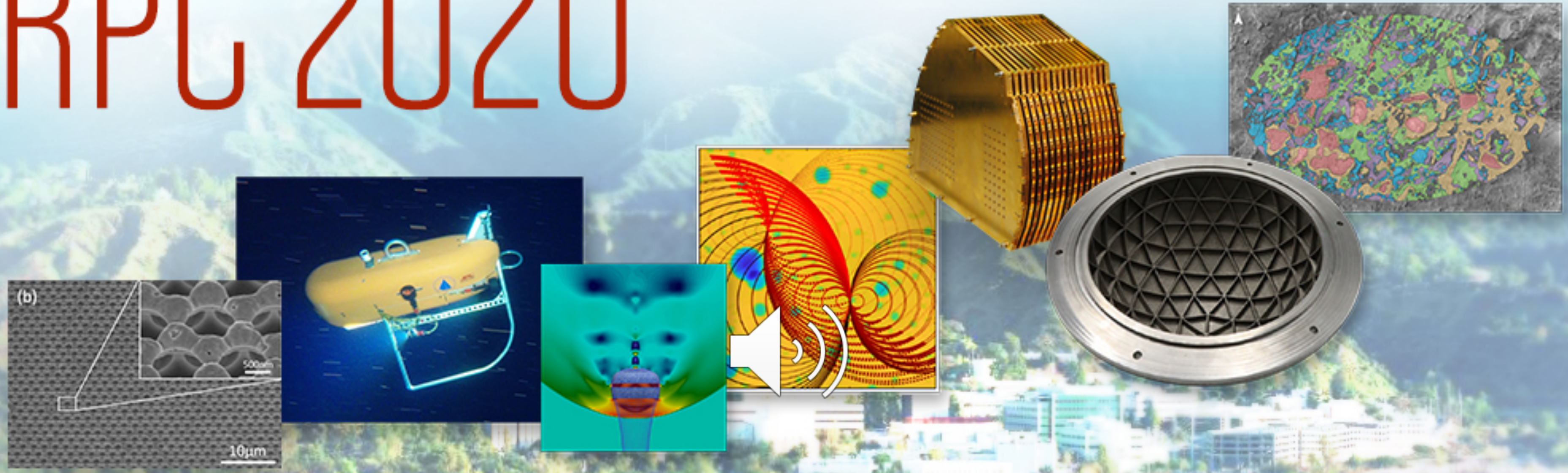
RPC 2020



Virtual Research Presentation Conference

Error quantification in stereophotoclinometry and stereophotogrammetry for planetary body shape determination using onboard imagery

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Program: Innovative Spontaneous Concepts

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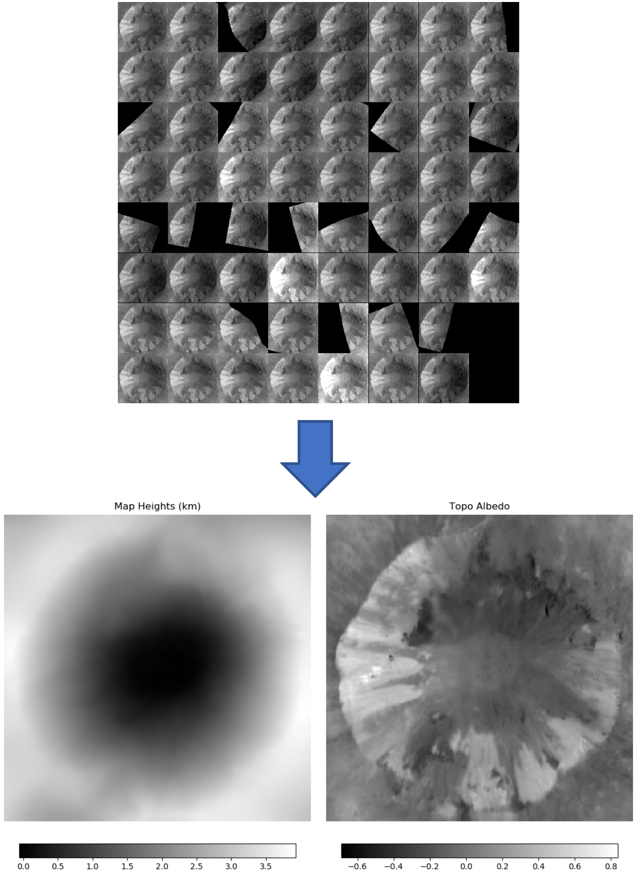
Assigned Presentation #RPC-070

