Ground-based thermal mapping of Venus: HDO & SO_2 monitoring and upper limits of PH_3, NH_3 and HCN at the cloud top

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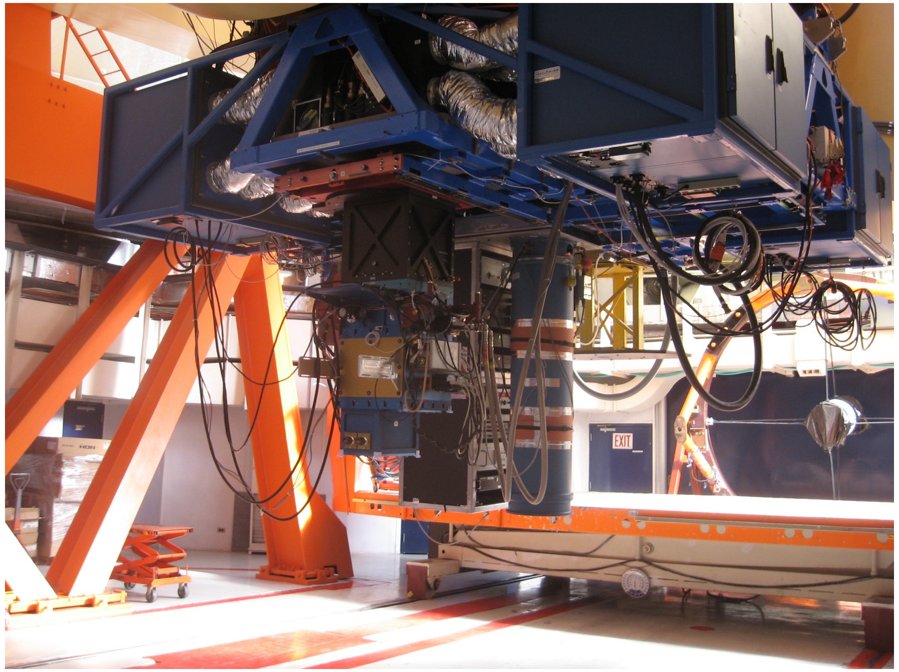
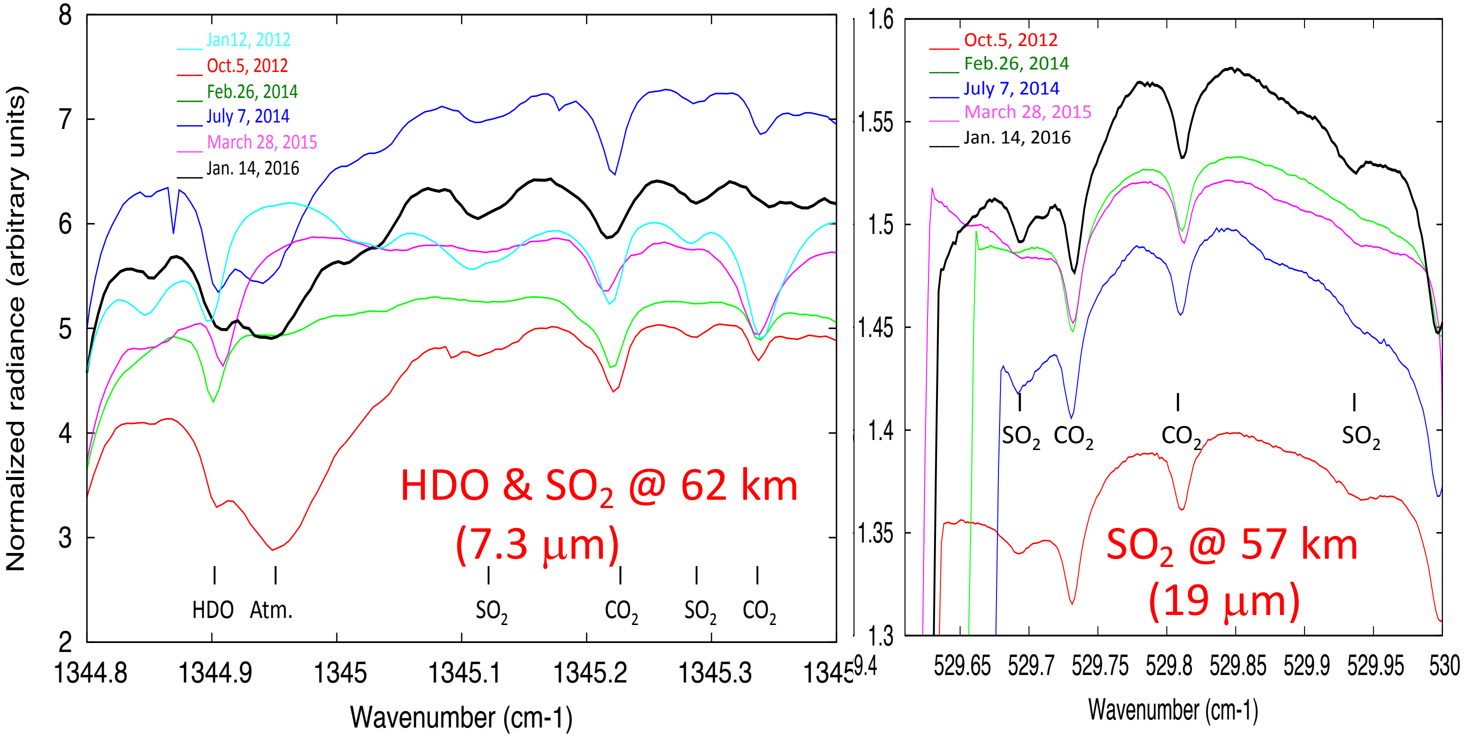
TEXES @ IRTF, Mauna Kea Observatory, Hawaii



TEXAS Echelon Cross Echelle Spectrograph 5 – 25 μm,
R = 8 10^4 @ 7 μm
Main question: To understand the SO_2 & H_2O cycles above and within the clouds

