Oxygen isotopic ratios in RGB & AGB stars

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Outline

1. How stellar models are constructed and the main uncertainties in stellar evolution calculations.

1. Powerful constraints on our parameter choices: $^{16}O/^{17}O$ surface abundances of low-mass Red Giant stars.

1. Investigating standard vs non-standard calculation.

2. Sensitivity of $^{16}O/^{17}O$ to the uncertainties in nuclear reaction rates.

3. What about $^{16}O/^{18}O$?

4. Comparison with other calculations.

5. Conclusions.

Evolutionary Code

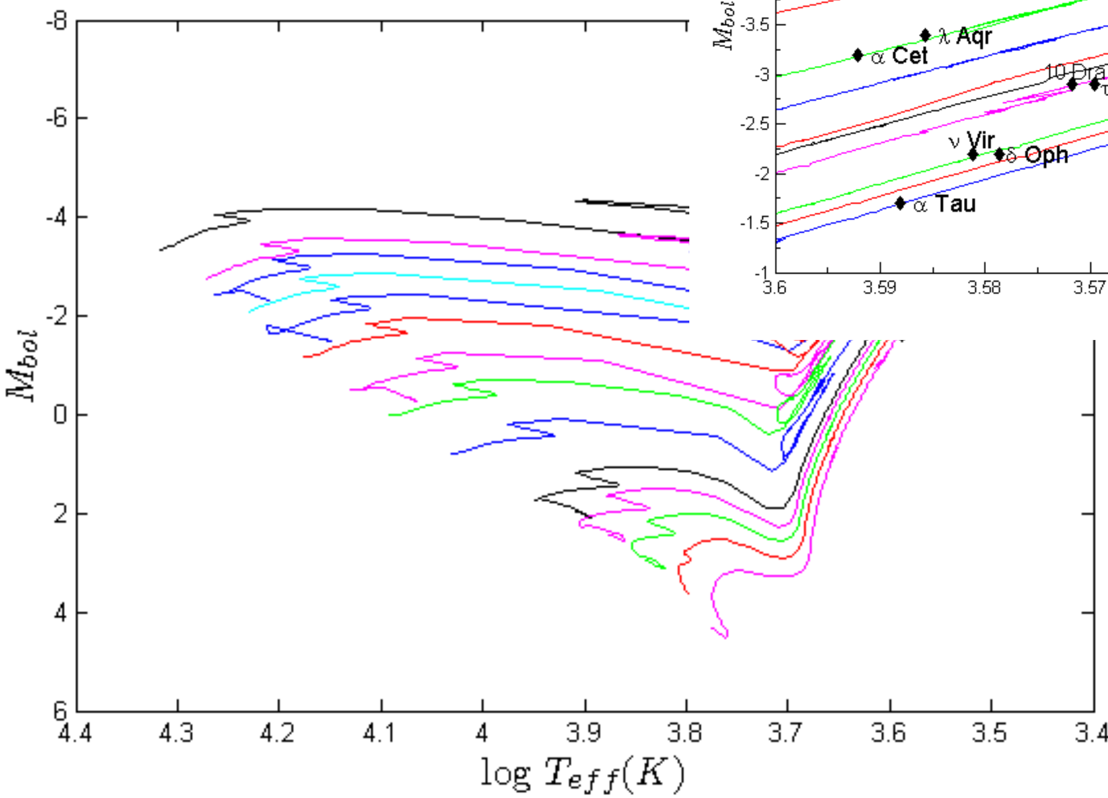
- Models are constructed using a Lagrangian 1D **hydrodynamic evolutionary code** that solves the partial differential equations describing stellar structure & evolution on an adaptive grid.
- Updated input physics (equation of state, opacities, nuclear reaction rates..)

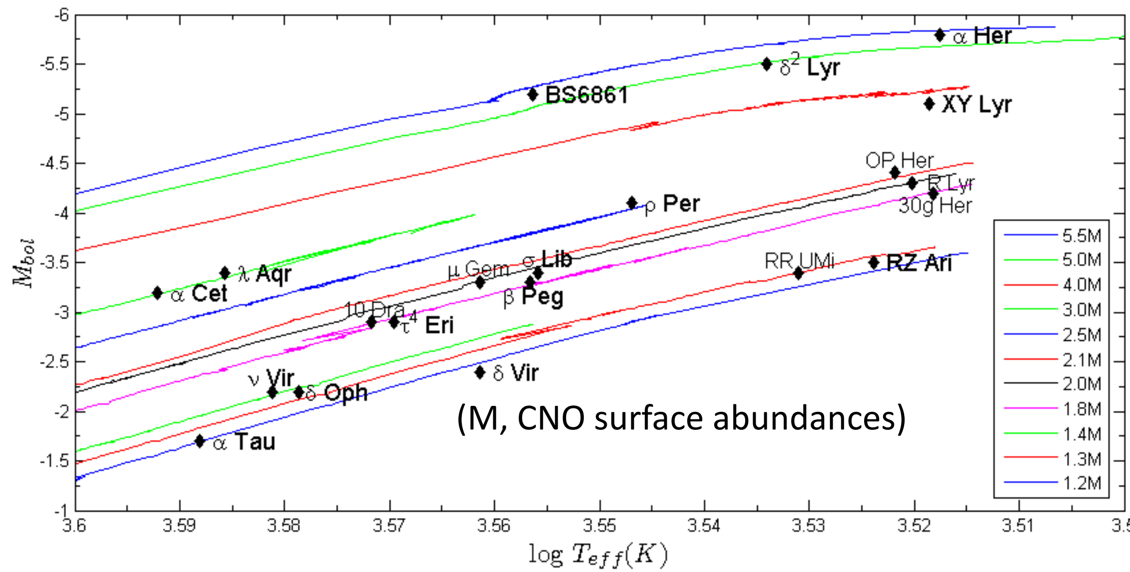
Uncertainties

- Convection is described within the framework of the local 1D MLT. So the treatment of **convective boundaries** includes free parameters which need to be constrained by observations.
- Existing uncertainties in the experimental evaluation of certain key **nuclear reaction rates** at the low energies encountered in stars. These uncertainties propagate into the stellar models affecting their fidelity and the nucleosynthesis yields.

