THREE-DIMENSIONAL SHAPES OF COSMIC SPHERULES: DEFORMATION OF DUST PARTICLES MOLTEN IN THE EARTH ATMOSPHERE. Masao Doi[1, 2], Taishi Nakamoto[2], Tomoki Nakamura[3] and Yuji Yamauchi[3], [1]Pure and Applied Sciences, University of Tsukuba, Japan; doi@geo.titech.ac.jp, [2]Earth and Planetary Sciences, Tokyo Institute of Technology, [3]Department of Earth and Planetary Sciences, Kyushu University.

Introduction: Cosmic spherules are extraterrestrial-origin round-shaped dust particles collected from the stratosphere, polar ice, and ocean floor sediments. When extraterrestrial dust particles enter the Earth atmosphere, they are heated by the gas friction and melted. Because of the surface tension, the molten particles become spherical and form cosmic spherules when they solidify. They are thought to originate from asteroids or comets and caught by the Earth.

Tsuchiyama *et al*. [1] have examined 3-D structures of cosmic spherules and found that there are both prolate and oblate shapes. The ram pressure, the surface tension, and the centrifugal force acting on the particles deform the shape when they are molten. Thus, is seems natural to consider that the variation of the observed cosmic spherule shapes may originate from the shape of dust particles when they solidified. In this study, we evaluate the ram pressure and the centrifugal force when the dust particles solidify by solving the equation of motion and the energy equation of the dust particles entering the Earth atmosphere [2]. And we calculate the magnitude of deformation of the dust particles by using analytic solutions for the shape of the molten particles [3,4]. We also measure the 3-D shape of more cosmic spherules to extend the number of samples. Finally, we compare the results of calculations with observations.

Shape of the Cosmic Spherules: When a molten dust particle does not rotate, it forms oblate shape due to the ram pressure from one direction [3]. On the contrary, when a molten dust particle rotates fast, it forms prolate shape [4]. If the shape of the dust particle before the Earth entry is asymmetric, the particle generally obtains the angular momentum due to the ram pressure and begins rotation. In this case, the rotational axis becomes perpendicular to the direction of the particle motion. If the ram pressure exceeds the centrifugal force, the rotating molten particle can form prolate shape elongating along the rotation axis. In this study, we define the magnitude of the deformation of the molten particle as $X \equiv \{(1-B/A)^2 + (1-C/B)^2\}^{1/2}$, where A, B, and C are axial radii approximated as three-axial ellipsoid ($A \geq B \geq C$). To calculate X, we use the analytic solutions both for the fast rotating molten particles and for the no rotating molten particles.

Model: **A**ssuming that the inside of the dust particle is isothermal and gas flow is the free molecular flow, we calculate the velocity, temperature, and the radius of the dust particle [2]. In our model, the effect of evaporation is also taken into account. We examine the cases with a wide variety of entry parameters: the initial radius (from 0.1 mm to 2 mm), the entry velocity (from 11.2 km/s to 20 km/s), and the entry angle (from 0 to 90 degrees, the angle 0 corresponds to the entry from the zenith direction).

We measure three axial radii (A, B, and C) of once molten stony cosmic spherules, which are collected from Antarctica, in a radius range between 40 μm and 120 μm. After shape parameter measurement, each spherule was polished to have flat surface and analyzed for major element concentrations using an electron microprobe analyzer.

Results: Fig. 1 and Fig. 2 show the calculated magnitude of the deformation X as a function of the radius in the case of no rotation. The coefficient of the surface tension is taken from the molten basalt T = 400 dyn cm^{-1}. The measured values of X are also shown in the same figures. Note that cosmic spherules only in the yellow-colored radius range were measured. We can see that the calculated X is less than 0.1 in the radius range between 40 μm and 120 μm, while the measured X distributes up to X = 0.3.

Fig. 3 and Fig 4 show X in the case of fast rotation. In this case, we can see that X is less than 0.05 in the radius range between 40 μm and 120 μm.

Discussion: We have found a discrepancy between the calculated and the measured X. Here we discuss three possibilities that may cause such a large deformation. (1) A low surface tension: We calculated X with different T and found that if T is as low as 50 dyn cm^{-1}, X becomes almost 0.3 in the radius range between 40 μm and 120 μm. However, the chemical composition of the measured cosmic spherules does not show a large variation. So, it seems difficult to assume that the surface tension is significantly different among samples. (2) A very high viscosity: If the viscosity of the molten particle is very high, the timescale of the deformation is longer than a period when the particle is molten. Then the shape of the particle may be determined by the ram pressure at the moment earlier than the solidification. Since the ram pressure at that moment is higher, the deformation may be large. However, we cannot expect such a large difference of the viscosity among samples because of the chemical homogeneity. (3) Crystallization generally elongates the particle in a certain direction. But we do not see a prominent crystalline structure in large-deformed spherules. Therefore, it is hard to consider that such a large deformation is caused by possibilities discussed above.

