Investigating and computer modeling of erupting comets and comet tails

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Abstract. The paper investigates several erupting comets, mostly the comet 17/PHolmes, using their photographic images and develops a computer program for modeling of their tails, taking into account the acceleration given to the ejected cometary dust particles by the solar radiation pressure. Estimated is the typical size of the dust particles ejected during the eruption of the comet 17/P Holmes in 2007. A model of the feather-like tail of the comet C/2006 P1 McNaught is proposed based on the idea that there are some active regions on its nucleus and considering the nucleus rotation.
Key words: comets, comet outbursts, computer modelling of comets, comet tails simulations

1 Introduction

The comet 17/P Holmes (hereafter Holmes) was discovered in 1892. It has an orbital period of about 7 years and so far a number of its returns have been observed. The comet became especially popular with its unexpected outburst in the period of 23$^{\rm rd}$ to 24$^{\rm th}$ October 2007, when within an interval of 42 hours it increased its brightness from 17^m to 2.8^m, i.e. by 14 units of stellar magnitude, ejecting gas and dust that formed a coma greater than the size of the Sun. The initial prediction for the comet Holmes during its return in 2007 was that it would be seen only through a telescope, but when it exploded, it became visible by naked eye. Interestingly, the comet Holmes exploded 172.3 days after its perihelion passage.

We developed a mathematical model of the influence of radiation pressure on the cometary dust particles, based on which we created a computer program simulating the movement of the particles, the shape and size of the comet's coma and tail. Varying the particles' sizes, we created a number of simulations and estimated the particles' size, which fits best to the photographical data. We made more complicated simulations involving dust particles of different sizes, demonstrating that the larger and more massive particles stay nearer to the comet's orbit and the lighter ones move away faster. We compared our results mainly with the investigations presented in [7, 8].

With an improved version of the program we took into account the different values of the accelerations given to the dust particles by the solar radiation pressure depending on their different positions relative to the comet nucleus and their different distances to the Sun. We considered also the rotation of the nucleus, as well as the possible existence of more active and less active regions on its surface. We took into account the uneven distribution of the particles by sizes. We also obtained computer simulations of several other erupting comets. Then we simulated the feather-like structure of a hypothetical comet similar to the comet McNaught. We intended to test the idea that the strips in the comet

Fig. 1. The comet Holmes after its unexpected eruption (photo taken by Ivan Eder on 4 November 2007)

tail can be created because of the rotation of the nucleus and the existence of an active region on its surface.

2 Method of investigation

According to the model created by Fred Whipple in 1950 and confirmed by a number of observations and explorations in the next decades, the comet nuclei are composed predominantly of ices – frozen H_2O, CO_2, NH_3, mixed with some meteoritic rock material [6]. The nuclei of the comets circling around the Sun are in a process of continuous destruction. They move along highly elliptical orbits. When they are close enough to their perihelion, they are heated by the solar radiation. Since the cometary nuclei contain a lot of ice, due to the heating their substance evaporates. The solar radiation pressure and the solar wind blow away the evaporated matter and so the comet tails are formed. Often from the interior of the comet nucleus the evaporated material is ejected into powerful jets, or sometimes eruptions take place. At the same time, dust particles and larger pieces are released along with the comet's vaporous gases, and sometimes the nucleus undergoes fragmentation and even complete destruction. The dust particles are ejected with an initial velocity V_0. It is called terminal velocity and it is the velocity taken from the collisions with gas molecules in the nucleus. Then the solar radiation pressure gives them an acceleration which changes their trajectories. We will not take into account the influence of the solar wind because it affects only the ionized gases released by the comet's nucleus. The subject of our investigation are the dust particles which are electrically neutral. When composing the mathematical model of the comet Holmes' outburst we have to determine the initial velocity V_0 by which the particles are ejected. For this purpose we have selected a number of consecutive photographs of the comet Holmes made by Dalibor Hanžl and Miloslav Druckmüller of the Technological University of Brno, the Czech Republic [3], and by measuring the comet images we determined the real size of the coma, or the head of the comet in kilometers.

To determine the size of the comet's head, we first measure the dimensions d and D, denoted on the photograph (Fig. 2), in *cm*. Then, from the comet Holmes' ephemeris for the day when the picture was taken, we find the coordinates for a general orientation, we select two stars from the photograph, identify them through the Stellarium program, and find them on the computer star chart. Using the Stellarium's Angle Tool, we measure the angular distance between the two stars.

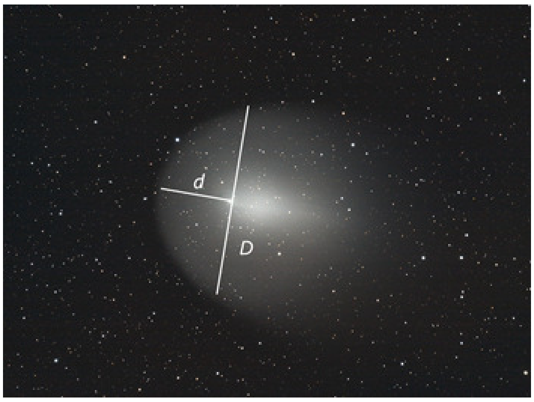

Fig. 2. Parameters measured on the photographs of the comet

We measure the distance between the same stars on the picture in centimeters. From these two distances, expressed in different units, we can easily find the scale of the picture. Once we have found the angular sizes of d and D, we can turn them into kilometers – to determine their real values. This is done through the formula:

$$D = \frac{2\pi\, \varDelta \cdot \delta \times 149,6 \times 10^6\,\mathrm{km}}{360^\circ \times 60^\circ},$$

where $\varDelta$ is the distance between the comet and the Earth in AU (which we turn in km), δ is the value of D in arc minutes. The distance $\varDelta$ we take from the ephemeris of the comet for the day on which the picture was taken [4]. For the parameter d we use a similar formula.

