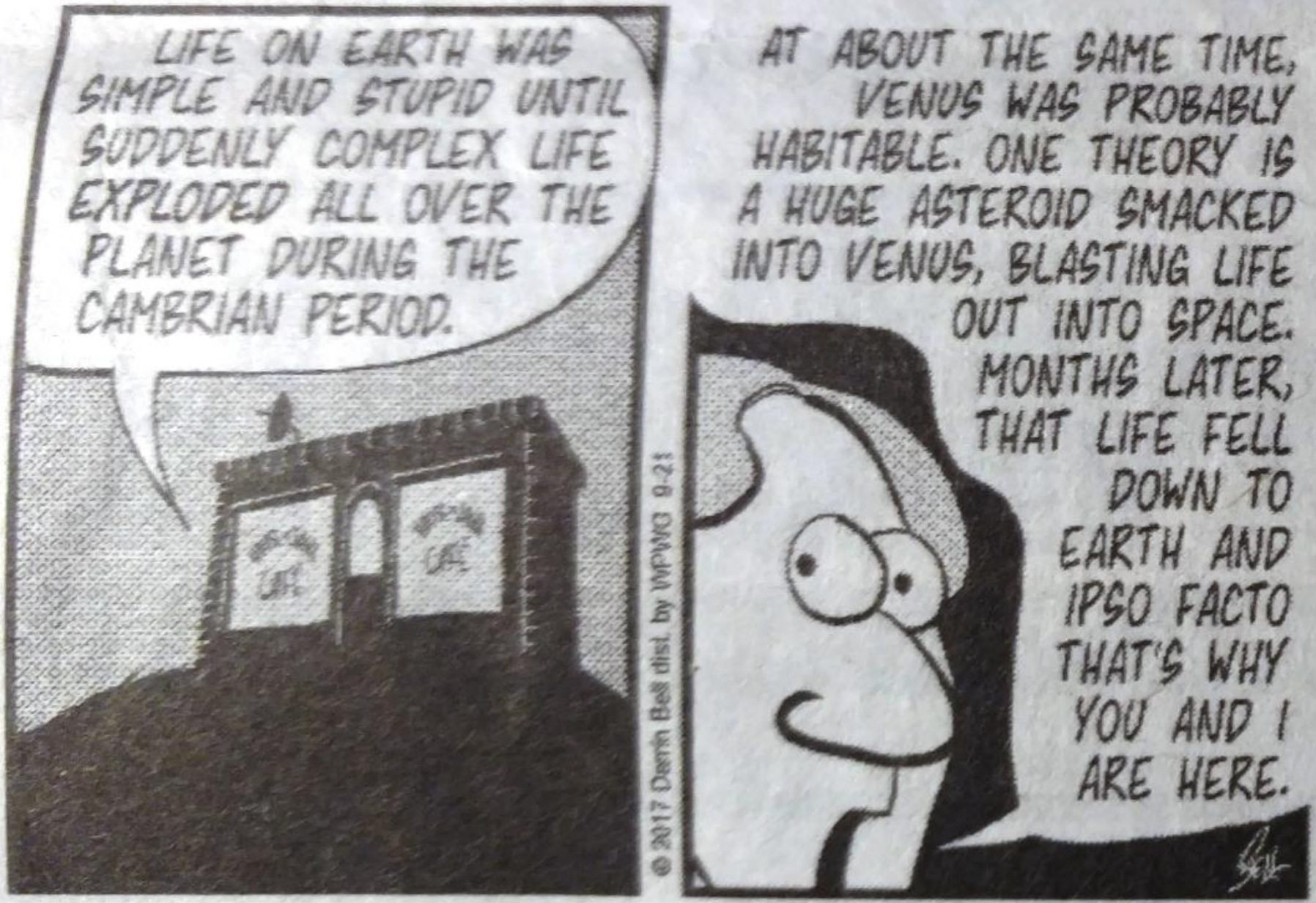
ASTR/GEOL-2040: Search for life in the Universe: Lecture 10

