TEM/STXM CHARACTERIZATION OF PRESERVED PRIMITIVE MATERIAL FROM THE COMET WILD2. J. Stodolna[1], Z. Gainsforth[1], A. Butterworth[1] and A. J. Westphal[1]; [1]Space Sciences Laboratory, University of Berkeley, California, USA. j.stodolna@ssl.berkeley.edu.

Introduction: Cometary nuclei accreted from the colder, icy regions of the solar nebula, beyond the snow line (> 5AU-100AU). Cometary dust is believed to have preserved signatures of the primitive material at the origin of the solar system. Dust from the comet 81P/Wild2 was captured in silica aerogel cells and aluminum foils carried by the Stardust mission [1]. Despite originating in cold regions of the solar system, a significant fraction of the material collected consists of minerals formed at high temperature: coarse grains, including CAI-like and chondrule-like assemblages [2-3]. Fragments of the expected primitive fine-grained material are found in the walls of the tracks. The study of this material is complex because it was significantly modified due to strong interaction with aerogel during the capture. This resulted in the formation of amorphous pockets by melting, mixing and cooling processes [4-5].

After a long and careful survey, we report the discovery of preserved primitive fine-grained material from the comet 81P/Wild2. It is composed of silica-rich amorphous matrix embedded with iron sulfides and silicates. An enstatite whisker is identified inside the matrix.

Sample and analytical procedure: The sample is a terminal particle called "Iris" from the track C2052,2,74. It is 23x10x15µm in size. We prepared the sample by keystoning and ultramicrotomy, and performed microstructure and chemical composition analyses by Transmission Electron Microscopy at the National Center for Electron Microscopy at the Lawrence Berkeley National Laboratory. Fe-XANES spectrum acquisitions were done by Scanning Transmission X-ray Microscopy (STXM) at the Advanced Light Source beamline 11.0.2 at LBNL.

Results: Iris consists of a complex assemblage of grains with at least 9 distinct crystals embedded in an SiO_2-rich glassy mesostasis containing Al, Na, Ca, Fe, and Mg in decreasing order of abundance (Fig.1). The crystals are Fe-rich olivines ($Fo_{60–68}$) with minor amounts of Ca, Mn, and Al, along with multiple spinels which are enriched in Cr and Fe (one spinel is $Chr_{61}Sp_{34}$) with minor Ti, V and Mn, sodic plagioclase ($An_{14–22}$) and a chromium rich diopside. The compositions of the minerals along with their textural relationships and the evidence for high temperature diffusion and rapid cooling strongly resembles type II chondrules seen in chondritic meteorites. Petrologic and isotopic measurments are described in the recent paper from Ogliore et al. [6].

The primitive material was found on a TEM grid close to olivine grains and consists of amorphous material embedded with iron sulfides and silicates (Fig.2). The crystals of iron sulfide and silicate are randomly distributed in nature and size within this matrix. The iron sulfide grains are angular and unmelted and characterized as pyrrhotite and troilite by electron diffraction. This indicates that the temperature reached by this material during the collection event was lower than 1000°C and thus it was not modified by melting and mixing with aerogel, which requires temperature >1000°C. Three Mg-rich clinoenstatite grains have also been identified embedded in the amorphous matrix next to iron sulfide grains. The microstructure shows (100) planar stacking faults. One of them has a whisker shape (Fig. 3). The grain size of iron sulfides and silicates is from tens of nanometers up to 200nm.

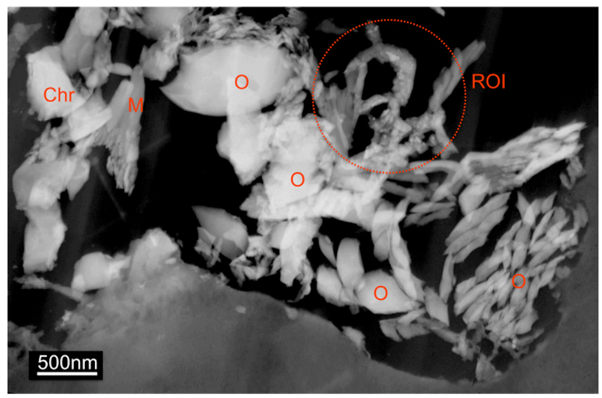

Fig.1: *STEM image of a TEM slice from the terminal particle Iris. O are olivines, Chr chromite, M mesostasis and ROI is the region of interest containing primitive fine grained material.*

The amorphous material comprises mainly silica, magnesium, iron and calcium. The composition is different from the amorphous material defined as mesostasis in Iris which is Mg-poor and Na, Ca and Al-rich. The Fe-XANES signature of the amorphous material shows Fe^{2+} valence state. The average composition of the primitive material area for the elements Mg, Fe, S and Ca is very close to CI and is Al-rich (~3.3 times for the Al/Mg ratio), though the quality of the chemical composition analyses is low due to the small volume of material.

Enstatite whisker: One of the three silicate grains identified (Fig.3) presents the characteristics of an enstatite whisker as defined by Bradley & Brownlee (1983) [7]:

- It has a elongated shaped with an aspect ratio of five.
- (100) stacking faults are visible by TEM and SAED.
- The elongation is roughly along [100].
- An axial screw dislocation is observed.
- EDX chemical composition reveals a Mg-rich grain.