The pictures of the comet Holmes we used were made in the period 26 October – 28 November 2007.

After we measure the comet head on each of the 14 selected pictures we draw a graph showing the change of these parameters with time (Fig. 3). Using the graph we can determine the initial velocity V_0, by which the particles are ejected. For this purpose, we should not use the whole graph, because at later times the velocity is changing substantially, and measurements are more inaccurate because the coma fades and it is difficult to determine its boundary on the pictures. That is why we use only the initial section of the graph. The approximate result is $V_0 \approx 560\,\mathrm{m/s} \approx 2016\,\mathrm{km/h}$. It is in good agreement with the values we find in all other sources [7]. For our calculations we used the change of the dimension D of the comet head because it is perpendicular to the acceleration given to the particles by the light pressure. That is why the component of the particles' velocity in this direction should not be changed by the radiation pressure.

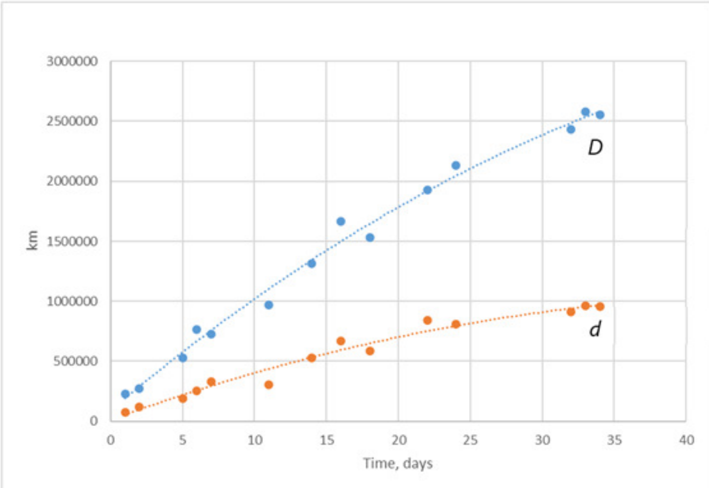

Fig. 3. Changing of the dimensions of the comet head with time, measured on the photographs

3 Comparison between the initial velocities of particles from other comet's nuclei

We chose three more erupting comets: 174P/Echeclus, ASASSN1 and 29P/Schwassmann-Wachmann 1. For each of them we made the same measurements on a series of photos.

The initial velocities of the particles of the comets calculated by us are presented in Table 1. As it could be expected, we see that during the comet outbursts that take place at farther distances the dust particles are ejected by lower velocities from the comet nuclei.

4 Theoretical model of the eruption of the comet Holmes

The model we use resembles the classical "*fountain model*" introduced by Friedrich Bessel based on his observations of the comet Halley during its appearance in 1835. Bessel gave the first interpretation of the motion of cometary material as being ejected towards the Sun and then repelled away from the Sun by a non-gravitational force. The nature of that force was unknown to Bessel, but now we know that it is the solar radiation pressure (Fig. 4).

Table 1. Initial velocities of the particles ejected by four erupting comets.

Comet	**Distance from the Sun at the time of the eruption, AU**	**Initial velocity of the particles**
17P/Holmes	1.6	560 m/sec
ASASSN1	1.9	468 m/sec
174P/ Echelcus	5.5	73 m/sec
29P/ Schwassmann -Wachmann 1	6.2	62 m/sec

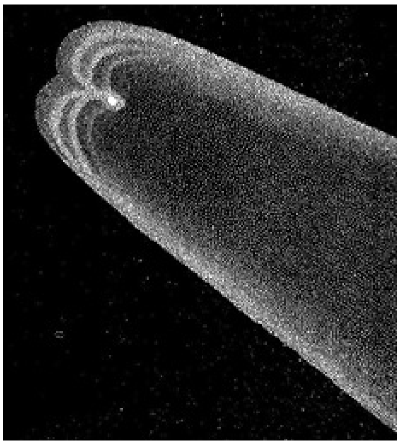

Fig. 4. A drawing made by Friedrich Bessel illustrating his fountain model of the comet nucleus proposed by him as a result of his observations of the comet Halley in 1835.

Once we obtained the value of the initial velocity V_0, we need to find the acceleration given to the cometary dust particles by the radiation pressure. The first approximation we make is that in the outburst we have a single discharge of a certain amount of particles. They, of course, have various masses and various initial velocities. However, we want to model for simplicity only the development of the outer border of the comet's head. Therefore, we only consider the fastest dust particles that in a given time reach the farthest distances from the comet nucleus. As a next approximation, we assume that these fastest particles are dispersed in all directions with equal initial velocities. We examine the motion of the particles in a reference frame associated with the comet nucleus, i.e. we are interested in the motion of the particles relative to the nucleus. Two forces act on each particle – the gravitational attraction of the Sun and the solar radiation pressure. We neglect the gravitational attraction of the comet nucleus. We also do not take into account the influence of the solar wind on the cometary dust particles, because it is in an order of magnitude weaker than the influence of the radiation pressure. The comet nucleus moves freely around the Sun with the acceleration attributed to it by the gravitational force of the Sun. The same acceleration is attributed to the particles separated from the nucleus. Since our considerations are in a reference frame that moves along with the comet nucleus, it is not necessary to take into account the gravitational acceleration given to the particles by the Sun when we examine their motion with respect to the comet nucleus. We will also neglect the tidal effects. What remains is only the acceleration a_l, which is given to the comet particles by the solar radiation pressure and which practically has no effect on the nucleus because of its greater mass. We will calculate this acceleration.

