Exploding Shells on Accreting White Dwarfs

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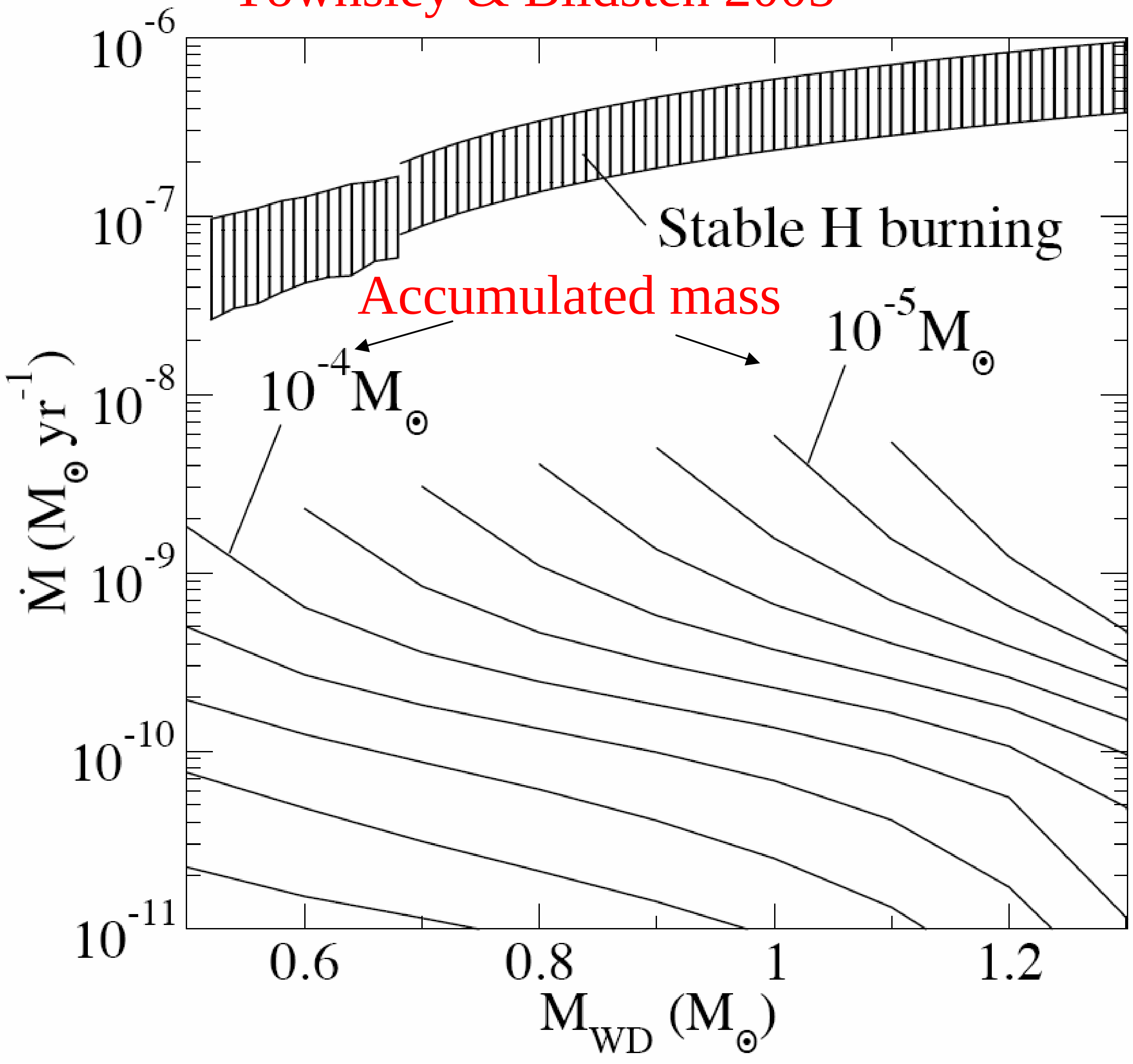
Barring a complete explosion (i.e. Type Ia SN), the brightest manifestation of mass transfer onto a white dwarf are the explosions of the accreted shells of matter. In H donors, these are Classical Novae, in He donors, these are He novae or explosions. Observing these phenomena provide a census of the numbers of such binaries in distant galaxies, allowing for comparison to the Type Ia rate and tests ▪ of the population synthesis predictions.

Collaboration with Gijs Nelemans (Nijmegen) and Dean Townsley (Chicago)

Townsley and Bildsten, 2004, Ap. J., 600, 390 (Theoretical overview)
Townsley and Bildsten, 2005, Ap. J., 628, 395 (Classical Novae)
Bildsten, Townsley, Deloye and Nelemans 2006, Ap. J. in press

