JAVA MISSION-PLANNING AND ANALYSIS FOR REMOTE SENSING: "MISSION-PLANNING" IS JMARS' MIDDLE NAME P. F. Wren[1], S. Dickenshied[1], S. Anwar[1], W. Hagee[1], D. Noss[1], S. Carter[1], K. Rios[1], M. Burris[1], Z. Anderson[1], N. Piacentine[1], P.R. Christensen[1] [1]Mars Space Flight Facility, 201 E Orange Mall, Arizona State University, Tempe, AZ 85281 USA (pwren@mars.asu.edu)

Introduction: JMARS is a widely used planetary GIS application developed by ASU's Mars Space Flight Facility. It is used by NASA missions, researchers, students and the general public [1].

While most users are not familiar with the mission planning side of JMARS, it was the primary intent of developing this software. JMARS began as the mission planning tool for the THEMIS instrument onboard the Odyssey spacecraft.

In order to plan effectively and maximize science, one needs to create new observations in the context of previously acquired data and cross-instrument opportunities. This need for spatial contextual data launched JMARS into a planetary data analysis tool. Over the course of various missions, JMARS has been expanded to include data from many more planetary bodies big and small. The science community can use this free tool to quickly locate and view planetary data for Mars, the Moon, Vesta, Ceres, Mercury, Earth, Pluto, Europa, Phobos, Deimos, and many of the outer planet moons and asteroids.

JMARS continues as the mission planning tool for THEMIS, and has added planning capabilities for several additional missions.

So, what's a planning layer? JMARS presents most of its capabilities to users as layers, and mission planning tools are no different. We create planning layers that typically allow a mission planner to:

- View where a spacecraft instrument will be pointing, and when
- Choose to capture images (or spectra, or radar, or reflected laser light, or…) of desired locations at desired times (i.e., create an observing plan)
- Display outlines on the planetary surface showing where the data would be collected
- Review any operational rules that might be broken if the planned observations are executed
- Revise their observing plan and review it again
- Save the observing plan so it can be revisited and ultimately sent to the spacecraft

What's the secret sauce? You may be wondering: how does JMARS know at any given time where a planet is, which way it is facing, where a spacecraft may be, and which way it is pointing? The good news for us is that data files containing the location and orientation of each solar system body and each active spacecraft are created by, or in coordination with, NASA's Navigation and Ancillary Information Facility [2]. The wonderful people at NAIF maintain a software library that allows software to access these "SPICE" data files, and determine positions, orientations, and a lot more, all in four dimensions: the usual three dimensions plus time.

Private version for each mission: While JMARS is best known as a publicly-available tool that anyone can use, our mission-specific planning versions can only be accessed by users who have been granted permission as part of the mission team. The following sections contain overviews of the planning layers created in JMARS.

THEMIS Planning Layer: The THermal EMission Imaging System (THEMIS) aboard Mars Odyssey [3] continues to take both visible and thermal infrared images of the surface of Mars. Since its 2001 arrival in Mars orbit, THEMIS observations have been planned in advance using the THEMIS Planning Layer in JMARS.

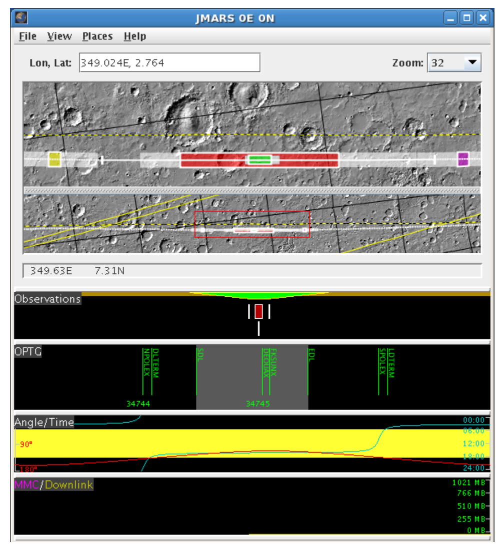

Figure 1: THEMIS Planning Layer showing the spatial view (top) and a timeline views (bottom).

The user begins by picking a planning time range specified by Odyssey orbit numbers, and is shown the associated nadir ground track. The user can then target observations anywhere along this ground track, providing observation parameters (visible or infrared, exposure time, etc.). The planning layer shows the observation spatially, on a timeline view as well as in a tabular view (see Figure 1). Observations violating any flight rules or constraints are highlighted, allowing the user to take corrective actions.

The observing plan is saved, and once approved can be uploaded to the spacecraft.

Mars Reconnaissance Orbiter Planning: A JMARS planning layer was created for the MRO spacecraft, known as the MTT (Mars Targeting Tool). It is used to create observing plans for the HiRISE and SHARAD instruments, and it is used at the project level to reconcile observing plans of all the instruments. That is, they make sure they all play well together!

