

SPECTROPHOTOMETRY OF 25 COMETS: POST-HALLEY UPDATES FOR 17 COMETS PLUS NEW OBSERVATIONS FOR EIGHT ADDITIONAL COMETS

RAY L. NEWBURN, JR.

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109

HYRON SPINRAD

Astronomy Department, University of California, Berkeley, California 94702

Received 13 September 1988; revised 24 October 1988

ABSTRACT

The best possible production figures within our current post-Halley framework and available observations are given for H₂O, O[¹D], CN, C₃, C₂ and dust in 25 comets. Of these, the three objects with the smallest mixing ratios of all minor species have moderate to little or no dust and appear "old." Comets with large amounts of CN are very dusty, and there is a clear correlation of CN with dust, although comets with little or no dust (SSF, Encke) still have some CN. Thus, CN appears to have at least two sources, dust and one or more parent gases. Also, the C₂/CN production ratio changes continuously with heliocentric distance in every comet for which we have data, suggesting that C₂ production may be a function of coma density as well as parental abundance. Dust production ranges from essentially zero in Comet Sugano-Saigusa-Fujikawa up to 67 000 kg s⁻¹ for Halley on 14 March 1986. Yet, none of the 25 comets observed was a new comet in the sense of having $1/a < 200 \times 10^{-6} \text{ AU}^{-1}$.

I. INTRODUCTION

In the year following the multiple spacecraft encounters with P/Halley in March 1986, it became obvious that some of the assumptions based upon limited evidence in our earlier papers in this series (Newburn and Spinrad 1984, 1985, hereafter referred to as papers I and II) could now be improved. Halley was larger, darker, perhaps less dense, more irregularly shaped, and more uneven in activity than had been predicted. Infrared studies of comets *IRAS-Araki-Alcock* (Hanner *et al.* 1985), *Arend-Rigaux* (Tokunaga and Hanner 1985), and *Neujmin 1* (Campins, A'Hearn, and McFadden 1987) have shown that "old" comets can still have large, dark nuclei, while *Sugano-Saigusa-Fujikawa* (Hanner *et al.* 1987) was old, small, and depleted in minor species relative to water. All of these suggest that in some cases the nucleus *does* make a significant contribution to continuum light and that the gravity effect in the dust escape velocity (Eqs. (16) and (17), Paper II) is sometimes larger than previously assumed. We have found that the mixing ratio CN/O[¹D] cannot always be assumed to be near 1/50 (Paper I), although that is not a bad assumption when no actual measurements are available. In Paper II we assumed the total gas flow to be water plus 10% of other gases. At least Halley had about 20% of "other stuff." There is also evidence that the dust grains have a much lower bulk density than previously assumed.

Several new studies of Haser scale lengths have appeared since papers I and II were submitted, notably Cochran (1985, 1987) and Combi and Delsemme (1986). The brightness profiles versus distance from the nucleus used in these studies contain many more points than were available to us in Paper I. Our abundances deserve reanalysis with the newer parameters. We considered comparing our water results with a more accurate analysis using Festou's (1981a,b) vectorial model, for which he had kindly sent us the code. Combi and Delsemme's (1980a) average random-walk model would have been another possibility, less complex and nearly as accurate. Unfortunately, the reactions and their lifetimes leading to the formation and loss of the principal minor species CN, C₂, and C₃ are not certain enough to allow

unambiguous use of either model for them. In this paper, we remain loyal to the Haser paradigm. All O[¹D] measurements have been reduced using the full Haser expressions rather than the approximation in Spinrad's (1982) Eq. (4).

During the period 1983-1986, we acquired data on eight other comets, especially a large number of observations of P/Halley. Only the data on *Sugano-Saigusa-Fujikawa* have been previously detailed (Hanner *et al.* 1987), and we include those in the tables for comparison purposes. The dataset numbering used in papers I and II is retained here, though with some sets dropped and many sets added.

II. THE OBSERVATIONS

Observational technique and details for datasets through 105 were described in Sec. II of papers I and II. Datasets 108, 110, and 113 were obtained with the 1 m Nickel reflector at Lick Observatory using the same IDS (image-dissector scanner) as the previous datasets, which on that telescope implies 8 arcsec diam apertures 85 arcsec apart. The remaining sets through 135 were obtained with CCD spectrometers utilizing various apertures as indicated in the tables. In the data reductions, rectangular apertures are treated as circular apertures having the same area, which causes a slight error but saves a large computational effort. The other telescopes involved were the 3 m Shane reflector of Lick Observatory (22 datasets), the 4 m Mayall reflector at Kitt Peak National Observatory (three datasets), and the 4 and 1.5 m reflectors of the Cerro Tololo Inter-American Observatory (one dataset each).

The Lick CCD spectrometer at the 3 m Cassegrain focus utilizes a Texas Instruments 800×800 chip (UV flooded since 1986). Descriptions can be found in Lauer *et al.* (1983) and Robinson *et al.* (1987). Dispersing elements were a set of grisms, which could be placed in the beam for spectral order separation. Spectrophotometry was usually done with a 2"1×120" slit, the tabular values being a computer extraction of the nucleus-centered segment. These usually were 7 pixels in width, which project to 5 arcsec on the sky. In general, separate, nonsimultaneous sky measures were taken well outside the cometary coma.

Standards were the same Stone (1974, 1977) and Oke (1977) stars previously used for the IDS work reported in papers I and II. The flux errors on photometric nights are thought to be under 20%, and in the red may be below 10% in the best cases.

III. DATA REDUCTION

a) Emission Data

All nucleus-centered data, old and new, were reduced from the original irradiance measurements using new constants discussed below. The coma points are not rediscussed, since their primary use was in the measurement of scale lengths.

1) [CN]

The emission-rate factors are now taken from Tatum (1984). The new tabulation covers a range of velocity and heliocentric distance and can be read more accurately than the graph in Tatum and Gillespie (1977). The new factors were also calculated, using a whole-disk spectrum of the Sun rather than just a disk-center spectrum.

The question of an appropriate parent scale length for CN has been made more difficult by the discovery of CN jets in P/Halley (A'Hearn *et al.* 1986). If indeed dust acts as an extended CN parent out to many tens of thousands of kilometers, as A'Hearn *et al.* suggest, the Haser model is totally inapplicable to this CN component. On the other hand, Combi (1987) suggests that it is physically feasible for a gas jet originating on the surface to remain nearly collimated, in which case there is no more problem than the usual Haser limitation.

The accepted CN parent scale length for some years has been the $2.2 \times 10^4 r^2$ value of Combi and Delsemme (1980b). In their new work (Combi and Delsemme 1986), they suggest a best fit of $1.6 \times 10^4 r^{1.5}$, while acknowledging that the scatter is large and the data not inconsistent with an r^2 law (which then requires a slightly larger constant). Cochran (1985) finds $1.7 \times 10^4 r^2$ using a larger dataset than available to Combi and Delsemme. Our own value from Paper I ($1.2 \times 10^4 r^2$) is excellent for some comets but poor for others. Rees, Meredith, and Wallis (1986) obtained 3.1×10^4 km from 12 images of P/Halley for which accurate background correction was not possible. Reviewing all datasets, we have selected a value of $1.8 \times 10^4 r^2$ as an acceptable compromise for all the data.

The CN (radical) scale length has proven difficult to determine observationally because of large-scale coma asymmetries and activity fluctuations. The "traditional" value has been an ill-determined $3 \times 10^5 r^2$, with suggestions that it could be larger (Combi and Delsemme 1980; A'Hearn 1982). Rees, Meredith, and Wallis (1986) have used 19 very large CN images of Halley (field of view $\sim 10^7$ km) taken with patrol-type lenses (focal length 180 and 300 mm) and an imaging photon detector to obtain a mean value of $4.2 \times 10^5 r^2$. These should have provided the best observational value ever obtained, at least for one very active comet. We have used the Rees *et al.* value in all cases.

2) [C₂]

The emission-rate factor for C₂ used in Paper I, and generally for a number of years, has been discovered to be in error by a factor of 2 (A'Hearn *et al.* 1985). The new g value, used in this paper, is $4.5 \times 10^{-20} r^{-2}$ W mol⁻¹.

A variety of C₂ parent scale lengths have been used recently, ranging from 1.7×10^4 (A'Hearn 1982) through 2.5×10^4 (Cochran 1985) to 3.8×10^4 (Paper I). The most significant difference was the linear variation with heliocentric distance, suggested originally by Delsemme and Moreau (1973) and apparently confirmed by A'Hearn and Paper I data, versus the 2.5 power variation in the Cochran data. The new Combi and Delsemme (1986) work suggests $3.1 \times 10^4 r^2$, which seems an acceptable, if not perfect, fit to all of the data and is used here. A new study of P/Halley (O'Dell *et al.* 1989) gives evidence that C₂ is a third-generation molecule rather than second, but it is difficult to be sure whether their improved fit represents physical reality or is just the product of an additional free parameter. Chemical modeling suggests that it is the latter (Allen, private communication). The traditional value for a C₂ lifetime suggested by Delsemme and Moreau (1973) and used generally over the past decade is $1.2 \times 10^5 r^2$. Combi and Delsemme (1986) are still happy with this value, and so are we.

3) [C₃]

A'Hearn (1982) suggested using an emission-rate factor of 1×10^{-19} W mol⁻¹, based upon a simple averaging of various modern theoretical and experimental oscillator strengths reviewed by Cooper and Jones (1979). This was a factor of 40 larger than the value commonly in use until then. Cochran (1987) suggests a value for g of 4×10^{-20} W mol⁻¹, based upon an oscillator strength from an interstellar cloud study of Clegg and Lambert (1982). Clegg and Lambert did no new theoretical or experimental work however, they simply reviewed a subset of the data reviewed by A'Hearn. We see no reason to change from the previously (Paper I) adopted A'Hearn value of 1×10^{-19} W mol⁻¹.

For C₃ scale lengths, we have used compromise values that fit all of the data moderately well, namely $3 \times 10^3 r^2$ for the parent and $1 \times 10^5 r^2$ for the radical. The constants used are collected in Table I.

4) O[¹D] and H₂O

The same basic constants have been used as in Paper I. The full Haser formula (Eq. (5), Paper I) has been used for reduction of all O[¹D] data rather than the approximate formula (Eq. (4), Spinrad 1982), however, and cases where aperture diameter values had been used incorrectly instead of radius have been corrected.

Conversion of O[¹D] to H₂O is handled more realistically than in Paper II, where we assumed a constant ratio of H₂O:O[¹D] equal to 12.5 based upon Festou's (1981b) calculation that the O[¹D] production varies from 6% to 9% from sunspot minimum to maximum. We have taken the actual solar Ly α flux for the time of each observation from

TABLE I. Gas-production constants. r is heliocentric distance in AU.

	CN	C ₂	C ₃
Emission Rate Factor g (W molecule ⁻¹)	Tatum (1984)	$4.5 \times 10^{-20} r^{-2}$	$1.0 \times 10^{-19} r^{-2}$
Parent Scale Length (km)	$1.8 \times 10^4 r^2$	$3.1 \times 10^4 r^2$	$3.0 \times 10^3 r^2$
Radical Scale Length (km)	$4.2 \times 10^5 r^2$	$1.2 \times 10^5 r^2$	$1.0 \times 10^5 r^2$

Ajello *et al.* (1987) for 1978 through 1984 and assumed the sunspot minimum value for the 1985–86 data. The photodissociation of water by all wavelengths other than Ly α varies only from 1.3% to 1.0% over the sunspot cycle (Festou 1981b), so we have assumed a constant 1.15% production from these. Only 92% of the water is photodissociated at all, the rest being lost to ionization and ion–molecule reactions. Therefore, we can summarize

$$\text{H}_2\text{O} = [0.92(0.0115 + \text{Ly}\alpha\text{O})]^{-1}\text{O}[\text{D}]. \quad (1)$$

where Ly α O is the fraction of H₂O photodissociated to O[¹D] by Ly α . Festou (1981b) has given exact calculations for 3×10^{11} and 6×10^{11} photons s⁻¹ cm⁻² Å⁻¹. Since for all practical purposes the equivalent width of Ly α is 1 Å, we have scaled these results, given in Table II, to reduce all of our observations.

