anisotropy causes it to concentrate vibrational energy into modes parallel to the embedded titanate layers. As a proof-of-principle experiment, the team balanced a glass plate atop hydrogel pillars supported by a mechanically oscillating table, as shown in figure 3. When the hydrogel's stiff axis is aligned vertically, the plate remains level, even as the table underneath it shakes. When the nanostructured hydrogel is swapped out for a more conventional hydrogel, the plate wobbles, and the sphere that rests above tumbles from its tee.

"The vibrational isolation capabilities are especially relevant and promising," says Aida. "After all, Japan is a country of earthquakes."

Ashley G. Smart

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Giant impacts may explain the origin of chondrules

Long thought to be the building blocks of planets, the small orbs in meteorites may instead be a by-product of planetary accretion.

Chondrules, such as the one shown in figure 1, are millimeter-scale, previously molten droplets that make up more than half the volume of most meteorites that fall to Earth. Isotopic dating suggests they formed during the roughly 5 million years when the solar nebula was coalescing into solids (see the article by Robin Canup, PHYSICS TODAY, April 2004, page 56). Unfortunately, there's no consensus as to how they formed. The conventional and perhaps still leading view holds that chondrules originated as rapidly melted dust balls—flash heated by shock waves, lightning bolts, solar flares, or some other process—that crystallized in hours to days and sometime afterward became part of accreting

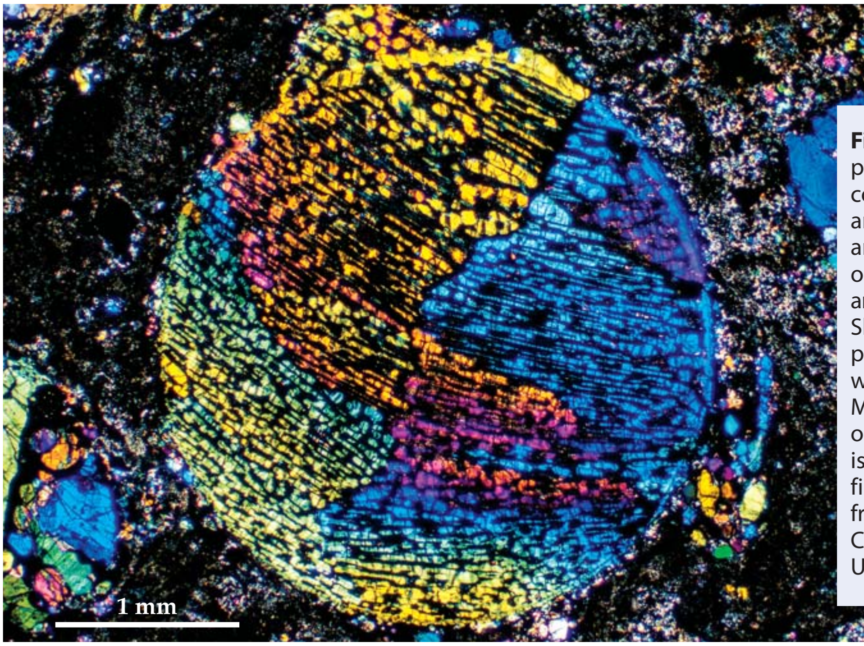


Figure 1. Crack open a meteorite and you'll probably find chondrules whose chemical compositions, millimeter-scale diameters, and igneous textures—the shapes, appearance, and crystal orientations of the mostly olivine and pyroxene minerals—constrain any compelling model of chondrule formation. Shown here sliced wafer thin and viewed in polarized light, this richly colored chondrule was embedded in a meteorite known as Maralinga. The barred texture shows the orientation of olivine crystals. The chondrule is surrounded by other inclusions and a fine-grained matrix (black) of mineral fragments. (Courtesy of Laurence Garvie, Center for Meteorite Studies, Arizona State University.)

