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ON OBSERVING COMETS FOR NUCLEAR ROTATION

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Introduction

The prevalent non-gravitational motions among comets (Marsden, Sekanina and Yeomans, 1973; Hamid and Whipple, 1953; and Whipple 1950-1951) demonstrate that the sublimination does not reach a maximum at the instant of maximum insolation on the nucleus. The occurrence of halos or "parabolic" envelopes in the comae of some comets (Fig. 1) and of jets, rays, fans, streamers and similar phenomena very near the nucleus in the brightest comets (Fig. 2) demonstrates that the sublimation process is not uniform over the nuclei. In other words, the nuclei of many comets contain relatively small active regions which provide much or most of the sublimation when these areas are turned toward the Sun. The period of rotation, P, can thus be determined by measurement of the diameters of the halos or of the latus recta of the "parabolic" envelopes, if the expansion velocities are averaged from observations as a function of solar distance. This method was applied for comet Donati, 1858VI (P=4.6 hr.) and the P/Schwassmann-Wachmann 1 (Whipple, 1978, 1977). My experience from similar analyses of some 80 well observed comets shows that the nuclei are "spotted" for more than a third of all comets, regardless of the "age" as measured by the original inverse semimajor axis including correction for planetary perturbations. Max Beyer has been by far the major single contributor to the field of nuclear rotation. His uniform series of observations over more than three decades is a treasure trove of data and a model for visual observers. J. F. Julius Schmidt's observations last century are priceless.

The delay or "lag angle" in sublimation after the active region passes the solar meridian on the nucleus should clearly result in an observed asymmetry of the inner coma if the geometry of Sun, comet and Earth is suitable (Fig. 3). For P/Schwassmann-Wachmann 1 the direction of the polar axis and the sense of rotation are clearly delineated in this fashion although the active areas do not generally pass through the subsolar point nor is the lag angle always positive for this slowly rotating comet (P=5.0 days, Fig. 4). Sekanina (1979) determined the poles of spin axes and the lag angles for four short-period comets assuming that the region of maximum sublimation did indeed pass through the subsolar point. He has also had great success in analyzing the observed rays, jets, fans and streamers near the nucleus of comet Swift-Tuttle 1862III to determine the axis of rotation and the specific locations of several active areas on the nucleus (Sekanina, 1981a). Furthermore he has interpreted the forms of the jets and the streamers to determine particle-size distributions and the sublimation rate of icy grains ejected along with the gas. For a complete summary and in-depth discussion of the analytical aspects and results regarding rotation and precession of cometary nuclei the reader is referred to Sekanina's review (1981b).

Visual observations have provided the majority of the observational data concerning halos, envelopes, rays, fans, jets and streamers that have led to determinations of rotation characteristics of cometary nuclei. Measurements are made of angular diameters and position angles or else drawings of the near-nucleus region are provided. Photographic as well as visual observations have been extremely valuable in determining asymmetrical ejection. The analysis of such observations is still in the developing stage but it has already given us new insights with regard to the physical properties of the nucleus such as lag angle, inhomogeneities or active areas on the nuclei, axes of rotations, the existence of oblateness and precession in the nucleus of Comet Encke (Whipple and Sekanina, 1980) and suggestions with regard to the detailed heating, sublimation and ejection processes on cometry nuclei. The methods may lead to an understanding of the still mysterious process of cometary splitting.

F. W. Bessel (1836) first suggested a method of determining the period of comet rotation by analysis of oscillations in the tail rays and streamers. Schmidt (1863) applied the method to P/Swift-Tuttle obtaining P=2.8 days. This value is confirmed by Sekanina. I found one-half this

