



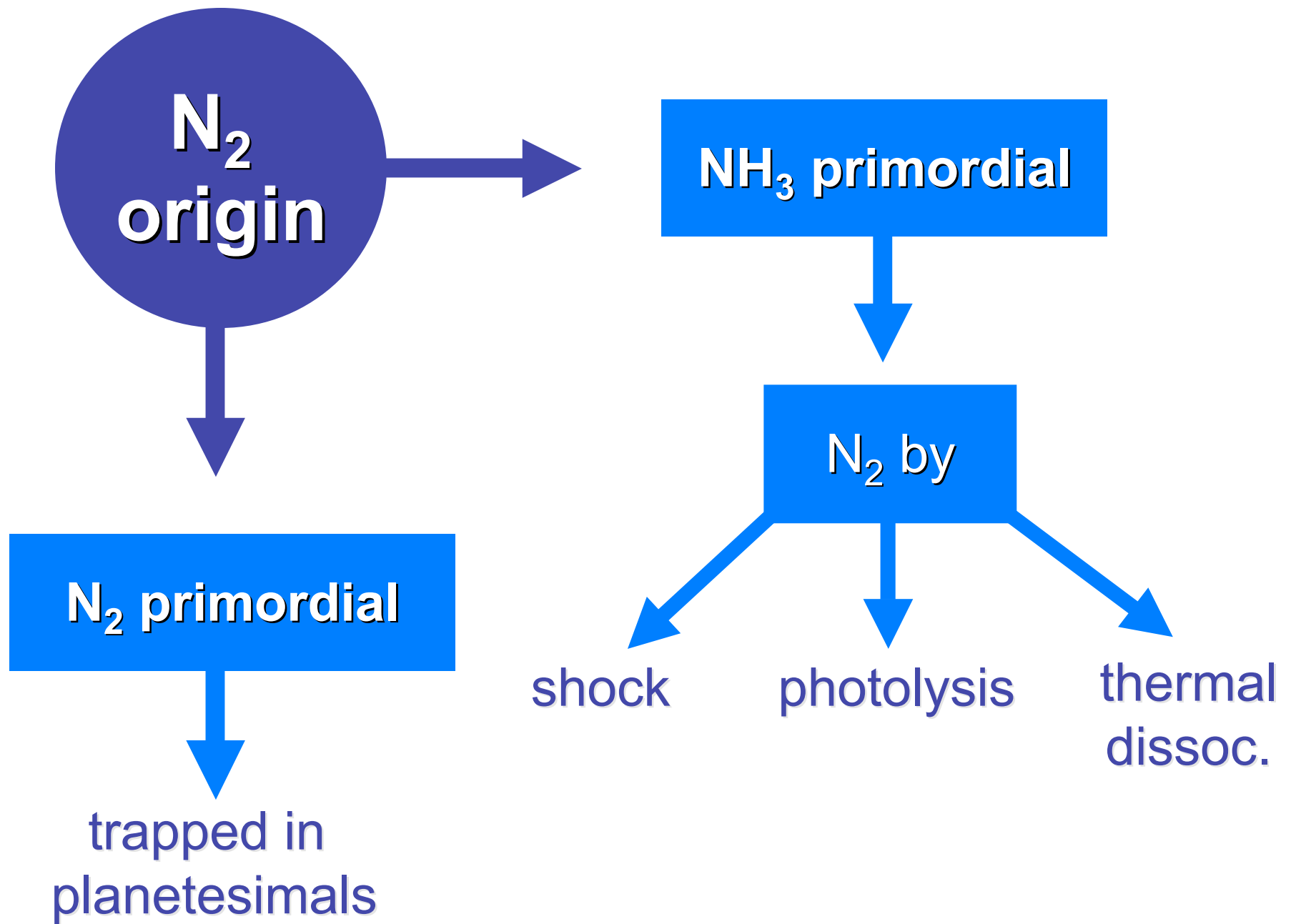
Titan's Methane Cycle

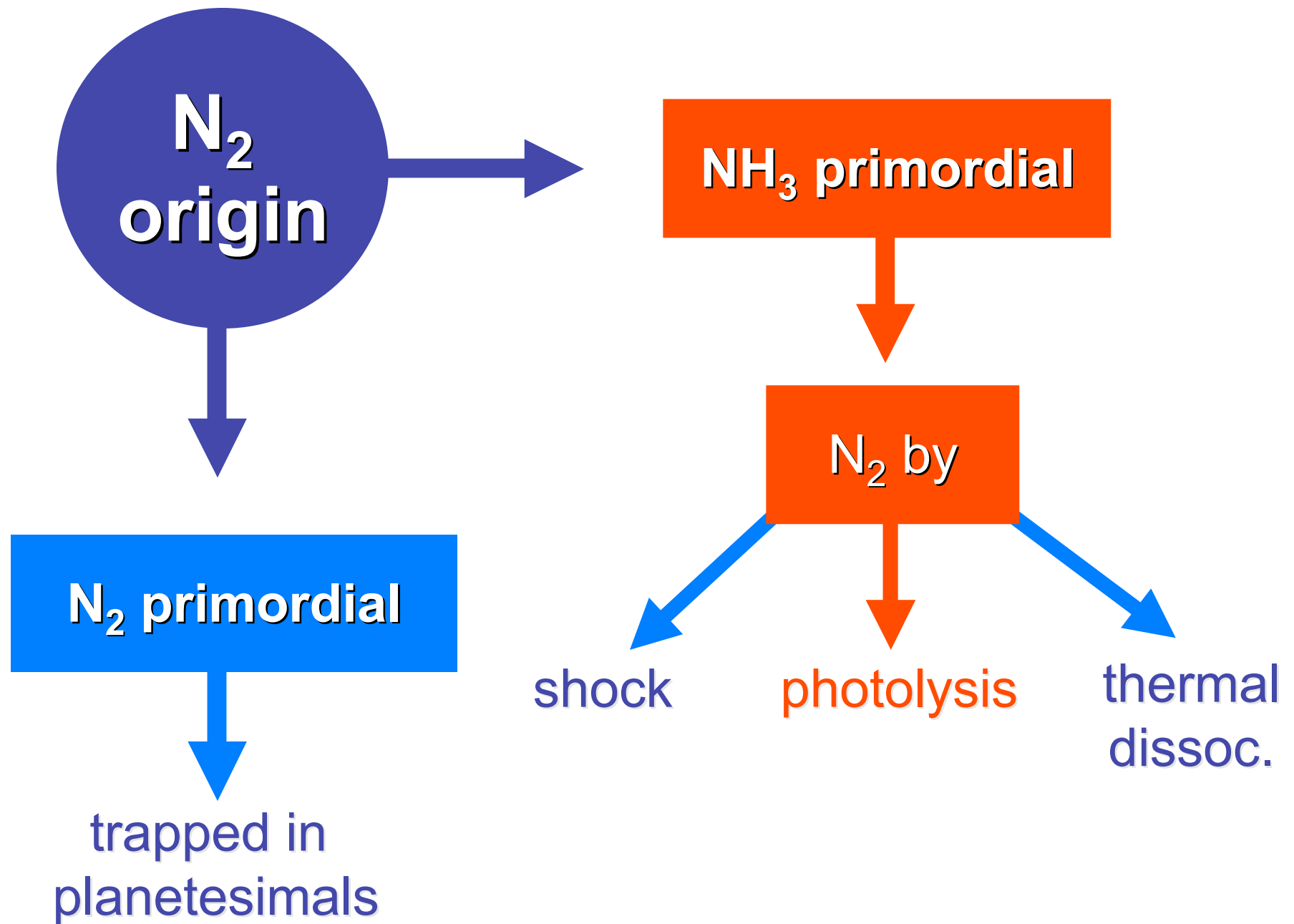
Sushil Atreya
Hasso Niemann
Toby Owen

SPACE WEEK, IKI, Moscow, 2 October 2007

**a mystery: why does Titan have a
large nitrogen atmosphere?**







why methane?

atmosphere: CH₄ 5%; N₂ 95% (Earth CH₄ 1750 ppbv; N₂ 78%)

methane-nitrogen intertwined

- CH₄ provides “greenhouse” warming, due to CH₄-derived hydrocarbon haze in stratosphere (~100 K), and H₂-N₂ and CH₄-N₂ opacity in troposphere (~20 K)
