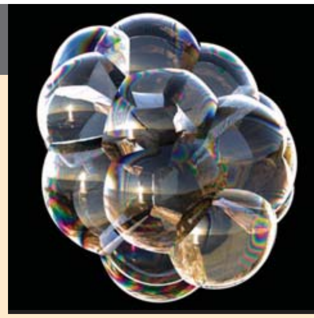
Separating scales to model bursting bubbles



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 geometries[1] 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 10^9-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.

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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-μs 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: