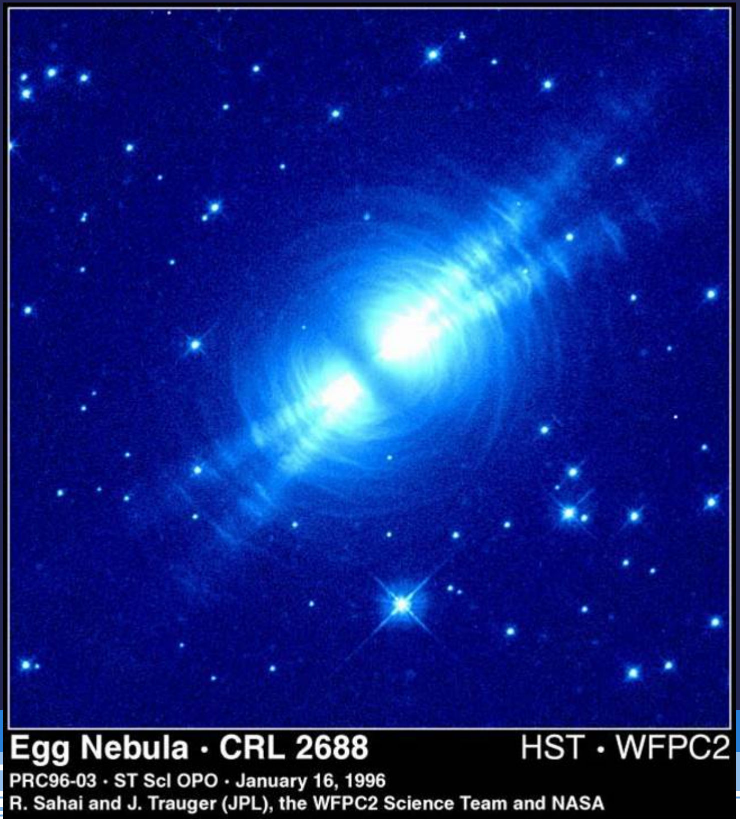
The final stages of low- and intermediate-mass stars



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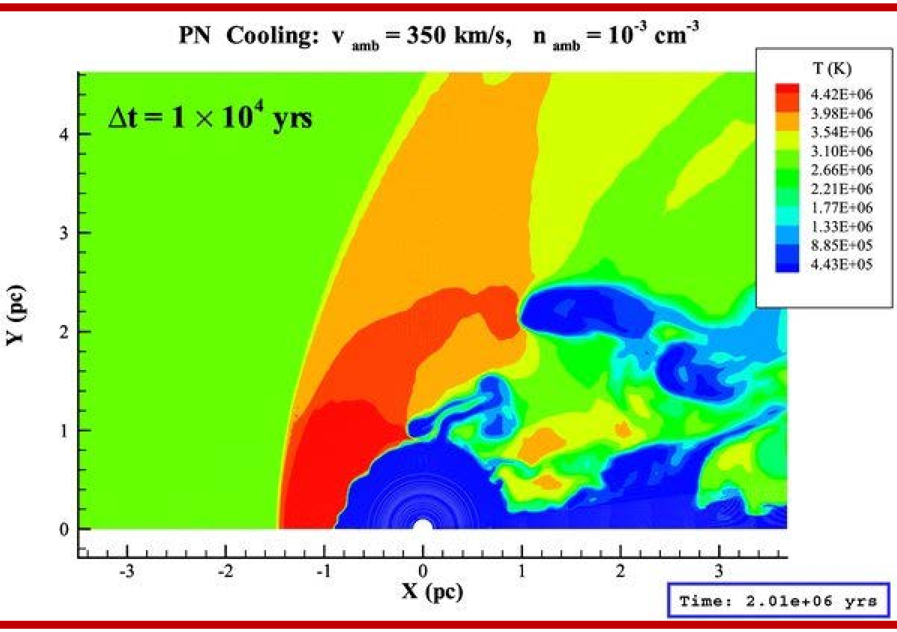
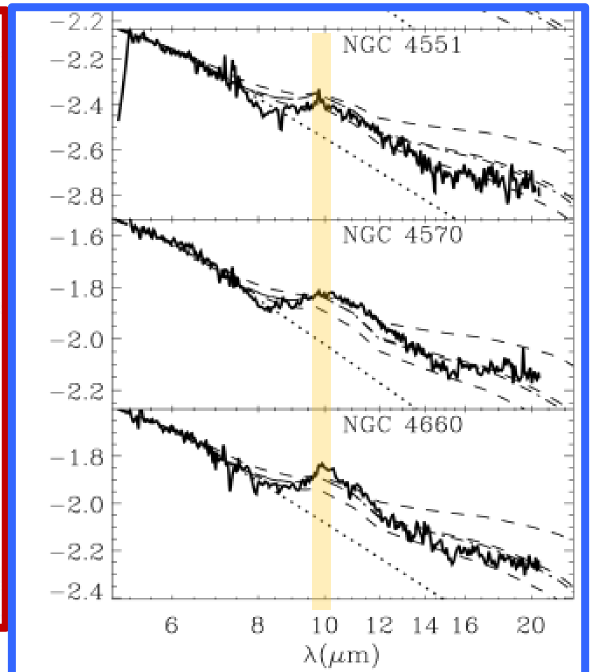
Quenching and Quiescence — MPIA Heidelberg — July 17, 2014

UNIVERSITÀ DEGLI STUDI DI PADOVA

Origin of the hot gas and silicate emission in ETGs: AGB stellar winds and PN ejection?





Spitzer spectra of early-type galaxies in Virgo

Bressan et al. 2006, ApJ, 639, L55

Silicate emission at 10μm due to O-rich mass-losing dusty AGB stars?

2D hydrodynamical simulations of the interaction between the ambient ISM and the AGB wind + PN ejection

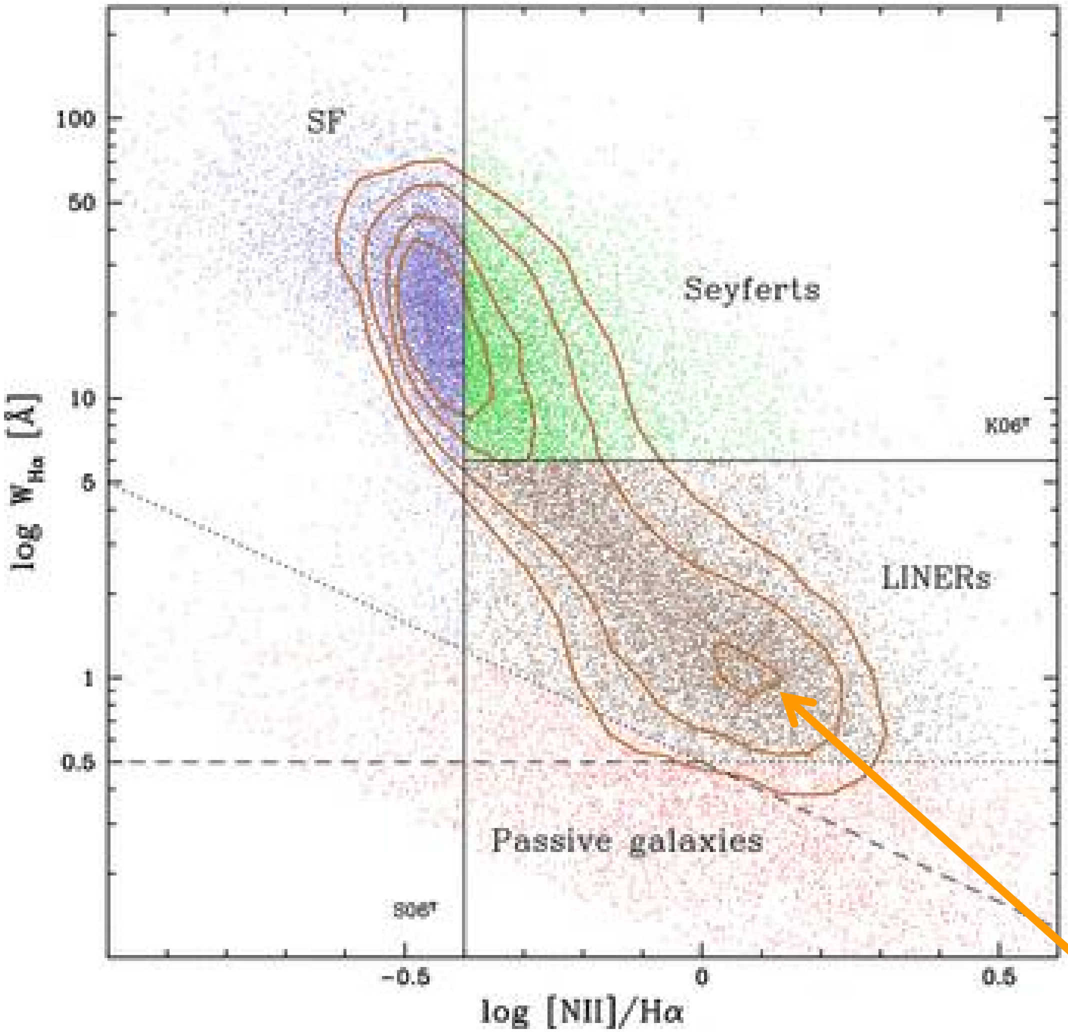
Parriott & Bregman, 2008, ApJ, 681, 1215

Bregman & Parriott 2009, ApJ, 699, 923

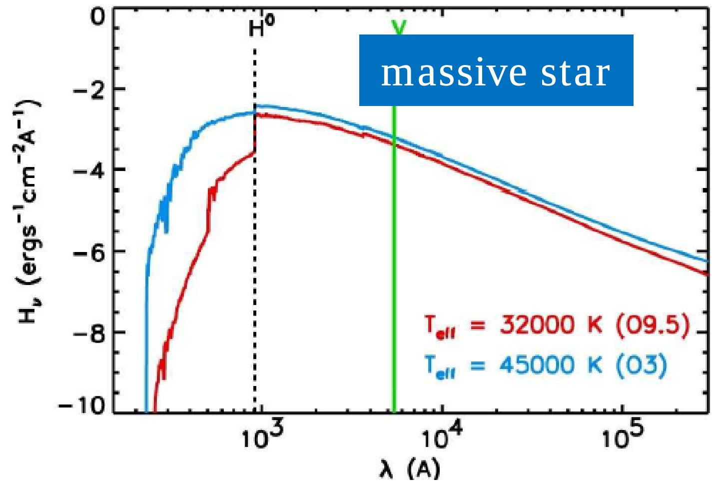
Input stellar parameters:

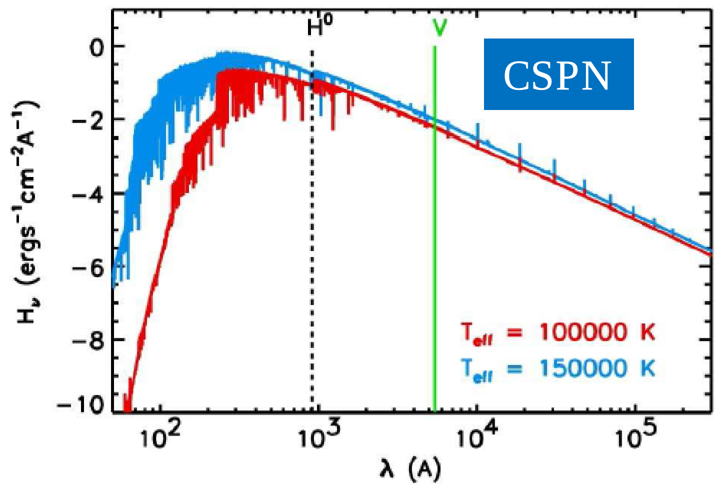
- AGB mass loss rates
- duration of the super-wind phase
- PN masses
- expansion velocities

Origin of LINERS: ionizing photons from Post-AGB stars?



