SOURCES OF SiC GRAINS WITH LOW $^{12}C/^{13}C$ AND HIGH $^{15}N/^{14}N$ AND $^{26}Al/^{27}Al$.
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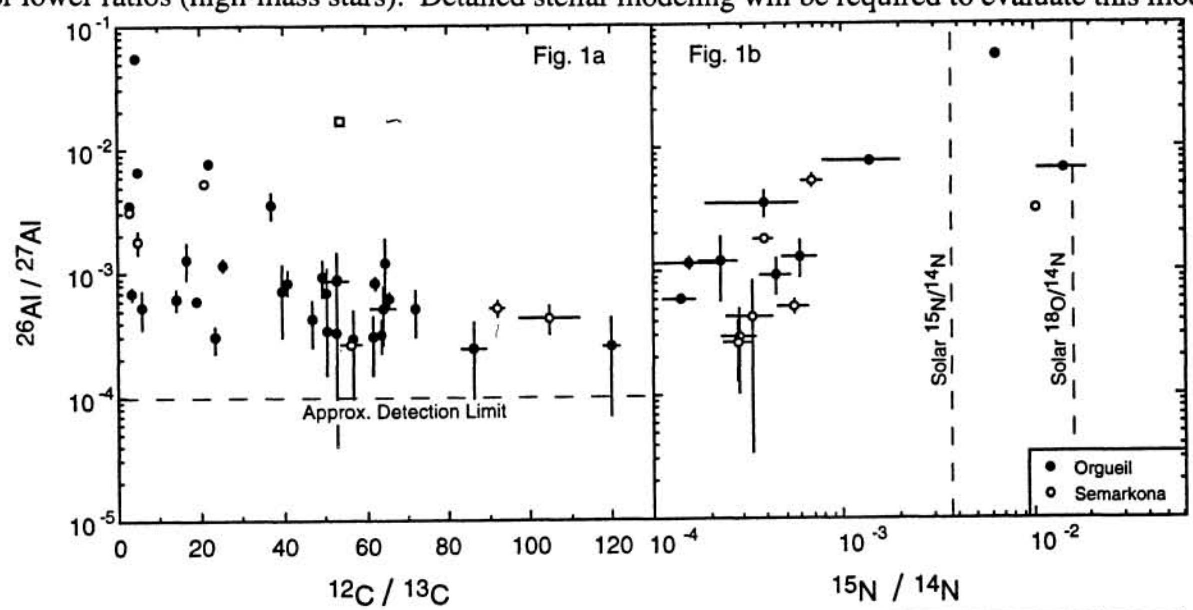
The isotopic characteristics of most presolar SiC grains (mainstream grains) from primitive chondrites are consistent with an origin in low-mass AGB stars [e.g., 1]. Small groups of grains require a different origin, such as the X grains which appear to have come from supernovae [2]. Grains with $^{12}C/^{13}C$ ratios below ~20, which make up 5-10% of the presolar SiC in chondrites, are not currently understood. Standard models of partial H burning at the base of the stratified stellar envelope during the Main Sequence followed by First, Second, and Third Dredge-up cannot produce $^{12}C/^{13}C$ ratios below ~20 because: 1) homogenization of the envelope dilutes material processed by H burning ($^{12}C/^{13}C \approx 3.5$) with unprocessed envelope material ($^{12}C/^{13}C \approx 89$), and 2) ^{12}C is mixed into the envelope from the He shell during Third Dredge-up, the process which produces a carbon star [1,3,4]. These grains also tend to have higher $(^{26}Al/^{27}Al)_o$ and $^{15}N/^{14}N$ ratios than mainstream SiC grains (Fig. 1). Low $^{12}C/^{13}C$ ratios can be produced by hot bottom burning at the base of the convective envelope during the AGB phase, which occurs in stars more massive than ~4 $M_\odot$, but if too much nuclear processing occurs, most of the C is converted to ^{14}N and the star cannot become a carbon star [3]. Models of slower deep circulation below the standard convective envelope, which transports material into the H-burning zone in 1-2 $M_\odot$ stars, appear capable of producing low $^{12}C/^{13}C$ and $^{18}O/^{16}O$ ratios while still permitting the stars to become carbon stars [4]. But, since ^{26}Al is efficiently produced only at temperatures above $\sim 30\times10^6$ degrees [5], higher ^{26}Al is not predicted by a deep circulation model in 1-2 $M_\odot$ stars. The base of the convective envelope may achieve such temperatures in more massive stars during hot bottom burning, allowing extra production of ^{26}Al [3, 5], but no AGB model appears capable of explaining high $^{15}N/^{14}N$ ratios, particularly when the ratios exceed the solar value (Fig. 1b).

