Sensitivity of the Methane Sensor of the Indian Mars Orbiter Mission

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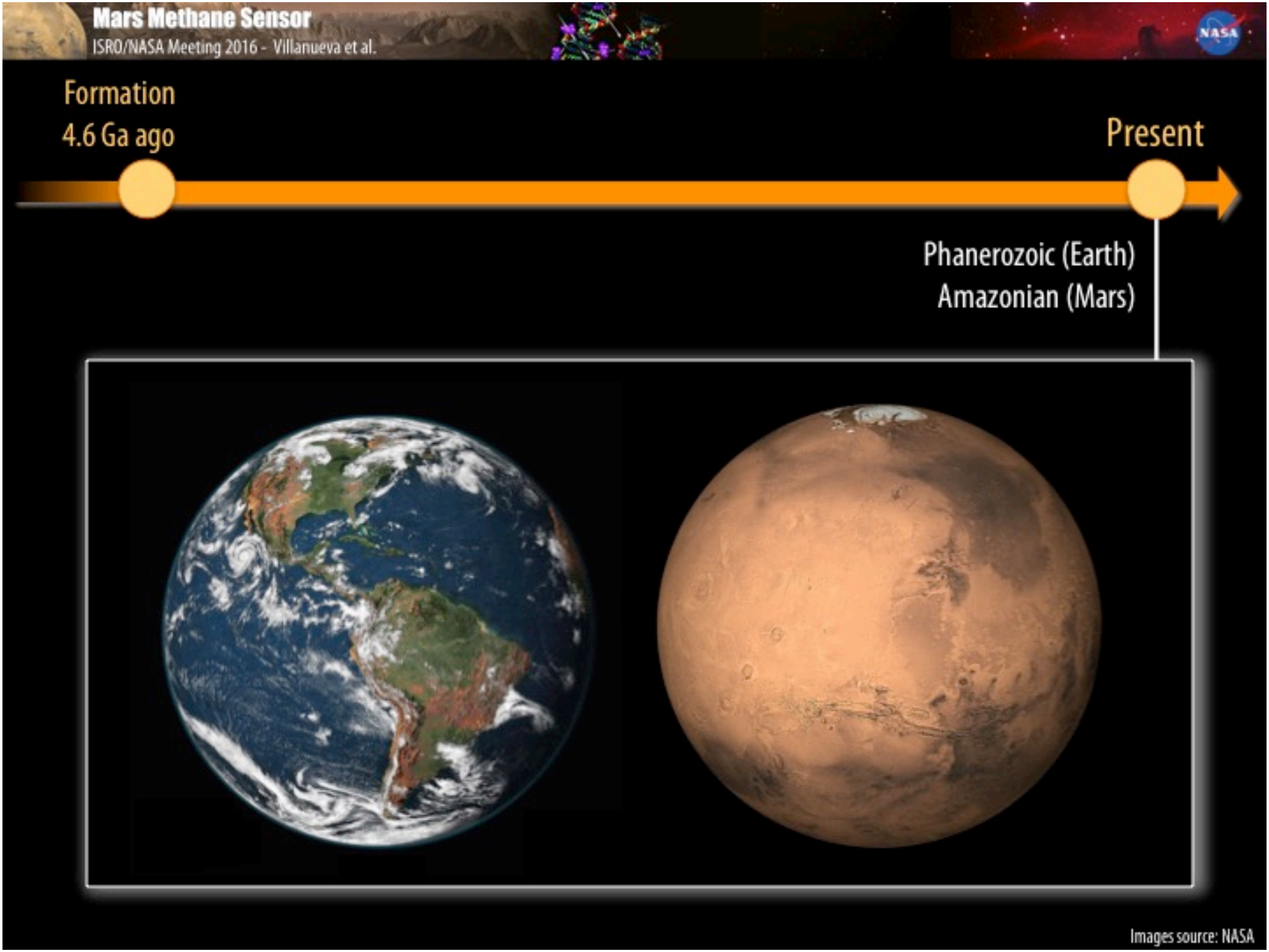
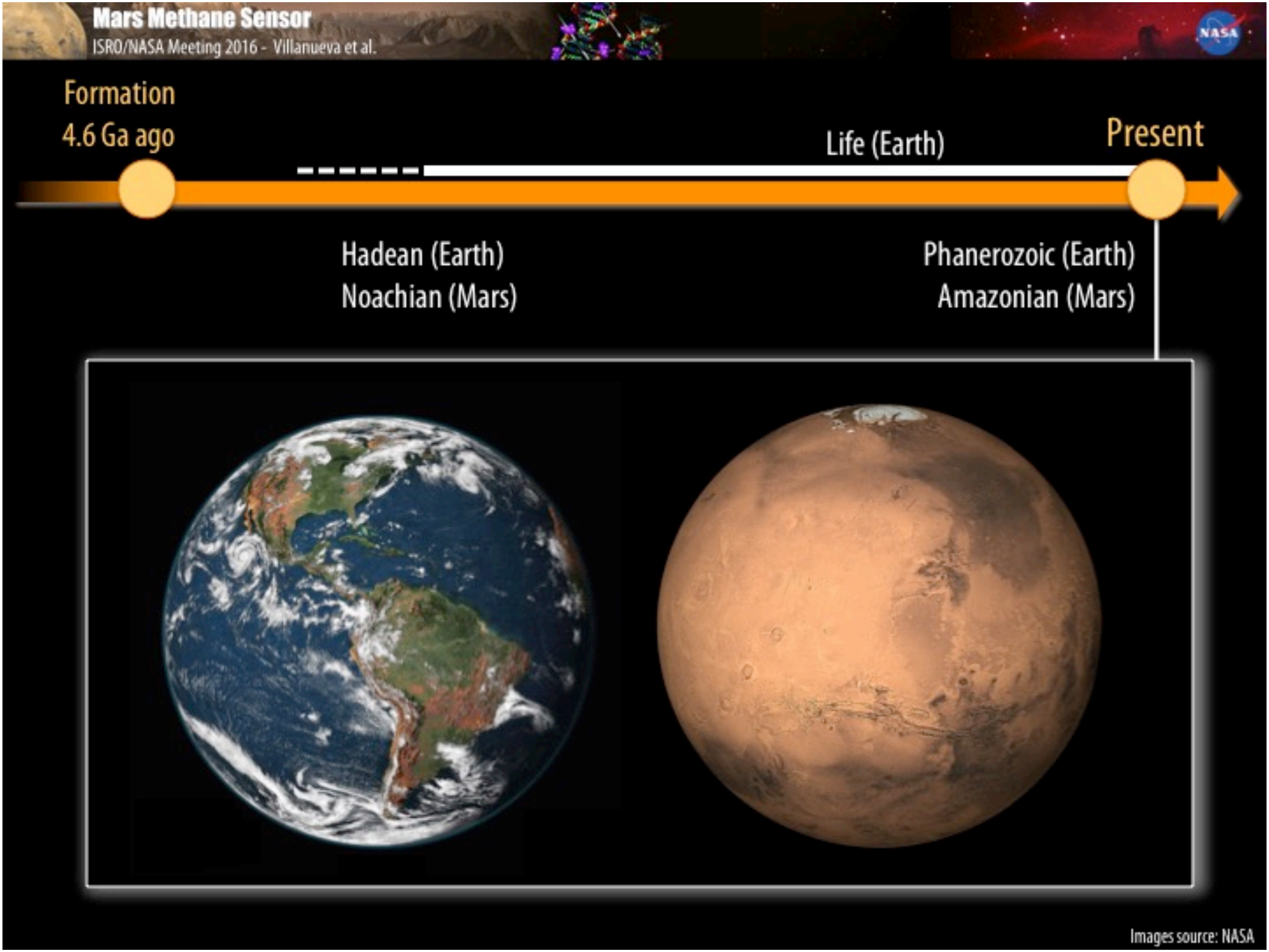
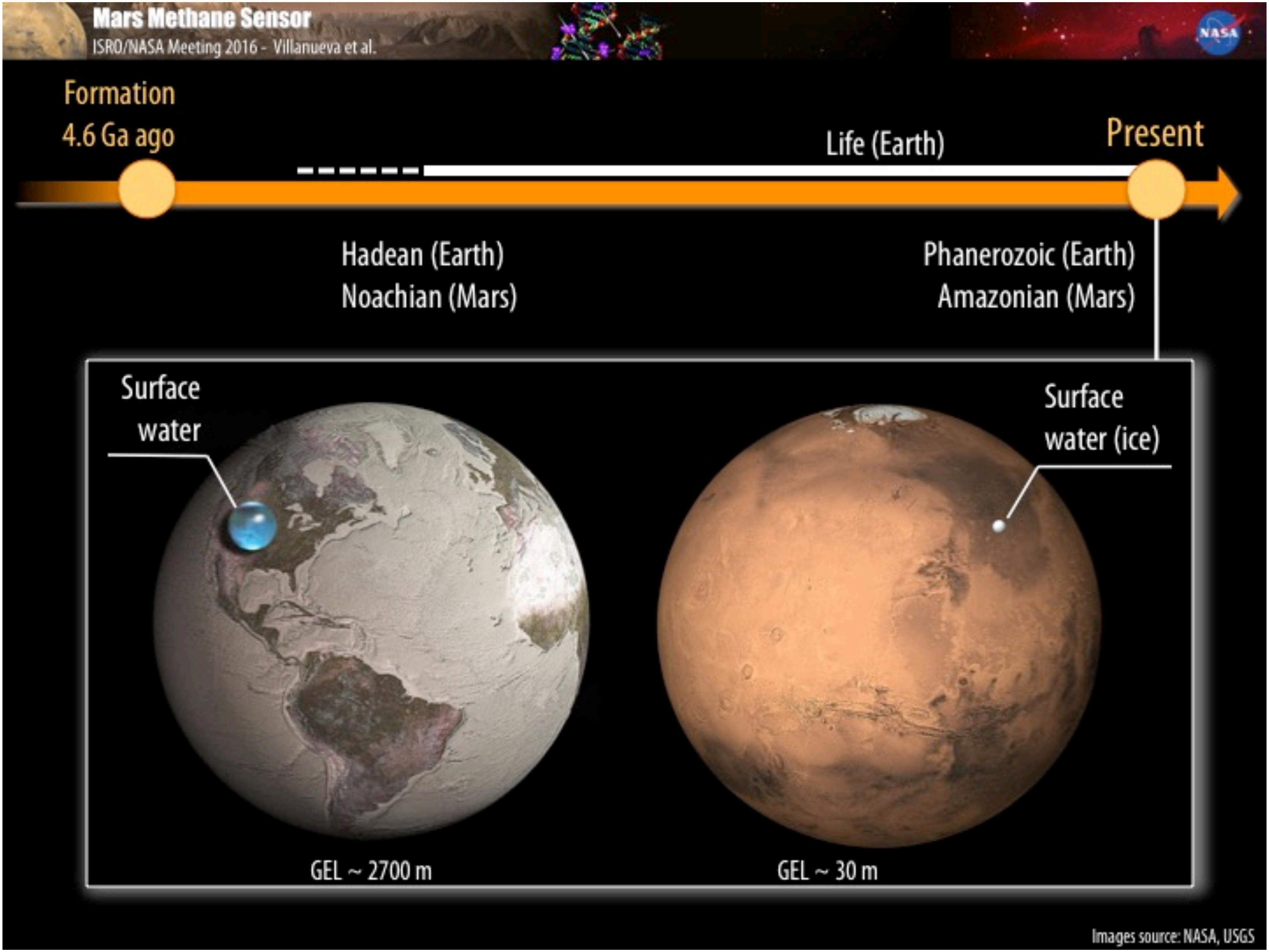
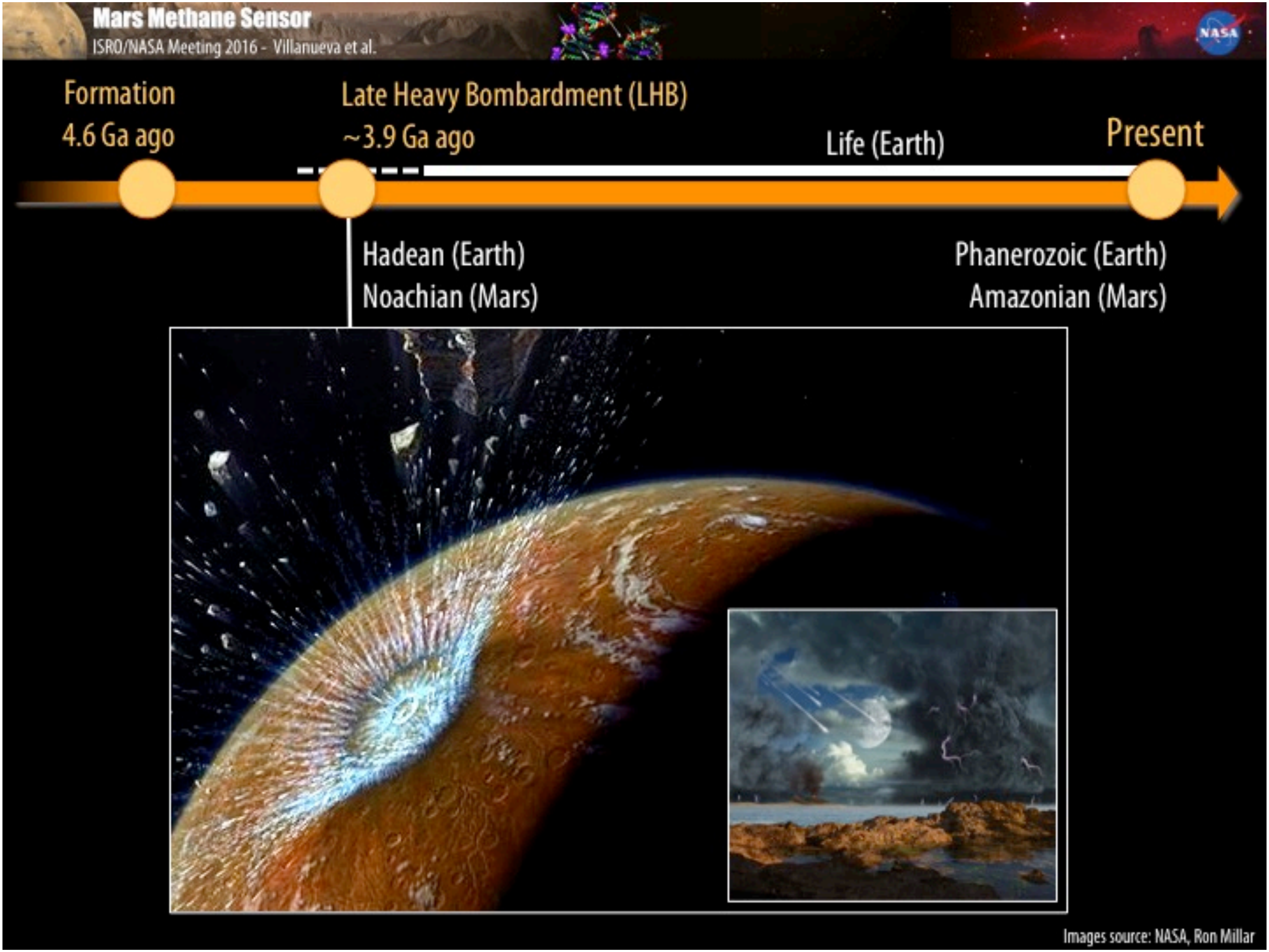
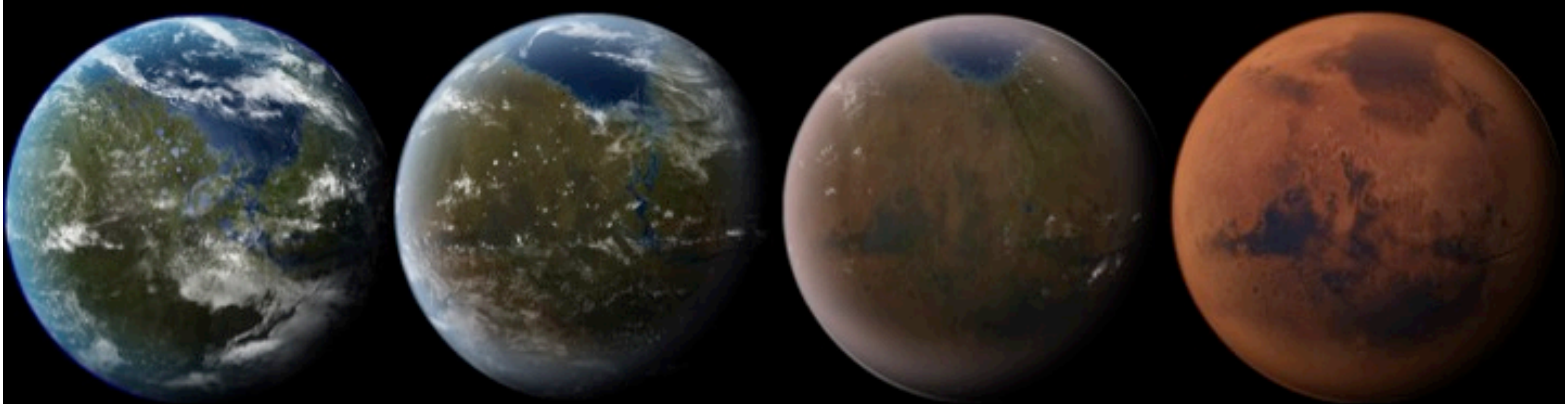

