# Physics of Novae Accumulation and Explosion

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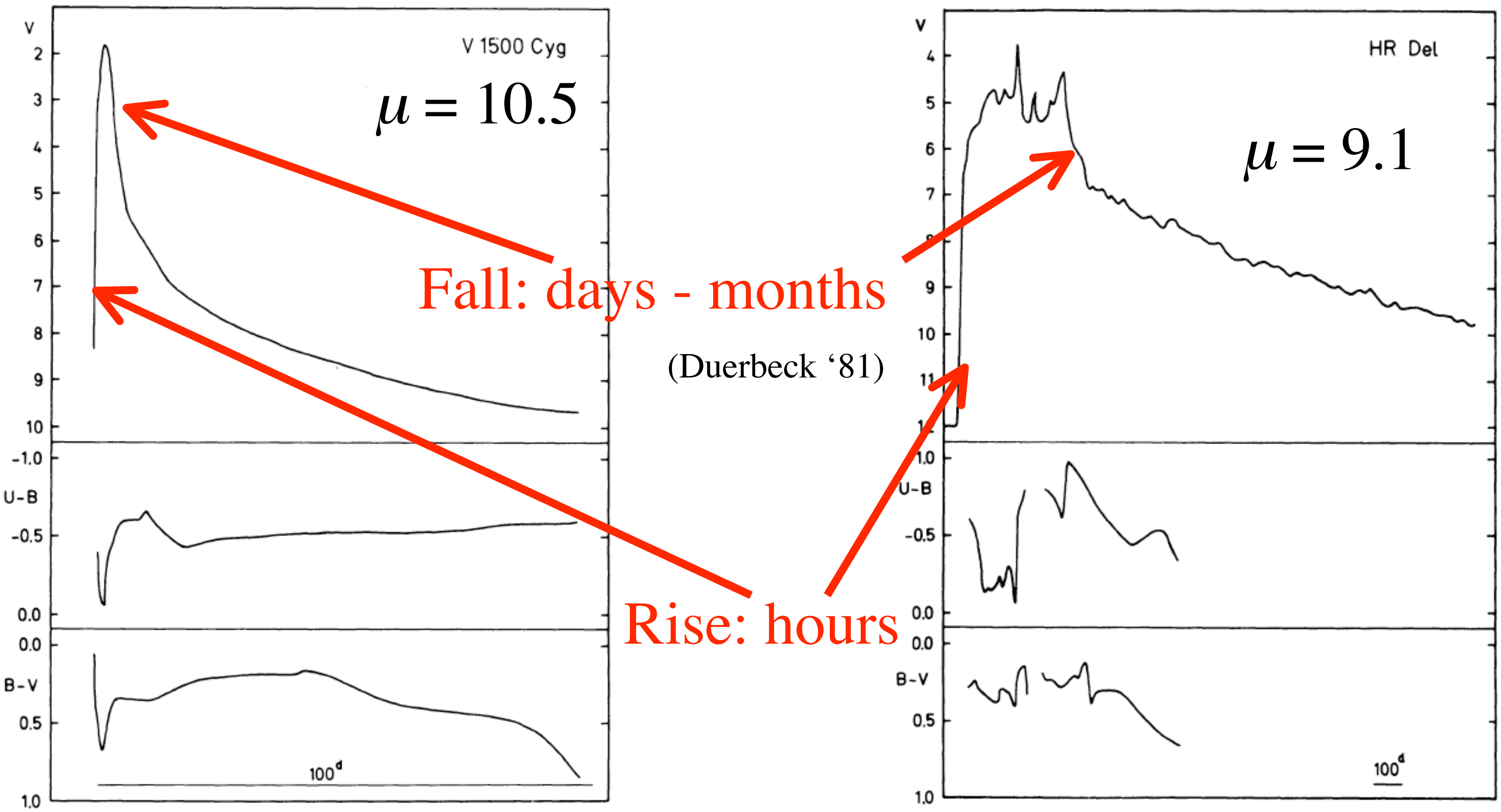
# Better off-line reviews

