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"Secular Light Curves of Comets, II:

133P/Elst-Pizarro,

an Asteroidal Belt Comet"

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“ Secular Light Curve of Comet 133P/Elst-Pizarro “

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Abstract

We present the *secular light curve* (SLC) of 133P/Elst-Pizarro, and show ample and sufficient evidence to conclude that it is evolving into a dormant phase. The SLC provides a great deal of information to characterize the object, the most important being that it exhibits outburst-like activity without a corresponding detectable coma. 133P will return to perihelion in July of 2007 when some of our findings may be corroborated.

The most significant findings of this investigation are: **(1)** We have compiled from 127 literature references, *extensive* databases of visual colors (37 comets), rotational periods and peak-to-valley amplitudes (64 comets). 2-Dimensional plots are created from these databases, which show that comets do not lie on a linear trend but in well defined areas of these phase spaces. When 133P is plotted in the above diagrams, its location is entirely compatible with those of comets. **(2)** A positive correlation is found between cometary rotational periods and diameters. One possible interpretation suggest the existence of *rotational evolution* predicted by several theoretical models. **(3)** A plot of the historical evolution of cometary nuclei density estimates shows no trend with time, suggesting that perhaps a consensus is being reaches. We also find a mean bulk density for comets of $<\rho> = 0.53 \pm 0.06$ g/cm^3. This value includes the recently determined spacecraft density of comet 9P/Tempel 1, derived by the Deep Impact team. **(4)** We have derived values for over 18 physical parameters, listed in the SLC plots, Figures 6-9. **(5)**The secular light curve of 133P/Elst-Pizarro exhibits a single outburst starting at +42±4 d (after perihelion), peaking at LAG = +155±10 d, duration 191±11 d, and amplitude 2.3±0.2 mag. These properties are compatible with those of other low activity comets. **(6)** To explain the large time delay in maximum brightness, LAG, two hypothesis are advanced: a) the existence of a deep ice layer that the thermal wave has to reach before sublimation is possible, or b) the existence of a sharp polar active region pointing to the sun at time = LAG, that may take the form of a polar ice cap, a polar fissure or even a polar crater. The diameter of this zone is calculated at ~1.8 km. **(7)** A new time-age is defined and it its found that T-AGE = 80 cy for 133P, a moderately old comet. **(8)** We propose that the object has its origin in the main belt of asteroids, thus being an asteroid-comet hybrid transition object, an asteroidal belt comet (ABC), proven by its large density. **(9)** Concerning the final evolutionary state of this object, to be a truly extinct comet the radius must be less than the thermal wave depth, which at 1 AU is ~250 m (at the perihelion distance of 133P the thermal wave penetrates only ~130 m). Comets with radius larger than this value can not become extinct but dormant. Thus we conclude that 133P can not evolve into a truly extinct comet because it has too large a diameter. Instead it is shown to be entering a dormant phase. **(10)** We predict the existence of truly extinct comets in the Main Belt of Asteroids (MBA) beginning at absolute magnitude ~21.5 (diameter smaller than ~190 m). **(11)** The object demonstrates that a comet may have an outburst of ~2.3 magnitudes, and not show any detectable coma. **(12)** Departure from a photometric R^{+2} law is a more sensitive method (by a factor of 10) to detect activity than star profile fitting or spectroscopy. **(13)** Sufficient evidence is presented to conclude that 133P is the first member of a new class of objects, an old asteroidal belt comet, ABC, entering a dormant phase.

1. Introduction

133P/Elst-Pizarro, 107P/Wilson-Harrington and 1996 PW are three of many interesting objects of the solar system minor bodies. In a review, Yeomans (2000) has proposed that the three blur the transition between comets and asteroids because they share properties of both categories. In fact two of the objects (comets 107P and 133P) have dual designations as asteroids 4015 1949 W1 and 7968 1979 OW7. The confusion about their nature comes from the fact that 107P exhibited a blue tail without coma in only one night in 1949 (Fernández et al., 1997), while 133P exhibited a tail without coma in 1996 and 2001 (Hsieh et al., 2004). With an orbit entirely inside the asteroidal belt, it could be considered a member of the Themis family. Its Tisserand invariant, Tiss = 3.18, implies that it can not belong to the Jupiter Family (JF) of comets. To add to the puzzle, 1996 PW is an asteroid that has never exhibited activity, but that has an orbit coming from the Oort Cloud (OC) (Weissman and Levison, 1997). Thus we have an asteroid (1996 PW) in a comet's orbit, and a comet (133P) in an asteroidal orbit.

Another worrying piece of evidence is that asteroids seem to have large amounts of water. It has been found that 253 Mathilde and 45 Eugenia have bulk densities of 1.3 g/cm^3, just above water (Yeomans et al., 1997; Veverka et al., 1997; Merline et al., 1999). Yeomans (2000) cites the case of a freshly fallen chondrite that contained salt crystals dated to the very beginning of the solar system.

The blurring of the distinctions between comets and asteroids has become fairly well-established with the discovery of activity in at least 11 Centaurs (Meech and Svoren, 2005; Jewitt, 2005; Fernandez, 2006) and two additional asteroidal belt objects (Hsieh and Jewitt, 2006), P/2005 U1 Read and 118401 (1999 RE70). It is natural to have doubts about their cometary or asteroidal nature, and the question arises as to how to distinguish between the two possibilities.

In this work we have compiled 154 photometric observations to create the *secular light curve* (SLC) (not to be confused with the *rotational light curve*) of 133P, with the intention of detecting cometary activity. What we found is that the activity is very feeble and without a corresponding detectable coma, and the SLC is quite different from those of the Jupiter family of comets (Ferrín, 2005, from now on Paper I). For example, it turns on *after* perihelion, contrarily to the 8 normal comets previously presented in Paper I all of which turn on *before* perihelion. This has important consequences for evolutionary and interior models of these objects.

Since the plots presented in this work are a continuation of those published in Paper I, it is recommended to take a look at the information previously presented, to get acquainted with the 16 parameters there defined and the results shown for 8 normal JF comets. It may also be useful to visit the web site cited at the end, where an updated key to the parameters is kept. A comparison of the SLCs presented here with the 8 previous ones, shows that the activity is more outburst-like than sustained. The photometric information will help us to get familiar with this new type of unusual object.

2. Observations

Observations of this object were carried out by the author in 1996, November 06 (exposure time 5 minutes) and 07 (exposure time 20 min). The two nights were photometric. The images are shown in Figure 1. The field size of these images is 5.3x5.3' of arc. The instrument used was the 1 m Schmidt telescope of the National Observatory of Venezuela coupled with a Thompson 7883 CCD, of 576x384 pixels. Since this detector had a fairly low quantum efficiency, no filter was used to increase the signal to noise ratio. The maximum response curve between 6500 and 7500 A, is approximated fairly well by a broad band R filter. The CCD is quite blind at 4500 A. Processing was done using standard reduction procedures. Calibration of the magnitudes was done using the R magnitudes of the USNO A2.0 catalog. To avoid errors from poor magnitude stars, a least squares calibration of the field was done using no less than 15 stars. Stars deviating from the linear fit were dropped. The fact that the magnitudes derived for the two nights using a different set of standard stars differ by a very small amount, imply that this calibration method is good to ±0.1 magnitudes. Since these are snapshot observations partially affected by the rotational error (Paper I), there is no need for a higher precision of the data. Using the mean color index < V-R > = 0.40 from Table 1, the R magnitudes were converted to visual and are listed in Table 2. These values are plotted in the SLC and by good luck lie in the region were the comet is turning off, thus helping to define the extent of activity of 133P.

3. Statistical Databases

In order to distinguish between comets and asteroids, and to compare 133P with other comets, we need *extensive* databases of a) visual color indices (Table 1), and b) rotational periods and peak-to-valley amplitudes of the rotational light curve (Table 3), for many objects. So we made a special effort to gather this information from the literature, detecting 127 scientific references on the subject. Additionally, c) we compiled the evolutionary history of density estimates of cometary nuclei (Table 4) from 20 papers. 133P does not have its infrared colors or albedo determined, so it is not possible to use this data for classification purposes. The empty entries and the missing ID numbers in the Tables indicate where observational work is needed.

a) Visual Color Indices of Comets Combining the databases of Green et al. (1997) (5 comets), Campins and Fernández (2002) (13 comets), Lamy et al. (2005) (21 comets), Hainaut and Delsanti (2002) (14 comets), and including our own database, we list 142 measurements of B-V, V-R, and R-I indices for 37 comets in Table 1, information taken from 36 scientific references. These values are plotted in Figures 2 and 3 where it is seen that they define a well delimited area of their respective phase space.

Some published V-R values are suspect. In Table 1, a V-R=0.02 for 14P/Wolf plotted in Figure 3 and shown entirely outside of the main distribution, a V-R=0.99 for 74P/Smirnova-Chernyk, and a V-R= - 0.11 for 87P/Bus. Another observer measured V-R=0.55 for comet 87P/Bus (confirmation Table 1) making the first determination suspect. Also 86P/Wild 3 has a very small V-R= 0.12 measured. All the above observations should be confirmed. They might be real.

It was found observationally that even those comets that exhibited a small coma fall inside the distribution. This is presumably due to the fact that light scattered from grains larger than the wavelength of light does not know if it hit a grain or if it hit the real nucleus. Large grains mimic the nucleus. Comets with comas composed of small grains depart significantly from the distribution but a small coma contamination does not.

In this work the mean value of variable x will be denoted by <x>. From these extensive number of measurements the mean values can be quoted as (confirmation Table 1): <B-V>= 0.76±0.16 (26 observations), <V-R>= 0.48±0.13 (77 observations), <R-I>= 0.34±0.22 (30 observations). However the range of values is an equally valid and perhaps more significant statistics: 0.35 < B-V < 1.08, 0.20 < V-R < 0.88, 0.19 < R-I < 0.91.

b) *Rotational Periods and ptv-Amplitudes* Combining the databases of Samarasinha et al. (2005) (25 comets), Lamy et al. (2005) (26 comets) and including our own database, 82 rotational periods, and 58 rotational peak-to-valley (ptv) amplitudes of 64 comets have been collected in Table 3. This information has been extracted from 78 scientific references. Notice that A_{ROT} as defined here and in Paper I equals the peak-to-valley amplitude of the rotational light curve.

Some A_{ROT} have been measured from data given by the authors, when the author did not measure this parameter. Comets marked with UR are unpublished results of rotational periods by the author, listed here for completeness. The A_{ROT} measured are frequently lower limits of the ptv-values, unless we are looking on the comet equator on. If the pole has a significant obliquity then the ptv-amplitude, A_{ROT}, will be near zero twice in the orbit. Three plots can be constructed from Table 3: A_{ROT} of the rotational light curve vs the rotational period (A_{ROT} vs P_{ROT}) and two histograms of asteroidal and cometary A_{ROT} (Number vs A_{ROT} , and Number vs P_{ROT}). None of these plots are shown in this work, but they are available at the web site cited at the end. The first two plots show the populations of comets and asteroids as superimposed. A_{ROT} is a non-constraining variable, and does not help to discriminate comets from asteroids. Accordingly, A_{ROT} is not considered further. A positive correlation is found between P_{ROT} and diameter of the object, shown in Figure 4 and discussed in the next section.

From this extensive data set the following statistics can be derived: 3.47 h < P_{ROT} < 540 h, <P_{ROT}>= 40.0±82.6 h (82 observations), 0.05 < ptv-Amplitude < 1.3 magnitudes, <ptv-Amplitude> = 0.52±0.26 (58 observations)

c) Historical Evolution of Density Estimates for Cometary Nuclei Methods to study the density and structure of cometary nuclei have been reviewed by Weissman et al. (2004). A previous compilation of density estimates of cometary nuclei was made by Meech (1996a).

A most significant development has taken place recently, when the density of comet 9P/Tempel 1 has been measured from observations made from the Deep Impact spacecraft. A'Hearn et al. (2005) using the ejecta fallback after impact, measured ρ = 0.62 (+0.47, -0.33) g/cm^3. This is the first time a density is inferred from spacecraft *in situ* data. Interestingly, this value is in accord with ground based estimates, suggesting that perhaps a consensus is being reached (Figure 5).

Including our own database in Table 4, and discarding non-constraining values, Figure 5 shows the historical evolution of 21 density estimates using 10 independent methods. It is interesting to notice that the estimates do not show a trend with time.

The estimated mean density is $<\rho> = 0.52\pm0.06$ g/cm^3. A better descriptor could be the range, $0.40 < \rho < 0.70$ g/cm^3 .There are two discrepant values. The density of comet 19P/Borrelly has been estimated by Davidsson and Gutiérrez (2004) from 0.18 to 0.30 g/cm^3 , 2σ below the mean. However this result is contradicted by the density previously determined by Farnham and Cochran (2002) who obtained a value of 0.49 (+0.34, -0.20), and who claim that *"this result is the least model-dependent comet density known to date".* The other discrepant value is that of 133P/Elst-Pizarro for whom Hsieh et al. (2004) have deduced $\rho > 1.3$ g/cm^3 , 7σ above the mean.

These Tables are available in ASCII format at the web site cited at the end, which also contains updated log and time plots for these and other comets. These tables represent the largest data sets ever compiled on these properties.

The most notable characteristic found in Figures 2 to 4 is that comets do not distribute themselves over a linear range, but instead they are located on *well defined areas of occupancy in the specific phase space.* This will allow a precise 2-dimensional classification of 133P.

4. 1-Dimensional vs 2-Dimensional Classification.

In the current literature it is common to use 1-dimensional classification to try to separate suspicious objects from asteroids. This is a sensible thing to do when dealing with small number databases. However, a 1-dimensional classification may give erroneous results, especially if the distribution of objects is tilted like in Figures 3 and 4. Take for example an object with colors V-R= 0.33 (that of 6P/d'Arrest) and R-I= 0.91 (that of 21P/Giacobinni-Zinner) which are entirely reasonable for a comet when taken separately. If we plot these values in Figure 3, they lie entirely outside the region defined by comets, thus not describing a comet. The same happens with a hypothetical object with P_{ROT}= 69 h (that of comet 109P/Swift-Tuttle) and D= 1.2 km (that of 46P/Wirtanen). Plotted in Figure 4 this hypothetical object does not lie in the area defined by comets and thus could not represent a comet. In conclusion, *a 1-dimensional classifications may give misleading results.*

When we leave the realm of small numbers and begin to deal with medium size numbers (like in Tables 1 and 2), a 2-dimensional, more accurate classification becomes possible. For 133P we will attempt 3 2-dimensional classifications. The idea is that by plotting 133P in as many as possible 2-dimensional diagrams, other objects will be filtered out. In an N-dimensional phase space of physical properties, comets define a volume. It is claimed that if N is sufficiently large, only comets populate that volume. In this work we will use 9 physical properties for classification purposes (see below), so N=9.

