The Impact of Extra Mixing in Low-Mass Stars on Presolar Grain Abundance Predictions

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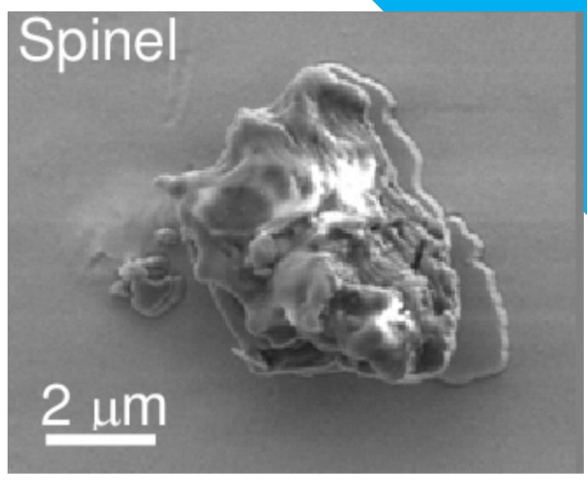

Presolar grain photo credit: Max Planck Institute for Chemistry

Presolar grains are dust particles which predate the formation of the solar system. The isotopic ratios observed in grains provide insight into the nucleosynthesis and mixing in their progenitor star. Stellar nucleosynthesis models fail to reproduce measured isotopic abundances in group 2 oxygen-rich presolar grains, which are characterized by ^{18}O depletions relative to solar abundances[1]. The proposed source of such grains are the surfaces of low- or intermediate-mass AGB stars with extra mixing[1][2]. Cool bottom processing is a proposed form of slow extra-mixing in low mass stars which extends mixing below the convective envelope [3].

