

Spectral Mixing Analysis of Laboratory Emissivity Spectra for Improved VenSpec-M/VEM Data Interpretation

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ABSTRACT

The Planetary Spectroscopy Laboratory (PSL) in the Department of Planetary Laboratories (PLL), German Aerospace Center (DLR) in Berlin is working on a database that will encompass a wide range of spectral measurements, studying different effects such as grain sizes, temperature, mixing and weathering. Our goal is to create a database large enough to address the diverse range of spectral characteristics that might be observed on planetary surfaces, thereby enhancing our capabilities to interpret orbital data coming from their surfaces. A part of this database is an extensive spectral library to interpret and validate data from the Venus Emissivity Mapper (VenSpec-M/VEM) of the ESA EnVision and NASA VERITAS missions. VenSpec-M/VEM will remotely collect data about the surface of Venus in the Near-InfraRed (NIR) spectral range, covering five spectral windows in the Venus atmosphere between 0.85 and 1.18 μm , to map rock types and study Venus surface composition and activity, by comparing orbital data with laboratory spectra. Here we present the first results of a study aimed at understanding the NIR spectral behavior of particulate mixtures in emissivity at Venus surface temperature varying the grain size of the components and the actual physical distribution of particles in the mixture. Spectra are acquired using a high-temperature emissivity setup coupled with a Bruker FTIR 80V spectrometer to measure NIR emissivity spectra of Venus analogs at relevant Venus surface temperatures in a vacuum environment. Detailed image analyses are performed using a Digital Microscope Keyence VHX-7000 to ensure precise mixing ratios and quantify modal mineralogy. Results show that linear mixing does not reproduce laboratory emissivity spectral behavior accurately in this wavelength range, leading to the future exploration of non-linear mixing approaches. This data provides important insight on the need for Machine Learning models as they are planned for the VEM and VenSpec-M data analysis and will be invaluable to train those algorithms. Furthermore, the datasets can help in the planning of instrumentation for future aerial and lander missions exploring the surface of Venus.

Keywords: VenSpec-M, VEM, EnVision, VERITAS, Venus surface, near-infrared spectroscopy

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1. INTRODUCTION

Understanding the spectral characteristics of planetary surfaces is crucial for interpreting remote sensing data and advancing our knowledge of planetary composition, activity and evolution. The Planetary Laboratories Department (PLL) at the German Aerospace Center (DLR) in Berlin plays a crucial role in this pursuit, particularly through its efforts in supporting instrument development, calibration, and data analysis for several planetary missions [1]. Among the planetary objects that are a focus of study at PLL is our neighbor planet, Venus. PLL is working together with The Optical Sensor System (OS) department of DLR on the development and calibration of the Venus Emissivity Mapper (VEM/VenSpec-M) of the NASA VERITAS and ESA EnVision missions. Venus, similar to Earth in mass and size among terrestrial planets, remains enigmatic regarding its surface composition due to a persistent cloud cover. The VEM/VenSpec-M instrument aims to collect near-infrared (NIR) spectra of Venus' surface, using spectral filters that cover five spectral windows around 1 μm in the Venus' atmosphere thus aiming to unveil and map the Venus' surface composition and study the planet activity and evolution. Accurate interpretation of these remote sensing data necessitates a comprehensive spectral library of emissivity spectra, along with a deeper understanding of NIR emissivity spectroscopy. It is crucial to investigate the impacts of particle size, mixing and weathering under Venusian atmospheric conditions on emissivity. The Planetary Spectroscopy Laboratory (PSL) of PLL is dedicated to building an extensive spectral library for the interpretation and validation of VEM/VenSpec-M data [2] and to exploring the fundamental properties of mineral mixtures in high-temperature emissivity spectra. To the latter point, this study focuses on investigating the spectral behavior of laboratory-simulated mixtures under Venus surface temperature conditions in the NIR spectral range. These mixtures are created to showcase the effects of non-linear mixing in the NIR and to investigate the comparison of intimate versus areal mixtures spectral behavior in emissivity. For this purpose, as the starting point of our analysis we created 50:50 mixtures. Although the large percentages in the analyzed mixtures (see **Section 2**) are unrealistic as analogs for the current expected percentages on the Venus surface, they are intended as a starting point for our analysis to understand the areal versus mixing emissivity behavior. We will subsequently adjust these percentages to reflect more accurately those likely to be observed on Venus.

The spectral behavior of mixtures of particulate materials is a crucial aspect in the study of planetary surfaces. Planetary surface materials include minerals, amorphous material, and volcanic and impact glasses in complex mixtures that require detailed spectral analysis to be accurately interpreted. Understanding how these mixtures behave spectrally, influenced by the characteristics of individual components, is essential for deciphering observational data from planetary missions. Moreover, in the case of Venus and in general of hot planetary surfaces, the effect of high-temperature needs to be considered. Although nonlinear and linear mixing properties of visible-near-infrared (VNIR) reflectance spectra are being extensively studied at room temperature for other bodies in the Solar System, the mixing properties of high-temperature emissivity spectra remain unclear and largely untested. Specifically, NIR emissivity spectra at 440°C are crucial for interpreting remote-sensing data from Venus. The dense CO₂-rich cloud cover of Venus allows observations only within a narrow wavelength around 1 μm .

Venus surface temperature conditions are replicated at PSL using a specialized high-temperature emissivity setup within a controlled vacuum environment [1, 2]. This setup allows for the precise

measurement of NIR emissivity of Venus-analog materials at temperatures up to 480°C, covering those found on the Venus surface. Hemispherical reflectance measurements on fresh and post-heated samples are also acquired, along with detailed sample image analysis using advanced digital microscopy, ensuring accurate characterization of sample compositions and mixing ratios. By selecting pure end-member samples with diverse spectral features and mixing them, we simulate various mixtures of basalts with alteration phases resulting from interactions with the Venus atmosphere (hematite) and more localized hypothetical interactions with SO₂ from active volcanism and the mixing of basaltic glass with phenocryst minerals.

