Stellar evolution update for <8$M_\odot$ [and implications for accreting WD] and maximum mass that makes a White Dwarf

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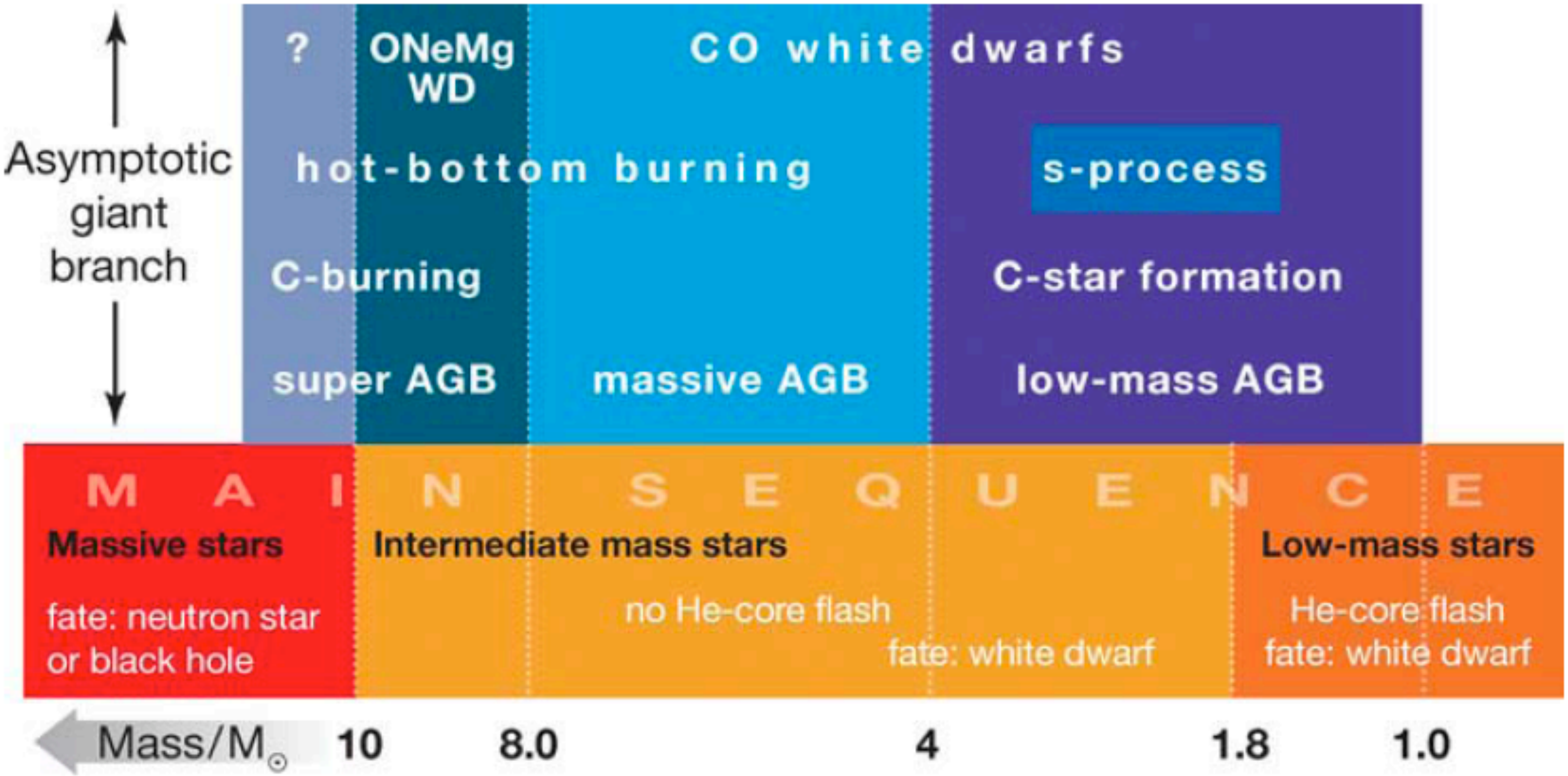
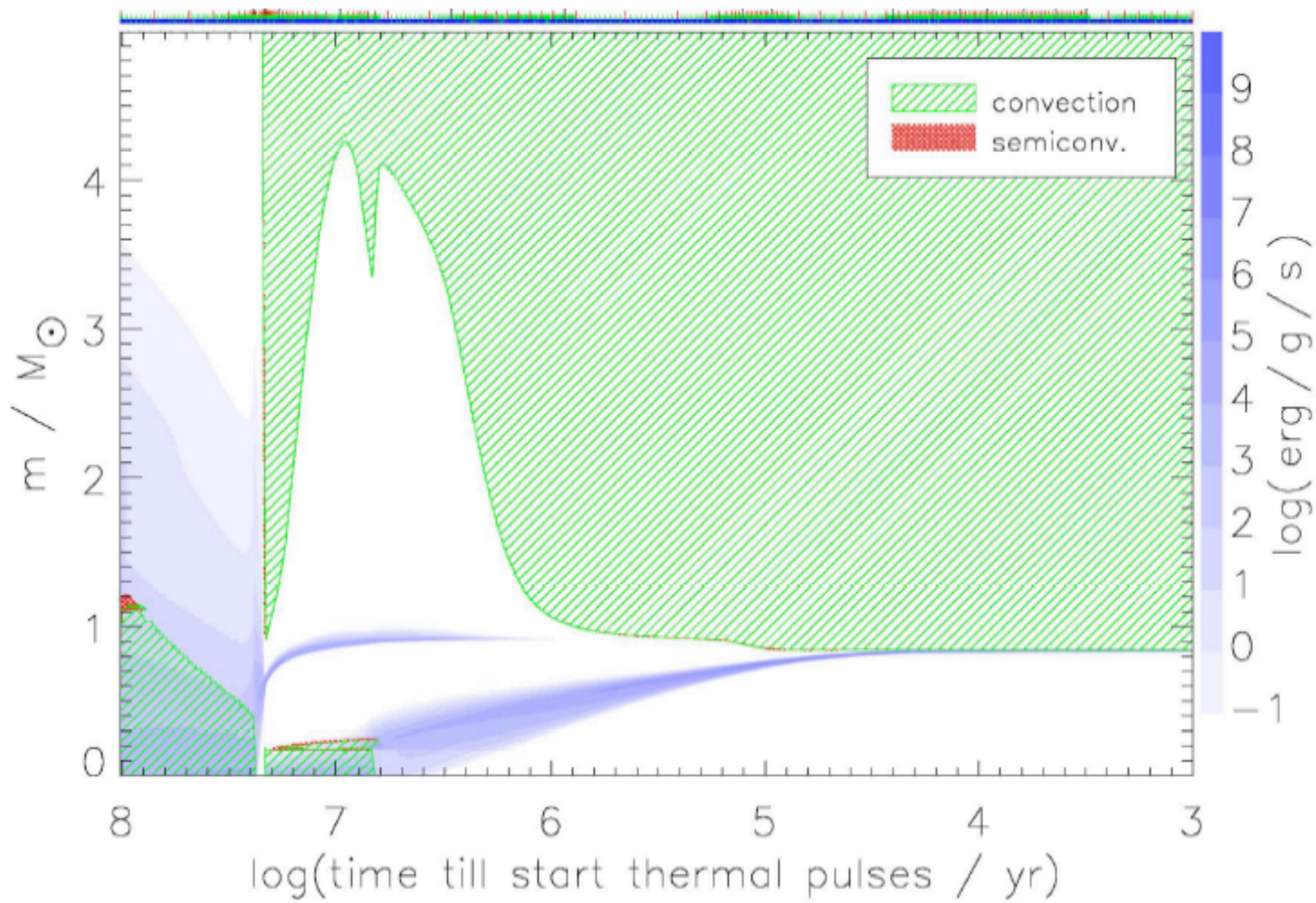
Initial mass and evolutionary outcome for intermediate mass stars



Herwig 2005, ARAA 43, 435

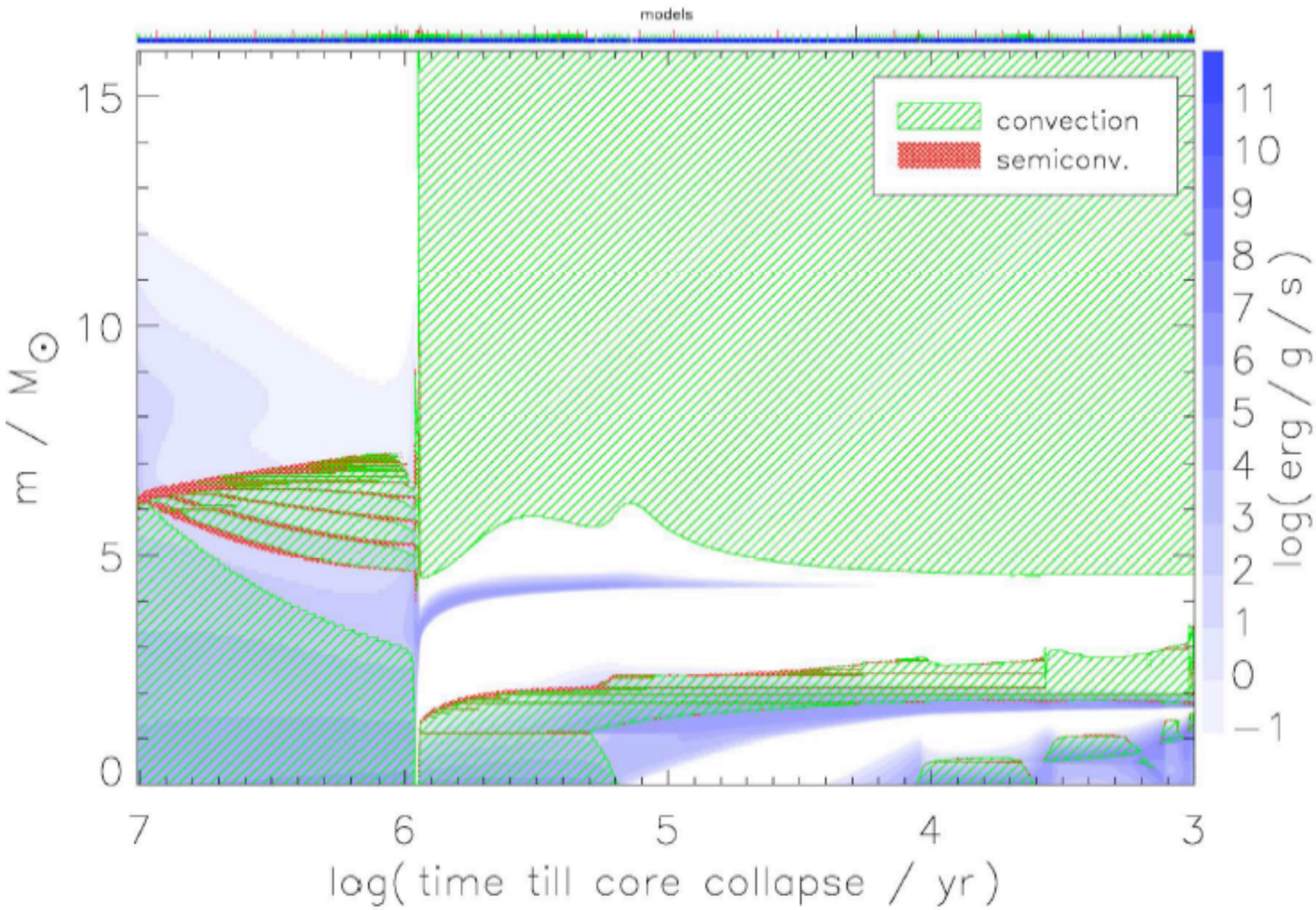
$M_{ZAMS} = 5M_{\odot}$ -> massive AGB star → N,O-rich giant star
↓
CO white dwarf

