Life Resurrected

Traveling backwards in evolutionary time

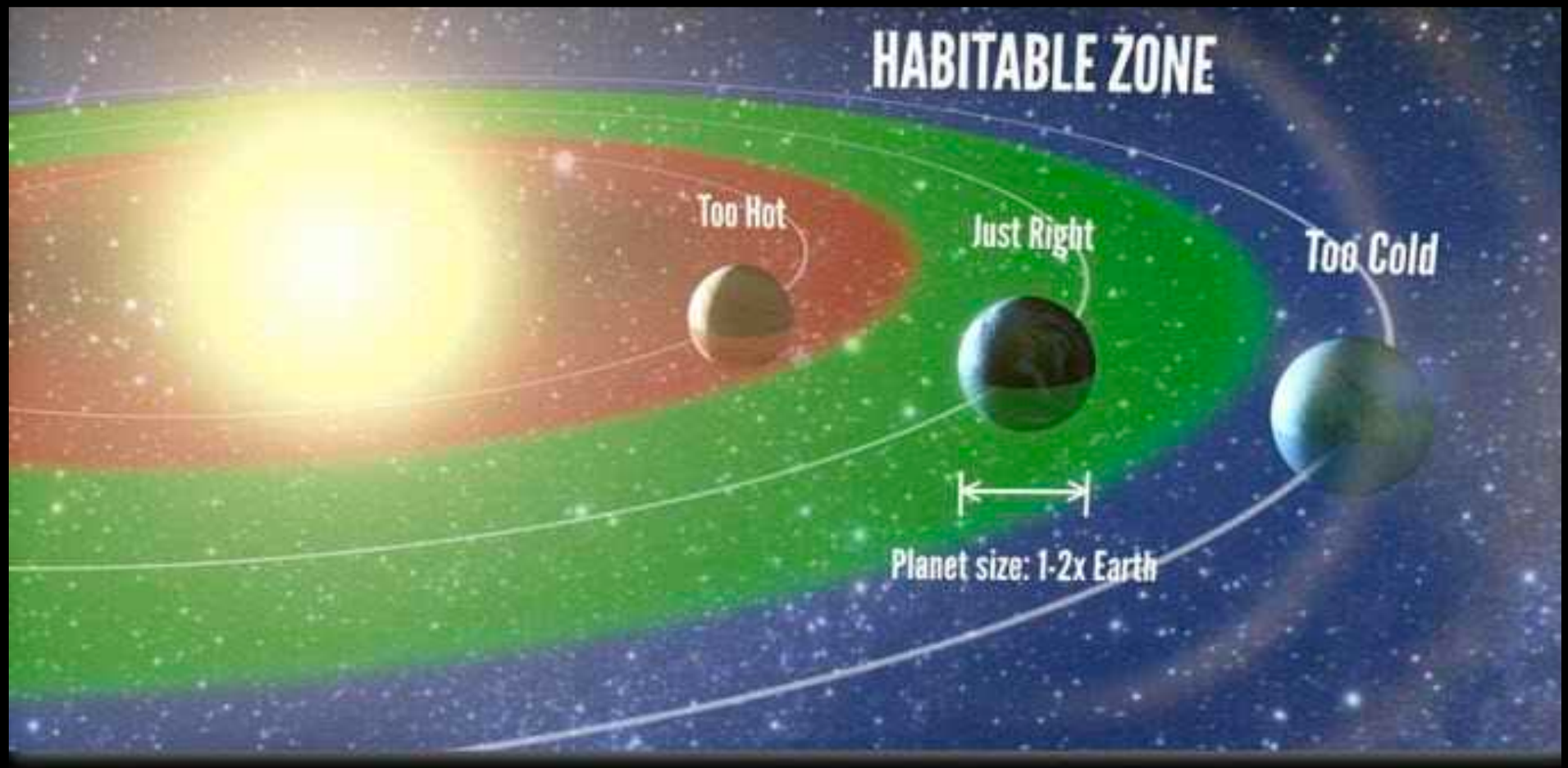
Betul Kacar (Harvard)

Host: NASA

John Templeton Foundation

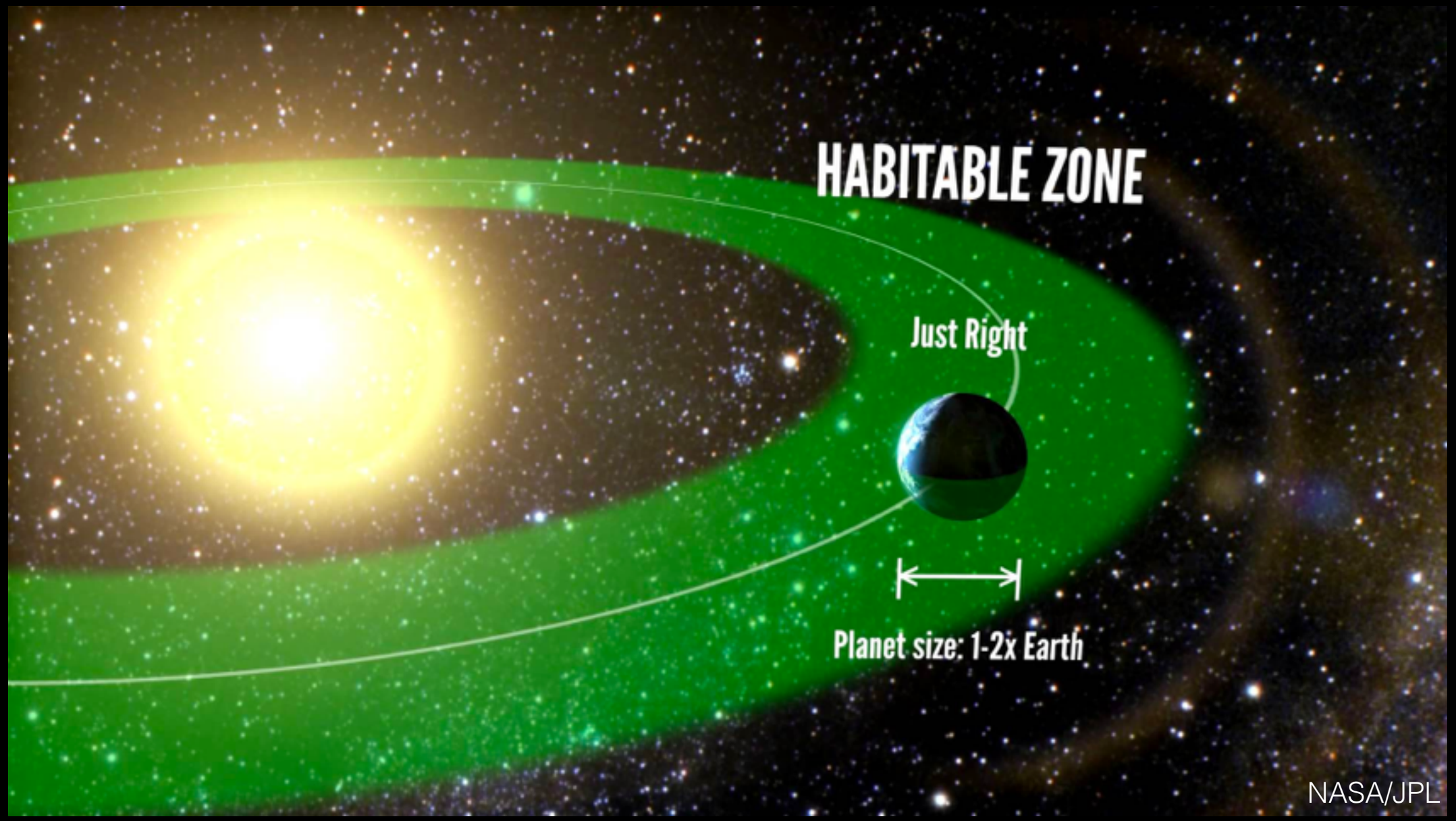
- Are we alone?
- Is there life elsewhere?
- How did life on Earth begin?

There could be as many as 40 billion Earth-sized planets orbiting in the habitable zones of Sun-like stars



The habitable zone corresponds to the range of orbital distances where liquid water can exist on a planet's surface.

Hubble reveals an estimated 100 billion galaxies in the universe



Understand (and protect) life here on Earth (One of the main goals of NASA)

Astrobiology is the study of the origin, evolution, distribution, and future of life in the **universe**: extraterrestrial life and life on **Earth**.

Curiosity Rover is the first applied astrobiologist

Curiosity Rover is the first applied astrobiologist

Followed by Matt Damon…

Who am I and what do I do?

(My grandmother raised me, despite never having went to school)

(My first day of school, 1990)

(I immigrated to the USA from Turkey, in 2003)
to study Biochemistry (undergraduate)

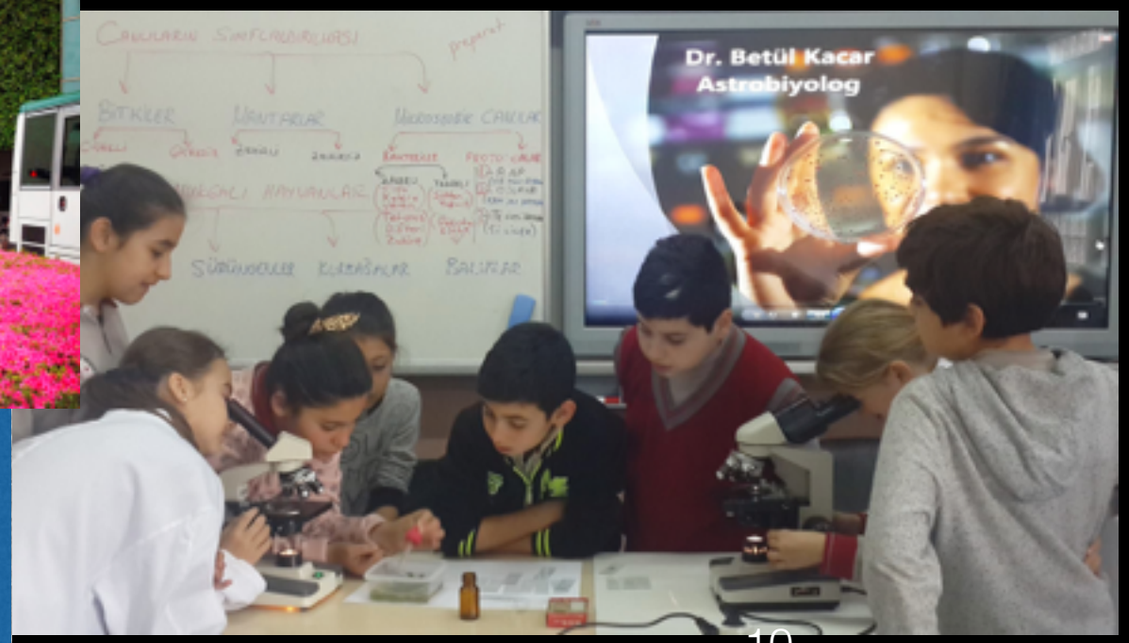
NASA Astrobiology Institute

Turkey

Georgia Tech

Uppsala, Sweden

ELSI Origins of Life Institute, Tokyo



Smithsonian Institute

PBS LearningMedia

LPI Girls! Mars Now!
PBS Learning Media Origins of Life

http://www.lpi.usra.edu/education
http://www.pbslearningmedia.org/collection/origins-of-life/

National Standards

Benchmarks for Science Literacy

5F/H4a (Grades: 9-12): Heritable characteristics can be observed at molecular and whole-organism levels—in structure, chemistry, or behavior.

5F/H5 (Grades: 9-12): New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells. Changes in other cells of an organism cannot be passed on to the next generation.

5F/H6b (Grades: 9-12): Chance alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism.

5F/H8 (Grades: 9-12): Life on earth is thought to have begun as simple, one-celled organisms about four billion years ago. Once cells with nuclei developed about a billion years ago, increasingly complex multi-cellular organisms evolved.

5F/M3a (Grades: 6-8): Many thousands of layers of sedimentary rock provide evidence for the long history of the earth and for the long history of changing life forms whose remains are found in the rocks.

5F/M3b (Grades: 6-8): More recently deposited rock layers are more likely to contain fossils resembling existing species.

I am a project leader at Harvard University

Moving to University of Arizona as an Astrobiology faculty!

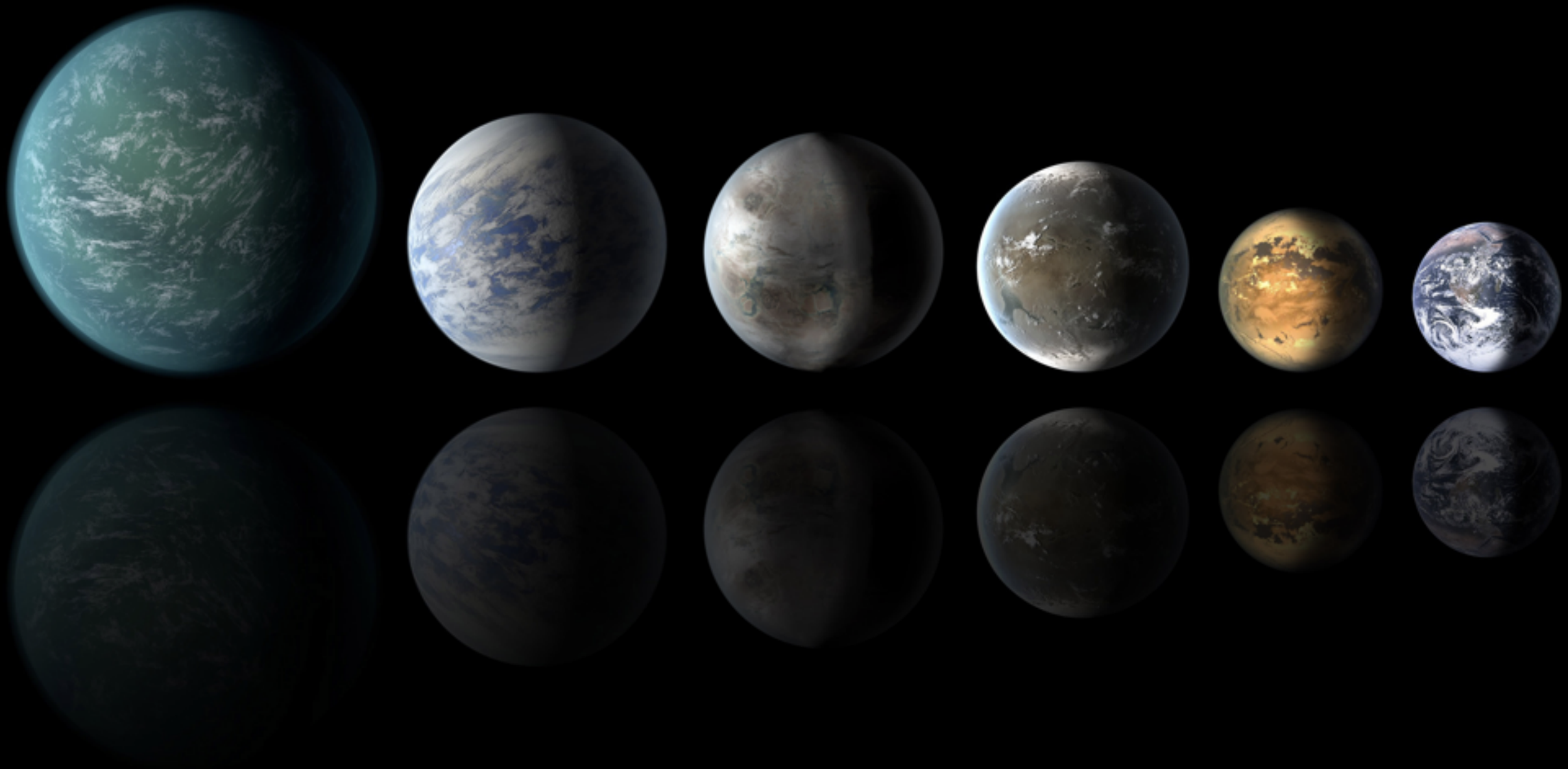
Goal of my research:

I aim to understand ancient life:

How did life evolve?

