# THE MASTCAM-Z FILTER SET AND PLANS FOR MULTISPECTRAL IMAGING WITH MARS-2020 AT JEZERO CRATER.

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**Introduction:** The Mastcam-Z instrument onboard the Mars-2020 rover [1] is a pair of multispectral, stereoscopic zoom-lens cameras that provide broadband red/green/blue (RGB), narrowband visible to near-infrared color (VNIR, 442-1017 nm wavelength range), and direct solar imaging capability. The 4:1 zoom lenses provide continuously variable fields of view (FOV) ranging from ~5° to ~23°, and will allow Mastcam-Z to resolve features ~1 mm in size in the near field. While Mastcam-Z shares significant design heritage with its predecessor, the Mars Science Laboratory (MSL) Mastcam instrument [2,3], the zoom mechanism and the narrowband filter set (Table 1, Fig. 1) are new.

**The Mastcam-Z Filter Set:** Mastcam-Z images are acquired through a Bayer pattern of RGB filters and telecentric microlenses bonded onto the charge-coupled device (CCD), and an 8-position filter wheel in front of each camera's optics (Fig. 2) that provides the ability to obtain additional narrowband images through visible, near-infrared, and solar neutral density filters. A "clear" filter with an infrared cutoff (L0, R0) allows each camera to image in approximate true color. The narrowband "geology" filters (L1-6, R1-6) have been selected to maximize Mastcam heritage while optimizing the instrument's ability to characterize potentially-diagnostic features of iron and alteration minerals.

Compared to Mastcam, the Mastcam-Z filter set has less stereo overlap (redundancy) between the two cameras; two of Mastcam's redundant filters have been replaced with new filter positions at 605 nm and 978 nm. The locations of these band centers were selected to optimize Mastcam-Z's characterization of iron oxides with local reflectance maxima near 600 nm and hydrated minerals with narrow absorption bands near 980 nm (e.g., Fig. 3). Another significant change from Mastcam is the arrangement of the Mastcam-Z narrowband filters: the short wavelengths are combined in the Left camera, and the longer wavelengths in the Right camera, with stereo overlap in the Bayer RGB and 805 nm filters. When full-filter Mastcam-Z images are acquired, data from the Left and Right camera can be scaled to their average value at 805 nm to produce a single "spectrum" with 14 wavelength positions.

**Table 1.** Mastcam-Z Multispectral Filters

| **Mastcam-Z Left** | | *Mastcam heritage* |
|---|---|---|
| **Filter Position** | **Effective Band Center[1] ± HWHM[2] (nm)** | |
| **L0 (Red Bayer)** | **634 ± 43** | *640 ± 44* |
| **L0 (Green Bayer)** | **542 ± 42** | *554 ± 38* |
| **L0 (Blue Bayer)** | **476 ± 46** | *495 ± 37* |
| **L1** | **801 ± 9** | *805 ± 10* |
| **L2** | **754 ± 10** | *751 ± 10* |
| **L3** | **677 ± 11** | *676 ± 10* |
| **L4** | **605 ± 9** | --- |
| **L5** | **528 ± 11** | *527 ± 7* |
| **L6** | **442 ± 12** | *445 ± 10* |
| **L7** | **590 ± 88, ND6[3]** | *440 ± 20, ND5* |

| **Mastcam-Z Right** | | *Mastcam heritage* |
|---|---|---|
| **Filter Position** | **Effective Band Center[1] ± HWHM[2] (nm)** | |
| **R0 (Red Bayer)** | **634 ± 43** | *640 ± 44* |
| **R0 (Green Bayer)** | **542 ± 41** | *554 ± 38* |
| **R0 (Blue Bayer)** | **476 ± 46** | *495 ± 37* |
| **R1** | **800 ± 10** | *805 ± 10* |
| **R2** | **866 ± 10** | *867 ± 10* |
| **R3** | **910 ± 12** | *908 ± 11* |
| **R4** | **939 ± 12** | *937 ± 11* |
| **R5** | **978 ± 10** | --- |
| **R6** | **1017 ± 18** | *1013 ± 21* |
| **R7** | **880 ± 10, ND5[3]** | *880 ± 10, ND5* |

Notes: (1) Effective band center wavelength including optics and CCD spectral responses; (2) Half-width at half-maximum; (3) Filters L7 and R7 are for direct imaging of the Sun using Neutral Density (ND) coatings that attenuate the flux by factors of $10^6$ and $10^5$.

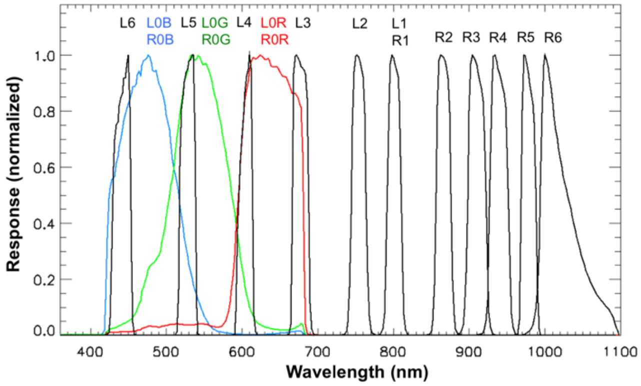

**Figure 1:** Normalized Mastcam-Z system-level spectral response profiles for the Bayer RGB filters and the narrowband filters.