Poelarends etal (2007)



$M_{ZAMS} = 16M_{\odot}$ -> massive star -> Fe core-collapse

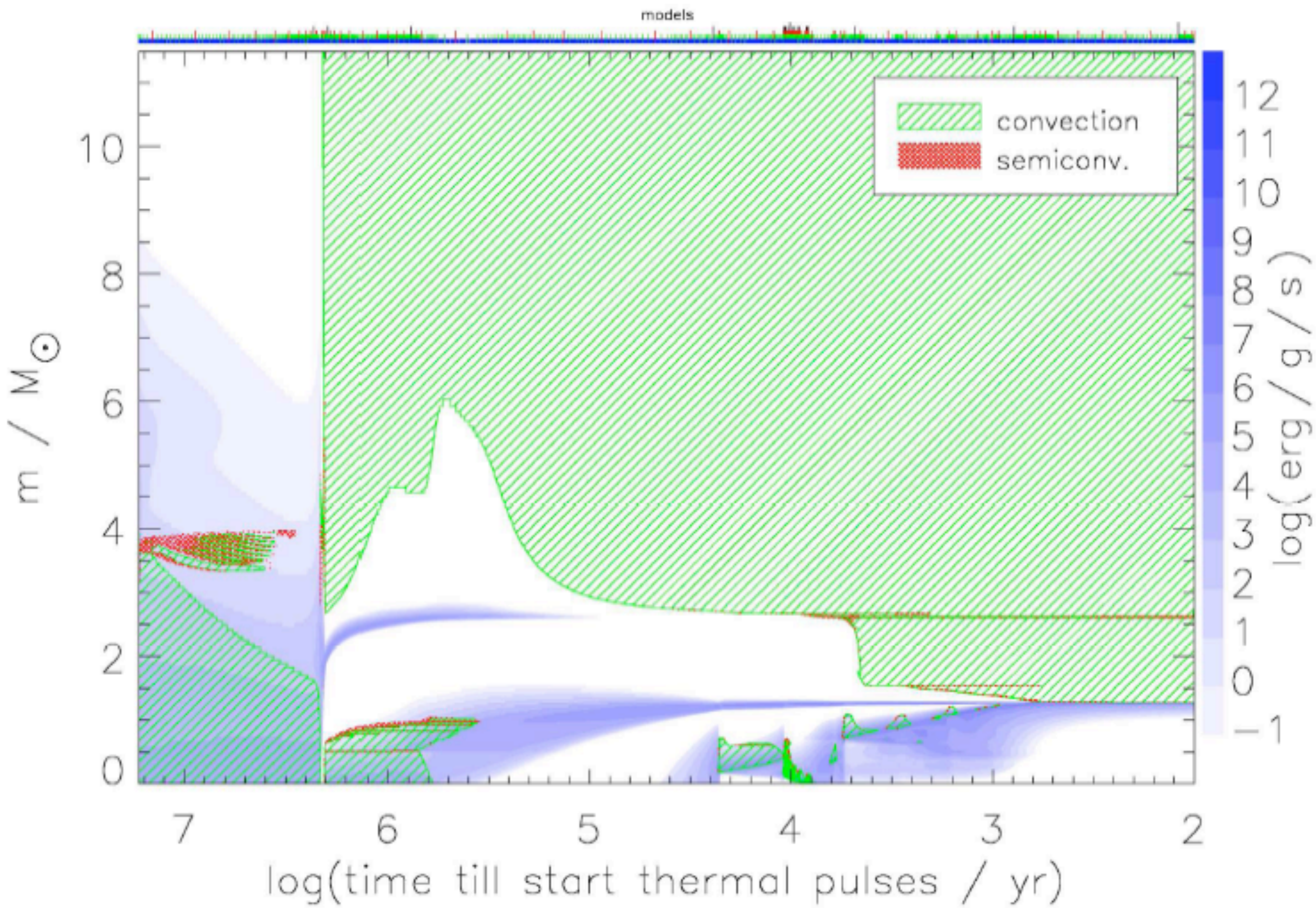
Poelarends etal (2007)

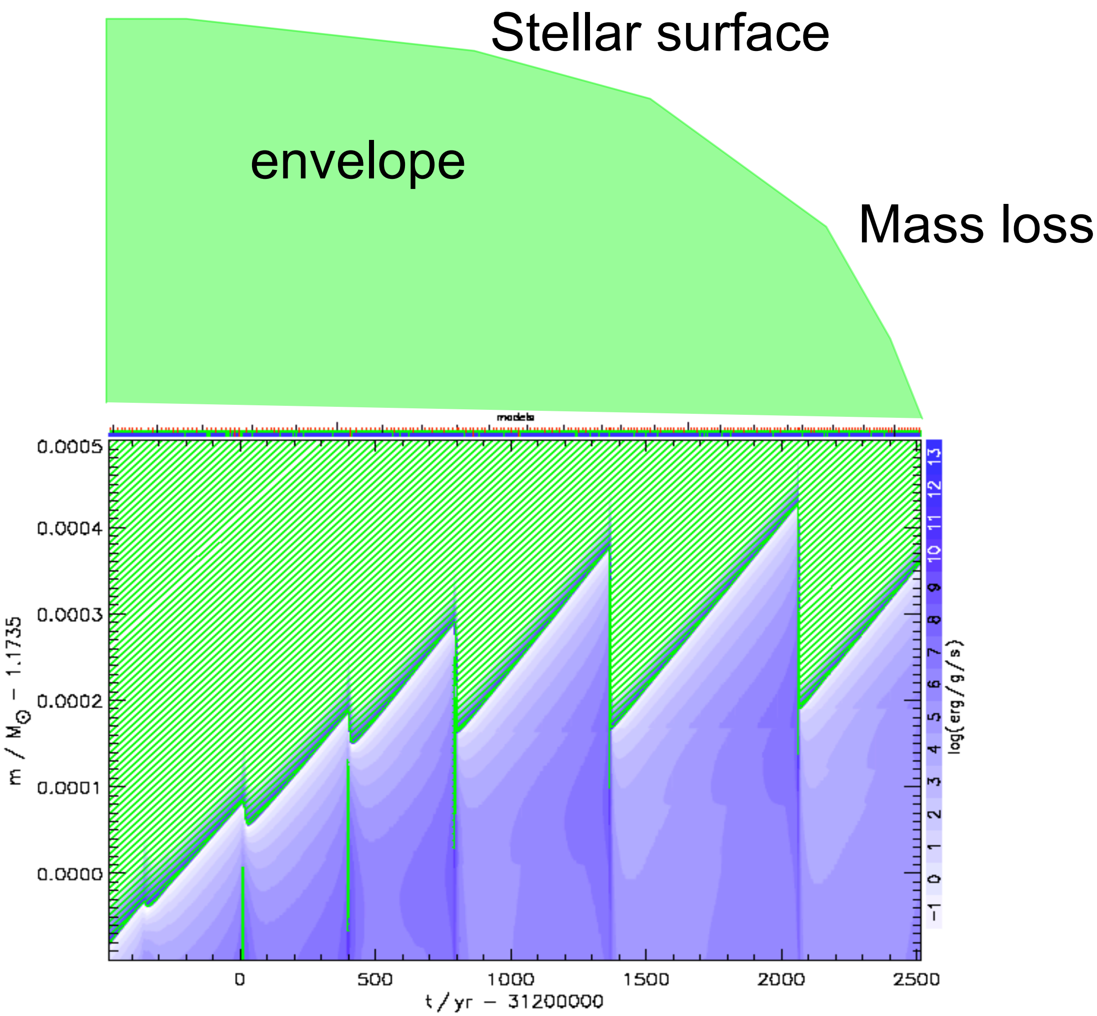


$M_{ZAMS} = 11.5M_{\odot}$ -> super-AGB star → ONe white dwarf

→ e^--capture core-collapse supernova

Poelarends etal (2007)

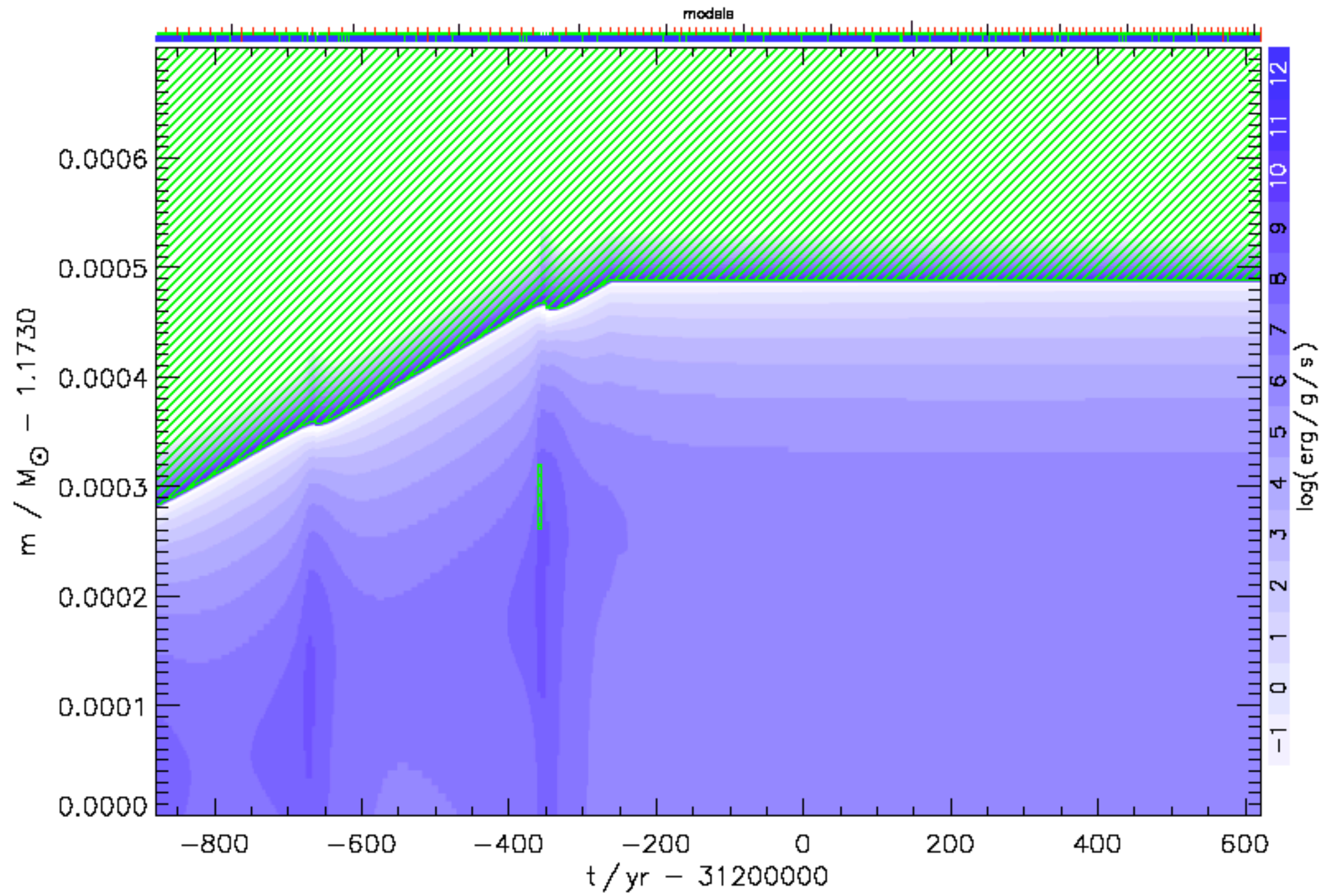




- Mass loss: How much time is there to grow the core to CC?
- How fast does the core grow?
  - Dredge-up: depends on convection and nuclear physics
  - Hot-bottom burning: depends on convection

One of the sources of uncertainty:

Hot-bottom burning: depends on convection

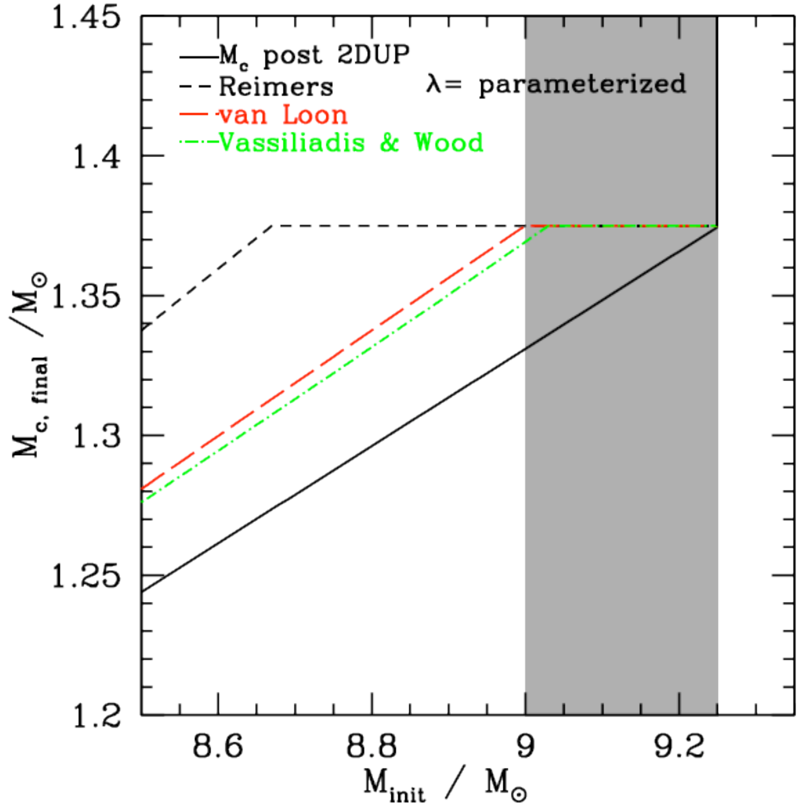


Depending on convection parameters one might encounter a stationary shell-burning without effective core growth at all.

Some super-AGB evolution results

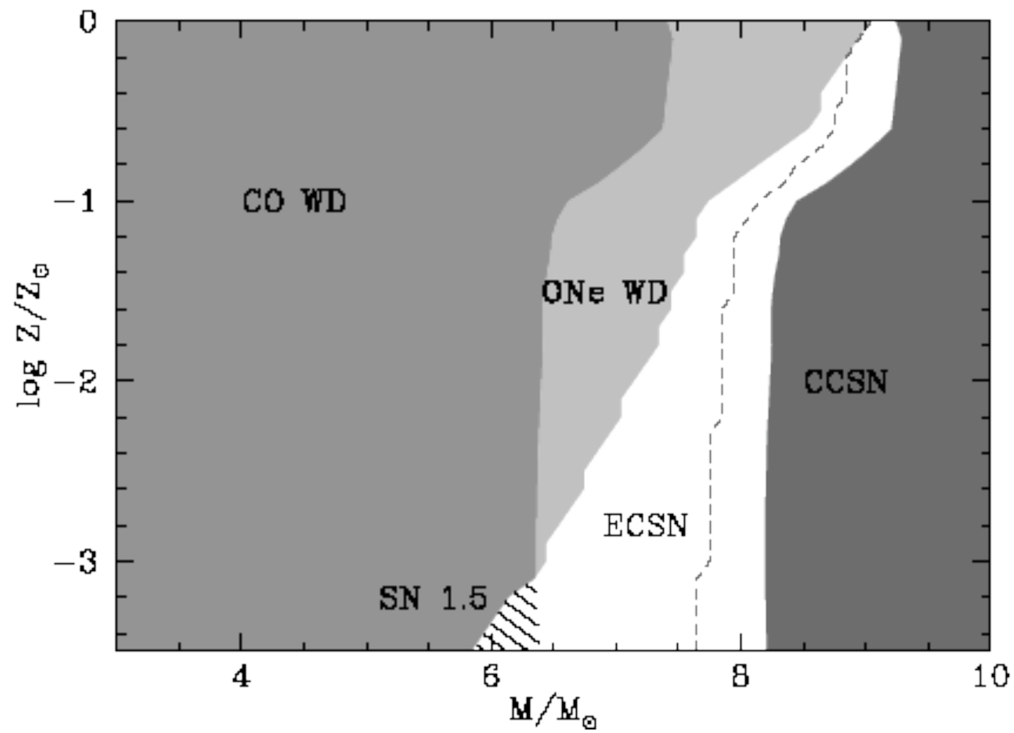
(Poelarends, Langer, Herwig, Heger)

Initial-final mass relation for Z=0.02



Poelarends etal 2007a, submitted

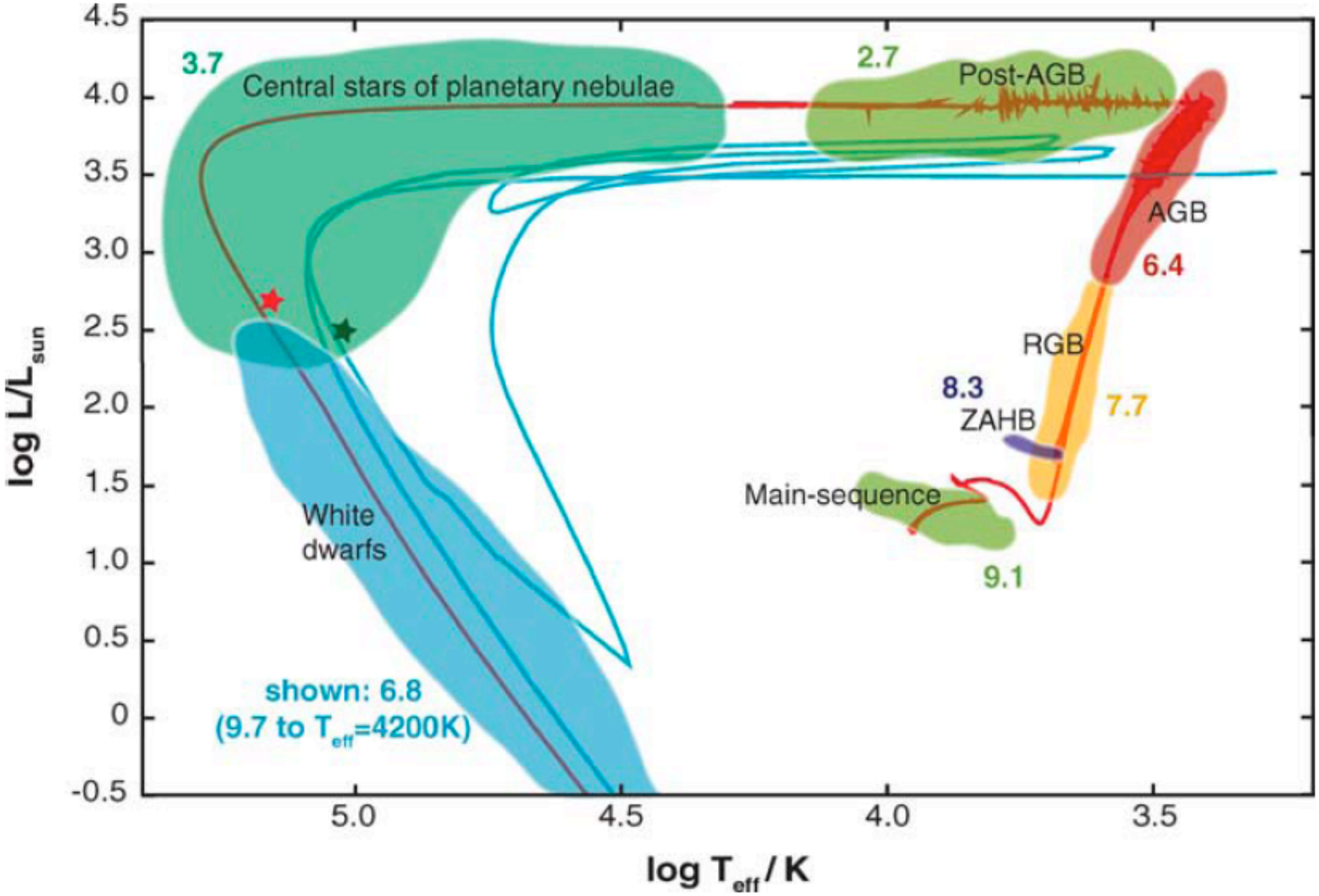
Evolutionary outcome according to synthetic model as a function of metalicity and mass



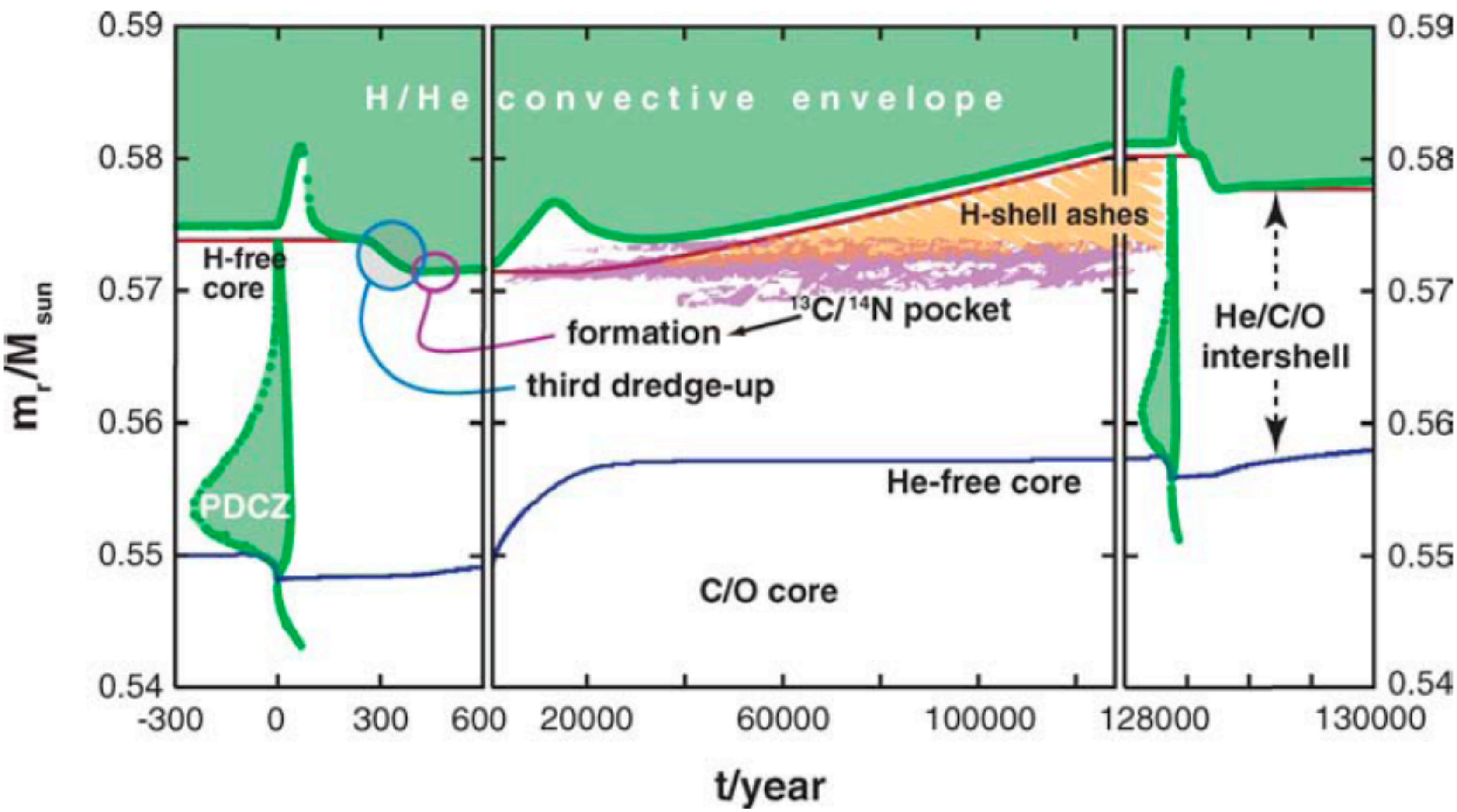
Poelarends etal 2007b, in prep.

