Challenges raised by the observed variations of methane on Mars

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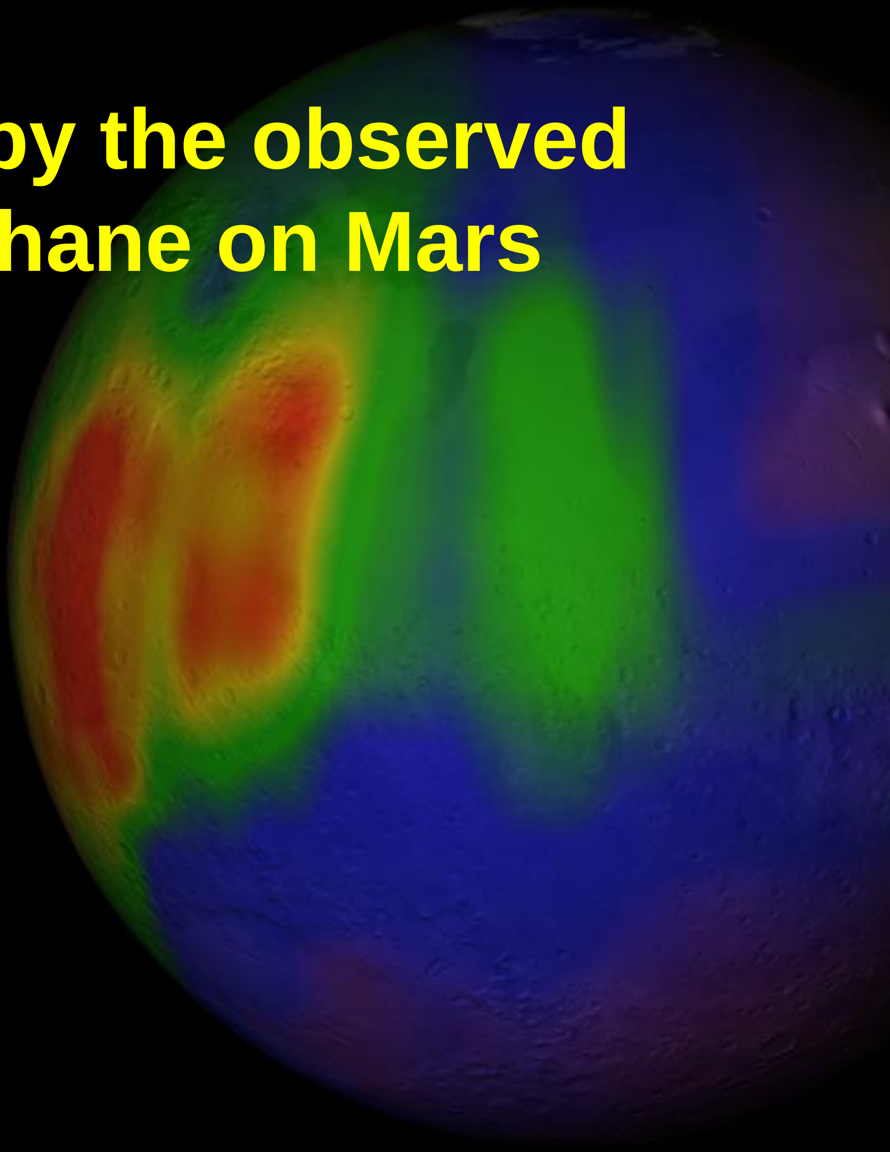
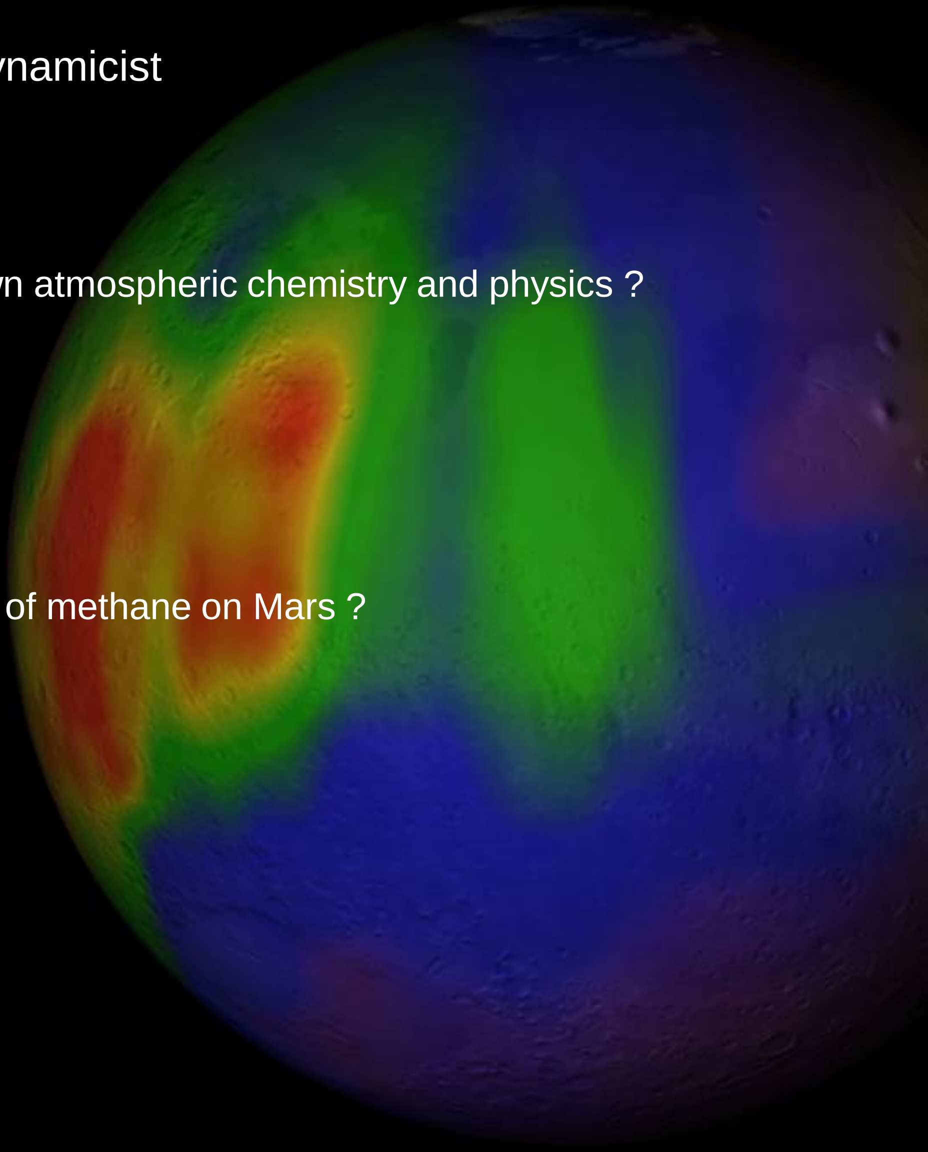


