THE MARS 2020 ROVER MAST CAMERA ZOOM (MASTCAM-Z) MULTISPECTRAL, STEREOSCOPIC IMAGING INVESTIGATION.

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Introduction: Mastcam-Z is a multispectral stereoscopic imaging instrument aboard NASA's Mars 2020 rover. Mastcam-Z consists of an essentially identical pair of zoom-lens cameras that provide broadband red/green/blue (RGB), narrowband visible/near-infrared (VNIR, 400-1000 nm wavelength range) color (Table 1), and direct solar imaging capabilities with continuously variable fields of view (FOV) ranging from ~5° to ~23°. The cameras are capable of resolving (across 4-5 pixels) features ~1 mm across in the near field and ~3-4 cm across at a distance of 100 meters. Mastcam-Z shares electronics and mechanism design heritage from the Mars Science Laboratory (MSL) Curiosity rover Mastcams [1,2], augmented by a 4:1 zoom lens and improved multispectral filters to enhance stereo and spectroscopic performance.

Instrument Summary: The Mastcam-Z investigation is led and managed by Arizona State University, working closely with prime subcontractor Malin Space Science Systems (MSSS). MSSS has significant experience leading the Mastcam, MAHLI, and MARDI instruments on the MSL/Curiosity rover mission, which are the direct heritage systems upon which much of Mastcam-Z is based. Additional major MSSS subcontractors that have played important roles in the development of the cameras include Motiv Space Systems (zoom, focus, and filter wheel mechanisms), Synopsys Optical Solutions Group (optics design), Ghaemi Optical Engineering (optics assembly), and Materion Precision Optics (filters). In addition, JPL has provided critical oversight and software/hardware testing support.

Each Mastcam-Z camera consists of a zoom lens and associated focus, zoom, and filter wheel mechanisms, a CCD (charge-coupled device) detector assembly, and a Digital Electronics Assembly (DEA) inside the rover body. A set of primary and secondary Mastcam-Z reflectance and color calibration targets (fabricated and supplied by the University of Copenhagen in Denmark [3]) are mounted on the rover top deck. The two Mastcam-Z camera heads are mounted with a 24 cm stereo separation baseline and 1.25° toe-in per camera on the rover's Remote Sensing Mast (RSM), located ~2 m above the surface beneath the rover. Additional basic instrument parameters for the Mastcam-Z cameras are summarized in Table 2.

Table 1. Mastcam-Z Multispectral Filters

Filter Number	$\lambda_{eff} \pm$ HWHM (nm)	
	Left Camera	Right Camera
L0/R0 (Red Bayer)	638 ± 43	638 ± 43
L0/R0 (Green Bayer)	546 ± 42	545 ± 42
L0/R0 (Blue Bayer)	471 ± 45	470 ± 45
L1 / R1	801 ± 9	801 ± 10
L2 / R2	754 ± 10	866 ± 10
L3 / R3	678 ± 11	910 ± 12
L4 / R4	605 ± 9	940 ± 13
L5 / R5	529 ± 11	979 ± 10
L6 / R6	441 ± 12	1012 ± 18
L7 (RGB) / R7	590 ± 88, ND6	880 ± 10, ND5

Notes: (1) λ_{eff} is the effective band center wavelength including optics and CCD spectral responses; (2) HWHM is the half-width at half-maximum for each filter; (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, respectively; (4) Filter L7 enables RGB Bayer filter color imaging of the Sun at the same effective band center wavelengths as the L0 and R0 filters.

Investigation Goals and Requirements: In addition to the over-arching objective of supporting the primary goals of the Mars 2020 mission, Mastcam-Z multispectral, stereo, and panoramic images will be important for understanding the geologic context of the scene along the rover's traverse in Jezero crater, for monitoring and characterizing atmospheric and astronomical phenomena, and for characterizing and categorizing the Mars sample return core sample locations. Targeted high-resolution Mastcam-Z images will also provide key engineering information to support sample selection and other rover driving and instrument operations decisions, as well as aid in problem diagnosis and hardware inspections.

