Alternative Chemistries of Life

Empirical Approaches

Briefing to the NAS Committee on Astrobiology and Planetary Sciences
1st April, 2015

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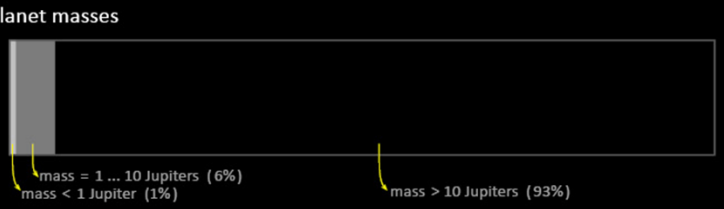
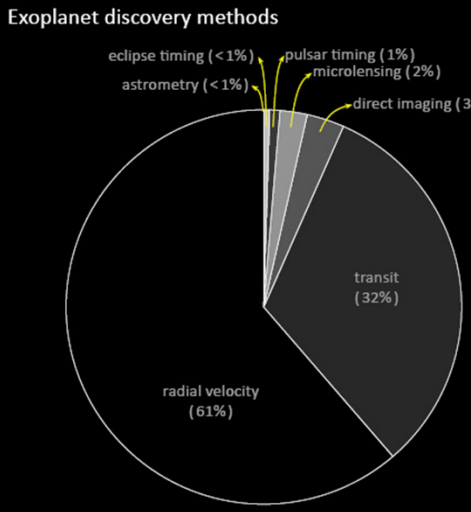
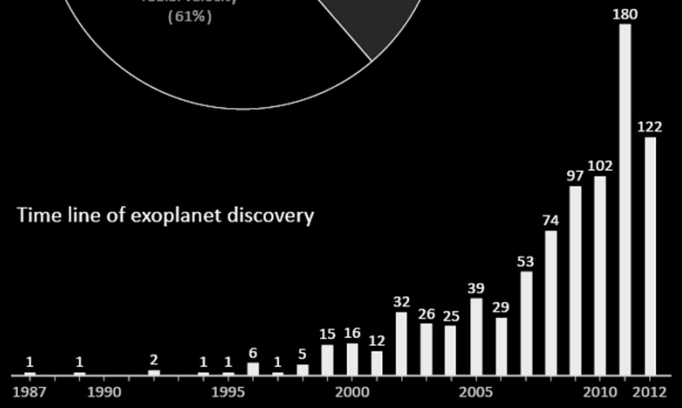
EMORY UNIVERSITY

Other Worlds

Sizes of the 840 known exoplanets



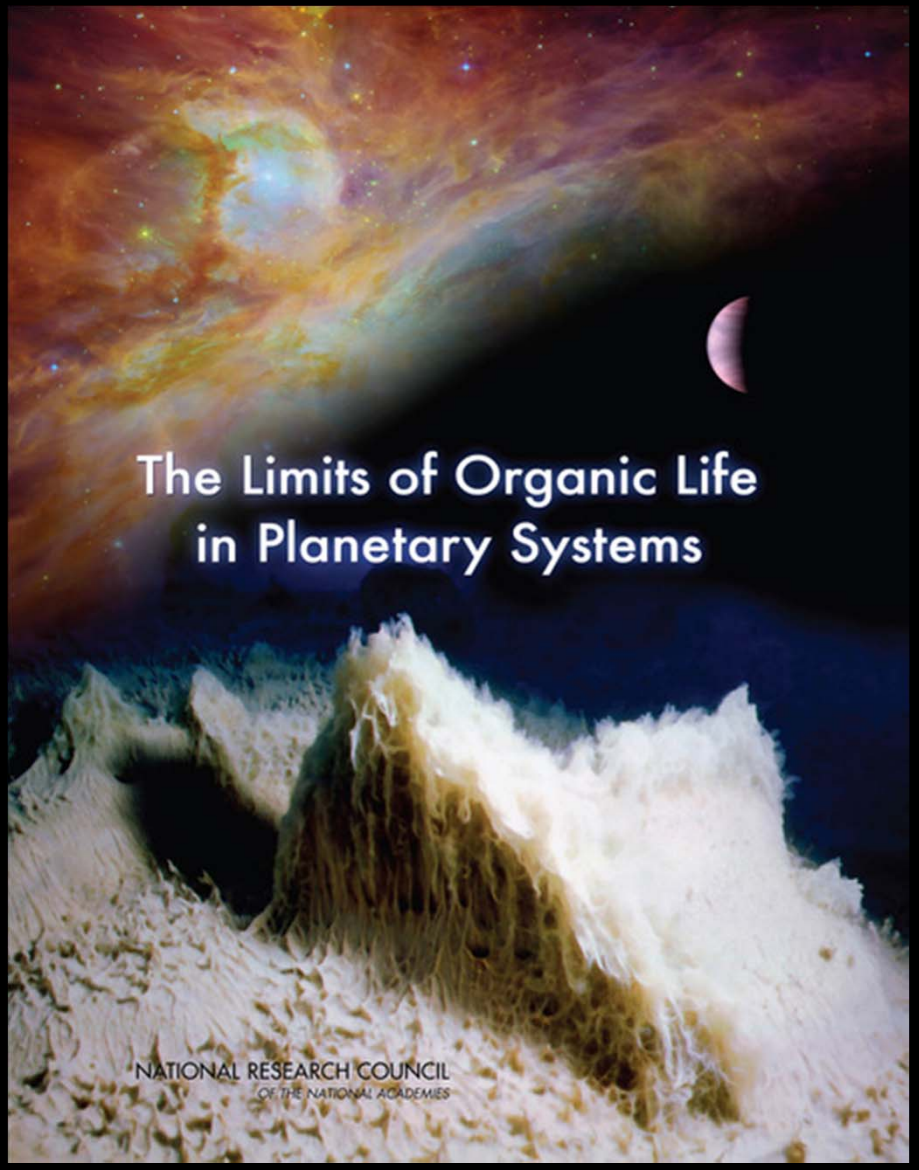




The rate of discovery of the 840 confirmed exoplanets, up to December 2012. As at June 2013, the confirmed total stands at 865, with 2 781 additional candidates awaiting confirmation.

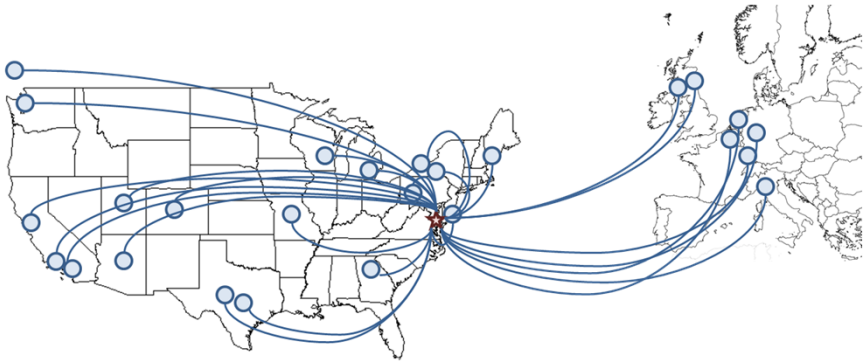
Data from the NASA Exoplanet Archive — http://exoplanetarchive.ipac.caltech.edu

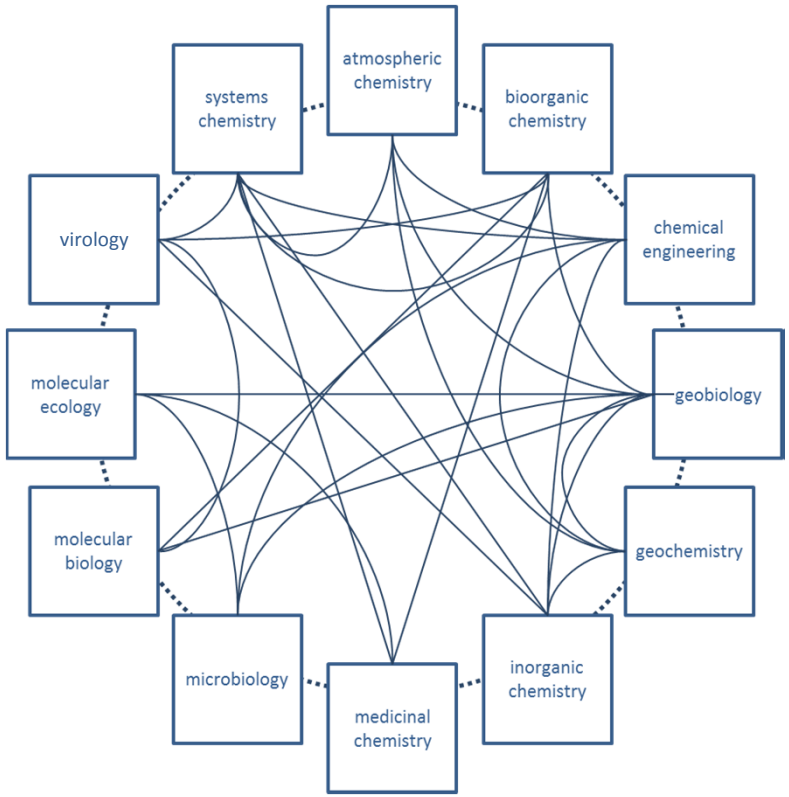
http://www.psychohistorian.org/display_article.php?id=201306052318_exoplanets840.content



