The Astrophysical Conditions of Classical Nova Nucleosynthesis

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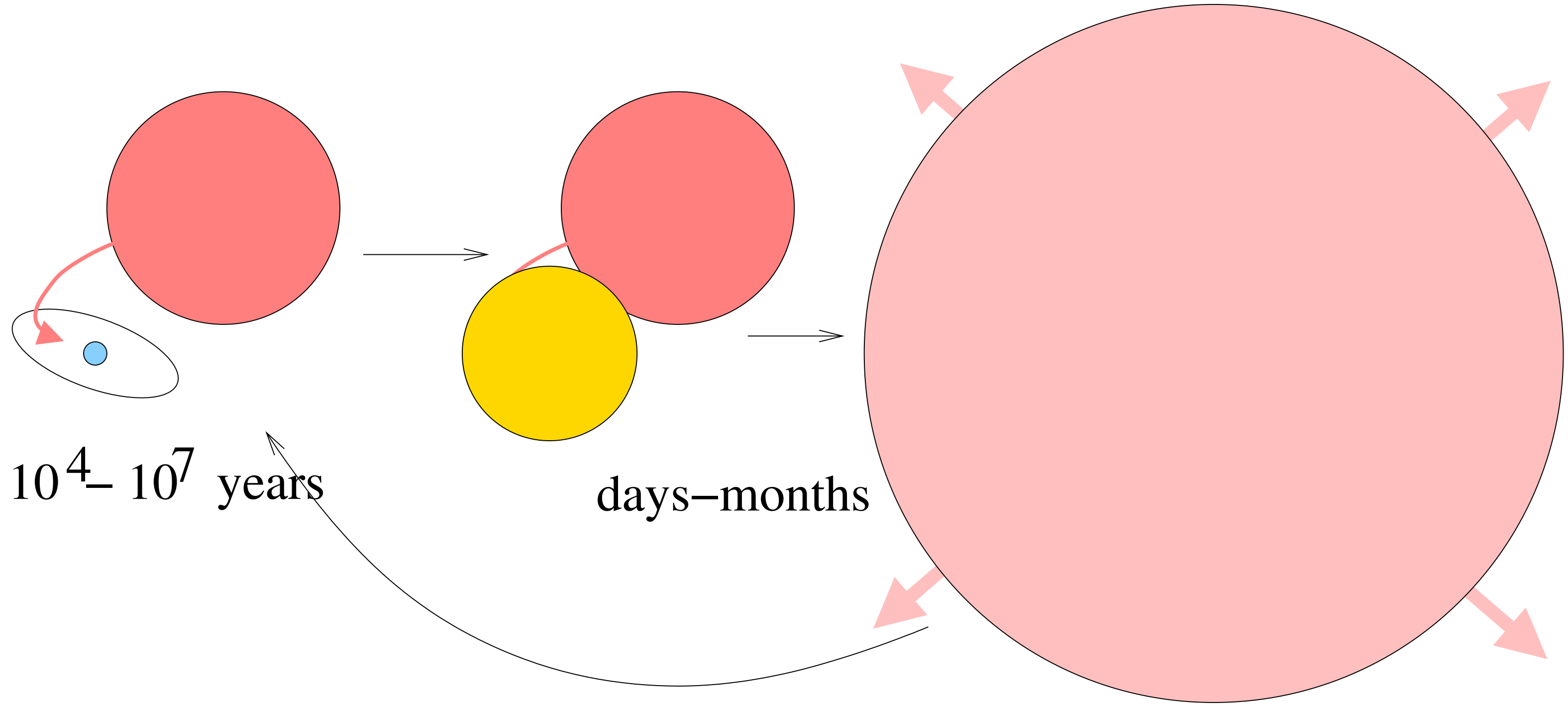
Classical Novae



WD accreting steadily from a low mass MS star = Cataclysmic Variable (CV)

$\Longrightarrow$ $P_{\rm orb} = 1.5$ – 6 hours

- short timescale thermonuclear outburst event, over in $\sim$ a year
- long recurrence time, $\sim 10^4$-10^7 years
- a single binary will have many thousands of oubursts over its life each ejecting $M_{\rm ej} \sim 10^{-4} M_\odot$ into the ISM

Contribution of Novae to the ISM

How is the nova contribution to an abundance in the ISM calculated?

$$X_{i,\mathrm{Nova}} = \frac{1}{M_{\mathrm{gas}}} \int \frac{M_{\mathrm{ej}}}{t_{\mathrm{rec}}} X_i \Phi(M_{\mathrm{WD}}, \langle \dot{M} \rangle) \, dM_{\mathrm{WD}} d\langle \dot{M} \rangle dt$$

All the factors depend on M_{WD} and $\langle \dot{M} \rangle$

M_{ej} – Nova ejected mass

t_{rec} – Nova recurrence time

X_i – Abundance in ejecta

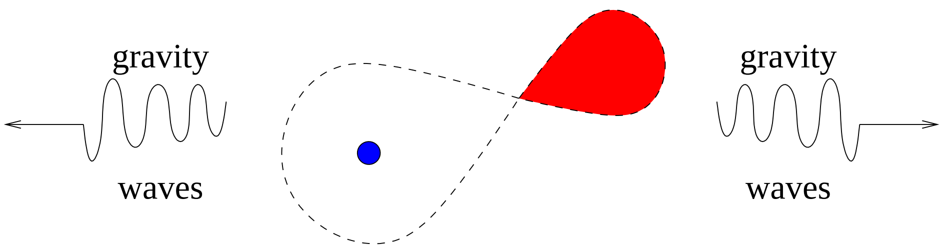
Φ – distribution of H Accreting WDs in M_{WD} and $\langle \dot{M} \rangle$

