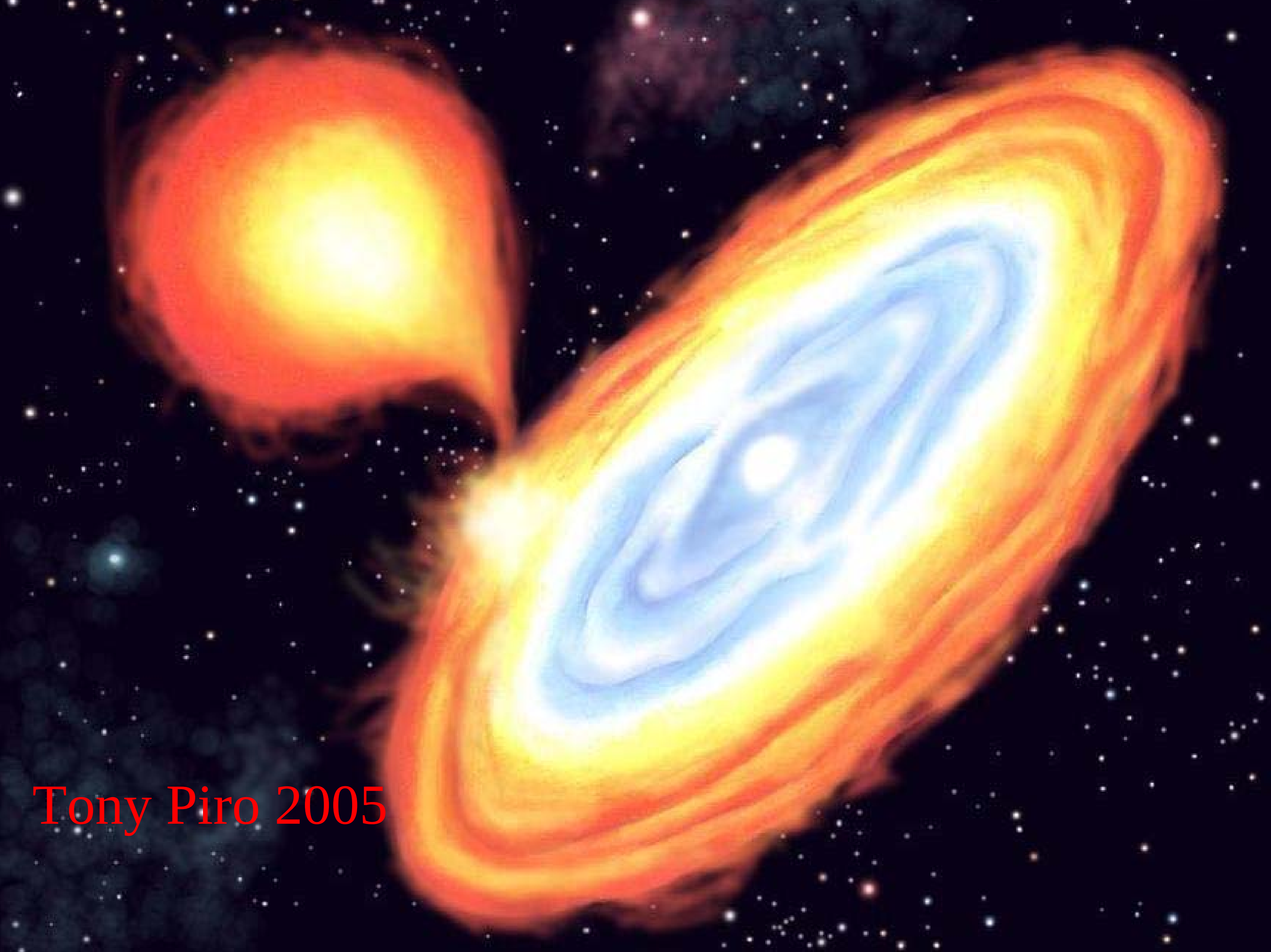
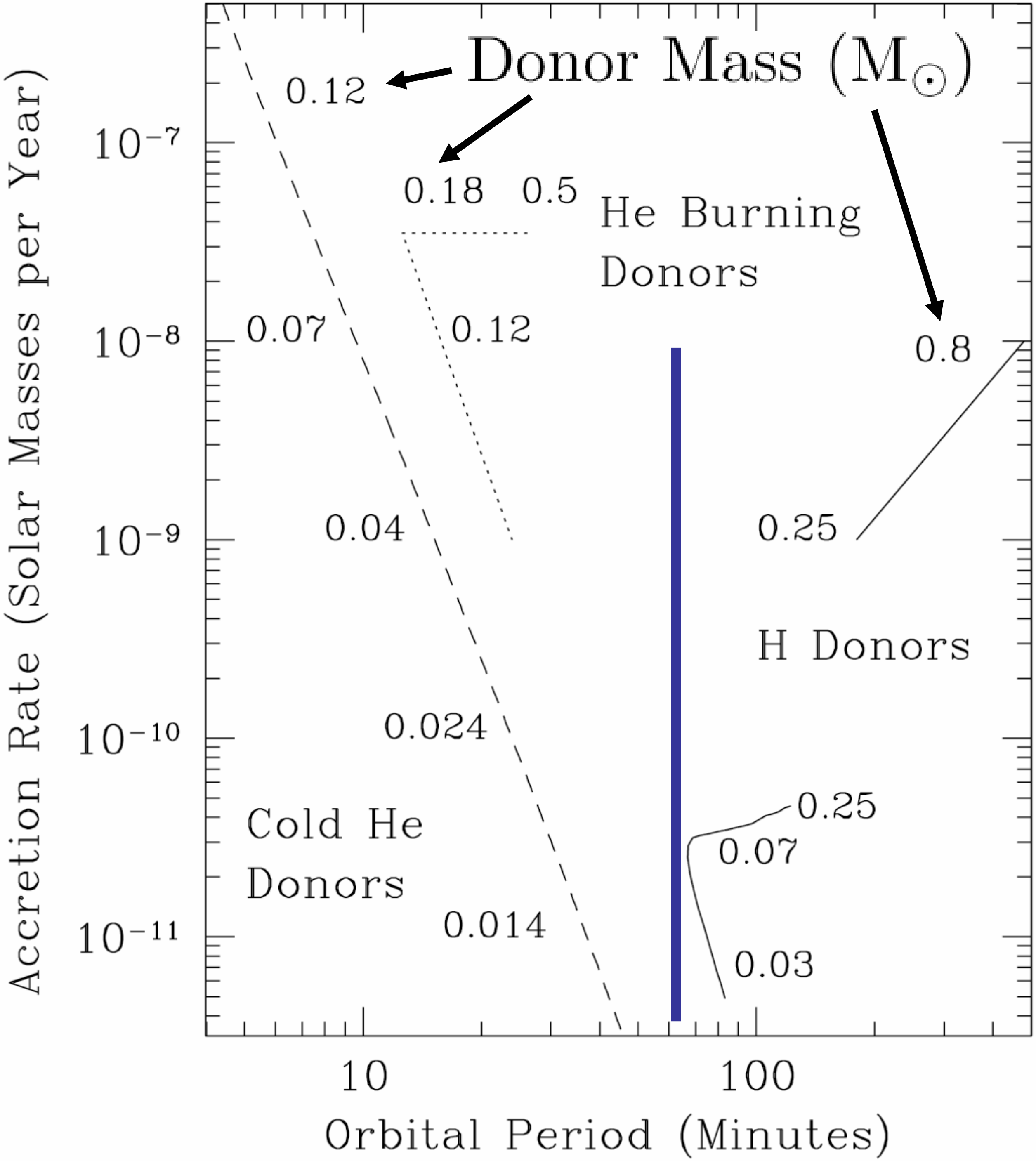


Tony Piro 2005

Accreting White Dwarfs (about 1 in 100)