All of our water abundances assume there to be no significant source of O[¹D] in our data other than water. A known

source of contamination is the dissociation of OH (Van Dishoeck and Dalgarno 1984). A study of Halley by Roesler *et al.* (1986) shows that this component only makes a measurable contribution more than about 5×10^4 km from the nucleus, as would be expected from the scale length of OH. Our small apertures assure freedom from this problem. Neutral CO₂, sometimes discussed as an O[¹D] source, was seen in a comet for the first time in Halley, but again the scale length for loss is quite large and its abundance was only 1%–2% of water (Combes *et al.* 1986). Our approach to H₂O abundance determination seems reasonably secure.

b) Continuum Data

We are still far from a perfect understanding of exactly what occurs on the surface of a comet nucleus in sunlight. Observations from the armada of Halley spacecraft improved our knowledge of some details of one comet, and we have used these details, along with new ground-based data on other comets, to improve our continuum theory. The new observations have changed some aspects of how we view and model the nucleus, although sparse data on individual comets often make the results difficult to quantify. In particular, the continuum contribution from the solid nucleus itself has become more difficult to separate from the dust in many sparse data cases.

Perhaps the best example of changing perspective is our view of jets. In the past, they were seen as major sources only of dust, with just enough heavily loaded gas to lift it. Most of the gas was thought to be emitted, with some dust, much more uniformly over the lighted surface. Now we tend to view the jets as the major source of both dust and gas, while at most a small amount of gas and little or no dust diffuse out more uniformly from the lighted “hemisphere” or perhaps even the entire “sphere.” The *Giotto* Halley Multicolor Camera team concluded that all of the larger dust, perhaps all of the dust, and most of the gas originate on 20% of the lighted surface (Huebner *et al.* 1986). Yet studies of tiny Comet Sugano–Saigusa–Fujikawa (SSF) (Hanner *et al.* 1987) require that at least the entire lighted hemisphere produce gas at a rate appropriate to a 200 K ice sphere, while producing no dust at all. In the nomenclature of Paper II this would give Halley $f = 0.1$ and SSF $f = 0.5$, while they have mean radii $\bar{R} \approx 6.9$ and $\bar{R} \approx 0.4$ km, respectively. This means one cannot gauge nucleus size strictly by gas production. This is not really surprising, but it makes it appear less viable to so derive nuclear radii, as we did in Paper II, in the absence of other data.

Accurate continuum photometry through nucleus-centered apertures of different sizes permits separation of the contributions from dust and from the nucleus in those cases where the dust contribution does not completely dominate. When dust dominates, no information on nucleus size remains, and there is no objective way to measure the gravitational pull of the nucleus on the dust. When a spectrometer is used to take the data and the aperture is fixed, pure dust data can be taken in principle by moving off the nucleus, but given the lack of isotropy in dust emission, a complete dust-coma mapping would be required to have real confidence in the result. Given the photometric errors in background subtraction in our few, weak, off-nucleus continua, accurate values are not available from our own data, although the continua were clearly present.

Given all the difficulties discussed, we have done the following. There is a lower limit on nucleus size set by water

TABLE II. Ly α intensity and the production of O[¹D] from H₂O, as per Eq. (1), for the various dates of observation.

Date	Ly α Intensity* (photons cm ⁻² s ⁻¹)	Fraction O[¹ D] from Ly α	Ratio H ₂ O/O[¹ D]
Dec. 73	2.60	.056	16.1
Jan. 74	2.60	.056	16.1
June	2.80	.058	15.6
Oct. 78	3.40	.067	13.8
Feb. 79	3.70	.070	13.3
Mar.	3.60	.069	13.5
Feb. 80	3.55	.068	13.7
Mar.	3.50	.0675	13.8
May	3.75	.0705	13.3
June	3.70	.070	13.3
Aug.	3.45	.0675	13.8
Sept.	3.60	.069	13.5
Oct.	3.60	.069	13.5
Nov.	3.55	.0685	13.6
Dec.	3.35	.067	13.8
Feb. 81	3.20	.063	14.6
Mar.	3.20	.063	14.6
Apr.	3.20	.063	14.6
Sept.	3.40	.067	13.8
Oct.	3.65	.0695	13.4
Nov.	3.75	.0705	13.3
Jan. 82	3.80	.071	13.2
June	3.30	.066	14.0
May 83	3.00	.060	15.2
June	3.05	.061	15.0
Feb. 84	2.90	.0595	15.3
1985	2.40	.055	16.3
1986	2.40	.055	16.3

* Ajello, *et al.* 1987

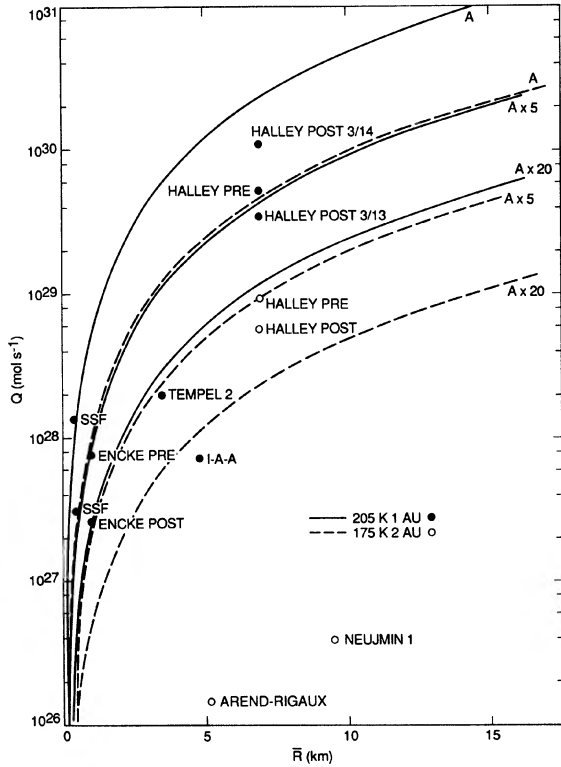


FIG. 1. Production rate of water Q (molecules s^{-1}) vs cross-section of mean radius \bar{R} (km) at two heliocentric distances having sublimation temperatures of 175 and 205 K. The curves marked $A \times 5$ and $A \times 20$ assume areas five and twenty times the active production area (surfaces 20% and 5% active). Specific comet data not from the paper are from the following sources: SSF (Hanner *et al.* 1987), Neujmin 1 (Campins *et al.* 1987), Arend-Rigaux (Millis *et al.* 1988), Encke-post (A'Hearn *et al.* 1985; Kamoun *et al.* 1982), IAA (Sekanina 1988b), Tempel 2 (Sekanina 1987), and Halley (Keller *et al.* 1987). Water production was scaled from the nearest heliocentric distance as r^{-3} when not available at exactly 1.0 or 2.0 AU.

production. On average, the energy of sublimation required to produce the gaseous water cannot exceed the solar energy falling on the nucleus minus the reradiation, although extra energy stored in various forms may become available briefly on occasion. Sekanina kindly supplied a printout of solutions to the energy-balance equation, from which we selected values for heliocentric distances of 1 and 2 AU, visual albedo of 0.05, infrared emissivity of 0.95, and normal incidence. The resulting temperatures are 205 and 175 K. The minimum area $A = \pi \bar{R}^2$ normal to the Sun required to produce a given amount of water is shown in Fig. 1. Recognizing that only a small fraction of most cometary nuclei is active, we have also shown curves for comets with 20% and 5% of their cross sections active. Also plotted in Fig. 1 are actual locations for comets of which we have some physical knowledge of their size.

It can readily be seen that "ordinary" periodic comets fall generally toward the middle of the curves drawn in Fig. 1, while Arend-Rigaux and Neujmin 1, which have often been referred to as dead or nearly dead, are far to the right. This implies that little of their surfaces is active. The Earth-grazer, *IRAS-Araki-Alcock*, also lies to the right. There is

no completely objective way to separate the "worn-out" group from the "ordinary" group. Appearance alone would have placed Sugano-Saigusa-Fujikawa in the "worn-out" group. Most of the time, treating our comets as "ordinary" seems the best procedure, and nucleus radii for the dust-velocity equation given in Table III are scaled to either 1 or 2 AU and are then taken largely from the middle of the curves in Fig. 1.

The latest value of mean density derived for Halley is $0.6 [_{-0.4}^{+0.9}] g cm^{-3}$ (Sagdeev, Elyasberg, and Moroz 1988). This may eventually be further refined with an improved theory and modeling of the nongravitational (jet) forces. At the moment, we see no strong reason to depart from the canonical $1 g cm^{-3}$ used in Paper II. In Paper II, we used a dust particle density varying from $3.3 g cm^{-3}$ for the smallest grains to $0.8 g cm^{-3}$ for the larger ones. There was no evidence from the *VEGA* spacecraft of densities in excess of $1 g cm^{-3}$, and values nearer $0.3 g cm^{-3}$ seemed more able to fit the observations (Krasnopolsky *et al.* 1987; Smirnov, Vaisberg, and Anisimov 1987). None of the Halley flight instruments were designed or calibrated to measure density accurately, however, and some scientists continue to use $1 g cm^{-3}$ for small particles. *DUCMA* has given convincing evidence that large particles are fragmenting or "coming unglued" at some distance from the nucleus (Simpson *et al.* 1987), but this problem should not greatly concern us with our small nucleus-centered apertures. Crifo (1988a) has ar-

TABLE III. Constants used in calculating dust production. See Sec. IIIb (and Paper II) for details.

Comet	Heliocentric Distance AU	M	Nucleus Radius (km)	f
P/Encke	1.89	20	1.0	0.1
	1.70-1.69	18		
	1.15	15		
	0.85-0.78	12		
P/Tuttle	1.92	21	1.3	0.1
	1.75	19		
	1.35-1.17	15		
P/Stephan-Oterma	2.04-1.93	20	5.0	0.1
	1.73-1.57	18		
Kohoutek	0.96	13	4.5	0.1
Bradfield	1.75	19	1.0	0.1
	1.15-1.14	15		
P/Grigg-Skjellerup	1.04	24*	0.6	0.05
P/Swift-Gehrels	1.53-1.41	17	1.7	0.1
	1.36	16		
P/Kearns-Kwee	2.27-2.22	22	1.3	0.1
P/Gehrels 2	2.36	23	2.0	0.1
Meier	2.19	22	5.0	0.1
Panther	1.86	19	5.5	0.1
P/Borrelly	1.34	16	3.5	0.1
P/Wild 3	2.41	23	1.2	0.1
P/Brooks	1.86	20	1.2	0.05
Sugano-Saigusa-Fujikawa	1.08-1.06	14	0.37	0.05
P/Kopff	1.68	18	5.0	0.1
P/Tempel 2	1.39	16	3.5	0.1
	1.74	18		
IRAS-Araki-Alcock	1.01	14	4.8	0.02
	0.75	12	1.2	0.05
P/Crommelin	1.73	18	2.5	0.1
P/Giacobini-Zinner	1.48	17		
	1.23	15		
	1.05	14		
P/Wild 2	2.27	22	3.0	0.1
	2.84	26	6.9	0.1
P/Halley	2.60-2.56	24		
	2.21-2.14	22		
	1.76	19		
	0.90	13		

* Abnormally large. Hanner, private communication.

gued that a density of 0.3 g cm^{-3} or less is required to produce the observed $10\text{--}20 \mu\text{m}$ emission features. Our preferred calculations this time have been done with a constant particle density of 0.3 g cm^{-3} , but results for 1 g cm^{-3} are given also. The constant M (see Paper II) changes with heliocentric distance as before, becoming larger at a greater distance. Larger M implies a shift to slightly larger particles. This may be observational evidence of delayed fragmentation at larger solar distances.

In Paper II it was assumed that the gas and dust evolved more or less uniformly from the entire lighted hemisphere, unless there was definite observational evidence to the contrary, such as an observed fan. Here it is assumed that dust and gas evolve together from very limited areas, jets, and the value of f for all comets for which the nucleus radius has not been determined is taken as 0.1 or 0.05 (20% or 10% of the lighted hemisphere), in accordance with the data in Fig. 1. The lower value is taken for the fainter objects. The values of R , M , and f used in this data reduction are collected in Table III.

