Tracing the Origin of Methane and Water on Mars: The Role for SOFIA.

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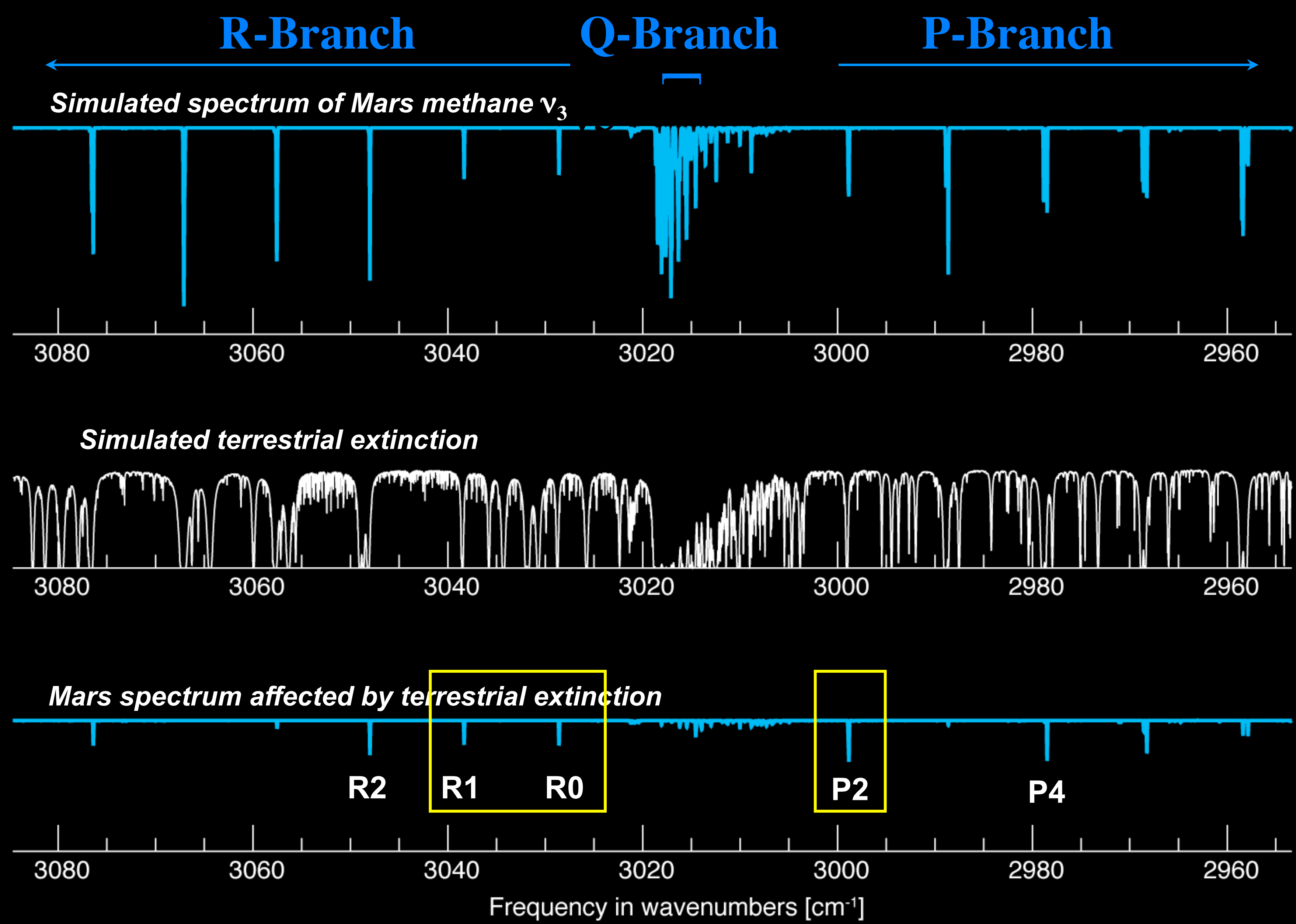
SOFIA - SCTF **17 February 2010**

The Search for Mars methane

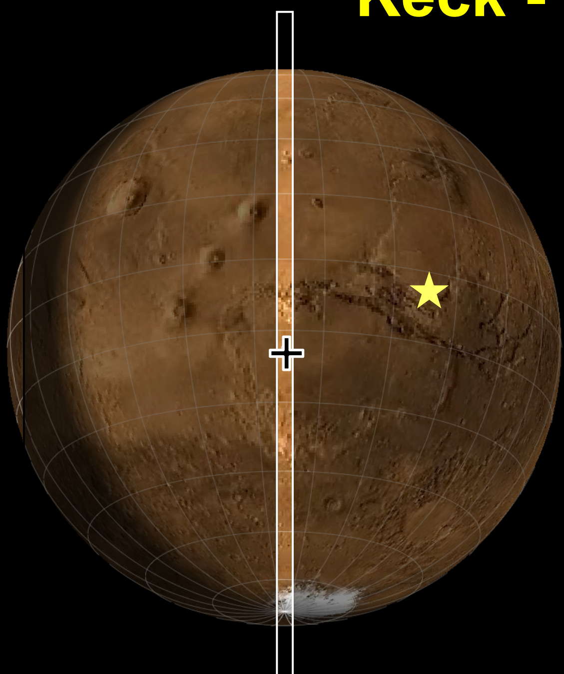
- The measurement approach
- Improvements in Analysis
- Our spectral detections
- The current campaign
- A Role for SOFIA

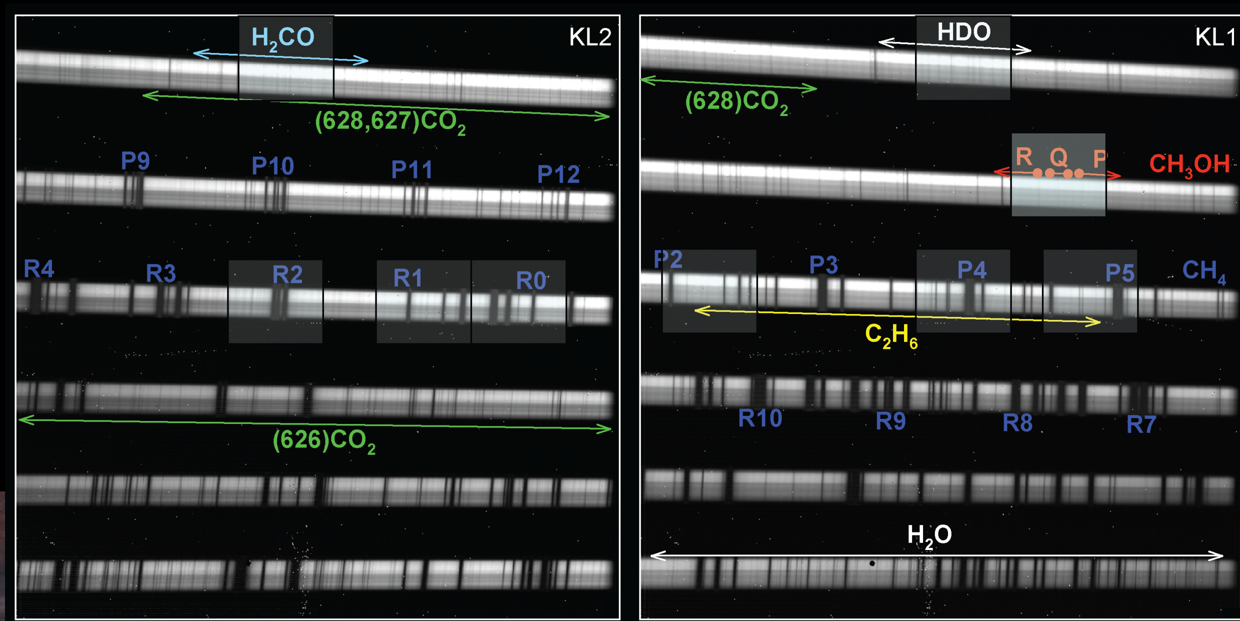

R-Branch
Q-Branch
P-Branch
Simulated spectrum of Mars methane ν_3
3080
3060
3040
3020
3000
2980
2960
Simulated terrestrial extinction
3080
3060
3040
3020
3000
2980
2960
Mars spectrum affected by terrestrial extinction
R2
R1
R0
P2
P4
3080
3060
3040
3020
3000
2980
2960
Frequency in wavenumbers [cm^{-1}]

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)

CH_4 :