Let L be the luminosity of the Sun and r be the distance between the Sun and the comet. Then, the radiation flux created by the Sun at a distance r will be:

$$E = \frac{L}{4\pi r^2}.$$

We assume that the cometary dust particles are little spheres with a radius R. The amount of radiation energy falling on a particle per unit of time will be:

$$\frac{\Delta\varepsilon}{\Delta t} = E.\pi R^2 = \frac{LR^2}{4r^2}.$$

The momentum given to a particle per unit of time due to this action will be:

$$\frac{\Delta p}{\Delta t} = (1+A)\frac{1}{c}.\frac{\Delta\varepsilon}{\Delta t} = \frac{(1+A)LR^2}{4r^2c}, \tag{1}$$

where c is the speed of light and A is the albedo (reflection coefficient) of the particle. According to the law of conservation of momentum, the change of the momentum per unit of time is equal to the force acting on the particle:

$$F = \frac{\Delta p}{\Delta t} = ma_l,$$

where m is the mass of the particle and a_l is the acceleration given to the particle.

If the density of the cometary matter is ρ, then the mass of the particle is:

$$m = \frac{4}{3}\pi R^3\rho.$$

Hence:

$$a_l = \frac{1}{m}.\frac{\Delta p}{\Delta t} = \frac{3}{16}.\frac{(1+A)L}{\pi c\rho R r^2}.$$

From here follows the important conclusion that the acceleration is determined by the particle's size and smaller particles receive greater accelerations.

From the comet's ephemeris we take its distance r to the Sun for each moment of time. In one extreme case we can assume the density ρ to be equal to that of the water ice, which is $\rho = 917\,\mathrm{kg/m^3}$, and the albedo of the ice to be equal to 1. So the coefficient $(1 + A)$ should be equal to 2. In another extreme case, we can assume that the particles are of a carbon-rich rocky composition. Therefore their albedo may be significantly less than 1. Moreover, in our model the coefficient $(1 + A)$ in the expression for the momentum (Eq. 1) implies that the particles reflect the photons falling on them exactly in the opposite direction – as if these particles were small flat mirrors oriented perpendicular to the solar rays. This is obviously not correct. Then let us consider in this second extreme case for the coefficient $(1+A)$ that it is equal to 1 and for the dust particles' density again we can assume a value similar to that of the ice, since they are of a porous and loose substance. This is shown by the examinations of the Stardust spacecraft which has studied the tail of the comet Wild 2, as well as by the results of the experiments with the special MIDAS microscope mounted on the Philae probe which works on the surface of the Comet Churyumov-Gerasimenko's nucleus [9, 10]. For the radius R of the comet particles, when modeling the comet outburst, we can test different values.

We will compose the model of the comet head considering the particles that at a certain moment of time after the ejection from the nucleus, have reached to greatest distances away from it and outline the "boundary" of the comet's head.

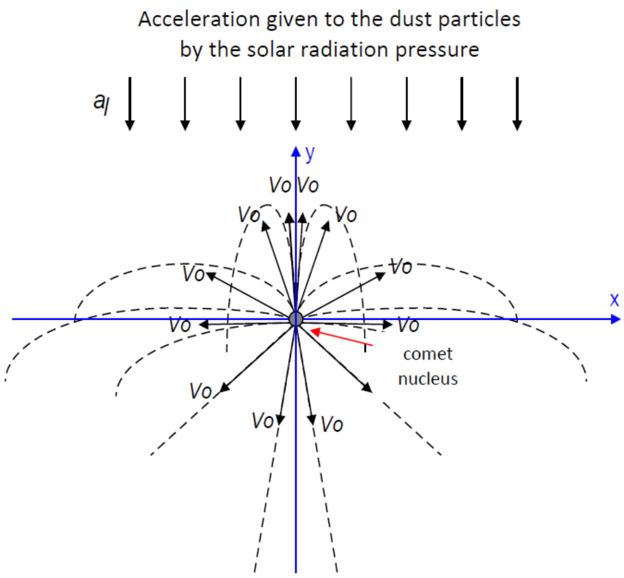

Fig. 5. Motion of the particles ejected from the comet nucleus.

We assume that these particles are ejected from the nucleus in all directions with the same initial velocity V_0 and have equal masses and sizes. We also assume that in the close vicinity of the comet's head the distance to the Sun for each of the separated cometary particles is approximately the same. So the particles will receive the same acceleration (with the same direction and of the same magnitude) generated by the solar radiation pressure.

5 Computer simulation

The program we created is written in C♯ language and is based on the formulae and approximations described above. Considered are consecutive portions of particles ejected from the comet nucleus with equal velocity in all directions. The gravitational attraction of the comet nucleus is not taken into account because within the frames of the simulation its impact on the dust particles is of the orders of magnitude smaller than the solar radiation pressure (Fig. 6).

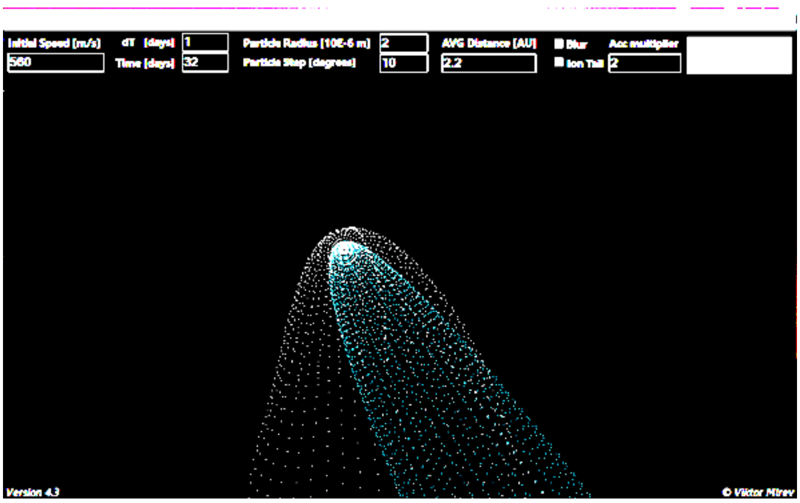

Fig. 6. Design of the computer simulation program.

