SUBMICRON PARTICLES IN METEOR STREAMS

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Submicron particles (mass<10^{-15} g) were observed in certain meteor streams by impact detectors on satellite Explorer 46. This unexpected finding leads to conclusions about the nature and origin of the particles and about the importance of nongravitational forces.

The MTS (Meteoroid Technology Satellite) - Explorer 46 carried a variety of experiments, including a simple ultrasensitive impact detector (1). The MOS detector is a solid-state capacitor, consisting of a metal coating, a silicon dioxide dielectric, and a silicon substrate. The threshold of the detector is set by the thickness of the dielectric, generally at either 0.4 μm or 1.0 μm. (See Table I for details of the experiment.)

TABLE I: Summary of the Small Meteoroid Detection Experiment

EXPLORER 46:		
Altitude	660 km	
Inclination	38^{o}	
Eccentricity	.02	
DETECTORS:		
Dielectric Thicknesses	0.4 μm	1.0 μm
Threshold (At 15 km/sec)	10^{-17} g	10^{-15} g
Detector Area	365 cm^2	548 cm^2
Raw Impact Rate	∿2/day	∿1.2/day

During the nearly 6 months of detector operation (August 1974 through January 1975), enhancements in counting rates were observed during certain meteor showers, but not during others. (See Table II.) Enhancements were generally most pronounced for submicron particles (except for the Leonids). The degree of enhancement seems to be inversely related to the time elapsed since the most recent perihelion passage of

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TABLE II: Data Taken Over 6 Days Centered on Predicted Shower Maximum

	FLUX ($x10^{-4}$ m^{-2} sec^{-1})	
Sensor Dielectric Thickness	0.4 μm	1.0 μm
Background Rate	4.6	2.0
Orionids (Halley) Oct. 21	7.8	0.3
Taurids (Encke) Nov. 4	27.3	5.7
Leonids (1866 I) Nov. 17	10.1	7.1
Geminids (------) Dec. 14	----	5.6
Ursids (Tuttle) Dec. 22	10.3	2.2
Quadrantids (---) Jan. 3	2.6	1.4

the comet associated with the meteor stream. The results, though sparse, are statistically significant and leave no doubt that submicron particles are affiliated with at least some meteor streams.

This result is unexpected. There have been no prior reports of such associations of submicron particles with meteor streams, even though instruments of adequate sensitivity have been exposed to the space environment. Beyond this, observations of comet tails have shown no evidence for submicron particles (2). Finally, theoretical expectations have been that submicron particles released from comets, usually near perihelion, would be immediately ejected from the solar system by radiation pressure (3).

The fact that such particles are observed in meteor streams leads immediately to some upper limits on the effects of radiation pressure, and indirectly on the composition, density, and shape of the particles. It is customary to define the ratio of radiation pressure to solar gravity as β. Prior calculations had shown that β exceeds 1.0 as particles become smaller, except for particles that are dielectrics. For example, if the refractive index is below ∿1.20, then even the presence of absorption cannot obtain a β-value > 1.0. In fact, β reaches a maximum for particles of radius around 0.1 μm, and then declines for smaller particle radii (4). The particles could either be organic molecules, synthesized from free radicals in the nucleus of the comet, or silicate particles (with the impurity absorption centers split off, as suggested to us by Thomas Gold). They cannot have too low a density or too nonspherical a shape.

Aside from radiation pressure, electromagnetic forces are of major importance in removing the submicron particles from the orbit of the meteor stream. Since both Lorentz force and convective drag vary as the first power of the particle radius, they soon exceed radiation pressure and Poynting-Robertson effects. Convective drag, which relates to the solar wind velocity, is always at least an order of magnitude greater than the Lorentz force which relates to the particle's Keplerian velocity (5).

"Lifetime" is defined as the time required to remove a particle from the meteor stream orbit. It will depend on the detailed structure of the interplanetary magnetic field. For a sector field and non-zero average azimuthal field, and for particles of radius ~ 0.1 μm, this time is $\gtrsim 3$ years, or 10^8 seconds (under certain assumptions about the particle and about interplanetary conditions, leading to a particle potential of +3.3 volts) (4,5). This calculated lifetime accords with the observed high counting rate for the Taurids (corresponding to Encke's comet passage of <1 year earlier) and with the essentially zero rate for the Orionids (corresponding to Halley's passage and presumed injection of particles 65 years ago).

Using these observations in support of a calculated lifetime, one can derive a budget for submicron particles, leading to an injection of the order of several thousand tons of material for a cometary perihelion passage. (See Table III.) This value is in good accord with the injection mass derived from direct observations of comet tails (6).

TABLE III: Sample Mass Injection Calculation for Encke

Observed Flux (of particles $<10^{-15}$ g)	$F \sim 3 \times 10^{-3}\ m^{-2}\ sec^{-1}$
Nominal Velocity	$V \sim 30$ km/sec
Spatial Concentration (near Earth)	$N \sim 10^{-7}\ m^{-3}$
Lifetime ∿ Taurids period ∿ 3.3 years	$T \sim 10^{8}$ sec
Injection Rate ∿ 1/NT	$I \sim 10^{-15}\ m^{-3}\ sec^{-1}$
Volume $\sim 10^{11} \times 10^{10} \times 10^{10}\ m^3$	$Vol \sim 10^{31}\ m^3$

Total Mass Injected $\sim 10^{-15} \times 10^{31} \times 10^{-15} \sim 10$ g /sec
Or $\sim 10^9$ g per orbital period
Or $\sim (2\text{-}5) \times 10^9$ g at perihelion

Better data are urgently needed in order to draw more definitive conclusions. The ideal platform is an LDEF (Long Duration Exposure Facility) launched by a space shuttle, which would allow counting rates of several hundred per day during meteor showers. This would make it quite feasible to study the decay of submicron particles with time (assuming

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they are all injected by the comet's perihelion passage), or the year-to-year variability, including any spreading of the stream due to electromagnetic and other forces.

Finally, this experiment affords an ideal opportunity to study Halley's Comet. Baseline studies should be made well in advance of 1985 and continue for several years thereafter. Observations on the mass distributions, the temporal decay, and the spatial spreading can be combined to give unique information on the origin and nature of the very smallest particles released by comets into interplanetary space.

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DISCUSSION

Elford: To what extent could these observed flux enhancements be due to chance associations with the times of occurrence of meteor streams?
Singer: Less than one in a thousand for Poisson events.

Reply to *Millman:* The Taurid increase involved 50 impacts over 6 days.

Sekanina: To confirm the effect for P/Encke you should 1) repeat the experiment in successive years and 2) see if the enhancement is present in June at the time of the daylight beta-Taurids.
Singer: We agree completely; ideally an experiment on LDEF.

Grün: I do not believe that electromagnetic effects will allow these particles to remain for times as long as you propose.

Kresák: The duration of the Taurid meteors is about 2 months. Was there any supporting evidence, say impact directions and velocities, that you were in fact observing meteoroids from P/Encke?
Singer: No.

Hughes: Lack of any enhancement during the Quadrantids is consistent with your requirement for a comet in relatively close proximity. This should apply also to the Geminids and the Halley streams.
Could these be particles ejected from the Moon by impact of larger stream meteoroids?
Singer: We could not distinguish between the two.

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