Cid Fernandes R et al. MNRAS 2011;413:1687-1699

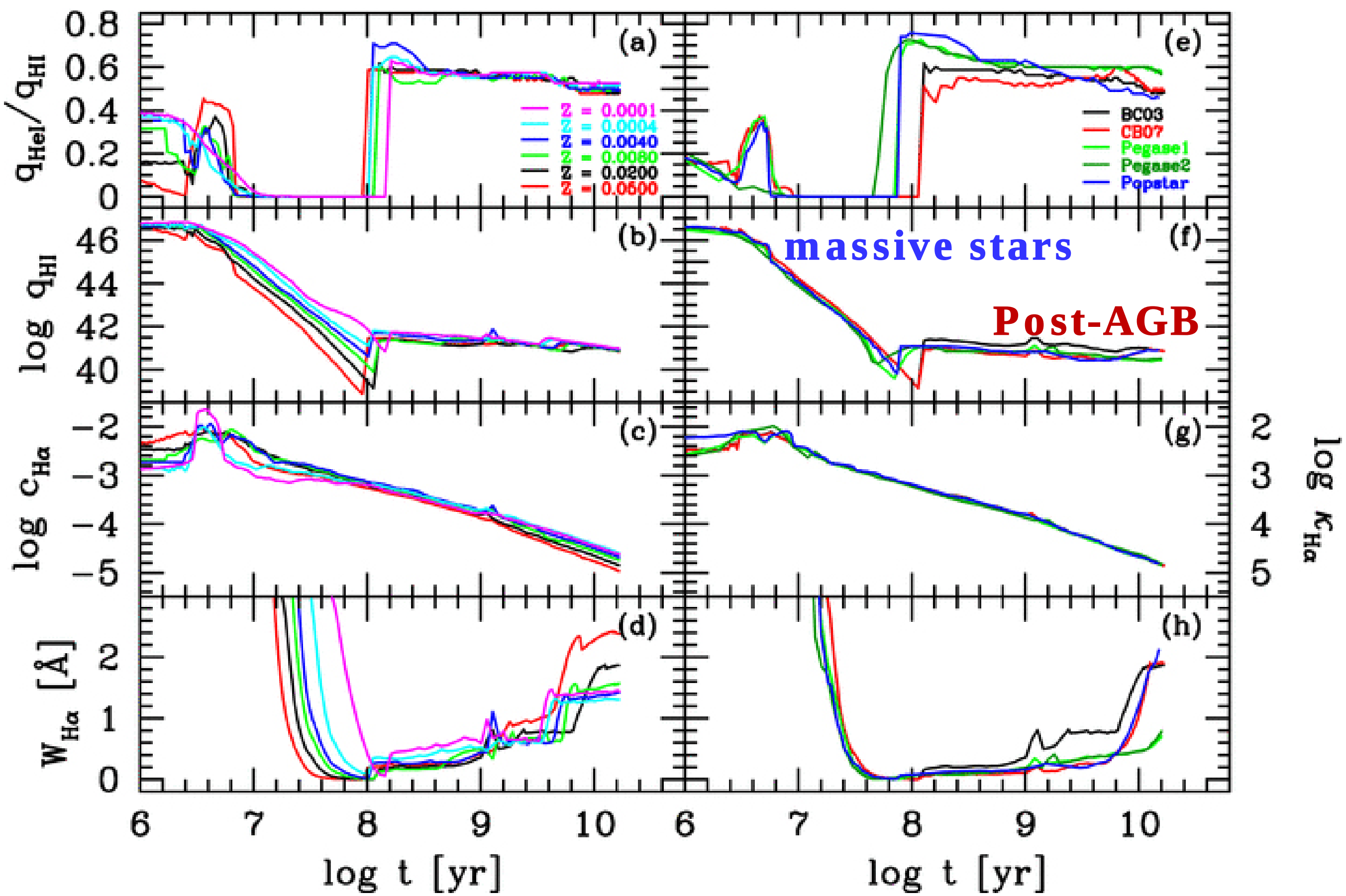




Debate on ionizing sources:

- Low accretion-rate AGNs
- Old post-asymptotic giant branch stars (Stasińska et al. 2008, MNRAS , 391, L29)

Ionizing photon rates of simple stellar populations



Post-AGB stars:

- harder ionization field than massive OB stars
- Drop of ~ 5 orders of magnitude in q_H at ages ~ 10^8 yr, then flat evolution.

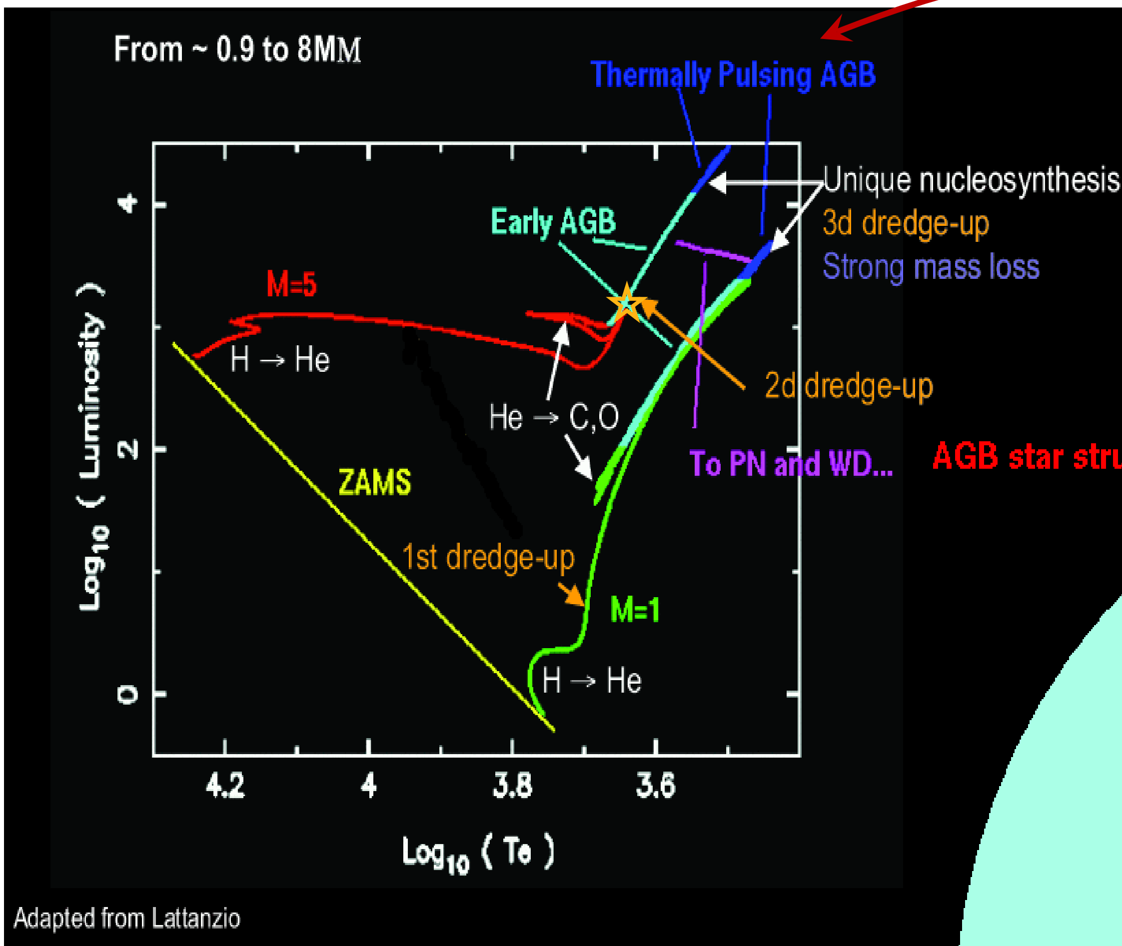
Agreement between different SSPs models only qualitative. Variations in q_H by up to 1 dex for ages > 10^8 yr.

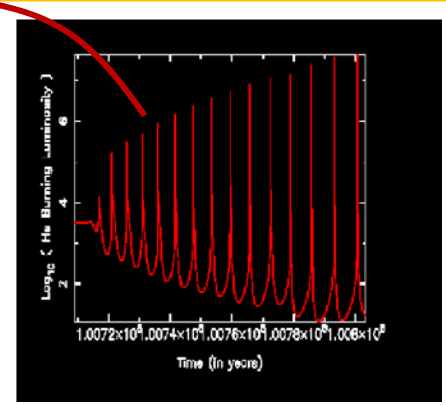
Cid Fernandes R et al. MNRAS 2011;413:1687-1699

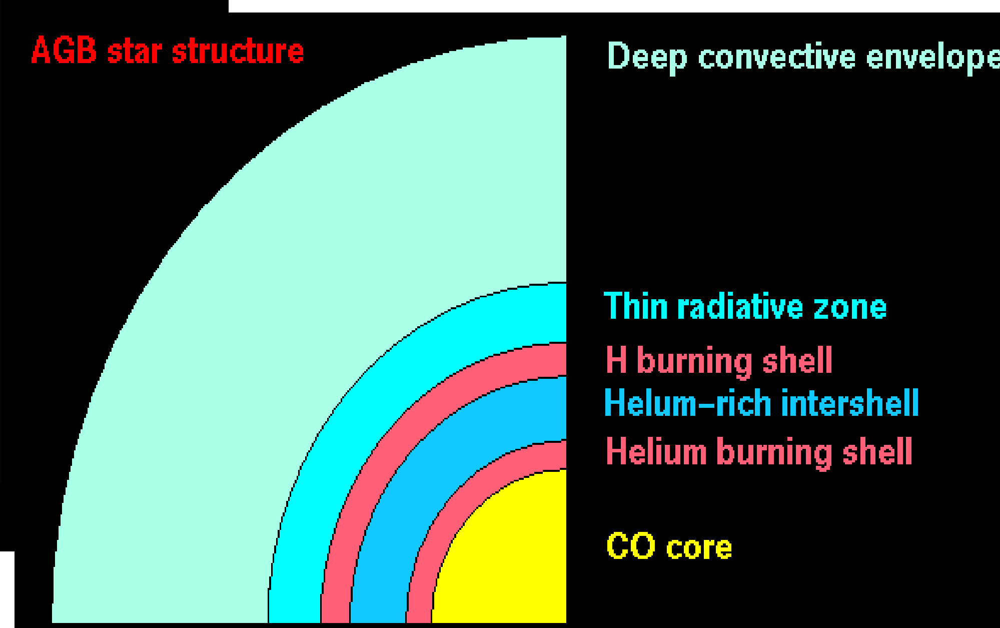
Differences in ionizing flux for ages $\geq 10^8$ yr should be attributed to:

- Different treatments of the TP-AGB phase (initial-final mass relation)
- Different treatments of the post-AGB phase (evolutionary time-scales)
- Metallicity
- IMF

