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TWENTIETH CENTURY LIGHT CURVES AND THE NUCLEUS OF COMET P/TEMPEL 2

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Abstract

Observations of P/Tempel 2 from 1899 to 1988 corresponding to 13 apparitions are analysed in order to estimate the perihelion asymmetry of the gas production curve for different periods of its evolution. Using the correlation found by Festou *et al.* (1990) between the perihelion asymmetries and the delay in perihelion passage due to the action of nongravitational forces , we estimate the mass of the comet to be $M \approx 1.6 \pm 0.5 \cdot 10^{14}$ kg. Assuming a volume of 500 km^3, based on nuclear observations, a density of 0.3 ± 0.1 g/cm^3 is obtained.

Introduction

In a recent paper (Festou *et al.* 1990) we studied the correlation between the perihelion asymmetries of the gas production curves of periodic comets and the nongravitational perturbations of their orbital periods. The result was that, in general, the perihelion asymmetries give the dominant contribution to these nongravitational effects and that for comets with strongly asymmetric production curves, a reasonable approximation is to neglect any remaining contribution whatsoever. This means in particular that if the asymmetry parameter E can be estimated in such a case, the reduced nongravitational effect $\Delta P'$ for the interval in question can be used to estimate the ratio Q_m/M of the maximum gas production rate to the mass of the nucleus. Since in general it is possible to estimate Q_m with fair accuracy, cometary mass estimates are thus sometimes feasible. For a discussion of uncertainties associated with this procedure, see Tancredi *et al.* (1991).

A case of considerable interest is comet P/Tempel 2, being a candidate spacecraft target. Indeed, its light curve data as compiled by Kamél (1991) indicates a strongly asymmetric gas production curve. Only a small amount of data is as yet available on the OH production rate, but the direct measurements are in good agreement with the expectation based on visual magnitude (Roettger *et al.* 1990) so the light curves can tentatively be used to indicate both the shape and the level of the gas production curve. Here we present an analysis of light curves of P/Tempel 2 during the 20th century. The gas production curve of the comet will thus be studied as a secularly evolving feature and correlated with the evolution of the non-gravitational effect. The aim is to deduce an estimate of the mass and density of the nucleus.

Light Curves

Table 1 summarizes the magnitude data that we had available for 13 apparitions of P/Tempel 2 from 1899 to 1988. This is the data contained in the Comet Light Curve Catalogue/Atlas (Kamél 1991). In order to estimate reliably the value of E, it is important to have a good coverage of the light curve both before and after perihelion. While in general terms the 1899, 1925, 1967, 1983 and 1988 apparitions were well observed, the material is sometimes heavily weighted to either side of perihelion. Thus we have to restrict our analysis to only a few composite light curves spanning several apparitions each. The 1957, 1972 and 1978 apparitions were even too badly observed to be included at all (e.g., in 1978 all magnitudes are explicitly nuclear). Some care has to be applied when joining the apparitions into composites since, as will be evident from Figs. 1–3, the shape and level of the curve has not remained constant during this century.

Fig. 1 shows a composite of the 1899-1930 apparitions, denoted by different symbols as indicated. The plot shows only magnitudes reported as total, but in some cases they are nonetheless so conspicuously faint that they must be regarded as quasi-nuclear. The curve denoted "nuclear mag." is the magnitude of the real nucleus, assumed to vary as $m_{\rm nuc} = M_{\rm nuc} + 5 \lg r$ with $M_{\rm nuc}$ determined from the observations by Jewitt and Luu (1989). We take the same approach as in earlier investigations (Rickman *et al.* 1987; Festou *et al.* 1990), in general trusting the brightest magnitudes as the best approximations to the true heliocentric magnitude. The abscissa of the diagram is $u = \pm \lg(r/q)$, where the sign is that of the true anomaly and q is the osculating perihelion distance for the apparition in question. Thus the chain of straight-line segments fitting the upper envelope of the set of points means that we are modelling the heliocentric magnitude $m_H(r)$ by means of stepwise constant photometric indices. Using the formula $\lg Q_{OH} = 32.0 - 0.4m_H$ (Festou 1986), we get a locally exponential gas production curve which can easily be integrated to yield the value of E. The fit must be regarded as very uncertain concerning the leftmost segment owing to the lack of observations with $u \lesssim -0.08$, but our choice of a steep increase is supported by the fact that Jewitt and Luu (1989) purportedly observed the bare nucleus at $u \approx -0.2$. After perihelion we have two alternatives marked by (a) and (*b*). The (a) curve gives credence to a critical observation in Nov. 1920 by Barnard (1931), for which the aperture correction is important. The (*b*) curve assumes that this particular magnitude is too bright. The rapid fall-off of curve (a) just after the critical point is based on assumed similarity to a post-perihelion fit to later apparitions [curve (a) in Fig. 2]. The values of E obtained from fits (a) and (*b*) in Fig. 1 are $E = 0.19$ AU and $E = 0.16$ AU, respectively, indicating a pronounced post-perihelion excess. Nonetheless, the post-perihelion magnitudes appear undersampled, and thus it is likely that these fits underestimate the real value of E.