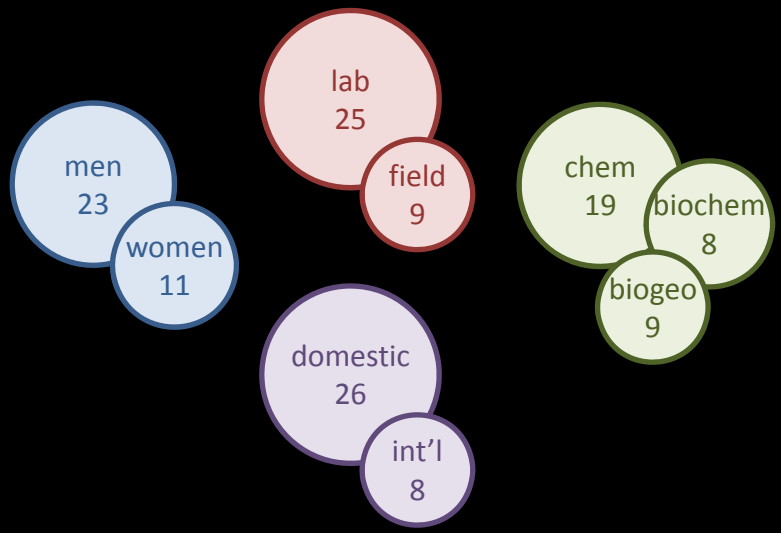
Mono Lake

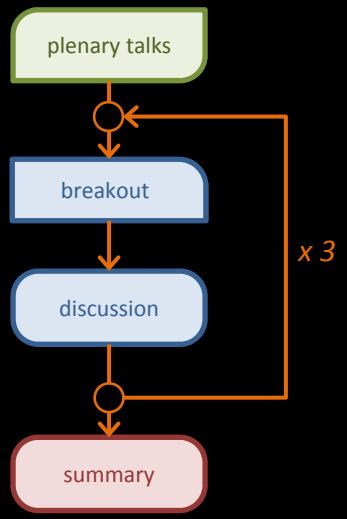
http://www.nydailynews.com/news/nasa-announces-discovery-alien-microbe-lives-arsenic-article-1.116203





Workshop structure





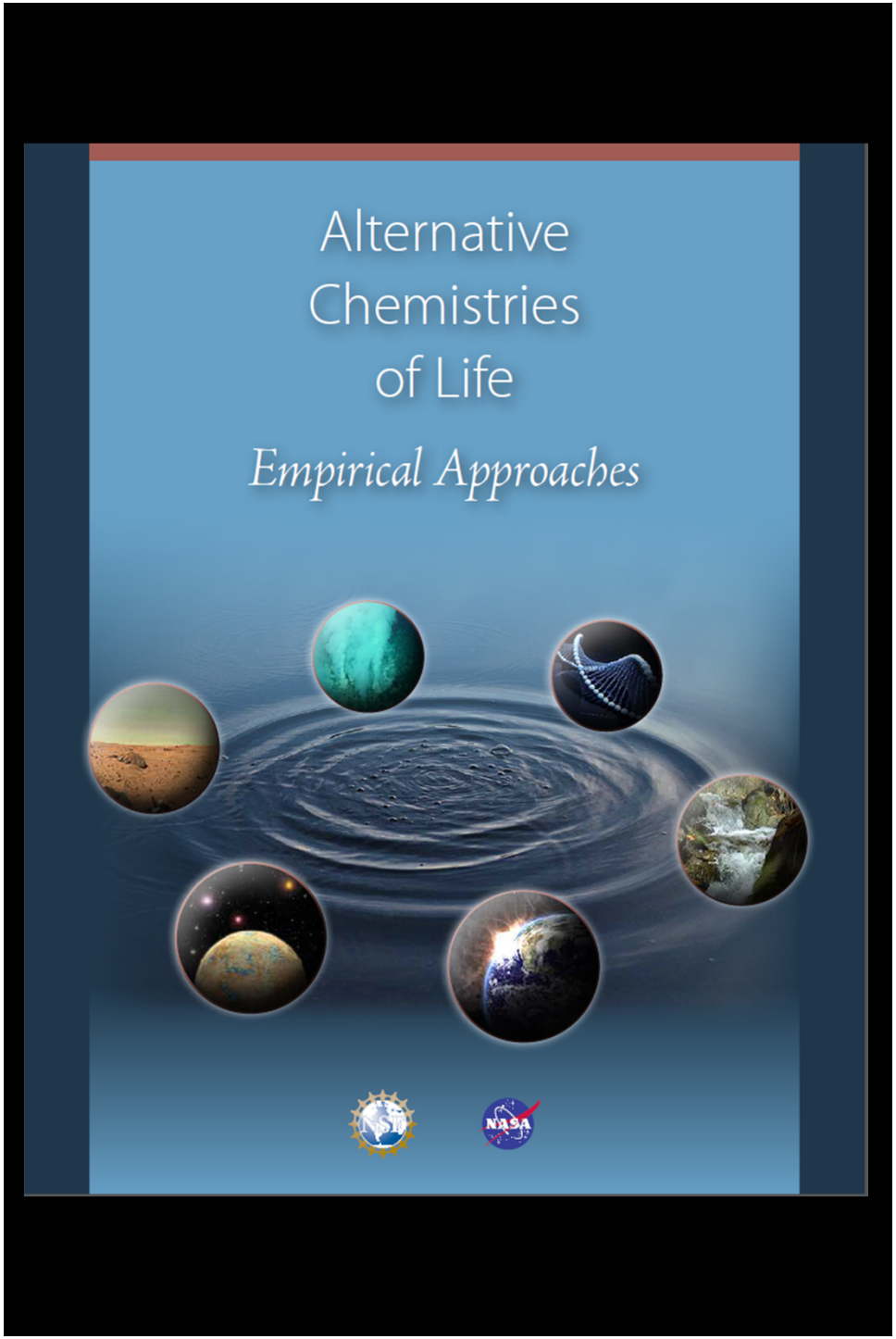
Workshop Charges

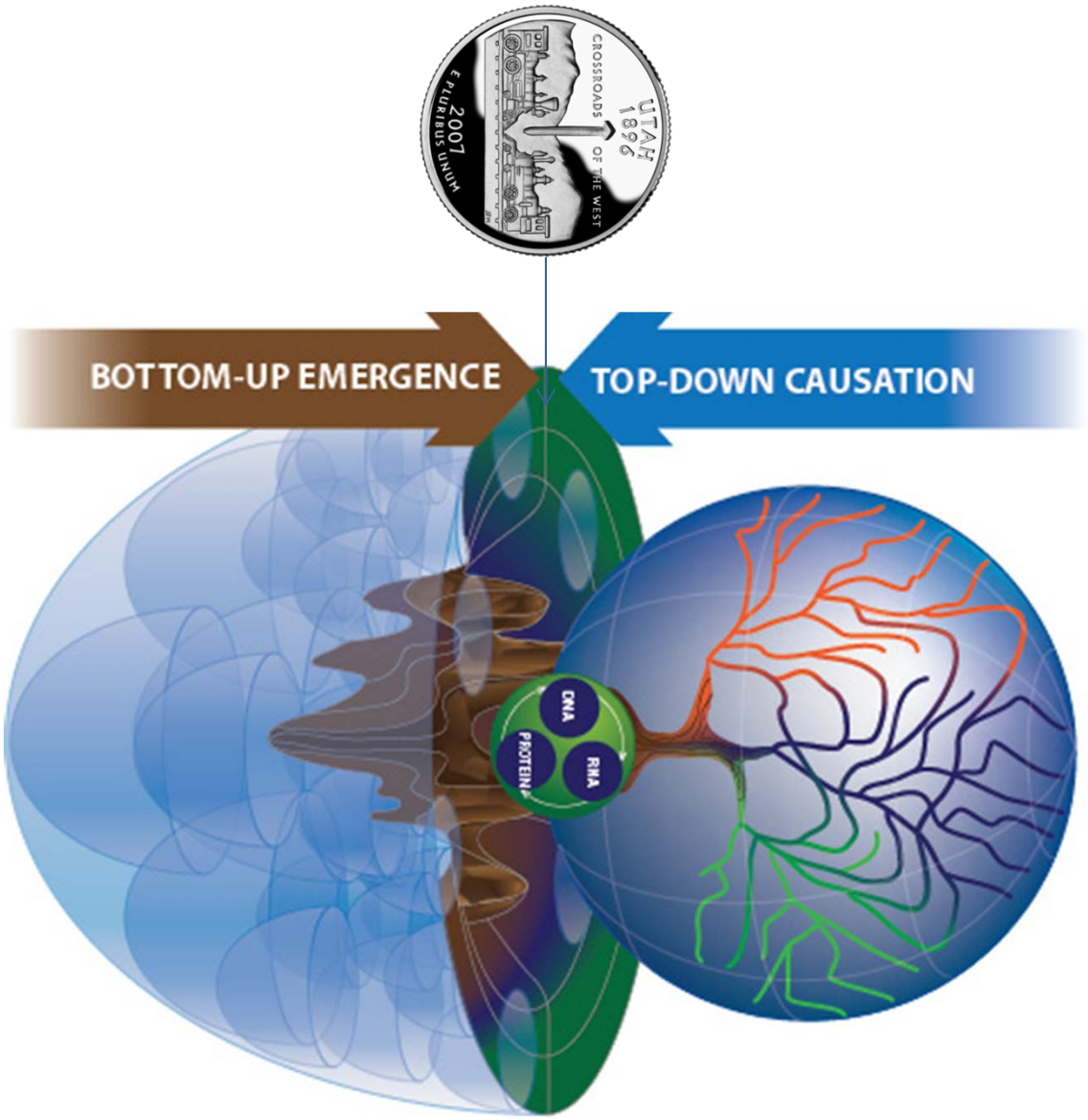
Properties life's building blocks
- physical constraints?
- different biochemical reactions?
- systems of reactions, distinct metabolisms?

