Challenges raised by the observations of Martian methane

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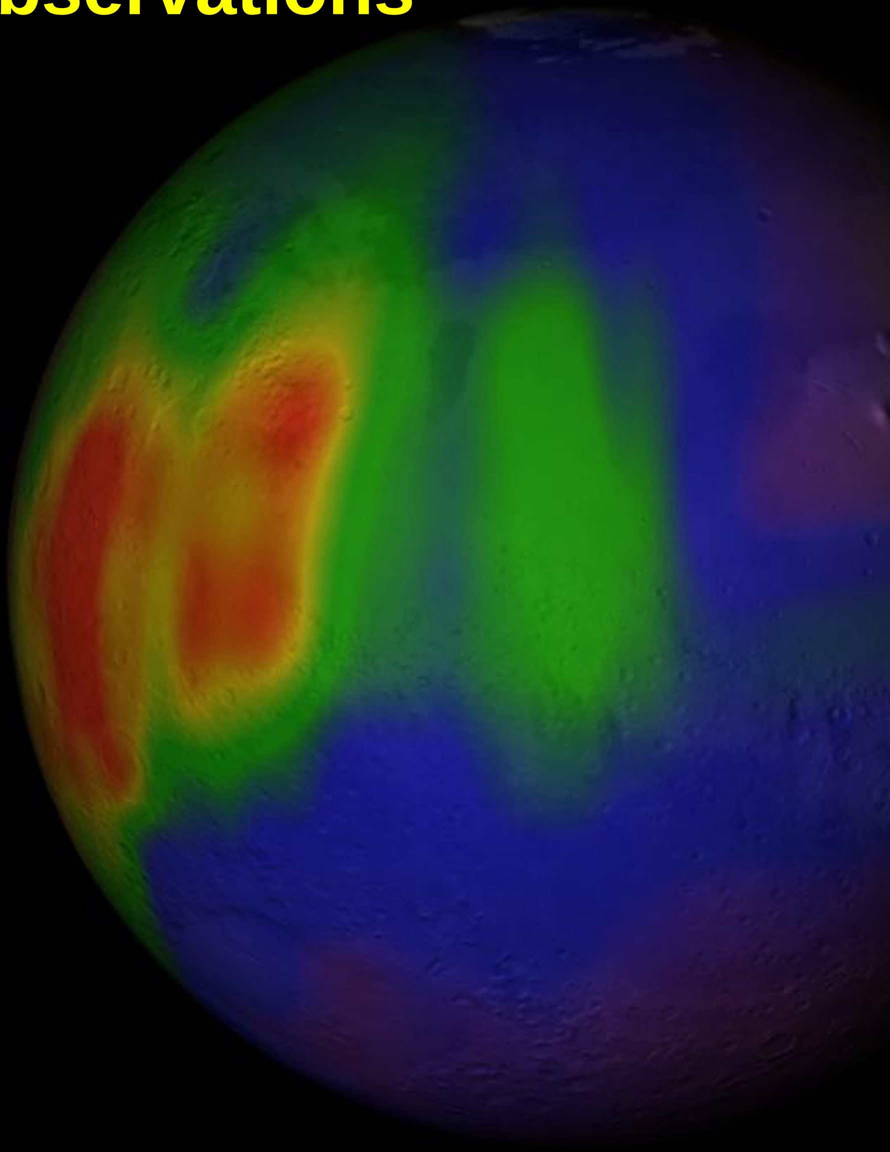
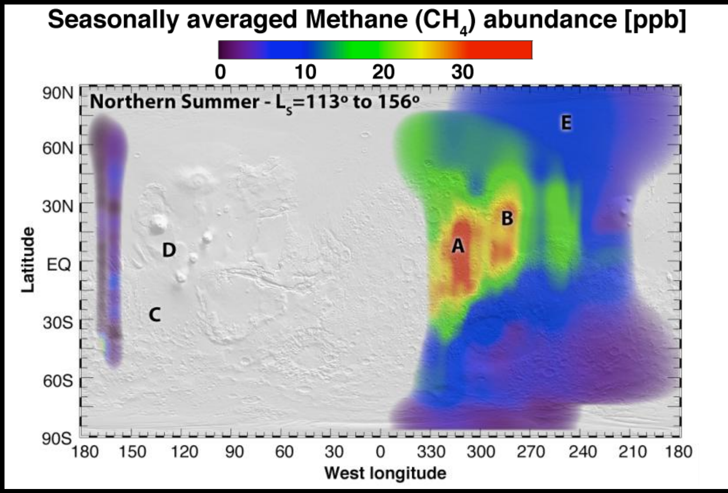
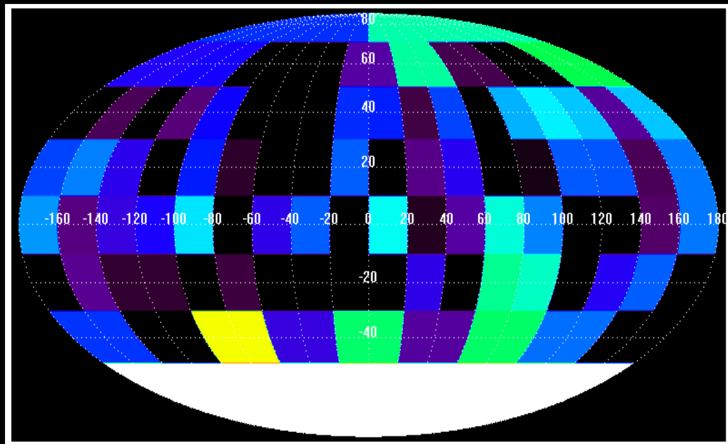






