the loss of interference visibility with increasing separation.

Indeed, as shown in figure 2, Sgr A* was detected on the Arizona–Hawaii baseline in only 4 of the 15 scans. And the California–Hawaii baseline yielded no interferometric Sgr A* sightings at all. On the other hand, calibration scans of half a dozen quasars on the same two days invariably produced successful interferometric sightings on all three baselines.

Fitting for size

Meager as they are, the Sgr A* detections on the 4600-km Arizona–Hawaii baseline yielded the principal information about the spatial extension of the source. That's because the falloff of the visibility function is what measures the source size, and the short-baseline data show little falloff.

To estimate the source size from so few measurements, the collaboration fitted simple illustrative models of the source geometry to the data. Figure 2 shows the best fit to a model that simply assumes a circularly symmetric source on the sky whose radio intensity has a gaussian falloff with distance from the central maximum. The fit yields a source diameter (at half maximum) of 43 μas. But that's still uncorrected for the smearing effect of scattering by the intervening plasma.

Extrapolating from scattering-dominated VLBI measurements of Sgr A* at longer wavelengths, the group concluded that the source's intrinsic width in the absence of scattering would be about 37 μas. That's actually three standard deviations smaller than the minimum 52-μas gravitationally lensed image expected for a source symmetrically centered on the black hole. And even if the black hole is spinning rapidly, general-relativistic spin distortion could only bring that minimum down to 45 μas.

Doeleman and company point out that this marginal discrepancy might be indicating that the radio source is not symmetrically centered on the black hole. If, for example, the source is a rapidly spinning accretion disk seen edge on, relativistic Doppler beaming would make the disk's approaching side appear much brighter than the receding side. Or the source might be the radio-loud nozzle of one of a pair of jets of relativistic material expelled in opposite directions along the disk's spin axis.

To emphasize that the new data cannot yet discriminate between various plausible source geometries, figure 2 also shows a satisfactory fit with a ring-shaped source seen face on, with inner and outer diameters of 35 and 80 μas. The ring model's dark inner circle is meant to suggest the black hole silhouette found in detailed general-relativistic simulations of an accretion disk at Sgr A*. "But over the next year or two," says Doeleman, "as we add more telescopes and start observing at submillimeter wavelengths, we hope to constrain ever more sophisticated models."

"That's important, because decades of theoretical calculations have thus far failed to converge on a consensus about the shape and character of Sgr A*'s accretion disk," says Harvard theorist Avi Loeb, who has recently joined in the analysis of the new observations. "But this first VLBI size determination already has largely foreclosed the possibility that the central object is anything other than a black hole." If the accreted material were landing on a physical surface that small—perhaps some sort of supermassive compact star—rather than disappearing behind an event horizon, there would have to be far more IR radiation from Sgr A* than what's been seen.

The modest IR luminosity of Sgr A* is known occasionally to flare up and oscillate with periods on the order of half an hour. The conjecture is that those oscillations represent occasional hot spots rotating near the accretion disk's inner edge. "By next spring," says Doeleman, "we should be able to follow the movement of such hot spots as they spiral toward the event horizon."[2] General relativity predicts that the orbital period of the disk's inner edge has some dependence on the black hole's spin. Independent of the hot spots, Doeleman, Loeb, and coworkers have now reported modest constraints on the black hole's spin gleaned from the VLBI data already in hand.[3]

Real 2D imaging of Sgr A* is perhaps five years away. That's when ALMA, the Altacama Large Millimeter/submillimeter Array of advanced 12-meter radio telescopes now under construction in the high desert of Chile, should be ready to join a VLBI network. "It's the best site on the planet for submillimeter observing," says Doeleman.

Bertram Schwarzschild

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Two models combined can forecast lava flow accurately and promptly

Changes in an erupting volcano can be monitored by satellite, but computing their consequences is a challenge.

Volcanoes claim lives in different ways, by spewing hot ash clouds and projectile tephra or by triggering tsunamis and mudflows. But flowing lava from a so-called effusive eruption does not often endanger life. Since lava rarely flows faster than people can walk, it's usually easy to get out of the way. But a lava flow destroys all the roads, buildings, and agricultural land in its path, as shown in figure 1. It's therefore important for scientists to be able to forecast the direction and distance that lava will flow, so that civil authorities can order evacuations or take other appropriate measures.

One precaution that's sometimes employed is the building of earthen dams to divert lava away from developed or otherwise valuable land. Good forecasts can ensure that the dams, which take time and money to construct, are placed where they will be most effective. But modeling the flow of lava over uneven terrain is a complicated challenge in thermodynamics and rheology. As lava cools, it solidifies and eventually stops flowing. And uncertainty in measurements of the terrain complicates the prediction of what directions a flow will take.

In 1999–2000 Massimiliano Favalli, Maria Teresa Pareschi, and their colleagues from the National Institute of Geophysics and Volcanology in Pisa, Italy, developed DOWNFLOW, a stochastic model that forecasts the flow's direction but not its distance.[1] In 2001 Andrew Harris and Scott Rowland of

Figure 1. On 13 February 2003, flowing lava from the Pu`u `O`o volcanic cone inundated Chain of Craters Road in Hawaii Volcanoes National Park on Hawaii's big island. Mobile structures maintained by the park were towed up the road and saved. (Courtesy of the US Geological Survey.)

