Craving continuity from cosmochemistry to cosmochemists

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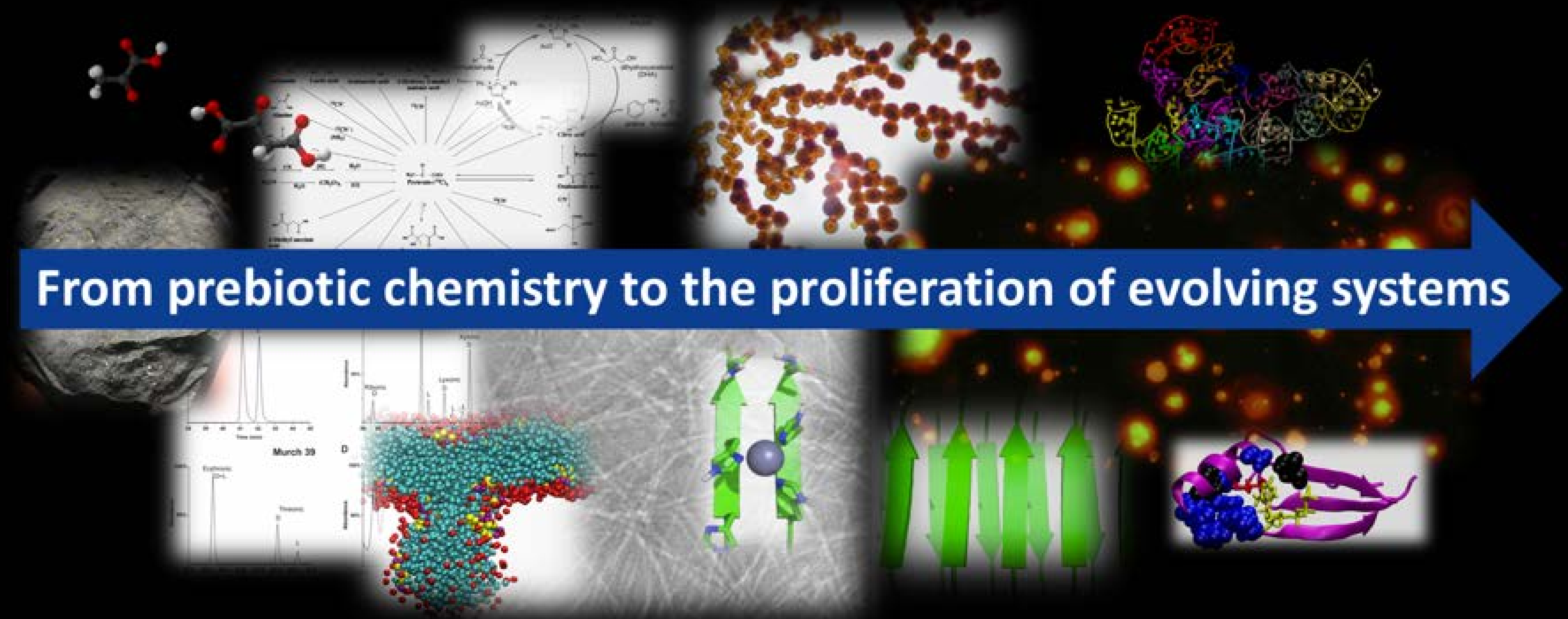
February 27th 2019

Center for the Emergence of Life

We ask fundamental questions

What processes drove the emergence and early evolution of life on Earth?

What is the potential for life to emerge in other habitable environments?



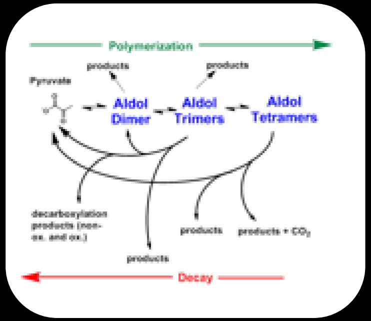
Center for the Emergence of Life

www.nasa.gov/content/center-for-the-emergence-of-life

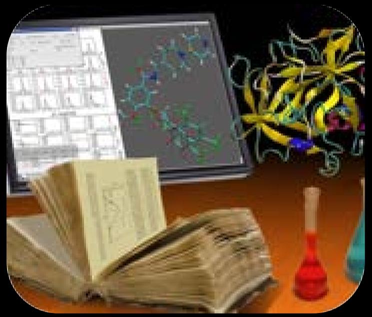
We are interdisciplinary

Cosmochemistry

Systems Chemistry

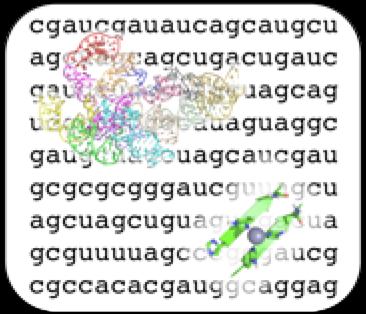


Molecular Modeling



In vitro Evolution

Bioinformatics

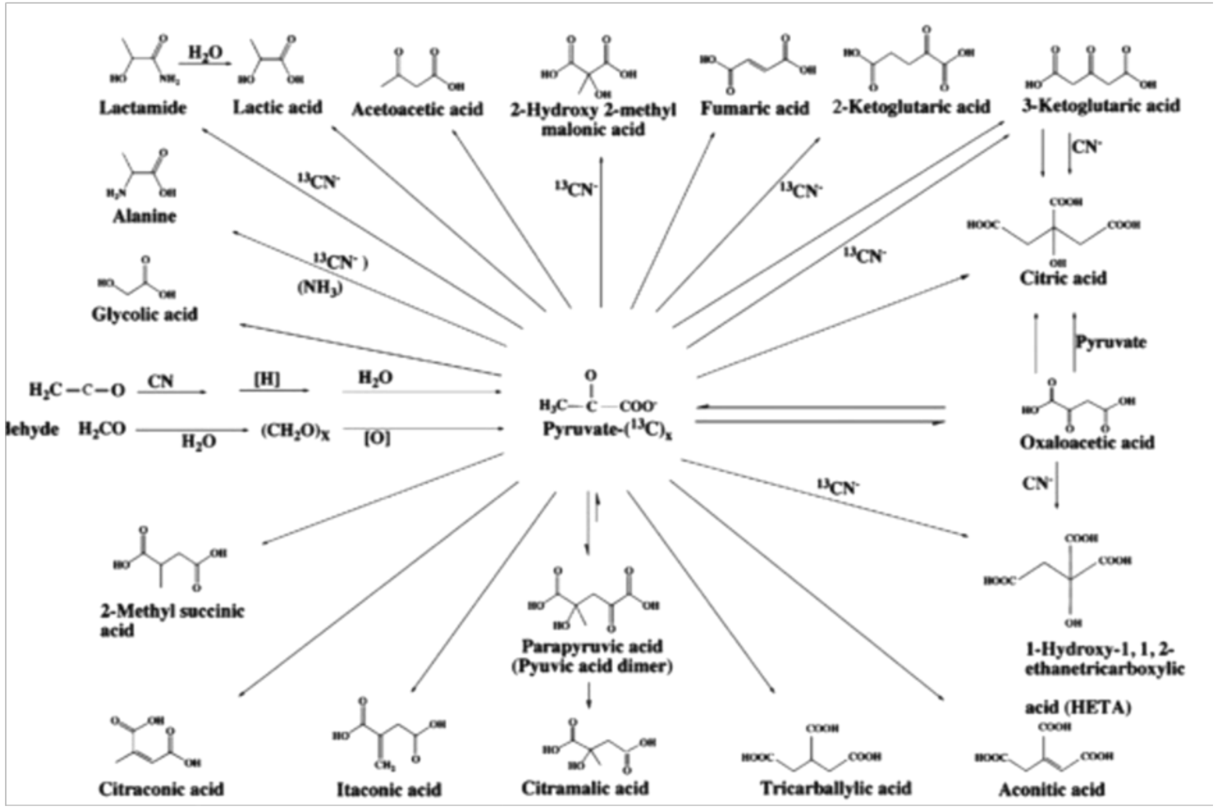


Synthetic Biology

Potential proto-life pieces plop down from the sky

Tons of carbon per year rains down on the Earth (IDPs and meteorites)

