Choosing and Using Multispectral Filters

for Data-Limited Dynamic Planetary Surface Exploration with Linear Discriminant Analysis

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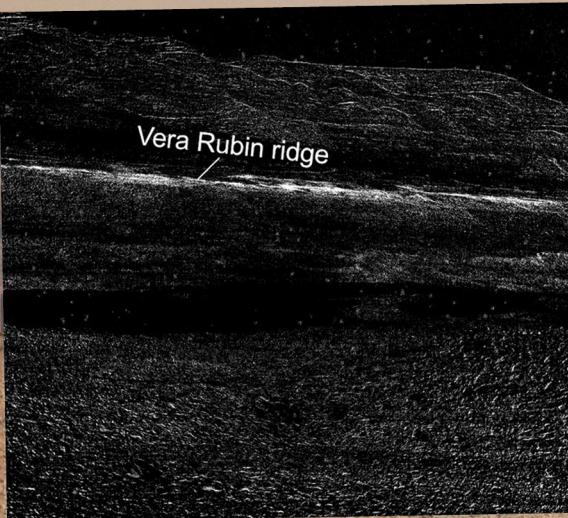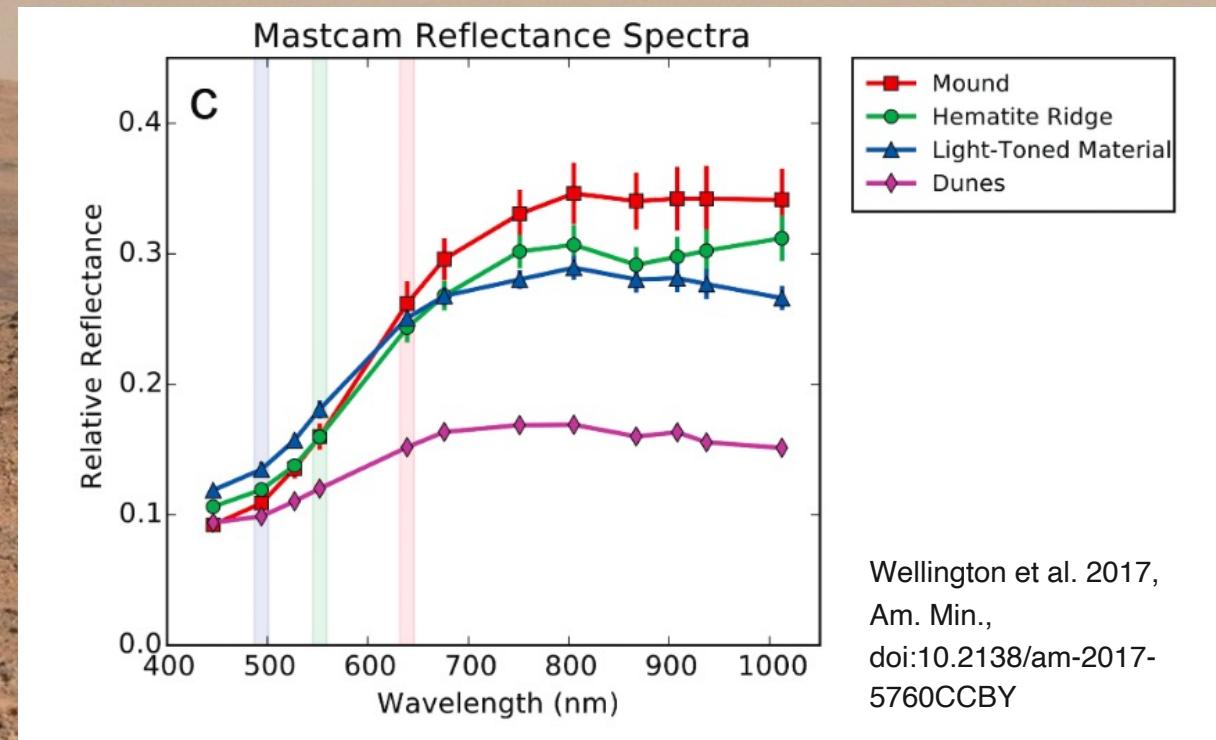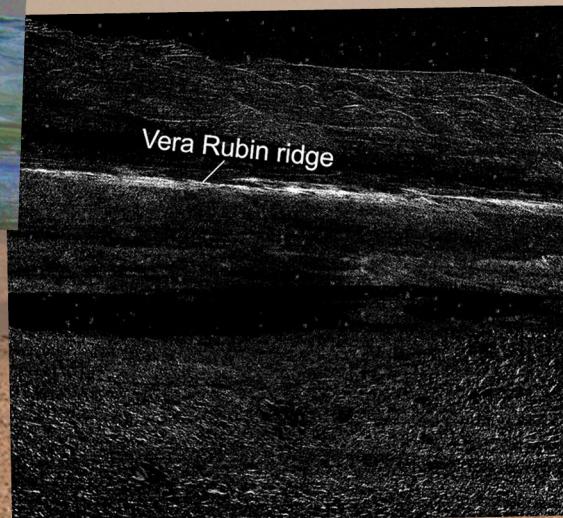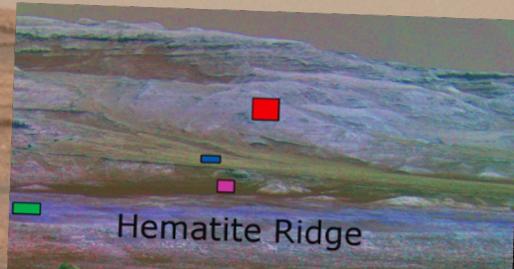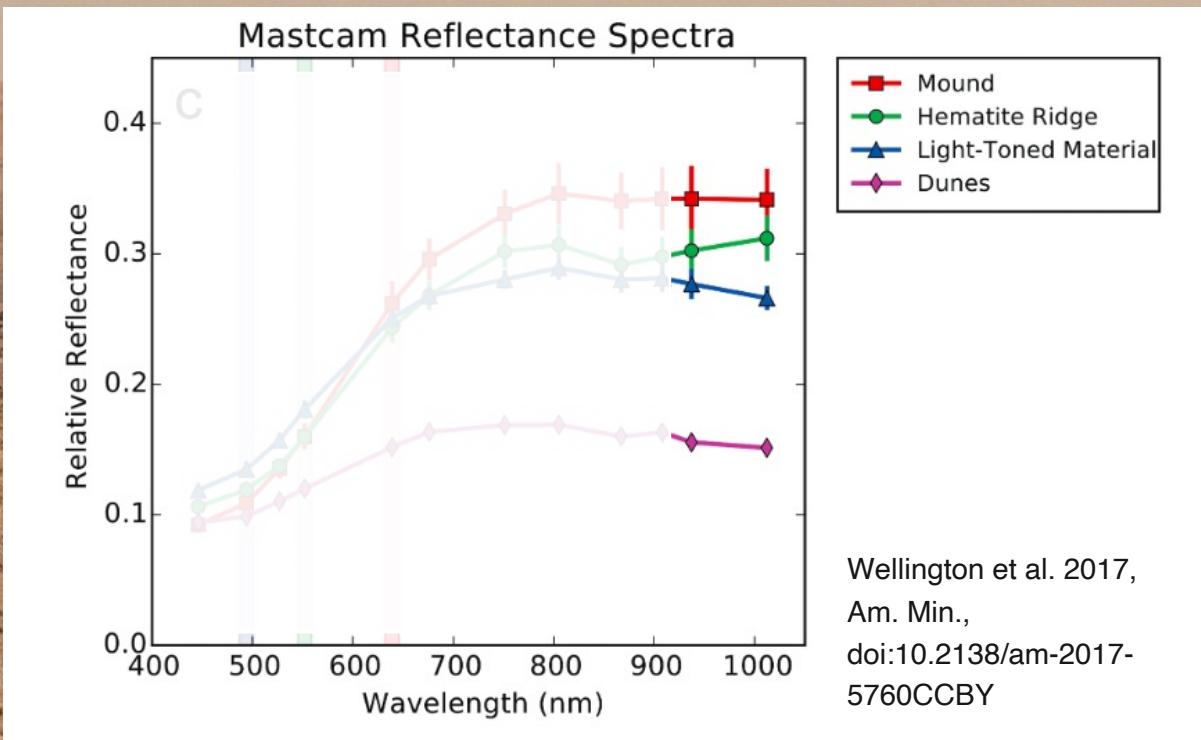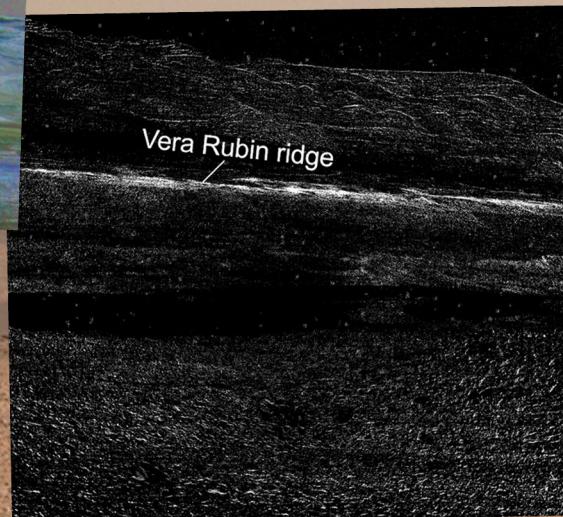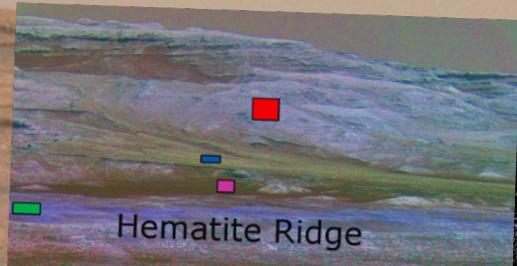
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Vera Rubin ridge

Vera Rubin ridge

NASA/JPL/ASU/MSSS/Mastcam

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Hematite Ridge

Vera Rubin ridge

Mastcam Reflectance Spectra

C

Mound
Hematite Ridge
Light-Toned Material
Dunes

Relative Reflectance

Wavelength (nm)

