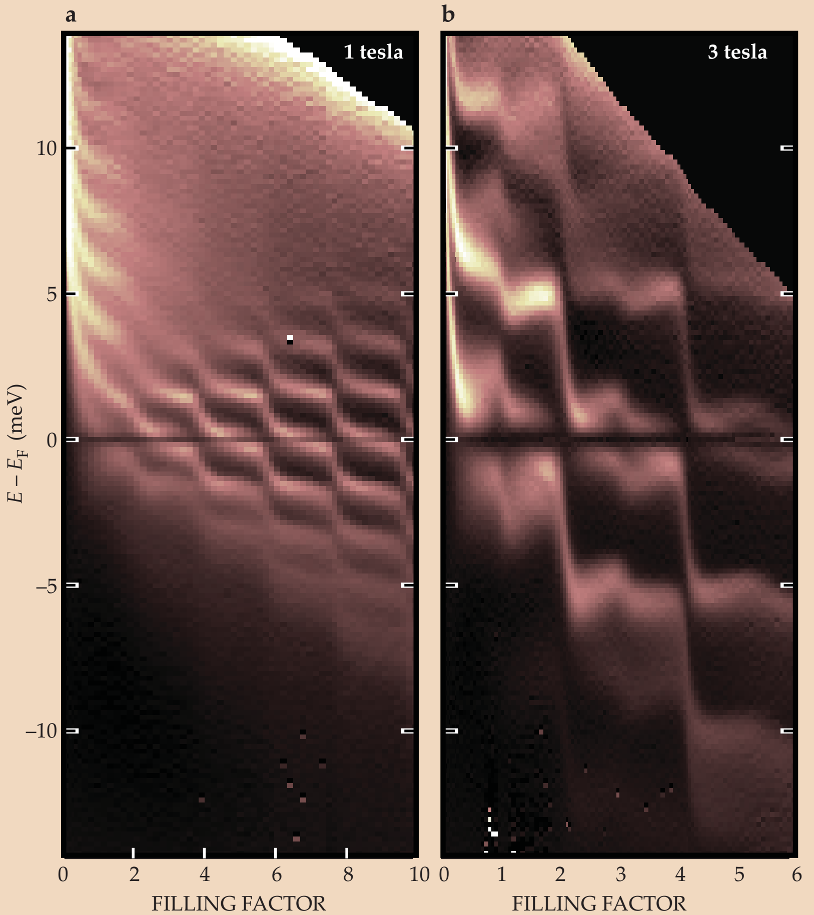

Figure 3. Applying a magnetic field to a two-dimensional electron system puts electrons into Landau levels. To see the levels and other features, MIT's Ray Ashoori and Oliver Dial force electrons to tunnel into the 2DES. The *y*-axis corresponds to the energy *E* of the tunneling electrons measured with respect to the Fermi level E_F. The *x*-axis corresponds to the density of the 2DES, which is measured here in terms of the Landau filling factor, the number of half-filled Landau levels below the Fermi level. (Adapted from ref. 1.)

field *B*. They found $E_{ex} \propto \nu^{-1/2}B$. That dependence is not predicted by theory.

Ashoori and Dial also measured the lifetime of the states occupied by the tunneling electrons. Lifetime, which corresponds to energy broadening, shows up in DOS spectra because the magnetic field pushes the electrons into narrow Landau levels. When scattering or some other process causes the electrons to lose or gain energy, the Landau levels widen.

Fermi liquid theory predicts that lifetime depends on the number of states the electron can decay into when it uses all or some of its energy to eject an electron from the Fermi sea. A low-energy electron has only enough energy to knock out electrons from the shallow top layer. A high-energy electron, by contrast, can knock out electrons from a greater range of depth. In the DOS spectra, lifetime broadening therefore increases away from the *x*-axis.

Disorder, in the form of impurities and lattice defects, also broadens levels through inelastic scattering. The effect of disorder can be mitigated somewhat by the presence of electrons, which screen defects and impurities. Screening increases with electron density, so lifetime broadening increases away from the *y*-axis.

In 1971 Alexander Chaplik derived an analytic expression for lifetime broadening.[2] In the parts of the spectrum where disorder is unimportant, Chaplik's expression provides a good fit with no free parameters.