Masses & Surface Abundances (I): Observational data

Observational data by Tsuji (2008)





(M, CNO surface abundances)

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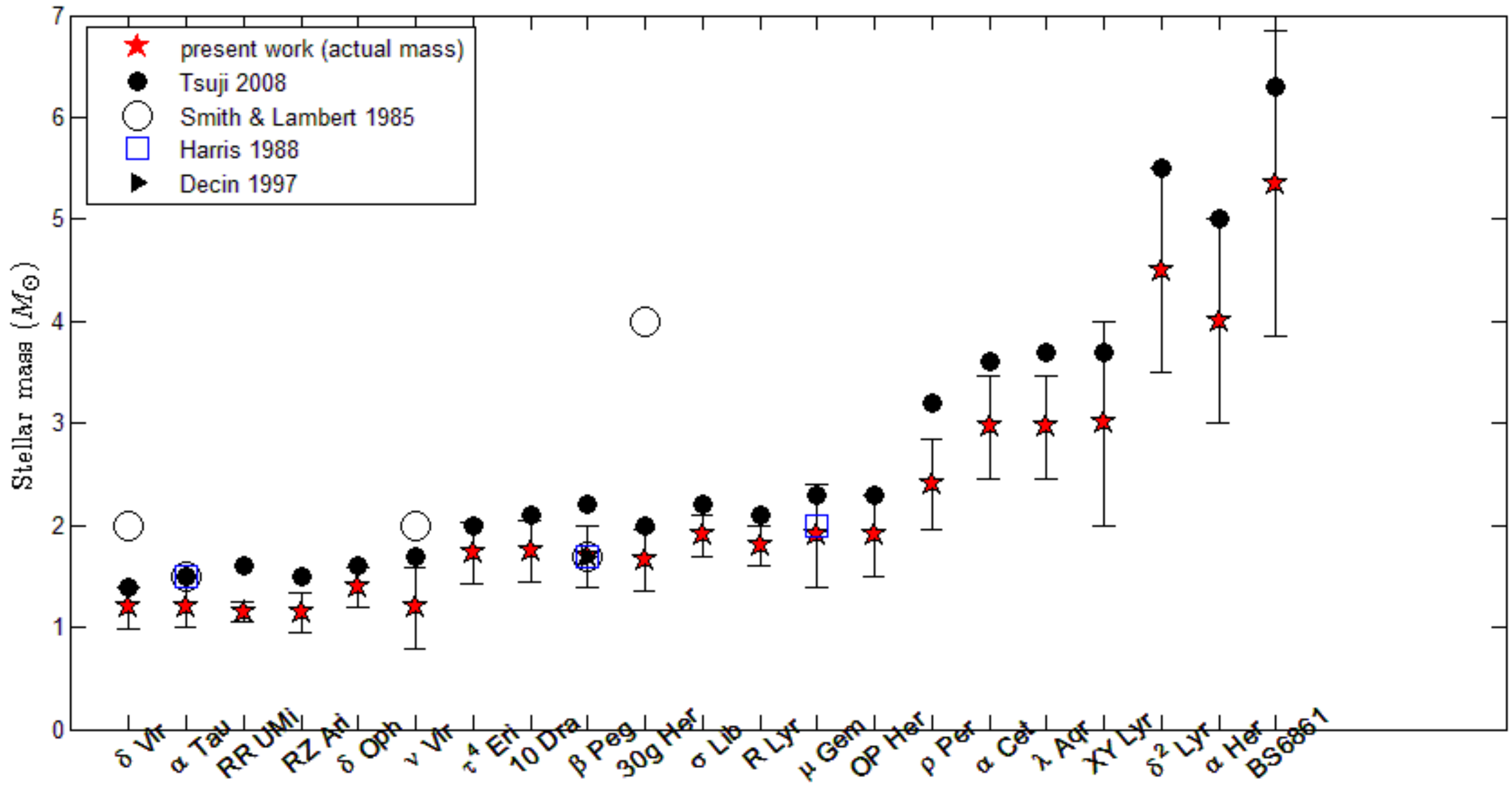
Masses & Surface Abundances (II): Mass Determination



- Mass-loss taken into account
- Lower error bars than Tusji (2008)

