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The historical investigation of cometary brightness

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Abstract
The interpretation of the way in which the brightness of a comet varied as a function of both its heliocentric and geocentric distance was essentially started by Isaac Newton in his book *Philosophiae Naturalis Principia Mathematica*, published in 1687. Astronomers have argued about the form of this variability ever since, and for many years it was regarded as an important clue as to the physical nature of the cometary nucleus and its decay process. This paper reviews our understanding of the causes of cometary brightness variability between about 1680 and the 1950s.

Key Words: *comet; brightness, nucleus, solar system*

1 INTRODUCTION

Comets exhibit a great range of brightness. Not only do comets differ one from another in absolute brightness but also the brightness of a specific comet changes as it moves along its orbit. Many ancient cometary records mentioned that certain Great Comets were, at times, comparable in brightness to the Moon and even the Sun. These comets then faded until they disappeared from sight not only to the naked eye but also in the field of view of the largest of Earth's telescopes. Typical examples are the comets of 146 BC (C/–146 P1: "There appeared shortly before the Achæan war a comet as large as the sun."), 136 BC (at the birth of Mithridates "the heavens appeared on fire; the comet occupied the fourth part of the sky, and its light exceeded that of the Sun"), AD 1402 (C/1402 D1: "A very large and very brilliant comet; no one remembers to have seen such a prodigy. It increased day by day in size and brilliancy as it drew near the Sun. On Palm Sunday, the 19th of March, and the two following days, it increased prodigiously; on Sunday, its tail was twenty-five fathoms long; on Monday, fifty, and even one hundred; on Tuesday, more than two hundred. It then ceased to be visible at night, but during the eight following days it was seen in the daytime close to the Sun, which it preceded. Its tail was not more than one or two fathoms long; it was so bright that the light of the Sun did not prevent it being seen at noon-day"), and 1882 (C/1882 R1: "this Great Comet could be seen when only about 4 degrees from the Sun"). Most of these examples have been taken from Guillemin (1877:233-237).

The intermittent and diverse nature of cometary appearances makes it impossible for ancient astronomers not to have realized that specific comets changed enormously in brightness as time passed. The first attempt, however, to quantify this variation in terms of sensible physical characteristics was made by Isaac Newton around 1680. The present paper traces the development of our understanding of the underlying causes of cometary brightness variability, from the time of Newton up to the 1950s, when the formula that is still in use today became firmly established.

2 EARLY COMETARY PHOTOMETRY

The great breakthrough in cometary *science* as opposed to cometary *speculation* occurred with the publication of the *Principia* in 1687. In this book, Isaac Newton showed, for the first time, how the orbit of a comet could be calculated if its celestial coordinates were accurately known at three times (these times being separated by a week or two). This complicated geometrical exercise was illustrated by the calculation of the orbit of the Great Comet of 1680 (C/1680 V1), and this became the first comet to have five out of its six orbital parameters known. Newton's method assumed that the orbital eccentricity was unity, that is, that the comet was on a parabolic path (see Hughes, 1985). The *Principia* also contained considerable speculation about the physical characteristics of cometary nuclei, comae, and tails, and even went so far as to propose that impacting comets formed a refreshing and revitalizing fuel for a Sun that was losing mass due to the emission of corpuscular light particles (see Hughes, 1988).

In the *Principia*, Isaac Newton discussed how cometary distance might be estimated from measurements of cometary brightness. In the chapter titled "The Motion of the Moon's Nodes", in Book III: The System of the Worlds, Lemma IV, Newton reiterated Tycho Brahe's observation that the lack of cometary diurnal parallax (i.e. their position on the sky did not change due to the observer being moved through the night by the rotation of the Earth's globe) placed comets "beyond the Moon". Their annual parallax (i.e the observed celestial movement produced by a combination of the orbital motion of both the Earth and the comet around the Sun), convinced Newton that the comets were "... in the region of the planets ... commonly lower than the orbit of Jupiter ..." and that they often "... descend below the orbits of Mars and the inferior planets." But,

> ... since their light may be often compared with the light of Saturn, yea, and sometimes exceeds it, it is evident that all comets in their perihelions must either be placed below or not far above Saturn; and they are much mistaken who remove them almost as far as the fixed stars; for if it were so, the comets could receive no more light from our sun than our planets do from the fixed stars.