Enstatite whiskers are found in anhydrous CP-IDPs. They were likely formed by direct gas-to-solid condensation from a nebular gas either in the solar nebula or presolar interstellar environments [7]. This enstatite whisker is embedded with the amorphous material and the sulfides. It shows that this area of material is probably very primitive even though it was found attached to a chondrule-like object.

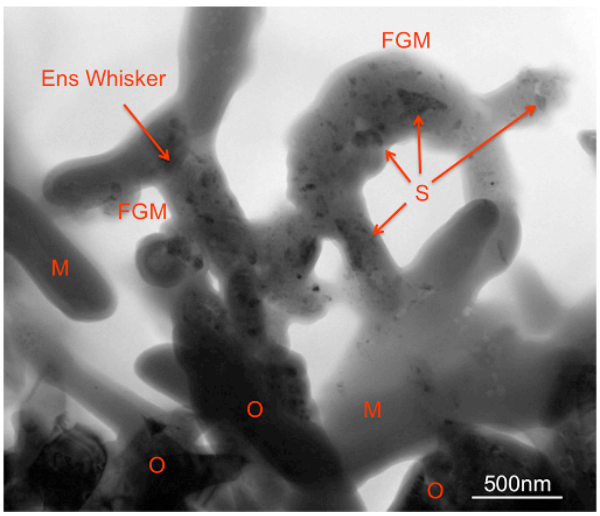

Fig.2: *TEM bright field image of the fine grained material (FGM) identified in Iris. The iron sulfides (S) are sharp, showing that the temperature of this area stayed below 1000°C during the collection. The material is connected with mesostasis (M) and the mesostasis with olivine (O) grains. The enstatite whisker (Fig. 3) is indicated but the contrast is weak in this image.*

Comparison with the GEMS-like material: The fine-grained material from the comet 81P/Wild2 was strongly modified during the collection into aerogel. This resulted in the formation of GEMS-like material, extensively studied to understand the nature of the precursor material [4-5;8-11]. It is believed to be an aggregate containing small grains, probably silicates and iron sulfides embedded with amorphous material [8;11]. It could represent up to 50% of the Stardust collection [11]. The silica-rich amorphous material containing Mg and Fe (Fe^{2+} valence state) embedded with iron sulfides and silicates described in this study (Fig.2) is a very good candidate for the precursor of the GEMS-like material of Stardust. The average CI compostion for Mg, Fe and S is similar for the two materials [4;8;11]. The iron sulfides are decomposed during the collection and form the typical iron metal core / iron sulfide rim beads [5]. The silicates, after melting and mixing with the amorphous matrix and the surrounding aerogel, form the shadow grains defined by Leroux et al. [8].

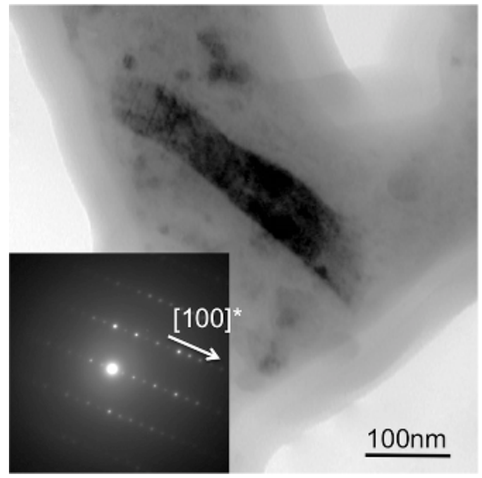

Fig.3: *TEM bright field image and electron diffraction of an enstatite whisker. The electron diffraction reveals a clinoenstatite (zone axis patern [021]). It has an elongated shaped with an aspect ratio of five. It is roughly elongated along the [100] direction and stacking fault are visible in the planes (100).*

Conclusions: It is possible to find preserved fine-grained material in the Stardust samples. Here it is preserved in the same impactor as a chondrule-like object. The observation of an enstatite whisker in a comet confirms that such phases may have been important components of the early Solar System nebula. The primitive material from Wild 2 that was highly modified during the collection contains some of this material. The presence of an enstatite whisker is a link between the Wild2 material and the CP-IDPs. The association with the chondrule is not yet understood.

References: [1] Brownlee D. E. et al. (2006) *Science*, *314*, 1711-1716; [2] Zolensky M. E. et al. (2006) *Science 314*, 1735-1739; [3] Nakamura T. et al. (2008) *Science 321, 1664-1667;* [4] Leroux H. et al. (2008) *Meteorit. & planet. Sci.*, *43*, 97-120; [5] Ishii H. et al. (2008) *Science 319*, 447-450; [6] Ogliore R. et al. (2012) *Earth and Planet. Sci.,* accepted; [7] Bradley J. P. Et al. (1983) *Nature 301,* 473-477; [8] Leroux H. et al. (2009*) Geochim. Cosmochim. Acta*, *73*, 676-677; [9] Velbel M. A. & Harvey R. P. (2009) *Meteorit. & planet. Sci.*, *44*, 1519-1540; [10] Rietmeijer et al. (2008) *Meteorit. & planet. Sci.*, *43*, 121-134; [11] Stodolna J. et al. (2011) *LPSC 42nd* abstract #2025.