# Organics on Titan, Water on Enceladus: Worlds of possibilities for life

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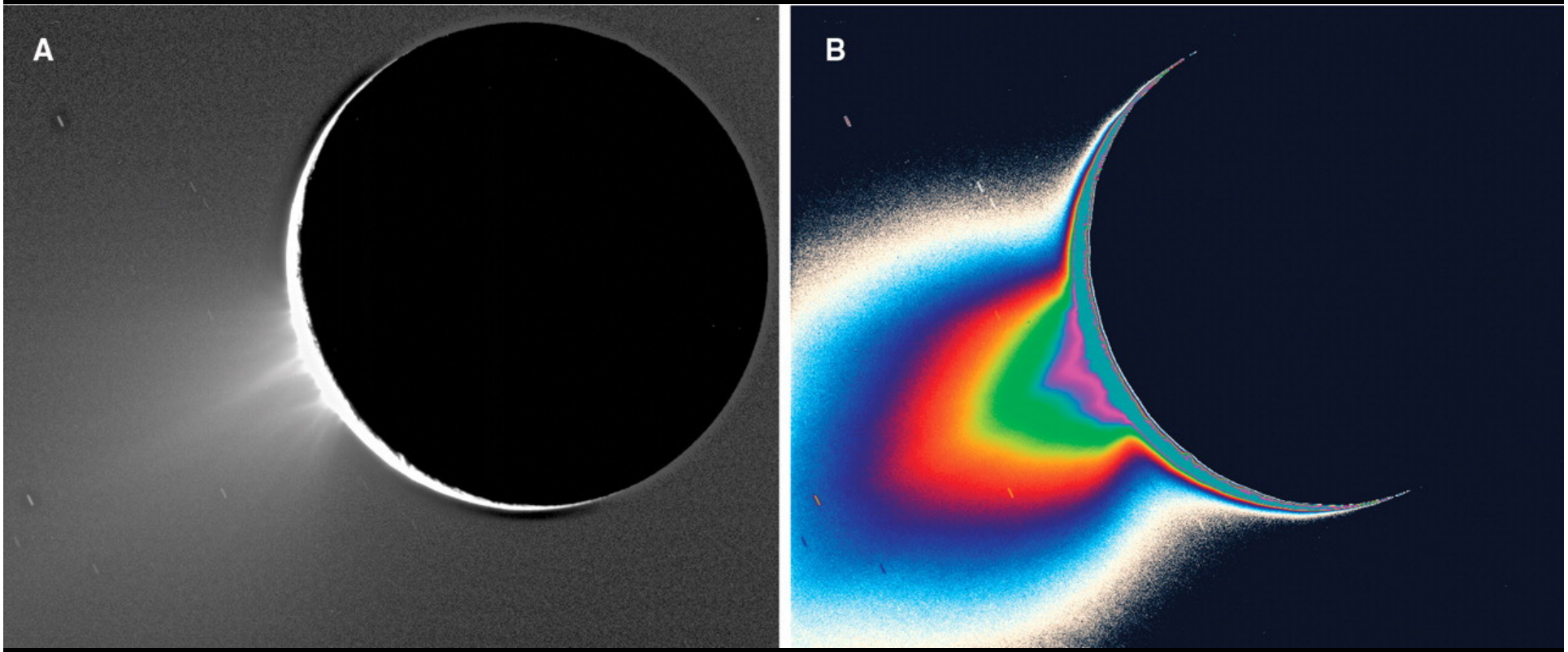
This talk is a compilation based on the work of many colleagues over many years. My thanks and acknowledgements to all of them.

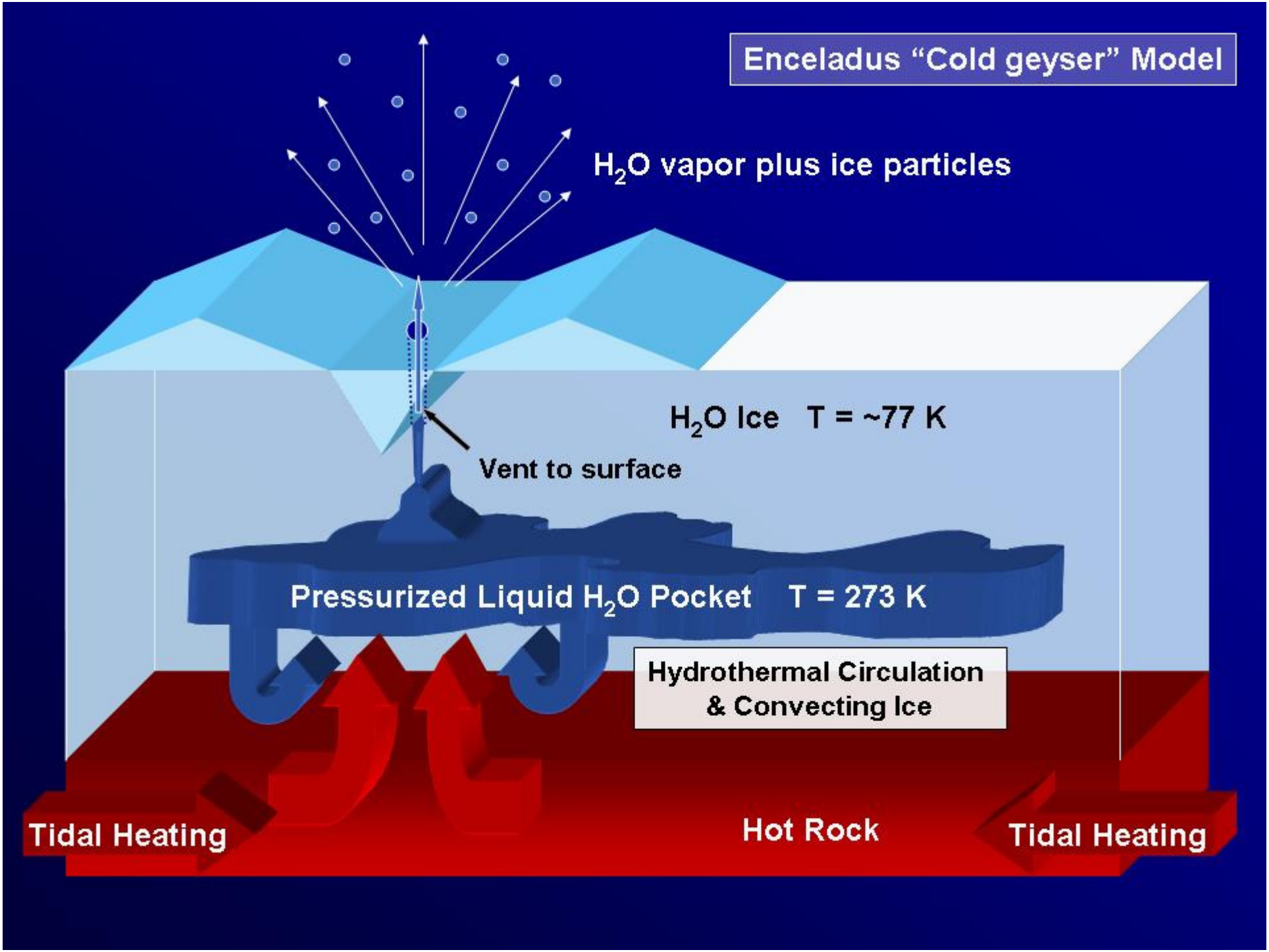
# Why is Life on other Worlds Interesting?

- The possibility of a second genesis of life:
  ⇒ comparative biochemistry
  ⇒ life is common in the universe (yeah!)

