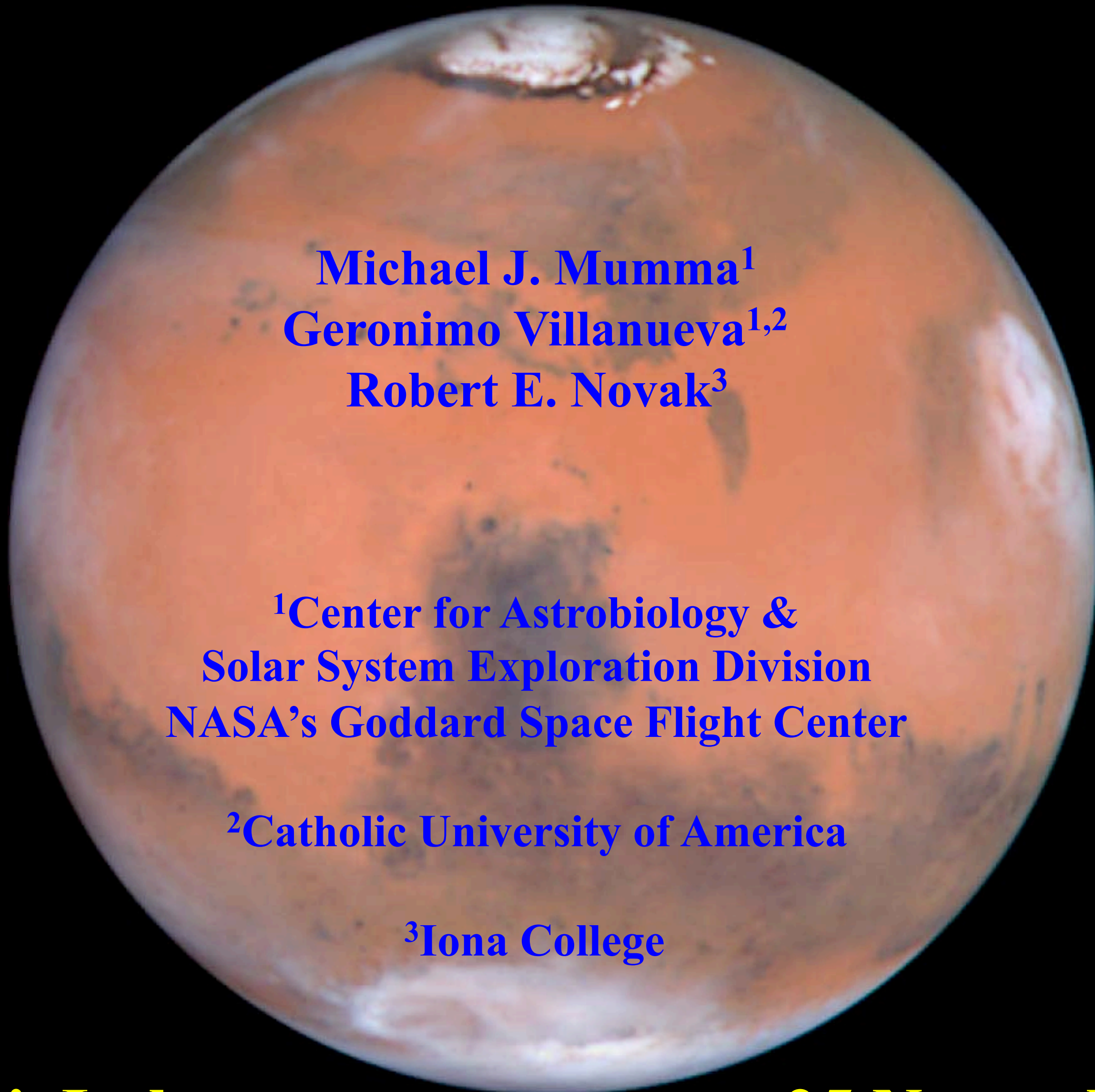
Absolute Measurements of Methane on Mars



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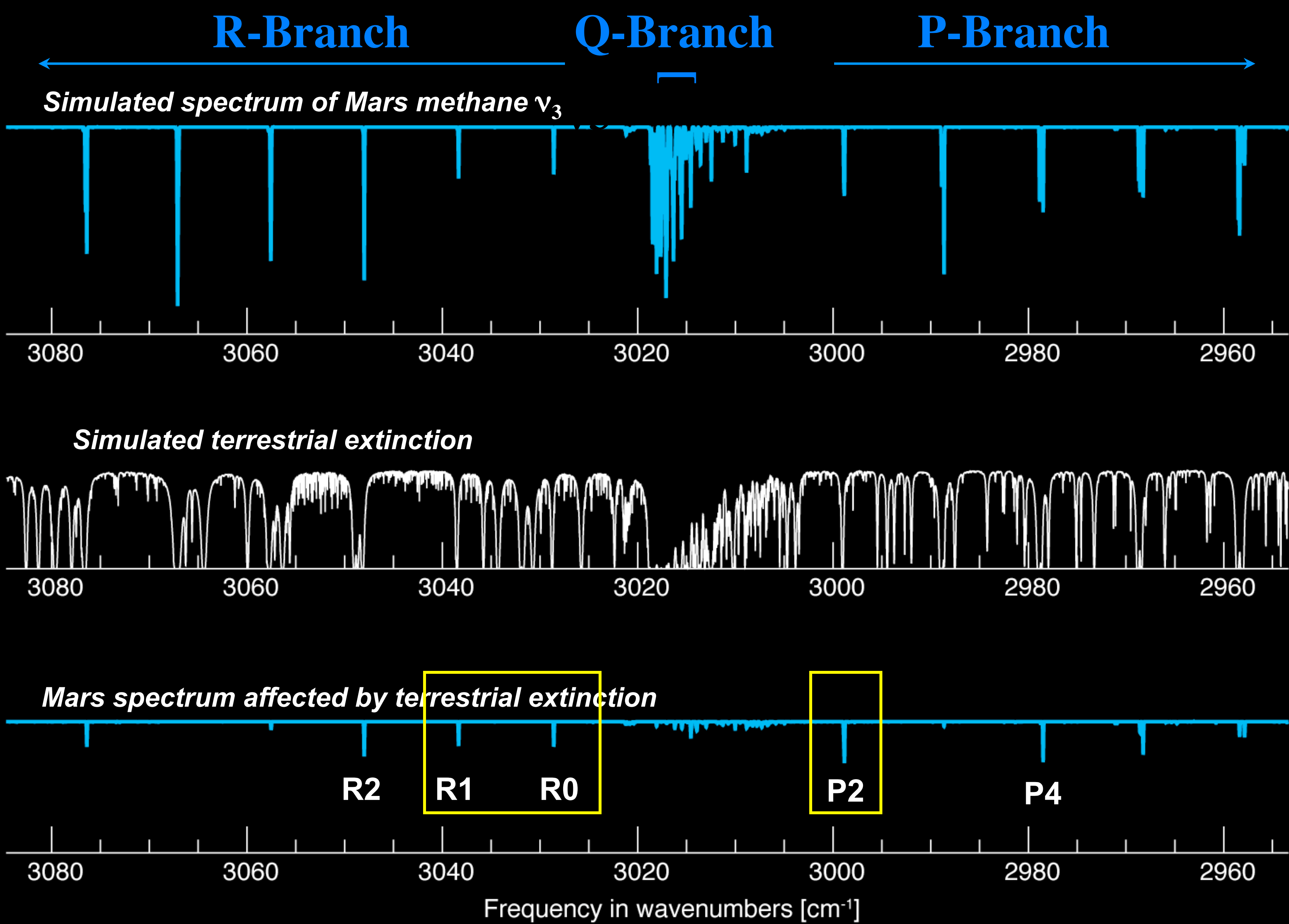
Frascati, Italy **25 November 2009**

The Search for Mars methane

- The measurement approach
- Improvements in Analysis
- Our spectral detections
- The current campaign


R-Branch
Q-Branch
P-Branch
Simulated spectrum of Mars methane ν3
3080
3060
3040
3020
3000
2980
2960
Simulated terrestrial extinction
3080
3060
3040
3020
3000
2980
2960
Mars spectrum affected by terrestrial extinction
R2
R1
R0
P2
P4
3080
3060
3040
3020
3000
2980
2960
Frequency in wavenumbers [cm-1]

CH_4 :

3 nuclear spin species,

A, E, F

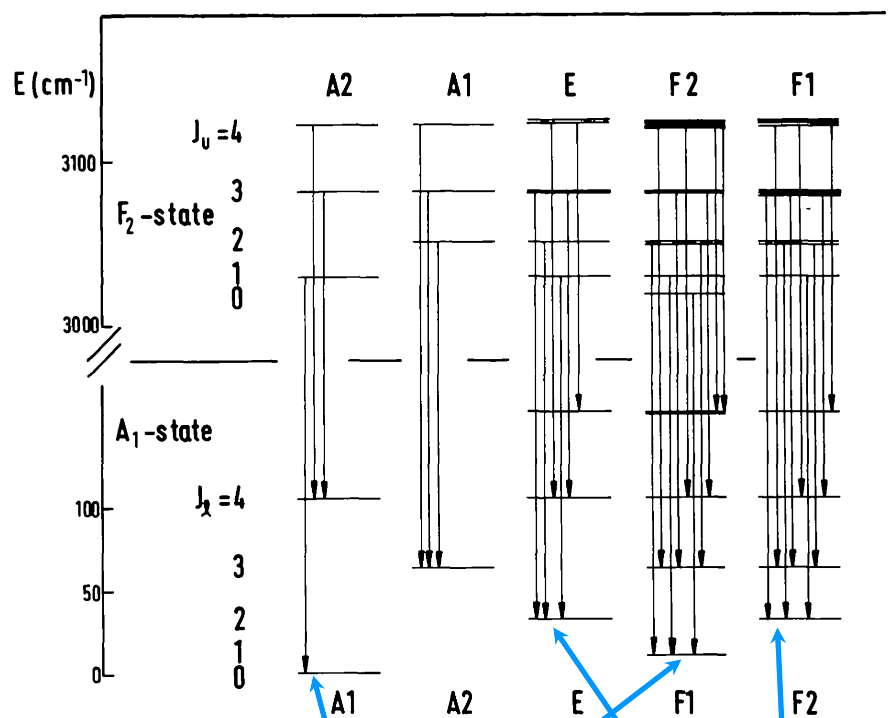
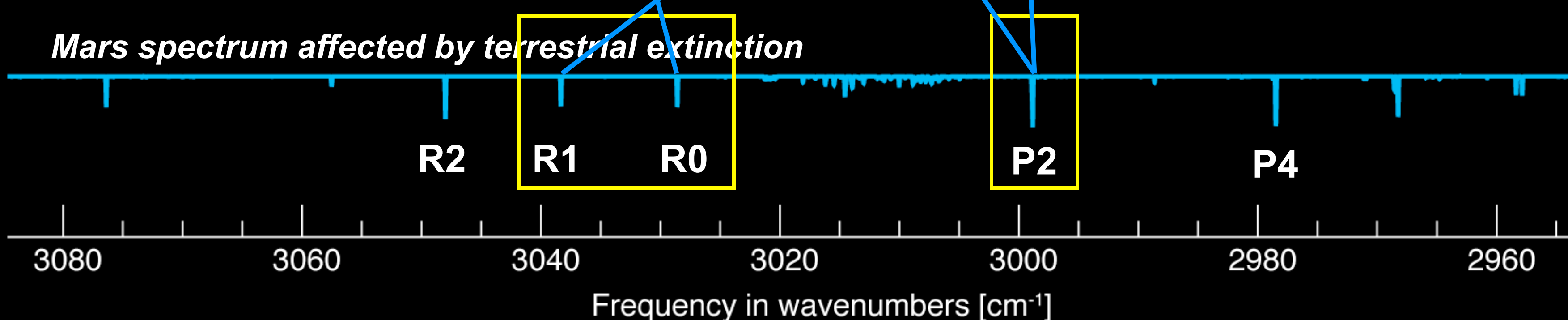
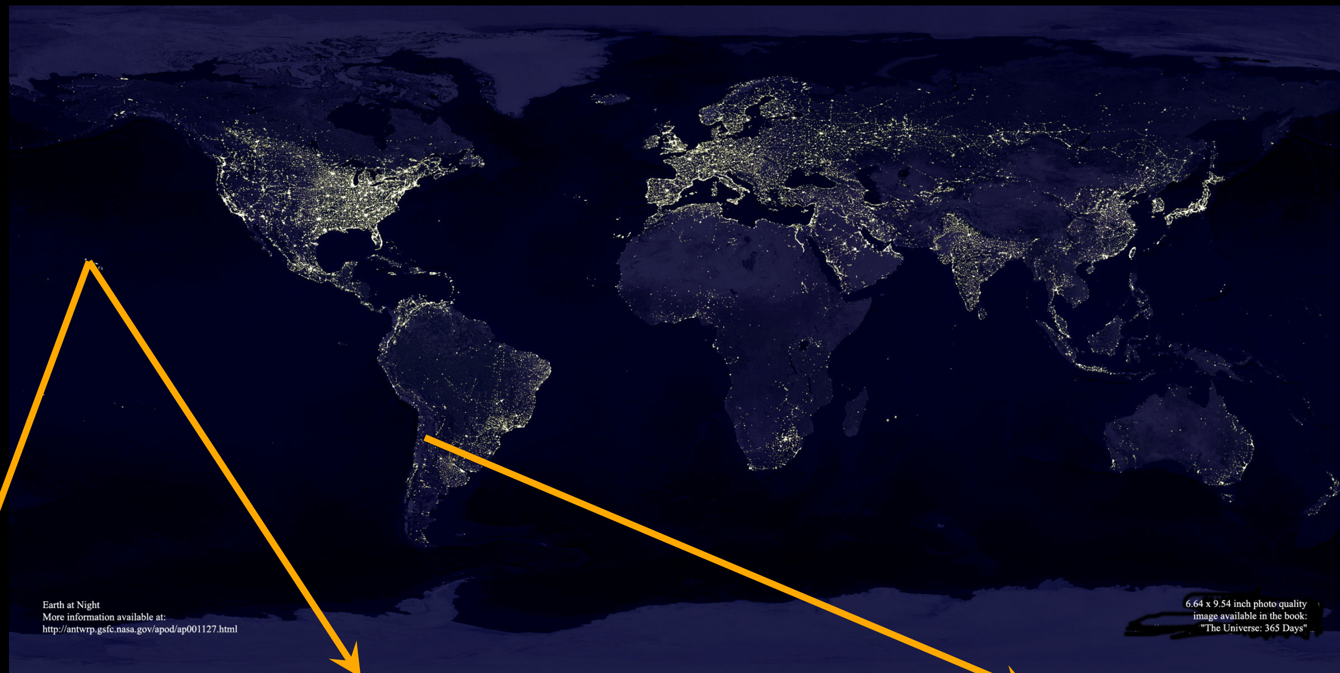


Fig. 2. Lower rotational states of the A_1 ground state and F_2 excited state of the ν_3 vibrational band of CH_4. Rotational levels of one species (A, E or F) can only combine with levels of the same species (After Drapatz et al. A&A 1987)

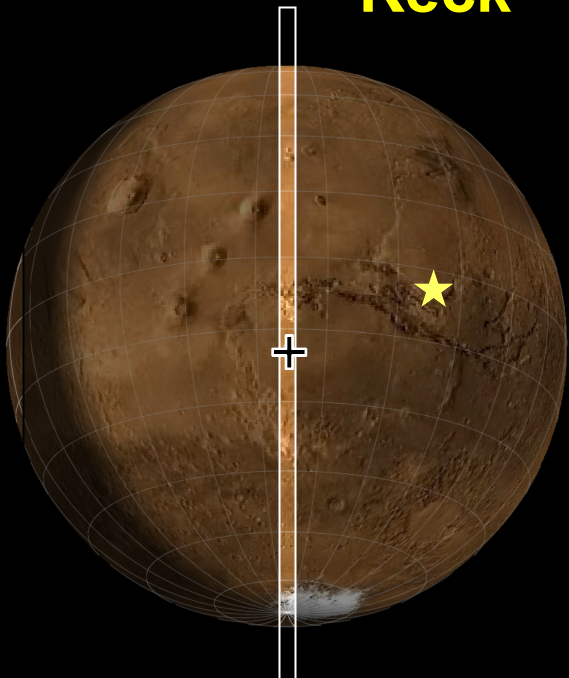


How did we search for methane?

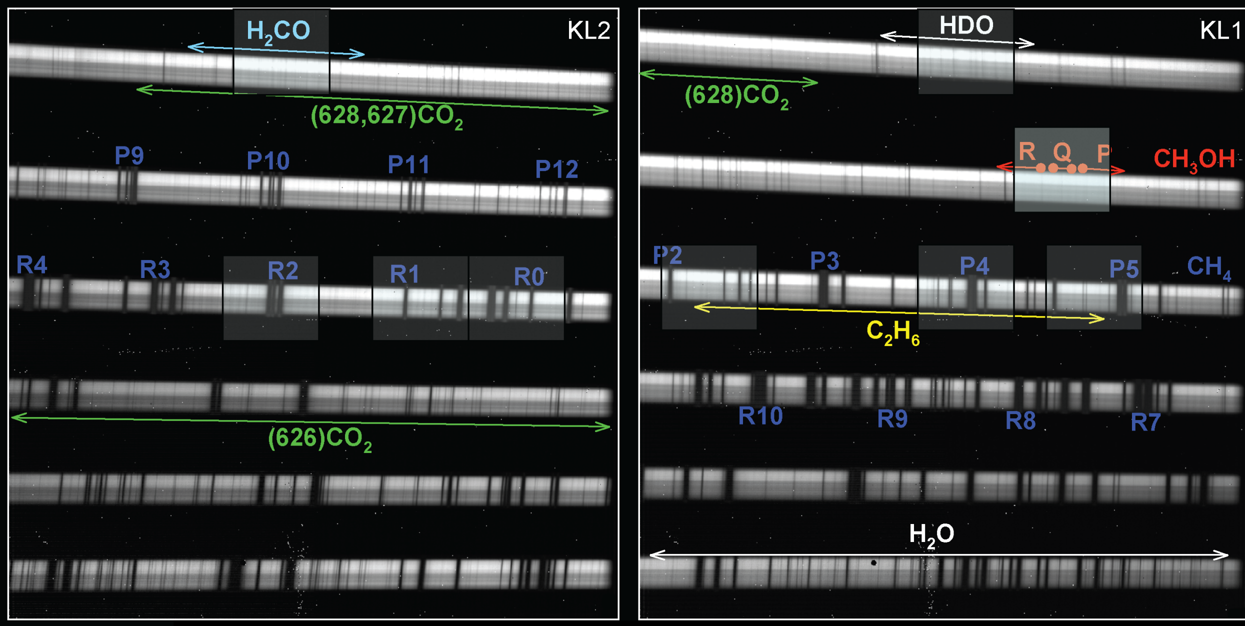


IRTF - CSHELL : shaded boxes (lots of observing time!)

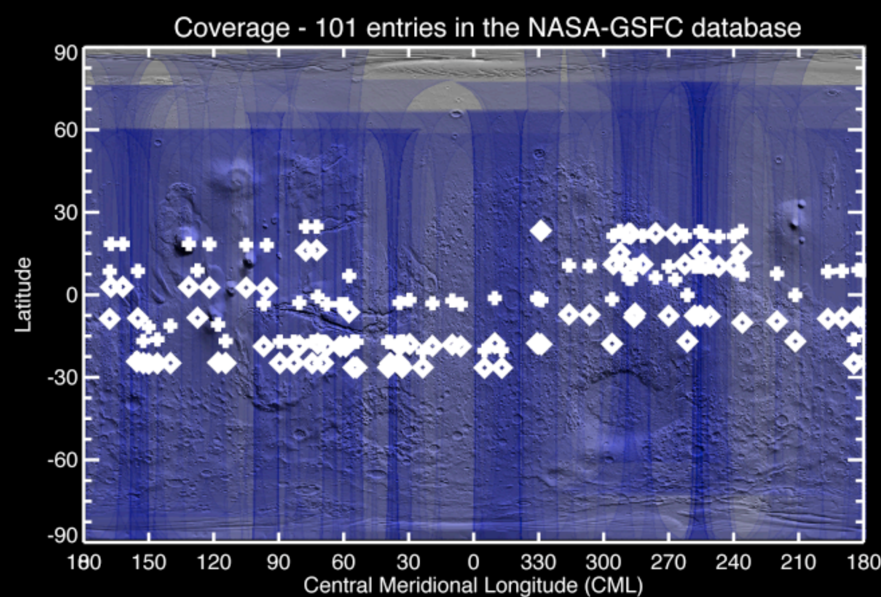
Keck - NIRSPEC : Large Spectral & Spatial Grasp

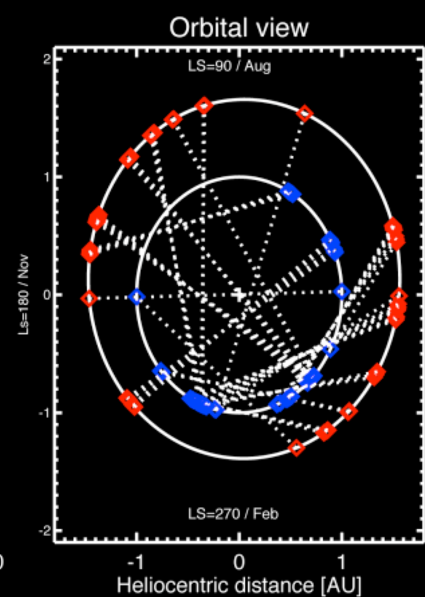


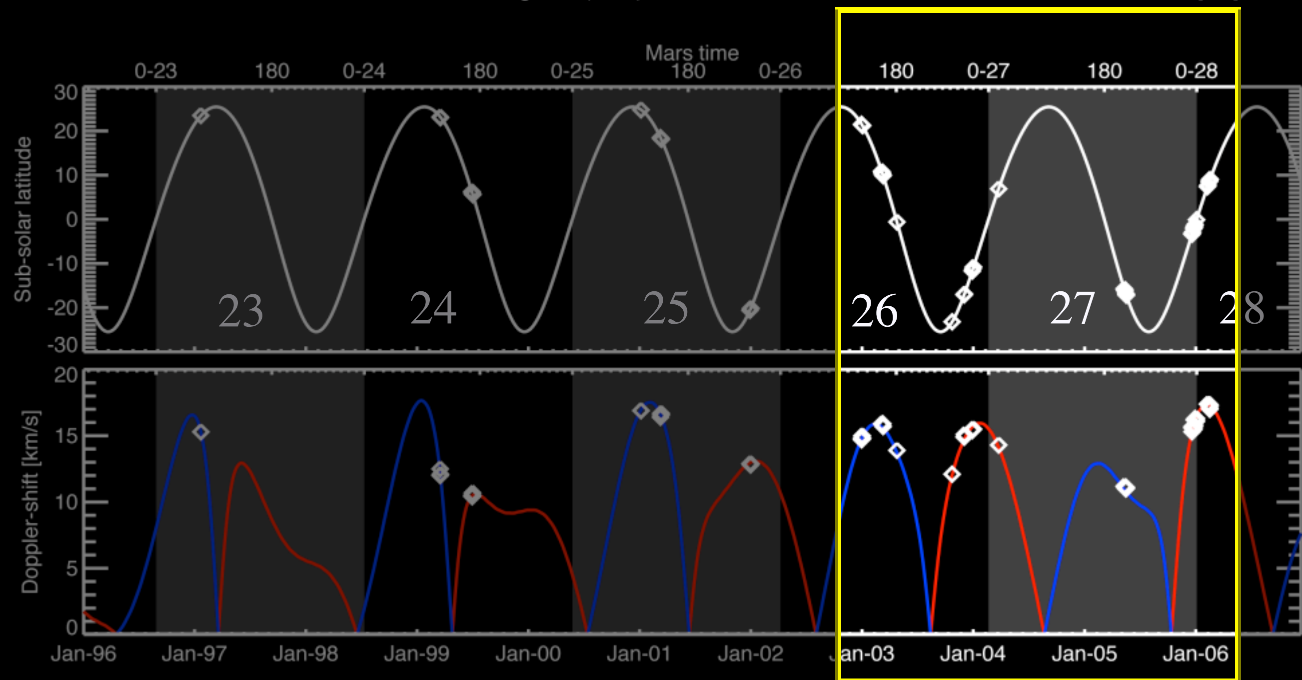
Data taken on 06 January 2006 09:00 UT (L_S = 352°)



Frequencies between 2700-3400 cm^{-1} (3.7-2.9μm)

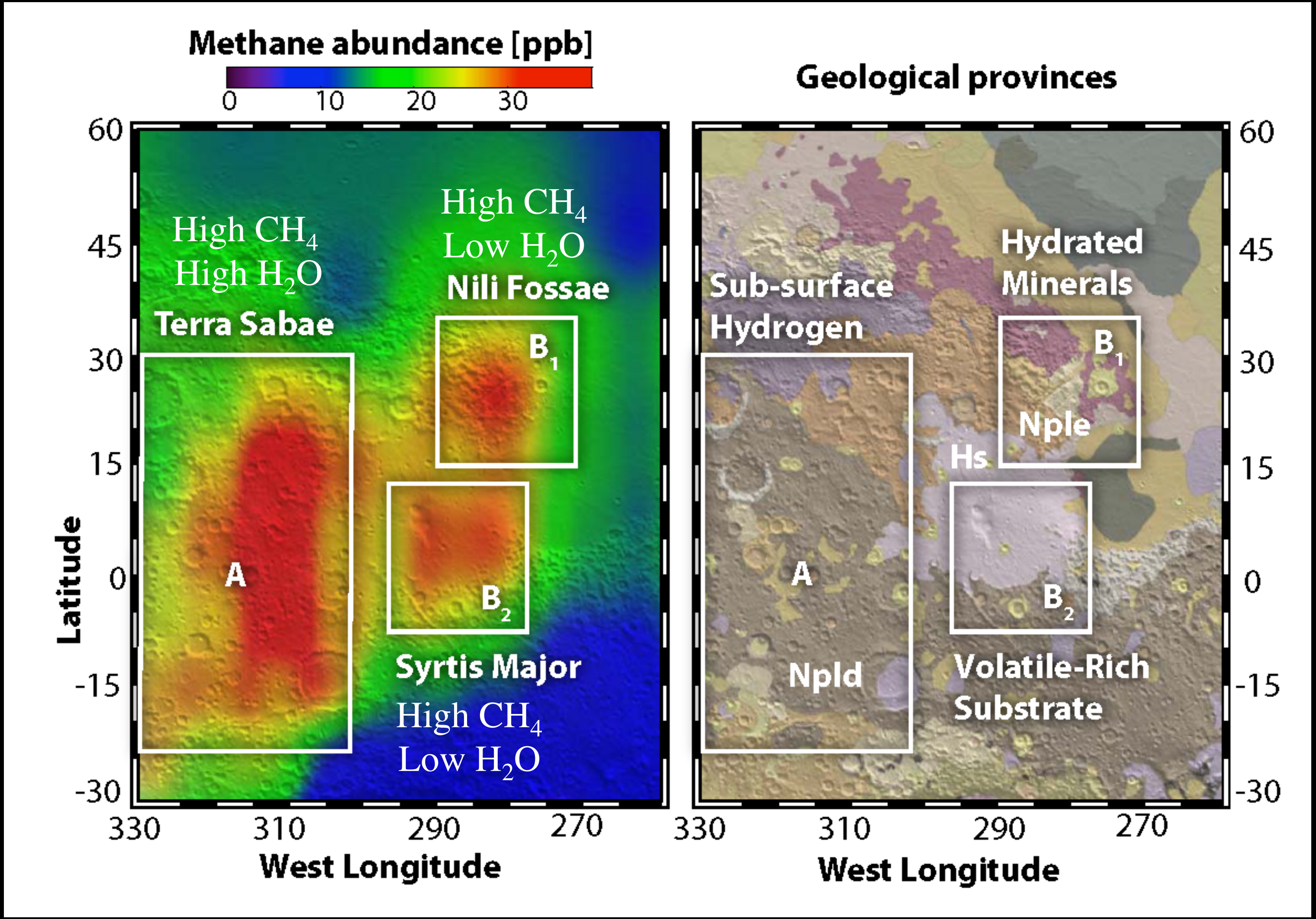

Coverage - 101 entries in the NASA-GSFC database
Latitude
90
60
30
0
-30
-60
-90
180 150 120 90 60 30 0 330 300 270 240 210 180
Central Meridional Longitude (CML)

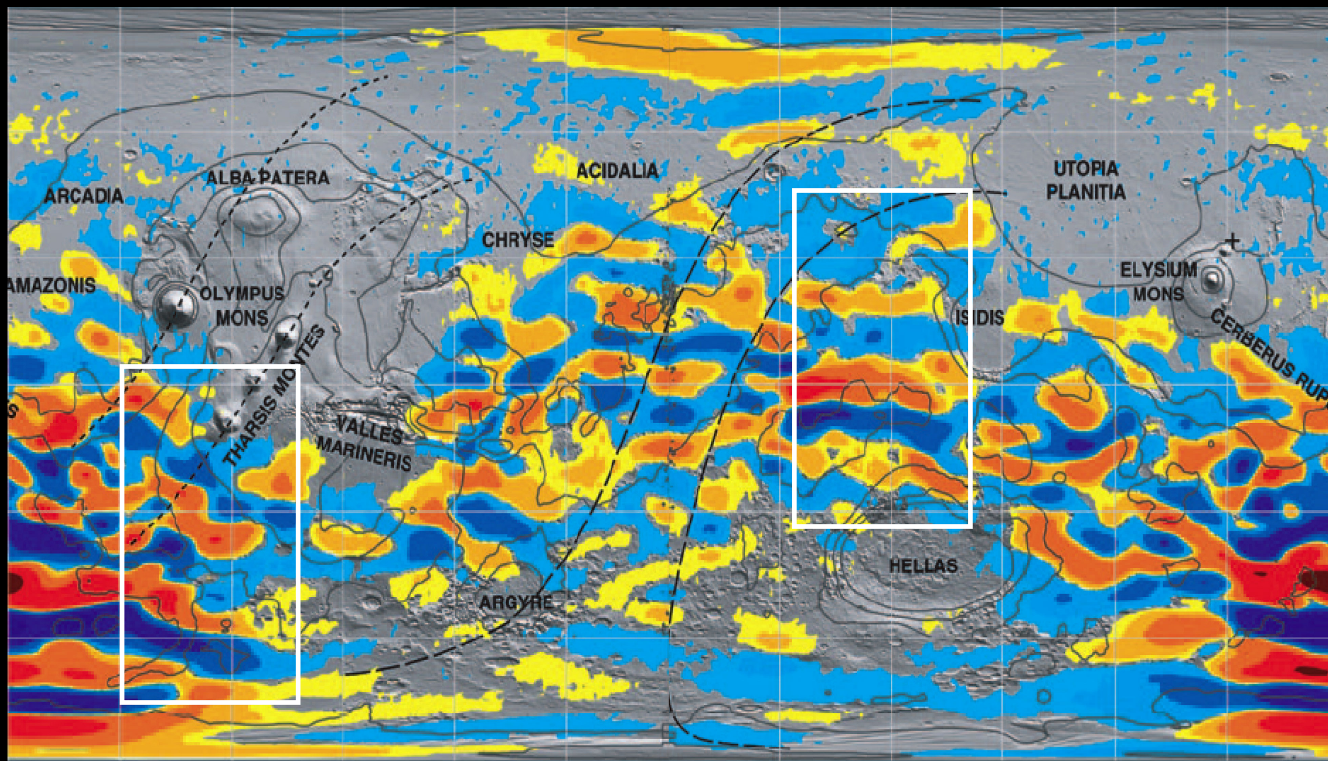

Orbital view
LS=90 / Aug
LS=270 / Feb
Ls=180 / Nov
-1 0 1
Heliocentric distance [AU]


Mars time
0-23 180 0-24 180 0-25 180 0-26 180 0-27 180 0-28
Sub-solar latitude
30
20
10
0
-10
-20
-30
23
24
25
26
27
28
Doppler-shift [km/s]
20
15
10
5
0
Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06

Mumma, Villanueva, Novak, et al. (Science 2009)

Resolution-limited Spatial Maps reveal local methane plumes on scales of 500 km.
Is the release relatively uniform over these regions – or is it strongly localized?





Maximum abundance Observed at L_s 220° (mid-spring in South)

Maximum abundance Observed at L_s 155° (late summer in North)

Methane Issues

✓Origin —

When was it produced ? (recent vs. ancient)

How was it produced ? (abiotic vs. biotic)

reduce carbon in mantle (CO_2, H_2O, heat)

release H_2 : serpentinization, pyrite production, H_2O radiolysis

microbes metabolize H_2, reduce CO, CO_2, or acetate

How is it released? Is it seasonal?

thermal activation of near-surface? (supra-permafrost)

by opening pores /fractures in scarps ? (sub-permafrost)

✓Sinks —

Atmospheric – triboelectric, photochemical, other?

Sub-surface (oxidants) – peroxides, perchlorates

Sequestering (adhesion, gettering)

✓Re-charge Mechanism (if released annually)

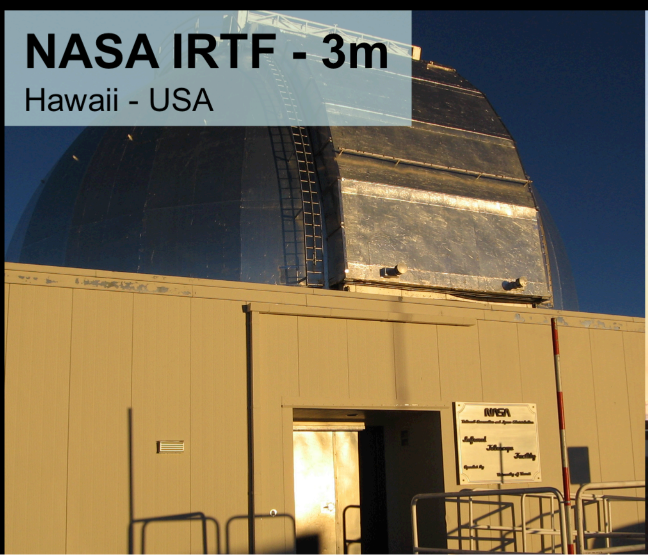
- We want higher spectral resolution to improve detection sensitivity.
    - We want higher spatial resolution to test source properties.

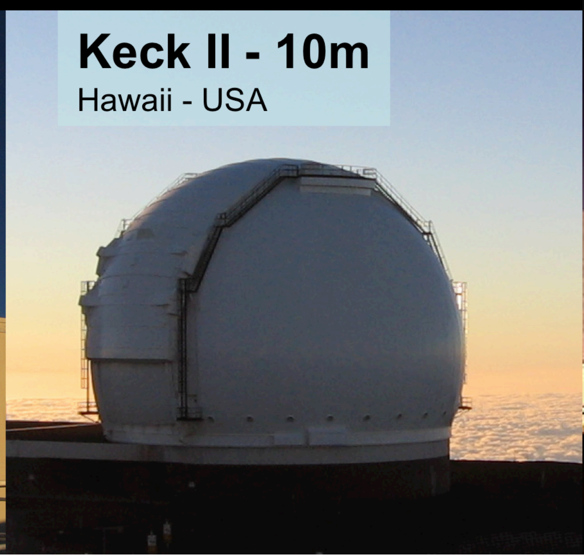
✓Spectral Resolving Power:

CRIRES	$\lambda/\delta\lambda \sim 100{,}000$	0.2” x 30” slit
NIRSPAO	$\lambda/\delta\lambda \sim 40{,}000$	0.036” x 2.4” slit

✓Spatial resolution :

CRIRES – UT1	AO, without re-imaging	0.086” pixels
NIRSPEC – Keck 2	AO, with re-imaging	0.018” pixels





Current Campaign
Scheduled runs 2009B

Dates	Instrument	Mode	Diameter	Velocity km/s	Season L_s
19 - 24 Aug	CRIRES	AO	5.6”	- 9.7	325°
05 -10 Sept	CRIRES	AO	6.0”	-10.6	334°
29 Oct - 1 Nov	CRIRES	AO	7.8”	-13.8	1.9°
6 – 7 Nov	CSHELL	–	8.2”	-13.8	5.4°
10 - 11 Nov	NIRSPEC	non-AO	8.5”	-13.8	7.3°
18 - 21 Nov	CRIRES	AO	9.2”	-13.9	11.7°
23 Nov	CSHELL	–	9.4”	-13.9	13.6°
25 Nov	CSHELL	–	9.4”	-13.9	14.5°
1 - 2 Dec	NIRSPEC	non-AO	10.0”	-13.5	17.4°
11 - 12 Dec	NIRSPEC	AO	10.8”	-12.6	22°
12 -15 Dec	CSHELL	–	11.0”	-12.3	23°
15 - 16 Dec	NIRSPEC	non – AO	11.1”	-12.2	24°

Analysis Changes Leading to Absolute Extractions (2005 Onward)

Pipeline Processing

From raw spectral-spatial frames to calibrated & registered frames

- Re-sample wavelength scale to milli - pixel accuracy (row-by-row)
- Use non-linear wavelength re-sampling (atmospheric emission)
- Remove second order fringing (Lomb periodogram analysis)
- Remove internal scattered light
- Correct residual dark current
- Correct residual terrestrial radiance

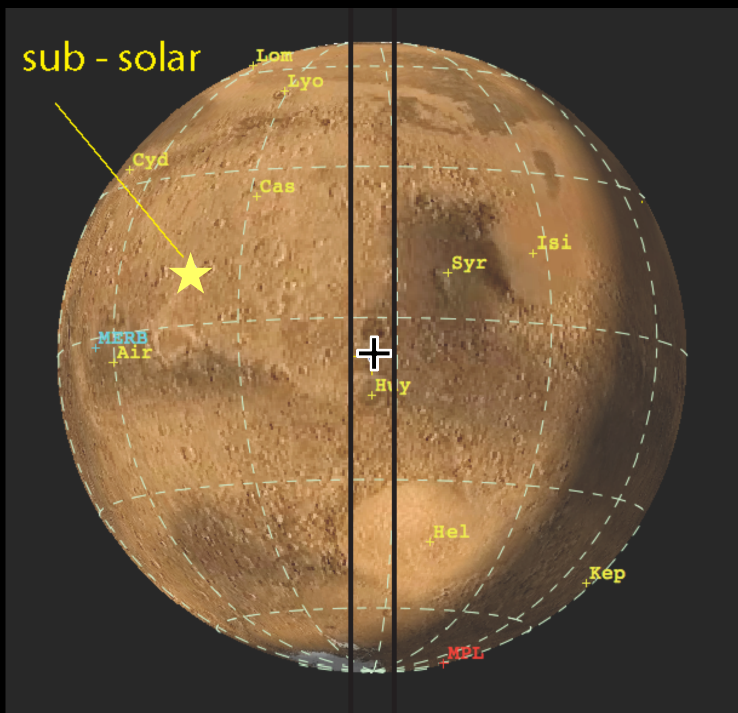
Science Analysis

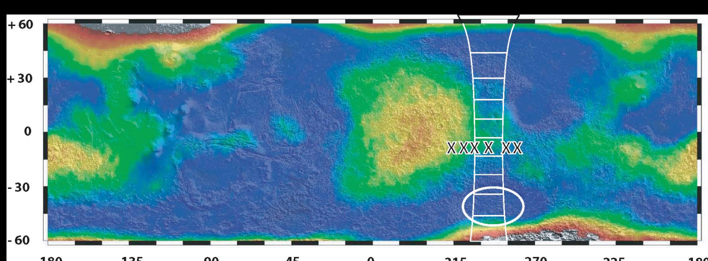
Atmospheric transmittance -

- Replaced SSP with GenIn2 v4 — and corrected pressure shift code
  - [In 2008: Replaced GenIn2 with LBLRTM]
- Upgraded molecular atlas (now HITRAN '08 with additional upgrades)
- Model synthetic spectra using variable resolving power along the slit

Before 2005

CSHELL slit position
UT 20.73 March 2003

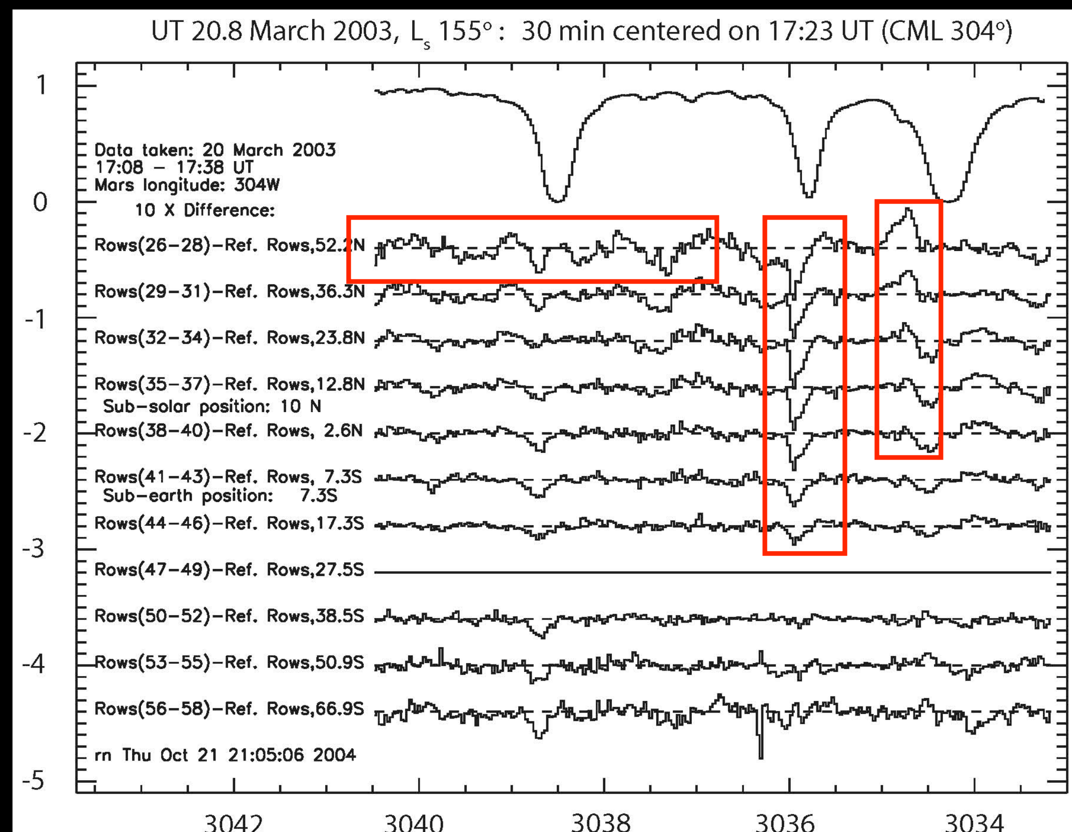




Methane and Water on Mars

CH_4 R1 | H_2O -- |-------|--

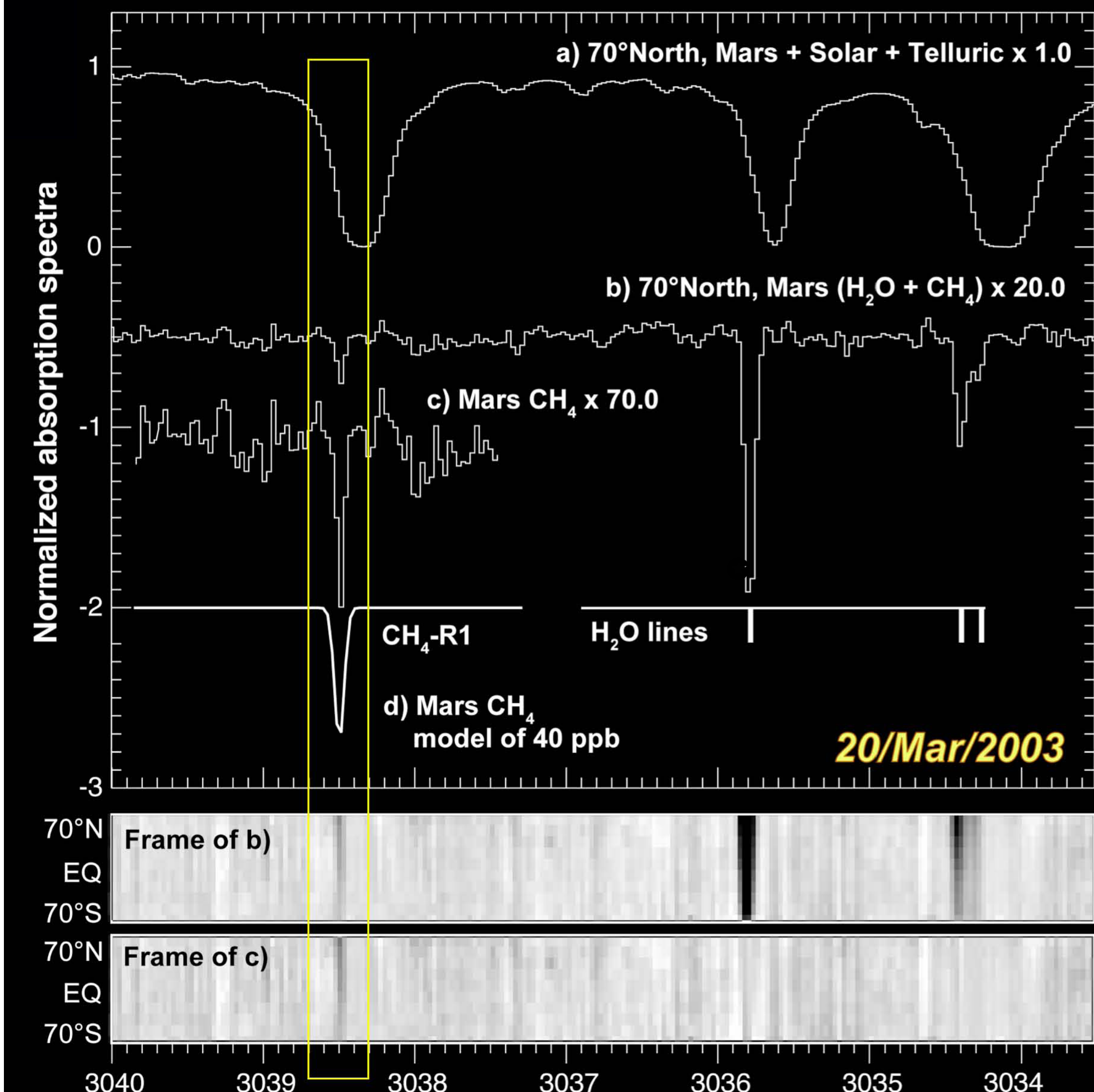
ISSUES :



Wavenumber, cm^{-1}

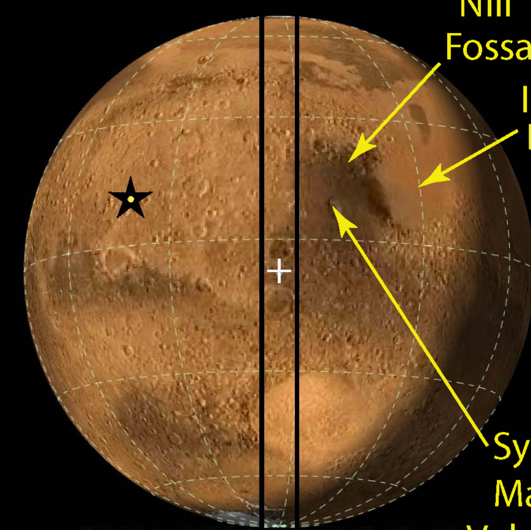
TODAY

Clear Detections of Methane and Water on Mars



Northern late-summer

$L_s = 155°$



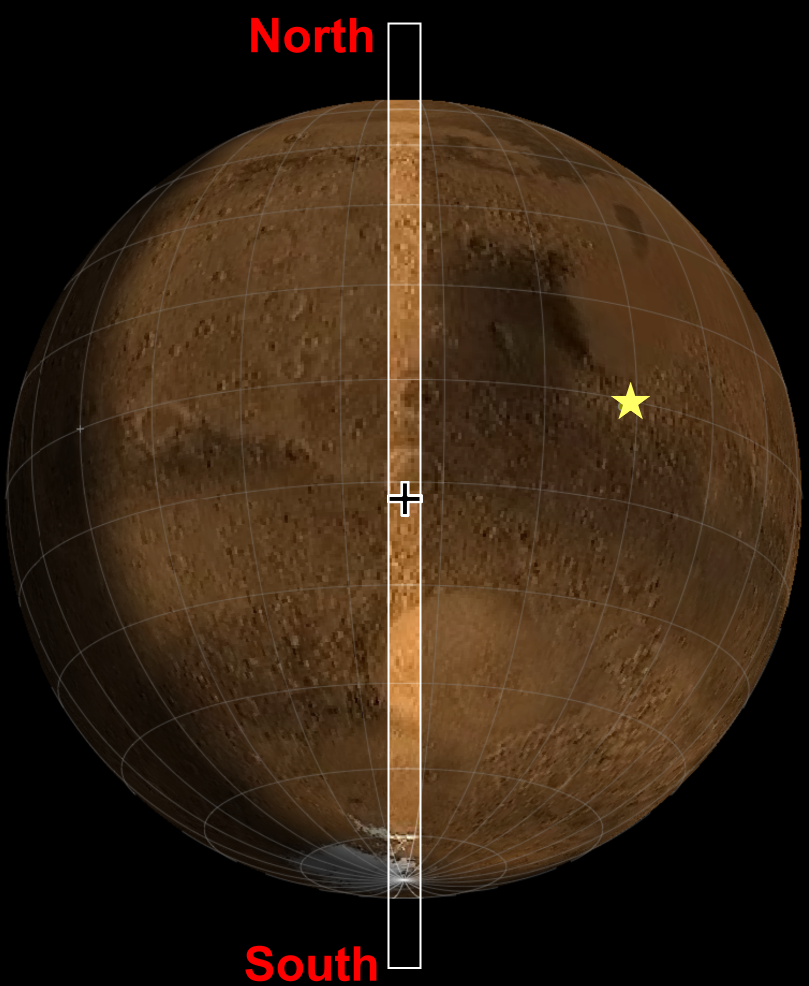
} Both gases are enhanced towards the North

