Understanding Mass Transfer in Extremely Low Mass WD Binaries

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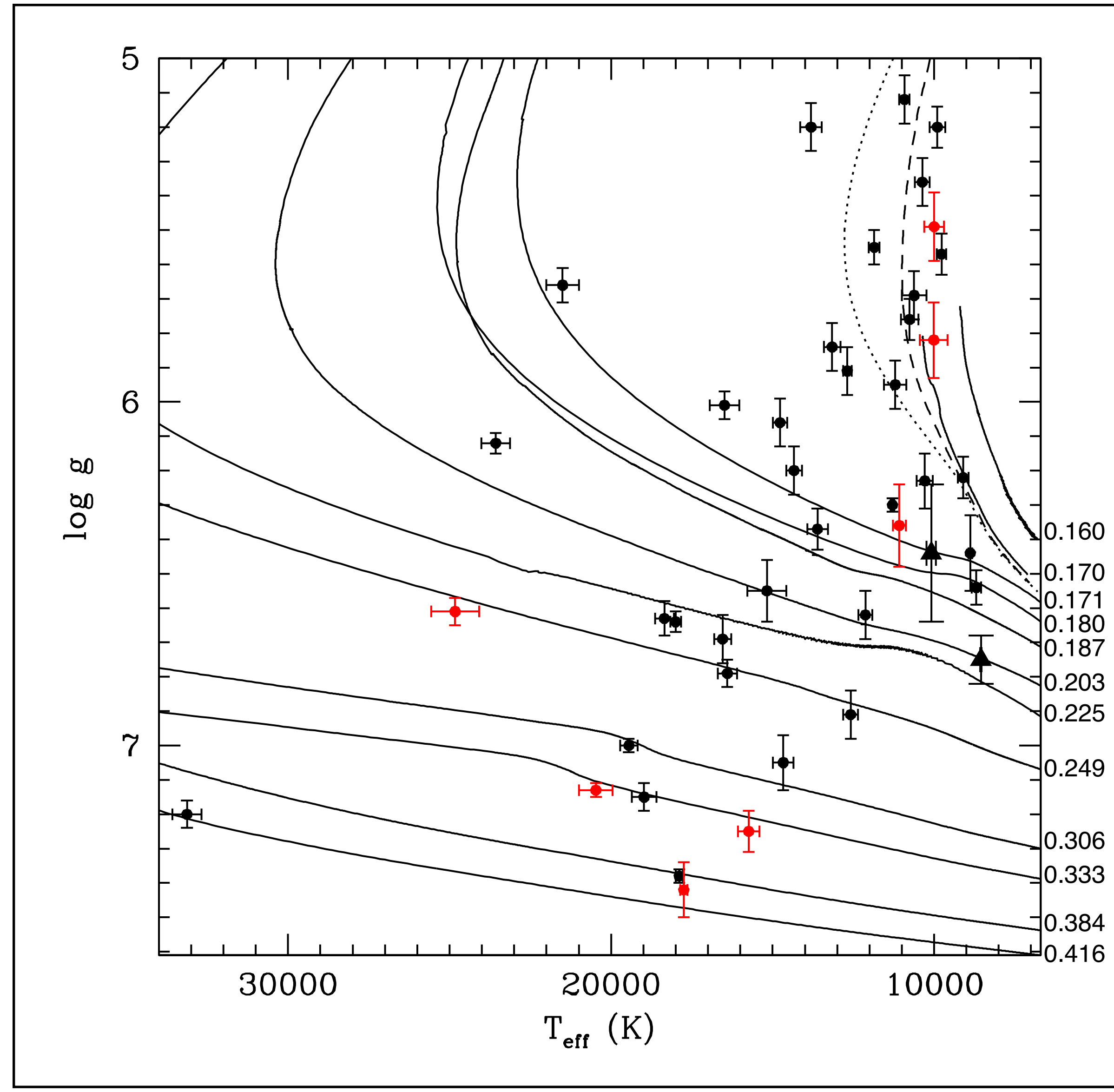
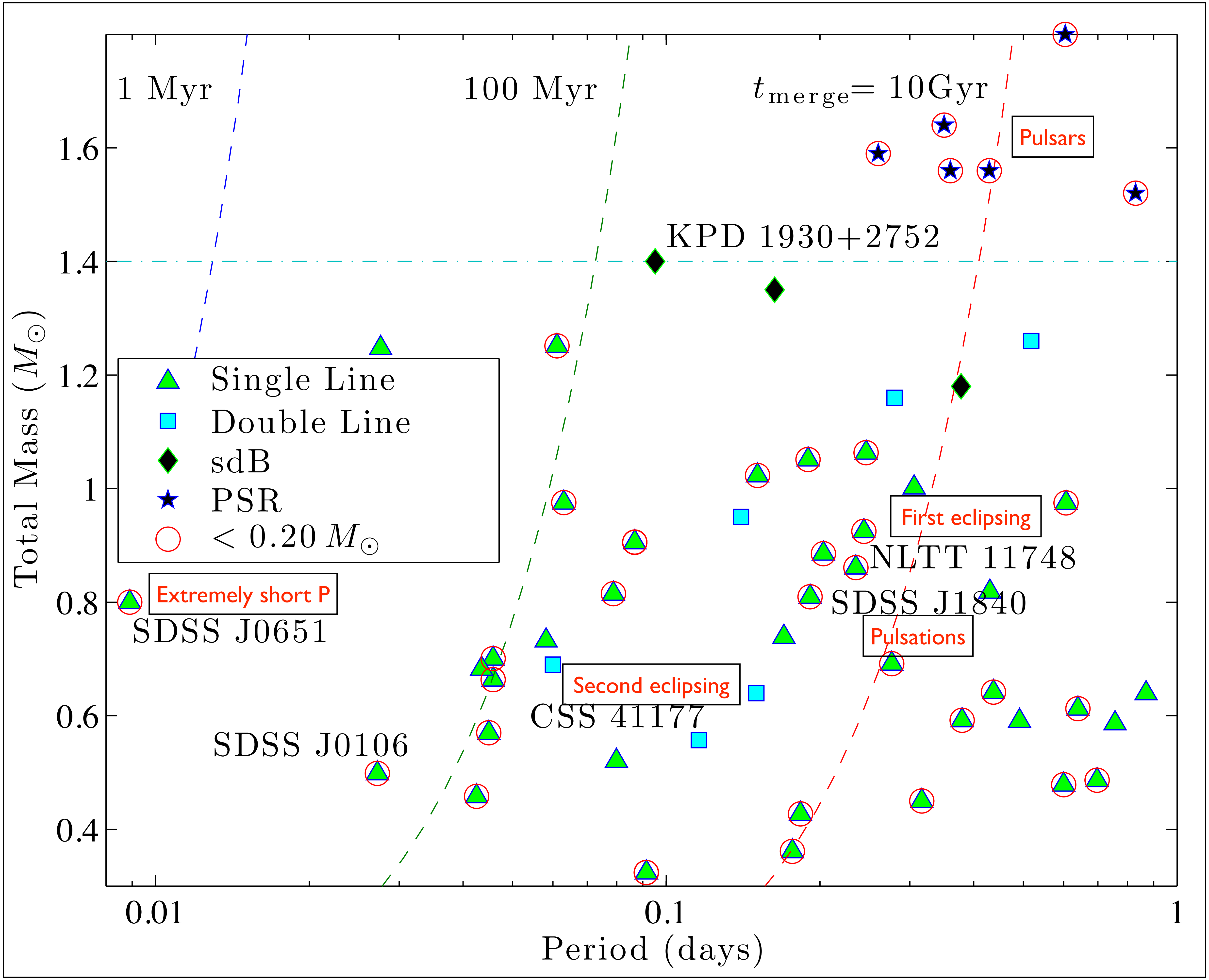
How To Form AM CVn

- Or, what happens to double WDs with Extremely Low Mass (ELM; <0.2 $M_\odot$) He WDs
    - SDSS finding **many** of these (Kilic, Brown, ...)
    - Stay bright (large & hot) for Gyr due to stably burning H shell (Panei et al. 2007)
        - 10^{-3} to 10^{-2} $M_\odot$ of H
    - Many found in tight orbits with other WDs (or pulsars), will reach contact in < 10 Gyr (Badenes, Brown, Kawka, Kilic, Mullally, Steinfadt, Vennes, ...)



