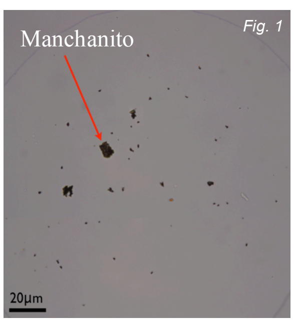
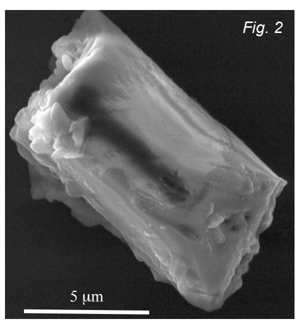
Q-GASES IN AN UNUSUAL IDP: A NOBLE GAS LINK TO CARRIERS IN STARDUST TRACK 41. R. L. Palma[1,2], R. O. Pepin[1], D. J. Schlutter[1], J. Stodolna[3], A. J. Westphal[4], and Z. Gainsforth[4], [1]Depart. of Physics, University of Minnesota, Minneapolis, MN 55455, USA: pepin001@umn.edu, [2]Depart. of Physics & Astronomy, Minnesota State University, Mankato, MN 56001, USA, [3]Centre d'Elaboration de Matériaux et d'Etudes Structurales, CNRS, 31055 Toulouse, France, [4]Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA.

Introduction: Studies of light noble gas distributions in Wild 2 coma particle fragments from track 41, Stardust aerogel cell C2044, revealed Ne isotope ratios within error of Ne compositions in "phase-Q" [1], a minor but gas-rich macromolecular organic phase ubiquitous in chondritic and achondritic meteorites [2]. A similar signature in an interplanetary dust particle (IDP) would point to a likely cometary provenance and to a common origin of the IDP and the track 41 comet particle in an ancient Q-rich reservoir. However, indigenous noble gases in IDPs, except those rapidly captured from Earth-crossing comet dust streams, are effectively masked by an abundant solar wind component implanted during their long residence in space [3]. Here we report Ne and He compositions that closely replicate the Q-gas isotopic pattern in "Manchanito", a solar-wind-free particle with unusual chemistry and morphology, found in a cluster IDP [4].

Sample: Manchanito is a ~10μm x 6μm x 6μm grain extracted from cluster IDP L2071F1 (Fig. 1). It has an euhedral shape (Fig. 2) and is fully amorphous,

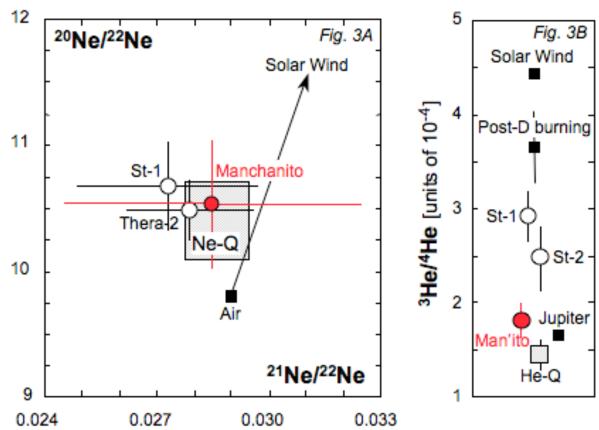




with a homogeneous Ca,Al-rich and Mg,Fe-poor refractory composition: O-61.9%, Si-20.7%, Ca-9.9%, Al-6.5%, Na-0.6%, Mg-0.2%, Ti-0.2%, and Fe-0.1%, all in atom % [4]. The sample was embedded in an epoxy bullet and microtomed, creating twelve ~100 nm-thick sections mounted on TEM grids for Al-Mg ion microprobe analyses, and a ~8μm x 6μm x 6μm potted butt on which microprobe O isotope measurements were performed (details in [4]). No evidence was found for extinct ^{26}Al; the 2σ upper bound for initial $^{26}Al/^{27}Al$ is 1.1 x 10^{-6}. The O isotopic composition of $\delta^{17}O = 7.0 \pm 0.7$, $\delta^{18}O = 14.0 \pm 0.6$, $\Delta^{17}O = 0.4 \pm 1.3$ (±2σ) lies within error on the terrestrial fractionation line in a $\delta^{17}O$ vs. $\delta^{18}O$ diagram. The $^{26}Al/^{27}Al$ and O data above have been updated from values given in [4].

