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The Effect of Heterogeneities in the Interstellar Medium on the CNO Isotopic Ratios of Presolar SiC and Corundum Grains

M. Lugaro,[a] R. Gallino,[b] S. Amari,[c] E. Zinner[c] and L. R. Nittler[d]

[a]Institute of Astronomy, University of Cambridge, Madingley Rd, Cambridge CB3 0HA, United Kingdom

[b]Dipartimento di Fisica Generale, Universitá di Torino, and Sezione INFN di Torino, Via Pietro Giuria 1, 10125 Torino, Italy

[c]Laboratory for Space Sciences and the Physics Department, Washington University, St Louis, MO 63130-4899, USA

[d]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241, Broad Branch Rd NW, Washington DC 20015, USA

We discuss CNO isotopic ratios in the light of the GCE and possible inhomogeneities in the ISM and we find that this approach could help to explain the range of ratios measured in presolar SiC and corundum grains.

1. Introduction

In recent years the effect of local heterogeneities in the Interstellar Medium (ISM) on the Galactic Chemical Evolution (GCE) has become the subject of several studies (see e.g. [1,2]). Incomplete mixing of stellar ejecta has been shown to provide a possible explanation, concurrent with the main GCE trend, for the distribution of Si isotopic ratios measured in the mainstream population (>90%) of presolar silicon carbide (SiC) grains from meteorites [3]. SiC grains can condense when C > O, and mainstream SiC are believed to have formed in the envelopes of Asymptotic Giant Branch (AGB) stars of close to solar metallicity in the mass range expected to reach a C-rich phase ($1.5\ M_{\odot} < M < 4\ M_{\odot}$). Mainstream grains show $^{12}C/^{13}C$ ranging from $\simeq$20 to 100 and $^{14}N/^{15}N$ from $\simeq$200 to $\simeq$10,000 (see Fig. 1 of [3]).

SiC grains do not contain O in measurable abundance. However, O isotopic ratios can be measured in presolar corundum grains. Their ratios vary from $\simeq$300 to $\simeq$5000 and from $\simeq$200 to $\simeq$40,000 for $^{16}O/^{17}O$ and $^{16}O/^{18}O$ respectively (see Fig. 5 of [4]). In contrast to SiC, oxide grains do not need a C-rich environment to form and their parent stars can represent a larger population: from Red Giant (RG) to AGB stars with a wider range of masses and metallicities than SiC grain parent stars.

During the evolution of low-mass stars C, N and O isotopic ratios at the stellar surface change from their initial values because of First Dredge Up (FDU) during the RG phase and Third Dredge Up (TDU) during the AGB phase. In stars of solar metallicity, starting

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from the solar ratio of 89 and according to canonical models, $^{12}C/^{13}C$ drops to 20 after FDU and then grows to ~100 because of TDU. Starting from the solar (terrestrial) ratio of 272, $^{14}N/^{15}N$ increases to $\sim 800 - 1500$ after FDU and it remains unchanged during the AGB phase. Extra mixing during the RG (and perhaps also during the AGB phase [5]) in stars with $M \lesssim 2.5\ M_\odot$ would shift in variable extent the C and N ratios towards the composition of equilibrium for the CN cycle: 3.5 and 25,000 respectively. Mainstream SiC with $200 \lesssim {}^{14}N/^{15}N \lesssim 700$ are left out of this interpretative picture. If GCE and/or inhomogeneities in the ISM could produce a spread of initial $^{14}N/^{15}N$ down to ~70 in the SiC grain parent stars, then it would be possible after FDU and TDU to obtain the lowest ratios shown by SiC. The FDU modifies the initial solar O isotopic ratios of $^{16}O/^{17}O$=2660 and $^{16}O/^{18}O$=500 down to ≃300 and up to ≃600 respectively [6]. Oxygen-18 is strongly destroyed by proton captures, resulting in $^{16}O/^{18}O$ ratios up to a few 10^4. This can occur at the base of the convective envelope if the temperature is high enough, i.e. for stars of mass $M \gtrsim 5\ M_\odot$, or because of extra mixing in lower-mass stars.

