

ical predictions of nuclear excitations (not shown) disagree with each other beyond ^{52}Ca .

Figure 2a also shows the Darmstadt theory team's latest predictions, out to ^{58}Ca . Since 2010, Holt and Achim Schwenk, leader of the Darmstadt team, have been spearheading attempts to produce reliable shell-model predictions for neutron-rich nuclides by considering only two- and three-nucleon interactions derived from low-energy approximations to fundamental particle theory. The results reproduce well all the measured Ca binding energies and excitation energies. Yet they involve no empirical nuclear inputs except for the binding energy of the triton (^3H) and the

charge radius of the alpha particle (^4He).

The team's approach seeks to describe the interactions of individual valence neutrons—beyond the last closed shell—in terms of an effective field theory (EFT) that approximates quantum chromodynamics, the fundamental theory of the quarks and gluons, at the low energies appropriate to nuclear physics. Thus the EFT ignores quark degrees of freedom and describes nucleon interactions by the exchanges of virtual pions rather than gluons.

Beyond two-nucleon interactions due to pion exchange, the theory team includes three-nucleon interactions that involve, for example, the simultaneous exchange of pions between one neutron

and two others. It's the three-nucleon interactions that, in the EFT approximation, require the empirical triton and alpha-particle inputs.

"The inclusion of three-nucleon interactions turns out to be essential for correctly predicting the newly measured masses," says Schwenk. Without them, one can't even reproduce the ^{48}Ca mass. "As experimenters impressively advance our understanding of extreme nuclei," he says, "we look forward to comparing our predictions beyond ^{54}Ca with measurements still to come."

Bertram Schwarzschild

Reference

1. F. Wienholtz et al., *Nature* **498**, 346 (2013).

physics update

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

Modeling a volcano's hum. A form of volcanic seismicity known as harmonic tremor—sustained vibrations in the infrasound range of 0.5–5 Hz—often precedes a major eruption as magma courses through underground cracks and conduits. A new analysis of a series of eruptions from Alaska's Re-



doubt Volcano (shown here) in March 2009 examines how the initially low-frequency rumble rose over several minutes from 1 Hz to audible frequencies near 30 Hz—the highest yet recorded from a volcano—before ending abruptly 30–60 seconds prior to erupting. Ksenia Dmitrieva (Stanford University), Alicia Hotovec-Ellis (University of Washington), and their colleagues modeled the unusual frequency pattern of that seismicity and found it consistent with a frictional-faulting mechanism. Recent work this year by Hotovec-Ellis and others linked the harmonic tremor at Redoubt to a sequence of small earthquakes, each slipping just a millimeter on a fault several kilometers beneath the volcanic vent. The source of the slipping remains ambiguous. But in the new work, the researchers postulate that as thick magma moves upward through a narrow conduit, it becomes obstructed or sticks to the rocky walls until the pressure builds up enough to overcome friction, a process that repeats at ever-higher frequencies. The onset of seismic quiescence then occurs when the rate at which stress accumulates on the fault is high enough—about 20 MPa/s,

according to their calculations—that the stick-slip behavior evolves into stable sliding. (K. Dmitrieva et al., *Nat. Geosci.* **6**, 652, 2013.)

—RMW

Dynamics of a geyser. Only about a thousand geysers are known to exist, and roughly half of them are found in Yellowstone National Park in the western US. Given a suitable—and rare—geology, underground liquid and vapor are heated and pressurized until turbulently vented to the atmosphere. To study an eruption jet's dynamics, a multi-institutional team of geophysicists spent four days monitoring Yellowstone's Lone Star Geyser, which has erupted reliably every three hours for many decades. Similar to other geysers, Lone Star had four distinct event stages. The main eruption stage has a notably unsteady flow with maximum velocities of 16–28 m/s, near the sound speed of the erupting bubbly mixture, and forms a fountain up to 13 m high, as seen in this IR image. The image also reveals some of the conduits within the 3-m-tall mineral-crust cone. The other stages are relaxation to ambient conditions; recharging during which the plumbing refills; and a preplay period during which the geyser puffs and pulses. The team deployed high-quality visible and IR video cameras; acoustic, IR, and seismic sensors; and stream-discharge instruments. Among other things, the researchers



saw flow oscillations with periods of roughly 30–70 seconds, likely due to boiling instabilities in the underground plumbing. They also learned that as the underground reservoir progressively emptied, the dominant discharge changed from mostly liquid to mostly steam. Chemical analysis of outflowing water revealed the reservoir temperature to be about 170 °C; water's boiling point is 93 °C at Lone Star's elevation. The geyser's total heat output was about 1.4 MW. (L. Karlstrom et al., *J. Geophys. Res. [Solid Earth]*, in press.)

—SGB