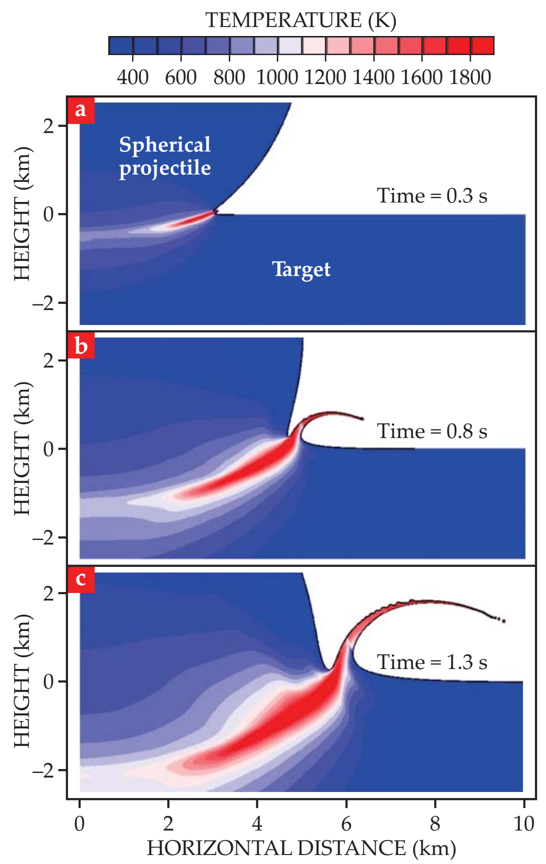


Figure 2. A spherical projectile 10 km in diameter collides with a rectangular slab at 3 km/s. **(a)** As the projectile penetrates the slab, molten material (red) forms within 0.3 second at the edge of the contact region of the two. (The origin in this two-dimensional simulation is the point of collision.) **(b)** A well-formed jet develops within 0.8 s and squirts a plume of melt, gas, and lightly shocked rock from the edge. **(c)** As the projectile penetrates the plate, the jetting region moves rightward, following the edge of the projectile. The fastest ejecta reach a velocity of 6 km/s, twice the impact velocity. (Adapted from ref. 2.)

planetesimals and planetary embryos. But no one has convincingly explained which of those potential heat sources was actually responsible.

Other theories posit collisions between asteroids as the source of chondrule-forming droplets. The idea goes back to the 1950s and gained traction a decade ago when planetary scientists realized that asteroids could grow as large as the Moon within tens of thousands of years—a much shorter time than the millions of years previously believed. But the drag on bodies from nebular dust and gas should slow their relative speeds to just a few kilometers per second, too slow to melt solid objects in a collision. And even if the bodies were to somehow collide fast enough to melt, such events would produce far more fragments of broken rock than melted rock, which doesn't match the meteorite record.[1]

MIT postdoc Brandon Johnson, his former Purdue University thesis adviser Jay Melosh, and their colleagues now propose an often overlooked process known as impact jetting that overcomes those objections and revives the plausibility of a solid-collision origin.[2] The process describes the high-speed squirting of superheated solid, molten, and gaseous debris from the explosive collision of two objects whose curved or irregular surfaces close together like scissors blades. Long exploited in military applications—impact jetting explains how an armor-piercing bazooka rocket works—the pinching of material generates up to several times the pressures encountered in planar impacts. Simulating the jetting process at high spatial resolution is computationally expensive, though, and the MIT–Purdue researchers are the first to numerically resolve it in a planetary context.

Blobs and droplets

Jetting isn't the only process that can melt relatively slow-moving bodies. The decay of short-lived radioisotopes, such as aluminum-26, whose daughter product, magnesium-26, is found in the most ancient meteorites, would supply more than enough heat to populate the solar nebula with molten asteroids. And the inevitable splashing of any one of them during even low-speed collisions would spew out magma as great plumes of droplets.

But chemical differentiation, which happens as dense metals sink to the center of a large enough body, particularly one already molten, would alter the splashed melt's composition. Chondrites, by contrast, contain dense metal and reflect the primitive, undifferentiated composition of the solar nebula. Moreover, while working on another project last year, Johnson and Melosh realized that splashing among molten asteroids would produce liquid blobs roughly 40 m in diameter—hardly droplets.