The calculations of the positions and the velocities of the particles are made for small intervals of time – time steps. It is assumed that in each of these small time intervals and within the comet's head, the particles receive equal and constant acceleration. We use time steps equal to one day. We cannot achieve a better accuracy since the ephemeris of the comet give data for each day.

Entry data in the program are:

- Initial velocity of the particles [m/s].
- Time step for calculation of the positions of the particles [days].
- Time interval from the start and the end of the simulation [days].
- Radius of the particles [10^{-6} m].
- Angle step of the particles depicted (by angle of ejection from the nucleus).
- Mean distance between the comet nucleus and the Sun (during the simulated period of about one month the distance does not change considerably).
- There is an option to add an ion tail too, with a significant acceleration. It is not an exact physical model – it is for illustration only, depicted in blue color, naturally in the opposite direction to the Sun.

– Since for each new day the position of the comet relative to the Sun changes, the direction in which the light pressure acts on the particles is also changing. We calculated the rotation angle for each day from the comet ephemeris and we used these values in the program. Because of this rotation, a specific curving of the comet's tail takes place and it is seen in the images.

The aim of the program is to reproduce the shape of the comet at a given moment of time after the onset of the outburst. After each time step is completed, the program simulates a discharging of a new layer – a new portion of particles. Therewith the endpoints at that moment of all the layers that are ejected before it, are kept and depicted. The shape of the comet that is produced depends on the particles' size (which determines the acceleration given to the particles by the radiation pressure), the distance to the Sun and the comet's orbit.

6 Estimation of the particles' sizes

We use our computer program and the actual data about comet Holmes, obtained by measurements on the images, to estimate the size of the dust particles ejected at the outburst. We determined the initial velocity of the particles using the photographs, as described above, and we took the distance to the Sun from the comet ephemeris. On each of the photographs the parameter d is measured (Fig. 2). It is the one that is influenced by the acceleration, which depends on the sizes of the particles. We create a series of simulations with the program to see what sizes of the ejected particles give the values for the parameter r that best match the values measured on the images.

The section of the comet Holmes' orbit, travelled by it in the frames of our considerations, is not significantly inclined to the ecliptic. That is why we make the approximation that it lies in the plane of Earth's orbit. From the ephemeris we have taken the comet's elongation (the angle Sun-Earth-comet) and the phase angle (the angle Earth-comet-Sun). We have calculated the orientation of the comet head and tail relative to an observer on Earth. The images created by the program give us a view of the comet head as seen from the north ecliptic pole. So we determine in which direction the parameter d is relative to the shape of the comet's head and we can measure it on the computer images generated by the program. Then we compare it with the value measured on the photos and choose the simulated image that best fits to it. In the process of this work, we had to generate a large number of images, testing various values for the sizes of the particles, to get the necessary result.

Fig. 7 shows a display of the simulation program, and a tool for measuring of angles and distances in pixels is superimposed on it. Shown are the directions to the Sun and Earth, which are calculated for each moment of the simulation. Knowing these angles, we can plot the parameter d, which is the distance from the comet's nucleus to the point where the straight line passing through the nucleus and perpendicular to the direction toward the Earth, crosses the boundary of the comet's head.

The program creates images at a scale of 7 839 km/pixel. From this we can calculate how many kilometers correspond to the distance d of the simulation and compare it to that of the images. Experimenting with different particle

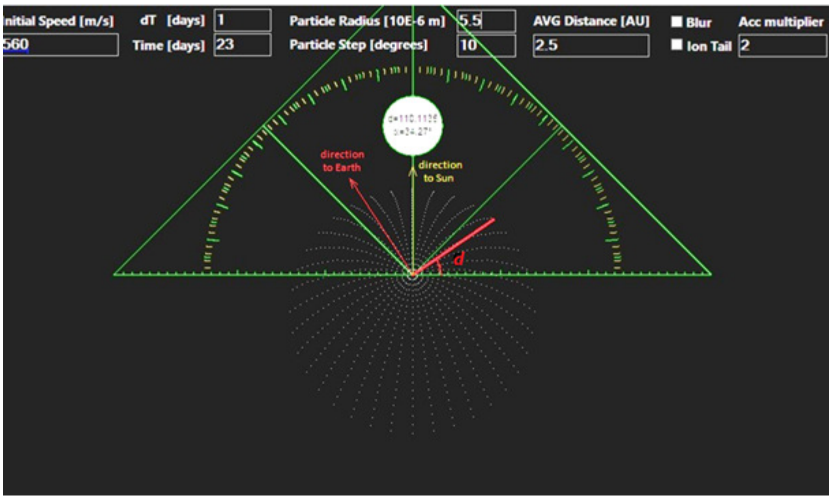

Fig. 7. Computer simulation of the comet Holmes.

sizes, we try to get the simulation data as close as possible to the actual comet's photos.

The parameter d (measured on the images) best corresponds to the value obtained from the simulations with a diameter of the particles equal to 11 μm for the extreme case of ice particles, and a diameter of 5.5 μm for the extreme case of porous rock particles. We can conclude that the particles ejected from the comet nucleus have a typical size of about $5 \div 10\,\mu m$. This is in a good correspondence with the sizes of the particles expelled by the comets, obtained by the Stardust spacecraft, which gathered and delivered to Earth particles from the tail of the comet Wild 2.