Simulated Star

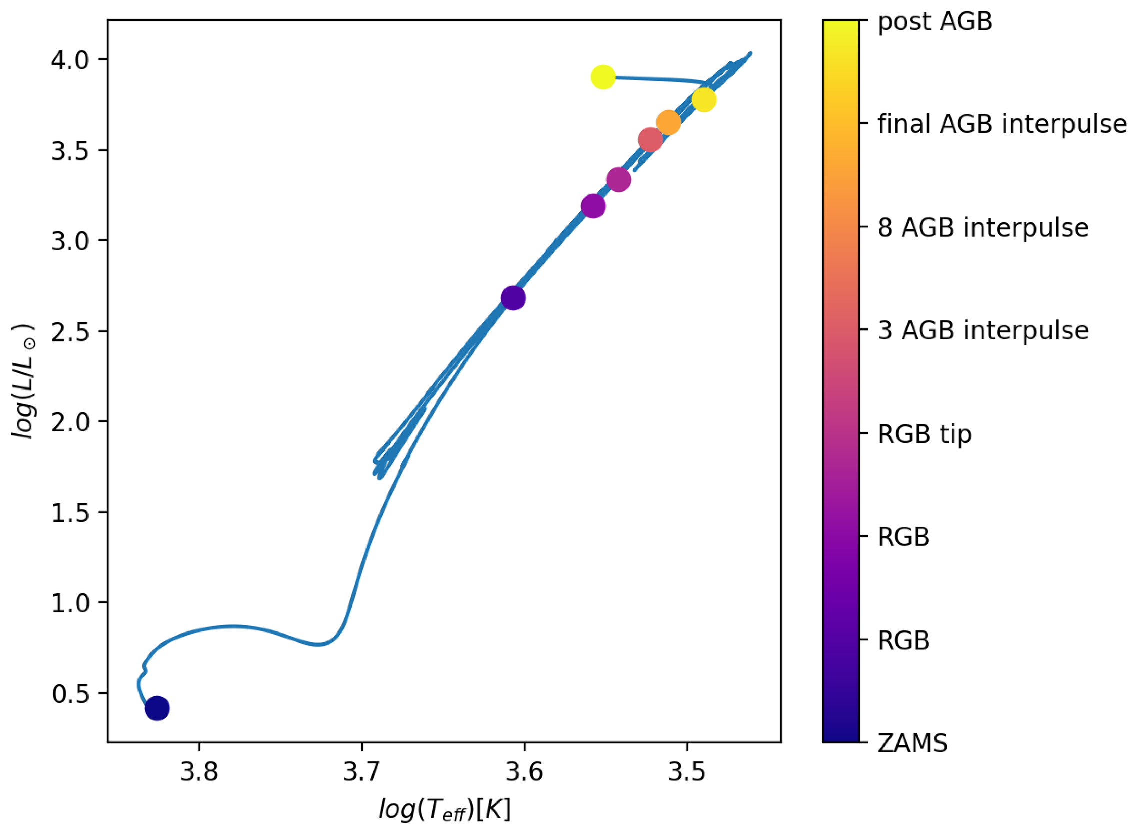

Figure 1: Hertzsprung-Russell diagram (HRD) of the $1.2M_{\odot}$ star with solar metallicity that was simulated using MESA. The Reimers and Blocker wind schemes were used to simulate mass loss during the RGB and AGB phases, respectively. Important evolutionary stages are marked.

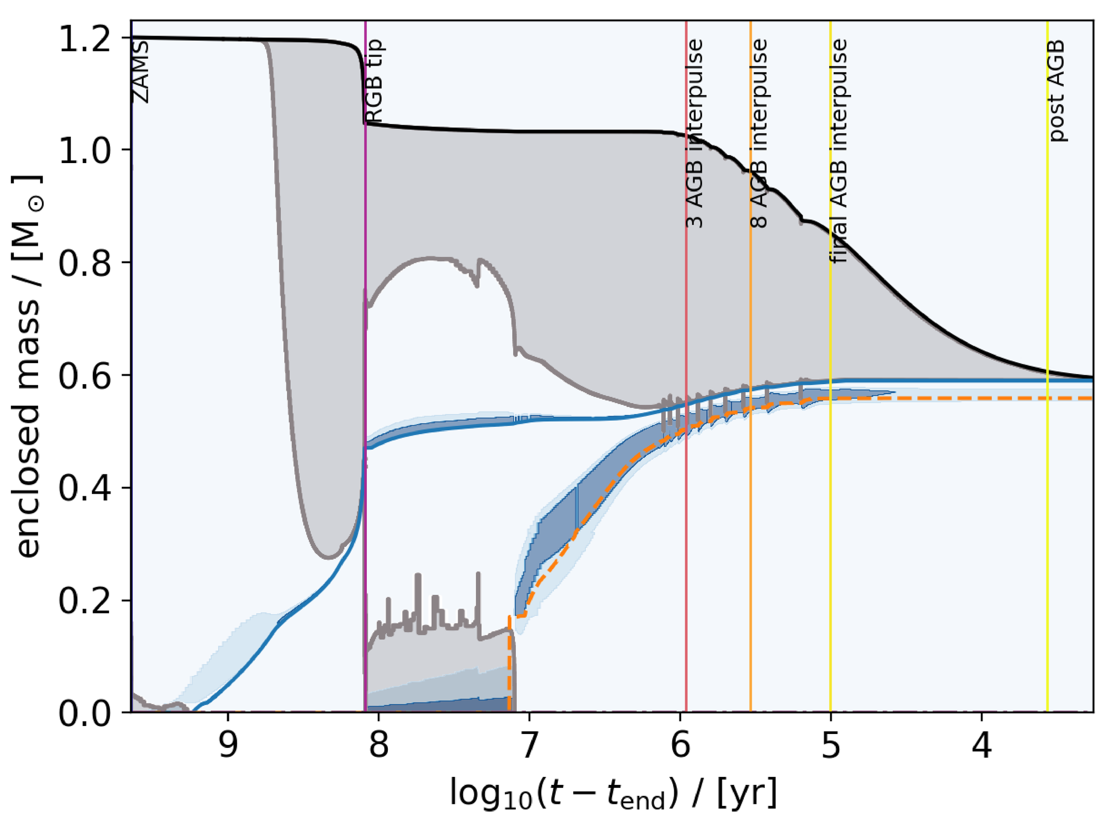

Figure 2: Kippenhahn diagram of the simulated star with lines at the times marked in Fig 1. The surface of the star is marked by a solid black line*, the hydrogen free core is marked by a solid blue line, the helium free core is marked by an orange dashed line, convective mixing is marked by grey shading, and energy generation is marked by blue shading.*