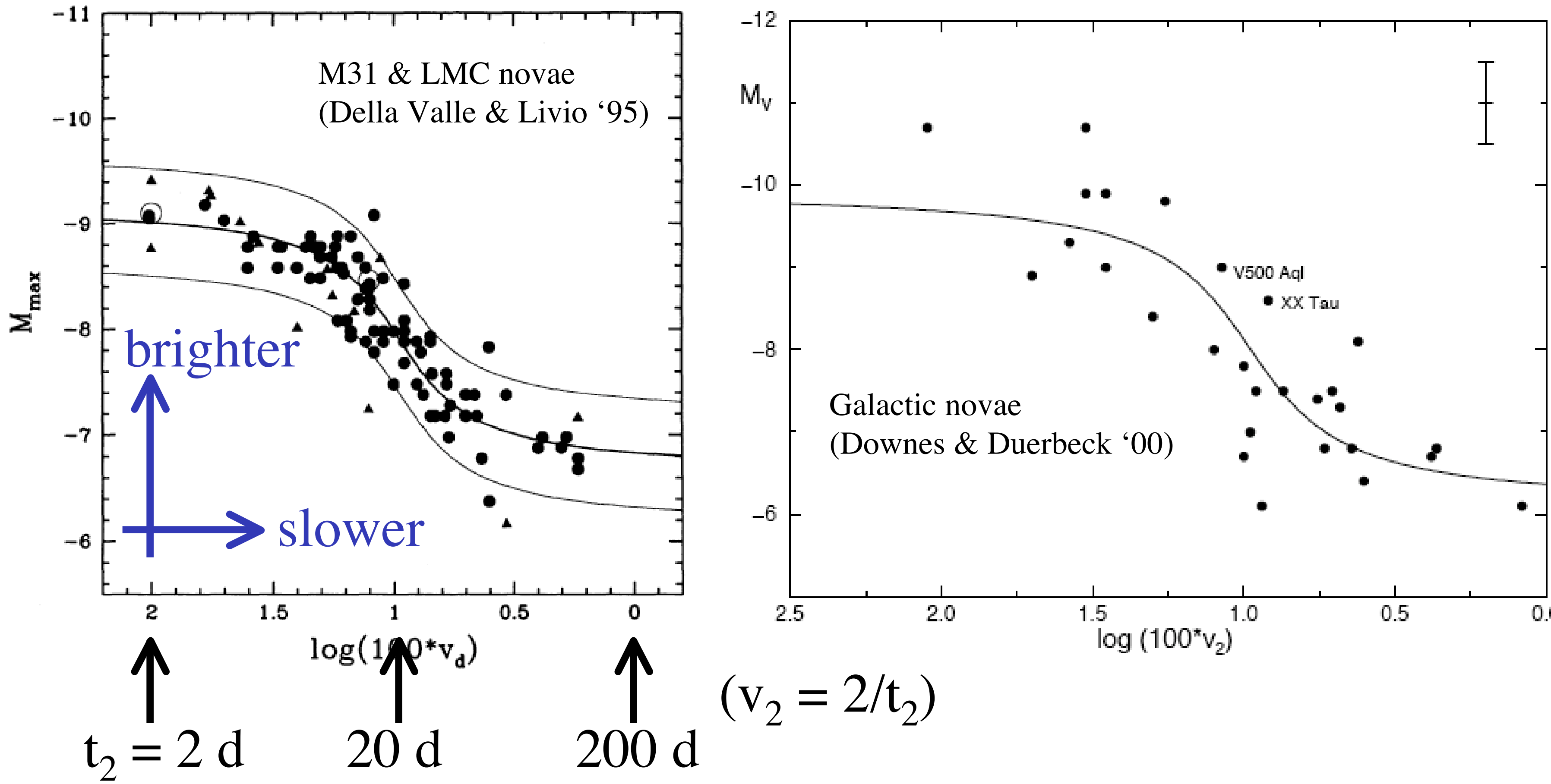
- Warner's CV book ('95)
- Bode & Evans nova book ('89); new version coming next year (Shafter's extragalactic nova review came from this)

# What's a nova look like?



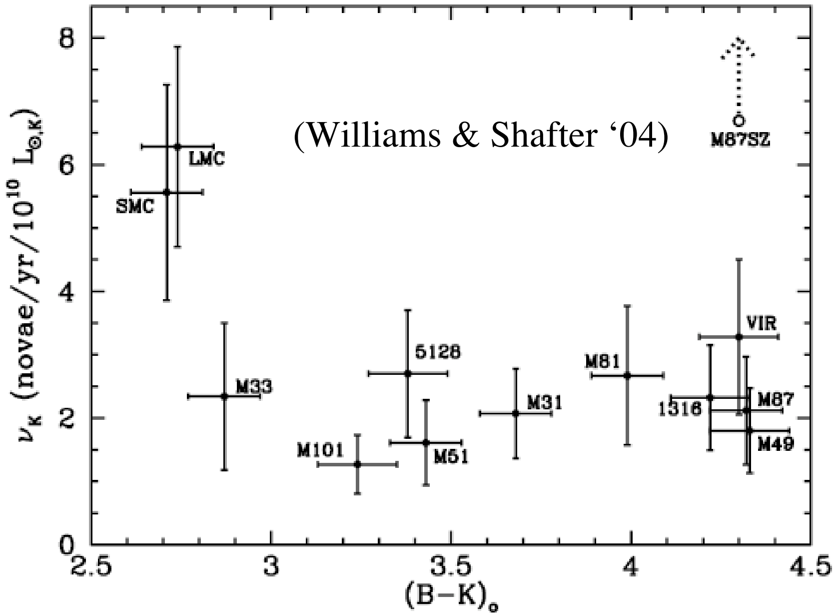

(Duerbeck '81)

