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Activity in the Imphotep region on comet 67P/Churyumov – Gerasimenko: dynamics of slow ejecta and landslides

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Abstract

In this work we investigate slow ejecta from comet 67P/Churyumov–Gerasimenko. We calculated trajectories of the ejecta from the Imhotep region, the locations of their deposition and stability of the deposited material. For initial velocity ~0.6 m s^{-1} the ejecta are deposited mainly on the Northern Hemisphere contrary to the ejecta from depression Hatmehit that are deposited mainly on the Southern Hemisphere.

1. Introduction:

Rosetta mission has indicated the activity in several sites of nucleus of comet 67P/Churyumov–Gerasimenko [1]. In present research we investigate trajectories of ejecta from depression Imhotep.

Comets and other small celestial bodies have very weak gravity field, so it was believed that probability of slope instability is low there. Even low cohesion could prevent instability. However, data from space missions to comets 9P/Tempe 1 and 67P/CG revealed existence of such instabilities. Large inclination of slopes in respect to the gravity makes instability more probable.

According to our best knowledge it is the first paper which treats about: (a) trajectories of slow ejecta from the Imhotep region, (b) places of their deposition, and (c) stability of these deposits.

2. Endogenic activity and ejecta

According to [2] an endogenic activity is responsible for formation of depression Hatmehit. Transformation of amorphous ice into crystalloid hexagonal ice could provide some heat that leads to vaporization of volatiles. Eventually a cavity is formed where the pressure of gas could reach a few dozens of Pa. If the pressure exceeds a critical value the upper crust could be crushed and its parts could be ejected into space. Their velocity could be lower than the escape velocity (therefore we use the term slow ejecta for them). Note also that initial velocity vector tends to be approximately perpendicular to the surface of the comet (the pressure force is perpendicular to the surface).

The flow of gas in cracks is another possible mechanism of grains' acceleration [3]. The gas can flow with the sound velocity (i.e. ~300 m s^{-1}). The velocity of grains in such jet depends on their size. Very small particles (dust) can reach high velocity but large grains cannot reach high velocity as a result of this mechanism. Both considered mechanisms of acceleration lead to segregation of the grains (the larger ones are usually slower). The details of the mechanism responsible for origin of ejecta is not critical for the present considerations.

3. Gravity field of the model

Model of gravity developed by [4] is used. It is based on the shape model published by ESA (given by 45994 faces and 24997 vertices). The distribution of mass is approximated with the use of 21890 spherical masses. Fig. 1 presents the distribution of masses (enveloped in the green surface). It should be noted that the shape of the nucleus does not resemble the shape of any surface with a constant value of the gravitational potential.

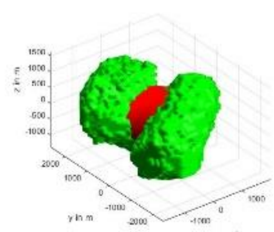

Fig. 1. The assumed mass distribution in the comet (the green volume) and the surface of the constant gravitational potential value: (red) for -0.45 $m^2 s^{-2}$. Note non-spherical shape of the red surface. After [4].

On the highly asymmetric comet determination of the slope of the surface is not a trivial problem – e.g., [5]. [3] found that the most of the surface (~74%) has the slope in the range $0< \alpha<40^o$. The slope in the range $40^o < \alpha<70^o$ is found on ~17% of the surface and on ~6% of the surface the slope is $70^o < \alpha<90^o$.

4. Equation of motion

To investigate the motion of ejecta we use Newton equation for motion in a non-inertial frame of reference in the form:

$$\frac{d\boldsymbol{v}}{dt} = \boldsymbol{g} - 2\boldsymbol{\omega} \times \boldsymbol{v} - \boldsymbol{\omega} \times (\boldsymbol{\omega} \times \boldsymbol{r}), \qquad (1)$$

where $\boldsymbol{v}$ is the velocity, $\boldsymbol{g}$ is the local gravity, $\boldsymbol{\omega}$ is the angular velocity of comet and $\boldsymbol{r}$ is the position of the ejecta. The equation is solved numerically using the standard Runge-Kutta method.

5. Results and conclusions

We performed calculations for the following velocities of ejecta: 0.3, 0.4, 0.5, 0.6, 0.7 m s^{-1}. Fig. 2 shows the trajectories of the grains ejected vertically (relative to the local physical surface) from 15 points inside the Imhotep region at the speed of 0.6 m s^{-1}. Please note that the most landing sites are situated on the large lobe (Body) of the comet.

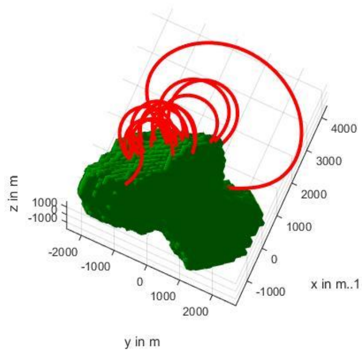

Fig. 2. The trajectories of matter (red lines) ejected vertically (relative to the physical surface) from chosen 15 sites inside the Imhotep region at the speed of 0.6 m s^{-1}.

Fig. 3 presents 145 starting points (red points) and the corresponding distribution of landing points for the speed 0.6 m s^{-1}. Moreover, landing sites are supplemented with information about the angle of fall (see the caption). Low angles (yellow marks) indicate stable position of deposits. Large angles (cyan marks) indicate that ejecta after landing are unstable and they could give rise to a landslide.

Note that the neck of the comet is a region of low gravitational potential, so it is a natural place for stable deposits (independent of discussed angles).

[6] performed similar calculations for ejecta from depression Hatmehit. Comparison of both calculations enables us for a few interesting conclusions:

(1) At the same speed, ejecta from the Imhotep region fell closer than from the depression Hatmehit, which is due to the higher mass of lobe Body compared to Head.

(2) Ejecta from the Imhotep region move on a trajectory directed towards the Northern Hemisphere and they are deposited there. Therefore, probably the ejecta from the Imhotep region are not substantially responsible for depositions in the Southern Hemisphere.

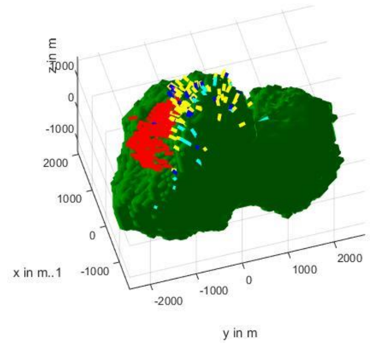

Fig. 3. The starting 145 sites inside the Imhotep region (red marks) and landing sites for ejectas (with the speed 0.6 m s^{-1}). Colors give information about the angles of the fall (i.e. angle between the velocity vector and normal to the surface) and inclination of the ground at the site of landing. The ranges of angles are given by the colors: 0^o - 30^o (yellow marks), 30^o - 45^o (blue marks), 45^o - 80^o (cyan marks), and other (magenta marks).

(3) Depositions of ejecta from the Imhotep region are generally less stable than depositions from Hatmehit.

We hope that determination of the place of origin of the surface deposits could be useful for choosing the objectives of the research goals of the CAESAR mission.

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