Known ELM WDs from Kilic et al. (2012)



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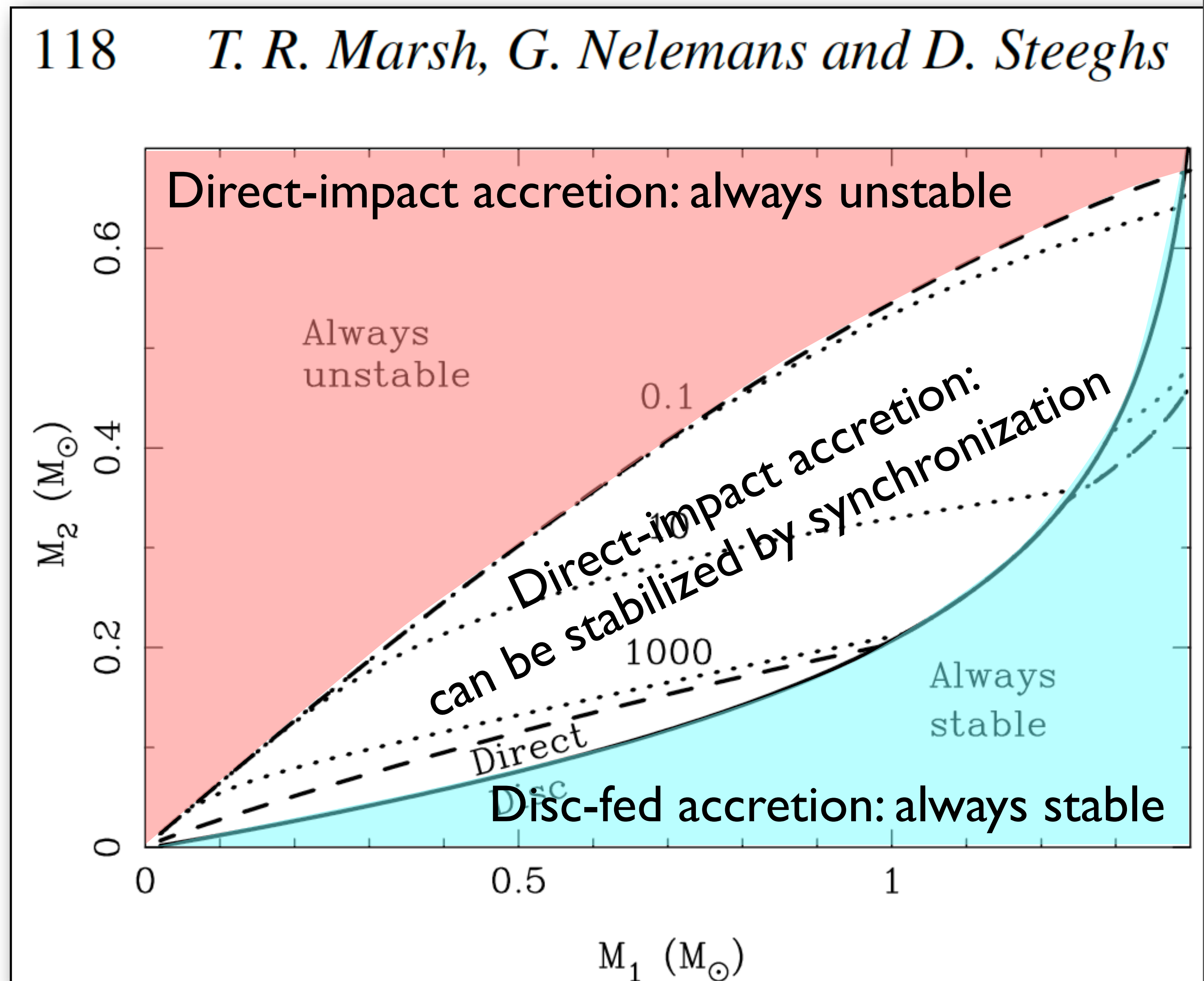
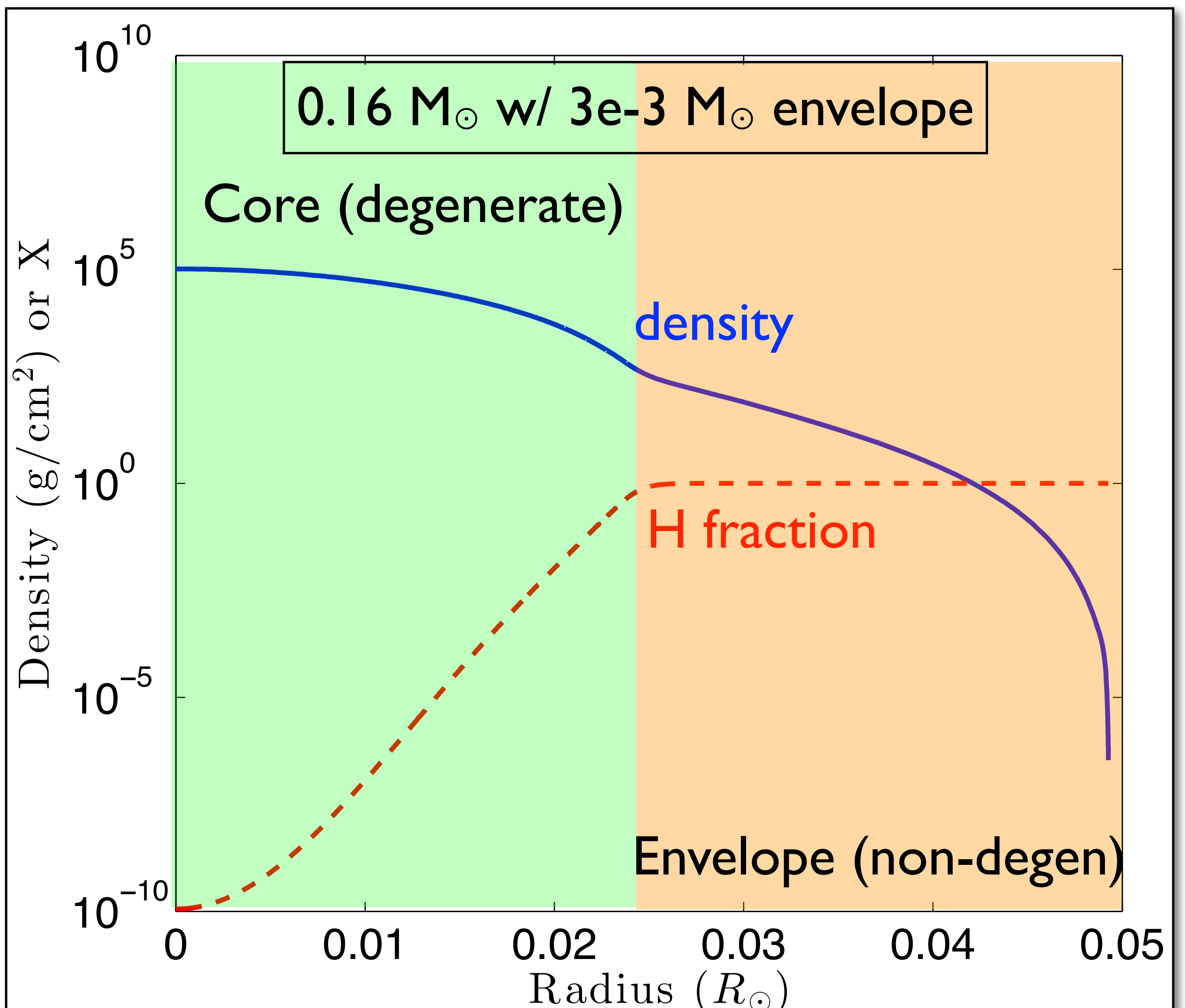
What Happens at Contact?

