

COMET BOWELL (1980b): AN ACTIVE-LOOKING DORMANT OBJECT?

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ABSTRACT

It is argued that solid particles in the coma and tail of the distant Comet Bowell are not recent ejecta and that the comet has probably been dormant. These conclusions are extensively documented by the circumstantial evidence which, as of early 1981, includes: the absence of molecular emissions in the spectrum of the comet; a nearly constant amount of dust in the coma, suggested by the photometric data; a slow expansion rate of the coma and implied low particle velocities, inconsistent with the theory of dust ejection instigated by expanding gas; a tail width that does not increase with increasing distance from the nucleus, also in defiance of the ejection theory; the absence in the tail of all particles ≤ 0.5 mm in diameter, the dominant component of ejecta in comets at small heliocentric distances; and the development of an elongated coma that appears to be a signature of the comet's angular momentum. It is speculated that an estimated mass of more than 10^{13} g of particles observed in the coma and tail of the comet is either a leftover pristine material that has never been in contact with the nucleus surface or a product of the comet's erratic activity associated with its chemical instability at temperatures below ~ 40 K that could be stimulated by cosmic ray and/or ultraviolet light irradiation of the surface layer during the comet's long stay in the Oort cloud. Predicted variations with time in the apparent coma diameter and in the projected direction of its elongation are based on a model of continuous escape of particles from the comet's gravity field due to the Sun's gravitational perturbations, effected at heliocentric distances less than ~ 12 AU on the incoming leg of the orbit. As a by-product, the position of the spin axis of Comet Bowell—the first among "new" comets—is determined. It is not ruled out that the comet may temporarily become active near perihelion.

I. INTRODUCTION

Comet 1980b, discovered by E. Bowell, Lowell Observatory, on 13 March 1980 at a heliocentric distance of 7.3 AU, has shown signs of considerable activity. In 1980 and early 1981 its spectrum was a pure continuum (Cochran and McCall 1980; Spinrad 1980, 1981), thus the observed light was due entirely to solid particles. On its way to perihelion at 3.4 AU in mid-March of 1982, the comet has always been a diffuse object. It displayed a round coma and no tail at the time of discovery and for several months afterwards. More recently, the coma has become appreciably elongated. The tail is for the first time clearly documented on Spinrad's photographs in early January 1981; its presence is only hinted at on a 17 November 1980 plate taken for position (Bowell 1981, private communication).

The tail is exactly of the type that other comets of large perihelion distance, almost all of which turned out to be "new" in the Oort-Schmidt (1951) sense, had exhibited in the past (Roemer 1962; Sekanina 1975): it is straight, narrow, has fairly well defined boundaries, and lies in the comet's orbit plane. Because this plane is inclined only 1.7° to the ecliptic, a circumstance that is unique in the sense that no other known long-period comet has ever had an orbit inclination of less than 2° , Comet Bowell is seen practically "edgewise" from the Earth at all times and its tail can project in only two discrete directions that are parallel to the ecliptic and

separated from each other by 180° . From the standpoint of activity diagnostics, the unusual orientation of the comet's orbit plane has both its advantages and disadvantages. A major advantage is the fact that because of the edge-on projection the observed widths of the coma and tail are unaffected by radiation pressure and their variations with time provide valuable information on the component of the particle velocity that is normal to the orbit plane. A major disadvantage is that the tail orientation cannot be used (except in special cases) for the determination of particle emission times (Sekanina 1973, 1975). This shortcoming can, fortunately, be remedied to some extent by comparing the well defined tail lengths at various times.

II. THE OBSERVATIONS AND THEIR INTERPRETATION

The development of the comet's appearance during a 12-month period is depicted in Fig. 1 on three long-exposure photographs, information on which is presented in Table I.

The magnitude of the particle-velocity component normal to the orbit plane, V_n (in m/s), is related to distance z (in km) of the particle from the orbit plane of the nucleus at time t by

$$V_n(t_s) = 1.99 \times 10^{-4} z(t) \frac{p^{1/2}}{r_s r \sin|v - v_s|}, \quad (1)$$

where p is the semilatus rectum of the orbit, and r_s and v_s

COMET BOWELL (1980b)

