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## DYNAMICS AND PHYSICS OF BODIES OF THE SOLAR SYSTEM

# Model of the Dust Tail of Comet C/2011 L4 (PANSTARRS)

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**Abstract**—Results of dynamic modeling of the dust tail formation for the comet C/2011 L4 (PANSTARRS) are presented. To simulate the dust tail, the trajectories of 100 million dust particles were traced. Their sizes, ejection moments, outflow directions, and initial velocities were defined by the Monte Carlo algorithm. The obtained three-dimensional model tail was projected onto the celestial sphere to compare with the observed image. The brightness distribution and synchronic features in the comet tail were reconstructed. According to our model experiments, the observed tail could be formed by particles with sizes from 0.22 to 82 μm, with ejection velocities from 460 to 12 m/s, and with a power index of the size distribution of −3.1. Our model experiments showed that the rotation period of the comet is 17.2 hours.

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## INTRODUCTION

While examining the sky to find potentially dangerous asteroids, a large group of scientists detected comet C/2011 L4 (PANSTARRS). It was named after the 1.8 m telescope Pan-STARRS 1 located on the island of Maui (Hawaii, United States), which is equipped with the biggest digital camera in the world (1.4 billion pixels) [8]. At the moment of discovery, the comet had a brightness of $19.5^m$ and it was located at the distance of 7.9 au from the Sun. On March, 5 2013, the comet reached the minimal distance from the Earth (1.1 au). And on March, 10 2013, it crossed the perihelion at 0.3 au. Its eccentricity hardly exceeds 1. According to the results of observation, the comet reached its maximal brightness, $-3^m$ on March 10, 2013 [8].

For modeling, we chose the image obtained by amateur astronomer Lorenzo Comolli on March 21, 2013, at 18:56 UT with the use of 140 mm refractor with sensitive CCD detector [http://www.astrosurf.com/comolli/com38.htm]. At the same time, slight synchronous stripes in the comet dust tails were observed. The image a combination of seven frames obtained at the distance of 0.46 au from the Sun and 1.19 au from the Earth [http://ssd.jpl.nasa.gov/horizons.cgi#results].

## MODEL AND DISCUSSIONS

To simulate fitting the dust tail of comet C/2011 L4, we used the model developed by P.P. Korsun [6]. In the process of simulating the dust tail of the comet, we traced the trajectory of each separate particle of dust from the time of outflow from collision zone around the nucleus until observation started. With this purpose, we set the radius of dust particle and also direction and velocity of its outflow from collision zone using the Monte Carlo algorithm. Then, for each dust particle, we solved the system of equations regarding the movement under effect of two main forces: solar gravitation and solar radiation pressure. When the equations were solved, we obtained the coordinates of one dust particle at the moment of observation, and their combination had the modeled dust tail of comet. And at last, the obtained cometocentric coordinates of dust particles were projected onto the sky plane to compare them with the observation data.

Mostly comet dust moves under the influence of two main forces: solar gravitation and solar radiation pressure. To describe this movement, we used the following correlation $\beta = F_R/F_G$, which means the ratio of solar radiation pressure and solar gravitation at the same distance. As [2]

$$F_G = GM_S/r^2(4/3\pi a^3\rho), \quad F_R = Q_{\rm pr}/c(L_S/4\pi r^2)\pi a^2,$$

then

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

where $c$ is light velocity, $G$ is gravitational constant, $M_S$ is weight of the Sun, a is radius of dust particle in nanometers, ρ is density of dust particle, $r$ is heliocentric distance of dust particle, $Q_{\rm pr}$ is efficiency of radiation pressure, and $L_S$ is total energy generated by the Sun during 1 c. For dust particles of $a \geq 0.2$ μm the