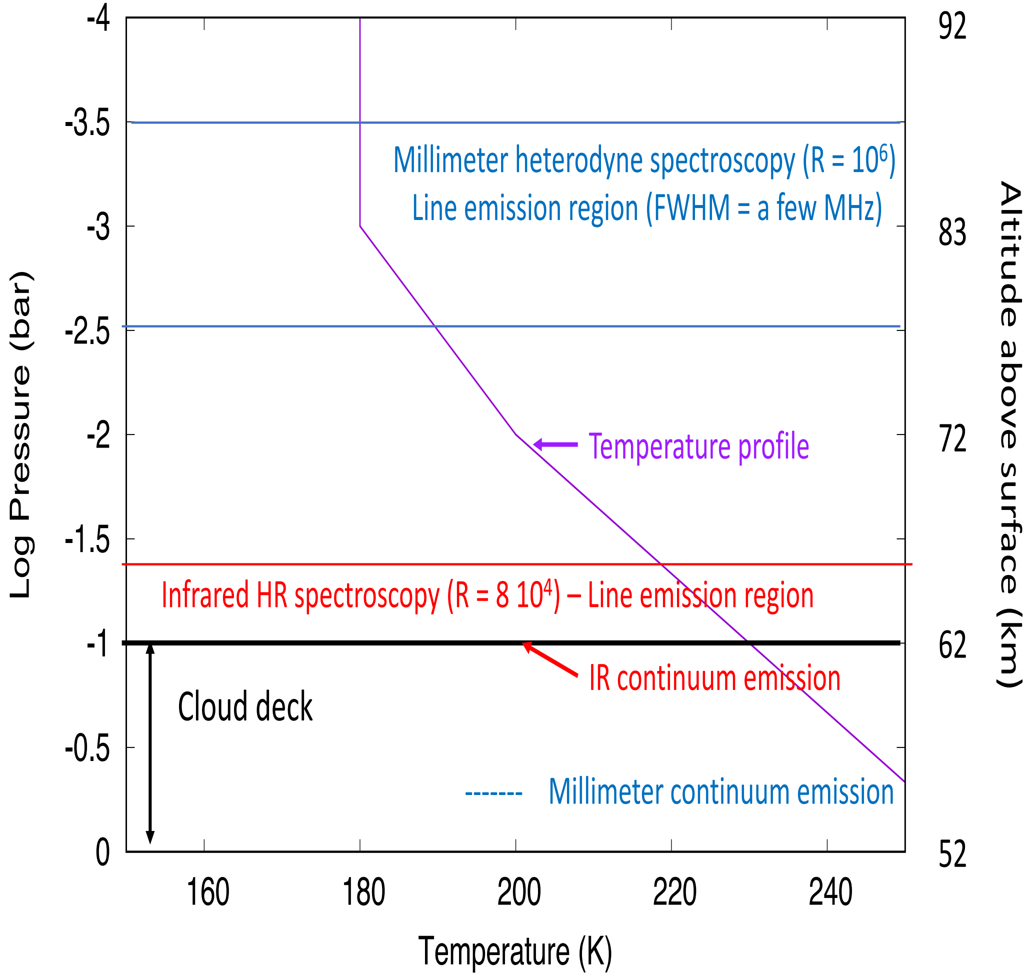
Observing program: Mapping of SO_2 (at 7 and 19 μm) and H_2O (through HDO) at 7 μm

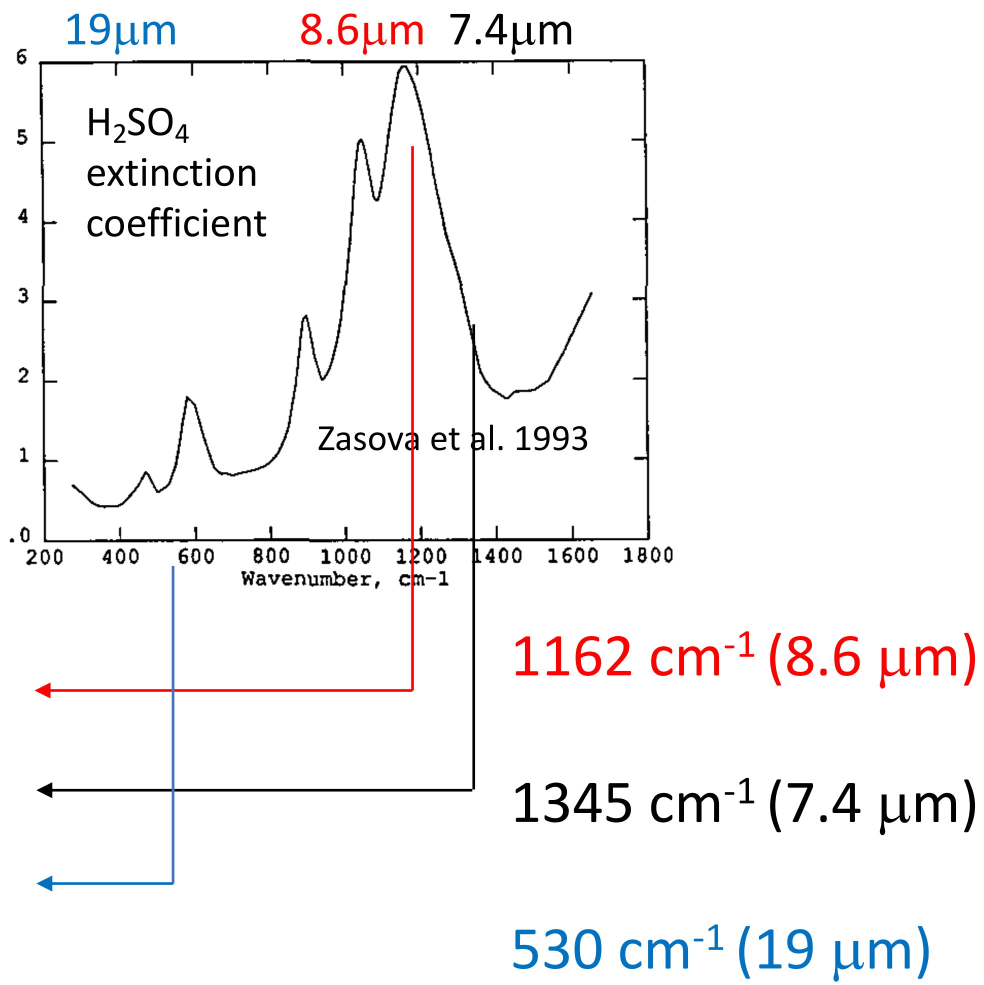
- Cloud top probed at 7 μm (z = 62 km, T = 235 K, P = 150 mbar)
- Within the cloud at 19 μm (z = 57 km, T = 241 K, P = 250 mbar)
- Above the clouds at 8.6 μm (z=67 km)
- 12 campaigns between January 2012 and April 2019; 11 campaigns since 2021: June, Sept. & Nov. 2021, Feb. & June 2022, March, July, Oct. & Dec. 2023, Feb. 2024



Where does the radiation come from?