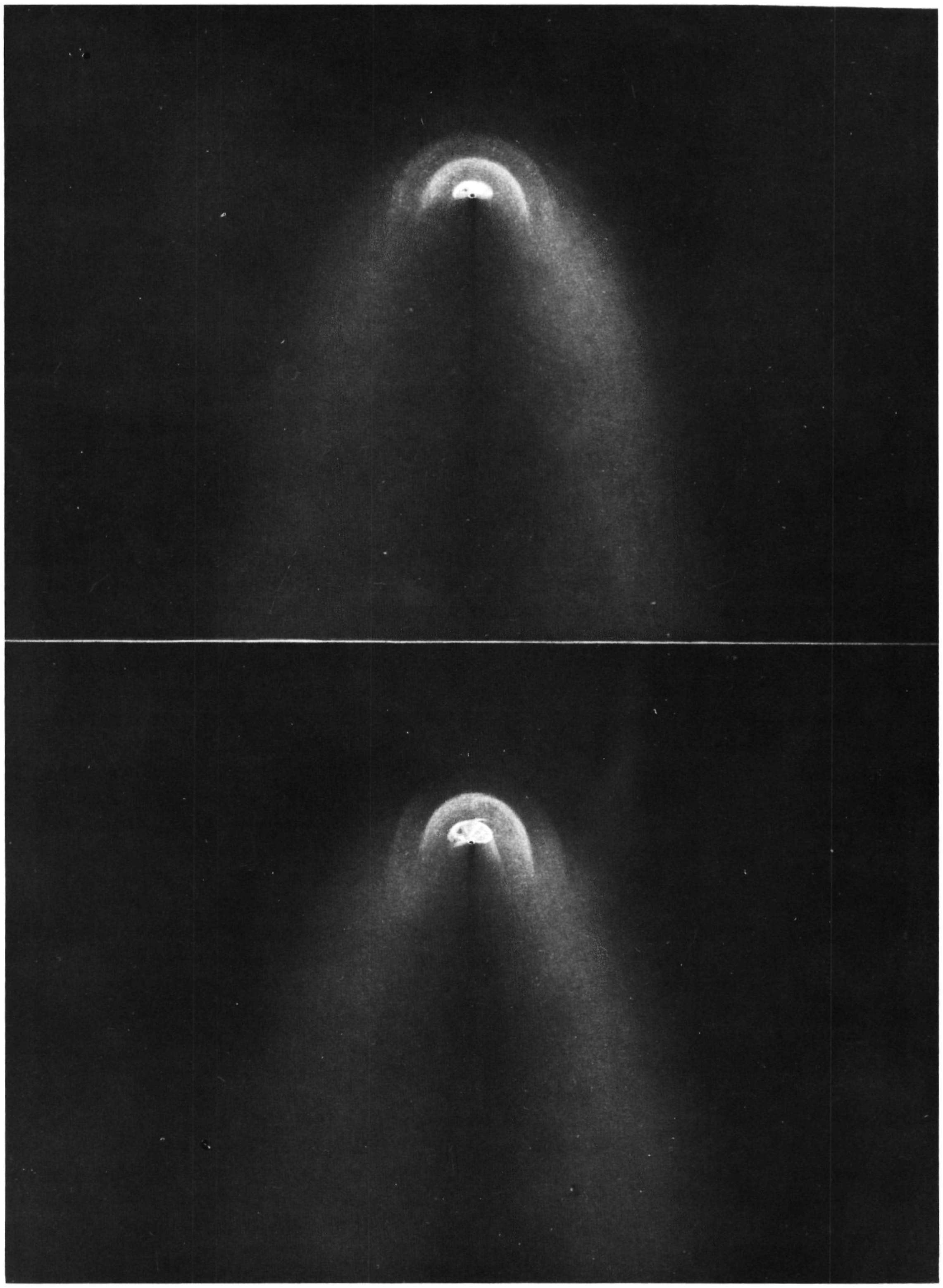
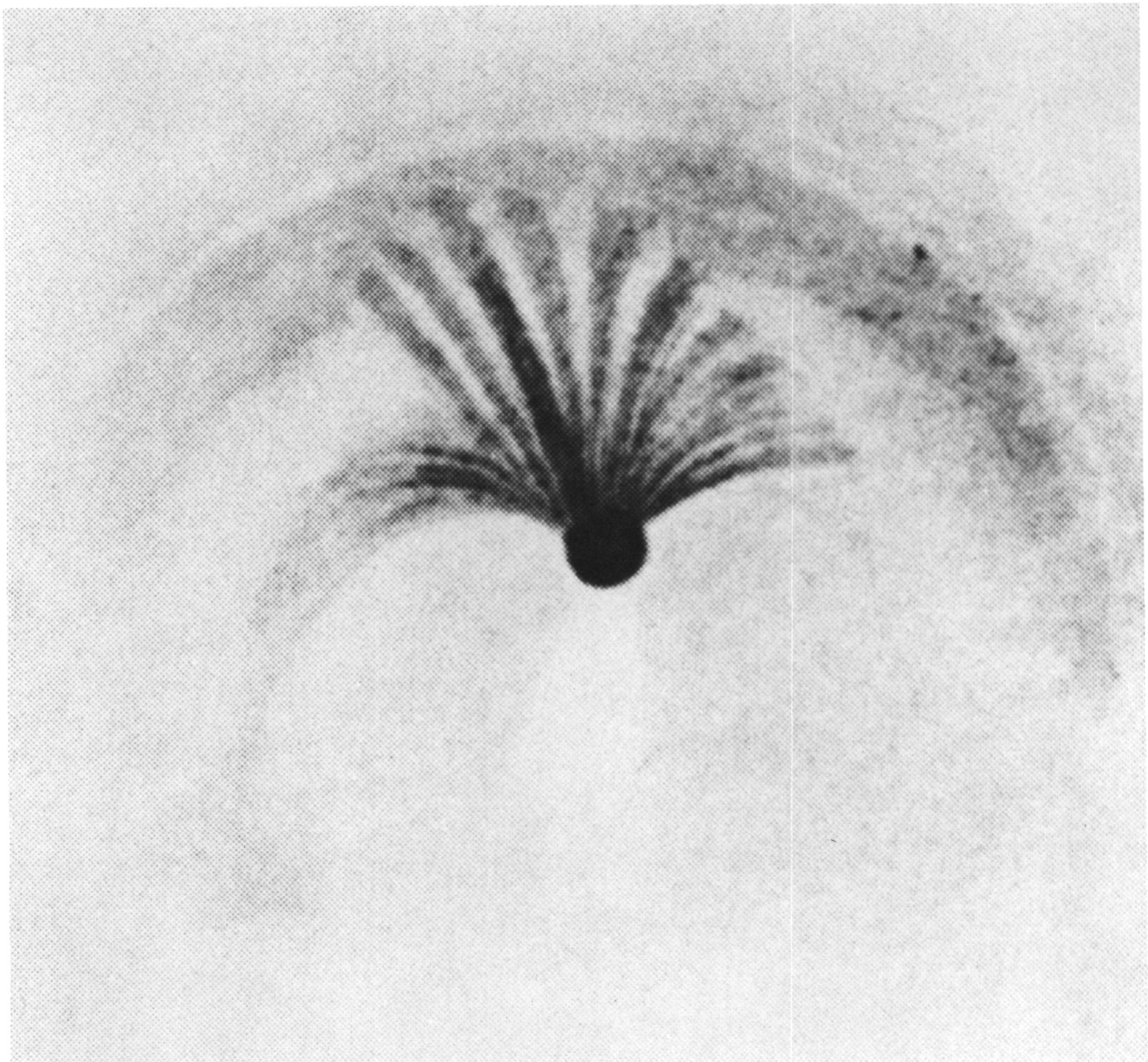


