DEEP IMPACT EJECTION FROM COMET TEMPEL 1 AS A TRIGGERED OUTBURST. S. I. Ipatov[1] and M. F. A'Hearn, [1]Catholic University of America, Washington, DC, siipatov@hotmail.com, [2]University of Maryland, College Park, MD, ma@astro.umd.edu.

Analysis of images: In 2005 the Deep Impact (DI) impactor collided with Comet 9P/Tempel 1 [1]. Our studies [2] of time variations of the projections v_p of characteristic velocities of ejected material onto the plane perpendicular to the line of sight and of the relative rate r_{te} of ejection (mass ejected per second) were based on analysis of the images made by the DI cameras during the first 13 min after the DI collision with the comet. We considered velocities of the particles that give the main contribution to the brightness of the cloud of ejected material, i.e. mainly of particles with diameter d<3 μm.

Below we present mainly only conclusions obtained. Details of studies and more figures and references are presented in [2]. We analyzed the sizes of regions inside different levels of CPSB (calibrated physical surface brightness) at different times, paying particular attention to the studies of local maxima and minima of the sizes for different levels of brightness and different series of images (Fig. 1). Based on this analysis, we calculated the relative rate r_{te} of ejection at different times t_e of ejection for the model in which characteristic velocities v_{expt} of the edge of the observed bright region (usually with CPSB greater than 3) at time t are proportional to $t^{-\alpha}$. Theoretical values of α are between 0.6 and 0.75 [3]. The plots of the rate for four values α between 0.6 and 0.75 are presented in Fig. 2. In Fig. 3 we present the relative volume f_{ev} of material ejected with velocities greater than v vs. v for the same model as above. Theoretical values of the rate and the relative volume are proportional to $t^{0.2}$ and v^{-2} at α=0.6 and to $t^{-0.25}$ and v^{-1} at α=0.75 [3].

Conclusions: The rates and velocities of material ejected after the DI impact were different from those for experiments and theoretical models. Holsapple and Housen [4] concluded that the difference was caused by vaporization of ice in the plume and fast moving gas. In our opinion, the greater role in the difference could be due to the outburst triggered by the impact. This outburst was maximum at time t_e of ejection ~10 s. Instead of monotonic decrease predicted by theoretical models, there was a local maximum of the rate of ejection at ~10 s (Fig. 2) with typical projections of velocities v_p~100-200 m/s. At the same time, considerable excessive ejection to a few directions (rays of ejecta) began, the direction to the brightest pixel quickly changed by about 50° (the direction was mainly close to the direction of the impact in images made during the first 10-12 s; after the jump it slowly became closer to the direction of the impact, Fig. 4), and there was a local increase of brightness (Fig. 5).

There was a maximum of production of observed ejected material at time of ejection t_e~0.6 s (Fig. 2). Due to the outburst, at t_e~1-60 s the rate of ejection was mainly greater than for theoretical models. There could be a sharp decrease of the outburst at t_e~60 s. Our studies do not allow one to estimate accurately the time of the end of ejection. They do not contradict to a continuous ejection of material during at least 10 minutes after the collision.

Comparison of the observed DI ejection with theoretical models shows that after the first second the ejection was mainly governed by momentum, and the observed time dependence of velocity was close to theoretical estimates for sand or dry soil. Material of the nucleus ejected during the first second could be more solid. Our studies testify in favor of a model close to gravity-dominated cratering, i.e. in favor of greater amounts of ejected material and a greater size of the crater.

Projections of velocities of most of observed material ejected at t_e~0.2 s were about 7 km/s. Some particles ejected during the first three seconds had velocities greater than 1 km/s. As the first approximation, the time variations of characteristic velocity at t_e>1 s can be considered to be proportional to $t_e^{-0.75}$ or $t_e^{-0.71}$, but they could differ from this exponential dependence. Our estimates of projections of mean velocities of the fast material that mainly contributed to the brightness of the observed dust cloud onto the plane perpendicular to the line of sight are ~100-200 m/s and are in accordance with the previous estimates based on various ground-based observations and observations made by space telescopes. The fractions of bright material ejected (at t_e≤6 s, t_e≤15 s, and t_e≤100 s) with v_p≥200 m/s, v_p≥100 m/s, and v_p≥30 m/s were estimated (Fig. 3) to be about 0.07, 0.2, and 0.5 respectively, if we consider only material observed during the first 13 min.

The excess ejection of material to a few directions (rays of ejected material) was considerable during the first 100 s, took place during several minutes, and was still observed in images at t~500-770 s. It shows that the outburst continued after 60 s and could be at t_e~10 min. The sharpest rays were caused by material ejected at t_e~20 s. In particular, there were excessive ejections, especially in images at t~25-50 s after impact, in directions perpendicular to the direction of impact. Directions of excessive ejection could be different at different time intervals.

The work was supported by NASA DDAP grant NNX08AG25G.

References:

[1] A'Hearn M. F. et al. (2005) *Science*, 310, 258-264.
[2] Ipatov S. I. and A'Hearn M. F. (2008) submitted to *Icarus*, http://arxiv.org/abs/0810.1294 .
[3] Housen K. R. Schmidt R. M., Holsapple K. A. (1983) *J. Geophys. Res.*, 88, 2485-2499.
[4] Holsapple K. A. and Housen K. R. (2007) *Icarus*, 187, 345-356.

