INITIAL PERFORMANCE ASSESSMENT OF THE MASTCAM-Z RADIOMETRIC CALIBRATION TARGET ON NASA'S PERSEVERANCE ROVER OVER THE FIRST 200 SOLS ON MARS.

M. Merusi[1], K.M. Kinch[1], M.B. Madsen[1], J.F. Bell III[2], A. Hayes[3], C. Tate[3], J. Joseph[3], D. Applin[4], E. Cloutis[4], J.R. Johnson[5]. [1]Niels Bohr Institute, University of Copenhagen (Denmark, marco.merusi@nbi.ku.dk), [2]Arizona State University (Tempe, AZ), [3]Cornell University (Ithaca, NY), [4]University of Winnipeg (Canada), [5]Johns Hopkins University (Laurel, MD)

Introduction: Since landing on Mars on February 18th, 2021, the NASA *Perseverance* rover achieved unprecedented milestones of space exploration within its landing site, the Jezero crater. In the first 200 sols (i.e., martian days) of the mission, the Mastcam-Z camera on the rover delivered amazing views of landscapes and rocks. Before any deeper analysis, all images undergo radiometric calibration, a key step to make pixel data scientifically consistent and comparable. For this purpose, the Mastcam-Z Calibration Target (or cal-target) is the most imaged object by the camera. Here we present a first assessment of the dataset of Calibration Target images.

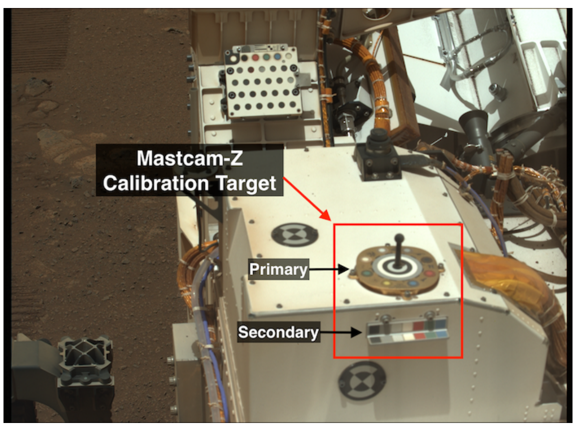

Figure 1. *Context image of the Mastcam-Z primary and secondary Calibration Target taken by the left eye of Mastcam-Z on sol 23.*

Mastcam-Z camera: Mastcam-Z [1] is a multispectral, stereoscopic couple of cameras mounted on the Remote Sensing Mast of the rover, at ~2m above the ground. Its two "eyes" are capable of focus and zoom-in (focal length ranging from 26mm to 110mm), providing images of significant resolution of close and distant targets. The camera system is capable of imaging through 3 broadband RGB and 11 narrowband filters, spanning the Visible and Near-Infrared spectrum (442-1022nm). Therefore, a series of images of the same target in all filters (a multispectral sequence) can produce a 14-point reflectance spectrum in each pixel (i.e., how intensely the sunlight is reflected by the target towards the observer).

The calibration target: The last step of the radiometric calibration [2] converts images from units of radiance to either reflectance factor R* or radiance factor I/F (IOF, given by IOF = R*·cos(*i*), where *i* is the solar incidence angle on the target, measured from zenith). This enables consistency in the comparison between spectra of objects imaged at different illumination conditions. The process is performed using the cal-target [3], a pair of physical devices mounted on the deck of the rover (fig. 1). The primary target consists of 8 round color and greyscale ceramic patches, 4 concentric greyscale rings and a shadow post on a gold-plated support. The 8 patches are fixed above strong hollow-cylinder magnets capturing airborne martian dust on the external portion of each patch, while the inner circle (clean spot) is expected to remain rather clean (fig. 2), even though it may experience accumulation of small fraction of non-magnetic dust.

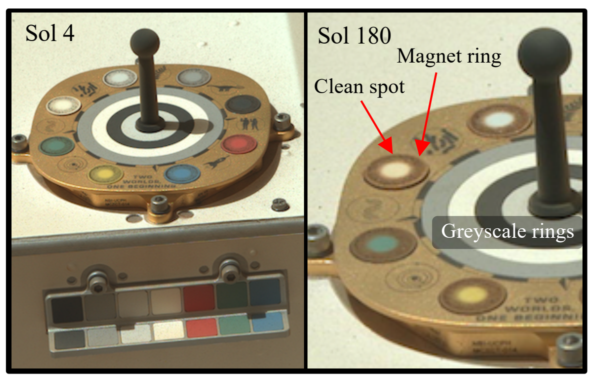

Figure 2. *Complete image of the Calibration Target from sol 4 (on the left) and close-up on the primary target from sol 180 (on the right). The dust accumulation over time on the magnet rings is evident between the two images.*

The secondary target is made of 7 pairs of square color tiles mounted vertically and horizontally, and it is mainly used to validate the primary target and to study dust deposition in an environment unaffected by the strong magnets of the primary.

The radiance-to-reflectance calibration: Every time Mastcam-Z takes a multispectral sequence of some target, a similar sequence of the cal-target is acquired close in time. For each radiance-calibrated image of the cal-target, a 1-term linear fit is made between the observed radiance values of the 8 clean spots and the reflectance factor R* (fig. 3). The R* factor is known from pre-flight laboratory measurements for any wavelength, patch color, and illumination geometry.

