DERIVING AN ULTIMA THULE DIGITAL SHAPE KERNEL. C. B. Beddingfield[1,2] R. Beyer[1,2], P. Schenk[3], J. Moore[2], H. A. Weaver[4], C. B. Olkin[5], J. R. Spencer[5], S. A. Stern[5], and The New Horizons Team, [1]The SETI Institute, Mountain View, CA, [2]NASA Ames Research Center, Moffett Field, CA (chloe.b.beddingfield@nasa.gov), [3]The Lunar and Planetary Institute, Houston, TX, [4]John Hopkins University Applied Physics Laboratory, Laurel, MD, [5]Southwest Research Institute, Boulder, CO.

Introduction: We present a technique to create a digital shape kernel (DSK) for 2014 MU_{69}, nicknamed Ultima Thule (Fig. 1), for use with New Horizons Long Range Reconnaissance Imager (LORRI) and Multispectral Visible Imaging Camera (MVIC) images. This technique was created in preparation for images acquired during the New Horizons Ultima Thule flyby.

We will create the DSK from a shape model of Ultima Thule, derived using stereopairs acquired by LORRI and MVIC cameras on the Ralph instrument. Initial images are available, as of January, 2019, and additional images are planned to be downlinked from the New Horizons spacecraft by the end of February, 2019.

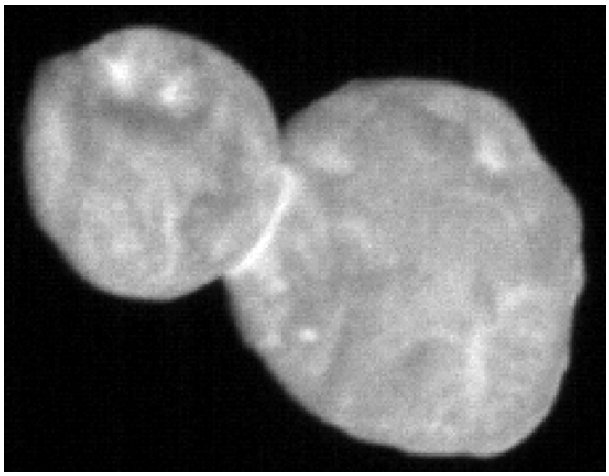

Figure 1: The Kuiper Belt Object (KBO) Ultima (bottom right, ~19 km diameter) and Thule (top left, ~14 km diameter). The LORRI image ID used for this figure is 0408624825.

DSKs are used to enable SPICE application, and provide shape information to accurately process and project images acquired from spacecraft cameras. This processing, in turn, allows for accurate geometric measurements of planetary surfaces for irregular bodies to be taken for scientific analyses. The DSK will be made publicly available through the Planetary Data System (PDS) to use with the NASA Navigation and Ancillary Information Facility (NAIF) SPICE toolkit [1] and the Integrated Software for Imagers and Spectrometers (ISIS) [2].

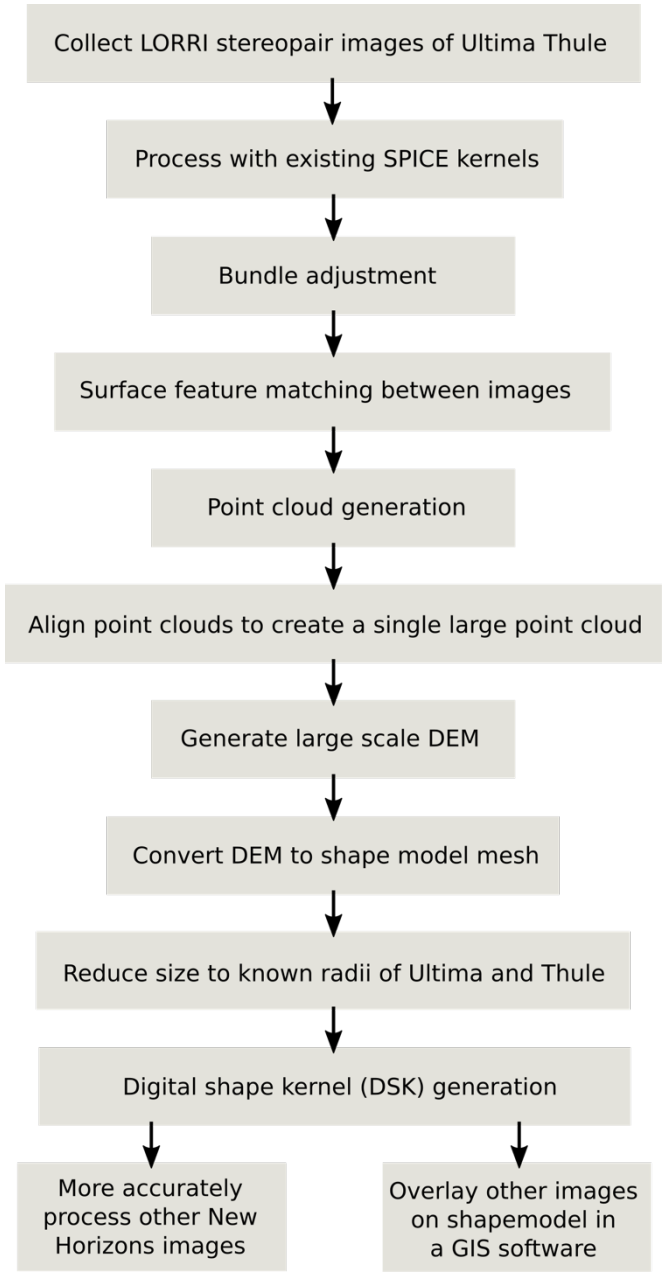

Figure 2: Flowchart summary of process to create an Ultima Thule digital shape kernel (DSK) and shape model. This methodology will utilize applications provided in the SPICE toolkit [1], the Integrated Software for Imagers and Spectrometers (ISIS) [2], Ames Stereo Pipeline (ASP) [3], and the Ceres Solver [4].