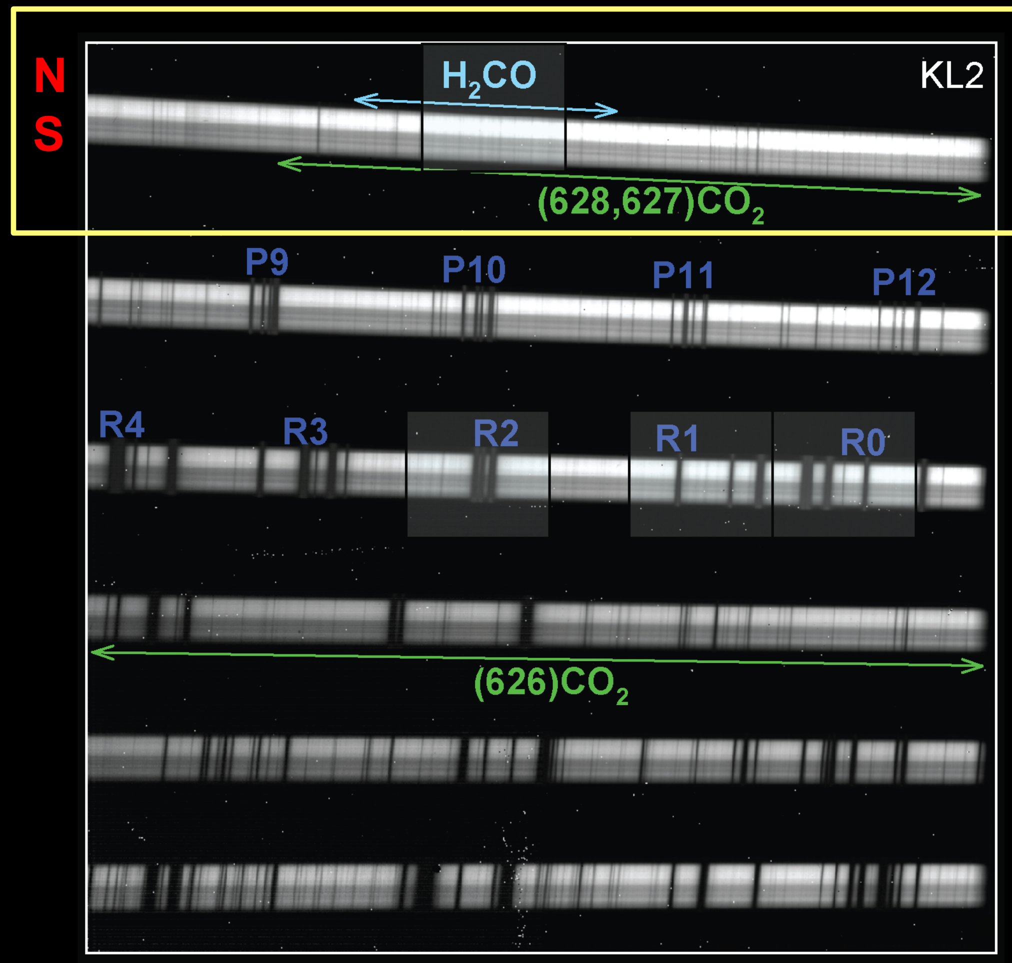
Mars 16 January 2006 05:00 UT $L_s = 357°$

Diameter 11.5" Velocity +16.4 km/s

NIRSPEC

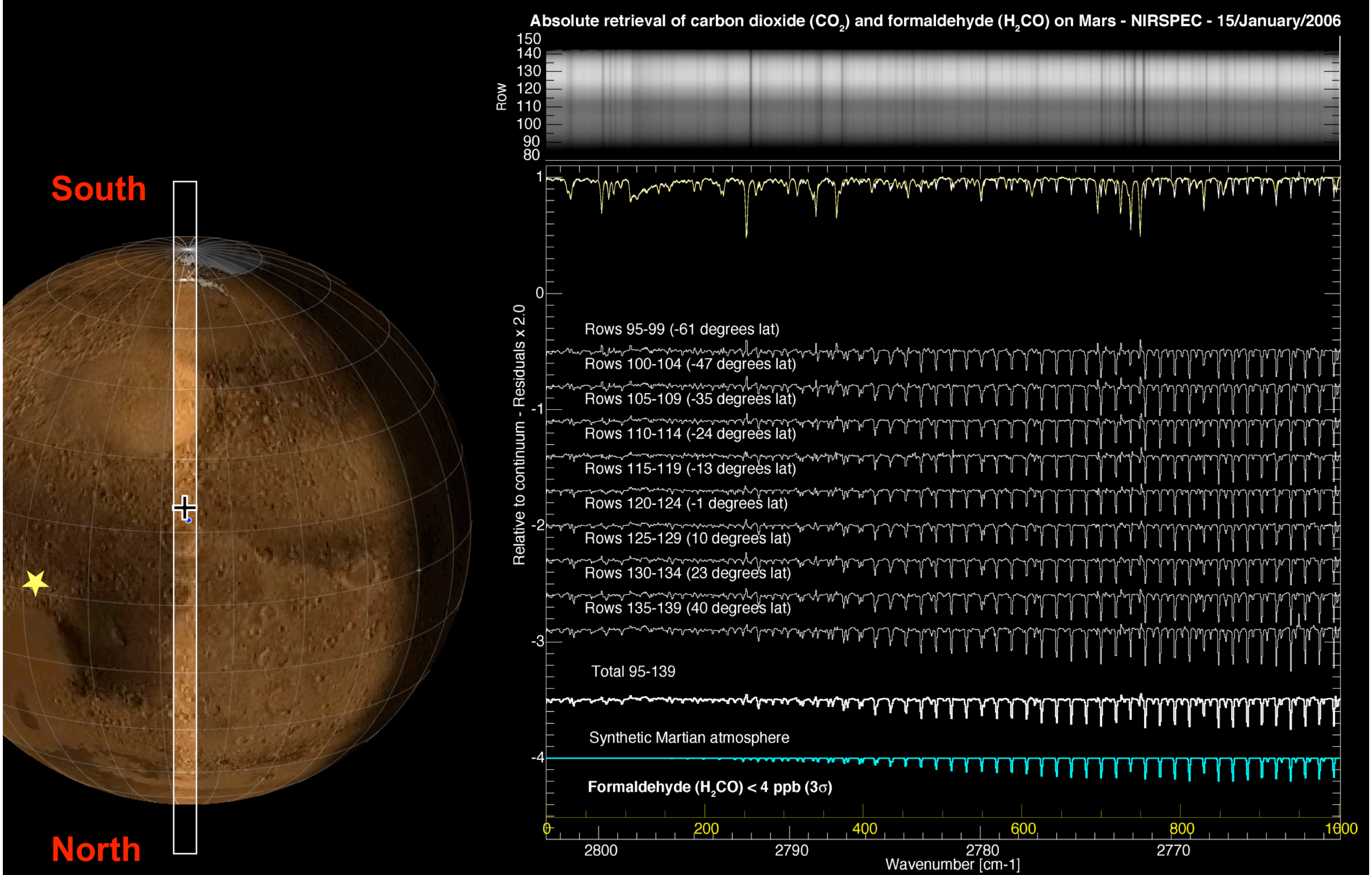
Spectra at L-band

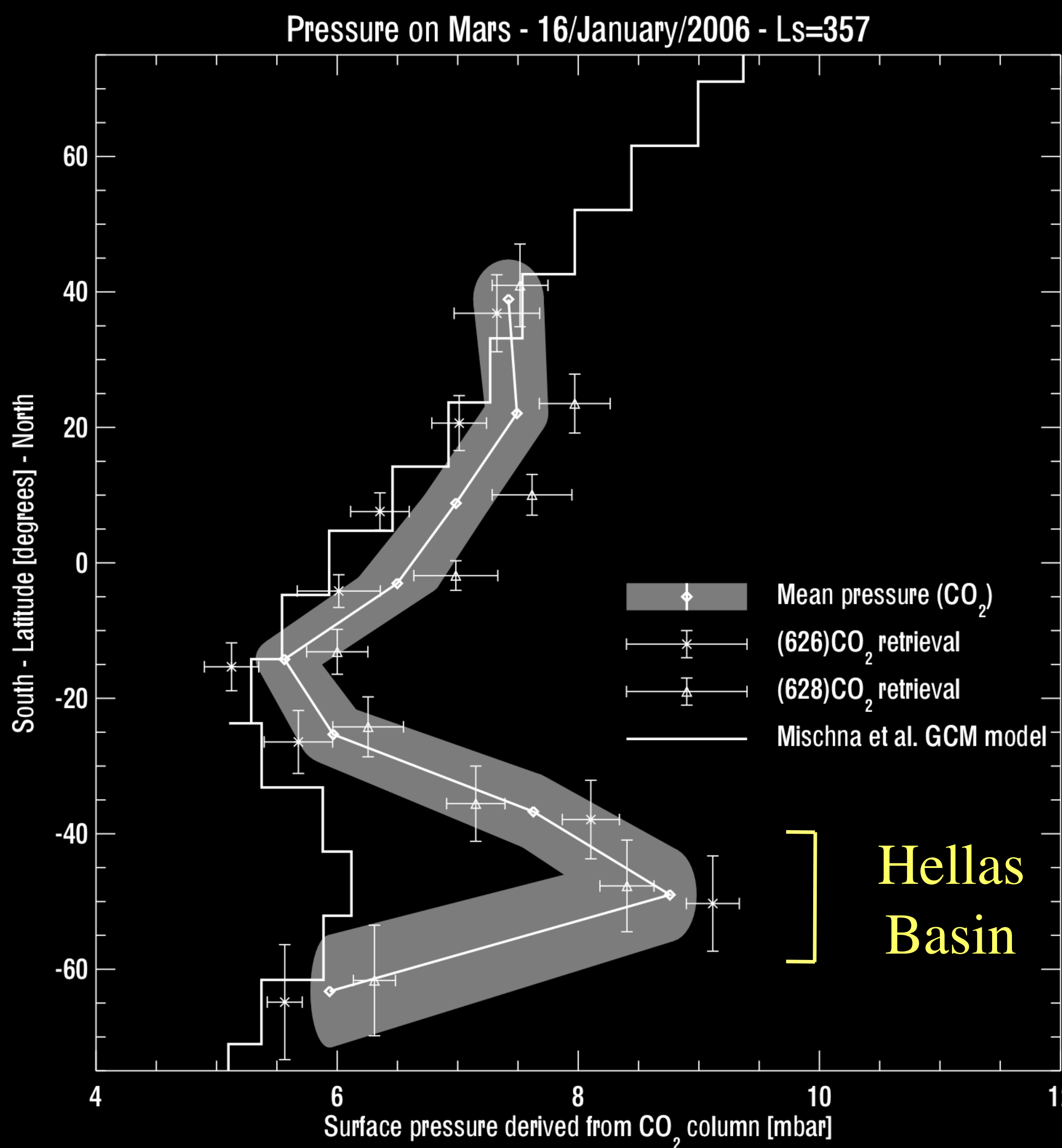


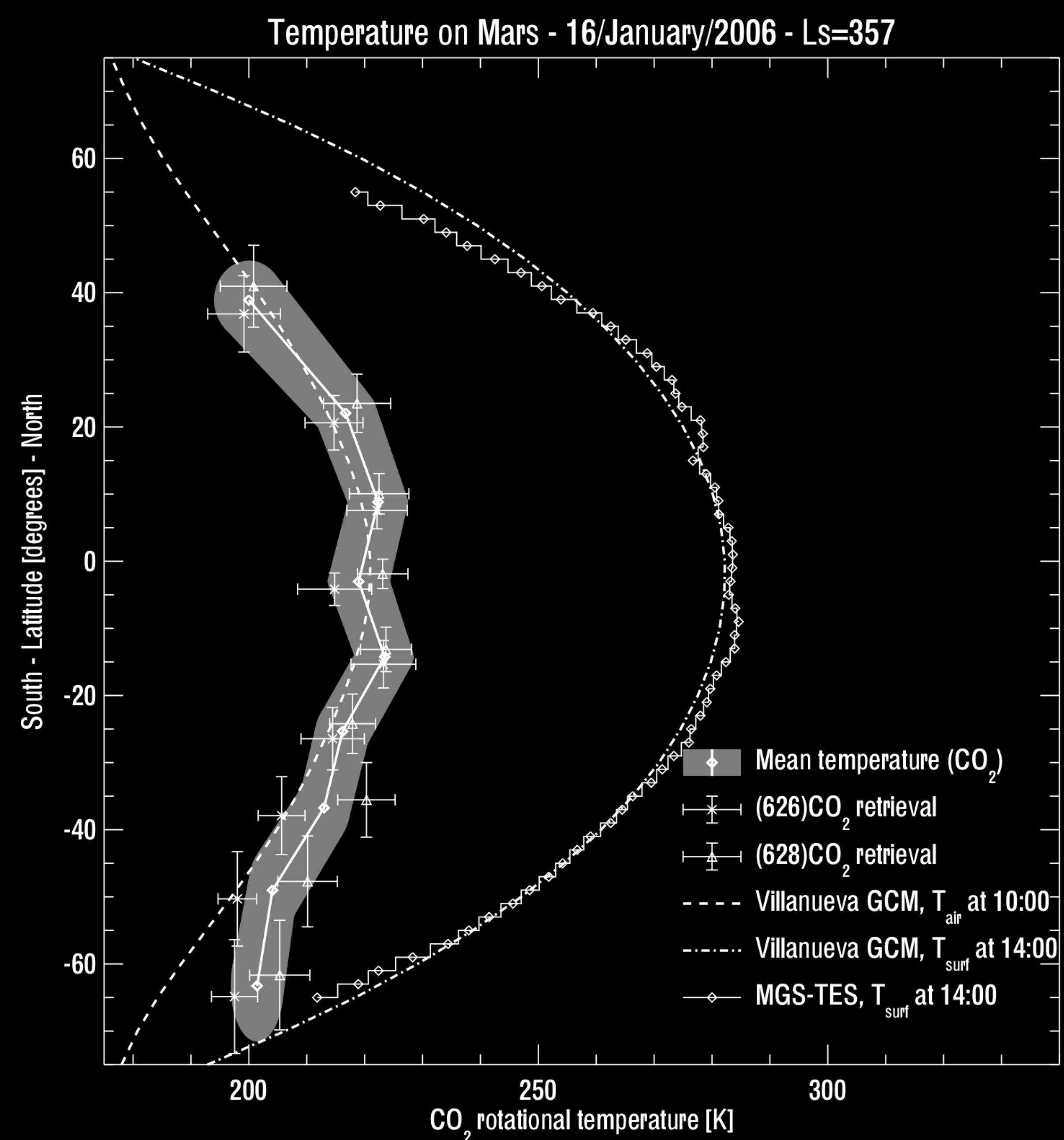


Frequencies between 2700-3400 cm^{-1} (3.7-2.9μm)

Mars image credit: Mars24, NASA

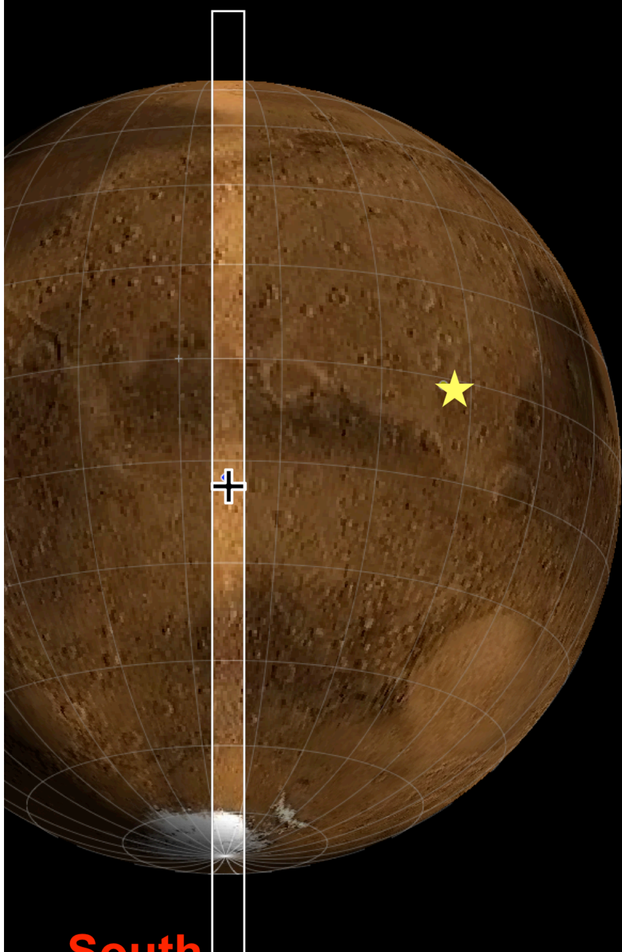

South
North
Absolute retrieval of carbon dioxide (CO_2) and formaldehyde (H_2CO) on Mars - NIRSPEC - 15/January/2006
Row
150
140
130
120
110
100
90
80
Relative to continuum - Residuals x 2.0
1
0
-1
-2
-3
-4
Rows 95-99 (-61 degrees lat)
Rows 100-104 (-47 degrees lat)
Rows 105-109 (-35 degrees lat)
Rows 110-114 (-24 degrees lat)
Rows 115-119 (-13 degrees lat)
Rows 120-124 (-1 degrees lat)
Rows 125-129 (10 degrees lat)
Rows 130-134 (23 degrees lat)
Rows 135-139 (40 degrees lat)
Total 95-139
Synthetic Martian atmosphere
Formaldehyde (H_2CO) < 4 ppb (3σ)
0
200
400
600
800
1000
2800
2790
2780
2770
Wavenumber [cm-1]


Pressure on Mars - 16/January/2006 - Ls=357
South - Latitude [degrees] - North
60
40
20
0
-20
-40
-60
4
6
8
10
12
Surface pressure derived from CO2 column [mbar]
Mean pressure (CO2)
(626)CO2 retrieval
(628)CO2 retrieval
Mischna et al. GCM model
Hellas
Basin

