# LARGE COARSE-GRAINED SOLID PARTICLES IN COMETS – A UBIQUITOUSLY DISTRIBUTED COMPONENT IN THE SOLAR NEBULA?

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**Introduction:** The presence of 2-50µm large solid particles (LSPs) in comet Wild 2 was a major surprise in the samples returned by the Stardust mission. They are the dominant materials that produced small cone angle capture tracks in aerogel and they are the most deeply penetrating components in bulbous tracks. Due to their thermal inertia and strength, LSPs are the best-preserved samples collected by Stardust and accordingly they are ideal components to compare Wild 2 with other types extraterrestrial materials. Smaller or porous components were usually degraded or even dissolved in molten silica during the capture process.

Most of the transparent Wild 2 LSPs are large non-porous components that appear to have formed by high temperature (1400K-2200K) processes, an origin that seems incompatible with conditions that must have existed when this active ice-bearing Jupiter Family Comet accreted beyond the orbit of Neptune. It seems likely that these components formed in the inner regions of the solar nebula and were radially transported tens of AU to the Kuiper Belt. Because Wild 2 LSPs include both chondrule and CAI fragments, by analogy with meteorites, it appears that the cometary LSPs formed over a period of time that lasted several million years. They could not have formed by a single isolated event. It seems likely that they are samples of a population of materials that were distributed across the full breath of the solar system, possibly for most of the gas-retention lifetime of the solar nebula accretion disk. Possible origins of Wild 2 LSPs include the processes that formed chondrules, AOA's and CAIs as well as condensation. To date, no Wild 2 LSPs have been found to be isotopically anomalous pre-solar grains.

**Hypothesis:** As a testable hypothesis, we suggest that the Wild 2 LSPs are representative of a population of widely distributed components that accreted onto all early solar system bodies. Accordingly, similar LSPs should be found in all comets that accreted from nebular materials during the same time period as Wild 2. They should also be found as minor components in primitive meteorites that accreted in the asteroid belt region. If the hypothesis is correct, the large rocky components in comets are erratics transported over long distances. In contrast, bodies that accreted in the asteroid belt are likely to be dominated by locally made components whose compositions give chondrite classes their distinctive properties. Widely distributed materials like the Wild 2 LSPs, CAIs, AOAs, pre-solar grains and pre-chondrule relict phases should reside in all early SS materials but only as minor components in the asteroid region where they become diluted by locally made nebular and parent-body products.

**Testing the Hypothesis:** In an effort to test the hypothesis of solar system ubiquity of Wild 2 LSPs, we are examining selected aggregate IDPs that are likely to have cometary origins and that contain numerous large translucent components in the 2-50 µm size range. An ironic aspect of IDP studies is that large solid components have largely been ignored, in part because they are difficult to section. This is an area that is ripe for investigation and one that can provide data critically needed for comparison with the Wild 2.

No IDP has a proven origin but it is expected that a portion of IDPs collected in the stratosphere and in Antarctic snow are cometary. The recent zodiacal cloud model of Nesvorny et al. [1] matches the broad latitudinal distribution of IR flux observed by IRAS and implies that comets dominate the dust sized interplanetary particles reaching Earth. Previous estimates based on IRAS data [2] reached an opposite conclusion but is generally agreed that a least a significant fraction of IDPs are comet samples. IDP collections must contain material from inner SS asteroids and outer SS comets but there is no known way to determine which is which. Any sample-based criteria is complicated by the asteroid-like nature of the only proven cometary materials [3]. IDPs collected during Earth's low velocity intersection with comet orbits have remarkable properties and have enhanced probability of cometary origin [4,5].

To date, we have focused this study on large solid transparent grains from the 350µm diameter "Giant Cluster Particle" IDP found on the collector U2-20. This remarkable pancake of debris contains many thousands of fine grains and dozens of solid translucent particles of 5-40µm size all of which accreted at one site. Cluster IDPs fragment on collection, and they are the most fragile and porous extraterrestrial samples for laboratory study. It seems unlikely that such particles could have survived inside a parent-body without the presence of a sublimable pore-filling material- either ice or volatile organics. On the basis of composition and loose aggregate structure, they are model candidates for cometary material.

We have extracted the largest transparent particles from this cluster and removed loose adhering surface fines by repeatedly rolling each particle back and forth in high viscosity silicone tar so shear removes weakly bonded surface material. The cleaned particles usually have some adhering fine-grained chondritic composition material and they are analogs for particles that make thin Stardust tracks. In aerogel, most of the adhering material would be stripped off in the upper track regions.

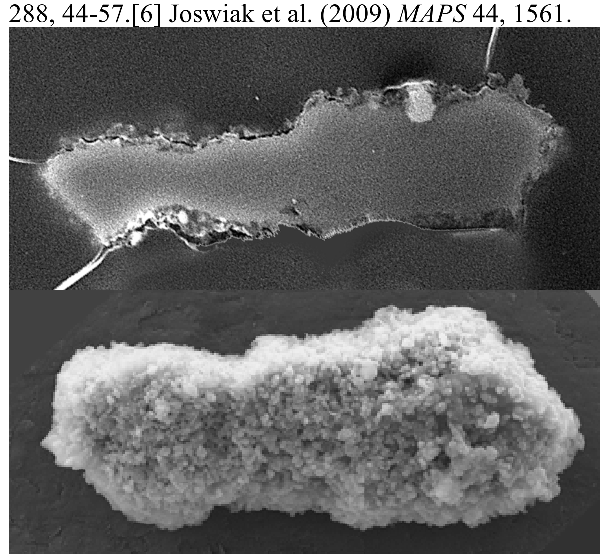
The particle surfaces were examined in detail by optical and SEM methods and then they were embedded in epoxy or acrylic and microtome sections made for TEM studies. The textural relationship between phases was tracked by comparison of TEM studies on sections and BSE studies of the potted butts.