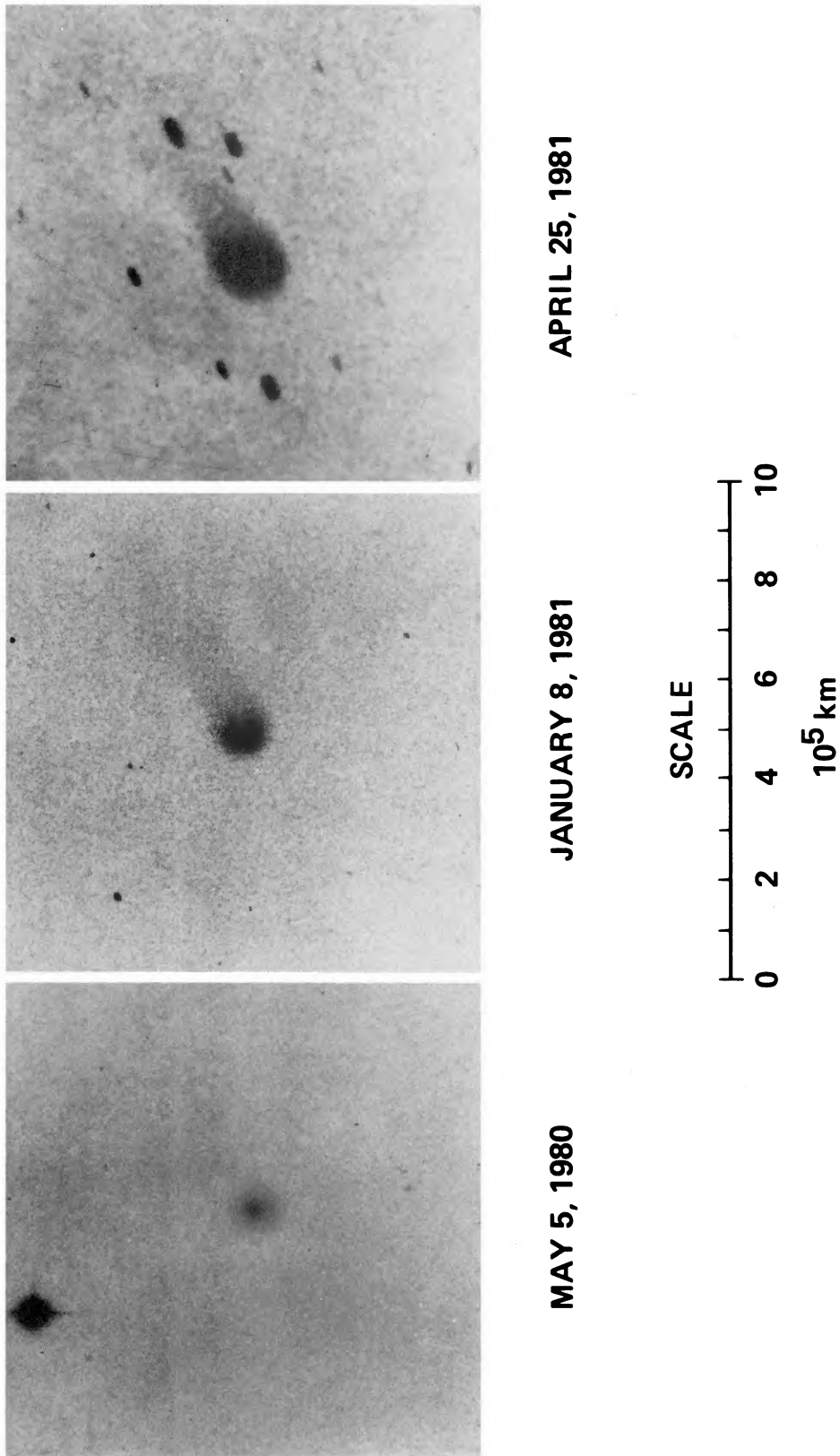


FIG. 1. Changing appearance of Comet Bowell between May 1980 and April 1981. The photographs have been reduced to a common linear scale. Note the development of a tail and a lopsided coma in 1981. [Original prints courtesy of: H. D. Ables and H. H. Guetter, U.S. Naval Observatory (left); H. Spinrad and Cerro Tololo Inter-American Observatory (middle); and E. Everhart, Chamberlin Observatory (right).]

TABLE I. Photographic observations of Comet Bowell.

	Date (UT)		
	May 5, 1980	January 8, 1981	April 25, 1981
Geocentric distance, Δ (AU)	6.53	4.95	3.63
Heliocentric distance, r (AU)	6.90	5.20	4.52
Phase angle	8°	11°	7°
Apparent coma diameter ¹ , D_n	20"	32"	47"
Real coma diameter ¹ (km)	95,000	115,000	124,000
Position angle of tail	2	294° ± 2°	292° ± 4°
Apparent tail length	<10"	75"	105"
Real projected tail length (km)	<47,000	269,000	276,000
Observer(s)	H. D. Ables, H. H. Guetter	H. Spinrad	E. Everhart
Telescope	150-cm reflector	400-cm reflector	41-cm reflector
Exposure time (min)	60	10	60
Emulsion	IIaD	103a0	Hypersensitized 2415 ³
Observatory	U.S. Naval Observatory, Flagstaff Sta.	Cerro Tololo Inter- American Observatory	Chamberlin Observatory, Dick Mountain Field Sta.