Due to the spectral dependence of the H_2SO_4 absorption coefficient, different levels are probed at 1162 cm^{-1} (67 km), 1345 cm^{-1} (62 km) and 530 cm^{-1} (57 km)

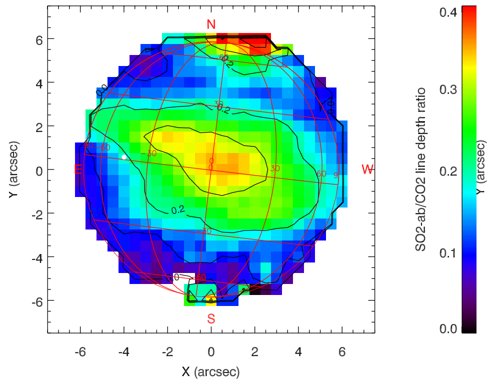




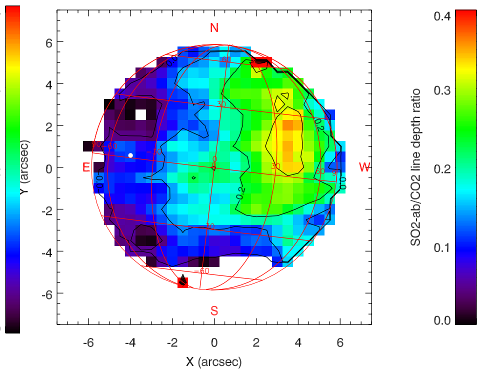
SO_2 & HDO maps exhibit a different behavior

The SO_2 plume follows the 4-day rotation of the clouds at the cloud top over a time scale of a few hours