Hydrogen Accreting Binaries

Townsley & Bildsten 2005

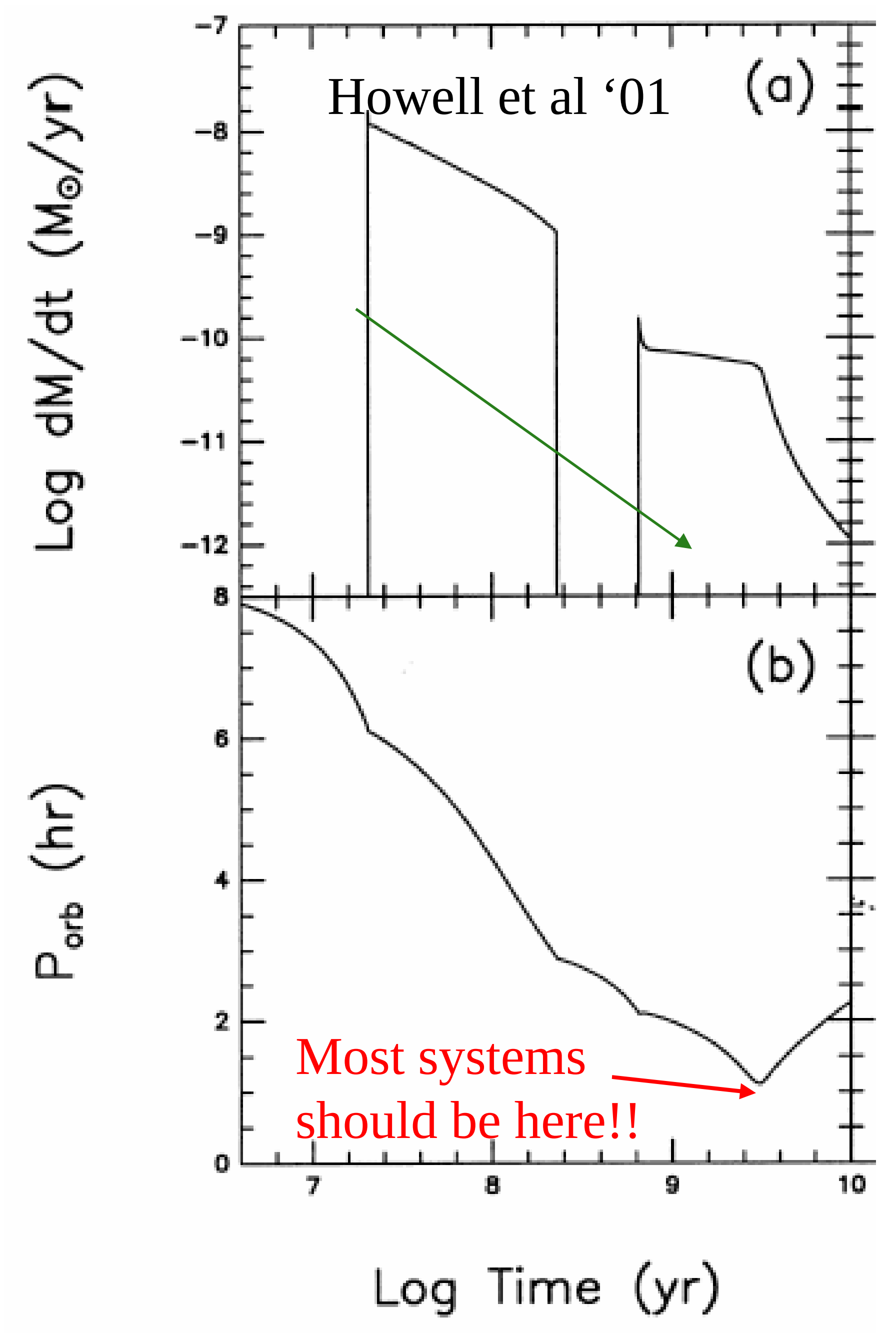


Supersoft Sources: Burn H Stably (van den Heuvel et al 1992)

Cataclysmic Variables all undergo unstable H burning, leading to Classical Novae

The WD mass range is quite uncertain.

Cataclysmic Variables



Howell et al ‘01

Most systems should be here!!

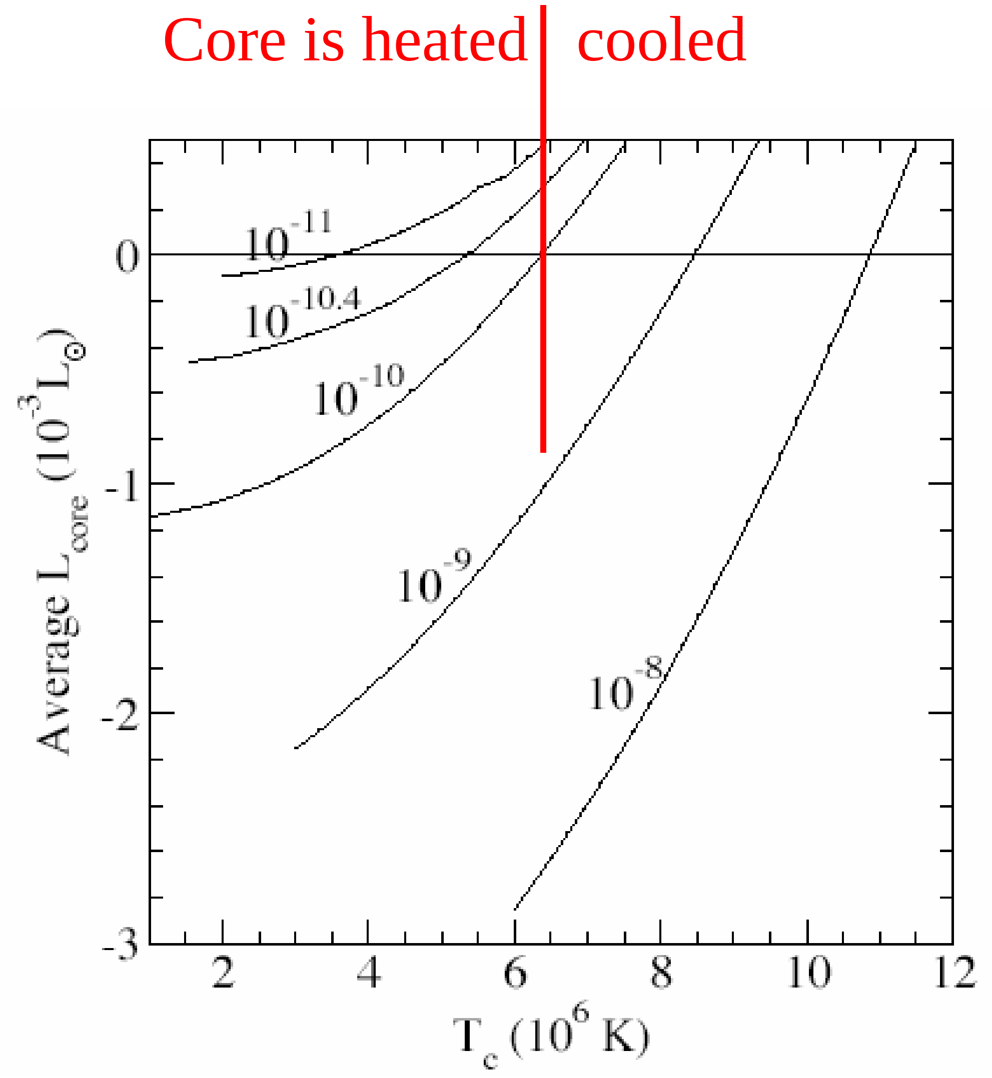
- 1 in 100 WDs end up in a CV, local space density is 1 every ~40 pc
- Optically variable objects with strong emission lines. At low M_dot’s, the accretion disk is thermally unstable, leading to dwarf novae outbursts
- Very uncertain whether the WD mass increases or decreases, but it is clear that 0.3-0.8 solar masses of matter is put on the WD over its lifetime….