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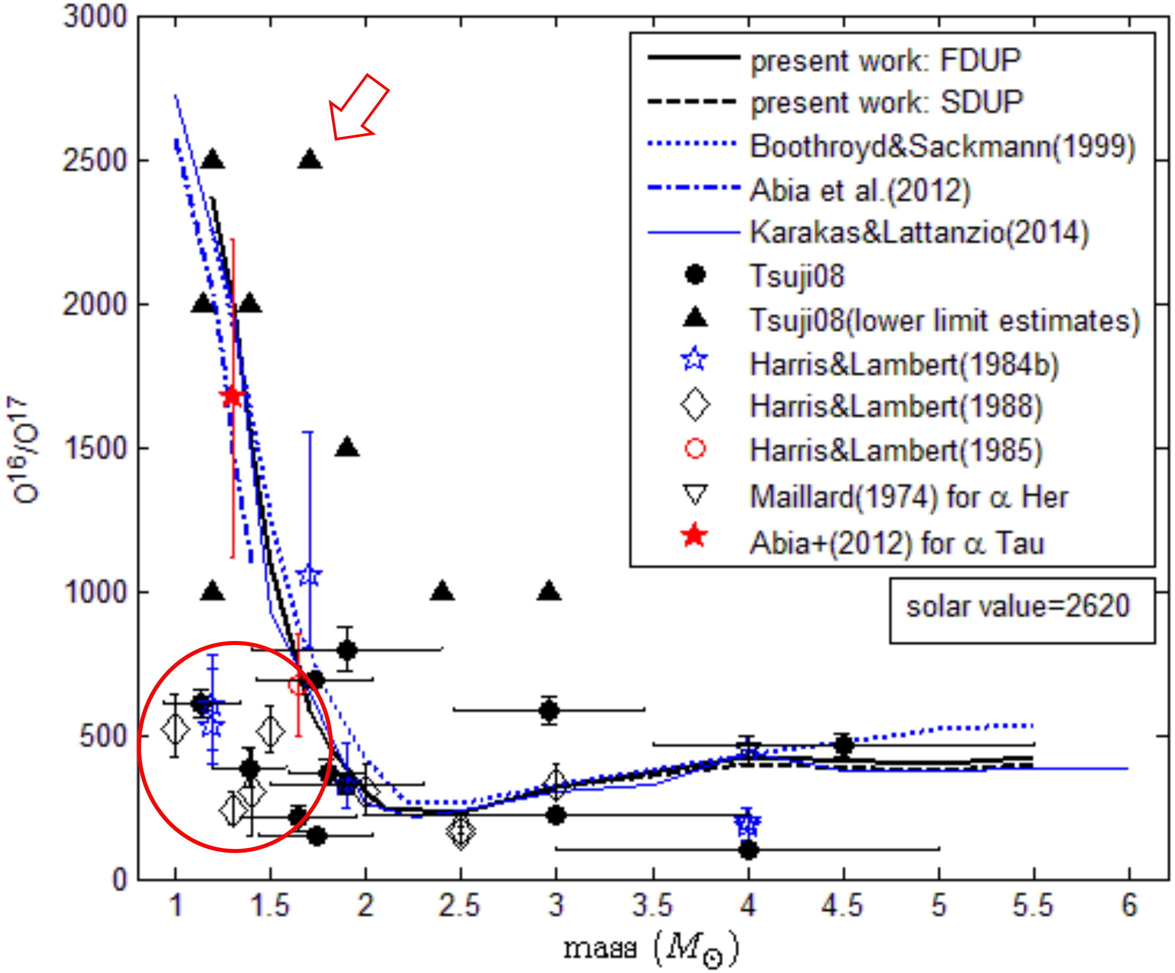
Masses & Surface Abundances (III): Surface Abundance of $^{16}O/^{17}O$



Standard Calculation

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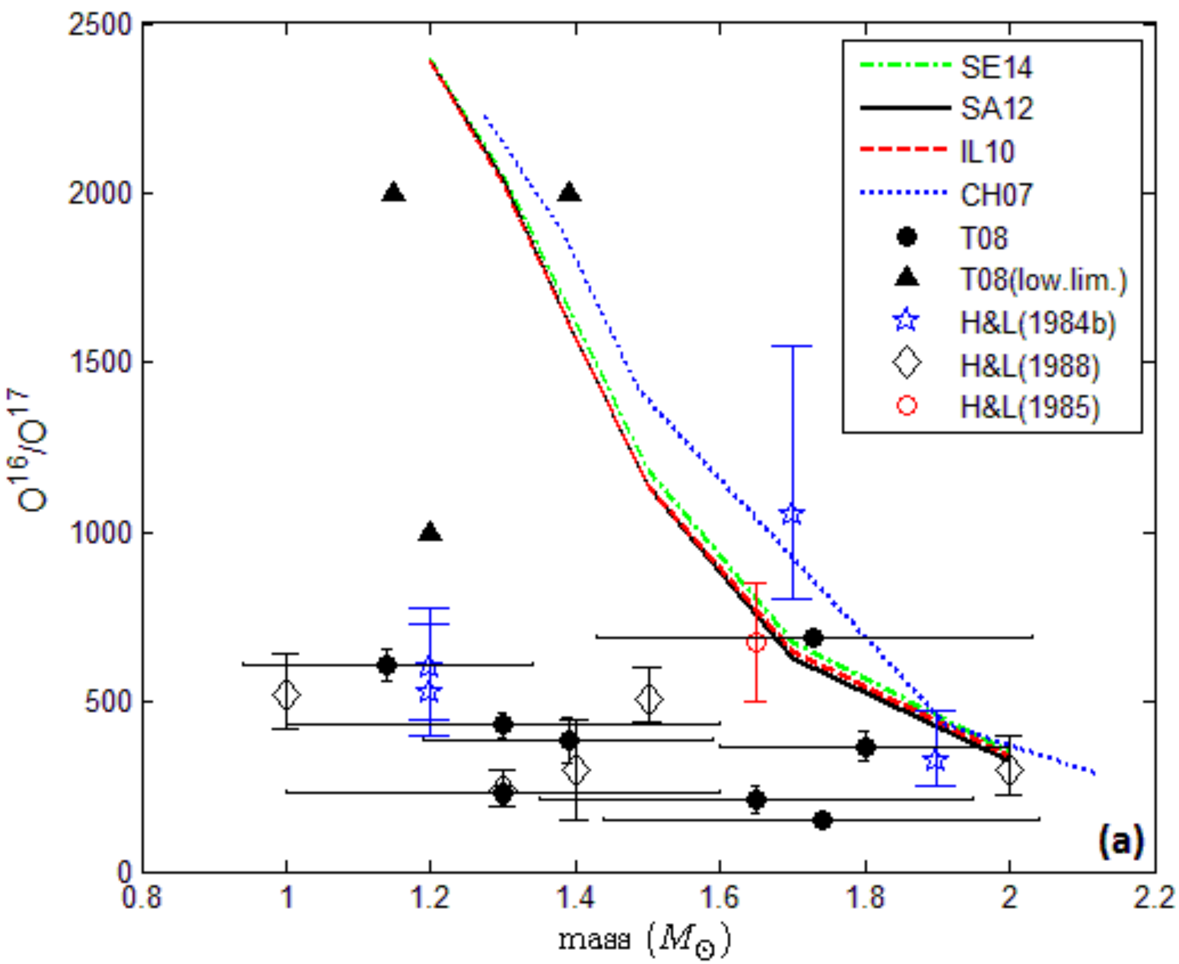
Masses & Surface Abundances (IV): Surface Abundance of $^{16}O/^{17}O$