NASA/JPL/ASU/MSSS/Mastcam

Hematite Ridge

Vera Rubin ridge

Mastcam Reflectance Spectra

Relative Reflectance

0.4

0.3

0.2

0.1

0.0

400 500 600 700 800 900 1000
Wavelength (nm)

- Mound
- Hematite Ridge
- Light-Toned Material
- Dunes

NASA/JPL/ASU/MSSS/Mastcam

a

clay-bearing unit

clay-bearing unit

dark resistant unit

A'

f

d

b

c

A

e

dark resistant unit

dense mantling unit field

1500 m

ESA/Thales Alenia Space

a

clay-bearing unit

clay-bearing unit

dark resistant unit

A'

f

d

b

c

A

e

dark resistant unit

dense mantling unit field

1500 m
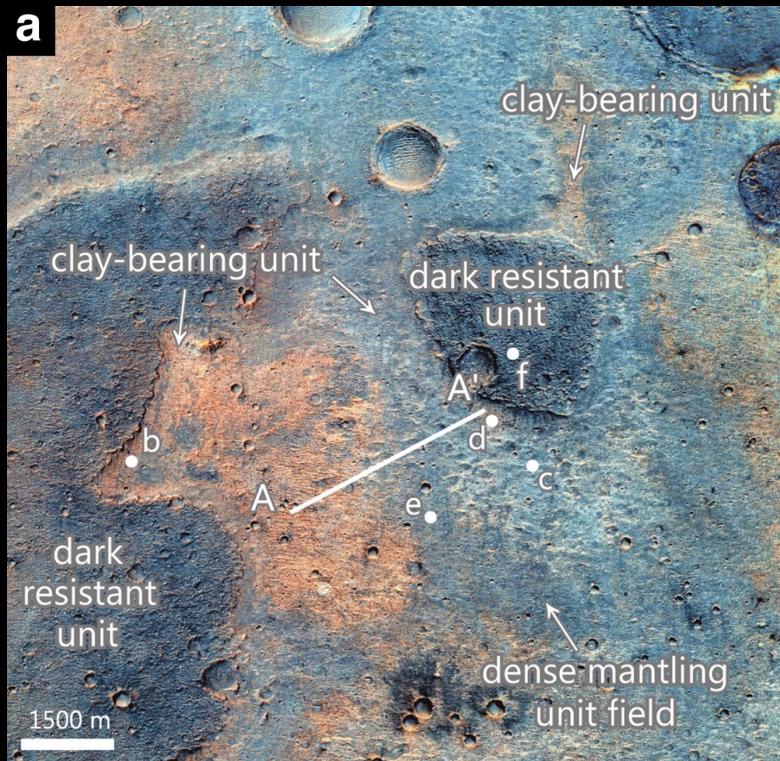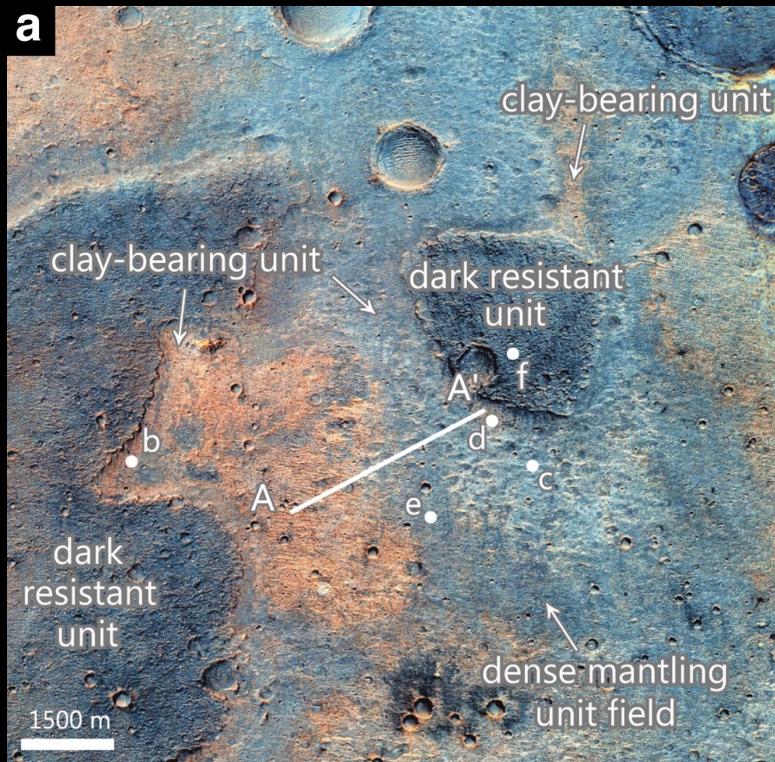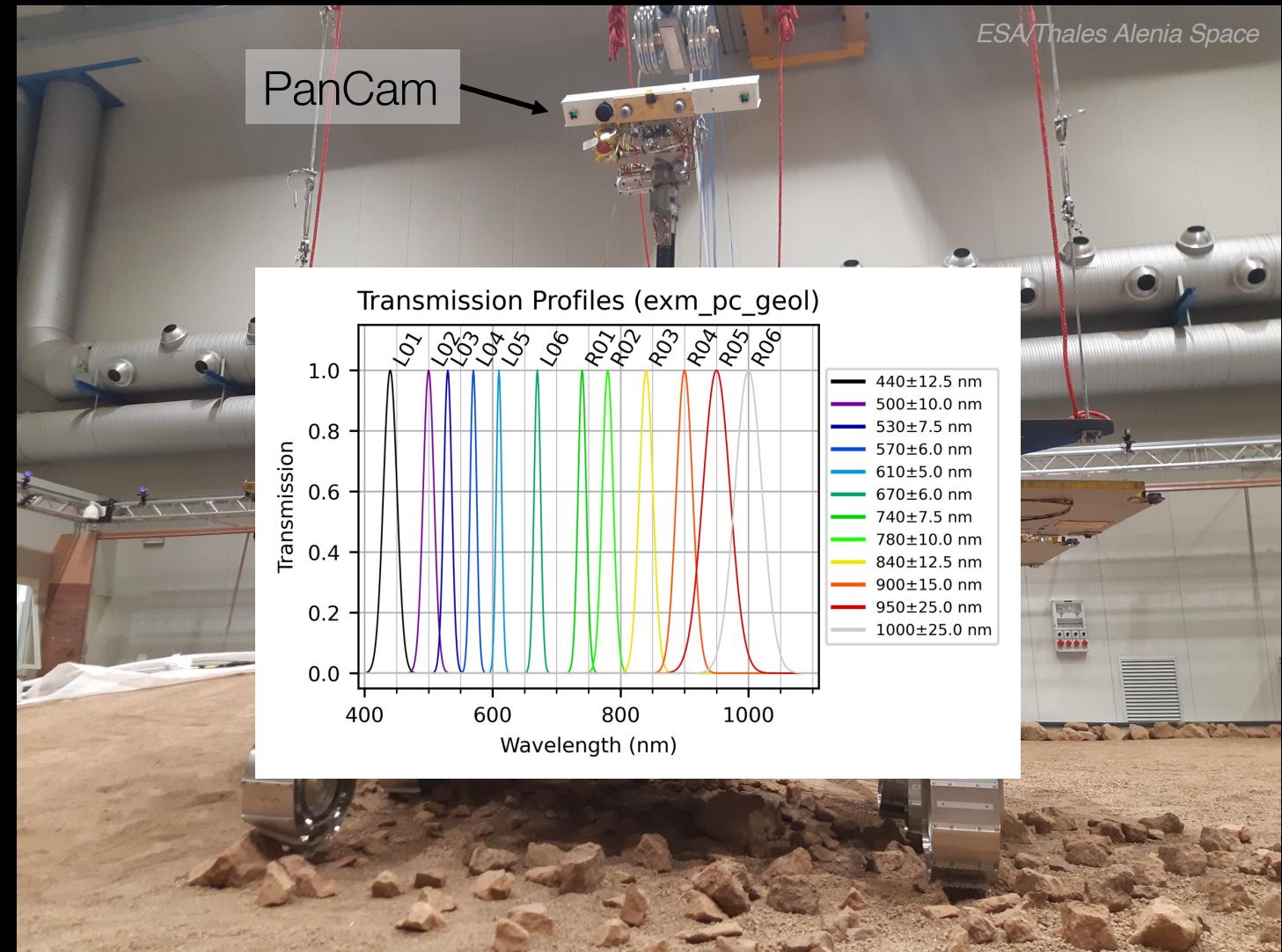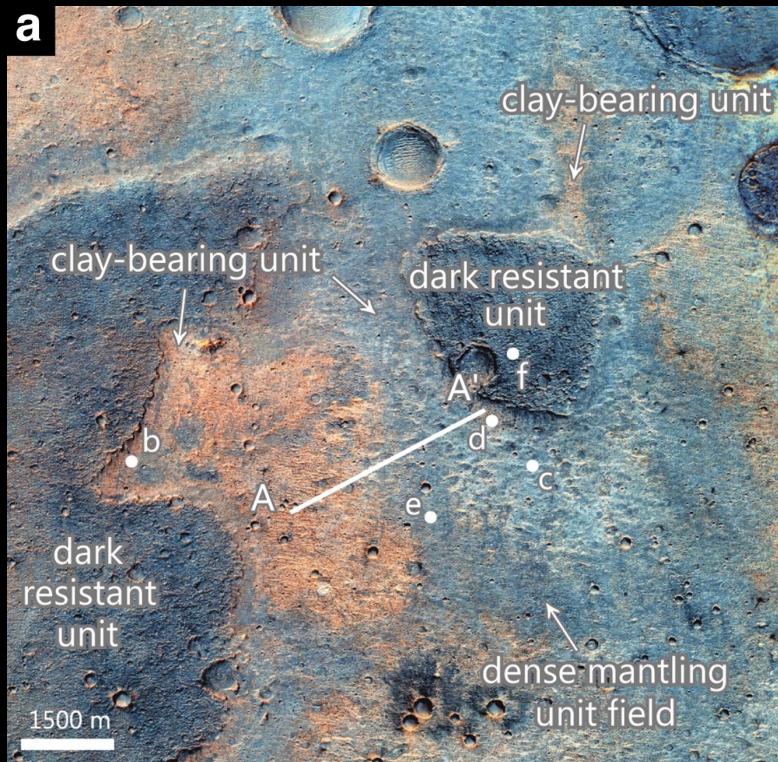
Quantin—Nataf et al. 2021, Astrobiology,
Oxia Planum: The Landing Site for the ExoMars "Rosalind Franklin" Rover Mission: Geological Context and Prelanding Interpretation
DOI: 10.1089/ast.2019.2191

