SEARCHING FOR THE SIGNATURES OF PRESOLAR GRAINS IN MASSIVE STARS. V. V. Dwarkadas[1], S. Dilmohamed[2], S. Ekstrom[3], G. Meynet[3], N. Liu[4], Meyer, B.[5], N. Dauphas[2], [1]Astronomy and Astrophysics, UChicago (vikram@astro.uchicago.edu), [2]UChicago, [3]UGeneva, [4]Washington University, [5]Clemson University

Introduction: The early Solar System (ESS) is characterized by an initial $^{26}Al/^{27}Al$ ratio that exceeds the Galactic average [1,2,3,4], while the inferred initial $^{60}Fe/^{56}Fe$ value is about an order of magnitude less than the Galactic value [4,5]. These results disputed the existence of a supernova near the solar system at the time of formation. An alternative source of ^{26}Al is Wolf-Rayet (W-R) stars [5,6,7,8,9,10,11]. [12] showed that a single W-R star could be sufficient to provide the inferred amount of ^{26}Al in the ESS. W-R star winds sweep up the surrounding medium to form wind bubbles bordered by a dense shell. The ^{26}Al is carried out by dust grains in the wind from the star to the dense shell, where it is released. No ^{60}Fe is ejected in the wind. The solar system is formed by triggered star formation in the dense shell.

Dust grains and massive stars: A question arises as to whether dust grains found in meteorites can be traced back to W-R stars. In the model of [12], wind material emitted by the star throughout its evolution is collected within the W-R bubble. Thus grains formed in earlier phases would be contained within this bubble and could be injected into the presolar cloud that formed the ESS. Dust grains in meteorites whose isotopic signatures match those in massive (> 10 $M_\odot$) stars would therefore provide solid evidence to support this model. Herein we concentrate on oxygen-rich grains. Carbon-rich grains will be explored in future.

Extensive isotopic studies suggest that > 90% of SiC grains arise from AGB stars, whereas the remaining are ascribed to supernovae, novae, or born-again AGB stars [13]. Oxygen-rich oxides and silicate grains are divided into 4 groups [14]. Group 1 grains show excess ^{17}O, with $^{17}O/^{16}O < 0.007$. Group 2 grains are enriched in ^{26}Al and ^{17}O, but show ^{18}O depletions much greater than solar values. Some Group 2 grains were once suggested to have originated from W-R stars [15, 16, 17], although recent results [18] using a revised proton-capture rate suggest an origin in AGB stars of 4-8 $M_\odot$. W-R stars were postulated as a possible source for circumstellar graphite grains [19, 20] to account for their C, N, and s-process isotopic composition, with several caveats. In addition, W-R and red supergiant (RSG) stars were implied as the source of a fraction of Group 1 and Group 2 oxide grains [21].

Oxygen-rich grains from massive stars: Presolar oxide grains are classified by their $^{17}O/^{16}O$ and $^{18}O/^{16}O$ ratios. The grain data shown in the plots was obtained from the presolar grain database at Washington University. The oxygen ratios were compared to model predictions at the surface of massive stars at various timesteps (the surface abundance denoting material carried out in the wind), using a grid of stellar evolution models for stars from 20 to 120 $M_\odot$ computed by the Geneva group [22, 23, 24]. We only plot ratios at those times when the surface C/O < 1, used as a proxy for an oxygen-rich environment. In Figure 1 we show observed presolar oxide and silicate grains, compared to the isotopic ratios for rotating and non-rotating stars. The data-model comparison shows clear overlap between the stellar and grain isotopic ratios. We emphasize that while overlap points to a potential source of grains, it is not sufficient, and dust formation needs to occur. How that happens, mass of dust formed, and the role of binary stars and colliding winds, are all topics under investigation. Hydrodynamic instabilities and mixing between layers must be considered, which we will do in future using the MESA code.

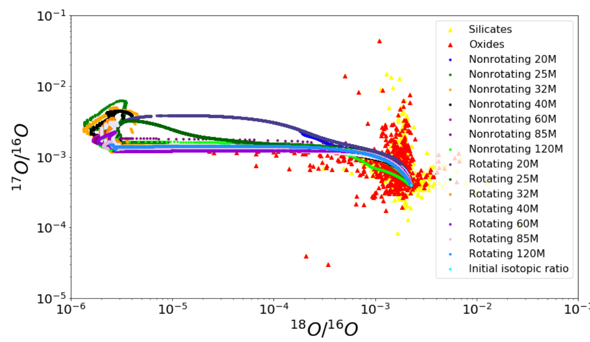

Figure 1: Oxygen isotopic ratios of oxide and silicate grains, compared to model predictions for rotating and non-rotating stars, mass > 20 $M_\odot$, C/O > 1.