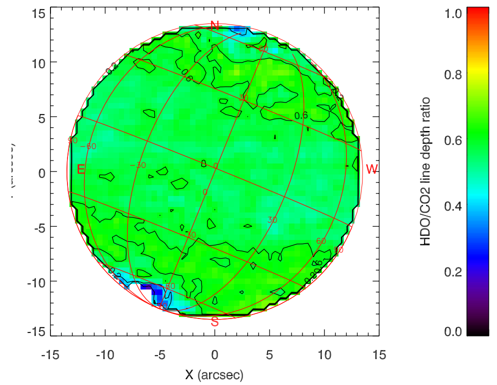
July 7, 2014
17:00 UT



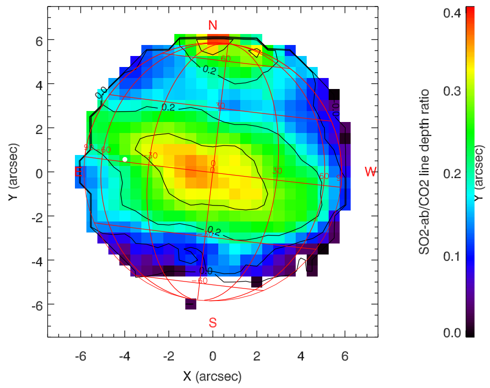
July 8, 2014
17:00 UT



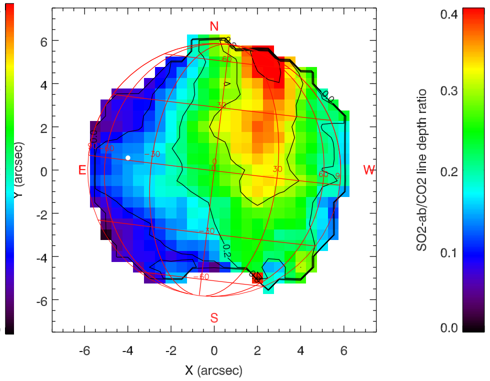
January 21, 2017



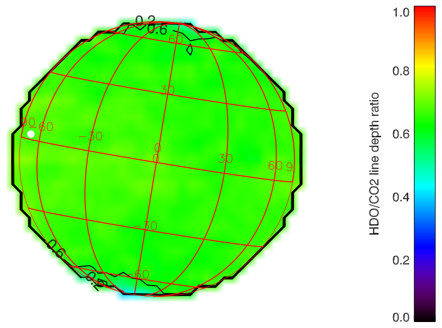
July 7, 2014
19:00 UT



July 8:2014
19:00 UT



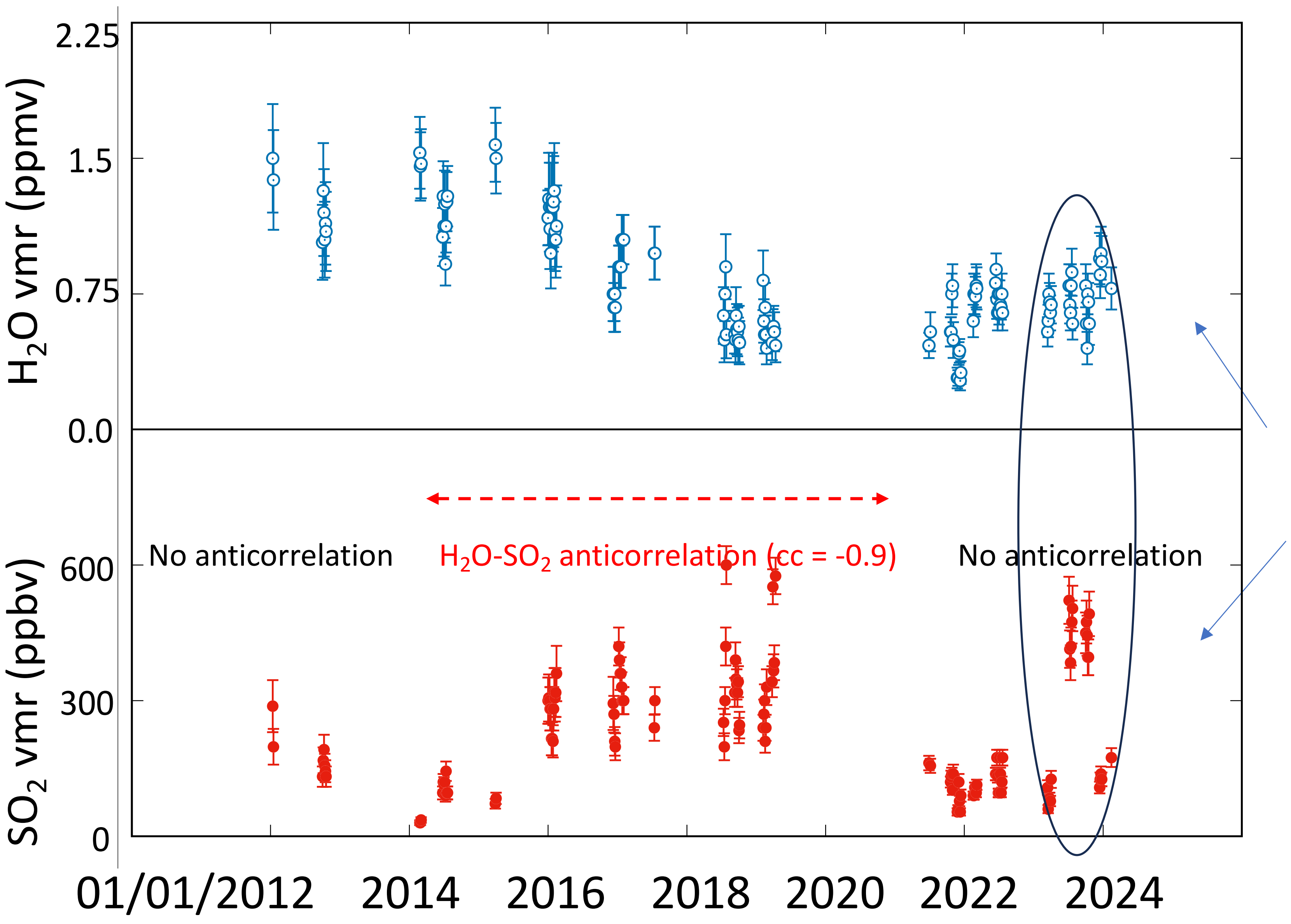
July 12, 2017



SO_2 maps are very inhomogeneous over the disk and show strong variations with time

HDO maps are uniform over the disk and +/- constant over time

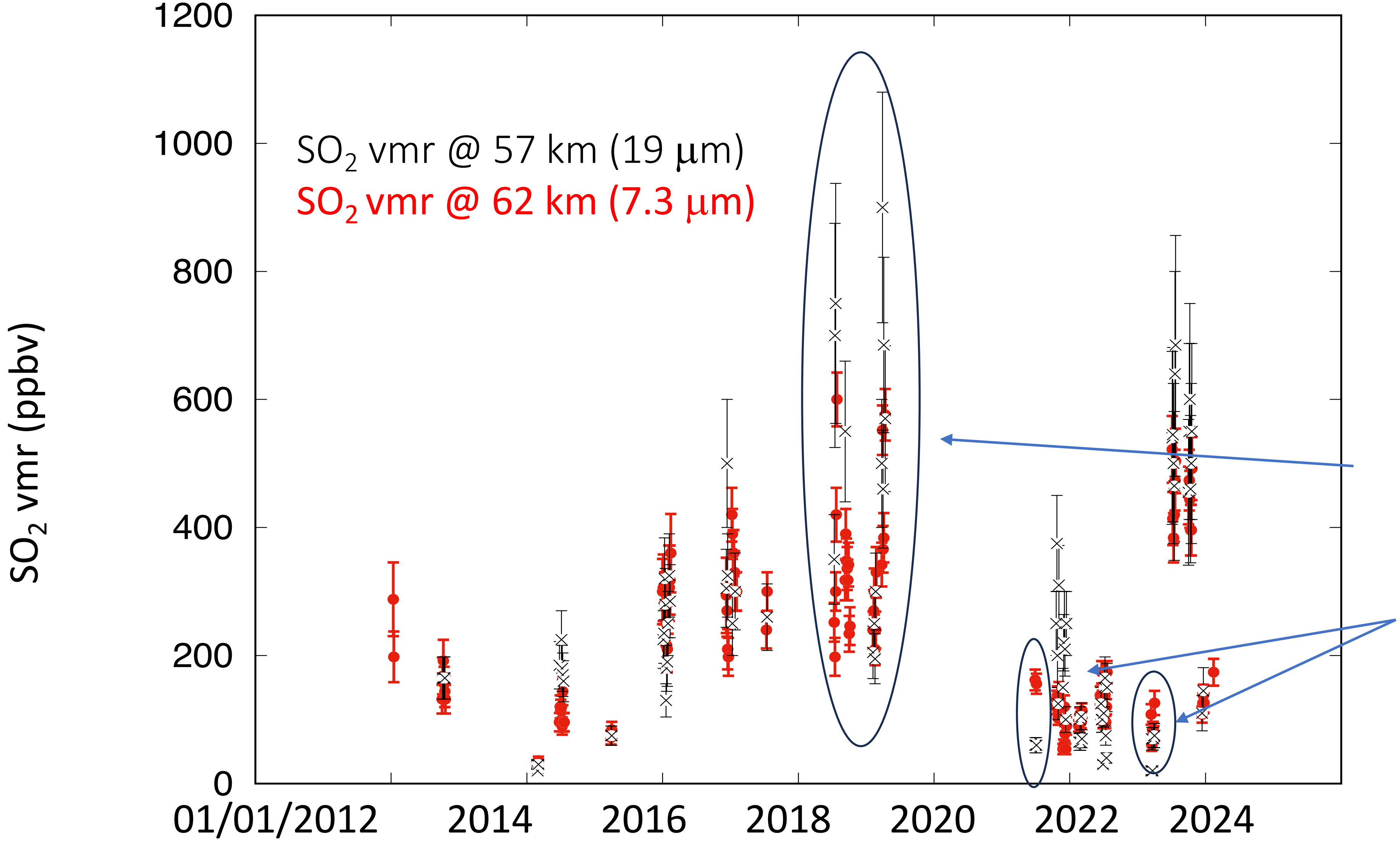
Long-term variations of H_2O and SO_2 at the cloud top (z = 62 km)



July – September 2023:

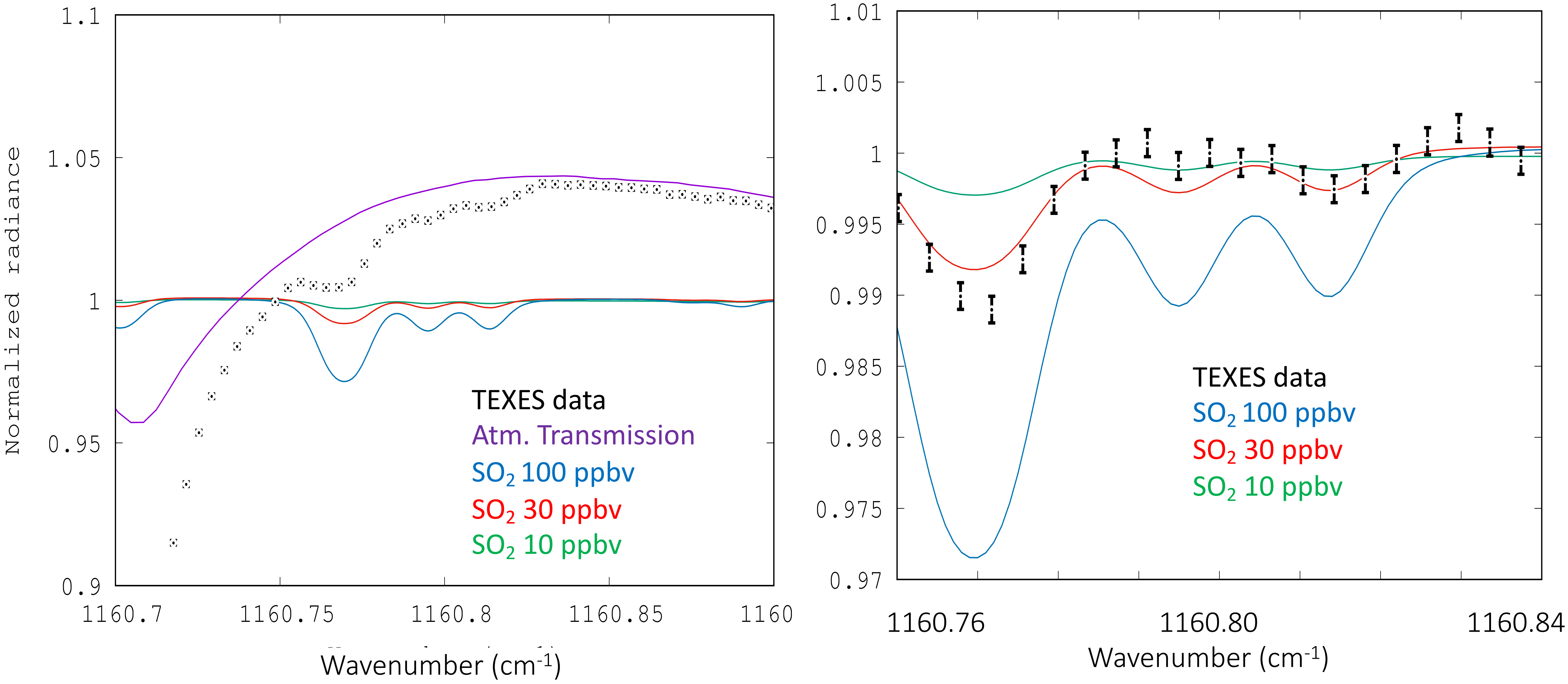
Sudden increase of SO_2, no change in H_2O

Long-term SO_2 variations at the cloud top (z = 62 km) and within the cloud (z = 57 km)

