Methane

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Surface Processes and Methane Panel Discussion
Planetary Science Decadal Survey
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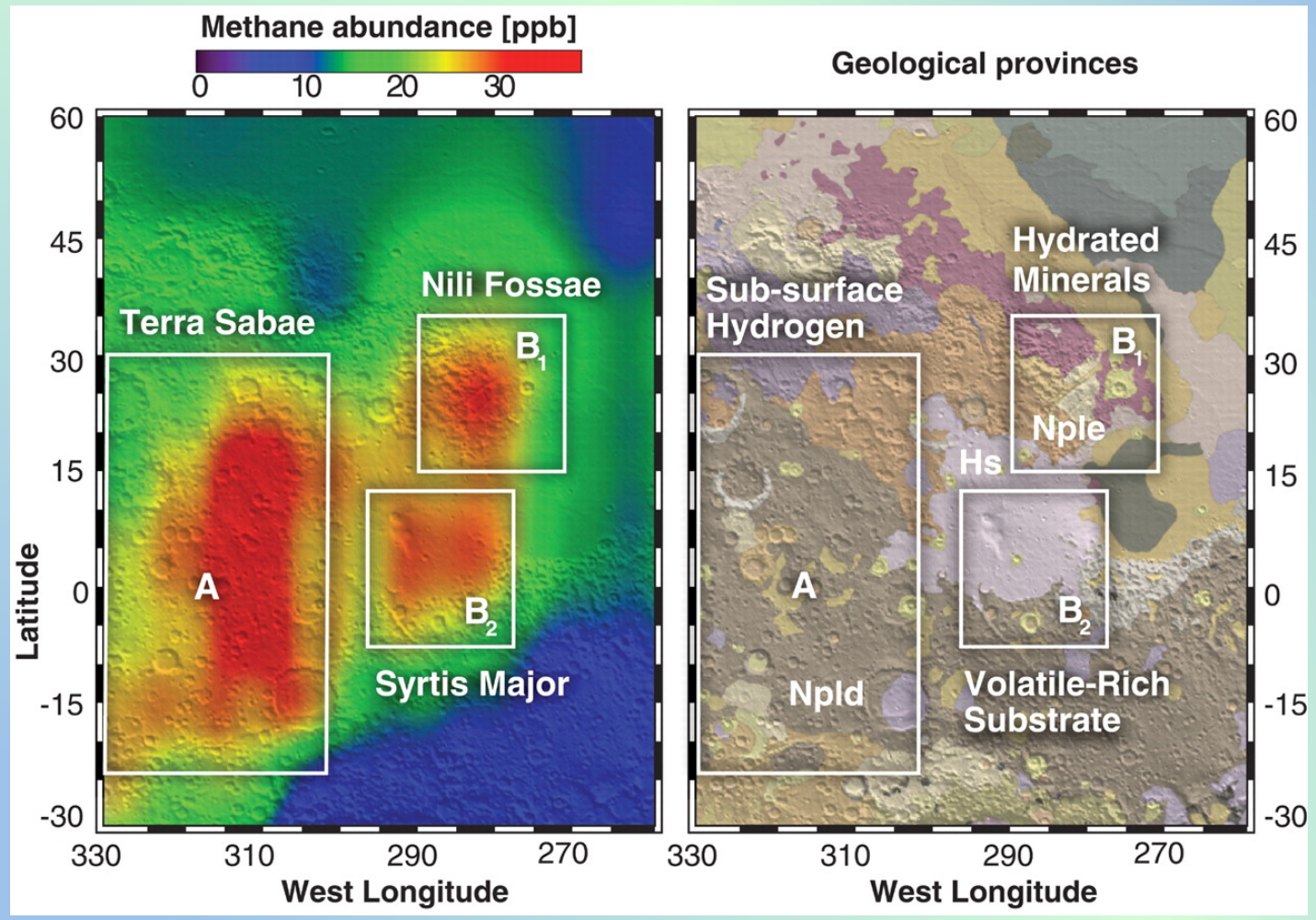
map

- Methane, a potential signature of
  - Microbial life on Mars, past or present, or
  - Water-rock reactions (serpentinization), or
  - Both of the above
- Pre-MSL search for methane (remote sensing)
- MSL observations (in situ)
- TGO-MSL discrepancy, and possible ways of reconciling it
- What next?