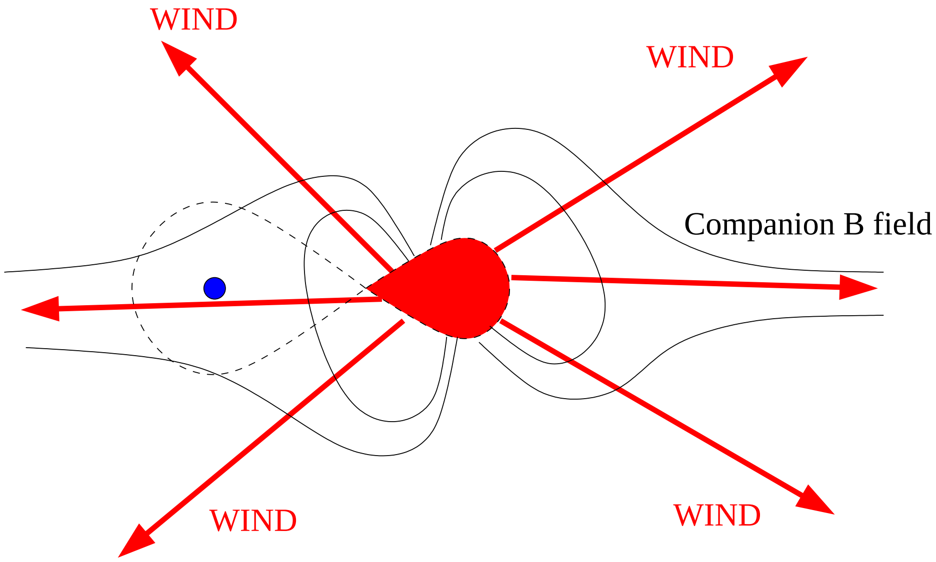
In this talk: What is $\Phi(\langle \dot{M} \rangle)$

- Binary evolution – Angular momentum loss
- Predicted $\langle \dot{M} \rangle$ and observational evidence
- Obital period distribution of novae rate
- distribution of nova $\langle \dot{M} \rangle$
- Abundance variations

Angular Momentum Loss

$\dot{J}$ determines evolution of compact binary





Gravitational Radiation

low $\dot{J}$

Magnetic Braking

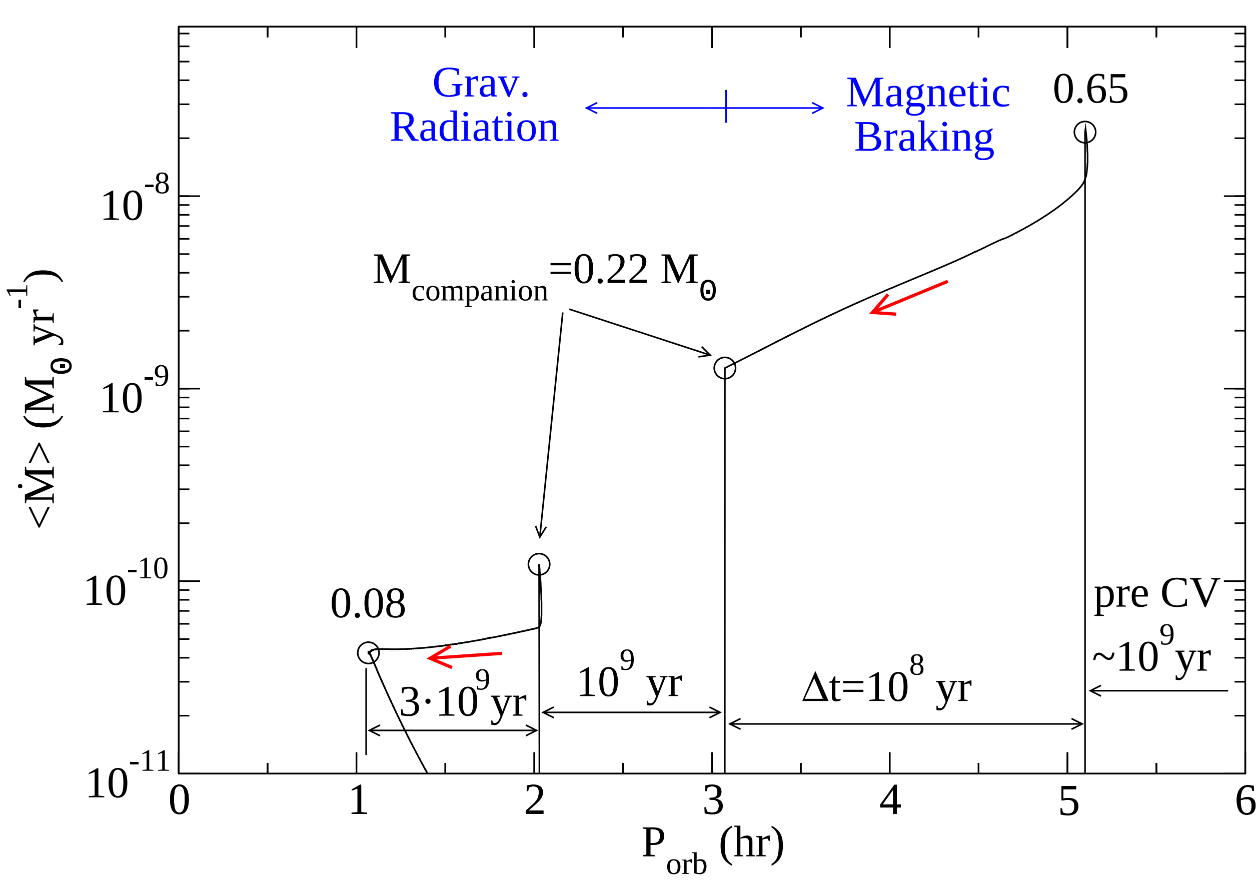
high $\dot{J}$, $P_{\rm orb} \gtrsim 3$ hours

