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# Ground-based mapping of $SO_2$ and HDO on Venus in the thermal infrared

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## Abstract

Since January 2012 we have been monitoring the behavior of sulfur dioxide and water on Venus, using the Texas Echelon Cross-Echelle Spectrograph (TEXES) imaging spectrometer at the NASA InfraRed Telescope Facility (IRTF, Mauna Kea Observatory). Data were recorded around 1345 $cm^{-1}$ (7.4 µm) and 530 $cm^{-1}$ (19 µm). The molecules $SO_2$, $CO_2$, and HDO (used as a proxy for $H_2O$) were observed at the cloudtop of Venus at 7.4 µm, and a few km below at 19 µm. The volume mixing ratio of $SO_2$ was estimated using the $SO_2/CO_2$ line depth ratios of weak transitions; the $H_2O$ volume mixing ratio was derived from the HDO/$CO_2$ line depth ratio, assuming a D/H ratio of 200 times the terrestrial value (VSMOW). The $SO_2$ mixing ratio shows strong variations with time and over the disk, showing evidence for the formation of $SO_2$ plumes with a lifetime of a few hours; in contrast, the $H_2O$ abundance is remarkably uniform over the disk and shows moderate variations as a function of time. We performed a statistical analysis of the behavior of the $SO_2$ plumes, using all TEXES data at 7.4 µm between 2012 and 2018. The plumes appear mostly located around the equator. Their distribution as a function of local time seems to show a depletion around noon, which remains to be confirmed. There is a good agreement between the TEXES results and those obtained in the UV range (SPICAV/Venus Express and UVI/Akatsuki) at a slightly higher altitude. A comparison of TEXES data at 7.4 and 19 µm can be used to retrieve information about the vertical distribution of $SO_2$, which shows a depletion above the cloudtop [1-4].

## 1. Short-term variations of $SO_2$

Figure 1 shows examples of $SO_2$ and HDO maps recorded with TEXES. The two pairs of $SO_2$ maps, separated by 2 hours, were taken on two consecutive days. It can be seen that the $SO_2$ distribution is very patchy; the $SO_2$ plumes sometimes follow the 4-day rotation of Venus at the cloudtop over a timescale of 2 hours, but disappear within 24 hours. In contrast, the HDO distribution is very uniform over the disk.

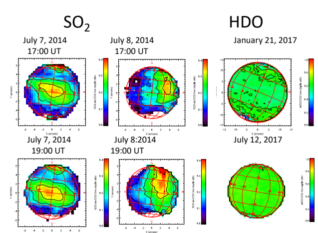


Figure 1: Examples of TEXES maps of $SO_2$ (left and middle) and HDO (right)

## 2. Long-term variations of $SO_2$ and $H_2O$

Figure 2 shows the variations of the disk-integrated mixing ratios of $H_2O$ and $SO_2$ between January 2012 and September 2018. While the $H_2O$ abundance shows a slow decrease by a factor of about 2 (from about 1 ppmv to 0.5 ppmv) between 2016 and 2018, the $SO_2$ abundance exhibits changes by as much as a factor 20, with a minimum of 30 ppbv in February 2014 and a maximum of 600 ppbv in July 2018.

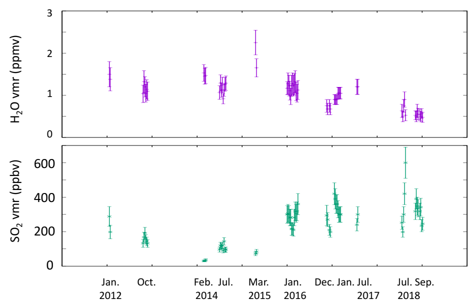


Figure 2: Long-term variations of the disk-integrated mixing ratios of $H_2O$ (top) and $SO_2$ (bottom) measured by TEXES between 2012 and 2018.

## 3. Statistical analysis of the $SO_2$ plumes: comparison with space data

We have analyzed the behavior of the $SO_2$ plumes as a function of latitude, longitude and local time. This study has shown that they are mostly located around the equator, with a depletion around noon and two possible maxima around the terminators. More data will be needed to confirm the existence of a semi-diurnal wave. The depletion around noon is also observed in the $SO_2$ distribution retrieved in the UV by SPICAV/VEx [5] (Fig. 3); a very good agreement is also observed between the $SO_2$ measurements recorded by TEXES and the ones obtained in the UV by UVI/Akatsuki (Fig. 4). This comparison shows that the $SO_2$ measurements obtained in the thermal infrared can be used to complement, in the night side, the space data recorded in the UV on the dayside.

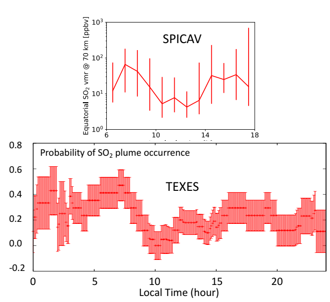


Figure 3: The $SO_2$ abundance recorded by SPICAV (top) and the probability of the $SO_2$ plume occurrence as measured by TEXES (bottom) as a function of local time.

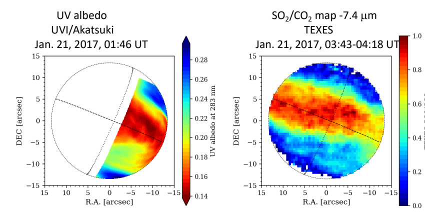


Figure 4: The $SO_2$ abundance measured in the UV by UVI/Akatsuki (left) and in the IR by TEXES (right)

## 4. Vertical distribution of $SO_2$

Simultaneous observations of TEXES at 7.4 µm and 19 µm have allowed us to probe $SO_2$ at two different levels, at the cloudtop and a few kilometers below within the clouds. In addition, the widths of the $SO_2$ lines, broader than the $CO_2$ lines, have allowed us to constrain the $SO_2$ vertical profile which shows a clear depletion above the cloudtop [2]. By combining the use of weak and strong $CO_2$ lines, we have shown that, in the polar collars, the morning terminator is colder than the evening one, showing evidence for a cold diurnal longitudinal wave [2]. In a forthcoming study, we are going to analyze the whole TEXES dataset at 7.4 and 19 µm to refine the vertical distribution of $SO_2$ as a function of latitude and local time.

## Acknowledgements


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## References


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