complexity of their observations. The force–time data in figure 3a show the molecule hopping among adjacent intermediates several times a millisecond. Figure 3b sketches the first five intermediates, corresponding to the unfolding of half of the first helix. The thicknesses of the purple and orange connecting lines represent the prevalence of transitions between pairs of intermediates. Notably, transitions were not limited to adjacent intermediates, and both unfolding and refolding transitions were observed.

The surfeit of data is just the beginning; just what it all means remains to be seen. Comments Michael Woodside of the University of Alberta in Edmonton, “As we’ve seen repeatedly in other contexts, an order-of-magnitude increase in resolution often leads to big changes in understanding of the underlying physics. I expect something similar to happen here.”

Off the shelf

Perkins and colleagues’ modified AFM apparatus isn’t the only way to obtain a microsecond view of biomolecular folding. Last year, Woodside and colleagues achieved similar resolution by tethering each end of a molecule to a bead held in an optical trap. (See PHYSICS TODAY, June 2016, page 14.) That approach is useful for some applications, but it has the disadvantage of requiring a custom-built setup. Using a commercial AFM instrument, even with a few modifications, is much easier.

And Perkins is hoping for a day when researchers won’t have to make those modifications themselves. “None of our cantilever improvements are covered by a patent or pending patent,” he says, “and there’s no reason why cantilever companies and AFM manufacturers can’t implement 90% of them using wafer-scale manufacturing.” In the short term, he’s collaborating with other groups to demonstrate the cantilevers’ scientific applicability; in the longer term, he hopes those studies will spur demand for manufacturers to commercialize the modified cantilevers.

Johanna Miller

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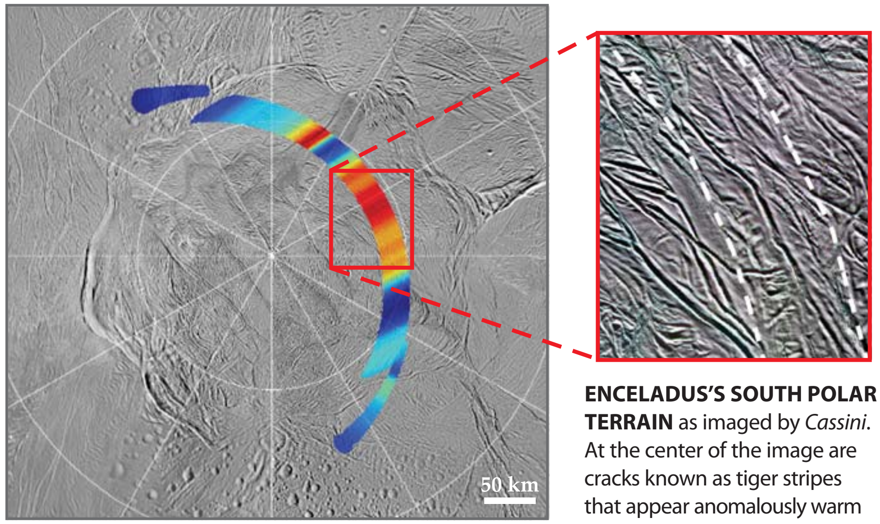
Radar reveals new hot spots on Enceladus

A snippet of data has important implications for figuring out the moon’s structure.



ENCELADUS’S SOUTH POLAR TERRAIN as imaged by *Cassini*. At the center of the image are cracks known as tiger stripes that appear anomalously warm in IR heat maps. The colored band shows surface-brightness temperatures measured by *Cassini*’s radar; the data reveal that the heat source is broadly distributed across the south pole terrain. Each of the hottest spots, shown in red, is centered on a feature that’s structurally similar to the tiger stripes, including the crack between the white dashed lines in the inset. (Adapted from ref. 1.)

Since the *Cassini* spacecraft began orbiting Saturn in 2004, its nearly two dozen flybys of Enceladus have offered up a series of increasingly tantalizing observations of the icy Saturnine moon. (See the article by John Spencer, PHYSICS TODAY, November 2011, page 38.) At the moon’s south pole, four parallel cracks, dubbed “tiger stripes,” appear anomalously warm in IR images, and they spew jets of salty ice and water vapor into space. Taken together, those signs point to a liquid water ocean, similar to the one on Jupiter’s moon Europa, beneath the moon’s frozen outer shell and in contact with its rocky core. Enceladus is thus on the short list of the best places in the solar system to look for extraterrestrial life.

