Reflectance spectra of metal-rich meteorites and implications for the Psyche Discovery-class mission's Multispectral Imager

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Summary - When convolved to Psyche Imager filter bandpasses, spectra of various metal-rich meteorite compositions can be discriminated based on band ratios.

Introduction

- Measurements of radar albedo, thermal inertia, mid-infrared emissivity, and visible to near-infrared reflectance of the asteroid (16) Psyche indicate a largely metallic surface with distributed fine-grained silicate minerals [*e.g.,* 1-4].
- Metal-rich meteorites (irons, pallasites, mesosiderites, and some chondrites) are consistent with density estimates of (16) Psyche and may represent compositions similar to (16) Psyche surface materials [5].
- The *Psyche* mission will carry a Multispectral Imager designed to map the surface at high spatial resolution and at key wavelengths useful for discriminating metal, silicate, and potential sulfide components on the surface [6,7,8].

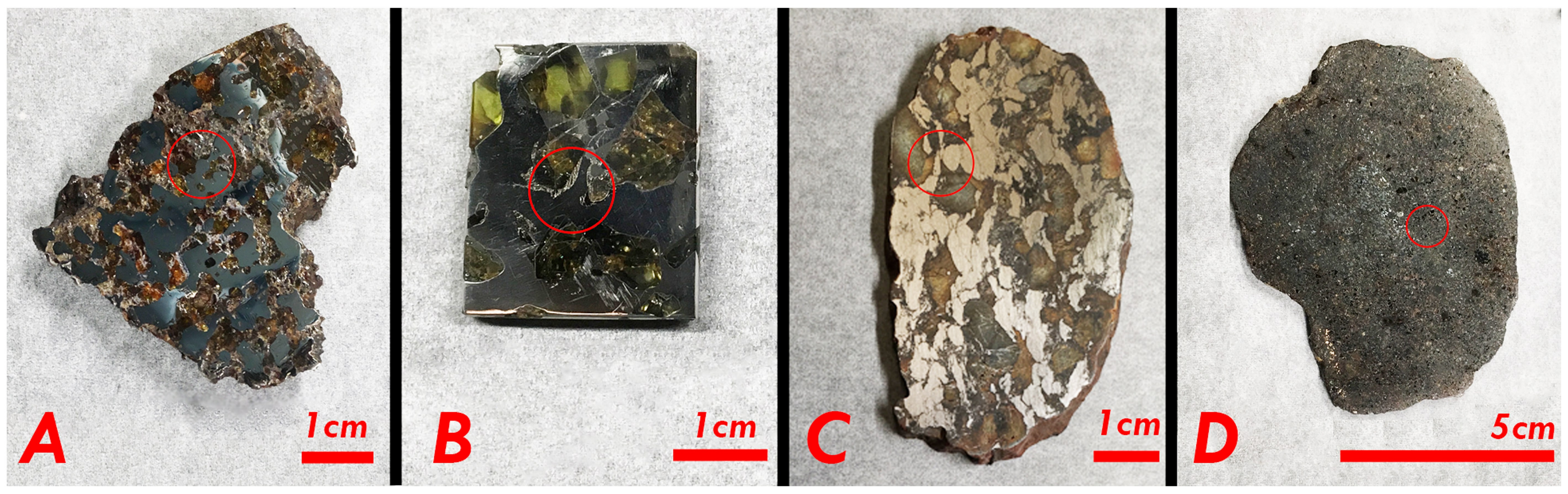

Figure 1. Metal-rich meteorites may be similar to materials on the surface of (16) Psyche. In these images, the red circle represents the approximate field of view of the ASD spectrophotometer used in this study. A - Steinbach (IVA iron), B - Esquel (pallasite), C - QC 001 (CBa chondrite), and D - NWA 8234 (C2 mesosiderite).

Method

- Reflectance spectra of 26 meteorites were collected using an ASD FieldSpec 4 spectrophotometer. All meteorites used in this study (*e.g.,* Figure 1) were generously loaned by ASU's Center for Meteorite Studies.
- The phase angle for the spectral measurements was 30°. Samples were analyzed as roughened surfaces and powders when available.
- Convolution to Imager bandpasses (Table 1) and calculation of band ratios shown in Table 2 was performed in Python 3.6.

