PROCEEDINGS OF SCIENCE

Nitrogen isotopic ratios in Galactic AGB carbon stars

Rubén Pedro Hedrosa[∗ a], **Carlos Abia**[a], **Bertrand Plez**[b], **and Inmaculada Domínguez**[a]

[a] *Departamento de Física Teórica y del Cosmos, Universidad de Granada, 18071 Granada, Spain*
[b] *Laboratoire Univers et Particules de Montpellier, Universitè Montpellier II CNRS, Montpellier, France*
E-mail: hedrosa@ugr.es

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 ratios in N-type stars are similar to that in TX Psc (1700) covering nicely the range found in the mainstream SiC grains. This result supports their carbon star origin. In stars of SC-type we find lower N ratios by a factor from three to five (or -0.8 dex $\leq [^{14}N/^{15}N]_{TXPsc} \leq -0.5$ dex, relative to TX Psc), 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. Correlations with other abundance features such as F and Li are also investigated.

XII International Symposium on Nuclei in the Cosmos
August 5-12, 2012
Cairns, Australia

[∗] Speaker.

PoS(NIC XII)006

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 ($1 \leq \mathrm{M}/\mathrm{M}_\odot \leq 8$) and are believed to be important producers of several elements (Li, C, N, F, s-elements etc., see e.g. [10]) through internal nucleosynthesis. AGB carbon (C) 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 C-rich star when the C/O ratio exceeds unity in the envelope. AGB stars loose mass efficiently ($\dot{M} \approx 10^{-7}$ to 10^{-5} $\mathrm{M}_\odot$ 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 stellar winds, some of these grains can be trapped in meteorites which are now recovered in the Solar System. After diamond, silicon carbide (SiC) grains are the most abundant type of stellar dust found in meteorites (see e.g. [12]). These grains are classified mainly depending of their nitrogen, carbon and silicon isotopic ratios (see e.g. [27]). The named mainstream (MS) which constitute 93% of all SiC grains, show a huge range in the $^{14}\mathrm{N}/^{15}\mathrm{N}$ ratio (see Figure 2) and are believed to form in the cool envelopes of low mass (< 3 $\mathrm{M}_\odot$) 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. [23]). Grains of type AB ($\sim 4\%$ of presolar SiC) show $^{12}\mathrm{C}/^{13}\mathrm{C} < 10$ and also a large range of $^{14}\mathrm{N}/^{15}\mathrm{N}$ ($\sim 40 - 10^4$, see Figure 2) but their origin is still unclear. Amari et al. [7] proposed that the most likely sources of those AB grains with no s-process enrichment 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; [8]) was proposed as as a possible source of the AB grains with s-process enrichment and high $^{14}\mathrm{N}/^{15}\mathrm{N}$ 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 $^{14}\mathrm{N}/^{15}\mathrm{N} \sim 1000$ is predicted at the beginning of the AGB phase ([11]); 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.

Wannier et al. [25] estimated the N ratio in C-rich circunstellar envelopes surrounding a few C-stars using the $\mathrm{H^{13}CN}$ and $\mathrm{HC^{15}N}$ molecules in the radio domain. However, circunstellar N ratios might be affected by the incoming UV radiation from the ISM triggering non-kinetic equilibrium chemistry and thus, might no represent the stellar photospheric ratios. In this sense, the work presented here represent a very important step forward in the study of the nucleosynthetic processes occurring in the interior of AGB stars.

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 (S/N> 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 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 (see [21] and [22]). 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 [3] and [5]).

Our sample of galactic C-stars has been widely studied in the literature in other chemical studies ([15]; [2]; [3]), so that their stellar parameters (T_{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 ([13]). For each of the atmosphere model, synthetic LTE spectra were calculated in the 2.2 μm and 8000 Å regions using the *Turbospectrum* v10.1 code described in [6] and [20] and the line lists 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 by fitting a number of weak and unblended C_2 and CO lines in the 2.1-2.4 μm region (in the stars where these spectra were available). 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). Then, N abundance as well as the final C/O ratio were derived from CN lines in the 8000 Å region in an iterative way until agreement with the values obtained in the infrared spectral range was reached. We note however, that the absolute N abundance obtained in the present analysis is not very accurate but we checked that variations until $\pm$0.3 dex in the N abundance marginally affect the nitrogen isotopic ratio derived. The $^{12}C/^{13}C$ ratios were also taken from the literature. 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 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 ratios derived from the selected features in this way were then combined to give a mean. To compute this mean the features placed at $\lambda\lambda$7980 and 8063 Å were considered twice.