Mars Methane Sensor
ISRO/NASA Meeting 2016 - Villanueva et al.
Formation
4.6 Ga ago
Present
Phanerozoic (Earth)
Amazonian (Mars)
Images source: NASA


Mars Methane Sensor
ISRO/NASA Meeting 2016 - Villanueva et al.
NASA
Formation
4.6 Ga ago
Life (Earth)
Present
Hadean (Earth)
Noachian (Mars)
Phanerozoic (Earth)
Amazonian (Mars)
Images source: NASA


Mars Methane Sensor
ISRO/NASA Meeting 2016 - Villanueva et al.
NASA
Formation
4.6 Ga ago
Life (Earth)
Present
Hadean (Earth)
Noachian (Mars)
Phanerozoic (Earth)
Amazonian (Mars)
Surface
water
Surface
water (ice)
GEL ~ 2700 m
GEL ~ 30 m
Images source: NASA, USGS

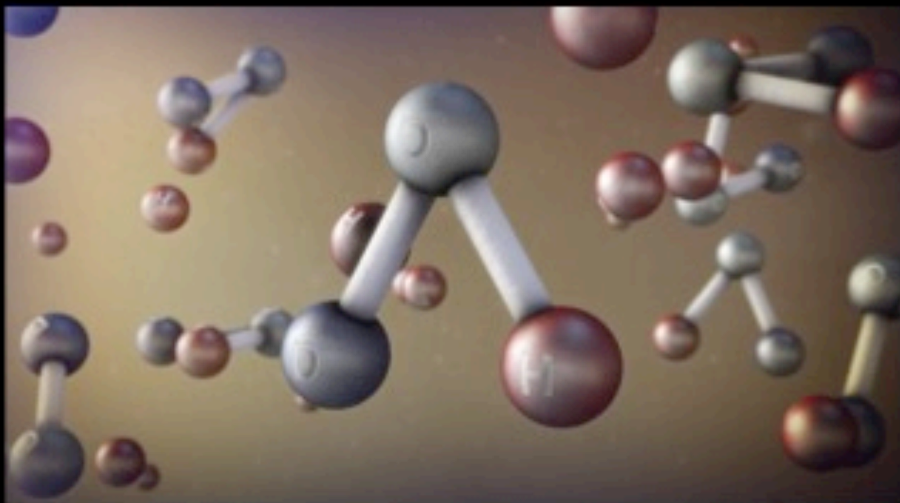

Mars Methane Sensor
ISRO/NASA Meeting 2016 - Villanueva et al.
NASA
Formation
4.6 Ga ago
Late Heavy Bombardment (LHB)
~3.9 Ga ago
Life (Earth)
Present
Hadean (Earth)
Noachian (Mars)
Phanerozoic (Earth)
Amazonian (Mars)
Images source: NASA, Ron Millar

- Was Mars ever habitable?
- How much water did the planet have?
- Are there habitable niches below the surface?



Images source: NASA

Searching for evidence of a habitable past – Where? When?

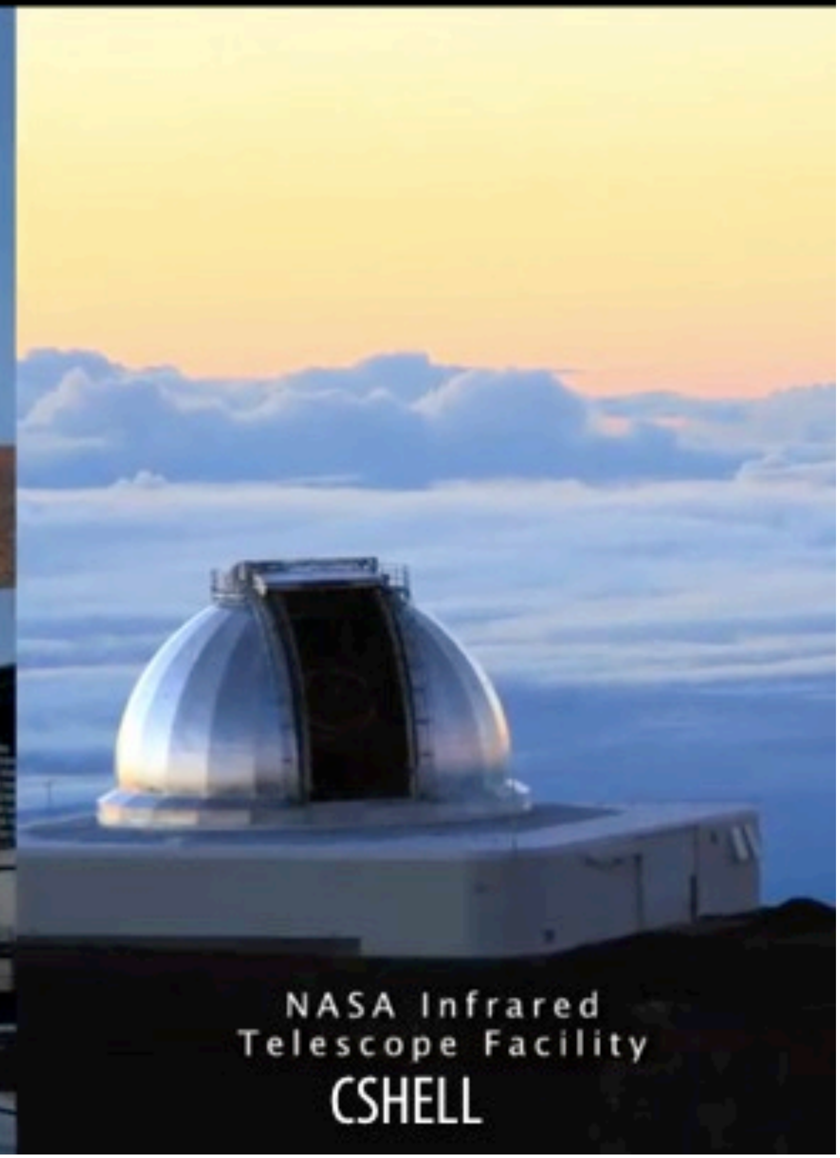


Primordial Mars water (4.5 billion years old) is known to have a D/H enrichment similar to Earth's oceans (1.275 VSMOW, Usui+2014).

