Simulating Spectral Sampling for Planetary Surface Exploration

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Introduction

Reflectance spectroscopy and spectral imaging are efficient methods for exploring the distribution of materials across a planetary surface.

To be spectrally distinct, the materials of a given set must have distinct chemical and crystalline properties, that result in statistically distinct signals across the spectral range and resolution of the sampling instrument (fig. 1).

Here we present methods and computational tools built toward comprehensive simulation of the measurement chain, for use during design, preparation and operation of a spaceborne instrument.

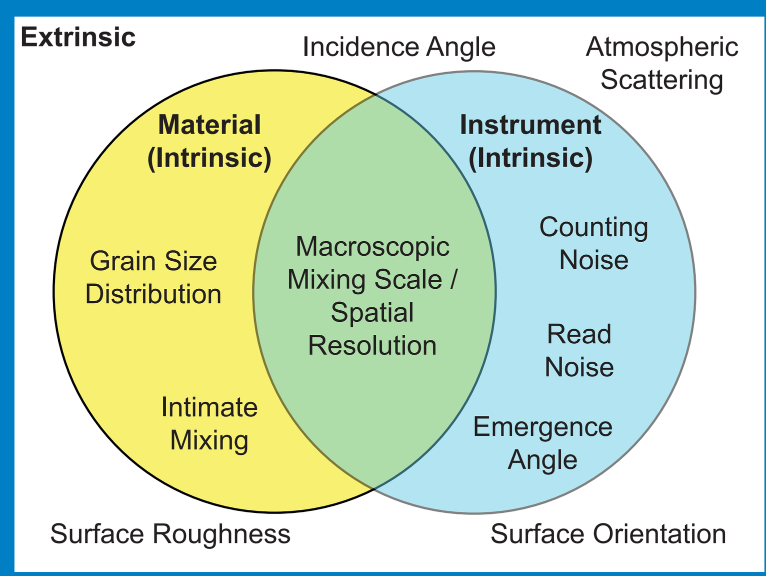

Figure 1. Influences attributed to the material, instrument, both, or neither, that contribute to the variance of a spectral reflectance measurement.

Simple Spectral Sampling

We can make a simple approximation of spectral sampling according to the instrument spectral channel transmission and noise and the material spectral reflectance:

$$R[\lambda_c] = \frac{\int R(\lambda)T(\lambda|\lambda_c,\Delta\lambda)d\lambda}{\int T(\lambda|\lambda_c,\Delta\lambda)d\lambda} + \varepsilon$$

$$\varepsilon \sim N(0,\sigma^2) \qquad \sigma = \left(\frac{R}{R_{sat}}\right)^{1/2} \mathrm{SNR}_{sat}$$

