

**IDENTIFICATION OF AN  $^{16}\text{O}$ -POOR SOLAR SYSTEM CONDENSATE IN THE MILLER RANGE 090019**

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**Introduction:** Oxygen isotopic compositions of ancient solar system materials reflect their source regions and subsequent interactions with isotopically distinct reservoirs. Calcium-, Aluminum-rich inclusions (CAIs), Amoeboid Olivine Aggregates (AOAs), and refractory grains that condensed in the inner solar nebula are  $^{16}\text{O}$ -rich ( $\delta^{17}\text{O}$ ,  $\delta^{18}\text{O}$  near the composition of the Sun) and most other planetary materials, including most chondrules and meteorite matrix grains, are relatively depleted in  $^{16}\text{O}$  ( $\delta^{17}\text{O}$ ,  $\delta^{18}\text{O}$  near 0 ‰). The O isotopic distribution of these solar system materials fall along the carbonaceous chondrite anhydrous mineral (CCAM) [1, 2], and Young and Russell (Y&R) [3] lines and are generally explained by mixing of material from  $^{16}\text{O}$ -rich and  $^{16}\text{O}$ -poor reservoirs in the solar nebula.

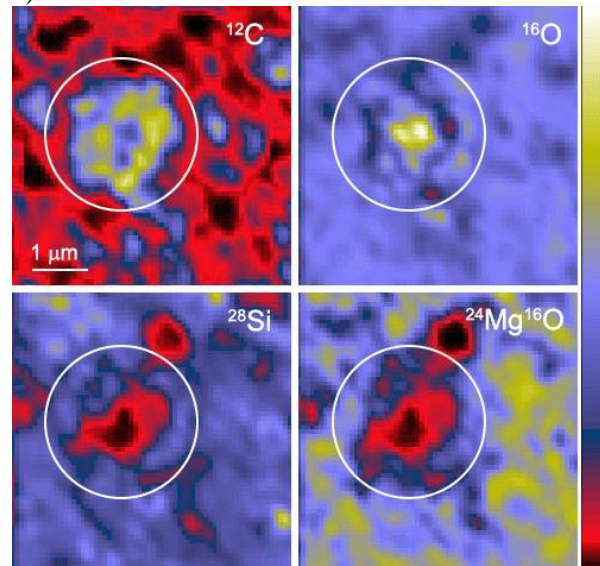
The  $^{16}\text{O}$ -poor reservoir is thought to be isotopically heavy  $\text{H}_2\text{O}$  produced by self-shielding during photodissociation of  $\text{C}^{17,18}\text{O}$  [4, 5]. The first evidence of this reservoir was identified in the Acfer 094 meteorite as isotopically heavy cosmic symplectite (COS), intergrowths of pentlandite and magnetite having  $^{17}\text{O}$  and  $^{18}\text{O}$  enrichments up to  $\sim 180$  ‰ [6, 7]. The COS likely formed by oxidation and sulfidization of Fe-, Ni-metal by early solar system  $^{16}\text{O}$ -poor water either in the solar nebula or on an icy planetesimal [7]. Other identified  $^{16}\text{O}$ -poor materials include ferromagnesian silicates found in interplanetary dust particles (IDPs) [8] and Na-rich sulfates within a cometary xenolith found in the LaPaz Icefield (LAP) 02342 chondrite [9]. An aggregate of Ca carbonate and Fe carbonate or Fe oxide having intermediate  $^{16}\text{O}$ -poor composition was identified in Miller Range (MIL) 07687 [6]. In general,  $^{16}\text{O}$ -poor grains are rare.

We have been conducting detailed O isotopic studies of CAIs [10, 11] and presolar grains [Nguyen et al., this meeting] in the MIL 090019 CO3.1 chondrite. This meteorite has affinities to the primitive chondrites Acfer 094, Dominion Range (DOM) 08004/6 (CO3) and Allan Hills (ALH) 77307 (CO3). Here we report on nebular grains in MIL 090019 that have non-mass dependent O isotopic anomalies to further our understanding of the O isotopic reservoirs in the solar system.

