Seeking extraterrestrials

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Why the excitement?

Many things are "ripe"

Opportunities to:

- **Find a second example of life**
- **Test basic theories for life**

Teaching the excitement

- **Teach how science really works**

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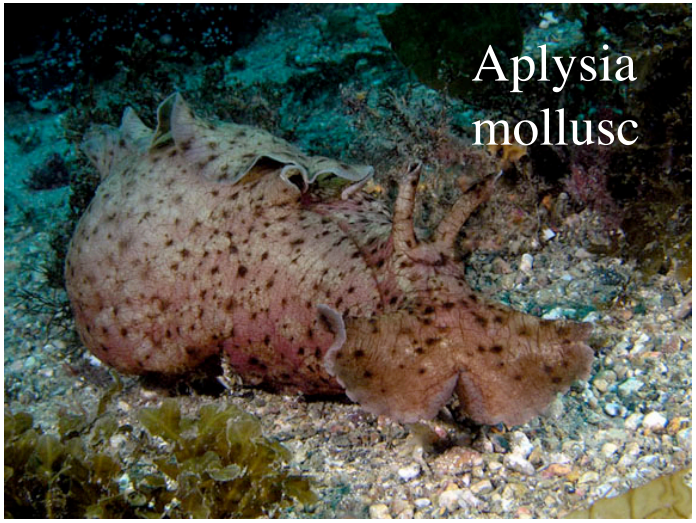
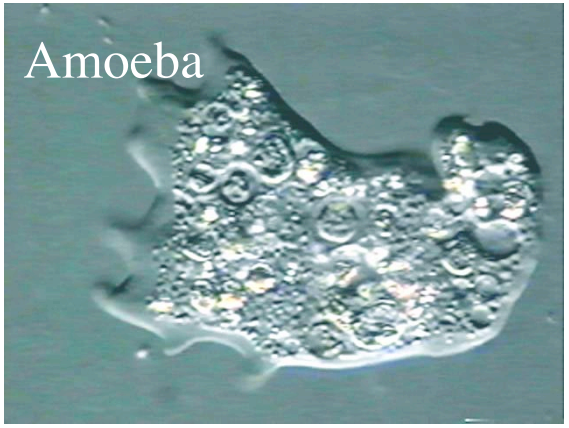
A second example of life???

Don't we already have millions of examples?





The closer you look,
the more similar all terran life seems

10^{0} 10^{-2} 10^{-4} 10^{-6} 10^{-8}

Powers of Ten; Charles and Ray Eams
http://microcosm.web.cern.ch/microcosm/P10/english/welcome.html

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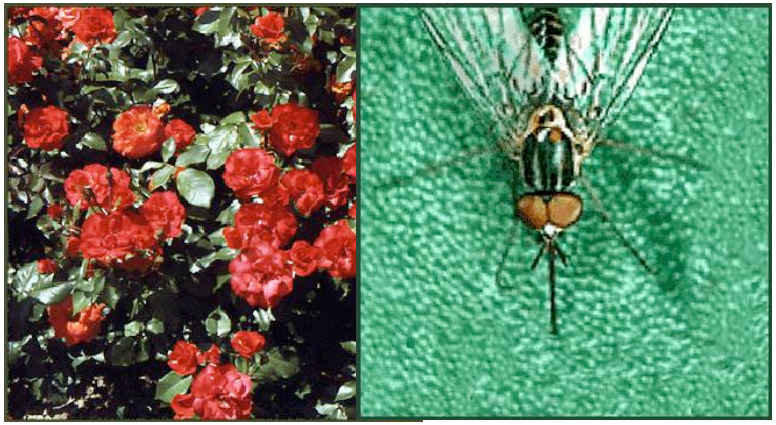

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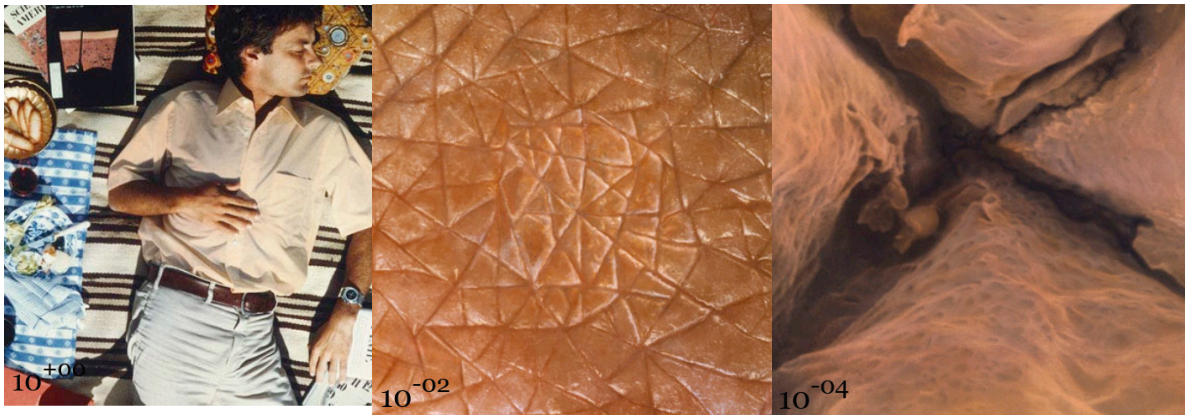

