Search of CH_4 on Mars by SOFIA/EXES

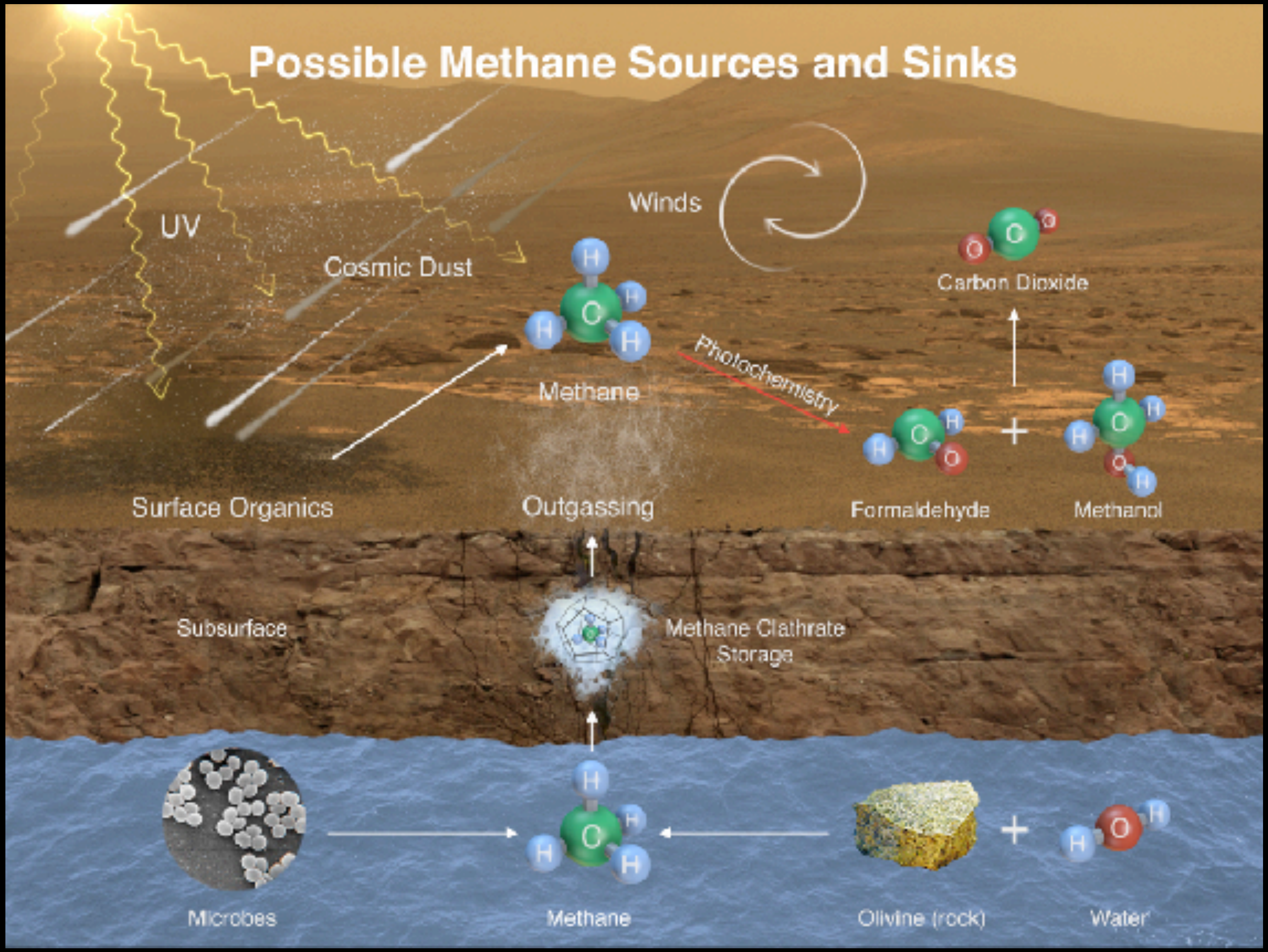
S. Aoki[1], M. J. Richter[2], C. DeWitt[2], A. Boogert[3], T. Encrenaz[4], H. Sagawa[5], H. Nakagawa[6], A.C. Vandaele[1], M. Giuranna[7], T. K. Greathouse[8], T. Fouchet[4], A. Geminale[7], G. Sindoni[7], M. McKelvey[2], M. Case[2], and Y. Kasaba[6]

1. IASB-BIRA, 2. Univ. of California Davis, 3. Univ. of Hawaii, 4. Paris Observatory, 5. Kyoto Sangyo Univ., 6. Tohoku Univ., 7. IAPS-INAF, 8. SwRI

Mars Science Workshop: “From Mars Express to ExoMars” ESAC, Madrid, Spain, 27–28, Feb, 2018.

CH_4 on Mars: Origin of geological/biological activity?

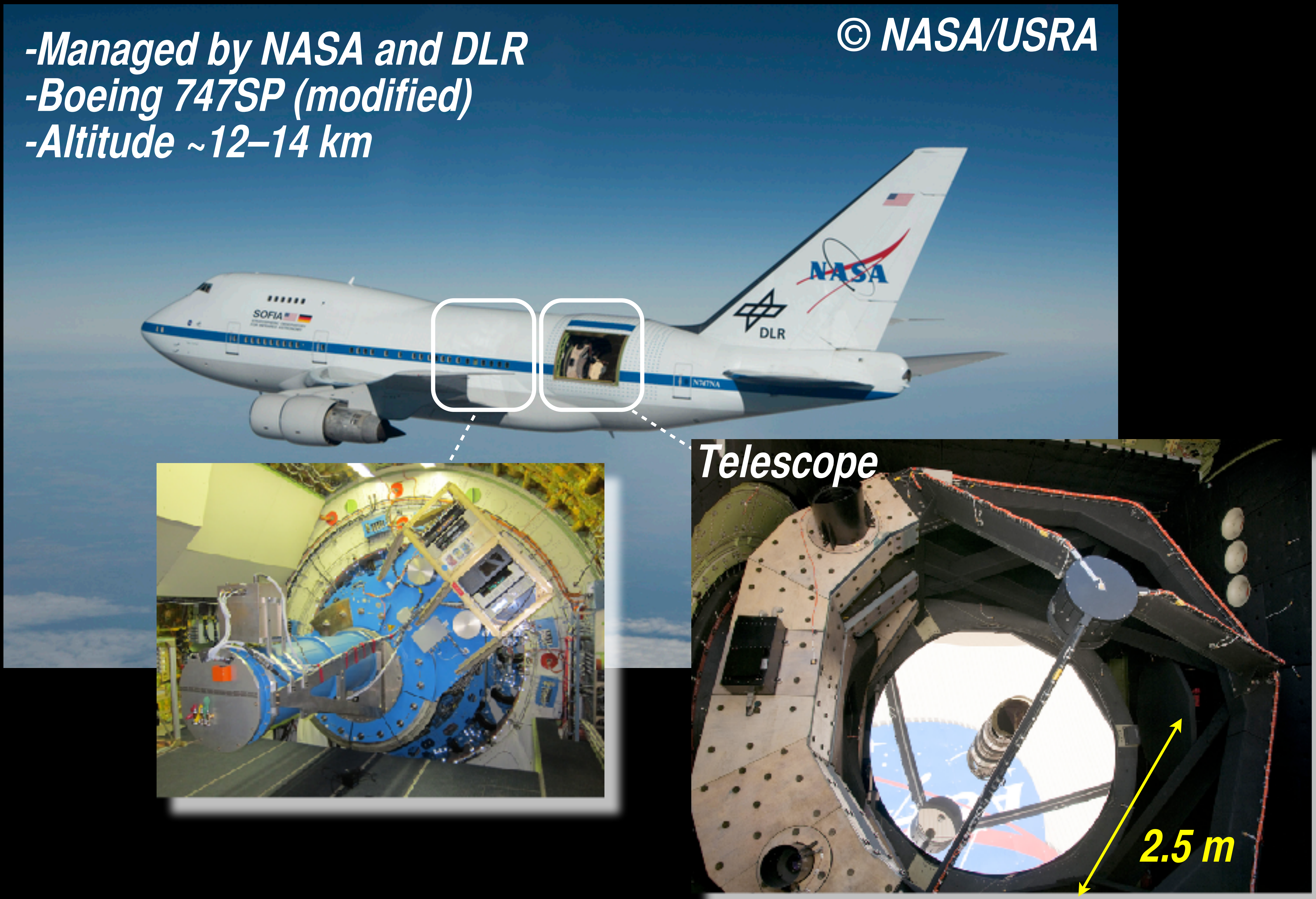
- ✓ Discovery of CH_4 on Mars (Formisano et al., 2004; Krasopolsky et al., 2004)
- ✓ Much discussion: a signature of on-going/past biological/geological activities.



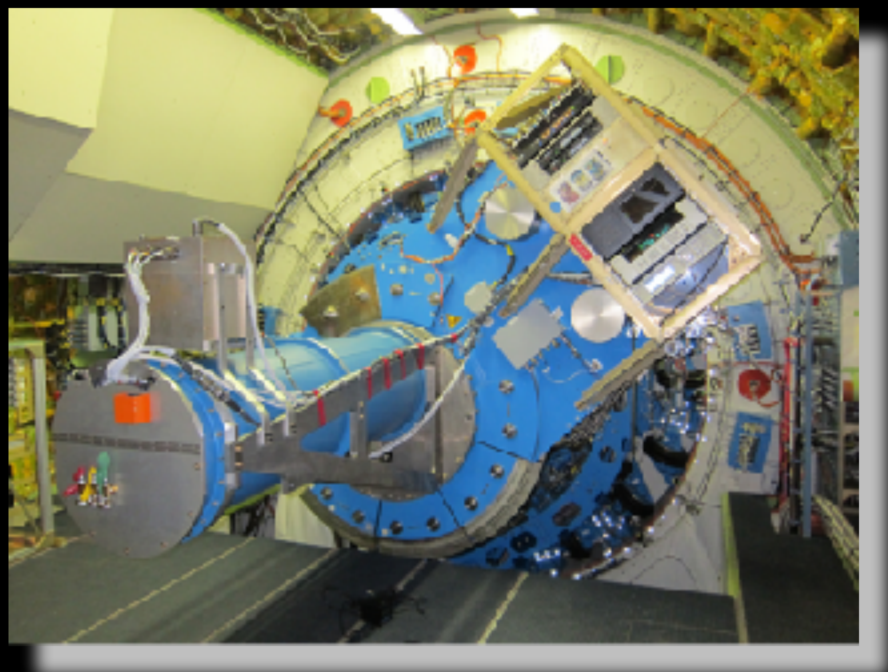
© NASA/JPL-Caltech/SAM-GSFC/Univ. of Michigan

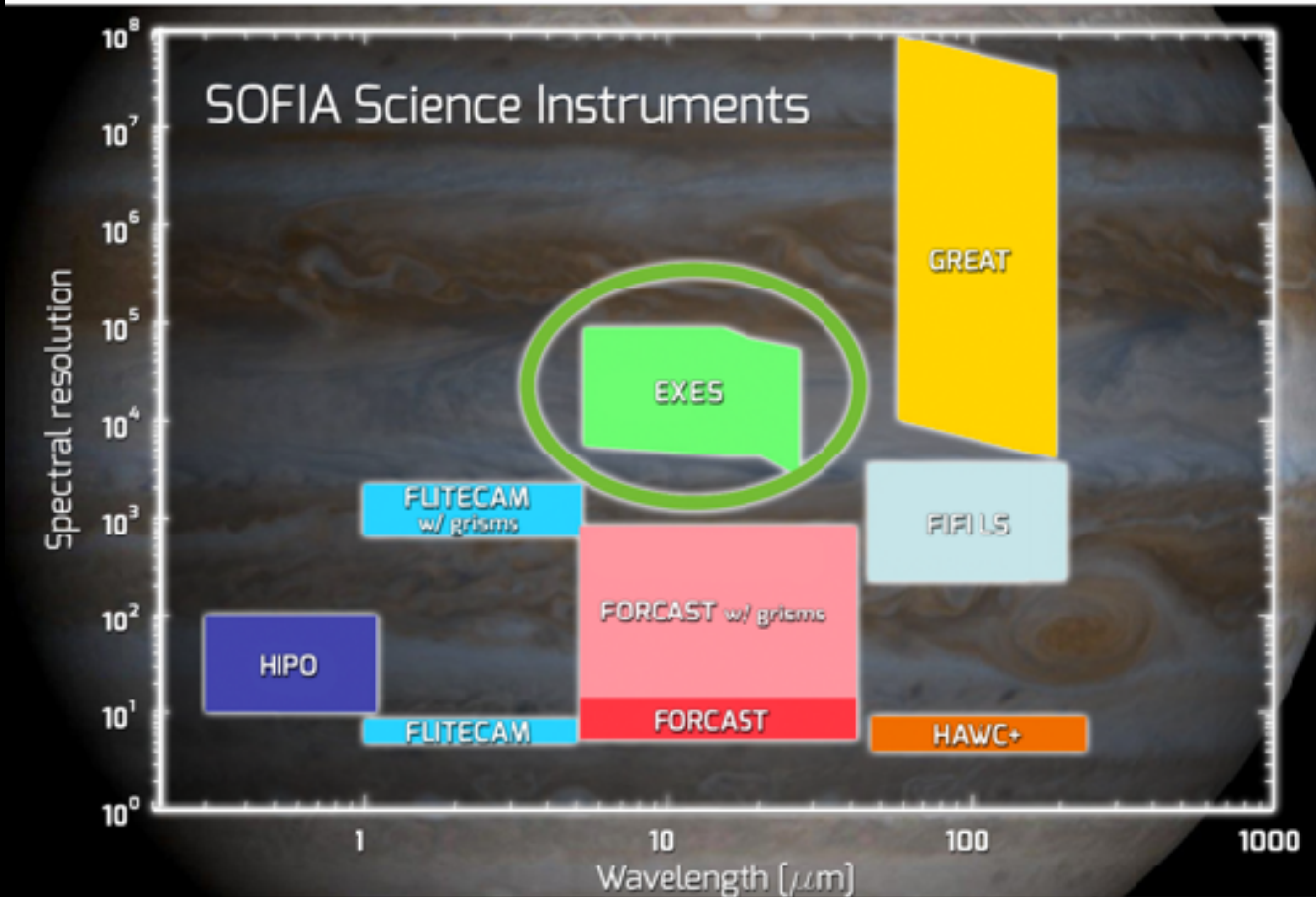
Purpose: New remote sensing observations for sensitive search of CH_4 on Mars, <u>with higher reliability by using SOFIA/EXES</u>

What is SOFIA ?