Newton then introduces cometary photometry by stating:

> The near approach of the comets is further confirmed from the light of their heads; for the light of a celestial body, illuminated by the sun, and receding to remote parts, diminishes as the fourth power of the distance; namely, as the square, on account of the increase of the distance from the sun, and as another square, on account of the decrease of the apparent diameter. Therefore, if both the quantity of the light and the apparent diameter of a comet are given, its distance will be given also, by taking the distance of the comet to the distance of a planet directly as their diameters and inversely as the square root of their lights.

Newton accompanies this statement with an example. Using Flamsteed's observation of Comet Halley (1P/1682 Q1), on an unspecified day in 1682 (a fact that might be taken to indicate that temporal variations in the quantities mention below were not noticed), Newton recorded that (i) the cometary nucleus appeared from Earth to be about 12" in angular diameter, (ii) the comet had an apparent magnitude between one and two, (iii) Saturn, combining both globe and ring, was about four times more lucid than the comet, and (iv) the Saturn system was equivalent to the globe of Saturn having a diameter, as seen from Earth, of 30". Thus it follows that the distance of the comet was to the distance of Saturn inversely as 1 to √4, and directly as 12" to 30"; that is, as 24 to 30, or 4 to 5, that is,

$$\Delta_{\mathrm{comet}}/\Delta_{\mathrm{Saturn}} = \sqrt{4}/1 \times 12/30,$$

where Δ represents the distance between Earth and the object in question.

There are three serious problems with this section of the *Principia*:

(a) The 4/5 ratio given above shows that Newton thought that Comet Halley was at the time about 8 AU from Earth whereas throughout the 1682 August 15 to September 12 period of its visibility the comet actually stayed within the range $1.03 > \Delta > 0.42$ AU and $0.93 > r > 0.59$ AU (see Yeomans *et al*., 1986). On the other hand, it should be noted that the figure in the *Principia* that showed the orbit of the Great Comet of 1680 clearly indicates that it was seen to be moving in the $0.0062 > r > 2$ AU range.

(b) The calculation that leads to the 4/5 ratio mentioned above is clearly based upon the assumption that

$$J = J_0\,\Delta^{-4}\,, \qquad (1)$$

where Δ is the comet-Earth distance and J represents the cometary brightness.

(c) The section of the *Principia* that mentions "the fourth power of the distance" (see above) intimates, however, that Newton was suggesting that cometary brightness varied as

$$J = J_0\,\Delta^{-2}\,r^{-2}\,, \qquad (2)$$

where r is the distance between the comet and the Sun. This is certainly the interpretation given by Vsekhsvyatskii (1964).

It has been pointed out by Brian Marsden and Alan Gilmore (pers. comm., 1998) that it is rather strange that Isaac Newton should, at the time, be still attempting to estimate cometary distance by using cometary brightnesses and angular diameters when he had just pioneered a geometrical technique for computing the orbit of a comet, and thus mathematically deriving its distance from both the Earth and the Sun at *any* specific time.

Equations similar to (2) have been used to express the brightness variation of asteroids, planets and other objects that merely scatter sunlight, these equations, however, being augmented by a phase term so that they become

$$J = J_0\,\phi(\alpha)\,\Delta^{-2}\,r^{-2}\,. \qquad (3)$$

The function $\phi(\alpha)$ takes into account the fact that when the phase angle α (i.e. the angle Sun–object–Earth) is small, the object has the appearance of the 'full' moon, whereas when $\alpha = 90°$ the object appears like a quartered moon and when $\alpha > 90°$ the object appears as a crescent. For a single solid reflecting body this variability would clearly affect the brightness.

Nearly a century and a half later we find Olbers (1816) using Newton's relationship (i.e. equation (2)) to estimate cometary brightnesses, so that these could be recorded in ephemerides. This practice continued throughout the nineteenth century, and other examples of the use of equation (2) can be found in the work of Schmidt (1863) and Müller (1897).

There was, however, again during the nineteenth century, a completely different school of thought. William Herschel (1812) used his large Slough telescope to observe highly-magnified images of comets, and his observations of the Great Comets of 1807 (C/1807 R1) and 1811 (C/1811 F1) convinced him that these comets shone by their own light (that is, like stars). Chambers (1889:409) was convinced that spectroscopic observations of comets underlined their self-luminous nature. J H Schröter followed Herschel and the 'self-luminous' school and replaced the equations above by

$$J = J_0\,\Delta^{-2} \qquad (4)$$

Guillemin (1877:310) summed up this problem by writing:

> Other savants have assumed that comets are planets of a particular kind, and do not receive their light from the sun, but shine by their own brilliancy; but no observation or proofs have been given in support of this opinion.