Although AGB models currently fail to explain SiC grains with low $^{12}C/^{13}C$ and high $(^{26}Al/^{27}Al)_o$ and $^{15}N/^{14}N$ ratios, there are several reasons to believe that source stars for these grains are closely related to those for mainstream SiC grains. First, the trend of increasing $(^{26}Al/^{27}Al)_o$ with decreasing $^{12}C/^{13}C$ is continuous (Fig. 1a), and, among grains with detectable ^{26}Al, there is a good correlation between ^{26}Al and ^{15}N (Fig. 1b). This continuity implies the increasing influence of a single process, not a completely different source. In addition, the maximum $^{15}N/^{14}N$ ratios observed in these grains do not exceed the solar $^{18}O/^{14}N$ ratio. While not conclusive, this suggests that ^{15}N is being produced by a (p, α) reaction on ^{18}O, not neutrino reactions on ^{16}O or α capture on ^{14}N, and implies production via H burning. Also, otherwise-mainstream grains are observed with $^{15}N/^{14}N$ ratios up to 0.003.

The primary reason that standard AGB models fail to predict high $^{15}N/^{14}N$ ratios is that at low temperatures ($\leq 25\times10^6$ degrees) the rate for the primary destruction reaction for ^{15}N ($^{15}N(p,\alpha)^{12}C$) is 500-750 times faster than the primary production reaction ($^{18}O(p,\alpha)^{15}N$) [6]. Both are faster than other reactions affecting CNO isotopes [6]. Since much of the nucleosynthesis affecting these isotopes in AGB envelopes takes place at low temperatures at the base of the envelope during the Main Sequence, and since the initial $^{18}O/^{15}N$ ratio is only 4-5, lower abundances of both ^{18}O and ^{15}N relative to ^{14}N are expected. However, under the right conditions a different result is possible. Figure 2 shows the ratio of the rates of the primary destruction reactions for ^{15}N and ^{18}O (which produces ^{15}N) as a function of temperature. At 100-200$\times10^6$ degrees, production of ^{15}N is actually faster than destruction. A gas with 4-5 times as much ^{18}O as ^{15}N, if subjected to these temperatures would show an *increase* in the ^{15}N abundance relative to both the starting abundance and to ^{14}N. These same conditions also drive the $^{12}C/^{13}C$ ratio toward the CNO equilibrium ratio (~3.5) and facilitate production of ^{26}Al via $^{25}Mg(p,\gamma)^{26}Al$. Low $^{12}C/^{13}C$ and high $^{15}N/^{14}N$ and $(^{26}Al/^{27}Al)_o$ are the characteristics observed in the grains.

In order for production of ^{15}N from ^{18}O to be responsible for the high $^{15}N/^{14}N$ ratios in the grains, a stellar scenario must be found which rapidly transports essentially unprocessed envelope material into a suitable high-temperature region and then removes it again before the reactions go too far. Grains must form before lower-temperature processing destroys the newly-produced ^{15}N. While it is not clear how this would work, it is clear that such high temperatures can only be reached in relatively high-mass stars [e.g., 3].

We propose the following model. First Dredge-up in low- and intermediate-mass stars produces envelopes with $^{12}C/^{13}C$ ratios of ~20. In low-mass stars, Third Dredge-up mixing events add ^{12}C to the envelope and $^{12}C/^{13}C$ ratios increase. Deep circulation [4] could keep the $^{12}C/^{13}C$ ratio low, but would not produce ^{15}N or ^{26}Al, so grains with large excesses of these isotopes cannot be products of this processing. With increasing stellar mass, the temperature at the base of the AGB convective envelope increases, and in stars of 5-6 $M_\odot$, may approach 100×10^6 degrees [3]. Unprocessed material is rapidly transported to the high temperature region where ^{15}N and ^{26}Al are produced and the $^{12}C/^{13}C$ ratio decreases. The most extreme grains, which have $^{12}C/^{13}C$ below ~5, $^{15}N/^{14}N$ ratios exceeding solar, and high $(^{26}Al/^{27}Al)_0$ probably come from the largest stars (> 5 $M_\odot$?). Grains with high to moderate $^{15}N/^{14}N$ but only moderate $^{12}C/^{13}C$ ratios and lower $(^{26}Al/^{27}Al)_0$ come from lower mass stars (4-5 $M_\odot$). Grains from stars of even lower mass have low ^{15}N abundances and $^{12}C/^{13}C$ and $(^{26}Al/^{27}Al)_0$ and can be understood in terms of the standard models. Such a model may explain why there are few SiC grains and carbon stars with $^{12}C/^{13}C$ ratios ~20. Although many stars may have this ratio in their envelopes shortly after First Dredge-up, they evolve away from this composition to either higher ratios (low-mass stars) or lower ratios (high-mass stars). Detailed stellar modeling will be required to evaluate this model.



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