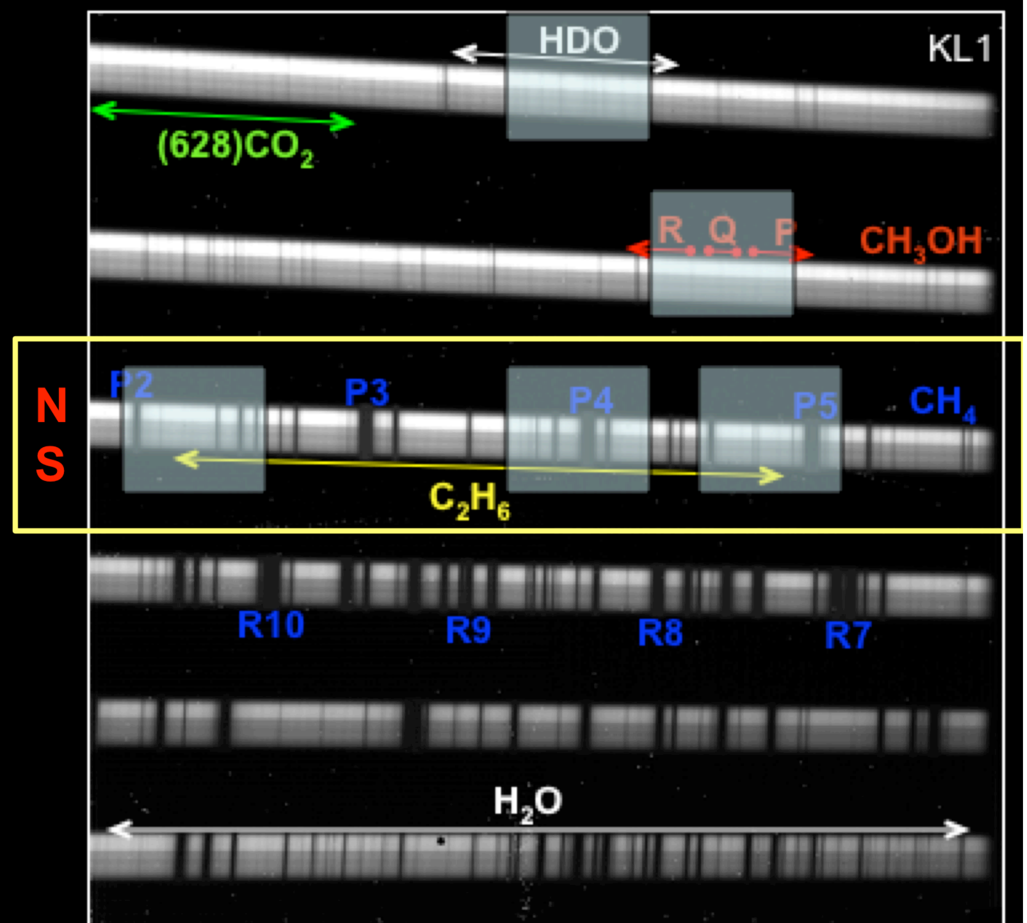

Temperature on Mars - 16/January/2006 - Ls=357
South - Latitude [degrees] - North
60
40
20
0
-20
-40
-60
200
250
300
CO2 rotational temperature [K]
Mean temperature (CO2)
(626)CO2 retrieval
(628)CO2 retrieval
Villanueva GCM, Tair at 10:00
Villanueva GCM, Tsurf at 14:00
MGS-TES, Tsurf at 14:00

Mars 16 January 2006 08:15 UT L_s = 357°
Diameter 11.5” Velocity +16.4 km/s

NIRSPEC
Spectra at L-band



South

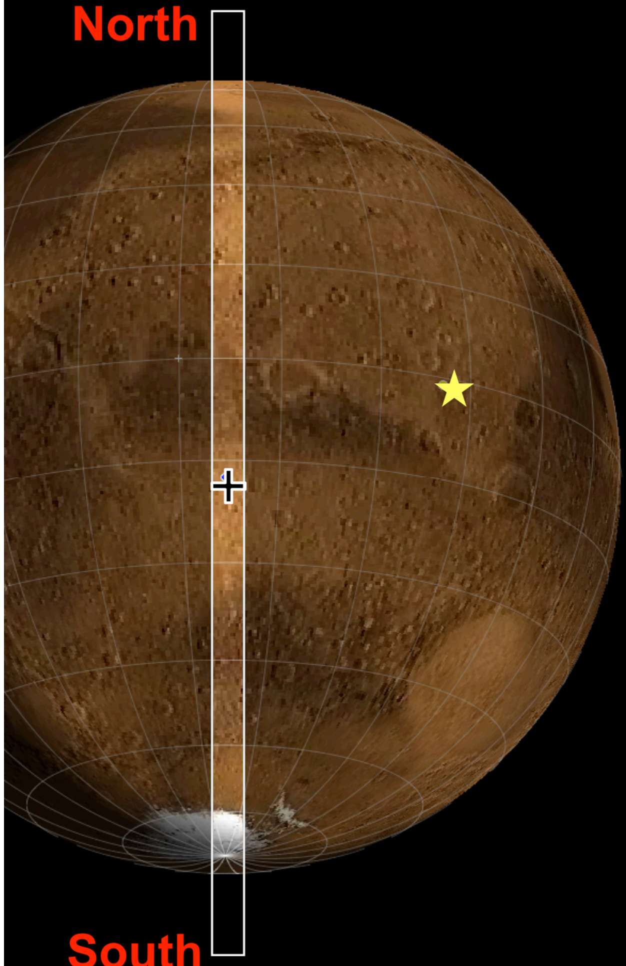


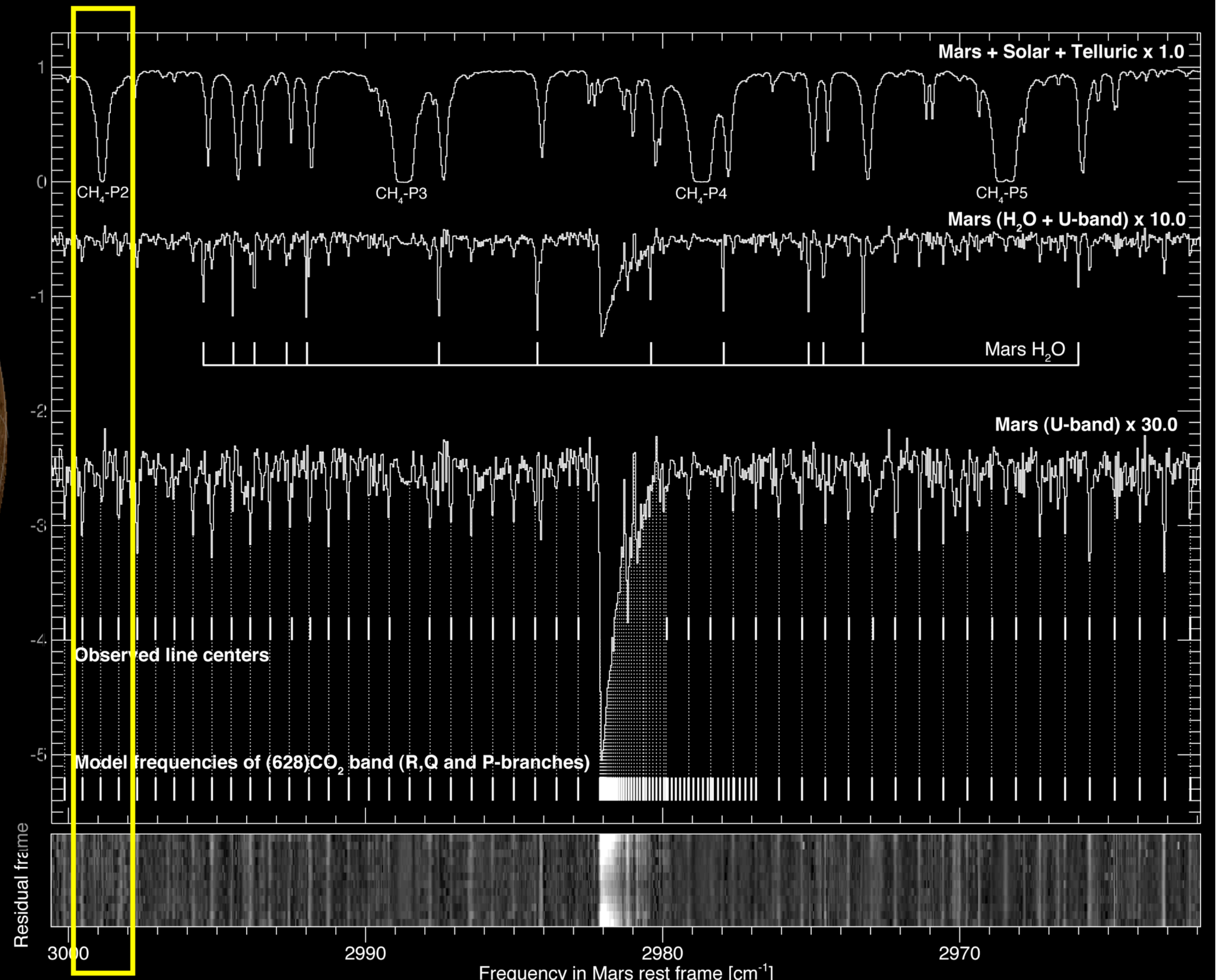
Frequencies between 2700-3400 cm^{-1} (3.7-2.9μm)

Mars image credit: Mars24, NASA

NIRSPEC Today : Extreme Sensitivity (2 minutes on source)

Data taken on 16 January 2006 08:15 UT L_S = 357°

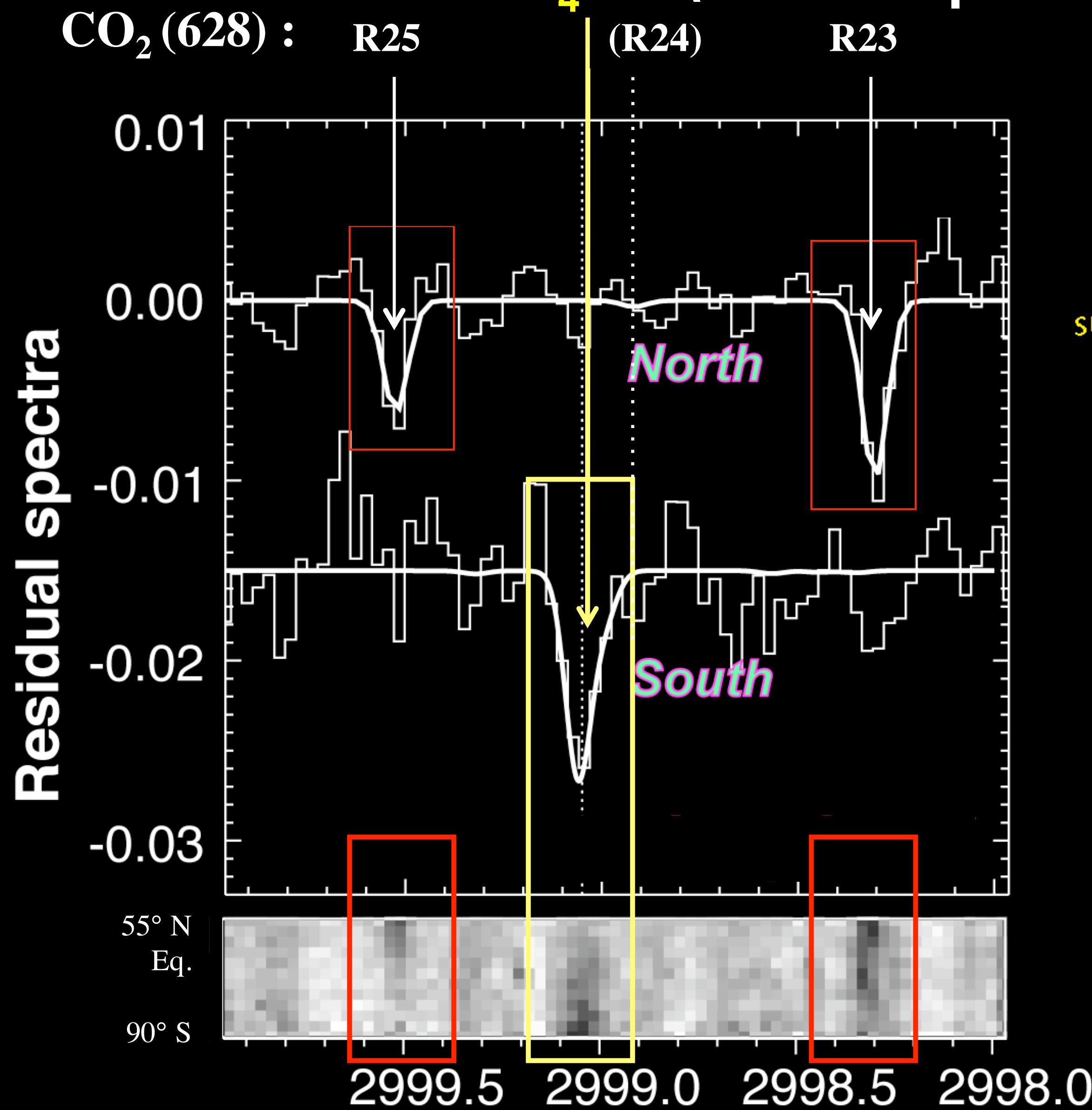




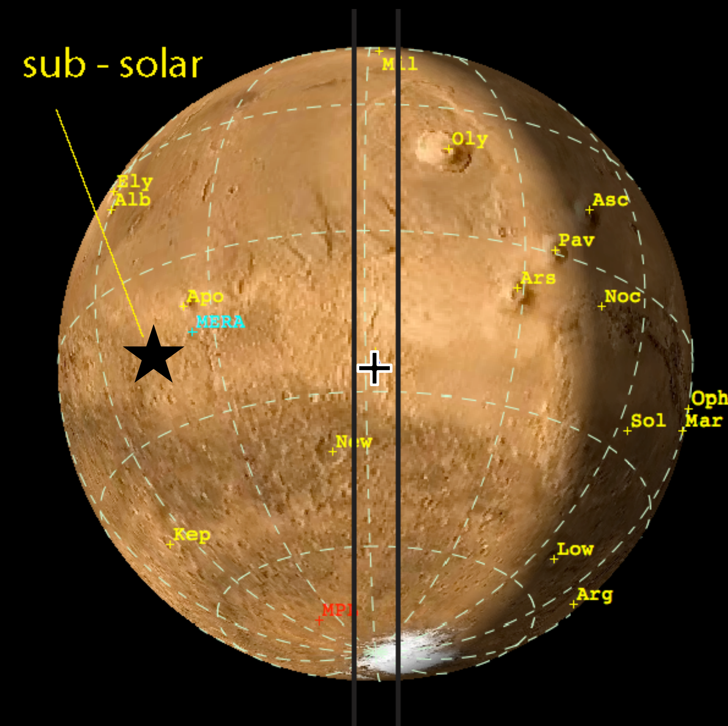
Villanueva et al. 2008, Icarus

After Mumma, Villanueva, Novak, et al. (Science 2009)

CH_4 P2 (two components)



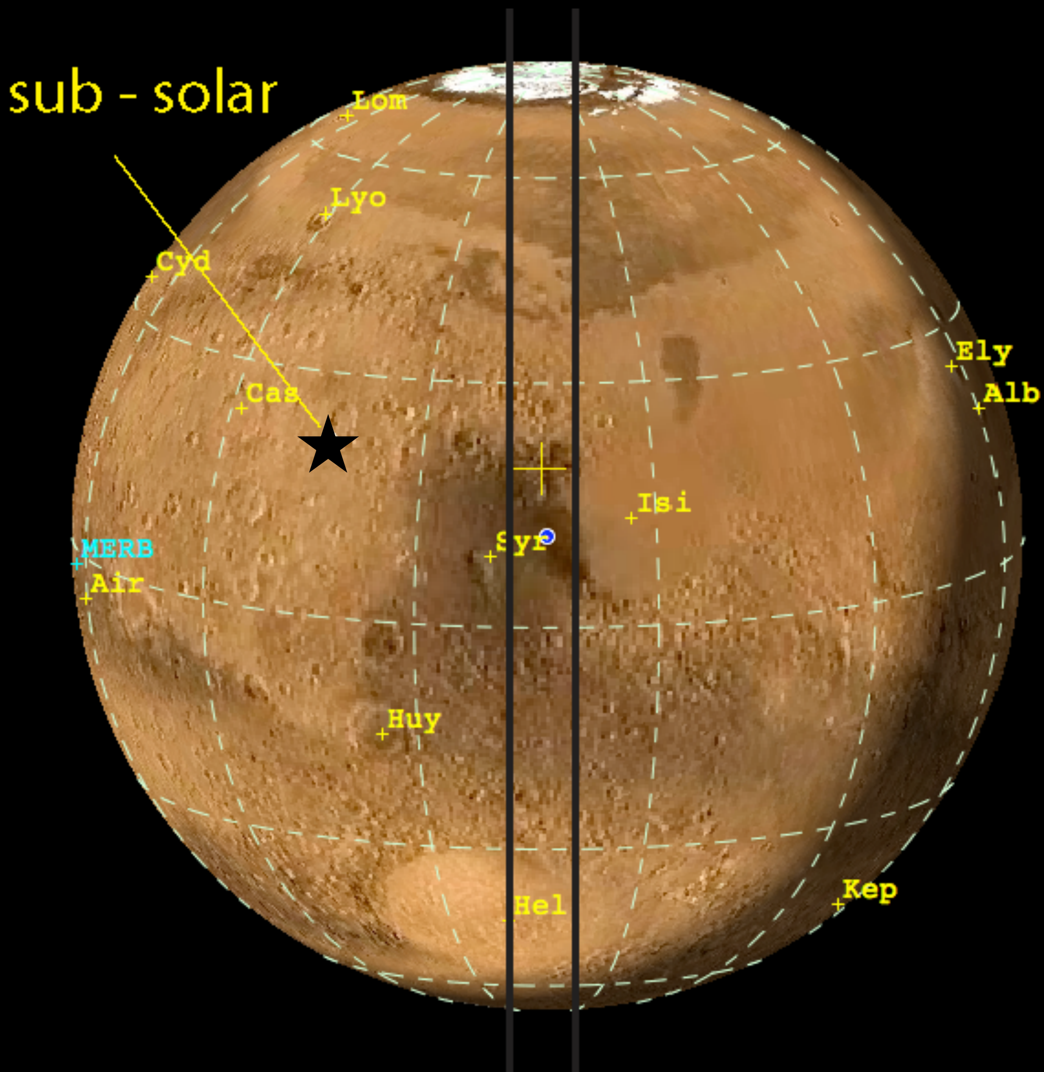
29 May 2005
L_S = 220°
(Mid-spring, South)

