The origin of life and the search for a second genesis of life on other worlds as problems in information science

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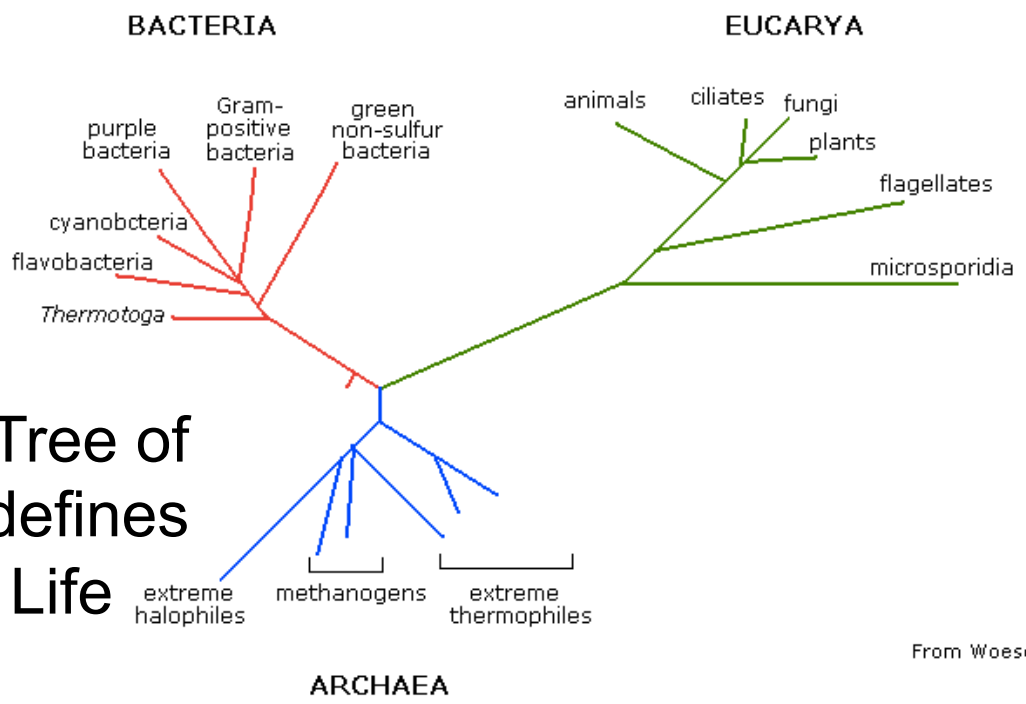
The search for a second genesis of life

⇒ comparative biochemistry (life 2.0)

⇒ life is common in the universe (yeah!)



From Woese, 1987

"The Tree of Life" defines Earth Life

Aliens: not on our tree of life

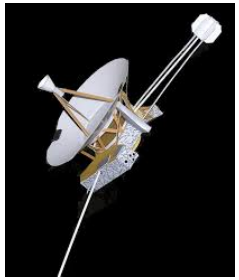
Second Genesis:

How will we get our second example of Biochemistry

Listen for them to call

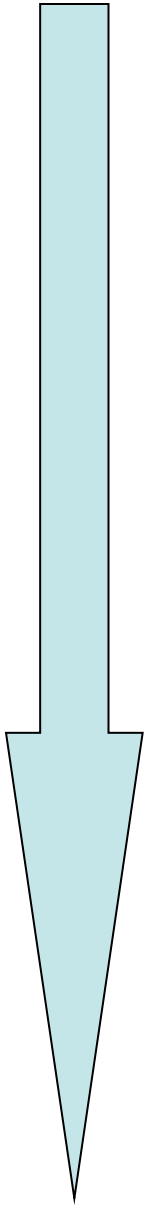
Make it in the laboratory

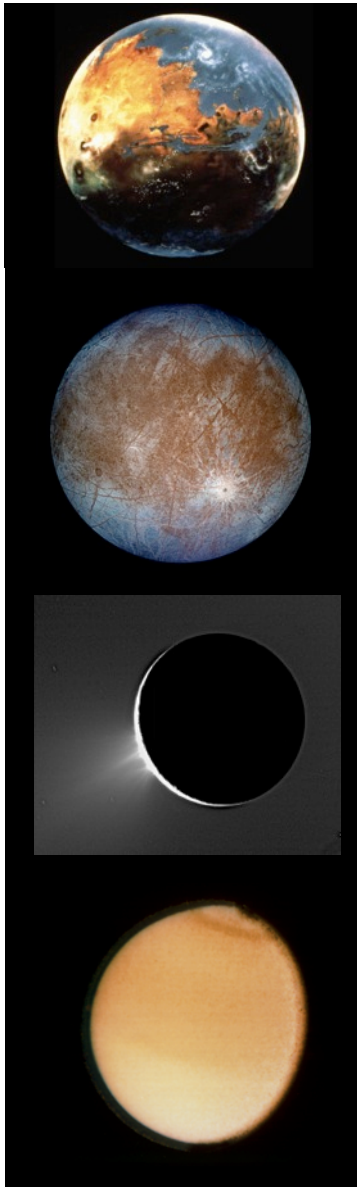
Find it on another world



Where to look for life?

Increasing chance of life not related to Earth life



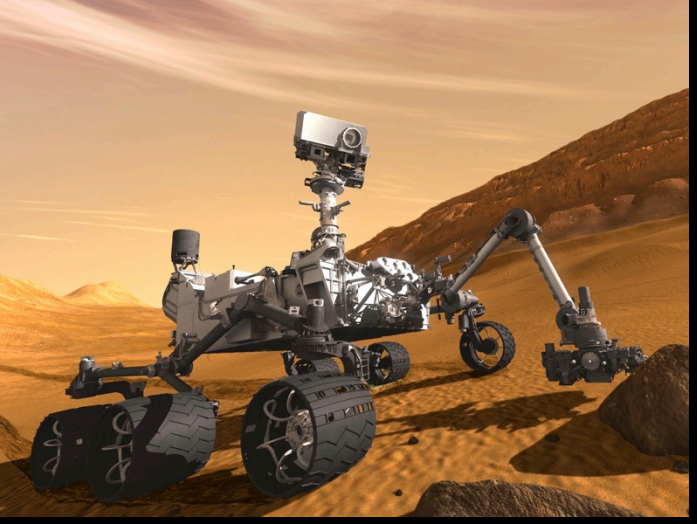


Mars: past liquid water, no organics (yet), current surface destroys organics

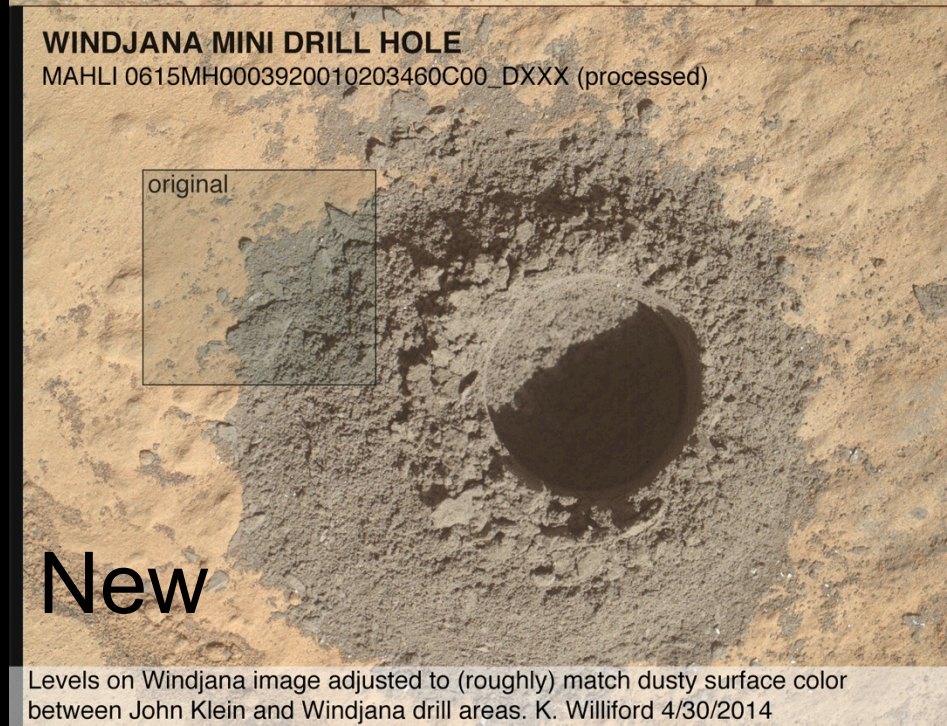
Europa: has ocean,
No direct evidence of N or organics

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

Titan: liquid - not water, organics

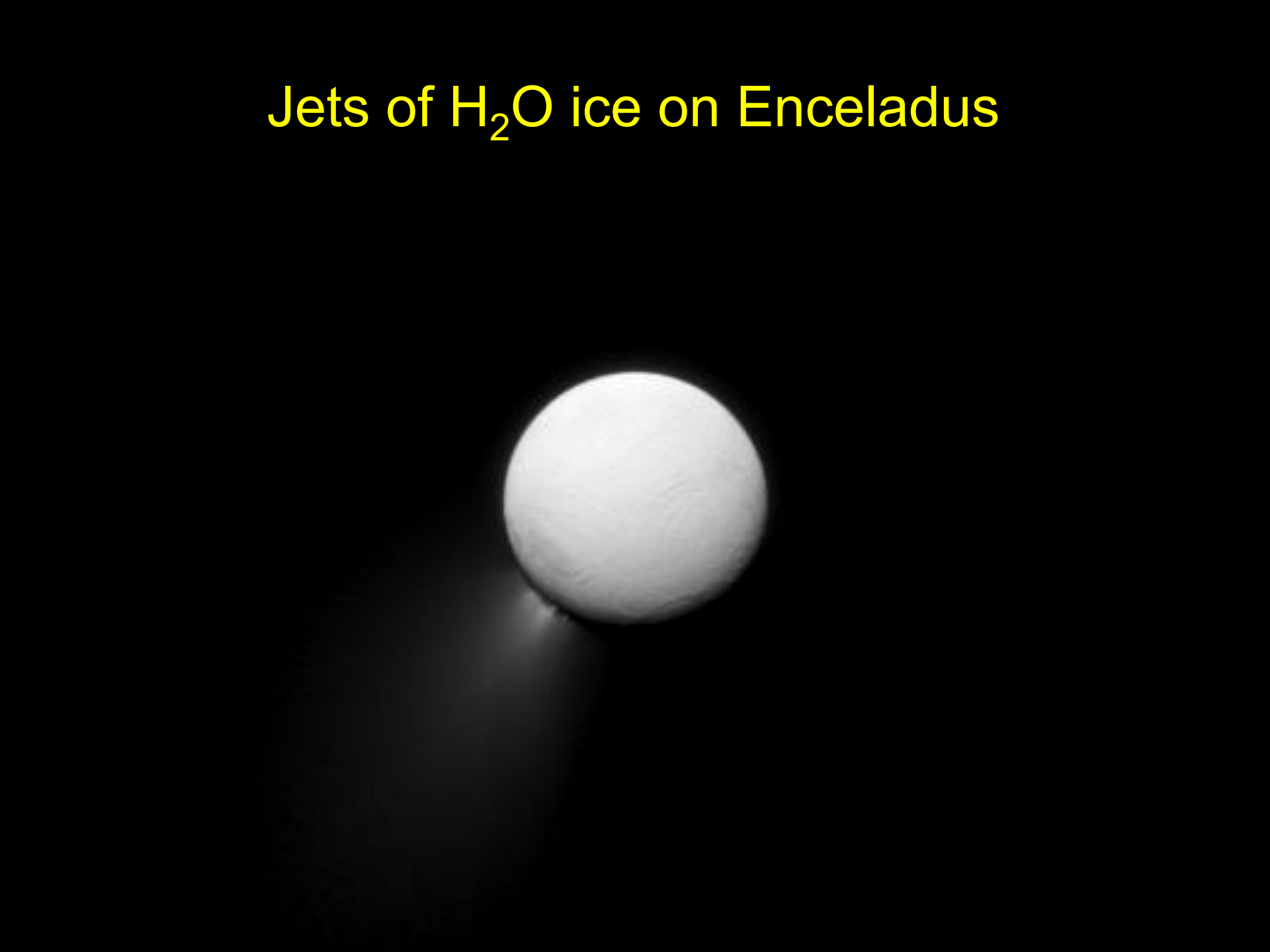


New drill hole and even darker material beneath.

