Mapping D/H on Mars using EXES aboard SOFIA

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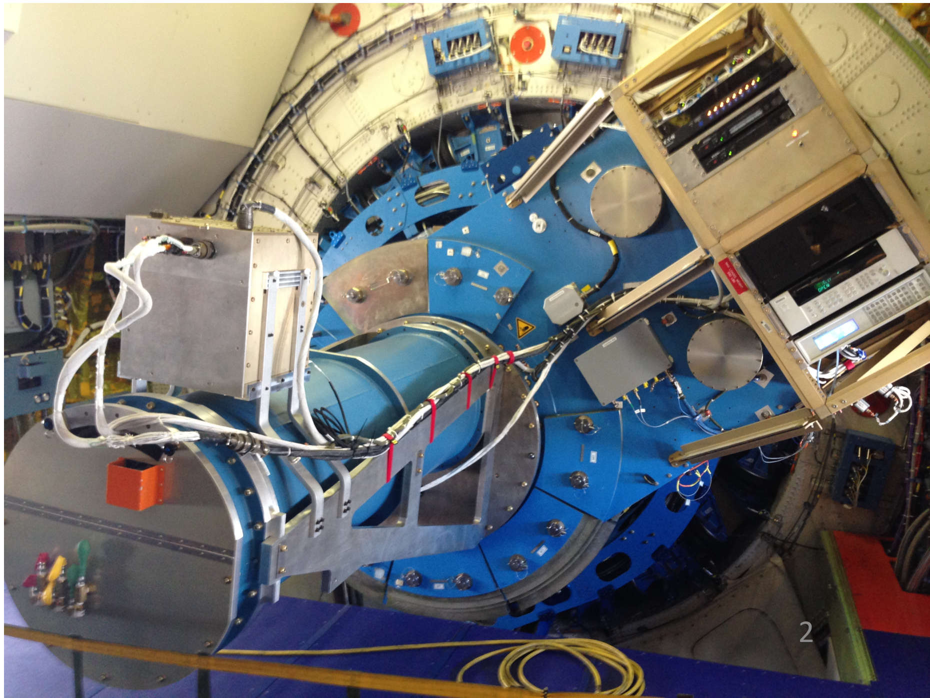
EXES aboard SOFIA

SOFIA: A Stratospheric Observatory for Infrared Astronomy (NASA/DLR)

- Boeing 747 + 3.5m telescope
- First operation: 2010
- Limitation: poor image capability (3 arcsec)

EXES: Echelon Cross-Echelle spectrograph

- PI: M.J. Richter, UC Davis, CA
- λ range: 4.5 – 28.3 μm,
- R = 10^5, 15000, 4000
- Heritage: TEXES at IRTF
- First operation: 2014



Why study D/H on Mars ?

- An indicator of the **loss of water** over the history of Mars, through differential escape -> A diagnostic of past water content
  - Owen et al. 1988: D/H = 6 +/- 3 x VSMOW
  - Several attempts (1997-2015): D/H in the range 4 – 5 x VSMOW
  - Villanueva et al. 2015: D/H mapping ->Strong variations over the Martian disk (<3 ->8 x VSMOW)
  - > Objective of the present study: To obtain a D/H value averaged over location and seasons
- An indicator of **the water cycle** through fractionation due to differential condensation processes
- -> A diagnostic of the water cycle and exchange with surface
  - Expected mechanism: Vapor Pressure Isotopic Effect (VPIE), Montmessin et al. Icarus 2005
  - > To be checked by the present study

D/H Observations of Mars with EXES/SOFIA

Objective: Simultaneous mapping of H_2O and HDO in the thermal infrared (1383-1390 cm^{-1} (7.19 – 7.23 μm) + 1326-1338 cm^{-1} (7.47 – 7.54 μm)

Four flights: April 8, 2014 (Encrenaz et al. AA 2016),

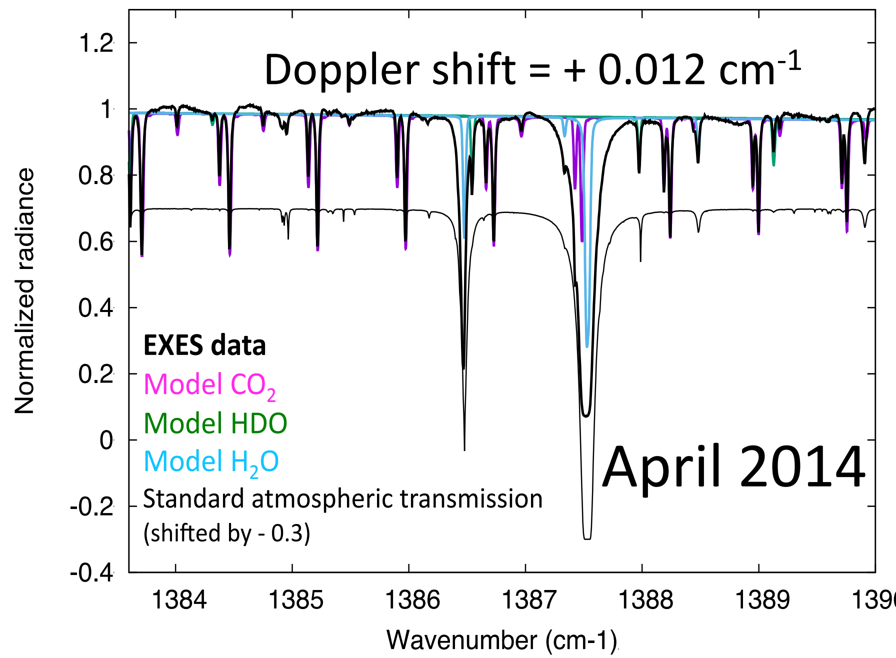
March 16 & 24, 2016 and January 24, 2017 (AA 2018, in press)