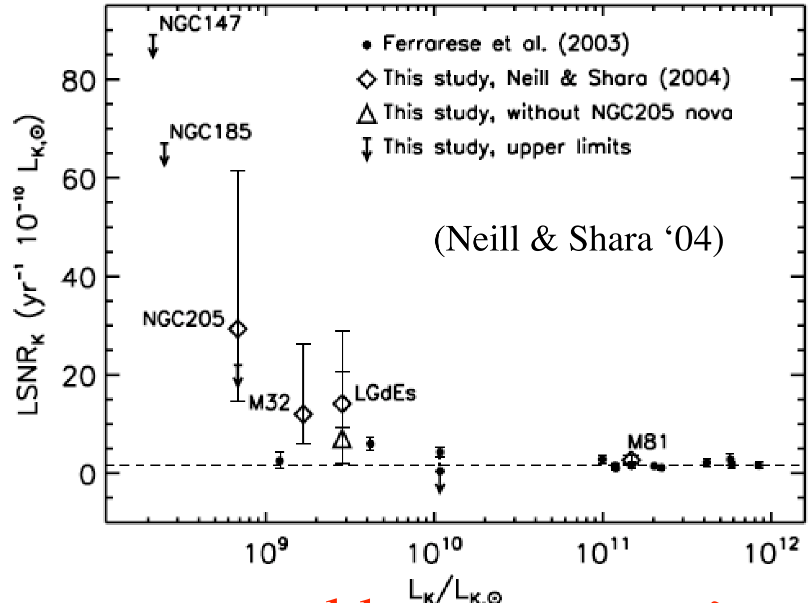
# Maximum [Visual] Magnitude - Rate of [Visual] Decline (MMRD)




- "Faster-brighter" and "slower-fainter" (opposite of Ia's)
- Not great for doing distance measurements

# Luminosity specific nova rate (LSNR)



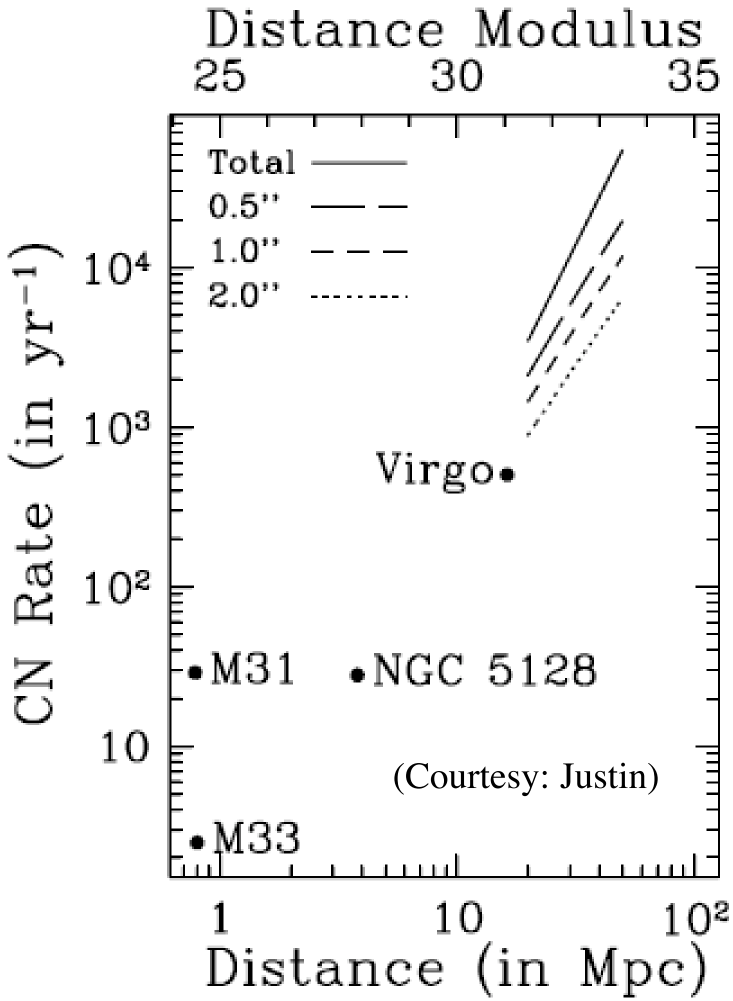




← more active

more old stars →

- Pop. synth. (Yungelson et al. '97; Matteucci et al. '03) predicts dependence on SFR
- Observed LSNR pretty consistent with being constant…
- …but maybe higher for irregulars / dwarf ellipticals
- Optical surveys will clean up here!

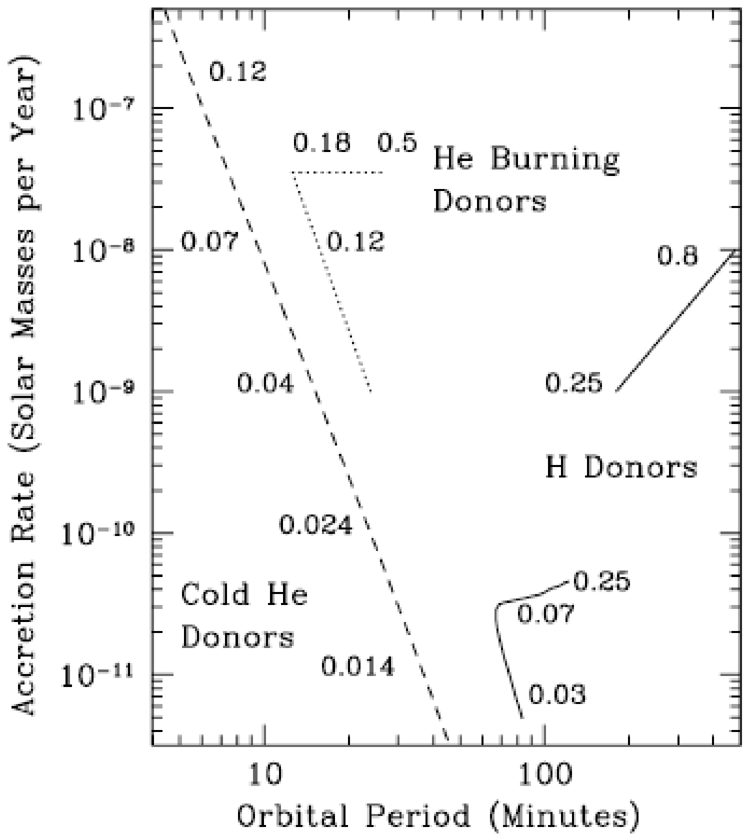
# How many classical novae will we see with new optical surveys? LOTS.