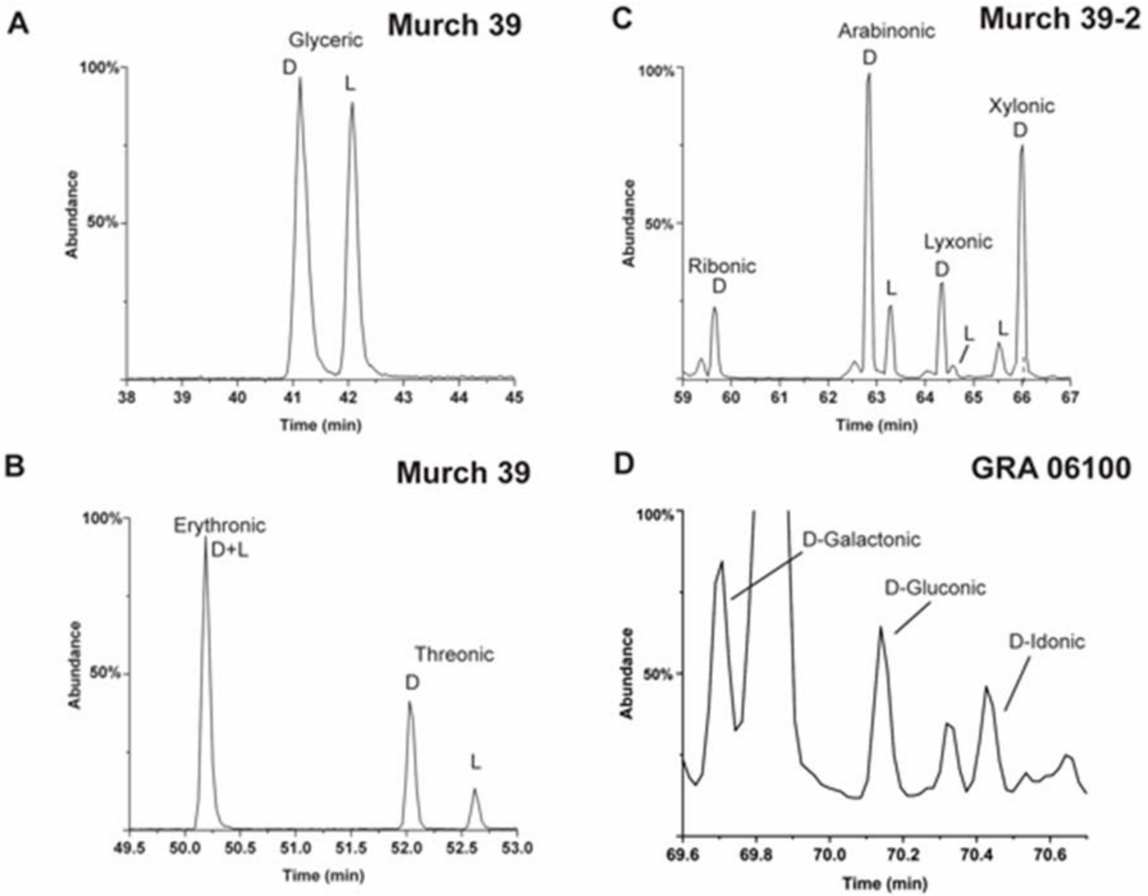
e.g. Murchinson

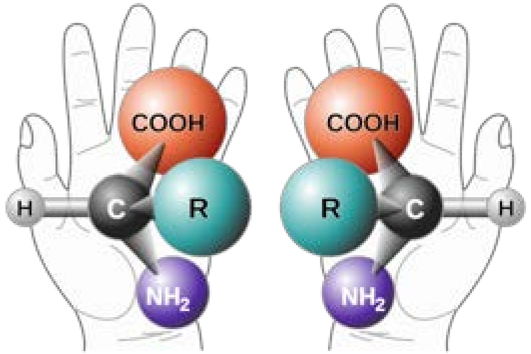


George Cooper

Cooper, G., Reed, C., Nguyen, D., Carter, M., & Wang, Y. (2011). Detection and formation scenario of citric acid, pyruvic acid, and other possible metabolism precursors in carbonaceous meteorites. *Proceedings of the National Academy of Sciences,* 108(34), 14015-14020.

Curiously, cosmochemistry can cause chiral preference





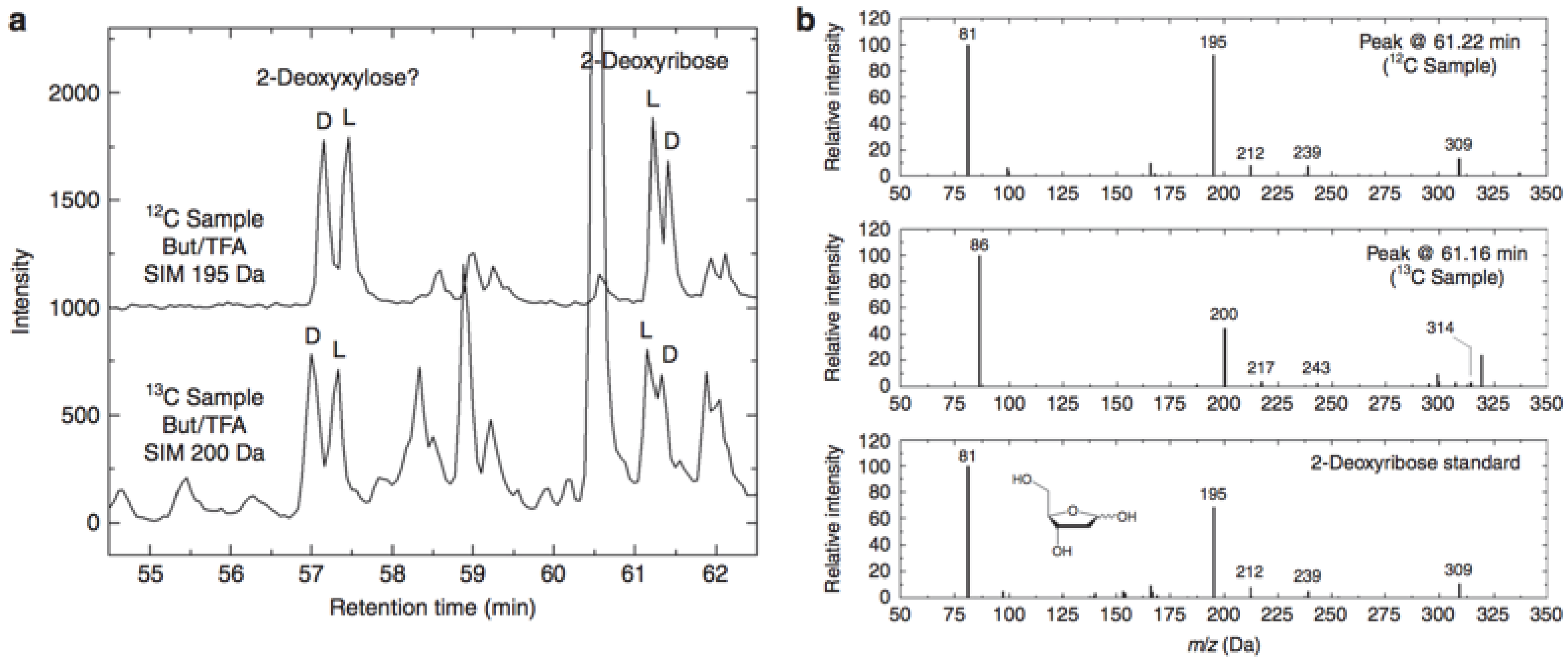
George Cooper

Andro Rios

Cooper, G., & Rios, A. C. (2016). Enantiomer excesses of rare and common sugar derivatives in carbonaceous meteorites. *Proceedings of the National Academy of Sciences*, 113(24), E3322-E3331.

Investigating irradiated ices indicates irrelevant “building blocks” can be identified