- Information about the early planetary environment
- Relevant to the origin of life on Earth

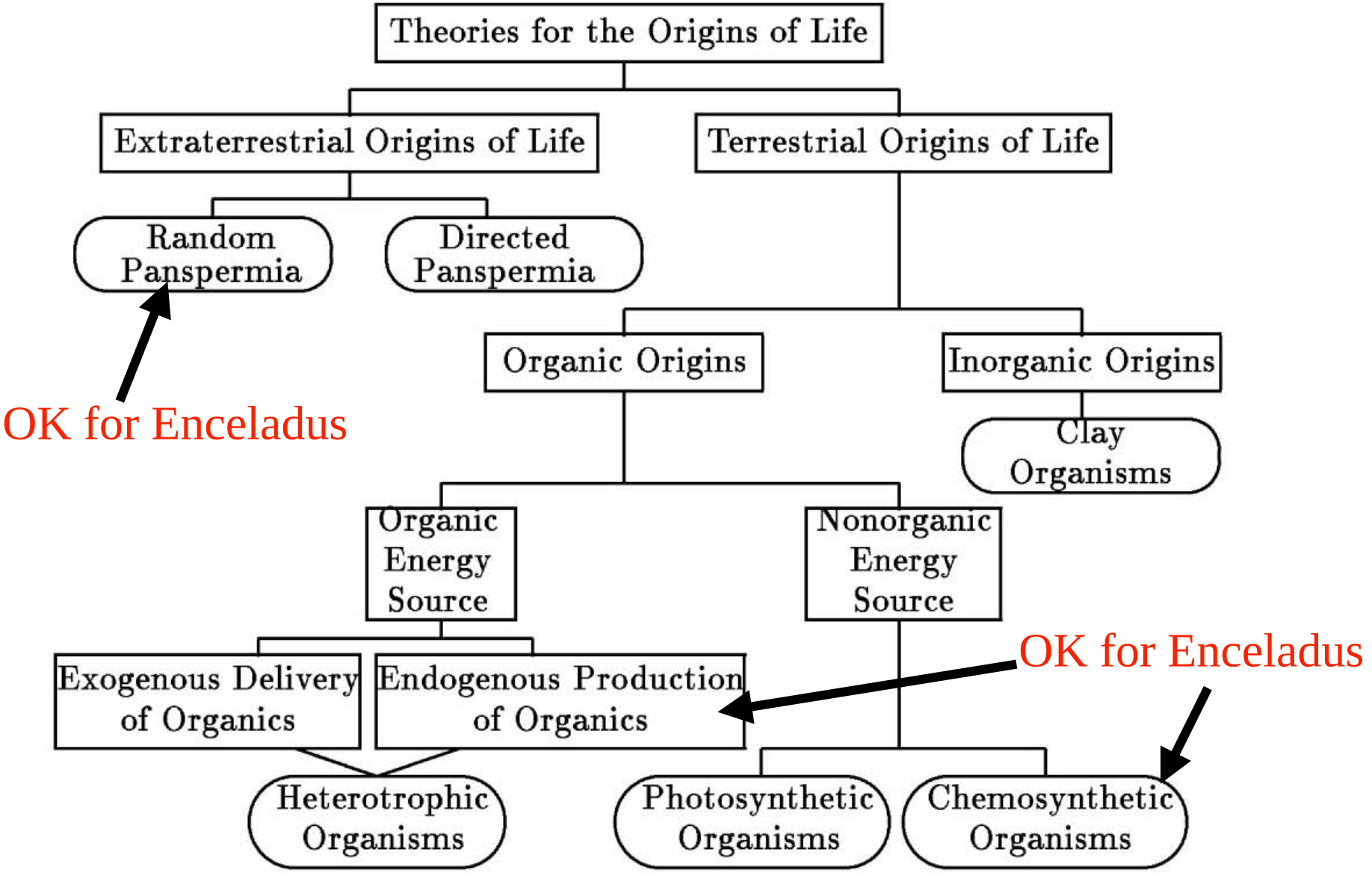
# Jets of $H_2O$ on Enceladus




Enceladus "Cold geyser" Model
$H_2O$ vapor plus ice particles
$H_2O$ Ice T = ~77 K
Vent to surface
Pressurized Liquid $H_2O$ Pocket T = 273 K
Hydrothermal Circulation & Convecting Ice
Tidal Heating
Hot Rock
Tidal Heating

Given liquid water on Enceladus is there:

- a plausible origin of life?
- a plausible ecology?




Davis & McKay, *Origins Life Evol. Biosph.* **26**, 61-73, 1996.

# Plausible Ecologies

- The known laws of physics

  energy from thermal gradients, electric fields, radiation

- My favorite "extremophile" *D. radiodurans*

  radiation resistance, salt tolerance, etc.

- Actual ecosystems

  actual microbial ecosystems that require no light & no $O_2$

# Examples of ecologically isolated microbial ecosystems (no $O_2$, no light, no organic input)

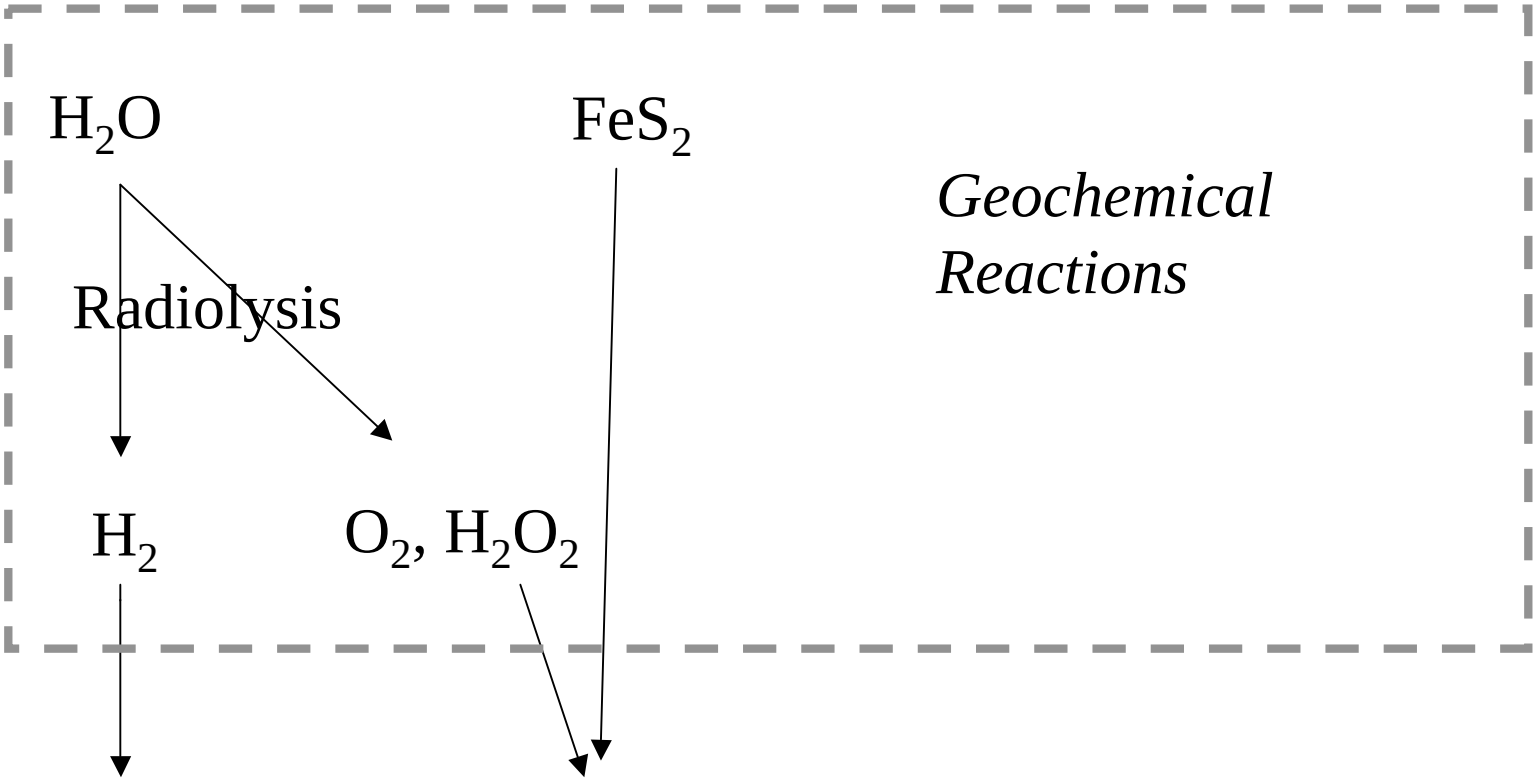
Only three examples are known:

Two are are based on $H_2$ from rock reactions
($H_2 + CO_2 \rightarrow CH_4 + H_2O$)

- Stevens, T.O. and J.P. McKinley 1995. Lithoautotrophic microbial ecosystems in deep basalt aquifers, Science 270, 450-454.
- Chapelle, F.H., K. O'Neill, P.M. Bradley, B.A. Methe, S.A. Ciufo, L.L. Knobel, and D.R. Lovley 2002. A hydrogen-based subsurface microbial community dominated by methanogens, Nature 415, 312-315.

