Interactions between Macromolecules and Membranes

CAS/MPG Partner Group on Membrane Biophysics
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Dr. LIU Yonggang with his partner at MPG, Prof. Dr. Reinhard Lipowsky at the Changchun Institute of Applied Chemistry, CAS.

Photos/Images: By courtesy of Prof. LIU Yonggang.

The Partner Group on Membrane Biophysics was established in 2013 at the State Key Laboratory of Polymer Physics and Chemistry in Changchun Institute of Applied Chemistry, Chinese Academy of Sciences (CAS).

The Partner Group aims at research on hybrid systems built from two types of soft matter systems: water-soluble polymers and biomimetic membranes. The main goal of the group is to investigate the macromolecule-membrane interactions and their roles in the transformation of lipid bilayers in contact with aqueous polymer solutions. The experimental investigations are supplemented by theoretical studies. The results from this project also contribute to a deeper understanding of some basic problems in polymer physics, for example, how the conformations and dynamics of macromolecules will be altered by the confinement of the membrane. The system of interest is at the cutting edge of polymer physics and membrane biophysics, combining complementary experience and expertise from the two partners.

Reported by Group Leader LIU Yonggang

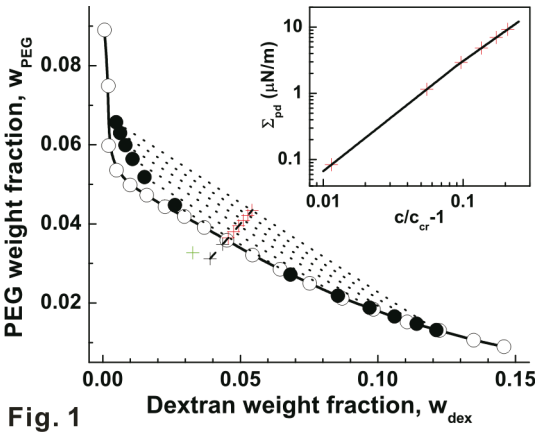

Fig. 1

Figure 1: Phase diagram of aqueous solution of dextran and polyethylen glycol. Inset shows the interfacial tension between the co-existing phases as a function of the distance from the critical point for phase separation.

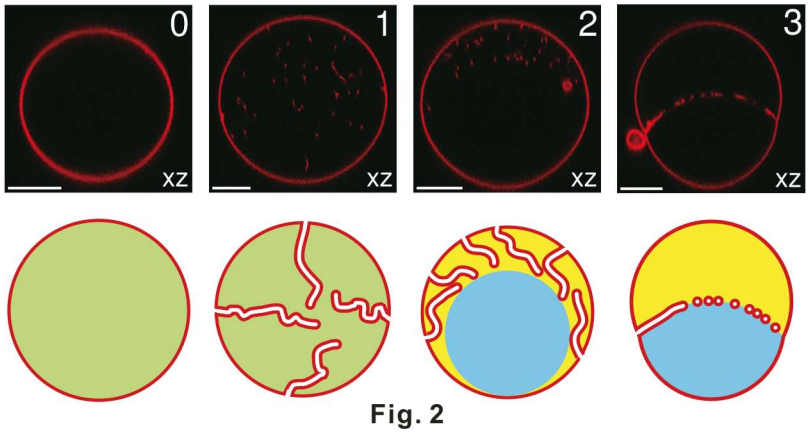

Fig. 2

Figure 2: Morphologies of giant unilamellar ves enclosing aqueous solution of dextran and polyethylen glycol upon osmotic deflation.

SCIENTIFIC ACTIVITIES

Aqueous solutions containing several species of water-soluble polymers such as dextran and polyethylen glycol (PEG) undergo phase separation when the polymer concentrations exceed a few weight percent (Figure 1). Such a polymeric aqueous two-phase system (ATPS) provides a particular mild environment for biomolecules and cells, making it a convenient biomimetic model system for the macromolecular crowding in the cytoplasm. The Partner Group is currently focusing on the membrane transformation of giant unilamellar vesicles (GUVs) exposed to different aqueous phases, as well as the molecular mechanisms underlining the observed membrane processes.

1. Spontaneous tubulation of GUV enclosing ATPS

We prepared GUVs from lipid mixture of dioleoylphosphatidylcholine, dipalmitoylphosphatidylcholine, and cholesterol encapsulating homogeneous aqueous polymer solutions. The vesicles were deflated to induce aqueous phase separation of the polymer solutions within the vesicles. The associated phase transition shows a crossover from Ising model behavior in the vicinity of the critical point to mean field behavior further away from this point (Liu, Y. *et al*, 2012). The deflation leads to a reduction of the vesicle volume and generates excess area of the membrane which leads to budding transformations of the vesicle shape (Figure 2) and, more dramatically, to the formation of many membrane nanotubes protruding into the interior vesicle compartment (Figure 3). Theoretical analysis showed that the tubes were stabilized by a negative spontaneous curvature, which leads to a spontaneous tension dominating the membrane tension. The latter can be obtained from the force balance along the three-phase contact line by measuring the effective contact angles and the interfacial tension between the PEG-rich and the dexran-rich phases. The estimated spontaneous curvature of the membrane segment varies between 1 and 10 μm^{-1} when tuning the compositions of the vesicles and the polymer solutions. The lower value is consistent with the results from direct microscopic observations of the large membrane tubes above the optical resolution (Liu, Y. *et al*, manuscript in preparation).

