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LIGHT CURVES OF SOME PERIODIC COMETS

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RESUMEN

Hemos derivado curvas de luz de varios cometas periódicos, combinando observaciones hechas durante diferentes apariciones. Se presenta el análisis de las curvas de luz para los cometas Encke y Tempel 2. Se concluye que no hay una manera simple de reducir las observaciones fotométricas de cometas, pero la comparación con observaciones fotoeléctricas parece ser la forma más segura de proceder.

ABSTRACT

We have derived some reliable light curves for several periodic comets, combining observations made at different apparitions. We present our analysis of these light curves for comets Encke and Tempel 2. It is concluded that there is no simple way to reduce photometric observations of comets, but comparison with photoelectric observations seems to be the safest way to proceed.

Key words: COMETS – SOLAR SYSTEM-GENERAL

I. INTRODUCTION

Many determinations of visual magnitudes of comets re available in the literature, from this century as well s the last one. However, most of the data are eterogeneous, in the sense that they have been obtained y different observers using different instruments. In is work, we have attempted to produce some reliable bservational light curves for the periodic comets Enke 1 nd Tempel 2, by selecting only observations of experienced observers, and by combining observations ade at different apparitions. Whenever possible, we ave used photoelectric observations to normalize the ata and to compare the reliability of the visual and hotographic observations. These observational light rves will be interpreted theoretically, in order to erive physical information.

II. LIGHT CURVE

The usual way to present the light curve of a comet, in a plot of $m_{V\Delta}$ vs. log R, where $m_{V\Delta}$ is the visual agnitude of a comet reduced to $\Delta = 1$ AU; where Δ is e comet-Earth distance and R is the comet-Sun istance. $m_{V\Delta}$ (R,Δ) gives the magnitude of the comet distances R and Δ, and

$$m_{V\Delta} = m_V(R, \Delta = 1\text{ AU}) =$$

$$= m_{V,\text{ observed}} - 5\log\Delta \qquad (1)$$

A schematic plot is presented in Figure 1. This figure presents the history of the brightness of a comet, as it moves along its orbit. At point A, the comet is farthest from the Sun, at aphelion. There is no atmosphere or coma surrounding the nucleus, since the temperature is very low and thus there is no evaporation. When the comet moves closer to the Sun, it does so along the line marked R^{-2}, which is the expected behaviour of the nucleus with no atmosphere.

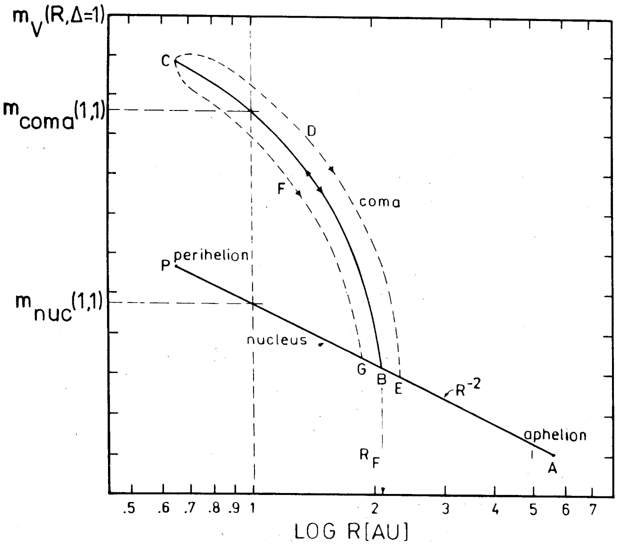

Fig. 1. Evolution of the brightness of a comet along its orbit.

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Eventually the comet reaches point B, at a distance from the Sun, R_F, where the coma starts to form. At this point the evaporation of the nucleus becomes important. This is usually a rather sudden occurrence, because the vapour pressure is very sensitive to temperature. The point R_F may occur at any distance between 1.5 to 15 AU, depending on the composition of the nucleus. If the nucleus is made of water ice, the distance ranges from 1 to 4 AU.

Next, the coma brightens along the track BC on its way to perihelion, while the nucleus continues along the R^{-2} line. However, close to perihelion it becomes more difficult to observe the nucleus since it is usually many magnitudes fainter than the coma. The path BC may be a straight line or it may show some curvature, depending on the chemical composition of the nucleus and on the energy loss mechanism. For a water ice comet, the path BC shows some curvature.