How did life, at the cellular level, behave in the past?

Earth’s past is a strange planet (different atmosphere, temperature, etc.)

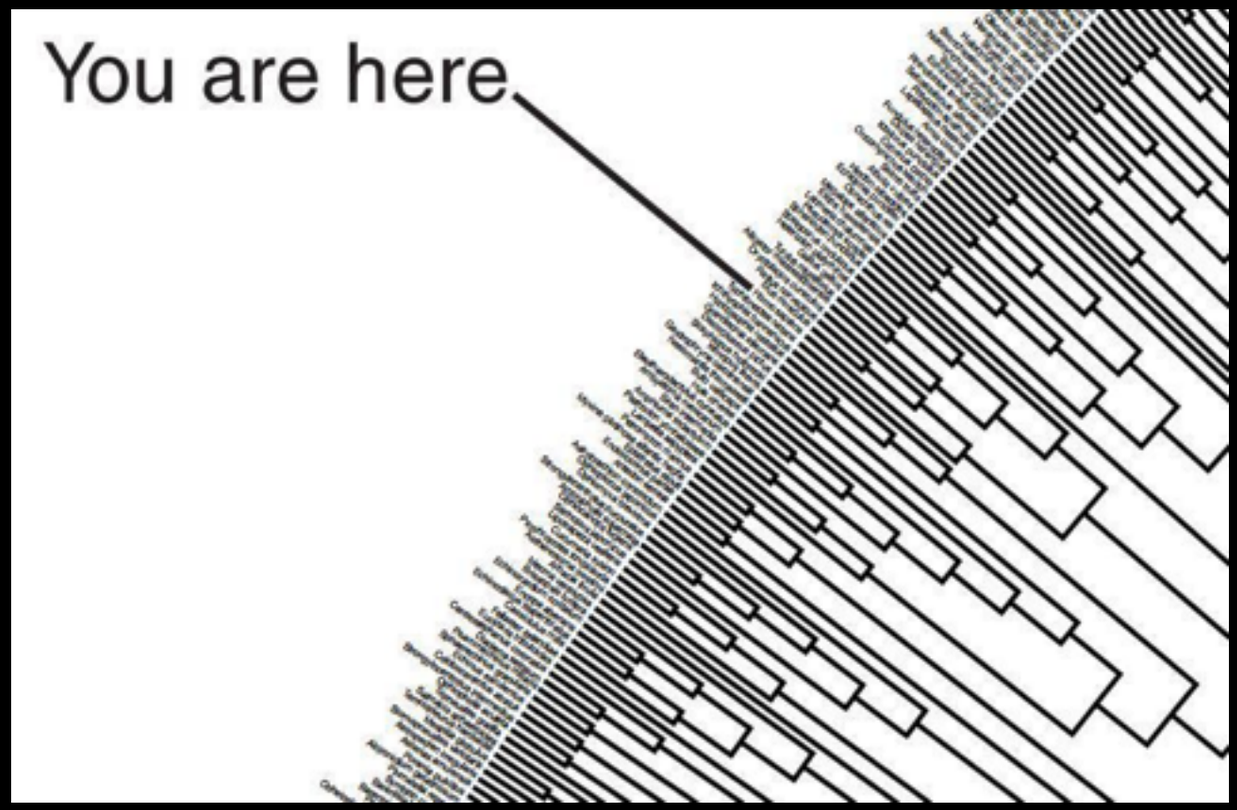


How did microorganisms behave in the past?

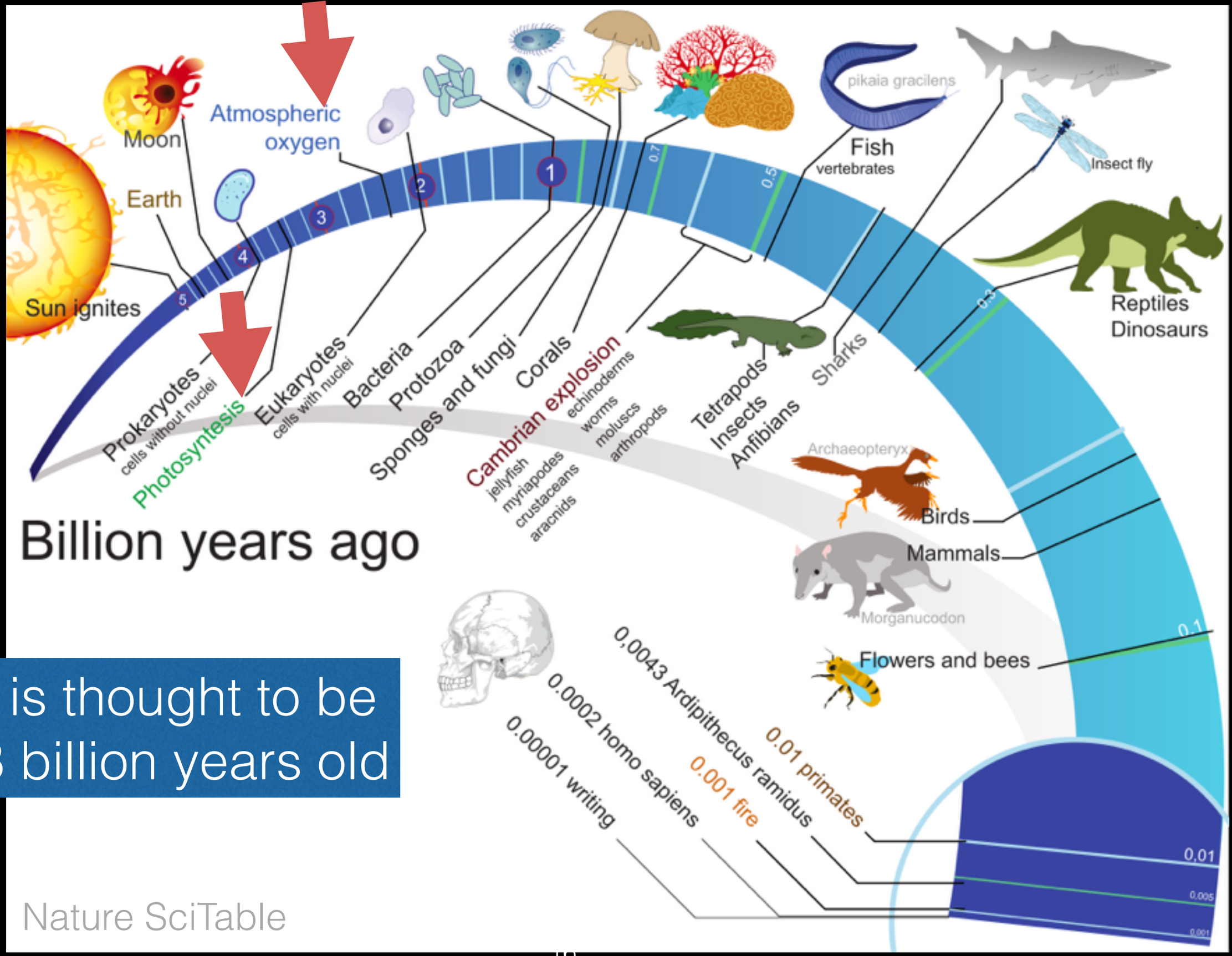
Rocks provide the global chemical picture

Two main approaches to understand the past:

Life provides a mix of specific molecular patterns



Evolution of Life Timeline

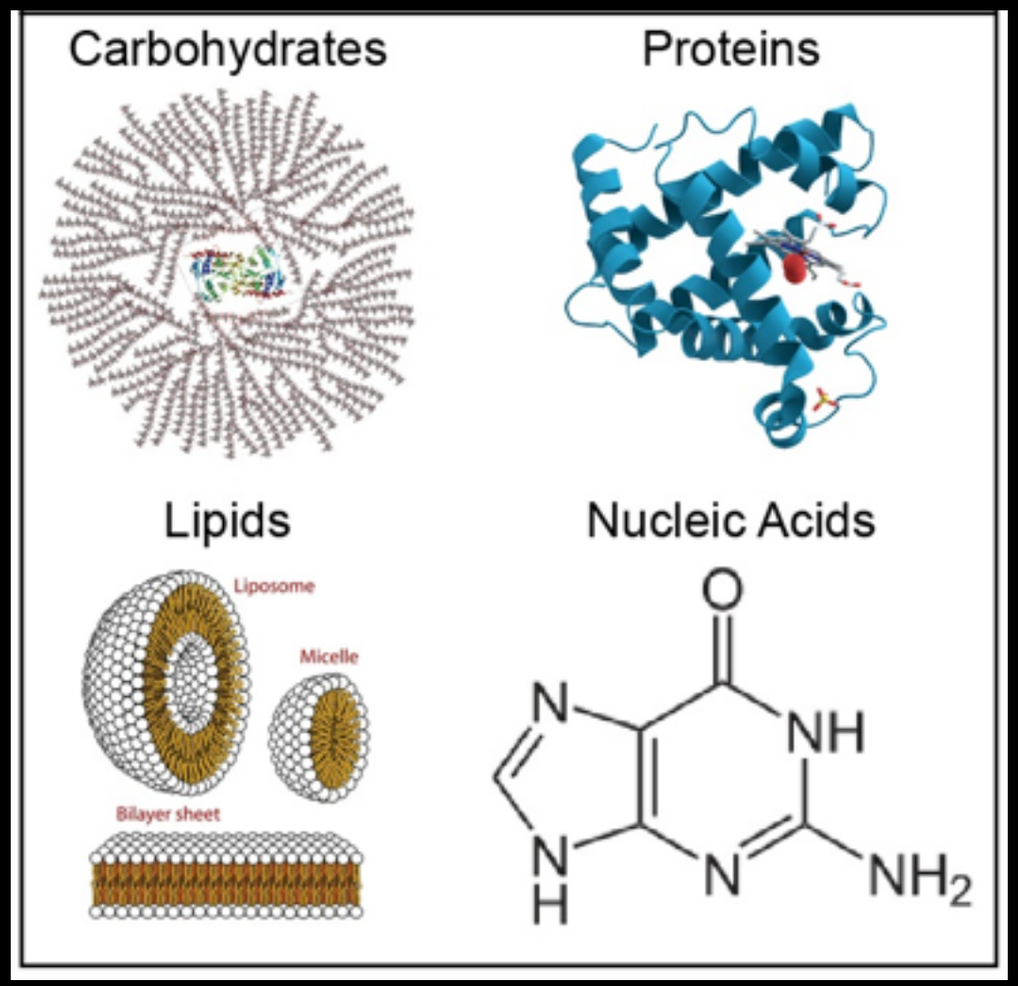


Life is thought to be ~3.8 billion years old

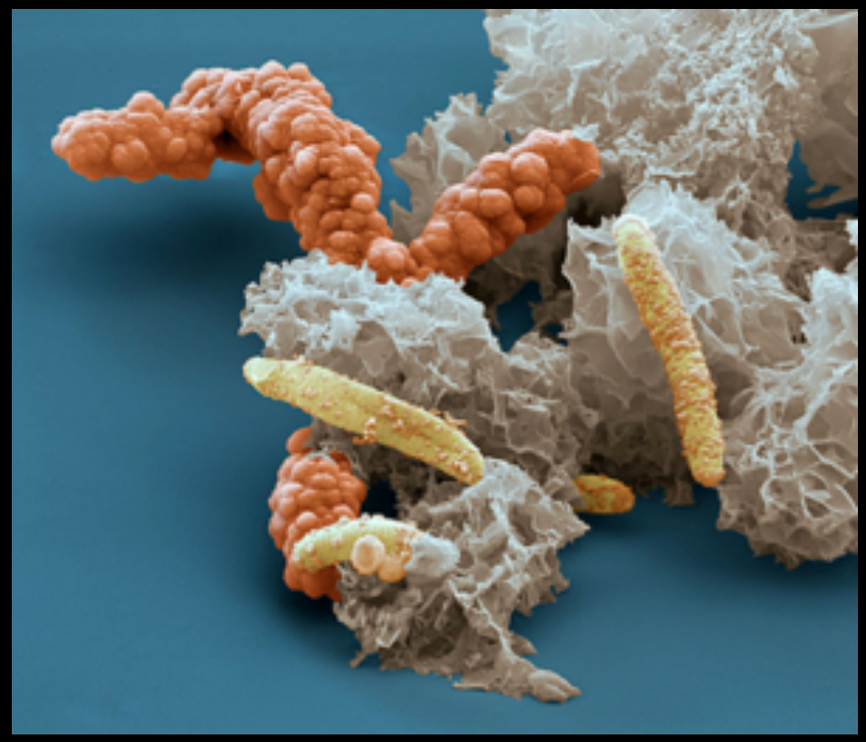
Nature SciTable

Biosignatures

Any substance – such as an element, isotope, molecule, or phenomenon – that provides scientific evidence of past or present life.



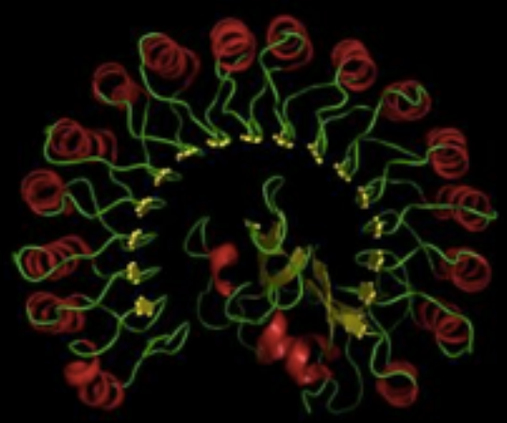
Biomolecules

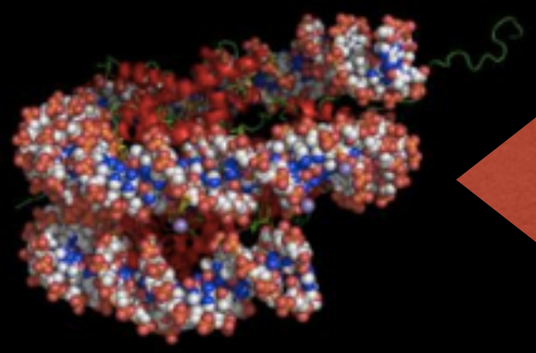


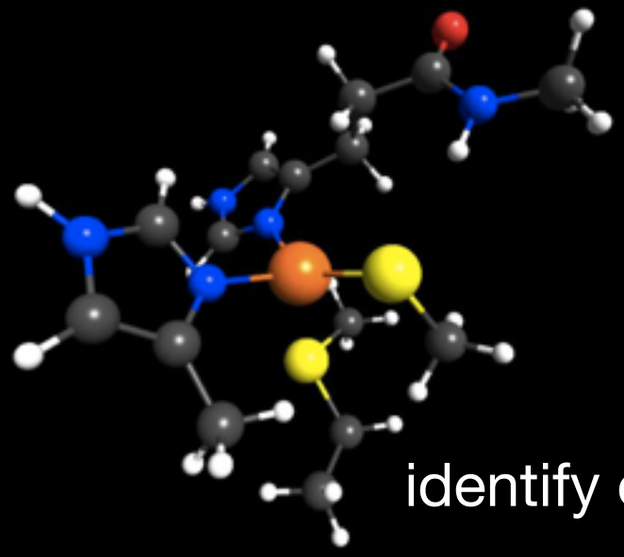
Microbes, Minerals

Genetics

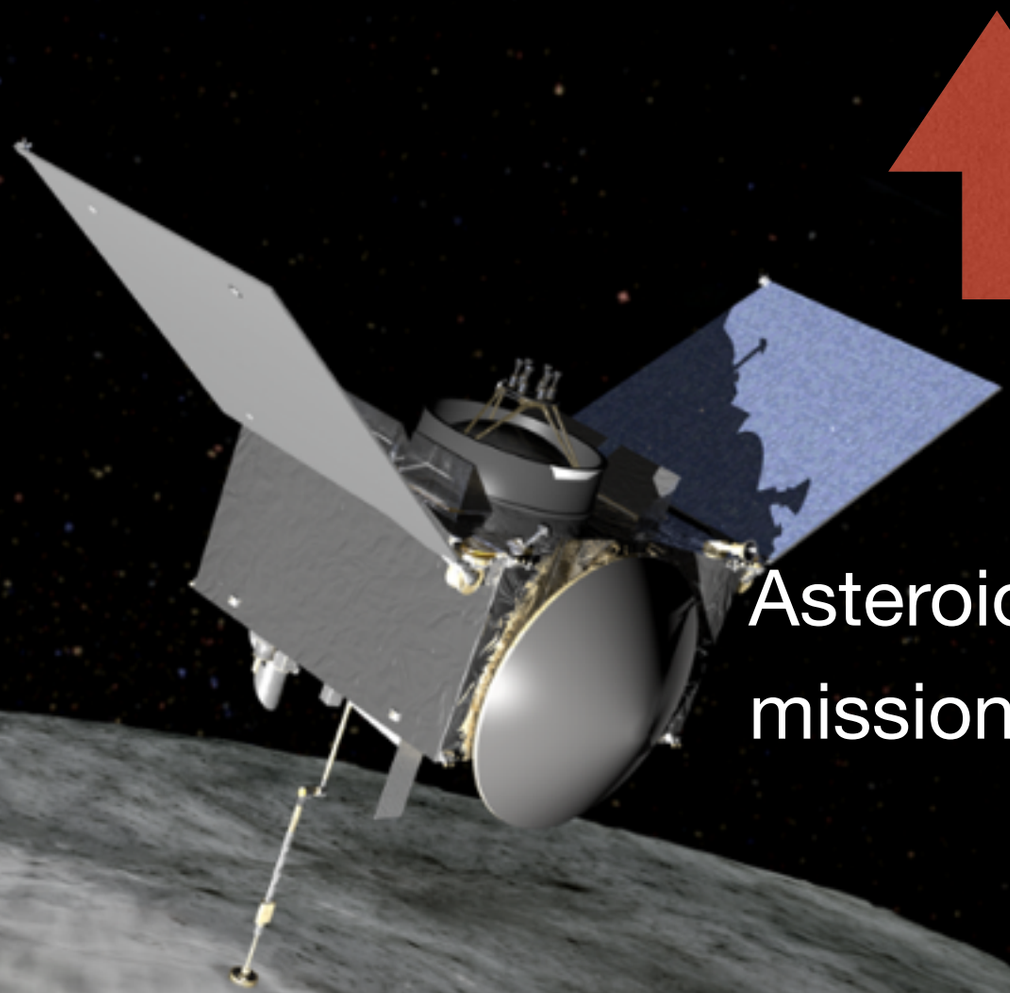
Search for Biosignatures







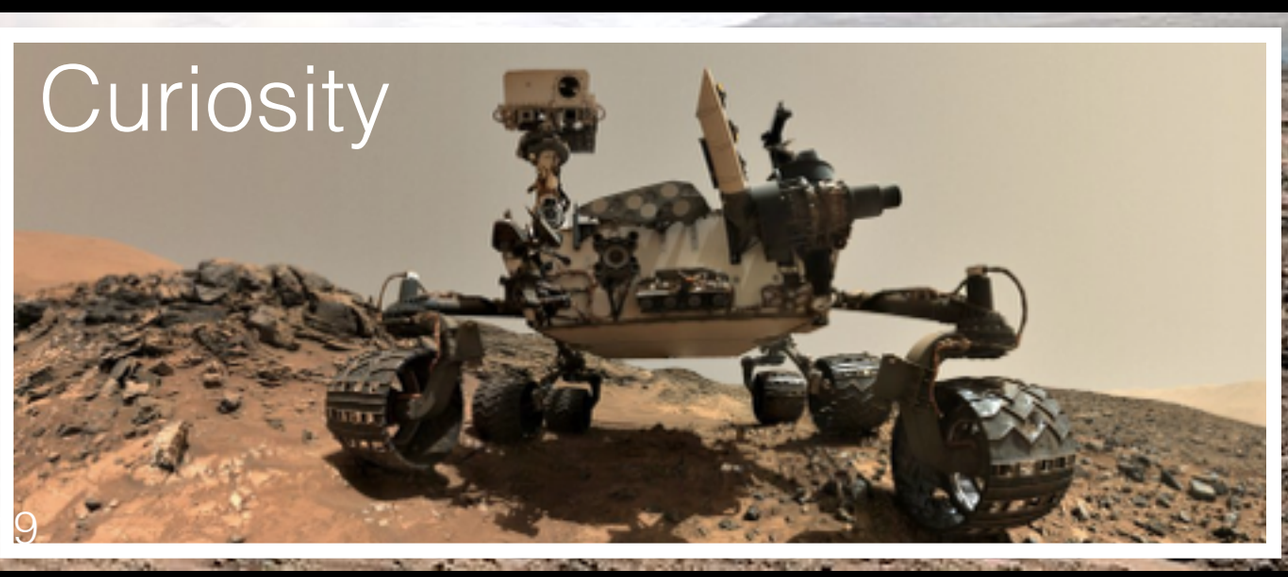
identify organics



Asteroid landing missions

Search for Biosignatures

Earth’s past and Mars’ present (any resemblance?)

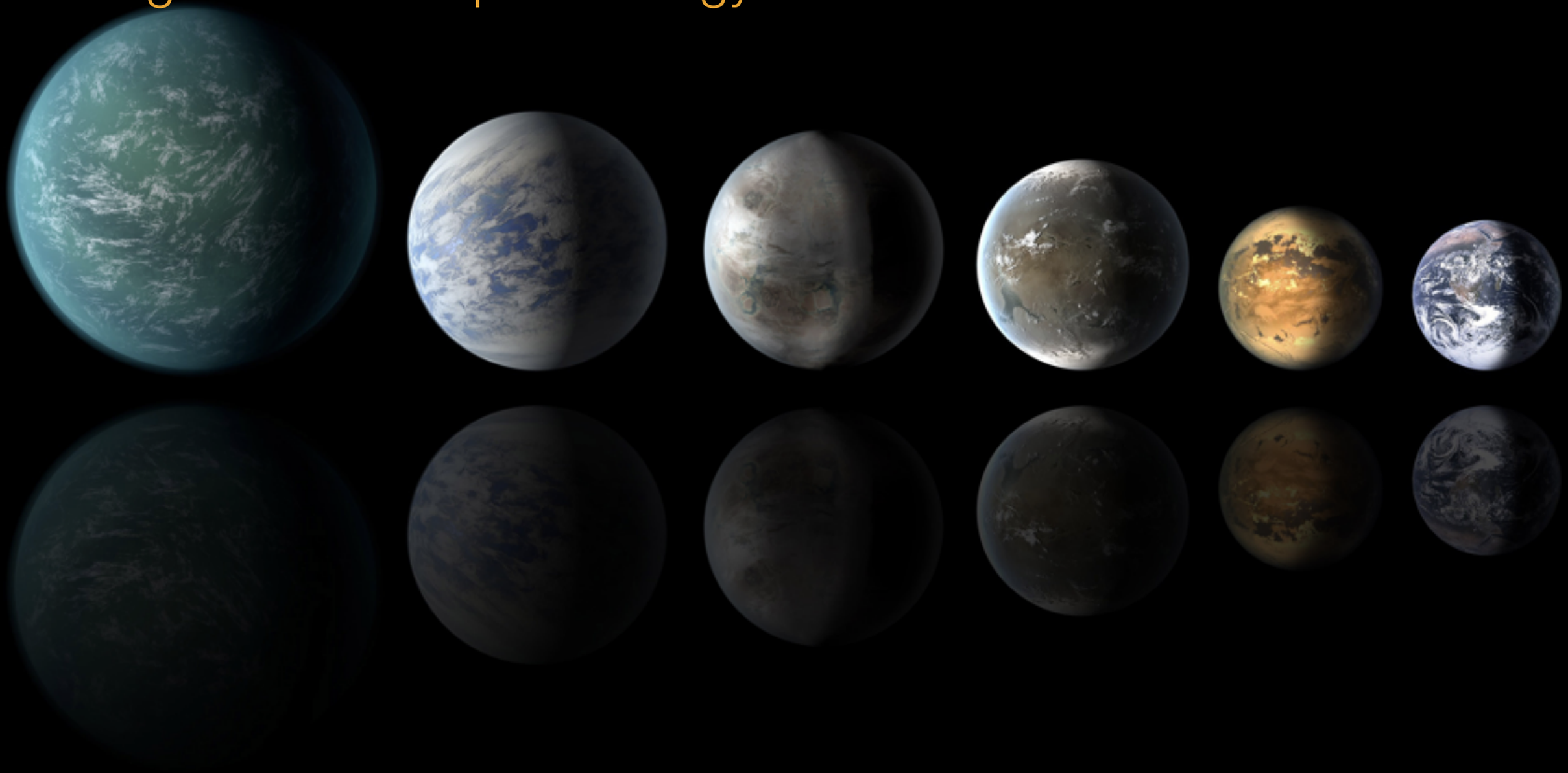


Earth's past is an alien planet

Can we reconstruct its past (alien) biology?

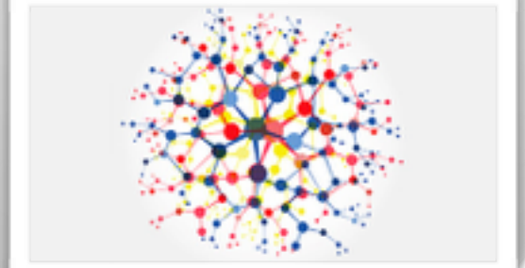
My lab:

Learning more about past biology could aid search for life elsewhere



Approach

Molecular Level
(Gene, Protein)



Evolution Level
(Phylogenetics,
(Laboratory Evolution)

Engineering
Systems Level
(Networks, Bacteria)

Synthetic Biology

Origins of Life

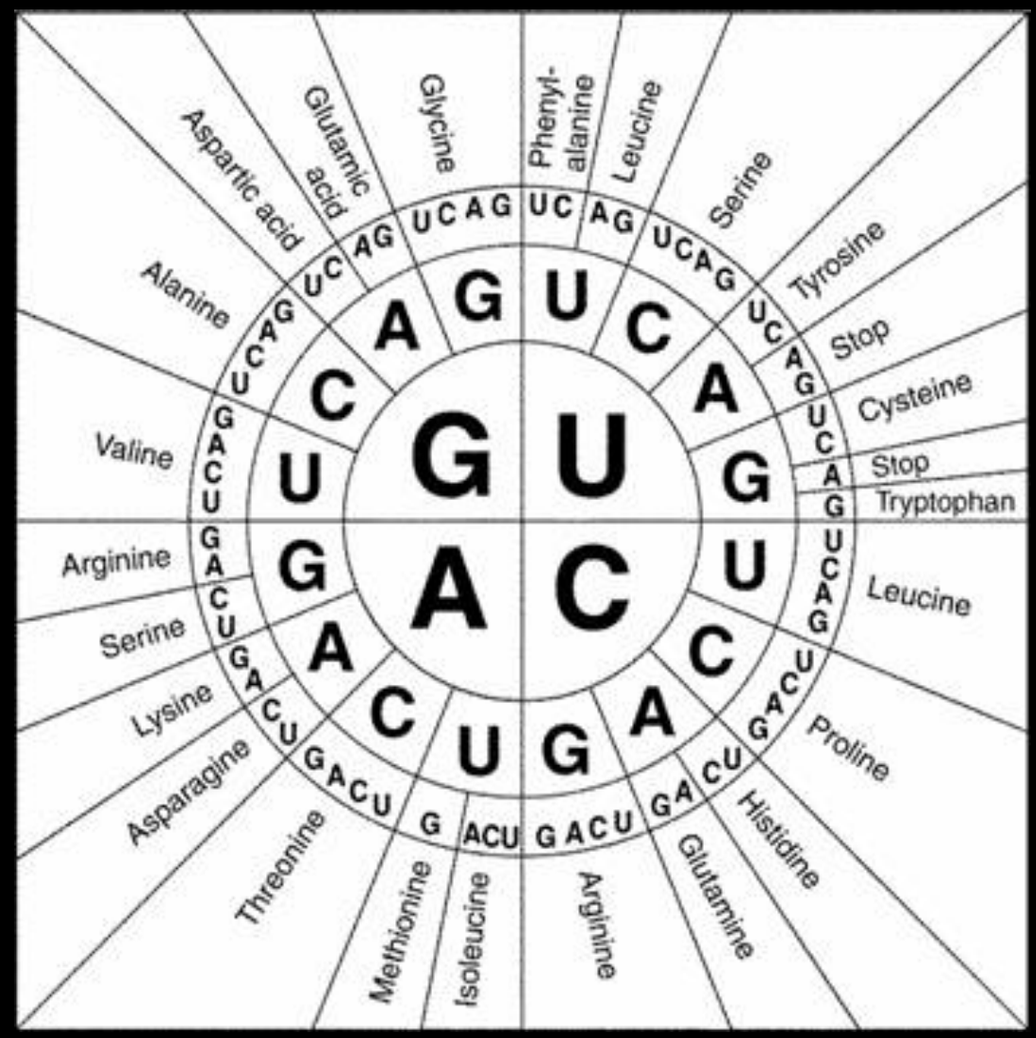
Bacterial Evolution

Environmental Level
(Rock Record)

Revenant Genetics
kacarlab.org

- Linguists make arrangements in life's alphabet to make inferences about the past

- Can we use 'Nature-made' words (amino acids) to make inferences about the past?



How do we travel back in time?

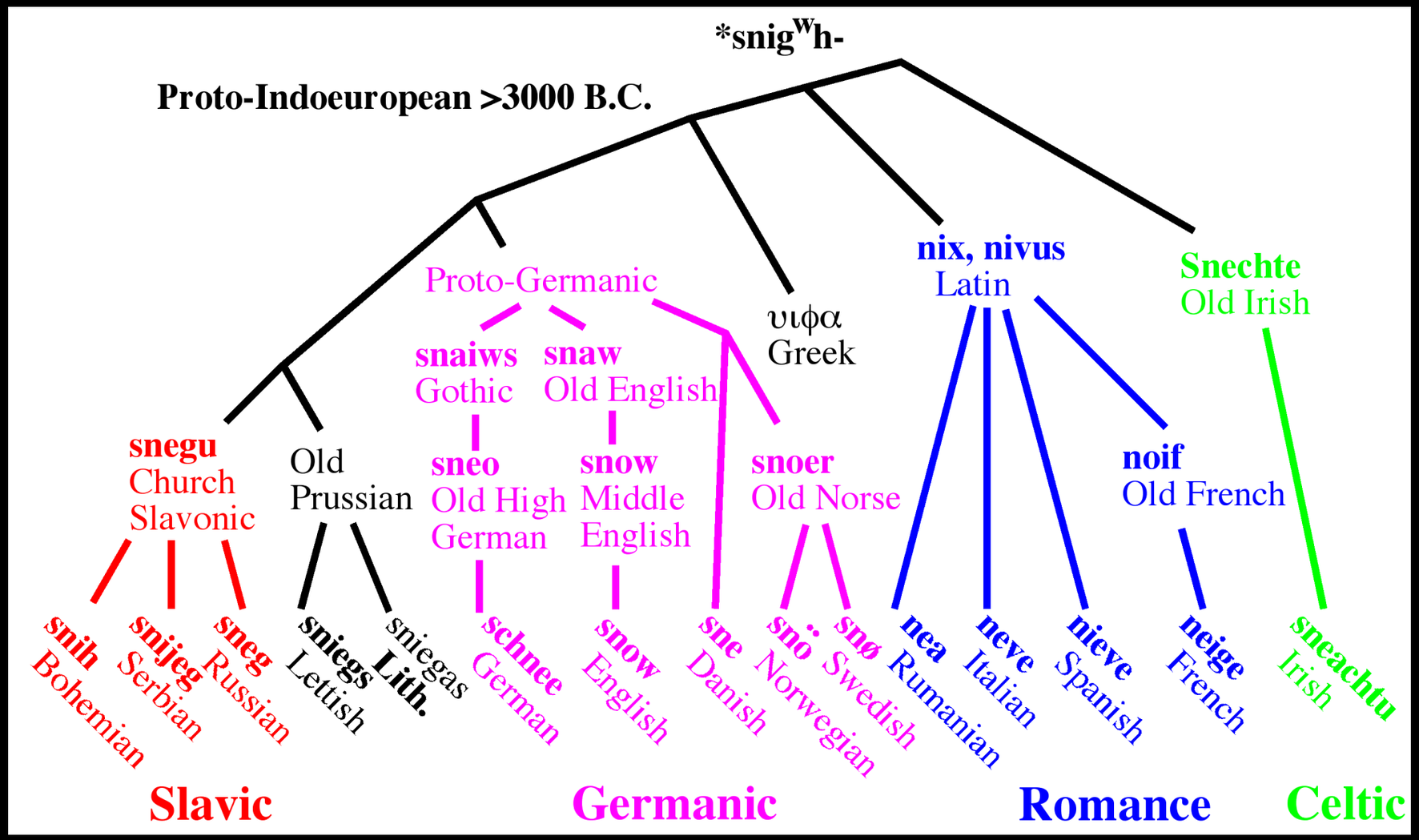
Hollywood’s version

How do we travel back in time?

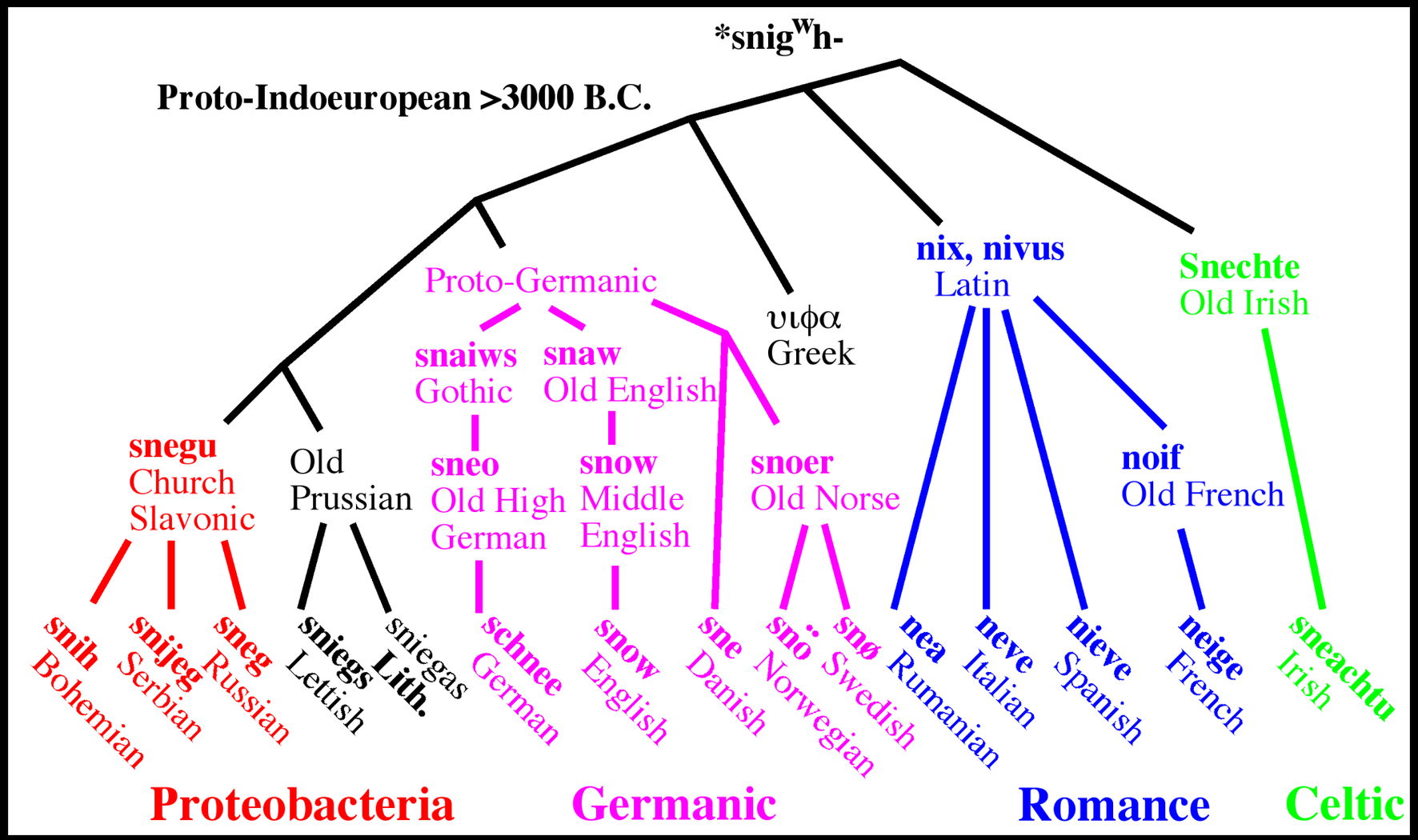
Hollywood’s version

Science’s version:

Rewinding the tape: Phylogenetics



Rewinding the tape: Phylogenetics



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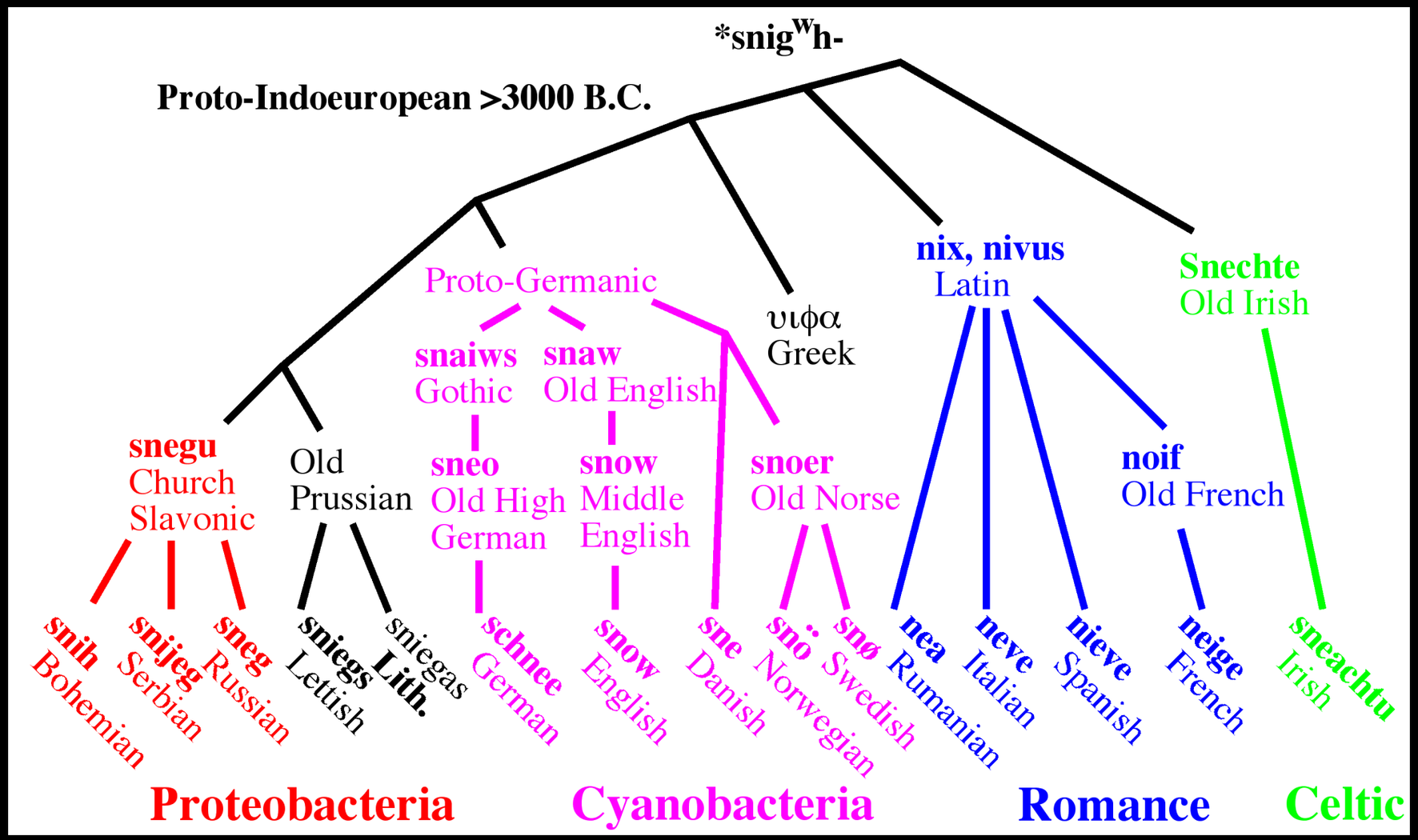

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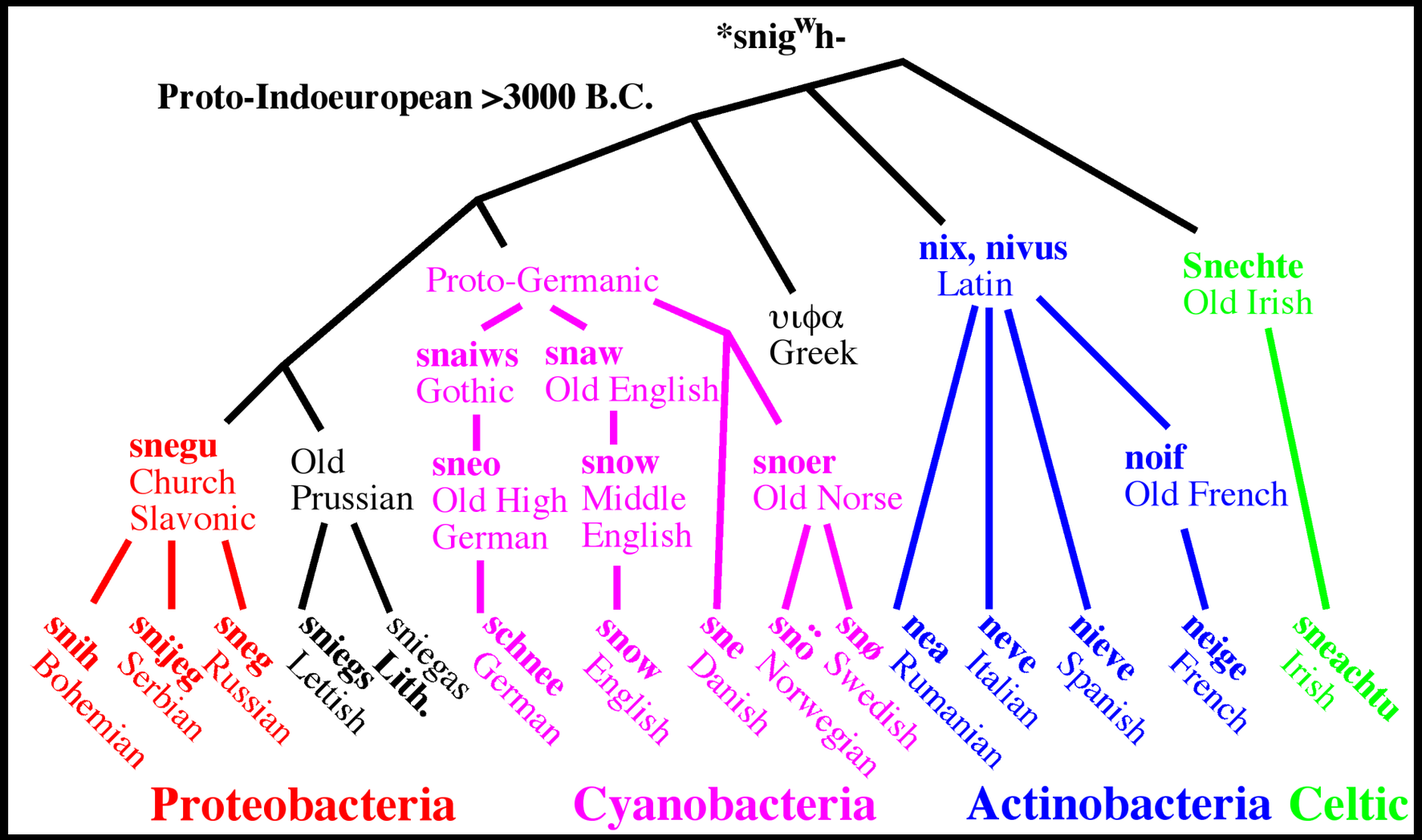