Critical limits on evolvable molecular systems
- chemical reactivity?
- range on energy inputs?
- maintaining far from equilibrium?
- range of containments

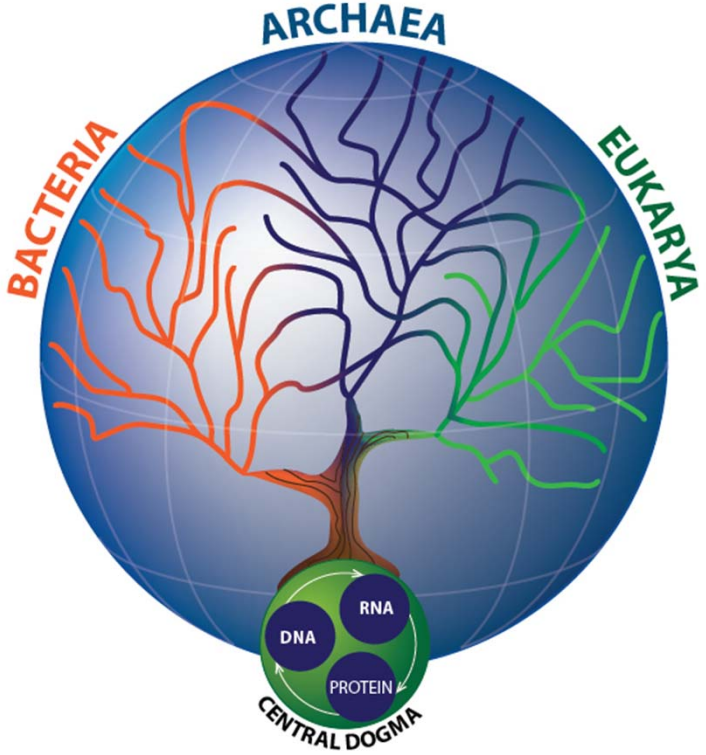
Earth as our laboratory
- how diverse is life?
- how does life evolve?
- how does it deal with resource limitations?
- how far can it be pushed?

What are the lab & field methods/tools needed to advance science?



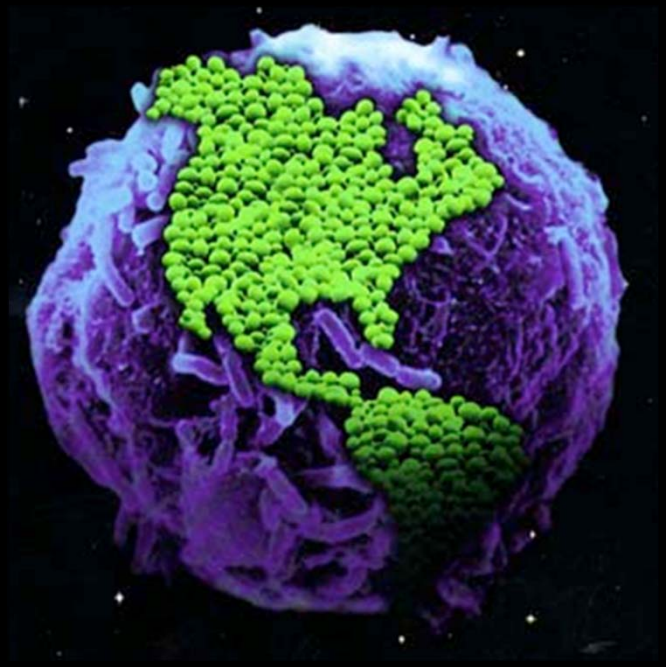

UTAH
1896
CROSSROADS OF THE WEST
E PLURIBUS UNUM
2007
BOTTOM-UP EMERGENCE
TOP-DOWN CAUSATION
DNA
RNA
PROTEIN

‘Top-down’ causation



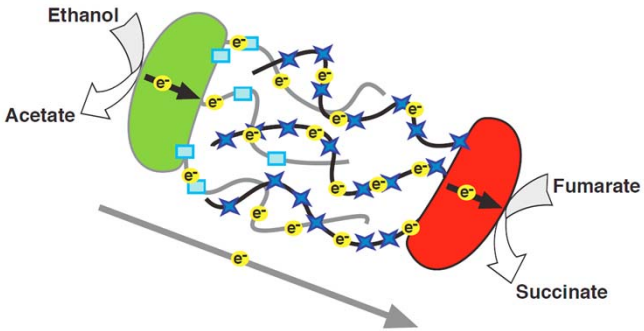
No. of microorganisms on Earth = 10^{30}

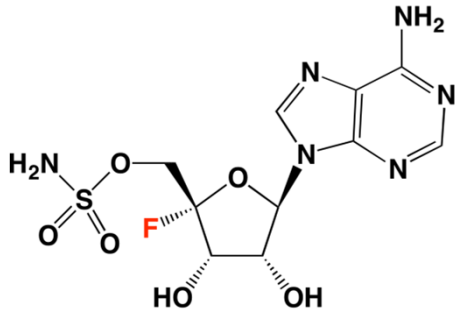
No. of stars in the universe = 10^{22}



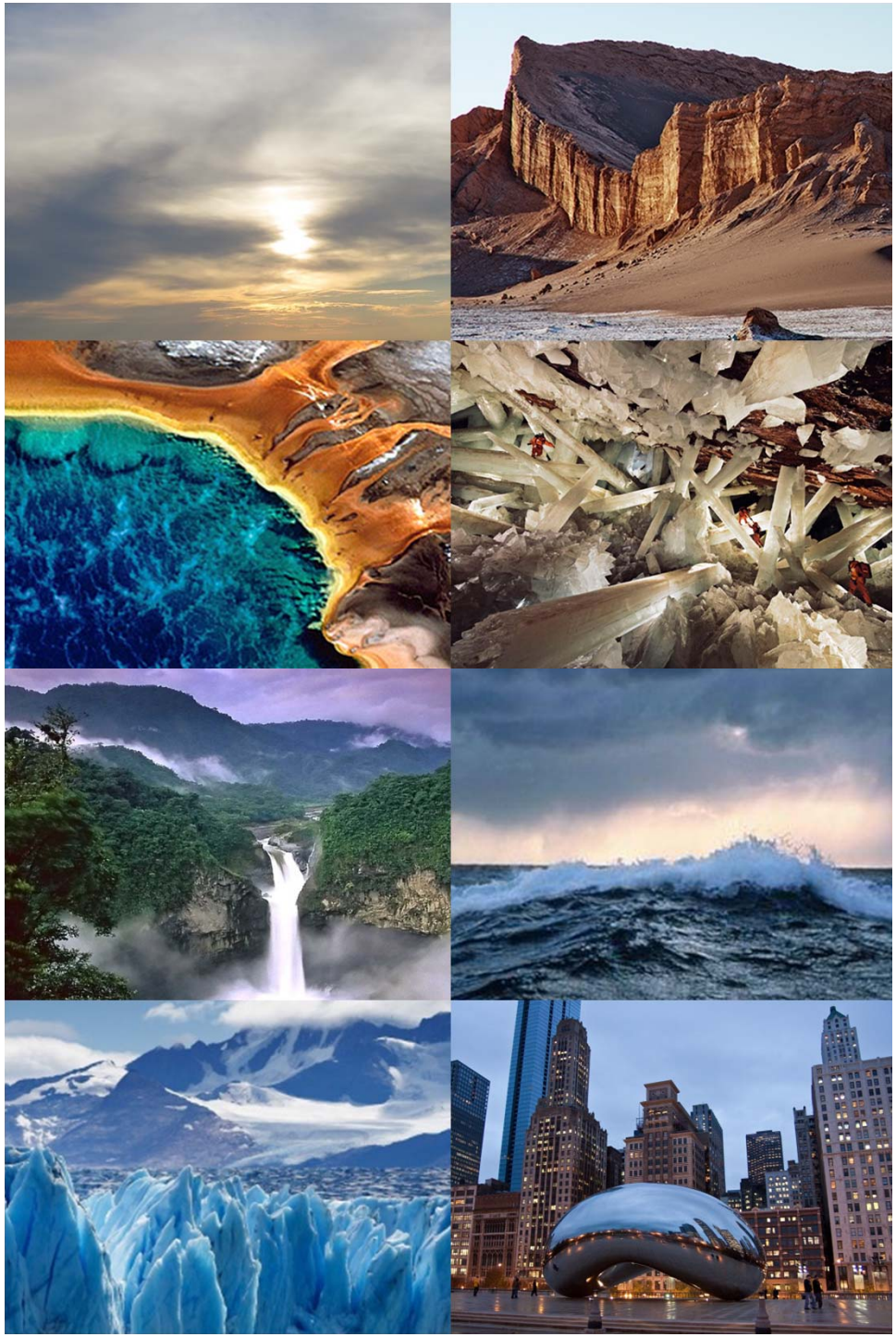
Mutualistic System

http://schaechter.asmblog.org/schaechter/2014/04/the-oldest-gem-tells-its-tale.html