In Fig. 2 the 1946-1967 apparitions are combined. Comparing with Fig. 1, we note a marked change of the light curve. The bright magnitude at $u = -0.01$, observed by Van Biesbroeck (1946), is of low accuracy and possibly half a magnitude too bright. Therefore we have disregarded it. It seems that a change in the comet's physical behaviour must have occurred, such that it settled on a lower level of activity than at previous apparitions with a broader maximum for several apparitions to come. This change might, for instance, be the mantling of a previously active region on the nucleus. In view of the results by Rickman *et al.* (1991) on rapid mantling and purging in response to changes in the perihelion distance, one is tempted to look for a correlation with orbital changes. Although not conclusive, an encouraging feature is that the 1946 apparition is unique among those hitherto observed in that q had a sudden increase by 0.075 AU with respect to the preceding ones. Thus a dust mantle might persist on a previously protected part of the nuclear surface.

In this case the coverage is reasonably uniform all over the curve although the spread in magnitude is considerable. Our pre-perihelion fit disregards a few observations in 1967 that are deemed too bright, in part due to the observed lack of activity at $u \approx -0.2$ in 1988. Analogously to Fig. 1, we have plotted two alternative post-perihelion fits, and the critical observation was made in Nov. 1946 by Giclas (1947). The (a) curve, giving credence to this observation, yields a steep fall-off reminiscent of curve (a) in Fig. 1. The (*b*) curve, disregarding Giclas' observation, indicates a much slower fall-off reminiscent of curve (*b*) in Fig. 1. The E values differ considerably, being $E = 0.42$ AU for curve (a) and $E = 0.28$ AU for curve (*b*).

Fig. 3 shows a composite of the 1983 and 1988 apparitions. The shape of the light curve seems to have changed again, but there is still serious uncertainty over its post-perihelion behaviour. In addition, there is a problem with the pre-perihelion observations made in 1988 (u-values from –0.15 to –0.1). Negative results obtained at the same time, in part by the same observers, indicate a lower brightness. Nevertheless, we

Table I. Statistics of available magnitude data for P/Tempel 2. N_{tot} is the total number of magnitude estimates available, with N_{pre} and N_{post} as the number of pre- and post-perihelion estimates, respectively.

Apparition	N_{tot}	N_{pre}	N_{post}
1899 IV	83	61	22
1920 II	22	1	21
1925 IV	94	83	11
1930 VII	11	5	6
1946 III	25	6	19
1951 VIII	19	14	5
1957 II	3	0	3
1962 VI	24	9	15
1967 X	112	80	32
1972 X	8	7	1
1978 V	4	1	3
1983 X	206	18	188
1988 XIV	308	241	67

Table II. Results. Symbols are explained in the text

Linkage	Q_m (10^{28} s^{-1})	E (AU)	M (10^{14} kg)
1899-1930	9.3	0.18	1.1
1946-1967	3.8	0.35	1.7
1983-1988	9.7	0.27	1.6

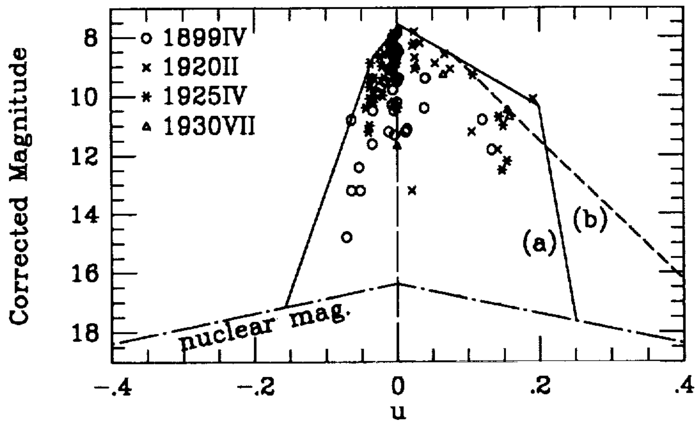

Fig. 1. Light curve data for comet P/Tempel 2, 1899-1930. Magnitudes obtained at different apparitions are marked by different symbols, as indicated. The observed magnitudes have been corrected for geocentric distance and observational effects. The u coordinate used as abscissa is explained in the text. Two possible fits to the post-perihelion data ($u > 0$) are shown as (a) -solid lines - and (b) - dashed line.