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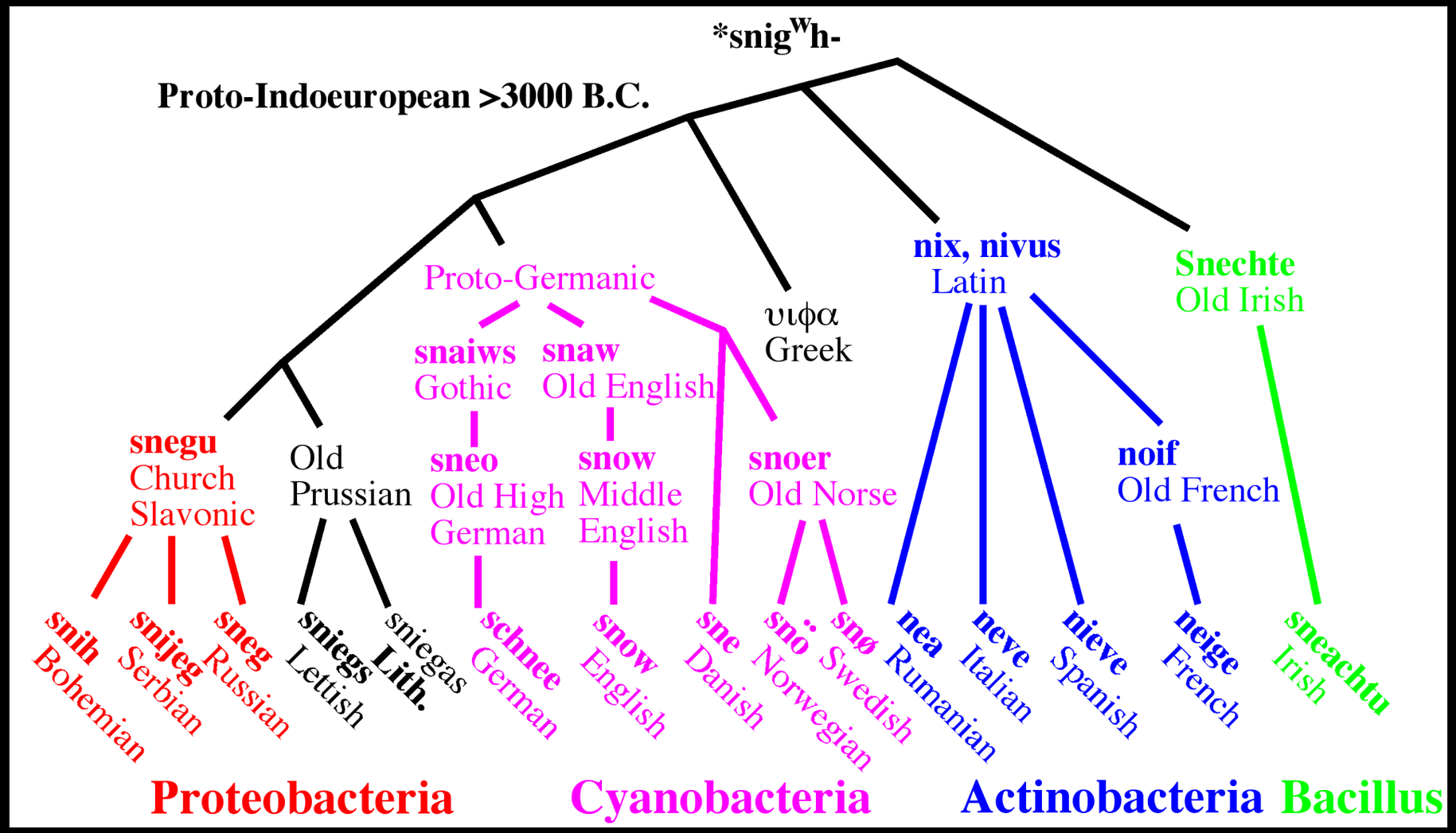

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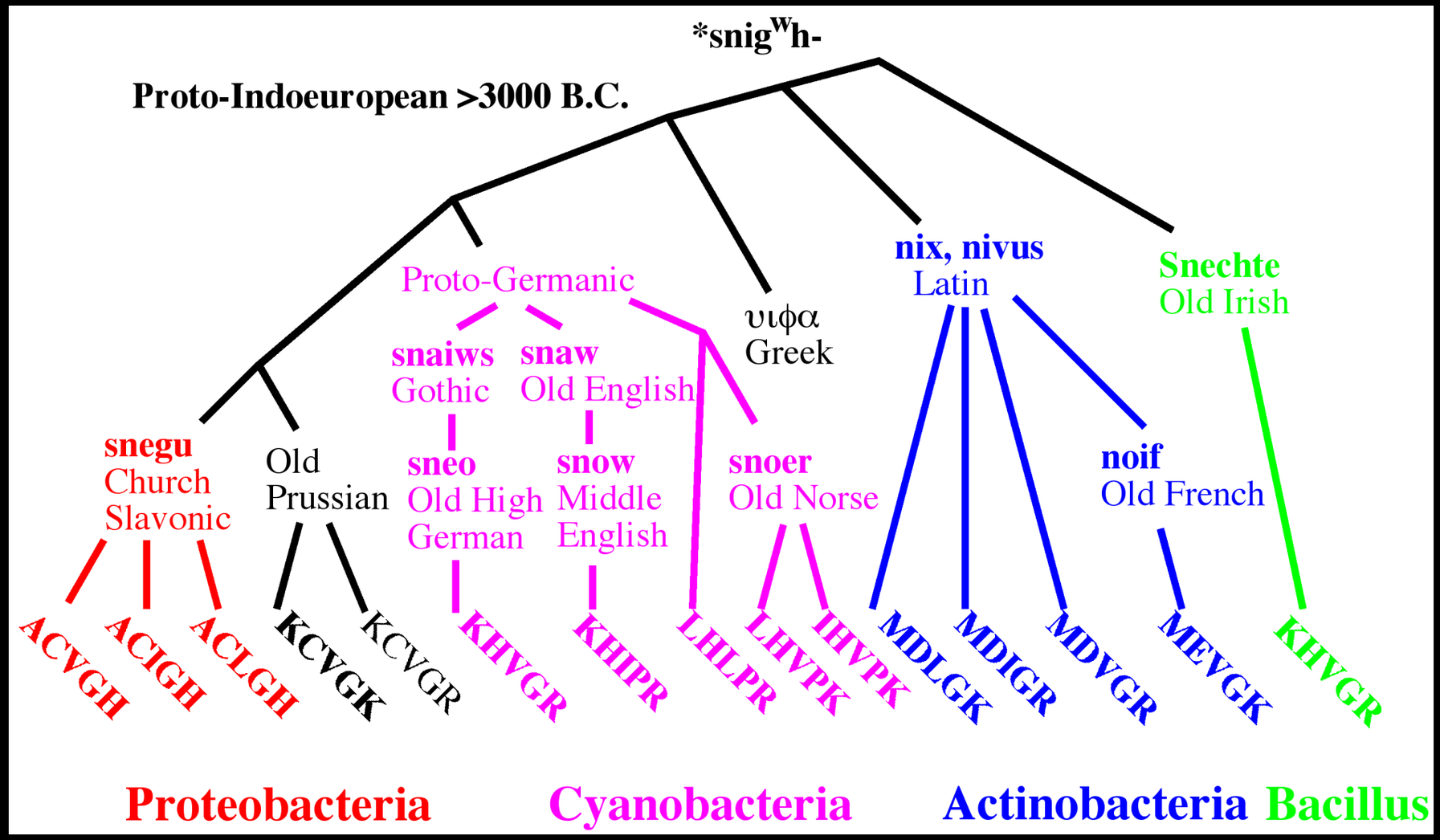

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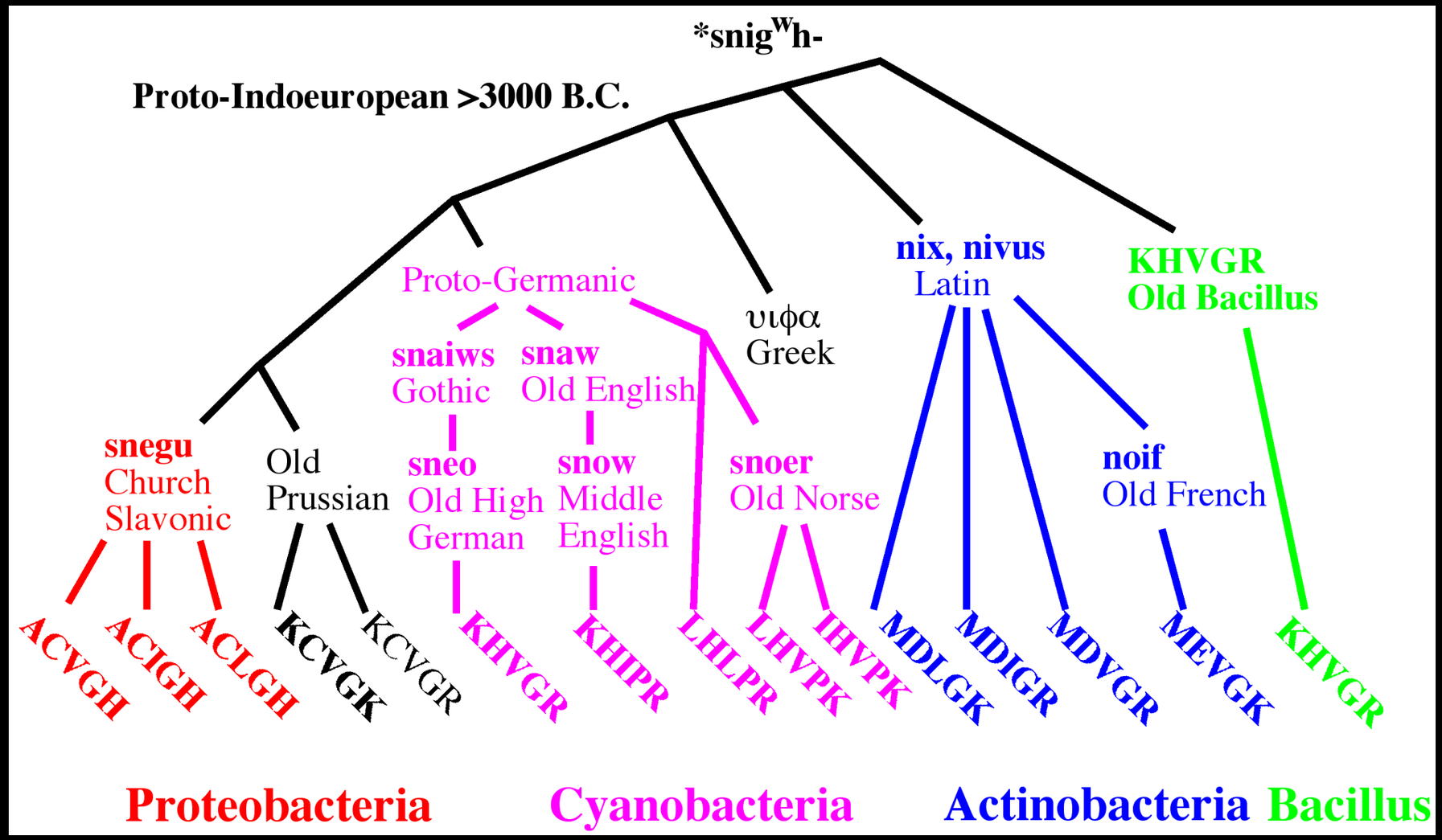

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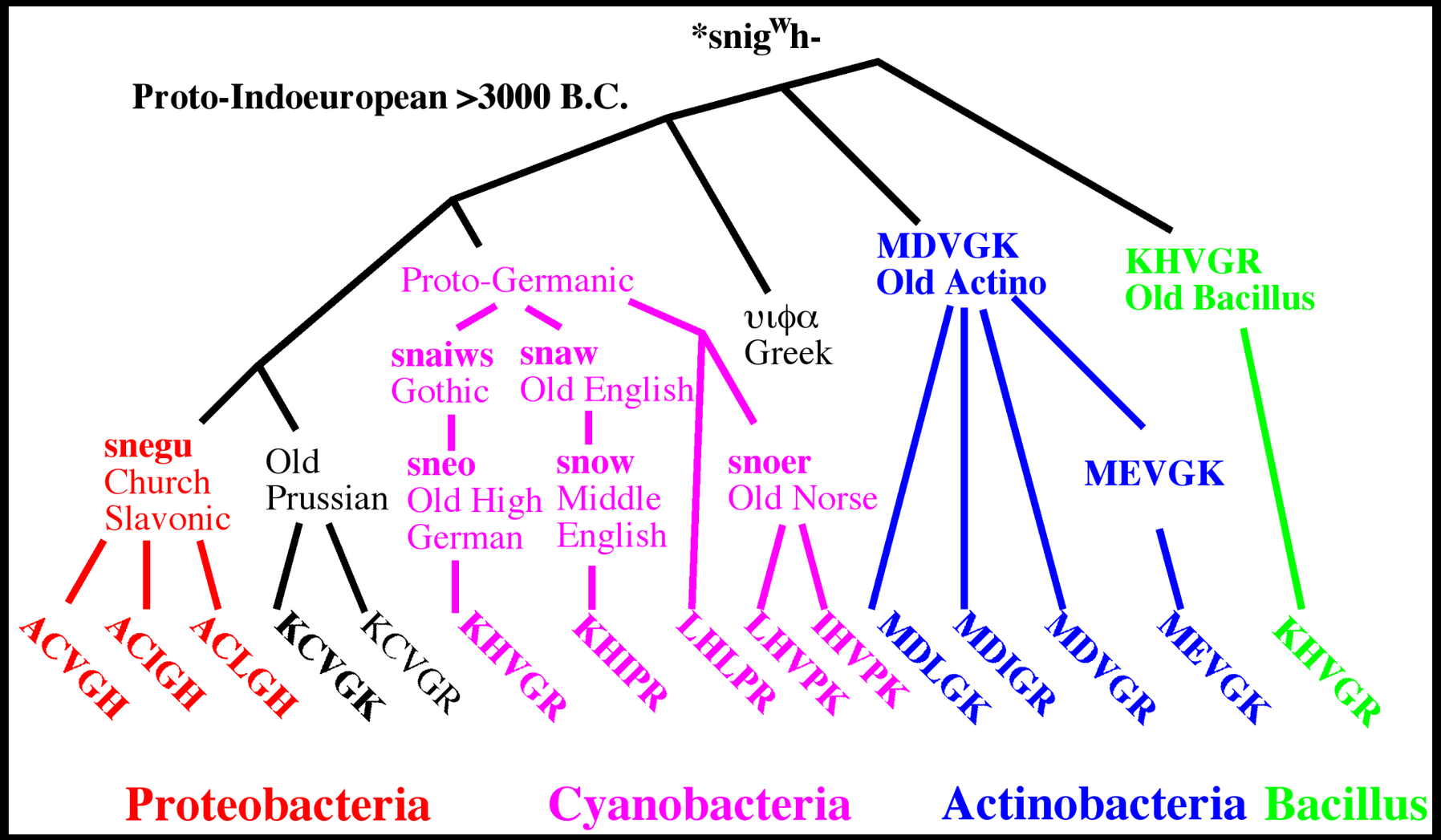