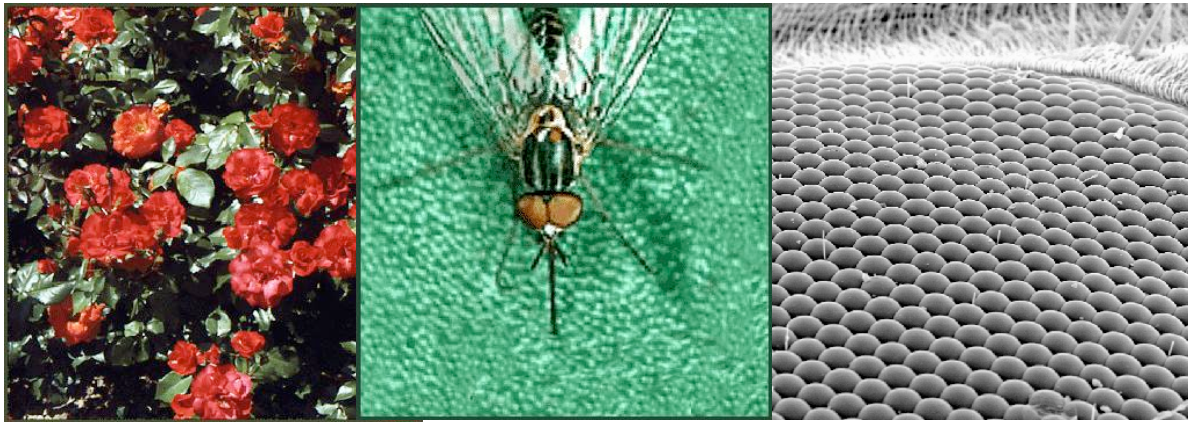

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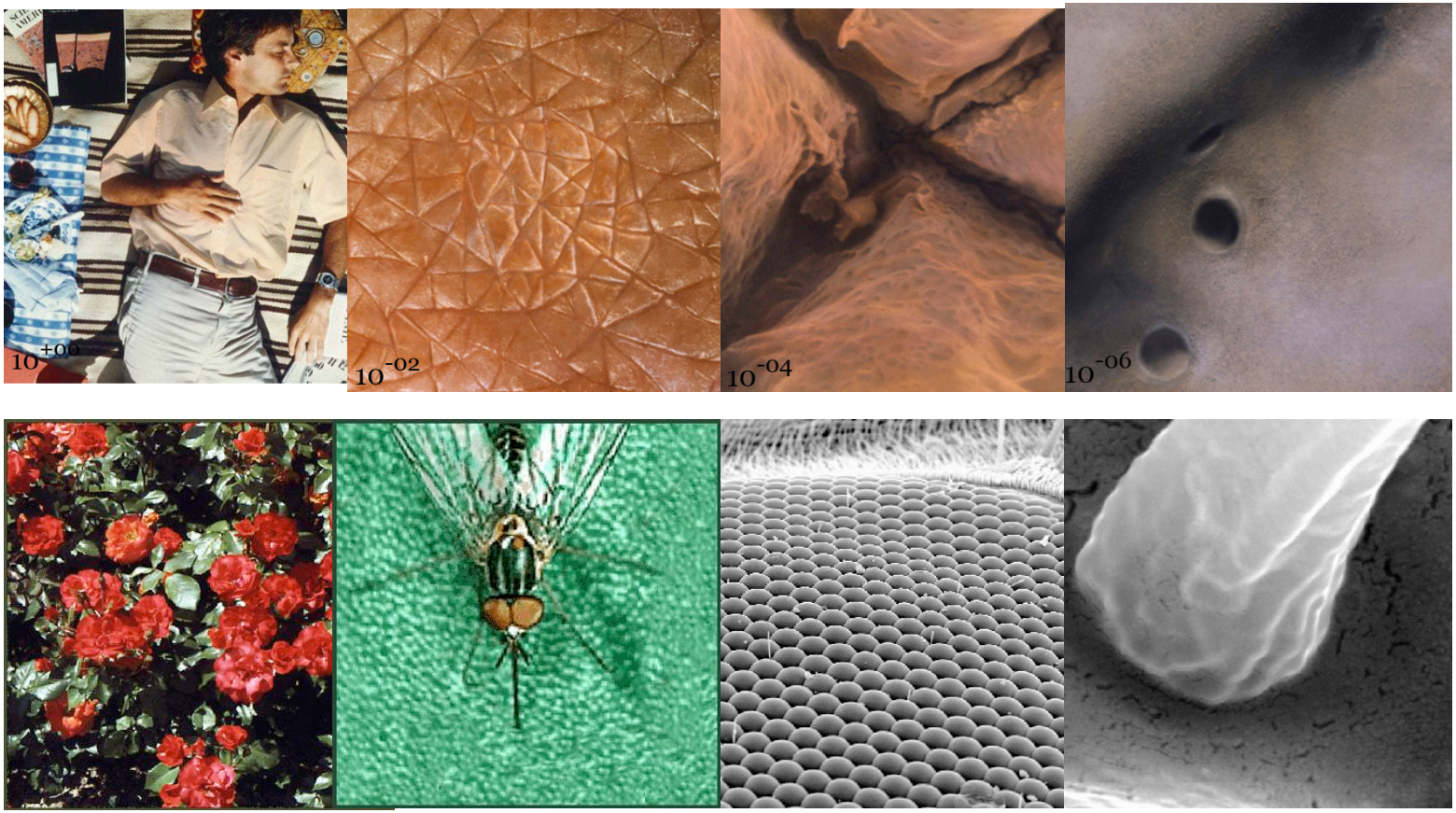

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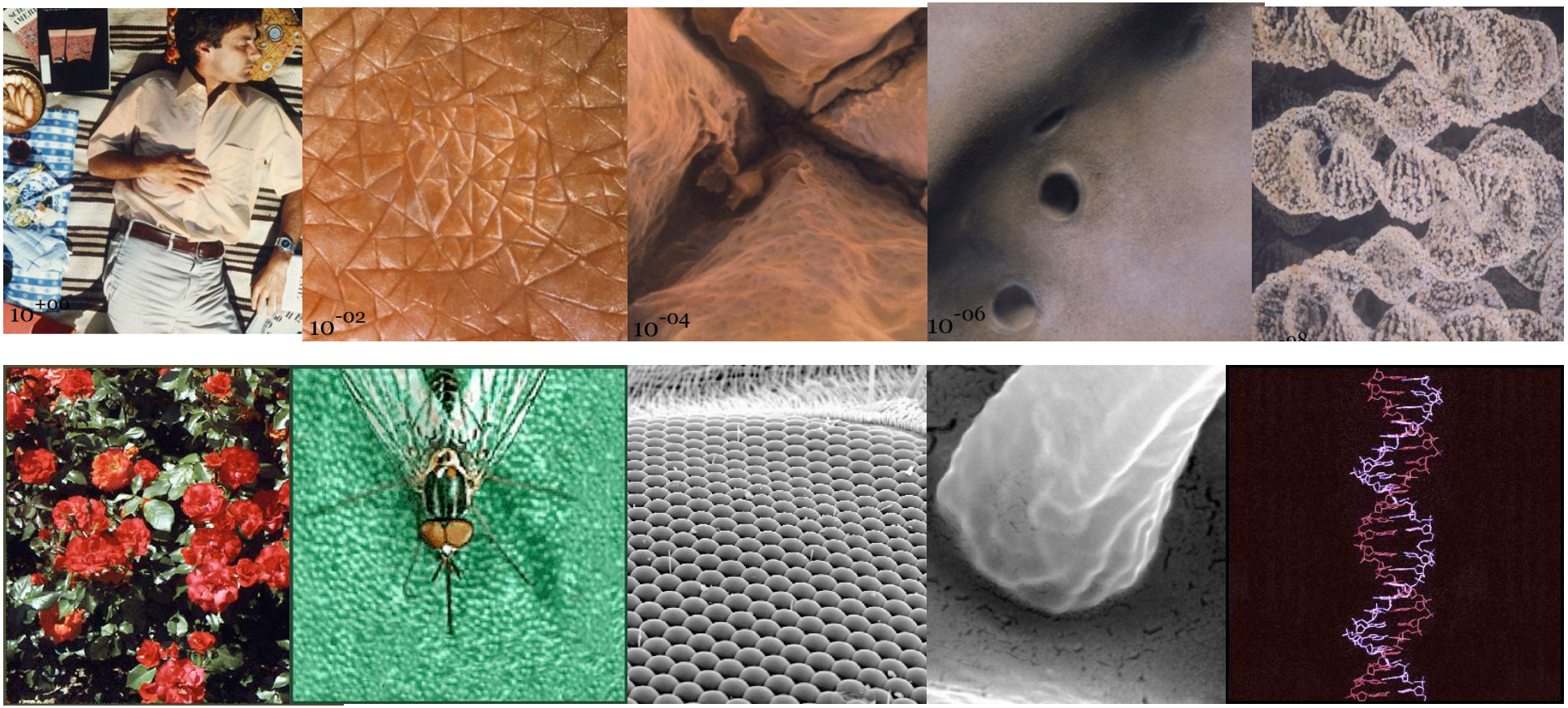

Powers of Ten; Charles and Ray Eams

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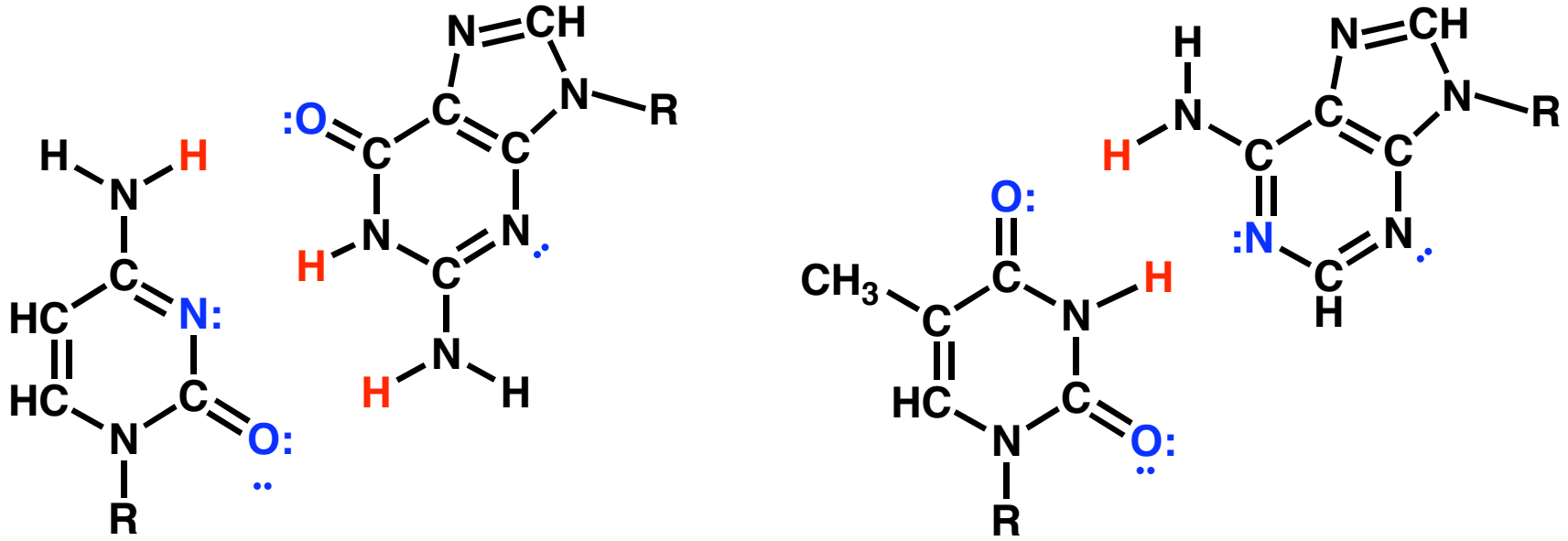
At the molecular level

terran life is pretty much all the same

cytosine **guanine** **thymine** **aminoadenine**

C **G** **T** **A**



The four nucleobases of DNA are shared by all terran life.