- RNA world & LUCA
- Top-down approach

George Craft's email

RUDY PARK


LIFE ON EARTH WAS SIMPLE AND STUPID UNTIL SUDDENLY COMPLEX LIFE EXPLODED ALL OVER THE PLANET DURING THE CAMBRIAN PERIOD.
AT ABOUT THE SAME TIME, VENUS WAS PROBABLY HABITABLE. ONE THEORY IS A HUGE ASTEROID SMACKED INTO VENUS, BLASTING LIFE OUT INTO SPACE. MONTHS LATER, THAT LIFE FELL DOWN TO EARTH AND IPSO FACTO THAT'S WHY YOU AND I ARE HERE.
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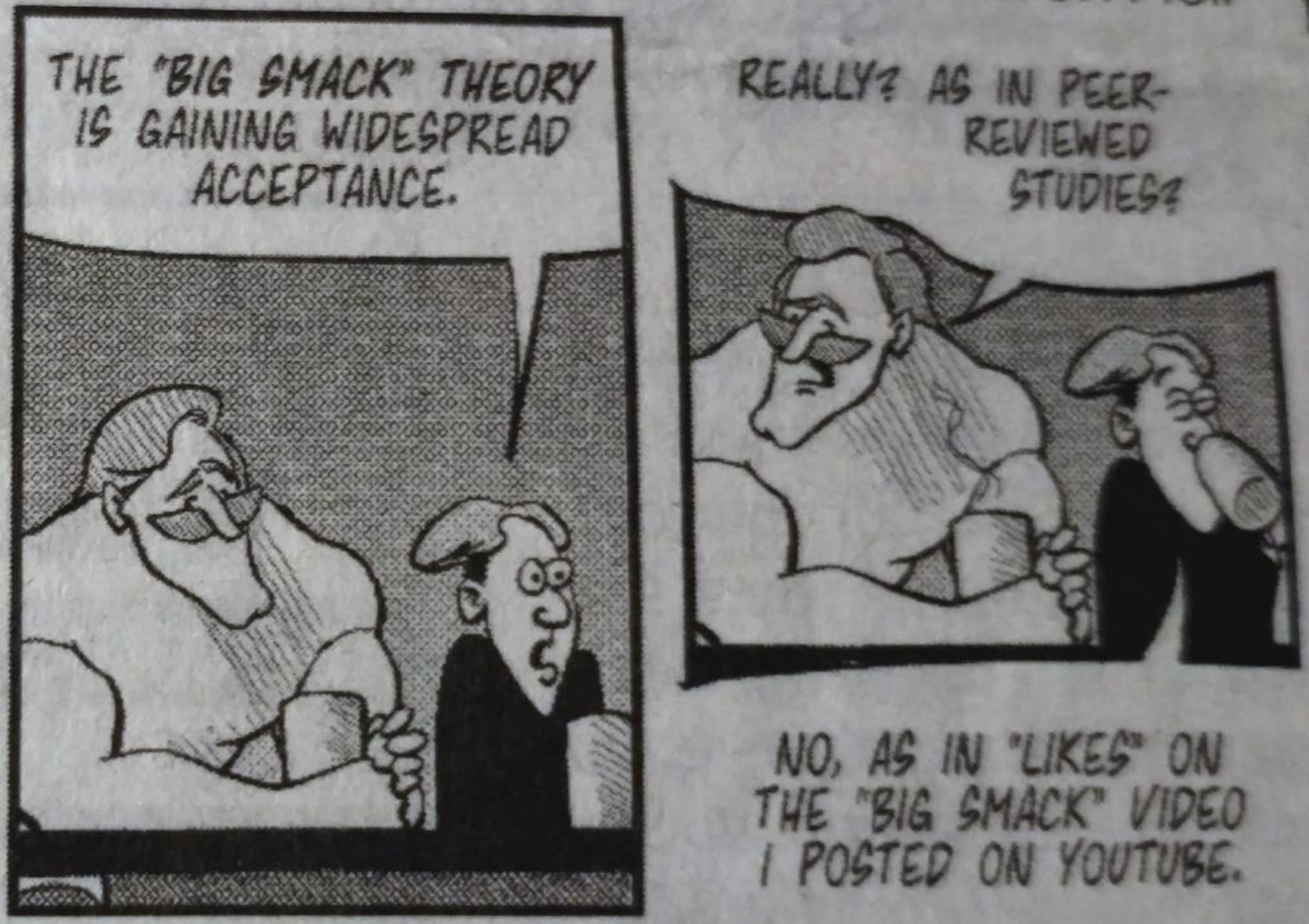
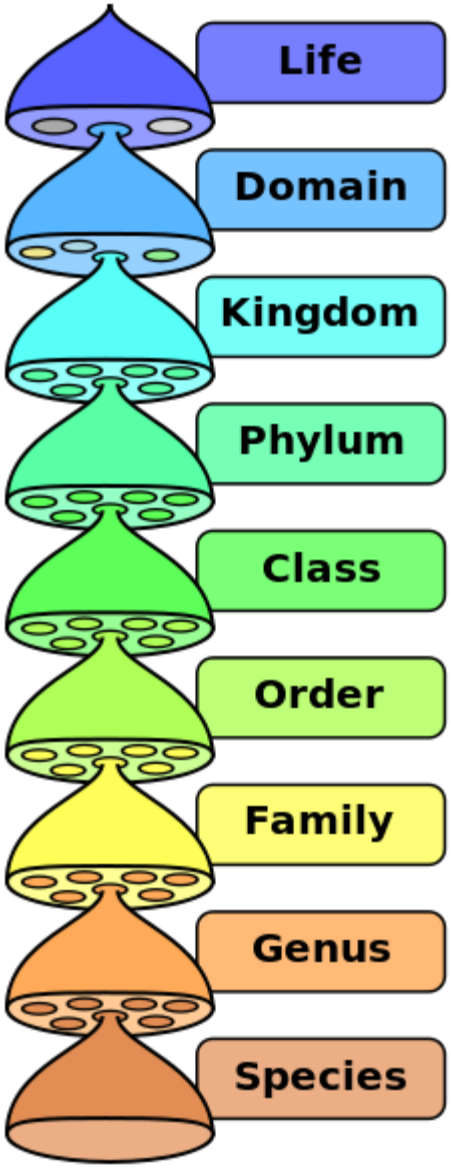
Darrin Bell and Theron Heir



Position in classification scheme



bacteria	
bacteria	
deinococcus-thermus	*proteobacteria*
deinococcales	*enterobacteriales*
deinococcaaceae	*enterobacteriaceae*
deinococcus	*escherichia*
radiodurans	*coli*

Phylogenetic Tree

- Based on physical & genetic differences
  - Taxa: group of populations
- Darwin (1857): the time would come "when we shall have very fairly true genealogical trees of each great kingdom of nature."
  - RGS: life does not reject what evolution has created, but simply builds on what has gone before.