Related work by Ritossa etal. 1996, Siess 2006, Garcia-Berro etal. 1997, Iben etal 1997

Evolution of single intermediate mass stars from the main sequence to the white dwarf stage

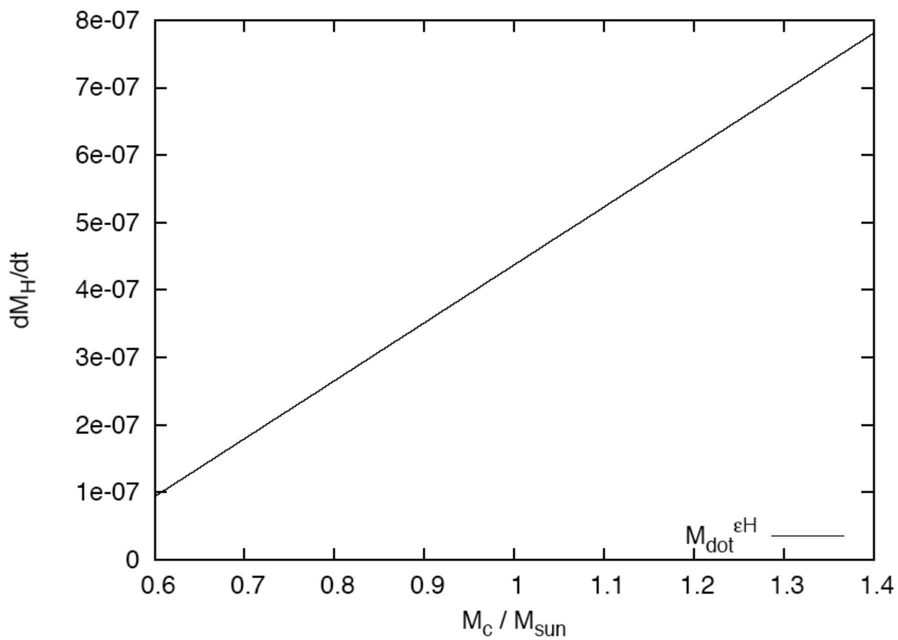


Evolution of burning H- and He-shell and convection zones



Some well-known properties of AGB stellar evolution

Linear core-mass luminosity relation

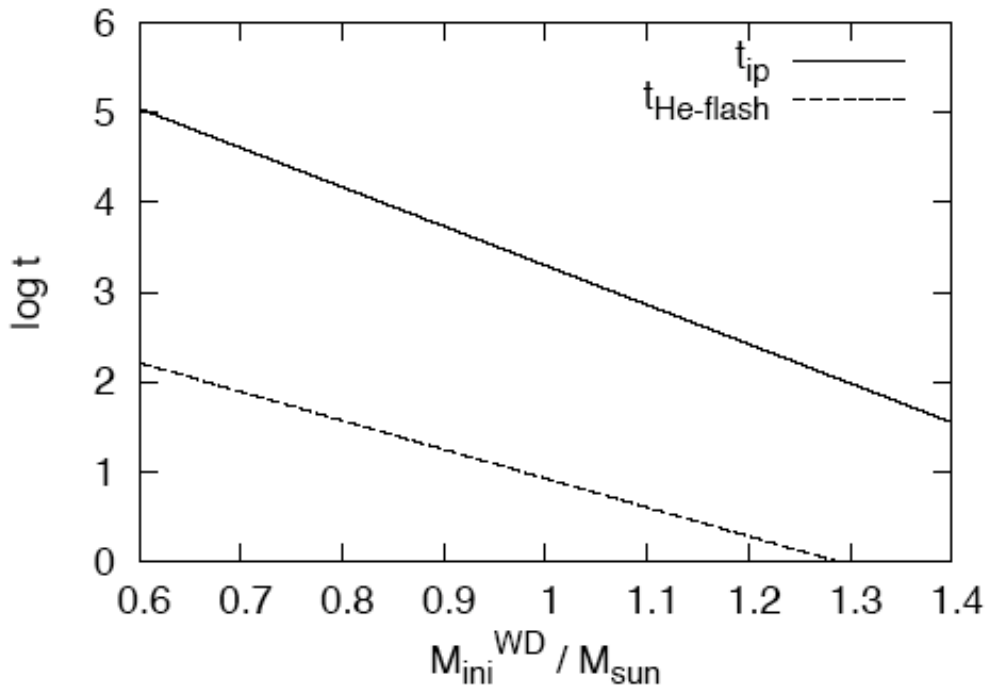


For most of the time the AGB star is quiescently burning H:
$M'_H = L_{Hyd}/X_H Q$
L_{hyd}: H-shell burning luminosity
X_H: H-mass fraction
Q: energy released per mass unit

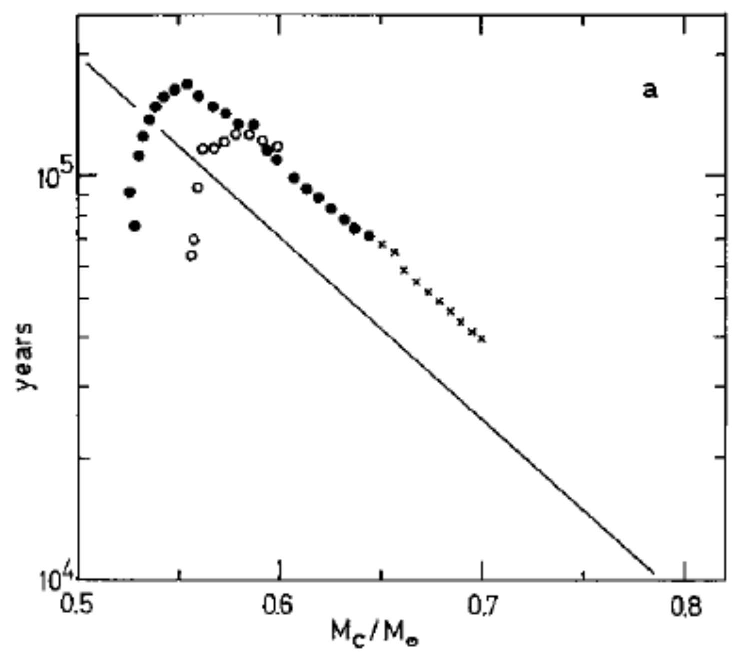
This one is from Mowlavi 1995, but there are as many as people who have ever run an AGB stellar evolution model.

Some well-known properties of AGB stellar evolution

Core-mass inter-pulse relation and core-mass He-flash duration relation

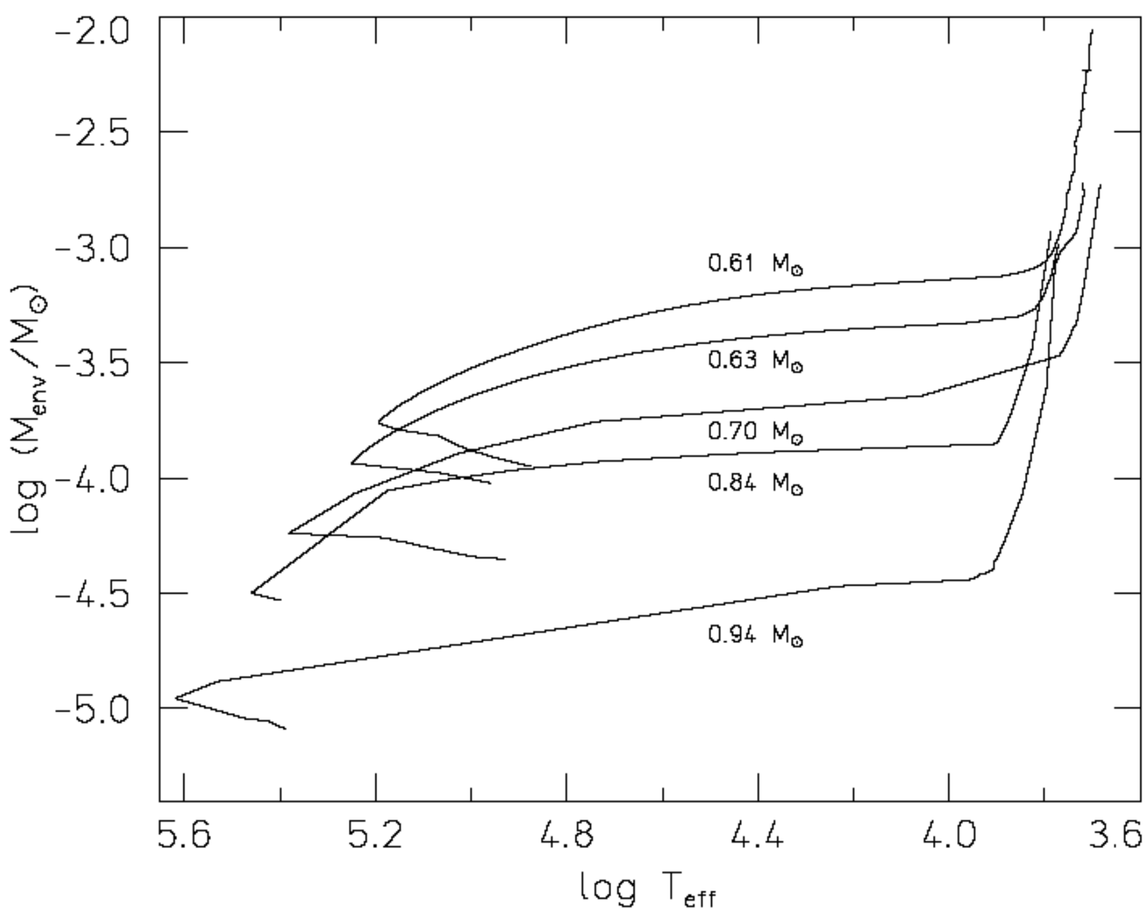


Mowlavi 1997



Schönberner 1979

Envelope mass for post-AGB tracks: M_{env} determines the position of the star on the post-AGB track