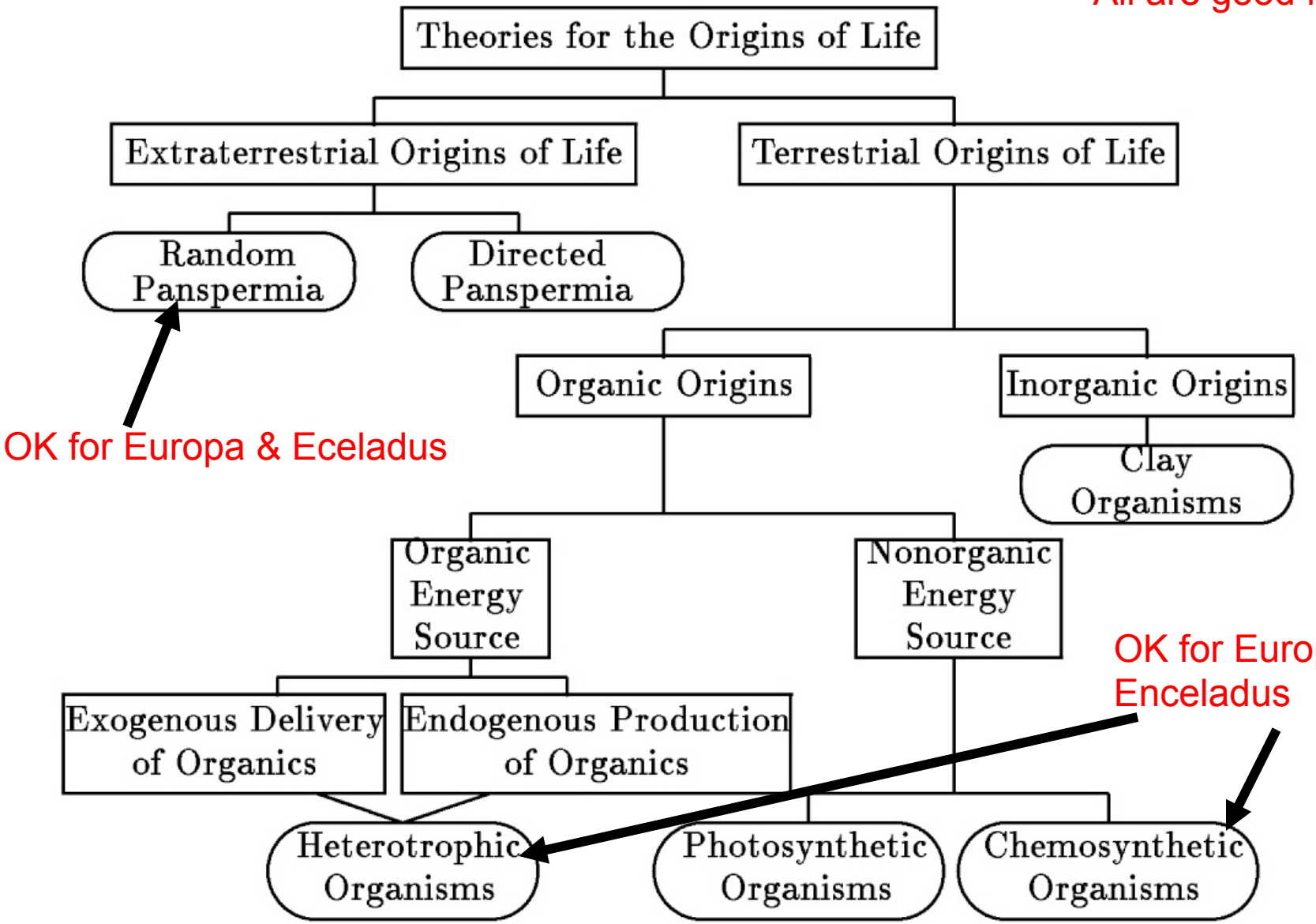


Levels on Windjana image adjusted to (roughly) match dusty surface color between John Klein and Windjana drill areas. K. Williford 4/30/2014

Jets of H_2O ice on Enceladus



All are good for Mars



OK for Europa & Eceladus

OK for Europa and Enceladus

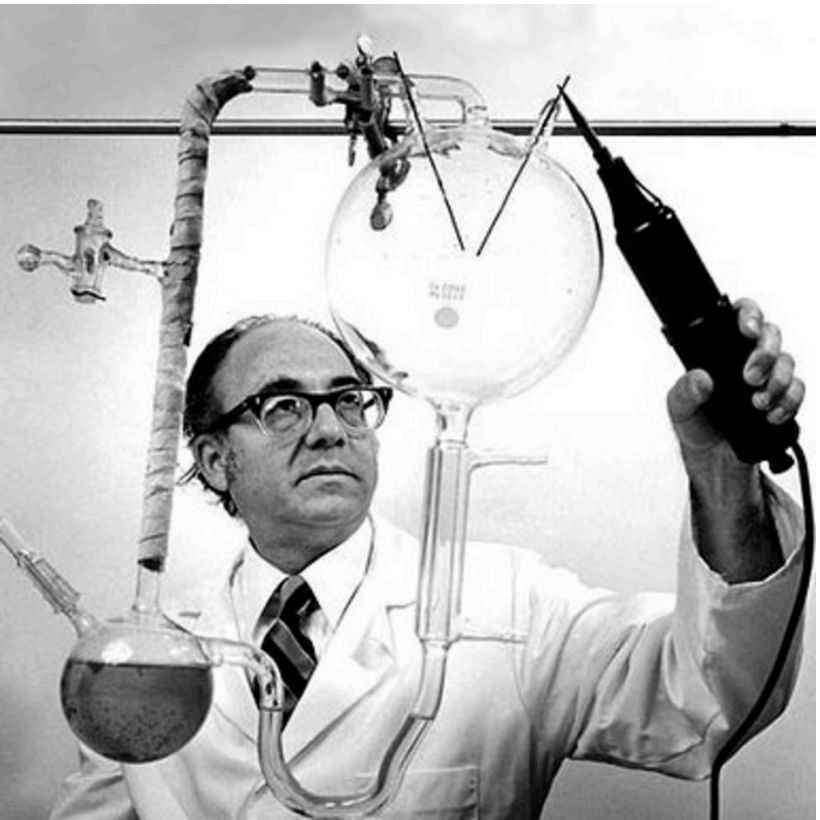
Davis & McKay, *Origins Life Evol. Biosph.* **26**, 61-73, 199

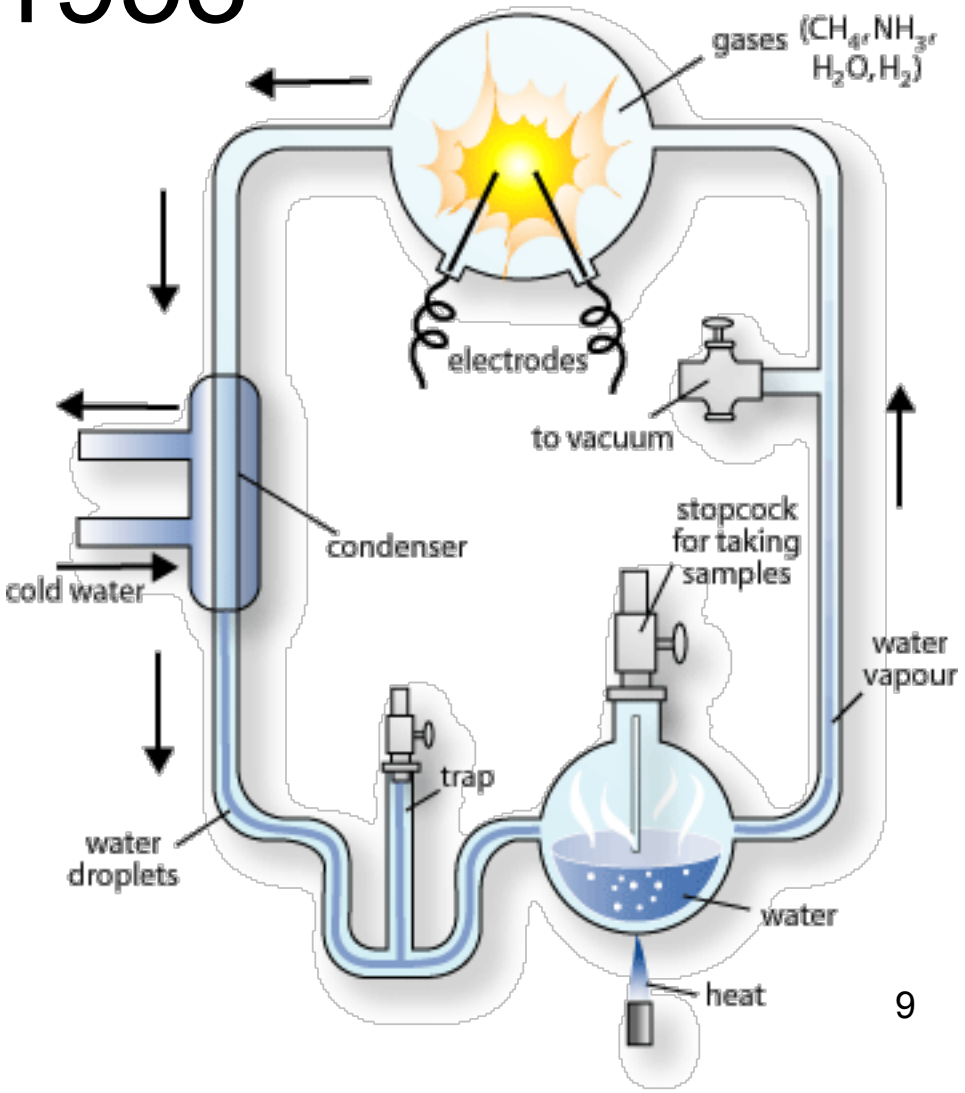
Two approaches to the origin of life

1. Metabolism first
   (eat first, encode information later)
   (hardware first, software later)

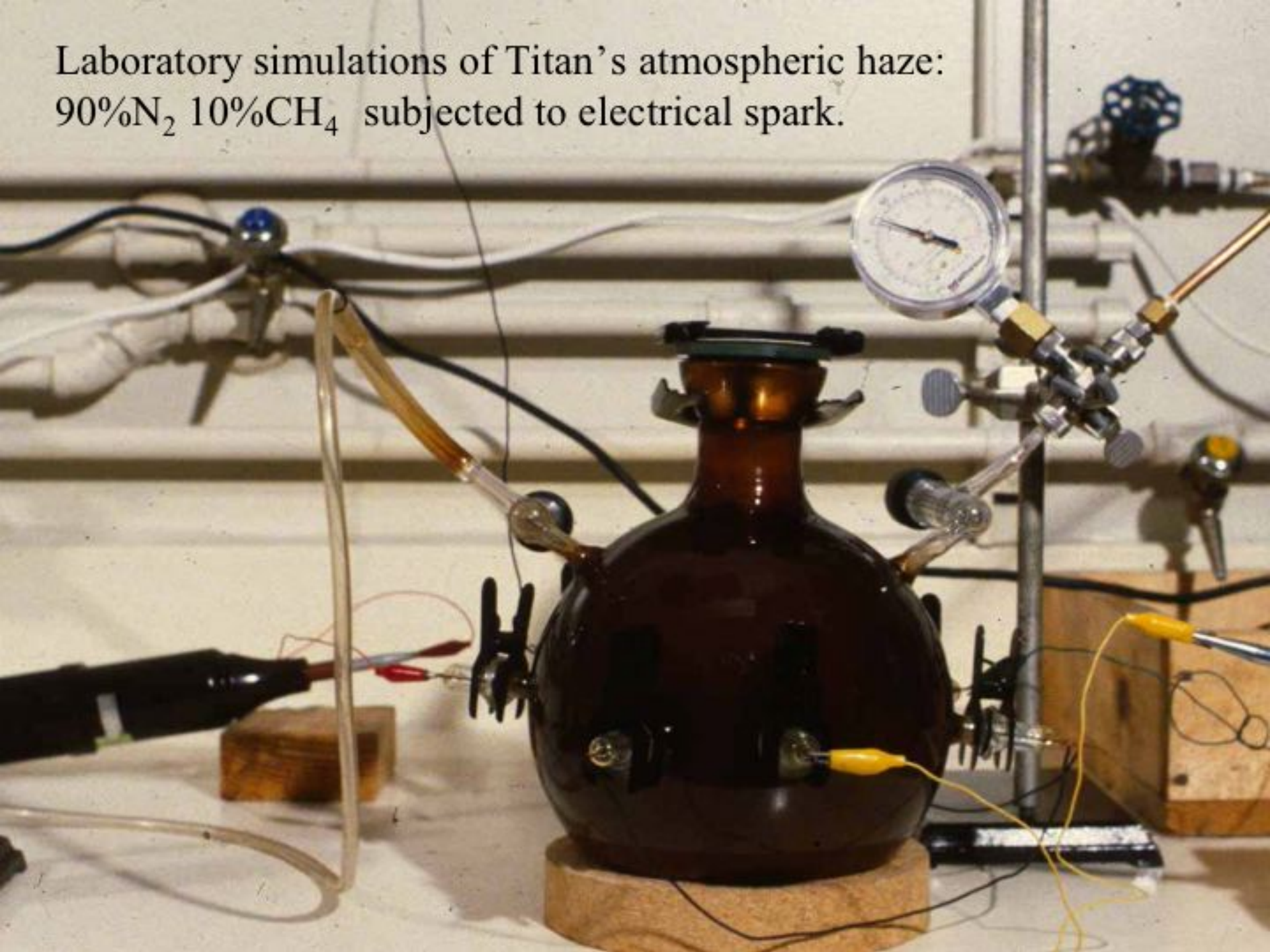
2. Replicator first
   (encode information first, eat later)
   (software first, hardware later)

