30 Stars notes 2019/11/13 - Wed - thin shell; white dwarf masses

30.1 thin shell instability continued

Previously argued that a thin shell will have constant pressure, set by surface gravity and column depth. This leads to instability...

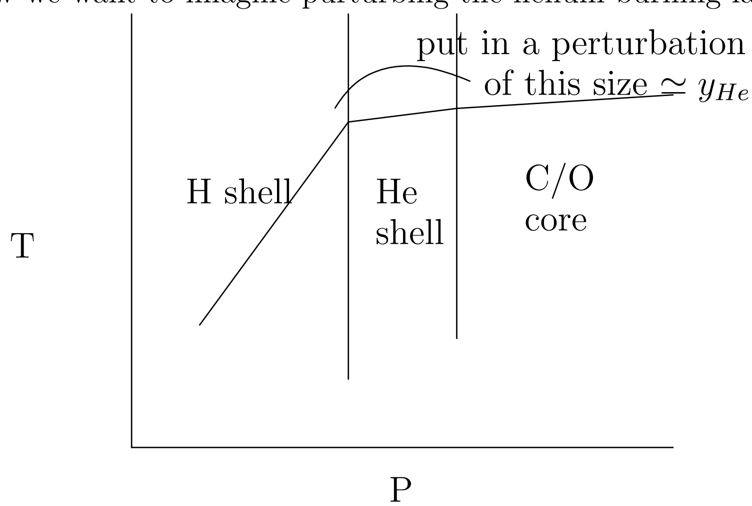
In the constant pressure limit ($dP = 0$), assuming s is a function of T and P, $s(T, P)$,

$$T ds = T \left(\frac{\partial s}{\partial T}\right)_P dT + T \left(\frac{\partial s}{\partial P}\right)_T dP = T \left(\frac{\partial s}{\partial T}\right)_P dT = c_P dT,$$

where we have used the definition of $c_P = dQ/dT$ at constant pressure. So we have

$$c_P \frac{dT}{dt} = \epsilon_{3\alpha} - \frac{1}{\rho}\frac{\partial}{\partial z}\left(\frac{c}{3\kappa\rho}\frac{\partial}{\partial z}(aT^4)\right)$$

now we want to imagine purturbing the helium burning layer as a whole,



(Note a small purturbation would be wiped out by diffusion, we need one the size of the He shell) so we write that

$$c_p \frac{dT}{dt} = \epsilon_{3\alpha} - \frac{acT^4}{3\kappa y^2} = \epsilon_{3\alpha} - \epsilon_{\text{cool}}$$

(second term is often called ϵ_{cool} You might think that you can just balance these two to get a steady state, the problem is that such a balance is unstable!

We want to show this. Imagine you have a solution where $\epsilon_{cool} = \epsilon_{3\alpha}$, neglecting ρ dependence (e.g. degenerate) we have

$$c_P \frac{dT}{dt} = \epsilon_0 \left(\frac{T}{T_0}\right)^{\nu} - \epsilon_0 \left(\frac{T}{T_0}\right)^4$$

this is unstable if $\nu > 4$. Recall ν is a strong power at the temperatures we consider. Since the helium birning has $\nu > 4$ the helium burning shell is thermally unstable.

$$\nu = 44/T_8$$

(this temp is set by the base of the Hydrogen shell.)

See plot below with cyclic Helium burning, Ritossa et al. These flashes succeed in mixing some of this stuff up to the surface of the star.

See also figures 24 and 26 from the first MESA instrument paper.

See also figures in Herwig 2005, ARA&A, 43, 435, particularly figure 3, as compared to figure 26 in the MESA paper.

Should stare at these convection diagrams (Kippenhahn diagrams) for a while, as they are complicated. Shows that the He burning covection zone and the outer H convection zone (i.e. the giant star's outer layers) – while the two convection zones never "touch" or merge, they do trade material by mixing into the same regions one after the other. This transports burning products out to the surface.

