Long Term Variation of Quiescent Effective Temperatures of CV White Dwarfs

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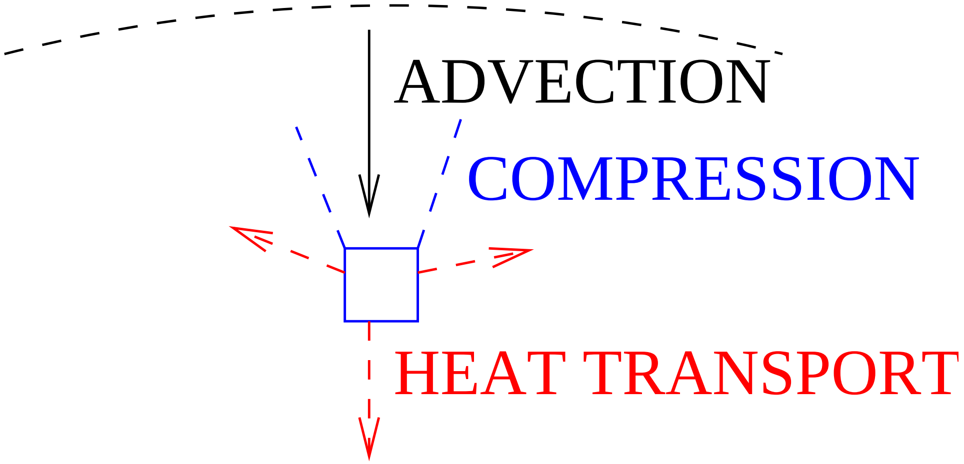
Outline