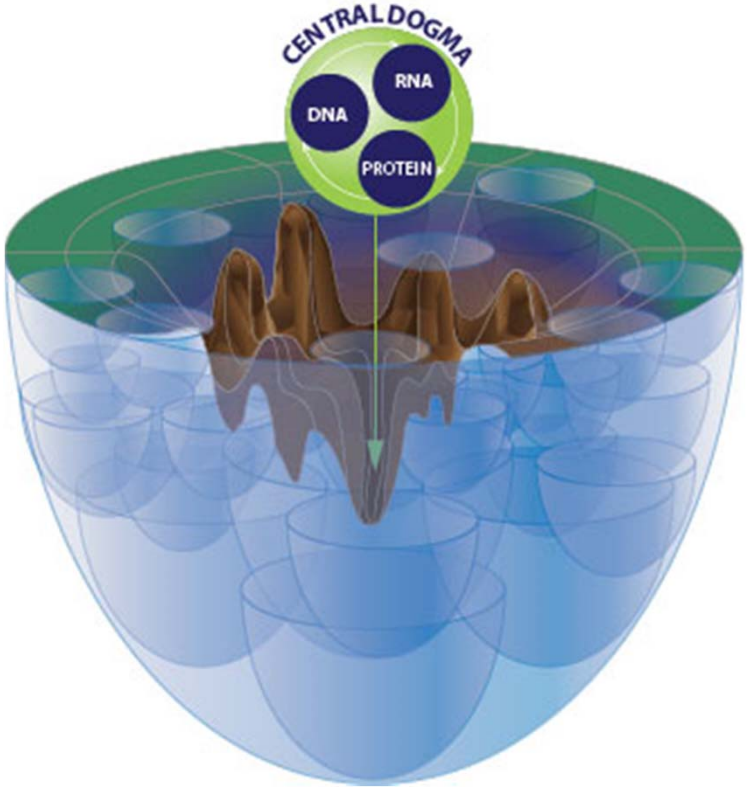
O'Hagan, Deng *Chem Rev* **2015,** 115, 634
http://biology.st-andrews.ac.uk/stories/images/2011_12_06_img02.jpg



‘Top-down’ findings

- Earth remains our under-explored laboratory
- life depends on connected chemical systems
- define the range of its chemistries
  - improving signal to noise
    - single-cell genomic and metabolic analyses
    - tracking flow of energy across networks
    - defining flow of genetic information
  - mapping its complexity
  - collaborating across scientific disciplines
    - big data management
    - interdisciplinary partnerships
    - field studies across large physical domains

‘Bottom-up emergence’



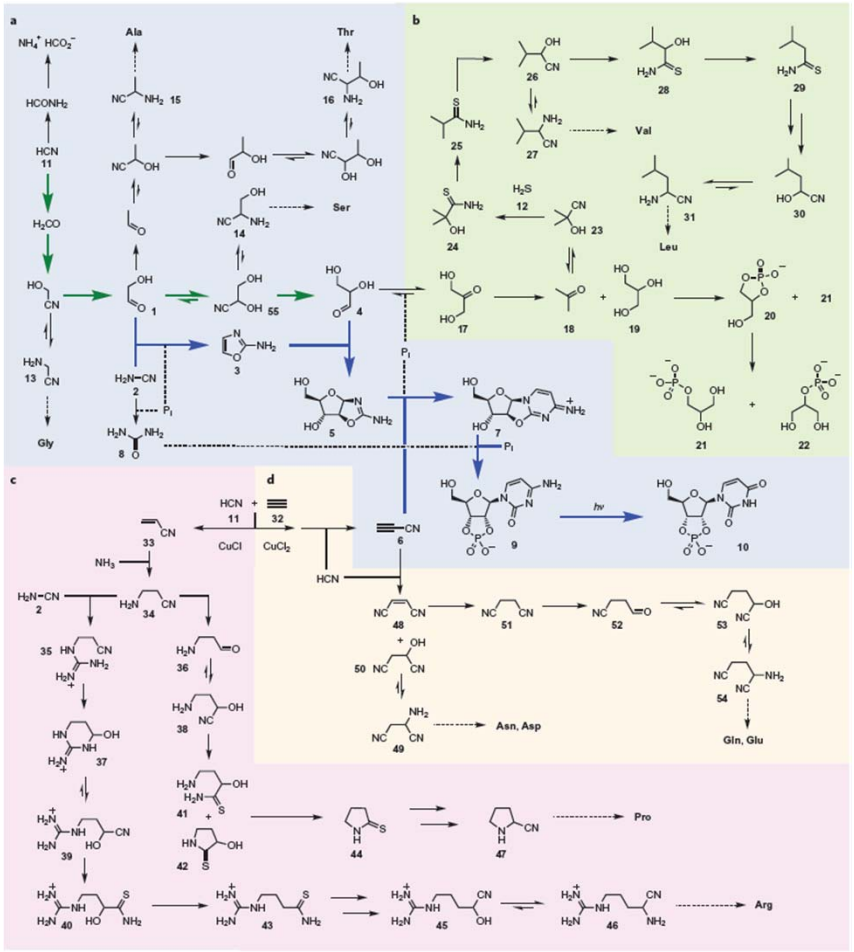
Darwin’s warm ponds

Darwin’s letter to JD Hooker about origins stated,

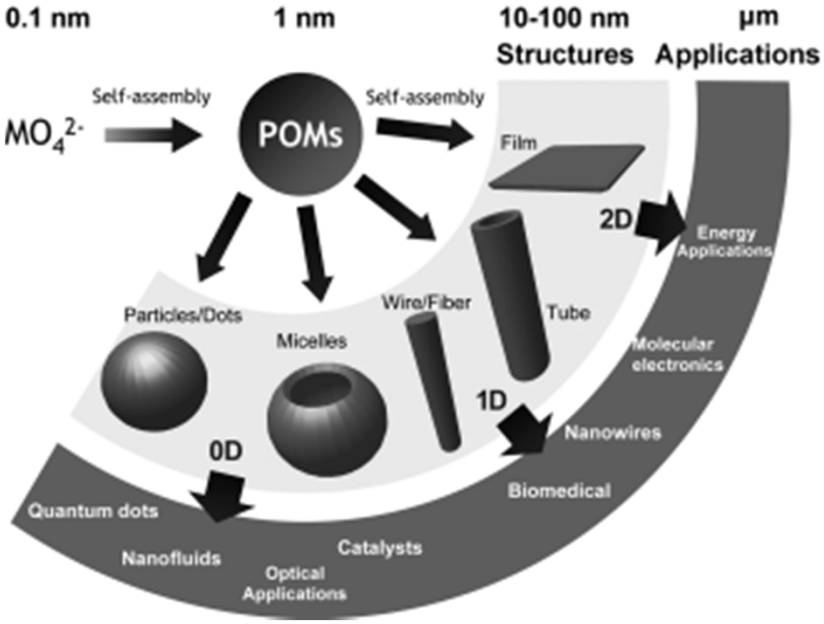
It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present. But if we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, & etc., present, that a proteine [sic] compound was chemically formed ready to undergo still more complex changes…