p-capture reactions

Sergi+ (2014) (THM)
Sallaska+ (2013) (MCS)
Iliadis+ (2010) (MCS)
Chafa+ (2007)

Standard Calculation

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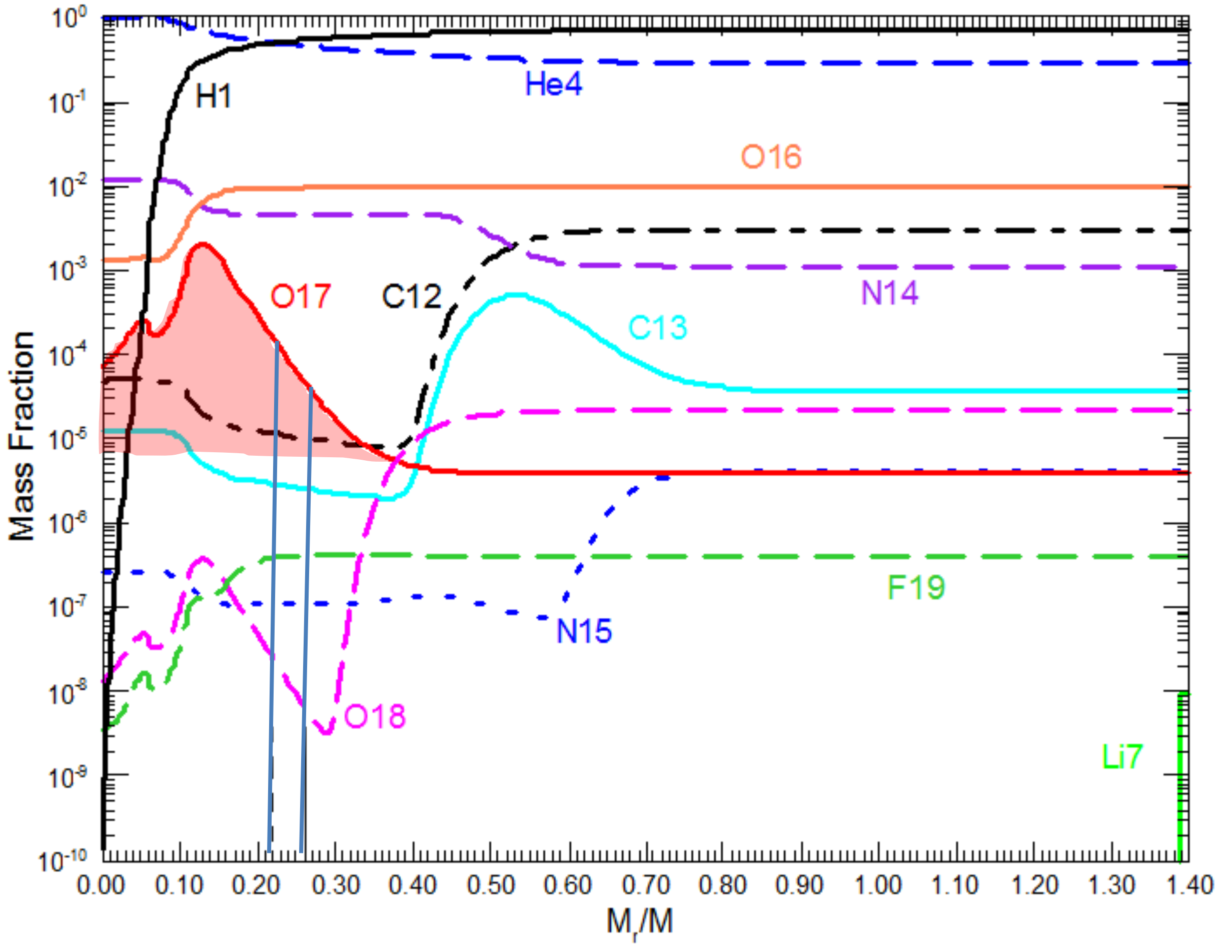
Masses & Surface Abundances (V): Abundance Profiles

Abundance profiles after H-burning, before FDUP



$^{16}O/^{17}O$

Critical indicator of the depth of convective mixing.