- (warming) critical to sustain the very atmosphere of nitrogen, no CH₄ → little N₂ (condensation)

methane loss

- destroyed irreversibly by photochemistry in 10-30 million years

methane replenishment

map

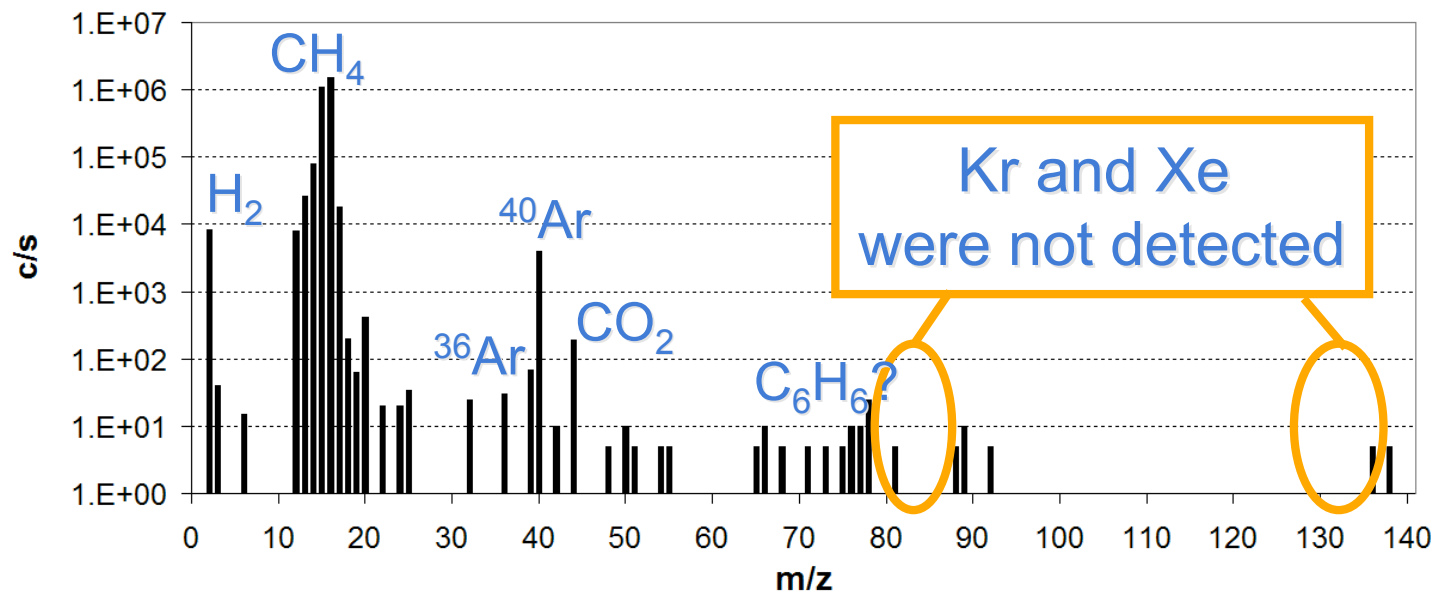
Methane sources, loss, replenishment

- **source**
delivered to or produced on Titan?
- **loss**
photochemical
“methalogical” cycle: a net loss?
- **replenishment**
biology
meteorology
hydrogeochemistry

Where do we go from here?

