Probing Rock Type, Iron Redox State, and Transition Metal Contents with 6-Window VNIR Spectroscopy under Venus Conditions

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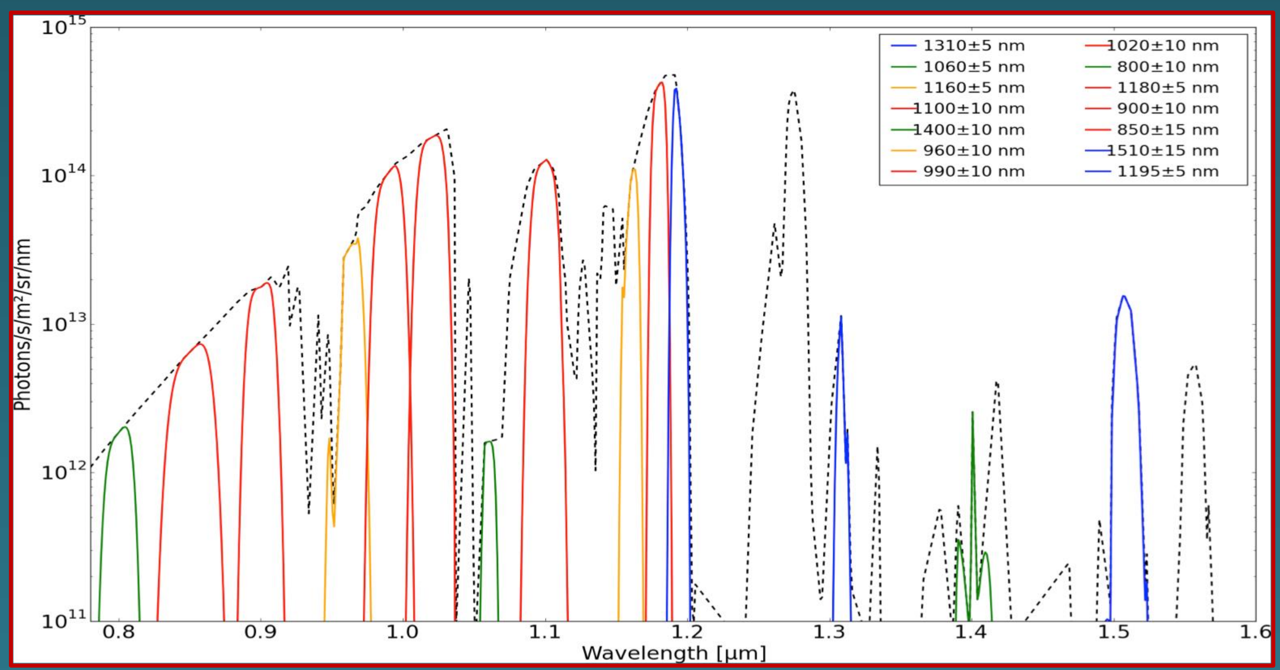
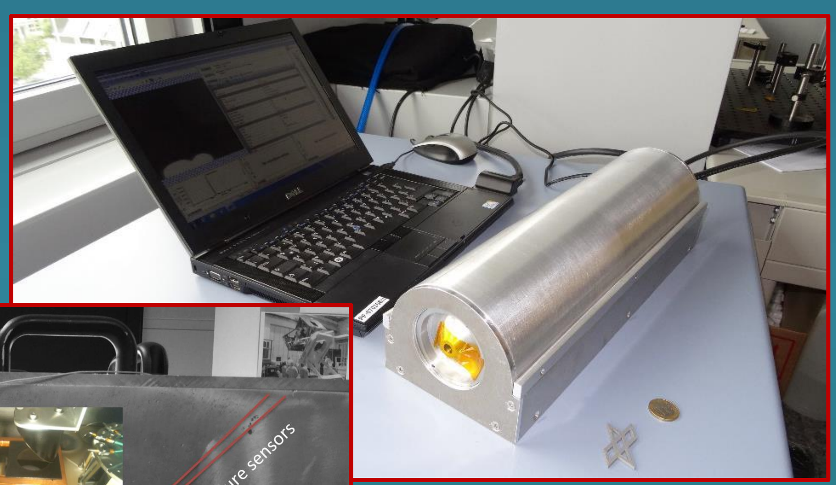
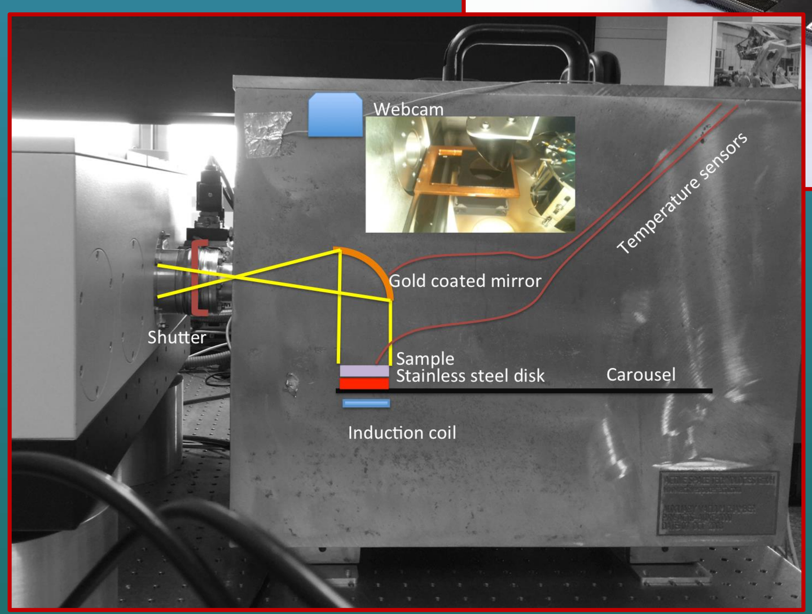
Motivation