Schoenberner 1981, Bloecker 1995b

M'_{env} = - M'_{nuc} - M'_{wind}

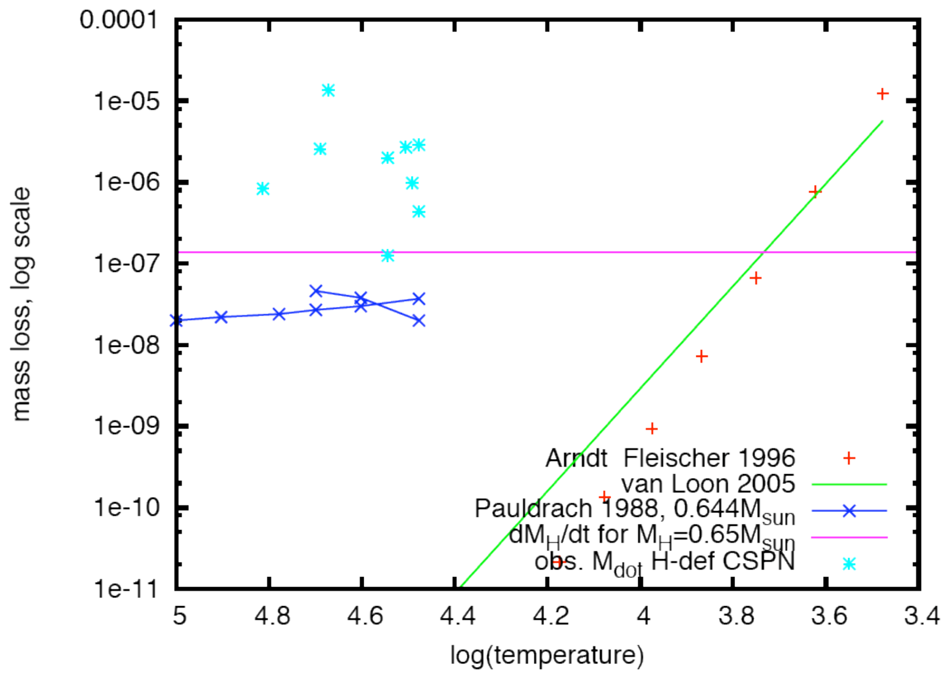
M'_{wind}: Radiatively driven wind of Pauldrach (1988) -> mass loss (following Bloecker 1995b)

$$\dot{M}_{\rm CPN} = 1.3 \cdot 10^{-15}\, L^{1.9}$$

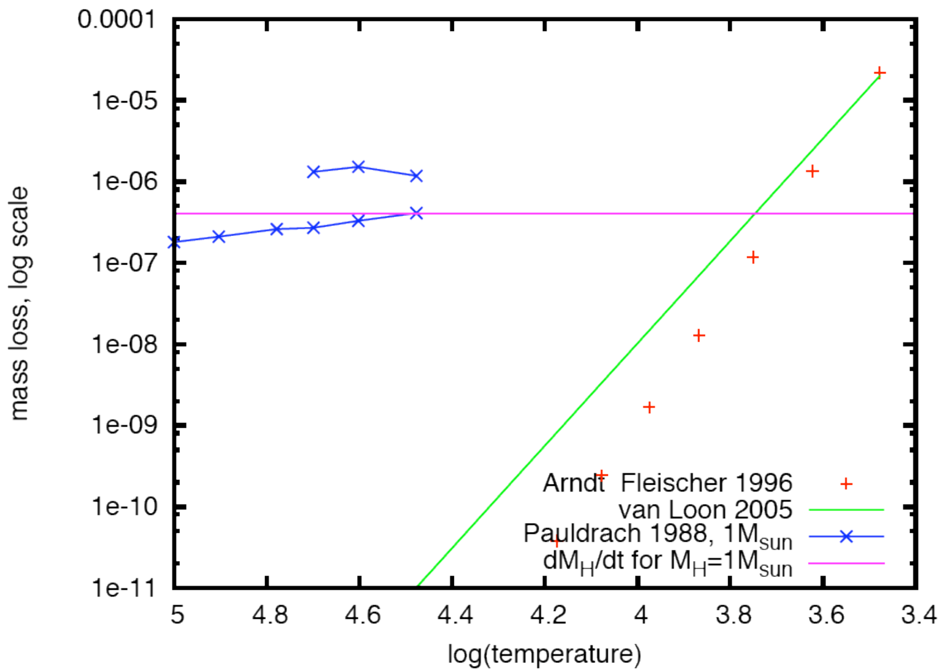
M'_{nuc}: follows from the core-mass luminosity relation

Wind mass loss for post-AGB / hot WD (rad. driven) and AGBs (ra./dust driven)

$M_{WD}=0.65M_\odot$

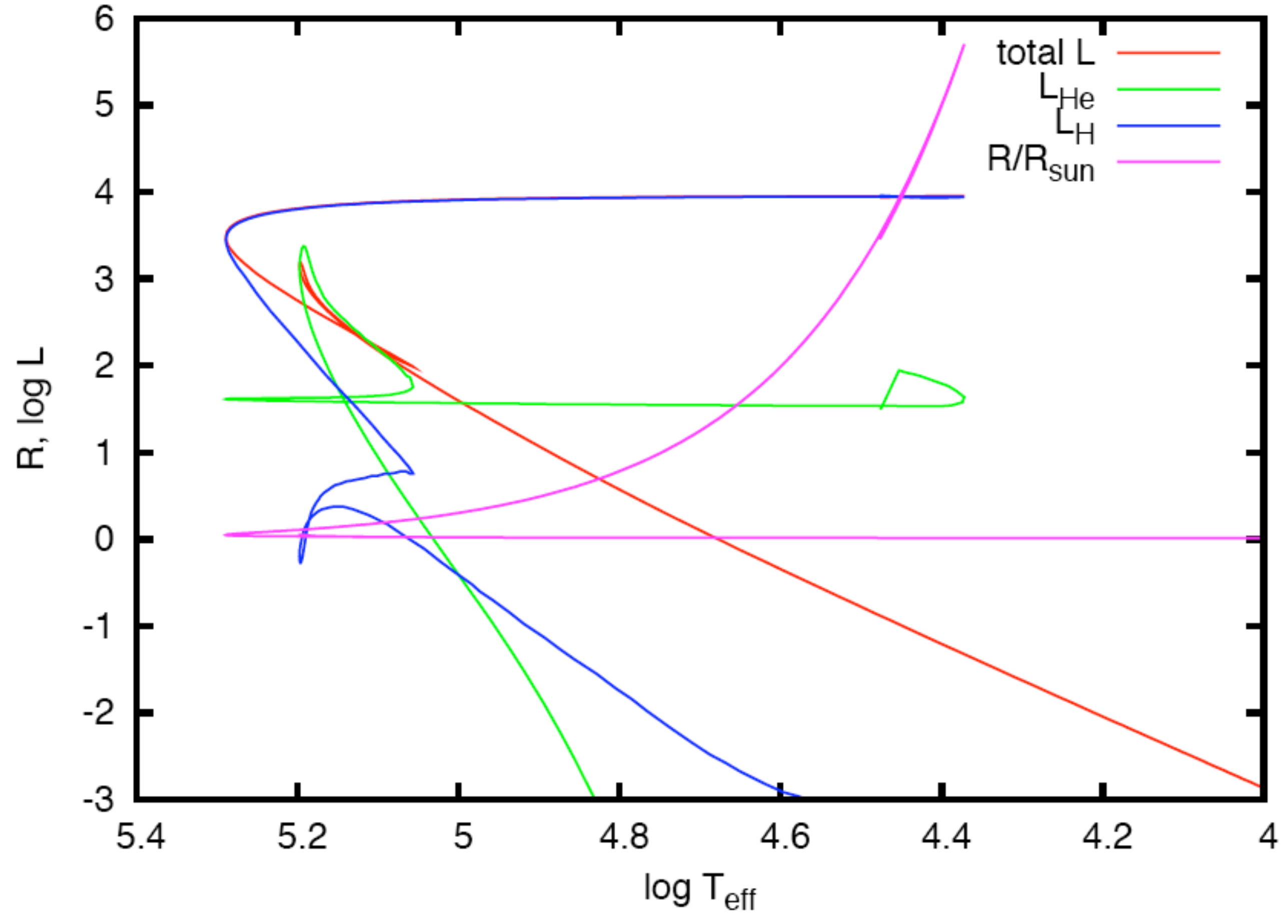


$M_{WD}=1.0M_\odot$



The radiative wind mass loss M'_{wind} is a substantial fraction of the nuclear burn rate $M'_{nuc.}$ For large M_{WD}: $M'_{wind} > M'_{nuc}$!

Single post-AGB to WD evolution

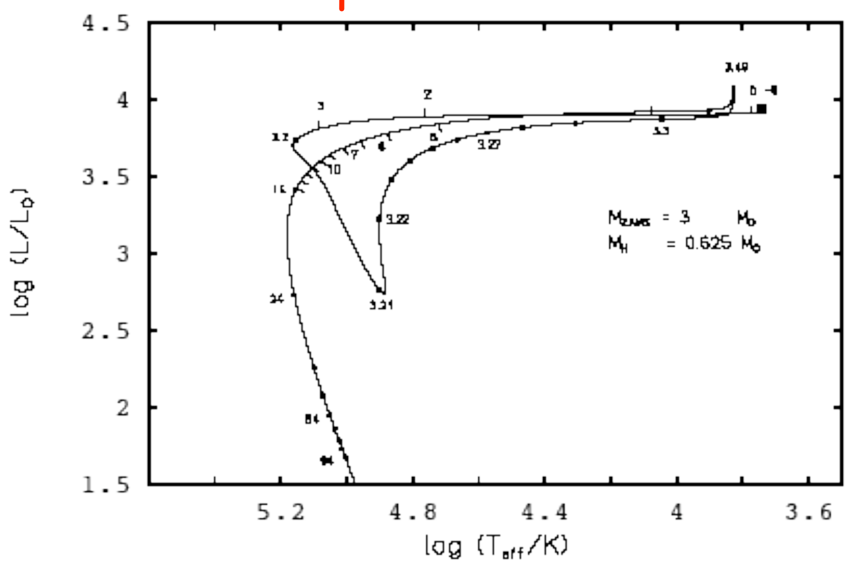


On the horizontal L=const part of the track $L = L_{hyd}$

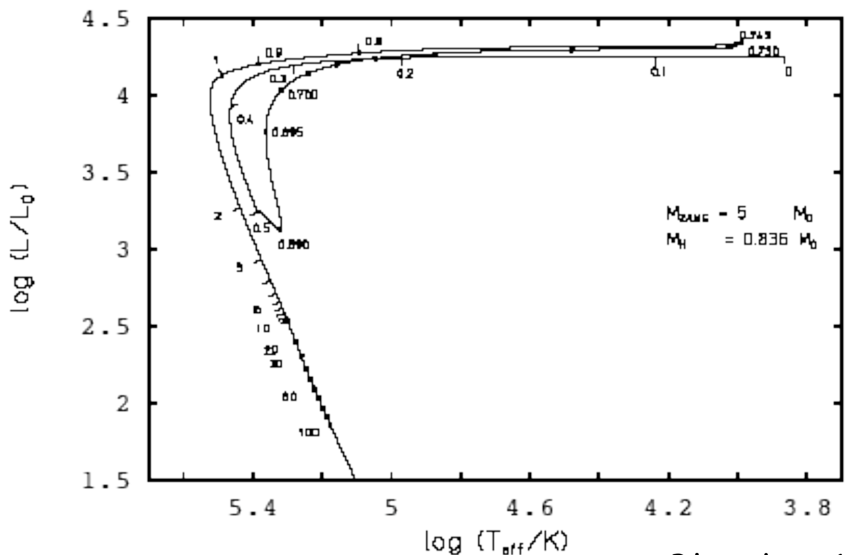
At the 'knee' M_{env} too small to support H-shell, L_{hyd} drops

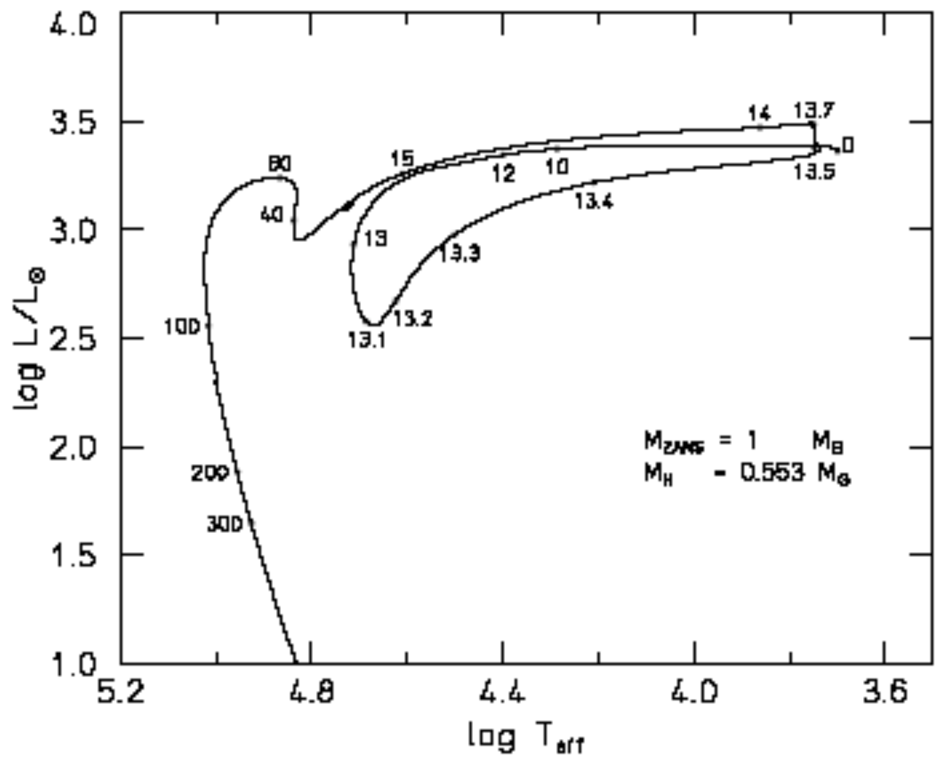
Tiny He-shell!

