr}$

Longer timescale variations reach deeper into the envelope and cause more variation in surface flux.
Time dependence of $T_{\text{eff}}$

Response to moderately long timescale variations

$q\times10^4$ yr

\[
\langle \dot{M} \rangle = 5 \times 10^{-11}, \ M = 0.9 M_\odot
\]

With no information about cycle, this introduces an uncertainty in what $\langle \dot{M} \rangle$ corresponds to the observed $T_{\text{eff}}$. 
Timescale and variation

In steady state

\[ \frac{\partial F}{\partial y} = c_P \dot{m} \frac{T}{y} \left[ \left( \frac{\partial \ln T}{\partial \ln P} \right)_{\text{ad}} - \frac{\partial \ln T}{\partial \ln y} \right] \]

Contribution to surface flux depends logarithmically on local thermal time.

Contribution from layer will change on its thermal time

Flux contribution vs. thermal time gives magnitude of variation on given timescale

- Higher \( \langle \dot{M} \rangle \) has shorter thermal times
- Reaching degenerate portion of envelope lengthens thermal time
Heating in Magnetics

Material is confined to poles until $P \approx 10^{15}(g_8 \ell_8 B_7^2)^{5/7}$ erg cm$^{-3}$

After spreading over star, compressional energy release as in nonmagnetic case

- 60-80% of non-magnetic quiescent luminosity emerges away from polar regions
- Heat released at shallow depths will be near poles
- Due to deep energy deposition will be even less sensitive to $\dot{M}$ variations

![Graph showing L/L vs. P (erg cm$^{-3}$) with curves for M=0.6 M$\odot$ and M=0.9 M$\odot$]
Mag Braking and Polars

Sample favoring least ambiguous measurements of $T_{\text{eff}}, q$, • nonmag, ◇ mag

Interrupted magnetic braking evolution from

GR only evolution from secondary $M-R$ relation in HNR01

Clear contrast between non-magnetics and magnetics in 3.5-5 hour range.

Magnetics consistent with GR losses at all periods.
Improving MB treatments

Sample favoring least ambiguous measurements of $T_{\text{eff}}, q$, • nonmag, ◇ mag

Empirical fit from

Howell, Nelson, 

Ivanova & Taam 2004, 

Andronov, 
Pinsonneault, Sills 

Classic IMB a bit high

Laws consistent with DN will may have period gap problem

VY Scl stars far above MB
Hibernation

Overestimate of $\langle \dot{M} \rangle$ due to extended intervals of accretion quiescence

CVs are only identified while accretion is active

Thus long-term hibernation intervals with low duty cycles can cause $T_{\text{eff}}$ to overestimate the true average of $\dot{M}$.

$$\frac{L_{q,\text{active}}}{L_q(\langle \dot{M} \rangle)} = 1 + \frac{2R(t_{\text{active}})}{f}$$

$f = \text{duty cycle}$

$R(t_{\text{active}}) = \text{response function}$

Proximity to $\langle \dot{M} \rangle$ floor due to GR limits $f$ for low $\langle \dot{M} \rangle$ systems

Scatter among several systems may reveal transients

for $\langle \dot{M} \rangle = 5 \times 10^{-11} M_\odot \text{yr}^{-1}$, $M = 0.9 M_\odot$
Conclusions

- Unconstrained long-term variations of $\dot{M}$ may influence observed $T_{\text{eff}}$. Less so for low $\langle \dot{M} \rangle$ systems.

- Clear contrast between magnetic and non-magnetic systems in the 3-5 hour period range. Implies that wind braking is disrupted by WD magnetic field.

- Classic IMB (HNR01) has $\langle \dot{M} \rangle$ somewhat higher than DN above gap. Newer relations more consistent with data, may have problems with period gap. (?)

- Appears that there is a class of novalikes at 3-3.5 hours (VY Scl/SW Sex) which have $\langle \dot{M} \rangle$ much higher than even predicted by wind braking.

- True hibernation scenarios with low duty cycles and high $\dot{M}$ during active times are difficult to constrain with $T_{\text{eff}}$. May improve with more $T_{\text{eff}}$ measurements.