One based on radioactive decay

- Lin, L.-H., et al. 2006. Long-Term Sustainability of a High-Energy, Low-Diversity Crustal Biome, Science 314, 479-482

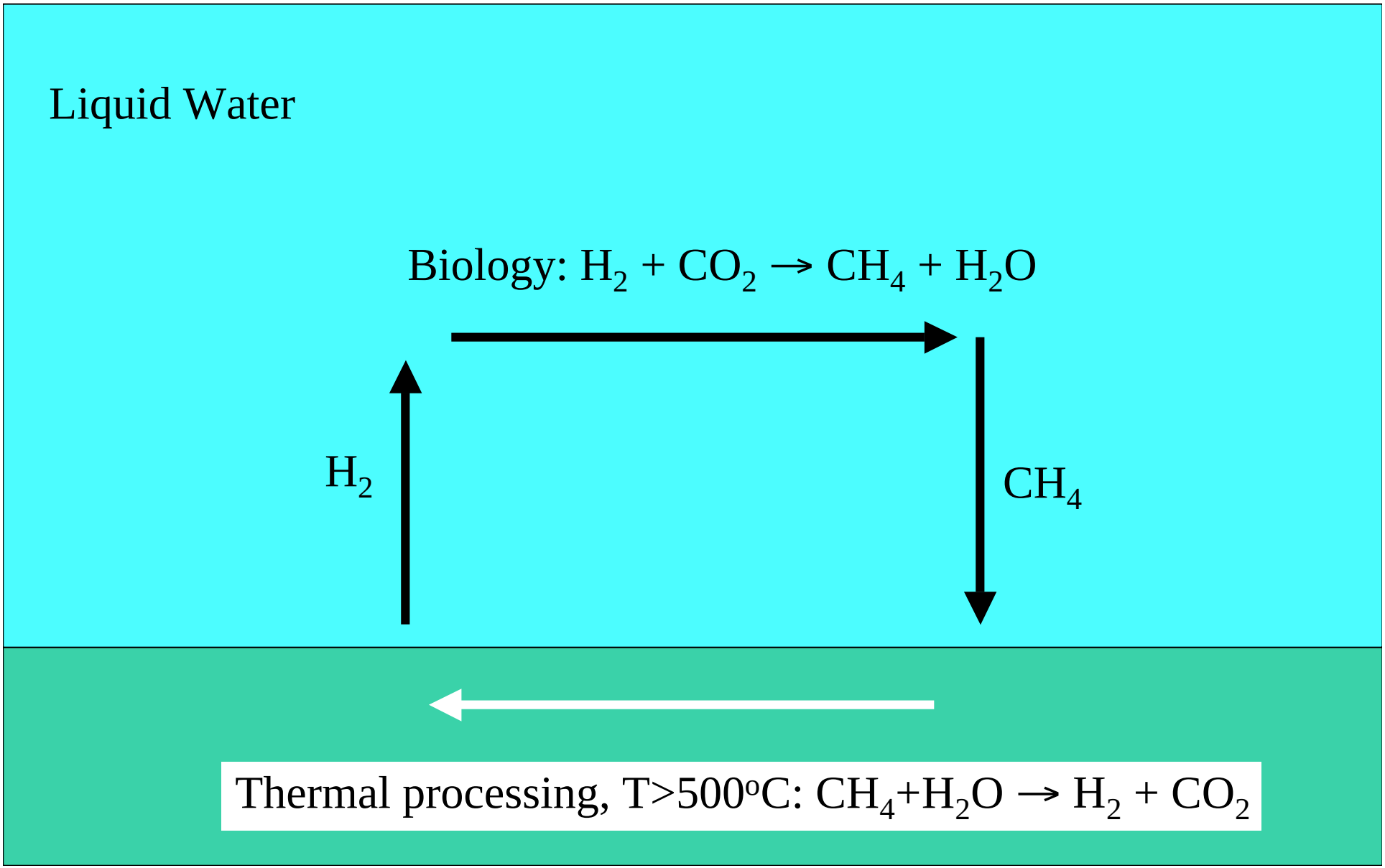



$$4H_2 + H^+ + SO_4^{2-} \xrightarrow{SRB} H_2S + 2H_2O + 2OH^-$$

*Desulfoprofundis tokoloshe*

Lin et al. 2006, slide courtesy of T. Kieft

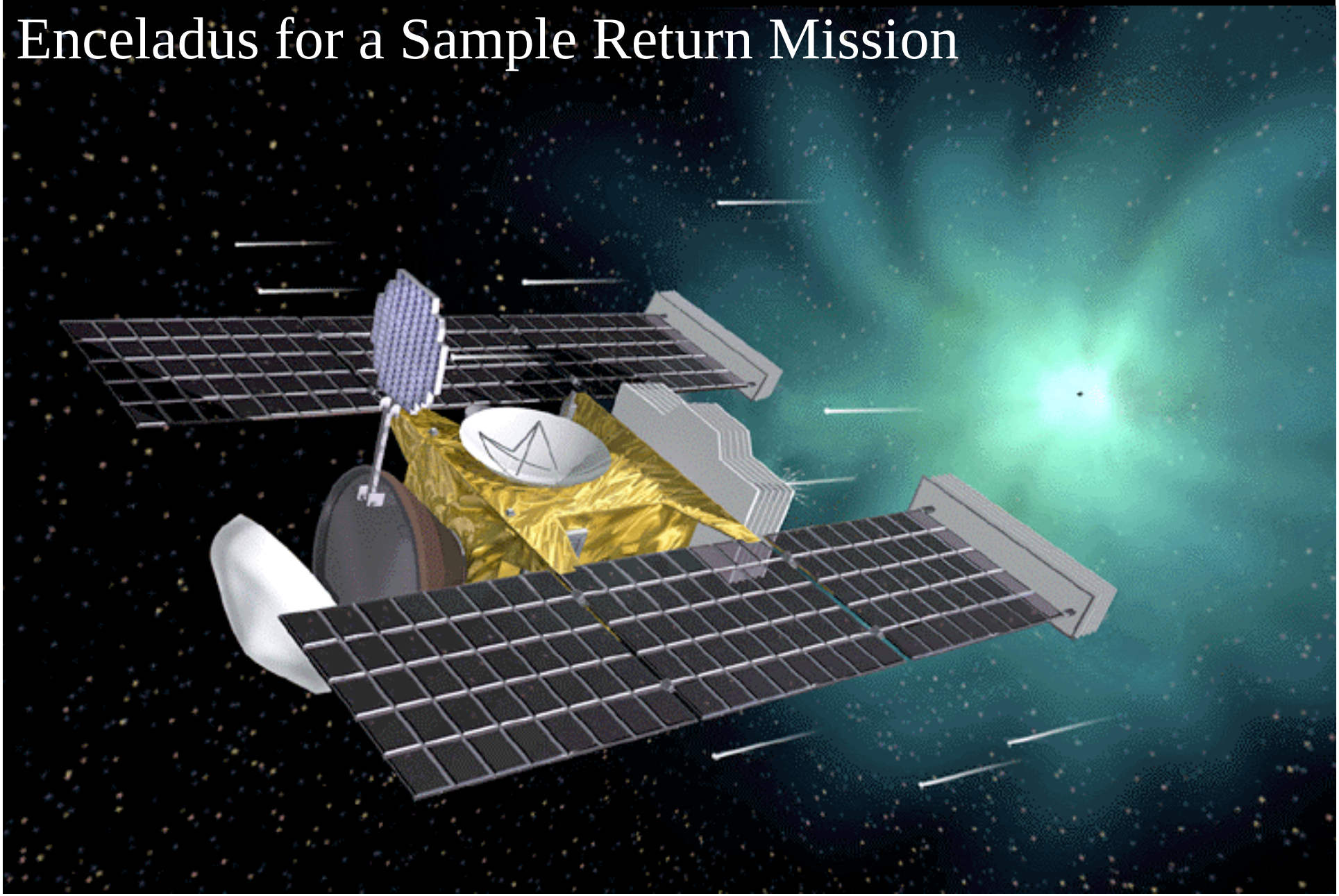
Ice Cover


Liquid Water
Biology: $H_2 + CO_2 \rightarrow CH_4 + H_2O$
$H_2$
$CH_4$
Thermal processing, T>500°C: $CH_4+H_2O \rightarrow H_2 + CO_2$

$H_2S + O_2$ is the metabolic basis of deep sea vents.