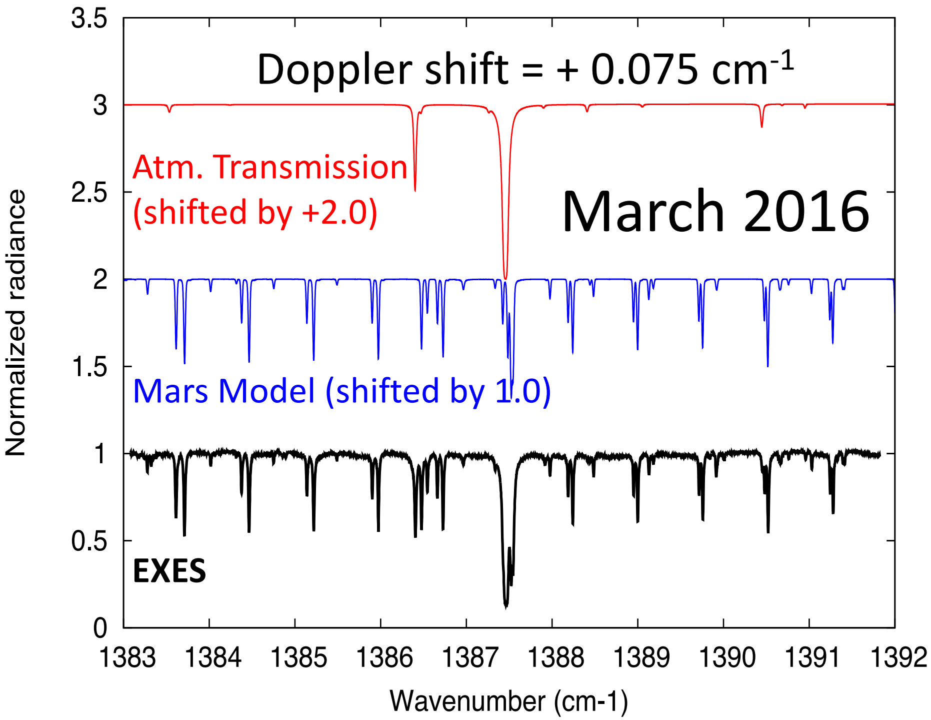
Date	Ls	Mars diameter (arcsec)	Sub-Obs longitude (°W)	Spectral range (cm^{-1})
April 8, 2014	113°	15	160	1383-1390
March 16, 2016	123°	10	250	1326-1338
March 24, 2016	127°	11	167	1383-1391
January 24, 2017	304°	5.2	350	1326-1338
January 24, 2017	304°	5.2	357	1383-1391

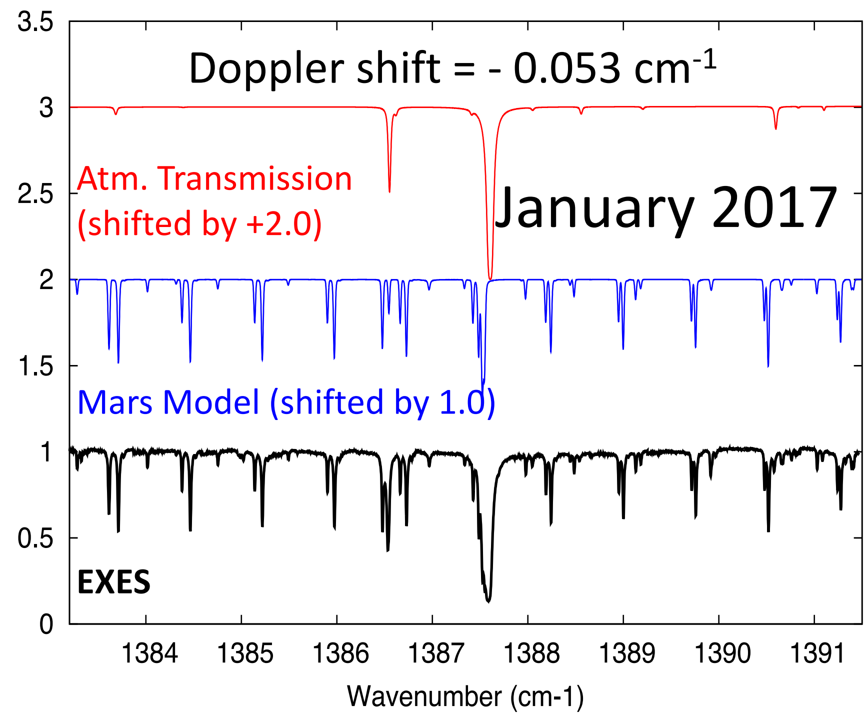
1. The 1383-1391 cm^{-1} spectral range

(disk average)