Correlation of Rotational Periods and Diameters Cross-correlating the rotational periods, P_{ROT}, given in Table 3 and the diameters given by Meech et al. (2004) and Lamy et al. (2005) it is possible to create Figure 4, where comets exhibit a tilted oval-like distribution of rotational periods. The probability that this distribution is drawn from a random sample is P=0.0025. The rotational periods get shorter with age, going from ~30 hr for a ~30 km nucleus, to ~10 hrs for a ~3 km nucleus.

Removing the two extreme left data points, 147P and 46P, only makes the correlation stronger with the probability of being drawn from a random sample diminishing from P= 0.0025 to P= 0.0011 and the slope going from 0.50 to 0.73 (confirmation Figure 4). However there is no reason to do so since these two points are well determined.

What this exercise teaches us is that additional observations of rotational periods, *specifically of small nuclei*, are critically needed to define the slope precisely. Slope is a necessary condition for rotational evolution, and the distribution does exhibit slope.

The question is how to understand this correlation. We have two hypothesis. In the first one the diameter of a comet remains constant as a function of time. Perhaps only the ice recedes inside the nucleus and a crust is formed making sublimation more and more difficult with time. In this case the speed up of rotation seen for smaller objects may simply be due to their smaller mass, making it easier for the jets to induce a torque and a rotation. Let us remember that the moment of inertia scales as ~(radius)^2, so smaller objects are much more easier to spin up.

In the second hypothesis the diameter is a function of time. There is plenty of evidence to support the idea that comets lose great quantities of gas and dust to space. A crust may still form, but the diameter would diminish as a function of time. If D diminishes with time, objects in Figure 4 would move to the left, and then Prot would move down (spin-up), *suggesting* rotational evolution.

Is there theoretical evidence supporting that scenario?. There is. Rotational evolution is expected theoretically. Whipple (1950) was the first to suggest that outgassing can alter cometary spin. Hartmann and Tholen (1990) proposed the same idea. In particular Samarasinha and Belton (1995) studied the evolution of Halley-type (almost prolate) cometary nuclei under the influence of sublimation induced torques. They "... predict a spin-up of the nucleus providing the same set of active areas are present over many orbits. This spin-up is presumably the major cause for nuclear splittings..." They also find that if an active area changes, the comet might spin down for a while and then later spin up again. Neishtadt et al. (2002) concluded that "....a comet nucleus' rotational angular momentum will tend to increase over time, potentially contributing to the observed phenomenon of comet nucleus splitting....". Gutiérrez et al. (2003) present models of the rotational evolution of a small nucleus under the influence of non-gravitational forces. For three models whose rotational period as a function of time are presented, the nucleus may initially spin down but after a few orbits all three models spin up significantly, confirming Samarasinha and Belton's result.

In view of these theoretical studies the second hypothesis is more probable than the first. But since we do not know yet in what direction a particular comet will move, we believe *we may have detected rotational evolution in a statistical sense*.

Additional observations of rotational periods, *specifically of small nuclei*, would help confirm of deny the present results.

5. 133P/Elst-Pizarro

Introduction. 133P/Elst-Pizarro is a rather strange object that has defied classification as an asteroid or as a comet and has a dual designation. It is characterized by exhibiting during a short period of time post perihelion, a tail without a coma (Elst et al., IAUC 6456). Marsden (IAUC 6457) linked it with a previously known asteroid, 1979 OW7.

It has been observed only in two apparitions. The discovery took place in 1996 and the coverage was sparse. In 2002 it was observed again and many of its physical properties were determined by Hsieh et al., (2004), which may be considered as the most complete study of this object to date. Weissman and Levison (1997) find it equally likely that the object is an asteroid or an extinct comet. On the other hand (Hsieh et al., 2004) based on the activity and dust emission, conclude that 133P satisfies the classical physical definition of a comet.

Data Sets Hsieh et al. (2004) have collected a table of past photometric observations of 133P, mostly photographic. In Table 2 we have compiled 40 historical magnitudes and tail data to initiate a photometric study of this object. Delahodde et al. (2004) have also made a study of 133P refining the rotational period, colors and absolute magnitude. Additionally since this object has a dual designation, it appears in the Asteroid-Dynamic Site maintained by Milani et al. (2005) that contains photometric observations of asteroids based on astrometric measurements. These values are of low accuracy, must be interpreted with care, and the data should only be used in a statistical sense to *corroborate* V and R band independent measurements.

Origin 133P has a Tisserand invariant of 3.18, an orbital inclination of 1.8º, and an orbit entirely inside the outer main belt. With an aphelion distance of 3.68 AU it is not clear how this object could belong to the JF of comets. The object might belong to the Themis family.

Work done by Levison and Duncan and presented by Weissman and Levison (1997), shows that 8% of objects originated between 3.3 AU and Jupiter's orbit, are ejected to bound orbits in the Oort Cloud. Moreover, recent work by Levison et al. cited by Weissman (1999) has shown that the source of the OC comets is the entire Jupiter-Neptune region, further in than previously thought. Relative capture efficiencies into the Oort Cloud were 0.03, 0.08 and 0.12 for the Jupiter-Saturn, Saturn-Uranus and Uranus-Neptune zones. Additionally they found that the relative number of planetesimals was larger near the orbits of Jupiter and Saturn, compensating for their smaller ejection efficiency.

Thus to explain the origin of 133P we do not need a paradigm change but only a paradigm shift. It is plausible to assume that some comets may have originated inside Jupiter's orbit, reaching to the outer asteroidal belt. If such a comet were produced, it would be made part of rock and part of ice, raising its overall density. Thus there is a significant chance that 133P is a comet formed in the asteroidal belt since Hsieh et al. (2004) derived a minimum density of $\rho > 1.3$ g/cm^3.

Binzel (Chaikin, 2004) proposed to name such an object "activated asteroid", which implies two words. Chaikin (2004) suggested comet-asteroid or "cometoid", but there is the doubt if "astermet" could be a better choice. Following Hsieh and Jewitt (2006) who proposed Main Belt Comet (MBC) which is short, we decide to adopt ABC for Asteroidal Belt Comet, which is short and easy to remember.

It is postulated then, that the outer fringes of the asteroidal belt might have originated a family of objects sharing characteristics of comets and asteroids, that could best be designated as ABCs. Physically, ABC implies an origin in the asteroidal belt and a density larger than that of comets (confirmation Figure 5, where 133P lies 7σ above the mean).

Due to their narrow formation region, these objects should be few. The region of formation does not have to have been uniform. Perhaps only lumps and clouds of icy material were sent in the direction of the MB asteroids, and some asteroids and not others picked up this material.

We believe that 133P is the first member of this class, proven by its density. It should be remembered that 95P/Chiron was the only and first member of its class for a long time, until new centaurs were found. The same situation is taking place with 133P. Hsieh and Jewitt (2005) are conducting a MBA search for asteroids that may exhibit activity and have already found two new objects (Hsieh and Jewitt, 2006), P/2005 U1 Read and 118401 (1999 RE70).

Nuclear Magnitude and phase coefficient Hsieh et al., (2004) found β = 0.044±0.007 mag/deg. The phase coefficient lies within the ranges found in Paper I ($0.025<\beta<0.069$ mag/deg). However Delahodde et al. (2004) mention that their phase curve is not consistent with that of Hsieh et al. (2004) but did not publish any further details. The only available nuclear magnitude is that of Hsieh et al. (2004), who found $V_N(1,1,0)= 16.02\pm0.03$.

Colors We first ask if 133P shares common B-V, V-R, R-I, P_{ROT} and diameters with those of comets. This is done through the use of 3 2-dimensional plots (Figures 2 to 4). The colors of this object have been measured by Hsieh et al. (2004) and Delahodde et al. (2004) (see Table 1). In Figures 2 and 3 a 2-dimensional classification shows that 133P lies confortably inside the area defined by JF comets.

Infrared Colors and Albedo. There are no tabulated values of these parameters in the literature. It would be a good scientific objective to determine them in the next apparition that will take place in July, 2007.

Rotational Period Reviews of the rotational properties of comets have been published by Jorda and Gutiérrez (2002) and Samarasinha et al. (2005). Toth (2006) has concluded that the direction of the rotational pole of this comet is still unknown. Hsieh et al. (2004) have derived a rotational period P_{ROT}= 3.471±0.001 hr, and Delahodde et al. (2004) have refined this value to 3.47113±0.00001 hr. This is the shortest rotational period of all known comets. When this information is correlated with the diameter determined by Hsieh et al. (2004) of D= 4.6±0.6 km, it is possible to plot this value in Figure 4. It can be perceived that the location of 133P *is not inconsistent* with that of other JF comets.

Secular Light Curve Figures 6, 7 and 8, show the log and time plots that constitute the secular light curve of 133P/Elst-Pizarro. The pyramidal line at the bottom describes the nucleus. The nuclear lines have a slope of 5 = 2.5 n, where n=2 for a bare nucleus. Consult Paper I or the web site for other parameter definitions. The SLCs provide a large amount of new information.

Turn-on point The comet turns on *after* perihelion at R_{ON} = +2.641±0.002 AU, and has a LAG= +155±10d, where LAG is the time delay after perihelion. For comparison all comets in Paper I have turn on points *before* perihelion and very small LAG times (the largest one being that of 67P/Churyumov-Gerasimenko with LAG= 33±8 d). So 133P is a record holder.

There are two possible interpretations of this large delay: a) if the pole is perpendicular to the orbit, then there is no way to produce such a large LAG unless the sublimating layer is deep inside the nucleus, and the thermal wave has to reach it before sublimation is possible. b) If on the other hand the pole of the comet is parallel to the orbit and points to the sun at LAG = +155 d, then the approach to maximum brightness would be a very slow affair, which is not seen. The only way to circumvent this inconvenience is to postulate the existence of a polar active region that could take the form of a polar ice cap, a polar fissure, or even a polar crater. However to explain the sharp turn on and turn off, this active region would have to be very sharp. This is not unlikely, since both Earth's and Mar's polar caps are sharp.

The first hypothesis would explain the low ejection velocity of the dust (Hsieh et al., 2004), since the gas would have to percolate through the crust above, and be carried out by the solar wind producing a narrow tail in accord with observations. Activity originated by gas jets results in much larger ejection velocities, wider tails and comas. A suitable thermal model assuming a thermal conductivity would be capable of estimating the depth of this layer but is beyond the scope of this paper. This hypothesis also implies that the object is completely covered with a crust layer, which would additionally be consistent with its old age (discussed further down).

If on the other hand we assume the second hypothesis, a polar active region, then the diameter of this region can be estimated. From the turn on and turn off distances, R_{ON}, R_{OFF}, the true anomaly can be calculated. We find $\nu_{ON} = 9.9^{o}$ and $\nu_{OFF} = 55.0^{o}$. Thus the active region has a radius of ~22.5° , a diameter of ~1.8 km, and a surface area of ~2.5 km^2. This hypothesis has the advantage that the activity at aphelion (if it were confirmed), could be explained with the opposite polar cap.

Activity Without Coma The fact that 133P has repeated its behavior in 1996 and 2001 (Hsieh et al., 2004) excludes the possibility that the activity is due to a collision event as proposed by Toth (2000). The activity is more outburst-like than sustained. We are going to define “outburst” as a low intensity, small duration, single episode of activity.

Hsieh et al. (2004) had previously calculated an approximated minimum period of activity of 5 months or ~150 days. The above Figures extend this estimate and show an outburst-like period of activity starting +42±4 d after perihelion (Sekanina, IAUC6473), peaking at LAG = +155±10 d, duration $T_{ACTIVITY}$ = 191±11 d, and range 2.3±0.2 mag with no detectable coma (confirmation Figures 7 and 8). In Table 2 there are 15 observations of non-coma detection. For comparison 26P/Grigg-Skejellerup had an active time $T_{ACTIVITY}$ = 203±10 d and a well-developed coma. The two error bars overlap, which implies a value entirely compatible with other comets. The comet with the smallest amplitude of the SLC that exhibited a coma was 28P/Neujmin 1 with A_{SEC} (1,1)= 3.2±0.2 mag (Paper I), above the nucleus.

The end of activity is known with a surprisingly small error, due to fortuitous observations by Lowry and Fitzsimmons (2005) (R_{OFF}= +2.805±0.005 AU). Our own observations in the turn off leg of the SLC also help to constrain the period of activity.

Two nuclear observations taken far from the Sun exhibit an excess of 0.6 magnitudes and suggest that this comet might be active at aphelion (confirmation Figures 7 and 8).

Photometric-Age (P-AGE), and Time-AGE (T-AGE) From Figure 7 we know R_{ON} and R_{OFF} quite well. A_{SEC} (1,R), the amplitude of the secular light curve at the Earth's distance 1 AU, solar distance R, can also be derived from Figure 7. However A_{SEC} (1,1) (the absolute amplitude defined in similar way to the absolute magnitude) remains uncertain because the object never reaches to that distance since q = 2.63 AU. There are two ways to find A_{SEC}(1,1). The first one is to make a theoretical model that will explain the activity past perihelion and use its predictive power to predict the amplitude of the activity at R = 1 AU. Calculation of such a time-dependent thermal model of the interior of a comet is a major undertaking and is beyond the scope of this paper. The second way is to use the comets studied in Paper I as *templates* to extrapolate the activity to R = 1 AU. This is what has been done in Figure 6, where 4 comets have been scaled up or down to fit the maximum value of the 133P outburst. Using this information we find A_{SEC} (1,1) = 6.0±1.5. Figure 6 also shows the complete SLC of this object, enlarged for clarity in Figures 7 and 8.

