Popular science abstract

Self-organization and collective behavior in soft matter are fascinating phenomena that constantly attract the attention of researchers due to their fundamental scientific importance and at the same time great potential for applications. Nature itself provides prominent examples: lipids and proteins in cell membranes organize themselves into domains of nanoscopic size. The causes and effects of the formation of these structures are still the subject of intense research, from attempts to understand their hierarchical evolution both in space and time, to the physiological implications of domain formation for protein function, for example, in the activation of immune cells. On the other hand, aiming at development of new materials, research laboratories are looking for ways to autonomous self-organization into ordered structures with the desired physico-chemical properties, using a variety of building blocks, such as, for example, specially designed colloidal particles.

Behind the self-organization and collective behavior of soft matter there are statistical forces that are not at all direct microscopic interactions of particles or molecules but emerge as a collective medium effect. The nature of these effective forces generally depends on the particular system, but when a medium is subject to correlated thermal fluctuations, such as a mixture of two liquids close to the critical point of mixing, they acquire the universal characteristics known as the Casimir effect. Due to their unique properties, Casimir forces can be extremely useful for the precisely controlled crystallization of colloidal particles by small changes in temperature. This is one of the hypotheses in this project that we want to verify for a mixture of two different types of particles based on a theoretical model supported by experimental data from the laboratory of Peter Schall from the University of Amsterdam. An image of example of such structure, taken in the laboratory in Amsterdam, is shown below. Complex crystalline alloys are important in many applications, including materials used in photonics and optoelectronics. Moreover, through the similarity between colloidal and atomic systems, our research will provide insight into the basic mechanism of the (atomic) crystallization process. We also hypothesize that forces with characteristics similar to Casimir forces may appear between proteins embedded in binary lipid cell membranes as a result of deformation of the thickness or shape of the membrane caused by these inclusions. It is a new mechanism that we intend to model theoretically and that may be one of the causes of the formation of groups of proteins in cell membranes.

With the advances in the science of colloids and the advent of self-propelling particles that move autonomously, new possibilities have opened up for the processes of spontaneous self-assembly. Doping with active particles may accelerate the crystallization of colloids, increase the range of its occurrence, or enable the implementation of ordered structures previously unavailable. The long-term goal is to create active materials in analogy to their biological counterparts. To achieve this goal, it is necessary to understand the physics of interactions between active particles and active and passive particles. In the case of a medium, which is a mixture of water with another organic liquid and close to its critical point of mixing, the colloidal particles are activated by laser light creating a local temperature and concentration gradient. For this type of active colloids, we want to understand the nature of pair- interactions based on a theoretical model combining a description of fluctuating non-equilibrium dynamics and flow of a medium. We expect to discover complex dynamic states of particle pairs, such as periodic orbits, that could be used to construct nano-machines. These behaviors will be verified in experimental systems carried out in the group of J. R. Gomez Solana at the University of Mexico. Our well-controlled model systems will provide insight into the fundamentals of non-equilibrium physics.