With the nucleus sometimes making a significant contribution to the continuum, we have calculated $A p(\lambda)\phi(\alpha)$ from Eq. (2) of Paper II, and then subtracted the nucleus contribution $\pi R^2 p(\lambda)\phi_n(\alpha)$ calculated using the value of R in Table III and an asteroidal nucleus phase function ϕ_n of 0.035 mag per degree (as given in Table VIII). The resulting dust contribution $A_d p(\lambda)\phi_d(\alpha)$ is then converted to $A_d p(\lambda)$, also given in Table VIII, using Divine's dust-scattering function as before (Divine 1981) for use in Eq. (11) of Paper II. Results in Table VIII were calculated using a mean geometric albedo p_g of 0.04, rather than 0.05 as in Paper II, in order to reflect the latest results for Halley (Hammel *et al.* 1987; Tokunaga *et al.* 1986) and for other comets (Hanner 1985). In a few cases, noted in Table VIII, where water production was not available at almost the same time as the continuum data, water production was derived by multiplying water production on another nearby night by the ratio of CN production on the two nights. (CN production seems to hold a sensibly constant ratio to H_2O in a given comet for at least a short period of time.) In addition, two values of water production were calculated by assuming $Q(\text{O}[^1\text{D}]) = 50 Q(\text{CN})$ as in Paper I.

IV. RESULTS

a) Emission Features

The production of CN, C_3 , C_2 , and $\text{O}[^1\text{D}]$ under the assumptions of Sec. III are given in Tables IV–VII, respectively. Table VII also gives the water production calculated from $\text{O}[^1\text{D}]$ using Festou's (1981b) cross sections. A graphical overview of the H_2O production is given in Fig. 2. Obvious features are the expected increase in water production as an individual comet approaches the Sun, an intrinsic scatter, especially in the Halley points, showing real short-term variations, and a range of some three orders of magnitude in water production among various comets at a given heliocentric distance. P/Stephan–Oterma was less active postperihelion than at the same distance preperihelion. P/Halley showed the opposite behavior in 1985–1986, just as it probably did in 1910 (Divine *et al.* 1986). P/Halley was the most active comet observed, but our observations were strongly biased toward short-period comets. None of the five “long-period” comets we observed at $\text{O}[^1\text{D}]$ were new in the sense of having $(1/a)_{\text{orig}} < 200 \times 10^{-6} \text{ AU}^{-1}$. Bradfield has a pe-

riod of 291 yr and IRAS–Araki–Alcock about 1000 yr (Marsden 1986). Sugano–Saigusa–Fujikawa, Meier, and Panther had $(1/a)_{\text{orig}}$ equal to 378×10^{-6} , 3973×10^{-6} , and 581×10^{-6} , respectively (Everhart and Marsden 1983, 1987), and neither Meier nor Panther came very close to the Sun.

Most of the production figures for CN, C_3 , and C_2 are plotted in Figs. 3–5. In general, the changed reduction constants have resulted in slightly increased CN production, decreased C_2 production, and slightly increased C_3 production. The limited data available still seem to show a steeper decrease in C_2 production beginning at about 1.8 AU for any given comet, although large amounts of C_2 are produced at much greater distances in several comets for which we have no coverage over a range of distances. There is no evidence of this behavior in CN, and only Stephan–Oterma shows it for C_3 . The ratio of C_2 to CN is given in Table VI and also plotted in Fig. 6. This linear plot shows that the C_2/CN ratio appears to change continuously as a function of heliocentric distance for any given comet. Since the C_2 and CN data were largely acquired simultaneously, these ratios are much more reliable than the ratios of $\text{O}[^1\text{D}]$ to other species given in Table VII. (The $\text{O}[^1\text{D}]$ data were always taken at a different time of night from CN or C_3 , since they require a different grating tilt, and part of the C_2 data were also taken at different times.) A possible interpretation is that the parent or parents of CN are a more or less constant admixture with water, while C_2 is, at least in part, the product of chemical reactions that decrease as the coma density drops. Detailed studies of the huge Halley dataset being archived by the International Halley Watch should help to settle this question.

Looking at individual comets, it is interesting to note that the three objects that have the smallest amounts of CN, C_3 , and C_2 relative to water are Grigg–Skjellerup, Brooks 2, and Sugano–Saigusa–Fujikawa (SSF), all apparently rather “old” comets with moderate (Brooks 2) to no dust (SSF). Tempel 2 is depleted in CN and C_3 , more normal in C_2 , and has little dust. Borrelly is depleted in C_2 and somewhat in C_3 but not in CN, and it is a very active, dusty short-period comet. Kearns–Kwee and Wild 3 show even more abundant CN and normal C_2 , and both are very dusty. This might be taken as evidence that dust is in fact a parent of CN. The dust-to-gas ratio ψ is plotted against the CN-to-oxygen ratio in Fig. 7. Indeed, dusty comets tend to have more CN, but Encke and SSF, which have little dust, still have CN, which argues that dust and one or more parent molecules are both CN sources. No such case can readily be made for C_2 or C_3 . Figure 8 has $\text{C}_2/\text{O}[^1\text{D}]$ plotted against ψ . It is a “scatter diagram.”

Our picture of “normal” cometary behavior has changed significantly since Paper I as a result of the spacecraft encounters and particularly the studies of Sekanina (e.g., Sekanina 1988a,b,c). Daily fluctuations in production rates as a nucleus rotates and “seasonal” changes as active areas receive changed insolation are now expected. Unfortunately, inverting the problem and determining nucleus shape, rotation period, axial inclination, precession, and jet location is not feasible without a great deal of data over a long period or intense, very precise, two-dimensional photometry over a shorter period (but still at least one and preferably two or more revolutions). The photometry reported here was intended to study the range of cometary behavior and is not by itself adequate for detailed nucleus or coma modeling. In the

TABLE IV. CN production. r is heliocentric distance in AU. Δ is geocentric distance in AU. In the location column, N is nucleus centered and remote sky subtracted data. N - nn¹ is nucleus centered data with coma subtraction nn¹ away and corrected to pure N within the assumptions of the Haser theory.

Object	Data		r	Δ	Irradiance (Wm ⁻²)	Aperture Diameter	Location	Corrected	$v = 1 \text{ km s}^{-1}$	
	Set	Date						Column Density (m ⁻²)	Production (mol s ⁻¹)	
P/Encke	1	21 Aug.	80	1.89	1.47	6.20×10^{-18}	4"	N	1.82×10^{13}	1.51×10^{24}
1980 XI	3	7 Sept.	80	1.69	1.09	2.13×10^{-17}	4"	N	4.66×10^{13}	3.04×10^{24}
	7	16 Oct.	80	1.15	0.37	3.65×10^{-16}	8"	N-85"	1.23×10^{14}	4.02×10^{24}
	8A	" " "	" " "	" " "	" " "	6.70×10^{-16}	8"	N	2.26×10^{14}	7.39×10^{24}
	11	4 Nov.	80	0.84	0.31	1.80×10^{-15}	4"	N	1.28×10^{15}	2.12×10^{25}
	16	6 Nov.	80	0.78	0.32	1.70×10^{-15}	4"	N	1.02×10^{15}	1.51×10^{25}
P/Tuttle	20	21 Aug.	80	1.92	1.96	5.86×10^{-18}	4"	N	1.93×10^{13}	1.74×10^{24}
1980 XIII	21	6 Sept.	80	1.75	1.71	1.37×10^{-17}	4"	N	3.74×10^{13}	2.83×10^{24}
	23	16 Oct.	80	1.35	1.06	7.63×10^{-16}	8"	N-85"	3.08×10^{14}	1.65×10^{25}
	25	4 Nov.	80	1.19	0.76	4.52×10^{-16}	4"	N	5.79×10^{14}	2.01×10^{25}
	32	6 Nov.	80	1.17	0.73	6.31×10^{-16}	4"	N	7.89×10^{14}	2.64×10^{25}
P/Stephan-Oterma	36	20 Aug.	80	2.04	1.63	1.82×10^{-17}	4"	N-35"	8.04×10^{13}	7.67×10^{24}
1980 X	40	6 Nov.	80	1.62	0.72	1.95×10^{-16}	4"	N	4.75×10^{14}	2.67×10^{25}
	45	8 Dec.	80	1.57	0.59	1.91×10^{-16}	4"	N-35"	6.43×10^{14}	3.31×10^{25}
	50	1 Feb.	81	1.73	0.90	1.08×10^{-16}	4"	N	2.39×10^{14}	1.56×10^{25}
	52	6 Mar.	81	1.94	1.31	3.13×10^{-17}	4"	N	8.99×10^{13}	7.58×10^{24}
Comet Kohoutek	57	29 Jan.	74	0.96	0.93	7.6×10^{-15}	2" x 3"	N	1.38×10^{16}	3.30×10^{26}
1973 XII										
Comet Bradfield	58	7 Feb.	80	1.14	0.51	6.02×10^{-15}	8"	N	1.99×10^{15}	6.90×10^{25}
1979 X	63	17 Mar.	80	1.75	1.90	5.6×10^{-15}	4"	N-35"	1.71×10^{16}	1.32×10^{27}
P/Grigg-Skjellerup	66	6 Jun.	82	1.04	0.34	9.13×10^{-17}	4"	N	6.98×10^{13}	1.66×10^{24}
1982 IV										
P/Swift-Gehrels	73	30 Nov.	81	1.36	0.68	9.87×10^{-17}	4"	N	2.39×10^{14}	1.00×10^{25}
1981 XIX	78	24 Jan.	82	1.53	1.04	1.32×10^{-16}	4"	N	2.28×10^{14}	1.26×10^{25}
P/Kearns Kwee	84	30 Oct.	81	2.24	1.62	1.42×10^{-17}	4"	N	7.78×10^{13}	8.62×10^{24}
1981 XX	86	30 Nov.	81	2.22	1.32	2.94×10^{-16}	4"	N	1.84×10^{13}	1.93×10^{24}
	88	24 Jan.	82	2.27	1.37	1.22×10^{-17}	4"	N	7.01×10^{13}	7.68×10^{24}

TABLE IV. (continued)

Object	Data		r	Δ	Irradiance (Wm^{-2})	Aperture Diameter	Location	Corrected Column Density (m^{-2})	$v = 1 km s^{-1}$ Production ($mol s^{-1}$)
	Set	Date							
P/Gehrels 2 1981 XVII	91	30 Nov. 81	2.36	1.53	4.57×10^{-16}	4"	N	3.24×10^{15}	3.86×10^{24}
P/Borrelly 1981 IV	95	1 Feb. 81	1.34	1.47	8.91×10^{-16}	4"	N	1.69×10^{16}	8.18×10^{25}
P/Wild 3 1980 VII	100	17 Jun. 80	2.41	1.91	1.02×10^{-17}	4"	N	1.39×10^{14}	1.79×10^{26}
P/Brooks 2 1980 IX	104	4 Nov. 80	1.86	1.23	2.7×10^{-16}	4"	N	1.05×10^{15}	8.17×10^{23}
Sugano-Saigusa-Fujikawa 1983 V	108	13 Jun. 83	1.08	0.065	4.58×10^{-16}	8"	N	1.38×10^{14}	2.94×10^{24}
P/Kopff 1983 XIII	110	13 Jun. 83	1.68	0.73	2.12×10^{-16}	8"	N	1.35×10^{15}	9.26×10^{25}
P/Tempel 2 1983 X	113	13 Jun. 83	1.39	1.20	5.48×10^{-16}	8"	N	2.99×10^{14}	1.73×10^{26}
	114	11 Sept. 83	1.74	1.00	3.43×10^{-17}	2".8	N	1.55×10^{14}	9.72×10^{24}

future, a new level of sophistication in observing will be required.

b) The Continuum

Numbers associated with the continuum analysis are given in Table VIII. Two sets of "final" results are given, those for $\rho = 1$ and $p = 0.03$, and those for $\rho = 0.3$ and $p = 0.04$. The former, multiplied by 0.6 to compensate for the lower geometric albedo used here, are similar to the figures in Paper II. The differences are caused by the use of constant density rather than density varying with size, and by changes in nucleus size and fraction of the nucleus that is active. The second set of figures are those we consider to be the best for use, given the current understanding of comets. It is this set that is referred to in the following discussion. In general, the dust and mass ratios quoted for $\rho = 0.3$ are down from those given in Paper II, of course. The effect of increased escape velocity, which is the product of larger nucleus size, is often compensated by the higher gas density, which results from the gas being supplied from a smaller fraction of the nucleus. The dust-to-gas mass ratio of Encke still decreases as it approaches the Sun, while those of Tuttle, Stephan-Oterma,

and Swift-Gehrels are fairly constant, as previously noted. Now we have added several comets, among them Giacobini-Zinner (GZ) and Halley, and these data at first appear surprising. The GZ mass loading is nearly constant, but was almost twice as high as in any previous comet we had observed. The meteors from GZ are well known to burn up higher in the Earth's atmosphere, which implies a lower bulk density than for even ordinary cometary debris (Ceplecha 1977; Sekanina 1985), so a lower density of perhaps $0.2 g cm^{-3}$ could have been used to decrease the loading. When we began to reduce Halley data, however, the loadings grew once again, now typically to values between 1 and 3!

