2.3.7 NEAR-EARTH FRAGMENTATION OF COSMIC DUST

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Abstract

Cosmic dust fragmentation in near-earth space is strongly suggested by the high fluxes ($\sim 10^2/m^2s$) of submicron particles observed in the upper atmospheric collection experiments, the lower fluxes ($\sim 10^{-1}/m^2s$) observed in near-earth space by the lower sensitivity detection experiments and the much lower fluxes ($\sim 10^{-4}/m^2s$) observed in the deep-space experiments. Various possible fragmentation mechanisms are discussed.

Evidence for Near-Earth Fragmentation

During particle collection experiments by rockets in the earth's upper atmosphere (≥ 80 km) clusters of particles are found which suggest particle breakup at a higher altitude. Fig. 1 shows a solid-type cosmic dust particle cluster collected with the aid of in-flight shadowing[1]. The particle appears to have broken up at a higher altitude and the breakup energy given to the fragments is small compared to the kinetic energy of the original particle.

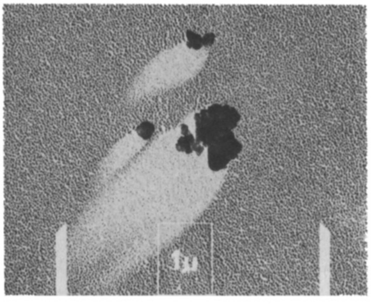

Fig. 1
Collected Particle Cluster

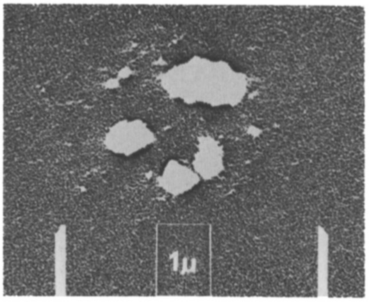

Fig. 2
Collected Hole Cluster

Recovered near-earth satellite exposure of thin films and polished surfaces also provide evidence of particle breakup. Fig. 2 shows a cluster of holes[2] found in a thin film exposed in the Gemini cosmic dust experiment (S-12) at an altitude of 230 km during Gemini 9. The particle appears to be of a similar nature to that shown in Fig. 1 and probably has broken up at a still higher altitude. Similar thin film

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penetration hole evidence[3,4] has been found in the SKYLAB cosmic dust experiment (S-149) which provided three recovered, month-long exposures at an altitude of 430 km. In addition, evidence of clustering of impact craters has been found in the S-149 experiment. For example, forty 1-4 μ diameter impact craters were found[5] in an area of 4 cm^2 which would be equivalent to a localized particle flux enhancement about 100 times the average near-earth flux[3]. The high sensitivity Prospero micrometeorite detection experiment[6] has found evidence of clusters of submicron particles at altitudes ranging from 547 to 1582 km. At higher altitudes ranging from about 500 to 240.000 km the HEOS coincidence micrometeorite detection experiment has also found evidence of time clustering[7]. Furthermore, the HEOS experiment has shown in near-earth space ($\leq$10 earth radii) that most of the particles (93 %) are parts of clusters and that submicron particles were detected primarily when the HEOS sensor was facing the direction of the earth.

In addition to the type of particle shown in Fig. 1, evidence exists in the collection experiments[8] for the existence of submicron particles which in interstellar space would be called "core-mantle" particles. Fig. 3 shows an example of a particle having a high density core and an extremely low density, fragile mantle. Such particles appear to have been detected at higher altitudes by thin film penetration experiments[2,4] in which the core penetrates the thin film whereas the mantle does not. An example of the resulting "evil-eye" structures from the S-149 experiment is shown in Fig. 4.

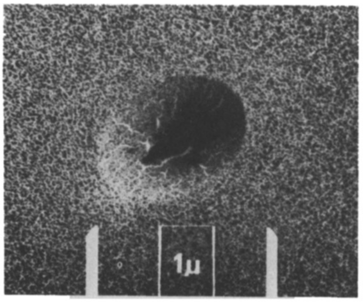

Fig. 3
"Core-Mantle" Particle

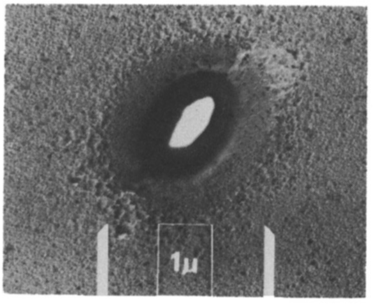

Fig. 4
"Evil-Eye" Hole Structure

Table 1 shows the fluxes of submicron particles (including "core-mantle" particles) and the fluxes of holes (including "evil-eyes") as

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a function of altitude. It suggests that the submicron particle influx in the earth's atmosphere is approximately constant with altitude over a remarkably large range of atmospheric pressures and that the particle breakup occurs in the ionosphere. Table 1 also indicates that the near-earth submicron particles flux is more than 100 times the lunar submicron flux[10], thus providing additional evidence of particle fragmentation in near-earth space.