Deoxyribose: it is there but I doubt that’s why we use it

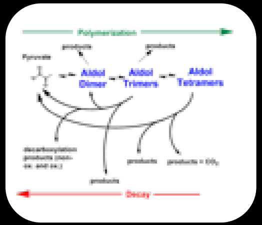


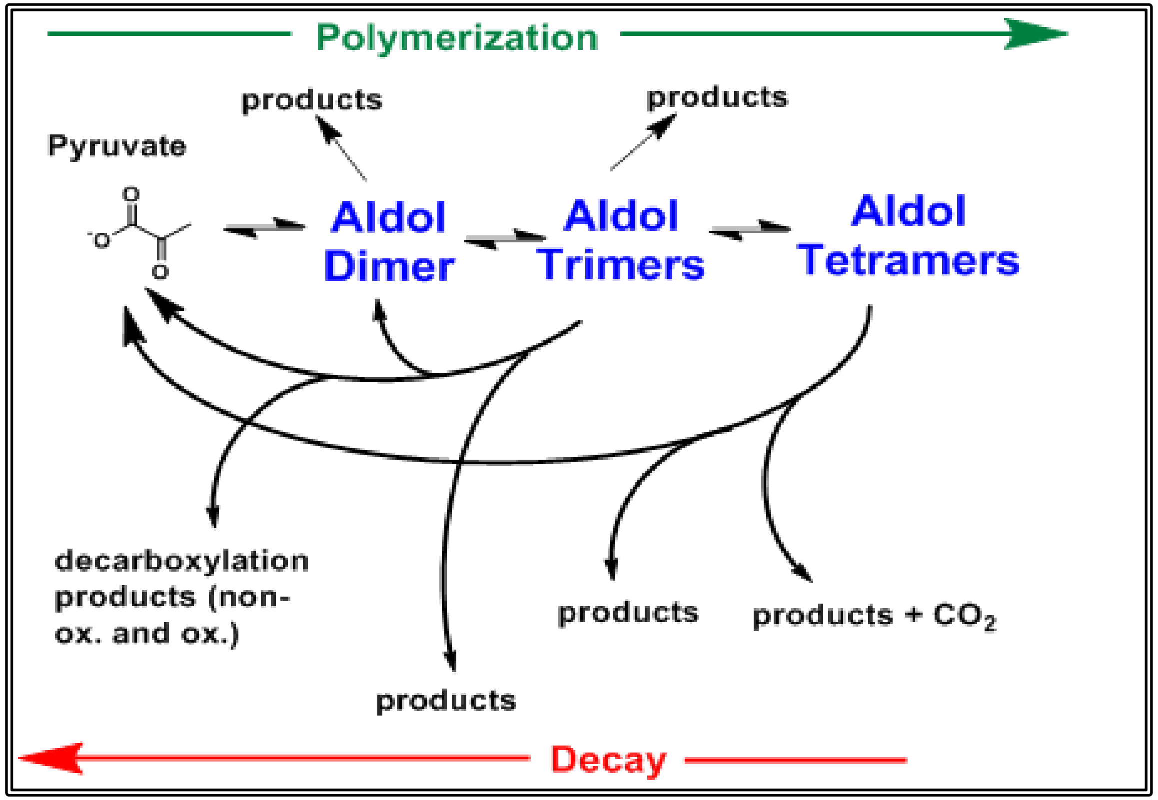
Michel Nuevo

Scott Sandford

Nuevo, M., Cooper, G., & Sandford, S. A. (2018). Deoxyribose and deoxysugar derivatives from photoprocessed astrophysical ice analogues and comparison to meteorites. Nature Communications, 9(1), 5276.

The process of providing the pieces (pyruvate polymers)





Network model for the pyruvate reaction network (PRN).

Andro Rios

George Cooper

Explain what is observed in meteorites and predict how this can lead to metabolism

Interesting insights from in vitro evolution

In vitro evolution can be used to ask…

What RNA can do?

How can RNA evolve new functions?

How common are functional RNAs in sequence space?

How complex do functional RNAs need to be?

What were the roles of chance and necessity in the evolution biological RNA structures?

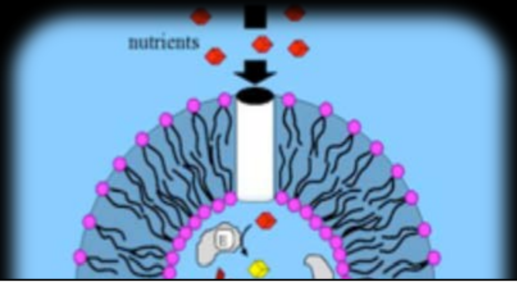
Initial DNA template library (~10^{15} unique sequences)

Geochemical, cellular, and genomic context of early evolutionary processes

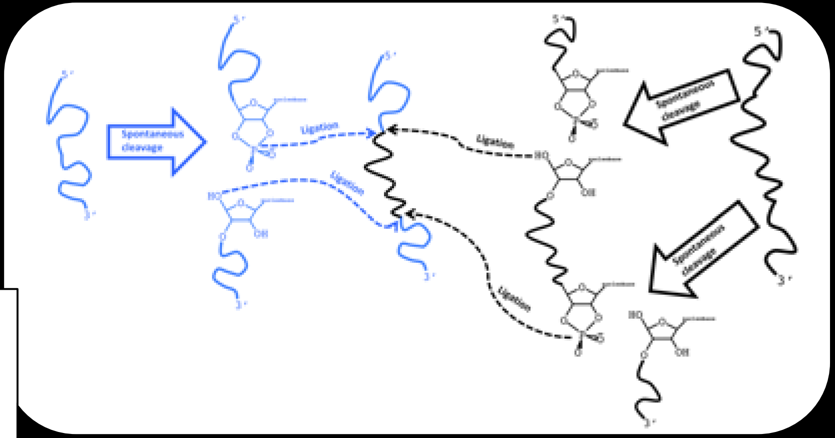
The early geochemical environment

PREBIOTIC CHEMISTRY AND EARLY EARTH ENVIRONMENTS
PCE3

The emerging cellular environment



Early and dynamic genomic environment



7070–7082 *Nucleic Acids Research, 2015, Vol. 43, No. 14* *Published online 29 June 2015*
doi: 10.1093/nar/gkv648

In vitro evolution of distinct self-cleaving ribozymes in diverse environments

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Received March 06, 2015; Revised June 10, 2015; Accepted June 11, 2015

Harbor Laboratory Press for the RNA Society

Evolution of ribozymes in the presence of a mineral surface

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Journal of Molecular Evolution (2019) 87:240–253
https://doi.org/10.1007/s00239-019-09906-3

ORIGINAL ARTICLE

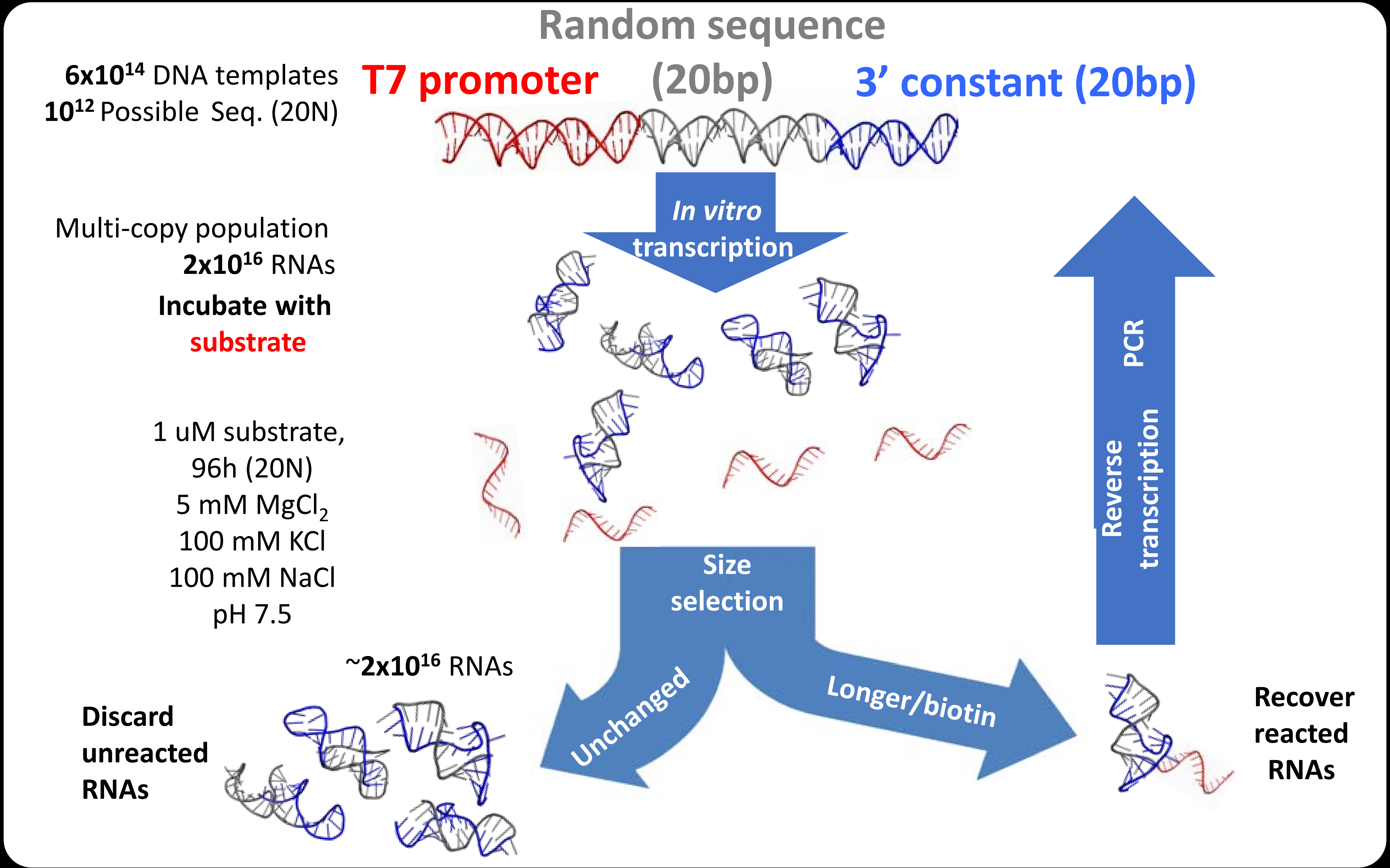
Big on Change, Small on Innovation: Evolutionary Consequences of RNA Sequence Duplication

Andrew Plebanek[1,2] · Caleb Larnerd[3] · Milena Popović[1,4,5] · Chenyu Wei[1,2,4] · Andrew Pohorille[1,2,4] · Mark A. Ditzler[1,4]