You are nourished by other terran life

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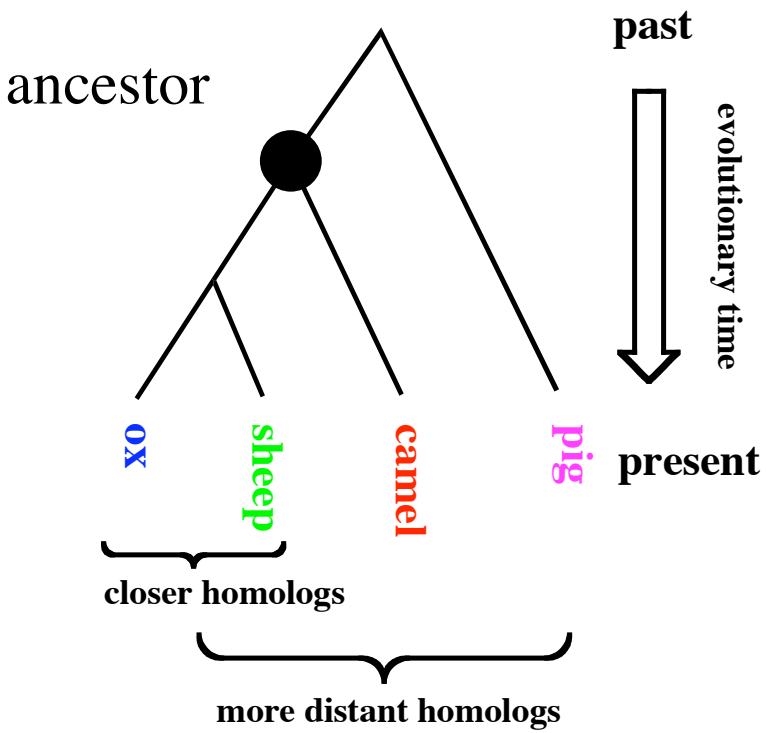
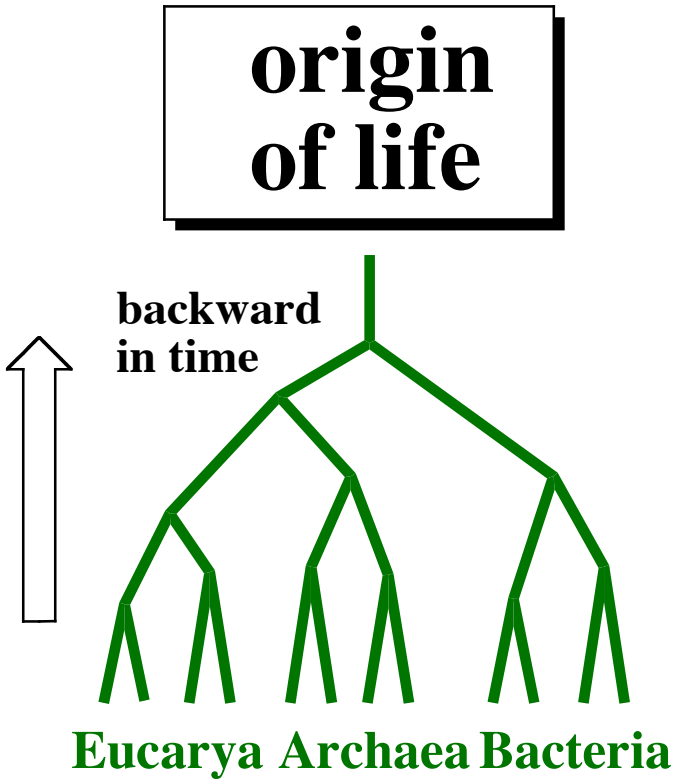
Because of this, can build a historical model for all terran life

```
ox          KETAAAKFERQHMDSSTSAA
            ||  |||||||||||||||  |
sheep       KESAAAKFERQHMDSSTSSA
camel       SETAAEKFERQHMDSYSSSS
Ancestor    KETAAAKFERQHMDSSTSSA
pig         KDTAAEKFERQHMDSGTPSA
```





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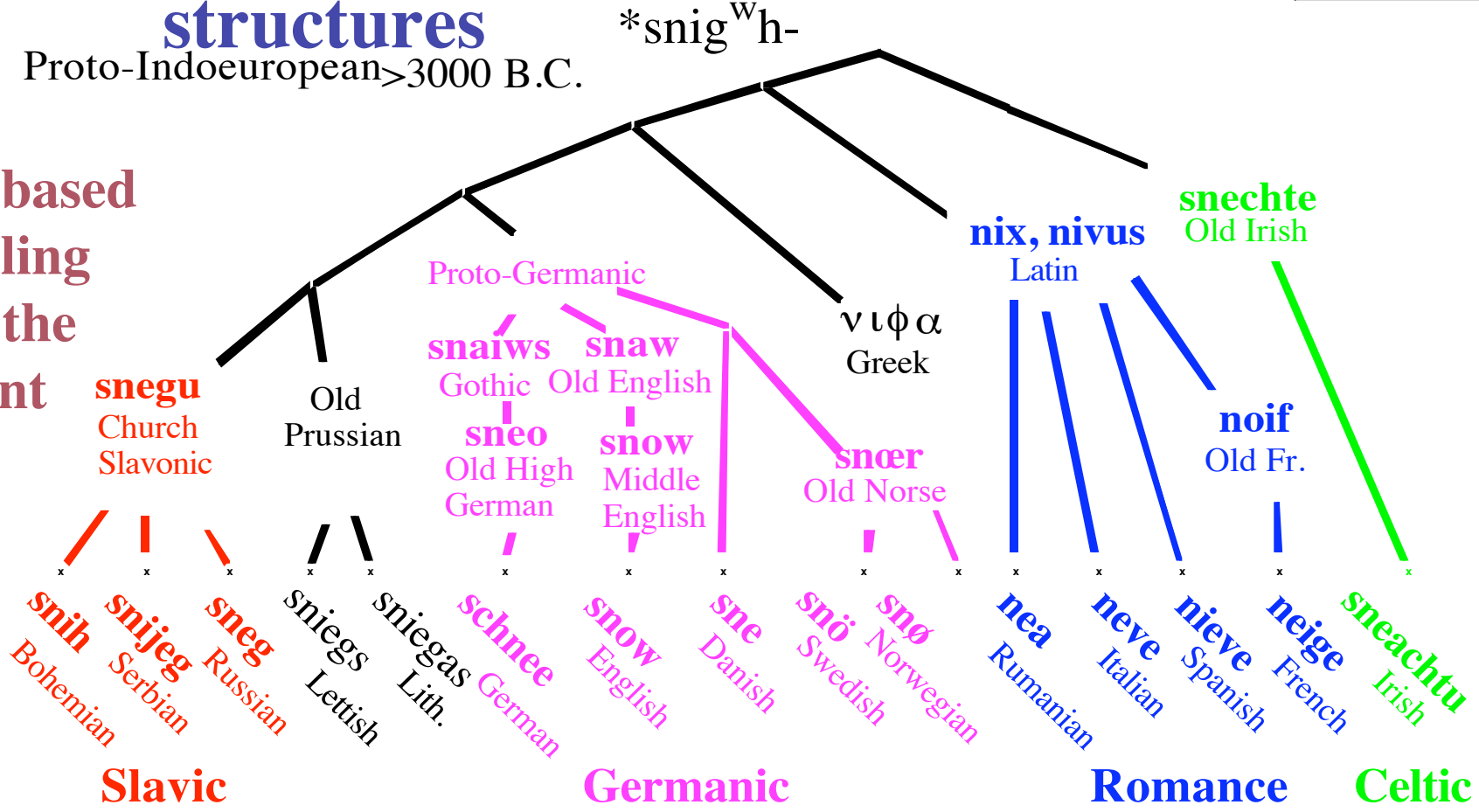
How we infer ancestral structures



Reconstruction says something about Proto-Indoeuropeans. ***They lived in a cold climate.*** No gold or silver. But they had dogs (*kwón-), horses (*ék^{w}o-), sheep (*^{H3}éwi-), ox (*g^{w}ów-), pigs (*su^{H}-), grain (*yewo), and vehicles (*wogho-) with wheels (*k^{w}ek^{w}lo-); They count to 100 (*kmtóm).