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

Heat Sources

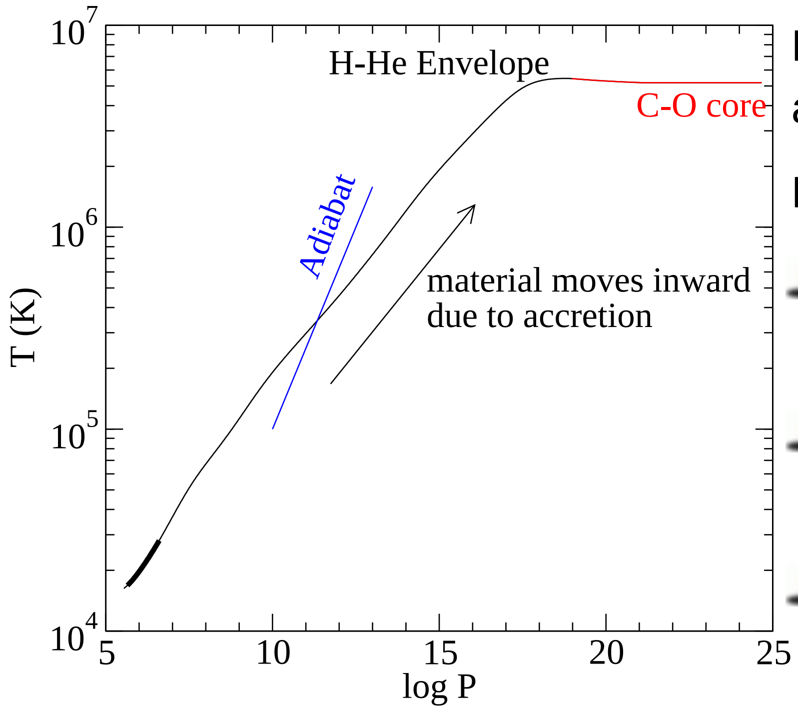


ADVECTION

COMPRESSION

HEAT TRANSPORT

(very) leaky entropy advection

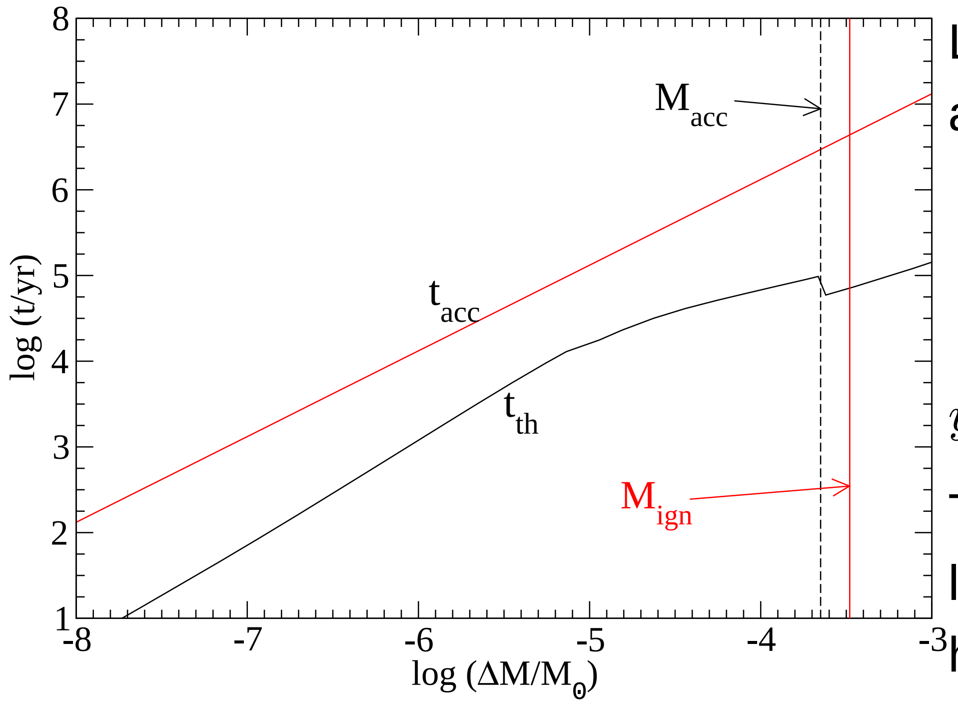


Heat liberated by compression is transferred out to surface and in to core. Often called “compressional heating”.

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

$$t_{\rm th} \equiv \frac{c_P T}{\left(\frac{4acT^4}{3\kappa y^2}\right)} \quad < \quad t_{\rm acc} \equiv \frac{\Delta M}{\langle \dot{M} \rangle}$$

$y = \Delta M / 4\pi R^2 \approx P/g$ is column depth.

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

Heat equation near surface:

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

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

$$L \simeq \frac{kT_c}{\mu m_p} \langle \dot{M} \rangle$$

Energy release related to heat content of compressed material.

Quiescent $T_{\rm eff}$

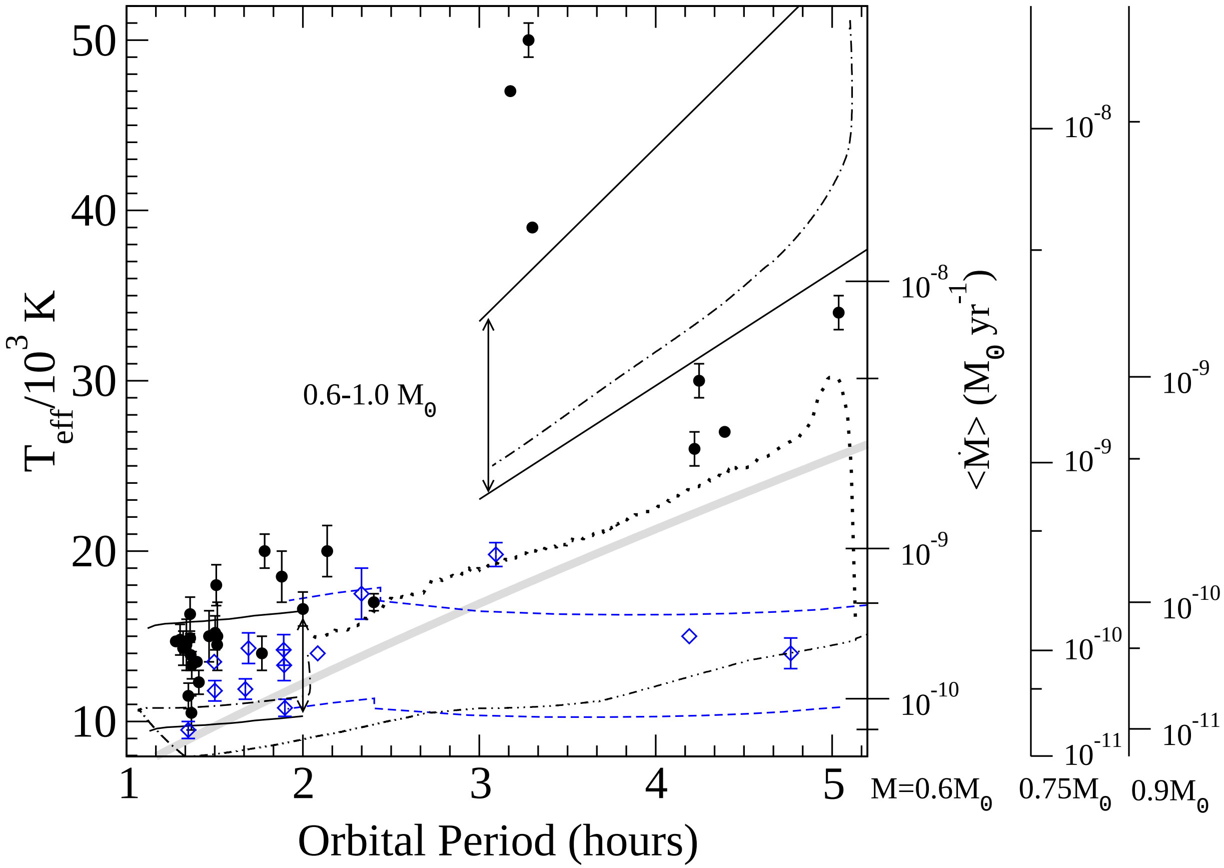
In steady state, under constant $\dot{M} = \langle \dot{M} \rangle$, *quiescent* surface has

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

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

More directly useful for comparing evolutionary expectations to data

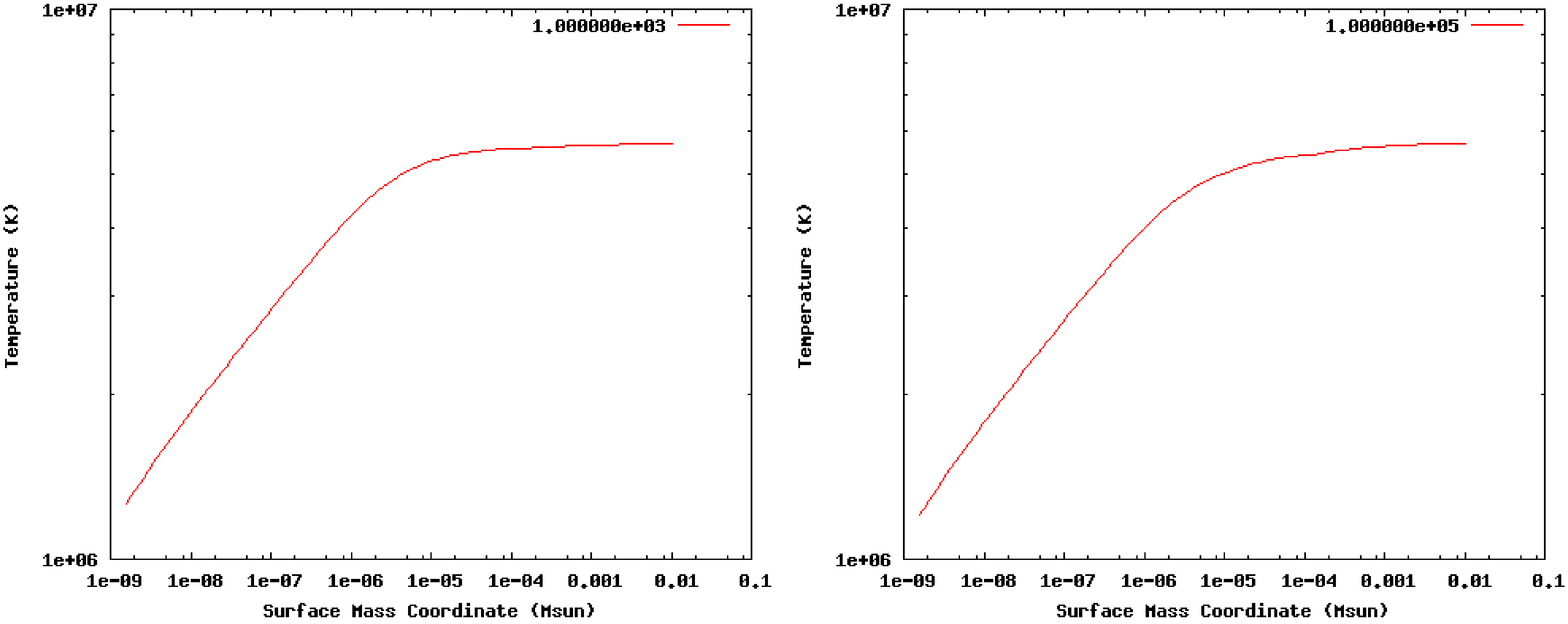
Important question: how robust is $T_{\rm eff}$ as indicator of actual average $\dot{M}$?



