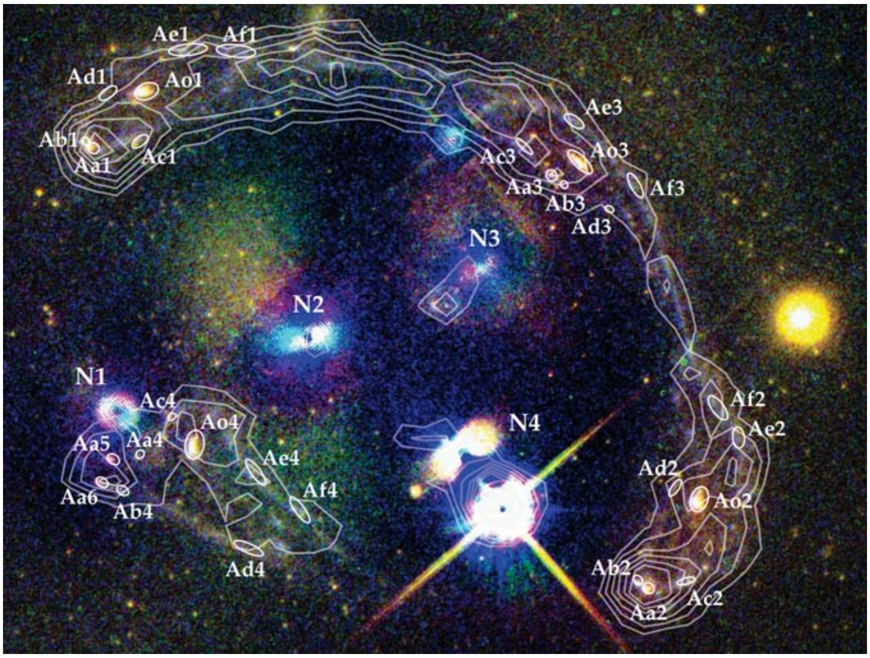



**The core of the galaxy cluster Abell 3827** includes four galaxies, here labeled N1–N4. This *Hubble Space Telescope* image also shows a distorted, gravitationally lensed distant galaxy. Spectral contours guide the eye to the 30 lensed-galaxy structures labeled here. An analysis of the lensing detail indicates that the dark matter associated with N1 is farther from the cluster center than the luminous material. (Adapted from ref. 1.)

of the 30 lensed images labeled in the figure to the core of the lensed galaxy (denoted by Ao) or to one of the galaxy's six bright, star-forming regions (labeled Aa–Af). Armed with those identifications, the research team turned to a pair of independent computer models to map the locations of the lensing dark-matter halos in the core of Abell 3827 (not shown). They found N1 to be significantly offset from its halo, by $1.6 \pm 0.5$ kpc in the cluster-image plane, with the luminous matter closer to the cluster center.

Massey's group was not the first to see a halo–galaxy offset in Abell 3827, nor the first to suggest that it might be a manifestation of dark-matter self-interactions. Those honors go to Liliya Williams (University of Minnesota) and Prasenjit Saha (University of Zürich),[2] who have joined Massey in the more recent work. Assuming that the offset was entirely due to dark-matter self-interactions, Williams and Saha obtained a lower bound for the interaction strength $\sigma$ per unit mass $m$. Massey and company used the same assumptions and with their offset obtained an estimate of $\sigma/m = (1.7 \pm 0.7) \times 10^{-4}\ \mathrm{cm^2/g}$. The deduced interaction strength depends on the duration of the galaxies' movement to the cluster center; the team's value of $\sigma/m$ used a ballpark estimate of $10^9$ years. The interaction strength is expressed in particle physicists' conventional cross-section units; by way of comparison, the cross section for hydrogen gas is roughly $\sigma/m = 10^8\ \mathrm{cm^2/g}$.

An assertion that dark-matter self-interactions have been unambiguously observed would require extraordinary evidence, and Massey and company do not claim to have made an ironclad case. The challenge of determining experimental uncertainties and the modeling required to obtain the halo locations are formidable, and even given those locations, the researchers note that "interpreting an offset between mass and stars is difficult."[1] The combined effects of matter along the line of sight to Abell 3827 and conventional physics in the complex environment of the cluster could somehow be responsible for the inferred misalignment of dark and luminous matter. Detailed simulations in the future should help clarify whether frictional dark-matter interactions exist.