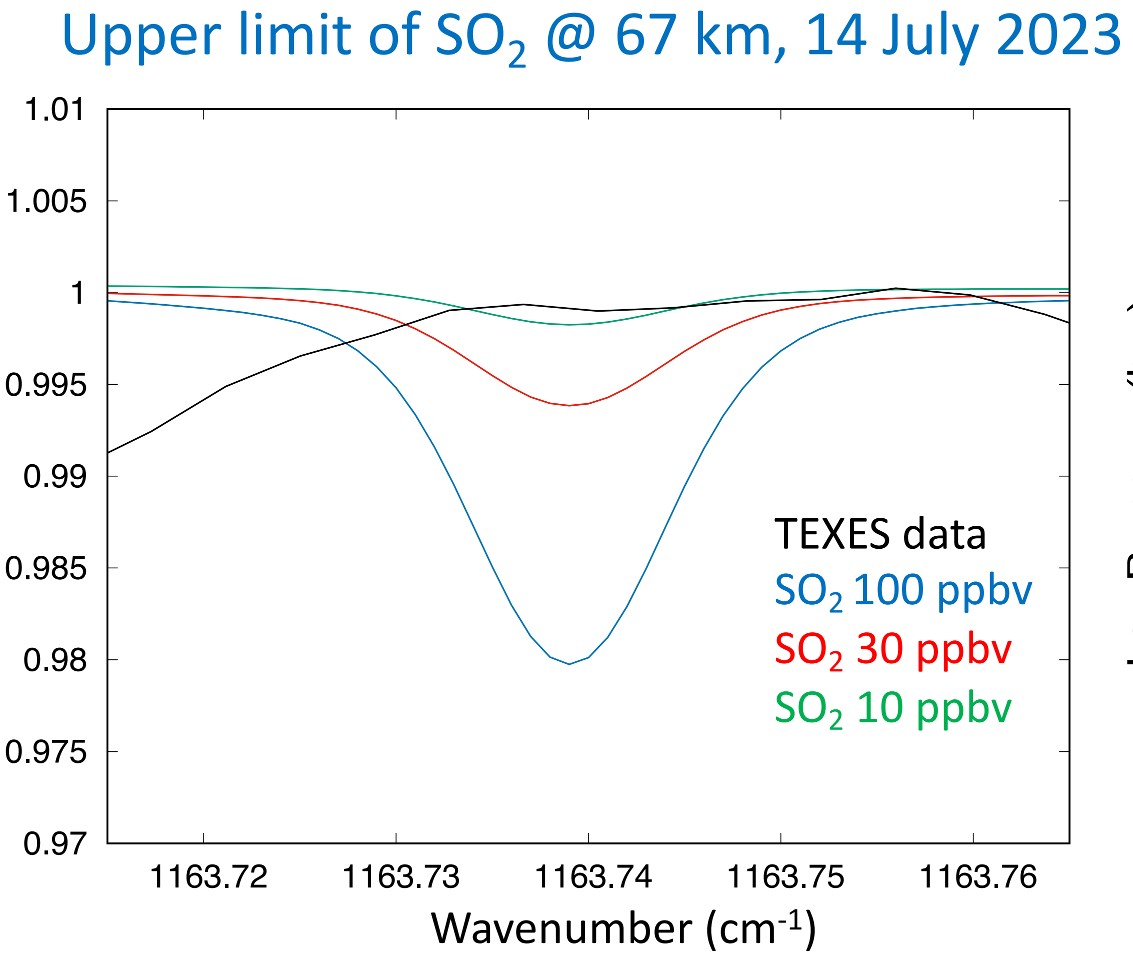


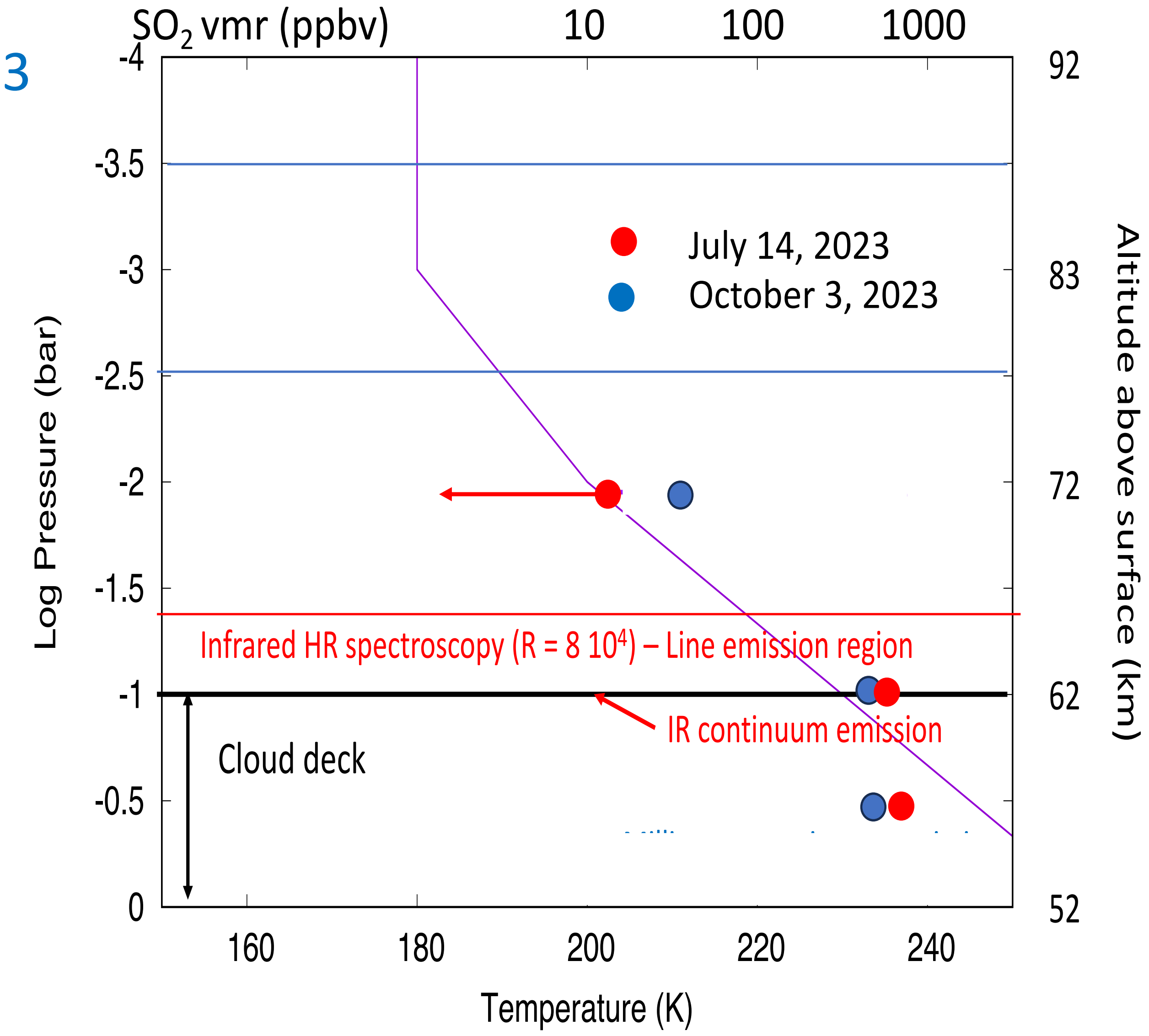
SO_2 @ 57 km is usually comparable to SO_2 @ 62 km, but, in some cases, may be **much larger** (2019) or **even lower** (June 2021, March 2023)

First detection of SO_2 in the ν_1 SO_2 band at 1160 cm^{-1} (8.6 μm)
October 3, 2023