He-shell flashes in post-AGB / hot WD single stars are as common phenomenon in stellar evolution



Known as 'born-again evolution' in the literature

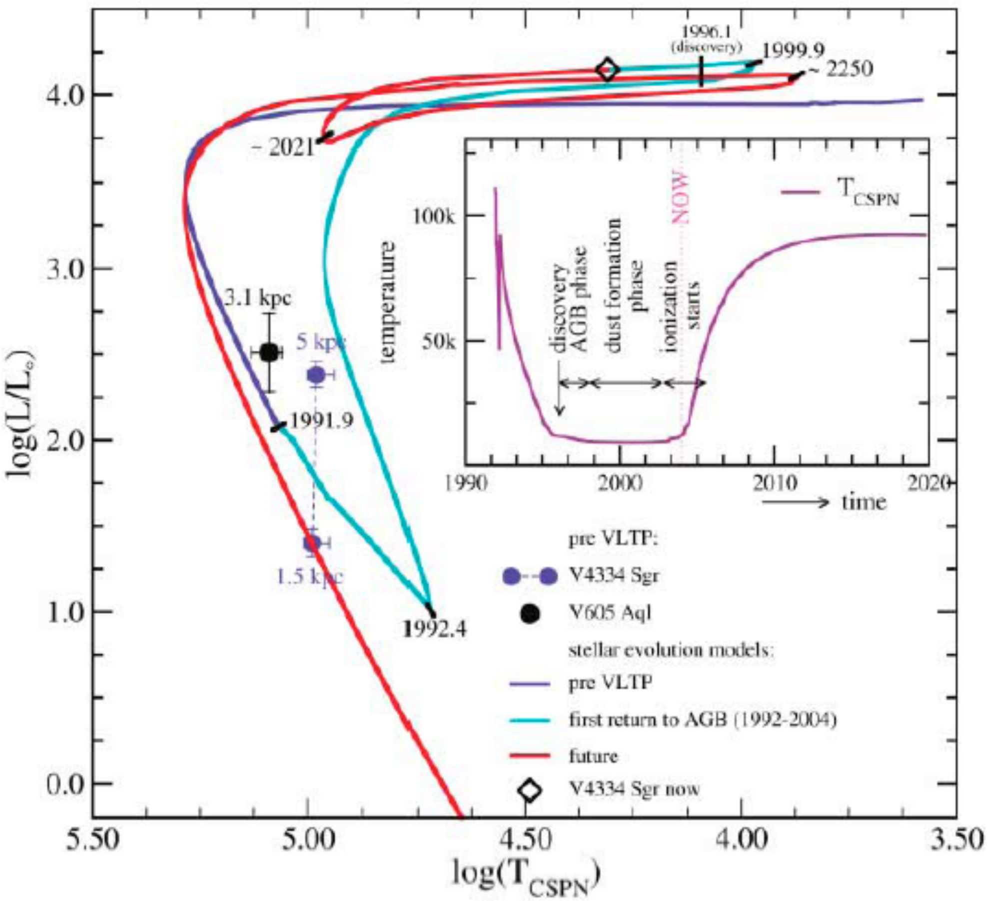




Bloecker 1995b

Some well-known properties of post-AGB stellar evolution

Young WD make He-shell flashes: born-again evolution



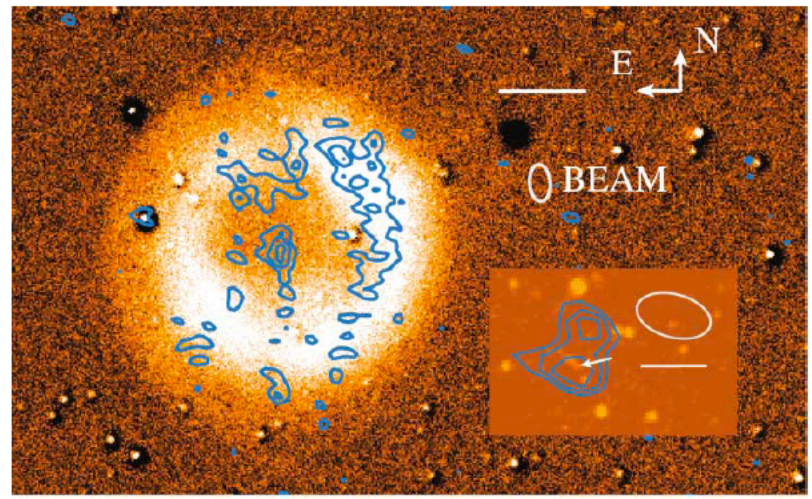
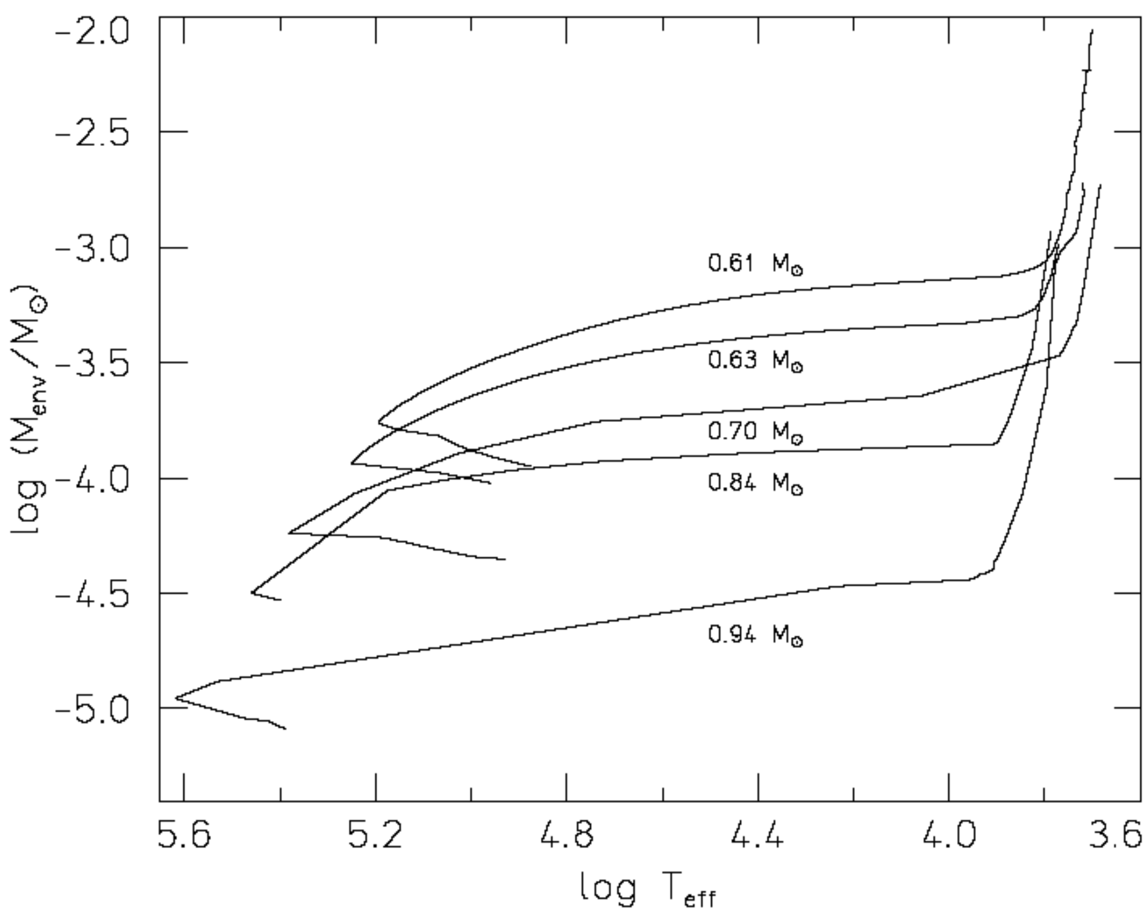


Fig. 1. Continuum-subtracted O^{2+} image showing the extended planetary nebula. Radio (8.6 GHz) contours are shown superposed at 30, 50, and 70 μJy per beam. A natural weighted map (beam of 4.2 × 2.4 arc sec indicated by the oval) is shown. Scale bar, 10 arc sec. (Inset) An HST I-band (F814W) image taken 29 August 2001. Sakurai's object (fainter of the two components, 0.2 arc sec apart) is indicated by an arrow. The superposed radio data show a uniform weighted map (beam of 2.2 × 1.3 arc sec, indicated by the oval) with contours at 25, 35, and 45 μJy per beam. The old planetary nebula is 41 arc sec in diameter; its brighter inner ring is 29 arc sec across. Scale bar, 2 arc sec.

Hadjuk etal, Science 2005

Envelope mass for post-AGB tracks: M_{env} determines the position of the star on the post-AGB track



Schoenberner 1981, Bloecker 1995b

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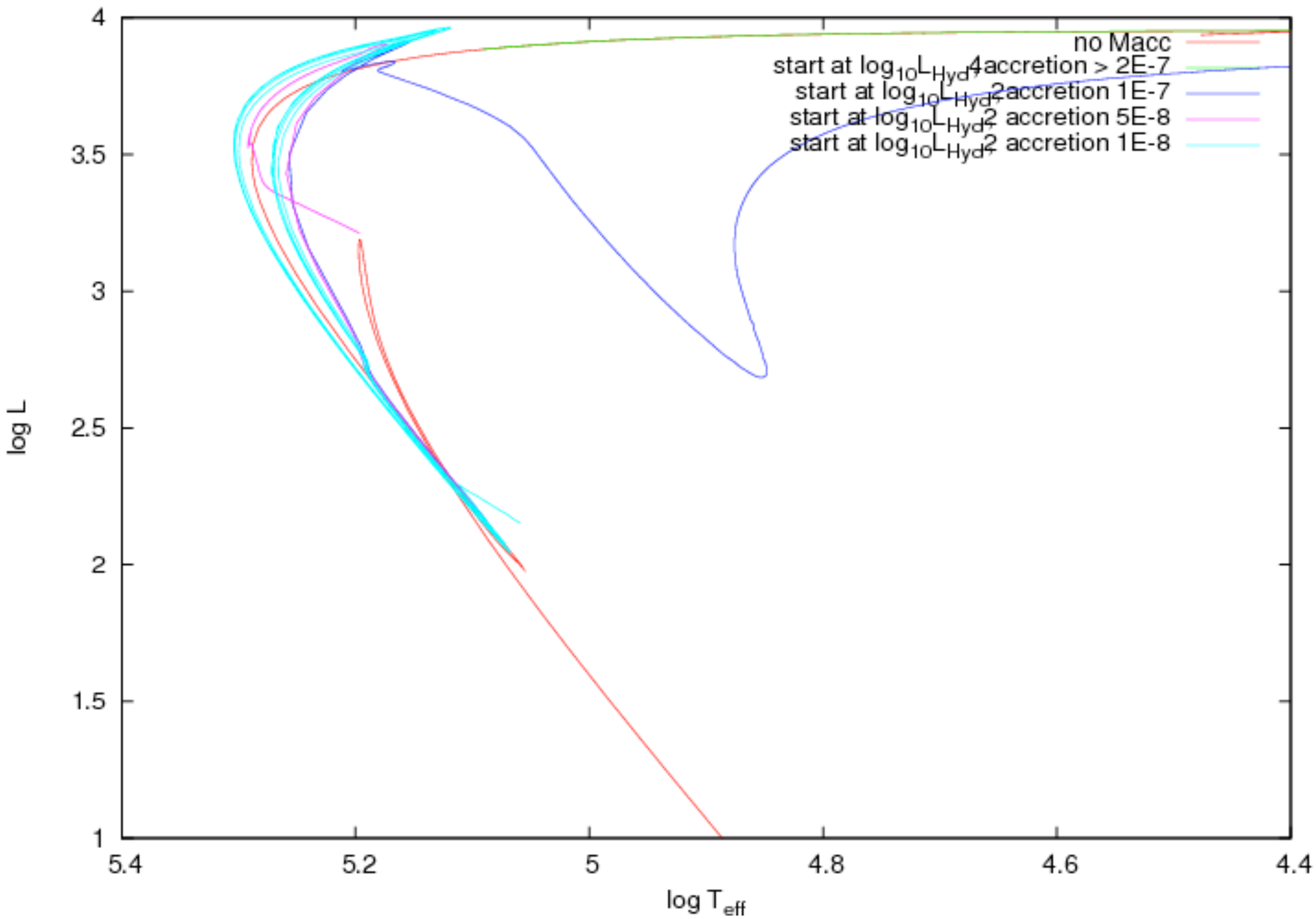
M'_{wind}: Radiatively driven wind of Pauldrach (1988) -> mass loss (following Bloecker 1995b)