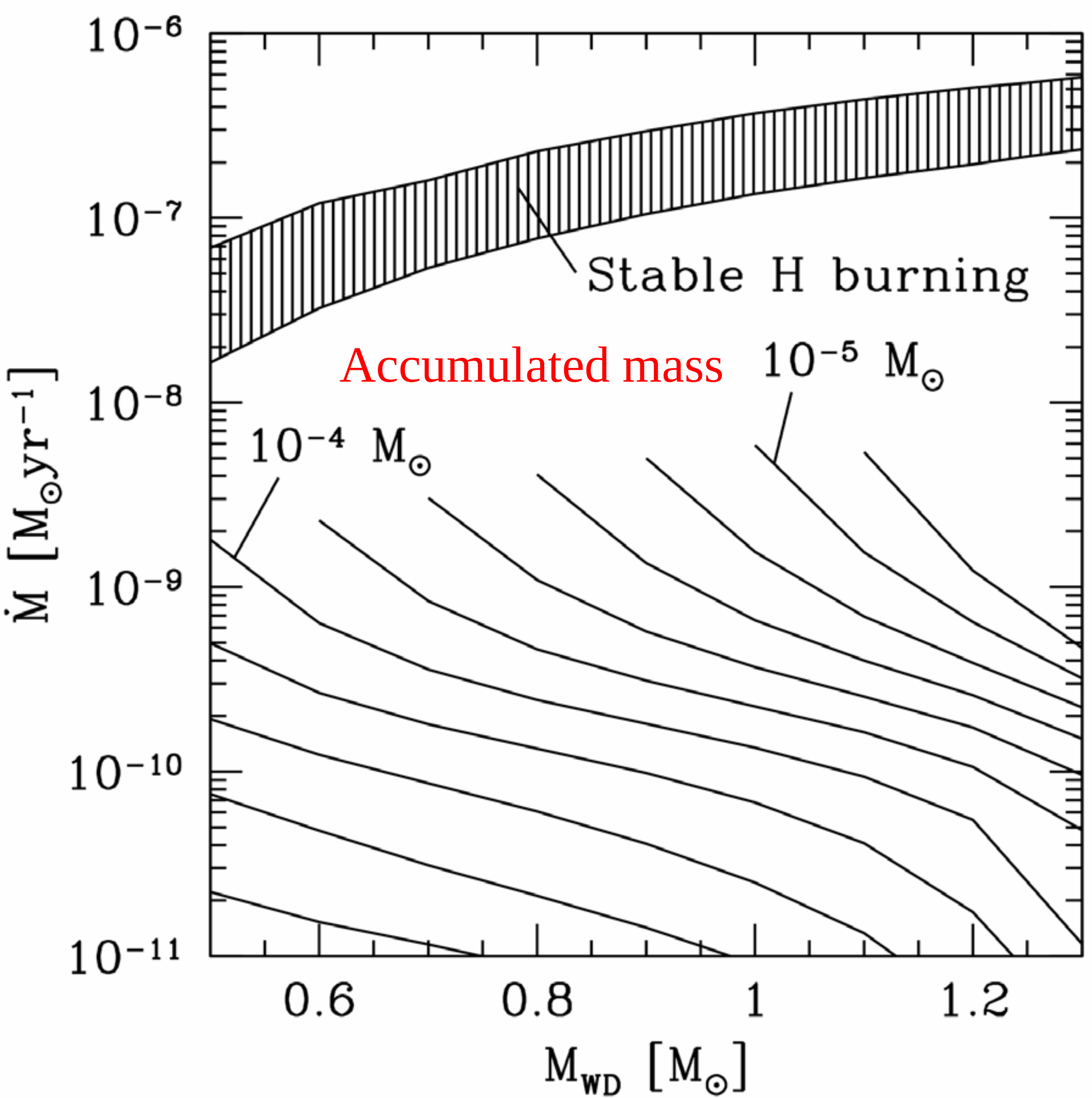


Angular momentum loss is gravitational wave emission, setting accretion rates!

- P>60 minutes, the donors are Hydrogen rich main sequence stars.
- H-rich stars have a minimum radius of ~0.1 R_sun, so that P<60 min. implies He-rich donors

Hydrogen Accreting Binaries

Townsley & Bildsten 2005



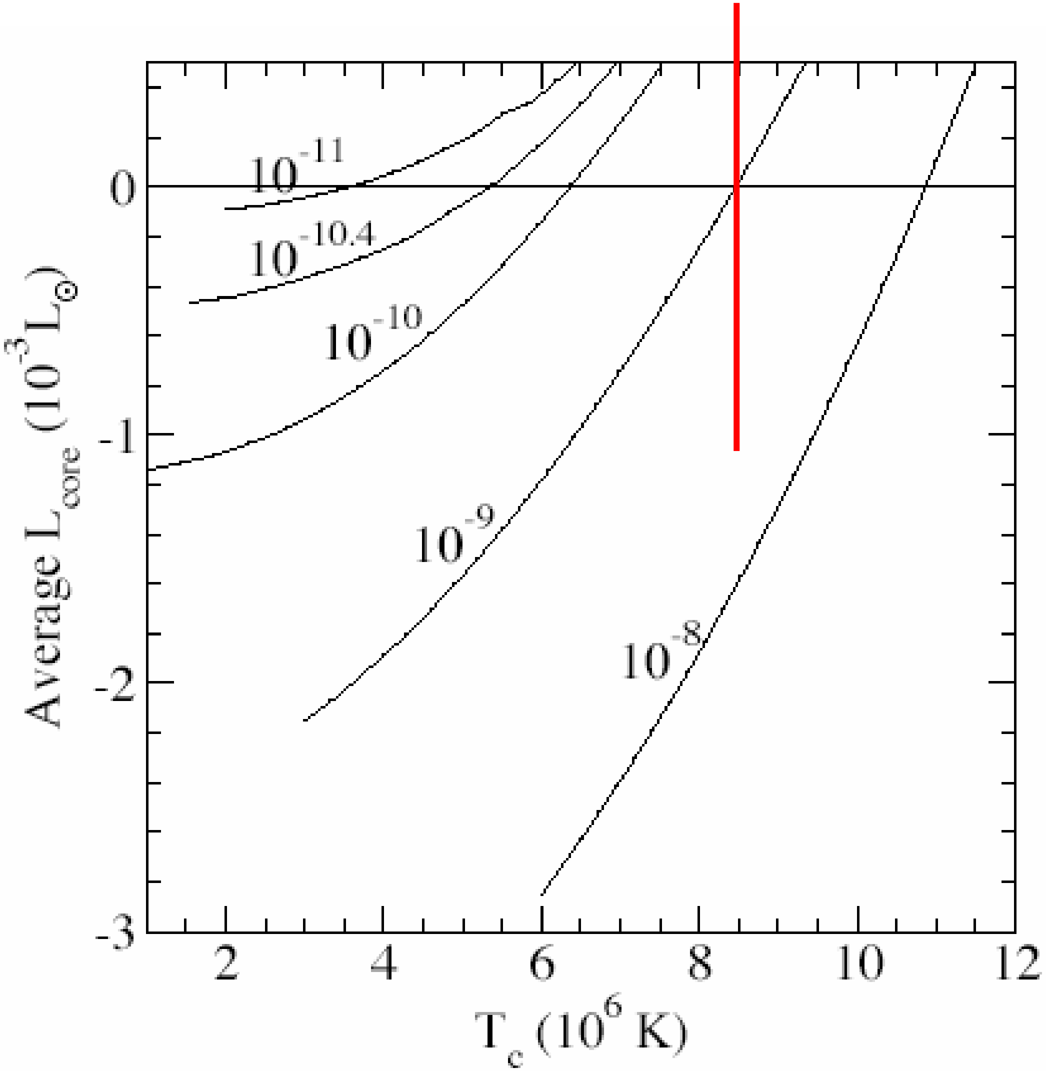
Supersoft Sources: Burn H Stably (van den Heuvel et al 1992), or Symbiotics/RN

Cataclysmic Variables undergo unstable burning, leading to Classical Novae. Whether the mass stays or goes is uncertain