sptk

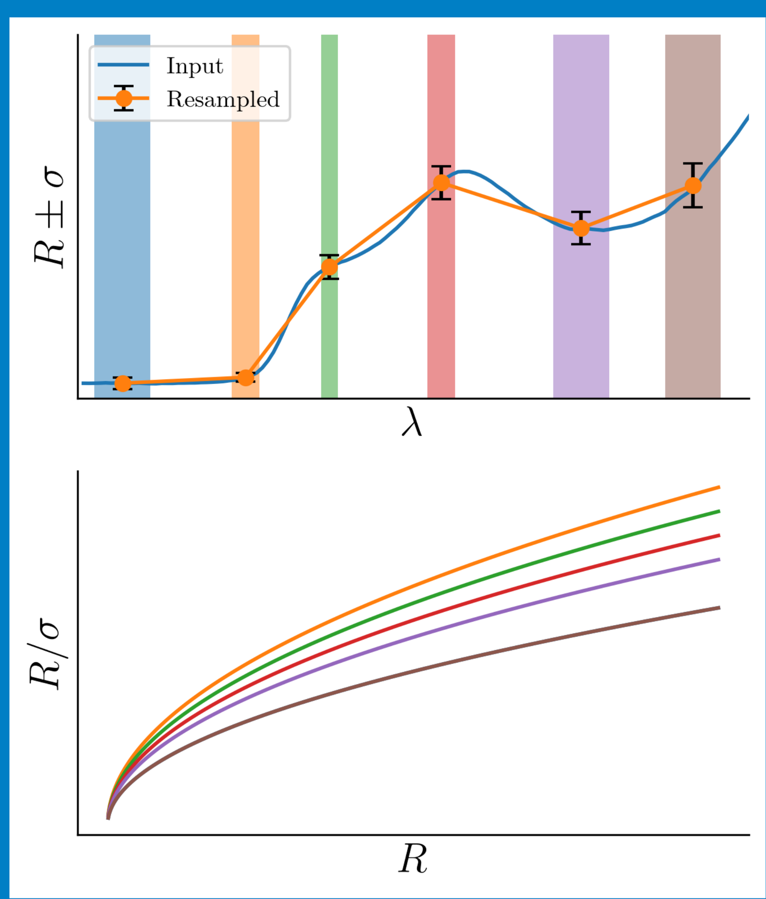

Figure 2. Resampled reflectance spectrum according to transmission profiles and noise of example multispectral instrument (top), given by signal-to-noise ratio as a function of reflectance (bottom).

We can estimate the noise by assuming Poisson distributed shot-noise, and by defining the saturation SNR for the saturation reflectance of an observation.

IR Spectrometer Simulation: *ExoMars RF Enfys*

We used this simple sampling method to investigate the performance requirements for a replacement infrared spectrometer for the ExoMars *Rosalind Franklin* rover. We produced the visualisation of figure 3 (right) to show band depth locations.

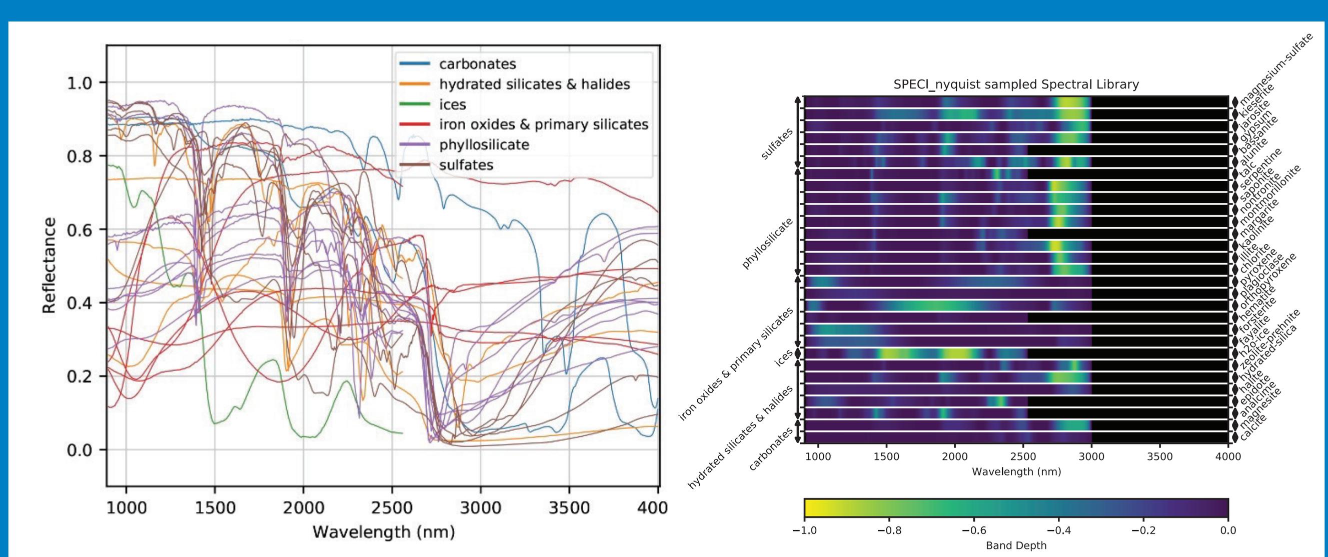

Figure 3. Sampling of Mars-relevant minerals [1] with candidate spectrometer resolution, and visualisation of locations of continuum removed absorption features.

Spectral Parameter Exploration: ExoMars RF PanCam

We used this simple sampling method to search for spectral parameter combinations (SPCs) that highlight a target material against a background. We ran LDA on all SPCs of PanCam, to find the minimal filters needed to separate hematite from the mineralogy expected at Oxia Planum [2, 3].

