A STEREOPHOTOCLINOMETRY MODEL OF COMET TEMPEL 1.
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Introduction: In 2005, the Deep Impact (DI) spacecraft performed an active experiment by impacting comet 9P/Tempel 1, and carried with it three visible imagers: the High-Resolution Instrument (HRI), the Medium-Resolution Instrument (MRI), and the Impactor Targeting Sensor (ITS). The nucleus was shown to have smooth areas, scarps, pits, knobs, and even possible impact craters [1] (Figure 1).

In 2011, the repurposed Stardust-NExT (SD-N) spacecraft also flew by Tempel 1. Images from the NavCam provided a unique second view of a comet nucleus, including areas not seen by DI. Layering, smooth areas, and pits were re-imaged, and changes were detected along the margins of smooth flows [2].

The combined data of DI and SD-N provide a wealth of information about Tempel 1. However, co-registration and comparison of datasets obtained by multiple instruments and spacecraft are difficult, due to complexities of coordinating spacecraft positioning, instrument pointing, data calibration, and data archives. Yet this synthesis is critical for proper interpretation of the datasets. The irregular shape of Tempel 1 also poses considerable obstacles. Visualizing and mapping features on such bodies becomes a difficult task: two-dimensional map projections lead to severe distortions of spatial relationships and size, and rapidly changing photometric angles make spectral analyses impossible without accurate photometric corrections.

The best-available shape model of Tempel 1 is a 2º, or 157-m ground sample distance, limb-based shape model made by Peter Thomas using both DI and SD-N images [3]. This resolution is sufficient for broad interpretations and mapping, but is insufficient for local, high-level details, like those seen in the images or the spectra. For example, many slopes on the surfaces of the nucleus are not resolved by the 2º model, making it difficult to determine up- vs. down-slope direction, which is needed to assess surface material mobilization. . The determination of absolute ice abundance is dependent on a photometric correction, which is highly sensitive to the lighting conditions, and thus the shape.

We have co-registered images from both DI and SD-N and used them to construct a high-resolution, global shape model of Tempel 1 using stereophotoclinometry (SPC).

Image Curation and Management: We have performed quality assessments of all images of Tempel 1 from DI (318 HRI images, 379 MRI images, and 83 ITS images) and SD-N (72 NavCam images) for which there

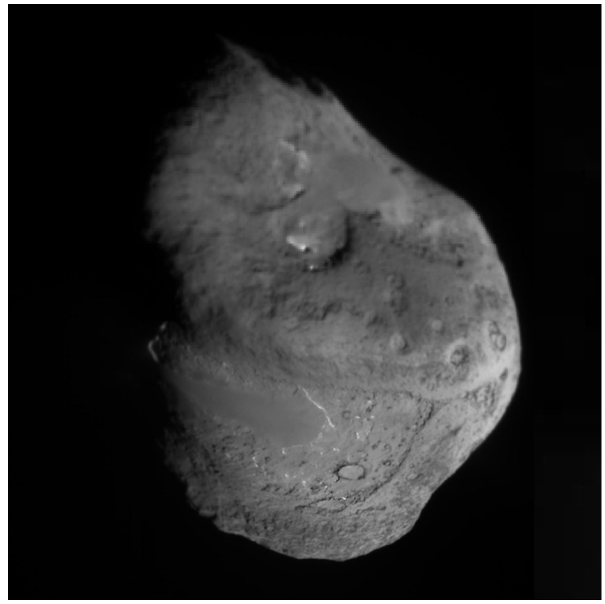

Figure 1. The nucleus of Tempel 1. This is a composite of the best ITS images. Image credit: NASA/JPL-Caltech/UMD

are at least 10 pixels across the nucleus. Of these, ~90% are of sufficient quality (e.g., not saturated, no major artifacts) to be of use for analysis. The combined DI and SD-N images cover 70% of the surface.

Updated Shape Model: We used SPC [4] to create a detailed shape model of Tempel 1, incorporating images from both DI and SD-N. SPC uses images obtained across a range of viewing geometries, combined with knowledge of the spacecraft's location and camera pointing, to generate a detailed shape model of the object of interest [4]. In the workflow we are using, images were first registered to the Thomas shape model [3]. This shape was then tiled with maplets tied to landmarks viewed in multiple images with different viewing geometries. Monte Carlo integration allows the determination of local terrain heights relative to the landmarks. Constraints from overlapping or lower-resolution maplets, limbs, shadows, and geometric stereo condition the solution. SPC maplets were then combined to determine the global topography model for the body.

Our model currently has a ground sample distance of 8 m globally, where data exist (~60% of the surface). This model provides ~20x improvement in the resolution of the shape model compared to the limb-based Thomas model [3] and for the first time resolves flow

