# Mapping the D/H Ratio in Venus's Lower Atmosphere

## With NASA IRTF/iSHELL Telescope

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**Key message:** Venus' D/H ratio is ~150× VSMOW, but its lower atmosphere and D/H spatial variability remain poorly constrained. This study analyzed new IRTF/iSHELL nightside observations. Simulations with radiative transfer calculations show that $H_2O$ and HDO spectral signatures at 2.32-2.42 μm are both sensitive to the same ~35-40 km region. Preliminary retrieval attempt shows that the D/H is sensitive to model assumptions such as cloud opacity, which suggests a comprehensive sensitivity analysis is needed to evaluate the final uncertainty.

## 1. Scientific Background

- **Venus** and **Earth** were initially similar but their climate diverged completely
- The **D/H ratio** is a key tracer of the planet's water history as it reveals **atmospheric escape**

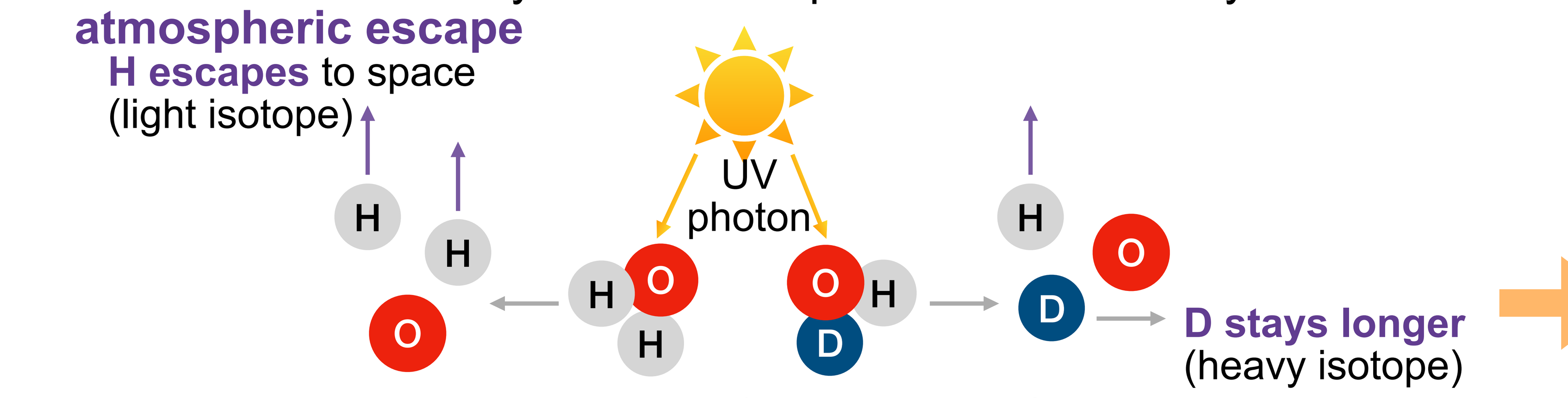



**Fig. 1.** Photodissociation and preferential escape of H relative to D.

**2 evolutionary scenarios**

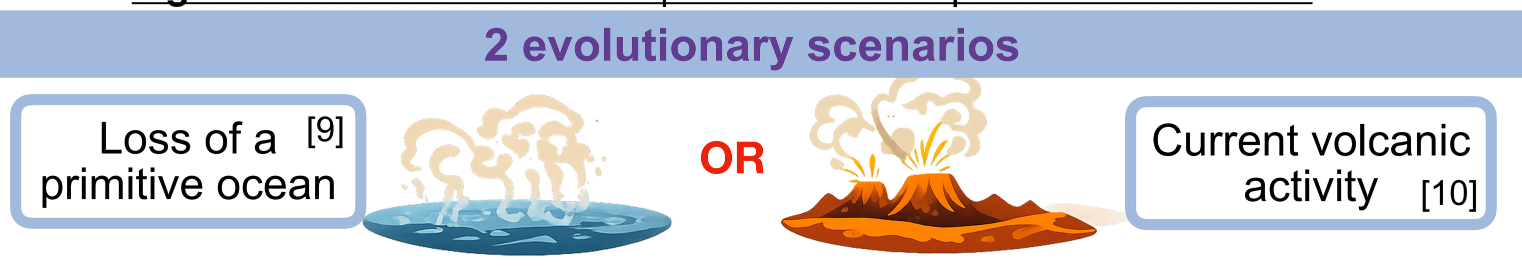
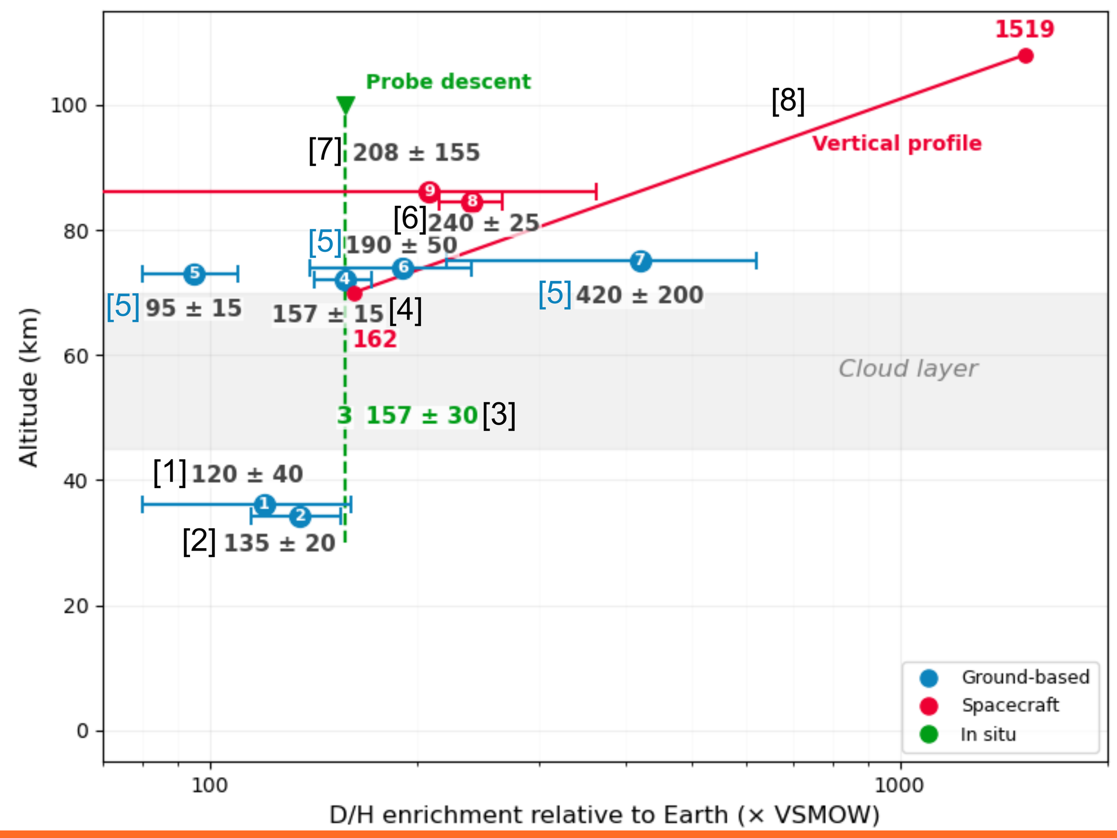



**Fig. 3.** Proposed interpretations of Venus' high D/H

**Fig. 2.** Previous D/H measurements in Venus's atmosphere.




$D/H_{Venus} \approx$ **120 - 150** × $D/H_{Earth}$

- Only **two** measurements **below the clouds**
- No **spatial information** (global values only)
- **Vertical profile** remains poorly constrained
- Large **uncertainties**