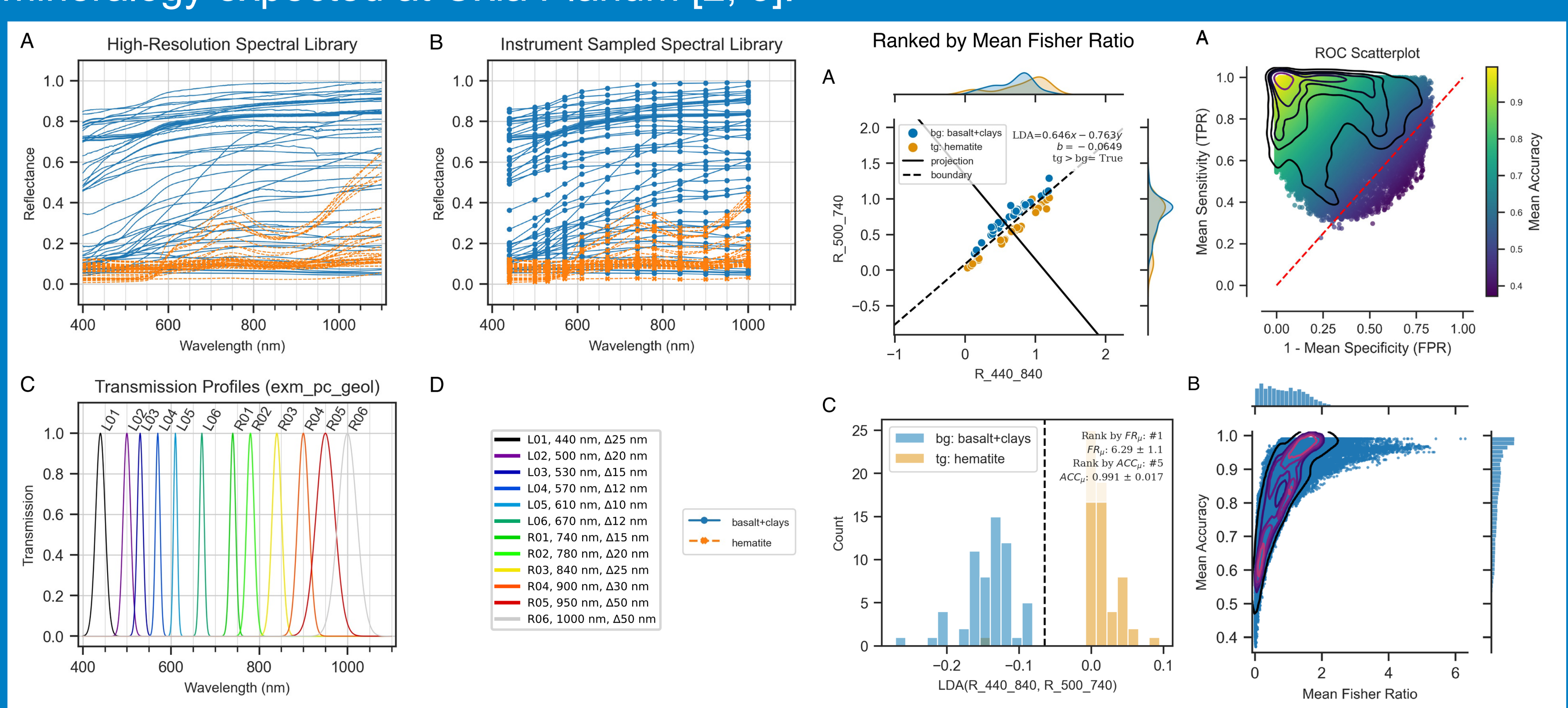

Figure 4. Sampling of hematite and Oxia Planum materials with PanCam, and the SPC with the highest Fisher Ratio. Also shown are the range of accuracy values for all SPCs, and the relationship between the Fisher Ratio and the accuracy.