When the comet receeds from the Sun, it may do so along there paths: CFG, CDE, or CB. Path CFG may occur for example when the comet has exhausted its volatile material. Path CDE may may occur if there is a thermal lag in the nucleus, then it achieves highest temperature after perihelion.

After some time, the comet reaches point G, B, or E, and thus the R^{-2} line, while it moves toward aphelion. We can then define a R_f, at which the coma disappears or fades. R_F may be larger, equal or smaller than R_f. If we are dealing with a periodic comet, after reaching aphelion, the sequence is repeated.

The absolute magnitude of the comet, $m_{V,coma}$ (1,1) is obtained for R = 1; the absolute magnitude of the nucleus, $m_{V,nuc}$ (1,1), is obtained in the same way. Both have been marked in Figure 1.

III. DATA REDUCTION

Using the large number of observations of comets available in the literature, it is possible to construct light curves for some of them, However, care must be exercised in order to avoid heterogeneity in the data. Many comets have been assigned brightness fluctuations that reflected only improper methods of observation and not real changes. We decided to include only observations by persistent and experienced observers; mainly, using observations by G. Van Biesbroeck, E. Roemer and M. Beyer. The first of these authors made observations of nuclei and comas of comets. Roemer's values are mostly of nuclei. Beyer has made observations of nuclei and comas, but some of his nuclear observations refer to a "false nucleus" (as we will see), and thus had to be discarded.

All observations published by Van Biesbroeck, Roemer and Beyer later than 1920 were compiled. Observations by other observers were used whenever they were needed.

We tried to include the available photoelectric observations. They have mostly been obtained in the *UB* system, and with diaphragms of different sizes. Thes observations have been used to verify and normalize th other visual observations. But two difficulties arise wit photoelectric observations. First, there is the probl that comets are extended sources, while most photometers are designed for observing stars. Therefore not al the comet is included in the measurement; and thu there are partial magnitudes available and what we nee are total magnitudes. The procedure for obtaining tot magnitudes from partial ones will be considered elsewhere (Ferrín 1981); it involves extrapolating th magnitude to an infinite size diaphragm. The procedur is very similar to the one followed by Svoren and Trenk (1975). The total magnitude so obtained can in principl be compared with the visual observations. The secon difficulty, is that the *UBV* system is not totall appropriate for observing comets. The *V* observation cover a range of wavelengths in which the mos important emission bands come from the C_2 molecule But the *U* and *B* bands include a mixture of bands o different molecules, and thus the derived magnitudes ar not very informative. Therefore we have used the observations only.

Another important conclusion about the recorde magnitudes for a comet is the following. When th comet is bright, the measurement refers to the coma, (i the *IAU Circulars* these magnitudes are denoted by m_1) When the comet is faint, the recorded magnitude ma refer to the nucleus alone, or it may refer to the nucleus plus a faint coma. If the magnitude refers to the nucleu the it is denoted by m_2. But there are many cases i which a faint magnitude is registered as m_2 when i really should be m_1, and viceversa. So we have t conclude that a clear distinction between a "nuclear and a "total" magnitude of a comet can only be mad when the data are plotted in the $m_{V\Delta}$ vs. log R diagram This allows to decide which magnitude has been determined; or, alternatively the observer would have t hnow the values R_F and R_f. Then it would be possible t know if a coma is present or not; but this information i not available for most comets. In fact, this is the firs case in which such a determination is attempted.

IV. COMETS P/ENCKE AND P/TEMPEL 2

The procedure used to obtain the light curve o comet P/Encke, will be explained in detail. We starte by reducing the *V* observations of Mianes (1958) carrie out with diaphragms of different sizes. These ar therefore partial magnitudes, which correspond to th 1957 apparition. They were converted to total magnitudes using the procedure outlined before. They ar shown in Figures 2 and 3 as crosses.

