Gaining a global perspective on the surface composition of Venus from orbit through near infrared observations – with a little help from machine learning approaches

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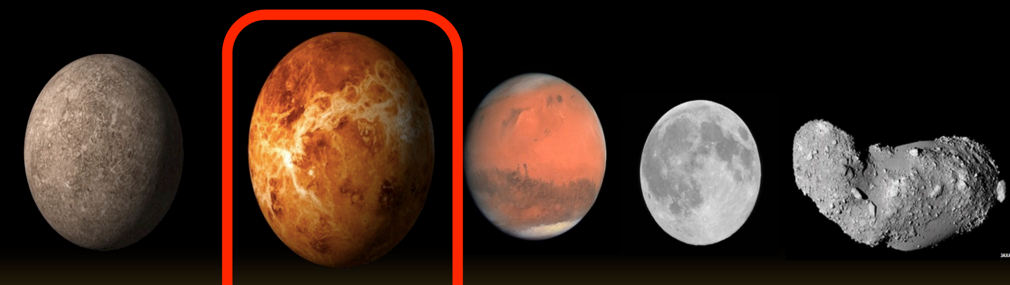
Abstract

Venus is the most Earth-like of the terrestrial planets, though very little is known about its surface composition. Thanks to recent advances in laboratory spectroscopy and spectral analysis techniques, this is about to change. Although the atmosphere prohibits observations of the surface with traditional imaging techniques over much of the EM spectral range, five transparent windows between ˜0.86 µm and ˜1.18 µm occur in the atmosphere's CO2 spectrum. New high temperature laboratory spectra from the Planetary Spectroscopy Laboratory at DLR show that spectra in these windows are highly diagnostic for surface mineralogy [1]. The Venus Emissivity Mapper (VEM) [2] builds on these recent advances VEM is the first flight instrument specially designed to focus solely on mapping Venus' surface using the windows around 1 µm. Operating in situ from Venus orbit, VEM will provide a global map of composition as well as redox state of the surface, enabling a comprehensive picture of surface-atmosphere interaction on Venus. VEM will return a complex data set containing surface, atmospheric, cloud, and scattering information. Total planned data volume for a typical mission scenario exceeds 1TB. Classical analysis techniques have been successfully used for VIRTIS on Venus Express [3-5] and could be employed with the VEM data. However, application of machine learning approaches to this rich dataset is vastly more efficient, as has already been confirmed with laboratory data. Binary classifiers [6] demonstrate that at current best estimate errors, basalt spectra are confidently discriminated from basaltic andesites, andesites, and rhyolite/granite. Applying the approach of self-organizing maps to the increasingly large set of laboratory measurements allows searching for additional mineralogical indicators, especially including their temperature dependence. [1] Dyar M. D. et al. 2017 LPS XLVIII, #1512. [2] Helbert, J. et al. 2016. San Diego, CA, SPIE. [3] Smrekar, S.E., et al. Science, 2010 328(5978), 605-8. [4] Helbert, J., et al., GRL, 2008 35(11). [5] Mueller, N., et al., JGR, 2008 113. [6] Dyar M. D. et al. 2017 LPS XLVIII, #3014.



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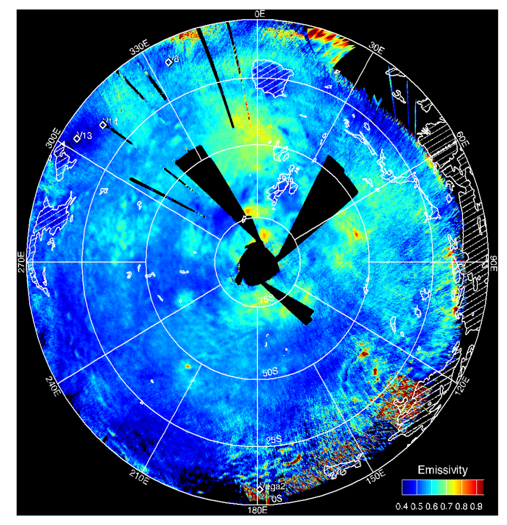
Abstract

Venus is the most Earth-like of the terrestrial planets, though very little is known about its surface composition. Thanks to recent advances in laboratory spectroscopy and spectral analysis techniques, this is about to change. Although the atmosphere prohibits observations of the surface with traditional imaging techniques over much of the EM spectral range, five transparent windows between ~0.86 µm and ~1.18 µm occur in the atmosphere's CO_2 spectrum. New high temperature laboratory spectra from the Planetary Spectroscopy Laboratory at DLR show that spectra in these windows are highly diagnostic for surface mineralogy.