L_S = 90-180

CSHELL/NIRSPEC

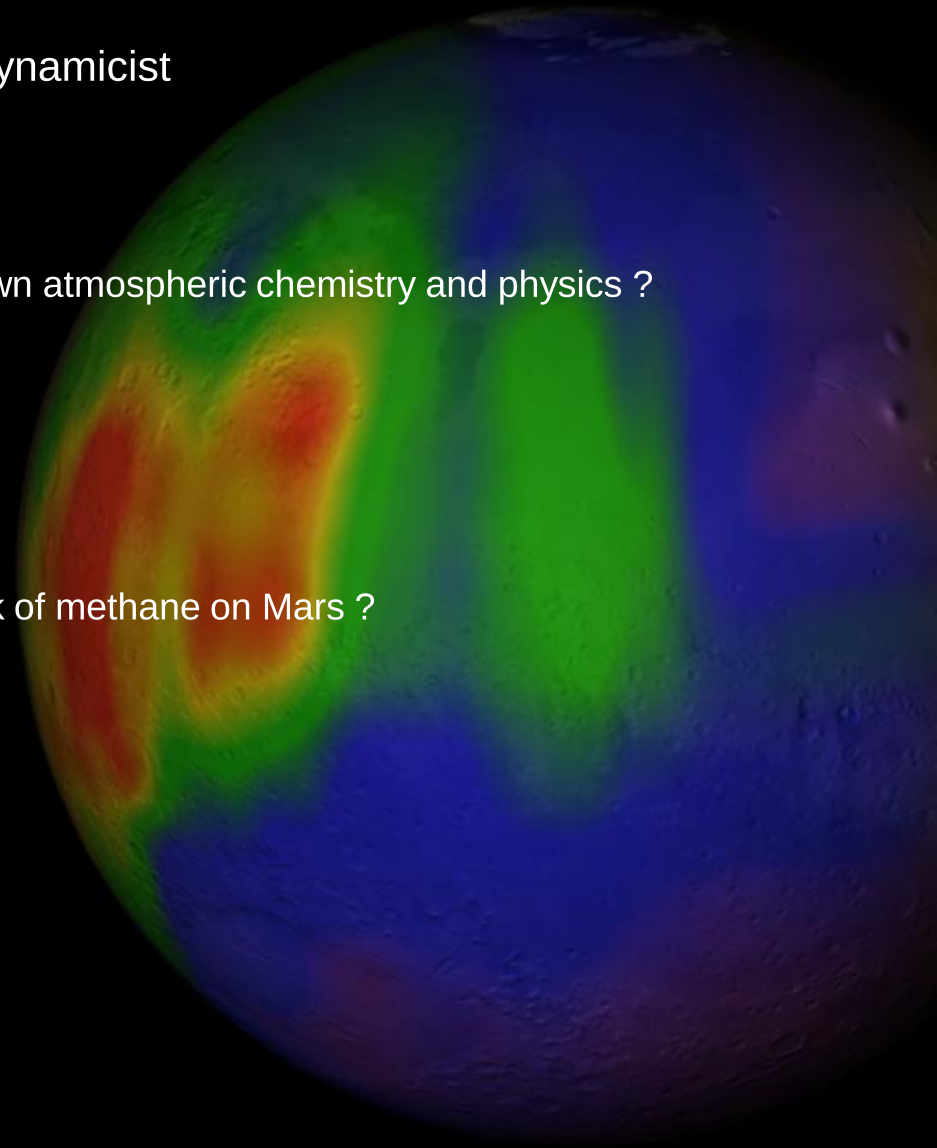
Mumma et al.
Science, 2009

PFS

Formisano et al.
ESA-ASI Methane workshop, 2009

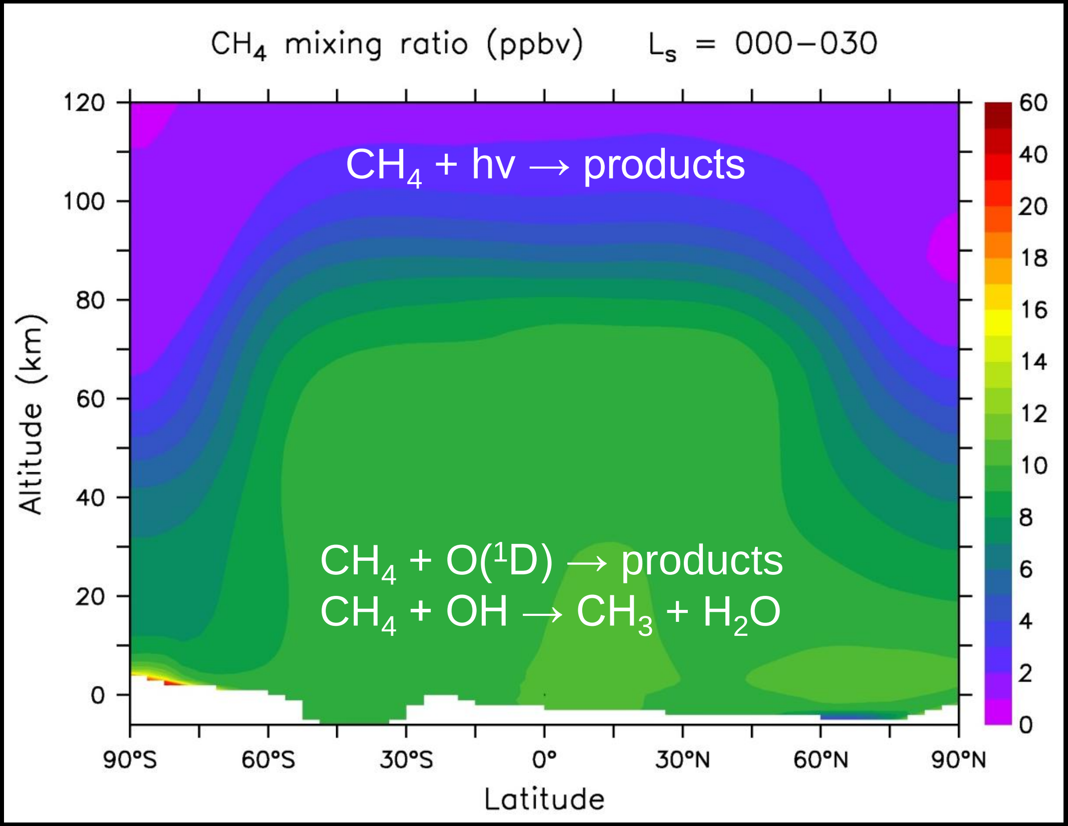
The point of view of the atmospheric chemist & dynamicist

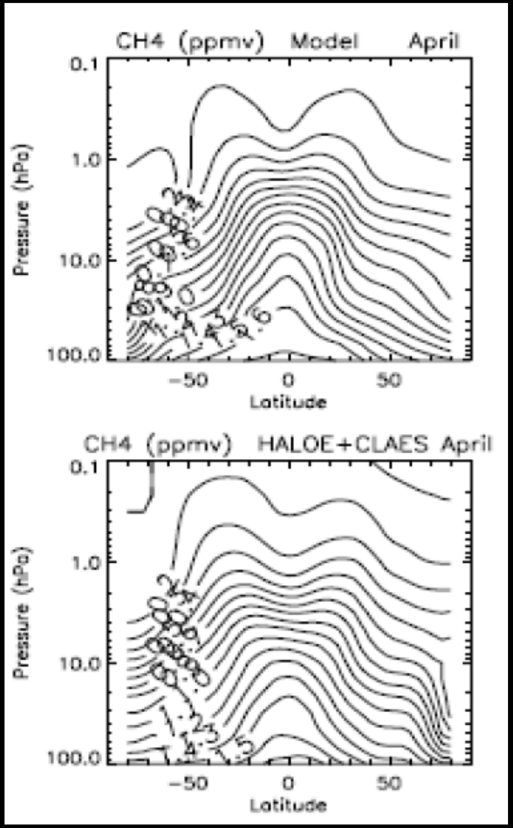
- Are the observed variations consistent with the known atmospheric chemistry and physics ?
- Can the Mars atmosphere create variations ?
- What happens if the source is localized ? episodic ?
- What are the implications on the lifetime/source/sink of methane on Mars ?