The Miller-Urey experiment 1953

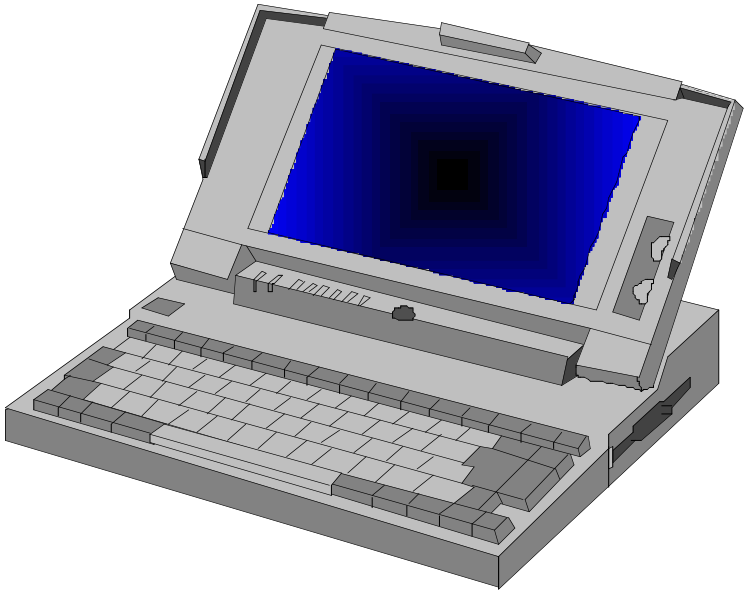




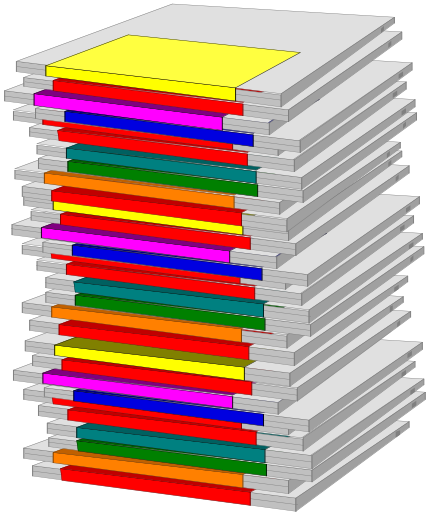
Laboratory simulations of Titan's atmospheric haze:
90%N_2 10%CH_4 subjected to electrical spark.



Life is like a computer, it is made up of:



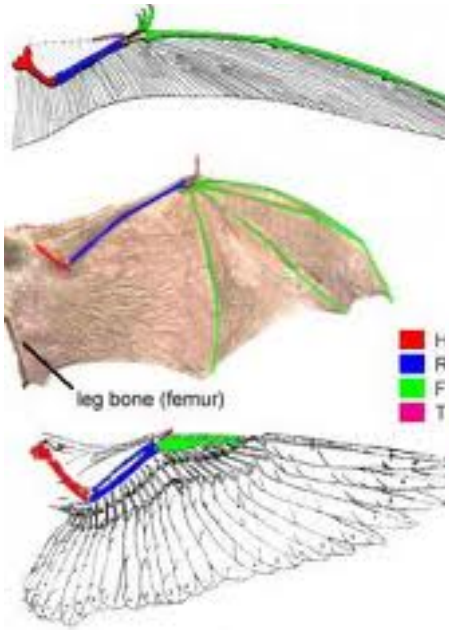
Hardware

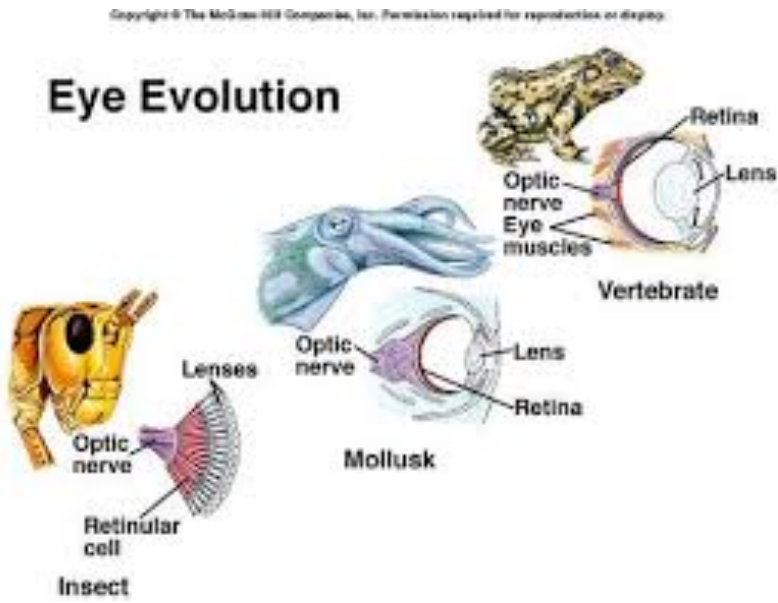


Software

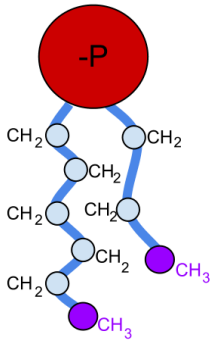
Where is information in biology?

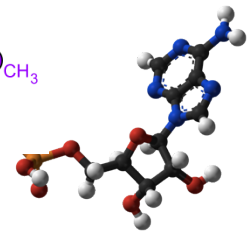
Not in morphology

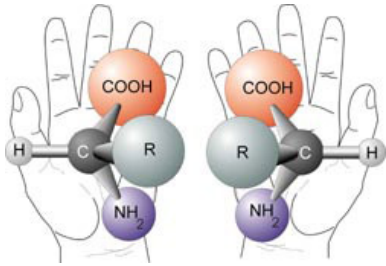




In biochemistry







ATP

chiral amino acids

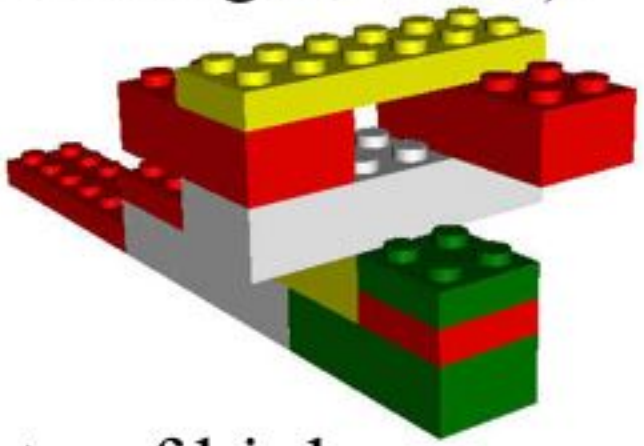
The Lego® Principle

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

-20 L amino acids

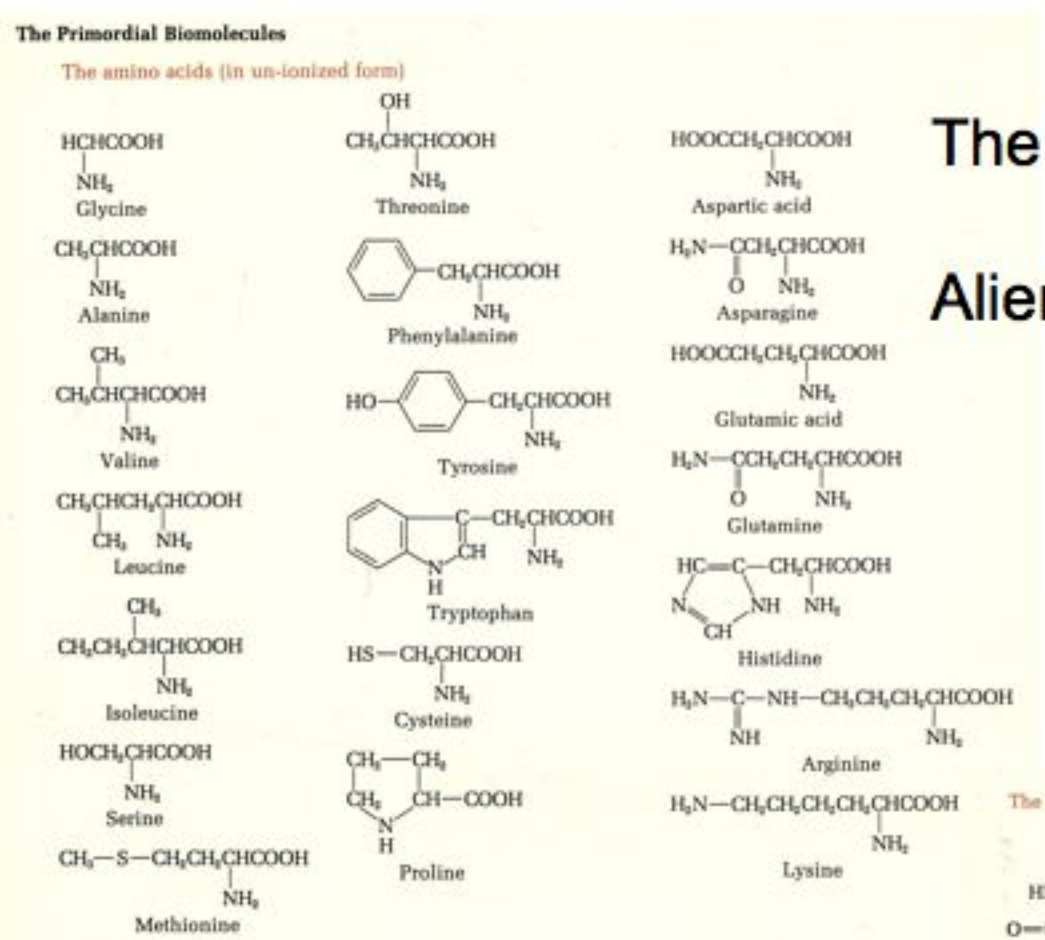
-5 nucleotide bases

-few D sugars, etc.



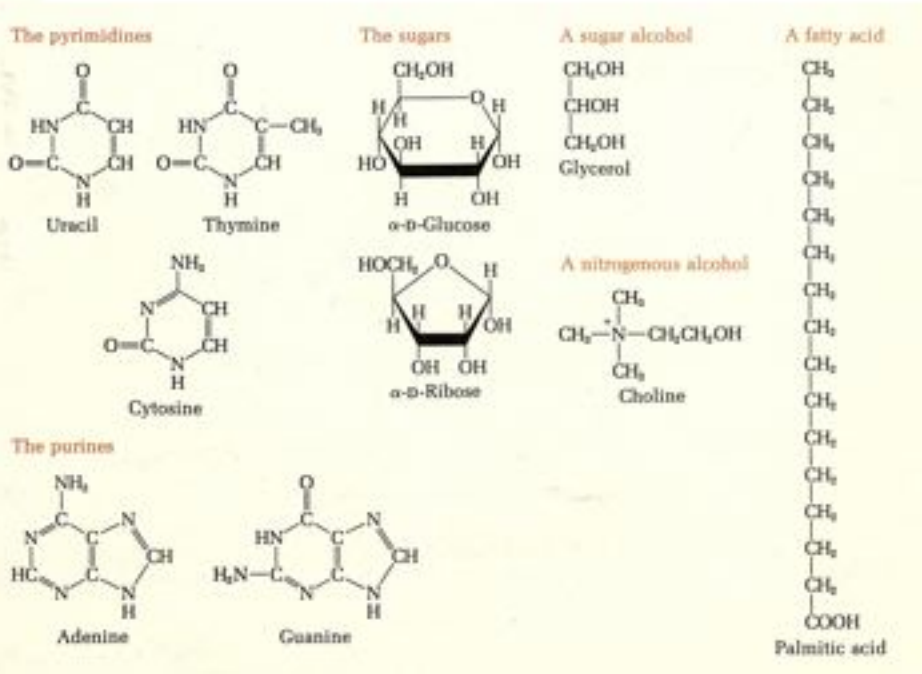
•Likely a common property of biology (and mass-produced children's toys) throughout the universe.

