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The Venus Emissivity Mapper Concept

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ABSTRACT

The Venus Emissivity Mapper (VEM) is the first flight instrument specially designed with a sole focus on mapping the surface of Venus using the narrow atmospheric windows around 1μm. VEM will provide a global map of surface composition as well as redox state of the surface, providing a comprehensive picture of surface-atmosphere interaction on Venus. In addition, continuous observation of the thermal emission of the Venus will provide tight constraints on current day volcanic activity. These capabilities are complemented by measurements of atmospheric water vapor abundance as well as cloud microphysics and dynamic. Atmospheric data will allow for the accurate correction of atmospheric interference on the surface measurements and represent highly valuable science on their own. A mission combining VEM with a high-resolution radar mapper such as the NASA VOX or the ESA EnVision mission proposals in a low circular orbit will provide key insights in the divergent evolution of Venus.

Keywords: Venus, near infrared, spectroscopy

1. INTRODUCTION

The permanent cloud cover of Venus prohibits observations of the surface with traditional imaging techniques over much of the EM spectral range. Therefore it was once thought that information about the composition surface of Venus could only be derived from lander missions. Given the harsh environmental conditions on the surface, any type of landed mission will have high complexity and therefore a higher associated risk than orbiting missions. In addition, mission concepts for Venus landers typically focus on one landing site instead of a global reconnaissance, forcing difficult choices to be made between different types of surface units.

The mapping of the southern hemisphere of Venus with VIRTIS instrument on Venus Express using the 1.02μm thermal emission band can be viewed as a proof-of-concept for an orbital remote sensing approach to surface composition and weathering studies for Venus [1-6]. Recent advances in high-temperature laboratory spectroscopy at the Planetary Spectroscopy Laboratory at DLR show that the five atmospheric windows in the CO_2 clouds of the Venus atmosphere, ranging from 0.86μm to 1.18μm, are highly diagnostic for surface mineralogy.

The Venus Emissivity Mapper [7] proposed for the NASA's Venus Origins Explorer (VOX) and the ESA EnVision proposal builds on these recent advances. It is the first flight instrument specially designed with a sole focus on mapping the surface of Venus using the narrow atmospheric windows around 1μm. By observing with six bands, VEM will provide a global map of surface composition as well as redox state of the surface. Continuous observation of Venus' thermal emission will also provide tight constraints on current day volcanic activity [3, 8]. Measurements of atmospheric water vapor abundance as well as cloud microphysics and dynamics will permit accurate correction of atmospheric interference on the surface measurements. A mission combining VEM with a high-resolution radar mapper such as VOX or EnVision in a low circular orbit will provide key insights in the divergent evolution of Venus.

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2. THE VEM CONCEPT

2.1 System design

VEM consists of three units mounted together in a mono-block structure to allow for simplified SC interfaces: VEM-Camera including optics and detector, VEM-Baffle functionally dedicated to the camera including the transparent window unit, and VEM-electronics, including PCB's for power supply and instrument control and internal harness. The electronics box is the mechanical base of the instrument, providing interfaces to VEM-Camera and VEM-Baffle.

The three units are also the main thermal subunits of the VEM supported by spacecraft interfaces according to their requirements. One thermal reference point (TRP) is the instrument mounting plate, which handles the electronics thermal control in an appropriate operating range with heater maintenance as needed. It also connects the optics/detector section via thermal strap to a stabilized spacecraft interface, which is the second TRP. Thermal interference of the both units is controlled by the optics mounting elements to the electronics unit. The unit with the least stringent temperature requirement is the VEM-Baffle, mounted with thermal isolation to the instrument to mitigate environmental interactions of this unit.

The VEM system design was discussed in detailed in [7], so only a top-level summary is provided here. VEM is a pushbroom multispectral imaging system. The VEMO telecentric optics image the scene onto a filter array, and the image is relayed by a three-lense objective onto the detector. VEM's optical sub-system (VEMO) sits on top of the electronics compartment, which includes the Instrument Controller (VEMIC) and the power supply (VEMPS). A two-stage baffle (VEMBA) protects VEM from scattered light. A 45° FOV yields a swath width of 207 km at an altitude of 250 km, providing a thorough sampling of surface emissivity and orbit-orbit repeat coverage.