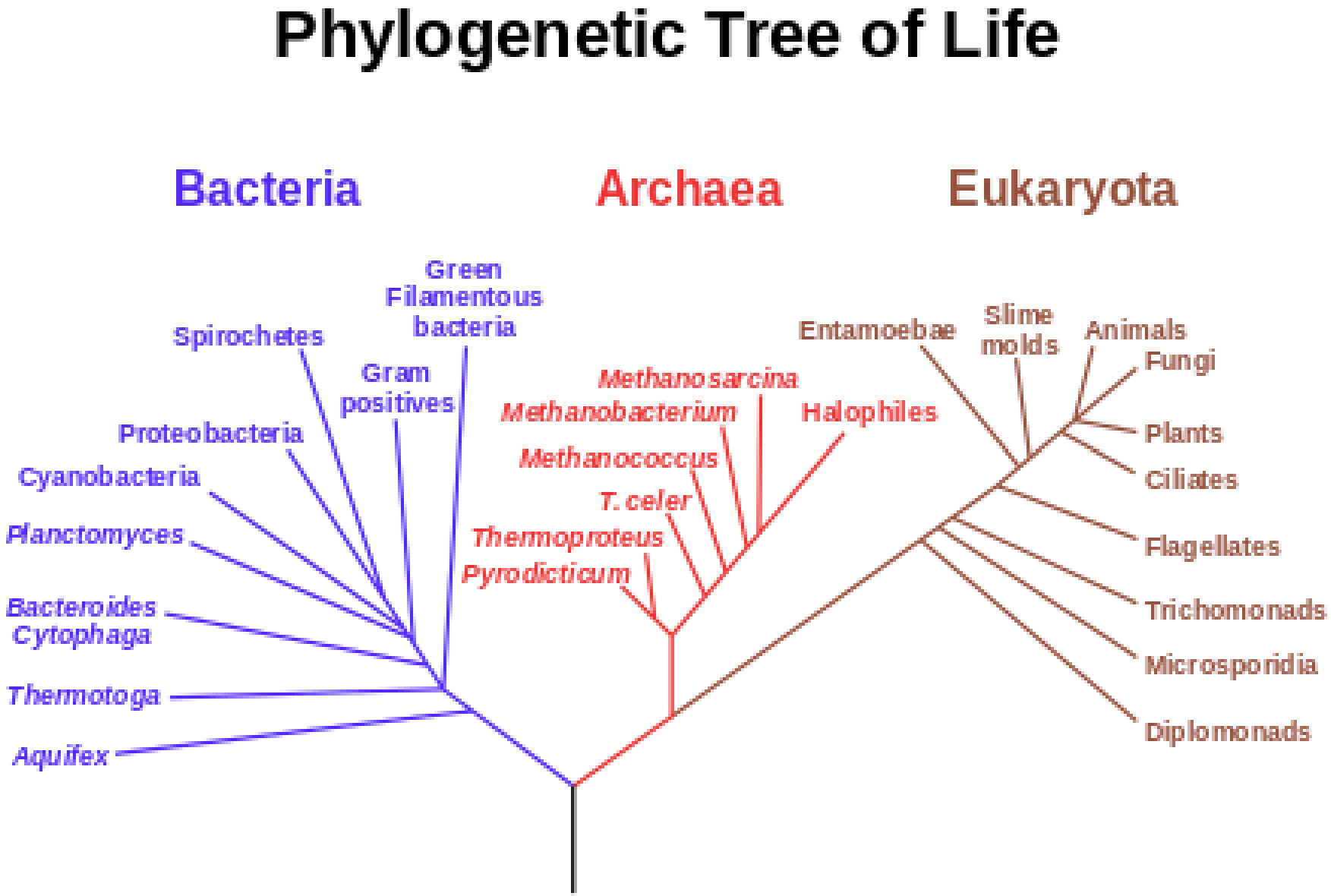
Phylogenetic Tree

- RGS: life does not reject what evolution has created, but simply builds on what has gone before.
  - Biological record of continuous additions/modifications in genetic material
- Tree construction:
  - Similar molecules in different creatures
  - Similar parts inherited from common ancestor