Finding the Equilibrium Core Temperature

- Previous workers assumed a WD core temperature, whereas we (Townsley & Bildsten ‘04) calculate it, eliminating it as a free parameter.

- We find the core temperature such that, through the CN cycle, there is no net heating or cooling of the WD.

- The time to reach/track the equilibrium depends on the rate of change of M_dot compared to WD cooling, work underway by Townsley and collaborators on this important aspect.

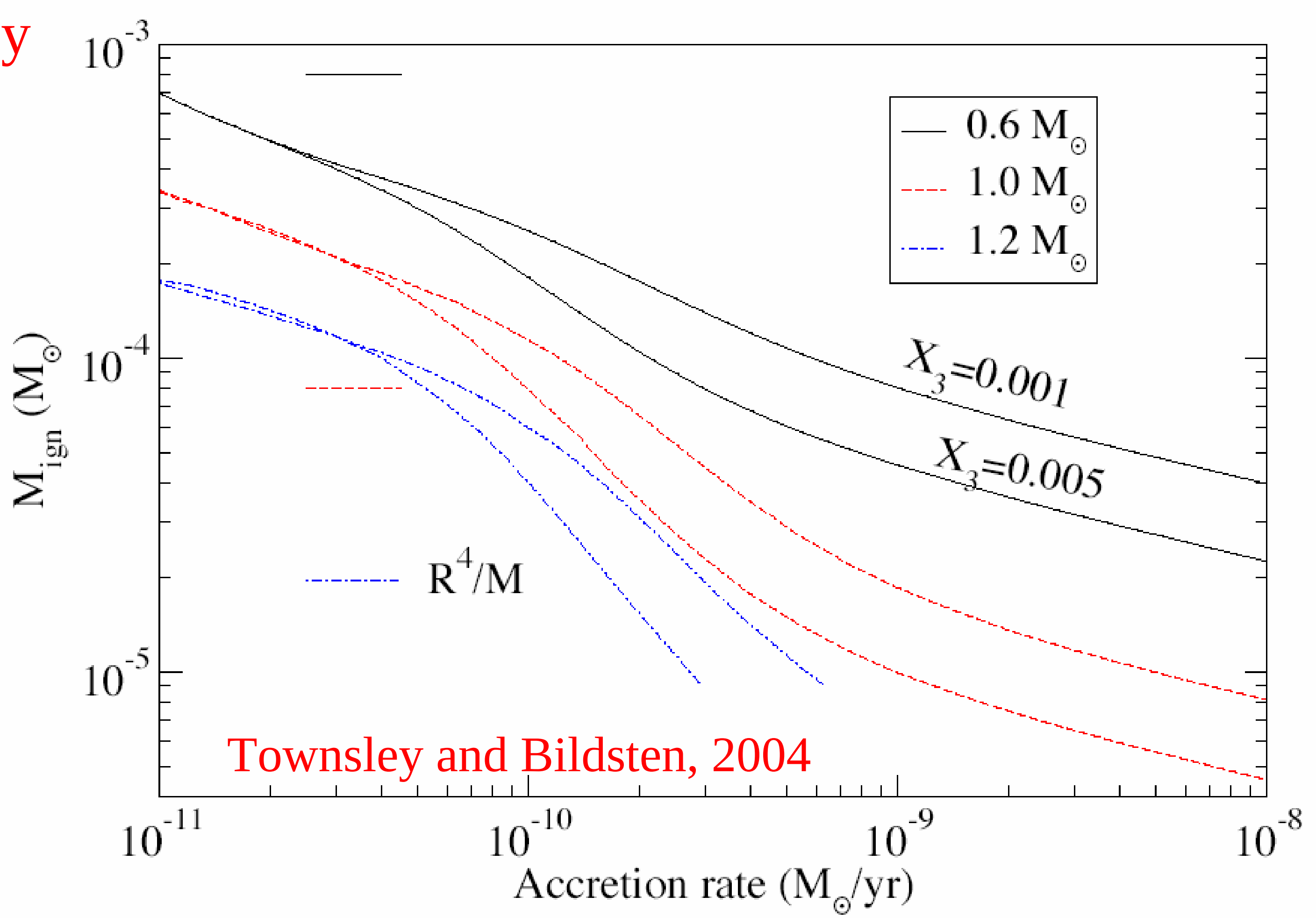


Core is heated | cooled

Classical Novae Ignition Masses

- The ignition mass depends most on the accretion rate and was previously underestimated!!!
- The WD mass dependence is LESS STRONG than previously assumed
- Helium-3 can make a difference above the period gap (Shara '80)

These self consistent CN ignition masses allow for a comparison to the ejected masses and a calculation of the CN rate for the CV population.