In Paper I we defined a quantity that seeks to assign a relative photometric age to a comet, P-AGE, based solely on the activity shown in the light curve. The ability to assign a relative photometric age to comets may be an important tool to understand a number of events in the history of these objects and to rank them. In that paper the youngest comet was 1P/Halley with P-AGE= 7.1±0.4 cy, while the oldest was 28P/Neujmin 1 with 100 cy, where *cy* stands for *comet-years*, to distinguish them from real Earth years. In other words, this is a relative calibration. The absolute SLC amplitude is A_{SEC} (1,1) = V_N (1,1,0) – m(1,1), where V_N (1,1,0) is the absolute nuclear magnitude at 1 AU from de sun and 1 AU from Earth and phase angle equal to zero, and m(1,1) is the absolute coma magnitude. Then the definition is:

$$\text{P-AGE} = 1440 \,/\, [\, A_{SEC}(1,1) \,.\, (\, R_{ON}+R_{OFF}\,)\,] \qquad (1)$$

where R_{ON} is the turn on distance and R_{OFF} the turn off distance. Since 133P turns on *after* perihelion actually R_{ON} is negative and when the value of P-AGE is calculated using the data presented in Figure 7, a P-AGE= 1460 (+600. –340) cy is obtained. This implies a very old object. The value is larger than any previously obtained, thus there is the question if this calculation is valid and how to check it. It may be possible to validate this conclusion by defining another age for a comet.

Our SLCs plots present the information in the space and time domain simultaneously. But because the distance to the sun, R, is a highly non-linear function of time, t, they are both practically independent. Take for example a low activity comet near perihelion where R does not change practically for a short period of time but time continues running linearly. Thus $T_{ON}+T_{OFF}$ is independent of R and is a more reliable indicator of activity than $R_{ON}+R_{OFF}$. Accordingly, a new time-age can be defined by analogy with P-AGE thus:

$$\text{T-AGE} = 90240 / [A_{SEC}(1,1) \,.\, (T_{ON}+T_{OFF})] =$$

$$= 90240 / [A_{SEC}(1,1) \,.\, T_{ACTIVE}] \text{ cy} \qquad (2)$$

where T_{ACTIVE} is the total activity time of the comet in days and cy stands for comet years. T-AGE is calibrated setting 28P/Neujmin 1 at 100 cy, as in the case of P-AGE. Equation 2 does not have the problem that afflicts equation 1 because T_{ACTIVE} is always positive.

Regardless of the shortcomings of these definitions, the advantage of P-AGE and T-AGE is that they can be defined for any comet for which R_{ON}, R_{OFF}, T_{ON} and T_{OFF} can be measured, independently if the comet belongs to the JF or to the Oort cloud. It must be emphasized that P-AGE and T-AGE are not yet calibrated in Earth's years but rather they monitor the activity of the comet as an indication of age.

When T-AGE is calculated for the 8 comets presented in Paper 1, and for 133P, the following ranking is found for the comets (P-AGE, T-AGE, cy): 1P/Halley (7.1, 4.2), 81P/Wild 2 (<13, <7.4), 19P/Borrelly (<14, <13), 21P/Giacobini-Zinner (<20, <12), 9P/Tempel 1 (21, 15), 26P/Grigg-Skejellerup (89, 85), 28P/Neujmin 1 (100, 100), 133P/Elst-Pizarro (1460, 80). It can be ascertained that the correlation between the two ages is excellent, the only discrepant value being that of 133P. We suspect it is due to the fact that 133P turns on *after* perihelion contrarily to the other 8 comets that turn on *before* perihelion. It seems that P-AGE is more applicable to comets that turn on before perihelion.

If the light curves of 26P and 133P are compared (see Paper I), they are remarkably similar in several parameters: T_{ACTIVE} = 203 vs 191 d, A_{SEC} (1,1) = 5.2 vs 6.0, effective diameter D_{EFFE} = 3.0 vs 4.6 km. T-AGE = 85 vs 80 cy. The most significant difference is that the activity of 133P is displaced by LAG = +155 vs +14 d and that 26P exhibits a coma. In conclusion the parameters derived in this paper for 133P resemble those of comet 26P.

Departure From R^2 Law and Threshold Coma Magnitude (TCM) Identifying a comet as such has up to now involved the detection of a coma. For this purpose Luu and Jewitt (1992b) have proposed a method of searching for low-level activity by comparing observed profiles with seeing-convolved models of nuclei plus varying amounts of coma. However 133P exhibits activity without coma (Figures 7 and 8) and thus it seems that the profile comparison method has a limit of detection of about ~3 magnitudes above the nucleus. If a coma is not resolved within a seeing disk, it will never be detected no matter how deep one can go.

An alternative method to detect activity from a low level activity object is spectroscopy. In particular the CN band at 3883 A is easy to detect and Bus et al. (1991) confirmed the identity of 95P/Chiron = 2060 as a comet with a 5-σ detection of CN.

Since the photometric error of many modern nuclear measurements is less than ±0.1 magnitudes, the departure from a R $^{+2}$ law is a more sensitive method to detect activity than star profile fitting or spectroscopy (confirmation Figure 7 and 8), by a factor of ten. 133P exhibits activity of amplitude ~2.3 mag easily measured, while at the same time no coma has been detected. This has profound implications for our definition of what

is a comet. In Paper I comet 28P/Neujmin 1 exhibited a coma with a secular amplitude A_{SEC} (1,1)= 3.2 mag, while 133P does not exhibit a coma with A_{SEC} (1,R) = 2.3 mag. Thus it seems that there is an intermediate value at which the coma becomes undetectable. We call that a threshold coma magnitude, TCM, and we estimate its value at TCM= ~2.8±0.4 mag *above the nucleus*. Below TCM the comet is active but the coma is below detection level.

Recently, a most important development has taken place. Meech et al. (2001, 2004) and Belton et al. (2005a) presented evidence that comet 2P/Encke exhibits activity without a detectable coma at aphelion. Our compilation of the SLC of comet 2P/Encke not shown here but available at the web site cited at the end of this paper, also shows aphelion activity at previous apparitions. 133P shows a magnitude enhancement of ~2.3 magnitudes at +2.70 AU from the sun, while 2P/Encke shows a magnitude enhancement of ~2.5 magnitudes at +4.1 AU from the sun. The activity of 2P is surprisingly strong.

In view of these results and taking into consideration the evidence presented in this paper it is clear that the existence of a coma is no longer a requirement for identification of an object as a comet.

Density In Table 4 we have compiled and in Figure 5 we have depicted the historical evolution of density estimates of cometary nuclei. One of this values due to A'Hearn et al. (2005) represents the first direct spacecraft determination of a cometary density, based on the impact ejecta affected by the nucleus gravity. *Notice the absence of a trend with time.*

21 independent estimates using 10 different methods suggest a mean value of $<\rho> = 0.52\pm0.06$ g/cm^3. In this plot 133P lies 7 sigma above the mean value. The minimum density of the comet required to avoid rupture by centrifugal forces (Hsieh et al., 2004) is $\rho > 1.3$ g/cm ^{3}. This can be explained if this object is part asteroid, part comet. The density of 253 Mathilde has been found to be 1.3 g/cm^3 (Yeomans et al., 1997), thus 133P has the density of an asteroid, justifying its classification as a different type of object. The value above is a lower limit, and implies that the object has a large fraction of rock.

Comet movie We did compile the few images available of this comet in the literature and in Internet, with the intention of creating a movie of the apparition. However this was not possible because some images lack the scale and orientation. Thus we had to settle for the *photographic history of the comet* which is available as a .ppt presentation at the web site cited at the end.

Tail Length To complete the data given in the past plots, it is interesting to have a plot of tail length vs time. To that effect all the collected images of 133P were measured for tail length, including images by Rauer and Boehnhardt (1996), Balam (1996), Scotti (2004), Ticha et al. (2004) and Hsieh et al. (2004) and our own observations.

The observed angular tail lengths, OATL, were converted to linear tail lengths, LTL (in the same units as Δ, the comet-Earth distance) using the equation:

$$LTL = \Delta \,.\, \sin OATL / [\, \cos (90^{\circ} + OATL - \alpha) \,] \qquad (3)$$

where α is the phase angle. The result is plotted in Figure 9. The 1996 observations can be fitted with an exponential decay. The 2001 observations follow the same trend, but a) they were made with a large telescope (University of Hawaii's 2.2 m) and very long exposures (typically 1 hour), thus detecting longer tails, or b) the event was more intense in 2001 than in 1996. Thus two exponential decays appear in Figure 9, one with a decay rate of only 14 days, and the other with a decay rate of 94 days. They represent different limits of detection, but are useful for planning observations.

Boehnardt (IAUC 6473) made Finson-Probstein calculations, and concluded that a normal anti-sunward tail could be developed if the dust emission episode began +65 d after perihelion, and that earlier times could be indicated by position angles about 300-252 degrees. Sekanina (IAUC 6473), using measurements by Offutt, obtained an initiation time of +42±4 d. The maximum tail length (0.057 AU) is measured from Figure 9 at Δt = +125±10 d . The tail was last seen active at Δt = +398 d (~ 1 year), and no tail was reported in deep images at +531 and +668 d.

Measuring Tail Length Measuring the tail length is not a simple matter. It depends on exposure time, sky background, telescope diameter, f/ ratio, CCD sensitivity, and even field size (confirmation Table 2 and Figure 9). In order to reduce these measurements to a standard value, the easiest solution may be to see how the tail length grows with exposures of different times, and to scale those values with that of other observers.

Time Evolution of Perihelion Distance, q Figure 10 shows the future time evolution of perihelion distance, q, determined from the ephemeris provided at the Central Bureau for Astronomical Telegrams (CBAT). It can be seen that q will increase systematically over the next 6 perihelion passages. An increase in q of 0.085 AU implies a decrease in total magnitude of approximately 0.85 magnitudes. Thus besides its normal aging, 133P will suffer dormancy due to a secular increase in q. Future observations of this comet are thus of great interest.

Is 133P a comet ? Hsieh et al., (2004) based on the activity and dust emission, have previously concluded that 133P satisfies the classical physical definition of a comet. This investigation supports and extends their conclusion. The 2-dimensional classification into 3 plots implies 5 physical parameters. Including the phase coefficient, it is 6 properties compatible with those of comets. If we add to this the detection of a tail in 1996 and 2002, and the SLC with amplitude and duration compatible with those of other comets (in particular 26P), we are considering 9 physical properties. If we consider each of these as a yes/no (belongs/does not belong to the class of comets) question, then the probability of answering no to 9 properties is $1/2^9 = 1/512 = 0.00019$, thus achieving a 9-dimensional classification. There is no doubt that we are in the presence of a comet. More specifically, *133P is a moderately old (T-AGE= 80 cy) ABC (origin in the asteroidal belt and* $\rho > 1.0$ g/cm^3 *) entering a dormant phase (normal aging and increasing q).*

The only property that does not agree with what we know about comets, is the density (Figure 5). However this can be explained if we assume that 133P is an ABC.

Future Observational Conditions In Table 5 we have compiled orbital data and the next perihelion passage of the three ABCs known to date, where T_{ISS} is the Tisserand invariant, and $T_{P\text{-}NEXT}$ is the next perihelion passage. Observations of 133P/Elst-Pizarro in 2007 are strongly encouraged to follow the evolution of this object. In that regard Figures 7, 8, 9, and 10 are very useful for planning observations. The ephemeris given at CBAT calculates that 133P reaches perihelion around 2007, July 4th. The predicted period of onset of activity of the tail is at $\Delta t = +42 \pm 4$ d = 2007 August 15±4 based on the onset of activity determined by Sekanina (IAUC 6473). At that time the object will be slightly past opposition at an elongation angle of 153º, declination –20º, and moving to higher declinations. Thus the object is reasonably well placed for observations in the evening sky. Tail activity may last for more than a year depending on telescope aperture and exposure time (Figure 9).

6. Extinct and Dormant Comets

Having established the identity of 133P/Elst-Pizarro as a comet we ask into what final phase it is evolving. Hartmann et al. (1987) introduced the concept of *pristine*, *dormant* and *extinct* comets. There are two destructive phases, *collided* and *vanishing*, and two non-destructive final phases, *extinction* and *dormant* phases (Weissman et al., 2003, and Jewitt, 2005).

Truly Extinct Comet If at any given perihelion passage the thermal wave were to get to the very center of the nucleus, it would eventually (after several such passes) be able to sublimate all volatiles, and then the object would become truly extinct. Hughes (2003) had already recognized that the thermal wave penetration does not reach to the center of the nucleus for most comets, and thus that truly extinct comets are scarce. A calculation of the penetration of the thermal wave inside a cometary nucleus would clarify this situation.

Herman and Weissman (1987) constructed a *highly idealized* (sic) thermal conductivity model of the nucleus of a comet. They included in their calculation the penetration of the thermal wave for two cases: a comet with q = 1 AU, e = 0.95 resembling the orbit of comet 1P/Halley, and a comet with q = 1 AU, e = 0.667 resembling the orbits of comets 10P/Tempel 2, 81P/Wild 2 and 22P/Kopff. The SLCs of 1P and 81P were studied in detail in Paper I. They also did the calculation for crystalline ice, and for amorphous ice. It is important to take into consideration that this calculation is approximated due to the fact that particular values of the albedo, thermal conductivity and internal structure were chosen, which are different from the ones that would be selected today, and the model has not been tested for sensitivity to parameters. Additionally comparison with 133P might not be valid because it has a different bulk density and therefore it might be made up of a very different material with different thermal inertia and thermal wave depth. We will consider only their results for comet 1P/Halley and crystalline ice because they represents an upper limit.

Having emphasized the approximated nature of this calculation, what can be deduced from their Figure 2, is that the thermal wave gets exhausted at a depth of only

~250 m for known comet materials. Thus at 1 AU this is the radius of a comet for which the thermal wave has penetrated to the very center of the nucleus and presumably all volatiles have been exhausted after several perihelion passes. *Thus truly extinct comets are scarce, small, faint, hard to find and characterize and they may not even exist. On the other hand dormant comets should be very abundant.*

There must also be extinct comet candidates among the main belt asteroids (MBA), starting at absolute magnitude fainter than ~21.5 (diameter ~<190 m). The reason this value gets smaller with increasing solar distance is that the thermal wave penetrates even less at those distances. Thus they are of even smaller size.

Since 133P has a diameter of 4.6 km, the thermal wave could not have penetrated to the very center of the nucleus, and thus it can not be evolving into an extinct comet. Instead it is entering a dormant phase by merely exhausting its volatiles. This condition is aggravated by the fact that the perihelion distance is increasing significantly, thus decreasing the solar radiation and making the comet fainter.

