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DYNAMICS AND PHYSICS OF BODIES OF THE SOLAR SYSTEM

Model Analysis of the Dust Tail of Comet C/2012 K5 (LINEAR)

S. V. Kharchuk[a], O. V. Ivanova[a], P. P. Korsun[a], and O. R. Baransky[b]

[a] *Main Astronomical Observatory, National Academy of Sciences of Ukraine, ul. Akadademika Zabolotnoho 27, Kyiv, 03680 Ukraine*

[b] *Astronomical Observatory, Shevchenko National University, ul. Observatornaya 3, Kyiv, 04053 Ukraine*

e-mail: kharchuk@mao.kiev.ua, sandra@mao.kiev.ua, korsun@mao.kiev.ua

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Abstract—From the dynamic modeling of the process forming the dust tail of comet C/2012 K5 (LINEAR), the brightness distribution in this dust tail has been retrieved. The model developed by Korsun on the basis of the statistical Monte-Carlo approach was used. The adequacy of the model was determined by fitting the observed and modeled isophots. The following parameters of dust particles composing the dust component of the cometary atmosphere have been estimated: the range of radii (0.7–100 μm), the power index of the size distribution law (–2.4), the range of velocities (6–135 m/s), and the maximum age of dust particles (88 days).

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INTRODUCTION

The study of the nature of comets is important in the context of understanding the evolution of the solar system. Since comets dwell on the periphery of the solar system, where the radiation field is weak, they contain the primary material that remained practically unimpaired from the time of the solar system formation. Because of this, the investigations of dynamically new comets that appear in the inner part of the solar system for the first time may yield new information on the conditions of their formation, the physical properties of their dust and gas, and the mechanisms of interaction with the interplanetary medium.

Model interpretation of the processes forming the dust tails is to yield the information on the nature of particles in the cometary tails, the sizes and size distribution of particles, and their lifetime in the solar radiation field. The obtained results will widen the notions on the variety of the dust contained in different comets and on the origin of different comets and their contribution to the interplanetary dust cloud.

The paper is focused on the dynamical modeling of the dust tail of a dynamically new comet C/2012 K5 (LINEAR). The comet was discovered in the framework of the Lincoln Near-Earth Asteroid Research (LINEAR) program on May 25, 2012, when its brightness was 18.5 m. The comet passed the perihelion on November 28, 2011 ($q = 1.14$ AU, $e = 0.9985$), though its brightness reached the maximum (8^{m}) in early 2013.

IMAGE PROCESSING AND MODEL DESCRIPTION

The set of photometric images of comet C/2012 K5 (LINEAR) obtained on September 27, 2012, was used in the dynamical modeling. At that time, the comet was at a distance of 1.5 AU from the Sun and 1.8 AU from the Earth. The comet was observed by Baransky at the AZT-8 telescope (Astronomical Observatory, Shevchenko National University, v. Lesniki). The photometric data were obtained with the broadband R filter. The PL47-10 FLI CCD matrix with 1024 × 1024 pixels was used as a radiation detector. The size of the obtained images is $16 \times 16'$, and the scale in the 2×2 binning instrument mode is $0.99''$ per pixel.

The reduction of the obtained data was performed with the Interactive Data Language (IDL) codes. This preprocessing allowed us to take into consideration the properties of the matrix, to clear the images from the traces of cosmic-ray particles, and to take into account the flat field.

Since the comet moves relative to the field stars, all of the frames were shifted in such a way that the image of the comet remained “fixed”. For this purpose, the locations of the photometrical centers of the selected field stars and the center of the comet were measured. All of the images were reduced to the common center with the coordinates corresponding to those of the center of the comet’s image chosen in one of the frames. After taking into account the sky background, the interframe median filtration was applied to all of the transformed images. This procedure allowed the signal-to-noise ratio to be increased and the field stars to be partially removed. After median filtration, this set of the resulting frames yielded the image that was used for the further dynamical modeling of the dust tail of the comet. Finally, the orientation and the scale of the obtained resulting image were determined, which is necessary for the correct modeling of the dust tail of the comet.

The simulation of the comet's dust tail was provided by the model developed by Korsun [12] on the base of the statistical Monte Carlo approach [3]. The model was successfully tested in the simulations of the tails of comets C/1995 O1 (Hale-Bopp) [2], C/2003 WT42 (LINEAR) [12], etc. In the model analysis of the dust tail of comet C/2012 K5 (LINEAR), which was relatively close to the Sun (1.5 AU) at the moment of observations, we took into consideration that the ice component of the conglomerate completely sublimated and the motion of strongly porous refractory dust particles is analyzed.