Pre-MSL Methane Observations

10-15 ppbv global, 3-60 ppbv localized, Plumes, Transient

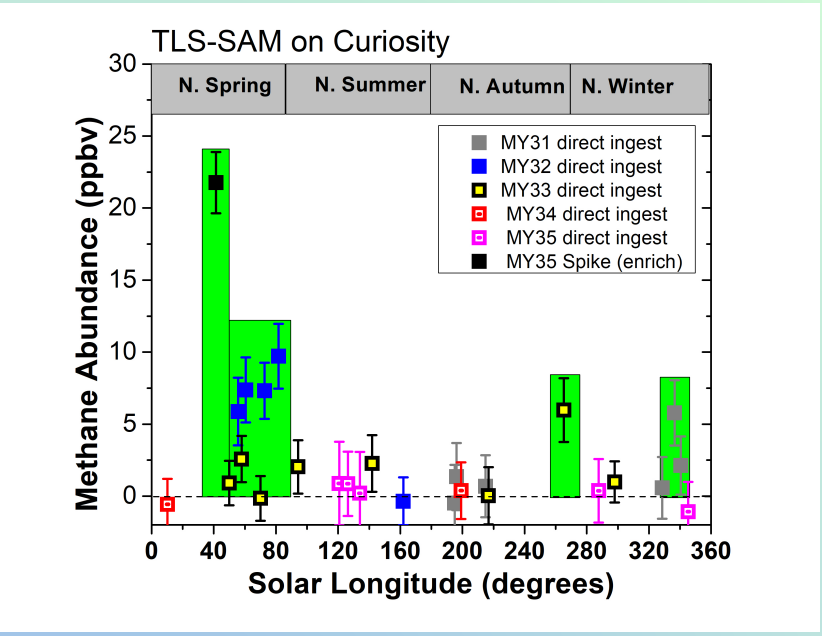


[Mumma et al. 2009]

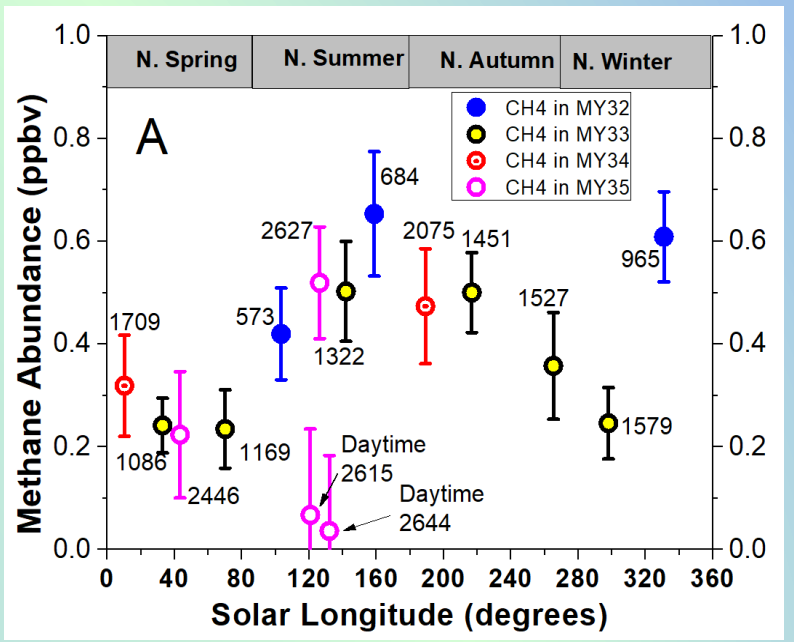
- 1999/CFHT/R=180,000: 10±3 ppbv, hemispherical average (Krasnopolsky et al. 2004).
- 2003 & 2006/ IRTF & Keck-2/ R=spectrally resolved: Plumes 10-45 ppbv. Red-shifted spectra avoid 20x stronger terrestrial $^{13}CH_4$ but give only 3 ppbv (Mumma et al. 2009).
- 2004-2009/MEx-PFS/R=1500: 15 ppbv global, 25-61 ppbv localized (Formisano et al. 2004, Geminale et al. 2008, 2011).
- 2006/IRTF/R=40,000: 3-10 ppbv, and <8 ppbv in 2009 (Krasnopolsky 2012).

MSL Methane Observations, using SAM-TLS (Res. Pwr. 10^7)
Spikes, and Seasonally Varying Background

Spikes, up to 21 ppbv



Background 0.41 ±0.16 ppbv



- Occasional spikes of up to 21 ppbv indicate that Mars is currently geologically active.[(a)]
- Methane is always present at a low background level.
- CH4 background varies between 0.25 and 0.65 ppbv seasonally, and is repeatable from one MY to the next over the past 8 years.
- Seasonal variation was not expected for methane, which is a non condensible gas with a ~300-year photochemical equilibrium lifetime on Mars.

