Organics and Life

An important focus for the future of planetary science and the Outer Solar System in particular.

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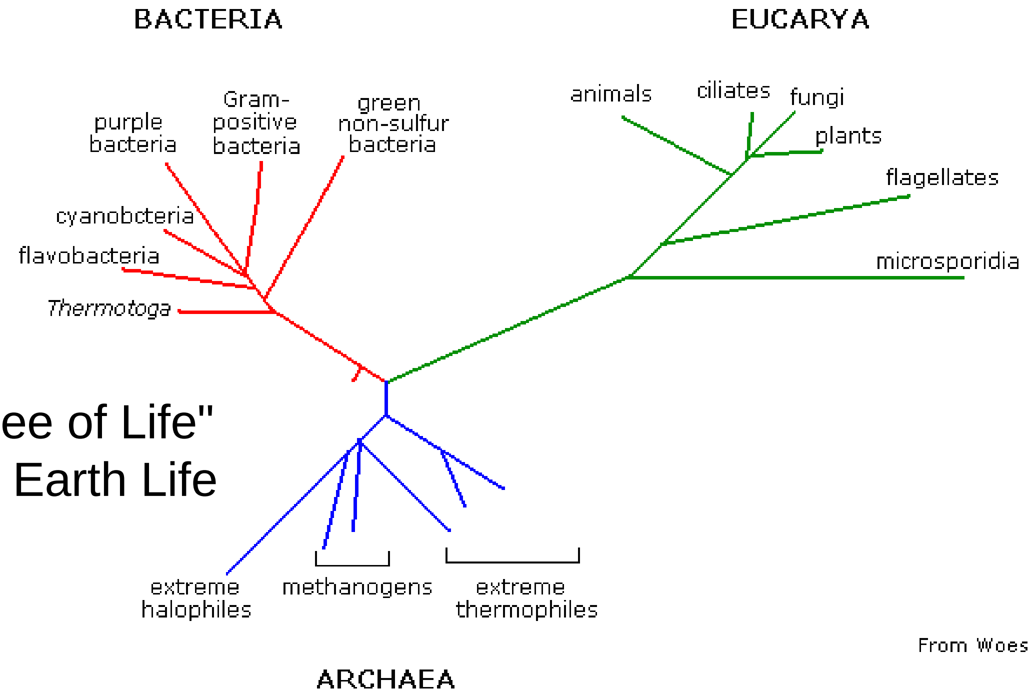
The search for a second genesis of life

⇒ comparative biochemistry (life 2.0)
step to understanding the origin of life

⇒ life is common in the universe (yeah!)

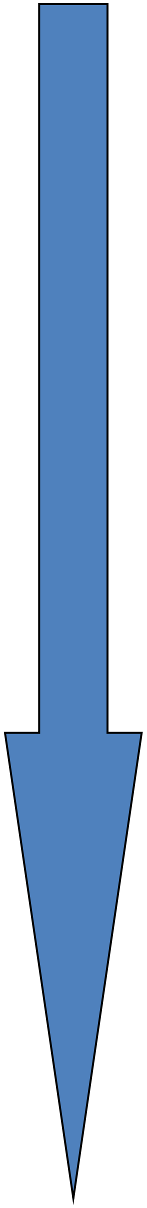


From Woese, 1987

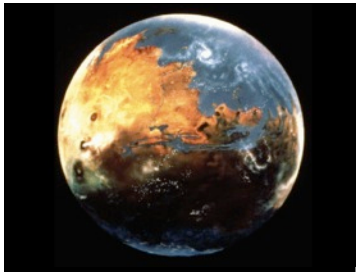
"The Tree of Life"
defines Earth Life

Aliens:
not on our tree of life

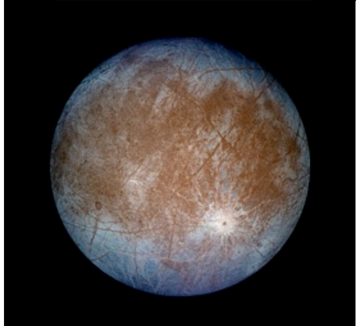
Where to look for life?



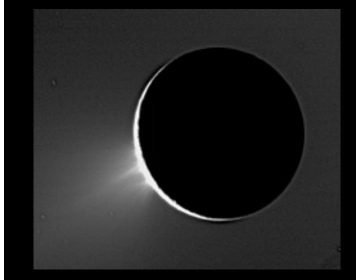
Increasing
chance of life
not related to
Earth life



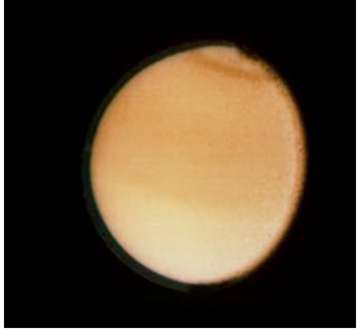
Mars: past liquid water, no organics (yet), current surface destroys organics



Europa: has ocean,
No direct evidence of N or organics



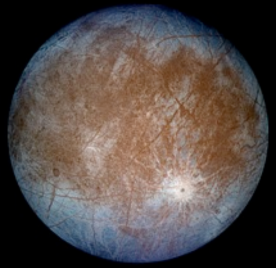
Enceladus: has icy jet,
liquid water, organics, nitrogen



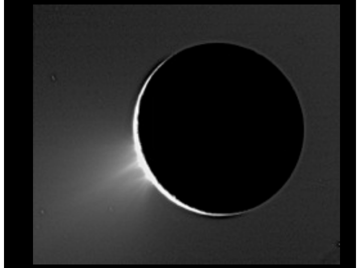
Titan: liquid - not water, organics

Organics

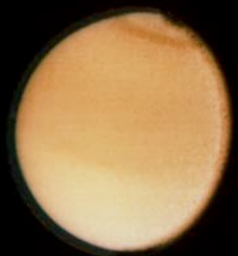
No evidence of organics.



Organics present in the plume.



Organics present in the atmosphere and surface.



