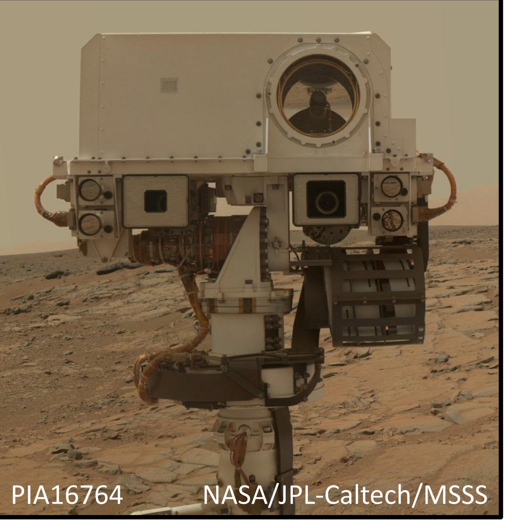

Iron Meteorite Candidates Within Gale Crater, Mars, From MSL/Mastcam Multispectral Observations

#1832

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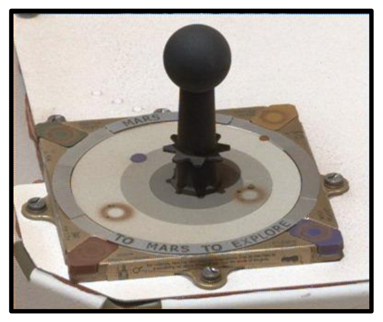
Dataset and Methods



Mastcam calibration target, sol 66

- The Mastcam instruments on the MSL Curiosity rover are capable of acquiring multi-filter image sequences over the wavelength range 400-1100 nm [1,2].
- These can be calibrated [2,3] to a quantity independent of the amount of incident light, i.e. reflectance (I/F).
- By plotting values from each filter image against the band center wavelength, we can construct multi-point spectra.
- In the visible and near-infrared, spectral features are strongly dependent on the presence of Fe-bearing phases and their oxidation state. Within Gale Crater, most materials show evidence of either Fe^{2+} or Fe^{3+} features [e.g. 3,4,5,6].
- In this context iron meteorites are often relatively easy to identify, as they have reflectance spectra that increase smoothly to the near-IR [7,8].

Mastcam Spectra

- Mastcam reflectance spectra of acknowledged and suspected iron meteorites are shown in Fig. 1.
- These are very similar and possess distinctly positive near-infrared slopes. Visible-wavelength slope is primarily related to dust cover.
- Most fragments are appear to be spectrally homogeneous to the limit of resolution. Aeolus Mons 001 may be an exception, with minor differences in slope and a 527 nm band that may reflect compositional differences on a mm scale.

