PHYSICAL CHARACTERISTICS OF COMETARY DUST FROM DYNAMICAL STUDIES: A REVIEW

Z. Sekanina
Harvard-Smithsonian Center for Astrophysics
Cambridge, Massachusetts, U.S.A.

1. INTRODUCTION

In this review attention is focused on those areas of the dynamical investigation of cometary dust in which significant progress has been achieved since the previous review papers (Sekanina 1976a, 1977). Much of the progress stems from work based on the model of dust comets formulated by Finson and Probstein (1968a). Their introduction of a new technique for dust-tail studies has made it possible for the first time to gain insight into such properties of cometary dust as the size distribution function of particles shortly after emission from the comet nucleus, the distribution of particle ejection velocities, and the production of dust versus time. Since the Finson-Probstein approach is of a combined dynamical/photometric type, information on particle sizes and masses is provided indirectly, through parametric functions determined from the observed distribution of light intensity in the tail. The basic limitation is that particle radius a cannot be separated from particle density ρ, as their product is related to a directly observed quantity β, the acceleration exerted on the particle by solar radiation pressure. Expressed in units of solar attraction, β for a spherical particle is given by

$$\beta = c_0 \frac{Q_{pr}}{\rho a}, \tag{1}$$

where $c_0 = 0.585 \times 10^{-4}$ g/cm^2 and Q_{pr} is the integrated scattering efficiency of the particle for radiation pressure, which varies significantly with a for particles whose dimensions are smaller than the effective wavelength of solar radiation.

2. DUST TAILS AS CONTINUOUS PARTICLE-FLOW PHENOMENA

Many dust tails show little if any structure. Continuous light intensity variations in such tails are suitable for applications of Finson and Probstein's method and recent accomplishments achieved in this direction are highlighted in this section.

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 237–250.

2.1. Particle Size Related Distribution Function

One of the most important products of the Finson-Probstein type of analysis is the determination of a parametric function $f(\beta)$, where β is given by Eq. (1). This function is closely related to the particle-size distribution function $g(a)$; see Finson and Probstein (1968a) for details.

The practical applications of the Finson-Probstein method to Comets 1957 III (Finson and Probstein 1968b) and 1970 II (Sekanina and Miller 1973) indicated that in both cases the function $f(\beta)$ had the following general characteristics:

(1) terminated at a certain critical value β_0, i.e., $f(\beta) = 0$ at $\beta \geqq \beta_0$, which is readily understood in terms of a progressively increasing "transparency" to radiation pressure of particles with sizes below $\sim$0.5 micron; as a result, β attains a maximum at a particle radius $\sim$0.1 micron for strongly absorbing materials and at a radius $\sim$0.2-0.3 micron for dielectrics;

(2) was sloping down at a more or less constant rate as β approached β_0, i.e., $df(\beta)/d\beta \simeq \text{const} < 0$ at $0.35\,\beta_0 \lesssim \beta \lesssim \beta_0$, which provides an empirical expression for $f(\beta)$ in the transition interval;

(3) could be approximated by a constant within a range of moderate β, centered on $\sim 0.1\,\beta_0$ for 1957 III and on $\sim 0.2\,\beta_0$ for 1970 II, which is the maximum value the function attains; in other words, $df(\beta)/d\beta \simeq 0$ at $0.05\,\beta_0 \lesssim \beta \lesssim 0.25\,\beta_0$, which means that in the domain of particle dimensions from $\sim$1 to $\sim$10 microns the size distribution can be approximated by $g(a)\,da \propto a^{-4}\,da$; and

(4) was essentially indeterminate at $\beta \ll 0.1$; this reflects simply the fact that particles with sizes exceeding 10 microns have a much lower area-to-mass ratio than smaller particles, which makes them optically unimportant; the observations of both comets could formally be fitted with $f(\beta)$ corresponding to the size distribution law $g(a)\,da \propto a^{-5}\,da$, but the sole purpose for the choice of this law was to avoid the divergence of the particle-mass integral, which would result from the extension of the law $f(\beta) = \text{const}$ to $\beta = 0$.

