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Nitrogen isotopic ratios in Galactic AGB carbon stars of different spectral types

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Abstract

We derive for the first time the $^{14}N/^{15}N$ ratios in a sample of near solar metallicity Galactic AGB carbon stars of different spectral types. The analysis is based on CN lines at ~ 8000 Å using high resolution and high signal-to-noise spectra. High quality spectra at 2.2 μm were also used to measure accurately CNO abundances and the metallicity in some of the stars. A differential chemical analysis was done with respect to the normal (N-type) carbon star TX Psc to minimise systematic errors. The analysis reveals that the N isotopic ratio in normal carbon stars is similar to that in TX Psc (1700), and covers nicely the range found in the mainstream SiC grains. This result supports their carbon star origin. In stars of SC-type we find typically lower ratios ($[^{14}N/^{15}N]_{\rm TXPsc} \leq -0.5$ dex), which opens the possibility that some of the SiC grains with low N isotopic ratio may have been formed in these peculiar stars. Finally, J-type stars present nitrogen isotopic ratios close to those of N-type stars. However, considering the low $^{12}C/^{13}C \leq 15$ ratios usually found in these stars, we conclude that there is a contribution to the SiC grains of AB type from J-type stars.

1 Introduction

Asymptotic giant branch (AGB) stars play an important role in determining the chemical evolution of galaxies. AGB stars represent the final stages of low and intermediate mass stars ($1 \leq M/M_\odot \leq 8$) and are believed to be important producers of several elements (Li, C, N, F, s-elements etc., see e.g. [9]) through internal nucleosynthesis. AGB carbon stars form as a result of the third dredge-up (TDU) episodes when fresh carbon produced in the He-burning shell is transported to the surface after the thermal pulses, transforming an originally oxygen-rich AGB star into a carbon-rich (C) star when the C/O ratio exceeds unity in the envelope. AGB stars loose mass efficiently ($\dot{M} \approx 10^{-7}$ to 10^{-5} $M_\odot$ yr^{-1}) due to their pulsation and the formation of solid particles enriched by products from the internal nucleosynthesis. After their ejection into the interstellar medium by these stellar winds, some of these grains can be trapped in meteorites which are now recovered in the Solar System. After diamond, SiC grains are the most abundant type of stellar dust found in meteorites (see e.g. [11]). These grains are classified mainly depending of their nitrogen, carbon and silicon isotopic ratios (see e.g. [23]). The named mainstream (MS) which constitute 93% of all SiC grains, show $^{12}C/^{13}C = 20 - 100$, $^{14}N/^{15}N > 270$ (see Figure 1) and are believed to form in the cool envelopes of low mass (< 3 $M_\odot$) AGB C-stars. Indeed, these grains present isotopic anomalies which can be only explained if they have been formed from material exposed to the s-process nucleosynthesis, which is thought to occur during the AGB phase of low-mass stars (e.g. [21]). Grains of type AB ($\sim 4\%$ of presolar SiC) show $^{12}C/^{13}C < 10$ and a large range of $^{14}N/^{15}N$ ($\sim 40-10^4$, see Figure 1) but their origin is still unclear. [6] proposed that the most likely sources of those AB grains with no s-process enrichments are J-type C-stars (although this has not yet been confirmed), while *born again* AGB stars (post-AGB stars that undergo a very late thermal pulse; [7]) have been invoked as a possible source of the AB grains with s-process enrichments and high $^{14}N/^{15}N$ ratios. Nevertheless, the full range of the measured N isotopic ratios (10^2-10^4) in both types of SiC grains, cannot be explained by standard low-mass AGB nucleosynthesis models. Indeed, a minimum value of $^{14}N/^{15}N$ ~ 1000 is predicted at the beginning of the AGB phase [10]; this value is not expected to vary significantly during the AGB evolution regardless of the initial stellar mass and metallicity. One way to try to understand this problem is to estimate the nitrogen isotopic ratio in individual C-stars, which has never been done to date. The combined chemical analysis of AGB atmospheres and stellar dust can then be used to constrain theoretical AGB nucleosynthesis models.

2 Observations and analysis

The stars were observed using the 3.5 m TNG telescope with the SARG spectrograph at the highest resolution mode (R $\sim$ 170000). We studied the $7900 - 8100$ Å spectral region where the CN lines show a significant isotopic splitting and are rather sensitive to variations of the nitrogen ratio. Very high signal-to-noise spectra (> 200) were acquired with this instrumental set-up, which is mandatory to unambiguously detect the existing $^{12}C^{15}N$ features. The sample of stars is formed by 20 normal (N-type), 8 J-type and 5 SC-type C-stars of metallicity close to solar. For fifteen of them, we also profit from high resolution (R $\sim$ 50000) and high signal-to-noise (S/N > 80) infrared spectra around 2.2 μm obtained with the 4 m telescope at Kitt Peak Observatory and a Fourier transform spectrometer (FTS), kindly provided by K. Hinkle. This spectral range was used to derive the C and O abundances from C_2 and CO lines since an accurate determination of the C/O ratio is critical in the chemical analysis of C-stars. We made use of an improved CN molecular line lists in the 8000 Å region. The wavelength positions and intensities of these lines were updated after the new energy levels calculated by [19] and [20]. For $^{12}C^{15}N$ they were supplemented by laboratory data kindly supplied by Professor R. Colin. These data were used to check that our calculations of isotopic shifts were within the observational errors. The rest of the molecular and atomic line lists in both spectral regions are the same that those used by us in other works (see references in [2, 4]).