The chemistry-as-we-know-it scenario

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





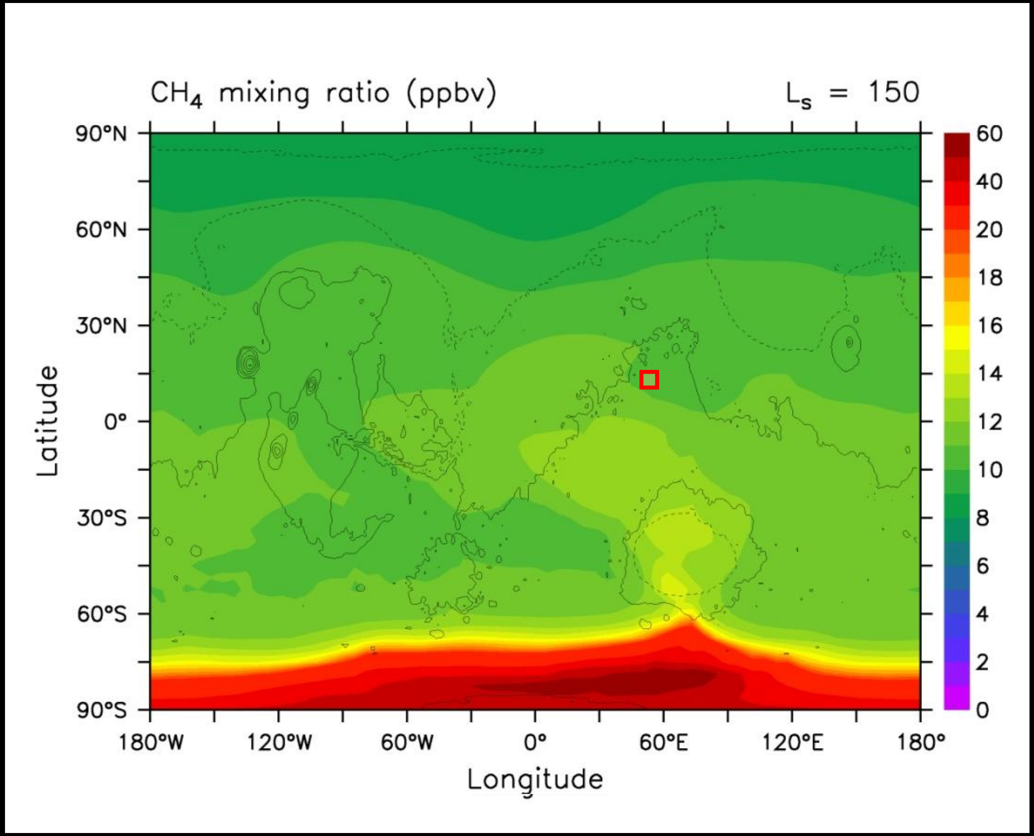
Jourdain et al., 2008

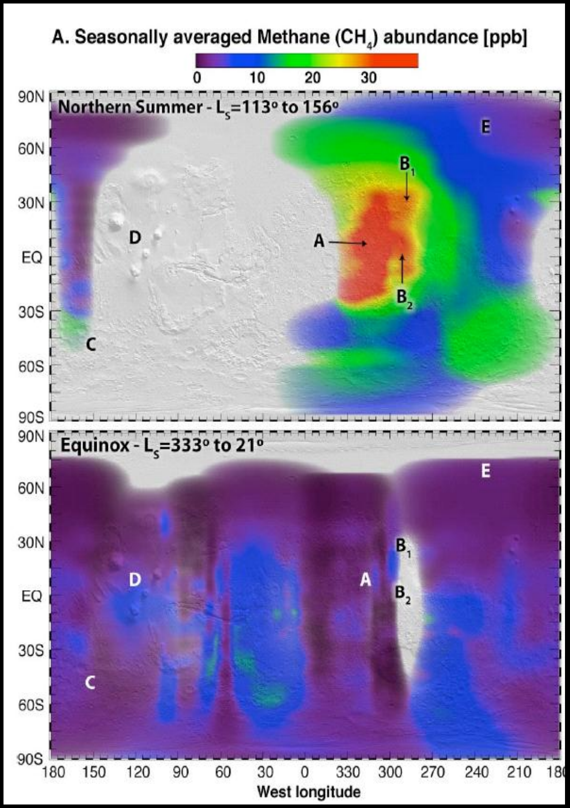
- Lifetime: 330 terrestrial years
- Source: 260 t terrestrial year^{-1} (Earth: 582×10^6 t year^{-1})

The chemistry-as-we-know-it scenario

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

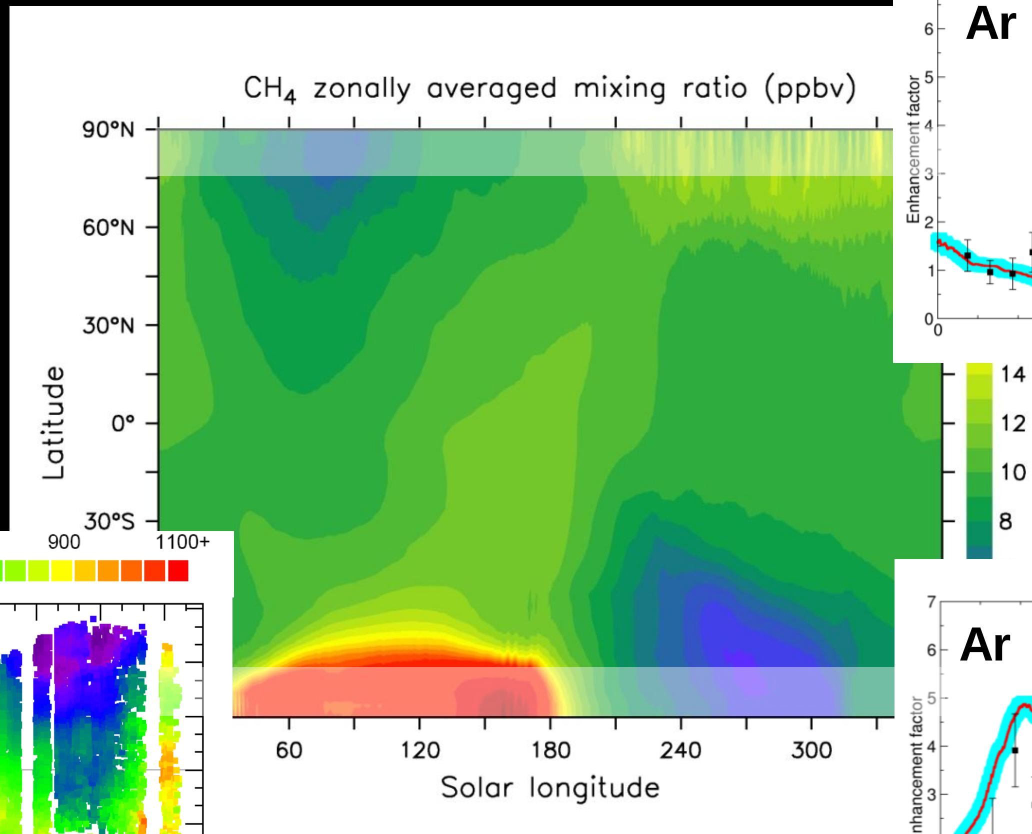
release: L_s = 135-166° (60 sols) ⇒ most favourable case!



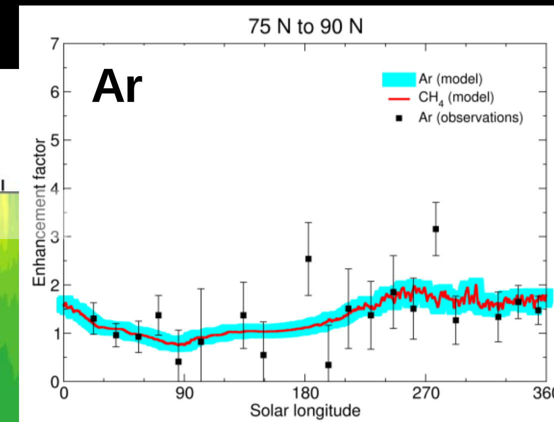


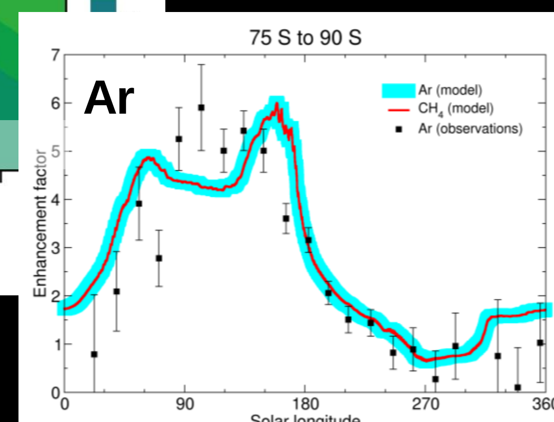
Villanueva et al.
ESA-ASI Methane workshop, 2009

