Wide distribution of oxygen isotopic compositions in Stardust fragments: Wild 2 materials from ^{16}O- and ^{17,18}O-rich nebular reservoirs. D. J Joswiak[1], D. E. Brownlee[1], D. Nakashima[2], T. Ushikubo[2], N. T. Kita[2] and G. Matrajt[1], [1]Dept. of Astronomy, University of Washington, Seattle, WA 98195 USA, [2]Department of Geoscience, University of Wisconsin-Madison, Madison, WI 53706 USA, joswiak@astro.washington.edu

Introduction: The Stardust (SD) spacecraft returned to Earth a large variety of high temperature minerals and rocks that appear to have formed in the inner Solar System which were transported to the Kuiper belt and incorporated into comet Wild 2. Mineralogical and isotopic studies from individual fragments recovered from the aerogel tracks have shown some are consistent with CAIs [1,2] and chondrule fragments [3,4] two of the major components observed in chondrites. These and numerous other SD studies have shown that comet Wild 2 appears to be composed of a diverse range of materials.

Recently, we performed high precision oxygen isotopic measurements from coarse fragments (typically 3 – 10 μm in size) from a number of Stardust tracks. The oxygen isotopic studies were coordinated with TEM and SEM studies with the goal of assessing similarities of the SD fragments to other extraterrestrial materails such as chondrites. A second goal is to build a Stardust mineralogical+oxygen isotope database. Here, we present the mineralogical and isotopic results from coarse-grained Stardust fragments that we have studied to date along with previously published results from other SD grains.

Techniques: Whole Stardust tracks isolated in keystones [5] were flattened between clean glass slides and embedded in acrylic resin. Large optically transparent fragments (terminal particles, sub-terminal particles, fragments in bulbs) were identified and cut individually (or sometimes in groups) from the flattened aerogel tracks and microtomed for TEM analyses. The microtome sections were studied in a FEI TF20 TEM with bright-, dark-field- and STEM-imaging, electron diffraction and compositionally by standard thin-film techniques with a EDAX Genesis EDX light element detector. The portion of each fragment that remained behind in acrylic after microtoming (potted butt) was used to obtain BSE images and EDX spectra with an FESEM. From the combination of TEM studies on the microtome sections and BSE images from the potted butts, the textures and mineral associations of each fragment were characterized. The fragments were then cut from their acrylic mounts, embedded in indium metal and analyzed for oxygen isotopes with a high-precision Cameca IMS-1280 ion microprobe at the University of Wisconsin. Detailed analytical techniques of the isotopic measurements from this instrument are described in [3,6].

Results: We obtained mineralogical and oxygen isotopic compositions from 7 individual fragments from four separate Stardust tracks. A summary of the mineralogy and other characteristics of the fragments is provided in Table 1. The oxygen isotopic compositions of the fragments, plotted on a oxygen 3-isotope plot are shown in Figure 1 along with the isotopic compositions from 6 additional Stardust fragments that were previously measured [3,7]. The isotopic composition of the embedding medium acrylic is also shown (one point includes minor Bidi) [7, this study]. The plot shows two distinct populations of Wild 2 materials;; one is ^{16}O-rich and is similar to CAIs, the other is rich in ^{17,18}O and is similar to chondrules. The ^{16}O-rich population is composed of a variety of materials including a LIME (low-iron, manganese-enriched) forsterite, a small Fo_{98} fragment, an Mg-rich olivine (Fo_{95}) from a probable ferromagnesian (FMG) chondrule fragment [3] and Inti, the previously studied CAI fragment from track 25 [1,7]. Most analyses fall on the CCAM line except for the Mg-rich olivines, Fo_{98} from Febo, and Fo_{95} from Gozen-sama, which are slightly above. The latter two points, displaced slightly above the CCAM line, may reflect instrument mass fractionation. In the ^{16}O-poor population, 10 inidividual Stardust fragments are represented which vary in δ^{18}O from -12.2 to +6.8 ‰. Two are Fe-rich olivines (Fo_{65}, $Fo_{58\text{-}61}$), one is an Al-rich chondrule fragment (Bidi) [4], one is a single Mn-rich augite (Puki-C, frag. 9) and four are mineralogically similar to ferromagnesian chondrules (Aton-B, frag. 7; Torajiro, Gozen-sama and Gen-chan – [3]). Additionally, a single Mg-rich olivine (Mg_{95}, track 22) and low-Ca pyroxene are present [7]. The ^{17,18}O-rich fragments define a loose array and span the range from slightly above the TF to directly overlapping the CCAM lines. Many points occupy the region between the lines.

