Mary Voytek
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NASA Headquarters

NASA strategy for the search for life

(image by Andy Christie for Scientific American July 99)

Arthur C. Clarke's three laws:

- When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.
- The only way of discovering the limits of the possible is to venture a little way past them into the impossible.
- Any sufficiently advanced technology is indistinguishable from magic.

NASA's Strategy for searching for life beyond Earth

You can't always get what you want.
But if you try sometimes, you just might find
you get what you need.

-- Mick Jagger

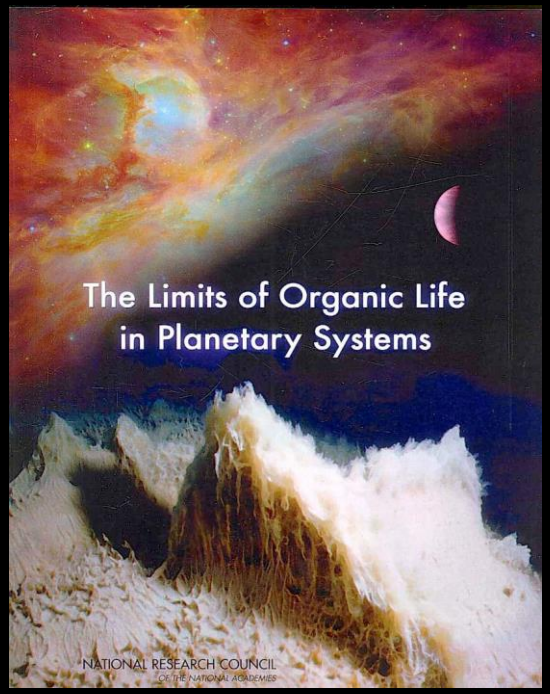
(How) does our knowledge of Earth's life inform/constrain:

What life needs

What is the full range of conditions that can satisfy life's requirements?

What life can do when it gets what it wants

What is the full potential of life to impact its environment? How does this potential vary as a function of environmental conditions?

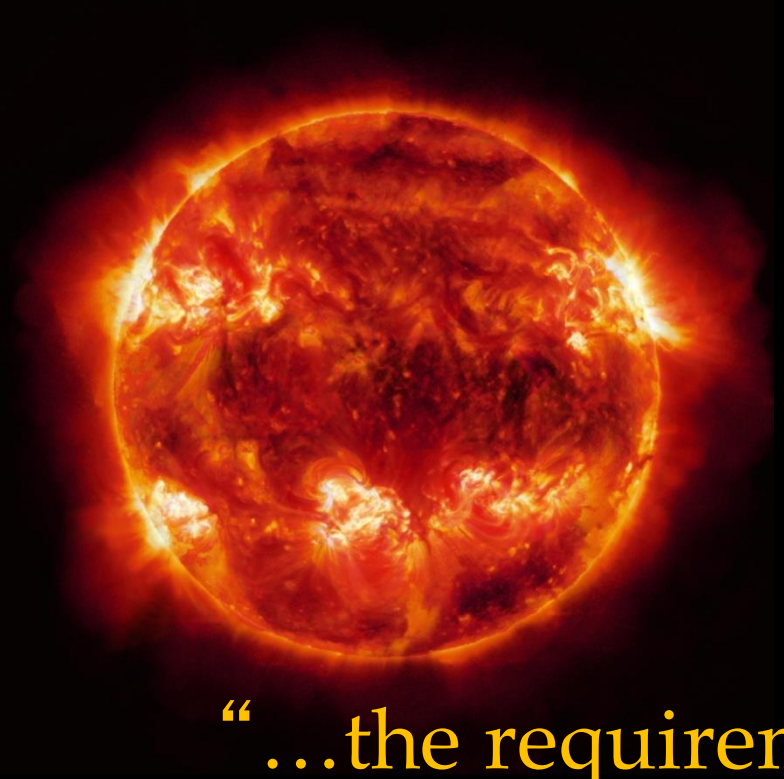


What Life Needs

"The Weird Life Report"

Theory, data, and experiments suggest that life requires (in decreasing order of certainty):

- Thermodynamic disequilibrium (Gibbs energy)*
- An environment capable of maintaining covalent bonds, especially between C, H, and other atoms
- A liquid environment**
- A molecular system that can support Darwinian evolution



Thermodynamic Disequilibrium

(Gibbs Energy)

"…the requirement for thermodynamic disequilibrium is so deeply rooted in our understanding of physics and chemistry that it is not disputable as a requirement for life.

Other criteria are not absolute."

