Dynamic 3D Context Provision for Planetary environments: PRo3D Sequence Bookmarking

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ABSTRACT

Tactical and strategic tasks in planetary exploration rely on context awareness for Rover navigation and utilize 3D data products for visualization. Tools visualizing these data sets at various levels of detail are useful for translating and interpreting planetary scenery to scientists and engineers, who benefit from the ability to navigate in a repeatable manner. Here, we provide a strategy and solution for the so-called “Sequenced Bookmarks” capability of the Planetary Robotics 3D Viewer PRo3D which enables recording the exploration and analysis of a scene by defining states (sequenced bookmarks). They incorporate the view, visibility of scene objects and graphical annotations and are arranged in a specific order. Users either re-play them interactively or assemble story-telling videos by offline rendering to present a scientific interpretation based on the 3D data. We report on the workflow and demonstrate several use cases from Mars 2020 Mastcam-Z images, wherein 3D vision scientific products are generated. These use cases scenarios include an immersive experience, wherein geologic interpretations and science rationale can be assembled within minutes.

Keywords: Visualization & Rendering, Planetary Exploration, 3D-GIS, 3D Vision, Geologic Storytelling

1. BACKGROUND: 3D DATA OBTAINED AND VISUALIZED FROM ROVER CAMERA IMAGES

In planetary exploration, various tactical and strategic tasks such as geologic interpretations or context awareness for rover navigation greatly profit from the availability and usage of 3D data products such as Digital Terrain Models (DTMs), ortho images, or (textured) meshes. Such products are available from satellite imagery such as the HiRISE sensor onboard the Mars Reconnaissance Orbiter, and in particular from rover cameras.

Mars 2020 Mastcam-Z [1] stereo camera 3D products contain necessary information for subsequent visualization and unique analysis of rocks, outcrops, and other geological and aeolian features. The Planetary Robotics Vision Processing framework PRoViP [2][3], processes Mastcam-Z sequences on a tactical time frame to generate panoramas, distance maps, textured meshes, and derived products. Ordered Point Clouds (OPCs) [4] created with Mastcam-Z stereo mosaics are georeferenced using the tactical rover localizations, provided by the Mapping Specialists on the Mars 2020 team. The OPCs are loaded into the Planetary Robotics 3D Viewer (PRo3D, [5]) for interactive 3D exploration, measurement and annotation. Multiple OPCs can be overlain on textured Digital Terrain Models (DTMs) from Mars Reconnaissance Orbiter [6] HiRISE stereo images for global context and large-scale spatial reference (Figure 1).

2. NARRATIVE VIDEOS FOR IMMERSIVE SIENTIFIC STORY TELLING

A typical workflow to explain physical processes on a planetary surface based on its 3D virtual representation incorporates the following steps:

- A spatial and thematic overview showing the environmental context, typically at km-scale, illustrating the rover trajectory, local landmark features and scale bars

- All relevant 3D data (shape and texture as well as thematic / spectral) layers are collected and maintained for viewing various products on top of each other. Starting from the planet environment, this may consist of products from various instruments on all scales down to individual regolith grains (e.g., tens of microns) from the close-up instruments at specific regions of interest
- Moving towards a specific region, zooming-in, letting new surface layers appear, or annotating a target of interest attracts attention to a particular part of the landscape
- Speed & timing of (virtual) camera animations (scene navigation by fly-through) varies tension, allows time for spoken or annotated explanations and supports the viewers' story understanding
- Viewing specific features from different positions and smoothly transiting between them adds further immersion.