**This motivates new high-resolution observations.**

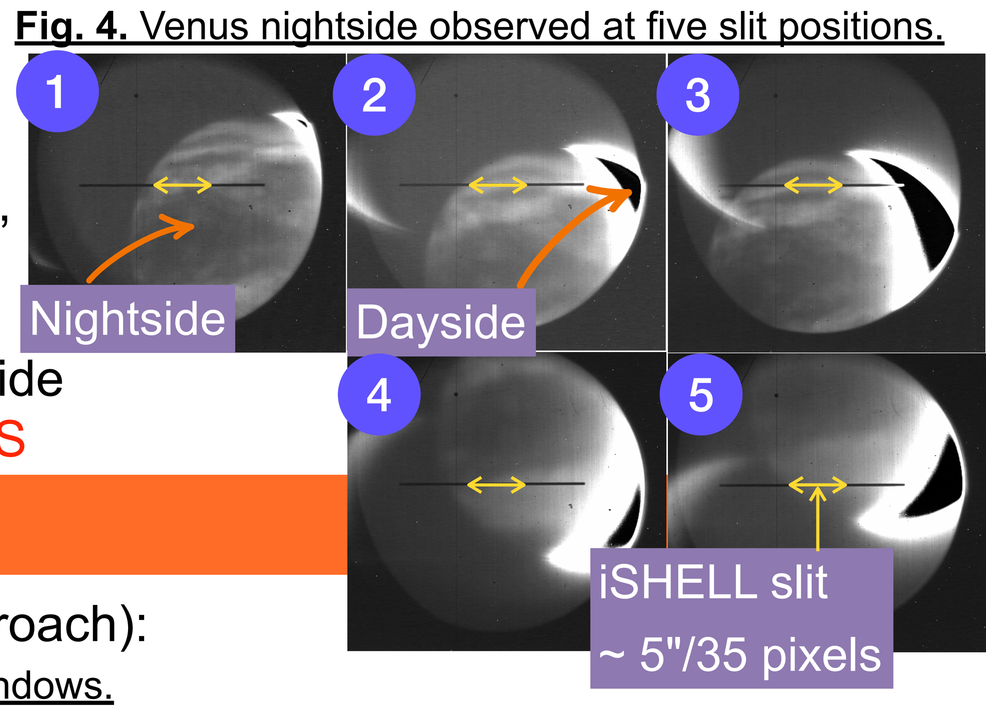
## 2. Scientific Questions and Objectives

1. What is the **D/H ratio below the clouds**?
2. Does D/H **vary spatially**?
3. In the longer term, can spatial variations in D/H provide **clues about present-day activity or Venus's water evolution**?

## 3. Observations

- Data collected on 11 Feb. 2022,
- **Telescope**: NASA Infrared Telescope Facility (IRTF)
- **Instrument**: iSHELL
- **Spectral range**: K3 band (2.26-2.55 μm, 3912-4440 cm-1),
- **Venus angular diameter**: ~41.2"
- **Doppler shift between Earth and Venus**: ~11.31 km/s
- We observe at 5 different positions to cover Venus's nightside
- **Detectable molecules**: $CO_2$, $H_2O$, HDO, CO, $SO_2$, HF, OCS

