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Analysis of Venusian UV phase curves acquired by the UV camera onboard Akatsuki

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The 100% cloud coverage of Venus leads to its high reflectance of the solar irradiance. However, in the ultra-violet (UV) range Venus' brightness is reduced due to the absorptions of an unknown absorber and SO_2 gas. The unknown absorber is a mystery not only for its chemical composition, but also for its vertical location. This latter factor is an important constraint to estimate a solar heating rate. In this study, we use disk-integrated phase curves and estimate a possible vertical location of the unknown absorber, relative to the cloud top level. We also expand the same method to estimate the SO_2 gaseous abundance at the cloud top level.

We used 283 and 365-nm narrow filter images taken by the UV camera onboard Akatsuki (UVI, [1]). We have selected global Venus images with a sufficient signal over 3 years (2016-2018) to calculate the disk-integrated reflectance. Total ~6,000 images per filter have been collected in a broad range of solar phase angle, 0-155°, and we calculated mean phase curves at the two UV wavelengths as shown in Fig.1. We used a pre-conditioned backward Monte Carlos (PBMC) algorithm that solves the vector radiative transfer equation [2] to fit the observed mean phase curves. This PBMC was successfully used to analyze Venus' phase curves in the visible range [3]. In this study, we assumed a global Venus cloud top structure with a 70-km cloud top level (unity tau) and a 4-km aerosol scale height, and changed a relative location of the unknown absorber layer from the assumed cloud top level. Cloud aerosols' microphysical properties were taken from previous observation analysis [4,5]. We find that the 365-nm phase curve is sufficiently sensitive on the vertical location of the unknown absorber, as this is the only one absorption agent. Our best fits suggest that the unknown absorber layer should be centered at 3 km below the cloud top level, or lower, regardless of its thickness (2, 6, 10 km thickness, Fig. 2 shows that with the 6-km thickness). The 283-nm phase curve has been analyzed for the first time. However, we find a difficulty on a distinction of absorbing agents between the SO_2 gas and the unknown absorber (Fig. 3), using only the phase curve.

We have analyzed the 3-year mean solar phase curves at 283 and 365 nm acquired by UVI/Akatsuki. Our results at 365 nm suggest that the unknown absorber layer should be located near and below the cloud top level, but not above. This supports the analysis of Pioneer Venus observations [6], suggesting that the unknown absorber is a layer below the cloud top level. We rule out a well-mixed layer above the cloud top level, which was suggested as a possible solution [7].

Our analysis shows its limit at 283 nm to understand abundance of the SO_2 gas due to the overlapped absorption of the unknown absorber. This limitation perhaps can be able to overcome with spectral information, such as planned observation by the UV spectrometer onboard BepiColombo during its cruise phase (August 2020).

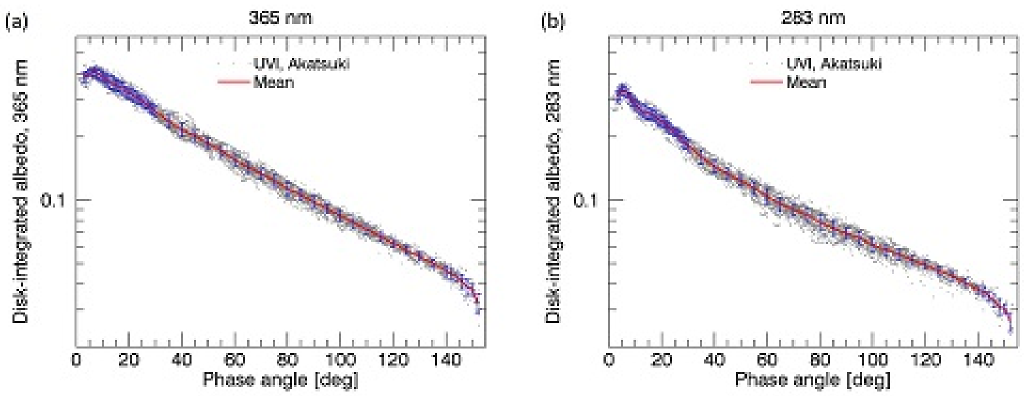

Figure 1 Observed mean disk-integrated reflectance at 365 nm (a) and 283 nm (b) as a function of solar phase angle (degree). Grey dots are individual data points, and the red curve is an average over 3 years (2016-2018).