Report of the NRC Committee on the Limits of Organic Life in Planetary Systems

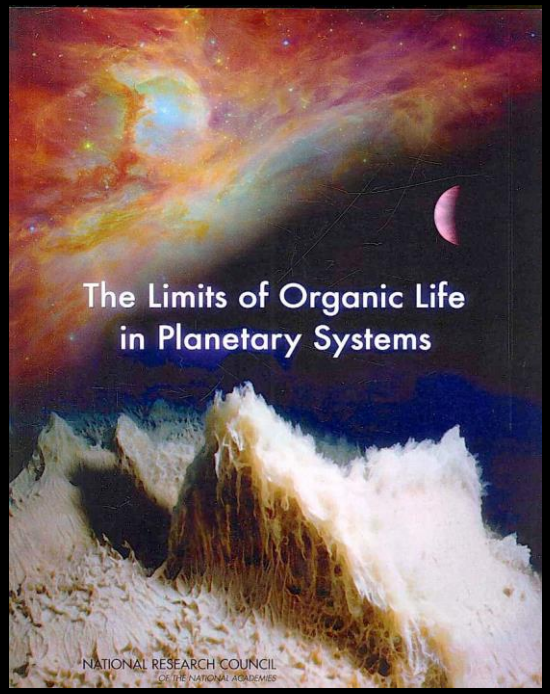
Light in the visible to NIR (approx. 400-1025 nm); flux > 10^{15} photons·m^{-2}·s^{-1}

Biological Requirements for Energy

The Earthly Example

Redox chemistry

Earth life uses only a subset of available light and chemical energy, which themselves are a subset of available forms



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Physicochemical Environment?

Temperature: -25 to 122˚C

pH approx. 0-13

Pressure to at least 200 MPa

Water activity to 0.6

Physicochemical Environment?

Tabulated ranges reflect laboratory “record holders”; real world frequently more restrictive (many environments have multiple challenges requiring additional adaptations and costs)

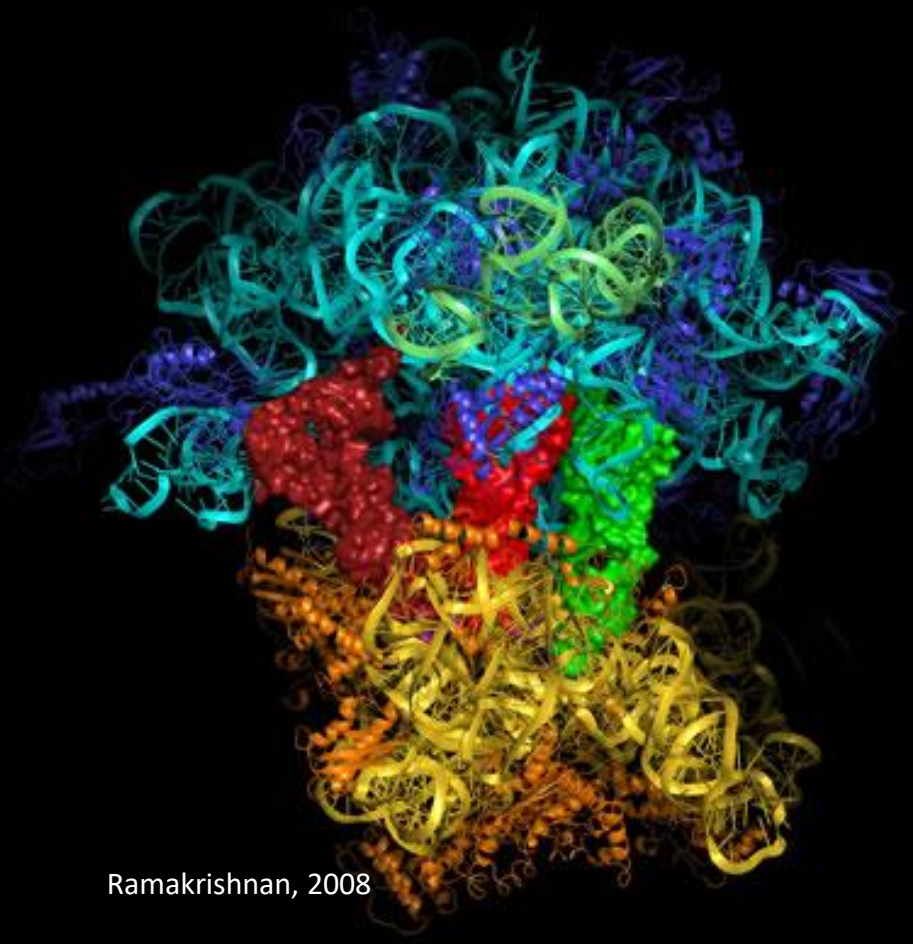
“Extremes” (relative to what’s “nominal” for a given biochemistry) may be tolerated at the expense of diversity, abundance, productivity

Tolerated ranges reflect extant life following extensive evolution; clement range for OoL potentially much narrower

