

Separating scales to model bursting bubbles

Bubbles of soap and other liquids have long been known to adopt the shape that minimizes their surface area. An isolated bubble is a sphere; bubbles in a foam or cluster meet so that their surfaces form 120° angles at junctions. But the shapes of the bubble surfaces in a cluster don't succumb so easily to analytical description. The numerical techniques to treat arbitrary stable bubble geometries¹ didn't begin to mature until the early 1990s.

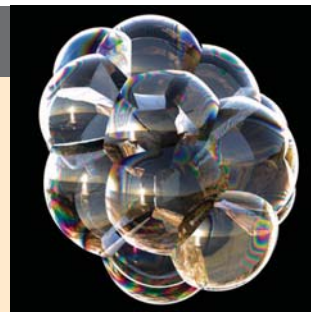
And that equilibrium picture is far from a complete physical description of a bubble cluster, an inherently nonequilibrium system. Under pressure gradients and gravity, fluid drains from the liquid films that constitute the bubble walls. When one of the films gets too thin, it ruptures. The remaining bubbles are left to rearrange into a new configuration, and the cycle begins again. Each of the processes affects the others, but they occur on such different time scales—ranging from a fraction of a millisecond to tens or hundreds of seconds—that re-creating them all in a single numerical simulation has been computationally prohibitive.

Now mathematicians Robert Saye and James Sethian (University of California, Berkeley) have created a framework for capturing the essential physics from the various scales while efficiently using computer resources.² For each of the three processes—drainage, rupture, and rearrangement—they developed a separate numerical model with its own equations, simplifying assumptions, and characteristic time step. By treating each process in turn with the appropriate model, they can transmit the critical information from one scale to another and produce realistic simulations of large bubble clusters.

For small systems, such as two bubbles merging into one, the researchers can compare their numerical results with experiment, and they find excellent agreement. For larger systems, such as the simulated 27-bubble cluster shown in the figure, matching the initial conditions between simulation and experiment would be too difficult. But the simulations reproduce the qualitative features seen in real bubble systems, including rupture cascades in which the bursting of a small bubble induces several larger bubbles to burst in rapid succession.

The researchers anticipate that by modifying their models to include additional physics—evaporation, liquid-solid phase transitions, and so forth—they'll be able to address a variety of "bubble problems" that have industrial and scientific applications. For example, solid plastic and metal foams, materials of interest for their light weight, are produced by hardening liquid foams. (See the article by John Banhart and Denis Weaire, *PHYSICS TODAY*, July 2002, page 37.) Simulations of the processes involved in their production may suggest new ways of controlling their properties.

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References

1. D. L. Chopp, *J. Comput. Phys.* **106**, 77 (1993); K. Brakke, *Exp. Math.* **1**, 141 (1992).
2. R. I. Saye, J. A. Sethian, *Science* **340**, 720 (2013).

In particular, Damour and Esposito pointed out an unanticipated consequence of such nonlinear scalar elaborations: Within a particular range of coupling parameters, those theories imply that the coupling strength of the scalar field to neutron-star matter increases steeply at some critical binding energy. They call that abrupt transition spontaneous scalarization and compare it to the onset of ferromagnetism. Given a fast enough white-dwarf companion, scalarization would strongly increase a binary's dipole radiation and manifest itself as an increase of a few orders of magnitude in the orbit's decay rate.

Having found no such excess in the uniquely auspicious J0348 binary, the

MPIR team effectively excludes almost all of the Damour–Esposito parameter space that predicts spontaneous scalarization. "More generally," says Wex, "we've placed an upper limit on the effective coupling strength of long-range extra gravity fields to matter in a previously unexplored strong-gravity regime."

Most proposed extra gravity fields are "long range" in the sense that, like the GR tensor field, the Brans–Dicke scalar field, and the electromagnetic field, their quanta are massless. The J0348 results would be insensitive to short-range fields with quanta heavier than 10^{-19} eV—that is, a Compton wavelength shorter than the binary's 10^3 -km gravitational wavelength, which is given by $cP_b/2$.