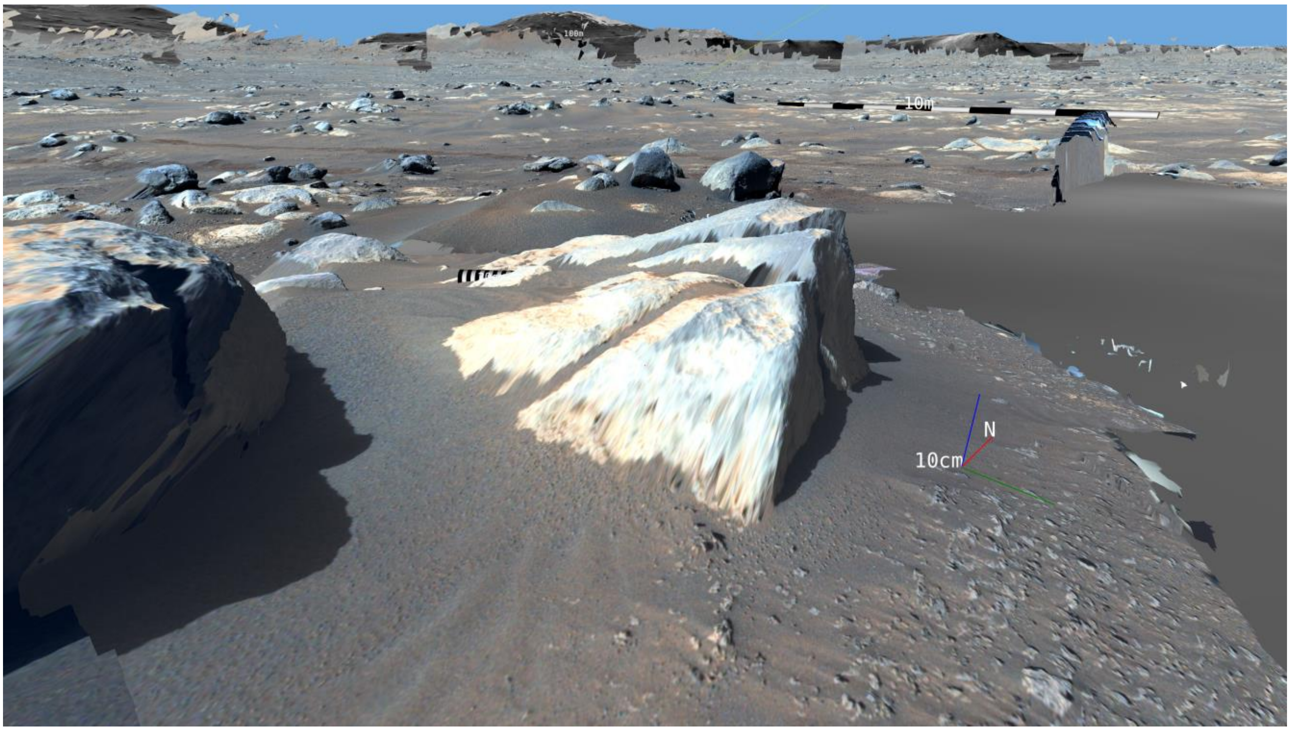

Figure 1: Visualizing global-to-local scale: Mastcam-Z OPCs from Sol 363-369 overlaid on HiRISE DTM / Ortho, with scale bars and coordinate frame. NASA/JPL/CalTech/ASU/MSSS/JR/VRVis.

Tools that visualize those data sets in various levels of details are in most cases used to interactively navigate through the terrain, make measurements, display scaling information, annotate on the virtual surface, and aid data fusion between products from different instruments. Generating a planetary scene that is a shared reference between scientists and engineers, greatly improves navigating in a repeatable manner and overall exploring capabilities. Providing a step back by zooming out to improve overall understanding of an outcrop to see the "whole picture", virtually approaching a target for annotating details of interest, disabling and enabling annotations and surface patches, and being able to record and playback sequences is a user-friendly way to share interpretations, similar to joint personal presence at the very site. As shown in Section 3, PRo3D – the Planetary Robotics 3D Viewer – allows for such functionality, both in interactive and offline rendering mode.

3. PRO3D SEQUENCED BOOKMARKING WORKFLOW

PRo3D implements a dynamic scene-based "Sequenced Bookmarks" (SB) workflow in a repeatable way, applied to the relevant elements defining a view and the displayed scene (Figure 2). SBs define specific 3D viewpoints and scene states, their sequence, as well as duration and transition times (i.e. the duration of motion between one bookmark and the next). Surfaces (e.g. from different rover camera sequences, or satellite data meshes), their possible variations in geometric and radiometric sense as well as rendering priorities between them and activation status can be selected per SB. The scale bar facility, disabling/enabling the display of individual surfaces and annotations, displaying rover tracks and locations, dip-and-strike annotations, measurements and profiles (also vertically projected to define true thicknesses), in conjunction with the embedding of photospheres (a virtual reality element based on panoramic images) and multi-temporal surface layers, are combined to create video stories highlighting the scientific observations and their context. A sequence is played back via its "play" button, and high-resolution (up to 8k) offline rendering can be invoked to produce smoothly rendered videos. The components of the PRo3D SB Graphical User Interface (GUI) are displayed in Figure 3.