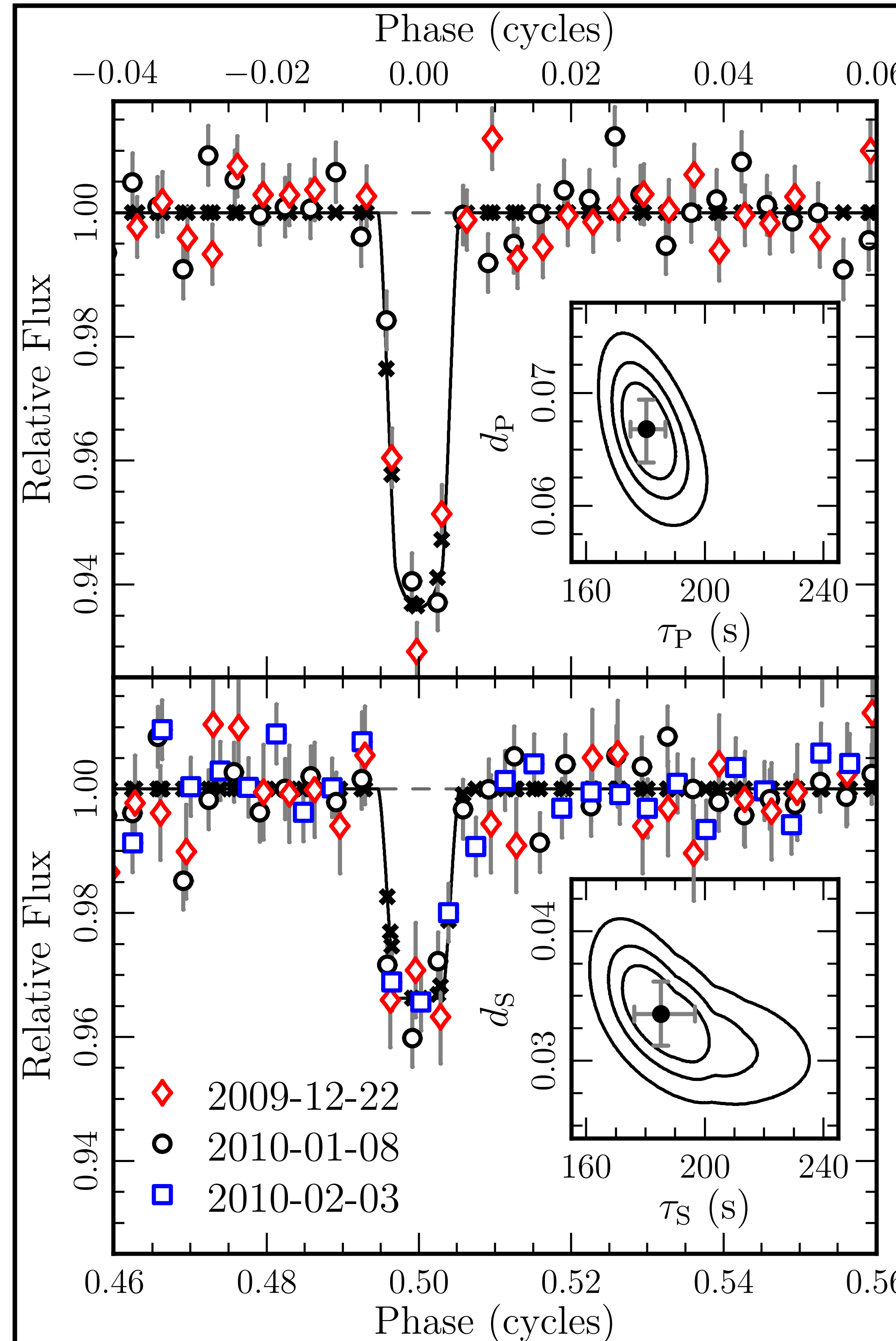
- Marsh et al ('04):
  - Detailed mass transfer, including stability
  - But: used cold EOS for both accretor (CO WD) and donor (He WD)
    - OK for accretor
    - But what about for donor?



<0.2 $M_\odot$ He WDs are Large

- Steinfadt et al.: eclipse observations of NLTT 11748 show R≈0.04 $R_\odot$ for M≈0.16 $M_\odot$
  - Cold EOS: 0.02 $R_\odot$ (e.g., Eggleton)
  - Outer portions are not degenerate