methane source - clue

– no Xe, Kr detected



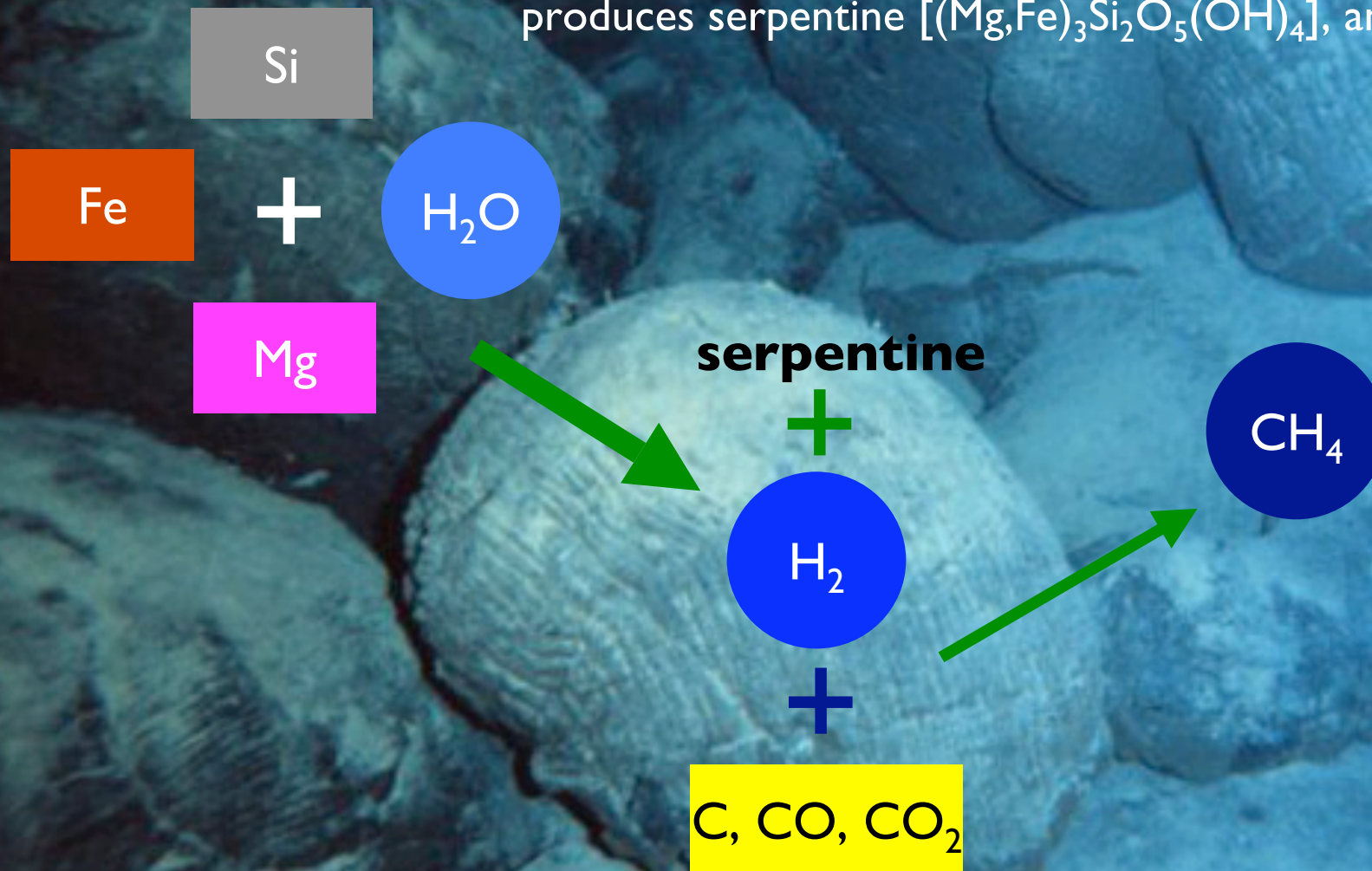
rare gas experiment averaged spectrum
(with background subtracted) [Niemann et al., 2005]

methane origin

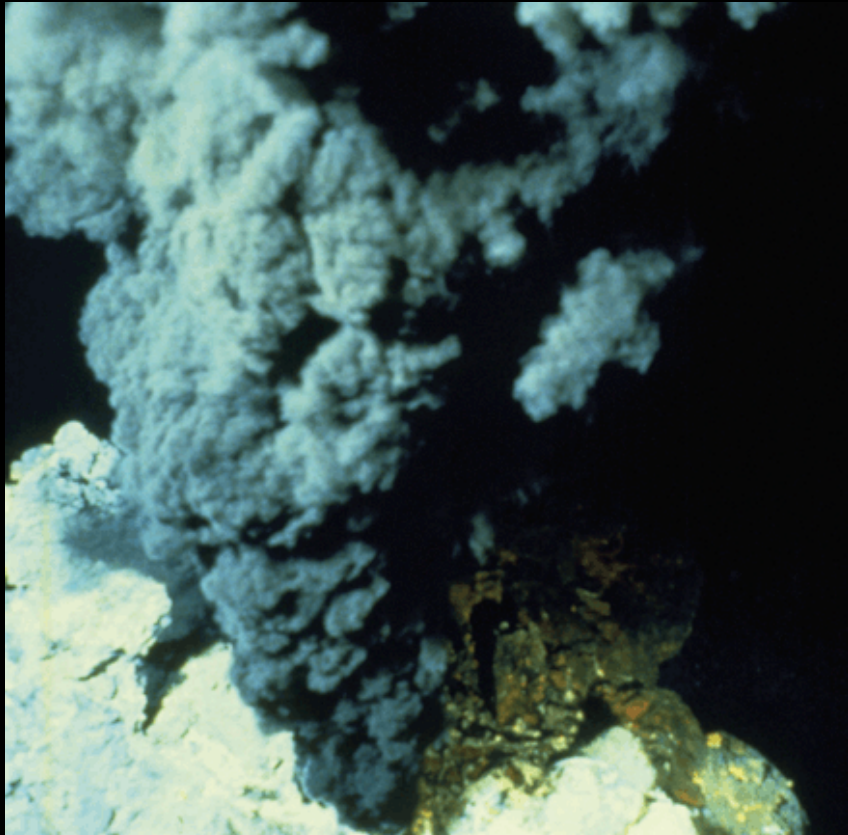
1. delivered to Titan as methane clathrate - *unlikely*:
no Xe, Kr detected by Huygens GCMS
2. methanogens - *no*: ^{13}C deficiency not seen
 - Earth
 - biogenic $^{12}\text{C}/^{13}\text{C}$ 92- 96 (organic)
 - inorganic $^{12}\text{C}/^{13}\text{C}$ 89.4 (V-PDB inorganic std.)
(similar to Saturn, Jupiter, Sun)
 - Titan $^{12}\text{C}/^{13}\text{C}$ 82.3 ± 1
3. produced on Titan - *si!* → hydrothermal source

serpentinization

hydration of ultramafic silicates (olivine/pyroxene)
produces serpentine $[(\text{Mg,Fe})_3\text{Si}_2\text{O}_5(\text{OH})_4]$, and methane