- Orbital VNIR spectroscopy of Venus is hampered by Venus' thick, CO_2-rich atmosphere, though observations are possible through transparent windows in the CO_2 spectrum near 1 μm (below).
- Venus Emissivity Mapper (VEM) was developed for the VERITAS mission to study the surface of Venus through six different windows at 0.86, 0.91, 0.99, 1.02, 1.11, and 1.18 μm.
- Two specific issues are addressed here:
  1) the ability of VEM-window data to distinguish among key rock types on Venus, and
  2) their capability to evaluate redox state and transition metal contents of Venus surface rocks.



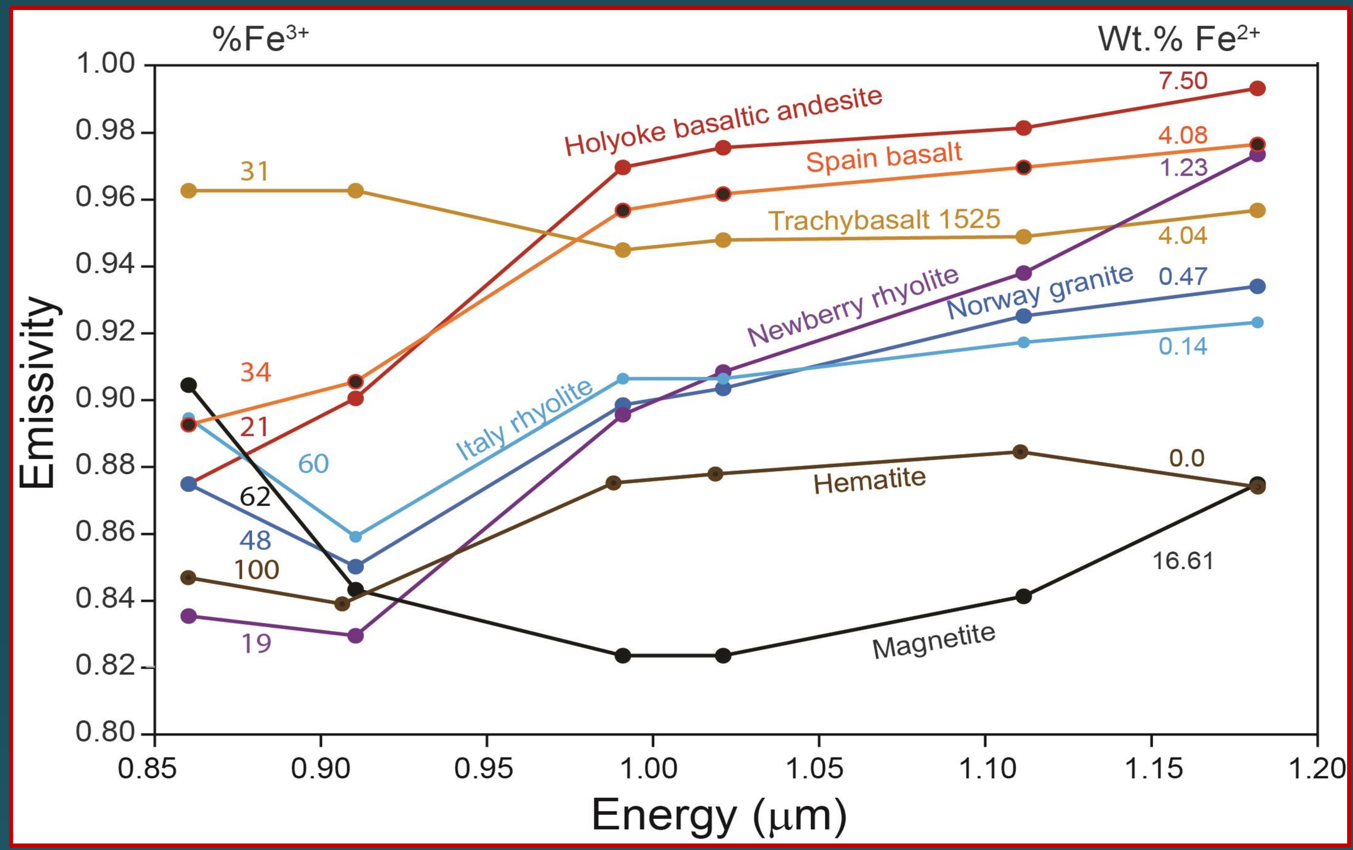
FILTERS ON VEM compared against a synthetic Venus night side spectrum (dashed envelope). Red are surface bands, blue bands for cloud correction, green stray light correction and yellow bands to detect water vapor.