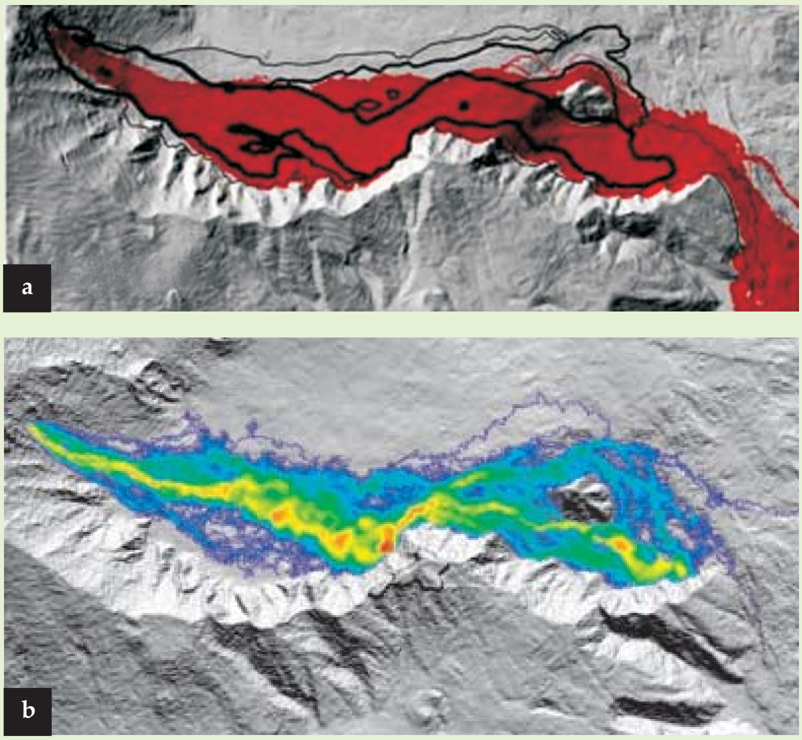

Figure 2. A lava flow from the 1991–93 eruption of Mount Etna in Italy. The lava originates from the vent in the upper left corner of each panel. **(a)** The black lines indicate the actual extent of the lava on 2 January (outermost line), 11 January, and 31 May (innermost line) 1992. The red area shows the results of the DOWNFLOW model, which forecasts the lava's direction but not its distance. (Adapted from ref. 1, Favalli et al.) **(b)** A DOWNFLOW/FLOWGO simulation of the same flow based on the lava effusion rate on 2 January 1992. Colors indicate the likelihood of inundation: red for most likely, purple for least likely. The flow in the figure is 7 km long and extends to within 3 km of the town of Zafferana Etnea. (Adapted from ref. 3.)

the University of Hawaii in Honolulu presented FLOWGO, a model that forecasts how far lava will flow but not in what direction.[2] Now, Robert Wright (also of Hawaii), Harris, and programmer Harold Garbeil have combined the two models to yield a computationally efficient tool for forecasting the direction and extent of a lava flow.[3]

Go with the flow

In the late 1990s Wright and Harris were both interested in the possibility of using satellite data to produce more realistic lava-flow forecasts. A satellite measurement of the IR radiation from an active lava flow can be used to derive the effusion rate, the volume of lava emitted per unit time: The greater the heat flux, the greater the effusion rate. That rate, in turn, affects how far the lava can flow before it cools and solidifies. Over the course of an eruption, the effusion rate often changes substantially, but as Wright explains, "All the numerical models published at that time used a single, unchanging effusion rate to generate their predictions." Satellites could provide updated effusion rate measurements as often as several times per day.

The FLOWGO model translates effusion rates into forecasts of lava flow lengths. It simulates lava flowing in a channel, meaning that the upper surface of the lava flows along with the bulk. As a parcel of lava moves through the channel, it loses heat to the ground below the channel, the levees to the sides, and the atmosphere above. The greater the effusion rate, the faster, wider, and deeper the lava is at its source, and the farther it can flow before solidifying.

With DOWNFLOW, Favalli and colleagues took a different approach. The model doesn't explicitly simulate the lava flow to predict its direction but is instead a convenient means of getting the right answer. It's based on the idea that given a terrain map of an area, calculating the path of steepest descent is easy. But that calculated path doesn't fully represent the lava's path. First, because terrain maps have finite resolution, the terrain is not exactly known. Second, a stream's depth affects its flow: A deep enough stream can surmount obstacles to send branches flowing off in multiple directions.