Hydrothermal vents: Black Smoker

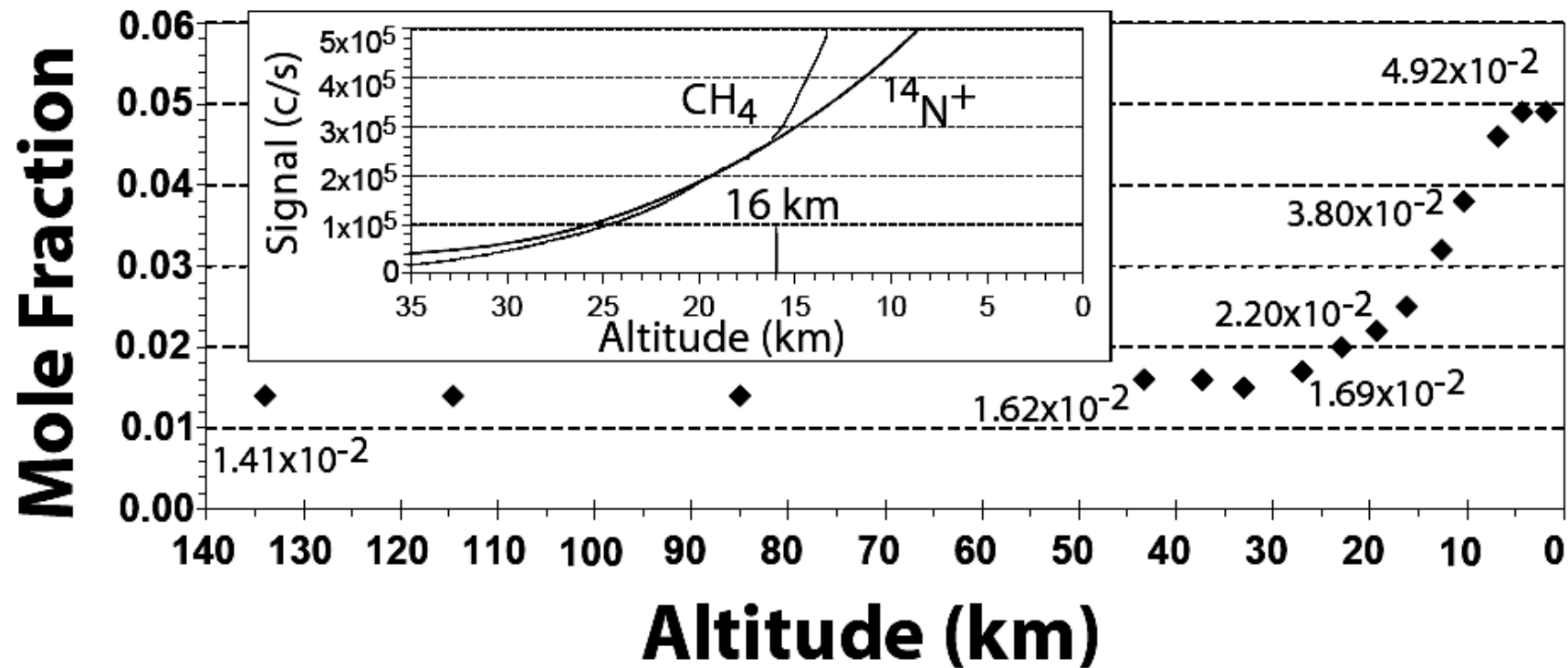


Mid-Atlantic Ridge

Juan De Fuca Ridge
depth 2222 m
exit temp 342 C
chimney ht. 10 m

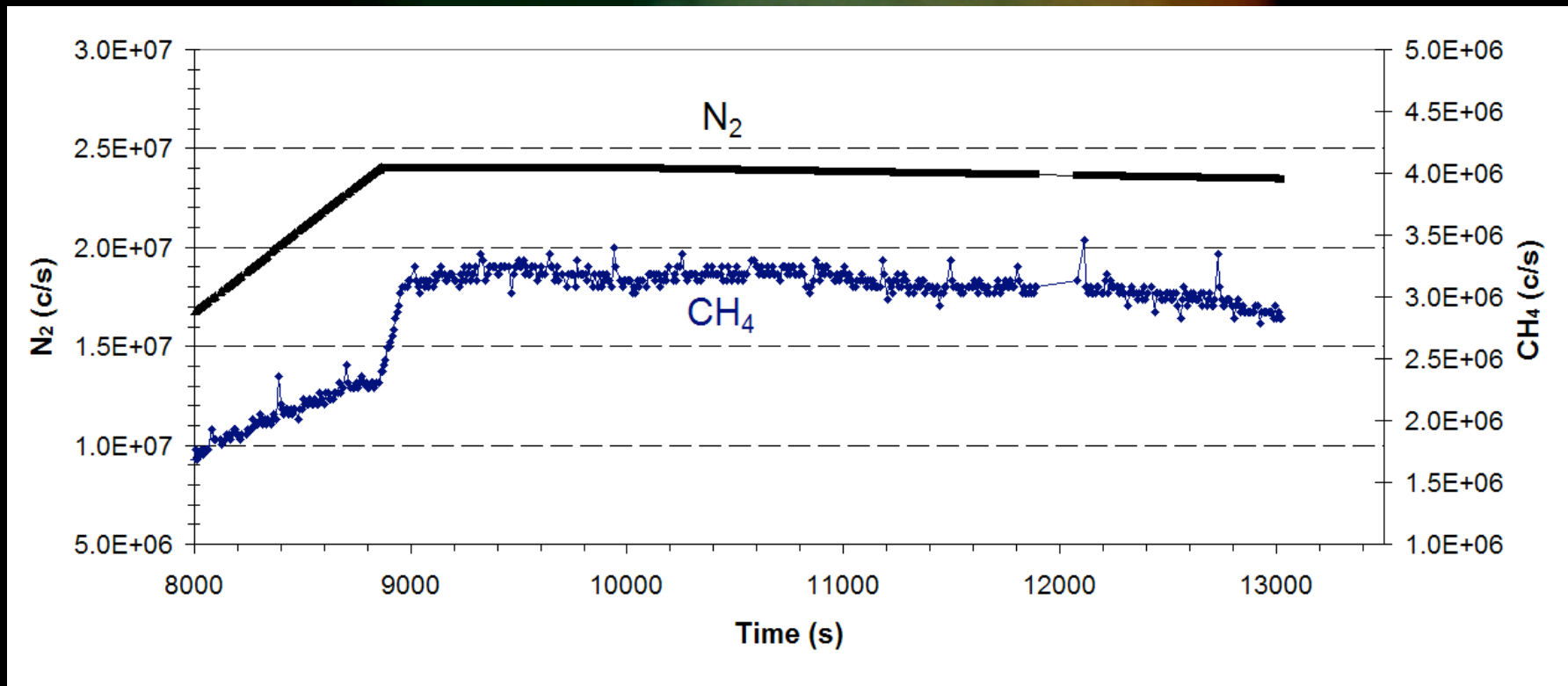


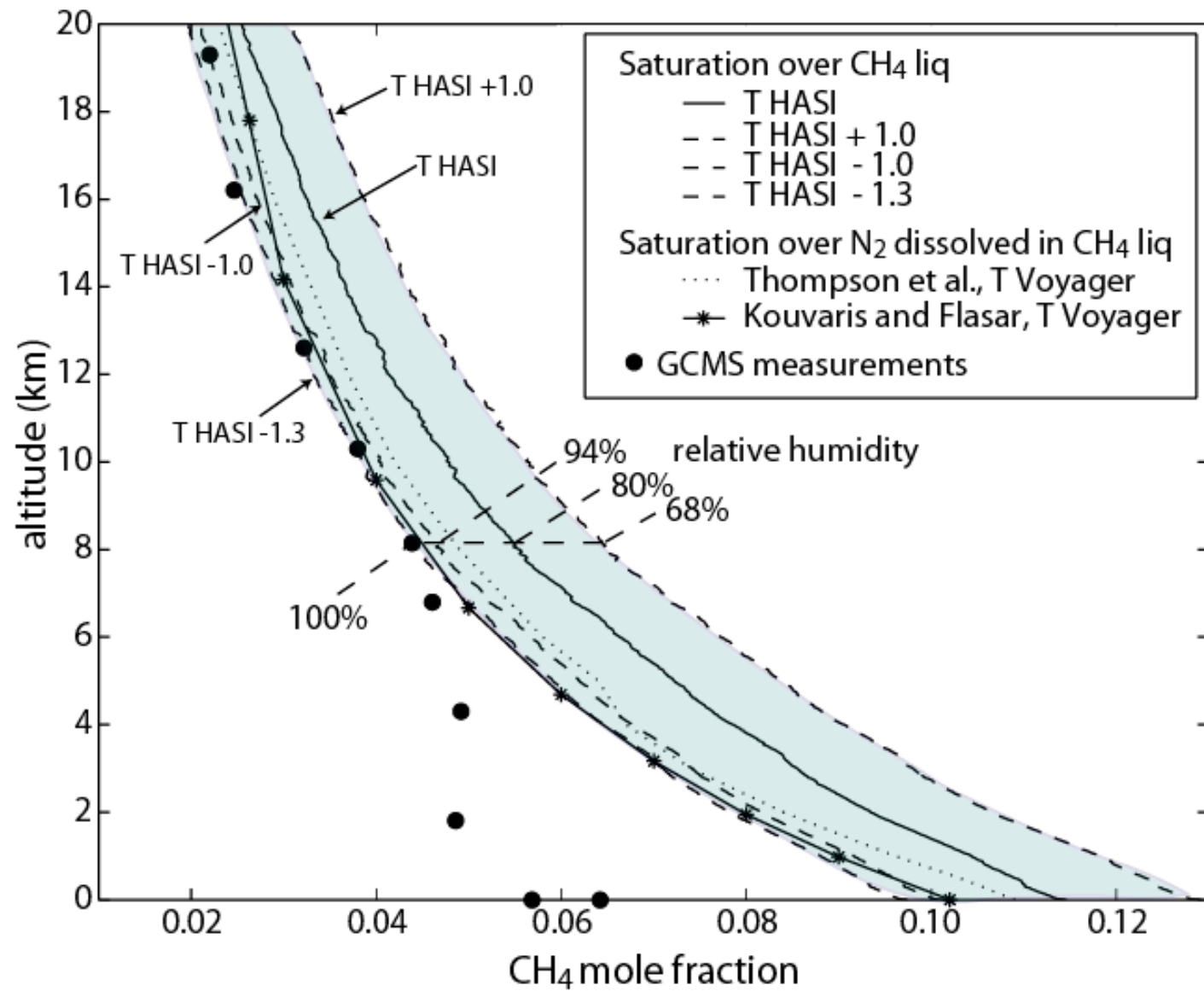
methane mole fraction (GCMS)



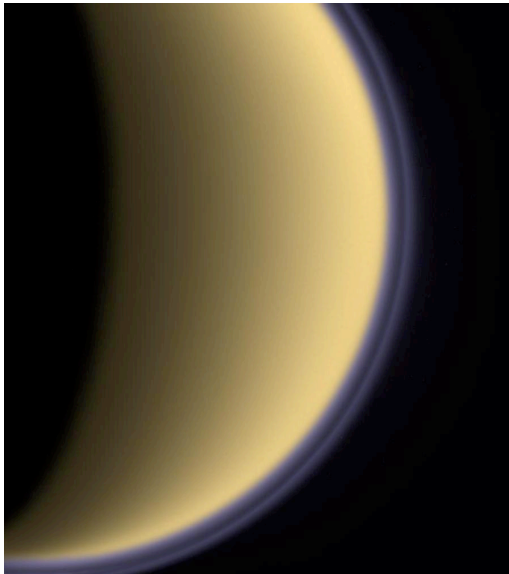
Surface Observations

Methane evaporated from the surface after warming from the heated sample inlet as observed by an increase of the methane signal after impact. A moist area with liquid methane in the near sub-surface is indicated.