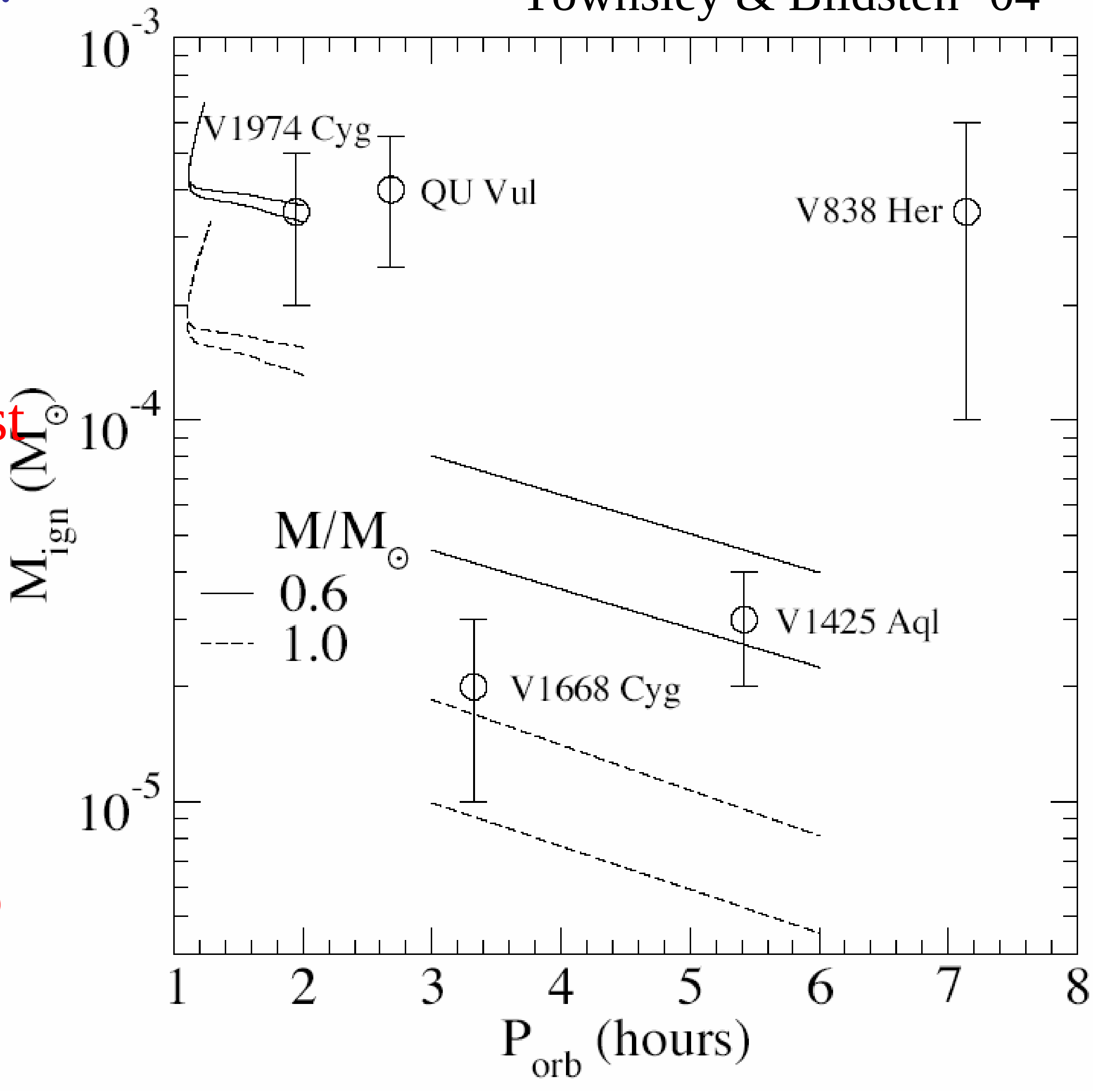
Townsley and Bildsten, 2004

Classical Novae Ejecta Masses

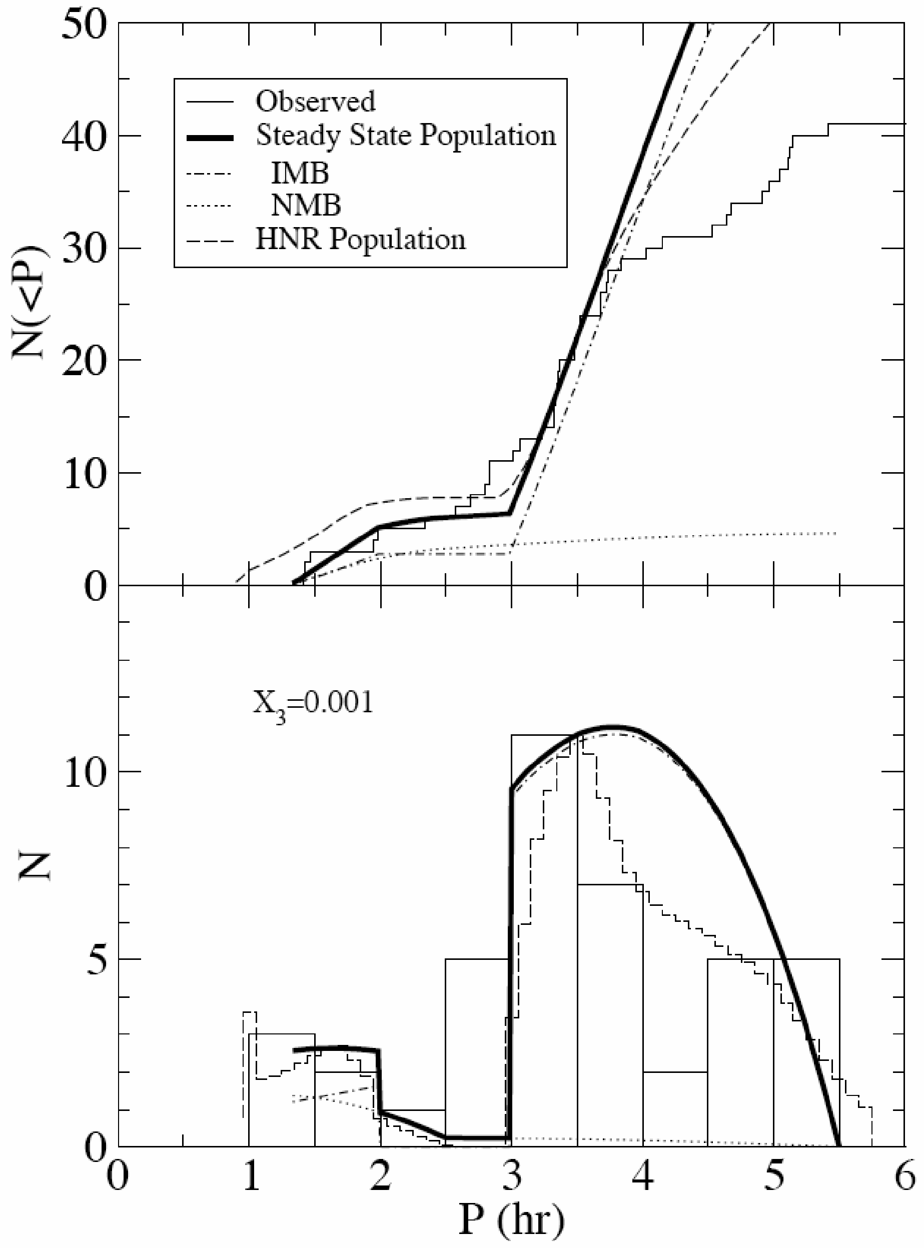
We could only find 5 CN for which an orbital period AND ejected mass were measured. We conclude:

1. No strong evidence for ejection of more than accreted
2. Confirmation of the accumulated mass contrast above and below the gap, agreeing with "standard" CV evolution
3. Some CN show C/O enrichment that clearly implies some dredging up from the underlying WD

Townsley & Bildsten '04



CN Orbital Periods



Townsley & Bildsten, '05

Is the observed CN orbital period distribution consistent with binary evolution?

