THREE-DIMENSIONAL SHAPES OF COSMIC SPHERULES: DEFORMATION OF DUST PARTICLES MOLTEN IN THE EARTH ATMOSPHERE. Masao Doi[1], Taishi Nakamoto[1], Tomoki Nakamura[2] and Yuji Yamauchi[2], [1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology; doi@geo.titech.ac.jp, [2]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 (Rugby-ball like) and oblate (pancake-like) shapes. Also we have examined 3-D shapes of cosmic spherules and found that they have deformed with a large variety [2]. The ram pressure, the surface tension, and the centrifugal force acting on the particles deform the shape when they are molten. Thus, it seems natural to consider that the variation of the observed cosmic spherule shapes may originate from the shape of dust particles when they solidified. Especially, the differences of the liquidus temperature among cosmic spherules may generate the variety of deformations.

In this study, we measure the 3-D shapes of more cosmic spherules to extend the number of samples and analyze their major element concentrations to estimate the liquidus temperature. Then 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 [3]. And we calculate the magnitude of deformation of the dust particles by using analytic solutions for the shape of the molten particles [4,5]. 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 [4]. On the contrary, when a molten dust particle rotates fast, it forms prolate shape [5]. 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 is likely to become 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.

Measurements: 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 the shape parameter measurement, each spherule was polished to have a flat surface and analyzed for major element concentrations using an electron microprobe analyzer. Then, we calculate the liquidus temperature using the model by Hewins *et al*. 1993[6].

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).

Results: Samples have various shapes (oblate, prolate, sphere and asymmetrical three-axial ellipsoids) and some textures (porphyritic, glass and barred olivine). Then we show the measurement results of samples, which are oblate and prolate shape with barred olivine texture. Fig. 1 shows the measured magnitude of the deformation X against the calculated liquidus temperature using the measurements. We can see a good correlation between the X and the liquidus temperature. The coefficient of correlation is 0.52 and 0.68 in the oblate and prolate shapes respectively. Fig. 2 shows that the measured values of X against the size. Fig. 3 shows the calculated magnitude of the deformation X as a function of the radius in the case of no rotation. Each panel shows the cases of different liquidus temperature. Fig. 4 shows X in the case of fast rotation.

Discussion: In our model, the magnitude of the deformation of the oblate spherules is larger than that of prolate spherules, because the ram pressure acted on rotating particle is averaged with respect to azimuth angle and is one-fourth times lower than that of particle from one direction. Fig. 2 shows that the measurements results are consistent with our model, i.e., the magnitude of deformation of oblate spherules is larger than that of prolate spherules. So, it seems that their shapes are varied whether or not the dust particle is rotating while it is melting.

We have found that the measured X of some oblate shapes are less than the calculated X. It may suggest that they are solidified below the solidus temperature, i.e. they have experienced a supercooled state. On the other hand, we have not found the samples with prolate shapes which experienced the supercooled state. These results may suggest that the dust particle has stopped the rotation due to the gas friction. The speed of rotation of the molten particle is decreased by the gas friction and the spin down time scale is comparative to the duration of melting. Therefore dust particles experienced the supercooled state has stopped rotation and may be observed as oblate spherules. However, it is not clear how molten dust particles crystallized with supercooled state in a pulse heating, so 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 and calculated the liquidus temperature of them. 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 may explain the observed results; the origin of oblate and prolate shapes and the various magnitude of the deformation. The differences between oblate and prolate shapes are derived from whether samples are rotating or not while they are melting. And, the differences of the liquidus temperature among natural cosmic spherules generate the variety of deformation.

References: [1] Tsuchiyama, A. *et al*. (2004) WCPD 9033-9034. [2] Doi, M. *et al.* (2008) *LPS* **XXXIX** 1548-1549. [3] Love, S. G. and Brownlee, D. E. (1991) *Icarus* **89** 26-43. [4] Sekiya, M. *et al*. (2003) *Prog. Theor. Phys.* **109**, 717-728. [5] Miura, H. *et al*. (2008) *Icarus* **197**, 269-281. [6] Hewins, R. H. and Radomsky, P. M. (1990) *Meteoritics* **25**, 309-318.

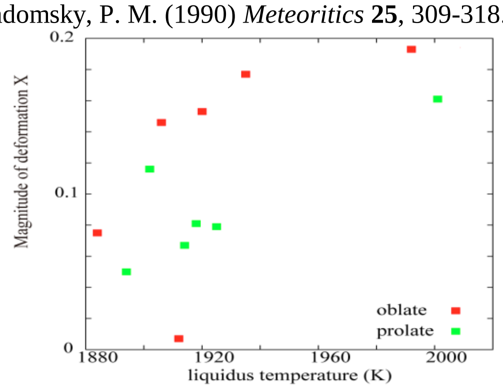

Fig. 1: The measured magnitude of deformation X against the calculated liquidus temperature using the measurements. Red and green squares represent oblate and prolate spherules respectively.

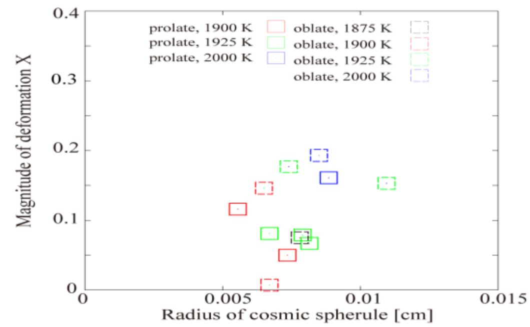

Fig. 2: The measured X against the size. Dashed and solid symbols represent oblate and prolate respectively. Each color represents the liquidus temperature.

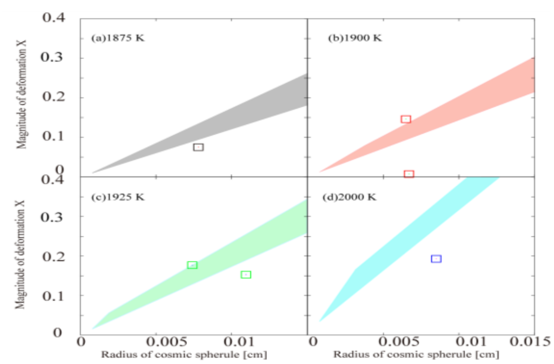

Fig. 3: The calculated X as a function of the radius in the case of no rotation. Each panel shows the cases of different liquidus temperature; (a)1875 K, (b)1900 K, (c)1925 K and (d)2000 K. Symbols represent our measurements.

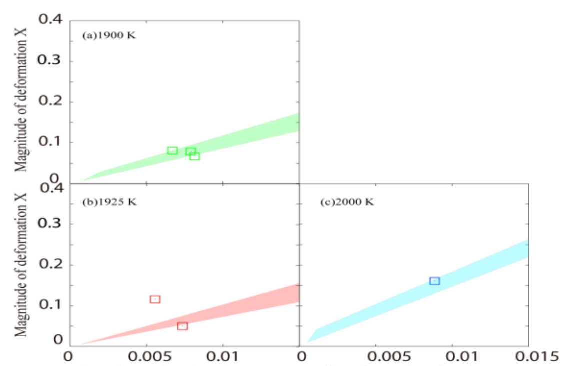

Fig. 4: The calculated X in the case of fast rotation. Each panel shows the cases of different liquidus temperature; (a)1900 K, (b)1925 K and (c)2000 K.