For all its impressive range and resolution, TDCS has some limitations. The DOS depends not only on energy but also on momentum *k*. Angle-resolved photoemission spectroscopy can measure the *k* dependence, unlike TDCS and other tunneling spectroscopies. But because ARPES works by ejecting electrons and measuring their momenta, it can't be used in applied magnetic or electric fields.

The Coulomb gap provides another limitation. As the applied magnetic field is increased, the gap widens and blots out more of the DOS—just where Ashoori and Dial have started to see new and interesting features. High fields also cause high-energy electrons to lose energy and fall into the Coulomb gap. To get them out and restore equilibrium in time for the next pulse, Ashoori and Dial apply an extra discharge pulse, whose timing and amplitude require painstaking feedback.

That the approach requires a heterostructure is also somewhat of a limitation. Not all materials are amenable to molecular beam epitaxy, the technique Pfeiffer, West, and others use to make heterostructures. Still, there are some promising candidates. Ashoori has teamed up with Ivan Bozovic at Brookhaven National Laboratory. Bozovic is making a heterostrucure out of another interesting 2DES, the high-T_c superconductor lanthanum strontium cuprate. **Charles Day**

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Stromboli volcano's explosions have deep origins

Real-time spectroscopic measurements of emitted gases probe activity far beneath the surface.

Stromboli is an unusual volcano. Located on an island of the same name, just north of Sicily, it has been erupting continuously for at least 2000 years. Tourists flock to Stromboli to climb the mountain and witness the explosions that send clots of lava flying out of the volcano's vent every 10 to 15 minutes. Figure 1 shows the attraction. (Mount Yasur, halfway around the world in the island nation of Vanuatu, erupts in the same way and draws a similar crowd.) The clots usually land within the volcano's crater and pose no threat to anyone. But once or twice a year, larger explosions endanger the visitors, their guides, volcanologists, and sometimes the few hundred inhabitants of the island's two small villages.

Forecasting the larger, more dangerous eruptions more than a few minutes

Figure 1. An eruption of Stromboli volcano, typical of those that have occurred several times an hour for at least two millennia. The eruptions are driven by slugs of gas that rise to the surface and burst.

in advance is not currently possible. Little is known about the arrangement of the conduits, or plumbing, of Stromboli or any other volcano, so models of volcanic activity are poorly constrained. Now, Mike Burton and his colleagues at the National Institute of Geophysics and Volcanology in Catania, Sicily, have made a substantial addition to that sparse body of knowledge by determining the depth from which Stromboli's explosions originate.[1]

Volcanic eruptions are classified into types named after famous prototypes. Hawaiian eruptions, for example, are relatively gentle flows of low-viscosity lava. Plinian eruptions, named after the AD 79 eruption of Mount Vesuvius described in a letter by Pliny the Younger and more recently exemplified by the 1980 eruption of Mount Saint Helens, are huge explosions that drive large quantities of smoke and ash high into the sky. Strombolian eruptions, seen also in Yasur and other volcanoes throughout the world, are the result of gases dissolved in the magma coalescing into large bubbles called slugs that ascend and burst at the surface, propelling lava into the air. The slugs take up most of the width of the conduits through which they travel, more like the bubbles in a drinking straw than those in a pot of boiling water.

Tiny bubbles

Two mechanisms have been proposed for slug formation. In one, small bubbles coalesce into slugs as bubbles of different sizes rise through the magma at different rates. In the other, many small bubbles accumulate at a structural discontinuity deep within the volcano, where they form slugs that then shoot to the surface.

Burton and colleagues sought to distinguish between the two mechanisms by measuring the composition of the slugs. Different gases have different solubilities in magma, all of them pressure dependent. As magma rises to the surface, the pressure on it decreases, and the gases dissolved in it come out of solution—but not all at the same time. Carbon dioxide comes out of solution first, followed by water vapor, sulfur dioxide, and hydrogen chloride. The ratio of the amounts of any two of those gases gives a measure of the pressure at which a slug formed. Slugs also contain carbon monoxide and carbonyl sulfide, but the amounts of those gases aren't determined solely by the pressure at which the slug originated. Rather, they form in chemical reactions among the other gases, in amounts that depend on the temperature.

