Geophysical Research Abstracts, Vol. 8, 06798, 2006
SRef-ID: 1607-7962/gra/EGU06-A-06798

Deep Impact: The first second

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Introduction: The Deep Impact spacecraft hard-landed on the surface of comet Tempel 1at about 05:44:36 UTC on 4 July 2005[1]. The impact occurred at a velocity of 10.3 km/sec, delivering about 19 GJ of kinetic energy, and the 370 kg impactor spacecraft struck the surface of the comet obliquely, at an angle of about 30˚ from a plane tangent to the surface, creating an impact crater estimated to be between 100 and 200 m in diameter. The earliest stages of the impact event were recorded in a series of 64 x 64 pixel subframes of the MRI (Medium Resolution imaging) camera system. Each exposure lasted about 51 msec and the field of view was nearly centered on the impact site, thus catching the earliest phases of the impact process. These frames witnessed the beginning of the conical ejecta plume's expansion. In addition, they caught the expansion of a cloud of incandescent, probably liquid silicate, droplets that sprayed away from the impact site

The Impact "Flash": The first indication of the impact was a tight group of bright, but not saturated, pixels centered on a single pixel (an area of roughly 80 m x 80 m on the comet's surface). In the next two frames the bright spot expanded from one to about four pixels in width, still not saturated. Then, in the frame exposed about 0.22 seconds after the impact, a group of 26 adjacent pixels became saturated and the image indicated bleeding of the electrons from the brightest wells in the CCD into adjacent wells. The brightness declined in subsequent images and an elongated, parachute-shaped, arc of bright material appeared downrange from the impact site while a bright, probably conical, plume of opaque material rose behind the arc and cast a prominent shadow on the comet's surface. The leading edge of the arc moved very rapidly, with an apparent velocity in the plane of the sky of approximately 4.8 km/sec (if the arc material is assumed to ricochet from the surface at an angle equal to the approach angle of about 30˚, then it moved toward the camera at an angle of about 60° out of the viewing plane, implying an actual velocity of 9.6 km/sec relative to the initial bright pixel, similar to the velocity of the impactor itself). The arc also expanded in breadth at a velocity of roughly 3.3 km/sec. Although the arc expanded at constant velocity, within measurement errors (roughly $\pm$100 m), extrapolation back to the origin suggests that expansion began about 0.1 sec *after* the first bright pixel was observed. This period of time is far too long to represent expansion of an initial hot volume of gas (this time scale is only a few ms, according to hydrocode simulations of an expanding sphere of SiO_2 vapor) and must therefore reflect the interval during which the impactor entered the surface and deposited its energy.

Glowing Melt Droplets: Analysis of the brightness of the central region in this arc indicates that the initial brightness declined too rapidly to represent the expansion of a cloud of particles reflecting sunlight. Only later, about 0.42 sec after impact, does the brightness decline as a function of t^{-2}, as expected for an optically thin cloud of dust expanding at constant velocity. However, the observed decline is consistent with blackbody radiation emitted from a cloud of incandescent liquid droplets expanding at a radial velocity of 1.7 km/sec (if this were the cloud's radial expansion velocity, then the leading edge velocity of 9.6 km/sec implies that the center of mass of the arc material moved at about 7.9 km/sec—in fair agreement with the apparent velocity of the arc's center of brightness). A model of this process indicates good agreement between the expected central brightness of a cloud of 150 μm diameter particles and the observed arc.

Conclusion: We conclude that the parachute-shaped bright arc that expanded rapidly away from the impact site during the first second after contact was an incandescent cloud of condensed, probably liquid, droplets that cooled from an initial temperature of about 3000 K down to 1000 K after about 0.42 second. It remained in view for another 0.4 sec, illuminated by reflected sunlight. Assuming an albedo of 0.1, appropriate for mafic silicate liquids, the total mass of the droplets was about 4000 kg. Because this is 10 times the mass of the impactor, we assume that the glowing material originated mainly from the comet and is thus probably silicate in composition. The delay in the peak brightness may represent the interval between formation of the hot vapor beneath the surface of the comet and its appearance at the surface. This delay, however, is one of the current mysteries of the impact event. The interval is too long for mere burial of the projectile in the target, or ricochet of projectile out of the crater.

References: .[1] A'Hearn, M.F., *et al.* (2005) *Science* **310**, 258.