ESA/Thales Alenia Space

PanCam

Transmission Profiles (exm_pc_geol)

L01 L02 L03 L04 L05 L06 R01 R02 R03 R04 R05 R06

—	440±12.5 nm
—	500±10.0 nm
—	530±7.5 nm
—	570±6.0 nm
—	610±5.0 nm
—	670±6.0 nm
—	740±7.5 nm
—	780±10.0 nm
—	840±12.5 nm
—	900±15.0 nm
—	950±25.0 nm
—	1000±25.0 nm

Transmission

Wavelength (nm)

a

clay-bearing unit

clay-bearing unit

dark resistant unit

A'

f

d

b

c

A

e

dark resistant unit

dense mantling unit field

1500 m

ESA/Thales Alenia Space

Transmission Profiles (exm_pc_geol)

L01 L02 L03 L04 L05 L06 R01 R02 R03 R04 R05 R06

Transmission

1.0
0.8
0.6
0.4
0.2
0.0

400   600   800   1000

Wavelength (nm)

440±12.5 nm
500±10.0 nm
530±7.5 nm
570±6.0 nm
610±5.0 nm
670±6.0 nm
740±7.5 nm
780±10.0 nm

?

sptk: the Spectral Parameters Toolkit
A python library for exploring multispectral sampling


- target material
- background materials
- filters

Input

sptk

Output

Rank	Spectral Parameters	Score	# Uniq. Filters	Filters
1	R:440-780, R:500-740	8.74	4	G01, G08, G02, G07
...	...		...	...

Data

Model Preparation

Parallel Model Learning

Model Ranking
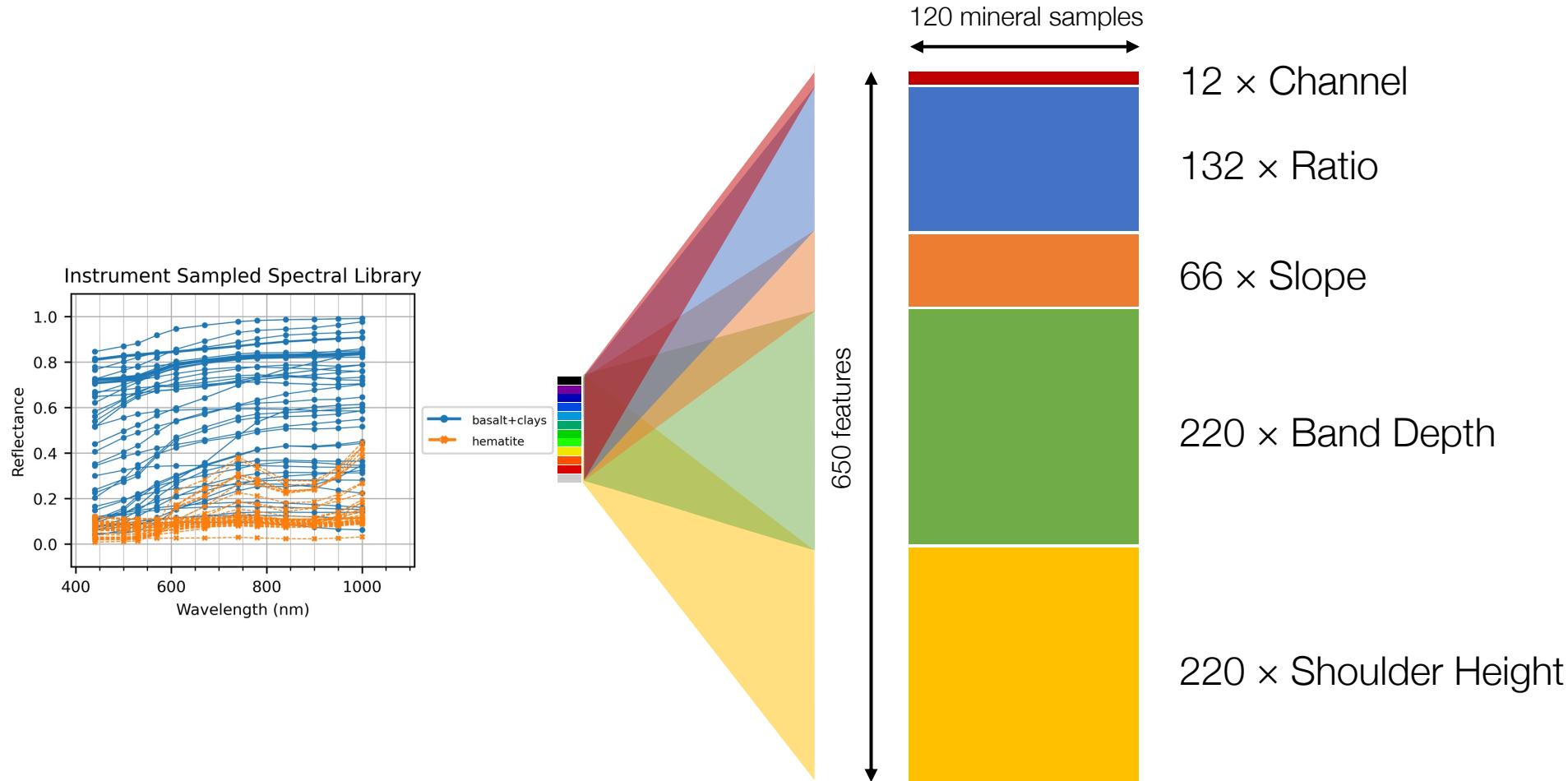
Pipeline Overview
Spectral Library Sampling