Figure 1: Mastcam Reflectance Spectra

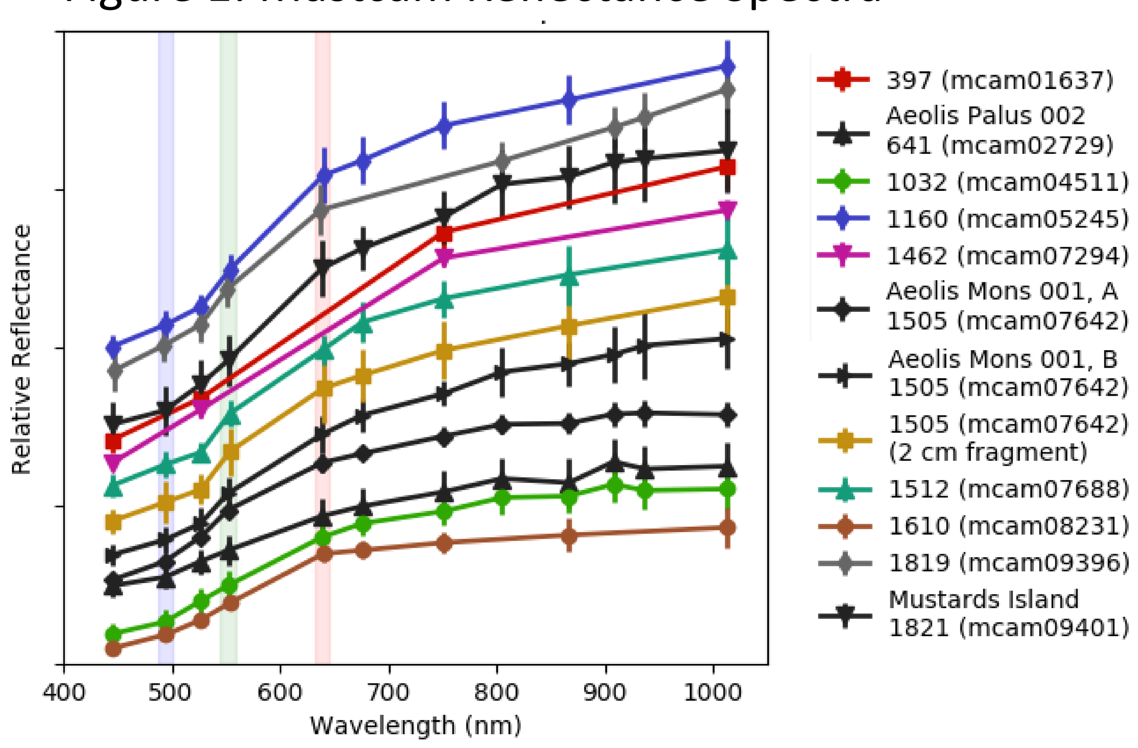


Figure 1: Mastcam spectra from the candidate iron meteorites listed in Table 1 (for clusters, a spectrum from a single rock is given), offset for clarity; y-ticks are intervals of 0.1. The number of points shown for each data series represents the number of filters acquired in the observation. The broadband filter is shown as three points by Bayer channel. Spectra in black are confirmed irons from either strong morphological evidence (in the case of the sol 641 fragments) or chemical LIBS data.

