Mixing Water, Tranducing Energy, Shaping Membranes

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The physical properties of membrane interfaces, quasi-two dimensional, bilayer lipid membranes, which together with membrane proteins delimit cellular boundaries, are now largely well-understood at thermodynamic equilibrium. But generic descriptions of far-from-equilibrium behaviors of membranes – which allow living cells to sense, respond, and adapt to environmental perturbations while displaying extraordinary stability – are conspicuously lacking. Here, non-equilibrium activities of membrane-proteins, underlying cytoskeleton, and osmotic activities of water bathing the membrane, all couple with membrane's physical, chemical, and mechanical degrees of freedom producing long-lived out-of-equilibrium structures with emergent reconfigurable morphologies and cooperative behaviors.

Drawing from recent experiments in our labs employing simple models for the cellular chassis (i.e., giant vesicles composed of amphiphilic lipids and polymers), this talk considers how the osmotic activity of water is transduced across cell-like compartments. It highlights how water activity and accompanying dissipation of osmotic energy couples with the compartmental boundary, mechanically remodeling the membrane shape and spatially reorganizing membrane and the aqueous-phase components through well-orchestrated cooperative dynamics. Comparing these processes as elemental events in the homeostatic working of a living cell, these findings support the idea that water is not a mere solvent for life – a blank canvas on which biomolecules become animated – but an active medium that directs the molecular-level organization and mesoscale dynamics in complex, subtle, yet essential ways.