The DOWNFLOW model accounts for both of those complications by randomly varying each point on the terrain within a range defined by the terrain's uncertainty and the expected flow depth. The path of steepest descent is calculated for the modified terrain. That process is repeated many times—usually thousands or tens of thousands—and the flow area is taken to be the union of all the computed paths, as shown in figure 2a. When the model is applied in practice, as it has been for recent eruptions of Mount Etna in Italy, flow lengths are estimated based on the statistics of past eruptions. Says Favalli, "I am still surprised that such a simple model is able to predict so well the areas invaded by gravity-driven fluids."

To combine the models, Wright and colleagues used FLOWGO to compute the expected termination of each path computed by DOWNFLOW. Even with the extensive repetition, results can be generated more quickly than with other simulation techniques: Some 10 000 paths can be computed in just 20 minutes, whereas other methods take several hours. Furthermore, as Wright explains, "When we compared the DOWNFLOW/FLOWGO combination with other models, we found that it performed as well, and, in fact, better."

The researchers are still working on implementing their model in real time. To test it, they instead used the early 1990s eruption of Mount Etna. Figure 2b shows the results for the effusion rate measured on 2 January 1992; the actual extent of the lava flow is shown by the largest outlined area in figure 2a. For that date and several others during the same eruption, the model's results agree well with observations. Says Wright, "The model doesn't predict every twist and turn that a lava flow might take. Then again, no model can do that."

Johanna Miller

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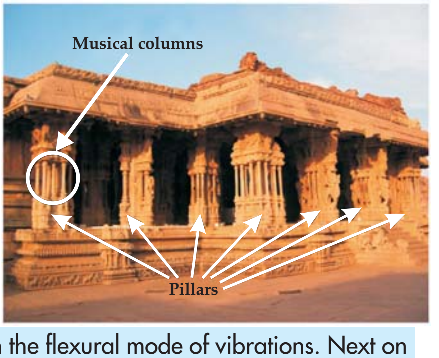
physics update

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

Simulating whistler turbulence. In plasma physics as in fluid dynamics, turbulence remains one of the most challenging fundamental problems to understand. The nonlinear processes that lead to characteristic turbulence power spectra observed in the solar wind—the plasma that flows from the Sun out through the solar system—are poorly understood. So too are the dissipation mechanisms by which plasma turbulence transfers its energy to plasma electrons and ions. Most research in plasma turbulence has assumed that dissipation is weak and the plasma may be approximated as a fluid. But interest has increased in the so-called short-wavelength regime, in which dissipation plays out. Recently, an international team performed the first kinetic, particle-in-cell simulations of decaying short-wavelength whistler-mode turbulence in a collisionless plasma, using parameters similar to those of the solar wind near Earth. (Whistlers acquired their name from World War I radio operators who frequently heard what they thought were outgoing artillery shells, brief whistling sounds that decreased in frequency.) Limited not by any approximations but only by computing resources, the researchers found steep power-law magnetic fluctuation spectra consistent with those observed in space. In addition, they found and analyzed anisotropies in the turbulence whereby stronger initial fluctuations generated more magnetic energy perpendicular to the background magnetic field than along it. Because of the anisotropies, the whistlers were found to be more compressible than expected. The physicists also demonstrated the first simulation results of whistler turbulence dissipation by showing signatures of two well-known types of wave–particle interactions. (S. Saito et al., *Phys. Plasmas*, in press.) —SGB

Musical pillars made of solid granite. The Vitthala Temple in the south Indian city of Hampi is more than 500 years old. The image here shows its most curious feature—numerous pillars, each of which includes separate columns that sound musical notes when struck with a finger. Different columns in a pillar produce sounds of different frequencies. Moreover, several multi-columned pillars make sounds similar to specific Indian musical instruments such as the ghanta (bell), mridanga (percussion), or veena (strings). Well known for centuries, the musical pillars are only now beginning to be studied scientifically. Anish Kumar of the Indira Gandhi Center for Atomic Research in Kalpakkam, India, and colleagues took the first steps to characterize the columns: The physicists applied three techniques to learn about the structure of the columns and also analyzed recordings of generated sound. In situ metallography showed the granite to have typical microstructures; both low-frequency ultrasound and impact-echo testing revealed all the columns to be solid shafts. From those studies and spectral analyses, the researchers conclude that the pillars' sounds arise from the flexural mode of vibrations. Next on their agenda is to study how the columns can be excited by just the tap of a finger. (A. Kumar et al., *J. Acoust. Soc. Amer.* **124**, 911, 2008.) —SGB



Finding the Ω_b^- baryon. The Ω^- baryon played an important role in the evolution of particle theory. Its much heralded discovery in 1964 at precisely the mass (1.67 GeV) predicted by symmetry arguments about charge and strangeness led promptly to the quark model of the strongly interacting particles. The quark model described the Ω^- as a bound state of three strange (s) quarks. The relatively straightforward "naïve" quark model has long since been incorporated into quantum chromodynamics, a much more complete theory from which, however, precise predictions are notoriously hard to extract. But QCD does predict that the Ω^- should have a heavy-quark analogue, called Ω_b^-, with a mass of about 6.0 GeV—more than six times that of the proton. In the Ω_b^-, one of the three s quarks is replaced by the much heavier bottom (b) quark. Now,