# THE SOLAR NEBULA'S FIRST ACCRETIONARY PARTICLES (FAPs) - ARE THEY PRESERVED IN COLLECTED INTERPLANETARY DUST SAMPLES?

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The first generation of accretionary particles in the solar nebula initiated the growth processes that led to the formation of rocks, boulders, planetismals and ultimately planets. The first (also the fundamental) accretionary particles (FAPs) were grains of nebular and pre-solar origin and they were probably of submicron size, the size of interstellar grains and also the initial size of condensates. The dust released by comets provides direct evidence that FAPs at the edge of the solar nebula disk were typically less than a micron in size. The 10µm infrared "silicate feature" observed in comets requires that a substantial fraction of the dust be micron and smaller in size [1]. When comets "generate" dust by the incredibly gentle process of ice sublimation, they liberate solids that accreted along with ice in the outer fringes of the solar nebula. That submicron particles are liberated by comets implies that they were primary components of the solar nebula and by virtue of their small size, they are presumably the first generation solids in the Kuiper Belt region of the solar nebula. Their liberation by sublimation also implies that they were only very loosely consolidated into larger structures and have not been appreciably altered by internal parentbody processes. With high area/mass ratios, submicron particles are notoriously difficult to liberate from other materials.

It is likely that FAPs from the comet-region and perhaps even asteroid-regions of the solar nebula are preserved in existing collections of interplanetary dust particles (IDPs). Many IDPs are fragile aggregates of submicron grains that appear to be preserved without compaction, aqueous alteration or parentbody heating since the earliest history of the solar system. It is likely that at least some of these samples are merely aggregates of FAPs. It is also likely that the porous aggregates formally contained ice, a component that was incorporated into solids over most of the areal extent of the solar nebula, including large regions of the asteroid belt.

The most fragile aggregate IDPs fragment during collection and are called cluster IDPs. Cluster particles contain widespread deuterium and nitrogen isotopic anomalies attributed to pre-solar molecular cloud processes [2] and in this sense, they are the most "primitive" meteoritic materials and the most likely ones to preserve FAPs. Cluster particles also contain pre-solar silicate grains [3]. In addition to their isotopic properties, a critically important aspect of some cluster IDPs is simply that they are porous uncompacted aggregates of largely sub-micron grains. One of the most significant aspects of cluster IDPs is that they fragment on collection, in extreme cases into perhaps a million components. Cluster IDPs are the most weakly consolidated IDPs and it is possible that this rare subset of IDPs are well preserved collections of FAPs.

All collected IDPs are composed of components bonded to each other, a necessary requirement for intact survival of atmospheric entry. Some are very strongly bonded, perhaps related to their distant history or in some cases to atmospheric entry heating. In our search for FAPs, we have endeavored to find ideal IDPs that are not strongly bonded and to develop means for gently tearing them apart into their original accretional components (FAPs). We purposely select cluster particles that severely fragment during collection and then we attempt to fully disaggregate them into individual grains. It is a challenge to just pull the components apart with enough pressure to separate billion year old contacts but without enough pressure to fracture silicate or sulfide grains. We have been successful at this task using the shear forces in ultrahigh viscosity silicone oil between two closely spaced moving plates.

After separating the components, we wash them to remove oil and then mount them on carbon films using a collodion transfer method. We then analyze the submicron components by a variety of imaging and analysis techniques, including SEM for surface detail and the full range of TEM and STEM techniques for transmitted electrons- including high angle annular dark field and zero loss energy filtered imaging. Compositional imaging is done by EDX and EELS. So far, the analyses have been done on unsectioned grains. The traditional means of doing TEM studies of IDPs is by examination of microtome sections but this approach has limitations for study of potential FAPs. Examination of whole submicron grains enables study of surface detail, by FESEM, and provides access to all of the components of a particle, not just the ones in a section plane. A good analogy for the limitations of sections would be the difficulty of understanding the true structure of a city merely by examination of only a few thin-sections taken parallel to the ground. High resolution SEM observation of surfaces, in combination with all TEM/STEM techniques, provides a powerful means to evaluate these samples.