This confusion underlines the poor accuracy of cometary brightness estimates at the time, coupled with problems introduced by the fact that most comets were only observed for short periods of time and thus over short ranges of Δ and r.

3 BRIGHTNESS AS A CLUE TO COMETARY STRUCTURE

Much of the confusion as to the law that relates cometary brightness to both heliocentric and geocentric distance was due to the fact that no one had a clear view as to the physical form of the cometary nucleus. Guillemin writes (1877:309):

> ... in the last century [i.e. the 17th] astronomers were almost entirely preoccupied with the study of cometary movements, the nature of cometary orbits, the periodicity of comets, and with every question that tends to prove that comets are subject to the universal law of gravitation.

So the physical and chemical form of a comet was a mystery. Some thought that the nucleus was a solid, reflecting, planet-like body, while others believed that it was no more than an agglomeration of atoms, molecules, and dust. William Herschel (1808) had the best of both worlds and insisted not only that comets collected nebulous matter as they travelled through interstellar space and then transferred this to stars in order to replenish the fuel used in making light, but also that older comets had less nebulous material and thus more modest tails and that, with each solar passage, they became more consolidated and dense. To Herschel, the ultimate fate of a comet was that it would lose all of its nebulous material and become a planet.

The reported observations of cometary phase effects caused much confusion. To quote Chambers (1889:409): "... if the existence of phases could be certainly known, this would furnish an irrefragable proof that the comet exhibiting such shone by reflected light." Unfortunately there was absolutely no consensus. Concerning the 1682 observations of Comet Halley, Jean-Baptiste Joseph Delambre (1821) mentions that the registers of the Royal Observatory at Paris showed strong evidence for the existence of phases, whereas neither Edmond Halley nor any other astronomer who observed this comet gave the slightest intimation that a phase phenomenon was visible. The comet of 1744 revealed phases to James Cassini (1744), but Gottfried Heinsius (1759) and Jean Phillippe Loys de Chéseaux (1744) denied seeing anything of the kind.

This phase discussion did not go away very quickly either. Sir John Herschel (1847) remarked that nothing which could bear the least resemblance to a phase was perceptible in Halley's comet (1P/1835 P1). Orlov (1913), however, discussed phase effects in the 1910 apparition of Halley's Comet (see also, Curtis, 1913), and the effect was still being discussed by Richter in 1954 (see Richter, 1963:41, 68).

Alexandre Guy Pingré (1783-1784) was more positive and wrote that comets only send back light they receive from the Sun, and that

> ... the light of a comet is feeble and dull; its intensity varies; we can perceive in it sensible inequalities and even gaps. It does not appear that these phenomena can be explained otherwise than by supposing comets to be opaque bodies, possessed of no other light than that which they receive from the Sun, and surrounded by an atmosphere similar to that on the Earth. Clouds are formed within this atmosphere, just as in our own atmosphere; these clouds weaken or totally intercept the rays of the Sun, and successively deprive us of the sight of a portion of the comet.

Arago (1836), observing Comet Halley in 1835, used a telescope with a polarimeter and proved to his own satisfaction that at least some of the cometary light was not "direct light" (i.e. was not self-generated), but was "reflected" and thus came from the Sun.

In the mid-nineteenth century, cometary spectroscopy revealed a continuous spectrum at all wavelengths, which indicated that dust in the cometary atmosphere was reflecting sunlight. Strong emission bands also were visible, these being produced by absorption and florescence by gas molecules and radicals (see Clerke, 1885:395-396).

Studies of the source of cometary brightness and its variability were not helped by the fact that certain comets acted most oddly. To quote Proctor (1886:197):

> Astronomers have not hitherto been fortunate in their theories respecting comets. These mysterious objects present so many perplexing appearances, and seem regulated by laws apparently so incongruous, that it has not been found possible to form an hypothesis which shall account even for the most important cometic characteristics.

At about the same time, Chambers wrote :

> ... the appearance of the same comet at different periods of its return is so varying that we can never certainly identify a given comet with any other by any mere physical peculiarity of size or shape until its 'elements' have been calculated and compared. (Chambers, 1889:399).