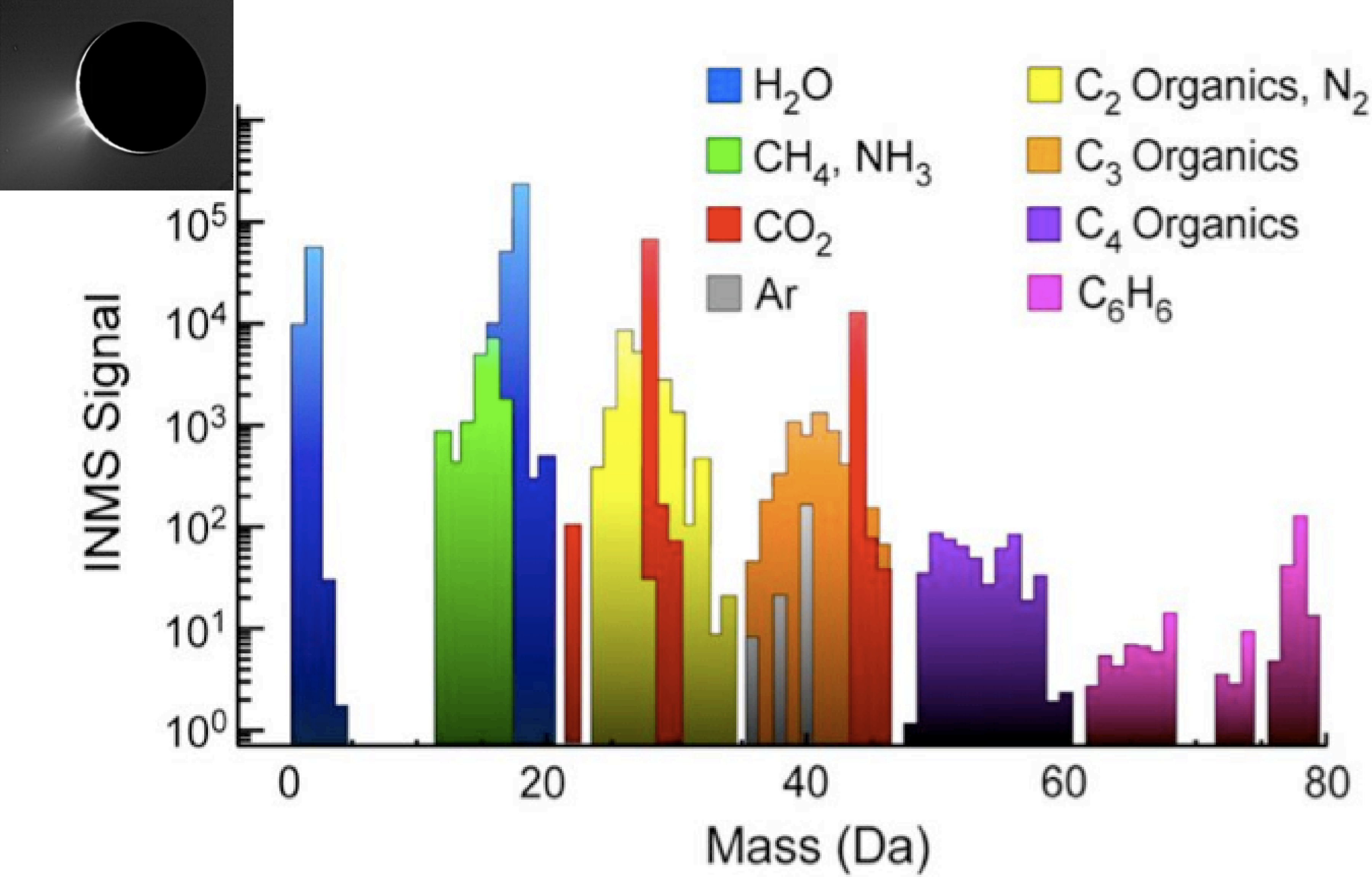
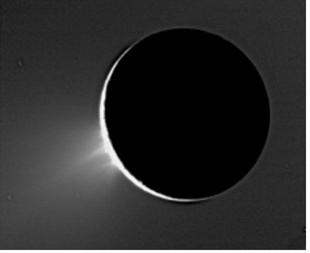


Figure 22.18 Mass spectrum of the Enceladus plume from the October 9th 2008 flyby (Waite et al. 2009). The colors show contributions from various species and their breakdown products using the composition shown in Table 22.3.



Enceladus Organics

- Is H_2 present, redox?
- Diagnostic compounds:
  C_2H_2 stable energetic compound
  CO unstable energetic compound
  HCN important source of N
  C_2H_4 not in comets, FFT and thermal
- Simultaneous CH_4 and NH_3 usually from decaying biomass.
- Are amino acids present?

Titan Organics

Even with Cassini/Huygens our knowledge of the organics processes on Titan, especially the surface is rudimentary.

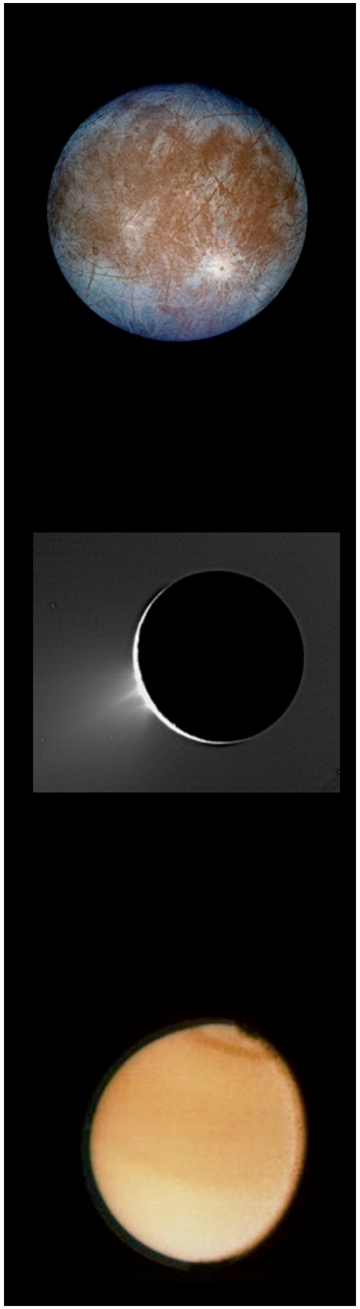
- C_2H_6 surface mixing ratio
- C:H:N ratio in the haze
- Surface processing of solid organics
- Solutions & residues seen in receding lakes
- Any curious depletions of H_2