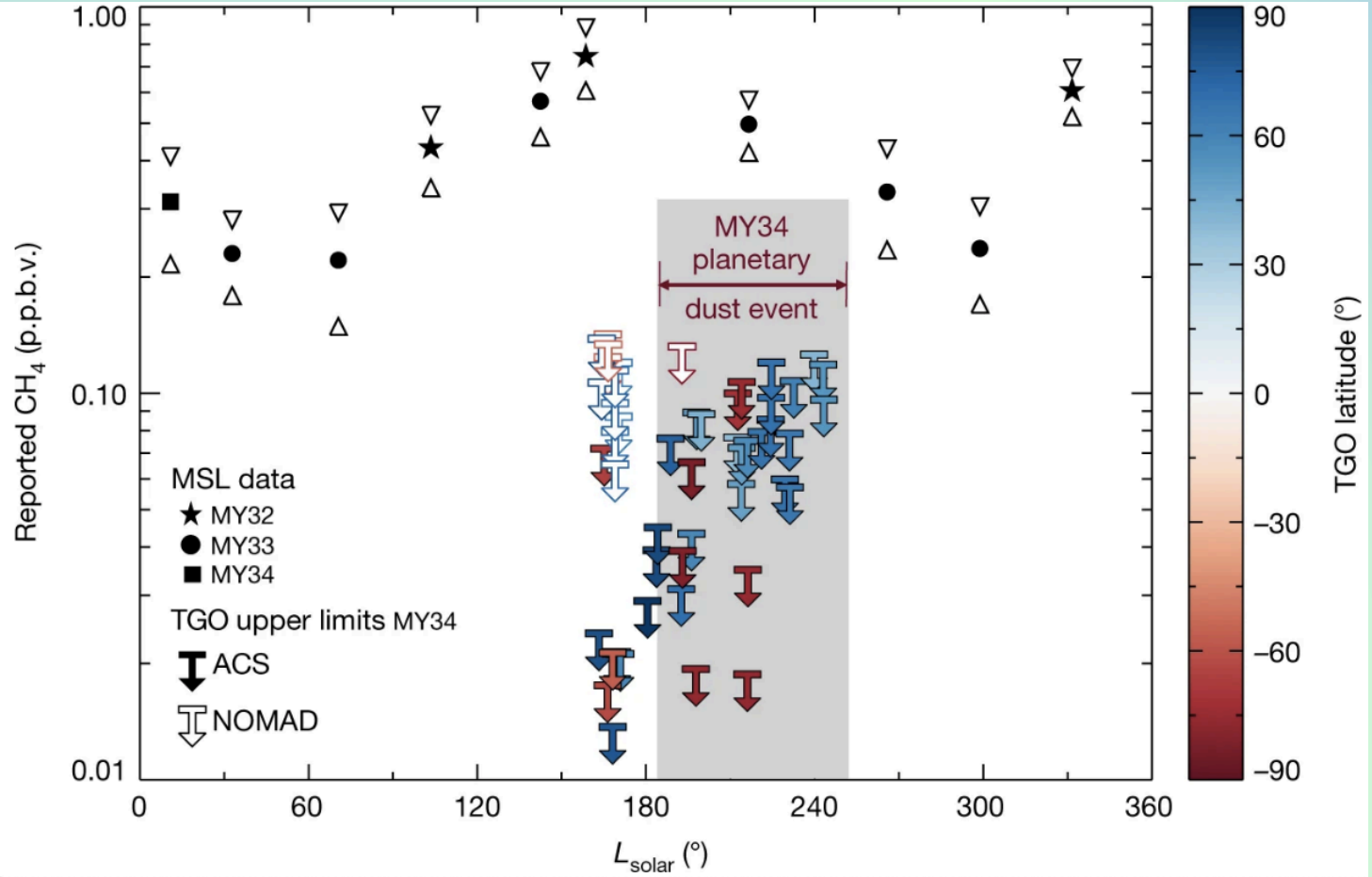
Pre-enrichment by a factor of 25 using SAM's quadrupole mass spectrometer enables TLS to detect the low seasonal background (right).

[Webster et al. Science 2015, 2018, 2020/submitted]

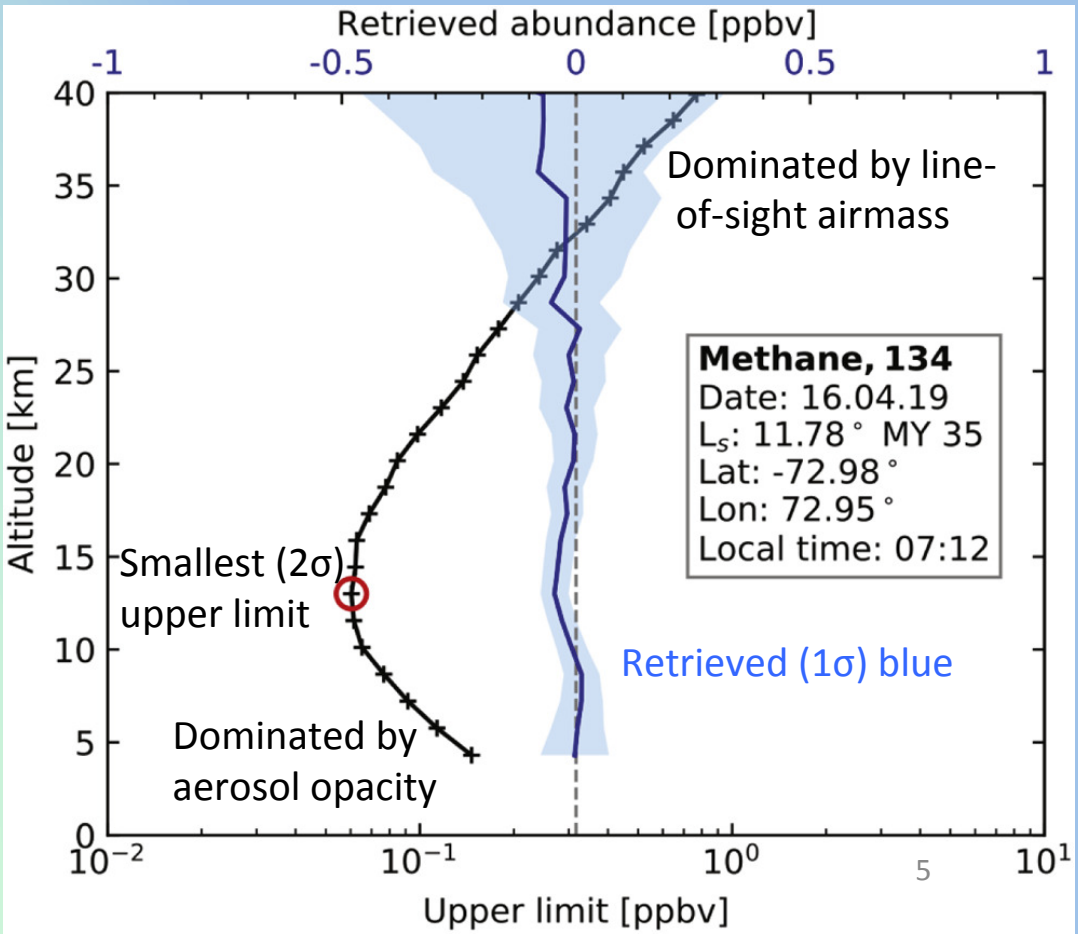
(a) 16 June 2013 (Ls 336, sol 306) spike confirmed by PFS in spot tracking mode, Giuranna et al. 2019)

