An optical tractor beam sorts microscopic particles

A change in the polarization of a light field can sufficiently change the scattering forces experienced by spherical particles to reverse their direction of motion.

Light typically pushes particles forward thanks to radiation pressure. But it can also pull them backward. A gradient in laser intensity, for instance, can produce optical forces large enough to move the particles—either upstream or down—toward a beam's focus, where they remain trapped, a phenomenon known as optical tweezing (see PHYSICS TODAY, December 1997, page 17). In 2006 Philip Marston of Washington State University realized that even a nonspreading beam could pull particles backward and do so over a far broader range than is possible with optical tweezers. As if caught in a tractor beam à la Star Trek, the particles may be reeled all the way back to the source of the beam, at least in principle.

Marston presented his theory in the context of acoustic waves,[1] but it applies equally to photons.[2,3] His trick was to use a Bessel beam, which has the unusual property of not dispersing as it propagates. It's essentially the superposition of plane waves whose wavevectors are canted at an angle with respect to the propagation axis and form a cone along it. If that angle is steep enough, once such a beam encounters an object, more of the photons can be scattered forward than backward. By conservation of momentum, the object has no choice but to recoil backward.

But even slight changes in the object's size, shape, surface roughness, or refractive index can alter the photon scattering direction. Exploiting that sensitivity, Pavel Zemánek from the Institute of Scientific Instruments of the Academy of Sciences of the Czech Republic, Tomáš Čižmár of the University of Saint Andrews in the UK, and their colleagues have now designed an elegant scheme that uses a tractor beam to separate different types of particles in a mixture.[4]

Key to the achievement was their realizing that two plane waves, steeply angled toward each other and symmetric along the propagation axis, mimic a Bessel beam well enough to be used in the way Marston envisioned, at least over the range where the beams overlap. Illustrated in the figure, the team's experimental geometry could hardly be simpler. A single, relatively wide Gaussian laser beam is reflected from the mirrored bottom of an aqueous cell containing two sizes of polymer spheres. Interference of the incident and reflected waves forms fringes that determine the spheres' net deflection—either to the right or left.

From their calculations, the researchers also realized that changing the beam polarization—with the electric field pointed either parallel or perpendicular to the plane of incidence—changes the scattering pattern enough that it can be used as a knob to reverse, on demand, the sign of the recoil force on certain sized spheres and thus their motion. Indeed, although the difference in optical force is slight, on the scale of piconewtons, only a perpendicularly polarized beam produced a pulling effect in the group's liquid-cell experiments. In one example, tens of

physics update

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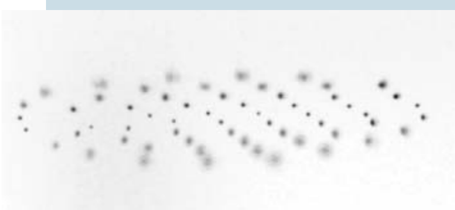
Light-field camera snaps dusty plasma. Dusty plasmas consist of charged microparticles embedded in a lightly ionized gas (see PHYSICS TODAY, July 2004, page 32). In space, such plasmas pervade planetary rings. In the lab, where higher microparticle densities can be achieved, the plasmas form crystals, melt, carry waves, and exhibit other collective behavior. Observing the microparticles, which dominate the dynamics, is tricky. Although individual particles are large enough to resolve using optical techniques, monitoring all of them requires a combination of magnification and depth of field that standard cameras lack. Péter Hartmann of the Institute for Solid-State Physics and Optics in Budapest, Hungary, and his colleagues are tackling the problem by using a nonstandard camera, the Lytro. Thanks to an array of microlenses that sits between the camera's main lens and detector, the Lytro and its built-in software can determine not only the direction of incoming light (corresponding to the x and y of a two-dimensional image), but also where in the scene it originated (x, y, and z; the light field). Processing the three-dimensional data yields a set of sharp images for all values of z. Despite the novel optics, a typical plasma cloud, which measures a few tens of millimeters in diameter, still exceeds the camera's depth of field. Nevertheless, peripheral particles are resolved well enough for an algorithm that Hartmann devised to crunch through the images and reconstruct the 3D particle distribution. The accompanying figure shows one such reconstruction: of a flat, circular cloud about 14 mm across and containing 60 particles. (P. Hartmann, I. Donkó, Z. Donkó, *Rev. Sci. Instrum.* **84**, 023501, 2013.) —CD



A sharpened meteor-impact dinosaur-wipeout connection. About 65 million years ago, dinosaurs and other species died out in a geological eye blink. Many scientists attribute the disappearance to environmental changes precipitated by a meteor slamming into the Yucatán Peninsula of Mexico. But other factors—volcanic eruptions, for example—may have played an important role. Unraveling the principal cause of the extinction has remained problematic in part because the best that geochronological evidence could do was to place the meteor impact and mass extinction within a few hundred thousand years of each other. Indeed, some data indicate that the impact postdated the extinction. Now a multinational research group led by Paul Renne of the Berkeley Geochronology Center and the University of Cali-