EPSC Abstracts
Vol. 6, EPSC-DPS2011-586, 2011
EPSC-DPS Joint Meeting 2011

Cavities as a source of outbursts from comets

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Abstract

Observations of natural and triggered outbursts from different comets testify in favor of existence of large cavities with material under gas pressure below a considerable fraction of comet's surface. Ejection of observed particles from Comet 9P/Tempel 1 after the collision of the impact module of the Deep Impact spacecraft with the comet was greater than theoretical estimates. The difference was caused by the outburst triggered by the impact. The excavation of a relatively large cavity began at 8 s after the impact.

1. Introduction

In 2005 the impact module of the Deep Impact (DI) spacecraft collided with Comet 9P/Tempel 1 [1]. Based on analysis of images of the cloud of ejected material made by the DI flyby spacecraft during the first 13 min after the impact, Ipatov and A'Hearn [4] studied the time variations in the rate and velocities of ejection of observed particles (mainly with diameter d<3 μm). These variations differed from those for the model based on theoretical studies of impact events and can give information about composition of the comet. We studied the motion of small particles with velocities greater than the escape velocity. These particles constituted a small part of the total mass of all ejected material, but contributed much to the brightness of a cloud of ejected material.

2. Triggered Deep Impact outburst

Analysis of maxima or minima of plots of the time variations in distances R of contours of constant brightness from the place of ejection (at R>1 km, i.e. outside of regions of saturated pixels) allowed us to estimate the characteristic velocities of particles at several moments in time t_e of ejection after impact for $t_e \leq 115$ s [4]. Other approaches for estimates of the velocities were also used. All these estimates are in accordance with the same exponential decrease in characteristic velocity (with exponent about -0.7). Analysis of time variations in the size of the bright region of ejected material allowed us to estimate the time variations in the relative amount of observed ejected particles. There was a local maximum of the rate of ejection at t_e~10 s with v_p~100 m/s. At the same time, the considerable excessive ejection in a few directions (rays of ejecta) began, there was a local increase in brightness of the brightest pixel, and the direction from the place of ejection to the brightest pixel quickly changed by about 50°. In images made during the first 12 s and after the first 60 s, this direction was mainly close to the direction of the impact. Between 8 and 60 seconds after the impact, more small bright particles were ejected than expected from crater excavation alone (e.g. [2]). An outburst triggered by the impact could cause such a difference. The sharp (by a factor of 1.6) decrease in the rate of ejection at $55<t_e<72$ s could be caused by a decrease in the outburst that began at 8-10 s. Our studies did not allow us to estimate accurately when the end of ejection occurred, but they do not contradict a continuous ejection of material during at least the first 10 minutes after the collision. The duration of the outburst (up to 30-60 min) could be longer than that of the normal ejection, which could last only a few minutes.

3. Cavities with dust and gas under pressure

Our studies of the DI outburst testify in favor of that there were cavities at the place of the DI ejection. The beginning of the increase of the main outburst at 8 s after the DI impact could be caused by excavation of a relatively large cavity that contained dust and gas under pressure. The upper boarder of the cavity could be located at about 5-10 meters below the surface of the comet [3]. This cavity could be deep because the excavation from the cavity could last for at least a few tens of seconds. With the increase of the crater, more cavities could be excavated. The distances from the upper borders of large cavities to the surface of a comet of about 5-10 m, and sizes of particles inside the cavities of a few microns obtained for Comet Tempel 1 are in a good agreement with the results obtained by Kossacki and Szutowicz [5], who made calculations for several models of explosion of Comet 17P/Holmes. Porosity of comets (0.6 g/cm^3 for Comet Tempel 1, according to [1]) also testifies in favor of existence of cavities.

The 'fast' DI outburst with velocities ~100 m/s probably could continue for at least several tens of seconds, and it could significantly increase the fraction of particles ejected with velocities ~100 m/s compared with theoretical models of ejection (see e.g. [2]). Velocities of outburst particles ejected from several other comets were also ~100 m/s.

Besides the 'fast' outburst caused by ejection from cavities, there was a 'slow' outburst ejection, which was similar to the ejection from a 'fresh' surface of a comet and could be noticeable during 30-60 min. The outburst ejection could have come from the entire surface of the crater, while the normal ejection was mainly from its edges.

The triggered DI outburst was one of many other outbursts of comets. The DI spacecraft observed natural outbursts from Comet Tempel 1. Analysis of observations of the DI cloud and of outbursts from different comets (see references in [3-4]) testifies in favor of the proposition that there can be large cavities, with material under gas pressure, below a considerable fraction of a comet's surface. Internal gas pressure and material in the cavities can produce natural and triggered outbursts and can cause splitting of comets.

It is usually considered (see references in [3]) that the main sources of gas pressure are crystallization of amorphous ice in the interior of porous nucleus, water ice sublimation, and sublimation of a more volatile ice such as CO or CO_2 at a lower temperature than required for water ice. Several other potential mechanisms of outbursts are also discussed: (a) the polymerization of hydrogen cyanide HCN; (b) thermal stresses; (c) and anneling of the amorphous water ice; (d) meteoritic impacts.

4. Summary and Conclusions

Observations of natural and triggered outbursts from different comets testify in favor of existence of large cavities with material under gas pressure below a considerable fraction of comet's surface. Ejection of observed (mainly with diameter d<3 μm) particles from Comet 9P/Tempel 1 after the collision of the impact module of the Deep Impact spacecraft with the comet was greater than theoretical estimates. The difference was caused by the outburst triggered by the impact. The excavation of a relatively large cavity began at t_e≈8 s after the impact. This cavity could be deep because the excavation from the cavity could last for at least a few tens of seconds. The beginning of the main excavation of the cavities at t_e~8 s shows that the upper boarders of the cavities could be located at about 5-10 meters below the surface. The outburst decreased at ~60 s after the impact. Besides the 'fast' outburst caused by ejection from the cavities, there was a 'slow' outburst ejection, which was similar to the ejection from a 'fresh' surface of a comet and could be noticeable during 30-60 min. The 'fast' outburst with velocities ~100 m/s probably could continue for at least several tens of seconds. It could significantly increase the fraction of particles ejected with velocities ~100 m/s compared with the theoretical models.

Acknowledgements

This research was supported in part by American Astronomical Society's Small Research Grant Program.

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