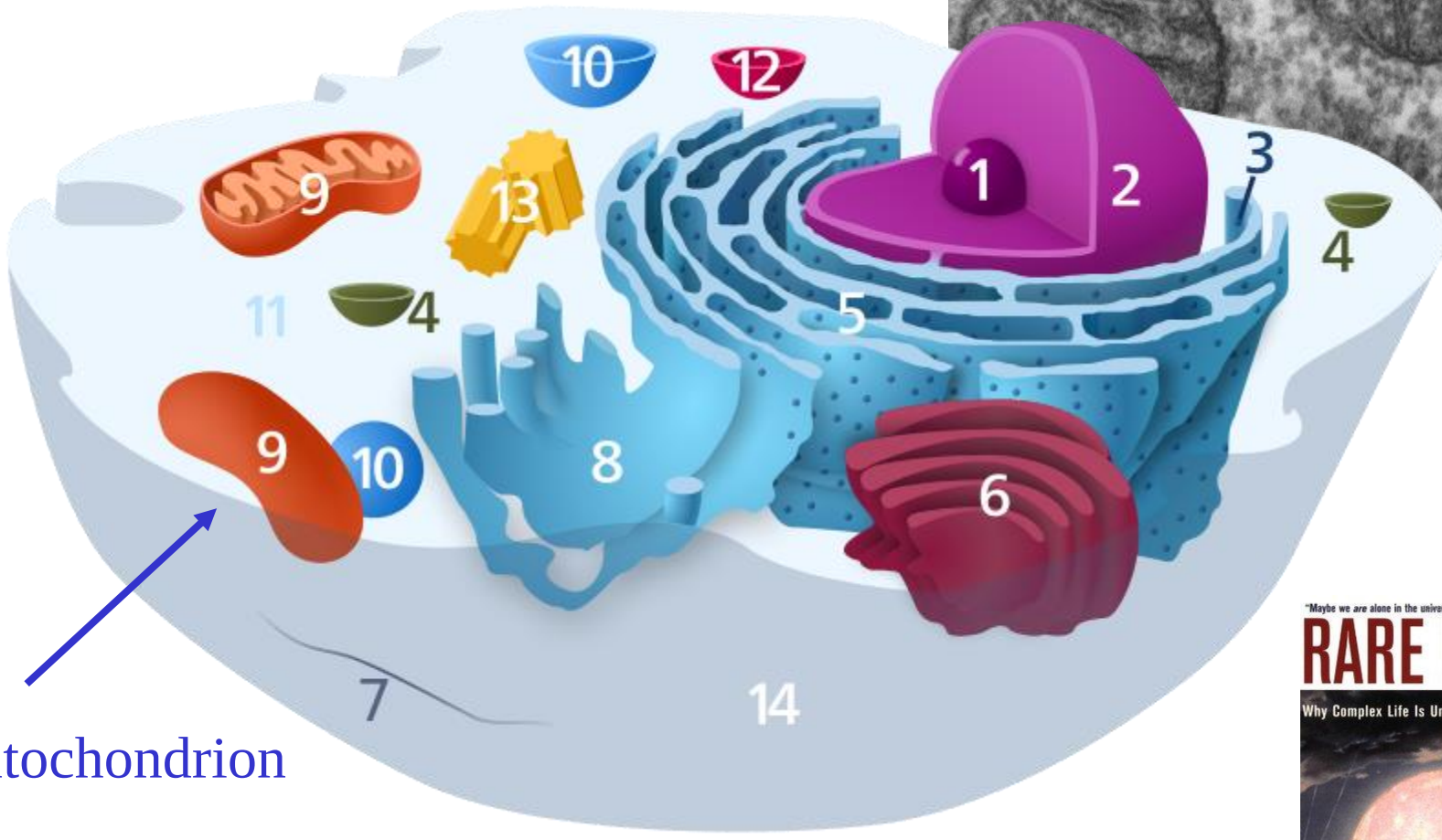
Modern tree building

- Uses ribosomal RNA (rRNA)
  - Branch length = difference in rRNA
- Three clear "domains"
  - Bacteria, archea, eukarya
- Root on tree → LUCA
  - Last universal common ancestor
- Closest to tree: thermophiles, hyperthermophiles
  - Evolution from hot → cold
  - chemotrophs

Rooted Tree


Phylogenetic Tree of Life
Bacteria
Archaea
Eukaryota
Green Filamentous bacteria
Spirochetes
Gram positives
Proteobacteria
Cyanobacteria
Planctomyces
Bacteroides
Cytophaga
Thermotoga
Aquifex
Methanosarcina
Methanobacterium
Halophiles
Methanococcus
T. celer
Thermoproteus
Pyrodicticum
Entamoebae
Slime molds
Animals
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Diplomonads