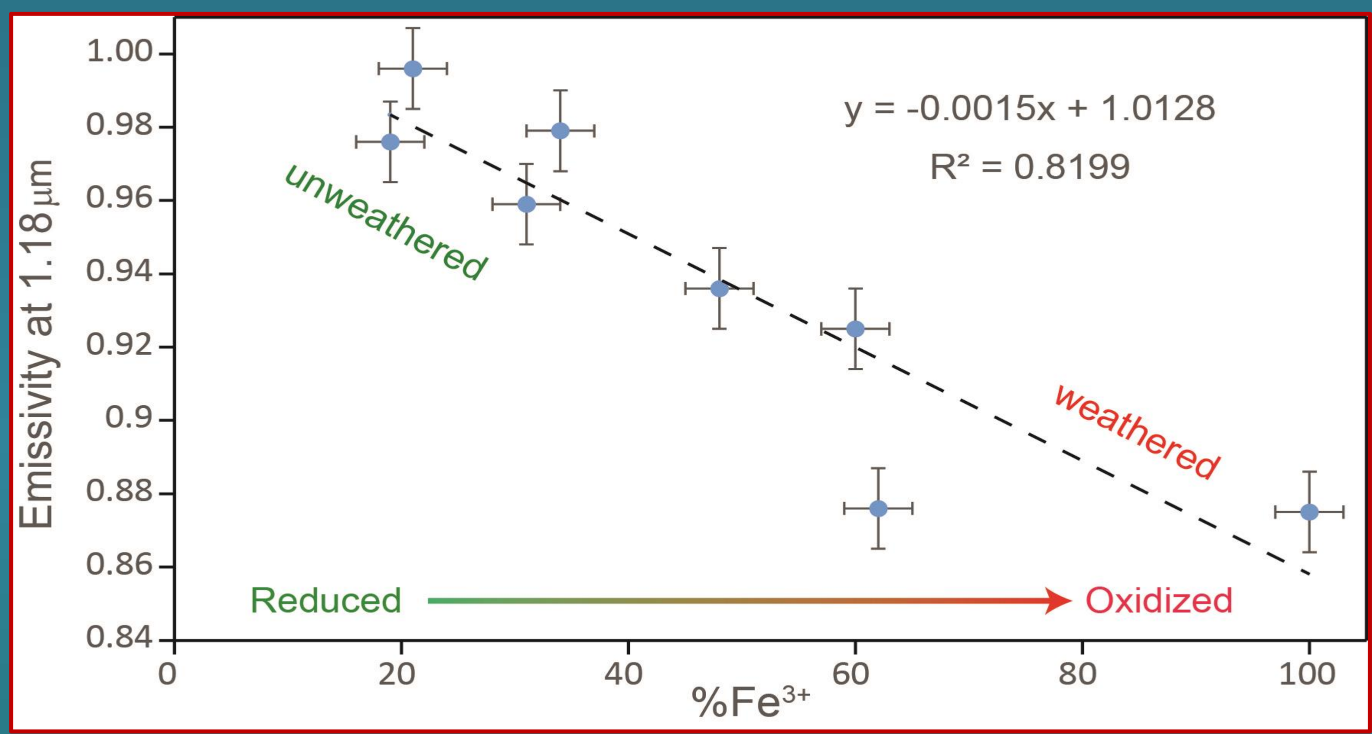
VEM LABORATORY PROTOTYPE uses flight-like optics and the COTS version of the flight detector. The new configuration at DLR's PSL allows emissiivity spectra of Venus analogs to be obtained for the first time at Venus surface temperatures for all atmospheric windows.