Figure 1 shows examples of theoretical synthetic fits to these features in two of the stars studied for different N isotopic ratios. As can be seen from these examples, the dispersion in the N isotopic ratios obtained from the different lines is significant. Therefore, we performed a differen-

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

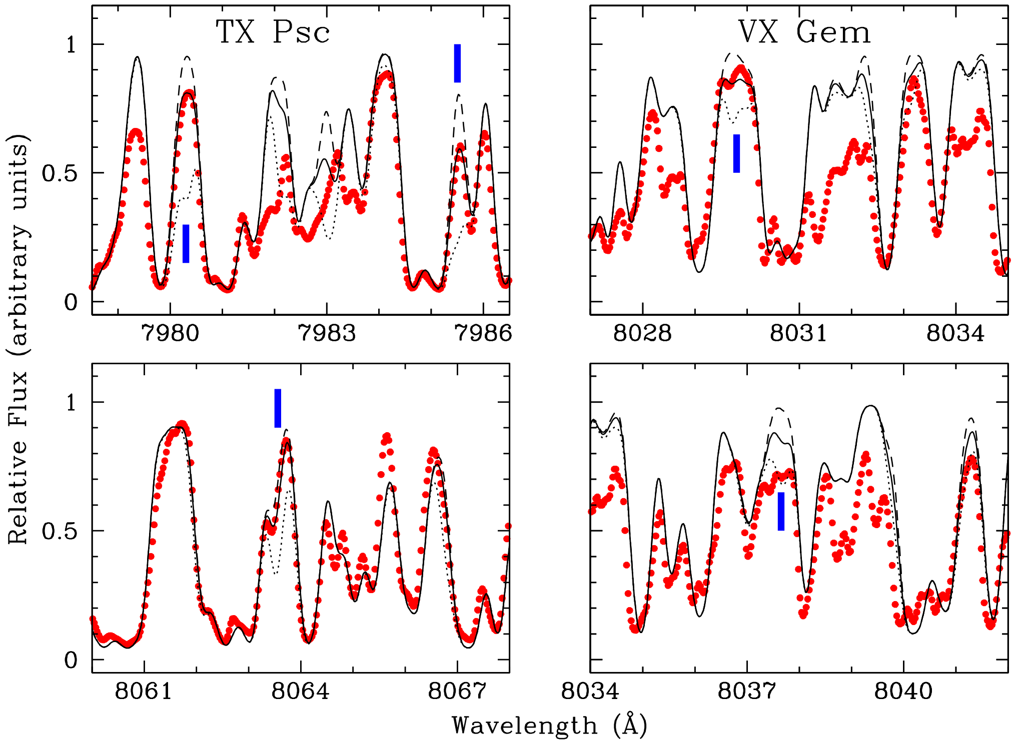

Figure 1: Observed (big red dots) spectra of TX Psc (left panels) and VX Gem (right panels) as compared with synthetic fits in the spectral regions of the selected $^{12}C^{15}N$ features. The used features are marked with vertical lines. For TX Psc the fits shown are for no ^{15}N (*dashed line*), $^{14}N/^{15}N = 100$ (*continuous line*) and 900 (*dotted line*), while for VX Gem for no ^{15}N (*dashed line*), $^{14}N/^{15}N = 200$ (*continuous line*) and 600 (*dotted line*). For these stars the final ratios derived were 1700 $\pm$ 1500 and 500 $\pm$ 500, respectively.

tial analysis line-by-line with respect a reference star, TX Psc, which is a very well studied N-type C-star with parameters C/O $= 1.02$, $T_{eff} = 3000$ K, $\xi = 2.5$ kms^{-1}, and $^{12}C/^{13}C = 42$ (e.g. [4]). Errors due to the uncertainty in the atmospheric parameters plus the dispersion in the $^{14}N/^{15}N$ ratio derived among the different $^{12}C^{15}N$ features, 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, $[^{14}N/^{15}N]_{TXPsc}$. Systematic errors may be present, such as the uncertainty in the continuum position and departures from LTE, but they should be reduced significantly in a relative analysis.

