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THE GAS PRODUCTION RATE OF PERIODIC COMET d'ARREST

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ABSTRACT

Comet P/d'Arrest is a potential target for a rendez-vous mission to a short period comet. Its light curve is rather peculiar, the comet being active only after perihelion passage. One apparition out of two is easy to observe from the ground. The 1995 apparition of the comet will offer a unique opportunity to characterize the outgassing properties of its nucleus.

I. INTRODUCTION

Comet P/d'Arrest is a short period comet of period about 6.5 years. Its minimum magnitude is between 5 and 6 and one apparition out of two is a favorable sighting. The orbit is chaotic: in 1600, the comet perihelion distance was about 1 AU; in 2200, it will be close to 2 AU. Since it was discovered - in 1851 - the comet has circulated on one of three orbits having perihelion distances of ≈1.17, ≈1.28 or ≈1.36 AU, respectively. Carusi et al.'s (1991) identification of comet P/d'Arrest with comet La Hire of 1678 (q = 1.16 AU) requires a strong non-gravitational effect that remained constant over a few centuries. Since the comet makes close and easy to observe approaches to the Earth, the light curve of that comet is well documented. The comet brightness increases very rapidly just before perihelion and then remains nearly constant, or even slightly increases, during a few weeks while the comet is receding from the sun. In this brief study, we will review the main available observations of that comet, including unpublished results obtained in 1982 with the International Ultraviolet Explorer (IUE), and discuss the implications of the rather unusual light curve (LC) shape of the comet.

II. THE VISUAL LIGHT CURVE FROM THE ICQ ARCHIVE

The visual observations listed in the International Comet Archive (ICQ) were used to derive the recent visual LC shown in Fig. 1. A detailed investigation by Kamèl (1991) shows that there is a strong indication that the shape of the LC (hence the light curve asymmetry) has not much changed since the discovery of the comet. Note that the non gravitational parameter listed in Table 1, A_2, remained constant since the comet discovery in 1851, and even probably since 1678 (Carusi *et al.* 1991). Festou *et al.* (1990) showed that this can be expected if the light curve shape does not change since the non gravitational effect is primarily induced by the light curve asymmetry. Brightness maxima occur 40 ± 20 days after perihelion, depending mostly on the geocentric distance and the elongation of the comet. There is some indication that the brightness decreases rapidly about 100 days after perihelion passage (apparitions in early spring and late fall are not good - $\Omega + \omega = 315°$ - and, since the comet is then always far south, few observations are then available). With the exception of 1976, the minimum of the apparent magnitude occured at the time of the minimum indicated in column 3 of Table 1. When the 10 log R_h factor artificially applied to the original data by Kresák and Kresáková (1989) is reintroduced, the very very similar LCs of Fig. 1 become slightly different and, more important, the determination of the time of occurence of the brightness maximum depends obviously on the exact observing geometry. The maxima of brightness given by Kresák and Kresáková (1989) sample the real LC in a manner that is not well characterized. Due to the fact the perihelion distance is changing, one would expect a slight deformation of the LC near perihelion time: comparison of the 1976 and 1982 apparitions shows no significant differences between the two LCs. However, one should note that the 1976 magnitudes may have been globally underestimated because of the proximity of the comet (about 0.3 to 0.4 AU against of 0.8 to 1.4 at most of the other apparitions). It appears highly desirable to monitor well photometrically the favorable apparition of 1995 (the comet will be well placed for a six month period starting about two months prior to perihelion passage).