¹ Normal to the tail direction.

² No tail observed; its apparent length less than coma radius.

³ A panchromatic film emulsion.

are the heliocentric distance and true anomaly at the time of separation t_s , r and v at time t ; p , r_s , and r are all in AU (Sekanina 1978). An upper limit on z is given by

$$z \leq 362.6 D_n \Delta, \quad (2)$$

where D_n is the apparent coma diameter normal to the orbit plane (in arcseconds) and Δ the comet's geocentric distance (in AU). The maximum V_n , calculated from Eqs. (1) and (2) and plotted versus heliocentric distance at the time of assumed separation in Fig. 2, comes out to be extremely low.

A property of the tails of the distant comets that distinguishes them from the regular dust tails of comets near the Sun is that their width does not increase with distance from the nucleus. For Comet Bowell, which has been approaching the Sun essentially in the plane of the ecliptic, this property leads to two conclusions: (a) the particle velocity does not increase with decreasing particle size (cf. Sec. III), plainly in conflict with the theory of particle ejection by expanding gas; (b) the boundaries of the coma and tail have been determined by particles separating from the comet very long before observation. Indeed, if, for example, the projected width of the coma on the 8 January photograph in Fig. 1 had been due to particles released from the comet shortly

before, by 25 April the coma or the tail would have extended to much greater distances from the orbit plane. Yet, the observed width of the coma and tail did not increase by more than 8% between 8 January and 25 April. From Fig. 2 the very modest rate of expansion of the coma with time is readily understood, if it is determined by velocities of the particles that had separated from the comet between 11 and 12 AU from the Sun. If this hypothesis is correct, the relevant normal component of particle velocity amounts, on the average, to only 0.78 m/s.

The tail length provides information on the maximum particle acceleration β_{\max} by radiation pressure versus the time of assumed separation. Figure 3 shows the results of calculations for the three dates in Fig. 1. While the tail lengths on the two 1981 dates are reasonably consistent with each other for a wide range of assumed times t_s and are therefore of no diagnostic value by themselves, the absence of the tail on the 1980 plate does, in comparison with the 1981 photographs, provide important constraints on the model. The tail observed in 1981 could not contain particles that had left the comet at heliocentric distances of more than ~ 14 AU, or else in May 1980 the tail would have reached beyond the visible limits of the coma. A better estimate of the pro-

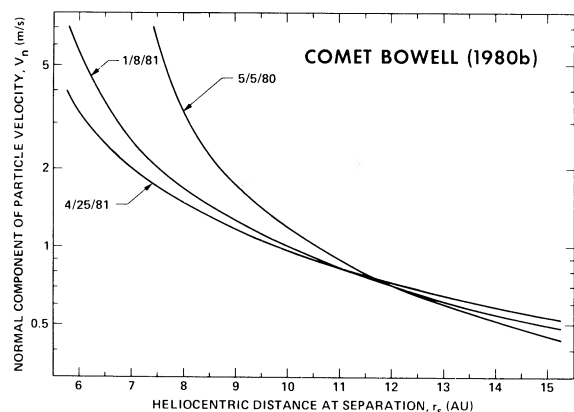


FIG. 2. A component of the particle velocity normal to the orbit plane of the comet vs heliocentric distance at the time of assumed separation, calculated from the observed coma diameters on the three photographs.

jected tail length, one-half of the apparent coma radius, implies a probable onset of tail formation between 11 and 12 AU, consistent with the estimate for the onset of coma expansion.

Another interesting piece of information results from a pair of near-infrared observations, made by A'Hearn, Dwek, and Tokunaga (1981) on 8 November 1980 and by Veeder and Hanner (1981) on 10 March 1981. From the reported apparent magnitudes in the J , H , and K bands and the used beam sizes, I calculate the total brightness of the coma (neglecting the much fainter tail) within the diameters of 112 000 km on 8 November and 122 000 km on 10 March, derived from a fit to the data in Table I. The result depends on the assumed brightness variation with distance R from the nucleus. Fragmentary information suggests that the brightness varies as R^{-1} in the infrared (Ney 1976), but steeper profiles were found for some comets in the visible. In the near

infrared, A'Hearn, Dwek, and Tokunaga's (1981) data for P/Stephan-Oterma suggest $R^{-1.3}$, much like Newburn, Bell, and McCord's (1981) results do for P/Ashbrook-Jackson in the visible. Radial variations less steep than R^{-1} seem rare. Since no information is available on the radial brightness profile of Comet Bowell, I list the extrapolated normalized magnitudes in Table II for the assumed distributions $R^{-1.2}$, R^{-1} , and $R^{-0.8}$. The magnitudes refer to dust in the defined volumes of the coma and are reduced to unit geocentric and heliocentric distances by the inverse-square power law. If the brightness varies more steeply than R^{-1} , I find either no change or a decrease with time in the comet's normalized brightness between November 1980 and March 1981. Accordingly, no particles appear to have been injected into the coma between the two dates. Even if the brightness distribution is somewhat less steep than R^{-1} , the most optimistic conclusion one can make is that the comet's particle production has failed to increase with decreasing heliocentric distance, again a result that is hard to reconcile with the ejection theory. The most likely conclusion is that the release of particles had ceased by November 1980, possibly much earlier.