At first glance, our Halley result for 14 March 1986, dataset 132, seemed to be in conflict with the reported *Giotto* result (McDonnell *et al.* 1987, Table VI). The *Giotto* gas production of $2.1 \times 10^4 kg s^{-1}$ or $7 \times 10^{29} mol s^{-1}$ is half our result, but our measurement was global rather than local and the data taken about 11 hr later, so that difference is acceptable given Halley's rapid fluctuations. If the McDonnell *et al.* total dust emission is extrapolated to our largest particle radius of 1.05 m, their result far exceeds our $67,000 kg s^{-1}$ figure, which seemed so large. Our mass distribution function (Paper II, Eq. (7)) has an *incremental* radius slope

TABLE V. C₃ production. Comments same as in Table IV.

Object	Data		r	Δ	Irradiance (Wm ⁻²)	Aperture Diameter	Location	Corrected Column Density (m ⁻²)	v = 1 km s ⁻¹ Production (mol s ⁻¹)
	Set	Date							
P/Encke 1980 XI	1	21 Aug. 80	1.89	1.47	2.03 × 10 ⁻¹⁸	4"	N	3.09 × 10 ¹²	6.65 × 10 ²²
	3	7 Sept. 80	1.69	1.09	6.05 × 10 ⁻¹⁸	4"	N	7.35 × 10 ¹²	1.24 × 10 ²³
	7	16 Oct. 80	1.15	0.37	1.40 × 10 ⁻¹⁸	8"	N-85"	2.05 × 10 ¹³	1.81 × 10 ²³
	8A	" " " " " "	" "	" "	2.96 × 10 ⁻¹⁸	8"	N	4.17 × 10 ¹³	3.68 × 10 ²³
	11	4 Nov. 80	0.84	0.31	7.81 × 10 ⁻¹⁸	4"	N	2.35 × 10 ¹⁴	1.02 × 10 ²⁴
	16	6 Nov. 80	0.78	0.32	7.24 × 10 ⁻¹⁸	4"	N	1.88 × 10 ¹⁴	7.47 × 10 ²³
P/Tuttle 1980 XIII	20	21 Aug. 80	1.92	1.96	7.76 × 10 ⁻¹⁸	4"	N	1.22 × 10 ¹³	2.95 × 10 ²³
	21	6 Sept. 80	1.75	1.71	4.93 × 10 ⁻¹⁷	4"	N	1.44 × 10 ¹³	2.94 × 10 ²³
	23	16 Oct. 80	1.35	1.06	3.75 × 10 ⁻¹⁸	8"	N-85"	7.56 × 10 ¹³	1.23 × 10 ²⁴
	25	4 Nov. 80	1.19	0.76	2.17 × 10 ⁻¹⁸	4"	N	1.31 × 10 ¹⁴	1.22 × 10 ²⁴
	32	6 Nov. 80	1.17	0.73	3.77 × 10 ⁻¹⁸	4"	N	2.20 × 10 ¹⁴	1.98 × 10 ²⁴
P/Stephan-Oterma 1980 X	36	20 Aug. 80	2.04	1.63	6.46 × 10 ⁻¹⁸	4"	N-35"	1.21 × 10 ¹³	2.99 × 10 ²³
	40	6 Nov. 80	1.62	0.72	1.03 × 10 ⁻¹⁸	4"	N	1.15 × 10 ¹⁴	1.61 × 10 ²⁴
	45	8 Dec. 80	1.57	0.59	9.03 × 10 ⁻¹⁷	4"	N-35"	9.97 × 10 ¹³	1.26 × 10 ²⁴
	50	1 Feb. 81	1.73	0.90	4.56 × 10 ⁻¹⁷	4"	N	5.81 × 10 ¹³	9.53 × 10 ²³
	52	6 Mar. 81	1.94	1.31	2.72 × 10 ⁻¹⁸	4"	N	3.04 × 10 ¹²	6.55 × 10 ²²
Comet Koboutek 1973 XII	57	29 Jan. 74	0.96	0.93	2.7 × 10 ⁻¹⁸	2" × 3"	N	2.22 × 10 ¹⁵	1.48 × 10 ²⁵
Comet Bradfield 1979 X	58	7 Feb. 80	1.14	0.51	1.63 × 10 ⁻¹⁸	8"	N	2.26 × 10 ¹⁴	2.22 × 10 ²⁴
	63	17 Mar. 80	1.75	1.90	1.6 × 10 ⁻¹⁷	4"	N-35"	2.19 × 10 ¹³	4.64 × 10 ²³
P/Grigg-Skjellerup 1982 IV	66	6 June 82	1.04	0.34	4.70 × 10 ⁻¹⁷	4"	N	2.00 × 10 ¹³	1.20 × 10 ²³
P/Swift-Gehrels 1981 XIX	73	30 Nov. 81	1.36	0.68	6.31 × 10 ⁻¹⁷	4"	N	2.69 × 10 ¹³	2.90 × 10 ²³
	78	24 Jan. 82	1.53	1.04	3.57 × 10 ⁻¹⁷	4"	N	1.52 × 10 ¹³	2.20 × 10 ²³
P/Kearns Kwee 1981 XX	84	30 Oct. 81	2.24	1.62	4.27 × 10 ⁻¹⁸	4"	N	1.82 × 10 ¹²	5.11 × 10 ²²
	88	24 Jan. 82	2.27	1.37	3.97 × 10 ⁻¹⁸	4"	N	1.69 × 10 ¹²	4.61 × 10 ²²
P/Gehrels 2 1981 XVII	91	30 Nov. 81	2.36	1.53	7.39 × 10 ⁻¹⁸	4"	N	3.15 × 10 ¹²	9.37 × 10 ²²
P/Borrelly 1981 IV	95	1 Feb. 81	1.34	1.47	1.67 × 10 ⁻¹⁸	4"	N	7.11 × 10 ¹³	9.81 × 10 ²³
P/Wild 3 1980 VII	100	17 Jun. 80	2.41	1.91	2.45 × 10 ⁻¹⁸	4"	N	1.04 × 10 ¹²	3.40 × 10 ²²
Sugano-Saigusa-Fujikawa 1983 V	108	13 June 83	1.08	0.065	1.18 × 10 ⁻¹⁸	8"	N	1.46 × 10 ¹³	7.25 × 10 ²²
P/Kopff 1983 XIII	110	13 Jun. 83	1.68	0.73	1.15 × 10 ⁻¹⁸	8"	N	1.22 × 10 ¹⁴	2.24 × 10 ²⁴
P/Tempel 2 1983 X	113	13 Jun. 83	1.39	1.20	3.65 × 10 ⁻¹⁸	8"	N	3.88 × 10 ¹³	6.89 × 10 ²³
	114	11 Sept. 83	1.74	1.00	6.75 × 10 ⁻¹⁸	2".8	N	5.86 × 10 ¹²	9.04 × 10 ²²

TABLE VI. C₂ production. Comments same as in Table IV.

Object	Data		r	Δ	Irradiance (Wm ⁻²)	Aperture Diameter	Location	Corrected	v = 1 km s ⁻¹	C ₂ /CN
	Set	Date						Column Density (m ⁻²)	Production (mol s ⁻¹)	
P/Encke 1980 XI	1	21 Aug. 80	1.89	1.47	2.14 × 10 ⁻¹⁸	4"	N	7.23 × 10 ¹²	9.87 × 10 ²³	.654
	3	7 Sept. 80	1.69	1.09	8.92 × 10 ⁻¹⁸	4"	N	2.41 × 10 ¹³	2.59 × 10 ²⁴	.852
	4	" " " " " "	"	"	1.51 × 10 ⁻¹⁷	4"	N	4.08 × 10 ¹³	4.39 × 10 ²⁴	
	7	16 Oct. 80	1.15	0.37	2.57 × 10 ⁻¹⁶	8"	N-85"	8.39 × 10 ¹³	4.51 × 10 ²⁴	1.122
	8A	" " " " " "	"	"	5.21 × 10 ⁻¹⁶	8"	N	1.63 × 10 ¹⁴	8.77 × 10 ²⁴	1.187
	11	4 Nov. 80	0.84	0.31	1.55 × 10 ⁻¹⁵	4"	N	1.03 × 10 ¹⁵	2.81 × 10 ²⁵	1.325
	16	6 Nov. 80	0.78	0.32	1.35 × 10 ⁻¹⁵	4"	N	7.76 × 10 ¹⁴	1.89 × 10 ²⁵	1.252
P/Tuttle 1980 XIII	20	21 Aug. 80	1.92	1.96	2.44 × 10 ⁻¹⁶	4"	N	8.50 × 10 ¹²	1.26 × 10 ²⁴	0.724
	21	6 Sept. 80	1.75	1.71	9.74 × 10 ⁻¹⁶	4"	N	2.82 × 10 ¹³	3.51 × 10 ²⁴	1.240
	22	" " " " " "	"	"	1.14 × 10 ⁻¹⁷	4"	N	3.30 × 10 ¹³	4.11 × 10 ²⁴	
	23	16 Oct. 80	1.35	1.06	5.29 × 10 ⁻¹⁶	8"	N-85"	2.38 × 10 ¹⁴	2.08 × 10 ²⁵	1.261
	25	4 Nov. 80	1.19	0.76	3.90 × 10 ⁻¹⁶	4"	N	5.22 × 10 ¹⁴	2.98 × 10 ²⁵	1.483
	26	5 Nov. 80	1.18	0.74	4.24 × 10 ⁻¹⁶	4"	N	5.58 × 10 ¹⁴	3.13 × 10 ²⁵	
	32	6 Nov. 80	1.17	0.73	4.63 × 10 ⁻¹⁶	4"	N	5.99 × 10 ¹⁴	3.30 × 10 ²⁵	1.250
P/Stephan-Oterma 1980 X	36	20 Aug. 80	2.04	1.63	5.80 × 10 ⁻¹⁹	4"	N-35"	2.41 × 10 ¹²	3.80 × 10 ²³	0.050
	37	6 Sept. 80	1.93	1.39	6.01 × 10 ⁻¹⁸	4"	N	2.12 × 10 ¹³	2.96 × 10 ²⁴	
	38	16 Oct. 80	1.70	0.90	2.10 × 10 ⁻¹⁶	8"	N-85"	1.50 × 10 ¹⁴	1.80 × 10 ²⁵	
	39	3 Nov. 80	1.63	0.74	3.25 × 10 ⁻¹⁶	8"	N-85"	2.13 × 10 ¹⁴	2.30 × 10 ²⁵	
	40	6 Nov. 80	1.62	0.72	1.30 × 10 ⁻¹⁶	4"	N	3.23 × 10 ¹⁴	3.00 × 10 ²⁵	1.124
	45	8 Dec. 80	1.57	0.59	2.26 × 10 ⁻¹⁶	4"	N-35"	5.56 × 10 ¹⁴	4.74 × 10 ²⁵	1.432
	49	" " " " " "	"	"	3.75 × 10 ⁻¹⁶	4"	N	8.74 × 10 ¹⁴	7.44 × 10 ²⁵	
	50	1 Feb. 81	1.73	0.90	3.90 × 10 ⁻¹⁷	4"	N	1.10 × 10 ¹⁴	1.19 × 10 ²⁵	0.763
	51	" " " " " "	"	"	4.59 × 10 ⁻¹⁷	4"	N	1.30 × 10 ¹⁴	1.40 × 10 ²⁵	
	52	6 Mar. 81	1.94	1.31	1.21 × 10 ⁻¹⁷	4"	N	4.31 × 10 ¹³	6.00 × 10 ²⁴	0.792
Comet Kohoutek 1973 XII	57	29 Jan. 74	0.96	0.93	2.9 × 10 ⁻¹⁵	2" × 3"	N	5.31 × 10 ¹⁵	1.27 × 10 ²⁶	0.385
Comet Bradfield 1979 X	58	7 Feb. 80	1.14	0.51	4.79 × 10 ⁻¹⁵	8"	N	1.47 × 10 ¹⁵	8.36 × 10 ²⁵	1.212
	63	17 Mar. 80	1.75	1.90	2.56 × 10 ⁻¹⁷	4"	N-35"	7.81 × 10 ¹³	9.95 × 10 ²⁴	
	64	" " " " " "	"	"	2.87 × 10 ⁻¹⁷	4"	N-35"	8.76 × 10 ¹³	1.12 × 10 ²⁵	
P/Grigg-Skjellerup 1982 IV	66	6 Jun. 82	1.04	0.34	3.90 × 10 ⁻¹⁷	4"	N	3.99 × 10 ¹³	1.57 × 10 ²⁴	0.946
	67	" " " " " "	"	"	3.43 × 10 ⁻¹⁷	4"	N	3.51 × 10 ¹³	1.38 × 10 ²⁴	