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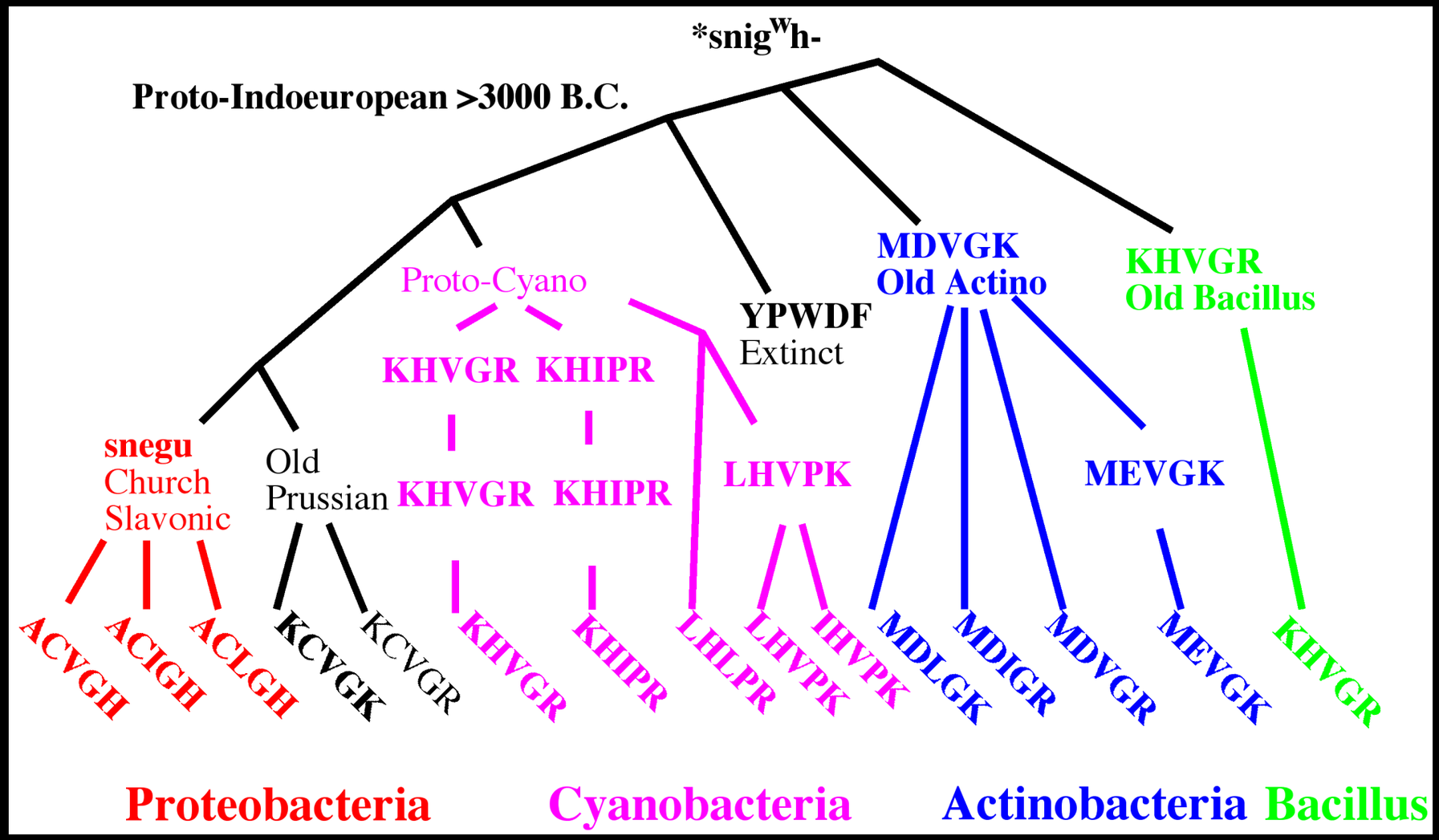

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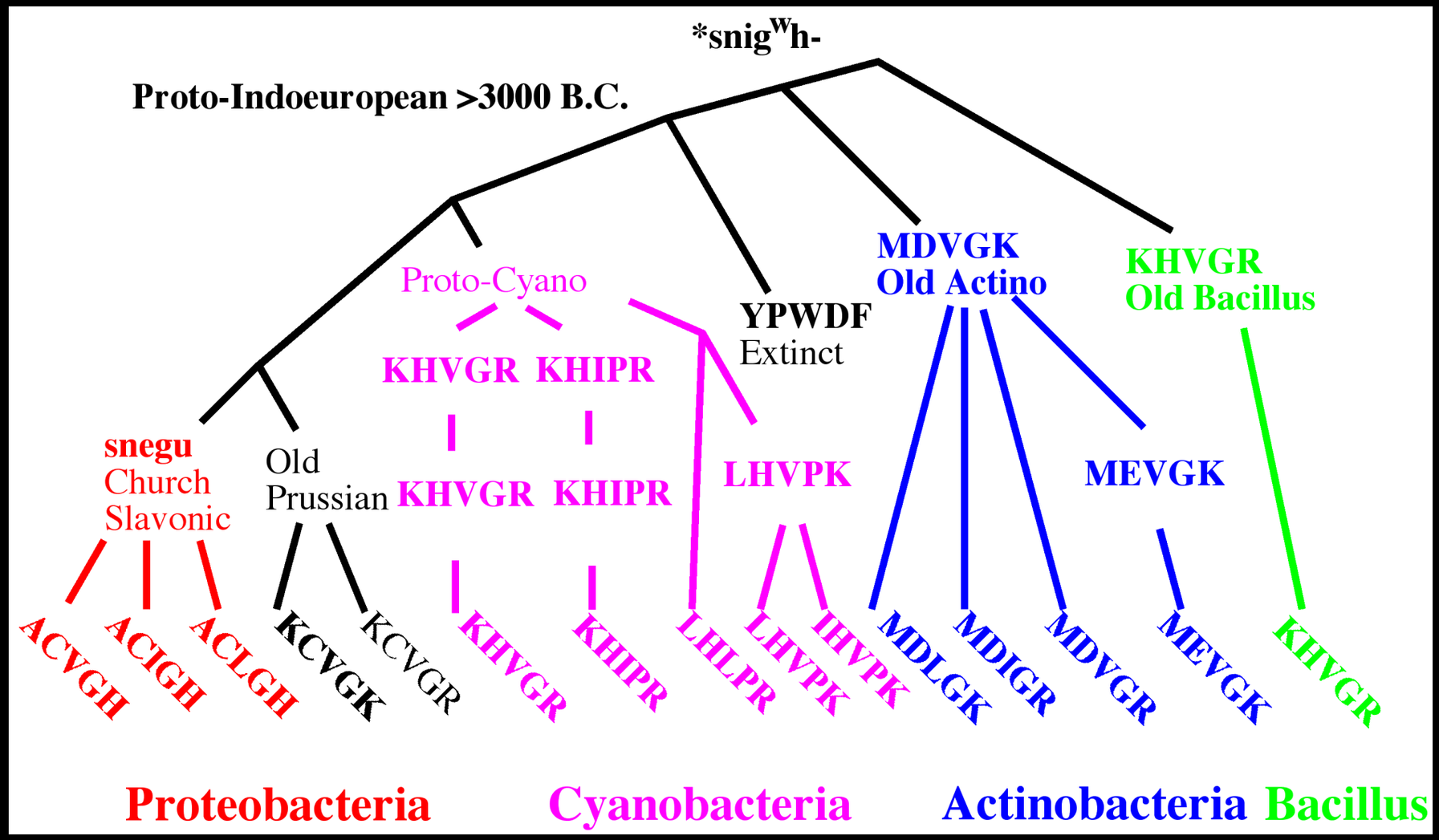

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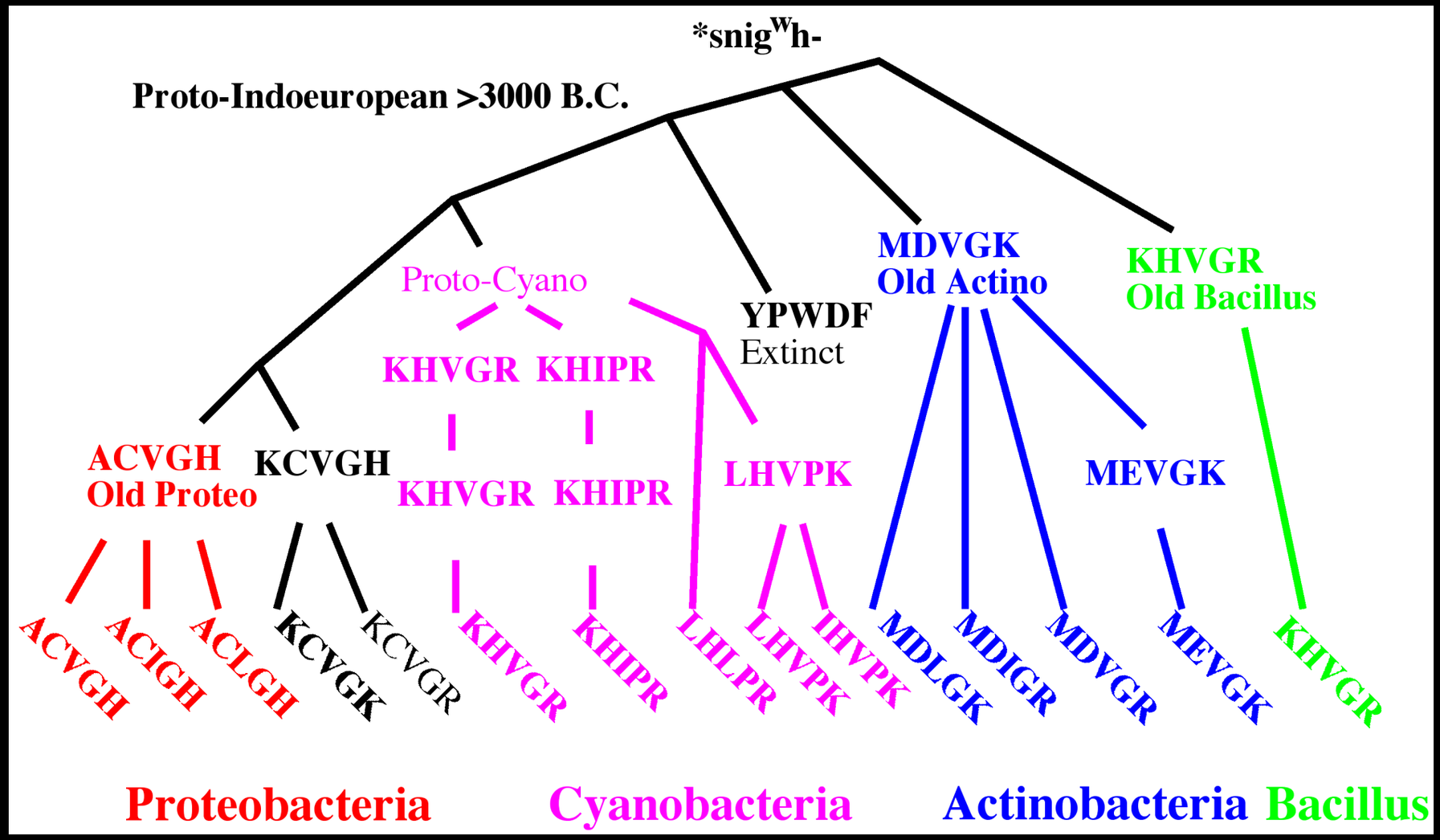

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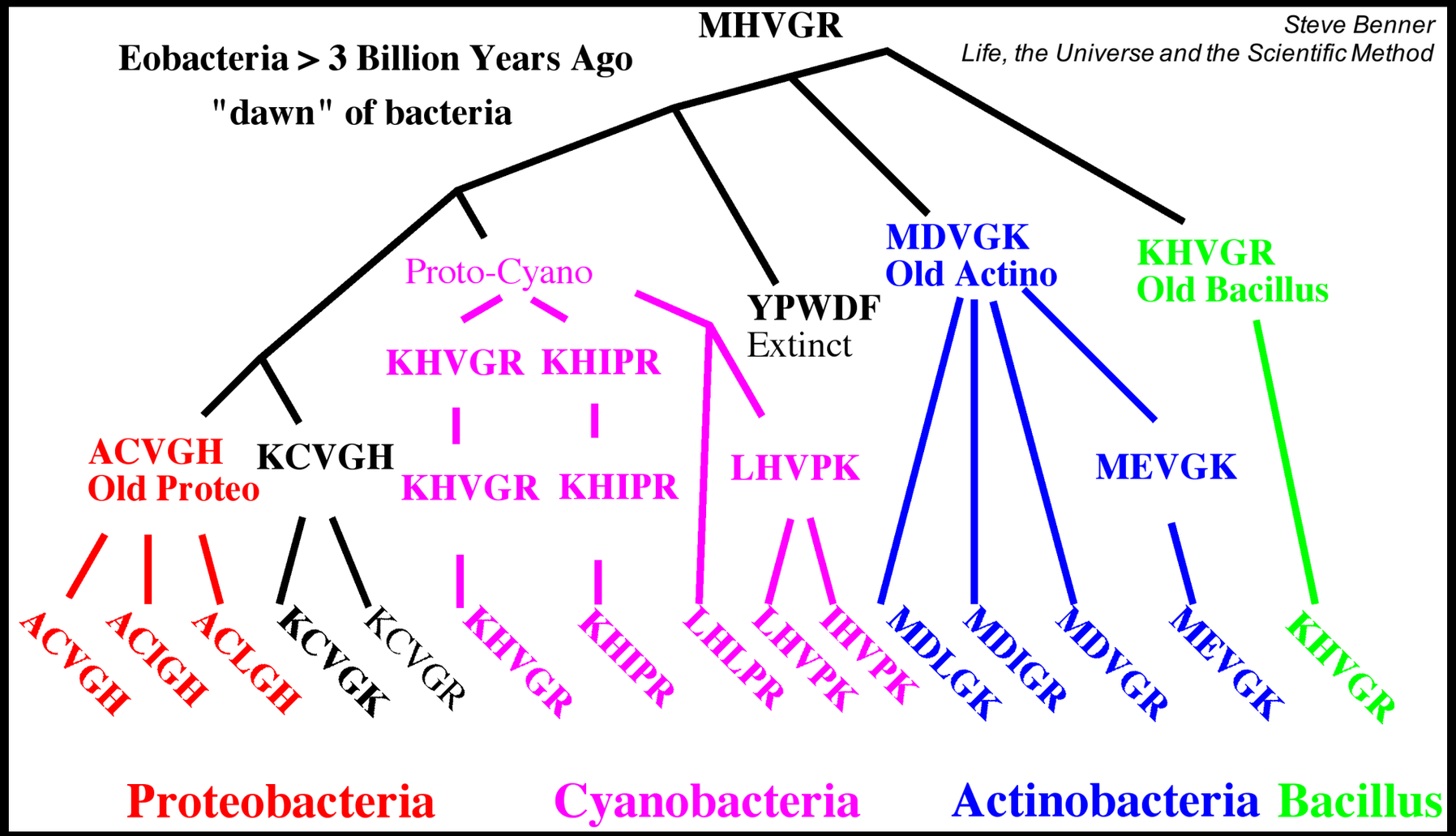
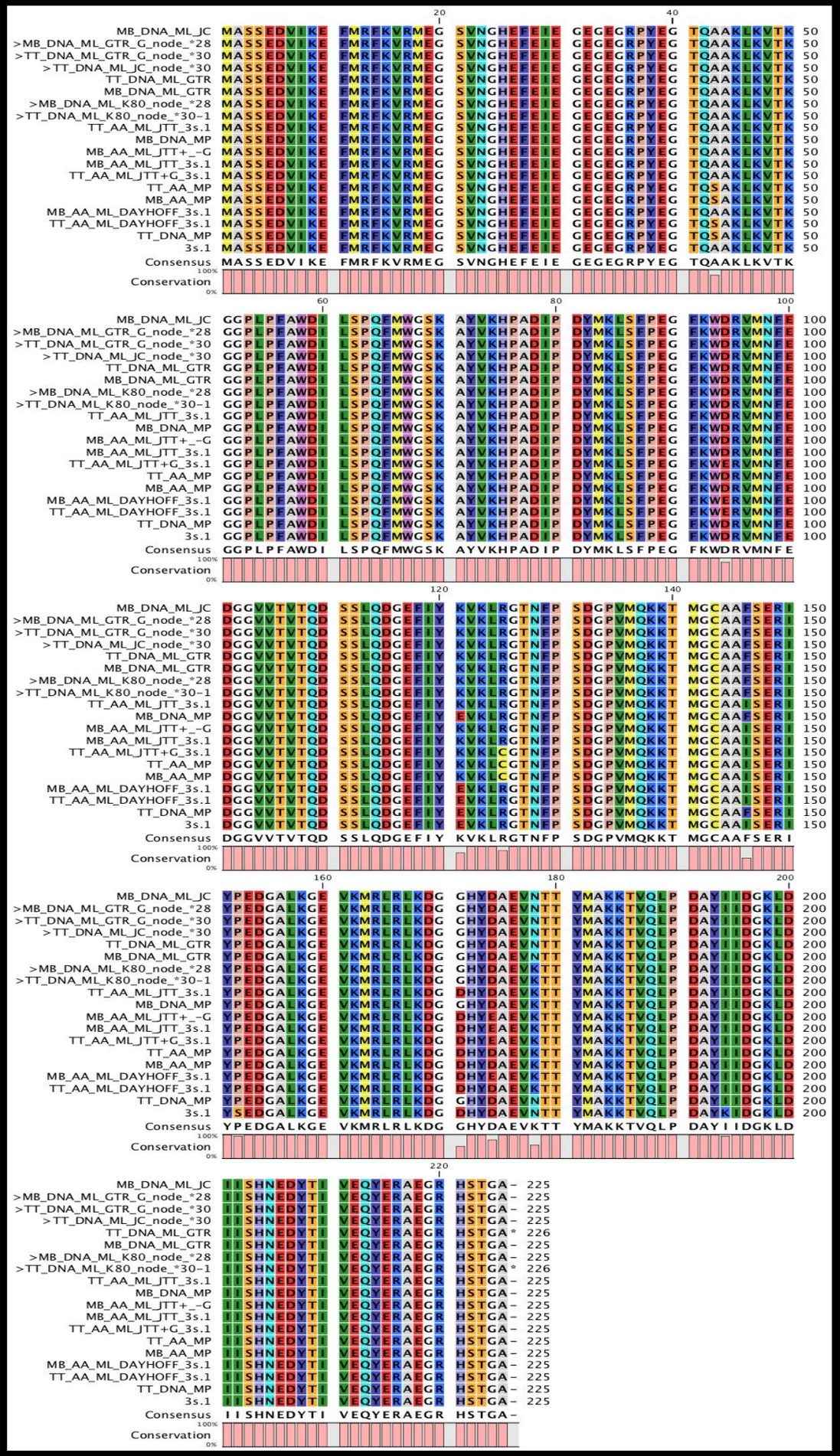