The WD masses are not known

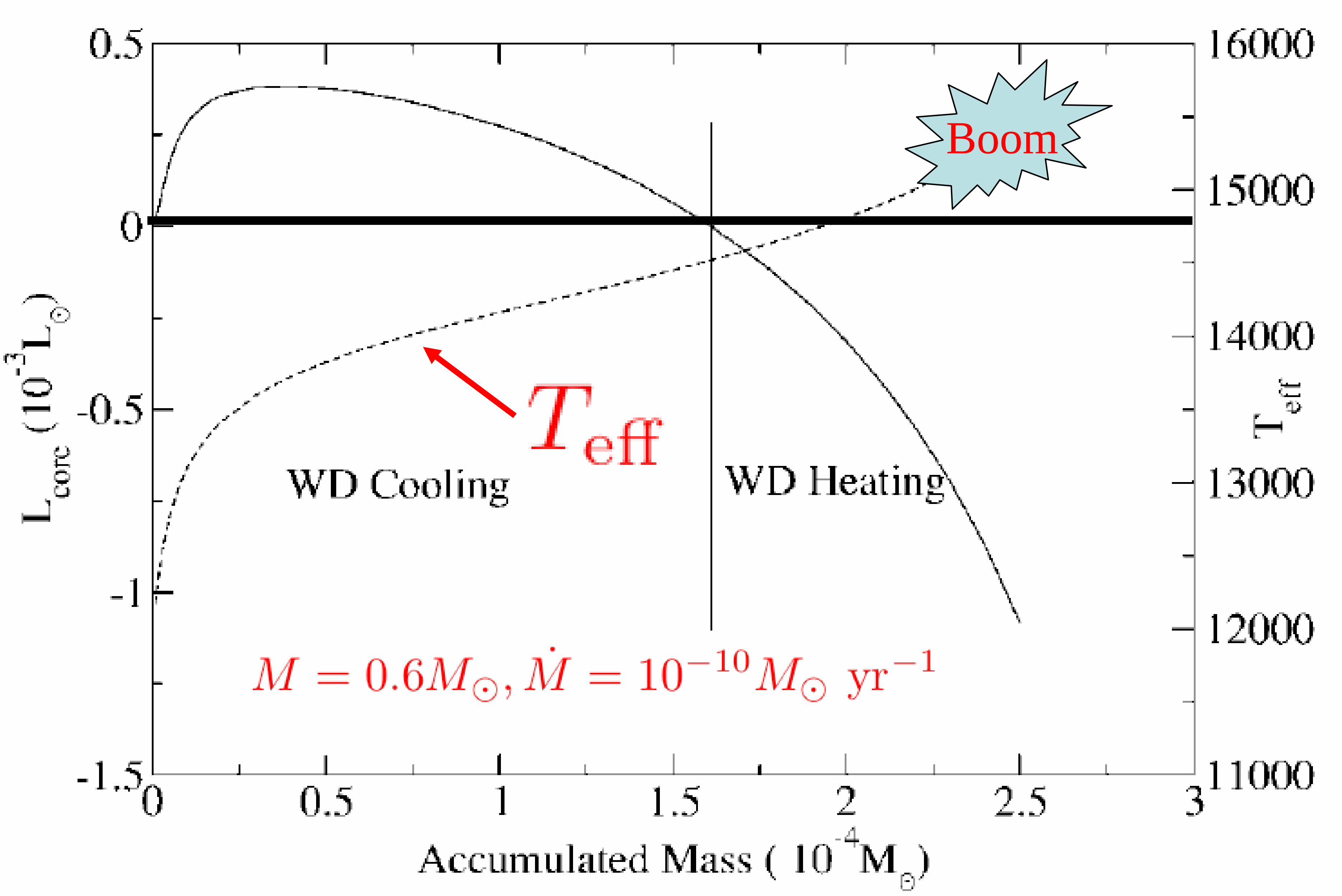
Finding the Equilibrium Core Temperature

- Previous workers assumed a WD core temperature, whereas we (Townsley & Bildsten ‘04) calculate it
- 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, at late times, the WD simply cools


Core is heated cooled

At Equilibrium

Townsley and Bildsten, 2004

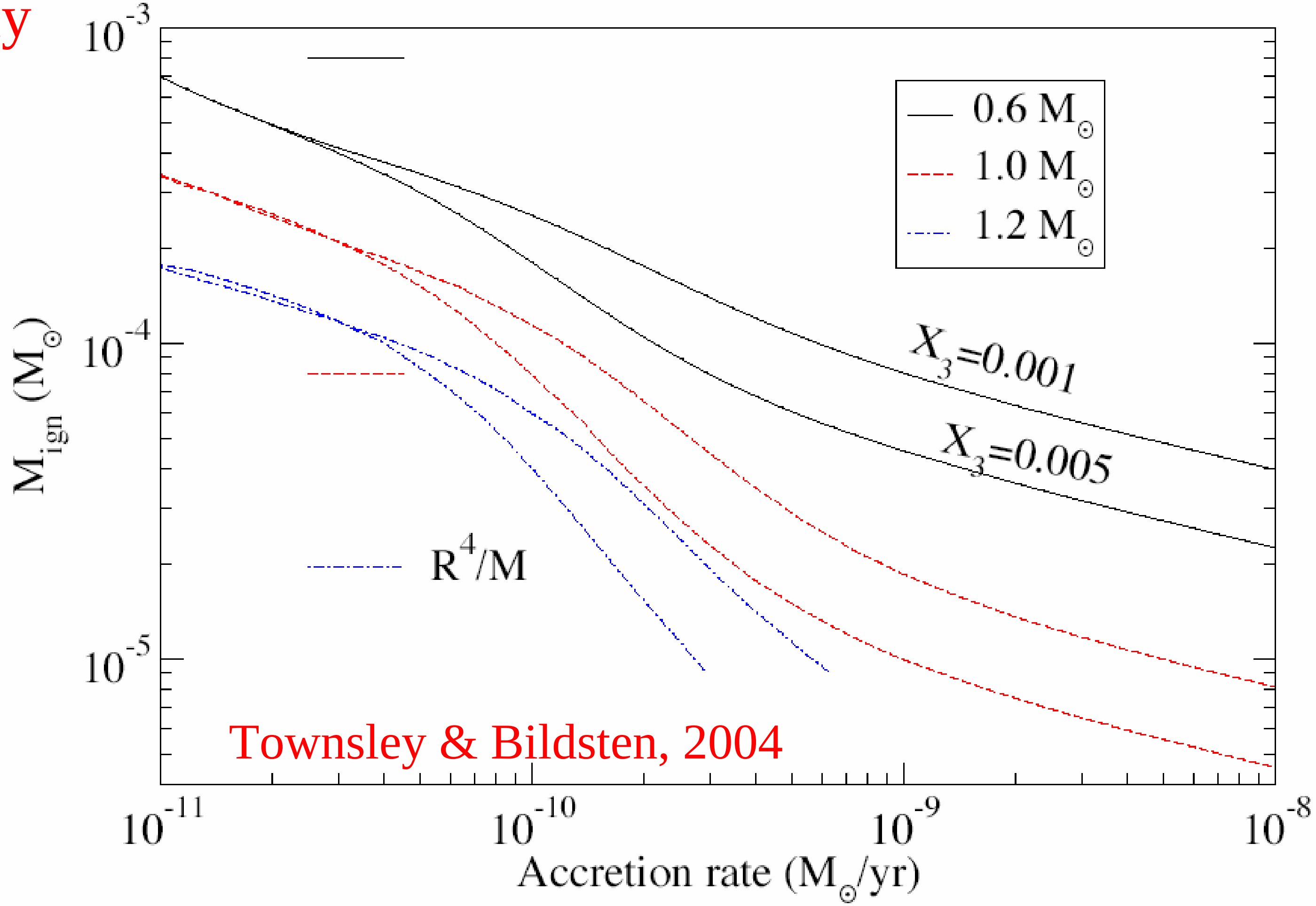


$$M = 0.6 M_\odot, \dot{M} = 10^{-10} M_\odot \ \mathrm{yr}^{-1}$$

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 yield a mass comparison to the ejected masses and a calculation of the CN rate for the whole CV population.