7 Comet gallery

After we estimated the sizes of the dust particles ejected by the comet Holmes, we made a series of simulations of hypothetical comets with different orbits and particle sizes ranging from 20 to 1 micrometers. On the simulated images the dust particles are white in color and the ion tail (not simulated but given only for illustration) is shown in blue.

On Fig. 8 a simulation of comet Holmes is given, and Fig. 9 shows one of the simulations of hypothetical comets.

8 Examination of the spatial distribution of the particles by size

After evaluating the particle sizes in the comet head, we also created a modified version of the computer simulation. It generates a comet model that shows particles not of single size, but with a whole range of sizes because in reality

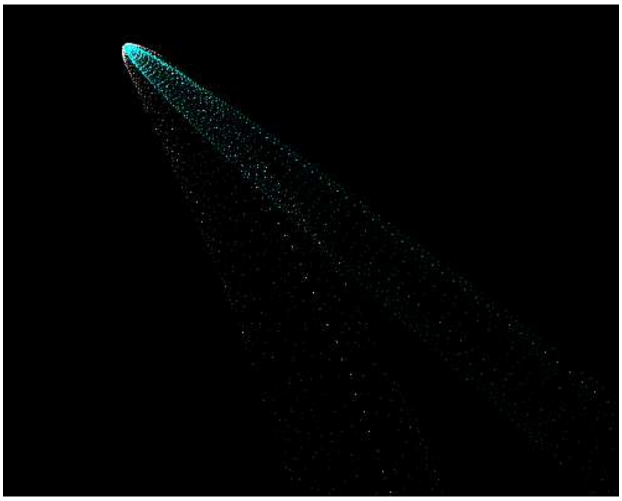

Fig. 8. Simulation of the comet Holmes.

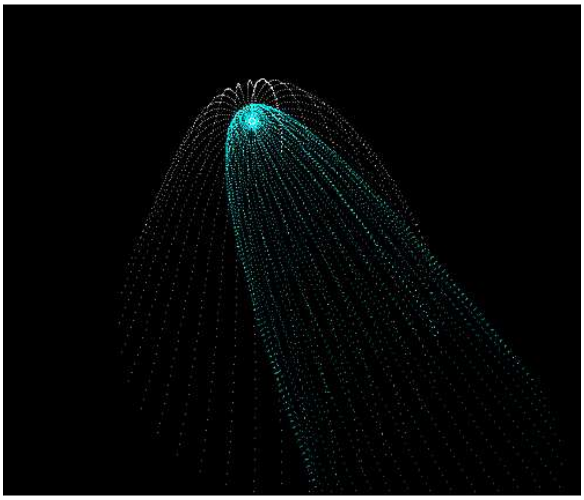

Fig. 9. Simulation of a hypothetical comet.

the particles are different. In the program we have to input the largest radius we want the particles to have and a step in micrometers for simulating the movement of particles with other radii, the smallest one being equal to 1 micrometer.

In the following simulations the largest particles (first three steps by size in the series) are depicted in blue color and the rest are in white (Fig. 10, 11, 12).

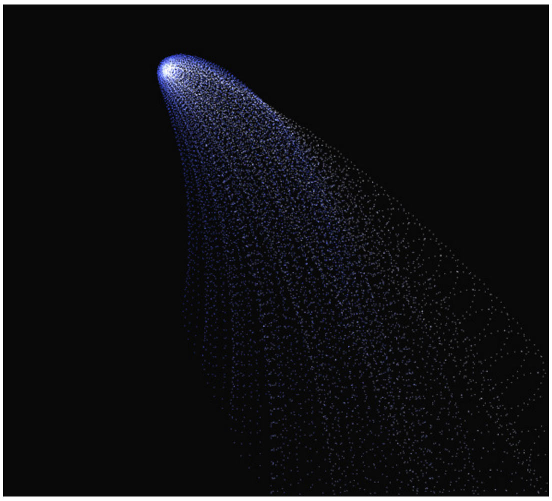

Fig. 10. Computer simulation for a period of 70 days of a hypothetical comet with an orbit similar to that of the comet Holmes. The radii of the particles range between 1 and 7 micrometers. The initial velocity of the particles is 460 m/s.

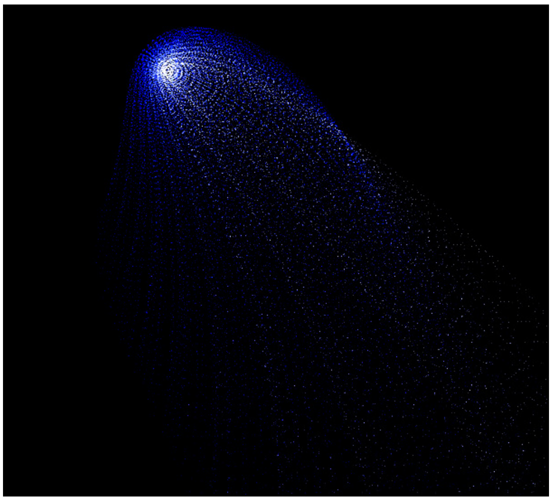

Fig. 11. Computer simulation for a period of 70 days of a hypothetical comet with an orbit similar to that of the comet Holmes. The radii of the particles range between 1 and 9 micrometers. The initial velocity of the particles is 700 m/s.