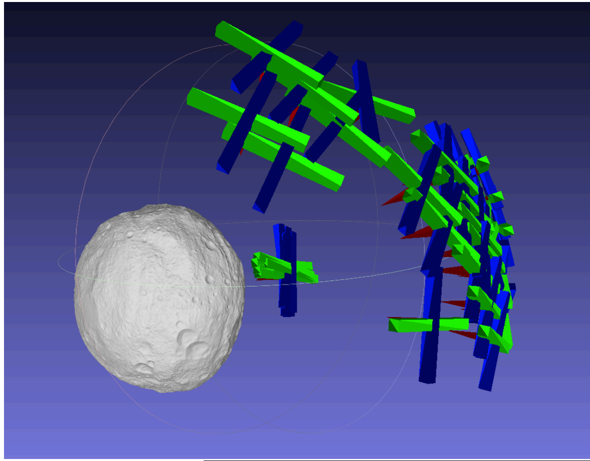
Tutorial Introduction

Abstract

An accurate shape model is essential for understanding the geophysical and geomorphological nature of planetary bodies as well as for safely, and accurately, navigating a spacecraft near the target body. For deep-space missions, stereophotogrammetry (SPG) and stereophotoclinometry (SPC) are widely used to reconstruct the target body's shape. SPG is a well-established technique for producing 3-dimensional shape using stereo pairs of images. In general, SPC has many similarities to SPG, such as the need for a large range of image emission angles. However, there are also substantial differences, key among them the need for a large variation in incidence angle in both elevation and azimuth for SPC. In practice, SPC has been used for most of missions that require optical navigation (e.g., Dawn, OSIRIS-REx, Rosetta, Hayabusa 1 & 2, etc.) through landmark tracking (i.e., triangularization using control points). All past missions with JPL's optical navigation were successful and JPL's SPC capability is currently consistent with the state-of-the-art capability in the field. However, there have also been cases where SPC and SPG-derived products showed substantial differences (i.e., multi-sigma level). This study would perform SPC and SPG under a controlled environment and would perform statistical analysis to quantify the error in the image-derived topography.

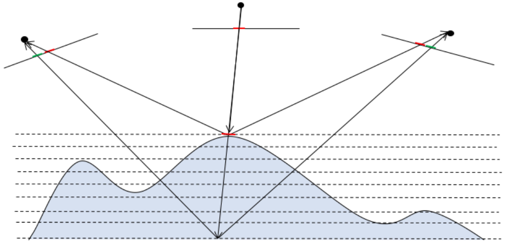


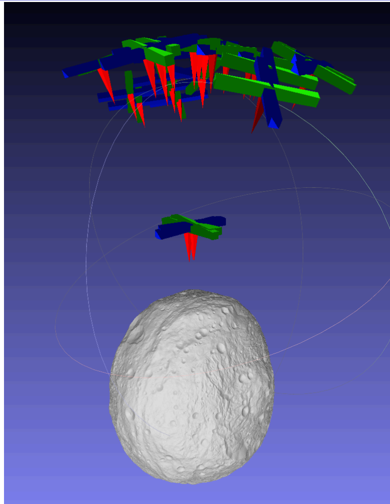
Problem Description



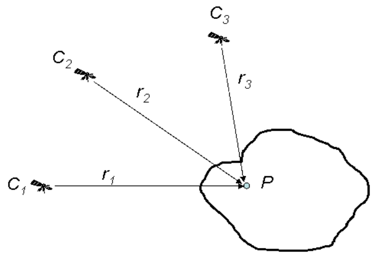
Unlike Earth-orbiting missions, where the spacecraft position is known with high accuracy with pre-existing control points on the globe, deep-space missions have to simultaneously solve for both the camera position, pointing, and the 3-dimension shape of the target, which is likely visited for the first time. The navigation process critically depends on having rigorous formal error models associated with navigation techniques. An important deficiency of SPC, due to an internal random-perturbation “annealing” process in lieu of estimation, there is no formal numerical error model.

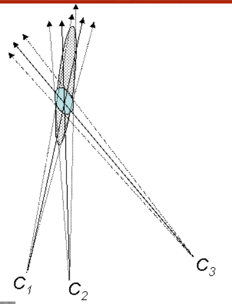
An important innovation of this work is the quantification of such an error model, which will entail comparing numerical results against SPG, and synthesizing those errors with intermediate error products from orbit determination and image correlation, thus producing a reusable and reliable error model that would benefit nearly all future missions that require optical navigation and that involve SPC for shape determination.





