THE NASA MARS 2020 MISSION PERSEVERANCE ROVER MASTCAM-Z DATA ARCHIVE UPDATE.

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Introduction: The Mastcam-Z instrument [1-3] onboard the Mars 2020 Perseverance rover is a multispectral, zoomable, and focusable camera pair located on the rover's remote sensing mast (RSM) [Figure 1]. Each camera has an 8-position filter wheel and is capable of acquiring color images using Bayer pattern red, green, and blue (RGB) filters bonded onto the charged-coupled device (CCD) detector; multispectral images using six other narrowband filters (~440 nm to ~1000 nm); or solar images using neutral density filters. The cameras acquire color, multispectral, stereo, and panoramic images of the surface and rover hardware. Mastcam-Z is also capable of taking videos. As of sol 290, Mastcam-Z has acquired 67,539 image and video frames approximating 16.5 terabytes (TB).

Figure1: Cropped up close Perseverance Rover selfie with Ingenuity helicopter [NASA/JPL-Caltech/MSSS]

The Mastcam-Z team at Arizona State University (ASU) generates radiance (RAD) and radiance factor (IOF) calibrated data products "level-1B" for all applicable observations [2,4].

Sols 0-179 ASU RAD and IOF calibrated data products are publicly available through the PDS. In addition to .IMGs and PNG browse products; supporting documentation, and 10 videos of Ingenuity helicopter using ASU calibrated images are available for a total of 1.2 TB of data. The next release will cover sols 180-299 and be available on March 22nd, 2022.

Data Acquisition: Mastcam-Z acquires images in a variety of product types, including: full-frame (1648 x 1200 pixels), subframe, thumbnail, compressed video groups of pictures (GOPs), and focus merges (z-stacks). All of these product types can be stored in the camera Digital Electronics Assembly (DEA). Typically, a full resolution image is written to the DEA as a raw uncompressed image that can be later copied to the rover as a "virtual data product" (VDP) pointer back to the original DEA image. When queued for downlink, the VDPs are processed in the rover's computer into requested data product (DP) format, and then downlinked by way of orbiter passes using the Deep Space Network (DSN) [5]. Once images have been downlinked, they get thoroughly checked for accurate pointing, metadata, saturation, and data dropouts.

Sometimes partial products come down and have to be retransmitted on the next sol. Reprioritizations can be requested to receive the images sooner if they are needed for tactical decisions on where to drive, sample, etc., and recovered and cloned images can be requested in order to acquire an image in a compression or format that is different from how it was originally downlinked, as long as it has been stored in raw format in the DEA. There are four kinds of "level-0" raw data products: (1) color JPEGs (images & thumbnails); (2) Losslessly-compressed images; (3) compressed color videos; and (4) raw 11-bit images [1,6].

Data Products: The ASU team acquires the raw and Instrument Data Subsystem (IDS) generated experimental data records (EDRs) which go through the Mastcam-Z-team developed RAD and IOF pipelines [2,4].

A RAD or radiance calibrated images create better mosaics which are not only more seamless but also more scientifically useful for tactical rover planning and morphologic and multispectral analyses. The ASU RAD calibration process removes the effects of the camera optics (e.g., vignetting) and electronics (e.g., transfer smear) to convert the image into a true representation of the observed scene in physical units. RAD calibration is performed on all images except 0-second exposure shutter frames, which are sometimes acquired and subtracted from the actual images when high radiometric fidelity is required. Otherwise, the shutter frames are simulated using pre-flight calibration data [2,7].

An IOF or radiance factor calibrated images are used for scientific analysis. The calibration process converts a RAD image to an IOF using the calibrated radiance (RAD) images of the primary and/or secondary caltarget. Almost all RAD calibrated images get converted to IOF, excluding solar filter (L7/R7), 0-second exposure images (shutter frames), and post-sunset/pre-sunrise observations [2,7].

Calibration target (cal target) images are acquired near-in-time to most multispectral image sequences and

used in nominal calibration. Mastcam-Z has a primary and a secondary cal target. The primary is used to verify and validate preflight calibration while on the surface, as well as, tactical conversion from radiance to reflectance. The secondary cal target is used to affirm the results of the primary in calibration as well as to monitor dust buildup [4,5].

