DERIVATION OF THERMAL EMISSION FROM VIRTIS ON VENUS EXPRESS 1000-1400nm SPECTRA.

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Introduction: Venus surface thermal emission is observable through spectral windows in the atmosphere near 1000 nm wavelength. Thermal emission depends on surface emissivity, which is indicative of surface mineralogy [1] when compared to laboratory spectra of samples at Venus temperatures [e.g., 2]. The Visible and Thermal Imaging Spectrometer (VIRTIS) on board of Venus Express observed a part of this spectral region. The derivation of surface emissivity from VIRTIS spectra is complicated by the relatively low radiance signal of the Venus nightside and the variable atmosphere, which must be accounted for using atmospheric thermal emission observations and a model of atmospheric radiative transfer [e.g., 3].

To date a map of the full surface coverage has been derived at 1020 nm. Other bands have a weaker signal and require more robust data reduction. The low ratio of signal to instrumental and atmospheric noise can be improved by averaging over many observations. However most VIRTIS observations are affected by instrumental straylight caused by the bright Venus dayside close to the field of view and an extremely short baffle. It is therefore necessary to create a robust method to remove this artifact from the spectra. In their analysis of a Galileo NIMS flyby image, Hashimoto et al. [1] subtract a scaled image at 1400 nm, assuming that all radiance in that band is straylight and that the straylight spectrum is uniform over the image. In a similar approach, Mueller et al. [4] derive a straylight spectrum from a linear regression of all data to the collocated radiances at 1360 nm. Kappel et al. [5] fit the straylight as linear combinations of two spectral shapes derived from a principal component analysis (PCA) of deep space spectra

In this study, we compare the principal component analysis approach [5] to the older approach by [4], and check the residual straylight at bands where the radiative transfer model predicts negligible radiance for systematic deviations that might affect emissivity retrieval.

Data processing: VIRTIS spectra in the ESA Planetary Science Archive show a non-linear detector response and some straylight from the bright side of the planet [5]. The non-linear detector response is manifested as a deviation alternating in sign between even and odd bands depending in amplitude on the observed radiance. We correct for this sawtooth-like pattern by deriving correction curves from dayside spectra with shorter exposure durations, following the work of [5]. After applying these corrections, the next step is derivation of the spectral shape of straylight.

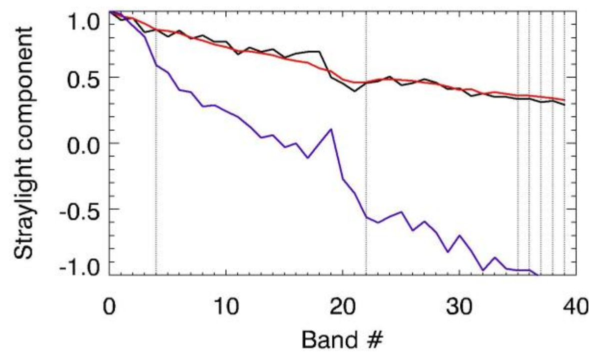

Figure 1. Straylight spectral base functions [normalized at band 0]. Black: from linear regression of all bands to radiance at 1360 nm [4], Red and purple: first and second principal components of radiance observed at deep space.

In many VIRTIS observations, deep space is visible beyond the limb of the planet, but similarly affected by straylight. A PCA of a set of these spectra produces base functions ranked by their impact on data variance. The function with the greatest impact is very similar to the average straylight shape derived from nightside data by [4] (**Figure 1**). The second-most base function contributes much less to data variance.

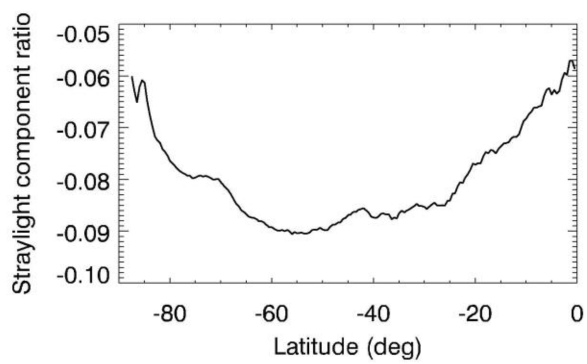

Figure 2. Ratio of the weights of the second to the first principal components of straylight fitted at bands 4, 22, and 35-39.

A linear combination of these two base functions is fitted to the VIRTIS nightside spectra at darks bands 4, 22, 35-39, and subtracted from each total spectrum. In the work of [4], the single base function is matched to the average of bands 36-39 and subtracted from the whole spectrum.

Results: Due to Venus Express' eccentric orbit with apocenters above the south pole, latitude is strongly correlated with the amount of straylight present in the spectra. Corrected spectra are binned to create latitudinal profiles, together with additional parameters such as the coefficients of the linear combination. The latter shows that the shape of the straylight indeed changes systematically with latitude (**Figure 2**). The residual straylight, i.e., the radiances at the bands assumed to be dark are much smaller than with the method of [4], still show small systematic deviations from zero as function latitude (**Figure 3**). The overall effect on corrected radiance using the two straylight approaches is differences in the latitudinal profiles of corrected window radiances (**Figure 4**).