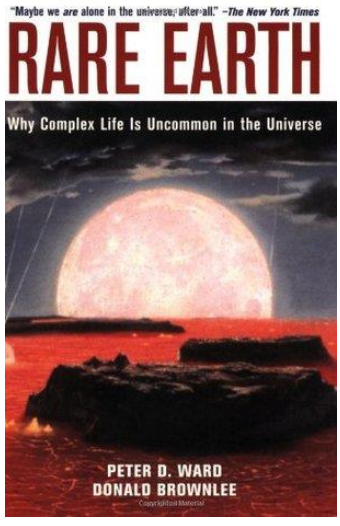
Eucarya



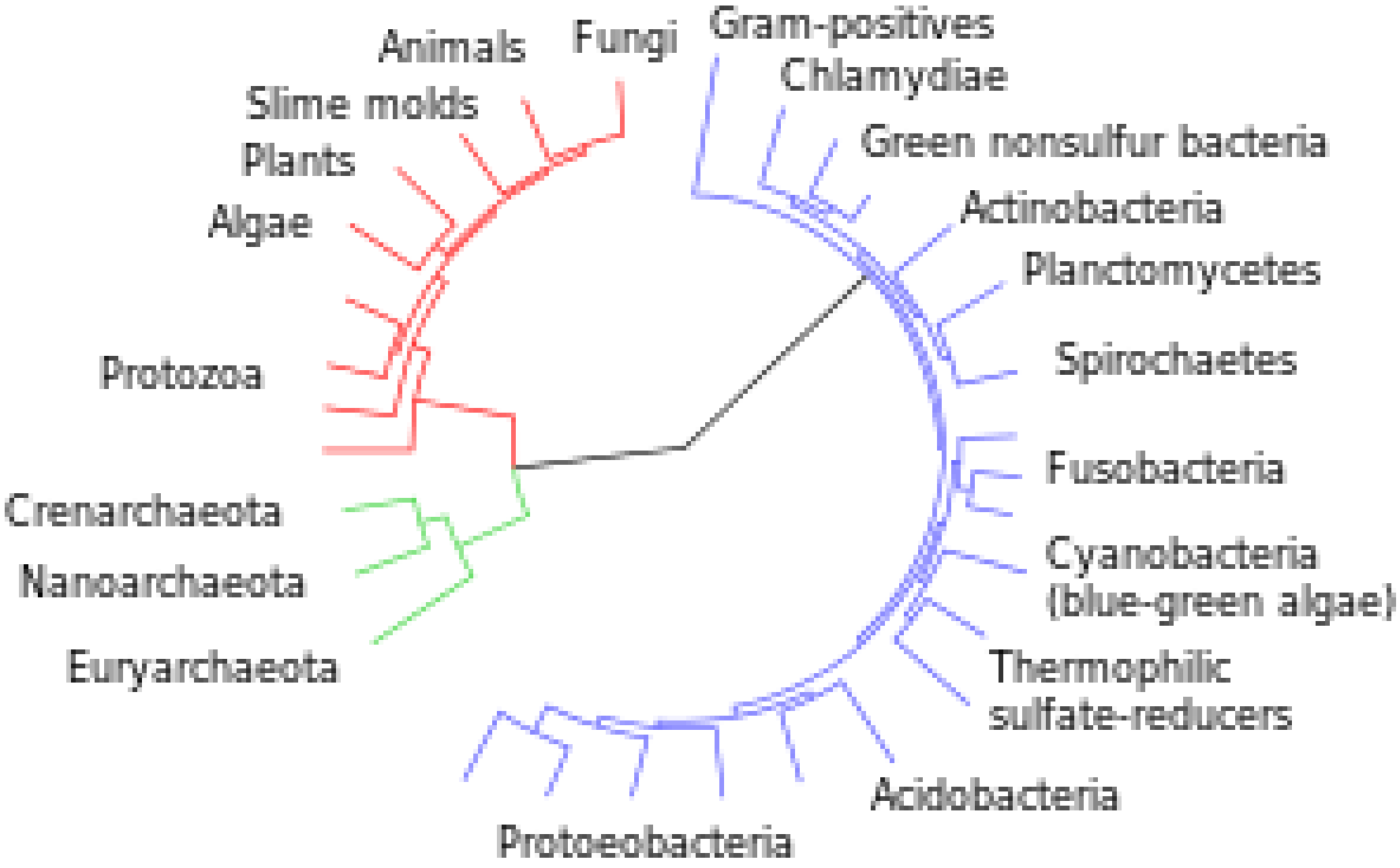
mitochondrion

Cells within cells ("organelles")
Choroplasts is another example

p. 84
Ocean liner
Toy sailing boat

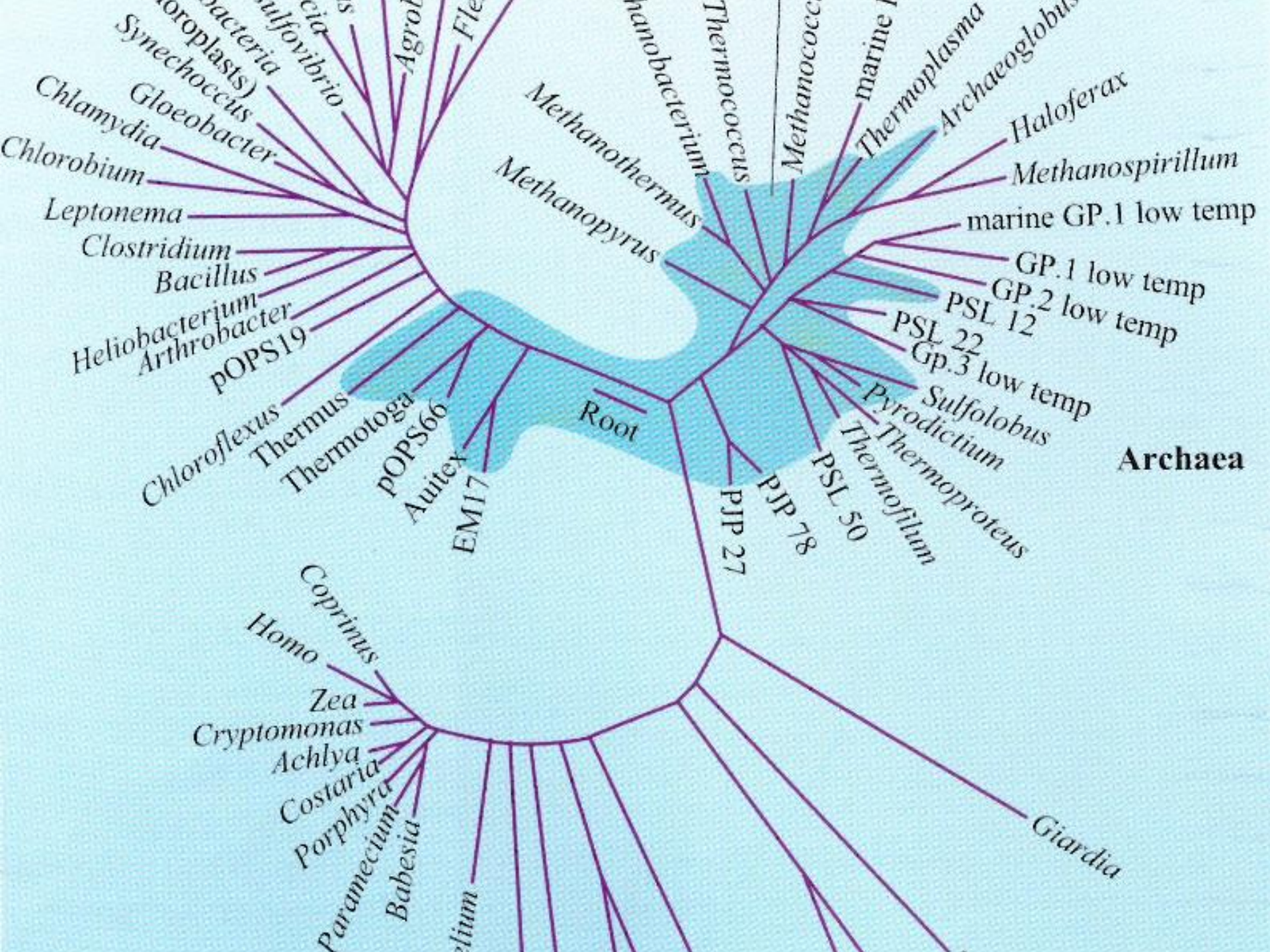


Unrooted Tree



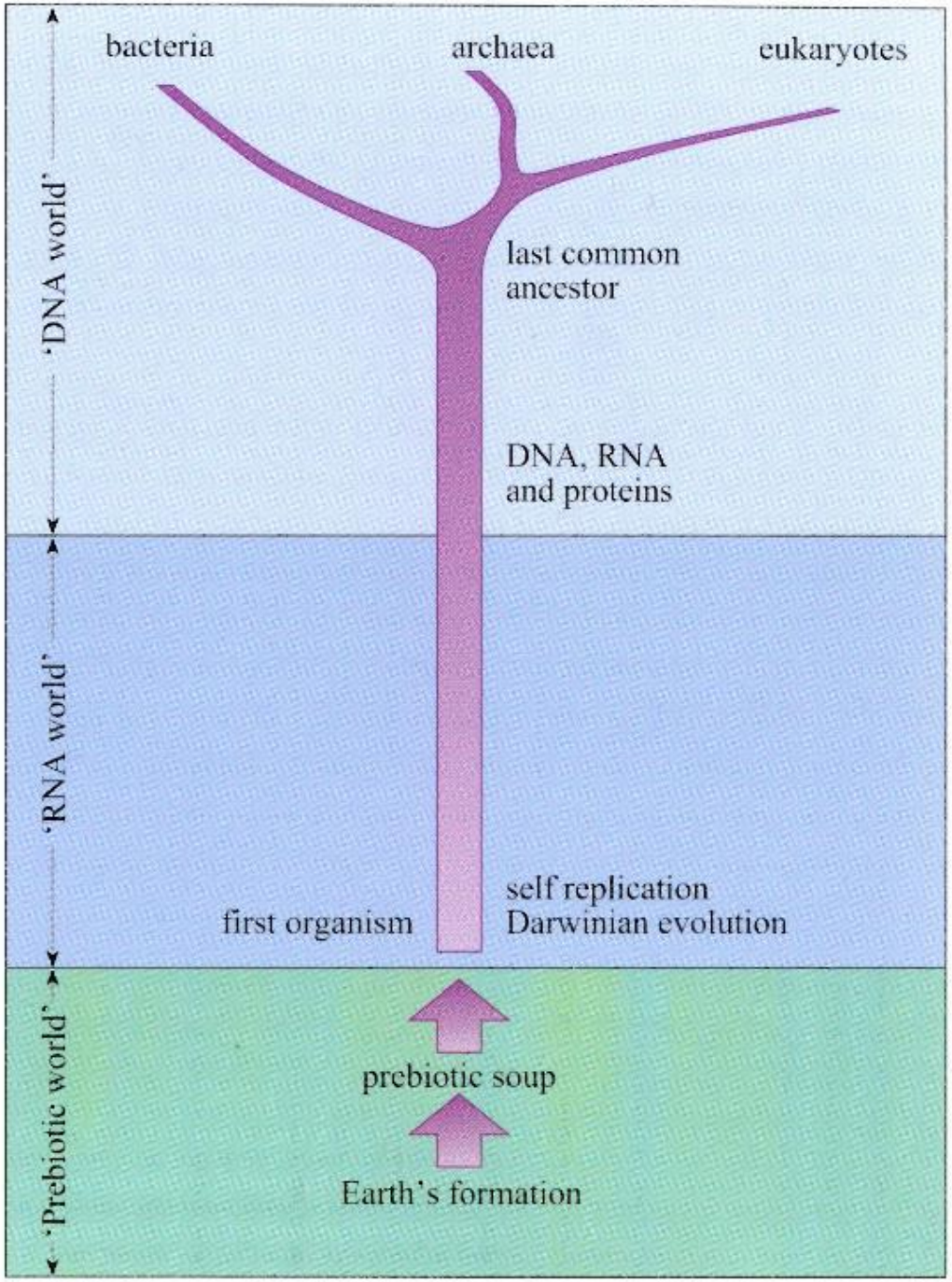
Modern tree building

- Uses ribosomal RNA (rRNA)
  - Branch length = difference in rRNA
- Three clear "domains"
  - Bacteria, archea, eukarya
- Root on tree → LUCA
  - ***Last universal common ancestor***
- What types of organisms closest to the root?


Synechococcus
Gloeobacter
Chlamydia
Chlorobium
Leptonema
Clostridium
Bacillus
Heliobacterium
Arthrobacter
pOPS19
Chloroflexus
Thermus
Thermotoga
pOPS66
Auitex
EM17
Root
PJP 27
PJP 78
PSL 50
Thermofilum
Thermoproteus
Pyrodictium
Sulfolobus
Gp.3 low temp
PSL 22
PSL 12
GP.2 low temp
GP.1 low temp
marine GP.1 low temp
Methanospirillum
Haloferax
Archaeoglobus
Thermoplasma
marine
Methanococcus
Thermococcus
Methanobacterium
Methanothermus
Methanopyrus
Archaea
Giardia
Coprinus
Homo
Zea
Cryptomonas
Achlya
Costaria
Porphyra
Babesia

Put into perspective

- DNA world
  - Now
- RNA world
  - then
- Prebiotic word
  - at the beginning



Key feature of RNA world idea?

A. RNA simple to synthesize
B. RNA is less stable than DNA
C. RNA can act as a catalyst
D. RNA can attach to clays
E. RNA can attach to proteins

Walter Gilbert
(1986, Nature 319, 618)

The RNA world

- Central dogma of chemistry of life
  - DNA → RNA → protein

store messenger enzyme

- Dilemma in bottom-down approach!
- RNA world: only RNA
  - RNA acts as enzyme, messenger, and store for itself!
  - Ribonucleic acid enzyme = Ribozyme (mRNA, etc)

Key feature of RNA world idea?

A. RNA simple to synthesize
B. RNA is less stable than DNA
C. RNA can act as a catalyst
D. RNA can attach to clays
E. RNA can attach to proteins

RNA itself acts as enzyme
– in addition to proteins!

The Nobel Prize in Chemistry 1989

"for their discovery of catalytic properties of RNA"