3 nuclear spin species,

A, E, F

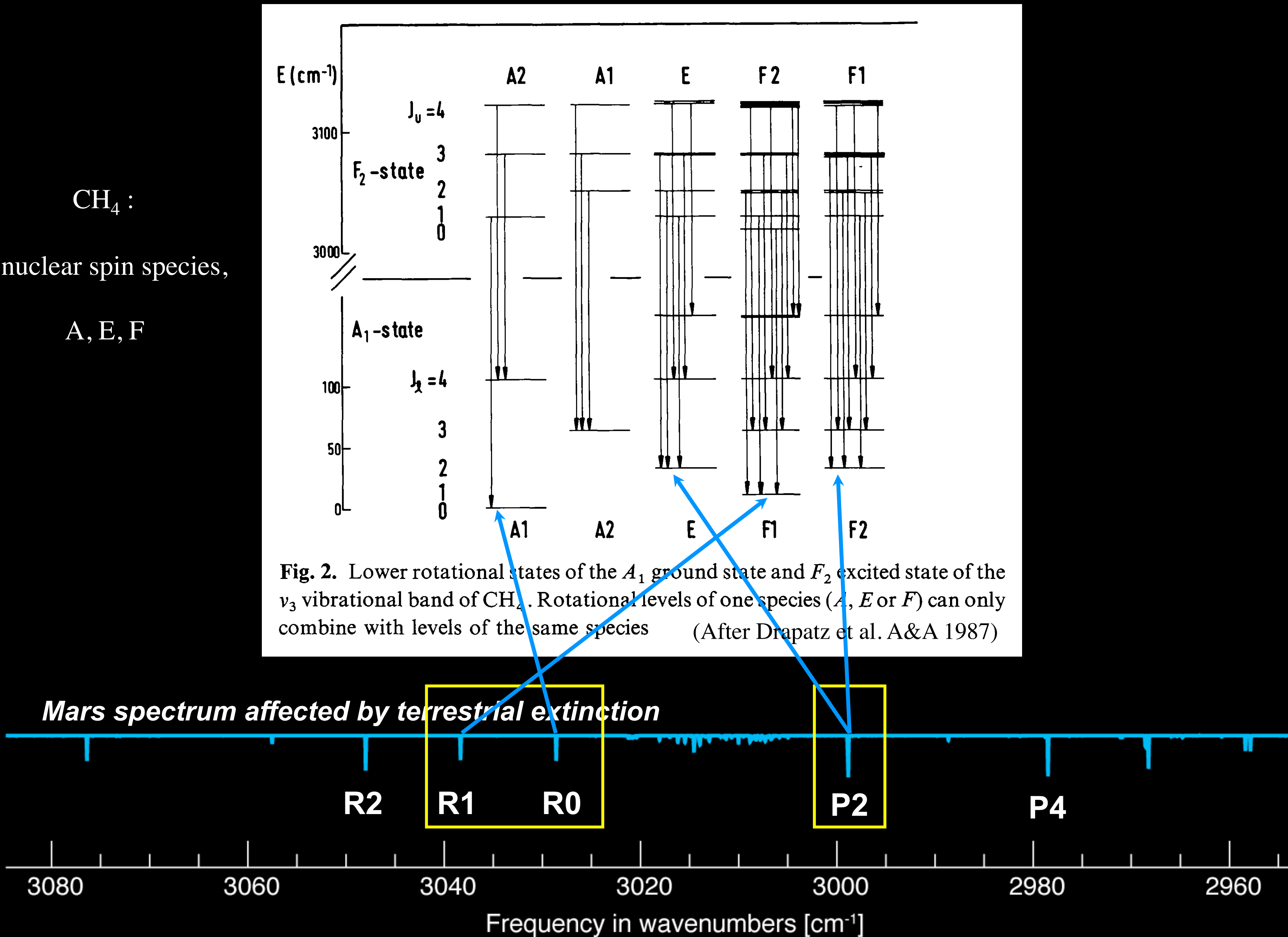
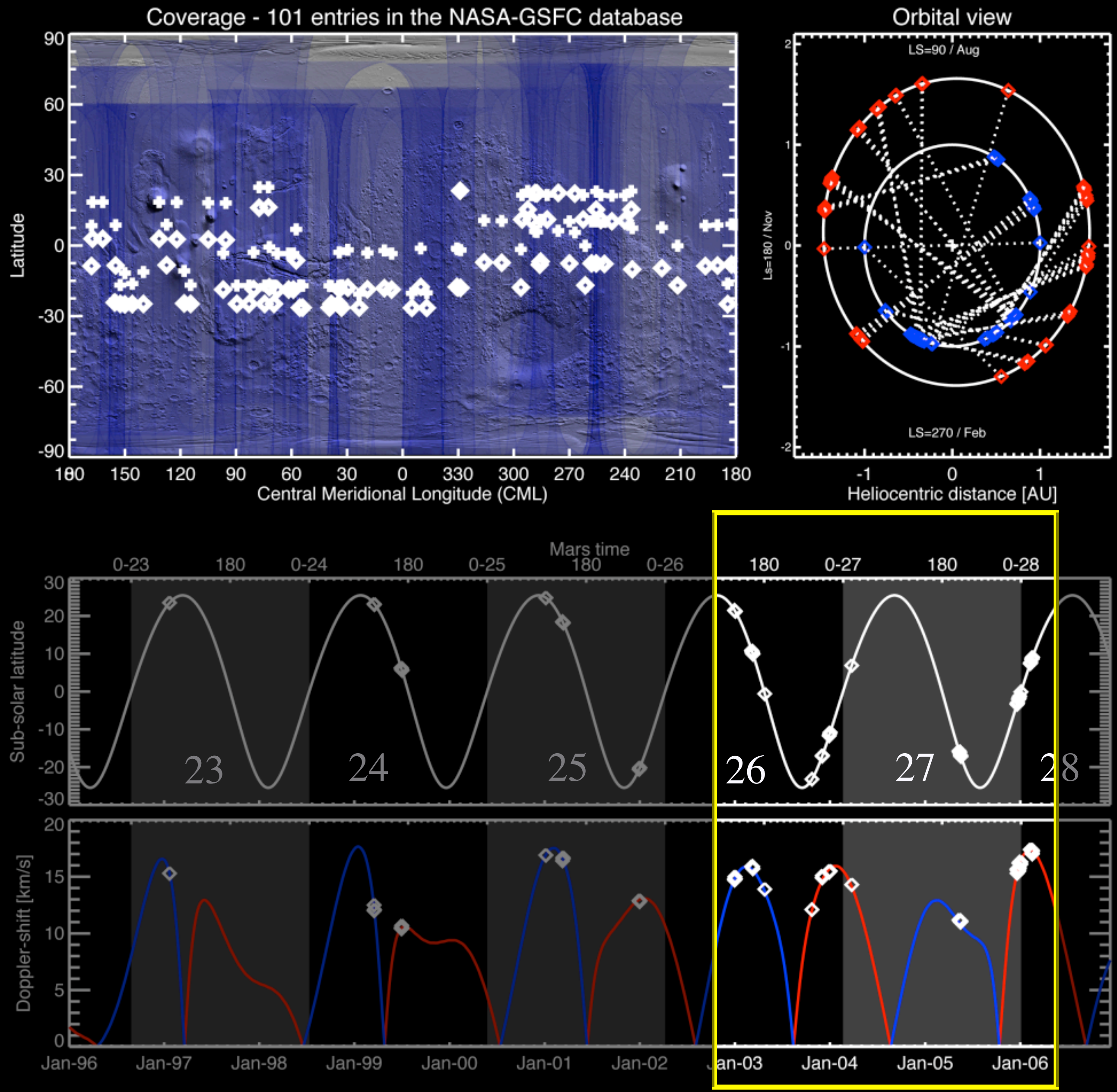
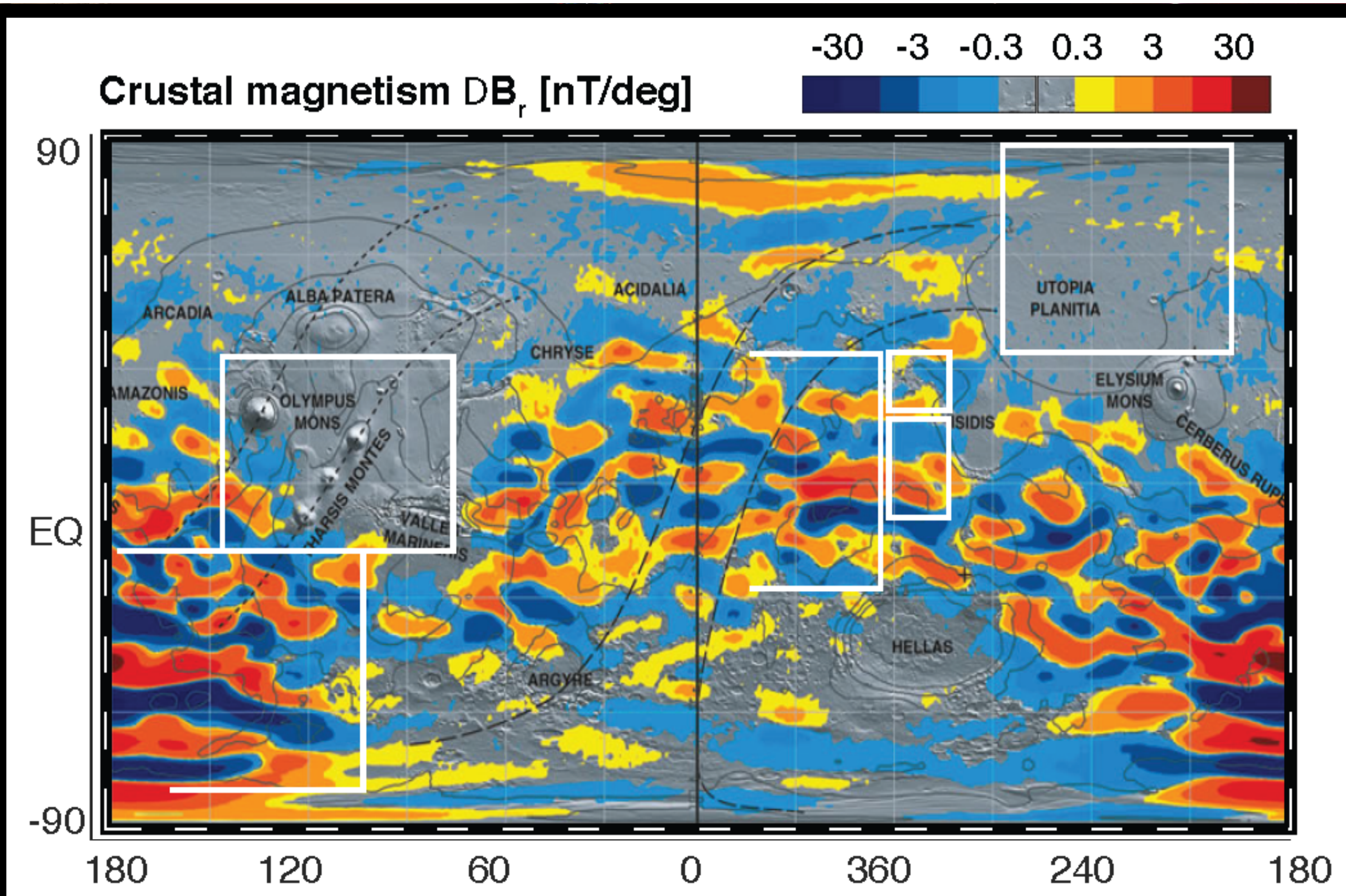


Fig. 2. Lower rotational states of the A_1 ground state and F_2 excited state of the ν_3 vibrational band of CH_4. Rotational levels of one species (*A*, *E* or *F*) can only combine with levels of the same species (After Drapatz et al. A&A 1987)


Coverage - 101 entries in the NASA-GSFC database
Latitude
Central Meridional Longitude (CML)
Orbital view
LS=90 / Aug
LS=180 / Nov
LS=270 / Feb
Heliocentric distance [AU]
Mars time
0-23
0-24
0-25
0-26
0-27
0-28
Sub-solar latitude
23
24
25
26
27
28
Doppler-shift [km/s]
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06

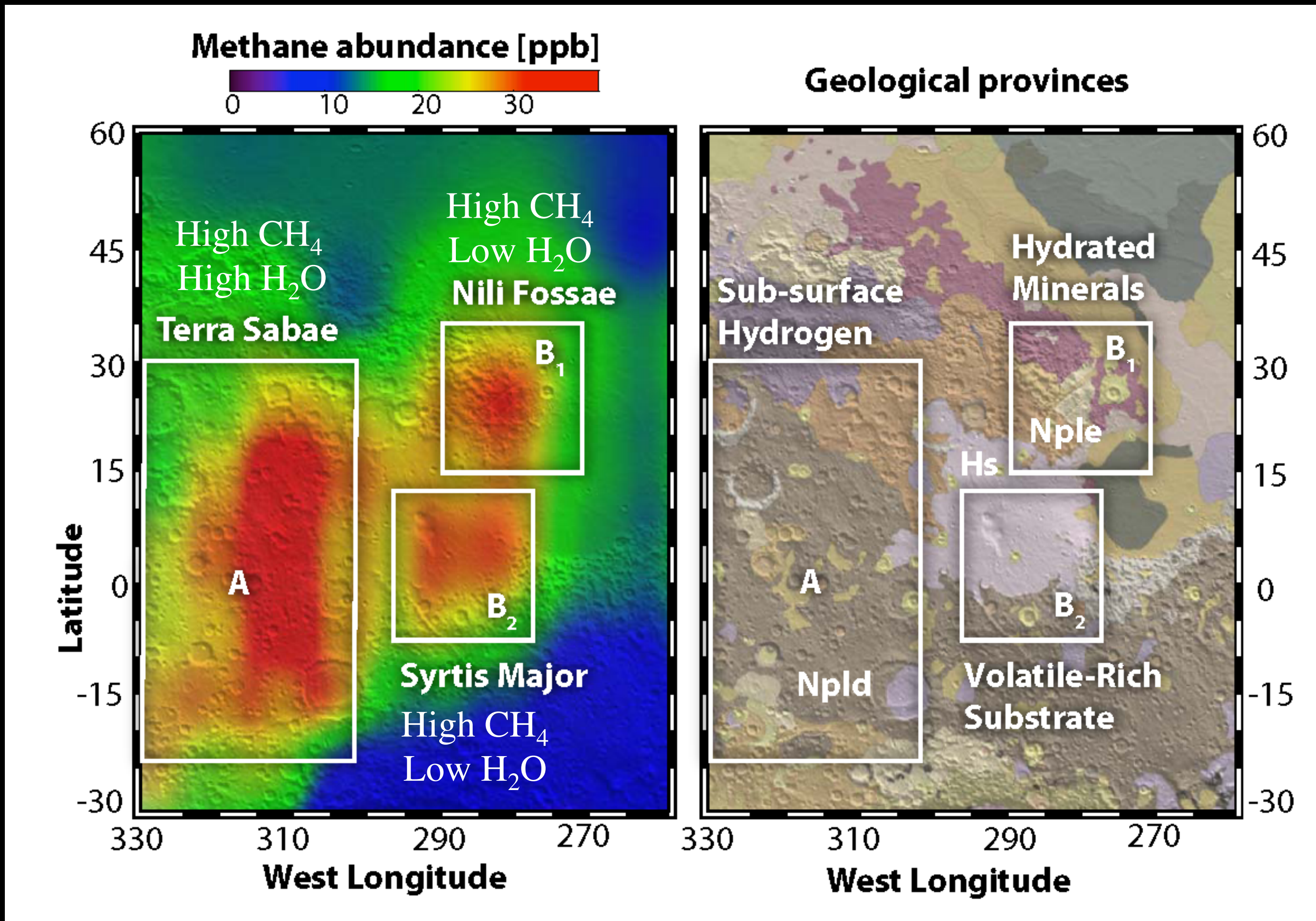


Maximum abundance
Observed at L_s 220°
(mid-spring in South)

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

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?



Methane Issues

? Origins —

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 to methane

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)

Next steps –

✓**Spectroscopy**

Higher spectral resolution (improve sensitivity, improve specificity)

Larger spectral grasp

- **detect additional trace species (C_2H_6, N_2O, H_2CO, OCS, etc.)**
- **simultaneity with CO_2 (obtain mixing ratios directly)**

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✓The SOFIA Niche

Extend CH_4 detections to 7.7 μm (ν_4 band), with EXES

- simultaneity with CO_2 (obtain mixing ratios directly)
- improved orbital coverage (Mars year)

Detect additional trace species (H_2O, HDO, H_2S, CO, CH_3OH, H_2CO, etc.)

- measure line shapes => altitude distribution

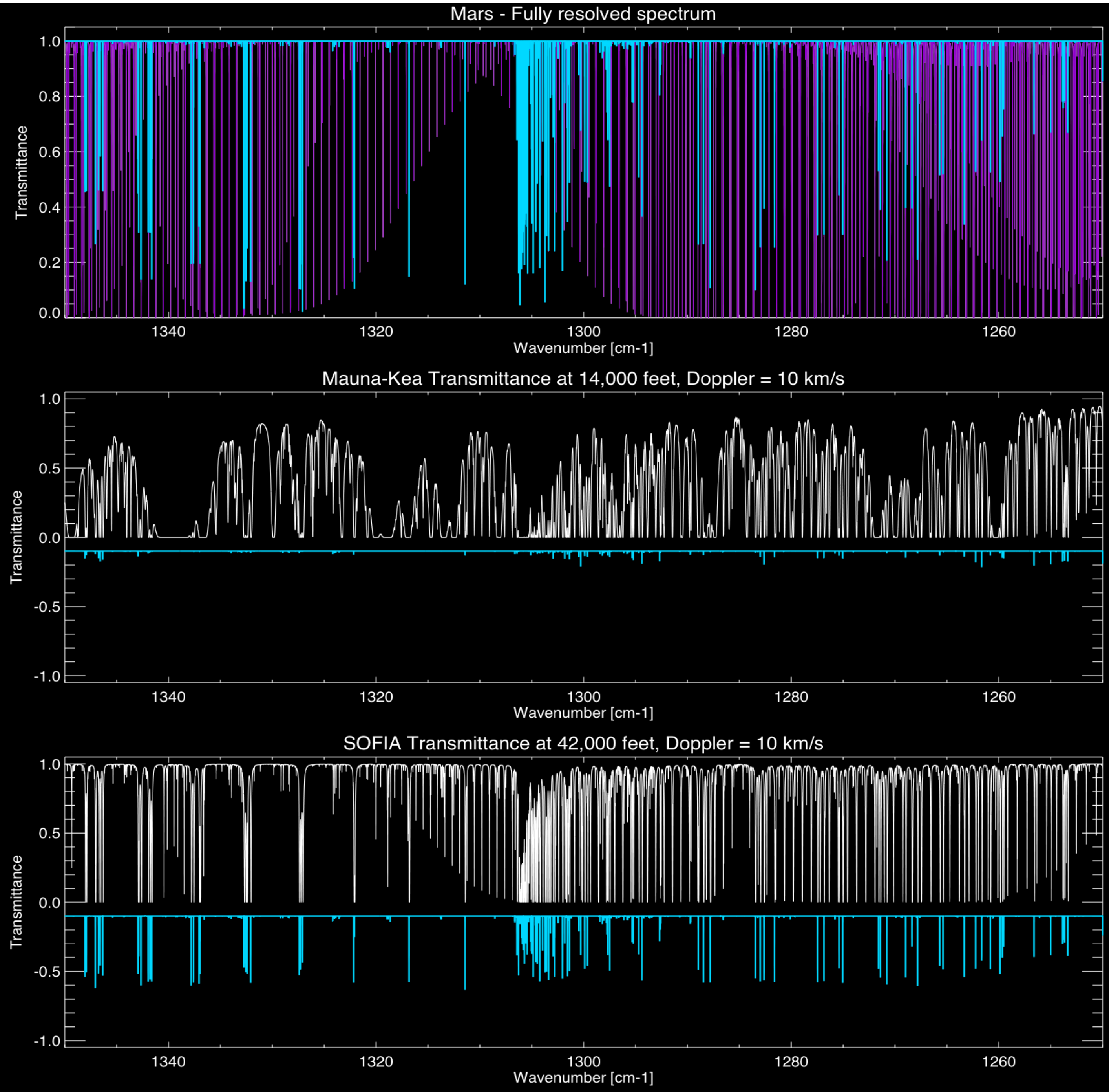
Spatial resolution: 2” = 1200 km at 10 km/s (10” Mars)

A Niche For SOFIA

CH_4

CO_2

N_2O



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

✓Spectral Resolving Power:

CRIRES	$\lambda/\delta\lambda \sim 100{,}000$	slit :	0.2″ x	30″
NIRSPEC	$\lambda/\delta\lambda \sim 40{,}000$	slit :	0.027″ x	2.26″

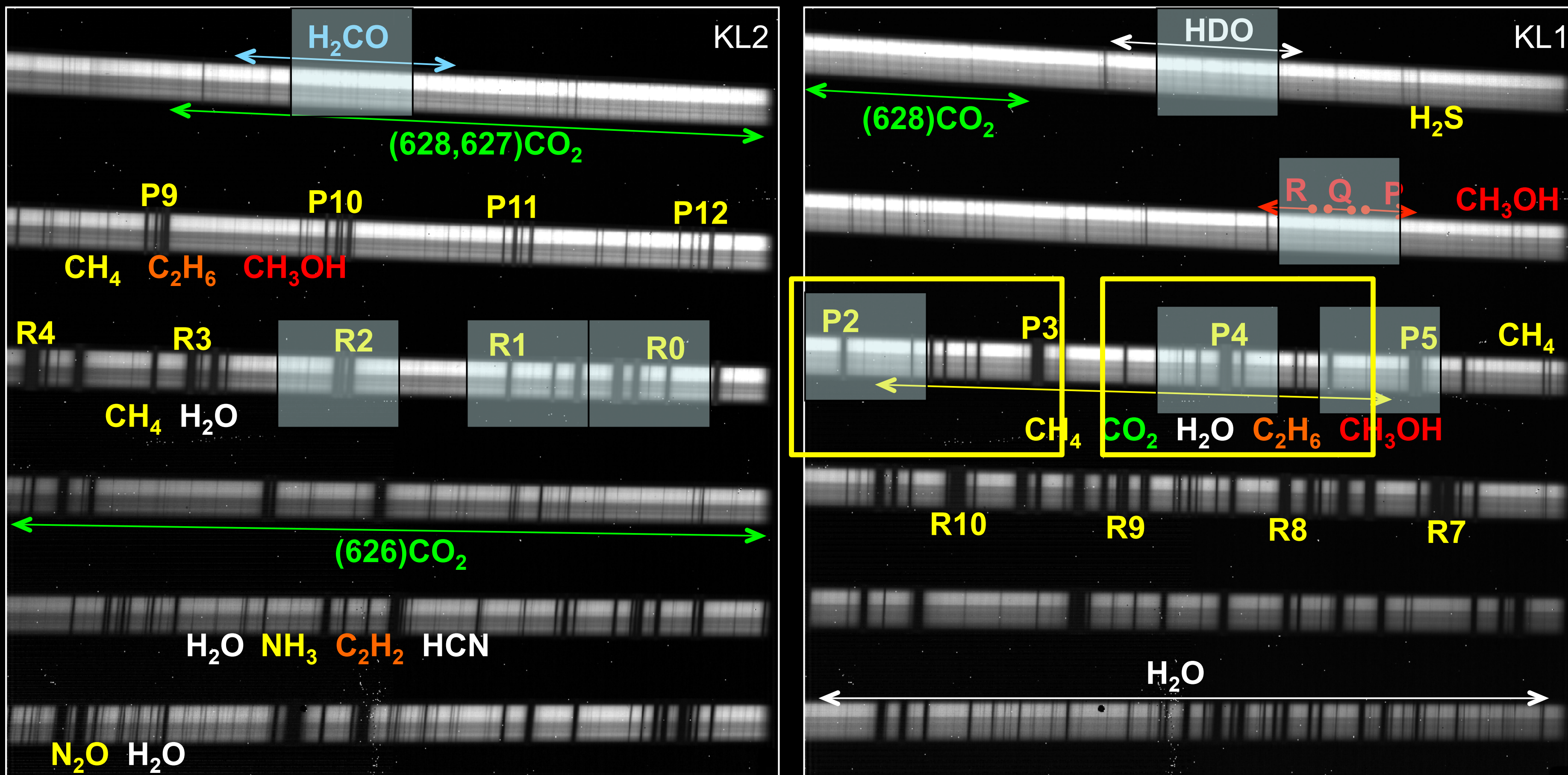
✓Spatial resolution: Correct 'seeing' with Adaptive Optics (AO)

CRIRES – UT1	PSF 0.104″	68 km on 10″ Mars
NIRSPEC – Keck 2	PSF 0.083″	56 km on 10″ Mars

High Resolution Astronomical Spectroscopy today:

NIRSPEC echellograms (two settings); CSHELL grasp in shaded boxes.

CRIRES grasp (single order) shown in yellow boxes (Detectors 3 & 4 shown).



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

Current Campaign: Completed Runs – 2009B

Dates	Instrument	Mode	Diameter arc-sec	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°
19 - 23 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°

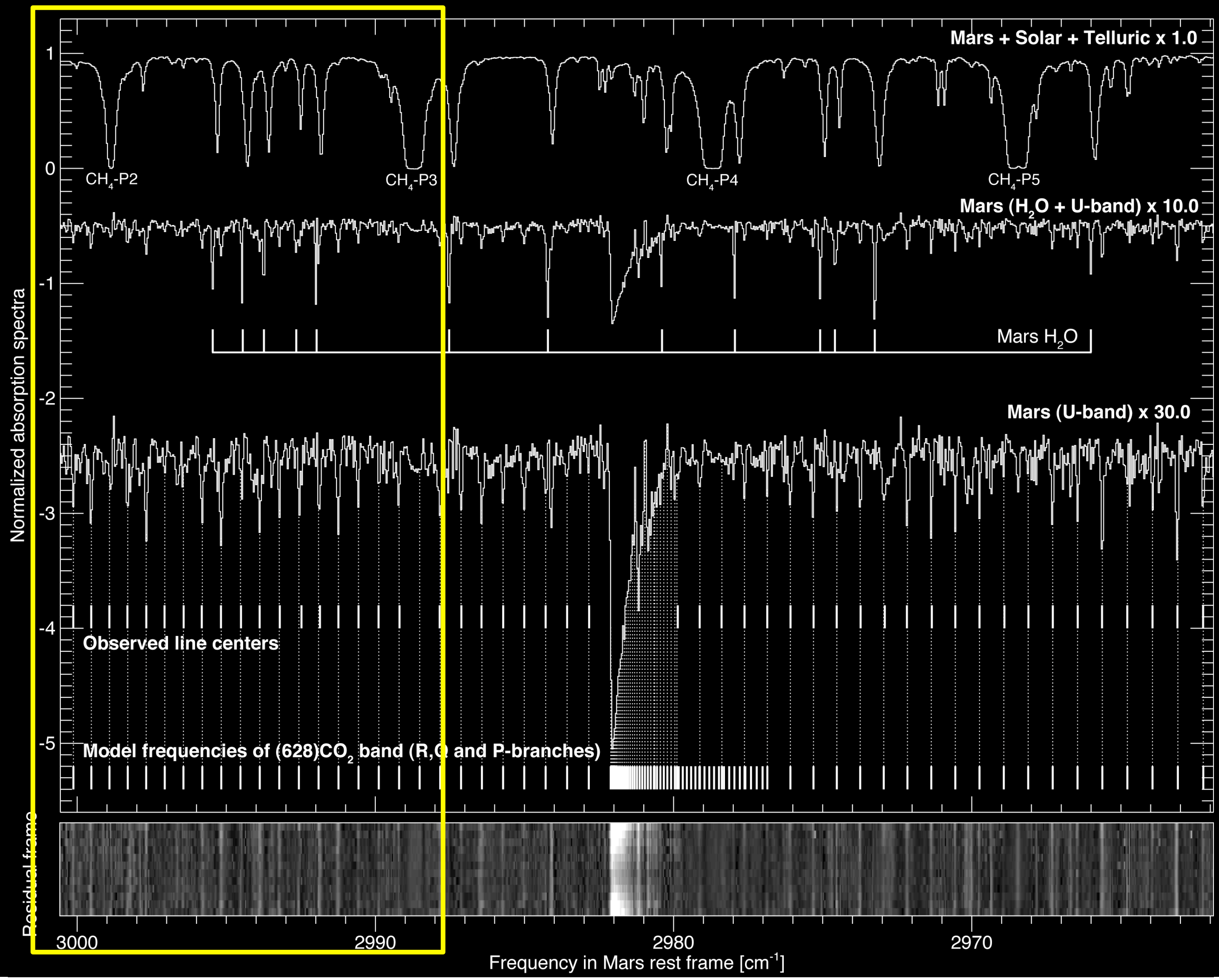
Current Campaign: Scheduled runs – 2010A

Dates	Instrument	Mode	Diameter arc-sec	Velocity km/s	Season L_s
27 - 28 March	CSHELL	–	9.6”	14.5	69°
29 March	NIRSPEC	non-AO	9.5”	14.6	70°
3 & 5 April	NIRSPEC	AO	9.0”	14.9	73°
13 - 14 April	*CRIRES*	*AO*	*8.3”*	*15.3*	*77°*
24 - 25 April	NIRSPEC	non-AO	7.6”	15.4	82°
27 April	NIRSPEC	non-AO	7.5”	15.4	83°
1 – 2 May	*CRIRES*	*AO*	*7.25”*	*15.3*	*85°*
6 - 7 May	CSHELL	–	7.0”	15.2	88°
12 - 13 May	*CRIRES*	*AO*	*6.7”*	*15.0*	*90°*
1 – 2 June	*CRIRES*	*AO*	*6.0”*	*14.1*	*99°*
8 - 9 June	CSHELL	–	5.7	13.7	102°

Preview :

CRIRES – VLT (Preliminary)

$L_s = 156°$ late northern summer   Geocentric velocity : -15.9 km/sec



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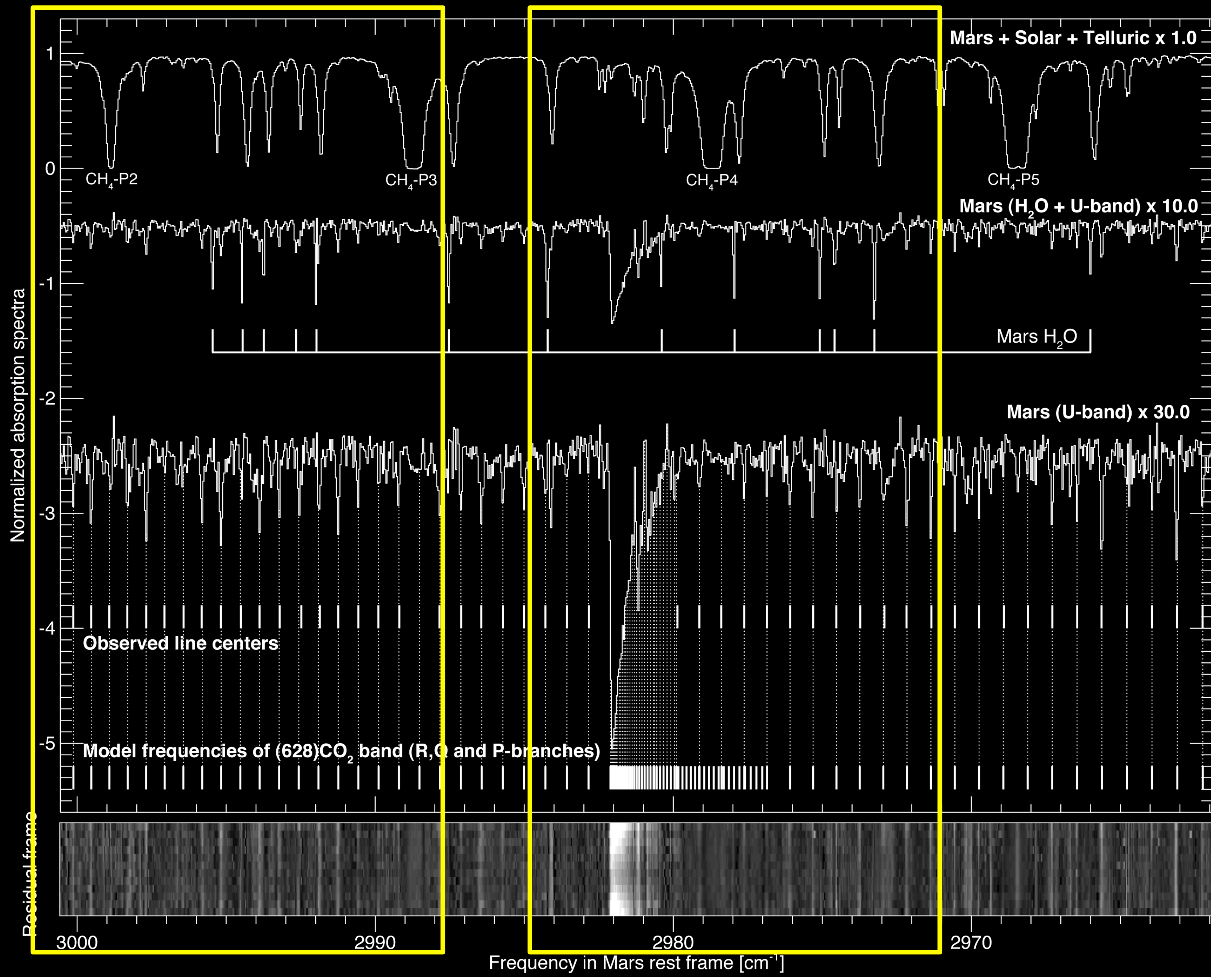


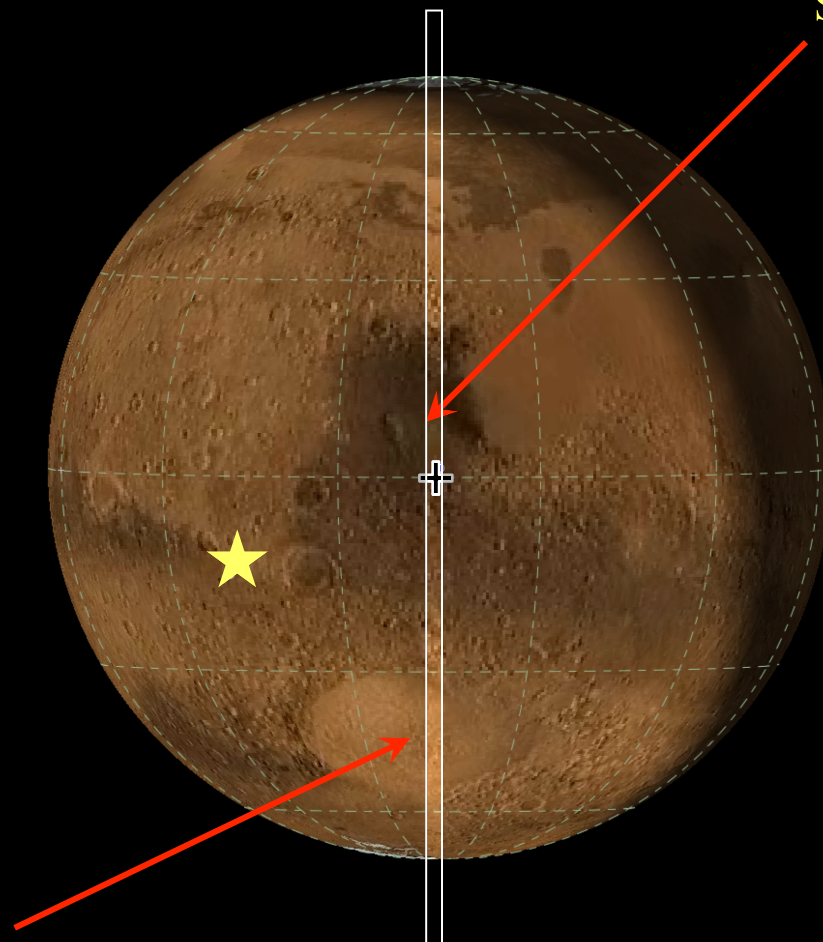
CRIRES on Mars - First night
UT 19 August 2009 10:20

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

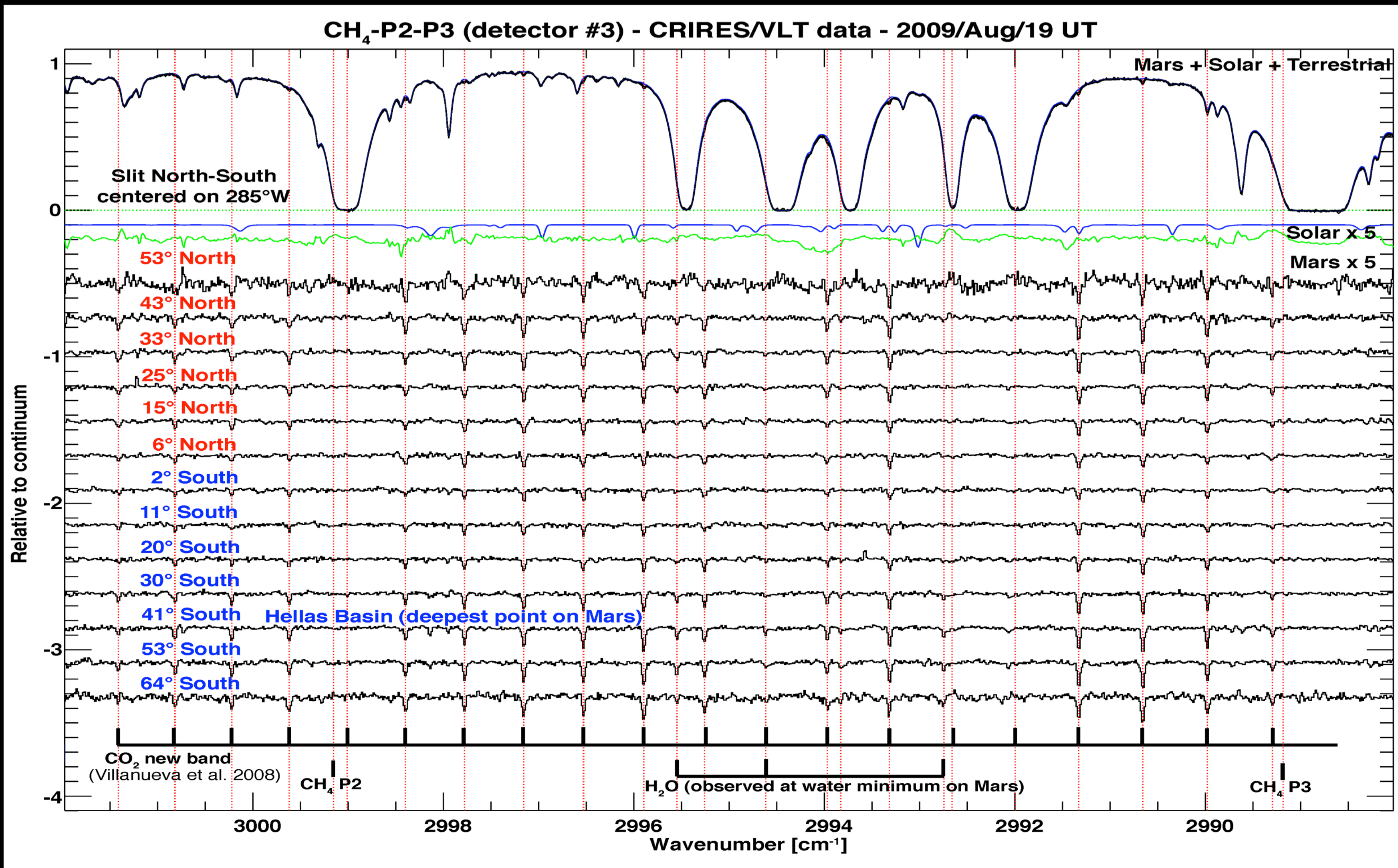
CRIRES 0.2" slit, 0.086" pixels
Centered on 285° W



NASA GISS Mars24 5.5

CRIRES L_s = 325° NH mid-winter Geocentric velocity : – 9.4 km/sec

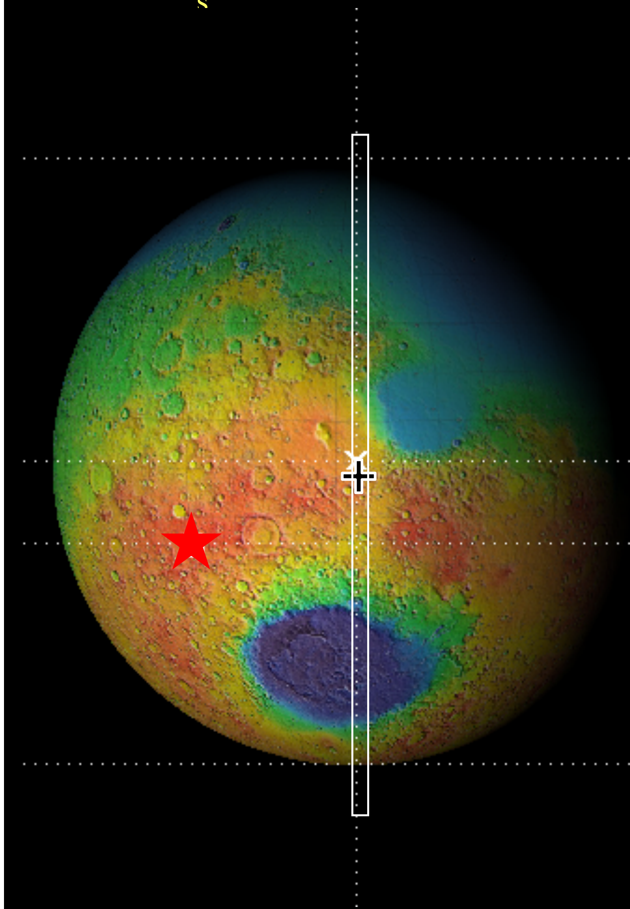
D1 3041.01 - 3025.36 D2 3021.06 - 3006.25 D3 3002.36 - 2988.37 D4 2984.80 - 2971.62

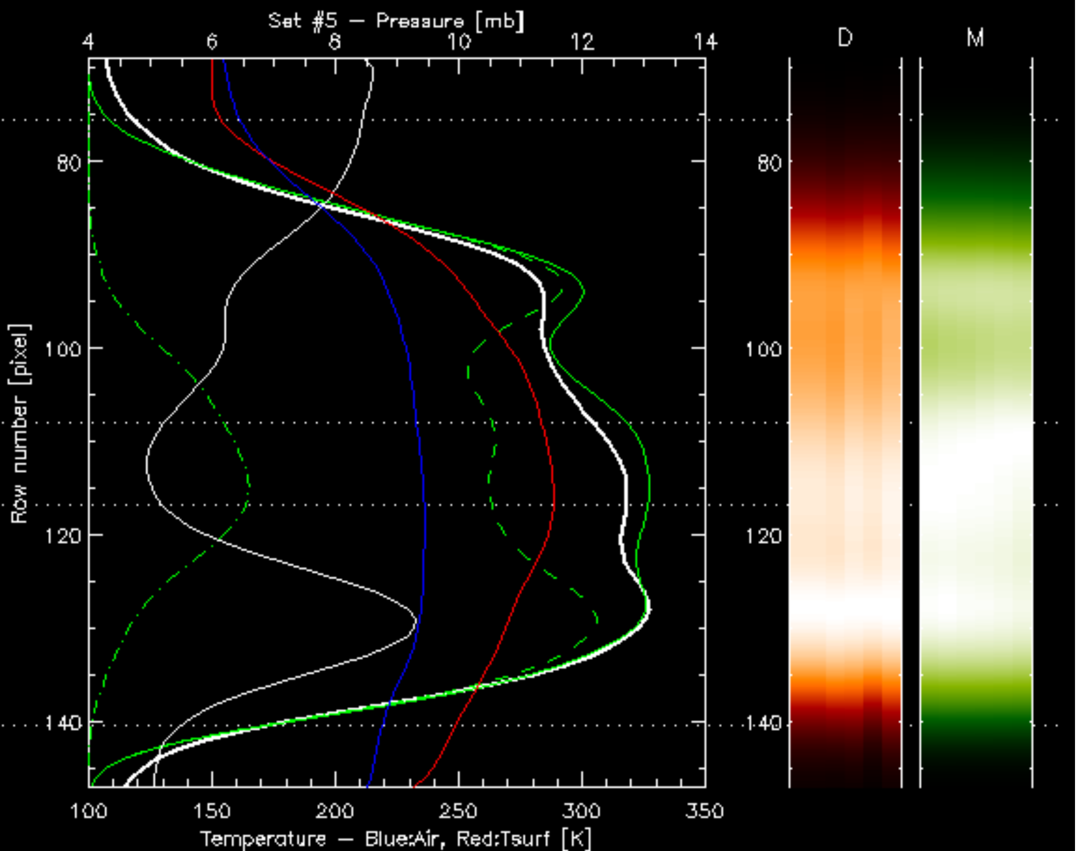


CRIRES on Mars - First night
UT 19 August 2009 10:20
Mars Diameter 5.6 arcsec
L_s = 325° mid NH winter