7. Conclusions and Observational Issues

The numerical conclusions of this paper have been listed in the abstract and will not be repeated here. Additional conclusions are:

1) In Section 4 we have shown that a 2-dimensional classification is more accurate than a 1-dimensional classification. The final aim is a N-dimensional classification.
2) In this work we have given precise definitions of several cometary parameters and phenomena: a) We have defined a new parameter, time-age or T-AGE (equation 2) that attempts to measure the age of a comet through its activity. b) We define a quantity, Threshold Coma Magnitude, TCM, whose current estimate is TCM ~2.8±0.4 magnitudes above the nucleus, below which the comet is active but does not exhibit a coma (Section 5). c) We define extinct comet as one for which the thermal wave has penetrated to the very center of the nucleus exhausting (after several perihelion passes) all the volatile ices. We estimate that for this to happen the nucleus must be very small (radius ~<250 m). d) Comets that have a radius much larger than this value, can not become extinct but dormant. e) We have introduced the concept of photographic history of a comet in Section 5. f) We have compiled the history of density estimates of comets, and concluded that there is no trend with time suggesting that perhaps a consensus is being reached. g) We have defined outburst as a low intensity, small duration, single episode of activity.

Several observational issues have been raised in this work and need to be worked out. Figures 6, 7 and 8 are very useful for planning observations.
3) Photometric observations previous, during, and after maximum activity are most important.
4) Two observational points suggest that this comet may be active at aphelion. Follow up at this distance is needed to confirm or deny this activity.
5) As can be ascertained from Figure 9, the comparison of tail lengths from images with different exposure times, telescope diameters and f/ ratios is not a simple matter. This problem will reappear in 2007.
6) 133P does not have its infrared colors and albedo measured, and this would be important scientific objectives in 2007.
7) Continued observations of visual colors, rotational periods and ptv-amplitudes will help

map the areas of occupancy of comets defined in the phase spaces of Figures 2 to 4.
8) The empty entries and the missing ID numbers in Tables 1 and 3 indicate where observational work is needed.

The photographic history of this comet, the plots and all the tables in ASCII format can be downloaded from the site
http://webdelprofesor.ula.ve/ciencias/ferrin

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Table 1. Visual Color Indices of Comet Nuclei.

COMET	B-V	V-R	R-I	References
01P/Halley	0.73±0.03	0.44±0.03	0.48±0.07	Green et al., (1997)
	0.70±0.05	0.65±0.05	---------	Gerasimenko et al., (1985)
	0.72±0.04	0.41±0.03	0.39±0.06	Thomas and Keller, (1989)
02P/Encke	0.81±0.03	0.47±0.03	---------	Green et al., (1997)
	0.78±0.02	0.48±0.02	---------	Luu and Jewitt, (1990)
	---------	0.39±0.06	0.41±0.06	Meech et al., (2004)
	---------	0.43±0.05	---------	Lamy et al., (2005)
04P/Faye	---------	0.51	---------	Lamy and Toth, (1995)
06P/D'Arrest	0.77±0.04	0.56±0.07	0.45±0.04	Meech et al., (2004)
	---------	0.54±0.04	---------	Lamy et al., (2005)
	---------	0.62±0.08	---------	Meech et al., (2004)
	1.08±0.12	0.33±0.09	0.33±0.12	Lowry and Weissman, (2003)
07P/Pons- -Winnecke	---------	0.40±0.05	0.41±0.06	Snodgrass et al., (2005)
09P/Tempel 1	0.46±0.18	0.37±0.22	---------	Lowry et al., (1999)
	---------	0.47±0.01	---------	Meech et al., (2004)
	---------	0.56±0.02	---------	Belton et al., (2005b)
10P/Tempel 2	0.60±0.19	---------	---------	Zeller et al., (1979)
	---------	0.53±0.03	---------	Jewitt and Meech, (1988)
	---------	0.53±0.17	0.81±0.17	Mueller, (1991)
	---------	0.53±0.03	---------	Mueller and Ferrin, (1996)
	0.94±0.03	0.56±0.03	---------	Green et al., (1997)
	---------	0.53±0.03	---------	Green et al., (1997)
	---------	0.47±0.03	---------	Mueller, (1991)
	---------	0.58±0.03	---------	Jewitt and Luu, (1989)
	---------	0.56±0.02	---------	Meech et al., (2004)
14P/Wolf	---------	0.02±0.22	0.25±0.35	Lowry et al., (2003b)
	---------	0.57±0.07	0.51±0.06	Snodgrass et al., (2005)
19P/Borrelly	---------	0.25±0.78	---------	Lowry et al., (2003b)
21P/Giacobini- -Zinner	---------	0.51±0.20	0.91±0.19	Mueller, (1991)
	---------	0.52±0.09	0.51±0.12	Mueller, (1991)
	---------	0.49±0.02	---------	Green et al., (1997)
	0.80±0.03	0.50±0.02	---------	Luu, (1993)
22P/Kopff	---------	0.54±0.02	---------	Meech et al., (2004)
	---------	0.53±0.02	---------	Meech et al., (2004)
	0.77±0.05	0.50±0.08	0.42±0.03	Lamy et al., (2002)
26P/Grigg- Skjellerup	---------	0.42±0.14	---------	Meech et al., (2004)
28P/Neujmin 1	---------	0.50±0.06	---------	Jewitt and Meech, (1988)
	0.84±0.04	0.47±0.04	---------	Green et al., (1997)
	---------	0.50±0.04	---------	Green et al., (1997)
	0.86±0.04	0.41±0.03	0.58±0.04	Davies et al., (1998)
	---------	0.51±0.08	0.44±0.08	Hainaut and Delsanti,(2002)
	---------	0.48±0.06	---------	Meech et al., (2004)
	---------	0.45±0.05	---------	Delahodde et al., (2001)
32/Comas-Sola	0.82±0.12	0.57±0.08	---------	Lowry et al., (1999)
45P/Honda-Mrkos -Pajdusakova	1.16±0.07	0.43±0.05	0.22±0.07	Lamy et al., (1999)
46P/Wirtanen	---------	0.45±0.07	---------	Lamy et al., (1999)
	---------	0.36±0.07	---------	Meech et al., (2004)
	0.76±0.01	0.46±0.01	0.37±0.01	Meech et al. (1997)
	0.83	0.38	---------	Fink et al. (1997)

Table 1, continued. Color Indices of Comet Nuclei.

Comet	B-V	V-R	R-I	Reference
47P/Asbrook-Jackson	---------	0.36±0.23	0.19±0.31	Lowry et al., (2003b)
48P/Johnson	---------	0.50±0.30	---------	Licandro et al., (2000)
49P/Arend-Rigaux	---------	0.47±0.01	0.51±0.02	Green et al., (1997)
	---------	0.49±0.11	0.54±0.14	Lowry et al., (2003b)
	---------	0.40±0.30	---------	Licandro et al., (2000)
	0.77±0.03	0.47±0.01	0.43±0.02	Millis et al., (1988)
53P/Van Biesbroek	---------	0.34±0.08	---------	Meech et al., (2004)
67P/Churyumov-Gerasimenko	---------	0.54±0.26	0.52±0.33	Mueller, (1991)
	---------	---------	0.72±0.42	Licandro et al., (2000)
	---------	0.51	---------	Lamy et al., (2003)
73P/Schwachmann-Wachmann 3	---------	0.48±0.23	---------	Boehnhardt et al., (1999)
	---------	0.53±0.14	---------	Sekanina et al. (1996)
74P/Smirnova-Chernykh	---------	0.35±0.15	---------	Licandro et al., (2000)
	---------	0.99±0.16	0.44±0.10	Lowry et al., (1999)
86P/Wild 3	---------	0.12±0.14	---------	Meech et al., (2004)
87P/Bus	---------	-0.11±0.21	---------	Lowry et al., (1999)
	---------	0.55±0.02	---------	Meech et al., (2004)
89P/Russell 2	---------	0.88±0.27	---------	Lowry et al., (1999)
92P/Sanguin	---------	0.54±0.04	0.54±0.04	Snodgrass et al., (2005)
96P/Machholz 1	---------	0.3 ±0.1	---------	Licandro et al., (2000)
	---------	0.43±0.03	---------	Meech et al., (2004)
103P/Hartley 2	---------	0.5 ±0.1	---------	Licandro et al., (2000)
	---------	0.32±0.12	---------	Lowry et al., (2003b)
107P/Wilson-Harrington	---------	0.41±0.02	---------	Meech et al., (2004)
	---------	0.31±0.03	---------	Chamberlin et al., (1996)
	0.61±0.05	0.20±0.04	---------	Lowry and Weissman, (2003)
	0.75±0.06	---------	---------	Lowry and Weissman, (2003)
109P/Swift-Tuttle	---------	0.55±0.07	0.78±0.07	Green et al., (1997)
119P/Parker-Hartley	0.82±0.12	0.52±0.08	---------	Lowry et al., (1999)
133P/Elst-Pizarro	0.63±0.06	0.39±0.04	0.24±0.04	Delahodde et al., (2004)
	0.69±0.02	0.42±0.03	0.27±0.03	Hsieh et al., (2004)
137P/Shomaker-Levy 2	---------	0.53±0.29	0.45±0.33	Lowry et al., (2003b)
143P/Kowal-Mrkos	0.82±0.03	0.58±0.02	0.56±0.02	Meech et al., (2004)
	0.80±0.02	0.58±0.02	0.57±0.02	Lamy et al., (2005)
152/Helin-Lawrence	0.35±0.15	0.77±0.12	---------	Lowry et al., (1999)
	---------	0.28±0.08	---------	Meech et al., (2004)
C/2001 OG108	0.76±0.03	0.46±0.02	0.44±0.03	Abell et al., (2003)

Statistics: Range 0.35 < B-V < 1.08, <B-V>= 0.76±0.16 (26 observations)
0.20 < V-R < 0.88 <V-R>= 0.48±0.13 (77 observations)
0.19 < R-I < 0.91 <R-I>= 0.34±0.22 (30 observations)

Number of comets, 37
Number of measurements, 142
Number of references, 36

Table 2. Photometric and Tail History of Comet 133P/Elst-Pizarro.

DATE	MT	V	Δt	Coma	Tail	R	Δ	α	REFERENCE
1979 07 24-25	M	----	+10	No	-----	2.629	1.614	1.1	IAUC6457
1979 07 24-25	P	18.5	+10	No	-----	2.629	1.614	1.1	IAUC6473
1985 09 15	P	19	+285	No	-----	2.774	1.774	2.7	IAUC6473
1996 07 14.27	P	18.3	+87	--	>1'	2.654	1.773	13.4	IAUC6456
1996 08 09.24	P	18.0	+113	No	-----	2.672	1.665	3.3	IAUC6456
1996 08 20.89	P	17.1	+125	No	>3'	2.682	1.673	2.0	IAUC6456
1996 08 21		----	+125	--	1.9'	2.682	1.673	2.0	Ticha et al.(2004)+TW
1996 08 21.26	P	18.2	+125	No	>3.9'	2.682	1.673	2.0	IAUC6456
1996 08 21.28	P	18.5	+125	--	-----	2.682	1.673	2.0	IAUC6456
1996 08 21.97	-	----	+125	No	3.5'	2.683	1.675	2.4	IAUC6459
1996 08 23	-	----	+127	No	>5.5'	2.683	1.678	2.8	Rauer & B. (1996)+TW
1996 08 23.00	C	18.0	+127	--	-----	2.683	1.678	2.8	ICQ101
1996 08 25.10	M	19.3	+129	--	-----	2.685	1.684	3.7	1996-R07
1996 08 25.13	M	18.3	+129	--	-----	2.685	1.684	3.7	"
1996 08 25.14	M	18.3	+129	--	-----	2.685	1.684	3.7	"
1996 08 26.28	M	18.0	+130	--	-----	2.686	1.687	4.1	"
1998 08 28	-	----	+132	--	4.7'	2.688	1.695	4.9	Balam(1996)+TW
1996 09 2.52	C	17.5	+137	--	4.9'	2.692	1.718	7.0	ICQ100
1996 09 06.93	C	18.5	+141	--	-----	2.697	1.748	9.0	ICQ101
1996 09 09.13	M	19.0	+144	--	-----	2.699	1.761	9.7	ICQ100
1996 09 09.14	M	19.0	+144	--	-----	2.699	1.761	9.7	"
1996 09 09.15	M	19.1	+144	--	-----	2.699	1.761	9.7	"
1996 09 09.16	M	18.9	+144	--	-----	2.699	1.761	9.7	"
1996 09 14.58	C	17.5	+149	--	3.4'	2.703	1.799	11.1	ICQ100
1996 09 21		----	+156	--	4.7'	2.710	1.860	13.7	Scotti(2004)+TW
1996 09 21.23	V	18.5	+156	--	-----	2.710	1.860	13.7	ICQ101
1996 09 21.24	V	18.4	+156	--	-----	2.710	1.860	13.7	ICQ101
1996 10 04.51	C	18.0	+169	--	2.1'	2.724	1.999	17.0	ICQ100
1996 10 16.50	C	18.0	+181	--	3.4'	2.737	2.148	19.1	"
1996 11 06.04	V	18.9	+202	No	1.1'	2.762	2.454	20.8	TW
1996 11 07.02	V	18.8	+203	No	1.8'	2.764	2.469	20.9	TW
1997 10 01	V	21.3	+531	No	-----	3.272	2.562	14.0	1997-T03
1997 10 03.38	P	20.4	+533	--	-----	3.275	2.543	13.6	"
1997 10 03.41	P	21.1	+533	--	-----	3.275	2.543	13.6	"
1997 10 04.28	P	19.3	+534	--	-----	3.276	2.533	13.3	"
1997 10 04.31	P	19.5	+534	No	0.0'	3.276	2.533	13.3	"
1997 10 10.49	V	20.8	+540	--	-----	3.287	2.471	11.7	ICQ104
1998 12 21.67	C	20.8	+977	--	-----	3.681	2.772	6.8	ICQ109
2000 04 01	-	----	-601	No	0.0'	3.373	2.470	8.3	Delahodde
2000 05 05	-	----	-567	No	0.0'	3.325	2.772	15.9	et al. (2004)
2002 07 13	R	20.4	+231	No	-----	2.806	2.421	20.8	Lowry and F. (2005)
2002 07 14	R	20.5	+232	No	-----	2.807	2.410	20.7	"
2002 07 14	V	20.6	+232	No	-----	2.807	2.410	20.7	"
2002 08 19	V	20.5	+269	--	3.3'	2.857	2.059	14.7	Hsieh et al.
2002 09 07	V	20.1	+287	--	4.1'	2.885	1.942	8.7	(2004) + TW
2002 11 05	V	20.7	+346	--	1.6'	2.977	2.170	13.0	"
2002 12 27	V	21.6	+398	--	1.3'	3.060	2.916	18.7	"
2003 09 22	-	----	+668	No	0.0	3.456	3.203	16.7	"
2003 11 17.66	C	20.6	+735	--	----	3.518	2.607	7.3	ICQ129
2005 01 16	-	----	-822	No	----	3.65	2.70	4.8	Toth (2006)
2005 03 01	-	----	-779	No	----	3.62	2.76	8.9	"
2005 03 02	-	----	-778	No	----	3.62	2.77	9.1	"

TW= This Work, ICQ= International Comet Quarterly

MT = Magnitude Type, M=MPEC, C= No Filter CCD = V, V= V Band, P= Photographic

Δt= Time from Perihelion [days], Tail = Tail Length [‘], α = phase angle [º] .