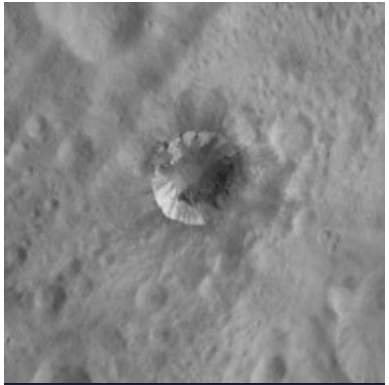
Methodology



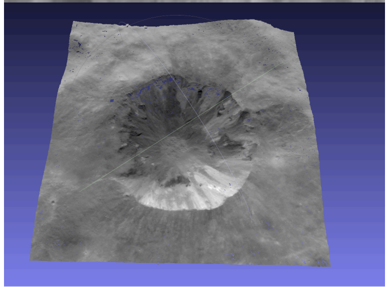


The topography of a Vesta crater, called Cornelia, was computed using two SPG techniques and one SPC technique. Cornelia is about 15-km in diameter located at (15.57°E, 9.37°S), and is a well-studied crater. The two SPG techniques used were sliding plane correlation method and multi-base line stereo matching method. The SPC technique used was the standard method used for Dawn optical navigation at Vesta.

The Dawn gravity science team provided the ephemeris of the Dawn spacecraft (i.e., camera position), corrected camera pointing directions, and a Vesta rotation model that were derived using SPC and DSN radio tracking data (Ryan Park, Drew Vaughan, and Ed Riedel from 392). Co-Investigators (Adnan Ansar and Yang Chang from 347) have led the SPG modeling and have confirmed that image registrations using SPG techniques were near perfect and no adjustments were needed, indicating that the products from the Dawn gravity science team provided the mapping accuracy to better than a sub-pixel level. In this study, only Dawn's High Altitude Mapping Orbit (HAMO) images were used, which had the ground sample distance (GSD) of about 60 m.



