INTERNSHIP PROPOSAL

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Physics models for the origins of Darwinian evolution

Life is understood to be both the result and the engine of Darwinian evolution. Darwinian evolution, also known as evolution by natural selection, occurs when three ingredients are present: (1) Variation: a population of individuals exhibits different traits. (2) Inheritance: these individuals reproduce and pass on their traits, at least in part, to their offspring. (3) Differential reproduction: some traits lead to greater survival and reproductive success than others. When these conditions are present, natural selection can occur, leading to changes in the population over time.

In modern life forms, the mechanisms underlying variation, inheritance, and differential reproduction are complex and themselves the products of billions of years of Darwinian evolution. At the origin of life, however, Darwinian evolution must have emerged from simpler processes. What could they be? We approach this question from a physics perspective, aiming to identify fundamental physical and chemical processes that can possibly give rise to Darwinian-like evolutionary dynamics beyond the specific pathway that led to life on Earth [1].

To this end, we develop and analyze statistical physics models. Inspired by results from the physics of catalysis [2,3] and from theoretical ecology [4,5], we recently proposed a novel class of models [6] in which systems of coupled chemical reactions exhibit key features of Darwinian evolution, such as diversity, selection, inheritance, and adaptation, despite the absence of autocatalysis, assembly processes, or compartments, which are often considered essential. Our goal is to further develop these models to understand how other key biological features, such as complex information processing, hierarchical organizations and individuality, can emerge.

The internship will involve both analytical and numerical work, employing concepts and methods from statistical physics. Prior experience with Darwinian evolution is not required, though a strong curiosity about the subject is expected. The project is primarily theoretical, but our models are developed with experimental applications in mind and a possibility is to contribute to such implementations.

The internship will take place in a diverse group of theoreticians and experimentalists whose backgrounds span physics, chemistry and biology. The group shares a broad interest in molecular evolution and a common approach based on statistical physics.

References:

[1] N. Goldenfeld & C. Woese (2011). *Life is physics: evolution as a collective phenomenon far from equilibrium.* Annu. Rev. Condens. Matter Phys., 2 : 375-399.

[2] O. Rivoire (2023). *How flexibility can enhance catalysis.* Phys. Rev. Lett. 131 : 088401.

[3] Y. Sakref & O. Rivoire (2024). *Design principles, growth laws, and competition of minimal autocatalysts.* Comm. Chem. 7 : 239.

[4] G. Bunin (2017). *Ecological communities with Lotka-Volterra dynamics.* Phys. Rev. E, 95(4), 042414.

[5] G. Bunin (2021). *Directionality and community-level selection.* Oikos 2020130 : 489.

[6] G. Bunin & O. Rivoire (2025). *Evolutionary features in a minimal physical system: diversity, selection, inheritance, and adaptation.* Proceedings of the National Academy of Sciences, 122(31) : e2425753122.