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A energy-accuracy tradeoff in the physics of cellular sensing
SARAH HARVEY, SUBHANEIL LAHIRI, SURYA GANGULI, Stanford University — Single cells are capable of complex information processing about their environment, particularly in the form of highly accurate external concentration sensing. The fundamental limit of this accuracy set by diffusion has been studied since the 1977 Berg-Purcell limit, however, thermodynamic constraints on the design of these sensors have remained theoretically obscure. We derive energy-accuracy tradeoffs in nonequilibrium molecular processes underlying cellular sensing receptors using stochastic thermodynamics. These receptor systems are often modeled as arbitrary continuous time Markov networks, with an external signal modulating the transition rates. We derive a fundamental limit on sensing accuracy by calculating the Fisher information for a Markov chain trajectory with respect to an external signal, and then consider more biophysically plausible systems with large deviation theory. These lower bounds, confirmed by numerical simulations, reveal a tradeoff when the network is driven out of equilibrium between the power dissipated by the system, the sensing accuracy, and the observation time. Moreover, the classic Berg-Purcell limit is reproduced at equilibrium. Overall, our work reveals fundamental thermodynamic limits on sensing accuracy for any Markovian signaling system.

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