PHYSICS UPDATE

These items, with supplementary material, first appeared at www.physicstoday.org.

HOW STARS VISIT THE SOLAR NEIGHBORHOOD

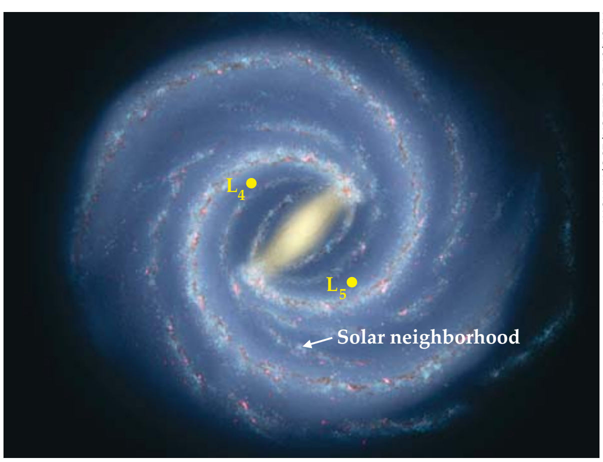
About 10% of the stars in the solar neighborhood belong to a large group that exhibits an oddly distinctive collective motion. Known as the Hercules stream, the group includes stars that are moving away from the center of the galaxy while falling behind the galaxy's general rotation. The cause of that motion is the subject of a new study by Angeles Pérez-Villegas and her colleagues at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany.

New stars typically condense with other new stars out of the same dense cool region of gas and dust. Because stars are born more or less around the same time, they inherit the motion around the galaxy of their birthplace. The Hercules stream is different. Spectroscopic observations have revealed that it's made up of stars of widely different ages. Whatever is causing the streaming motion operates across large scales of time and space.

One candidate is the dense central bar of stars from which two of the galaxy's spiral arms sprout (see accompanying figure). The solar neighborhood lies beyond the orbit of the ends of the bar, but the Sun and the stars of the Hercules stream are close enough to feel the bar's gravitational influence. Generally speaking, as stars orbit the galaxy, they oscillate toward and away from the galactic center. If a star's radial oscillation resonates with the bar's rotation, the star can end up with an extra kick away from the galactic center.

That resonance, the outer Lindblad resonance (OLR), has been invoked to explain the Hercules stream, but new observations have identified a flaw in the explanation. The bar rotates more slowly than originally thought. Consequently, the OLR is too far away from the solar neighborhood to be the stream's prime mover.

Pérez-Villegas and her colleagues used those new observations to test a detailed dynamical model of the stars in and around the bar. The model not only re-created the positions and velocities of the Hercules stream, it also revealed what causes its unusual motion: The stream's stars are orbiting two local maxima—the L_4 and L_5 Lagrange points—in the bar's effective



NASA/JPL-CALTECH/ESO/R. HURT

gravitational potential. The maxima are situated on the bar's perpendicular bisector close to the distance where stars corotate with the bar. In the model, most of the stars in the Hercules stream originate from the inner part of the galaxy, where the stars tend to be older than the Sun. Their looping orbits around L_4 and L_5 take them all the way into the solar neighborhood, but not much beyond it. (A. Pérez-Villegas et al., *Astrophys. J. Lett.* **840**, L2, 2017.)

—CD

PRINTING GLASS IN 3D

NEPTUNLAB/KIT

These days it seems you can make anything with 3D printers—but not if you want to make it out of glass. The main complication is that the printers create structures that are rather coarse, at least at the millimeter scale and smaller. For glass, such a rough surface hinders the transmission of light.

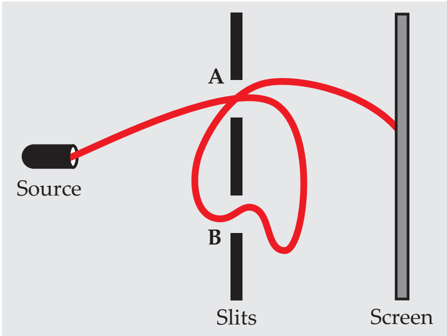
Now Bastian Rapp at the Karlsruhe Institute of Technology in Germany and colleagues have used off-the-shelf chemicals and a commercially available 3D printer to create transparent structures out of glass that is nearly indistinguishable from pure fused silica glass. The team's big advance was dissolving large amounts of silicon dioxide nanoparticles—between 30% and 45% by volume—in their polymer "ink." A \$7500 stereolithography printer composed the desired structure layer by layer using the silica-infused polymer. After burning off the polymer, Rapp's team sintered together the enduring nanoparticles at 1300 °C to create the final solid product (such as the one shown here). Both Raman spectroscopy and x-ray photoelectron spectroscopy confirmed that the printed glass, which was highly transparent for wavelengths above 350 nm or so, had nearly identical optical properties to fused silica.