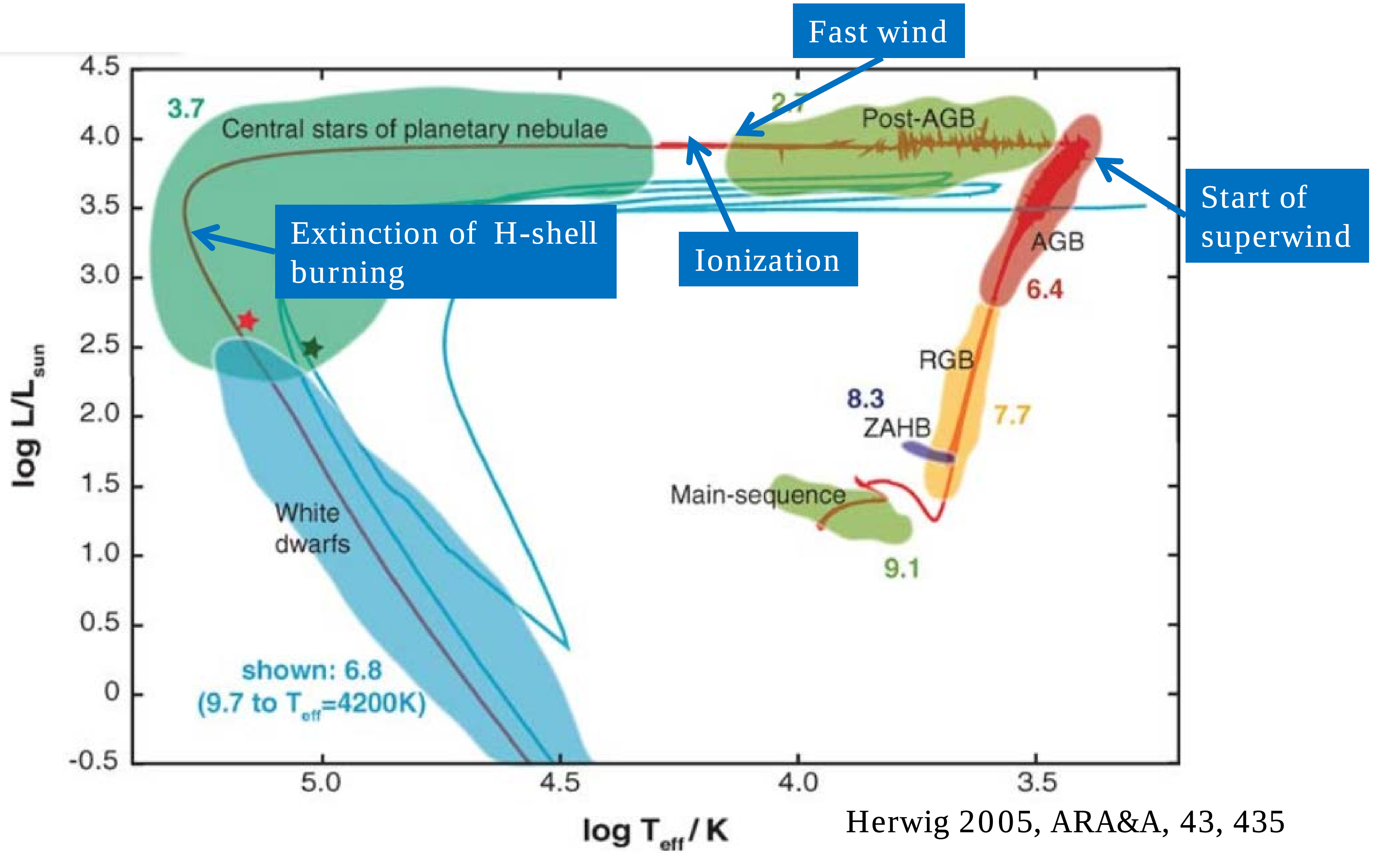
Basic Stellar Evolution of C-O WD Progenitors







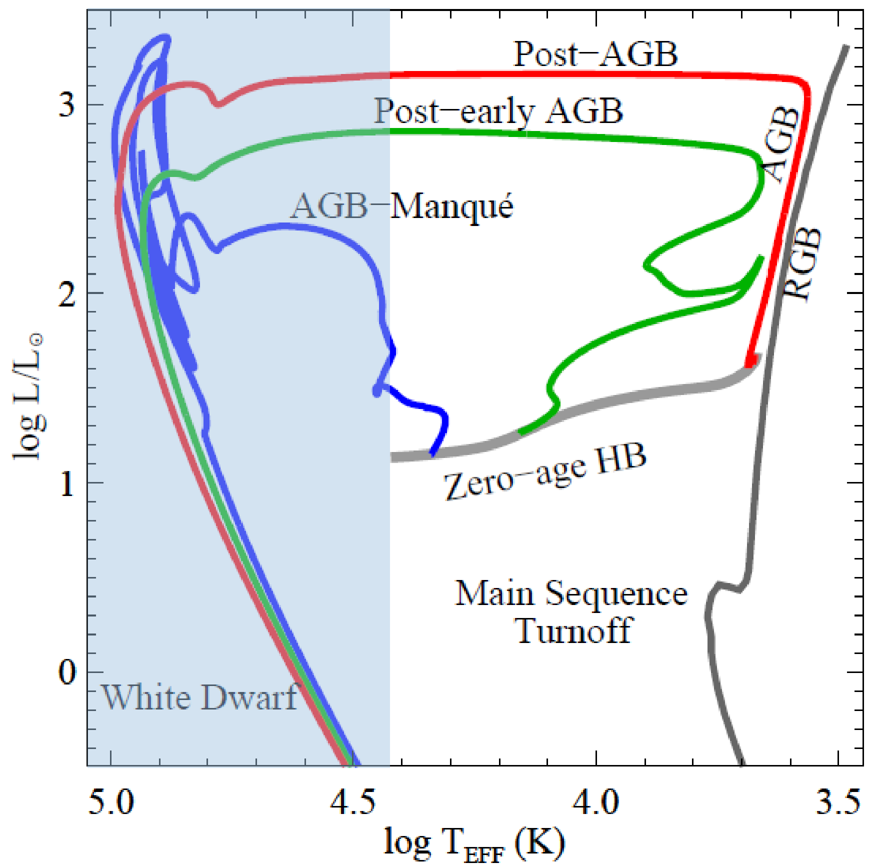
AGB and Post-AGB evolution

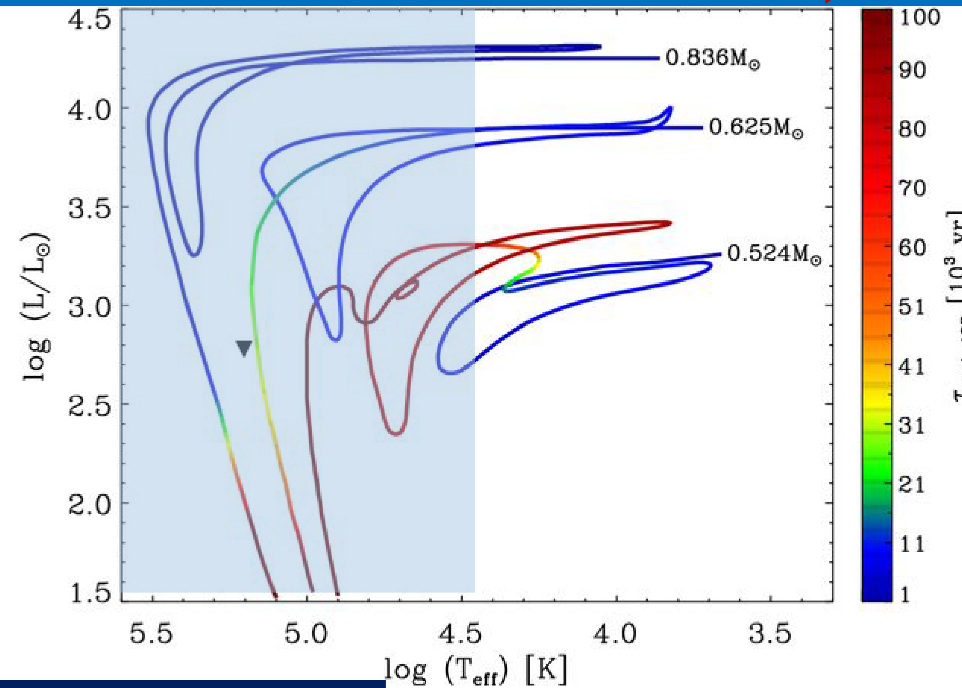


Herwig 2005, ARA&A, 43, 435

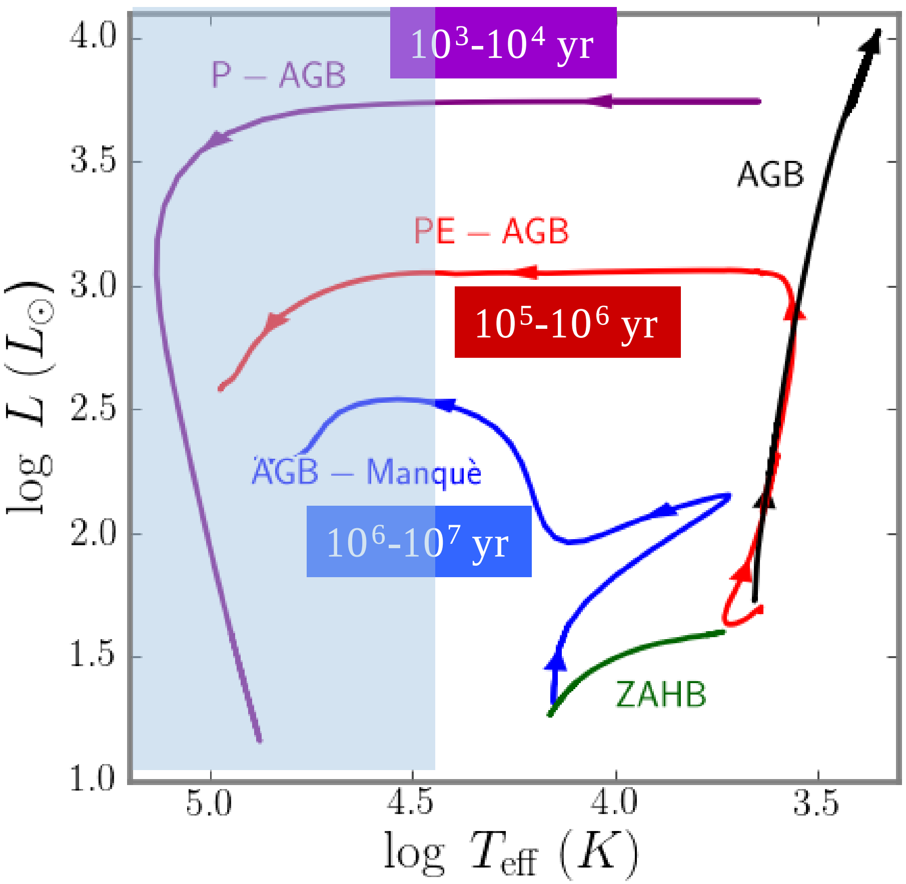
Hot Advanced Evolution of Low- and Intermediate-Mass Stars

- Post-AGB: H-burners
- Post-AGB: He-burners
- Post-early AGB
- Hot HB and AGB-manquè stars





UV evolutionary paths for low-mass and intermediate-mass single stars



PAGB: Vassiliadis & Wood '94

All others: Bressan,Marigo,Girardi et al.2012

Post-AGB (P-AGB) stars:

- the end result of the AGB phase
- expected in a wide range of stellar populations

Initial masses 0.8 -8 $M_\odot$

MS lifetimes: 10^8- 10^{10} yr

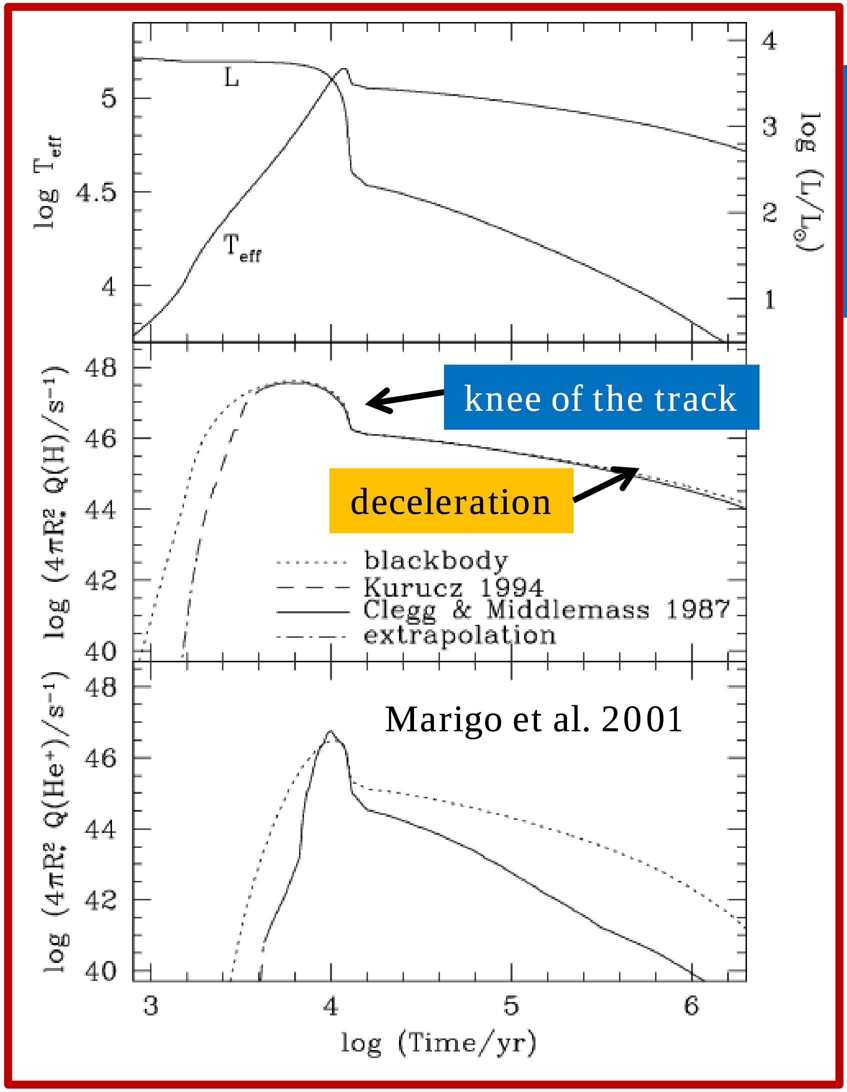
PE-AGB and **AGB-manqué** stars:

- the result of insufficient envelope masses to allow a full AGB phase.
- are expected to be particularly prominent at high helium or α abundances when the mass loss on the RGB is high.

Initial masses < 2 $M_\odot$

MS lifetimes $\gtrsim$ 0.6 10^9 yr

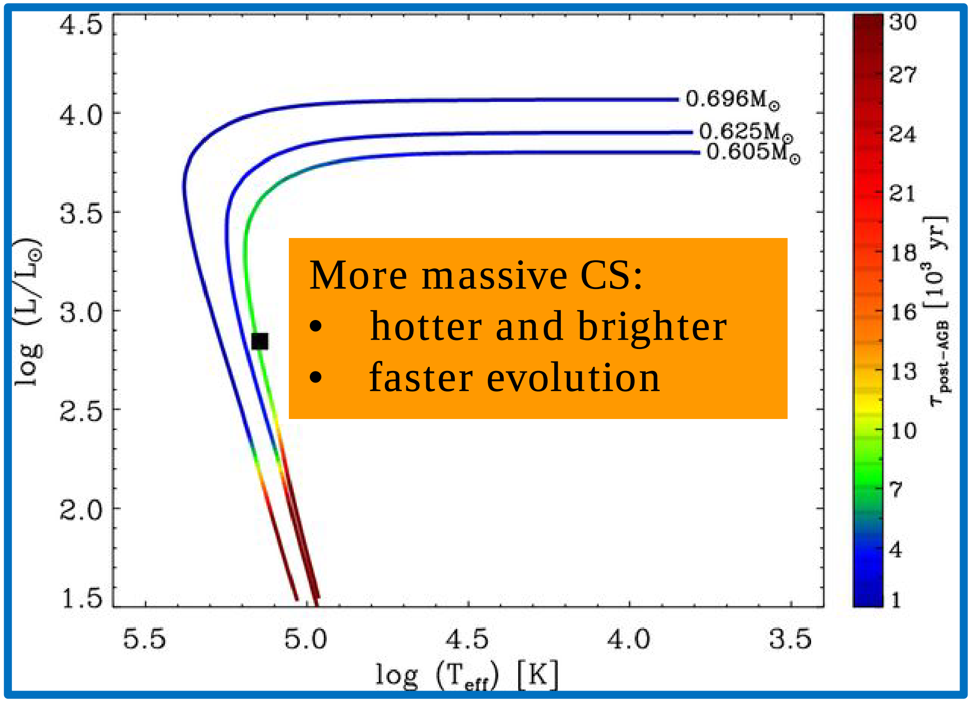
Ionisation rates during the Post-AGB evolution of the central star



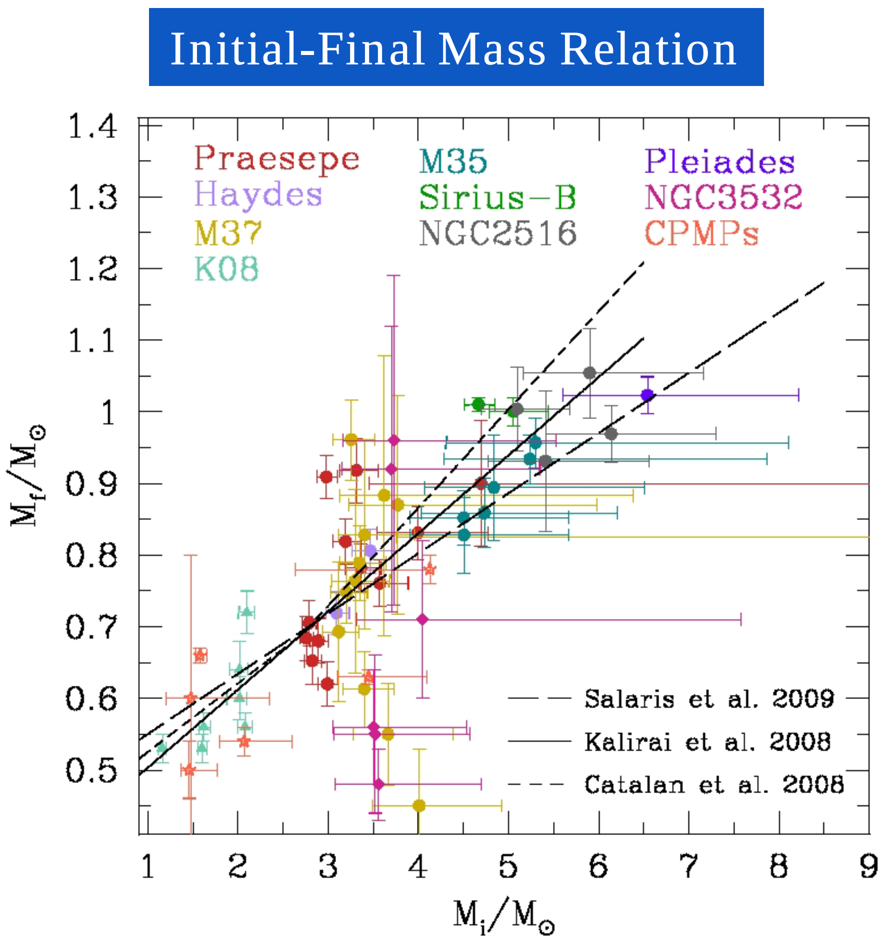
MAIN PARAMETERS:

- Luminosity ∝ CS mass ⇒ AGB evolution
- Effective temperature
- Evolutionary speed

⇒post-AGB evolution



Post-AGB evolution:
I. the central star mass



62 white dwarfs, most in open clusters

Extension to the low-mass end:

CPMPs Catalan et al. 2008

old open clusters Kalirai et al. 2008

change of slope at $M_i \approx 4\ M_\odot$

M_{WD} and $t_{cooling}$: spectral fitting
(Teff and g) +
grid of WD models and
theoretical M-R relation

M_i: $\tau(M_i) = \tau(\text{cluster}) - t_{cooling}(\text{WD})$

Uncertainties due to stellar evolution

Age and metallicity of clusters

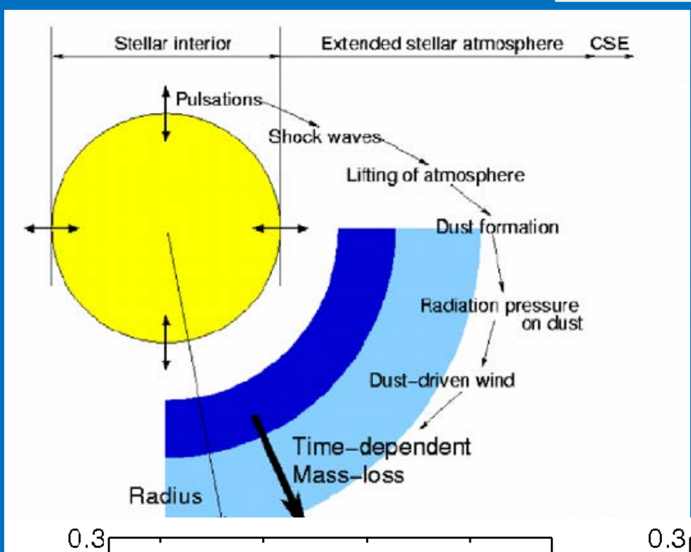
overshooting

Thickness of the WD H/He layers

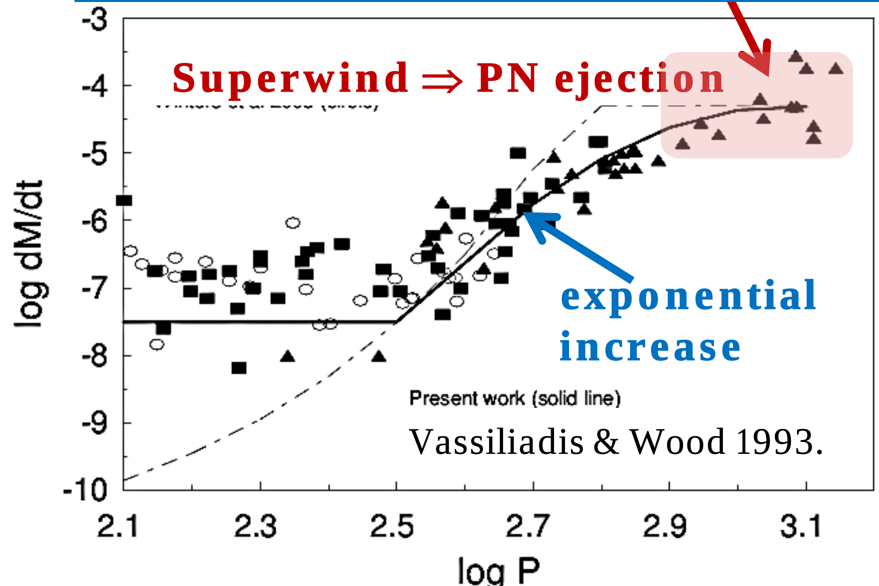
Composition of the WD core
(He, C-O, O-Ne)

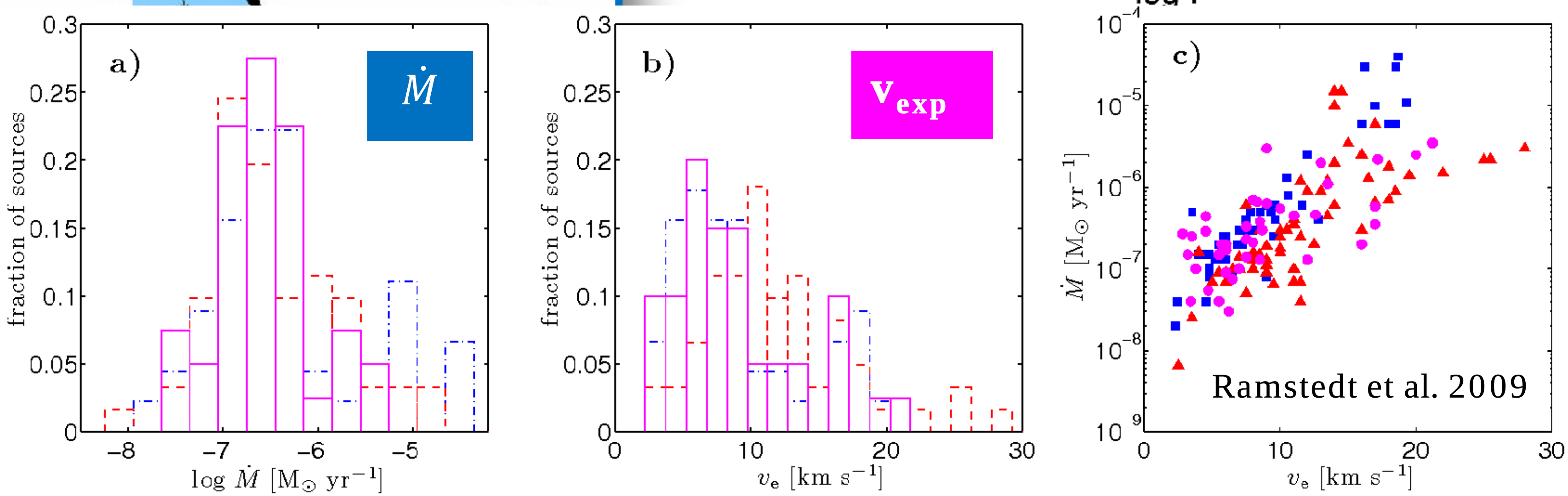
The core mass growth on the TP-AGB depends on (1) the efficiency of stellar winds (uncertain)

