Venus Express VIRTIS-M visible-channel: Diffracted and scattered light corrections

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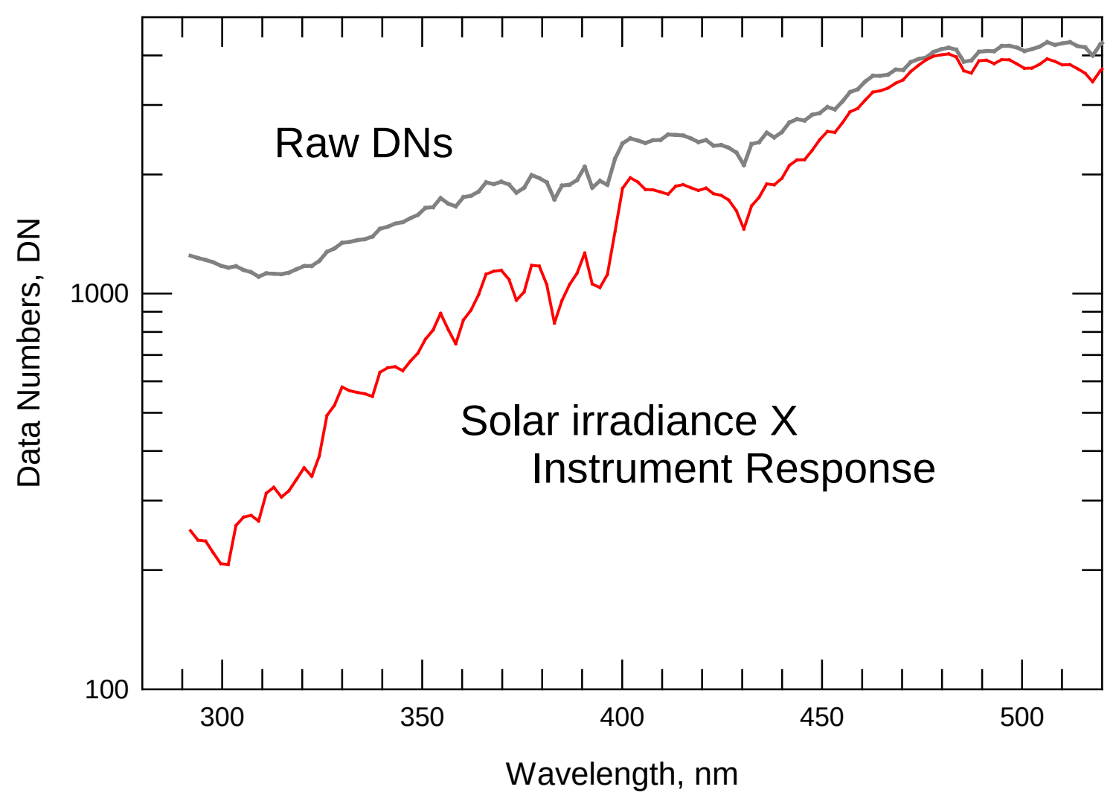
Why Correct the Spectra?

Grating spectrometers, in general, suffer from scattered light due to imperfections of the grating and mirrors, and from spurious reflections of the central order. In addition, VIRTIS uses a bi-partite grating with different ruling densities, a coarse density for dispersing the infrared (IR) spectrum on the IR detector and a finer density for the visible (VIS) spectrum and its array detector. Although the IR portion diffracts most of the energy in the first positive order toward the IR detector, some energy is diffracted in the negative orders and can strike the VIS detector.

The net effect is to add additional components to the VIS spectrum, especially in the blue and ultraviolet regions. This added component is evident in the VIRTIS spectra by the contrast reduction in the Fraunhofer structure and the apparent factor-of-ten increase in albedo at 300 nm compared to 500 nm (Fig. 1). This introduces difficulties for studying Venus's UV absorber.



Fig, 1. Raw VIRTIS spectrum of Venus compared to the solar spectrum at the same spectral resolution.