At the time, the pair were running simulations of droplet-forming, crater-making impacts,[3] such as the dinosaur-killing Chicxulub impact 65 million years ago (see PHYSICS TODAY, May 1982, page 19). In that incident, the asteroid hitting Earth was larger than 10 km and its fireball spewed countless spherules that, apart from their chemical compositions, are indistinguishable from chondrules. When Johnson calculated how quickly a big cloud of debris would cool after an even larger solid impact—between planetary embryos hundreds to thousands of kilometers in diameter—he found cooling rates of 10–1000 K/hr, consistent with what molten chondrules must have experienced.

The researchers were puzzled, however, at what mechanism might give rise to the melt needed to make the chondrules, given the constraint of slow collision speeds in the solar nebula. Melosh wondered if the porous nature of rocky asteroids might account for it, since the rock should heat up during compression just like air in an inflating bicycle tire. Johnson, meanwhile, hit on impact jetting.

High-speed jets

Johnson simulated the effect for a variety of embryos, large and small, at a range of collision speeds. When the edge of a spherical projectile collides with and penetrates either a flat plate, as shown in figure 2's simulation, or another embryo, he found that the resulting high pressures—exceeding 80 GPa in some cases—and nearly 2000-K temperatures can create a pocket of melt and vapor next to the near vacuum of outer space.[2,4] The enormous pressure gradient then accelerates a plume of molten rock and gas into the nebula at speeds well above the impact velocity.

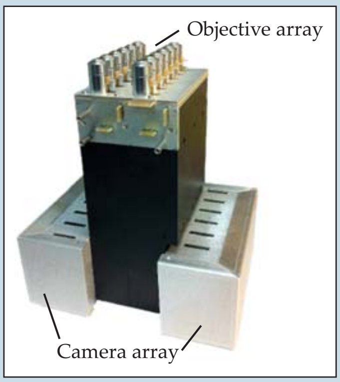
The ejecta's speed explains how the impacts—which spew much more, but slower, broken rock than melt—can end up making chondrule-rich meteorites. The only material that escapes the gravitational pull of the embryo, the researchers argue, is a jetted mixture of melt (nascent chondrules) and lightly shocked solids in which the chondrules eventually become embedded. And although the amount of melt squirted into space turns out to be small—just 1% of the impactor's mass—Johnson's simulations reveal that collision speeds as low as 2.5 km/s can create it.

To place the jetting model into a planetary context, Purdue University's David Minton simulated the orbital dynamics of bodies that would grow to become the planets and asteroids we see today. Starting with a reasonable mass of planetary embryos, whose initial size distribution ranged from 100 km to

physics update

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

Biomechanical measurements in the fast lane. The mechanical properties of cells and their environments strongly influence how biological systems function. They can determine the cells' shapes, dictate how the cells move, and even affect gene expression. When it comes to investigating those properties, though, traditional biophysical techniques, such as bulk rheological measurements, take a long time and can require large sample volumes. Now Richard Superfine, Leandra Vicci, and their colleagues at the University of North Carolina at Chapel Hill have built a microscope system to speed up the process. Shown here, their shoebox-sized instrument is an array of 12 independent fluorescence microscopes, whose objectives are spaced to work with a standard lab plate with 96 sample wells. Three stepper motors move the lab plate in an automated sequence over the objective array. The package is designed for a technique called passive microrheology, which measures the mechanical properties of a biofluid by tracking the thermal motion of small, fluorescent tracer beads embedded in it. In their demonstration, the researchers confirmed that the microscopes could correctly measure the viscosities of several well-known Newtonian fluids. Then they simultaneously measured 12 solutions of hyaluronic acid, a biopolymer found in extracellular tissue, at different concentrations. The measured viscosities compare well with other groups' reported measurements. And with the new microscope, the researchers say such measurements can be made nearly 100 times faster than with conventional techniques. (J. Cribb et al., *Rev. Sci. Instrum.*, in press.) —SC