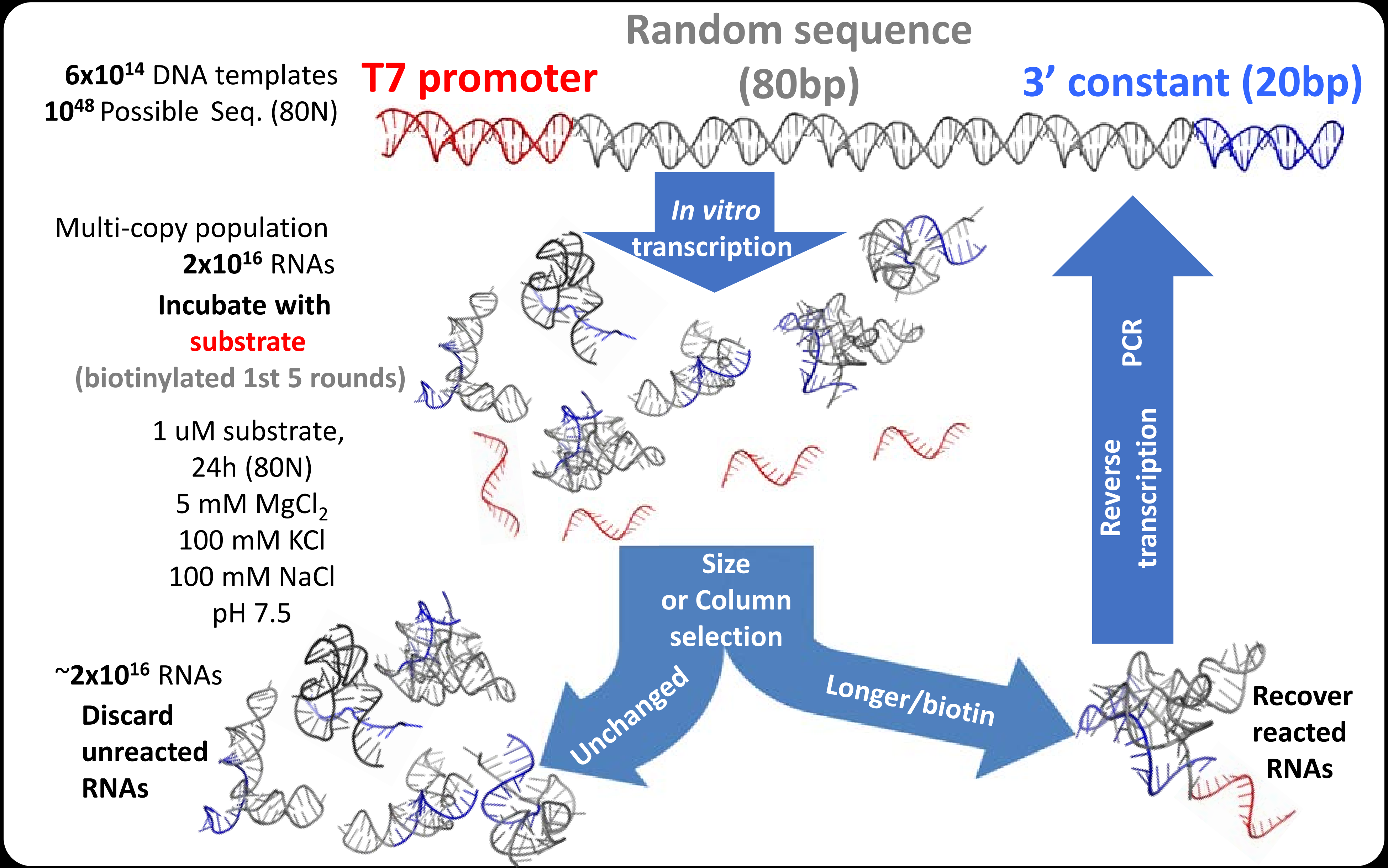
Early and dynamic genomic environment

What is the role of polymer length in RNA evolution?

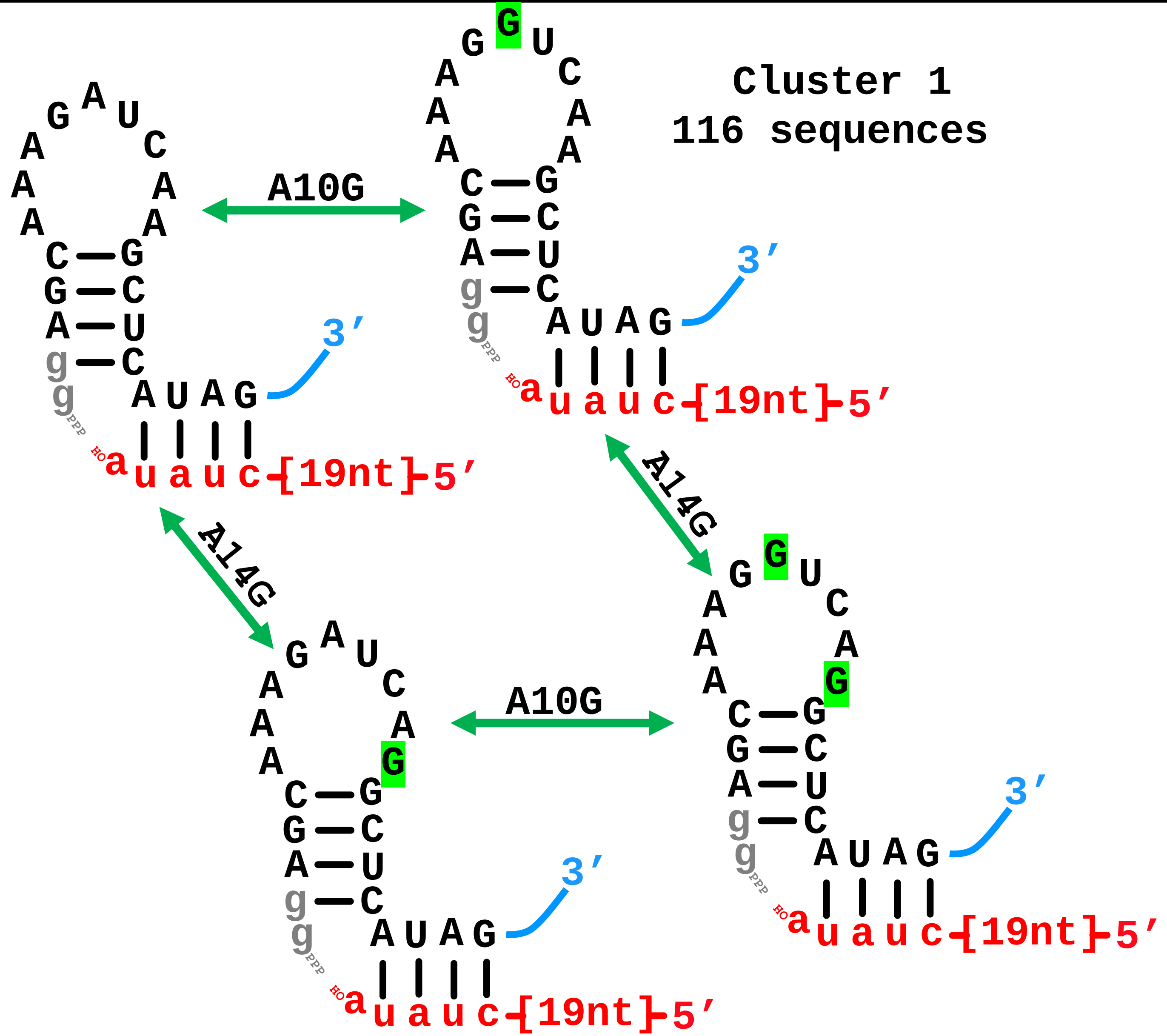
In vitro evolution of ligase ribozymes (20N)



In vitro evolution of ligase ribozymes (80N)