Table 1. The Psyche Imager is equipped with a set of narrowband visible to near-infrared filters selected to meet mission science objectives.

#	ECAS Band	Wave-length (nm)	FWHM (nm)	Filter Objective
1	clear	540	280	Unfiltered CCD for OpNav, topography, and geologic characterization
2	b	437	50	Oldhamite detection and blue component of true color
3	o	495	25	Oldhamite detection
4	v	550	25	Oldhamite detection and green component of true color
5	w	725	40	Typical peak reflectance continuum and red component of true color
6	x	850	50	Search for evidence of low-Ca pyroxene, other ~1.0 micron features, capture Psyche Earth-based feature
7	p	948	50	Search for evidence of higher-Ca pyroxene and characterize weak Psyche Earth-based feature
8	z	1041	90	Search for evidence of olivine
9	--	--	--	Opaque "sun safe" blocking filter

References - [1] Shepard, M.K. et al., Icarus 281, 388, 2017. [2] Matter, A. et al., Icarus 226.1: 41, 2013. [3] Landsman, Z.A. et al., Icarus 304, 58, 2018. [4] Sanchez, J.A. et al., Astron. J. 153, 29, 2016. [5] Viikinkoski, M. et al., Astr. & Astrophys. 619, L3, 2018. [6] Elkins-Tanton, L.T. et al., LPSC XLVII #1366, 2016. [7] Bell III, J.F. et al., LPSC XLVII #1631, 2016. [8] Dibb, S.D. et al., IPM4 #024, 2018. [9] Bus, S. and Binzel, R. P., Small Main-belt Asteroid Spectroscopic Survey, Phase II. EAR-A-I0028-4-SBN0001/SMASSII-V1.0. NASA Planetary Data System, 2003.

Results

- Spectra of select meteorites with high metal content are shown in Figure 2, separated by class. Ratios between convolved spectra in four longest-wavelength filters are shown in Figure 3.
- Mesosiderite and pallasite compositions can be readily discriminated, while silicated iron and CB chondrite compositions are more difficult to differentiate and may represent the limit of silicate-metal mixing that can be measured with Imager filters.