Effects of changing $\dot{M}$

Evolution of thermal profile

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



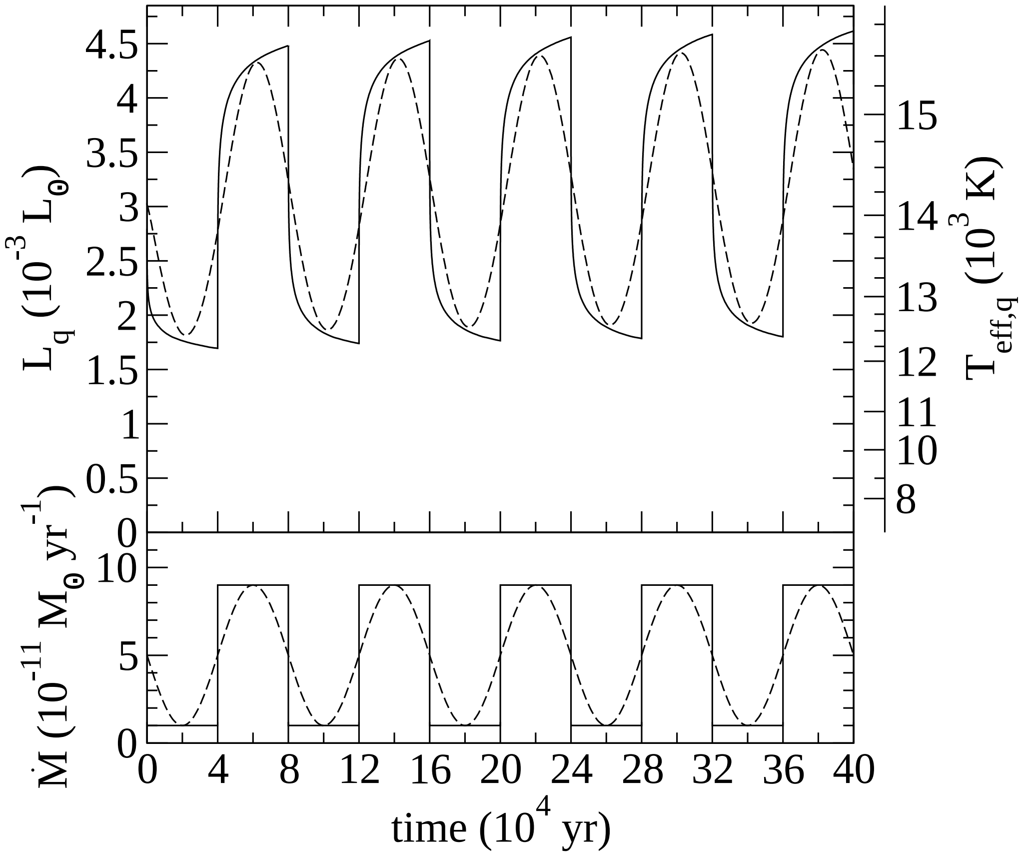
10^3 yr

10^5 yr

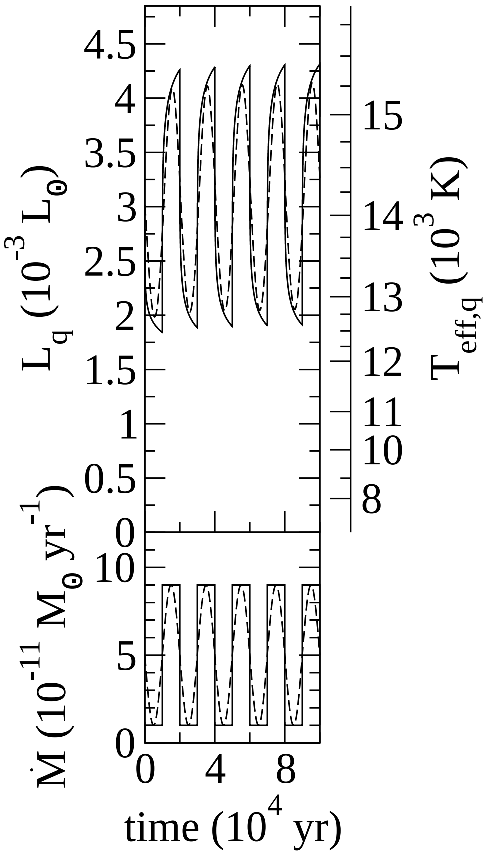
Longer timescale variations reach deeper into the envelope
and cause more variation in surface flux.

Time dependence of $T_{\rm eff}$

Response to moderately long timescale variations



4×10^4 yr



10^4 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 $T_{\rm eff}$.

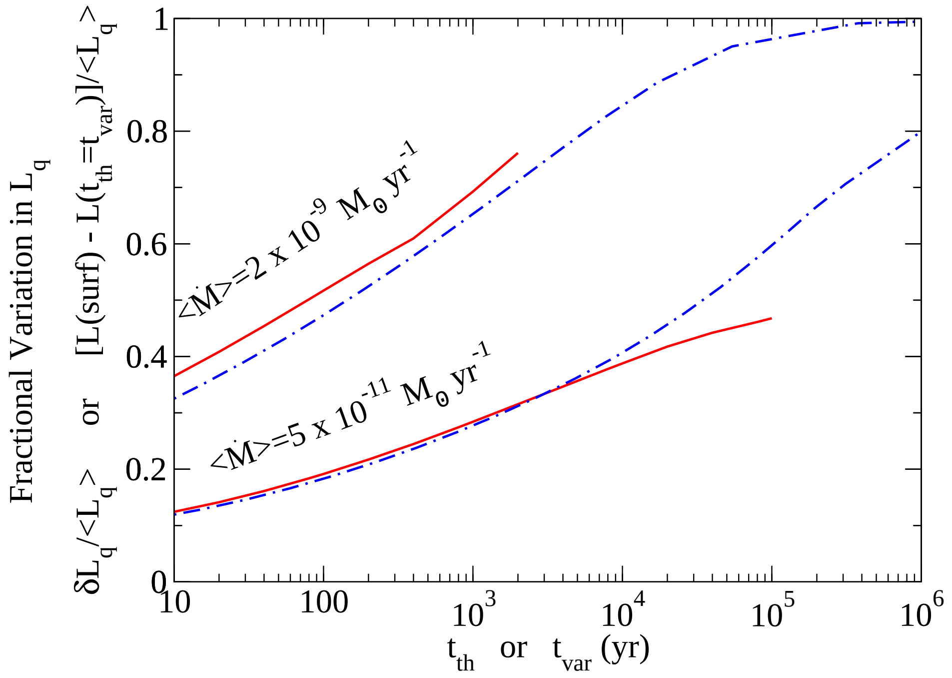
Timescale and variation

In steady state

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

Contribution to surface flux dependends logarithmically on local thermal time.