2. Adsorption of water-soluble polymers on supported lipid bilayers

Membrane curvature can be induced locally by anchored or adsorbed biomolecules, or globally by the elastic properties of membrane domains as well as by the interactions of the mem-

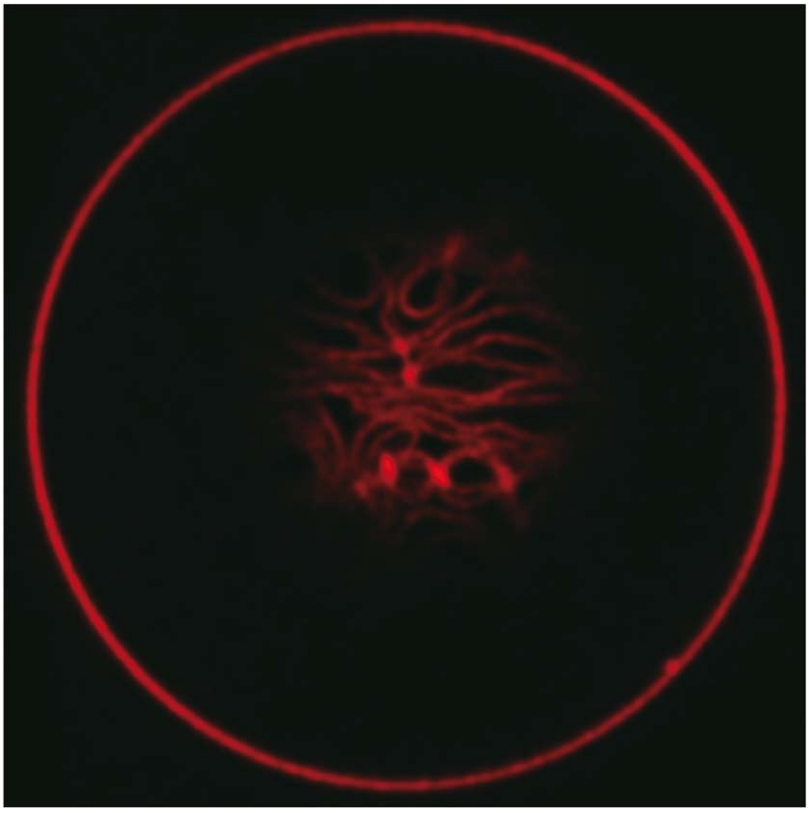

Figure 3: Membrane nanotubes formed in a fluorescently labeled giant unilamellar vesicle encapsulating a polymeric aqueous two-phase system of dextran and polyethylen glycol.

branes with the surrounding aqueous solutions. To elucidate the mechanism of spontaneous curvature in our GUV/ATPS systems, we employed quartz crystal microbalance with dissipation (QCM-D) to study the adsorption behavior of dextran and PEG on supported lipid bilayers (SLB). The results on polymer solutions covering a broad range of molecular weight and concentrations followed by solvent washing did not indicate any detectable adsorption, but one cannot rule out the possibility of weak adsorption with a fast dissociation rate. Meanwhile, QCM-D was proven to be a convenient way to measure the viscoelasticity of polymer solutions at high frequencies (Zhao, Z. et al, manuscript in preparation). More recently, the adsorption and/or depletion of polymer solutions on SLB are investigated with the newly installed total internal reflection fluorescence microscope in Potsdam.

SELECTED PUBLICATIONS

1. **Liu, Y.; Lipowsky, R.; & Dimova, R.** (2012) Concentration dependence of the interfacial tension for aqueous two-phase polymer solutions of dextran and polyethylene glycol. *Langmuir* 28, 3831–3839.

2. **Liu, Y.; Kusumaatmaja, H.; Dimova, R.; & Lipowsky, R.** (2014) Biomimetic membranes exposed to chemically distinct environments acquire spontaneous curvature. (Manuscript in preparation)

3. **Zhao, Z.; Liu, Y.; Ji, X.; Dimova, R.; & Lipowsky, R.** (2014) Probing the adsorption behaviors of polyethylene glycol on supported lipid bilayer by quartz crystal microbalance with dissipation. (Manuscript in preparation)

FUTURE PLANS

Membrane processes including budding and fission, adhesion and fusion, or transport of membranes and vesicles, will be studied to deepen our understanding of cellular membrane processes. The GUV/ATPS systems provide a unique way to determine the spontaneous curvature of the membrane, which is induced by other nanostructures such as macromolecules or colloids that interact with the membrane. Thus, one can extend the current system to reconstitute certain membrane-anchored receptors together with their water-soluble ligands and to use the GUV/ATPS systems to determine the spontaneous curvature arising from the receptor-ligand complexes. The receptor-ligand interactions and the adsorption/depletion of water-soluble macromolecules from the model lipid bilayers will be further studied with the advanced facilities in Germany.

Throughout the collaboration, the group leader and his team in China had the chance to work in Germany and develop their research with their partners at the MPI in Potsdam, and the German scientists visited Changchun to bring on-site instructions. We expect that the scientific objectives of the Partner Group will be achieved in the forthcoming years, as a result of the continuous and productive collaborations between the two partners. ◂

INFO

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