TABLE VI. (continued)

Object	Data		r	Δ	Irradiance (Wm^{-2})	Aperture Diameter	Location	$v = 1 \text{ km s}^{-1}$		C_2/CN	
	Set	Date						Column Density (m^{-2})	Production ($mol \text{ s}^{-1}$)		
P/Swift-Gehrels	73	30 Nov.	81	1.36	0.68	9.19×10^{-17}	4"	N	1.61×10^{14}	1.11×10^{25}	1.110
1981 XIX	74	" "	" "	" "	" "	9.13×10^{-17}	4"	N	1.60×10^{14}	1.11×10^{25}	
	78	24 Jan.	82	1.53	1.04	4.09×10^{-17}	4"	N	9.05×10^{13}	8.22×10^{24}	0.652
	79	" "	" "	" "	" "	5.11×10^{-17}	4"	N	1.13×10^{14}	1.03×10^{25}	
P/Kearns Kwee	84	30 Oct.	81	2.24	1.62	9.95×10^{-18}	4"	N	4.72×10^{13}	8.64×10^{24}	1.002
1981 XX	85	31 Oct.	81	2.24	1.61	8.14×10^{-18}	4"	N	3.86×10^{13}	7.06×10^{24}	
	86	30 Nov.	81	2.22	1.32	6.69×10^{-18}	4"	N	3.12×10^{13}	5.42×10^{24}	
	87	" "	" "	" "	" "	1.20×10^{-17}	4"	N	5.59×10^{13}	9.71×10^{24}	
	88	24 Jan.	82	2.27	1.37	6.84×10^{-18}	4"	N	3.33×10^{13}	6.04×10^{24}	0.786
	89	" "	" "	" "	" "	8.78×10^{-18}	4"	N	4.28×10^{13}	7.77×10^{24}	
P/Gehrels 2	91	30 Nov.	81	2.36	1.53	3.17×10^{-18}	4"	N	1.67×10^{13}	3.29×10^{24}	0.852
1981 XVII											
Comet Meier	93	5 Apr.	81	2.19	1.39	5.06×10^{-17}	4"	N	2.29×10^{14}	3.93×10^{25}	
1980 XII											
Comet Panther	94	4 Apr.	81	1.86	1.55	1.59×10^{-18}	4"	N	5.20×10^{14}	6.99×10^{25}	
1981 II											
P/Borrelly	95	1 Feb.	81	1.34	1.47	2.57×10^{-18}	4"	N	4.36×10^{14}	3.46×10^{25}	0.423
1981 IV	96	" "	" "	" "	" "	2.53×10^{-18}	4"	N	4.29×10^{14}	3.40×10^{25}	
P/Wild 3	99	16 Jun.	80	2.41	1.90	3.77×10^{-18}	4"	N	2.07×10^{13}	4.40×10^{24}	
1980 VII	100	17 Jun.	80	2.41	1.91	5.69×10^{-18}	4"	N	3.12×10^{13}	6.64×10^{24}	0.371
P/Brooks 2	105	4 Nov.	80	1.86	1.23	4.5×10^{-19}	4"	N	1.47×10^{12}	1.89×10^{23}	0.231
1980 IX											
Sugano-Saigusa-Fujikawa	106	13 Jun.	83	1.08	0.065	3.24×10^{-18}	8"	N	8.03×10^{13}	3.17×10^{24}	1.078
1983 V											
P/Kopff	110	13 Jun.	83	1.68	0.73	1.53×10^{-15}	8"	N	1.02×10^{15}	1.15×10^{26}	1.242
1983 XIII											
P/Tempel 2	113	13 Jun.	83	1.39	1.20	7.87×10^{-16}	8"	N	3.59×10^{14}	3.39×10^{25}	1.960
1983 X	114	11 Sept.	83	1.74	1.00	1.19×10^{-17}	2".8	N	6.95×10^{13}	7.23×10^{24}	0.744

TABLE VII. O[¹D] and H₂O production and ratios of O[¹D] to other species. Active area is the area normal to the Sun at 205 K required to produce the observed water. § corrected for NH₂ contamination and for chopping against the coma (in those few cases, noted under location, where this was done). * taken from Spinrad (1982). # taken from Newburn and Spinrad (1984). † indicates data of lower quality. Other comments as in Table IV.

Object	Data		r	Δ	Phase Angle	Telescope	Aperture Diameter	Location**	Corrected †		Active Area (km ²)	O[¹ D]/OH	O[¹ D]/O ₂	O[¹ D]/O ₃		
	Set	Date							O[¹ D] atoms in Lov.	V = 1 km s ⁻¹ Production O[¹ D]					V = 1 km s ⁻¹ Production H ₂ O	
P/Bode 1980 XI	1	21 Aug. 80	1.89	1.47	33°	Lick-3m	4"	N	2.6 × 10 ²⁶	1.80 × 10 ²⁶	3.06 × 10 ²⁷	0.631	99.3	2266	182	
	4	7 Sept. 80	1.69	1.09	34°	Lick-3m	4"	N	3.7 × 10 ²⁶	2.33 × 10 ²⁶	3.16 × 10 ²⁷	0.925	76.6	1879	831	
	8	16 Oct. 80	1.15	0.37	57°	Lick-1m	8"	N-88*	4.92 × 10 ²⁶	2.19 × 10 ²⁶	2.96 × 10 ²⁷	0.929	64.5	1310	48.6	
	11	4 Nov. 80	0.84	0.31	113°	Lick-3m	4"	N	1.5 × 10 ²⁷	9.75 × 10 ²⁶	1.33 × 10 ²⁸	0.647	48.0	966	34.7	
	16	6 Nov. 80	0.78	0.32	128°	Lick-3m	4"	N	taken from Nov. 4 to 6 CN ratio		9.47 × 10 ²⁷					
P/Tuttle 1980 XIII	30	31 Aug. 80	1.92	1.98	30°	Lick-3m	4"	N	taken from Aug. 21 to Sept. 6 CN ratio		1.40 × 10 ²⁷					
	22	6 Sept. 80	1.75	1.71	34°	Lick-3m	4"	N	4.0 × 10 ²⁶	1.60 × 10 ²⁶	2.28 × 10 ²⁷	0.409	59.7	575	41.1	
	26	5 Nov. 80	1.18	0.74	57°	Lick-3m	4"	N	2.9 × 10 ²⁷	1.36 × 10 ²⁷	1.85 × 10 ²⁸	1.504	88.8	850	43.5	
P/Stephan-Oterma 1980 X	36	30 Aug. 80	2.04	1.63	20°	Lick-3m	4"	N-85*	1.13 × 10 ²⁷	6.79 × 10 ²⁶	9.37 × 10 ²⁷	2.379	88.5	2371	1787	
	37	6 Sept. 80	1.93	1.39	30°	Lick-3m	4"	N	1.3 × 10 ²⁷	8.36 × 10 ²⁶	1.11 × 10 ²⁸	2.426			379	
	38	16 Oct. 80	1.70	0.90	28°	Lick-1m	8"	N-88*	2.15 × 10 ²⁷	8.16 × 10 ²⁶	1.10 × 10 ²⁸	1.859			45.3	
	39	3 Nov. 80	1.63	0.74	54°	Lick-1m	8"	N-88*	5.84 × 10 ²⁷	4.74 × 10 ²⁷	6.44 × 10 ²⁸	9.999			206	
	40	8 Dec. 80	1.57	0.69	12°	Lick-3m	4"	N	3.6 × 10 ²⁷	3.80 × 10 ²⁷	5.25 × 10 ²⁸	7.561	114.8	2018	61.1	
	51	1 Feb. 81	1.73	0.90	25°	Lick-3m	4"	N	1.0 × 10 ²⁷	8.08 × 10 ²⁶	1.18 × 10 ²⁸	2.053	51.8	848	57.7	
52	6 Mar. 81	1.94	1.31	28°	Lick-3m	4"	N	93.46 × 10 ²⁶	2.35 × 10 ²⁶	3.44 × 10 ²⁷	0.756	21.0	3588	20.2		
Comet Kohoutek 1973 XII	57	29 Jan. 74	0.94	0.93	64°	Lick-3m	2" × 3"	N	taken from Q ₂₈ × 60 × 16.1		2.66 × 10 ²⁹					
Comet Bradfield 1979 X	58	7 Feb. 80	1.14	0.61	61°	Lick-1m	8"	N	1.8 × 10 ²⁷	5.61 × 10 ²⁶	7.68 × 10 ²⁷	0.583	8.1	253	6.7	
	64	17 Mar. 80	1.75	1.50	31°	Lick-3m	4"	N-36*	4.74 × 10 ²⁶	1.80 × 10 ²⁶	2.49 × 10 ²⁷	0.445			16.1	
P/Grigg-Skjellerup 1981 IV	67	6 Jun. 82	1.04	0.34	74°	Lick-3m	4"	N	92.36 × 10 ²⁶	2.09 × 10 ²⁶	2.93 × 10 ²⁷	0.185	125.9	1742	151	
P/Swift-Gehrels 1981 XIX	74	30 Nov. 81	1.36	0.68	45°	Lick-3m	4"	N	65.81 × 10 ²⁶	3.95 × 10 ²⁶	5.25 × 10 ²⁷	0.568	39.5	1262	473	
	79	24 Jan. 82	1.53	1.04	40°	Lick-3m	4"	N	61.37 × 10 ²⁷	7.45 × 10 ²⁶	9.84 × 10 ²⁷	1.245	59.1	2386	965	
P/Keenan Kwee 1981 XX	85	31 Oct. 81	2.24	1.61	24°	Lick-3m	4"	N	61.72 × 10 ²⁶	1.27 × 10 ²⁶	1.70 × 10 ²⁷	0.496			241	
	87	30 Nov. 81	2.22	1.32	15°	Lick-3m	4"	N	67.77 × 10 ²⁶	6.87 × 10 ²⁶	9.13 × 10 ²⁶	0.263	35.5		94	
	89	24 Jan. 82	2.27	1.37	14°	Lick-3m	4"	N	61.45 × 10 ²⁶	1.29 × 10 ²⁶	1.70 × 10 ²⁷	0.512	16.8	2798	219	
P/Gehrels 3 1981 XVII	91	30 Nov. 81	2.26	1.53	17°	Lick-3m	4"	N	taken from Q ₂₈ × 60 × 13.3		2.57 × 10 ²⁷					
Comet Meier 1980 XII	93	5 Apr. 81	2.19	1.39	20°	Lick-3m	4"	N	2.4 × 10 ²⁷	1.96 × 10 ²⁷	2.86 × 10 ²⁸	8.006			728	
Comet Panther 1981 II	94	4 Apr. 81	1.86	1.55	33°	Lick-3m	4"	N	7.5 × 10 ²⁷	3.96 × 10 ²⁷	5.78 × 10 ²⁸	11.677			827	
P/Borely 1981 IV	96	1 Feb. 81	1.34	1.47	41°	Lick-3m	4"	N	1.2 × 10 ²⁸	3.51 × 10 ²⁷	5.13 × 10 ²⁸	5.382	42.9	3580	1509	
P/Wild 3 1980 VII	99	16 Jun. 80	2.41	1.90	23°	Lick-3m	4"	N	61.43 × 10 ²⁶	1.01 × 10 ²⁶	1.35 × 10 ²⁷	0.457			2971	307
P/Brooks 2 1980 IX	105	4 Nov. 80	1.86	1.33	30°	Lick-3m	4"	N	2 × 10 ²⁸	1.34 × 10 ²⁸	1.82 × 10 ²⁹	0.369	164		9630	
Sugano-Saigusa-Fujihawa 1983 V	106	12 Jun. 83	1.06	0.063	46°	Lick-3m	2" × 3" 6	N	1.23 × 10 ²⁸	1.76 × 10 ²⁸	2.08 × 10 ²⁷	0.176				
	107	13 Jun. 83	1.08	0.065	20°	Lick-3m	2" × 3" 6	N	5.07 × 10 ²⁸	7.17 × 10 ²⁸	1.09 × 10 ²⁸	0.743	244	9890	2433	
P/Kopff 1983 XIII	109	13 Jun. 83	1.68	0.73	18°	Lick-3m	2" × 3" 6	N	3.38 × 10 ²⁷	4.28 × 10 ²⁷	6.51 × 10 ²⁸	10.722	46	1911	566	
P/Tsapek 2 1983 X	111	12 Jun. 83	1.39	1.20	45°	Lick-3m	2" × 3" 6	N	3.95 × 10 ²⁷	2.00 × 10 ²⁷	3.04 × 10 ²⁸	2.434				
	113	13 Jun. 83	1.39	1.20	45°	Lick-3m	2" × 3" 6	N	6.92 × 10 ²⁷	3.51 × 10 ²⁷	5.23 × 10 ²⁸	6.016	202.9	5094	104	
	114	11 Sept. 83	1.74	1.00	20°	Lick-3m	2" 8	N	taken from Sept. 11 to 13 June CN ratio		2.99 × 10 ²⁸					
G/IRAS-Araki-Alcock 1983 VII	115	9 May 83	1.012	0.0806	88°	KPNO-4m	6"	N	1.0 × 10 ²⁸	5.01 × 10 ²⁸	7.51 × 10 ²⁷	0.449				
P/Crommelin 1984 IV	116	29 Feb. 84	0.75	0.89	75°	Lick-3m	2" × 3" 8	N	9.1 × 10 ²⁷	1.85 × 10 ²⁷	2.23 × 10 ²⁸	0.931				
P/Giacomini-Kanner 1985 XIII	117	21 May 85	1.73	1.58	38°	Lick-3m	2" 0 × 3" 1	N	1.2 × 10 ²⁷	7.35 × 10 ²⁶	1.18 × 10 ²⁸	2.069				
	118	18 Jun. 85	1.48	0.97	43°	Lick-3m	2" 0 × 3" 1	N	2.21 × 10 ²⁷	1.22 × 10 ²⁷	2.15 × 10 ²⁸	2.748				
	119	19 Jul. 85	1.23	0.70	54°	Lick-3m	2" 0 × 3" 1	N	4.6 × 10 ²⁷	2.71 × 10 ²⁷	4.41 × 10 ²⁸	3.900				
	120	22 Aug. 85	1.05	0.50	70°	Lick-3m	2" 0 × 3" 1	N	3.9 × 10 ²⁷	2.46 × 10 ²⁷	3.99 × 10 ²⁸	2.873				
P/Wild 2 1984 XIV	121	24 Feb. 84	2.27	2.07	26°	KPNO-4m	2" 2 × 3" 0	N	1.2 × 10 ²⁷	5.63 × 10 ²⁶	8.61 × 10 ²⁷	2.593				
P/Halley 1986 III	122	23 Aug. 86	2.84	2.24	17°	Lick-3m	2" 1 × 4" 9	N	4.6 × 10 ²⁸	2.92 × 10 ²⁸	4.76 × 10 ²⁷	2.243				
	123	11 Sept. 86	2.69	2.64	22°	Lick-3m	2" 1 × 4" 9	N	2.7 × 10 ²⁷	1.76 × 10 ²⁷	2.87 × 10 ²⁸	11.226				
	124	12 Sept. 86	2.58	2.61	22°	Lick-3m	2" 1 × 4" 9	N	3.2 × 10 ²⁷	2.09 × 10 ²⁷	3.41 × 10 ²⁸	13.267				
	125	14 Sept. 86	2.55	2.55	23°	Lick-3m	2" 1 × 4" 9	N	1.8 × 10 ²⁷	9.82 × 10 ²⁶	1.60 × 10 ²⁸	6.078				
	126	21 Sept. 86	2.47	2.36	24°	Lick-3m	2" 1 × 4" 9	N	3.3 × 10 ²⁷	2.19 × 10 ²⁷	3.58 × 10 ²⁸	12.747				
	127	11 Oct. 86	2.21	1.72	26°	Lick-3m	2" 1 × 4" 9	N	2.5 × 10 ²⁷	1.85 × 10 ²⁷	3.01 × 10 ²⁸	8.586				
	128	16 Oct. 86	2.14	1.56	26°	Lick-3m	2" 1 × 4" 9	N	6.3 × 10 ²⁷	4.82 × 10 ²⁷	7.87 × 10 ²⁸	21.058				
	129	8 Nov. 86	1.82	0.88	15°	Lick-3m	2" 1 × 4" 9	N	4.9 × 10 ²⁷	4.90 × 10 ²⁷	8.14 × 10 ²⁸	15.760				
	130	10 Dec. 86	1.246	0.740	47°	Lick-3m	1" 0 × 4" 9	N	1.3 × 10 ²⁸	1.23 × 10 ²⁸	2.17 × 10 ²⁹	22.265				
	131	18 Mar. 86	0.898	0.977	64°	CTIO-4m	1" 0 × 4" 8	N	8.9 × 10 ²⁸	3.00 × 10 ²⁸	4.90 × 10 ²⁹	22.232				
	132	14 Mar. 86	0.910	0.960	65°	Lick-3m	2" 1 × 4" 9	N	3.8 × 10 ²⁸	9.14 × 10 ²⁸	1.49 × 10 ²⁹	72.064				
	133	6 May 86	1.707	0.945	20°	CTIO-1.5m	3" 0 × 5" 1	N	1.6 × 10 ²⁸	1.06 × 10 ²⁸	1.73 × 10 ²⁹	29.511				
	134	10 May 86	1.766	1.085	31°	KPNO-4m	2" 2 × 3" 0	N	2.8 × 10 ²⁸	3.10 × 10 ²⁸	3.43 × 10 ²⁹	62.498				
	135	8 Jun. 86	2.123	1.928	28°	Lick-3m	2" 1 × 4" 9	N	7.8 × 10 ²⁷	4.74 × 10 ²⁷	7.73 × 10 ²⁸	20.524				