SOFIA/EXES (similar to TEXES at IRTF)



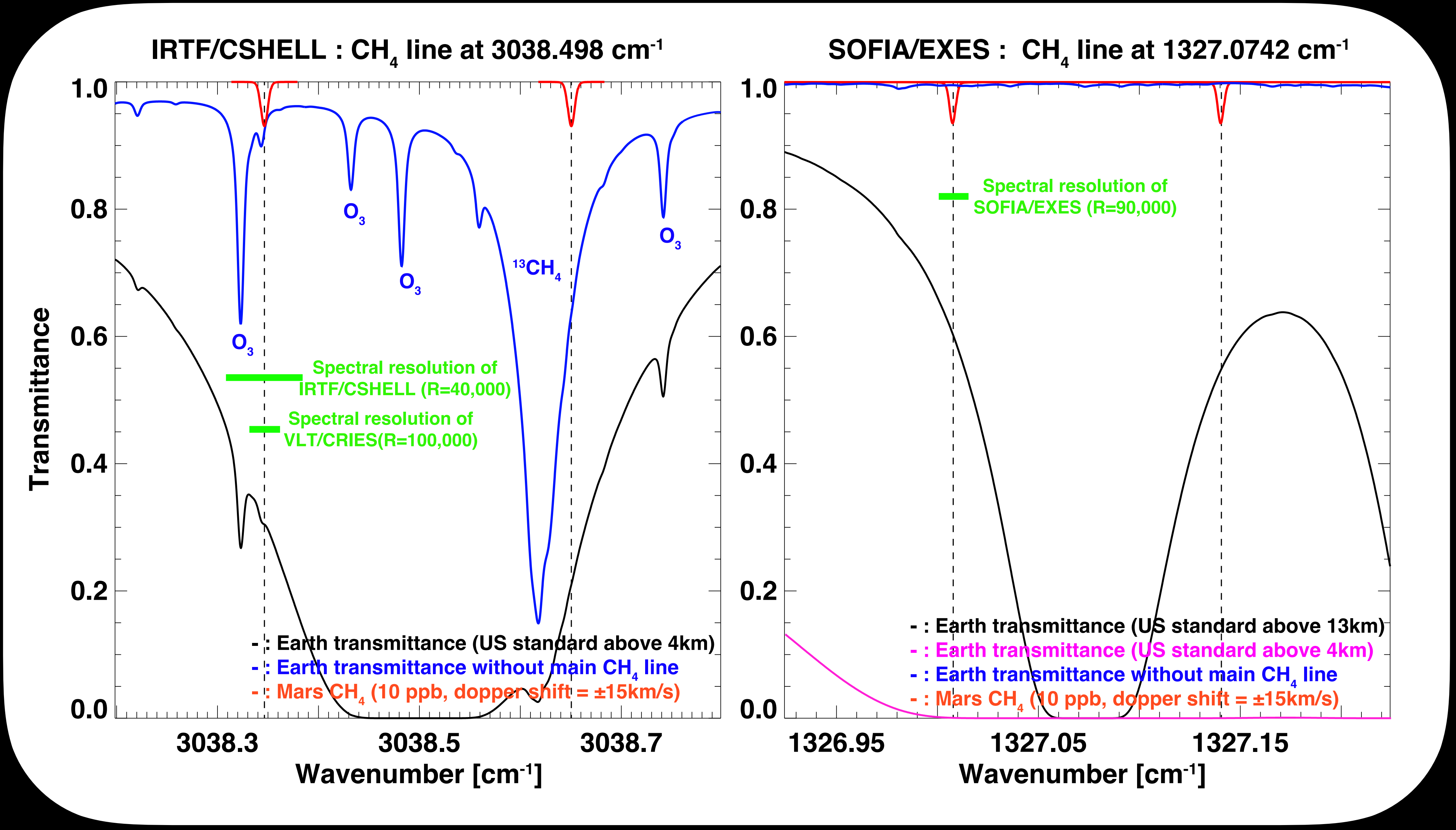


- Grating (echelon) Spectroscopy
- Operation wavelength: 4.5 – 28.3 µm
- Spectral resolution: 1,000–3,000 (low-resolution mode, long slit [90”]),

  5,000–20,000 (low-resolution mode, long slit),
  50,000–100,000 (high-resolution mode, cross-dispersed by echelle graiting)

  →Fits for Mars trace gas observations

Advantages/disadvantages of SOFIA/EXES



Significantly reduce the effects of terrestrial atmosphere

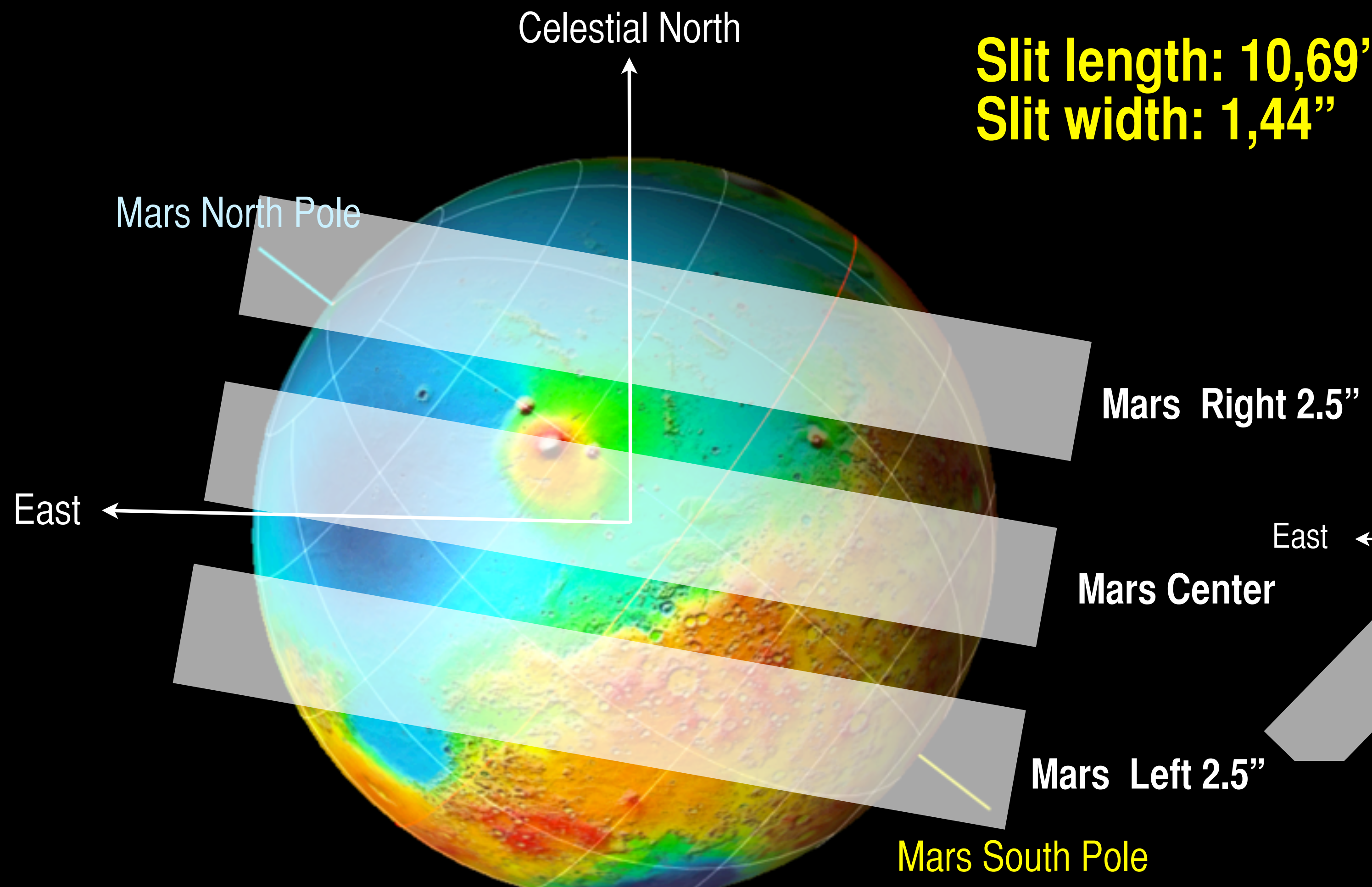
-> improve SNR (a few times better than previous obs.), allows to use 7.5 μm band

✓ 7.5 μm band : Intrinsic intensities of the CH_4 lines at 3.3 and 7.5 μm are comparable, but less contamination of minor terrestrial lines ($^{13}CH_4$, O_3, etc)

Observations and data analysis (1/2)

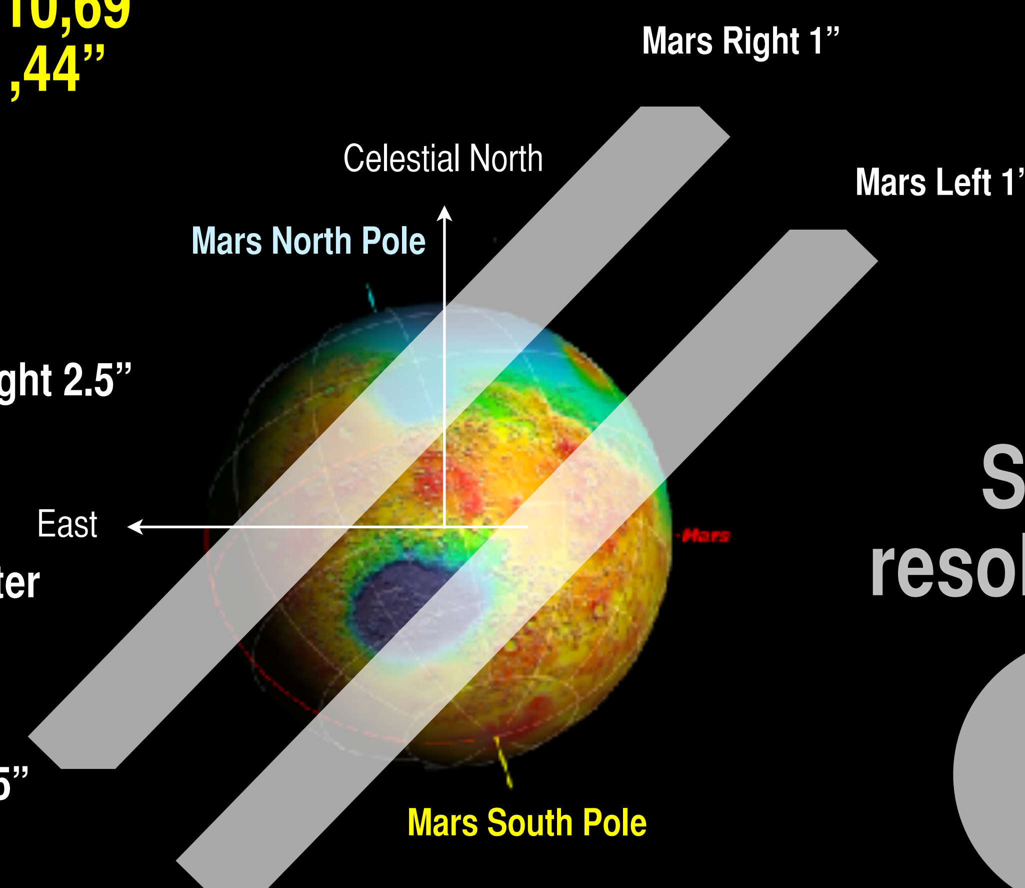
Date and Time (UT)	Ls	MY	Doppler Shift	Diameter of Mars	Sub-observer longitude	# of slit positions and integration time	Aircraft Altitude
16/March/2016 9:59–10:32	123.2°	33	-16.2 km/s	10.0”	247–253°W	Mars center (x2): 9&6 min Mars Left 2.5”: 9 min Mars right 2.5”: 9 min	~13.7 km
25/Jan/2017 1:40–2:11	305.2°	33	+11.7 km/s	5.2”	347–353°W	Mars Left 1”: 6 min Mars Right 1”: 6 min	~11.9 km

16/March/2016



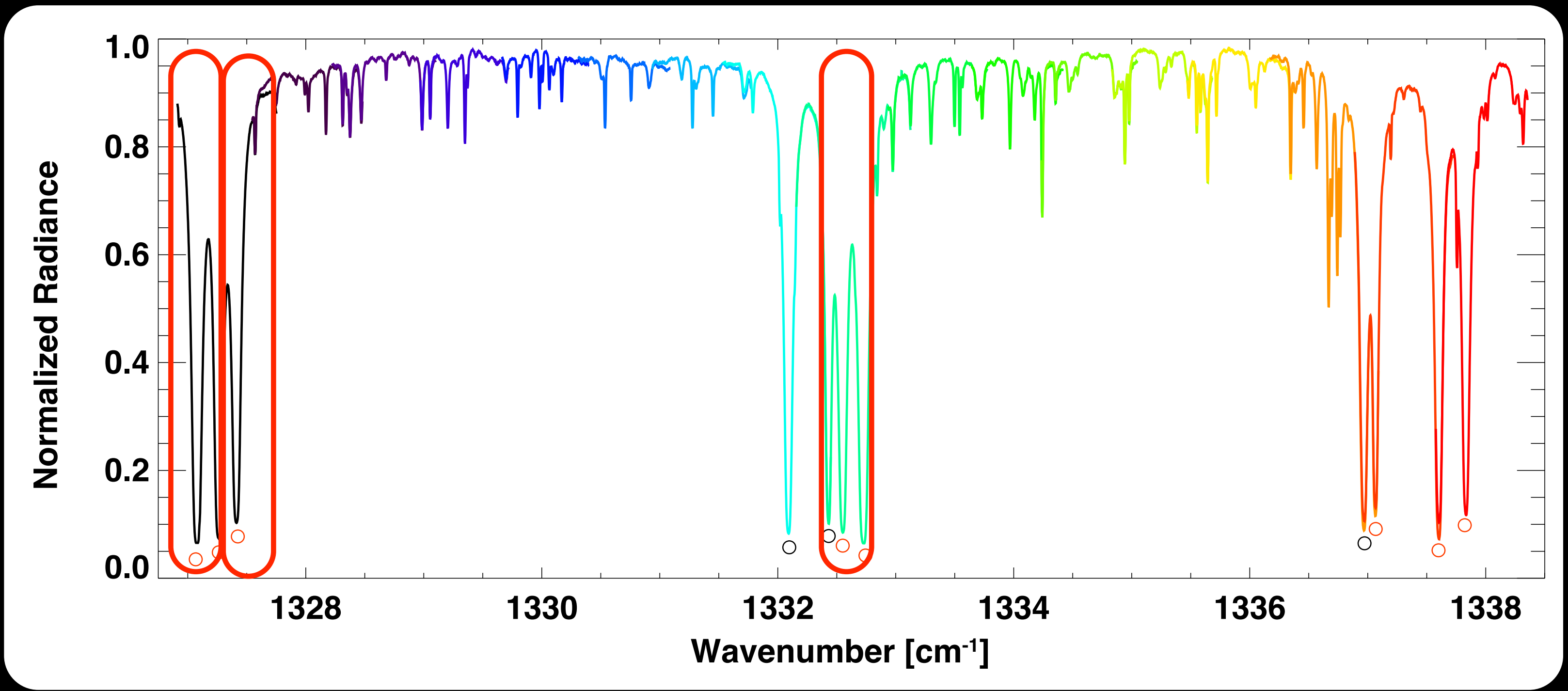
Slit length: 10,69”
Slit width: 1,44”