Next we compiled the observations by Van Biesbroeck (1924, 1928, 1935, 1938, 1942, 1948, 1953

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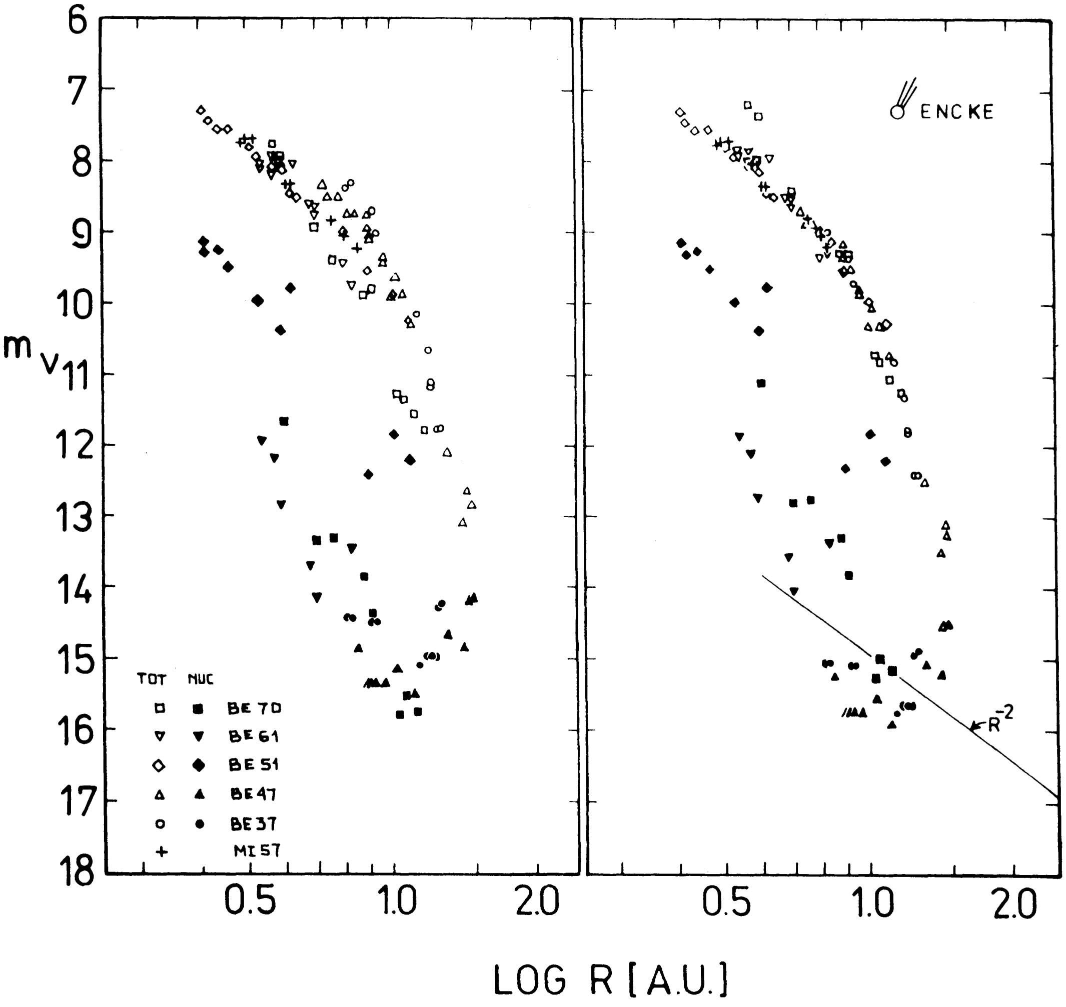

Fig. 2. Measurements of the total and nuclear magnitudes of comet Encke made by Beyer (1938, 1950, 1955, 1962, 1972). The left side shows the reported measurements. On the right side vertical corrections of +0.65, +0.39, 0.0, −0.09 and −0.55, respectively, have been applied to the above apparitions. Crosses indicate photoelectric V magnitudes of this comet carried out by Mianes (1958) and corrected as explained in the text. The two sets of data agree not only in absolute value but also in their derivative. The "false nucleus" is represented by the nuclear observations between magnitudes 9 and 13.5, which do not follow and R^{-2} law.

