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On the contribution of the sublimation process to the disintegration of 1P/Halley's comet nucleus in 1986

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This paper presents an analysis of the modeling results obtained and an assessment of the contribution of the sublimation process to the general breakdown of the cometary nucleus during the passage of comet 1P/Halley in 1986. The moments and heliocentric distances of the appearance and attenuation of the sublimation process are determined. It is suggested that a possible mechanism of disintegration of the nucleus, which caused an unexpected flash of comet's brilliance at a considerable distance from the Sun after the perihelion passage, is possible. It is shown that the main disintegration of the comet nucleus at any heliocentric distances is primarily caused by emission processes arising from various physical and chemical factors. In any case, the contribution of the sublimation process is a small proportion of the several emission points in a given part of the comet's orbit, which changes the shape of the torus of a meteoroidal formation, so that during the life cycle of a comet the associated meteor current has different durations of observation.

Keywords: Comets, sublimation, 1P/Halley's comet

1 Introduction

It is believed that when a comet approaches the Sun, the gas stream generated by heating carries with it a solid component of the comet nucleus, fragments of which form meteoroidal formation with orbits that are not too different from those of the comet. These formations during the evolution of the comet's life cycle move with it, creating a specific meteoroid complex with the comet inside. Such a meteoroid complex has the shape of a torus, the dimensions of which depend on the characteristics of the orbits of the ejected solid fragments, and the process takes place in a certain part of the cometary orbit directly near the Sun. However, to date, there are a number of observations of various comets, flashes of brightness of which were

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recorded at heliocentric distances of more than 2 a.u. The process responsible for this phenomenon is still unclear (Chepurova et al., 2000). Since the removal of the solid component by the gas flow is characterized by moderate discharge velocities, and the observers record comet glare flashes, mainly for high emission rates of dust matter (up to 1 km/s), it can be assumed that the main process the comet nucleus disintegration is an explosive process with as yet undefined ejection mechanisms. When a comet approaches the Sun due to the heating, the sublimation process arises and increases with approaching the perihelion. Based on these assumptions, the authors using the available computer technology (Kulikova et al., 2012), simulated comet 1P/Halley's passage of the perihelion in 1986 with the aim of clarifying the contribution of the above-mentioned disintegration processes to the destruction of the comet nucleus. The key features and capabilities of computer technology modeling were applied to the comet 1P/Halley and its perihelion in 1986 in order to determine the contribution of the above disintegration processes to the destruction of the cometary nucleus (Chepurova et al., 2010, 2016; Kulikova et al., 2012, 2016).

2 Problem statement and results

We assumed that the cometary nucleus is a conglomerate of frozen ices of various gases with interspersed refractory constituents and the sublimation process appears as a gas stream that intensifies with gradual approach to the Sun and forms the solid fraction as small dust particles. The qualitative theory of the process was thoroughly developed in the last century by F. Whipple (Whipple et al., 1950, 1951). The mathematical algorithm of the calculation model of such a process, used by the authors in the numerical calculations of the model experiment, is presented in detail in (Kulikova et al., 2013). The goal of the authors was to create an independently working module for calculating the sublimation process using an updated mathematical algorithm and to include it as a working option in the "Disintegration" block of the basic technology version. We conducted numerical calculations for comet 1P/Halley with the initial data for the passage of 1986 for two cases:

(1) only probabilistic (stochastic) disintegration taking into account all gravitational effects (i.e. modeling of the ejection effect at any point of the cometary orbit);

Table 1

Initial calculation angle (in degrees)	0.0
Final calculation angle (in degrees)	360.0
Angle increase interval (in degrees)	10.0
Ejection speed maximum value (in km)	0.1; 0.2; 0.4
Number of ejection speed subintervals	10
Orbit major semi-axis (a.u.)	17.941
Eccentricity	0.967277
Angle of the orbit plane inclination to the ecliptic plane (in degrees)	162.2422
Perihelion angular distance (in degrees)	111.8657
Ascending node longitude (in degrees)	58.8601
Revolution period (in years)	76