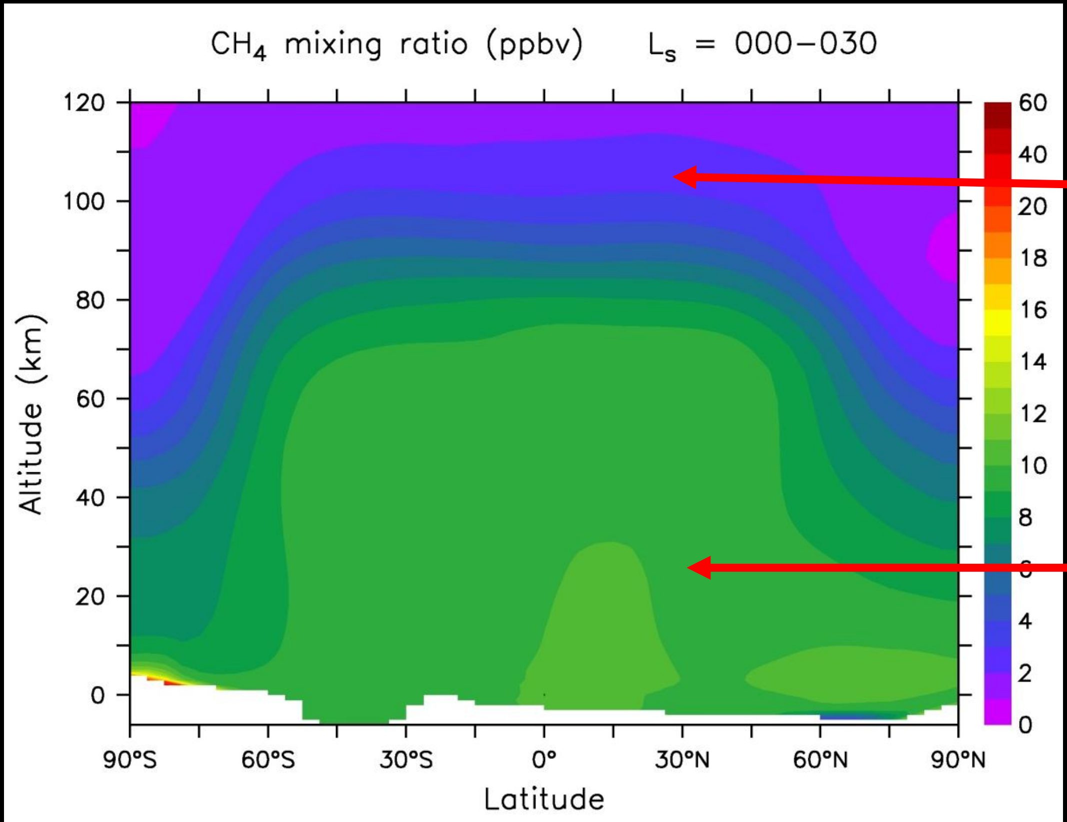
The point of view of the atmospheric chemist & dynamicist

- Are the observed variations consistent with the known atmospheric chemistry and physics ?
- Can the Mars atmosphere create variations ?
- What happens if the source is localized ? episodic ?
- What are the implications on the lifetime/source/sink of methane on Mars ?



The chemistry-as-we-know-it scenario

- Methane implemented in the LMD global climate model with coupled photochemistry



$CH_4 + h\nu \rightarrow$ products

$CH_4 + O(^1D) \rightarrow$ products

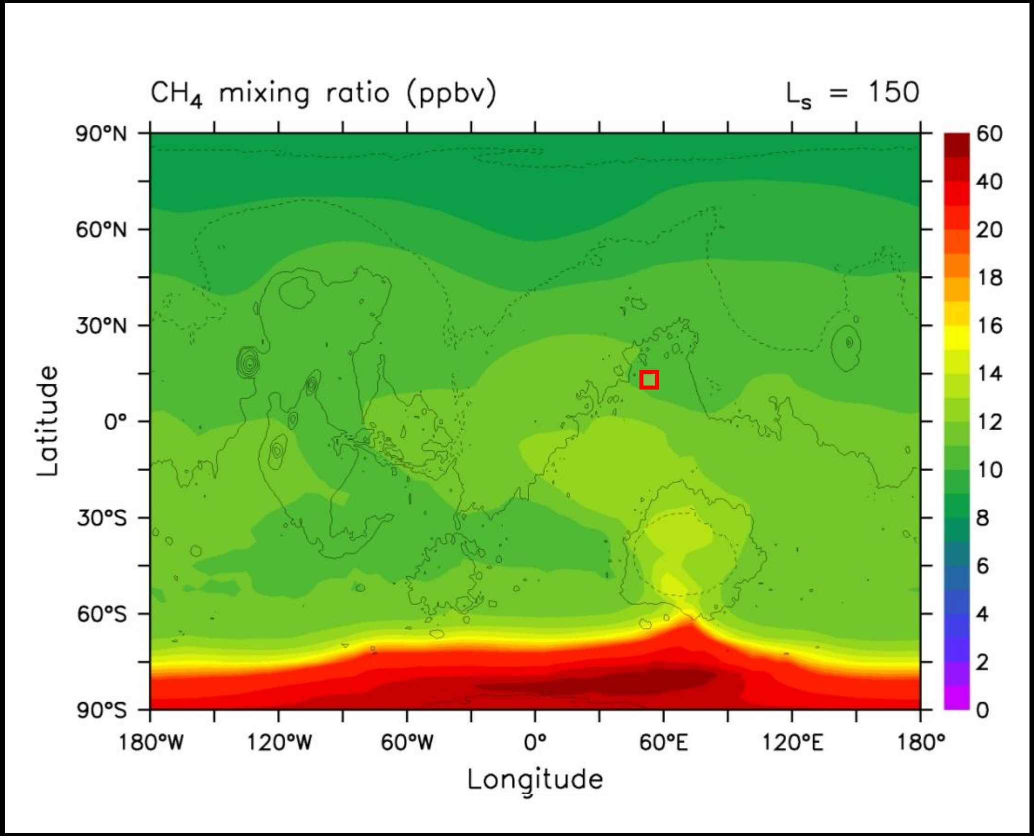
$CH_4 + OH \rightarrow CH_3 + H_2O$

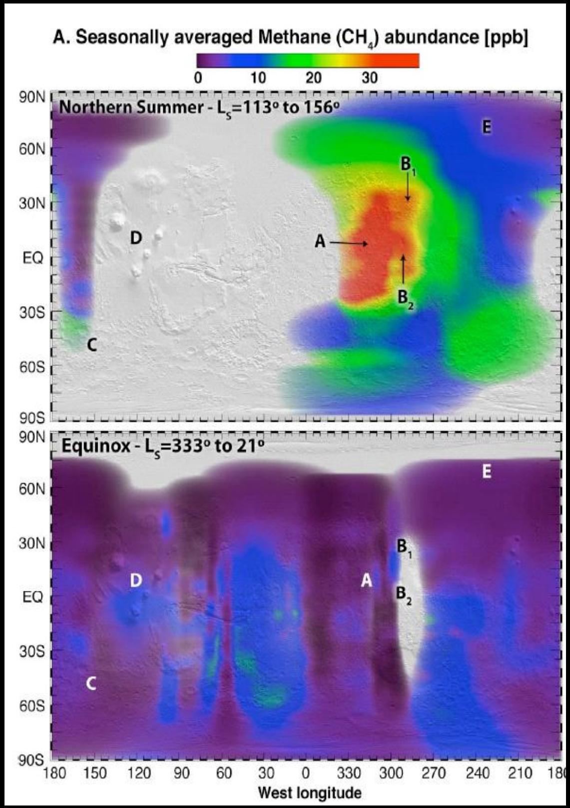
- Lifetime: 330 terrestrial years
- Source: 260 t terrestrial year^{-1} (Earth: 582×10^6 t year^{-1})