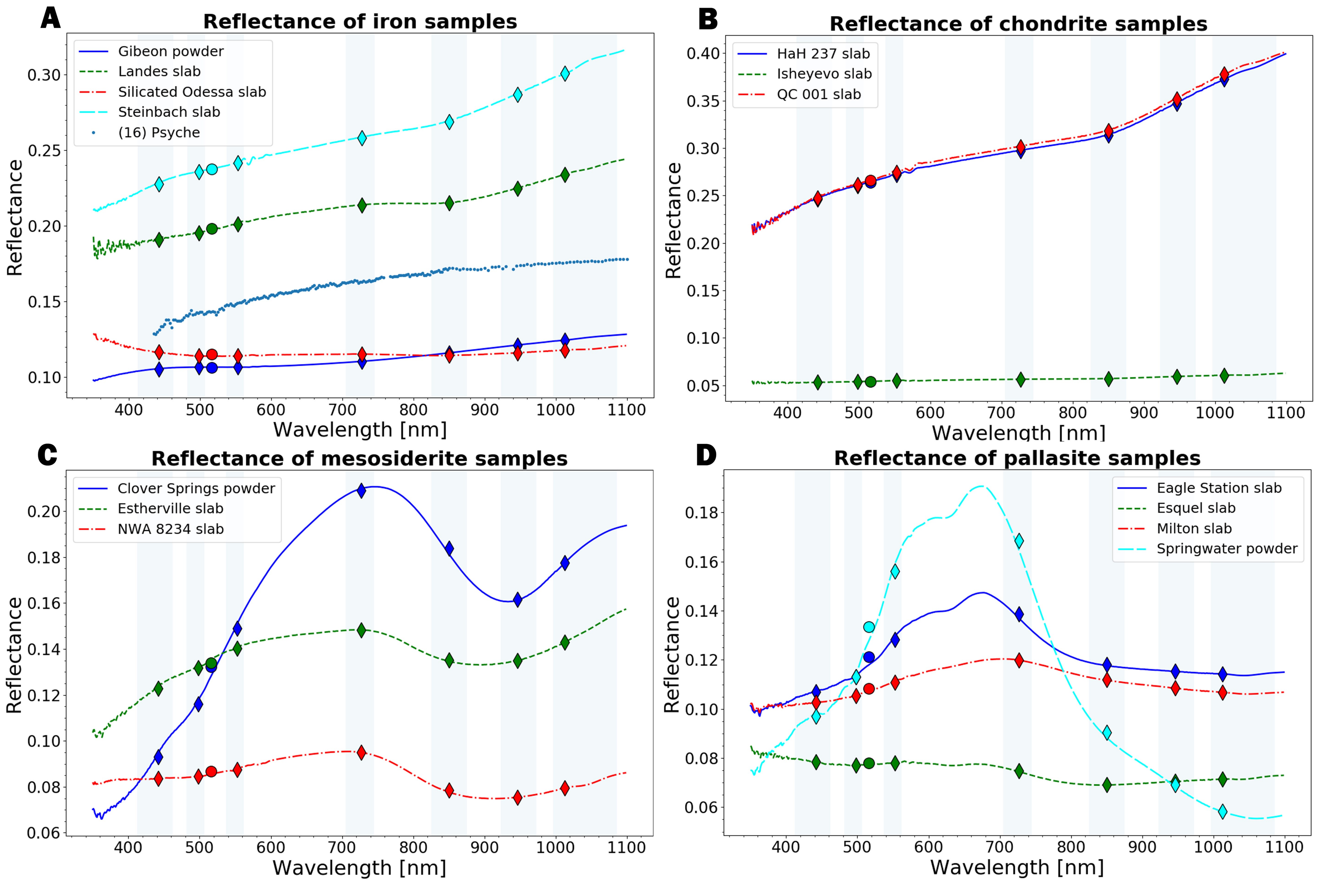

Figure 2. Imager filters capture key absorption features in reflectance spectra of metal-rich meteorites. 2A - iron meteorites, 2B - chondrites, 2C - mesosiderites, 2D - pallasites. For comparison, a spectrum of (16) Psyche from [9] is shown in 2A, normalized to 0.15 reflectance at 560 nm.

Table 2. Meteorites in this study cover a range of metal contents.

Sample	Metal Content	550 nm reflectance
Clover Springs[a]	37 wt. %	16.1%
Estherville[b]	56.4 wt. %	14.3%
NWA 8234[c]	35 vol. %	8.9%
Eagle Station[d]	21.4 vol. %	13.4%
Esquel[d]	32 vol. %	8.0%
Milton[e]	27 vol. %	11.3%
Springwater[d]	27.9 vol. %	17.0%
Gibeon[f]	>90 wt. %	10.7%
Silicated Odessa[g]	50 wt. %	11.4%
Landes[h]	81 wt. %	20.3%
Steinbach[i,j]	32.3 vol. %	24.1%
HaH 237[k]	75 vol. %	27.4%
Isheyevo[l]	~60 vol. %	5.5%
NWA 5492[m]	22.6 vol. %	18.1%
QC 001[n]	~60 vol. %	27.6%

Red = mesosiderites, green = pallasites, gray = irons, blue = chondrites

a - Mittlefehldt, et al., 1998
b - Powell 1971
c - Ruzicka, et al., 2015
d - Buseck 1977
e - Russell, et al., 2003
f - Schaudy, et al., 1972
g - Strait 1983
h - Bunch, et al., 1972
i - Reid, et al., 1974
j - Scott, et al., 1996
k - Zipfel, et al., 1998
l - Ivanova, et al., 2008
m - Weisberg, et al., 2012
n - Koch, et al., 2016