Critical to this investigation is the evaluation of unmixing models for NIR emissivity spectra, aimed at improving our understanding of this spectral region and the areal versus intimate mixtures behavior. As expected from previous room-temperature measurements and the well-developed theory for unmixing in this nonlinear spectral range, we observed that linear mixing models do not accurately reproduce laboratory emissivity spectra, prompting the future exploration of non-linear approaches. Ultimately, this study seeks to assess how mineral mixing influences emissivity spectra, thereby contributing to our ability to detect and interpret spectral signatures from the surface of Venus.

2. SAMPLE SELECTION AND PREPARATION

Pure end-member samples were selected for measurements in the high-temperature emissivity chamber and spectrometers of PSL [1, 2]. Sample end-members were chosen to:

- Case Study 1: simulate mixtures of basalts with alteration phases that result from interactions with the Venus atmosphere (hematite) and more localized hypothetical interactions with SO₂ from active volcanism. We assess how the addition of these phases, albeit in geochemically not expected large amounts, might affect the emissivity spectra of basalts in intimate and areal mixtures (one example that falls in this category is the mixture basalt + gypsum);
- Case Study 2: represent mixing of basaltic glass with phenocryst minerals that occur in basalt (e.g., basalt + bytownite);
- Case Study 3: explore spectral mixing between coexisting mineral phases (e.g., olivine + hematite).
- Case Study 4: explore spectral mixing between the same material in different grain sizes (here we use different grain sizes of a Saddleback basalt).

Two basalt samples have been selected for this study: a tholeiitic basalt from Húsavík, Iceland (57% glass, 24% feldspar, 11% pyroxene, 4% Fe-Ti oxides, 3% olivine) [3]; and a Saddleback basalt sample (main components are SiO₂ ~ 47.7 %, TiO₂ ~ 0.89 %, Al₂O₃ ~ 16.5%, Cr₂O₃ ~ 0.04%, Fe₂O₃ ~ 10.80%, MgO ~ 6.45 %, CaO ~ 10.30 %, Na₂O ~ 2.51% [4]) sieved in different grain sizes samples. Pure end-member minerals selected for this study are a pure calcite sample (CaCO₃), a pure synthetic gypsum sample (Ca₂SO₄, anhydrous Puratronic 11116 Lot Y07E050), a synthetic hematite (Fe₂O₃ Puratronic 10716 Z24G018), a bytownite feldspar (Crystal Bay, Minnesota); and a forsteritic olivine sample (Globe, Arizona) (**Table 1**) [5].

Table 1. List of all sample end-members and mixtures analyzed in this study

Sample ID	Sample name	Grain size	Mixing	Case Study
End 1	Húsavík Basalt	>125 μm	-	1, 2
End 2	Saddleback Basalt	< 25 μm	-	1, 2
End 3	Saddleback Basalt	>250 μm	-	4
End 4	Calcite	>125 μm	-	1
End 5	Gypsum	>125 μm	-	1
End 6	Bytownite feldspar	>125 μm	-	1
End 7	Hematite	< 25 μm	-	1, 3
End 8	Globe olivine	< 25 μm		3
Mix 1	Húsavík Basalt + Gypsum	>125 μm	50:50 A_mix 50:50 I_mix	1
Mix 2	Húsavík Basalt + Calcite	>125 μm	50:50 A_mix 50:50 I_mix	1
Mix 3	Saddleback Basalt + Hematite	< 25 μm	50:50 A_mix 50:50 I_mix	1
Mix 4	Húsavík Basalt + bytownite feldspar	>125 μm	50:50 A_mix 50:50 I_mix	2
Mix 5	Olivine + Hematite	< 25 μm	50:50 A_mix 50:50 I_mix	3
Mix 6	Saddleback basalt mix	< 25 μm + > 250 μm	50:50 A_mix 50:50 I_mix	4

For the bulk samples, different grain sizes have been prepared in the rock preparation laboratory of our department, equipped with tools for sample grinding and sieving [1].

For the purposes of this work we created intimate mixtures 50:50 in weight and areal mixtures of our end-members. Areal mixture measurements are performed using custom-designed divided ceramic sample cups to each half to be filled with material from only one end-member, keeping the two samples spatially separated (see **Figure 1**). Intimate mixtures are created mixing 50% in weight of one end-member with 50% in weight of the other end-members. **Figure 1** shows example pictures of sample areal vs intimate mixtures samples analyzed in this study.

For Case Study 1 2 and 3, different end-members with similar grain sizes have been matched and mixed together. For Case Study 4, the same end-member with different grain sizes has been measured in areal and intimate mixtures (see **Figure 2**).



Figure 1. Examples of mixtures samples analysed in this study. From left to right: - A_mix Hematite-Olivine; I_mix hematite-Olivine; A_mix Husavik basalt-bytownite feldspar; I_mix Husavik basalt-bytownite feldspar.



Figure 2. From left to right: Saddleback basalt sample $< 25 \mu\text{m}$; Saddleback basalt sample $> 250 \mu\text{m}$; A_mix and I_mix between the first two samples.