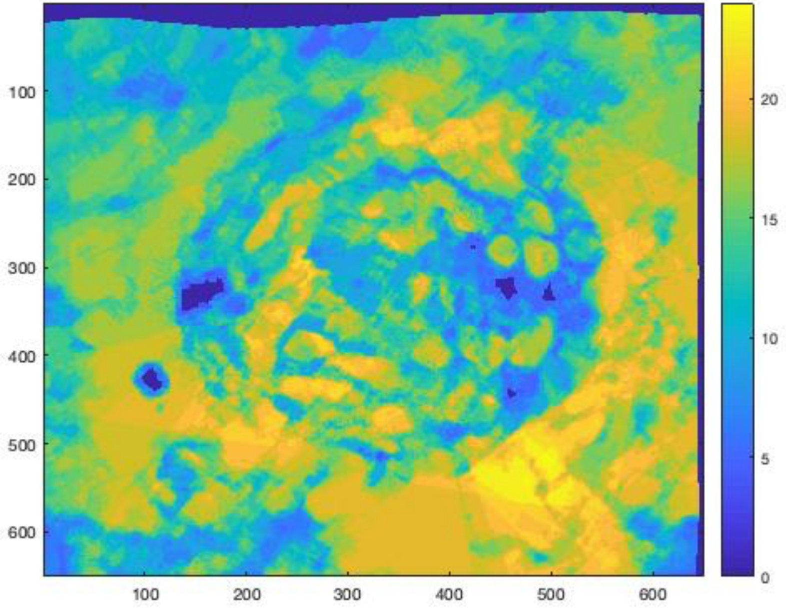
Original Image



3D Topography

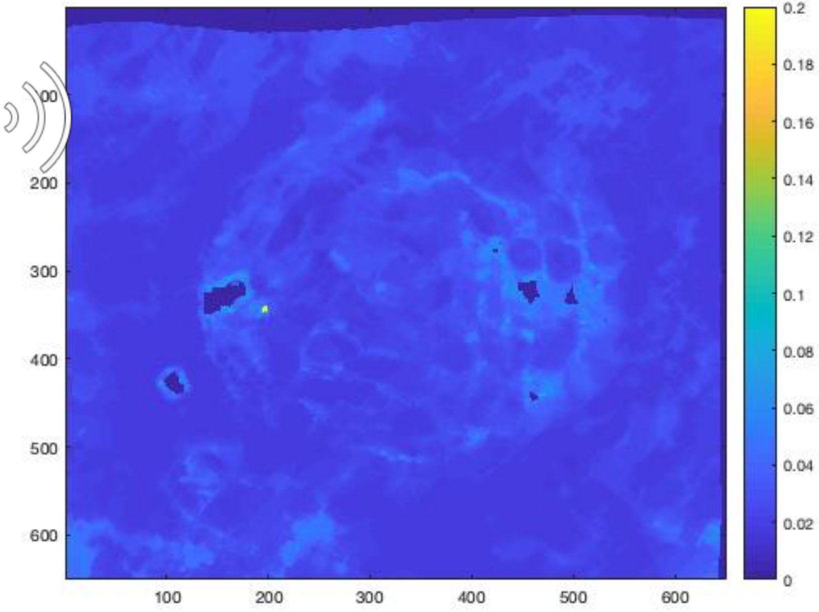
Results (Accomplishments)

