VELOCITIES OF MATERIAL EJECTED AFTER THE DEEP IMPACT COLLISION. S. I. Ipatov, *Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D.C.* (siipatov@hotmail.com), M. F. A'Hearn, *University of Maryland, College Park, MD*.

1. Introduction: Evolution of the cloud of material ejected after the impactor collided with Comet Tempel 1 [1] was observed by Deep Impact (DI) cameras, by space telescopes (e.g., Rosetta, Hubble Space Telescope, Chandra, Spitzer), and by over 80 observatories on the Earth. The values of the mean fastest projected ejecta velocity v_m were about 110-125 m/s, 150-200 m/s, 230 m/s, 200-260 m/s, and 150 m/s for observations made 1-2 h, 4 h, 15 h, 20-24 h, and 40 h after the impact.

In contrast to the papers based on ground-based observations and observations made by spacecraft other than DI, we obtained similar values of the mean fastest projected ejecta velocity v_m based on images made by DI cameras during the first 7 minutes. Based on analysis of three images made by the DI camera at time t~8-15 s, Ipatov and A'Hearn [2] concluded that the projection of velocity of the brightest material onto the plane perpendicular to the line of sight was ~100 m/s. Studies presented below are based on many more DI images made at t<7 min. At t≤20 s we analyzed not the images themselves as it was done in [2], but the differences in brightness between the images and the image made just before the impact.

Based on analysis of DI images, we discuss the amount of material and typical velocities of particles ejected at different times. For studies of such amounts and velocities, other authors used other observations, theoretical models, and laboratory experiments. The velocities that we consider, likely correspond mainly to small (<2 μm) icy particles, which give the main contribution to the brightness. Velocities of large particles can be different from these velocities. It is considered that maximum velocities of particles with radius a are proportional to a^{-1}, i.e., more massive particles move slower. Therefore the contribution of slow moving particles to the brightness of the cloud of ejected material was smaller than their contribution to the mass of the cloud, and this difference can explain why slow moving material was not well observed. Except as othervise noted, below we discuss projections v_p of velocities on the plane perpendicular to a line of sight, but not the velocities themselves.

2. Images considered: Our studies were based on analysis of reversibly calibrated (RADREV) images made by DI cameras. The images made by MRI (Medium Resolution Instrument) and HRI (High Resolution Instrument) can be found on the website of the Small Bodies Node of the Planetary Data System (e.g., http://pdssbn.astro.umd.edu/holdings/dif-c-mri-3_4-9p-encounter-v2.0/dataset.html). We analyzed several series of images made by the same camera with the same total integration time (INTTIME). A CLEAR filter was used for all these images. Considered time t corresponds to the middle of the exposure. Our studies were based on analysis of the contours of constant calibrated physical surface brightness (hereafter CPSB, always in W m^{-2} sterad^{-1} micron^{-1}) of a cloud of ejected material. Conclusions presented below are based on analysis of the plots that can be found on http://www.dtm.ciw.edu/ipatov/dps2007.ppt. Our paper with more detailed studies will be submitted to Icarus, and will be put on arxiv.org after the submission. In some cases below we present only conclusions, and details of the analysis will be presented in the paper.

3. Velocities of material ejected during the first five seconds after the impact: Results presented in this section are based on analysis of MRI images. The maximum brightness (i.e., CPSB of the brightest pixel) on an MRI image has peaks at t~0.22-0.28 s and at t~0.46-0.7 s. The peaks correspond to the increase of ejection of material per unit of time.

Velocities of most of observed material ejected at t~0.2 s were about 10 km/s. In our opinion, conservation of energy limits the mass with such velocities to less than the mass of the impactor. At t=0.34 s the maximum brightness was smaller by a factor of two than at t=0.28 and t=0.4 s. One possible explanation of the decrease in the maximum brightness is that a considerable fraction of the brightness at t~0.22-0.28 s was due to the light from the hot place of impact. More likely, the ejecta were very hot and cooled rapidly. In images at t=0.34 s and t=0.4 s, there are two spots of ejected material corresponding to two different ejections. The first flash can be associated with vaporization of the impactor and part of the comet. The second flash may be associated with the first eruption of material at the surface.

Our estimates show that some material ejected at t<0.5 s had velocities of about several km/s. Some particles ejected during the first three seconds had velocities greater than 1 km/s, but the contribution of such material to the total amount of material ejected after the impact was small.