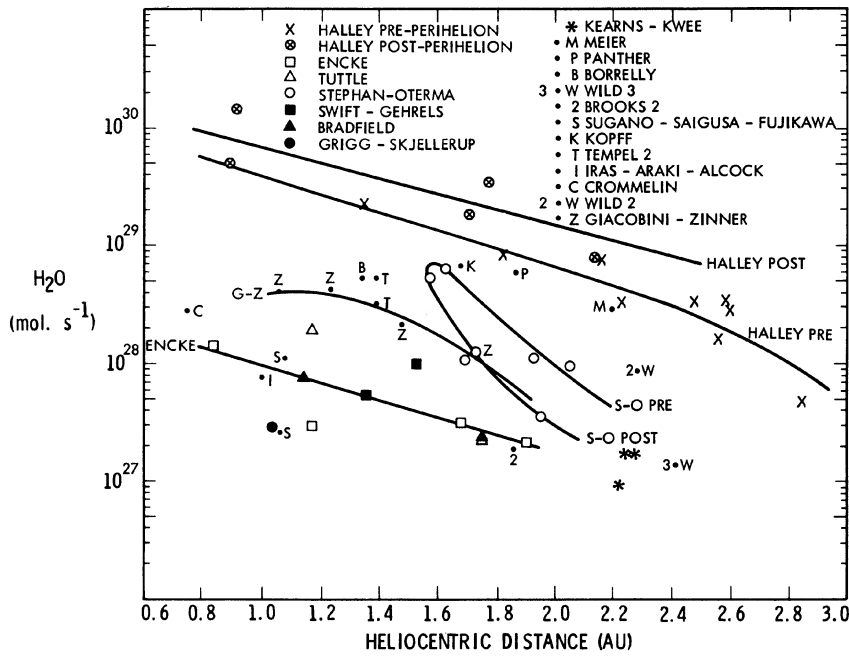


FIG. 2. Production rate of water for 20 comets as a function of heliocentric distance.

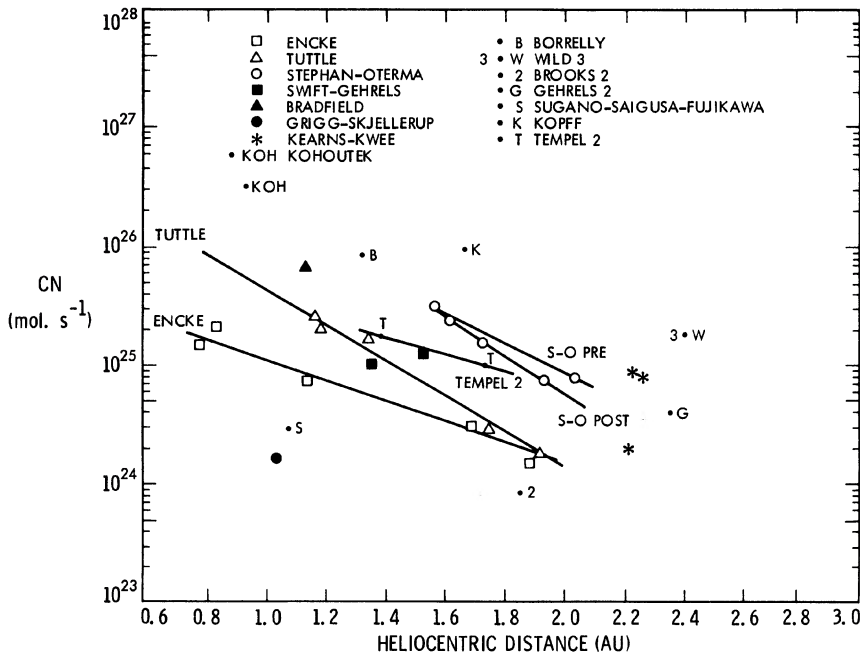


FIG. 3. Production rate of CN for 15 comets as a function of heliocentric distance.

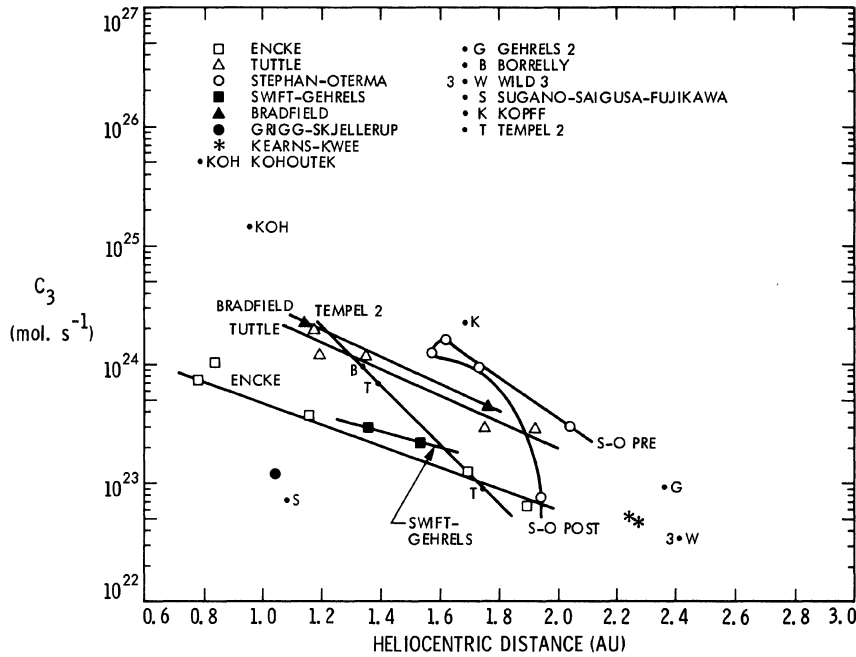


FIG. 4. Production rate of C_3 for 14 comets as a function of heliocentric distance.