Table 1

Altitude	Experiment	Flux	Pressure	Type of Event
430 km	S-149	$3x10^{2}m^{-2}s^{-1}$	$3x10^{-8}$mb	Submicron Holes
230 km	S-12	$2x10^{2}m^{-2}s^{-1}$	$7x10^{-6}$mb	Submicron Holes
80 km	Pandora Collections +)	$10^{2}m^{-2}s^{-1}$	10^{-3}mb	Submicron Particles
26 km	Balloon Detection ++)	$10^{2}m^{-2}s^{-1}$	20 mb	Submicron Particles

+) The Pandora collections[8] free from special enchancements such as Noctilucent clouds are given here.

++) Submicron particle numerical density data[9] above the Junge layer converted to fluxes through estimated particle falling velocities.

Possible Particle Breakup Mechanisms

Evaporation Breakup: Fig. 5 shows a sketch of a fluffy particle made up of "core-mantle" elements. If the cores were stony and the mantles were icy, such icy mantles would be expected to evaporate and the particle might breakup upon entering the earth's atmosphere (or approaching the sun). However, such a breakup mechanism does not explain the relatively high altitude breakup implied by the near-earth observations.

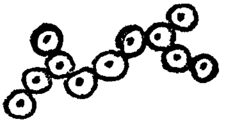

Fig. 5
"Fluffy" Particle

Phase Change Breakup: If the dirty ice of comets were amorphous rather than crystalline, then the particle entry into the earth's ionosphere might trigger the phase change into crystalline ice and the resultant energy release be partially responsible for the near-earth particle fragmentation. Such a process cannot be excluded at present.

Chemical Breakup: If the cores of the schematic fluffy particle shown in Fig. 5 were refractory or stony and the mantles primarily carbon

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soaked with hydrogen, chemical breakup as a result of oxidation in the earth's ionosphere would be possible. The carbon would react with the atomic oxygen to make CO or CO_2 and the hydrogen to make H_2O. Both reactions would be expected to release relatively large amounts of thermal energy and the remaining ash of a mantle would be quite fragile as observed in particles such as that shown in Fig. 3. It must be remembered that cosmic dust (no matter what its origin - comets, stellar atmospheres, etc.) is formed in a hydrogen-rich environment and would not be expected to be chemically stable in an oxygen-rich environment such as the ionosphere or the earth's atmosphere. Indeed, submicron cosmic dust particles and "evil-eye" hole samples to be stored in argon in order to be kept without corrosive destruction by atmospheric oxygen. Table 2 shows the number of oxygen atoms that a particle of 1 cm^2 cross section would be expected to encounter during passage through the earth's ionosphere on a 90^o scattering trajectory as a function of minimum altitude above the earth's surface. The data in Table 2 indicates that passage through the ionosphere would not be expected to seriously oxidize a solid particle of about one gram mass.

Table 2

Min. Altitude	200 km	500 km	800 km
Sunspot Maximum	$1x10^{18}O^+$atoms/cm^2	$3x10^{16}O^+$atoms/cm^2	$2x10^{15}O^+$atoms/cm^2
Sunspot Minimum	$7x10^{17}O^+$atoms/cm^2	$2x10^{15}O^+$atoms/cm^2	$4x10^{13}O^+$atoms/cm^2

However, a fluffy particle such as that shown in Fig. 5 made up of "core-mantle" elements with .1 dimensions with hydrogen soaked, carbon mantles could be broken up by oxidation during transit through the earth's ionosphere. This chemical breakup mechanism would be sensitive to sunspot activity and may be playing a role in larger fluffy bodies such as radio meteors. Furthermore, oxidation of materials exposed in near-earth space has been detected[3].

Collisional Breakup: Collisional breakup would be expected to be less effective for fluffy particles than for solid particles. Particle collisional breakup would not be expected to play a major role in near-earth space, although the ß meteoroids may result in part from such fragmentation between 1 AU and the sun. A fluffy particle would be expected to breakup upon hitting a foil having a thickness approximating the size of the individual elements of the particle or breakup upon encountering the equivalent mass/cm^2 of a spacecraft atmosphere. Such a thin-film effect was discovered by laboratory experiments[12] and found in SKYLAB. This S-149 data clearly shows the existence of fluffy particles in near-earth space[4].

Electrostatic Particle Breakup: Particles entering the earth's ionosphere would be expected to change their charge significantly by increased electron accretion, especially upon entry into the shadow of the earth. Particle breakup by this means requires the particles to be extremely fragile. More work should be done on this possibility.

Crater Particle Formation: This process can be important when a small body hits a large one with high velocity. Small particles are formed during the crater-forming process as noted in laboratory experiments[13]. If the impact occurs in a stony or glassy surface a concoidal fracture pattern may appear around the impact crater and indicates additional fragmentation. The moon is likely providing small particle clusters to near-earth space as a result of particle impacts[7].

Conclusions

Evidence from a variety of experiments indicates a great deal of cosmic dust fragmentation in the ionosphere. Oxidation fragmentation can account for the relatively high fluxes of submicron particles collected in the earth's atmosphere.

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