On all of these images, it is seen that the particles of smaller sizes (shown in white color), which get higher accelerations due to the radiation pressure, have less curved trajectories. These particles move faster away of the comet

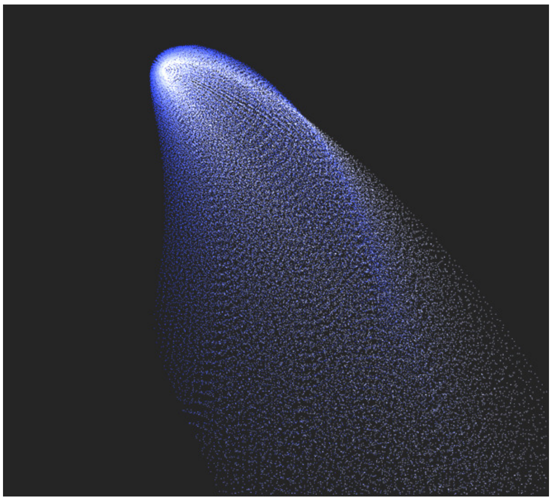

Fig. 12. Computer simulation for a period of 70 days of a hypothetical comet with an orbit similar to that of the comet Holmes. The radii of the particles range between 2 and 9 micrometers with a step of 0.3 micrometers. The initial velocity of the particles is 560 m/s.

nucleus. The larger particles (shown in blue) have more curved trajectories. They recede more slowly from the comet nucleus.

9 Program for a more accurate modeling of comets

The first program we created, was designed especially for modeling of the outburst of comet Holmes. We used the fact that within the period of the simulation the distance from the comet to the Sun does not change significantly. So the program didn't take into account the change of this distance. Also, we had in mind that in the time interval covered by the simulation, the dust particles ejected by the comet do not travel far away from the nucleus. Therefore, it was assumed that at each subsequent position in the course of their movement, the different particles are illuminated by sun rays coming from the same direction. Here we consider the direction from the Sun to the comet nucleus. This direction is inclined in the corresponding moment of time at a certain angle to the given initial direction in a reference frame fixed to the center of the comet nucleus.

As a next step we decided to create more precise models which apply to a situation when during the time of simulation the distance to the Sun and the position of the comet change significantly. Such is the case, for instance, with the comet McNaught which in the perihelion of its orbit is at a distance of 0.17 AU from the Sun and only a few days later it is already at 0.3 AU from the Sun. Here we have to take into account the change of the distance from each particle to the Sun and the fact that the particles are located at different positions and are illuminated by sun rays coming from different directions.

The new program works in a reference frame fixed to the Sun and not to the comet nucleus like the first one. At first, a file is created with data about the distance of the comet nucleus to the Sun and the comet's velocity along its orbit, given at consecutive moments of time which are separated by small intervals – time steps (in seconds). Based on these data, a special algorithm "places" the comet nucleus in positions with different coordinates. For each new position of the nucleus, a function is activated that creates a portion of particles which are expelled by the nucleus. The particles are spread in all directions. Their motion is defined taking into account the given initial velocity of ejection and the current velocity of the comet. Also, after creating the new portion of particles, for each new position of the comet nucleus, the algorithm reconsiders all the rest of the particles expelled in the previous moments. For each of these particles, the algorithm calculates the vector sum of its current velocity and the additional velocity, given to the particle due to the solar radiation pressure during the corresponding time step. When calculating the additional velocity the size of the particle and its distance to the Sun are taken into account. These parameters are related to the acceleration obtained by the particle from the solar photons that hit it. The new velocity is used for calculation of the new position of the particle at the next time step. During a certain time step it is assumed that the particle moves with a constant acceleration. The smaller the time steps are, the more precise is the simulation.

Another advantage of the new program is that the data in the initial file can be given with smaller time steps. In the first version of the program the minimal time step was one day. It was defined by the interval with which the comet's coordinates were given in the ephemeris data available.

So we needed an algorithm for calculating the initial comet ephemeris data with shorter time intervals (for example 4 hours). And we created an auxiliary program which, based only on the perihelion distance of the comet to the Sun and its perihelion velocity, calculates the parameters needed for the simulation with whatever small time step. The calculations of the comet's coordinates, used for the simulations presented here, give maximum deviation of 0.05 AU from the published ephemeris data.

9.1 Function for creation of new particles

The function used in the first program was constituted assuming that in each moment the comet expels equal number of dust particles in each direction. The particles could have various sizes, with a certain step between some given minimal and maximal size and the function created equal number of particles with each size.

The improved version of the program has significantly better capabilities helping us to create simulations which are very close to reality.

9.2 The particles are not ejected uniformly in all directions

In the more accurate model of the comet, it is supposed that the side of the comet nucleus which is illuminated by the Sun at some moment, ejects more particles due to the higher temperature. From the dark side, a given standard number of particles is expelled, multiplied by a certain coefficient K. Also, it is possible that some regions of comet nucleus are more active. This can be seen on the images of the comet Halley's nucleus, taken from a distance of 600 km by the Giotto spacecraft in 1986 (Fig. 13, left panel). In our model such an active sector can be defined with a certain size in degrees. This is because our simulated image is two dimensional and the active region is an arc of a circle. In fact, the image that is generated is a cross section of the comet with a plane coinciding with its orbital plane. Respectively, that active zone ejects the standard number of particles multiplied by a coefficient A. The coefficients A, K and the size of the active sector can be set in the program, as well as the rotational period of the comet T. On high resolution images of the comet Hale-Bopp we can see a jet of particles, expelled from a small active region, which is whirled into a spiral due to the rotation of the nucleus (Fig. 13, right panel).