Now Alice Le Gall (LATMOS/University of Versailles–Saint Quentin in Yvelines, France) and her collaborators have found that the Enceladean ocean may be closer to the surface than previously thought.[1] Instead of tens of kilometers, the south polar ice could be just 2 km thick. That’s thin enough that on a hypothetical future mission, ground-penetrating radar could see right through the ice—or a lander could penetrate the crust and reach the ocean.

Thin ice

The conclusion is based on data from *Cassini*’s radar. Developed primarily to image the moon Titan by sending microwave pulses through its optically opaque atmosphere, the radar can also passively detect thermal radiation at a wavelength of 2.2 cm. The longer wavelength means that radar is sensitive to lower temperatures and greater depths than IR detectors are.

Cassini’s radar and IR instruments can’t operate simultaneously; the latter usually took priority during flybys of Enceladus, so the researchers had little passive radar data from the south polar region to work with. In fact, their new results are based on just a minute and a half of data collected during a single flyby. The results of that observation, shown as the colored arc in the figure, reveal hot spots, shown in red, in areas 30–50 km away from the tiger stripes. The IR images show no sign of excess heat in those areas.

The colors represent the measured surface-brightness temperature, which depends on both the surface emissivity and the physical temperature averaged over the near-surface depths from which radiation can escape. The average emission depth is typically between 10 and 100 times the measurement wavelength, or up to a few meters for *Cassini*'s microwave measurements. The exact relationship of the surface-brightness temperature to the physical temperature depends on the scattering properties of Enceladean crustal ice, which are known only roughly. The researchers analyzed the data under several different assumptions; in each case, the region they observed was considerably warmer than expected.

Enceladus, like Europa, is heated by tidal deformations from the gravity of the planet that it orbits. Because Enceladus is so small (just 500 km across, compared with Europa's 3100 km), details matter: A thin ice crust deforms more than a thick one, so it generates more heat. Furthermore, tidal friction is concentrated where the crust is cracked. From the jets of ice and vapor that erupt from them, the tiger stripes are known to be cracks. Each of the hottest spots in the radar data is centered on a feature that looks structurally similar to the tiger stripes; one such crack is shown in the figure inset. Though not the source of jets, the cracks could still be geologically active and generate frictional heat under tidal forces.

When Le Gall and company modeled the tidal-heating process to account for their observations, they found that the crust should be around 2 km thick in the area of the tiger stripes. The crust is probably thicker elsewhere, including in the region of the radar observations. An uneven crustal thickness could explain both why the new hot spots aren't the source of jets and why they don't show up in IR images: The liquid water and frictional heat are buried too deeply to make their way to the surface.

What lies beneath

The radar data were collected during *Cassini*'s 16th flyby of Enceladus, in November 2011. The researchers noticed the thermal anomalies immediately, and Le Gall presented preliminary results at a workshop in 2012. "But some people would not believe it," she says, "because at that time it was commonly understood that the ocean was tens of kilometers below the surface." So they held off on publishing the results until they'd refined the instrument's calibration[2] based on their observations of Titan from 2004 through 2014.

In the intervening years, other results emerged to make the thin-ice picture seem more feasible. For example, an analysis of Enceladus's libration—how much its surface wobbles under Saturn's gravity—revealed that the subsurface ocean must be global, with the icy crust decoupled from the rocky core. (See PHYSICS TODAY, December 2015, page 25.) Previously, it had seemed feasible that the ocean might exist only in the south polar region beneath the tiger stripes.

A thin, active Enceladean crust doesn't just mean that the ocean will be easier to study, Le Gall explains: "It also increases the probability that there's life in the ocean." Life as we know it requires both liquid water and the right chemical building blocks. (See the article by Charles Cockell, PHYSICS TODAY, March 2017, page 42.) *Cassini*'s mass spectrometer has detected molecular hydrogen in the vapor plumes that erupt from the tiger stripes; H_2 must therefore also exist in the subsurface ocean, where it could help to power a primitive metabolic pathway.[3] Organic material could be delivered to Enceladus's surface by comets and asteroids, but it still must make its way to the liquid ocean. The thinner and more cracked the crust, the more likely that is.

The question of habitability is not the only unsolved mystery about Enceladus. Researchers are also particularly curious about how the moon acquired its ocean in the first place. A liquid ocean requires tidal heating, which requires a crust that's thin enough to deform. Enceladus could just as easily have remained frozen solid, as its neighboring moon Mimas shows: Mimas is similar in size to Enceladus and closer to Saturn, but it shows no signs of geological activity.

Cassini's mission, originally scheduled to last until 2008, has been extended twice. But now the orbiter is running out of fuel, and its mission must end in September of this year: It will plunge into Saturn's atmosphere to avoid contaminating any of the moons with terrestrial material. It will make no more visits to Enceladus during its remaining time. Further insight into the moon's secrets will have to wait until the next mission to Saturn. No such mission is yet in the works, although several have been proposed, including the Enceladus Life Finder, which would look for possible biomolecules in the icy jets.