Habitability

Water, and presumably
nutrients and energy

Water, organics, N,
probably redox energy

Liquid (not water)
redox energy (H_2 + C_2H_2),
organics (lots)



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

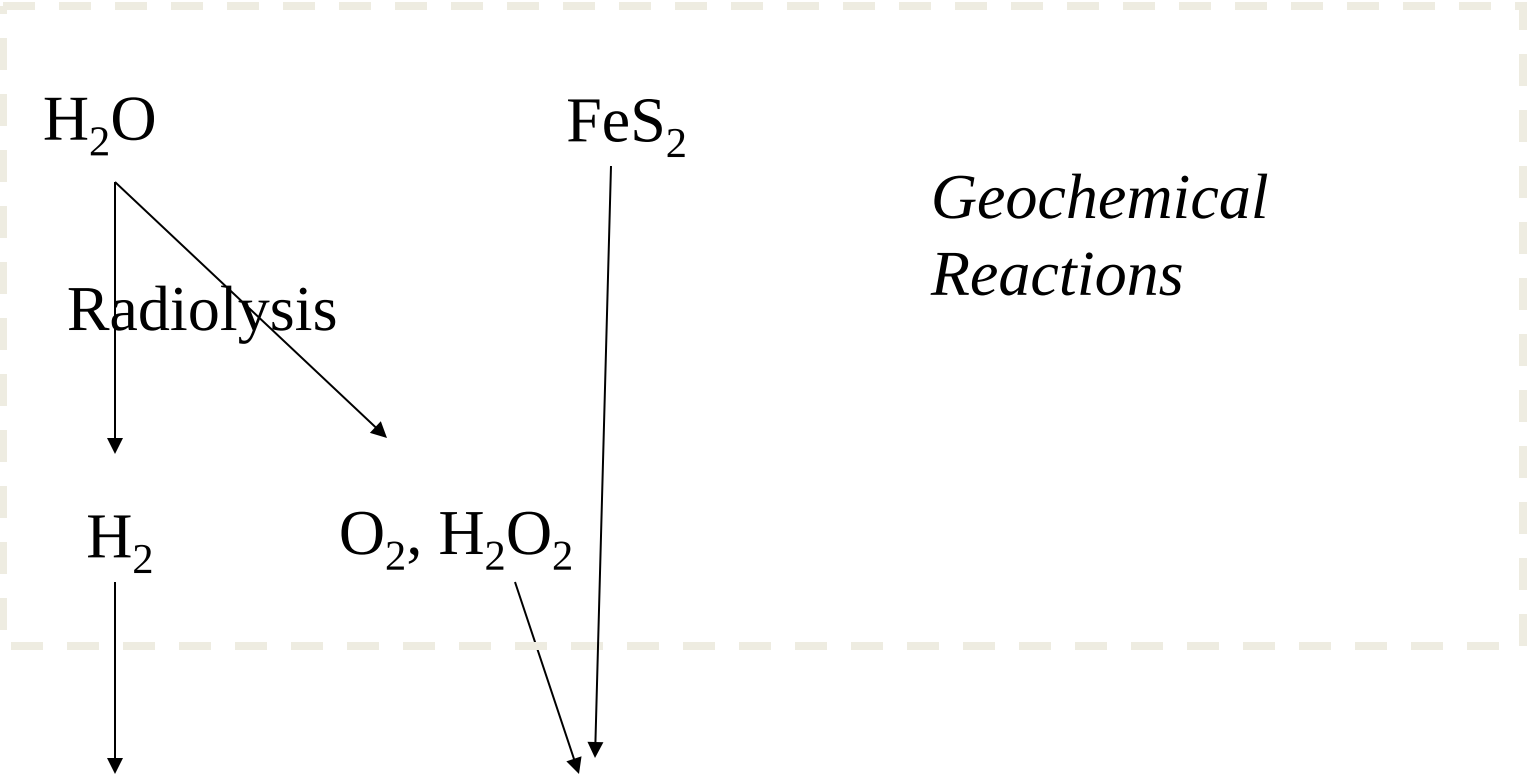
Only three examples are known:

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



H_2O

FeS_2

Geochemical Reactions

Radiolysis

H_2

O_2, H_2O_2

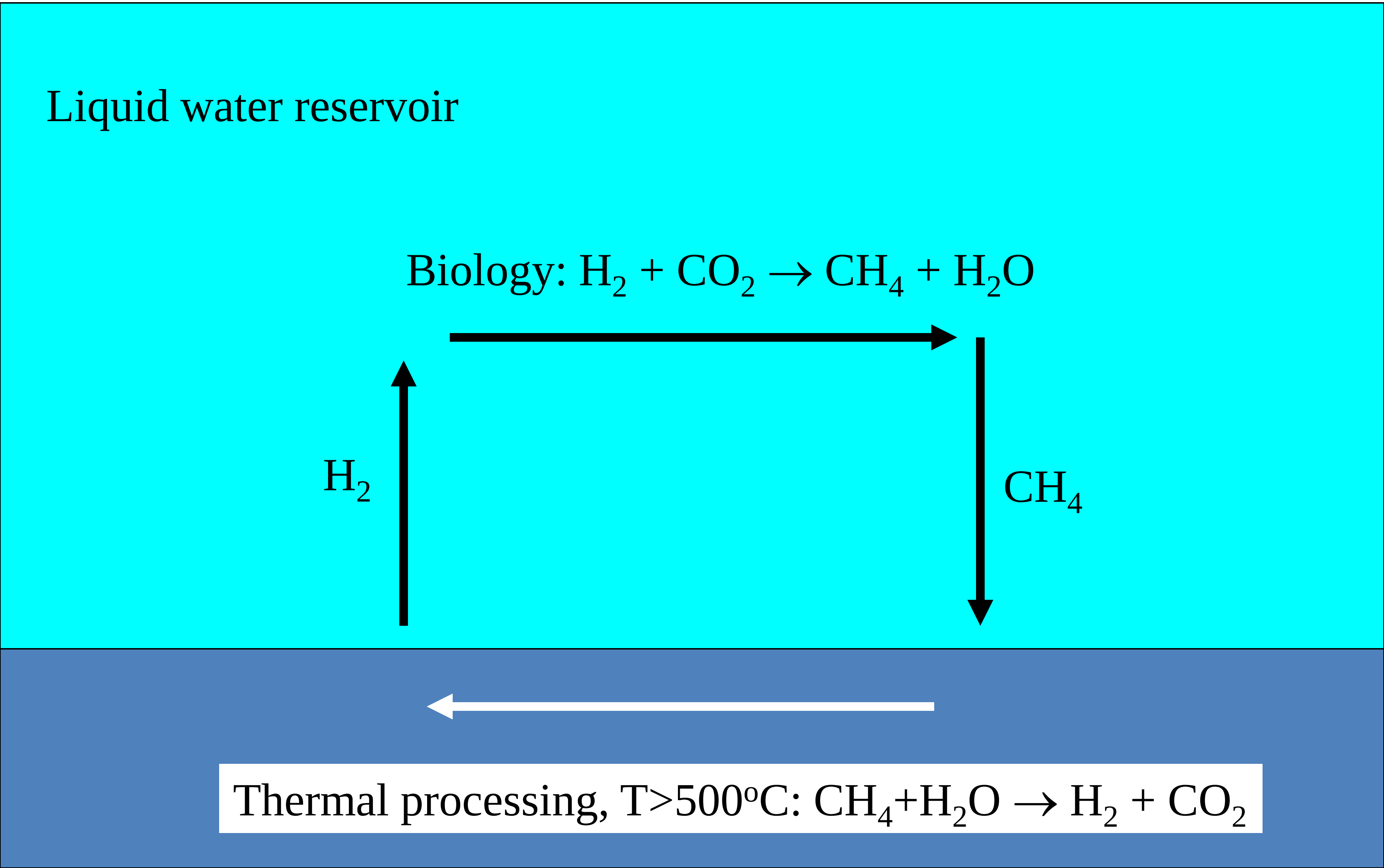
$$4H_2 + H^+ + SO_4^{2-} \xrightarrow{SRB} H_2S + 2H_2O + 2OH^-$$