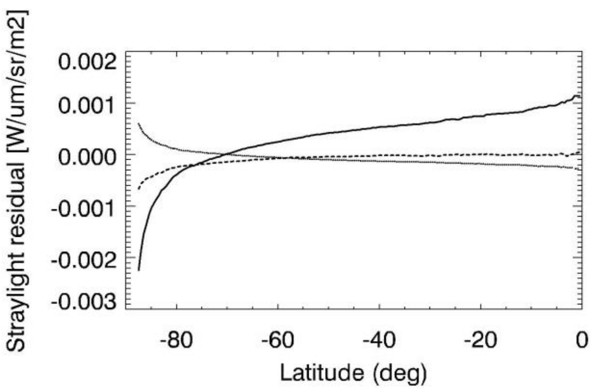

Figure 3. Residual radiance at wavelengths that should be dark after straylight correction. Solid: band 22, dashed: band 33, dotted: band 4.

Discussion: The two base function straylight fit is superior to the single component subtraction. However, the spectral shape of the straylight is not yet fully reproduced, as is evident in the the straylight residuals that are on the order of 10 % of the atmospheric window at 1310 nm (Figure 3). While large scale deviations over latitude do not preclude regional interpretation of emissivity variation, problems may arise when other parameters also correlate with latitude. Cloud opacity is, on average, a function of latitude (Figure 4). Mueller et al.

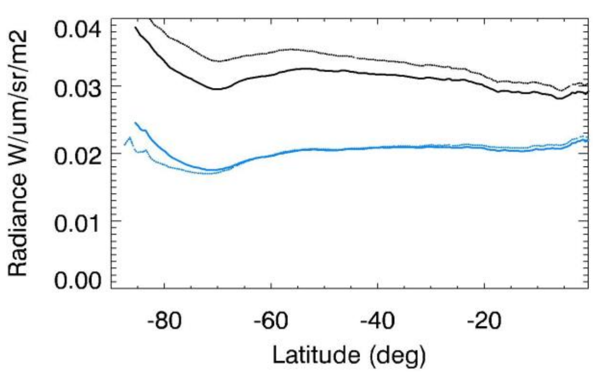

Figure 4. Window radiance profiles comparing the two methods of straylight correction. Black: band 8 at 1100 nm, blue band 30 at 1310 nm multiplied by 3 for clarity. Solid: PCA, Dashed, single component straylight [4].

[4] rely on statistically derived relations between surface and atmospheric emission windows, which are affected if there is residual straylight as a function of latitude.

The shape of the base functions might provide a clue of how to improve the straylight removal procedure. Correlation of some features of the second base function with the spectral slope of first base function indicates that the strength of the second component would spectrally shift the feature in the straylight spectrum. Base functions are only functions of band number, so the actual wavelength registration can shift for more than one band between spectra. Ideally, this spectral shift, the changing instrument bandwidth, and residual emissions from the window flanks would all be taken into account.

Alternative approaches to straylight correction fit analytic functions to the dark bands, to interpolate straylight for the windows [7]. Our straylight base functions can (in some regions, including the windows) be approximated by such functions, indicating that this approach might produce comparable results. In any case, it is our intention to develop the best possible reduction of thermal emission data and to make it (or the algorithms needed to reproduce it) available to the community. Our current progress toward this goal is shown in **Figure 5**.

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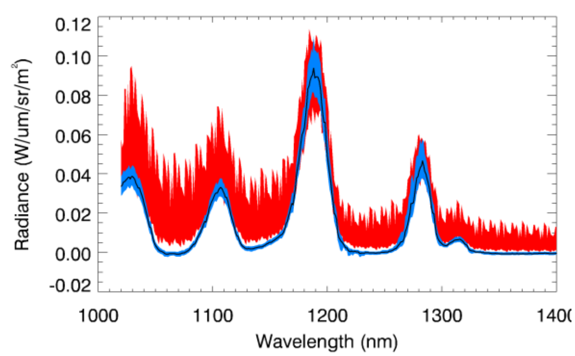

Figure 5. Correction of 26 million VIRTIS spectra for detector nonlinearity and straylight. Red: calibrated data mean ±1 standard deviation. Blue: corrected data.

References: [1] Hashimoto G.L. et al. (2008) *JGR, 113*, E00B24. [2] Helbert et al.(2017): First set of laboratory Venus analog spectra for all atmospheric windows, this meeting #1512. [3] Tsang C et al. (2008) *J. Quant. Spectrosc. Radiat. Transf.*, *109*, 1118–1135. [4] Mueller N. et al. (2008) *JGR, 113*, E00B17. [5] Kappel D. et al. (2012) *Adv. in Space Res.*, *50*, 228–255[6] Cardesín Moinelo A. et al. (2010) *IEEE Trans. Geosci. Remote Sens.*, *48*, 3941 [7] McGouldrick & Tsang (2016). *Icarus*, in press. doi:*10.1016/j.icarus.2016.10.00*