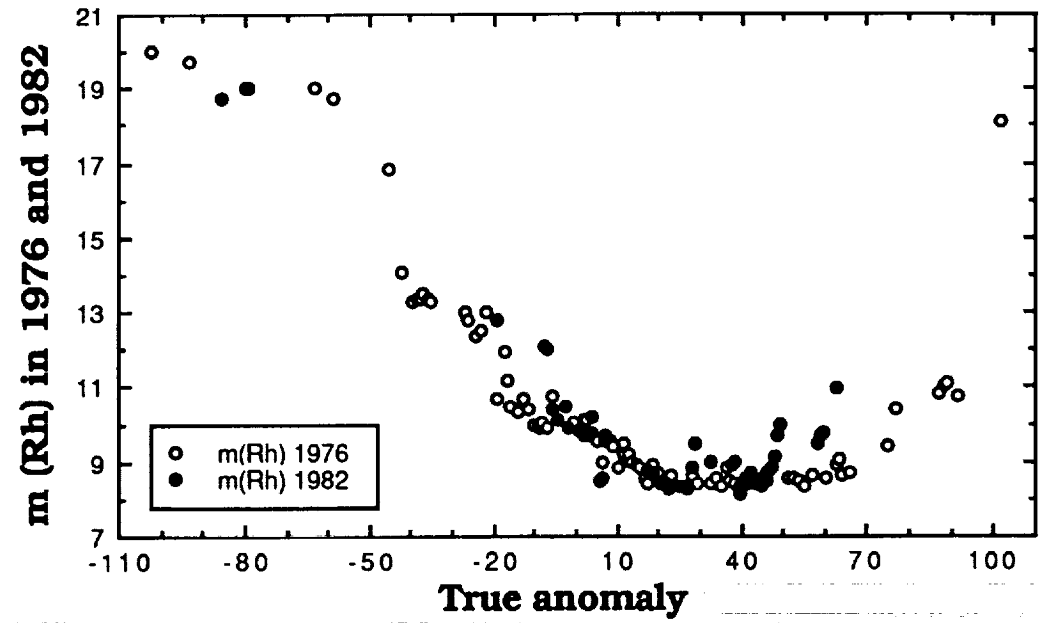

Fig. 1: The heliocentric magnitude of P/d'Arrest in 1976 and 1982. This parameter is a measure of the total outgassing rate of the comet. Only lower values of the magnitude (say inside a [m_{max}, m_{max} + 0.4] bracket) have been considered: all other measurements reflect the difficulties experienced by the observers to capture a good sighting of the comet.

Table 1: Magnitude of comet P/d'Arrest at its 15 observed apparitions[1]

Comet number	Perihelion distance	$t-t_P$ (days)	min [m(1,1)] 2	$m(R_h)$ 3	A_2 4,5	R_h (at time $t-\tau_P$)	Δ
1678	1.164	≈ 45	≈ 7.5	≈ 8.5	≈ 0.10	≈ 1.28	≈ 0.35
1851 II	1.173	56	8.7	10.1		1.375	0.820
1857 VII	1.170	8	7.4	8.5	0.104	1.296	1.315
1870 III	1.280	26	7.4	8.5		1.281	1.327
1877 IV	1.318	61	6.7	8.7		1.590	1.858
1890 V	1.321	30	8.0	9.4	0.096	1.367	0.913
1897 II	1.326	69	7.2	8.4		1.330	1.455
1910 III	1.270	38	8.8	10.4		1.442	1.027
1923 II	1.357	57	8.0	9.6	0.094	1.437	1.015
1943 III	1.385	12	9.8	10.6		1.194	0.964
1950 II	1.377	15	7.8	9.2	0.098	1.389	0.850
1963 VII	1.369	73	8.8	10.8		1.596	1.938
1970 VII	1.167	58	7.7	8.5	0.120	1.197	1.549
1976 XI	1.164	42	6.7	7.5		1.198	0.348
1982 VII	1.291	29	7.7	8.3	0.116	1.336	0.869

1- Minimum magnitudes are taken in Kresák and Kresáková (1989); orbital parameters are from Marsden (1983). 2- Observed brightness maxima after correction of the observations for the 5 log (Δ) + 10 log (R_h) factor. In other words, that magnitude is m (observed) - 5 log Δ - 10 log R_h. The heliocentric magnitude is m (observed) - 5 log Δ. 3- Heliocentric magnitude = 4th column corrected to remove the 10 log (R_h) factor introduced by Kresák and Kresáková. 4- From Rickman *et al.* (1991). Except for the last value given, which results from linking the 1976 and 1982 orbits, A_2s given here represent the linkages with three consecutive orbits.

III. IUE OBSERVATIONS IN 1982

Comet P/d'Arrest (1982 VII) was observed with the IUE during the first 30 days following the 1982 perihelion passage. During this long period, both the heliocentric and geocentric distance varied very little, allowing thus a quasi model independent comparison of the observations. Table 2 summarizes the observations and gives the water production rates, derived in the usual manner using vectorial model parameters valid for the stable activity level of the sun in September-October 1982:

v(water) = 0.85 km/s; v(OH) = 1.05 km/s

tau^{Total} (water) = 65 000 s; tau^{Diss} (water) = 72 500 s; tau^{Total} (OH) = 160 000s

OH(0-0) g-factors were taken in Schleicher and A'Hearn (1982). The water production shows the trend exhibited by the visual LC and increases with increasing distance to the sun. It is quite possible that the gas production increased by some 10-20% after our last observation. The CS emission was never detected. A conservative upper limit of the CS emission is 50 R (10 by 20 arc sec slit) which corresponds to an upper limit of the CS production of 1.5 10^{25}/s (with g_{CS} = 7e-4/s). This limit is slightly larger than what one could have expected from past IUE observations (Weaver *et al.* 1981; Azoulay and Festou, 1985). Upper limits for the other species are too high to be of any usefulness.