1.4M$_\odot$
Z=0.02

Treatment of convective boundaries: Overshooting

$$\frac{dX_i}{dt} = \frac{\partial}{\partial M_r}\left[(4\pi r^2 \rho)^2 \boxed{D} \frac{\partial X_i}{\partial M_r} \right]$$

D = 0 in radiative zones

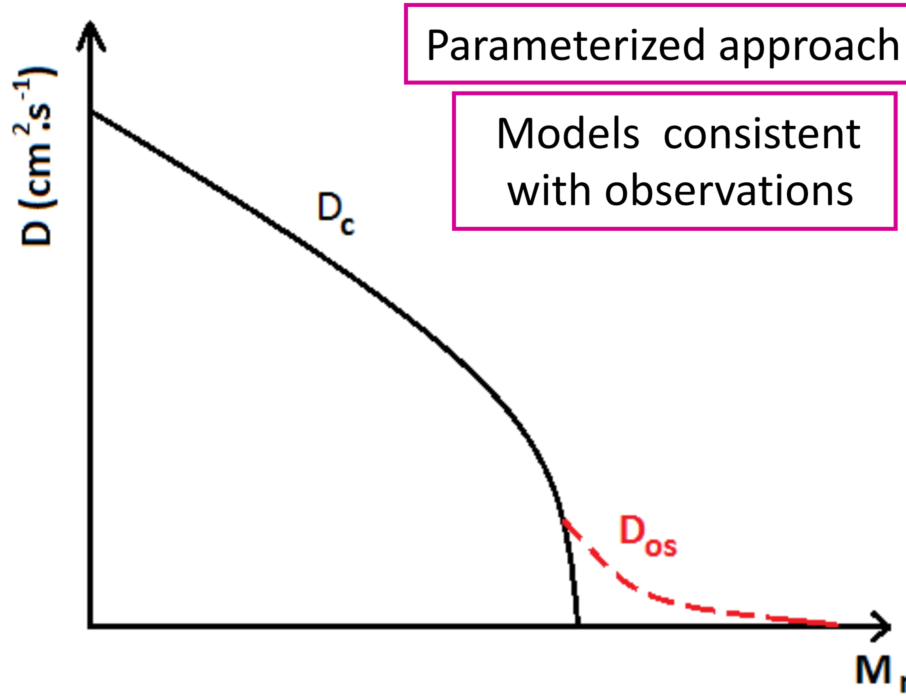
D ≠ 0 in convective zones calculated according to the MLT

D at **convective boundaries** given by:

$$D_{os}(z) = D_c e^{\frac{-2z}{fH_p}} \qquad z = |r_0 - r|$$

(Freytag et al. 1996)

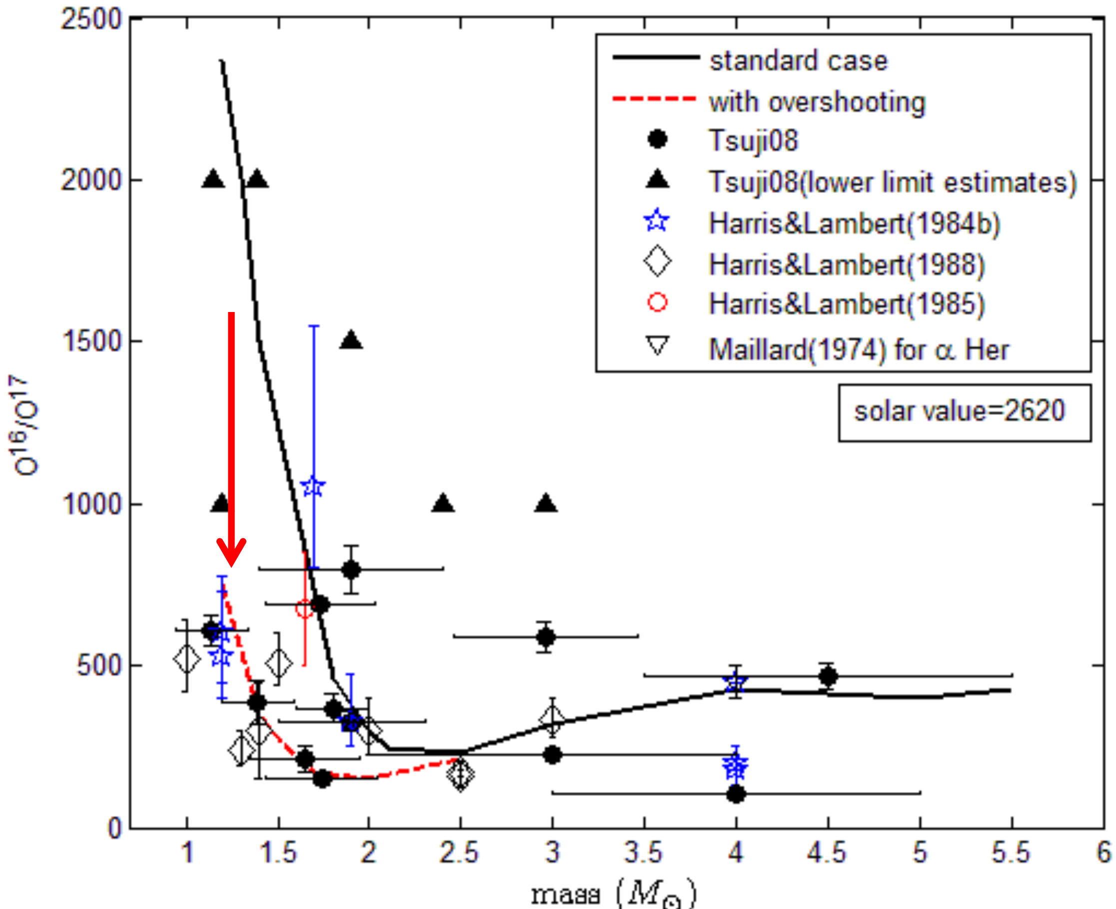
f is dependent on the stellar parameters and the evolutionary phase