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



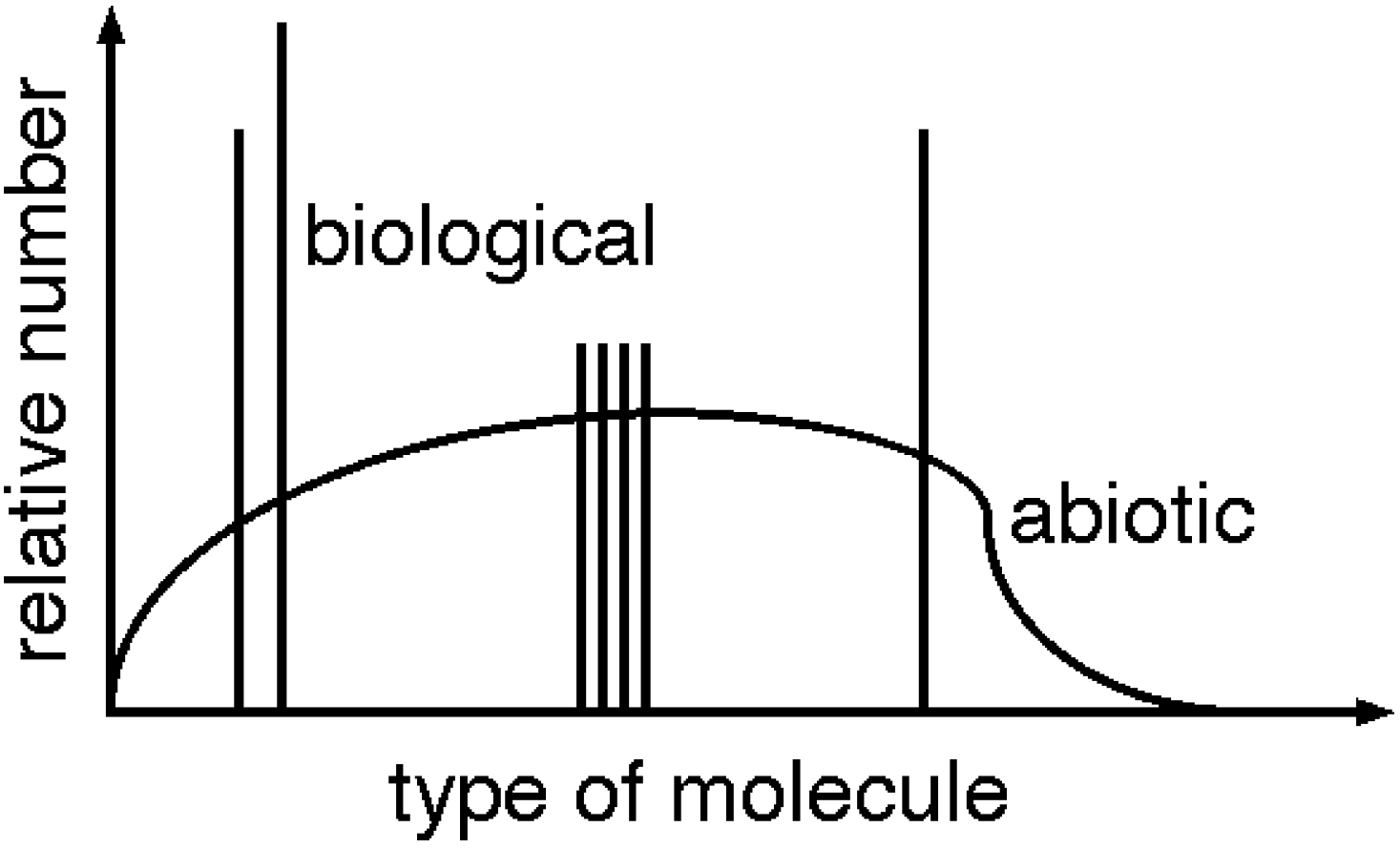
The building blocks of Earth life

Alien life could use a different set



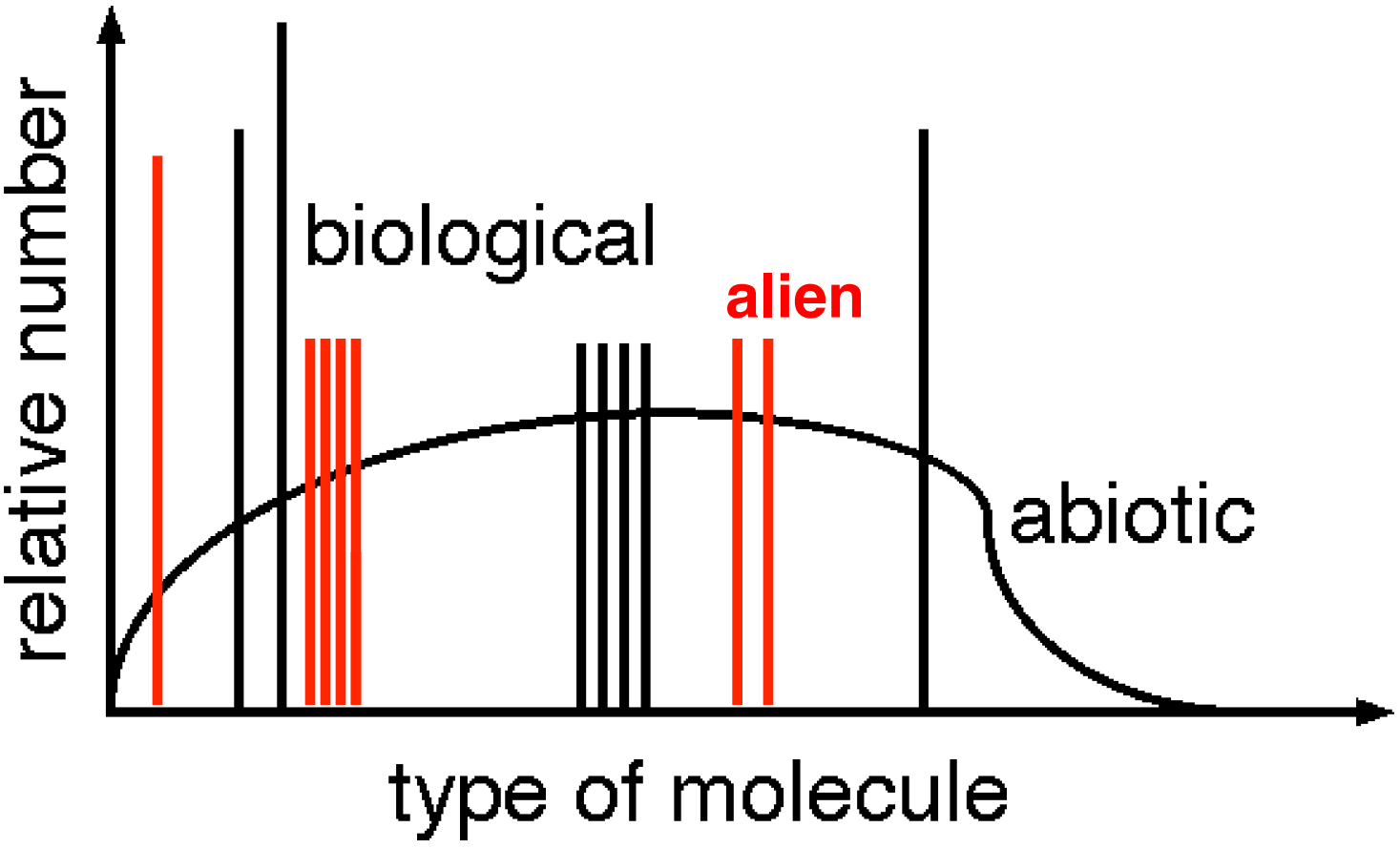
From Lehninger, 1975

Abiotic distributions are smooth
Biotic distributions are spiked



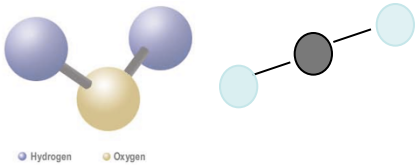
McKay 2004 *PLoS Biol* 2(9)1260-12623

Abiotic distributions are smooth
Biotic distributions are spiked



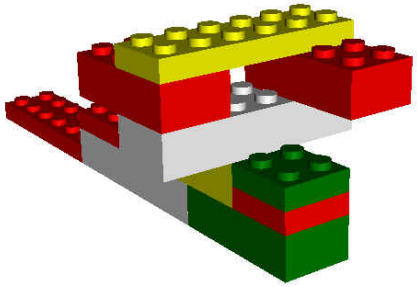
McKay 2004 *PLoS Biol* 2(9)1260-12623

Atomic level



C=C=C H_2O

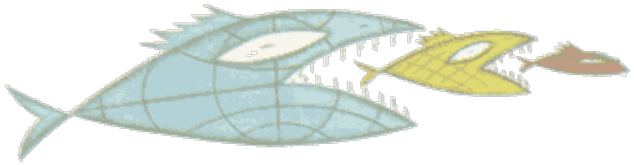
Biochemical level
(L amino acids, ATP)

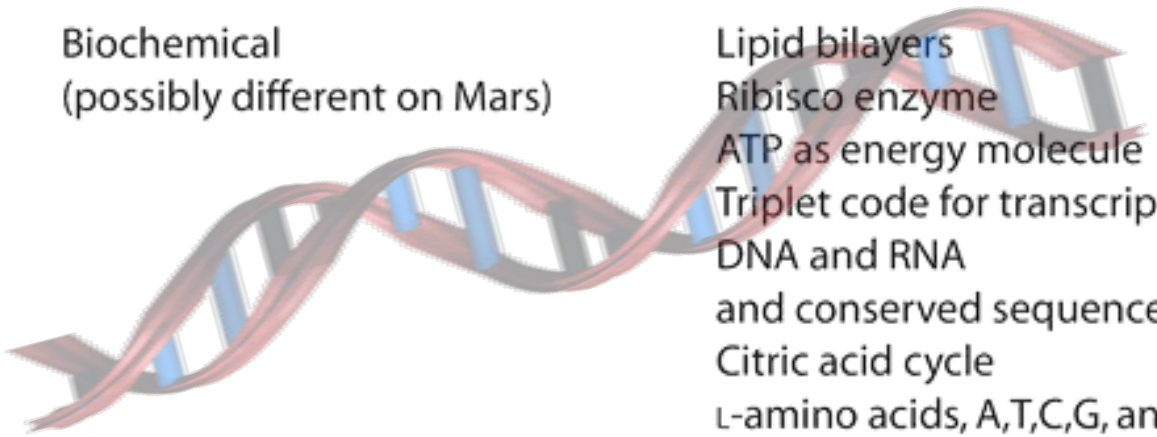


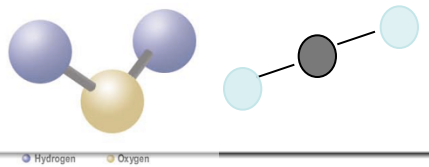
Ecological level
(phototaxis, CO_2 uptake)

Guessing at how aliens compare to Earth Life

Levels of Life	Examples
Ecological (probably the same on Mars)	Sunlight based autotrophs, heterotrophs, predators. Life in liquid water, using carbon dioxide Multicellular organisms Compartmentalization by cell membranes and cell walls
Biochemical (possibly different on Mars)	Lipid bilayers Ribisco enzyme ATP as energy molecule Triplet code for transcription DNA and RNA and conserved sequences in genome Citric acid cycle L-amino acids, A,T,C,G, and U nucleotide bases
Chemical (same on Mars)	Carbon and water Matter