the chemistry-as-we-know-it scenario

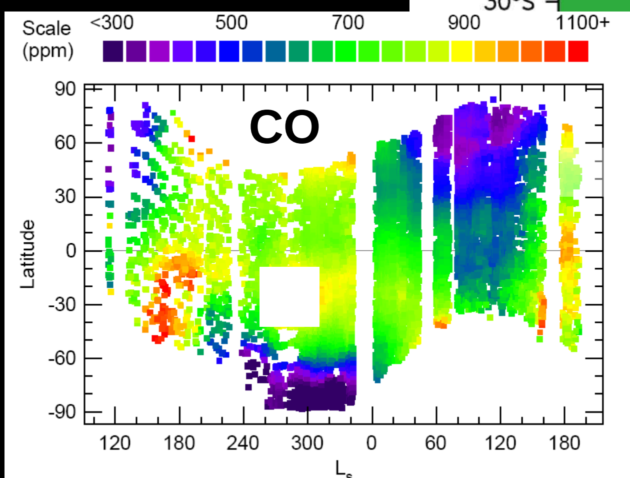


et, 2009





Sprague et al., 2004; 2007



Smith et al., 2009

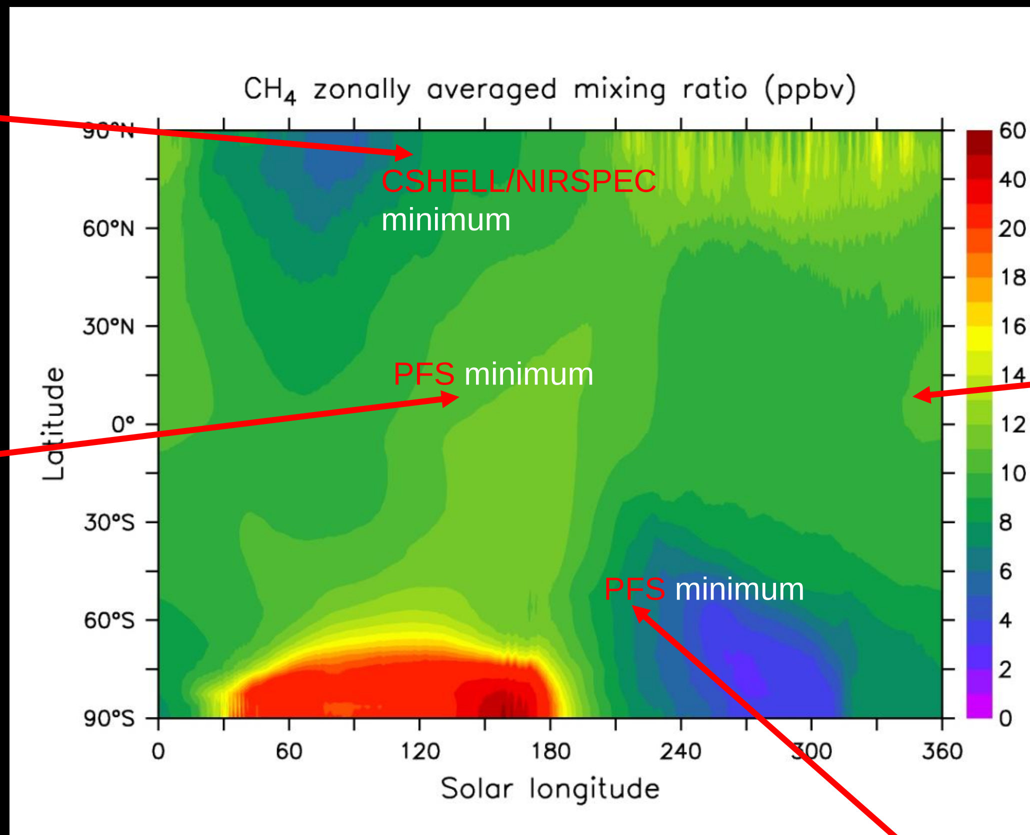
The chemistry-as-we-know-it scenario

PFS observes a maximum here

Geminale et al., 2009

CSHELL/NIRSPEC observe a maximum here

Mumma et al., 2009



CSHELL/NIRSPEC and PFS observe a minimum here

Geminale et al., 2008

Mumma et al., 2009

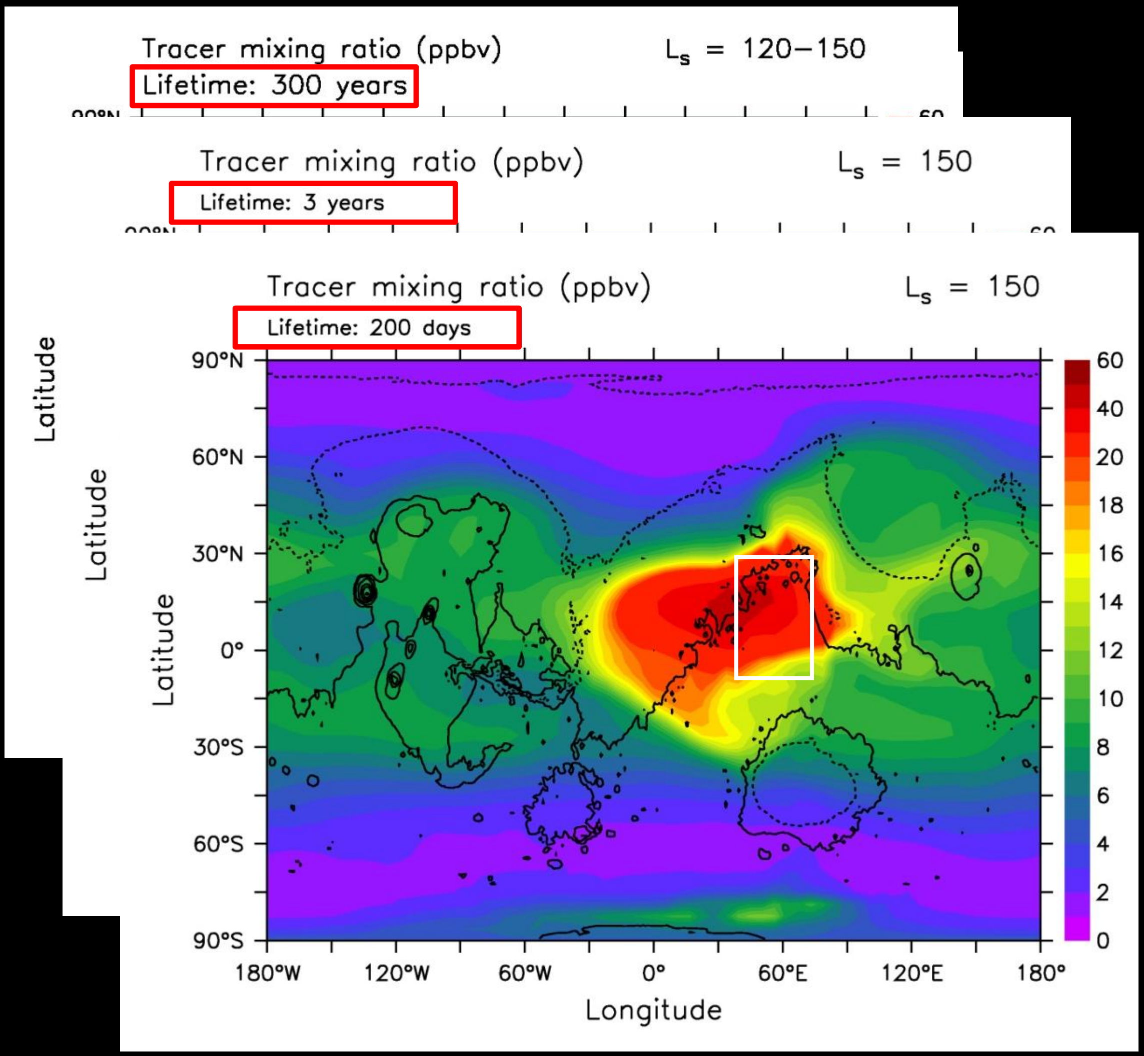
CSHELL observes a maximum here

Villanueva et al., 2009

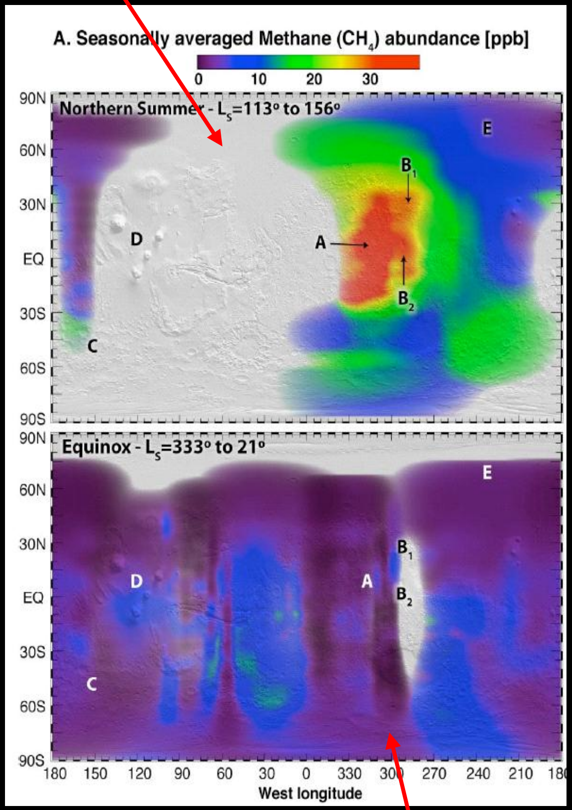
- A (much) stronger source is needed → stronger sink → shorter lifetime

Shorter lifetime ?