The chemistry-as-we-know-it scenario

• what if the methane source is localized ? episodic ? both ?

release: L_s = 135-166° (60 sols)





Villanueva et al., this workshop

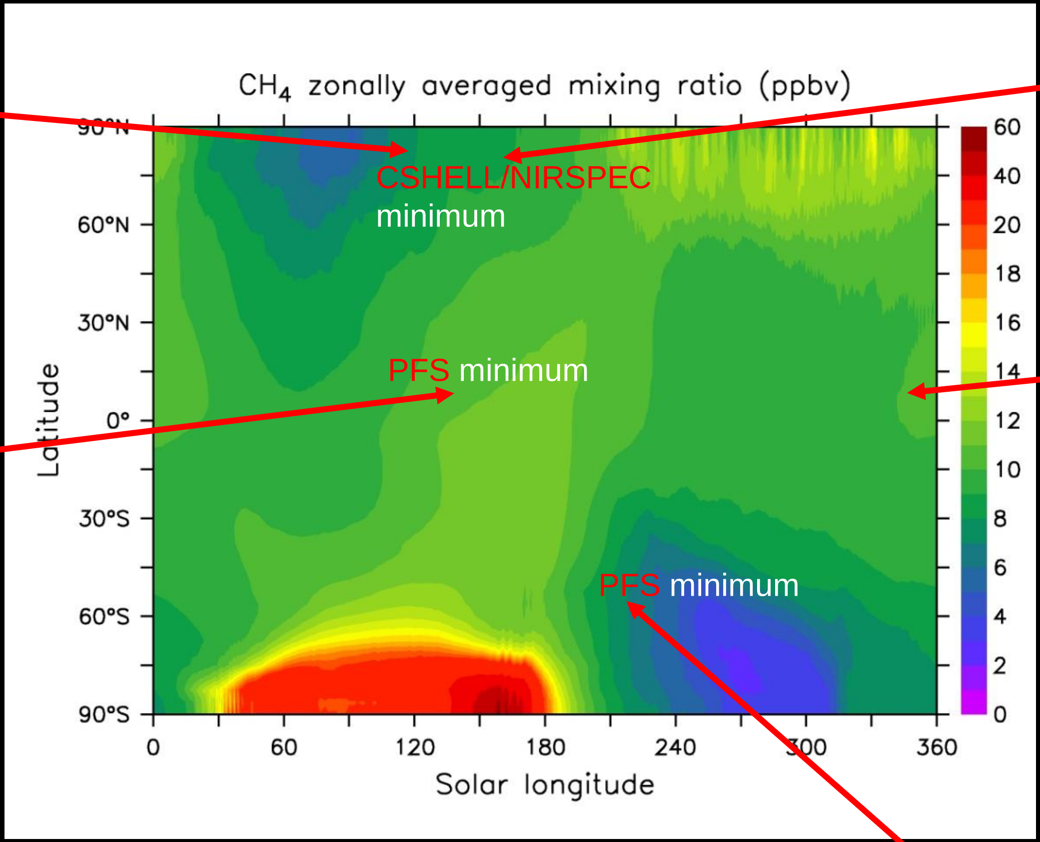
The chemistry-as-we-know-it scenario

PFS observes a maximum here

Geminale et al., this workshop

CSHELL/NIRSPEC observe a maximum here

Mumma et al., 2009



PFS observes a maximum here

Geminale et al., this workshop

CSHELL/NIRSPEC observes a minimum here

Geminale et al., 2008

Mumma et al., 2009

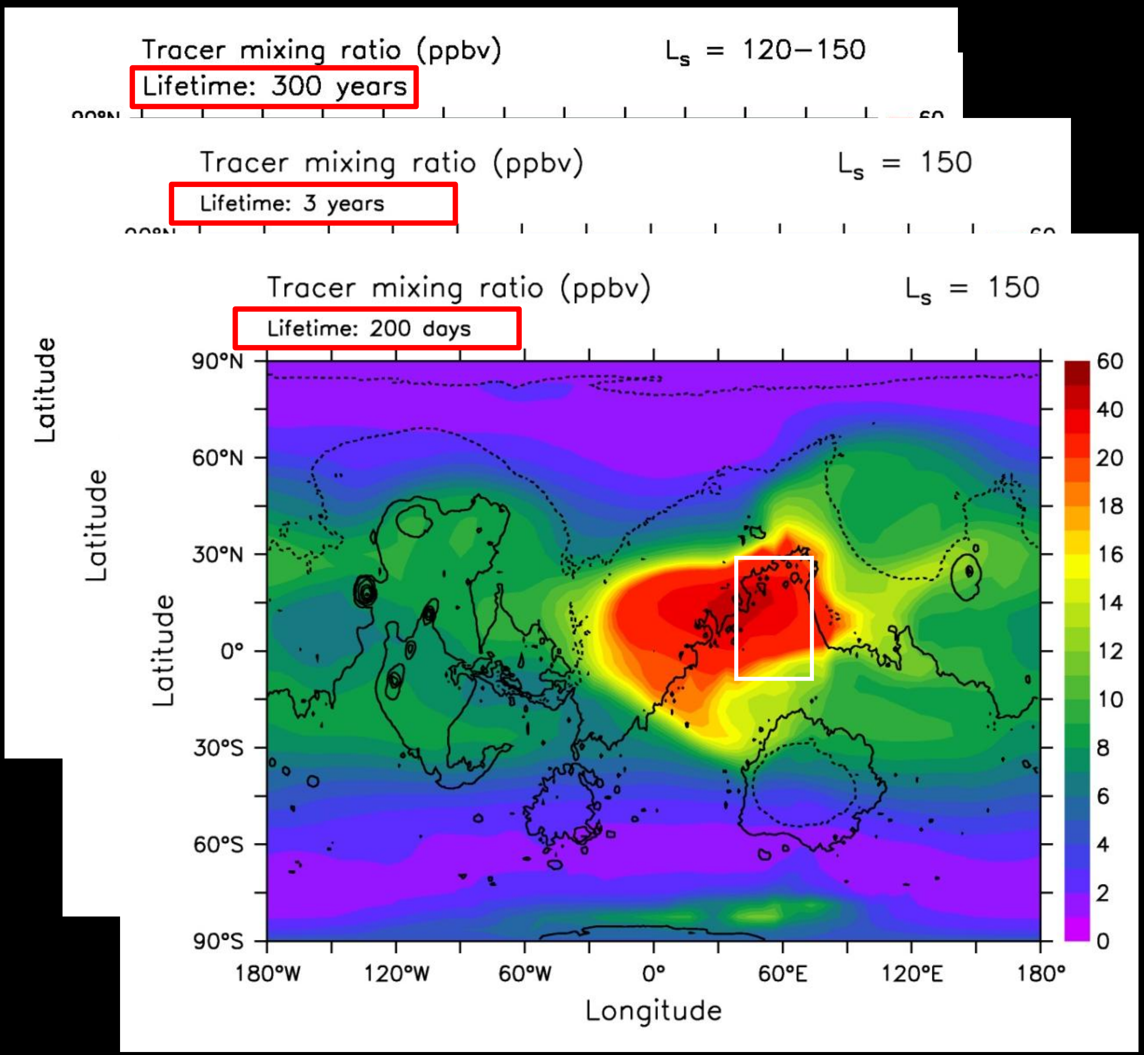
CSHELL observes a maximum here

Villanueva et al., this workshop