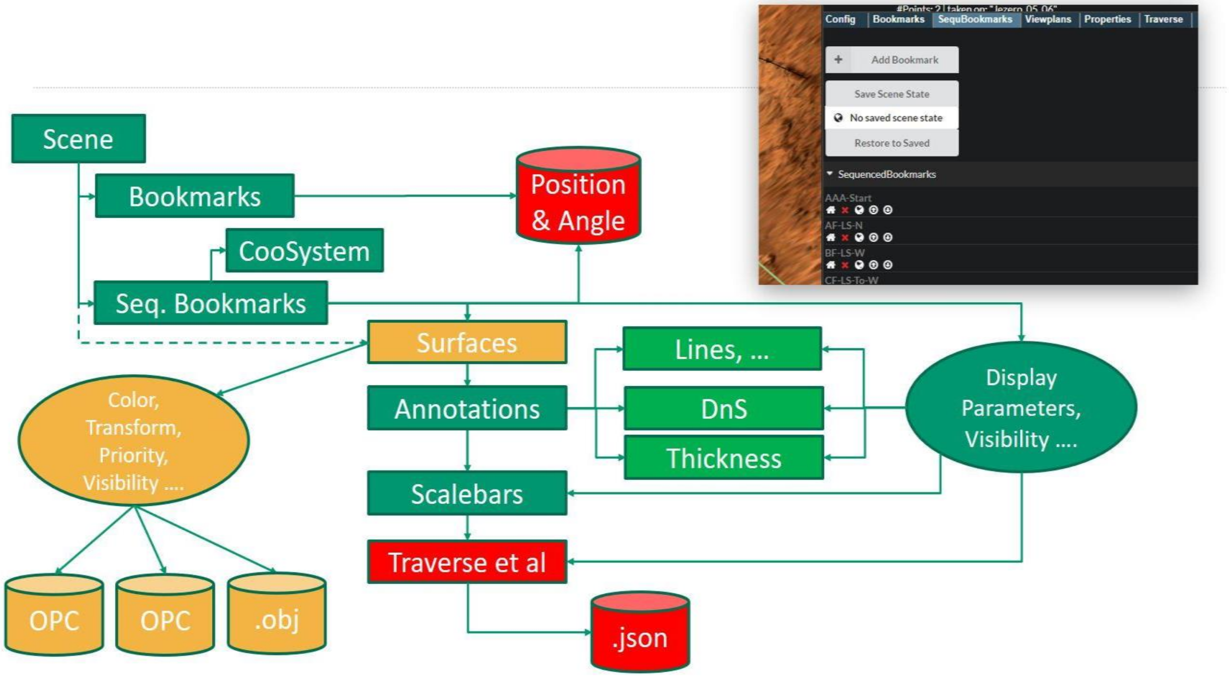

Figure 2: PRo3D visualization elements reflected in Sequenced Bookmarks as individual scenes

PRo3D's *SB* capability allows for various modes of operation and use cases for story-telling. Workflows, specific features and example products from different scientific applications in the domain of Mars 2020 Mastcam-Z 3D data exploitation and visualization can be and have already been realized, as pointed out in the following list of individual activities in the workflow, achieving presentation-ready story-telling video footage in a matter of minutes:

a) Fusing HiRISE and Mastcam-Z OPCs at various scales [9][11]
b) Radiometric adaptations of imported surfaces allow highlighting, contrast adaptation and continuity of appearance
c) Defining bookmarks (virtual camera poses) allows for repeated views, as well as definition of their order and transition timeframe
d) Measurement of distances and slopes, placing short- and mid-range scale bars, a coordinate frame, dip and strike and the rover trajectory assemble the specific analysis and interpretation scenery
e) Disabling, enabling and modifying interactively created and imported objects

such as the previously defined scale bars, annotations, measurements, rover track/s and the OPC-coded surfaces themselves, as well as adapting visibility and radiometric settings on surfaces for each bookmark individually allows the viewer to focus attention on the most relevant elements of scene understanding

f) Generating screenshots with up to 16k pixels resolution provides images for publication illustrations

