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Diverse origins of cometary materials

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Having formed at the cold outer margins of the Solar System, comets are thought to contain the least altered remnants of the Solar System starting materials. Spectroscopic studies of comets and laboratory studies of cometary materials suggest that comets have mostly escaped significant parent-body processing. Comets are thus essentially pristine aggregates of nebular and presolar materials.
Two types of cometary materials have been studied in the laboratory; a subset of interplanetary dust particles (IDPs) collected in the Earths stratosphere, and direct samples of comet Wild-2 returned by the Stardust spacecraft in 2006. Anhydrous, porous IDPs with chondritic bulk elemental abundances (CP-IDPs) have been linked to comets based on their mineralogy, composition, and inferred Earth-encounter velocities. CP-IDPs are aggregates of mostly submicrometer amorphous silicates, enstatite, olivine, Fe,Ni-sulfides and other minor phases bound together by carbonaceous material. Silicate stardust grains are also found in CP-IDPs with varying abundances (100-10,000 ppm) and are distinguished by their exotic O isotopic compositions which point to origins in evolved stars [1].
Some minerals in these cometary CP-IDPs appear to have formed by vapor phase condensation in the solar nebula. The olivine and pyroxene grains are Mg-rich (Mg/Mg+Fe >0.9) and often Mn-rich (up to 5 mol. %), consistent with nebular condensation models. These silicates are predicted to condense from a gas of solar composition at 1380-1310K at 10-4 bar pressure [2]. Some enstatite and forsterite crystals display distinct whisker and platelet morphologies and crystallographic defects that are characteristic of vapor phase growth [3].
Other crystalline silicates formed by thermal annealing. These equilibrated aggregates (EAs) are submicrometer aggregates of (Type 1) forsterite and enstatite subgrains or (Type 2) crystalline silicates and Fe-sulfide grains with a silica-rich amorphous matrix [4]. Type 1 EAs appear to be clusters of high-temperature nebular condensates that underwent slight annealing. Type 2 EAs likely formed by sub-solidus thermal annealing of amorphous silicate precursors.
The oxygen isotopic compositions of the great majority of amorphous and crystalline components in CP-IDPs fall within the range of Solar System materials. The mineralogical and isotopic compositions of these grains are most easily explained by formation in high-temperature processes near the Sun and subsequently transported to the Kuiper belt early in Solar System history.
Comet Wild-2 Stardust Mission samples also show clear evidence of extensive radial mixing in the nebula. Stardust samples include a diverse mineralogy, mostly pyroxene, olivine, and Fe,Ni-sulfides. Most fine grained materials did not survive the 6.1 km/s capture process intact, and the abundance of amorphous silicates is still uncertain. However, the most resilient phases were collected intact. Representatives of all major nebular components in meteorites have now been found in Stardust samples, including a small calcium,aluminum-rich inclusion (CAI), several chondrule-like objects, and a potential ameboid olivine aggregate (AOA) fragment [5-7]. Oxygen isotopic measurements of these components are all consistent with formation in the inner Solar System.
While it is difficult to quantify the abundance of these inner Solar System materials in cometary materials, these materials are common. The combined information from studies of cometary CP-

IDPs and Stardust comet Wild-2 samples shows that cycling of material from the inner Solar System to the outer reaches of the nebula was very efficient.
[1]Floss & Stadermann (2009) GCA 73,2415 [2] Lodders (2003) ApJ 591,1220 [3] Bradley et al (1983) Nature 301,473 [4] Keller & Messenger (2005) in Chondrites and the Protoplanetary Disk [5] McKeegan et al 2006 Science 314,1724 [6] Nakamura et al (2008) Science 321,1664 [7] Messenger et al (2008) MPS 43,5308