It is important to note however, as already mentioned, that we started to analyze the NIR emissivity mixtures behavior and modeling the NIR region with 50:50 mixtures to use our custom designed-cup and being able to compare and study areal vs intimate mixture emissivity response, but those percentages do not reproduce the mixing percentages that we expect to find on Venus, especially in Case Study 1. As showed in [6], geochemical data from the Vega and Venera landers shows that interactions between basalt and the atmosphere do not go to completion (i.e., completely break down surface rocks, creating intimate mixtures of basalt with alteration products in the percentages like the ones studied here). Rather, gas-solid reaction experiments under SO_2 -bearing CO_2 and pure CO_2 atmospheres at relevant Venus temperatures, pressure, and oxygen fugacity [7, 8] show limits on the formation of surface alteration products due to constraints imposed by diffusion rates of the necessary cations to the surface. The resultant gradients are controlled by concentrations of elements present, depending on the composition of the basalt and its degree of crystallinity [9]. Initial reactions occur rapidly (albeit at nanometer scales) in the presence of SO_2 , which we expect to be localized around active volcanoes [9], and to a far lesser degree under CO_2 only – the pervasive condition on Venus. The experimental data also show that diffusion rates are not constant. Fresh surfaces react rapidly only in the presence of SO_2 . Formation of coatings or alteration products reduces communication between the surface atmosphere and the interior cations and eventually effectually shuts down diffusion to the surface. It remains unclear if it is even feasible to form thick enough coatings to affect spectroscopic measurements.

For all these reasons, the mixtures created in this study are intended only to understand and learn how to model the areal vs intimate mixing processes seen in emissivity data but cannot be used to directly make interpretations about spectra of the Venus surface itself, but they will be indirectly used for this scope since they serve as a base to train machine learning model for a correct data interpretation.

Moreover, for some of these mixtures, to match the grain size of our endmembers samples and study the grain size effects we have been using really fine grain size materials ($< 25 \mu\text{m}$). Studying the grain size effects is really important to understanding the areal vs intimate mixing behavior, even though once again these very fine grain sizes are not expected to be found on Venus.

In fact, several studies indicate that on Venus we expect mainly coarse-grained sediments: - emissivity spectra from Venera-9 and Venera-10 landing sites [10] align with laboratory data for basalt slabs and coarse sediments ($>250 \mu\text{m}$) [11]; - on Venus, the transformation of coarse blocks into loose material is inefficient due to slow wind speeds ($\sim 1 \text{ m/s}$) [12], lack of water, that makes wind erosion inefficient compared to other terrestrial planets. As a result, sediment sizes are mainly determined by impact-generated particle sizes; - Venera images show no large areas of fine dust. The sediment-to-rock ratio

decreases from Venera 9 to 14, with Venera 14 mostly bedrock. Particle sizes are suggested to be $<10,000 \mu\text{m}$, similar to slabs, and Venus lacks a global fine regolith [13, 14]; - particulate materials on Venus are often cemented into lithified duricrusts, which have higher emissivity than the original sediments [15, 16, 17]; - sediment production from volcanism on Venus is rare due to the thick atmosphere, which inhibits explosive eruptions [18, 19]; - VIRTIS studies of impact craters and associated parabolas show no emissivity change at $1.02 \mu\text{m}$, indicating grain sizes are not significantly smaller than $250 \mu\text{m}$ [20]. Schaller and Melosh (1998) [21] estimated these grain sizes to be 2-20 cm, which are coarse and spectrally similar to slabs; - particulate sediments detected on Venus, mostly impact-derived, are found in small areas like dune fields, yardangs, and wind streaks [22]. Bedrock dominates the surface at scales relevant for future observations, as fine-grained material does not match radar-measured dielectric constants.

Based on these initial emissivity mixtures spectra analysis and on the more abstract understanding of the mixing behavior, we are planning then to adjust the percentages and grain sizes of our mixtures to more closely reflect and study in the laboratory what is likely to be observed on Venus.

3. EXPERIMENTAL SETUP AND MEASUREMENTS

End-member and mixed samples were measured and analyzed at the Planetary Analog Simulation LABORatory (PASLAB) of PLL by means of Digital Microscope Keyence VHX-7000. Microscope images were used to check for grain impurities and to measure the percentage of each component on the samples' surface for the intimate mixtures. Intimate mixtures were confirmed to present 50% of one endmember and 50% of the other on the surface within 0.4% errors. (Figure 3). Analysis has been performed used the Microscope Software that allows counting and analysis of numbers, shape and dimensions of the different grains on the sample's surface.

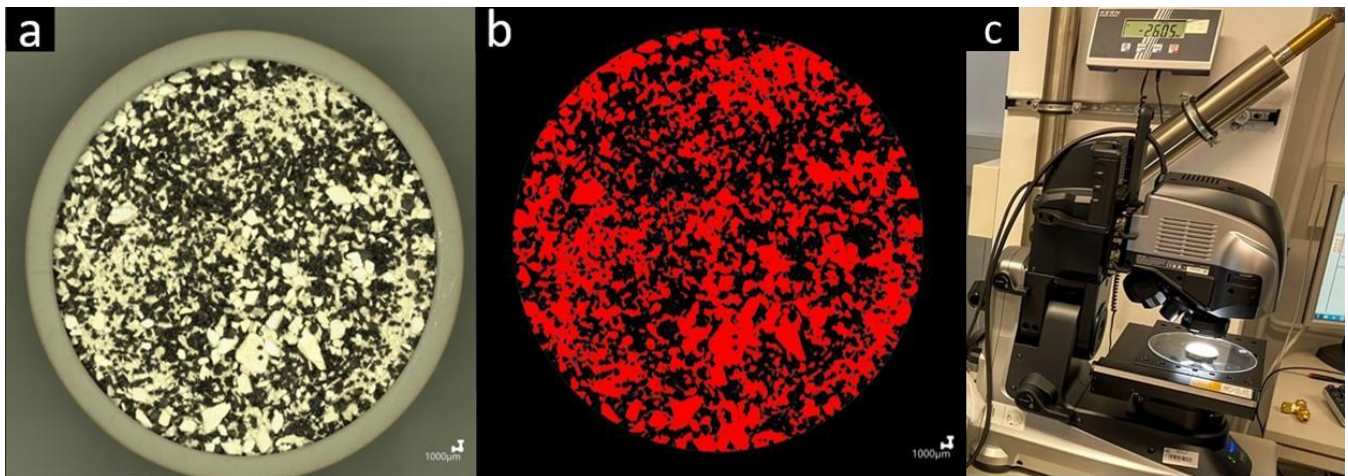


Figure 3. a) example of intimate mixture (50% of basalt - 50% of gypsum; b) same sample view obtained through the Digital Microscope Keyence VHX-7000 (white grains shown in red – 50% percentage of white grains measured on the sample surface); c) Digital Microscope Keyence VHX-7000.