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



Jan-Mar 2003 (MY26)



Villanueva et al., ESA-ASI methane workshop, 2009

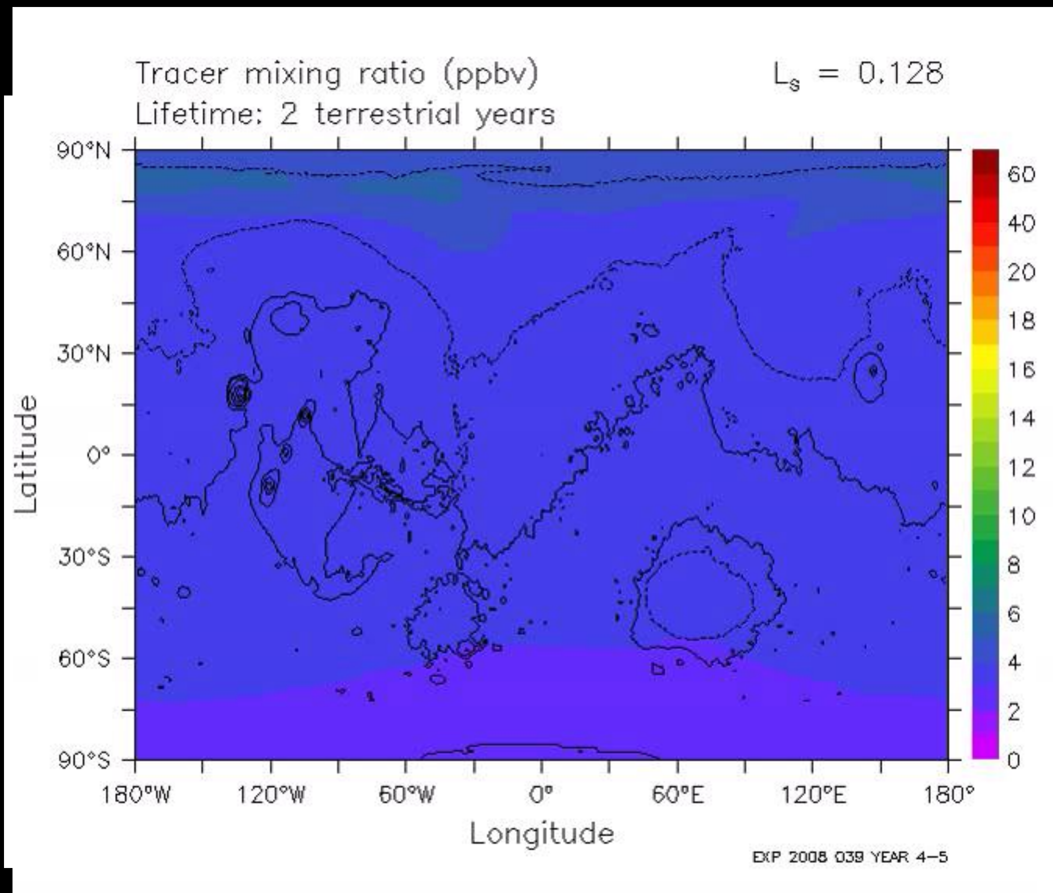
Jan-Mar 2006 (MY27-28)

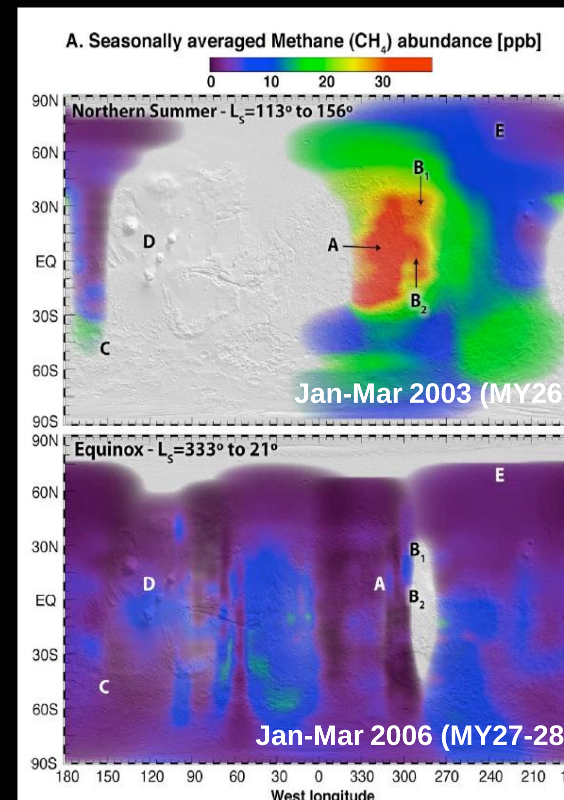
Lifetime: 200 days

The CSHELL/NIRSPEC scenario

Lifetime in the atmosphere: 2 terrestrial years

release: L_s = 120-183° (120 sols)





Villanueva et al., 2009

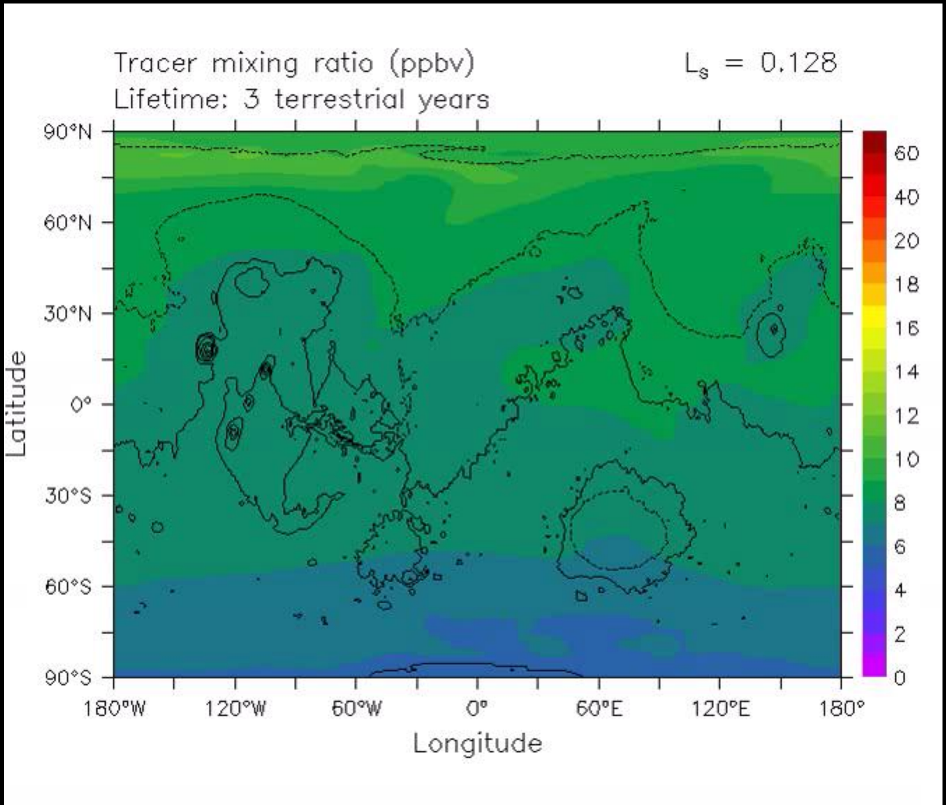
Source: ~ 80 000 t (~ 150 000 t if seasonal)