Method: Direct ratios of H_2O/CO_2, HDO/CO_2, HDO/H_2O line intensities





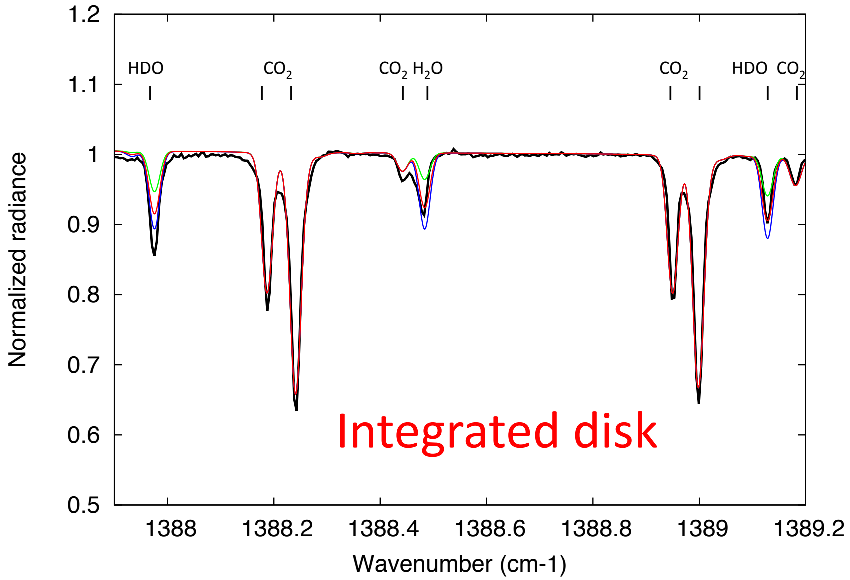


April 2014 – Ls = 113°

Integrated disk

H_2O = 240 +/- 53 ppmv, HDO = 350 +/- 14 ppbv

D/H = 4.4 (+1.0,-0.6) x VSMOW



Northern region

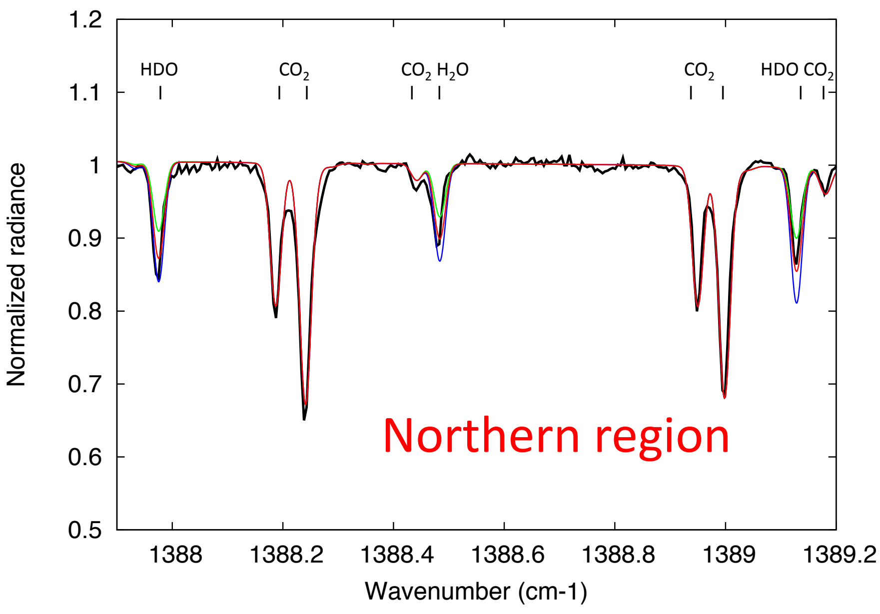
H_2O = 400 +/- 68 ppmv, HDO = 650 +/- 20 ppbv

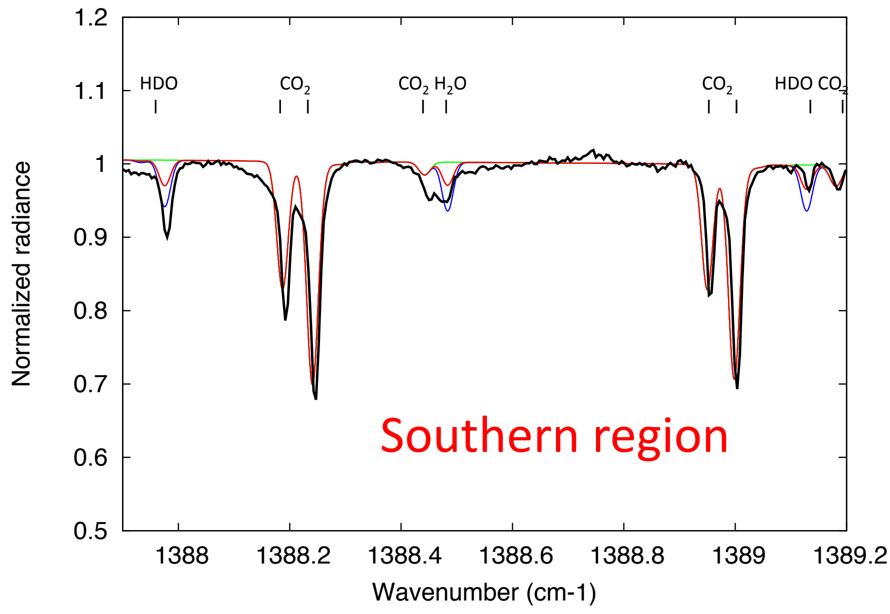
D/H = 4.7 (+0.8,-0.6) x VSMOW

Southern region

H_2O = 125 +/- 68 ppmv, HDO = 150 +/- 15 ppbv

D/H = 3.9 (+1.5,-0.8) x VSMOW

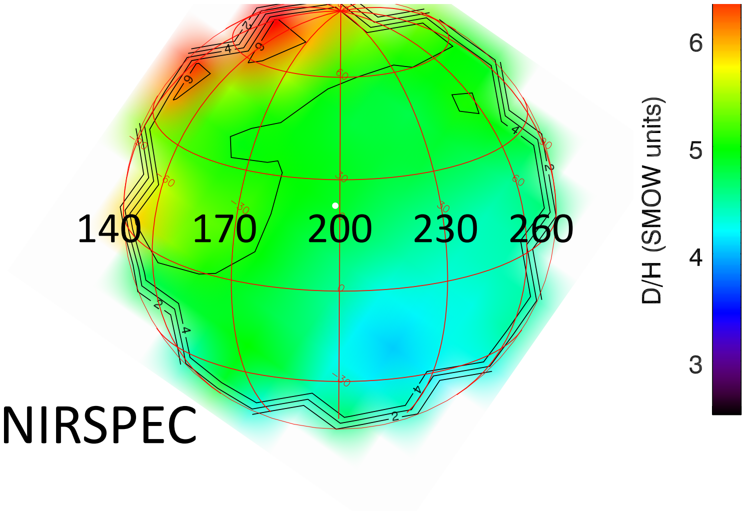




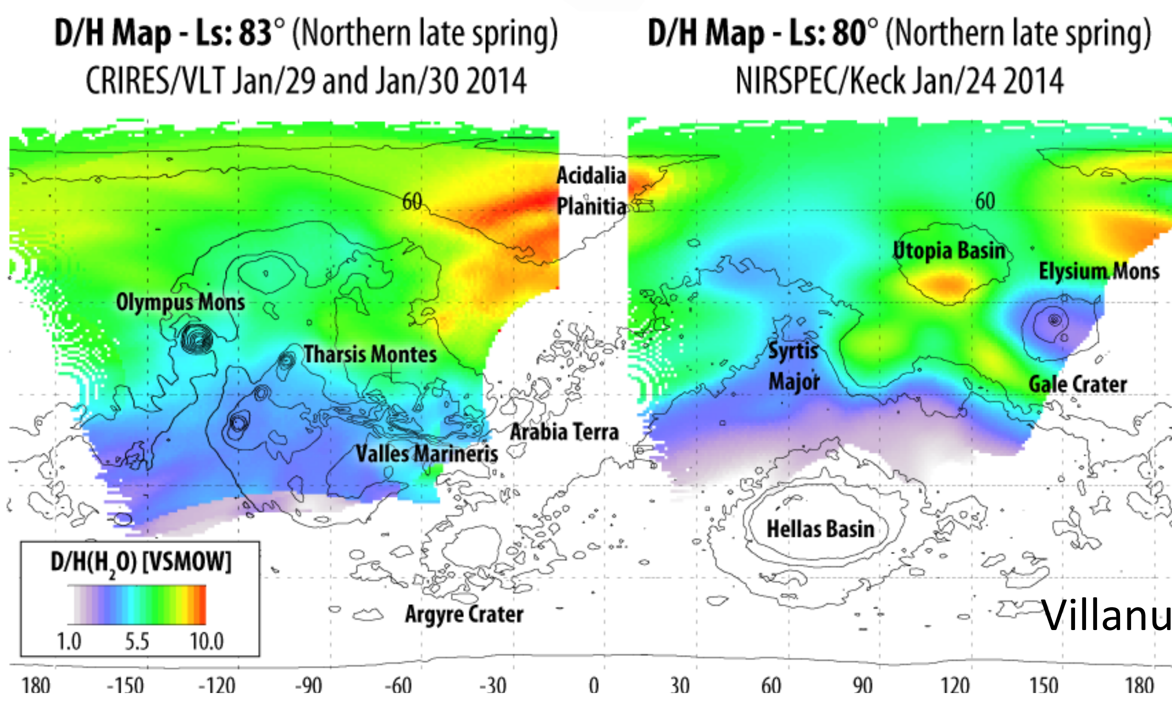
D/H on Mars with EXES – April 2014 – Ls = 113°