Discussion: Although a limited number of isotopic analyses are available from Wild 2 materials, the distribution of isotopic compositions (Figure 1) suggests that the materials that accreted to Wild 2 were derived from either ^{16}O-rich or ^{16}O-poor reservoirs. The apparent bimodal distribution may imply that the various Wild 2 particles experienced little gas-solid interaction outside their reservoirs in which they formed suggesting that residence times were short prior to transport to the Kuiper belt. The distribution also supports the hypothesis that the Wild 2 particles did not reside in asteroidal parent bodies, at least those which experi-

enced significant thermal metamorphism or aqueous alteration.

The ^{16}O-rich grains comprise a diverse set of materials including CAIs, ferromagnesian chondrules (fragments) and possible condensates (i.e., LIME forsterite, [8]). This ^{16}O-rich group which varies in δ^{18}O from -55 to -36 ‰, ovelaps many bulk CAIs and approaches the composition of the Sun as measured by the Genesis mission [9]. This group is isotopically similar to hibonite inclusions and the most ^{16}O-rich CAIs [9] showing that a portion of Wild 2 materials may be related to the reservoir that produced some of the most refractory materials known in chondrites.

The mineralogically-diverse ^{16}O-poor group which plots near the TFL is isotopically similar to components (such as chondrules) in different chondrite groups including carbonaceous [3] and possibly ordinary chondites [4]. This is illustrated in the oxygen 3-isotope plot (Figure 1) showing the locations of the ^{16}O-poor grains on and around the TF and CCAM lines with δ^{18}O values ranging from -12.2 to +6.8 ‰.

Taken together, our results, along with the mineralogic and isotopic data from other studies show that comet Wild 2 is composed of a mineralogically and isotopically diverse range of materials that were probably derived from ^{16}O-rich and ^{16}O-poor reservoirs that did not communicate signficantly.

Conclusions: Combined oxygen isotopic measurements and mineralogical data from this and previous studies show that comet Wild 2 is composed of a diverse range of high temperature materials that were likely extracted from where they formed in either ^{16}O-rich or ^{16}O-poor reservoirs. This supports the idea that comet Wild 2 is truly a primitive body whose constituent grains were not derived from a chemically homogeneous, well-mixed reservoir and whose grains likely did not reside in large asteroidal parent bodies prior to incorporation into the comet.

References: [1] Simon S. B. et al. 2008. *MAPS* 43: 1861-1877. [2] Matzel J. E. P. et al. 2010. *Science* 328: 483-486. [3] Nakamura T. et al. 2008. *Science* 321: 1664-1667. [4] Joswiak D. J., Matrajt G., Brownlee D., Nakashima T., Ushikubo T., Kita N. T., Messenger S. and Ito M.. in preparation. [5] Westphal A. J. et al. 2004. *MAPS* 39: 1375-1386. [6] Nakashima D. et al. 2011. *LPSC XLII*, abstract 1240. [7] McKeegan K. D. et al.. 2006. *Science* 314: 1724-1728. [8] Klöck W., Thomas K. L., McKay D. S. and Palme H. 1989. *Nature* 339: 126-128. [9] McKeegan K. D. et al. 2011. *Science* 332: 1528-1532.

Table 1: Properties of Stardust fragments in this study.

Sample	Track #	Apparent Size (µm)	Fragment Mineralogy	Comments
Bidi, TP	130	4 x 6	Fo_{97}+An+Cpx	Al-rich chond. frag.
Puki-A, frag 1	77	7 x 4	Fo_{62-67}	TP
Puki-C, frag 4	77	2 x 2	Fo_{58-61}	Single mineral
Puki-C, frag 6	77	2 x 2	LIME Fo	MnO > FeO
Puki-C, frag 9	77	4 x 4	Mn-rich augite	MnO = 12.3 wt%
Aton-B, frag 7	22	3 x 5	Fo_{79}+glass	FMG chond. frag.
Febo-E, frag 10	57	2 x 2	Fo_{98}	Single mineral

Fo=forsterite, An=anorthite, Cpx=clinopyroxene, TP=terminal particle, chond=chondrule, FMG=ferromagnesian