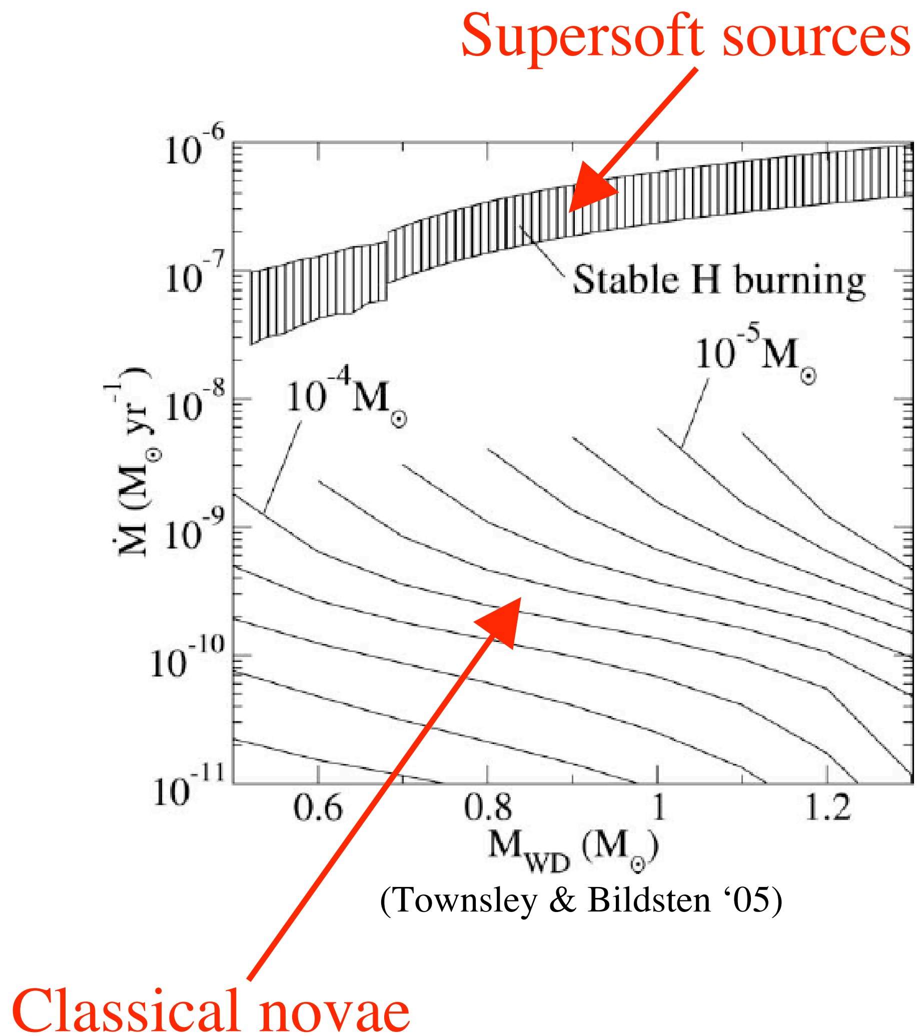



- Typical nova: $M_V \sim -8$
- V ~ 24 survey (Pan-Starrs / LSST) will see novae out to 25 Mpc (Virgo: 20 Mpc)
- ~ 2 novae per $10^{10}$ $L_{\odot,K}$ per yr
- ~ $5\times10^8$ $L_{\odot,K}$ per $Mpc^3$
- Depending on seeing / cadences / sky coverage, that's ~3000 novae per yr!