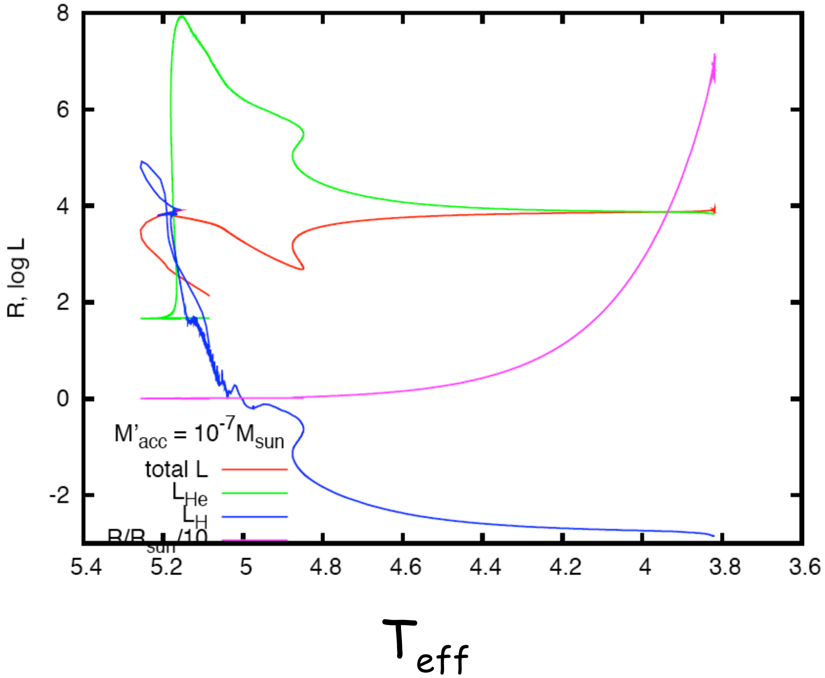
$$\dot{M}_{\rm CPN} = 1.3 \cdot 10^{-15} L^{1.9}$$

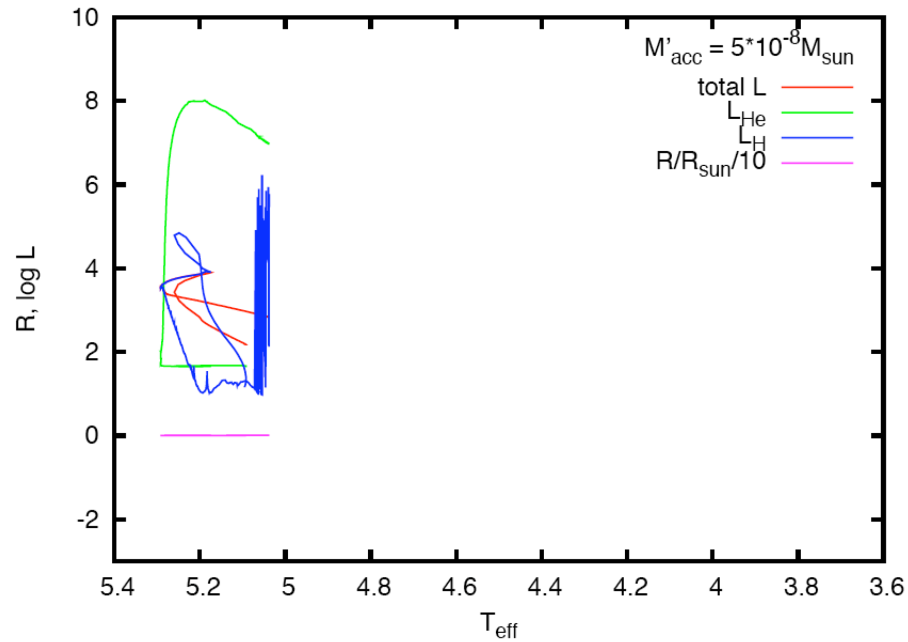
M'_{nuc}: follows from the core-mass luminosity relation

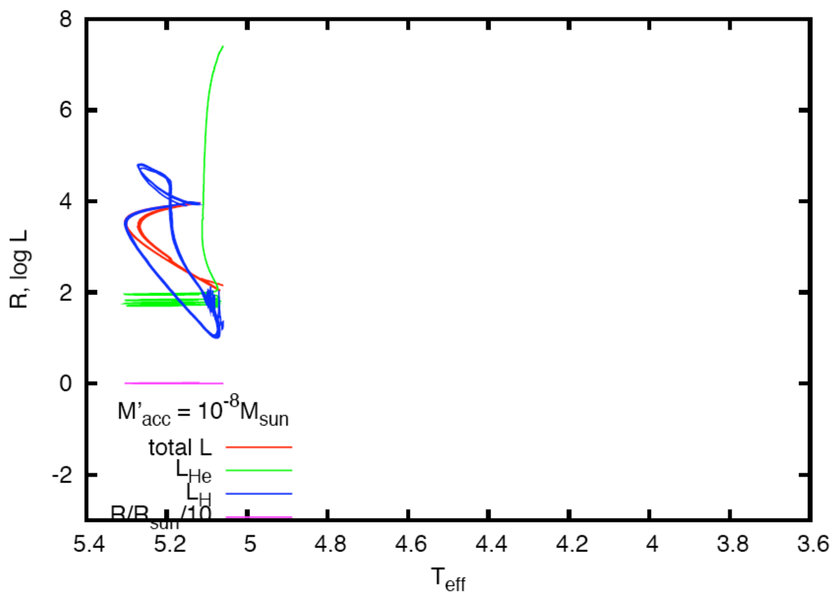
$M'_{env} = - M'_{nuc} - M'_{wind} + M'_{acc}$

Where are the accreting WD? $M'_{env}=0 \rightarrow -M'_{acc} = -M'_{nuc} - M'_{wind}$




R, log L
M'acc = 10-7Msun
total L
LHe
LH
R/Rsun/10
Teff

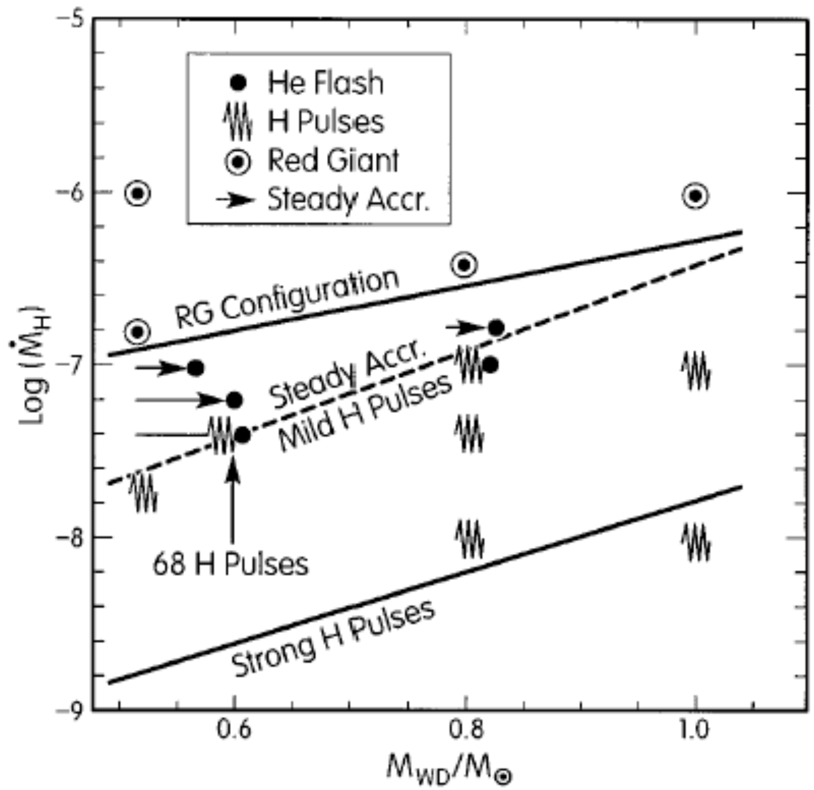

M'acc = 5*10-8Msun
total L
LHe
LH
R/Rsun/10
R, log L
Teff


R, log L
M'acc = 10-8Msun
total L
LHe
LH
R/Rsun/10
Teff

Implications:

No matter how stable the H-burning is - accreting WD will make He shell flashes on their evolutionary path toward SNIa! (Cassisi, Iben, Tornambrè 1998).

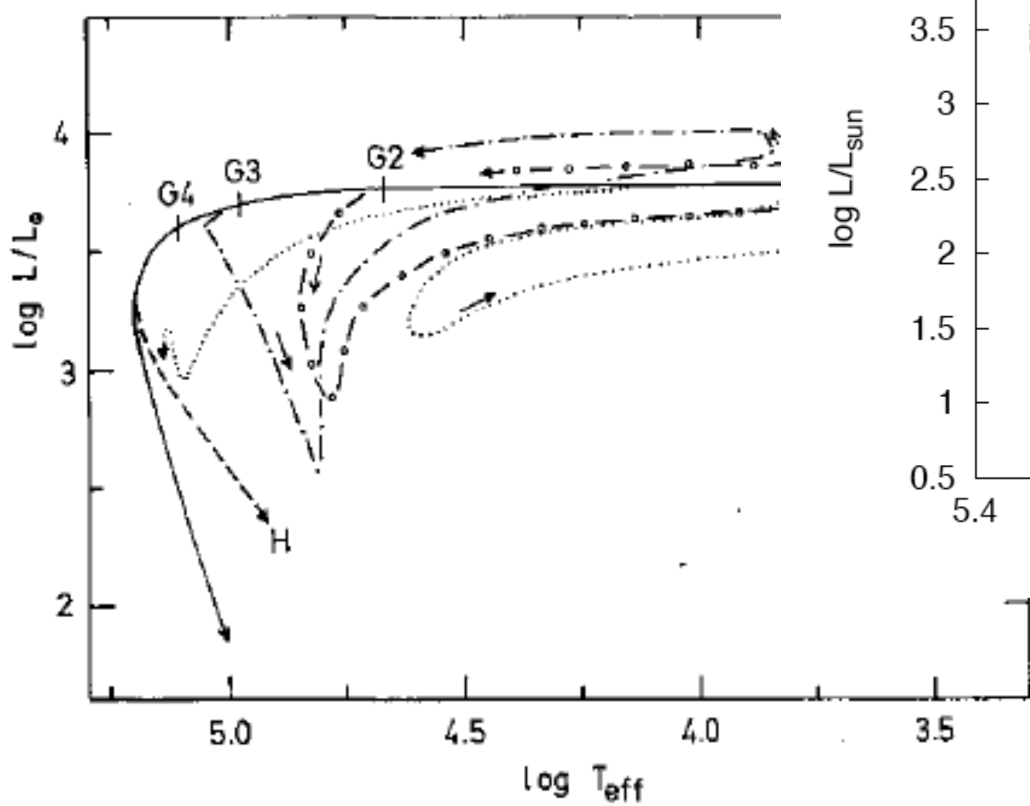
These flashes are 'born-again' like, leading the star back to the AGB, inducing wind mass loss that will affect the further evolution.