R = Heliocentric Distance [AU], Delta = Geocentric Distance [AU]

Table 3. ROTATIONAL PERIODS, AND PTV-AMPLITUDES (PEAK-TO-VALLEY) OF THE ROTATIONAL LIGHT CURVE.

COMET	P_{ROT}[hr]	A_{ROT}[mag]	REFERENCES
001P/Halley*	53.96	1.1	Belton et al. (1986)
	177.6	----	Millis and Schleicher (1986)
	52.8	----	Sagdeev et al. (1989)
	177.6	----	Sagdeev et al. (1989)
	-----	0.81	Meech et al. (1986)
002P/Encke*	15.08	0.62	Luu and Jewitt (1990)
	14.95	0.88	Jewitt and Meech (1987)
	15.21	>0.7	Fernández et al. (2000)
	11.01	0.28	Lowry et al. (2003a)
004P/Faye	-----	0.51	Lamy and Toth, (1995)
006P/D'Arrest	7.20	0.18	Lowry and Weissman (2003)
007P/Pons-Winnecke	8.2	----	Sekanina, (1989)
008P/Tuttle	-----	>0.2	Licandro et al. (2000)
009P/Tempel 1	40.7	0.3	Meech et al. (2000)
	41.85	0.7	Belton et al. (2005b)
	-----	0.34	Lamy et al. (2001)
010P/Tempel 2	8.9	----	Jewitt and Meech, (1988)
	8.93	0.67	Sekanina (1991)
	8.95	0.75	Jewitt and Luu (1989)
	8.9	0.6	A'Hearn et al. (1989)
	8.94	0.62	Mueller and Ferrin (1996)
014P/Wolf	7.53	0.29	Snodgrass et al. (2005)
019P/Borelly	25.0	0.95	Lamy et al., (1998)
	26.0	1.0	Mueller, Samarasinha(2002)
021P/Giacobini-Zinner	-----	0.4	Mueller (1991)
	9.5	----	Leibowitz and Brosch, (1986)
022P/Kopff	12.30	0.55	Lowry and Weissman (2003)
023P/Brorsen-Metcalf	13.5-15.0	----	Watanabe and Nakamura,(1990)
	30-40	----	Watanabe and Nakamura,(1990)
026P/Grigg-Skjellerup	-----	>0.3	Licandro et al. (2000)
028P/Neujmin 1	12.67	0.5	Jewitt and Meech (1988)
	-----	0.71	Campins et al. (1987)
	12.6	0.42	Wisniewski et al. (1986)
	12.7	0.56	Mueller and Heinrichs (2002)
	12.75	0.45	Delahodde et al. (2001)
029P/Schwachmann-Wachmann 1	14-32	----	Meech et al. (1993)
	5.0	----	Whipple (1980)
	>1440.	----	Stansberry et al. (2004)
	6.	----	Jewitt (1990)
	10.	0.50	Luu and Jewitt, (1993)
030P/Reinmuth 1	-----	0.7	Scotti(IAUC6072)
031P/Schwachmann-Wachmann 2	5.58	0.53	Luu and Jewitt, 1992a
037P/Forbes	-----	>0.5	Licandro et al. (2000)
044P/Reinmuth 2	-----	1.3	Scotti (1993)
046P/Wirtanen	7.6	>0.09	Meech et al. (1997)
	6.0	0.22	Lamy et al., (1998)
048P/Johnson	29.00	0.32	Jewitt and Sheppard (2004)
049P/Arend-Rigaux	6.78	0.38	Jewitt and Meech (1985)
	-----	0.55	Vedeer et al, (1987)
	13.47	0.72	Millis et al. (1988)
	13.6	0.53	Wisniewski et al. (1986)
055P/Tempel-Tuttle	15.31	0.76	Hainaut et al. (1998)
	14.79	----	Jorda et al. (1998)

Table 3. (Continued) ROTATIONAL PERIODS AND PTV-AMPLITUDES

Comet	P_{ROT} [hr]	A_{ROT}[mag]	REFERENCES
065P/Gunn	-----	>0.3	Licandro et al. (2000)
067P/Churyumov-	12.3	----	Lamy et al. (2003)
Gerasimenko	-----	>0.61	Mueller (1991)
073P/S-W 3	-----	0.57	Boehnhardt et al. (1999)
074P/Smirnova-Chernykh	-----	>0.3	Licandro et al. (2000)
081P/Wild 2	-----	0.55	Ferrin (2005)
082P/Gehrels 3	-----	>0.6	Licandro et al. (2000)
092P/Sanguin	6.22	0.40	Snodgrass et al. (2005)
095P/2060 Chiron	5.92	0.05	Campins et al. (1994)
096P/Machholz 1	6.38	0.3	Lamy et al. (2005)
097P/Metcalf-Brewington	-----	>0.7	Licandro et al. (2000)
098P/Takamizawa	-----	>0.6	Licandro et al. (2000)
103P/Hartley 2	-----	>0.1	Licandro et al. (2000)
107P/Wilson-Harrington	6.1	0.21	Osip et al. (1995)
109P/Swift-Tuttle	69.36	----	Yoshida et al, (1993)
	67.5	----	Fomenkova et al. (1995)
	66.5	----	Sekanina, (1981)
110P/Hartley 3	10	----	Lamy et al. (2005)
126P/IRAS	4.9	----	Grousin et al. (2004)
133P/Elst-Pizarro	3.47	0.39	Hsieh et al. (2004)
137P/Shoemaker-Levy 2	-----	>0.4	Licandro et al. (2000)
143p/Kowal-Mrkos	17.2	----	Lamy et al. (2005)
147P/Kushida-Muramatsu	9.5	----	Lamy et al. (2005)
P/Levy 1991 XI	8.34	0.35	Fitzsimmons, Williams (1994)
C/1995 O1 Hale-Bopp	11.23	----	Ortiz and Rodriguez (1999)
	11.47	----	Lecacheux et al. (1997)
	11.35	----	Jorda et al. (1999)
Levy 1990 XX	17.0	----	Feldman et al. (1992)
	18.9	----	Magdziarz et al. (1995)
	37.8	----	Schleicher et al. (1991)
Alcock 1963b	24	----	UR
Whipple-Fedtke-Tevzadze 1942g	540	----	Bobrovnikoff (1945)
Bennett 1970 II	35	----	Larson and Minton (1973)
Hyakutake 1996B2	6.30	----	Lisse et al., (1999)
Burnham 1960 II	91	----	UR
Austin 1982g	84	----	UR
Comet 1744	115.2	----	Pansechi and Fulle (1991)
Brooks 1893 IV	91	----	Vorontsov-Velyaminov, (1930)
West 1976 VI	48	----	Sekanina and Farrel, (1978)
Mrkos 1957 V	19.7	----	Sekanina and Farrel, (1982)
Iras-Araki-Alcock 83VII	51	----	Sekanina, (1988)
Bakharew-Macfarlane--Krienke	474	1.1	Ferrín (2002)
C/2004 F4 Bradfield	12	----	Sekanina (IAUC8326)
C/2001 Q4 NEAT	23.2	----	Lecacheux and Frappa (2004)
2002 V1 NEAT	60	----	Navarro and Riquelme (2003)
2001 OG 108 LONEOS	57.19	0.3	Abell et al. (2003)
C/2004 Q2 Machholz	9.1	----	Sastri&Vasundhara(IAUC8480)

*1P/Halley and 2P/Encke exhibit complex rotation (two periods).
Statistics: 4.9 h<Prot<540 h, <P_{ROT} >= 39.98±82.60 h (80 observations) 0.05<ptv-Amplitude < 1.3 magnitudes, <ptv-Amplitudes> = 0.52±0.26 (58 observations). Totals: 64 comets, 82 rotational periods, 58 peak-to-valley rotational amplitudes, 78 references. UR= Unpublished Results by this author.

Table 4. Historical Evolution of Density Estimates of Cometary Nuclei.

Density ρ[g/cm^3]	Reference	Technique
0.48±0.15	Donn (1963)	Realistic packed snow in Alpine glaciers.
0.33-0.54	Delsemme and Wenger (1970)	Formation of Clathrate snows in laboratory.
0.28-0.65	Rickman (1989)	H2O Outgassing and gaseous forces on comet 1P/Halley.
0.6 +0.9,-0.4	Sagdeev et al. (1988)	H2O Outgassing and gaseous forces of comet 1P/Halley.
0.54	Sekanina (1991)	Jacobi Ellipsoid of 10P/Tempel 2.
>0.46	Luu & Jewitt (1992)	Centrifugal rotation of 32P/SW2.
0.5	Prialnik and Bar-Nun (1992)	Outburst of 1P/Halley at 14.3 AU.
<0.7-1.5	Boss (1994)	Model of disruption of SL9.
0.5	Asphaugh and Benz (1994)	Tidal Breakup of non-rotating nucleus of comet SL9.
0.5	Solem (1994)	Tidal disruption of SL9.
0.55	Solem (1995)	Tidal disruption of SL9.
0.6	Asphaugh and Benz (1996)	Tidal disruption of SL9.
<0.4	Samarasinha Belton (1995)	Numerical Simulation of rotational state of comet nuclei.
<1.0	Meech et al. (1996)	HST observations of 95P’s atmosphere.
0.45	Harmon et al. (1999)	Radar observations of comet Iras-Araki-Alcock.
0.49 (+.34,-.20)	Farnham and Cochran (2002)	Non-gravitational acceleration of 19P.
0.18-0.30	Davidsson and Gutiérrez(2004)	H2O Outgassing and gaseous forces o comet 19P/Borelly.
>1.3	Hsieh et al. (2004)	Centrifugal rotation of comet 133P.
>0.49	Snodgrass et. al., (2005)	Centrifugal rotation of comet 92P
0.62 (+.47,-.33)	A’Hearn et al. (2005)	Expansion of the base of conical ejecta from the impactor of 9P.
0.5-1.0	Harmon & Nolan (2005)	Radar observations of 2P.
<0.58	Davidsson & Gutiérrez(2006)	Water production and non gravitational forces of comet 81P.

* Statistics: 22 constraining estimates, 10 different methods, 22 references.
Mean $\langle\rho\rangle = 0.52 \pm 0.06$ g/cm^3 . Non-constraining values have been dropped.
Range $0.40 < \rho < 0.70$. No significant trend with time.

Table 5. Orbital Data and Next Perihelion Passage of Asteroidal Belt Comets (ABC).

ABC	a [AU]	i [º]	q [AU]	Q [AU]	T_{ISS}	$P_{ORBITAL}$ [y]	T_{P-NEXT}
133P	3.156	1.386	2.636	3.677	3.184	5.61	2007 07 02
P/Read	3.165	1.267	2.365	3.965	3.153	5.63	2011 03 15
118401	3.196	0.238	2.581	3.811	3.166	5.71	2011 07 05

Figure Captions

Figure 1. Images of 133P\Elst-Pizarro = 7968, taken by the author with the 1 m f/3 Schmidt telescope of the National Observatory of Venezuela. The size of each image is 5.3x5.3' of arc. The magnitudes derived from these images are compiled in Table 2.
A) Date = 1996 11 06.04. Exposure = 5 min. V=18.9±0.1. Tail = 1.1'. Δt= +202 days. R= 2.762 AU. Δ= 2.454 AU. α= 20.8º.
B) Date = 1996 11 07.02. Exposure = 20 min. V=18.8±0.1. Tail = 1.8'. Δt= +203 days. R= 2.764 AU. Δ= 2.469 AU. α= 20.9º.

Figure 2. Comet nuclei color indices diagram for comets. The B-V and V-R values from Table 1 have been plotted and define an area in this phase space. 133P has colors compatible with those of other comets. The edges of all the distributions shown, are diffuse, because for clarity we have not plotted the errors associated with each measurement.

Figure 3. Comet nuclei color indices diagram of comets. The values R-I and V-R from Table 1 have been plotted and define an area in this phase space. 133P has colors compatible with those of other comets. HO marks the location of a non-cometary hypothetical object discussed in Section 4, resulting from a 1-dimensional classification.

Figure 4. The rotational period vs diameter distribution. The data comes from Table 3. It can be seen that comets are not located randomly over the plot, but instead define a two dimensional area in this particular phase space, which is tilted with respect to the horizontal axis. This plot suggest the existence of rotational evolution. See the text for a more complete discussion of this issue. The location of 133P is compatible with those of other comets. A symmetrical ellipse has been drawn around the least squares linear fit, to aid the eye. Notice that eliminating 147P and 46P makes the correlations stronger (dotted line) and much more tilted (slope 0.73 vs 0.50). However there is no reason to do so because these are well determined points. What this exercise teaches us is that additional observations of rotational periods, *specifically of small nuclei*, are critically needed to define the slope precisely. HO marks the location of a non-cometary hypothetical object discussed in Section 4, resulting from a 1-dimensional classification.

Figure 5. Historical evolution of density estimates of cometary nuclei. Notice the absence of a significant trend with time implying that perhaps a consensus is being reached. There are two discrepant values, that of 133P and that of 19P. It can be seen that 133P is 7 sigma above the mean value for comets. 133P seems to be a *hybrid* object partial rock, partial ice. Notice also the recent estimate of the density of 9P made by A'Hearn et al. (2005) from data taken with the Deep Impact spacecraft, using the expansion of the base of the conical ejecta from the impactor. This is the first *in situ* determination of a cometary density.