Map: Suspected & Confirmed Meteorites

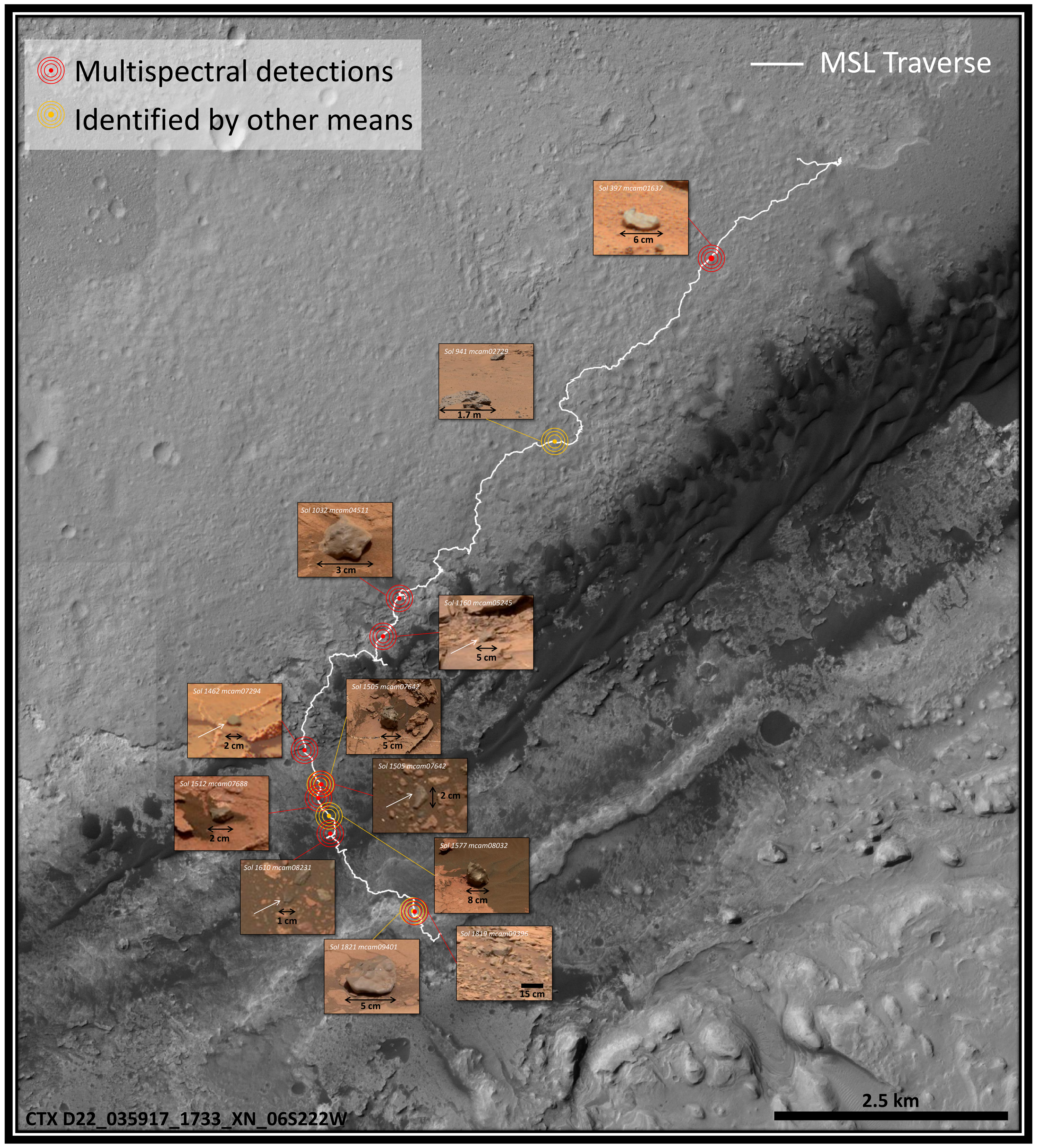


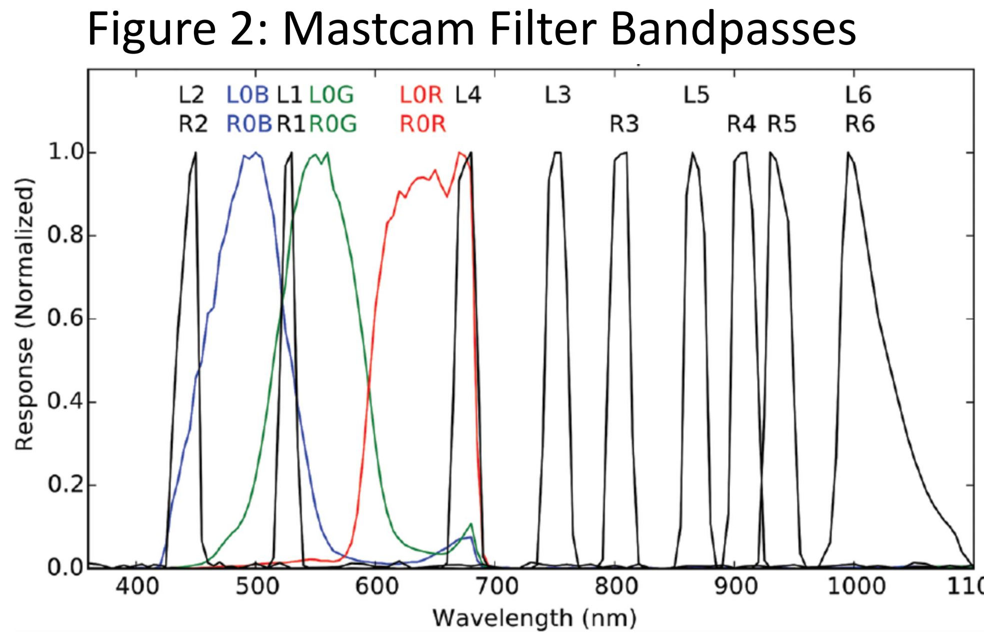
Table: Suspected & Confirmed Iron Meteorites