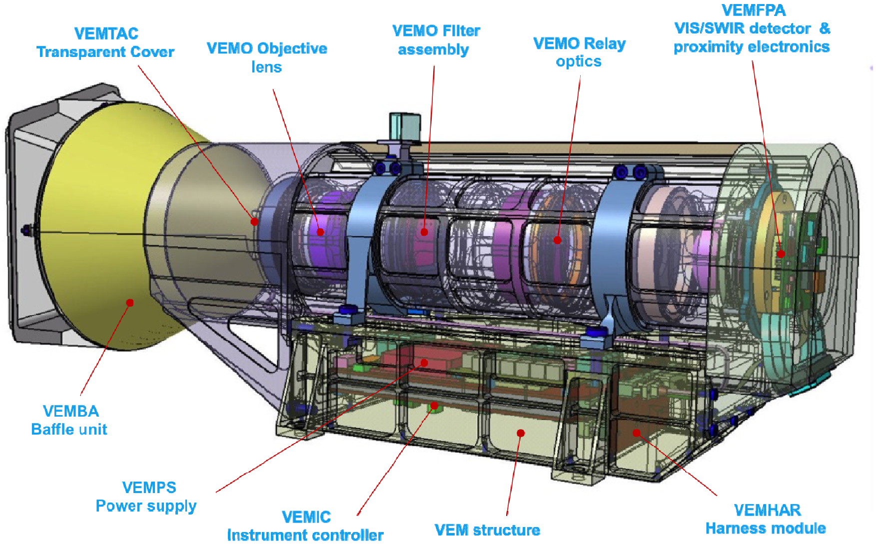

Figure 1. VEM design with strong design heritage from the MERTIS instrument on BepiColombo.

VEM uses a multilayered dielectric-coating ultra-narrow-band filter array to split the light into 14 bands. The filter array is located at an intermediary focus of the optical path. Each band is imaged by a two lenses relay optic onto 33×640-pixel rows on the FPA. Surface mineralogy bands are spatially interleaved between cloud bands to provide before and after calibration.

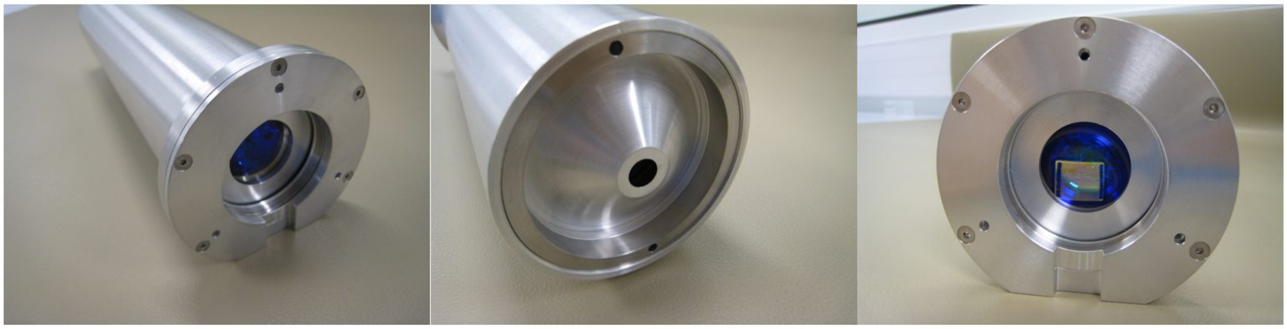

Figure 2. Optics for the Laboratory prototype of VEM.

During the study phase for the NASA Discovery proposal VERITAS, a full VEMO prototype (Figure 2) was built. Lenses in the laboratory prototype optics were fabricated with the radiation-resistant Schott K5G20 radiation resistant glass planned for the flight optics. For the laboratory prototype filter array, the substrate is fused silica and the deposition materials are Ta_2O_5 and SiO_2. The DMC (dark mirror coating / mask) was Cr + SiO_2. The same materials are planned to be used for 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. Instead of the full 14 filter strips, the laboratory prototype (Figure 3) has only 2 filter strips and a clear area, each of them with the same dimension as for the final flight array.