Magnetically attached wind from companion star

$$\dot{J}_{\rm gr} = -\frac{32 G Q^2 \omega^5}{5c^5}$$
$$= -2.7 \times 10^{37}\,{\rm erg}\left(\frac{a}{R_\odot}\right)^4 \left(\frac{M_{\rm WD} M_2}{M_t M_\odot}\right)^2 \left(\frac{P_{\rm orb}}{\rm hr}\right)^{-5}$$

$$\dot{J}_{\rm mb} = -9.4 \times 10^{38}\,{\rm erg}\left(\frac{M_2}{M_\odot}\right)\left(\frac{R_2}{R_\odot}\right)^3 \left(\frac{P_{\rm orb}}{\rm hr}\right)^{-3}$$

Interrupted Magnetic (Wind) Braking?



$M_{\rm WD} = 0.7 M_\odot$, Howell, Nelson, & Rappaport 2001, ApJ 550, 897

Through Roche-lobe constraint, $\dot{J}$ prescription sets

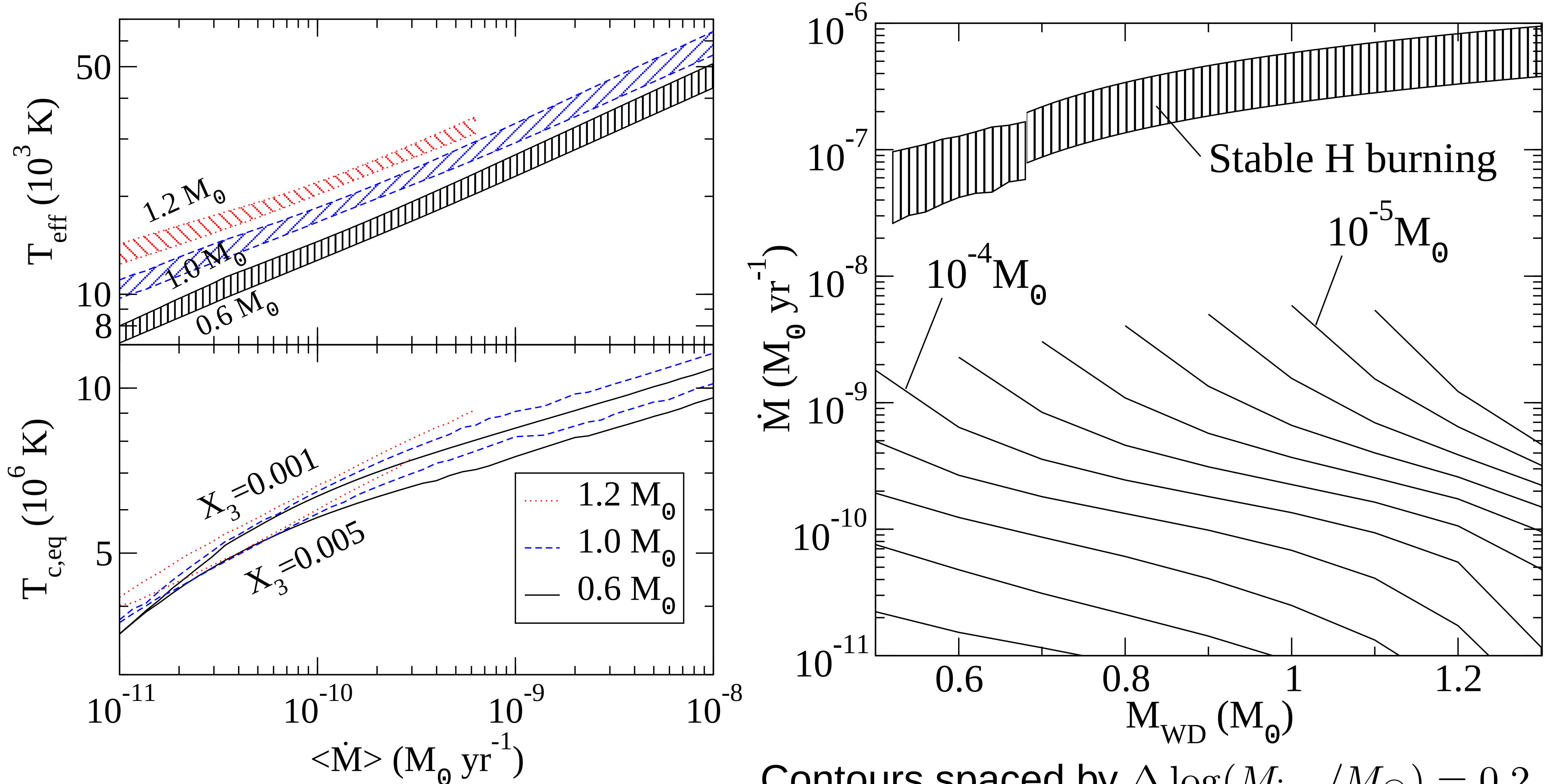
$\langle\dot{M}\rangle(P_{\rm orb})$ and $\Phi_P(P_{\rm orb})$