Spectacular as Stromboli's eruptions are, the slugs that cause them constitute only about 1% of the volcano's total gas output. The rest comes from quiescent degassing of the magma at the surface. Gas bubbles in the magma that don't coalesce to form slugs make the magma less dense and cause it to rise to the surface, where the gases are released. The dense, degassed magma then sinks back down through the conduit, pushing a new batch of gas-rich magma to the surface. The composition of the quiescent emissions is different from that of the slugs, but no one knew just how different before Burton and

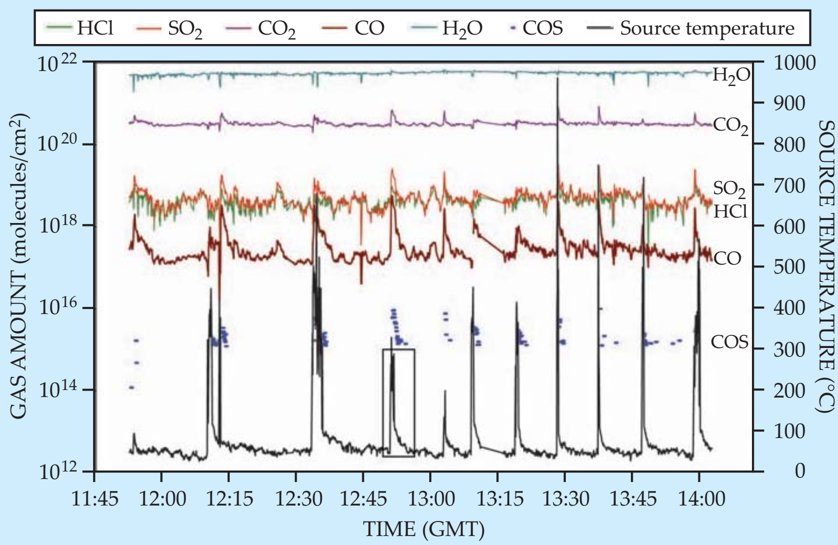

Figure 2. Fourier-transform IR spectroscopy measurements of the gases emitted by Stromboli volcano. A spectrometer situated 240 m from the volcano vent captured the IR radiation emitted by the ejected lava during an eruption or by the crater floor between eruptions. The volcanic gas amounts (colored lines and points) were derived from the IR absorption spectra of the gas between the source and the detector; amounts are given in molecules per unit area perpendicular to the line of sight. Eruptions coincided with changes in both the source temperature (black line) and the gas composition. When the measurements were corrected to account for the water and carbon dioxide in the air, quiescent gas emissions between eruptions were found to contain 83% H_2O and 14% CO_2, and had a CO_2/SO_2 ratio of 7.8. The gas released in one typical explosion, marked by the black box, was 64% H_2O and 33% CO_2, and had a CO_2/SO_2 ratio of 18.4. (Adapted from ref. 1.)

colleagues made their measurements.

Measuring the composition of the slugs is not easy. Because collecting a gas sample in the midst of a volcanic eruption is hazardous, a remote sensor is necessary. The gas from a slug dissipates quickly, mixing with the surrounding air and quiescent emissions, so that getting an accurate measurement requires adequate time resolution. And determining the gas ratios requires measuring many different molecular species simultaneously.

Burton and colleagues met all those requirements with a technique called open-path Fourier-transform IR spectroscopy, which quantifies the composition of the slugs based on the characteristic molecular vibrations of the component gases. With a spectrometer 240 m away from the volcano's vent, they sampled the IR radiation emitted from the hot surfaces inside the crater. That radiation was passed through a Michelson interferometer and Fourier transformed to give the frequency spectrum. The resulting absorption lines correspond to the vibrational transitions of the gas molecules between the magma and the detector. The composition of the slug gas could then be inferred from the relative strengths of the absorptions. Measurements of H_2O and CO_2 had to be corrected to account for the presence of those gases in the intervening air, so those measurements had higher uncertainties (20–25% and 10%, respectively) than the measurements of other gases (4–6%).