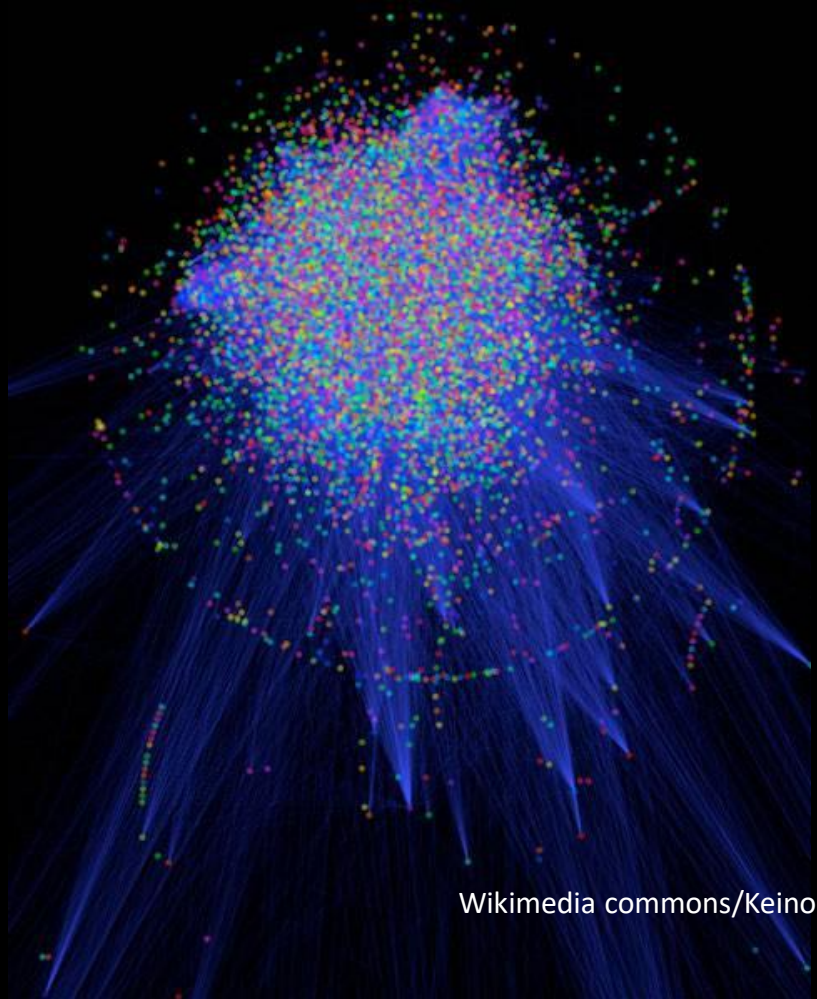
Are (must be) compatible with both covalent bonding *and* non-covalent interactions *in water*

"Reversible [non-covalent] molecular interactions are at the heart of the dance of life…these bonds are profoundly affected by the presence of water."

-- Stryer, 1988



Ramakrishnan, 2008



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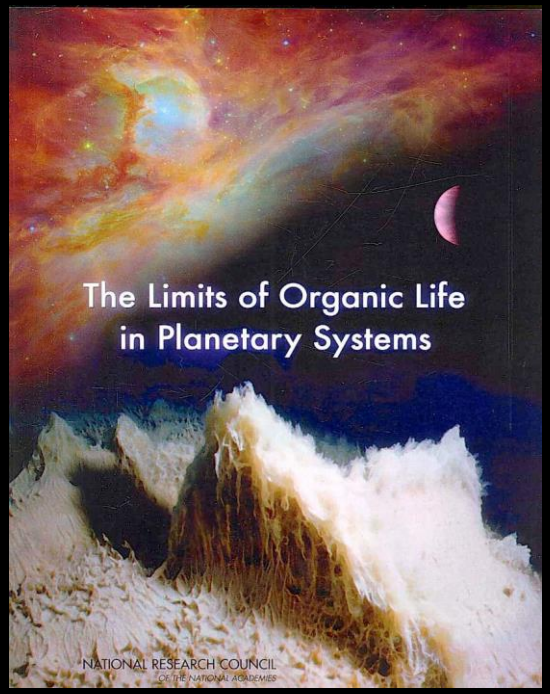

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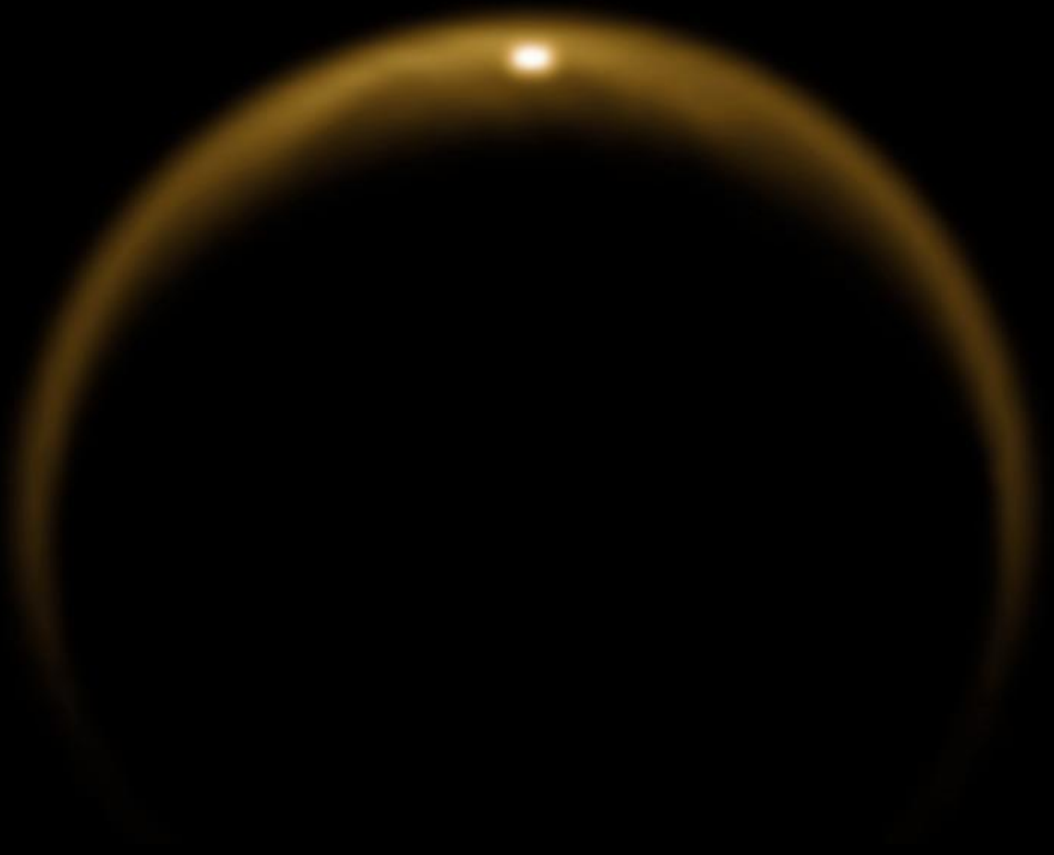
BREAKING NEWS

