THE SMALL BODY MAPPING TOOL (SBMT) FOR ACCESSING, VISUALIZING, AND ANALYZING SPACECRAFT DATA IN THREE DIMENSIONS. O. S. Barnouin[1], C. M. Ernst[1], R. T. Daly[1], and the Small Body Mapping Tool Team[1]. [1]The Johns Hopkins University Applied Physics Laboratory, 11101 Johns Hopkins Road, Laurel, MD, 20723, USA (sbmt@jhuapl.edu).

Introduction: Spacecraft missions return massive amounts of valuable data, but those data can be hard to access, visualize, and analyze. Most asteroids, comets, Kuiper belt objects, and small moons present additional challenges because two-dimensional map projections severely distort features on irregularly shaped bodies. The Small Body Mapping Tool (SBMT) developed at the Johns Hopkins University Applied Physics Laboratory addresses these challenges [1].

The SBMT lets users search for spacecraft data and project it onto shape models of small bodies. As a result, users can quickly find the data they need, look at the data in context, and do their science in three dimensions, without worrying about map projection issues or wading through the Planetary Data System (PDS) archives. Alternatively, the SBMT can be a starting point: users can pinpoint the data they need using the SBMT and then download the raw data from the PDS. The Tool includes a diverse suite of bodies and data types (images, spectra, altimetry data, see "Available Data") and supports co-registration of these data products. It has been or is being used by multiple mission teams, including Dawn, Rosetta, OSIRIS-REx, and Hayabusa2.

The Small Body Mapping Tool is publically available as a free download at sbmt.jhuapl.edu. It works on Mac, Linux, and Windows operating systems and has an easy-to-use graphical user interface. The SBMT is written in Java and uses the Visualization Toolkit (VTK), an open-source, freely available software system for 3D computer graphics, rendering, and visualization [2]. Some datasets and functionality, such as those for active missions, have restricted access; however, such features become publically available in the SBMT once the data have been archived with the PDS.

Features: The SBMT facilitates interactive searches for spacecraft data. This capability allows users to quickly and easily identify the images, spectra, or altimetry data that will help them achieve their science or engineering objectives. Once selected, data can be projected onto the shape model and analyzed using the SBMT's built-in analysis tools, thereby integrating data discovery and data analysis. Alternatively, users can export data for use in analysis tools of their choice.

The Tool's graphical user interface includes several tabs next to a large viewing area. Once users choose a body from a menu, each tab provides access to a different dataset. Users can set shape model illumination and simulate camera pointing. In the viewing area, users can interactively manipulate the shape (rotate, zoom, etc.).

Body tab: The body tab allows users to visualize a shape model at a variety of resolutions, view a basemap (where available), and overlay color maps of elevation, slopes, gravitational potential, and gravitational acceleration onto the shape. Such geophysical maps have proven useful in studies of asteroids [3–5].

Data tabs: Once users choose a body, the SBMT interface populates tabs based on the available data. Once a particular data tab is selected, users can search based on many parameters, including emission, incidence, and phase angles; pixel scale; data acquisition time; and wavelength. Users can also search for data by location by selecting a region of interest on the shape. The SBMT displays the footprints of images, spectra, and altimetry data found by the search so that users can decide which to load (Fig. 1). Users can simulate lighting to match the conditions when the data were acquired.

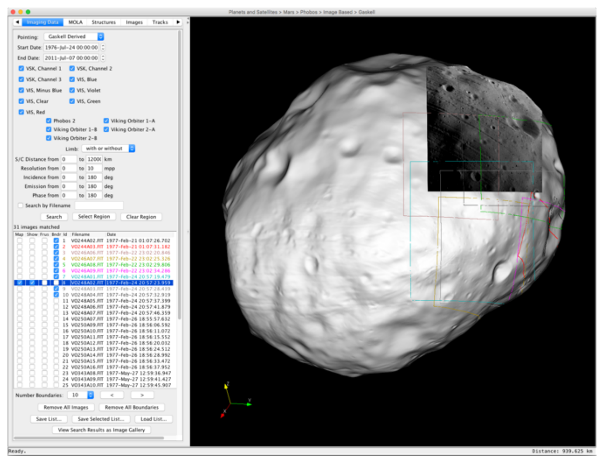

Figure 1. The SBMT lets users easily search for data. Here, available data footprints are shown (colored squares), and one image has been projected directly onto the shape model of Phobos.

The data tabs include several tools for data analysis. The functionality depends on the data type (e.g., capabilities for images differ from those for lidar tracks). For images, the SBMT can generate image cubes for overlapping images. These cubes can then be used to make RGB composites or be exported (e.g., to ENVI). The custom bands feature for spectral data allows users to do band math [e.g., 6]. For laser altimeters, transects can be used to measure topography (Fig. 2).

Structures tab: The structures tab lets users map features on the shape model even while viewing images or other data. Paths and polygons can be used to map lineaments, regions, and geologic units [e.g., 7–10]. Craters and blocks can be mapped with circles or ellipses [e.g., 11, 12] (Fig. 3). Points can be used to mark the locations of features. The data are saved as human-

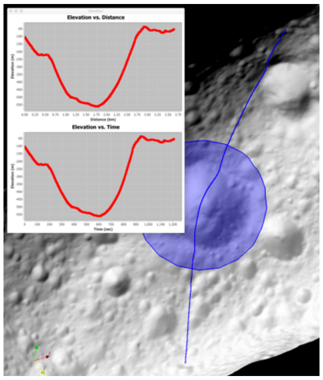

Figure 2. Topographic profiles can be extracted from lidar tracks and DTMs, such as this example from Eros.

readable XML (paths, polygons) or ASCII (circles, ellipses, points) files that can be easily imported into other tools or codes. The files contain both the measurements (e.g., polygon area, crater diameter) and regional geophysical data (e.g., elevation, slope).