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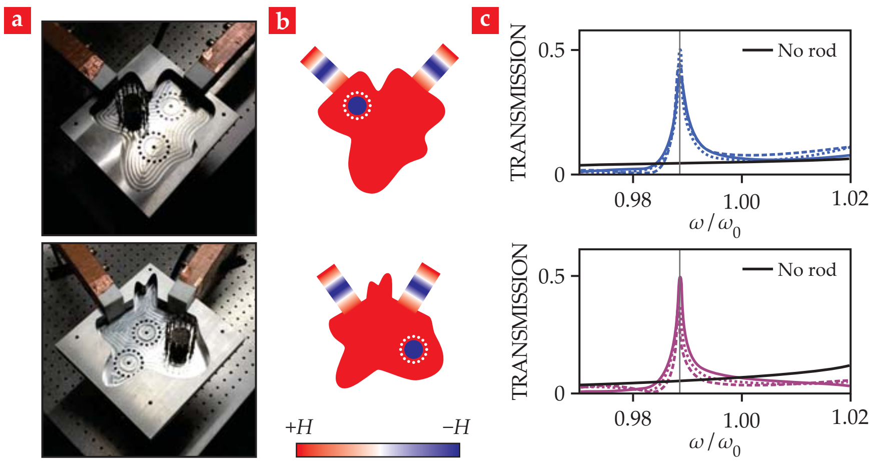
Photonic doping tunes transparent media

When a material's index of refraction is zero, strange things happen to an electromagnetic wave passing through it.

By definition, a material's refractive index n is the ratio of the speed of an electromagnetic wave in vacuum to its phase velocity in the material. It's also given by $(\varepsilon\mu)^{1/2}$, where ε is the material's electric permittivity and μ the magnetic permeability. So the phase velocity becomes effectively infinite if ε (and thus n) ever approach zero, which can happen when free electrons in materials such as metals and heavily doped semiconductors are driven by the electromagnetic wave to oscillate at their resonance (plasma) frequencies. And for an incident wave of fixed frequency, a huge phase velocity implies a huge wavelength.

In 2006 Mário Silveirinha (now at the University of Lisbon) and the University of Pennsylvania's Nader Engheta showed theoretically that one can exploit the ultralong wavelength at microwave frequencies to connect two separate waveguides with a long, narrow, two-dimensional channel filled with an ε-near-zero (ENZ) material.[1] As it flows from one waveguide into the channel, the radiation becomes so delocalized that it can efficiently traverse the channel and enter the other waveguide regardless of the channel's length or curvature. Counterintuitively, the narrower the channel, the greater the wave transmission. Two years later the researchers had designed and built a working device.

Engheta and his collaborators have now shown how to generalize that efficient transmission for an ENZ medium that fills any 2D area.[2] The achievement gives engineers room to better showcase the materials' advantageous properties. They act as directional filters because only normally incident radiation can penetrate them. By the same token, they are also light shapers because the wavefront of an emerging beam must be parallel to the contours of the interface. The radiation pattern from an ENZ antenna, for instance, can be made sharply directional. The ENZ literature abounds with potential applications: light trapping, nonlinear wavemixing, quantum information processing, and heat management, among others.[3]



PHOTONIC DOPING. An impurity introduced into a medium with near-zero permittivity produces a near-zero permeability and resonant transmission. **(a)** The copper-clad waveguides (brown) are the input and output ports for a metamaterial comprising two parallel metal plates separated by an air-filled cavity doped with a black dielectric rod. Two configurations are shown, with the top plates removed to show the cavities' different geometries and possible positions of the rod (dashed circles). **(b)** Snapshots of the simulated microwaves' magnetic field **H** reveal its predicted spatial uniformity in the cavities. **(c)** As the microwave frequency ω nears the cavities' cutoff frequency ω_0, the measured transmission spikes when the rod is in any of the three locations, but is featureless in the absence of the rod. (Adapted from ref. 2.)

The dope on dielectrics

The trick to the generalization is modifying an ENZ material's near-infinite impedance, given by $(\mu/\varepsilon)^{1/2}$, so that it matches that of the surrounding finite-impedance material and prevents reflections of the normally incident wave at the entrance and exit ports. Narrow-channel constrictions sidestep the need for such matching at the boundaries. But for an unconstricted interface, impedance matching requires that both ε and μ be near zero, a combination that no natural material can boast at any frequency.

Using a technique they call photonic