The potential and flux landscape theory for non-equilibrium systems

Jin Wang

Stony Brook University

The complex systems are everywhere around us ranging from the physical to the biological objects. These are often open systems with inputs of energy and information from outside. Uncovering the organization principles and physical quantification of the complex non-equilibrium open systems are essential for understanding the global function and stability. This presents us a great challenge. In this talk, we summarize our recent efforts in this direction. We found that the dynamics of the complex systems are determined by the two driving forces. One is the gradient of the underlying landscape and the other is from the curl flux. The underlying landscape is linked to the probability distribution of the steady state and provides a global picture for describing the complex system. We found that the landscape can be used to quantify the global stability and robustness of the system. The non-zero flux breaks the detailed balance and therefore gives a quantitative measure of how far away the system is from the equilibrium state, reflecting the degree of the energy input to the system. Our decomposition of the driving forces of the complex systems into landscape gradient and curl flux establishes the link between the dynamics and the underlying thermodynamic non-equilibrium natures. We applied our theory to several physical and biological systems such as cell cycle, stem cell differentiation and reprograming, neural networks, evolution, ecology and chaos. For cell cycle oscillations, we found the underlying landscape has a Mexican hat ring shape topology. The height of the Mexican hat determines the global stability. The landscape gradient attracts the system down to the oscillation ring. The curl flux is the driving force for coherent oscillation on the ring. Further discussions on non-equilibrium thermodynamics, fluctuation-dissipation theorem and gauge theory will be given. Applications to active matter are expected.

Figure: Mexican Hat Landscape for Cell Cycle