Contribution from layer will change on its thermal time



flux profile simulation

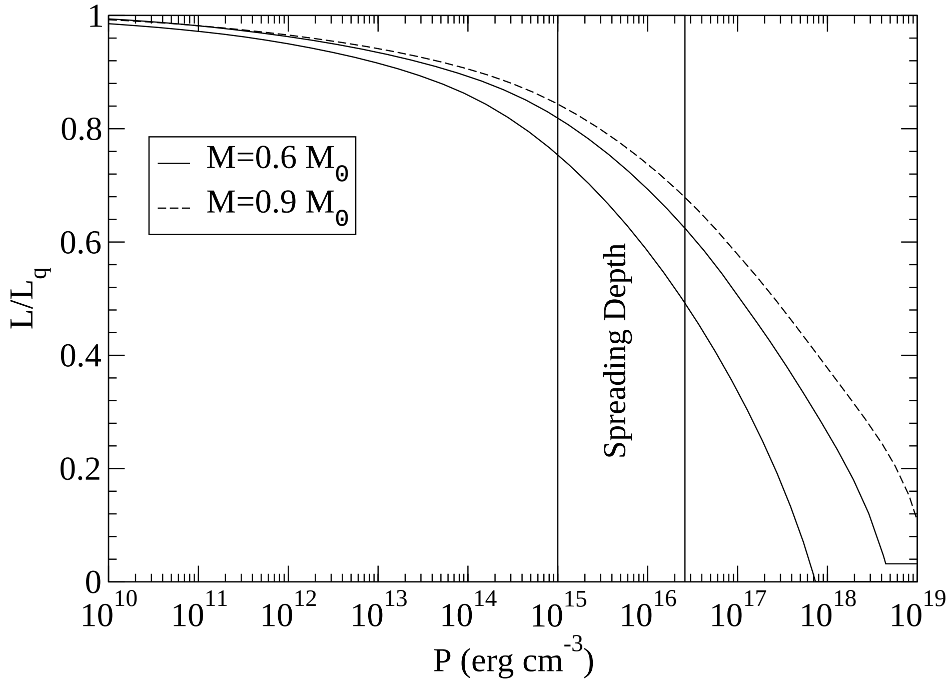
Flux contribution vs. thermal time gives magnitude of variation on given timescale

- Higher $\langle \dot{M} \rangle$ has shorter thermal times
- Reaching degenerate portion of envelope lenthens thermal time

Heating in Magnetics

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

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



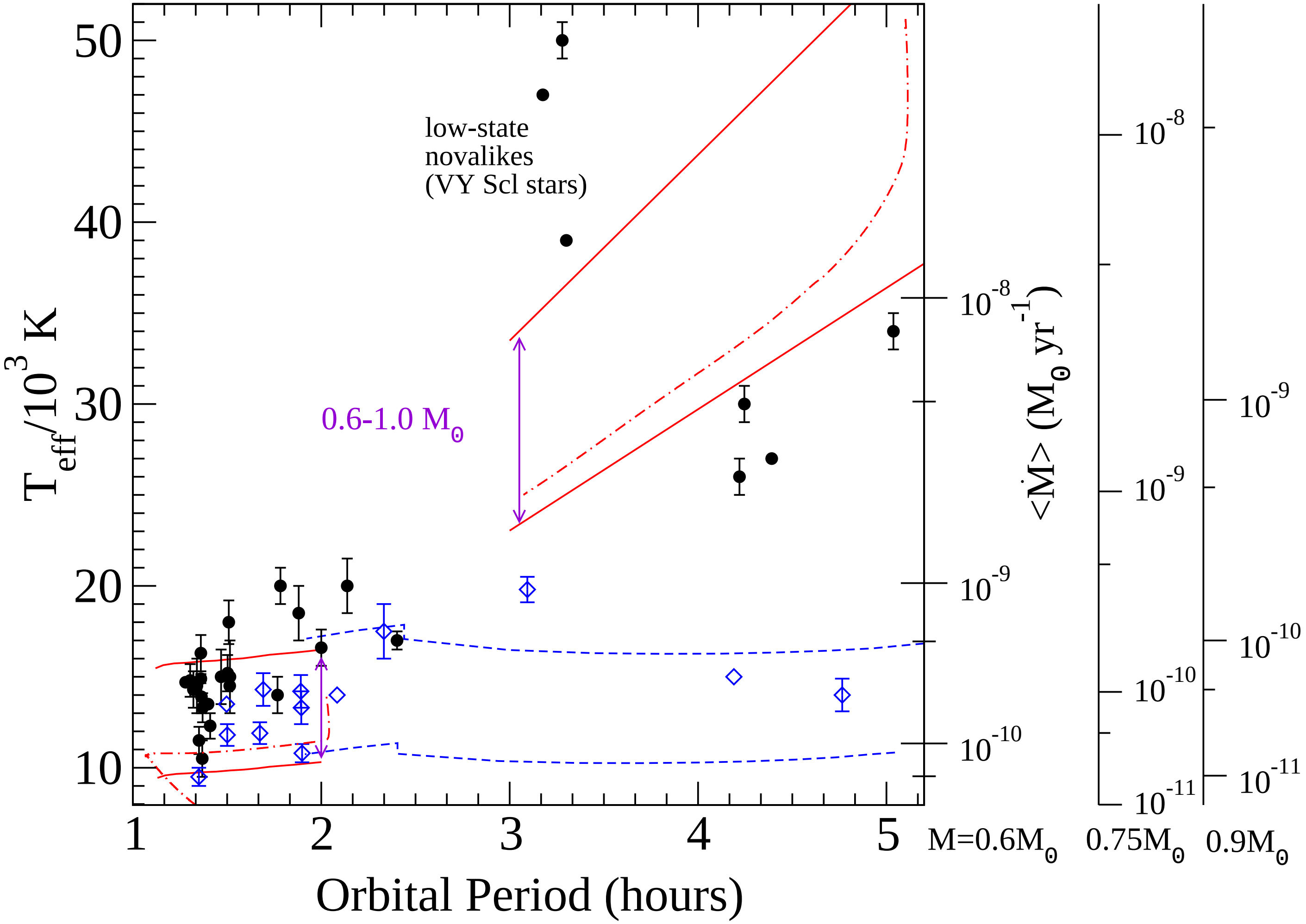
- 60-80% of non-magnetic quiescent luminosity emerges away from polar regions
- Heat released at shallow depths will be near poles
- Due to deep energy deposition will be even less sensitive to $\dot{M}$ variations