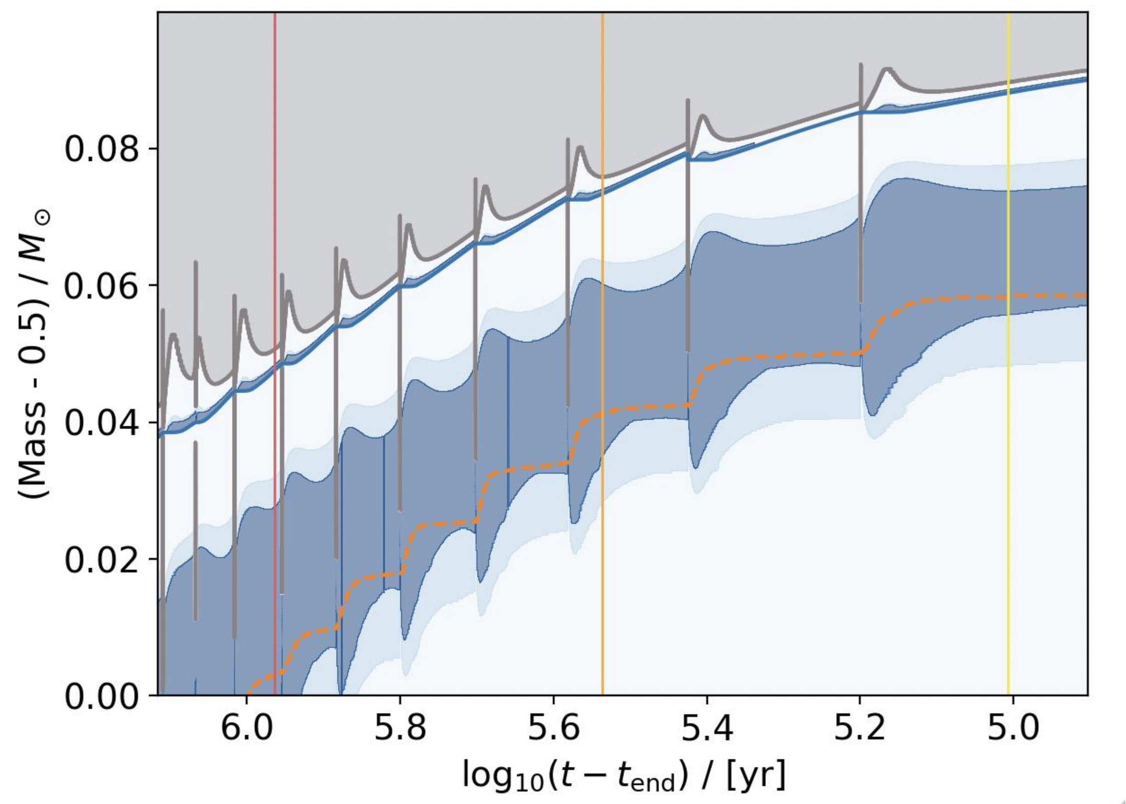

Figure 3: Enlarged Kippenhahn diagram of the thermally pulsing AGB. Pulse-driven convective zones form beneath the convective envelope, and during interpulse periods, displaced material can react or mix to the surface. Most dust formation occurs during or immediately after this phase.

Implementation of Extra Mixing

- Extra mixing below the convective envelope is included in addition to the third dredge up.
- The extra-mixing diffusion coefficient was set as a sub-unitary fraction (0.2) of the thermal diffusivity, which preserves the thermal stratification.
- To simulate a low energy process the depth of the extra mixing was limited by the steep increase in the mean molecular weight gradient.
- To match observed grains the extra mixing must overcome an increase in mean molecular weight by a factor of $1 + 10^{-5}$.
- Extra mixing is included during the RGB phase until the first helium shell flash and during the interpulse periods of the AGB phase.
- The interpulse periods were identified using the ratio of helium and hydrogen luminosity.
- The star was simulated into the post-AGB phase where it is no longer losing mass and forming dust.