Anaerobic chemoautotrophic ecosystems may be present below the surface.

# Stardust flys through the Plume of Enceladus for a Sample Return Mission



If we find organic material in the plume of Enceladus (or Europa & Mars) how can we tell if it was ever alive?

If its like us then easy, less interesting
If its alien then hard, but interesting

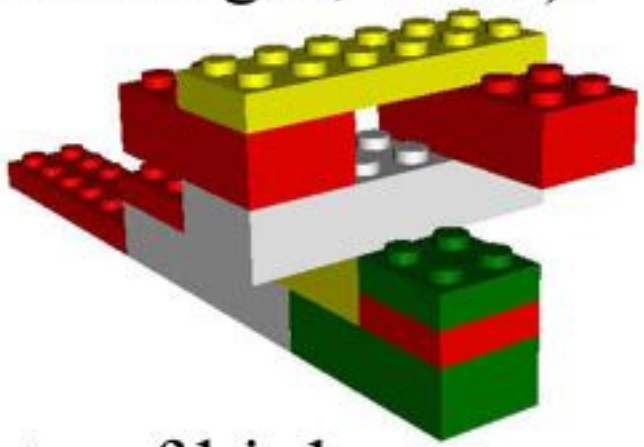
# The Lego® Principle

•Biology is largely built from on a small number of components (Lehninger, 1975):

-20 L amino acids

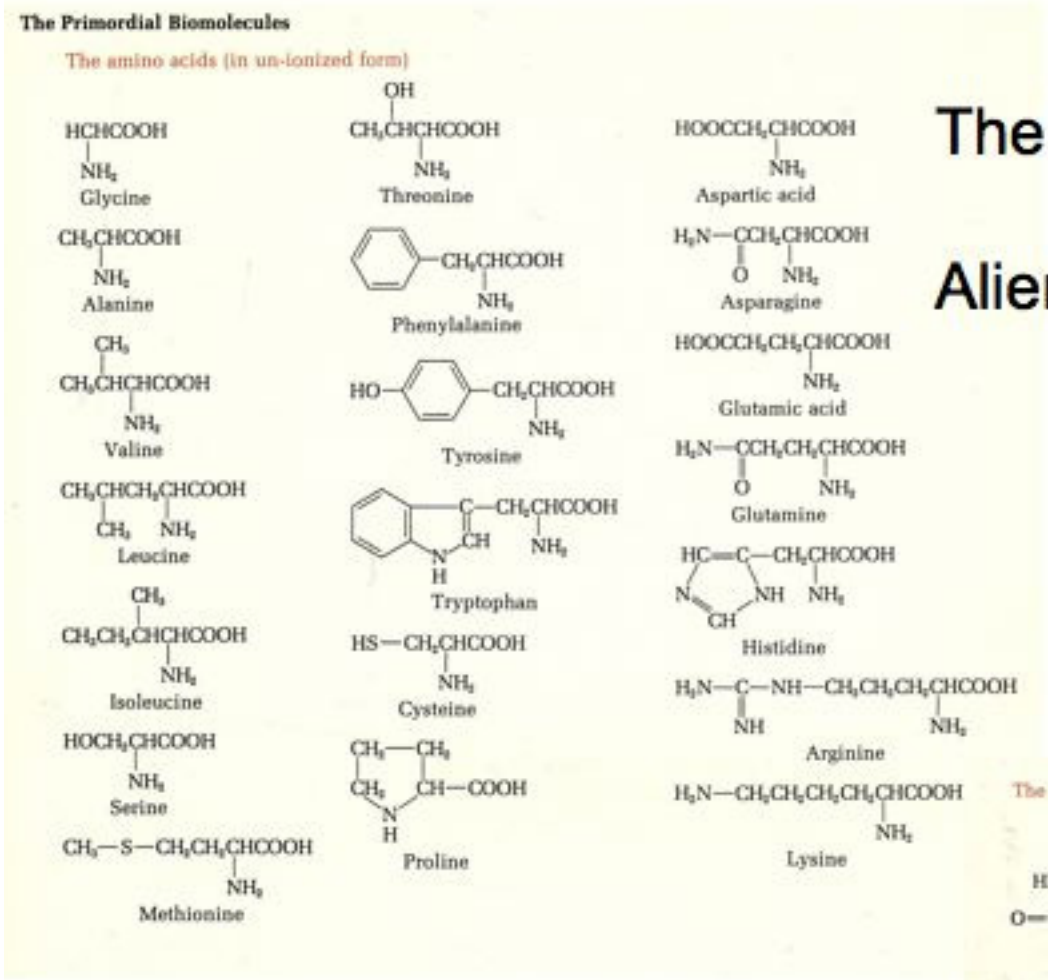
-5 nucleotide bases

-few D sugars, etc.



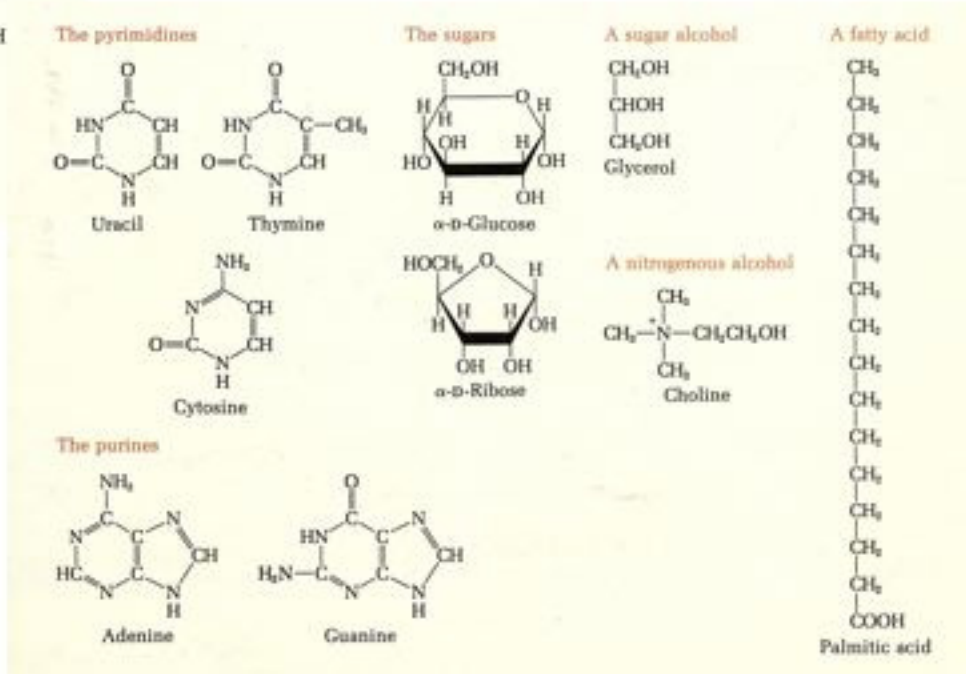
•Likely a common property of biology (and mass-produced children's toys) throughout the universe.