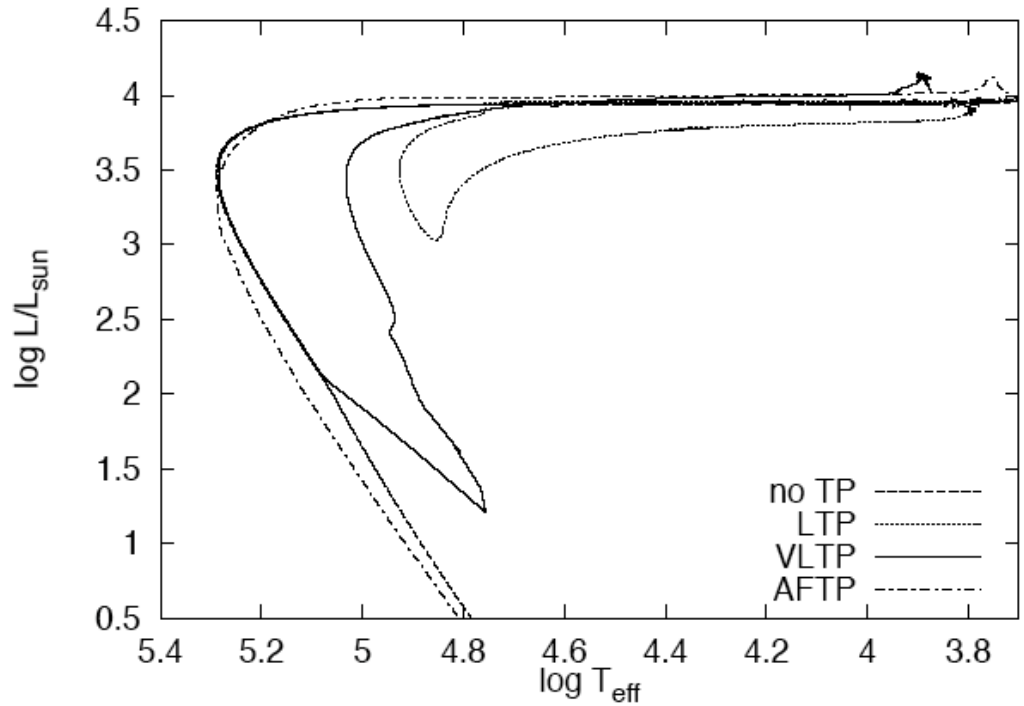


Cassisi etal 1998

Depending on M'_{acc} (which determines the pre-He flash position on the post-AGB track) the He-flash may be of the H-ingestion kind (which is 10-100 times faster than the He-flash).

He-shell flashes on the post-AGB -> WD track, depending on L_{hyd} (which depends on M_{env} and thus on T_{eff})





Herwig 2000
arXiv:astro-ph/9912353

Schönberner 1979, related work by Iben etal 1983, Iben & McDonald 1995, Herwig etal 1999

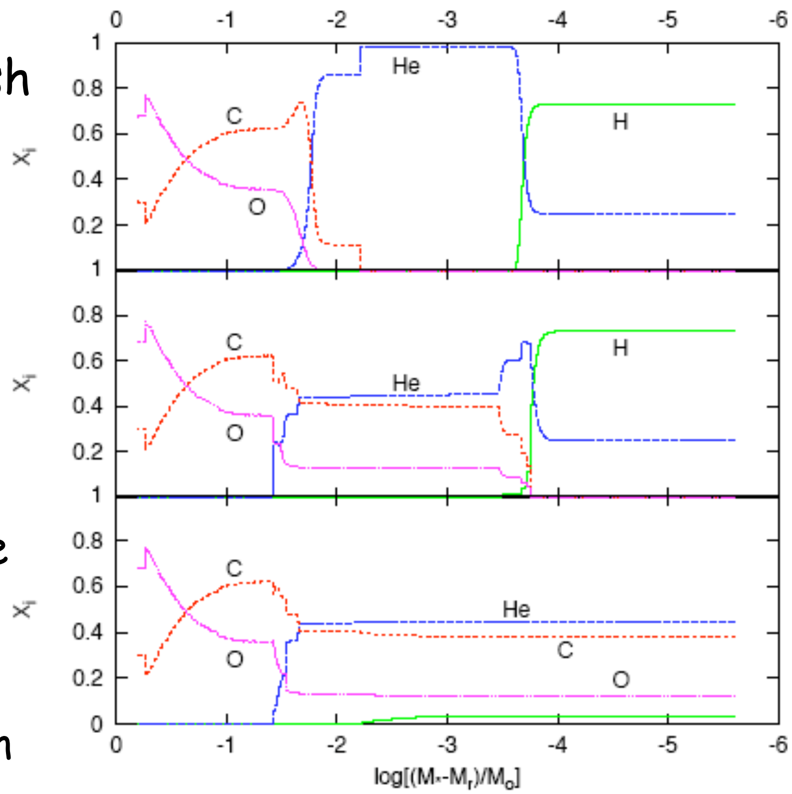
He-flashes will play an important role to determine the internal composition of the growing accreting WD:

Before post-AGB He-flash in single star:

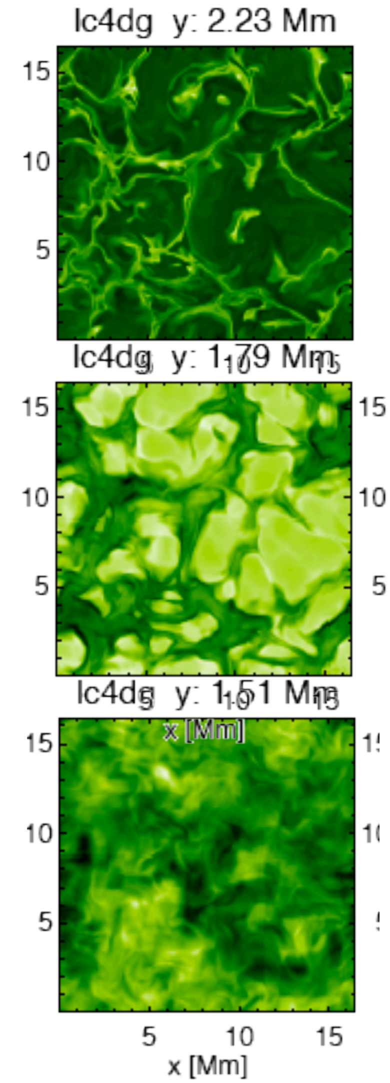
During He-flash:

After He-flash, when the star is cool:

Transient H-deficiency, then quickly covered up by accreted material.



Herwig etal. 1997, Blöcker 2000

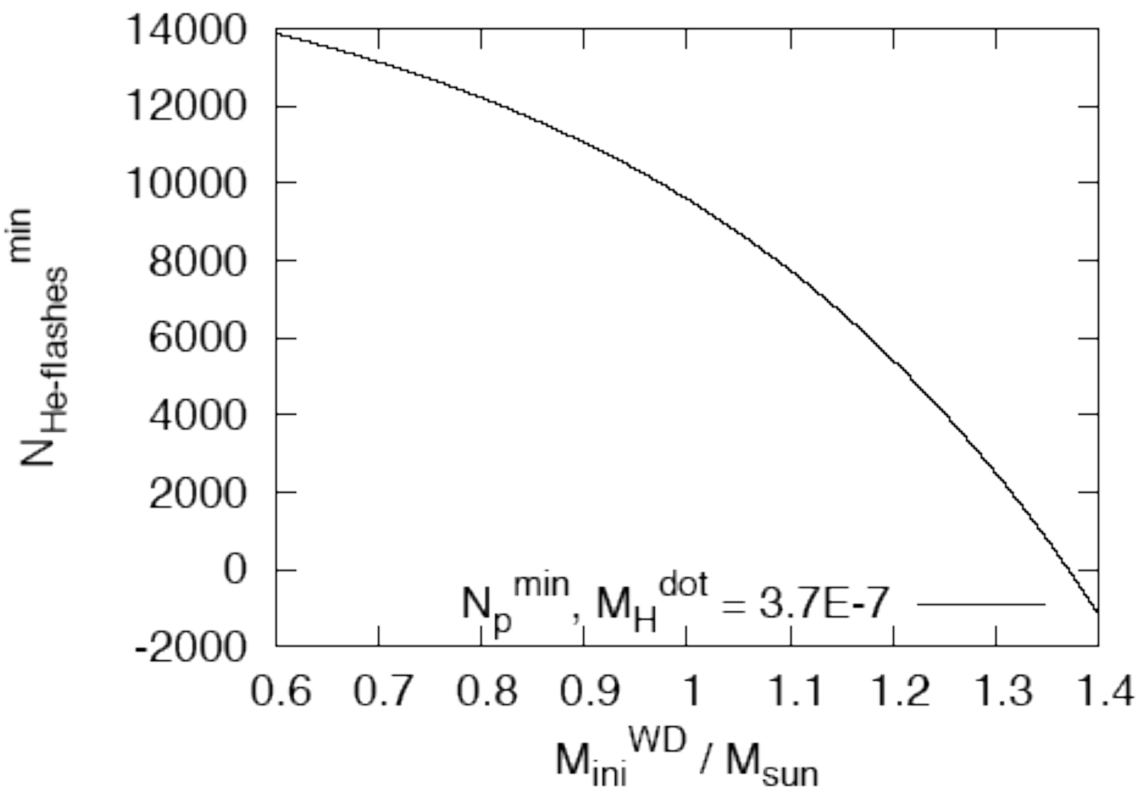


He-shell flash convection simulations, see poster

How many He-flashes will there be up to reaching M_{Chan}?

M'_H and t_{ip} from AGB core-mass relations:

$$N_{He\text{-}flash} = \int_{M_{ini}}^{M_{Chan}} \frac{1}{t_{ip} dM_H/dt} dM$$



Thousands! Many could be fast H-ingestion flashes. Wide range of light curves …. but this is a separate talk.

Final remarks

- The processes that enter quantitative predictions for the supernova rate from super AGB stars have been identified, but currently uncertainties remain high. There is indication for a higher supernova rate from this channel at lower metallicity.
- The single-degenerate path toward SNIa leads through a possibly very large numbers of He-shell flashes, no matter how stable H-shell burning is. In analogy to single star born-again events: rad./dust driven winds. In the down-phase (interpulse): luminous O, B stars.
- Even hotter accreting WD at high L will have significant rad. M'_{wind} which adds to the required fine tuning of M'_{acc}.
- If several thousands, maybe 10.000s He-flashes scare you: astro-ph/0703453, Geoff Clayton etal: extreme excess of ^{18}O - a case of a He-CO WD DD merger