Desulfoprofundis tokoloshe

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

McKay et al. 2008

Surface material



Liquid water reservoir

Biology: $H_2 + CO_2 \rightarrow CH_4 + H_2O$

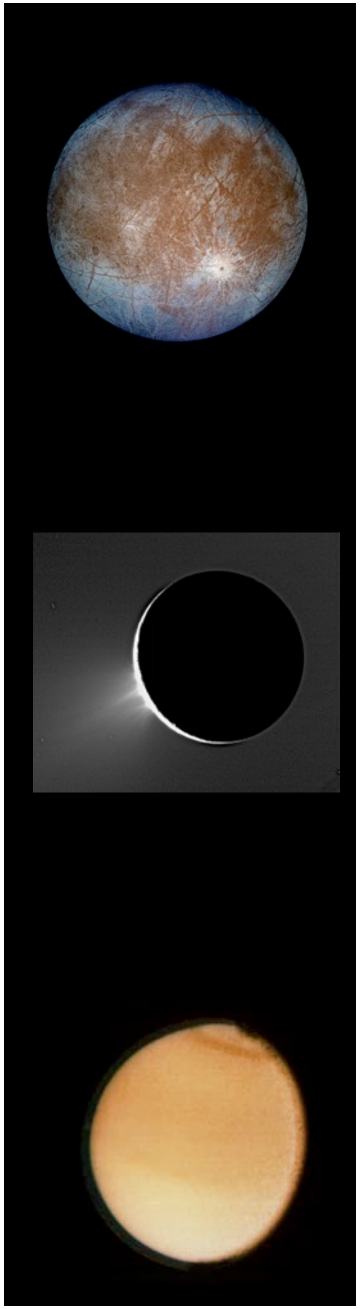
H_2

CH_4

Thermal processing, T>500^{o}C: $CH_4 + H_2O \rightarrow H_2 + CO_2$

Origin of Life

?



The only fact we have about the origin of life is that it happened more than 3.5 Gyr ago.

We do not know where, when, how it happened, or how long it took.

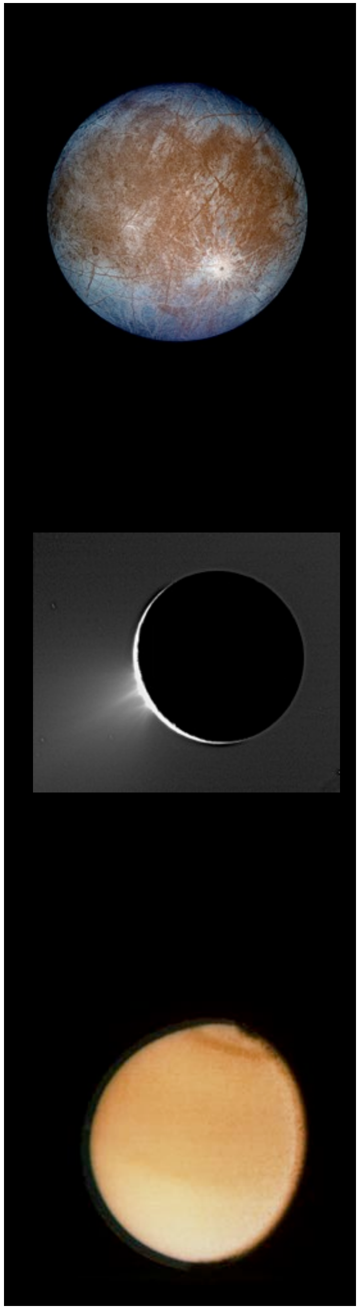
The view that it occurred on Earth and/or took a long time is unsupported by any evidence.