Parameterized approach

Models consistent with observations

Masses & Surface Abundances (VI): Surface Abundance of $^{16}O/^{17}O$



with envelope overshooting

Direct evidence that overshooting is needed in low mass stars

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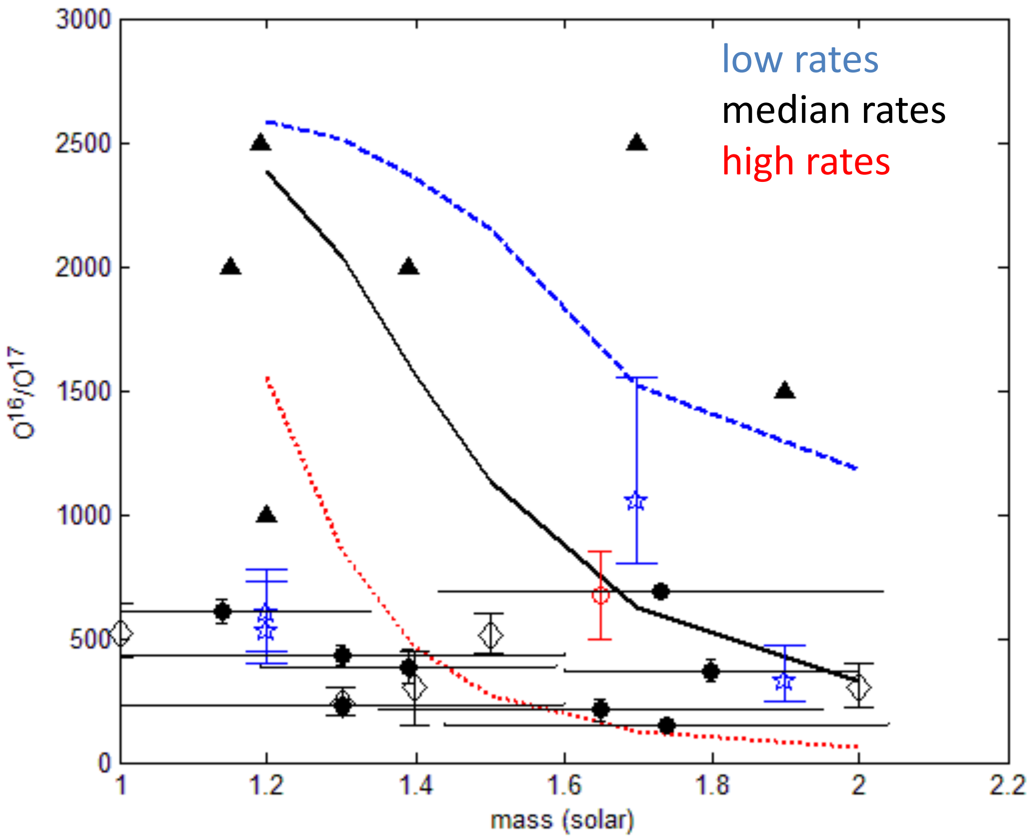
Masses & Surface Abundances (VII): Surface Abundance of $^{16}O/^{17}O$: Rate uncertainties

The Sallaska et al. (2013) compilation of p-capture reaction rates is based on a Monte Carlo simulation.

The rates have statistically well-defined uncertainties (Longland 2012; Iliadis et al. 2014).



