THE SMALL BODY MAPPING TOOL (SBMT) FOR ACCESSING, VISUALIZING, AND ANALYZING SPACECRAFT DATA IN THREE DIMENSIONS: 2021 UPDATE. R. J. Steele[1], N. R. Lopez[1], J. M. Peachey[1], C. M. Ernst[1], O. S. Barnouin[1], R. T. Daly[1], A. C. Martin[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 allows users to find, access, and analyze spacecraft data in three dimensions, directly on small body shape models. 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, Hayabusa2, and DART.

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 that has been refined and improved over the past several years. 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]. Although datasets and functionality specific to active missions may be temporarily restricted to team members, such features become publicly available once the data have been published or archived with the PDS.

New Features: The basic features of the SBMT have been discussed in previous publications [1,3]. Here we discuss recent improvements to the Tool.

Regional DTMs tab: The regional digital terrain maps (DTMs) tab has received a complete overhaul (Fig. 1). This tab is used to browse existing databases of DTMs (e.g., OSIRIS-REx) or import custom DTMs for visualization on the global shape model. User interface updates make information easily available to the user in the data table (e.g., ground-sample distance [GSD]). Performance has been streamlined, allowing the visualization and manipulation of hundreds of simultaneous DTMs. A new pop-up analysis windows allows users to examine each DTM in detail, apply plate colorings (e.g., slopes, uncertainties), and draw profiles.

Structures tab: The structures tab lets users map features on the shape model while viewing images or other data. Paths and polygons can be used to map lineaments, regions, and geologic units. Craters and blocks can be mapped with circles or ellipses. Points can be used to mark the locations of features. The data are saved as XML (paths, polygons) or ASCII (circles, ellipses, points) files that can be easily imported into other software tools. The files contain both the measurements (e.g., polygon area, crater diameter) and regional geophysical data (e.g., elevation, slope).

Recent changes to the structures tab include user interface improvements, the ability to import/export certain structures as ESRI shapefiles, and under the hood performance improvements allowing simultaneous display and manipulation of a large number of structures.

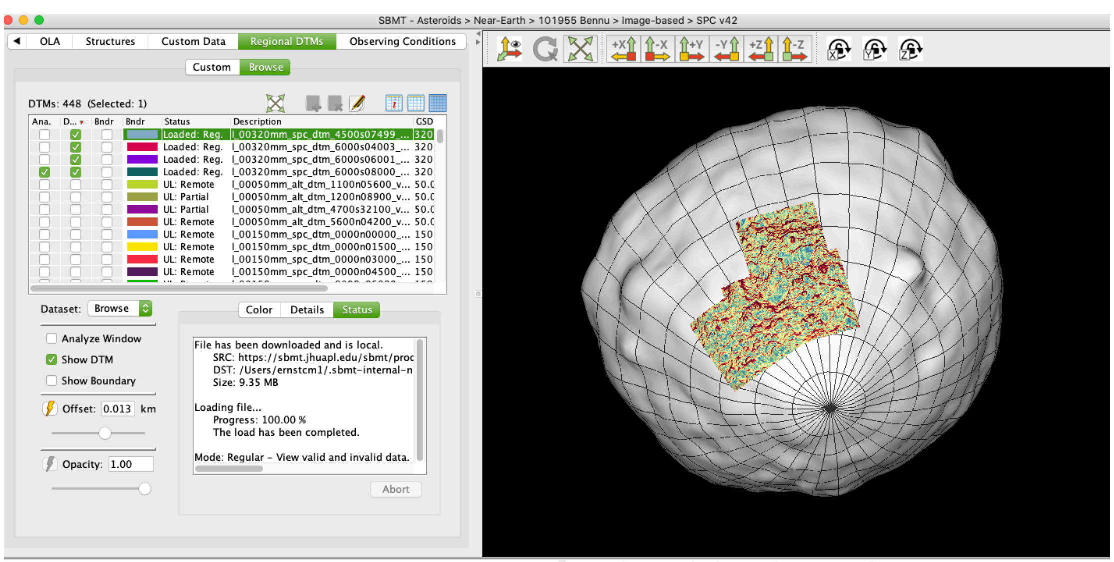

Figure 1. The Regional DTM tab has received a complete user interface and performance overhaul. Here, a low-resolution Bennu shape model is shown with four high-resolution, local DTMs overlain. The DTMs have been colored by slope.

LIDAR tab: The LIDAR tab in the Tool has the ability to display tracks from altimetry-based instruments such as OLA on OSIRIS-REx as well as visualize track profiles over regions of the surface. The LIDAR tab has received a user interface overhaul including an option to color tracks based on either constant colors or features such as distance or intensity. In-development improvements to parsing tools will allow the SBMT to accept a broader set of LIDAR data.