Instrument Comparison: *MMX OROCHI vs LOROS*

We used simple spectral sampling to make comparisons between the expected spectral sampling of the MMX OROCHI Flight Model and our COTS Laboratory Simulator (LOROS). We produced visualisations of all spectral parameter values, to show where changes in filter CWL/FWHM produced above-noise changes.

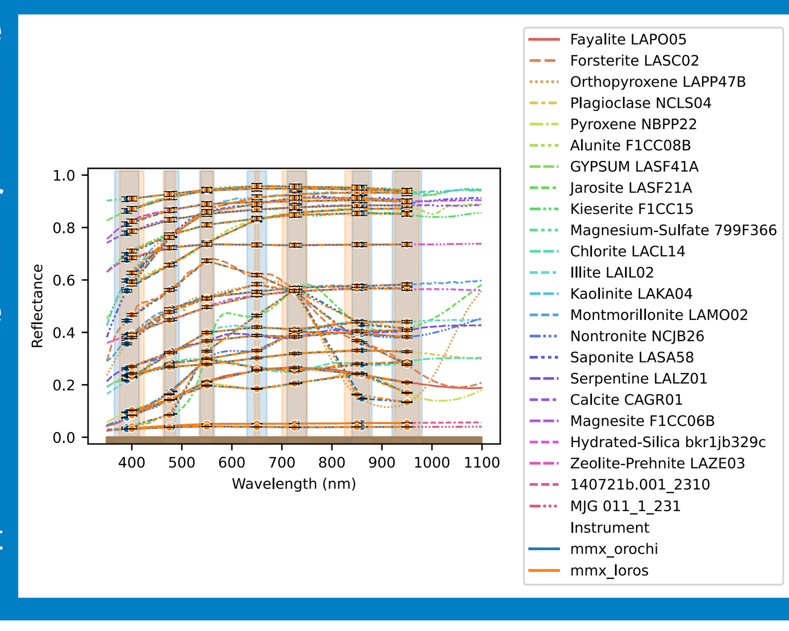

Figure 5. Difference in sampling of Mars relevant minerals and CCs for OROCHI and LOROS.