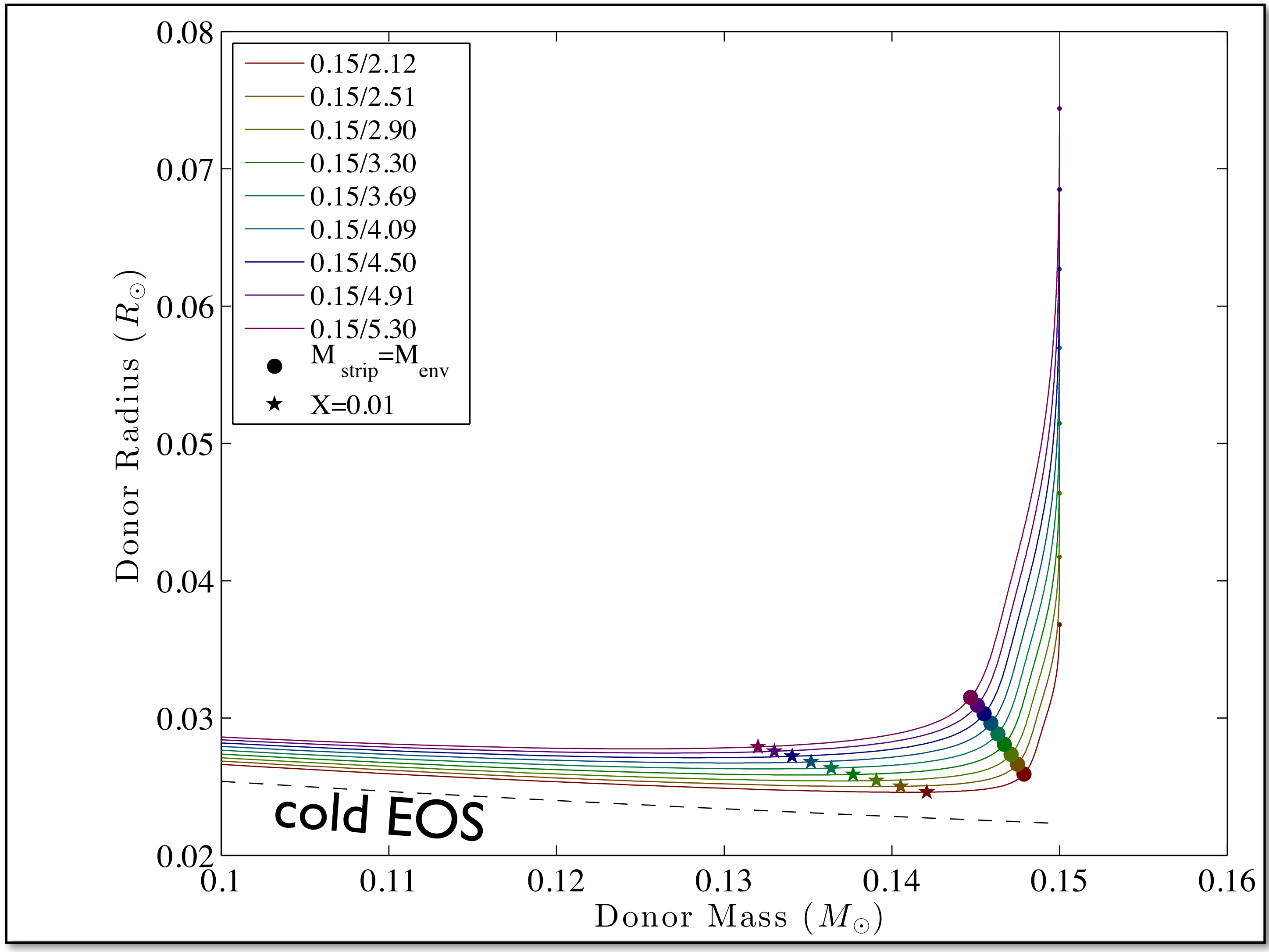


Also see Driebe et al. ('98); Sarna et al. ('00); Serenelli et al. ('01); Bassa et al. ('03 & '06); van Kerkwijk et al. ('05), ...

Our Calculation

- Orbital evolution of ELM He WD + CO WD (0.7-1.0 $M_\odot$)
- He WD follows models of Steinfadt et al. (2010): used to determine (dR/dM, X) as mass is stripped
- Follow mass transfer & orbital evolution
  - Consider disk/direct impact
  - Stability of accreted matter to burning
  - Do not deal with synchronizations torques
  - Range of envelope masses (i.e., ages) for each core mass

0.15 $M_\odot$ core, with (2-5)x10^{-3} $M_\odot$ envelope

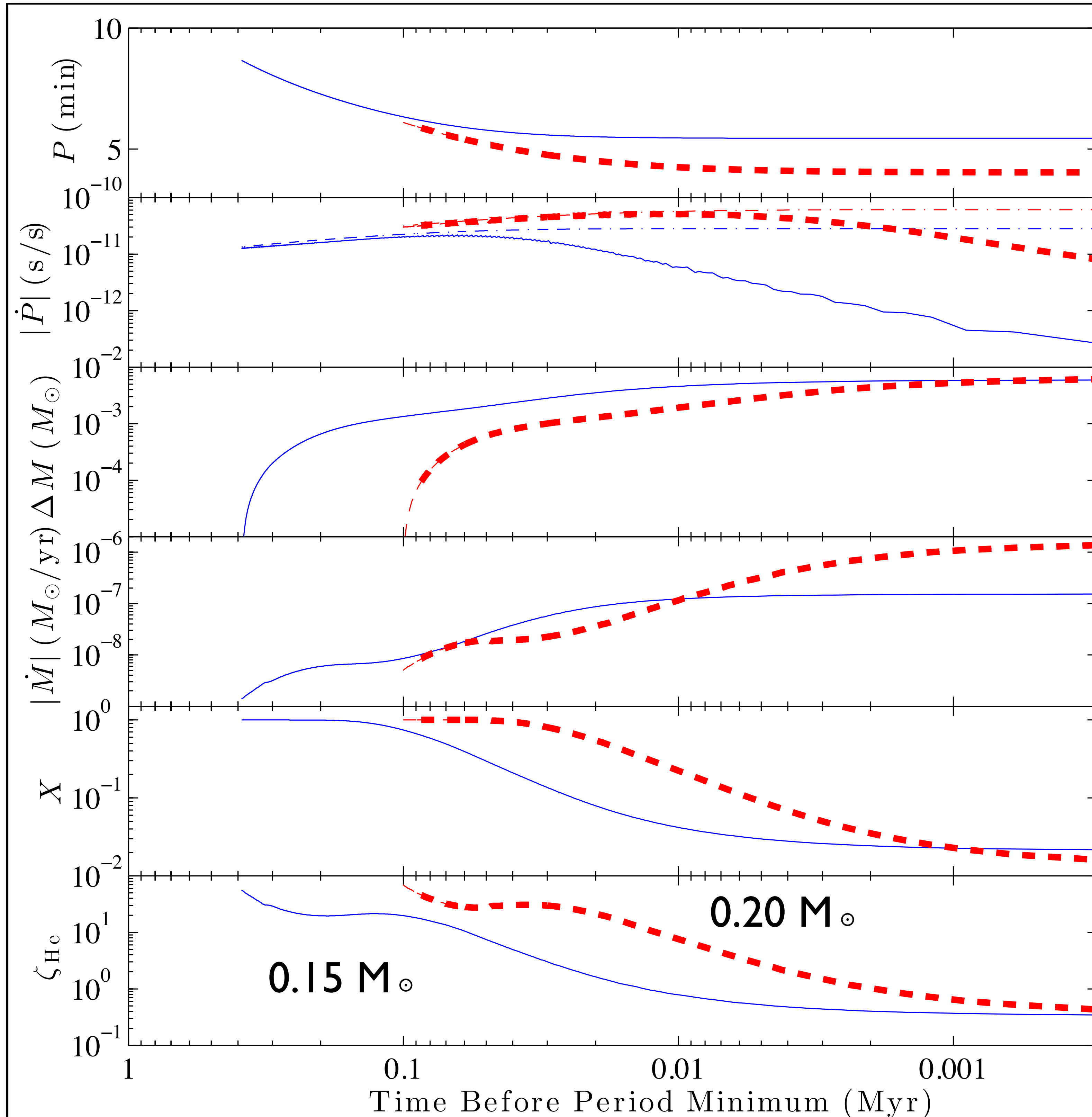


Kaplan et al. (2012)

Response to Mass Loss

- Normal WD: $R \sim M^{-1/3}$
- Mass transfer stable if $\frac{M_{\rm donor}}{M_{\rm accrete}} < \frac{5}{6} + \frac{\zeta}{2}$
- $\zeta \equiv \frac{d \log R}{d \log M}$ is -⅓ for a normal WD, so need mass ratio < ⅔
- ELM He WD:
  - Outer layers not degenerate, $\zeta \gg 1$
  - Disk accretion guaranteed stable; even without disk, more stable systems (reduce $\dot{M}$, as in D'Antona et al. or Deloye & Roelofs)

- Early evolution: prolonged period of hydrogen accretion
- $\dot{P}$ just set by GR
- Once on accretor, is H burning stable? pp only!