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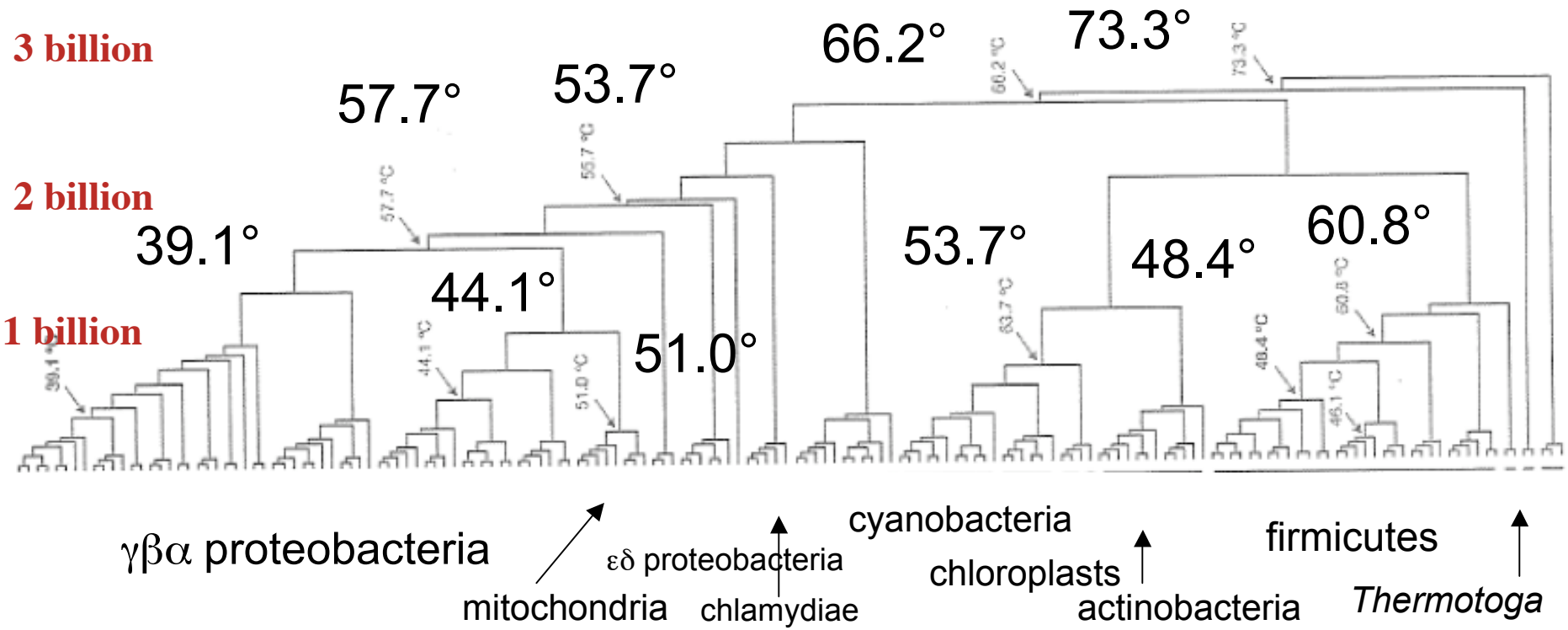
We *resurrect* parts of ancient life

Paleogenetics, a new field telling us about past life



Gaucher, E. A. et al. (2003) Inferring the paleoenvironment of ancient bacteria. *Nature* **425**, 285-288

Gaucher, E. A. et al. (2008) Paleotemperature trend for Precambrian life. *Nature* **451**, 704.

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Three billion year old genes and proteins in our hands

Now *that* is exciting

This is possible *only* because the life on Earth shares common ancestry

But is this the *only* kind of life

So it is difficult to develop a theory about life as "a universal" by examining the terran biosphere

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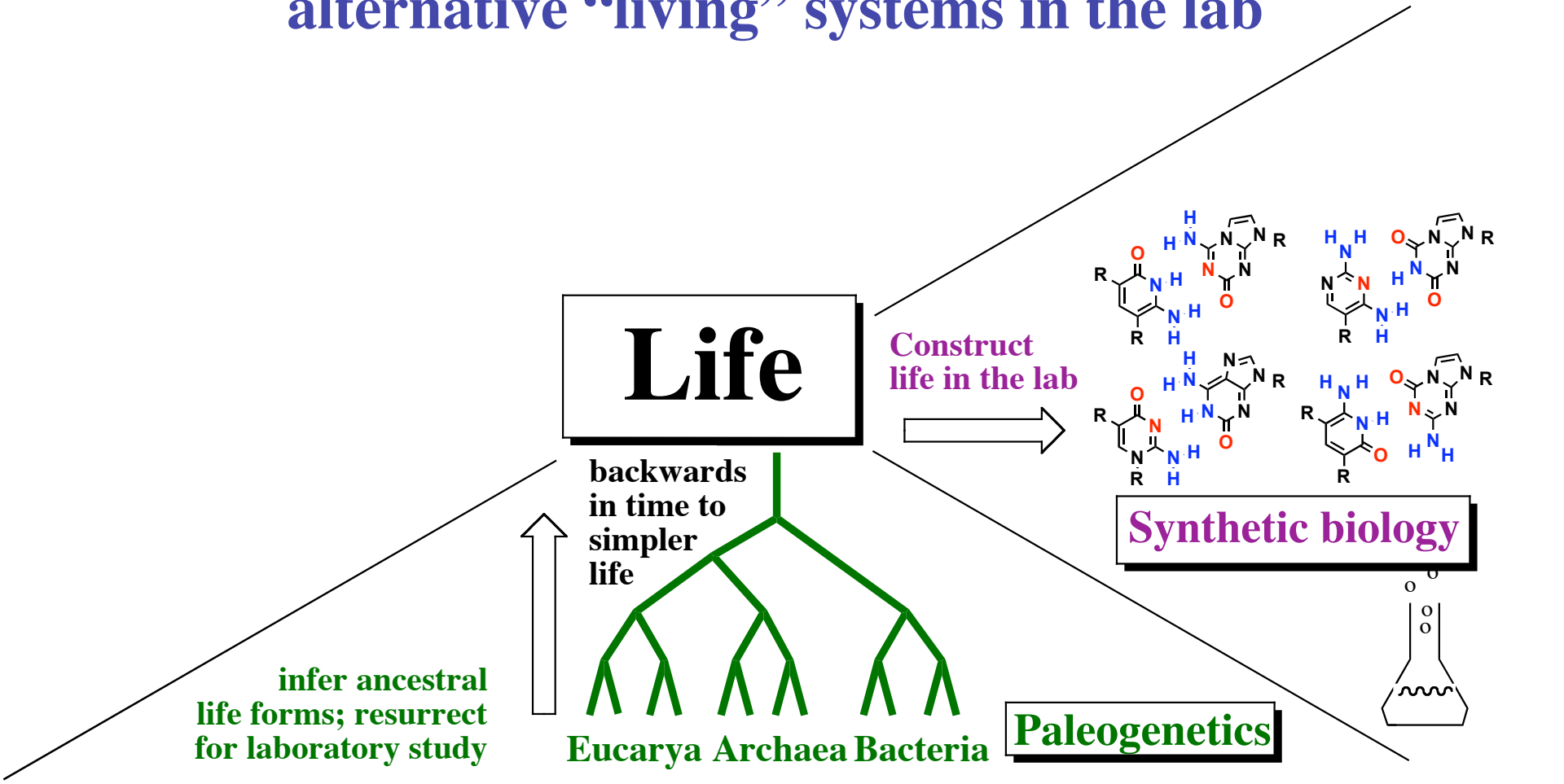
As chemists, we can try to explore possible life forms by making alternative "living" systems in the lab