Printed optical-grade glass could prove useful for lenses, fiber-optic cables, and photonic applications. And because the technique doesn't require a custom printer, the properties of printed glass should become even more finely tunable as 3D printing technology improves. Rapp hopes to devise a similar nanoparticle–polymer mix for soda-lime glass, which is used for everyday items like windows, windshields, and drinking glasses. (F. Kotz et al., *Nature* **544**, 337, 2017.)

—AG

SHEDDING LIGHT (AND DARK) ON QUANTUM PROBABILITIES

For more than a century, Thomas Young's seminal double-slit experiment was seen as a convincing demonstration that light is a wave phenomenon. The modern interpretation provided by quantum mechanics is radically different: Light comprises discrete entities called photons, and the photon wavefunction at a given location on a detector screen receives contributions from all paths that pass from the photon source through the slits (call them A and B) and on to the screen. The intensity at any location on the screen is proportional to the probability that the photon arrives at that location. According to the Born rule, that probability is given by the absolute square of the wavefunction. Interference was famously observed with light, but it is not a phenomenon limited to light. Any particle can, in theory, exhibit an interference pattern determined by the absolute square of its wavefunction.



You can destroy the characteristic double-slit interference by determining which slit the particle passes through. As textbooks typically describe it, when you check, paths passing through slit A are distinguishable from paths passing through slit B, and the slit-A intensity adds to the slit-B intensity. But as emphasized in a new theoretical paper by James Quach, a postdoc at the Institute of Photonic Sciences in Barcelona, Spain, if a detector registers a particle traversing slit A, it could be that the particle followed a classically nonsensical path that passed through both slits in succession. Such paths typically have only a small effect on the intensity pattern, but their contribution can become significant when the light's wavelength is commensurate with or larger than the slit separation.

Observations of interference patterns can serve as a direct test of the Born rule. In particular, as observed by the Perimeter Institute's Rafael Sorkin, the Born rule implies that a cleverly chosen combination of three-slit-experiment intensities will vanish. Last year Urbasi Sinha and colleagues from the Raman Research Institute implemented Sorkin's intensity combination with microwaves and found a nonzero value. The Sorkin observation, however, assumes that classically nonsensical paths may be ignored.

Theoretically, the Sorkin prescription can be corrected to account for those neglected paths, but the exact calculation is currently beyond theorists' reach. The classically nonsensical paths mean that the Sorkin approach cannot be simply implemented. But in return they generate a new simplicity: As Quach demonstrates, the strange paths mean that the Born rule can be tested with an appropriate combination of intensities observed in two-slit experiments in which zero, one, or both slits are monitored. Quach's suite of observations requires two kinds of experiment in which a detector monitors both slits. In one, the detector can tell whether the particle passes through slit A, slit B, or both. In the other, the detector can tell whether the particle passes through one slit or both, but cannot distinguish passage through A from passage through B. Before experimenters can carry out Quach's suggested test, however, they'll need to meet the challenge of fabricating reliable detectors that don't destroy the particles they register. (J. Q. Quach, *Phys. Rev. A* **95**, 042129, 2017.)

—SKB

THE OCELLATED LIZARD IS A COMPUTER GAME COME TO LIFE

Timon lepidus, known familiarly as the ocellated lizard, wears the signs of aging on its scaly back. As the lizard matures, the spots that adorn its youthful skin break up and rearrange into a labyrinthine design that marks adulthood. Michel Milinkovitch of the University of Geneva and his colleagues don't know why the lizard transforms that way—perhaps to camouflage itself, perhaps to signal potential mates—but they now know how.

COLD PERIODS ACCELERATE EVOLUTION

When Charles Darwin visited the Galápagos Islands in 1835, he was struck by the diversity in bill size exhibited by the local finches. Evolutionary biologists attribute such divergences of species to adaptive radiation, which arises when organisms mitigate competition for resources by branching out into ecological niches. Those niches change when Earth's climate warms or cools, thereby affecting evolution. But shifts in temperature also influence metabolism and, potentially, evolution too. Julien Clavel and Hélène Morlon of the École Normale Supérieure set out to untangle those two temperature-dependent effects. Their starting point was a family tree of 6100 bird species and 3550 mammal species from the Cenozoic era, which began 66 million years ago with the extinction of the dinosaurs and continues, through periods of advancing and retreating glaciation, to the present. Besides ancestries, the database also contained the species' body size. Clavel and Morlon developed a statistical model for the rate of evolution that incorporated an adjustable temperature dependence. When they fed their model with Cenozoic climate data and compared it with the body sizes in their family tree, they found the best match occurred with a strong negative dependence of evolution on temperature. That is, body size changed fastest when the climate was coldest. Given that the metabolism of birds and mammals slows when the ambient temperature drops, Clavel and Morlon conclude that climate influences evolution primarily through its effect on the environment. (J. Clavel, H. Morlon, *Proc. Natl. Acad. Sci. USA* **114**, 4183, 2017.)

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KEVIN COLE