High-resolution IR imaging spectroscopy of Mars with TEXES Perspectives with EXES

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SCTF Telecon, January 20, 2010

Outline

- H_2O_2 mapping
- H_2O mapping
- Temperature mapping
- C and O isotopic ratios in CO_2
- Search for CH_4 -> upper limit
- Perspectives with EXES

The scientific case

- H_2O_2 has been searched for since Viking
- Very weak abundance expected (a few 10^{-8})
- Very high spectral resolution required -> TEXES well suited
- Results: IR detection, mapping and seasonal monitoring
- By-products:
  - H_2O mapping
  - Ts and T(P) mapping
  - C and O isotopic ratios in CO_2
  - Search for CH_4

Mars with TEXES: The data set

- Dates:
  - Feb. 2001, Ls = 110° (summer solstice) (N)
  - June 2003, Ls = 206° (mid-autumn)
  - December 2005, Ls = 332° (end winter)
  - May 2008, Ls =80° (summer solstice)
  - October 2009, Ls = 352° (equinox)
- Spectral range: 1230-1236 cm^{-1},1237-1244 cm^{-1} (8.04-8.13 mm) + 995-1005 cm^{-1}(10 mm)
- Spectral resolution: 0.016 cm^{-1} ($R = 7.7\ 10^4$)
- Spatial resolution (after convolution): 1.5x1.5 arcsec

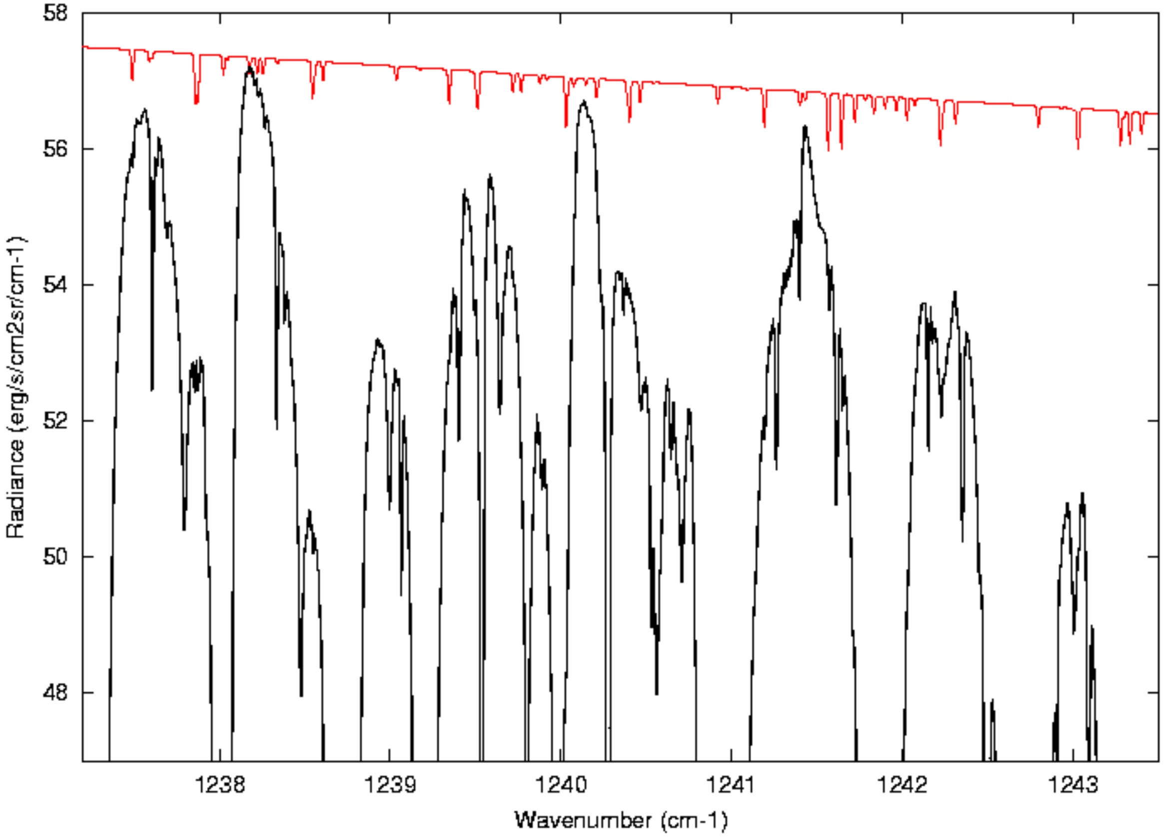
The 1237-1243 cm^{-1} spectrum of Mars (TEXES, IRTF)

All lines identified down to depths of 0.3%

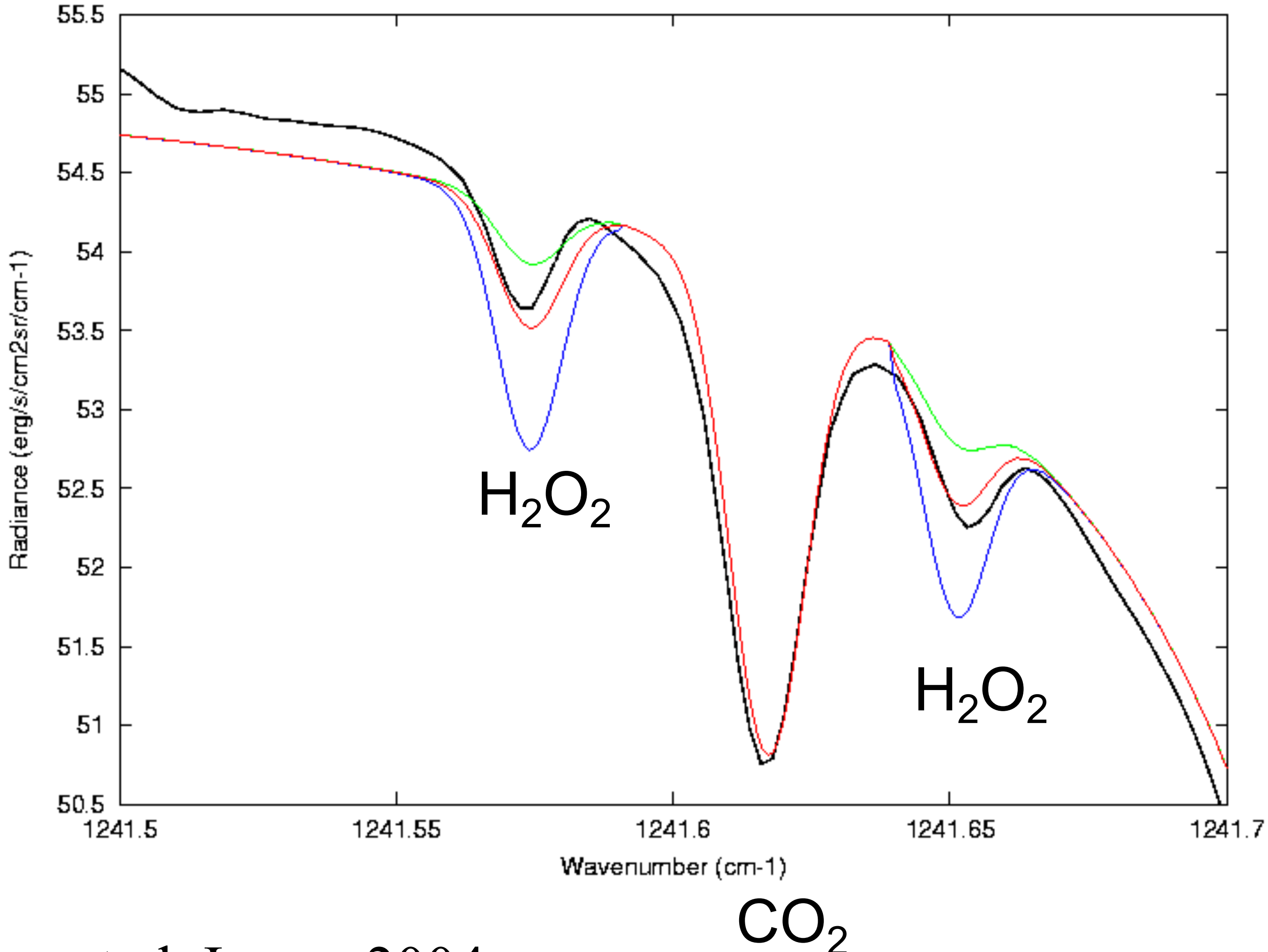
S/N > 1000 in the continuum

H_2O_2, 10^{-7} synthetic

TEXES data

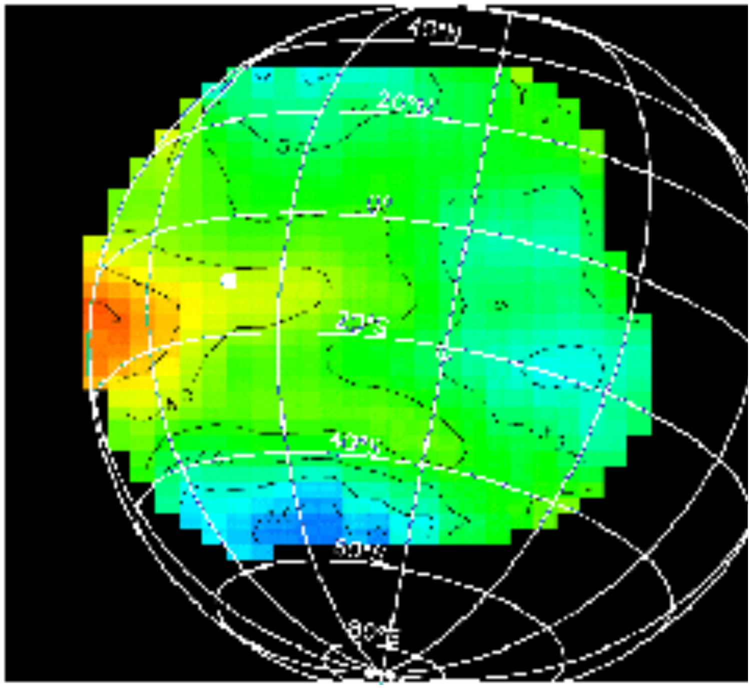


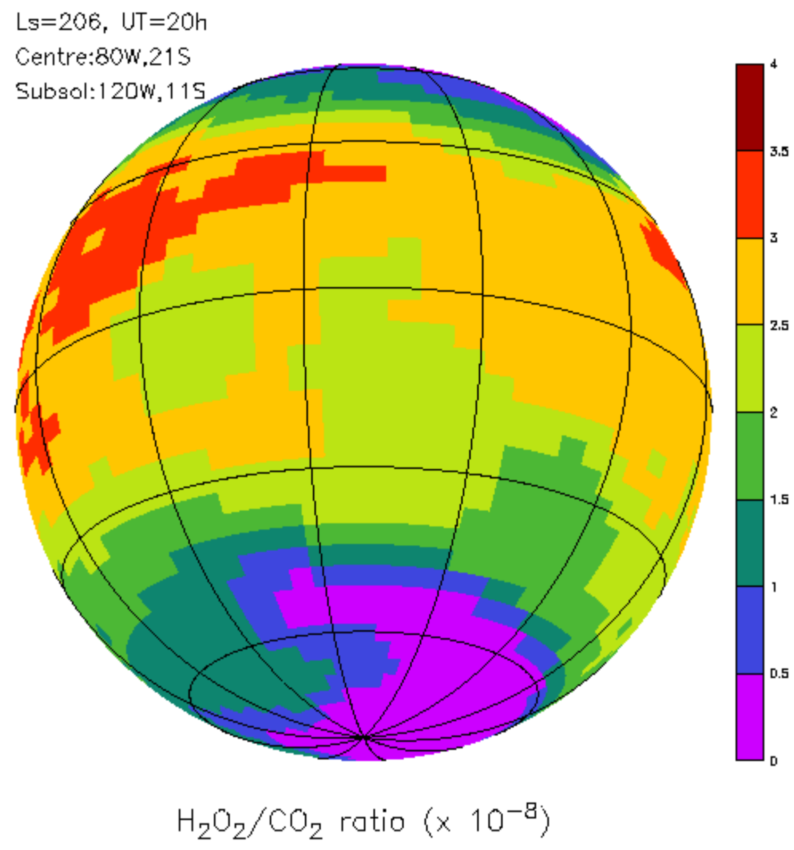
First IR detection of H_2O_2 on Mars
H_2O_2 and CO_2 lines at 1241.6 cm^{-1}