D/H map obtained from HDO/H_2O line depth ratio

EXES



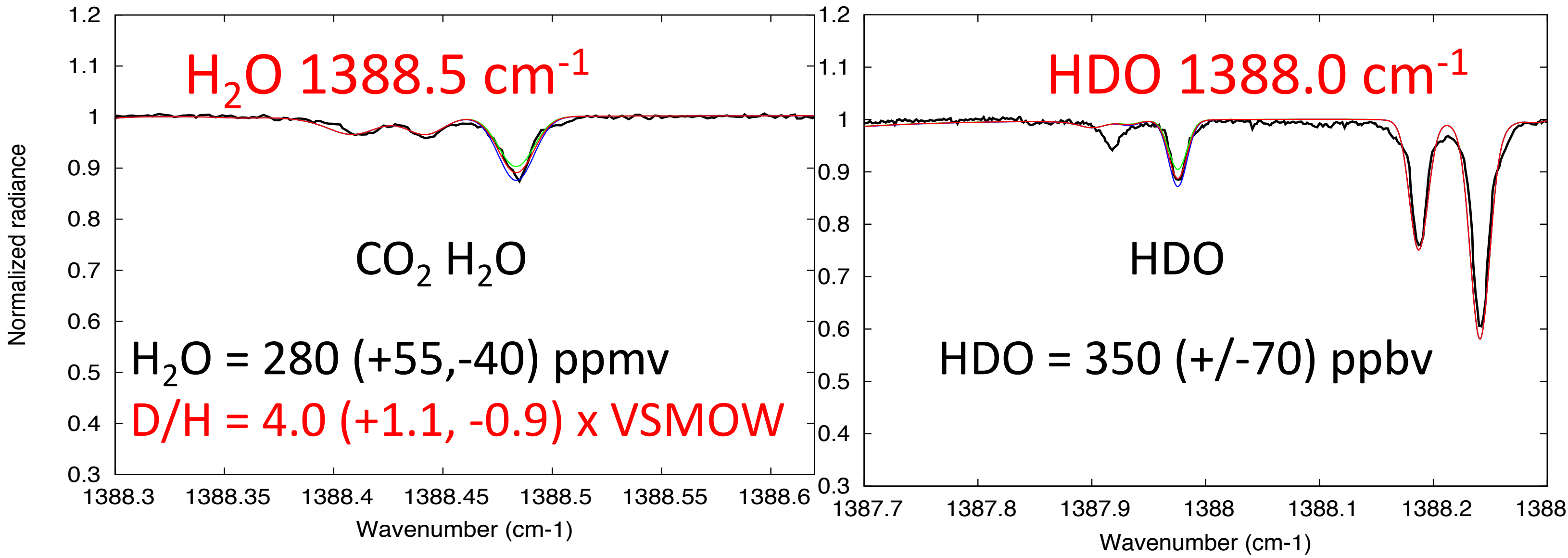
CRIRES/NIRSPEC



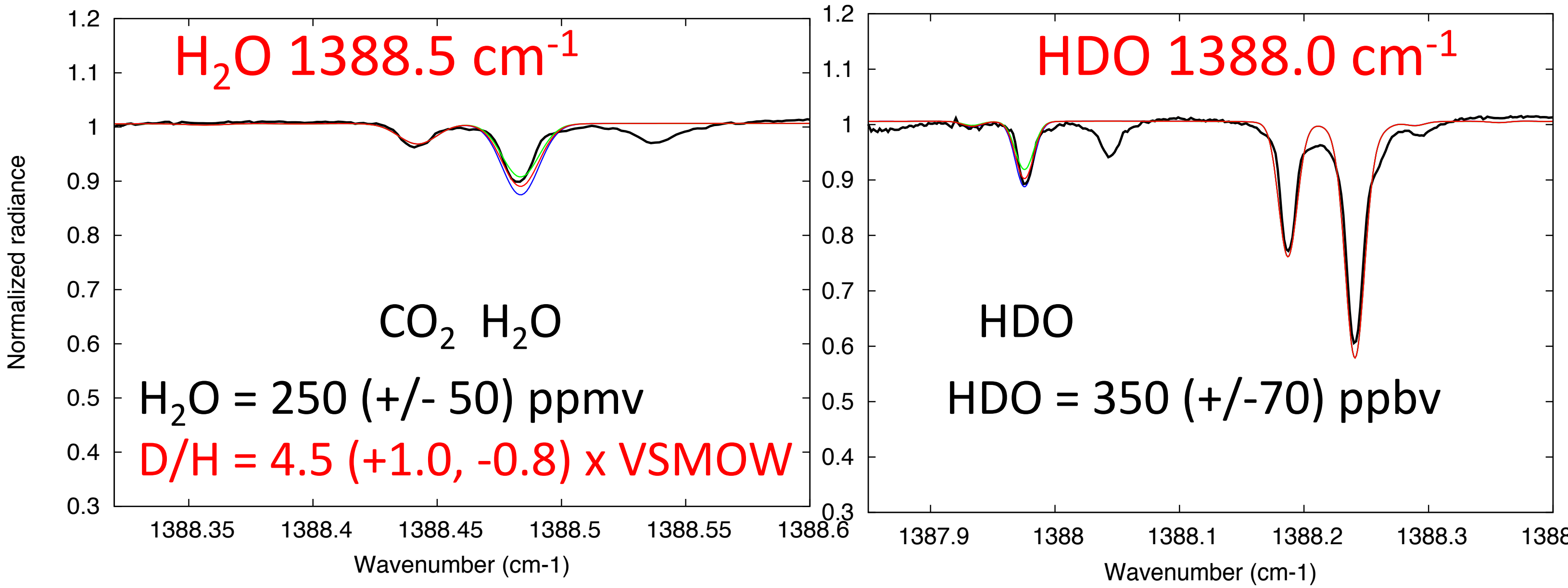
Villanueva et al. 2015

March 2016 & January 2017: H_2O & HDO transitions (integrated disk)

