Transport phenomena and mechanics of biological lipid membranes

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Not only are living cells subject to the laws of physics, but they take advantage of them to carry complex biological functions at a lesser energetic cost. Identifying and understanding such biophysical processes is therefore of great interest for the development of bioinspired engineering solutions such as drug delivery systems and decontamination processes. In this talk, I will illustrate through a series of examples how transport phenomena and mechanics play key roles in cellular systems, focusing on biological lipid membranes.

Cellular lipid bilayers are found to display incredibly diverse shapes and dynamics, both at the plasma membrane surrounding the cell and at membrane bound organelles. First, we will examine the dynamic response of cell-sized lipid vesicles exposed to solute imbalance. Based on observations that giant vesicles in hypotonic condition exhibit a non-intuitive pulsatile behavior characterized by series of swell-burst cycles, we will present a mathematical model that accounts for membrane elasticity, transport, and statistical mechanics, to quantitatively capture the essential features of the system. We will then extend this framework to account for surface stressors, and show how distinct membrane pore dynamics can be reached in lipid vesicles undergoing solubilization and photooxidation. Finally, we will turn our attention to the chemo-mechanical mechanism allowing cells to encapsulate, transport, and secrete collagen fibres, the main components of skin and other biological tissues. Thanks to a computational model based on Onsager's non-linear formalism, we will show how the coupling between membrane bending and in-plane protein transport enables the robust formation of large membrane carriers able to encapsulate bulky collagen fibres.