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

Thermal Analysis – atmosphere and solid surface

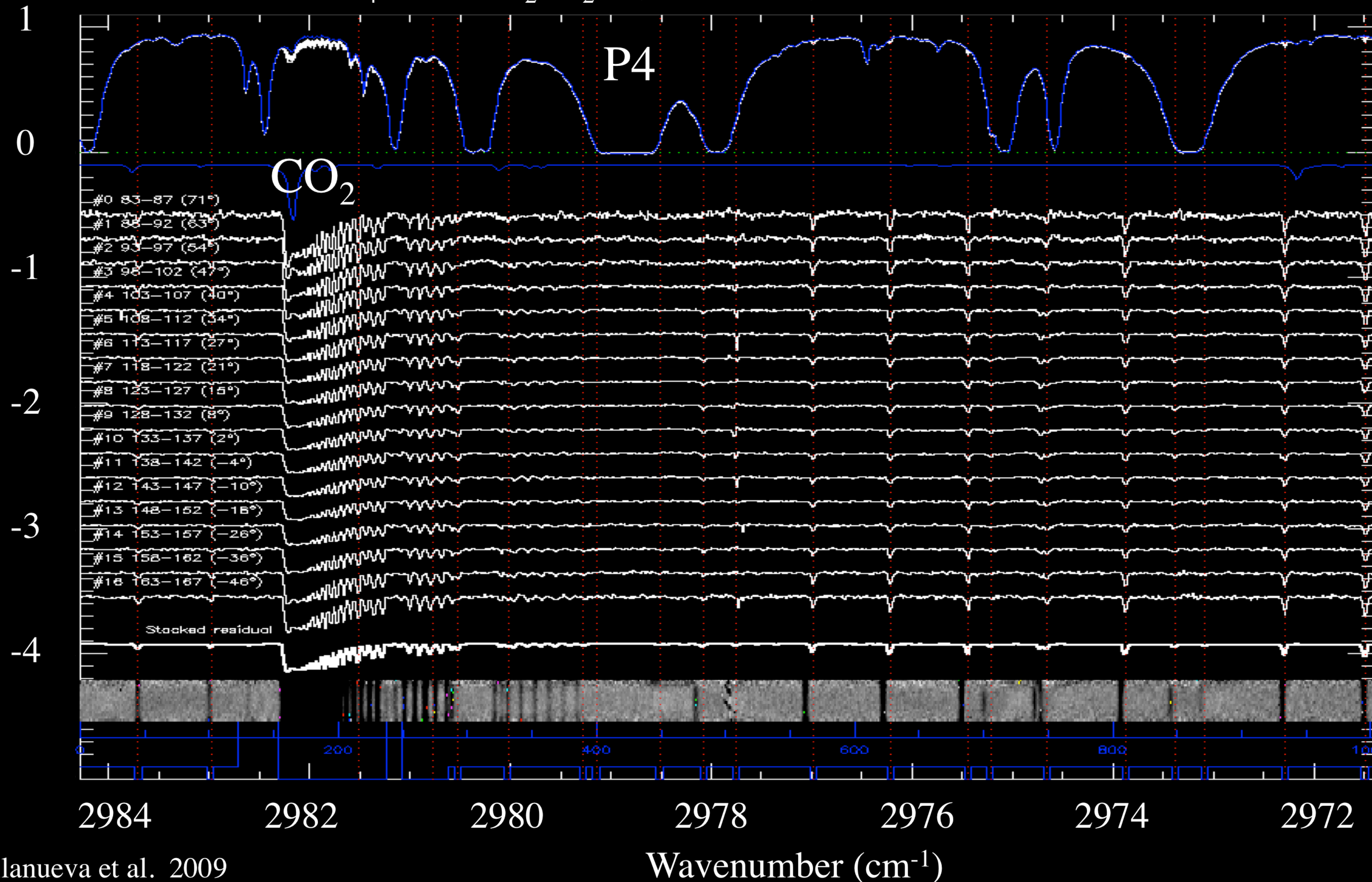




CRIRES L_s = 1.9° Vernal Equinox Geocentric velocity : – 13.8 km/sec

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

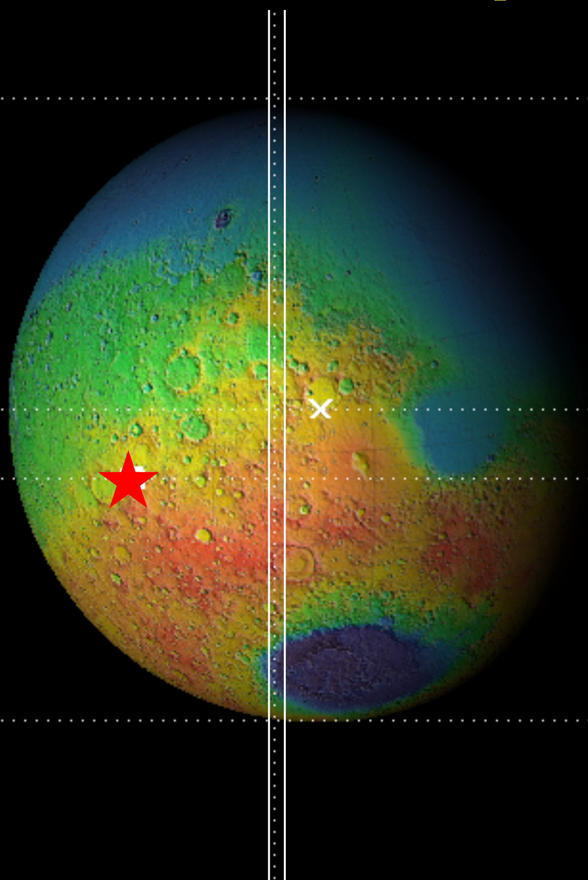
CH_4 –P4 , CO_2, H_2O (detector #4) 2009/Oct/29 UT

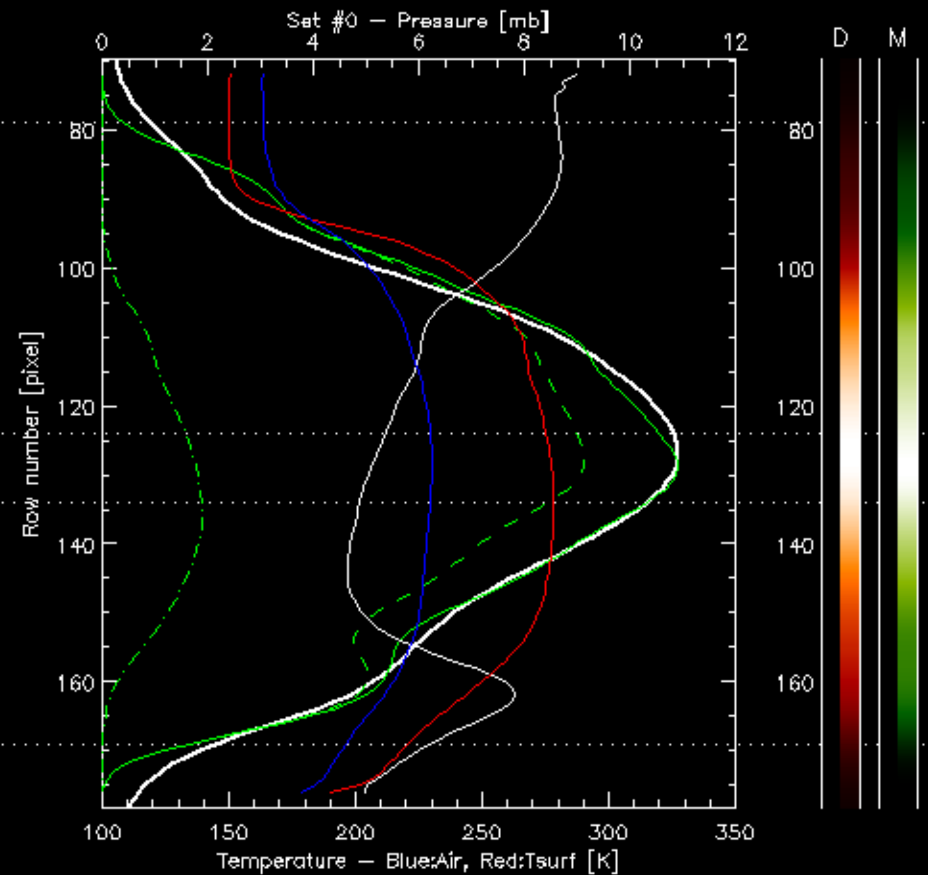


Villanueva et al. 2009

CRIRES on Mars – 3rd run UT 29 October 2009 09:00 L_s = 1.9° vernal equinox
Mars Diameter 7.8 arcsec Geocentric velocity : – 13.8 km/sec

CRIRES 0.2” slit, 0.086” pixels





CRIRES on Mars – Four runs
Aug, Sept, Oct, Nov 2009

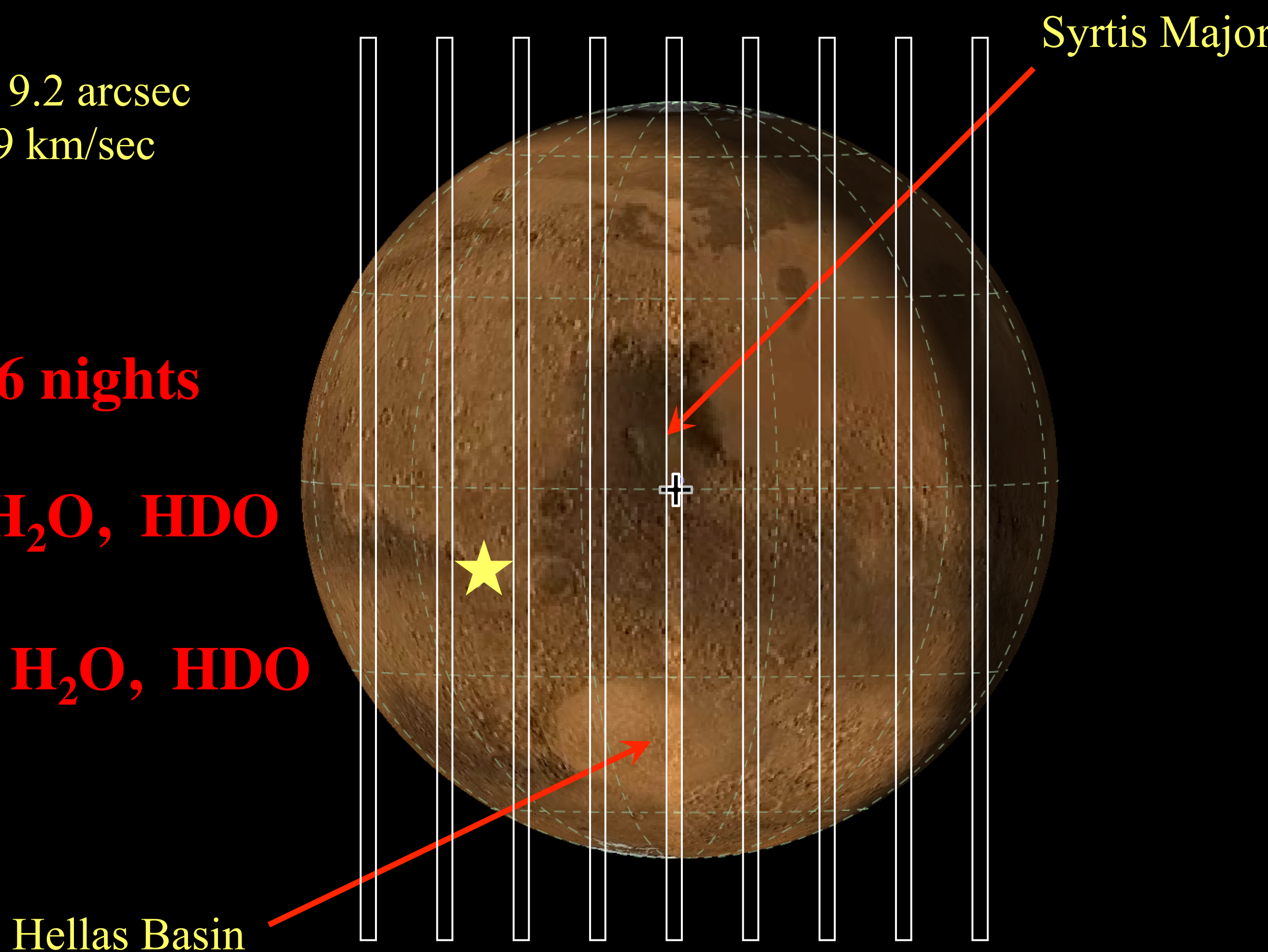
Mars Diameter : 5.6 to 9.2 arcsec
Velocity : – 9.4 to -13.9 km/sec
L_s : 325° to 11.7°