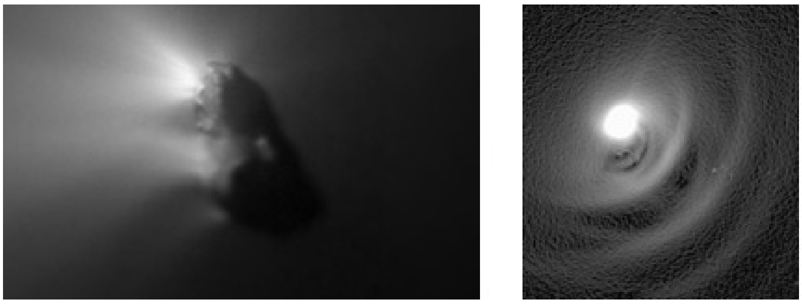

Fig. 13. [Left panel]: The nucleus of comet Halley photographed by Giotto spacecraft on 13 March 1986 (European Space Agency). [Right panel]: Spiral jet from the nucleus of the comet Hale-Bopp (Terry Jay Jones, 1997).

9.3 Calculating the number of particles ejected in a certain direction

Taking into account the rotational period of the comet nucleus and the time interval from the beginning of the simulation, for each direction in which the particles are ejected, the program can determine whether it ensues from the active sector of the nucleus and whether it is at the dark or the illuminated side. Based on this, the program calculates the full coefficient by which the standard number of particles ejected in this direction should be multiplied. Thus, for each direction from the nucleus the number of ejected particles is determined.

9.4 The ejected particles are not uniformly distributed by size

The number of ejected dust particles depends on their size exponentially by a power of -3.5 [5]. This has been set in the program and the number of ejected particles becomes smaller with the increasing of their size.

9.5 Color representation of the particles

Since the larger particles are brighter in the simulated image, the pixels representing the larger particles are brighter, and the pixels representing smaller particles are darker.

9.6 Option for various scales

When simulating different comets, we consider particles with different velocities at the moment of ejection. It is inappropriate to use the same scale, because the image may be too small, or not fit within the set boundaries. That is why it is possible to set a single scale in the program (how many meters correspond to one pixel).

For the creation of the new program we were inspired by the photographs of the magnificent comet McNaught. We supposed that the beautiful feather-like structure of its tale is obtained because of the periodical ejection of denser portions of particles from a certain active region of the rotating comet nucleus in the moments when this region is illuminated by the Sun.

Fig. 14. The comet McNaught photographed in January 2007 by S. Deines, European Southern Observatory, Chile.

10 Computer models, created by the more accurate program

We used the orbital elements of the erupting comets 174P/ Echelcus, ASASSN1 and 29P/Schwassmann-Wachmann 1, and the initial velocities of the particles ejected by their nuclei, which we determined from the images, and we created computer simulations of these comets.

With the comets Schwassman-Wachman and ASASSN1 (Fig. 15), the coefficient characterizing the number of ejected particles by the active sector was set equal to 1, because on the photographs of these comets we don't observe strips which would imply an existence of some active sector. Taken into account is only the coefficient characterizing the number of particles ejected by the dark side of the nucleus, which we assume to be equal to 0.2.

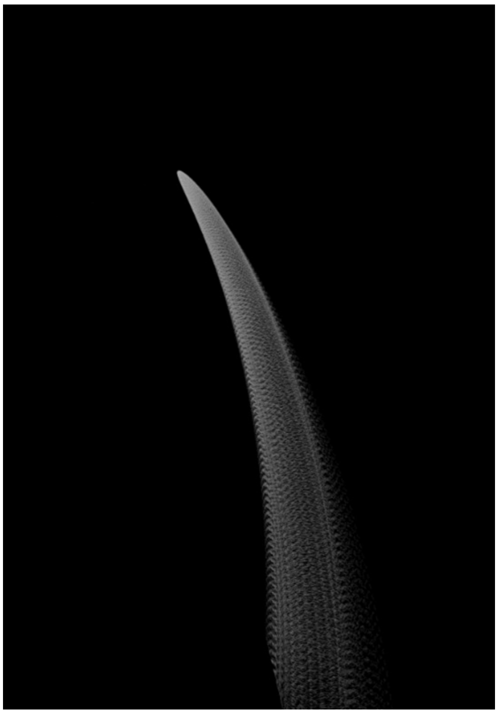

Fig. 15. Comet ASASSN1, scale 16 000 000 m/px, 60 days, initial velocity of ejected particles 468 m/s, with a higher concentration of the represented particles.

The comet McNaught is interesting because of the strips seen in its tail. We suppose that they are a result of the existence of an active sector on the comet's nucleus (part of its surface delivers significantly more particles than the rest of the surface). In the course of the nucleus rotation this sector is periodically illuminated by the Sun and expels more particles. That is how the subsequent lighter and darker strips in the comet's tail appear.

Little is known about this comet. The rotational period of the nucleus is unknown, as well as the initial velocity of the ejected particles. The orbital plane is highly inclined to the ecliptic, and this makes the calculations of the necessary parameters from the ephemeris data very difficult. We created several simulations of a hypothetical comet, moving along the orbit similar to that of the comet McNaught, for various intervals of time, various initial velocities and rotational periods. The initial velocities of ejected particles we used are mainly in the interval $200 \div 500\,\mathrm{m/s}$. Some of the simulations are made with lower initial velocities, but due to the fact that at perihelion the comet is as close as at only 0.171 AU to the Sun, it should be heated more efficiently and after the dust particles are ejected from the comet nucleus, the radiation pressure that accelerates them in the antisolar direction should be higher (Fig. 16, 17, 18).