$N = 4.2$ on the surface or roughly $N' = 3.7$ in space after velocity sorting. This is equivalent to a cumulative mass slope $\alpha = 0.9$ [$\alpha = (N' - 1)/3$]. McDonnell *et al.* use a much shallower slope of $\alpha = 0.54$ for large particles. Divine and Newburn (1987) fit the same *Giotto* data with a slope of 0.94. Arbitrarily truncating the mass integral at a radius of 1.0 cm, a bit larger than the largest particle to actually hit *Giotto*, our total dust flow is reduced to $58\,650\text{ kg s}^{-1}$, now an order of magnitude larger than the result of McDonnell *et al.* summed to that radius. Truncating the mass distribution

at particles of $100\ \mu\text{m}$ would further reduce the dust flow to $31\,000\text{ kg s}^{-1}$. Figure 9 shows the effect on the calculated dust flow of changing the assumed dust density. The upper curve is for the full untruncated integral, while the lower curve is truncated at $100\ \mu\text{m}$. Crifo's (1988b) thorough analysis of the *Giotto* data and ground-based techniques gives a best dust-to-gas mass-loss ratio of 3.46 compared to our 1.01, but he suggests that it could be anywhere between 0.8 and 18.6 because there is so little real data on the larger particles. Our figures for the mass lost in smaller particles

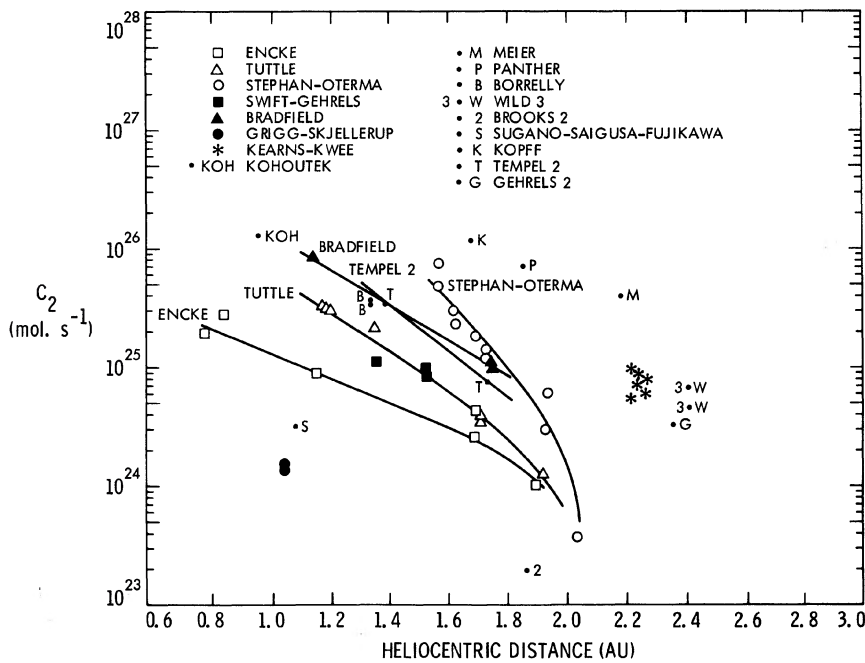


FIG. 5. Production rate of C_2 for 17 comets as a function of heliocentric distance.

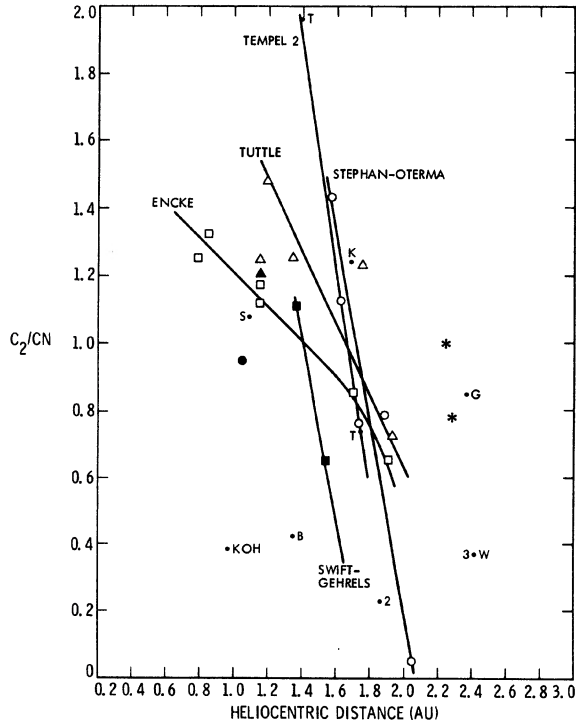


FIG. 6. Ratio C_2/CN as a function of heliocentric distance. Symbols are the same as those in Fig. 5.

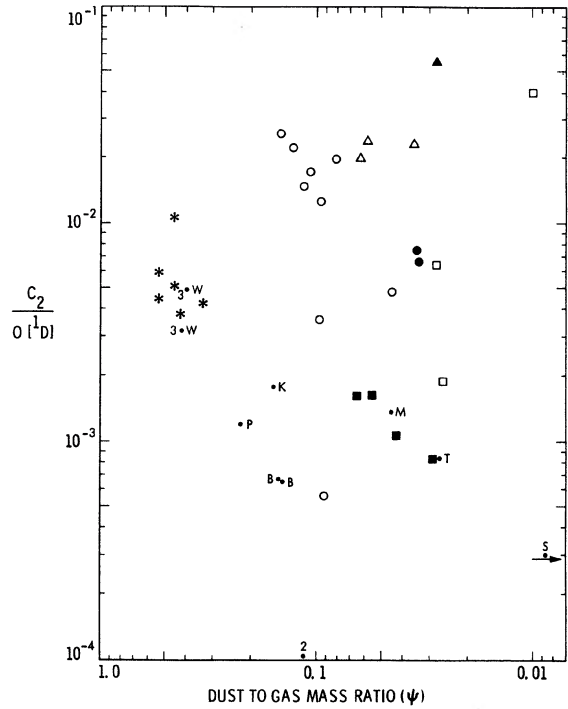


FIG. 8. Ratio $C_2/O[{}^1D]$ vs dust/gas (ψ). This is effectively the ratio of C_2 to dust with both normalized to total cometary activity.

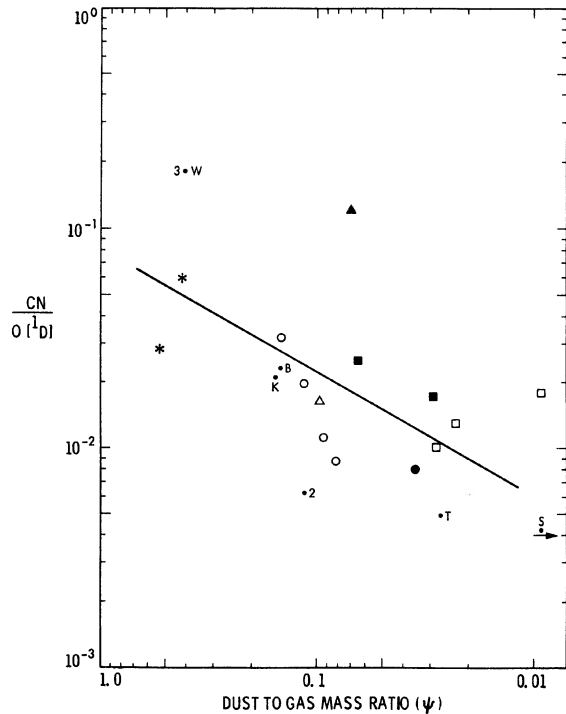


FIG. 7. Ratio $CN/O[{}^1D]$ vs dust/gas (ψ). This is effectively the ratio of CN to dust with both normalized to total cometary activity.

are larger than McDonnell's, because our particle velocities are higher and because there are differences between our global and *Giotto*'s local measurements. Our particle velocities are higher because our measured gas loss was higher and because the analytic approximation to Probst's theory for the velocities (Paper II, Eq. (16)) taken from Sekanina (1981) gives values somewhat larger than Gombosi's (1986) numerical solution. In sum, our Halley figures are not grossly different from the *Giotto* values, and such differences as exist are quite understandable. There is room for improvement in our particle velocities, but any velocity errors are completely overshadowed by the uncertainties in the particle-size-distribution function. We have emphasized the *Giotto* results because our observations were made the same day, only about 11 hr later in time.

Halley really is outstanding among short-period comets. It was more than an order of magnitude more active in gas and dust production than any other comet we observed, although long-period Meier or Panther brought in to 0.9 AU heliocentric distance might equal it. All of our mass-production figures are plotted in Fig. 10.

V. SUMMARY

Thirty new datasets, including 14 of P/Halley, have been added to the 120 datasets of Papers I and II. The 30 new sets and 50 of the old nucleus-centered sets have been reduced using improved reduction constants as well as improved theory based upon knowledge gained from the Halley spacecraft encounters. As a result, the production figures for H_2O , $O[{}^1D]$, CN, C_3 , C_2 , and dust have changed, water and dust most of all. The C_2/CN ratio now appears to change continually in any given comet as a function of heliocentric dis-

TABLE VIII. Continuum analysis. α_m is the radius of the largest particle that can be lifted off the nucleus. \mathcal{M} is the mass-production rate of dust, and ψ is the ratio of its mass to total gas. * implies that the bandpass was $\lambda\lambda$ 4784–4830. § implies that the bandpass was $\lambda\lambda$ 4790–4830.: indicates data of lower quality.