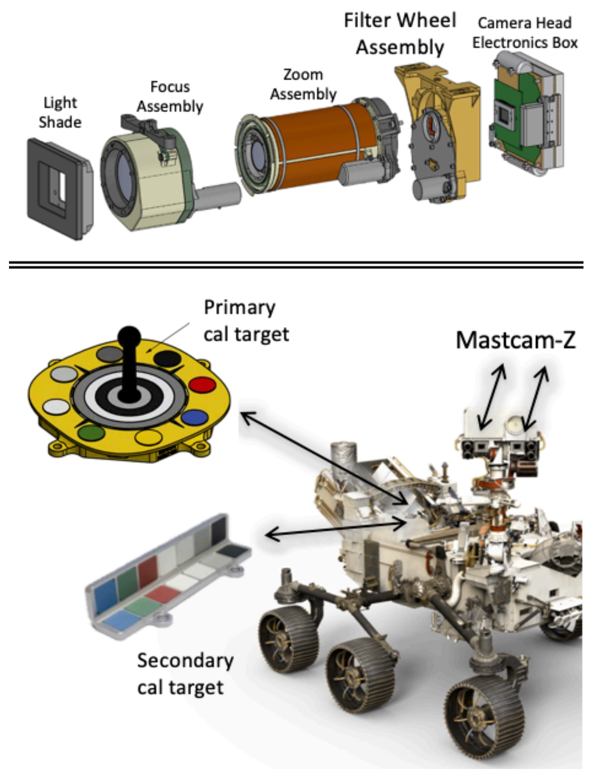

**Figure 2:** Above: Components of each Mastcam-Z, including the filter wheel assembly in front of the Bayer filter CCD in the camera head electronics box. Below: Location of the Mastcam-Z cameras and calibration targets on the Mars-2020 rover.

The final filter position in each camera (L7, R7) utilizes spectral filters with $10^5$-$10^6$ attenuating neutral density filters for direct "solar filter" imaging of the Sun. The R7 filter (880 nm + ND5) draws from Mastcam heritage, and the L7 filter enables RGB Bayer filter color imaging of the Sun to retain full resolution and to distinguish between dust versus water ice cloud sources of opacity [4].

**Mastcam-Z Multispectral Imaging Strategies:** Near-simultaneous observations of the Mastcam-Z calibration targets (Fig. 2) [5] will be used with pre-flight calibration coefficients [6] to calibrate Mastcam-Z surface observations to I/F. Due to limitations in the expected data volume downlink from Mars-2020, full-filter Mastcam-Z observations will need to be acquired judiciously. The majority of Mastcam-Z observations will utilize the L0 and/or R0 filters only. These single-filter observations allow for approximate true color RGB images which can be "white balanced" to enhance visible color variability in the scene [2]. Decorrelation stretches can also highlight subtle spectral variations in L0 or R0 images, and can be "reconnaissance" for identifying outcrop targets for filter and/or zoomed-in imaging.

Subsets of narrowband filters can be used to search for specific spectral characteristics (e.g., R1, R2 and R6 can characterize the 866 nm hematite band depth; R4, R5 and R6 can characterize the 978 nm hydration band depth; L4, L5 and L6 can characterize the 528 nm iron oxide band depth). Full-filter observations will be acquired for the highest-priority targets, such as those being considered for sample caching. Mastcam-Z spectra can also be used in coordination with SuperCam VISIR reflectance spectra to extend wavelength coverage from 1.3-2.6 µm [7]. Ultimately, the multispectral imaging strategies will depend on the available resources as well as the spectral characteristics of surface materials observed *in-situ* at Jezero crater.

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**References:** [1] Bell J.F. III *et al.,* submitted to *Space Sci. Rev*. [2] Malin M. et al. (2017) *Earth & Space Sci., 4,* 506–539. [3] Bell J.F. III et al. (2017), *Earth & Space Sci., 4*. [4] Lemmon M.T. et al. (2004) *Science*, 306, 1753-1756. [5] Kinch K. *et al.,* submitted to *Space Sci. Rev*. [6] Hayes A.G. *et al.,* submitted to *Space Sci. Rev*. [7] Weins R. *et al.,* submitted to *Space Sci. Rev*.

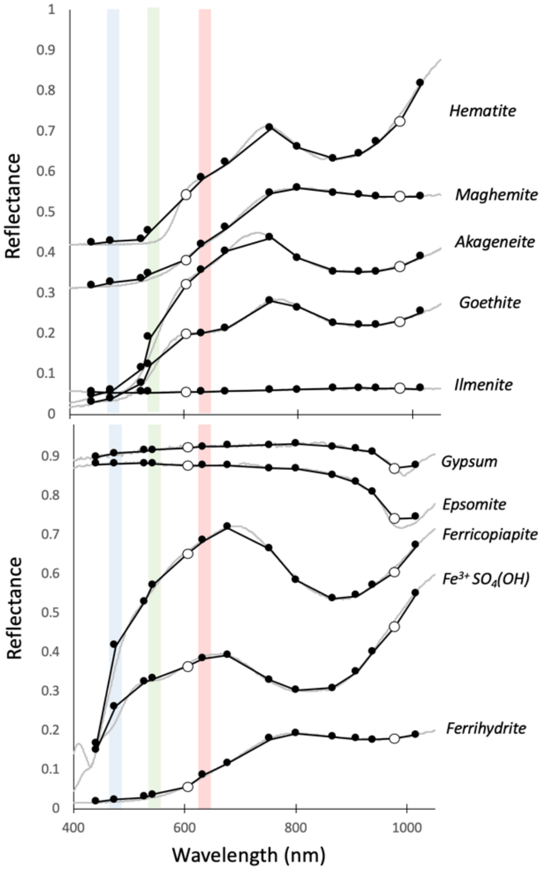

**Figure 3:** Laboratory spectra [7] of iron oxides and hydrated minerals as full-resolution spectra (gray lines) and convolved to Mastcam-Z bandpasses (circles). Vertical lines indicate positions of the Bayer RGB filters. Black circles indicate filters that have MSL-Mastcam heritage; white circles indicate new Mastcam-Z filter positions.