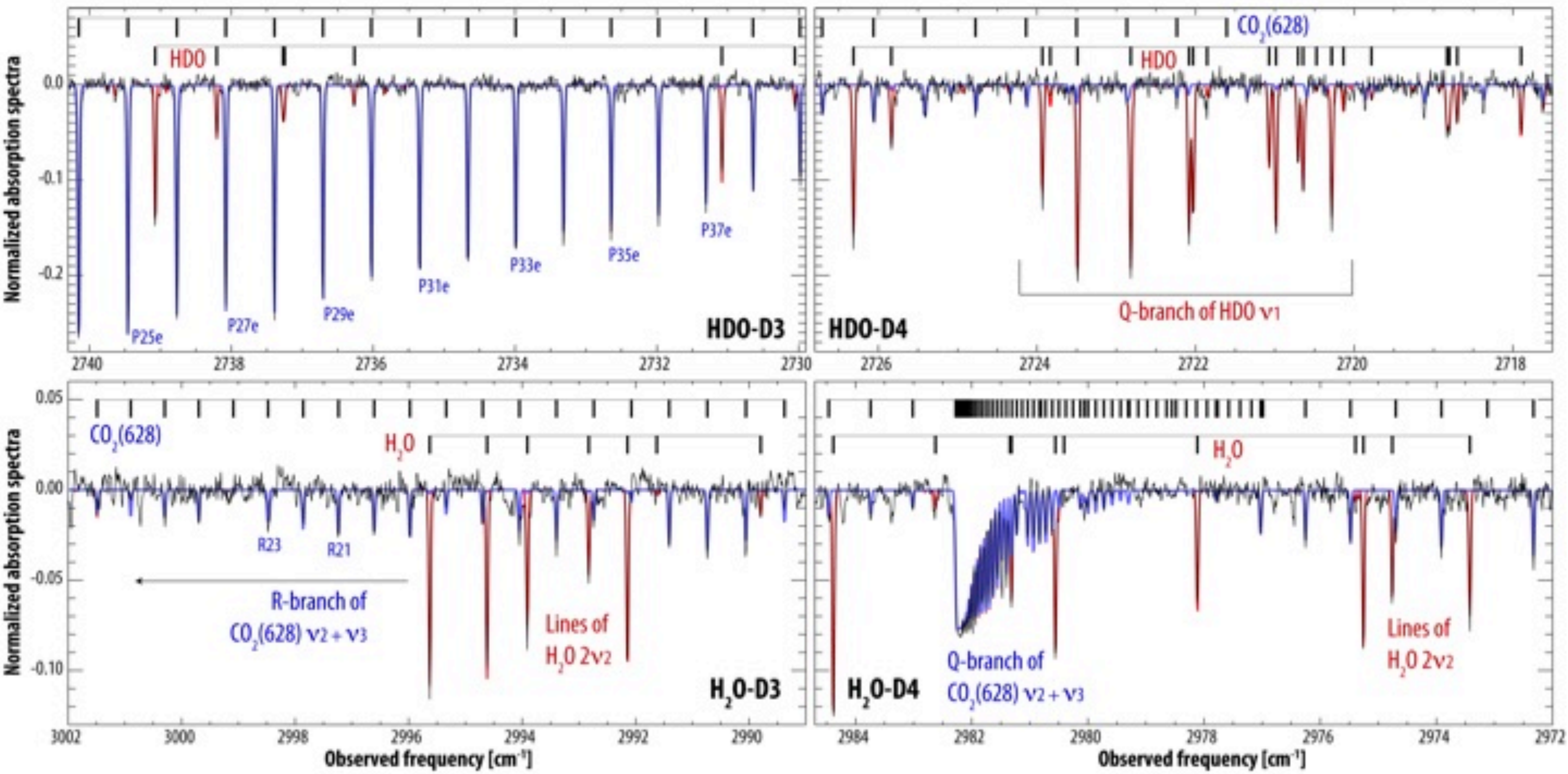
Curiosity measured a D/H of 3 VSMOW for material in Gale crater 3 billion years old (Mahaffy+2015)

No maps of water D/H exist

We mapped the D/H of water on Mars following the sublimation of the northern polar cap



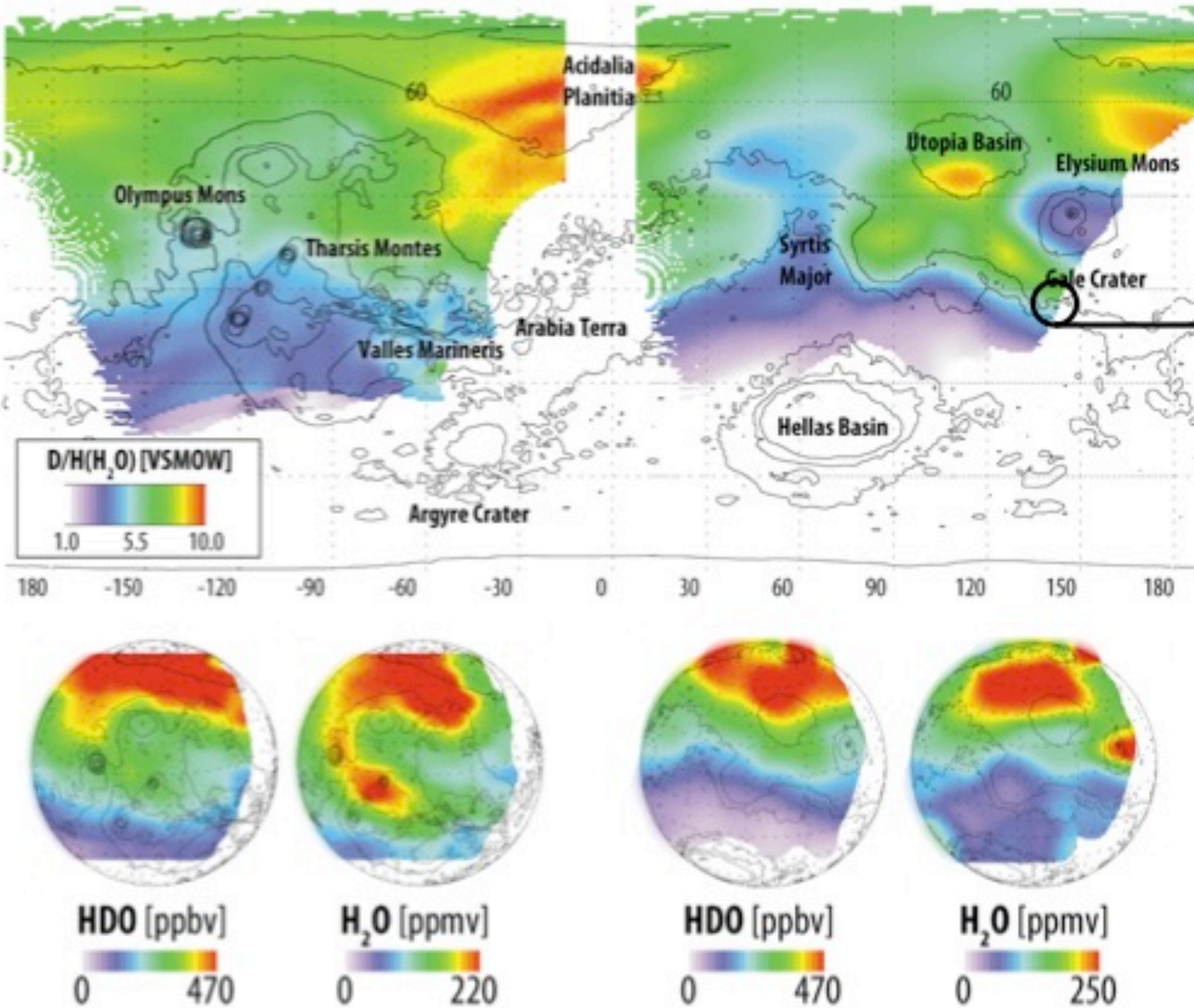
CRIRES spectra – January 2014



Villanueva+2015, Science

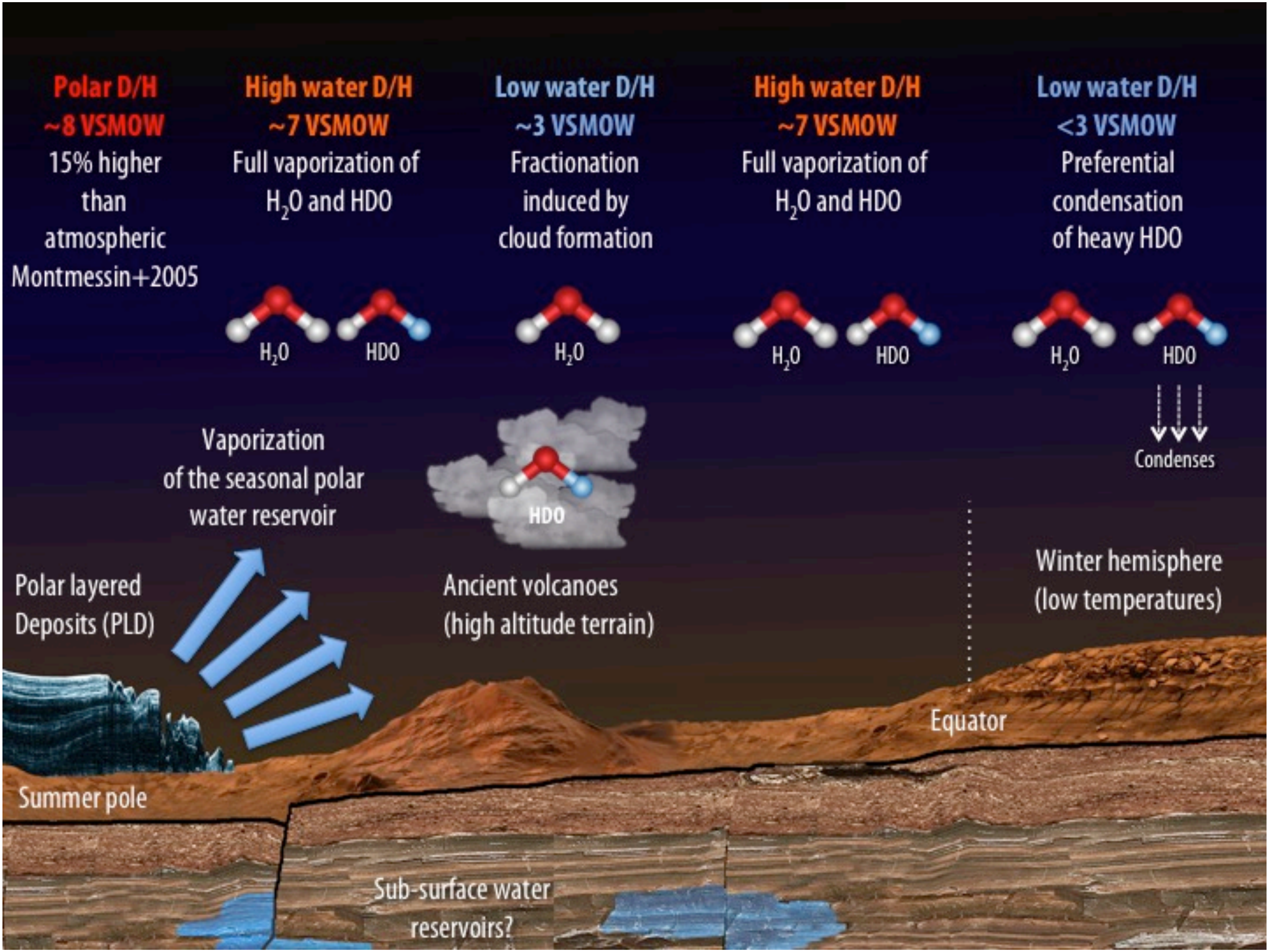
D/H Map - Ls: 83° (Northern late spring)
CRIRES/VLT Jan/29 and Jan/30 2014

