Adapt to oscillate: a nonequilibrium thermodynamic view of dynamic quorum sensing

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Cell-density-dependent rhythmic behavior, also known as dynamic quorum sensing, has been suggested to coordinate population level activities such as cell migration and embryonic development. Quantitative description of the oscillatory phenomenon is hitherto hampered by incomplete knowledge of the underlying intracellular processes, especially when isolated cells appear to be quiescent. Here we present a nonequilibrium thermodynamic scenario where adaptive sensing drives oscillations of a dissipative signaling field through stimulated energy release. We prove, on general grounds, that adaptation implies phase reversal of the linear response function in a certain frequency range, in violation of the fluctuation-dissipation theorem (FDT) under restricted coupling between a cell and the signal. Consequently, at sufficiently strong coupling, an oscillating signal in a suitable frequency range becomes self-sustained due to the energy outflow from adaptive cells. We find this overarching principle to be at work in several natural and synthetic oscillatory systems, and it may help to guide the design of further experiments on glycolytic oscillations in yeast suspensions.