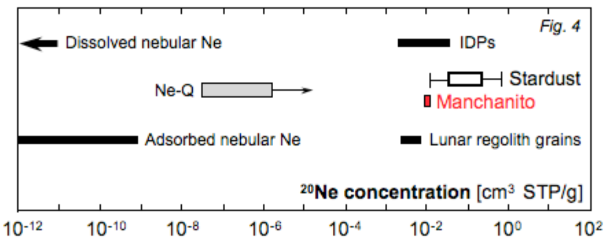
Noble Gas Analysis: The Manchanito potted butt, with most of its adhering epoxy removed by FIB milling, was loaded in a gas extraction furnace and baked at ~150ºC for three days. It was next heated in two 10-second steps at ≲200ºC to remove any surface contamination. No noble gases above blank levels were released in these steps. Stepped heating to higher temperatures, as described in [3], was then applied. Substantial He and Ne evolution occurred in the 2nd and 3rd heating steps at ≲750-800ºC. At this point heating was interrupted and the accumulated He and Ne analyzed by mass spectrometry. Gas releases at or below ~750-800ºC comprised the totals in the sample; no detectable He or Ne was evolved in subsequent heating to ~1400ºC. Measured amounts were well above system blanks, by factors of ~8 and 32 for ^{3}He and ^{4}He and by factors of ~12, 5, and 8 for ^{20}Ne, ^{21}Ne, and ^{22}Ne.

Results. Ne and He isotope ratios measured in Stardust track 41 are shown in Figs. 3A,B, taken from [1]. Manchanito data from the present study are superimposed in red. The two track 41 measurements in Fig. 3A, St-1 and Thera-2, are consistent within error with the Ne-Q compositional range determined by [2]. The



nominal Manchanito value falls squarely in the Ne-Q data field, although uncertainties are larger, particularly for $^{21}Ne/^{22}Ne$. The close correspondence of Manchanito compositions to phase-Q is further evident in Fig. 3B, where its $^{3}He/^{4}He$ ratio differs only marginally from He-Q. Both agree within error with Jovian $^{3}He/^{4}He$ [5], generally taken to represent protosolar He. Here, however, the track 41 ratios are significantly higher. This offset probably reflects the presence of solar wind He in track 41. Helium of approximately solar composition has been detected in aerogel bordering the track [6]. Its carrier and origin are unknown.

Strikingly high noble gas concentrations were measured in the Stardust track 41 particles, comparable to those implanted into lunar fines and many IDPs by solar wind ions (Fig. 4) and suggesting a similar gas acquisition mechanism, in this case by Q-ion irradiation, for the track carrier grains [1]. A correspondingly large loading of Q-gases is observed in Manchanito: measured ^{20}Ne abundance ($9.45 \pm 0.37 \times 10^{-12}$ ccSTP)



combined with the estimated mass of the potted butt (~0.85 ng) yields the Ne concentration shown in Fig. 4.

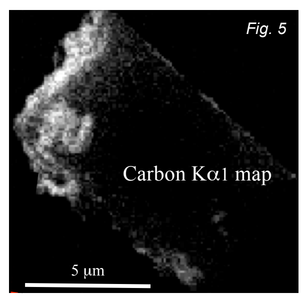
Discussion: *Evidence for cometary origin.* Q-type isotopic distributions are observed in Manchanito and in a Wild 2 coma particle, and both exhibit comparably high gas loadings. Moreover the large difference in $^3He/^4He$ between the solar wind and Manchanito (Fig. 3B) indicates a minimal solar wind component. This points to a short residence in space, characteristic of grains captured from recently generated comet dust streams crossing Earth's orbit (e.g., [3]). An arguable source might be dust from comet Schwassmann Wachmann 3 (SW3). However cluster L2071F1 was collected 1-2 months after Earth encountered the peak of the SW3 dust stream on June 1, 2008 [7]. Whether L2071F1 could still have been settling through the stratosphere this long after the encounter depends on its overall density and shape [7], both unknown.