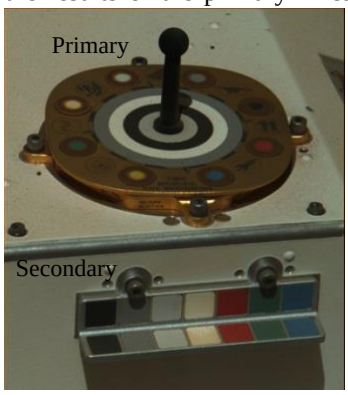

Figure 2: Mastcam-Z primary and secondary calibration targets located on the rover deck. [ZL0_0290_0692686494_910EDR_N0090000ZCAM03014_048085J] [NASA/JPL-Caltech/ASU/MSSS]

Images that are missing key metadata among other issues are not calibrated because their products could be misleading and inaccurate.

What goes to the PDS: The ASU team archives RAD and IOF data products in the form of .IMGs and a complimentary browse PNG product for easy viewing.

All archived products get an external Extensible Markup Language (XML) label generated for PDS4-compliant archiving. The .IMGs with attached Object Descriptive Language (ODL) and detached XML labels have individual tools that check the product validity and compliance to PDS4 requirements. All of the images (IMGs and PNGs) are reviewed by Mastcam-Z personnel prior to PDS delivery. The filenames, label values, and label keywords are all vetted before archiving to ensure high quality products reach the hands of archive users. The IOF products are separately validated by the Mastcam-Z science team to ensure all released products are valid science data products and useable for analysis.

In addition, some products, like videos of Ingenuity taking flight, made with the ASU calibrated images are also available in the miscellaneous collection. Supporting documentation is also available within the ASU calibrated bundle. All other products, like tactically-generated Mastcam-Z data products, not archived by the ASU team will be archived in the PDS by IDS.

Archive: All Mastcam-Z data products will be available through the Planetary Data System (PDS) every 4 months in 120 sol increments through primary mission. The first two releases were available every 3 months in 90 sol increments, that schedule has been revised.

The first release was made available in August, 2021 under the mars2020_mastcamz bundle which was delivered with ASU calibrated and IDS generated products in separate collections under the same bundle. This bundle has since been superseded to better accommodate the data that both ASU and IDS deliver by splitting our products into separate bundles. Now all ASU calibrated products can be found in the mars2020_mastcamz_sci_calibrated bundle.

All sol 0-89 products delivered in the first release have been re-delivered to the new bundle with updated filenames (due to an IDS reprocessing error) and updated calibration (new shutter frame model coefficients, ODL header updates, improved sky flats, improved flat fielding for the solar filters). A document matching the updated filenames with the superseded ones will be available in the document collection (release 3) [7].

The Mastcam-Z release notes found in the document collection will point users to any issues within the images, labels, or changes to earlier delivered products.

Future Plans: Derived atmospheric properties like opacity will be archived in the form of an ASCII table, pre-flight calibration data acquired during ATLO testing, as well as cruise data products will be available in a future release [8]. Expect support files used during science calibration, to be contained in a new *calibration* collection in an upcoming release.

The product data quality will be cataloged for the Mastcam-Z science team and public use of the image products in a future release [9]. The infrastructure for this process is currently under development. Another new product to eventually be included in the archive will be mosaics using calibrated images. The mosaics will be archived in the *miscellaneous* collection. These mosaics are not considered science data products and their use on the mission is typically for rover planning.

References: [1] Bell, J.F., *et al. Space Sci Rev* **217,** 24 (2021). https://doi.org/10.1007/s11214-020-00755-x. [2] Hayes, A.G., *et al. Space Sci Rev* **217,** 29 (2021). https://doi.org/10.1007/s11214-021-00795-x. [3] Farley, K.A., et al. Space Sci Rev (2020) 216:142 (2020). [4] Kinch, K.M., *et al. Space Sci Rev* **217,** 46 (2021). [5] Bell, J.F. et al., Mars 2020 Mastcam-Z Investigation Experiment Operations Plan (EOP) v3.1, (2018) JPL D-101346. https://doi.org/10.1007/s11214-020-00762-y. [6] Malin, M.C. et al. (2013). Mars Science Laboratory Project Software Interface Specification (SIS). https://doi.org/10.1007/s11214-021-00828-5. [7] Mastcam-Z Derived Product SIS (2021) *PDS archive* [8] Mehall, L. K., et al., (2019) *4th Planetary Data Workshop* Abstract #7060. [9] Bailey, A. M.,et al, (2020) *5th Planetary Data Workshop* Abstract #7038.