All pure end-members as well as intimate and areal mixtures were measured in hemispherical reflectance prior to heating for the emissivity measurements at Venus surface temperatures and

afterwards. Hemispherical reflectance measurements were performed by means of a reflectance Infragold coated labsphere unit that can be mounted in the sample compartment of the Bruker VERTEX 80V spectrometer, and it is optimized for NIR hemispherical reflectance measurements under vacuum.

Emissivity measurements are performed using an in house-built high-temperature emissivity setup that allows routine measurements of NIR emissivity spectra of Venus analogues at relevant Venus surface temperatures (400°C, 440°C, and 480°C) in a vacuum (0.7 mbar) environment [23, 24]. The Venus emissivity chamber, attached to a Bruker Vertex 80V FTIR spectrometer, measures emissivity of solid (in 5-cm disks) and granular samples (filling a 5-cm volume). Samples are heated in custom-made sample cups using a very powerful induction system. To avoid glowing of steel in the NIR, hot ceramic cups with a steel disk (the heater) enclosed are used. The hot ceramic is opaque in the studied spectral range therefore the emitted radiance from the cup does not affect the measurements. Several temperature sensors are located in the emissivity chamber to allow monitoring of sample and chamber temperatures, including one touching the side of the sample cup and a second one placed on the sample surface. A Black Body (BB) reference sample is measured and used for calibration of each sample emissivity measurements. A webcam mounted inside the chamber allows monitoring of the whole experiment during the heating and cooling process.

Figure 4 shows webcam pictures collected for some of the measured samples and a schematic side-view of the emissivity chamber setup. During the measurements the amplitude of the irradiated signal is checked and registered at each measurement step and temperature before acquiring the measurements.

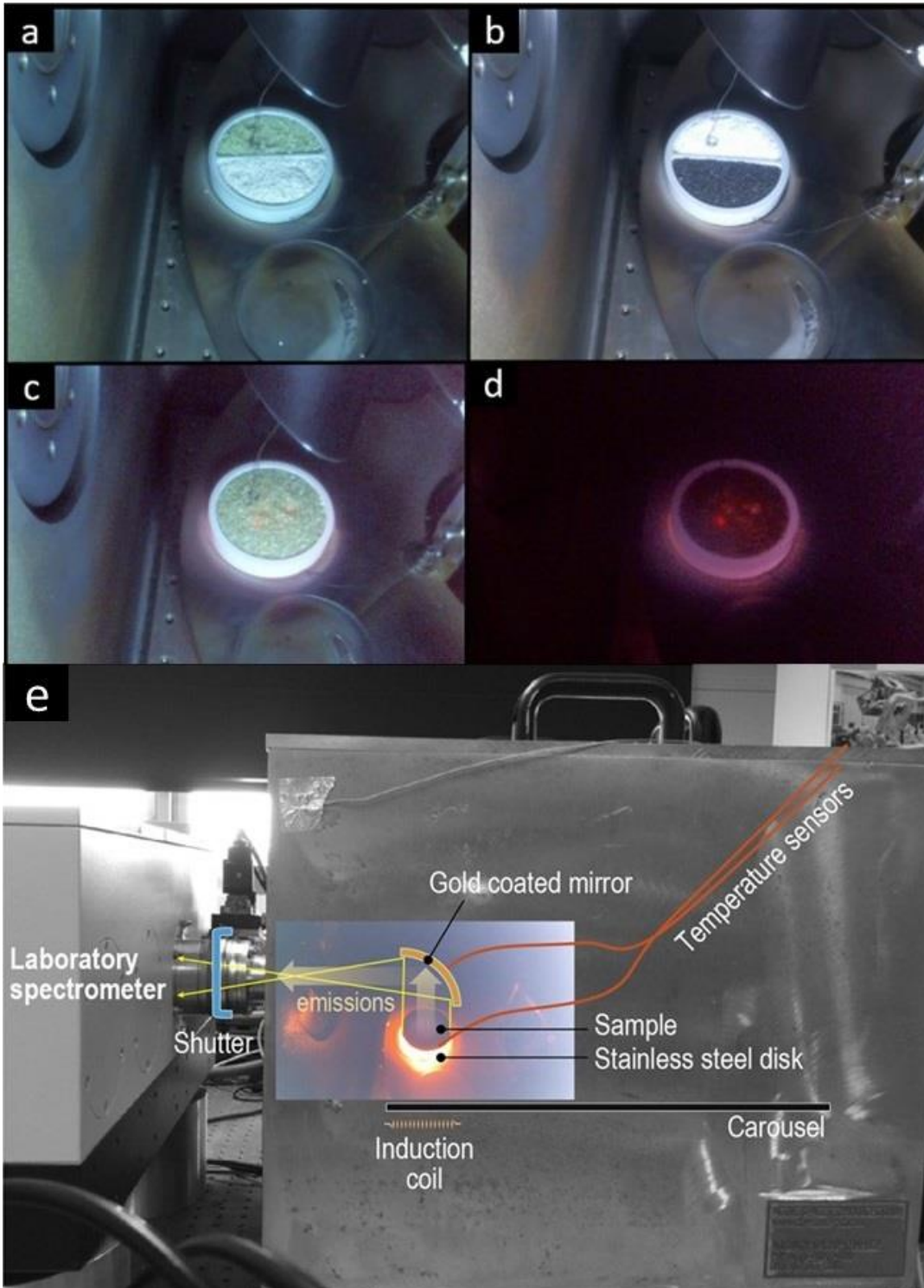


Figure 4. Samples in the PSL emissivity chamber during the heating process. a) globe olivine+ bytownite feldspar areal mixture; b) basalt + gypsum areal mixture; c) globe olivine+ bytownite feldspar intimate mixture; d) same mixture as in c but with webcam light off at $T \sim 400^{\circ}\text{C}$; e) schematic representation of the setup of the emissivity chamber.