D/H Map - Ls: 80° (Northern late spring)
NIRSPEC/Keck Jan/24 2014

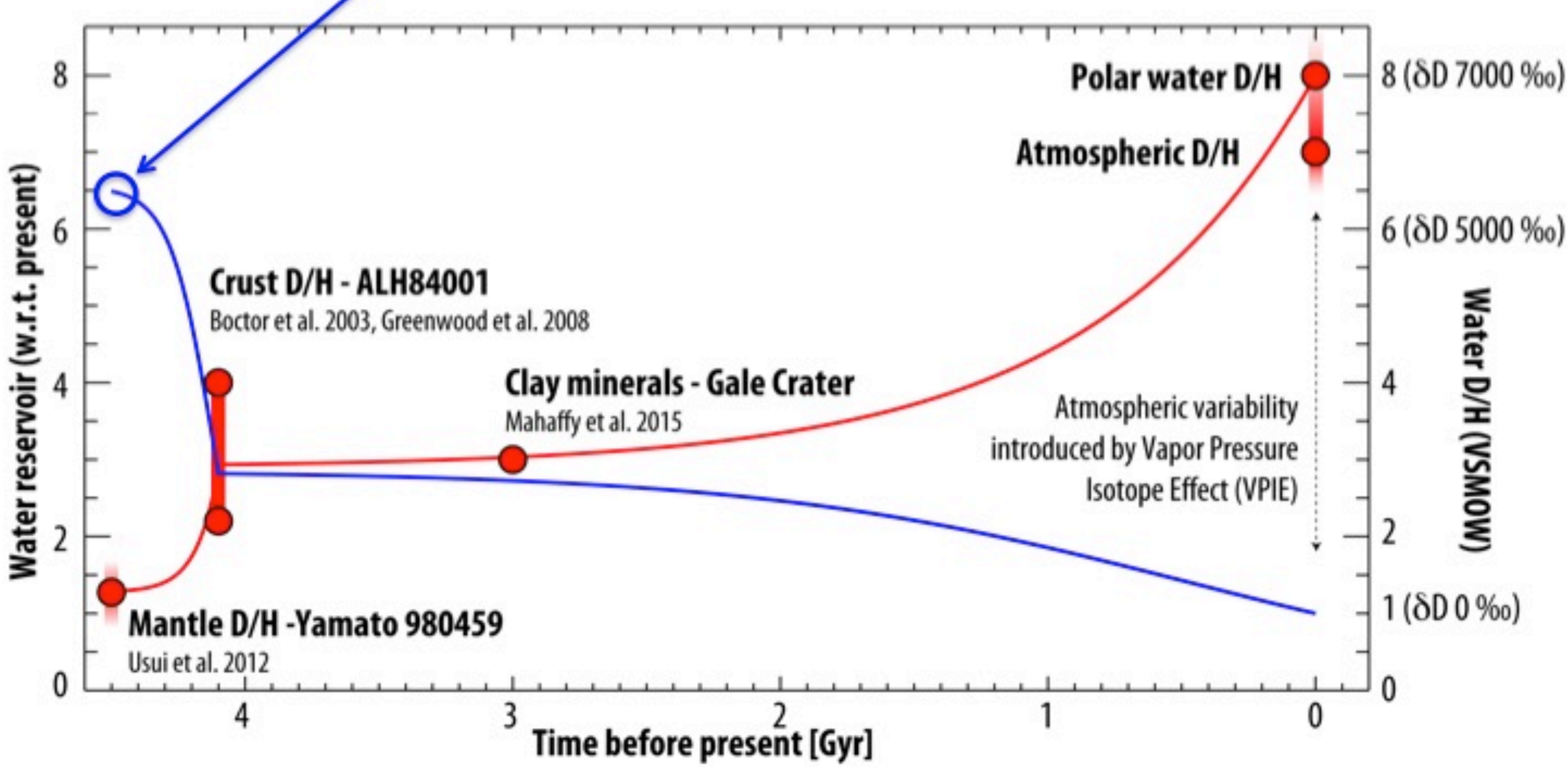


MSL Rover Curiosity

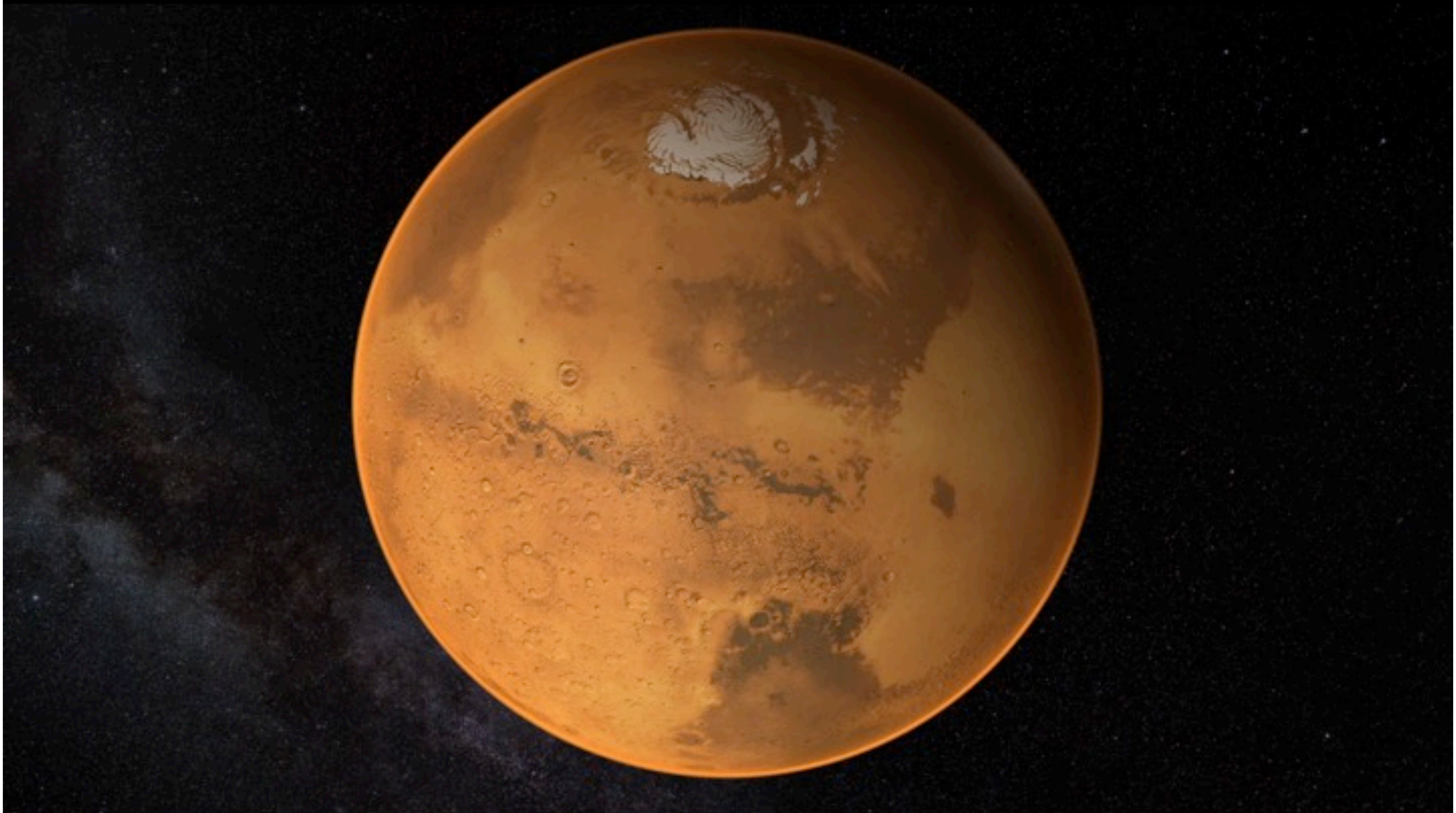
Villanueva+2015, Science


Polar D/H
~8 VSMOW
15% higher than atmospheric
Montmessin+2005
High water D/H
~7 VSMOW
Full vaporization of H_2O and HDO
Low water D/H
~3 VSMOW
Fractionation induced by cloud formation
High water D/H
~7 VSMOW
Full vaporization of H_2O and HDO
Low water D/H
<3 VSMOW
Preferential condensation of heavy HDO
H_2O
HDO
H_2O
H_2O
HDO
H_2O
HDO
Condenses
Vaporization of the seasonal polar water reservoir
HDO
Polar layered Deposits (PLD)
Ancient volcanoes (high altitude terrain)
Winter hemisphere (low temperatures)
Equator
Summer pole
Sub-surface water reservoirs?