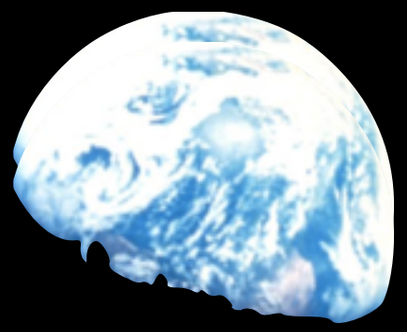


Ancestral Sequence Reconstruction

Reconstruct ancestral (ancient) proteins using modern biology

Motivating Questions

- How can we travel back in evolutionary time?
- How repeatable is life's evolution?
- Can we resurrect early life biosignatures?



Big astrobiology question: Is life repeatable?

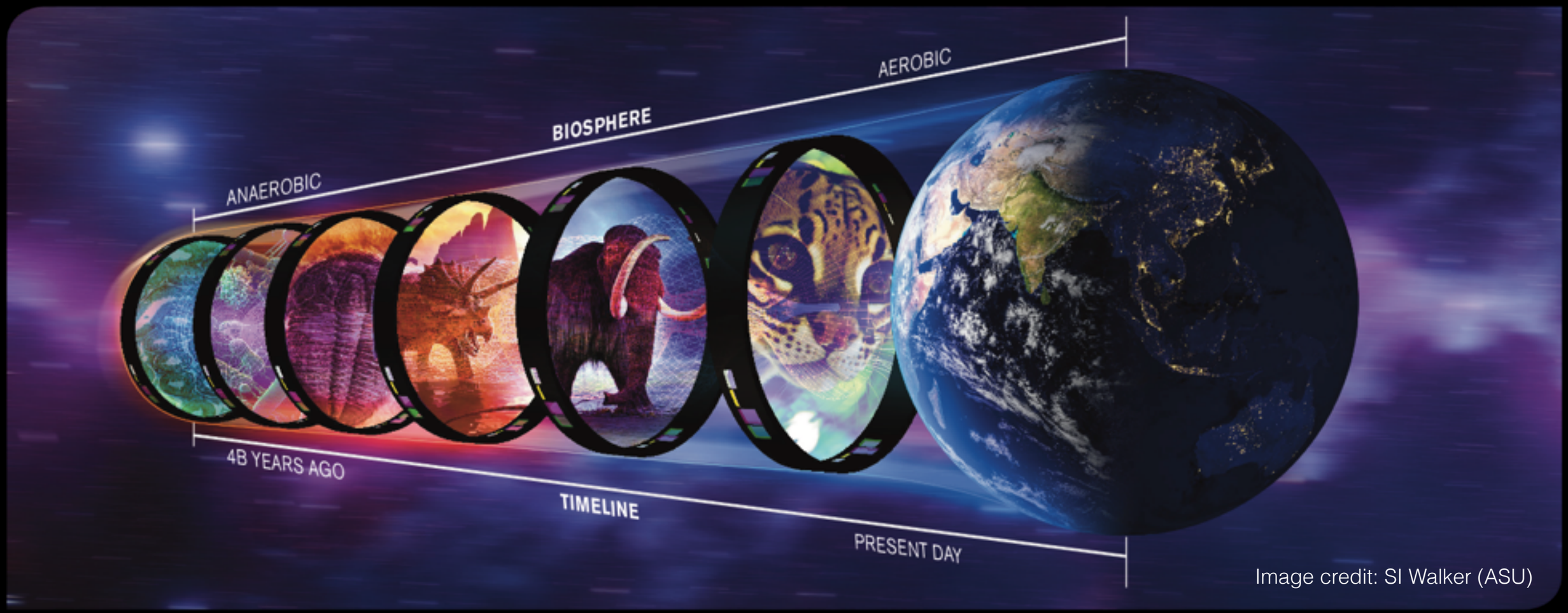


Image credit: SI Walker (ASU)

“I call this experiment "**replaying life's tape**".
You press the rewind button and, making sure you thoroughly erase everything that actually happens, go back to any time and place in the past. Then let the tape run again and see if the repetition looks at all like the original”.

Stephen Jay Gould
***Wonderful Life*, 1989**

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Stephen Jay Gould
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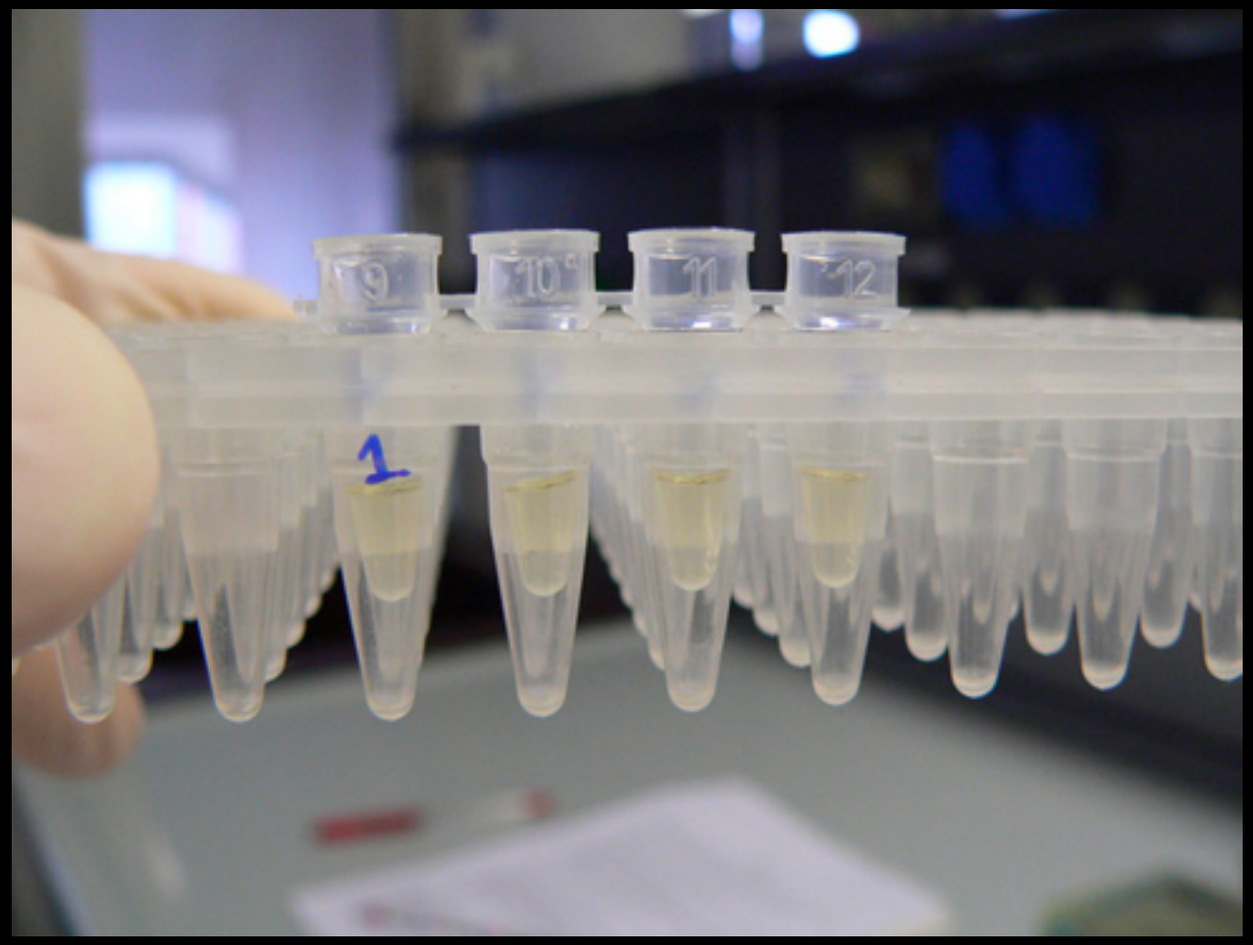
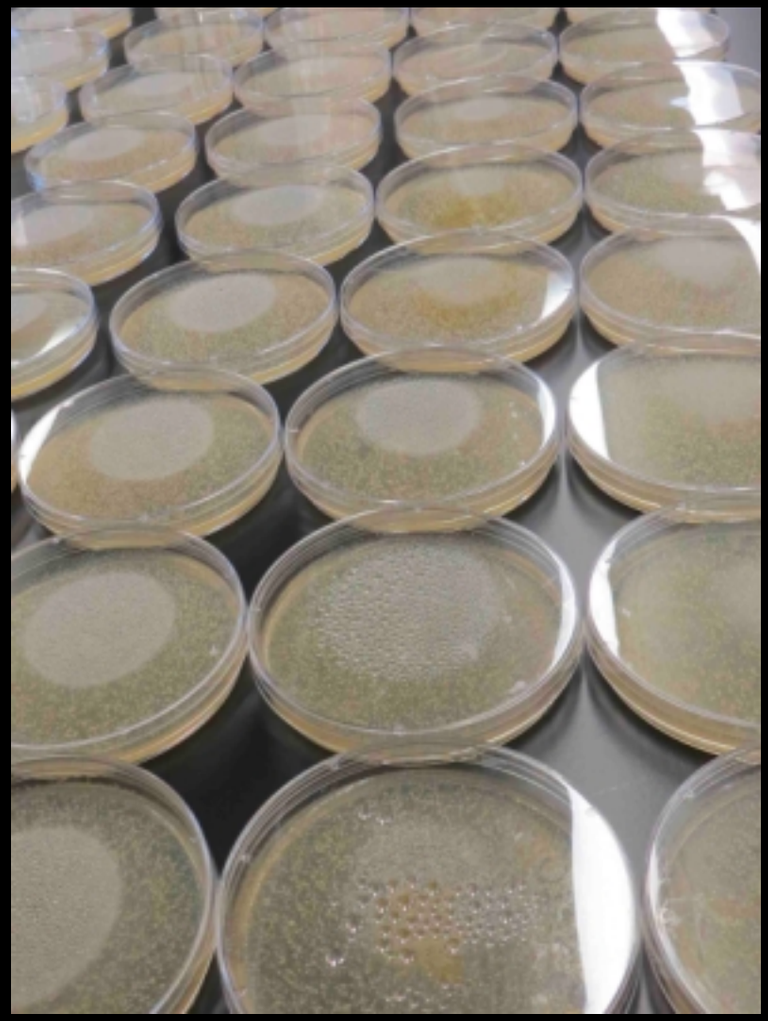
Experimental evolution of ancient genes in the laboratory using engineered microbes





Rewind and replay the tape of life (one molecule at a time)