A bookmark sequence can be replayed in the viewer to see a 1:1 preview of the created camera animation. Finally, it can be exported as high-resolution frame sequence to produce a storytelling movie using an external video editing tool.

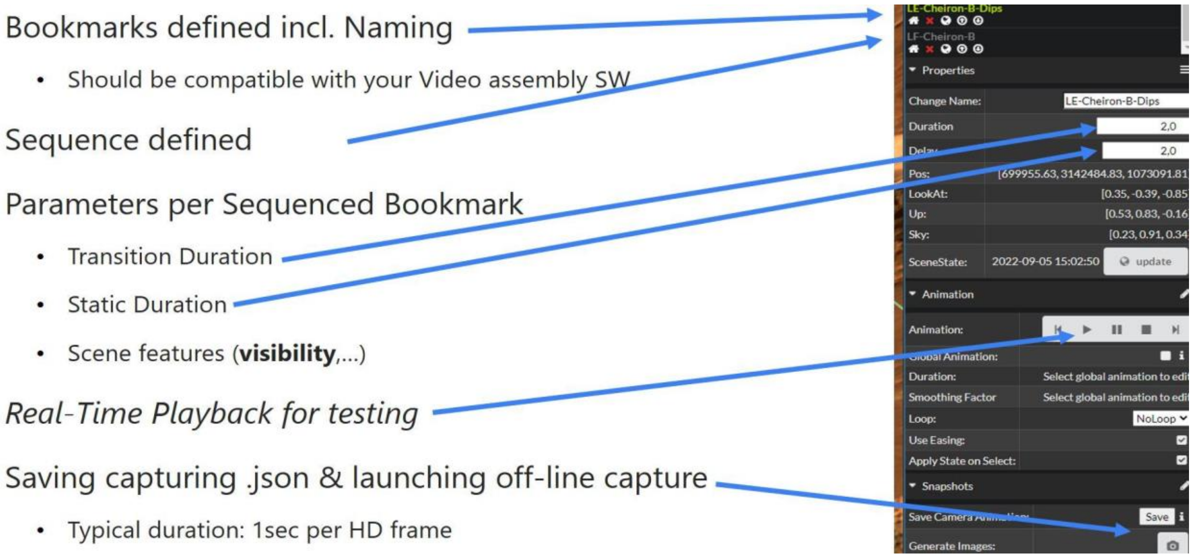

Figure 3: PRo3D Sequenced Bookmarks GUI elements

4. EXPLOITATION CASES & OUTLOOK

By PRo3D's *Sequenced Bookmarks* capability, the dynamic 3D presentation of an exploration scene becomes a standard, low-effort and immersive means of sharing observations and findings. SB have been applied to visualizations of the Mars 2020 landing [8], atmospheric processes (e.g., ventifacts [12]), the accumulation of measurements as the rover drives to connect to subsurface observations, or 3D change documentation [10]. A typical workspace may be documented from afar as well as in detail. These immersive 3D images connect across spatial scales and generate geologic context for investigated workspaces. Here, the sampled regolith workspace (Figure 4) documents the spatial properties and extent of the megaripple investigated. These results inform the composition of the respective Target sampled and dropped/cached for Mars Sample Return [7]. By utilizing multiple measurements of the megaripple, wheel track scarp observations are comparable to areas sampled providing insights into the physical structure and regolith components with depth.

Various products demonstrate already the effective capability to generate illustrative video documentation of a 3D data manipulation and analysis process such as fine co-registration of Mastcam-Z to HiRISE, followed by long-range scale bar placement & visualization [11]. The toolset is not restricted to the Martian environment. Due to the open source origin of PRo3D [13], it will be available and applicable to other missions seeking other planets, moons, and asteroids [14].