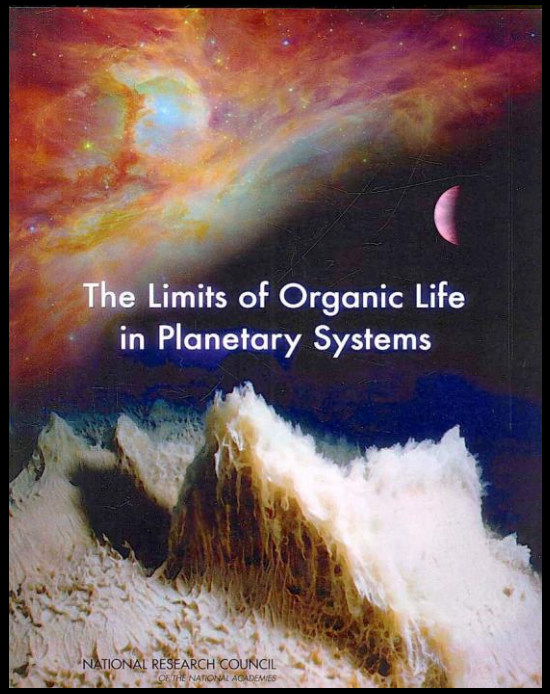
LIQUID WATER HAS BEEN SPOTTED ON MARS

DIY.DESPAIR.COM

Is Water Special?



Alternatives to liquid water as a *solvent* for life must be evaluated not only on their potential to support covalent synthesis, but also on their ability to properly mediate the full range of non-covalent interactions required by living systems.



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SPONCH: Everything a Body Needs?

Scaffolding element (C):

Creates a diverse library of possible structures through multiple bonding to itself and a variety of other elements

Dominantly in intermediate oxidation state*

Heteroatoms (SPON):

Relatively labile covalent bonding/reactivity

Electrostatic interactions

➡ Tertiary structure, molecular recognition, coordination chemistry, reactivity

Hydrogen (H):

Hydrogen bonding

Alternatives to SPONCH must be evaluated on their ability to support the requisite covalent & non-covalent chemistry and in reference to the properties, reactivity, and phase stability of the solvent (or vice-versa…)

THE PERIODIC TABLE FOR BIOLOGISTS

	I	II	III	IV	V	VI	VII	VIII
1	1.01 **1** **H** hydrogen							4.00 **2** **He**
2	6.94 **3** **Li**	9.01 **4** **Be**		non-metals				20.18 **10** **Ne**
3	22.99 **11** **Na** sodium	24.31 **12** **Mg** magnesium						39.95 **18** **Ar**
4	39.10 **19** **K** potassium	40.08 **20** **Ca** calcium	transition-metals					
5	85.47 **37** **Rb**	87.62 **38** **Sr**						131.30 **54** **Xe**
6	132.91 **55** **Cs**	137.33 **56** **Ba**						
7	223.02 **73** **Fr**	226.03 **74** **Ra**						

44.96 **21** **Sc**	47.90 **22** **Ti**	50.94 **23** **V**	52.00 **24** **Cr**	54.94 **25** **Mn** manganese	55.85 **26** **Fe** iron	58.93 **27** **Co** cobalt	58.71 **28** **Ni** nickel	63.55 **29** **Cu** copper	65.38 **30** **Zn** zinc
88.91 **39** **Y**	91.22 **40** **Zr**	92.91 **41** **Nb**	95.94 **42** **Mo**	98.91 **43** **Tc**	101.07 **44** **Ru**	102.91 **45** **Rh**	106.42 **46** **Pd**	107.87 **47** **Ag**	112.41 **48** **Cd**
	178.49 **72** **Hf**	180.95 **73** **Ta**	183.85 **74** **W**	186.21 **75** **Re**	190.23 **76** **Os**	192.22 **77** **Ir**	195.09 **78** **Pt**	196.97 **79** **Au**	200.59 **80** **Hg**

10.81 **5** **B**	12.01 **6** **C** carbon	14.01 **7** **N** nitrogen	16.00 **8** **O** oxygen	19.00 **9** **F**	20.18 **10** **Ne**
26.92 **13** **Al**	28.09 **14** **Si**	30.97 **15** **P** phosphorous	32.06 **16** **S** sulphur	35.45 **17** **Cl** chlorine	39.95 **18** **Ar**
69.74 **31** **Ga**	72.59 **32** **Ge**	74.92 **33** **As**	78.96 **34** **Se**	79.91 **35** **Br**	83.80 **36** **Kr**
114.82 **49** **In**	118.69 **50** **Sn**	121.75 **51** **Sb**	127.60 **52** **Te**	126.90 **53** **I** iodine	131.30 **54** **Xe**
204.37 **81** **Tl**	207.19 **82** **Pb**	208.98 **83** **Bi**	210.00 **84** **Po**	209.99 **85** **At**	222.02 **86** **Rn**

