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Helium and neon in single presolar grains from the meteorites Murchison and Murray

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Abstract. In this study we present single grain analyses of He and Ne in presolar SiC extracted from the meteorites Murchison and Murray and find a larger fraction of noble gas-rich grains using an improved instrumental detection limit. We combine our study with NanoSIMS ion microprobe analyses to classify the grains, and compare our isotopic data with new AGB star nucleosynthetic model predictions.

Key words. dust, extinction — circumstellar matter — methods: laboratory — methods: analytical — nuclear reactions, nucleosynthesis, abundances

1. Introduction

Helium and neon are prominent nuclear fusion products of AGB stars and can be implanted by stellar winds into circumstellar condensates such as silicon carbide (SiC). Laboratory analyses of He and Ne in single presolar SiC grains extracted from primitive meteorites have been pioneered by Nichols et al. (1991, 1992) and revealed that only ∼5% of the grains contained detectable amounts of nucleosynthetic noble gases.

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2. Methods

Presolar grains were extracted from the carbonaceous chondrites Murchison and Murray at the MPI for Chemistry in Mainz with standard acid dissolution methods (Ott & Merchel 2000, Amari et al. 1994). The acid-resistant residue which includes the SiC was deposited on an ultra-clean Au-foil sample mount. SiC grains were identified and selected with SEM/EDX. Using the NanoSIMS ion microprobe, Si, C- and N-isotopes were analyzed in order to classify the grains after Hoppe & Ott (1997). Subsequently (Murray samples), or prior to NanoSIMS analyses (Murchison samples), noble gases were extracted by complete melting of single grains with an IR laser and measuring He- and Ne-isotopes using an ultra-high sensitivity mass-spectrometer equipped with an compressor ion-source at ETH Zurich (Baur 1999). With this instrument we improve our detection limit by ∼10x compared to the previous studies. New predictions for nucleosynthetic He and Ne in the He-Shell, and C and N in the envelope of AGB stars of different masses and metallicities where computed at the University of Torino using new stellar models based on the FRANEC code (Straniero et al. 1997) and will be compared to our laboratory data. The predictions for both He-shell and envelope are calculated for the last thermal pulse with third-dredge up.

3. Results

We measured He and Ne in 45 presolar SiC grains from Murray (0.6 to 3.6 μm diameter) and 65 grains from Murchison (0.6 to 6.3 μm diameter). We found a fraction of 52% of the grains from Murray and 35% from Murchison which contained detectable amounts of nucleosynthetic ^{22}Ne and/or ^{4}He. 19% and 15% of the samples from Murray and Murchison, respectively, were gas-rich in both ^{4}He and ^{22}Ne.

Our instrument detection limits for ^{4}He were (2.4 to 38) x 10^6 atoms and for ^{22}Ne (5.9 to 19) x 10^4 atoms. The gas amounts we detected were in the ranges (2.6 to 180) x 10^6 atoms ^{4}He per grain and (8.3 to 310) x 10^4 atoms ^{22}Ne per grain.

Due to the high abundance of ^{20}Ne in the terrestrial atmosphere it was not possible to distinguish stellar nucleosynthetic ^{20}Ne from the blank signal, dominated by terrestrial ^{20}Ne. However, the most-gas rich sample SiC070 allows constraining the upper limit of the ^{20}Ne/^{22}Ne ratio to <0.36. This is consistent with the theoretical ratio expected for the production site of ^{22}Ne, the AGB He-shell (Ne-G: ^{20}Ne/^{22}Ne=0.0827, Lewis et al. 1994) and is clearly different from AGB envelope (Ne-N: ^{20}Ne/^{22}Ne=∼8.4, Lewis et al. 1994) and terrestrial atmospheric composition (^{20}Ne/^{22}Ne=9.8, Eberhardt et al. 1965). From this we estimate that the measured ^{22}Ne consists of more than ∼95% of AGB He-shell Ne-G.

The Si-isotopic analyses classified the majority of the grains as mainstream grains. Low ^{12}C/^{13}C ratios revealed 5 grains as being of type A/B, 3 of them containing measurable amounts of ^{22}Ne and/or ^{4}He.

4. Discussion

We find that the most gas-rich grains always contained detectable amounts of both ^{22}Ne and ^{4}He. Their He- and Ne-isotopic compositions are in qualitative agreement with stellar model predictions of He-shell isotopic compositions of low-mass AGB stars (< 3 M_{solar}) with close-to-solar metallicities and >½ solar metallicites for 1 M_{solar} AGB stars (see Fig. 1). However ^{4}He/^{22}Ne ratios tend to be lower in most grains than the model ratios. We presume that this is due to diffusive ^{4}He loss from the grains. We can exclude major ^{4}He loss in the laboratory due to ion microprobe analysis prior to noble gas extraction, since grains from Murchison where noble gases have been analyzed before NanoSIMS analysis, show similar ^{4}He/^{22}Ne ratios as the Murray grains, where we analyzed nobles gases after ion-microprobe investigation. The C-isotopic compositions of most of the analyzed gas-rich grains are consistent with the model predictions for the same stellar masses and metallicities (see Fig.1; the low ^{12}C/^{13}C grains are discussed below). This is further supported by the Si-isotopic compositions of the gas-rich grains which classify them as mainstream grains, attributed to originate from 1-3 M_{solar} AGB stars (e.g. Hoppe & Zinner 2000).