Figure 6. Secular light curve of 133P/Elst-Pizarro, Log plot. Most of the data is taken after perihelion, where the object shows a brief outburst enlarged in Figure 5. In order to calculate the photometric age of the comet, the amplitude of the secular light curve at R=1 AU must be known, $A_{SEC}(1,1)$. Due to the lack of a suitable physical model for this type of object, we have chosen to use the light curves of 4 other comets as *templates* for extrapolation. In this way the estimated magnitude at R= 1 AU is 10.0±1.6 magnitudes, and the amplitude of the secular light curve is then A_{SEC} (1,1) = 6.0 ±1.5 . In this way a P-

AGE = 1460 cy can be calculated. However see the text for a calculation using time-Age giving a value of T-AGE= 80 cy. HJF= Hsieh et al. (2004).

Figure 7. Secular light curve of 133P/Elst-Pizarro, Log plot expanded after perihelion. The small amplitude, short duration outburst is clearly shown. The Asteroid Dynamic Site data is plotted as open squares, and is used to corroborate the photometric data (black circles and squares). The magnitude increase at Log R = +0.516 has not been corroborated with photometric measurements. The main outburst is not well sampled. The nuclear magnitude by Hsieh, Jewitt and Fernández (2004) has been indicated by HJF. Two magnitudes near aphelion and 0.6 magnitudes above the nucleus, may suggest activity at aphelion. The turn on and the turn off points can be measured from this plot and allow a calculation of P-AGE= 1460 cy which is not validated by Time-Age (see text). The turn off is determined with great accuracy thanks to our own observations (downward open triangles) and to serendipitous observations made by Lowry and Fitzsimmons (2004)=L&F (dark up triangles).

Figure 8. The secular light curve of 133P, time plot. The shape of the outburst is clearly seen, as well as the possible activity at aphelion. The outburst was initiated at T_{ON} = 42±4 d (Sekanina, IAUC 6473), reached a maximum amplitude of $A_{SEC}(1,R)$ = 2.3±0.2 magnitudes at LAG=155±10 d, and turned off at T_{OFF}= 233±10 d. A Time-Age, T-AGE = 80 (+30, -20) cy can be calculated from this plot. We believe this value is more related to reality, by comparison with comet 26P which 133 resembles. By good luck our own observations (open down triangles) and those of Lowry and Fitzsimmons help define the extent of activity. The date of the next perihelion is indicated. N_{APPA} = numbered apparitions used /number of recorded apparitions. L&F= Lowry and Fitzsimmons (2005).

Figure 9. Tail length of comet 133P/Elst-Pizarro. The 1996 and 2001 observations can be fitted with an exponential decay. The 2001 observations a) were made with a large telescope (University of Hawaii 2.2 m) and very long exposures (typically ~1 hour), thus detecting longer tails, or b) the event was more intense in 2001 than in 1996. SEK= Sekanina (IAUC 6473).

Figure 10. Time evolution of the perihelion distance of 133P deduced from the CBAT ephemeris. It can be seen that besides its normal aging due to sublimation it is subject to an additional aging caused by an increase in its perihelion distance starting in 2014, thus accelerating its entering into dormant phase. It would be extremely interesting to see how the comet responds to changes in perihelion distance, but to measure these changes a good photometric coverage is needed in the upcoming apparitions.

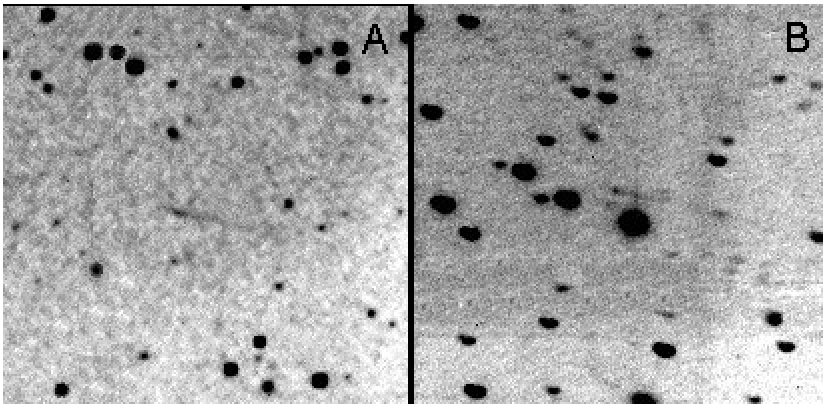

Figure 1 (Ferrín, 2006, I09469)

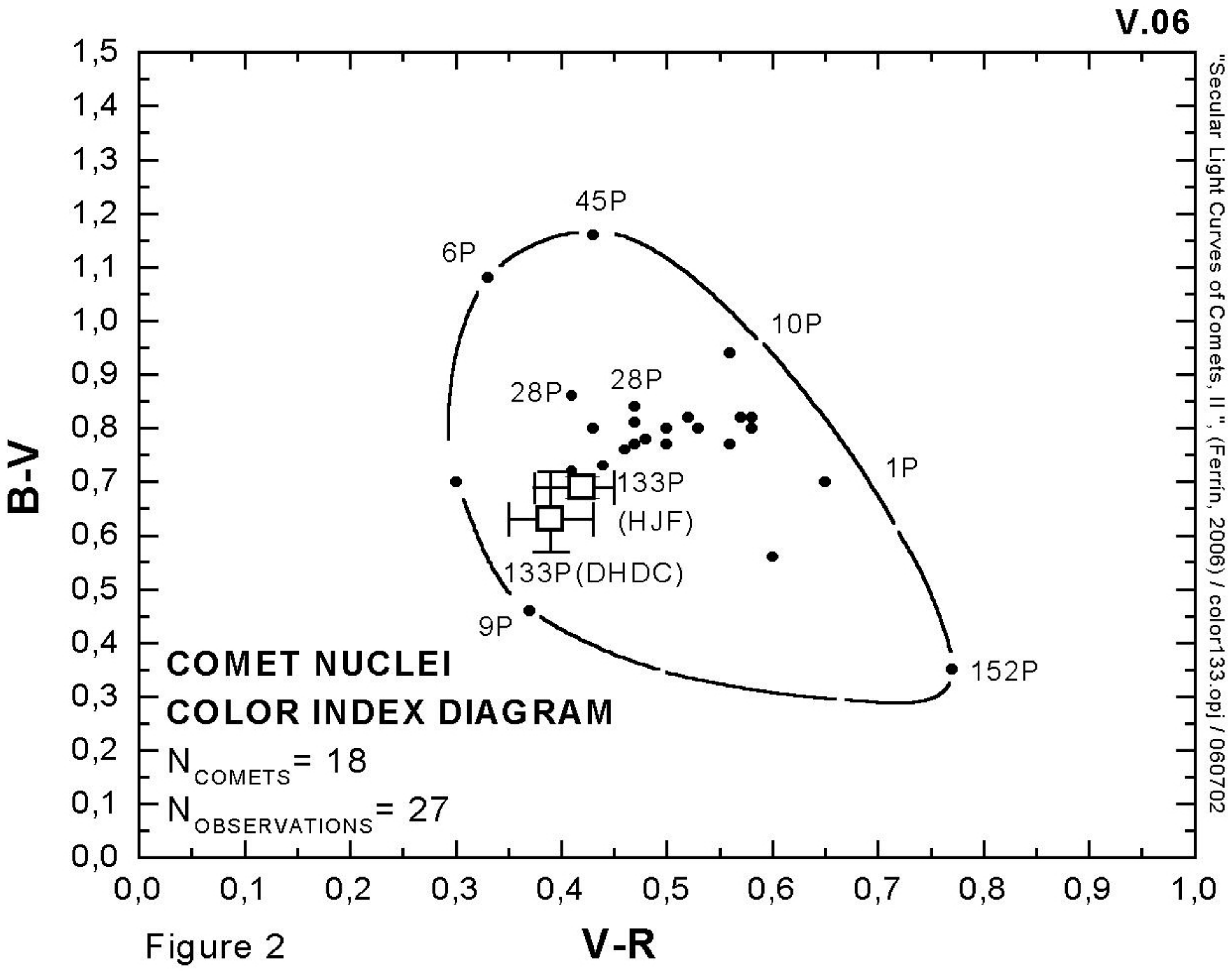
V.06
"Secular Light Curves of Comets, II ", (Ferrín, 2006) / color133.opj / 060702
B-V
V-R
1,5
1,4
1,3
1,2
1,1
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
45P
6P
10P
28P
28P
1P
133P
(HJF)
133P(DHDC)
9P
152P
COMET NUCLEI
COLOR INDEX DIAGRAM
N_{COMETS}= 18
$N_{OBSERVATIONS}$= 27