We believe that we have seen materials that are strong candidates for being the first (or fundamental) accretionary particles. Some primitive IDPs are made almost entirely of submicron components that are likely to be FAPs. They are generally equant and range from 0.1 to 1 μm across. They average about a quarter of a micron and very few are smaller than 100nm. They are solid materials composed of amorphous silicates, organic material, GEMS, and crystalline materials including Fo, En and Fe sulfides. Some are single mineral phases but most are made of several components. They are solid (non-porous) rocks and we refer to them as "femtorocks" because of their mass and multi-component nature. The femtorocks often contain organic materials and silicates and we believe that they are functionally equivalent to Mayo Greenberg's core-mantle interstellar grain model even though they consist of multiple cores and not a single core surrounded by a single organic mantle. The elemental composition variation among femtorocks is remarkable. As seen in Figure 1, their Fe, Mg and Si compositions vary widely with little modulation due to mineralogical control. They contain minerals but the amorphous components dominate their compositional spread. In the Fe-Mg-Fe ternary , the only first order effect is the scarcity of compositions with Mg/Si appreciably greater than unity (enstatite). IDPs made of femtorocks (FAPs?) similar to those seen in figure 1 match CI relative abundances for aggregates larger than 3 microns but at the submicron, fundamental component, level they vary all over the map.

The compositional dispersion shown in Figure 1 is very similar to that seen at comet Halley, supporting the notion that comets, FAPs and pre-solar grains might be intimately related. An interesting aspect of the analysis of comet samples returned by the Stardust mission will be to search for FAPs and femtorocks.

If FAPs have been found, the question is where did these odd bodies form? Did they typically form around other stars, in the ISM, in the collapse phase of the nebula or in the solar nebula disk? Future TEM and isotopic studies may answer this question.

[1]Hanner M. S. (1996) Composition and Optical Properties of Cometary Dust. ASP Conf. Ser. 104: IAU Colloq. 150: Physics, Chemistry, and Dynamics of Interplanetary Dust 367. [2]Messenger S., 2000, Nature, 404, 968 [3]Messenger S., Keller L.P., Stadermann F.J., Walker R.M., Zinner E., 2003,Sci.,300,10.

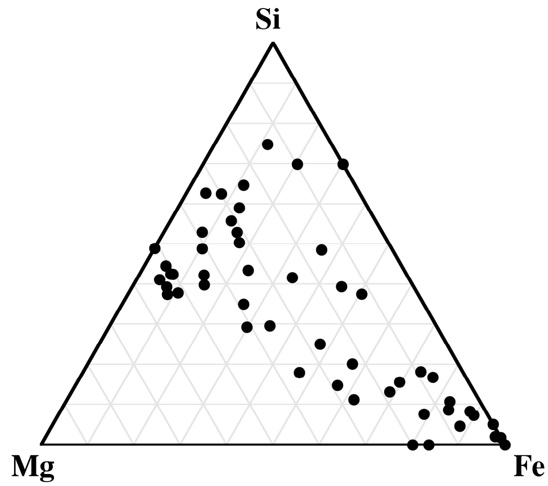


Figure 1 Atom fraction ternary of submicron grains (femtorocks) from U2-20 GCA- a cluster IDP. The large heterogeneity at the submicron scale is remarkable and relatively unconstrained by mineralogical stoichiometry. The large dispersion is similar to data on particle compositions obtained at comet Halley.

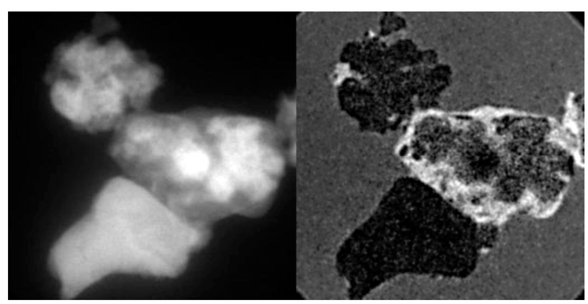

Figure 2 Three possible FAPs from the above IDP. The left image is a bight field STEM image and the right image is an EELS carbon image with carbon shown as white. The upper and right grains are carbon-bearing femtorocks composed of carbonaceous matter and GEMS while the lower grain is a pure silicate. Width of field =250nm.