THREE-DIMENSIONAL STRUCTURES OF INTERPLANETARY DUST PARTICLES AND IDP-LIKE LARGE MICROMETEORITES USING SYNCHROTRON RADIATION MICROTOMOGRAPHY. A. Tsuchiyama[1], K. Uesugi[2], T. Nakano[3], T. Okazaki[1], K. Nakamura[4], T. Nakamura[5], T. Noguchi[6] and H. Yano[7], [1] Department of Earth and Space Science, Osaka University, 1-1 Machikaneyama-cho, Toyonaka 560-0043, JAPAN, akira@ess.sci.osaka-u.ac.jp, [2] JASRI/SPring-8, Mikazuki, 679-5198 JAPAN, [3] AIST/GSJ, Tshukuba, 305-8567 JAPAN, [4] NASA Johnson Space Center, KR, Houston, TX 77058, USA, [5] Department of Earth and Planetary Sciences, Kyushu University, Fukuoka 812-8581, JAPAN, [6] Department of Material Sciences and Biological Sciences, Ibaraki University, Mito 310-8512, JAPAN, [7] JAXA/ISAS, Sagamihara 229-8510, JAPAN.

Introduction: Cosmic dust falling onto the Earth was divided into three categories: (1) interplanetary dust particles (IDPs) those are collected in the stratosphere (ten to a few tens μm in size), (2) micrometeorites (MMs) those are collected from ice or snow in the polar regions (a few tens to a few hundreds μm in size) and (3) cosmic spherules those were melted during their atmospheric entries. IDPs are classified into anhydrous and hydrated IDPs. Some of anhydrous IDPs possibly originated from comets (e.g., [1]). Lately, MMs with a large amount of carbonaceous material (ultracarbonaceous MMs) were found from Antarctic ice [2]. They are large in size (> 200 μm), and their mineralogical, compositional and isotopic signatures are different from those of matrix of primitive chondrites but analogous with carbon-rich anhydrous IDPs. Large MMs having anhydrous IDP-like appearance were also found from Antarctica [3].

X-ray computed tomography (CT) is a method to obtain internal structures of objects without damaging the samples and provide 3-D structures by stacking successive sliced images. Synchrotron radiation (SR) source provides monochromatized and collimated X-ray beams useful for X-ray CT technique. In this study, an X-ray mictotomographic system using SR was applied to IDPs and IDP-like large MMs, and their three-dimensional structures were examined.

Experiments: The attenuation CT experiments were performed at the beamline BL47XU of SPring-8, Japan, using a projection CT system (SP-μCT), which is composed of a high precision rotation stage for a sample and a beam monitor for X-rays [4]. In the beam monitor, the transmitted X-ray was transformed to visible light by a fluorescent screen, expanded by a relay lens and subsequently detected by a 2-D CCD camera to obtain projection images. The projection images were reconstructed to CT images using a convolution back projection algorithm. The size of the voxel (pixel in 3-D) in CT images is $0.195 \times 0.195 \times 0.195 - 0.23 \times 0.23 \times 0.23$ μm^3, which gives the effective spatial resolution of ~0.5 μm. As we used monochromatized beams (7-10 keV depending on the samples), we can obtain CT images showing spatial distribution of X-ray linear attenuation coefficient (LAC), which is a function of the chemical composition and the density of material and X-ray energy [5]. 3-D iron mapping was also done for some samples using the X-ray adsorption edge of iron by subtraction method [6].

Four hydrated IDPs (L2036H1, L2011F2#5, L2011Q5 and L2005AC11) and three anhydrous IDPs (L2036B1#20, L2008A8 and L2008D3) were imaged by the microtomography. For large MMs (50-200 μm), seven ultracarbonaceous MMs (to54CC, tt51A155, tt51A012, T5H01, T5H02, T5H03 and T5H05) and three IDP-like MMs (one CP-like (D03IB02) and two CS-like (B03IB05 and T5H04)) were imaged. Each sample was held by a glass fiber (3 μm in diameter) with glycol phthalate as glue.

Some samples were examined by SR-XRD at the beamline BL3A of Photon Factory, Japan, to determine the mineral phases in the samples. One hydrated IDP (L2036H1) was sectioned by an ultramicrotome and observed under a TEM at NASA/JSC to compare the CT images.

Results and discussion:

IDPs. Figure 1 shows an example of the hydrated IDP samples, showing complimentary textural information of the CT and TEM images. The sample shape is recognized well in the CT image by this non-destructive method, while in the TEM image the sample was slightly deformed and some portions were plucked by the sectioning. On the other hand, detailed fine structures cannot be seen in the CT image due to the insufficient spatial resolution. Figure 2 shows an example of the anhydrous samples. In the CT image, the spatial resolution is not enough to recognize each grain of possibly ~0.1 μm although porous texture is recognized in some extent.

MMs. Porous textures can be well recognized for some ultracarbonaceous MMs even in the CT images (Fig.3a). The dark portions in the CT image must correspond to voids or carbonaceous material. Fe maps obtained by the subtraction method show that some large silicate crystals are Fe-poor (Fig.3b). Porous textures can be also recognized for a CP-like MM (Fig.4a).

This sample is composed of Fe-rich (bright) and Fe-poor (dark) regions. CS-like MMs (Fig.4b) shows a texture similar to hydrated IDPs (Fig.1a) although the size is different.