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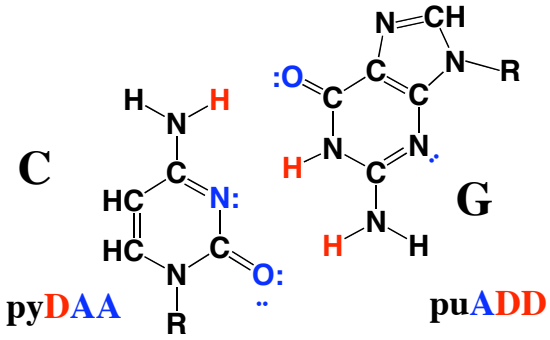
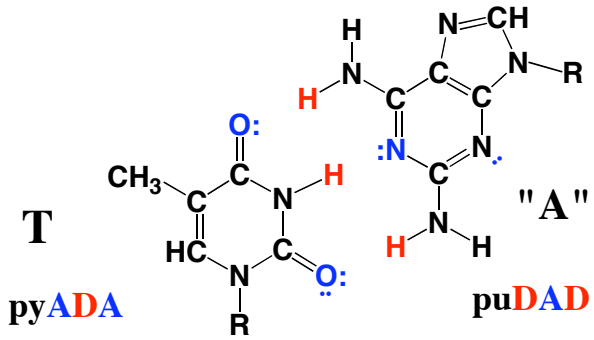
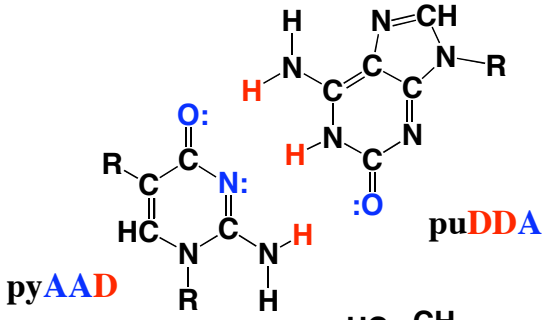
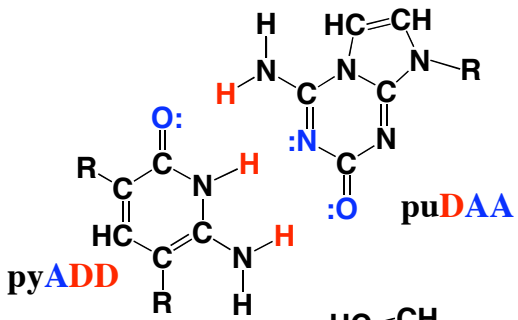
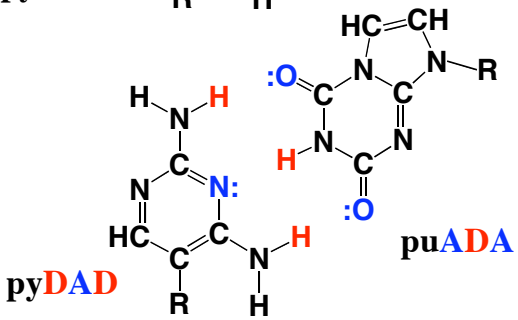
Synthetic biology has created in the lab a *different* genetic system capable of Darwinian evolution with 12 letters

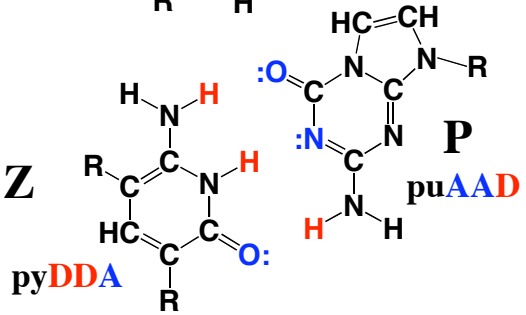












Yang *et al.* (2010) *Angew. Chem.* **49**, 177-180

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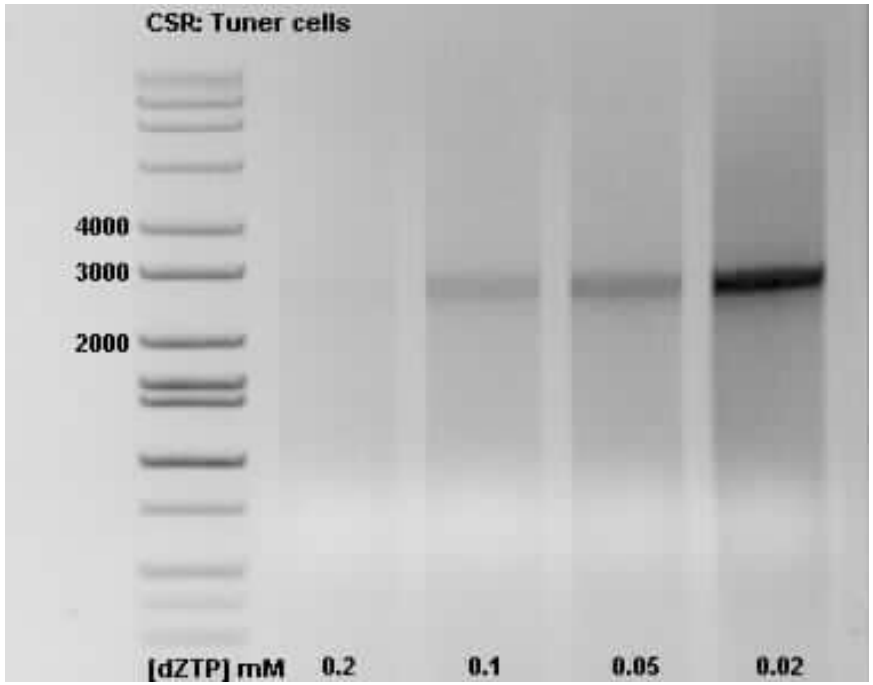
Weird synthetic life in the laboratory



***This* is exciting**

13'th generation GACTZP children

Terran biochemistry *need not* be universal

Look for aliens with weird DNA?
But are there *any* universals?

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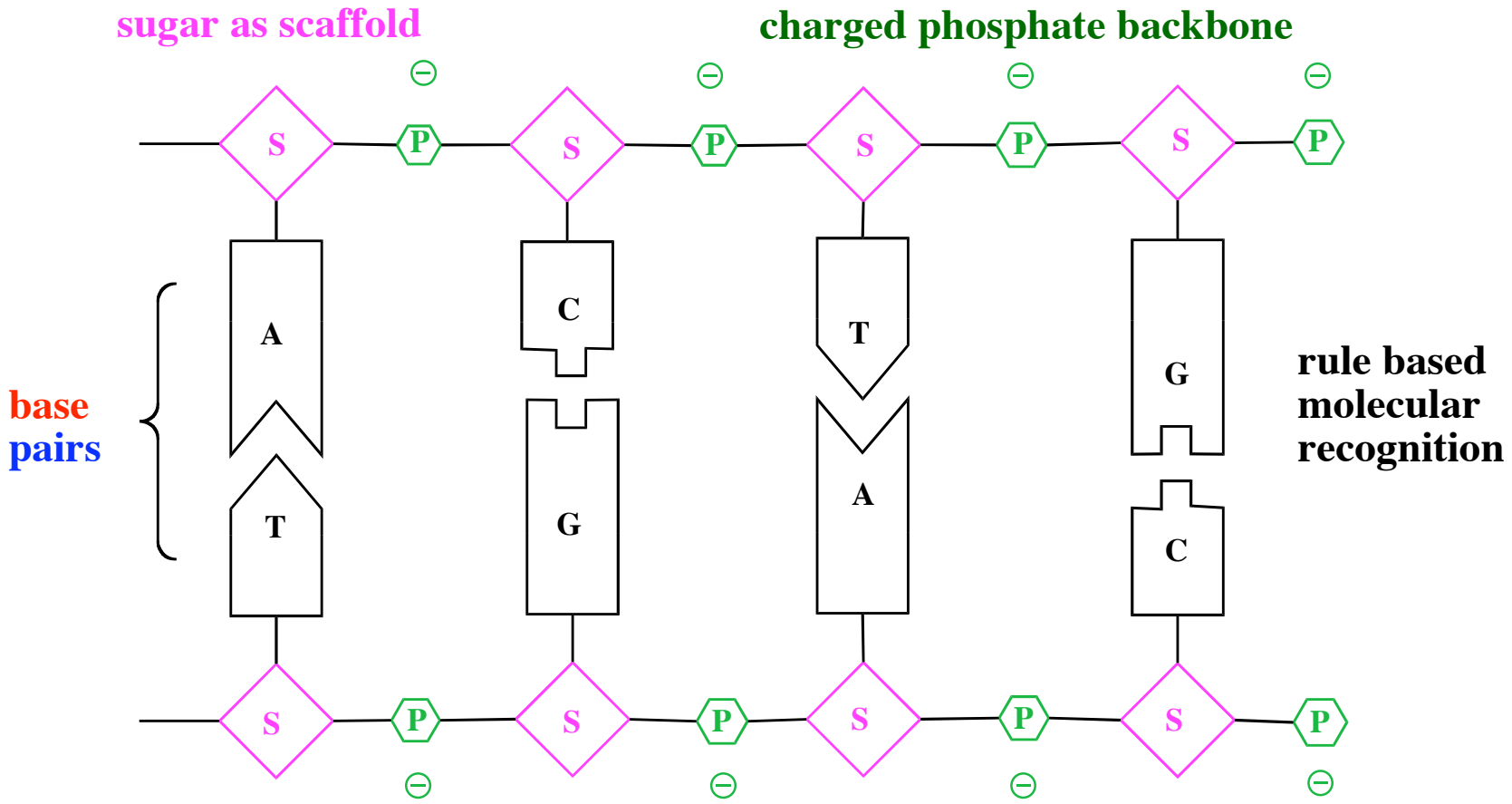
Attempts to remove backbone charge fails