Correction Methods

The correction process is iterative, with each iteration step consisting of a correction for the diffracted light followed by a scattered light correction. The diffracted light correction uses laboratory measurements of the efficiencies for the various orders of diffraction as a function of the incident wavelength (Filacchione et al., *Rev. Sci. Instrum.* **77,** 103106, 2006) . A monochromator illuminated the *Rosetta* VIRTIS (nearly identical to the VEx version) and the signal was recorded (Fig. 2) at each wavelength position of the monochromator. These measurements are used here to compute the contributions for negative orders 2, 3, 4, 6, 7, 8 for the Venus spectra. This itself is an iterative calculation

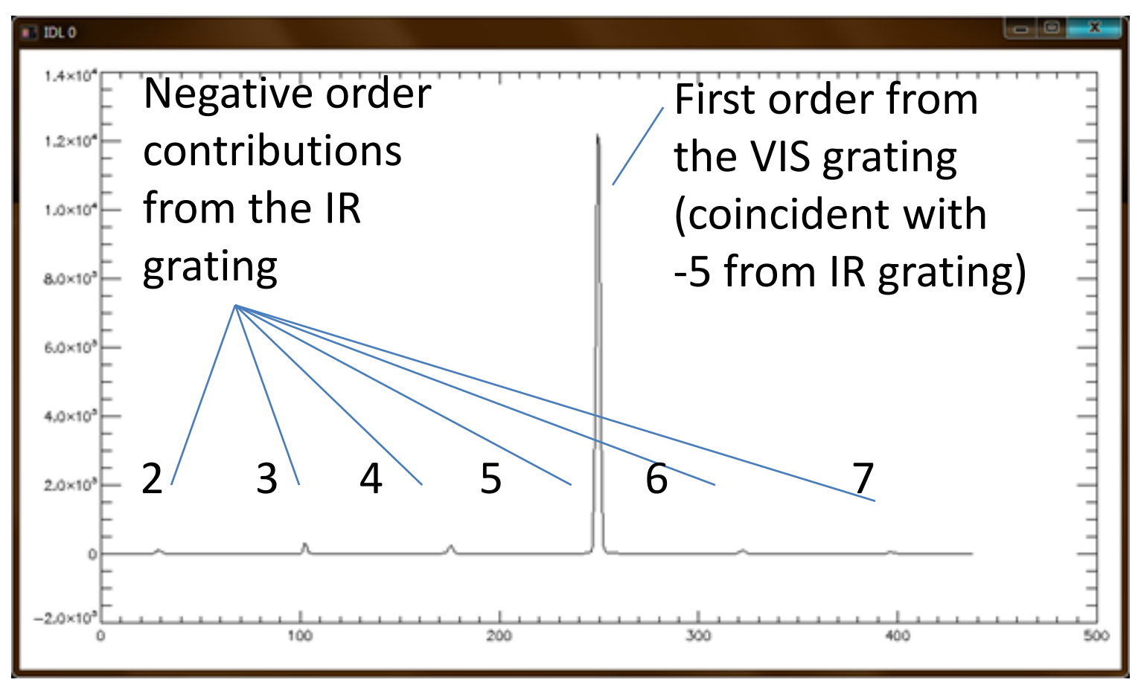
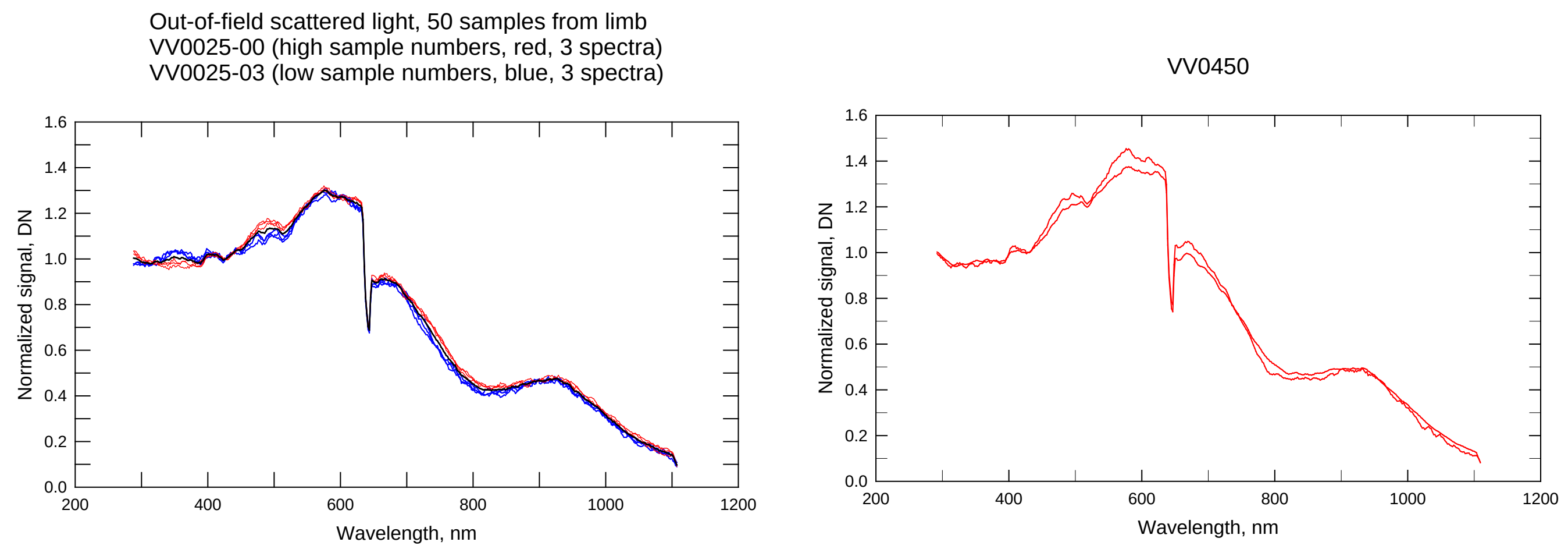