The MTT works similarly to the THEMIS Planning Layer, but also incorporates requested features to support this very different spacecraft.

Lunar Reconnaissance Orbiter Planning: Not just for Mars, JMARS also supports observation planning for the Lunar Reconnaissance Orbiter Camera (LROC) [4] with a version called J-Moon. It is also similar to the Mars Targeting Tool, showing proposed imaging of the lunar surface in the two-dimensional main display of JMARS.

OSIRIS-REx at Bennu Planning: The next generation of JMARS planning layers began with the development of J-Asteroid for Bennu [5], a planning layer and data visualization tool developed for the OSIRIS-REx mission to the near-Earth asteroid Bennu.

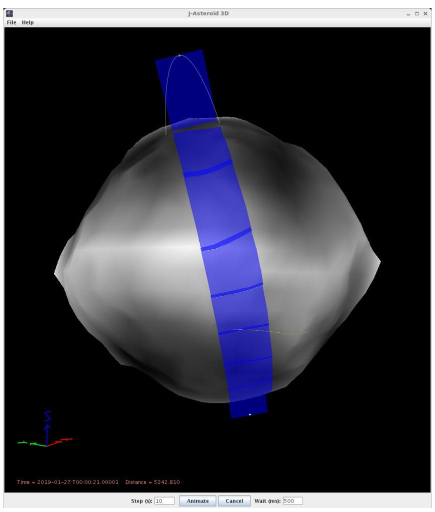

Figure 2: J-Asteroid 3D depicting a linear mosaic of planned OCAMS images projected onto the surface of a Bennu shape model.

Planning in three dimensions. All previous JMARS planning layers targeted planetary bodies that could generally be treated as a sphere, but the irregular shapes of asteroids require a new approach. J-Asteroid features a 3D window in which a shape model of an asteroid can be rotated and zoomed (See Figure 2). It allows the draping of mission data and planned observations onto the shape model of the asteroid, thanks to the NAIF team's Digital Shape Kernel (DSK) functionality [2].

Planning and commanding. J-Asteroid not only supports science targeting for all the instruments aboard OSIRIS-REx, but also generates the necessary spacecraft commands for those instruments to perform the planned observations. Once a plan is accepted, spacecraft command sequence files are generated that can ultimately be uploaded to the spacecraft.

EMIRS Planning at Mars: JMARS has created a layer to support the Emirates Mars InfraRed Spectrometer (EMIRS) instrument [6] aboard the Hope spacecraft now headed to Mars. This plan verification layer ingests a pre-constructed command sequence for the instrument representing a series of observations, and shows where the observations will be placed on the surface of Mars in both 2D and 3D (see Figure 3). Several constraints are checked to ensure the planned observations will be successful and avoid any harm to the instrument.

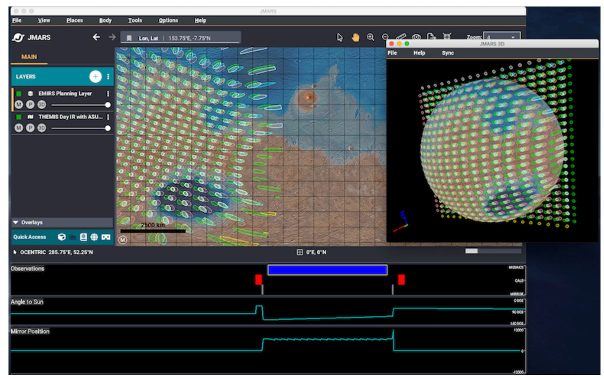

Figure 3: EMIRS plan verification in 2D and 3D.

Other Planning Layers: The JMARS team created a planning layer to support an ASU student-led CubeSat mission to study urban heat islands on Earth [7]. We are currently building a layer to create and visualize flyby observations of Jupiter's moon Europa for the E-THEMIS instrument aboard the Europa Clipper [8], slated for launch in 2024.

References: [1] Christensen P. R. et al. (2009) *Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract #IN22A-06.* [2] Acton, C. H. et al. (2018) *Planet. Space Sci.*, 150(1). [3] Christensen, P. R. et al. (2004) *Space Sci. Rev.*, *110*(1-2), 85-130. [4] Robinson, M. S. et al. (2010) *Space Sci. Rev.* 150(1-4), 81-124. [5] Christensen, P. R. et al. (2018) *LPI*, (2083), 2788. [6] Edwards, C. et al. (2018) *cosp*, *42*, B4-2. [7] Rogers S. et al. (2020) phxcubesat.asu.edu. [8] Howell, S. M., & Pappalardo, R. T. (2020). *Nature Comm. 11*(1), 1-4.

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