and thus $\Phi(\langle\dot{M}\rangle)$.

Open Questions:

- Is Mag. Braking prescription right?
- Does this fit observed population?

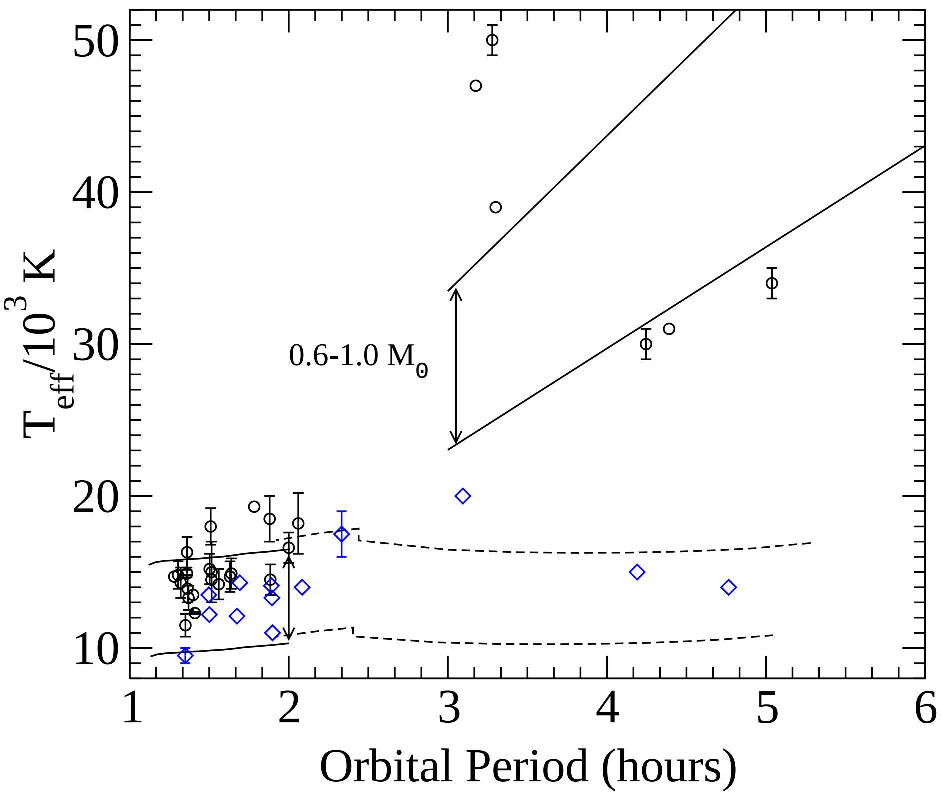
Equilibrium $T_c \rightarrow M_{\rm ign}, T_{\rm eff}$



Contours spaced by $\Delta \log(M_{\rm ign}/M_\odot) = 0.2$

$X_3 =$ mass fraction of ^{3}He in accreted material

$T_{\rm eff}$ vs. $P_{\rm orb}$



○ Low disk state systems (DN, SW Sex)

◇ Magnetics

Townsley & Gänsicke, in preparation

Theory range shown: 0.6-1.0$M_\odot$

Factor of $\sim 10\ \langle \dot{M} \rangle$ contrast across period gap confirmed

