**Parameters Measured from the Plots. NEW VERSION 050701.**

Two plots are needed for each comet and provide a wealth of information much of it new, since over 16 new parameters are measured from them.

*Log plots.* The title of each plot identifies the comet in the new and old system to facilitate identification. The first apparition of the comet is also identified. The labels JF and OC indicate if the comet belongs to the Jupiter Family or to the Oort Cloud, and the number after it is the photometric age, P-AGE. The reason for using P-AGE as a label here is that its definition is robust, as will be demonstrated later on. Next is the Version of the plot. Although most plots have gone through many versions in the course of arriving at a final solution (usually more than 15 versions), all plots are identified as Version 1. Future updates will have higher versions. The upper left hand side of each plot gives the perihelion distance, q, the aphelion distance, Q (for that epoch), and Log Q to identify the extent of the plot. These points are labeled at the bottom of the plots.

*The Epoch label identifies the apparition that has contributed most significantly to the definition of the envelope.* The importance of this label is that future apparitions will be plotted in a new Epoch plot, to be compared with the former one. After many apparitions, a movie of the secular light curve could be built with the individual plots, showing evolutionary changes and actually, the photometric history of the comet.

1) $R_{ON}$ [AU]. The turn on distance of the coma. The negative sign in this parameter, in $T_{ON}$ and in Log R in the plots, is a label, not a mathematical sign, and indicates values before perihelion. Physically $R_{ON}$ corresponds to the onset of *steady* activity. It is the interception of the nuclear line and the coma envelope. Browsing the secular light curves it can be seen that the turn on and turn off points are very sudden affairs. When there are enough data points these parameters can be measured easily and accurately because of the sharp change of slope. In the present data set $R_{ON}$ takes place always *before* perihelion, but nothing restricts it to take place after perihelion.

2) $R_{OFF}$. The turn off distance of the coma, usually larger than $R_{ON}$. This is the interception of the coma envelope and the nuclear line. Since it measures the end of activity of the nucleus, it is sensitive to the whole history of that particular apparition. In the present data set $R_{OFF}$ takes place always *after* perihelion.

3) $V_{ON}$. The magnitude at which the nucleus turns on.

4) $V_{OFF}$. The magnitude at which the nucleus turns off.

5) $R_{ON}$ / $R_{OFF}$. An asymmetry parameter for the secular light curve.

6) m(1,1). The absolute magnitude of the coma, measured by extrapolation to Log R = 0 . When the secular light curve is highly asymmetric, there may be a need to define this parameter before ( $m_B$ (1,1)) and after ($m_A$ (1,1)) perihelion.

7) $m_{1A}$ (1,1) = The absolute magnitude of the coma, after perihelion (for those comets with q < 1 AU, since there are two interceptions with the R=1 AU axis).

On the upper right hand side of the plot are listed the geometric albedo, $p_V$ , and phase coefficient, $\beta$, if these have been measured by any investigators, with the initials of the paper's authors. For the nucleus the following parameters are listed:

8) V(1,1,0) = $V_{NUC}$. Absolute nuclear magnitude measured by different authors. The authors are listed in the individual comments of each comet.

9) $A_{SEC} = V_{NUC} - m(1,1)$ = amplitude of the secular light curve. In case there are several values of $V_{NUC}$ and m(1,1) the mean values are used. $A_{SEC}$ is a measure of the activity of the nucleus (see later on). Do not confuse with $A_{ROT}$ the amplitude of the *rotational* light curve.

10) $D_{EFFE}$, the effective diameter of the comet. The mean nuclear magnitude of a nucleus of semi-axis a, b, c, is defined in terms of the mean V value of the *rotational* light curve, thus it is important to see to what diameter this corresponds to:

$$V_{MAX} = C + 2.5 \, \text{Log } a \, . \, c$$

$$V_{MIN} = C + 2.5 \, \text{Log } b \, . \, c$$

$$V(1,1,0) = V_{NUC} = (V_{MAX} + V_{MIN}) / 2 = C + 2.5 \, \text{Log } (a.b.c^2)$$

$$D_{EFFE} = 2 \, (a.b.c^2)^{1/4} \qquad (4)$$

where C is the zero point constant. Notice the weight of semi-axis c which is usually poorly determined and thus assumed equal to b, and also that $a \geq b \geq c$.

11) P-AGE = Photometric Age. It is an objective of this paper to be able to define a parameter that measures the age of a comet solely from the secular light curves. Although it is not possible from this data set to assign an actual physical age, it is nevertheless possible to define a parameter related to activity that ranks the comets by age. We call it P-AGE to distinguish it from a real age. It should be emphasized that P-AGE is not a dynamical age (although it may be related to it), but rather it is related to the loss of volatiles. The capability to order comets according to their relative ages, could be a useful tool to understand a number of events in the history of these objects.