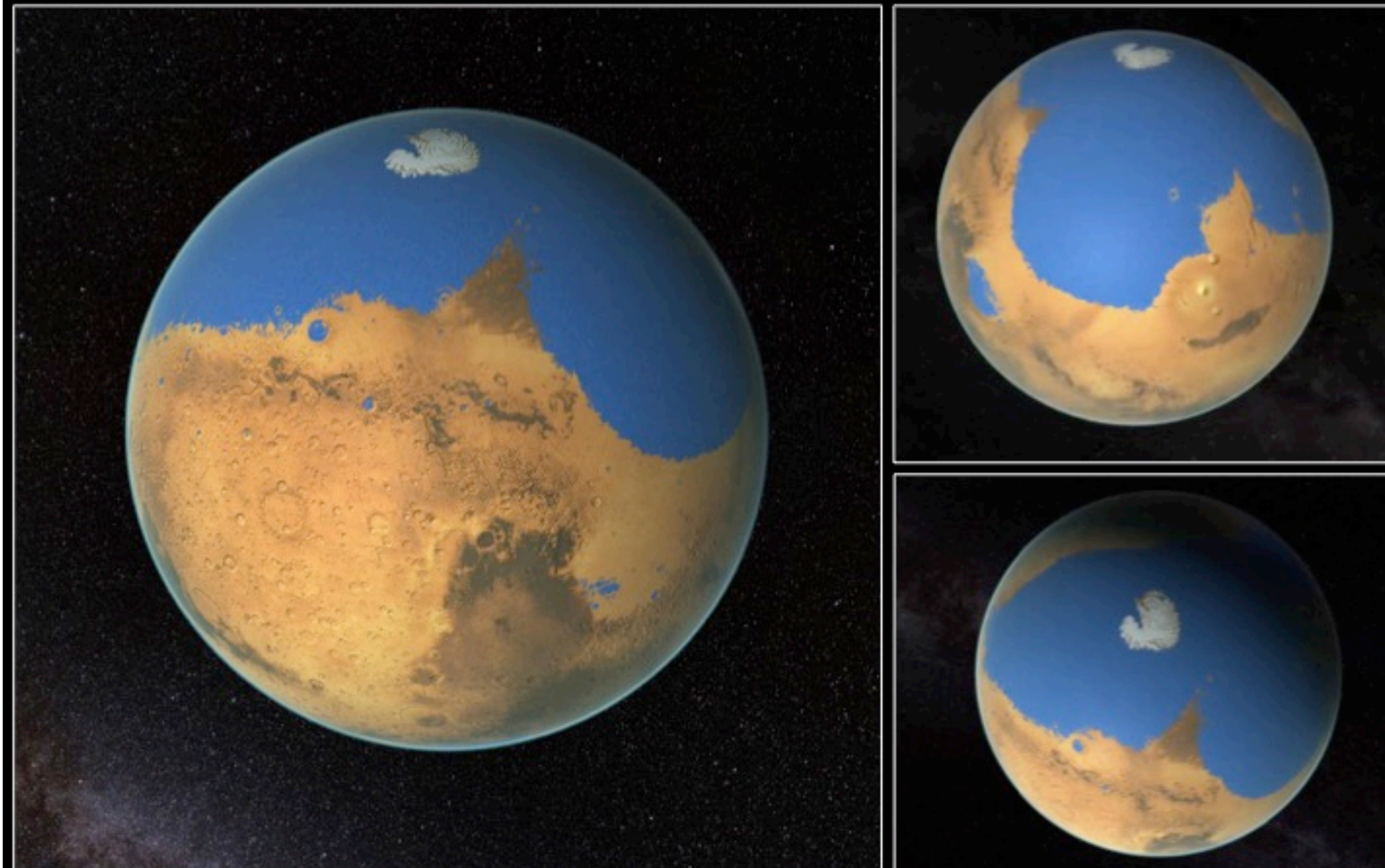
Mars had 6.5 times the water that it has today (i.e., lost 87% of its water)



Villanueva+2015, Science



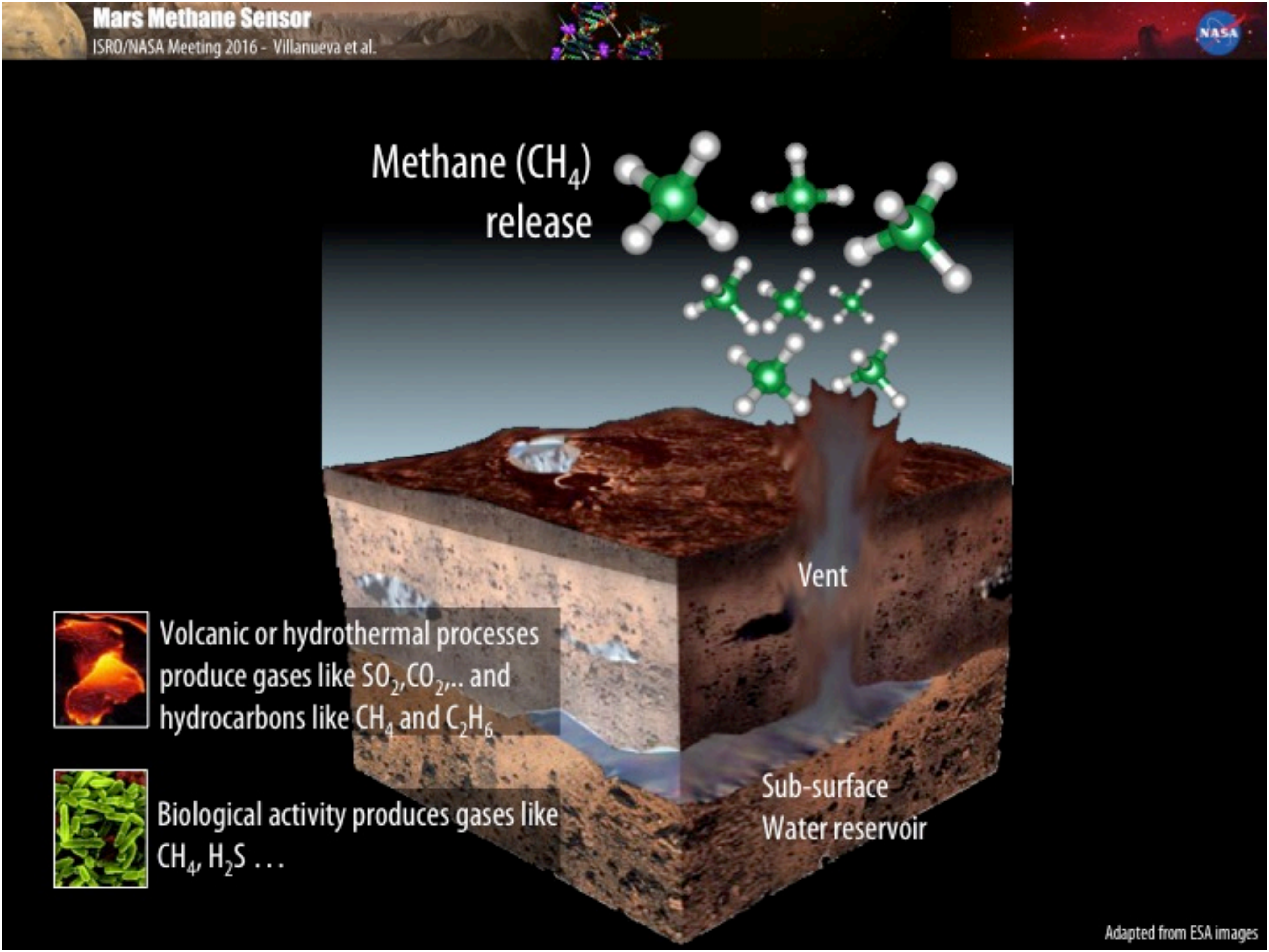
Villanueva+2015 - Rendered by NASA's Scientific Visualization Studio

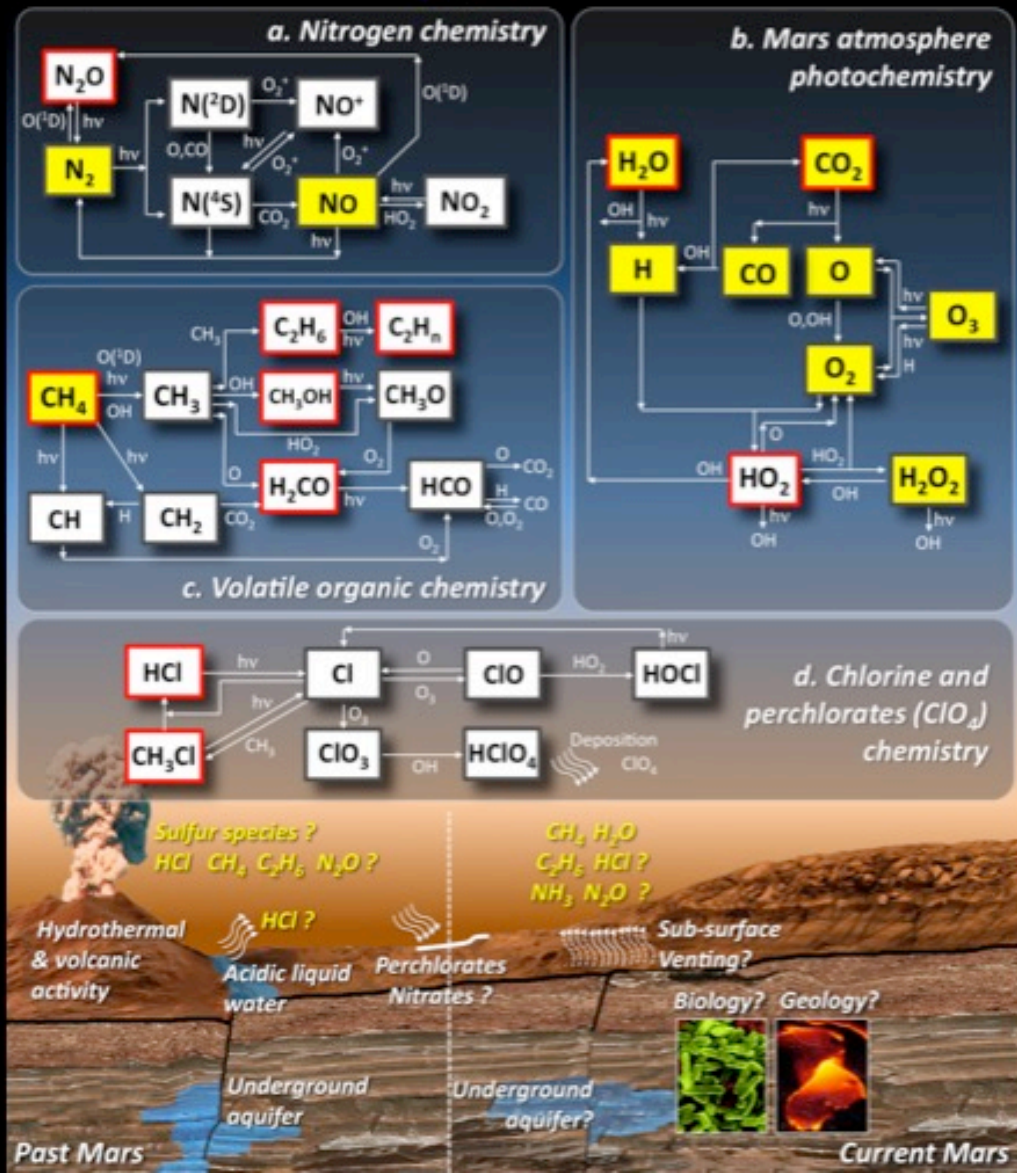


Equivalent ancient ocean (Noachian)

Villanueva+2015 - Rendered by NASA's Scientific Visualization Studio

If Mars was so vastly covered by water, are there habitable niches now?


Mars Methane Sensor
ISRO/NASA Meeting 2016 - Villanueva et al.
Methane (CH_4) release
Vent
Sub-surface Water reservoir
Volcanic or hydrothermal processes produce gases like SO_2,CO_2,.. and hydrocarbons like CH_4 and C_2H_6
Biological activity produces gases like CH_4, H_2S …
Adapted from ESA images



Villanueva+2013

Organics in the Martian atmosphere: *recent source*

Apart from our ground-based CH_4 detections, three other teams report detections (two from orbit (3.3 and 7.7 μm), one using CFHT and IRTF).

In 2015, the TLS instrument onboard Curiosity (MSL, Webster +2015) reported *highly variable methane on Mars*, with peak abundances of ~10 ppbv and a background value of ~1 ppbv.