Methodology: Our technique includes processing two stereopair images at a time (Fig. 2). These images will first be processed with ISIS using existing SPICE kernels. This step allows for more accurate matches to be made between images using automated detection in later steps with Ames Stereo Pipeline (ASP) [3]. Because Ultima Thule is an irregularly shaped body, we will use realignment methods that do not require map projecting the images. This method will reduce spatial distortion, allowing for easier matching of features and locations between the two images.

Bundle adjustment will be performed using the Ceres Solver [4] in ASP. This step allows for the adjustment of camera pointing information based on apparent locations of surface features in the two images. Bundle adjustment allows for even more accurate alignment of the images for better matching of the same features and locations. Match points will be made using an automated process. If needed, manual match points will be made to allow for better registration between images using the stereo_gui application in ASP.

The amount of parallax distortion of features in each image will be used to create a three-dimensional point cloud, using applications in ASP. We will then align all pair-wise created point clouds into a single point cloud. To conduct this process, we will use the pc_align application in ASP.

The point cloud will then be used to create a large scale digital elevation model (DEM), and then a shape model mesh. The generated shape model will be provided in the form of a .OBJ file (a geometry definition file). We will then adjust the shape model dimensions so that they match the known radii of Ultima and Thule.

Locations in the shape model that are outliers, and therefore inaccurate estimates of surface elevation, will be removed from the shape model. The shape model will then be converted into a DSK using the SPICE toolkit application MKDSK [1].

To prepare for the arrival of Ultima Thule stereopair images, we tested our method on a stereopair of similar quality for Itokawa (Fig. 3). To conduct this test, we used Hayabusa Asteroid Multi-band Imaging Camera (AMICA) stereopair images st_2490253205_v and st_2493031594_v.

Discussion: Ultima Thule exhibits a surface that may exhibit a large variation in albedo. This type of albedo variation causes a large error in shape-from-shading (photoclinometry) techniques [5]. Therefore, we will apply shape-from-shading methods in regions with low variations in surface albedo when deriving a DSK of Ultima Thule.

The DSK generated from this method can be used to more accurately process New Horizons images, and it can be used with the SPICE toolkit and with ISIS. The shape model produced can be used in a Geographic Information System (GIS) software, including the Small Bodies Mapping Tool (SBMT) [6], and LORRI images can then be draped over this shape model for better visualization and more accurate measurements and analyses of Ultima Thule surface features.

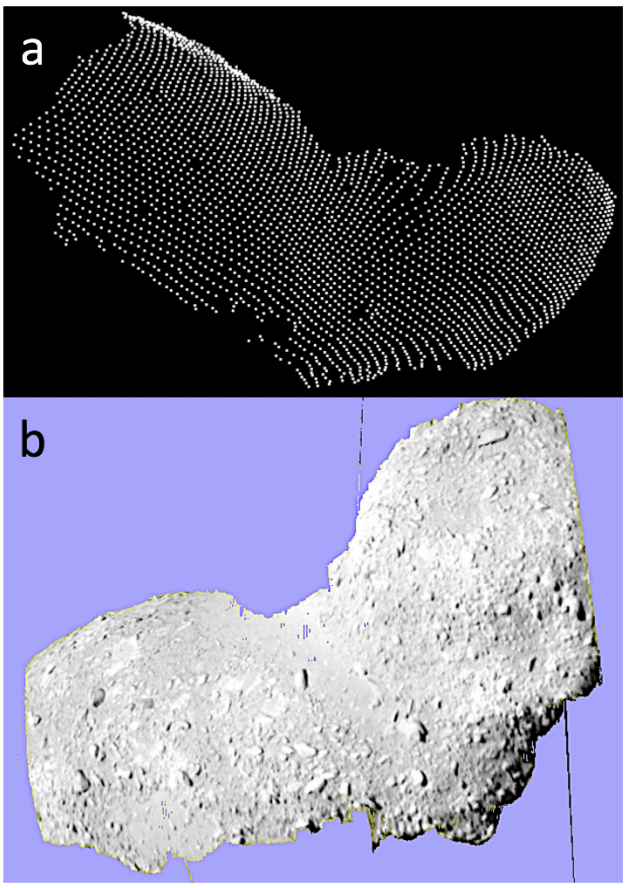

Figure 3: An example of a shape model created from our methodology, applied to the asteroid Itokawa. a) Point cloud of Itokawa shape model, created from Hayabusa Asteroid Multi-band Imaging Camera (AMICA) stereopair images st_2490253205_v and st_2493031594_v. b) An image of Itokawa's surface, draped over the derived shape model. Note that the body shown in a and b are different for illustration purposes.

References: [1] Acton, C., et al. (2018) *Plan. Space. Sci., 150,* 9-12. [2] Gaddis, L., et al. (1997) *LPSC, 28,* 387. [3] Beyer R. A. et al. (2018) Earth Space Sci., 5(9), 537-548. [4] Agarwal, S., & Mierle, K. (2012) *Google Inc., 2, 72.* [5] Alexandrov, O. & Beyer, R. A. (2018) Earth and Space Sci. 5(10), 652-666. [6] Ernst, C. M., et al. (2018) LPSC, 49, 1043.