March 24, 2016
Ls = 127°



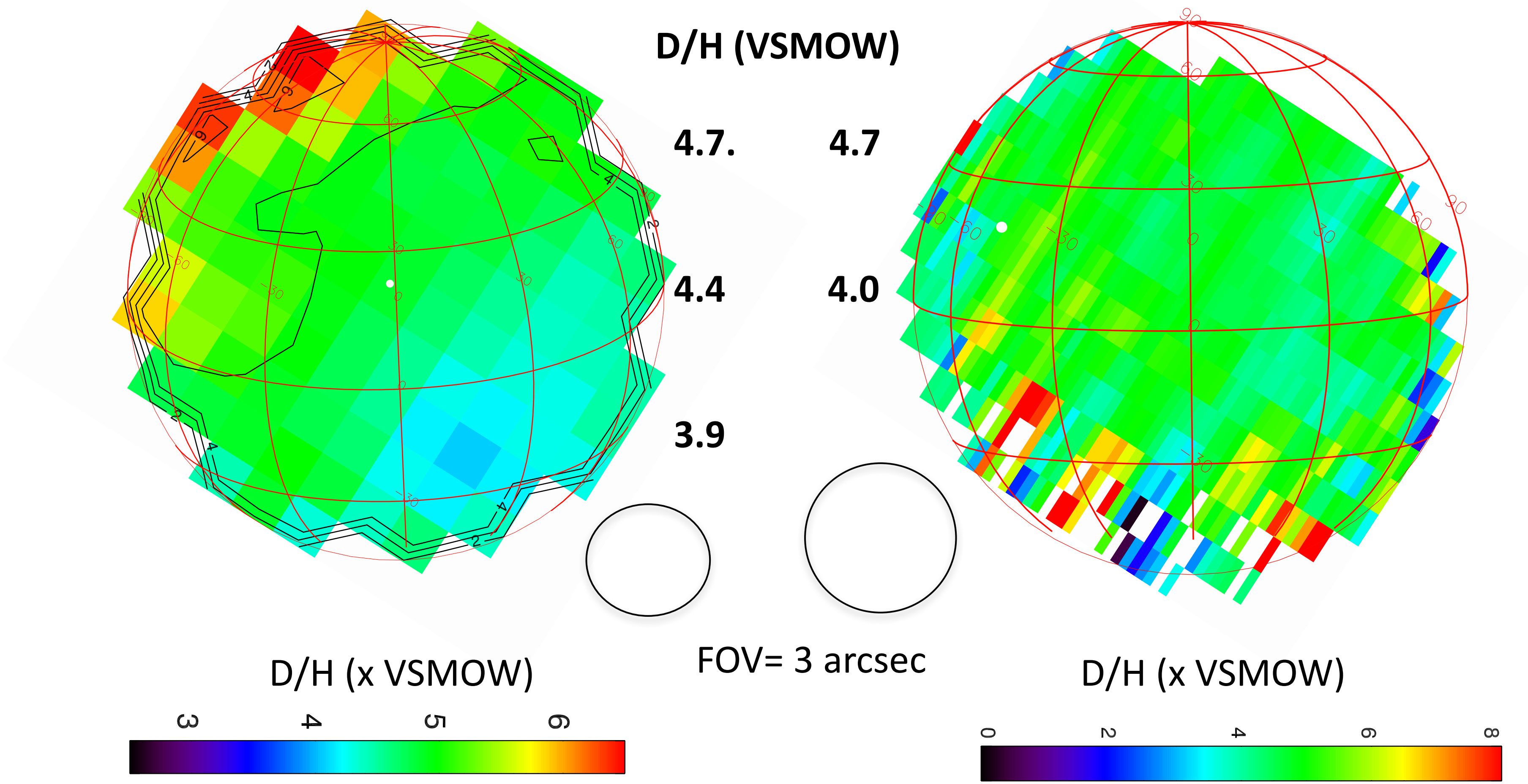
January 24, 2017
Ls = 304°



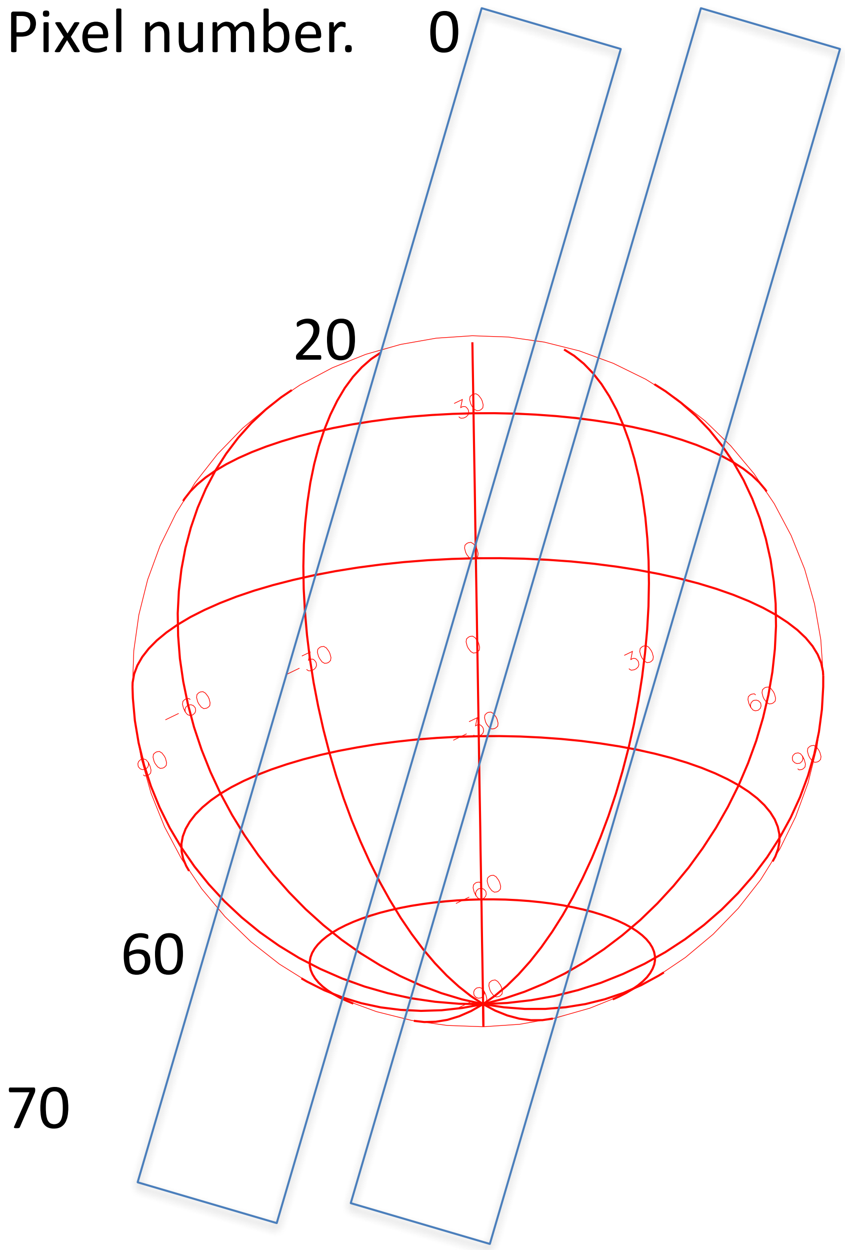
D/H on Mars

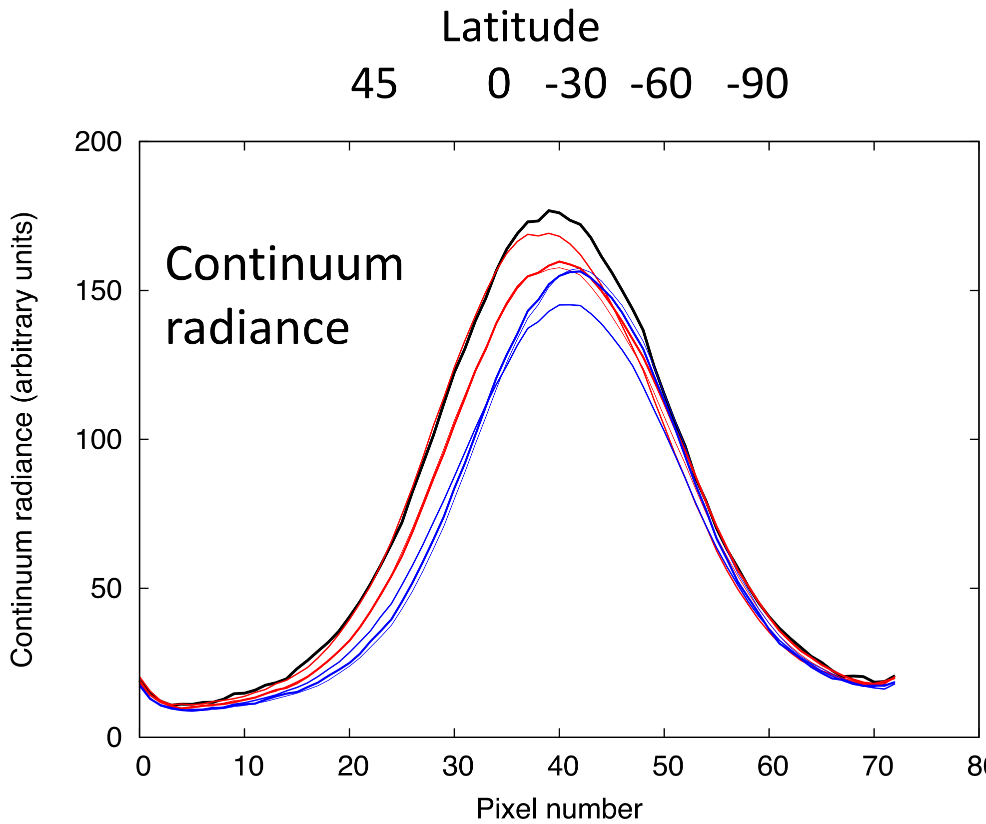