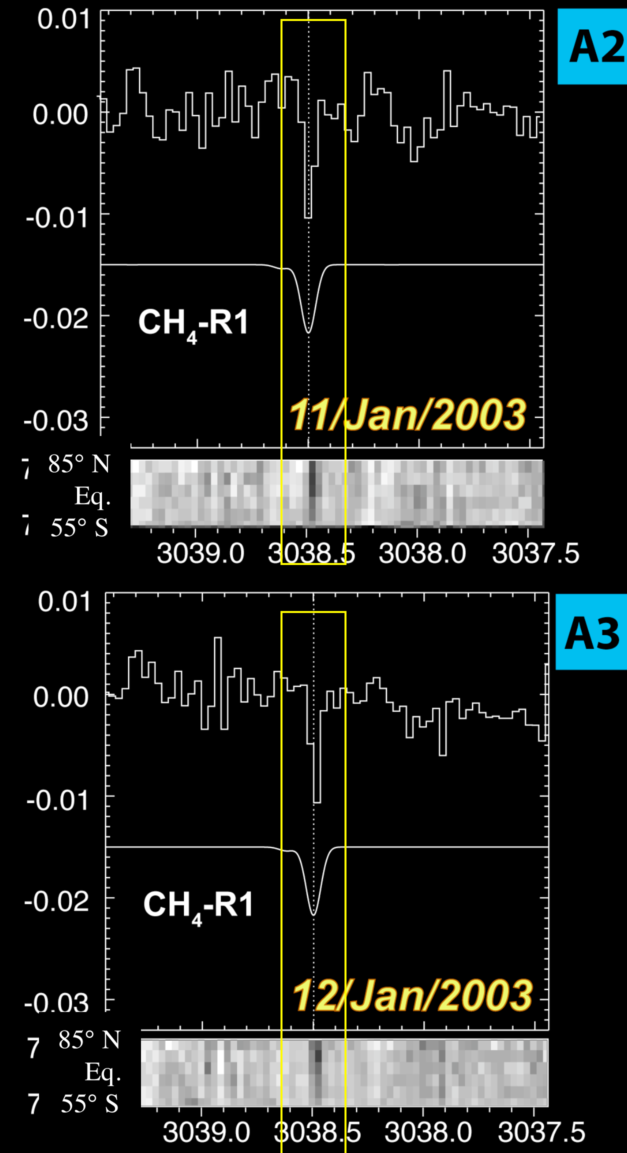


CO_2 enhanced in North
CH_4 enhanced in South

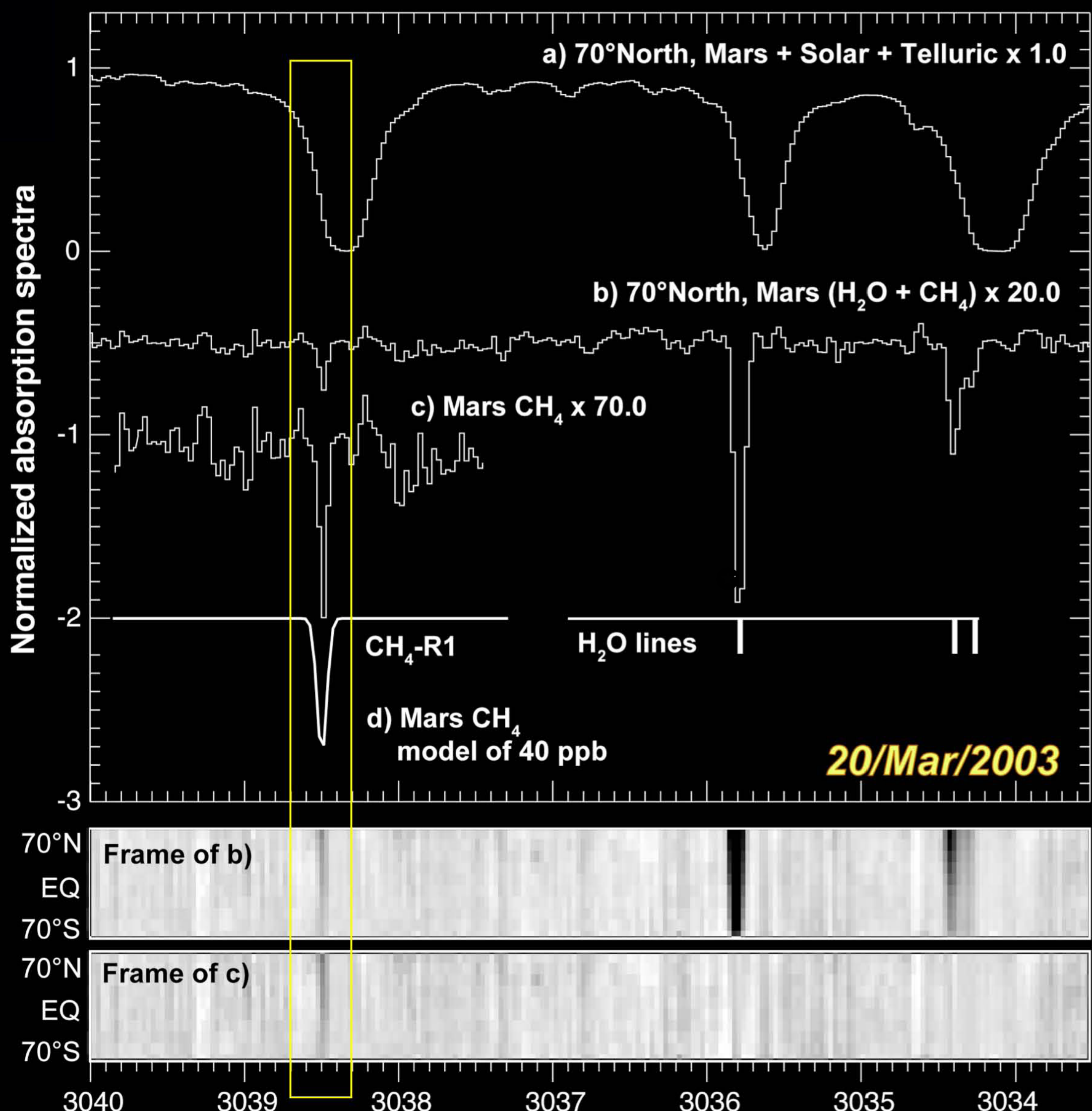
Clear Detections of CH_4 R1 on Successive Days

Early summer (North, L_S = 121°)



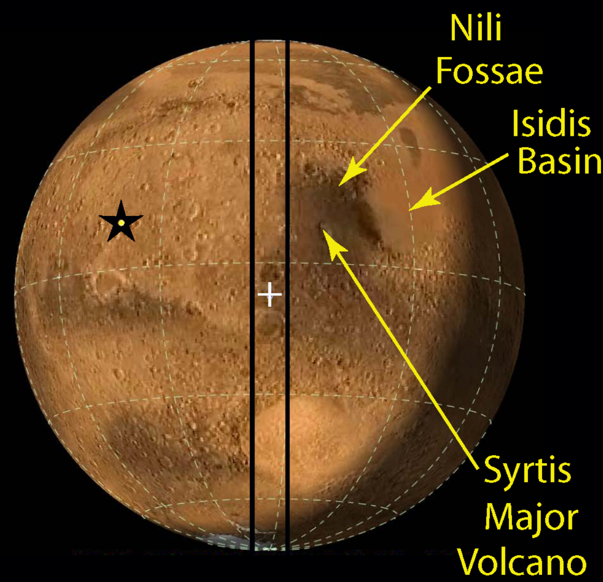


Clear Detections of Methane and Water on Mars



Northern late-summer

$L_s = 155°$



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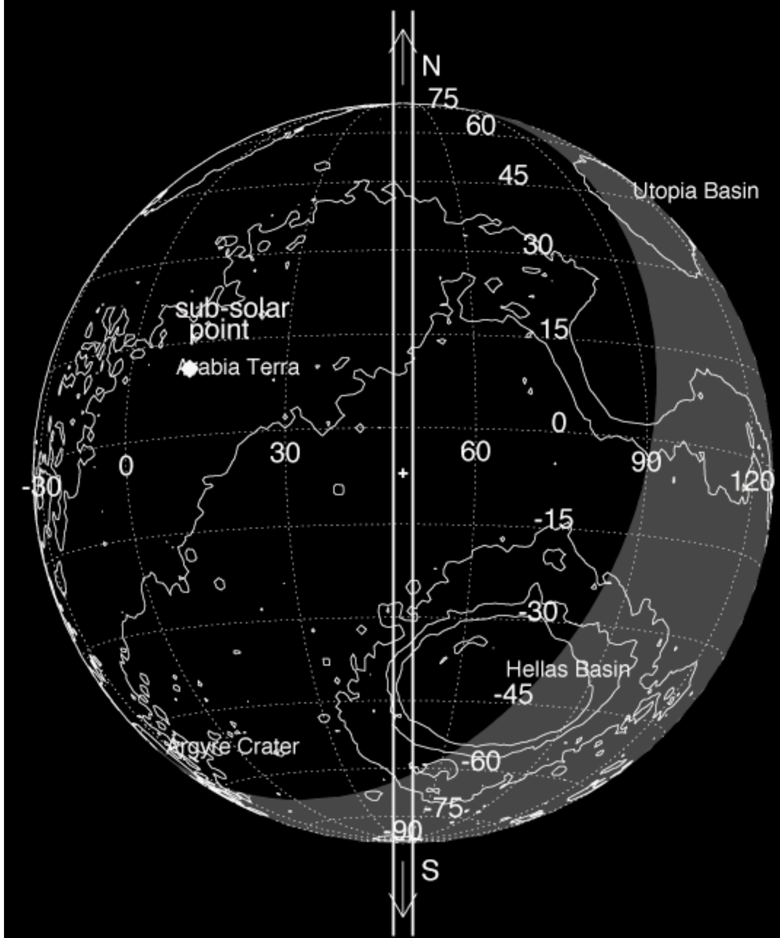
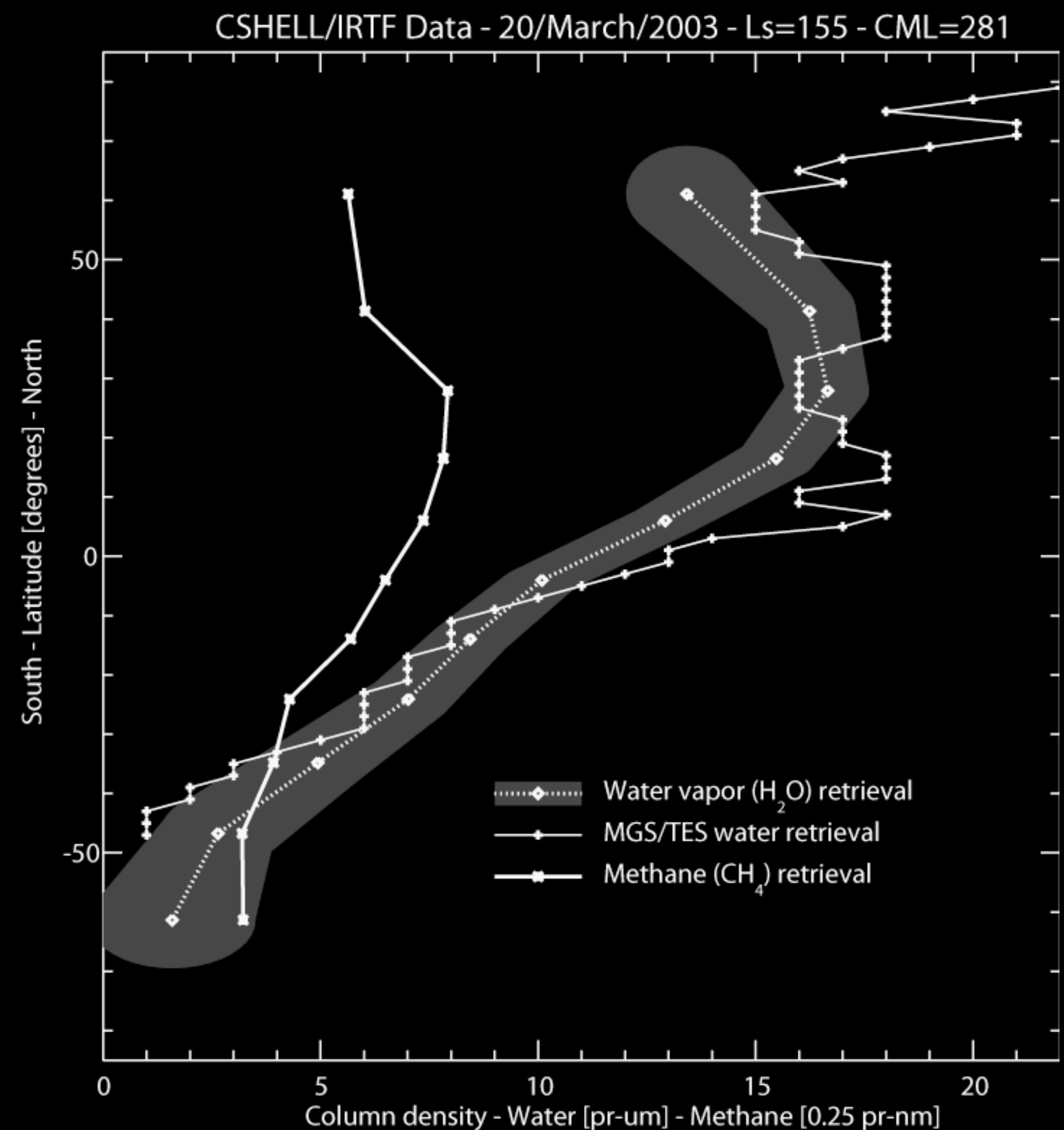
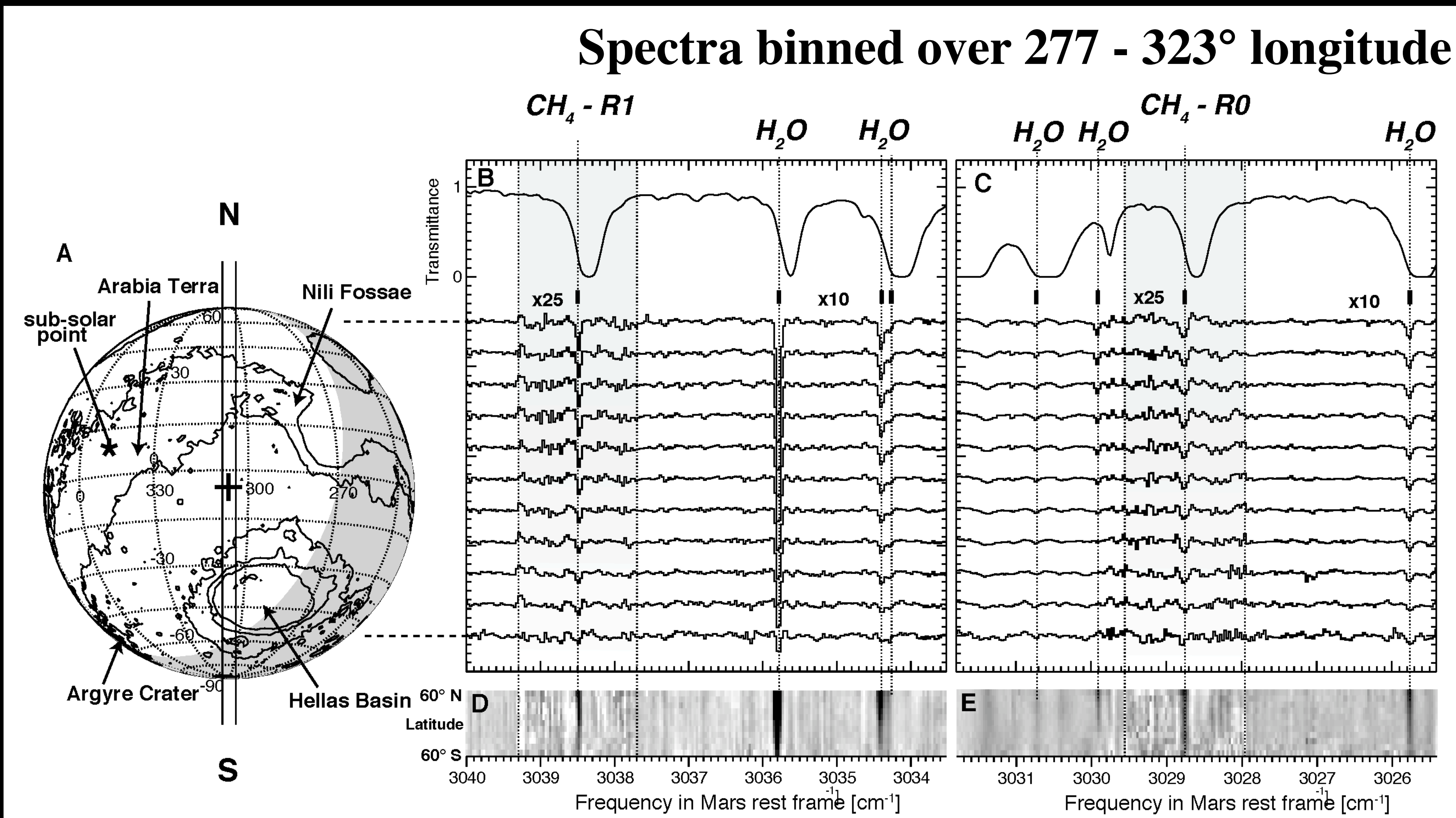