Western Washington University Visible-Infrared Spectral Browser

https://westernreflectancelab.com/visor/

High-Resolution Spectral Library

120 mineral samples

12 features

R440
R500
R530
R570
R610
R670
R740
R780
R840
R900
R950
R1000

Case Study:
Hematite at Oxia Planum

target: Hematite

- hematite

background: Clays & Basalts

- vermiculite
- saponite
- montmorillonite
- basalt
- basaltic soil

Pipeline Overview
Computing Spectral Parameters
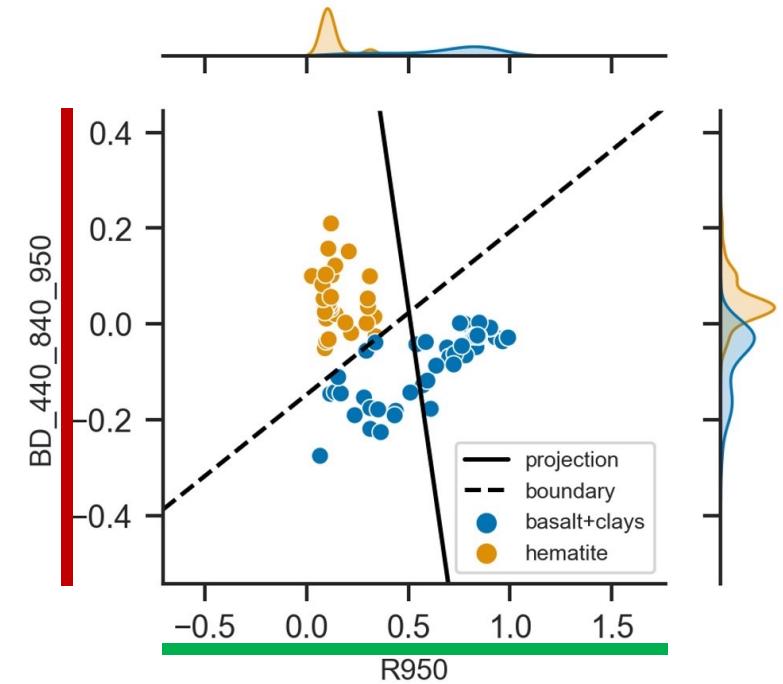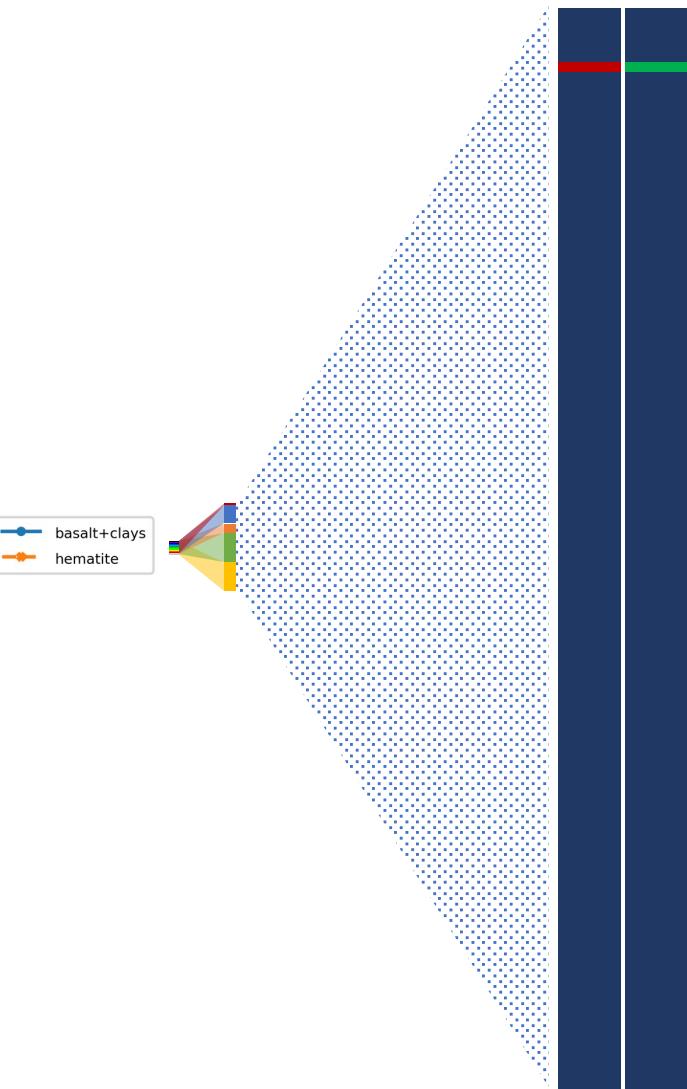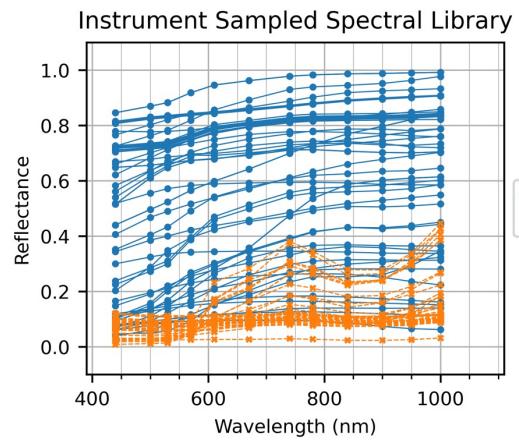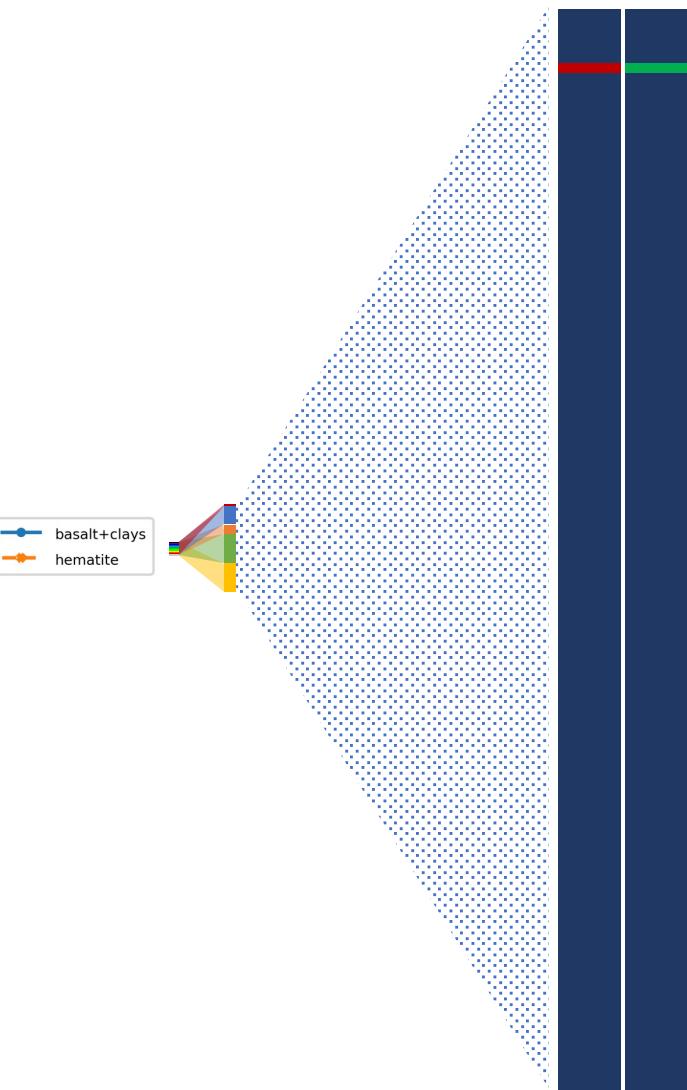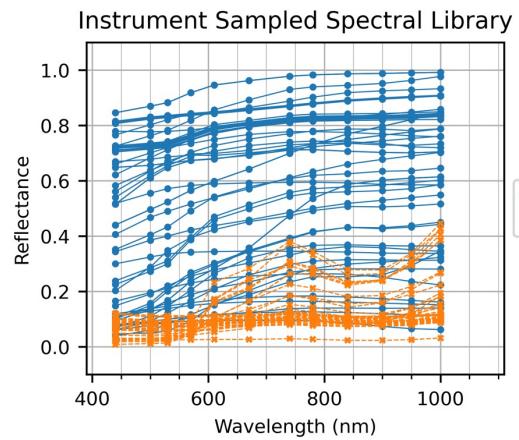
Pipeline Overview
Combining Spectral Parameters

Instrument Sampled Spectral Library

120 mineral samples

120 mineral samples

Spectral Parameter A

Spectral Parameter B

Spectral Parameter Pair Combinations (×211576)

Pipeline Overview
Combining Spectral Parameters

120 mineral samples

SP a   BD_440_840_950

SP b   R950

Instrument Sampled Spectral Library

Spectral Parameter Pair Combinations (×211576)