Fig. 2, at left. Scanning monochromator measurements of the *Rosetta* VIRTIS unit showing the spectrum for one position on the entrance slit as a function of channel number.

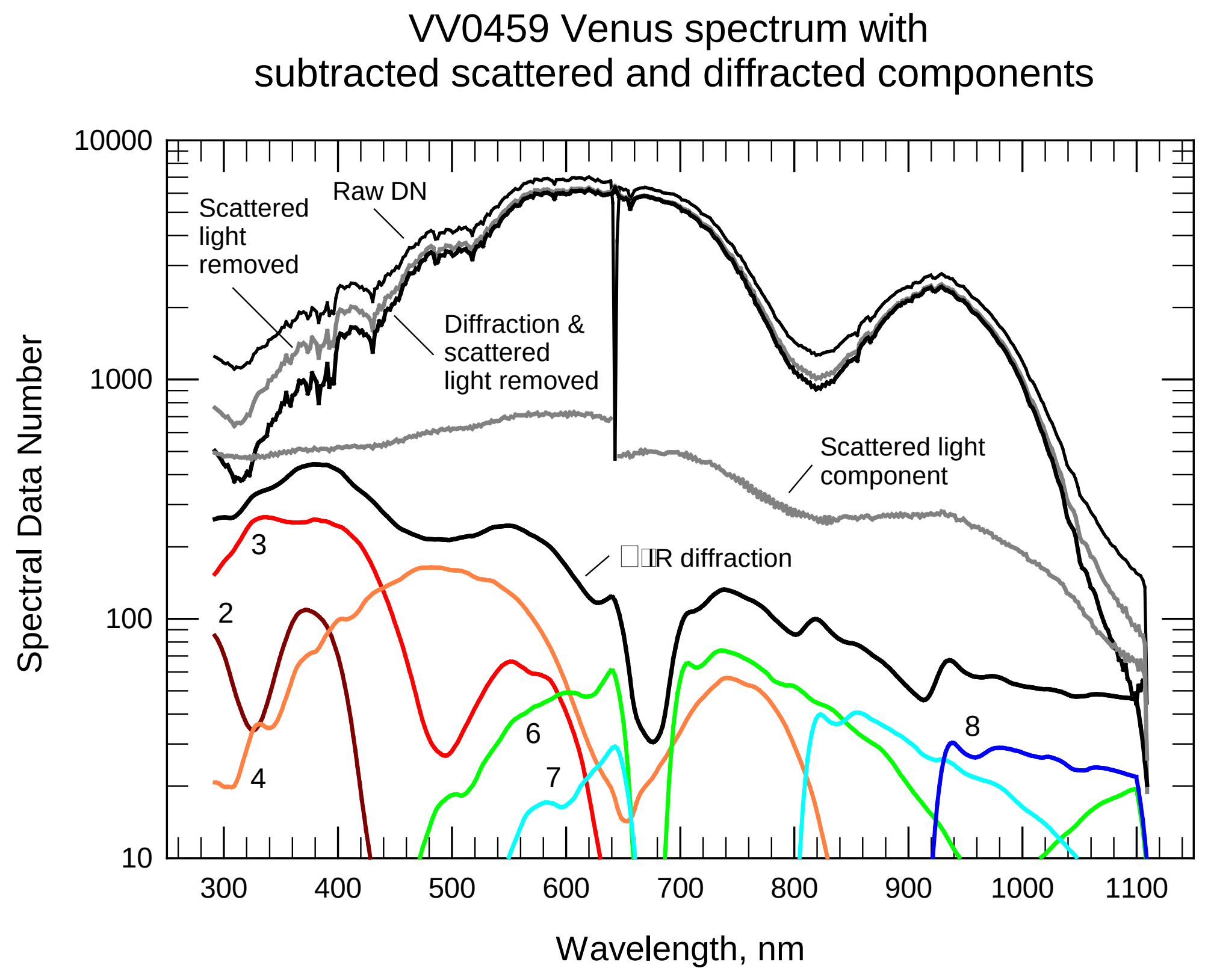
Fig. 3, below. Examples of off-limb scattered light spectra from different orbits VV0025 and VV0450) and different limbs (east & west, VV0025), normalized to show the similarity in shape.



Having an estimate of the diffraction contribution, we now perform the second correction, finding how much scattered light to subtract in order to give a minimum variance fit to the Fraunhofer structure (using the highly-structured 370-390 nm region). The shape of Venus spectra is similar for most illumination and observation geometries, so the shapes of the scattered light spectra are themselves similar, as illustrated in Fig. 3. A characteristic scattered light spectrum is used and normalized to the subtraction value found from the least-squares fit.

The combined corrections are iterated until the difference in consecutive results is << the measurement noise; this takes only about 5 iterations. Results for one VIRTIS Venus spectrum are shown in Fig. 4.

Fig. 4. A Venus spectrum as observed and corrected. The scattered and diffracted components (individual and summed) are shown as well as spectra with the components removed. The black line shows the corrected DN signal. The upturn at the shortest wavelengths is not a real feature from Venus but is unremoved stray light.



The effectiveness for removing scattered and diffracted light can be investigated using high-pass filtered spectra and comparing the uncorrected and corrected spectra to that of the sun, as shown in Fig. 5. For the uncorrected spectrum, the spectrum is similar to the sun's, but becomes progressively weaker at shorter wavelengths. The corrected spectrum shows improved fits down to about 330 nm.