4. SPECTRAL DATA ANALYSIS

Emissivity spectra acquired are calibrated against a Black Body (BB) sample measured at the same temperatures following our standard calibration procedure described in [25], which has remained the same over the years. Nevertheless, some tests have been carried out to identify potential improvements in the procedure [26]. A graphite slab is currently being used as a BB reference sample: this slab shows a featureless spectrum in the NIR spectral range and heats very efficiently, thus behaving as a good BB for the calibration of our measurements. Emissivity spectra measured in the laboratory on end-members and mixtures are compared with retrieved emissivity from hemispherical reflectance measurements (1-hemi) on the same samples.

We observed that in all cases, the presence of the second component affects the emissivity intensity and sometimes also the shape of the single end-member spectra in the NIR spectral range.

In Case Study 1 (see **figure 5**), we simulated mixtures to assess how sulfates and oxides influence and modify the emissivity spectra of basalts in both intimate and areal mixtures. Our observations indicate that the addition of sulfate significantly reduces the emissivity when mixed into basalt. Moreover, in basalt – hematite mixtures, the spectral slope of hematite becomes apparent in the emissivity spectra. It must be acknowledged that, as explained before, the extreme amounts of sulfate and hematite used in these mixtures far exceeds what can occur on Venus because the formation of those alteration phases is controlled by kinetic constraints that limit the extent to which the necessary cations can diffuse to the surface [6]. Moreover, the presence of SO₂ gas in Venus' atmosphere is expected to be highly local and limited by proximity to active volcanism.

Changes in Case Study 1 appear different when comparing the calibrated emissivity for areal mixtures to those of intimate mixtures (see **Figure 5**). This demonstrates the expected non-linear nature of mixing in the NIR as well as the effects of scattering, which are different in the two scenarios. When the two components are physically separated, as in our areal mixtures, the emissivity level decreases more in mixtures of basalt with calcite and hematite than in the corresponding intimate mixtures.

In Case Study 2 and 3 (see **Figure 6**), the mixture spectra are also significantly affected by the mixing, resulting in notable changes in emissivity levels. As described in Section 2, Case Study 2 examines the mixture of basalt + bytownite, representing the mixing of basaltic glass with the lowest-Fe phenocryst mineral that might occur in basalt. Case Study 3 explores the spectral mixing between coexisting mineral phases, such as in the mixture of olivine + hematite.

