Inflationary Metabolic Evolution and Heterogeneous Reaction Popularity

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Bacterial metabolism exhibits both universality and diversity across species. Although most bacterial species contain similar numbers of metabolic reactions, the popularity of reactions across species is highly heterogeneous and follows a broad power-law distribution. We investigate how such statistical organization emerges from the evolutionary dynamics of metabolism by combining network evolution modeling with large-scale comparative analysis of bacterial metabolic repertoires [1].

Our framework describes metabolism as a growing evolutionary system in which reactions are recruited into metabolic networks and inherited along branching species lineages. We further reconstruct metabolism-based evolutionary histories directly from empirical reaction sets of thousands of bacterial species, allowing evolutionary trajectories to be inferred from present-day metabolic compositions. The analysis reveals an early inflationary phase of metabolic expansion, followed by increasingly heterogeneous reaction recruitment during diversification. These evolutionary patterns naturally explain the broad distribution of reaction popularity across species and indicate that extant metabolic repertoires retain measurable signatures of their evolutionary history.

[1] M.J. Lee and D.-S. Lee, Heterogeneous Popularity of Metabolic Reactions from Evolution, Phys. Rev. Lett. 132, 018401 (2024).