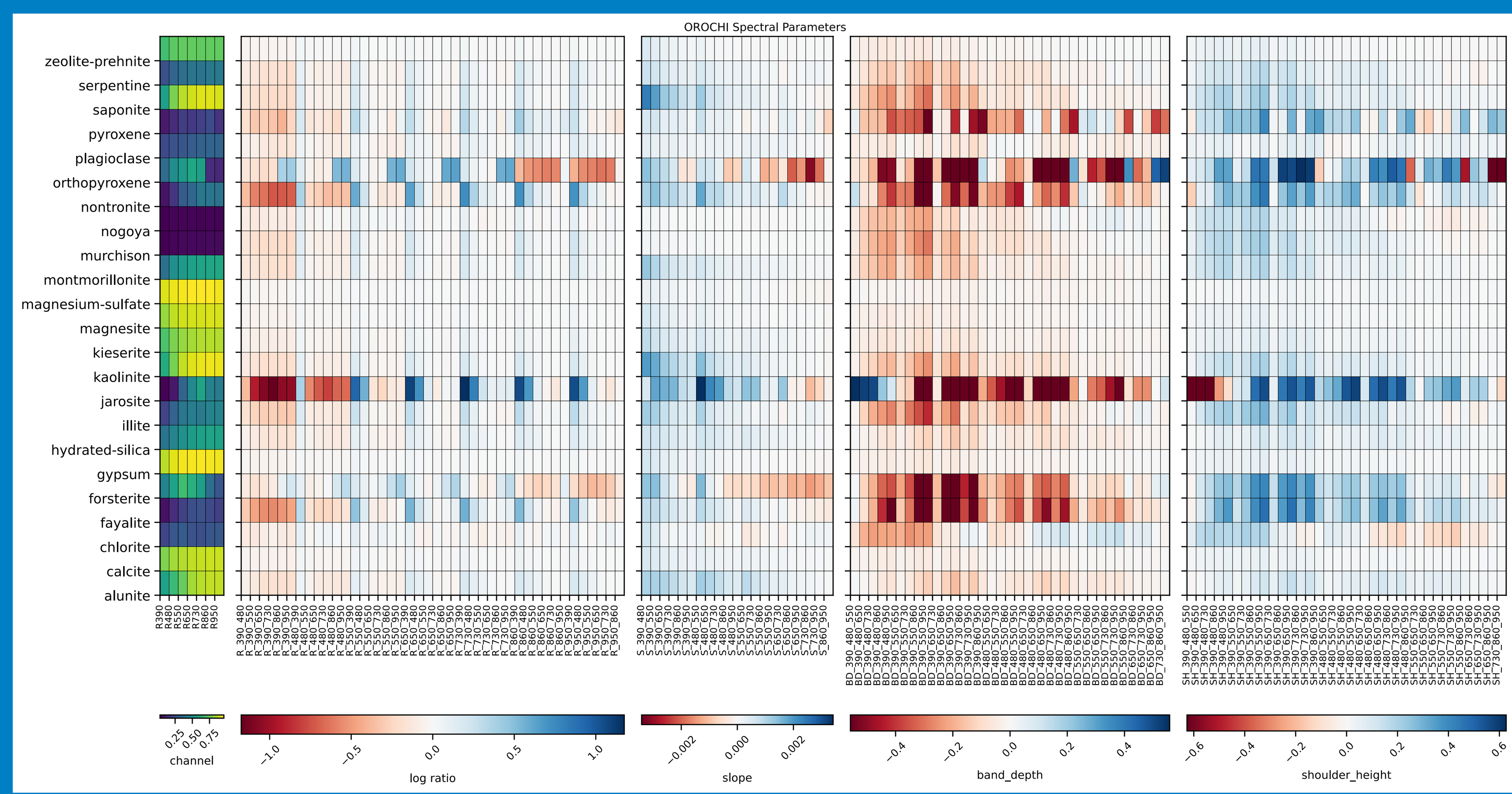

Figure 6. OROCHI Spectral Parameter values for Mars relevant minerals and CCs.