Previous workers said no, as they assumed an ignition mass that was independent of accretion rate.

When our ignition masses are used, we conclude:

1. The number of CN above and below the period gap is consistent with the drop in accretion rate
2. Above the period gap, there must be injection of systems roughly like that shown by HNR
3. Most of these systems must have an enhanced J loss above the period gap.

Nova Rates

We have the CN recurrence rate as a function of all orbital periods, so we can measure the underlying CV population from the observed CN rate. Using the K-band specific CN rate of 2 per year in a 10^10 L_sun, K galaxy (Williams and Shafter 2004) we find:

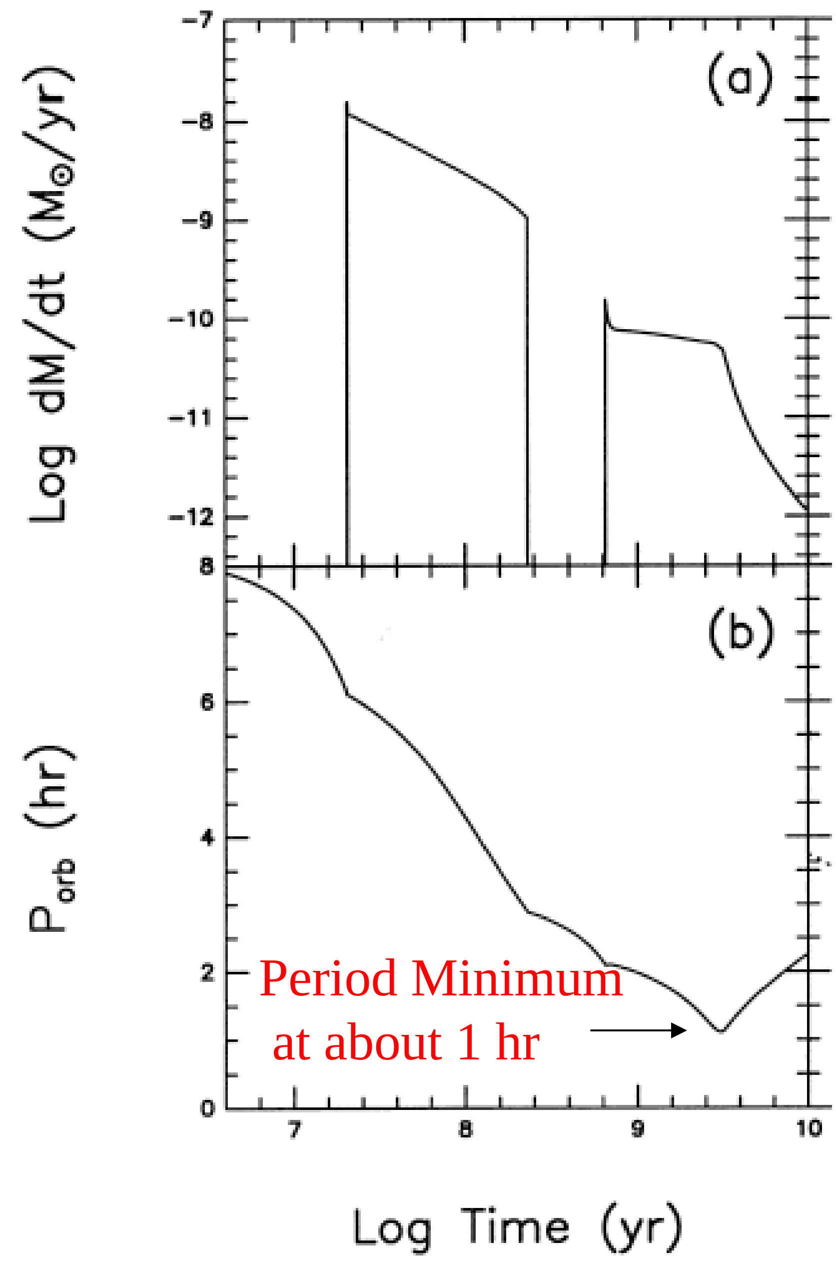
$$2(4) \times 10^{-4} \mathrm{CVs\ yr}^{-1} \text{ in a } 10^{10} L_{\odot,K} \text{ galaxy}$$

Or 60-180 CVs above the period minimum for every 10^6 L_sun,K (factor of 3 from assuming 0.6 vs. 1.0 Msun (think GCs). In addition, the local CV space density implied by the K-light density agrees with prior estimates, so all looks good.

Perhaps the most intriguing comment is that this CV birthrate is identical to the observed Ia rate. However, the WD masses appear too low to ignite the C/O in the core. . . So unlikely that they are progenitors . . However one would like to imagine that constraining the size of the CV population informs the Ia problem.