Our sample of galactic C-stars has been widely studied in the literature in other chemical studies [14, 1, 2], so that their stellar parameters ($T_{\rm eff}$, $\log g$, ξ, and metallicity [Fe/H][1]) are relatively well known. We adopted these parameters from the literature mentioned above. Then, a C-rich spherical MARCS model atmosphere was chosen for each star according to its stellar parameters from an unpublished grid of C-rich models (K. Eriksson, private communication). These atmosphere models are based, on the same assumptions and data as the recent MARCS grid of model atmospheres for cool stars [12]. For each of the atmosphere model, synthetic LTE spectra were calculated in the 2.2μm and 8000 Å regions using the *Turbospectrum* v10.1 code described in [5] and [18] and the line list given above. The theoretical spectra were convolved with a Gaussian function with the corresponding FWHM to mimic the spectral resolution in each range plus the macroturbulence parameter (typically $9 - 13$ km s^{-1}). We first derived the C and O abundances from the 2.2 μm region (in the stars where these spectra were available) from a number of weak and unblended C_2 and CO lines. For the stars for which there were no available spectra in the near infrared region, we adopted the C and O abundances from previous studies (see references above). The ^{12}C/^{13}C ratio was also taken from the literature. This isotopic ratio is known to be weakly dependent on the stellar parameters in C-stars [1]. Once the C/O ratio was determined, N abundances were estimated from CN lines in the $\sim$ 8000 Å region; however, these lines are not very sensitive to variations of the N abundance within ± 0.3 dex. Therefore, the absolute N abundance obtained in the present analysis is not very accurate. Then, in each star the absorption features caused mainly by ^{12}C^{15}N were carefully selected. We choose these features avoiding blending as much as possible and lines placed in spectral zones where the position of the pseudo-continuum was regarded as uncertain. Also we selected only ^{12}C^{15}N features which are expected to be in the linear part of the curve-of-growth. This resulted in a few useful ^{12}C^{15}N lines placed near $\lambda\lambda$7980, 7985, 8029, 8037 and 8063 Å. The N isotopic ratio derived from the various features selected in this way were then combined to give a mean. In this mean the features placed at $\lambda\lambda$7980 and 8063 Å have an average weight twice as high as the other features.

Unfortunately the dispersion in the N isotopic ratios obtained from the different lines is significant in most of the cases. Therefore, we decide to perform a line-by-line differential analysis with respect to the reference star TX Psc, a very well known N-type C-star with parameters C/O = 1.02, $T_{\rm eff} = 3000$ K, $\xi = 2.5$ km s^{-1}, and ^{12}C/^{13}C = 42 (e.g. [3]). Errors due to the uncertainty in the atmospheric parameters are important. These sources of error, once added quadratically, give typically a total uncertainty of about $0.3 - 0.4$ dex in the relative N ratio with respect to TX Psc, $[^{14}{\rm N}/^{15}{\rm N}]_{\rm TXPsc}$. Systematic errors may be present, such as the uncertainty in the continuum position and departures from LTE. Nevertheless, Figure 1 remains almost equal when plotting either the absolute N isotopic ratios or the relative ratios with respect to TX Psc, which indicates that systematic errors in the analysis are probably small.

[1]In the present work, we adopt the standard notation $[{\rm X/H}] = \log({\rm X/H})_\star - \log({\rm X/H})_\odot$ where (X/H) is the abundance of the element X by number in the scale $\log({\rm H}) \equiv 12$.

3 Results and discussion

Our measurements of the 14N/^{15}N ratio in Galactic AGB C-stars of near solar metallicity can be summarised in Figure 1. This figure shows the N isotopic ratios (with respect to TX Psc, ^{14}N/^{15}N = 1700) against the carbon ratio in our sample of C-stars of different spectral types. We compare our findings with the similar ratios found in the MS and AB SiC grains (e.g. [13]). The corresponding updated Solar System ratios [15] are drawn with dotted lines for reference. Also, dot-dashed lines represent the expected isotopic ratios at the beginning of the AGB phase for a 2M$_\odot$ model star with [Fe/H] ~ 0 [10]. Indeed, standard low-mass AGB evolutionary models show that the C-rich material added into the envelope by the TDU episodes would just increase continuously the $rm^{12}C/^{13}C$ ratio starting from a minimun value of $\sim$ 30, while ^{14}N/^{15}N is kept nearly constant at the first dredge-up value (~ 1000). Figure 1 suggests that the N isotopic ratios in C-stars are distributed in different groups depending on the spectral type. We note that this result remains when plotting absolute N isotopic ratios (instead of relative) against the C isotopic ratios. The N isotopic ratios derived in normal C-stars nicely cover the ratios found in MS grains (i.e. $[^{14}\mathrm{N}/^{15}\mathrm{N}]_{\mathrm{TXPsc}} \geq -0.2$, $^{12}\mathrm{C}/^{13}\mathrm{C} > 30$). Note that the range of ^{14}N/^{15}N ratios derived in a C-star may be strongly dependent on the initial N ratio. Preliminary evolutionary calculations in low-mass stars made by us show that the exact ^{14}N/^{15}N ratio after the first dredge-up depends dramatically on the initial ^{14}N/^{15}N value, this result being nearly independent on the mass and metallicity of the stellar model. This ratio, as mentioned before, is sligthly altered during the AGB evolution. Evidence of a spread in the N ratio in the Solar System has been recently reported [15, 8]. In any case, considering that most of the N-type stars analysed here show s-process enhancement [2], the similarity between the N and C isotopic ratios derived in these stars and those observed in the MS grains reinforces the idea that these grains have their origin in N-type AGB C-stars.