Consider the three parameters $A_{SEC}$, $R_{ON}$ and $R_{ON}+R_{OFF}$. As a comet ages, the amplitude of the secular light curve, $A_{SEC}$, must decrease. In fact $A_{SEC}$ must be zero for an inert nucleus. Thus $A_{SEC}$ must be related to activity and age. In this work we take both as synonymous. $R_{ON}$ is also related to age. As the comet ages, the crust on the nucleus increases in depth, sublimating ices must recede inside the nucleus, sustained sublimation is quenched, and the comet needs to get nearer to the sun to be activated (Yabushita and Wada, 1988; Meech, 2000). Thus $R_{ON}$ decreases with age. On the other hand, $R_{ON}+R_{OFF}$ measures the total space of activity of the comet. Comets that have exhausted their CO and $CO_2$, must get nearer to the sun to be active. In fact, water ice comets get active much nearer to the sun than CO or $CO_2$ dominated comets (Delsemme, 1982; Meech, 2000). Figure 17 confirms this fact. Thus a parameter that measures age and activity at the same time, and that includes the three above quantities could be $A_{SEC}$ ( $R_{ON}$ + $R_{OFF}$ ). This value defines the area of a rectangle in the phase space $A_{SEC}$ vs R.
So defined, P-AGE would give small values for old comets and large values for new comets, inverted from what we would like. It would be interesting to scale these values to human ages. We will call these *“comet years”* to reflect the fact that they have not yet been scaled to Earth’s years. To calibrate the scale, we will

arbitrarily set to 28P/Neujmin 1 (the oldest comet in our data set) an age of 100 cy. With this calibration we define P-AGE thus:

$$\text{P-AGE} = 1440 / [ A_{SEC} \cdot ( R_{ON} + R_{OFF} ) ] \text{ comet years (cy)} \qquad (5)$$

This definition produces the following age ranking for the comets presented in this data set in order of increasing age(Table 2): 1P ( 7.1 cy), 81P (13 cy), 19P (14 cy), 21P (20 cy), 9P (29 cy), 67P (32 cy), 26P (89 cy), 28P (100.0 cy).

What can be deduced from the previous ranking is that 1P is the youngest object of this data set, as expected. 81P, 19P, and 21P are also young objects. 9P and 67P have not yet reached middle age, while 26P and 28P are old.

Scaling to human ages may seem naïve and unorthodox. However it places the comets in perspective and provides a scale to compare with. This enhances the usefulness of P-AGE, and when the evolution of $A_{SEC}$, $R_{ON}$ and $R_{OFF}$ with time is studied and calibrated with a suitable physical model, it will be possible to convert these values to a real physical age, thus achieving the objective we have set in this paper. The validity of this parameter is tested in the next section but we can say in advance that it classifies the secular light curves by shape, an interesting property and a proof of its validity.

The definition of P-AGE is rather robust. a) Since the onset and offset of activity are very sudden affairs, the error in the determination of $R_{ON}$ and $R_{OFF}$ is small. So is the error of $A_{SEC}$. b) If the slope of the secular light curve at onset or offset is uncertain, then $R_{ON}$ or $R_{OFF}$ increases when $A_{SEC}$ decreases (or vice versa), and the product is insensitive to the values. c) If only $R_{ON}$ or $R_{OFF}$ can be determined, the other one can be estimated from the mean $R_{OFF}/R_{ON}$ value of the other comets ($1.44 \pm 0.29$). In conclusion, the error of P-AGE is small (as can be ascertained from the plots), and the definition is robust.

12) $n_{ON}$ , the slope parameter of secular light curve in equation (1).

13) $n_{qB}$ , the slope of the curve in equation (1) just before perihelion.

14) $n_{qA}$ , the slope of the curve in equation (1) just after perihelion.

*Time plots (Figures 9 to 16).* On the upper left hand side the orbital period around the sun, $P_{ORB}$, is given, with the *approximate* date of the next apparition for planning purposes, $T_{PERI\text{-}NEXT}$ . Also the total number of observations used in the secular light curve, $N_{OBS}$ , and a listing of the apparitions identified as the perihelion time in the format YYYYMMDD, with identification symbols for each apparition.

In the upper right hand side the following parameters are measured:

15)$R_{BP}$ = distance of the break up point of the envelope, in AU.

16)$m_{BP}$ = magnitude of the break up point of the envelope.

17) LAG, the shift in maximum light measured from perihelion in days.

18) $T_{ON}$ [days], the time at which the nucleus turns on. The negative sign in this parameter is a label, not a mathematical sign, and indicates pre-perihelion quantities. It corresponds to $R_{ON}$ but in the time domain.

19) $T_{OFF}$, the time after perihelion at which the nucleus turns off.

20) $T_{OFF}/T_{ON}$, an asymmetry parameter but in the time domain.

21) $T_{ACTIVE} = ( T_{ON} + T_{OFF} )$, in days. It is a measure of the total time that the comet is active.

22) $m_{MAX}(1,LAG)$ = maximum reduced magnitude measured at the time LAG.
23) $S_{ON}$ = The slope of the envelope at $T_{ON}$, for planning purposes.
24) $S_{OFF}$ = The slope of the envelope at $T_{OFF}$, for planning purposes.
25) $p_V$ = geometric albedo.
26) $\beta$ = phase coefficient.
27) R – V = Color index red – visual.
28) Tiss = Tisserand Invariant
29) i = orbital inclination
30) $A_{ROT}$ = Amplitude of the rotational light curve (in the log plot).