1958, 1962). When the magnitudes were reduced, it was pparent that there was no convincing way of supermposing the different apparitions, even if instrumental orrections were applied. Moreover, in the range of listances covered by the photoelectric observations of Mianes, the mean magnitude and the derivative of the wo curves (photoelectric and photographic) were different. Even the visual and the photoelectric curves were lifferent. It was clear that the photographic observations aken with blue plates (Roemer 1965) isolated the N-bands and did not include the C_2 bands. These bservations were therefore not used. However, the $n_{V\Delta}$ vs. log R plot permitted the selection of the uclear magnitudes, for which the contribution of the oma is negligible. Observations by Roemer (1965, 1972, 1973) and Roemer and Lloyd (1966) were reduced in the same manner. These referred to the nucleus, and are presented in Figure 3, corrected as indicated below. Figure 3 shows that a large dispersion is present in the observations, but a least squares fit to the data gives a solution that goes as $R^{-1.996}$. This is so close to R^{-2}, that we may conclude that the nucleus of comet Encke is a solid object with no atmosphere. From observations of the spectra of the nuclei of comets, a color index of $B - V = 0.85$ was adopted. Thus if all nuclear observations are corrected by this amount, we should have a visual plot of the behaviour of the nucleus as a function of R. This is the correction applied to the nuclear observations of Figure 3.

The only reliable source of visual magnitudes of comet Encke, are the publications of Beyer that correspond to the apparitions of 1937, 1947, 1951, 1960 and

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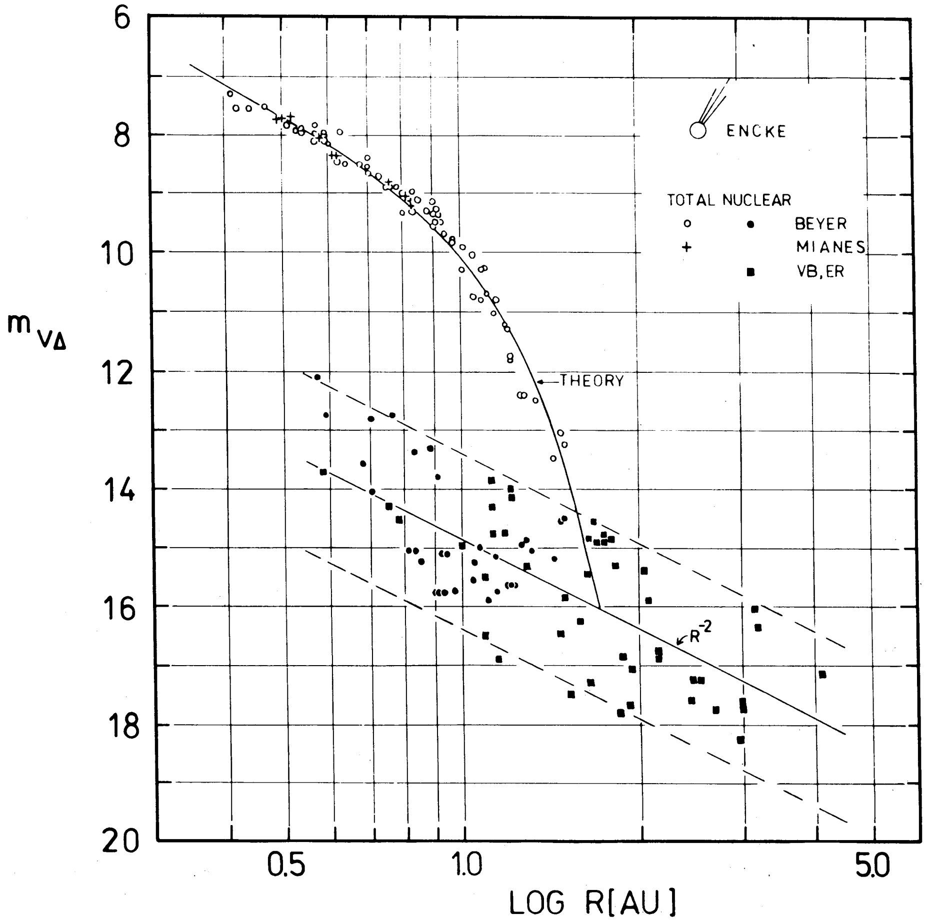

Fig. 3. Final light curve for comet P/Encke. The line marked "theory" is for a nucleus of 0.80 km in radius, it is due to Ferrín and Naranjo (1980) and fits the observations over their whole span. The large dispersion of the nuclear observations is probably due to the difficulty of obtaining photometry at such low light levels. Least squares fit to the nuclear observations yields a $R^{-1.996}$ dependence.