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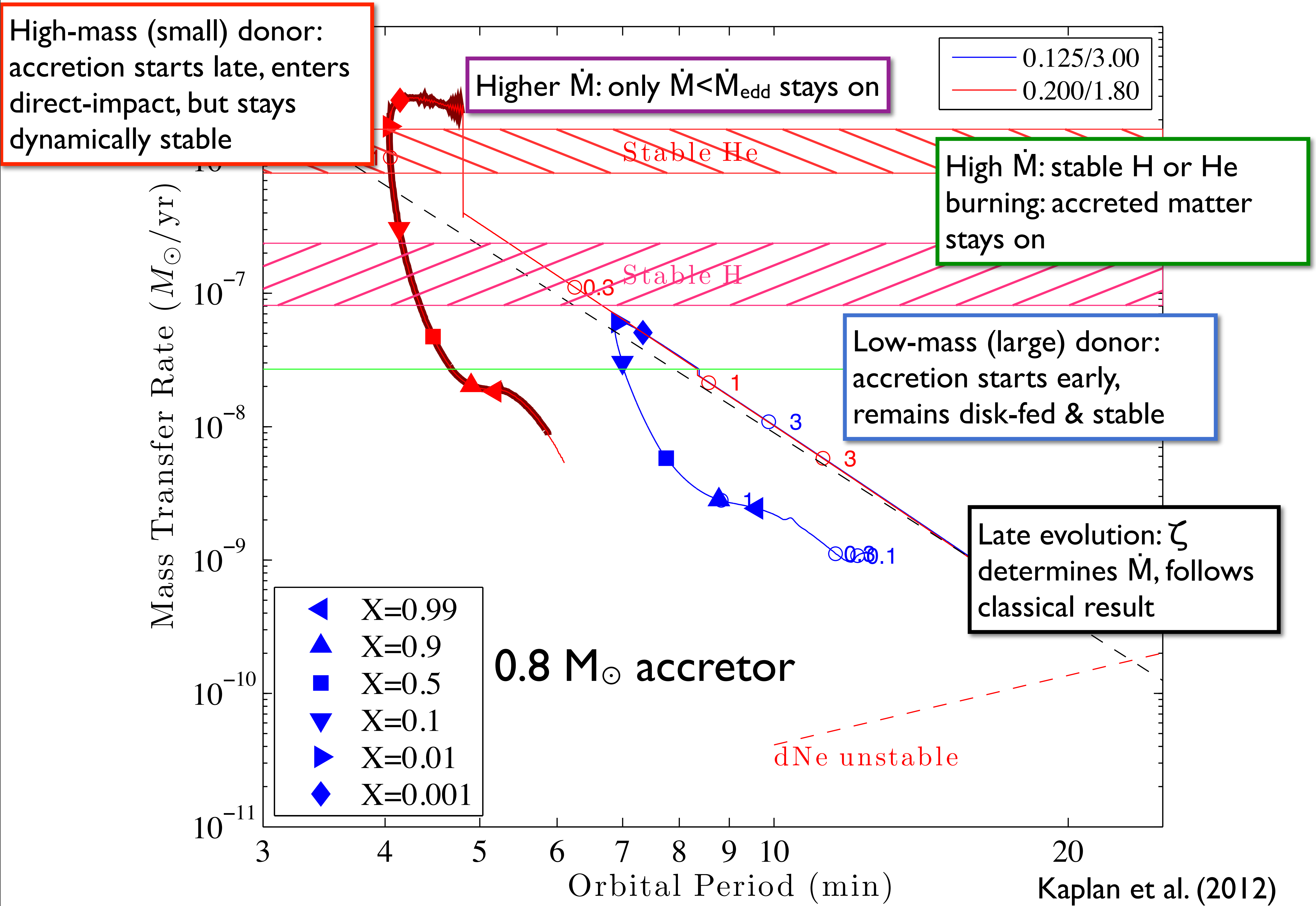
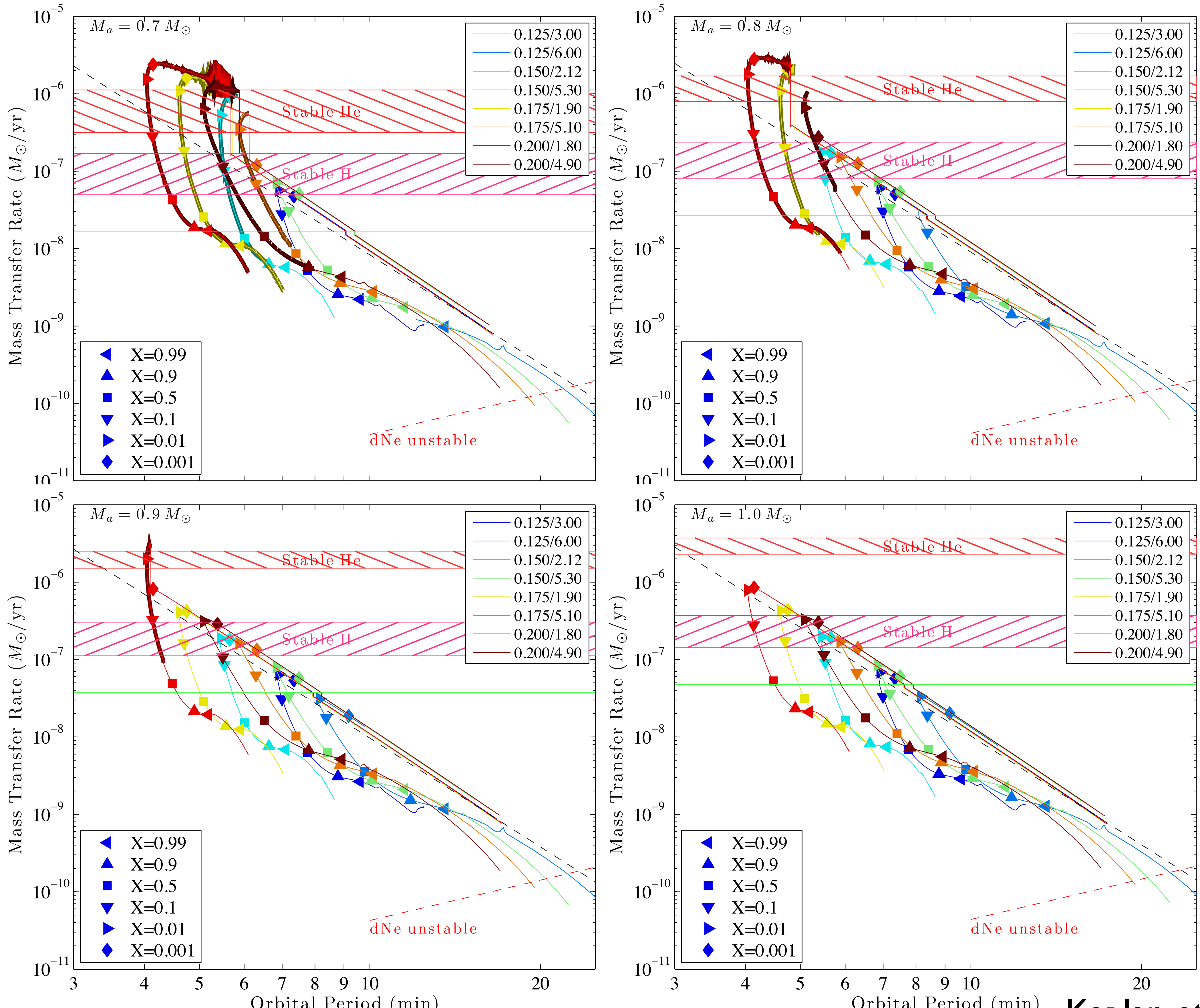