Minimum Orbital Periods For Hydrogen Donors

Howell, Nelson and Rappaport, 2001

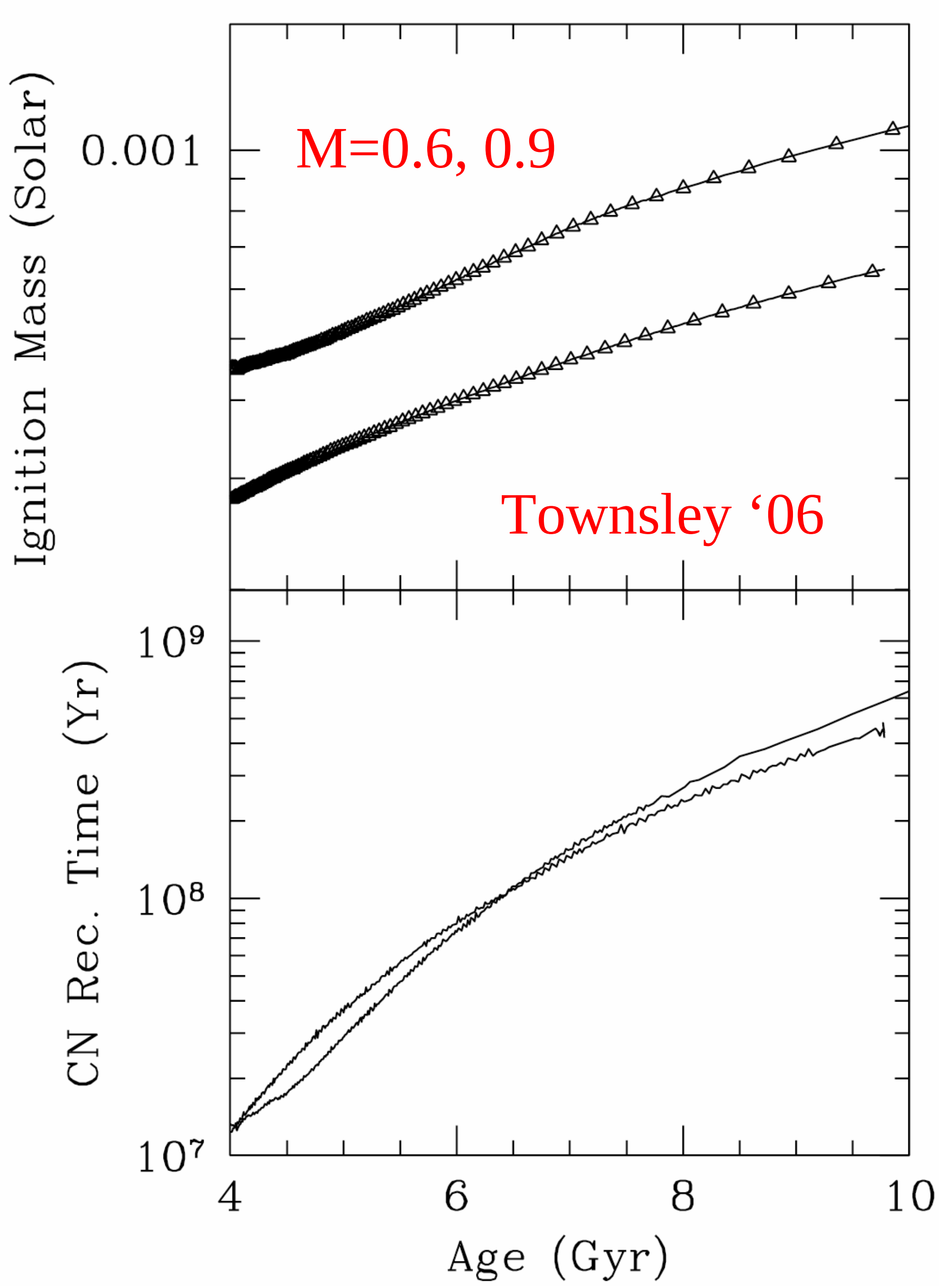


Period Minimum at about 1 hr

As the donor gets whittled down to the brown dwarf regime, its entropy remains fixed (Paczynski & Sienkiewicz 1981) and the radius asymptotes to 0.1 solar radii. In this limit

$$P_{\rm orb} = 1\ {\rm hr}\left(\frac{0.08 M_\odot}{M_2}\right)^{1/2}$$

Orbital periods less than an hour cannot be reached for a Hydrogen rich donor and in CVs there is evidence for a period minimum near 80 minutes (a little off).



M=0.6, 0.9

Townsley ‘06

- ~20 flashes in the 6-10 Gyr period with masses >0.0007 solar masses (out of 6000 CN), or 10X bigger
- Rate is ~1/1000 of CN rate, which is still 10X the Ia rate.
- If plateau phase is simply Eddington-limited, then the duration is longer… but we have yet to work out the appearance
- Iben and Tutukov identified these with M31-RV, a very super Eddington outburst.
- Work remains…..

AM CVn Binaries

- First of the class found by Humason and Zwicky (‘47) as faint blue stars and a spectrum by Greenstein and Matthews (‘57) only showed helium lines.
- Later work found P_orb=17.1 minutes.
- Helium WDs filling the Roche lobe, and the accretor is a C/O WD.

The defining properties are:

=> NO Hydrogen lines

=> He and N prevalent lines (N is there due to the complete conversion of C/O to N during prior CNO burning in main sequence star)

=> Optical/UV colors are combination of accretion disk and hot WD (Bildsten et al. 06)