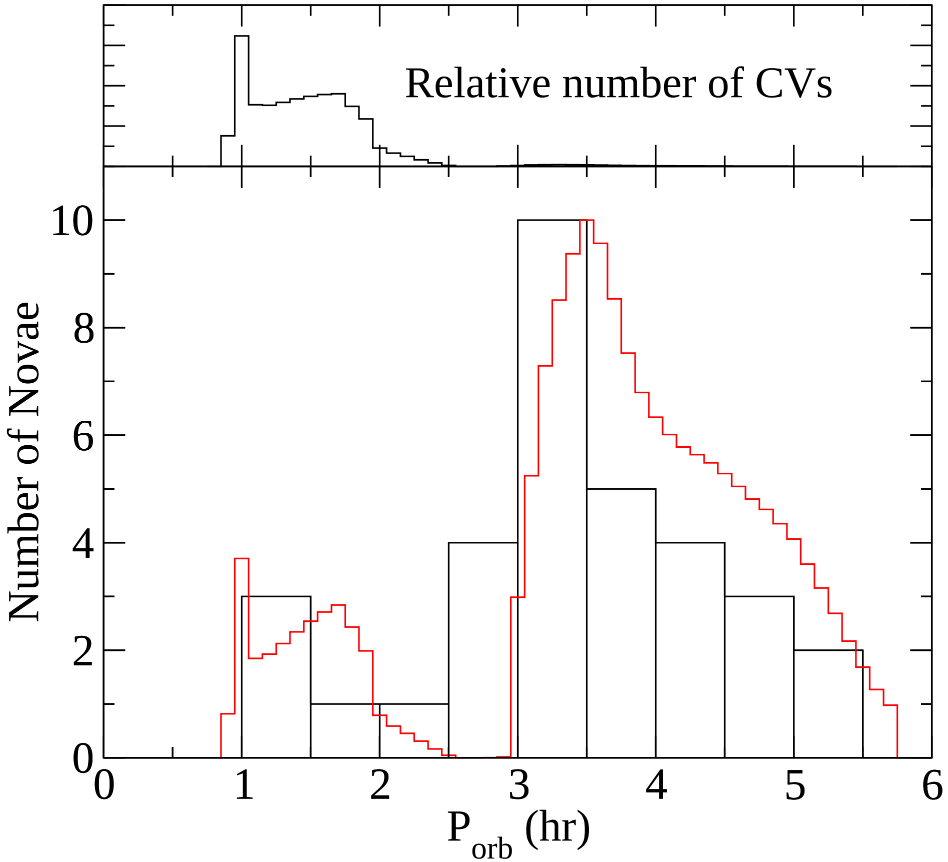
Current Mag. Braking prescription matches well with DN at 4-5 hours

Separate population of high $\langle \dot{M} \rangle$ at 3 hours?

Magnetic CVs above gap near Grav. Radiation prediction – WD magnetic field preventing magnetic braking?!

(Li, Wu, & Wickramasinghe 1994, MNRAS, 268, 61)

Classical Nova $P_{\rm orb}$ Distribution



Theory curve uses Interrupted Magnetic Braking for $\langle \dot{M} \rangle (P_{\rm orb})$ and population Φ_P

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

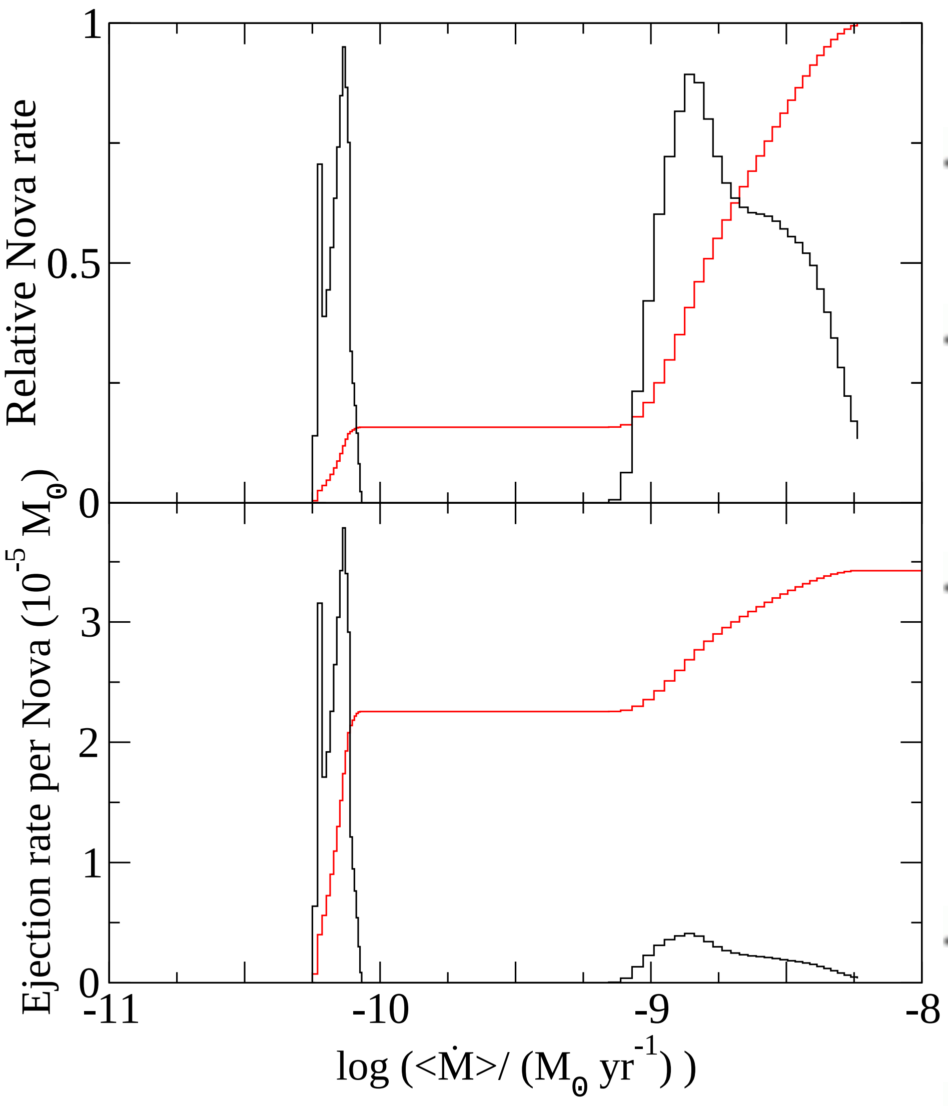
$$\nu_{CNP} = \Phi_P \frac{\langle \dot{M} \rangle}{M_{\rm ign}}$$