April 8, 2014 – Ls = 113°
Diameter: 15 arcsec

March 24, 2016 – Ls = 127°
Diameter: 11 arcsec



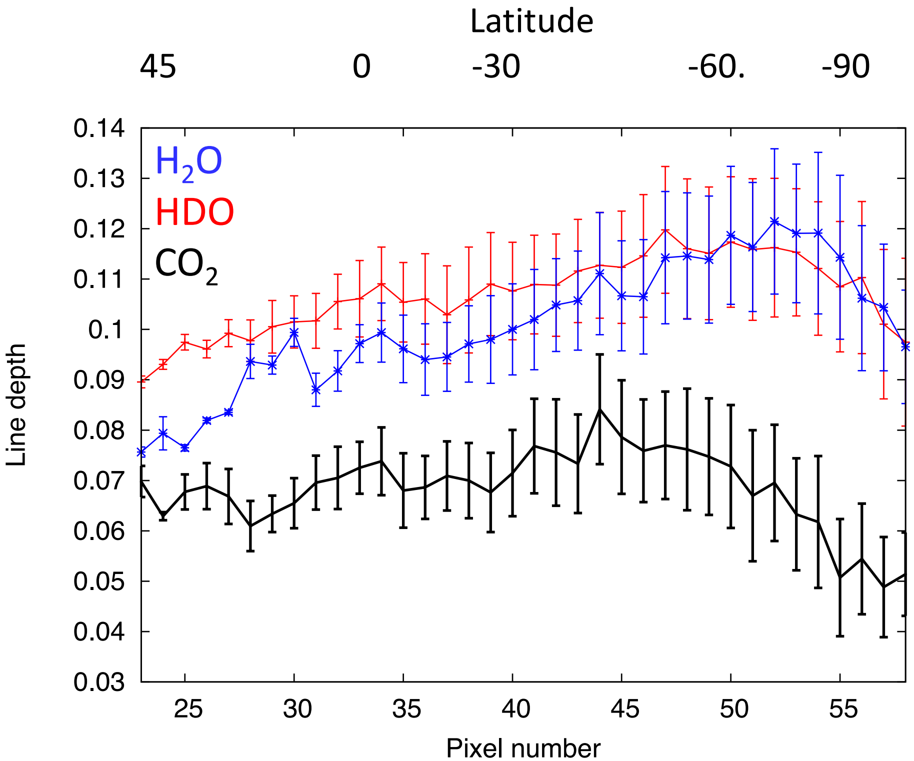
January 2017 (Ls = 304°)
(Mars diameter = 5.2 arcsec)
Observing geometry

