

PRESOLAR GRAINS FROM NOVAE: EVIDENCE FROM HELIUM AND NEON ISOTOPES IN INTERPLANETARY DUST PARTICLES (IDPs) FROM COMET DUST STREAM COLLECTIONS. R. O.

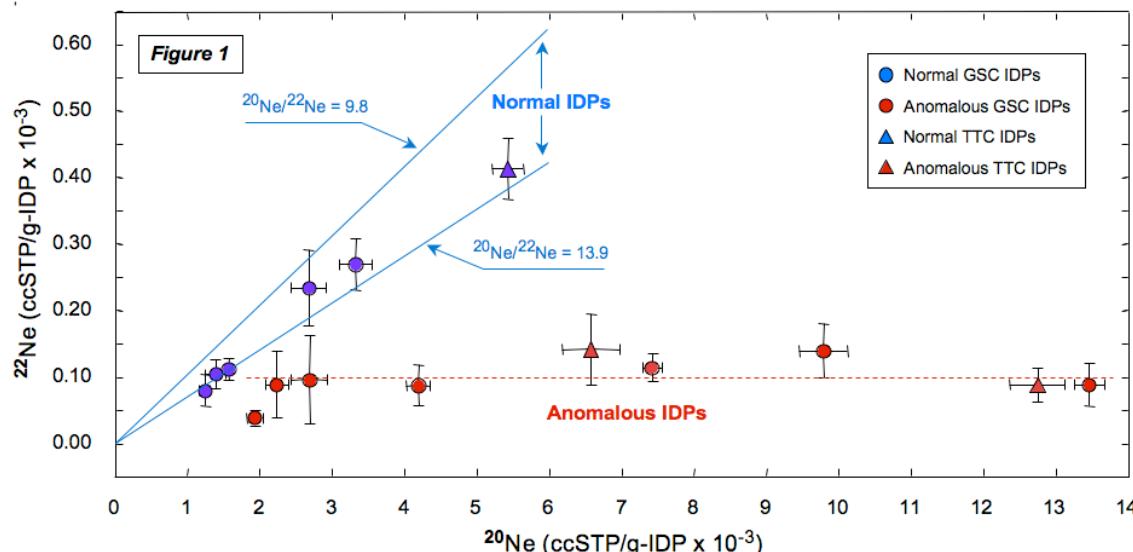
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Introduction: Many presolar grains in meteorites and IDPs carry isotopic signatures consistent with origins in supernovae and in red giant and asymptotic giant branch (AGB) stars [e.g., 1,2]. There have been suggestions that some grains were formed in classical nova explosions [3,4], but the evidence is ambiguous [5]. We report He and Ne compositions in particles captured on collectors flown to sample dust streams from comets 26P/Grigg-Skjellerup and 55P/Tempel-Tuttle that point to condensation of their gas carriers in the ejecta of a neon (ONe) nova. Agreement of measured isotope ratios with theoretical calculations of nucleosynthesis in such outbursts provides direct evidence for the presence of presolar grains from novae, now trapped in comets, in the early solar system.

Samples and Experimental: Modern searches for interstellar grains are carried out for the most part by scanning samples for small “hotspots” of isotopically anomalous H, C, N, O, Mg, Si and other elements utilizing secondary ion mass spectrometry (SIMS), scanning electron microscopy (SEM), and other analytic techniques with high spatial resolution [e.g., 3,6]. Instruments of this type, however, cannot detect trace amounts of noble gases. Measurement of these elements by conventional static mass spectrometry requires samples considerably larger than the sub- μm presolar grains typically found in hotspot searches. The Ne and He data reported here were obtained from $\sim 8\text{-}15\mu\text{m}$ bulk fragments of IDPs in stratospheric collections that maximized the chances of capturing infalling

