Chondrules in the short-period comet 81P/Wild II

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More than 10000 small particles have been captured and recovered from a short-period comet 81P/Wild II by the Stardust Mission [1]. They are very primitive dust having been present at outer regions of the early solar system, because short-period comets originally formed as Kuiper-belt objects that currently locate at 30-50AU from the Sun. In fact, the comet 81P/Wild 2, now orbiting between Mars and Jupiter, had been circulating on a wider orbit reaching the Kuiper belt [1]. On the other hand, asteroids, much closer (3-5AU) to the Sun, are parent bodies of the primitive class of meteorites, chondrites, and they formed by accretion of solid particles at inner regions of the early solar nebula. Chondrules are a major component of chondrites and formed around 4.565 Gyr by solidification of totally or partially melted material typically smaller than 1mm in diameter. Abundant chondrules in chondrites indicate that high-temperature heating events, that melted solid dust particles at temperatures of 1500C or higher, commonly took place in the inner solar nebula. However, it is unknown whether chondrules were present at outer regions of the early solar system. I and co-investigators listed in references [2, 3] performed a series of analyses on individual sample particles in order to find chondrule-like objects in a short-period comet 81P/Wild 2 and the results are briefly summarized below.

Individual small particles from the comet were first analyzed by X-ray diffraction using a thin 6-keV beam to characterize bulk mineralogy. Then the particles were again exposed to 9-keV X-ray to perform micro-tomography analysis to characterize internal structures with sub-micron spatial resolution. Up to now, approximately 70 samples were analyzed by synchrotron radiation and 6 samples were found to have bulk mineralogy rich in well-crystalline olivine, low-Ca pyroxene, and FeNi metal and show porphyritic internal structure suggestive of high-temperature partial melting during formation. The six samples were microtomed or polished to have flat surface for further investigation. Observation of polished surface of the six samples using a field emission scanning electron microscope (FE-SEM) revealed that they really show igneous texture and have mineral compositions and major and most minor element concentrations that are very similar to chondrules in primitive meteorites derived from asteroids. Oxygen isotope ratios show a wide range of values from -50 to +5 permil in delta18O nearly along the slope=1 mass independent fractionation line which characterizes chondrules in carbonaceous chondrites that comprise the outer asteroid belt. Furthermore, highly heterogeneous oxygen isotope ratios within a single particle suggest that they formed by remelting of prexisting solid precursors. Therefore, these particles are pieces of chondrules formed through the least degree of melting, crystallization, and elemental and isotope equilibration at high temperatures. The presence of chondrules in a short-period comet from the Kuiper belt indicates that chondrules migrated from hot inner nebula regions to cold outer regions and spread widely over the early solar nebula.

References: [1] Brownlee D. et al. (2006) Science 314, 1711-1716. [2] Nakamura T., et al. (2008) Meteoritics and Planetary Sciences. 43, 247-259. [3] Nakamura T., et al. (2008) Chondrulelike Objects in Short-Period Comet 81P/Wild 2. Science 321, 1664-1667.