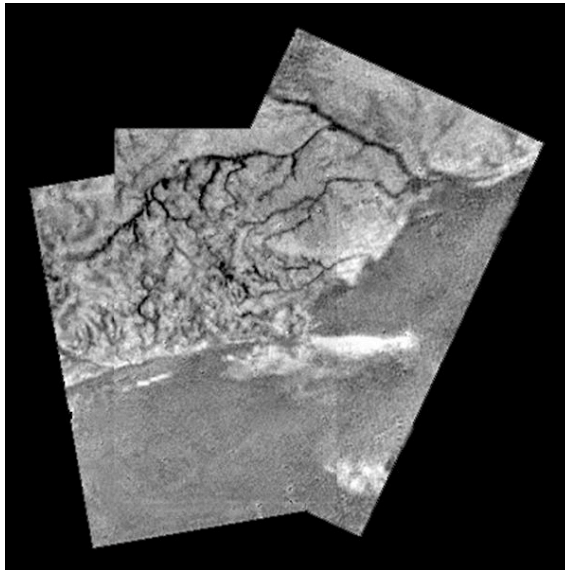




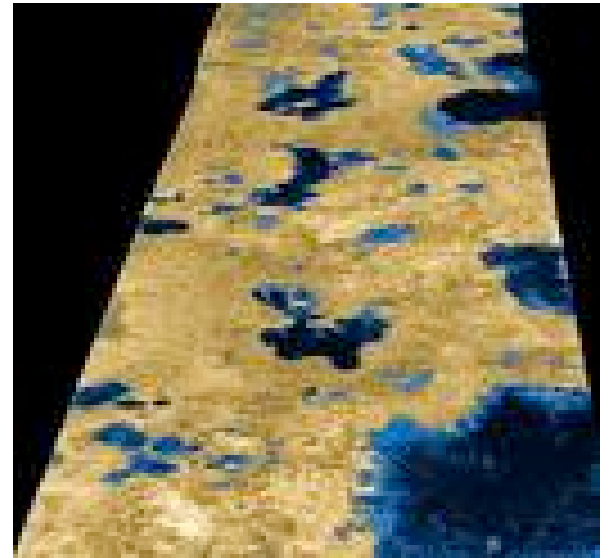
Atreya et al., 2006, PSS



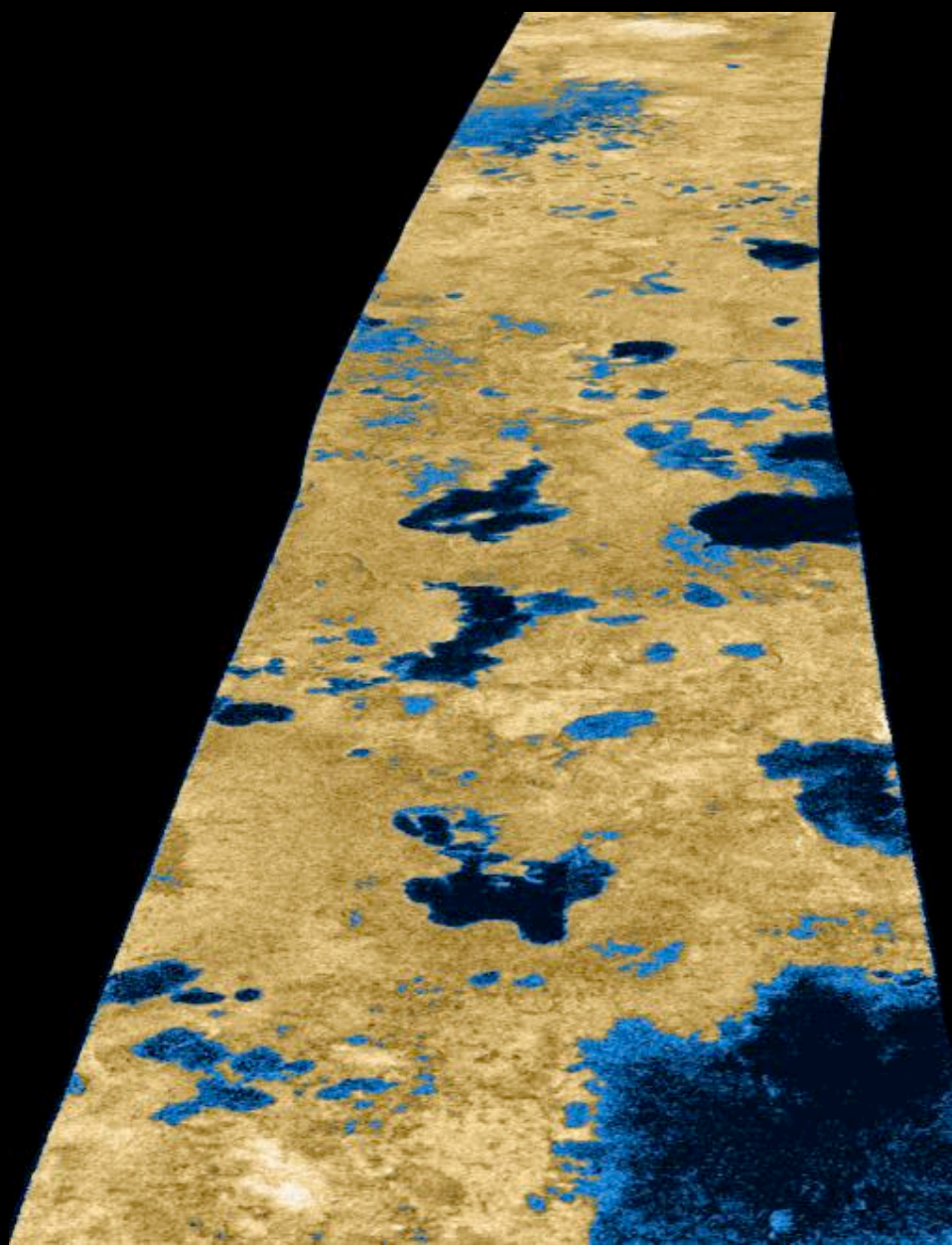
haze/Voyager

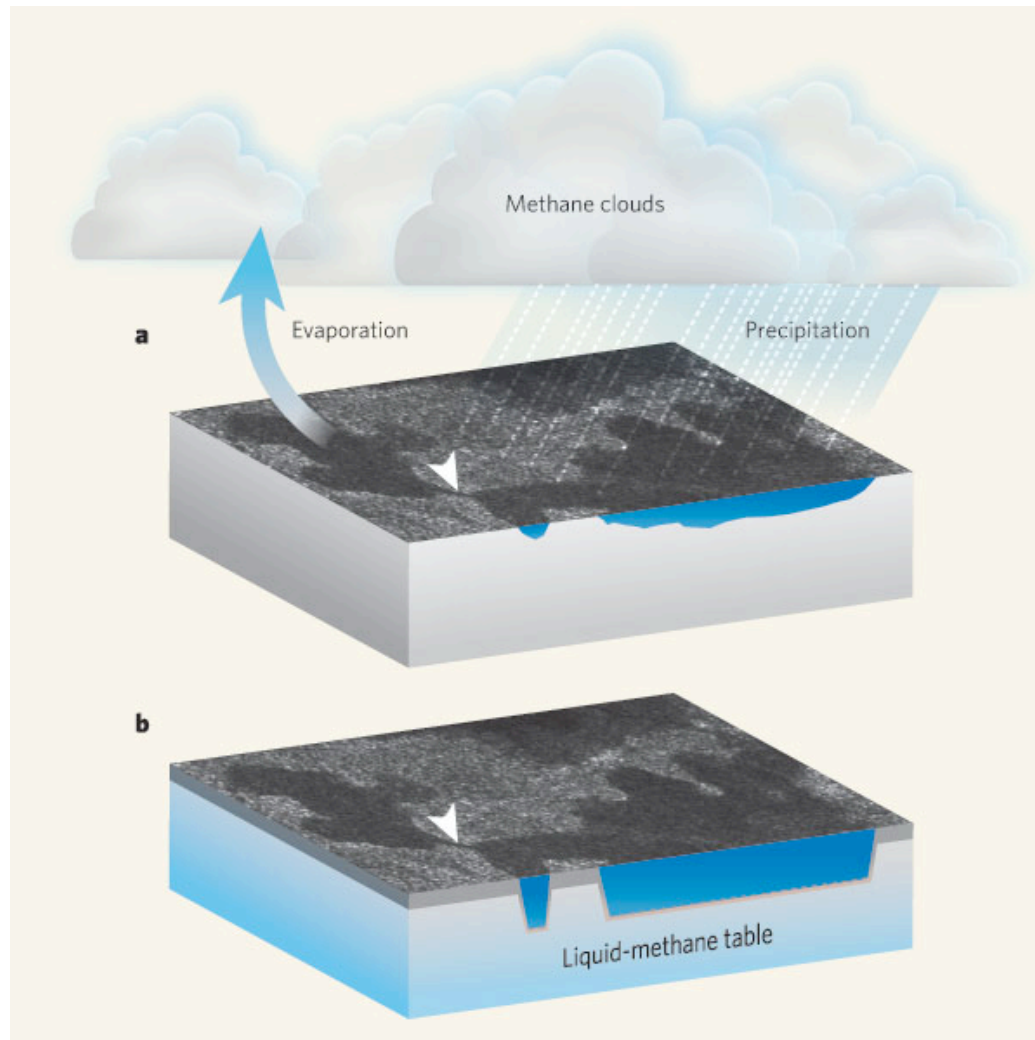


ivers/Huygens

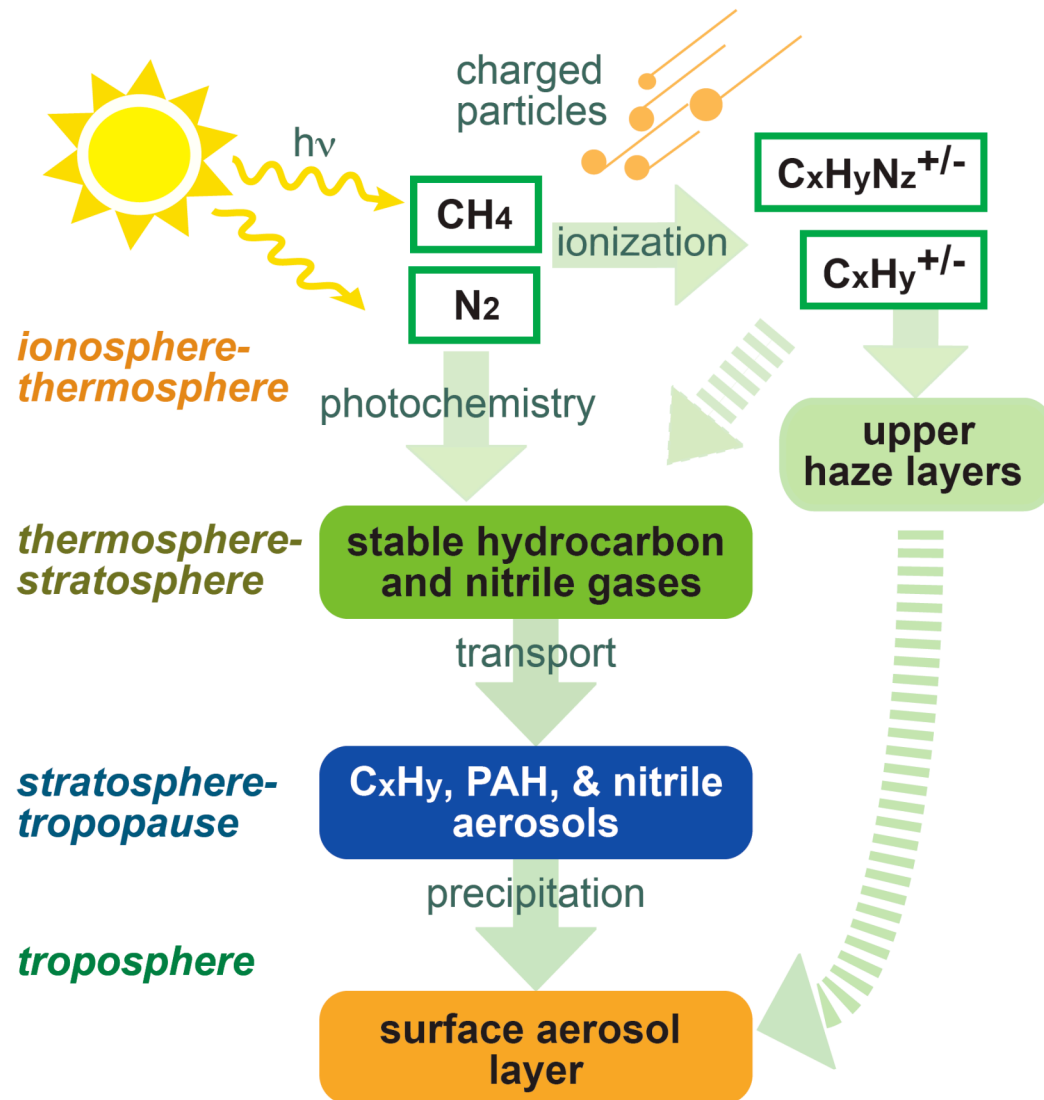


lakes & rivers/Cassini





Stofan et al, 2007



isotopes

$$^{14}\text{N}/^{15}\text{N}_{\text{Titan}} \ll ^{14}\text{N}/^{15}\text{N}_{\text{Earth}}$$



nitrogen
escape

$$^{12}\text{C}/^{13}\text{C}_{\text{Titan}} \sim ^{12}\text{C}/^{13}\text{C}_{\text{Earth}}$$