This defect can luckily be rectified thanks to the occurrences of anomalous tails, in which β is restricted to $\lesssim$0.01. Dynamical evidence shows that these tails must be large-particle dominated (Sekanina 1974). Nevertheless, because the repulsive acceleration from radiation pressure drops below 1 percent of solar attraction not only for particles larger than $\sim$10 microns in radius but also for dielectric particles smaller than $\sim$0.02 micron, doubts about the presence of large particles in anomalous tails have been expressed on at least two occasions. Combining this argument with the high polarization observed in the anomalous tail of Comet 1973 XII (Bücher *et al.* 1975), Lamy and Koutchmy (1976) have suggested that 0.02 micron size particles could make up the tail or that they might coexist in it with the large particles. However, the polarization argument was invalidated by Giese (1977) and by Giese *et al.* (1978), who have shown that fluffy absorbing particles whose dimensions exceed several microns can produce a very high degree of polarization. More recently, Greenberg (1979) has reported that nonabsorbing particles of a "bird's nest" structure can also be responsible for a moderate polarization such as that observed in the zodiacal light. In the case of Comet 1973 XII large particles were of course confirmed by Ney's (1974) infrared observations, which failed to reveal the 10-micron silicate signature in the anomalous tail. Very recently the presence of large particles in anomalous tails has been questioned by Vanýsek (1979), specifically with respect to Comet Encke. The fact is, however, that dielectric particles smaller than 0.1 micron in diameter can *never* make up an anomalous tail for a simple dynamical reason: because of their high ejection velocities (∿0.5 km/s) they can be recognized, if ever [1], for only a short time after expulsion to form a nearly spherical dust halo of huge dimension proportional to the square of ejection velocity and inversely proportional to the (very small) repulsive acceleration, and then rapidly disperse in space. Even in an old comet like P/Encke would the diameter of such a halo be on the order of one million km, whereas on the densitometer tracing studied by Sekanina and Schuster (1978a) the comet's image is clearly elongated in the directions consistent with those expected for large particles already at distances beyond some 20,000 km from the nucleus.

Thus, it is the combination of a small repulsive acceleration and a *low ejection velocity* which, besides other conditions (see Sekanina 1974; also Section 2.3 of this paper), makes the phenomenon of anomalous tail possible. As described in detail elsewhere (Sekanina and Miller 1976), a close relationship exists between the radial intensity gradient in anomalous tails and the parametric function f(β). Table I, which compiles the available data, suggests that for large particles f(β) can reasonably be approximated by a power law

$$f(\beta)\, d\beta \propto \beta^z\, d\beta\,, \qquad (2)$$

where the most probable z lies between 0 and ∿0.5. At an assumed constant

TABLE I. Slope z of Distribution $f(\beta)\, d\beta \propto \beta^z\, d\beta$ in Anomalous Tails

Comet	Perihelion distance (AU)	z	Reference
Arend-Roland 1957 III	0.32	0.0 [a]	Sekanina, unpublished
Kohoutek 1973 XII	0.14	0.8 [b]	Sekanina and Miller (1976)
P/d'Arrest 1976 XI	1.16	0.15	Sekanina and Schuster (1978b)
P/Encke 1977 XI	0.34	0.26	Sekanina and Schuster (1978a)

[a] Derived graphically from densitometer map of an April 27, 1957 photograph (Ceplecha 1958); Finson and Probstein (1968b) *assumed* z = 1.
[b] Corrected for particle-evaporation effects but somewhat uncertain.

density ρ the distribution function of large-particle radii, equivalent to this $f(\beta)$, is

$$g(a)\,da \propto a^{-u}\,da\,, \tag{3}$$

where u is between 4.0 and $\sim$4.5. Superseding the indeterminacy statement (4), formula (2) complements the other properties of $f(\beta)$.

From the above results for five comets ([2]) one finds a good deal of uniformity in the behavior of $f(\beta)$ at small values of β but enormous diversity at $\beta \gtrsim 0.1$. For the benefit of future applications of the Finson-Probstein approach to other comets, one would like to have a general empirical law for $f(\beta)$ that could approximate all the variety of behavior by changing only a few key parameters. Such a formula is the subject of another paper included in these Proceedings (Sekanina 1980).

2.2. Large Particles and the Source of Interplanetary Dust

Until recently little information other than from meteor studies was available on large particles (>10 microns in size) ejected from the short-period comets. A few years ago I proposed to attack this problem by photographic photometry of anomalous tails and predicted their future appearances to facilitate this task (Sekanina 1976b,c). The results of successful observations made for P/d'Arrest 1976 XI and P/Encke 1977 XI now indicate (Sekanina and Schuster 1978a,b) that such comets produce too little dust to replenish total losses of the self-destructive interplanetary cloud, thus confirming the conclusions from statistical considerations (Delsemme 1976, Röser 1976). The same appears to be true for periodic comets like Halley (Sekanina 1979a).