1970 (Beyer 1938, 1950, 1955, 1962, 1972). There were other observations of this comet scattered in the literature; but again they were not enough to be able to determine proper corrections, so they were not used. The observations of Mianes (1958) and those of Beyer (1955, 1962) agreed to within 0.09 magnitudes. This is a very small difference considering that visual observations of comets often have errors of ±0.8 magnitudes. The derivative of the $m_{V\Delta}$ vs. log R diagram was also the same for the two sets of data, photoelectric and visual, even for different apparitions. We concluded that the two sets were directly comparable. However the apparitions of 1937, 1947 and 1970 had to be displaced vertically by small amounts, in order to fit those of 1951, 1957 and 1960 (see Figure 2). This vertical displacement comes most probably from the use of different instruments, or from a different personal equation for different years. It is important to notice that visual and reliable photometric observations agree within 0.09 magnitudes in absolute value, as well as in their derivative. We decided to normalize all the observations to the 1951 apparition; for the apparitions of 1937, 1947, 1951, 1960 and 1970, the vertical corrections applied were +0.65, +0.39, 0.0, –0.09 and –0.55 respectively. These observations have been plotted in Figures 2 and 3. The observational light curve based on Beyer's measurements is remarkable in the small dispersion of the data. Notice also that the light curve shows some curvature.

Beyer also had observed nuclear magnitudes. These have been plotted as filled symbols in Figures 2 and 3. From these figures it is clear that some of the "nuclear" observations of Beyer (those between magnitude 9 and 13.5) refer to a "false nucleus" since they do not obey the R^{-2} law. This "false nucleus" appears whenever we are trying to observe a nucleus within a bright coma, and the nucleus is more than 3 or 4 magnitudes fainter. What is observed then is the inner core of the coma. The real nucleus begins to appear around magnitude 15 and at larger distances ($R \geqslant 1.7$ AU), as can be concluded from

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Figure 3. From that figure it can be seen that between R = 0.6 and R = 1.7 AU, the nuclear magnitudes are still contaminated by the coma. Only at R > 1.7 AU is the nucleus observed without the coma. To observe the nucleus at R = 0.6 AU is quite difficult, since the nuclear magnitude is about 14, while the coma magnitude is about 8. However, note that some of the nuclear magnitudes by Beyer, those below magnitude 14.9, do eem to refer to the nucleus. The adopted light curve for comet Encke is shown in Figure 3.

Essentially the same procedure has been followed for comet P/Tempel 2. In this case there were no photoelectric magnitudes available for the coma. Two phooelectric magnitudes for the nucleus have been made by Spinrad *et al.* (1979). The adopted light curve for this comet, is presented in Figure 4.

V. MODEL

Ferrín and Naranjo (1980) have calculated a theoretical light curve for a water ice comet, which is also shown in Figures 3 and 4. The light curve depends on the albedo A, and thus one gets a family of curves. A is not the Bond albedo, but the surface albedo; the Bond albedo can be obtained multiplying the surface albedo by 0.93. The best theoretical curves that fit the two comets discussed are shown in Figures 3 and 4.

We explain the light curve of these comets in the following way: For comet Encke, for example, from R = 4.1 to R = 1.7 AU, the comet is in the so called "radiative regime"; it just re-radiates the solar light. In this regime the comet cools off by re-radiating to space some of its energy; this establishes an equilibrium temperature. From R = 1.7 to R ∿ 1.0 AU, evaporation has become important, but the comet is still in its radiative regime. From R ∿ 1.0 AU, to R = 0.38 AU, cooling by evaporation dominates, and the comet is said to be in an "evaporative regime". In the radiative regime the light curve tends to be very steep, while in the evaporative regime the light curve tends to be almost flat. Although in reality the comet follows an approxi-