Repeating charge in a genetic molecule is *universal in water* & easy to look for

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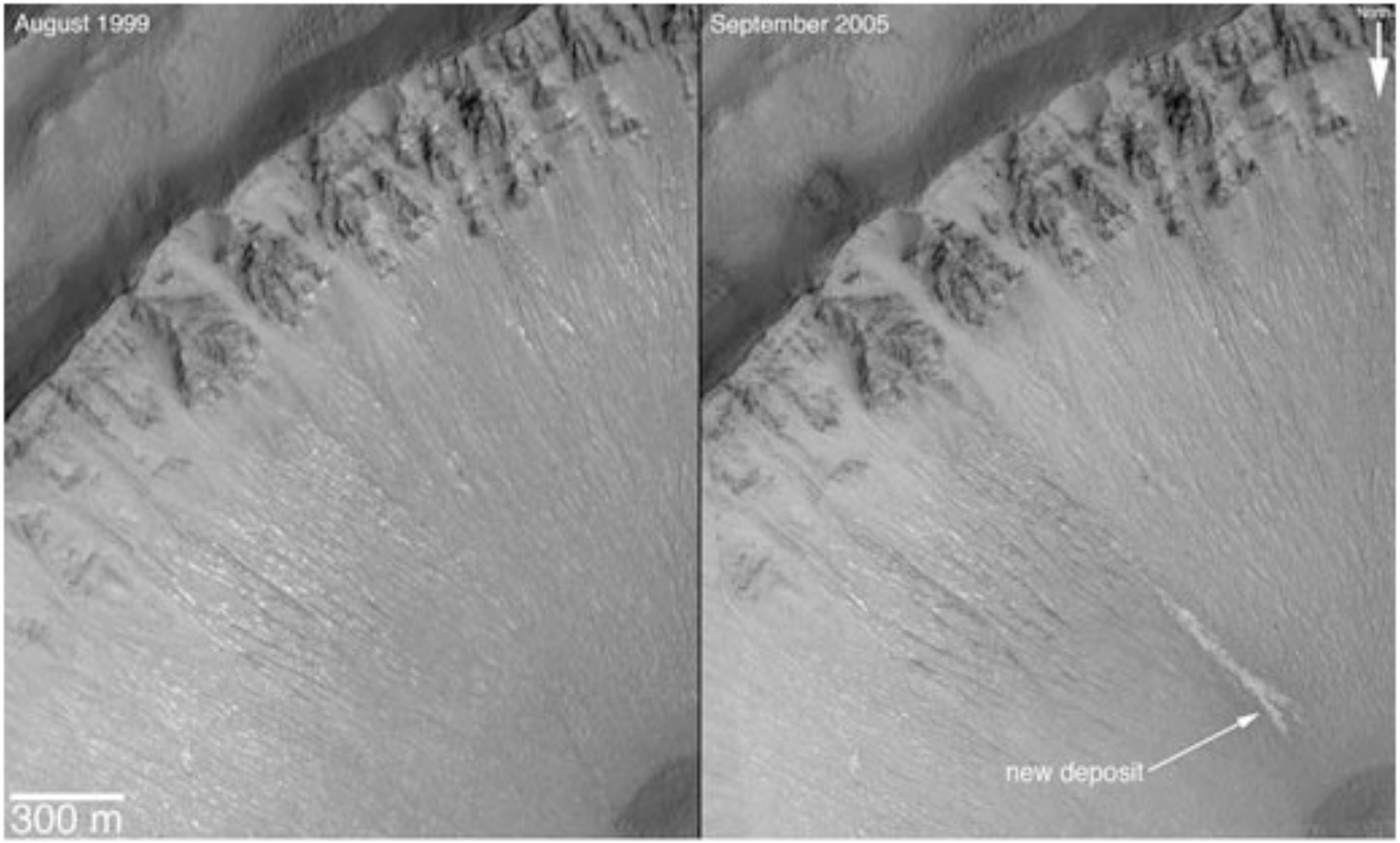
Mars had (has) water

New Gully Deposit in a Crater in the Centauri Montes Region 12.06.06



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Mars is no longer so hostile

An example of how science really works

- In 1976, scientists studying life from the Viking lander concluded that the Martian surface was highly oxidizing, "self-sterilizing".
- By 1999, it was clear that the experiments done by Viking could have overlooked a significant class of organic materials.
- By 2009, the surface was found to be slightly alkaline and modestly oxidizing, but not outside the range tolerable by conceivable life.
- And evidence continues to emerge for the past presence of surface liquid water, and possibly even the recent past presence.

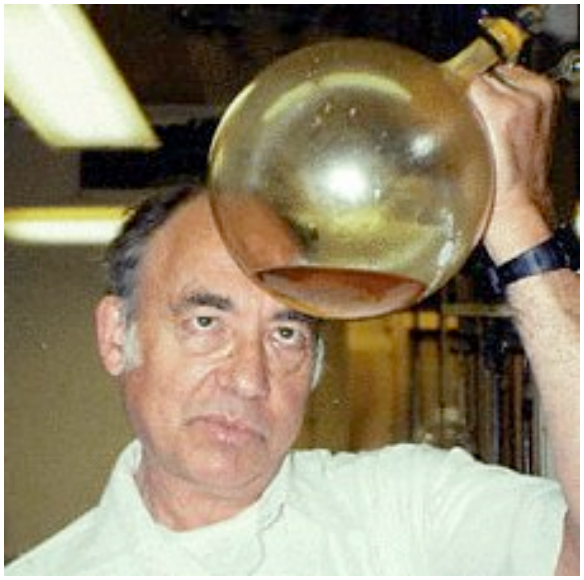
A way to look. A universal theory for the structure of the gene to guide our looking. A not-so-hostile place to look (Mars). And the technology adequate for us to look.

We are now talking about probabilities

NASA

The paradox of origins

On Earth, given liquid water, organic matter given energy decomposes to give "tar".



Stanley Miller

On Earth, given liquid water, Darwinian evolution exploits energy to give the chemical order called life.

Future Stanley Miller

How does one make the leap from "chemistry" to "Darwinian chemistry"?