Pipeline Overview
Combining Spectral Parameters

Pipeline Overview
Combining Spectral Parameters


120 mineral samples

SP a — BD_440_840_950

SP b — R950

Instrument Sampled Spectral Library
- basalt+clays
- hematite
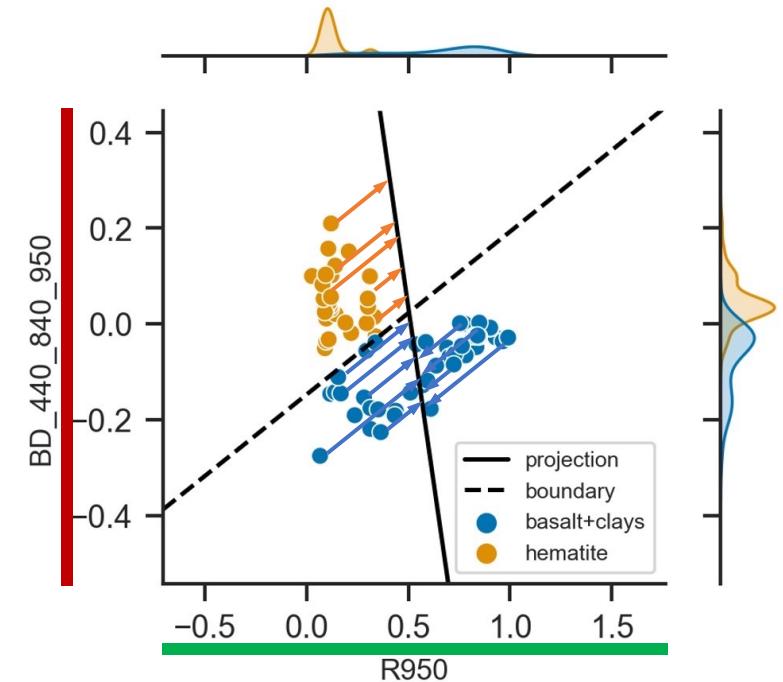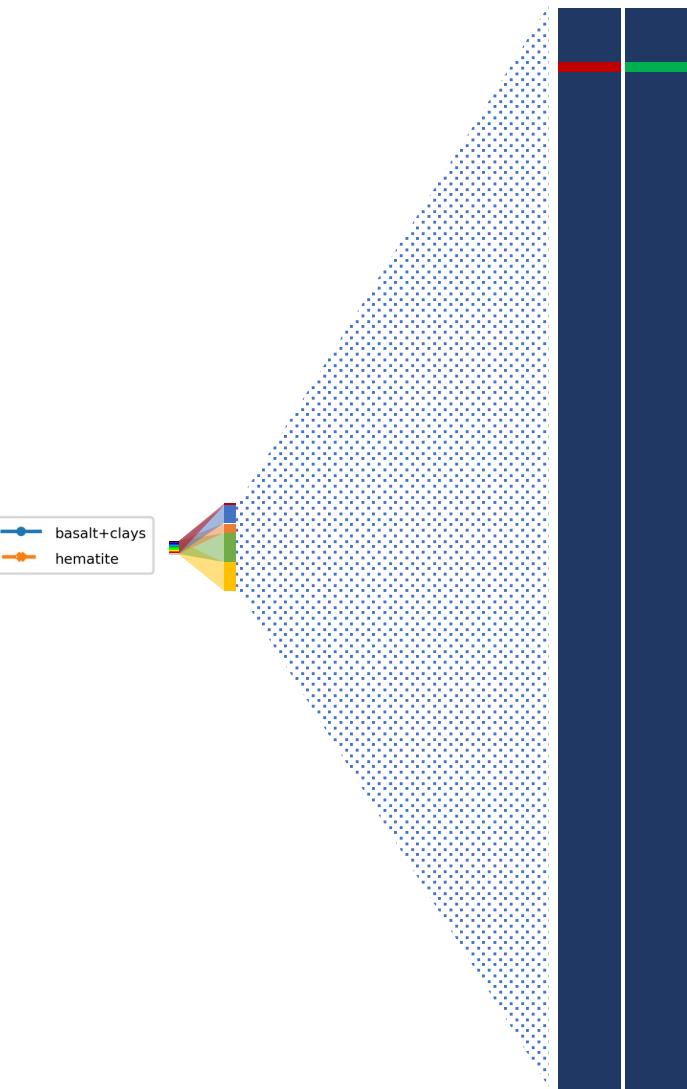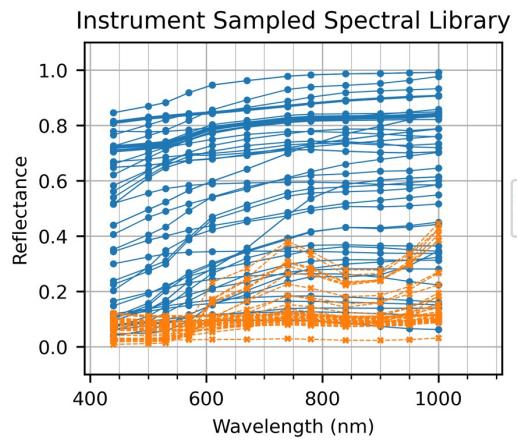
Spectral
Parameter
Pair
Combinations
(×211576)
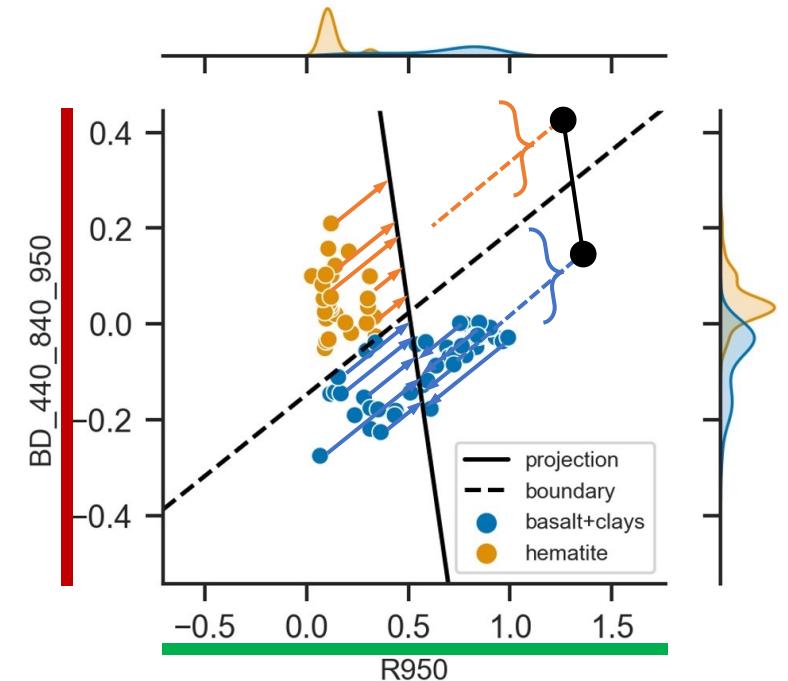