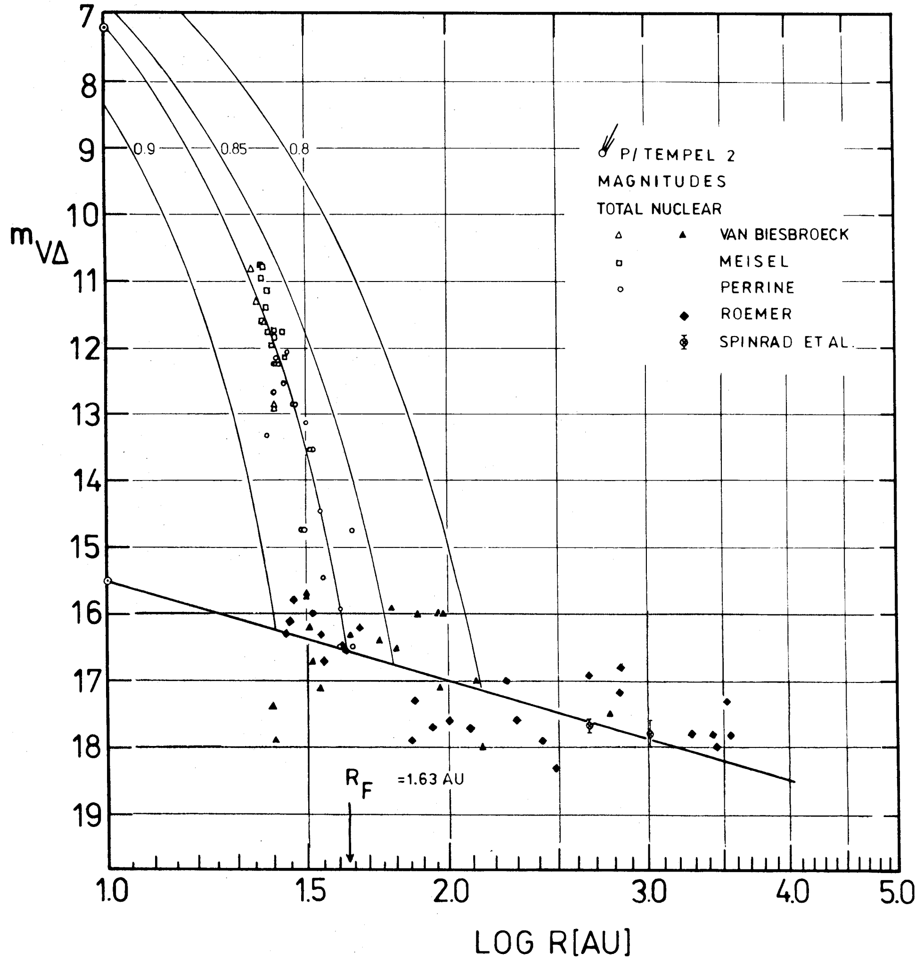

Fig. 4. Final light curve for comet P/Tempel 2. The same commentaries applied to Encke are valid here.

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mately R^{-2} law, there is no possibility to confuse this part of the light curve with the nuclear magnitudes since this region is close to the Sun, and the comet is bright. The R^{-2} region describing the nucleus is far from the Sun, and the comet is faint. When we mention evaporation, we refer to the ices contained in the nucleus, mostly water ice, but perhaps CO_2 ices, methane ices or ammonia ices.

VI. RESULTS

From plots like those presented in Figure 3 and 4, several conclusions may be drawn:

1) These two comets seem to be composed of water ice, since both fit the theoretical curves very well: both comets show some curvature in their light curves.

2) Absolute magnitudes for the nucleus and the coma can be easily obtained from the diagrams. The absolute magnitudes of P/Encke and P/Tempel 2 are respectively 10.0 and 7.2.

3) It is common to fit the light curve of many comets with a formula of the type

$$m = m_0 + 2.5\, n \log R + 5 \log \Delta \ , \qquad (2)$$

This relationship is a straight line in Figures 3 and 4. So it is futile to try to fit the magnitudes of water ice comets with such a formula.

Sekanina (1980) has proposed another function, that once adapted to the 1951 observations of comet Encke gives:

$$m = 10.0 + 5 \log \Delta + 3.55\, (R^{1.88} - 1) \ ; \qquad (3)$$

This function allows for curvature, and thus fits much better.

4) For comets that do not reach $R < 1$ AU, it is to misinterpret the data by extrapolating the light curve to $R = 1.0$ AU in order to find the absolute magnitude, using a linear law of type (2). If a linear law had been used for comet P/Tempel 2, an absolute magnitude of 2.0 would had been found, instead of 7.2 found using (3).