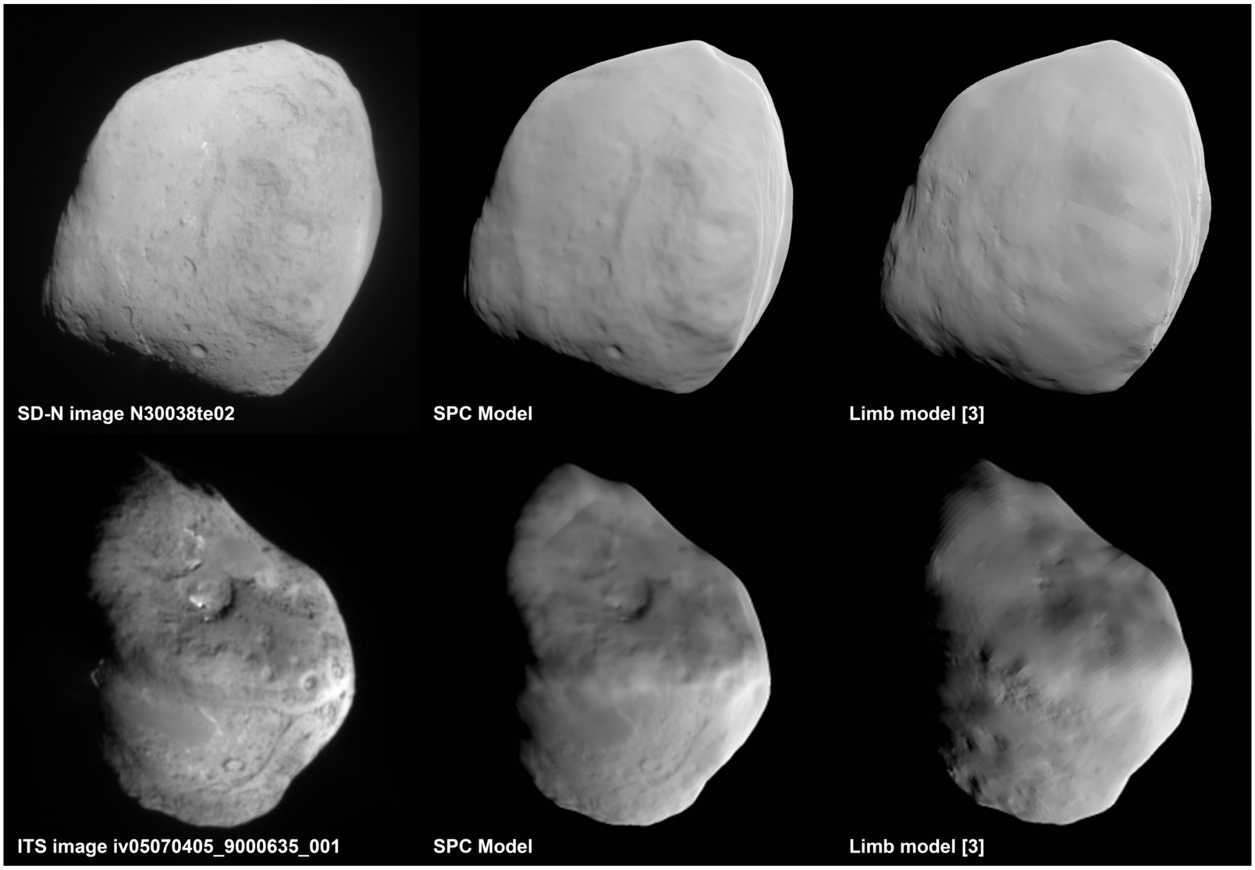

Figure 1. Left: Images from the SD-N and ITS; Center: The new Tempel 1 SPC shape model, with lighting simulated to match the images; Right: Farnham & Thomas limb-based model [3], with lighting simulated to match the images.

margins, scarps, and several impact crater candidates (Figure 2).

Challenges: Significant challenges were encountered in this SPC modeling effort. As with all flyby missions, viewing and lighting geometries are limited. Some stereo is available from the different viewpoints of the DI main and impactor spacecraft, and SD-N images provided a critical second viewpoint (different viewing and lighting geometries), including good intra-flyby stereo. However, the images and geometries are still limited, and parts of the body remain unseen.

A main requirement of the DI mission was, of course, to impact the comet. This complicates the shape modeling effort, as some of the best HRI and MRI images were acquired post-impact and include the expanding ejecta, which SPC interprets as the surface. We used post-impact MRI and HRI images only for pointing knowledge, and not to generate topography.

The HRI was found shortly after launch to be out of focus [5]. HRI images should be the highest-resolution global images available (there are higher-resolution, highly localized ITS images taken before impact) and allow us to see features and details that are not resolved (at least not unambiguously) by the MRI. However, recovering the resolution of the images requires the use of deconvolution techniques [6-8]. Circular ringing and noise artifacts are observed in the deconvolved images, which require caution in feature interpretation [8]. Currently, we have only incorporated non-deconvolved HRI images. Adding deconvolved HRI images has the potential to improve the resolution of the model, but we must proceed with caution. Our next step is to attempt to incorporate deconvolved HRI images, keeping the following in mind: 1) Knowledge that linear features and spikes will not be created by deconvolution; 2) Supplemental HRI images and stereo can be used to separate artifacts from real features; 3) ITS images can be used to confirm small features; 4) Features in lower-resolution MRI images can be confirmed for consistency; 5) Features should preserve geologic continuity.

References: [1] A'Hearn, M.F. et al. (2005) *Science*, *310*, 258–264. [2] Veverka, J. et al. (2013) *Icarus*, *222*, 424–435. [3] Farnham, T.L. and Thomas, P.C. (2013) *NASA PDS*. [4] Gaskell, R.W. et al. (2008) *MAPS*, *43*, 1049–1061. [5] Klaasen, K.P. et al. (2008) *Rev.of Sci. Inst.*, *79*, 091301. [6] Lindler, D. et al. (2007) *Pub. Astron. Soc. Pac. 119*, 427–436. [7] Busko, I. et al. (2007) *Icarus*, *187*, 56–68. [8] Lindler, D.J. et al. (2013) *Icarus*, *222*, 571–579.