3. Results and discussion

The main result of this study is shown in Figure 2. This figure displays the N isotopic ratios relative to TX Psc against the carbon ratio in our sample of C-stars. We compare our findings with the ratios found in the MS and AB SiC grains (e.g. [14]). The corresponding updated Solar System ratios ([16]) 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 2 $M_{\odot}$ star model with [Fe/H] ~ 0 ([11]). 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 $^{12}C/^{13}C$ ratio starting from a minimum value of $\sim$ 30 when the star becomes C-rich (C/O$>$ 1), while $^{14}N/^{15}N$ is kept nearly constant at the first dredge-up value (~ 1000). Figure 2 suggests that the N isotopic ratios in C-stars are distributed in different groups depending on the spectral type. This distribution remains almost equal when plotting absolute N isotopic ratios (instead of relative to TX Psc) against the C isotopic ratios. The N isotopic ratios derived in normal C-stars nicely cover the ratios found in MS grains (i.e. $[^{14}N/^{15}N]_{TXPsc} \geq -0.2$, $^{12}C/^{13}C > 30$). Note that the range of $^{14}N/^{15}N$ ratios derived in a C-star may be strongly dependent on the initial N ratio in the material from which the stars were form and thus, may help to explain the range of $[^{14}N/^{15}N]_{TXPsc}$ derived in the N-type C-stars. Indeed, 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 slightly altered during the AGB evolution. Evidence of a spread in the N ratio in the Solar System has been recently reported ([16]; [9]), which would open the possibility of considering a spread in the initial N ratio. However, from the observed N isotopic ratio gradient across the Galaxy ([26]), it seems difficult to admit this hypothesis as the sole explanation for the spread observed in Figure 2. In any case, considering that most of the N-type stars analysed here show s-process enhancement ([3]), 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.

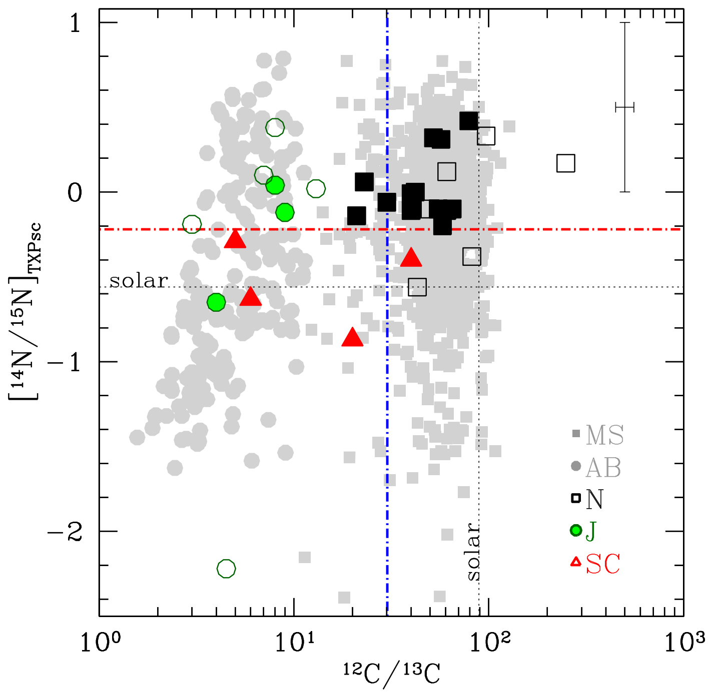

Figure 2: N isotopic ratios relative to TX Psc and C isotopic ratios in our stars as compared with the same ratios in SiC grains: N-type stars (*big black squares*), J-type stars (*big green circles*), SC-type stars (*red triangles*), MS grains (*small filled gray squares*), and AB grains (*small filled gray circles*). Open symbols indicate lower limits to the N isotopic ratios derived in the stars. The SiC grain compositions were obtained from the WUSTL Presolar Database ([14]). For the meaning of the lines, see text.