**Fig. 4.** Venus nightside observed at five slit positions.

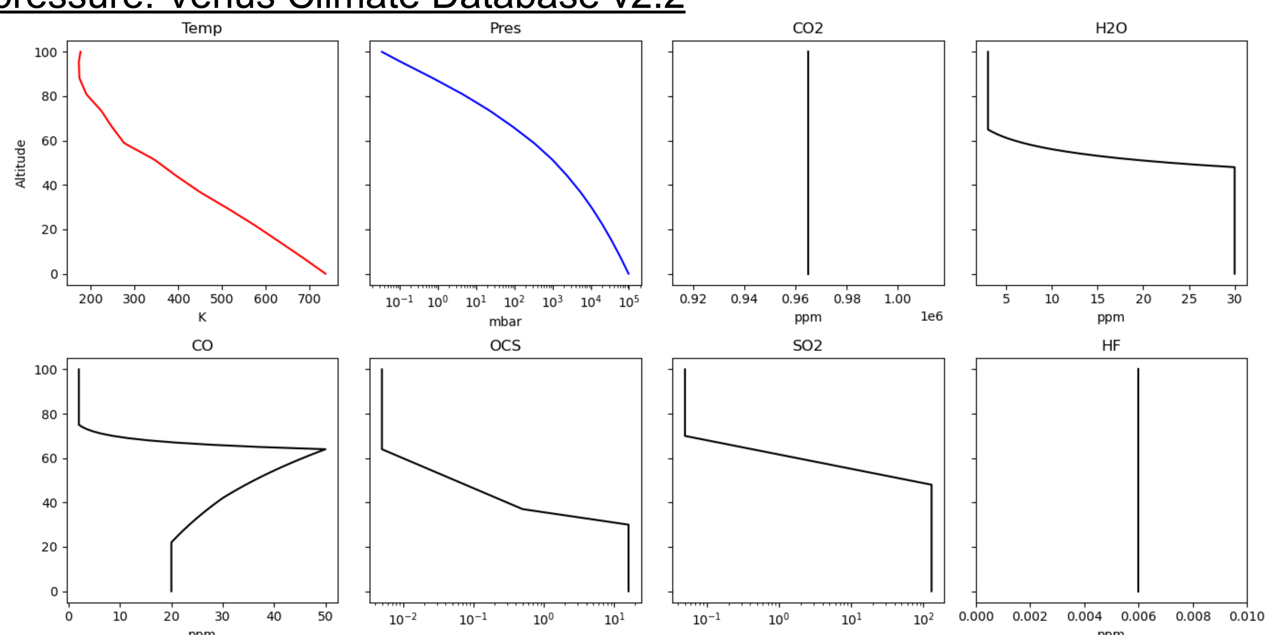



## 4. Method: retrieval of information using ASIMUT radiative transfer model

**Radiative transfer model**: Asimut-Lidort (Vandaele et al., 2006),

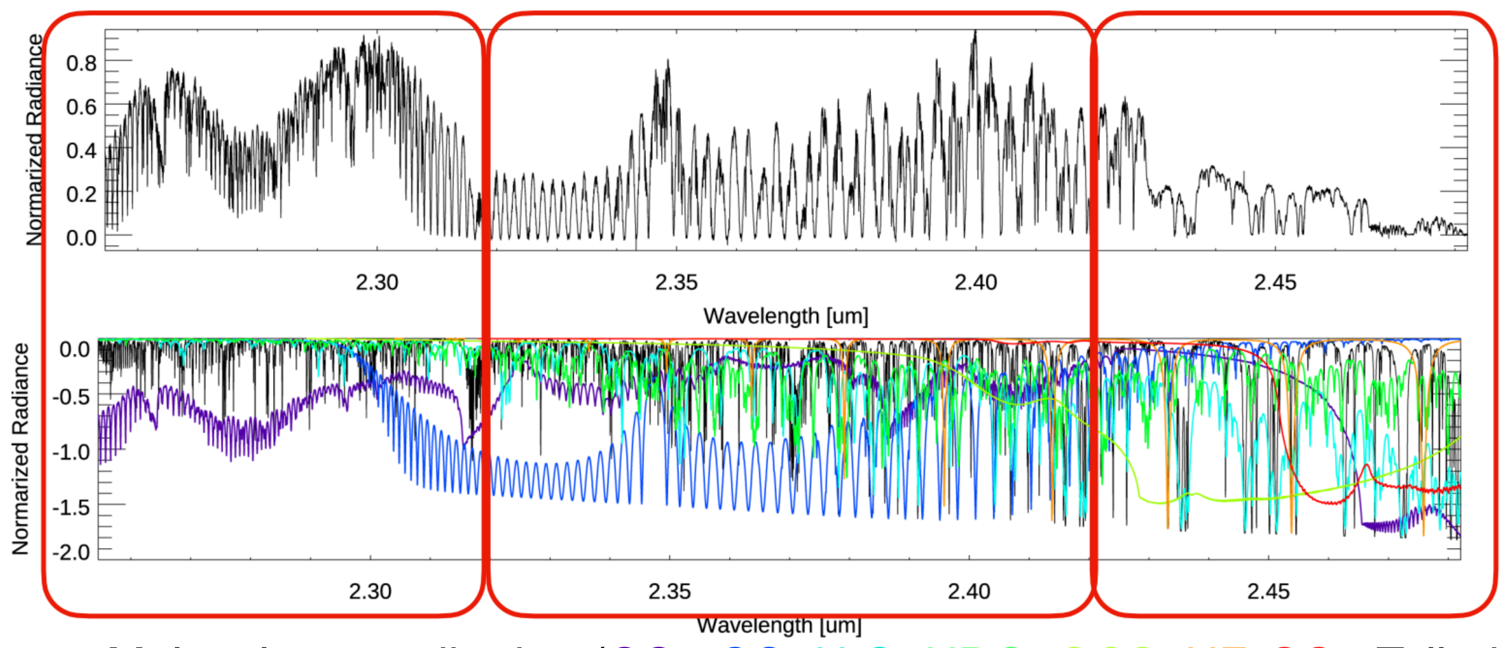
- **Spectroscopy**: HITRAN 2020 database
- **Aerosols**: mode-3 particles only, vertical profile from Haus et al. (2013)
- The effect of $CO_2$ continuum is considered (Bézard et al., 2009, 2011)