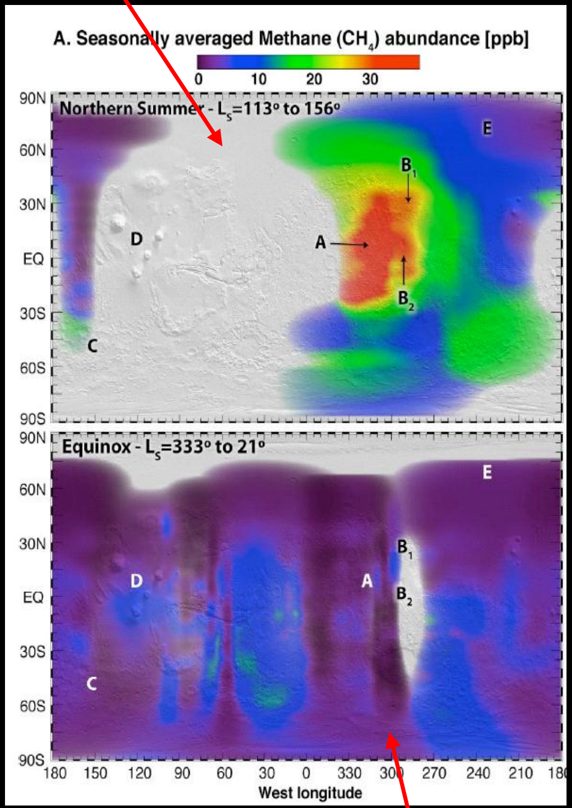
- A (much) stronger source is needed → stronger sink → shorter lifetime

Shorter lifetime ?

- Idealised tracers released from Syrtis Major
- Episodic source ($L_s \sim 150°$)
- Various lifetimes (1000 years to 100 days) in the atmosphere



Jan-Mar 2003 (MY26)



Villanueva et al., this workshop

Jan-Mar 2006 (MY27-28)

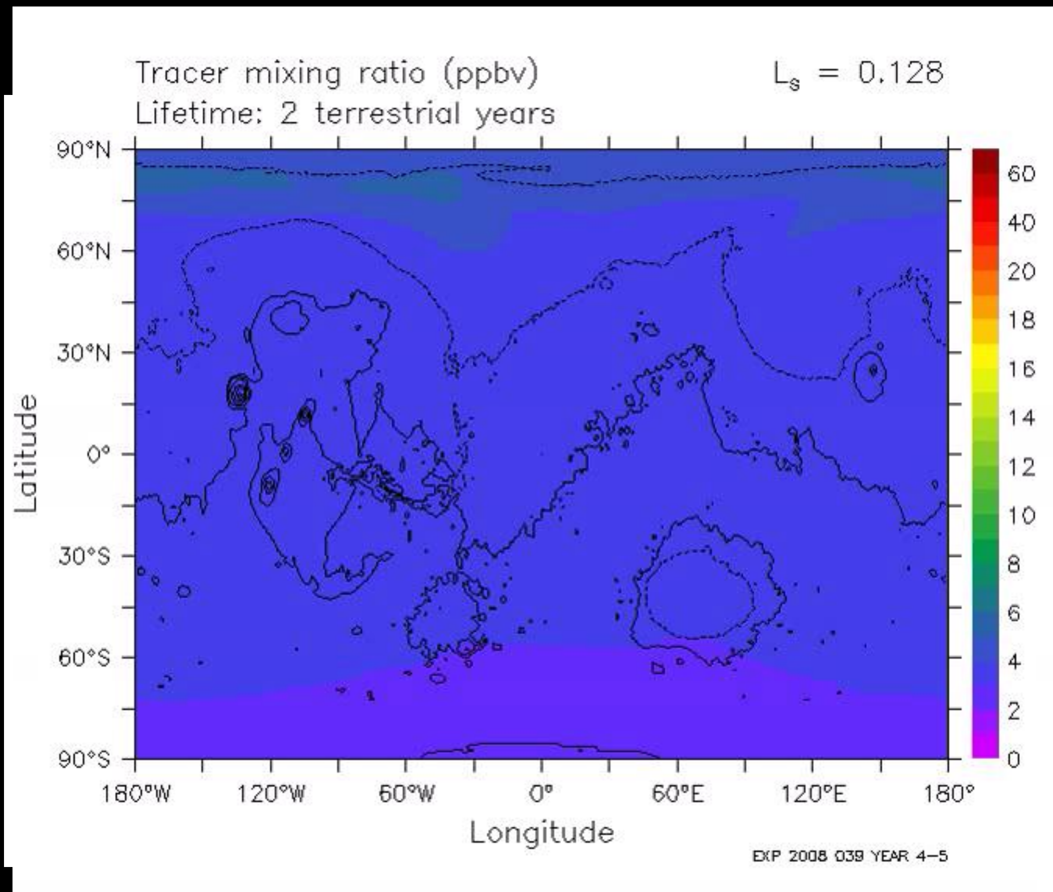
Lifetime: 200 days
Source: ~150 000 t

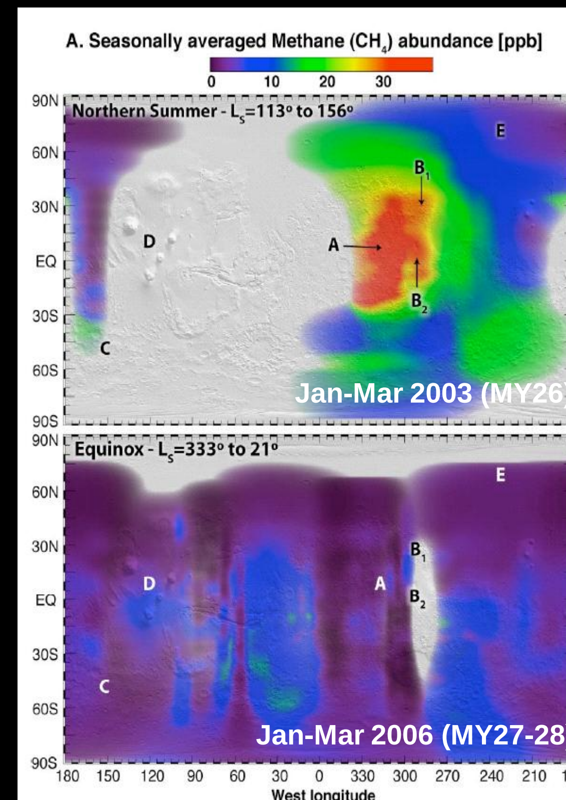
Lefèvre and Forget, *Nature*, 2009

The CSHELL/NIRSPEC scenario

Lifetime in the atmosphere: 2 terrestrial years

release: L_s = 120-183° (120 sols)