Standard case

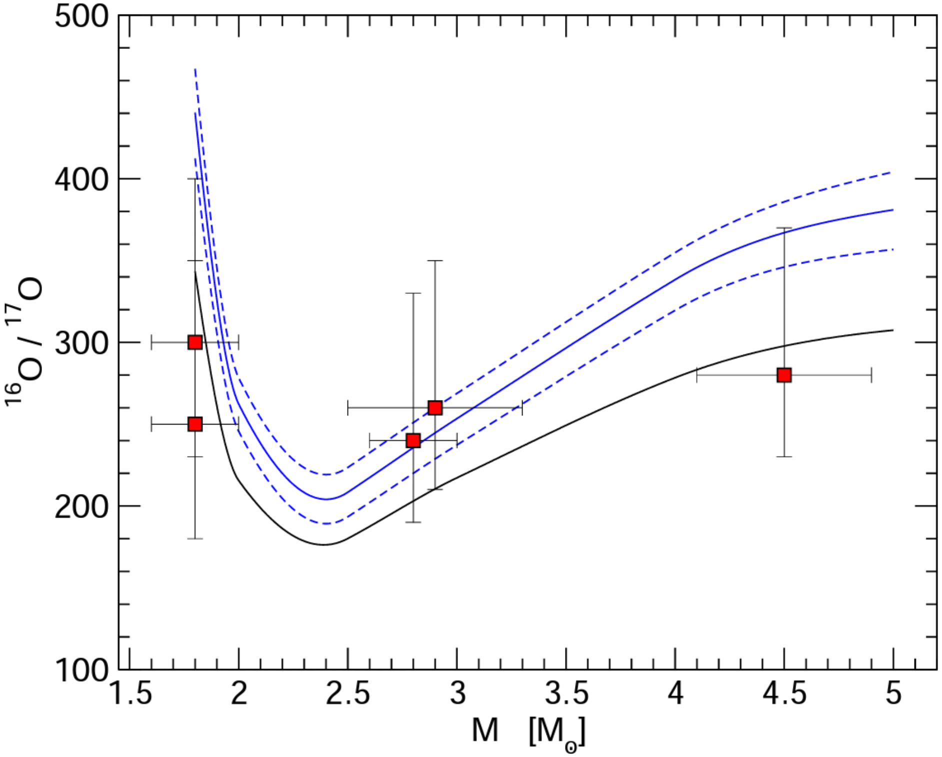
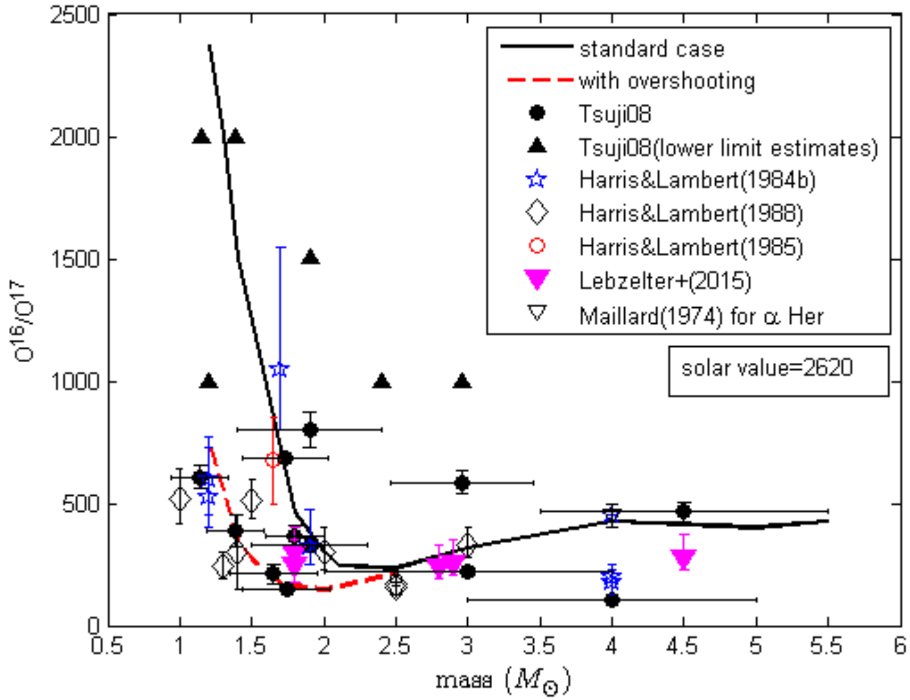
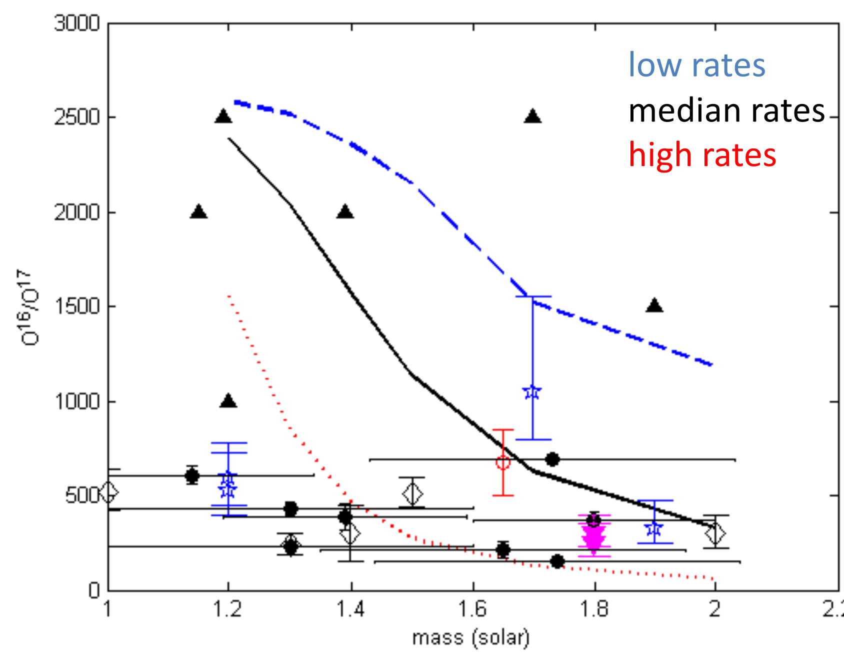