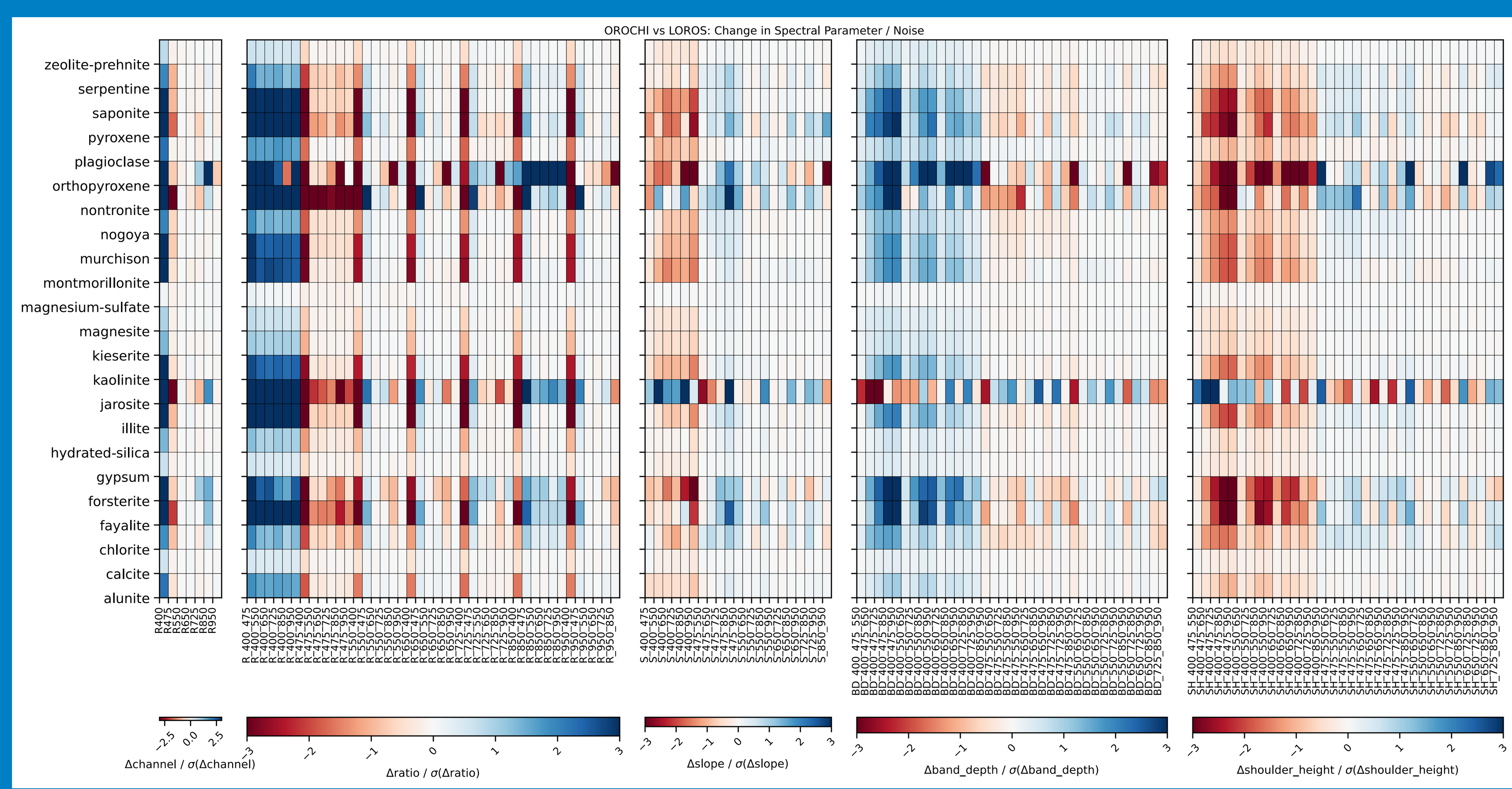

Figure 7. Change in spectral parameter values between LOROS & OROCHI vs Noise.

Hyperspectral Radiometric Path Tracing

We have interfaced with physically based rendering software *PBRT* to produce complete image product simulations from 3D environment models, computed with all quantities as floating point SI unit. We have coupled this with bespoke instrument radiometric models to give raw noisy images, that we have calibrated, to test end-to-end product generation [4].