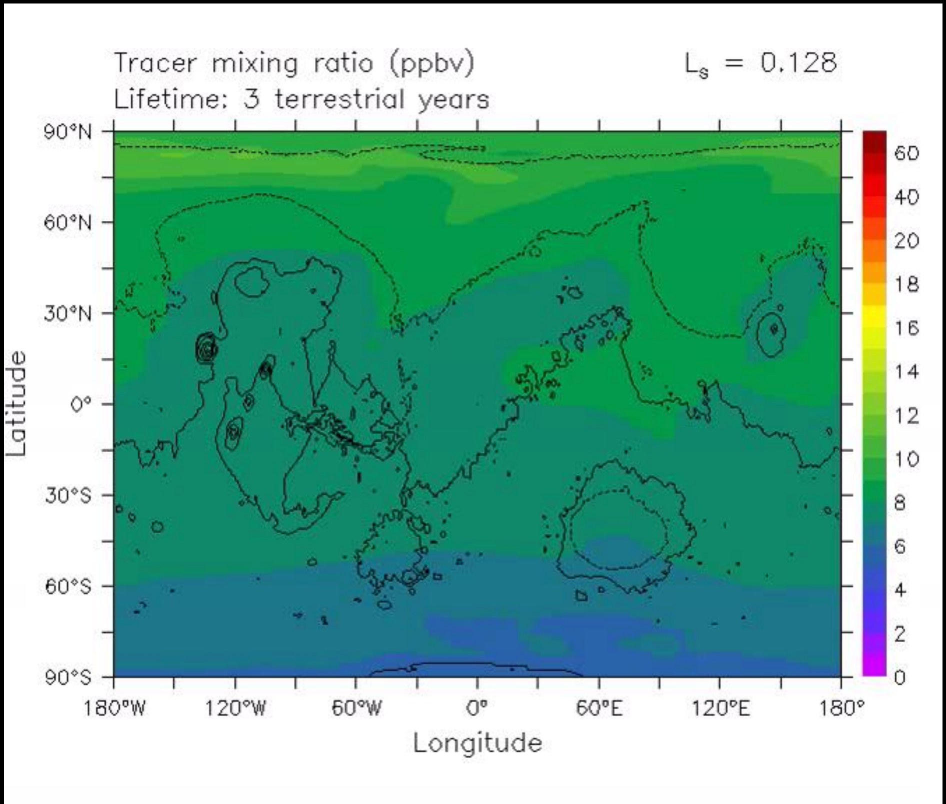
Villanueva et al., this workshop

Source: ~80 000 t

The PFS scenario

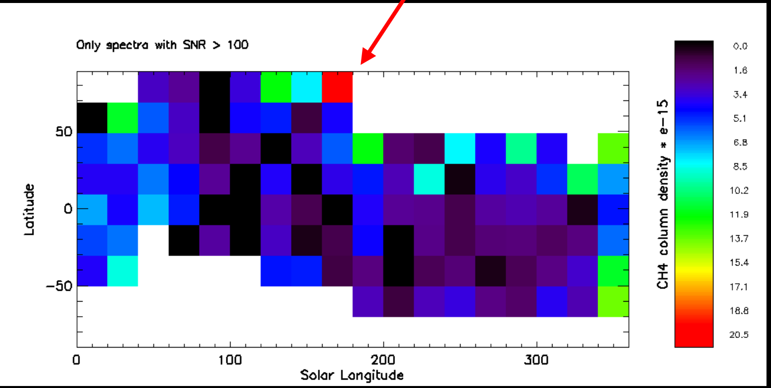
Lifetime in the atmosphere: 3 terrestrial years

release: L_s = 120-183° (120 sols)

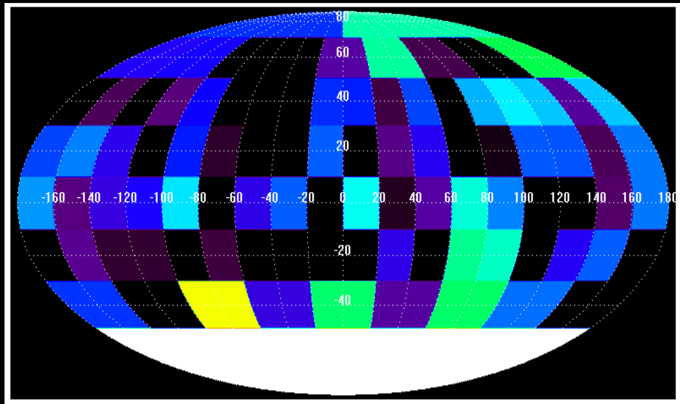


• methane source : between 25-30 km altitude

~40 ppbv



Geminale et al., this workshop



L_s = 90-180

Formisano et al., this workshop

A missing atmospheric loss of methane ?

Maybe!

but

1. This process must be extremely powerful (100-500 x faster than the « conventional » methane loss)

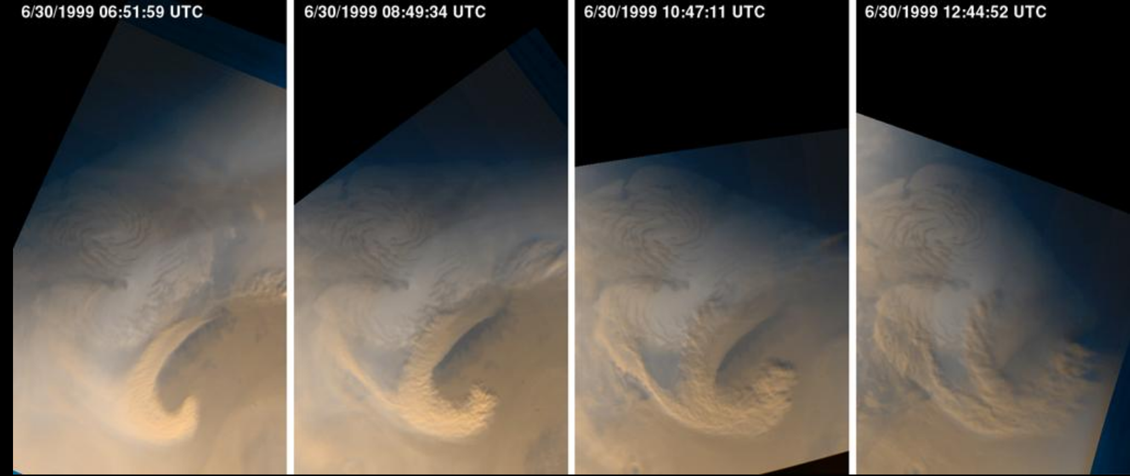
2. It must be consistent with the observed behaviour of

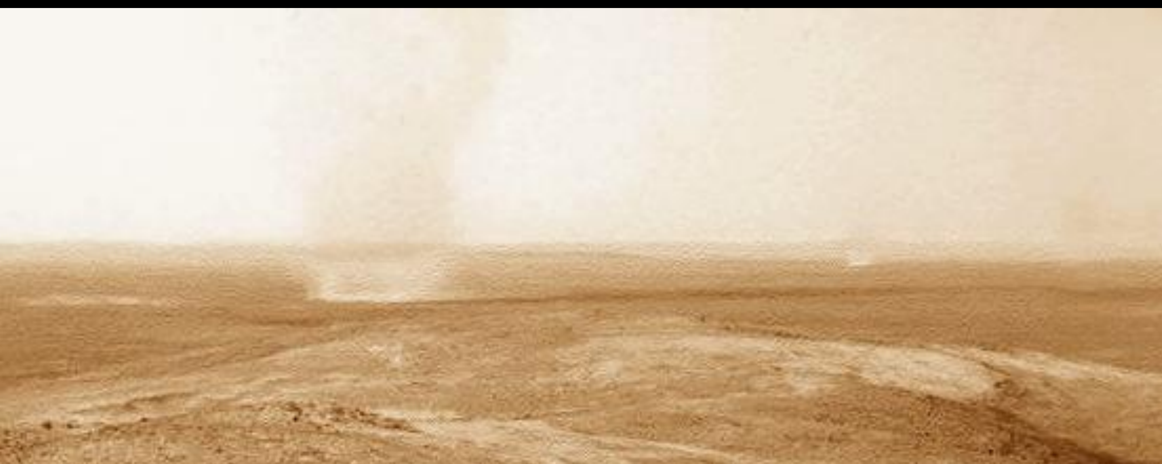
   – Methane on Earth
   – Other species on Mars