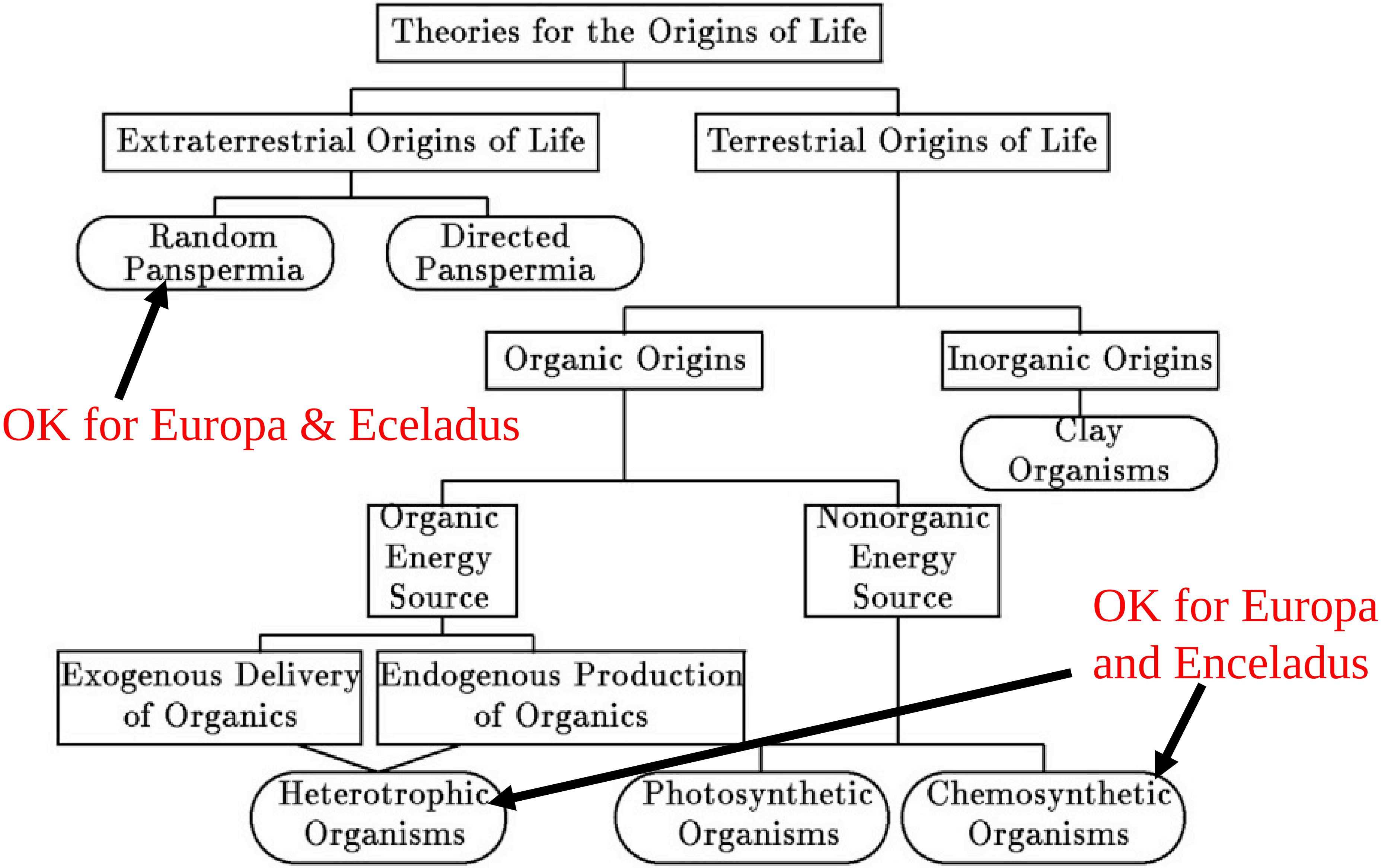
Origin of Life

"As with all fields where significant data are still sparse and where the most important breakthroughs probably lie well in the future, many books now claim to have completely solved the problem or to have at least opened the field sufficiently so that no other approach than the author's is significant."

Greenberg 1994 book review in Phys Today

The history of science suggests that the important breakthroughs will come not from theory but from observations in a new domain.





Theories for the Origins of Life

Extraterrestrial Origins of Life

Random Panspermia

Directed Panspermia

Terrestrial Origins of Life

Organic Origins

Inorganic Origins

Clay Organisms

Organic Energy Source

Nonorganic Energy Source

Exogenous Delivery of Organics

Endogenous Production of Organics

Heterotrophic Organisms

Photosynthetic Organisms

Chemosynthetic Organisms

OK for Europa & Eceladus

OK for Europa and Enceladus

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

Life Wanted: Dead or Alive

- The search for life is **<u>not</u>** a search for something alive.
  - No microscopes for motion
  - No Viking-like metabolism experiments
- At the scale of microorganisms, structure is not convincing.
- The best evidence of life is dead
  - biomolecular structures

[life: 1) a phenomenon, 2) a state variable, 3) a path integral]

Biomarkers

Organic

- Lipids
- Nucleic Acids
- Proteins
- Amino acid
- Amino acid selection
- Special molecules
  - (quinones, porphyrins, etc)

Inorganic

- Trace fossils
- Isotopes
- Mineralogy
- Cell-like shapes
- Magnetite chains

Red = could be convincing evidence
Blue = possibly convincing
Grey = context information only

Amino acids are in meteorites & comets

- Even without life they are likely to be present in plumes.
- Relevant to understanding sources and processing of organics.