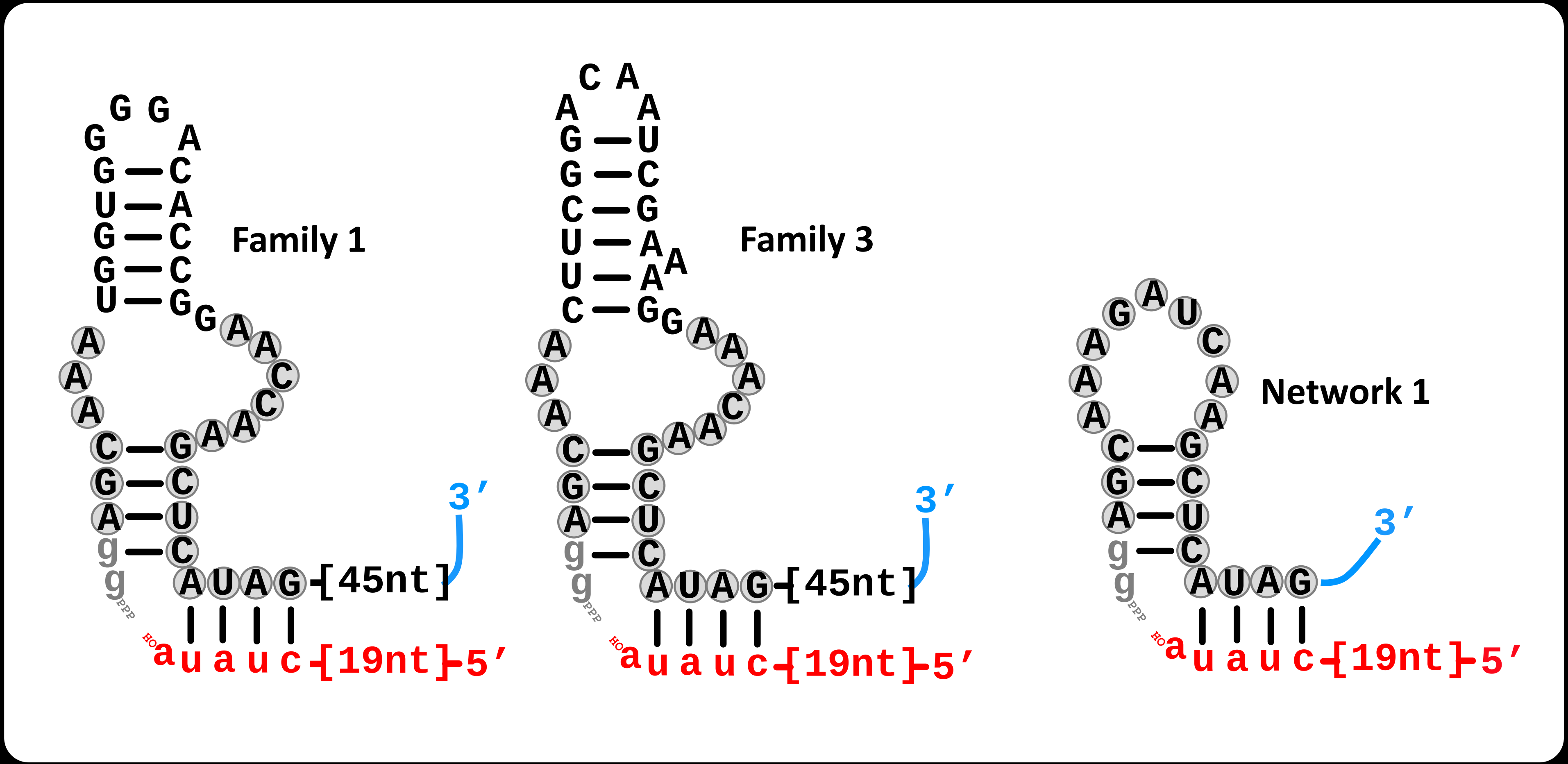
20N ligases: isolated networks for small RNAs



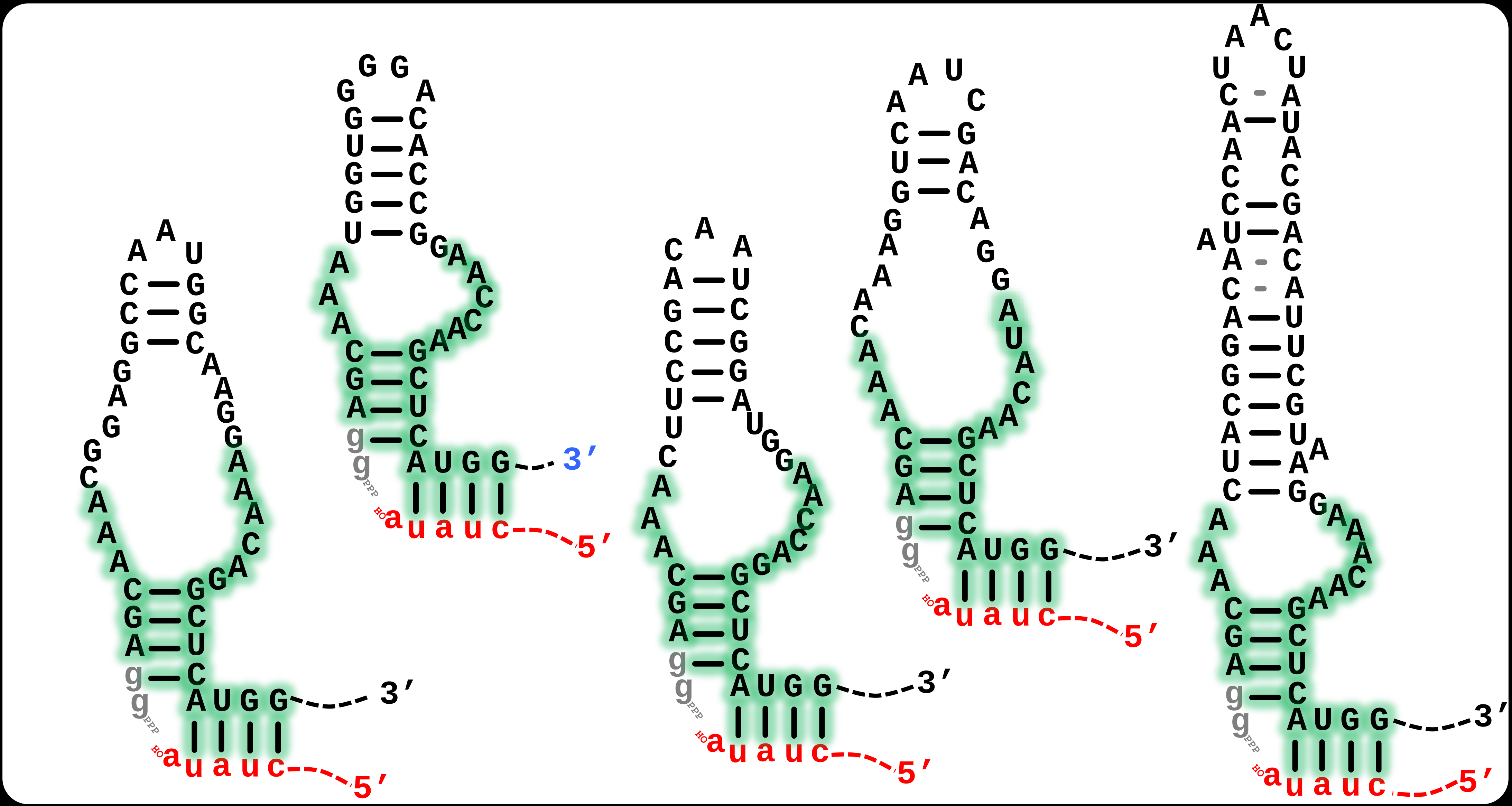
Milena Popović

Small networks of rare sequences are the most active

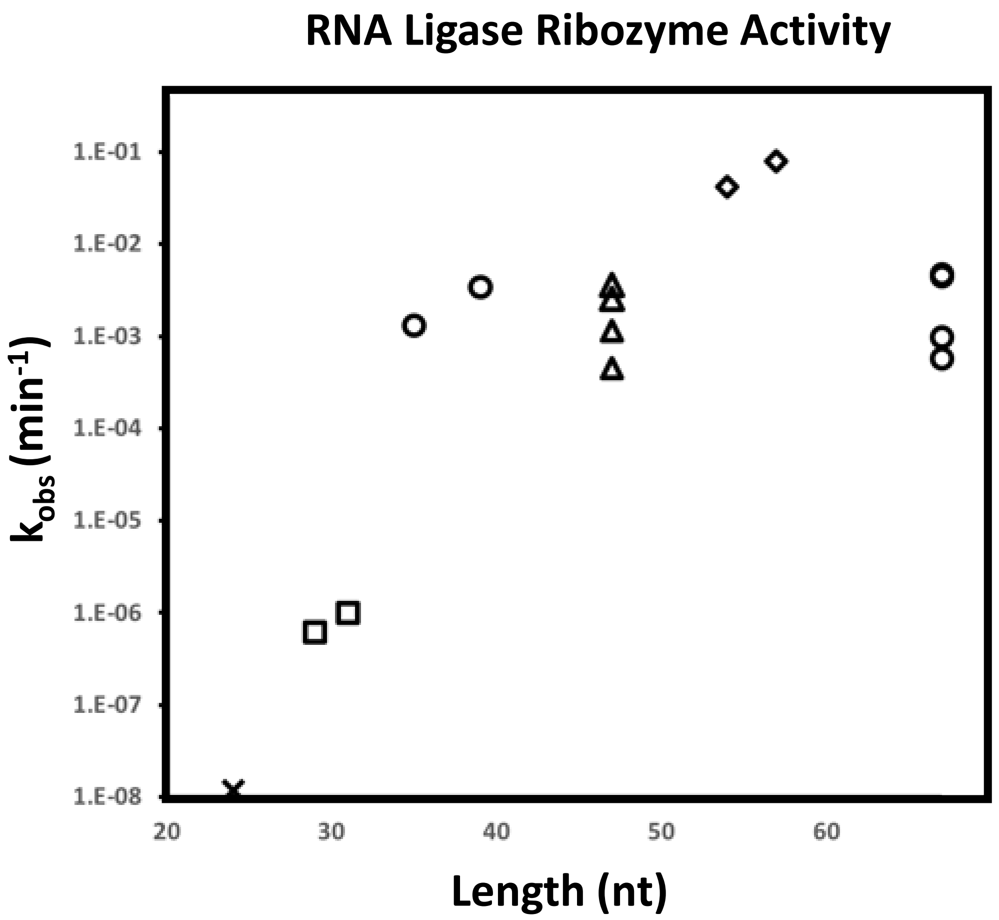
80N ligase: Independent lineages converge on the an internal loop motif with a terminal loop core