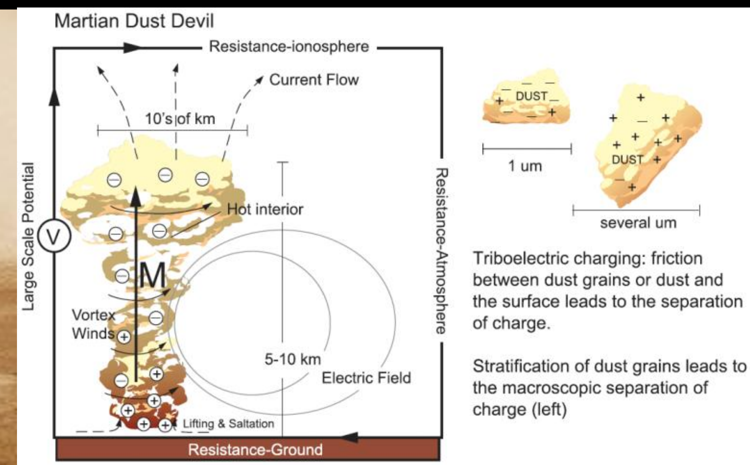
O_3	Perrier et al., 2006; Fast et al., 2008; Lefèvre et al., 2008; Krasnopolsky, 2009
CO	Smith et al., 2009
H_2O_2	Clancy et al., 2004; Encrenaz et al., 2004; 2008; Lefèvre et al., 2008

- Loss by chlorine
- Loss by triboelectricity
- Loss in the regolith

Methane loss by tribolectricity







DeLory et al., *Astrobiology*, 2006; Atreya et al., *Astrobiology*, 2006; Farrell et al., *Geophys. Res. Lett.*, 2007

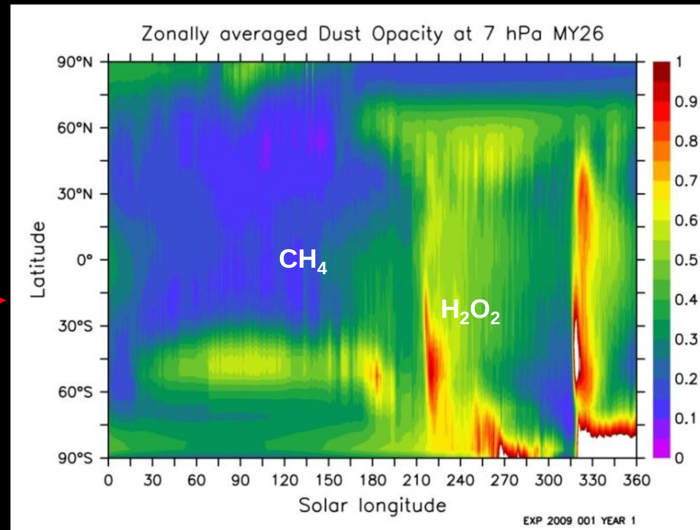
$CO_2 + e^- \rightarrow CO + O^-$

$H_2O + e^- \rightarrow OH + H^- \rightarrow \ldots \rightarrow H_2O_2$

$CH_4 + e^- \rightarrow$ products

Simulation with tribolectricity

$E \approx 25$ kV m^{-1} for $\tau_{vis} \geq 2$

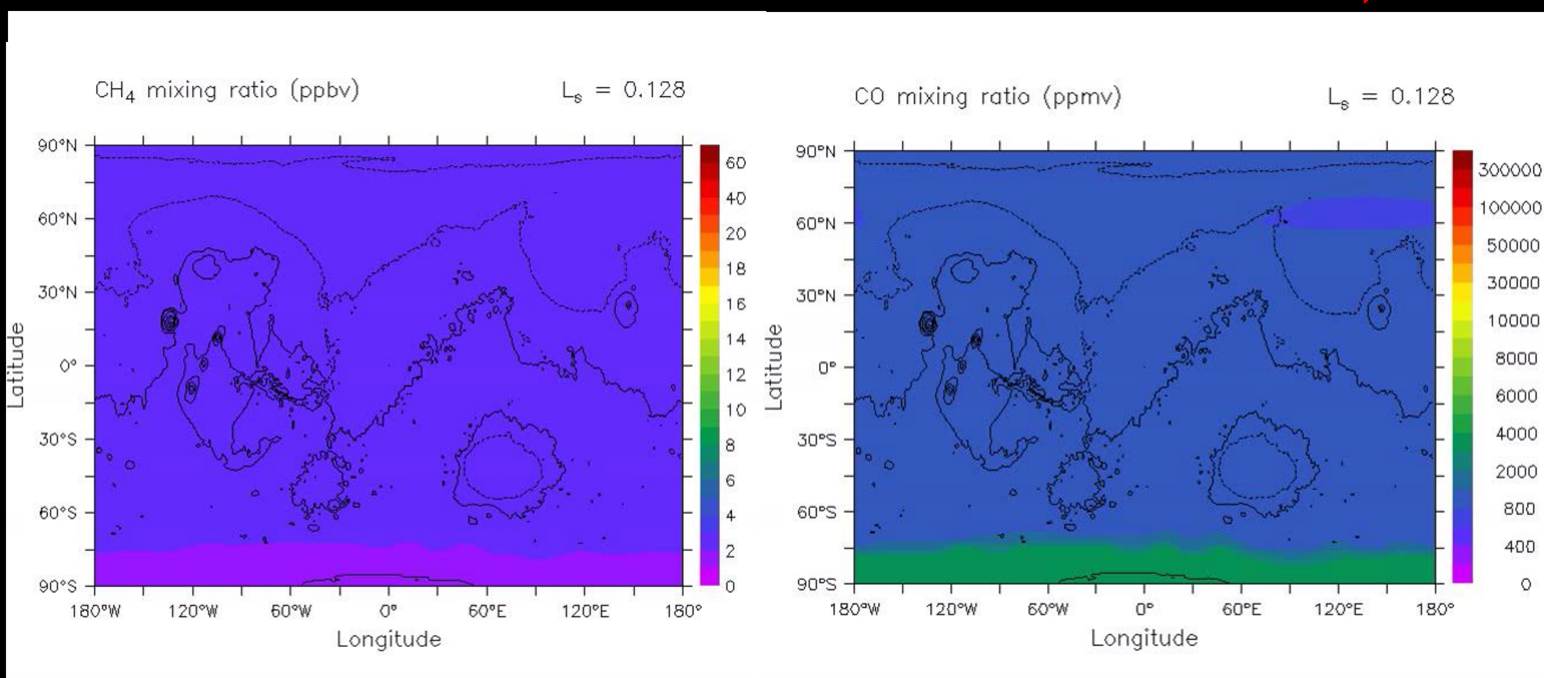


TES dust opacity

MY26 (2002-2004)