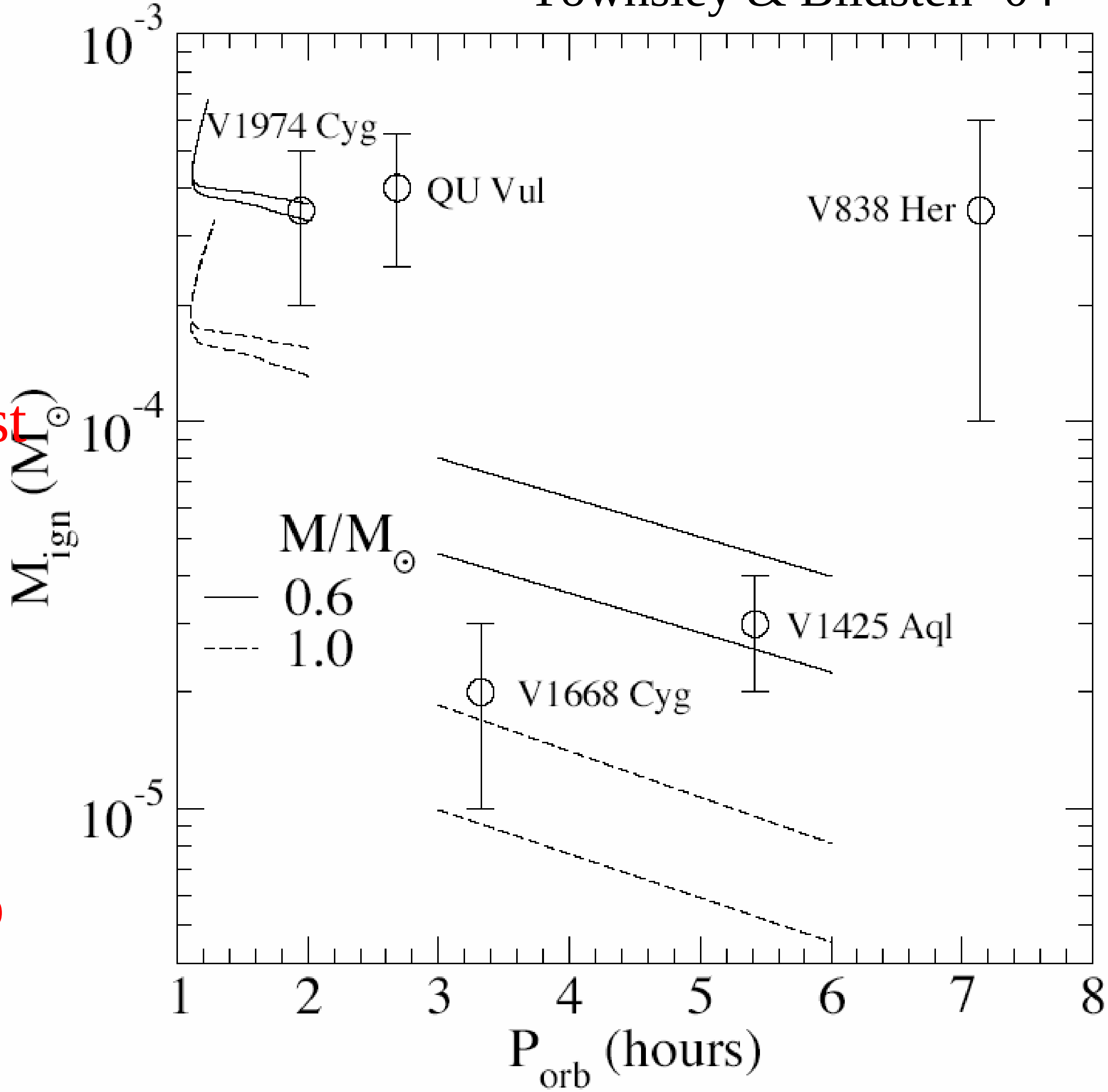
Townsley & Bildsten, 2004

Classical Novae Ejecta Masses

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

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



Nova Rates => Population Density

- From the CN recurrence rate as a function of orbital period, we measure the underlying CV population from the observed CN rate.

- The K-band specific CN rate of 2 per year in a 10^10 L_sun, K galaxy (Williams and Shafter 2004) gives a CV birthrate

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

- 60-180 CVs above the period minimum for every 10^6 L_sun,K (~3 for 0.6 vs. 1.0 Msun), agreeing with the local estimates of CV space density. Also agrees with the number of CVs inferred from X-ray observations of the Galactic center (Muno et al 2004) and galactic plane (Sazonov et al ‘06)

- The mass specific CV birthrate is identical to the Ia rate in E/SO’s. However, the WD masses in CVs appear too low to ignite the C/O in the core. . . So unlikely that they are progenitors . . But first time a relative rate comparison has been made.

FUSION REACTIONS IN MULTICOMPONENT DENSE MATTER

D. G. Yakovlev
Ioffe Physico-Technical Institute, Poliekhnicheskaya 26, 194021 Saint-Petersburg, Russia
Department of Physics & The Joint Institute for Nuclear Astrophysics,
University of Notre Dame, Notre Dame, IN 46556 USA

L. R. Gasques and M. Beard, M. Wiescher
Department of Physics & The Joint Institute for Nuclear Astrophysics,
University of Notre Dame, Notre Dame, IN 46556 USA

A. V. Afanasjev
Department of Physics and Astronomy, Mississippi State University, P.O. Drawer 5167, MS 39762-5167 USA

We analyze thermonuclear and pycnonuclear fusion reactions in dense matter containing atomic nuclei of different types. We extend a phenomenological expression for the reaction rate, proposed recently by Gasques *et al.* [11] for the one-component plasma of nuclei, to the multi-component plasma. The expression contains several fit parameters which we adjust to reproduce the best microscopic calculations available in the literature. Furthermore, we show that pycnonuclear burning is drastically affected by an (unknown) structure of the multi-component matter (a regular lattice, a uniform mix, etc.). We apply the results to study nuclear burning in a $^{12}\mathrm{C}^{16}\mathrm{O}$ mixture. In this context we present new calculations of the astrophysical S-factors for carbon-oxygen and oxygen-oxygen fusion reactions. We show that the presence of a CO lattice can strongly suppress carbon ignition in white dwarf cores and neutron star crusts at densities $\rho \gtrsim 3\times10^9$ g cm^{-3} and temperatures $T \lesssim 10^8$ K.