The inverse of the slope of each fit, which is unique for each filter, is a multiplicative factor that can be used to convert other Mastcam-Z images acquired close in time to R* (with knowledge or assumption about solar incidence on the scene) or IOF (using the known solar incidence on the calibration target) [3].

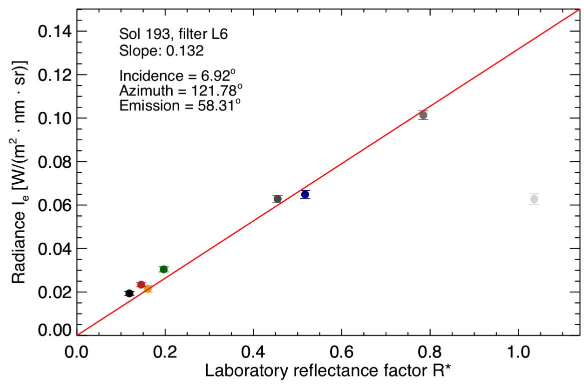

Figure 3. *Example of a radiance-VS-reflectance factor 1-term linear fit (red line) for a cal-target frame from sol 193 in filter L6 (442nm). The datapoints correspond to the 8 primary clean spots.*

Data analysis and discussion: From landing to sol 200, a total of 1320 narrowband-filter frames of the cal-target were captured by Mastcam-Z for calibration or visual inspection purposes (e.g., to assess the dust accumulation on the magnet rings, see fig. 2). For each one of them, a radiance-VS-reflectance 1-term linear fit was realized, and the related slope was extracted. Immediately after landing and increasing progressively during the mission, the white primary clean spot (AluWhite 98) started showing a visual yellowing effect in cal-target images. This misbehavior was also observed in the linear fits, where the white radiances had a much lower value than the fits, especially at shorter wavelengths, and was reflected in the R* and IOF spectra of the cal-target (figs. 3-4). Hence, the white primary spot was always excluded from the fit computation.

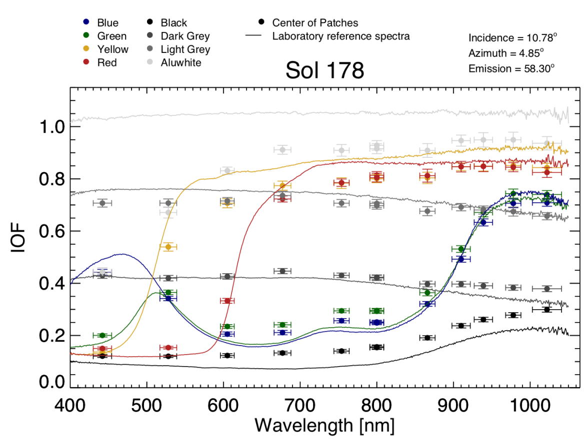

Figure 4. *Example IOF spectrum of the primary clean spots (dots) for the sol 178 cal-target. Solid lines represent the laboratory spectra at the same illumination conditions as the datapoints.*

Slope evolution. All the 1320 narrowband-filter slopes are represented in a plot versus time (fig. 5), from landing to sol 200, distinguishing among the different filters and between observations with incidence angle smaller ("high Sun") and larger ("low Sun") than 30°. The overall trend is smooth, displaying a shallow depression with minimum around sol 142 (July 12th, 2021) which corresponds to the martian aphelion, and therefore, totally in line with expectations due to the largest Sun-Mars distance.

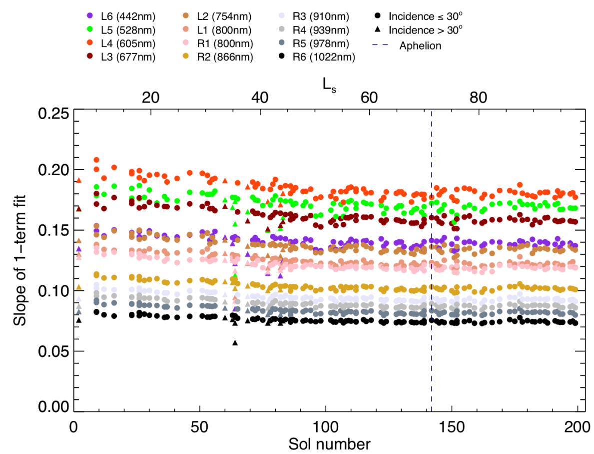

Figure 5. *Time evolution of the slopes of the 1-term linear fits between the radiance and the reflectance of the primary clean spots. The dashed vertical line marks the martian aphelion.*

Conclusion and future work: The preliminary analysis of Mastcam-Z radiometric calibration over the first 200 sols of NASA *Perseverance* mission shows that the Calibration Target is working well, especially thanks to the cylindrical magnets that keep the primary clean spots mostly free from dust, for the benefit of the linear fits. Further developments of the analysis are currently under investigation and will be included in a future publication by Merusi *et al*.

Acknowledgments: M. Merusi received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 801199. The project was supported by the Carlsberg Foundation (Grant CF19-0023), and we thank the teams at JPL, ASU, and MSSS for making this work possible.

References: [1] Bell *et al.*, Space Sci. Rev. 217:24, 2020. [2] Hayes *et al.*, Space Sci. Rev. 217:29, 2021. [3] Kinch *et al.*, Space Sci. Rev. 216:141, 2020.