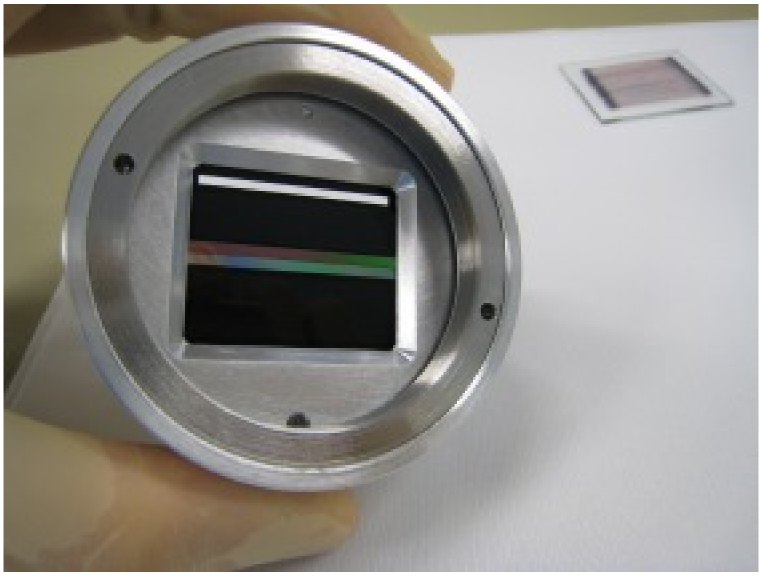

Figure 3. Filter array in the VEM laboratory prototype with 2 out of the 14 filter strips used in the flight model.

The core element of the focal plane array VEMFPA is the 640×512 pixel Xenics XSW-640 InGaAs detector. The FOV is 30°×45º; each 20-μm-pitch pixel sees a 0.07°×0.07º FOV. An integrated thermo-electric cooler is used to stabilize the working point of the detector. The FPA requires no cryogenic cooling, avoiding a single point failure. The same detector is currently successfully operating in the ACS instrument on the ESA ExoMars Trace Gas Orbiter [9]. The frontend electronics use the highly integrated AFE device LM98640QML-SP, a full qualified (radiation tolerant), 14 bit, 5 MSPS to 40 MSPS, dual channel, complete Analog Front End. It was specially designed for digital imaging applications by Texas Instruments.