When discussing the CNO isotopic composition in SiC and corundum grains and comparing it to the Si isotopic composition, it is important to keep in mind that Si isotopic ratios are affected only little by neutron-capture nucleosynthesis in AGB stars and also that they change very little because of GCE, up to 25% for a factor of two in metallicity [3]. In contrast, CNO isotopic ratios are strongly affected by nucleosynthesis in stars and can change by a factor of 2 or more because of GCE. Hence it is not surprising that the range of variation of Si isotopic ratios in SiC is much more limited, to ~20%, than the variations shown by CNO isotopic ratios.

2. The effect of Galactic Chemical Evolution

While it is well established that the heavier isotopes of C, O and Si become more enriched with time because of GCE and their solar isotopic compositions are relatively well determined, the GCE of N isotopes is a puzzling matter and its solar isotopic composition still uncertain within a factor of 2 (see Fig. 1 of [7]). The $^{14}N/^{15}N$ ratio observed in the local ISM appears to be close to or higher than the solar value, ranging from ≃250 to ≃650, with a spread at any given Galactic radius. These measurements seem to indicate a small positive Galactic gradient [8] that would validate the hypothesis that ^{15}N is mostly produced by nova bursts, but is at odds with the value of ≃1500 observed in the Galactic centre [9]. Ratios of $^{14}N/^{15}N$ ~100 have been observed in the Large Magellanic Clouds and in the (post-) starburst galaxy NGC 4945 [10]. These measurements support the hypothesis that ^{15}N is instead mostly produced in massive stars. Langer et al. [11] showed that massive stars can have large ^{15}N yields when rotation is included in the computation, even though definitive results are not yet available.

To test the possible effect of inhomogeneities in the ISM we have included in the Monte Carlo code we used to study Si [3] the stellar sources that are believed to produce CNO isotopes. On top of supernovae of type II (SNII) of solar metallicity and supernovae of type Ia (SNIa), we have added nova contributions [12], and yields from stars of solar metallicity with masses from 1.5 to 7 $M_\odot$ (kindly provided by Karakas & Lattanzio). We multiplied by 1.5 and 2.0 respectively the yields of ^{13}C and ^{14}N from the lowest mass stars to take into account the possible effect of extra mixing. Our first test case is performed assuming that novae are the major ^{15}N producers in the Galaxy, hence that the ^{14}N/^{15}N ratio decreases with time. We started from initial CNO ratios twice solar and sum up the yields from 600 SNe and 7000 low to intermediate mass stars chosen at random to obtain each composition. We estimated a Galactic novae/SNe rate ratio of 33/0.01 = 3,300 [13,14] from which we obtained the number of nova sources to be added to each computed composition being equal to 2×10^6. When adding such a large number of contributions the statistical fluctuations of the yields from each nova source are completely negligible. No statistical spread results and we obtain a very small range of compositions, with ^{12}C/^{13}C, ^{14}N/^{15}N and ^{16}O/^{17}O ratios lower than initial and around 50, 80 and 2000 respectively. To obtain a range of compositions the only possibility consists in randomly choosing a number of nova bursts to be added to each point. This would mean a range rather than a fixed value for the novae/SNe rate ratio throughout the Galaxy. Next we tried a test case assuming that rotating massive stars are instead the major ^{15}N producers in the Galaxy, hence ^{14}N/^{15}N increases with time. We discarded nova contributions, assumed the SNII ^{15}N yields to be increased at random, because of stellar rotation, by a factor up to 10, 50 and 100 for SNII of low, intermediate and high masses respectively and chose an initial ^{14}N/^{15}N ratio half the solar value. We obtained a range of values of $\simeq$100 - 200 for ^{14}N/^{15}N, while the final ^{12}C/^{13}C ratio is $\simeq$70 and the O ratios vary very little. Since the effect of inhomogeneities in the ISM on O isotopes is typically quite small, we conclude that to explain the large range of oxygen isotopic ratios one has to consider the main GCE effect [4].

It appears possible that GCE and/or inhomogeneities in the ISM could produce the ^{14}N/^{15}N ratios required to explain some mainstream grains. This is only a qualitative conclusion since there are large uncertainties regarding the GCE of the ^{14}N/^{15}N ratio and its solar value. More help will come from planned Galactic observations [15].

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