If there is an adequate source of interplanetary dust, it remains a mystery. One potential source can be the possible reservoir of short-period comets in low-eccentricity orbits at heliocentric distances comparable with that of Jupiter. Indeed, new short-period comets with perihelia much beyond 1 AU have recently been discovered in unprecedented numbers (often with large Schmidt cameras) and many of these turned out to have relatively recently been perturbed by Jupiter from less elongated orbits following close encounters with the planet. One of such distant short-period comets (though not one with a recent orbit transformation) has been shown by A'Hearn *et al.* (1979) to differ physically from comets of P/Encke type in that it is very dusty and that the color of its dust is essentially gray. Independently, P/Tempel 2 and P/Borrelly have been found (and other comets suspected) to develop a persistent "late" tail, indicative of slowly accelerating large dust (dirty ice?) particles (Sekanina 1979b).

There is some indication that the activity of large-distance short-period comets is controlled by an energy budget that is similar to that believed to operate in nearly parabolic comets. The distant short-period comets are largely absent from the statistics used for the interplanetary-cloud related dust-production estimates, but whether they shed enough dust to maintain the cloud in steady state remains to be seen.

2.3. A Monte Carlo Version of the Finson-Probstein Method

An extensive paper on the structure of dust tails has been published by Hiroshi and Liu Cai-pin (1977). Considering a general three-dimensional distribution of ejecta from Comet Arend-Roland 1957 III they show that the approximation by spherical, uniformly expanding shells, which Finson and Probstein (1968a) devised in their method to simulate the effect of the ejection-velocity distribution on particle trajectories, may sometimes be too crude. Because each particle ejected before perihelion with a nonzero normal velocity component and subjected to a repulsive acceleration smaller than the solar attraction must pass through the parent comet's orbital plane once again after perihelion (the second node), the expanding-shell approximation overestimates the effect, roughly speaking, the more the longer is the time since ejection. As a result, ejection velocities derived from the observed brightness distribution in the tail with the use of the approximation give a *lower* bound to true velocities ([3]). A consequence of this dynamical property is, according to Hiroshi and Liu Cai-pin, the rare phenomenon of extremely narrow sunward (anomalous) tail as displayed by Comet Arend-Roland. While the formation of an anomalous tail is of course well understood (e.g., Sekanina 1974), the sharpness of the sunward "spike" of Arend-Roland has generally been attributed to very small ejection velocities of particles, at least in the direction normal to the comet's orbital plane. Hiroshi and Liu Cai-pin now suggest that the spike was sharp because the earth transited the comet's orbital plane at a time when many particles from preperihelion emissions happened to be passing through their second node or at least were very near the orbital plane. As a result, a strong tendency developed toward the formation of a "neckline". In a way, this suggestion is an extension of Southworth's (1963, 1964) conclusion that the very narrow apparent width of the spike was due to the chance fact that it consisted of particles expelled 180° earlier in the orbit. With the introduction of a particle-size distribution, various sections of the "neckline" must of course have been formed by particles ejected at different times because of the dependence of the particle orbital velocity on the effective solar attraction.

As far as the method of analysis of dust tails is concerned, Hiroshi and Liu Cai-pin advocate a Monte Carlo type of approach. Unfortunately, the calculation of trial-and-error models of sufficiently high resolution becomes with this technique much more cumbersome than using the original approach, consuming large amounts of computer time. Hiroshi and Liu Cai-pin's numerical results for Comet Arend-Roland suffer from the fact that the production rate of dust was forced to vary according to an inverse-square power law of heliocentric distance. Since this comet is known to have undergone a number of explosions (Southworth 1963, 1964), such an approximation is clearly unsatisfactory, although it is difficult to estimate the extent of damage done by the forced production law. We notice though that the function $f(\beta)$ derived by Hiroshi and Liu Cai-pin resembles that found by Finson and Probstein (1968b) except for a slight shift in the position of the primary maximum toward a larger β.

From the existing applications of the Finson-Probstein method one can conclude that it has contributed significantly to the understanding of dust in comets, that its overall performance has been quite satisfactory, and that given low intrinsic precision of densitometer tracings of comet photographs, it probably offers maximum possible science return.