Sidney Altman

◐ 1/2 of the prize

Canada and USA

Yale University
New Haven, CT, USA

b. 1939

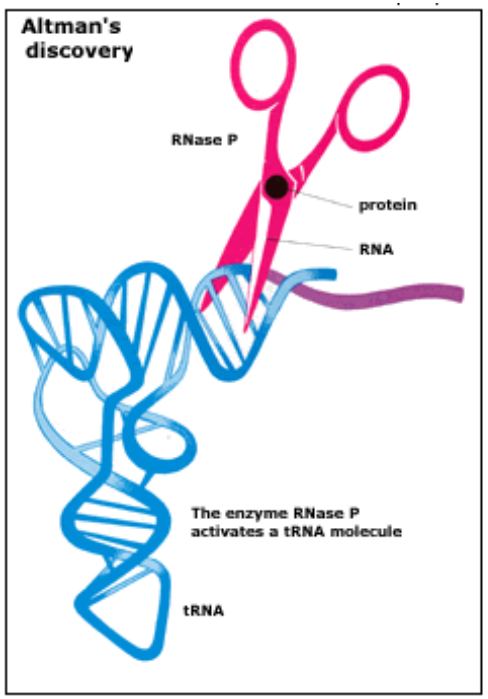
Thomas R. Cech

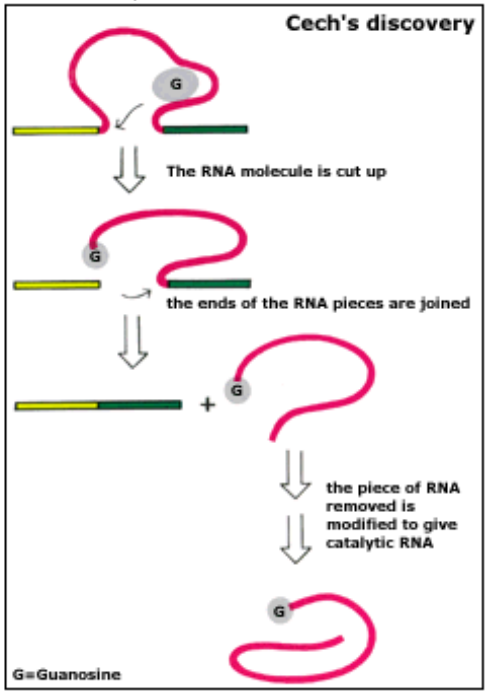
◐ 1/2 of the prize

USA

University of Colorado
Boulder, CO, USA

b. 1947





Ann. Rev. Biochem. 1986. 55:599–629

BIOLOGICAL CATALYSIS BY RNA

Thomas R. Cech and Brenda L. Bass[1]

Department of Chemistry and Biochemistry, University of Colorado, Boulder, Colorado 80309

Cell, Vol. 35, 849–857, December 1983 (Part 2), Copyright © 1983 by MIT

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The RNA Moiety of Ribonuclease P Is the Catalytic Subunit of the Enzyme

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Denver, Colorado 80206

hydrogen bonded nucleotide pairs with tRNA precursor molecules (Reed et al., 1982). The RNA moiety alone, in RNAase P or any other ribonucleoprotein aggregate, was not believed to be capable of performing the catalytic function presumed to be governed by the complex. Recently, however, Cech and coworkers showed that the precursor rRNA found in T. thermophila carries out self-splicing and circularization reactions (Kruger et al., 1982) in the absence of protein.

In this paper we present evidence that RNA may possess a wider range of catalytic capabilities than previously expected. In buffers containing high concentrations of Mg^{2+} the RNA subunits of RNAase P alone are sufficient

Similarity with viruses

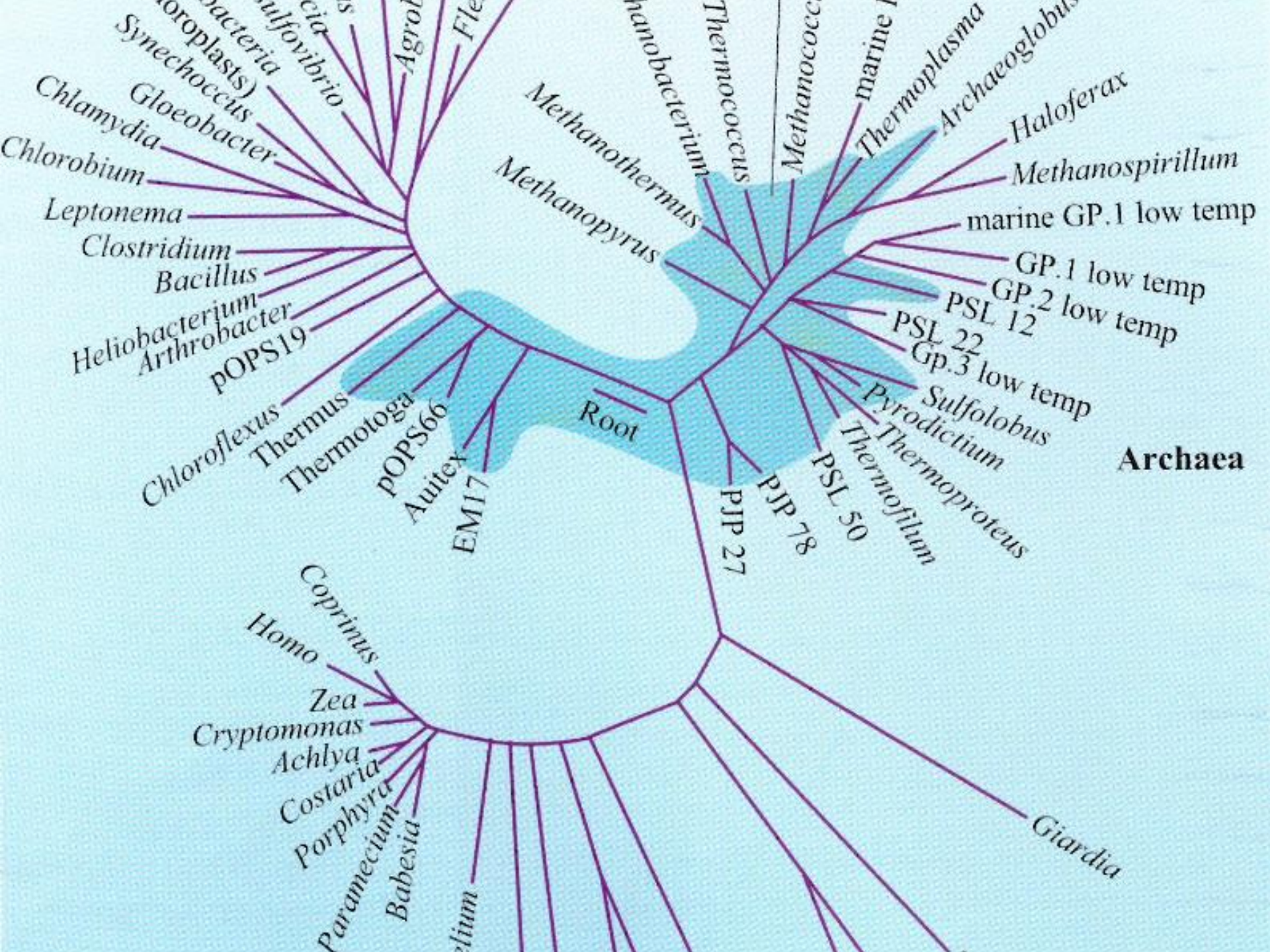
- Replicates only inside cell (all domains of life)
  - RNA or DNA + protein (+lipid) coat
- Edge of life: have genes, evol nat selection
  - But no metabolism
  - 20-300 nm size
  - Double-stranded: dsDNA, dsRNA
  - Single-stranded: ssDNA, ssRNA → retrovirus
  - High mutation rate