# Outcomes of H-accretion on WDs

1.0 $M_\odot$ WD




(Townsley & Bildsten '05)

# Accretion phase

- Thermal conditions set by compressing material:
  - accretion energy released in boundary layer (Piro & Bildsten '04) & nuclear burning negligible for now
  - calculation shows that $t_{\rm th} \sim t_{\rm acc}$ at the base of the layer, so profile set by conditions inside envelope
- Entropy equation yields

$$L_{\rm comp} = \dot{M} \int_{P_{\rm base}}^{0} T \frac{ds}{dP} dP = \frac{7}{4} \dot{M} \frac{k_B T_{\rm base}}{\mu m_p}$$

- Radiative diffusion gives trajectory of envelope base:

$$T_{\rm base} = 2 \times 10^7 \ {\rm K} \left( \frac{\dot{M}_{-8} \rho_3^2}{M_1} \right)^{2/11}$$

# Ignition conditions

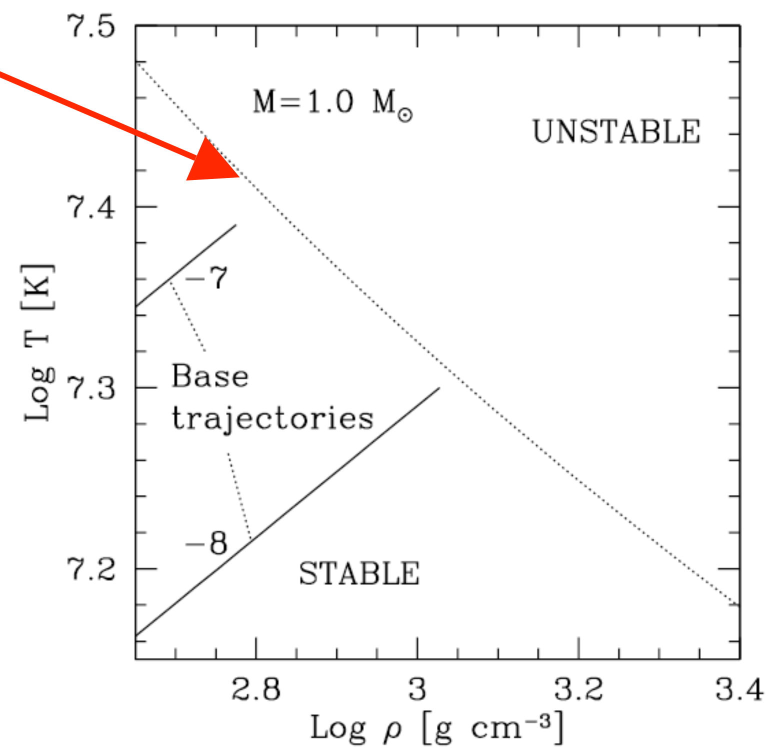
- Layer follows that trajectory until nuclear burning becomes non-negligible:

$$\left.\frac{\partial \epsilon_{\rm nuc}}{\partial T}\right|_P > \left.\frac{\partial \epsilon_{\rm cool}}{\partial T}\right|_P, \qquad \epsilon_{\rm cool} \sim \frac{L}{M_{\rm env}}$$

- First nuclear reaction to go is $p$+$^{12}$C (neglecting my current research)
- Rough scaling:

$$M_{\rm ign} \propto \dot{M}^{-1/2} M^{-1/2} R^3$$

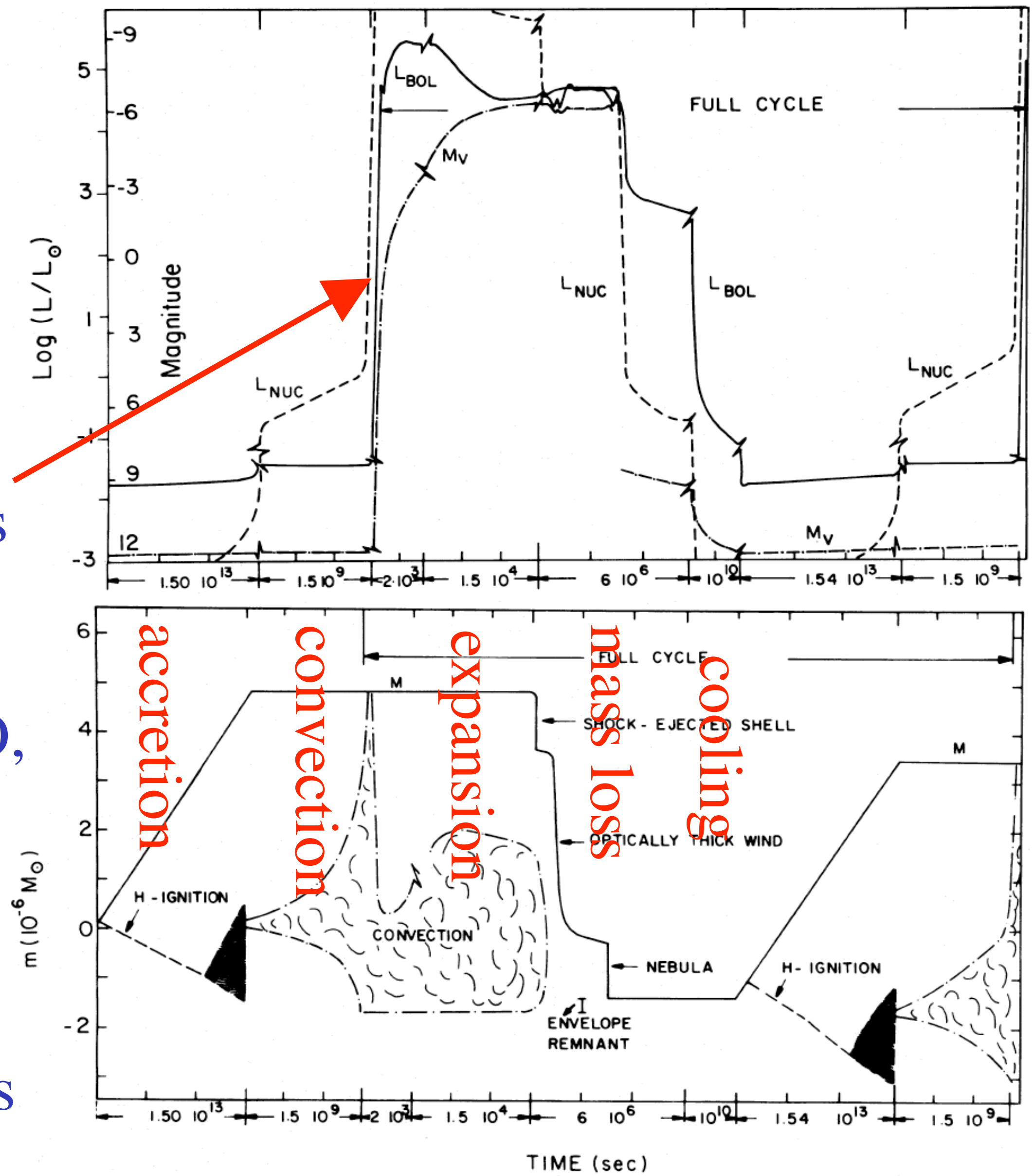
- Also depends on $T_{\rm core}$ (see Townsley & Bildsten ‘04 for self-consistent $T_{\rm core}$ calculations; Yaron et al. ‘05 for grid)