A somewhat exaggerated case in point was Comet Biela, in 1846. When it first appeared it was elongated, and pear-shaped in form. Some ten days later it had divided into two separate comets, which were travelling along practically the same orbit. Each of these components underwent marked changes in brightness that made first one and then the other the brighter of the two (see Lyttleton, 1953:43).

Another behavioural 'oddity' was the outburst. Comet C/1931 O1 (Nagata), for example, rapidly increased in magnitude from 12.5 to 8 on the night of 1931 October 6 (see Lyttleton, 1953:53).

4 COMETARY PHOTOMETRY IN THE FIRST HALF OF THE TWENTIETH CENTURY

The 'father' of modern cometary photometry was J. Holetschek, and he was working at the very end of the nineteenth century and the turn of the present one. He collected together many ancient cometary brightness records, and he also observed many comets himself and systematically estimated their brightnesses. These tasks were being performed in order to

(a) establish a law of brightness variation as a function of both heliocentric and geocentric distance, which could then be used to provide information on the mechanism of cometary light production;

(b) estimate the rate at which the absolute brightness of specific periodic comets changed as a function of time, which could then be used to monitor their decay; and

(c) use the brightness fluctuation of comets as a possible monitor of changes in solar activity.

Many astronomers had made notes on the brightness of cometary comae and nuclei, including (in chronological order) Kepler, Hevelius, Cysat, Flamsteed, Messier, Herschel, Olbers, Méchain, Pons, Harding, Struve, Winnecke, and Schmidt. Holetschek was following in their footsteps. He started his analysis of cometary photometric data by using equation (2), an expression that had been first suggested by

Isaac Newton just over 200 years earlier. Holetschek converted brightness, J, into apparent magnitude, m (remember that $\log (J_1 / J_2) = 0.4 (m_2 - m_1)$), to give

$$H = m - 5 \log r - 5 \log \Delta , \qquad (5)$$

where m is the observed apparent magnitude of a comet, and H is the 'absolute' magnitude, that is the apparent magnitude the comet would have if it was observed from a position where both r and Δ were 1 AU.

Holetschek repeatedly noticed that equation (5) gave a poor fit to the observations, and this was especially apparent in the case for Comet Encke. In 1894, he modified equation (2), and introduced the expression

$$J = J_0 \Delta^{-2} r^{-n} , \qquad (6)$$

where the cometary activity index, n, was found to have a value of ~4 (Holetschek, 1894). If n is *exactly* 4.0 it indicates (i) that the amount of dust and gas in the cometary coma is proportional to the amount of radiation being absorbed by the cometary nucleus and used for snow sublimation (this is proportional to r^{-2}), and (ii) that the amount of light scattered and/or re-radiated by this gas and dust is also proportional to r^{-2}. The combination of these two factors gives the expected r^{-4} dependence. Equation (6) emphasizes the fact that comets increase in brightness much more rapidly than can be accounted for by a mere distance effect as they approach the Sun.

Equation (6) can be written in magnitude terms as

$$m - 5 \log \Delta = H - 2.5\, n \log r . \qquad (7)$$

Graphs of $(m - 5 \log \Delta)$ vs. $\log r$ are often used to quantify H and n. This technique was employed extensively by Holetschek (1896-1917), and by Orlov (1911; 1912), who observed Comets C/1908 R1, C/1910 A1, C/1911 N1 and C/1911 O1 and concluded that the activity index, n, lay between 3 and 5. Kritzinger (1914) calculated values of n and H for ancient comets, and tried to find a relationship between these two quantities and the heliocentric distance at which tail formation started.

A powerful incentive to the investigation of cometary brightness was the return of Comet Halley in 1910. Photography, photometry, and spectroscopy were all applied on a very large scale for the first time. Observations revealed that the cometary brightness was distinctly asymmetrical with respect to perihelion passage: Comet Halley was brighter after perihelion than before.

Many astronomers have been applying the $(m - 5 \log \Delta)$ vs. $\log r$ analytical method since the turn of the century. F. Baldet (1925) suggested that the average value for n given in equations (6) and (7) was 3.32 ± 0.016. He also gave the range of observed values of n as being from -1.77 to $+11.40$.