The Venus Emissivity Mapper builds on these recent advances. It is the first flight instrument specially designed to focus solely on mapping Venus' surface using the windows around 1 µm. Operating in situ from Venus orbit, it will provide a global map of composition as well as redox state of the surface, enabling a comprehensive picture of surface-atmosphere interaction on Venus.



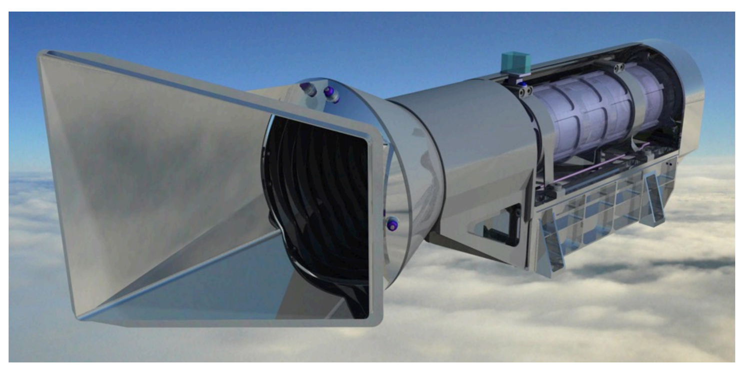
Müller et al. 2008, Helbert et al. 2008

The Venus Emissivity Mapper will return a complex data set containing surface, atmospheric, cloud, and scattering information. Total planned data volume for a typical mission scenario exceeds 1TB. Classical analysis techniques have been successfully used for VIRTIS on Venus Express and could be employed with the VEM data.

However, application of machine learning approaches to this rich dataset is vastly more efficient, as has already been confirmed with laboratory data. Binary classifiers demonstrate that at current best estimate errors, basalt spectra are confidently discriminated from basaltic andesites, andesites, and rhyolite/granite. Applying the approach of self-organizing maps to the increasingly large set of laboratory measurements allows searching for additional mineralogical indicators, especially including their temperature dependence.

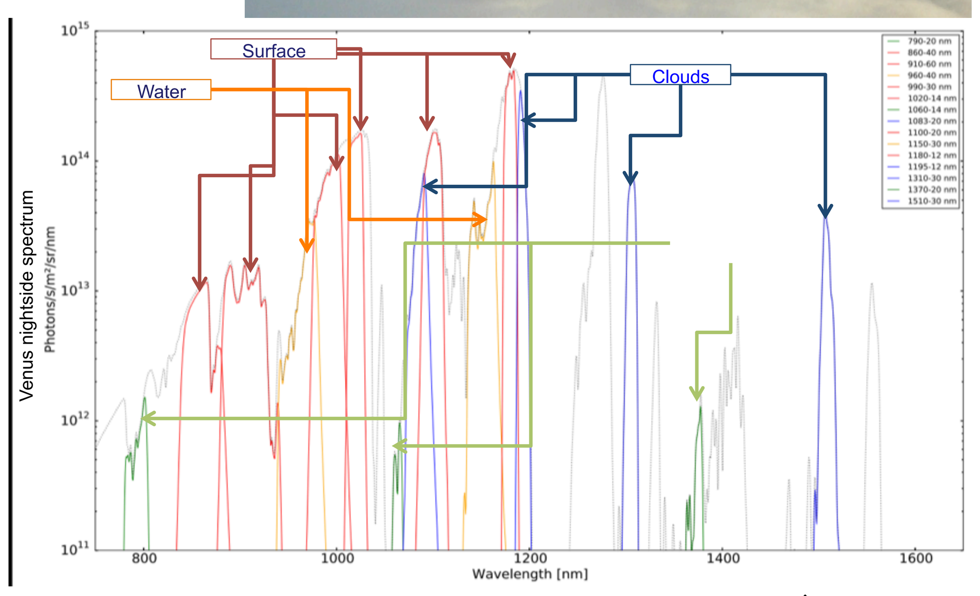
The Venus Emissivity Mapper

VEM leverages a proven measurement technique pioneered by VIRTIS on VEX and strong heritage from MERTIS