Gas carriers. Synchrotron SXRF assays of the track 41 bulb wall [1] identified mostly refractory crystalline minerals, primarily metal and metal-bearing compounds (~75%) and silicates (~25%). A more detailed TEM study of part of the wall found a wide variety of crystalline silicates [8]. Helium and Ne were released from their track host grains only at temperatures above ~1250ºC, pointing to refractory gas carriers [1]. In contrast, degassing of Manchanito was complete at ≲ 800ºC. This low temperature gas evolution is attributable to its vitreous nature; stepped heatings of natural terrestrial glasses show very similar He-Ne release profiles [9]. Whatever the track 41 gas carriers are, they are not amorphous grains like Manchanito.

Amorphization of Manchanito. The Ne loading in in Fig. 4 is consistent with ion implantation. Energetic heavy ion irradiation is a well-studied mechanism for inducing amorphization in crystalline minerals [e.g., 10]. Manchanito's Ne content divided by its average projected surface area —modeled as that of a randomly oriented, equal-area cylinder exposed to a directional ion flux— yields a minimum Ne fluence, assuming no impinging ions were lost from the sample, of ~4.5×10^{14} cm^{-2}. Argon fluence is ~25x higher, >10^{16} cm^{-2}, for Q-composition radiation [2]. A much smaller fluence of 0.4 MeV Ar ions, 5×10^{14} cm^{-2}, is sufficient to amorphize crystalline enstatite to the depth of the Ar ion range [10]. However at 0.4 MeV the range is only ~0.3 µm. Penetration to ~10x this depth, corresponding to Ar ion energies of several MeV, would be required to fully amorphize a particle of Manchanito's size.

Nature and location of the Q reservoir. A picture emerging from the Stardust track and Manchanito noble gas studies is one of an energetic Q-rich gas reservoir close to the young, intensely flaring sun. Grains condensing in this environment were exposed to MeV-level Q-ion radiation and were subsequently transported to distant comet-forming regions of the accretion disk [11,1]. An alternate view, that Manchanito might be a Q-carrying presolar grain amorphized in an interstellar environment, needs further study. However there is no hint in its oxygen composition for isotopically anomalous presolar O. Neon implantation by low-energy galactic cosmic rays (GCR) is ruled out by the low GCR-$^{20}Ne/^{22}Ne$ ratio of <2 [12]. Gas implantation and amorphization in shock-accelerated dust [13] is questionable for grains as large as Manchanito, and would require a Q-composition for ambient He and Ne impacted by the accelerated grain.

A carbonaceous carrier? Adhering organic matter (OM) was seen on one end of Manchanito's top face (Fig. 5). No record exists of which end of the sample



was microtomed, and so, pending further study of the TEM sections, there is a chance that the OM was in the potted butt. A minimum OM mass, estimated from its area in Fig. 5 and assuming ~0.1 µm thickness, is ~5 pg. If Manchanito's gases were sited in this mass, it would contain ~10^{-3} Ne and ~6×10^{-3} He atoms per C atom for a pure C carrier, levels that could plausibly be accommodated in an OM structure. Moreover a larger OM mass is likely since the weak carbon Kα X-ray from possible deposits on other faces of Manchanito would have been largely absorbed in transit to the detector. So an OM gas carrier cannot presently be ruled out. It probably would not have been populated by energetic amorphizing radiation; direct incorporation of ambient Q-gases seems more likely.

References: [1] Marty B. et al. (2008) *Science 319,* 75. [2] Busemann H. et al. (2000) *Meteorit. Planet. Sci. 35,* 949. [3] Pepin R. O. et al. (2011) *ApJ 742:86*. [4] Stodolna J. et al. (2012) *75th Meteoritical Society Mtg., abstract* #5392. [5] Mahaffy P. R. et al. (1998) *Space Sci. Rev. 84,* 251. [6] Füri & Marty (2012) LPSC 43rd, #1220; Palma R. L. et al. (2013) Poster, this conference. [7] Messenger S. (2002) *Meteorit. Planet. Sci. 37,* 1491. [8] Joswiak D. et al. (2012) *Meteorit. Planet. Sci. 47,* 471. [9] Matsuda J-i et al. (1989) *GCA 53,* 3025. [10] Jäger C. et al. (2003) *Astron. Astrophys. 401,* 57. [11] Brownlee D. et al. (2006) *Science 314,* 1711. [12] Webber W. R. et al. (1997) *ApJ 476,* 766. [13] Westphal A. J. & Bradley J. P. (2004) *ApJ 617,* 1131.