A major breakthrough occurred in the early 1920s when Vsekhsvyatskii (1925, 1928) observed many contemporary comets over large ranges of heliocentric distance and concluded that $n = 4.0$ was the "... characteristic value representing the nature of variation in a comet's luminosity with heliocentric distance, with occasional deviations attributable to observational difficulties and changes in solar influence." The term "observational difficulties" probably refers to the photometric problems inherent in estimating coma brightness by comparing the comet image with, for example, the images of defocused stars of known brightness, often under difficult lighting conditions caused by such things as small phases angles and moonlight. Holetschek (1896-1917) spent a considerable time devising accurate means of measuring the apparent magnitudes of cometary comae. 'Solar influence' was a topic of considerable interest at the time, and Berberich (1888) had recorded variations in the brightness of

Comet Encke as a function of sunspot activity, observations that were later confirmed by Bosler (1938). Similar variations in the case of Comet Halley were noticed by Orlov. Little interest is taken in this topic today.

Needless to say, not everybody immediately embraced equations (6) and (7). Richter (1948) was still advocating the use of phase curves, these being similar to the curves found for the particles in Saturn's rings, and in 1963 he was still insisting that cometary brightness was proportional to both Δ^{-2} and r^{-2} (Richter 1963:68). A further complication was introduced by Vanýsek (1952), who analysed the brightness variation of 99 comets observed between 1853 and 1951 and concluded that the parameter n was around 4.2 for "old" comets that had been in the inner solar system for a long time, but only 2.8 for "newer" fresher comets.

Supposed long-term secular variability acted as a spur to H and n measurements. Chambers (1910:5) noted that "... there is reason to believe that comets in general, for some unknown cause, decrease in splendour in each successive revolution ...", and he quoted Smyth (1844) in support of this proposition. Both Holetschek and Vsekhsvyatskii concluded that Comet Encke was decreasing in absolute magnitude by about one magnitude per century (see Lyttleton, 1953:52), and Markov (1927) used brightness to estimate cometary masses.

Levin (1943, 1948, 1966) introduced a different brightness formula to the one produced by Holetschek in 1893 (i.e. equation 6), and this provoked considerable interest during the 1950s. Levin suggested that the cometary brightness, J, was given by

$$J = J_0\, r^{-0.25}\, \Delta^{-2} \exp\left(- L\, r^{0.5} / R\, T_0 \right), \qquad (8)$$

where R is the universal gas constant, T_0 is the temperature of a rocky particle at 1 AU (this being taken by most people to be in the range 290 to 350 K), and L is the desorption heat (i.e. the energy needed to release adsorbed and occluded molecules from the rocky meteoritical bodies that supposedly make up the 'flying sandbank' comet.) Ignoring the $r^{-0.25}$ term, equation (8) can be expressed in terms of the magnitude of the comet as

$$m - 5 \log \Delta = -2.5 \log J_0 + 1.086\, (L / R\, T_0)\, r^{0.5}. \qquad (9)$$

Talk of desorption heating became less popular as the 'dirty snow-ball' model took over.

5 CONCLUDING REMARKS

The analysis of cometary brightness indicated that H varied from comet to comet and that typically $n = 4.0$. These findings then needed to be incorporated into a cometary model. Before the space age and the GIOTTO mission to Comet Halley there was no clear consensus as to the physical form of a comet, and opinions varied from the extremes of comets being thought of as single kilometric-sized bodies to comets being regarded as swarms of rocks ... a veritable 'flying sand bank'. The former, 'single body-monolithic' model was favoured by Isaac Newton in the *Principia*. Both Pierre-Simon de Laplace (1808) and Friedrich Bessel (1836) supported this idea, and both suggested that the nucleus consisted of material that had the potential to sublimate when close to the Sun. In the inner solar system, the absorbed solar radiation was thus used for gas production, and the temperature of the nucleus did not increase greatly above the boiling-point temperature. This 'single body-monolithic' model was reformalized by Whipple (1950, 1951), when he suggested that a cometary nucleus was a spinning 'dirty-snowball' with a phylosilcate dirt:H_20 snow mass ratio of about 1:2. The coma was formed by snow sublimation and dust emission, and the dirt acted as an insulating surface layer around the nucleus, thus enabling a comet to survive many perihelion passages. Gas sublimation broke off small dust particles, and these were then pushed away from the nucleus by momentum transfer to eventually form both the dust tail and a meteoroid stream. A thermal lag between the absorption of radiation and the emission of gas and dust, on a spinning nucleus, could explain the non-gravitational effect.