On the other hand, from Figure 2 it is also clear that J-type stars show low C isotopic ratios (as expected [2]) and a range of N isotopic ratios similar (except one object) to those of N-type stars. This is the first observational evidence of a possible contribution of J-type stars to the AB grains as already suggested by [7]. In these stars, extra-mixing processes occurring during (and/or prior) the AGB phase appear to be necessary ([17]; [18]) to explain the observed $^{12}C/^{13}C$ ratios. These extra-mixing mechanisms, whose nature are not yet known, may put in contact the convective envelope with the H-burning shell, dismissing the $^{12}C/^{13}C$ ratio and simultaneously increasing the N isotopic ratio in the stellar envelope. Finally the SC-type stars show typically $^{14}N/^{15}N < 1000$ ratios (or $[^{14}N/^{15}N]_{TXPsc} < -0.2$): we conclude that some of SiC grains with $^{14}N/^{15}N < 1000$ and $^{12}C/^{13}C < 30$ may have formed in these peculiar stars. Additional hints on the origin of the $^{14}N/^{15}N$ ratios derived in our stars can be extracted from Figure 3. This figure shows the N ratios derived against the lithium ([1]; [2]; or derived in this work) and fluorine ([4]) abundances observed in the same stars. Expected Li abundances at the beginning of the AGB for a 2 $M_\odot$, [Fe/H]$\sim$ 0.0 star model is marked with the vertical dash-dotted line (e.g. [19]). A large fraction of J-type stars are known to be enriched in Li ([2]), but Figure 3 also shows that those SC-type stars for which data are available, present the largest Li and F enhancements, both elements very probably produced by internal nucleosynthesis. However, it is far from clear which nucleosynthetic process might link these abundance anomalies with the ^{15}N production. Further studies like the derivation of the O isotopic ratios in these stars might help to enlight our understanding of the evolutionary scenarios which may give to a SC-type C-star.

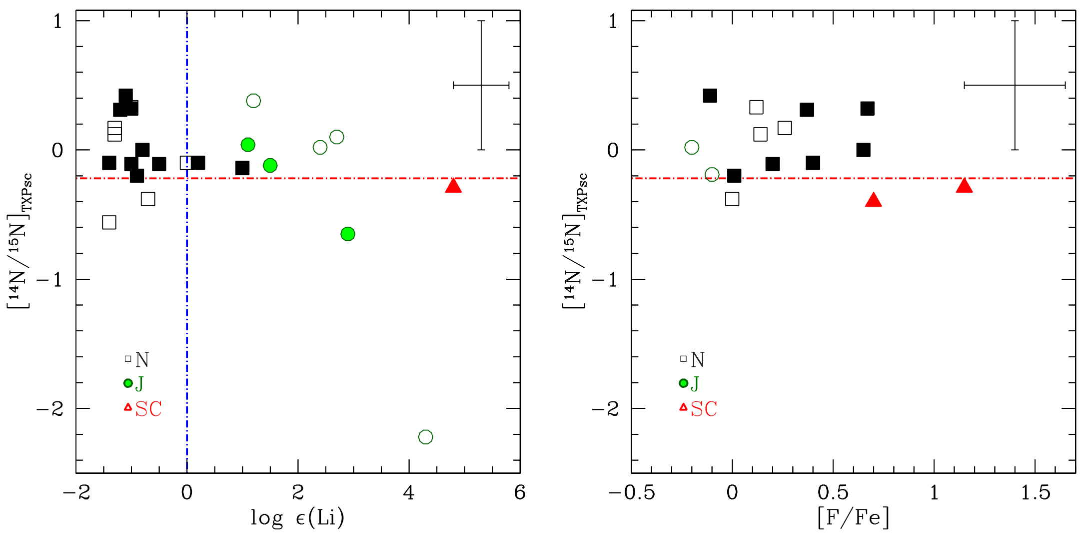

Figure 3: Nitrogen isotopic ratios relative to TX Psc as compared with lithium (left) and fluorine (right) abundances. SC-type stars seems to be peculiar in the N isotopic ratios, Li and F abundances. For the meaning of the lines, see text.