Table 2

Ejection point (in degrees)	Major semi-axis variation δa (a.u.)		Eccentricity variation $\delta e \cdot 10^{-2}$		Perihelion argument variation $\delta\omega$ (in degrees)		Ascending node longitude variation $\delta\Omega$ (in degrees)	
	1	2	1	2	1	2	1	2
0°	1.878	2.510	3.425	4.589	11.54	15.47	10.41	13.95
10°	1.875	2.466	3.420	4.497	10.90	14.33	9.55	12.56
20°	1.854	2.391	3.378	4.360	10.32	13.32	8.61	11.11
30°	1.821	2.304	3.318	4.197	9.86	12.48	7.42	9.38
40°	1.769	2.194	3.220	3.993	9.58	11.79	5.97	7.40
50°	1.703	2.069	3.095	3.760	9.33	11.33	4.25	5.16
60°	1.634	1.945	2.965	3.528	9.51	11.32	2.11	2.51
70°	1.544	1.798	2.792	3.253	10.34	12.04	0.54	0.63
80°	1.444	1.646	2.602	2.967	11.83	13.49	3.88	4.42
90°	1.328	1.481	2.382	2.656	14.57	16.25	8.19	9.13
100°	1.214	1.323	2.162	2.357	18.79	20.49	13.97	15.23
110°	1.080	1.151	1.907	2.031	25.34	27.01	22.00	23.43
120°	0.939	0.977	1.637	1.702	35.52	36.94	33.61	34.95

(2) probabilistic (stochastic) disintegration + sublimation on the arc of the main orbit at the intersection of the perihelion (the value of the calculated arc is specified in the source data).*

In this case, comet 1P/Halley turned out to be a very interesting object. Firstly, in the passage of 1986, the conditions for its observation were extremely unfavorable, second, on February 12, 1991, at a distance of more than 14 a.u. after the passage of the perihelion, a comet suddenly released a substance, accompanied by an outbreak (Chepurova et al., 2000), which released a significant cloud of dust (about 300 000 km across). Moreover, according to observers (Churyumov, private communication) an emission velocity of 400–500 m/s was recorded. The numerical calculations were carried out by the authors on the assumption of maximum values of the emission velocities of 100 m/s, 200 m/s, 400 m/s with automatic inclusion of the calculation for the sublimation process at that calculated point of true anomaly of the main orbit of the parent body where this algorithm becomes non-zero and grows closer to the Sun.

Some results are given above and below. The values of initial orbital parameters of the investigated object are presented in Table 1. The results obtained show that the qualitative picture of variations in the elements of the orbit of the ejected particles from the location of the ejection point in the orbit of the parent body with the inclusion of the sublimation process in the model remains the same (Kulikova et al., 1993), but the quantitative characteristics increase. Two questions arise: what is the magnitude of the arc of the parent orbit, on which sublimation must be taken into account, and how significant is the effect of this calculation on changes in the orbital elements of ejected solid particles. Tables 2–3 show some calculation data (Table 2, at an emission

*In each case, the simulation is carried out for ten specific values of speeds in the range from 0 to a given maximum value, i.e. for analysis, 30 different model variants were obtained with 500 000 tests each.

Table 3

Ejection point (in degrees)	Major semi-axis variation δa (a.u.)		Eccentricity variation $\delta e \cdot 10^{-2}$		Perihelion argument variation $\delta\omega$ (in degrees)		Ascending node longitude variation $\delta\Omega$ (in degrees)	
	1	2	1	2	1	2	1	2
0°	7.511	10.07	1.370	1.836	46.17	61.78	41.64	55.80
10°	7.501	9.864	1.368	1.799	38.21	57.33	41.36	50.25
20°	7.415	9.566	1.352	1.744	41.27	53.24	34.45	44.44
30°	7.285	9.216	1.327	1.679	39.45	49.90	29.37	37.54
40°	7.078	8.776	1.288	1.597	38.00	47.12	23.88	29.61
50°	6.812	8.276	1.238	1.504	37.28	45.30	16.99	20.64
60°	6.537	7.779	1.186	1.411	38.03	42.26	8.43	10.03
70°	6.175	7.194	1.117	1.301	41.35	48.18	2.16	25.10
80°	5.775	6.584	1.041	1.186	47.37	54.01	15.51	17.68
90°	5.312	5.923	0.953	1.063	58.38	66.55	32.75	32.75
100°	4.854	5.236	0.865	0.942	75.32	82.02	55.89	60.86
110°	4.321	4.602	0.763	0.812	101.60	108.21	88.15	93.74
120°	3.758	3.909	0.655	0.681	142.28	147.97	134.45	139.82