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

The PFS scenario

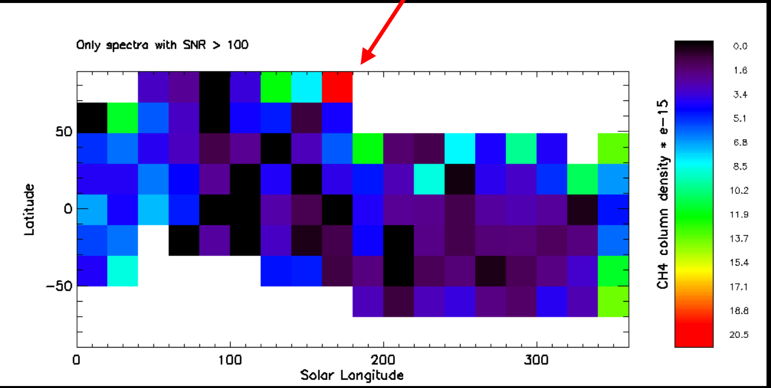
Lifetime in the atmosphere: 3 terrestrial years

release: L_s = 120-183° (120 sols)

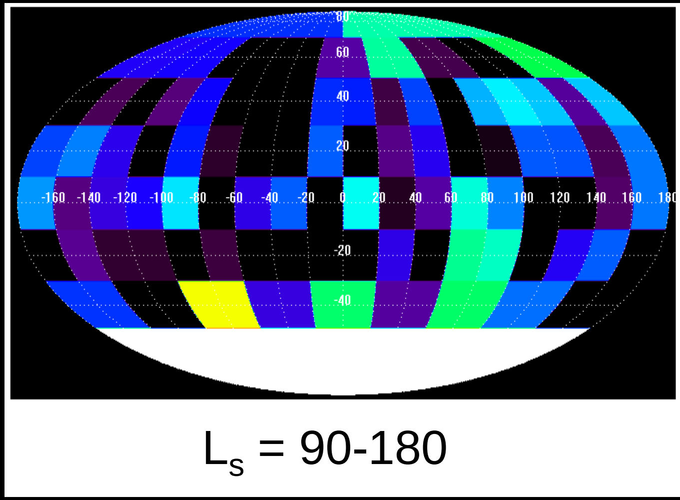


• methane source : between 25-30 km altitude

~40 ppbv



Geminale et al., ESA-ASI Methane workshop, 2009



Formisano et al., ESA-ASI Methane workshop, 2009

A missing atmospheric loss of methane ?

Maybe!

but

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

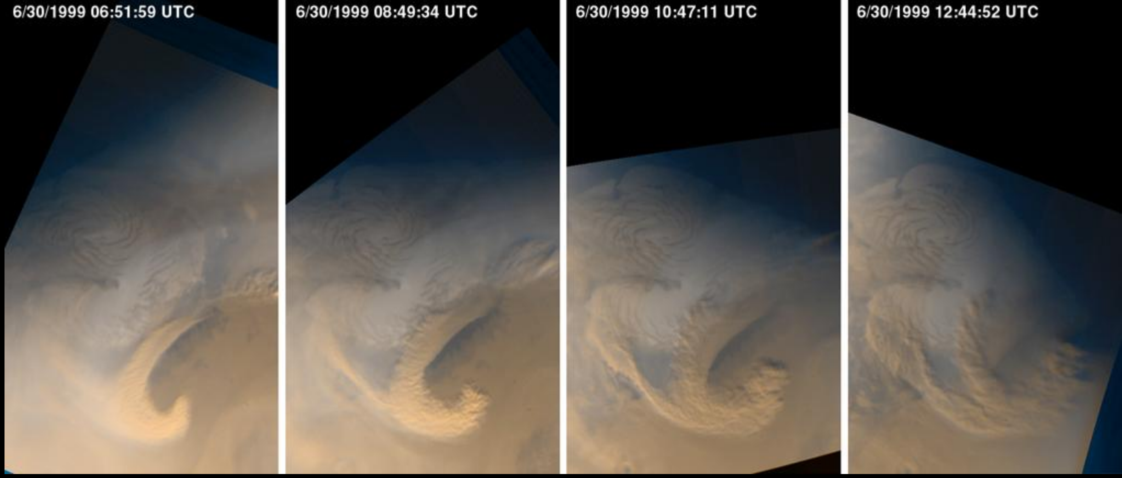
2. It must be consistent with the observed behaviour of methane on Earth

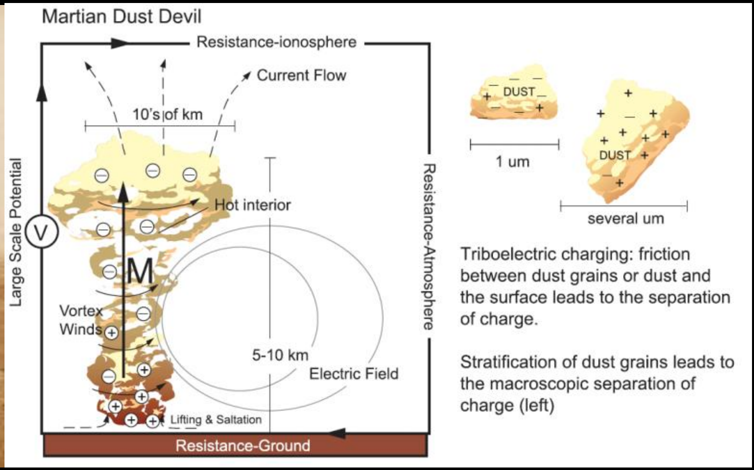
3. It must be consistent with the observed behaviour of other species on Mars:

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

- CH_4 loss by triboelectricity in the atmosphere
- CH_4 reversible adsorption in the regolith
- CH_4 irreversible 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