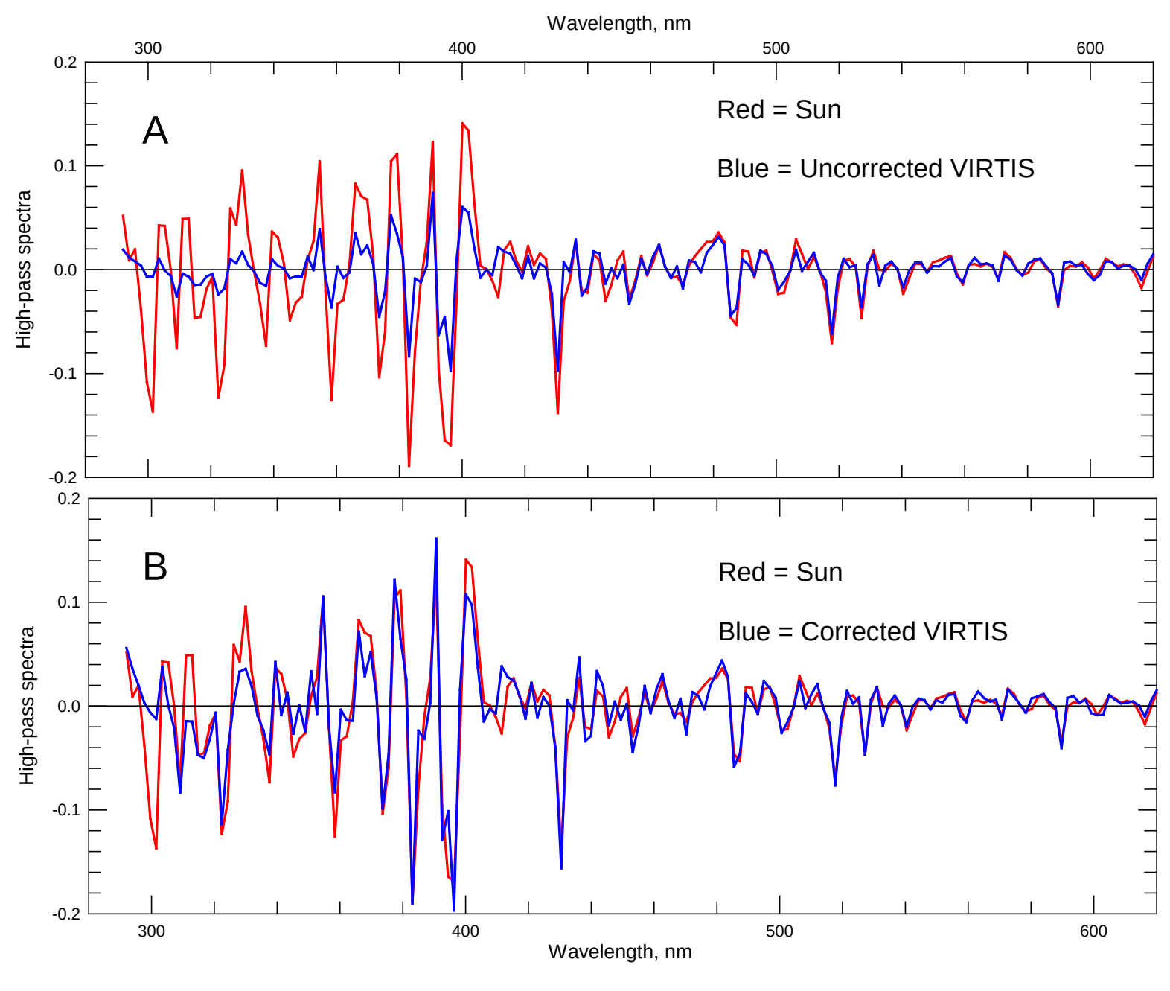


Fig. 5. High-pass ratio spectra

Calibrated and Relative Spectra

The original responsivity did not include these corrections so a new calibration is needed to obtain radiances, and albedos from the corrected spectra. We obtained Vega spectra with VIRTIS and performed the same grating correction as above (scattered light correction is unnecessary) and determined the VEx VIRTIS responsivity. Using Thullier et al.'s solar spectrum (*Solar Phys.* **214**, 1-22, 2003) , convolved to VIRTIS resolution, we form the product of the responsivity and the solar irradiance (Fig. 6, middle). Dividing the corrected spectrum (Fig. 6, top) by this gives the relative albedo (Fig. 6, bottom).

