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PRECISION REQUIREMENTS ON COSMIC DUST TRAJECTORY MEASUREMENTS

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It has been known for some time that the orbital parameters of certain major meteor streams rather closely match those of presently observed comets (Lovell, 1954; Whipple, 1954). There is therefore a clear parent-daughter orbital relationship between meteoroids in certain streams and the comets that they derived from. For meteoroids in the photographic meteor range, it has been estimated that from 1% (Kresák, 1980) to 10% (Cour-Palais et al., 1969) of the meteoroid mass is concentrated into the major streams. However, for the smaller, more numerous meteoroids observed as radar meteors, streams are less intense but there are more of them; Southworth and Sekanina identified 256 streams in their synoptic year search. Sekanina (1973) has established for the radar meteors that, in addition to comets, some of the parent bodies appear to be asteroids. As noted by Grün et al. (1985), meteoroid lifetimes, due to collisional destruction or Poynting-Robertson (P-R) drag losses, range from 10^5 yr downward to less than 10^3 yr; these meteoroids therefore need to be continuously be replenished by source bodies to maintain the meteoritic complex in some sort of temporal equilibrium.

It will also be very important to obtain their precise trajectories when meteoroids are collected with a capture apparatus in Earth orbit, as is made apparent with the following logic: a chemical, istopic, or other analysis of any particular meteoroid constitutes a similarly detailed analysis of a small part of the parent comet or asteroid that is orbitally associated with it. One can, consequently, do rather detailed cometary or asteroid science utilizing only an Earth-orbiting cosmic dust capturing facility. And it will be possible to know what parent body we are analyzing. There is also the possibility that interstellar grains will be collected and analyzed.

When a dust grain is ejected from a comet or an asteroid, it immediately proceeds on an altered orbit. There are two reasons for this. First, due to the drag of the outward flowing gas, grains are emitted from comets with a variety of velocity directions relative to the parent comet; similary, impacts of meteoroids onto asteroids cause grains to be ejected with a variety of velocities relative to the parent asteroid. Second, for small grains, radiation pressure is a significant factor relative to the gravitational pull of the sun, which causes a weaker inverse square force or "effective gravity" field to be felt by the grain; this causes the heliocentric orbital period and semi-major axis of a small grain to increase relative to large grains with identical heliocentric velocities. After ejection, gravitational perturbations and Poynting-Robertson (P-R) drag will modify, at different rates, the separate orbits of the parent comet or asteroid and the daughter dust grains. These perturbations and drag will generally produce increasing divergence, in time, between parent and daughter orbital parameters. Dust grains will seldom, if ever, be detected traveling in orbits identical to their parent bodies. As some of the perturbational forces depend upon particle size, the divergence of orbital parameters will depend upon particle size, as well as on the time since parent-daughter separation. In order to associate collected meteoroids with specific source bodies (such as a particular comet), these orbital evolution processes need to be understood in detail.

Southworth and Hawkins (1963) developed a semi-empirical "D" criterion to determine whether or not a meteor belonged to a stream. The D criterion is given by

$$\begin{aligned}(D(m,n))^2 = {} & (e_m-e_n)^2 + (q_m-q_n)^2 + (2\sin((i_m-i_n)/2))^2 \\ & + \sin(i_m)\sin(i_n)(2\sin((\Omega_m-\Omega_n)/2))^2 \\ & + ((e_m-e_n)\sin((\Omega_m+\omega_m-\Omega_n-\omega_n)/2))^2 , \qquad (1)\end{aligned}$$

where m represents the mean orbital parameters (eccentricity e, perihelion distance q, inclination i, longitude of ascending node Ω, and argument of perihelion ω) of the assumed stream and n represents the corresponding orbital parameters of a meteoroid whose membership in the stream is to be tested (q is in AU). If D is less than some value chosen from experience (e.g. D = 0.2), then the meteoroid is said to belong to the stream. Over some range of the parameters, according to Southworth and Hawkins, D is approximately equal to 3/2 times the velocity increment (in units of the Earth's orbital velocity) needed to derive one set of orbital parameters from the other.

Such a criterion is probably justifiable if members of a stream are related to one another by impulsive gravitational scattering. It is almost certainly not a universally valid criterion, however. This is especially true for small meteoroids that have largely evolved under P-R drag (which primarily changes e in Eq. 1). It should be a future theoretical effort to study the prior orbital evolution of meteoroids that intersect the Earth's orbit as a function of meteoroid size. The purpose of the study would be to derive new "D" criterion that would correctly relate daughters to parents via well understood orbital evolutionary paths. One could then more confidently establish true parent-daughter relationships.

Next it is asked what kind of precision is required in measuring the trajactory of an impacting meteoroid, in order to determine which parent object it derived from. The answer to this question will partly depend upon how well the orbital evolution of each meteoroid is understood, as noted in the previous paragraph. But it also depends upon how widely separated are the orbital parameters of the objects that are to be tested as potential source, or parent, bodies. Consider, for example, two meteoroids that have very similar orbital parameters except that the aphelion of one is at 5 AU (normally a cometary object) and the aphelion of the other is at 4 AU (potentially an asteroid). Depending on the inclination and perihelion distances assumed, one derives geocentric velocities that differ from one another by from 1% to 6% for the two cases. Therefore to be sure we can cleanly separate objects derived from these two great families of parent objects, precisions as high as 1% in measuring the trajectory are needed. Fuzziness introduced due to uncertainties of orbital evolution paths will make the required precision even higher. For reference, precision photographic meteor trajectories are obtained with accuracies of 0.1% to 0.4% (Jacchia and Whipple, 1961). One also would also like to separate different populations of Earth-orbiting spacecraft debris from each other (e.g. see Kessler, 1985 for a discussion of orbital debris issues) in order to determine sources for the debris; lunar ejecta should also be differentiated from man-made Earth-orbiting debris generated in geosynchronous transfer orbits.

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In short, the greater the precision, the greater the liklihood that many unique parent-daughter associations can be made. It is not now known how much precision will be required to make certain potentially interesting associations in the future, so near-maximum state of the art measurements should be sought. It appears both feasible and desireable to obtain a precision better than 1% in determining vector velocity components of impacting meteoroids.

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