Current stellar evolution theory suggests that single stars with initial mass below about 30-35 $M_\odot$ will end their lives as RSG stars, whereas a star of higher mass may lose its H and perhaps He envelope, ending its life as a W-R star. We plot in Figure 2 the phase of evolution, either main-sequence H-burning (O and B type stars) or post-main-sequence (RSG, yellow supergiant (YSG), and blue supergiant (BSG)) phase, irrespective of the mass (the W-R phase is not included here). Isotopic ratios of some main-sequence O and B stars are consistent with a few Group 2 grains. Similarly, some RSG stars show isotopic ratios similar to those measured in Group 2 grains. Group 2 grains have high inferred $^{26}Al/^{27}Al$ ratios, which is consistent with RSG winds, since ^{26}Al is expected to be released in the post-main-sequence mass-loss. Furthermore, infrared studies of dust features around RSG stars have revealed that dust around RSGs evolves from being Ca-Al-silicate and Al_2O_3 rich to (Mg, Fe)SiO_4 [25].

W-R stars go through various phases where nitrogen (WNE (early WN spectral type – hotter) and WNL (late WN spectral type - cooler)), carbon (WC) and oxygen (WO) lines are dominant. Figure 3 shows that possible overlap exists between WN stars and Group 2 grain ratios. However dust grains are not observed around WN stars. In the WC and WO phases, C/O > 1, so it is more likely to condense C-rich dust, as is observed in infrared observations. Non-equilibrium dust condensation calculations [26] have shown that SiC, TiC, AlN, CaS and Fe-rich grains are the most likely to condense around W-R stars, and their isotopic ratios remain a topic for future investigation.

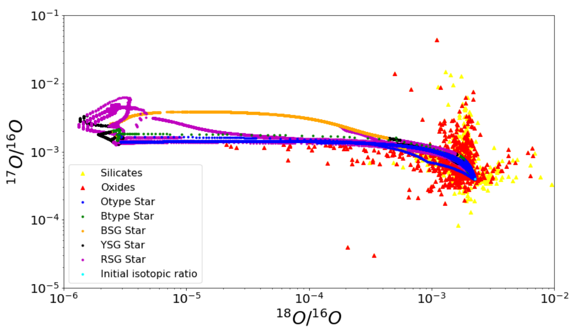

Figure 2: Oxygen isotopic ratios of stars in the main-sequence and post-main-sequence phases, compared to those of presolar oxides and silicates.

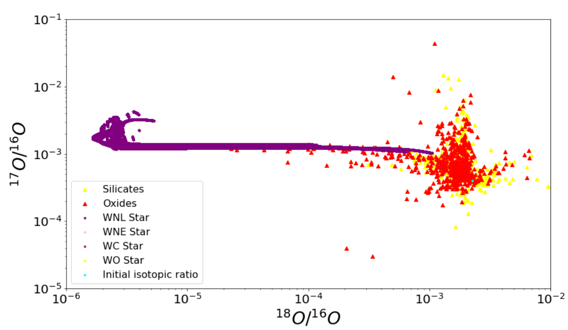

Figure 3: Oxygen isotopic ratios of massive stars evolving through the W-R phase compared to presolar oxide and silicate grains.

Oxygen Nucleosynthesis in Massive Stars: Oxygen isotopic ratios are sensitive to metallicity, initial stellar mass, mass-loss, and overshooting [27].

Oxygen-16 content decreases at the end of the main-sequence phase. Oxygen-17 decreases in the central region, but can be slightly produced in the outer regions, thus decreasing less than of ^{16}O. Oxygen-18 is almost all destroyed in the central regions. Thus the ratios tend towards the left during the main-sequence.

The core He burning phase is the main phase of ^{16}O production. Oxygen-17 does not vary much from core-H burning, while ^{18}O, although briefly peaking at the beginning of this phase, decreases overall.

During the WNL/WNE phase the composition is representative of CNO burning, which tends to decrease ^{16}O. Oxygen-17 may increase in a region of partial H-burning, otherwise it is destroyed along with ^{18}O. The plasma in WNL stars may consist of a mixture of material that has been processed by complete or partial CNO burning, and material that retains the initial composition. The $^{17}O/^{16}O$ ratio increases slightly due to the fact that first ^{16}O decreases slowly in the core, while ^{17}O is slightly increased in the region of partial H-burning. Oxygen-18 is primarily destroyed, hence $^{18}O/^{16}O$ decreases. During the WC phase, one sees products of core He burning, leading to an increase in ^{16}O, destruction of ^{17}O and a destruction/synthesis (at the very beginning of the He burning) of ^{18}O.

Conclusions: Investigation of isotopic ratios show that Group 2 oxygen-rich grains have isotopic compositions similar to model predictions for O, B, and RSG stars, as well as observed dust features around supergiant stars, and could arise from massive stars. Several issues, difficulties, and caveats have been identified, and further investigations are ongoing.

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