Furthermore, the dark-matter interaction model used to obtain $\sigma/m$ is greatly simplified. Indeed, within a couple of weeks of the publication of the Massey work, a team led by Felix Kahlhoefer (German Electron Synchrotron) considered a more sophisticated model of dark-matter self-interaction.[3] The theorists concluded that if the displacement observed by Massey and company is totally due to unconventional dark-matter physics, then $\sigma/m = 1.5–3\ \mathrm{cm^2/g}$, a value high enough to strain the upper bounds determined from the bullet cluster and other observations.

**Steven K. Blau**

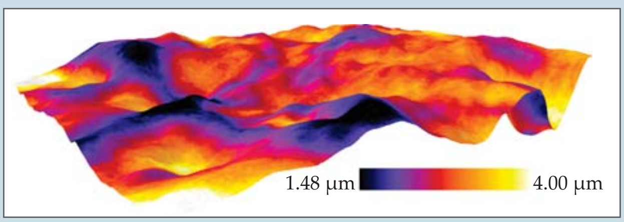
## References


1. R. Massey et al., *Mon. Not. R. Astron. Soc.* **449**, 3393 (2015).
2. L. L. R. Williams, P. Saha, *Mon. Not. R. Astron. Soc.* **415**, 448 (2011). See also I. Mohammed et al., *Mon. Not. R. Astron. Soc.* **439**, 2651 (2014).
3. F. Kahlhoefer et al., http://arxiv.org/abs/1504.06576.


# physics update

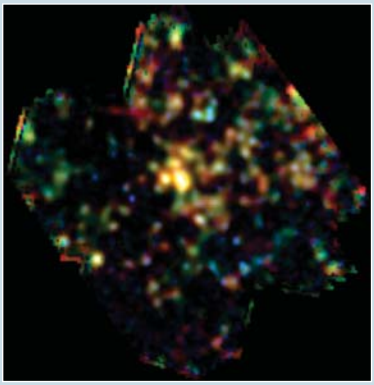
**These items, with supplementary material, first appeared at http://www.physicstoday.org.**

**The topography of ink on paper.** Dribble some ink or toner into water and it will diffuse uncontrollably. More sophisticated substrates are needed for controlled printing, and the interaction of ink with paper is of great importance to the ultimate quality and durability of the product. Coating paper with minerals or polymers is a common way to influence that interaction. Yet the microscopic three-dimensional structural characteristics of the ink–paper interface still remain mysterious. A group of researchers in Finland, led by Jussi Timonen (University of Jyväskylä), is working to clear that up. The team



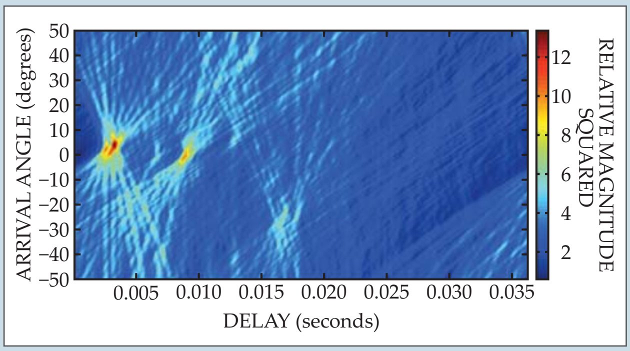

brought old techniques together in new ways for their analysis of 1-mm$^2$ samples of lightly coated paper—very heterogeneous substrates with almost no coating in some patches—covered with cyan toner. First, they used x-ray tomography on the printed paper to get a sample's underlying topography at 0.8-μm resolution in all three dimensions. That resolution was fine for looking at the sample laterally but not for studying the details of the very thin ink layer. So Timonen and coworkers then used a laser to gradually erode the less-than-one-micron-thick ink layer and, after each laser ablation step, obtained a depth profile with 70-nm resolution. The figure shows a 3D visualization of the inked paper's topography with the toner thickness superimposed. The researchers found that the thickness of the toner layer was dependent on the roughness of the coated paper rather than on variations of the coating. In particular, the ink was thinner where fibers protruded, even if those protrusions were in valleys rather than on peaks. (M. Myllys et al., *J. Appl. Phys.* **117**, 144902, 2015.) —SGB