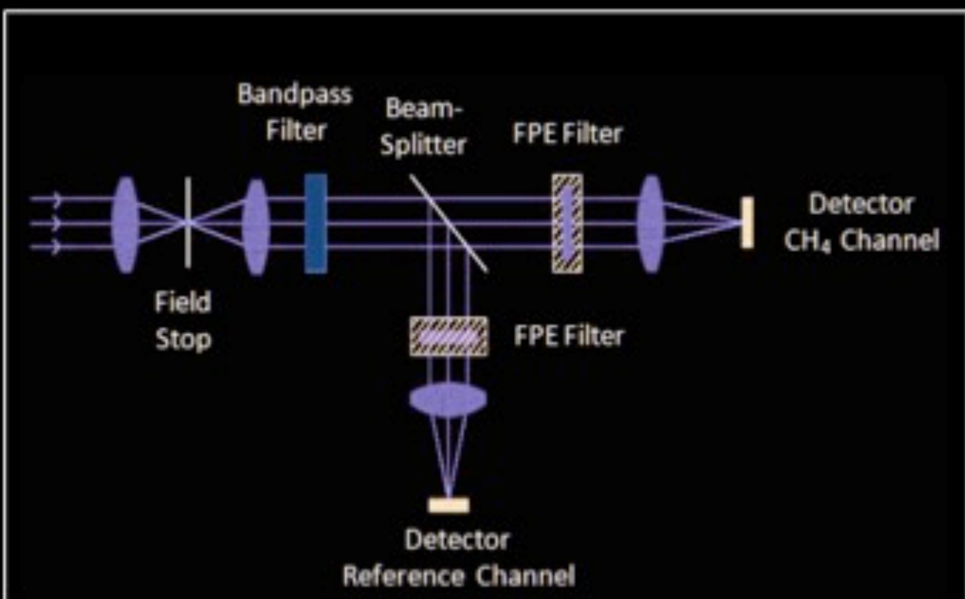
Certain scientists disagree. Considering the complexity of the available measurements, the quest to conclusively detect organics is still on.

We derive sensitive limits (<7 ppbv) in our recent ground-based work (Villanueva+2013).

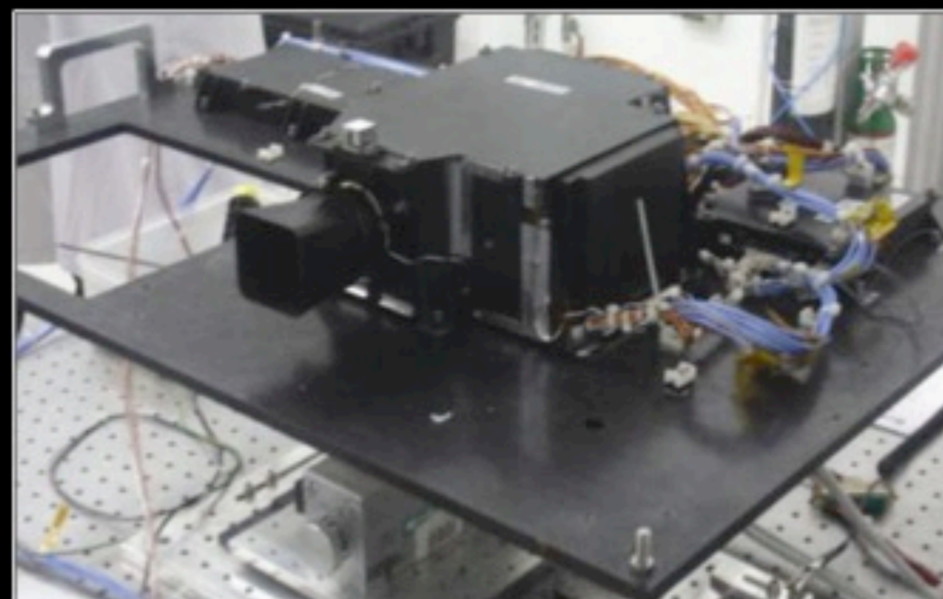
Searches for methane at shorter wavelengths (1.65 um) with MOM

- The Methane Sensor is a differential radiometer based on Fabry–Perot Etalon (FPE) filters.
- Accuracy and sensitivities of the order of 30 ppbv are estimated based on an integration time of 10 seconds.

