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DYNAMICS AND PHYSICS OF BODIES OF THE SOLAR SYSTEM

Striated Features in the Dust Tail of Comet C/2006 P1 (McNaught)

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Abstract—To explain the distinct transversal striae observed in the tail of comet C/2006 P1 (McNaught) near the perihelion, a dynamic model for the formation of the dust tail of the comet has been developed. It is supposed that, on the surface of the nucleus, there are three local active domains of the increased outflow of the material. Formation of the striated features is caused by different rates of material outflow from the active areas depending on which side of the rotating nucleus, illuminated or shadowed, these areas are located. It has been found that the period of the axial rotation of the comet is 21 h.

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INTRODUCTION

Comet C/2006 P1 (McNaught) was discovered by Robert McNaught on August 7, 2006, when its brightness was 17^m. The comet passed the perihelion point on January 12, 2007, at a distance of 0.17 AU, when its brightness reached approximately -5^m. The visible tail of the comet was maximal in length, 35°, during the first days after passing the perihelion. Comet C/2006 P1 (McNaught) is a dynamically new comet from the Oort cloud; and, probably, this is its first passage through the internal part of the Solar System [12]. When the comet passed the perihelion, a large amount of micron and submicron dust particles was ejected from its nucleus. The analysis of the infrared spectra obtained with the Spitzer space telescope yielded a lack of crystalline silicates in the dust component of the comet, which is not typical of the dynamically new comets [7]. Infrared observations also showed that the chemical composition of the comet is somewhat poorer in CO and CH_4, while the contents of C_2H_2 and NH_3 are noticeably higher than that in the majority of the comets [1]. From the *Odyssey* spacecraft, triply ionized oxygen O^{3+} was for the first time detected in the cometary tail [13].

In some images of the near-nuclear region of the comet, rather strong jets were found [18]. In the course of time, the morphology of the jets changes, which can be connected with the rotation of the nucleus. The characteristic feature of this comet was a wide, strongly elongated tail with distinctly structured striae. The striated features in the tail were earlier also detected in comets C/1743 X1 (de Chseaux), C/1901 G1 (Great Comet), C/1910 A1 (Great January Comet), and C/1975 V1 (West). Sekanina and Farrel attempted to explain the striated features in the cometary tails [15, 16]. Specifically, they suppose that the appearance of the striated structure in the tails of comets C/1910 A1 (Great January Comet) [15] and C/1975 V1 (West) is caused by concrete events of increased outflow of particles that are later destroyed [16]. The authors believe that this should result in the formation of the striae.

Our main purpose was to model the striated structure observed in the dust tail of comet C/2006 P1 (McNaught). In addition, the modeling should yield the physical properties of dust particles: their size range, the size distribution, the velocity of the particles escaping from the collision zone, and the maximal age of the particles forming the tail.

RESULTS OF MODELING

To model the dust tail of comet C/2006 P1 (McNaught), we choose one of the best images. It was obtained by David Headland on January 24.00766 UT, 2007 (http://www.cortinastelle.it/comete/2006P1-mcnaught-best.htm) (Fig. 3b).

Simulation of the dust tail of comet C/2006 P1 (McNaught) was based on the model developed by P.P. Korsun for studying comets demonstrating substantial activity at large distances from the sun [10]. Later, this model was modified for studying dust tails of comets at close distances from the sun; and, in

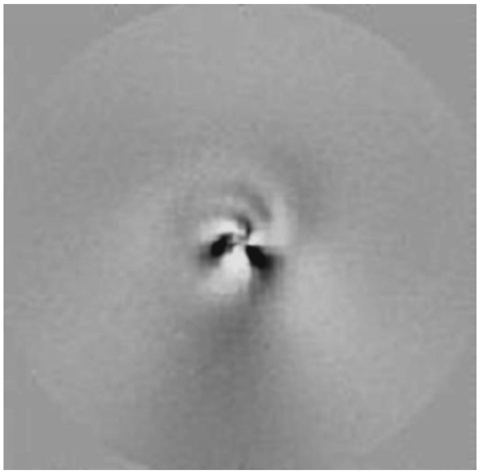

Fig. 1. Outflow of the material from three local active domains in the nucleus of comet C/2006 P1 (McNaught) [18].