Encrenaz et al. Icarus 2004

H_2O_2 mapping on Mars, Ls = 207° : In agreement with GCM





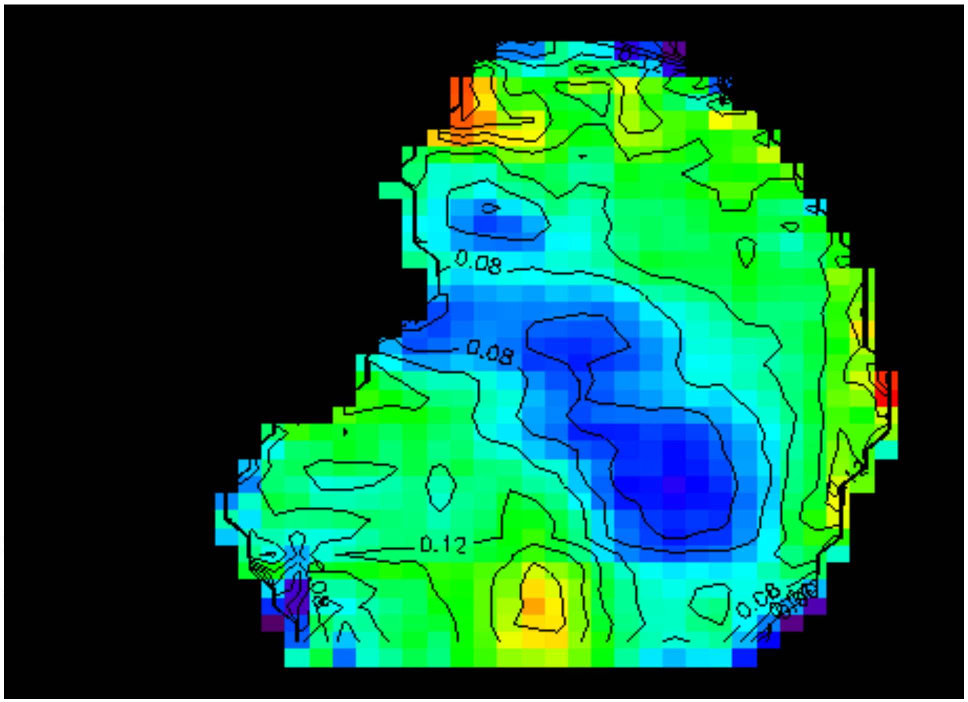
TEXES

$Q(H_2O_2)_{max} = 4\ 10^{-8}$

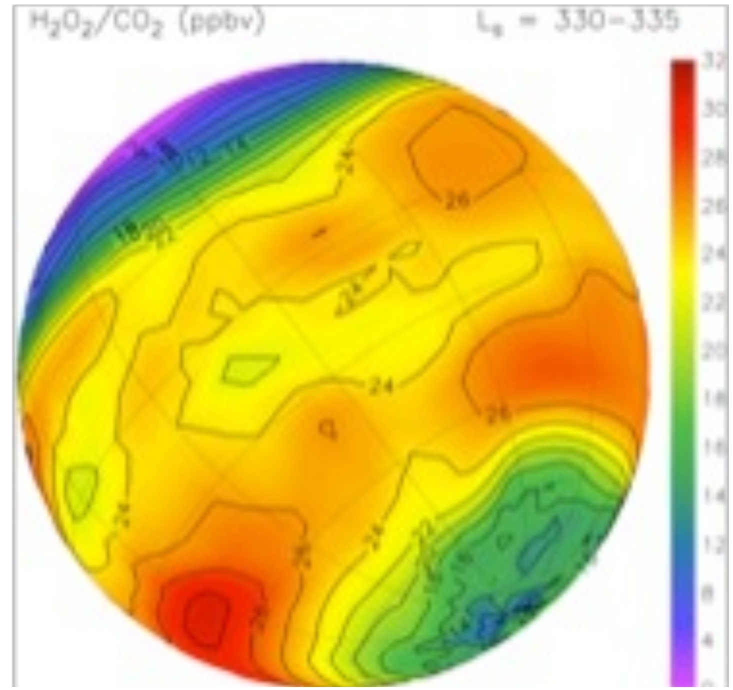
GCM

$Q(H_2O_2)_{max} = 4\ 10^{-8}$

Ls = 332° : H_2O_2 weaker than expected



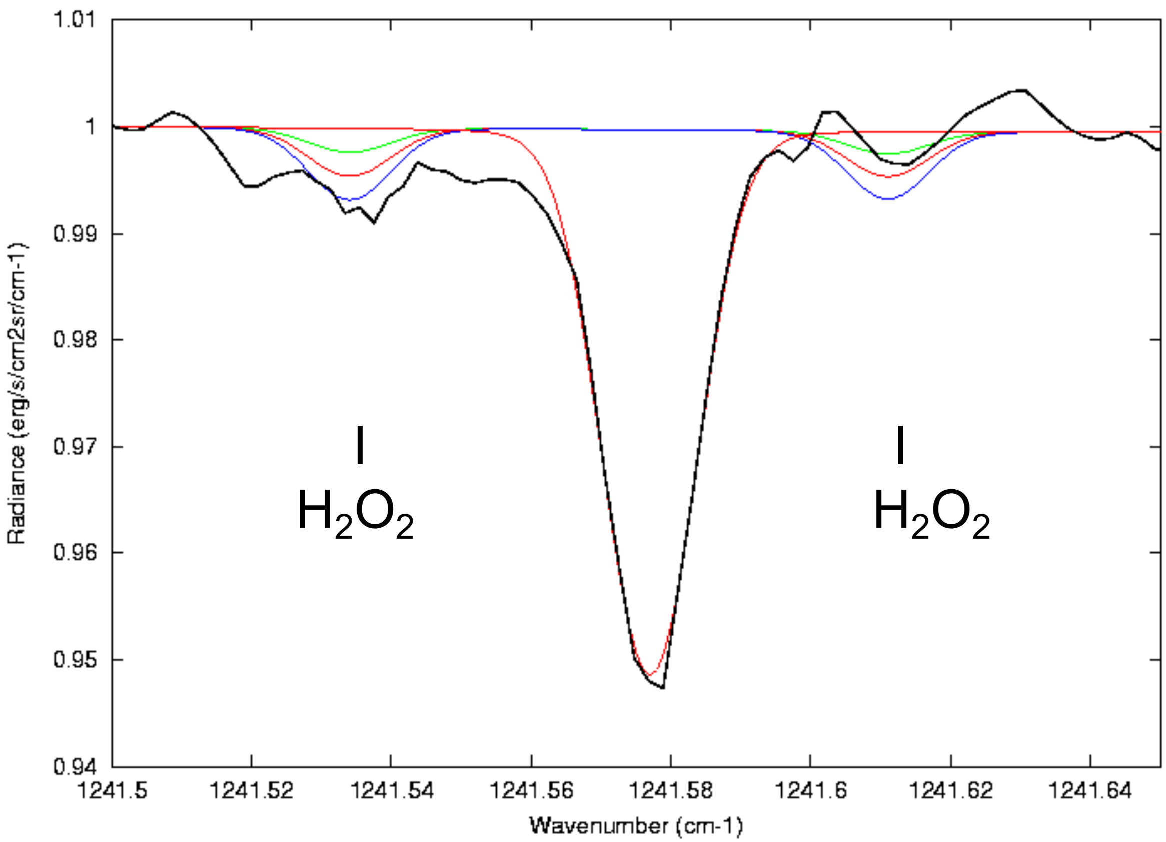
H_2O_2/CO_2 line depth ratio
TEXES
Green: H_2O_2 = 15 ppb



GCM/EMCD
Red: H_2O_2 = 32 ppb

Encrenaz et al. Icarus 2008

June 2008, Ls = 80°
Marginal detection over the full disk
$Q(H_2O_2)$ = 10 ppb

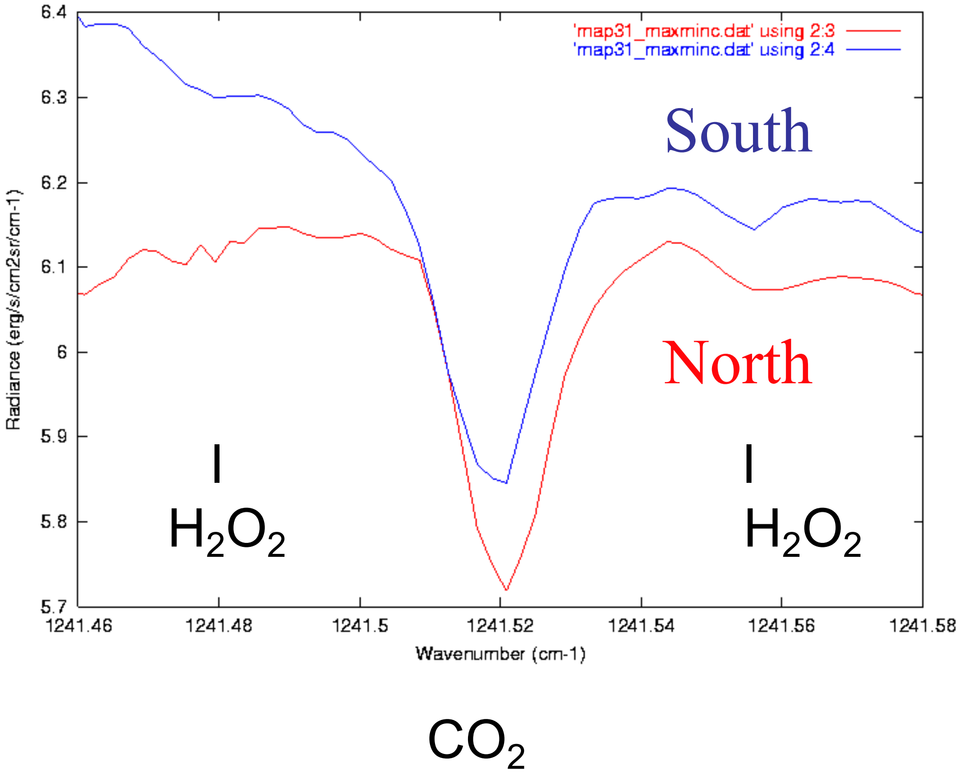


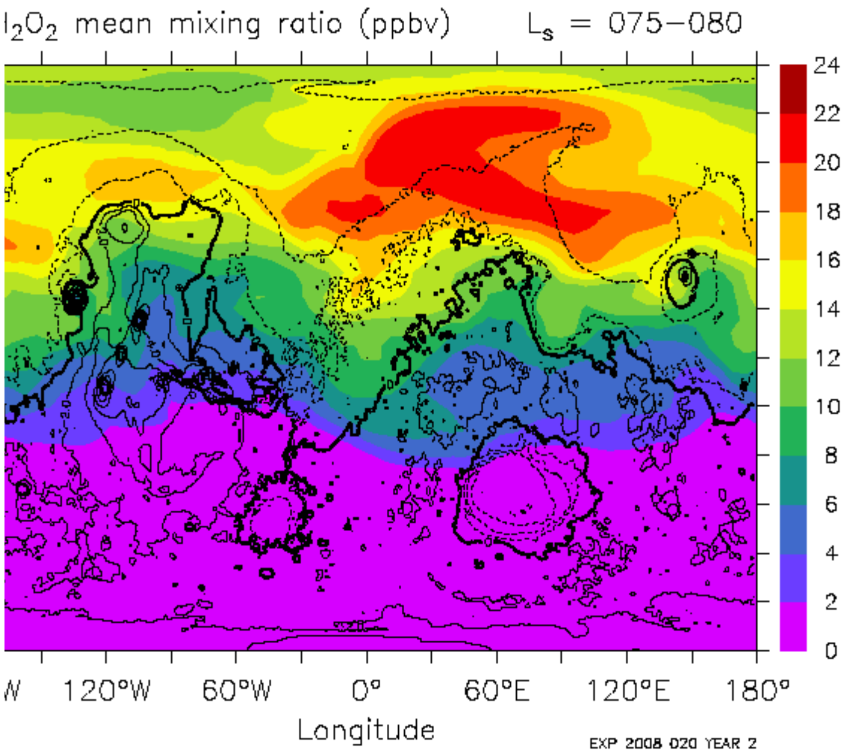
Black: TEXES data - Models: $Q(H_2O_2)$ = 5 ppb, 10 ppb, 15 ppb