The longer the AGB lifetime, the larger the final mass

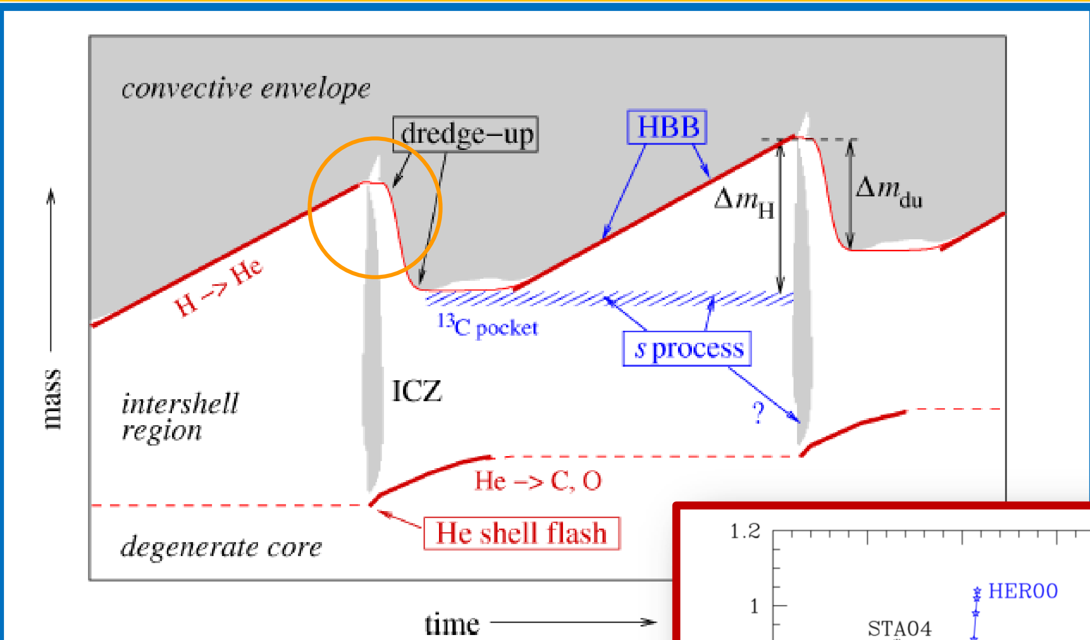


Pulsation-assisted dust-driven wind

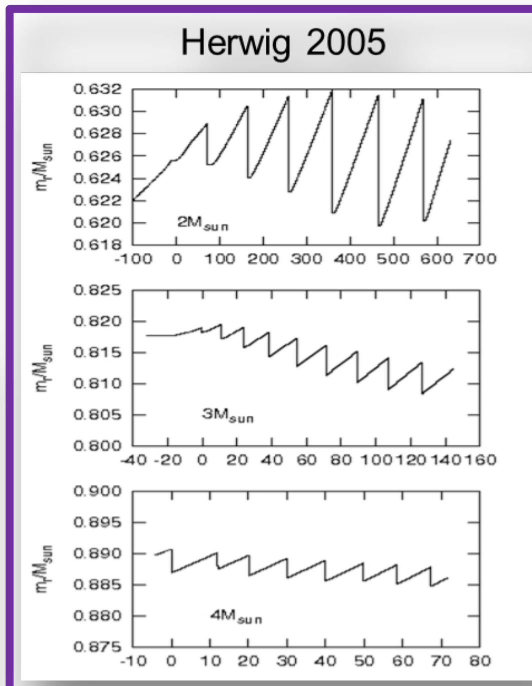




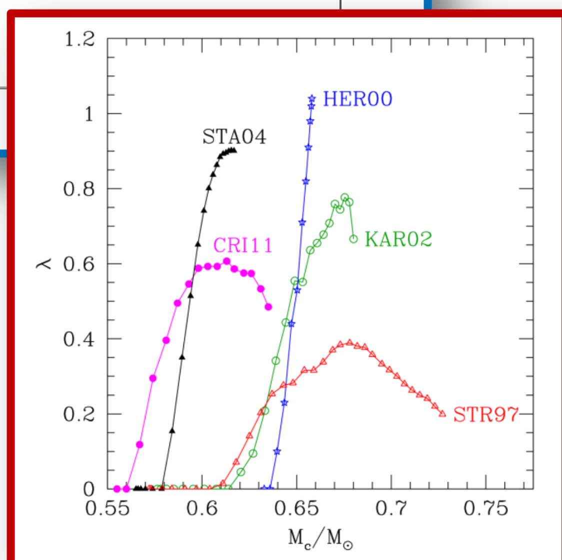
The core mass growth on the TP-AGB depends on (2) the efficiency of the third dredge-up (uncertain)



Reduction of the core mass

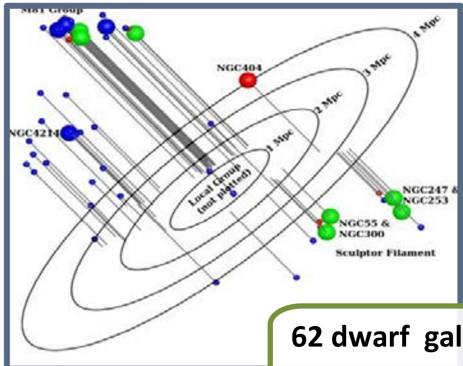


The efficiency $\lambda = \dfrac{\Delta m_{\rm du}}{\Delta m_{\rm H}}$ is poorly known



Calibration of the AGB phase needed!
Ongoing ERC project: STARKEY

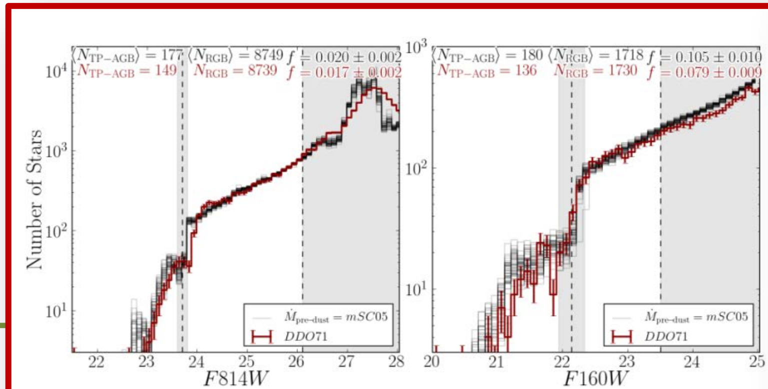
The ACS Nearby Galaxy Survey Treasury

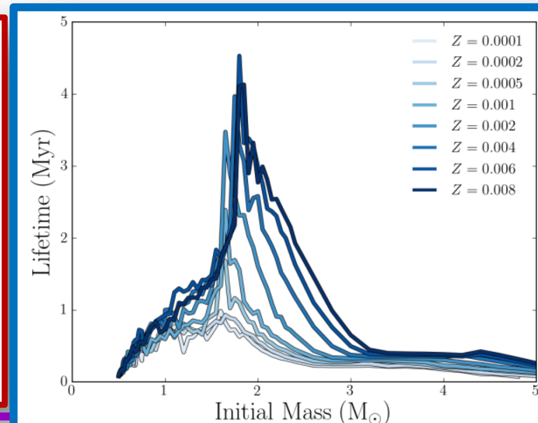


62 dwarf galaxies
d < 4 Mpc
All metallicities down to very low

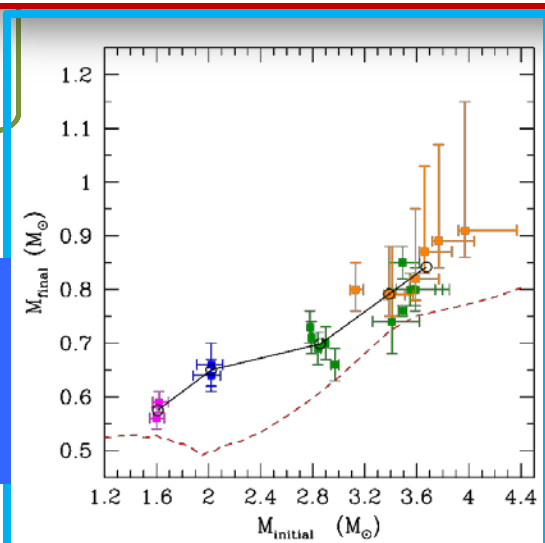
AGB LFs ⇒ lifetimes

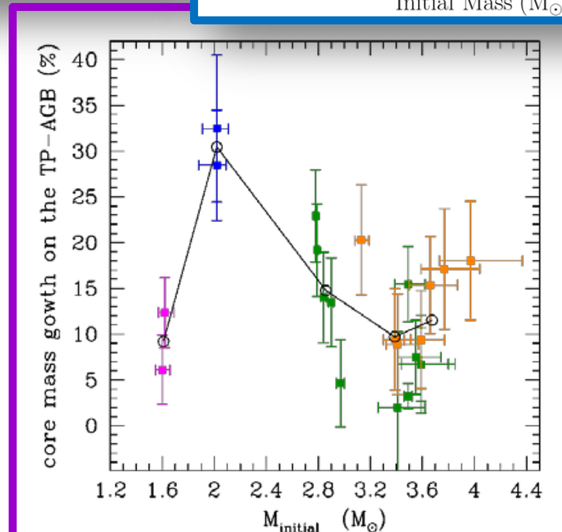
Rosenfield et al. 2014, 2014arXiv1406.0676R





initial-final mass relation of intermediate-age WD progenitors ⇒ core mass growth