Figure 1. Drawings of Comet Donati, 1858VI, by G. P. Bond of Harvard Observatory on October 4 (top) and October 5 (bottom), 1858, showing the halos. They are separated in time by 4.6 hours, taken to be the rotation period of the cometary nucleus. The inner halo on October 5 appears slightly larger than that on October 4. Actually it is the fifth halo to be formed after that of October 4.



JULY 1, 3^h a.m.

r(A.U.)	Δ(A.U.)	a
0.90	0.13	152°.7

Figure 2. Comet Tebbutt 1861II, drawn by P. A. Secchi, July 1, 1861. From "Atlas of Cometary Forms," Fig. 21, p. 20.

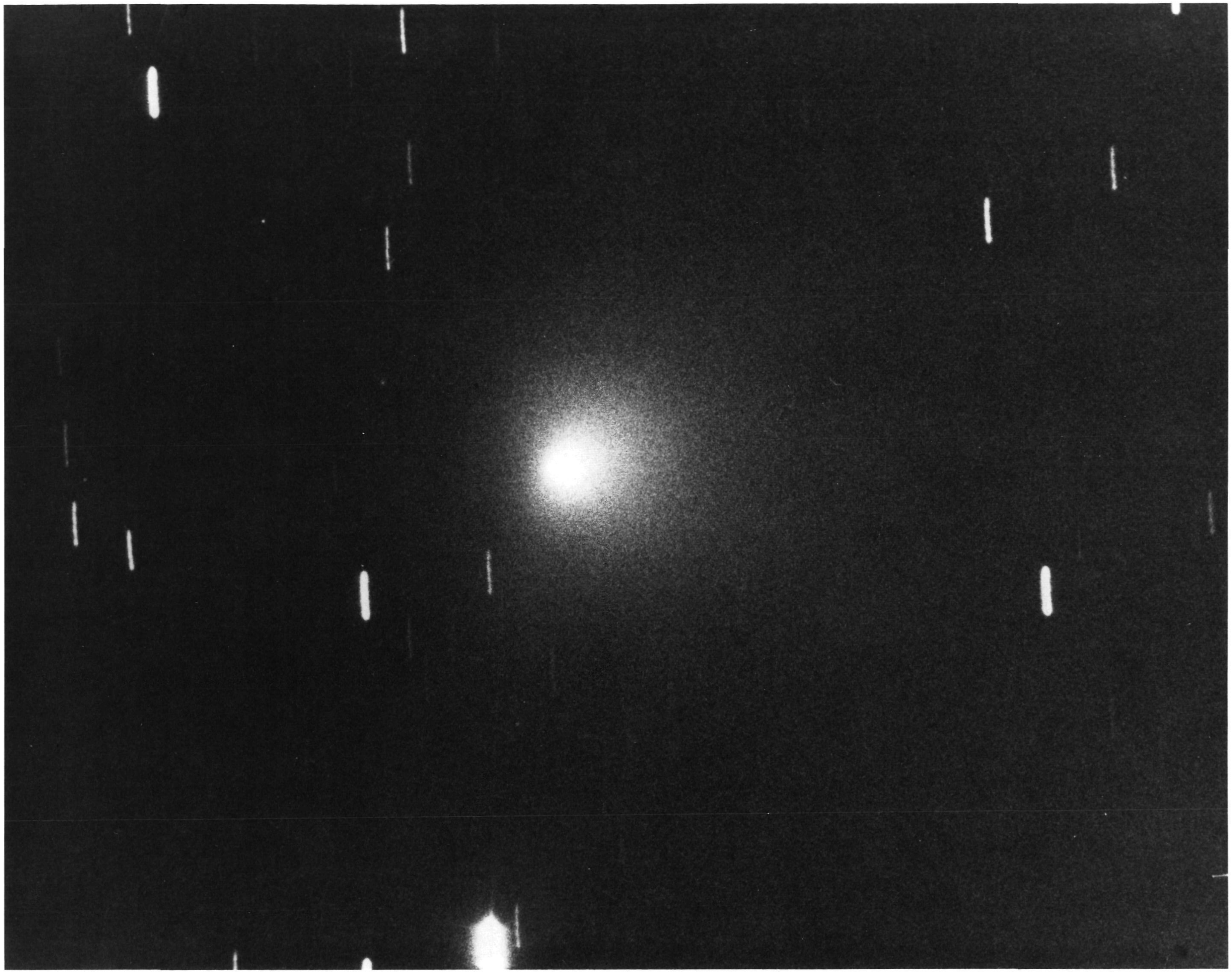


Figure 3. P/Tempel 2, photographed by H. M. Jeffers at the Lick Observatory in the Fall of 1946.

