3.2 THE PRODUCTION RATE OF DUST BY COMETS

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ABSTRACT: The present set of short-period comets produces only 250 kg/sec of dust whereas the flux of long-period and "new" comets produces an average of 20 tons/sec.

1. Production of Gas and Dust by Comets

The meteoritic dust cloud present in the solar system is self-destructive. Rather reliable estimates of the dissipating mechanisms (Whipple,1967) suggest that a source of some 10 tons per second would be required for maintaining an approximate steady state. Whipple (1955) has proposed, that cometary dust be the major source maintaining the meteoritic complex. Whipple (1967) has revised his assessment more recently, concluding that Comet Encke could have been, over the past several thousand years, the major support for maintaining the quasi-equilibrium of the zodiacal cloud.

However, recent evidence has changed several of the parameters he used, all in the sense of diminishing the cometary contribution. In particular, 1) recent evaluations of large albedos for the nuclei of three comets (Delsemme and Rud,1973), despite the fact that they may be upper limits (Sekanina,1975), suggest that the efficiency of the solar radiation for vaporizing snows was overestimated by a factor of two or more; 2) water snows, or snows of solid hydrates, seem to control the vaporization of the short period comets, and of many, but not all long-period comets (Delsemme and Swings,1952; Delsemme,1965; Delsemme and Miller,1970,1971; Marsden *et al.*,1973). Solid hydrates (clathrates) and water ice have a larger heat of vaporization than that used by Whipple (1967). Last but not least, the radiation losses of the nucleus back to space cannot be neglected any more for distances larger than 1.5 AU, because water snow sublimates there at approximately 200°K. As cometary dust is dragged away by vaporizing gases, the gas production by comets must be estimated first.

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2. Production Rate of Comet Halley

In order to reassess the whole situation, the water vaporized by Comet Halley has been integrated along its trajectory, by using the model proposed by Delsemme (1965) and developed by Delsemme and Miller (1970,1971). The albedo of the cometary nucleus for the visible light and for the radiative losses to space (near 15μ) have not to be specified, but have been assumed to be the same. The hydrogen production rate of Comet Bennett is assumed entirely produced by water dissociation and normalized for Comet Halley, in proportion to the absolute brightnesses of the two comets. (H_{10} = 4.5 for Bennett, 4.6 for Halley). No evaluation of the size or of the albedo of any cometary nucleus is needed.

The integration, extended to the whole orbit of Comet Halley, yields an average production rate of 63 kg/sec of water; (22 tons/sec at perihelion, 7.6 tons/sec at 1 AU, 800 kg/sec at 2 AU, but less than 1 gram/sec at Jupiter's distance).

3. Short-Period Comets

In order to extend the results to all other comets, a criterion (admittedly crude) was developed to pick up those comets whose production rate is not negligible. In the range where the vaporization is very large, a parabolic approximation of the ellipse can be used. Then, the exposure times per perihelion passage are obviously proportional to $q^{3/2}$, q being the perihelion distance, and the vaporization rate per unit area is proportional to q^{-2}, at least up to 1.5 AU. If the brightness at 1 AU is in proportion to the vaporizing rate, then the gas production rate G per century is

$$G = G_o\ 10^{-0.4\Delta H}\ q^{0.5}\ p^{-1}$$

where G_o is the gas production rate of Comet Halley, ΔH the difference between the absolute magnitudes of the comet considered and Comet Halley, q the perihelion distance and p the period, both in Comet Halley units. This index G, normalized for G_o = 100 for Comet Halley, has been computed for all 97 short-period comets (Marsden,1975). The major producers of gas and dust of the last two centuries are listed per century in Table I. To avoid overestimates of 18th and 19th century brightnesses, Comet Halley's 1835 passage has been again normalized to 100.

Swift-Tuttle is listed in the 1870-1970 period because the averaging procedure ignores where it is on its orbit (it comes back in 1982). As a matter of fact, more than half of the production rates of the short-period comets comes from four comets with rather long periods, namely Swift-Tuttle (120 years), Halley (76 years), Pons-Brooks (71 years) and Olbers (69 years).