**Fig. 5.** Vertical profiles assumed in ASIMUT. Trace-gases: Marcq et al. (2006), temperature and pressure: Venus Climate Database v2.2




- Retrieval in 3 spectral windows (sequential approach):

**Fig. 6.** Sequential retrieval approach using three spectral windows.




(Aoki+2024)[11]

- WIN1 → Telluric lines & Flux calibration factor (2.25-2.32 μm)
- WIN2 → CO, $H_2O$, HDO and HF → D/H (2.32-2.42 μm)
- WIN3 → OCS and $SO_2$ (2.42-2.48 μm)

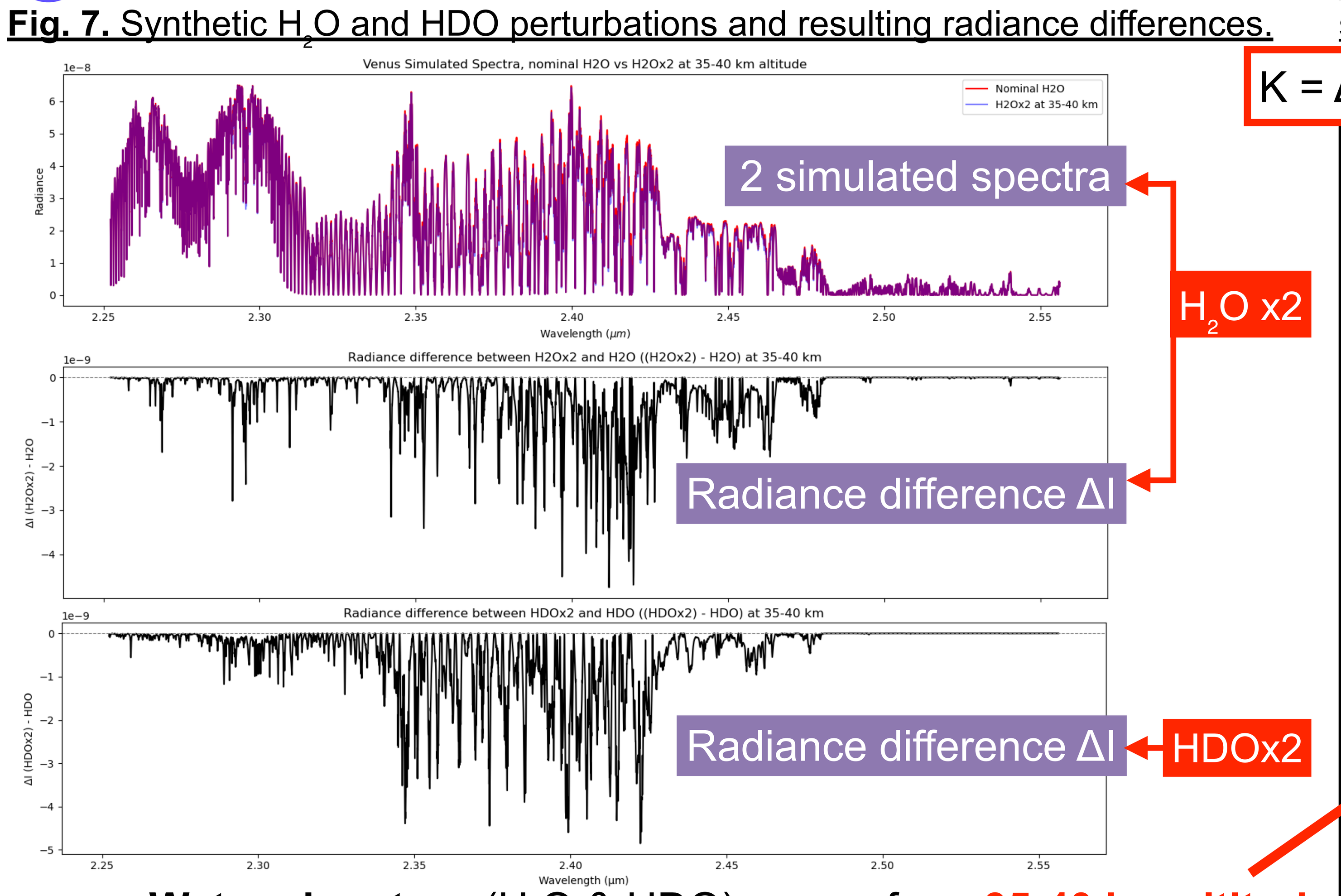
Molecules contribution ($CO_2$, CO, $H_2O$, HDO, OCS, HF, $SO_2$, Telluric features)