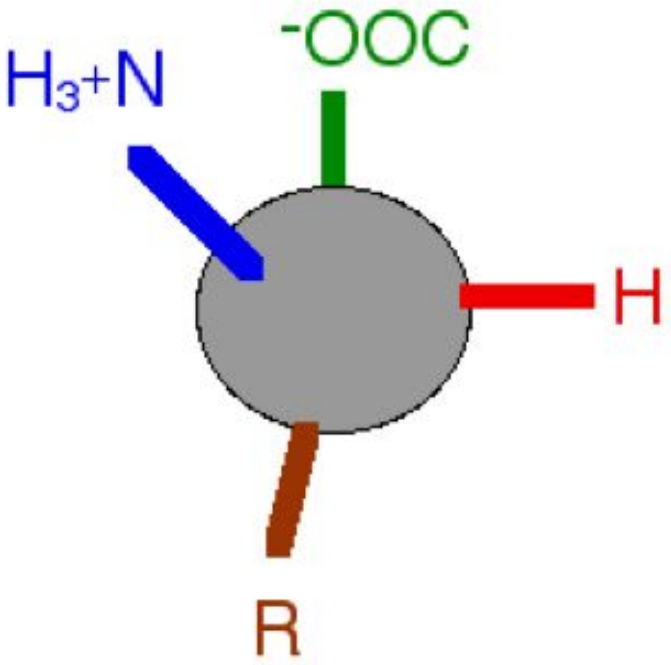




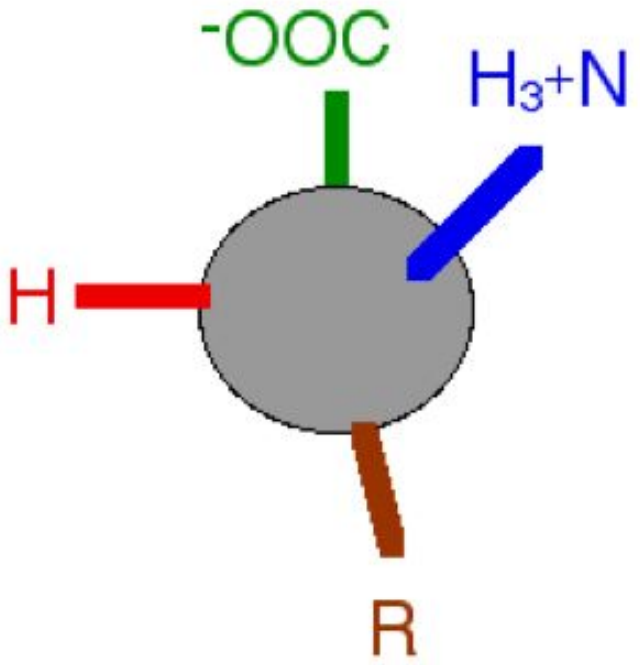


DOI: 10.1371/journal.pbio.0020302.t001

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

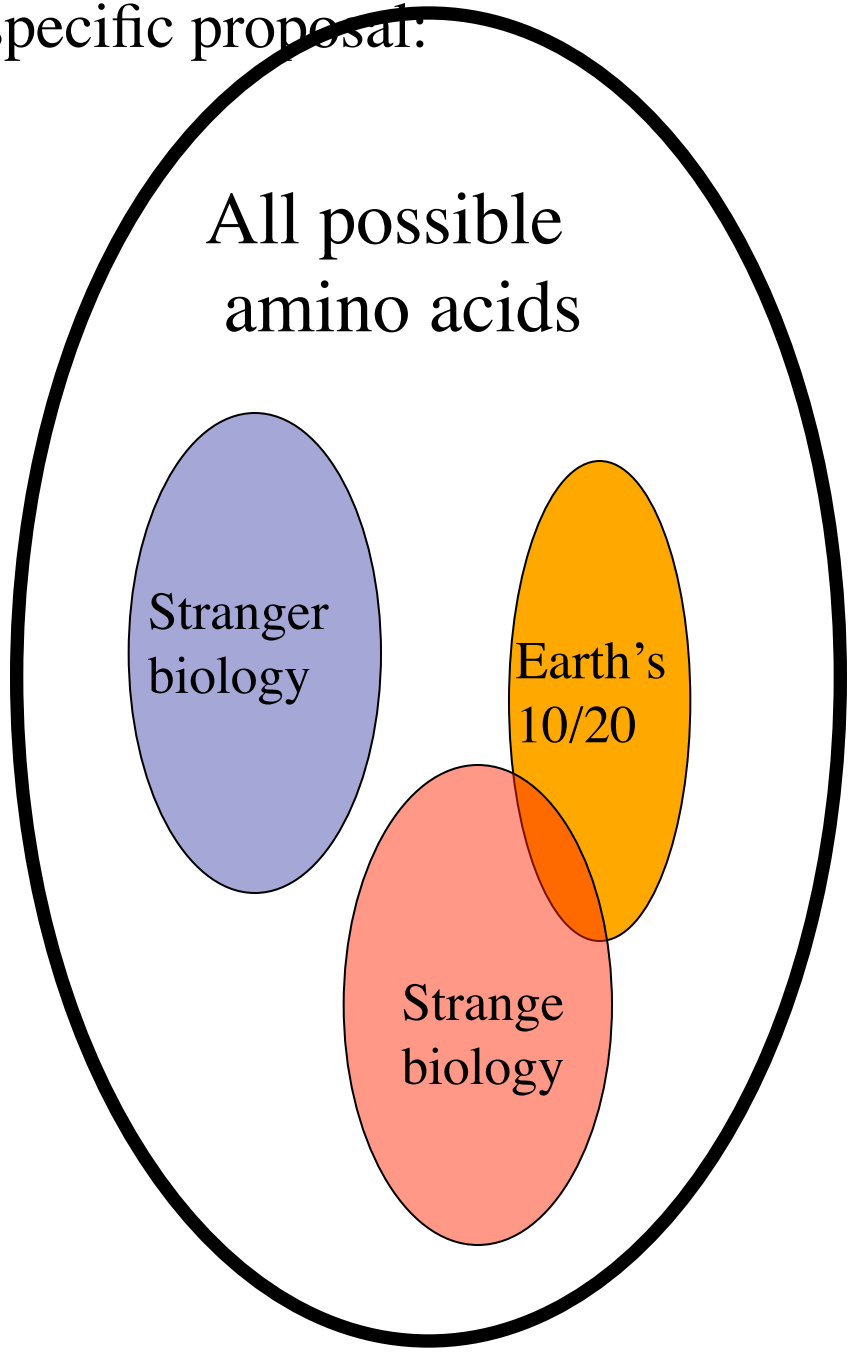


L - amino acids
used in proteins



D - amino acids
not in proteins

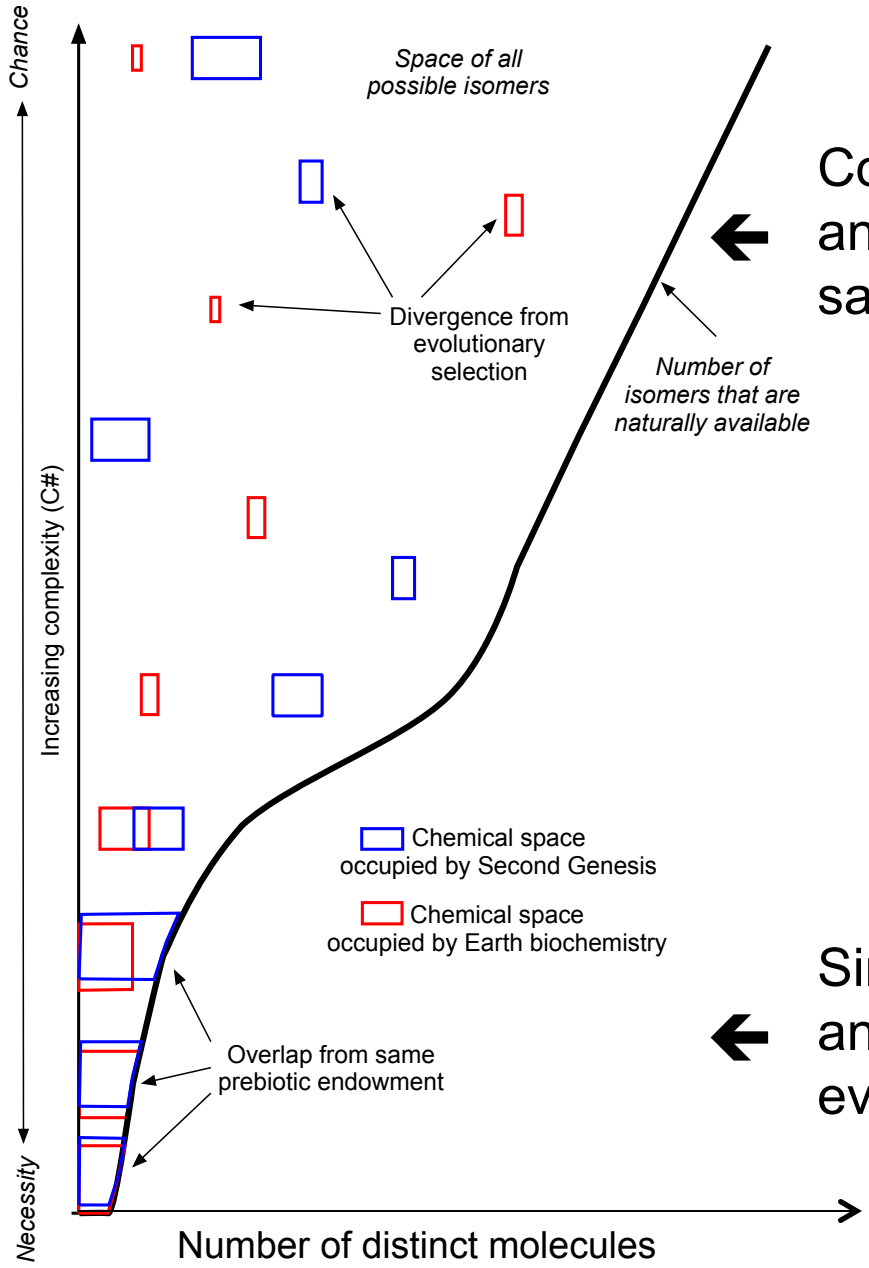
A specific proposal:



Strange biology is possible:

Alternative sets of 20 amino acids span the phase space of size, charge, and hydrophobicity properties and thus are plausible alternative construction sets for diverse proteins.

Philip, G. K., & Freeland, S. J. (2011). Did Evolution Select a Nonrandom "Alphabet" of Amino Acids?. Astrobiology, 11(3), 235-240.