Table 2: 1982 IUE observations of comet P/d'Arrest (LWP spectra only)

Exposure	expo time	R_h	Δ	phase	Cont. flux * **	OH(0-0) flux **	g(0-0) ***	Q(w) ****	t-τ
LWR 14181	60	1.2912	0.7410	50.97	-	337	2.33	1.451	1.141
LWR 14232	70	1.2949	0.7651	50.70	27?	280	2.60	1.228	8.268
LWR 14317	90	1.3089	0.8083	49.83	45	480	3.36	1.967	18.040
LWR 14347	85	1.3200	0.8353	49.18	26	522	3.73	3.025	23.057
LWR 14397	90	1.3366	0.8720	48.27	-	560	4.03	2.035	29.056

* 2920-3020 Å; ** 1e-14 erg/cm^2/s; *** 1e-4/s; **** 1e28/s (spectra are shown in Festou, 1990)

The continuum was clearly detected only once, at the end of September 1982. Interestingly, although the apparent flux was still increasing, there is some indication that the continuum emission was decreasing some 3 weeks after perihelion, which corresponds to the time the comet is described as having a more diffuse or no central condensation. Afρ was about 190 cm, a number to be compared to those observed in comet P/Halley near 1.4 AU pre- and post- perihelion, ≈ 1000 and ≈ 4500 cm, respectively (at similar phase angles of ≈50°). It is customary to state that short period comets are 'non-dusty': the present data rather suggest that the expression 'less dusty' is more appropriate, and that the lack of a conspicuous dust tail might actually indicate a deficiency in micron-sized particles or simply reflect an observational limitation due to the large R_h at which the comet is observed.

IV. PHOTOMETRIC OBSERVATIONS PRIOR TO 1982

Few observations of the comet are available. The largest set of published data is found in A'Hearn *et al.*, 1979 (see Table 3). The important conclusions from that study are i) the variation of the dust production rate is mostly due to a phase effect; i) the maximum of the gas production occurs at least 30 days after perihelion passage; iii) the ratio Q(CN) / Q(C_2) is nearly constant (= 0.38) which compares well with Cochran's 1987 value: comet P/d'Arrest is an 'average' comet. The data from A'Hearn *et al.* (1979) also

Table 3: summary of the results obtained by A'Hearn *et al.* (1979)

Date	R_h (AU)	Δ (AU)	Phase (°)	Q(dust)*	Coeff.**	Log Q(CN)	Log Q(C_2)
12.26/8/76	1.164	0.151	4.4	10.0	1.014	25.12	25.60
13.29	1.164	0.151	3.4	10.06	1.062	25.10	25.49
14.30	1.164	0.152	3.3	10.08	1.062	25.14	25.47
19.31	1.167	0.158	10.5	10.02	1.212	25.23	25.63
31.79	1.189	0.203	25.7	9.96	1.602	25.26	25.66
14.73/9	1.238	0.284	31.3	9.89	1.775	25.19	25.97
20.59	1.447	0.566	29.6	9.85	1.720	25.38	25.83

* logarithmic scale of arbitrary origin; ** correction to be brought to continuum measurements to compute the zero phase flux using Divine *et al.*'s, 1985, phase function.

show that the continuum light reflected by dust particles does not contribute much to the overall brightness of the coma, as shown in the Table 4 below and the coma brightness measures the gas content of the coma. This is confirmed by the direct comparison of visual and photometric (A'Hearn *et al.*, 1979) observations. It is found that the C_2 production rate and the heliocentric magnitude are proportional. This is to be expected

Table 4: relative brighthness of the dust and gas comae, after A'Hearn *et al.* (1979)

R_h (AU)	Δ (AU)	Phase (°)	Diaph. size (")	Log Q(C_2)	Log F(5236)
1.164	0.151	4.4	109	-9.4	-12.2
1.447	0.566	29.6	109	-9.66	-12.92

since, if the comet gas production is steady, the total brightness of the comet (propr. to $1/2.5^m$) is proportional to $Q(C_2)\ \tau^{-1}(C_2)\ g(C_2)$, where τ is the lifetime of the C_2 radicals. A similar result was obtained on a statistical basis by Festou (1986) using a data set of IUE observations on about 15 comets. The correlation observed in 1976 in A'Hearn *et al.*'s data shows that despite the comet was receding from the sun, thus making the comet cloud more diffuse and more extended to visual observers, the visual magnitude remained proportional to the coma content in C_2 radicals and that such a correlation certainly holds in the range R_h = [perihelion - 1.5 AU].