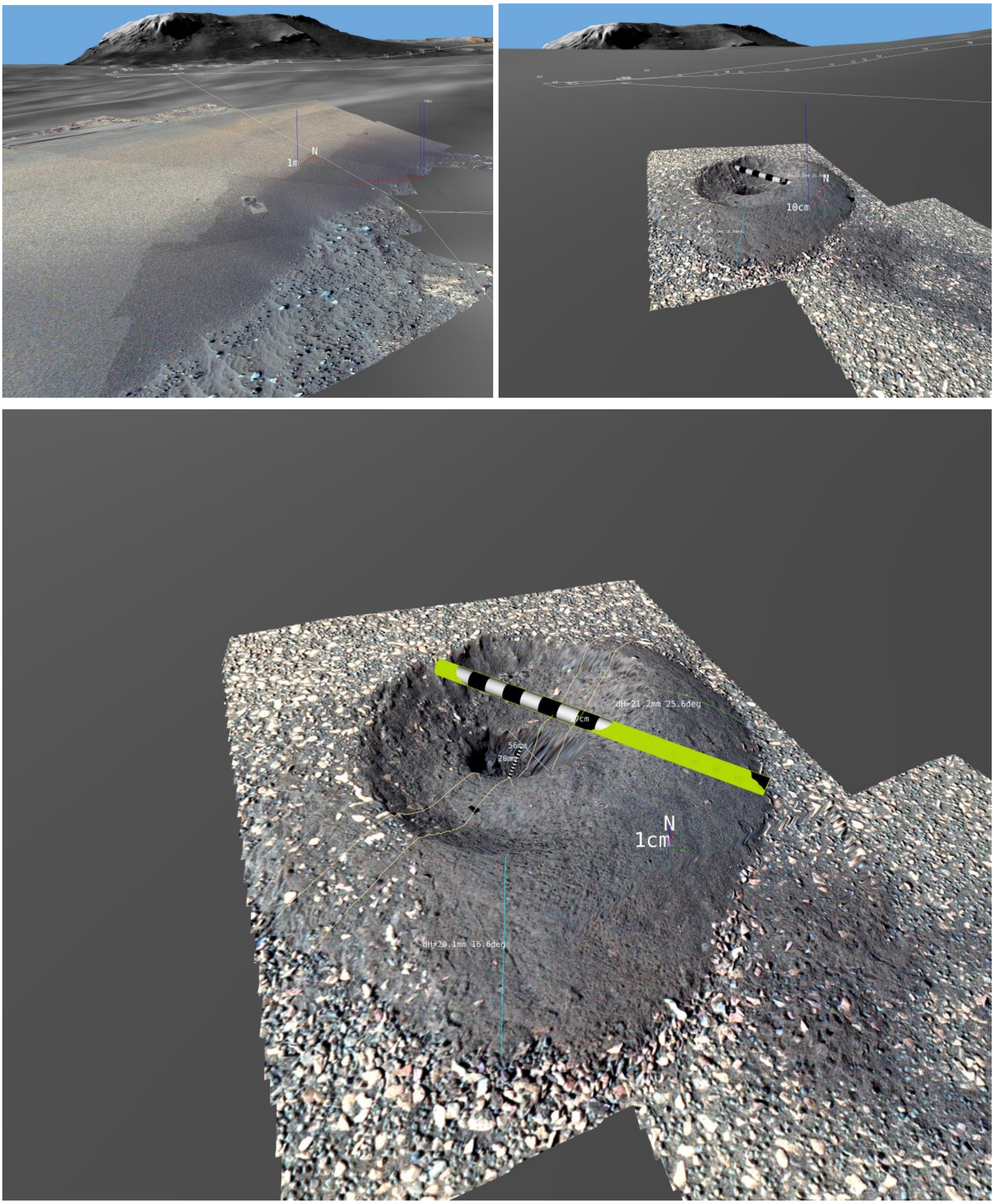

Figure 4: PRo3D Sequenced Bookmarks used for estimating the extent of sampling (Target: within the megaripple as well as the regolith angles of repose and compositional changes (grain size, color) with depth. These properties are critical information for the potential return and subsequent understanding of a regolith Target via Mars Sample Return. Three different states are shown, beginning with the context also displaying a part of the rover traverse, and zooming in (bottom).