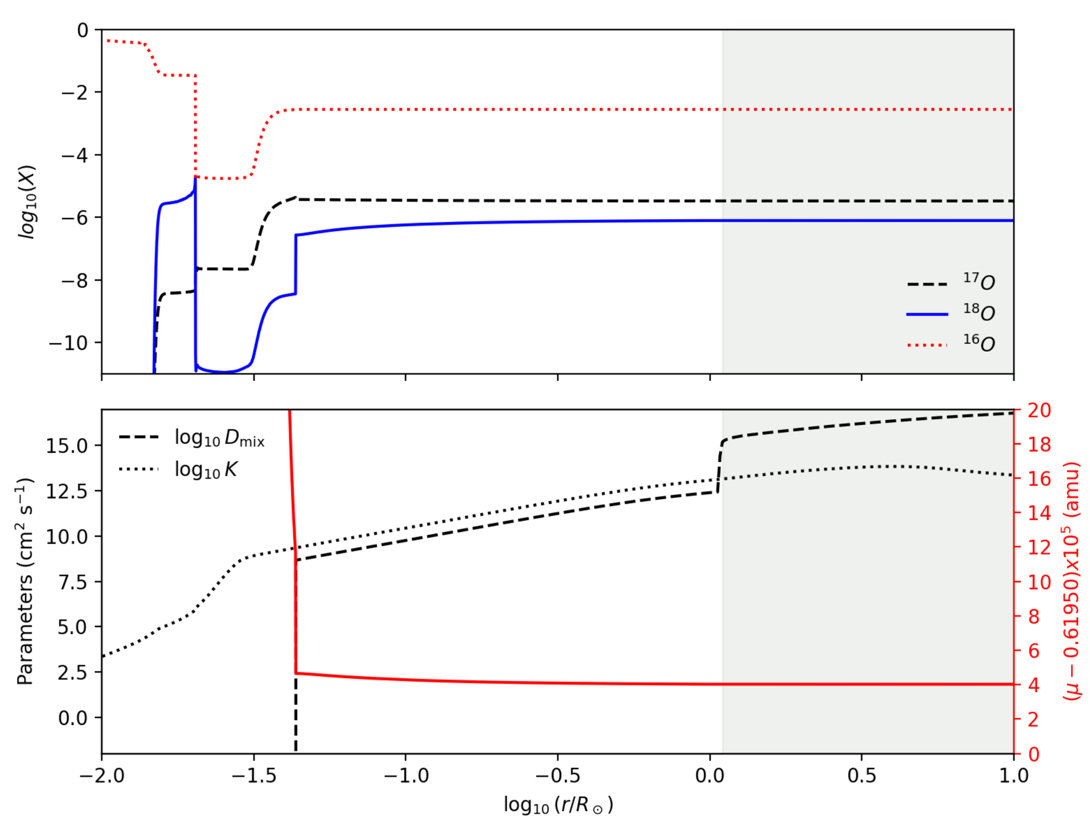

Figure 4: Radial profile of oxygen isotopic abundances, diffusion coefficient (D_{mix})(which determines the rate of mixing), thermal diffusivity (K) and mean molecular weight (μ) during the third interpulse period