25/Jan/2017



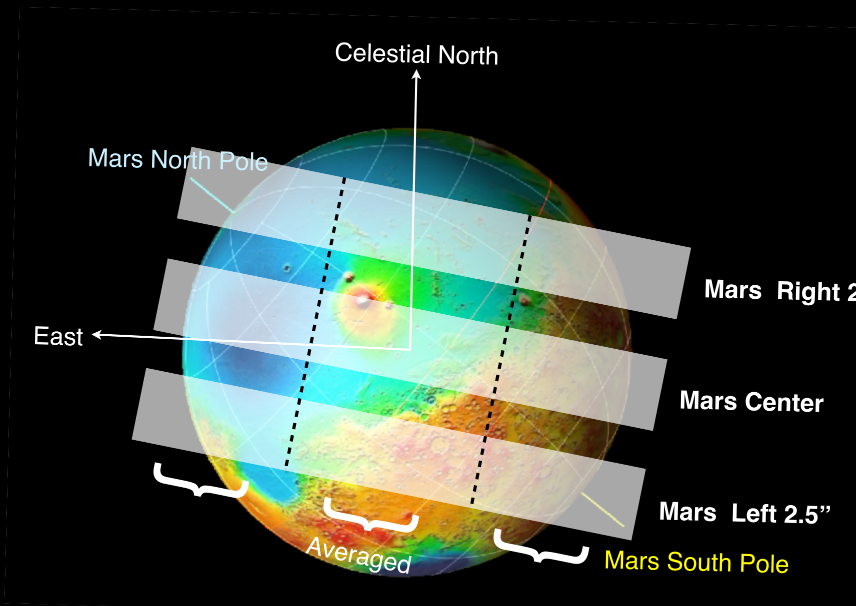
Spatial resolution~3”

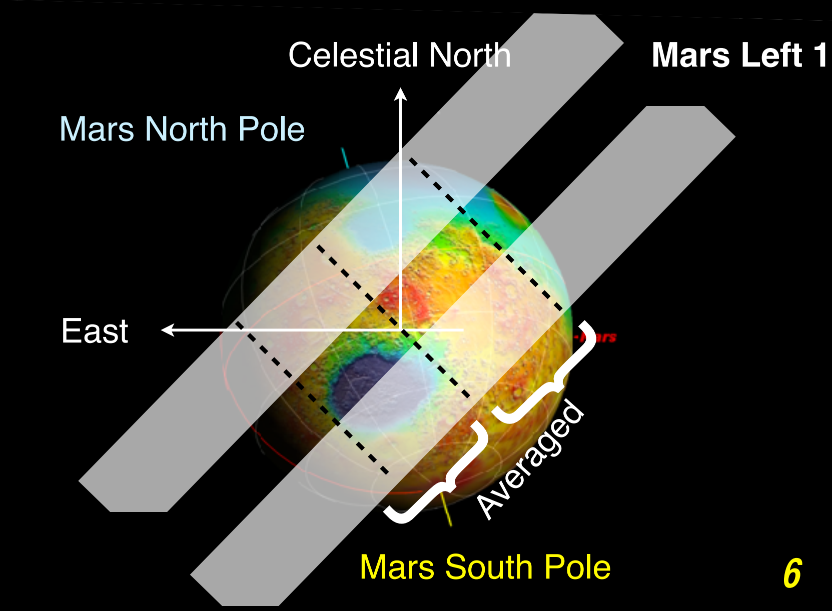
Observations and data analysis (2/2)



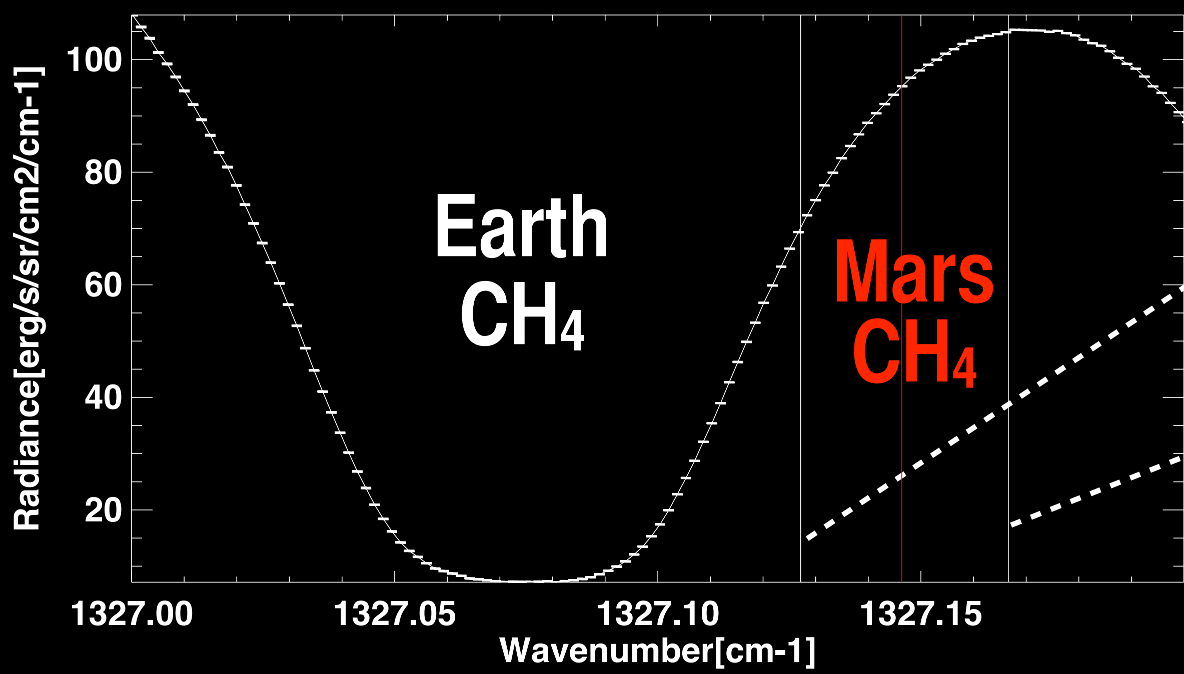
Wavenumber (cm^{-1})	Intensity (cm, for 296K)
1327.074219	9.631E-20
1327.409783	5.781E-20
1332.546743	5.732E-20

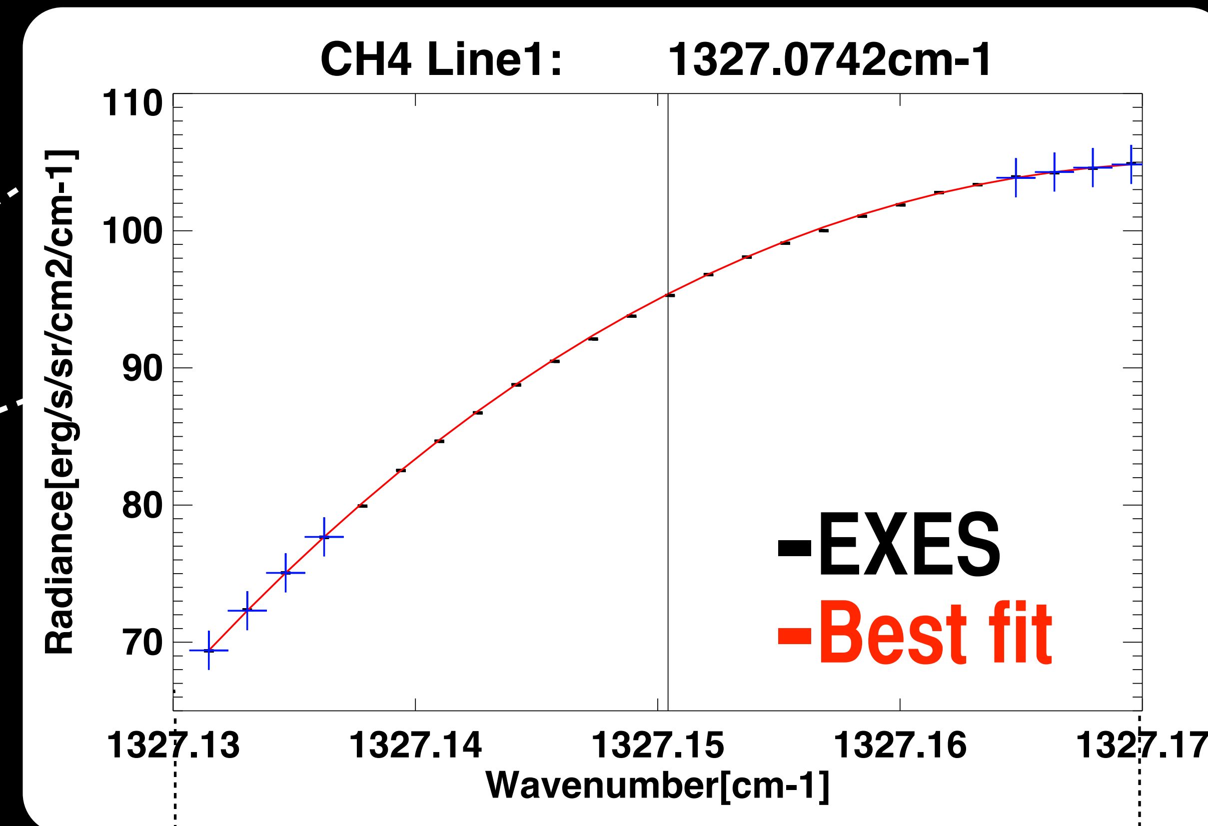
- ✓ Spectral resolving power is ~90,000.
- ✓ 17 different orders, covering at 1326 – 1338 cm^{-1}
- ✓ CH_4, H_2O, HDO, and CO_2 (627/628/638) lines
- ✓"Safe" three CH_4 lines have been analyzed.
- ✓15 pixels (~3") along the slit (to increase the SNR) are binned over. As a consequence, 3 (or 2) averaged spectra are obtained for each slit position.
- ✓ The averaged spectra are compared with synthetic spectra calculated by radiative transfer model