Optical design



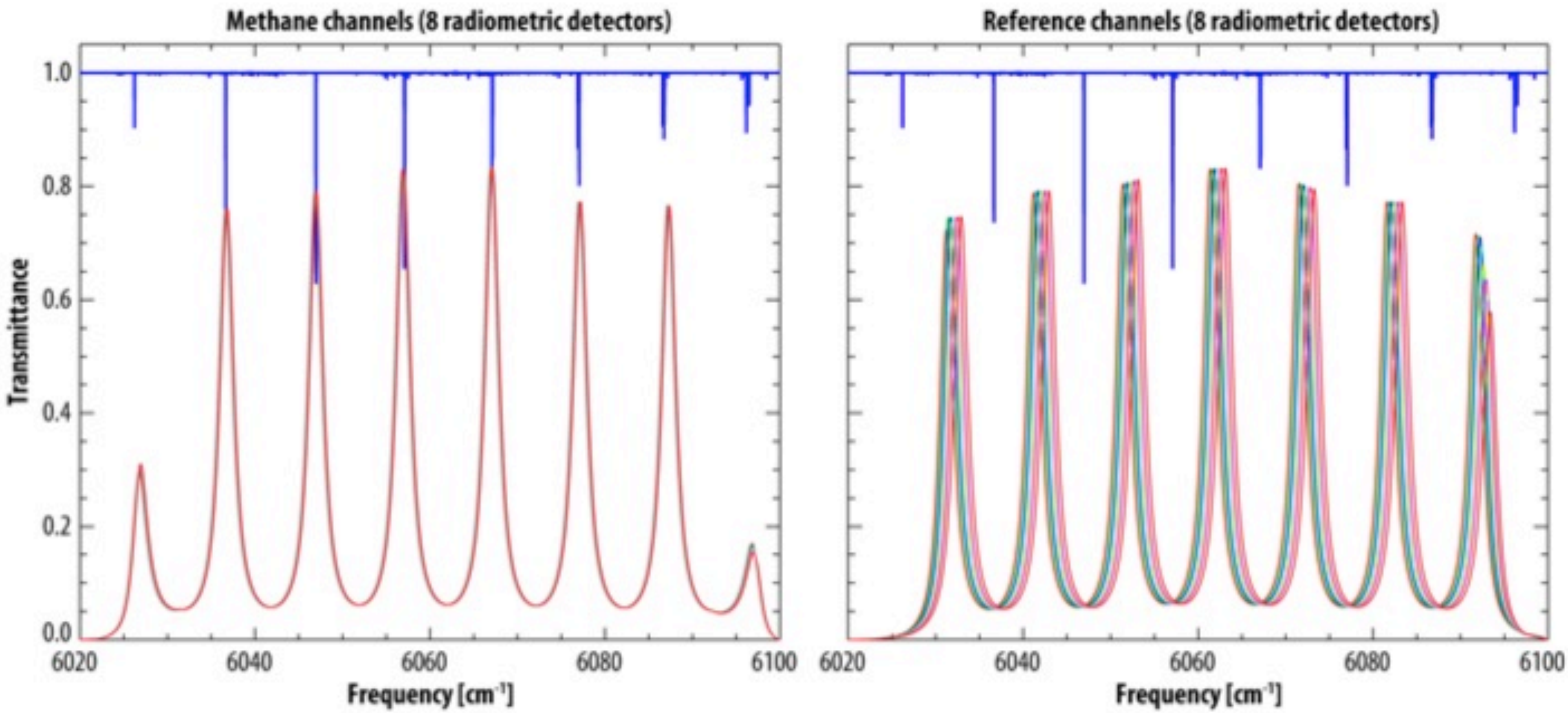
Methane Sensor Instrument



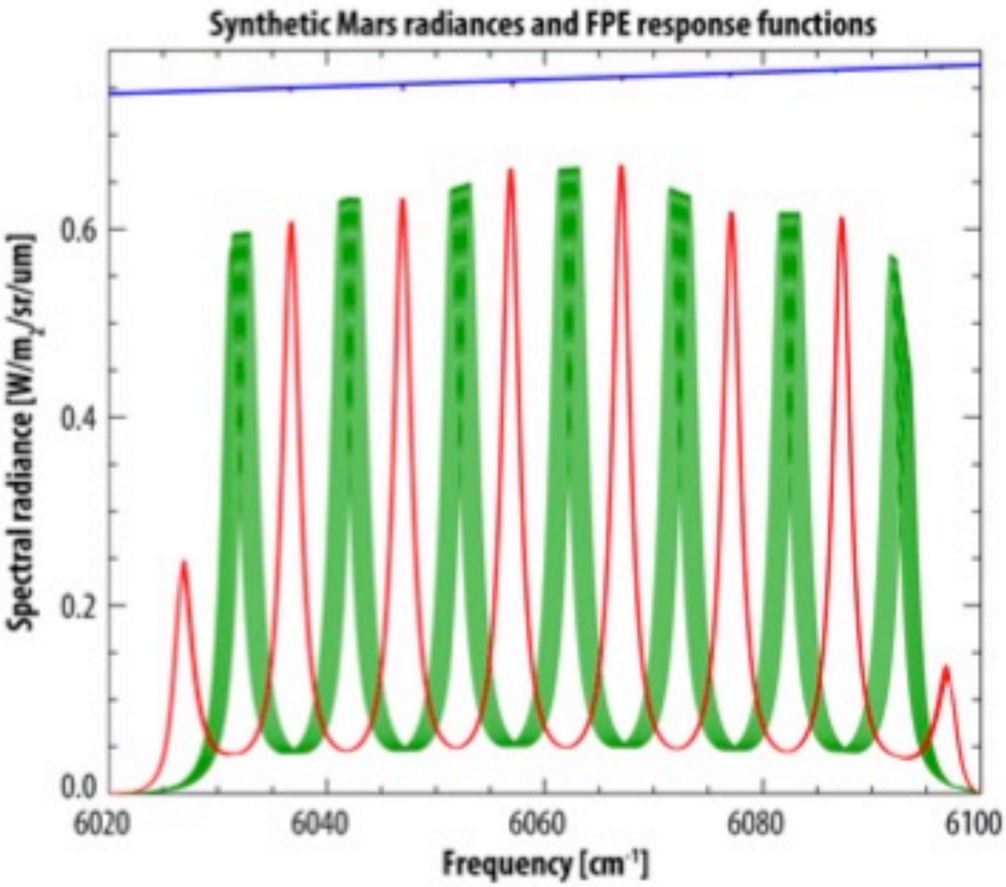
Mathew et al., 2015

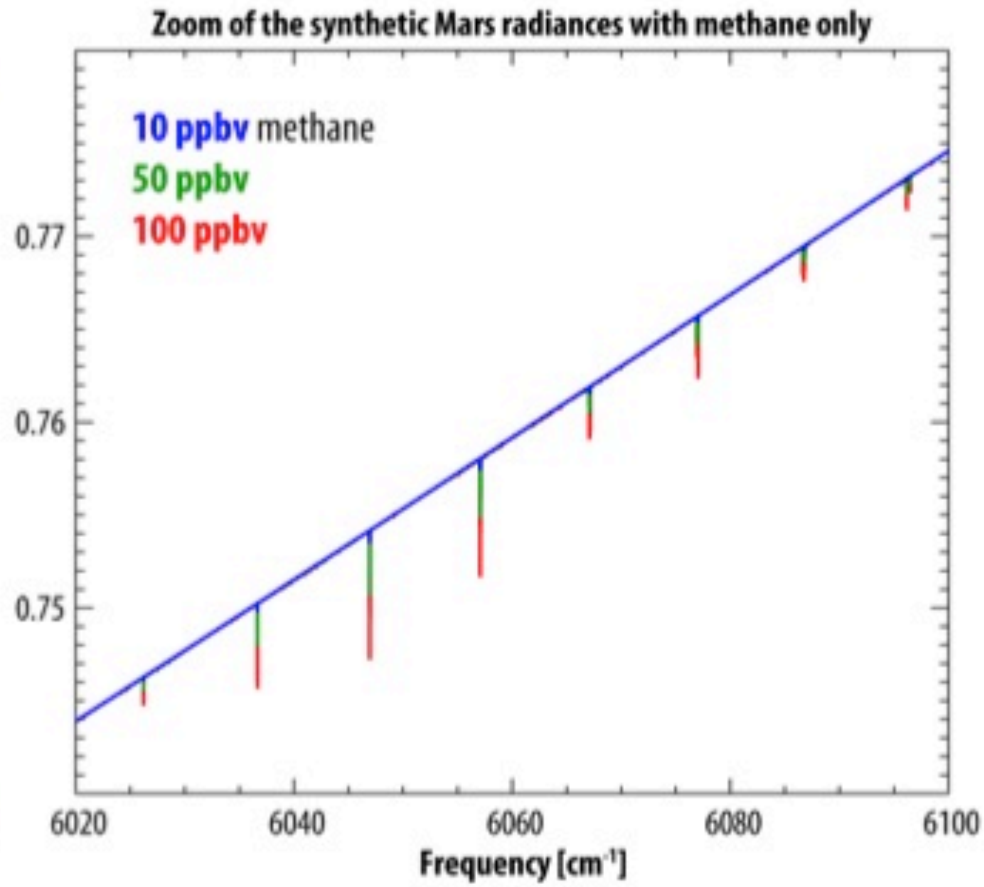
Analytical response functions of the FPE filters based on the measured responses reported in Mathew et al. 2015

5000 ppbv methane Mars model



Expected strength of the methane signal at these frequencies





Required differential radiometric accuracy, sensitivity and calibration precision

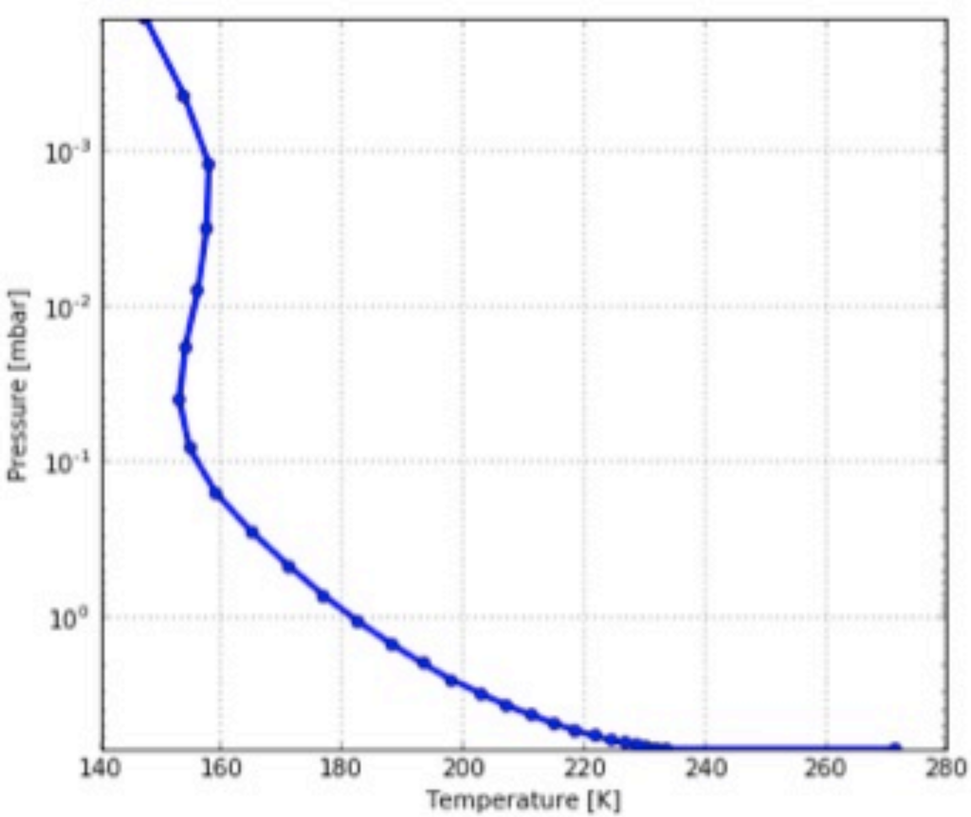
100 ppbv – Required radiometric accuracy > **12,000** (1-sigma)

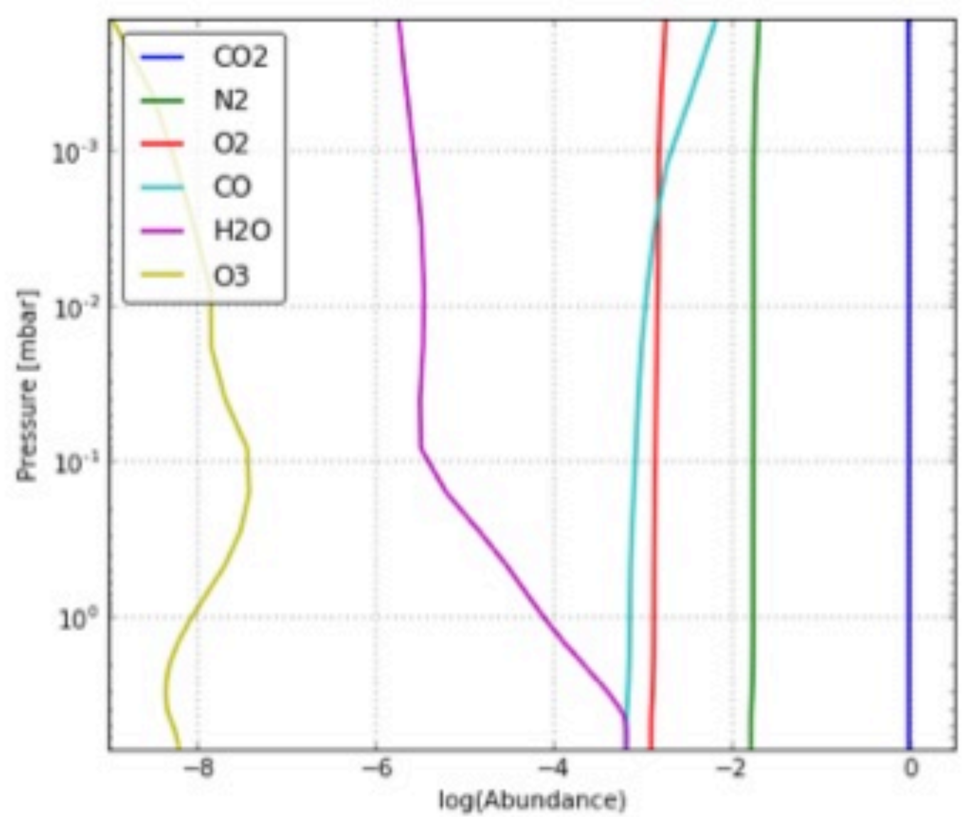
50 ppbv – Required radiometric accuracy > **24,000** (1-sigma)

10 ppbv – Required radiometric accuracy > **120,000** (1-sigma)

Atmospheric Mars vertical profile considered for the analysis

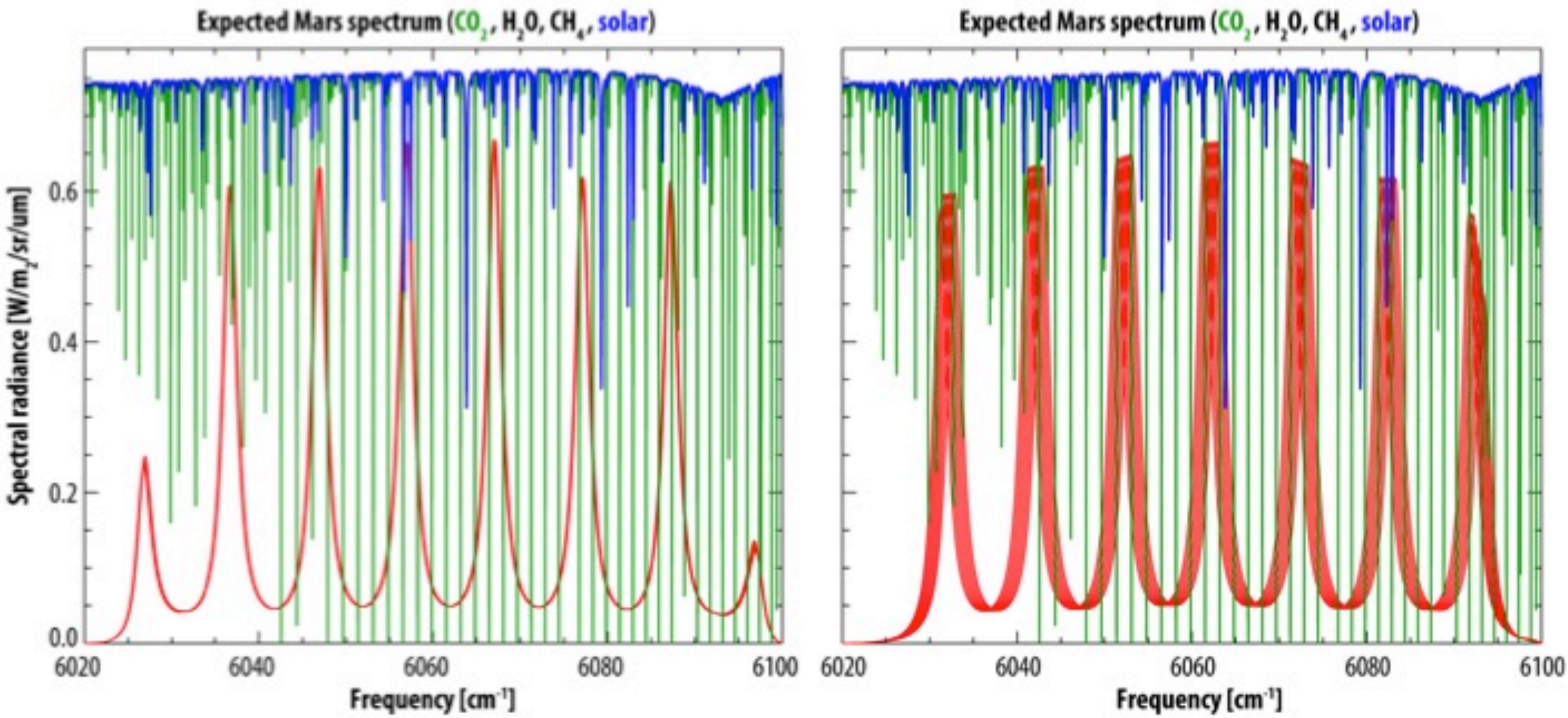
(AM1=1.0, AM2=1.24, Albedo=0.25)