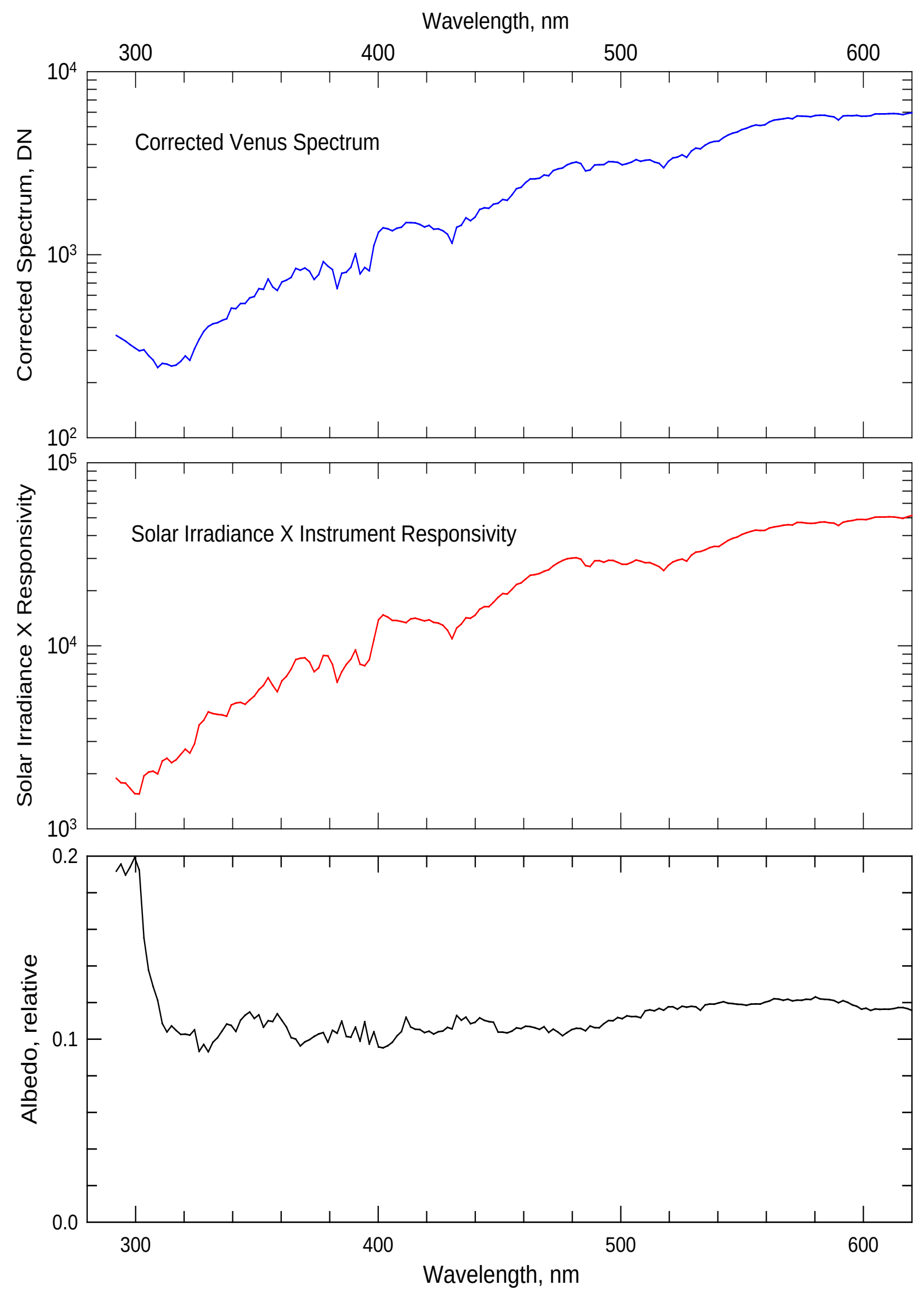


Fig. 6, Top, Corrected VV0459 spectrum, Middle, Solar flux X calibration, and Bottom, relative albedo.

There are remaining artifacts in the albedo spectrum. The rise at 310 nm is uncorrected stray light. Lower-amplitude anomalies from under-correction extend to longer wavelengths. Therefore, we presently use ratio spectra for VEx spectra, as illustrated in Fig. 7. The spectral ratio minimizes these artifacts and clearly shows useful spectra of Venus's UV absorber.