Observing Conditions tab: The observing conditions tab has received several upgrades. The SBMT now provides support for visualizing mission planning data on irregular bodies, including trajectories (that can be colored by attributed, e.g., spacecraft range) and instrument schedules (via their associated footprints and fields of view). Users can watch data coverage build up through time. Multiple items can be displayed simultaneously, allowing side-by-side comparisons of different mission scenarios (Fig. 2).

Available data: Public data released from the OSIRIS-REx mission (approach through early 2020) are now available in the SBMT. Future OSIRIS-REx data will become available as they are released to the PDS. New models for two saturnian moons, Janus and Epimetheus, are available in the Tool, along with co-registered images acquired by the Cassini Imaging Science Subsystem (ISS).

These new datasets complement the previously existing bodies, which include spacecraft data for several asteroids (e.g., Ceres, Vesta, Lutetia, Eros, Itokawa) and moons (e.g., Phobos, Deimos, Dione, Mimas, Phoebe, Tethys).

Future plans: *Imaging Framework:* The SBMT team is integrating the GDAL library via a PDART grant, which will enable a higher level of interoperability with existing image processing tools. The integration of GDAL will lay the groundwork for an overhaul of the imaging library, enhancing the capabilities and performance of the SBMT and bringing the Imaging tab user interface in line with other areas of the Tool.

MMX/MEGANE: Gamma ray and neutron spectrometer data will be introduced to the SBMT via support from the MEGANE instrument on MMX. MEGANE footprints will be used during the planning phase to confirm science goals can be met with planned trajectory and pointing. The Tool will also allow searching for and visualizing flight data of Phobos once they are acquired.

DART: Exploration of a multiple-body system will be incorporated via support from the DART mission. Users will be able to visualize data on more than one body in the SBMT, allowing images containing multiple bodies (e.g., Didymos and Dimorphos) to be completely rendered, manipulated, and analyzed within one composite model, rather than viewing each body separately within its own single-body model.

Community interface: The SBMT team is defining of a set of interfaces and tools that would enable new projects or users to more easily import, validate, and deliver the data to the Tool in a way that works with existing data import pipelines.

Conclusion: The Small Body Mapping Tool is a powerful, easy-to-use tool for accessing, visualizing and analyzing data from small bodies. We 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.

References: [1] Ernst et al., 2018, *LPS 49*, #1043. [2] Schroeder et al., 2006, *The Visualization Toolkit: An object-oriented approach to 3D graphics*, Kitware, Inc. [3] Steele et al., 2019, 4th Planetary Data Workshop.

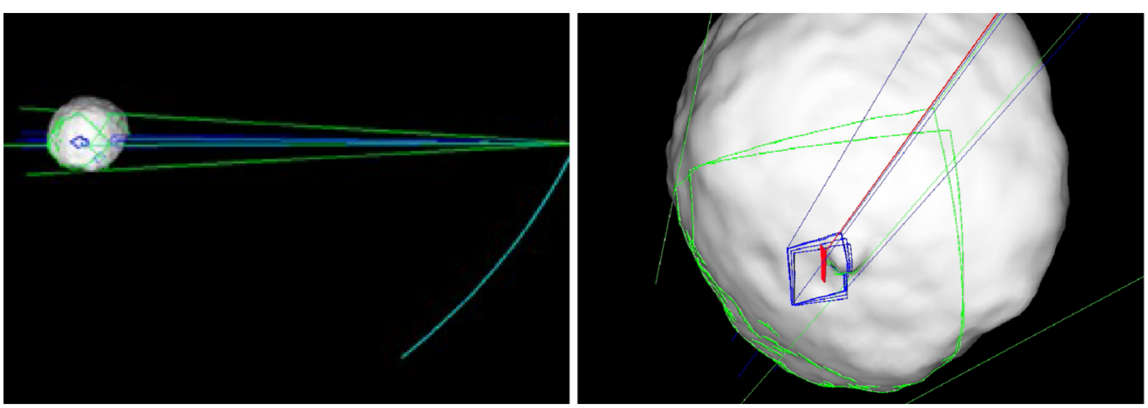

Figure 2. (left) The Observing Conditions tab allows visualization of trajectories (light blue), multiple instrument fields of view (green and blue frusta from the trajectory to the body), and the buildup of observations over time (green and blue footprints on the body). (right) Close-up inspection of an imaging plan can be used to explore the surface coverage built up over time.