VELOCITIES OF MATERIAL EJECTED FROM COMET TEMPEL 1. S. I. Ipatov, M. F. A'Hearn, and Deep Impact team, University of Maryland, College Park, MD 20740-2403.

Introduction: On July 4, 2005 the impactor (370 kg) collided with the comet 9P/Tempel 1 at velocity of 10.3 km/s [1]. It was an oblique impact, and the angle above the horizont was about 20-30 degrees. The Deep Impact (DI) team and ground-based observers concluded that most of ejected material consisted of particles of about 1 to 10 microns. Large debris were not seen among the ejected material. Similar ejection of material takes place when a small body collides with a comet. Keller et al. [2] studied velocities of particles after the DI collision based on *Rosetta* observations.

Considered images: Below we study the brightness of a cloud of ejected material on calibrated MRI (Medium Resolution Instrument) images made several seconds after the impact on comet 9P/Tempel 1 during the Deep Impact mission. In order to make more accurate conclusions on brightness, on some images we didn't consider pixels with brightness less than some limit. This allowed us to use higher-contrast images. For example, on Figs. 1a and 2a one can see original MRI images made t=7.67 and t=15.6 seconds after the impact, respectively (these times are smaller than those considered in [2]). On Figs. 1b and 2b only pixels with values of calibrated physical surface brightness (CPSB) greater than constant lim=0.01 are presented (the maximum value of CPSB for these images is 6.42 and 6.86, respectively). On the original image, pixels with CPSB=0.01 look similar to those with CPSB=0.

For several values of lim (3, 1, 0.3, 0.1, 0.03, 0.01, 0.003, in the same units as CPSB) and several values of time t after the impact, we calculated the distance dx of the values of x corresponding to the right edge of the cloud at CPSB>lim from the value of x corresponding to the place of impact. We also considered the difference dy between the value of y corresponding to the lower edge of the cloud at CPSB>lim and the value of y corresponding to the place of impact (x and y are orthogonal). For some images and values of lim, we obtained $dy \approx dx$; for other considered images dx was a little smaller than dy, but generally the motion was at 45° to the axes of the image.

Velocities of ejected material: The velocities of a level of brightness (the edge of the region of pixels with CPSB>lim) give us a lower limit of velocities of ejected particles. Actual velocities are greater than velocities of the level of brightness for several reasons: (1) we see only a projection of velocity on the plane perpendicular to a view of sight; (2) if the same amount of material moves from distance r_1 from the place of impact to distance r_2, then the number of particles on a view of sight (and so the brightness) decreases by a factor of r_2/r_1 .

We assumed that it was a continious ejection of material during several minutes. In Fig. 1b one can see that the left edge of the border of a region with CPSB>0.1 has two 'bumps' (the leftmost pixels of two ellipses). The upper bump can be caused by a pre-existing jet in this area. Let us consider another hypothesis of the origin of these two bumps. We suppose that these two bumps correspond to two cones, the more elongated cone with a right bump corresponds to material ejected from the surface of the comet just after the impact, and the more wide cone (more circular and with a lower bump) includes also the material ejected with a delay of t_d seconds after the impact. Based on the borders corresponding to these two cones, at t=10.7 s for lim=0.1 we got t_d=2 s. As we considered the motion of a level of brightness, but not real velocities of particles, this is an approximate estimate. At t=7.7 s (Fig. 1b) it is more difficult to estimate t_d, and it can be up to 3.5 s.

In Table 1 we present the velocities of a level of brightness as the ratio dy/t. Some material could be ejected a few seconds after the impact, so its velocities can be greater than those in the table. At most regions of the cloud there could be particles ejected at different times. For some low values of lim, the region of CPSB>lim occupied all the image, so in these cases we can only estimate that velocity is greater than some value.

Different particles moved with different velocities. The velocity of the center of the brightest spot on an image was about 70 m/s both at t=7.67 s and t=15.6 s if we consider that materal of this spot was ejected immediately at the impact. As the velocity is the same for different t, then probably the above assumption is correct. Some particles got much greater velocities, up to several km/s.

