

sketched in figure 2, was a pair of lenses to shape the line-source emission into a Gaussian beam.

Exposed to the circulating intracavity beam, a photomixing crystal should, in principle, emit higher-intensity terahertz radiation than it would were it illuminated by an external laser beam. The team's initial experiments, however, were rendered inconclusive due to calibration difficulties.

A second attempt last year—this time in collaboration with Desert Beam Technologies, a small University of Arizona spinoff company—was more decisive. The team's device, coined a terahertz external-cavity surface-emitting laser (TECSEL), yielded 2 mW of 1.9-THz radiation and, in a separate trial, 0.5 mW of 1-THz radiation—both records.

Catching waves

The TECSEL addresses one of astronomy's long-standing problems. The emission lines of several substances of

astrophysical interest, including singly ionized carbon (1.9 THz), carbon monoxide (1.27 THz), and singly ionized nitrogen (1.46 THz), fall squarely into the terahertz gap. So-called heterodyne receivers can detect over that range but must be driven by a local oscillator—a continuous, narrowband source tuned to the frequency of interest.

In a proof of concept at the University of Arizona's Steward Observatory, the TECSEL successfully drove a heterodyne receiver at 1.9 THz—a result that bodes well for terahertz astronomy applications. Explains Moloney, "A milliwatt of power at 1.9 THz could drive 100 pixels in a receiver array. That may not sound like much, but the current state of the art is a single pixel."

Still, Moloney acknowledges, more work remains to make the TECSEL a practical option for space- and balloon-borne observation. Aside from improving its conversion efficiency, the team hopes to shrink the device from its ini-

tial footprint of about 10×20 cm down to length scales of a few millimeters.

The utility of the continuous-wave terahertz source may not be limited to stargazing. Caltech's Peter Siegel envisions applications in areas as far-flung as communications, security screening, and atmospheric chemistry. In fact, he suggests, the most important applications might be at the level of basic science. "This may be a case where technology drives new science, instead of the other way around. It opens up a new area of development that I think will be quite fruitful."

Ashley G. Smart

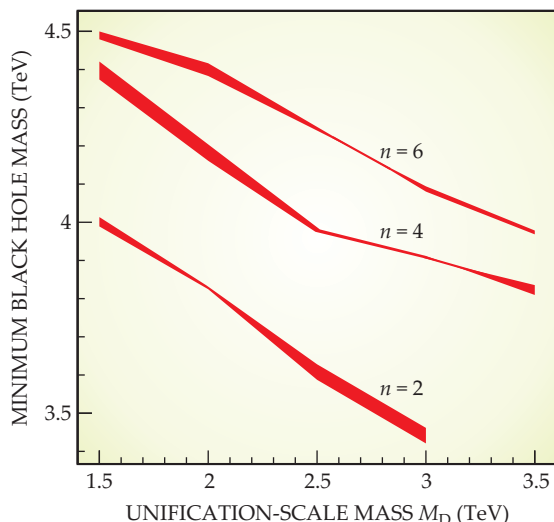
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physics update

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

No microscopic black holes yet. From among 10^{13} proton-proton collisions at 7 GeV in its first year of operation, the Large Hadron Collider (LHC) at CERN has as yet yielded no evidence of black hole production. The detectable creation of microscopic black holes at the LHC follows from speculative but attractive



theories that seek to explain the puzzling weakness of gravity by positing curled-up extra spatial dimensions accessible only to gravitons. In such theories, the intrinsic strength of gravity would be comparable to those of the electromagnetic and weak interactions at energies near 1 TeV, where electroweak unification occurs. But now the collaboration that runs the LHC's Compact Muon Solenoid (CMS) detector, having found no evidence of black holes, has published the first experimental lower limits on their masses. A black hole produced in a 7-TeV collision would