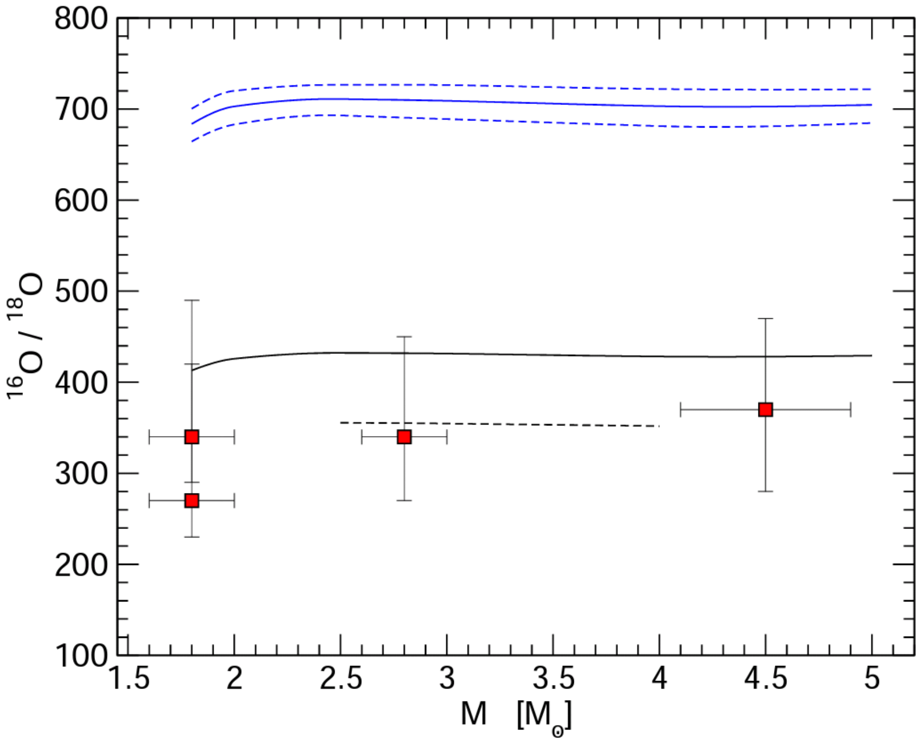
Fig. 4. $^{16}O/^{17}O$ ratios after the first dredge-up versus stellar mass in $M_\odot$. Lines represent the theoretical predictions, and the red squares are observations. Blue solid line: reference model (R). Blue dashed lines: ^{17}O proton capture rate modified within the suggested upper and lower rates (O17L and O17H). Solid black line: theoretical predictions as obtained by reducing the initial ^{16}O to $[^{16}O/H]$=-0.22 (C16OL).



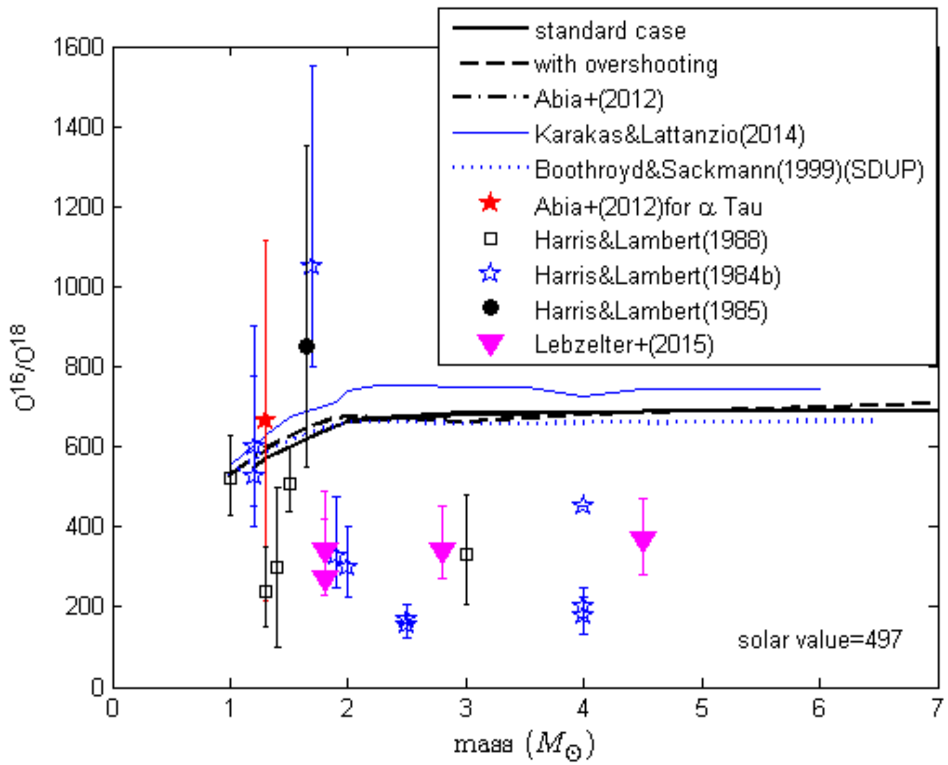


Lebzelter et al. A&A 578A, 33L (2015)

Masses & Surface Abundances (VIII): Surface Abundance of $^{16}O/^{18}O$



Lebzelter et al. A&A 578A, 33L (2015)



Conclusions

- A sample of **observed red giants** was considered and their masses were obtained using extended evolutionary tracks.
- **Overshooting** is needed to reconcile observational **oxygen abundances** with model predictions, particularly in low mass red giants.
- The **spread** in the observational data can be attributed to the inherent difficulties in analysing the spectra of these relatively cool stars and the uncertainties involved in measuring faint lines.
- The effect of recent evaluations of the **reaction rates** on the production and destruction of ^{17}**O** was explored. The experimentally suggested uncertainty of these rates provides a better fit of the ^{16}**O**/^{17}**O** observed in low-mass stars, yet does not exclude the need to invoke overshooting.