…emergence

Self-constructing & alternative networks



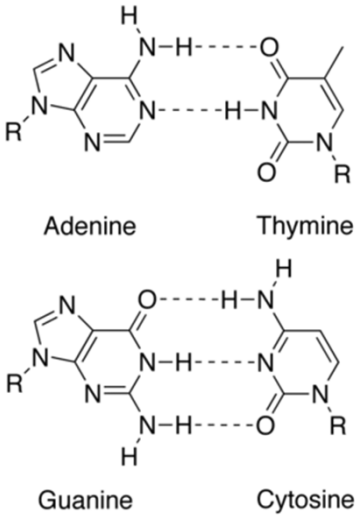
Inorganic self-assembling materials

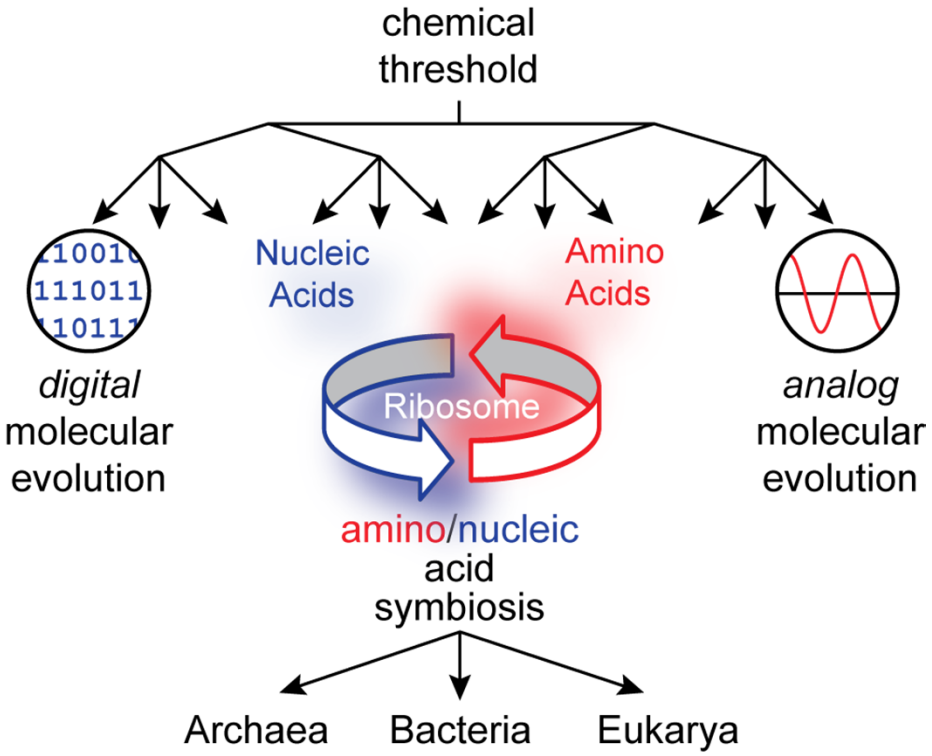


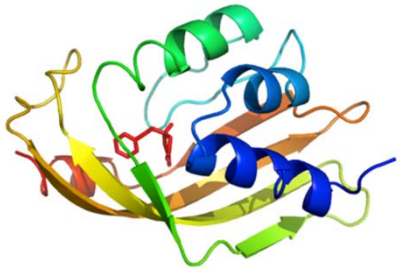
Patel, Percivalle, Ritson, Duffy, Sutherland *Nature Chem* **2015**; DOI: 10.1038/NCHEM.2202

Long, Tsunashima, Cronin *Angew Chem Int Ed* **2010**, *49(10)*, 1736

Darwinian threshold of cellular life



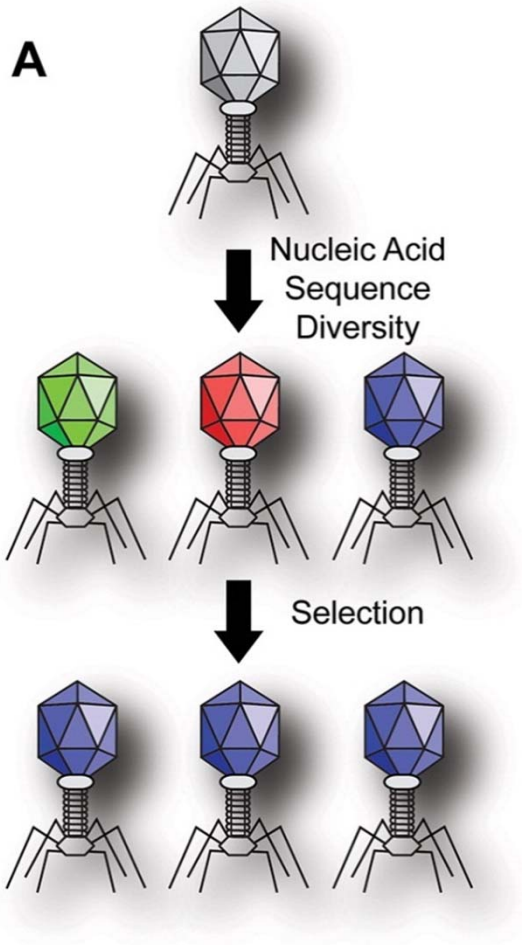




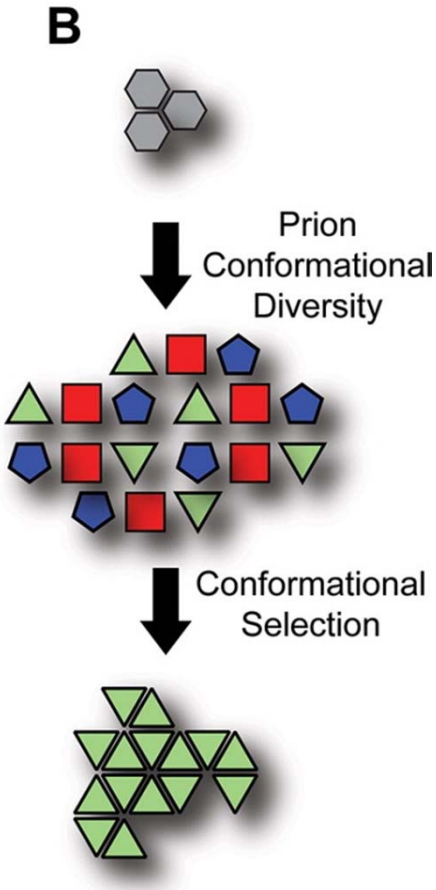
Ribosome as a Molecular Digital to Analog Converter (DAC)

Goodwin, Mehta, Lynn *Accounts Chem. Res.* **2012**, *45(12)*, 2189-99; Origins of Chemical Evolution