Ls = 80°   - June 2008

H_2O_2 weaker than GCM prediction

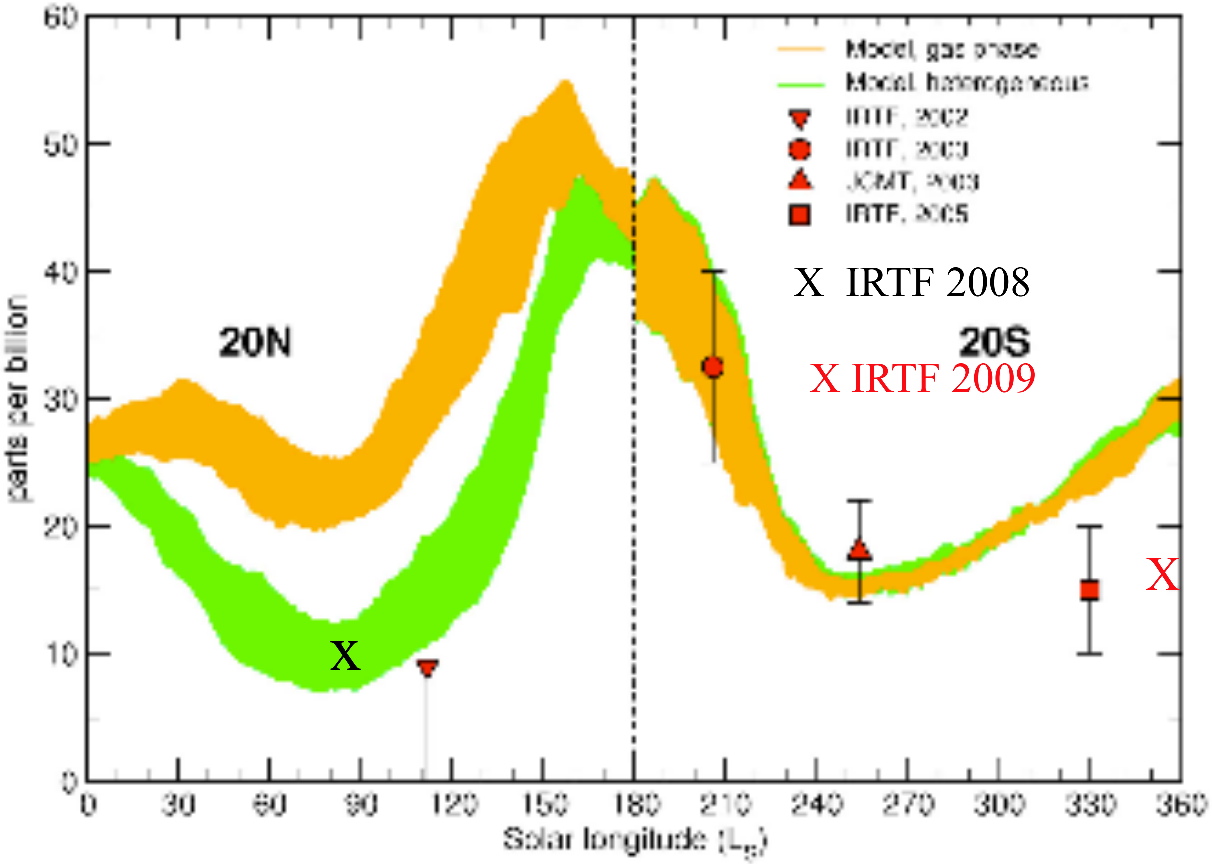
No evidence for the increase in the northern hemisphere predicted by the GCM





Seasonal variations of H_2O_2 on Mars:

A better agreement is reached if heterogeneous chemistry is taken into account (Lefèvre et al. Nature 2008)



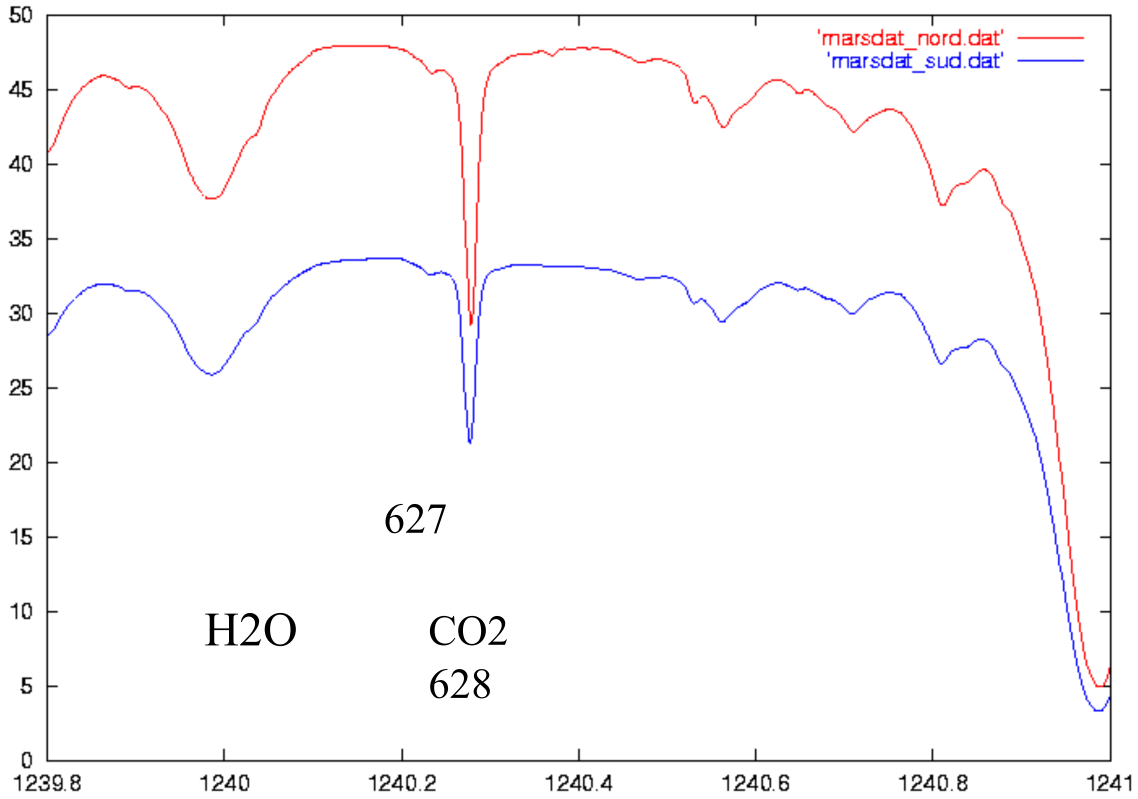
The 2001 and 2008 TEXES measurement supports the heterogeneous model

Water vapor mapping

- H_2O is mapped through a weak HDO transition (assuming $[D/H]_M = 5\ [D/H]_E$.
- The H_2O mixing ratio is inferred from the line depth ratio of the HDO line and a nearby weak CO_2 line
- Results: Good agreement wth GCM for Ls = 80°, 110° and 206°; significant discrepancies for Ls = 332°
- At northern solstice (Ls = 80° and 110°): strong maximum at high northern latitudes, as expected from the GCM

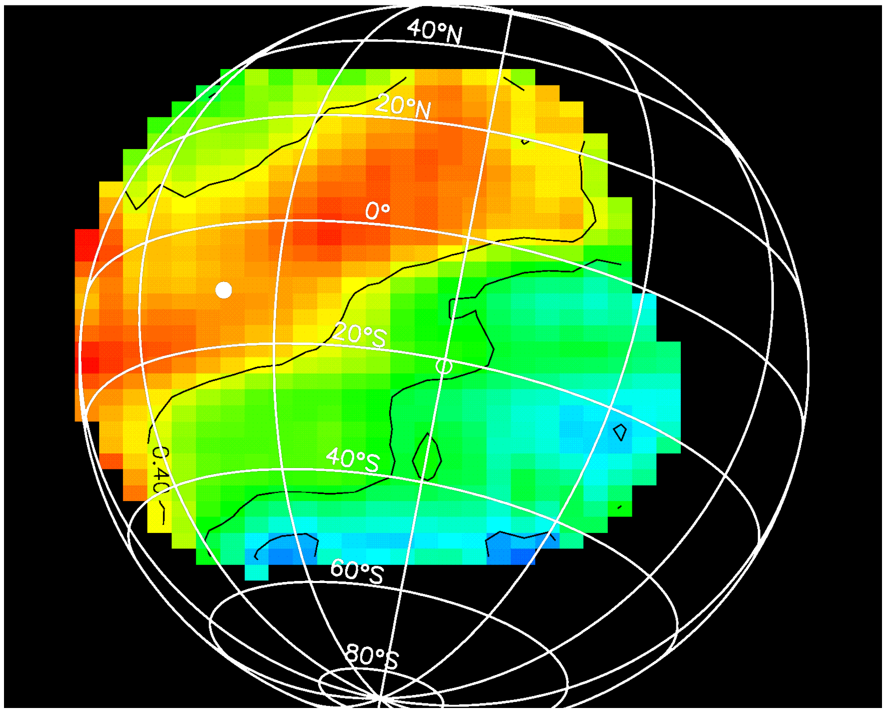
H_2O mapping, Ls = 206°

- 1 line usable at 1240.0 cm-1, depth = 1.5%
- Comparison with CO_2 @ 1241.6 cm-1 -> H_2O mapping



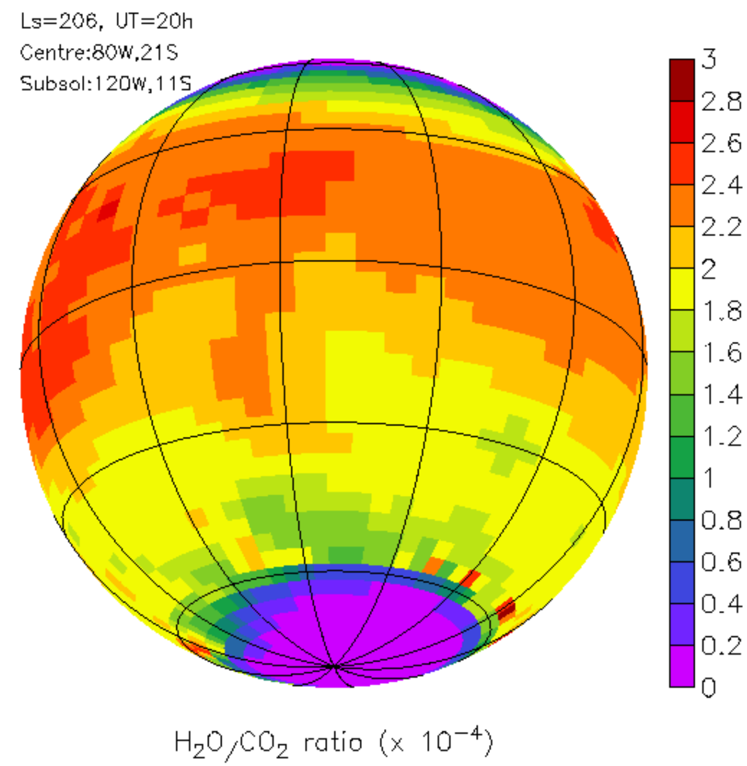
H_2O on Mars - Ls = 206°
Very good agreement with the GCM