TGO sees no methane
upper limit 0.06 ppbv, ~10 times smaller than TLS average bg

ACS and NOMAD (Korablev et al. 2018)

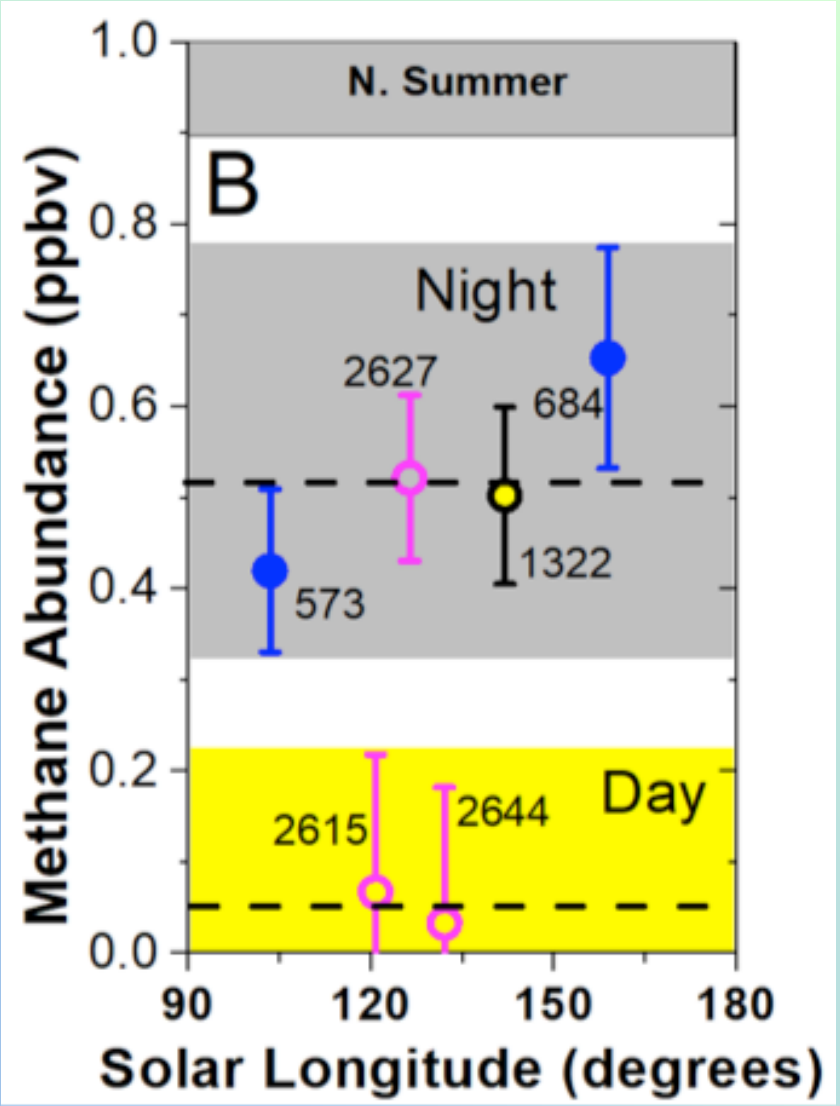


NOMAD 240,000 spectra (Knutsen et al. 2021)