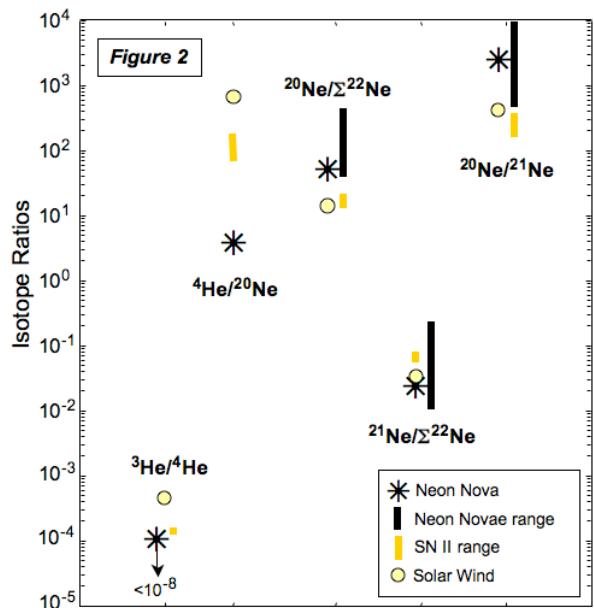
cometary material [7]. These collections are unusually rich in presolar grains [6]. All noble gas samples were fragments (masses ~ 0.3 to 2 nanograms) of larger “cluster” IDPs that shattered on impact with the collector plates. They were analyzed using a multi-step heating protocol for gas extraction and measurement and calibration techniques developed for static mass spectrometry of IDPs [8]. Careful attention was paid to blank subtractions from the low abundances of He and Ne in the “anomalous” samples (see below), with particular focus on upper limits for ${}^3\text{He}$ and corrections to the small amounts of ${}^{22}\text{Ne}$. Measured ${}^{22}\text{Ne}$ averaged 50% above blank, ~ 10 times the blank uncertainty.

Results: Neon concentrations in fifteen IDPs from the GSC (Grigg-Sjkellerup) and TTC (Tempel-Tuttle) collections are shown in Fig. 1. They clearly define two groups, one “normal” and the other “anomalous”. The normal population is characterized by correlated ${}^{20}\text{Ne}$ and ${}^{22}\text{Ne}$ concentrations with ${}^{20}\text{Ne}/{}^{22}\text{Ne}$ close to the solar wind ratio of 13.9, identifying these as particles experiencing substantial implantation of solar wind ions during their residence in space. The anomalous IDPs are strikingly different. They contain low and approximately uniform ${}^{22}\text{Ne}$ concentrations together with highly variable ${}^{20}\text{Ne}$. Measured ${}^{20}\text{Ne}/{}^{22}\text{Ne}$ ranges from ~ 25 to ~ 150 . These values greatly exceed the solar wind ratio, and have not been seen in meteorites or other IDPs. Of the theoretical nuclear reaction networks and hydrodynamic calculations of element synthesis in stellar environments, only those for neon

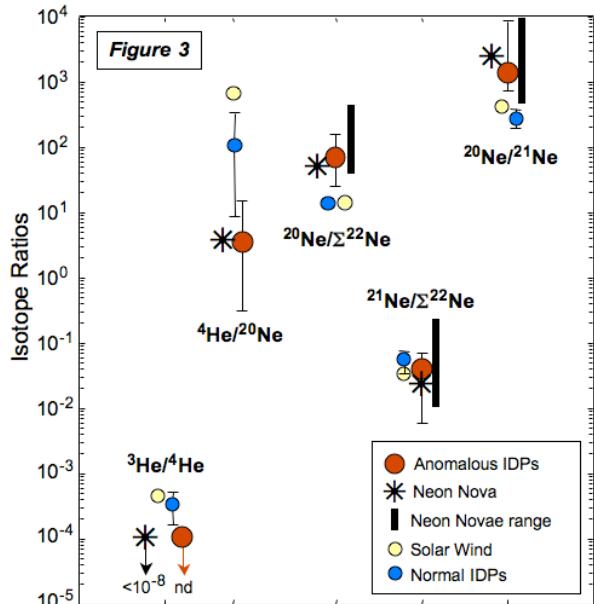


nova outbursts specifically predict $^{20}\text{Ne}/^{22}\text{Ne}$ ratios in and above this range in the total ejecta [4,9].

Calculated He and Ne distributions from recent modeling [9] of ejecta compositions (*) in a neon nova thermonuclear runaway (TNR) are plotted in Fig. 2.