III. THE SIZES, TOTAL MASS, AND SOURCE OF THE PARTICLES

The probable onset of coma and tail formation at 11 or 12 AU from the Sun sets an upper limit on the accelerations β by radiation pressure that particles in the tail of Comet Bowell are subjected to; I find $\beta_{\max} = 0.0015$ to 0.002 the solar gravity (Fig. 3). These extremely low accelerations cannot be attributed to dielectric particles with sizes below $\sim 0.01 \mu$ because of the absence of Rayleigh scattering, indicated by the $J-H$ and $H-K$ colors (A'Hearn, Dwek, and Tokunaga 1981; Veeder and Hanner 1981). The results on Comet Bowell thus confirm my earlier conclusion (Sekanina 1973, 1975) that the distant comets release submillimeter-sized and large-

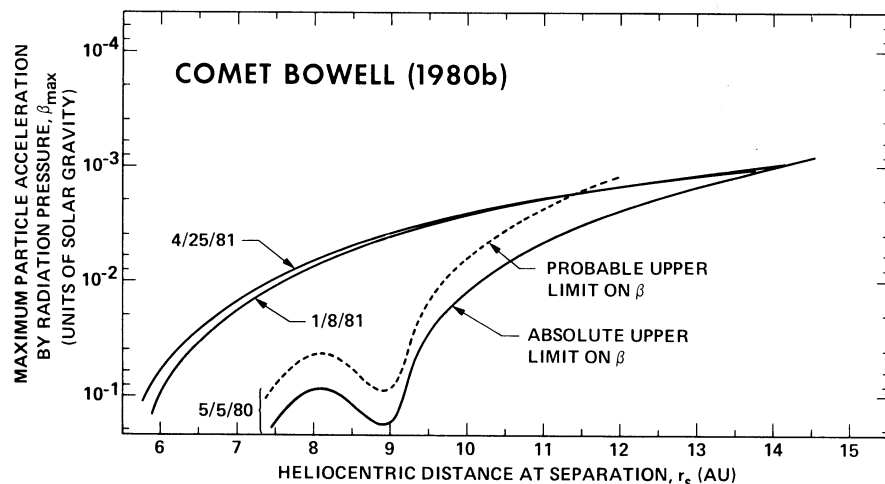


FIG. 3. The maximum particle acceleration by radiation pressure vs heliocentric distance at the time of assumed separation, calculated from the observed tail lengths on the two 1981 photographs; for the 1980 observation the two curves show the absolute and probable upper limits on the acceleration, derived from conditions that the projected tail length be shorter than the apparent coma radius and one-half of the coma radius, respectively.

TABLE II. Normalized magnitudes of Comet Bowell in three near-infrared passbands from observations on 8 November 1980 and 10 March 1981.

Passband	Date 1980/81	Assumed radial-brightness distribution		
		$R^{-1.2}$	$R^{-1.6}$	$R^{-2.2}$
J	Nov. 8	5.82	5.63	5.44
	Mar. 10	5.84	5.47	5.10
H	Nov. 8	5.37	5.18	4.99
	Mar. 10	5.38	5.01	4.64
K	Nov. 8	5.22	5.03	4.84
	Mar. 10	5.35	4.98	4.61

er grains. At an assumed density of 1 g/cm^3 and efficiency Q_{pr} of unity, the minimum particle radius, corresponding to the above β_{\max} , is in the range of $300\text{--}400 \mu$. Assuming that the distribution function of particle sizes s is proportional to $s^{-h} ds$, I find for the total mass of particles in the coma:

$$M = 1.04 \times 10^{12 - 0.4V_0} \frac{Q_{pr}}{a\beta_{\max}} \frac{h-3}{h-4}, \quad (3)$$

where V_0 is the total visual magnitude normalized to unit heliocentric and geocentric distances by the inverse-square power law and a is the particle albedo. With $4 < h \leq 5$, $a \leq 0.3$ (to allow for a possibly major share of ices), and $V_0 \approx 6.5$ mag (roughly extrapolated from the JHK photometry in Table II), $M \gtrsim 10^{13}$ g.

