EVIDENCE FOR FRAGMENTATION OF STRONGLY NONSPHERICAL DUST PARTICLES IN THE TAIL OF COMET WEST 1976 VI

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

J. A. Farrell
Los Alamos Scientific Laboratory, University of California
Los Alamos, New Mexico, U.S.A.

1. STRIAE AS PRODUCTS OF PARTICLE FRAGMENTATION

Following Sekanina's (1976a,b) suggestion that striae (also known as "synchronic" or pseudosynchronic bands) observed in the dust tails of several comets could be products of fragmentation of friable dust particles ejected from the nucleus, we have completed an investigation of these structures in Comet West 1976 VI (Sekanina and Farrell 1979, detailed paper in preparation), which shows that the dynamical solutions, provided by the fragmentation model on the assumption that solar attraction and radiation pressure are the only forces involved, are indeed in agreement with the observed motions of 16 striae through the tail over a time interval of more than three days. The match is so good that the probability of its being a coincidence of some sort must be virtually nil.

Although the physical nature of striae may turn out to be more complex than now believed, we regard two facts that follow directly from the dynamical calculations to be highly diagnostic:

(1) initiation times (i.e., ejection times of parent particles) for most of the 16 striae coincide with the times of discrete violent bursts of dust, determined from the motions of streamers (Sekanina and Farrell 1978, Sekanina 1980); notably, 5 to 7 striae are related to an outburst at 0.6 day after perihelion;

(2) fragments are subjected to repulsive accelerations between 0.6 and 2.7 the solar attraction, strongly indicative of submicron-size absorbing particles; whereas repulsive accelerations imparted to parent particles are *slightly lower* than the *average* acceleration on fragments, suggesting that the area-to-mass ratios of the parents and fragments are *nearly* the same.

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 267–270.

2. STRIAE AND STREAMERS

Photographs of Comet West exposed with fast wide-angle cameras in early March 1976 show streamers and striae superimposed on one another, as drawn schematically in Fig. 1. Consider the dust which, having been released from the nucleus during an outburst, is lined up in the tail along a streamer NZ. Parent particles subjected to three particular accelerations are represented in Fig. 1 by points A, B, and C, respectively. When these particles burst into fragments, three striae, oriented along the instantaneous radius vector, begin to develop. Observed long after the parents broke up, the striae are still pointing to A, B, and C, but their orientations now deviate from the radius vector toward the directions of the tangents to the streamer at A, B, and C the more the shorter is the interval between ejection and fragmentation.

Most of the observed striae in Comet West were located entirely on the convex side of the streamers (cf. stria a_1a_2 in Fig. 1), so that the fragments were subjected to somewhat higher repulsive accelerations than their parents. However, a few striae reached the streamers (cf. c_1c_2 in Fig. 1) or extended a little beyond the points of intersection (cf. b_1b_2) to imply that some fragments were subjected to accelerations equal to or very slightly lower than those imparted to their parents.

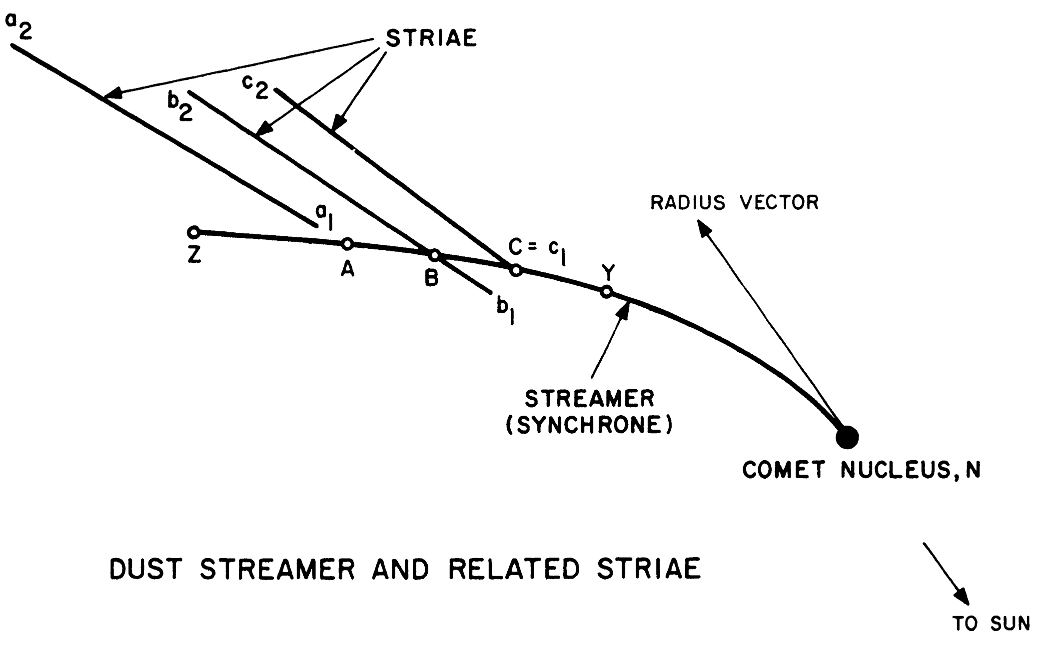

Fig. 1. A streamer and related striae in the dust tail (schematically). Some streamers can be followed throughout the striated region (i.e., from N to Z), others cannot even be traced to the stria nearest the nucleus (termination point Y).

