optics & photonics focus

Optically Unbalanced

Out-of-equilibrium phenomena can be the source of many a novel discovery. They are wondrous to work with, yet tough at the same time. And their very complexity is what makes them an interesting, albeit exacting challenge. The interaction between Brownian motion and optical forces now comes to provide us with new insights into these phenomena.

To be in *equilibrium*! To be *balanced*! Rather a desirable state, wouldn't you say? Who wouldn't wish to have a balanced budget, balanced accounts, or even a well balanced diet? Nevertheless, many interesting physical phenomena happen *out-of-equilibrium*. Think of the constant activity of living beings, for example; only death can restore a quiet equilibrium. However, non-equilibrium phenomena are inherently harder to study because they are messier than their clean and tidy *in equilibrium* counterparts. A new experimental model for out-of-equilibrium systems, developed by Aristide Dogariu and coworkers, Kyle Douglass and Sergey Sukhov, at CREOL, The College of Optics and Photonics in Florida, USA, is therefore a welcome addition to the experimental physicist's toolkit.

Still water in a glass. The helium that makes a hot air balloon fly. The bricks in the wall of your office. They all appear to be in equilibrium, since they do not change during a time that is not too long. The laws governing these systems are relatively simple, and physicists were already able to understand most of them by the end of the XIX century. This understanding constituted a real achievement that permitted scientists and engineers to make several important technological advances, of which skyscrapers and space stations are but two examples. However, things get much more challenging and interesting when we consider systems out-of-equilibrium, which are continuously activated by some energy coming into the system.

A school of fish, a flock of birds, or a herd of buffalos, are examples of out-of-equilibrium systems - examples of *active matter*. Their many constitutive parts interact with each other and trigger complex behaviors, where global order and local randomness interplay. For example, a fish can actively look around at what other fish are doing and decide where to swim accordingly. It is the extra energy provided by the collective muscles of the fish that drives the motion of a school out-of-equilibrium, and makes capturing it in a formula so organized and difficult! A pile of dead fish would very quickly go back to equilibrium and become not much more interesting than a pile of bricks — at least until they start to rot.

In order to grasp the laws governing active matter, we need to have some relatively simple model systems with which to run some experiments, and the parameters of which we are able to control. This is hardly possible with a school of fish, since it would be rather difficult to tell the fish how fast to swim and how to interact with other fish.

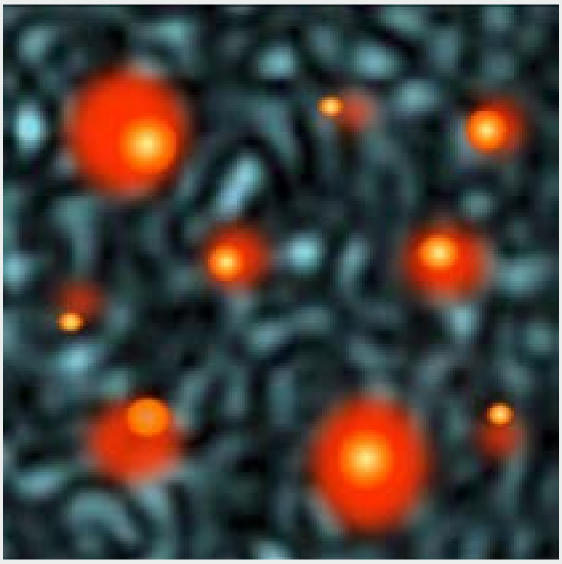

Figure 1: Optically activated medium. Many naturally occurring systems are "active" in the sense that their complex dynamics are driven by both thermal fluctuations and additional energy sources. The dynamic coupling between colloids and multiply scattered light creates a controllable, optically-driven active medium. Credits: Aristide Dogariu, CREOL.

Dogariu and coworkers thought of a simple model system. They took a small container, filled it with water and then added some spheres a thousand times smaller than a millimeter. Such small particles are known as Brownian particles because they are perpetually moving in a chaotic fashion due to the random hits from the water molecules — a phenomenon that was first described by Robert Brown at the beginning of the XIX century. Up to this point this presents a system in equilibrium, fully understood by the beginning of the XX century. Dogariu and coworkers have added a new factor: random optical forces.

Optical forces arise when light interacts with matter. When a photon goes against some material object it can be either *reflected* or *refracted*. In both cases its direction changes, which means that the object experiences a recoil and, therefore, a small push. This kind of forces are responsible for pushing the tails of the comets away from the Sun, a fact noted by Kepler as far back as the XVII century. This fact was also exploited in the realization of *optical tweezers*, which nowadays permit scientists to use a laser beam to trap and manipulate small particles, such as molecules and atoms.

Dogariu and coworkers had the idea of shining a powerful laser beam through their solution of microscopic particles. In this way, the photons get scattered all around by the interaction with the particle; this creates a very complex optical field, which exerts some random forces on the particles themselves. Therefore, a very complex interaction takes place: the positions of the particles determine the optical field and the optical field determines how the position of the particles changes.

Compared with other active systems, such as the schools of fish we spoke about earlier, Dogariu's system has the advantage of being completely controllable. "We can control the particle kind and size," explains Dogariu, "but also the strength of the interaction between the particles, using the laser power and the density of the particles. Also, we can change this as we like because it is as simple as switching on and off a laser." In this sense, this model system has the potential to shine new light on several aspects of complex active systems. "We are now going to use our experimental system," concludes Dogariu, "as a model system to investigate the properties of active systems, such as, for example, mobile bacteria."

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Kyle M. Douglass, Sergey Sukhov & Aristide Dogariu, **Superdiffusion in optically controlled active media**, Nature Photonics **6**, 834-827 (2012).