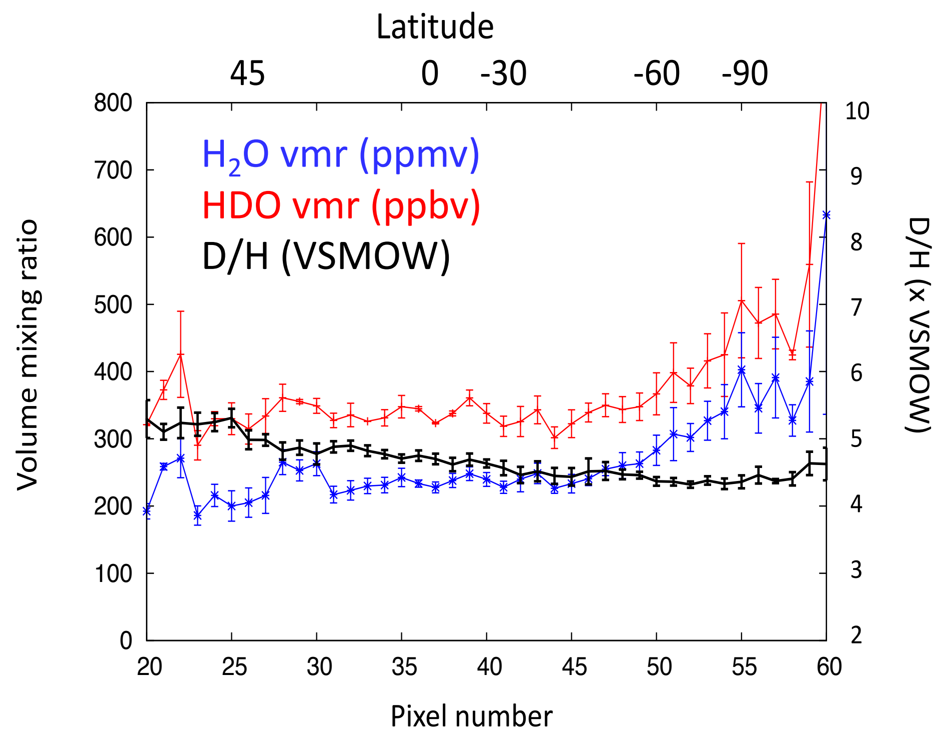




January 2017 (Ls = 304°)
Latitudinal variations of H_2O, HDO and D/H

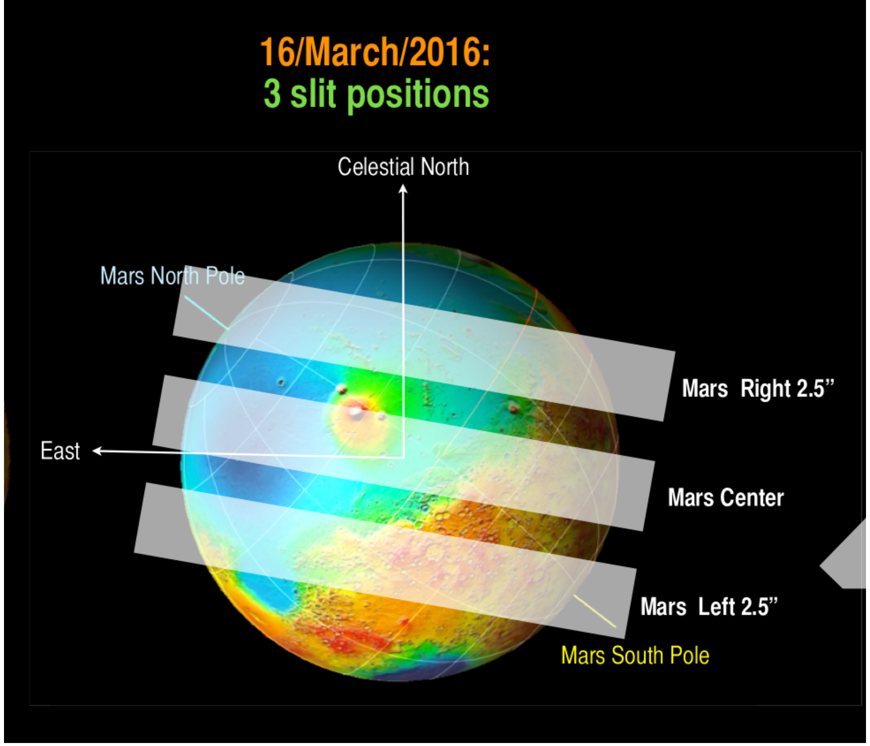
- H_2O and HDO increase from North to South, as expected by the GCM during southern summer
- **Surprise:** D/H seems to decrease from North to South, in contrast to GCM predictions -> ????