Kaplan et al. (2012)

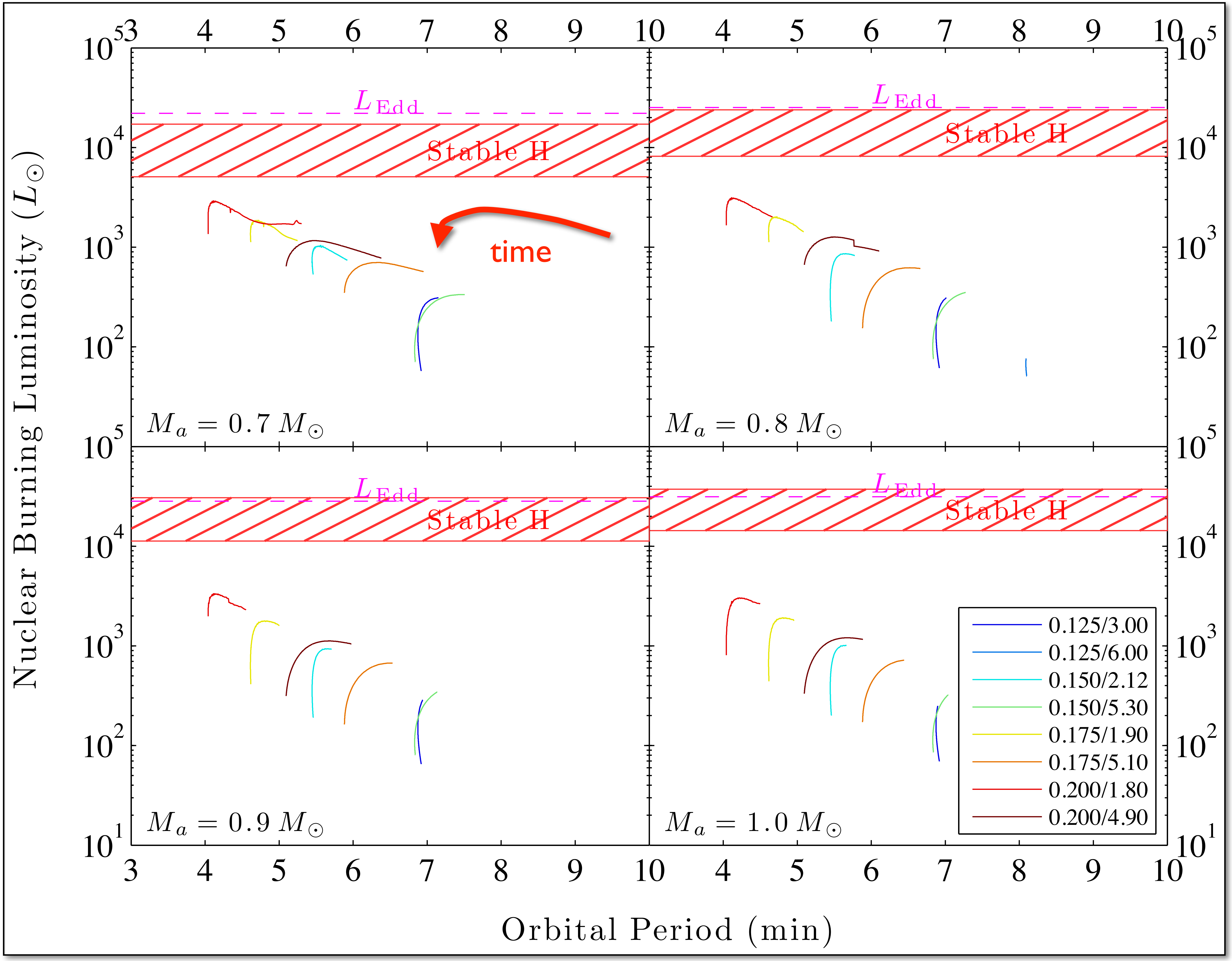
Stable burning calculations still preliminary (based on Nomoto et al. 2007 & Iben & Tutukov 1989)

Vary accretor mass:



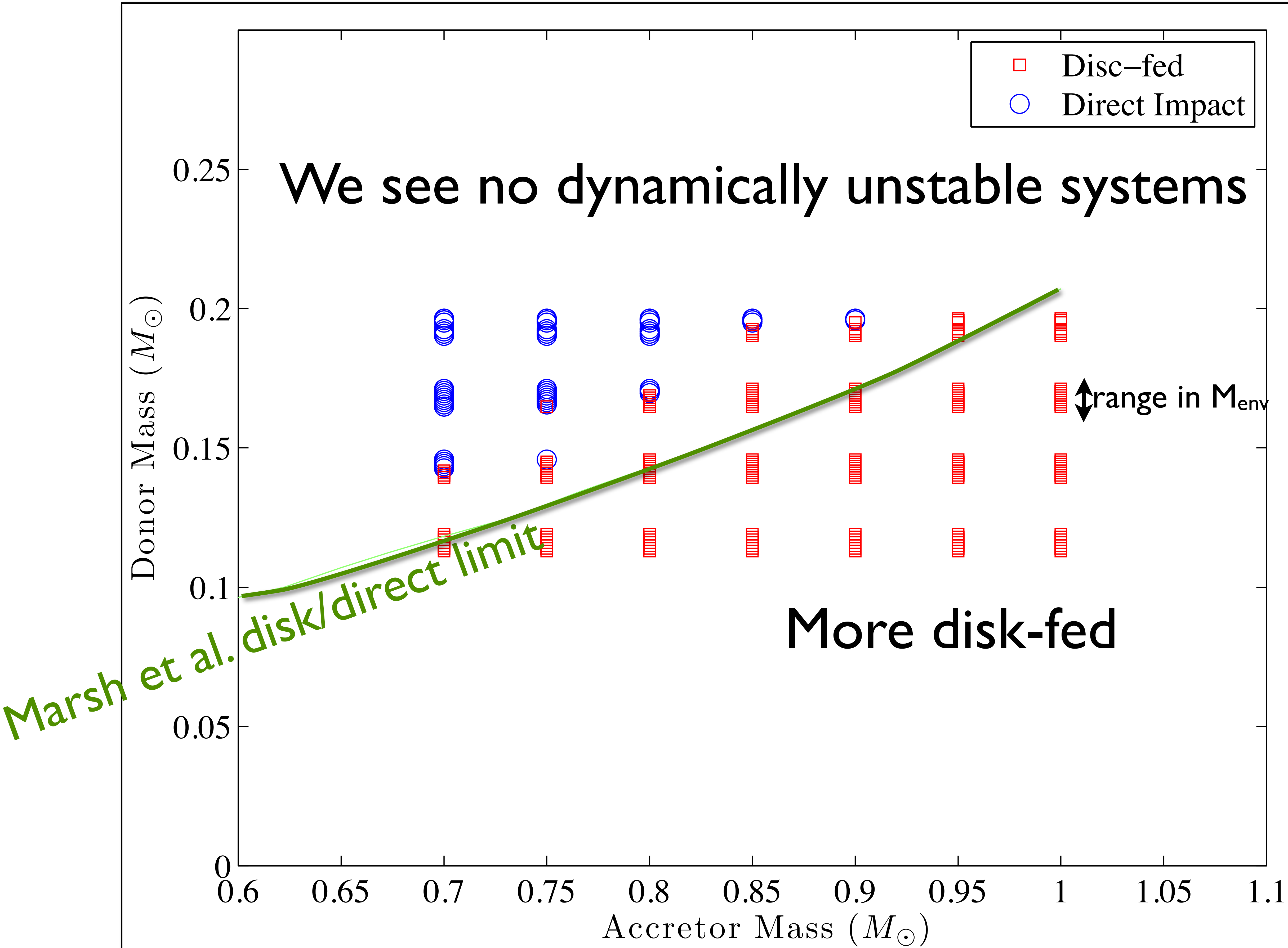
Kaplan et al. (2012)