Table 5: visual brightness and heliocentric magnitude, derived from A'Hearn *et al.* (1979)

$t_{obs}-t_{perih.}$	R_h	log [Q (C_2)]	m (R_h)	[Q(C_2) * 2.5^m] / 10^{28}
-0.6	1.164	25.60	9.4	2.2
0.4	1.164	25.49	9.4	1.7
1.4	1.164	25.47	9.4	1.6
6.4	1.167	25.63	9.0	1.6
19.0	1.189	25.66	8.4	1.0
32.9	1.238	25.97	8.4	2.0
49.7	1.447	25.83	8.3	1.4

The constancy of the ratio in the last column (known with an accuracy not better than about 50% because of the uncertainty attached to the evaluation of the heliocentric magnitude) shows that the visual magnitude and the C_2 production rate varied in parallel in the [perihelion - 1.45 AU] heliocentric distance range and that consequently, the visual magnitude is a good indicator of the C_2 production for the apparitions for which no photometric observations are available.

In 1976, comet P/d'Arrest was observed with COPERNICUS by Festou *et al.* (1983). The data show a large increase of the HI production at a time we described the comet as having a nearly constant gas production:

19 Sept. 1976, R_h =1.27 AU, Δ = 0.313, Q (water) = 1/2 Q (H) = 2.6 10^{28} s^{-1}

03 Oct. 1976, R_h = 1.33 AU, Δ = 0.425, Q (water) = 1/2 Q (H) = 9.0 10^{28} s^{-1}

Although a short term variability of the gas production is not excluded by the visual LC (possibly masked by the rapid rotation period indicated by Fay and Wisnieswki, 1978; high time resolution observations during the favorable 1995 apparition should certainly be secured to eventualy reveal it), this large change of Q(H) could be erroneous due to the difficulty to separate the geocorona and comet contributions to the signal. However, the possibility that the C_2 to water production ratio varied should not be disregarded too rapidly. Using the A'Hearn *et al.* (1979) data, the Q (CN) / Q (water) [= Q(H) / 2] and the Q (C_2) / Q (water) ratios are found to be $\approx$1.2 10^{-3} and $\approx$ 3 10^{-3} around mid-September 1976, respectively, which are almost the mean values given by A'Hearn (1982) from a large set of data. Unpublished data collected in 1982 by A. Cochran and her collaborators indicate a few interesting facts that reinforce our conclusion that the comet should be thoroughly observed in 1995. First, one observes that the CN to C_2 production rate is close to unity and that consequently the water to C_2 production ratio was perhaps in 1982 close to the upper

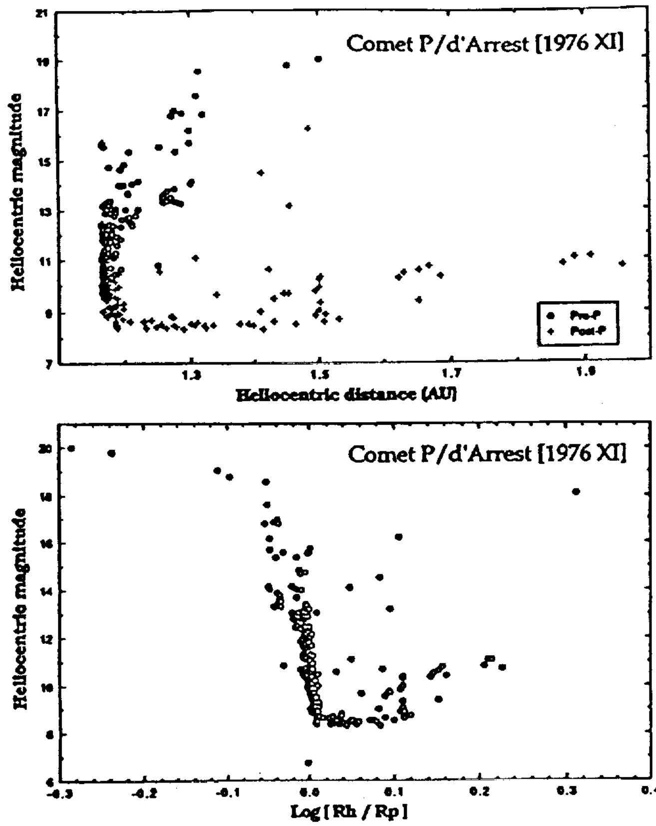

Fig. 2: two representations of the heliocentric magnitude (proportional to the outgassing rate) of comet P/d'Arrest. a- the outgassing rate remains nearly constant post-perihelion over a wide range of heliocentric distances. b- the extremely abrupt increase of the gas production within 1-2 weeks of perihelion passage appears very well in this plot.