Encrenaz et al. Icarus 2005



TEXES

$Q(H_2O)_{max}$=3 10^{-4}

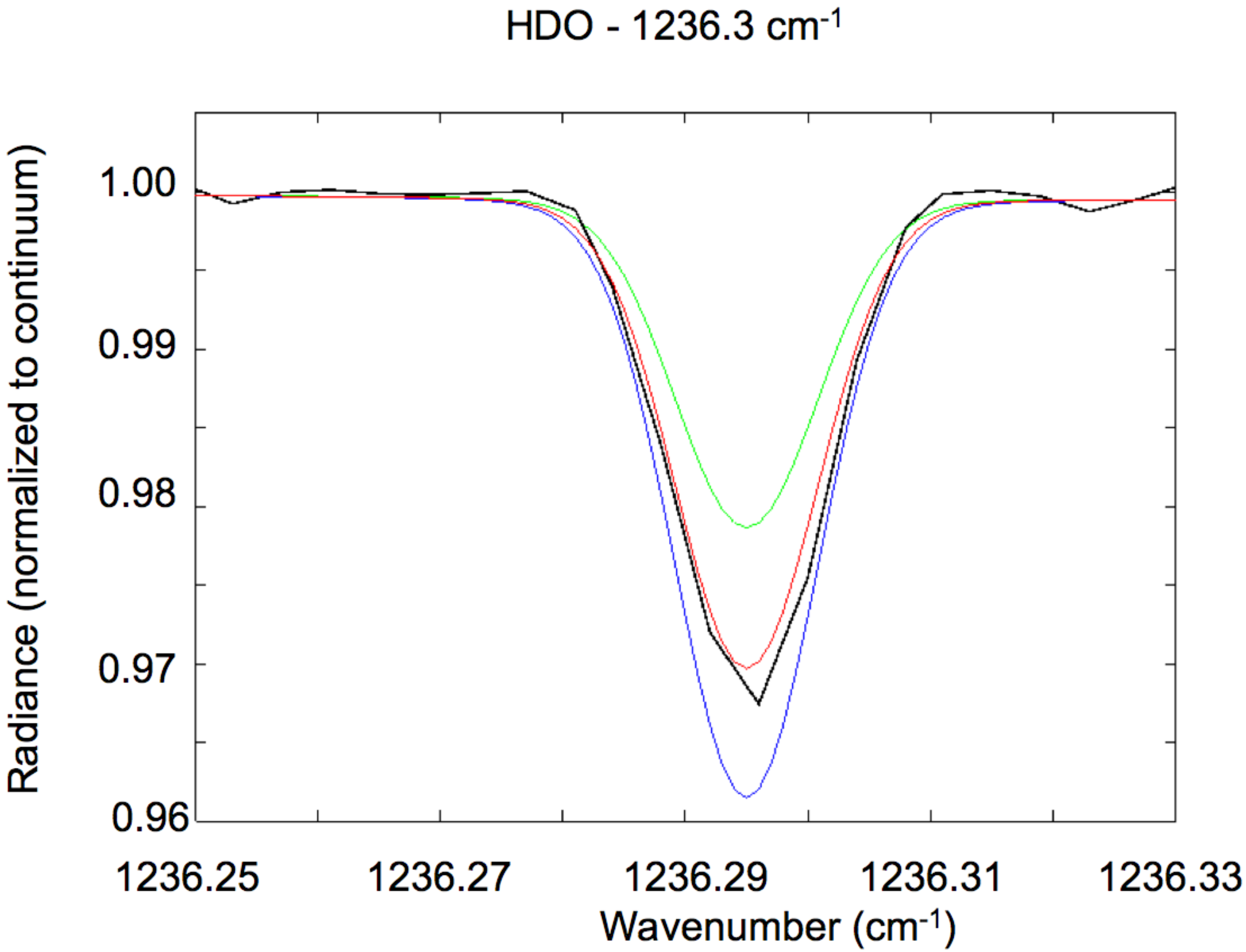


GCM

$Q(H_2O)_{max}$=3 10^{-4}

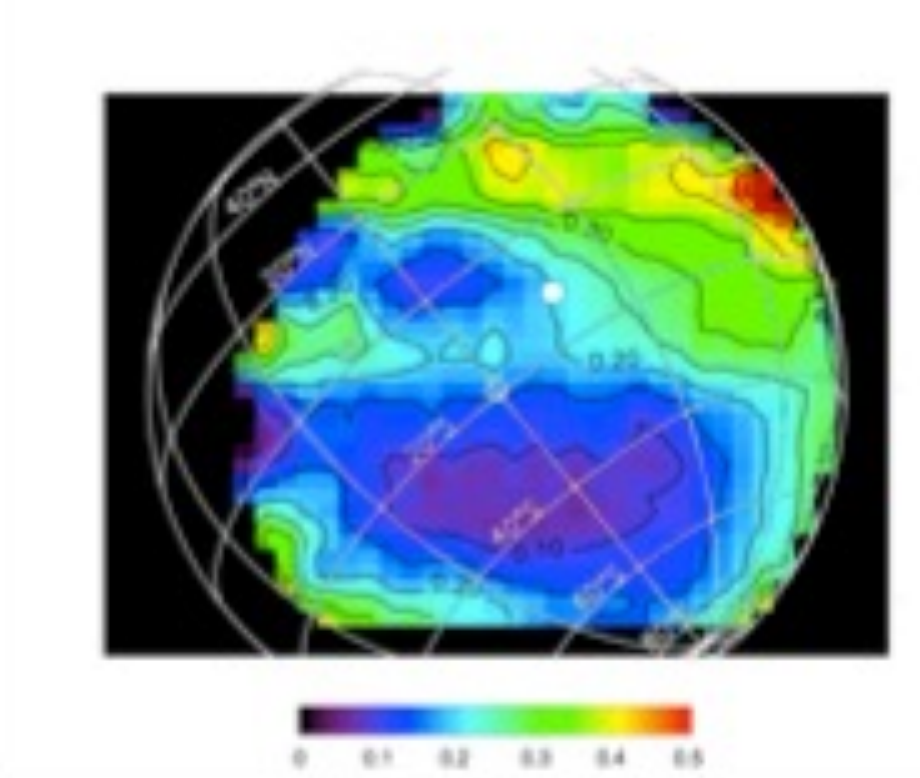
H_2O at Ls = 332°

HDO at 1236 cm^{-1}

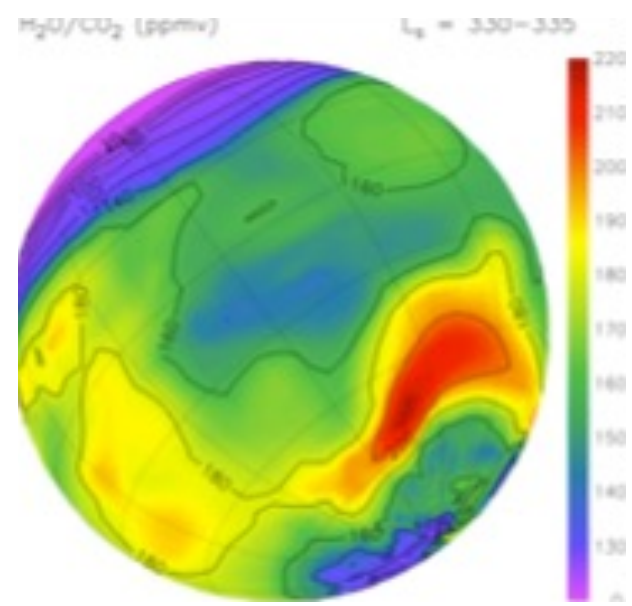


$[H_2O]$= 150 ppm

Ls = 332° : H_2O weaker than GCM prediction + discrepancies in the spatial distribution (effect of dust?)



HDO/CO_2 line depth ratio
TEXES
Green: H_2O = 150 ppm

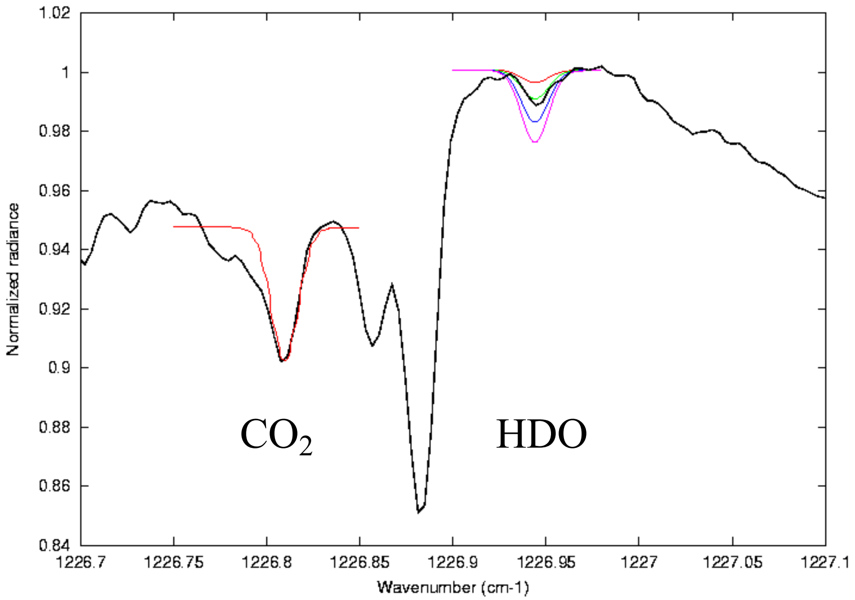


GCM/EMCD
Red: H_2O = 220 ppm

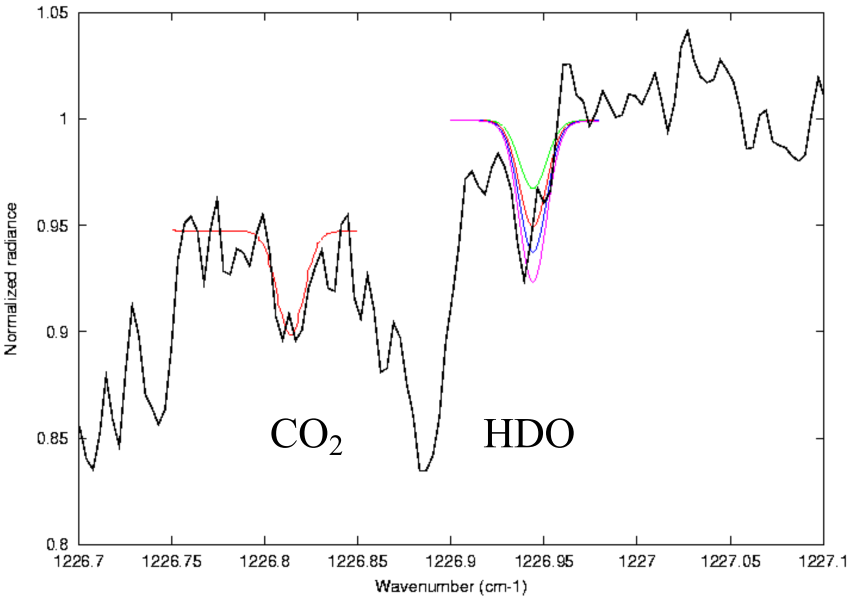
Summer solstice - Ls = 110°

CO_2 and HDO fits

Mean spectrum, 40N



Local maximum, 65N

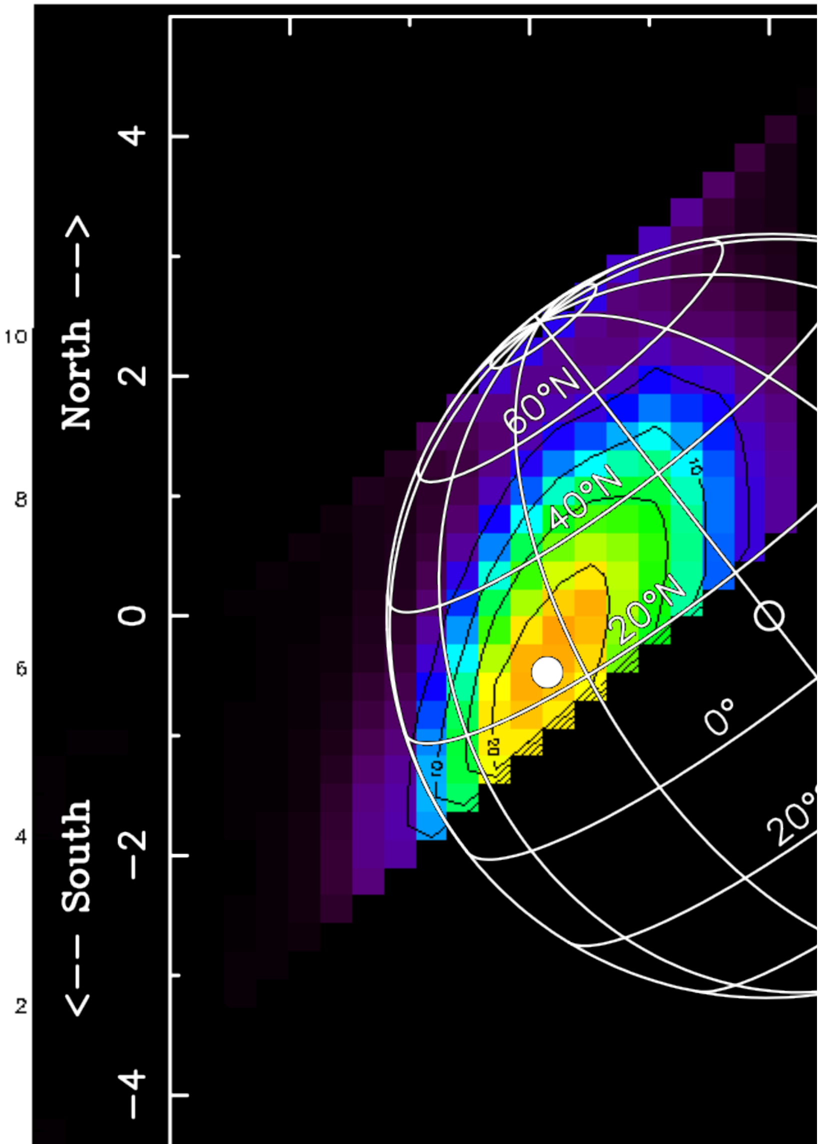


Models: $[H_2O]$ = 100 -> 750 ppm
Best fit: 40N: $[H_2O]$ = 250 ppm (15 pr-µm)