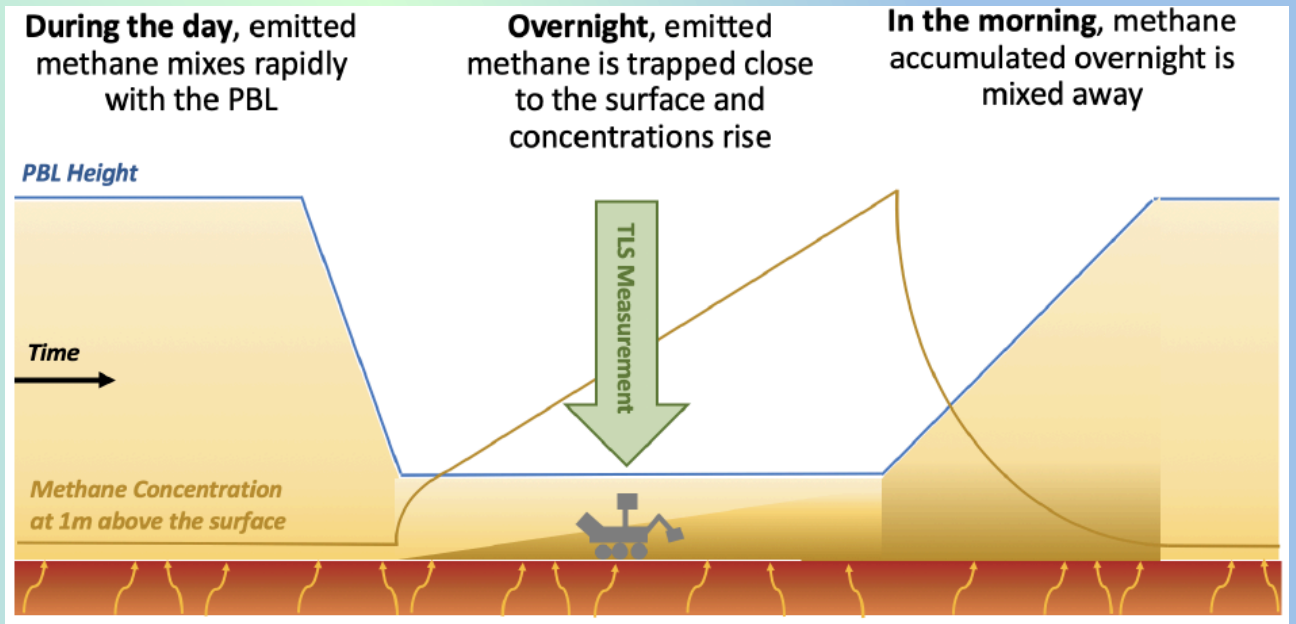


TGO-MSL discrepancy: comparing apples and oranges?

CH4 Diurnal Variation (TLS)

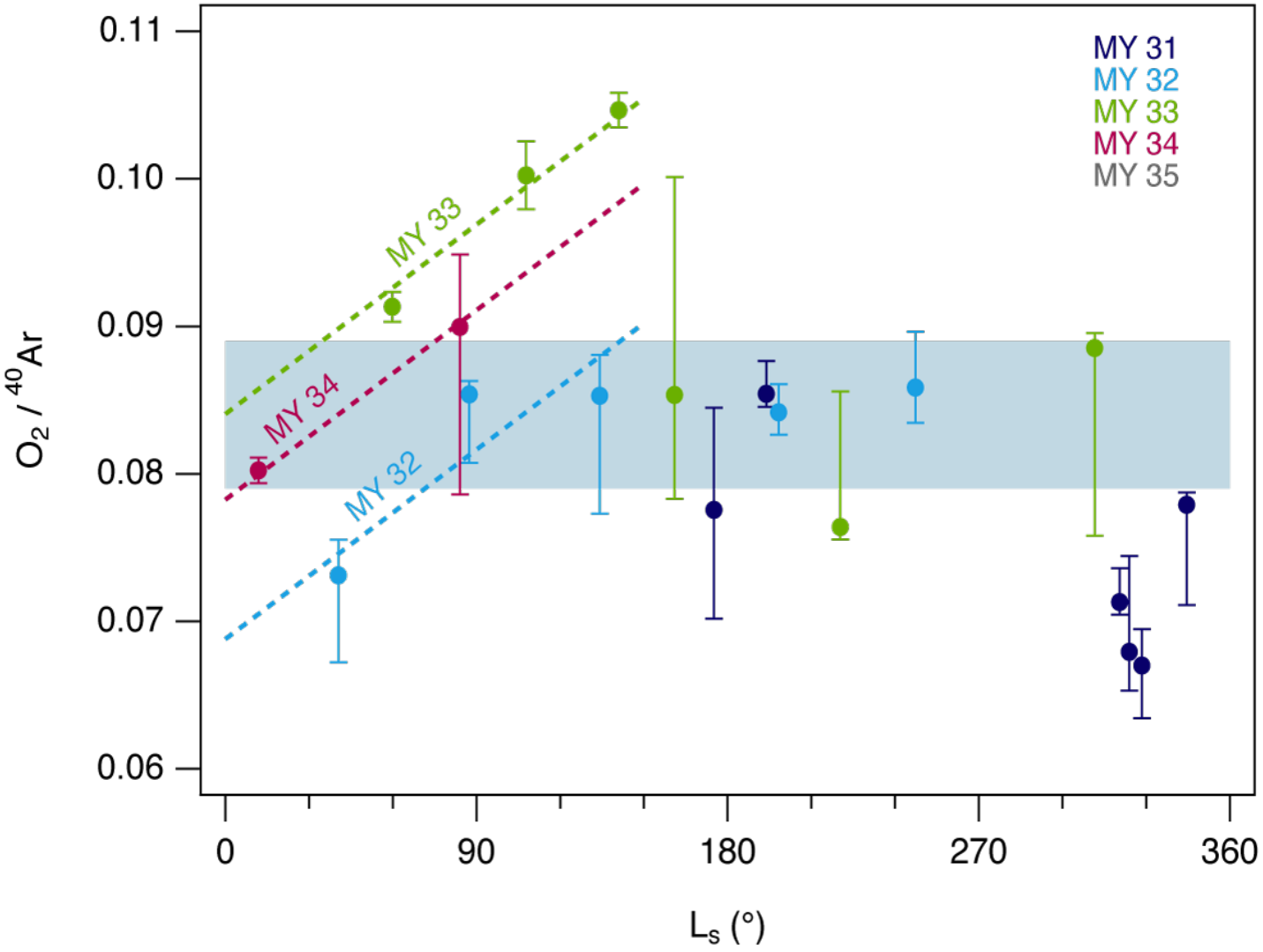


- MSL/SAM-TLS data taken *during night, at the surface*
- TGO solar occultations *done at dawn and dusk, above 6 km*
- CH_4 builds in the planetary boundary layer due to low mixing at night, and mixes away rapidly in the morning (Moores et al. 2019 a,b), but
- Fast destruction near the surface required, unless Gale Crater is the only source of methane, which is highly unlikely