BD_440_840_950 / R950
- projection
- boundary
- basalt+clays
- hematite
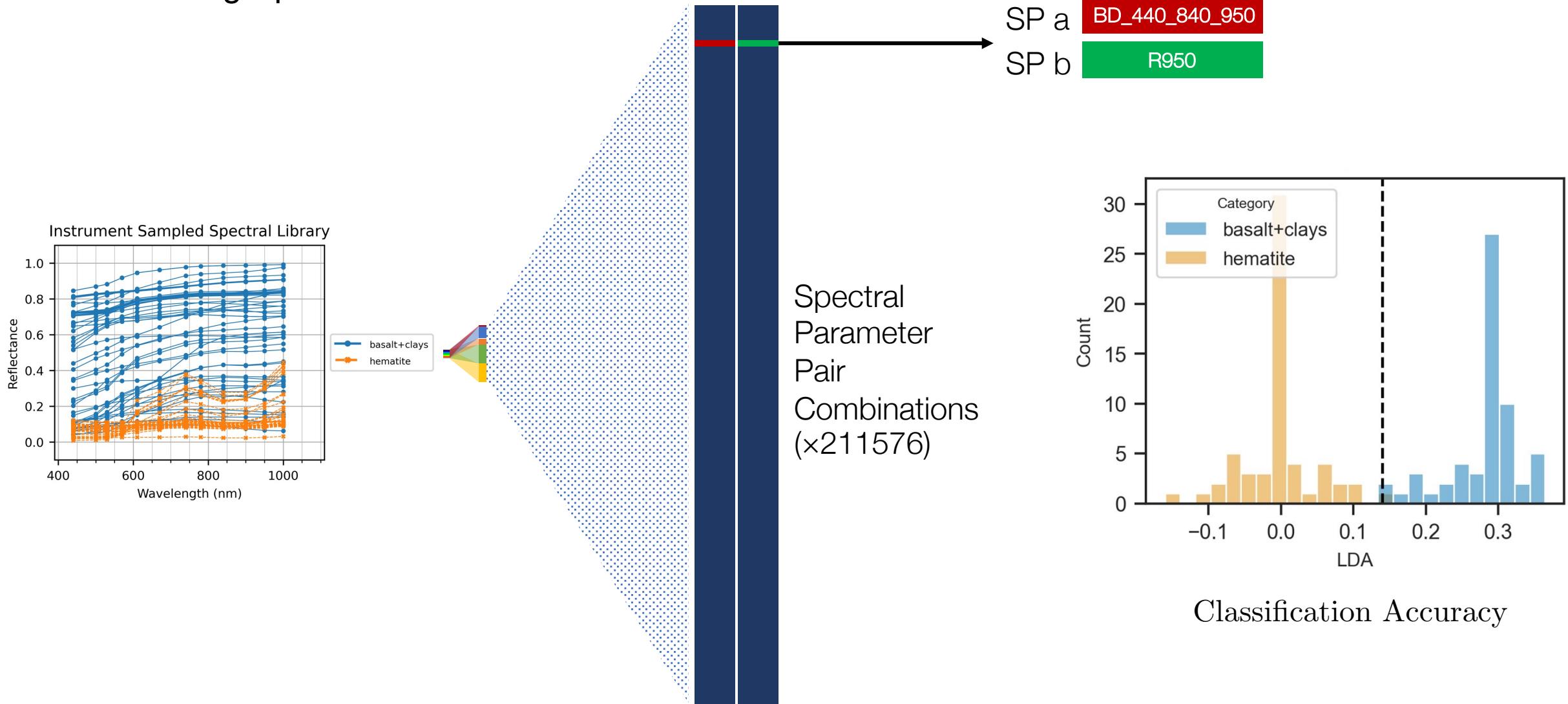
$$\text{Fisher Ratio} = \frac{\text{Between-Class Scatter}}{\text{Within-Class Scatter}}$$
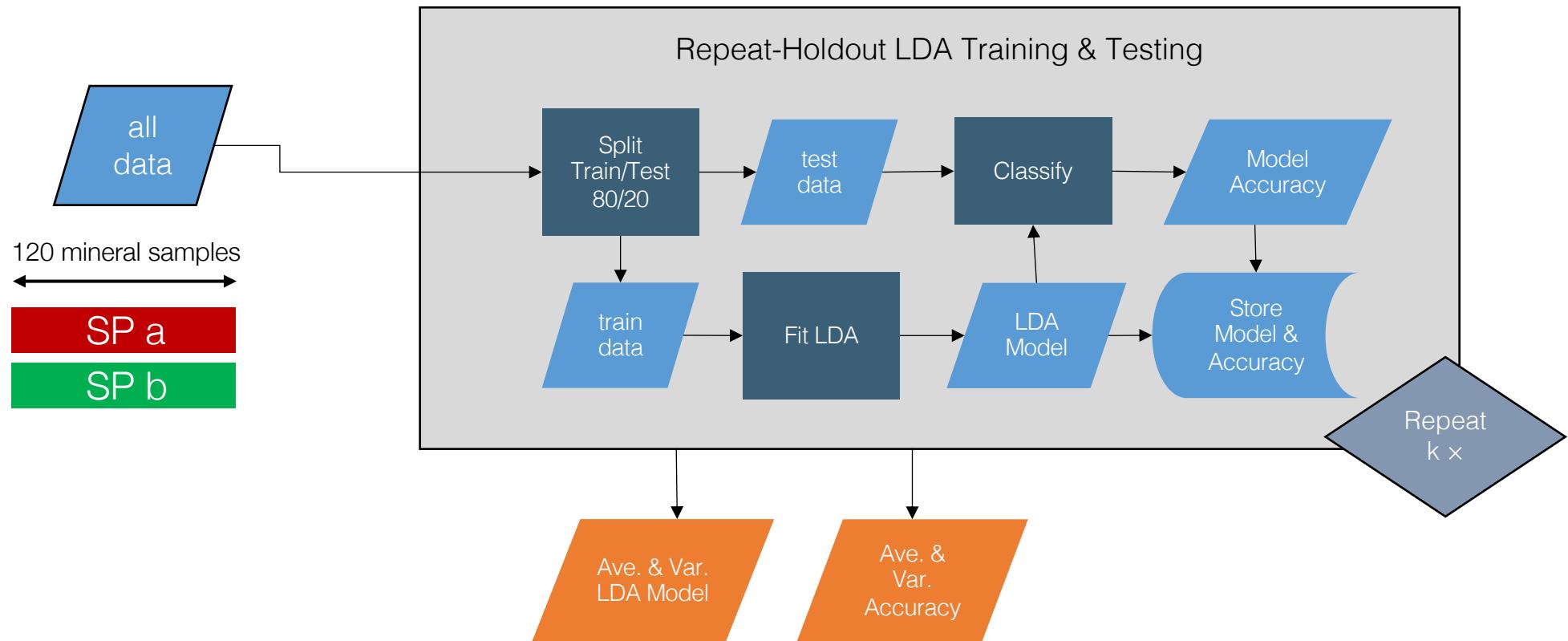
# Pipeline Overview
Combining Spectral Parameters
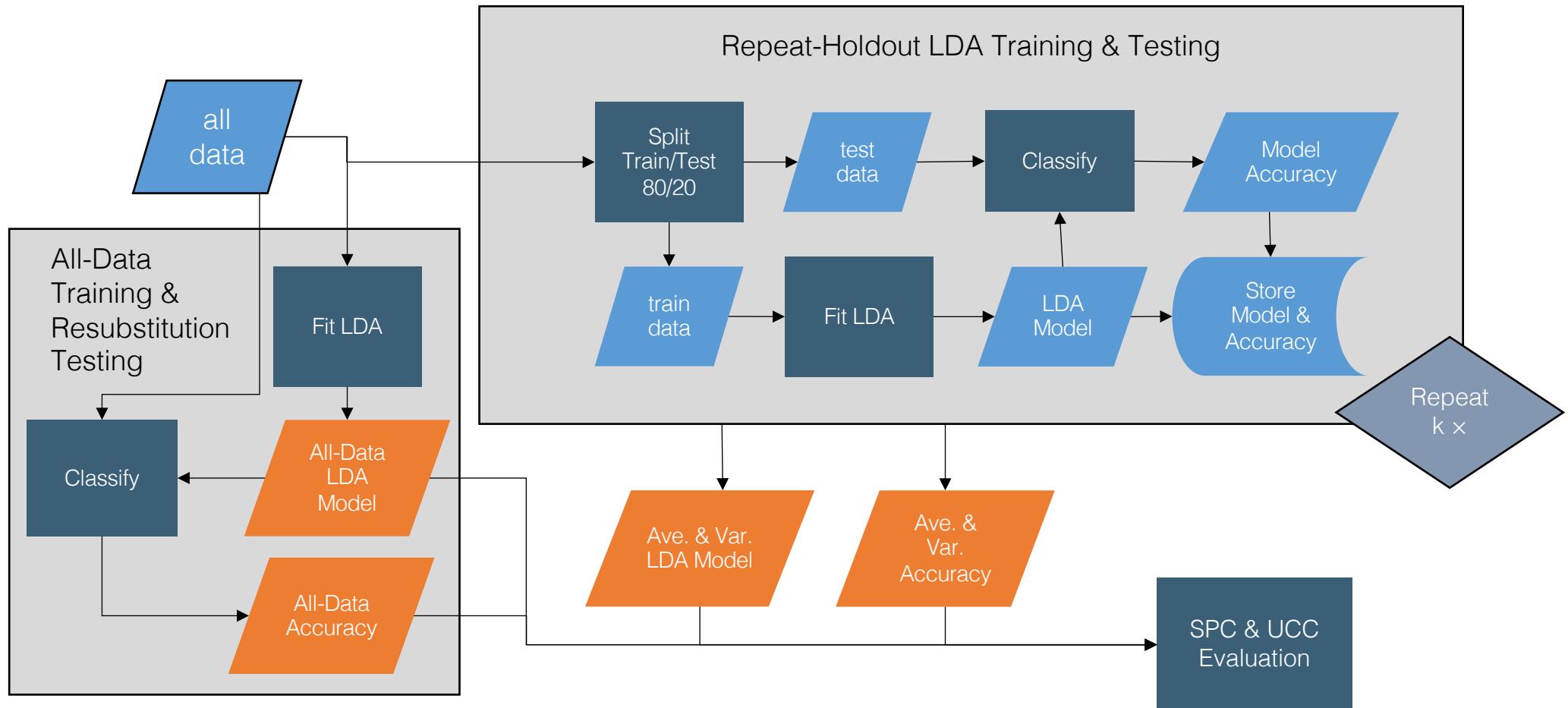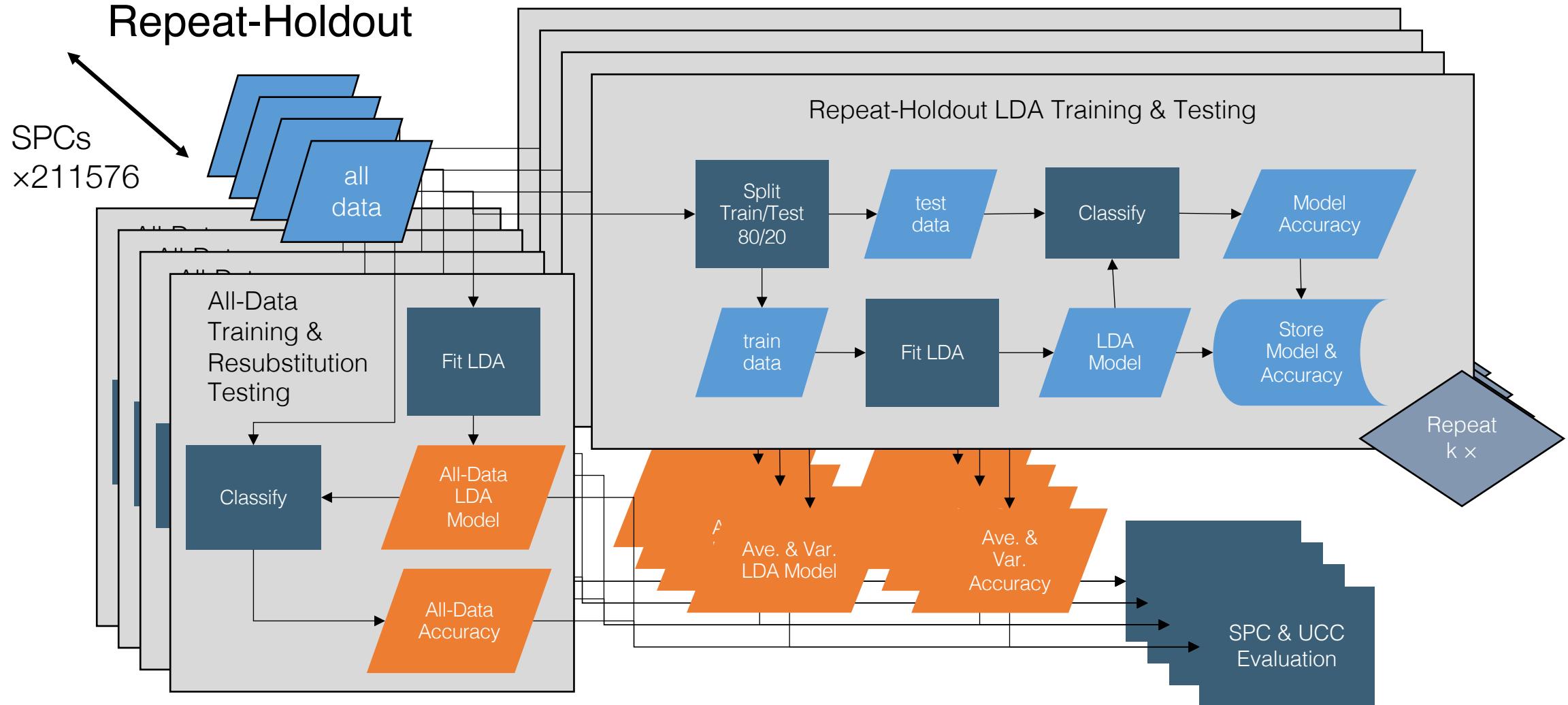
120 mineral samples