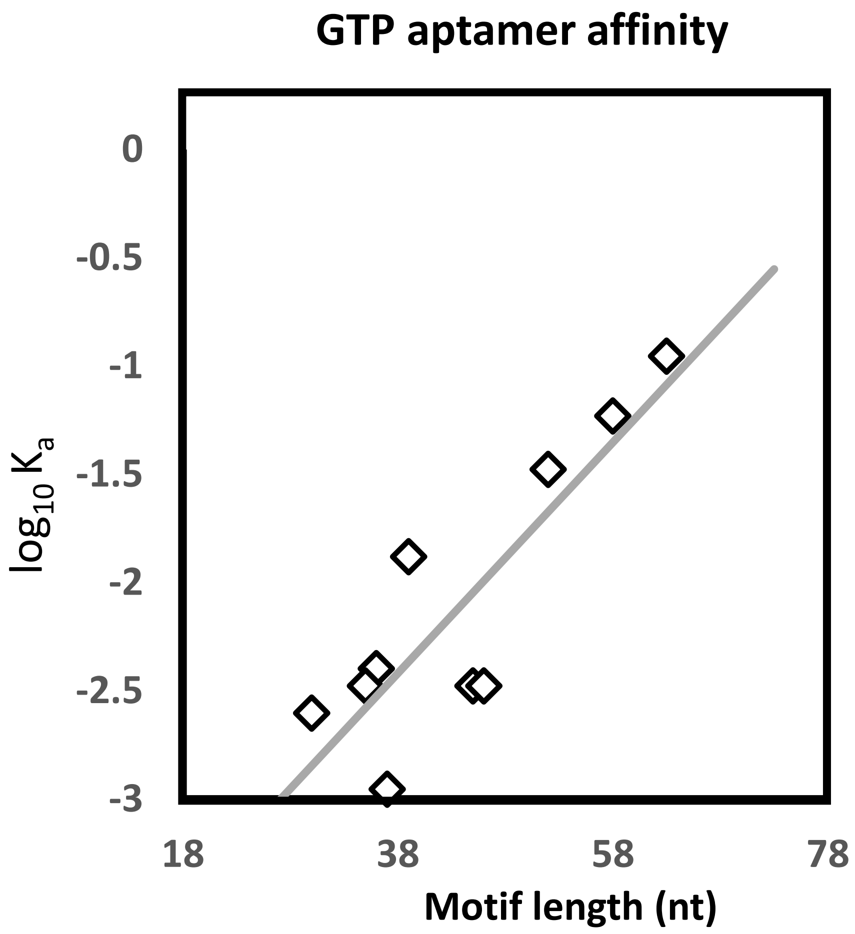


Reselection: Evidence for isolated network for long RNAs



Sequences expansion offers a tremendous selective advantage



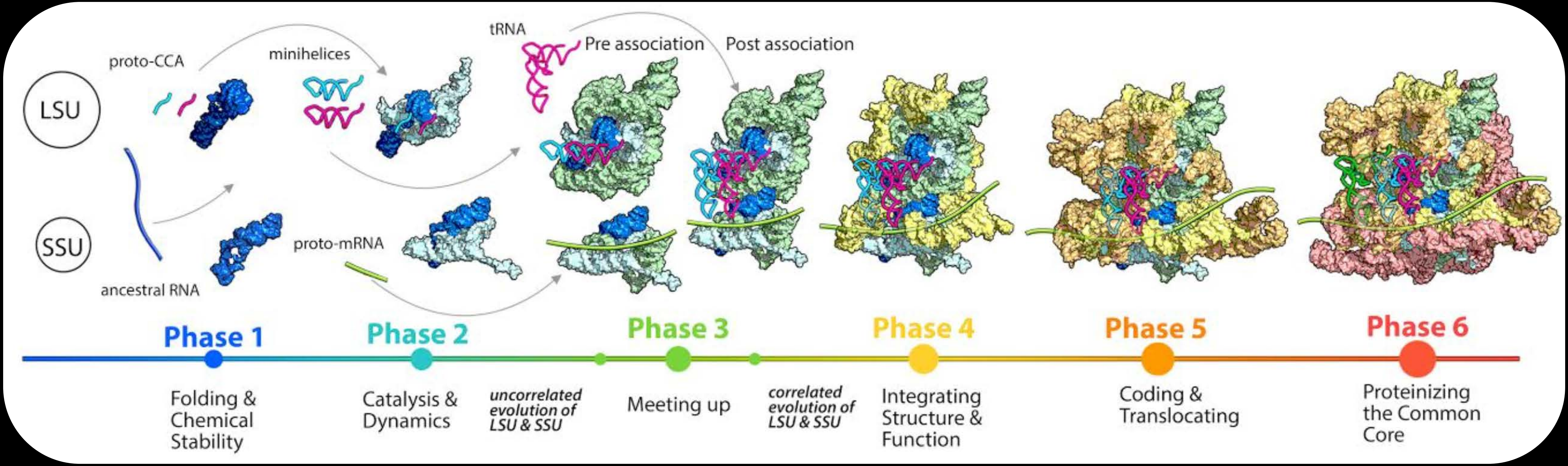


Carothers JM, et al. JACS. 2004 Apr 28;126(16):5130-7.

What about actual biological systems?

By examining the diversity of modern biological structures we infer features of ancient biochemistry.

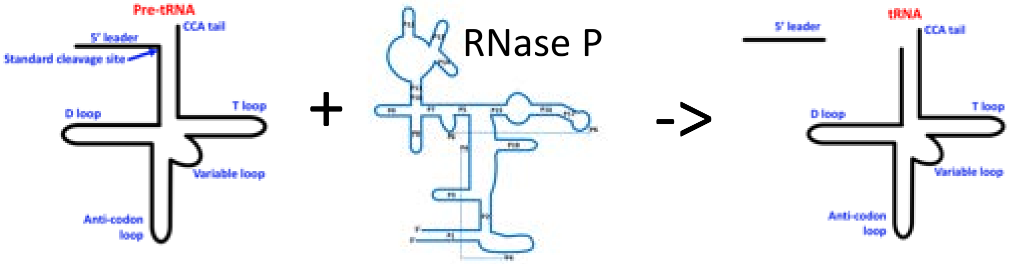
The Accretion Model of ribosome evolution



Petrov, A. S., Gulen, B., Norris, A. M., Kovacs, N. A., Bernier, C. R., Lanier, K. A., ... & Williams, L. D.
"History of the ribosome and the origin of translation."
Proceedings of the National Academy of Sciences 112, no. 50 (2015): 15396-15401

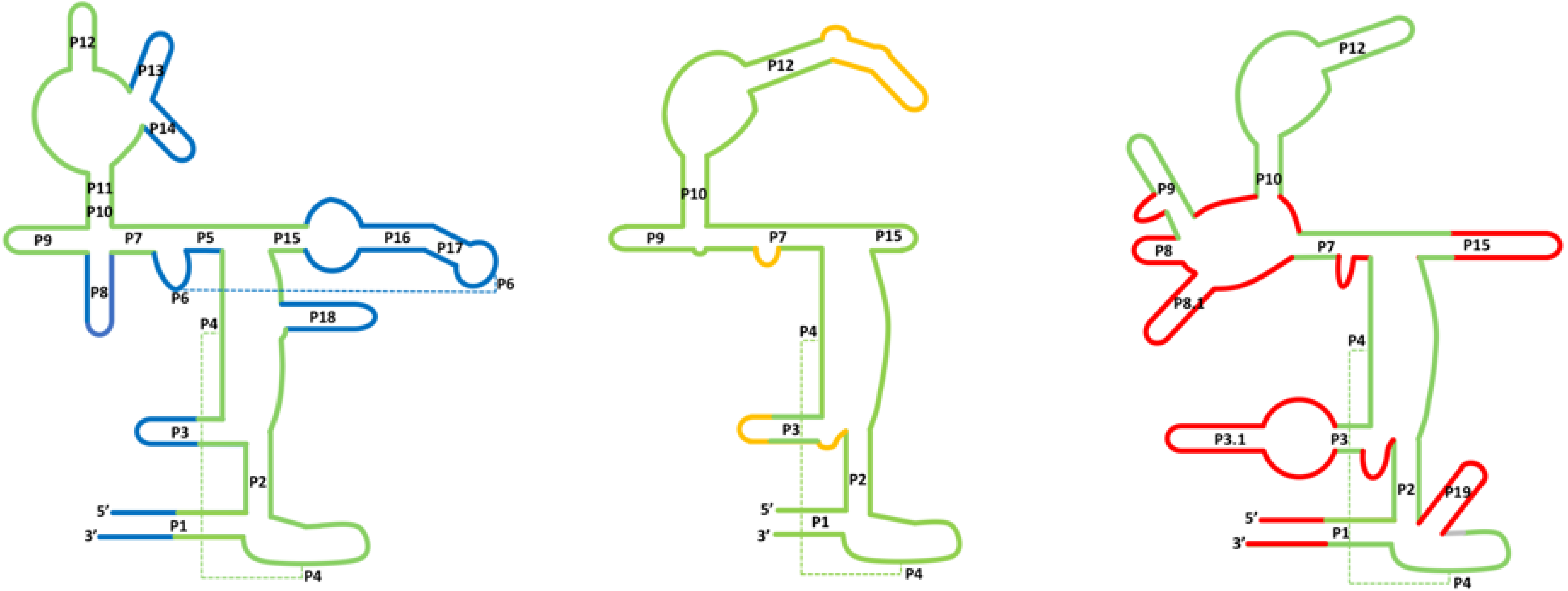
Ribonuclease P(RNase P): a near universal ribozyme with a deep evolutionary history