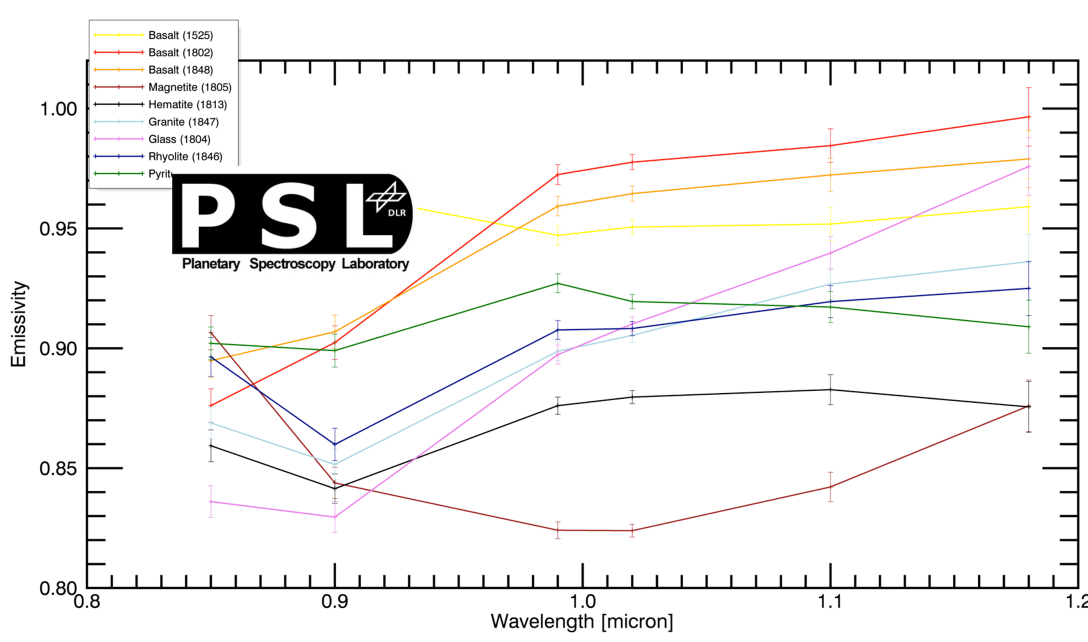


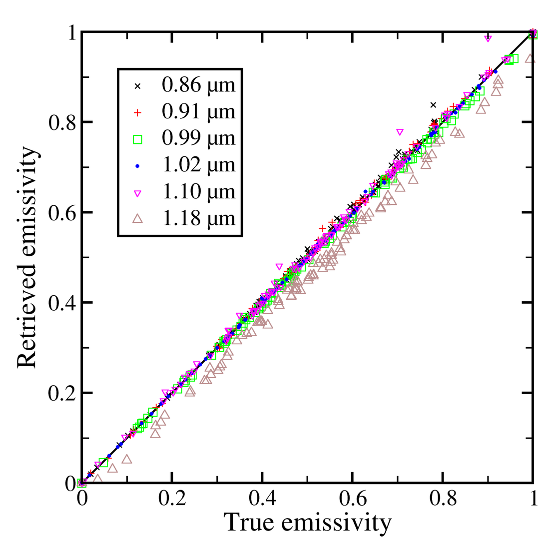
VEM will

- have greatly improved sensitivity and spectral and spatial coverage
- provide global surface composition and redox state of the surface
- address atmosphere-surface interaction, cloud dynamics and volcanic outgassing