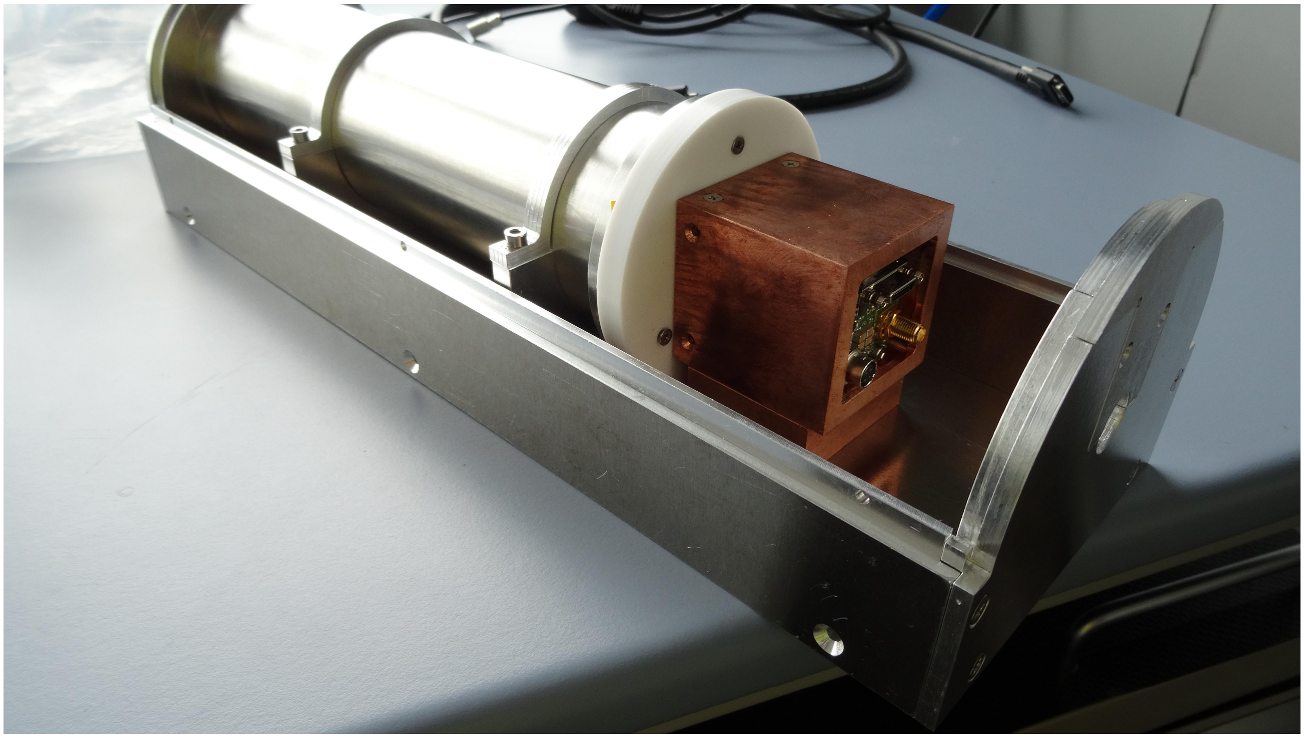

Figure 4. Commercial version of the Xenics XSW-640 InGaAs detector mounted in the VEM laboratory prototype.

The ICU (VEMIC) provides the electrical interface to the spacecraft and internal units, processes the detector data, performs binning, digital TDI and compression, and controls the sub-systems including digital and analog housekeeping electronics for acquiring VEM scientific and operational HKs. The ICU consists of one ACTEL FPGA including LEON-FT processor core, 128 Mbyte SDRAM and 2 MByte EEPROM. Baseline for VEMIC is the MERTIS instrument control unit (ICU) [10]. The design of the Power Supply Unit (VEMPS) is determined by the power requirements of VEMFPA and VEMIC. Baseline for VEMPS is to use the heritage of electrical and mechanical design of the proven MERTIS power supply unit (PSU). This PSU uses mainly a DC/DC converter from Interpoint's SMRT family, expanded by external LC-filters and a special circuit for supporting the TEC on the VEMFPA. Figure 5 shows the stacked MERTIS ICU and PSU and the resemblance to the VEM configuration (Figure 1).