Data from Ritter & Kolb 2005 CV catalog

- Supports a factor of > 10 drop in $\langle \dot{M} \rangle$ across gap
- Consistent with idea that CVs evolve across the gap
- Possible population of magnetic systems filling in gap
- Ignores selection effects – hard to quantify

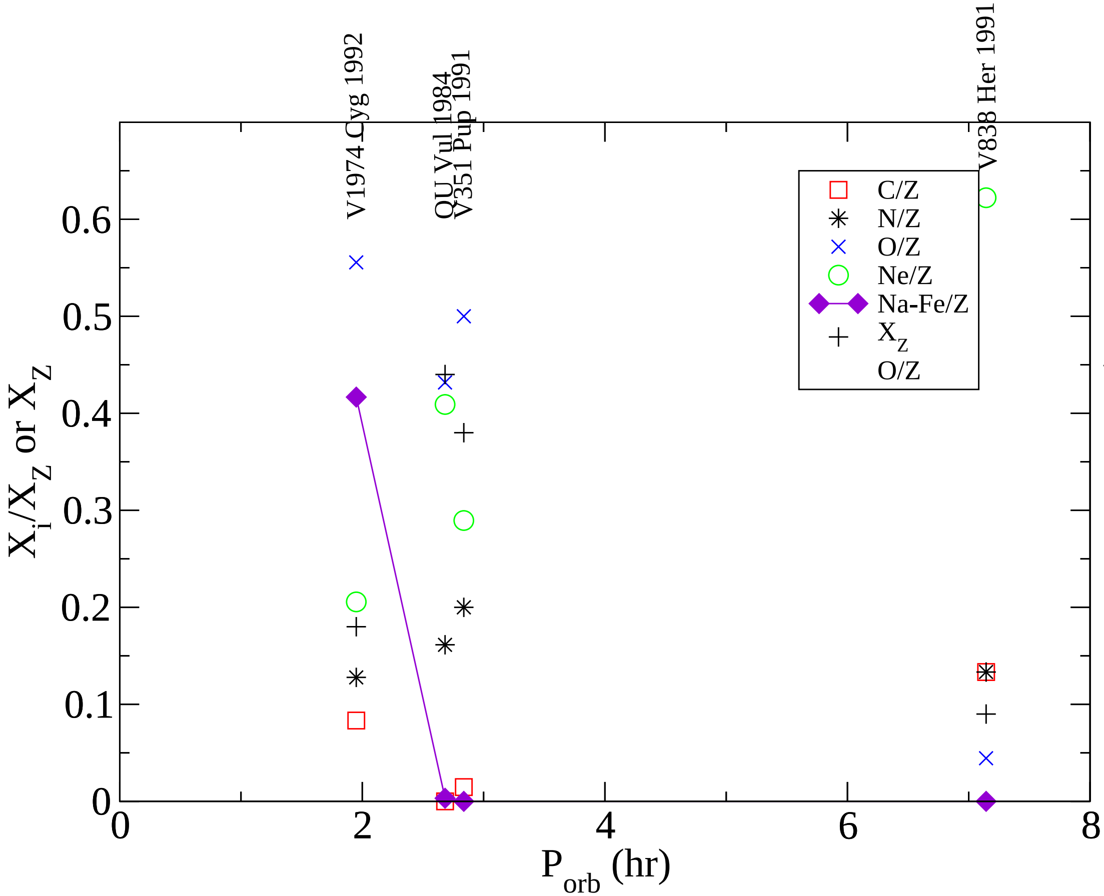
Classical Nova $\langle \dot{M} \rangle$ Distribution

$\Phi(\langle \dot{M} \rangle)$



- Most observed Novae have "high" $\langle \dot{M} \rangle \sim 10^{-9} M_\odot$ yr^{-1}
- Similar amount of matter is ejected from Novae with $\langle \dot{M} \rangle \sim 10^{-9} M_\odot$ yr^{-1} and $\sim 10^{-10} M_\odot$ yr^{-1}.
- Character of ignition very different for these two
  - direct Carbon or ^{3}He trigger
  - p-p heated deep envelope trigger
- Features of Novae which depend on $\langle \dot{M} \rangle$ are expected to have a bimodal character.
- The $P_{\rm orb}$ distribution below 6 hours shows initial indications of this.

Abundance variation with $P_{\rm orb}$



Shown: all Ne rich novae with known abundances and $P_{\rm orb}$ (not very many!)