The most commonly occuring elements in living organisms are:

C 6 carbon · **H** 1 hydrogen · **O** 8 oxygen · **N** 7 nitrogen

Other common elements are shaded in green.

relative atomic mass — atomic number

1.01 **1** **H** hydrogen

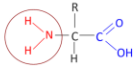
element name

Lanthanide and actinide elements (and 104 - 109) have been left off.

Some elements are used universally in nature—though their uses can be diverse.

N 7 nitrogen

- **Amino group** of amino acids (the monomers of proteins)



- Also used in chlorophyll.

S 16 sulphur

- Source of energy for chemosynthetic bacteria in hydrothermal vents
- Found in the R-Group of cysteine, an amino acid, and can form disulfide bridges in protein folding.

Na 11 sodium · **K** 19 potassium

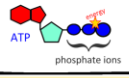
- Generate resting and action potentials in neurons.
- Used in maintaining osmosis. Sodium is the main cation (positive ion) in blood plasma, potassium in cytoplasm.
- Sodium-potassium pump is an example of active transport

Fe 26 iron

- Has a high affinity for oxygen
- Used in hemoglobin and myoglobin to carry oxygen in blood and muscles
- Used in ferredoxin in photosynthesis
- electron carrier in some bacteria

P 15 phosphorous

- Phospholipids make up the plasma membrane.
- Sugar-phosphate backbone of DNA structure.
- Bonds between phosphate ions store energy in ATP.



Ca 20 calcium

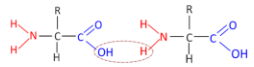
- Extracellular component of bone matrix
- Forms exoskeletons
- Stimulates synaptic transmission between neurons
- Used in muscle contraction

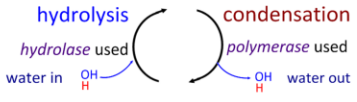
Condensation reactions **create bonds** between organic molecules, making **polymers**.

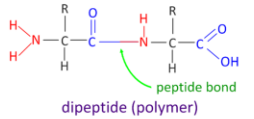
Hydrolysis reactions **break bonds**.

example:

amino acids (monomers)





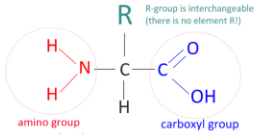


dipeptide (polymer)

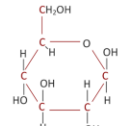
Organic Compounds

contain **carbon** and are found in **living organisms**.

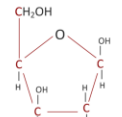
Some **examples** include:



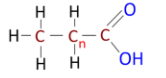
amino acids



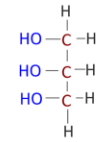
glucose



ribose



fatty acid



glycerol

Some **exceptions** are:

CO CO_2 oxides of carbon	CO_3^{2-} carbonates
HCO_3^- hydrogen carbonates	$CaCO_3$
Na_2HCO_3	Na_2CO_3

Resources used:

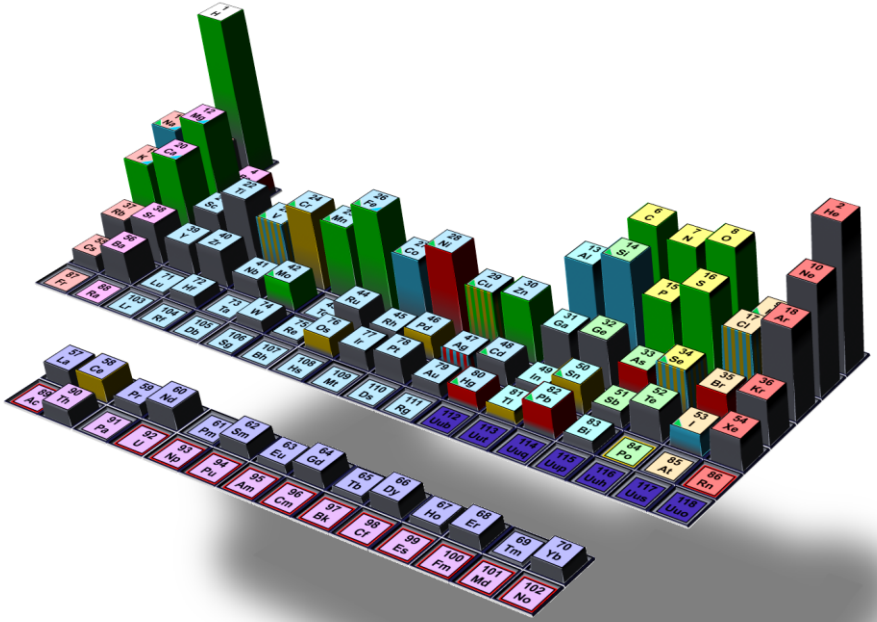
- Kent, M. Advanced Biology. Oxford University Press, 2000.
- Allott, A & Mindorff, D. Biology Course Companion. Oxford University Press, 2007.