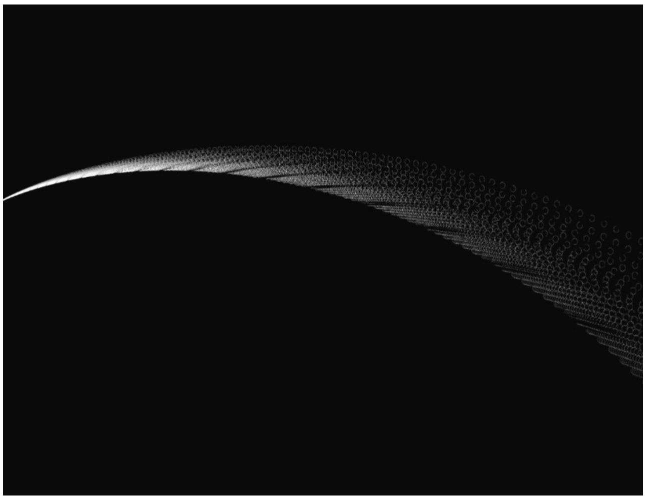

Fig. 16. Hypothetical comet moving along the orbit of the comet McNaught, scale 26 000 000 m/px, 20 days after perihelion, initial velocity of ejected particles 255 m/s, rotational period 0.6 days.

11 Conclusions

We made measurements on a series of 14 photographs of the comet Holmes, and we determined initial velocity of the expelled particles $V_0 = 560\,\mathrm{m/s}$, which is in good agreement with the data from other sources.

We developed a mathematical model of the influence of the solar radiation pressure on the cometary dust particles, based on which we created a computer program simulating the movement of the particles, the shape and size of the comet's coma and tail.

With the help of the program, using the results of our measurements on the comet's photographs, and varying the particles' sizes, we determined the value of their size, which fits best to the photographic observational data. Thus, we obtained an estimate of the typical particle size – about $5.5 \div 11$ micrometers. Despite the approximations we made, our results are in agreement with the data, obtained by the astronomers exploring the comets [9].

We made beautiful simulations of hypothetical comets, as well as more complicated simulations involving comet particles of different sizes. The images

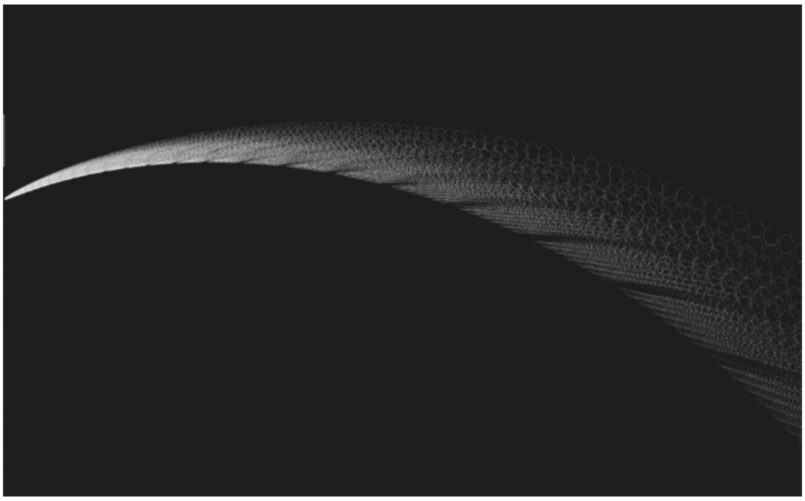

Fig. 17. Hypothetical comet moving along the orbit of the comet McNaught, scale 26 000 000 m/px, 20 days after perihelion, initial velocity of ejected particles 555 m/s, rotational period 0.6 days.

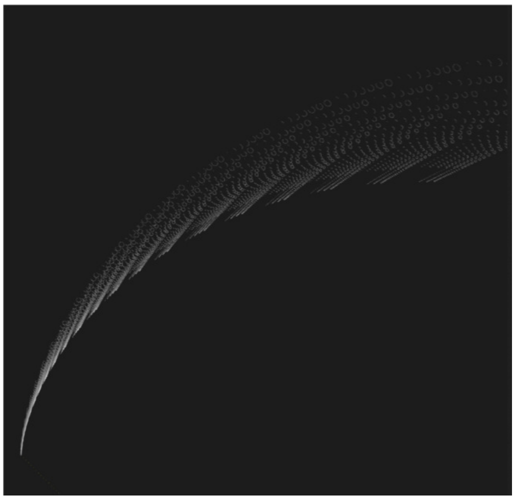

Fig. 18. Hypothetical comet moving along the orbit of the comet McNaught, scale 13 000 000 m/px, 8 days after perihelion, initial velocity of ejected particles 255 m/s, rotational period 0.3 days. The particles ejected from the nucleus have sizes from 0.1 to 9 micrometers varying with a step of 0.1 micrometers. The active sector produces three jets located at an interval of 15° from each other. The particles from each jet have an angle of scattering of 3°.

we produce show that the larger and more massive dust particles stay nearer to the comet's orbit, and the lighter ones move away faster, because under the action of the solar radiation pressure they get higher accelerations.

With the more accurate program we were able to take into account the different values of the accelerations given to the cometary dust particles by the solar radiation pressure, depending on their different positions relative to the comet nucleus and their different distances to the Sun. We considered also the rotation of the nucleus, as well as the possible existence of more active and less active regions on its surface. We took into account the uneven distribution of the particles by sizes. We obtained computer simulations of the comets ASASSN1 and 29P/Schwassmann-Wachmann 1. Then we simulated the feather-like structure of a hypothetical comet, similar to the comet McNaught.

The program can be used for modeling of real comets, for study of the parameters of the rotation of their nuclei and the mechanisms of ejecting of dust particles.

The simulations of the comet McNaught support the idea that the strips may be created because of the rotation of the comet and the existence of active regions.

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