Number of observations



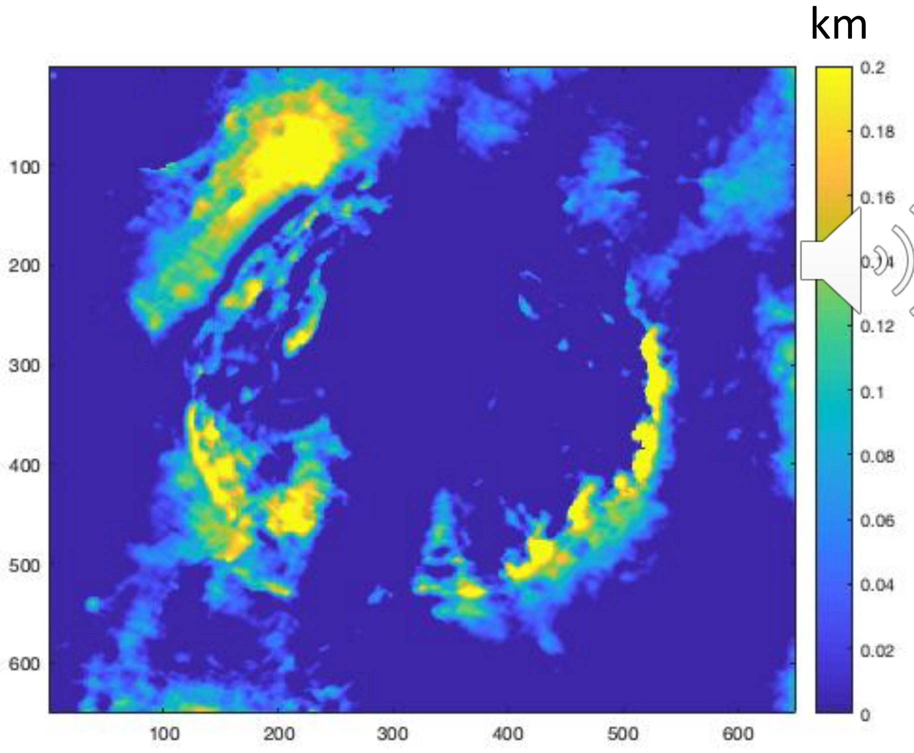
1-sigma height uncertainty from SPG

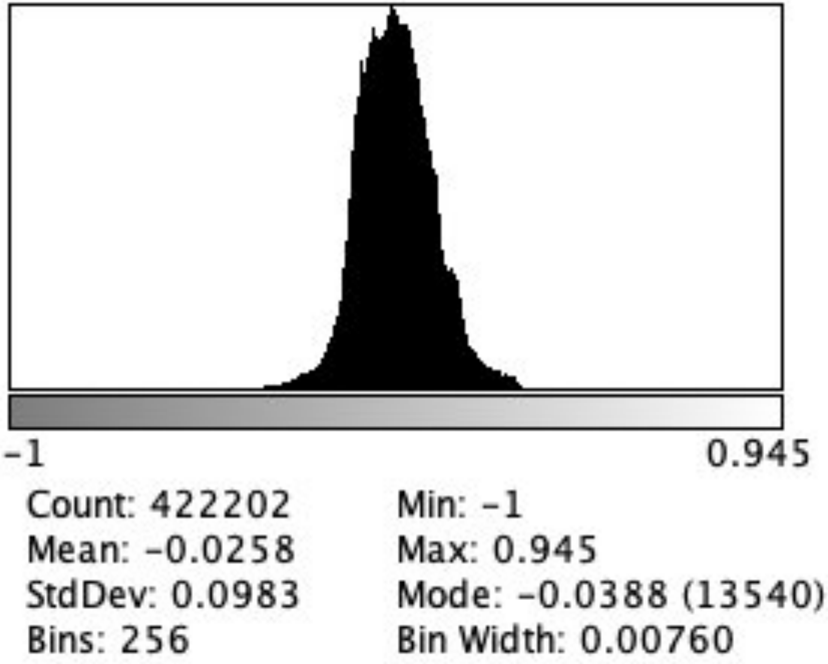
km



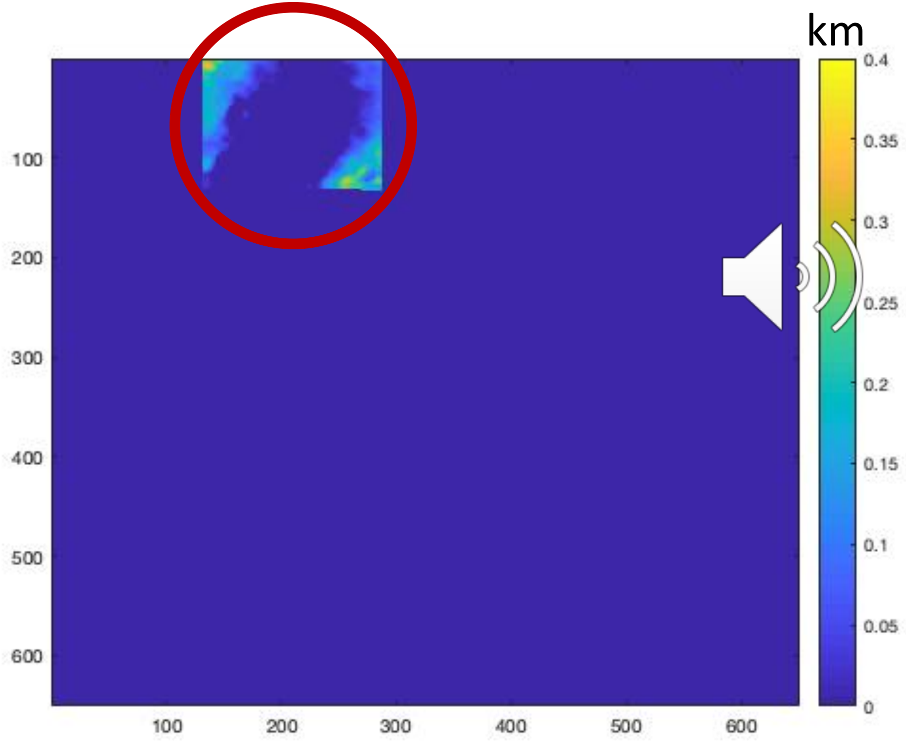
Please disregard the regions showing zero images in the height uncertainty figure.

Height Difference between SPG and SPC





Height Difference between SPG and SPC



Results (Significance)

- Both stereophotoclinometry (SPC) and stereophotogrammetry (SPG) techniques successfully derived a 3-dimensional topography model for the Cornelia crater on Vesta.
- The expected height uncertainty derived from the SPG technique was comparable to the expected height uncertainty derived from the SPC technique.
- The topography difference between JPL SPC and JPL SPG techniques agree much better compared to the topography difference between JPL SPC and DLR SPG from the Dawn mission.

Results (Next Steps)

- There are some differences between JPL SPC and JPL SPG at local scale that would need further analysis. This difference would not be a problem when navigating a spacecraft or performing geophysical analysis (i.e., problems that require a long wavelength signal) since the average of the difference is still very small.
- The findings from this study will be applied to determining the topography and shape of Psyche.

Publications and References

Final report and presentation package were submitted to OCSCT.

Park, R.S., A.T. Vaughan, A.S. Konopliv, A.I. Ermakov, N. Mastrodemos, J. C. Castillo-Rogez, S.P. Joy, A. Nathues, C.A. Polanskey, M.D. Rayman, J.E., Riedel, C.A. Raymond, C.T. Russell, M.T. Zuber, "High-resolution shape model of Ceres from stereophotoclinometry using Dawn Imaging Data," Icarus, 319, 812-827, 2019. https://doi.org/10.1016/j.icarus.2018.10.024