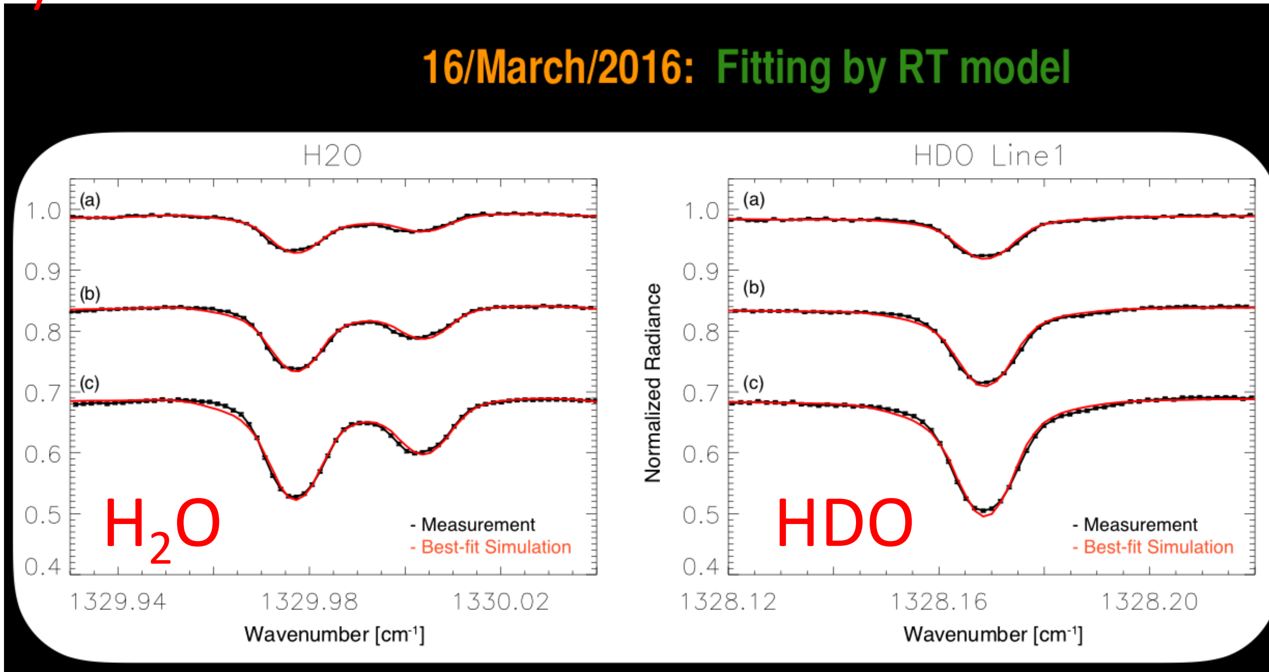


2. The 1326-1338 cm^{-1} spectral range

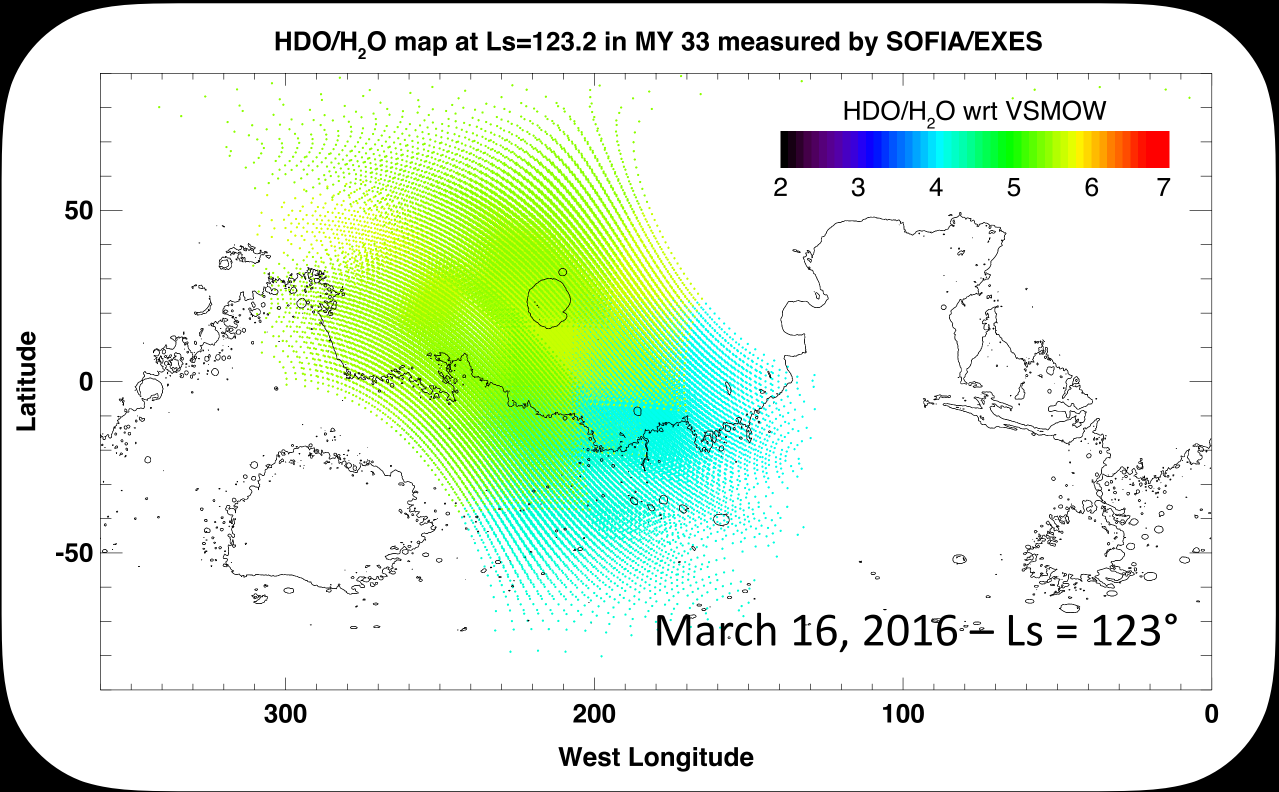
- First objective: Search for CH_4 (Aoki et al, this conference)
- **March 16, 2016 (Ls = 123°):** D/H retrieved from inversion RT code using GCM input
- (Aoki et al. A&A 2017)



- H_2O - 1329.98 cm^{-1}
- HDO - 1326.17 cm^{-1}



HDO/H_2O at Ls=123 (MY=33)



- ✓ No significant spatial variation
- ✓ Relatively low value in the southern hemisphere

(Aoki et al., in prep)

- In agreement with the EXES results at 1383-1391 cm^{-1} (Ls = 127°)
- In agreement with GCM (Montmessin et al. 2005)

Summary and conclusions

- The EXES observations of D/H show no strong variation of D/H as a function of location and season.
- Our D/H maps and disk-integrated values for April 2014 (4.0 x VSMOW, Ls = 113°) and March 2016 (4.4 x VSMOW, Ls = 127°) are consistent with GCM predictions and earlier measurements.
- In January 2017 (Ls = 304°), the disk integrated D/H ratio (4.4 x VSMOW) is consistent with the GCM and earlier measurements. However, the D/H ratio shows an unexpected enhancement from South to North, opposite to the variations of H_2O and HDO and the GCM predictions.
- Two new sets of observations with EXES/SOFIA are expected in 2018 (S. Aoki et al).