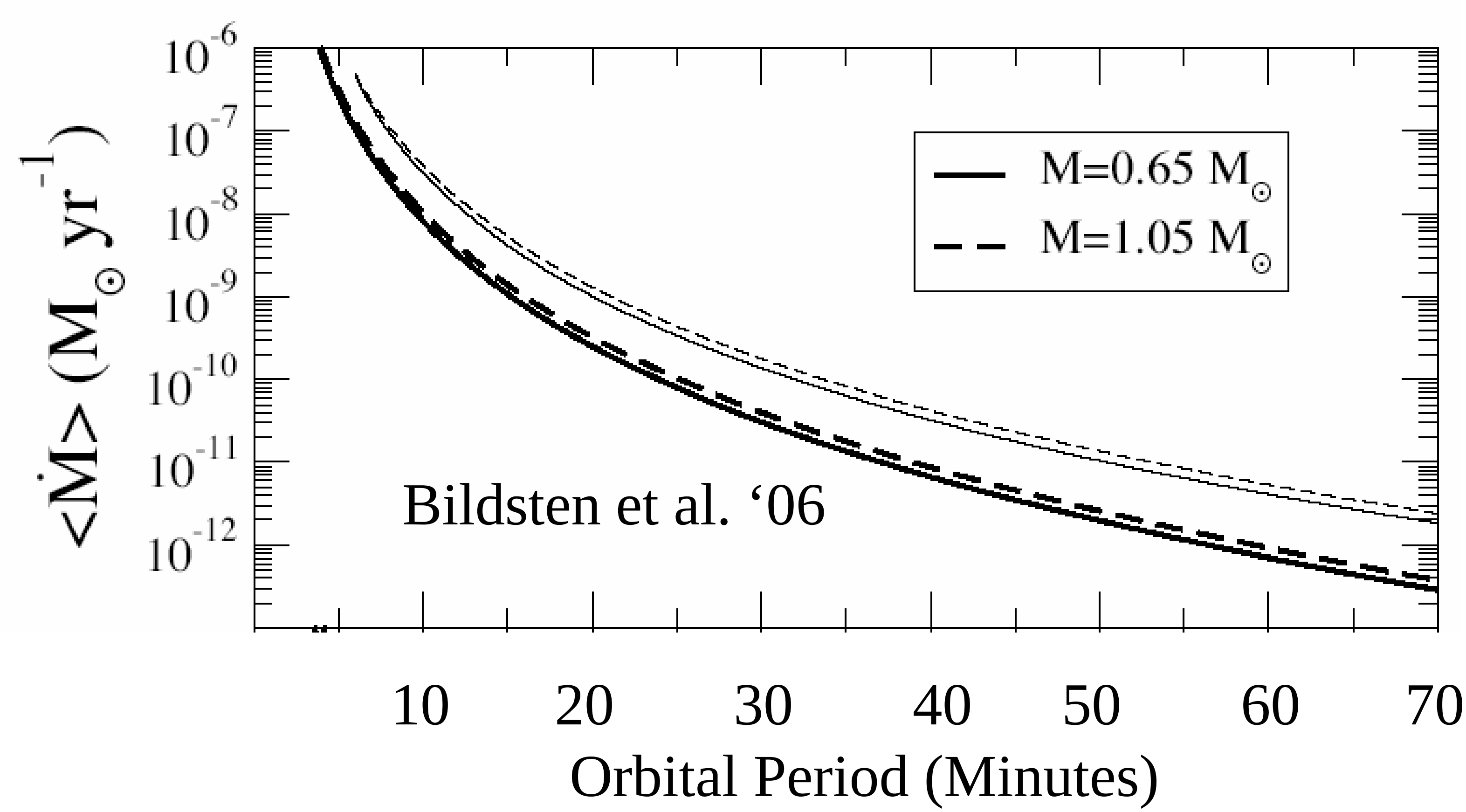
RXJ0806	5.35 min
V407 Vul	9.49
ES Cet	10.3
AM Cvn	17.1
HP Lib	18.4
CR Boo	24.5
KL Dra	25.0
V803 Cen	26.9
SDSSJ0926	28.3
CP Eri	28.4
SDSSJ1240	37.4
2003aw	33.8
GP Com	46.5
CE 315	65.1

+4 SDSS objects with no periods yet! (Anderson et al. ‘05)

The mass transfer rate and evolution of the binary is driven by loss of angular momentum via gravitational radiation (Faulkner, Flannery & Warner ‘72) at the rate

$$\frac{\dot{J}}{J} = -\frac{32}{5}\frac{G^3}{c^5}\frac{M_1 M_2 (M_1 + M_2)}{a^4}$$

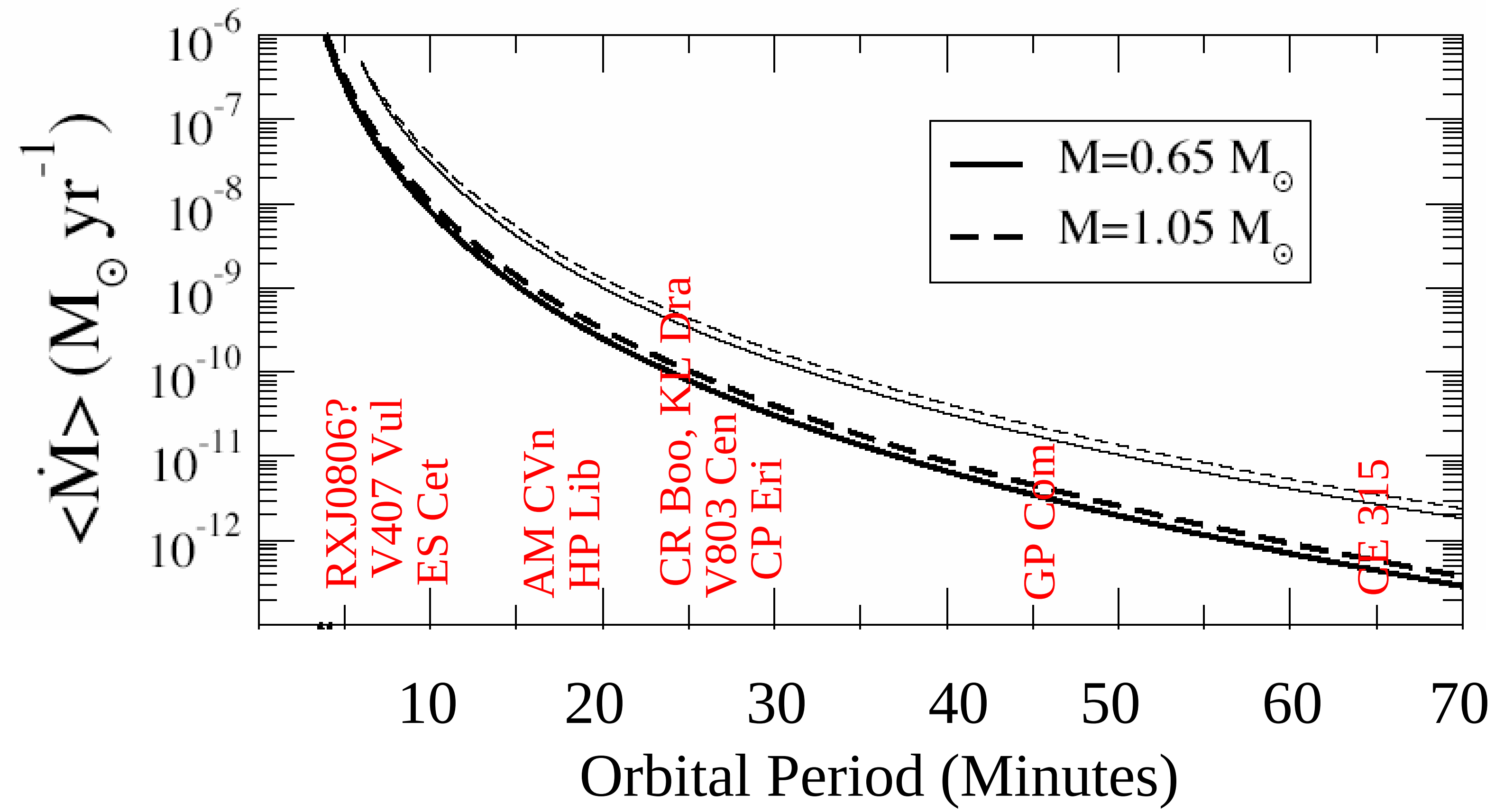
Allowing for a temporal integration once mass transfer commences