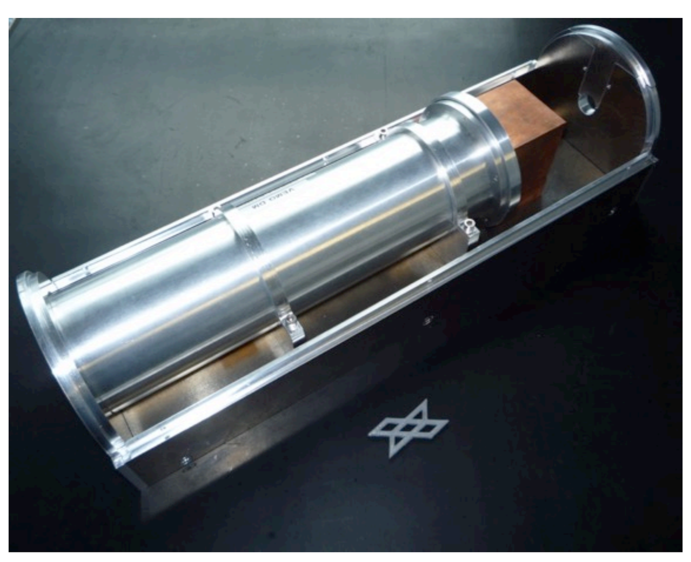
Emissivity with predicted uncertainties from system and atmospheric effects using a full RTM for VEM nominal observations shows the scientific potential





The detectability of pyrite provides a direct tracer for the chemical equilibrium at the surface: $3FeS_2 + 16\ CO_2 \rightleftharpoons Fe_3O_4 + 6SO_2 + 16CO$

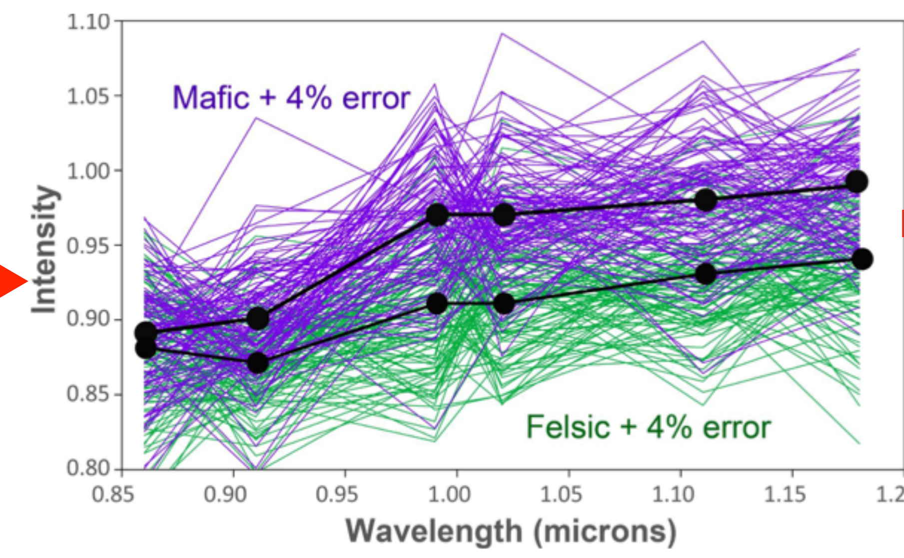
- **VenSpec-M is currently part of the EnVision ESA M5 study**
- **VEM is part of the NASA VERITAS Discovery proposal**
- **Development is ongoing**
- A VEM development model allows to conduct performance tests