AO closed: 14 of 16 nights

Step-maps: CH_4, H_2O, HDO

Filled maps: CH_4, H_2O, HDO

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



NASA GISS Mars24 5.5

Preview :

NIRSPEC – Keck (Preliminary)

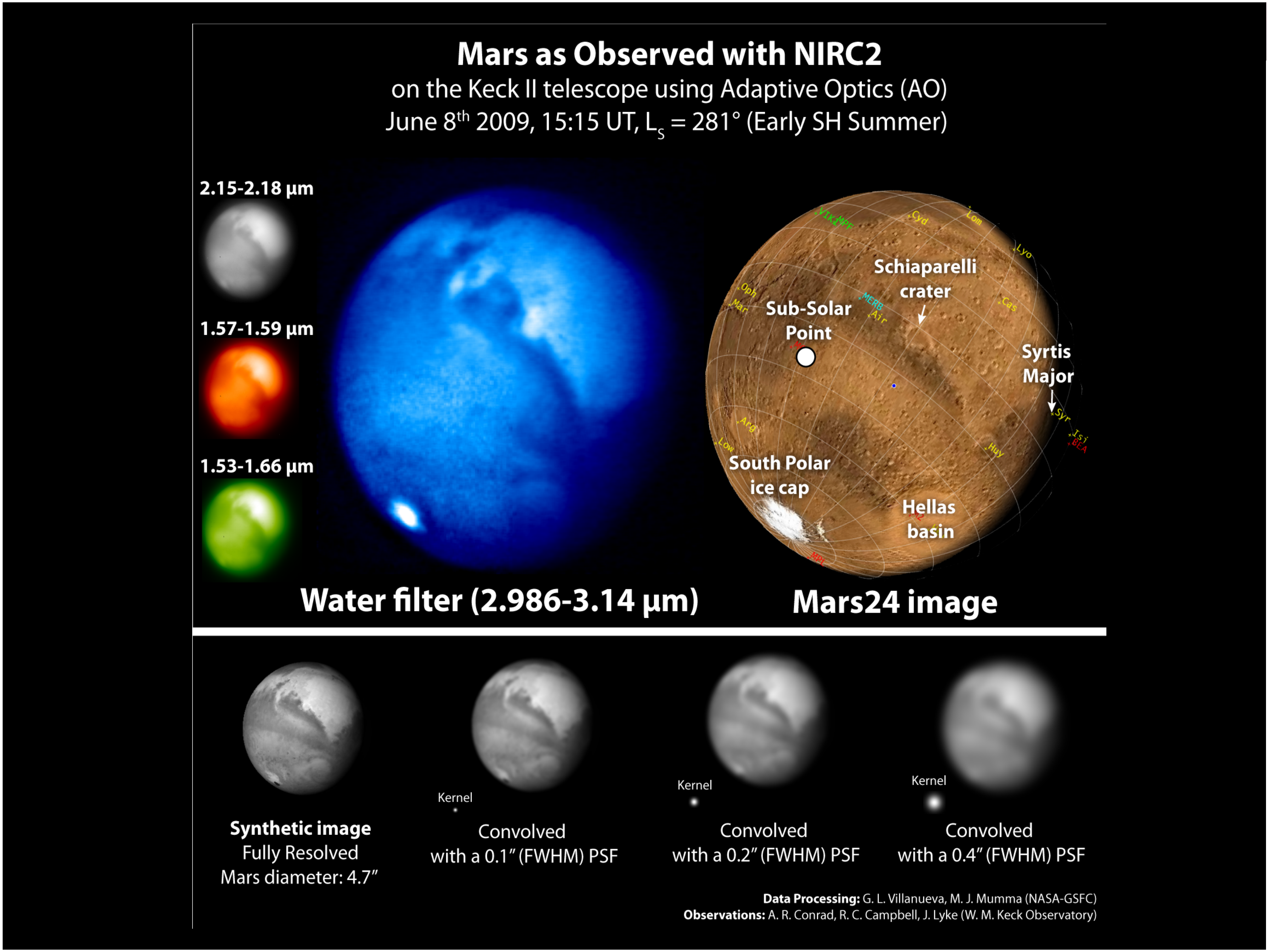
Status: AO on Mars with CRIRES and NIRSPEC

Problem # 1: AO was never demonstrated on Mars (issues: size & background)

Objective 1: Demonstrate AO on Mars (NGS mode) using NIRC2
ACHIEVED (June); additional tests (August, October, December)

Objective 2: Demonstrate AO on Mars using offset source as NGS
Deimos (CRIRES & Keck-2 = FAILED; mirror scatter too bright)

SURPRISE SOLUTION: AO closed on Mars albedo feature (CRIRES – August)

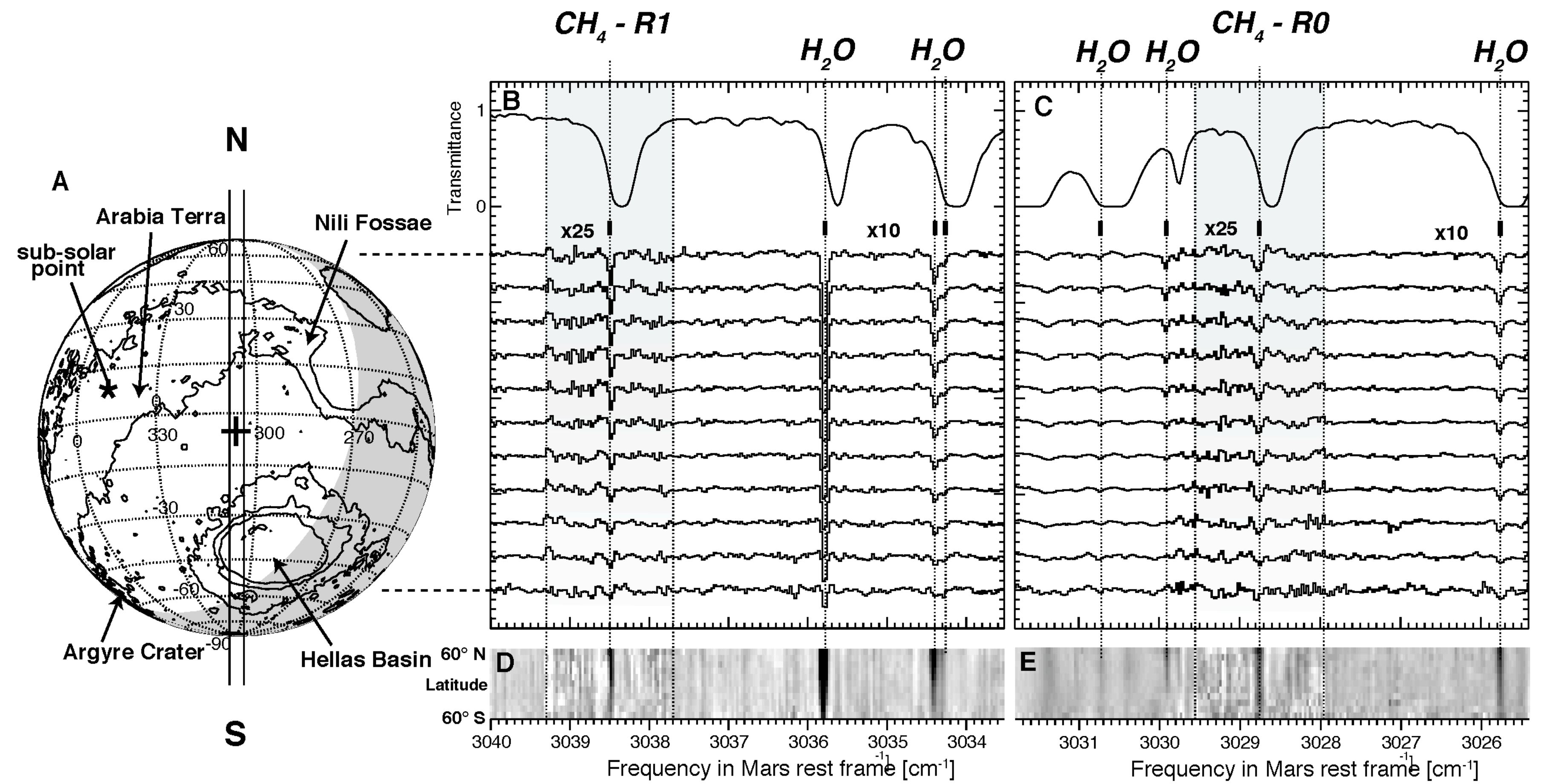

Mars as Observed with NIRC2
on the Keck II telescope using Adaptive Optics (AO)
June 8th 2009, 15:15 UT, Ls = 281° (Early SH Summer)
2.15-2.18 μm
1.57-1.59 μm
1.53-1.66 μm
Water filter (2.986-3.14 μm)
Schiaparelli crater
Sub-Solar Point
Syrtis Major
South Polar ice cap
Hellas basin
Mars24 image
Synthetic image
Fully Resolved
Mars diameter: 4.7″
Kernel
Convolved with a 0.1″ (FWHM) PSF
Kernel
Convolved with a 0.2″ (FWHM) PSF
Kernel
Convolved with a 0.4″ (FWHM) PSF
Data Processing: G. L. Villanueva, M. J. Mumma (NASA-GSFC)
Observations: A. R. Conrad, R. C. Campbell, J. Lyke (W. M. Keck Observatory)