3. STRUCTURES IN THE DUST TAILS

Violating the requirement by the Finson-Probstein method of reasonably smooth variations with time in dust emission, cometary outbursts entailing brief but sharp enhancement of dust production are handled by the method with some difficulty. The dynamical behavior of such ejecta was first considered by Norton (1861), who found that particles that left the nucleus simultaneously should be distributed in the tail along a nearly straight line that points roughly to the nucleus. Bredikhin, the author of the first classification of cometary tails, began his studies of this problem in the 1880's (Jaegermann 1903, pp. 400-401), followed by others. Reviewed here is the history of investigation of two types of dust structure believed to be related to comet outbursts: streamers and striae ([4]).

3.1. Streamers

By streamers we understand discrete bands or rays in or outside the main body of a dust tail, which:

(1) emanate from the nucleus in directions deviating perceptibly from the prolonged radius vector toward the reverse orbital-velocity vector;

(2) are of different width, sometimes cone-shaped, and either rectilinear or possessing a slight to moderate curvature; and

(3) number usually not more than a few at a time.

Point (1) implies that if there are more streamers, they all converge to the nucleus, subtending distinct angles with each other.

Bredikhin studied streamers in about 20 comets (Jaegermann 1903, pp. 390-391) and classified them as type III tails, i.e., syndynames or loci of particles subjected to the same repulsive acceleration, with β in the general range from 0 to 0.3 ([5]). In some comets the type III tail was superimposed on a diffused curved tail, in others it formed a secondary tail, and in a few cases it was the only tail observed.

Comet 1901 I, the last studied by Bredikhin (Jaegermann 1903, pp. 380, 441-452), was instrumental in bringing about the first major modification of his classification. Contrary to Bredikhin, Moiseyev (1925) found that the multiple structure of this comet's tail consisted entirely of separate synchrones, i.e., loci of particles ejected at discrete times. Orlov (1928, 1929) subsequently regarded all type III tails as synchronic formations of particles with β from 0 to 0.3, although Moiseyev obtained β up to $\sim$1.7 for the main synchrone of 1901 I. In recent versions of the Orlov classification the streamers have been called *complete synchrones* and the upper limit to β has been corrected first to 2.2 (Orlov 1945a,b) and later to 2.5 (Orlov 1960). Although for a limited period of time Orlov (1945b) preferred to classify the tails consisting of streamers as type II_0 tails [see Bobrovnikoff (1951) for a review in English], he later returned to the traditional term, type III tails (Orlov 1960).

Dust streamers were displayed by a relatively large number of comets and there is no doubt whatsoever that they indeed are products of isolated powerful bursts of dust from comet nuclei; it also seems that they are sometimes associated with other explosive phenomena in comets.

3.2. Striae

By contrast, striae are discrete bands or rays in a dust tail, which, unlike streamers:

(1) deviate from the direction of the prolonged radius vector to much lesser degree;

(2) are usually narrow, almost perfectly rectilinear, and nearly parallel to each other;

(3) are always separated from the nucleus by huge gaps;

(4) do not converge, as a rule, to the nucleus; when extended beyond visible length, they intersect the radius vector at different points, typically on the sunward side of the nucleus; and

(5) tend to cluster in groups, sometimes numbering more than a dozen at a time.

The above list of differences between streamers and striae is impressive enough to make the assumption of the same origin look unattractive; yet striae had until fairly recently been classified as authentic synchronic formations.

The first comet in whose tail striae were positively identified was Donati 1858 VI ([6]); see, for example, Bond (1862), Pape (1859), Winnecke (1859). The next comet with striae — and the first in which they were photographed — was 1910 I (e.g., Lampland 1912). The photographs show that most of the striae do not point to anywhere near the nucleus. Pokrowsky

TABLE II. Evolution of Terminology for Streamers and Striae in the Dust Tails of Comets

Author of Classification	Streamer	Stria
Bredikhin (Jaegermann 1903)	Type III tail (syndyname)	Isochrone or synchrone
Orlov (1928)	Type III tail (synchrone)	Synchrone in type II tail
Orlov (1945b)	Complete synchrone or type II_0 tail	Terminal synchrone in type II tail
Orlov (1960)	Complete synchrone or type III tail	Terminal synchrone in type II tail

(1911, 1915), who studied the striae in detail, took them for synchrones in spite of striking systematic differences in orientation between theory and observation in his graphical representation of the structures. The whole exercise was repeated, with the use of a different projection technique but with the same misinterpretation, by Orlov (1945a). Convinced of their synchronic nature, Orlov (1945a,b, 1960) incorporated striae into his classification under the name *terminal synchrones* to distinguish them from streamers (Section 3.1). In 1945 he assigned them a range of β from 0.6 to 2.2; in the 1960 version the upper limit was moved up to 2.5. In Table II we summarize the changes in terminology over the past 80 years.