To simulate the dust atmospheres of comets, the trajectory of each of the dust particles is traced in the model from the escape from the collision zone surrounding the cometary nucleus to the moment of the observation. For this purpose, the following model parameters are assumed: the maximum age of the dust particles that may form the tail, the power index γ of the size distribution of dust particles ($n(a) = a^{\gamma}$), and the geometric behavior of the dust production. According to the Monte Carlo algorithm, the radius of a dust particle and the time and direction of its escape are specified, and the velocity of the particle leaving the collision zone is finally calculated.

Further, for each of the dust particles, the system of equations of motion under the control of two main forces—the solar gravity F_G and the solar radiation pressure F_R—is solved. It is convenient to consider the motion of particles in the noninertial cometocentric coordinate system ξ, η, and ζ; the corresponding spherical coordinated r, φ, and θ were also used. Then, the system of motion equations for a dust particle can be presented in the following way [4, 5]

$$\ddot{\xi} = -\mu_S(1-\beta)\frac{r+\xi}{y^3} - \mu_C\frac{\xi}{x^3} + \ddot{\theta}\eta + \dot{\theta}^2\xi + 2\dot{\theta}\eta + \mu_S\frac{1}{r^2},$$

$$\ddot{\eta} = -\mu_S(1-\beta)\frac{\eta}{y^3} - \mu_C\frac{\eta}{x^3} - \ddot{\theta}\xi + \dot{\theta}^2\eta - 2\dot{\theta}\xi,$$

$$\ddot{\zeta} = -\mu_S(1-\beta)\frac{\zeta}{y^3} - \mu_C\frac{\zeta}{x^3},$$

where $\mu_S = Gm_s$ is the solar gravity parameter; $\mu_c = Gm_c$ is the gravity parameter of the comet; r, $\dot{\theta}$, and $\ddot{\theta}$ are the heliocentric distance of the comet, its angular velocity, and its angular acceleration relative to the Sun, respectively; $x = \sqrt{\xi^2 + \eta^2 + \zeta^2}$, and $y = \sqrt{(r+\xi)^2 + \eta^2 + \zeta^2}$. The first component of the system of motion equations is the gravity forces of the Sun corrected by the radiation pressure (β). The second component is the gravity of the cometary nucleus; the other terms are the corrections for the noninertial effects. The coordinates ξ and η are in the plane of the cometary orbit; ξ is in opposition to the direction to the Sun, η is in opposition to the movement of the comet around the Sun, and ζ is perpendicular to the plane of the orbit.

The solution of the system of motion equations yields the coordinates of a dust particle at the observation moment, and the array of these coordinates forms the modeled dust tail of the comet. To be compared to the observational data, the obtained cometocentric coordinates of dust particles are projected onto the sky plane.

The dimensionless quantity $\beta = F_R/F_G$ is calculated with the expression [8]

$$\beta = 0.57Q_{pr}/\rho a,$$

where Q_{pr} is the radiation pressure efficiency, ρ is the density (expressed in g/cm^3), and a is the radius of a dust particle (expressed in μm). For the particles with $a \geq 0.2$ μm, Q_{pr} is approximately constant, while the value of β is proportional to a^{-1} [8]. In these model calculations, the density of porous particles was assumed as $\rho = 1$ g/cm^3.

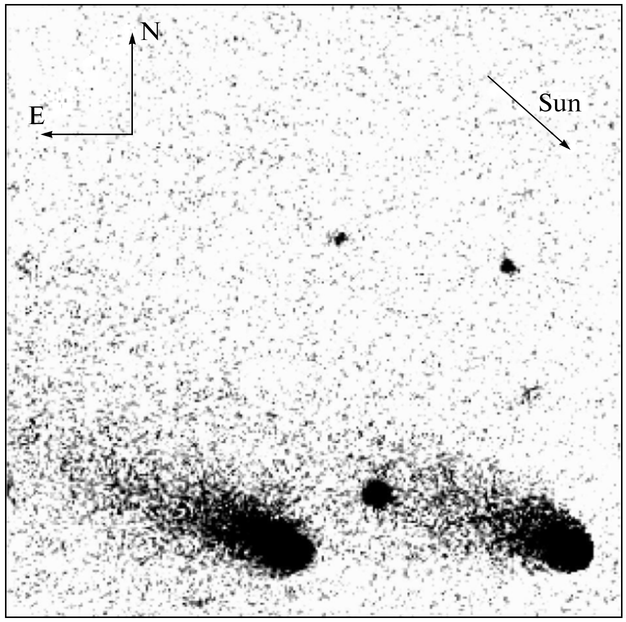

Fig. 1. Modeled (right) and observed (left) images of comet C/2012 K5. The image size is 4.7 × 4.7′, 375000 km.