END

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

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

Spectra binned over 277 - 323° longitude

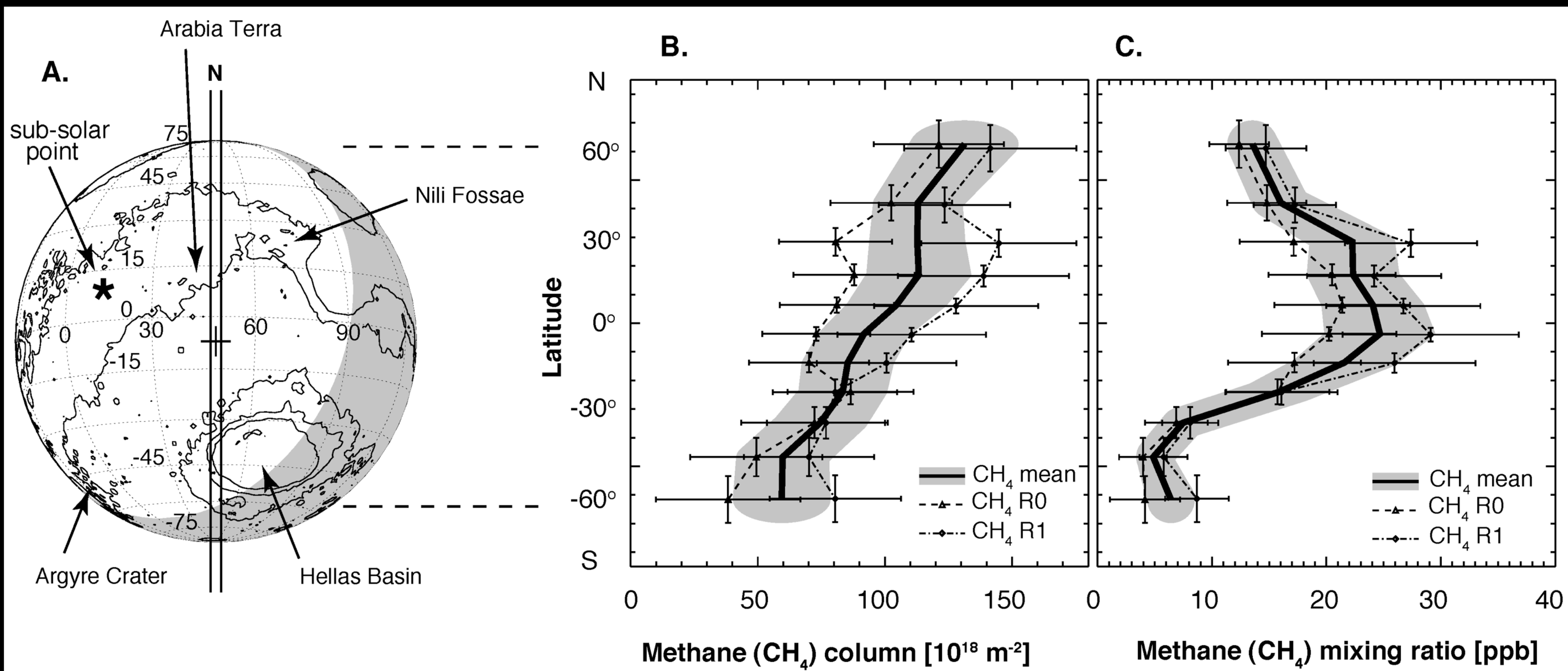


Mumma, Villanueva, Novak, et al. (Science 2009)

Additional Checks are satisfied :

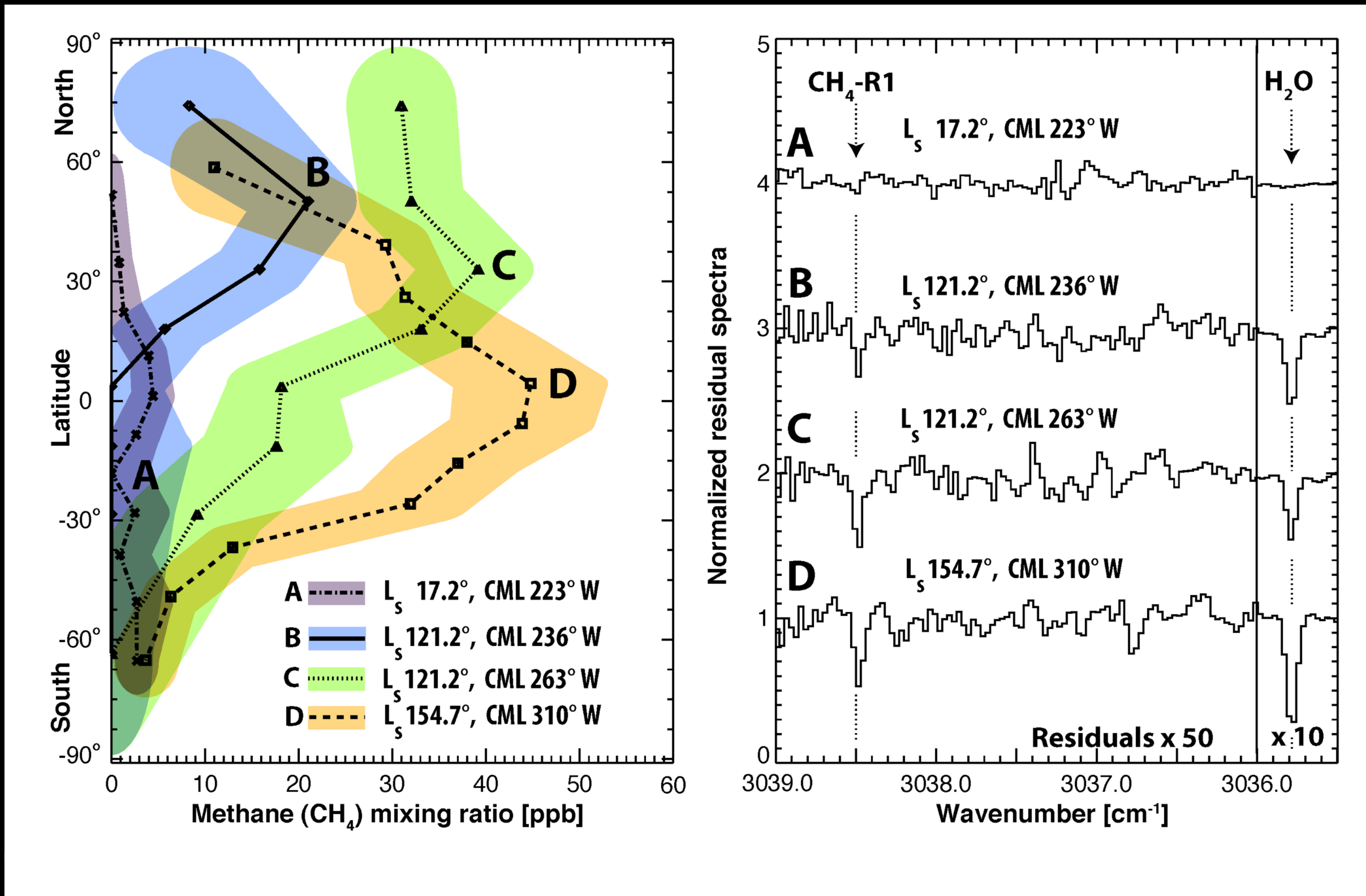
The column abundances obtained from two independent lines of methane agree within errors.
The mixing ratios obtained from two independent lines of methane agree within errors (right).
A pronounced maximum in mixing ratio is seen over equatorial latitudes (right).

Two more methane lines are detected (the P2 doublet) during Southern spring (not shown).



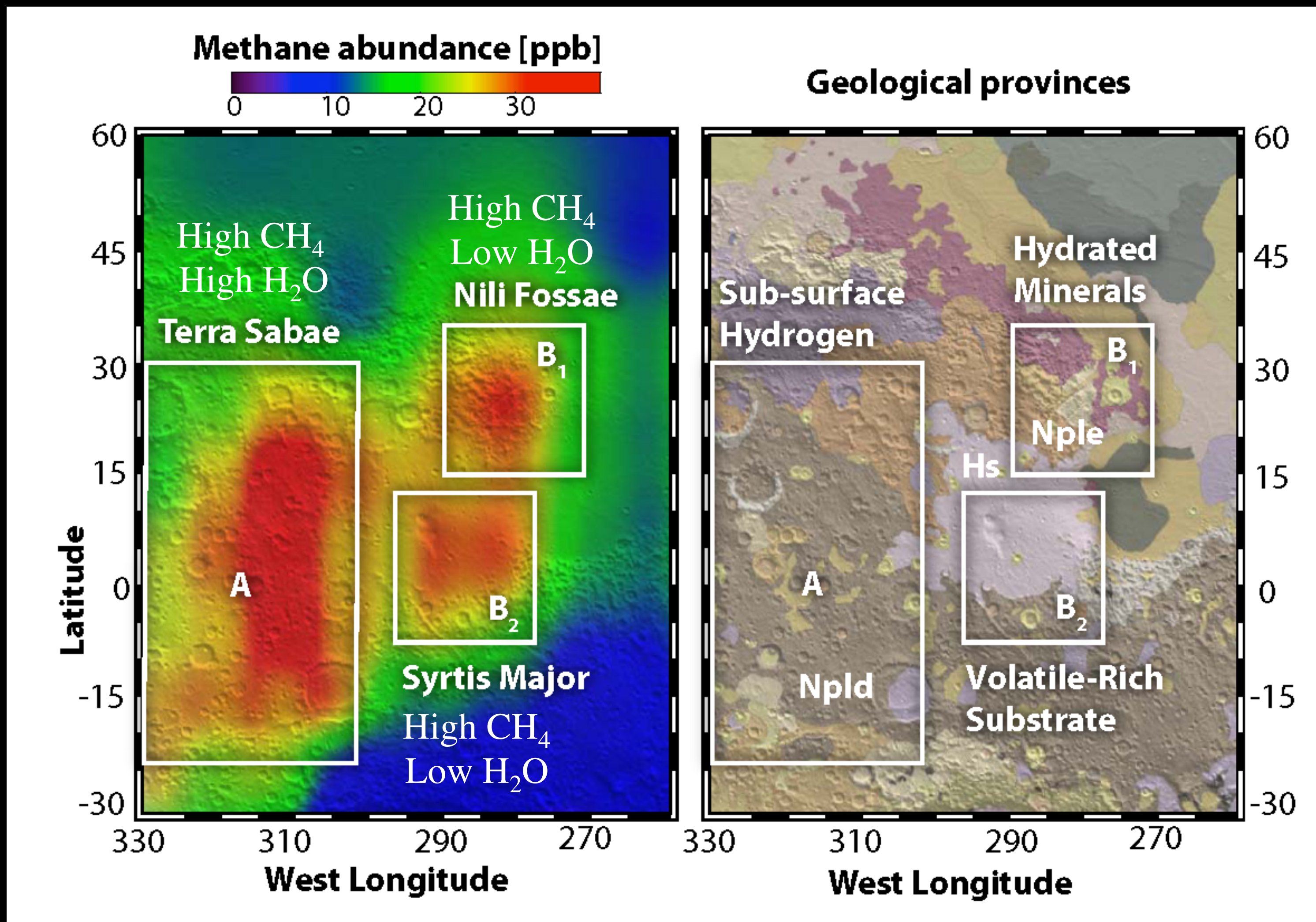
Mumma, Villanueva, Novak, et al. (Science 2009)

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)



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?



Villanueva, Mumma, and Novak (submitted 2009)

Methane varies with location and season :
Local methane plumes are not always correlated with water (e.g., D, E)
Methane varies strongly with season; its lifetime on Mars must be short (< 1 year)