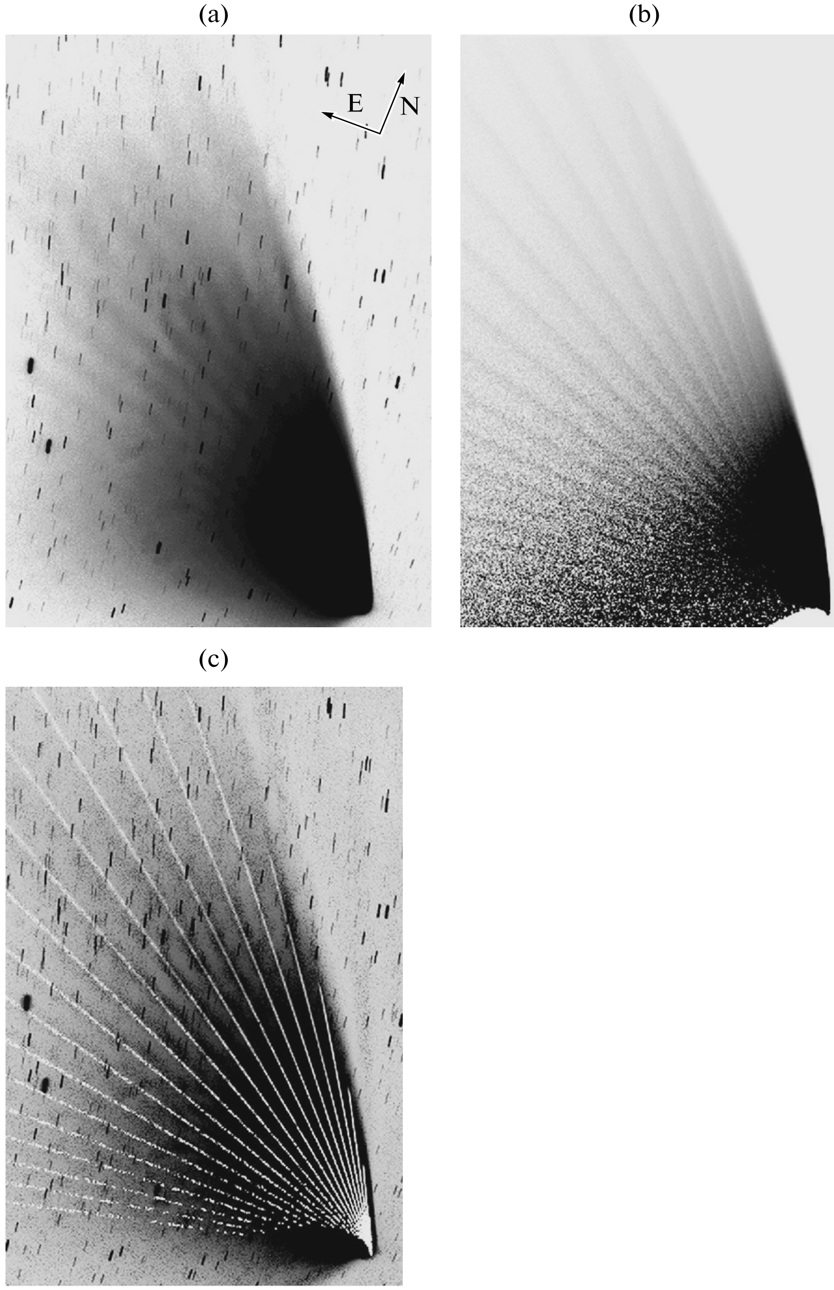


Image of tail of comet C/2011 L4: (a) obtained from observations, (b) modeled image, (c) observed image with superimposed modeled tail stripe. Antisolar direction is upward vertically, positional angle of the tail is 21°. The size of image is 1.7° × 2.65°.

value $Q$ remains approximately constant, but $\beta$ is proportionate to $a^{-1}$ [2]. We adopted that volume density of porous dust particles does not change with time and it is equal to 1 g/cm$^3$.

Outflow velocities of particles were determined according to the empirical formula proposed by Sekanina [10]:

$$V = r_d^{-0.5}/(A + Ba^{0.5}|).$$

Here $V$ is velocity of dust ejection, $A$, $B$ is numerical parameters, $r_d$ is heliocentric distance of dust particle, and $a$ is radius of dust particle.

As a result of modeling, we obtained optimal model parameters that characterize comet dust. We found that radii of dust particles that formed the dust tail of the comet have an interval of 0.22–82 μm and velocities of dust particles are between 12 and 460 m/s. This corresponds with the data of theoretical studies and observations that show that submicron particles of dust have velocities 360–740 m/s [9]. Maximal age of particles of dust is 47 days, the power index of their size distribution ($n(a) = a^{\gamma}$) does not change with time and has the value $\gamma = -3.1$. We obtained the value $\gamma = -3\ldots-4$ which is typical for many comets [3, 4].

Simulation showed that the stripe structures in the dust tail can be explained by activity of one local area. Due to axis rotation, active area can be on the light or dark hemisphere of the comet in turn. The level of dust and gas production is different and, as a result, dust clouds appear in the form of stripes. In the process of simulation, we consider the change of activity of the local area to be proportionate to the square of cosine of deviation angle towards the Sun. The determined period of comet's axial rotation of 17.2 h corresponds with the data [7], according to which values of rotation periods are in the range from 3.471 h (for comet 133P/Elst-Pizarro) to some days. This explanation of stripe formation was used earlier while simulating stripes formation in the dust tails of some comets, and we obtained the following values of rotation periods: 21 h for comet C/2006 P1 (McNaught), 15.4 h for C/1957 P1 (Mrkos), 8.5 h for C/1910 A1, and 7.35 h for C/1975 V1 (West).

Model analog of dust ejection from active area was a cone with the opening angle 100°. Physical characteristics of dust produced by active area are the same as characteristics of dust outflowed from the whole surface of comet. However, due to the fact that visibility of stripes is gradually getting worse, simulation showed that stripe formation involves dust particles 15 days old at least. Generally, model image was formed from 100 million dust particles.

Figures 1a and 1b show model and observed images of comet C/2011 L4 (PANSTARRS), and section c shows that these two images are matched.

## CONCLUSIONS

We managed to fit the distribution of brightness in the dust tail of comet C/2011 L4 by means of simulation according to the Monte Carlo algorithm. We also fitted stripes of the tail by means of simulation of activity of local area on the nucleus surface of rotating comet. We estimated the values of model parameters: maximal age of dust particles forming the tail is 47 days, range of outflow velocities $V = 12\ldots460$ m/s, typical size of dust particles $a = 0.22\ldots82$ μm, power-law index of distribution $\gamma = -3.1$, and the rotation period around axis $P = 17.2$ h.

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