**Galaxy clusters in formation.** Galaxies typically don't shine alone. Instead, like our Milky Way, they often are members of galaxy clusters, the largest bound objects in the universe. By studying the formation and evolution of those clusters, cosmologists hope to test their models and learn about the nature of dark matter and dark energy (see the article by Josh Frieman, PHYSICS TODAY, April 2014, page 28, and the news story in this issue, page 18). Now, by combining data obtained from the European Space Agency's *Planck* and *Herschel* observatories, cosmologists may have caught a number of galaxy clusters in the act of forming. *Planck*, celebrated for its exquisite maps of the cosmic microwave background, sees the entire sky, but with relatively poor resolution. Still, the satellite was able to spot about 230 highly redshifted, bright sources that appeared to be from an epoch when the universe was less than 4 billion years old. Scientists from the *Planck* collaboration followed up on those observations by procuring images from *Herschel*'s higher-resolution Spectral and Photometric Imaging Receiver; in the representative figure shown here, the different colors correspond to observations at different wavelengths. The *Planck* researchers caution against definitively concluding that the overdense regions revealed by the *Herschel* follow-up are protoclusters—galaxy clusters in the process of formation. However, the number of overdense regions they observe is consistent with theoretical predictions for protoclusters. And as determined by their IR luminosities, the individual members of the putative protoclusters are producing stars at the fantastic rate characteristic of young galaxies—roughly 1000 times that of today's Milky Way. (N. Aghanim et al., *Planck* collaboration, *Astron. Astrophys.*, in press.) —SKB



**Bacterial viruses fuse membranes.** To infect an *Escherichia coli* bacterium, a λ virus must get its DNA through the cell's outer membrane, through the mesh of cross-linked polymers that forms the cell wall, and then through the cell's inner membrane. How the viruses' progeny escape through those same three layers is the focus of a new paper by Ry Young of Texas A&M University and his collaborators. Previous research had elucidated two of the steps—opening a hole in the inner membrane and dissolving the polymer mesh. It had also implicated a pair of viral proteins, Rz and Rz1, in breaching the outer membrane. The longer molecule, Rz, binds to the inner membrane and has the potential to fold over onto itself; Rz1 binds to the outer membrane. Before the polymer mesh is dissolved, Rz and Rz1 bond to form spanin, a molecular complex that threads through the mesh to span the inner and outer membranes. From a set of biophysical and biochemical experiments, the researchers deduced spanin's role in viral escape. When the polymer mesh is dissolved, the spanins are freed to clump together. Clumping releases energy that enables the spanins to bend almost double about their Rz hinges, so that the inner and outer membranes are pulled together and fused. That change in topology creates holes through which the cell's contents, including the viral progeny, explosively debouch. (M. Rajaure et al., *Proc. Natl. Acad. Sci. USA* **112**, 5497, 2015.) —CD

**The many paths to underwater acoustic communication.** Because most electromagnetic waves are strongly attenuated underwater, communications—between a ship and remote sensors or unmanned autonomous vehicles, for example—typically rely on sound waves. But transmitting information acoustically through the noisy ocean environment presents its own challenges: Repeated scattering and distortions cause an acoustic signal to reach the receiver via multiple paths, arriving from varying directions with varying delays. (See the articles by Tom Sanford, Kathie Kelly, and David Farmer, PHYSICS TODAY, February 2011, page 24, and by Bill Kuperman and Jim Lynch, October 2004, page 55.) For extracting the information, so-called passive time reversal is an increasingly common approach. The transmitter precedes each message with a short pulse. Using an array of sensors, the receiver documents the pulse's spread in space and time; the figure shows the multiple paths experimentally recorded for one such pulse. By reversing the measurements in time and mathematically correlating them with the message that




follows, one can effectively aim the sensor array so that it focuses on the transmitter. (For more on time-reversed acoustics, see the article by Mathias Fink, PHYSICS TODAY, March 1997, page 34.) Surface waves and relative motion between the sender and receiver introduce variable, path-dependent Doppler shifts. Compensation techniques typically apply an overall Doppler correction. But Sérgio Jesus, Salman Siddiqui, and António Silva at the University of Algarve in Portugal demonstrate a method to calculate and incorporate frequency corrections separately for each arriving wavefront. Testing the method with real data, the team achieved a nearly 5-dB reduction in the transmission's mean square error. (S. M. Jesus, S. I. Siddiqui, A. Silva, *J. Acoust. Soc. Am.* **137**, EL300, 2015.) —RJF ■