"There are still lots of long-range scalar–tensor theories with strong-field effects that would be consistent with the [MPIR] team's data," says theorist Clifford Will (University of Florida). Many of those predict neutron-star effects much less dramatic than scalarization. Continued monitoring of J0348 should serve to test some of those still viable elaborations of GR.

Bertram Schwarzschild

References

1. J. Antoniadis et al., *Science* **340**, 1233232 (2013).
2. T. Damour, G. Esposito-Farèse, *Phys. Rev. Lett.* **70**, 2220 (1993); G. Esposito-Farèse, <http://arxiv.org/abs/gr-qc/0409081>.

physics update

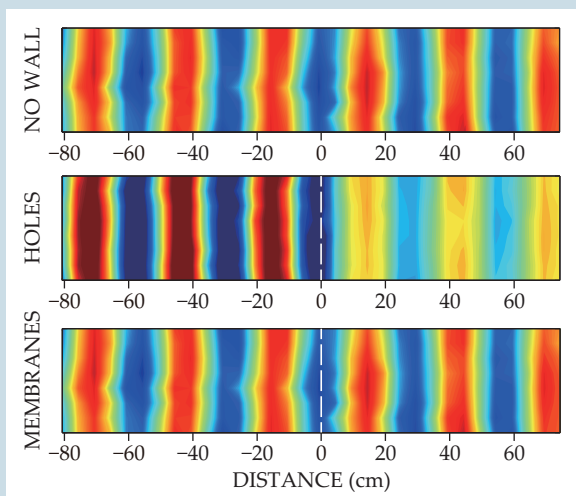
These items, with supplementary material, first appeared at <http://www.physicstoday.org>.

A neutron star suddenly slows its spin. A neutron star is a compact ball of matter in extremis—a sunlike mass stuffed into a sphere about 20 km across—left behind by a supernova explosion. Set spinning by the explosion, such a star is thought to consist of a kilometer-thick crust of electrons and nuclei encasing a rich superfluid. Thanks to their magnetic fields, neutron stars emit dipole radiation and accelerate charged particles outward through their crust; thus they are always losing energy and angular velocity. Curiously, that process is occasionally interrupted by "glitches" in which a star

abruptly spins up by a small amount. Those events, according to models, may be attributable to the faster-moving superfluid exerting enough stress to sometimes fracture the crust and transfer angular momentum. While monitoring a hypermagnetized neutron star known as a magnetar on 28 April 2012 using NASA's *Swift* observatory, astronomers noticed something unexpected: an "anti-glitch," the abrupt 2- μ s slowing of the spin from the star's roughly 7-s period. Just a week earlier, the same magnetar had produced a 36-ms x-ray burst, a telltale sign of events in the star that led to the anti-glitch. But in addition to the sudden slowing, *Swift* recorded an extended period after the anti-glitch when the magnetar's spin rate slowed further still. No theory accounts for the observations, but the researchers suspect two possible mechanisms:

The transfer of angular momentum from some part of the superfluid rotating more slowly than the crust, or the gradual untwisting of twisted magnetic field lines. (R. F. Archibald et al., *Nature* **497**, 591, 2013.) —RMW

An acoustically invisible, rigid wall. You can't have a conversation across a rigid wall—all the sound impinging on it is reflected. Moreover, drilling small holes in the wall won't do much to facilitate communication: Just as heat energy is poorly conducted through a thin wire, acoustic energy is poorly transmitted through small holes. But, reports a collabora-