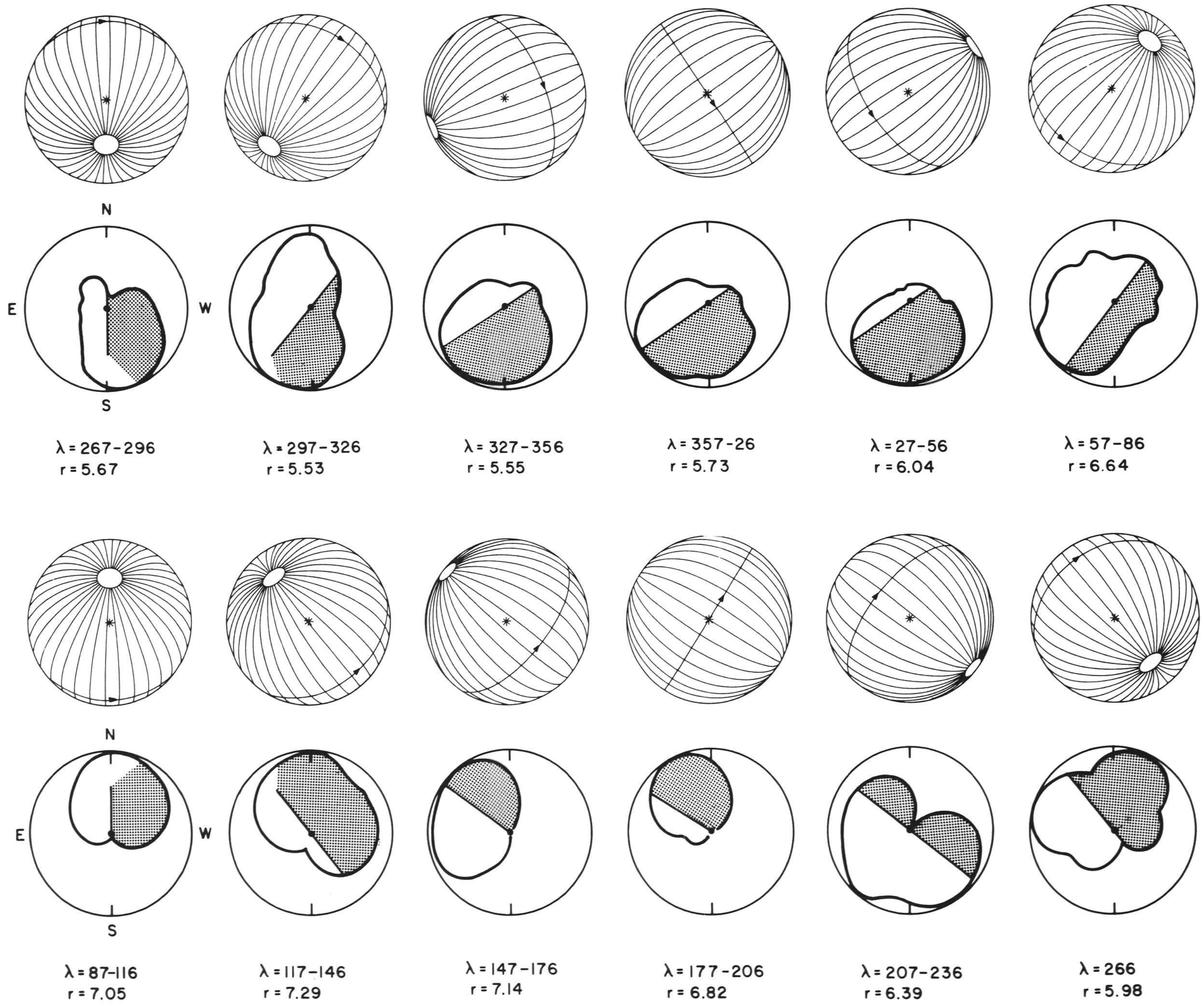


Figure 4. P/Schwassmann-Wachmann 1, model of rotating nucleus (upper figures) compared with directions of asymmetric coma (lower figures) for 12 positions around the orbit (λ=longitude in orbit, r=solar distance, AU).

period by the halo method, indicating that the nucleus has major active areas on opposing hemispheres. Horn (1908) applied Bessel's method to comet Daniel 1907IV, obtaining P=16.0±0.3 hours. From measures of six envelopes on five of Max Wolf's (1909) drawings I obtain P=14.1 hours, a tentative value but confirmed by the motion of the main jet. Larson and Minton (1972), utilizing the curvature of the near-nuclear jets, obtain P=1.4-1.5 days for comet Bennett 1970II. I find tentatively P=0.45 days with no indication of a period near their value. For P/D'Arrest, Fay and Wisniewski (1978) measured the unusual light curve to obtain P=5.17 hours. From 17 halos measured by Schmidt (1871) I find P=8.9 hours, generally confirmed by eight diameters I measured from 102-cm-reflector plates of the Naval Observatory taken by E. Roemer. Comet Coggia 1874III, a nearly perfect example of envelopes, gives a rotation period of $9^{h}.2$.

The purpose of the present paper is to encourage measurements of cometary coma with the hope that more measurements will be made and that they will be better standardized, utilizing the full potential of modern energy sensing devices and analytical techniques.

Envelopes and Halos

