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Thermodynamic Geometric Constraint on the Spectrum of Markov Rate Matrices

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The spectrum of Markov generators encodes physical information beyond simple decay and oscillation, which reflects irreversibility and governs the structure of correlation functions. In this work, we prove an ellipse theorem that provides a universal thermodynamic geometric constraint on the spectrum of Markov rate matrices. The theorem states that all eigenvalues lie within a specific ellipse in the complex plane. In particular, the imaginary parts of the spectrum, which indicate oscillatory modes, are bounded by the maximum thermodynamic force associated with individual transitions. This spectral bound further constrains the possible values of correlation functions of two arbitrary observables. We compare our result with a previously proposed conjecture, which remains an open problem and warrants further investigation.
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Presenter: XU, Guohua (The University of Tokyo)

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