Changing H fraction reduces luminosity



Kaplan et al. (2012)

Stability: many more systems avoid merger



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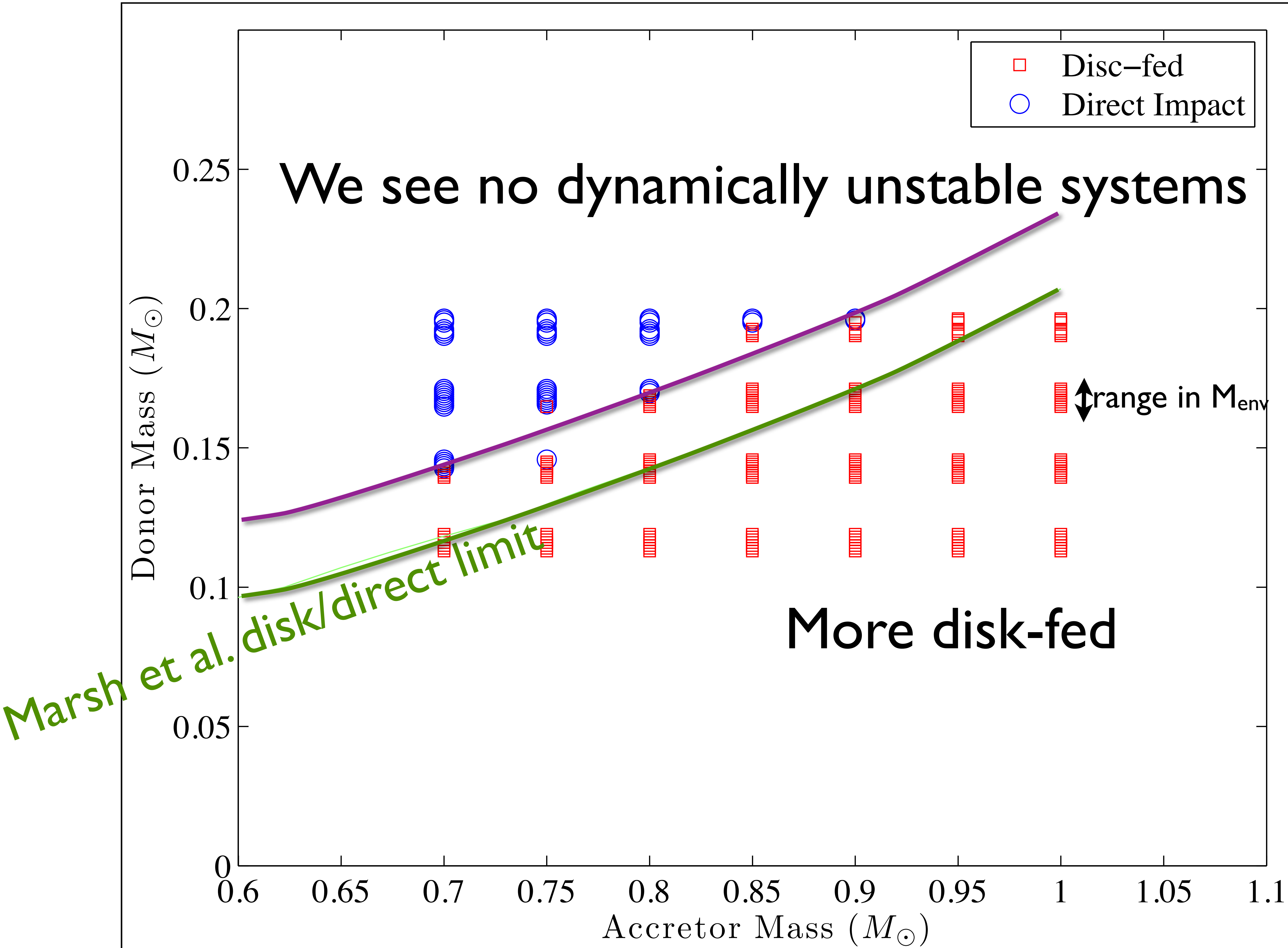
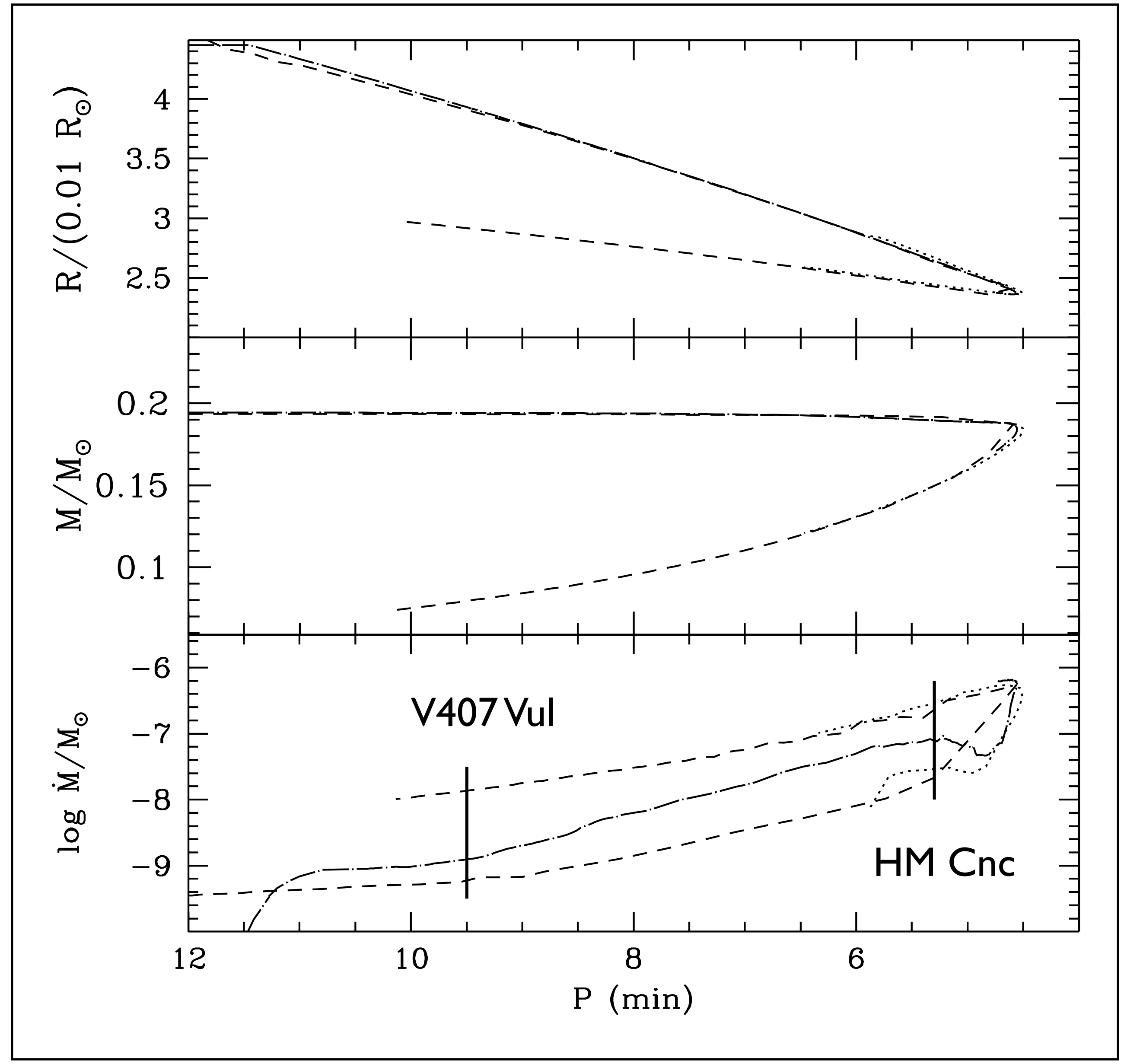