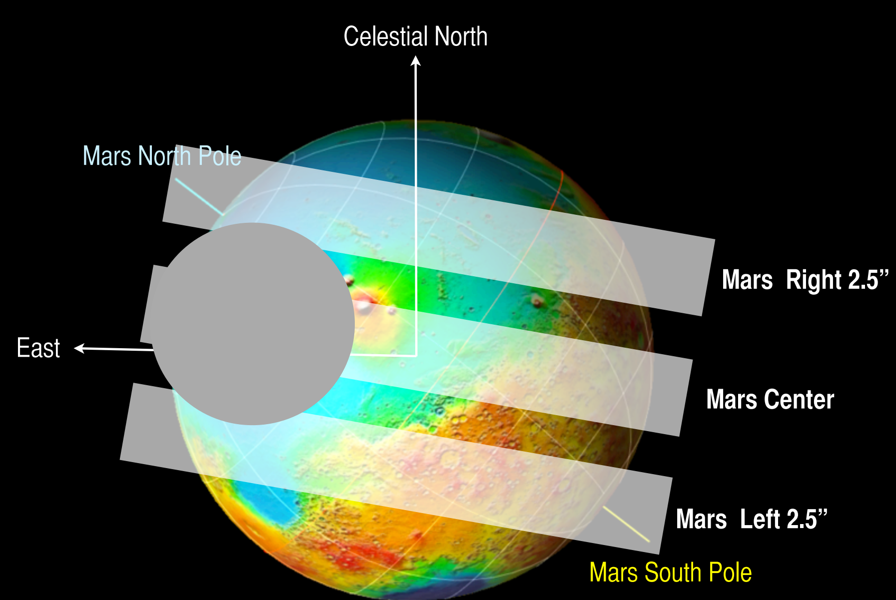


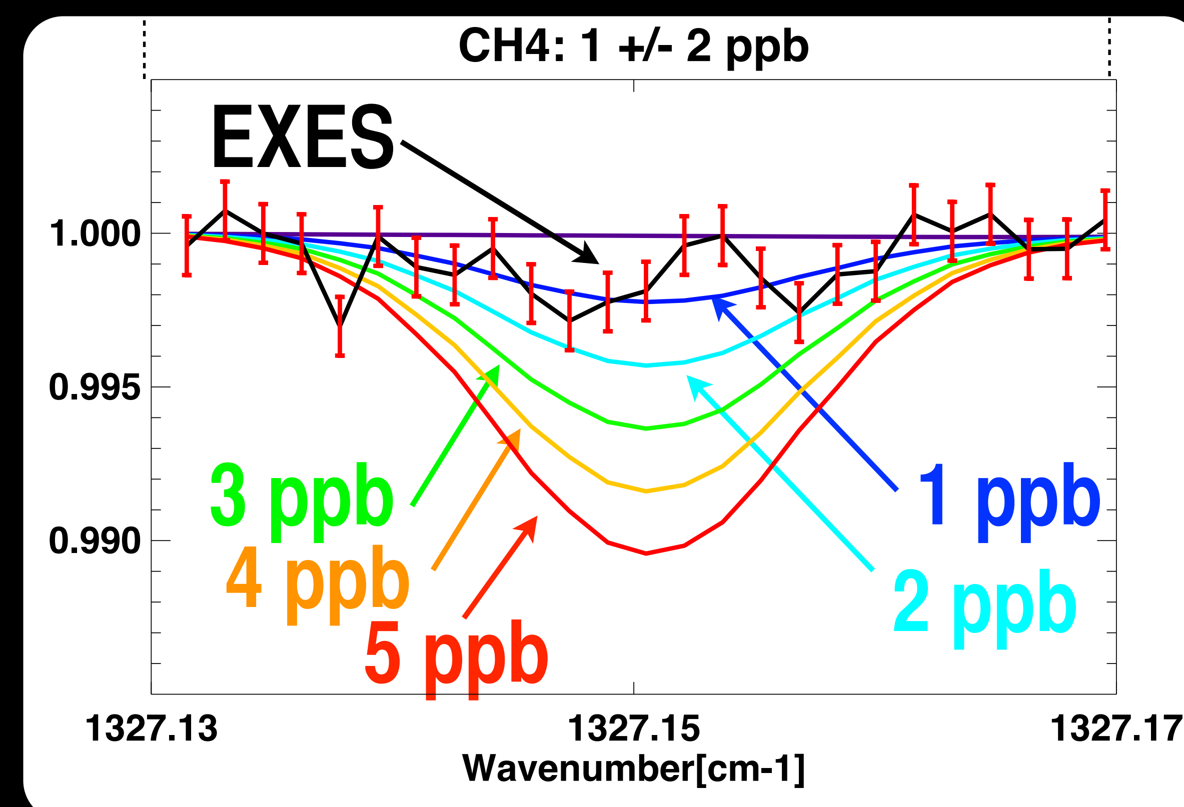


Results on 16/03/2016 data (Ls=123.2°)

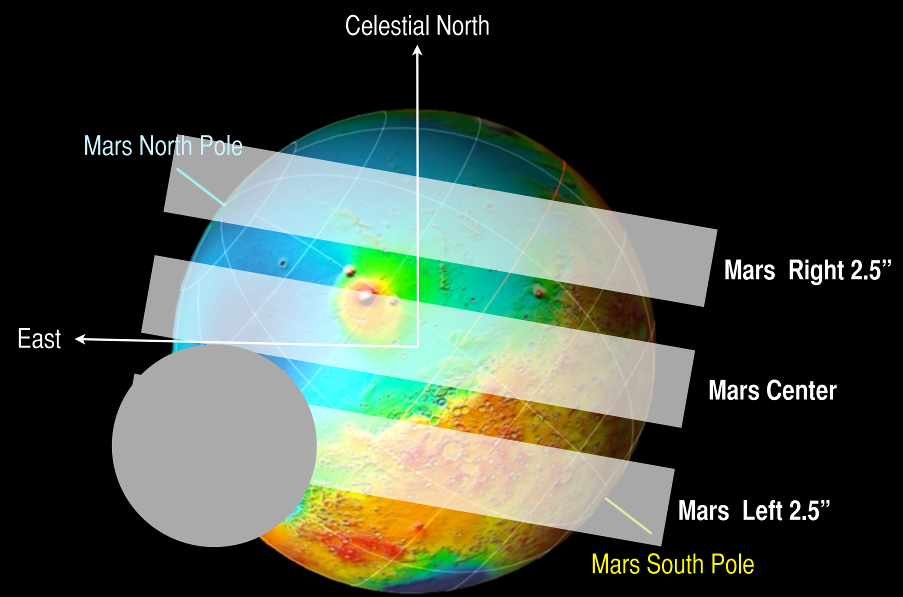




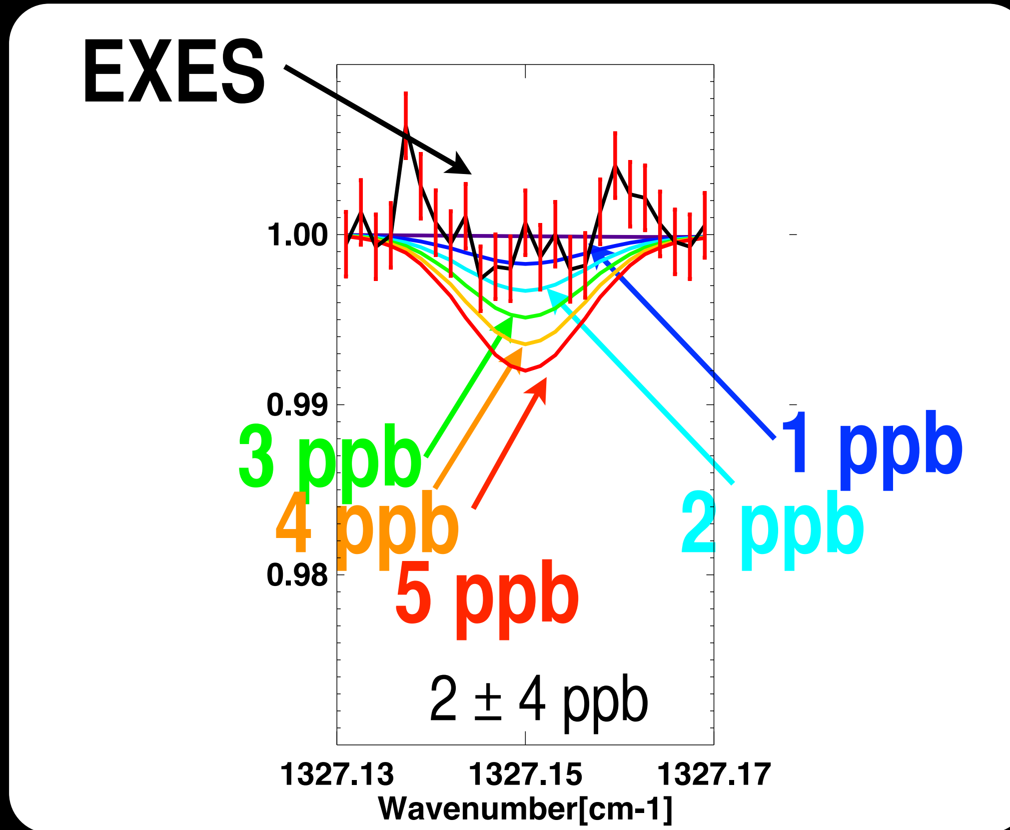


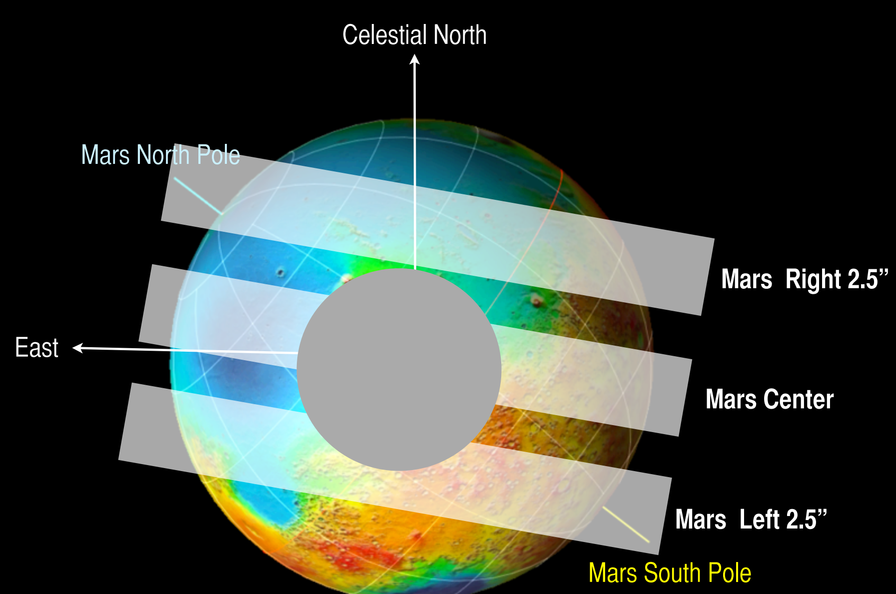


Results on 16/03/2016 data (Ls=123.2°)

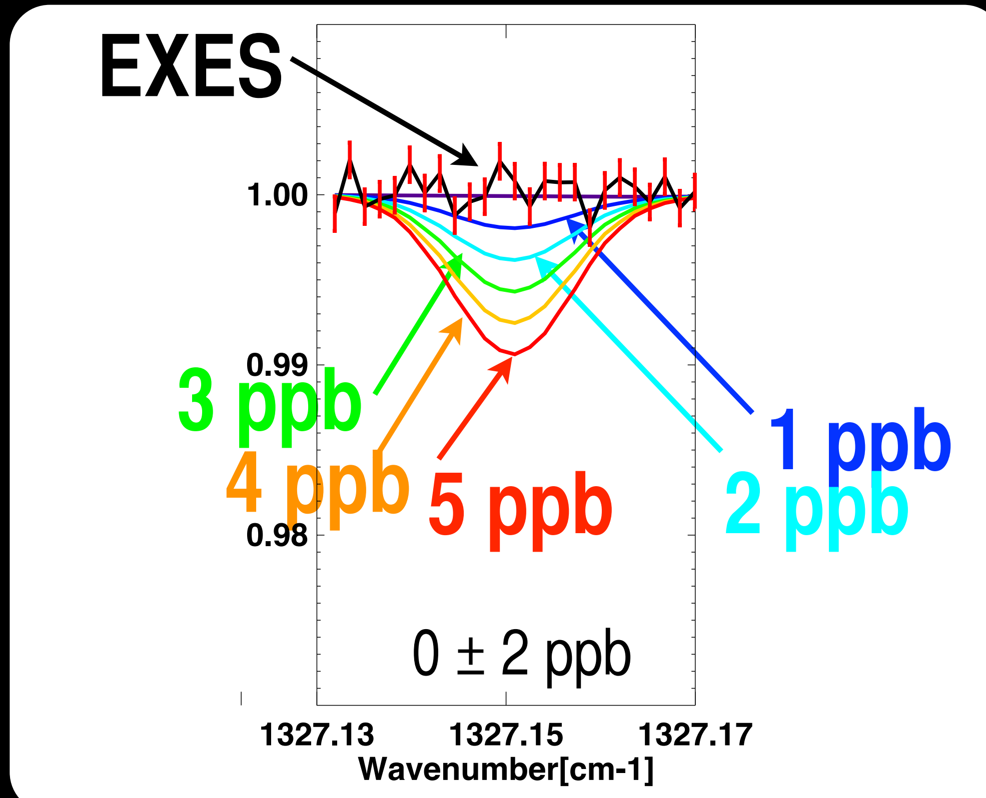


Including Nili Fossae / Syrtis Major (50%)
where Momma (2009) detected 40 ppb
at the same season but different MY



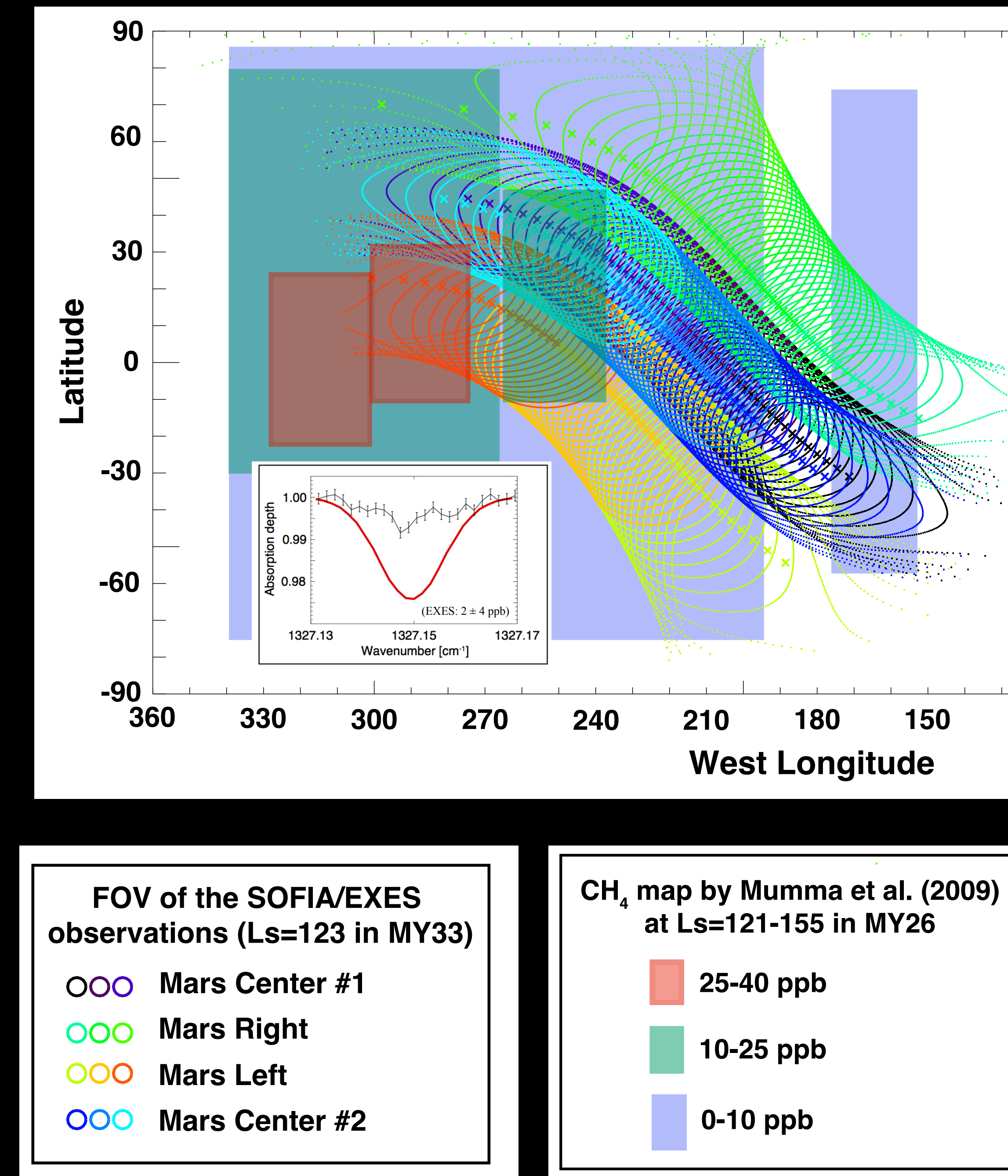


Including Gale crater where
Curiosity/TLS has been measuring CH_4



Results on 16/03/2016 data (Ls=123.2°)