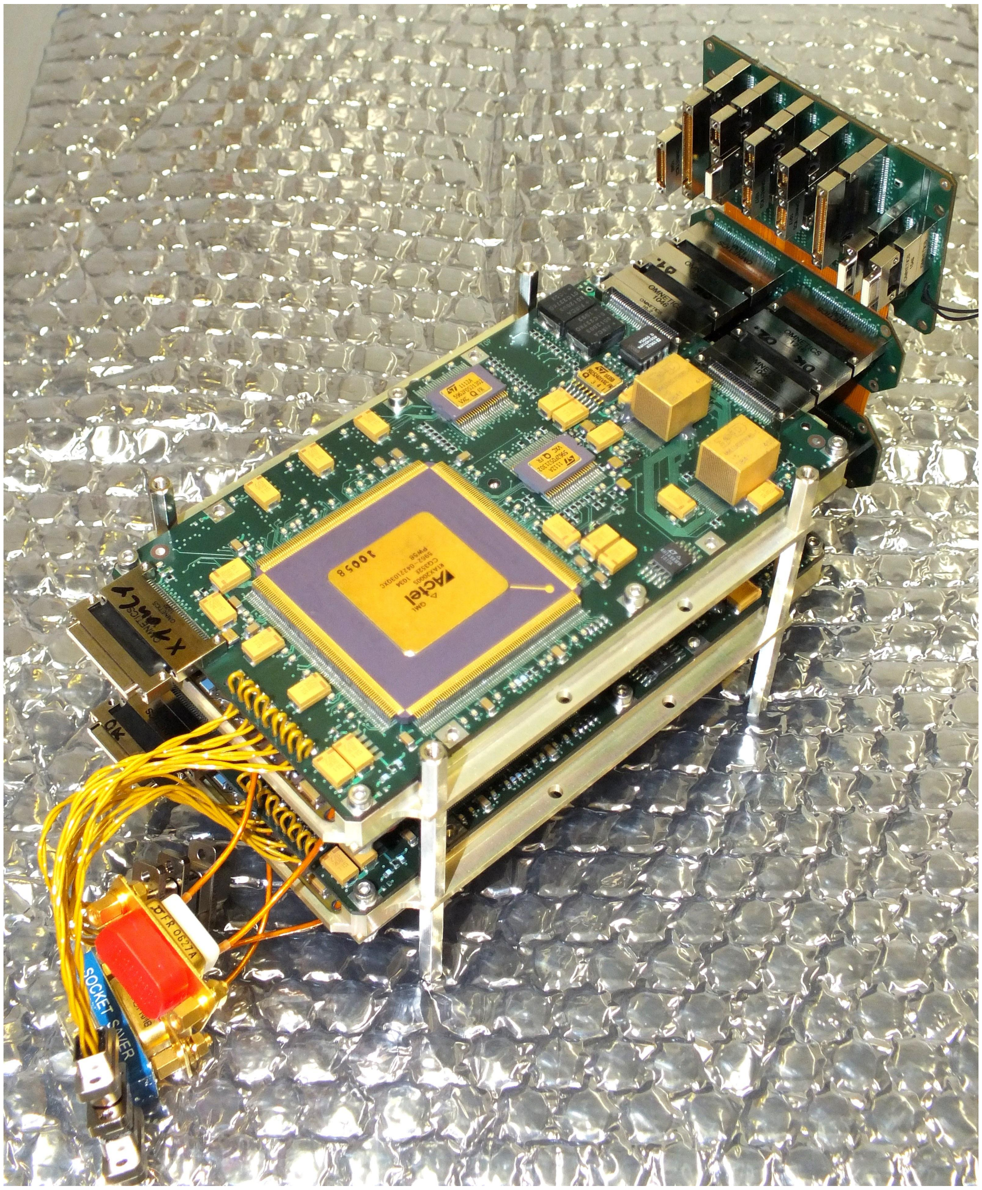

Figure 5. MERTIS instrument controller and power supply.

VEM minimizes the influence of stray light through two approaches. The first step is to physically reduce the amount of stray light entering the instrument aperture. VEMBA is a two-stage baffle with a light-weight front part that is mostly screening the S/C but might get sun (aluminum, white ceramic coating, high temperature range) and a back part suppressing stray-light (3D selective laser melting of $TiAl_6V_4$ – multiple black vanes, outside gold). The inner baffle is a multi-vane structure. Its baffle design exploits the arrangement as well as the number of the vanes, resulting in multiple internal reflection of out-of-field light [11]. The absorptive coating supports the function of the baffle. For the first iteration of the VEM baffle, 12 vanes were used to enhance the effectiveness of the baffle independent of the applied coating. That effect could be seen on the uncoated baffle shown at the site visit for VERITAS (as well as in the picture in Figure 6). The electrolytic oxide Kepla-coat surface processing results in a degree of absorption greater than 95%. The combination of the multi-vane structure and absorptive coating provides a significant margin to the required absorption of 80%.

The second step to minimize stray light is to remove residual stray during data processing using dedicated filter channels. A full stray light analysis and a stray light test with a fully assembled and coated baffle are planned for a Phase B of VOX as part of the functional performance test on the engineering prototype.