The 'flying sand-bank' model became popular in the later nineteenth century after the establishment of the connection between comets and meteoroid streams (see Hughes, 1990, for an historical account). In this model, a comet was a swarm of meteoroid (and in some cases ice) particles, each particle being on a separate independent orbit around the Sun. A typical comet was thought to consist of, say, 10^{25} particles, with an inter-particle spacing of tens of metres. The cometary swarm would be about 100,000 kilometres across and have a total mass of about 10^{18} grams. The coma was formed by gas desorption enhanced by inter-particle collisions. It was thought that the gasses were adsorbed when the comet was near its aphelion. Unfortunately this gaseous pick-up mechanism was thought to be inefficient, and this suggested that comets would de-volatilize rapidly and only last a few orbital revolutions.

Lyttleton (1953:33) was a great proponent of the 'flying sand-bank' model. Even though comets had a nucleus, "... a star-like point of light condensed within the coma ...", this was regarded as only being "... some kind of changing concentration of small particles." In 1945 H N Russell wrote:

> The accepted view of the nature of comets is that they are loose swarms of separate particles, probably of very different sizes, separated by distances great in comparison with their own diameters and accompanied by more or less dust or gas. The greater part of the mass is probably concentrated near the centre of the cluster, but even here the open spaces must be exceedingly large compared with the particles. (cited in Lyttleton, 1953:60).

Lyttleton (ibid.) also noted that "... similar views have been reached by numerous other lifelong cometary workers such as N.T. Bobrovnikoff, A.C.D. Crommelin, A.D. Dubiago, A. Guillemin, C.P. Olivier, H.C. Plummer, R.A. Proctor, N.B. Richter, and K. Wurm."

The apparent confusion between the 'dirty-snowball' and 'flying sand-bank' models was not helped by the fact that cometary appearances varied considerably as a function of the size of the telescope being used. In addition, from the Earth a 1 km diameter solid cometary nucleus situated at 1 AU subtends an angle of less than 0.002 seconds of arc, which is well below the resolving power of present-day telescopes. Nevertheless, during the 1950s the "flying sand-bank" model gradually drifted out of favour (but see Lyttleton, 1972) as the "dirty-snowball" model became generally excepted. Much later, the GIOTTO Mission to Halley's Comet proved the latter model to be well-founded.

It is interesting to note that only in the last half century has cometary photometry begun to help unravel some of the mysteries of the cometary nucleus. Today, interpretation of the activity index, n, and its variability relies on detailed study of the variability of cometary brightness as a function of heliocentric distance. This brightness is a function of the amount of gas and dust in the coma, and this in turn is a function of the amount of sunlight that strikes the few active regions on the cometary nucleus, and the mass loss from these regions (the GIOTTO Mission, for example, indicated that only 10% of the surface of Halley's nucleus was active). The problem is exacerbated by the fact that the typical nucleus is thought to be irregular in shape and spinning about an axis at a rate that is similar to that at which the spin axis precesses.

The $n \cong 4.0$ photometric clue is easily explained if the active areas of the nucleus not only receive sunlight at a rate that is proportional to the inverse square of the heliocentric distance, but also convert *all* absorbed energy into the latent heat of gas sublimation. Deviations from $n = 4.0$ can be produced by changing the physical extent of the comet's active area as a function of heliocentric distance (see Hughes, 1989), or by moving cometary active regions away from the comet's daytime sector and into its night. The ease with which the latter can happen depends upon the orientation of the cometary nucleus spin axis with respect to the normal to the comet's orbital plane. For a collection of comets, the distribution of this orientation is expected to be random.

The value of the absolute magnitude, H, has long been regarded as a reasonably strong indicator of the size and mass of the cometary nucleus (see, for example, Hughes, 1987a, 1987b). The relationship can, however, only be regarded as a statistical guide, as there are comets whose activities deviate considerably from the mean. Some comets with small nuclei have large percentages of their surfaces actively emitting gas and dust, while other comets have large, essentially inert, nuclei. One also has to guard against cometary flares and outbursts leading to atypically low values of H, as one might here be witnessing the fragmentation death-throws of a relatively small nucleus. Some observers have attempted to differentiate between total coma brightness and the actual brightness of the embedded nucleus. (e.g. see Delsemme and Rud, 1973; Roemer, 1966). Even though the latter parameter can be difficult to assess (mainly because the nucleus is way below the resolution limit of the telescope), it has been used with equations like (3) to give an estimate of the size of the nucleus.

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