When A'Hearn *et al.* observed the comet on 8 November 1980, its heliocentric distance was about 5.6 AU. If the particles residing in the coma had been released from the nucleus continuously between 11.5 and 5.6 AU from the Sun, one finds a nominal average particle production rate $\gtrsim 10^5$ g/s, a level of activity so high that it had not been reached by the very dusty Comet Bennett 1970 II until it was less than 1 AU from the Sun (Sekanina and Miller 1973)! An assumption of surface activation by energy release from a transition of water ice from the amorphous to cubic phase (requiring a temperature of 140 K and restricted to heliocentric distances of less than 8 AU even on the most exposed areas of the nucleus surface) or an *ad hoc* hypothesis of a major outburst at a distance of 11 to 12 AU from the Sun are unattractive both because of the stupendous production rate required (e.g., $> 10^8$ g/s for an outburst duration of 1 day) and because of the already discussed coma and tail properties.

I conclude that circumstantial evidence presented in this paper is sufficient to disregard the high inferred particle production of Comet Bowell as meaningless. I suggest that the comet has in fact been dormant, ejecting no dust whatsoever, and that the observed mass of particles, although gravitationally attached to the comet be-

yond ~ 12 AU from the Sun, may have never, or not for a long time, been in contact with the nucleus surface (Sec. IV). At heliocentric distances beyond 12 AU and in the absence of outgassing, particle motions at distances of up to 500 km or more from the nucleus should be controlled by the comet's gravity. The limit depends on the comet's mass and on the character of particle trajectories. Hence extensive coma and tail began to develop only at a distance from the Sun, where its gravitational perturbations started overcoming the attraction between the comet and the most distant particles. The heliocentric distance at the onset of coma and tail formation is a function of the comet's mass and of the volume originally occupied by the gradually dissipating perinuclear population of particles. If the particles extend all the way to the nucleus surface, the process can be completed, if ever, only when appreciable sublimation begins.

IV. THE ELONGATION OF THE COMA AND THE POSITION OF THE SPIN AXIS

A peculiar property of Comet Bowell has been the development of a lopsided coma, illustrated in Fig. 1. The 1980 photograph shows the comet to be quite symmetrical, its contours round. By January 1981, however, an asymmetry had developed, the coma becoming distinctly elongated in position angle $\sim 10^\circ$, that is, in the direction that makes about 75° with the tail axis. The coma was still lengthened in the same position angle in April 1981. The ratio of the minimum to the maximum dimension is estimated at about 0.8 on either photograph. In addition, Dr. E. Everhart informs me that the central condensation is displaced slightly toward the Sun and appears to be elongated in the same direction as the coma.

The slight displacement of the central condensation is probably due to a contraction of the coma, an effect of radiation pressure on particle trajectories along the radius vector. In projection onto the sky the resulting elongation depends on the comet's phase angle (Sun-comet-Earth), which happened to be very small and nearly constant for the three photographs (Table I). Yet, the coma as a whole was lopsided only in 1981. More important, if due to radiation pressure, the deformation ought to be symmetrical with respect to the orbit plane, and the coma, contrary to observation, ought to be elongated at a right angle to the tail axis.

A more plausible interpretation is based on the assumption that the observed shape of the coma is a result of the angular momentum distribution of the perinuclear population of particles (Sec. III), involving an effect of the comet's rotation. The extremely low particle velocities (Fig. 2) are comparable in magnitude with the expected velocity of escape at the surface of a kilometer-sized nucleus. Modified by the Sun's perturbations, these velocities do not necessarily measure an initial particle-velocity distribution relative to the comet. However, both a characteristic equatorial rotational velocity of the nucleus [based on Whipple's (1982) results on the

cometary spin rates] and a characteristic unperturbed circular velocity of gravitationally attached dust should be on the same order of magnitude as, though somewhat lower than, the maximum particle velocity derived from the photographs. The contribution of the comet's angular momentum to the observed particle velocities could therefore be statistically significant, in which case the coma should extend primarily in the equatorial plane of the comet. The parallel extensions of the coma and the central condensation, suspected by Everhart, are consistent with this hypothesis.