McKay 2004 *PLoS Biol* 2(9)1260-12623

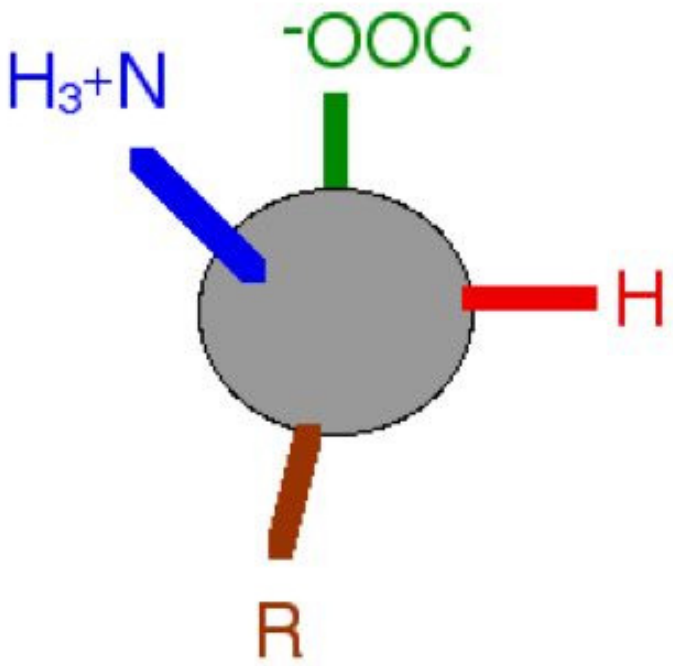



# The building blocks of Earth life

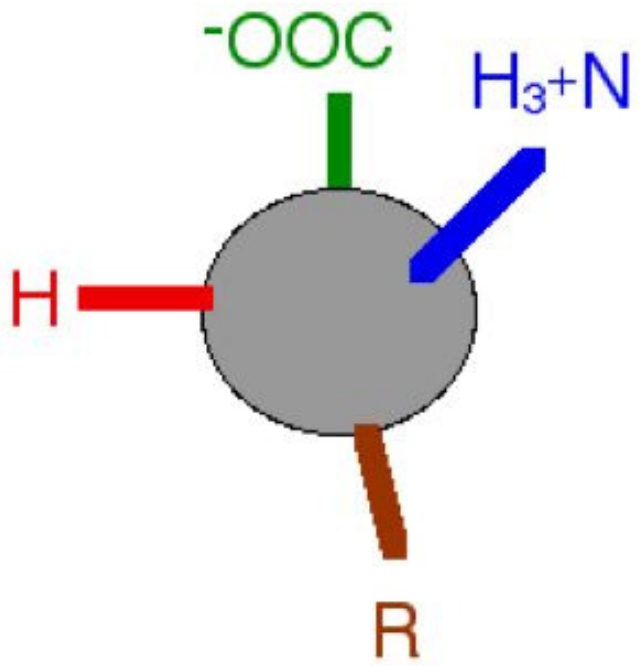
# Alien life could use a different set




*From Lehninger, 1975*

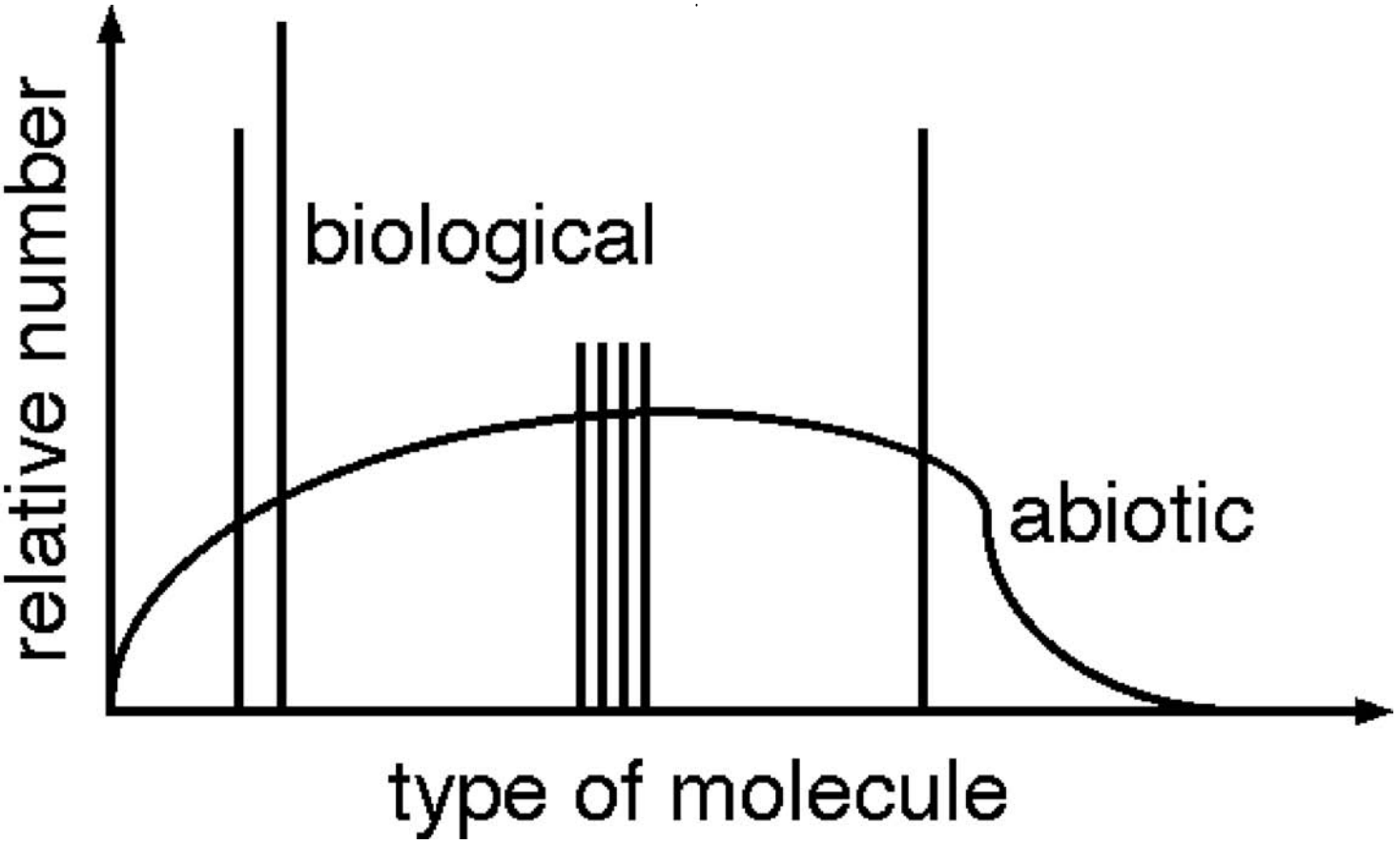



L - amino acids
used in proteins




D - amino acids
not in proteins

Abiotic distributions are smooth
Biotic distributions are spiked




McKay 2004 *PLoS Biol* 2(9)1260-12623

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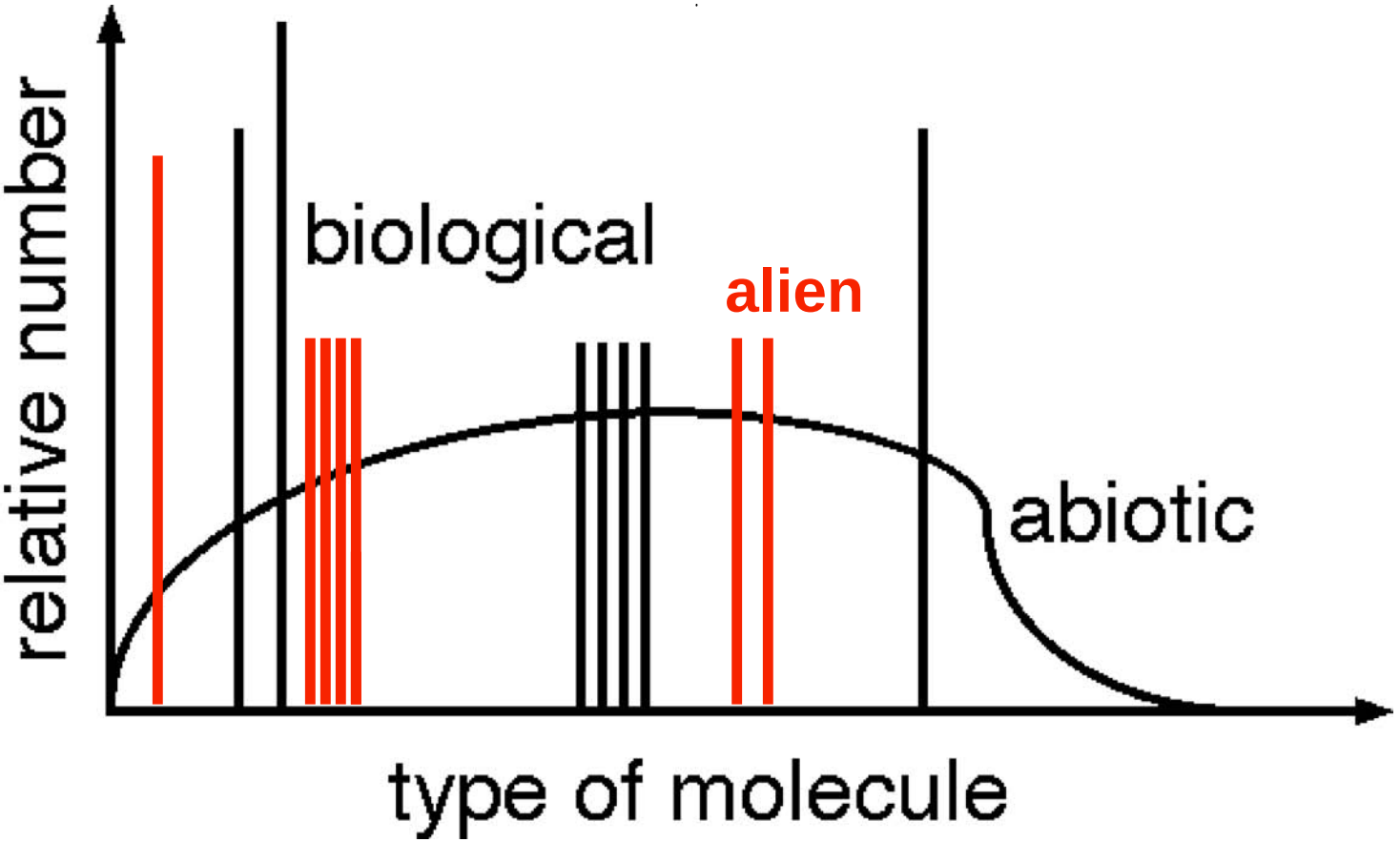
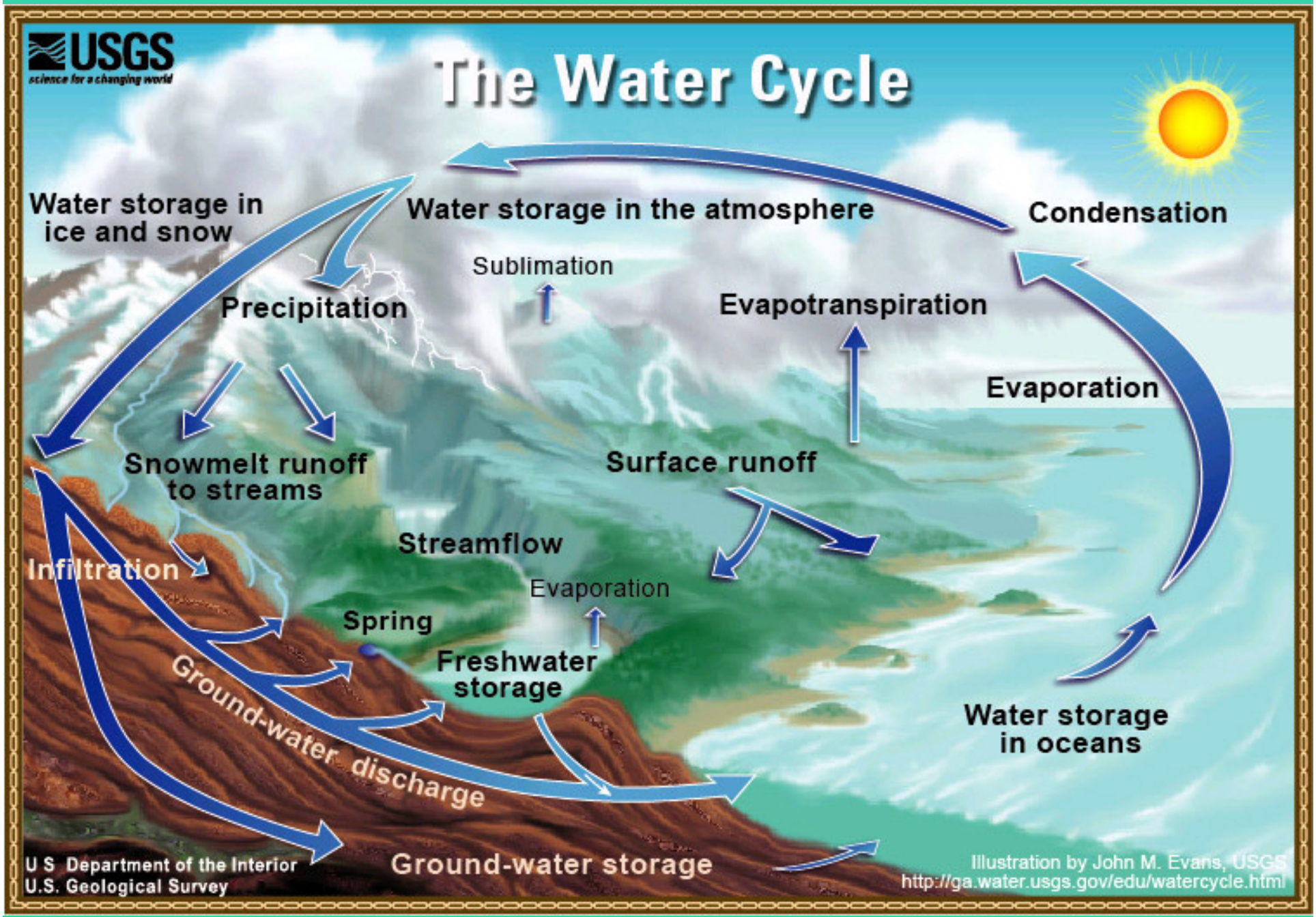