At lim=3 the velocity of a level of brightness was the same at t=7.67 s and t=10.7 s, but at t=15.6 s the corresponding region was even smaller than at t=10.7 s (but was greater than at t=7.67 s). We can conclude that the most bright material began to move at the beginning of the impact and moved with velocity of not more than a few hundred m/s during first 10 seconds. The farther is ejected material from the crater, the smaller is a spatial density, and so after some time the level of a fixed brightness begins to move with time back to the crater.

At 0.03≤lim≤1 the values of dx and dy at t=15.6 s were greater than those at t=7.67 s by a factor of not more than 1.2, though the values of *t* differed by a factor of 2. So velocities of a level of brightness in the table were smaller at greater *t*.

The ratio of semi-major axes of the ellipse corresponding to a level of brightness of bright ejected material is about 4/3. As material moved, the center of this ellipse moved to the right-down corner of a figure. The ellipse doesn't have an ideal form, as we see different sides of the cone from different angles.

Inside the bordering ellipse presented in Fig. 1c besides the most bright region which is more close to the right side, there is a less bright region to the left, which corresponds to a later ejection of material.

Conclusions: The most interesting conclusions depend on reasonable but not proven assumptions about the behavior of the ejecta. The higher velocities for fainter material is qualitatively consistent with both models and experiments that show the ejection velocity decreasing and the mass per interval of velocity increasing as one goes to smaller and smaller velocities. The brightest material moved at ~100 m/s in the sky-plane, while fainter material moved much more rapidly (fast enough that hydrodynamic flow yields the wrong answer in several ways).

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References: [1] A'Hearn M. F. et al., (2005) *Science, 310*, 258-264. [2] Keller H. U. et al. (2005) *Science, 310*, 281-283.

Table 1. Velocities (m/s) of a level of brightness (the edge of the region of pixels with CPSB>*lim*) for MRI images made *t* seconds after the impact

t\lim	3	1	0.3	0.1	0.03	0.01
7.67	190	320	520	820	1275	>2250
10.7	190	290	420	640	1035	>1200
15.6	120	190	290	425	745	1130

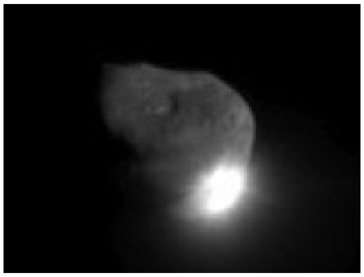

Fig. 1a. Original MRI image made 7.67 s after the impact.

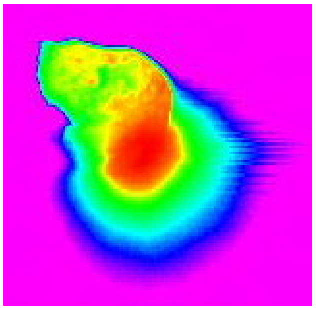

Fig. 1b. MRI image made 7.67 s after the impact. Only pixels with CPSB>0.1 were considered.

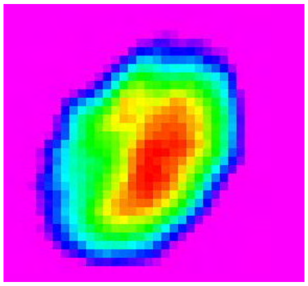

Fig. 1c. MRI image made 7.67 s after the impact. Only pixels with CPSB>3 were considered (scale is different from that for other figures).

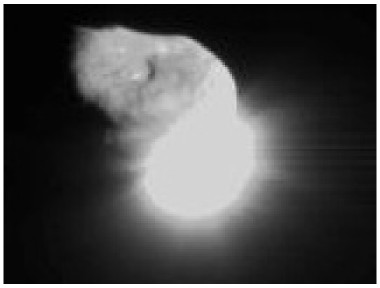

Fig. 2a. Original calibrated MRI image made 15.6 s after the impact.

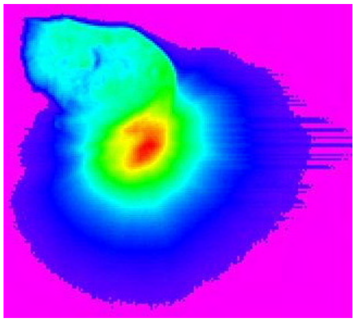

Fig. 2b. MRI image made 15.6 s after the impact. Only pixels with CPSB>0.1 were considered.