In the meantime, the controversy surrounding the subject developed. Vsekhsvyatsky (1959) remarked on the orientation discrepancy between the striae and synchrones in Comet 1910 I; showed that the striated tail of another comet, Mrkos 1957 V, displayed the same anomaly; and suggested the electromagnetic nature of striae. On the other hand, Notni (1964) did match positions of five striae in 1957 V on two consecutive days, but his solution required that dust particles in the striae be ejected from the nuclear region with velocities on the order of 10 km/s in the direction of the plasma tail ([7]). Particle velocities of this magnitude can only be acquired through a very strong coupling of dust with a plasma of high density and temperature and under repulsive accelerations of up to ∿1000 times the solar attraction; such physical conditions are extremely unlikely even in bright comets [see the discussion to Notni (1966)]. Besides, the positions of sunward ends of the individual striae are grossly inconsistent with the calculated loci for β = 0 one way or another. The derived particle velocities decrease systematically with ejection time from 20 to 6 km/s, whereas the maximum repulsive accelerations β at the outer ends of the striae increase systematically from ∿1.0 to ∿2.5. The magnitudes of both variations are too large to be explained, respectively, by a decrease in ionization efficiency and by particle dispersion, as the interval of ejection times spanned only about two days. Further problems are listed in Section 3.3.

Comet Mrkos was followed by at least three more comets with striated tails: Seki-Lines 1962 III (McClure and Schultz 1962), Bennett 1970 II (McClure and Milon 1970; Farrell, private communication), and, lately, West 1976 VI [see photographs in Sekanina (1976d)]. Unfortunately, too few appropriate photographs are available to warrant meaningful studies of striae in Comets 1962 III and 1970 II.

3.3. Comet West 1976 VI

Comet West displayed both striae and streamers; the striking differences between the two kinds of features can readily be seen on many photographs taken with fast cameras in early March 1976. Major investigations of the dust structures have been undertaken by Sekanina and Farrell (1978), by Lamy and Koutchmy (1979), and again by Sekanina and Farrell (1979, 1980).

The first study by Sekanina and Farrell is concerned mainly with the

TABLE III. A List of Discrete Bursts of Dust from Comet West 1976 VI

Burst (streamer)	Time of burst: Date 1976 (UT)	Time of burst: Time from perihelion (days)	β_{peak} (a)	Remarks
I	Feb. 19.4	-5.8	0.25	Major burst; coincides with primary breakup of nucleus (fragment D) and 2-magnitude visual flare-up.
II	Feb. 22.0	-3.2	0.4	Major burst; coincides with possible visual flare-up.
III	Feb. 23.3	-1.9	0.5	Probably major burst; may coincide with surge in thermal emission.
IV	Feb. 25.8	+0.6	0.6	Major burst; coincides with initiation of a number of striae, surge in thermal emission, and possible visual flare-up.
V	Feb. 26.6	+1.4	0.5	Minor burst; coincides with initiation of one stria; apparently accompanied by no surge in thermal emission.
VI	Feb. 27.2	+2.0	0.5	Minor burst; coincides with initiation of one or two striae.
VII	Feb. 28.0	+2.8	1.2	Major burst; coincides with initiation of a few striae; probably coincides with secondary breakup of nucleus (fragment B).
VIII	Feb. 29.2	+4.0	0.7	Minor burst.
IX	Mar. 1.0	+4.8	1.7	Major burst.
X	Mar. 4.2	+8.0	1.7	Moderate burst.
XI	Mar. 5.2	+9.0	0.6?	Existence of this burst dubious; if real it may coincide with tertiary breakup of nucleus (fragment C).
XII	Mar. 7.7	+11.5	2.8	Moderate burst; apparently accompanied by no surge in thermal emission.

(a) Derived from the apparent length of the streamer, this is only a very crude *lower* limit to the true peak β value, which is underrated the more the fainter and older is the streamer.

streamers. Consistent evidence is found for at least 5 discrete bursts of dust between February 19 and 28, the first coinciding with the primary breakup of the nucleus and with a 2-magnitude surge in visual brightness, some of the others with increased thermal emission as measured by Ney and Merrill (1976).