# Nova cycle

- Radiation can't transport heat away anymore, so convection sets in
- Convective phase lasts long time (10's of years), but $M_{ign}$ already set
- Once convective zone reaches surface, $L_{bol}$ jumps
- Super-Eddington due to convective transport of unstable $\beta$-nuclei ($^{13}$N, $^{14}$O, $^{15}$O, $^{17}$F; Starrfield et al. '72)
- Optical peaks during expansion (larger photosphere) and then falls during constant $L_{bol}$ phase

(Prialnik '86)



# Mass loss

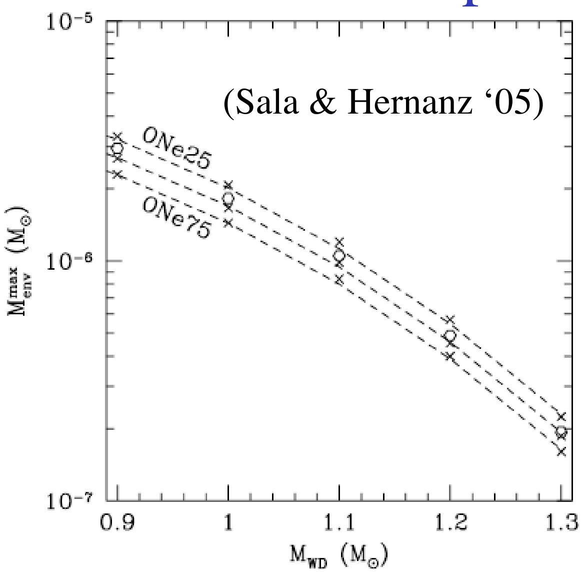
- Shock?
  - possibly in very energetic novae (Sparks '69), although MLT handling of convection isn't ideal
  - even if it exists, it doesn't play a huge role
- Optically thick wind (Kato & Hachisu '94):
  - radiation-driven wind from within photosphere
  - enabled by new OPAL opacities ('92); actually predicted by Kato & Iben ('92)
- Common envelope (e.g., MacDonald '80):
  - in CV, binary separation is roughly

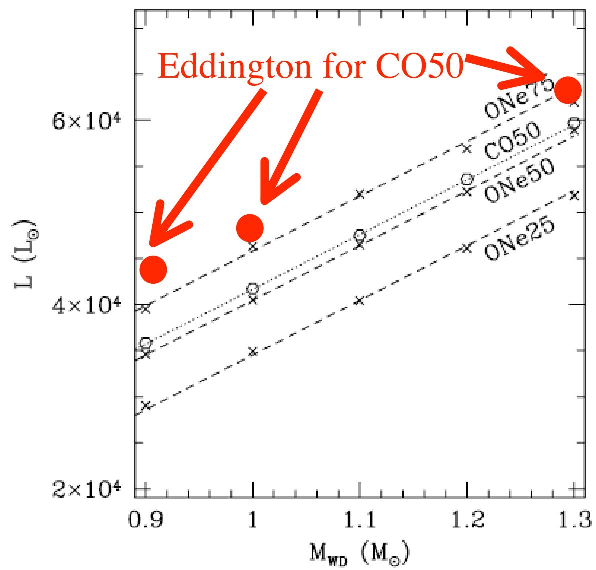
$$a \sim 10^{11}\ \mathrm{cm} \left(\frac{P_{\mathrm{orb}}}{5\ \mathrm{h}}\right)^{2/3} \left(\frac{M}{M_{\odot}}\right)^{1/3}$$

  - interesting that novae might be only practical way to observe CE's in real-time ("hey, look at me!")