To determine what position the rotation axis should have in order to be compatible with observational evidence, I calculate the position angle P of the maximum diameter of the coma as a function of the spin vector. The pole of rotation is determined by obliquity I of the comet's orbit plane to the comet's equator and by angle Φ of the subsolar meridian at perihelion, measured along the orbit from the ascending node of the orbit plane on the equator (for details see Sekanina 1979, 1981). At the comet's position in orbit described by true anomaly v , a unit spin vector ω has the following components: in the direction of the prolonged radius vector, ω_r ; in the direction perpendicular to the Sun in the orbit plane in the sense of the orbital motion, ω_t ; and in the direction of the northern orbital pole, from which the comet is seen to orbit the sun counterclockwise, ω_n :

$$\begin{aligned}\omega_r &= -\sin I \sin(\Phi + v), \\ \omega_t &= -\sin I \cos(\Phi + v), \\ \omega_n &= \cos I.\end{aligned}\quad (4)$$

Let a unit vector \mathbf{e} pointing from the comet to the Earth have components e_r , e_t , and e_n in the same system of coordinates. The position angle of the projected coma elongation is then given by

$$\tan(P - P_{RV}) = \frac{(e_r^2 - 1)\omega_r + e_r e_t \omega_t + e_r e_n \omega_n}{e_n \omega_t - e_t \omega_n}, \quad (5)$$

where P_{RV} is the position angle of the prolonged radius vector.

All three photographs of Fig. 1 indicate that if the coma elongation is related to the comet's spin, the obliquity must be near 90° . A symmetrical coma on the first photograph suggests that the polar axis was pointing nearly at the Earth in May 1980, so that

$$\frac{e_t}{e_r} \simeq \frac{\omega_t}{\omega_r} = \cot(\Phi + v), \quad (6)$$

$$\frac{e_n}{e_r} \simeq \frac{\omega_n}{\omega_r} = -\frac{\cot I}{\sin(\Phi + v)}.$$

The second of the two conditions has little diagnostic value, since e_n is very small (because of the near-zero inclination of the comet's orbit) and so is $\cot I$, when $I \simeq 90^\circ$. On the other hand, the first condition is independent of I and gives immediately

$$\Phi = 8^\circ. \quad (7)$$

Next I rewrite Eq. (5) with the help of Eq. (4) in the form

$$\tan I = [e_r e_n + e_t \tan(P - P_{RV})] \{ (e_r^2 - 1) \sin(\Phi + v) + [e_r e_t - e_n \tan(P - P_{RV})] \cos(\Phi + v) \}^{-1} \quad (8)$$

and look for obliquity I that satisfies $P \simeq 10^\circ$ on the two 1981 dates. The best fit gives

$$I = 97^\circ. \quad (9)$$

Because the sense of rotation remains unknown, a second, equivalent solution is described by $\Phi = 188^\circ$ and $I = 83^\circ$. Essentially, one pole of rotation is continuously exposed to the Sun before perihelion; the other pole, after perihelion.

It should be pointed out that the coma ellipticity of Comet Bowell is fundamentally different from the fan-like appearance of some, especially short-period, comets at smaller heliocentric distances. Their central condensation is always located near the apex of the fan on the generally antisunward side (Sekanina 1979).

V. FURTHER RESULTS AND CONCLUSIONS

Table III compares the model with the observations of the position angle of elongation and of the minimum-to-maximum coma size ratio, the latter being in an extreme case given by cosine of an angle subtended by vectors ω and \mathbf{e} . The fit is so good that one should consider seriously the possibility that the comet could have

TABLE III. Comparison of the model of coma elongation with observations.

Date (UT)	Position angle of elongation		Minimum-to-maximum diameter ratio of the coma		Calculated angle between comet's spin vector and direction to earth
	Observed	Model	Observed	Model	
1980 May 5	1	291°	-1.0	0.99	7°
1981 Jan. 8	~10°	11	-0.8	0.79	38
1981 Apr. 25	~10	9	-0.8	0.85	32

¹ No elongation observed.

originally possessed a ring in its equatorial plane, as suggested by Whipple (1981, private communication). The mode of origin and a long-term stability of such a formation are outstanding problems that should be addressed. One may speculate that the ring, or disk-shaped cloud of particles, could be made of a leftover pristine material (presumably rich in ice) that was available but failed to condense on the nucleus surface of the newly born comet. The concentration of particles toward the equatorial plane would suggest that the nucleus could be rather oblate. One can also envision a scenario in which the cloud of particles was formed much later, during the comet's voyage from the Oort cloud to the Sun, though still at very large heliocentric distances. Indeed, laboratory experiments with relevant ice mixtures in a very cold environment have confirmed earlier theoretical results (Donn 1976, Whipple 1977) that the ices, when irradiated by relatively moderate doses (compared to the total estimated exposure during $\sim 10^9$ yr in interstellar space) of protons (Moore and Donn 1981) or ultraviolet light (Greenberg 1982), become chemically unstable in the temperature range of some 15–40 K. The formation of new molecular species is accompanied by erratic activity that ceases at higher temperatures. Such processes could provide a mechanism for an early and possibly rather sudden ejection of a large amount of dust (or inert ice) from a new comet on its way to the Sun. Depending on the level of activity, particles smaller than a certain critical size would be lost; the rest, too heavy to escape, would fall back on the surface or start orbiting the nucle-

us. If the comet's spin is of real assistance in the expulsion of heavy particles, the equatorial region should be the primary source of the ejecta.