The dust particles captured from the nucleus surface by gases leave the collision zone with a fixed velocity that can be determined by the empiric formula [7, 14]

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

Here, V is the escape velocity of dust particles, A is a numerical parameter, r_d is the heliocentric distance of a dust particle, and a is its radius. It was additionally assumed that the escape velocities are characterized by the Gaussian distribution. The mean value of the distribution is the most probable value of V, and the relative standard deviation is 0.1.

As is known, after releasing from the cometary nucleus, the dynamically connected neutral gas and dust particles form a coma. However, in several tens of the cometary radii from the nucleus surface, the dust dynamically dissociates from the gas and forms the dust tail [6]. Our purpose in the simulation process was to fit successfully the observed isophots by the modeled ones.

MODELING PROCEDURE AND DISCUSSION OF THE RESULTS

The modeling was carried out with the computer code written in the Fortran programming language. To start computations and control the results, the IDL software package dealing with the image analysis was used. The fitting degree of the sets of isophots served as a main criterion of the agreement between the observed and modeled data. For convenience, the values of all model parameters were collected in a separate file. From the modeling, the optimal model parameters corresponding to the agreement between the isophots were obtained; these parameters are the characteristics of the dust forming a dust component of the atmosphere of comet C/2012 K5. The modeled image was produced from 200 million particles. The source of dust particles was a sunward cone with an opening angle of 100°, i.e., a substantial part of the sunlit surface of the comet was active. The modeling yielded the optimal model parameters (the radii of dust particles, their velocities, the maximum age, and the power index of the size distribution γ) that characterize the dust component of the cometary atmosphere. The values of the model parameters are the following: the maximum age of dust particles is 88 days, their radius a ranges from 0.7 to 100 μm, the power index of the size distribution law $\gamma = -2.4$, and the velocities of dust particles V vary from 6 to 135 m/s.

The observed (left) and modeled (right) images are shown side by side in Fig. 1, and the sets of the observed and modeled isophots are superimposed on each other in Fig. 2.

The value of the power index of the size distribution law obtained in our modeling ($\gamma = -2.4$) differs from those reported for many comets (γ ranges from –3 to –4), though it agrees with the power exponent obtained for comets Shoemaker–Levy 9 ($\gamma = -2.3$) [9] and 1P/Halley [13]. Measurements of the dust fluxes during

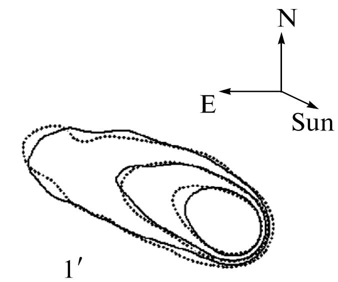

Fig. 2. Modeled (solid curves) and observed (dotted curves) isophots of the dust tail of comet C/2012 K5.

the spacecraft passages near the nuclei of comets 1P/Halley (*Giotto*) and 81P/Wild 2 (*Stardust*) also showed the presence of particles with the radii in a wide range—from nanometers to millimeters—distributed according to approximately a power law with the exponent varying from –2 to –4 in dependence on the size of dust particles and their location in the cometary coma [11].

The estimates of velocities obtained in the modeling (6–135 m/s) agree with those for the dust knocked out from the artificial crater in comet 9P/Tempel during the *Deep Impact* mission. The comet was at a distance of approximately 1.5 AU, and the velocities reached by dust particles with sizes from 0.1 to 100 μm were in the range from 10 to 600 m/s [10].

Earlier, the authors performed the modeling study of the dust component of the tail of comet C/2012 S1 (ISON) [1], when the comet was at a distance of 1.45 AU from the Sun. The modeling yielded the following estimates: the particles' radii were in the range from 0.5 to 16.6 μm and their velocities were from 17 to 130 m/s. The maximum age of particles that could form the tail was 25 days. The power exponent of the size distribution of dust particles was constant in time and amounted to $\gamma = -2.5$. As we see, at these distances from the Sun and with these values of γ, the ranges of the radii and velocities of dust particles having formed the dust tail of comet C/2012 K5 (LINEAR) are wider.

CONCLUSIONS

The relative distribution of brightness in the dust tail of comet C/2012 K5 (LINEAR) has been successfully simulated with the dynamical modeling on the basis of the Monte Carlo algorithm. The modeling yielded the model parameters that describe the physical characteristics of dust particles forming the cometary tail: the maximum age of dust particles is 88 days, the escape velocities vary from 6 to 135 m/s, the particles' radii are in the range from 0.7 to 100 μm, and the power index of the size distribution law is –2.4.

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