VNIR DATA collected in the Planetary Spectroscopy Laboratory (PSL) at the German Aerospace Center DLR in Berlin. SAMPLES STUDIED: basalt from Lanzarote Island, Spain; basaltic andesite from Holyoke, Massachusetts; amphibolite sample from Labrador (Canada); trachybasalt from PEL collections (locality unknown); rhyolites from Lofoten Islands, Norway, and Seiser Alm, Italy; and rhyolitic glass from Newberry Volcano in Oregon (USA). COMPOSITIONS determined by x-ray fluorescence (XRF) or by electron microprobe using standard methods. Fe^{3+} contents were measured using MÖSSBAUER SPECTROSCOPY in the Mineral Spectroscopy Laboratory at Mount Holyoke College [15] using standard methods.

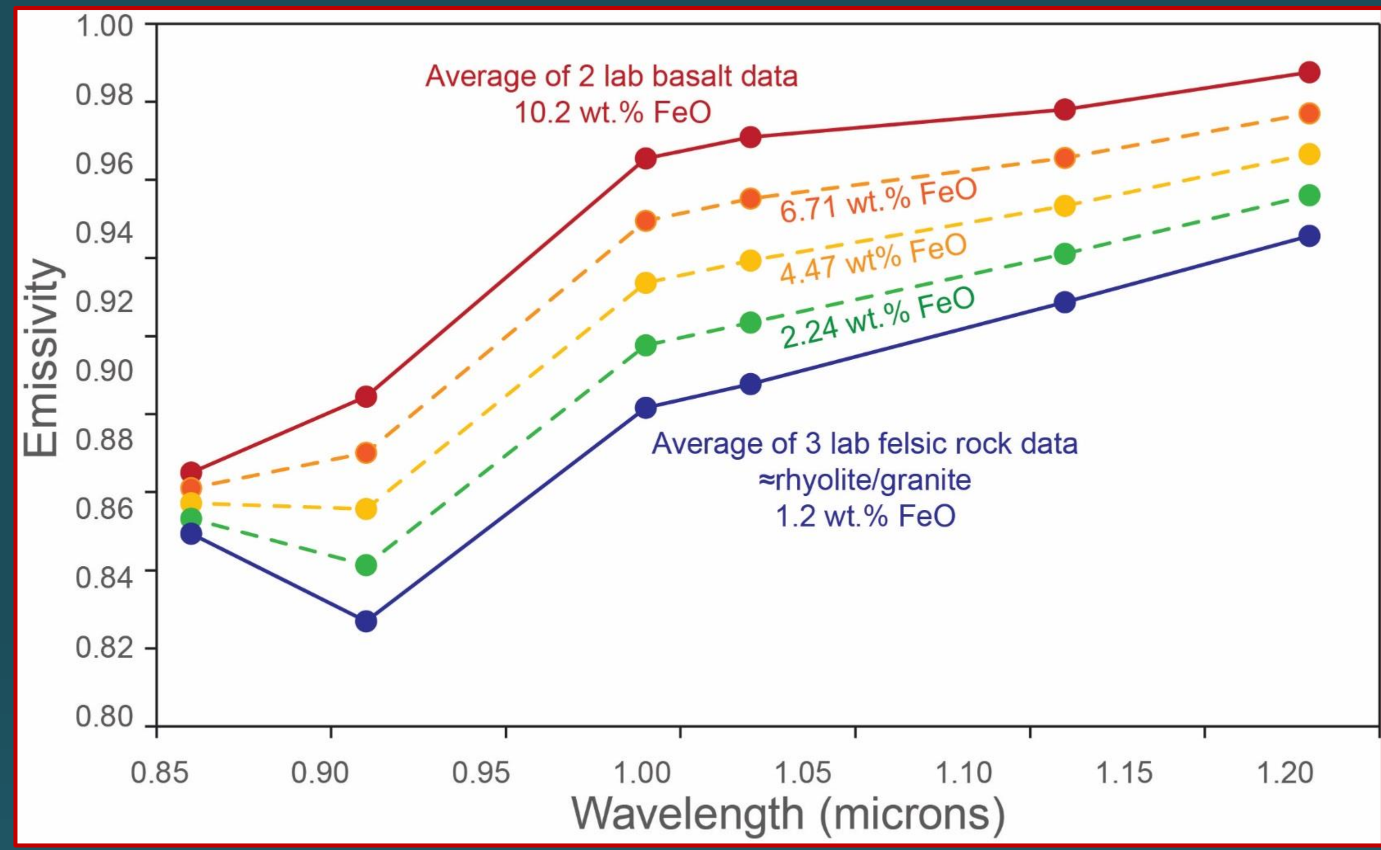


EMISSIVITY DATA (above) with $\%Fe^{3+}$ (left) and wt.% Fe^{3+} (right indicated as determined by combining Mössbauer, x-ray fluorescence, and electron microprobe., showing two trends:

1) **The wavelength region ca. 0.99 and 1.02 μm allows hematite to be distinguished from magnetite, and oxides from silicates**. In this region, Fe (and other transition metals in silicate minerals causes elevated emissivity, felsic rocks group separetly, and oxides have low emissivities.
2) **Even the 1.18 mm band can be used to determine oxidation state and thus infer weathering** (below). This distinction is key to understanding surface-atmospher interactions on Venus.
3) **Samples containing Fe oxides (rhyolite, granites, and the oxides themselves) have negative slopes** between the two lowest wavelength bands.



DISCRIMINATING AMONG ROCK TYPES: A key capability needed for understanding Venus is distinguishing between basalt plains on Venus and other igneous rock types that might occur in continental crust. To model this, we used averages of lab data and interpolated between them using FeO contents (figure at upper right) to obtain model spectra for basaltic andesite, andesite, and dacite. We then randomly applied model errors to created 100 synthetic spectra within a random distribution and parameterized the information contained in the six channels as shown below.



For 4% error spectra, we parameterized each of the spectra by calculating the slope between each pair of band (15 combinations) as well as the band ratios between each pair of bands (again, 15 possibilities), providing a total of 36 associated with each 4% error model. This full parameterization step was not necessary for the CBE spectra because 100% accuracy in classification was achieved using only the six channels of emissivity data (Table 1).