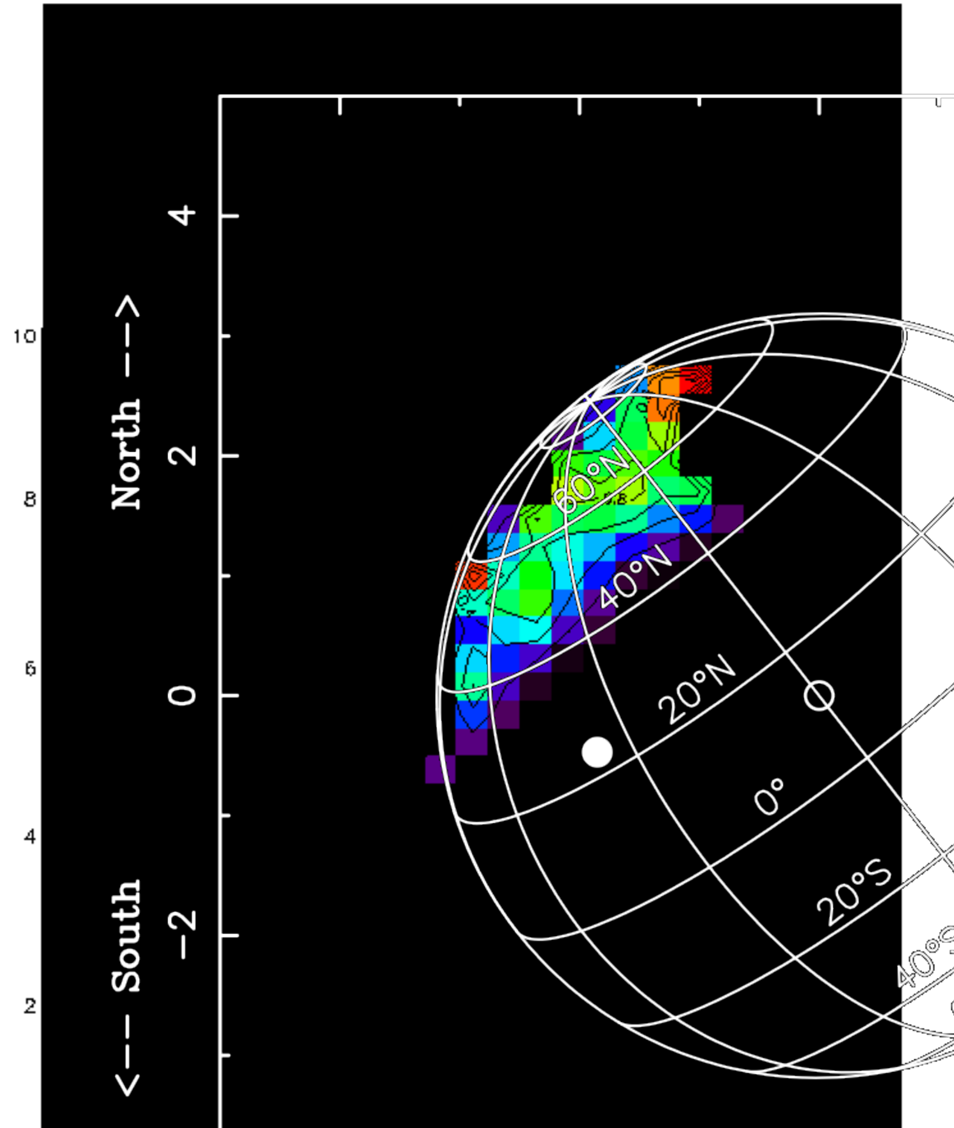
Models: $[H_2O]$ = 1000 -> 5000 ppm
-> $[H_2O]$ > 1000 ppm (> 70 pr-µm)

H_2O mapping - Ls = 110° (Feb. 2001)

Continuum - 1227 cm^{-1}

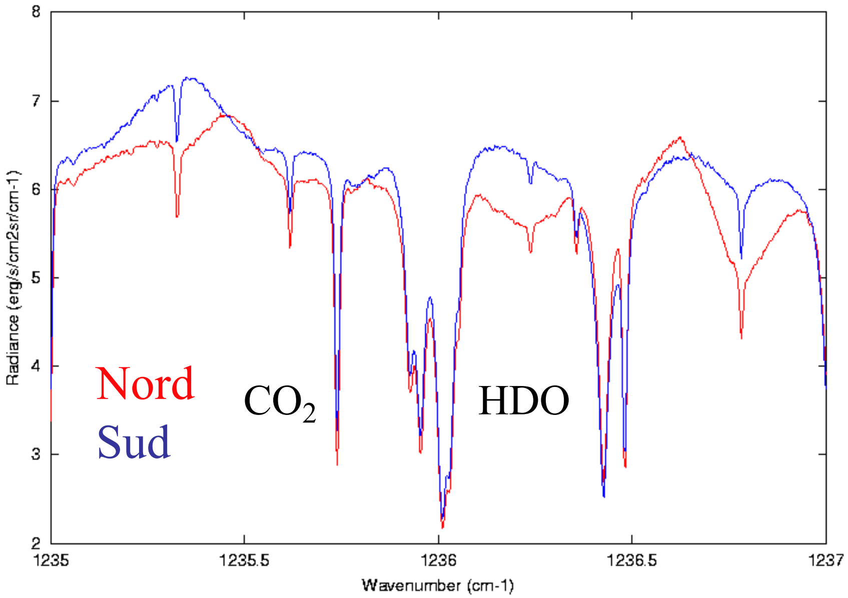


HDO/CO_2

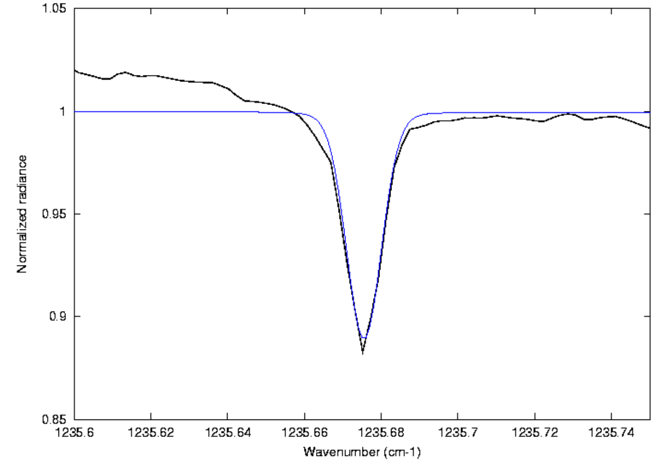


CO_2 and HDO fits - Ls = 80°   (June 2008)

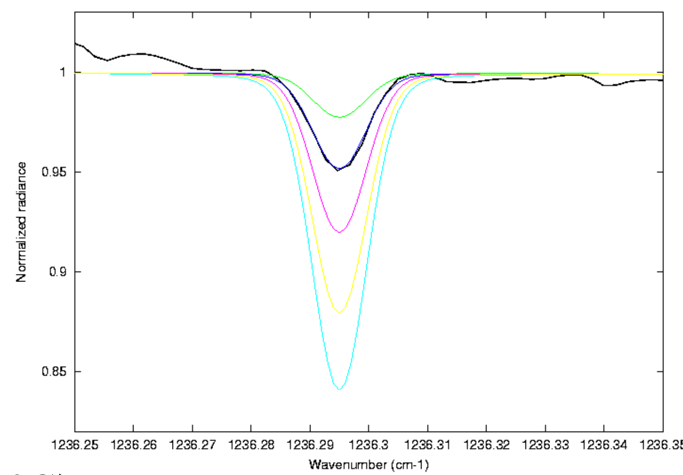
TEXES data



CO_2 - 1235.67 cm^{-1} (North)



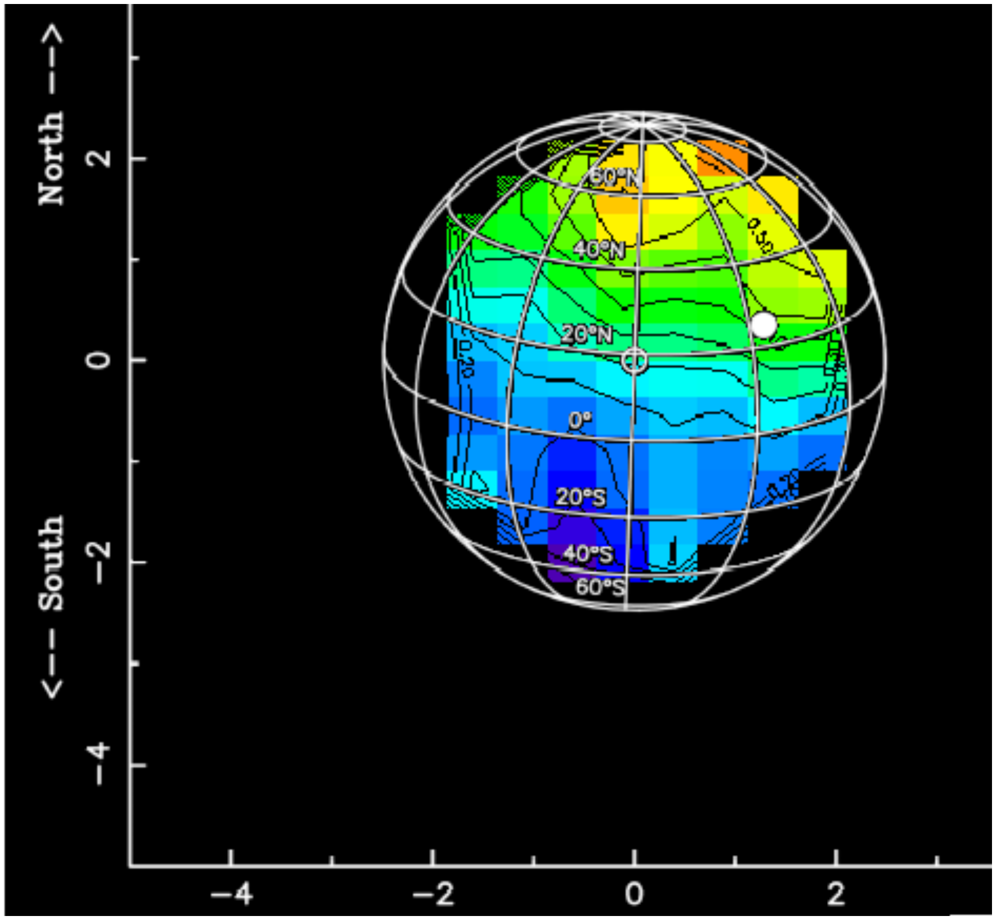
HDO - 1236.295 cm-1 (North)

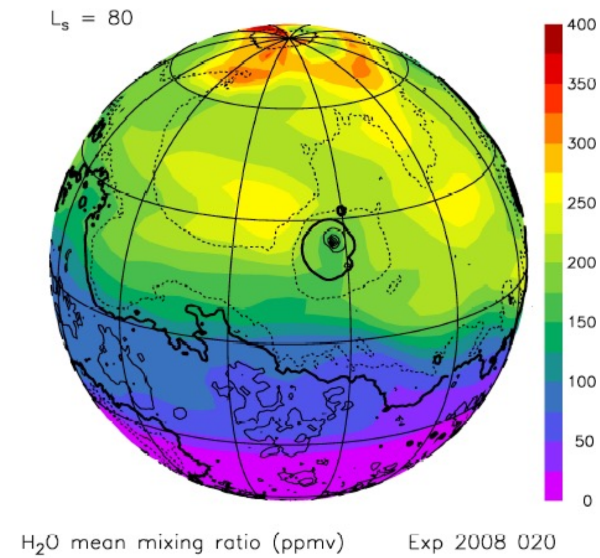


Models: $[H_2O]$ = 100 -> 1000 ppm

Best fit: $[H_2O]$ = 250 ppm (40N), 125 ppm (20S)