Sol(s)	Number[1]	Size(s)[2]	Filters[3]	Notes
397	1	~ 6 cm	L1236	In photometry sequences
640-641	3	~ 0.5-2 m	L0-6, R0-6[4]	Aeolus Palus 001-003
994-1032	8+	~ 3-5 cm	L0-6, R0-6[4]	In photometry sequences
1160	1	~ 5 cm	L0-6	
1462-1463	2	~ 2-5 cm	L1236	In photometry sequences
1505	1	~ 5 cm	L0-6, R0-6	Aeolus Mons 001
1505	1	~ 1 cm	L0-6	Same FOV as above
1512	1	~ 2 cm	L0-6	
1577	1	~ 8 cm	R0[5]	Aeolus Mons 002
1610	1	~ 1 cm	L0-6	
1819	many	< 15 cm	R0-6	~30 m from sol 1821 fragment
1821	1	~ 5 cm	L0-6, R0-6	Unofficially, "Mustards Island"

Table (above): All known potential iron meteorite fragments, to sol 1925. Highlighted rows are confirmed or recognized from other observations. [1]When potential fragments grade in size down to the limit of the camera's resolution, an exact count is not possible. [2]Estimate is based on the longest axis and is approximate. [3]See Figure 2, right. [4]Wavelength coverage varies by fragment. [5]No narrowband multispectral data, although ChemCam passive reflectance data do exist for this and other highlighted rows.

Figure 2 (right): Mastcam filter profiles showing the normalized bandpasses for both the broadband filter 0 (by Bayer pixel) and narrowband filters, from [3]. For stereo filters, only the left (M-34) profiles are plotted, for clarity, but the M-100 data is quite similar.

Figure 2: Mastcam Filter Bandpasses



Counts & Statistics

- The multispectral dataset to sol 1925 contains up to 9-10 (depending on grouping) spatially distinct clusters of rocks with spectra consistent with metallic iron, altogether consisting of more than 20 individual stones (see Table).
- It is possible to estimate the area covered by multispectral observations for a statistical approximation of iron meteorite abundance. For this, we make use of multispectral observations of four or more filters with pointings of less than 18° in elevation (near-field pointing that can identify a smaller, more prevalent size fraction and with less error from topography). We exclude observations explicitly targeted at meteorites identified from other imaging data (Mastcam workspace images or Navcam frames), and repeat imaging coverage.
- Likely meteorites imaged serendipitously within the constraints listed above occurred at four sites across approximately 440 m^2 of multispectral near-field spatial coverage.
- We estimate an abundance of approximately 1 "cluster" per 100 m^2, (~0.2-2, 95% CI but with some caveats/additional uncertainties) where meteorites imaged at the same site are considered part of one cluster.

Are they paired?

- Potential fragments are often identified within a few meters of others; these may be pairs, formed either on impact (of either the original stone or a spallation fragment), or by subsequent weathering.
- Unfortunately, Mastcam reflectance data is not sufficient to distinguish paired and unpaired meteorites. Chemical data (LIBS) is available for only a very few samples.
- MER observations from Meridiani Planum [9,10] suggested the presence of likely pairs over several kilometers of separation, i.e., on the order of the length of a rover's traverse distance.
- Thus, pairing concerns must be considered as a complicating factor in all cases.

Conclusions & Future Work

- Likely iron meteorite fragments are common and identifiable in multispectral imaging observations of approximately four or more filters. They appear to be typically small in size, of a few cm in diameter, and often occur in clusters. Pairing relationships between clusters are uncertain.
- Further work on photometry observations may provide additional information on interpretation of certain fragments as iron meteorites, although size and viewing geometry may be significant limitations. Refined estimates of the size of Mastcam image footprints may allow us to improve estimates of iron meteorite abundance.
- Additionally, comparisons can be made to MER counts, although this may be complicated by the effect of dust cover differences between landing sites.

References: [1]Bell, J.F., III et al. (2017) *Earth & Space Sci., 4,* 396. [2]Malin, M.C. et al. (2017) *Earth & Space Sci., 4,* 506. [3]Wellington, D.F. et al. (2017) *Am. Min. 102,* 1202. [4]Johnson et al. (2016) *Am. Min. 101,* 1501. [5]Johnson et al. (2017) *JGR 122,* 2655. [6]Horgan, B. et al. (2017) *LPSC XLVIII*, 3021. [7]Gaffey, M.J. (1976) *JGR 81*, 905. [8]Johnson et al. (2014) *AGU Fall Mtg.* #P51E-3989. [9]Schröder et al. (2008) *JGR 113*, E06S22. [10] Schröder et al. (2010) *JGR 115,* E00S09.