Two chemical evolution strategies

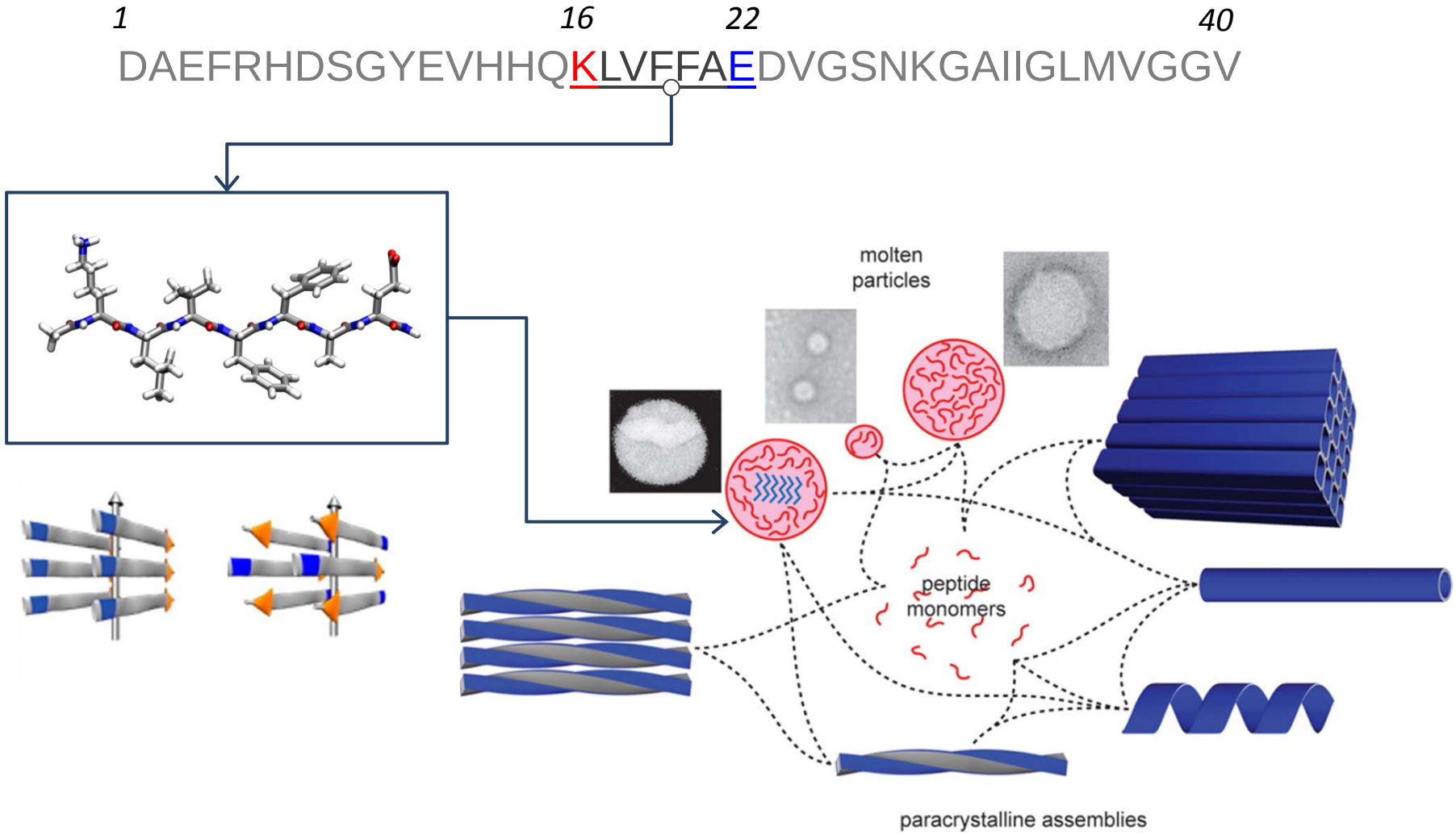


digital



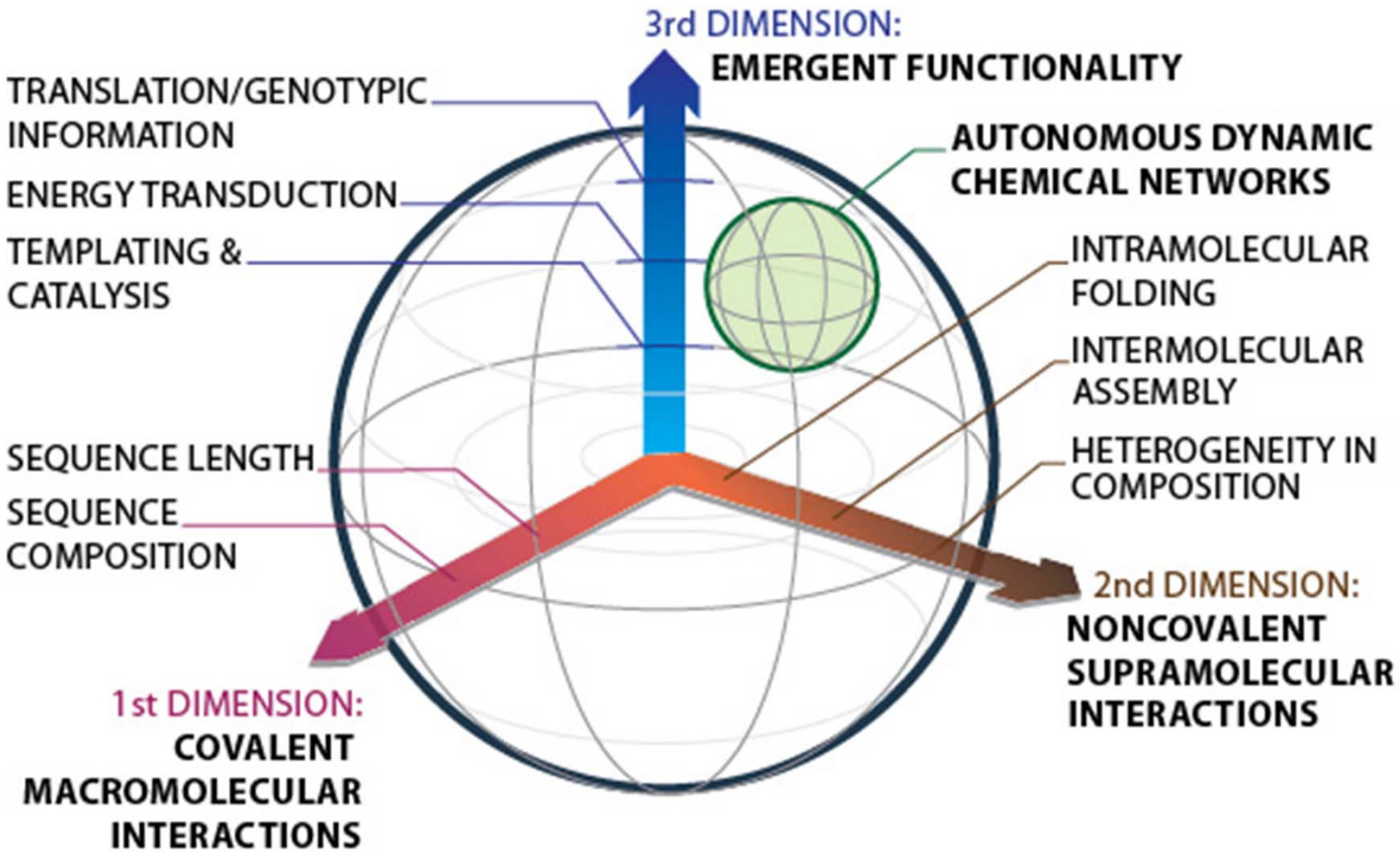
analog

‘Analog’ dynamic chemical networks



Childers, Anthony, Mehta, Berland, Lynn *Langmuir* **2012**, *28*, 6386

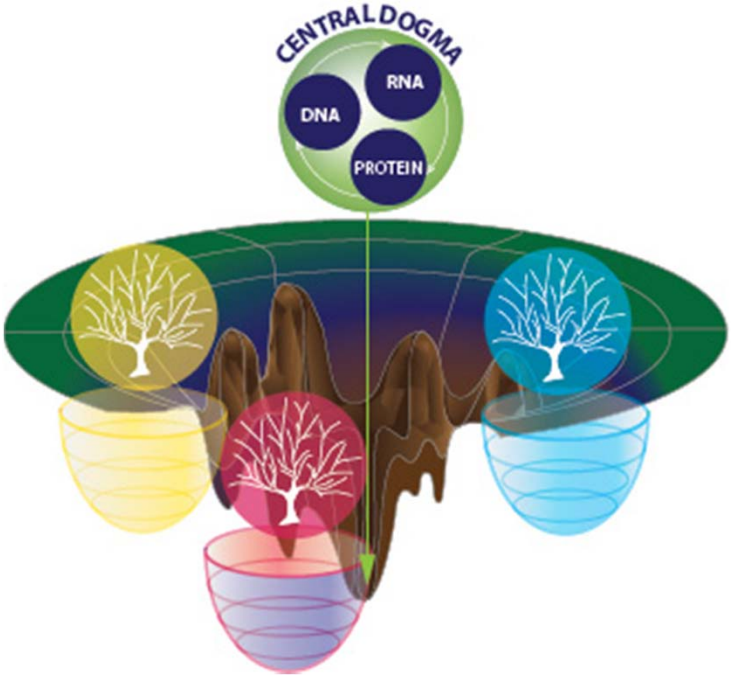
A ‘genotypic code’ for chemical evolution



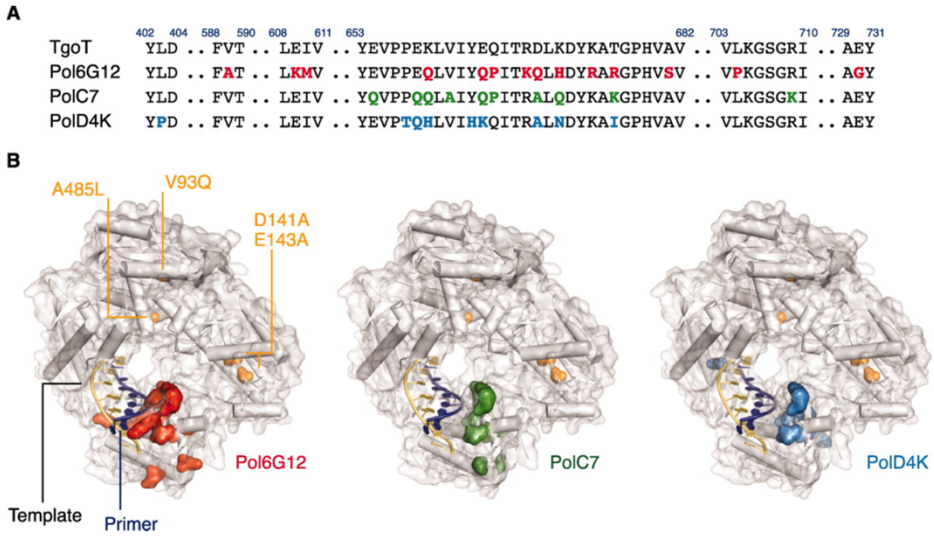
‘Bottom-up’ findings

- flow of nanoscale information
- states maintained far from equilibrium
- dynamic chemical networks coupled with physical processes of self-assembly, a ‘genotypic code’
- dialectic growth of molecular order
- self-organizing feedback
- achieve polymer scaffold mutualisms

The ‘Golden Spike’