If due entirely to gravitational perturbations by the Sun, the disintegration of the particle ring about the comet must commence on its outside, gradually advancing toward the nucleus. The particle velocity at the time of escape from the comet's gravity field should increase as the comet approaches its perihelion, varying, on the average, as an inverse square root of heliocentric distance. Although one may not entirely disregard a possible short-term effect of Jupiter's gravitational perturbations on the ring around the time of the comet's approach to the planet in December 1980, the dominant role of the Sun is evident from the fact that the process of particle escape had commenced long before the encounter.

Continuing observations will help us gain greater insight into the nature of Comet Bowell. *If the comet has been and should remain dormant* throughout this apparition, the intrinsic brightness of the coma should sooner or later start declining as more and more particles have been blown away into the tail. The expected variation in the apparent coma diameter (measured perpendicular to the orbit plane) with time is plotted in Fig. 4. This prediction is based on an assumption that the dimensions of the coma are determined by the most distant among the particles that have left the comet's gravity field continuously on the incoming leg of the orbit between 11.5 AU and perihelion with a velocity of 0.78

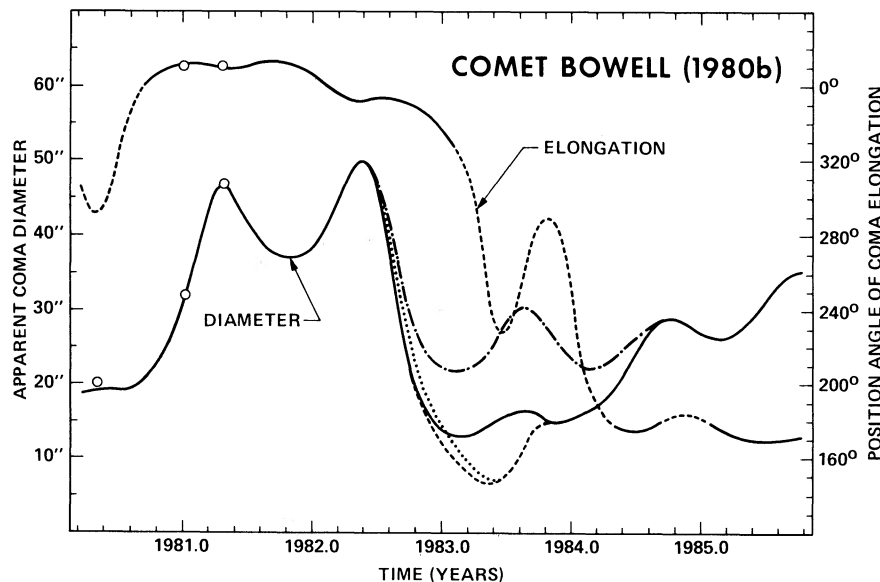


FIG. 4. Predicted apparent coma diameter normal to the orbit plane and position angle of the coma elongation vs time. The coma diameter, assumed to be determined by particles that have left the comet's gravity with a velocity of 0.78 m/s, is represented by the solid curve. A termination of the process at 8 AU before perihelion rather than at perihelion would result in deviations that are represented by the dashed curve. If particles leave the comet's gravity with a velocity that varies inversely as a square root of heliocentric distance, the prediction is modified as shown by the dash-and-dot curve. The termination at 8 AU would further change the prediction as indicated by the dotted curve. The position angle of the coma elongation is assumed to be determined by the position of the spin vector. When the rotation axis points within $\sim 20^\circ$ of the Earth, the elongation may be too small to detect; for such times the elongation curve is dashed. The coma diameters measured on the three photographs of Fig. 1 and the position angles measured on the two 1981 photographs are represented by circles.

m/s. If the process of particle escape had terminated at, say, 8 AU before perihelion rather than at perihelion, significant deviations from the above prediction could be detected only in the first three quarters of 1983. A possibly better prediction is offered on the assumption that the particle velocity varies with heliocentric distance as $0.78(11.5/r_c)^{1/2}$ m/s, affecting the above results between mid-1982 and mid-1984. If the interpretation of the coma asymmetry is correct, the variation in the position angle of coma elongation with time should follow the other curve in Fig. 4. The spectrum should of course remain a pure continuum and the color of the comet, if particle properties do not change with time, ought to stay the same. Important information will result from measurements of brightness variation in the coma with distance from the nucleus and with time. Such measurements are strongly encouraged.