Designed for the IB Biology course by Stephen Taylor

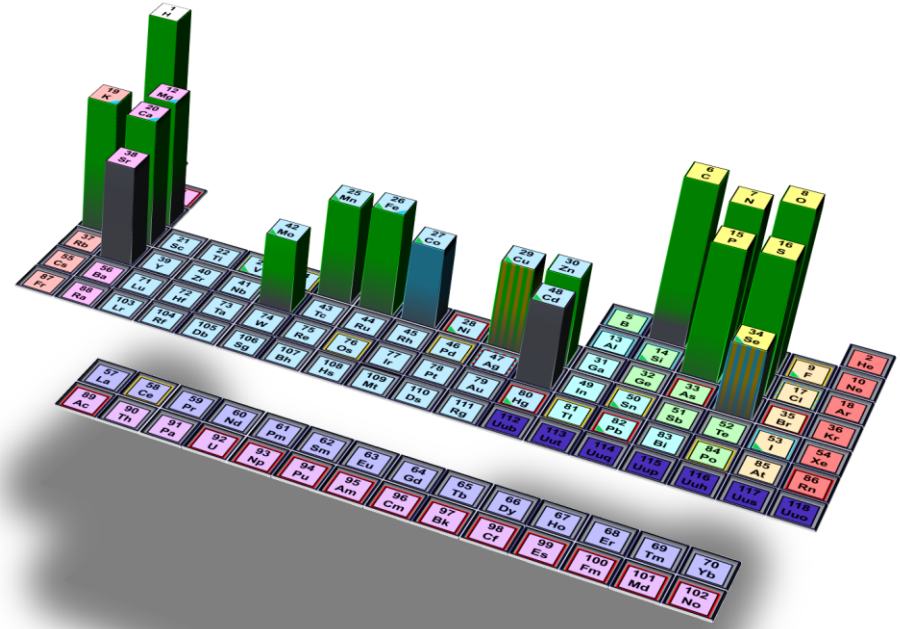
More resources: http://i-Biology.net

Twitter: @IBiologyStephen

Follow the Elements!