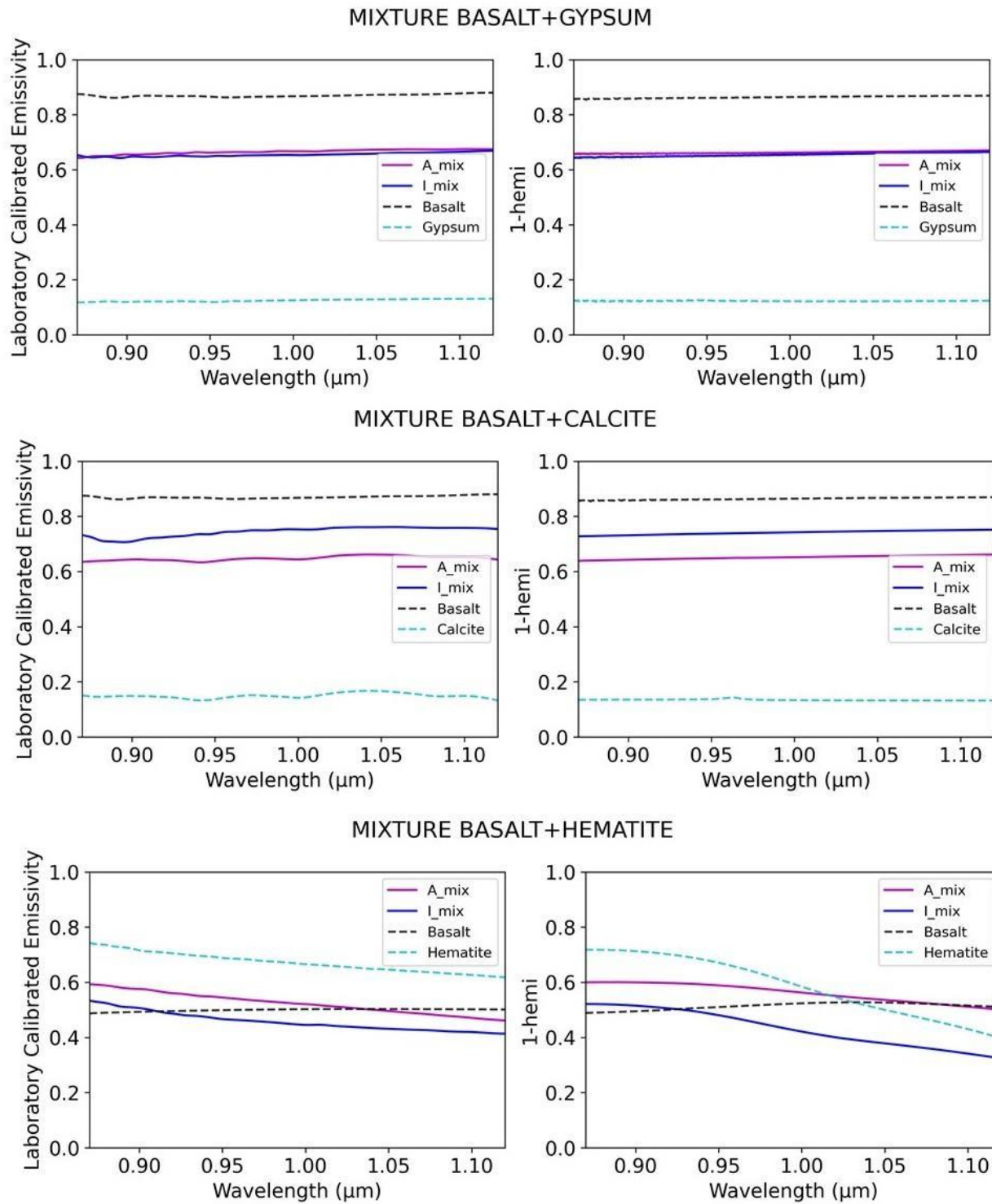


Figure 5. Laboratory calibrated emissivity spectra (left) vs 1-hemispherical reflectance laboratory calibrated spectra (1-hemi) (right) for the mixtures: Húsavík basalt + gypsum (both components with grain size > 125

μm); Húsavík Basalt + calcite (both components with grain size $> 125 \mu\text{m}$); Saddleback basalt + hematite (both components with grain size $< 25 \mu\text{m}$).

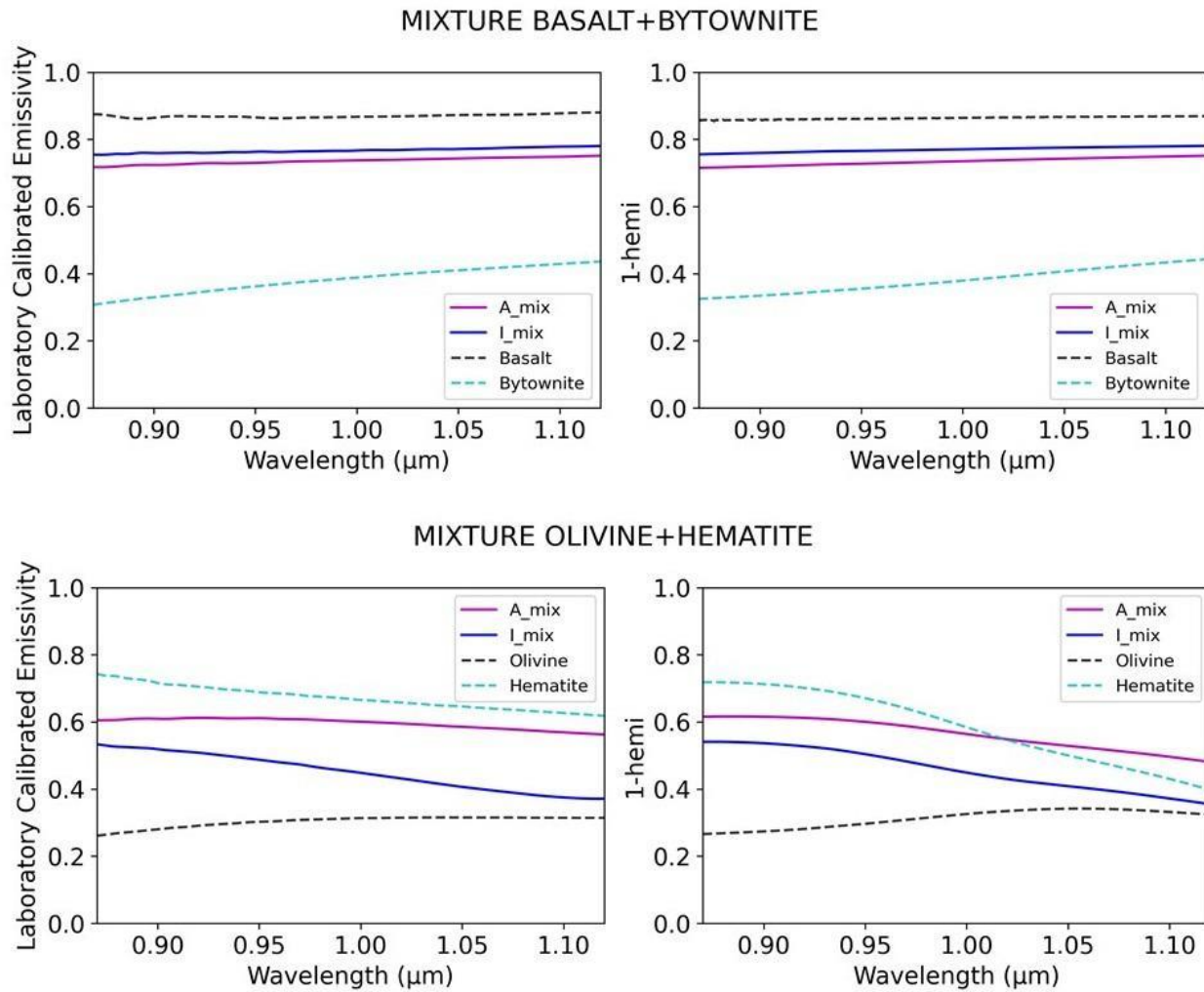


Figure 6. Laboratory calibrated emissivity spectra (left) vs 1-hemispherical reflectance laboratory calibrated spectra (1-hemi) (right) for the mixtures: Húsavík basalt + bytownite (both components with grain size $> 125 \mu\text{m}$); Globe olivine + hematite (both components with grain size $< 25 \mu\text{m}$).

Finally, in Case Study 4 (see **Figure 7**), we are investigating grain size effects, mixing the same sample in two different grain sizes and also comparing it with the slab spectrum. **Figure 7** shows that grain size significantly affects the emissivity spectra on our samples. Moreover, the spectrum of the intimate mixture tends much more towards the spectrum of the coarse end-member than the spectrum of the areal mixture, even though the small grains tend to stick to the bigger grains and cover them (see **Figure 2**). This strongly indicates that even in the presence of fine dust the bulk composition dominates the spectrum.