Ritossa et al ApJ 460 489 (1996)
10 M⊙ He Shell Pulses

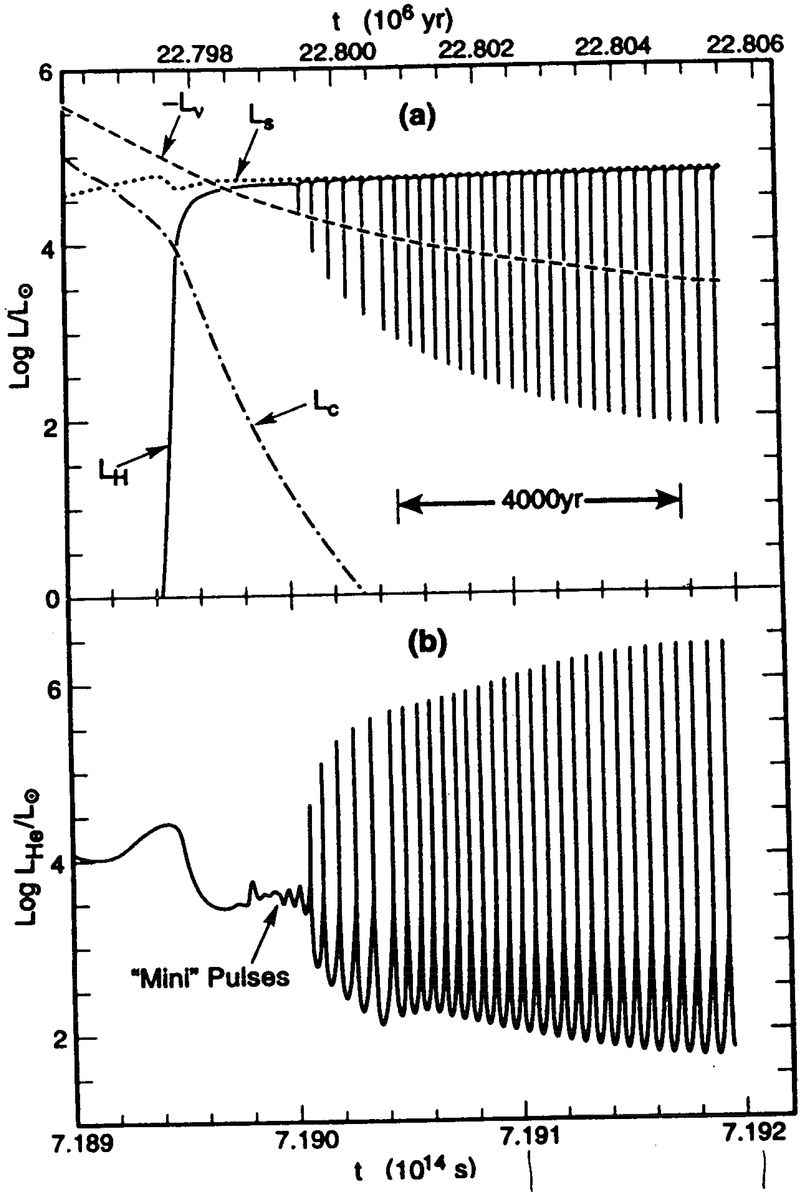


FIG. 12.—Reactivation of hydrogen-burning, demise of carbon-burning, and the onset of helium-shell flashes. (*a*) Time dependences of L_H (the hydrogen-burning luminosity), L_C (the carbon-burning luminosity), L_S (the surface luminosity) and $-L_\nu$ (the neutrino loss rate). (*b*) Helium-burning luminosity L_{He}.

$10^{-3} \cdot 10^{14} = 10^{11}$ sec
$\simeq 10^4$ yr.

30.2 Why are the White dwarf masses so much lower than the stars

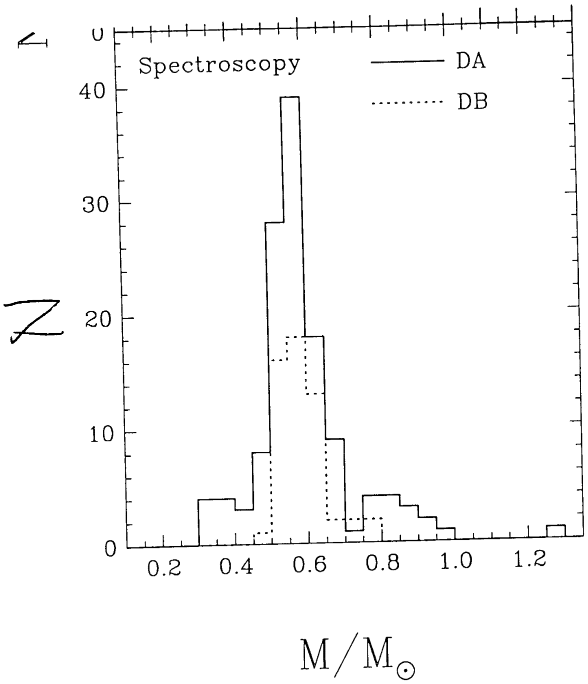
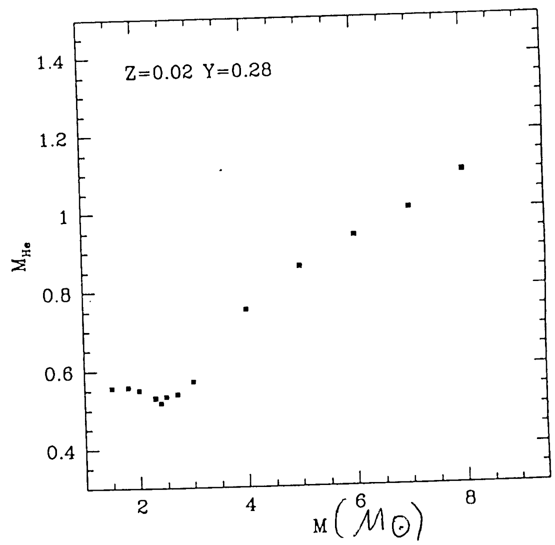