PBL diurnal mixing effect

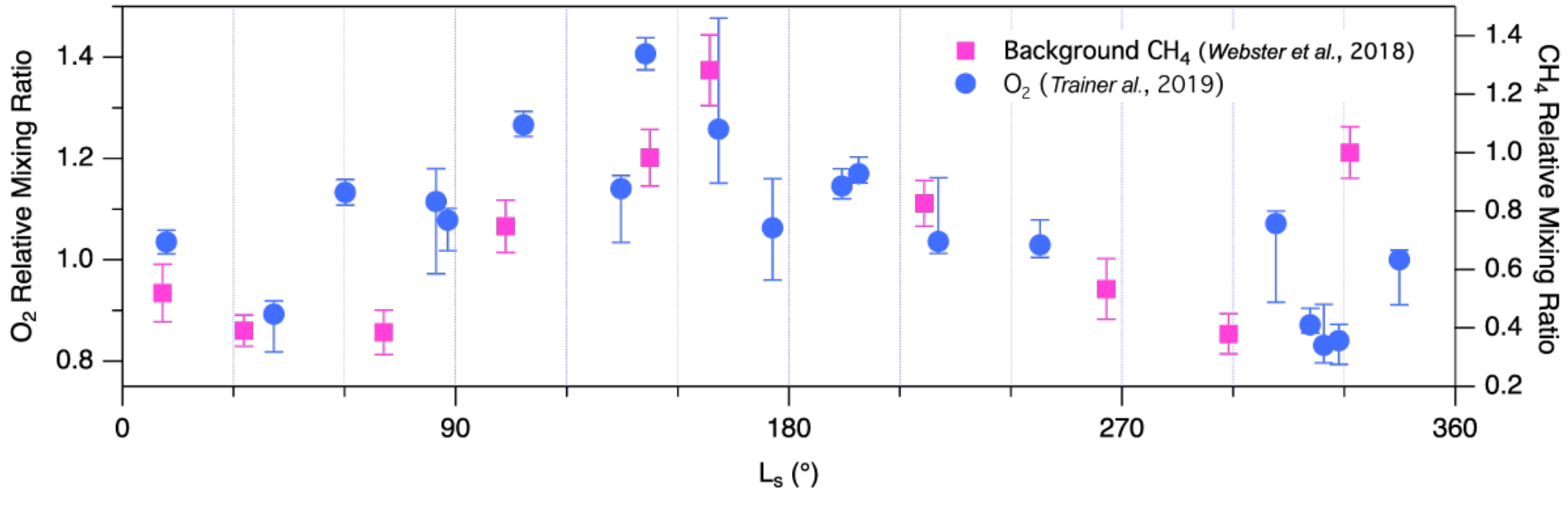
Methane is not alone:
Oxygen also shows unexpected seasonal variation



- Because of its long photochemical equilibrium lifetime of ~10 yrs and non-condensible nature, O2 mixing ratio is expected to be uniform throughout the year, but
- O2 is found to be seasonally variable, like CH4!
- O2 increases by as much as 30% in spring-summer, implying a surface flux; it then falls back down to expected levels, before declining in the winter, and
- Both the spring time excess and then the decline of O2 were unexpected.

[Trainer et al. JGR 2019]

Tantalizing correlation between oxygen and methane part of the year, at least in spring-summer



Indicates a common trigger for spring time release of O_2 and CH_4 from subsurface, and fast destruction

[Trainer et al. JGR 2019]

Potential mechanisms of fast destruction of methane on Mars (from 300 yrs to few months)

- Sequestration of CH_4 on dust grains (Jensen et al. 2014)
  - Fast enough?
  - Temporary sink?
  - Work near the surface?
- Energetic electrons from turboelectric process (Farrell et al. 2004)
  - Localized - applies only to times and regions of convective dust storms and devils
- Surface oxidants, such as hydrogen peroxide (H_2O_2) and perchlorates (ClO_4-)
  - H_2O_2 seems more effective, because (a) it can produce highly reactive superoxides (HO_2, O_2-, etc.) to destroy CH_4 near the surface, and (b) can both be a source and a sink of excess O_2
  - Dislodging chlorine from perchlorates is difficult

What needs to be done next for methane on Mars: a partial list

- Lab studies and modeling
  - Fast destruction - laboratory measurements - required under conditions that truly simulate the Martian environment and geochemistry
  - Fast destruction – modeling – quantitative modeling of the rate of destruction, cycling between atmosphere and surface/subsurface, and loss by escape (e.g. of hydrogen from H_2O_2)
- Data with current assets
  - Fill gaps in the data of CH_4, O_2 and other atmospheric gases – already underway with MSL/SAM, but unlikely to be frequent for building up statistics, because of limitations of consumables (turbo pumps, e.g.), demands of other pressing measurements (solid samples, e.g.), etc.
- Future measurements
  - Surface/subsurface oxidants – e.g. H_2O_2 has never been measured in the surface
  - Methane data at or near the surface at multiple locations
  - Methane storage in and seepage from just below the surface
  - But, **to advance from incremental science to breakthrough discovery needs a bold approach**