Glavin et al. 2011

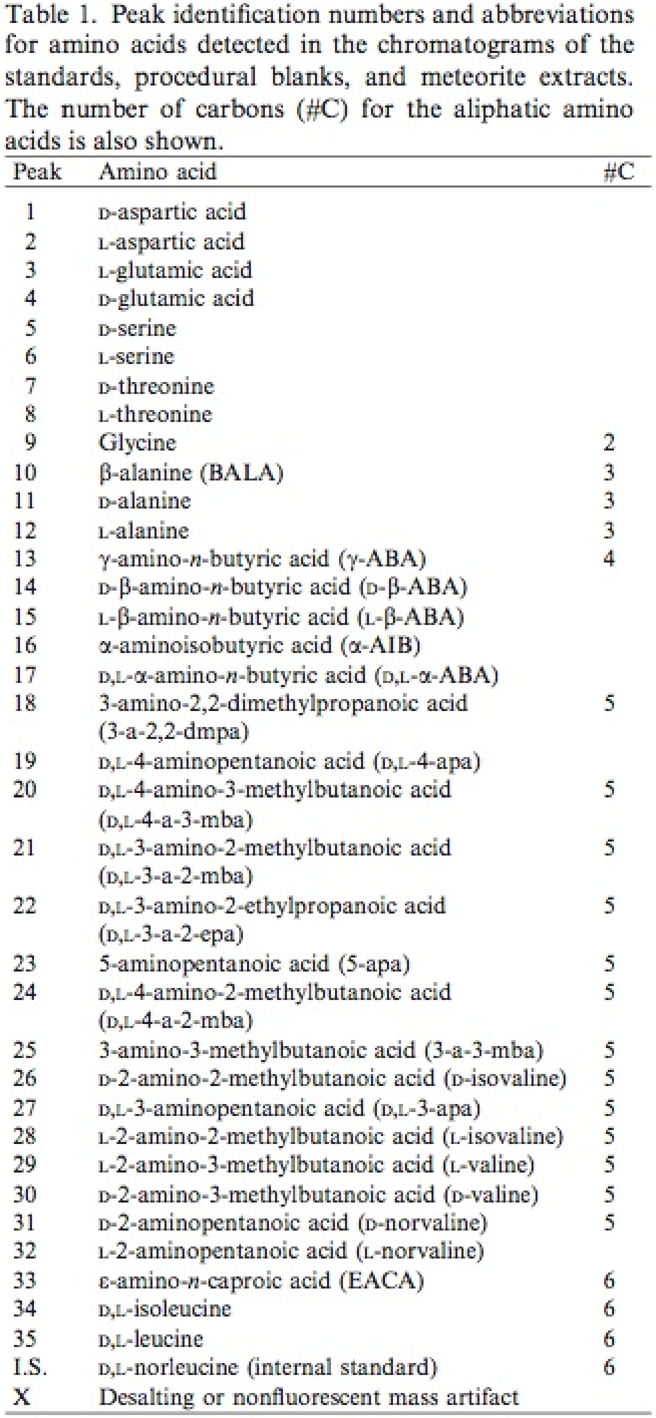
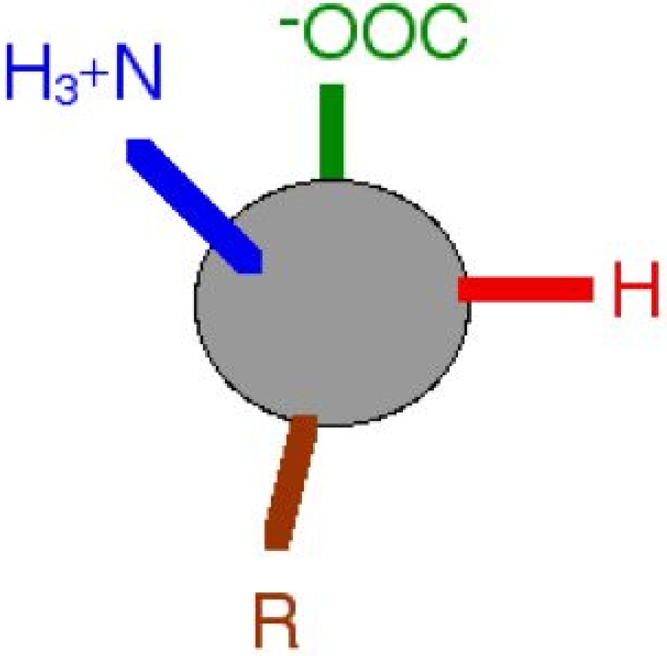
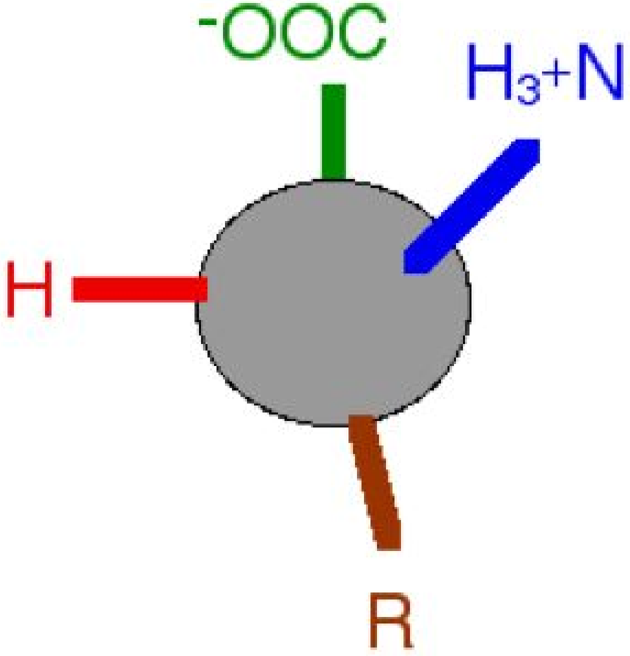


Table 1. Peak identification numbers and abbreviations for amino acids detected in the chromatograms of the standards, procedural blanks, and meteorite extracts. The number of carbons (#C) for the aliphatic amino acids is also shown.

Peak	Amino acid	#C
1	D-aspartic acid	
2	L-aspartic acid	
3	L-glutamic acid	
4	D-glutamic acid	
5	D-serine	
6	L-serine	
7	D-threonine	
8	L-threonine	
9	Glycine	2
10	β-alanine (BALA)	3
11	D-alanine	3
12	L-alanine	3
13	γ-amino-*n*-butyric acid (γ-ABA)	4
14	D-β-amino-*n*-butyric acid (D-β-ABA)	
15	L-β-amino-*n*-butyric acid (L-β-ABA)	
16	α-aminoisobutyric acid (α-AIB)	
17	D,L-α-amino-*n*-butyric acid (D,L-α-ABA)	
18	3-amino-2,2-dimethylpropanoic acid (3-a-2,2-dmpa)	5
19	D,L-4-aminopentanoic acid (D,L-4-apa)	
20	D,L-4-amino-3-methylbutanoic acid (D,L-4-a-3-mba)	5
21	D,L-3-amino-2-methylbutanoic acid (D,L-3-a-2-mba)	5
22	D,L-3-amino-2-ethylpropanoic acid (D,L-3-a-2-epa)	5
23	5-aminopentanoic acid (5-apa)	5
24	D,L-4-amino-2-methylbutanoic acid (D,L-4-a-2-mba)	5
25	3-amino-3-methylbutanoic acid (3-a-3-mba)	5
26	D-2-amino-2-methylbutanoic acid (D-isovaline)	5
27	D,L-3-aminopentanoic acid (D,L-3-apa)	5
28	L-2-amino-2-methylbutanoic acid (L-isovaline)	5
29	L-2-amino-3-methylbutanoic acid (L-valine)	5
30	D-2-amino-3-methylbutanoic acid (D-valine)	5
31	D-2-aminopentanoic acid (D-norvaline)	5
32	L-2-aminopentanoic acid (L-norvaline)	
33	ε-amino-*n*-caproic acid (EACA)	6
34	D,L-isoleucine	6
35	D,L-leucine	6
I.S.	D,L-norleucine (internal standard)	6
X	Desalting or nonfluorescent mass artifact	