All CPSB contours enclose a greater area at t=2 s than at t=1 s, i.e., for the same coordinates, any point at t=2 s is brighter than at t=1 s. All contours of a given brightness expand if there is continuously increasing ejection per unit time. Therefore the amount of material ejected during the 2nd second could be greater than during the first second, but such contours can be also caused by higher velocities of particles during the first second.

Regions with CPSB>3 did not differ much at $2 \leq t \leq 5$ s (the maximum diameter of such region corresponds to about 1.7 km), so the production of dust did not differ much during this time interval because the above regions should disappear without continuous supply. Regions with CPSB>1 did not depend on time at $3 \leq t \leq 5.7$ s., and at CPSB equal to 0.3 and 0.1, the contours moved from the place of the impact with time. The contour CPSB=0.1 moved with $v_p \approx 1$ km/s during $1 \leq t \leq 3$ s (each time the contour corresponded to parts of the cloud consisted of different particles, most of which moved with a greater velocity than the contour). Therefore real typical velocities of particles at such distances probably exceeded 1.5 km/s and could be ~2 km/s, and during the first 3 seconds there was material moving with $v_p > 1$ km/s. Ground-based observations made a few hours after the impact did not show a considerable amount of material ejected at such velocities. The maximum observed velocities of the outer part of the cloud were about 600 m/s. It shows that the total mass of material with $v_p > 1$ km/s was small compared to the mass of all ejected material (i.e., most of material was ejected after the third second). Spectral observations showed that there was a lot of water among ejected material. Therefore some ice particles ejected at high velocity have evaporated by the time Earth-based observers saw the cloud.

The distance of the contour CPSB=0.3 from the place of impact increased until t=3 s (with v_p about 1 km/s during the 2nd second and 0.4 km/s during the 3rd second), then it was about the same until t=5.7 s. The fact that the contour was not father from the origin for t>3 sec does not necessarily mean that the dust production decreased. It could equally well be explained by a steep decrease in the ejection velocity. The central pixels are probably optically thick at this time, so the amount of dust is likely not linearly related to the brightness.

4. Velocities of material ejected 5-400 seconds after the impact: Our studies of ejection velocities at t~5-400 s were based on analysis of CPSB contours in HRI and MRI images. These studies do not allow one to estimate accurately the time when ejection was finished. They do not contradict to a considerable continuous ejection of material during 7 minutes after the collision, but this time can be smaller. The amount of particles with d<2 μm ejected per unit of time probably mainly decreased with time t after the 4th second after the ejection, but this decrease could be slower at t~6 min or may be there was even a local increase of ejection rate at t~6 min (contours CPSB=3 enclose a greater area in images made at t~6 min than at t~1-2 min).

The contours CPSB=1 and CPSB=0.3 moved with $v_p \approx 60$-80 m/s at $8<t<20$ s. These data show that the amount of material ejected per unit of time at $8<t<20$ s could be greater than that at $4<t<8$ s. The contours CPSB=3 were practically the same at $25 \leq t \leq 43$ s and they enclose a greater area than those at t~1-2 s. It shows that the rate of ejection did not vary much at t~20-40 s.

Velocities of most of material that contributed to the brightness of the cloud and was ejected at t>4 s were smaller by an order of magnitude than those at t<1 s (hundreds of m/s instead of several km/s). Projections of mean velocities of the fastest material that mainly contributed to the brightness of the observed dust cloud onto the plane perpendicular to the line of sight were ~200 m/s and are in accordance with various ground-based observations and observations made by space telescopes.

Positions of the brightest pixel at t~4-12 s differ from positions at t~16-20 s. It can mean that direction of ejection could change at t~12-16 s. Direction from the place of impact to the brightest pixel does not depend on t for MRI images at $1 \leq t \leq 5.7$ s and for HRI images at $25 \leq t \leq 43$ s, but at t=109 s it was another than at $25 \leq t \leq 43$ s.

At v_p>100 m/s and t~1-100 s, velocities v of material ejected at time t can be considered proportional to $t^{-0.6}$, as it is predicted in [3], but ejection with v_p>100 m/s could last for a longer time interval than it is predicted by theoretical models [3-4], could take place when there was ejection with smaller velocities, and might continue up to the late stages of crater formation. Analysis of DI observations testify in favor of that particles with different velocities and masses could be ejected at the same time.

The excess ejection of material to a few directions (rays of ejected material) took place mainly during the first 100 s.

In our future studies we will integrate the motion of particles ejected at different velocities and will compare the variation of brightness of the model dust cloud with distance from the impact, with the variation in images obtained at observations.

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References:

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