Mag Braking and Polars

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

Interrupted magnetic braking evoluton from Howell, Nelson, Rappaport 2001, ApJ, 550, 897
Kolb & Baraffe 1999, MNRAS, 309, 1034

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

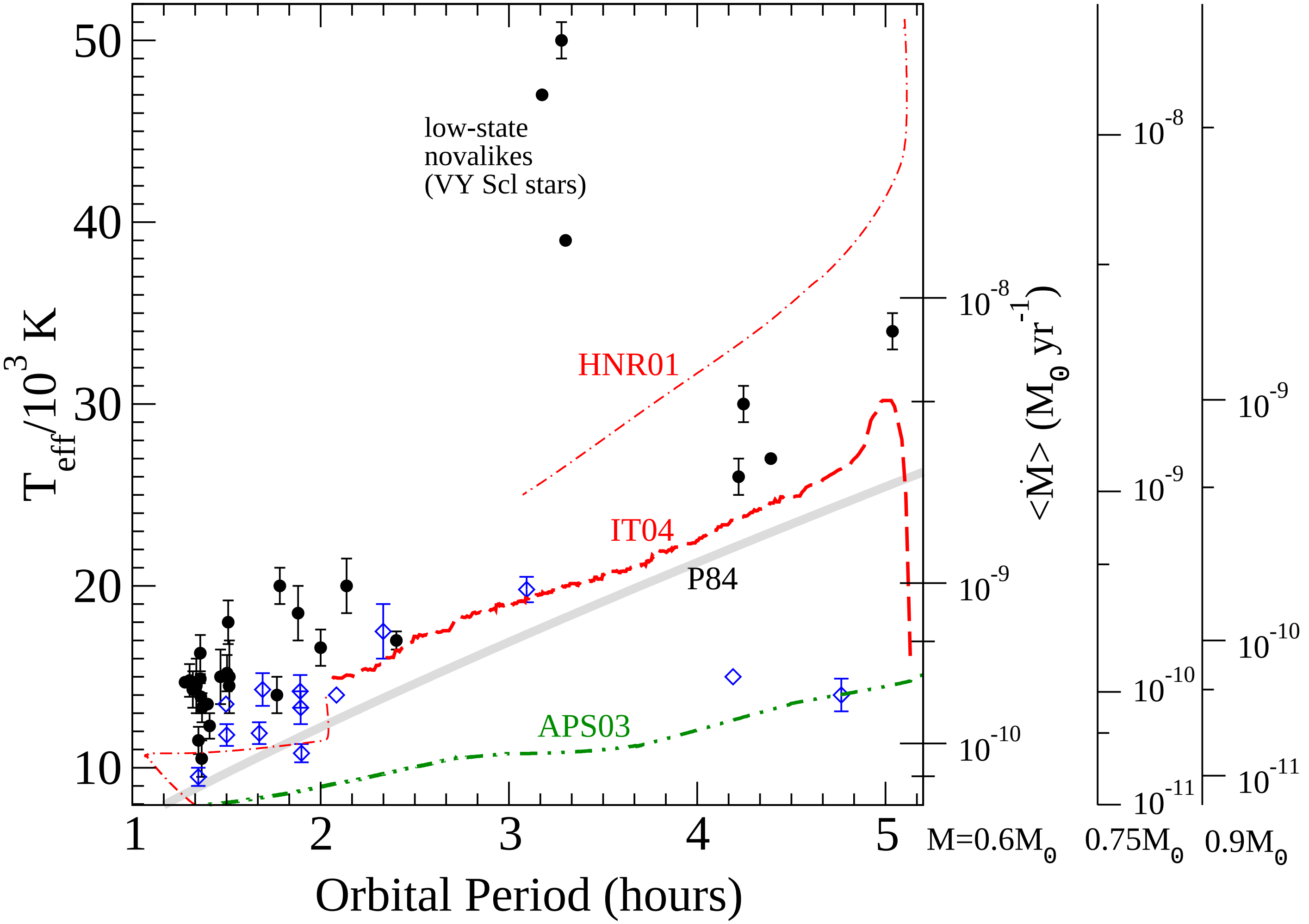
Sample favoring least ambiguous measurements of $T_{\mathrm{eff},\mathrm{q}}$, ● nonmag, ◇ mag