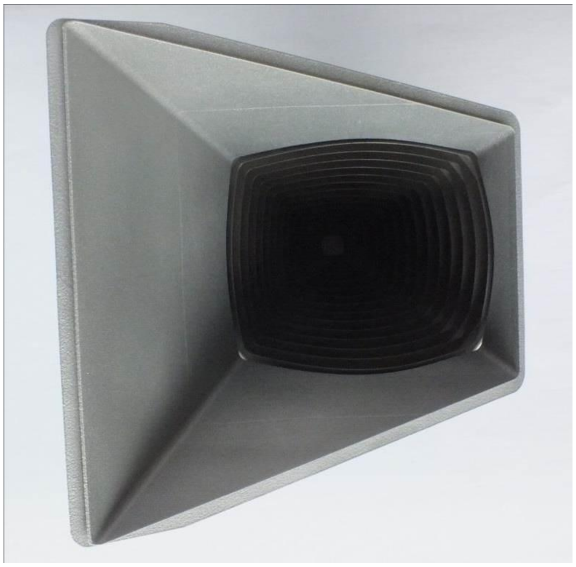

Figure 6. View into the VEM-Baffle, pre-manufactured without any absorbing or reflective coatings, shows the efficiency of the multi-vane design.

An optional transparent aperture cover (VEMTAC) using fused silica protects the optics in cruise. Observations can be performed through the window. In the case of contamination on the window, it may be opened useing a spring-loaded one-shot mechanism.

2.2 VEM development status

Following creation of the first breadboard model during the Phase A for the NASA Discovery proposal VERITAS, a laboratory prototype (LP) of the VEM instrument has been integrated (Figure 8). This prototype includes the development version of the VEM optics (Figure 2) 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 (

Figure 7).

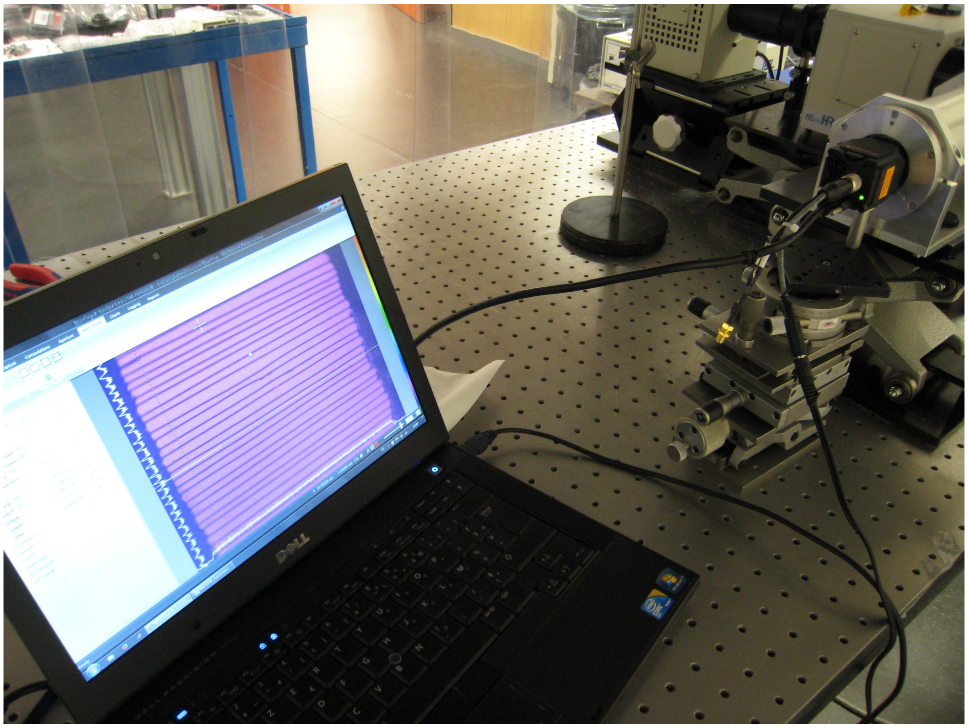

Figure 7. Verification of the VEM optics in the calibration facility at LATMOS.

The detector used is the commercial version of the flight detector (Figure 3) and off-the-shelf front-end electronics are used with a laptop as electrical ground support equipment (EGSE). Form and function are already representative of the top part of the VEM flight instrument. The LP has been integrated and passed functional verification in July of 2016.