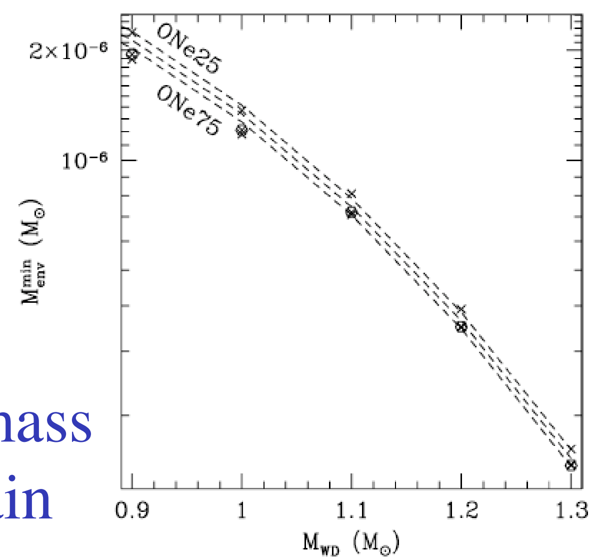
# Constant bolometric luminosity phase

- Just like max Mdot for stable burning (Fujimoto ‘82) and RG $M_{core}$-L relationship (Paczynski ‘71), there is a max $M_{env}$ and L for given $M_{WD}$
  - can think of this as an Eddington argument, but for the whole envelope (actually, it’s hydrostatic equilibrium)
  - also depends on envelope composition



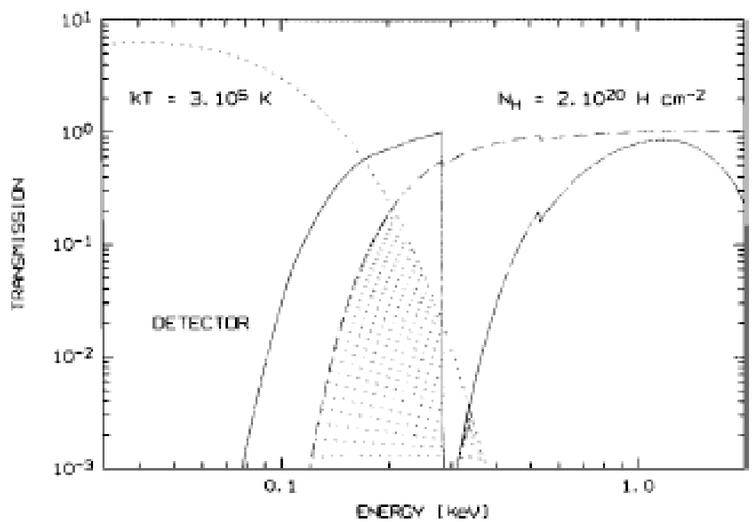



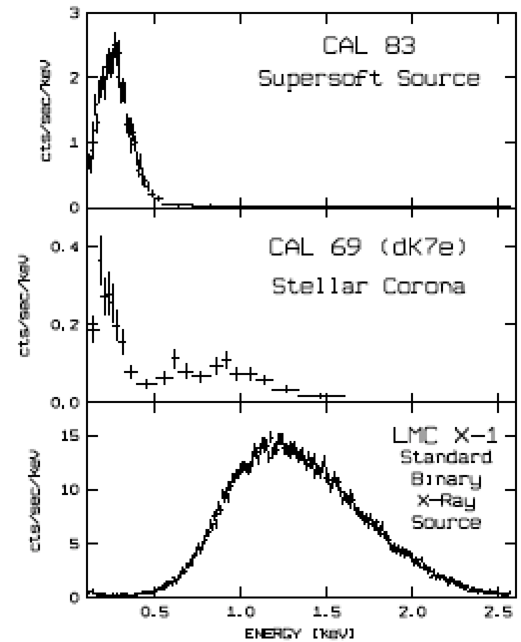

- Also a min $M_{env}$; once fuel consumption and mass loss get here, burning stops, and cycle starts again



# Constant bolometric luminosity phase

- Given $M_{env}$ and $L$, can calculate length of phase: months to years (and not decades, as might be expected if $M_{ign}$ used)
- What does this look like? Photosphere recedes back, so spectrum becomes harder, optical falls
  - $L \sim 10^4 L_\odot$, $R \sim 10^9$ cm: 10's of eV's
  - shows up in EUV / soft X-rays