Kacar et al. J Mol Evol 2017

Motivating Questions

- How can we travel back in evolutionary time?
- How repeatable is life's evolution?
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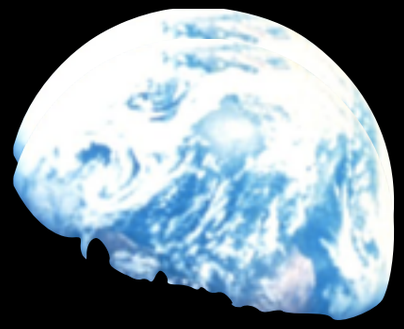
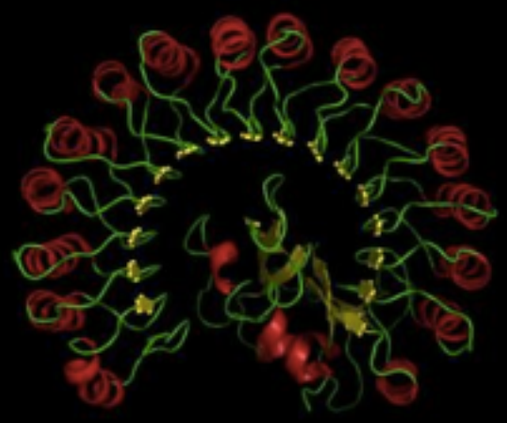
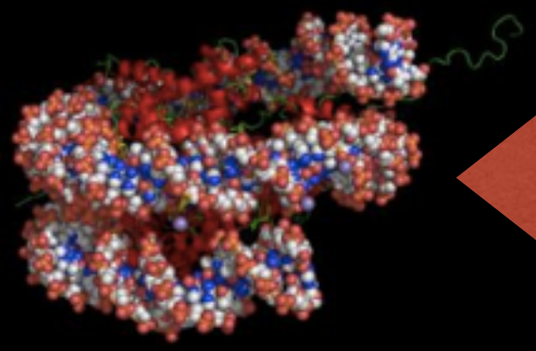
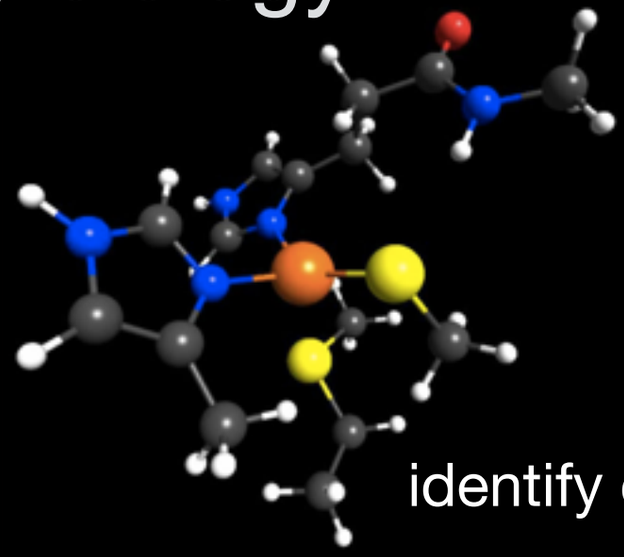


Modern life preserves signs of ancient protobiology

How are the chemicals used in early biology?







identify organics

reconstruct protobiology that used these types of primitive molecules

CH**N**O**PS**

Current / **Future**

Asteroid landing missions

Funding

ELSI Origins Network

Georgia Tech

John Templeton Foundation

NASA Postdoctoral Program
NASA Exobiology and Evolutionary Biology Program
NASA Early Career Science Award
NASA Astrobiology "Ribosome and Evolution" CAN5
NASA Astrobiology "Reliving the Past" CAN7

Blue Marble Space
Institute of Science

Science
Club
for Girls

HARVARD
Origins of Life

VWR®
We Enable Science

FAS Center
for Systems Biology

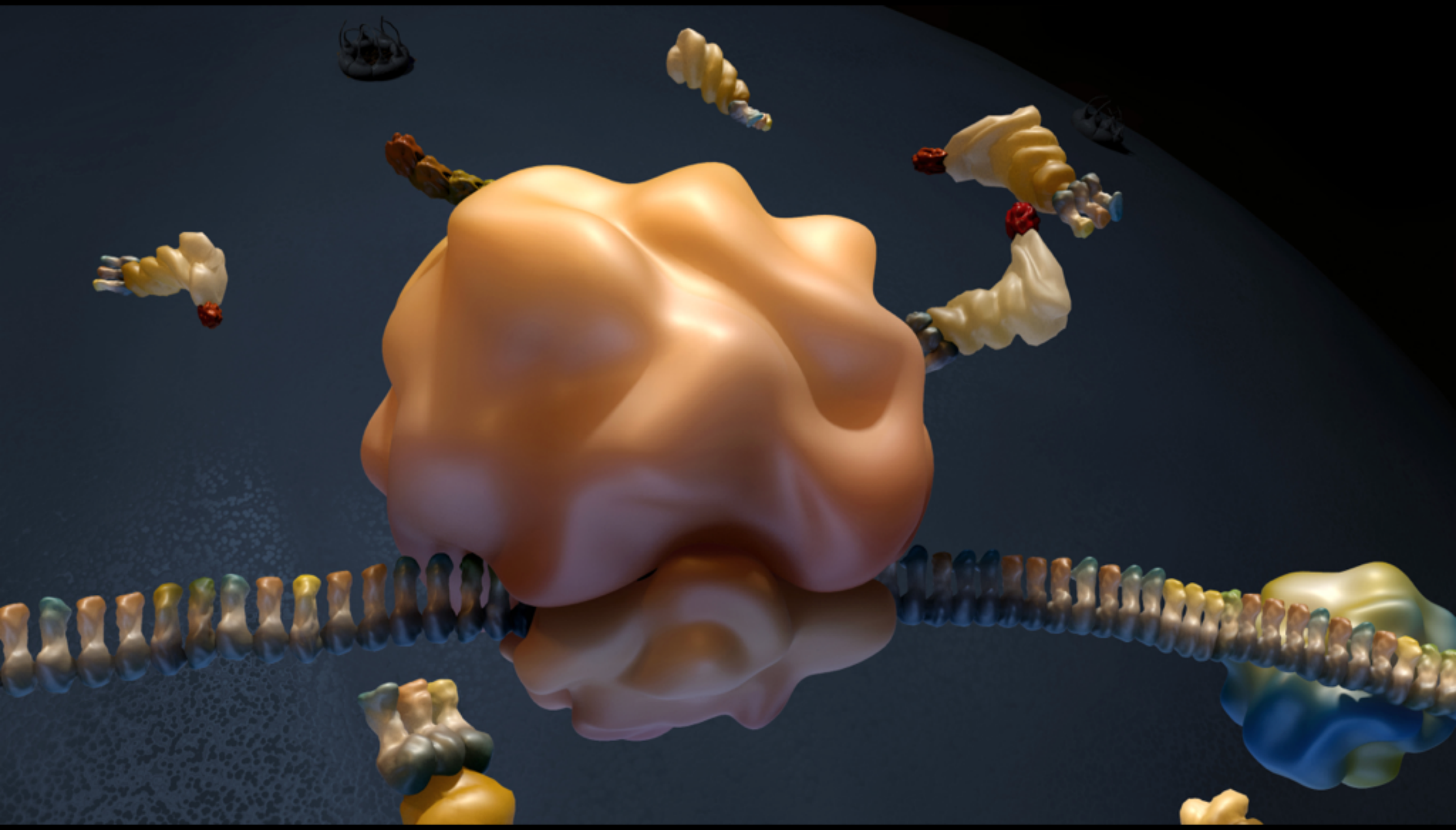
Current Collaborators

Kate Adamala (U Minnesota)
Dan Andersson (Uppsala)
John Baross (U Wash)
Michael Brenner (Harvard)
Church Lab (HMS)
Greg Fournier (MIT)
Lionel Guy (Uppsala)
Dave Johnston (Harvard)
O'Shea Lab (Harvard)
Margie Kinnersely (U Montana)
Sergey Kryazhimskiy (UCSD)
Ann Pearson (Harvard)
Desai Lab (Harvard)
Daniel Segre (Boston U)
Eric Smith (ELSI, Santa Fe)

Thank you NASA!

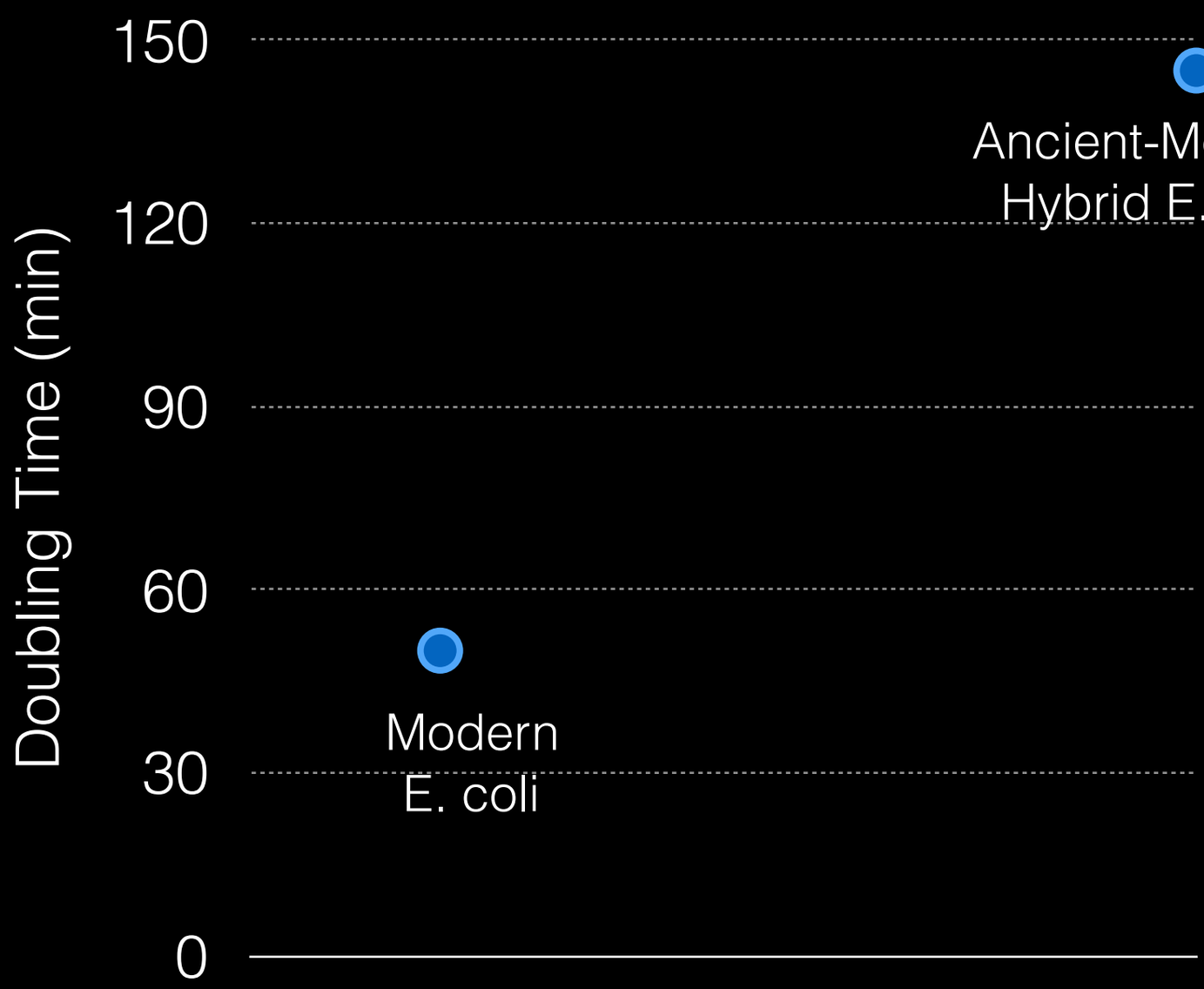
contact: kacar@g.harvard.edu

Ribosome is the protein making machinery of every terran cell



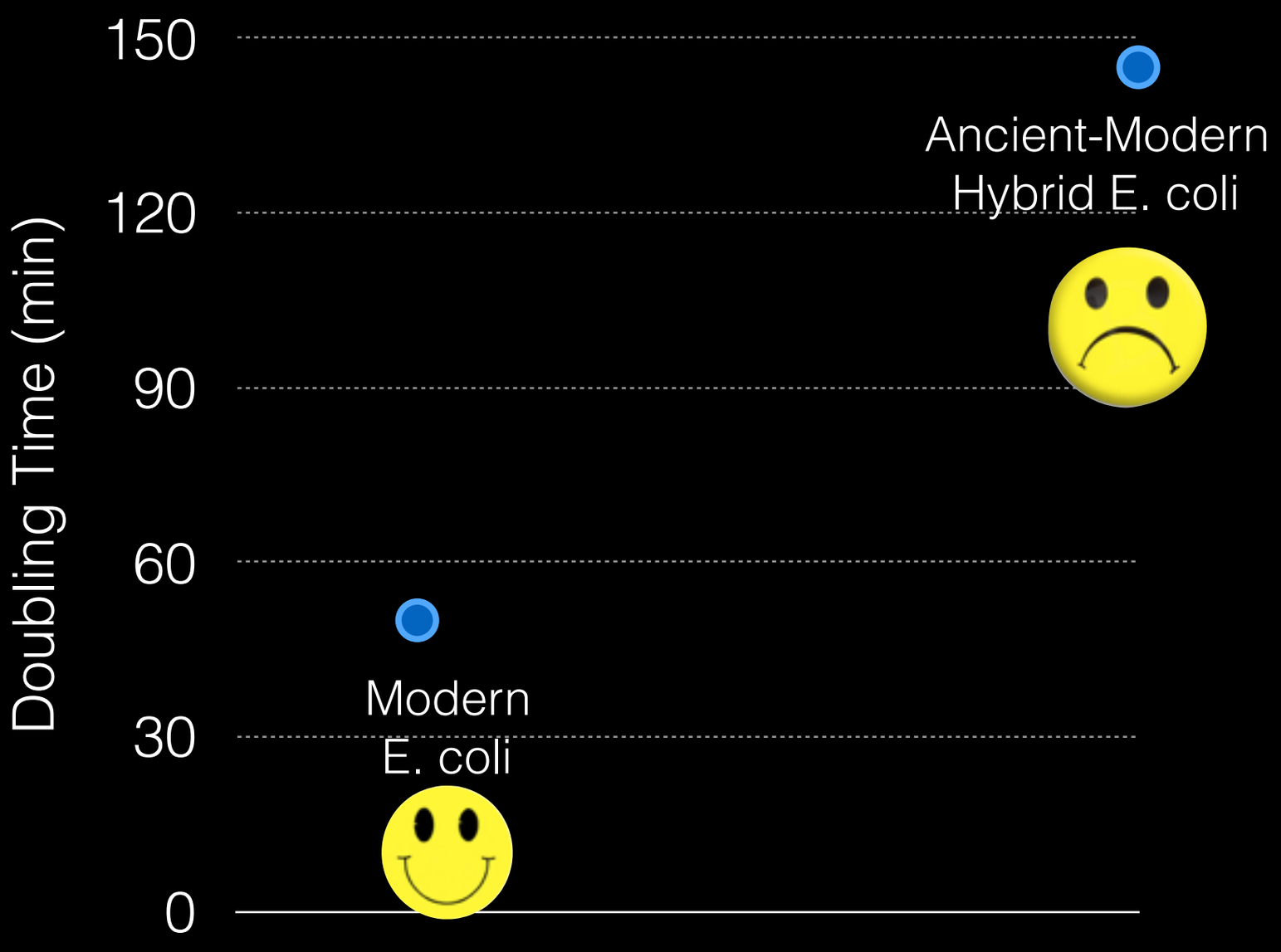
Replace ribosome components with ancient counterparts

Impact of ancient gene on bacterial growth



[Kacar and Gaucher, Artificial Life, 2013]
[Kacar and Gaucher, Biochem J, 2014]
[Kacar, Chance in Evolution, U Chicago Press, 2016]
[Kacar, Ge, Sanyal and Gaucher, J Mol Evol, in press]

Impact of ancient gene on bacterial growth



It's alive! (but sick)

[Kacar et al, Artificial Life, 2013]
[Kacar et al, Biochem J, 2014]
[Kacar, Chance in Evolution, U Chicago Press, 2016]
[Kacar et al, J Mol Evol, 2017]