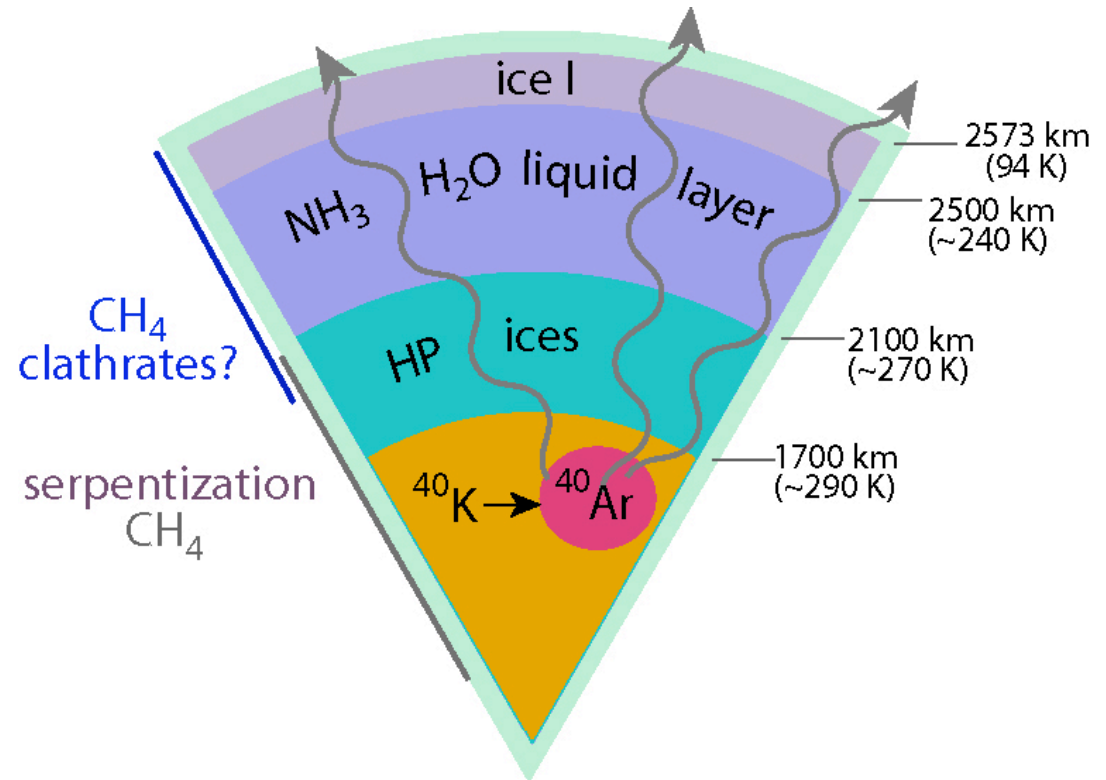
methane
replenishment

outgassing

- ^{40}Ar detection
($^{40}\text{K} \rightarrow ^{40}\text{Ar}$
1.3 Gyr half-life)

- cryovolcanism

→ CH_4 outgassing



(interior structure, after Grasset et al.)

conclusions and future

- Methane and Nitrogen were not delivered to Titan,
but arrived as carbon (grains, organics, CO, CO₂) and ammonia
- CH₄ and N₂ were produced on Titan
N₂ from NH₃ dissociation
CH₄ from hydrogeochemistry

Future:

- *explore Titan as a SYSTEM, i.e coupled interior-surface-atmosphere-ionosphere-beyond system
- *determine D/H in water, Xe, Kr, Ar to 10⁻¹¹ mole fraction
- *determine ^{36/38}Ar, isotopes of other noble gases (??)
- *characterize chemical composition of surface material

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With Fear and Wonder in Its Wake, Sputnik Lifted Us Into the Future

By JOHN NOBLE WILFORD
Published: September 25, 2007

Fifty years ago, before most people living today were born, the beep-beep-beep of Sputnik was heard round the world. It was the sound of wonder and foreboding. Nothing would ever be quite the same again — in geopolitics, in science and technology, in everyday life and the capacity of the human species.

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Cydon Rott

The Soviet Union had launched the first artificial satellite, a new moon, on Oct. 4, 1957. Climbing out of the terrestrial gravity well, rising above the atmosphere and into orbit, Sputnik crossed the threshold into a new dimension of human experience. People could now see their kind as spacefarers. Their enhanced mobility might someday prove as liberating as the first upright steps of hominid ancestors long ago.

The immediate reaction, though, reflected the dark concerns of a world in the grip of the cold war, a time of fear and division in which the two superpowers, the Soviet Union and the United States, stared each other down with the menace of mass destruction. Sputnik altered the nature and scope of the cold war.

It was an unprepossessing agent of alarm. A simple sphere weighing just 184 pounds and not quite two feet wide, it had a highly polished surface of aluminum, the better to reflect sunlight and be visible from Earth. Two radio transmitters with whiskery antennas issued steady signals on frequencies that scientists and ham operators could pick up, and so confirm the achievement.

The Russians clearly intended Sputnik as a ringing statement of their technological prowess and its military implications. But even they, it seems, had not foreseen the frenzied response their success provoked.

When the Soviet dictator Nikita S. Khrushchev received word of the launching, he was of course pleased, and he and his son, Sergei, turned on

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Titan's surface reflects its atmospheric composition, only in much greater concentration!

??????

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May 2007 *Scientific American* article:

“The Mystery of Methane on Mars and Titan”

and PERSPECTIVES in *Science* 11 May 2007”:

“Titan’s Organic Factory”

Titan Through Time

- Christianus Huygens discovers Titan, 1655
- mass = 1.35×10^{23} kg (0.023 x Earth's)
- radius = 2575 km (0.98 Ganymede; 1.48 x Moon; 0.76 x Mars)
- mean density = 1.88 g/cm^3 (50% ice, 50% rock)
- mean distance from Saturn = 1,211,850 km (~ 3.1 x Earth-Moon distance)
- orbital period = 15.94 days (Earth's moon 27.3 days)
- atmosphere: limb darkening (Comas Solas, 1908)
 - CH_4 detected (Kuiper, 1944)
 - N_2 detected as main component (Voyager, 1980)
- mean surface temperature = 93.5 K (-179.5 °C, -291 °F)
- atmospheric pressure = 1.5 bars
- atmospheric density = 4.4 x Earth's atmosphere
- Cassini arrives at Saturn on 30 June 2004
- Huygens lands on Titan 14 January 2005