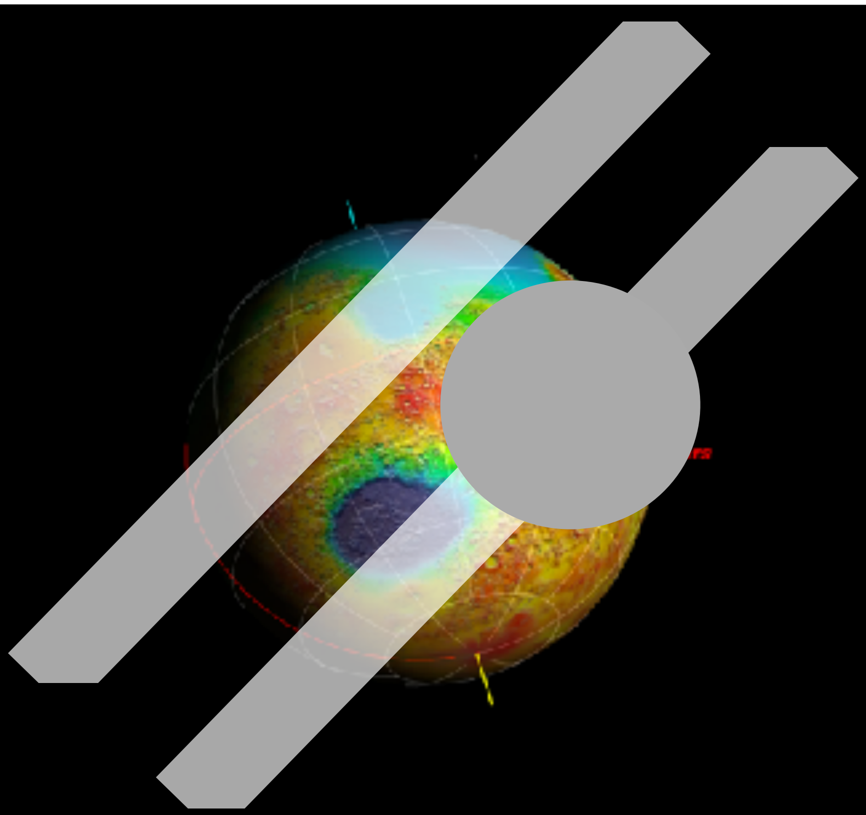
Slit position	Lat	ELon	LT	CH_4 VMR (3σ)
Mars center #1	-17	179	16	**2 ± 3 ppb**
Mars center #1	13	149	14	**1 ± 1 ppb**
Mars center #1	40	113	12	**1 ± 2 ppb**
Mars Left 2.5"	-41	153	15	**1 ± 5 ppb**
Mars Left 2.5"	-8	121	13	**0 ± 3 ppb**
Mars Left 2.5"	13	88	11	**1 ± 2 ppb**
Mars Right 2.5"	0	195	18	**3 ± 6 ppb**
Mars Right 2.5"	30	173	16	**0 ± 2 ppb**
Mars Right 2.5"	56	128	13	**0 ± 1 ppb**
Mars center #2	-17	172	16	**1 ± 4 ppb**
Mars center #2	13	143	14	**0 ± 1 ppb**
Mars center #2	40	107	12	**0 ± 2 ppb**



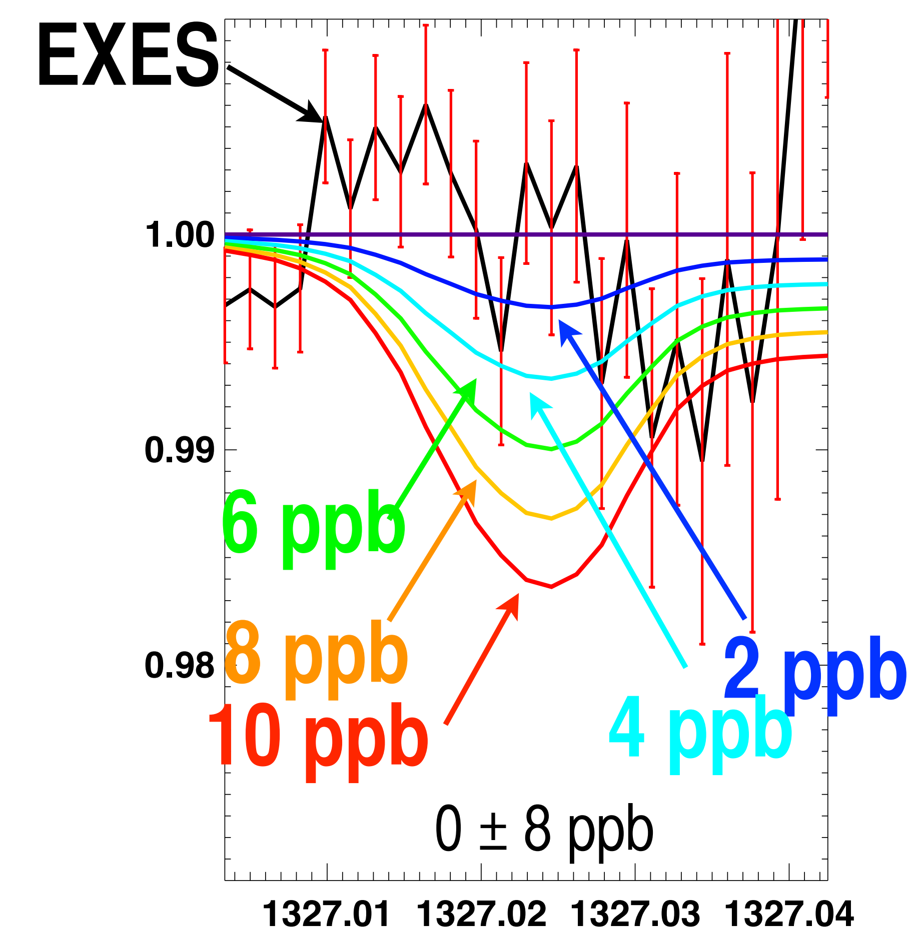
(Aoki et al., 2018 A&A, accepted)

There are NO definitive detections of CH_4 (Upper limits are 1–9 ppb), which is significantly less than detections in several other studies.

Results on 25/01/2017 data (Ls=305.2°)



Including Terra Sabae
where Momma (2009) detected 40 ppb



Slit position	Lat	ELon	LT	CH_4 VMR (3σ)	Note
Mars Left 1”	-3	33	11	**0 ± 7 ppb**	Terra Sabae
Mars Left 1”	-67	24	10	**2 ± 8 ppb**	
Mars Right 1”	4	341	8	**1 ± 11 ppb**	
Mars Right 1”	-39	306	5	**0 ± 13 ppb**	

From the 2017 January data, there are also NO definitive detections of CH_4 (Upper limits are 7–14 ppb)

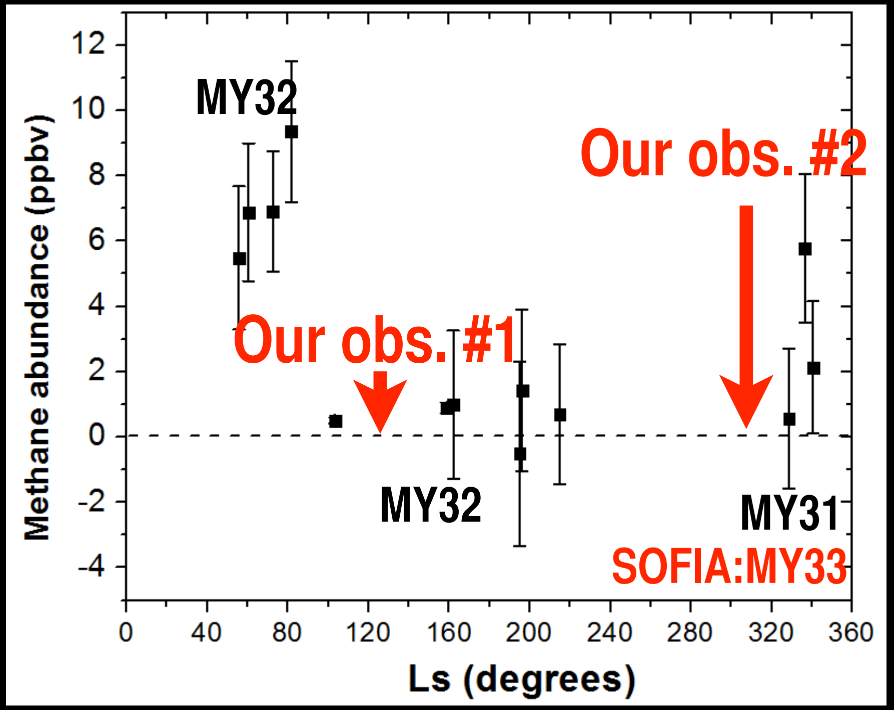
Summary, discussions, and future prospectives

- We don't detect CH_4 by SOFIA/EXES, which is probably most accurate remote sensing facility spectroscopically.
  - Spatial resolution is poor

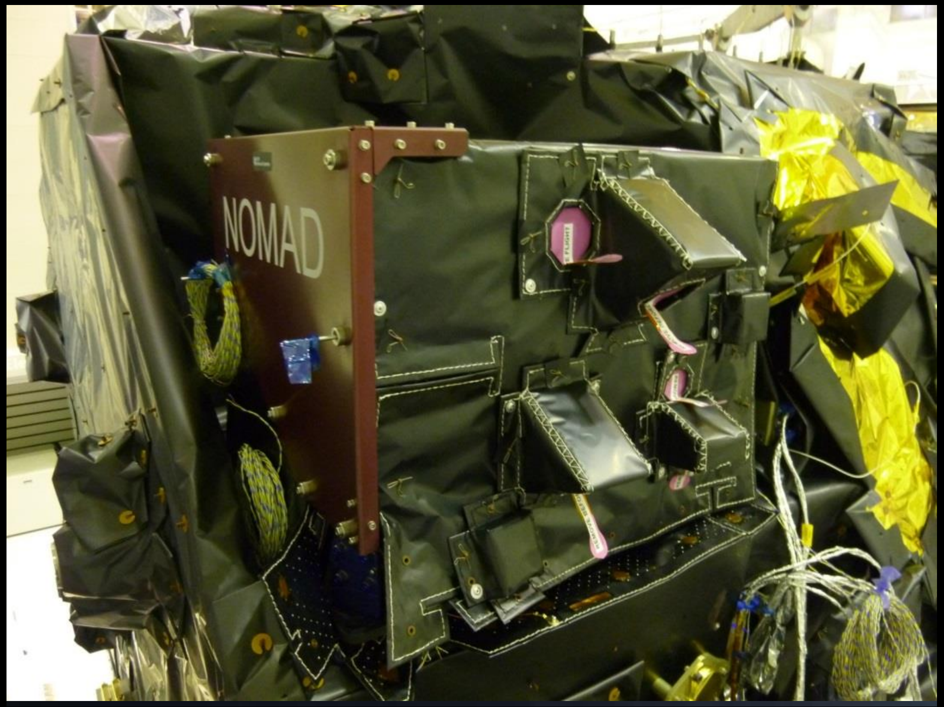
    → localized spatial distribution ?
  - Only two dates observations

    → strong temporal variation similar to what TLS has been measuring ?
- We will continue to monitor CH_4 by SOFIA/EXES (April). NOMAD&ACS will perform sensitive measurements from Trace Gas Orbiter (2018 Spring~).