In conclusion, in this work we have shown 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.

Acknowledgments

R.P.H. would like to thank the organisers for their financial support and to S. Palmerini for her commentaries and suggestions. Results are based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Fundación Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. This research has made used of the SIMBAD database, operated at CDS, Strasbourg, France. This work has been partially supported by Spanish grant AYA2008-04211-C02-02.

Questions and comments

Comment from Ernst Zinner: I am very happy that you identified J stars as sources of high AND low $^{14}N/^{15}N$ ratios, thus A+B grains with BOTH signatures come from J stars.

Comment from Maurizio Busso: Congratulations for beautiful results. Your N, Li, F data confirm that SC- and J-stars are very anomalous and fill for the first time the region of A+B grains previously attributed to novae. Their evolution might descend from the merging of two stars.

References

[1] Abia, C., & Isern, J. 1997, MNRAS, 289, L111

[2] Abia, C., & Isern, J. 2000, ApJ, 536, 438

[3] Abia, C., Domínguez, I., Gallino, R., et al. 2002, ApJ 579, 817

[4] Abia, C., Cunha, K., Cristallo, S., et al. 2010, ApJ 715, 94

[5] Abia, C., Palmerini, S., Busso, M., et al. 2012, A&A in press

[6] Alvarez, R., & Plez, B. 1998, A&A, 330, 1109

[7] Amari, S., Nittler, L. R., Zinner, E., et al. 2001, ApJ, 559, 463

[8] Asplund, M., Lambert, D. L., Kipper, et al. 1999, A&A, 343, 507

[9] Bonal, L., Hily-Blant, P., Faure, A., et al. 2012, M&PSA, 75, 5226

[10] Busso, M., Gallino, R., & Wasserburg, G. J. 1999, ARA&A, 37, 239

[11] Cristallo, S., Straniero, O., Gallino, R., et al. 2009, ApJ, 696, 797

[12] Davis, A. M. 2011, PNAS, 108, 48

[13] Gustafsson, B., Edvardsson, B., Eriksson, K., et al. 2008, A&A, 486, 951

[14] Hynes, K. M., & Gyngard, F. 2009, Lunar Planet. Sci. Conf., 40, 1198

[15] Lambert, D. L., Gustafsson, B., Eriksson, K., et al. 1986, ApJS, 62, 373

[16] Marty, B., Chaussidon, M. & Wiens, et al. 2011, Sci, 332, 1533

[17] Nollett, K.M., Busso, M., & Wasserburg, G.J. 2003, ApJ, 582, 1036

[18] Palmerini, S. & Busso, M. 2010, ApJ, 717, 47

[19] Palmerini, S., Cristallo, S., Busso, M., et al. 2011, ApJ, 741, 26

[20] Plez B. 2012, Astroph. Sci. Code Library, 1205.004

[21] Ram, R. S., Wallace, L. & Bernath, P. F., 2010, JMoSp, 263, 82

[22] Ram, R. S., Wallace, L., Hinkle, K. & Bernath, P. F., 2010, ApJS, 188, 500

[23] Straniero, O., Gallino, R., Busso, M., et al. 1993, A&A, 271, 463

[24] Wallerstein, G., & Knapp, G. R. 1998, ARA&A, 36, 369

[25] Wannier, P.G., Andersson, B-G., Olofsson, H., et al. 1991, ApJ, 380, 593

[26] Wilson, T. L. and Rood, R. 1994, ARA&A, 32, 191

[27] Zinner, E.K., Nittler, L.R., Gallino, R., et al. 2006, ApJ, 650, 350