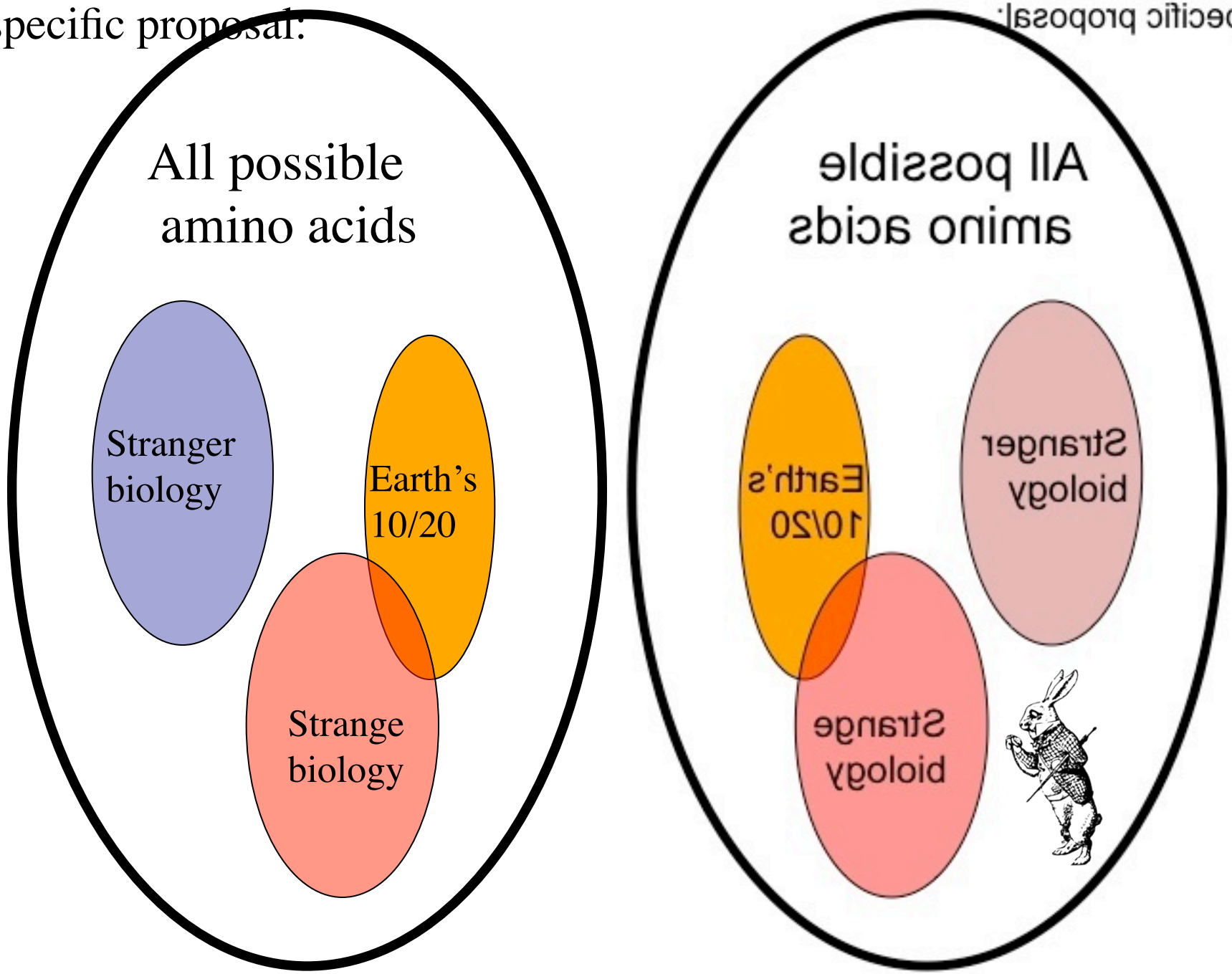


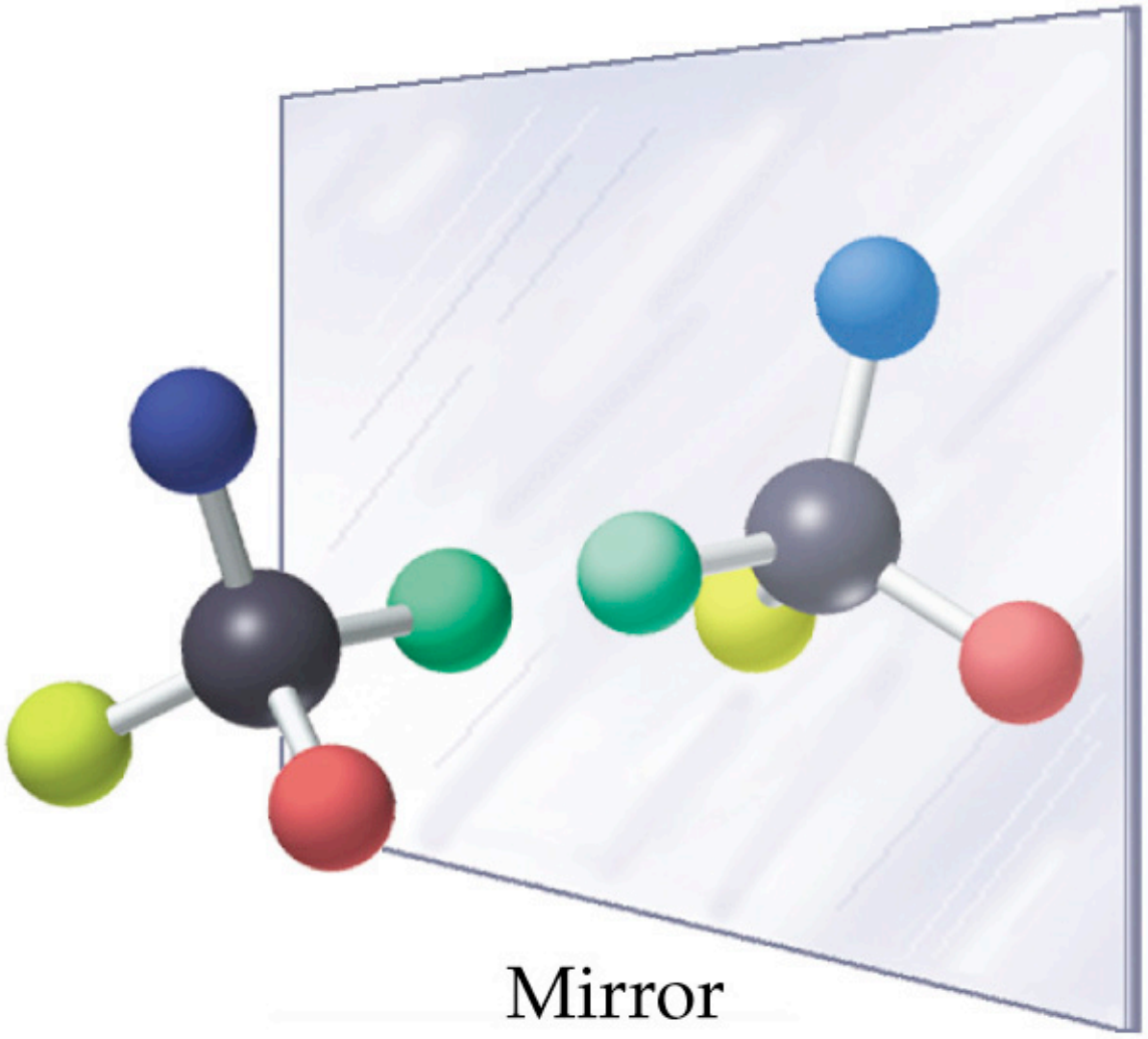
Complex amino acids are invented and with many choices: not the same everywhere.

Simple amino acids are prebiotic and with few choices: the same everywhere.

Davila and McKay 2014

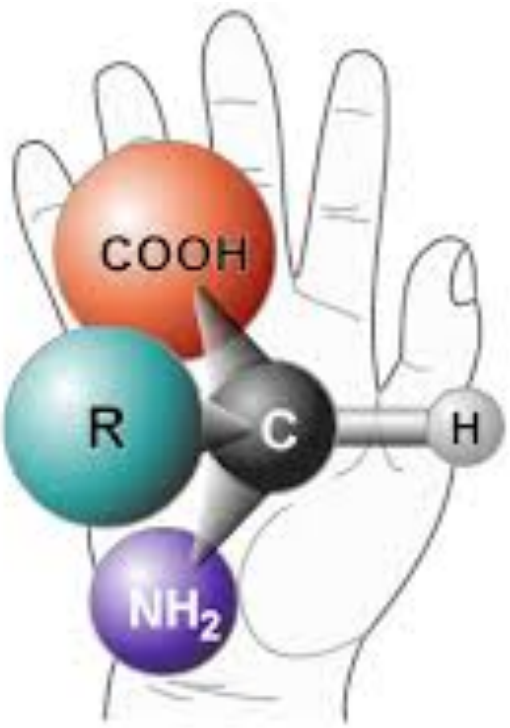
A specific proposal:

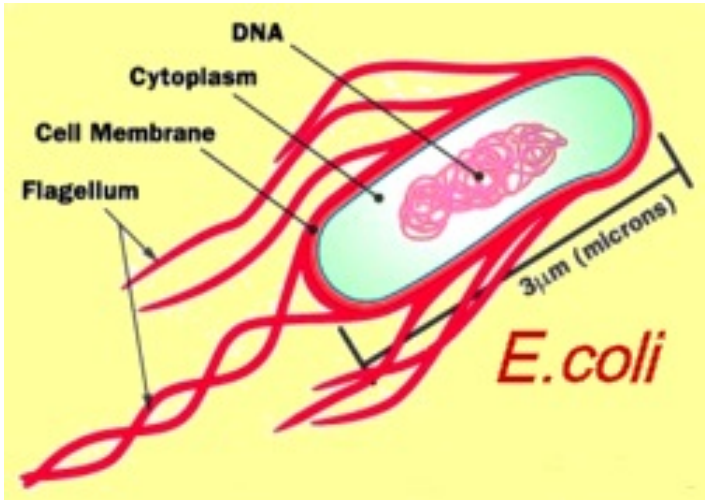


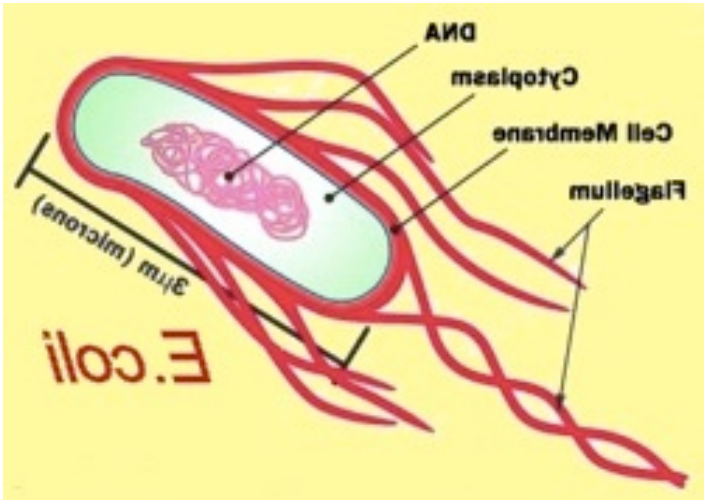


If you are right-handed, your reflection in a mirror is left-handed
(Why do mirrors reverse left and right, but not top and bottom?)

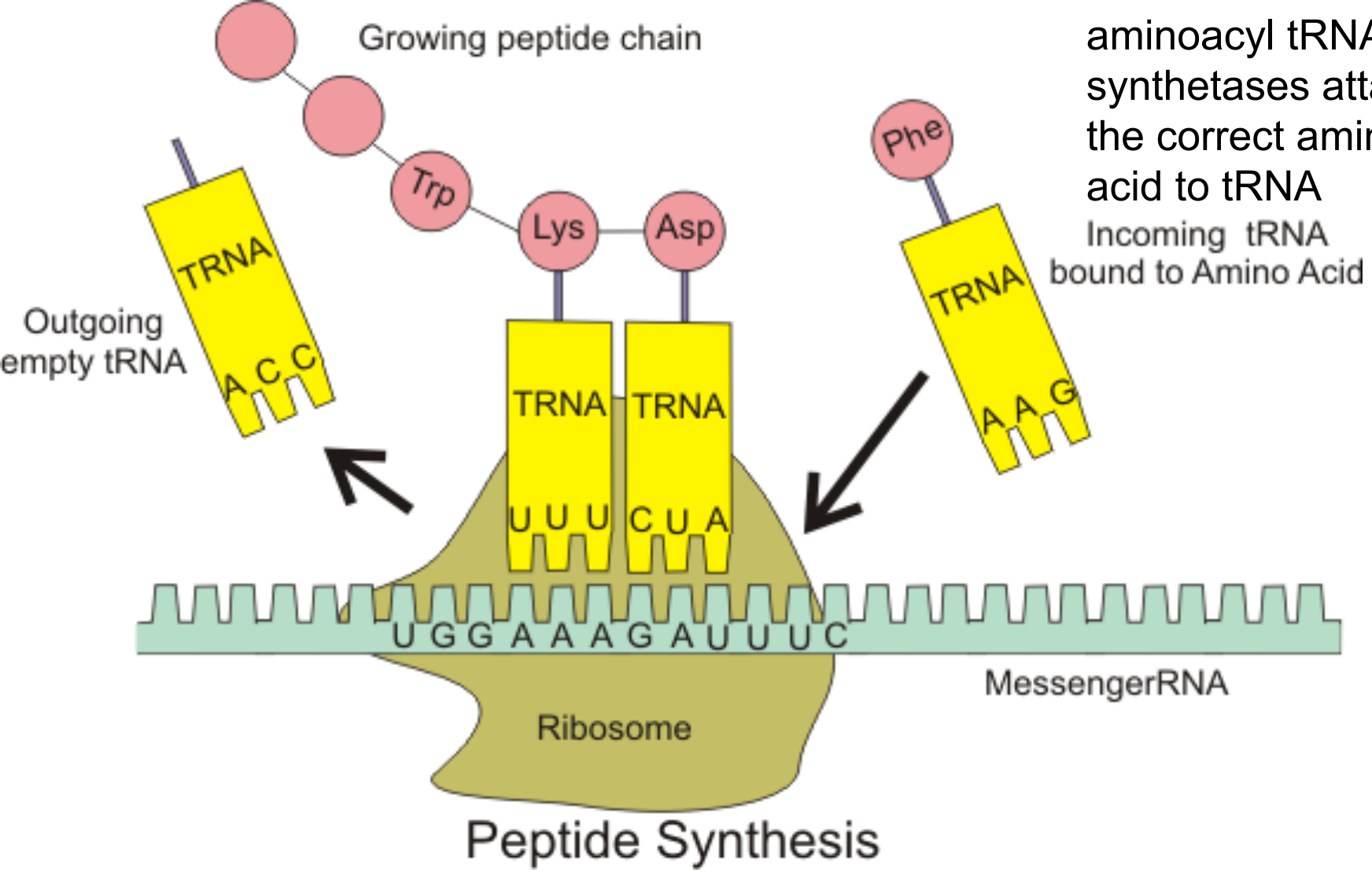

COOH
H
C
R
NH2


COOH
R
C
H
NH2

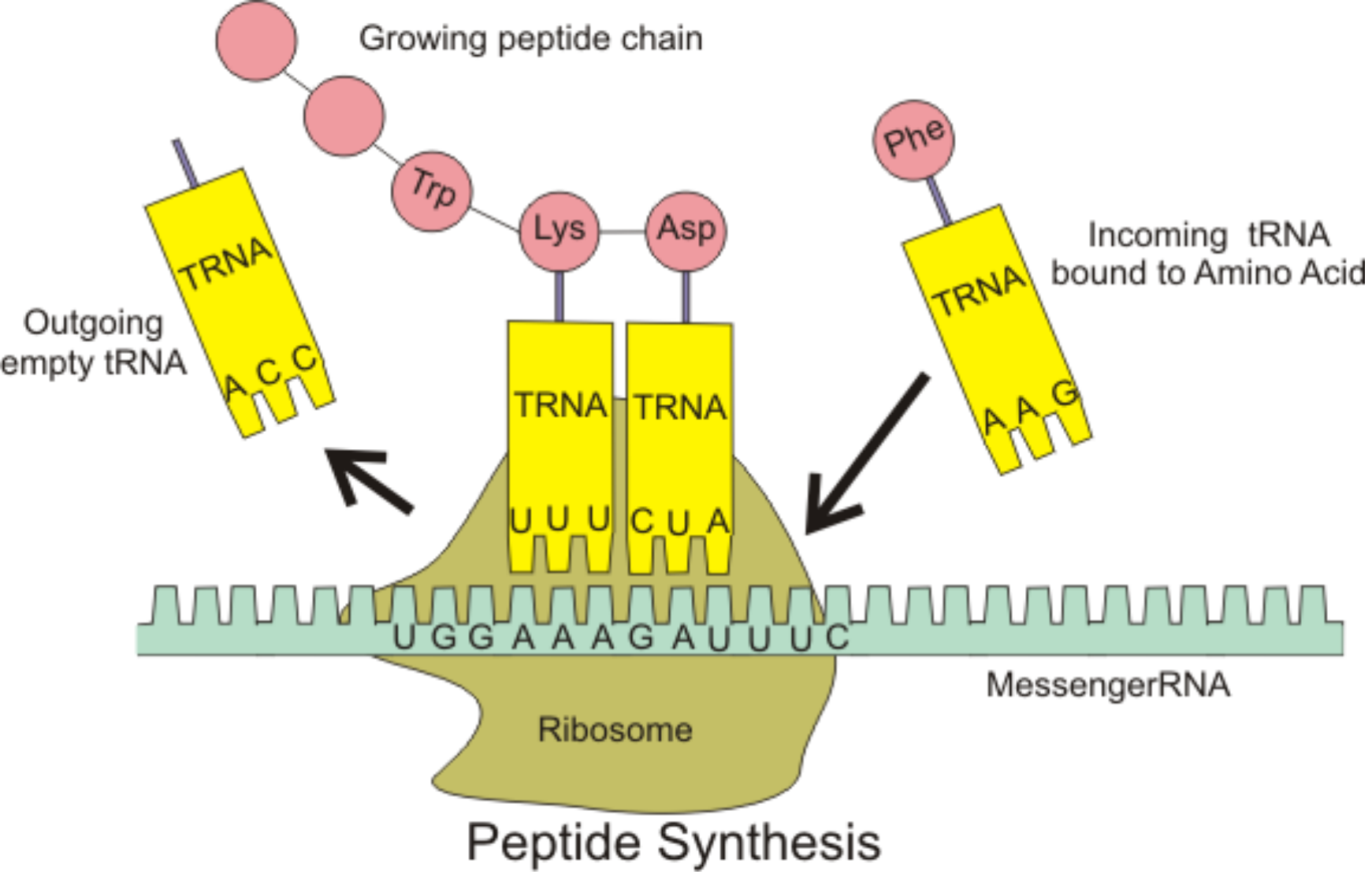

DNA
Cytoplasm
Cell Membrane
Flagellum
3µm (microns)
E.coli


DNA
Cytoplasm
Cell Membrane
Flagellum
3µm (microns)
E.coli

aminoacyl tRNA synthetases attaches the correct amino acid to tRNA



A protein, tRNA synthetases is the chiral gatekeeper.