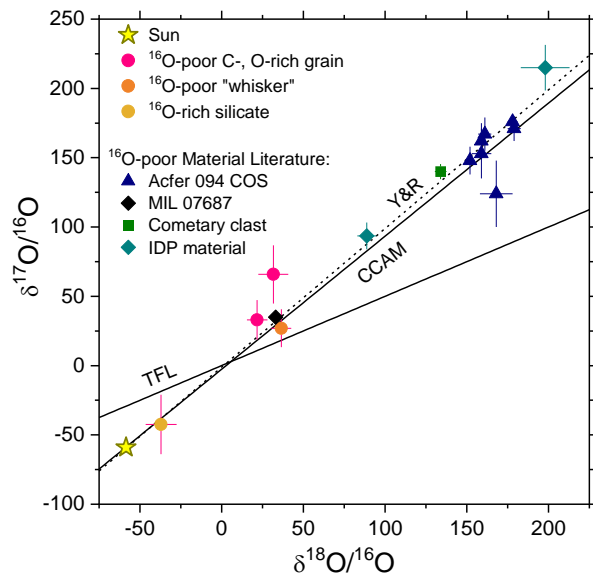
**Experimental:** A polished thin section of MIL 090019 was characterized by scanning electron microscopy and the mineralogy and petrography was performed using the JOEL JXA-8530F field emission electron probe microanalyzer at NASA JSC [11]. Three

matrix regions of the thin section were selected for C and O isotopic mapping using the Cameca NanoSIMS 50L at NASA JSC. Prior to data acquisition, each  $20 \times 20 \mu\text{m}^2$  area to be analyzed was sputtered with a high current  $\text{Cs}^+$  primary ion beam to remove the conductive C coat and to implant Cs. A focused  $\sim 1 \text{ pA}$   $\text{Cs}^+$  primary ion beam was then rastered over these areas for 30 planes and negative secondary ions of  $^{12}\text{C}$ ,  $^{13}\text{C}$ ,  $^{16}\text{O}$ ,  $^{17}\text{O}$ ,  $^{18}\text{O}$ ,  $^{28}\text{Si}$ , and  $^{24}\text{Mg}^{16}\text{O}$  were simultaneously detected in electron multipliers. An electron flood gun was used for charge compensation. Isotopically normal matrix grains served as the isotopic standard for normalization.

**Results and Discussion:** A total area of  $35,572 \mu\text{m}^2$  was analyzed ( $11,625 \mu\text{m}^2$ ,  $15,820 \mu\text{m}^2$ , and  $8,130 \mu\text{m}^2$  in Regions 1, 2, and 3, respectively). In addition to presolar grains, we identified three solar system grains with non-mass dependent O isotopic anomalies in Region 2: an  $\sim 1.3 \mu\text{m}$   $^{16}\text{O}$ -rich silicate grain ( $\delta^{17}\text{O} = -42 \pm 22$  ‰;  $\delta^{18}\text{O} = -37 \pm 10$  ‰;  $1\sigma$ ), an  $4 \times 1 \mu\text{m}$  oblong  $^{16}\text{O}$ -poor silicate grain ( $\delta^{17}\text{O} = 27 \pm 14$  ‰;  $\delta^{18}\text{O} = 37 \pm 6$  ‰;  $1\sigma$ ), and a  $\sim 1.9 \mu\text{m}$   $^{16}\text{O}$ -poor grain with an oxide core and C-rich rim (Fig. 1). The O isotopic composition of the core was  $\delta^{17}\text{O} = 66 \pm 21$  ‰;  $\delta^{18}\text{O} = 32 \pm 9$  ‰ and the rim was  $\delta^{17}\text{O} = 33 \pm 14$  ‰;  $\delta^{18}\text{O} = 22 \pm 6$  ‰. Their O isotopic compositions fall along the CCAM and Y&R lines (Fig. 2).