CH_4 VMR over Gale Crater by TLS



(Webster+2015)



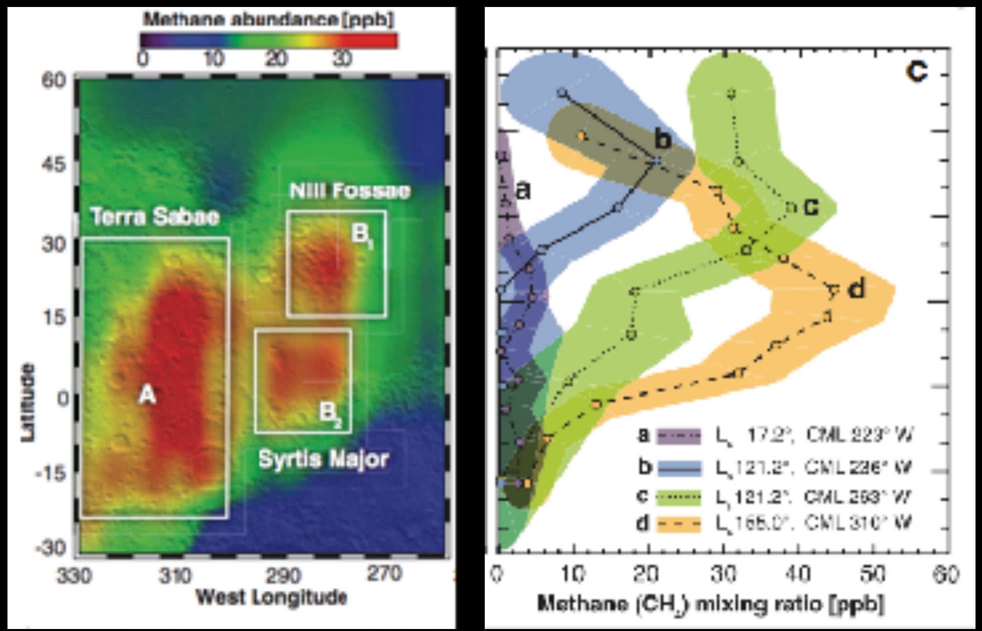
Previous remote-sensing observations

Ground-based telescopes

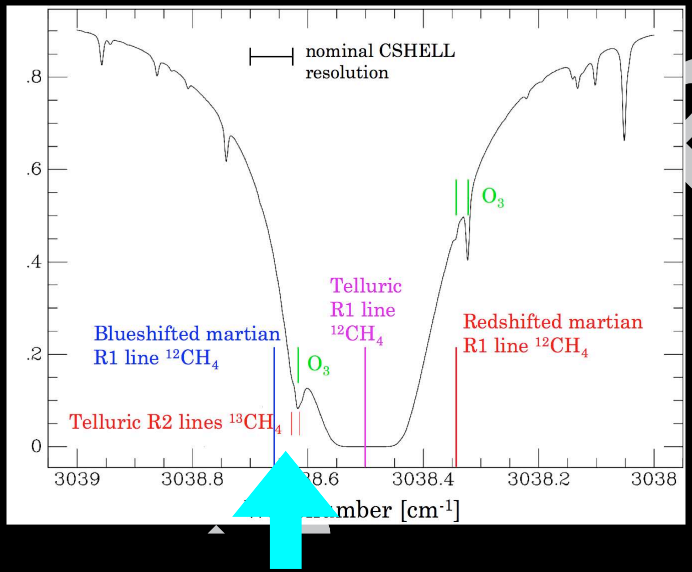
(Mumma+2009; Krasnopolsky 2012, Villanueva+2013)

✓ Detect CH_4 sporadically: 0 – 45 ppb

✓ Careful analysis to distinguish tiny Martian CH_4 line from terrestrial lines is necessary



(Mumma+2009)

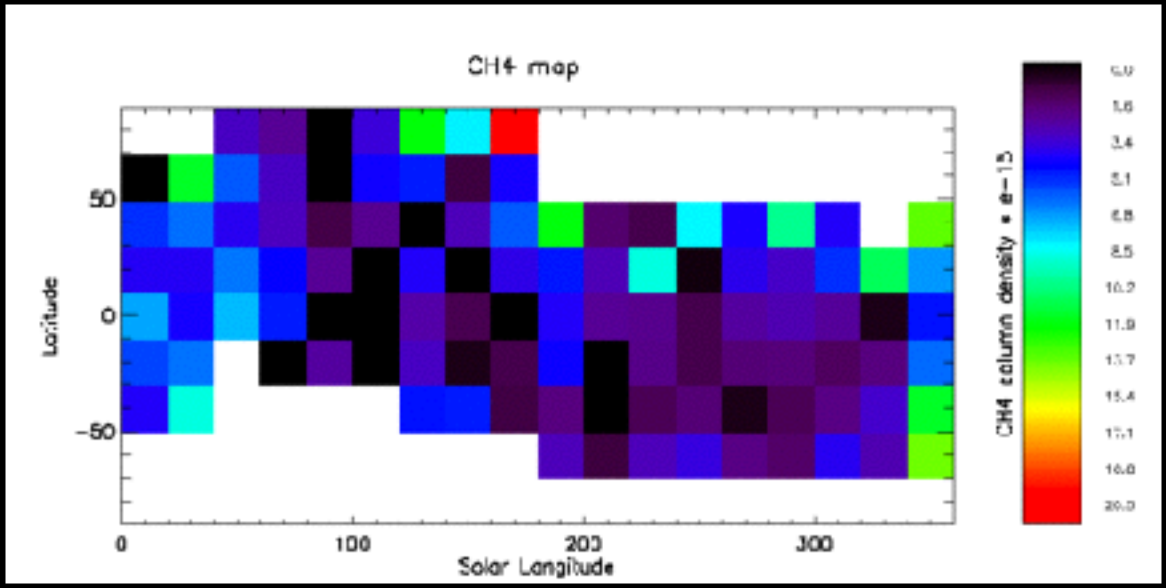


(Zahnle+2011)

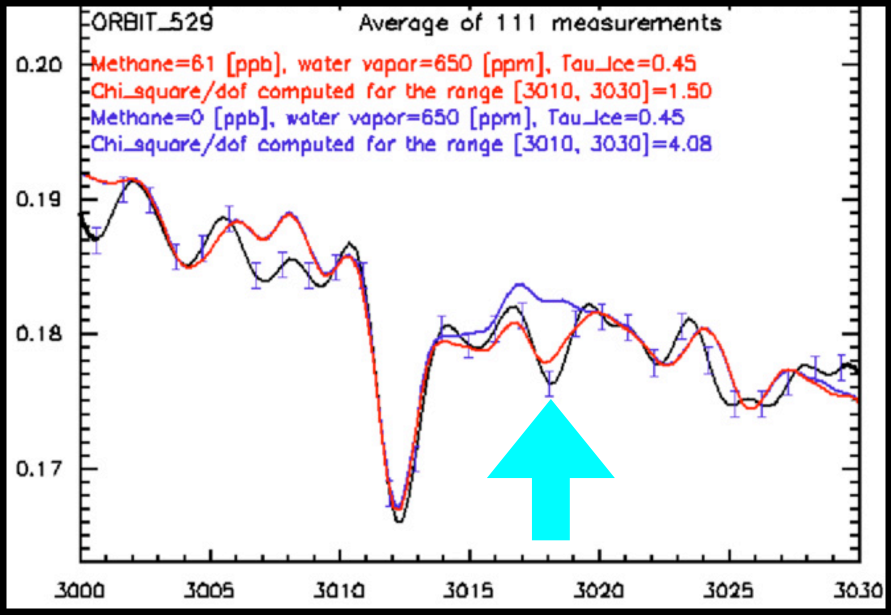
MEx/PFS (Geminale+2008; Geminale+2011)

✓ Seasonal Map: 0 – 60 ppb

✓ Spectral resolution is not enough for firm detection



(Geminale+2011)

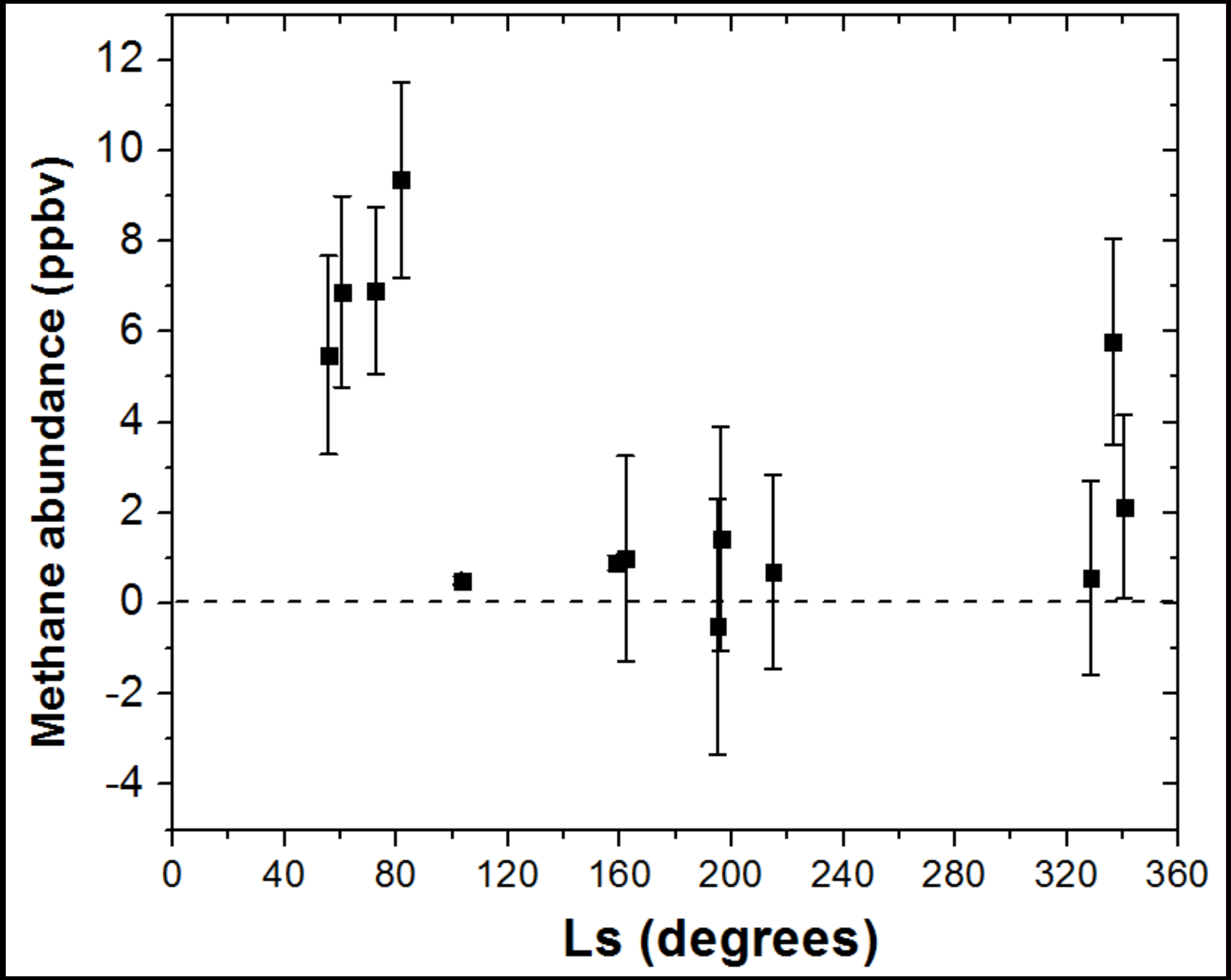


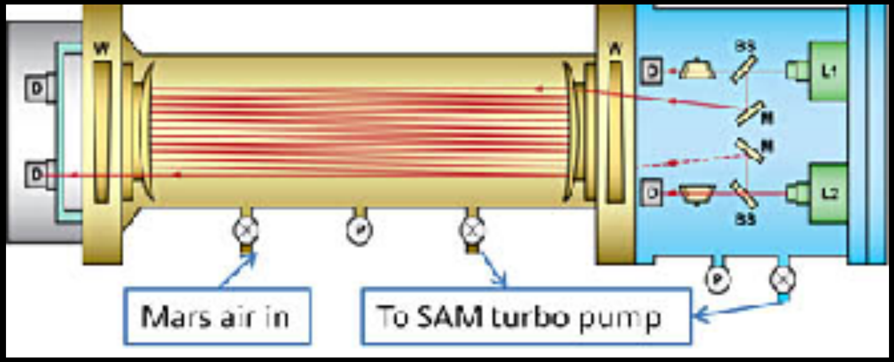
(Geminale+2008)

Much debate on the reliability of the previous remote sensing

Curiosity/TLS measurements

✓ Curiosity/TLS detected CH_4 signal and showed strong variability (0–9 ppb)





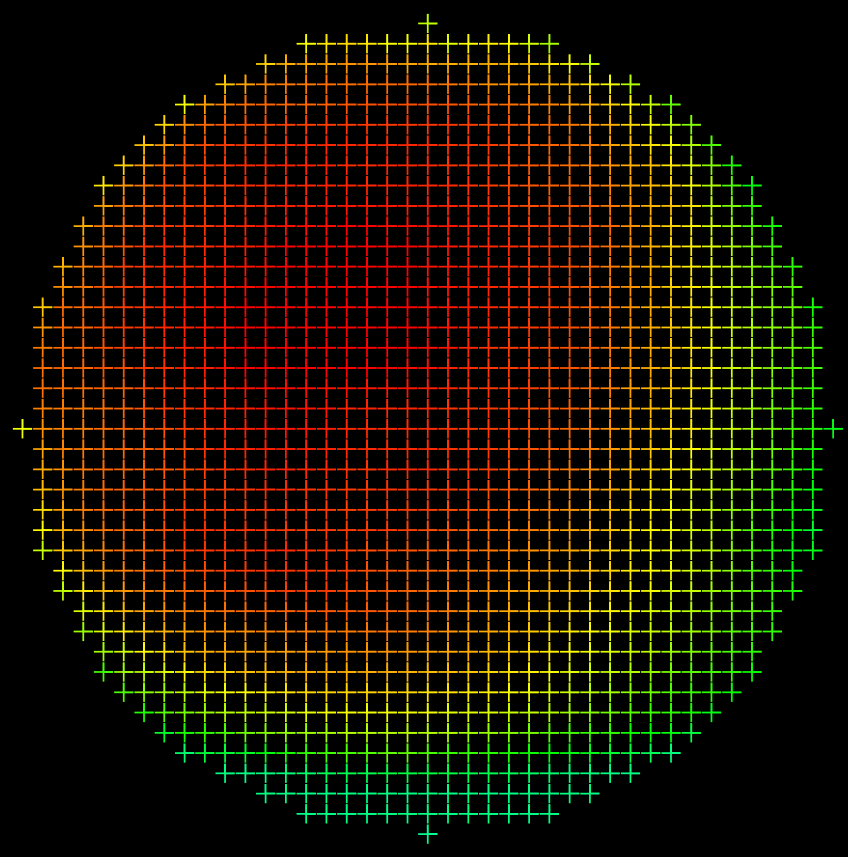
(Webster et al., 2015)

However, Since TLS can measure CH_4 variations only in the Gale Crater, sensitive remote-sensing observations is still important to search for the source.

Synthetic spectra (1/2)

(i) Observing geometry and orbital parameters are obtained using NASA-JPL ephemeris generator (Horizons)

(ii) Atmospheric parameters (surface pressure, temperature and 80 layers, dust, water ice) over the Martian disc (0.25” resolution) are computed for the observational period using the Mars Climate database ver 5.2 (Forget et al., 1999).



