

Oxygen isotopic ratios in RGB & AGB stars

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Abstract. Stars in the mass range $1.2-7M_{\odot}$, with solar-like initial composition are evolved from the zero age main sequence till the early AGB phase. Their predicted oxygen isotopic ratios are compared to observationally inferred values in red giants to investigate how well standard evolutionary calculation reproduces available observations and to illustrate the role of convective mixing. We find that extra mixing beyond the convective boundary determined by the Schwarzschild criterion is needed to explain the observational oxygen isotopic ratios, particularly in low mass stars. The effect of recent determinations of proton capture reactions and their uncertainties on $^{16}\text{O}/^{17}\text{O}$ is also shown.

1. Introduction

The evolution to the red giant branch (RGB) follows the ignition of shell H-burning surrounding the He core. The released energy flux causes the envelope to expand and a deep convective envelope develops, leading to a change in the surface composition of the star. In this contribution, an observed sample of red giants [1] is used to estimate the masses by matching their observationally derived effective temperatures and bolometric magnitudes to the values obtained from the evolutionary tracks in the HR diagram. This is possible since the stars are not pulsating Mira variables (see [2] for details). We then compare their calculated oxygen abundances to those inferred from observations. This comparison is useful in order to improve the treatment of convective mixing in the stellar interiors. In particular, the abundance profile of ^{17}O exhibits a steep gradient within the central region of the star, at the position of maximum convective penetration. This renders the ^{17}O surface abundance sensitive to the depth of the convective envelope, the stellar mass, as well as to the nuclear reaction rates involved in the ON cycle. Our results suggest the need for extra mixing below the edge of the convective envelope as determined by the Schwarzschild criterion in order to achieve a better agreement with observations. The effect of several determinations of p-capture ON reaction rates on $^{16}\text{O}/^{17}\text{O}$ is investigated.



This work is organized as follows. Section 2 describes the calculations. Some results are presented in Section 3. Concluding remarks are given in Section 4.

2. Model Calculations

The evolutionary sequences presented in this work are obtained using the stellar evolution code HYADES as described in [3]. Details on the calculation and results can be found in [2]. Mass-loss is included using semi-empirical rates adjusted to the global parameters of the star. Overshooting, or mixing beyond the Schwarzschild boundary is introduced according to the hydrodynamic simulations by [4], where an exponentially decaying diffusion coefficient is introduced at the convective boundary.

3. Results

3.1. Evaluation of the stellar masses

Using the bolometric magnitudes and effective temperatures of the star sample observed by [1], evolutionary tracks of (1.2-7) M_{\odot} stars are used to evaluate the stellar masses as shown in Fig. 1.

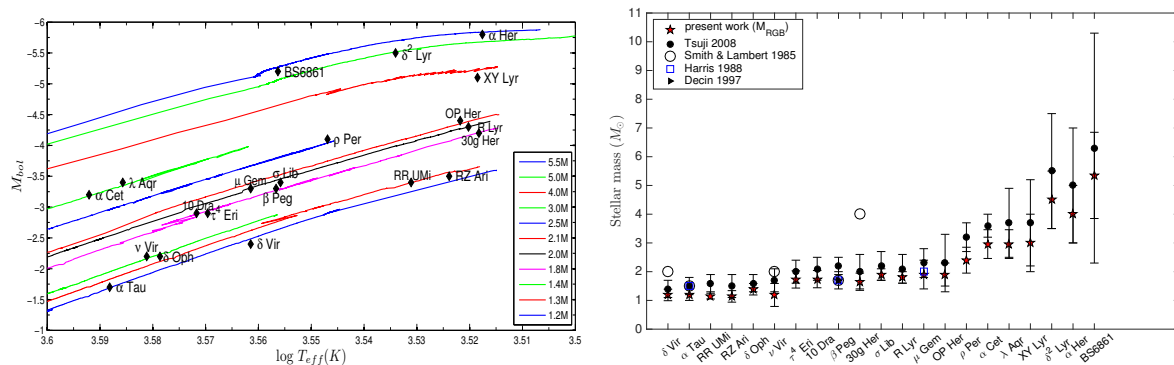


Figure 1. Left panel: Evolutionary tracks shown with the observed sample of red giants. Right panel: The stellar masses reported with the error bars in addition to other evaluations as shown, in solar units.

3.2. Oxygen Surface Abundances

We use the $^{16}\text{O}/^{17}\text{O}$ of the observed red giants, whose masses are determined, to constrain the extra mixing required on the RGB. The left panel of Fig. 2 shows the predicted $^{16}\text{O}/^{17}\text{O}$ ratios in the standard case (no extra mixing), along with other predictions and available observations. In the case of low-mass stars, the predicted $^{16}\text{O}/^{17}\text{O}$ ratio is higher than most data points obtained from observations. The results of standard calculation by other groups shown in the figure indicate a similar behavior. This shows that more ^{17}O needs to be mixed to the surface, which may be achieved by extra mixing or overshooting at the bottom of the convective envelope. Applying overshooting described in Sect. 2, our calculations show that $f = 0.125$ provides the best estimate for the overshooting efficiency in low mass stars. The right panel of Fig. 2 shows the results with overshooting. The low observational $^{16}\text{O}/^{17}\text{O}$ values in low mass stars can now be better fitted within the error bars on the stellar masses.