Ground-based water vapor mapping with TEXES
May 31, 2008 - Ls = 80°
Very good agreement with GCM predictions





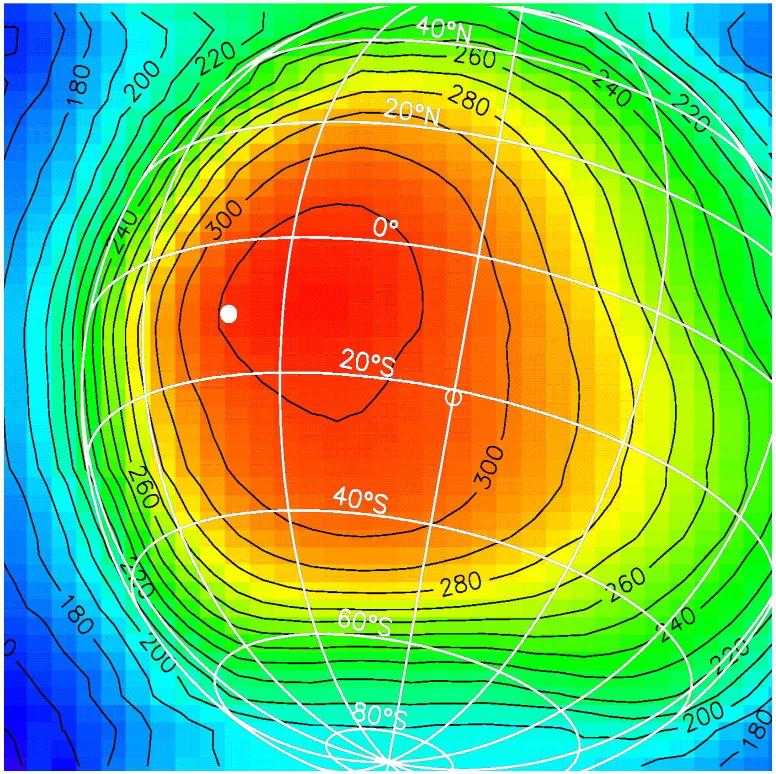
Very good agreement TEXES/GCM

-> No evidence from water adsorption from the regolith

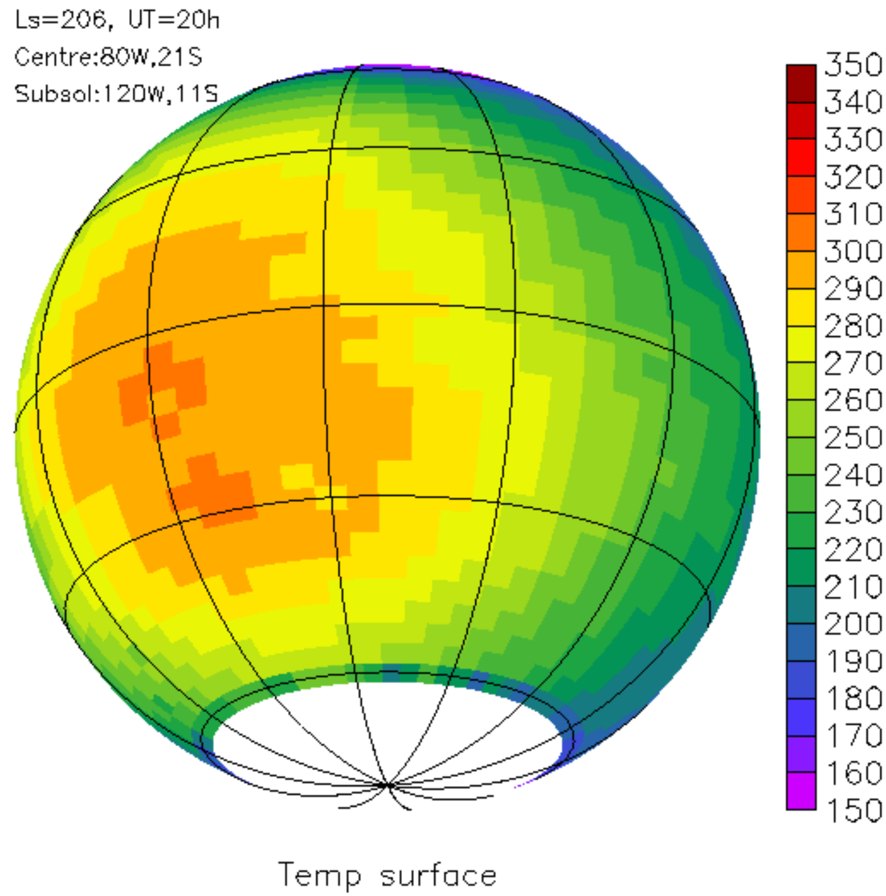
Ts and T(P), Ls = 206°

- From continuum -> Ts map
- From weak and strong CO_2 lines
  - Variations of T(P) in the lower atmosphere
- Comparison with GCM:
  - Ts OK except at the south pole (end of summer): implies a faster recession of the polar cap than expected in the GCM
  - T(P) OK with GCM: 30 K variation from morning to evening

Ts on Mars

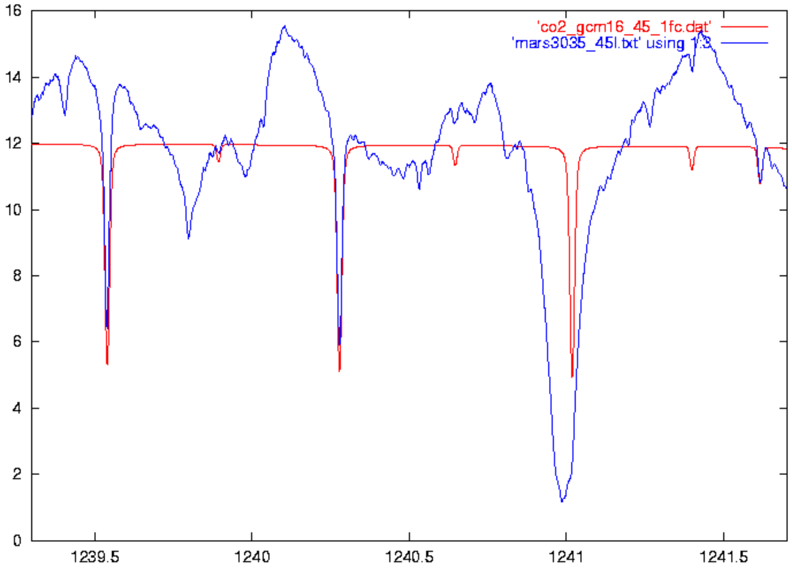


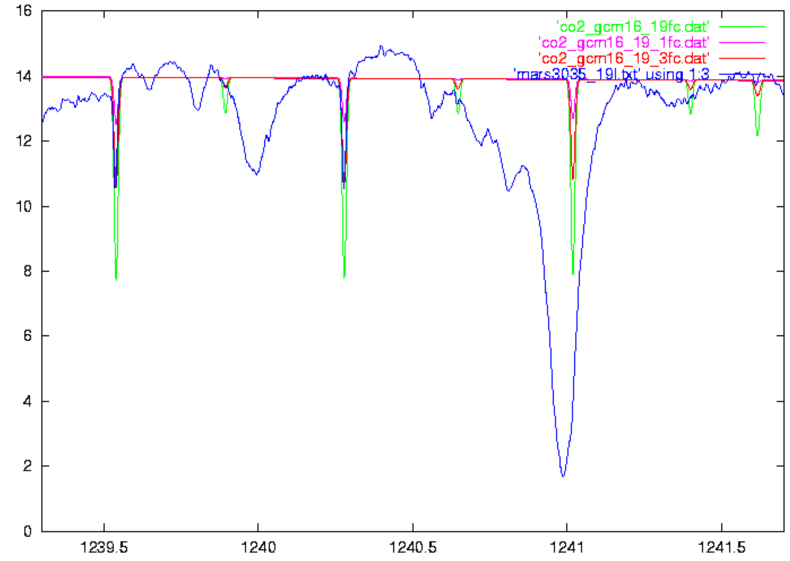
TEXES



GCM

T(P) in the lower atmosphere
(z = 5 - 20 km)