The highly descriptive term "parabolic" envelope is not as precise as it might be, even for comet Donati. Bond (1863) showed that the envelopes usually deviate greatly from parabolic form, being much narrower perpendicular to the nucleus and closely resembling catenaries. Although parabolic envelopes occur rather rarely even for the brightest comets, they can provide the most precise determinations of rotation periods. Early observers such as J. F. J. Schmidt standardized the visual measurement techniques. The most valuable angle is that of the pseudo latus rectum, p, measured from the nucleus perpendicular to the axis of the apparent parabola to the outer edge of the envelope or envelopes (Fig. 5). The angle from the nucleus to the vertex, v, of the parabola has not yet been fully exploited (see Sekanina, 1981a) but undoubtedly will be of great value when the theory of the envelopes is better developed. The ratio p/v is usually much nearer to 1.0 than to 2.0 for the parabola. The angle p, being generally normal to the solar direction, is probably the best average determinant of the rate of expansion of the gas. When divided by the velocity of expansion it provides a value of the time since the expansion begins, Δt. Since envelopes must arise from the initiation of sublimation in active areas on successive resolutions, the "zero dates", ZD's, so derived should be spaced at multiples of the period of rotation.

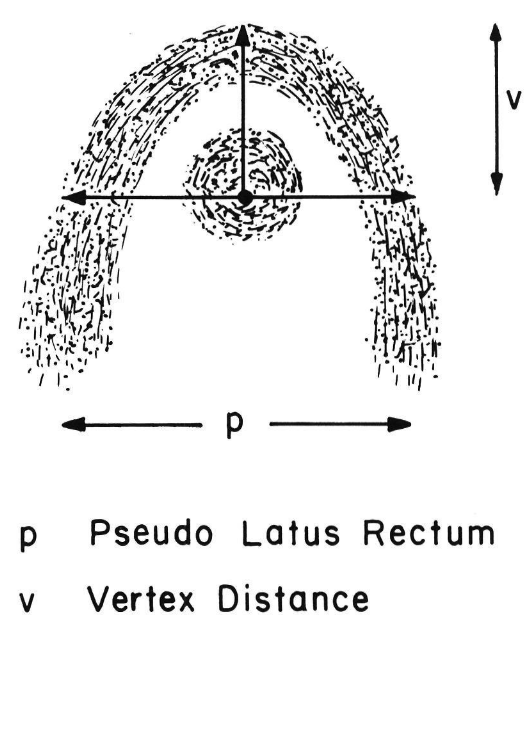


Figure 5. Idealized coma envelope with desired measurement angles identified. In this case another inner value of p could be measured.

The more perfect envelopes generally occur when the angle at the comet between the Sun and the Earth is near 90°. Away from this situation and dependent upon the rotation axis of the comet the envelopes are often symmetrical. Measurements of the semilatus rectum on the two sides may be different and a record of the two measurements is extremely important in analysis.

