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Prolate Cosmic Spherule Formation

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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 be originated from asteroids or comets and caught by the Earth, when they are falling into the Sun due to the Poynting-Robertson effect. Since cosmic spherules are once molten, their composition may be different from that before the entry. But it may be possible to estimate their original composition by examining the extent of heat and evaporation. By analyzing cosmic spherules, we may obtain some information about interplanetary dust particles.

The shape of cosmic spherules is not perfectly sphere; some cosmic spherules are prolate and some are oblate. These variations of the shape should originate from the shape when they solidified. It is easily seen that the oblate shape can be formed when a molten dust particle is pressed by the ram pressure from one direction. On the contrary, the origin of the prolate shape is not so simple. According to a model for that, the prolate shape forms when a molten dust particle is spinning. If the shape of the dust particle before entry is asymmetric, the particle generally obtains the angular momentum due to the ram pressure. In this case, the rotational axis becomes perpendicular to the direction of the particle's motion. If the ram pressure exceeds the centrifugal force, the rotating molten particle can form prolate shape elongating along the rotation axis. However, it is not clear if the prolate cosmic spherule is really formed in this way, because the magnitude of the centrifugal force and the ram pressure on the molten particle has not been examined. Thus, we studied the magnitude of them and examined if the prolate cosmic spherule can be formed.

First, we obtained an analytic solution for the shape of the molten particle. In this analysis, we assumed that the deformation of the dust particle is small enough and that the rotation is so fast that the ram pressure can be approximated as axisymmetric. As a result, we found that when the ratio of the centrifugal force to the ram pressure R is smaller than 19/5, the shape becomes prolate.

Secondly, we calculated the motion and the temperature of the dust particle entering the atmosphere to evaluate the magnitude of the ram pressure acting on the dust particle when it solidifies. In this calculation, the decrement of the size by evaporation is taken into account. Furthermore, we estimated the torque caused by the asymmetry, and obtained the angular velocity of the dust particle. We found that the angular velocity of the dust particle keeps constant during the evaporation phase.

We examined the cases for a wide variety of entry parameters: the initial radius ranges between 5 micron and 1 mm, the entry velocity ranges between 11.2 km/s and 30 km/s, and the entry angle ranges between 0 and 90 degrees (the angle 0 corresponds to the zenith direction). As a result, we have found that there are a lot of cases where R is smaller than 19/5. This is because the centrifugal force reduces as the size of the particle decreases by evaporation. In these cases, the shape of the dust particles is expected to become prolate. Therefore, it seems highly likely that some dust particles that have proper entry parameters form prolate cosmic spherules.