- The retrieval is performed sequentially in three spectral windows so that different absorbers are constrained in the regions where they contribute most.

## 5. Preliminary Results

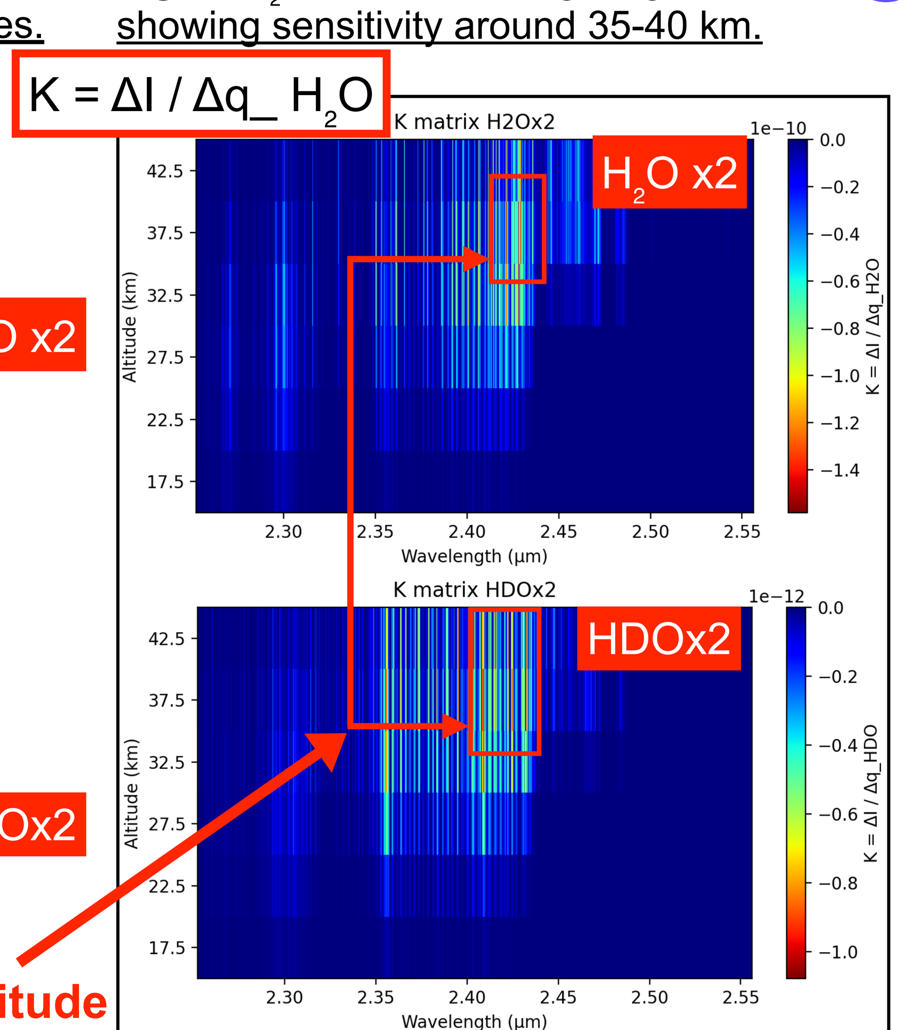
### 1 Synthetic spectra: testing the sensitivity of the model