https://doi.org/10.1017/S0074180900066821 Published online by Cambridge University Press

3. THE NONSPHERICAL PARTICLES

Parent particles whose area-to-mass ratio is comparable with that of their fragments are bound to be strongly nonspherical. Although needles or very thin disks also satisfy this condition, we regard chain-like particles as the most attractive candidates. Fuchs (1964) has published a comprehensive review of problems associated with the coagulation or agglomeration of small aerosol particles. He mentions that the formation of linear aggregates is a very common phenomenon for smokes (i.e., condensation aerosols) and that the rate of growth of such aggregates is accelerated in strong electric fields, for ferromagnetic particles in magnetic fields, and, in the absence of an external field, for particles that are permanent electric dipoles or magnets. Laboratory experiments for astrophysical application likewise show the strong tendency of many, particularly ferromagnetic, condensates to develop chain- or thread-like structures (Arnold 1977; Donn, personal communication). Since ferromagnetic particles are strongly absorbing, their existence in striated tails could explain simultaneously the implied chain-like nature of parent particles and sizable repulsive accelerations.

Our results provide limited information on sizes of the fragments. Calculations based on the Mie theory show that for spherical absorbing particles the repulsive acceleration peaks at a radius $\sim$0.1 micron and drops steeply on both sides of the maximum. Particle sizes in striae must be near 0.1 micron, because few materials are known to have peak accelerations exceeding the observed maximum, about three times the solar attraction. However, if the major contribution to their brightness came from particles on the smaller side of 0.1 micron, the striae would have to have been located primarily on the concave side of the related streamers, i.e., the distance b_1B in Fig. 1 would be greater than b_2B. Since this was not observed, the best guess is that particle sizes in the striae were between one tenth and a few tenths of a micron. This, incidentally, is exactly the size range of the small grains that make up the extraterrestrial aggregate particles collected by Brownlee (1978).

We are unable to detect any effect of the Lorentz force in the motions of the striae. Because the interplanetary magnetic field intensity and solar wind velocity are known to fluctuate rapidly with time, it is difficult to use the absence of the Lorentz-force effects for the calculation of a stringent upper limit on the charge that stria particles carried. However, for the quiescent solar-wind conditions and average large-scale structural properties of the magnetic field (Mariani *et al.* 1978), an 0.1 micron particle of density 3.5 g/cm^3 could not be charged to more than a few volts at 0.2 to 0.3 AU from the sun in order that the Lorentz acceleration be confined to less than about 10 percent the solar attraction, a conservatively estimated threshold of detection.

4. THE PROBLEM OF FRAGMENTATION MECHANISM

The identification of the fragmentation mechanism is the most difficult and speculative part of the investigation into the nature of the striated tails. We have been considering rotational bursting due to the "windmill" effect from radiation pressure (Paddack 1969, 1973, Paddack and Rhee 1976) and found that the formation of a discrete stria requires that all parent particles have the same torque factor (defined as a ratio of linear torque arm to maximum dimension), a condition that can hardly be satisfied for all chain particles released during an outburst. However, this condition could perhaps be relaxed, considering that the striae appear to have been superimposed on a moderately bright *structureless* "background" tail, although there was very little activity between bursts. It is reasonable to speculate that this "background" tail could have been made of *smeared* striae, whereas the *discrete* striae corresponded to sharp peaks in the torque-factor distribution.

Other fragmentation mechanisms are of course possible and the above discussion of rotational bursting should by no means be interpreted as our bias against such mechanisms.

This research was supported in part by Grant NGR 09-015-159 from the Planetary Atmospheres Program of the National Aeronautics and Space Administration.

REFERENCES

Arnold, J. R.: 1977, in A. H. Delsemme (ed.), *Comets, Asteroids, Meteorites: Interrelations, Evolution and Origins*, Univ. of Toledo, pp. 519-524.

Brownlee, D. E.: 1978, in J. A. M. McDonnell (ed.), *Cosmic Dust*, J. Wiley, Chichester, New York, Brisbane, Toronto, pp. 295-336.

Fuchs, N. A.: 1964, *The Mechanics of Aerosols*, MacMillan Co., New York.

Mariani, F., Ness, N. F., Burlaga, L. F., Bavassano, B., and Villante, U.: 1978, *J. Geophys. Res.* 83, pp. 5161-5166.

Paddack, S. J.: 1969, *J. Geophys. Res.* 74, pp. 4379-4381.

Paddack, S. J.: 1973, 'Rotational Bursting of Small Celestial Bodies: Effects of Radiation Pressure', Catholic Univ. of America (Ph.D. Thesis).

Paddack, S. J. and Rhee, J. W.: 1976, in H. Elsässer, H. Fechtig (eds.), *Interplanetary Dust and Zodiacal Light*, Springer, Berlin, Heidelberg, pp. 453-457.

Sekanina, Z.: 1976a, in B. Donn, M. Mumma, W. Jackson, M. A'Hearn, R. Harrington (eds.), *The Study of Comets*, NASA SP-393, Washington, D.C., pp. 893-939.

Sekanina, Z.: 1976b, *Sky Telesc.* 51, pp. 386-393.

Sekanina, Z.: 1980, review paper in this volume.

Sekanina, Z. and Farrell, J. A.: 1978, *Astron. J.* 83, pp. 1675-1680.

Sekanina, Z. and Farrell, J. A.: 1979, *Bull. Amer. Astron. Soc.* 11, p. 455.