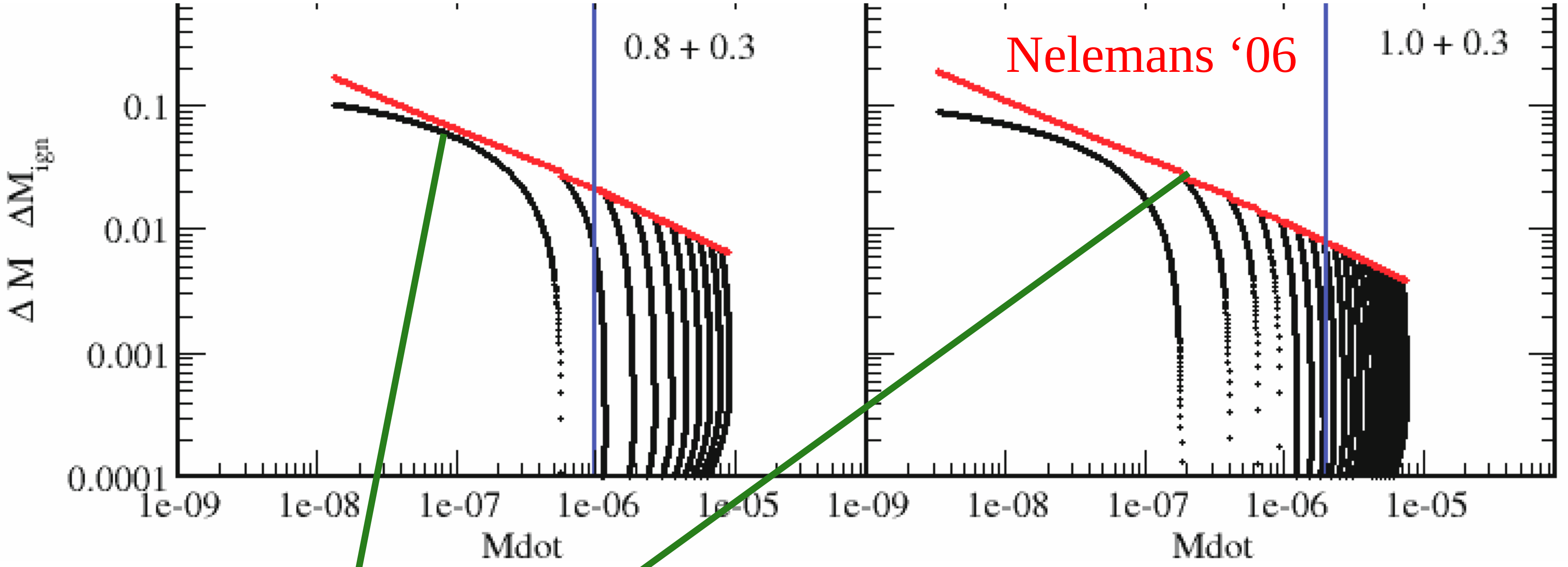
Helium Ignitions in AM CVns

Bildsten, Townsley, Deloye and Nelemans 2006,Ap J

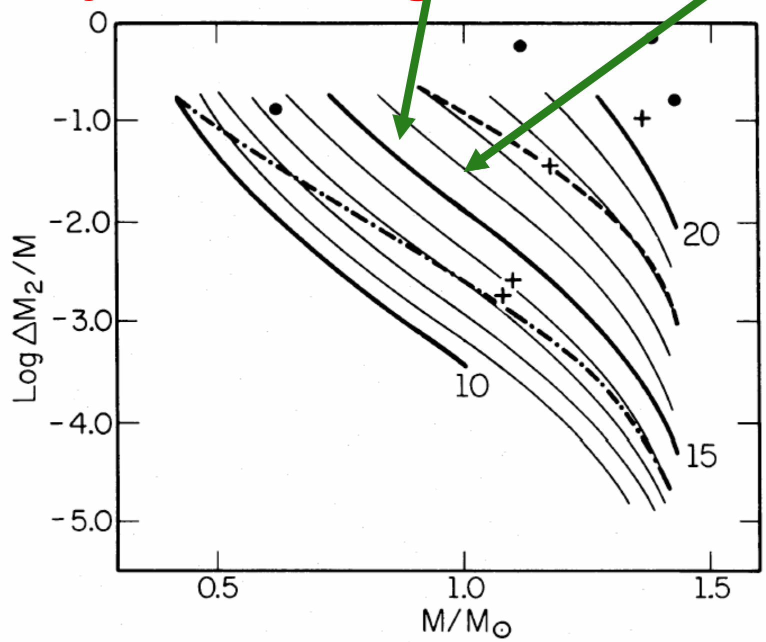
These systems initiate mass transfer from the lower mass He WD to the higher mass C/O WD long after the C/O WD was made (see Nelemans et al. ‘02). At the onset of accretion, M_dot>>10^{-7} M_sun/yr and the He layer undergoes weak explosions (Kato and Hachisu ‘99). However, once M_dot <10^{-7} (orbital periods >6 minutes) the required Helium shell mass to explode is > He donor mass



Nelemans '06



Fujimoto & Sugimoto '82



- Early flashes have small ignition mass and will appear as Eddington Limited events, ~20 He CN per system

- Pressures in last 1-3 flashes are high enough that the burning becomes dynamic (burning time << dynamic time), possibly ejecting 56Ni-rich matter as a 'faint' Ia SN (2002cx?)

Helium Flash Rates

The number of these binaries expected in a galaxy is tough to estimate. Best current estimates (Nelemans et al ‘04) give an AM CVn birthrate of

$$(1-3) \times 10^{-4} \mathrm{yr}^{-1} \text{ in a } 10^{10} L_{\odot,K} \text{ Galaxy}$$

This would result in a He novae rate of 0.04-0.12 per year in M31 (one in 300 CN), and a 56Ni rich event rate of about 1/10’th of the Type Ia rate. Hence, there is some phase space for new discoveries of such events, from which the population could be meaningfully constrained!

QUESTIONS??