Modeling the ejecta cloud in the first seconds after Deep Impact

L. Nagdimunov[1], L. Kolokolova[1], M. Wolff[2], M. A'Hearn[1], and T. Farnham[1]

[1]University of Maryland, USA
[2]Space Science Institute, USA

Although the Deep Impact experiment was performed nine years ago, analysis of its data continues to shed light on our understanding of cometary atmospheres, surfaces, and interiors. We analyze the images acquired by the Deep Impact spacecraft High Resolution Instrument (HRI) in the first seconds after impact. These early images reflect the development of the material excavation from the cometary nucleus, enabling a study of fresh, unprocessed nuclear material, and potentially allowing a peek into the interior. Simply studying the brightness of the ejecta plume and its distribution as a function of height and time after impact could provide some insight into the characteristics of the ejecta. However, the optical thickness of the ejecta offers an additional source of information through the resultant shadow on the surface of the nucleus and brightness variations within it. Our goal was to reproduce both the distribution of brightness in the plume and in its shadow, thus constraining the characteristics of the ejecta. To achieve this, we used a 3D radiative-transfer package HYPERION [1], which allows an arbitrary spatial distribution and multiple dust components, for simulations of multiple scattering with realistic scattering and observational geometries. The parameters of our dust modeling were composition, size distribution, and number density of particles at the base of the ejecta cone (the last varied with the height, h, as h^{-3}). Composition was created as a mixture of so called Halley-like dust (silicates, carbon, and organics, see [2]), ice, and voids to account for particle porosity. We performed a parameter survey, searching for dust/ice ratios and particle porosity that could reproduce a density of the individual particles equal to the bulk density of the nucleus, 0.4 g/cm^3, or 1.75 g/cm^3 used in [3] to model crater development. The size distribution was taken from [4] and the number density was varied to achieve the best fit. To further constrain the results, we compared them with those of crater modeling [3]. Based on the approach given in [3] and using the crater diameter from [5], the mass of the ejecta 1 sec. after impact was estimated as $9 \times 10^3 - 2 \times 10^4$ kg. The best fit to Deep Impact data and excavated mass constraints was achieved with ~10 % Halley dust, ~20 % ice, and the rest voids by volume for density 0.4 g/cm^3 and ~65 % Halley dust with 38–8 % ice, depending on porosity, for density 1.75 g/cm^3. Both cases result in a number density of ~10^4 particles/cm^3. The dust/ice mass ratio for each density is ≥ 1, which is consistent with [6]. To reproduce the correct position and geometry of the shadow, we had to modify the geometry of the ejecta cone originally prescribed in [3]. This was required, in part, by the use of a revised nuclear shape model [7]. Our estimate of cone tilt differs from the previous one by 13.2°. It appeared that the observed change in brightness of the plume and shadow during the first second cannot be reproduced by a hollow cone. This is consistent with lab simulations of oblique impacts [8] which showed that hollowness of the ejecta cone can develop somewhat later in the plume evolution. Variations of brightness within the plume and the shadow can reveal the structure of the upper layers of the nucleus.

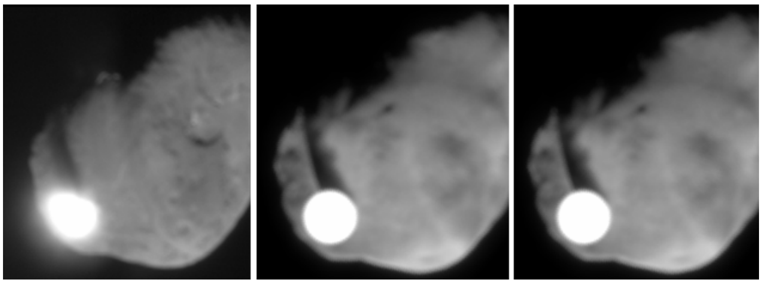

Figure: Image HV9000910007 [9] by HRI acquired 1.036 sec. after impact (left), and the modeled images for the individual particle density 0.4 g/cm^3 (middle) and 1.75 g/cm^3 (right).

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