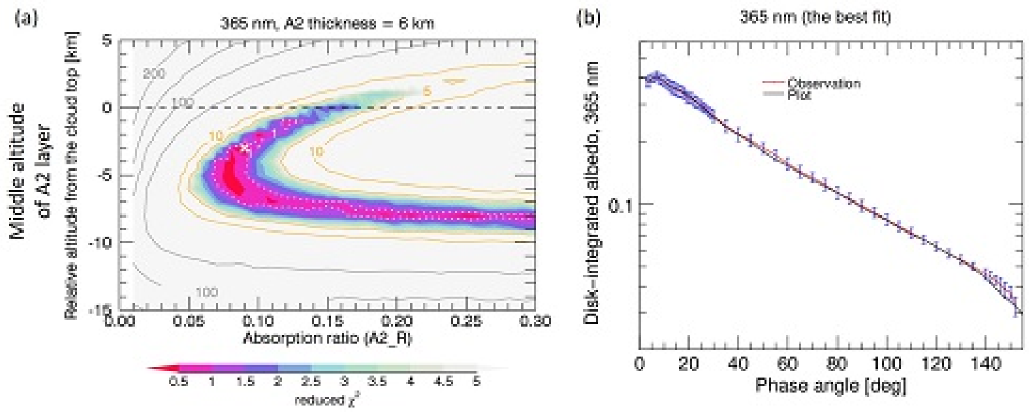

Figure 2 Analysis at 365 nm with an assumed 6-km thick unknown absorber layer. A2 refers to the unknown absorber. (a) Reduced Chi-square contour compared to the observed phase curve. Free variables are an absorption ratio of the unknown absorber (A2_R) at 365 nm and a vertical location of the unknown absorber layer. Dashed line indicates the cloud top level, 70 km, so '-' means below the cloud top level and '+' means above. (b) A comparison between the observed mean phase curve (red) and a simulated best-fit curve (black, the 'x' mark on (a)).

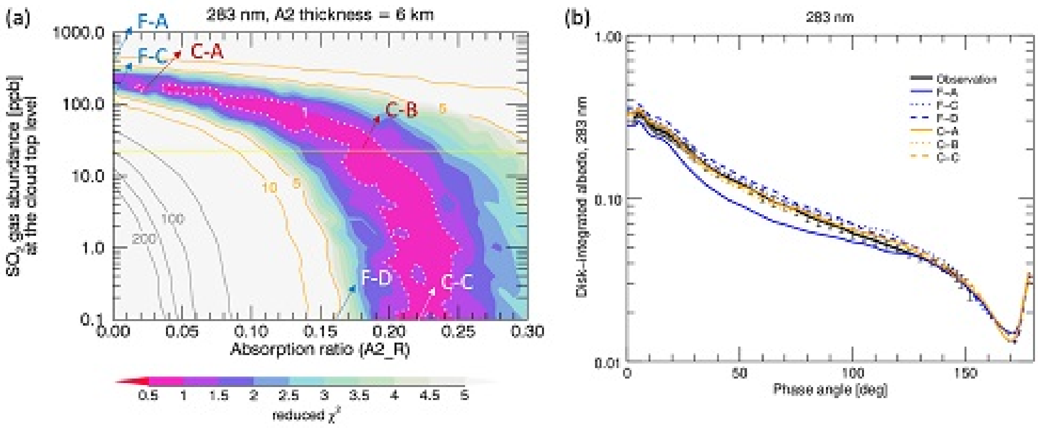

Figure 3 Analysis at 283 nm. This used the best-fit condition of the unknown absorber layer as retrieved in Fig.2: the 6-km thick layer of unknown absorber is centered at 3 km below the cloud top level. (a) Reduced Chi-square contour, compared to the observed phase curve. Free variables are an absorption of the unknown absorber (A2_R) at 283 nm and an abundance of SO_2 gas at the cloud top level (70 km). The yellow line indicates the mean SO_2 gas abundance retrieved from ground-based mid-IR observations cloud top level in 2016-2018 (22.4 ppbv at 70 km. This is a converted value from the 450 ppbv at 61 km [8] using the same manner in [9]). (b) Comparison between the observed mean phase curve (red) and simulated curves (blue and oranges), as indicated in (a).

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