**Fig. 7.** Synthetic $H_2O$ and HDO perturbations and resulting radiance differences.



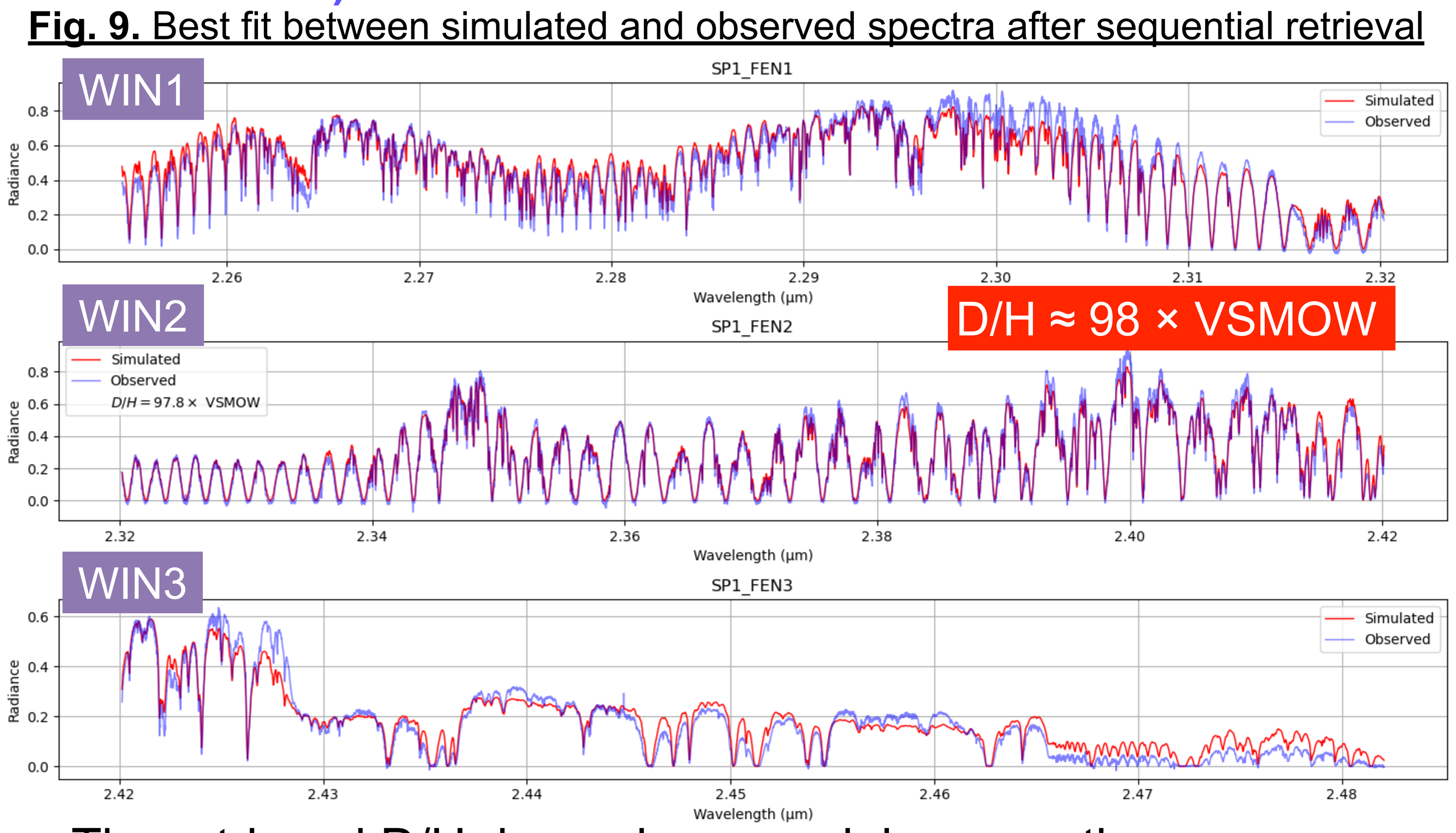

**Water signature** ($H_2O$ & HDO) comes from **35-40 km altitude**

**Fig. 8.** $H_2O$ and HDO weighting functions showing sensitivity around 35-40 km.




### 2 Retrieval of data from Feb. 2022 (spatial sampling: 1 pixel ≈ 42 × 110 km)

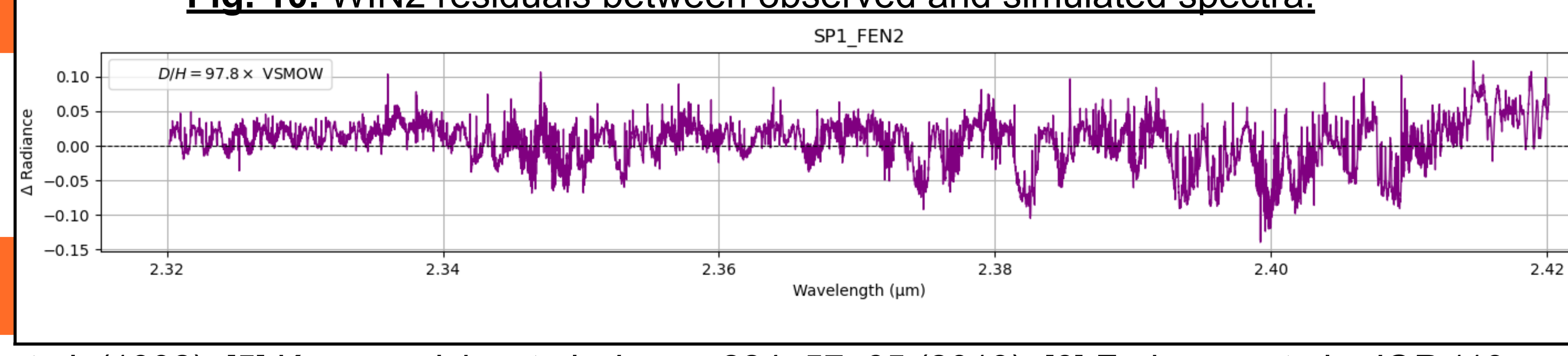
**Fig. 9.** Best fit between simulated and observed spectra after sequential retrieval




- The retrieved D/H depends on model assumptions. For example, **doubling the cloud opacity changes D/H** to:

D/H ≈ 88 × VSMOW

**Fig. 10.** WIN2 residuals between observed and simulated spectra.




## 6. Ongoing / Future Work

- **Next steps:** quantify uncertainties (clouds, aerosols, noise) → validate D/H retrievals → extend to spatial mapping.
- **New observations planned for mid-September and December**

## 7. References

[1] de Bergh et al., *Science* 251, 547–549 (1991). [2] Marcq et al., *Icarus* (2006). [3] Donahue & Russell (1997). [4] Bjoraker et al. (1992). [5] Krasnopolsky et al., *Icarus* 224, 57–65 (2013). [6] Fedorova et al., *JGR* 113, E00B22 (2008). [7] Vandaele et al., COSPAR (2014). [8] Mahieux et al., *PNAS* 121, e2401638121 (2024). [9] Donahue et al., *Science* 216, 630–633 (1982). [10] Grinspoon, D. H. (1993), Nature, 363, 428–431. [11] Aoki et al., COSPAR (2024).