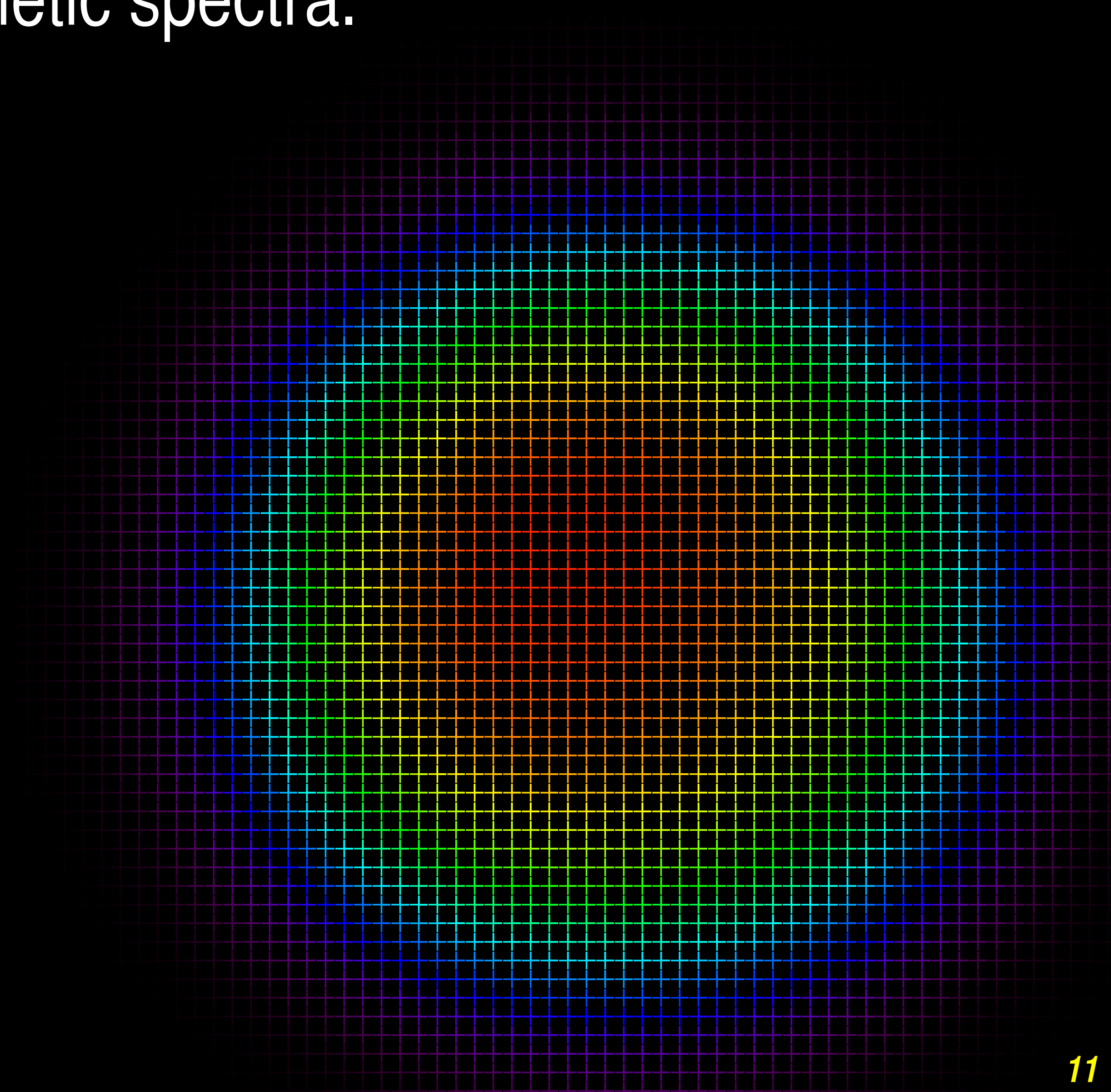
Synthetic spectra (2/2)

(iii) Synthetic spectra over the Mars disc (0.25” resolution) are calculated by line-by-line radiative transfer model including multiple scattering of aerosols (Ignatiev et al., 2005).

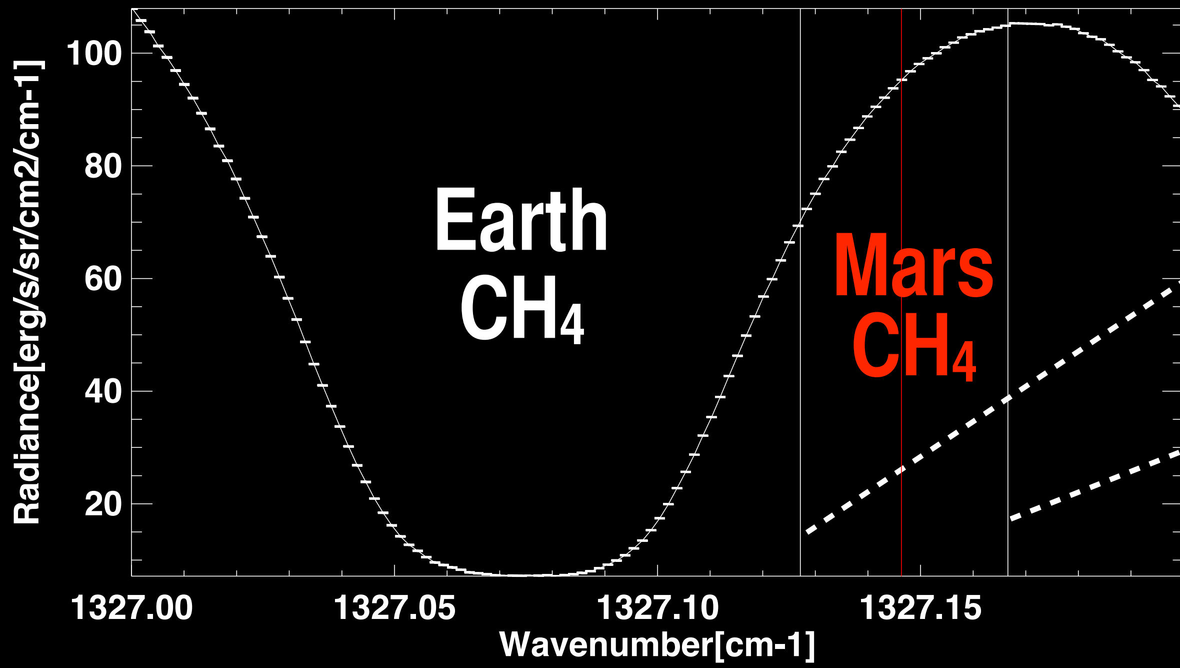
(iv) Spatial resolution of the observations is taken into account. Here, 2D Gaussian with 3” FWHM is applied to the synthetic spectra.

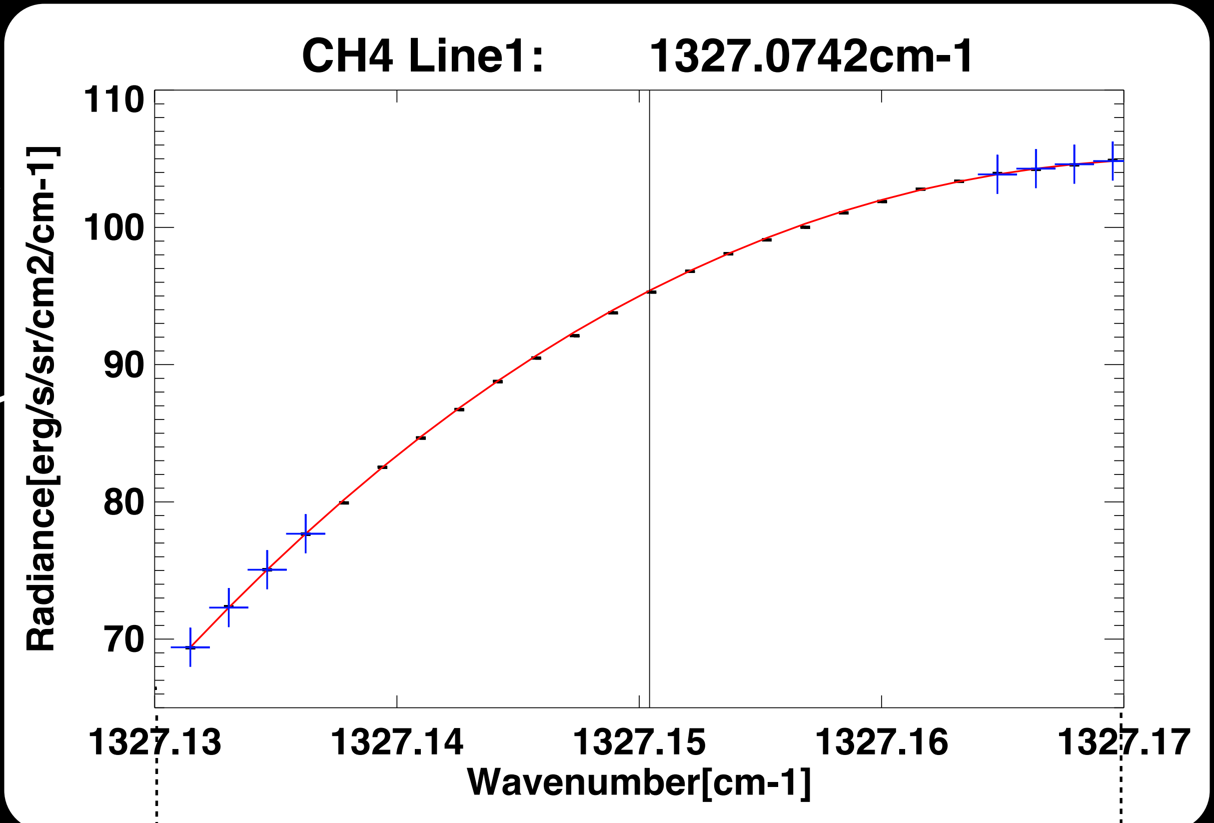
(v) The synthetic spectra over expected slit position are averaged to be compared with the measured spectra.

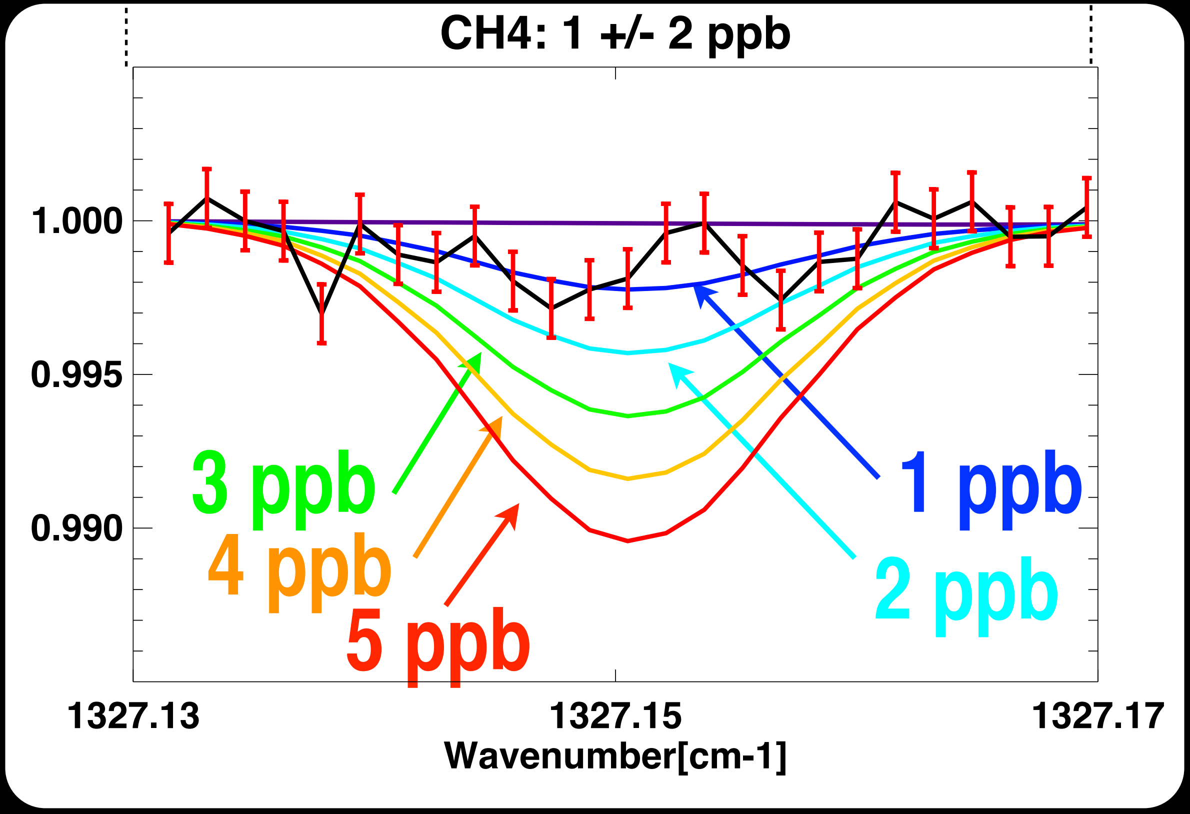
(vi) The synthetic spectra are convolved with a gaussian function which corresponds to the spectral resolution of EXES (R=90,000).