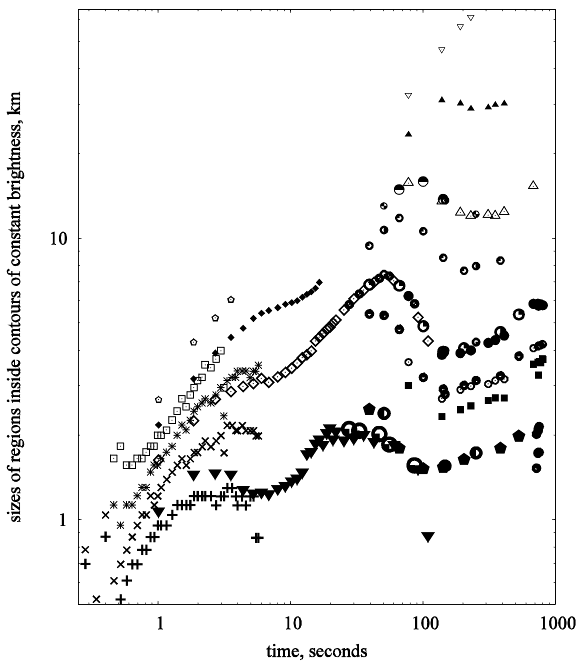

Fig. 1. Time variations of sizes L (in km) of regions inside contours of CPSB=C. Different signs correspond to different series of images at different C. The curves have local minima and maxima that were used for analysis of time variations of velocities.

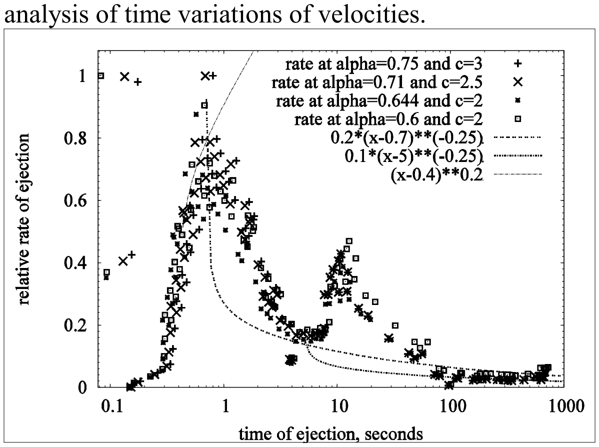

Fig. 2. Relative rate r_{te} of ejection at different times t_e of ejection for the model in which the characteristic velocities of the edge of the observed bright region at time t are equal to $v_{expt}=c\times(t/0.26)^{-\alpha}$ (in km/s), for four pairs of α and c. Three curves of the type $y=c_r\times(x-c_t)^{\beta}$ are also presented for comparison.

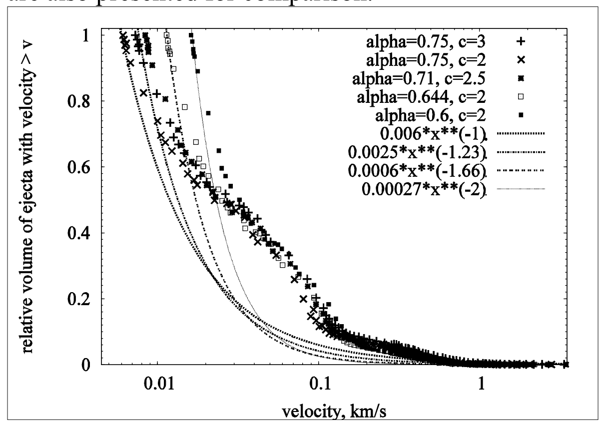

Fig. 3. Relative volume f_{ev} of material ejected with velocities greater than v vs. v for the model in which characteristic velocities of the edge of the observed bright region at time t are equal to $v=v_{expt}=c\times(t/0.26)^{-\alpha}$ (in km/s), for five pairs of α and c. $f_{ev}=1$ for material ejected before t_e corresponding to the edge of the bright region at t=803 s. Four curves of the type $f_{ev}=c_r\times x^{\beta}$ are also presented for comparison.

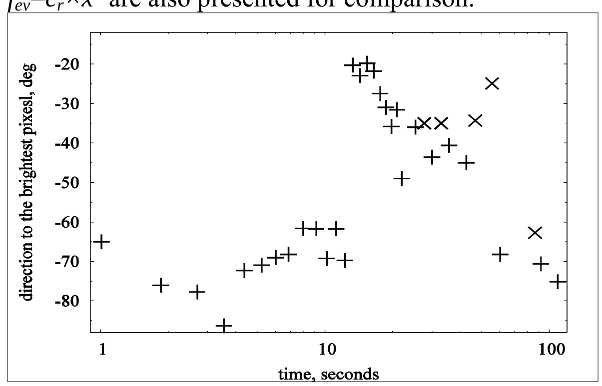

Fig. 4 The angle (in degrees) of the direction from the place of ejection to the brightest pixel at a current time. The angle corresponding to the direction of the impact was about -60°.

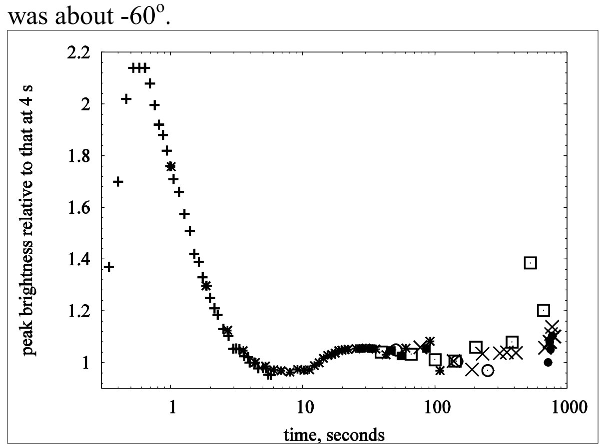

Fig. 5. Variation of the relative brightness Br of the brightest pixel with time t (in seconds). Br=1 at t=4 s.