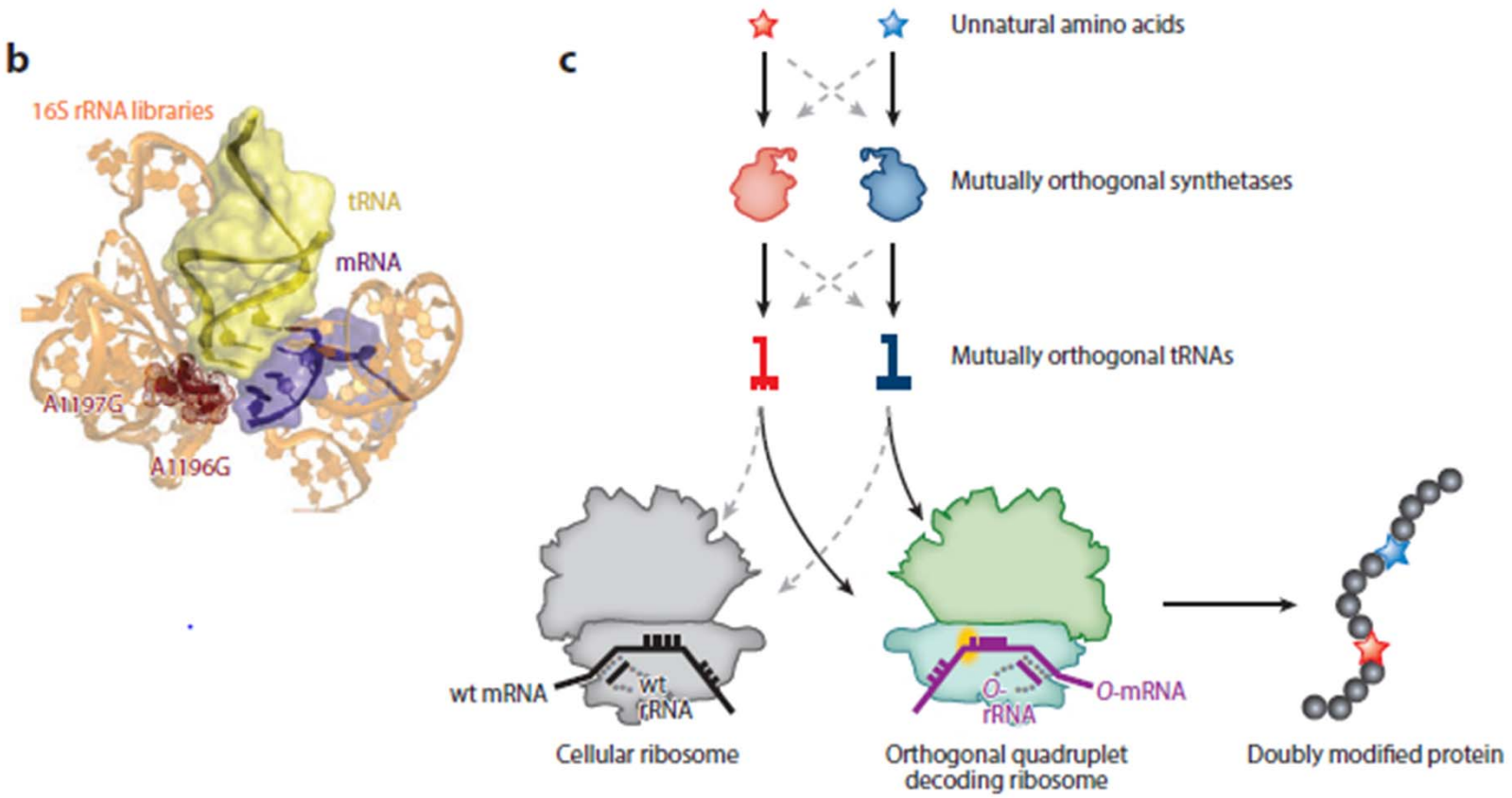


Alternative genotypic networks



Pinheiro, Holliger *Curr Op Chem Biol* **2012**, *16*, 245; Pinheiro et al *Science* **2012**, *336*, 341.

Alternative phenotypic networks



Chin *Annu Rev Biochem* **2014**, *83*, 379

‘Golden Spike’ findings

- move beyond extant biochemistry to alternative genetic platforms
- shape dynamic chemical networks to move beyond currently known environments
- provide signatures for transitions to new life forms
- creating technology for intelligent materials
- defining limits on evolvable networks
- demanding bioethics & biosafety dialog about this and other planets…

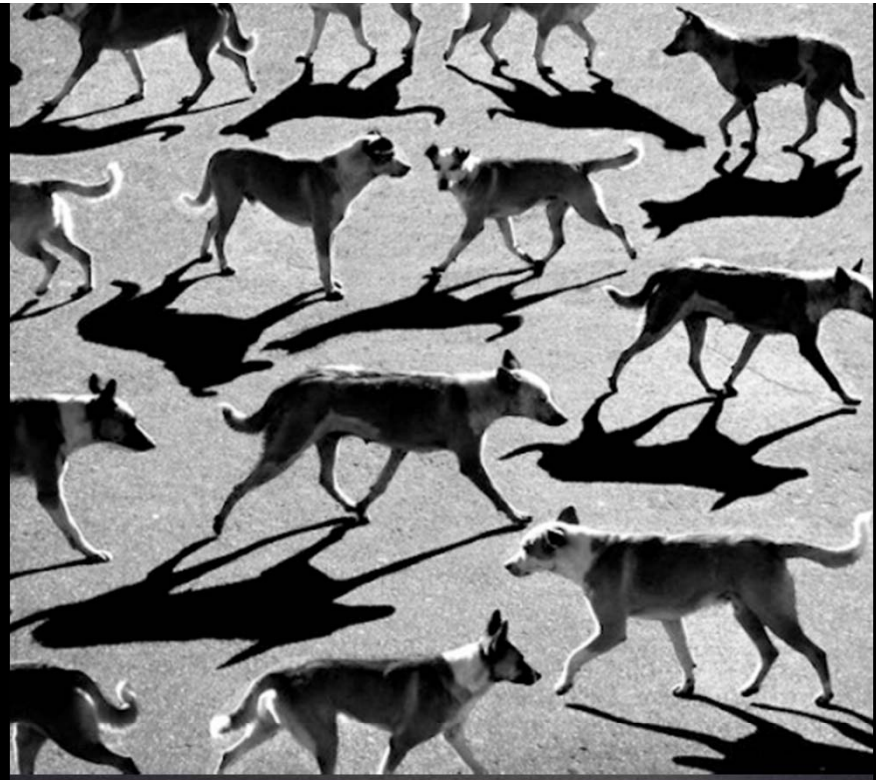
Implications

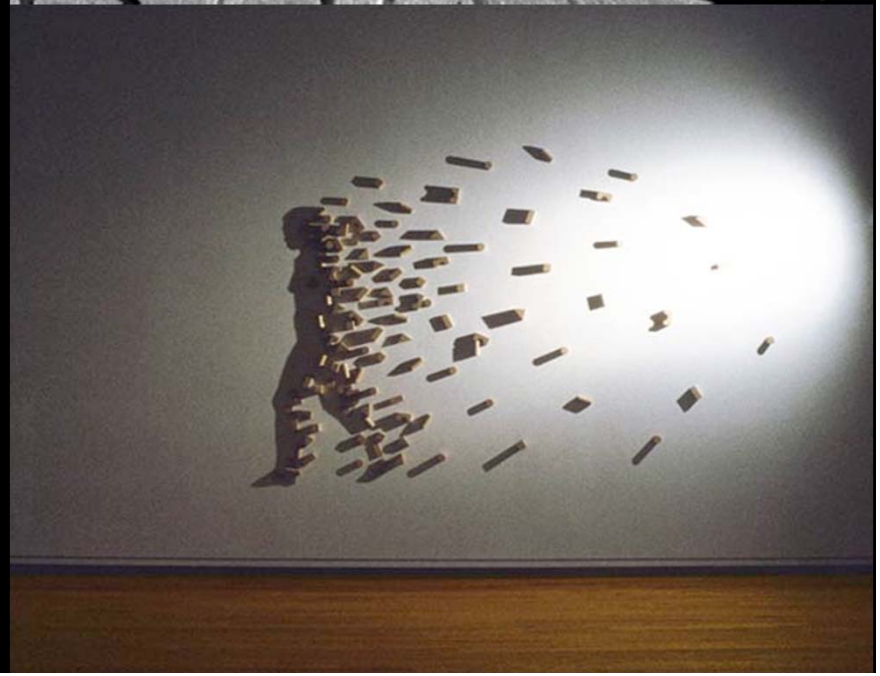
If it is so easy to evolve molecular information and symbioses differently?

To store molecular information in new forms and enable its flow into useful functions.

Other molecular forms must exist in the shadows of Earth, emerging from Darwin's warm pond, just not detected by our existing molecular tools

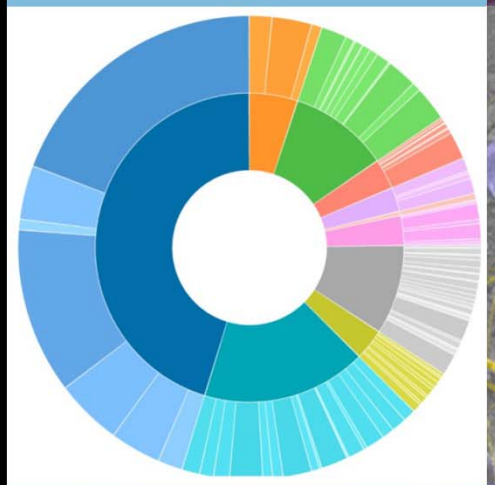
A biosphere in the shadows, just like the microbes that make the human form, and not detected by our existing molecular tools.