SP a   BD_440_840_950

SP b   R950

Spectral
Parameter
Pair
Combinations
(×211576)

Classification Accuracy

Pipeline Overview
Repeat-Holdout

Pipeline Overview
Repeat-Holdout

Pipeline Overview
Repeat-Holdout

SPCs
×211576

all data

Repeat-Holdout LDA Training & Testing

Split Train/Test 80/20 → test data → Classify → Model Accuracy

train data → Fit LDA → LDA Model → Store Model & Accuracy

Repeat k ×

All-Data Training & Resubstitution Testing

Fit LDA

Classify ← All-Data LDA Model

All-Data Accuracy

Ave. & Var. LDA Model

Ave. & Var. Accuracy

SPC & UCC Evaluation
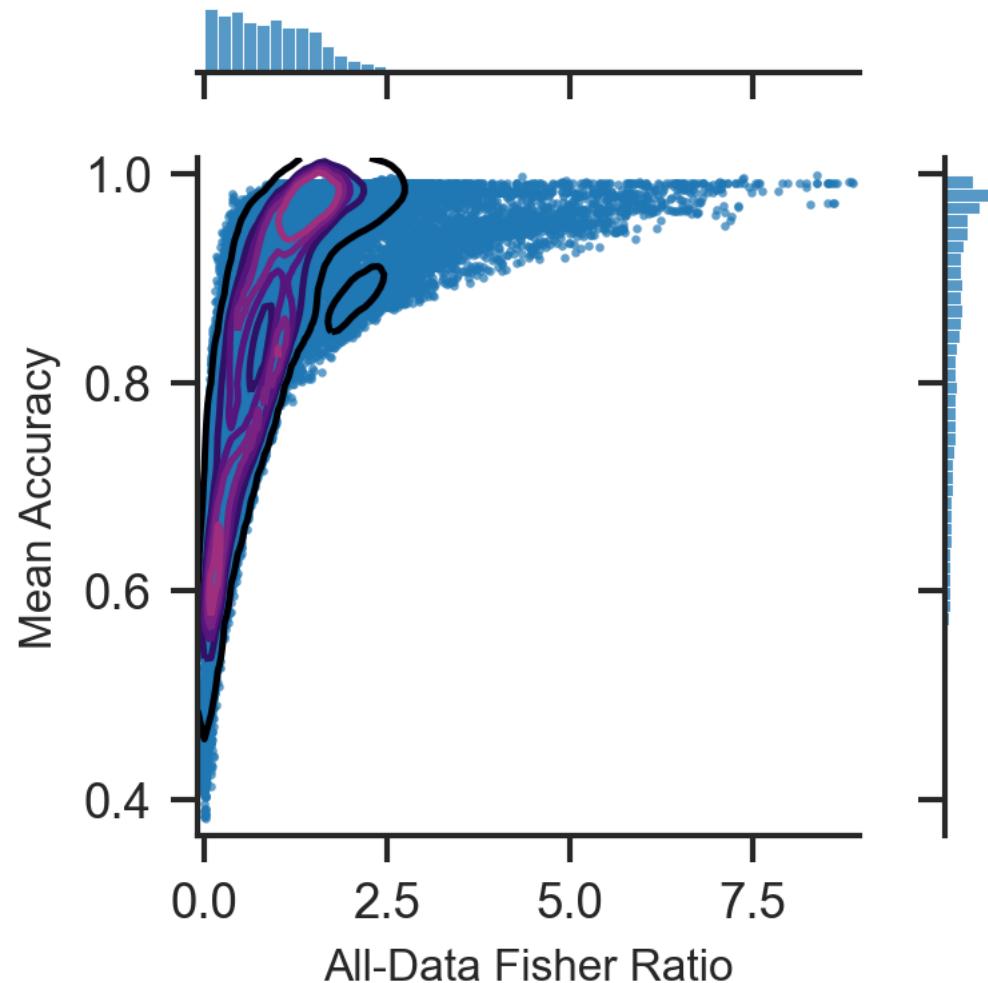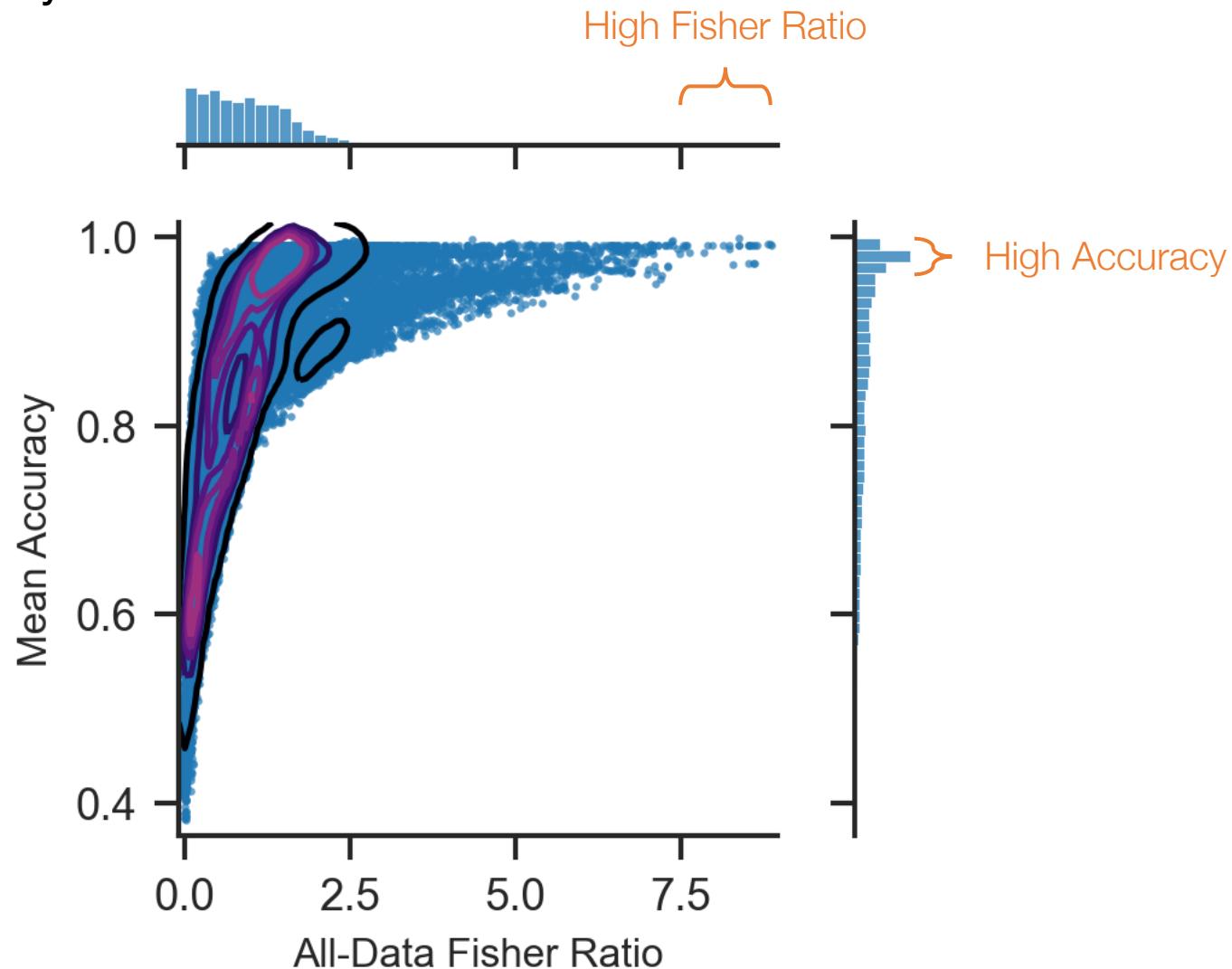
Analysis
Fisher Ratio vs Accuracy
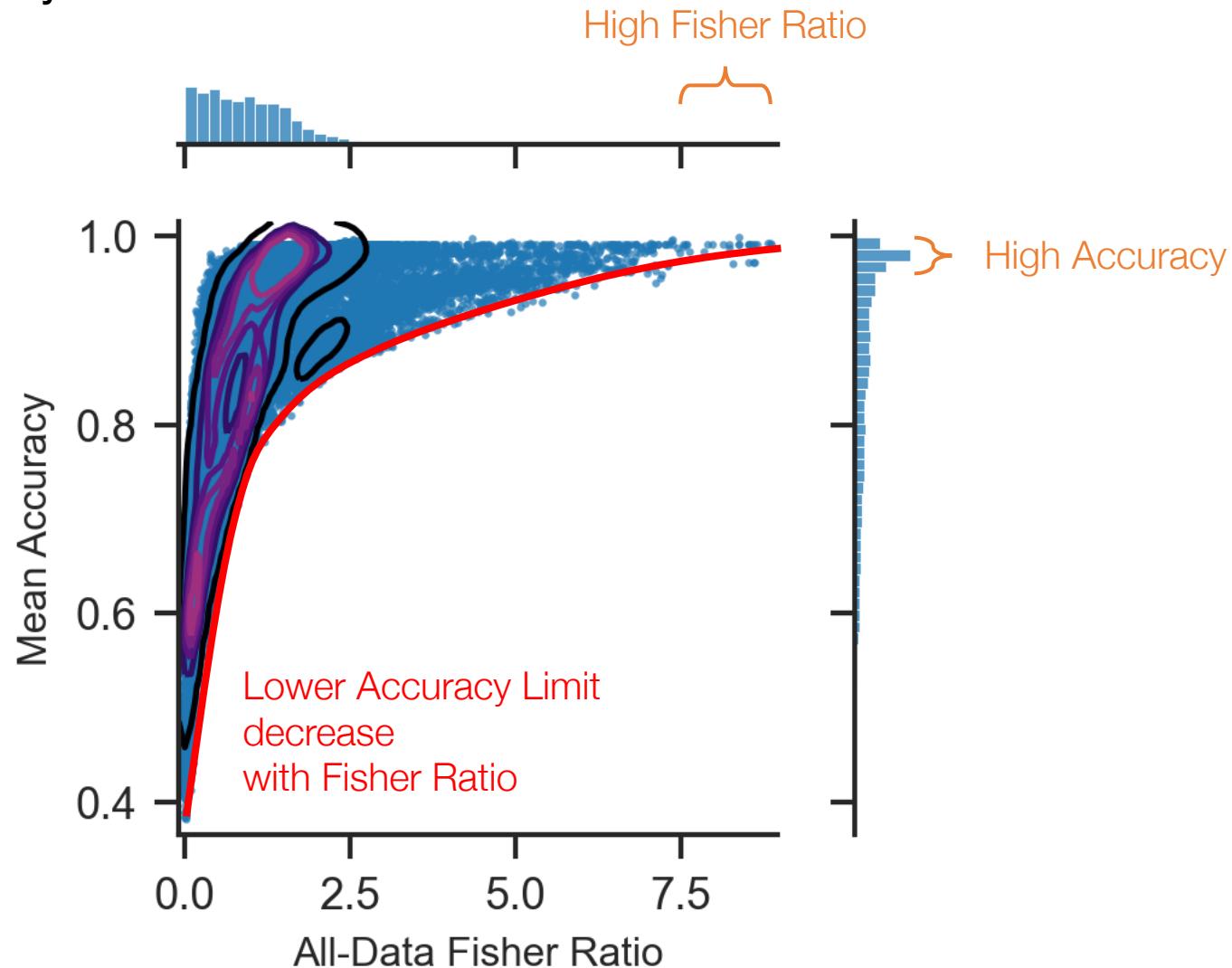
Analysis
Fisher Ratio vs Accuracy
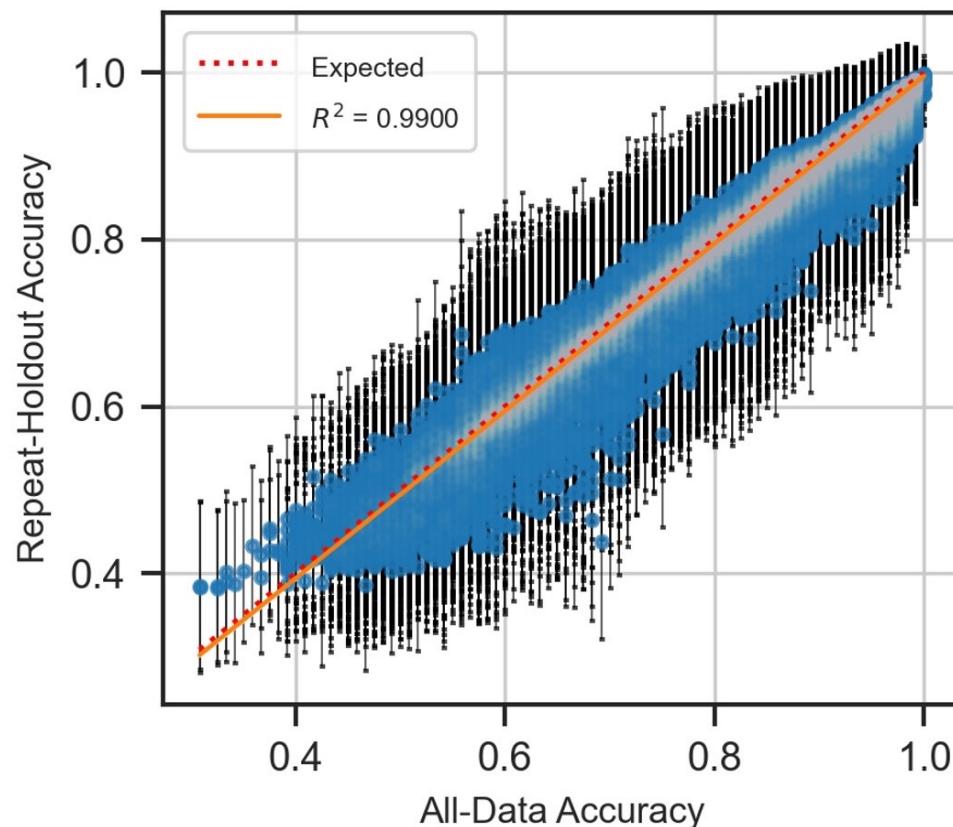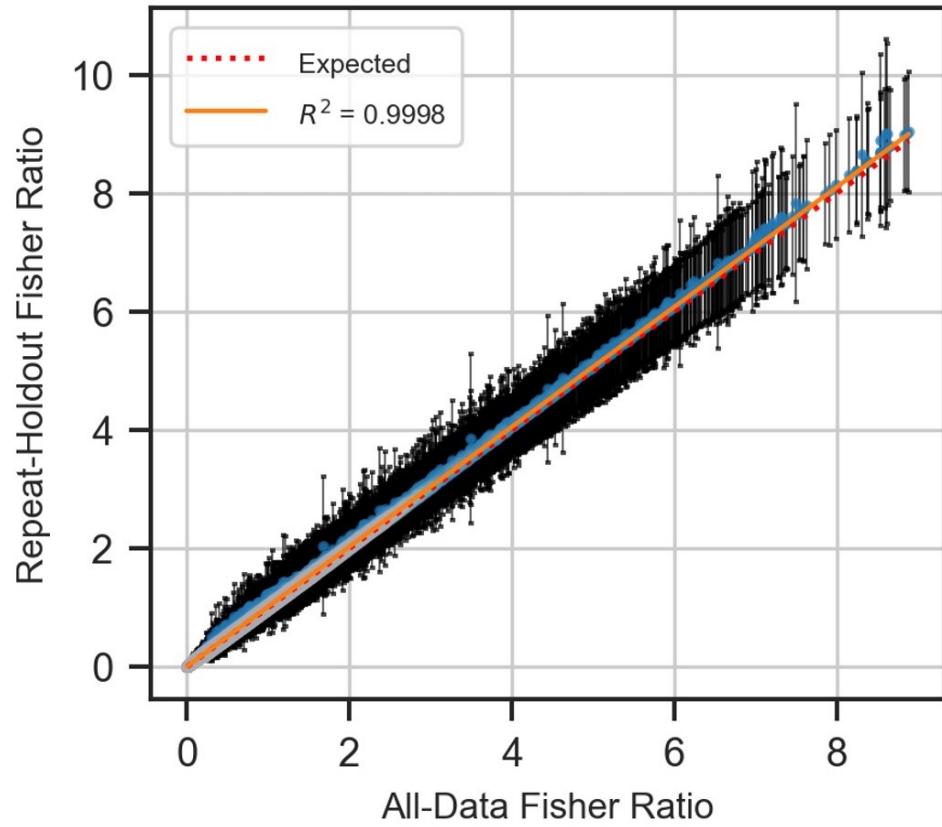
Analysis
Fisher Ratio vs Accuracy

