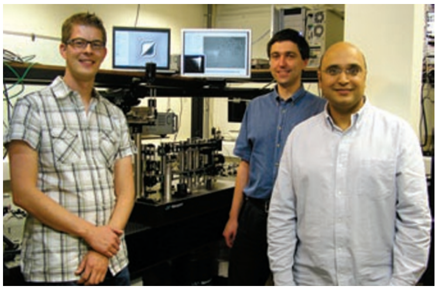
Airy's arc of surprise

The demonstration that Airy beams can transport small particles along curved paths of light may lead to a wealth of new applications in optical micromanipulation. *Nature Photonics* spoke to Kishan Dholakia from the University of St Andrews in Scotland about the idea.

Tell us about Airy beams and your use of them.
An Airy beam is a very unusual, counterintuitive beam that does not spread or diffract when it propagates in free space. The most intriguing feature is the fact that its light pattern is seen to 'accelerate' transversely to its direction of propagation. The result is that an Airy beam curves as it propagates. Such beams were not realized in the optical domain until last year, and up until now they have not been used for any applications. In our recent work (page 675 in this issue), we show the first use of this light field in optical micromanipulation. The beam allows us to send small microscopic particles on curved trajectories without requiring the light beam to be moved. When the beam interacts with a large group of particles, it essentially pushes and sends slots of particles on a curved trajectory, akin to a 'snowblowing' effect as coined by my colleague Jöerg Baumgartl.

What spurred the idea?
We are always trying to explore new topics in optical manipulation and in the use of novel light fields for applications in biophotonics. For example, we have previously investigated optical sorting (using light to physically separate cells and colloidal particles), optical binding, where light acts like a 'glue' to build 'optical molecules', and manipulation of particles using novel optical fields, such as vortex and Bessel beams. So, when Airy wave packets were realized in the optical domain by Christodoulides's group last year, we thought we could put them to good use.

Why are Airy beams so interesting?
No other light field used so far allows curved motion or the clearing effect like Airy beams, without an additional complex beam motion. Other advantages include its immunity to normal spreading (diffraction) and self-healing capability, which renders the light beam capable of 'repairing' itself as it goes around obstacles. The self-healing property is shared with other light modes, such as Bessel beams.


TOMÁŠ ČIŽMÁR

Jörg Baumgartl, Michael Mazilu and Kishan Dholakia (left to right) in their lab.

What are the applications of optical manipulation based on Airy beams?
Within colloidal science, it can be used to move colloidal particles or cells from one chamber to another, exposing the same sample within a microfluidic environment to different buffer media or solutions. As the response of different particles to a given Airy beam depends on their physical properties and the beam parameters, the beam can selectively 'snowblow' particles around, not only sorting particles in a novel way, but also providing a new understanding of these beams and their behaviour. Within biological science, Airy beams could potentially find novel applications, such as in light-mediated neuronal growth, cell separation, or sorting. As cells also 'respond' to light, we might be able to 'tease' cells to follow the curved, unusual geometry of an Airy beam and potentially use the beam to link neuronal cells together. It may also be possible (but much more challenging) to use an Airy beam to pass nutrients or chemicals around the curved membranes of living cells. The self-healing capability of the beam may be beneficial in dense colloidal or cell samples.

What about the manipulation capabilities of other optical fields?
There are other possible manipulating beams, for example, Gaussian beams, but these have limitations for trapping, as they give as-defined aspect ratios and diverge when passing beyond a focus — the tighter you focus, the quicker they diverge. A Laguerre–Gaussian beam is interesting, as this beam may take the form of an annulus and has what we term a singularity or dark centre. As such, this beam does not have planar wave fronts, but rather helical ones. So, the energy (Poynting vector) spirals leading to part of the Poynting vector moving in the azimuthal sense and an orbital angular momentum. That said, we can spin particles with those beams and create pumps or do other microrheology studies with rotation. Bessel beams are 'non-diffracting', and thus they overcome some limitations of Gaussian beams. They create optical rods of light in trapping that can guide particles or cells over extended distances. They have proven very useful for cell sorting, optical conveyor belts and have stimulated new studies of fundamental physics. I guess there will be other beams of interest, including the Mathieu beams and perhaps parabolic beams.

Tell us about your plans for future work.
We are looking at biological applications for Airy beams and also exploring the fundamental physics of their interaction with particles. Other ideas include the study of moving droplets or even nanosurgery in conjunction with the use of ultrashort-pulsed lasers.

What do you think will be the future of optical manipulation?
I think it will become part of the next-generation microscope that integrates subdiffraction imaging with manipulation tasks, such as the ability to move, trap, 'clear' or sort particles at will. Essentially we're talking about a powerful 'biophotonics workstation'. For optical manipulation at the single-molecule level, I think we will see many groups able to realize incredible studies with force measurements down to the femtonewton level and position accuracy of only a few ångströms.

Interview by Rachel Won.

Dholakia and co-workers have a Letter on optical micromanipulation using an Airy beam on page 675 of this issue.