Hypothesis: if the protein, tRNA synthetase was constructed from D amino acids it would bring D amino acids to the ribosome.

Working with SGI we may have a way to "flip" all 20 amino acids at the same time

The principle of the tricorder and its application to NASA missions

2014

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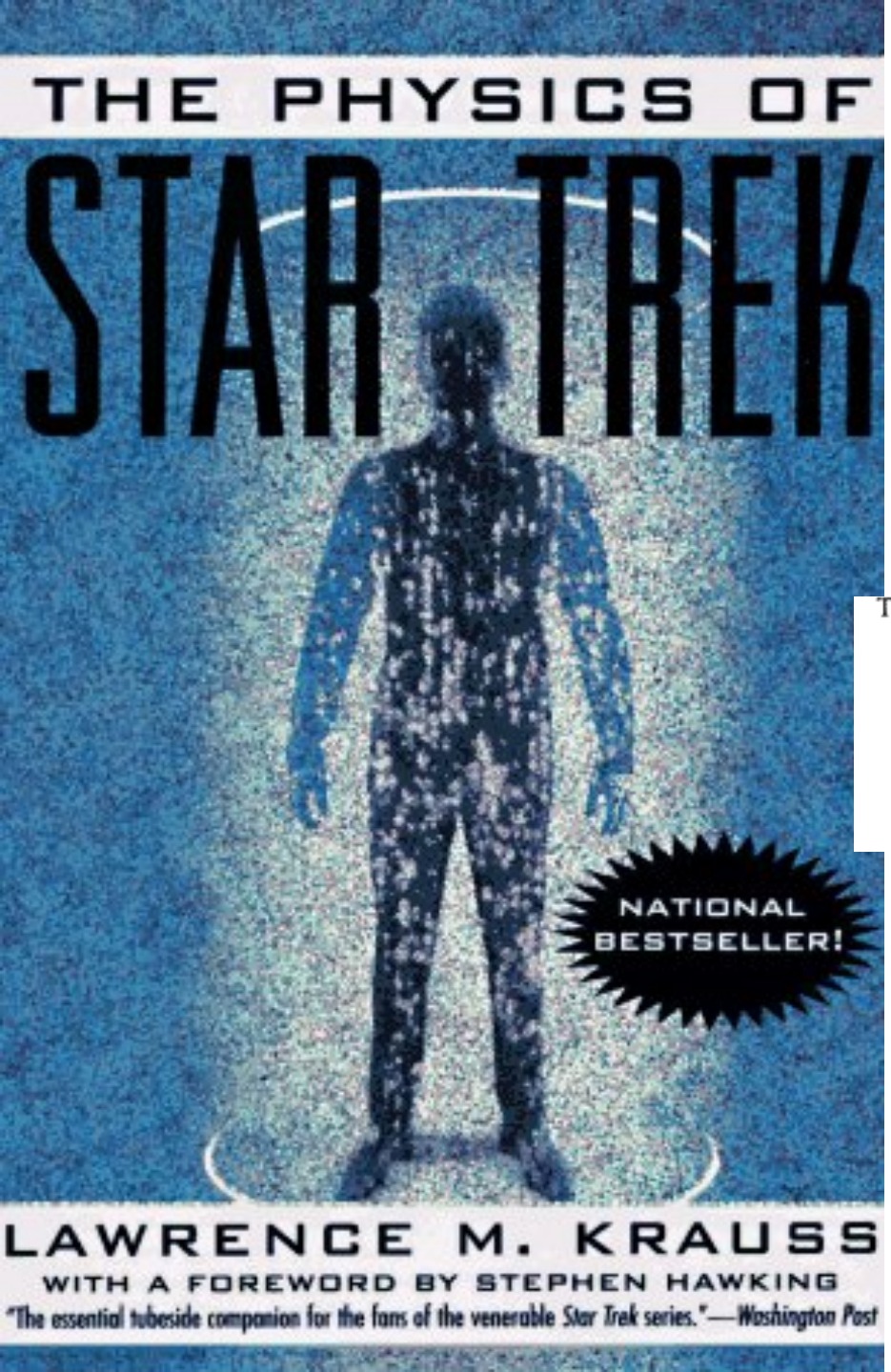
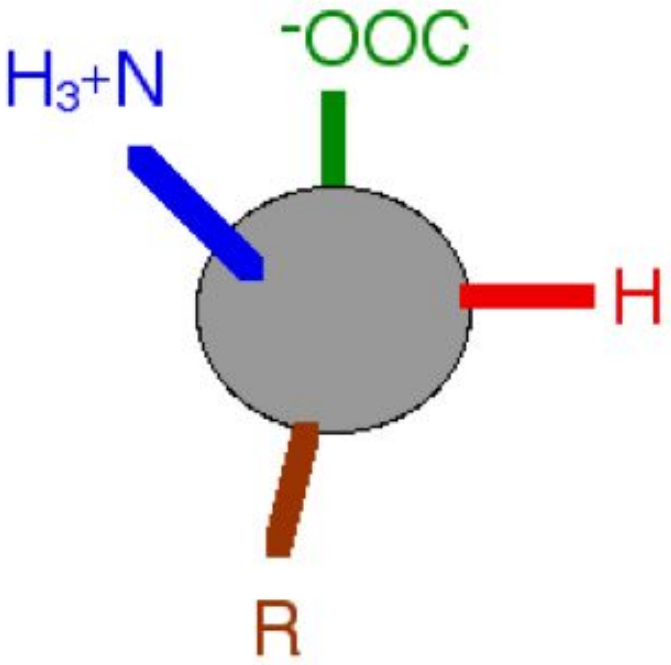
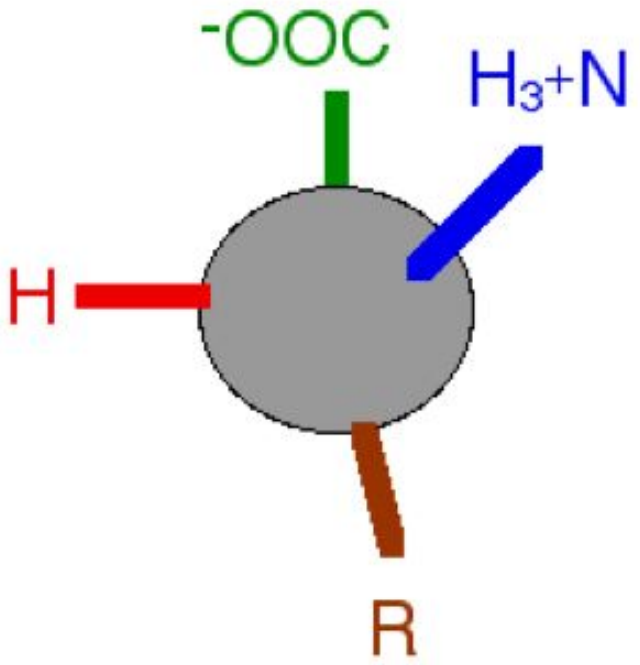