Analysis
## Repeat-Holdout vs All-Data Fisher Ratio and Accuracy
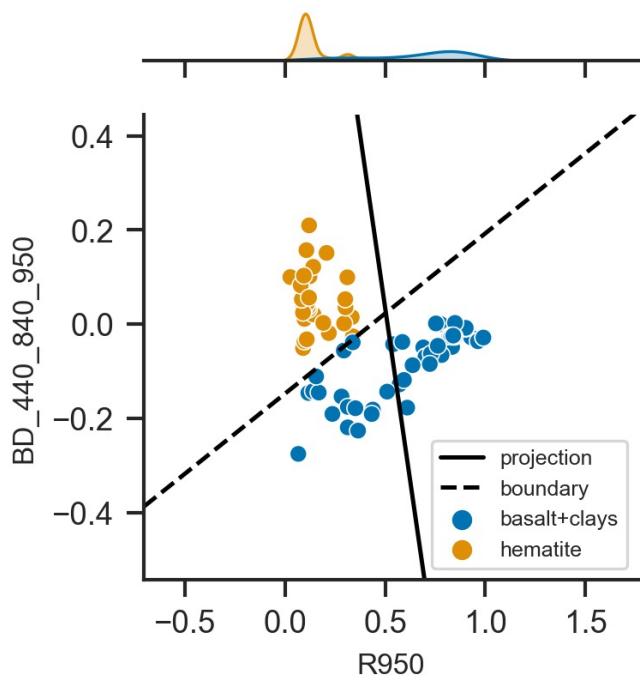
Results
Top Ranked Spectral Parameter Combinations

Ranked by Mean Accuracy

Rank 1, ID 6705

Ranked by Mean Fisher Ratio

Rank 1, ID 2204

Results
Top Ranked Spectral Parameter Combinations
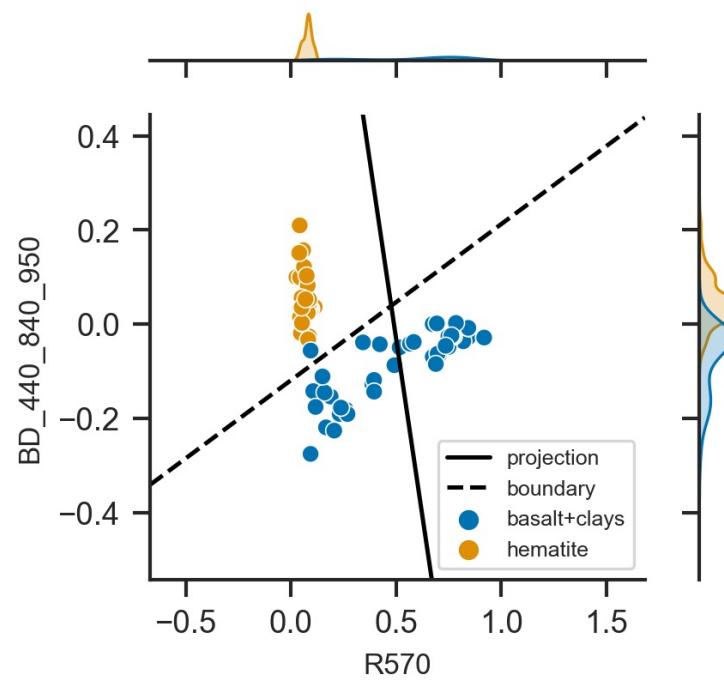

Ranked by Mean Accuracy
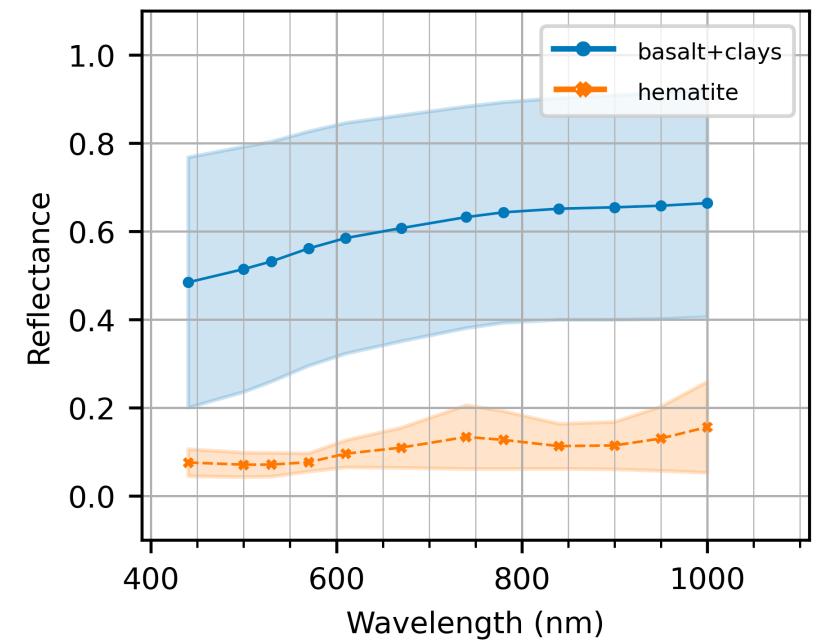
Rank 1, ID 6705

Ranked by Mean Fisher Ratio

Rank 1, ID 2204

Mean ± 1σ Sampled Spectral Library

Results
## Number of Unique Channels

Unique Channels for Top 1058 SPCs

Ranked by Mean Accuracy

Ranked by Mean Fisher Ratio
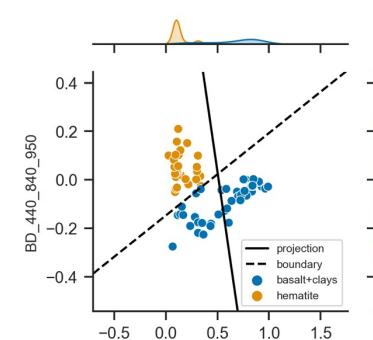
3 Unique Channels

4 Unique Channels
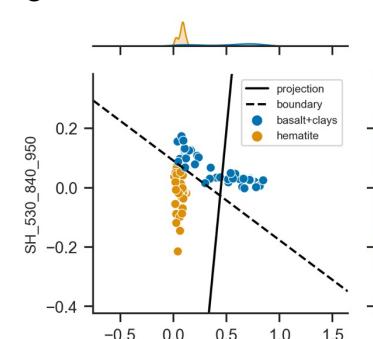
5 Unique Channels

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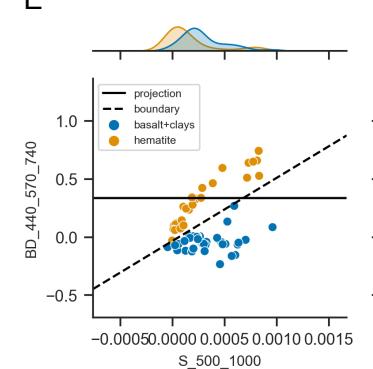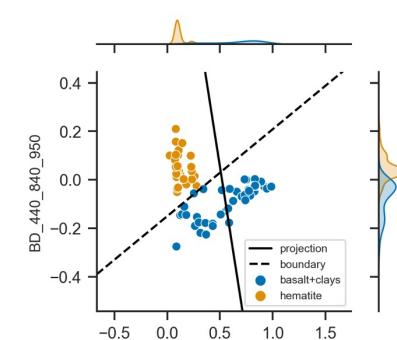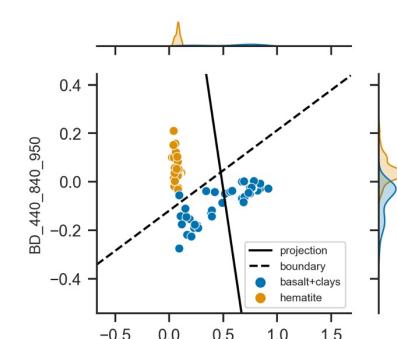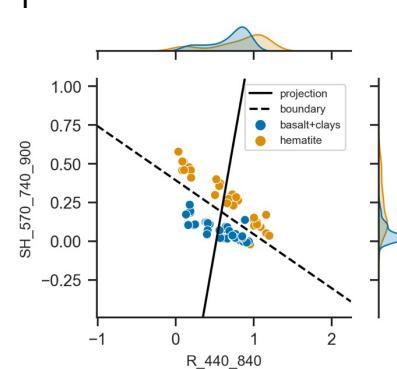
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for Data-Limited Dynamic Planetary Surface Exploration
with Linear Discriminant Analysis

Summary

- The Fisher Ratio is a computationally light-weight metric for finding good separation of materials

- provides interpretable recommendations of spectral channel combinations

- capable of exhaustive searching of spectral parameter space

- Ranking by Fisher Ratio is more robust to dataset variations than accuracy

- High Fisher Ratio implies High Accuracy, but not vice-versa

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