Lamy and Koutchmy compute the ejection time for one streamer, called tail A by them and clearly identical with Sekanina and Farrell's streamer II, and also note a higher level of activity from 3 to 5 days past perihelion (tail C).

My recent (unpublished) analysis of prints of plates of the comet by H. L. Giclas, taken with the 33-cm astrograph of the Lowell Observatory between March 8 and 13, resulted in the detection of further streamers. At present there is a total of 12 recognized bursts of dust, which span the interval from February 19 to March 7. Their updated list is in Table III, which gives: the time of each burst by date and by the time difference relative to perihelion passage on February 25.2 UT; an estimate of the peak repulsive acceleration β_{peak}; and the remarks. Table III leaves little doubt that $\beta \gtrsim 1$, characteristic of submicron absorbing particles, was rather common in the streamers. The large scale of the Lowell Observatory photographs made it possible to improve the time of the last burst on the Sekanina-Farrell (1978) list from February 28.1 to 28.0 UT and to detect two minor bursts between February 25 and 28. The 2-day period of increased activity, noticed by Lamy and Koutchmy, has been resolved into nearly overlapping streamers from three bursts. Further bursts were detected between March 4 and 7. Only a structureless dust tail is seen on a Lowell Observatory photograph of March 15, the date of the full moon.

The character of the streamers is fully understood in terms of discrete bursts of dust from the nucleus. The only difference between the Lamy-Koutchmy and the Sekanina-Farrell interpretations is that the first authors consider streamer particles to be in their overwhelming majority nonabsorbing (and mainly silicates), while the second authors find a significant contribution from conducting particles. In either case, however, no quantitative estimate is given. As for the striae, the two pairs of authors propose interpretations that differ from each other diametrically, their only common feature being total disregard of the possibility of a major role of ejection velocities, the basic idea of Notni's interpretation. Sekanina and Farrell (1978), like Moiseyev (1925) in the case of Comet 1901 I, find no effect of ejection velocity from the positions of streamer axes in Comet West, implying no measurable emission anisotropy. The position of the trailing boundary of the main body of the dust tail of West suggests velocities $\lesssim 1$ km/s at perihelion (Sekanina and Farrell 1978), well below those required by Notni for Comet 1957 V. Furthermore, I made reasonable efforts but failed to match the motions of striae in West using Notni's approach. Finally, from their observations of an occultation of a radio source by the plasma tail 2 days following the first burst Wright and Nelson (1979) estimate a *peak* electron density in the tail 1.8 million km away from the nucleus at less than 5×10^4 cm^{-3}, which remains below the *minimum* electron density required by Notni even after correction for variation with cometocentric distance.

The quantitative part of Lamy and Koutchmy's study is restricted to three prominent striae. Finding, by straightforward comparison with syndynames, repulsive accelerations up to about twice the solar attraction, and noting that the striae retain their basic configuration in the tail over a span of a few days, the authors suggest that the traditional dynamical approach is here inadequate and that the behavior of striae resembles that of plasma phenomena. Sharing Sekanina's (1976d) view that from the positions of striae in the tail their origin seems to lie near the trailing boundary (which is nearly, but not quite, identical with the perihelion synchrone), Lamy and Koutchmy conclude that the striae evolved from ejections at perihelion under repulsive accelerations typical for silicate particles and that, except for the observation on March 7, the picture is consistent with an assumption of their uniform motion throughout the tail at excess velocities on the order of 10 km/s, acquired presumably due to an interaction with the solar wind. Unfortunately, the March 7 observation is very important, since it extends the span of time by a factor of almost 2. Besides, the observed increase in the lengths of striae with time implies a velocity gradient along each stria. These comments suggest that the conclusion on constant velocity is problematic.

Accelerated motions of striae are advocated by Sekanina and Farrell (1979, 1980), whose results elaborate on the assumption of particle fragmentation (Sekanina 1976a,d) and attempt to demonstrate its feasibility. A surprising conclusion is the implication of strongly nonspherical, possibly chain-like, particles in comets. Interestingly, linear agglomeration of condensates (especially of ferromagnetic materials) is known to proceed spontaneously under a broad range of physical conditions.