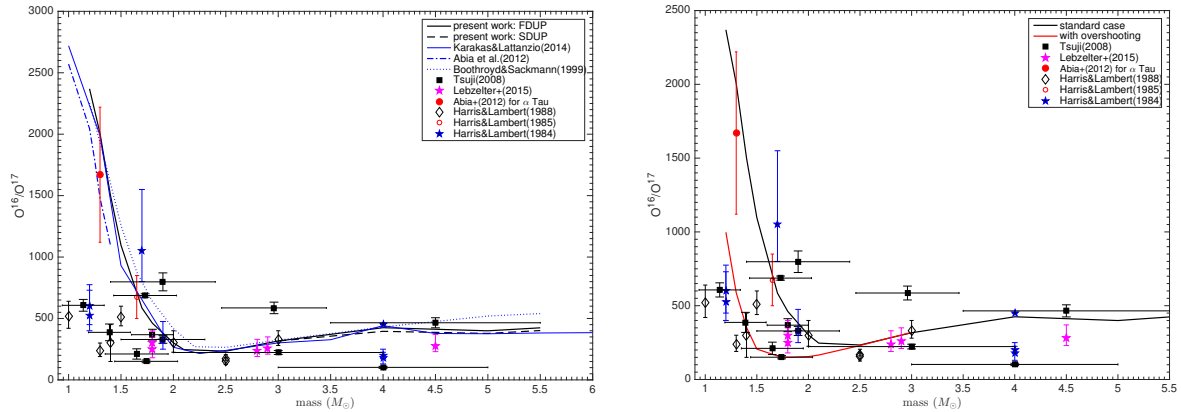


Figure 2. Left panel: $^{16}\text{O}/^{17}\text{O}$ ratios in the standard case. Calculations by other groups and observations are shown for comparison. Right panel: The ratios obtained with overshooting at the bottom of the envelope with $f = 0.125$. The solar value is 2620.

3.3. Effect of the ON p -capture reaction rates

To investigate the effect of the ^{17}O production and destruction rates on the $^{16}\text{O}/^{17}\text{O}$ ratios, four different evaluations of the proton-capture reactions $^{16}\text{O}(p, \gamma)^{17}\text{F}$, $^{17}\text{O}(p, \gamma)^{18}\text{F}$ and $^{17}\text{O}(p, \alpha)^{14}\text{N}$ are used. In particular, we use the compilations by [5] (SE14), [6] (SA13), [7] (IL10) and [8] (CH07). The ratios obtained with the four sets in the standard case are shown in the left panel of Fig. 3, exhibiting very similar values in the considered mass range. None provides a reasonable agreement between model predictions and observations unless overshooting is included.

The effect of rate uncertainties is also worth exploring. Since the SA13 compilation is based on a Monte Carlo simulation and the rates have statistically well-defined uncertainties, the ratios are calculated using the recommended, high and low rates, where the rate boundaries correspond to a 95% coverage probability. The $^{16}\text{O}/^{17}\text{O}$ ratios show a large sensitivity to these uncertainties, as shown in the right panel of Fig. 3. It is found that the discrepancy between predictions and observations becomes less pronounced when the uncertainty on the involved reaction rates is considered.

4. Conclusions

A sample of observed red giants was considered. Their masses were obtained using extended evolutionary tracks and their predicted oxygen abundances were compared to available observations. Overshooting based on the mixing of chemical elements by diffusion is needed to reconcile theoretical and observational $^{16}\text{O}/^{17}\text{O}$ ratios, particularly in low mass stars. Moreover, we find that the experimentally suggested uncertainty on relevant reaction rates may reduce the existing discrepancy but does not exclude the need to invoke overshooting.

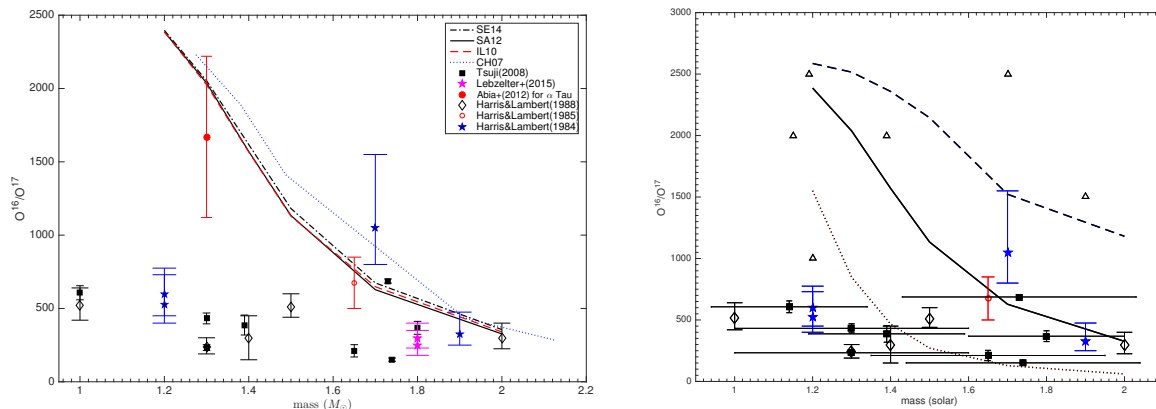


Figure 3. Left panel: $^{16}\text{O}/^{17}\text{O}$ ratios in the standard case using four different sets of reaction rates (see text for details). Right panel: The SA13 set of rates: recommended (solid line), high rates (dotted) and low rates (dashed).

4.1. Acknowledgments

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