**Figure 1.** NanoSIMS  $^{12}\text{C}$ ,  $^{16}\text{O}$ ,  $^{28}\text{Si}$ , and  $^{24}\text{Mg}^{16}\text{O}$  negative secondary ion images of  $^{16}\text{O}$ -poor material (circled).



**Figure 2.** Oxygen isotopic compositions of solar system grains identified in MIL 090019 along with  $^{16}\text{O}$ -poor materials identified in chondrites and IDPs [6-9]. Composition of the sun from [12]. Also shown are the CCAM, Y&R, and terrestrial fractionation (TFL) lines. Errors are  $1\sigma$ .

The phase identifications of the grains are based on the NanoSIMS  $^{28}\text{Si}/^{16}\text{O}$ ,  $^{28}\text{Si}/^{12}\text{C}$ , and  $^{24}\text{Mg}/^{16}\text{O}$  ratios. The core of the  $^{16}\text{O}$ -poor assemblage was devoid of Si and MgO (Fig. 1). The two silicate grains were also Mg-poor. FIB-TEM studies are planned to confirm the mineralogies and chemical compositions.

The isotopic composition of the  $^{16}\text{O}$ -rich silicate ( $\Delta^{17}\text{O} = -23\text{‰}$ ) is similar to low-iron, manganese-enriched (LIME) olivine and crystalline silicates in Wild 2 [13-15] and individual phases in CAIs [e.g., 10, 11, 16]. This grain likely has a condensation origin from a  $^{16}\text{O}$ -rich gas.

The oblong  $^{16}\text{O}$ -poor silicate ( $\Delta^{17}\text{O} = 8\text{‰}$ ) is shaped like an enstatite whisker, but the low  $^{24}\text{Mg}/^{16}\text{O}$  ratio suggests it is not enstatite. The isotopic composition is similar to some enstatite whiskers in IDPs [17]. However, one enstatite whisker in an IDP was found to be  $^{16}\text{O}$ -rich [18]. Interestingly, enstatite whiskers are believed to be vapor-phase condensates [19] and the isotopic data suggest these grains condensed from isotopically distinct gaseous reservoirs. The O isotopic mapping of the CAIs in MIL 090019 also reveal isotopic heterogeneity that suggest  $^{16}\text{O}$ -rich and  $^{16}\text{O}$ -poor gaseous reservoirs were present in the CAI forming region at the beginning of solar system formation [10, 11].

The oxide core of the  $^{16}\text{O}$ -poor assemblage has a  $\Delta^{17}\text{O}$  value of 49 ‰ while the C-rich region has a  $\Delta^{17}\text{O}$

value of 22 ‰. It is not as isotopically heavy as the COS, Na-rich sulfates, or IDP silicates (Fig. 2) and is chemically distinct from those materials. Its isotopic composition is, however, very similar to the isotopically heavy assemblage found in the ungrouped MIL 07687 chondrite [6]. The material from MIL 07687 is a fine-grained aggregate of Ca carbonate and either Fe carbonate and/or Fe oxide. The assemblage in this study could also be comprised of the same minerals but is distinct in its structure and presence of Si and Mg in the perimeter.

The  $^{16}\text{O}$ -poor grains in MIL 090019 and MIL 07687 could have been altered by distinct  $^{16}\text{O}$ -poor reservoirs, and perhaps in a different location in the nebula. The O isotopic composition of water ice in the outer disk or in a comet is expected to be more isotopically heavy [4, 5] and the most  $^{16}\text{O}$ -poor grains likely originated or were altered in the outer solar nebula. In this scenario, the MIL 090019 and MIL 07687 grains were altered inside the snow line. Alternatively, the MIL 090019 and MIL 07687 grains could have initially been altered by the primordial water reservoir but became more  $^{16}\text{O}$ -rich due to aqueous alteration on the asteroid parent body or in the inner solar nebula. The identification and study of these grains is essential for understanding the origins and evolution of the different isotopic reservoirs in the solar nebula.

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