Cosmic
Abundances



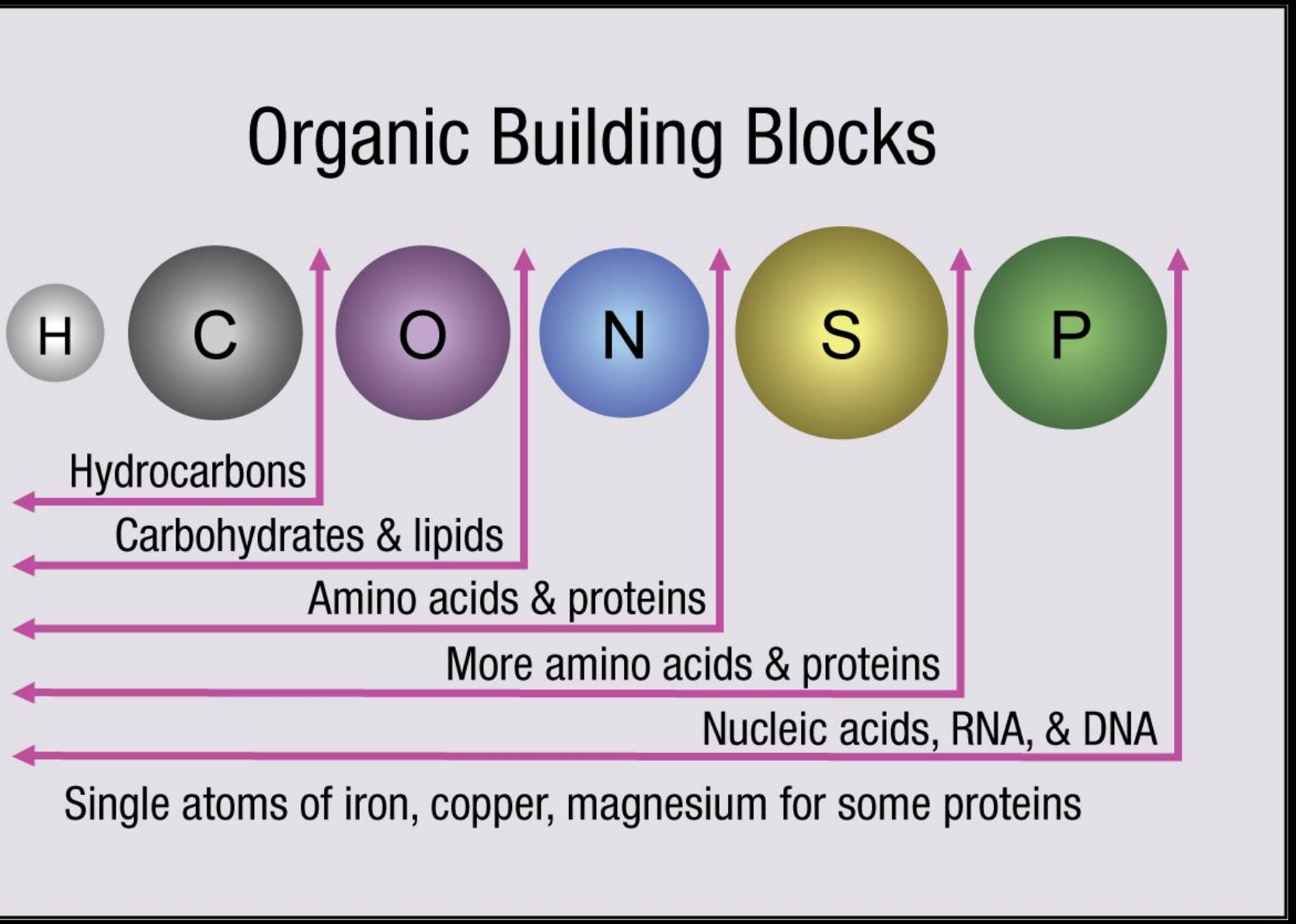
Biological
Abundances

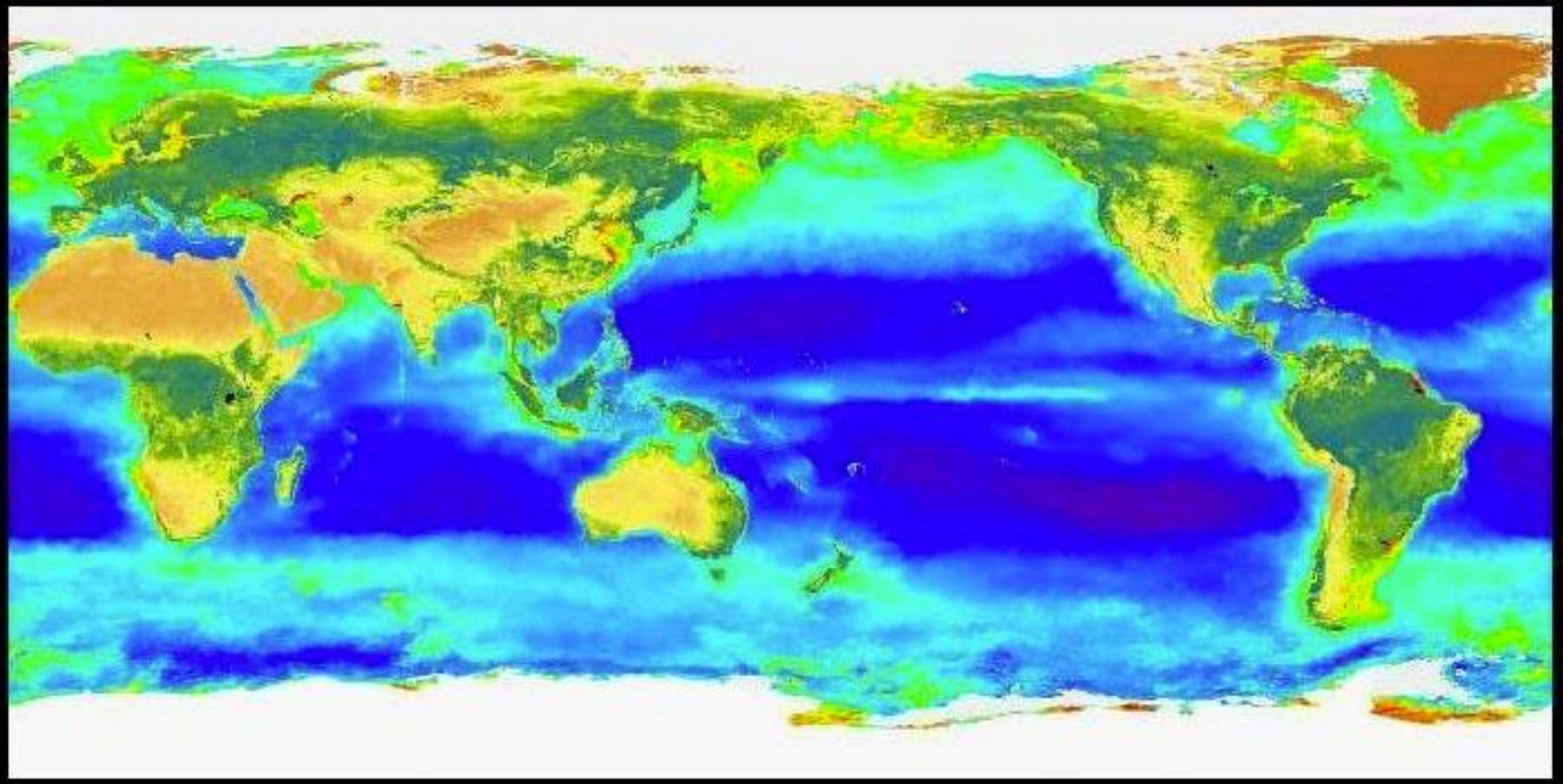
Redfield ratio- ecological stoichiometry, relatively consistent ratio of nutrients in biomass samples, doesn't include chemical energy.