While the physical interpretation of Sekanina and Farrell's (1979, 1980) model for the stria formation should be subject to further investigation, the dynamical solution is strongly supported by the observations. And although the fragmentation model imposes stringent limitations on the timing of the events involved, the straightforward correlation of the calculated initiation times for most striae with the dust bursts (Table III) is another strong point of the model. A byproduct of the analysis is the fact that no force other than solar attraction and radiation pressure has to be considered to fit the motions of 16 striae. In particular, no evidence whatsoever has been found of the Lorentz force, whose effect would have to show up as transverse displacement in the stria positions.

In retrospect, I see no reason for dividing dust tails into types II and III; the term type III tail has never enjoyed much popularity anyway. Since plasma tails are notoriously known to have nothing in common with syndynames and therefore to defy type I tails, the Orlov classification has no merit anymore. On the other hand, the principles of the mechanical theory are still relevant to dust tails. The definitions of synchrones and syndynames are very useful, despite their limited value in applications. The names streamer and stria, proposed for the two classes of structure, are descriptive, concise, and sufficiently discriminatory.

4. DIELECTRIC VERSUS ABSORBING PARTICLES IN COMETS

Dynamical studies of dust tails offer a mode of establishing a presence of (submicron) absorbing particles, based on the fact known from the Mie type calculations that (spherical) dielectric grains cannot be subjected to accelerations from radiation pressure exceeding about 0.6 the solar attraction. As already mentioned in Section 3.3, some of the dust streamers in Comet West clearly suggest absorbing grains (Table III).

This leads to the question of incompatibility of two or more lines of evidence with respect to particle type. Although cometary dust with the elementary cosmic abundance ratios should have only small average absorptivity, no comet obviously is composed *entirely* of dielectrics. Yet one line of evidence is sometimes rejected as incorrect, when it leads to inference of particle type that is inconsistent with that established from another piece of evidence that one may be more inclined to trust. I see no conflict between the existence of submicron-size absorbing particles in the striae of Comet West, as proposed by Sekanina and Farrell (1979, 1980), and the presence of micron-size dielectric particles in the inner coma, as concluded by Ney and Merrill (1976). The estimated mass of particles per stria, on the order of 10^9 grams, combined with the fact that a half dozen striae originated from burst IV (Sekanina and Farrell 1980), suggests that strongly absorbing particles should have made up only small part of the total production of dust from the explosion of such intensity, even if its duration were restricted to a fraction of an hour!

One must, of course, keep in mind that none of the existing lines of evidence is absolute. On the one hand, our conclusion on absorbing particles in striae can be invalidated, if radiation pressure contributes only minor share (less than about 25 percent) of the observed repulsive acceleration, the rest being due to an unknown force. On the other hand, Ney and Merrill's conclusion, based upon a tacit assumption that all particles contribute to measured scattered light and thermal emission proportionately, can be invalidated, if, for example, the scattered light happens to be due mostly to icy mantles of particles of one type, whereas the thermal energy is given off mainly by nonicy particles, whose temperature and near-infrared brightness must clearly exceed those of ice.

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NOTES

(1) Such tiny particles have a very low light scattering efficiency $Q_{scat} \sim (a/\lambda)^4$ (λ is the wavelength) and are therefore difficult to detect, whether visually or photographically.

(2) The results for a sixth comet, Seki-Lines 1962 III (Jambor 1973) are less relevant, because the observed size distribution in its tail was severely affected by particle evaporation.

([3]) Hiroshi and Liu Cai-pin (1977) have indeed obtained particle-ejection velocities that are higher than those determined by Finson and Probstein (1968b).

([4]) Because of the limited space, I have left out the discussion of other features, such as split tails (Jambor 1973, Sekanina 1976a); fine structures in the tail of Comet Ikeya-Seki 1965 VIII; and a sharp trailing boundary in dust tails (Sekanina 1976d, Sekanina and Farrell 1978).

([5]) Bredikhin kept changing the characteristic magnitudes of the repulsive accelerations for his three categories of tails as the sample of data grew. The number quoted here is from the final version of his classification, based on a total of 51 comets observed between the years 1472 and 1901 (Jaegermann 1903, p. 392).

([6]) The remarkable tail structure of Comet 1744, described by three observers, might have been a striation pattern, but the existing records (including drawings) leave open the possibility that the broad bands were in fact streamers.

([7]) Directed particle-ejection velocities substantially exceeding 1 km/s can indeed distort the shape of standard synchrones (for ejections at rest) to an extent that the discrepancy in orientation, objected to by Vsekhsvyatsky (1959), can formally be removed; they also cause detachment of the synchrones from the nucleus that gradually increases with time.

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