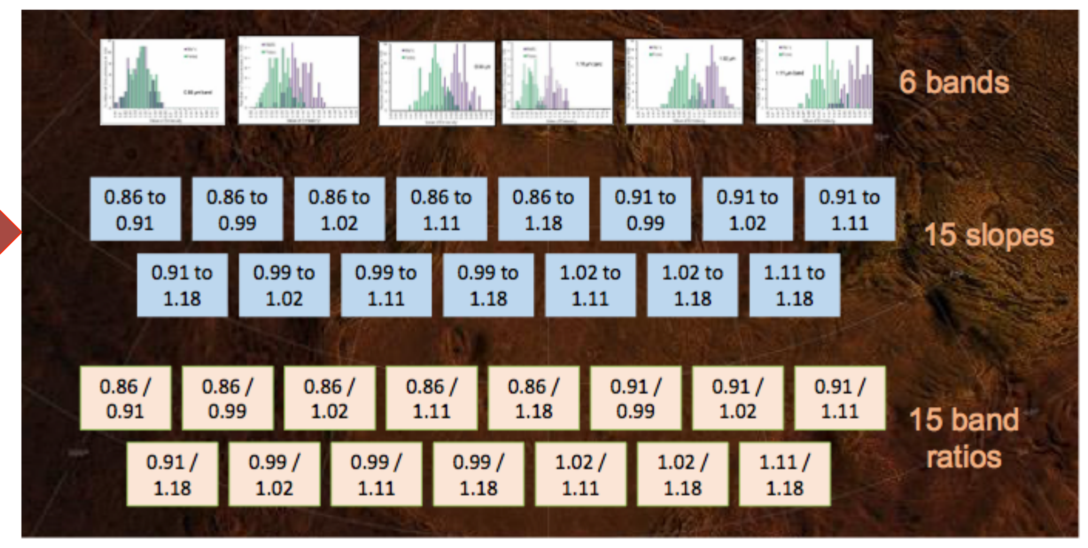


- Uncertainty from a single pixel measurement is <0.35%
- **This translates to a VEM SNR > 1000 for nominal operations incl. TDI and binning**

How well can we determine mineralogy of Venus from orbit?

VEM has an uncertainty of less than 4% based on full RTM, but lets assume the worst case of 4%

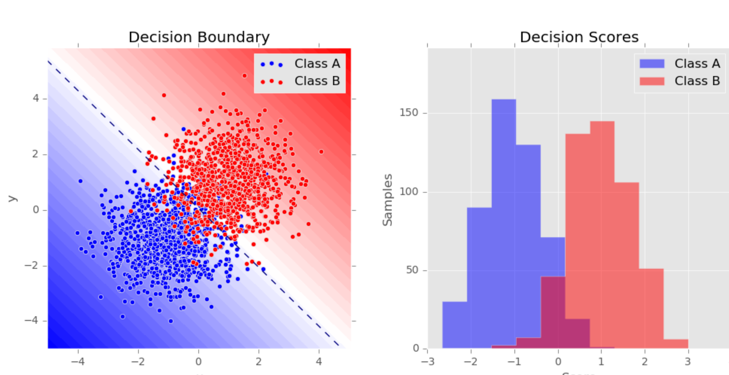




With a SINGLE SPECTRUM, we have 6 bands + 15 slopes + 15 band ratios (36 total, 21 independent)

Lets run a binary classifer to see how well we can do with these the orginal 6 representations and with the full 36 representations:

1.	Add 4% or CBE error to averaged lab spectra for felsic and mafic rocks at each of 6 wavelengths	6
2.	Parameterize other relationships in the data a. Slope between bands b. Band ratios	15+15
3.	Collect those 36 variables for each 200 model spectra	36 ×200
4.	Build binary classifier using 5-fold cross validation, repeated 100 randomized trials	



And the answer for our worst case scenario is better <u>than 90%:</u>

Distinguish felsic from mafic material	full 36 feature representation	original 6 channel representation
Accuracy	**93.1% ± 0.7%**	**90.0% ± 0.9%**
Precision	**93.9% ± 1.2%**	**90.3% ± 1.3%**

In reality we know already that VEM will do much better than 4% uncertainty – <u>allowing real mineralogy from orbit</u>

		CBE errors		4% errors (requirement)			
		6 components		36 components		6 components	
	ΔFeO content	Mean	Standard dev	Mean	Standard dev	Mean	Standard dev
Basalt and felsic	9.0	100	0	94.6	0.6	93.7	0.6
Basalt and dacite	6.75	100	0	88.5	0.9	86.4	0.9
Basalt and andesite	4.50	100	0	80.4	1.0	80.2	0.9
Basalt and basaltic andesite	2.24	100	0	65.4	1.2	60.1	1.3