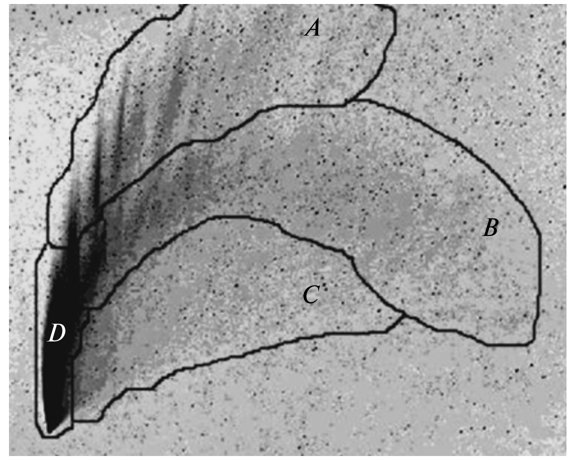

Fig. 2. Most characteristic zones in the tail of comet C/2006 P1 (McNaught).

particular, it was applied to the Hale–Bopp comet [8]. The main distinction of the modified model is that the particles forming the cometary tail are composed of a purely solid component (no ice admixture) and their sizes are much smaller and time-independent, since no ice sublimation occurs.

To model the dust tail of the comet, the trajectory of each of the individual particles should be tracked starting from a preceding moment to the moment of observations. To do this, the time point, the velocity of the particle's escape from the collision zone, its direction, and the particle's radius are assumed in the Monte-Carlo algorithm. Then, for each of the particles, the system of the motion equations is solved; the motion is assumed to be under the influence of two forces: the solar gravitation and the solar-radiation pressure. The solution of this equation system is the coordinates of a particle at the moment of observations, and their set yields the model of the dust tail of the comet. Finally, to be compared with the observations, the obtained cometocentric coordinates of the particles are projected to the plate plane.

To simulate the clearly expressed transversal striae in the tail of comet C/2006 P1 (McNaught), additional modification of the model is required. We will assume that the material outflows from the nucleus surface inhomogeneously: mostly from the active sources of gas and dust particles locally distributed through the nucleus surface. Due to the axial rotation of the nucleus, the sources are alternately illuminated by the sun and shadowed. Since the rates of the gas and dust outflow from the sources on the sunlit side and in the shadow substantially differ, the striated heterogeneities are formed in the tail.

In the image of the comet [18], the outflow of the material from at least three local active domains is clearly seen (Fig. 1). The modeling showed that, to simulate the characteristic features in the cometary tail caused by the activity of the local sources, it is necessary to take into account the material outflow during the period when the sources are in the night side of the comet rather than only during the period in the hemisphere directed to the sun. Examples of the activity of the local domains in the night side can be found in the observations of comets P/Halley and 81P/Wild 2 [4]. In the paper [6], it is shown that the crater formations of certain morphology can remain substantially heated and noticeably active on the night side of the cometary nucleus.

From expediency consideration, we selected four zones (A–D) in the considered image, as is shown in Fig. 2. Two local active domains are responsible for the formation of striae in zone A (Figs. 2, 3). They are the sources of approximately similar in size particles and differ only in their location on the surface of the cometary nucleus. The rate of the gas and dust outflow from these domains on the sunlit side (in zenith) is 35% higher than that on the night side. The third local active domain is the source of the heavier particles, and it produces 15% more dust on the sunlit side than on the night side. This active domain forms the structure of striae in zone B.

In the modeling, we took into account the changes in the activity of the local domains proportionally to the cosine of the angle of deviation from the direction to the sun. Just after passing the perihelion, the comet demonstrated a sharp unpredicted increase of brightness; later, the brightness returned to the calculated values [17]. In our model, this fact is displayed as the appearance of the local active zones while the comet is near the perihelion point and the subsequent gentle decrease of their activity in proportion to the cosine of the time scale in cube.