Kaplan et al. (2012)

Direct-Impact of H-Rich Material

- HM Cancri (5.4 min binary): 0.27 $M_\odot$ & 0.55 $M_\odot$ (Roelofs et al.; Israel et al., Cropper et al.; Strohmayer et al.)
- $\dot{P}$<0 but L_x ($\dot{M}$) puzzlingly low
- D'Antona et al. (2006): mass transfer will start from non-degenerate H envelope
  - Changes orbital evolution, since dR/dM<0
  - Largely can explain orbital evolution, luminosity of HM Cnc
- All metals sedimented out of H layer, somewhat out of He (Hebert et al.)



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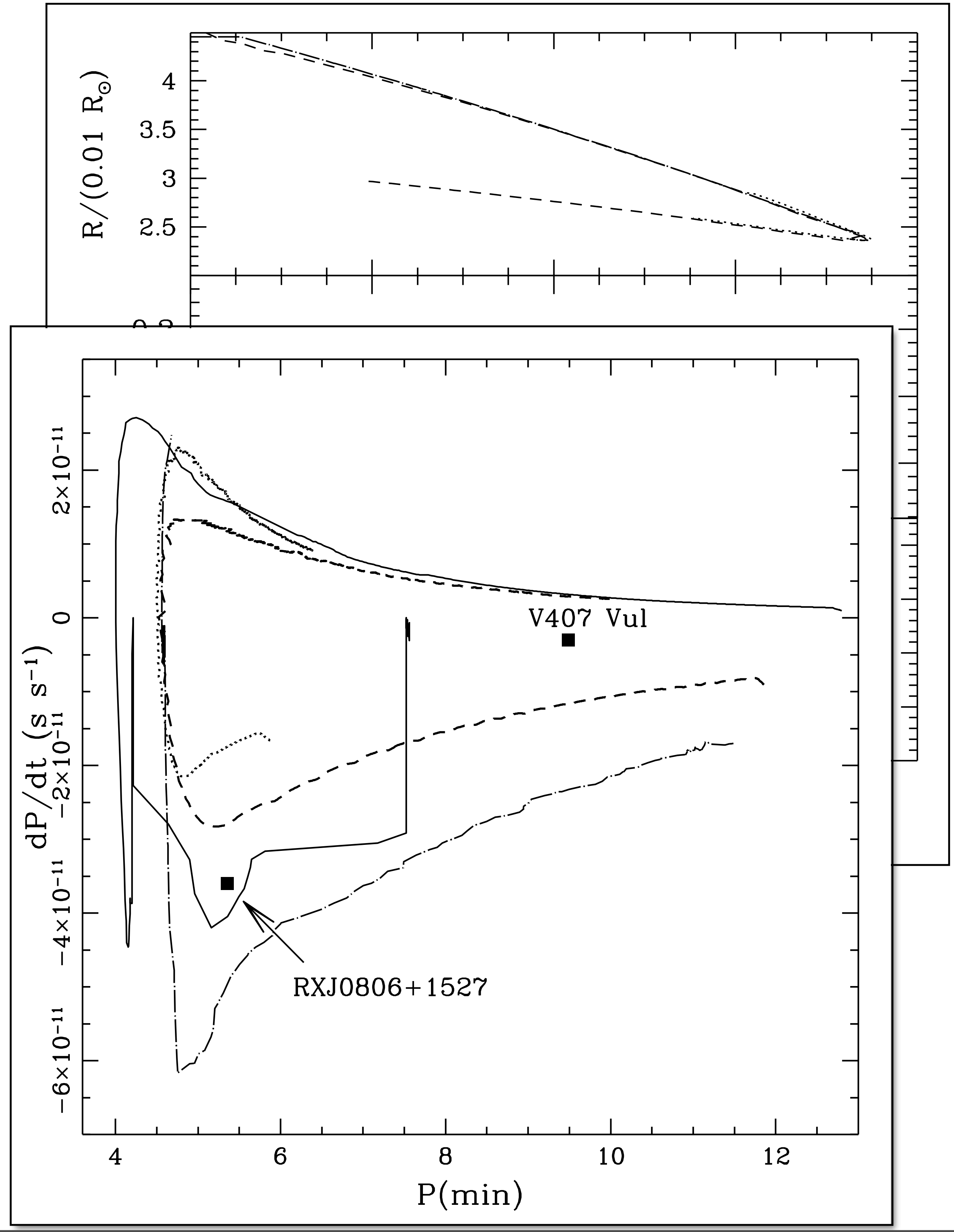

Conclusions

- Detailed calculation of mass transfer for ELM He WD and CO WD
- Hot, non-degenerate envelope prolongs period of stable mass transfer, significantly expands systems that will avoid merger
  - N_{out}/N_{in}~4 just based on $\dot{P}$; weight by $\dot{M}$ increases outgoing bias
  - If stable burning, that could change luminosity
- Long period of stable H burning kept He WD hot, explains high-entropy AM CVn donors?
- Still need to do fully self-consistent calculation of ζ and burning stability for these accretion rates and compositions (MESA)