C AND N ISOTOPE RATIOS IN DYING STARS: IMPLICATIONS FOR PRE-SOLAR GRAINS.

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Introduction: Isotopic studies of pre-solar SiC grains, particularly the $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios, suggest that they cluster into several distinct classes [1]. The bulk (93%) of these grains, called the "mainstream," have $^{12}C/^{13}C$ in the range ~10-200, while the $^{14}N/^{15}N$ ratios lie between ~200 and 20,000. The second classification, encompassing about 5% of the grains, are labeled "A + B" and are characterized by low $^{12}C/^{13}C$ ratios of order 1 to 10, and a wide range of $^{14}N/^{15}N$ values (~ 30 to 15,000). The remainder of the grains are classified as X, Y, Z and novae types. The X class has a wide spread of $^{12}C/^{13}C$ values (10 to 1,000), and relatively low $^{14}N/^{15}N$ ratios of about 5 to 300. The Y grains have ^{12}C enrichments relative to mainstream grains, but similar N isotopic composition; the Z grain population overlaps in C and N isotopic compositions with the mainstream grains, but on average show higher $^{14}N/^{15}N$ ratios. The mainstream, Y, and Z grains are all thought to be formed in the circumstellar envelopes of carbon-rich asymptotic giant branch (AGB) stars, as are the A + B sub-population, except they are believed to have formed in a special subclass called J-type stars. The X type, on the other hand, are thought to originate in supernovae.

Samples and Methods: In order to better understand the context and origin of presolar SiC grains, we have been measuring $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios in objects outside the solar system, using millimeter-wave spectra of isotopically-substituted gas-phase molecules, obtained with high sensitivity radio telescopes. The high spectral resolution (1 part in 10^6) afforded by radio astronomy enables a wide frequency separation between related isotopic species. For example, the fundamental transition of ^{12}CN lies near 113 GHz, while that of ^{13}CN is at 110 GHz, with a typical spectral resolution of 1 MHz. Molecules used for isotopic diagnostics include CN, HCN, HCO^{+}, and HNC, which are common circumstellar and interstellar species.

Results and Discussion: From observations of CN and HNC and their ^{13}C and ^{15}N isotopologues, we have better established the Galactic gradient for both the $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios, finding local interstellar values of 68 ± 15 and 290 ± 40, respectively [2,3]. ^{15}N is a particularly remarkable isotope because in standard CNO processing, the equilibrium nitrogen ratio is $^{14}N/^{15}N \sim 20{,}000/1$. Additional observations of these ratios using CN, CO, and HCN have also been carried out towards the envelopes of carbon and oxygen-rich AGB stars and supergiants, which are also O-rich. For the C-rich stars, other than J-type, $^{12}C/^{13}C$ is 25 to 90, while the oxygen-rich shells have values of 10 to 35 [4]. More recently, Adande et al. measured the ratio $^{14}N/^{15}N$ in C and O-rich envelopes using spectra of HCN, as well as towards supernovae remnants. For the oxygen-rich sources, the ^{15}N isotopologue could not be detected (with $^{14}N/^{15}N$ at least > 200), while for most carbon stars, the ratio fell in the range ~ 400 to 4400. For the O-rich stars, these values likely reflect mixing of CNO cycle products with the initial stellar composition. For the ordinary C-rich stars, they indicate addition of ^{12}C, generated by He-burning. Towards the J-type stars Y CVn and RY Dra, however, where $^{12}C/^{13}C \sim 3$, the $^{14}N/^{15}N$ ratios were found to be ~150 and 225, respectively. Hence, these stars showed strong enhancements of both ^{13}C and ^{15}N. The supernovae remnants were found to exhibit ratios of $^{14}N/^{15}N \sim 170\text{-}480$, with clear ^{15}N enrichment in the source IC443, supporting the notion of supernova production of this isotope. These observations also suggest that J-type stars are sources of ^{15}N, which might be created in a helium flash. The high temperatures in the flash would ignite the "hot" CNO cycle, producing ^{15}N, followed by a fast, plume-like ejection.

The ratios measured for the ordinary C-rich giant stars are identical to those found in mainstream SiC grains, while those determined for J-type stars fall in the range for the A + B sub-population. For the supernovae remnants, the ratios occur in the region for X type grains. The astronomical measurements therefore help confirm the assignments of SiC grains to different stellar sources, based on their C and N isotopic compositions.

New measurements of these ratios are also being carried out towards planetary nebulae (PNe), believed to be final stage of most stars of 1-8 solar masses. In this phase, nucleosynthesis has ceased, and almost all the initial mass of the star is ejected into the interstellar medium, forming a nebula around a white dwarf. From observations of HCN, HNC, and CN and their isotopologues in the PNe, $^{12}C/^{13}C$ and $^{14}N/^{15}N$ ratios have been determined. Curiously, many of the C-rich PNe exhibit enhanced ^{13}C, with ratios in the range $^{12}C/^{13}C \sim 3$ to 20 [5]. Such low ratios are anomalous, considering the higher values seen in the progenitor stars. Moreover, a recent detection of $HC^{15}N$ in the young PNe indicates $^{14}N/^{15}N \sim 20$. This extreme enhancement of ^{15}N may result from a J-type progenitor star.

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