Table 4

Ejection point (in degrees)	Ratio coefficient Δi	Ejection point (in degrees)	Ratio coefficient Δi	Ejection point (in degrees)	Ratio coefficient Δi
10°	1.315	50°	1.215	90°	1.115
20°	1.290	60°	1.190	100°	1.089
30°	1.264	70°	1.165	110°	1.066
40°	1.240	80°	1.140	120°	1.040

speed of 100 m/s; Table 3, at an emission speed of 400 m/s). According to the data in Tables 2 and 3, we can determine the coefficient $\Delta i = (Ai+Bi)/Bi$, where $(Ai+Bi)$ is a change in any orbital parameter under the action of the above two processes, Bi is a change in the same parameter only under the action of sublimation.

In Tables 2 and 3, the data in columns 1 are calculated without taking into account the sublimation process and in columns 2, with the inclusion of sublimation. It turned out that for all three design options (100 m/s, 200 m/s, 400 m/s), the values of the coefficient Δi are the same and change only from the location of the ejection point in the orbit of the parent comet (see Table 4 and Figure 1).

Conclusions

Based on the data in Table 4, we can conclude that the sublimation process in our case occurs when the comet approaches the perihelion in the region of the true anomaly $-120°$, slowly increases to $-30°$ and in the region $(-20°, 0°)$ increases the changes in the orbital elements 1.34 times maximum perihelion. Then the process fades in

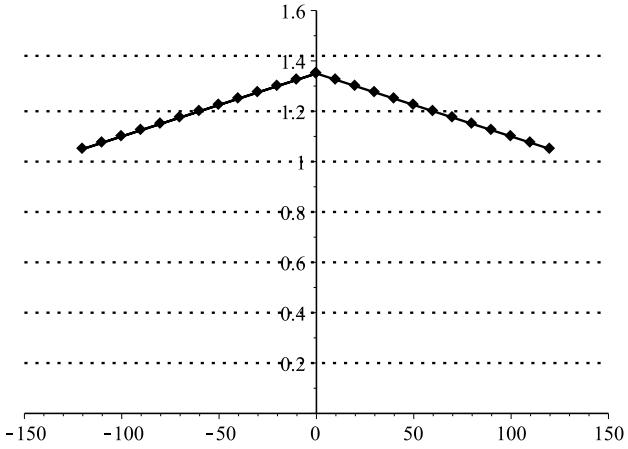


Figure 1 Variation of the coefficient Δi on the arc of the orbit from -120° to $+120^\circ$ during the period of the comet 1P/ Halley perihelion in 1986. $\Delta i = (Ai + Bi)/Bi$, where $(Ai + Bi)$ is a change in the orbital elements under the influence of various effects, including the sublimation process, Bi is similar only due to one sublimation.

the same mode. Thus, pure sublimation in itself has a certain effect on the removal of the solid fraction on an arc $(-60^\circ, +60^\circ)$.

Thus, it can be argued that the main importance in the collapse of cometary nuclei such as a conglomerate of frozen ice with a refractory fraction is emission phenomena. The mechanism of such emissions may be different. A flash of the comet's brilliance at a considerable distance after the passage of perihelion leads to the idea that heating, although it is not the main process of nucleus disintegration, acts as a catalyst for forces of a different natural property. Most likely, the heating and attenuation algorithms are not identical, then Figure 1 will not be symmetrical, but the Δ values are unlikely to change significantly.

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