Figure 2

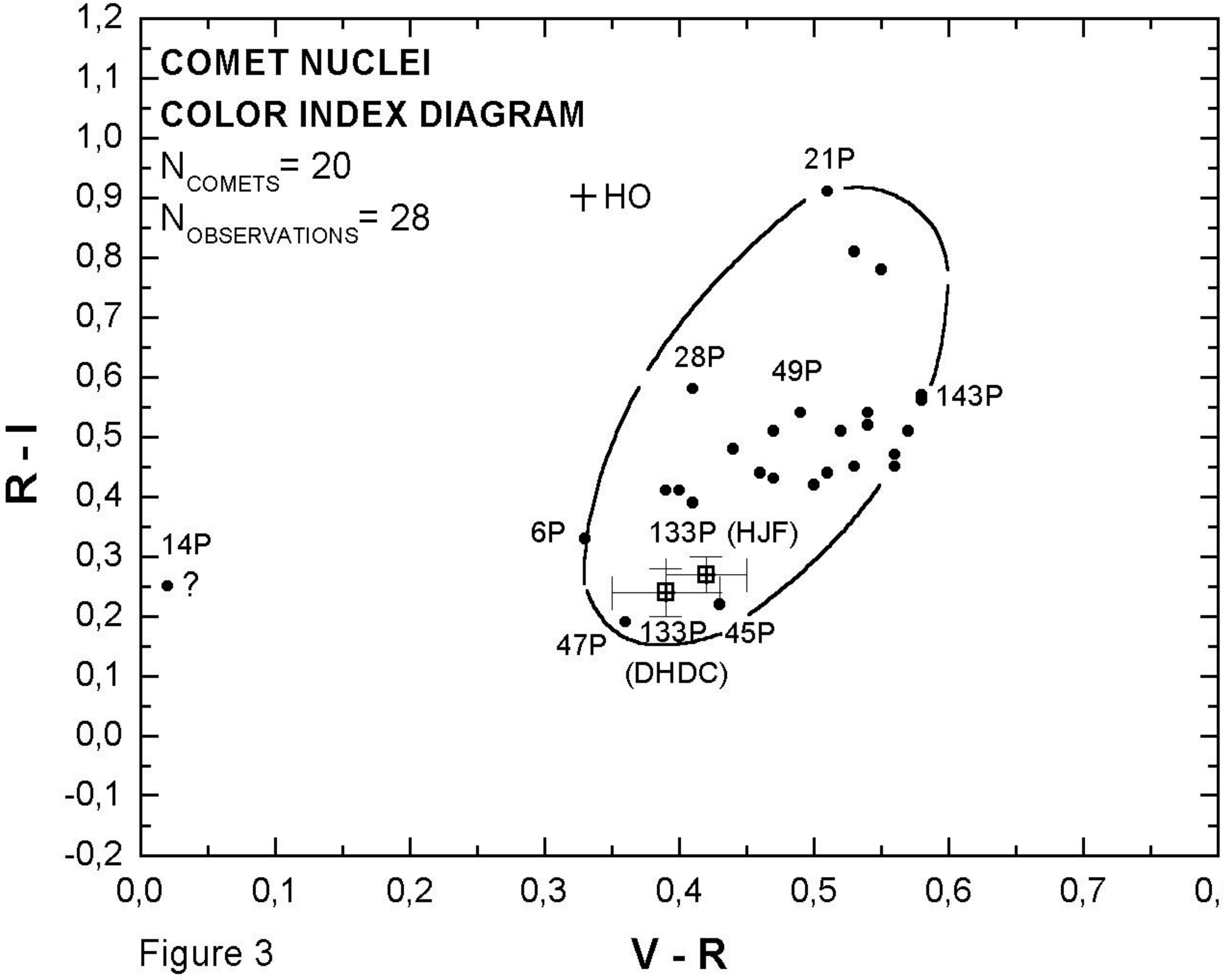

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Figure 3

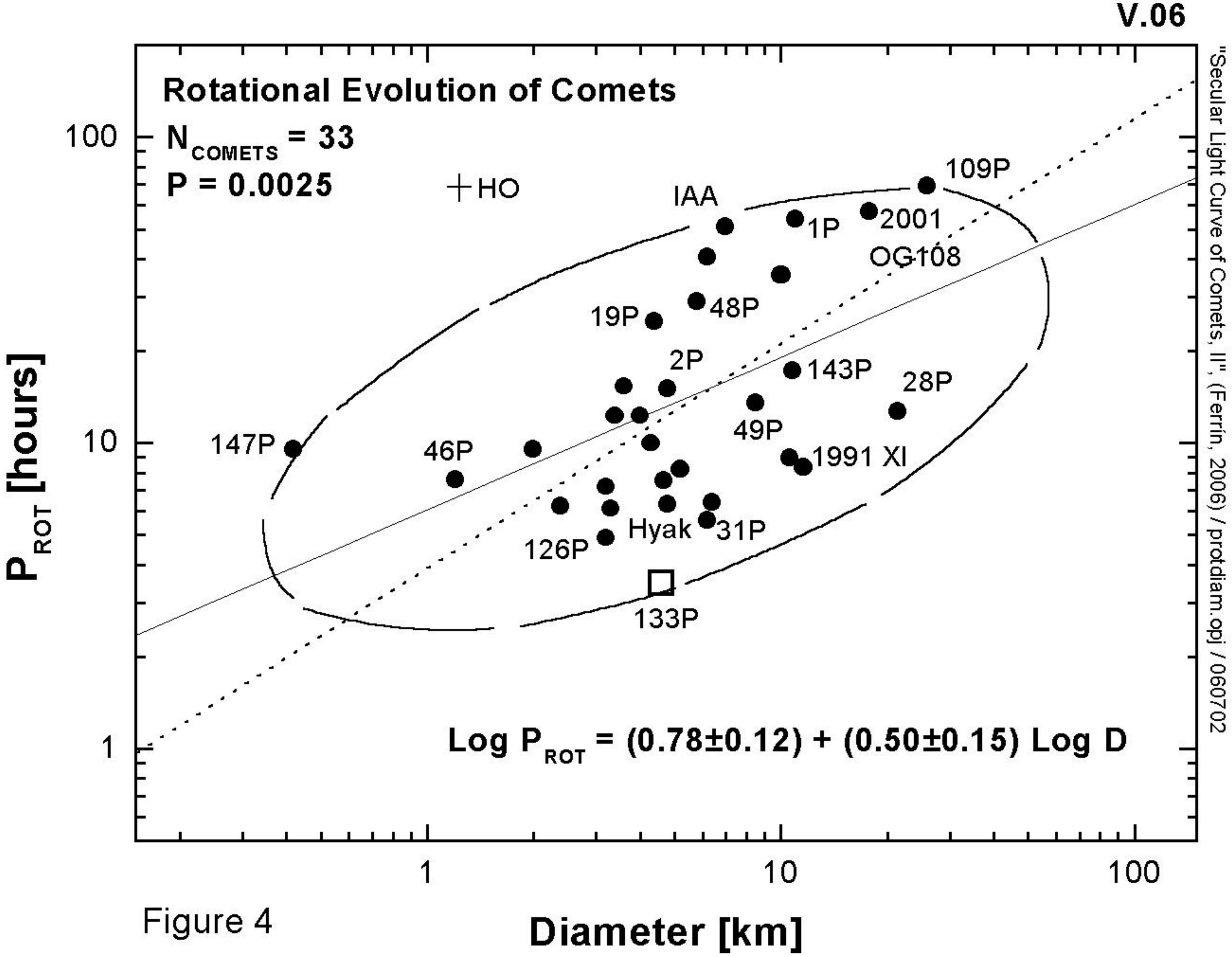

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Figure 4

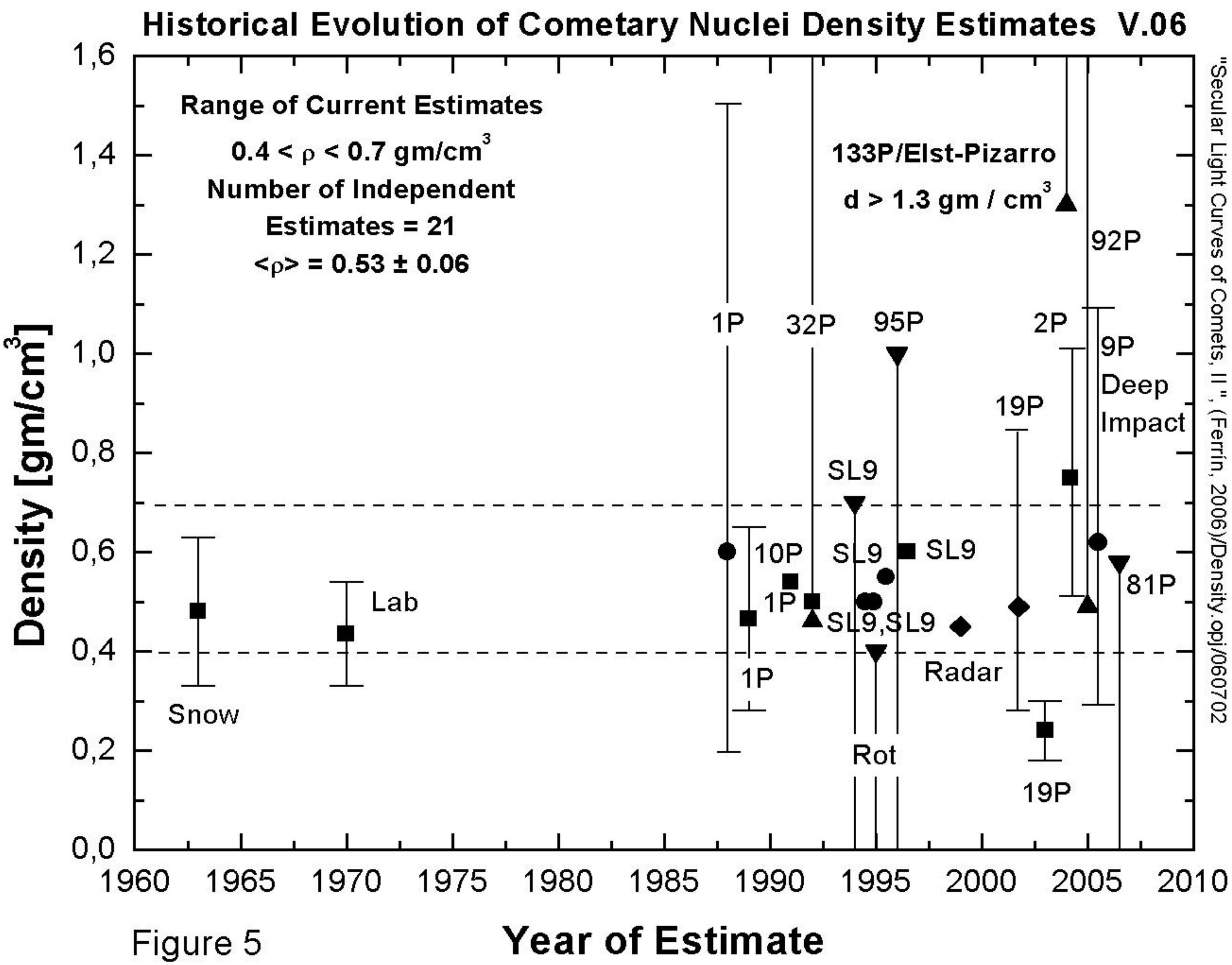
Historical Evolution of Cometary Nuclei Density Estimates V.06
"Secular Light Curves of Comets, II ", (Ferrín, 2006)/Density.opj/060702
Range of Current Estimates
0.4 < ρ < 0.7 gm/cm³
Number of Independent
Estimates = 21
<ρ> = 0.53 ± 0.06
133P/Elst-Pizarro
d > 1.3 gm / cm³
92P
1P
32P
95P
2P
9P
Deep
Impact
19P
SL9
10P
SL9
SL9
1P
SL9,SL9
81P
Lab
Snow
1P
Radar
Rot
19P
Density [gm/cm³]
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year of Estimate

Figure 5

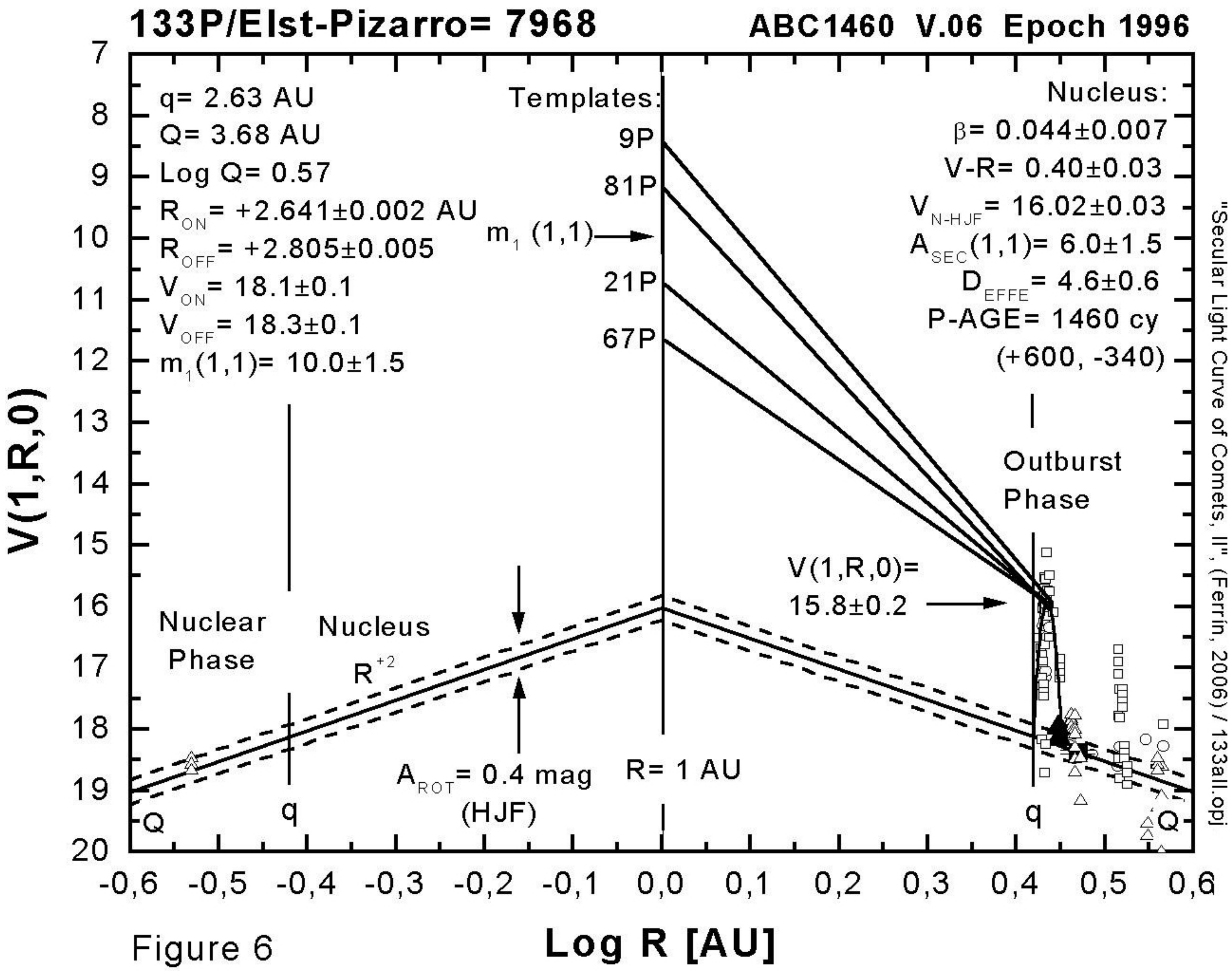

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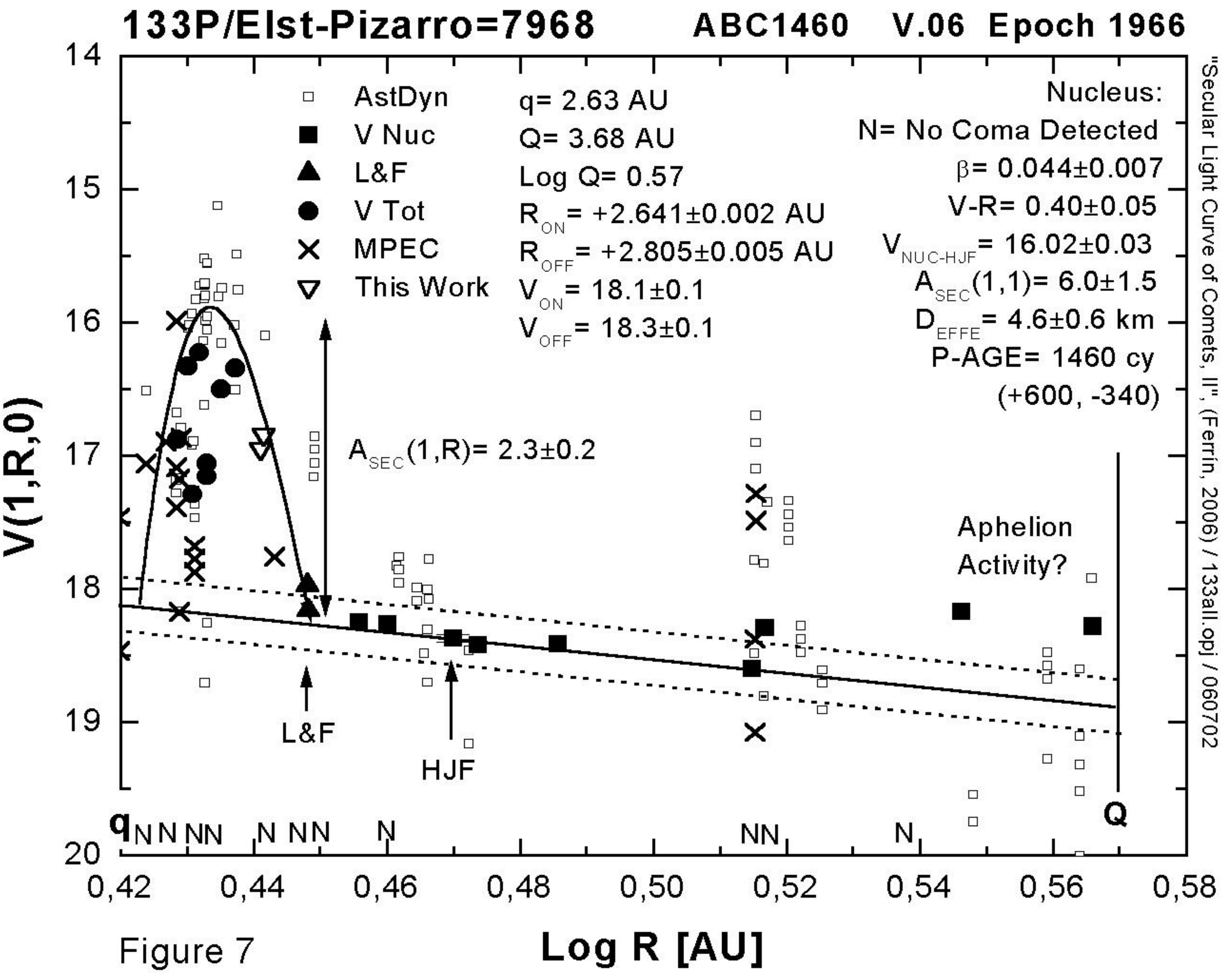
Figure 6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V Nuc
L&F
V Tot
MPEC
This Work
q= 2.63 AU
Q= 3.68 AU
Log Q= 0.57
R_ON= +2.641±0.002 AU
R_OFF= +2.805±0.005 AU
V_ON= 18.1±0.1
V_OFF= 18.3±0.1
Nucleus:
N= No Coma Detected
β= 0.044±0.007
V-R= 0.40±0.05
V_NUC-HJF= 16.02±0.03
A_SEC(1,1)= 6.0±1.5
D_EFFE= 4.6±0.6 km
P-AGE= 1460 cy
(+600, -340)
A_SEC(1,R)= 2.3±0.2
Aphelion
Activity?
L&F
HJF
q
N N NN N NN N NN N
Q
V(1,R,0)
14
15
16
17
18
19
20
0,42
0,44
0,46
0,48
0,50
0,52
0,54
0,56
0,58
Log R [AU]