106 C:16 N:1 P:0.1-0.001 Fe

Bioavailability:
Only select forms of P and Fe are biologically available. More energy needed for acquisition of certain forms of N

Redfield ratio



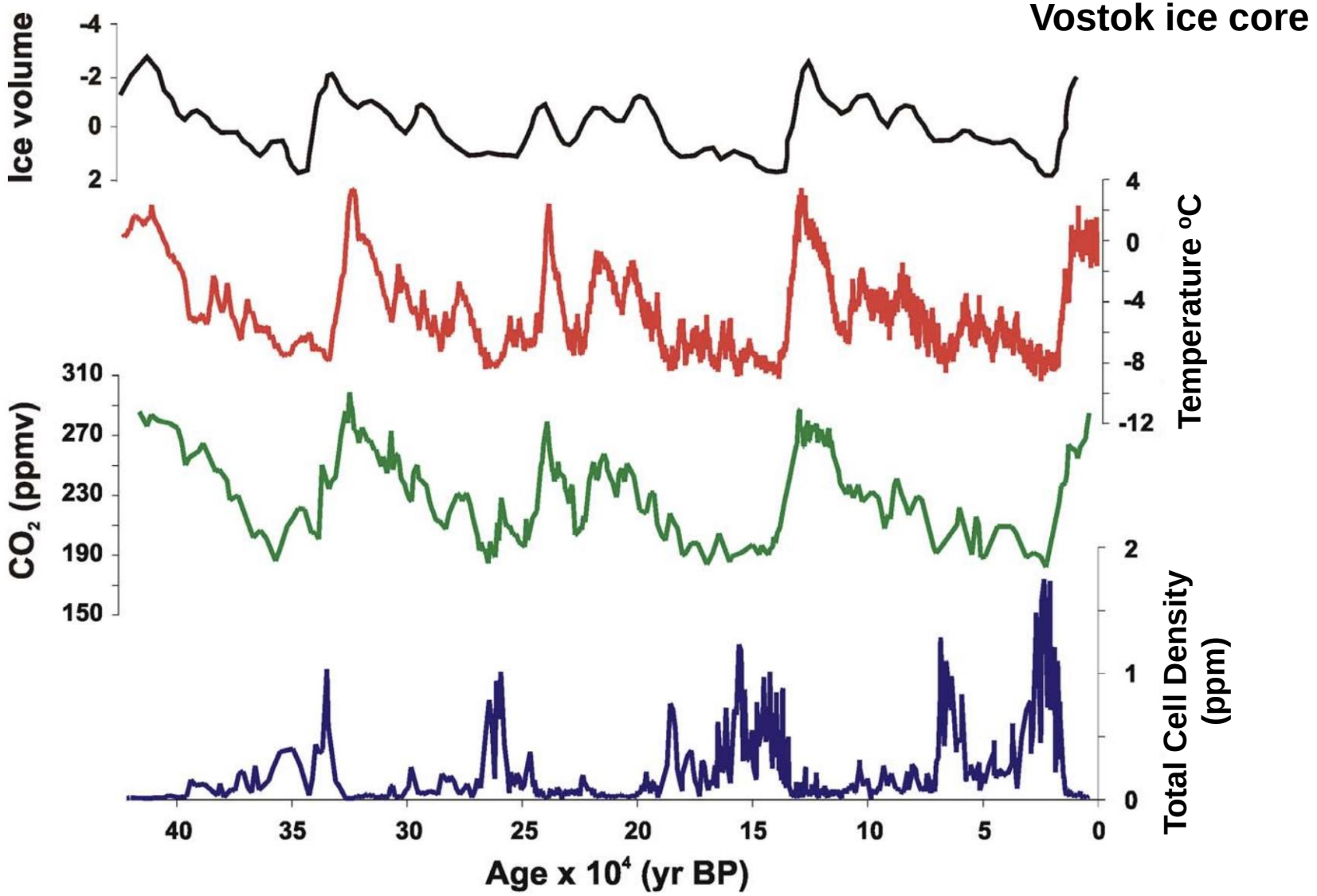


>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50

Ocean: Chlorophyll *a* Concentration (mg/m3)

Maximum Minimum

Land: Normalized Difference Land Vegetation Index


Vostok ice core
Ice volume
-4
-2
0
2
Temperature °C
4
0
-4
-8
-12
CO2 (ppmv)
310
270
230
190
150
Total Cell Density (ppm)
2
1
0
40
35
30
25
20
15
10
5
0
Age x 10^4 (yr BP)

Questions about Habitability

- What is the origin of potential biota in Venus clouds allocthanous or autochthonous?
- Can organisms survive and/or reproduce?
- What are the sources/sinks and concentrations of bio-essential elements (CHNOPS. Micro nutrients)
- What are the necessary conditions for aerosolized bacteria to acquire nutrients and reproduce?
- How would polyexyremophily be evaluated (UV, Temp, Press, pH, low water activity, low nutrient, etc)
- And how would that limit microbial candidates and biomass?

Questions about Detection

Biosignatures need to be reliable, unambiguous, resilient, and detectable.

- What is the minimum cell density necessary to explain the “absorber”?
- What other features (spectral) would be necessary to confirm biotic source (e.g. PS pigments, PP pigments)?
- What is required to measure life directly (sampling, processing and detection)?
- What are the costs to a mission (mass, power, etc)
- What ”best practices” can the Venus community learn from other communities (e.g. exoplanets)

Microbial Biomass on Earth

Nutrients

Environment	cells/ ml
Lake Sediments	5.00E+09
Sewage	5.00E+07
Eutrophic Lake	5.00E+06
Estuaries	5.00E+05
Open Ocean	5.00E+04
Atmosphere	5.00E+02
Stratosphere	??

Questions?

Image by john doe