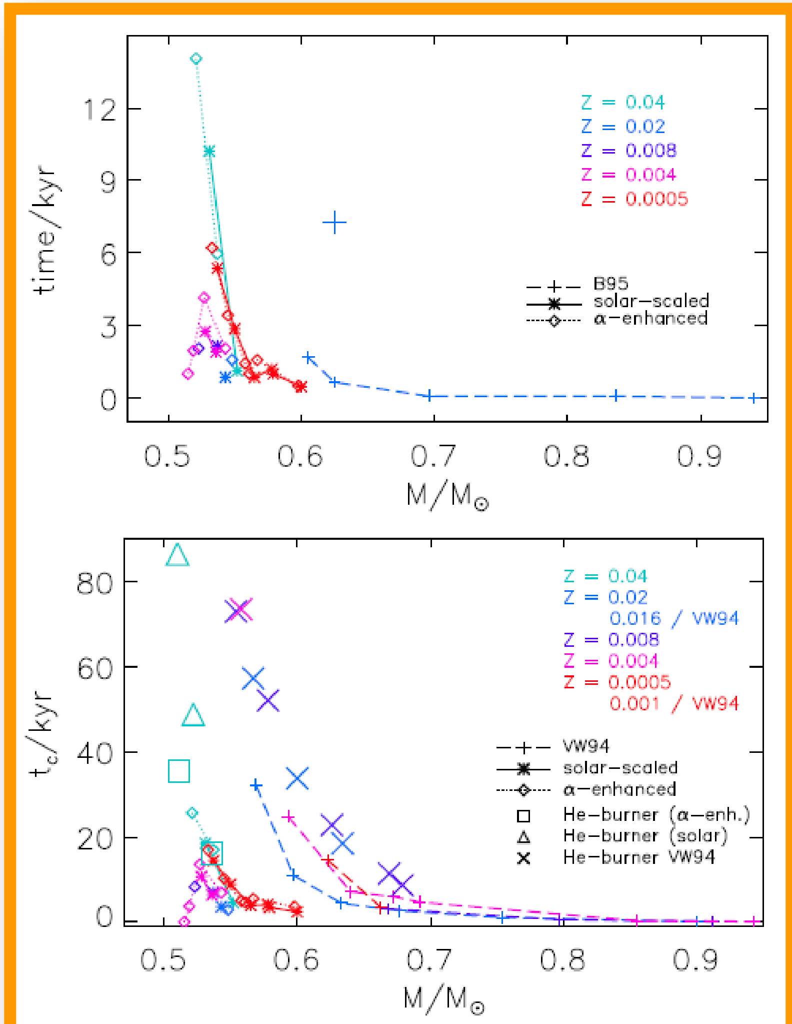


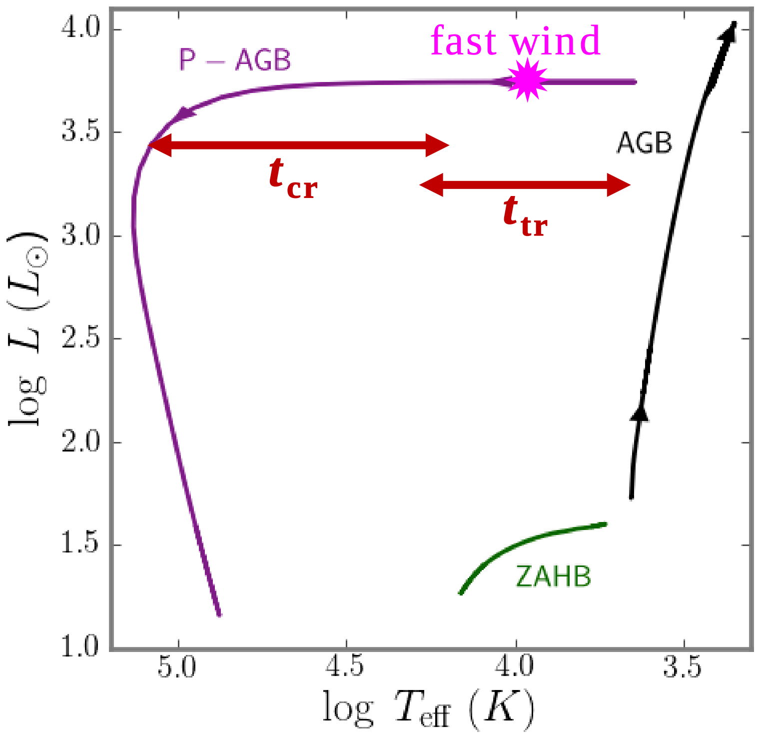


Kalirai et al. 2014, ApJ, 782, 17

Post-AGB evolution:
II. evolutionary speed

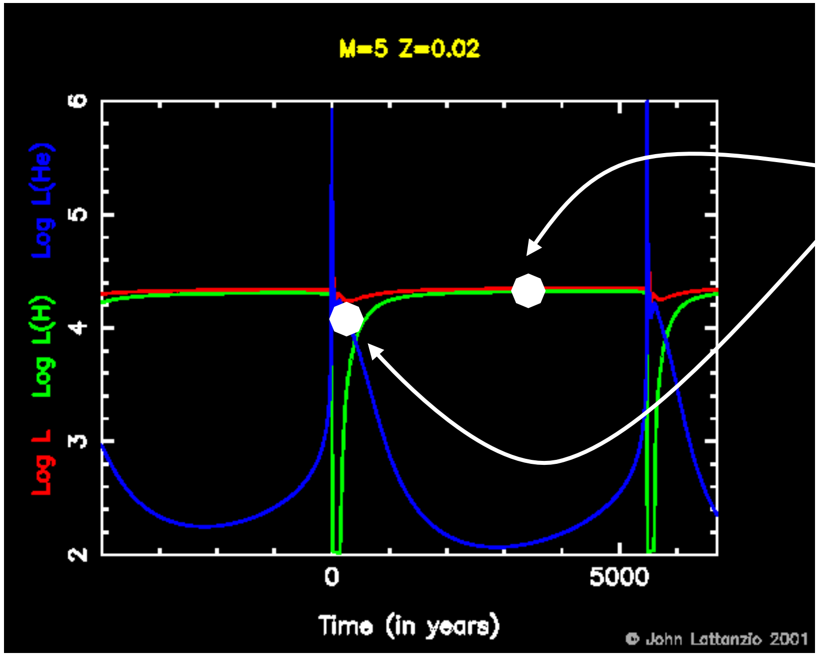
Depends on erosion rate of the envelope =
At the top: stellar wind (uncertain) +
At the bottom: displacement of the H-shell





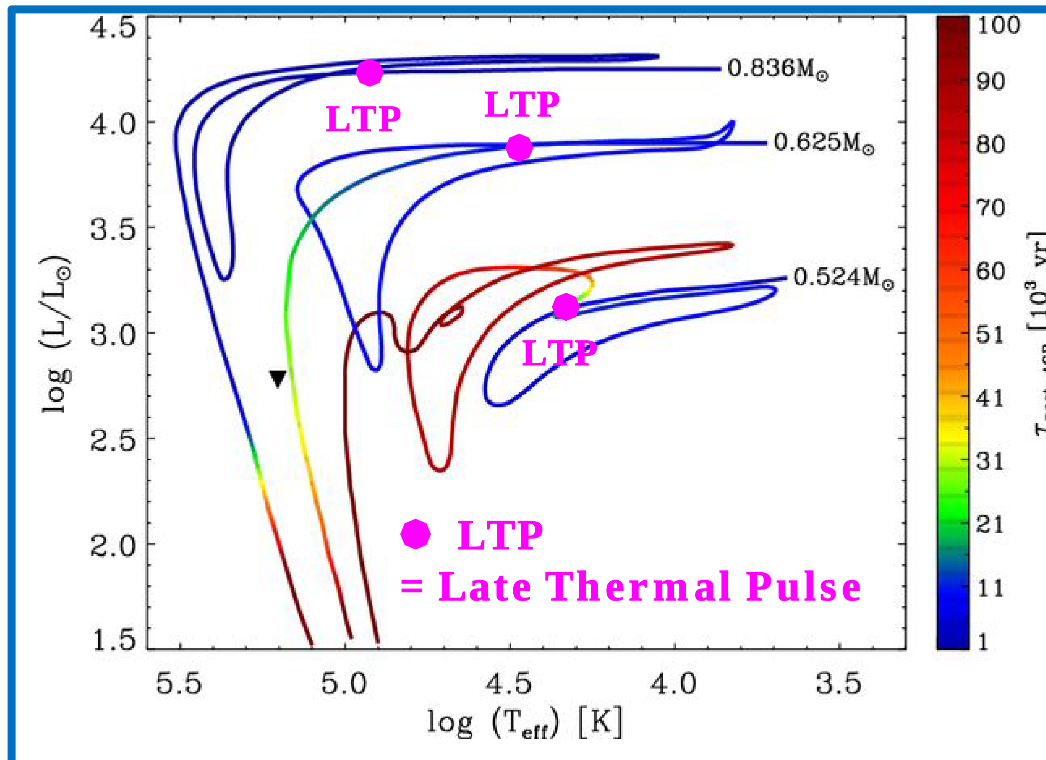
- t_{tr} : **transition time** from AGBtip to onset of H-ionization (few 10^2 – few 10^4 yr)
- Onset of the radiation-driven **fast wind**
- t_{cr} : **Crossing time** from ionization to hottest point

Post-AGB evolution:
III. H vs He burners



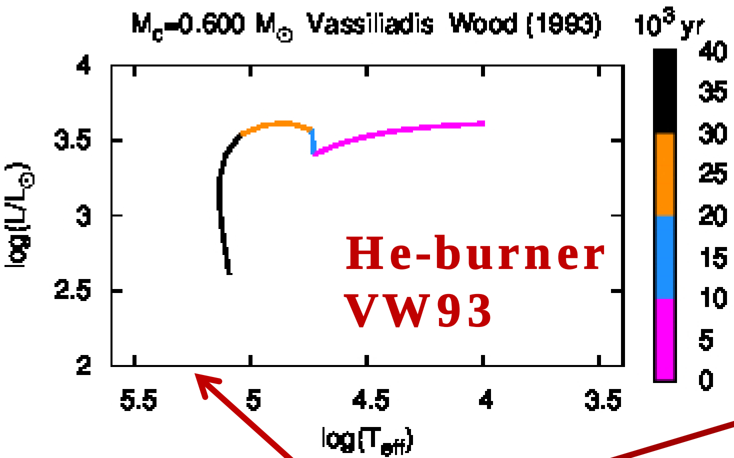
Luminosity and evolutionary speed affected by **TPC phase ϕ** at which the star leaves the AGB:

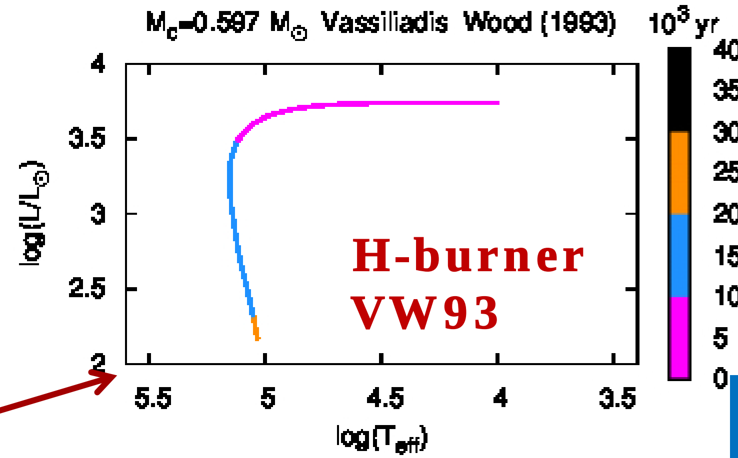
- **Larger ϕ** ⇒ H-burners ($L \sim L_H$)
- **Lower ϕ** (< 0.25) ⇒ He-burners ($L \sim L_{He}$)



He-burners (15-25%)

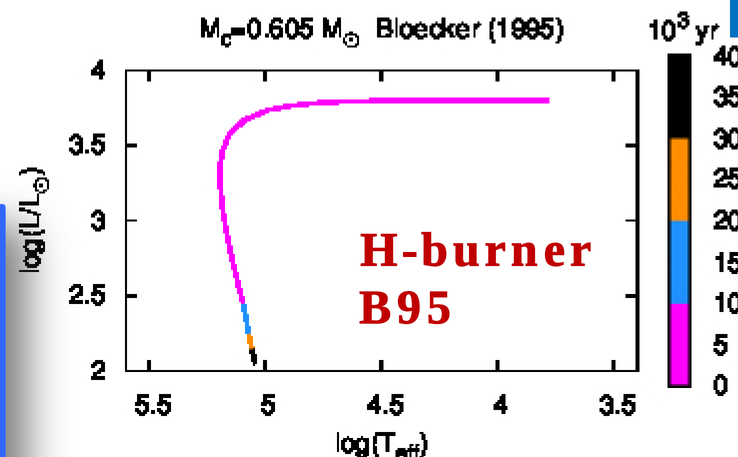
- ✓ more prone to experience a LTP
- ✓ Slower evolution
- ✓ Less luminous



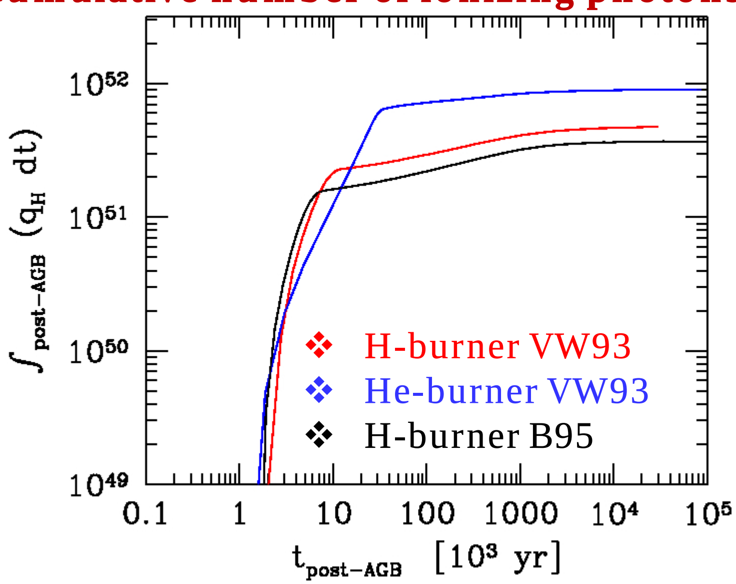


Different models: different timescales

He-burners have longer timescales than H-burners

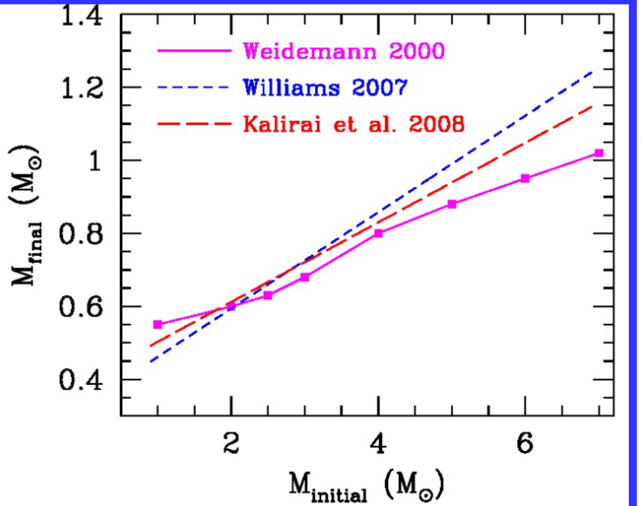


Cumulative number of ionizing photons

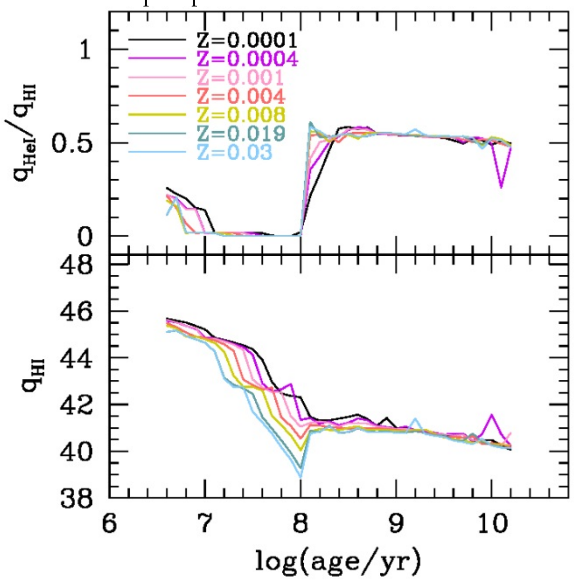


An example: a post-AGB star with M~0.6 $M_\odot$
The He burner emitts more ionizing photons than the H-burner does (factor of a few).