A representative set of measurements, with a spectrum taken every 4 s, is shown in figure 2. The baseline gas composition is that of the quiescent emissions, and the periodic spikes correspond to the slugs. The data show that the slugs have less H_2O, more CO_2, and a greater CO_2/SO_2 ratio than the quiescent emissions, all of which suggest a greater source pressure. "The enormous variation in the CO_2/SO_2 ratio, to 22 or 23 for the most intense explosions from a background level of 8, was a very pleasant surprise," says Burton. "No one really had any idea what type of variation there would be, if any." Smaller explosions gave off gases richer in H_2O than the larger slugs, and with a slightly smaller CO_2/SO_2 ratio.

To convert the gas compositions into a pressure or depth of origin, the researchers needed to know how much gas was dissolved in the magma to begin with, so they looked at the analyses of the products of Stromboli's most severe eruptions.[2] Some 10 km beneath the surface, pockets of basaltic magma become trapped in chunks of olivine (a mineral that solidifies at a much higher temperature than basalt), which are then propelled from the volcano in violent explosions. Starting from the volatile content of the basalt, Burton and colleagues ran a computer simulation of how the magma would degas as it rose through the volcano's plumbing. They found that the typical slug's composition corresponded to a depth of origin of about 3 km—right around the level of the sea floor.

That the slugs originate so far below the surface is a clue that they probably form from a foam that builds up at a structural discontinuity rather than from small bubbles that rise steadily through the conduits at different speeds. Although the smaller slugs had a different composition, indicative of a shallower origin of about 0.8 km, the researchers speculate that they might actually form at the same depth as the larger slugs. But because the smaller slugs rise through the magma more slowly, they could become contaminated by the bubbles in the shallow magma they pass through.

Burton and colleagues are currently working on setting up a permanent automatic system to monitor the Strombolian gases. Previously, they had to transport their spectrometer to the peak every time they wanted to take a measurement. That meant obtaining only snapshots of activity and taking no measurements during the larger explosions. The researchers also hope that their measurements will eventually lead to the discovery of a warning signal for the largest, most dangerous eruptions. "The slugs don't just bring gas from that depth," says Burton. "They also bring information, and that's extremely precious."

Johanna Miller

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Sonar mapping suggests that the English Channel was created by two megafloods

Until about 450 thousand years ago, Britain and France were connected by a land bridge, even at times of high sea level.

Catastrophic geological events that suddenly change the cartographic face of Earth are as rare as they are spectacular. When the isthmus that joined Iberia to North Africa was breached some 6 million years ago, the resulting superflood created the Strait of Gibraltar and refilled the long-dessicated Mediterranean basin in just a few decades. Some geologists argue that the Bosporus strait at Istanbul is the result of a similar breach eight thousand years ago: Mediterranean waters spilling into the lower-lying, previously landlocked Black Sea, they speculate, suddenly raised its level, sweeping away human communities around its littoral and giving rise to the flood myths of Gilgamesh and Noah.

In 1985 Alec Smith at Royal Holloway College London invoked a fragmentary seismic survey of the English Channel's floor to conjecture that the Dover Strait, which links the Channel to the North Sea, was created a few hundred thousand years ago by a sudden, catastrophic breach of the chalk ridge that had connected Britain to northeastern France (see figure 1). But the Channel-floor data available in 1985, and indeed for the next two decades, could not convincingly distinguish between Smith's bold hypothesis and more gradualist explanations for the opening of the Dover Strait: glacial erosion, tidal scouring, or ordinary fluvial erosion in glacial episodes of minimum sea level when the Channel basin was just a complex of river valleys.

But now a team led by Sanjeev Gupta and Jenny Collier at Imperial College London has reported that newly available high-resolution sonar mapping of several thousand square kilometers of the English Channel's floor (the black rectangle in figure 1) brings to light strong evidence of the catastrophic flooding that Smith had proposed.[1] The bathymetric data, mostly from unpublished shipborne sonar mapping over 24 years by the UK government's Hydrographic Office, chart the Channel floor with horizontal and vertical accuracies of 20 meters and 10 centimeters, respectively.