Object	Data Set	Date	r	Δ	Phase Angle	Phase Function		Scattering		Irradiance $\lambda\lambda$ 4780–4830 ($W m^{-2} Hz^{-1}$)	$A_p(\lambda) \psi$ (e)	Nucleus $A_g p(\lambda) \psi$ (e)	Dust		$\alpha = 1.0, p = 0.08$		$\alpha = 0.3, p = 0.04$	
						Nucleus ψ_N	Dust ψ_D	$A_g p(\lambda)$	α_n				M	Mass Ratio (ψ)	M	Mass Ratio (ψ)		
P/Roske 1980 XI	1	31 Aug. 80	1.80	1.47	32*	.386	.367	6.183×10^{-24}	0.911	0.084	0.313	0.476	7.18	0.076	3.87	0.028		
	3	7 Sept. 80	1.80	1.00	34*	.384	.355	1.166×10^{-23}	0.175	0.081	0.360	0.728	9.12	0.065	3.21	0.023		
	4	* * *	* * *	* * *	* * *	* * *	* * *	1.388×10^{-23}	0.193	0.081	0.393	0.728	10.38	0.073	3.62	0.026		
	7	16 Oct. 80	1.15	0.37	67*	.119	.177	5.606×10^{-23}	0.046	0.015	0.065	0.884	2.93	0.023	1.05	0.008		
	8	* * *	* * *	* * *	* * *	* * *	* * *	6.475×10^{-23} §	0.083	0.015	0.080	0.884	3.88	0.028	1.30	0.010		
	8A	* * *	* * *	* * *	* * *	* * *	* * *	6.483×10^{-23}	0.083	0.015	0.078	0.884	3.50	0.027	1.26	0.010		
	11	4 Nov. 80	0.84	0.31	112*	.0270	.306	1.403×10^{-23}	0.042	0.003	0.048	3.07	7.74	0.013	3.27	0.004		
	16	6 Nov. 80	0.78	0.32	126*	.0178	1.109	7.494×10^{-23}	0.021	0.003	0.017	2.19			0.76	0.009		
P/Tuttle 1980 XIII	20	31 Aug. 80	1.92	1.96	30*	.380	.380	8.353×10^{-24}	0.533	0.081	0.797	0.147			3.87	0.063		
	21	6 Sept. 80	1.71	1.71	34*	.384	.357	1.421×10^{-23}	0.803	0.063	0.086	0.340	17.00	0.171	6.35	0.063		
	22	* * *	* * *	* * *	* * *	* * *	* * *	1.461×10^{-23}	0.874	0.063	0.935	0.340	14.43	0.163	6.02	0.069		
	23	16 Oct. 80	1.36	1.08	47*	.230	.307	1.563×10^{-23}	1.449	0.085								
	26	4 Nov. 80	1.19	0.76	57*	.119	.177	1.968×10^{-23}	0.708	0.035	1.483							
	26	5 Nov. 80	1.18	0.74	57*	.119	.177	1.797×10^{-23}	0.605	0.035	1.316	1.946	96.23	0.116	39.23	0.086		
33	6 Nov. 80	1.17	0.73	58*	.184	.174	2.154×10^{-23}	0.884	0.035	1.411								
P/Stephan-Oterma 1980 X	26	30 Aug. 80	2.04	1.63	29*	.393	.384	8.988×10^{-24}	4.521	0.996	6.156	0.017	105.5	0.253	38.80	0.020		
	37	6 Sept. 80	1.93	1.39	30*	.380	.380	1.384×10^{-23}	4.403	0.996	6.047	0.021	131.9	0.267	47.84	0.027		
	38	16 Oct. 80	1.70	0.90	28*	.406	.393	7.137×10^{-23} §	7.533	0.967	11.001	0.020	176.1	0.260	63.33	0.139		
	39	3 Nov. 80	1.63	0.74	24*	.461	.435	1.144×10^{-22} *	7.531	1.086	10.296	0.119	410.4	0.143	199.4	0.046		
	40	6 Nov. 80	1.62	0.72	23*	.476	.436	3.705×10^{-24}	16.383	1.123	33.843							
	46	8 Dec. 80	1.57	0.59	17*	.579	.761	1.909×10^{-23}	7.481	1.600	7.689	0.007	683.3	0.292	236.1	0.007		
	49	* * *	* * *	* * *	* * *	* * *	* * *	1.729×10^{-23}	6.545	1.600	6.811	0.007	598.3	0.266	192.7	0.083		
	50	1 Feb. 81	1.73	0.90	15*	.447	.617	3.965×10^{-23} *	4.341	1.063	5.167	0.022	169.4	0.233	60.68	0.116		
	61	* * *	* * *	* * *	* * *	* * *	* * *	3.773×10^{-23} *	4.036	1.063	4.833	0.022	158.6	0.202	56.76	0.108		
	52	6 Mar. 81	1.94	1.31	28*	.406	.393	1.312×10^{-23} *	3.739	0.967	4.690	0.006	59.27	0.287	21.68	0.148		
	Comet Koboutek 1973 XII	57	29 Jan. 74	0.96	0.93	64*	.127	.461	9.393×10^{-23}	3.273	0.766	5.438	0.675			161.6	0.014	
	Comet Bradfield 1979 X	58	7 Feb. 80	1.14	0.51	61*	.140	.464	4.983×10^{-23}	0.737	0.013	1.560	1.775	72.78	0.313	33.56	0.060	
	63	17 Mar. 80	1.75	1.90	31*	.368	.373	5.925×10^{-24} :	0.296:	0.035	0.480	0.576	10.85:	0.096:	3.11:	0.028:		
64	* * *	* * *	* * *	* * *	* * *	* * *	3.421×10^{-24} :	0.172:	0.035	0.340	0.576	4.54:	0.041:	1.63:	0.016:			
P/Grigg-Skjellerup 1982 IV	66	6 Jun. 82	1.04	0.34	74*	.0930	.454	7.323×10^{-23}	0.040	0.003	0.081	3.136			4.54	.035		
67	* * *	* * *	* * *	* * *	* * *	* * *	7.146×10^{-23}	0.030	0.003	0.079	3.136			4.43	.034			
P/Swift-Gehrels 1981 XIX	73	30 Nov. 81	1.36	0.68	45*	.234	.513	1.333×10^{-23} *	0.503	0.064	0.856	0.247	42.20	0.186	15.10	.065		
74	* * *	* * *	* * *	* * *	* * *	* * *	1.152×10^{-23} *	0.436	0.064	0.723	0.247	36.55	0.156	12.83	.065			
78	24 Jan. 82	1.53	1.04	40*	.375	.533	4.763×10^{-23} *	0.533	0.075	0.850	0.483	37.97	0.087	12.76	.029			
79	* * *	* * *	* * *	* * *	* * *	* * *	6.707×10^{-23} *	0.749	0.075	1.267	0.463	55.78	0.127	18.76	.043			
P/Kearns Kwee 1981 XX	84	30 Oct. 81	2.34	1.62	24*	.461	.625	5.893×10^{-24} *	3.434	0.073	5.263	0.179	90.72:	1.199:	34.12:	.451:		
86	31 Oct. 81	2.24	1.61	24*	.461	.625	4.283×10^{-24} *	2.516	0.073	3.900	0.179	67.07:	0.887:	25.19:	.333:			
86	30 Nov. 81	2.22	1.32	16*	.617	.723	7.151×10^{-24} *	2.710	0.096	3.618	0.096	56.08:	1.280:	21.54:	.520:			
87	* * *	* * *	* * *	* * *	* * *	* * *	6.160×10^{-24} *	2.324	0.096	3.007	0.096	48.16:	1.186:	18.52:	.466:			
88	24 Jan. 82	2.27	1.37	14*	.637	.733	7.597×10^{-24} *	3.242	0.101	4.285	0.179	85.85:	1.135:	33.18:	.425:			
89	* * *	* * *	* * *	* * *	* * *	* * *	9.551×10^{-24} *	4.076	0.101	5.433	0.179	108.0:	1.428:	49.46:	.535:			
P/Gehrels 2 1981 XVII	91	30 Nov. 81	2.36	1.53	17*	.578	.691	4.088×10^{-24} *	3.351	0.318	3.087	0.074			20.79	.183		
Comet Meier 1980 XII	93	5 Apr. 81	2.19	1.39	30*	.524	.655	1.108×10^{-23} *	4.521	1.235	5.023	0.063	176.9	0.129	57.18	.045		
Comet Panster 1981 II	94	4 Apr. 81	1.86	1.55	35*	.345	.362	8.104×10^{-24} *	29.721	0.984	51.124	0.080	1779	0.692	577.3	.225		
P/Borely 1981 IV	96	1 Feb. 81	1.34	1.47	41*	.267	.525	8.996×10^{-24} *	15.268	0.308	28.686	0.277	1090	0.478	341.0	.149		
96	* * *	* * *	* * *	* * *	* * *	* * *	8.711×10^{-24} *	14.883	0.308	27.763	0.277	1069	0.464	330.0	.145			
P/Wild 3 1980 VII	99	16 Jan. 80	2.41	1.90	32*	.476	.628	2.956×10^{-23}	3.064	0.065	4.780	0.181	66.10	1.100	24.98	.416		
100	17 Jan. 80	2.41	1.91	32*	.476	.628	2.215×10^{-23}	3.010	0.065	4.689	0.181	64.77	1.078	24.40	.408			
P/Brooks 2 1980 IX	104	4 Nov. 80	1.86	1.23	30*	.380	.380	2.233×10^{-23}	0.528	0.062	0.821	0.487	2030	0.223	9.25:	.114:		
105	* * *	* * *	* * *	* * *	* * *	* * *	1.930×10^{-23}	0.447	0.062	0.681	0.487	21.63	0.267	7.80:	.096:			
Sugano-Sugano-Pujos 1982 V	108	13 Jun. 82	1.08	0.065	20*	.524	.652	3.37×10^{-23}	0.00737	0.007	0	9.96	0	0	0	0		
P/Kopff 1983 XIII	110	13 Jun. 83	1.68	0.73	18*	.500	.678	3.98×10^{-23}	26.101	1.219	26.553	0.120	1424	0.492	483.6	.157		
110A	14 Jun. 83	1.68	0.73	18*	.500	.678	2.34×10^{-23}	16.549	1.219	21.023	0.120							
P/Tempel 2 1983 X	113	13 Jun. 83	1.30	1.20	46*	.234	.512	3.76×10^{-23}	4.630	0.270	8.496	0.287	209.2	0.068	64.63	.027		
114	11 Sept. 83	1.74	1.00	30*	.380	.580	4.08×10^{-23}	0.502	0.430	0.109	0.161			2.73	.002			
P/Giacobini-Zinner 1985 XIII	117	21 May 85	1.73	1.38	35*	.234	.551	8.62×10^{-23}	18.688	0.191	33.572	0.175	1100	2.096	300.7	.744		
118B	18 Jul. 85	1.34	0.71	54*	.175	.467	9.14×10^{-23}	17.818	0.103	35.265								
119	19 Jul. 85	1.33	0.70	56*	.170	.483	7.907×10^{-23}	25.901	0.100	55.428	0.683	4189	2.119	1283	.860			
120	23 Aug. 85	1.06	0.60	70*	.106	.449	1.373×10^{-22}	16.721	0.062	27.103	0.690	2780	2.129	1225	.860			
120B	11 Sept. 85	1.03	0.47	74*	.092	.454	1.463×10^{-22}	15.155	0.064	33.262								
P/Halley 1986 III	122	23 Aug. 85	2.84	2.34	17*	.578	.694	2.090×10^{-23}	785.28	2.594	1124.7	0.003	5439	25.68	2126	10.08		
123	11 Sept. 85	2.59	2.64	22*	.492	.643	1.187×10^{-23}	252.70	2.208	240.57	0.020	6043	4.75	2196	1.72			
125	14 Sept. 85	2.55	2.55	22*	.476	.633	1.797×10^{-23}	246.46	2.136	543.06	0.011	6482	9.11	2402	2.27			
127	11 Oct. 85	2.31	1.72	26*	.423	.609	2.524×10^{-23}	161.17	1.943	261.46	0.021	6082	4.54	2175	1.62			
123	14 Mar. 86	0.910	0.960	65*	.123	.459	5											

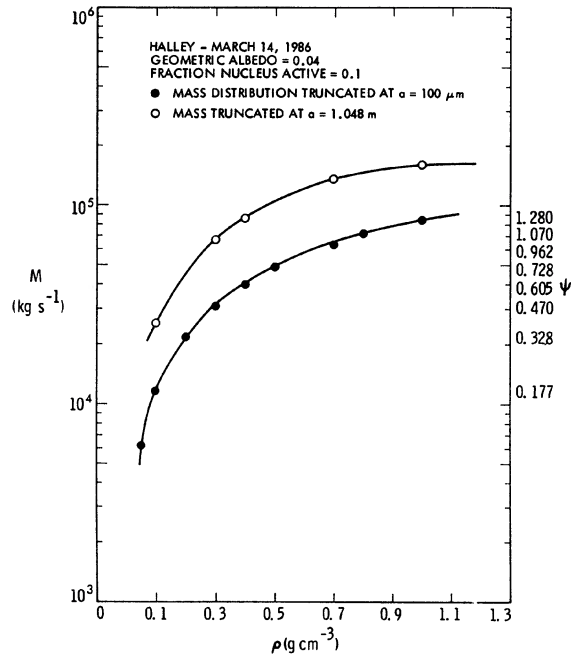


FIG. 9. Effect on the apparent dust-production rate of changing the dust density ρ .

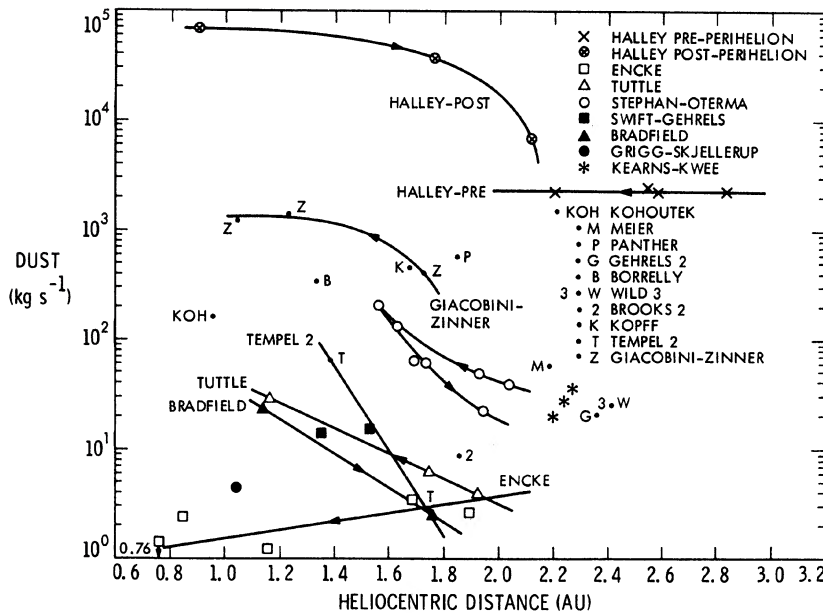


FIG. 10. Production rate of dust in 18 comets as a function of heliocentric distance.

tance, suggesting different formation mechanisms for the two radicals. Although there is CN in comets that have little or no dust, there is a definite correlation of CN with dust, suggesting at least two mechanisms for CN production, one associated with the dust. There is no obvious correlation of C₂ with dust. Because we have accepted evidence suggesting that the bulk density of dust particles is about 0.3 g cm⁻³, most of our mass-production and mass-loading figures are smaller than in Paper II, but Giacobini-Zinner shows a mass loading near 0.7 and Halley from 1 to more than 3. We find the dust in the coma of P/Halley on 14 March 1986, about 11 hr after the *Giotto* encounter, to be equivalent to a production rate of 67 000 kg s⁻¹!

Our colleagues were a big help as always. Don Yeomans furnished his always excellent ephemerides. Martha Hanner and Zdenek Sekanina offered useful suggestions on data presentation. Rem Stone took observations on the Nickel reflector while we worked with the Shane reflector in June 1983. John Stauffer, "George" Djorgovski, Patrick McCarthy, and Michael Strauss ably assisted on various observing runs. The Lick Observatory staff played their usual reliable roles. The research described in this paper was carried out in part by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. H. S. was supported by NSF grant no. AST 85-42631 and NASA grant no. NAGW-270.

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