50 times as large as the observations

CH_4



CO

observations: ~800 ppmv

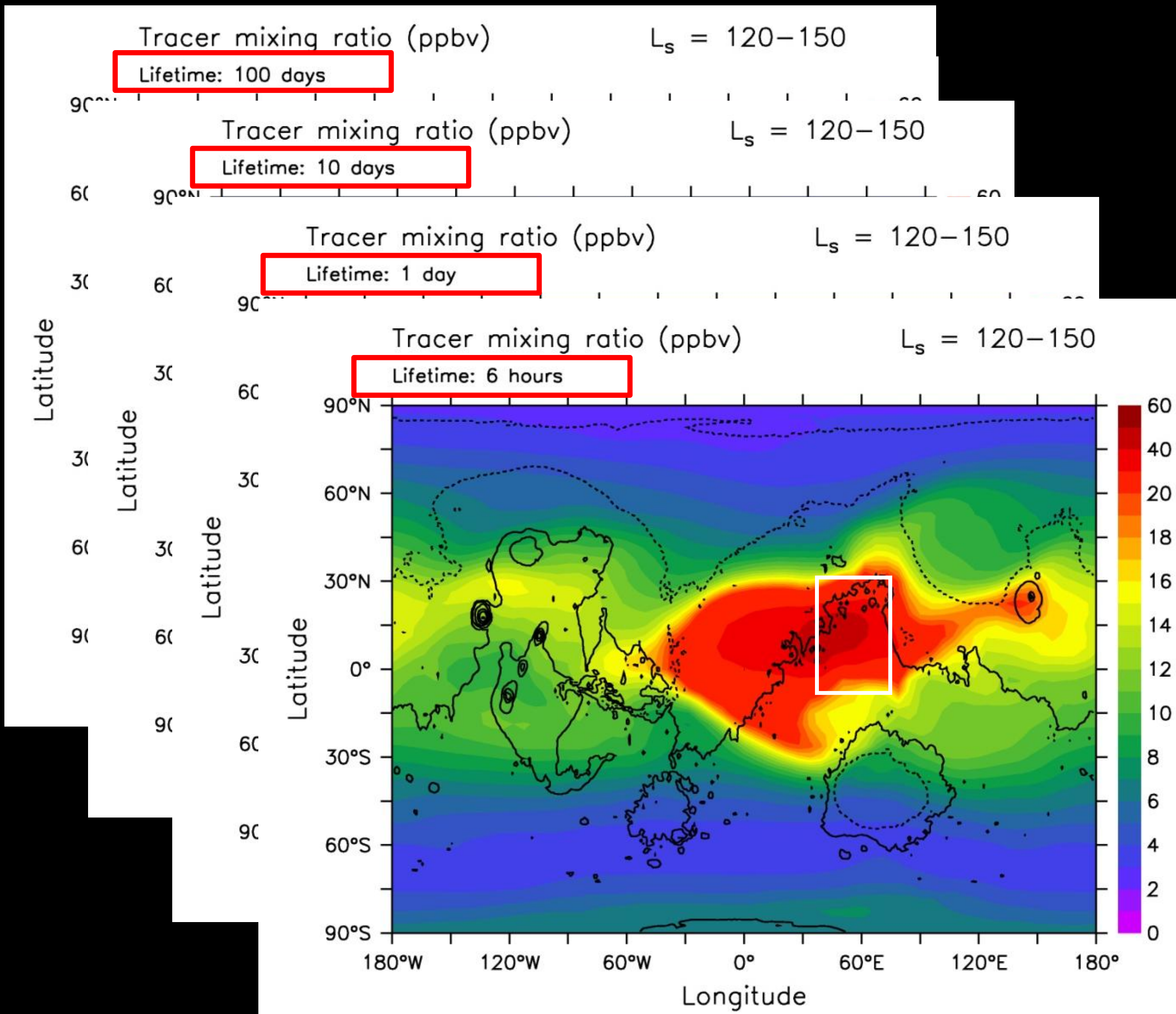
$CH_4 + e^- \rightarrow$ products

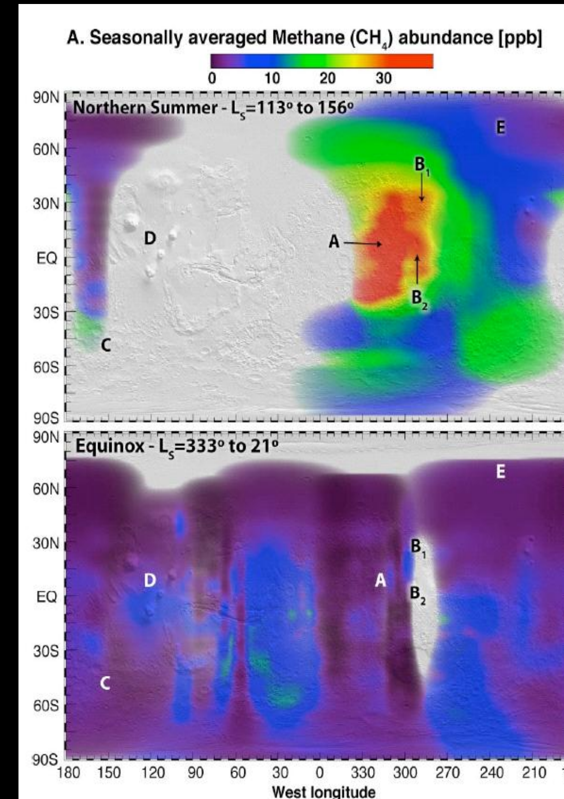
$CO_2 + e^- \rightarrow CO + O^-$

Methane loss in the regolith

- triboelectric production of H_2O_2 → precipitation → buildup of oxidants in the regolith — Atreya et al., 2006; 2007
- reversible adsorption of CH_4 — Gough et al., this workshop; Meslin et al. (see poster)
- in situ formation of H_2O_2 and other oxides/superoxides — Hurowitz et al., 2006; Davila et al., 2008