Topography map from MGS/MOLA, NASA

March 20 & 21, 2003 $L_s = 155°$ Northern summer

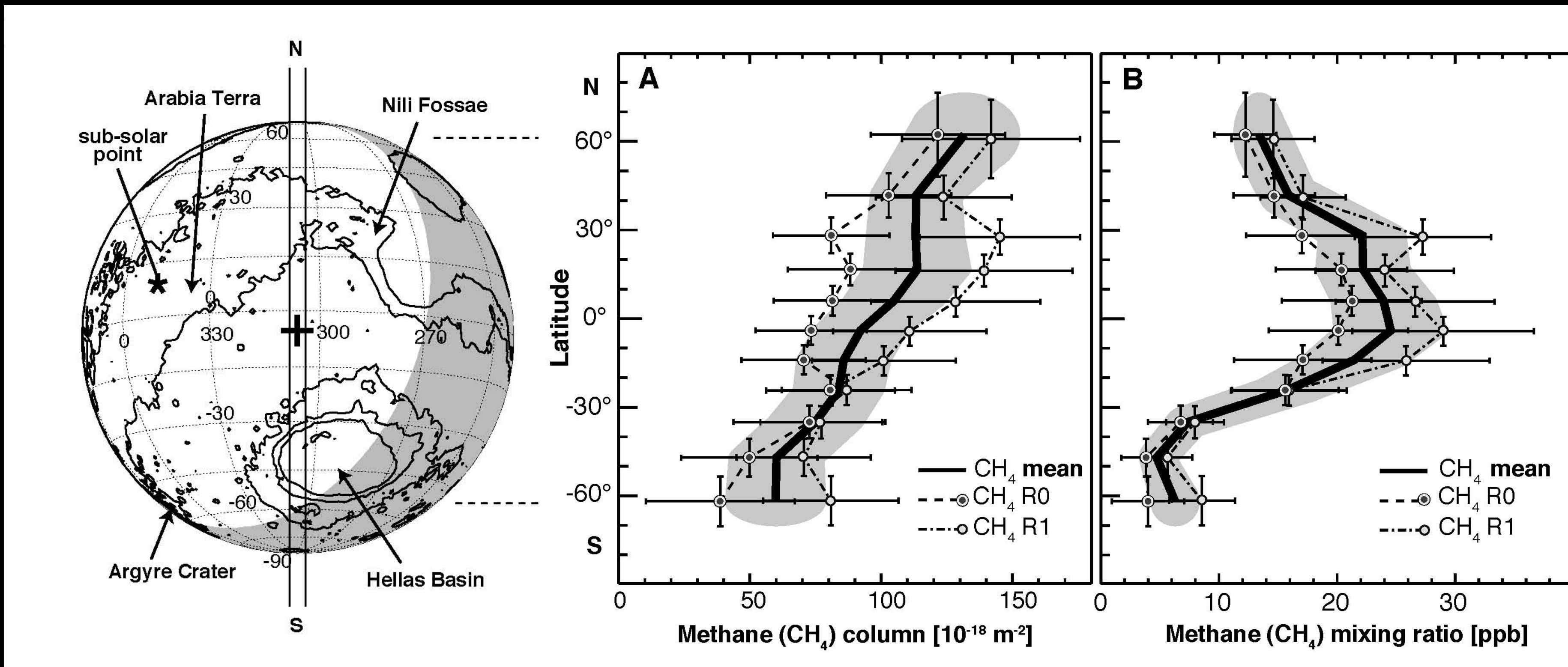
Two independent lines of methane are detected, and they show the same latitudinal dependence



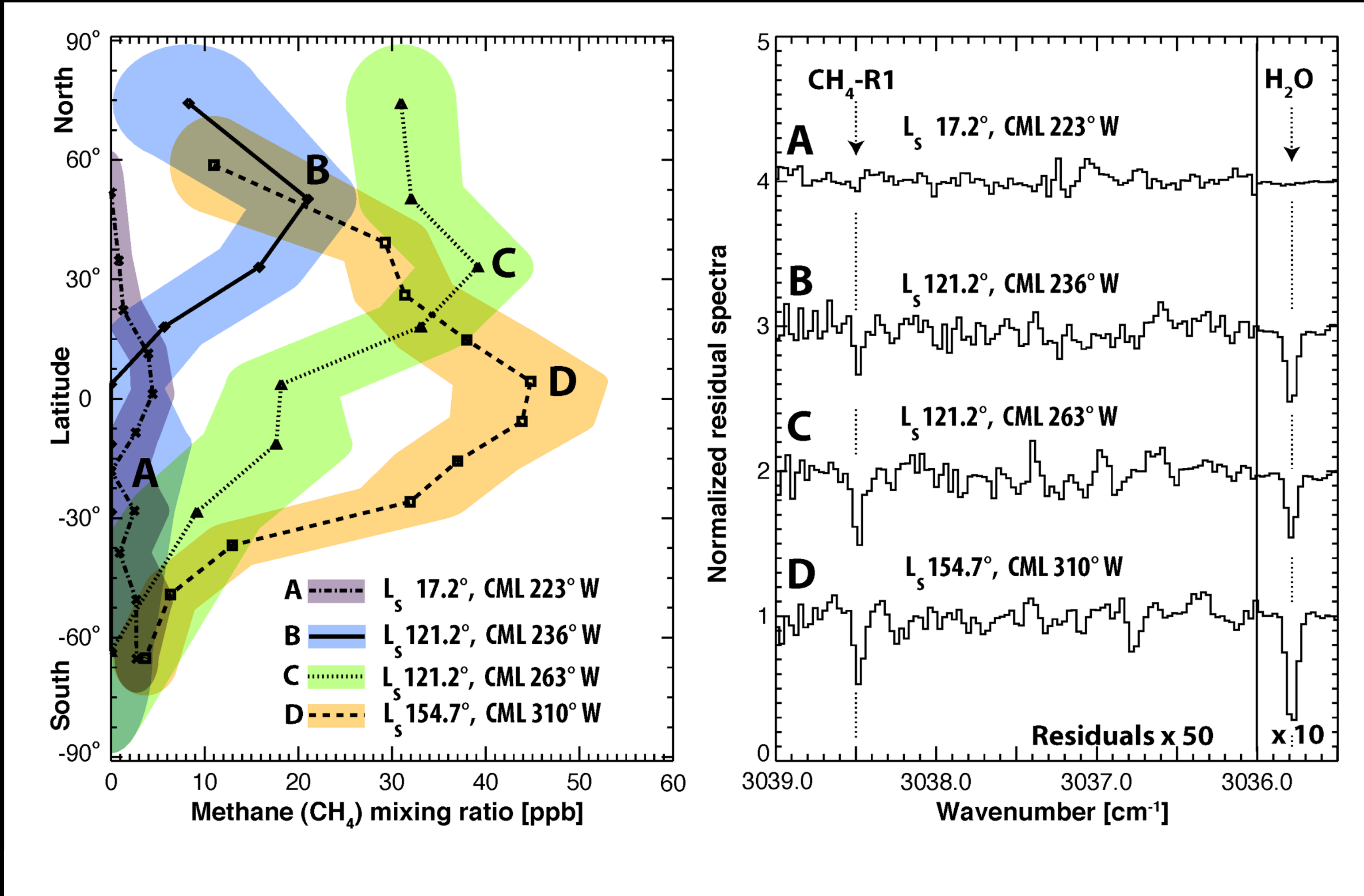
Mumma, Villanueva, Novak, et al. (Science 2009)

The column abundances obtained from two independent line of methane increase strongly from South to North but agree within errors (A). The agreement improves after accounting for the surface topographies sampled on successive days (B).

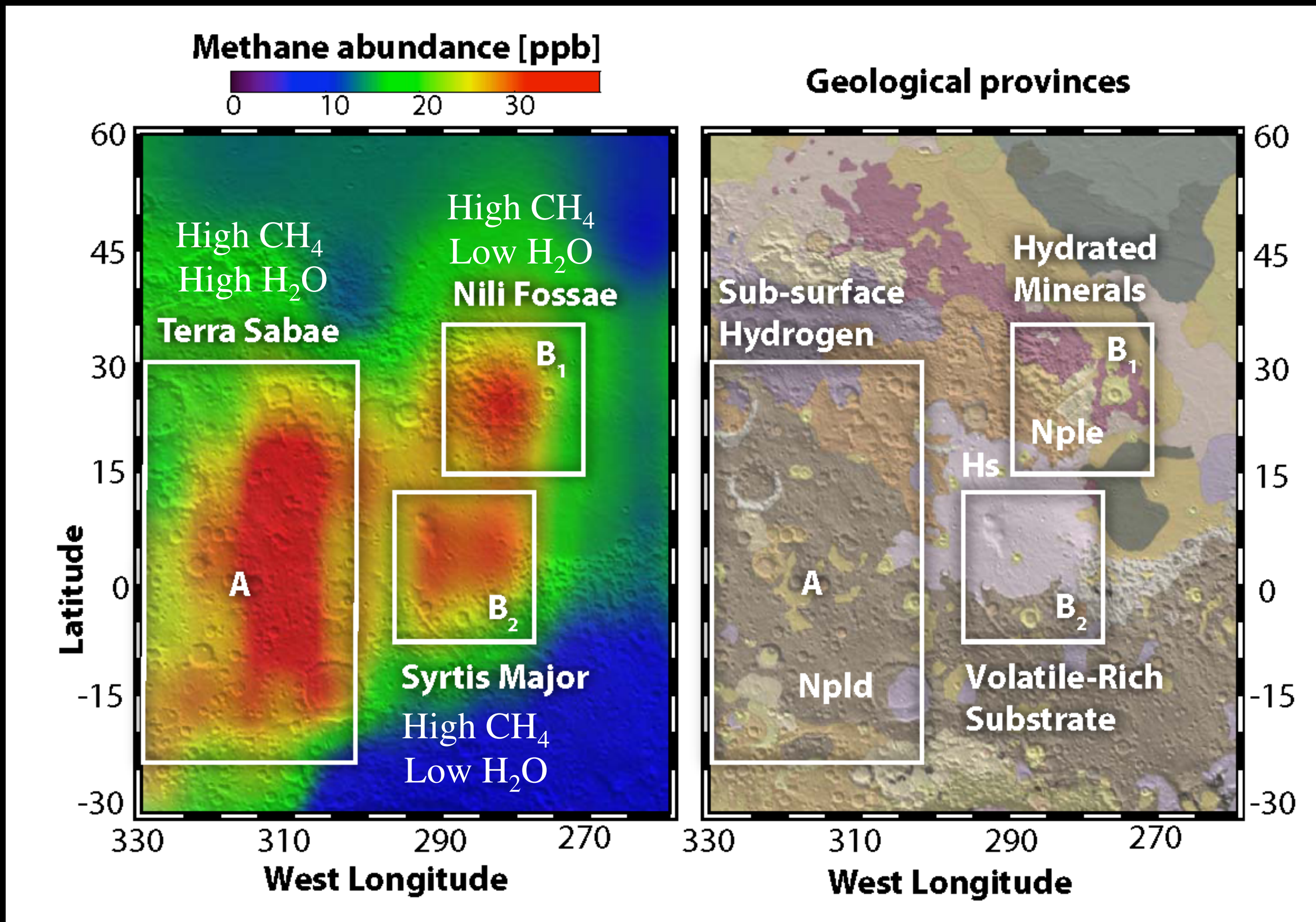
The mixing ratios obtained from two independent lines of methane agree within errors (B). A pronounced maximum in mixing ratio is seen over equatorial latitudes.



The methane mixing ratios vary with longitude, latitude, and season
The maximum in mixing ratio moves southward with the Sun
Methane is nearly absent at vernal equinox (after Southern Winter)



Resolution-limited Spatial Maps reveal local methane plumes on scales of 500 km.
Is the release relatively uniform over these regions – or is it strongly localized?



Summary of Observational Evidence

- **Four lines of Methane are detected: R1, R0, P2 (doublet)**
  - ***R1 is detected on successive dates Jan. 11 & 12, 2003***
  - ***R1 and R0 are detected on successive dates March 20 & 21, 2003***
    - ***The mixing ratios derived from individual lines agree***
  - ***P2 is detected in May 2005***
- ***Strong temporal changes are found***
  - ***Plumes are seen with peak mixing ratios up to 60 ppbv***
  - ***At vernal equinox methane is 3 ppbv or less at locations sampled***
  - ***The implied methane lifetime is less than one year***
- ***Methane varies with location***
  - ***The plume content in March 2003 is ~ 19,000 metric tons***
    - ***The source strength in March 2003 is ~ 1 kg/sec***
    - ***A strong peak is seen over Nili Fossae***
    - ***A strong peak is seen over Syrtis Major (South-east quadrant)***
  - ***CH_4 is detected near Arsia Mons & Terra Sabena, in Southern Spring***
- ***Methane and water are sometimes correlated, but not always so.***

Major Conclusions

Methane is released locally on Mars – the source strength rivals terrestrial gas seeps

Seasonal access to sub-permafrost regions, and/or wide-spread surface activity, is implied

Some release zones are correlated with geologically interesting features

Hydrated terrain, where craters show lobate ejecta associated with ice-rich soil

Nili Fossae, a region rich in phyllosillicates and carbonates

Syrtis Major, a volcano whose SE quadrant shows evidence of sub-surface collapse

Arsia Mons, site of the largest mountain glacier on Mars, and extensive Fossae

The lifetime of atmospheric methane is less than one Mars year

This requires a new model for its destruction, perhaps by oxidants on airborne soil particles

The Big Question: Is this methane produced by Biology, by Geochemistry, or by both?

Much follow-0n work is needed to address this fundamental question

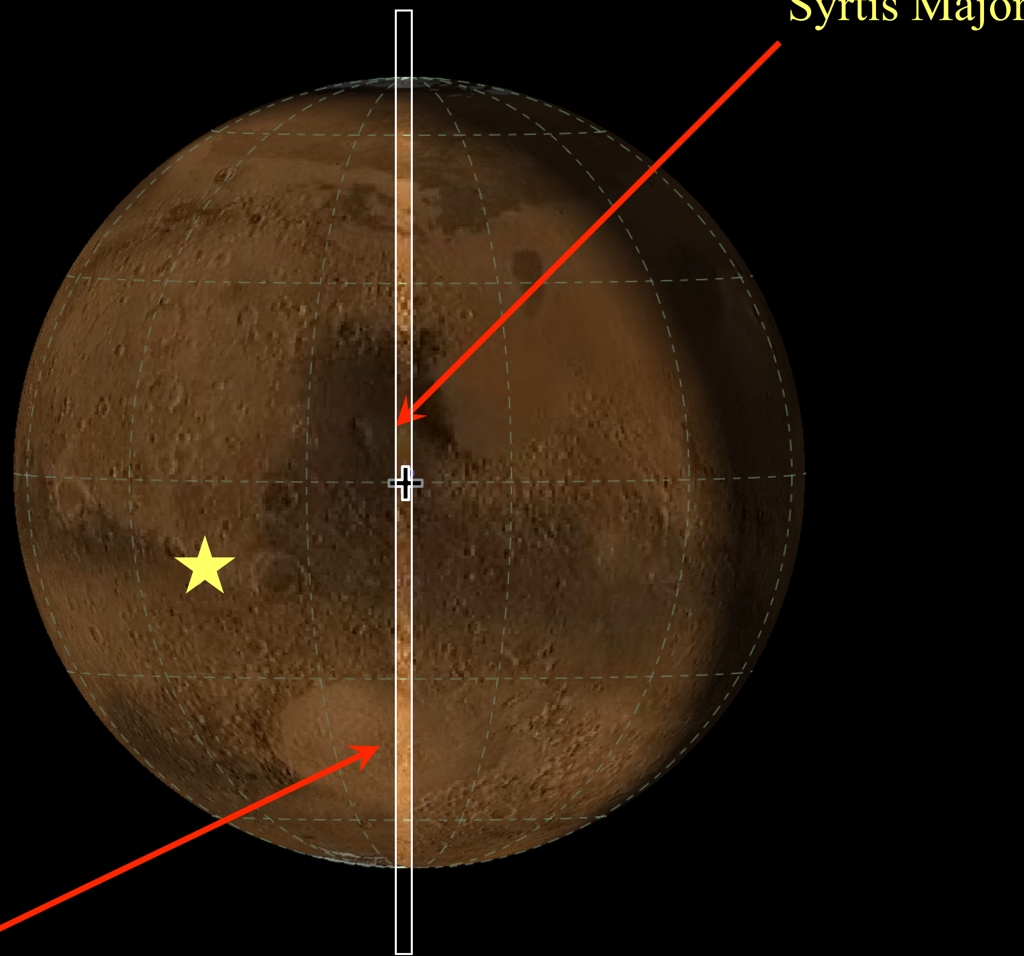
CRIRES on Mars - First night
UT 19 August 2009 10:20