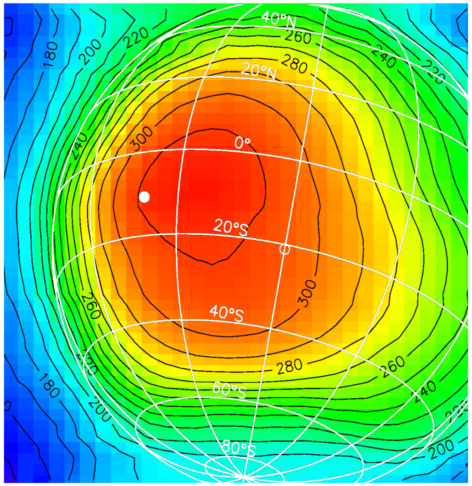


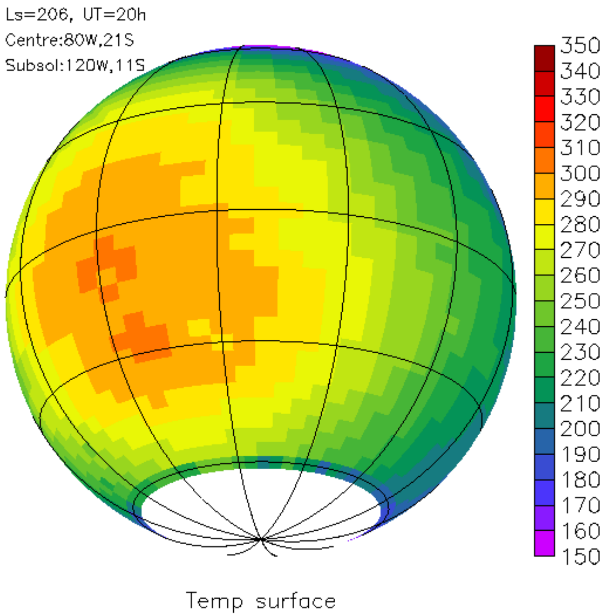
Morning side
Ts = 250 K
T0 = 220 K

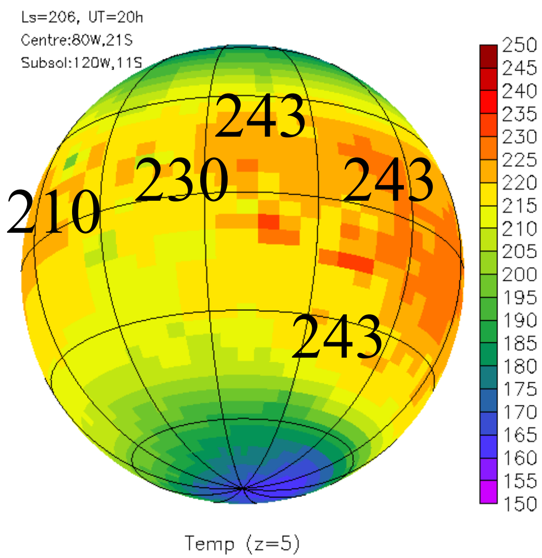
Evening side
Ts=250 K
T0=253 K

Ts and T(5km) on Mars

243

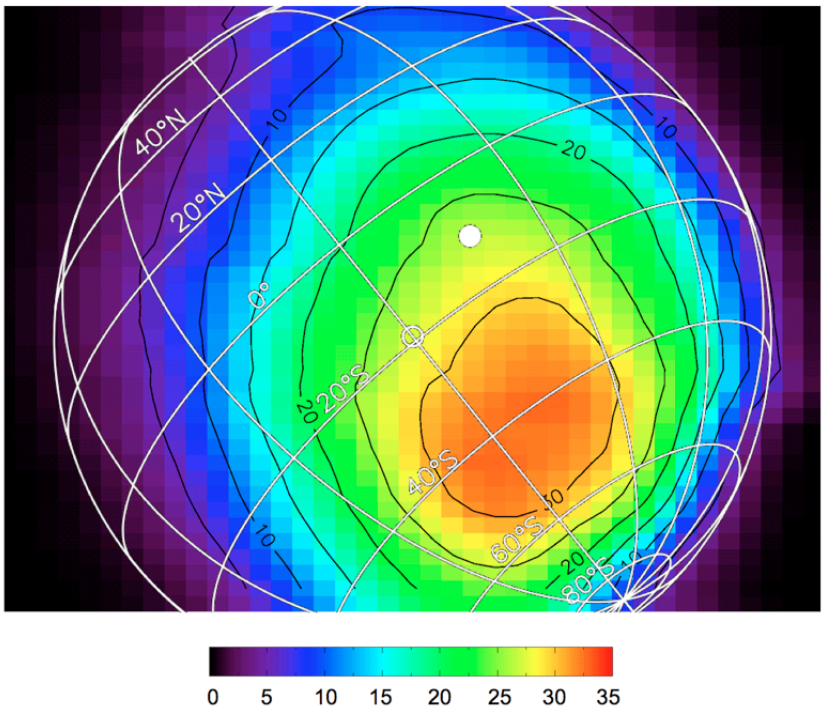


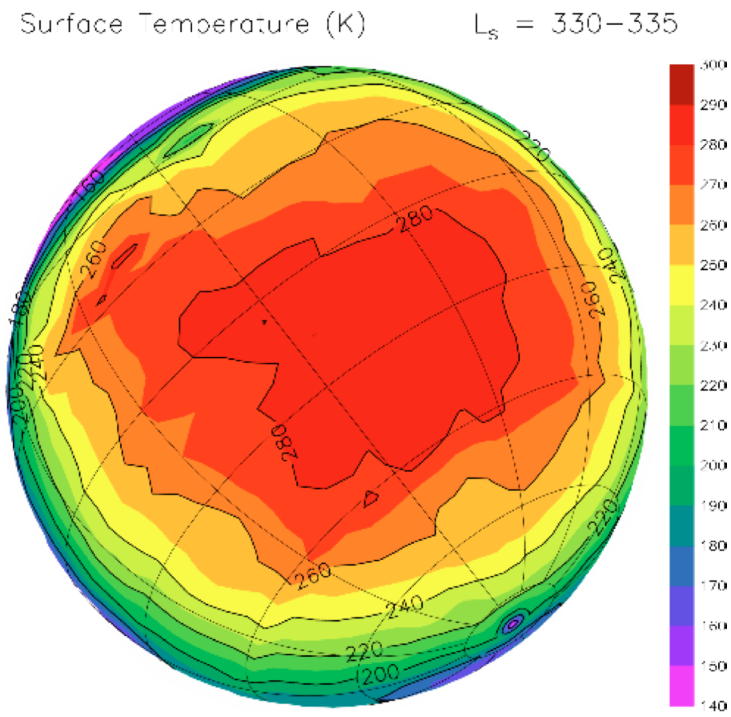




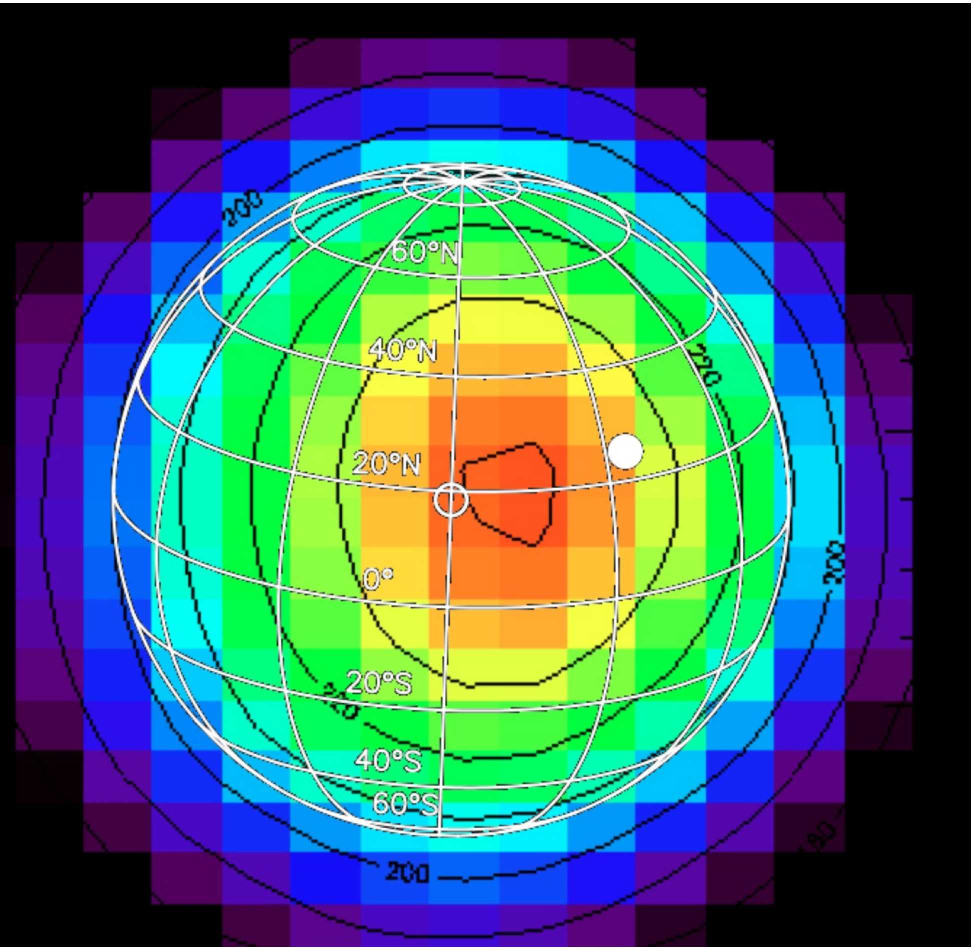
TEXES-Ts GCM-Ts GCM-T(5km)

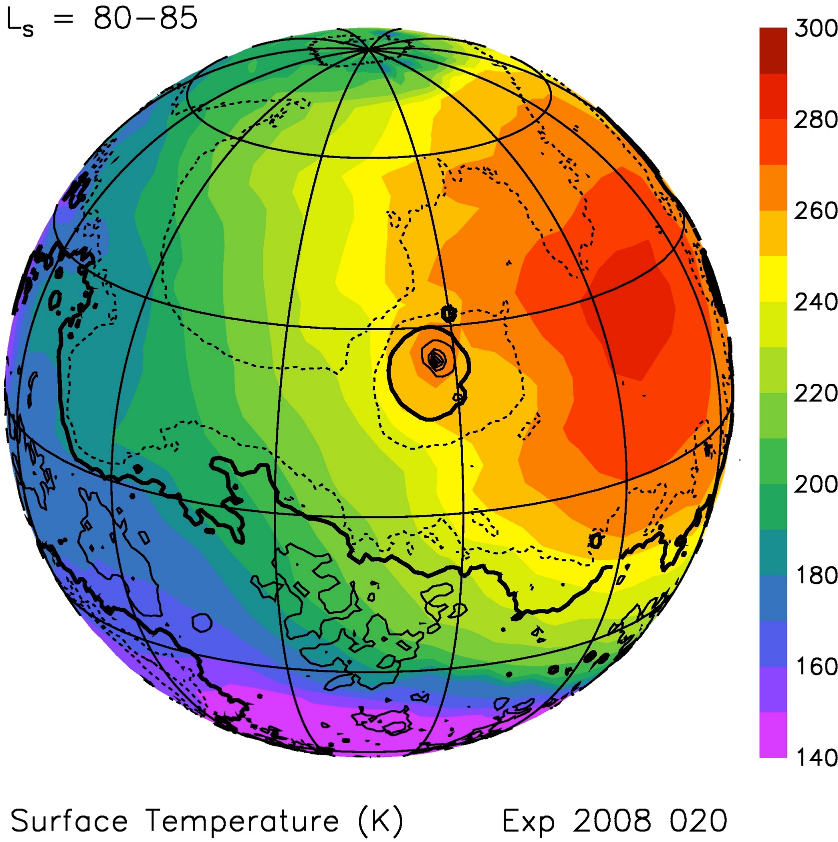
Ls = 332° : discrepancies in the surface temperature maps (effect of dust?)





Discrepancies in Ts also for Ls = 80°





Encrenaz et al. A&A 2010, submitted

CO_2 isotopic ratios in Mars

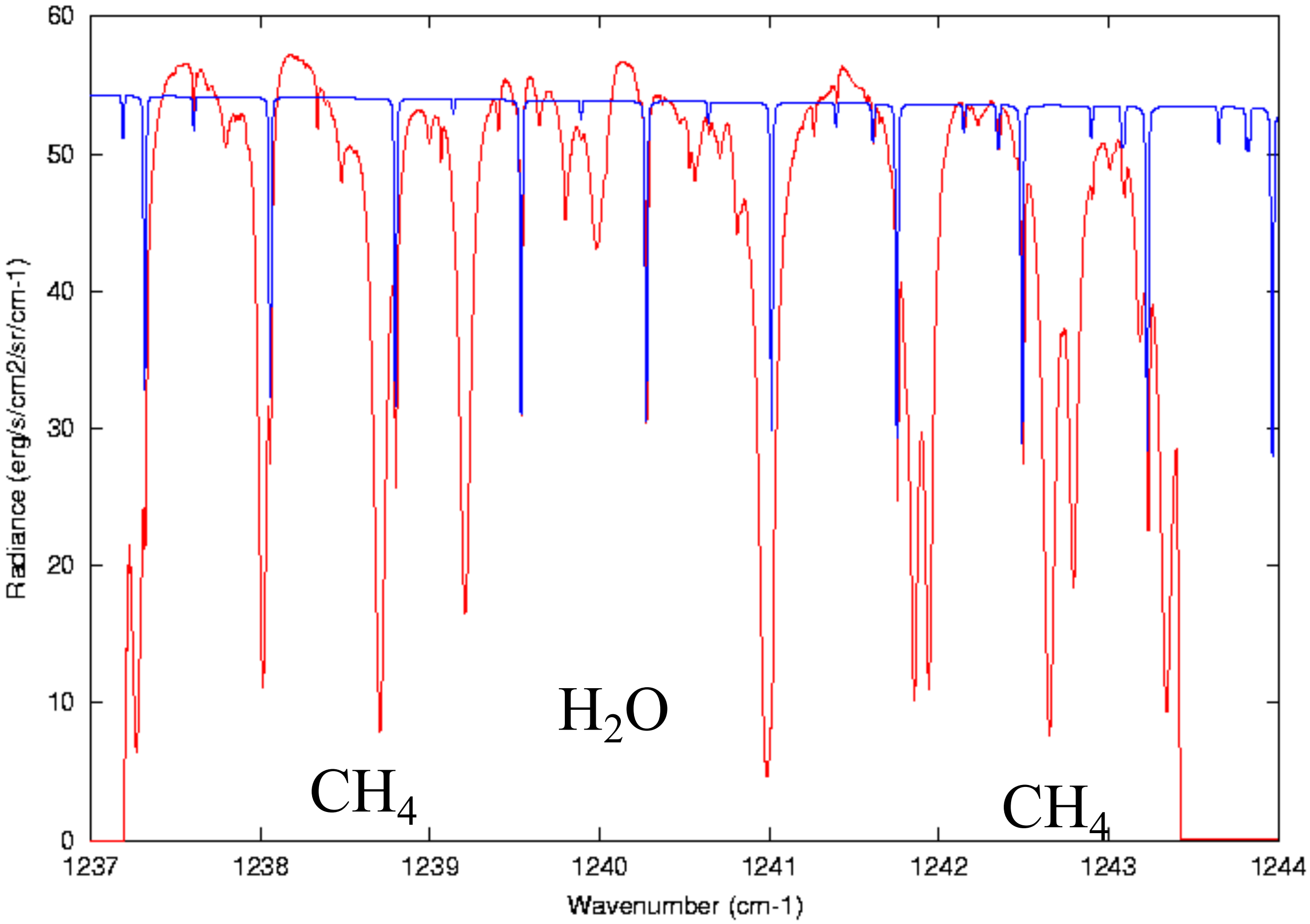
- In H_2O: possible departure from terrestrial values:
  - $^{17}O/^{16}O$=0.95 +/-0.01, $^{18}O/^{16}O$=0.90+/-0.03;
    -> $^{17}O/^{18}O$= 1.05+/- 0.04 (Bjoraker et al., 1989)
- In CO_2: departures from terrestrial values also reported in $^{12}C/^{13}C$ and $^{17}O/^{18}O$ by several percent (Krasnopolsky et al., 1996)