Detection of SO_2 at 67 km on Oct. 3, 2023





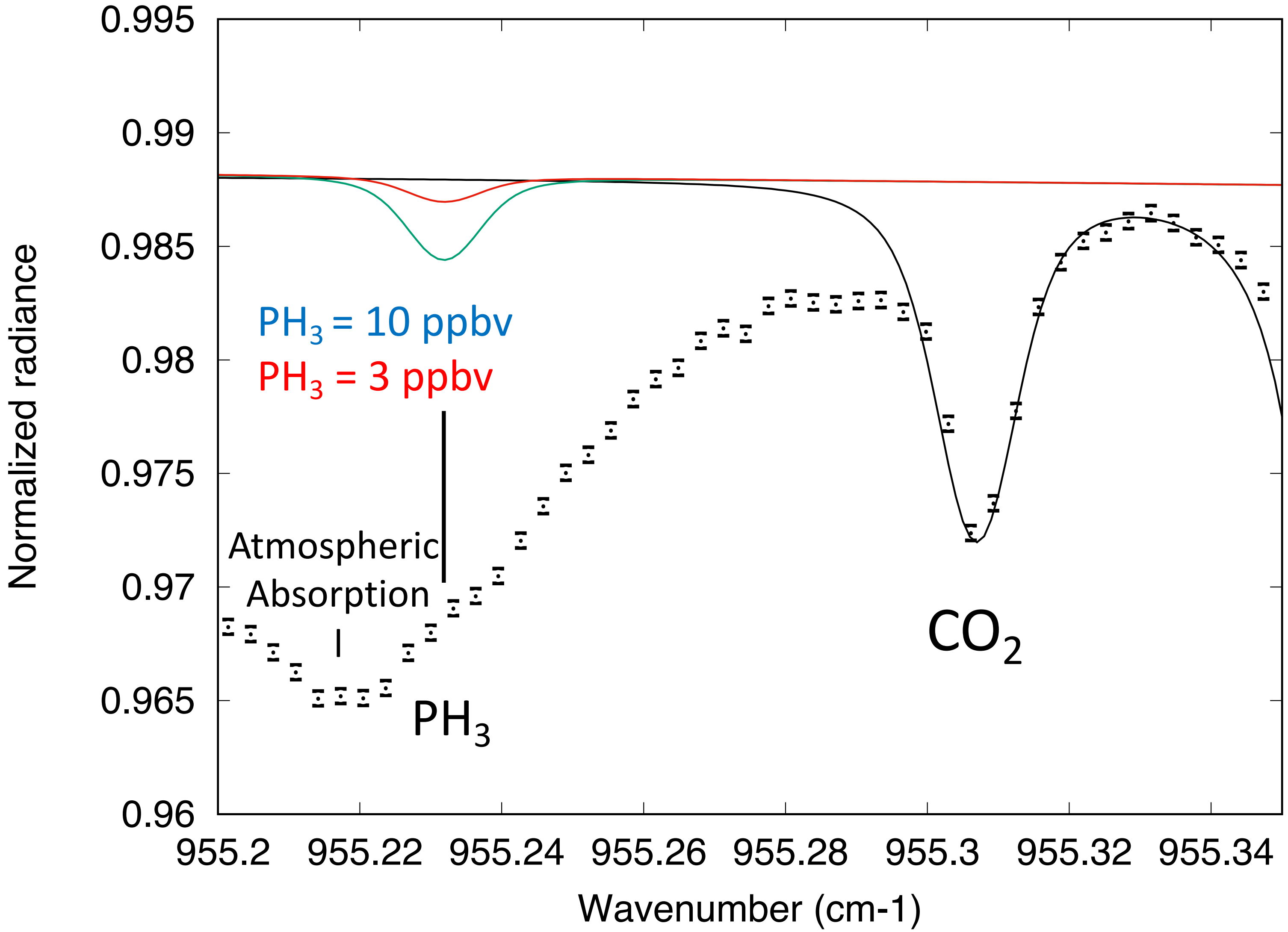
July 14, 2023: SO_2(67km)/SO_2(62km) < 50

October 3, 2023: SO_2(67km)/SO_2(62km) = 20

Upper limits of minor species at the cloud top of Venus

- Attempts to detect minor species in Venus have been reported in the literature :
  - PH_3: detection, up to 20 ppbv (Greaves et al. 2020, +)
  - HCN: upper limit, 38.3 +/- 7.9 ppmv @ 80 km (Mahieux et al. 2023)
  - NH_3: upper limit, 0.69 +/- 0.28 ppmv @ 80 km (Mahieux et al. 2023)
- New upper limits have been obtained with TEXES (present work):
  - PH_3: **1 ppbv** (σ) at the cloud top (62 km)
  - NH_3: **0.1 ppbv** (σ) at the cloud top (62 km)
  - HCN: **0.1 ppbv** (σ) at the cloud top (62 km)

PH_3 upper limit at the cloud top



Data: TEXES, July 16, 2023

Upper limit:

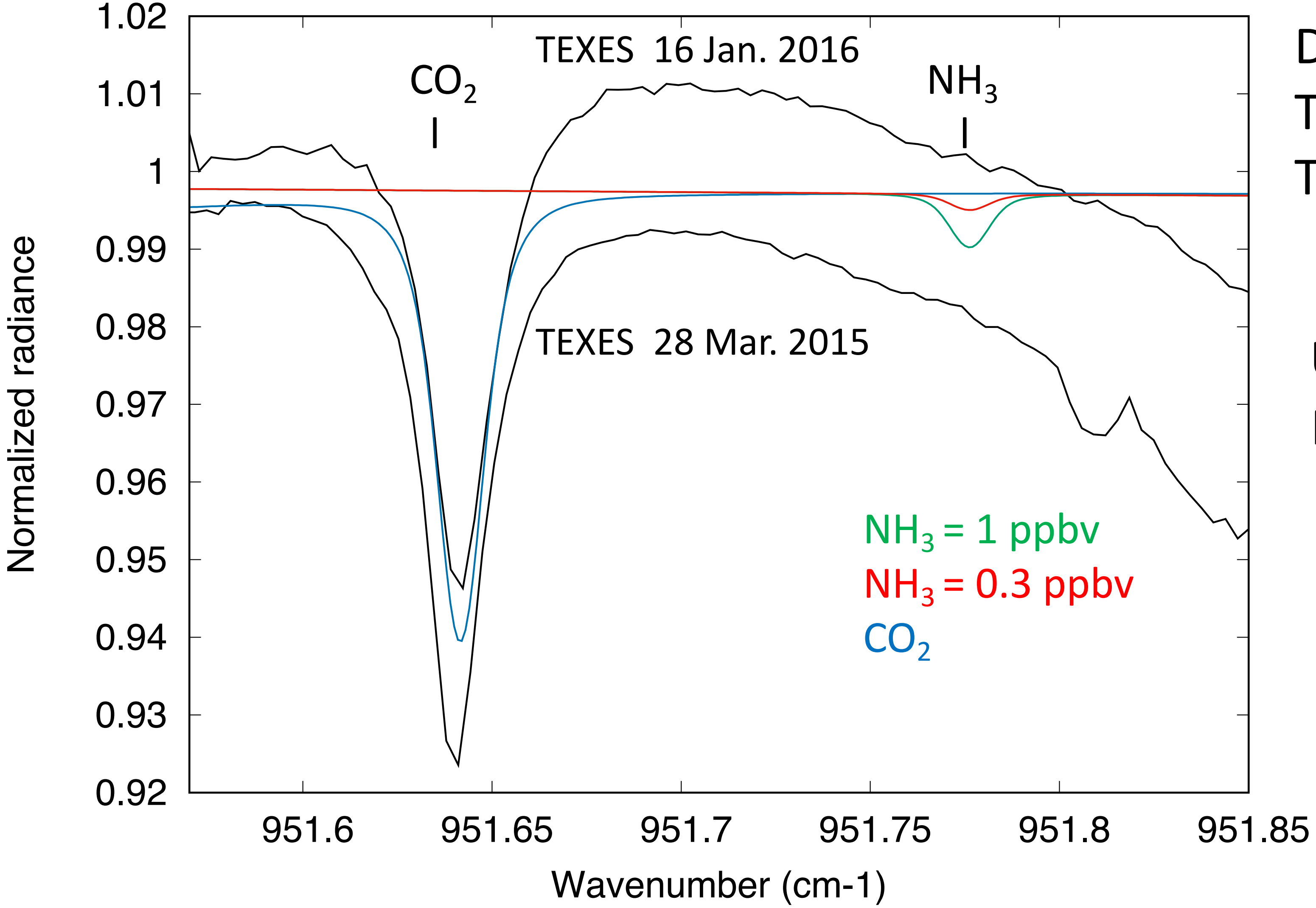
$PH_3 < 3$ ppbv (3σ)