The simplest explanation for grains which contain measurable amounts of ^{22}Ne or ^{4}He only is to attribute the non-detection of ^{4}He or ^{22}Ne to gas amounts just below our detection limits and assuming ^{4}He/^{22}Ne ratios in the same range as for the most gas-rich grains. The C-isotopic compositions of these samples dismiss the possibility that the grains have formed in the outflows of stars with different ^{4}He and ^{22}Ne outputs. Our model predictions indicate that the latter would be stars with M > 3 M_{solar} and Z < ½ Z_{solar} which produce ^{12}C/^{13}C ratios much higher than the ones measured.

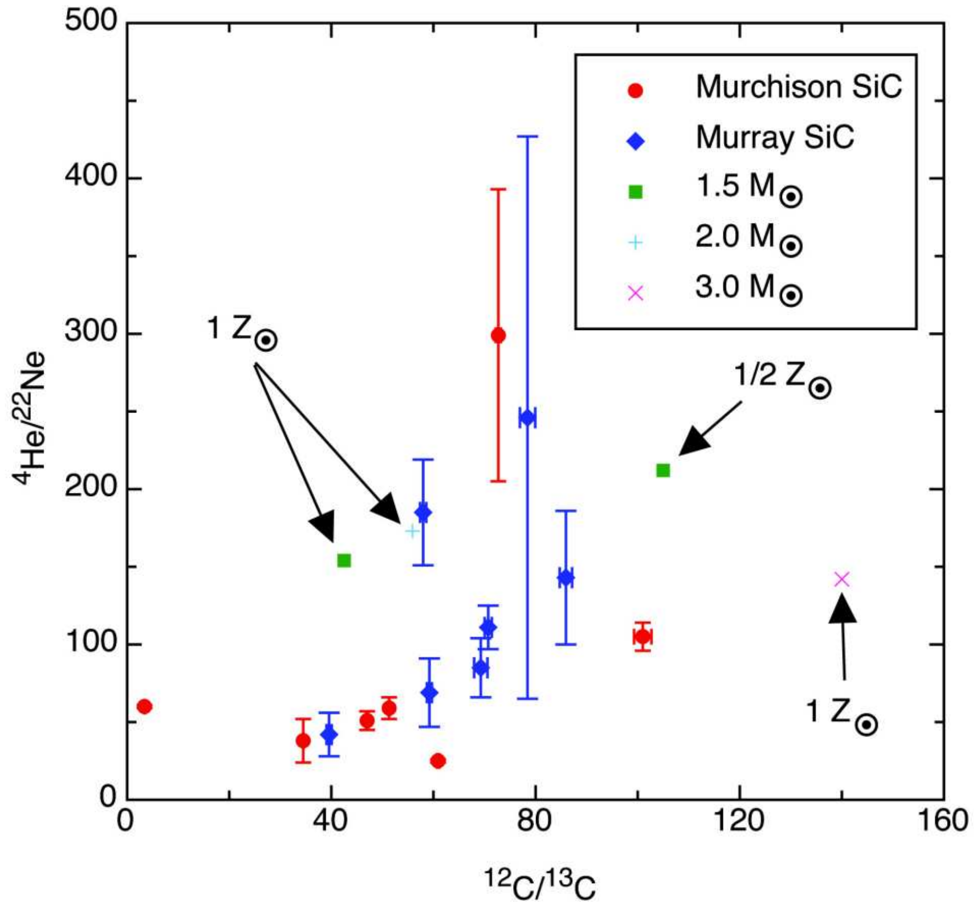

Fig. 1. Diagram showing $^{12}C/^{13}C$ ratio versus $^{4}He/^{22}Ne$ of single presolar SiC grains from the meteorites Murchison and Murray (error bars are 1σ) and isotopic ratios predicted by new nucleosynthetic model calculations for the He-shell ($^{4}He/^{22}Ne$) and the envelope ($^{12}C/^{13}C$) of AGB stars with different masses and metallicities.

The 5 A/B type grains are thought to originate in J-type carbon stars (Hoppe et al. 1994, 1996) and/or born-again AGB stars (Amari et al. 2001). We might even consider a nova origin for the one grain with the lowest $^{12}C/^{13}C$ ratio. This particular case and a systematic search for the rare nova and A/B type grains are discussed in Heck et al. 2006.

5. Conclusions

1. We find a 3-4 times higher fraction of SiC containing Ne- and He-G than found by previous studies. This suggests that most presolar SiC from AGB stars may contain Ne- and He-G, a possibility already mentioned by Nichols et al. It is then mainly a question of instrumental detection limits whether presolar gases can be detected.

2. A comparison of the measured isotopic compositions of Ne, He and C, with our new AGB star model predictions suggest the SiC grains analyzed originated in AGB stars with $M < 3\ M_{solar}$ with solar to close-to-solar Z and $Z > {}^1\!/_2\ Z_{solar}$ for 1 M_{solar} AGB stars.

3. The $^{4}He/^{22}Ne$ ratio of most of the gas-rich SiC grains is lower than predictions from AGB star models and can be explained be diffusive loss of ^{4}He from the presolar grains.

4. We report grains with detectable amounts of ^{22}Ne or ^{4}He only and also report noble gases in non-mainstream SiC.

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