We next created a binary classifier to assess how accurately each of intermediate rock type could be distinguished from the basaltic plains of Venus. We used a regularized maximum entropy classifier, randomly holding out 20% of the data while the other 80% were used to train the model. The model was then used to predict the classification of the remaining 20%. We repeated 100 randomized trials for each model, with results shown in Table 1 below.

This analysis shows that the highest accuracy in discriminating binary rock types is found (unsurprisingly) between mafic and felsic rocks. The most difficult distinction is between baslt and its closest compositional neighbor, basaltic andesite. At current best estimate (CBE) error levels, basalt spectra can easily be distinguished, even from basaltic andesite, at CBE levels.

Table 1. Accuracy of Binary Classifier Trained to Distinguish between Two Rock Types

	n		Basalt / felsic	Basalt /dacite	Basalt / andesite	Basalt / BA
CBE errors	6	$\bar{x}$	100.0	100.0	100.0	100.0
		s^2	0.0	0.0	0.0	0.0
4% errors	36	$\bar{x}$	94.6	88.5	80.4	65.4
		s^2	0.6	0.9	1	1.2
	6	$\bar{x}$	93.7	86.4	80.2	60.1
		s^2	0.6	0.9	0.9	1.3

n = number of components in model, $\bar{x}$ = mean and s^2 = standard deviation of 100 trials. CBE errors are 0.7%, 0.7%, 0.4%, 0.3%, 0.7%, and 1.2% for the 0.86, 0.91, 0.99, 1.02, 1.11, and 1.18 μm bands, respectively.

Summary

Even with only 6 channels of spectral data, VEM data inform the redox state and chemical composition of Venus' surface from orbit. Slopes between the lowest two channels and among the highest ones allow information about iron redox state and olivine/pyroxene abundances (≈transition metal abundances in those minerals), respectively, to be distinguished. A binary classifier easily separates possible rock types on Venus.

References

[1] Carlson R. W. et al. (1991) *Science*, 253, 1541-1548. [2] Mueller N. et al. (2008) *JGR* 113, 1–21. [3] Helbert J. et al. (2013) *IR Remote Sens. Instrum.* XXI, 8867, doi: 10.1117/12.2025582. [4] Helbert J. et al. (2008) *GRL*, 35, L11201. [5] Hashimoto G. L. et al. (2008) *JGR*, 113, E00B24. [5] Dyar M. D. et al. (2016) *LPS XLVIII*, Abstract #2205.