Many comets show halos, which are more readily seen and measured by the eye than on photographic images. This difference probably arises from the eye's remarkable ability to detect deviations from uniform intensity gradients over areas, or radially from the nucleus of a comet. The diameter of the halo should be measured along a direction generally perpendicular to the solar direction for the determination of zero dates and rotation. On the other hand, records of asymmetry along the solar direction may become of more interest as our understanding and analytical techniques improve.

Any asymmetry of the halo or coma with respect to the nucleus, particularly in inner regions, is of extreme importance in determining the axis of rotation (Fig. 3). It is mandatory that the observer give a brief description of the nature of the asymmetry and the position angle of the coma extension as seen from the nucleus. Photometric analyses, isophotes and multiple processing of coma photographs can undoubtedly be extended and improved to give more useful results for envelopes and halos (Fig. 6). Two-dimensional arrays of sensing devices both on the telescope and in analysis of photographic plates show great promise in attaining this result, aided by modern computer analysis. The adroit use of linear arrays can surely lead to improved results over either visual or photographic methods. On telescopes, the technique is limited because comets are so frequently observable only for short periods of time near the horizon, demanding rapid execution. The electronic sensing devices, however, have a unique advantage when the field is bright because the background light can be subtracted readily. Changes in the intensity gradient radially in the coma can be conspicuously displayed to reduce personal errors in diameter measures.

Visual observations have so far been the best for describing the nature of the central nucleus. A <u>stellar nucleus</u> indicates active sublimation there and sometimes heralds the beginning of a halo or <u>envelope emission</u>. A highly diffuse central nucleus, on the other hand, indicates a lack of active sublimation. On some comets these observations are important as positive or negative criteria of ZD's. The observations such as "condensed nucleus" or "concentrated nucleus" or "compact nucleus" would be much more useful if accompanied by a diameter measure or estimate. Often such a condensation represents an inner halo.

The Near Nucleus Region

With high resolving power or when the comet is very close to the Earth, detailed phenomena near the nucleus can frequently be observed. The apparently brightest comets such as P/Halley, Daniel 1907IV and many others show these short-lived highly variable activities. Even though their analytical interpretation is still in its infancy, observations of these rays, jets, fans and streamers will undoubtedly lead to extremely important progress in cometary understanding. Mention was made in the introduction of new results based on such observations, particularly the research by Sekanina.

A major problem for the observer is to preserve a precise record of the near-nucleus phenomena. Drawings are difficult to make while simultaneous observers often draw quite different pictures. Compare, for example, the drawings of P/Halley by Innes and Worsell (Fig. 7). Typically, however, the drawings by different observers show about the same features. The photographic resolving power, even with very short exposures, is usually inadequate to preserve the critical details. Furthermore, little if any effort has been expended in narrow-band or special filter studies to determine the best bands, lines or continuum in which to photograph the near-nucleus structure. It appears that Sekanina is correct in ascribing the near-nucleus jets and streamers to dust, so that a continuum filter would be indicated.

A second major problem arises from the transient nature of these structures that lie within a few arcseconds of the nucleus, the time constant sometimes being as short as a few minutes. Frequently the comet can only be observed at one observatory near twilight for a short time. Thus observations are needed at a number of observatories properly spaced in longitude to provide any useful continuity. Similar observing techniques are needed among the observatories to insure comparable records.