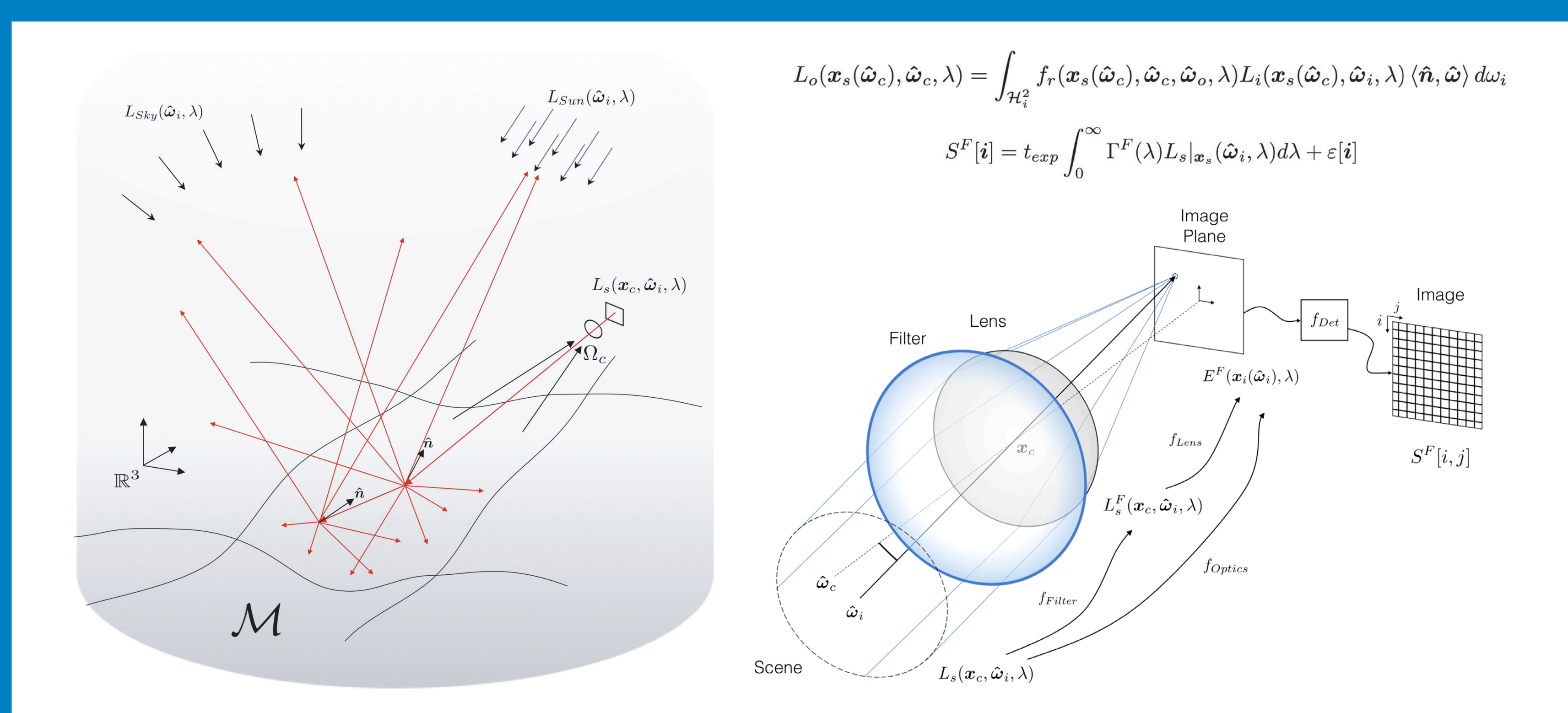

Figure 8. Schematic and equations of physically based rendering and camera simulation.

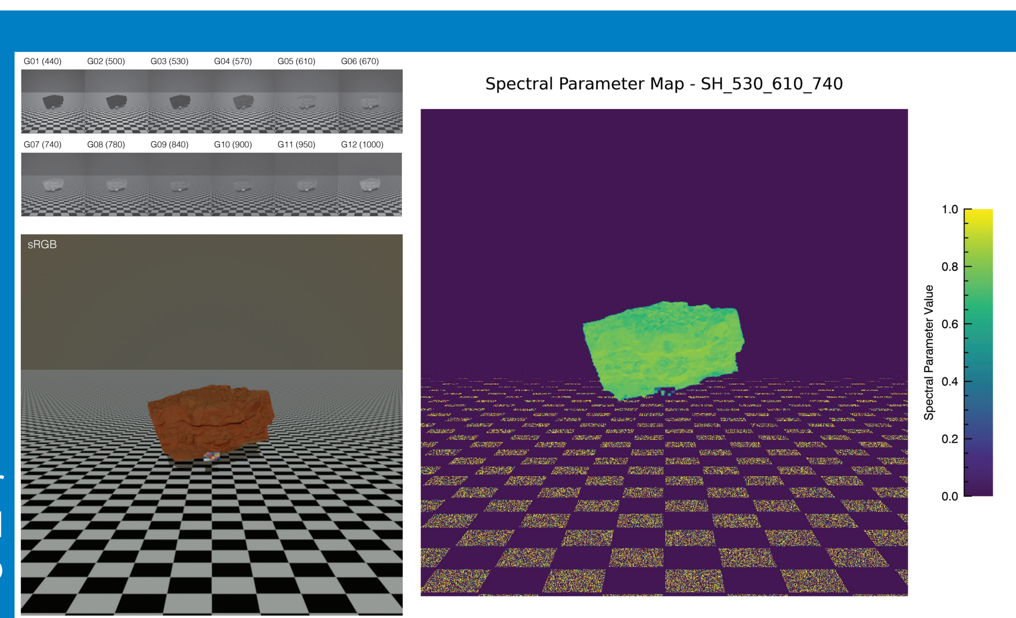

Figure 9. Simulated image products for ExoMars PanCam, showing simulated image products for imaging an outcrop hosting goethite and hematite.

References [1] MICA Files, http://crism.jhuapl.edu/data/mica/ [2] Stabbins et al, 2024, *ESS (in review)* [3] Stabbins et al, 2024, *sptk*, 10.5281/zenodo.10692531 (**scan QR code**). [4] Stabbins, 2022, Doctoral Thesis, UCL

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