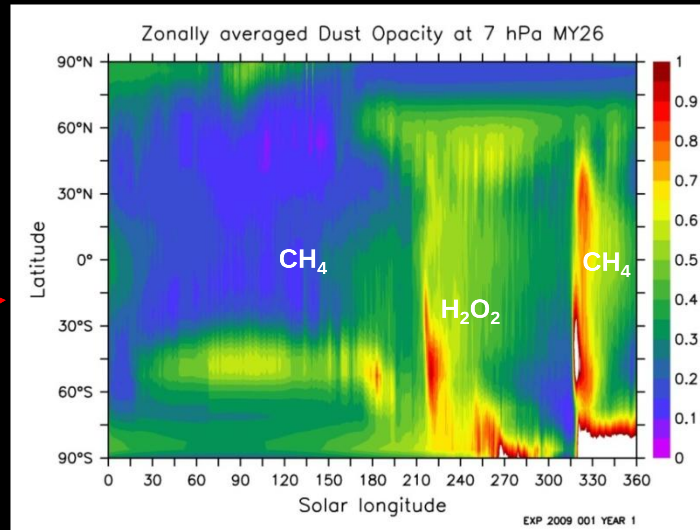
$CO_2 + e^- \rightarrow CO + O^-$

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

$CH_4 + e^- \rightarrow$ products

Simulation with tribolectricity

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

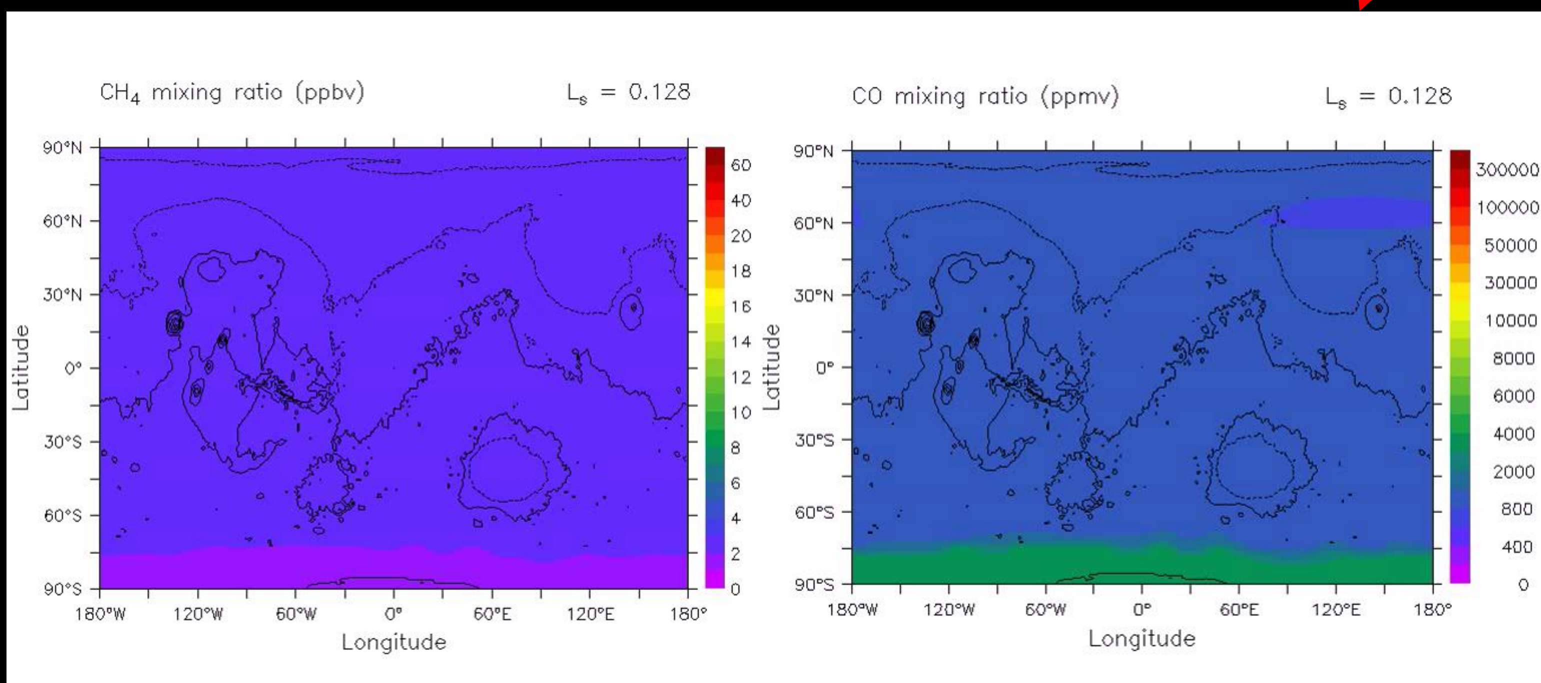


TES dust opacity

MY26 (2002-2004)

50 times as large as the observations

CH_4



CO

observations: ~800 ppmv

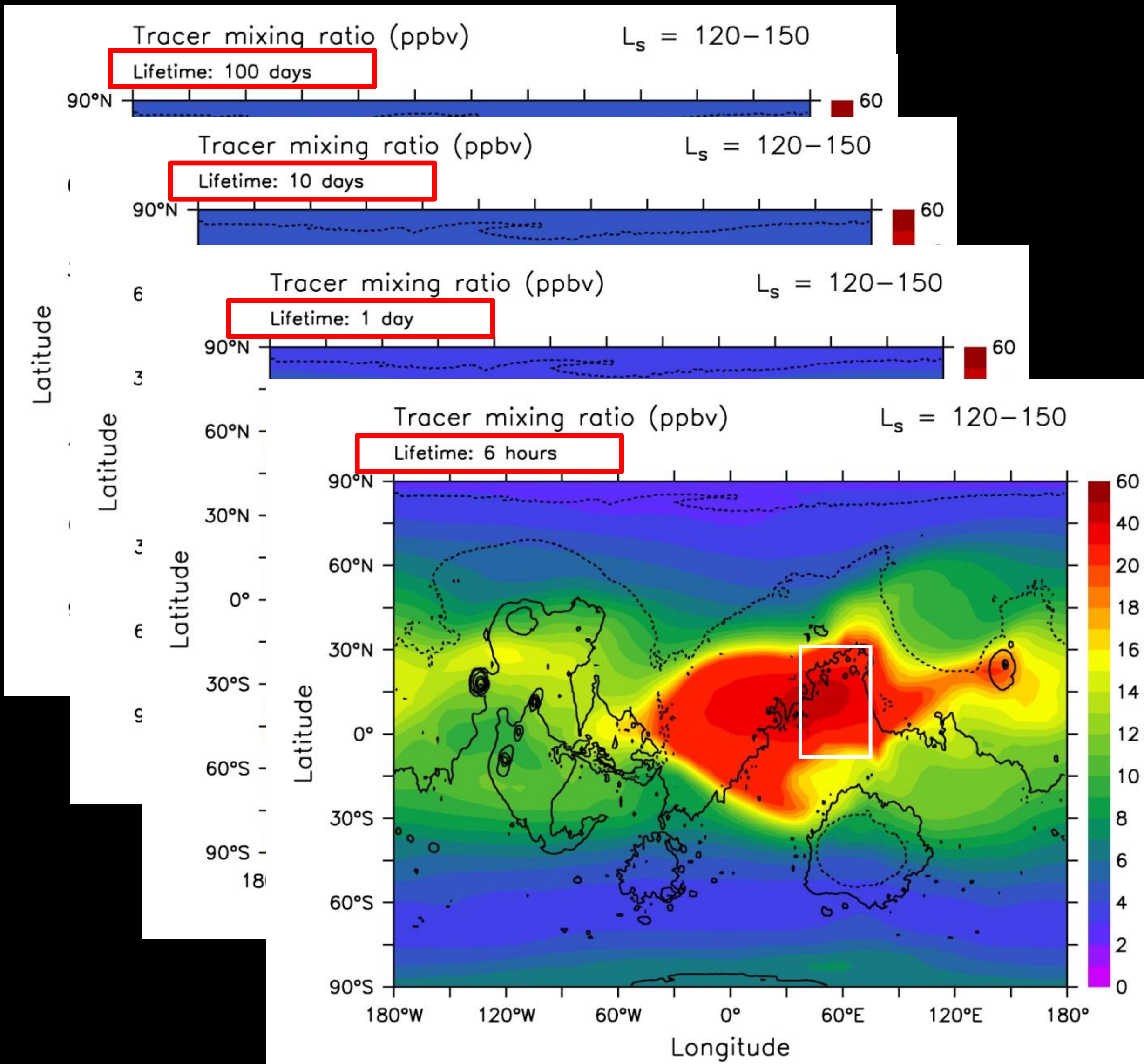
$CH_4 + e^- \rightarrow$ products

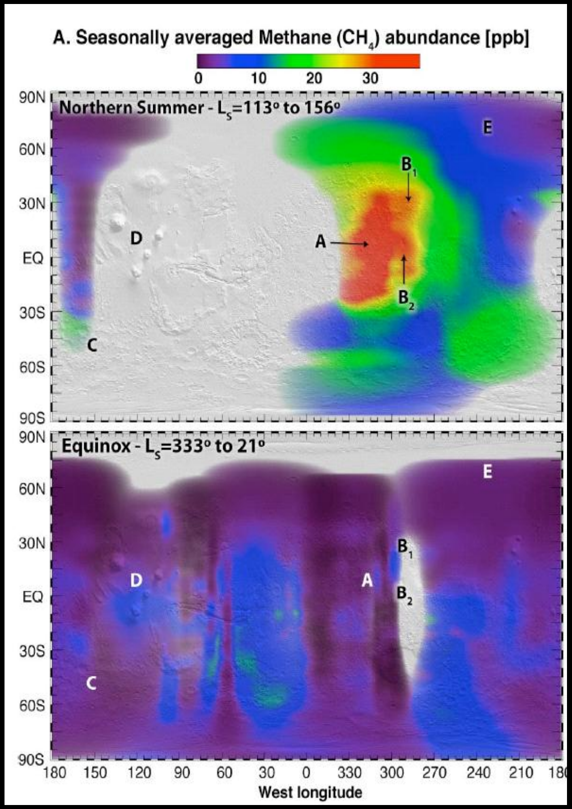
$CO_2 + e^- \rightarrow CO + O^-$

Methane loss in the regolith

- reversible adsorption of CH_4 — Gough et al.,in press; Meslin et al., submitted
- irreversible loss of CH_4 (reaction with oxidants in the regolith)
  - triboelectric production of H_2O_2 — Atreya et al., 2006; 2007
  - in situ production of H_2O_2 and other oxides/superoxides — Hurowitz et al., 2006; Davila et al., 2008