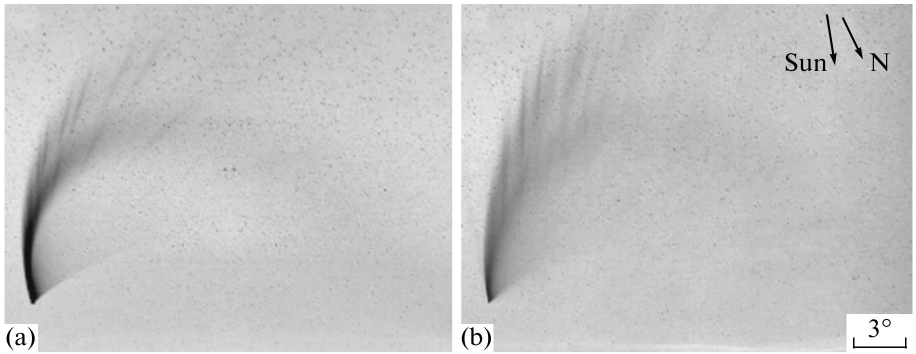

Fig. 3. Images of comet C/2006 P1 (McNaught) obtained (a) in the model and (b) during the observations on January 24, 2007.

To reproduce the material distribution observed along the striae, the law of the size distribution of particles suggested in the paper [3] was used:

$$n(a) = (1 - a_0/a)^M (a_0/a)^N,$$

where a is the radius of particles, a_0 is the minimal radius of particles, and M and N are the model parameters responsible for the position of the peak in the size distribution and its steepness. The most probable radius of a particle can be obtained from the formula $a_p = a_0(M + N)/N$. In the model, the following sets of values of the size-distribution parameters were used: $a_0 = 0.1$, $N = 50$, $M = 120$ and $a_0 = 0.1$, $N = 50$, $M = 170$ for the local active zones A and B, respectively. The size distribution with such high degrees M and N yields a narrow range of the particle sizes.

The best agreement between the modeled and observed images was obtained when the period of the axial rotation of the nucleus is 21 h.

The total number of particles for which the trajectories were traced is 5×10^7. To calculate the escape velocity of particles, we used the expression [2, 14]

$$V = Ar_d^{-0.5} a^{-0.5},$$

where V is the velocity of the ejected particles, r_d is the heliocentric distance of a dust particles, a is the radius of a particle, and A is the parameter.

The table contains the model parameters providing the best results in modeling. The values of the velocity V of dust particles are reduced to the distance of 1 AU from the sun. They are in reverse proportion to the square root of the particle radius. It is seen that the model image is composed of the particles with an age smaller than 12 and 11.2 days in the cases of the outflow from the active domains and from the whole surface of the nucleus, respectively. It is worth noting that this parameter strongly influences the position of the distinct lower boundary of the model image of the cometary tail (zone C in Figs. 2, 3), formed by the material outflow from the whole surface of the nucleus. The active domains produce particles with sizes limited within two very narrow ranges, while the particles escaping from the whole surface of the comet are in a wide size range. The presence of the active domains, which are the sources of particles different in size, can indirectly testify to the heterogeneity of the cometary nucleus. Such heterogeneity was, for example, inherent in the comet, from which comets D/1996 Q1 (Tabur) and C/1988 A1 (Liller) originated [9]. From the model interpretation of the morphology of the OH, CN, and C_2 components, the strong chemical heterogeneity of the nucleus of comet C/1995 O1 (Hale-Bopp) was inferred [11].

In our model analysis, the dust particles outflow from the whole surface of comet C/2006 P1 (McNaught) is according to the exponential law of the size distribution with the exponent typical of the

Optimal parameters of the model

Active zones	Maximal age of particles, days	a, μm	γ	V, m/s	a_p, μm
A		0.2–0.48	–	390–604	0.34
B	12	0.33–0.77	–	317–470	0.49
Homogeneous nucleus	11.2	0.35–65.0	–3.5	33–456	–

comets, $\gamma = -3.5$ [5]. The model parameter of the escape velocity of dust particles substantially influences the width of the component of the cometary tail denoted as zone D in Figs. 2 and 3. The period of the axial rotation has not been estimated earlier.

It is worth noting that the modeled and observed orientations of the striae differ by several degrees. This discrepancy can be explained under the assumption that the dust particles in the tail are charged, and this charge is subjected to the solar wind.

CONCLUSIONS

The dynamical modeling based on the Monte-Carlo technique allowed us to reproduce the clearly expressed structure of striae observed in the tail of comet C/2006 P1 (McNaught). We explain this phenomenon by the presence of three local active domains on the surface of the nucleus, which are alternately on the day and night sides due to the axial rotation of the comet. The different rates of the gas and dust outflow on the day and night sides of the rotating nucleus cause the quasi-periodic heterogeneities observed in the tail. The period of the axial rotation of comet C/2006 P1 (McNaught), which was the model parameter, turned out to be 21 h.

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