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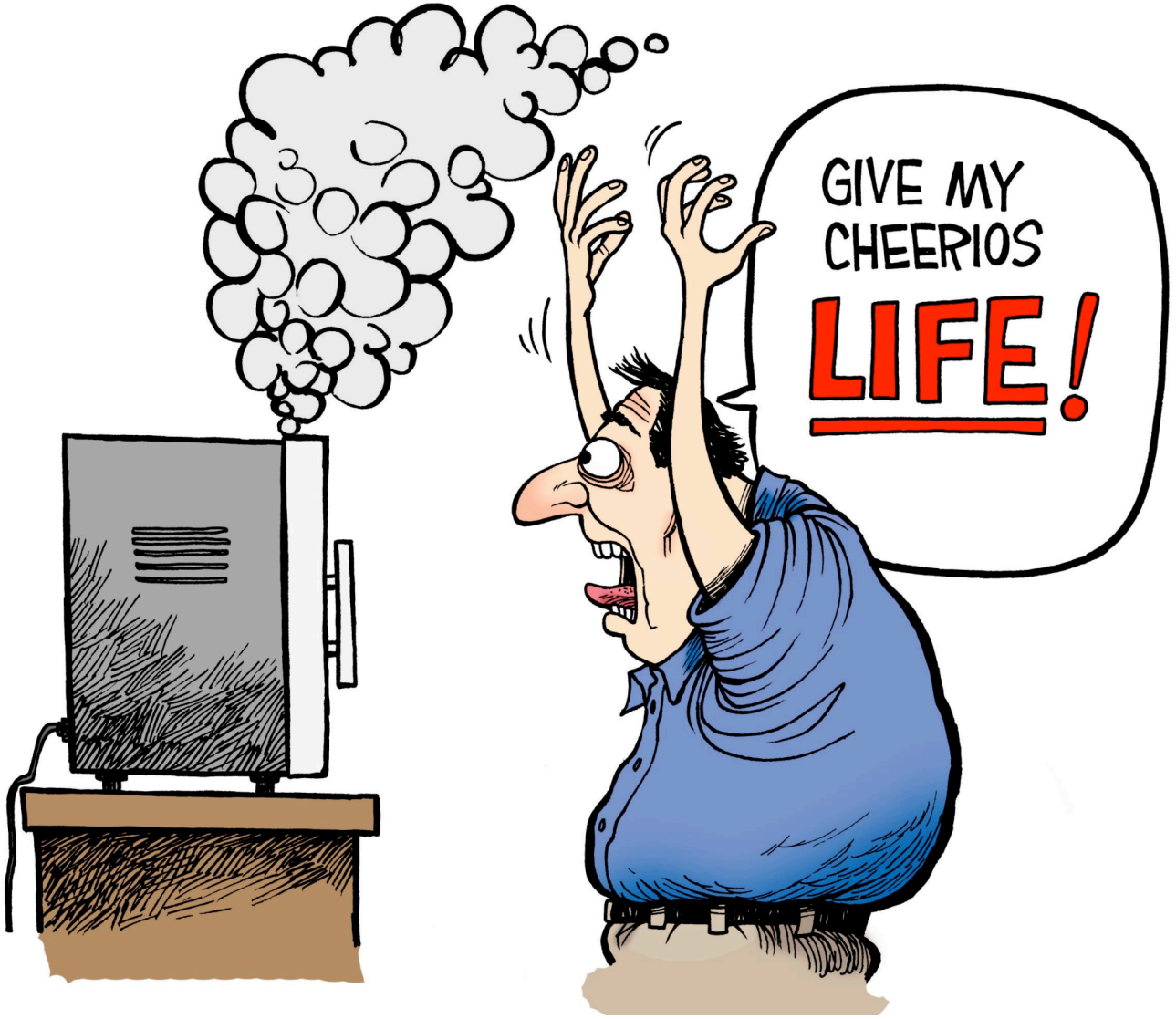
organics + energy = tar (≠ life)

well known in every kitchen



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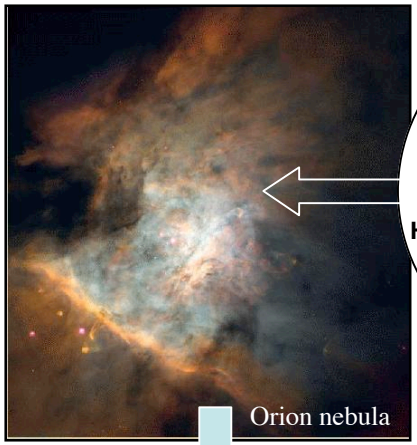
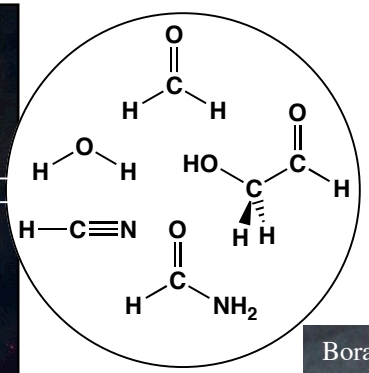
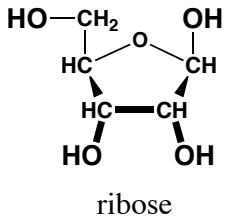
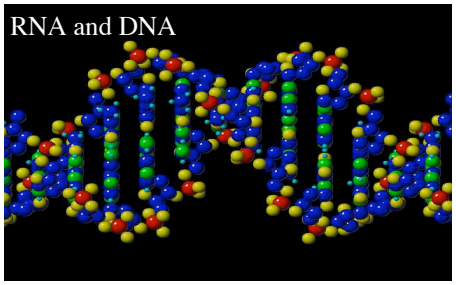
Mineral context may have helped life originate

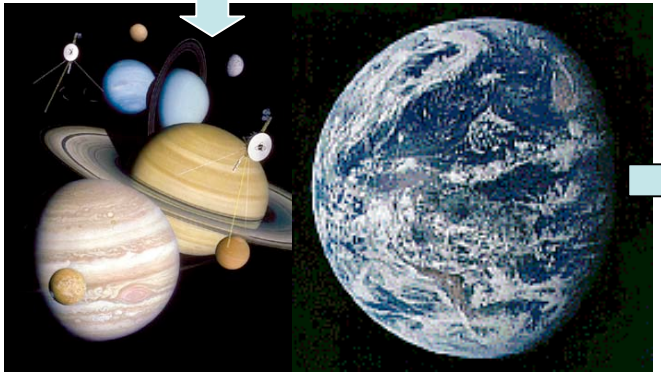


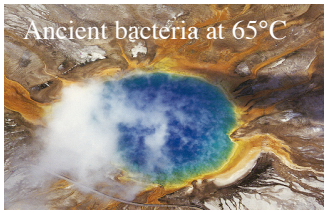




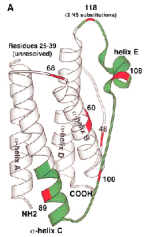
ribose

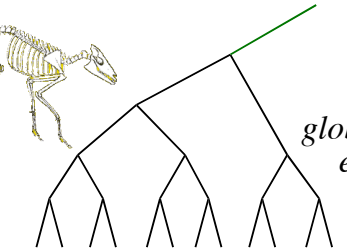






Origin of Life





global trauma
extinctions
climate change
adaptation

Eucarya Archaea Bacteria

But this problem continues be plagued by paradoxes beyond "tar" and complexity

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Water is bad for living things

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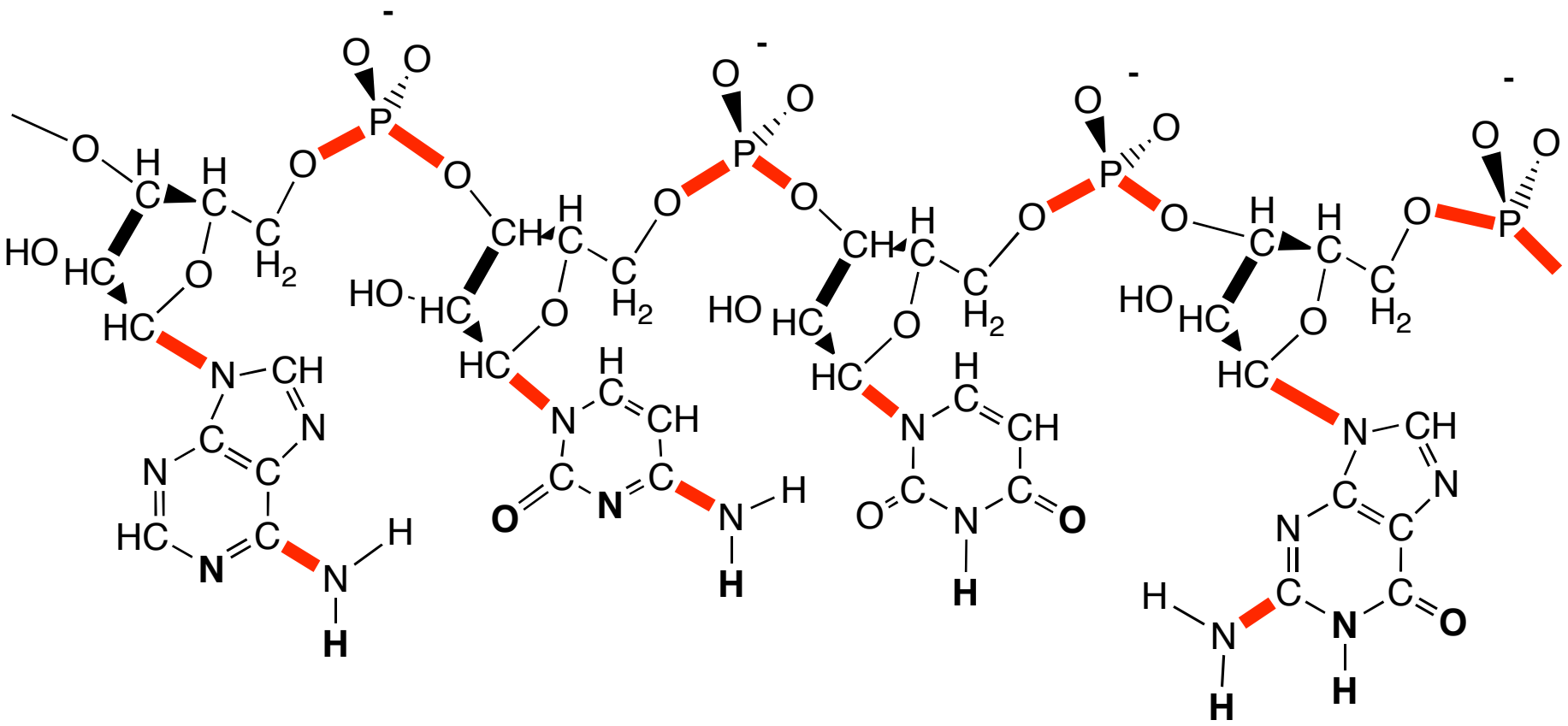
Here is RNA, perhaps the first genetic polymer on Earth



Every bond in red falls apart in water

Origin problem = tar + water + complexity problems

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But is water necessary?