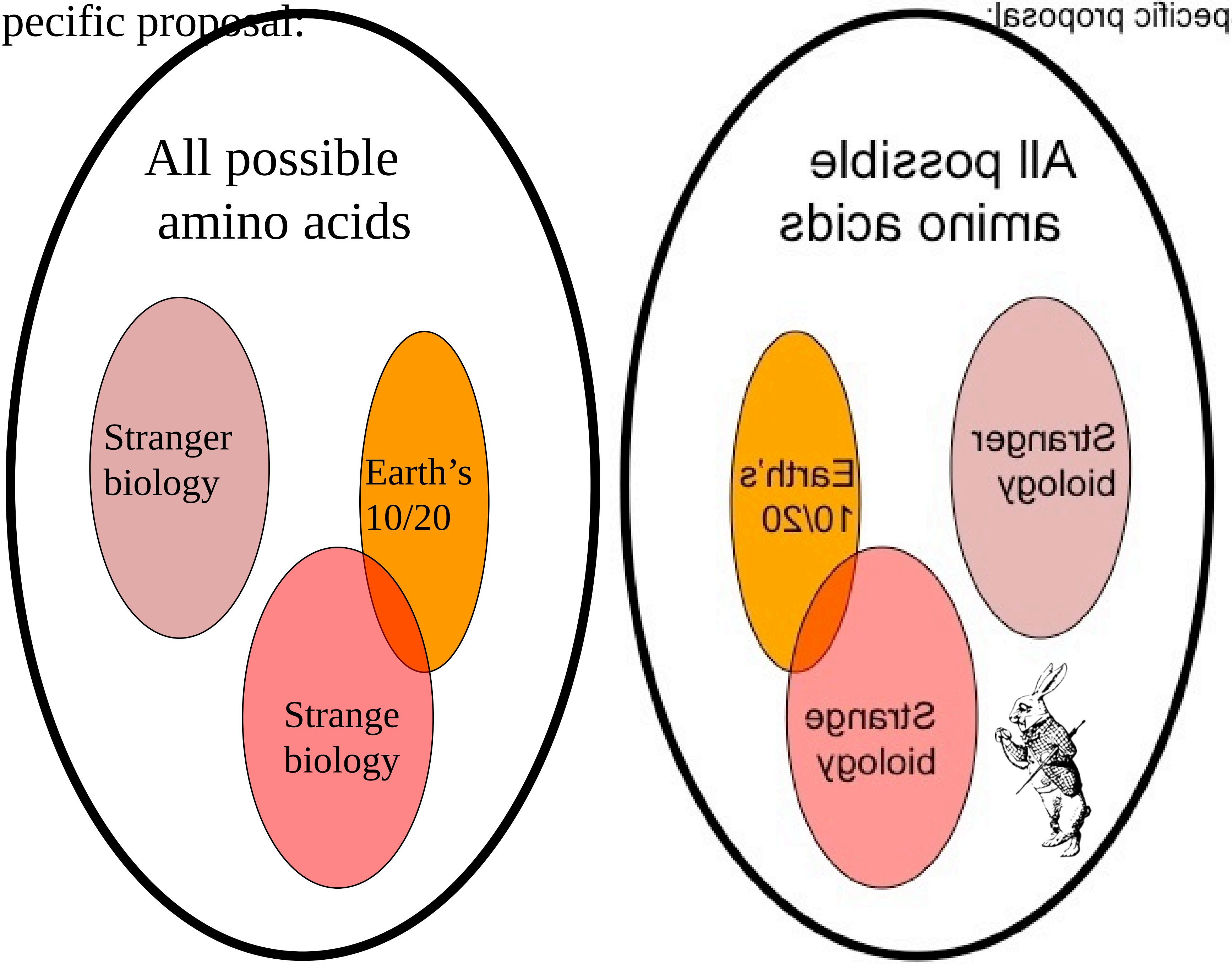


L - amino acids
used in proteins



D - amino acids
not in proteins

A specific proposal:



All possible amino acids

Stranger biology

Earth's 10/20

Strange biology

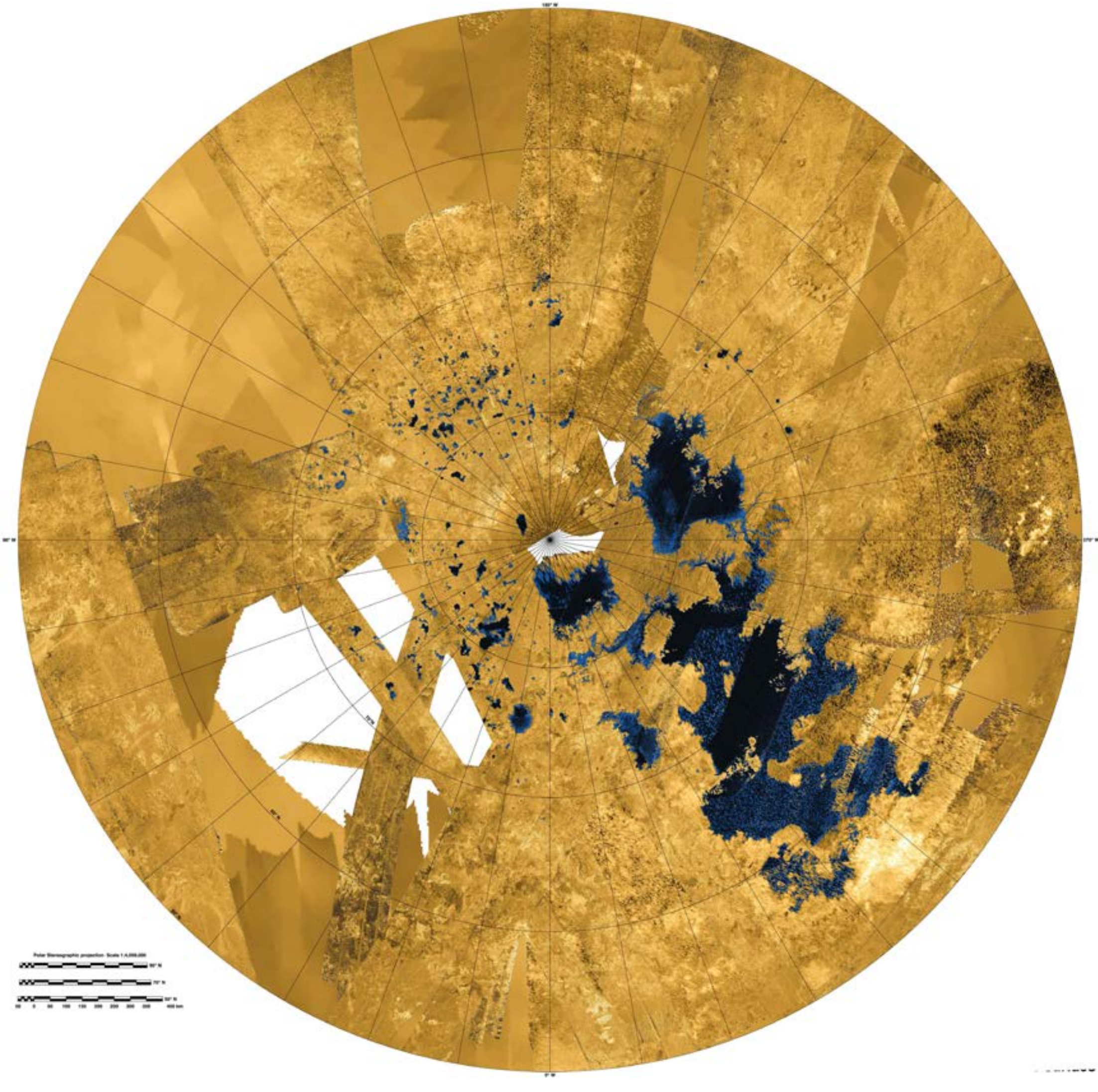
Why Sample Return

- If Nature conforms to our expectations and life elsewhere uses amino acids and these are present in a plume as a distinct group and of definite chirality then there is no need to sample return at this time.
- Nature does not have a good record of conforming to our expectations (eg. perchlorate on Mars).
- If life elsewhere has unexpected biochemistry then understanding this will require iterative investigations – virtually impossible in-situ methods.
- We need to learn to do astrobiology sample return.

We need to develop the requirements and technology for sample return from habitable environments.

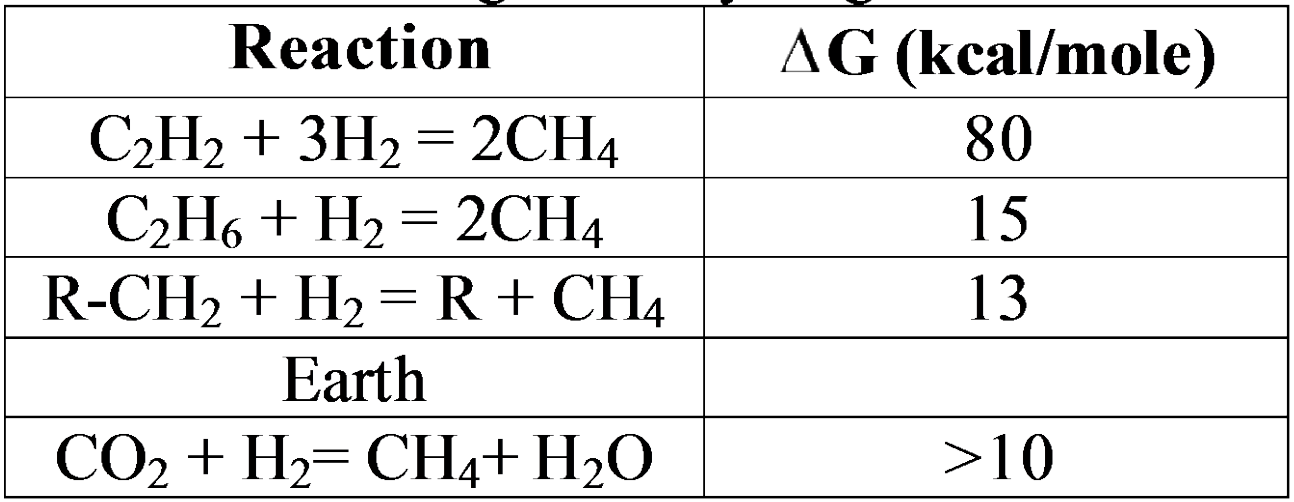
This is current a show-stopper.

Titan: on the beach



Could there be methane life on Titan? ☺

Table 1. Free Energies of Hydrogenation on Titan



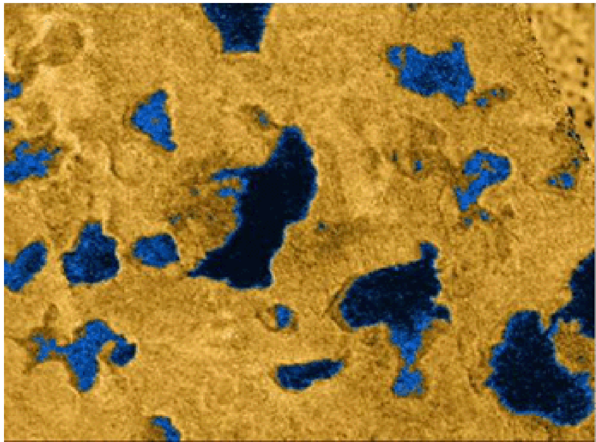
Reaction	**ΔG (kcal/mole)**
$C_2H_2 + 3H_2 = 2CH_4$	80
$C_2H_6 + H_2 = 2CH_4$	15
$R\text{-}CH_2 + H_2 = R + CH_4$	13
Earth	
$CO_2 + H_2 = CH_4 + H_2O$	>10

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

McKay and Smith, Icarus, 2005

Possibilities for Widespread Life on Titan

Earth	Titan
Carbon based	Carbon based
Liquid H_2O	Liquid CH_4
Widespread	If widespread then
Global pollution (O_2)	H_2 depletion



Opinions*

- The strongest support for outer Solar System missions beyond science comes from interest in life. Our planned missions do not adequately reflect this.
- We need to push harder for small innovative missions and technology demo.
  (eg. Mars Pathfinder, Philae)

*Not the opinion of the US gov't, NASA HQ, Ames, my Division, my colleagues or me.

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