The Venus Emissivity Mapper – Obtaining Global Mineralogy of Venus from Orbit on the ESA EnVision and NASA VERITAS missions to Venus. J. Helbert[1], D. Dyar[2], I. Walter[1], D. Wendler[1], T. Widemann[3], E. Marcq[4], G. Guignan[4], A. Maturilli[1], I. Varatharajan[1], S. Ferrari[5], N. Mueller[1], D. Kappel[1], M. D'Amore[1], A. Boerner[1], C. Tsang[6], G. E. Arnold[1], S. Smrekar[7], R. Ghail[8]; [1]DLR (Germany); [2]Mount Holyoke College and Planetary Science Institute (USA); [3]LESIA (France); [4]LATMOS (France); [5]Univ. degli Studi di Pavia (Italy); [6]Southwest Research Institute (USA); [7]Jet Propulsion Laboratory (USA); [8]Imperial College (UK).

Introduction: The Venus Emissivity Mapper is the first flight instrument designed to focus on mapping the surface of Venus using several atmospheric windows around 1 µm. After years of development, VEM now has a mature design. An existing laboratory prototype has verified an achievable instrument SNR of well above 1000, as well as predicted error in retrieval of relative emissivity of better than 1%, assuming the availability of improved Venus topography.

VEM science goals: The instrument will 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 the surface data.

The instrument is currently part of the payload suite of the ESA EnVision proposal as the VenSpec-M channel in the VenSpec spectrometer suite. It is also part of the NASA 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.

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.

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

VEM prototyping: VEM has been under development for several years with significantly financial investment from DLR. Part of this development was the Phase A study for the NASA Discovery proposal VERITAS in 2016 and the currently ongoing Phase A study for the ESA M5 proposal EnVision.

Following creation of the first breadboard model in 2015 during Phase A for the NASA Discovery proposal VERITAS, a laboratory prototype (LP) of the VEM instrument has been developed [6]. This prototype (Figure 1) includes the development version of the VEM optics with a filter array with two active filter strips. The optics underwent a set of calibration measurements on sub-unit level at LATMOS prior to delivery to DLR. All key optical design parameters including transmission and wavelength coverage have been verified using the VEMO prototype.

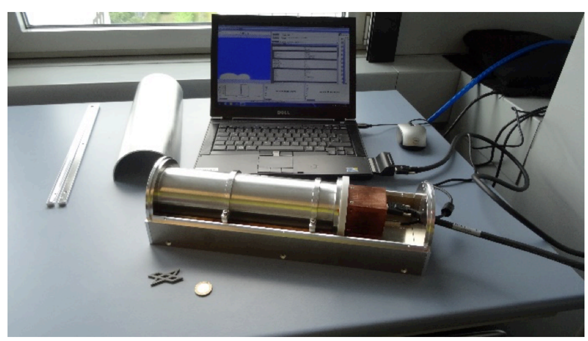

Figure 1. VEM laboratory prototype incl. COTS version of flight detector, optics with radiation hard lenses and simplified filter array (Figure 2) (top cover removed for display)

For the laboratory prototype filter array (Figure 2), the substrate is fused silica and the deposition materials are Ta_2O_5 and SiO_2. The DMC (dark mirror coating / mask) is Cr + SiO_2. The same materials are used for

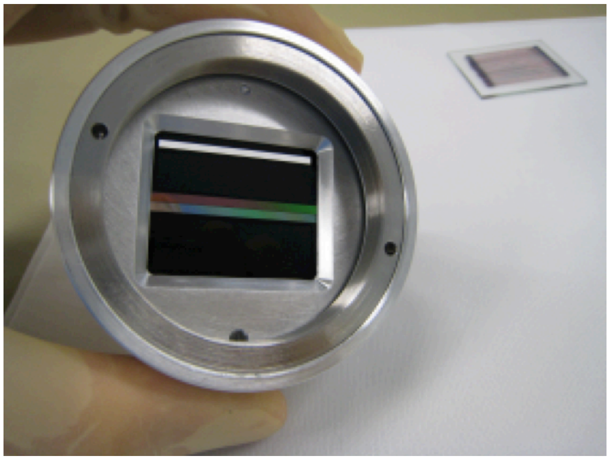

Figure 2. Filter array in the VEM laboratory prototype with 2 out of the 14 filter strips used in the flight model.

the FM units with the possible addition of Si for a few of the bands. All are materials that Materion routinely uses for space based optics. To reduce manufacturing time due to the time constraint in the Discovery Phase A study, the laboratory prototype has only 2 of the 14 filter strips in the flight array, as well as a clear area in the dimensions of a filter strip. However, the two filter strips have the same dimensions and spacing as in the flight array. This allows verification of the manufacturing process as well as testing of cross talk between adjacent filter strips. The clear area allows for a rapid verification of the performance of the whole optical system.

A first performance evaluation of the VEM prototype used two Venus analog samples heated to Venus surface temperatures. This was performed using the Venus simulations setup at the Planetary Spectroscopy Laboratory with the prototype mounted on the chamber [6, 12]. The retrieved emissivities match laboratory values, and uncertainty for a single unbinned exposure is <0.35%. VEM uses onboard software developed for MERTIS to bin, co-add, and losslessly compress data upon uplink command. During science orbits, VEM oversamples at 10 km spatial resolution (33×33 pixel binning). To further enhance SNR, VEM uses digitial TDI to provide 189× gain over single-pixel SNR. Based upon current performance of the laboratory prototype for a single unbinned exposure and SNR enhancement due to onboard processing, we expect a system SNR of well beyond 1000.

VEM atmospheric correction: 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) [13-16]. Surface emissivity retrieval techniques were developed based on Galileo NIMS observations at 1700, 1800 and 2300 nm [17]. VEM cloud bands occur at 1195, 1310, and 1510 nm [18], the first on the flank of the 1180-nm surface windows [19]. 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 [20] (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 [15] 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.

Conclusion: VEM builds on recent advances in the laboratory analog spectroscopy at PSL at DLR [4, 21]. It is the first flight instrument designed to focus on mapping the surface of Venus using atmospheric windows around 1 µm. VEM has a mature design with an existing laboratory prototype that verifies an achievable instrument SNR of >1000, as well as a predicted error in the retrieval of relative emissivity of better than 1%.

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