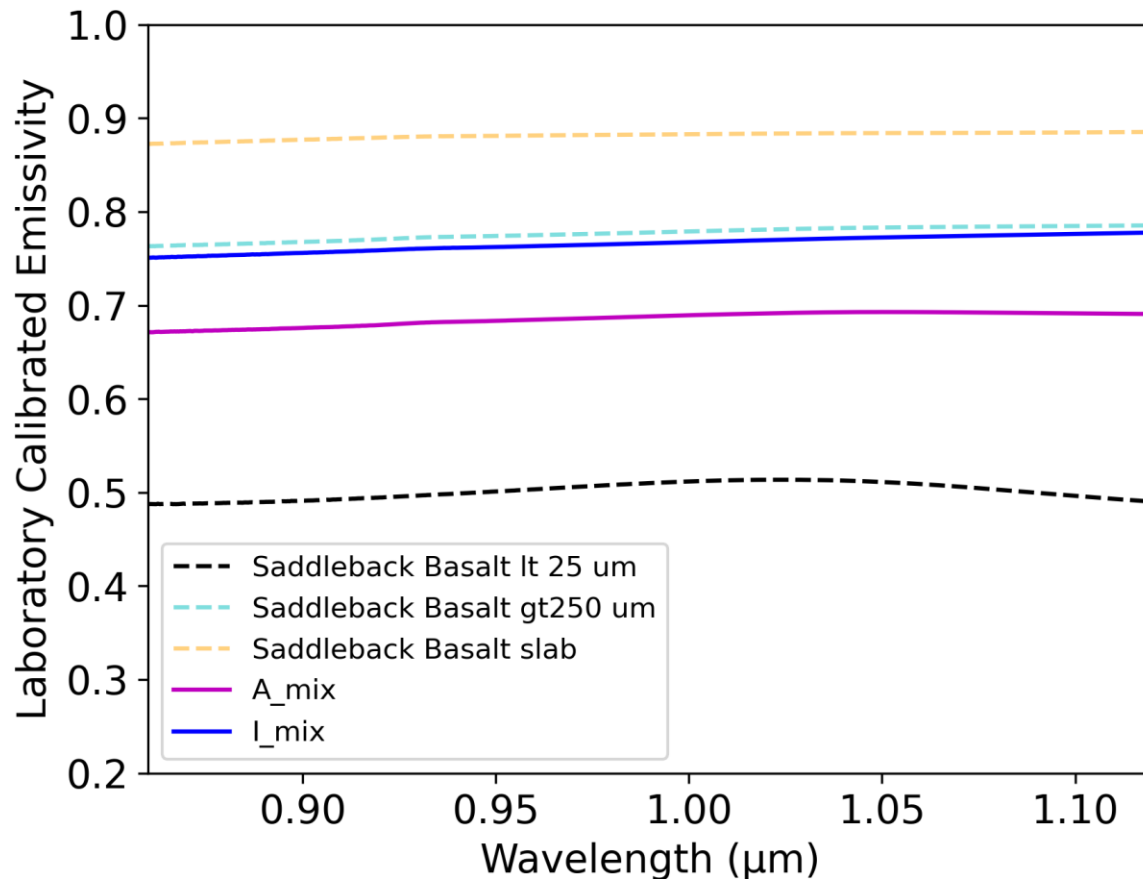


Figure 7. Laboratory calibrated emissivity spectra obtained for the intimate and areal mixtures (I_mix and A_mix respectively) of Saddleback basalt lt (less than) 25 μm with saddleback basalt gt (greater than) 250 μm . Mixture spectra are compared with end-members spectra (dotted lines). The spectrum of a Saddleback basalt slab has been added as well for comparison with the other samples.

This work demonstrates that both mixing and grain size must be carefully considered when interpreting spectral orbital data, in terms of both emissivity and reflectance.

In addition, mixtures spectra have been compared with modeled spectra obtained starting from the spectra of the end-members (**Figure 8**).

Unmixing models have been extensively applied in the thermal infrared region of the spectrum and proved to provide a good reproduction of the laboratory spectra of mixtures. In the study of reflectance spectra in the NIR, Hapke radiative transfer models [27, 28] are generally used to model non-linear mixing at these wavelengths. However, these models have not been extensively applied to NIR emissivity spectra due to the lack of available data, and our results will provide foundational data for such efforts. Using NIR emissivity spectra of mixtures at Venus condition, we are investigating the best approaches for modeling this spectral region.

As expected, our results on the 50:50 mixtures show that the linear mixing [29] does not reproduce the laboratory emissivity spectral behavior for some of the mixtures analyzed in the NIR. For example, in the case shown in **Figure 8**, the laboratory emissivity spectra of the two end-members, gypsum and

basalt, respectively, are compared with the spectra obtained in the laboratory for the intimate (I_mix) and areal (A_mix) mixtures. For comparison a linear modeled spectrum obtained starting from the laboratory spectra of the two end-members and linearly combining them at 50:50, is shown in orange (M_mix) in the same figure. The laboratory spectra obtained for I_mix and A_mix tend towards the spectrum of basalt, showing emissivity values around 0.65.