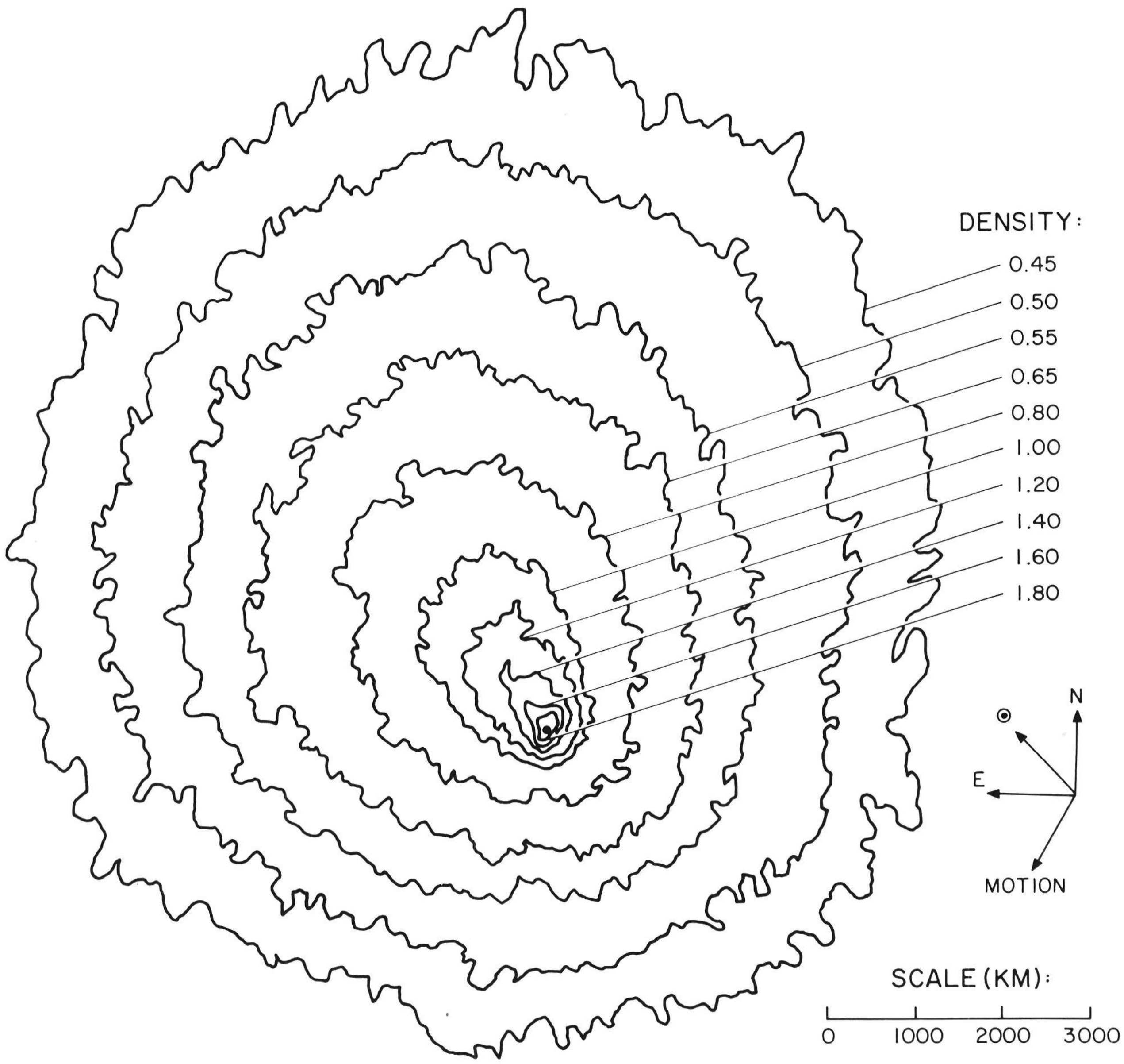


Figure 6. Isophotes from photograph of P/Pons-Winnecke, June 26, 1927. No suggestion of the strong coma elongation near the nucleus can be seen on the original, which looks much like Figure 3.

Figure 7. The inner coma of P/Halley drawn by R. T. A. Innes (left) and W. M. Worsell (right) nearly simultaneously on May 5, 1910, at the Transvaal Observatory, Johannesburg, S.A.

The problem is an ideal one for a two-dimensional sensing array on a telescope of high resolving power. Having a short time constant and computer output, such a system can provide continuity and compatibility with other such systems. In space there is hope for a longer observing interval with a single system.

General Comments

The moment of observation must be recorded and published for all physical as well as positional observations of comets. Many of George P. Bond's beautiful observations and drawings of the envelopes of comet Donati 1858IV are useless for determinations of the rotation period because he did not note the times of observation in his record book. In this case an uncertainty of 20 minutes or more becomes important. Many similar lapses could be cited for several of the best and most famous cometary observers even in this century (Fig. 8).

Another most frustrating record is the frequent and typical "bright nucleus asymmetric in coma" without a statement of the relative position angle. The spin axes and even spin vectors of a number of comets could now be calculated if the observers had recorded even approximate values of the position angles.

The term "stellar nucleus," very frequently appearing in visual observations of comets, is really not too meaningful unless something is stated about the seeing. This is rarely done. The term "sharp" nucleus is also ambiguous without a diameter measure or estimate.

On the other hand, observers are usually very careful to describe roughly the sky brightness, a most vital piece of information. In some comets where the halos are fairly clearcut, the coma-diameter measures usually apply to one of the halos, independent of the sky brightness. For most comets the diameters in bright skylight are not reliable for this purpose. Impersonal arrays should give significant diameters, almost independently of sky background.

To date, little use seems to have been made of measures or estimates of nuclear magnitude independent of or compared with values of the integrated magnitude. This may well be an oversight on the part of the analyst. Nuclear magnitudes may well be more significant than the integrated magnitudes, the latter being so dependent on telescope aperture and focal length, cometary distance, eyepiece or sensing equipment, spectral region, etc. I hope that more studies will be made to evaluate the significance of nuclear magnitudes and their dependence on these other factors. I intend to pursue preliminary studies relating the nuclear magnitudes to the phase of halo or envelope production.