REFERENCES

[1] Bell, J. F., et al. "The Mars 2020 perseverance rover mast camera zoom (Mastcam-Z) multispectral, stereoscopic imaging investigation." *Space science reviews* 217.1 (2021): 1-40.

[2] Traxler, C., Ortner, T., Hesina, G., Barnes, R., Gupta, S., Paar, G., ... & Willner, K. (2022). The PRoViDE Framework: Accurate 3D geological models for virtual exploration of the Martian surface from rover and orbital imagery. In *3D digital geological models: From terrestrial outcrops to planetary surfaces*, p33-55. Wiley. https://doi.org/10.1002/9781119313922.ch3

[3] Paar, G., Ortner, T., Tate, C., Deen, R. G., Abercrombie, P., Vona, M., ... & Maki, J. (2023). Three-Dimensional Data Preparation and Immersive Mission-Spanning Visualization and Analysis of Mars 2020 Mastcam-Z Stereo Image Sequences. *Earth and Space Science*, *10*(3), https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022EA002532

[4] Thomas Ortner, Gerhard Paar, Gerd Hesina, Robert F. Tobler, Bernhard Nauschnegg. Towards True Underground Infrastructure Surface Documentation. Proc. Real Corp, 2010

[5] Barnes, R., Gupta, S., Traxler, C., Ortner, T., Bauer, A., Hesina, G., ... & Tao, Y. (2018). Geological analysis of Martian rover-derived digital outcrop models using the 3-D visualization tool, Planetary Robotics 3-D Viewer—PRo3D. *Earth and Space Science*, *5*(7), 285-307. https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2018EA000374

[6] McEwen, Alfred S., et al. "Mars reconnaissance orbiter's high resolution imaging science experiment (HiRISE)." *Journal of Geophysical Research: Planets* 112.E5 (2007).

[7] Beaty, David W., et al. The potential science and engineering value of samples delivered to Earth by Mars sample return: International MSR Objectives and Samples Team (iMOST). *Meteoritics & Planetary Science* 54 (2019): S3-S152.

[8] Perseverance Descent Reconstruction in PRo3D, https://www.youtube.com/watch?v=-z1KySwtnuU

[9] QZCAM 0268 0255 ZCAM03258 8278 L0R0 110 034 HiRISE PRo3D Brac SampleHole1 E01, https://www.youtube.com/watch?v=5Sn4MpZdgpg

[10] QZCAM Sol0821 0822 ZCAM5068 8839 et al PRo3D 4k https://www.youtube.com/watch?v=H2zk4rb1Mbk

[11] Photosphere HiRISE ScaleBar PRo3D Tutorial https://www.youtube.com/watch?v=6MB1PJB3Gg0

[12] Herkenhoff, K. E., Sullivan, R. J., Newman, C. E., Paar, G., Baker, M., Viúdez-Moreiras, D., ... & Nuñez, J. I. (2023). Comparison of ventifact orientations and recent wind direction indicators on the floor of Jezero crater, Mars. Journal of Geophysical Research: Planets, 128(3). https://doi.org/10.1029/2022JE007599

[13] PRo3D GitHub page https://github.com/pro3d-space/PRo3D

[14] Steinlechner, H., et al. (2023). PROVEX – Approachable Data Provenance Tracking for Space Missions. Submitted to ASTRA 2023 conference.

ACKNOWLEDGEMENTS

JR, VRVis and ÖAW receive funding from FFG ASAP Project 892662. VRVis is funded by BMK, BMDW, Styria, SFG, Tyrol and Vienna Business Agency in the scope of COMET - Competence Centers for Excellent Technologies (879730) managed by FFG. We thank Rebecca Nowak for implementing the *Sequenced Bookmarks* suite. Mars 2020 Rover navigation data has been provided by the JPL Mars 2020 Navigation Team. The HiRISE DTM was assembled by USGS. The HiRISE RGB layer was provided by the JPL Mars 2020 Team. Mastcam-Z data was provided by the Mastcam-Z Instrument Team. The research was partially carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).