More processing is expected for nova below period gap

low $\langle \dot{M} \rangle \implies$ base of accreted layer more degenerate at runaway. $\implies$ higher temperatures

Abundances: Gehrz, Truran, Williams, Starrfield 1998, PASP, 110, 3

$P_{\rm orb}$: Ritter & Kolb 2005 CV catalog

Need More data!

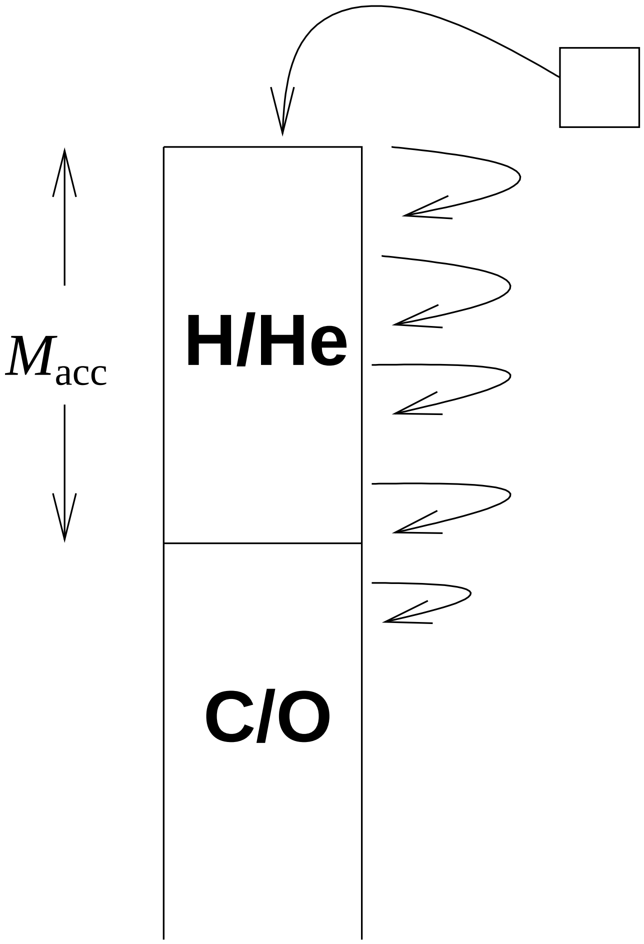
Only one other nova with well-measured abundances and $P_{\rm orb} < 2$ hours.

Abundances in nova ejecta

Due to difference in $\langle \dot{M} \rangle$ above and below gap, nova should demonstrate a bimodal character in properties including amount of nuclear processing.

- Difficult to observe due to rarity of events of the low $\langle \dot{M} \rangle$ variety.
- Most observed novae are of the high $\langle \dot{M} \rangle$ variety, while the two types may contribute nearly equally to nova ejecta in the ISM.
- Past dynamic nova calculations have typically used T_c higher than $T_{c,\rm eq}$, not fully exploring these low $\langle \dot{M} \rangle$, highly degenerate events.
- Measured $P_{\rm orb}$ systems provide a great opportunity for testing nova outburst calculations, we think we know $\langle \dot{M} \rangle$ and T_c.