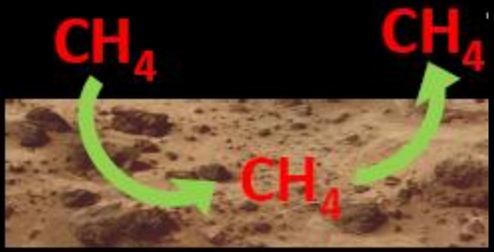
methane loss in the regolith





Villanueva et al., 2009

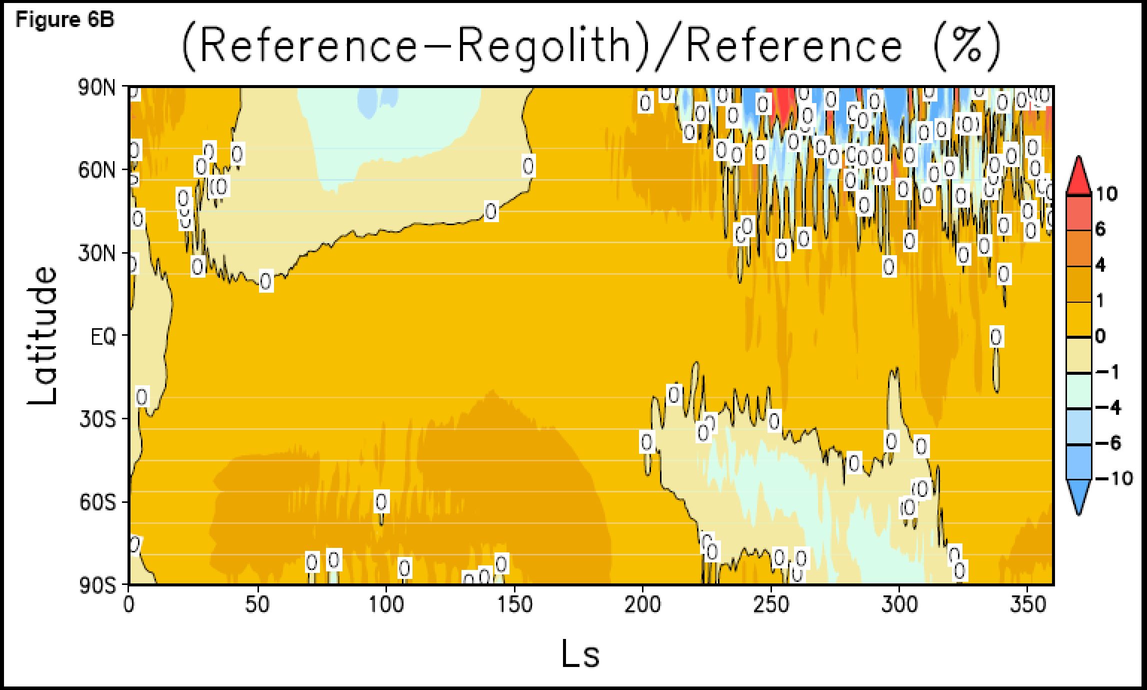
Lifetime: ~ 6 hours



CH_4 adsorption in the regolith

- Uptake coefficient (γ) of CH_4 measured experimentally on Martian soil analog (JSC Mars-I, Gough et al., in press)
- $\gamma(T)$ introduced in a full subsurface-atmosphere transport module, taking into account the thermodynamics and kinetics of the adsorption process

Impact on CH_4 seasonal cycle



Meslin et al., submitted

CH_4 permanent loss in the regolith

Raina Gough et al., *University of Colorado*
ESA-ASI Methane Workshop, Frascati, 2009

$TiO_2 \bullet H_2O_2$ (Quinn and Zent, 1999)

JSC-Mars-1 + H_2O_2 (Levin and Straat, 1981)

Na^+ and Mg^{2+} perchlorate

- Samples in vials with N_2 atmosphere were kept at 2°C
- Headspace was sampled,analyzed with gas chromatography (GC)
- After initial (t=0) measurement, organics or methane were added
- GC measurements taken at 24, 48, 72 hrs
- Several controls were used to rule out contamination

Oxidizes organics, but not methane

Oxidizes organics, but not methane

Nothing is oxidized

Conclusions

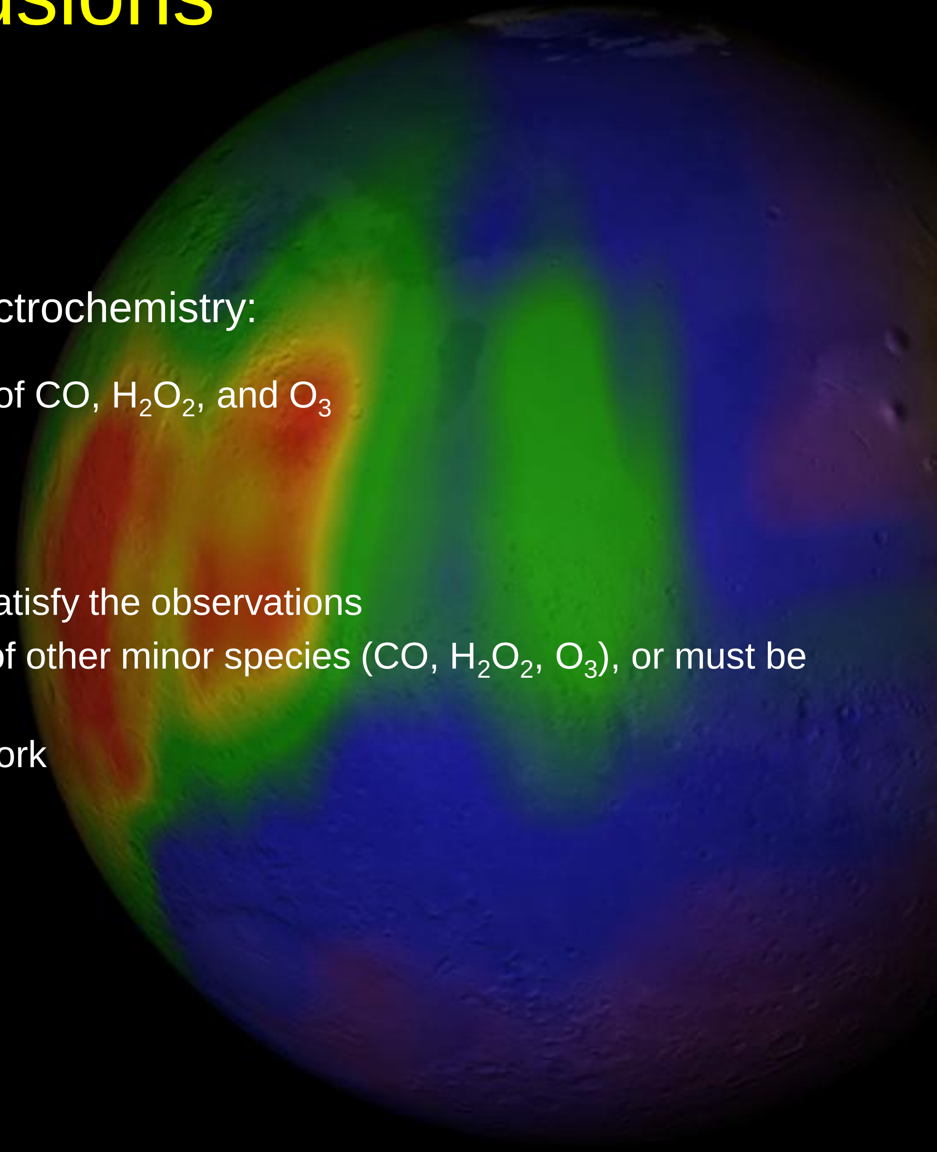
- The "conventional" atmospheric chemistry does not produce measurable methane variations on Mars, even in the case of a current, episodic, and localized source.

- CSHELL/NIRSPEC: an atmospheric CH_4 lifetime of less than 200 days (seasonal release) or ~2 Earth years (single event) is required to reproduce the observations (work with NASA Ames GCM leads to the same conclusion, Malynda Chizek, 2009).

- 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 amounts comparable to the most active hydrothermal sites on Earth.

Conclusions



Solutions ?

- 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 not supported by on-going laboratory work