On the other hand, from Figure 1 it is also clear that J-type stars show low C isotopic ratios (as expected [1]) and a range of N isotopic ratios similar (except one object) to those of N-type stars. In these stars, an extra-mixing process during the AGB phase seems to be necessary [16, 17] that may put in contact the convective envelope with the H-burning shell to explain the observed ^{12}C/^{13}C ratios. This extra-mixing mechanism would just increase the N isotopic ratio from the first dredge-up value. Thus, this is the first observational evidence of a contribution of J-type stars to the AB grains as already suggested by [6]. Finally the SC-type stars, which could represent a previous stage to the N-type in the chemical (spectral) evolution [22] along the AGB phase, show typically $rm^{14}N/^{15}N < 1000$ ratios (or $[^{14}\mathrm{N}/^{15}\mathrm{N}]_{\mathrm{TXPsc}} < -0.2$). Thus some of SiC grains with $^{14}\mathrm{N}/^{15}\mathrm{N} < 1000$ and $^{12}\mathrm{C}/^{13}\mathrm{C} < 30$ may have formed in these peculiar stars. Note that many SC-type stars show other chemical anomalies such as large Li and F enhancements, which probably have been produced inside the star. It is not clear whether these anomalies are related to the ^{15}N production.

In conclusion, in this work we show for the first time observational evidence that the origin of some types of SiC grains is connected with AGB C-stars. However, further observational and theoretical studies are mandatory to fully explain the N isotopic ratios observed in C-stars and SiC grains.

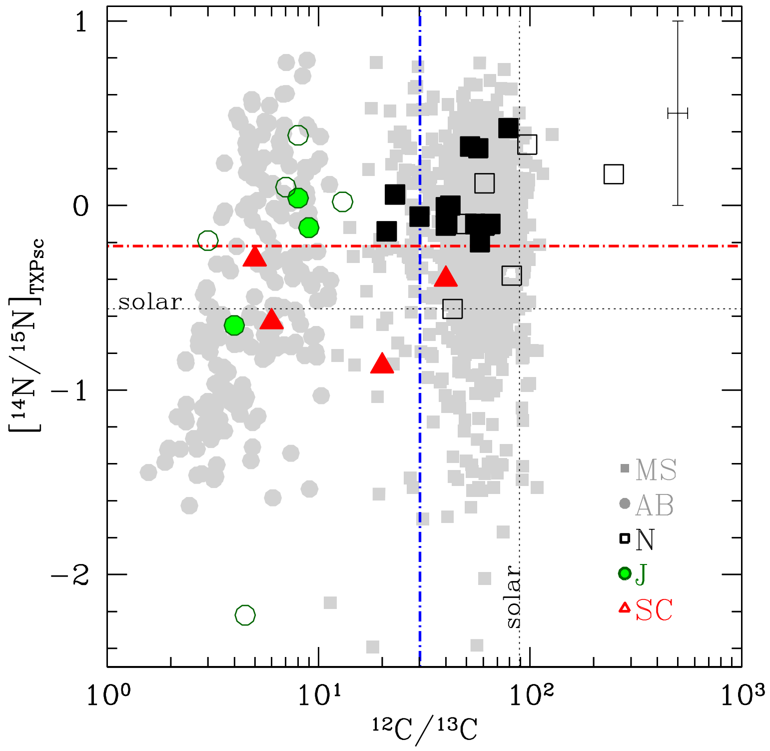

Figure 1: N isotopic ratios relative to TX Psc and C isotopic ratios in our stars compared with the same ratios in SiC grains: N-type stars (*big black squares*), J-type stars (*big green circles*), SC-type stars (*red triangles*), MS grains (*small filled gray squares*), and AB grains (*small filled gray circles*). Open symbols indicate lower limits to the N isotopic ratios derived in the stars. N isotopic ratios of SiC grains are relative to TX Psc $^{14}N/^{15}N = 1700$. SiC grain compositions obtained from WUSTL Presolar Database [13]. For the meaning of the lines, see text.

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