FIG. 22.—*Top panel*: Mass distributions for the hydrogen- and helium-rich atmosphere white dwarfs in our parallax sample. The mean mass of the hydrogen-rich subsample is $\langle M \rangle = 0.61\ M_\odot$ with a dispersion of $\sigma(M) = 0.20\ M_\odot$, and the corresponding values for the helium-rich subsample are $\langle M \rangle = 0.72\ M_\odot$ and $\sigma(M) = 0.17\ M_\odot$. *Bottom panel*: Mass distributions for hotter DA and DB stars determined from spectroscopic analyses. The mean mass and dispersion for the DA stars are $\langle M \rangle = 0.59\ M_\odot$, $\sigma = 0.13\ M_\odot$, and for the DB stars $\langle M \rangle = 0.59\ M_\odot$, $\sigma = 0.06\ M_\odot$.



Core mass at beginning of AGB.

The rate at which the C/O core grows in mass is set by the rate of hydrogen burning. There is a luminosity- coremass relation,

$$L = 6. \times 10^4 L_\odot (M_c - 0.5 M_\odot)$$

(weak dependence because the hydrogen burning is so hot that it has lost some of it's temperature sensativitiy) The characteristic time is

$$\tau = \frac{M_{C,O}}{\dot{M}_{C,O}} = 4 \times 10^6 yrs$$

This happens very quickly. In order to get the mass down during this trip up the AGB, one needs massive winds. These stars have these winds of $10^{-6} M_\odot / yr$.

Just to consider, if there were no mass loss, the C/O core would grow until the H envelope was exhausted. The intervention of the Chandrasekhar mass $M_{Ch} = 1.4 M_\odot$ for a white dwarf, at which point ρ increases until the C ignites. This might finally lead to an explosion? some interesting questions here.

Rather observations show that mass loss poceeds at $\dot{M} \simeq 10^{-6} M_\odot/yr$ and most of the envelope is sent to infinity. Really just a coincidence that the mass loss is enough to prevent the nova. (So one needs to be careful at low metallicity since the mass loss depends on metals.) We know there is dust formed in the photosphere. We think that the mass loss is driven by radiative forces on dust grains in the photosphere. The dust grains can change the opacity per gram (increaseing it), and then effectively change the Eddington limit (decresing it).

So now, What kind of dust? All the C and O forms CO. Thus:
O > C implies that there is O leftover
C > O implies that C leftover so you get graphite
Studying the isotopic ratios of dust grains tells us that most of the dust in the ISM forms in these AGB stellar winds. The hydrogen burning (with catalysts!) modifies this balance of C verses O.

30.3 Initial-final mass functions

Can measure correspondence of initial (ZAMS) mass to final (WD) mass observationally. Knowing the age of the cluster and the age of the white dwarf you can figure out what mass star the white dwarf came from. This constraints how much mass was lost.

From 2010ApJ...717..183R, Renedo et al 2010, figure 2:

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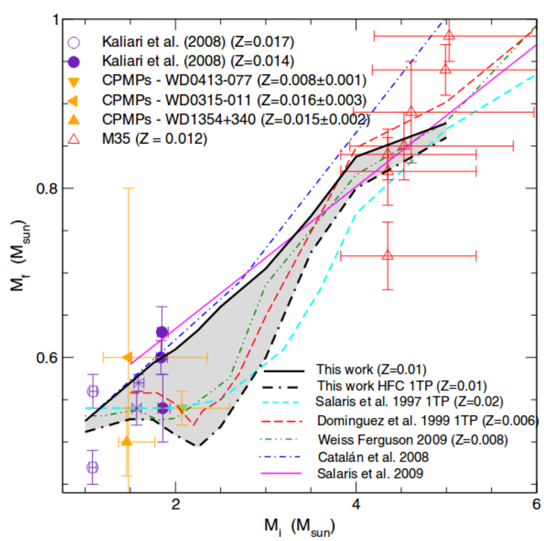

Figure 2. Theoretical initial-to-final mass relationship (thick solid line) and mass of the degenerate core at the beginning of the first thermal pulse (thick dot-dashed-dashed line) obtained in this work, both for the case in which the solar composition is adopted. The initial-to-final mass relationships of Salaris et al. (1997; short dashed line), of Domínguez et al. (1999; long dashed line), and of Weiss & Ferguson (2009; dot-dot-dashed line) are also shown. The observational initial-to-final mass relationship of Catalán et al. (2008a) and Salaris et al. (2009) are the dot-dashed and solid lines, respectively.