The set of short-period comets produces about 0.25 ton/sec. The observed fluctuations from one century to the other are understood, because large comets brighter than Halley's are not likely to be captured more often than once in two centuries (see Delsemme, 1973). At any rate, the production of the short-period comets does not contribute substantially to the production of gas and dust.

TABLE I

Gas Production Rates of Periodic Comets per Century

(p/Halley = 100)

1870-1970		1770-1870	
Swift-Tuttle	120	Swift-Tuttle	120
Halley	100	Halley	100
Olbers	30	Pons-Brooks(1)	70
Pons-Brooks	24	Olbers	47
Encke	16	Encke	44
Faye (2)	7	Faye (1)(2)	40
Gale	5	Biela	31
Schaumasse	4	Brorsen	12
Pons-Winnecke	4	Tuttle	10
Herschel-Rigollet	3	Pons-Winnecke	10
All Others	15	All Others	15
Total	328	Total	499

(1) the gas production of these comets was integrated from their discovery date, since it is not certain that they were in the inner solar system before.

(2) special integration because q>1.2.

4. Long-Period Comets

If we use the same formula (obviously without the p^{-1} term) to compare long-period comets to one passage of Comet Halley, the summation of all long-period comets for the last one hundred years (1870-1970) yields an average production rate of 4.9 tons/sec.

TABLE II

Gas Production Rates of Long-Period Comets per Passage

(One passage of Comet Halley = 100)

Six Recent Comets		Six Very Bright Comets	
Mrkos (1957V)	316	Comet 1577	66,000
Ikeya-Seki (1965VIII)	915	Comet 1729	16,500
Bennett (1970II)	148	Comet 1744	7,100
Kohoutek (1973XII)	135	Comet 1747	5,600
Arend-Roland (1957V)	85	Comet 1402	5,400
Seki-Lines (1962III)	68	Comet 1811 I	5,100

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Table II shows the gas production of a few recent comets. If all comets at least as bright as magnitude zero are excluded, the average of any particular century remains about constant at 5.0 tons/sec. However (see Table II) the rare bright comets like 1811 I (H_{10}=0), 1747 (H_{10}=-0.5), 1729 (H_{10}=-3.0) or 1577 (H_{10}=-1.8) must be included with their average frequency. This frequency is given by Vsekhsviatskii's (1964) "restored distribution" of the brightnesses, more exactly, by the average slope of the log N versus brightness diagram established from his data. Moreover, the Great Comet of 1729 must be excluded because perihelion was at 4.05 AU and the fourth power law used in H_{10} is probably not applicable; (its H_o probably is -0.5). The result depends now on the cutoff limit for the brightest comets. We accept H^o_{max}=-2, (almost observed in 1577). Vsekhsviatskii's curve predicts one comet like Comet 1577 in four centuries.

The new production rate yields 15.6 tons/sec for all comets at least as bright as magnitude zero, therefore 20.8 tons/sec for all comets. Faint comets play an insignificant role, therefore incompleteness does not introduce any corrections. No assessment of the production rate of the gases other than water vapor can be realistically tried at this stage, although there is little doubt that "new" comets (in Oort's sense) and anomalous comets like Humason, Morehouse, or Comet 1729 must contain materials much more volatile than water.

5. Dust Production Rate

Finson and Probstein's (1968) approach shows that the mass ratio dust/gas was of the order of 1.67 for Comet Arend-Roland near perihelion. For Comet Bennett, using Finson and Probstein's method, Sekanina and Miller (1973) find a ratio of 0.5. Since most long-period comets are very dusty, it is therefore reasonable to accept an average ratio of 1.0.

We conclude that comets provide an average source of dust of 20 tons/ sec, although the absence of bright comets has diminished it to 5 tons/sec for the last century. As the characteristic time for the establishment of the steady state is around 10^4 years, the rate to be used for the average source should clearly be rather 20 tons/ sec than 5 tons/ sec.

However, a large fraction of this dust may be lost at once on hyperbolic orbits. If comets are indeed the only source of dust,arguments must be found to demonstrate that approximatively half of this dust remains within the solar system.

I have reviewed the possible arguments on the final day of this colloquium. They are given hereafter under the title ; "Can Comets be the only source of Interplanetary Dust ? "

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