Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.25360

Early incorporation of sulfur-containing amino acids into the genetic code

SAWSAN WEHBI[1], ANDREW WHEELER[1], NANDINI MANEPALLI[1], MINH BUI[2], DANTE S. LAURETTA[1] AND JOANNA MASEL[1]

[1]University of Arizona
[2]The Australian National University

The order of amino acid recruitment into the genetic code has profound implications for understanding the origins of life on Earth and its potential emergence elsewhere. Previous frameworks underestimated the importance of sulfur-containing amino acids [1] due to biases in abiotic synthesis experiments, such as the Urey-Miller experiment, that excluded sulfur [2]. In this study, we used ancestral reconstruction of protein sequences from the last universal common ancestor (LUCA) relative sequences born post-LUCA to infer amino acid recruitment, independent of abiotic abundance metrics.

Our results reveal that cysteine and methionine, the sole sulfur-containing amino acids in the modern genetic code, were incorporated significantly earlier than previously thought. This early incorporation underscores the importance of sulfur metabolism in early biochemical systems, likely driven by H_2S-rich environments. The findings also highlight sulfur's critical role in early catalysis, particularly in iron-sulfur cluster formation, which may have been pivotal for life's metabolic innovation.

We observe a modern reflection of this early biochemical adaptation in organisms that thrive in H_2S-rich environments, such as certain extremophiles and sulfur-metabolizing microbes. These organisms tend to have higher proportions of cysteine and methionine in their proteome compared to their counterparts that live in similar environmental conditions (i.e temperature, pH, salinity and oxygen availability) but with lower H_2S abundance.

The implications of our results extend beyond Earth. Sulfur-rich environments, such as those hypothesized on Mars and in Europa's subsurface oceans [3], may harbor conditions analogous to early Earth, supporting sulfur-mediated prebiotic chemistry. These environments represent compelling targets for the search for life in the universe. By situating sulfur-containing amino acids as cornerstones of early life, this work not only reframes our understanding of terrestrial origins but also guides our search for life elsewhere in the universe.

References:

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