Mars Diameter 5.6 arcsec
Geocentric velocity : – 9.4 km/sec
L_s = 325° mid NH winter

VLT Paranal:

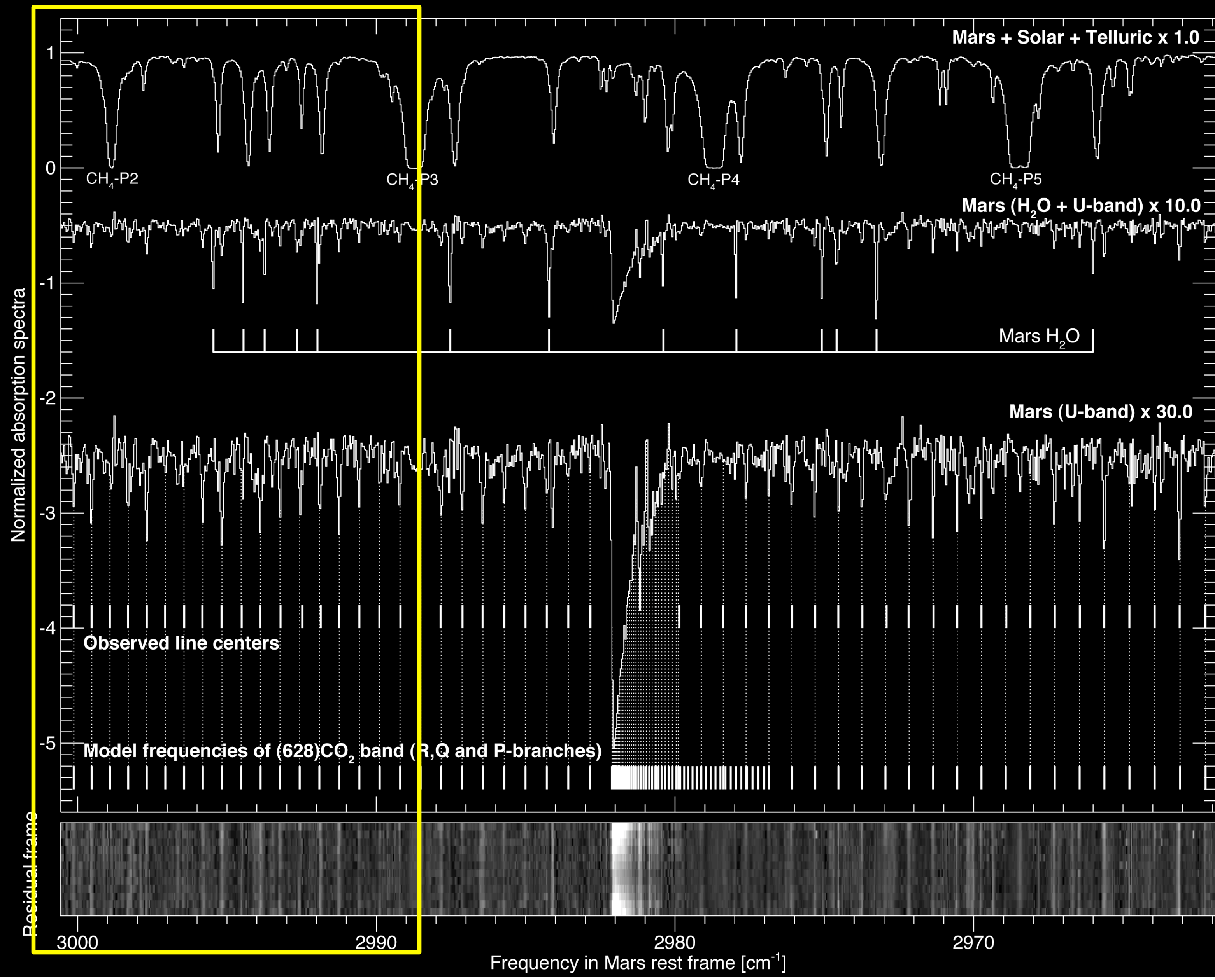
airmass	1.8
PWV	3.9 mm
FWHM	0.7 arcsec
AO	open loop

CRIRES 0.2” slit, 0.086” pixels
Centered on 285° W



NASA GISS Mars24 5.5

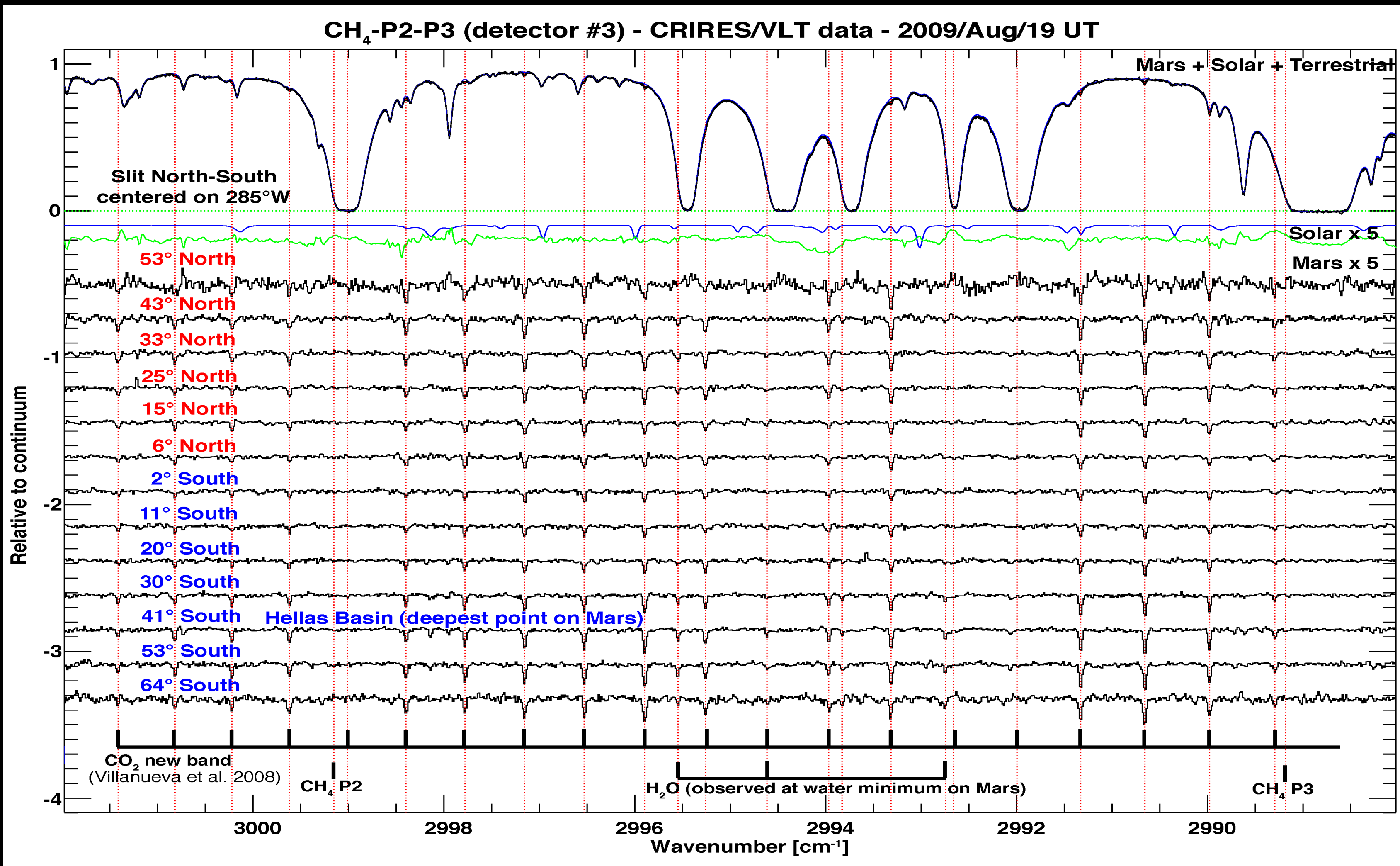
L_s = 357° vernal equinox   Geocentric velocity : – 9.4 km/sec



L_s = 325° mid NH winter

Geocentric velocity : – 9.4 km/sec

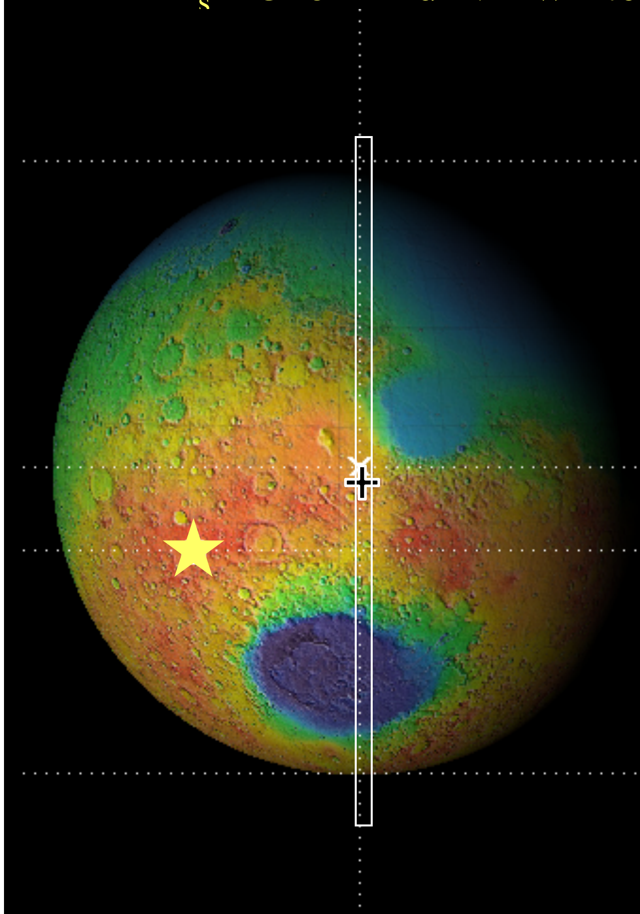
D1 3041.01 - 3025.36 D2 3021.06 - 3006.25 D3 3002.36 - 2988.37 D4 2984.80 - 2971.62

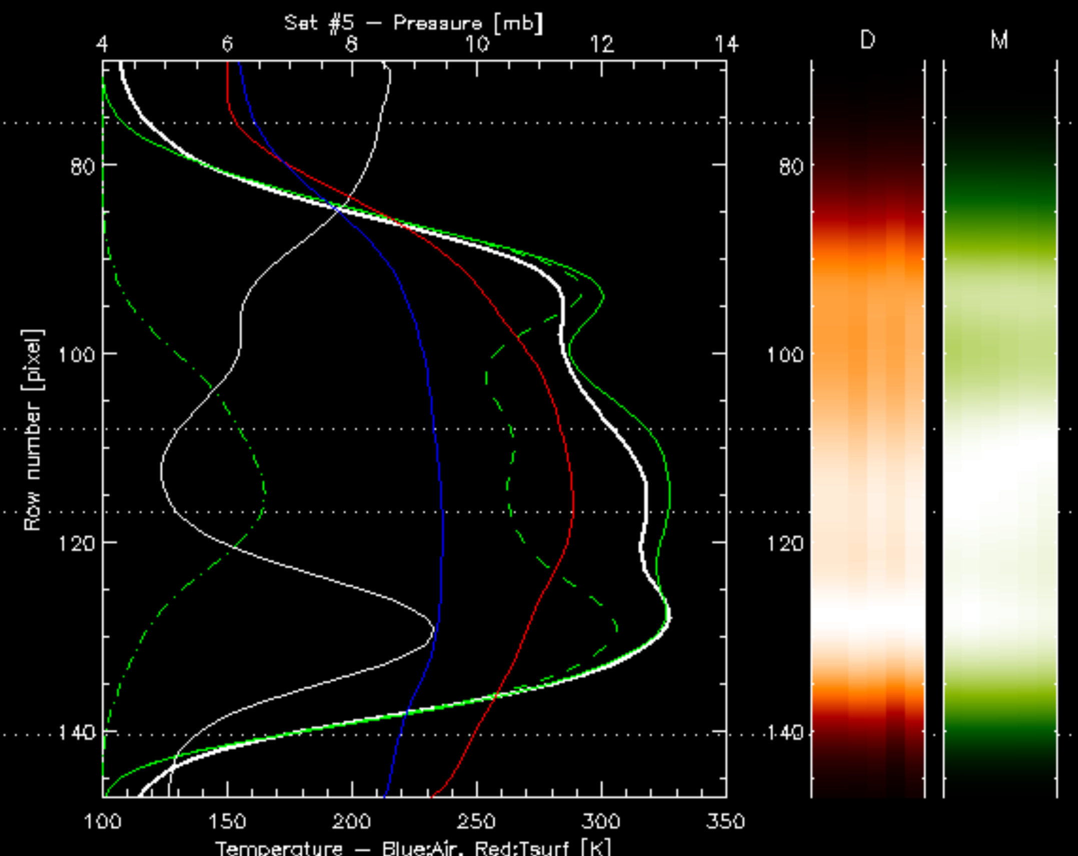


CRIRES on Mars - First night
UT 19 August 2009 10:20
Mars Diameter 5.6 arcsec
L_s = 325° mid NH winter

CRIRES 0.2” slit, 0.086” pixels
Centered on 285° W

Thermal Analysis – atmosphere and solid surface





CRIRES on Mars - First night
UT 19 August 2009 10:20

Mars Diameter 5.6 arcsec
Geocentric velocity : – 9.4 km/sec
L_s = 325° mid NH winter

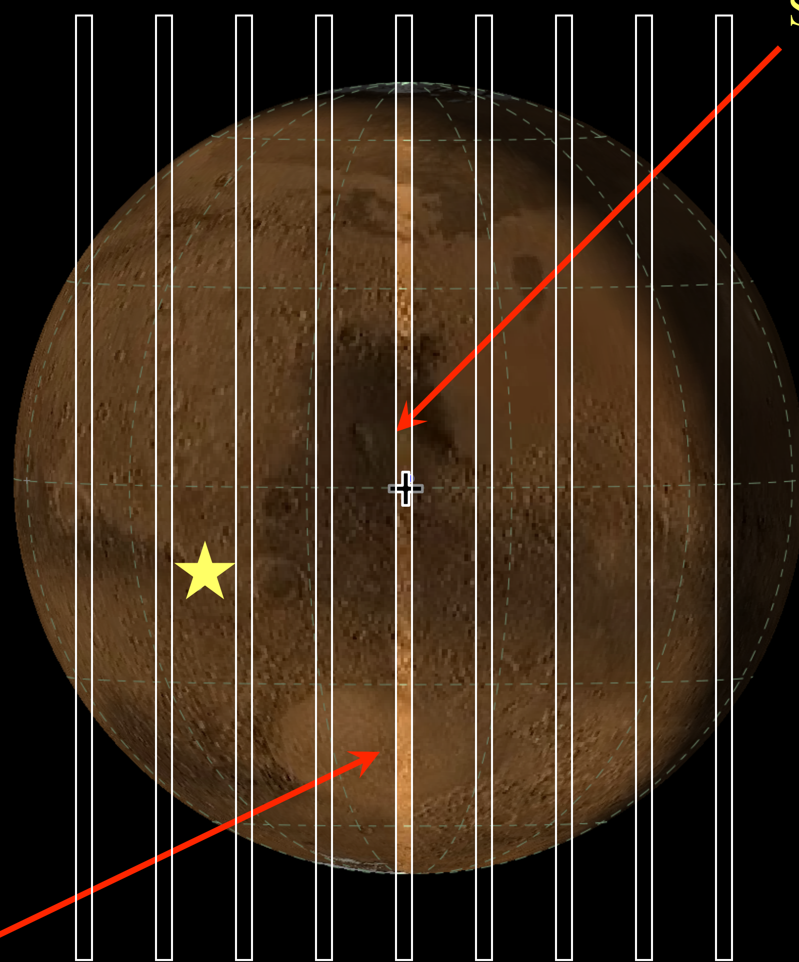
VLT Paranal:

airmass	1.8
PWV	3.9 mm
FWHM	0.7 arcsec
AO	open loop

AO closed: 10 of 12 nights

Step-maps: CH_4, H_2O, HDO

CRIRES 0.2” slit, 0.086” pixels
Centered on 285° W



NASA GISS Mars24 5.5

Methane Issues

✓Origin —

When was it produced ? (recent vs. ancient)

How was it produced ? (abiotic vs. biotic)

reduce carbon in mantle (CO_2, H_2O, heat)
release H_2 : serpentinization, pyrite production, H_2O radiolysis

microbes metabolize H_2, reduce CO, CO_2, or acetate

How is it released? Is it seasonal?

thermal activation of near-surface? (supra-permafrost)

by opening pores /fractures in scarps ? (sub-permafrost)

✓Sinks —

Atmospheric – triboelectric, photochemical, other?

Sub-surface (oxidants) – peroxides, perchlorates

Sequestering (adhesion, gettering)

✓Re-charge Mechanism (if released annually)

END