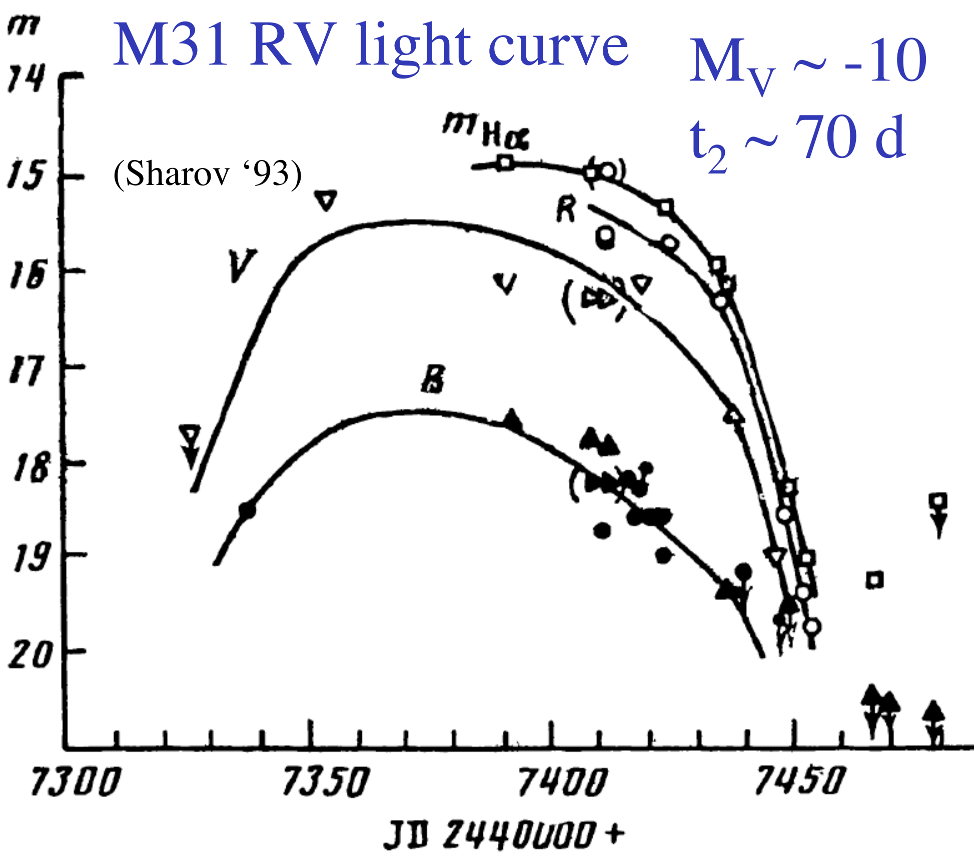


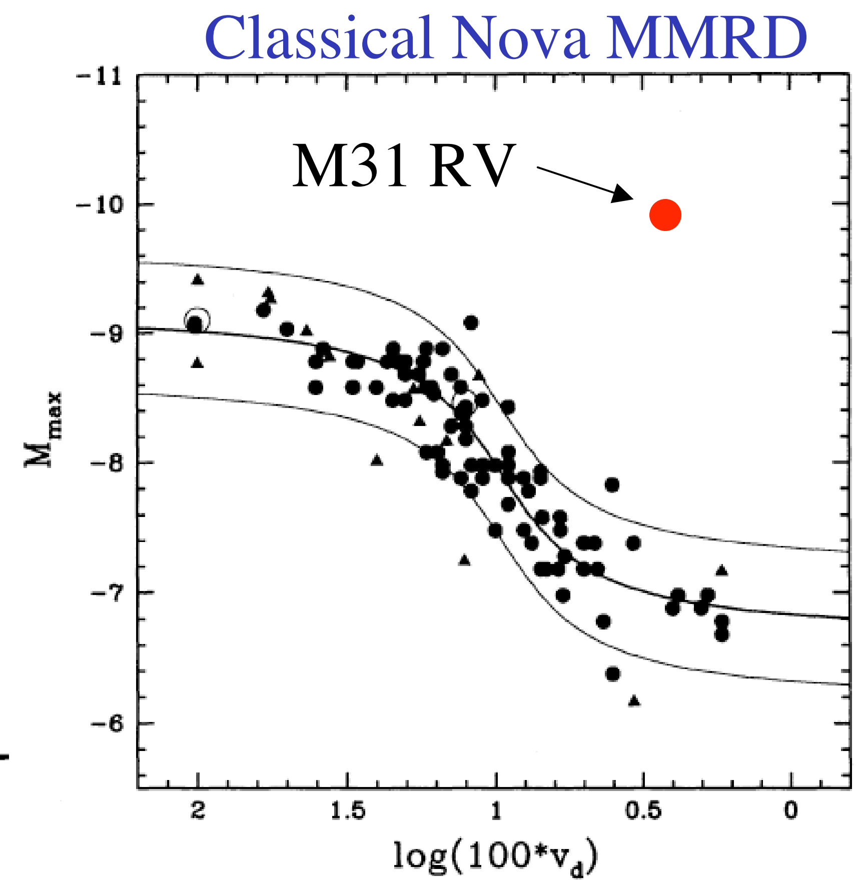




(Kahabka & van den Heuvel '97)

- Current M31 campaign (Pietsch et al. '05, '07) finding plenty of supersoft sources where optical novae occurred: bingo!

# M31 Red Variable ('88; Rich et al. '89) and V838 Mon ('02; Munari et al. '02)




- M31 RV much slower for its high *L*…big H shell? (Iben & Tutukov '92); V838 Mon had 3 separate peaks
- Tylenda & Soker ('06) argue against nova (no way for nova to stay cool) and argue for stellar mergers