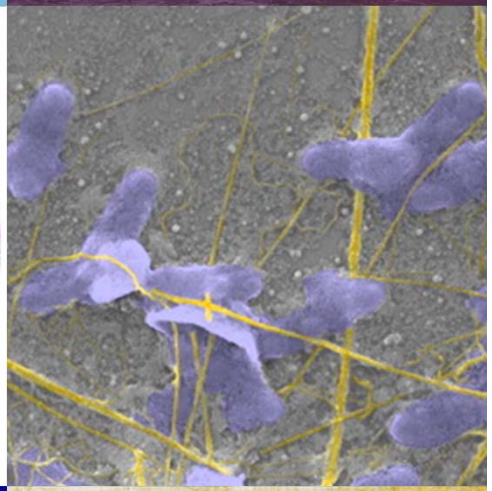


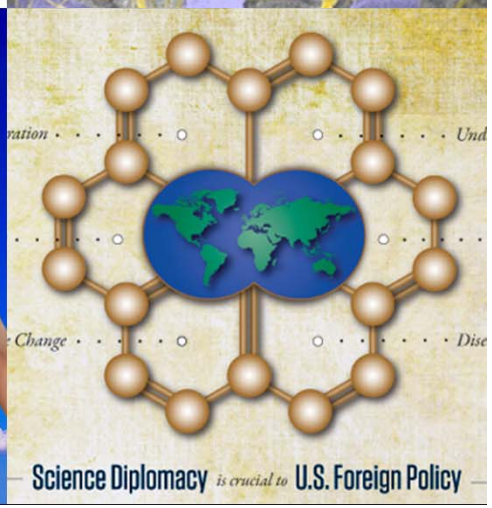


Broader Impacts

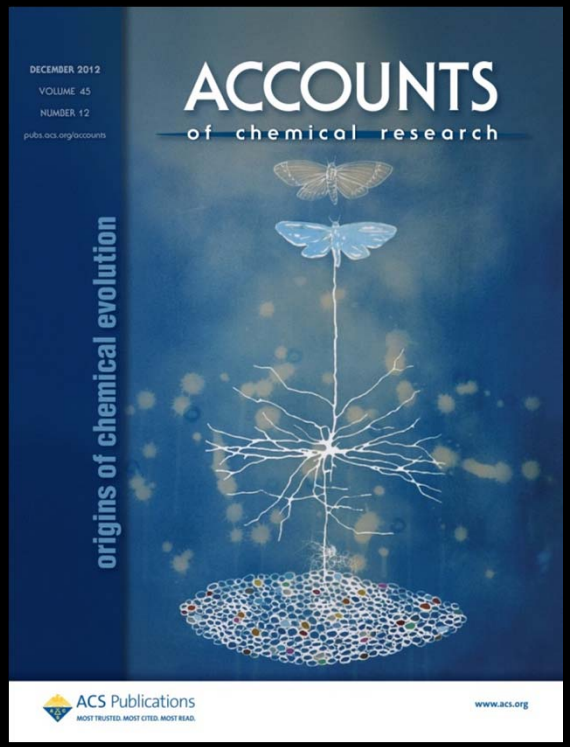
- Searching for life on exoplanets
- Big data
- Inanimate/living interface
- International collaborations
- Broadening participation in STEM
- Citizen science & materials discovery







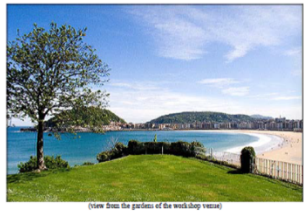
Outreach



Cost Action CM 1304 Meeting

EMERGENCE AND EVOLUTION OF COMPLEX CHEMICAL SYSTEMS

(SYSCHEM2014)



(view from the gardens of the workshop venue)

SAN SEBASTIAN – DONOSTIA, 9th-12th June, 2014

Local Organizers:
Kepa Ruiz-Mirazo (Chair) & Sara Murillo

cost
European Cooperation in Science and Technology

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LATEST NEWS

STEVE JURVETSON/FLICKR

Scientists have found life on Earth in extreme environments like this Yellowstone hot spring, but alien life might be more elusive.

'Shadow biosphere' might be hiding strange life right under our noses

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Email Emily

By Emily Conover | 14 February 2015 12:45 pm | 92 Comments

SAN JOSE, CALIFORNIA—If we came across alien life, would we even know it was alive? That was a central question posed at a session here yesterday at the annual meeting of AAAS (which publishes *Science*). All known life on Earth fits a particular mold, but life from other planets might break free from that mold, making it difficult for us to identify. We could even be oblivious to unfamiliar forms of life right under our noses.

Acknowledgements

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Kathy Covert

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Alternative Chemistries Workshop & Report

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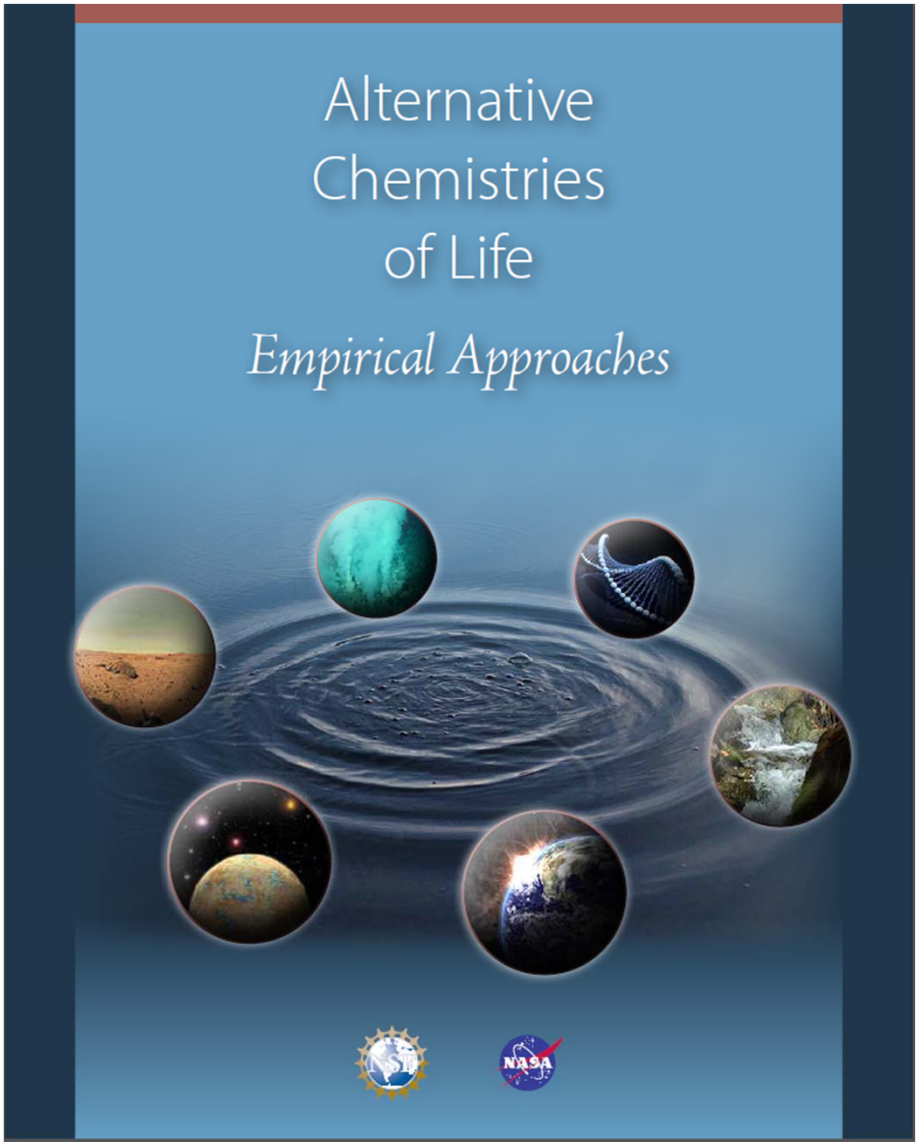
alternativechemistries.emory.edu



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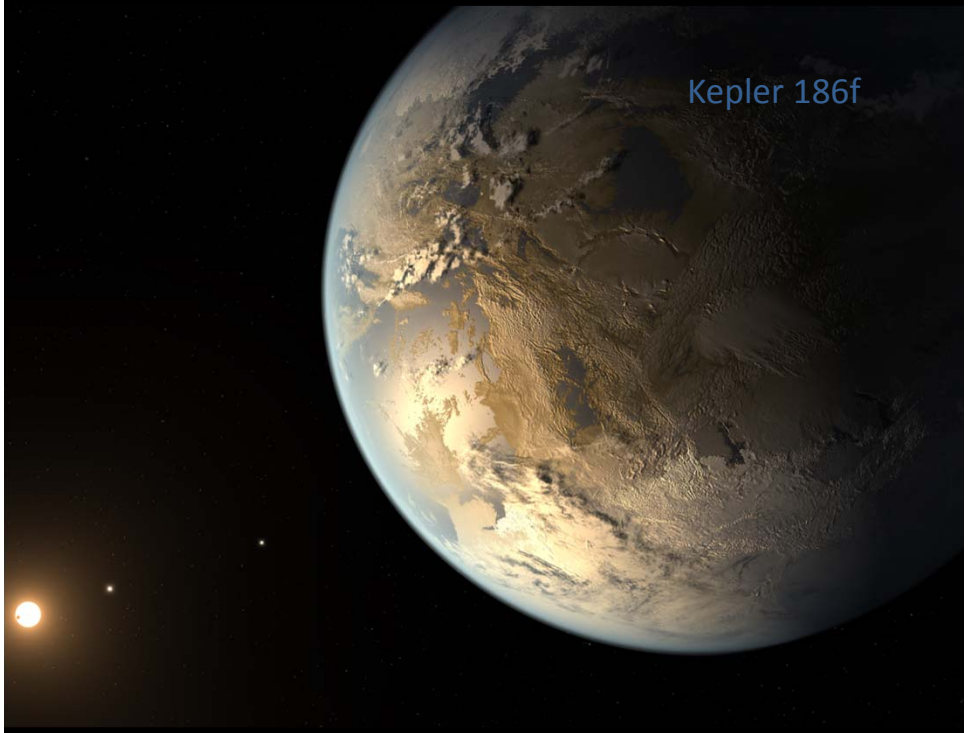

"The universe is a pretty big place. If it's just us, seems like an awful waste of space."

Carl Sagan