Titan: Oceans of liquid methane at 91 K

Can life exist in this environment?

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The Kaufman Hypothesis

The more complex the environment, the greater the likelihood life emerged within it

- **If complexity is *sufficient* for life, then Titan has life.**
- **If the corrosiveness of water is limiting, then Titan is *more* likely to have life.**
- **But if tar contains inhibitors of life, then complexity is inimical to life.**
- **But if minerals help manage organic complexity, then perhaps life is common on the right kind of planet.**

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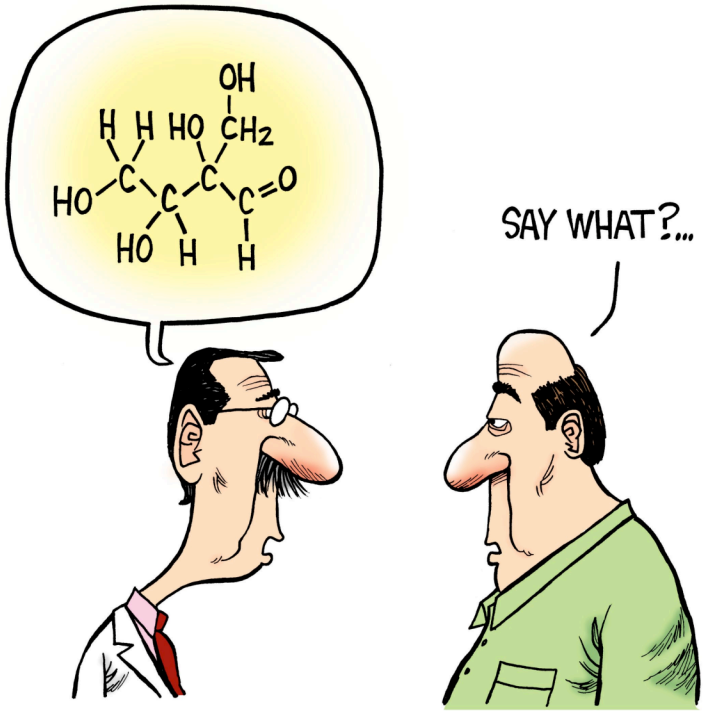
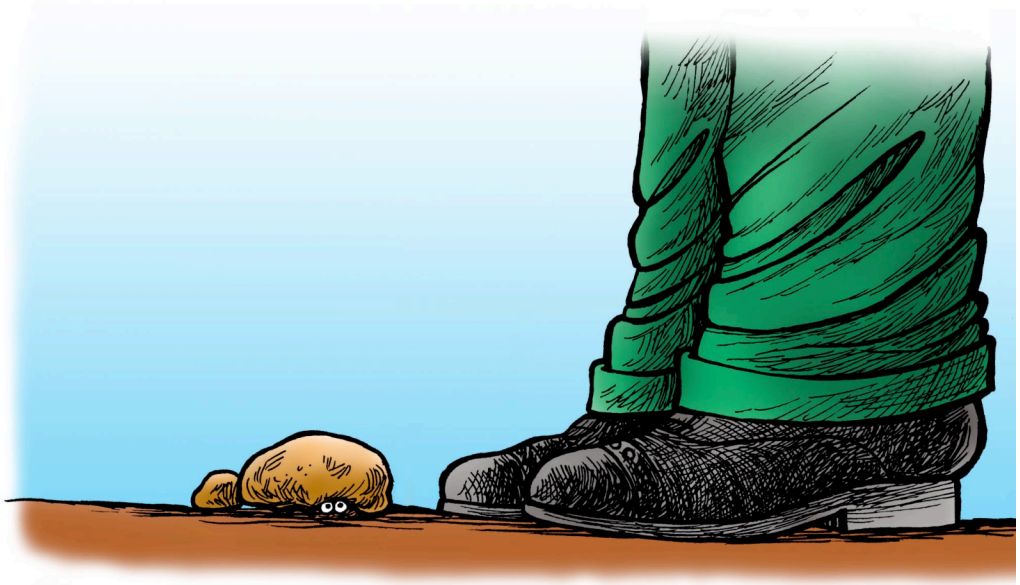
Current generation of problems are easily stated in language of chemistry

The tar problem
The water problem
The complexity problem
The universal genetic molecule
The universal metabolism?



Is weird life beneath our feet?



Don't laugh. It's happened before.

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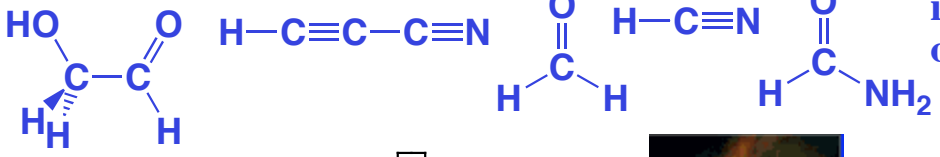
Four ways to look for life

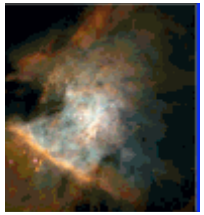
Prebiotic Chemistry



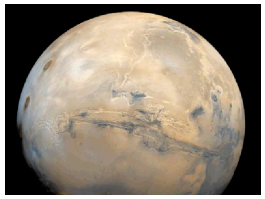
interstellar organics

Ricardo *et al*. (2004) *Science* **303**, 196

forwards from chemistry



Benner (2004) *Acc. Chem. Res.* **37**, 784-797



Search cosmos

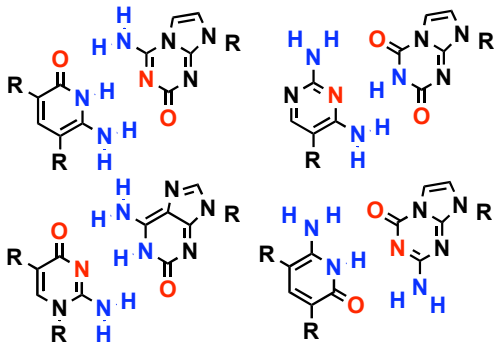
discover alien life

independent genesis?

A path to the simplest first life

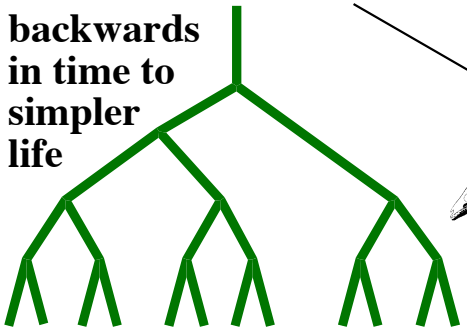
Life

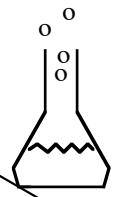
Construct life in the lab



Synthetic biology

backwards in time to simpler life





infer ancestral life forms; resurrect for laboratory study

Eucarya Archaea Bacteria

Paleogenetics

Baross, Benner *et al*. (2007) Natl. Res. Councl. *Limits to Life*

Benner *et al*. (2007) *Adv. Enzymol. Mol. Biol. Protein Evol.* **75**, 1-132

Excitement in each quadrant

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Seeking extraterrestrials

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Why the excitement?

Many things are "ripe"

Teaching the excitement.

National Academies (2008)

Baross, Benner …