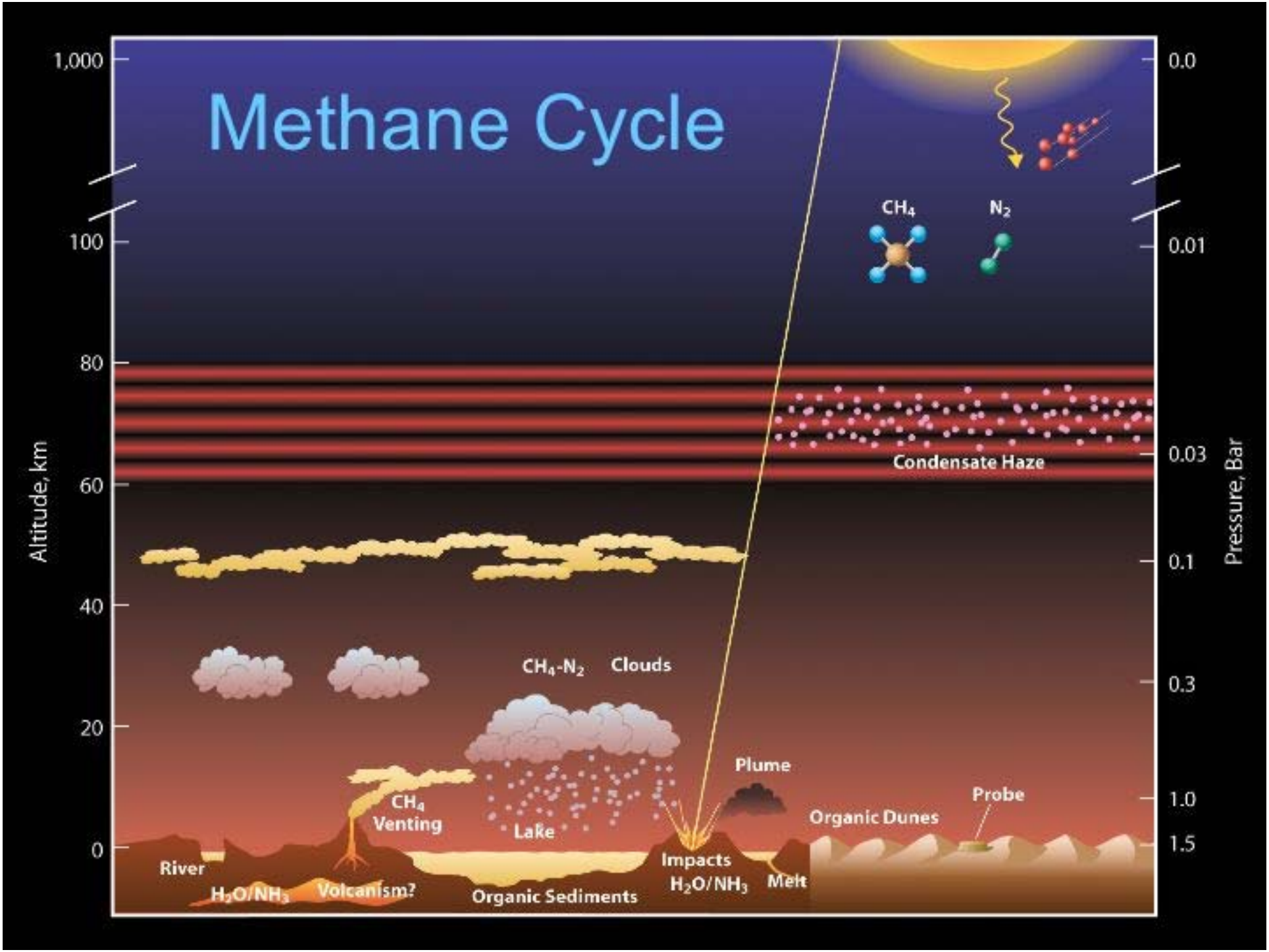

McKay 2004 *PLoS Biol* 2(9)1260-12623

# Titan's haze and clouds

# Comparing Titan and Earth

| Property | Titan | Earth |
|---|---|---|
| Gravity | 1/7 | 1 |
| Pressure | 1.5 atm | 1 atm |
| Atmosphere | $N_2$, $CH_4$, | $N_2$, $O_2$ , $CO_2$ |
| Clouds & Rain | $CH_4$, $C_2H_6$ | $H_2O$ |
| Greenhouse | $N_2$, $CH_4$, $H_2$ | $CO_2$, $H_2O$ |
| Temperature | -180°C | +15°C |
| Rotation | 16 days | 1 day |
| Solar Orbit | 30 years | 1 year |


USGS
science for a changing world
The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
Ground-water storage
U S Department of the Interior
U.S. Geological Survey
Illustration by John M. Evans, USGS
http://ga.water.usgs.gov/edu/watercycle.html


Methane Cycle
1,000
100
80
60
40
20
0
Altitude, km
0.0
0.01
0.03
0.1
0.3
1.0
1.5
Pressure, Bar
$CH_4$
$N_2$
Condensate Haze
$CH_4$-$N_2$ Clouds
Plume
Probe
Organic Dunes
$CH_4$ Venting
Lake
River
$H_2O/NH_3$
Volcanism?
Organic Sediments
Impacts
$H_2O/NH_3$
Melt

# Known composition of Titan's Atmosphere

## Major gases

| | |
|---|---|
| $N_2$ | 95-99% |
| $CH_4$ | 1-5% |
| $H_2$ | 0.1% |
| Ar | 40 ppm |

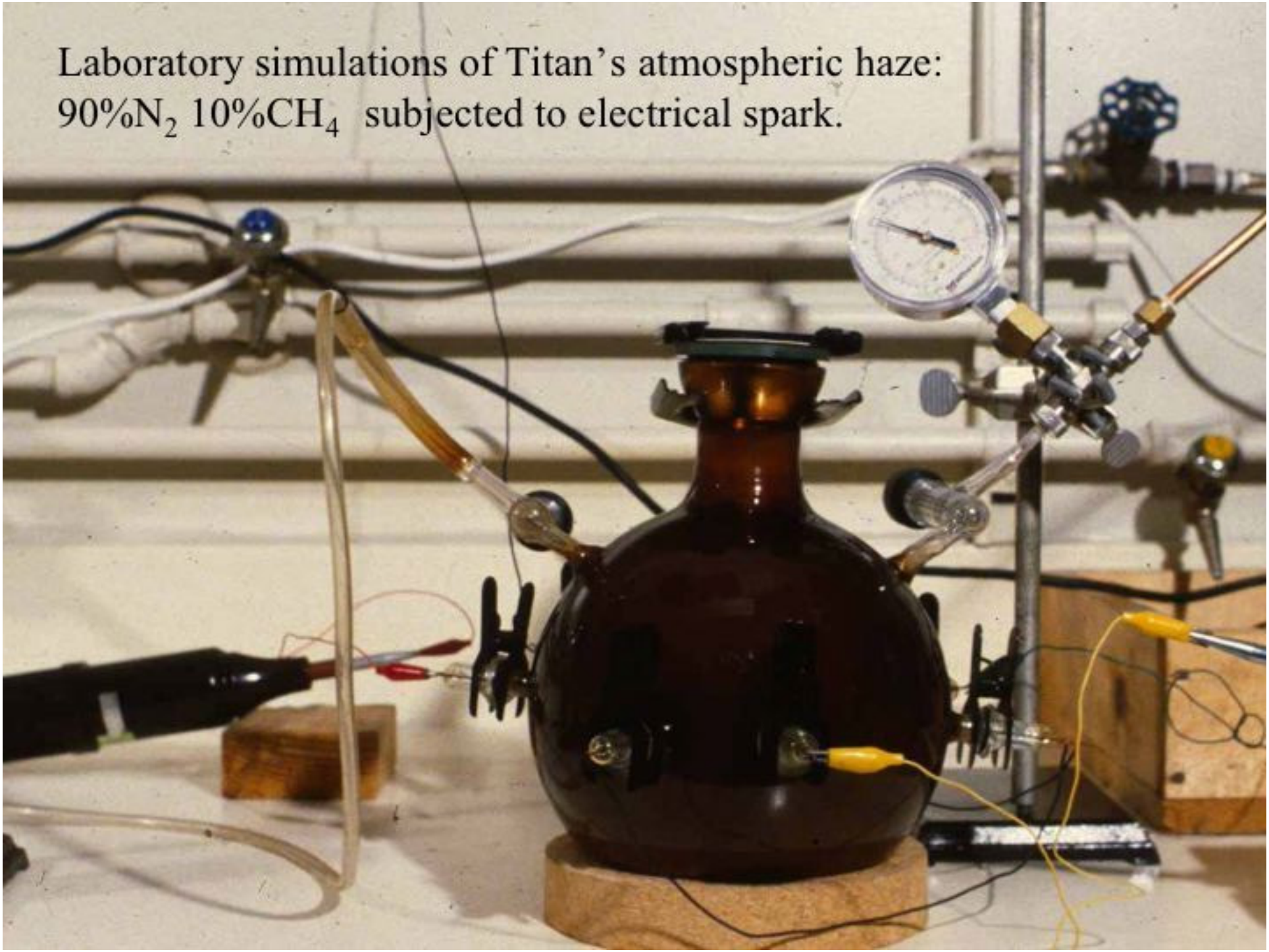
Surface pressure 1.5 atm

Surface temperature 95 K

-180°C

## Minor gases

| | |
|---|---|
| $C_2H_6$ | 20 ppm |
| $C_3H_8$ | 5-20 ppm |
| $C_2H_2$ | 2 ppm |
| $C_2H_4$ | 400 ppb |
| $C_4H_2$ | 30 ppb |
| $C_6H_6$ | 0.4 ppb |
| $CH_3C_2H$ | 30 ppb |
| HCN | 20 ppm |
| $HC_2CN$ | 10-1000 ppb |
| $C_2N_2$ | 10-100 ppb |
| $CO_2$ | 10 ppb |
| CO | 60 ppm |
| $H_2O$ | 8 ppb |


Laboratory simulations of Titan's atmospheric haze:
90%$N_2$ 10%$CH_4$ subjected to electrical spark.


Warning: this world contains
compounds known to the
State of California to cause cancer

# Titan mystery #6

Are there aliens?