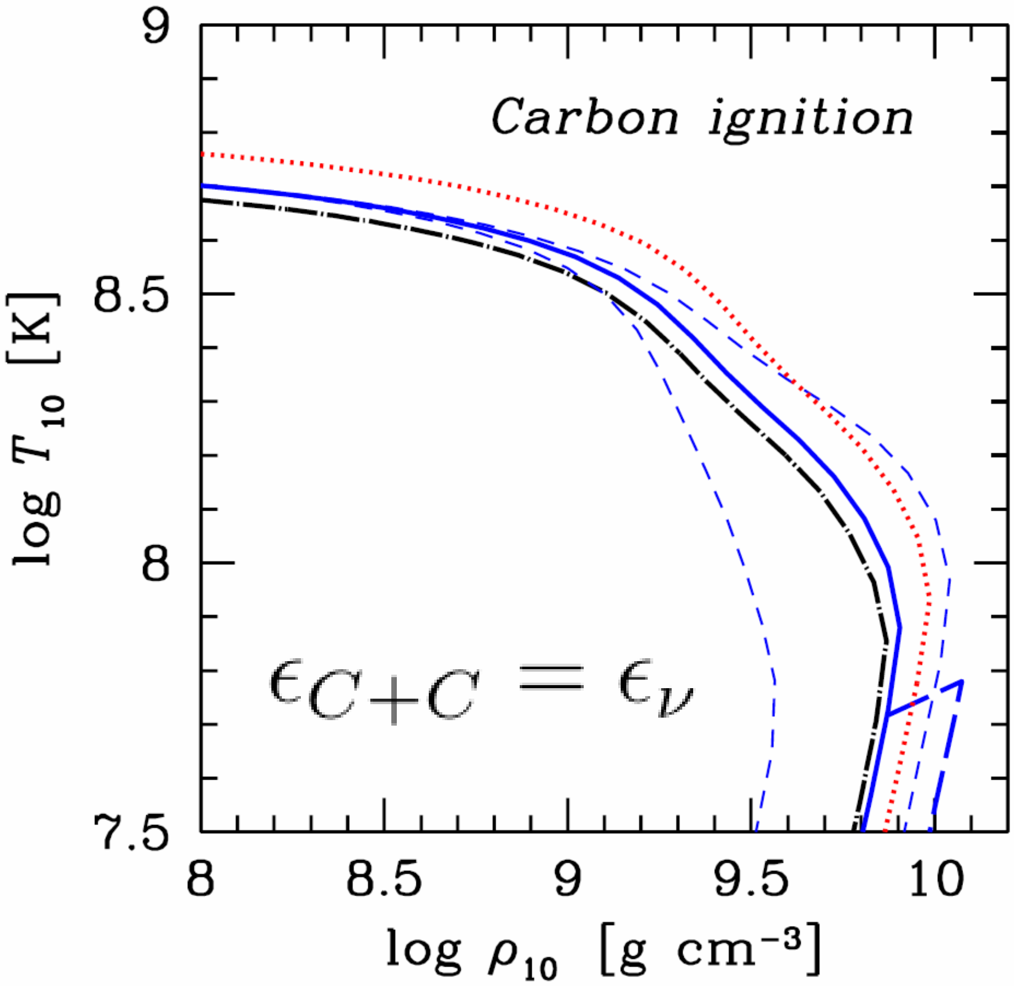


FIG. 5: (color online) Carbon ignition curves in ^{12}C^{16}O matter. The dot-and-dashed line is the optimal model for carbon burning in pure carbon matter. The solid and dotted lines are optimal models for uniform CO mixtures with $x_{\rm C}$ =0.5 and 0.1, respectively. Other lines are for CO BIMs with $x_{\rm C} = 0.5$. The short-dashed lines give the highest and the lowest theoretical ignition curves for uniform mixtures. The long-dashed line is for the CO bcc crystal at low temperatures.

$$C_P \frac{dT}{dt} = \epsilon_{C+C} - \epsilon_\nu$$

If cold (T<3e8 or so), then ignition is from high densities..which only occur near the Chandrasekhar mass.

