EPSC Abstracts
Vol. 13, EPSC-DPS2019-1358-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Spectroscopy of the Surface of Venus – in the Laboratory and from Orbit

J. Helbert[1], M. D. Dyar[2,3], A. Maturilli[1], T. Widemann[4], E. Marcq[5], Y. Rosas-Ortiz[1], I. Walter[6], M. D'Amore[1], G. Alemanno[1], N. Müller[1], S. Smrekar[7], [1]Inst. for Planetary Research, DLR, Berlin, Germany (joern.helbert@dlr.de), [2] Planetary Science Institute, Tucson, AZ, USA, [3]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA USA, [4]LESIA, Observatoire de Paris, France [5]LATMOS, Université Paris-Saclay, France, [6]Institute for Optical Sensor Systems, DLR, Berlin, Germany, [7]Jet Propulsion Laboratory, Pasadena CA, USA.

Abstract

Interpretation of mineralogy using VNIR spectroscopy data from orbiters requires spectral libraries acquired under conditions matching those on the surfaces being studied. Recent advances in high-temperature laboratory spectroscopy at the Planetary Spectroscopy Laboratory at DLR provide the necessary data and enable novel instruments like the Venus Emissvity Mapper.

The instrument is currently on the payload of the ESA EnVision proposal as the VenSpec-M channel in the VenSpec spectrometer suite. It is also part of the VERITAS mission proposal for the NASA Discovery call.

Combining VEM with a high-resolution radar mapper will provide key insights into the divergent evolution of Venus and Earth. Flying VEM on more than one mission will enable a long timeline of monitoring for volcanic activity on Venus. Combined with the existing VenusExpress data [1-3], VEM enables detection and mapping of surface changes over decades.

1. Introduction

Many efforts have been made since Venera 9 and 10 [1] to obtain optical spectra of Venus analog materials at relevant temperatures. [2] provided a first set of reflectance measurements of basaltic materials in the spectral range of 0.4 to 0.8 µm. Since then, efforts to extend these measurements to longer wavelengths have stalled.

It was commonly accepted that compositional data could only be obtained by landed missions because Venus' permanent cloud cover prohibits observation of the surface with traditional imaging techniques over most of the visible spectral range. Fortuitously, Venus' CO_2 atmosphere is actually partly transparent in small spectral windows near 1 µm. These windows have been used to obtain limited spectra of Venus' surface by ground observers, during a flyby of the Galileo mission at Jupiter, and from the VMC and VIRTIS instruments on the ESA VenusExpress spacecraft. In particular, the latter observations have revealed compositional variations correlated with geological features [3-8].

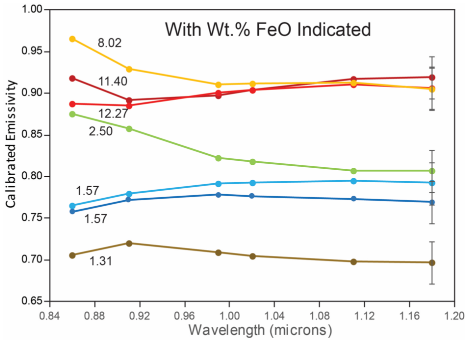

Figure 1: High temperature emissivity spectra of rock types covering some of the expecting range of surface compositions on Venus

These observations challenge the notion that landed missions are needed to obtain mineralogical information. However, any interpretation in terms of mineralogy of VNIR spectroscopy data from orbiters requires spectral libraries acquired under conditions matching those on the surfaces being studied.

2. Venus facility at PSL

The Planetary Spectroscopy Laboratory (PSL) at DLR took up this challenge, building on nearly a decade of experience in high temperature emission spectroscopy in the mid-infrared [9-11]. After several years of development and extensive testing, PSL is now in routine operation for Venus-analog emissivity measurements from 0.7 to 1.5 µm, the whole surface temperature range.

PSL has begun a database of Venus analog spectra including measurements of rock and mineral samples covering a range from felsic to mafic rock and mineral samples [12]. This first set already shows the potential for mapping of Venus mineralogy and chemistry *in situ* from orbit with six-window VNIR spectroscopy [13-15].

The Venus facility at PSL is open to the community through the Europlanet Research Infrastructure (http://www.europlanet-2020-ri.eu/).

3. Venus Emissivity Mapper (VEM)

This instrument can provide a global map of rock type from orbit, assessing iron contents and the redox state of the surface by observing the surface with six narrow band filters, ranging from 0.86 to 1.18 µm. Three additional windows allow corrections for cloud composition and variability, two measure water abundance, and three compensate for stray light. Continuous observation of Venus' thermal emission will also place tighter constraints on current volcanic activity. Eight channels provide measurements of atmospheric water vapor abundance as well as cloud microphysics and dynamics, permitting accurate correction of atmospheric interference on surface data.

4. VEM Design

The VEM system design, discussed in details in [4-6], is a pushbroom multispectral imaging system. It leverages a proven measurement technique pioneered by VIRTIS on Venus Express (VEX) [1-3, 7-11]. It also incorporates lessons learned from VIRTIS to achieve greatly improved sensitivity and spectral and spatial coverage:

- A filter array (rather than a grating) provides wavelength stability (band-center and width-scatter) ~5× more stable and maximizes signal to the focal-plane array (FPA).
- Spectral windows below 1µm are covered for the first time.
- A two-stage baffle decreases scattered light and improves sensitivity.
- Use of an InGaAs detector with an integrated thermal electric cooler (TEC) eliminates the need for cryogenic cooling.

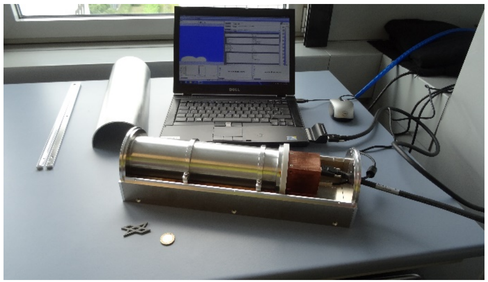

Figure 2 VEM laboratory prototype incl. COTS version of flight detector, optics with radiation hard lenses and prototype filter array (top cover removed for display)

VEM design draws on DLR's BepiColombo MERTIS instrument (launched and successfully commissioned in 2018). With this design maturity, combined with a standard camera optical design, development risk is low.

Methodology for retrieving surface emissivity is complex but well understood and demonstrated. To distinguish between surface and atmospheric contributions, VEM uses an updated version of the extensively tested pipeline developed to process VIRTIS data [2], combined with a radiative transfer model (RTM) [12-15]. Surface emissivity retrieval techniques were developed based on Galileo NIMS observations at 1700, 1800 and 2300 nm [16]. VEM cloud bands occur at 1195, 1310, and 1510 nm [17], the first on the flank of the 1180-nm surface windows [18]. VEM's cloud bands are close to surface bands, providing near-optimal correction. Only relative emissivity measurements are needed to calculate the spectral slope to meet our surface emissivity requirements [4]. We do not have a requirement on the accuracy of the retrieved emissivity. However, we can now tie an emissivity retrieval to in situ measurements to assess accuracy. For this comparison, the Venera 9 and 10 landing sites [19] (not observed by VIRTIS) will be observed by VEM both on EnVision and on VERITAS.

VEM observes each spot on the surface multiple times. Therefore both atmospheric and instrument noise are reduced by averaging image swaths acquired at different times. Applying the updated analysis of atmospheric error for VEM parameters [14] and taking multiple-look averaging into account, our capability for emissivity precision is better than 1.5% for all bands and better than 1% in most bands.

5. Conclusions

Venus is the only terrestrial planet for which we do not have a global map of the surface compostion. The Venus Emissvity Mapper will provide this much needed dataset, yielding new insights in comparative planetology of terrestrial planets in our solar system and beyond.

Acknowledgments: Europlanet 2020 RI has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654208.

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