"Tricorder" does not appear in the *Physics of Star Trek*

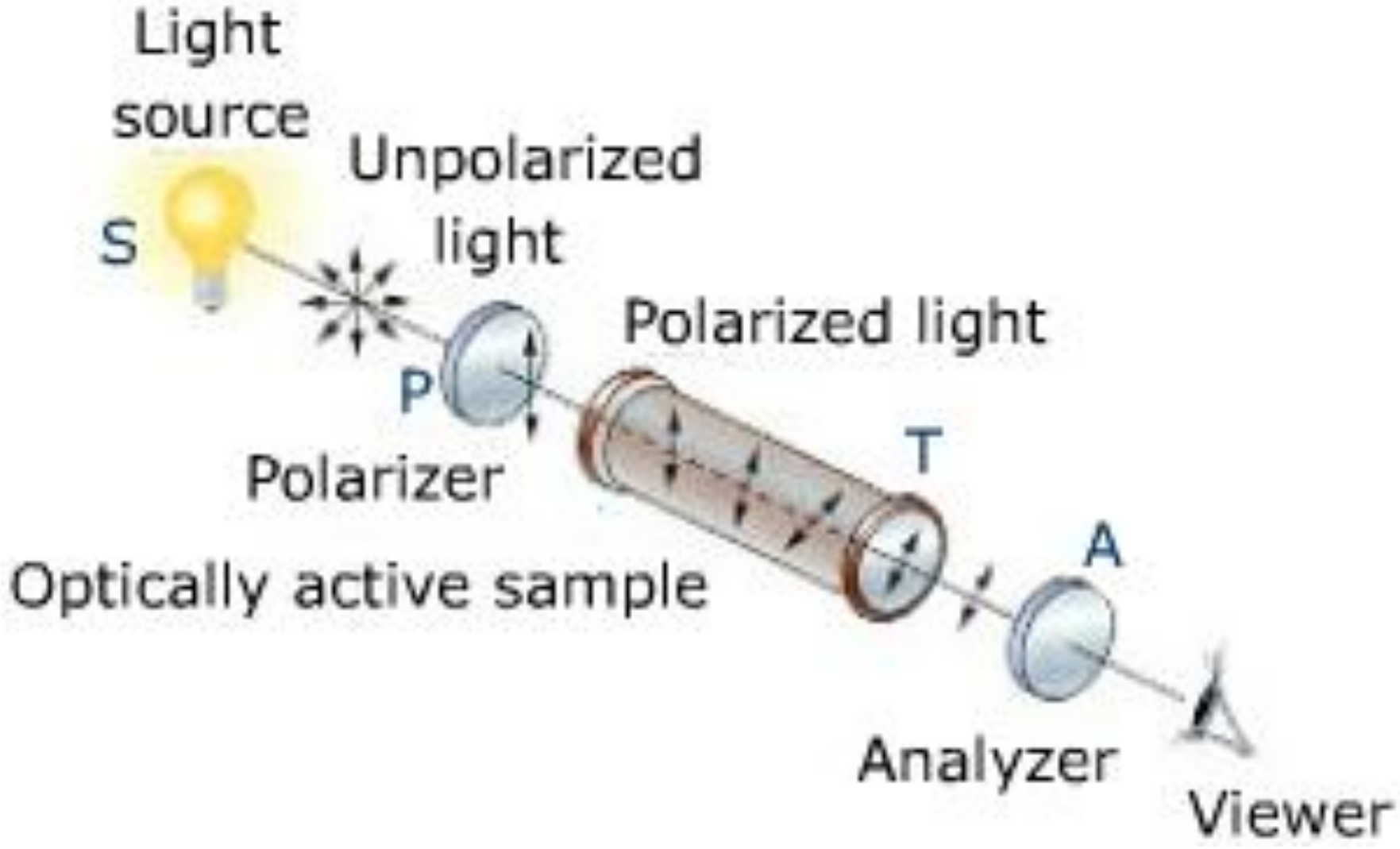


L - amino acids
used in proteins



D - amino acids
not in proteins

Optical Activity



detection of chiral molecules via microwave

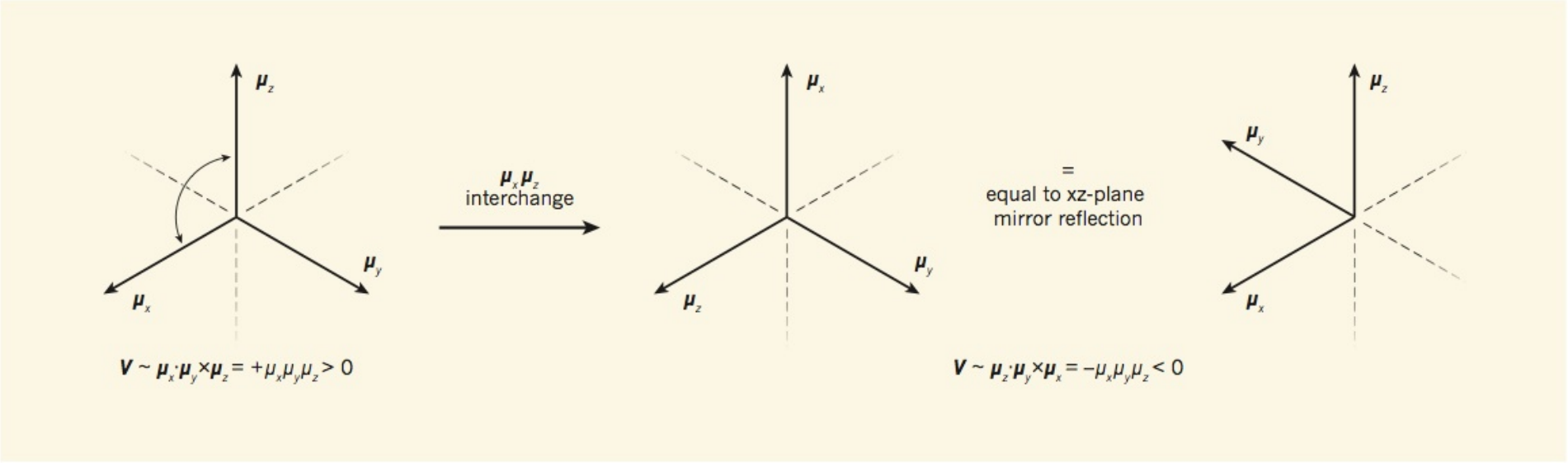


Figure 1 | A new mechanism for chiroptical spectroscopy. In Patterson and colleagues' method[2] for identifying molecular chirality, the measured quantity depends on the handedness of three mutually orthogonal electric-dipole rotational transition moments, μ_x, μ_y and μ_z, which are associated with the three rotational degrees of freedom of a molecule. When microwave radiation interacts with these moments, energy transfer changes the rotational state of the molecule, generating a spectroscopic signal. The moments are vectors, and can be represented by a scalar triple product of $\mu_x \cdot \mu_y \times \mu_z$. This product can be regarded as a dipole volume, V, that is equal to the product of the magnitudes of the three vectors. The sign of V depends on the order of the vectors. If any two vectors are interchanged (a process equivalent to a mirror reflection), the sign changes. Because V changes sign under spatial inversion (mirror reflection) and is even under time-reversal symmetry, it is a measure of true chirality[8].

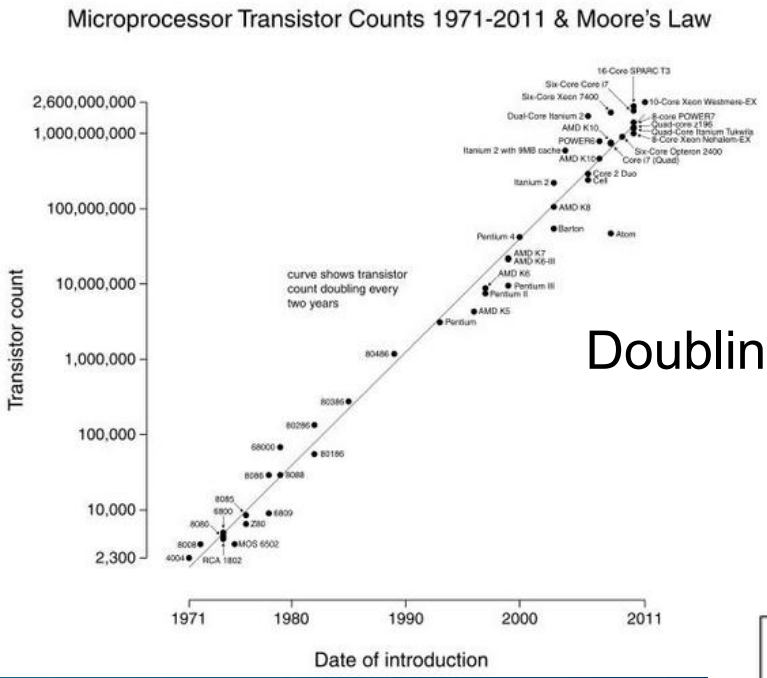
Nafie L.A. (2013) Handedness detected by microwaves. Nature 497, 446-448, commenting on Patterson et al. (2013). Enantiomer-specific detection of chiral molecules via microwave spectroscopy. Nature, 497, 475-477.

The Physics of tricorders:

Remote detection of life by detection of chiral asymmetry by analysis of microwaves and analysis of polarized reflections from planetary surfaces.

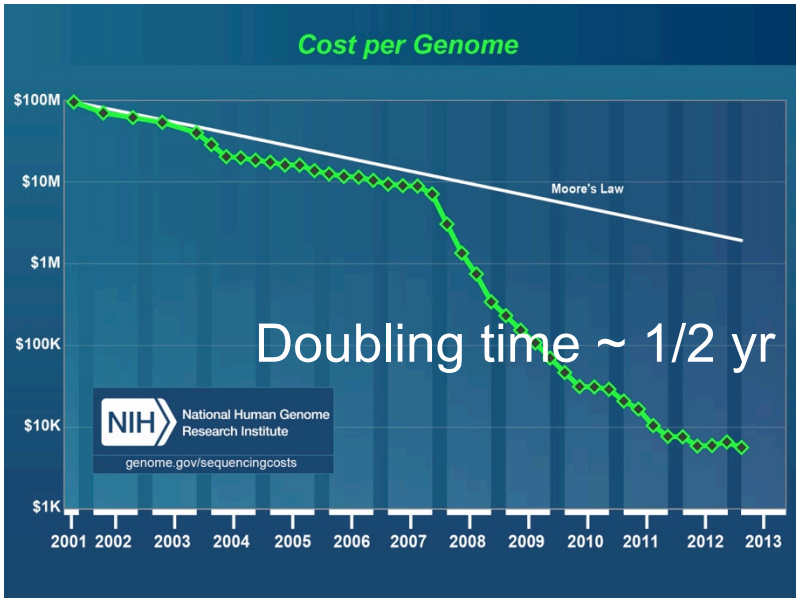
tricorders do exist
-not portable yet
-range is limited

Technology improvement rates



To the 23rd Century:
300 years = 10 – 150 doubling time
10^3 to 10^{45} improvement

Doubling time ~ 2 yrs



GC separation

Chirasil Dex-CB column consists of cyclodextrin directly bonded to dimethylpolysiloxane.

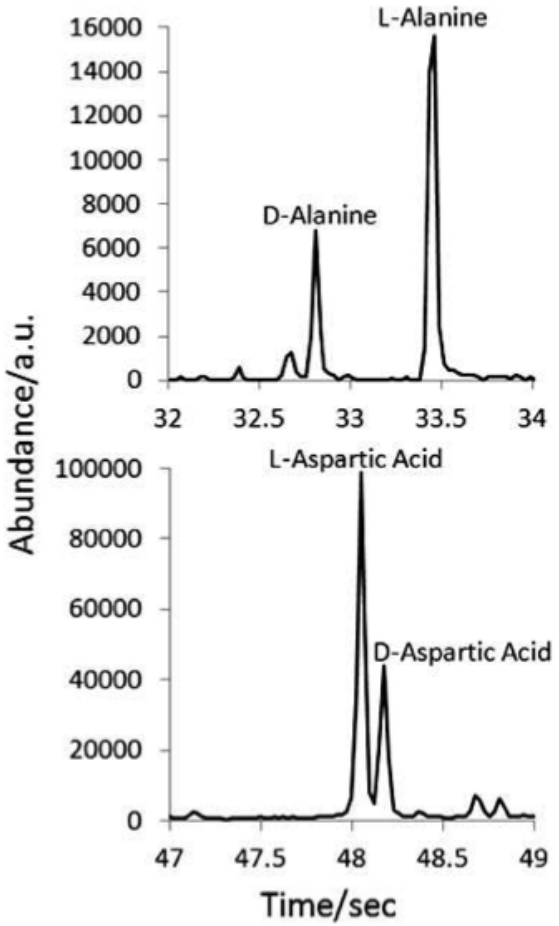
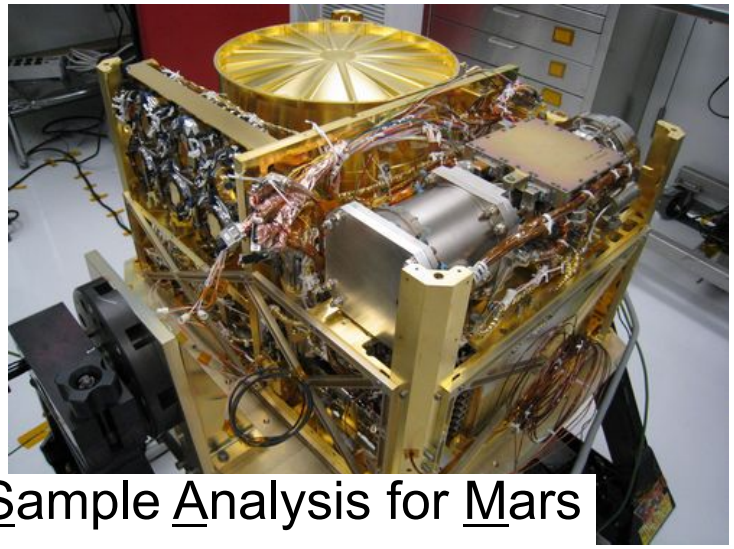


FIG. 5. GC-MS analysis results in D/L ratios corresponding to 0.433 and 0.447 for alanine and aspartic acid, respectively.

Tanaka et al. (2012)

SAM instrument on MSL PI: Paul Mahaffy, NASA GSFC

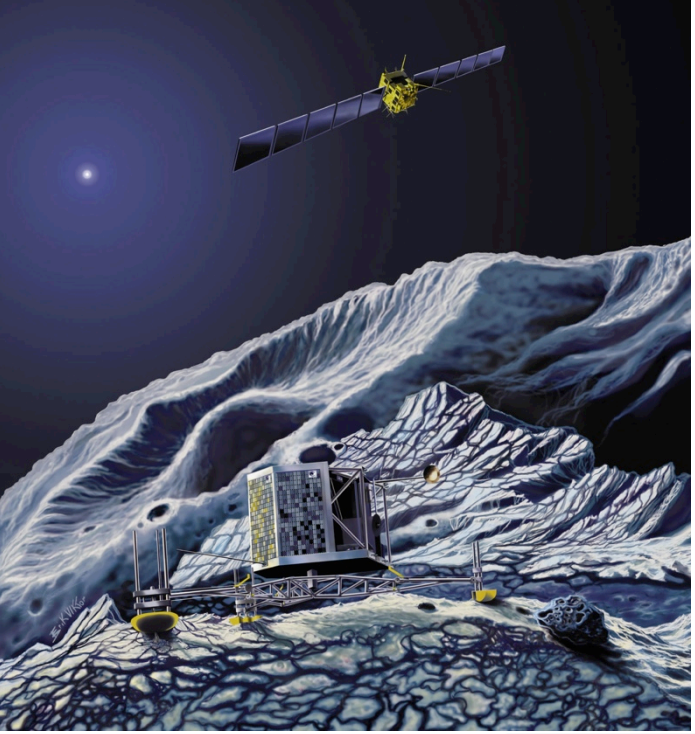


Sample Analysis for Mars

Table 9 Gas chromatograph columns

Column	Stationary phase	Species targeted
GC1-MXT 20 WCOT	Polydimethylsiloxane with 20 % of phenyl	Medium molecular weight organics (C5–C15 organics)
GC2-MTX 5 (WCOT)	Polydimethylsiloxane with 5 % of phenyl	High molecular weight VOCs including >C15 chemical derivatives
GC3-Carbobond (PLOT)	Carbon molecular sieve	Permanent gases and C1–C2 HCs
GC4-Chirasil-β Dex CB	β cyclodextrin	Enantiomers of VOCs
GC5-MXT CLP (WCOT)	Polydimethylsiloxane with phenyl and cyanopropyle	Medium molecular weight organics (C5–C15 organics)
GC6-MXT Q (PLOT)	Divinylbenzene or substituted divinylbenzene	C1–C4 VOCs NH_3, S containing compounds

PLOT = porous layer open tubes; WCOT = wall coated open tublar; VOC = volatile organic compounds



Chiral experiment on the ESA Rosetta mission

TABLE I

Columns used in the COSAC gas chromatograph.

No. of columns	Column	Inner diameter (mm)	Thickness of stationary phase (μm)	Length (m)
1	CarboBond	0.25	10	15
2	MXT U-PLOT	0.18	1.0	10
3	MXT 1701	0.18	1.2	15
4	MXT 20	0.18	1.0	15
5	MXT 1	0.18	0.1	10
6	Chirasil Dex CB	0.25	0.25	10
7	Chirasil L Val	0.25	0.12	12.5
8	Cyclodextrin G-TA	0.25	0.125	10

3 chiral columns

Goesmann, F., et al. (2007) Space Science Reviews, 128, 257-280.

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