For $M < 2M_\odot$ end core He burning with $M = 0.5M_\odot$ cores. (all built up 0.45 helium cores) Some added after that.

$2M_\odot < M$ – These basically have the same evolution as the lower mass case, BUT did not undergo the initial He core convergence. and so on average have smaller fractional C/O core masses.

From 2014ApJ...782...17K Kalirai et al 2014 (they give it in terms of mass added on the AGB, since models agree fairly well on the initial AGB core mass). Points are averages inferred from observed clusters:

THE ASTROPHYSICAL JOURNAL, 782:17 (12pp), 2014 February 10 KALIRAI, MARIGO, & TREMBLAY

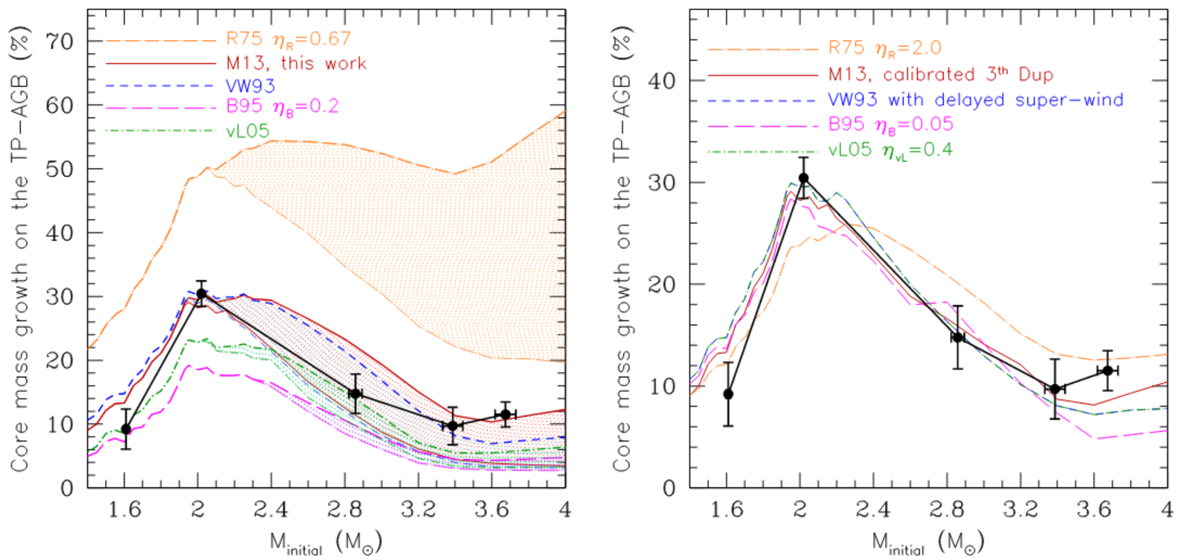

Figure 4. Same as in Figure 3, but showing the predictions with five different descriptions for mass loss on the TP-AGB phase, namely: the Reimers law (R75; orange curves), our reference prescription (Marigo et al. 2013; red curves), the Vassiliadis & Wood (1993, VW93; blue curves), the Blöcker (1995, B95; magenta curves), and the van Loon et al. (2005, vL05; green curves). Left panel: for each mass-loss case, the hatched region encompasses the range of core mass growth expected when varying the third dredge-up efficiency between two extremes, namely: $\xi_\lambda = 1$ (the original K02 prescription; thin line) and $\xi_\lambda = 0$ (no dredge-up; thick line). The latter case corresponds to the maximum growth of the core mass allowed by the corresponding mass-loss relation. Right panel: results obtained with modified versions of the same mass-loss prescriptions (except for the Marigo et al. 2013 case), adopting suitable efficiency parameters or revised relations so as to approach the observational constraints in our study.

Earlier handout this time had number distribution of white dwarfs in mass. Most are at $0.6M_\odot$. This is just that there are more $2M_\odot$ stars than $6M_\odot$ stars.