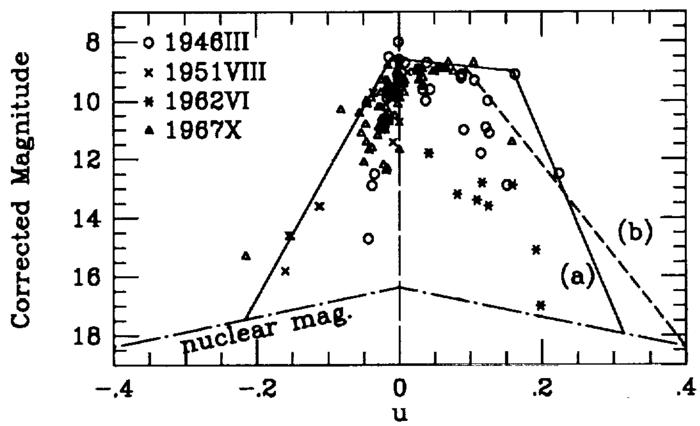

Fig. 2. Light curve data for comet P/Tempel 2, 1946-1967. Explanations are given in the caption to Fig. 1.

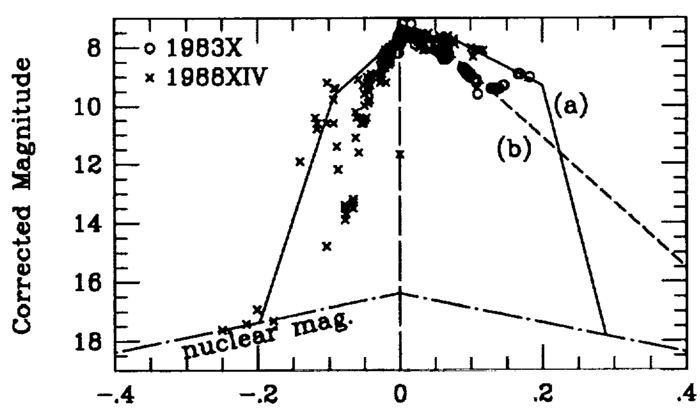

Fig. 3. Light curve data for comet P/Tempel 2, 1983-1988. Explanations are given in the caption to Fig. 1.

have some faith in the plotted magnitudes on the basis of their shear number and internal consistency, as shown by the fitted curve. After perihelion the two apparitions give quite different curves, and further work is needed in order to elucidate the internal relationship between these two curves as well as their possible similarity to earlier apparitions, in particular those in Fig. 1. For the moment we have only drawn the two fits in order to use a mean value of E as a rough estimate. Curve (a), based on the 1988 data, yields $E = 0.35$ AU, whereas curve (b), based on the 1983 data, yields $E = 0.18$ AU.

Analysis and Discussion

Under the assumptions mentioned above, using the theory of Festou *et al.* (1990), we get the mass of the nucleus from:

$$M \approx \frac{(3.5\mathrm{AU})^{5/2}}{(GM_{\odot})^{3/2}} \cdot 6\pi m \langle u_{\mathrm{g}} \rangle \cdot \frac{Q_{\mathrm{m}} E}{\Delta P'} \tag{1}$$

where G is the gravitational constant, $M_{\odot}$ is the solar mass, and $\langle u_{\mathrm{g}} \rangle$ is the net outflow speed of the gas from the nucleus averaged over the active part of the orbit. For the latter we estimate a value of 0.3 km/s (Rickman *et al.* 1987), and thus we obtain the results listed in Table 2. For each time interval we have taken an average of our two estimates of E and an average of the A_2 values listed by Marsden (1989) for computing $\Delta P'$. Considering the uncertainties involved in estimating E (and, to some extent, Q_{m}), the three mass values are quite consistent, indicating a true mass near $1.6 \cdot 10^{14}$ kg. The nucleus of P/Tempel 2 would thus be a near twin of that of P/Halley, not only regarding size and shape (Jewitt and Luu 1989) with a volume of around 500 km^3, but also regarding mass and density. The latter can be estimated at 0.3 g/cm^3, in good agreement with the result for P/Halley by Rickman (1989). The probable error of this estimate should amount to the order of $\pm 30\%$ in the mass, adding to an uncertainty of at least this order for the volume.

We note that the maximum water production rate inferred for the 1988 apparition from our composite light curve (Fig. 3) is more than twice as high as the rates reported from IUE observations and found to be consistent with visual magnitudes by Roettger *et al.* (1990). Further work is needed in order to resolve this discrepancy which has its origin in different correction procedures for the magnitudes. It should be evident that our results for the gas production curve as well as the mass and density of the nucleus are only rough estimates that further analysis may be able to refine to some extent. In any case a correlation seems to exist between the lower values of the nongravitational effect on P/Tempel 2 that occurred a few decades ago and the temporary drop in the level of gas production that we find from the light curves.

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