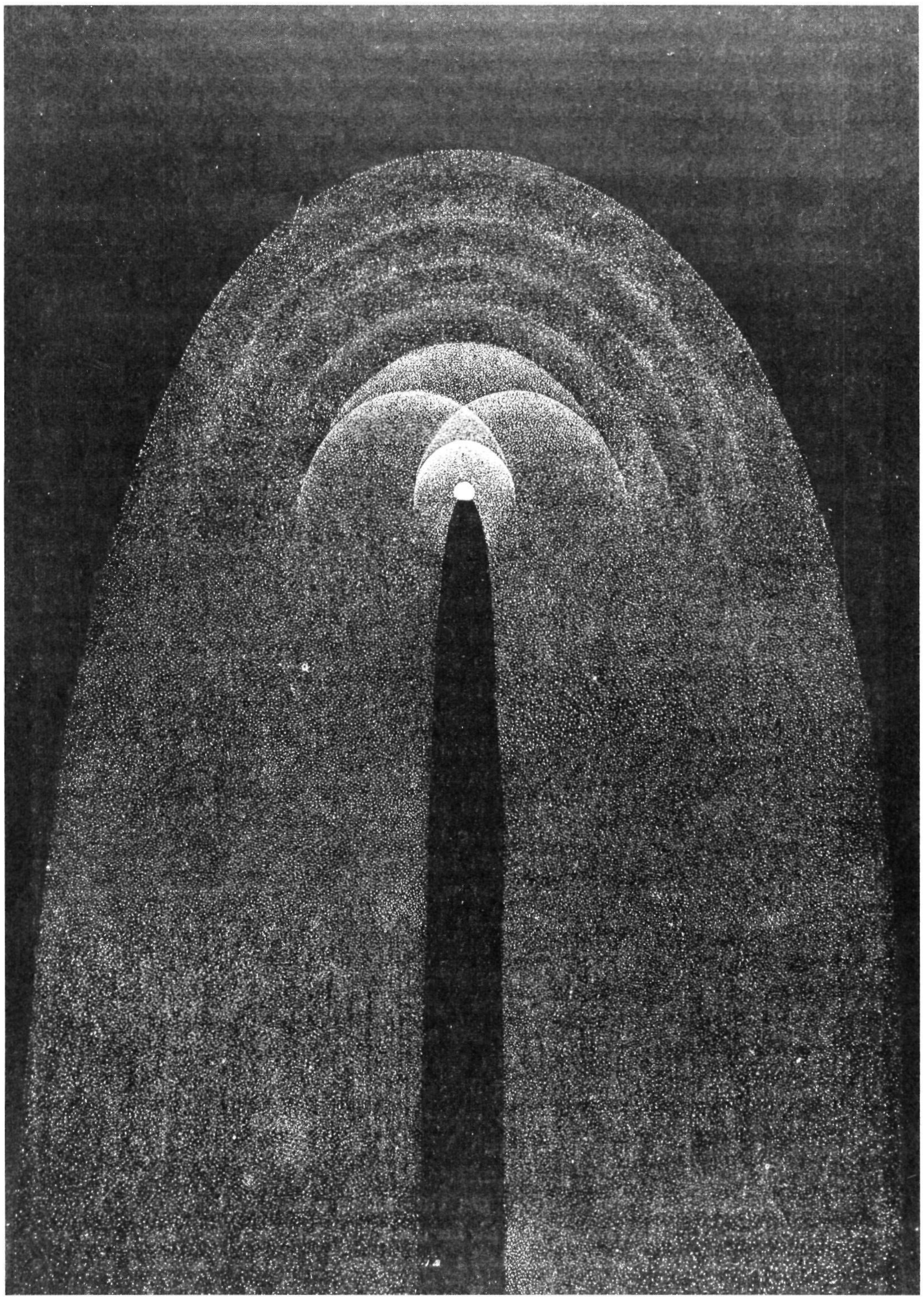


Figure 8. This startling drawing of Coggia's comet 1874III on January 13, 1874 was ascribed to Brodie by G. F. Chambers. No scale or moment of observation is indicated, making the observation nearly useless for determining the rotation vector of the nucleus.

In measuring diameters of halos and envelopes, the observer can increase his accuracy by averaging several measures. J. F. J. Schmidt usually made ten settings, perhaps the reason for the excellence of his observations. On photographic images, remeasurement is quite effective, but more useful when made at well separated time intervals.

In conclusion I stress that a "gold mine" of invaluable cometary observations exists in our libraries and in the photographic collections of many observatories. I expect soon to have a preliminary distribution curve of nuclear periods, highly relevant to the manner of origin of comets. A number of spin vectors can be determined, particularly from measures of extant photographic images.

Observers can now apply the old techniques with a better understanding of analytical and theoretical uses and can develop new techniques, which should greatly expand our knowledge of basic cometary phenomena and the nature of comets.

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