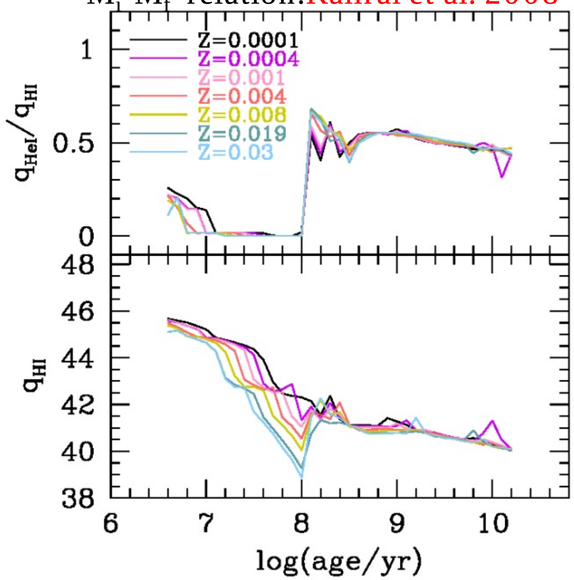
Ionizing rates of SSPs: M_i-M_f relations



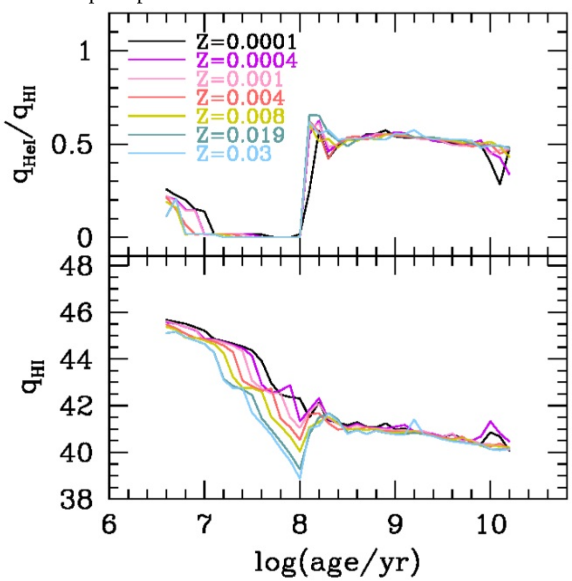
M_i-M_f relation:Williams 2007

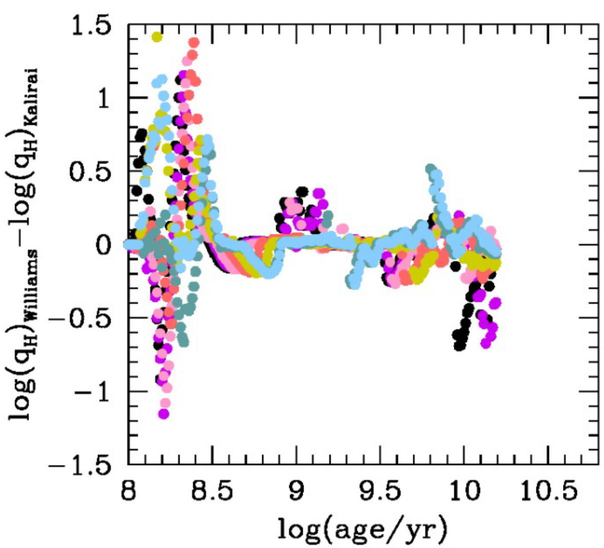


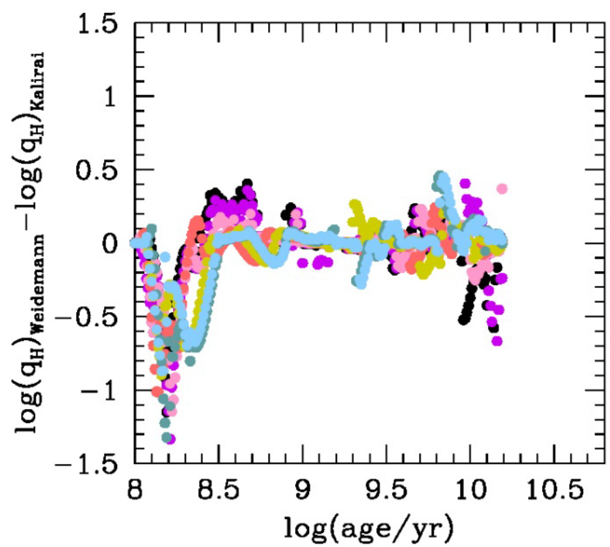
M_i-M_f relation:Kalirai et al. 2008



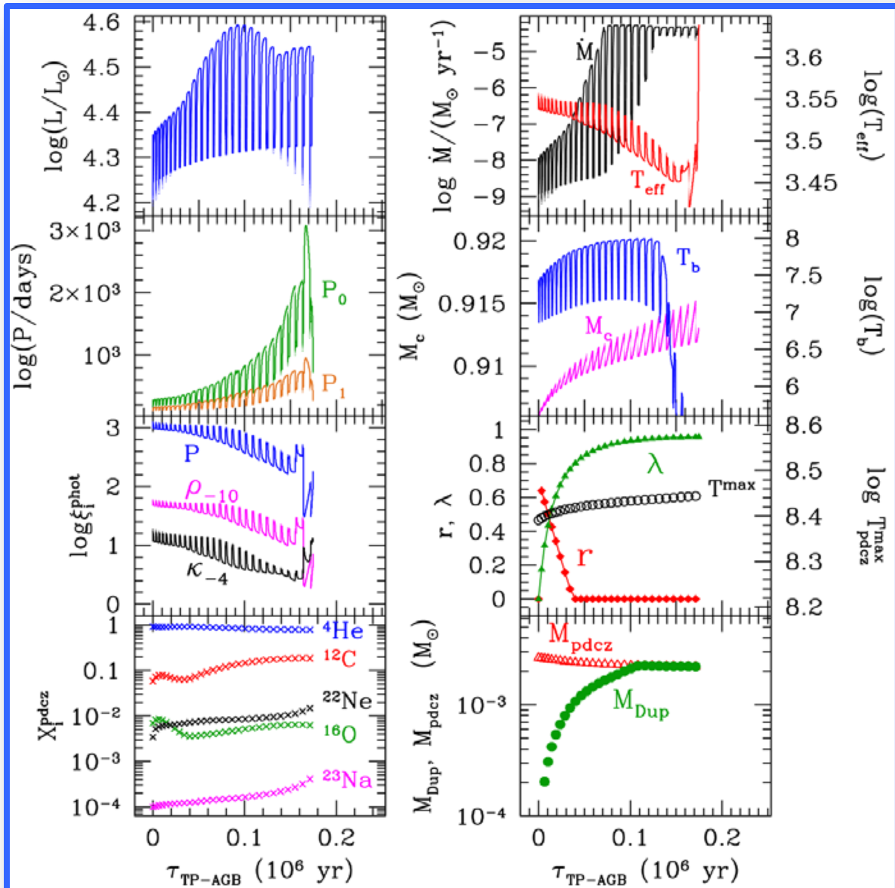
M_i-M_f relation:Weidemann 2000







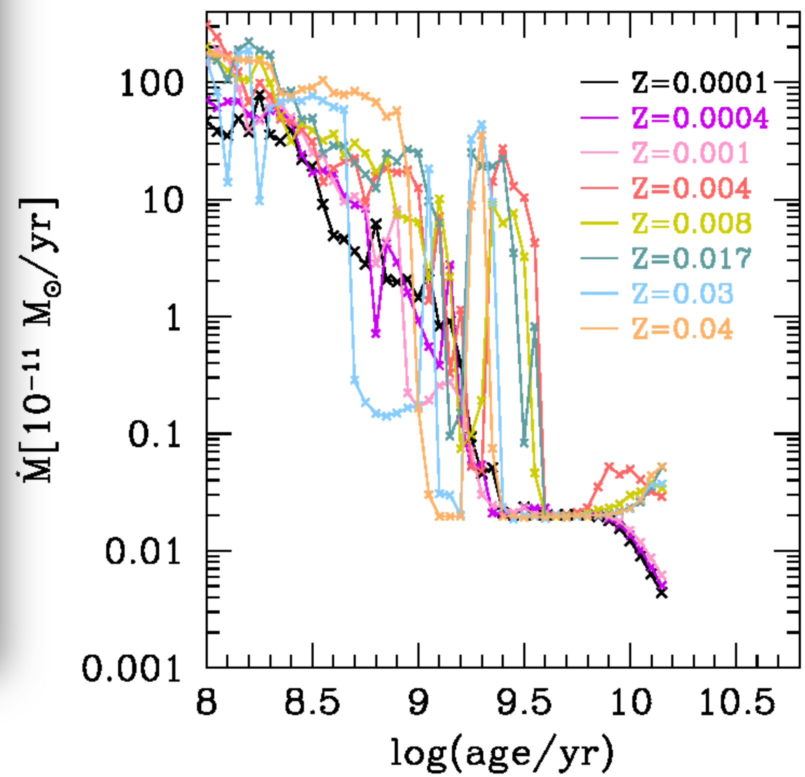
Stellar Mass-Loss rates from detailed AGB evolutionary models