- From the present data: martian ratios are consistent with terrestrial values
  - $^{17}O/^{18}O$=0.97+/-0.06, $^{18}O/^{16}O$=1.06+/-0.20
  - $^{13}C/^{12}C$ = 1.00 +/- 0.04
- The main limitation comes from the uncertainty in the CO_2 band strengths

The method

- Weak CO_2 lines (depth: about 1%)
  - 1230-1236 cm^{-1}: 628 (7 lines), 638 (7 lines)
  - 1237-1244 cm^{-1}: 637 (4 lines), 638 (3 lines)
  - 995-1005 cm^{-1}: 626 (1 line)
- $^{17}O/^{18}O$, $^{18}O/^{16}O$: 3 data sets (north, south, max)
- $^{13}C/^{12}C$: 4 data sets (north, south, max+Feb.2001)
- Line-by-line comparison with synthetic model -> mean ratio per isotopic species
- Error: due to uncertainty in the continuum (10% per line)

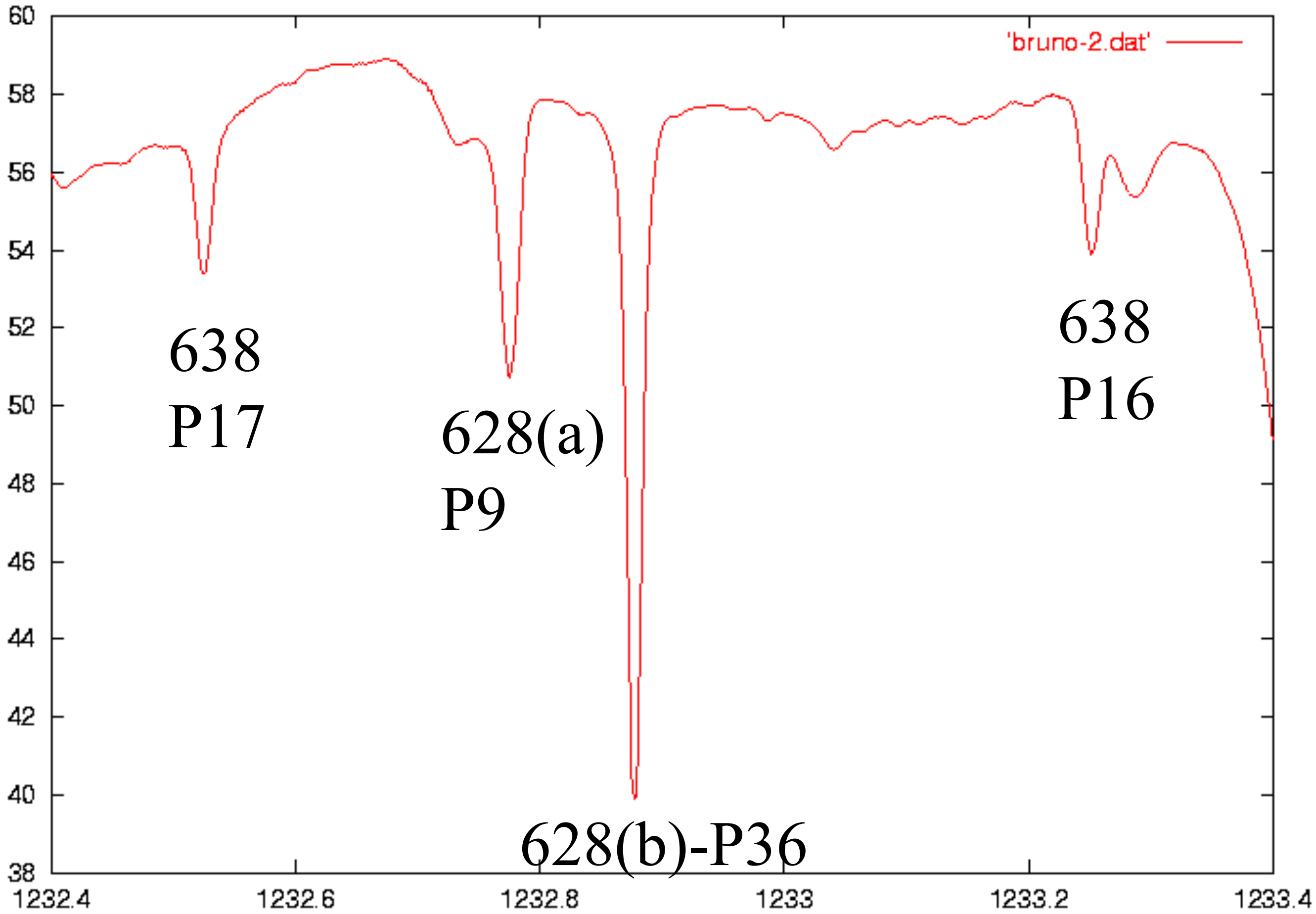
The CO_2 isotopic band



CO_2 synthetic

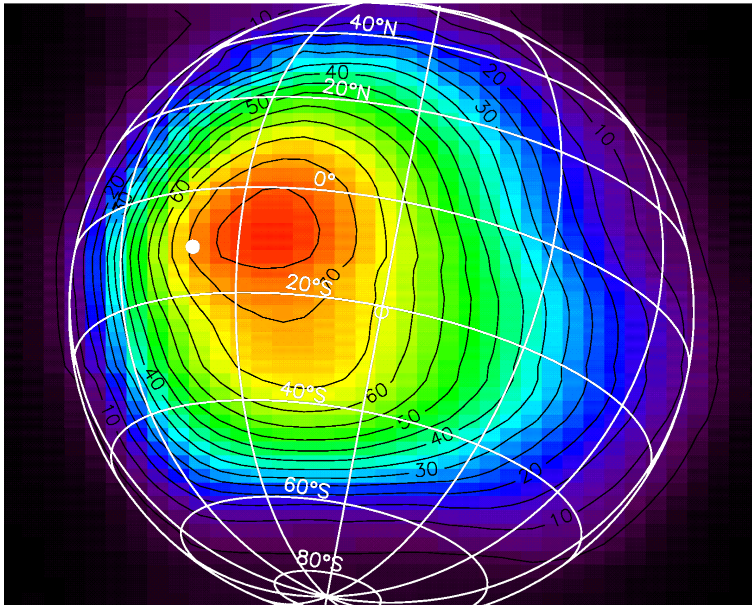
TEXES

The TEXES spectrum of Mars ($\Delta\nu$=0.016 cm^{-1})

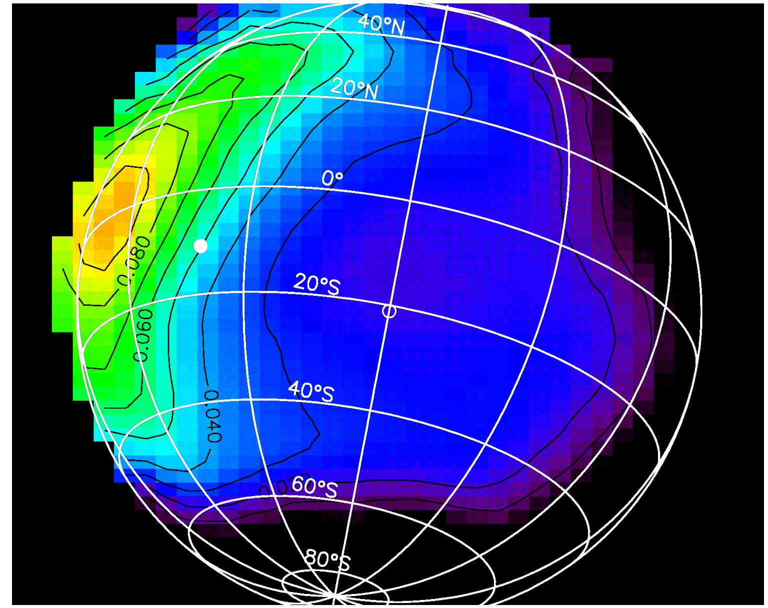


Search for CH_4

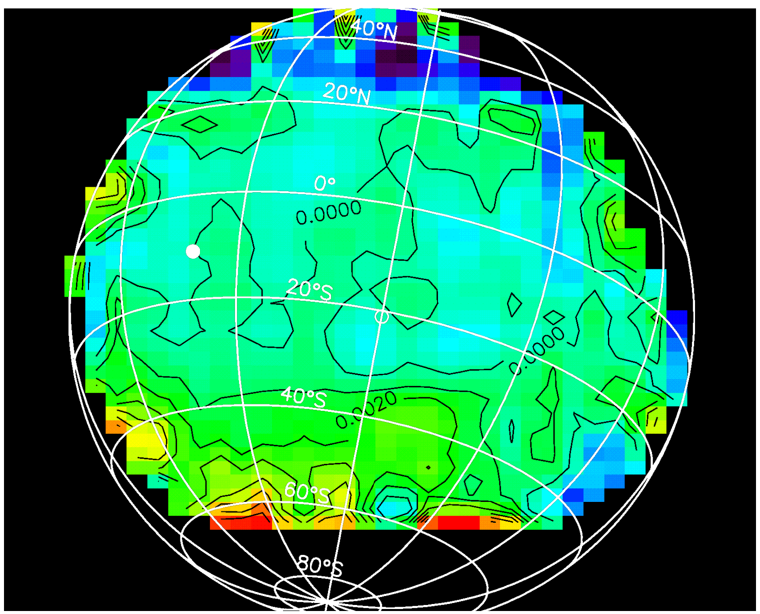
- 2 lines used: 1238.7 cm^{-1} & 1242.6 cm^{-1}
- No way to identify the lines (uncertainty on continuum in the wing of the terrestrial lines) -> search for variations
- Result: no variation seen above 0.1% depth
- Implies CH_4 variations below about 40 ppb (20 ppb on morning side, 80 ppb on evening side)
- Consistent with previous determinations (sources seen by M. Mumma are outside the FOV or on the evening side)



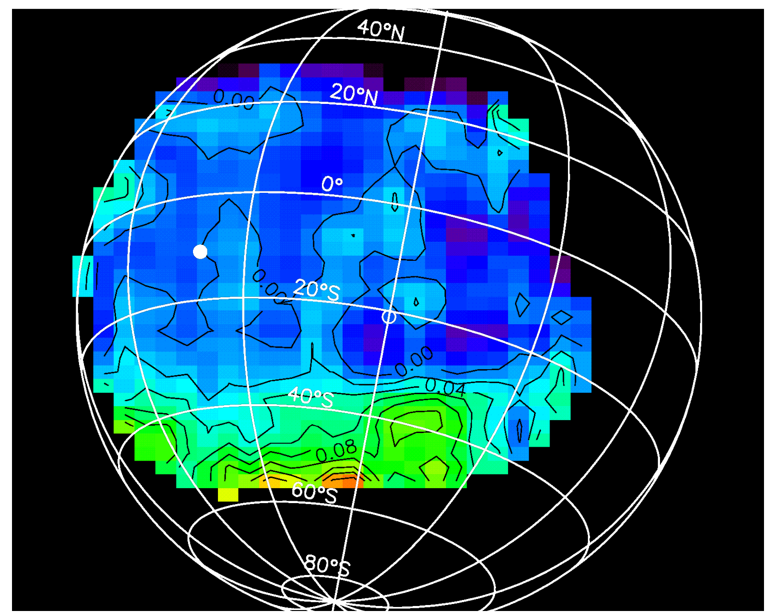
Ts



CO_2



CH_4



CH_4/CO_2

Perspectives with TEXES

- Access to GEMINI
  - > Improved spatial resolution

  Atreya et al. 2007: possible localized spots of H_2O_2
- Venus observations
  - H_2O and SO_2 mapping
  - Search for H_2O_2
  - In coordination with Venus Express observations (on-going debate about SO_2 distribution)

Perspectives with EXES

Mars

-Simultaneous access to HDO and H_2O lines -> D/H mapping and monitoring

(presently assumed to be 5 x terrestrial)

-Search for CH_4 (mapping capability)

-Other possible transitions (TBC):

HDO @ 7 μm, H_2O @ 20-25 μm (stronger transitions)

SO_2 @7.3 μm, H_2 @ 17 μm, H_2CO@ 5.7 μm, …

Venus

-HDO and H_2O -> D/H (present debate)

-SO_2 mapping (present debate)