tRNA maturation in all three domains of life by a conserved RNA structure

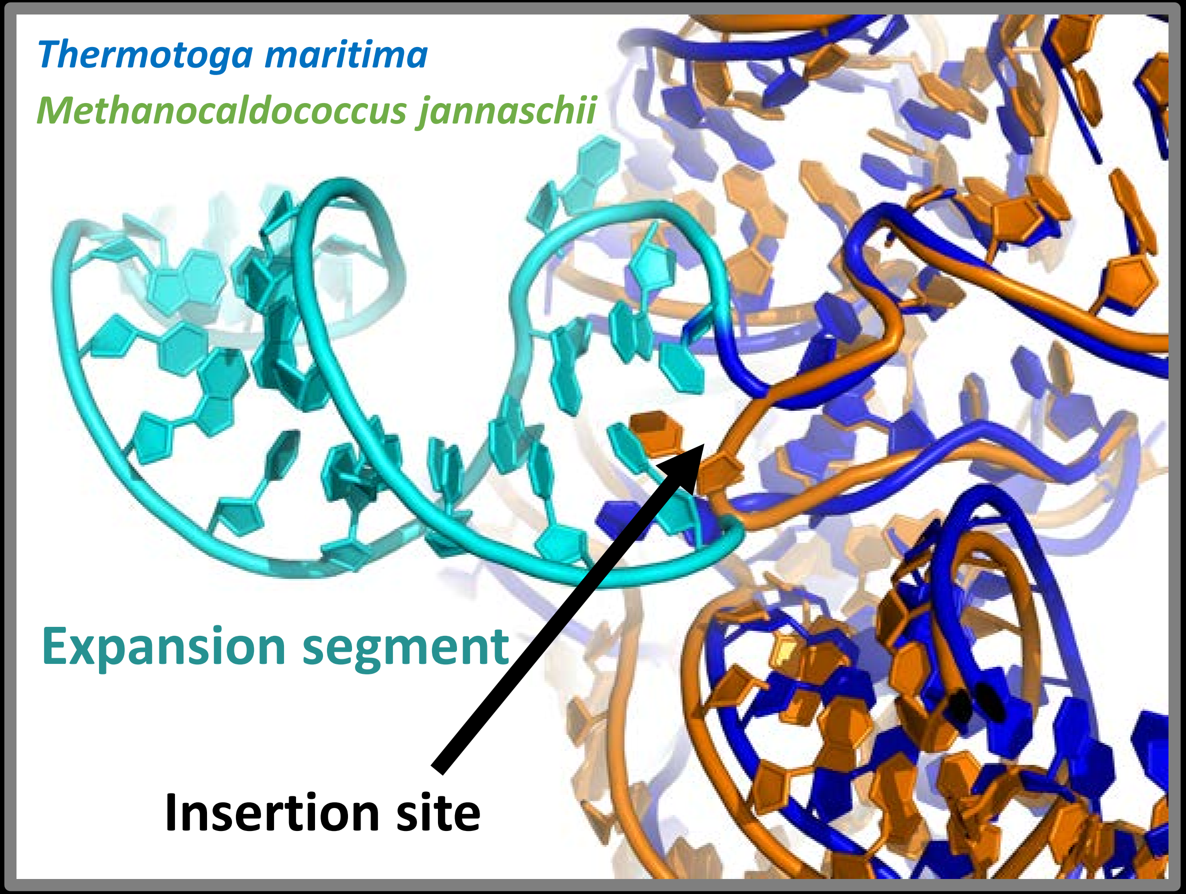


Conserved elements (structure and sequence)

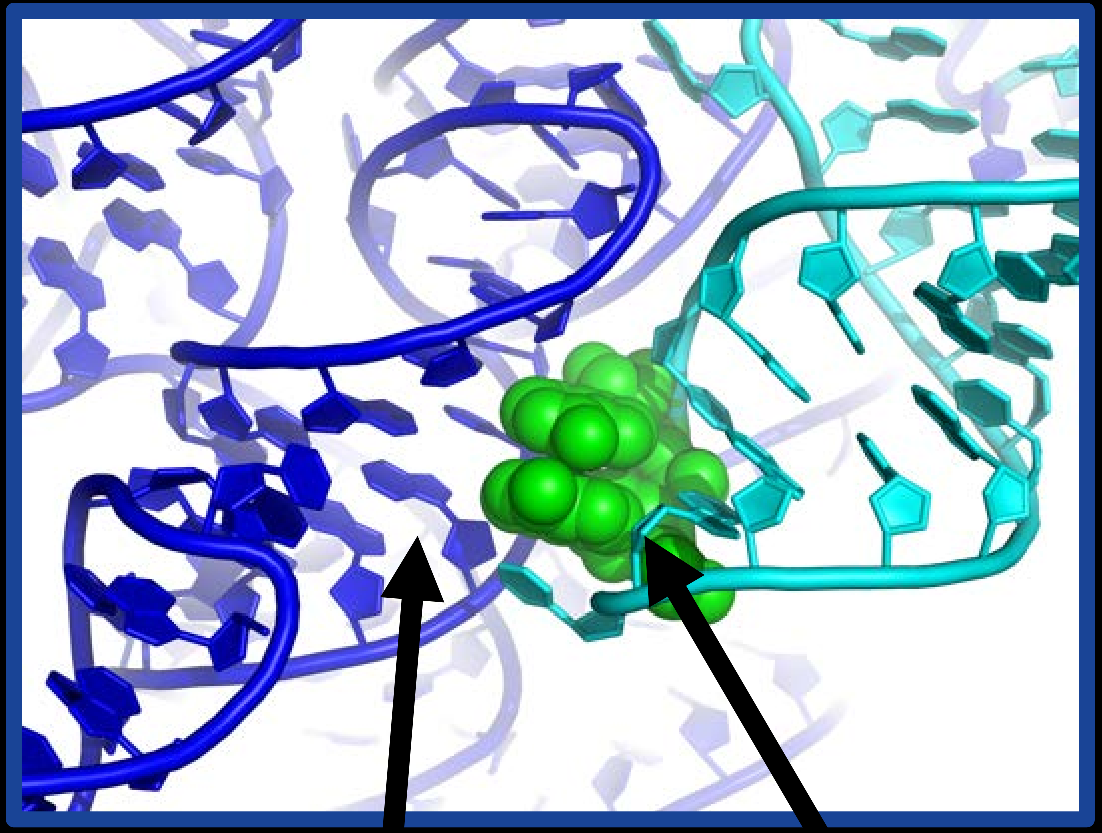
Thermotoga maritima *Methanocaldococcus jannaschii* *Saccharomyces cerevisiae*