Results

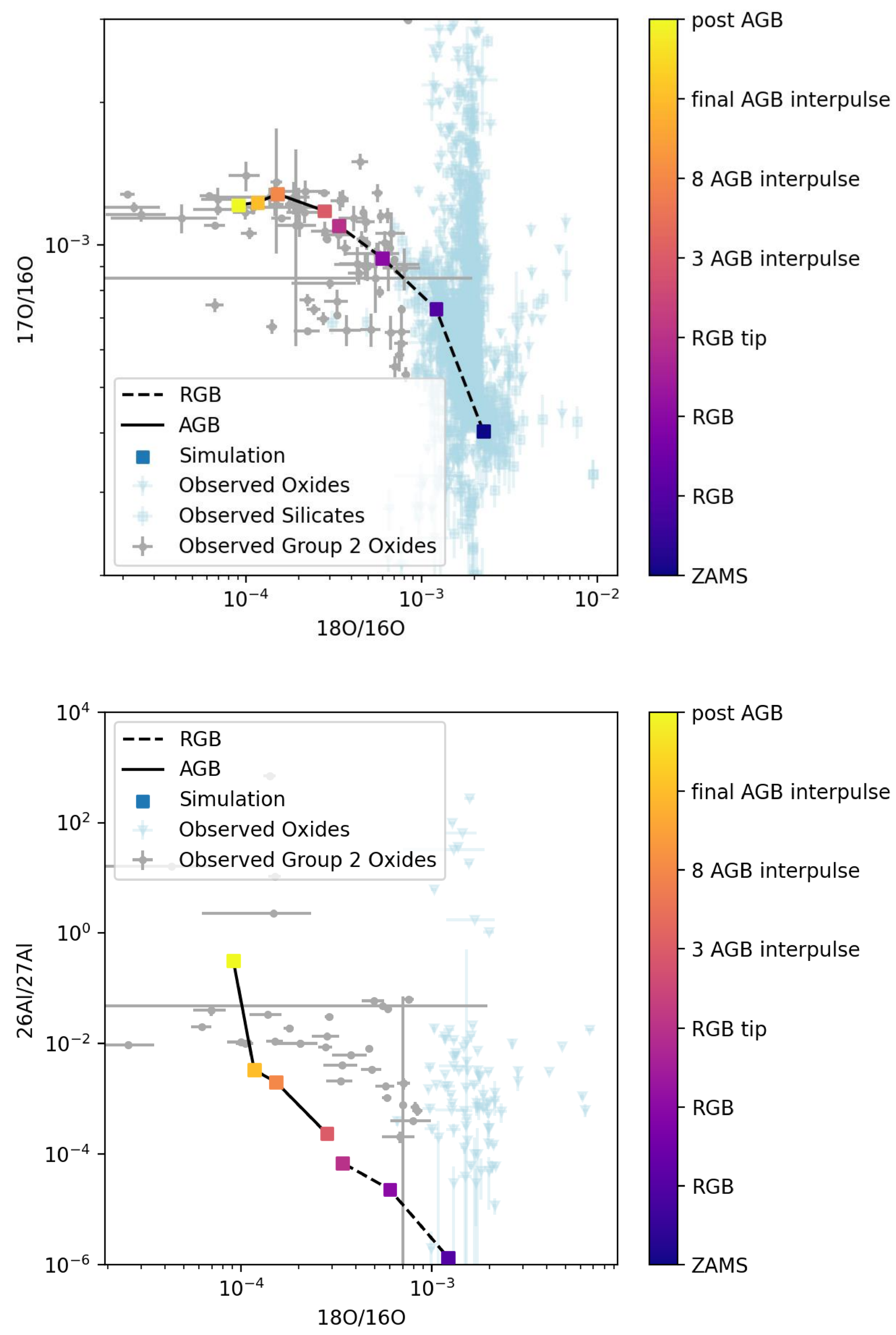

Figure 5: Comparison of observed oxygen and aluminum isotopic ratios and simulated ratios over the course of the star's evolution. Abundances are displayed at the same times indicated on Fig.1.

Conclusion

- Without extra mixing the simulated isotopic abundances fail to match measured ratios.
- The formation of presolar grains is possible from the late RGB to the post AGB. Over this period the simulated oxygen isotopic ratios fit observations very well.
- Extra mixing improves the simulated aluminum ratios' fit to observations but less so than for oxygen, possibly due to nuclear physics uncertainties.

Ongoing Work

- Perform a Monte Carlo impact study on a wide range of reaction rates including $^{18}O(p,\alpha)^{15}N$, $^{16}O(p,\gamma)^{17}F$, and $^{23}Na(\alpha,n)^{26}Al$.
- Calculate and compare the energy of the extra mixing and the work required to mix the increase in mean molecular weight through to the bottom of the convective envelope.
- Study the impact of varying overshooting below the pulse driven convective zones and mass loss on the length of the AGB and the surface isotopic ratios.

References

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Discovery, accelerated

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