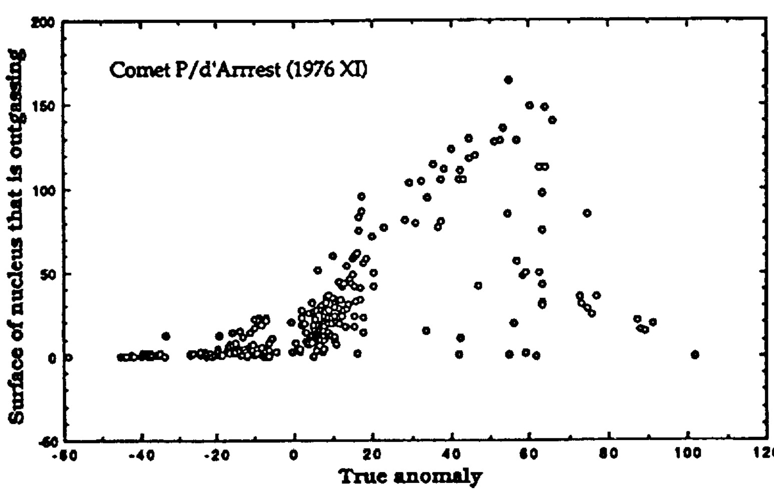

Fig. 2: the surface (km^2) of the nucleus that is outgassing if the insolating conditions are those of a uniformly lit spherical non rotating nucleus. The large distance of the comet from the sun implies a large outgassing surface, actually as large as that obtained for comet P/Halley under the same assumptions at the same heliocentric distance.

value indicated above. Second, the observations span a very long period, from May until December 1982.The C_2 production remained almost constant from October until mid-December 1982, suggesting that the 'plateau' of the LC might be wider than the visual observations suggest it. That the activity be due to an active area situated at high cometocentric latitude or simply to the peculiar orientation of an elongated nucleus is unclear. One will observe however that the outgassing surface that is required to justify the observed outgasing rate of the nucleus is quite high, of order the surface of half a nucleus of a few kilometer radius.

V. CONVERTING OUTGASSING RATES INTO OUTGASSING SURFACES

Whatever the way chosen to show the light curve of comet P/d'Arrest, one is struck by the fact the heliocentric brightness dramatically increases shortly before the comet reaches perihelion, then remains level for 4-6 weeks, then rather slowly decreases with increasing distance to the sun and finally possibly falls off quite rapidly. Fig. 2 shows two possible ways to present the behavior of the comet. In the two cases, there is a sharp brightness increase that occurs within 1-2 weeks of perihelion passage. This suggests the apparition of an active area into sunlight, although other mechanisms that could block the outgassing until a specific point on the orbit is reached are not ruled out. From the non observion of an increase of the dust to gas content, the assumption that a superficial layer breaks up rapidly does not seem likely. Using a simple model of a spherical nucleus in which the outgassing rate is simply a function of the distance to the subsolar point and ignoring the nucleus rotation, one can convert the heliocentric magnitudes shown above (equivalent to the C_2 or water productions) into outgassing surfaces, as shown in Fig. 3. This surface increases very rapidly after perihelion then remains almost constant. The position and width of the 'plateau' in Fig. 3 suggests a well marked seasonal effect. The quality of the data (is the width of the plateau significantly different from 180°?) does not allow us to state wether the active part of the nucleus is at a high cometocentric latitude or if a combination of shape and repartition of active areas is responsible for what is observed. However, the phenomenon is strongly pronounced and disserves further studies.

VI. IS COMET P/d'ARREST A SUITABLE TARGET FOR A COMET MISSION?

The preceding review of the available data shows that the comet is not very dusty (1/10 of P/Halley at a similar distance to the sun): it is consequently possibility to send a probe close to the nucleus without much danger for it. However, the counterpart of this is that few solid particles would be detected. The nucleus activity is not significant until a few weeks prior to perihelion passage: this would allow one to image the nucleus in great detail and to study the interaction of the solar wind with a solid body or an extremely tenuous atmosphere.Then, the activity sets in very rapidly: that phenomenon could be difficult to study since the time to accommodate to the changing conditions could be quite short (6-10 weeks). However, the activity might cease rapidly after perihelion passage, giving thus a great opportunity to image the nucleus after the cessation of its activity, i.e. to examine the change in the position and surface of active areas as well as to give an opportunity to determine the reality of a true seasonal effect.

VII. ACKNOWLEDGMENTS

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