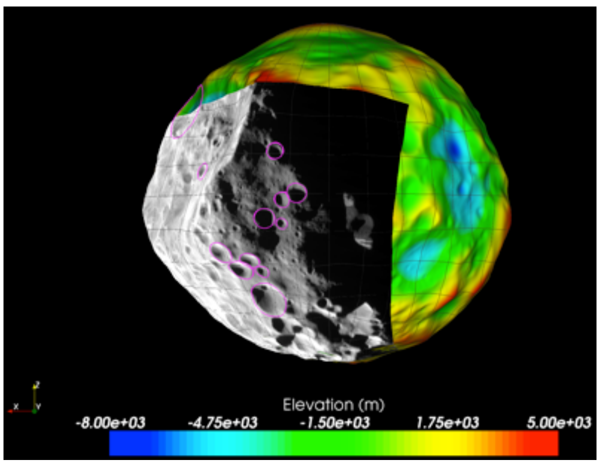

Figure 3. The SBMT lets users map craters, blocks, and other features directly on the shape. Here the user is mapping craters (magenta circles) on Phoebe. The shape is colored by elevation; a Cassini ISS image is draped on the shape.

Regional DTMs tab: For shape models generated using stereophotoclinometry [13], global shape models have lower resolution than the maplets on which the models are based. The regional DTMs (Digital Terrain Models) tab contains a database that allows users to construct higher-resolution regional DTMs, which can be overlain on the shape model or visualized independently in the SBMT. The SBMT allows users to collect topographic profiles across DTMs [e.g., 14].

Observing conditions tab: The observing conditions tab lets users visualize the relative positions of the spacecraft and the target body through time, including simulations of the lighting conditions and the sub-Earth, sub-spacecraft, and sub-solar points. Future enhancements to this tab will provide a way to link ground-based observations made at known times to specific parts of the object.

Custom data import: Each data tab allows users to import customized data and visualize it on the shape model. Users can apply pointing information from the SBMT to display imported data, as long as the files retain their original dimensions. Simple cylindrical global or regional basemaps can also be imported using this feature.

Available data: As of early 2018, the public version of the SBMT includes spacecraft data for several asteroids (Ceres, Vesta, Lutetia, Eros, Itokawa) and moons (Phobos, Dione, Mimas, Phoebe, Tethys). More bodies will soon be available, including an improved Phobos model, Deimos, 9P/Tempel 1, 67P/Churyumov-Gerasimenko, 81P/Wild 2, 103P/Hartley 2, and the saturnian moons Atlas, Calypso, Epimetheus, Helene, Hyperion, Janus, Pan, Pandora, Prometheus, Rhea and Telesto. The SBMT also works for large, spherical bodies like the Moon and Mercury [9, 15].

For each object, the SBMT includes a 3D shape model and available spacecraft datasets. Eros, for example, includes data from the NEAR-Shoemaker multi-spectral imager (MSI), near-infrared spectrometer (NIS), and NEAR laser rangefinder (NLR). Itokawa includes data from the LIDAR and AMICA imager.

In addition to those bodies detailed above, the SBMT has radar-, lightcurve, and image-based shape models for many objects, including those not yet visited by spacecraft.

Conclusion: The Small Body Mapping Tool is a powerful, easy-to-use tool for accessing and analyzing data from small bodies. The SBMT is actively being developed, and we will continue to release new datasets and functionality. Visit sbmt.jhuapl.edu to subscribe to the SBMT mailing list. We invite everyone in the community to reach out and discuss collaborations.

Acknowledgements: Much of the initial coding for the SBMT was done by E. Kahn at JHU/APL. In addition to the authors, many people have developed or supported the Tool, including D. Blewett, R. Klima, D. Buczkowski, J. Roberts, N. Chabot, L. Jozwiak, M. Zimmerman, J. Steele, L. Nguyen, J. Peachy, R. Turner, C. O'Shea, and A. Regeic. This work has been supported by grants from the NASA Planetary Science Division research and analysis programs.

References: [1] Kahn et al., 2011, *LPS 42*, abs. 1618. [2] Schroeder et al., 2006, *The Visualization Toolkit: An object-oriented approach to 3D graphics*, Kitware, Inc. [3] Cheng et al., 2002, *Icarus,* 155, 51–74. [4] Thomas et al., 2002, *Icarus,* 155, 18–37. [5] Barnouin-Jha et al., 2008, *Icarus,* 198, 108–124. [6] Klima et al., 2016, *LPS 47,* abs. 2572. [7] Buczkowski et al., 2008, *Icarus,* 193, 39–52. [8] Buczkowski et al., 2012, *GRL,* 39, L18205. [9] Ernst et al., 2015, *Icarus,* 250, 413–429. [10] Besse et al., 2014, *Planet. Space Sci.,* 101, 186–195. [11] Hirata, 2017, *Icarus,* 288, 69–77. [12] Mazrouei et al., 2014, *Icarus,* 229, 181–189. [13] Gaskell et al., 2008, *Met. Planet. Sci.,* 43, 1049–1061. [14] Roberts et al., 2014, *Met. Planet. Sci.,* 49, 1735–1748. [15] Deutsch et al., *Icarus,* 280, 158–171.