methane loss in the regolith





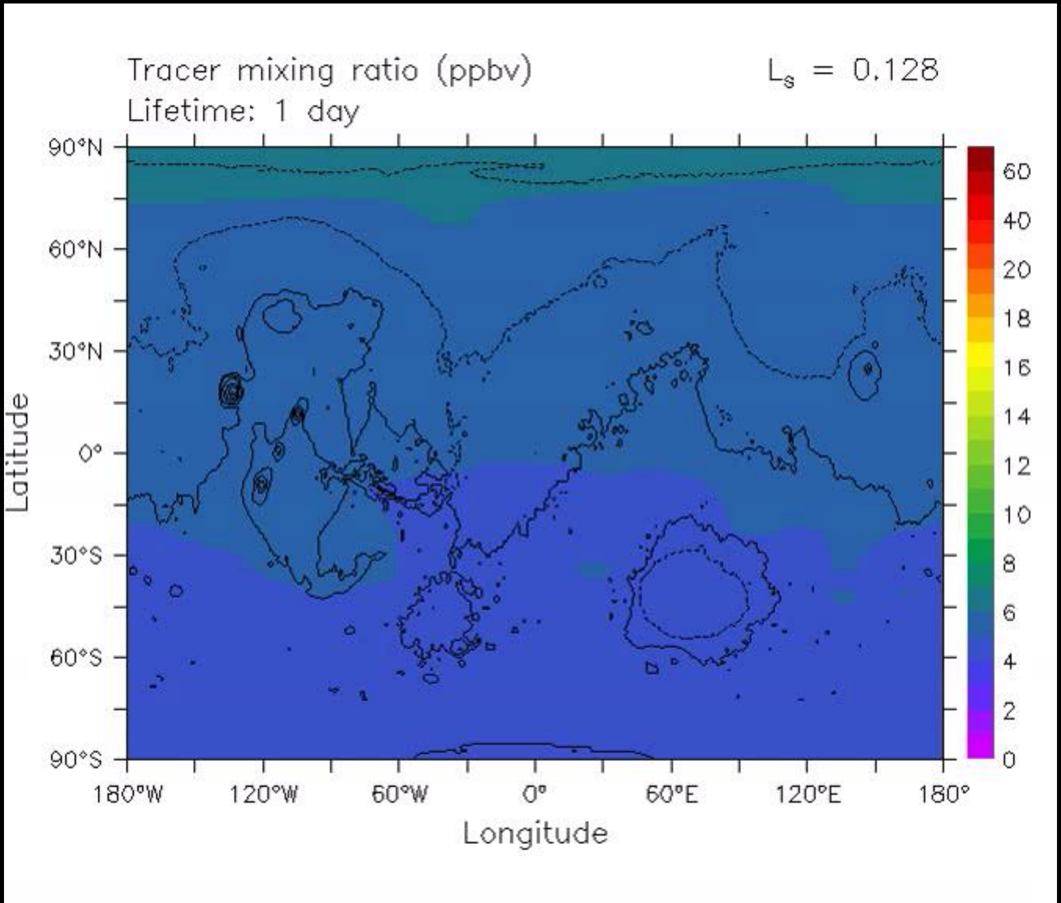
Villanueva et al., this workshop

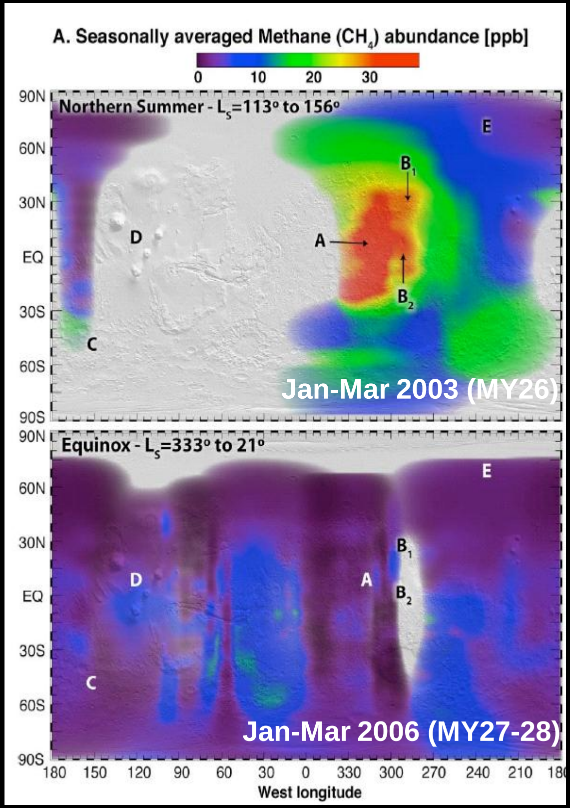
Lifetime: ~ 6 hours

Lefèvre and Forget, 2009

The CSHELL/NIRSPEC scenario

Lifetime in the regolith: 24 hours
release: L_s = 120-183° (120 sols)





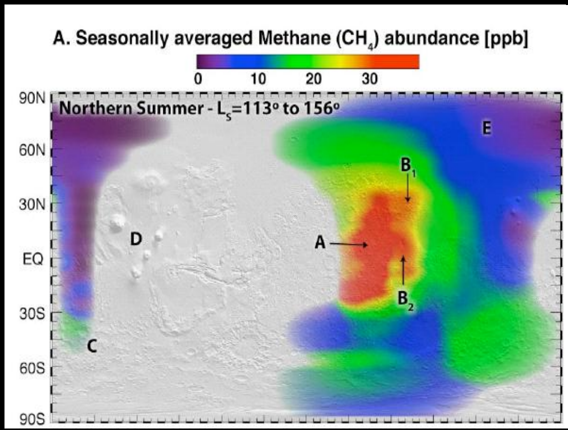
Villanueva et al., this workshop

Conclusions

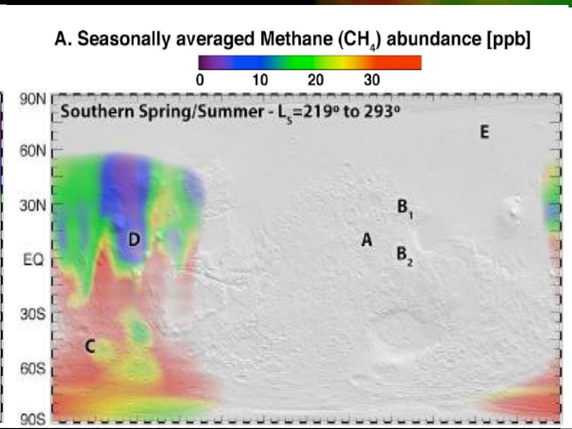
- The "conventional" atmospheric chemistry does not produce measurable methane variations on Mars, even in the case of a current, episodic, and localized source.

- The condensation/sublimation cycle of CO_2 should generate large-scale methane variations at high latitudes (*but they differ from what is observed*).

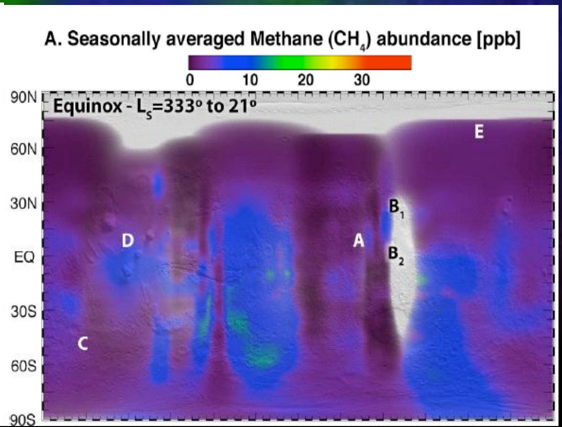
- CSHELL/NIRSPEC: In the most favourable case, an atmospheric CH_4 lifetime of less than 200 days (seasonal release) or ~2 Earth years (single event) is necessary to reproduce the observations.



Jan-Mar 2003 (MY26)



May-June 2005 (MY27)



Jan-Mar 2006 (MY27-28)

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- CSHELL/NIRSPEC: In the most favourable case, an atmospheric CH_4 lifetime of less than 200 days (seasonal release) or ~2 Earth years (single event) is necessary to reproduce the observations.

- PFS: measurements at high latitudes require a lifetime of less than ~3 Earth years. Longitudinal variations at high latitudes and seasonal trends at mid-to-low latitudes cannot be reproduced.

- The CH_4 source: quantitative agreement with the observations requires considerable amounts:

~150 000 tonnes	CSHELL/NIRSPEC, seasonal release
~ 80 000 tonnes	CSHELL/NIRSPEC, single event
~ 50 000 tonnes	PFS, polar summer

Mid-Atlantic Ridge: 50 000-130 000 t yr^{-1}
(Keir et al., 2005)

Conclusions

Solutions ?

- fast atmospheric loss of methane by chlorine:
  - is not supported by observations of HCl
- fast atmospheric loss of methane by electrochemistry:
  - is not supported by current observations of CO, H_2O_2, and O_3
- fast loss of methane in the regolith:
  - must be extraordinarily rapid (< 24 h) to satisfy the observations
  - is not supported by current observations of other minor species (CO, H_2O_2, O_3), or must be highly selective
  - is for the moment not supported by laboratory data (Gough et al., this workshop)

Observed variations of methane are unexplained by known atmospheric chemistry and physics