Comparative studies of Comet Bowell with other comets of large perihelion distance, with emphasis on differences between the group characteristics and individual characteristics, should also be pursued. Bowell is almost certainly a new comet in the Oort-Schmidt (1951) sense, judging from the tentative orbital data (Marsden 1981; Everhart 1981, private communication). Comparison with other new comets of large perihelion distance shows Comet Bowell to be average both in terms of the maximum effect by radiation pressure β_{\max} on the tail particles (Sec. III) and in terms of the heliocentric distance of particle release r_c (Sec. II). For two among the best observed new distant comets, Baade 1955 VI and Haro-Chavira 1956 I, β_{\max} was estimated at 0.002–0.003 on the average, while r_c reached up to 12 and 15 AU preperihelion, respectively (Sekanina 1973, 1975). A detailed study of the tail orientation and length on one particular photograph of Comet Baade gave $\beta_{\max} = 0.0012$ and $r_c \simeq 9$ AU as the best fit (Fig. 5 of Sekanina 1975). The extremely long lifetimes of tail particles suggest the absence of significant evaporation effects. In fact, if particle evaporation in the coma were severe enough to curtail its visible size, the tail could never have developed in the first place.

The proposed dormant condition is consistent with two well-known group characteristics of the distant comets: (a) the absence of detectable nongravitational forces in the orbital motions of these comets, demonstrated by the sharpness of the Oort cloud peak in the distribution of the "original" reciprocal semimajor axes, an effect that disappears among comets with smaller perihelion distances (Marsden and Sekanina 1973; Marsden, Sekanina, and Everhart 1978); (b) a slight suggestion of a gradual fading on the first approach to the Sun (Sekanina 1976), and distinct evidence of considerable loss of brightness on the subsequent return, illustrated by the dominant representation of the new comets in the available sample of orbits (Marsden and Sekanina 1973; Marsden, Sekanina, and Everhart 1978).

Excepting highly unusual comets, such as Humason 1962 VIII and P/Schwassmann-Wachmann 1, which

offer no resemblance to Comet Bowell, I find that for two Bowell-like distant comets evidence indicates some nucleus activity. One of them, Comet Wirtanen 1957 VI (perihelion distance of 4.4 AU), was observed double for several years. The motion of the companion relative to the principal component is represented most satisfactorily by a model which includes in the solution an effect of a slight, but perceptible, difference in the effective solar attraction that the two nuclei were subjected to—a product of a differential thrust by outgassing (Sekanina 1978). When this net force is neglected and the pair assumed to have drifted apart solely as a result of a differential momentum acquired at separation, the quality of fit deteriorates noticeably.

The other active comet is Stearns 1927 IV, which was remarkable in more than one respect. Although not a new comet (Marsden, Sekanina, and Everhart 1978), it also displayed the same type of tail as Bowell, seen on photographs published by Van Biesbroeck (1927a) and by Baillaud and Jasse (1927). Of perihelion distance comparable to that of Bowell, Comet Stearns showed C_2 emissions superimposed on a strong continuous spectrum at 3.7 AU (!) from the Sun (Bobrovnikoff 1927; Van Biesbroeck 1927b) and was observed as a diffuse object at a record distance of 11.5 AU from the Sun (Van Biesbroeck 1933). The coincidence with the heliocentric distance of Comet Bowell's onset of coma and tail formation is probably fortuitous, especially because the opposite legs of the orbits are involved.

Comets Stearns and Wirtanen show that there is always room for surprises. As far as Comet Bowell is concerned, however, there was—as of early 1981—no evidence of particle ejection triggered by outgassing and no definite evidence of outgassing itself. The dormant condition might, nevertheless, cease temporarily in the proximity of perihelion, in which case molecular emissions could be detected in the spectrum later in 1981 and/or in 1982. To summarize the arguments against particle ejection via outgassing from the comet in the period until early 1981:

(1) The spectrum has shown no definite trace of molecular emissions.

(2) In late 1980 and early 1981 the intrinsic brightness of the comet was nearly stable or decreased slightly with time, so apparently no dust was injected into the coma during that time; yet the implied huge amounts of dust already in the coma would require unreasonably high production rates.

(3) The slow expansion rate of the coma and the large quantities of dust in it are incompatible with the concept of particle ejection triggered by recently activated species, such as CO_2 , that have an appropriate degree of volatility for the heliocentric distances involved.

(4) The extremely low particle velocity (~ 1 m/s) which does not increase with decreasing particle size makes the concept of dust ejection via sublimation of highly volatile species equally unattractive.

(5) The absence of Rayleigh scattering combined with

the very low accelerations by radiation pressure indicates that only submillimeter-sized and larger particles are present in the coma and tail, unlike the size distribution in comets at much smaller heliocentric distances.

(6) The elliptical coma with its long axis tilted to the comet's orbit plane, apparently a signature of the comet's angular momentum, shows no resemblance to the fan-like coma asymmetry displayed by many comets at smaller distances from the sun.

(7) There is no evidence of particles evaporating significantly enough to invalidate any of the above conclusions.

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