# Possibilities for Widespread Life on Titan

| Earth | Titan |
| --- | --- |
| Carbon based | Carbon based |
| Liquid $H_2O$ | Liquid $CH_4$ |
| Widespread | ?? |

# Could there be methane life on Titan? ☺

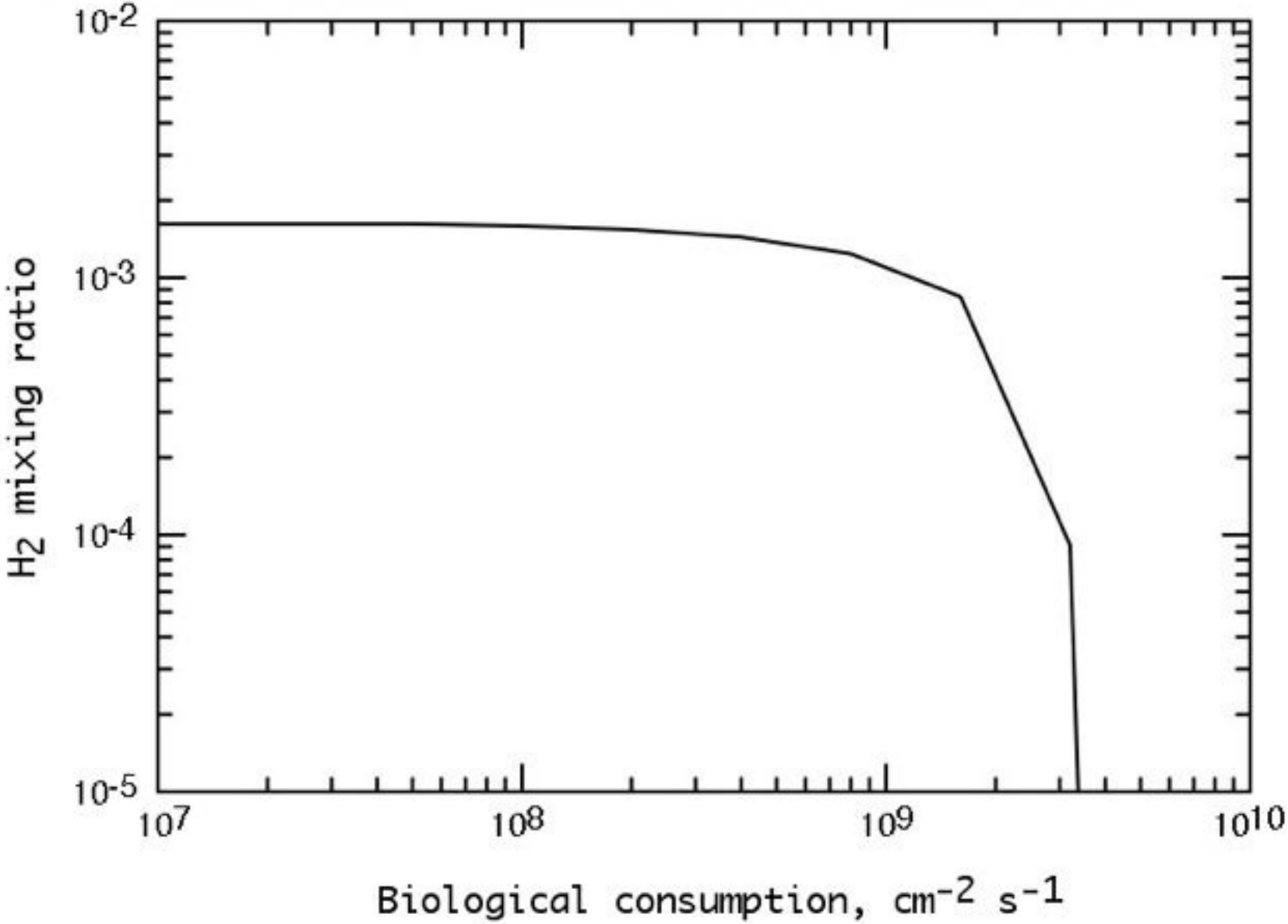
Table 1. Free Energies of Hydrogenation on Titan

| **Reaction** | **ΔG (kcal/mole)** |
|---|---|
| $C_2H_2 + 3H_2 = 2CH_4$ | 80 |
| $C_2H_6 + H_2 = 2CH_4$ | 15 |
| $R\text{-}CH_2 + H_2 = R + CH_4$ | 13 |
| Earth | |
| $CO_2 + H_2 = CH_4 + H_2O$ | >10 |

$$\Delta G = \Delta H - T\Delta S + RT \ln(Q)$$

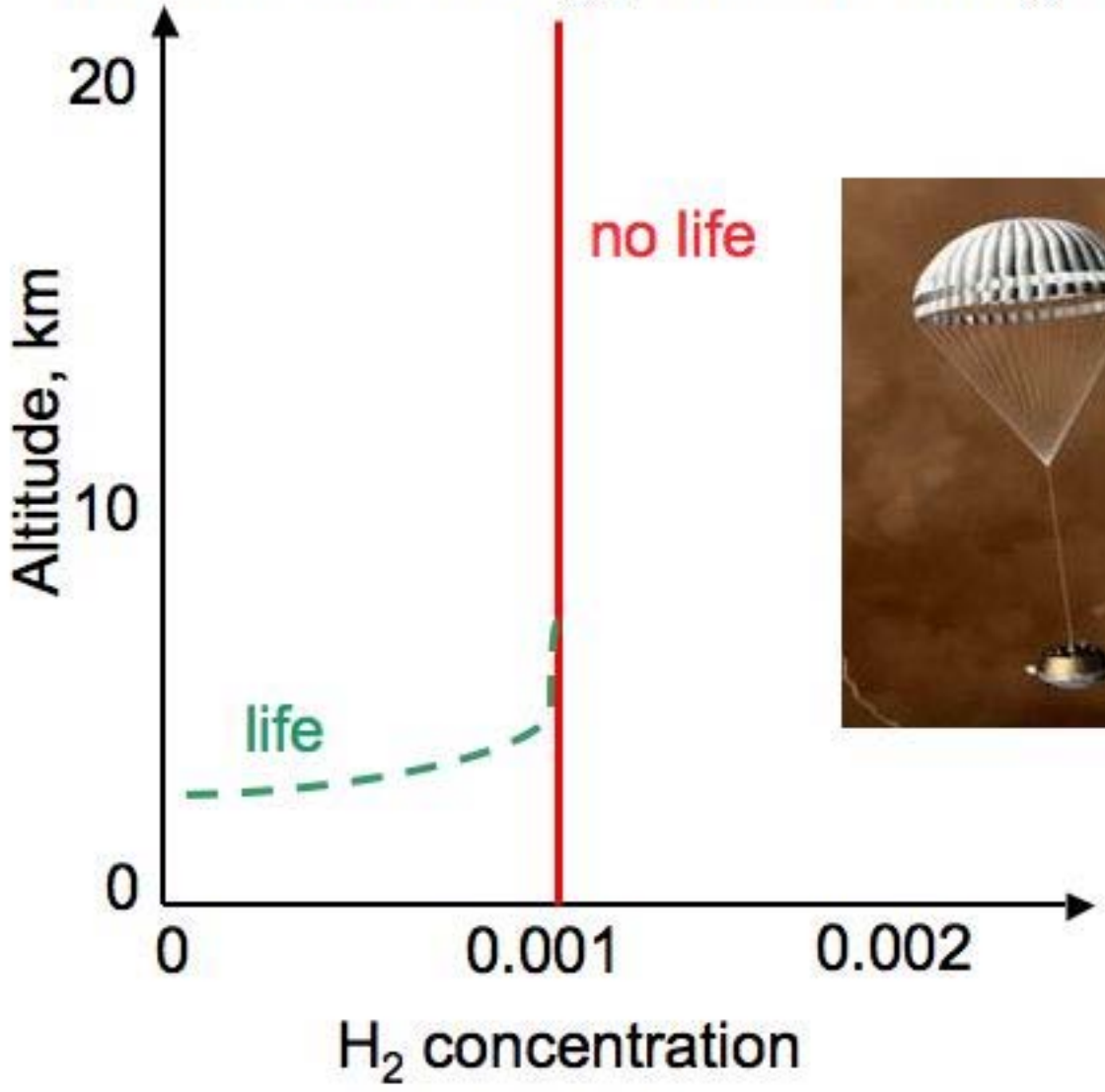
McKay and Smith, Icarus, 2005

# $H_2$ consuming life on Titan would deplete $H_2$ at the surface




*McKay & Smith Icarus 2005*

The Huygens Probe would detect a depletion of $H_2$ which would strongly indicate biological consumption






The Probe GCMS can detect H2 but the carrier gas is H2 …
so it will take more calibration.
Answers expected next year.

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