Insertion finger-prints in RNase P RNA



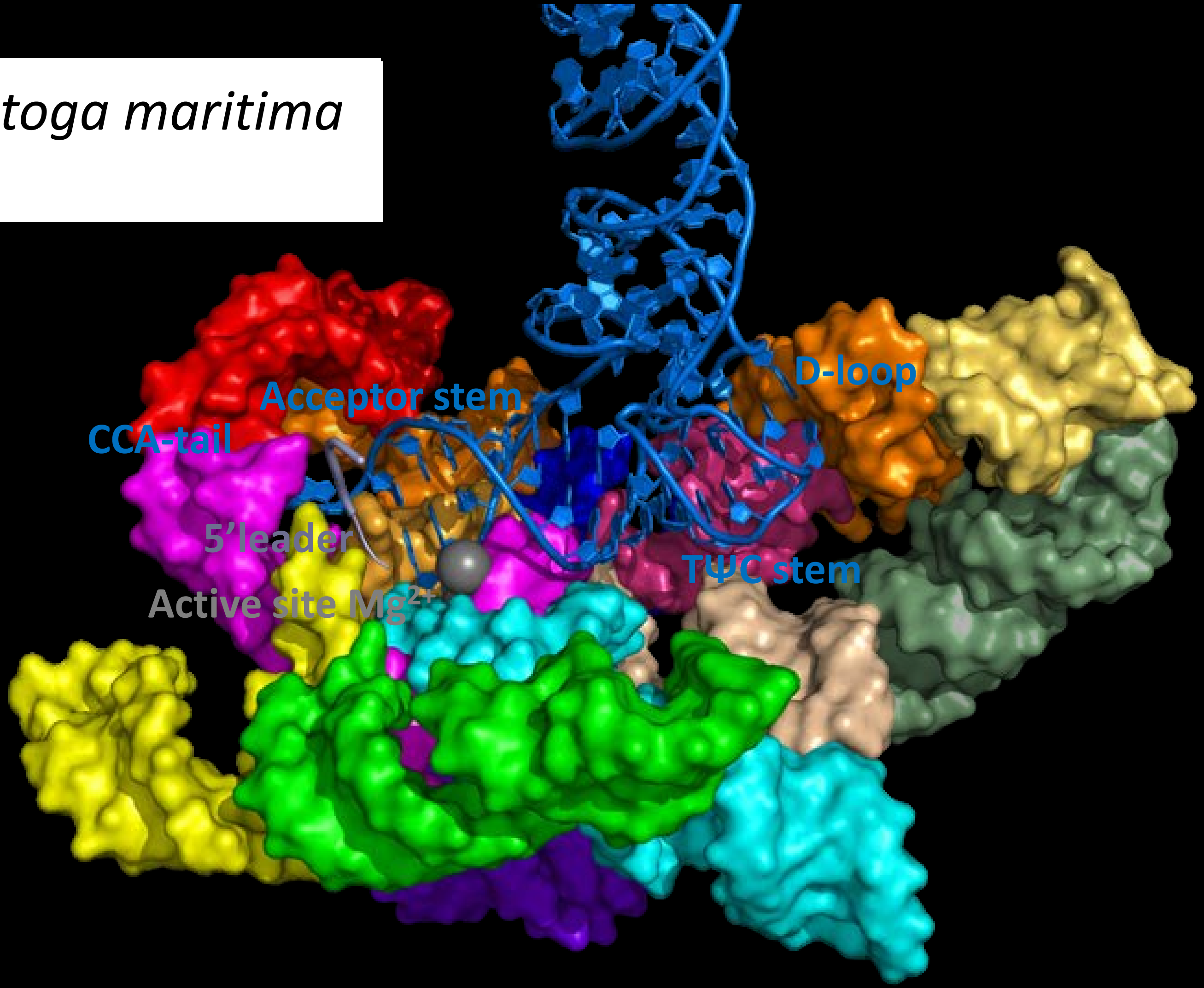
Chronology recorded in tertiary structures of RNase P



Independent stru ture
Older

Dependent structure
Younger

Thermotoga maritima

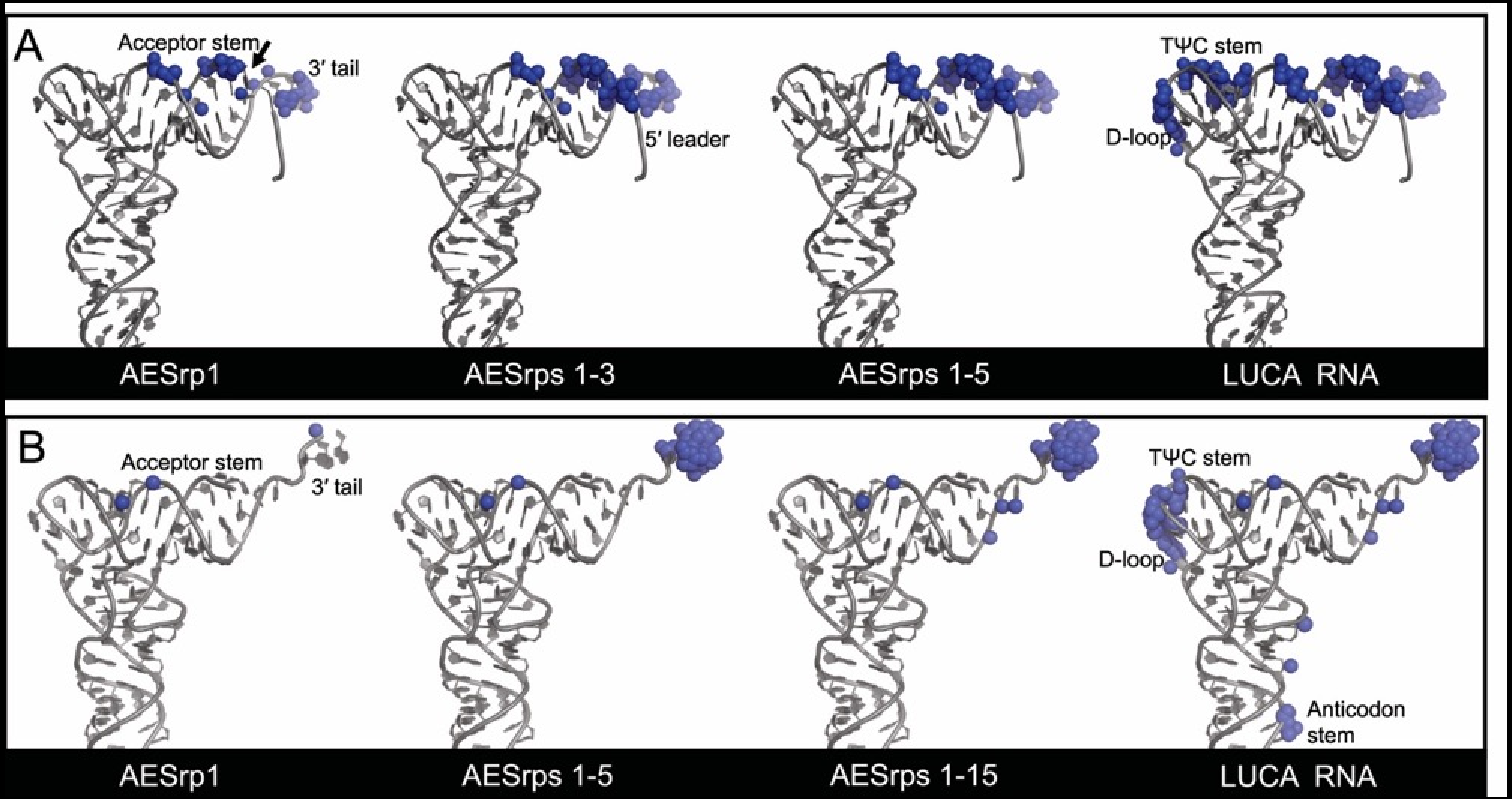


Can we synchronize timelines?

Linking time-lines through a shared substrate

RNase P

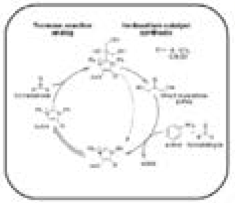
Ribosome
(A-site)



Systems protobiology: the future of studying the past

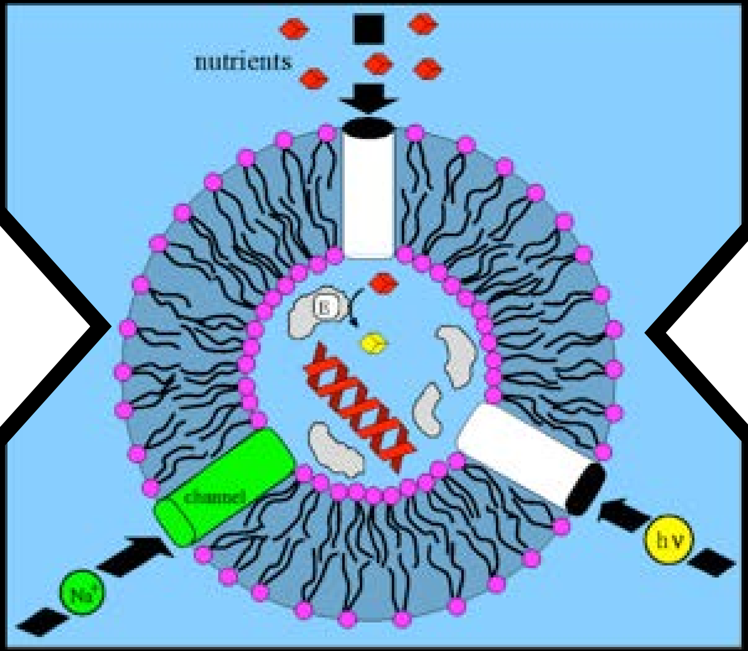
What evolves is a system, which in early evolution we identify as a protocell

Cosmochemistry

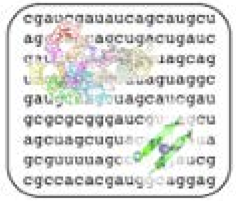


Systems chemistry

Molecular modeling



In vitro evolution



Bioinformatics

Synthetic biology

To support stability, growth, replication, and evolution, all components must work in concert.

Acknowledgments

People at Ames

George Cooper (NASA)
Scott Sandford (NASA)
Andrew Pohorille (NASA)
Andro Rios (BMSIS)
Milena Popović (BMSIS)
Theresa Chu (BMSIS)
Alexander Ellingson (BMSIS)
Andrew Plebanek (UCSF)
Chenyu Wei (UCSF)
Michel Nuevo (USRA)

Collaborators at Ga. Tech

Anton Petrov
Brooke Rothschild-Mancinelli
Loren D. Williams

The institutions

NASA
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Celebrating 10 years of exploration
USRA
Georgia Tech