Evidence for RNA world

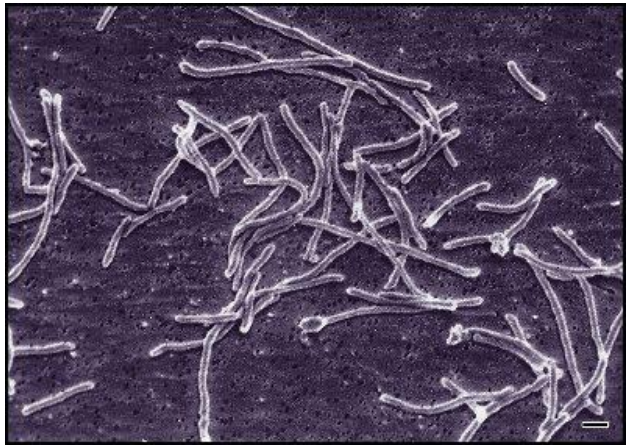
- Ribozymes have been synthesized
  - E.g. polymerase
- Catalyzed synthesis of 95 nucleotides
  - Itself able to manufacture another ribosome

Who is closest to the root?

- ……….
- ……….


Synechococcus
Gloeobacter
Chlamydia
Chlorobium
Leptonema
Clostridium
Bacillus
Heliobacterium
Arthrobacter
pOPS19
Chloroflexus
Thermus
Thermotoga
pOPS66
Auitex
EM17
Root
PJP 27
PJP 78
PSL 50
Thermofilum
Thermoproteus
Pyrodictium
Sulfolobus
Gp.3 low temp
PSL 22
PSL 12
GP.2 low temp
GP.1 low temp
marine GP.1 low temp
Methanospirillum
Haloferax
Archaeoglobus
Thermoplasma
marine
Methanococcus
Thermococcus
Methanobacterium
Methanothermus
Methanopyrus
Archaea
Giardia
Coprinus
Homo
Zea
Cryptomonas
Achlya
Costaria
Porphyra
Babesia

Thermus, thermofilum, methanopyrus,...



Deinococcus thermus

Thermofilum	
Scientific classification	
Domain:	Archaea
Kingdom:	Crenarchaeota
Phylum:	Crenarchaeota
Class:	Thermoprotei
Order:	Thermoproteales
Family:	Thermofilaceae
Genus:	***Thermofilum*** Zillig & Gierl, 1983

Methanopyrus is a genus of methanogen, with a single described species, *M. kandleri*. It is a hyperthermophile, discovered on the wall of a black smoker from the Gulf of California at a depth of 2000 m, at temperatures of 84–110 °C. Strain 116 was discovered in black smoker fluid of the Kairei hydrothermal field; it can survive and reproduce at 122 °C.[2] It lives in a hydrogen-carbon dioxide rich environment, and like other methanogens reduces the latter to methane. It is placed among the Euryarchaeota, in its own class.

Closest to the root?

- thermophiles, hyperthermophiles
  - Evolution from hot → cold
- Chemotrophs
  - Do not use light as energy source
  - Deep biosphere rather than surface

Cold organisms first?

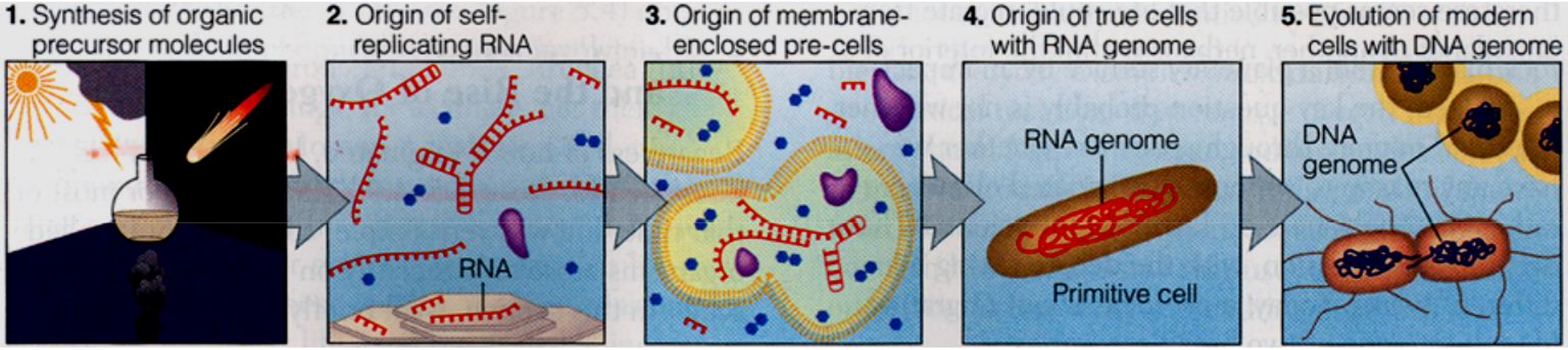
- .....
- ....
- ....
- ....

Cold organisms first?

- Yes, also possible:
- Hydrothermal vent first
- Then ocean-sterilizing impact
- Only thermophiles survives

Origin of Life: Summary

1. "Organic soup" vs. dilute solution.
2. Complex organics developed (mineral templates?).
3. "Pre-cells" enclosed complex organics.
4. Natural selection increased RNA complexity.
5. DNA developed within some successful cell(s).



A reasonable scenario, though many details are missing!

Next

- Summary
- Habitable zone
- Origin of life on Earth
- Chapter 2 of RGS pp 43-50
- + Box 2.1 and Fig.2.5