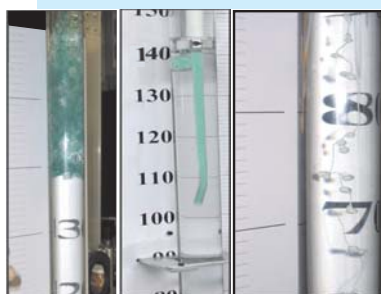
decay by Hawking radiation within 10^{-27} s into perhaps half a dozen extraordinarily energetic particles—mostly quarks and gluons manifesting themselves as jets of hadrons. Such a spectacular decay would be conspicuous not only by the number of emerging ultrahigh-energy jets, but also by their unusually isotropic distribution. Even in the absence of true black hole events, however, 10^{13} collisions will create many imposters. So determining limits on black hole production requires painstaking estimation of the resulting backgrounds. The figure shows the minimum black hole mass deduced from the CMS null result as a function of two parameters of the extra-dimension theories: the number n of extra spatial dimensions, and the characteristic mass scale M_D of the putative unification of the gravitational and electroweak interactions. (CMS collaboration, <http://arxiv.org/abs/1012.3375>) —BMS

Superplastic mantle minerals. Superplasticity is the ability of some crystalline materials to stretch up to several times their own length when heated. Although the minerals in Earth's mantle don't endure such large strains, circumstantial evidence suggests that superplasticity helps them respond to the subduction of continental plates and other tectonic processes. Now, a team led by Takehiko Hiraga of Tokyo University and Hidehiro Yoshida of Japan's National Institute for Materials Science has found direct evidence that mantle minerals are indeed superplastic. Like other superplastic materials—real or presumed—those in the mantle are polycrystalline aggregates. For their study, Hiraga, Yoshida, and their team sintered nanoscale powders to make two analogues of mantle minerals, both of which consisted mostly of forsterite (Mg_2SiO_4). In the absence of strain, a superplastic material is made up of nanoscale grains of the majority component interspersed with smaller grains of the minority component. When heated under strain, the majority and minority grains both grow by merging with their neighbors.



That response ensures that grains continue to abut each other, forestalling failure of the bulk material. As the accompanying figure shows for samples that consisted of 90% forsterite and 10% periclase (MgO), the materials could withstand strains of more than 500%. Moreover, two electronic diagnostics, electron back-scattered diffraction and transmission electron microscopy, revealed that grains in the mantle analogues grew like grains in materials whose superplasticity is established. Having measured the temperatures and strain rates for which mantle analogues become superplastic, the team estimated that superplasticity could help Earth's mantle accommodate a 200-km slab that takes 60 million years to penetrate 3000 km. (T. Hiraga, T. Miyazaki, M. Tasaka, H. Yoshida, *Nature* **468**, 1091, 2010.) —CD

What killed top-kill? Global news coverage of the blown-out BP-operated Macondo well documented several efforts to stem the roughly 8 million liters per day of crude oil that gushed into the Gulf of Mexico from April to July 2010. One notable failure was the “top-kill” method to plug the well by pumping a dense



slurry of drilling mud into it—reportedly, much of the mud was swept out by the spewing oil. A recent study by scientists at Lawrence Livermore National Laboratory and Washington University in St. Louis points to fluid shearing as the chief culprit in top-kill's failure. Turbulent eddies, caused

by the velocity differences between the counterstreaming mud and oil, likely sheared the mud, breaking it up into packets of fluid whose settling velocities were an order of magnitude smaller than the upward velocity. In laboratory experiments, the researchers confirmed their theory and demonstrated a possible solution, adding a viscoelastic polymer to an aqueous cornstarch mixture to represent the drilling mud. As the images show, the control fluid (left, in green) suffered turbulent breakup, but the polymer-laced fluid (center) descended as a coherent slug or, at lower flow rates (right), as stringy, connected globules. The researchers calculate that a polymer-doped slug of drilling mud at the Macondo well would have descended with a terminal velocity of roughly 7 m/s, nearly double the estimated 3.7 m/s ascent of escaping oil. (P. Beiersdorfer et al., *Phys. Rev. Lett.*, in press.) —JNAM