Table 2. Mastcam-Z Instrument Summary [4]

Focal length	27-110 mm zoom range
Focal ratio	*f*/7 at wide zoom; *f*/10 at narrow zoom
Pixel Scale (IFOV)	Wide zoom IFOV = 285 μrad/pix (~0.6 mm/pix at 2 m to ~3 cm/pix at 100 m) Narrow zoom IFOV = 67 μrad/pix (~0.13 mm/pix at 2 m to ~6.7 mm/pix at 100 m)
Field of View (1600×1200 pix)	23°×18° (wide) to 6°×5° (narrow)
Focus Range	1 m to ∞ for 27 to ~50 mm focal length 2 m to ∞ for ~50 to 110 mm focal length
SNR	30:1 worst-case narrowband filter >100:1 typical RGB
λ range	~ 400-1000 nm
Filters	Broadband RGB Bayer pattern imaging Multispectral imaging in 11 narrow filters Direct solar imaging in RGB and 880 nm
MTF	> 0.2 at Nyquist (full optical system)
Optics Type	All-refractive, athermalized
Detector	On Semi (Kodak) KAI-2020 CM interline transfer CCD; 1600×1200 active pixels
Pixel pitch	7.4 microns
Command & Data Interfaces	Synchronous LVDS: 8 Mbit/sec (Data) and 2 Mbit/sec (Command) serial link
Digitization	11 bits/pixel; single gain, no offset states
Compression	Lossless ~1.7:1; Lossy JPEG color or grayscale; 11- to 8-bit companding Realtime or deferred
Image memory	256 Mbytes SDRAM 8 Gbyte flash image buffer in each camera
Power	11.8 Watts imaging, per camera 7.5 Watts standby, per camera
Electronics Architecture	Actel FPGA in camera head, Xilinx FPGA in Digital Electr. Assembly (DEA)
Dimensions	11×12×26 cm (each camera head); separation = 24.1 cm; toe-in = 1.25° per camera; 22×12×5 cm (DEA)
Cal Targets (2)	Primary: 10×10×5 cm Secondary: 80×30×16 mm
Mass	Camera Heads: 1.38 kg each; DEA: 1.47 kg; Cal Targets: 110 g

Current Status: Both Mastcam-Z flight instruments (Figure 1) went through an extensive program of requirements verification and validation and science calibration in 2019 [5-8], during which time the flight DEA and flight calibration targets (Figure 2) were also installed in/on the rover. Extensive testing during ATLO at JPL has since verified the geometric and flight software performance of the cameras, and Mastcam-Z team members are now focusing on final development and testing of the on-ground operations, analysis, and calibration software in preparation for the 18 February 2021 landing on Mars.

Figure 1. The Mastcam-Z flight cameras. Pocket knife is 89 mm wide, for scale.

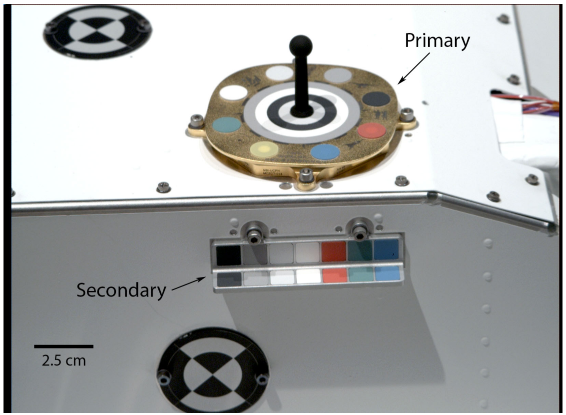

Figure 2. Mastcam-Z right camera image of the flight Primary and Secondary calibration targets, installed on the pyro firing assembly cover above the rover deck.

References: [1] Malin *et al*., *Earth & Space Sci*., *4*, 506–539, doi:10.1002/ 2016EA000252, 2017. [2] Bell *et al*., *Earth & Space Sci*., *4*, doi:10.1002/2016EA000219, 2017. [3] Kinch *et al*., submitted to *Space Sci*. *Rev*., 2020. [4] Bell *et al*., submitted to *Space Sci*. *Rev*., 2020. [5] Hayes, *et al*., this conference. [6] Tate, *et al*., this conference. [7] Rice, *et al*., this conference. [8] Hayes, *et al*., submitted to *Space Sci*. *Rev*., 2020.