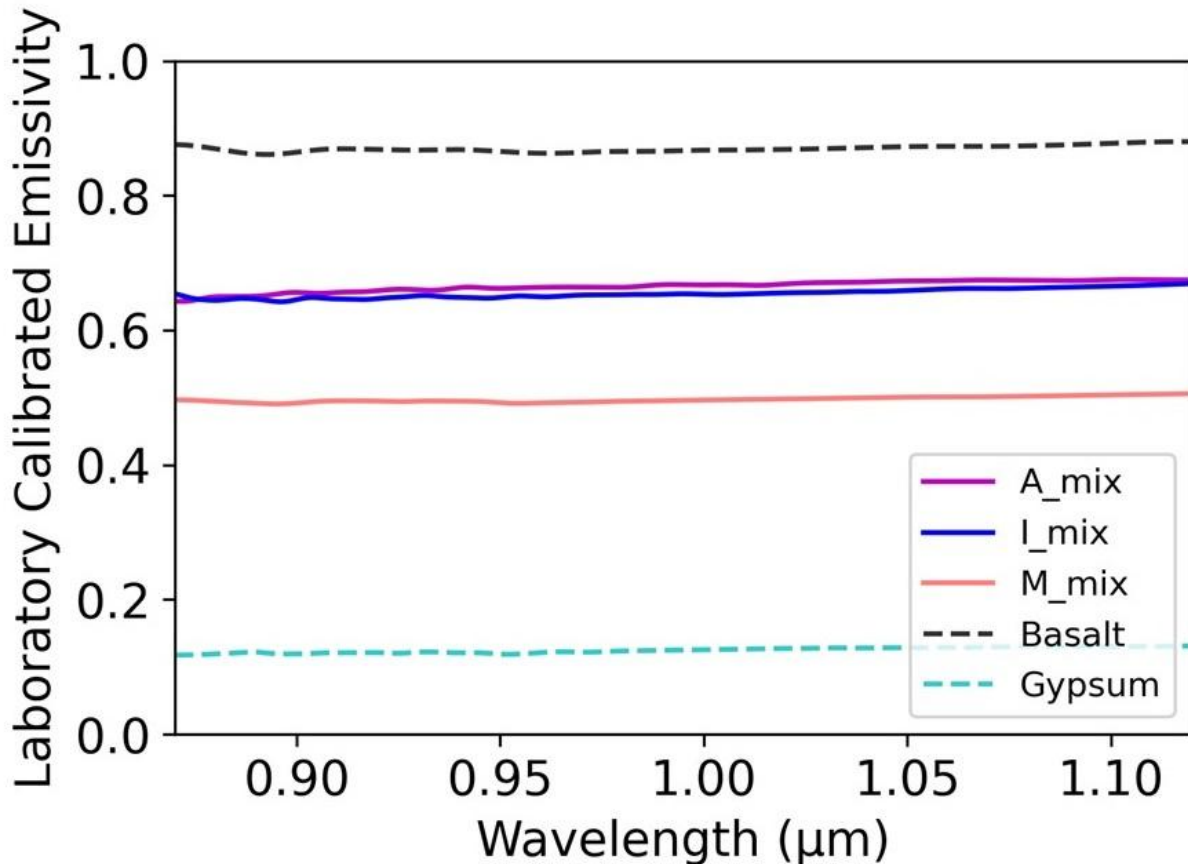


Figure 8. Emissivity spectra versus modeled spectrum obtained for the mixture 50% gypsum - 50% Húsavík basalt (both components with grain size > 125 μm). A_mix and I_mix are the laboratory spectra of the areal and intimate mixtures, respectively; while M_mix is a linear modeled mixed spectrum obtained starting from the laboratory end-members spectra.

Further analyses on more mixtures for each case of study previously described, are ongoing and non-linear mixing are being investigated. Furthermore, measuring and modeling of greater than two-component mixtures as well as two-component mixtures in different percentages is ongoing.

5. CONCLUSIONS

The analysis of the spectral mixtures' laboratory data reveals several important findings. First, sulfate components significantly reduce the emissivity levels of basalt with a non-linear trend as expected [6]. Therefore, these high-temperature experimental emissivity data are needed to understand how to

properly model this spectral region. Additionally, this study shows that mixing different components, such as basalt with hematite, calcite, or bytownite, leads to noticeable changes in both emissivity intensity and spectral shapes.

Significant changes produced by the addition of sulfate and hematite to basalt on the spectral of intimate mixtures have been observed by Leight et al. (2024) [29] in a detailed study of intimate mixtures behavior in order to constrain detectability of alteration in reflectance spectra. Room-temperature hemispherical reflectance spectra of mixtures of sulfates-basalts mixtures show major differences in spectral slope between the basalt-alteration mixtures and the endmembers spectra. These data have implications for the interpretation of in situ surface data from Venus, but emissivity data at Venus surface temperature are necessary for correctly interpreting VenSpec-M/VEM data.

In addition to the mixing of different components, this study investigates mixing properties of the same material in different grain sizes. It has been obtained that mixing basalts of a fine grain size even in the 50% percentage with coarse grain size of the same sample, the resulting spectra tend towards the spectrum of the coarse component. This emphasizes again the general need of considering both mixing and grain size effects when interpreting spectral orbital data from planetary surfaces, while at the same time showing that even in the presence of some fine material the bulk composition dominates. The differences between intimate and areal mixtures highlight the importance of physical proximity in spectral interpretation.

The study also demonstrates the challenges in modeling and unmixing spectra in the NIR range. Results obtained show that linear mixing models cannot consistently reproduce the laboratory emissivity spectral behavior in the NIR region, indicating potential nonlinear mixing effects. In terms of spectral modeling, the comparison between laboratory spectra and modeled spectra based on endmembers indicates a need for further refinement in modeling approaches to accurately capture spectral characteristics under Venus conditions.

Measurements here described strive to provide an understanding of the underlying science behind spectroscopy of mixed materials under high-temperature emissivity conditions. As such, they support the VenSpec-M/VEM data calibration and validation plan. This data offers crucial insights into the necessity of machine learning algorithms, which are being developed for VEM and VenSpec-M data analysis, and will be invaluable for training those algorithms. The main goal of these measurements is to investigate the mixing effects on emissivity. In a bigger perspective, this study provides valuable insights into the interpretation of planetary spectral orbital data, particularly regarding the identification and characterization of mineral mixtures on the planetary body surfaces.

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