Counting a mole of silicon atoms. Avogadro's number, N_A , links the microscopic and macroscopic worlds by specifying how many individuals make up a mole. Now an international team of metrologists has obtained N_A with an unprecedented precision of 30 parts per billion. The result: $N_A = 6.02214078(18) \times 10^{23}$. The idea behind the new experiment is simple. A sample from a crystalline silicon-28 boule, shown in the figure, was subjected to x-ray interferometry, which yielded the volume of the 8-atom Si unit cell. Other bits of the boule were painstakingly fabricated into spheres whose volumes and masses were



carefully measured. The spherical volume divided by the unit-cell volume gives the number of Si atoms; the mass gives the number of moles. Voilà, atoms per mole. The devil, of course, is in the details. The team needed to measure and account for such

flaws as pointlike defects in the boule and surface oxidation on the spheres. Furthermore, uncertainty in the isotopic composition of the silicon translates into an uncertainty in the mass of a mole. Indeed, questions of isotopic composition plagued earlier, similar experiments. In their most recent determination, the researchers worked with a crystal that was highly enriched in ^{28}Si and applied an innovative suite of mass spectrometry techniques to measure the minute remainders of ^{29}Si and ^{30}Si . The new N_A does more than tweak the size of a mole; in combination with other precision experiments, it will be used by metrologists to refine the values of several other fundamental constants. (B. Andreas et al., *Phys. Rev. Lett.*, in press.) —SKB

Iron in the night sky. Even in the absence of the Moon and stars, the night sky would not be black. Chemical reactions in the upper atmosphere emit faint light called airglow, whose spectrum has been studied for more than a century. Much of the emission comes from atomic and molecular oxygen, hydroxyl radicals, sodium, and, at higher latitudes, nitrogen dioxide. But after subtracting those species' contributions from the airglow spectrum at lower latitudes, observers have noted a broad band of unaccounted-for emission in the orange part of the visible spectrum, between roughly 550 and 650 nm. Using measurements from the Optical Spectrograph and Infrared Imager System (OSIRIS) on Sweden's *Odin* spacecraft, Dick Gattinger and Ted Llewellyn (University of Saskatchewan) and colleagues have now identified the source of that band: iron monoxide. Several factors supported the team's conclusions. Nitrogen dioxide was ruled out since sunlight destroys it at lower latitudes and, moreover, it has a different spectral signature. Laboratory measurements of FeO, on the other hand, yield a similar emission spectrum. Iron's atmospheric abundance is comparable to that of sodium, a known airglow contributor. And an orange emission band observed a decade ago originating from iron-containing meteors was also matched to the laboratory FeO spectrum. Subsequent ground-based measurements show that the FeO emission exhibits dramatic temporal fluctuations. The team postulates that FeO is generated through reactions between atmospheric iron and ozone. (W. F. J. Evans et al., *Geophys. Res. Lett.* **37**, L22105, 2010.) —RJF

Positronium in confinement. Porous materials have numerous scientific and technological uses, including catalysis, filtering, and, it turns out, atomic physics. By confining atoms within pores, one can reduce the effects of various mechanisms that broaden spectral lines. Moreover, porous materials can be very efficient for making positronium (Ps). As incident high-energy positrons scatter off the material's nuclei and electrons, they slow down and can bind with one of the electrons. The resulting Ps atoms subsequently diffuse into the pores, where they get trapped, further thermalize, and can have long lifetimes, upward of 50 ns. David Cassidy, Allen Mills, and colleagues at the University of California, Riverside and San Diego State University have now looked at the spectroscopic consequences of Ps confinement, in particular the effect on the $1S\text{--}2P$ Lyman- α transition. Working with a silica film with pores on the order of 5 nm, they compared the spectral lines of Ps atoms trapped in the film with those of Ps atoms that had escaped the film. The team found that the line is significantly shifted and that confinement indeed narrows the width. Calculations incorporating confinement's effect on not only a Ps atom's orbitals but also its center of mass explained the energy shift: Whereas the $1S$ state tends to keep away from the walls, the $2P$ state tends to fill cavities smaller than about 5 nm, and the wall interactions raise the state's energy. (D. B. Cassidy et al., *Phys. Rev. Lett.* **106**, 023401, 2011.) —RJF ■