5) In describing the photometric behaviour of a comet, two laws are needed. One for the nucleus, behaving as R^{-2}, linear, and valid for $R > R_F$ or R_f. Another for the coma, not necessarily linear, valid for $R < R_F$ or R_f.

6) Values for R_F can be deduced. For comet P/Encke we obtain $R_F = 1.70 \pm 0.10$ AU. For P/Tempel 2 we find $R_F = 1.63 \pm 0.10$ AU. These are the places where the comets ignite, turn on, or the coma appears. These values are indicative that these comets are made of water. R_F for a CO_2 comet is around 10 AU.

7) A "false nucleus" may appear whenever the comet is being observed far from R_F. It can be recognized in the m_{V_Δ} vs. log R diagram because it does not follow an R^{-2} law.

8) The confusion between "nuclear" and "total" magnitude can only be cleared up with a graph like Figure 1, especially for faint comets. Nuclear magnitudes follow an R^{-2} law. If $R < R_F$ or R_f, the observer is probably seeing the coma, and thus we get a value for m_1. If $R > R_F$ or R_f, the observer is probably measuring a bare nucleus, or m_2. Knowledge of R_F or R_f is needed in order to report the magnitude correctly. Unfortunately R_F is known only for these two comets.

In conclusion we may say that there is no simple way to reduce visual or photoelectric magnitudes of comets to a single photometric system. Using only observations by reliable observers, and comparing with total magnitudes deduced from *V* photoelectric observations, seems to be the safest way to proceed.

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REFERENCES

Beyer, M. 1938, *Astr. Nachr.*, **265**, 37.
Beyer, M. 1950, *Astr. Nachr.*, **273**, 217.
Beyer, M. 1955, *Astr. Nachr.*, **282**, 145.
Beyer, M. 1962, *Astr. Nachr.*, **286**, 219.
Beyer, M. 1972, *Astr. Nachr.*, **293**, 241.
Ferrín, I. 1981, in preparation.
Ferrin, I., and Naranjo, O. 1980, *M.N.R.A.S.*, **193**, 667.
Mianes, P. 1958, *Publ. Obs. Haute Provence,* **4**, No. 8, 1.
Roemer, E. 1965, *A.J.*, **70**, 397.
Roemer, E. 1972, *IAU Circ.* No. 2391.
Roemer, E. 1973, *IAU Circ.* No. 2586.
Roemer, E., and Lloyd, R.E. 1966, *A.J.*, **71**, 443.
Spinrad, H., Stauffer, J., and Newburn, R. 1979, *Pub. A.S.P.*, **91**, 707.
Svoren, J., and Tremko, J. 1975, *Bull. Astr. Inst. Czechoslovakia,* **26**, 132.
Van Biesbroek, G. 1924, *A.J.*, **36**, 41.
Van Biesbroek, G. 1928, *A.J.*, **38**, 157.
Van Biesbroek, G. 1935, *A.J.*, **45**, 17.
Van Biesbroek, G. 1938, *A.J.*, **47**, 157.
Van Biesbroek, G. 1942, *A.J.*, **50**, 29.
Van Biesbroek, G. 1948, *A.J.*, **54**, 81.
Van Biesbroek, G. 1953, *A.J.*, **58**, 79.
Van Biesbroek, G. 1958, *A.J.*, **63**, 296.
Van Biesbroek, G. 1962, *A.J.*, **67**, 422.

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DISCUSSION

Torres: ¿Qué opinas de la teoría de Lyttleton de los cometas, en particular sobre el hecho de que el núcleo es un enjambre de partículas?

Ferrín: Creo que hay varios hechos que la contradicen. En nuestras Figuras 3 y 4, se puede ver que a grandes distancias del Sol, se comporta como R^{-2}. La única manera simple de interpretar esto, a mi parecer, es diciendo que lo que estamos observando es una superficie sólida, o sea, el núcleo del cometa Encke. Si fuera un enjambre de partículas, la ley no sería R^{-2}.

Campins: En relación con la precaria situación sobre la fotometría fotoeléctrica de cometas, debo mencionar que la IAU decidió en la reunión de Montreal el establecer un sistema homogéneo de filtros para ser usados en la fotometría de cometas. Los filtros estarán disponibles para todos los observadores interesados.

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