Empirical fit from Patterson 1984, ApJS, 54, 443

Howell, Nelson, Rappaport 2001, ApJ, 550, 897

Ivanova & Taam 2004, ApJ, 601, 1058

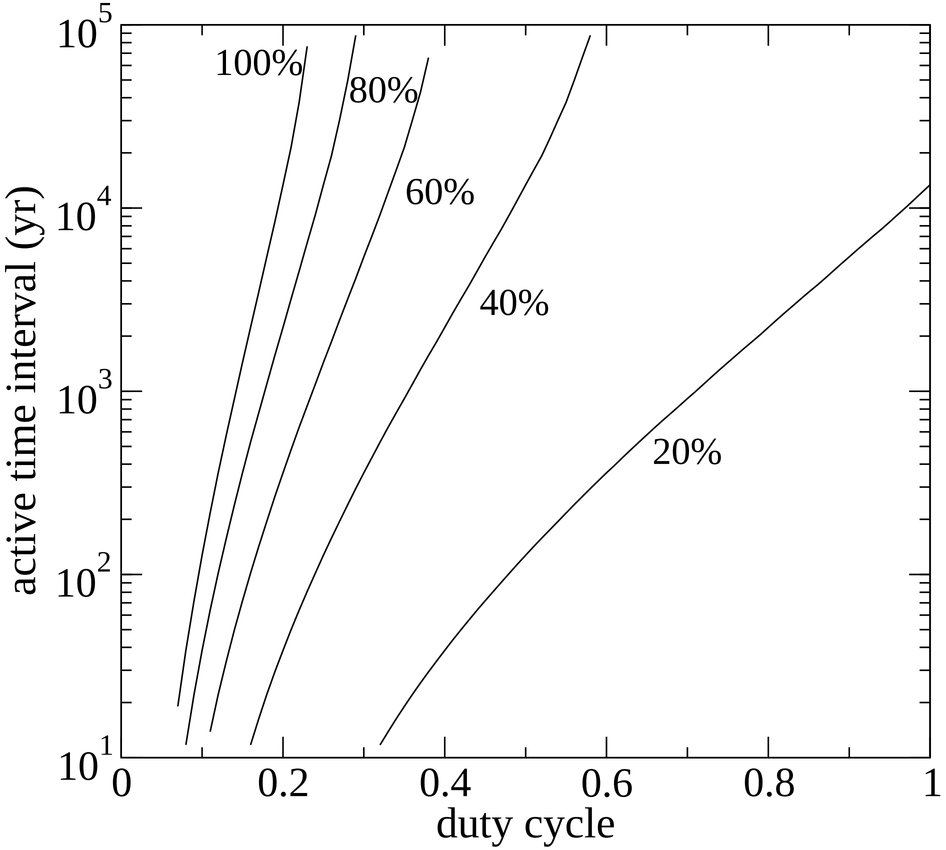
Andronov, Pinsonneault, Sills 2003, ApJ, 582, 358



- 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



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

CVs are only identified while accretion is active

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

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

$f =$ duty cycle
$R(t_{\rm active}) =$ 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

Conclusions

- Unconstrained long-term variations of $\dot{M}$ may influence observed $T_{\rm eff}$.
  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 $T_{\rm eff}$. May improve with more $T_{\rm eff}$ measurements.