Their non-solar character is evident for ratios involving the enhanced ^{20}Ne and severely depleted ^3He . Also shown are ratio ranges (black bars) derived from ten neon nova models based on differing selections for input parameters [4]. Preexisting ^3He and ^{22}Ne are virtually annihilated in the TNR by fusion to heavier spe-



cies while radiogenic ^{22}Na is produced [9], so total ^{22}Ne inventories ($\Sigma^{22}\text{Ne}$) in the nova models are dominated by decay of 2.6 year ^{22}Na . Models of nucleosyn-

thesis in type II supernovae [10] (orange bars) generate significantly less total ^{20}Ne , relative to ^4He , ^{21}Ne and $\Sigma^{22}\text{Ne}$, than is produced in neon nova TNRs. Production of ^{20}Ne is far lower in AGB nucleosynthesis [11].

He and Ne compositions in the normal and anomalous IDPs are shown in Fig. 3. Solar wind ratios and calculated ratios for neon nova outbursts from Fig. 2 are plotted for comparison. Normal IDP averages fall close to the solar wind, consistent with prolonged space irradiation, except for low $^4\text{He}/^{20}\text{Ne}$ suggesting variable loss of labile implanted He by heating during atmospheric entry. In contrast, measured isotopic averages and ranges (thin lines) in the anomalous IDPs, particularly the non-solar $^4\text{He}/^{20}\text{Ne}$ and $^{20}\text{Ne}/\Sigma^{22}\text{Ne}$ indicating high ^{20}Ne abundances, are in generally good agreement with theoretical predictions for neon nova ejecta. This is also true for ratios involving ^3He and ^{21}Ne , but these are less definitive; ^3He was not detected (nd), setting only the calculated $^3\text{He}/^4\text{He}$ upper limit of $<10^{-4}$ in Fig. 3, and ^{21}Ne was measurable, with large uncertainty, in just one of the anomalous IDPs.

Conclusions: A striking feature of Fig. 1 is the non-correlation of the ^{20}Ne and ^{22}Ne concentrations in the anomalous IDPs. With one exception, ^{22}Ne abundances are constant within their $\pm 1\sigma$ uncertainties in the nine samples, but ^{20}Ne varies by a factor of ~ 7 and $^{20}\text{Ne}/^{22}\text{Ne}$ ratios by a factor of ~ 6 . Noble gases incorporated into minerals by mechanisms such as irradiation, solution, or physical trapping closely reflect the isotopic compositions of their sources. An example is the normal IDP group in Fig. 1 where the correlated ^{20}Ne and ^{22}Ne concentrations yield $^{20}\text{Ne}/^{22}\text{Ne}$ ratios consistent with that in the irradiating solar wind. Uncorrelated ^{20}Ne and ^{22}Ne in the anomalous group requires separate sources for the two isotopes. We propose that most of the $\Sigma^{22}\text{Ne}$ derives from decay of ^{22}Na condensed in grains during their growth in the expanding nova outflow [12,13] and the non-condensable ^{20}Ne and ^4He reflect stochastic shock or stellar wind emplacement into the grains from an ambient gas-phase reservoir strongly depleted in ^{22}Ne and ^3He .

References: [1] Anders E. & Zinner E. (1993) *Meteoritics* 28, 490-514. [2] Zinner E. K. (2003) in *Treatise on Geochemistry, Vol. 1*, pp. 17-39. [3] Amari S. et al. (2001) *ApJ* 551, 1065-1072. [4] José J. et al. (2004) *ApJ* 612, 414-428. [5] Nittler L. R. & Hoppe P. (2005) *ApJ* 631, L89-L92. [6] Busemann H. et al. (2009) *EPSL* 288, 44-57. [7] Messenger S. (2002) *Meteorit. Planet. Sci.* 37, 1491-1505. [8] Pepin R. O. et al. (2000) *Meteorit. Planet. Sci.* 35, 495-504. [9] Starrfield S. et al. (2009) *ApJ* 692, 1532-1542. [10] Rauscher T. et al. (2002) *ApJ* 576, 323-348. [11] Heck P. R. et al. (2007) *ApJ* 656, 1208-1222. [12] Gehrz R. D. et al. (1986) *ApJ* 308, L63-L66. [13] Helton L. A. et al. (2010) *AJ* 140, 1347-1369.