$$\rho_c = 3 \times 10^8 \mathrm{g\ cm}^{-3} \rightarrow M = 1.25 M_\odot$$

$$\rho_c = 10^9 \mathrm{g\ cm}^{-3} \rightarrow M = 1.33 M_\odot$$

$$\rho_c = 2 \times 10^9 \mathrm{g\ cm}^{-3} \rightarrow M = 1.36 M_\odot$$

$$\rho_c = 3 \times 10^9 \mathrm{g\ cm}^{-3} \rightarrow M = 1.37 M_\odot$$

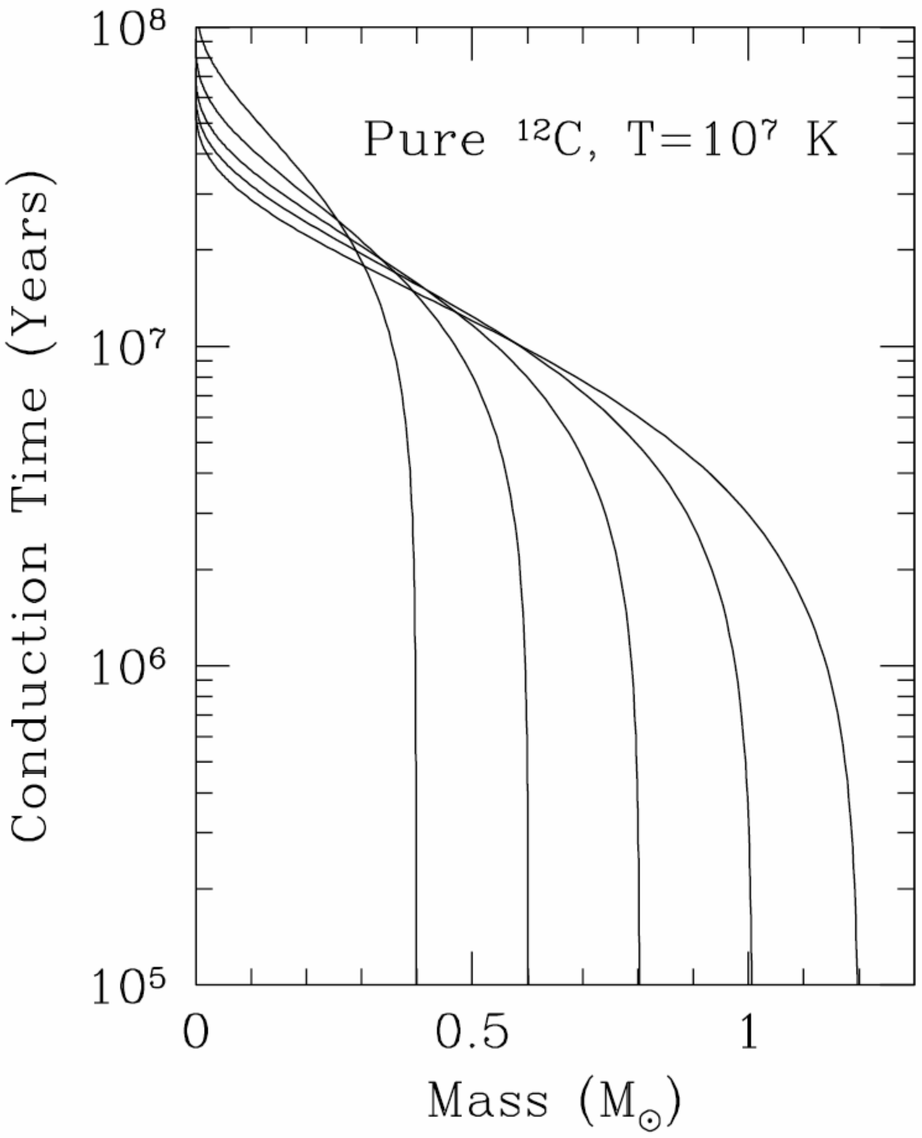


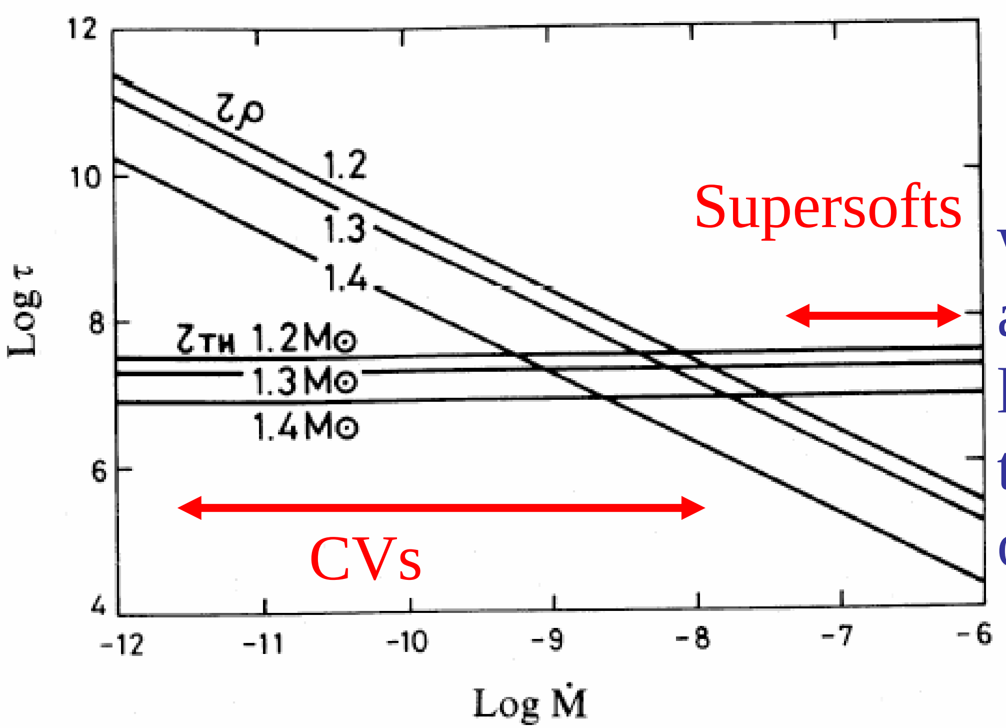
FIG. 11.—Thermal conduction time (t_{cond} in eq. [A2]) from the exterior of a pure carbon WD to an interior mass point. The curves are for isothermal WDs ($T = 10^7$ K) with masses $M = 0.4$, 0.6, 0.8, 1.0, and 1.2 $M_\odot$.

$$\tau_{\mathrm{th}} \approx \frac{C_P R^2}{K}$$

Carbon Ignition

Type Ia supernovae are triggered when the central density and temperature are high enough for unstable carbon burning. The competition for the central fluid element is between density compression at the rate set by accretion of matter (on average)

(Hernanz et al. 1988; Nomoto 1982)



Supersofts

CVs

FIG. 1.—Time scale (in yr) for propagation of a thermal wave by conduction, τ_{TH}, and for central density increase (close to Chandrasekhar's limit), τ_ρ, as functions of accretion rate (in $M_\odot$ yr^{-1}) and initial mass.

$$\tau_\rho = F\frac{M}{\dot{M}}$$

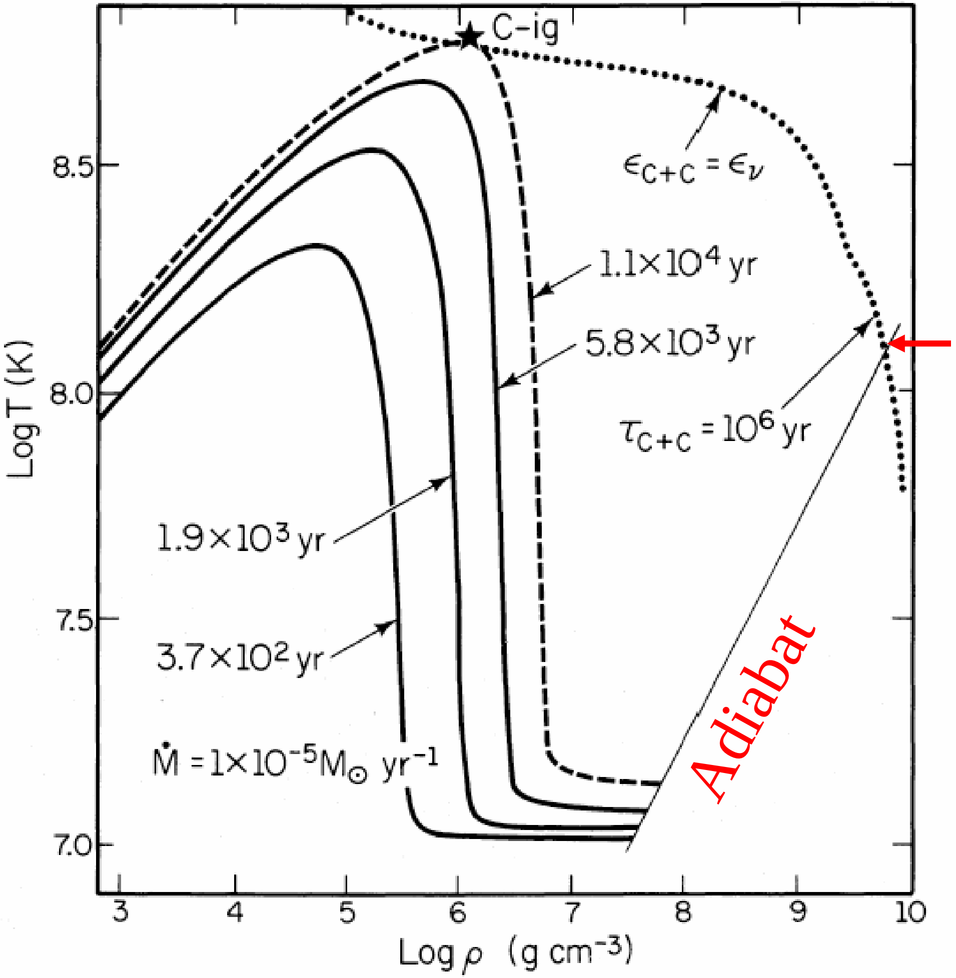
where F<<1 as the WD approaches the Chandrasekhar limit, and the time for heat to traverse the conductive (K) core of heat capacity C_P

$$\tau_{\rm th} \approx \frac{C_P R^2}{K}$$

Rapid C/O Accretion from Mergers

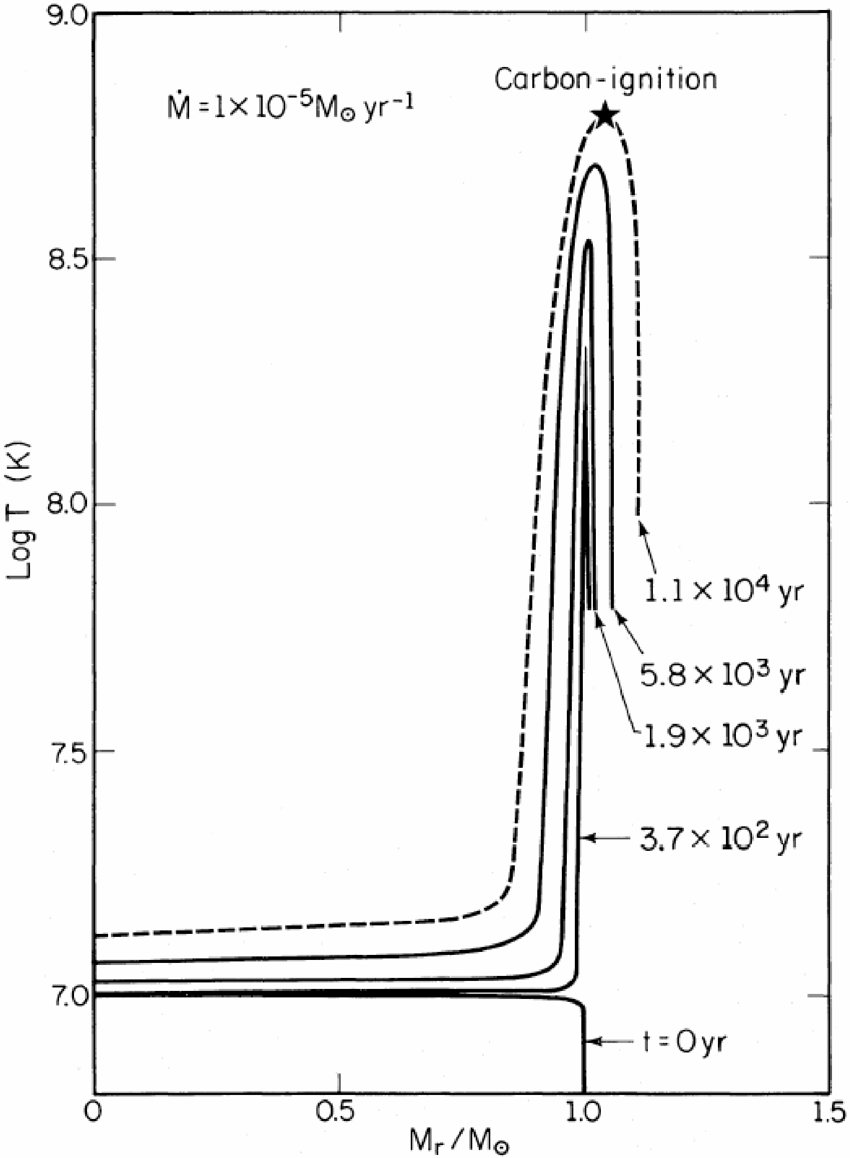
Accretion of C/O at a high rate leads to:

1. Adiabatic compression of the core
2. Ignition at the outer edge, where there is a larger density change from accretion



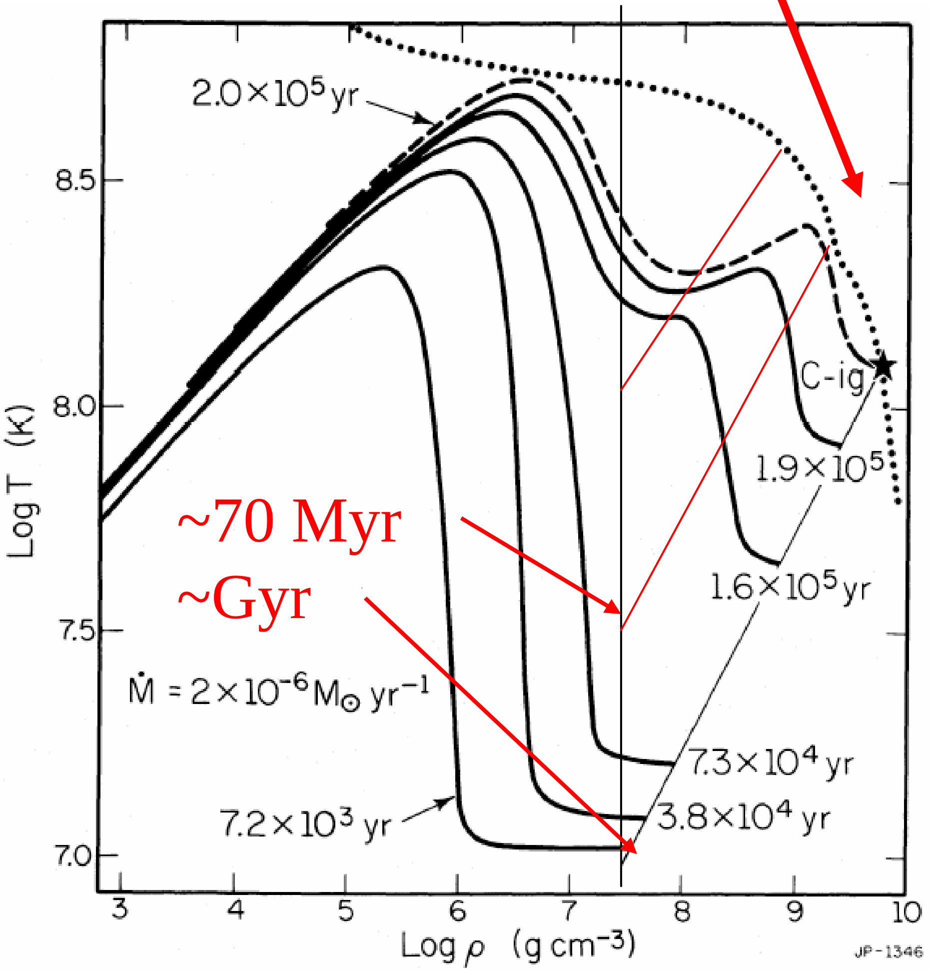
High density requires near Chandrasekhar mass

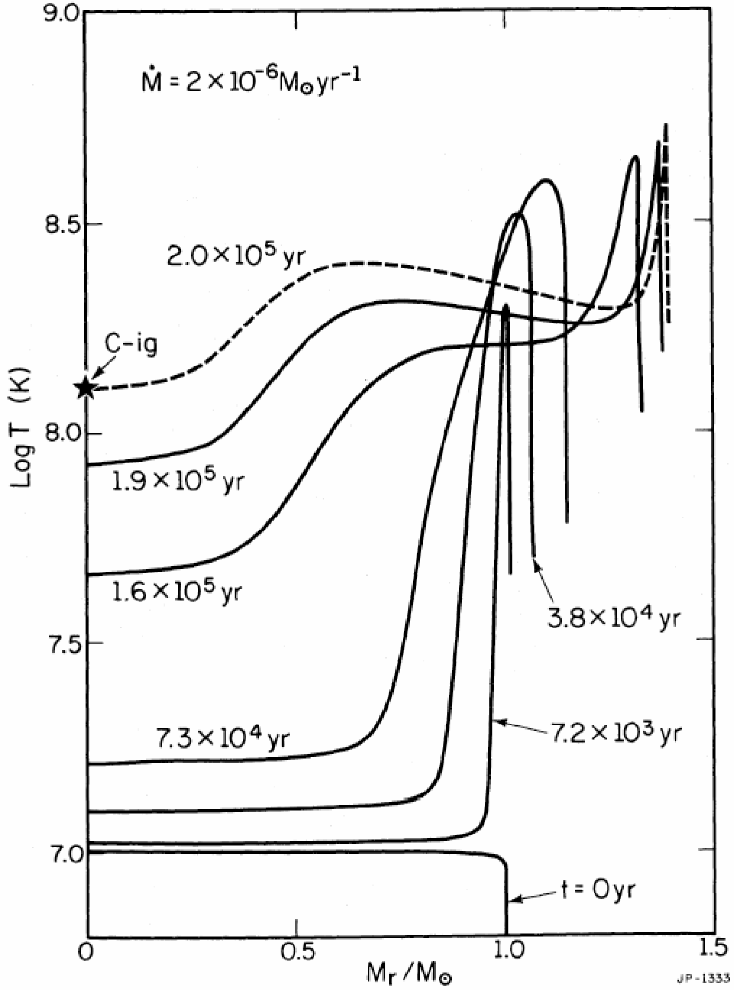
Nomoto and Iben 1985



Rapid C/O Accretion (Cont.)

Rapid accretion results in an off-center ignition that likely leads to burning C/O to O/Ne and maybe NS formation, not a Ia SN! The accretion rate needs to be <10^{-6}M_sun/yr to have core ignition and Ia SN. However that M_dot and M_tot depends on initial core temperature (i.e. age of the WD)!!