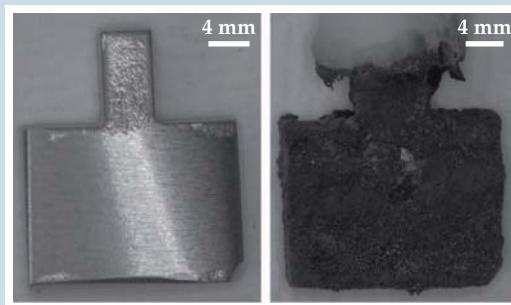


tion led by Sam Hyeon Lee of Yonsei University in South Korea and Oliver Wright of Hokkaido University in Japan, covering the holes with taut plastic film can make a world of difference. When excited at its resonance frequency, a membrane oscillates like a tiny loudspeaker and creates pressure waves that pass through the wall. The figure shows the results of a plane wave launched from the left and normally incident on a rigid, 5-mm-thick acrylic plate (white dashed line) perforated by four small holes. Red represents compression; blue, rarefaction; and yellow and green, near-zero excess pressure. Not much sound got through the uncovered holes, but the membrane-covered holes transmitted 80% of the acoustic energy. Follow-up experiments with different angles of incidence and cylindrical waves also found excellent film-enhanced transmission. Because the passageways are so tiny, the incident acoustic energy density becomes greatly concentrated in those conduits—by a factor of 5700 in one experiment. Moreover, the individual holes in the experimental trials had radii much smaller than the wavelength of the impinging sound. Those two features, say the study's authors, could lead to sensitive acoustic detectors that achieve subwavelength resolution. (J. J. Park et al., *Phys. Rev. Lett.*, in press.) —SKB

Quantum illumination. Detecting a specific target in a cluttered environment is never easy. In 2008 a quantum detection scheme was proposed in which entanglement provided an advantage over the best possible classical illumination source of the same average power. Start with two entangled light beams created, for example, via parametric down-conversion. One beam, called the signal, is sent into a noisy environment to see if a particular object is located there; the other beam, dubbed the idler, is held close to

home. As light returns from the targeted environment, the receiver combines it with the idler. If the signal beam reflects off the object before returning, then an unambiguous signal pops out of the noise—even if the original entanglement is lost. Two groups have now demonstrated the so-called quantum illumination (QI) experimentally. A group from Italy's National Institute of Metrological Research in Turin and the University of Milan demonstrated QI detection that outperformed the best similarly powered classical protocol by orders of magnitude, independent of noise. Meanwhile, in a new twist, a group at MIT used the QI protocol for encrypted communication and showed that messages transmitted through a noisy environment not only survive but remain immune from passive eavesdropping. Both results show that entanglement-related enhancements can survive the loss of that very entanglement, with potential for practical uses in real-world environments. (E. D. Lopaeva et al., *Phys. Rev. Lett.* **110**, 153603, 2013; Z. Zhang et al., *Phys. Rev. Lett.*, in press.) —SGB

Leaner, greener iron and steel. Among the various industrial sectors around the world, iron and steel manufacturing is the second-largest consumer of energy (behind petroleum and chemical processing), according to the International Energy Agency, and the largest emitter of carbon dioxide. The processing of raw iron ore is particularly energy- and CO₂-intensive: Carbon is typically added to chemically reduce iron oxide, producing iron and CO₂, and excess dissolved carbon is removed by reacting it with oxygen gas. An alternative, lower-energy, carbon-free method for removing oxygen from iron oxide and other ores may now be one step closer: molten oxide electrolysis. As common classroom demonstrations with water show, passing electricity through an oxide can strip water of oxygen at the anode. But in molten iron ore, the anode material must face extremely harsh conditions: reaction temperatures above 1500 °C, a highly corrosive environment, and an oxide that spontaneously reacts with most metals on contact. MIT's Donald Sadoway and colleagues have now demonstrated that chromium-iron alloys can, at



least at the laboratory scale, survive in that environment; moreover, the alloys are efficient and inexpensive. Compared with its initial size and shape (at left), the Cr₉₀Fe₁₀ anode (at right), though covered with electrolyte, showed little change in dimensions after several hours of electrolysis of magnetite, Fe₃O₄. Key to the alloy's stability is the formation of a conducting outer layer comprising a solid solution of Cr₂O₃ and alumina (which the researchers had in the electrolyte). The results present challenges to current theories of oxidation in extreme environments but nevertheless pave the way for assessing the alloys' performance at larger scales. (A. Allanore, L. Yin, D. R. Sadoway, *Nature* **497**, 353, 2013.) —RJF ■