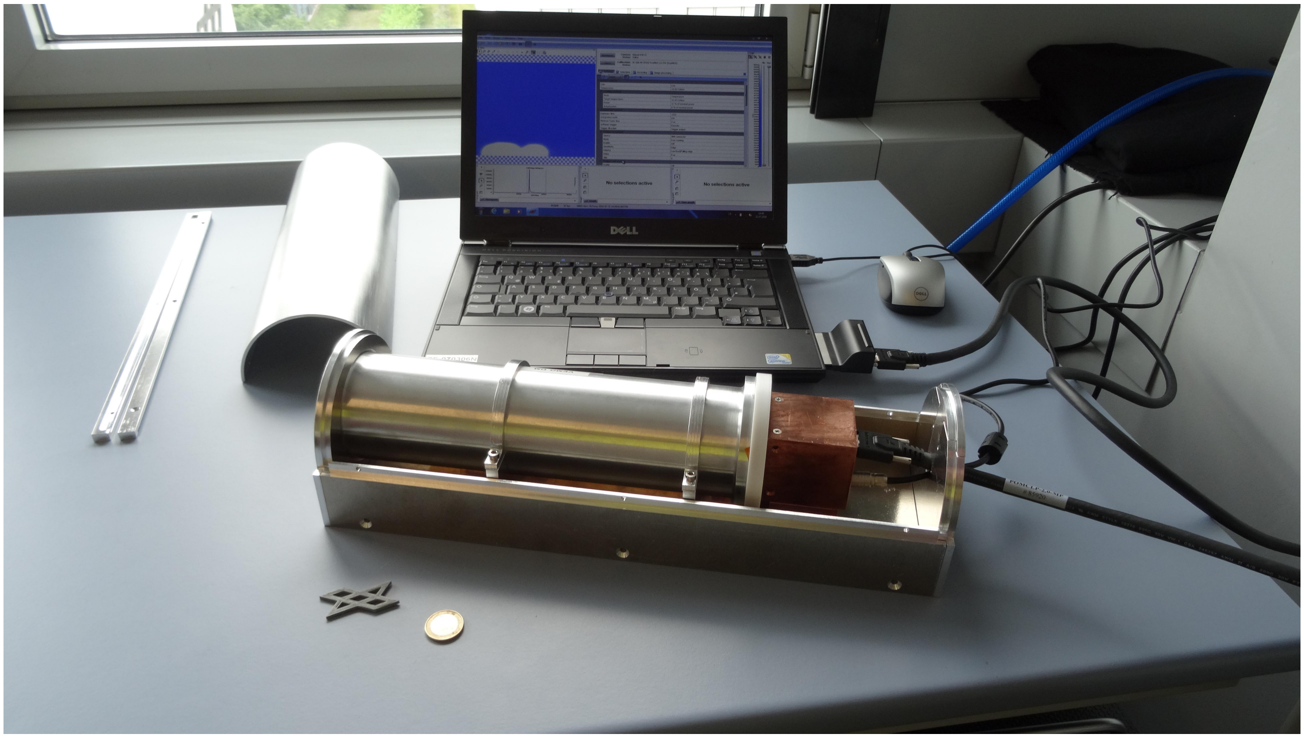

Figure 8. VEM laboratory prototype (LP) after integration with top cover removed.

The laboratory prototype has been used since then for limited design and performance verifications. Calibration measurements have been performed on the optics, along with functional verifications on the integrated system.

After the assembly and first test phase, the LP now resides in the DLR Planetary Spectroscopy Laboratory (PSL). The PSL can heat minerals to Venus surface temperatures and measure the emissivity in the spectral range from 0.7-1.5µm. Details of the set-up in PSL as well as the configuration for the VEM LP calibration measurements are discussed in detail in [7]. A newly developed ceramic sample cup was used to measure granular samples. A first performance evaluation of the VEM LP was performed using two Venus analog samples heated to Venus surface temperatures. A simple ratio algorithm was used to derive emissivity.