A Standard Example of Successful Ignition

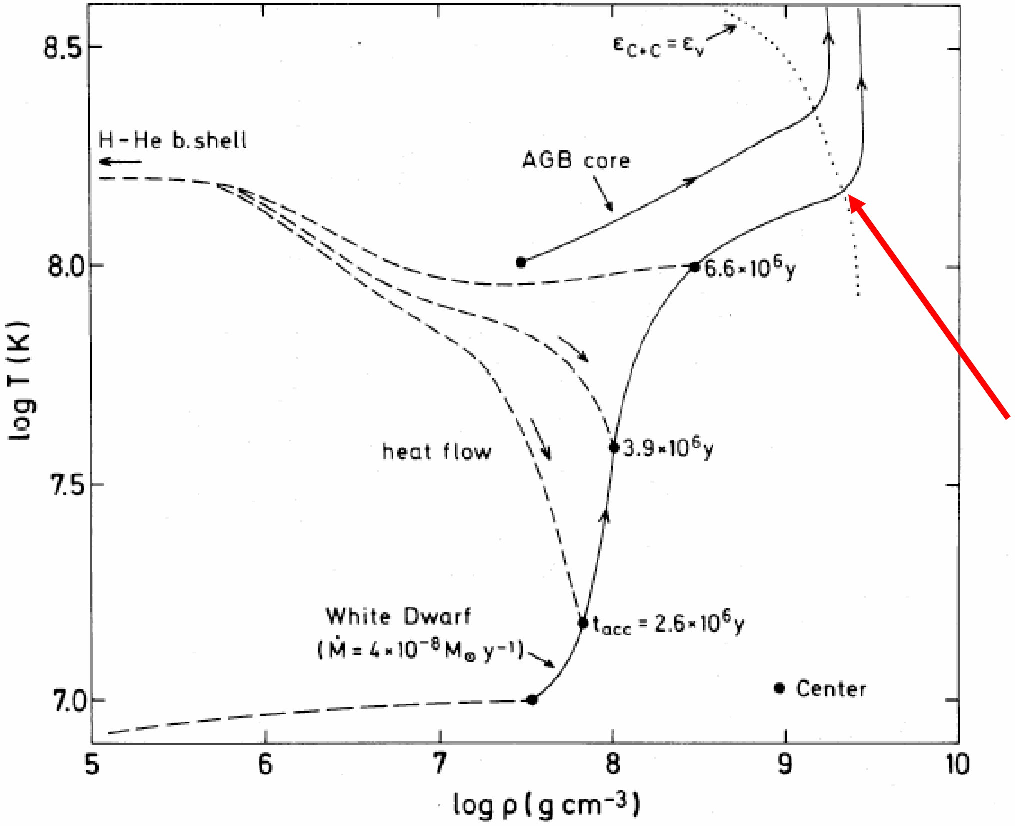


FIG. 2a

Runaway ignition

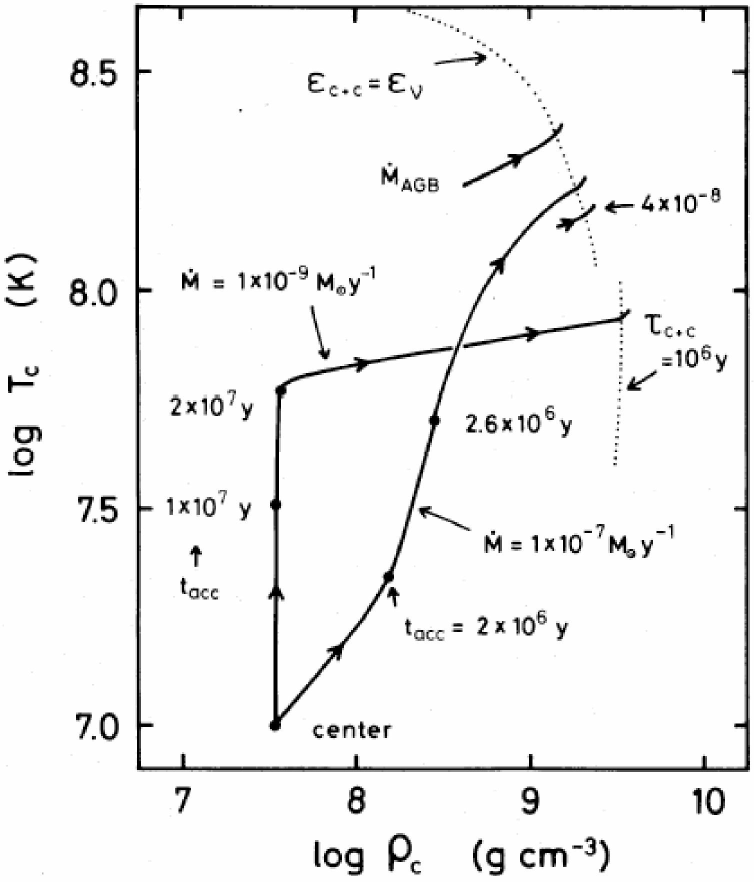
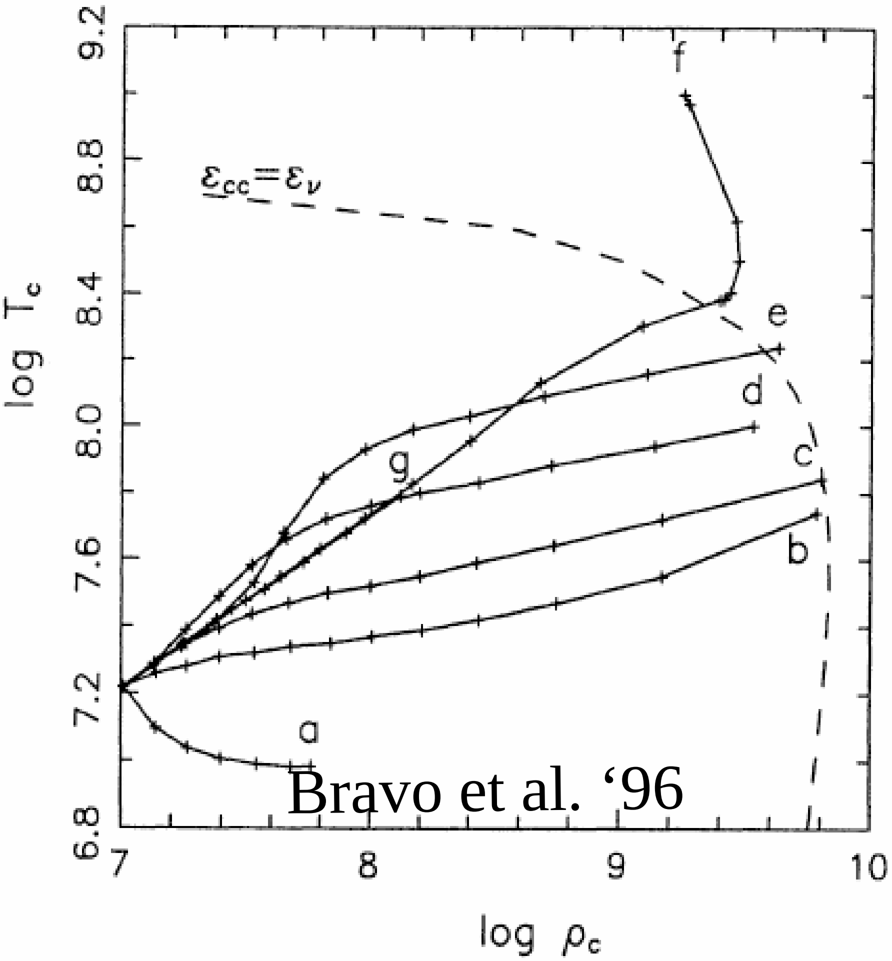


FIG. 2b

FIG. 2—(*a*) Accretion onto the white dwarf ($\dot M = 4 \times 10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$) and growth of the core in the AGB star. The evolution of (ρ_c, T_c) is shown by the solid lines. Time, $t_{\rm acc}$, is measured from the onset of accretion. Dashed lines are the structure lines of the white dwarf where heat flows from the surface into the interior. The dotted line is the ignition line of carbon burning defined by $\epsilon_{\rm C+C} = \epsilon_\nu$. (*b*) Same as Fig. 2*a* but for the accretion onto the white dwarf with $\dot M = 1 \times 10^{-7}$ and $1 \times 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$. For low temperature, the carbon ignition occurs approximately at $\tau_{\rm C+O} \equiv c_p T/\epsilon_{\rm C+C} = 10^6$ yr as indicated by the dotted line.

Nomoto, Thielemann and Yokoi 1984

Intermediate C/O Accretion Rates



Bravo et al. ‘96

Fig. 2. Evolution of the center of the star in the log T – log ρ plane for several different accretion rates: a) 10^{-10} $M_\odot$/yr; b) 5 10^{-10} $M_\odot$/yr; c) 10^{9} $M_\odot$/yr; d) 5 10^{9} $M_\odot$/yr; e) 5 10^{8} $M_\odot$/yr; f) 5 10^{7} $M_\odot$/yr; g) 5 10^{6} $M_\odot$/yr. The calculated values are represented by crosses, solid lines are to guide the eye. The dashed line is the ^{12}C ignition curve