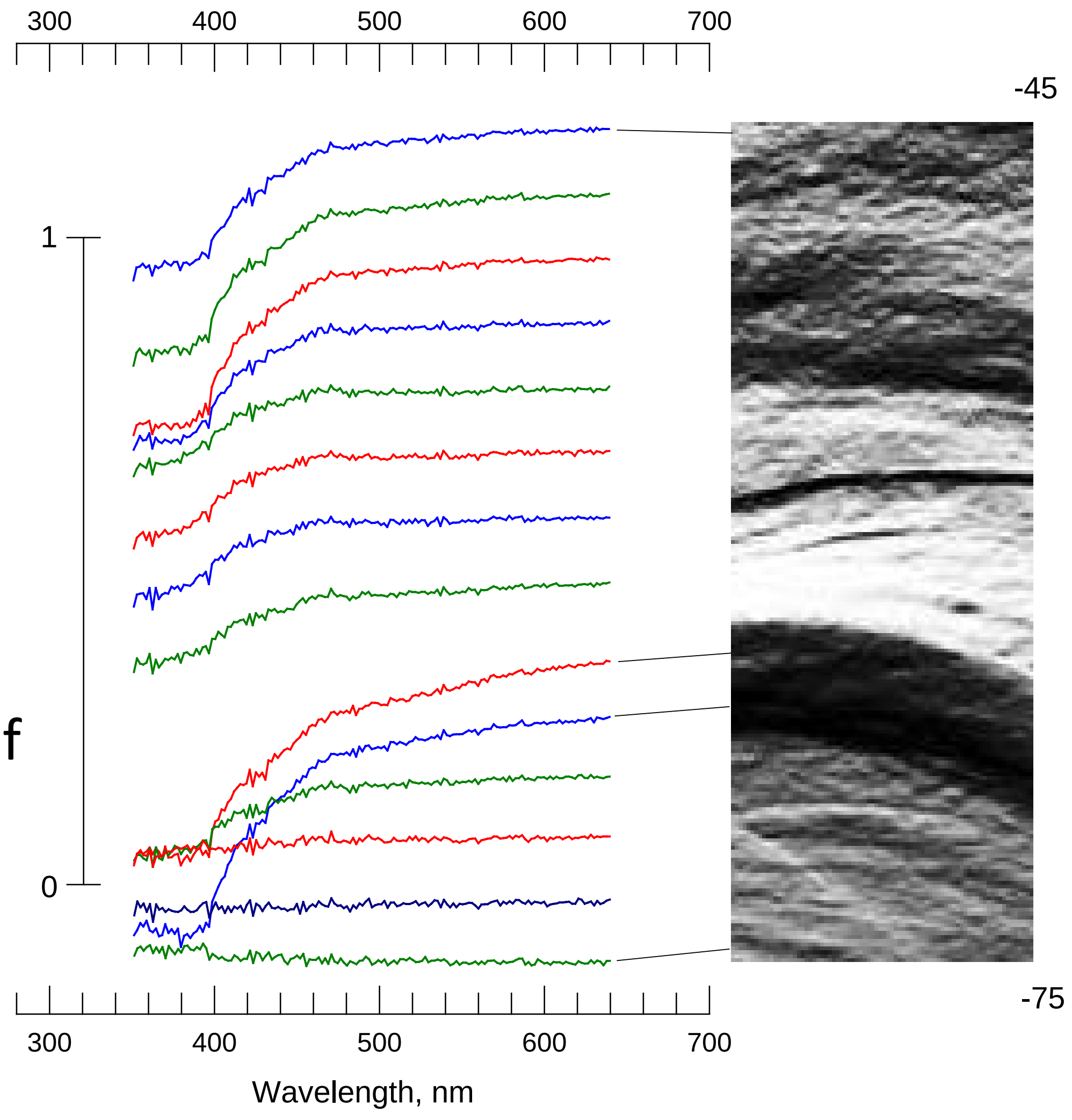


Fig. 7. VV0459 ratio spectra using a UV-bright cloud region at ~ -74° as a white reference. Note the polymeric sulfur absorption.