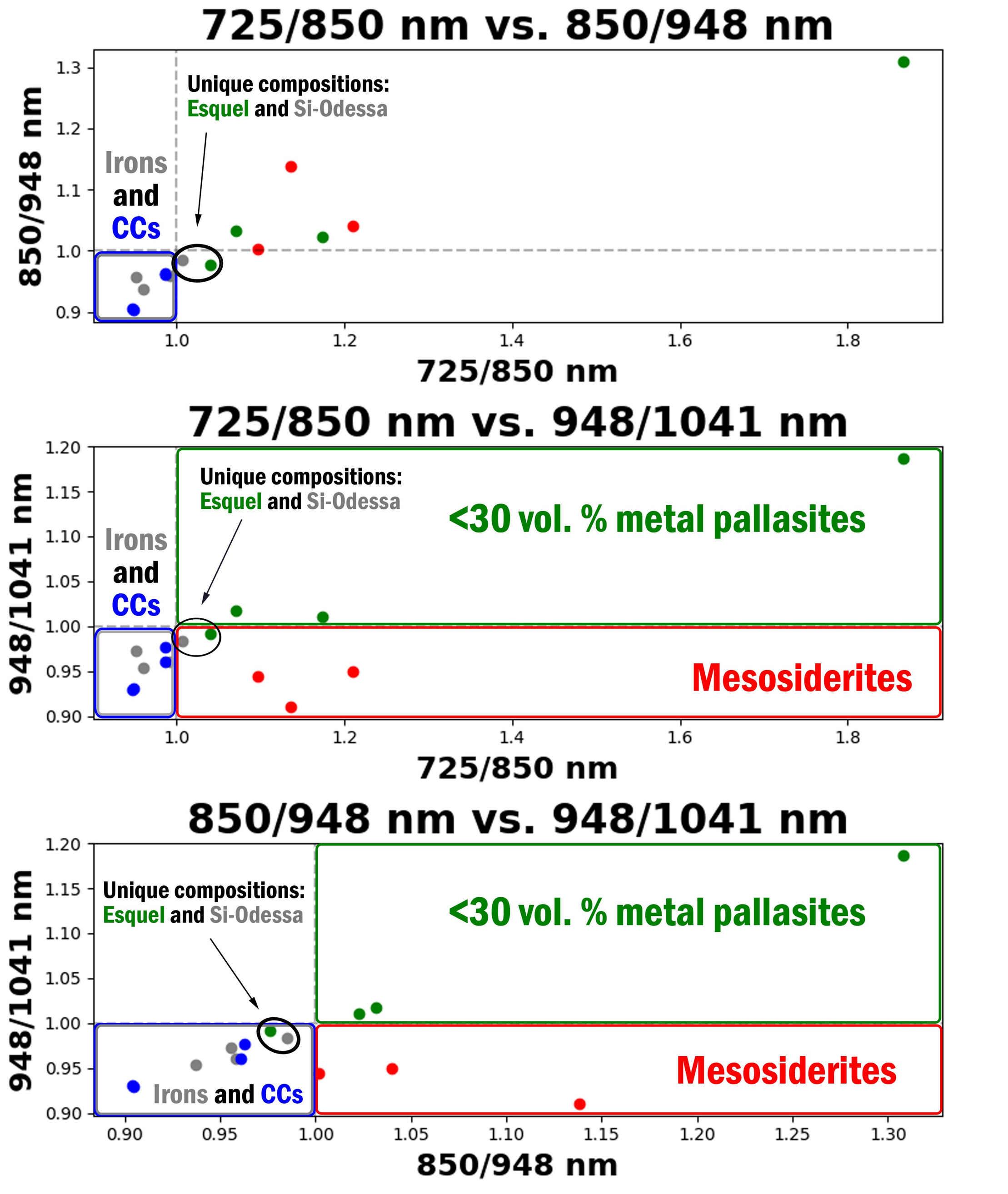

Figure 3. Ratios between convolved data in the four longest-wavelength filters are sensitive to different meteorite compositions (indicated by different outlined zones on the above plots) and can be used to make inferences about metal-silicate mixing. Two unique compositions make the discrimination more difficult: Esquel, which has a higher metal content than the other pallasites, and the silicated piece of Odessa, which contains 20 wt. % C. High metal moves points down and left by imparting a red spectral slope, and carbon serves to flatten spectra, moving ratios to values of 1.0. Uncertainty is smaller than the size of the point.