Synthetic radiances considering all species in this spectral region

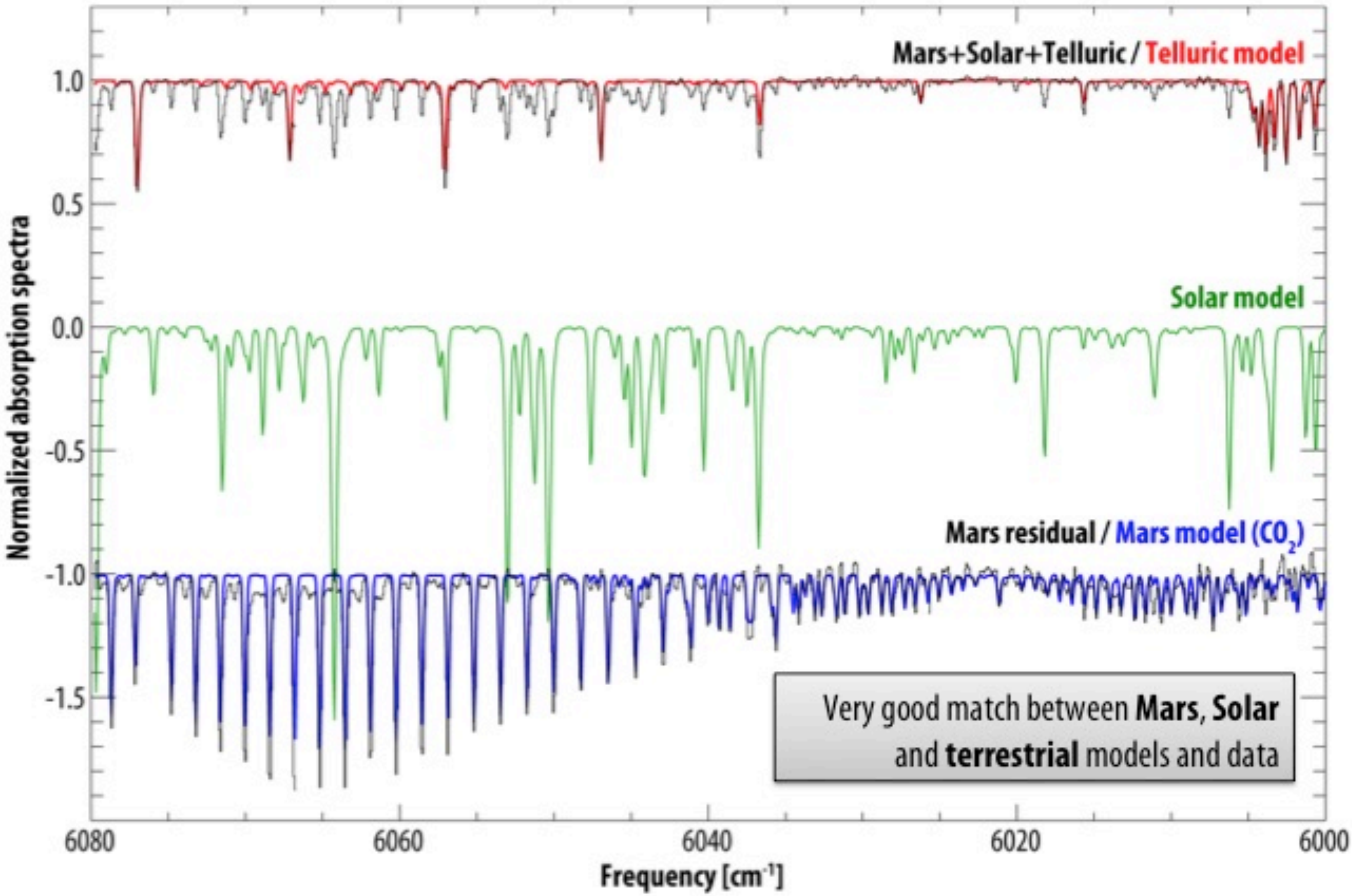
(methane is indistinguishable)



GENLN3 radiative transfer model (Villanueva et al. 2015, Edwards et al. 1992); HITRAN-2012 spectroscopic parameters (Rothman et al. 2012); Synthetic Solar spectrum (Kurucz et al. 2005)

Validation of the modeling methodology

Observations of Mars with Keck (NIRSPEC, $\lambda/\Delta\lambda$ ~ 40,000) – Feb/16/2016



Sensitivity study

Impact of varying atmospheric parameters on the observable differential and calibrated fluxes

50 ppbv CH_4 abundance → 0.004 %

1% change in the H_2O column → 2E-6 % (0.025 ppbv CH_4)

1% change in the CO_2 abundance or pressure → 7E-5 % (1 ppbv CH_4)

1% change in the depth of the Solar lines → 0.0015 % (18 ppbv CH_4)

10K change in the atmospheric column → 0.013 % (163 ppbv CH_4)

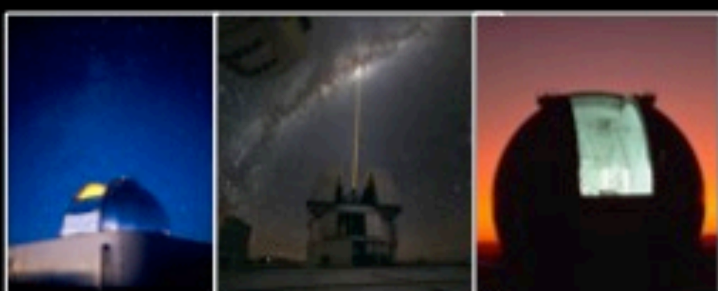
1 % change in albedo → 1.000 % (12500 ppbv CH_4)

The next steps

Ground-based observatories	Orbiters	Rovers / Landers
		
High spectral resolution and multi-wavelength facilities ✔	Focused instrumentation ✔	Complex species (GC-MS) and sub-surface drilling ✔
Modest spatial resolutions	Superb mapping capabilities ✔	Localized measurements
Column and vertical retrievals ✔	Occultation and nadir viewing ✔	Modest vertical sounding
Long baseline studies ✔	Typically short missions	Limited expendables

ALMA (Line retrievals and high-angular resolution)

- Characterization of the vertical structure of water, D/H and trace species.
- Dust and and upper-atmosphere studies.



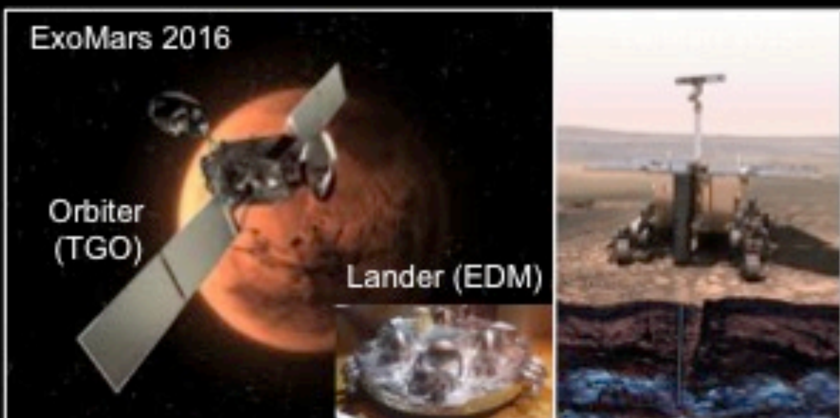
Infrared high spectral resolution and broad spectral coverage

- Comprehensive searches for trace species.
- Accurate isotopic studies (simultaneity).

A new era in infrared and optical astronomy

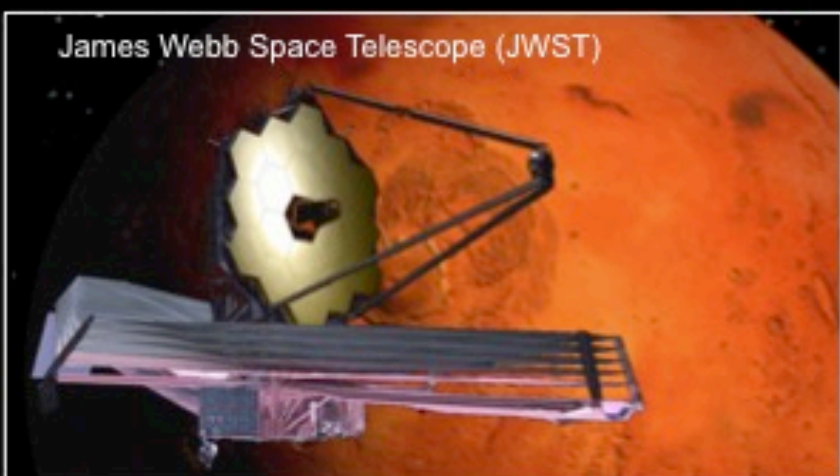
- High-resolution mapping of the whole hemisphere.
- Vertical retrievals at IR wavelengths.

Launch date	March 2016	May 2018/20	Oct 2018	July 2020
	ExoMars 2016	ExoMars 2018	JWST Observatory	



ExoMars (three components mission)

- High spectral resolution ($\lambda/\delta\lambda$ ~20,000) in the 0.7 to 25 μm region, targeting key trace species and atmospheric phenomena.
- Solar Occultation, Limb and Nadir sounding
- Probing of the sub-surface (2018)



James Webb Space Telescope

- L2 orbit provides instantaneous access to the whole Mars disk at very high spatial resolutions (mapping of transient events, diurnal and seasonal cycles).
- Imaging and spectroscopy in the 0.7 to 5.2 μm region available.

Conclusions

- The $2\nu_3$ band of methane is particularly weak at 6050 cm^{-1} (1.65 μm), reaching maximum absorptions ~0.4% for 50 ppbv.

- Extraordinary differential radiometric accuracy would be required to sample methane at the abundances previously reported (greater than 24,000 for 50 ppbv).

- Particularly problematic is the overwhelming spectral confusion with CO_2 and Fraunhofer solar lines at these wavelengths.

- A 0.004% in albedo, or a 3K change in the temperature of the atmospheric column or a 3% change in the depth Solar lines would produce the same differential radiometric signal as 50 ppbv of methane.

Thank you

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M1:Solar; M2:-1% Solar	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.7913615	8.8061554	-0.168277689	**0.001480192**
Flux measured with the ref detectors	8.9025447	8.9173937	-0.166795006	

M1:CO2,Solar; M2:+1% CO2	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.5916675	8.5904809	0.013811056	**6.74516E-05**
Flux measured with the ref detectors	8.6925832	8.6913768	0.013878498	

M1:CO2,H2O,Solar(220K); M2:210K	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.5870336	8.5793279	0.08973646	**-0.013443936**
Flux measured with the ref detectors	8.6882062	8.6815767	0.076304589	

M1:CO2,H2O,Solar; M2:+1% H2O	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.5912577	8.5912563	1.62956E-05	**3.26223E-06**
Flux measured with the ref detectors	8.6921535	8.6921518	1.95579E-05	

M1:CO2,H2O,Solar; M2:+10ppbv CH4	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.5912577	8.591188	0.00081129	**-0.000743419**
Flux measured with the ref detectors	8.6921535	8.6921476	6.78773E-05	

M1:CO2,H2O,Solar; M2:+50ppbv CH4	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.5912577	8.5908997	0.004167027	**-0.003725404**
Flux measured with the ref detectors	8.6921535	8.6921151	0.000441778	

M1:CO2,H2O,Solar; M2:+100ppbv CH4	Flux [mW/m2/sr]		Change [%]	
	Model #1	Model #2	Absolute	Differential
Flux measured with the CH4 detectors	8.5912577	8.5905368	0.008391088	**-0.007463291**
Flux measured with the ref detectors	8.6921535	8.6920728	0.000928424	