Porosity. The 3-D structures show that most of the pores (or carbonaceous materials in some samples) are connected to the sample exteriors three-dimensionally. Although it is difficult to obtain porosities strictly due to the connection of pores to the exteriors we can estimate the porosities by assuming simple sample surfaces. For example, the proportion of pore and carbonaceous material is >20 vol.% in tt51A012 (Fig.3).

Fractal dimension. Fractal dimension is one of the important parameters which determine the natures of the aggregation of grains in cosmic dust. Fractal dimensions of the samples were calculated from the 3-D structures. Some samples show the fractal dimensions of <3 by a box counting method (e.g., 2.74 for an ultracarbonaceous MM (tt51A012) and 2.94 for a hydrated IDP (L2036H1)). However, any multi-fractal spectrum cannot be obtained at least for the hydrated IDP sample. This indicates that the fractal dimension by the simple box counting method is apparent and does not mean the sample is fractal. The results are preliminary and the multi-fractal analysis of the other samples will be made.

Although the spatial resolution of the projection CT is not sufficient to describe detailed fine textures of IDPs and MMs, we can obtain non-destructive three-dimensional information of textures complimentary to TEM and SEM. This strongly indicates that the present technique is also useful to Stardust samples.

References: [1] Bradley J. P. et al., (1992) *Astrophys, 394,* 643-651. [2] Nakamura T. et al. (2005) *Meteoritics & Planet. Sci., 40,* A110. [3] Noguchi T. and Nakamura T. (2005) A private communication. [4] Uesugi K. et al. (2001) *Nucl. Instr. Methods Phys. Res., A, 467-468,* 853-856. [5] Tsuchiyama A. et al. (2005) *Am. Min., 90,* 132-142. [6] Ikeda et al. (2004) *Am. Min., 89,* 1304-1312.

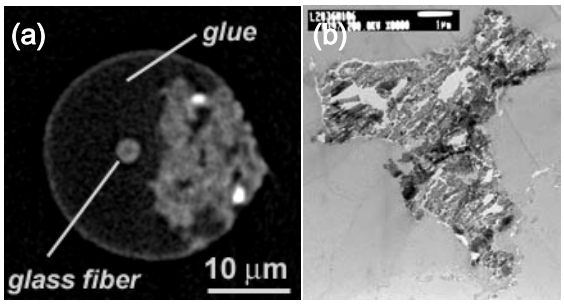

Figure 1. A hydrated IDP (L2036H1). (a) A CT image (10 keV). The sample is held by a glass fiber (3 μm in diameter) with glycol phthalate (glue). (b) A TEM image of a slice sectioned by an ultramicrotome. Bright spots in (a) and dark spots in (b) are troilite. Matrix is slightly dehydrated saponate.

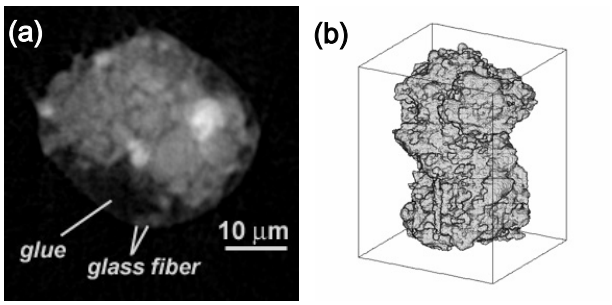

Figure 2. An anhydrous IDP (L2036B1#20). (a) A CT image (8 kV). Bright portions are pyrrhotite- or kamacite-rich and matrix is composed of olivine and Ca-rich pyroxene (mineral were determined by XRD). (b) The external shape of the sample (20.8 x 18.0 x 31.9 μm).

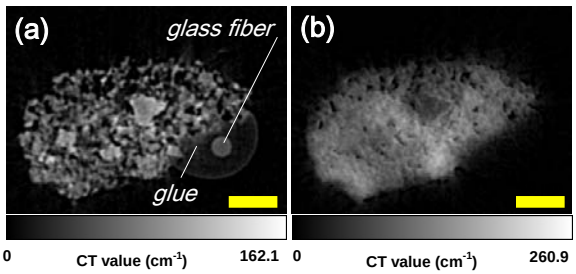

Figure 3. An ultracarbonaceous MM (tt51A012). (a) A CT image (10 keV). Silicates are olivine and low-Ca pyroxene based on the XRD study. (b) A Fe map obtained by a subtraction method (subtraction image: 7.122 keV - 7.102 keV). Scale bar is 10 μm.

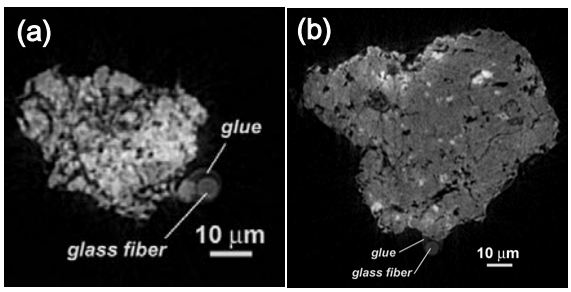

Figure 4. CT images of IDP-like MMs. (a) CP-like (D03IB02). (b) CS-like (D03IB05).