Data analysis

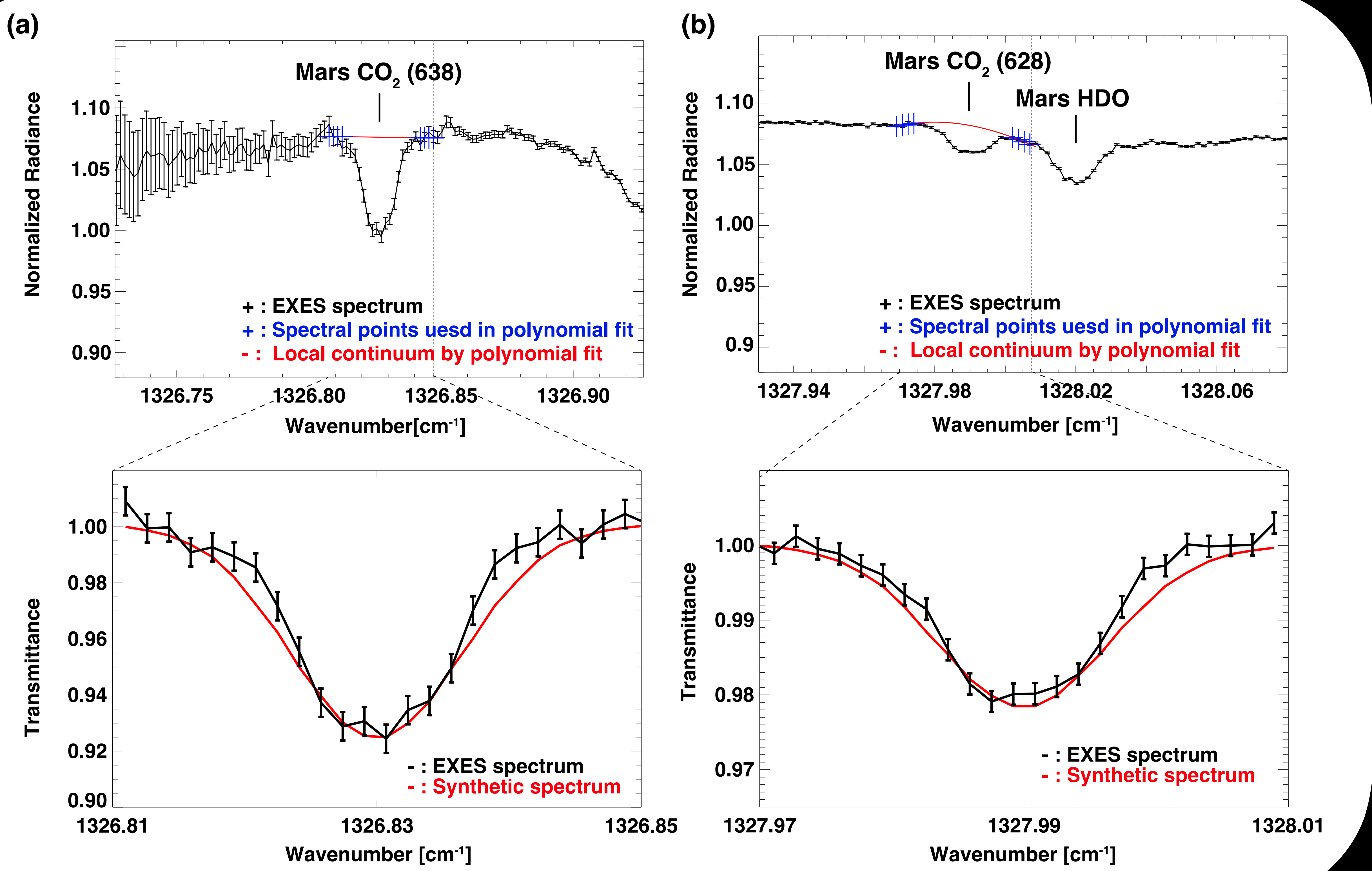






- ✓ Martian CH_4 features are extracted by establishing local continuum via Cubic polynomial fitting.
- ✓ The averaged spectra are fitted with cubic polynomials for the spectral intervals of 25 points without 17 center points, where the Martian lines are expected.
- ✓ Comparison with synthetic spectra calculated by RT model (with scattering)

Validation of the method using CO2 line



Error estimation

1. **EXES観測スペクトル模擬:** Calculate transmittance of earth atmosphere considering US-standard atmosphere (above 14 km), airmass of the observation, and spectral resolution and sampling of EXES.

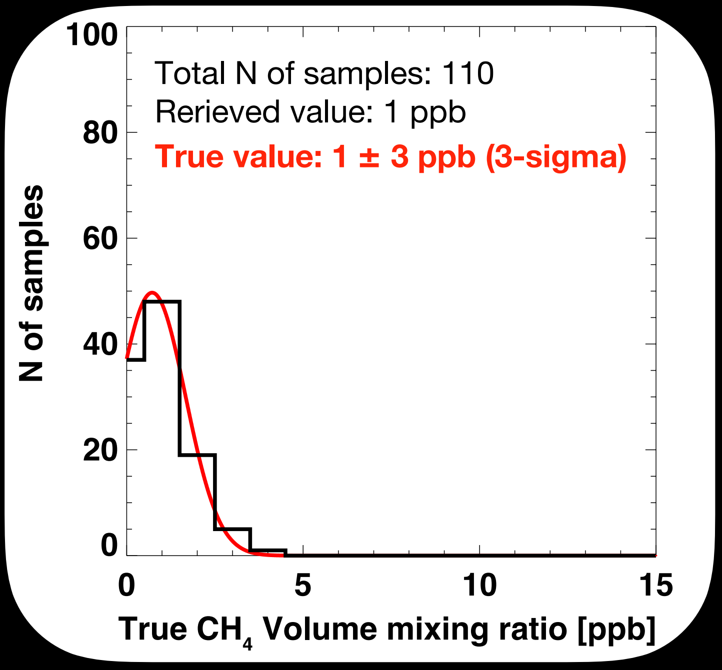
2. **ノイズ注入**: Input noise to the synthetic spectra.

- the noise values are defined as [standard deviations of cubic polynomial fit to establish local continuum] times [random number (following gaussian distribution, sigma=1)].
- total of 100 different "seed" values to initialize the random number are used (i.e., we have different 100 spectra in total).

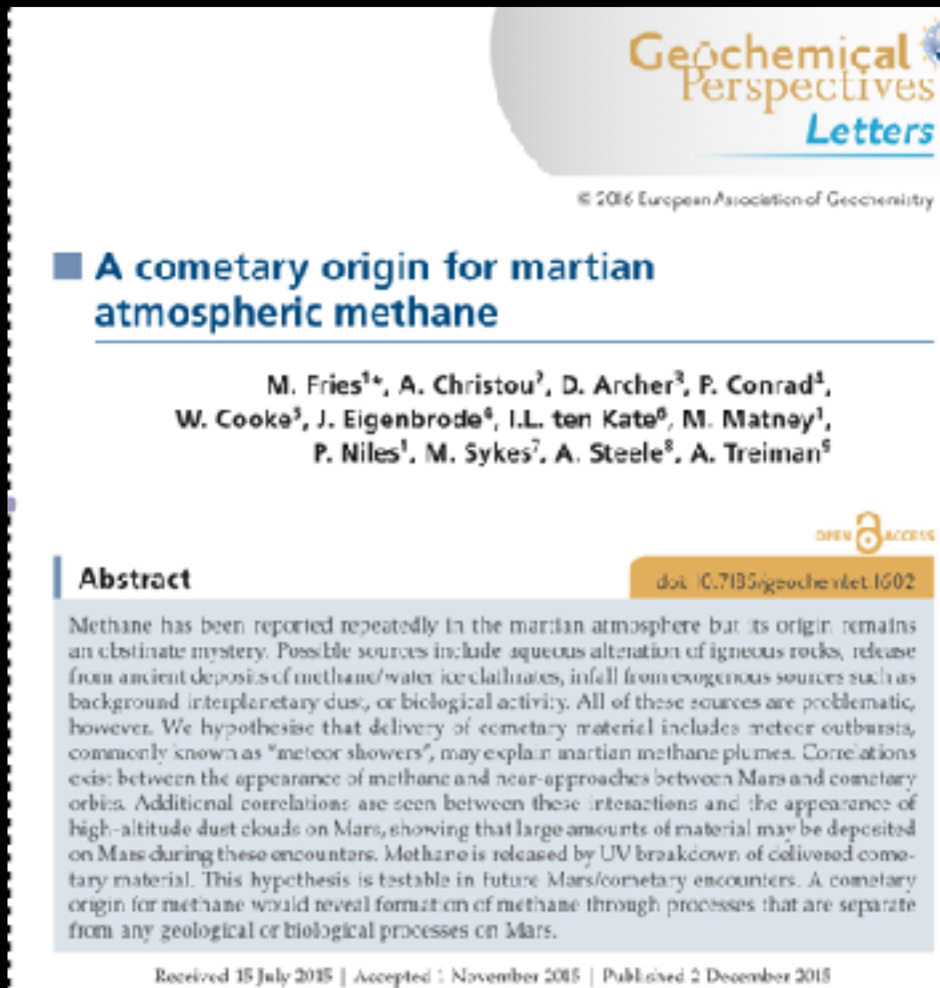
3. **メタン注入:** Input the Martian CH4 absorption to the synthetic spectra (CH4 volume mixing ratio from 0 to 30 ppb with intervals of 1 ppb) at the expected spectral position.(i.e., we have 100 x 31 = 3100 simulated spectra in the end)

4. **観測模擬スペクトルでリトリーバル, 真値-リトリーバル値のdatabase構築:** Apply current algorithm to the simulated EXES spectra and retrieve CH4 mixing ratio.
In this way, a "database" between retrieved and true values can be built. Based on this "database", uncertainty of the retrieval can be discussed.

5. **実際のリトリーバル値とdatabaseから, 誤差導出:** By comparing the retrieved value of the CH4 mixing ratio from EXES data and "database", the true CH4 mixing ratio and uncertainty is obtained.



Is origin Meteor shower ?



Geochemical Perspectives Letters

A cometary origin for martian atmospheric methane

M. Fries[1*], A. Christou[2], D. Archer[3], P. Conrad[4], W. Cooke[5], J. Eigenbrode[4], I.L. ten Kate[6], M. Matney[1], P. Niles[1], M. Sykes[7], A. Steele[8], A. Treiman[5]

doi: 10.7185/geochemlet.1602

Abstract

Methane has been reported repeatedly in the martian atmosphere but its origin remains an obstinate mystery. Possible sources include aqueous alteration of igneous rocks, release from ancient deposits of methane/water ice clathrates, infall from exogenous sources such as background interplanetary dust, or biological activity. All of these sources are problematic, however. We hypothesise that delivery of cometary material includes meteor outbursts, commonly known as "meteor showers", may explain martian methane plumes. Correlations exist between the appearance of methane and near-approaches between Mars and cometary orbits. Additional correlations are seen between these interactions and the appearance of high-altitude dust clouds on Mars, showing that large amounts of material may be deposited on Mars during these encounters. Methane is released by UV breakdown of delivered cometary material. This hypothesis is testable in future Mars/cometary encounters. A cometary origin for methane would reveal formation of methane through processes that are separate from any geological or biological processes on Mars.

Received 15 July 2015 | Accepted 1 November 2015 | Published 2 December 2015

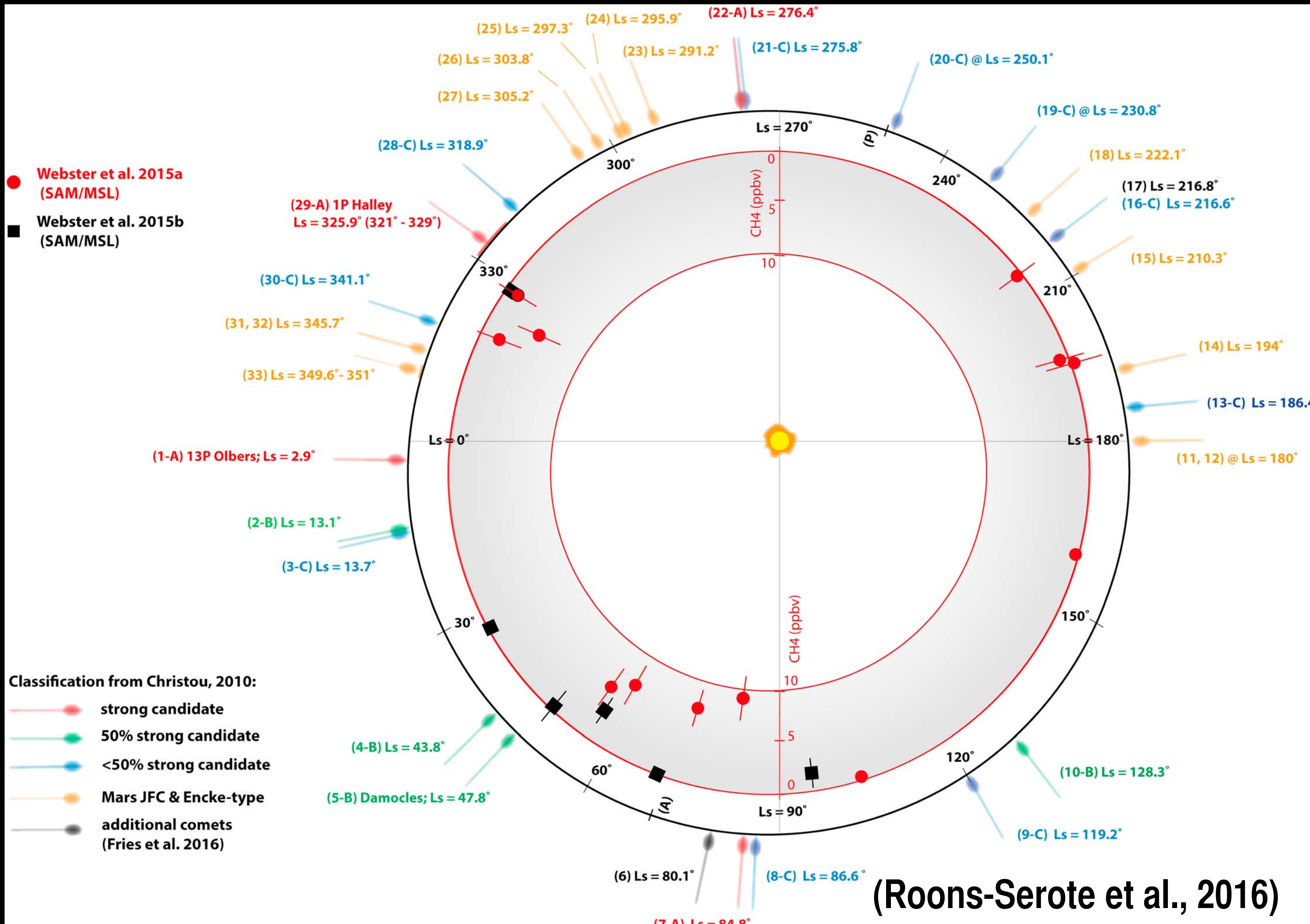
(Fries et al., 2016)

• Every detection of methane was made within 16 days of the proposed date of a martian meteor shower.

• Carbonaceous material is deposited into the martian atmosphere in meteor showers, which is disaggregated to expose new surface area. The ambient UV then generates methane from the carbonaceous material.

• One of the biggest was reported by Mumma et al, and it turns out that methane plume was measured only a couple of days after a Mars encounter with the orbit of comet C/2007 H2 Skiff. We found that comet Skiff would encounter Mars again around 08 Mar 2016, during the time period we were searching for methane with SOFIA.

Discussion



(Roons-Serote et al., 2016)

Curiosity/TLSの最新結果も流星起源説を支持しない.