We have to look for yet other reasons that cause such a large deformation. For example, fragments of a meteorite entering the Earth atmosphere may collide each other to form a large-deformed cosmic spherule. Or a bubbling in a liquid may deform the molten particle. Details of these effects should be investigated in a future work.

Summary: We measured the 3-D shape of once molten stony cosmic spherules collected from Antarctica. Also, we theoretically modeled the deformation of cosmic spherules and calculated the magnitude of deformation as functions of the radius, the entry velocity, and the entry angle. We compared the calculation and observation results and found that the model cannot explain the observed results; some of the natural cosmic spherules have a larger deformation than the model. The measured large deformation should be explained by reasons other than the variations of the surface tension and the viscosity, and the crystallization.

References: [1] Tsuchiyama, A. *et al.* (2004) WCPD 9033-9034. [2] Love, S. G. and Brownlee, D. E. (1991) *Icarus* **89** 26-43. [3] Sekiya, M. *et al.* (2003) *Prog. Theor. Phys.* **109**, 717-728. [4] Miura, H. *et al.* (2007) *LPS* **XXXVIII** 1505-1506.

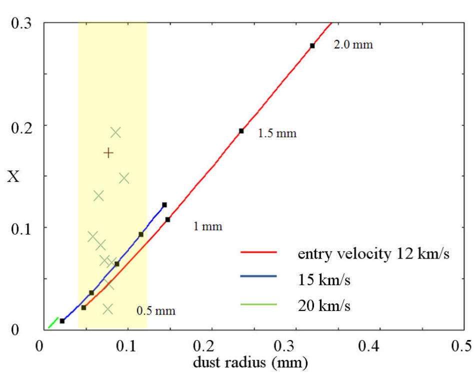

Fig.1: The magnitude of deformation of the dust particles X against the dust radius in the case of no rotation. Entry angle is 0 degree. Red, blue, and green curves correspond to the entry velocity of 12 km/s, 15km/s, and 20 km/s, respectively. Solid squares indicate the initial dust size. Crosses and plus represent our observations and observation by Tsuchiyama *et al.* [1], respectively.

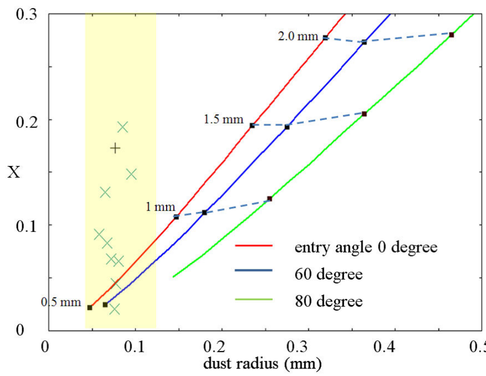

Fig. 2: The degree of deformation X in the case of no rotation and the entry velocity 12 km/s. Red, blue, and green curves correspond to the entry angle 0 degree, 60 degree, and 80 degree, respectively.

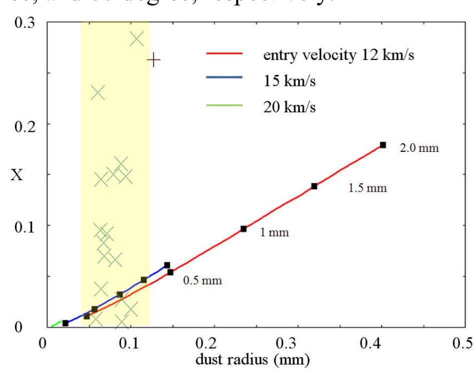

Fig. 3: Same as Fig. 1 except for the rotation; the fast rotation case. Meanings of curves and symbols are the same as Fig. 1.

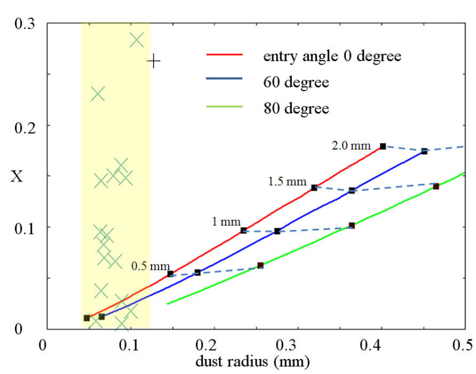

Fig.4: Same as Fig. 2 except for the rotation; the fast rotation case. Meanings of curves and symbols are the same as Fig. 2.