The six 10 to 40µm particles that have been examined to date do show general similarity to Wild 2 LSPs. Two of the particles are dominated by enstatite and appear to be largely monomineralic even though particle LT-4 does contain a 3µm sulfide inclusion and has an Fe rich olivine/Ko augite (Kool grain [6]) assemblage associated with it. The majority of the other particles are polymineralic but largely composed of olivine ($Fo_{76\text{-}95}$) and a range of pyroxenes including En, augite, and pigeonite. Minor phases include Mg-Al-Cr-Fe spinel, glass, metal and sulfide. Particle LT-1 is remarkable in that it is dominated by $Fo_{90\text{-}95}$ olivine but also contains $An_{98}$, fassite/diopside and albite. A very odd, and perhaps unprecedented finding, was the presence of 10nm refractory metal inclusions in the olivine. Some of these include Pt, Ru, Rh, Os , Ir and Mo in roughly solar proportions.

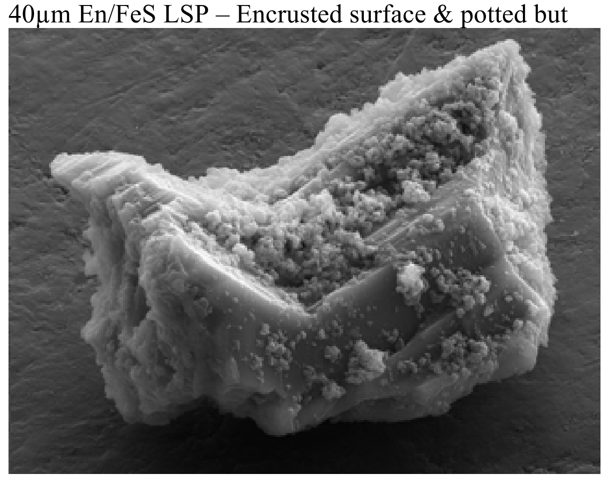
The work on these LSP particles provided a chance to examine what may be excellently preserved surfaces that were exposed to the solar nebula. Unlike grain surfaces in meteorites, it is possible that grain surfaces in loose cluster IDPs are very well preserved. All of the surfaces of Wild 2 particles were lost during capture. The large translucent samples from the Giant Cluster Particle have a variety of surfaces, ranging from those totally encrusted with bonded submicron materials to those that are relative clean of such material. Two of the particles examined showed evidence for growth steps and none showed obvious facture surfaces or had shard-like shapes. Several of the particles had what appear to be En whiskers, whose growth may have nucleated from the main particle.

**Conclusions & questions:** IDP cluster work in progress supports the hypothesis that Wild 2 LSPs are ubiquitous in the solar nebula. The following are examples of the many interesting questions about LSPs. Why are LSPs mineralogically different from submicron components? Is this related to transport? What fraction of LSPs are chondrule fragments? Were LSPs transported by an above-plane wind or in the disk? Do they record radiation effects? Did LSP surfaces nucleate condensation? Is LSP surface debris bonded by organics? Do cometary LSPs contain materials that have been modified b parent body effects such as thermal metamorphism or aqueous alteration?

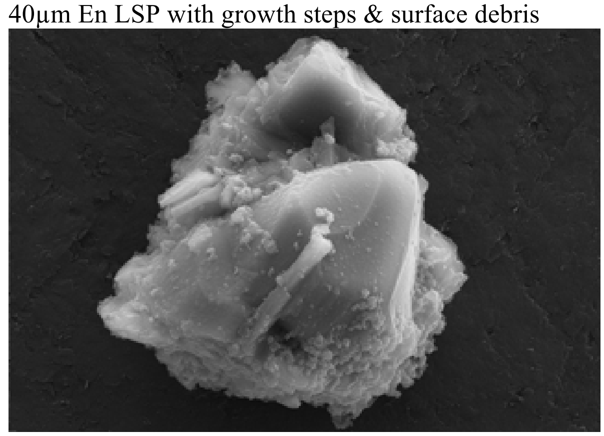
**References:**[1] Nesvorne; D., et al. (2010). *ApJ* 713, 816. [2] Dermott, S.F. et al. (2001) in Interplanetary Dust Springer, Grun et al. eds. pp569. [3] Ishii, H. et al. (2008) Science 319, 447.[4] Messenger S. (2002) *MAPS* **37**, 1491[5] Busemann, H. et al. (2009) *EPSL* 288, 44-57.[6] Joswiak et al. (2009) *MAPS* 44, 1561.



40µm En/FeS LSP – Encrusted surface & potted but



40µm En LSP with growth steps & surface debris



10µm polymineralic LSP