CHANGES TO METEOROID SHAPE, POROSITY AND INTERNAL STRUCTURE DURING HIGH VELOCITY ATMOSPHERIC ENTRY.
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Introduction: Cosmic dust recovered on Earth in the form of interplanetary dust particles (IDPs) and micrometeorites is, together with larger meteorites, a valuable source of primitive extraterrestrial material. Reliable determination of cosmic dust's bulk and grain density and porosity is an issue of key importance in planetology. Cosmic dust represents material released from asteroids and probably also comets into interplanetary space. It carries important information about the composition and structure of cometary dust or coma as well as of asteroid surfaces. Thus, knowledge of cosmic dust's physical properties is essential in the interpretation of ground-based or space-based observation of comets and asteroids. Some cosmic dust particles experience significant atmospheric processing during their entry while others survives almost unaffected. Thus, comparison of the physical properties of pristine cosmic dust particles to these significantly affected by atmospheric entry can give us insight into changes related to their atmospheric entry.

Physical properties of cosmic dust: In this study, we report physical properties measurements of cosmic dust in the form of micrometeorites collected from the northern ice cap of the Novaya Zemlya archipelago, Russia [1] and from soils collected in the Central depression of the Atacama Desert [2]. In total thirty-two samples were studied. Collection includes various micrometeorite types from melted ones (glassy, porphyritic olivine and barred olivine S-type cosmic spherules), partly melted (scoriaceous), up to well preserved unmelted ones (mostly fine grained).

Micrometeorites were investigated using x-ray microtomography (XMT) at the Department of Physics, University of Helsinki. Due to its high-voltage (20-180 kV) nanofocus x-ray tube, and variable imaging geometry, the XMT equipment allows scans of samples sized from10 cm down to 50 µm, with sub-micron resolution in the case of small samples. Quantitative volumetric 3D calculations of various compositional fractions as well as of pore space within scanned particles were done in similarly as by [3] and [4], but with higher resolution.

XMT results of micrometeorites are summarized in table 1 and indicate their predominantly silicate composition.

Unmelted micrometeorites represent almost pristine cosmic dust which entered the atmosphere slowly and thermal changes, if any, are limited to the presence of a magnetite rim covering some particles. Such a magnetite rim is analogous to the fusion crusts of larger meteorites covering a pristine meteorite interior. Physical properties of these particles thus remain almost unchanged and are representative of the cosmic dust in Earth's vicinity. These particles seem to be rather inhomogeneous with wide range of porosity(0-12%, with one sample as high as 51%), similarly as reported in [4, 5, 6].

Partially melted, scoriaceous, micrometeorites enter the atmosphere at slightly higher velocities. While highly porous fragmental particles probably completely disintegrate at higher entry velocity, more compact particles survive the heating and stress during atmospheric entry. The heat generated during meteoroid deceleration causes partial melting and evaporation, resulting in growth of large vesicles within the silicate matrix. However, the extent of melting is not large enough to cause homogenization of the meteoroid or to change its shape from irregular to quasi-spherical. Partial melting results in a general increase in the porosity (23-27%).

In contrast, cosmic spherules (melted micrometeorites) represent meteoroids entering the atmosphere at high velocities. Atmospheric entry heating causes meteoroid complete melting and change of its shape to droplet-like quasi-sphere. This is accompanied by almost complete reduction of porosity (0-3%). Their internal structure varies from glassy to barred or porphyritic olivine structure.

Changes to meteoroid properties during high velocity atmospheric entry: The comparison of the physical properties of cosmic spherules (melted micrometeorites) to those of partially melted or unmelted meteorites gives us the opportunity to evaluate the changes in meteoroid properties as a function of atmospheric entry velocity (Fig. 1). At low velocities meteoroid melting does not occur and there is no change in meteoroid physical properties. At higher velocities, where partial meteoroid melting occurs, there is increase in the meteoroid porosity caused by volatile evaporation (scoriaceous phase). Metal distribution seems to be unaffected at this stage. At even higher velocities, complete melting follows the scoriaceous phase (characterized by initial increase of porosity). Complete melting is accompanied in metal oxidation and redistribution and loss of porosity. Especially, the porosity behavior (initial increase followed with almost total loss during high velocity impacts) is an important fact to be considered during meteor phenomena modeling.

Conclusions: The porosity of pristine cosmic dust is highly variable from sample to sample. During low speed atmospheric entry the cosmic dust particles remain intact and preserve their original internal structure. At slightly higher velocities partial melting occurs accompanied with formation of vesicles and an increase of porosity. At high entry velocities complete melting occurs accompanied by homogenization of the internal structure and almost complete loss of porosity.

XMT proved to be a capable 3D non-destructive investigation tool suitable for extraterrestrial material studies and for quantitative evaluation of its physical properties and represents a significant improvement over the SEM based methods used in earlier work.

References:

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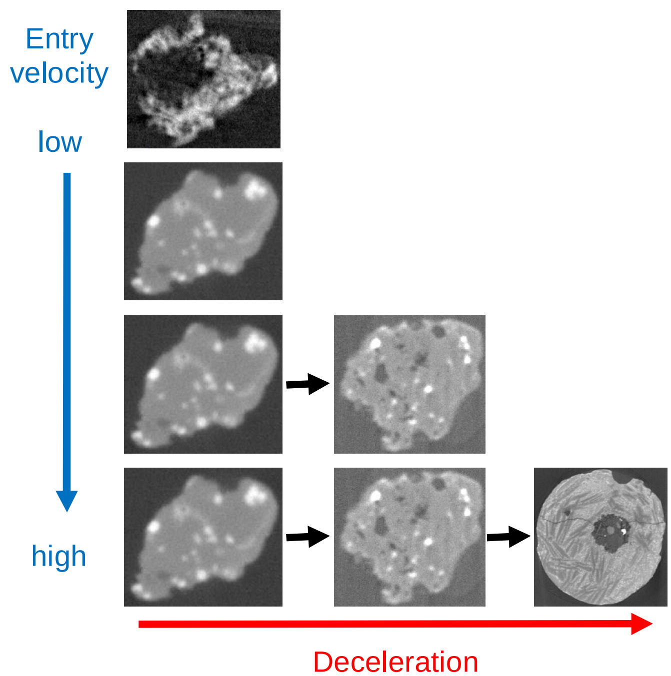

Fig. 1. Evolution of meteoroid physical properties as a function of its entry velocity.

Table 1. Internal structure and porosity of the micrometeorites.

Micrometeorite type	Internal structure	Porosity (%)
Unmelted	Compact fine/coarse, some fragmental	0-12, one sample 51
Partially melted	Vesicular fine/coarse	16-27
Entirely melted	Compact fine/coarse some with metal inclusion	0-5