Confirms our earlier analysis:

PH3 < 5 ppbv (3σ)

(Encrenaz et al. A&A 643, L5 (2020)

NH_3 upper limit at the cloud top



Data:

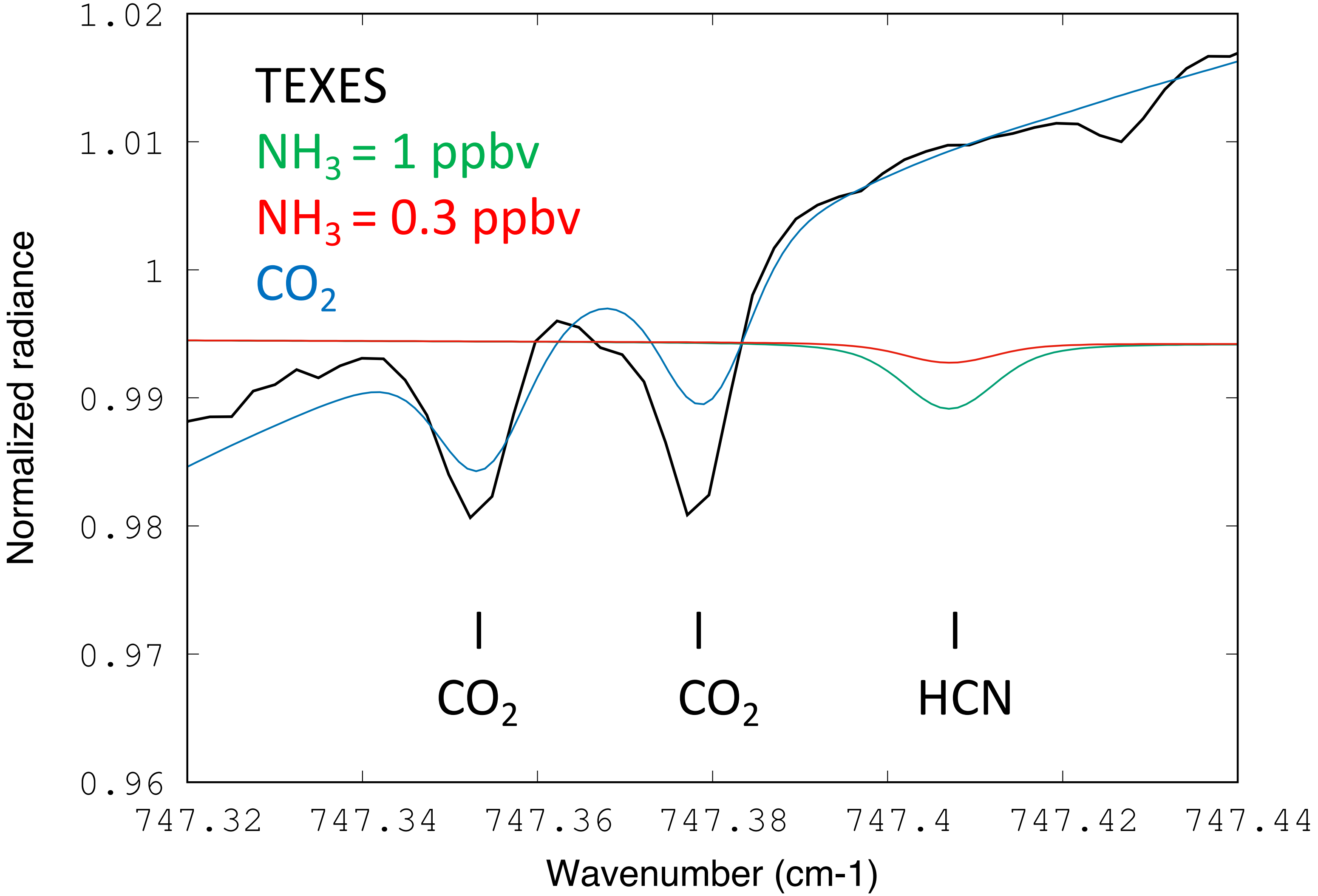
TEXES, March 28, 2015

TEXES, January 16, 2016

Upper limit:

$NH_3 < 0.3$ ppbv (3σ)

HCN upper limit at the cloud top



Data:

TEXES, July 15, 2023

Upper limit:

HCN < 0.3 ppbv (3σ)

Conclusions

- Since 2012, SO_2 has been mapped over the Venus disk and monitored at z = 62 km (cloud top, 7.4 μm) and 57 km (19 μm); it was searched for without success at 67 km (8.6 μm) until 2023.
- H_2O (using HDO as a proxy) was simultaneously mapped and monitored at the cloud top (7.4 μm).
- H_2O & SO_2 exhibit different behaviors at the cloud top of Venus:
  - H_2O is uniform over the disk and shows moderate temporal variations.
  - SO_2 shows strong spatial and temporal variations in the form of transient plumes and strong long-term variations .
- The long-term variations of H_2O and SO_2 were clearly anti-correlated between 2012 and 2019, but not before nor after.
  - The anticorrelation might be the result of photochemical processes, while convection might favor the mixing of the two species. The lack of anticorrelation after 2019 might indicate a change of regime within or below the clouds.
- **Main results:**
- **SO_2 is detected for the first time on Oct.3, 2023;** SO_2(67km)/SO_2(62km) = 1/20 (< 1/50 on 14/07/ 2023)
- **Stringent upper limits** are obtained for PH_3, NH_3 and HCN at the cloud top:
  - **PH_3 < 1 ppbv (1σ), NH_3 < 0.1 ppbv (1σ), HCN < 0.1 ppbv (1σ)**