Figure 7

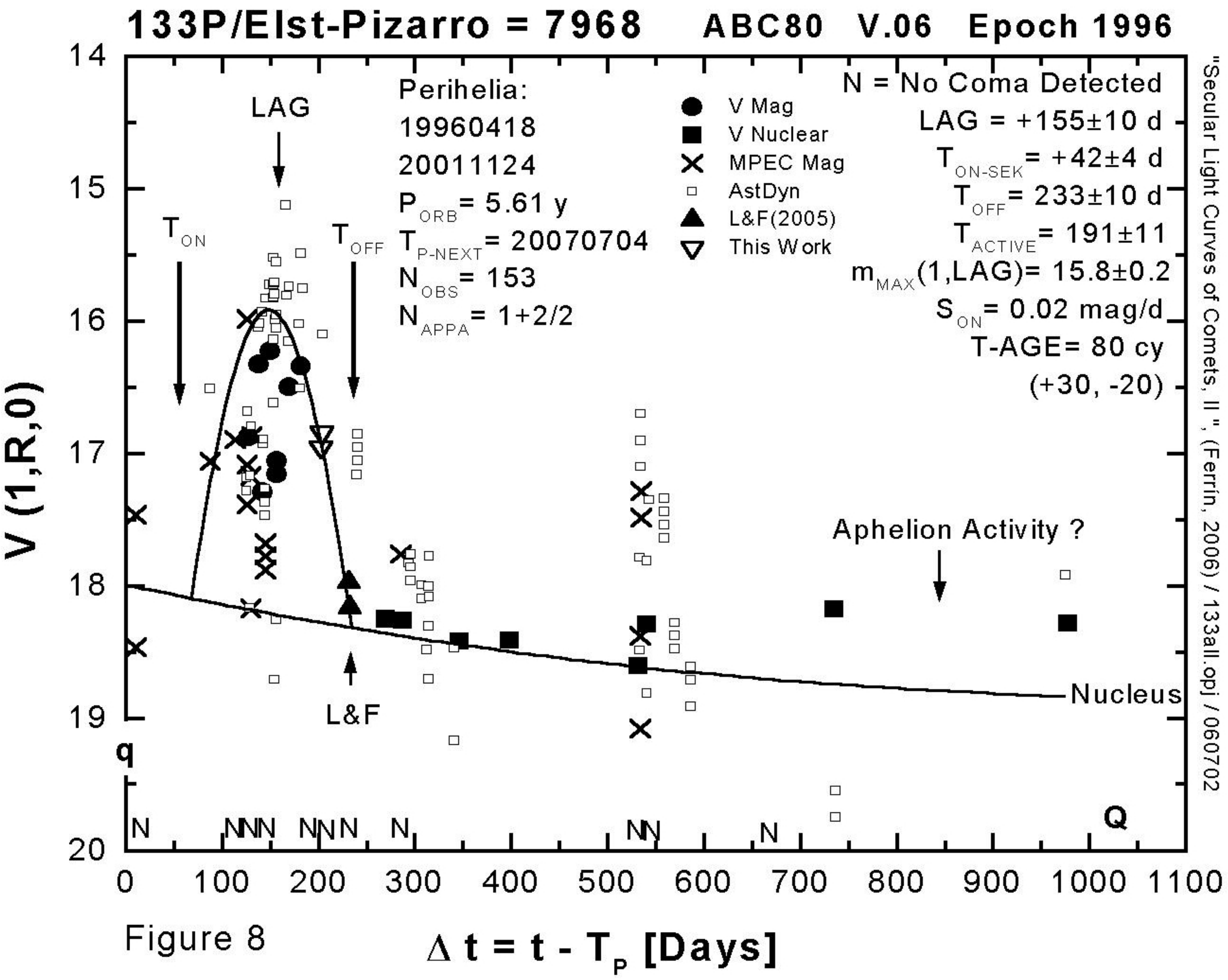

133P/Elst-Pizarro = 7968 ABC80 V.06 Epoch 1996
"Secular Light Curves of Comets, II ", (Ferrín, 2006) / 133all.opj / 060702
Perihelia:
19960418
20011124
P_{ORB}= 5.61 y
$T_{P\text{-}NEXT}$= 20070704
N_{OBS}= 153
N_{APPA}= 1+2/2
● V Mag
■ V Nuclear
✕ MPEC Mag
□ AstDyn
▲ L&F(2005)
▽ This Work
N = No Coma Detected
LAG = +155±10 d
$T_{ON\text{-}SEK}$= +42±4 d
T_{OFF}= 233±10 d
T_{ACTIVE}= 191±11
m_{MAX}(1,LAG)= 15.8±0.2
S_{ON}= 0.02 mag/d
T-AGE= 80 cy
(+30, -20)
LAG
T_{ON}
T_{OFF}
L&F
Aphelion Activity ?
Nucleus
q
Q
N
NNN
NNN
N
NN
N
V (1,R,0)
14
15
16
17
18
19
20
0
100
200
300
400
500
600
700
800
900
1000
1100
Δ t = t - T_P [Days]

Figure 8

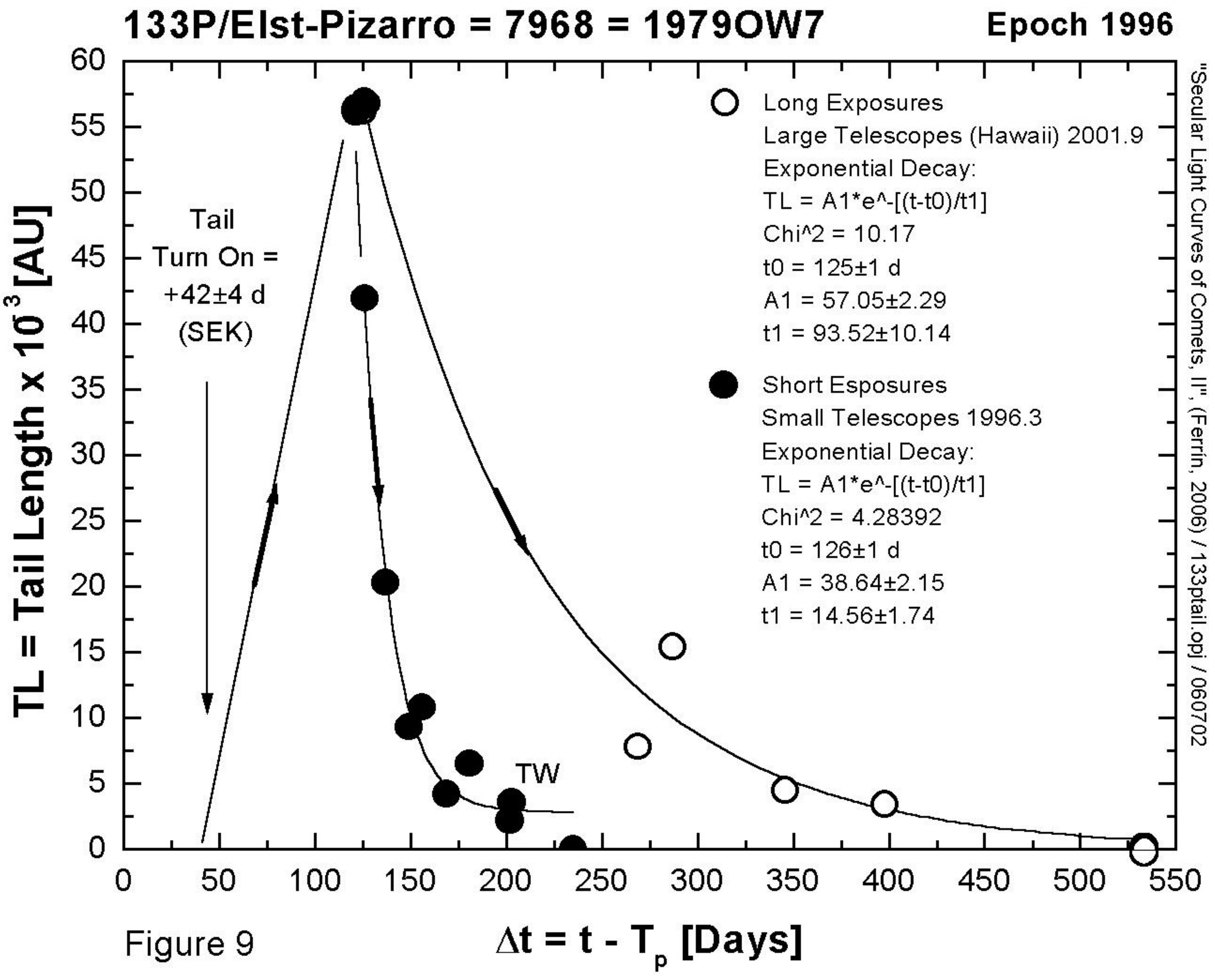
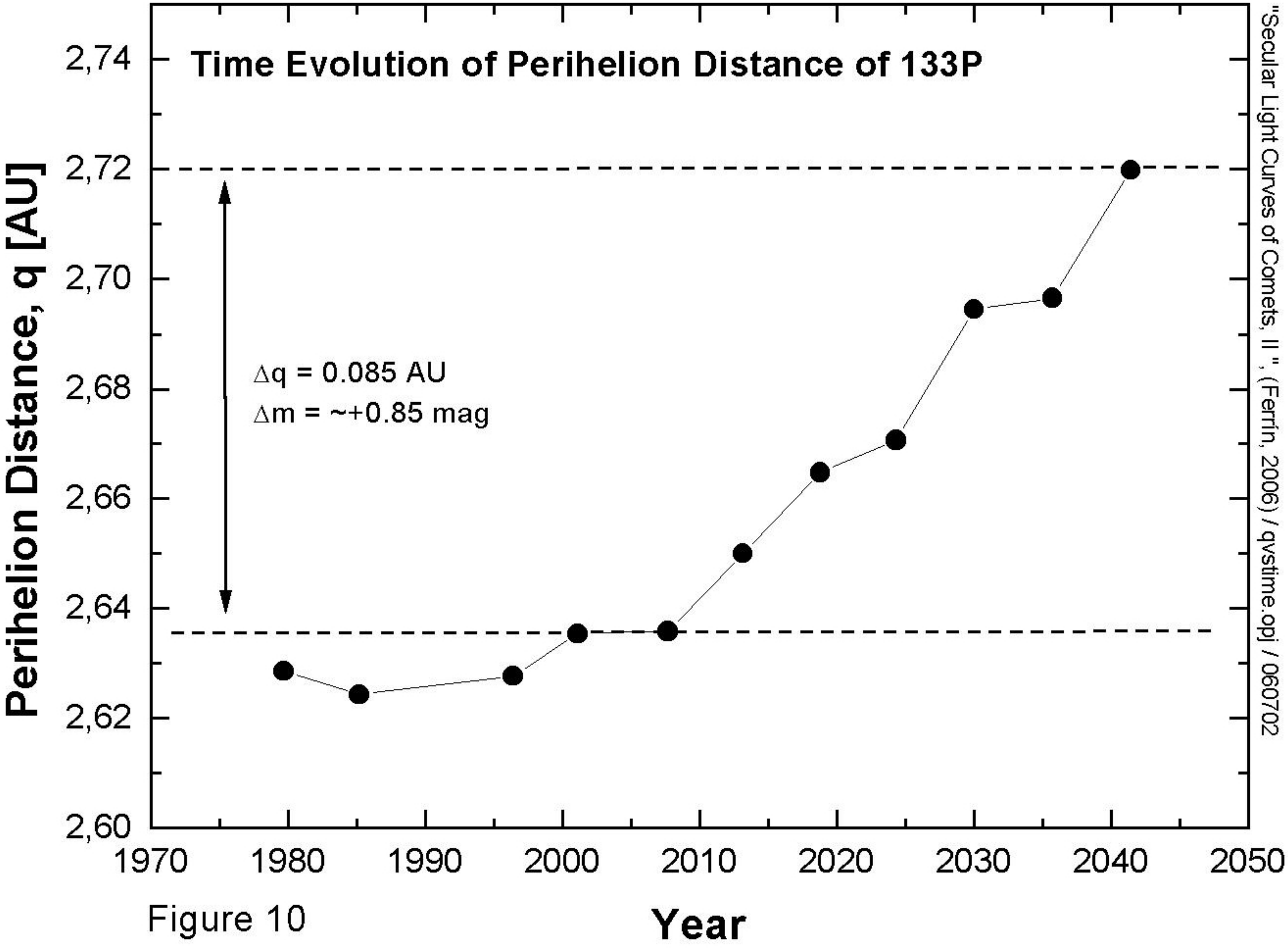

133P/Elst-Pizarro = 7968 = 1979OW7
Epoch 1996
"Secular Light Curves of Comets, II", (Ferrín, 2006) / 133ptail.opj / 060702
TL = Tail Length x 10^3 [AU]
Δt = t - T_p [Days]
0
5
10
15
20
25
30
35
40
45
50
55
60
0
50
100
150
200
250
300
350
400
450
500
550
Tail
Turn On =
+42±4 d
(SEK)
TW
Long Exposures
Large Telescopes (Hawaii) 2001.9
Exponential Decay:
TL = A1*e^-[(t-t0)/t1]
Chi^2 = 10.17
t0 = 125±1 d
A1 = 57.05±2.29
t1 = 93.52±10.14
Short Esposures
Small Telescopes 1996.3
Exponential Decay:
TL = A1*e^-[(t-t0)/t1]
Chi^2 = 4.28392
t0 = 126±1 d
A1 = 38.64±2.15
t1 = 14.56±1.74

Figure 9



"Secular Light Curves of Comets, II ", (Ferrín, 2006) / qvstime.opj / 060702

Figure 10