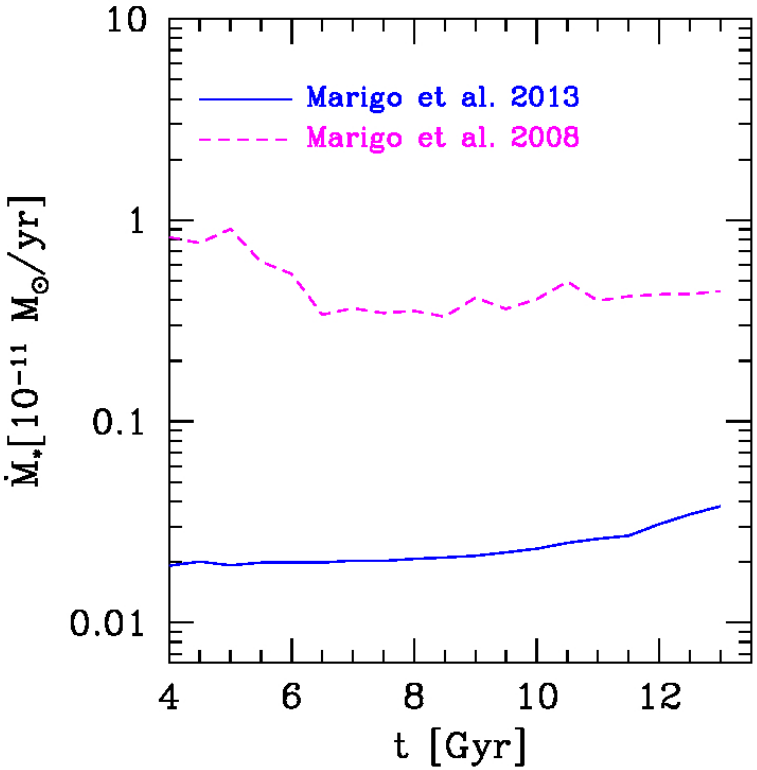
Marigo et al. 2013, MNRAS, 434, 488

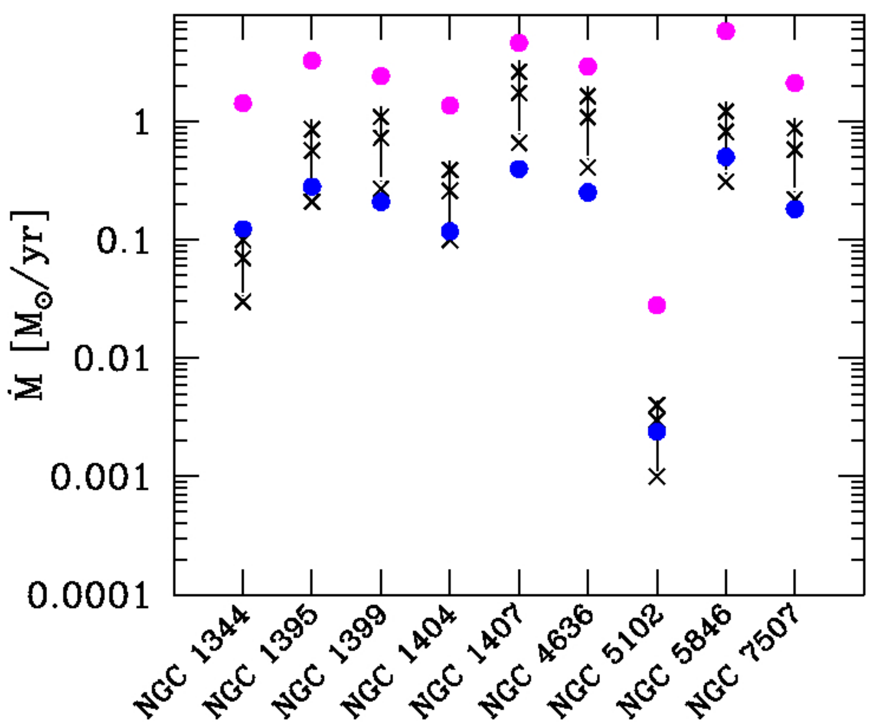
Sample output of a TP-AGB model (M_i=5 $M_\odot$, Z_i=0.008) computed up to the ejection of the envelope

Specific rate of mass loss from SSPs



Mass injection rates in ETGs: stellar winds and SNIa





Athey et al. 2002, ApJ, 571, 272

$\dot{M}_*(12\ \mathrm{Gyr}) = 3.6\ 10^{-12}\ L_B\ (L_{B,\odot})\ M_\odot\ \mathrm{yr}^{-1}$ **(ongoing calibration)**

$\dot{M}_*(12\ \mathrm{Gyr}) = 4.1\ 10^{-11}\ L_B\ (L_{B,\odot})\ M_\odot\ \mathrm{yr}^{-1}$

$\dot{M}_{SNIa}(12\ \mathrm{Gyr}) = 2.2\ 10^{-13}\ L_B\ (L_{B,\odot})\ M_\odot\ \mathrm{yr}^{-1}$

FINAL REMARKS

- Details of AGB and Post-AGB evolution critical to investigate the feedback of these stars on galaxy properties.

- Many uncertainties ⇒ AGB calibration needed , new post-AGB models needed

- Post-AGB ionizing rates: Mi-Mf relation, H/He burners, crossing times

- AGB mass injection: theoretical predictions with detailed AGB evolution models covering wide ranges of ages and metallicities are now feasible.

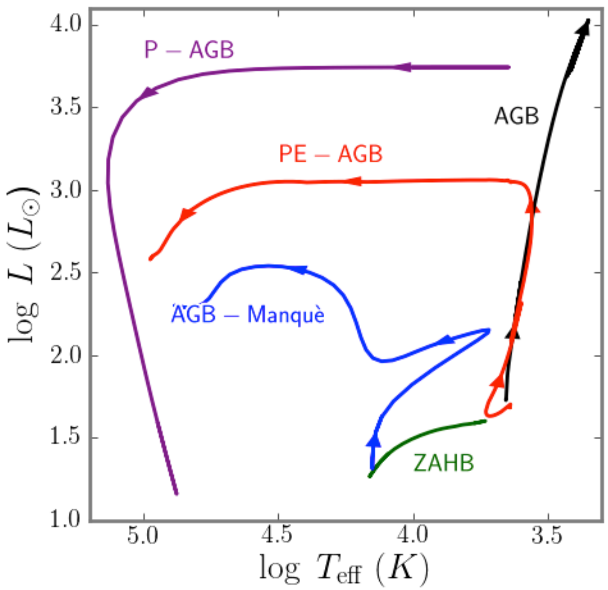
This research is supported under ERC Consolidator Grant funding scheme (project STARKEY)

UV evolutionary paths in UVIS and Galex filters

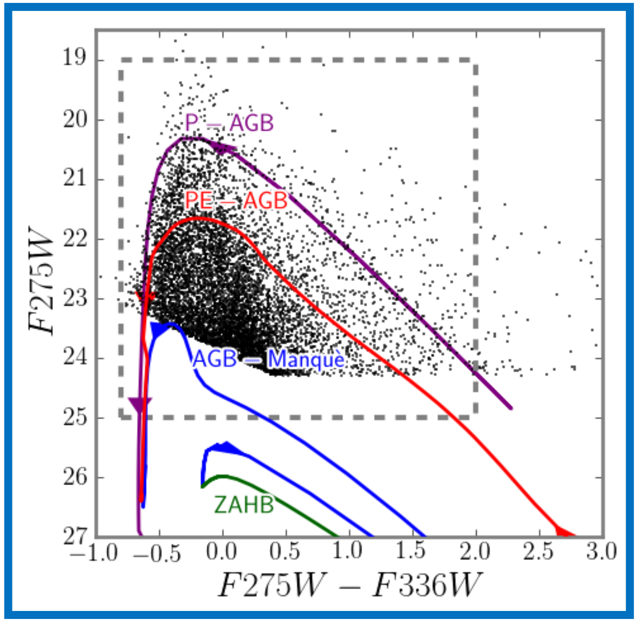
HST/WFC3-UVIS

GALEX

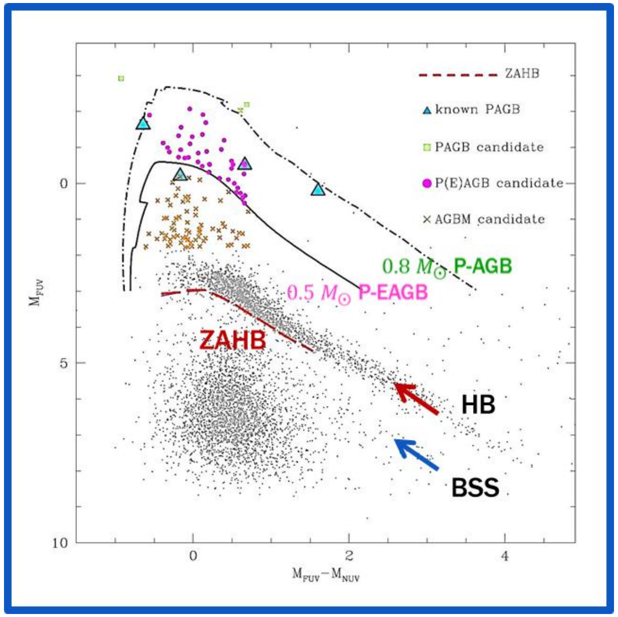
Evolutionary tracks



PHAT data of M31

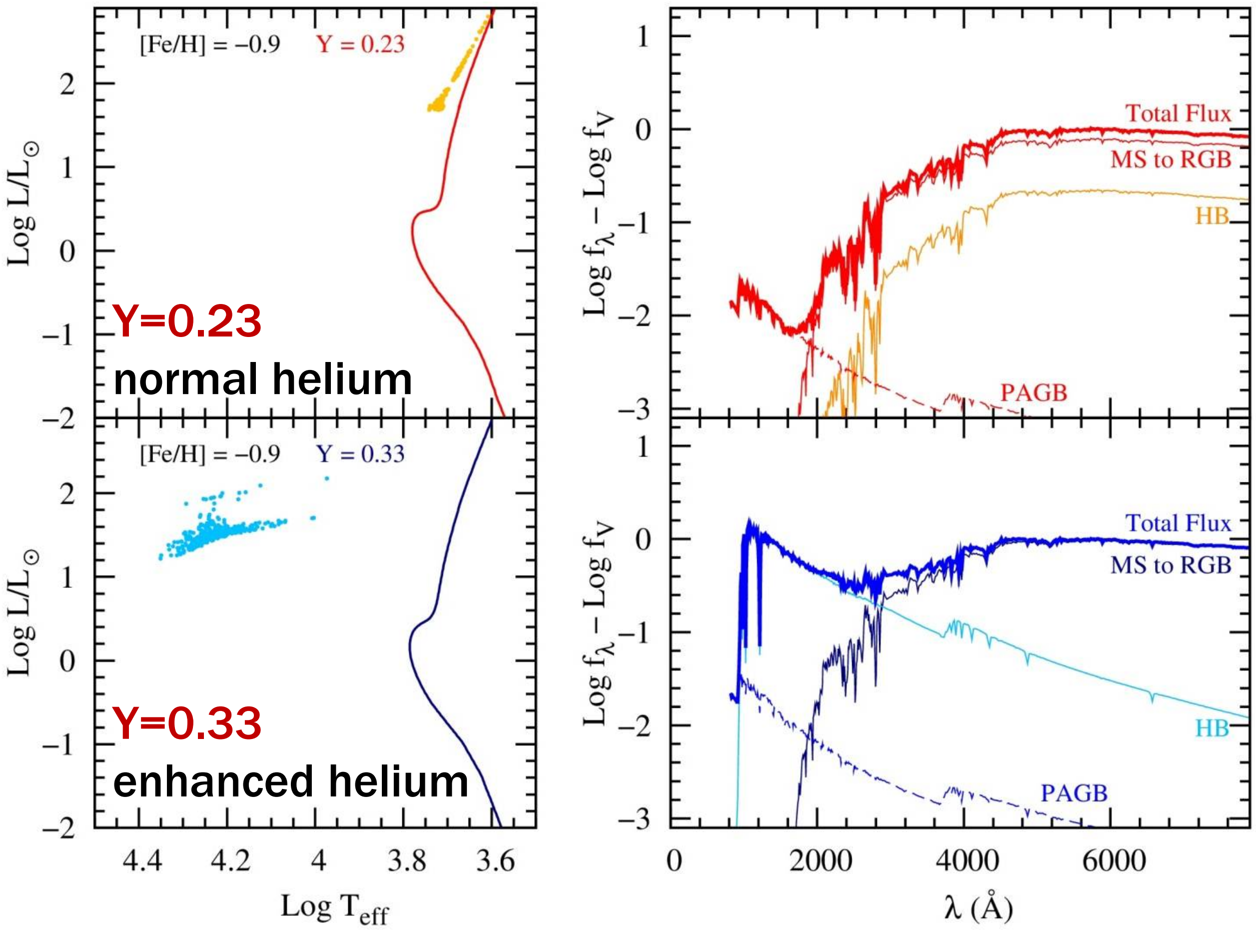


Globular Clusters



Rosenfield et al. 2012, ApJ, 755, 131
Schiavon et al., 2012, ApJ, 143, 121

Helium-enhanced HB models: stronger far-UV flux compared to the normal helium models



HR diagrams and SEDs of a simple stellar population
[Fe/H] = −0.9
age=11 Gyr

Helium-rich stars evolve faster ⇒ they have lower masses at given age.

<Teff> of HB stars with Y = 0.33 is ~ 11,500 K higher than for Y = 0.23

Chul et al. 2011, ApJ., 740, L45