Accreting WD Envelope



Envelope thermal time

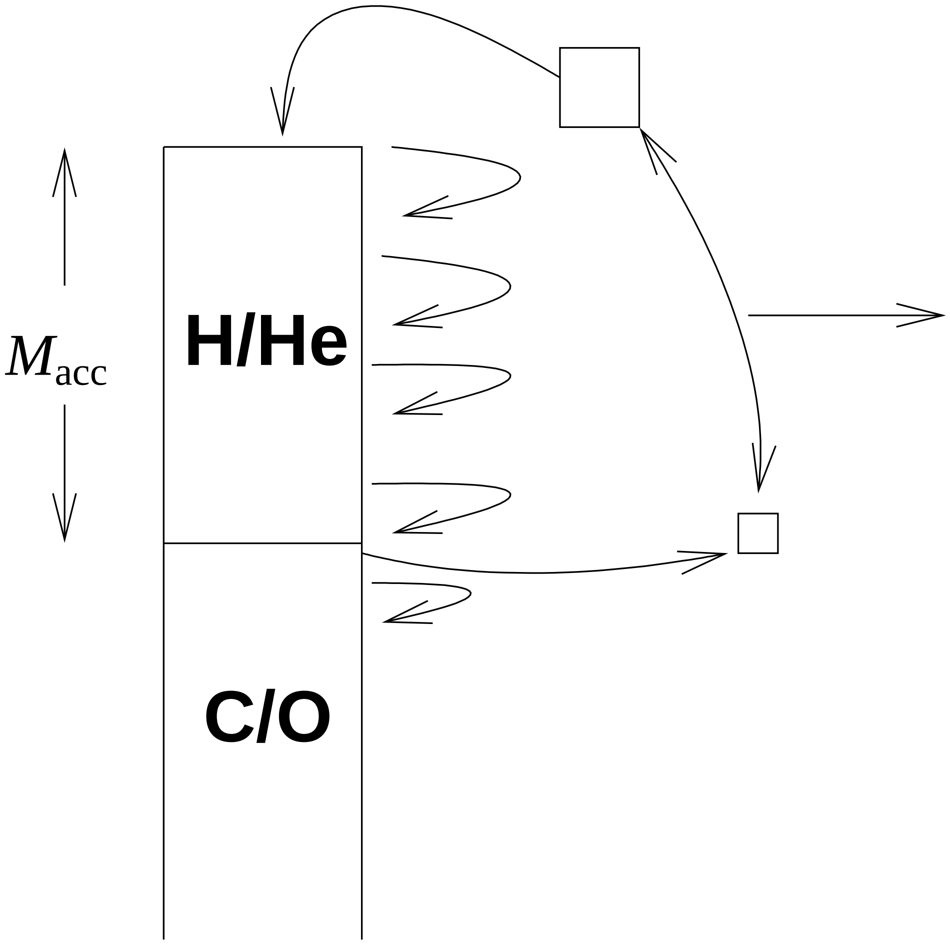
$$\sim 10^3 \text{ yr}$$

Infall energy deposited near surface and quickly radiated away

Interested in energy deposited deep in the envelope

Accreting WD Envelope

quasi-static envelope



$$L_{\rm env} \sim gh\langle\dot{M}\rangle$$
$$\sim \langle\dot{M}\rangle \frac{kT_c}{\mu m_p}$$

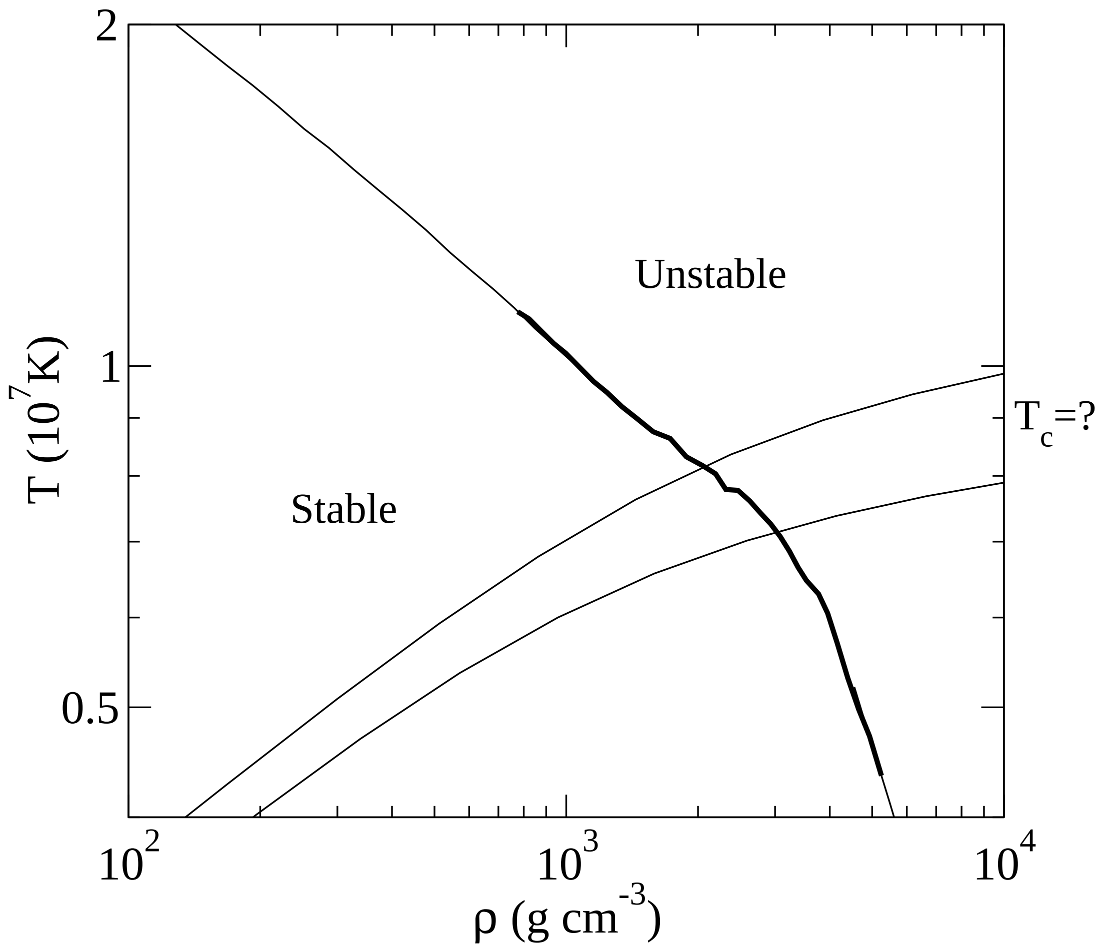
So actually:

$$\boxed{T_{\rm eff}(M, \langle\dot{M}\rangle, M_{\rm acc}, T_c)}$$

$$\boxed{M_{\rm ign}(M, \langle\dot{M}\rangle, T_c)}$$

T_c and Classical Nova Ignition

Conditions at base of H/He:



Evaluating envelope stability:

$$\frac{\partial \epsilon_N}{\partial T} = \frac{\partial \epsilon_{\rm cool}}{\partial T}$$

What thermal state (T_c) corresponds a given $\langle \dot{M} \rangle$?