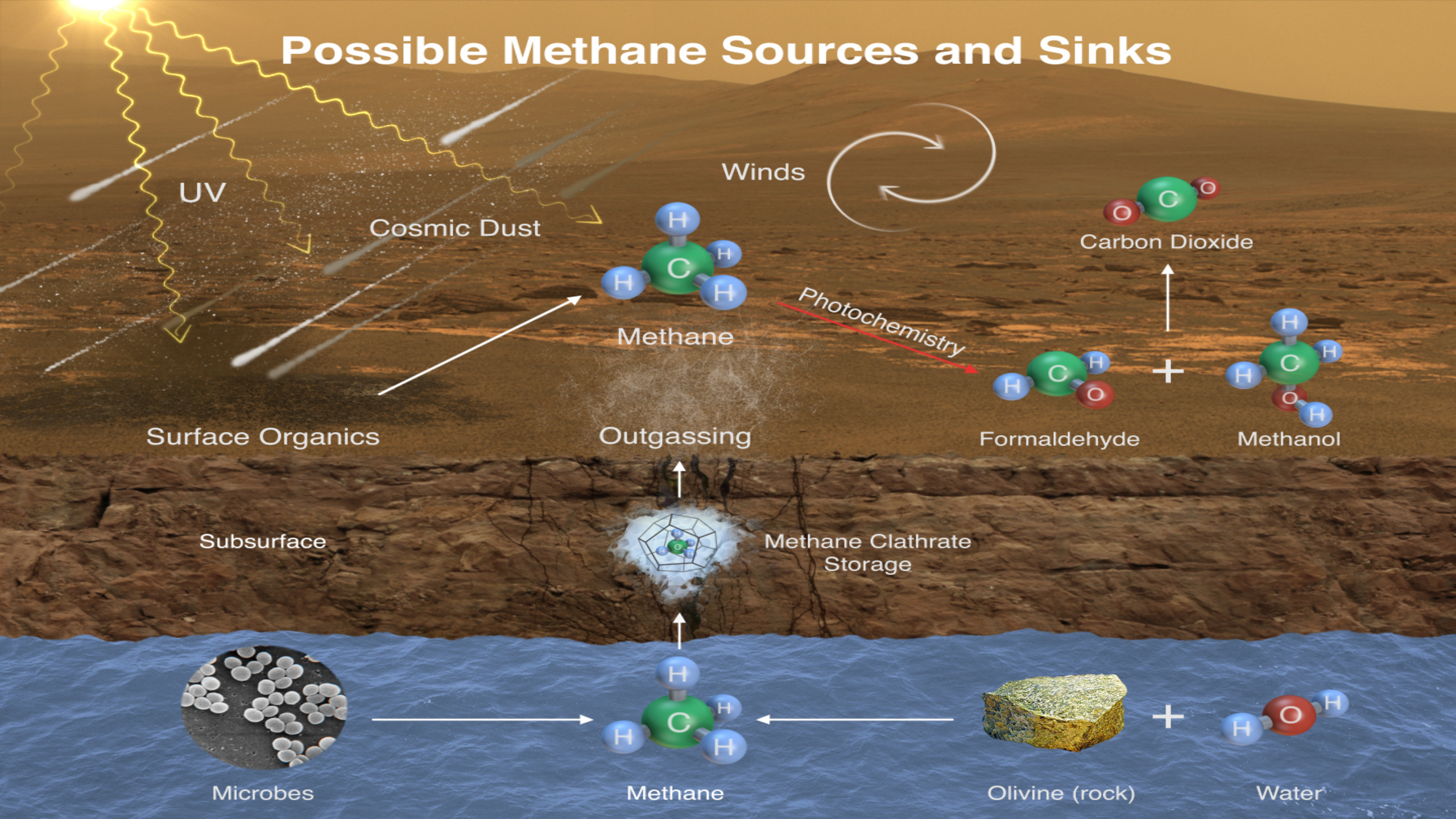
Takeaways

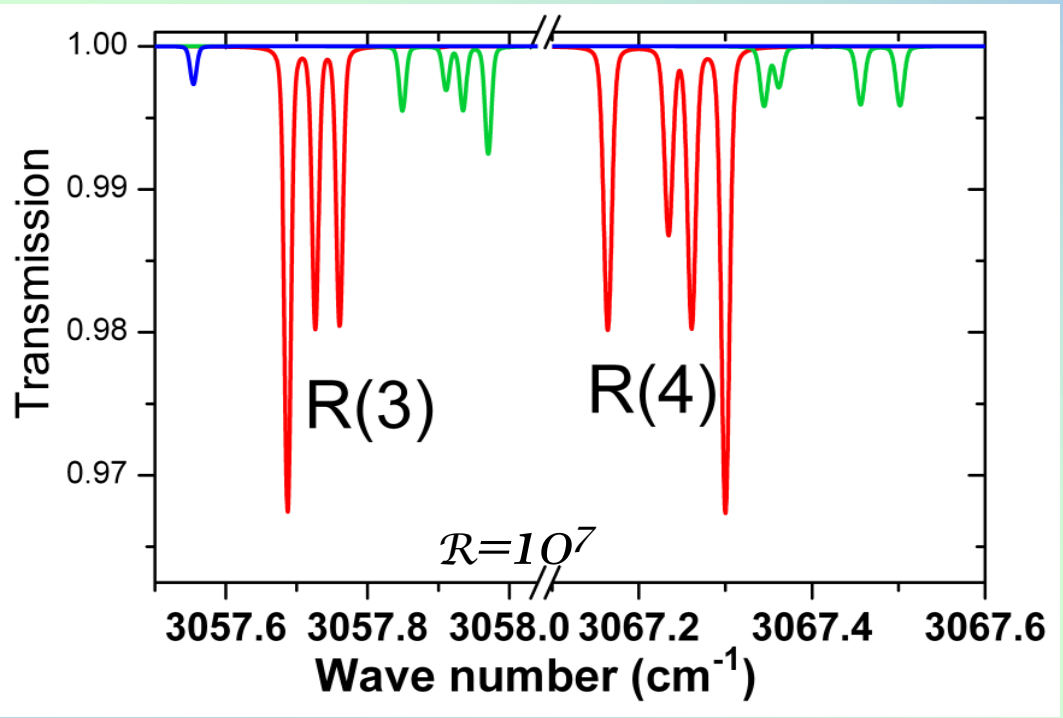
The big question: is methane biological or geological in origin?

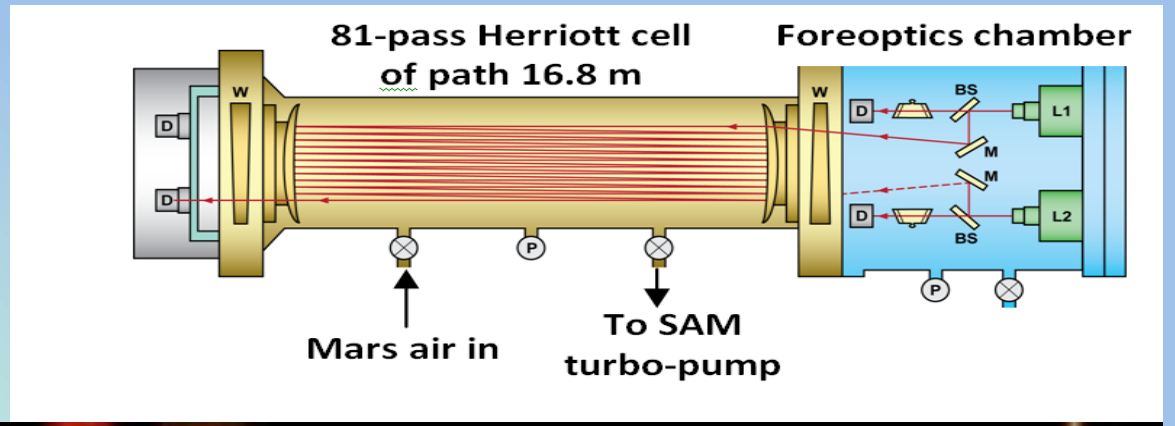
- Measure $^{13}C/^{12}C$ in CH_4 (life prefers light carbon, in general)
- Measure $CH_4/C_2H_6+C_3H_8$ (generally large biotic processes)
- Measure related trace gases, such as O_2

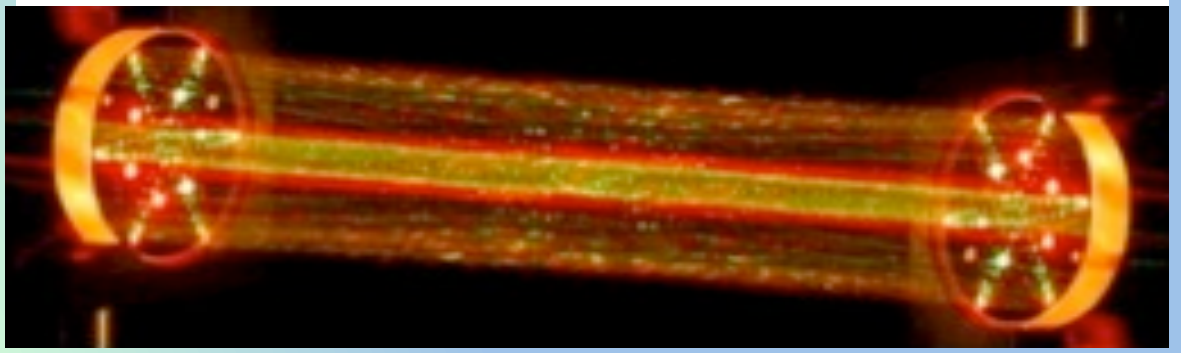
The big question of life on Mars via methane can be addressed to a large extent by returning an appropriate sample of Mars atmosphere.

Backup


Possible Methane Sources and Sinks
UV
Cosmic Dust
Winds
Methane
Photochemistry
Carbon Dioxide
Formaldehyde
Methanol
Surface Organics
Outgassing
Subsurface
Methane Clathrate
Storage
Microbes
Methane
Olivine (rock)
Water







Tunable Laser Spectrometer of SAM suite measuring methane on Mars for 8 years since Curiosity landed at Gale Crater
TLS Resolving Power 10^7

(Webster et al., 2015, 2018)