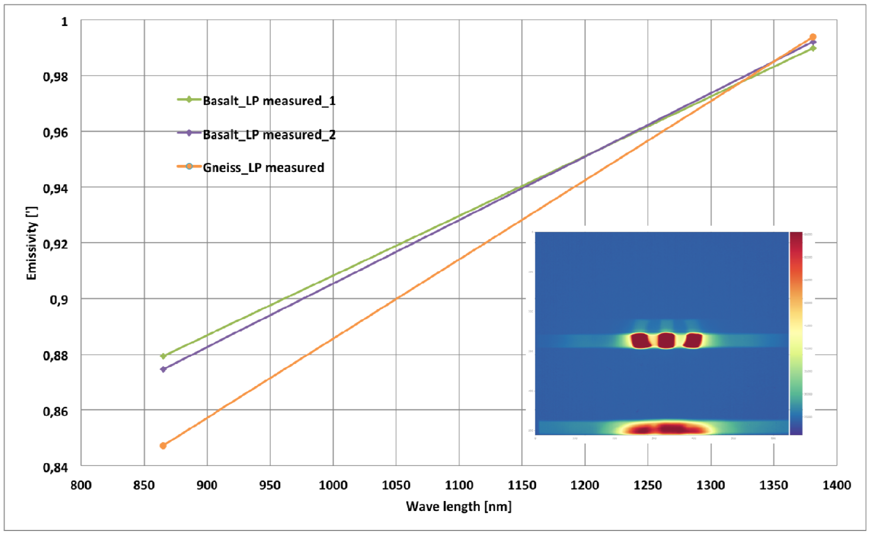

Figure 9. Example of calibration measurements with VEM laboratory prototype for 2 basalt samples and a granitic Gneiss sample - inset shows the raw image.

The retrieved emissivities match the laboratory values and the error from a single exposure is less than 0.35%.

2.3 VEM predicted performance

Scattering at the cloud particles limits the achievable spatial resolution at the surface to approx. 45km [12, 13]. The VEM optical system has a theoretical on-ground resolution of 300m from a 250km orbit. Using digital TDI, the data are reprocessed in the instrument at a spatial resolution of 1km, providing a significant gain in signal-to-noise ratio (SNR). Due to the low orbit required for the radar both on the NASA VOX and the ESA EnVision mission, the wide field of view of the VEM instrument allows every spot on the surface to be viewed between 5 and 10 times in consecutive orbits. This allows short-term variability in the atmosphere of Venus to be accounted for. To distinguish between surface and atmospheric contributions, VEM uses an updated version of the extensively tested data pipeline developed to process VIRTIS surface data [1], combined with a radiative transfer model (RTM) [14-17]. Data are processed at 10km spatial resolution and the data from consecutive orbits are stacked. Both provide an additional increase in the SNR.

Of VEM's 14 bands, six see the surface through all Venus atmospheric windows; three compensate for stray light; three measure cloud transparency; and two measure water abundance. The water vapor and cloud opacity channels are used as RTM inputs to constrain near-surface water vapor abundance and cloud particle distributions. Water concentrations at 1.16 μm have sufficient accuracy and precision to enable a search for active volcanic outgassing. Multiple observations over the duration of the mission are used to account for additional unknown atmospheric variability not accounted for in the RTM. This reduces both atmospheric and instrument noise by averaging image swaths acquired at different times. Applying the Kappel et al. (2016) [16] updated analysis of atmospheric error for VEM parameters, and taking multiple look averaging into account, our capability for emissivity precision is between 0.3 and 1.2%.

3. OUTLOOK

VEM leverages a proven measurement technique pioneered by VIRTIS on Venus Express (VEX) [1-6, 8, 18], but with greatly improved sensitivity and spectral and spatial coverage. VEM is optimized to map

Venus' surface composition using six spectral bands in five atmospheric windows, and incorporates lessons learned from VIRTIS. Band-center and width-scatter are ~5× more stable, a two-stage baffle decreases scattered light and improves sensitivity, a filter array (rather than a grating) provides wavelength stability and maximizes signal to the focal-plane array (FPA), and the use of an InGaAs detector with an integrated thermal electric cooler (TEC) eliminates the need for cryogenic cooling. VEM's design draws strongly on DLR's BepiColombo MERTIS instrument (scheduled for launch in 2018). This design maturity, combined with a standard camera optical design, leads to low development risk.

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