How did dwarf galaxies form? Dwarf spheroidal galaxies are small, are old, and contain a greater proportion of dark matter than either larger galaxies or globular clusters, which are also small and old. Only the dwarf spheroidals that surround the Milky Way and the nearby Andromeda galaxy are bright enough to study. Despite their quirks, dwarf spheroidals (such as the one shown here) are nevertheless similar enough to their galactic hosts that they could conceivably have started to form at the same time. But that formation scenario faces a challenge. About 60% of Andromeda's dwarf spheroidals occupy a more-or-less spherical halo around their host. The rest, however, occupy a thin pancake-shaped region that encompasses Andromeda's galactic plane (see PHYSICS TODAY, March 2013, page 12). Such a confined distribution is difficult to produce if all the dwarfs began forming with the host galaxy when it first collapsed. An alternative scenario entails the on-plane dwarfs forming after the off-plane dwarfs from material spread about the system after Andromeda merged with another galaxy. To shed light on the mystery, Michelle Collins of Yale University and her collaborators used the DEIMOS instrument at the Keck II telescope to observe two of Andromeda's on-plane dwarf spheroidals. Having determined the dwarfs' chemical makeup and other properties, the researchers then compared them with existing observations of 12 on-plane and 17 off-plane dwarf spheroidals in Andromeda. They

1000 km in diameter, he used his simulations, supplemented with a lookup table from Johnson's jetting results, to estimate the locations, frequency, sizes, and velocities of potential chondrule-forming impacts.[2] Those impacts began occurring a few thousand years into the simulation and continued for millions of years, a time span consistent with the life span of the nebula and the spread of ages found among real chondrules dated isotopically.

The simulation's conservative estimate of 10^{23} kg for the accumulated melt made by jetting is several times greater than the mass thought to reside in the asteroid belt, says Johnson. And his separate calculation of likely droplet sizes—determined by the balance of surface tension and inertial forces acting on the accelerated plume of gas and melt—reproduced a millimeter-scale distribution over a wide range of impactor sizes. Together, the results explain the chondrules' abundance in meteorites.

A reinterpretation

According to the impact-jetting theory, chondrules emerge from much larger bodies and preferentially accrete onto smaller ones, which have a larger collective surface area. That logic led the MIT–Purdue collaboration to a succinct conclusion stated in the final line of their paper: "Chondrules are not the direct building blocks of the planets, but merely a byproduct of their accretion."[2]

"That statement has outraged meteoriticists more than anything we could have said or done," says Melosh. "It had been believed that with up to 95% of chondrites chock-full of them, chondrules must be those building blocks, and generations of researchers have put the motherhood statement in their grant proposals. We're denying that and arguing that while chondrules are certainly part of the construction debris, they're not the main game."

That interpretation doesn't change the fact that meteorites reflect conditions in the early solar nebula. Rather, the new model is diagnostic of the process—how and in what environment our solar system was built. "Although more work is needed to investigate and test the new model," says the University of Chicago's Fred Ciesla, "it's likely to open a debate I expect to continue for years."

Mark Wilson

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found no measurable differences between the two populations, which suggests that Andromeda's on-plane and off-plane dwarfs formed at the same time from the same material. The prevailing cosmological framework struggles to account for such a starkly bimodal distribution. (M. L. M. Collins et al., *Astrophys. J. Lett.* **799**, 13, 2015.) —CD

Monitoring fog with cellular network infrastructure. In terms of economic consequences—including accidents, traffic delays, property loss, and injuries or casualties—fog can be as damaging as winter storms. Common fog-detection systems include satellites, visibility sensors, and human observations, but such methods can suffer from low spatial resolution, high cost, or low sensitivity near ground level, where the information may be particularly needed. A solution might be found, however, in cellular communication networks. Most microwave links in a network's infrastructure currently operate at frequencies between roughly 6 GHz and 40 GHz. Although rainfall produces measurable attenuation of signals at those frequencies, dense fog has a relatively slight effect. But to satisfy the growing demand for higher data rates and wider bandwidth, many countries are turning to higher frequencies, 70–80 GHz. Noam David, Omry Sendik, Hagit Messer, and Pinhas Alpert from Tel Aviv University show that because transmission at those frequencies is much more sensitive to fog, the new links could provide wide-scale, high-resolution monitoring of fog densities. In a proof of principal, the team took a map of existing microwave links in Israel and, for simulated fog, calculated the minimum liquid water content that could be detected using signal attenuation data at 20, 38, and 80 GHz. At 80 GHz, even light fog, with a visibility of up to 750 meters, had a measurable effect. And when the researchers analyzed actual 38-GHz signal data for an evening that was foggy in Tel Aviv but clear in Jerusalem, the visibilities and fog densities they calculated were consistent with recorded observations. (N. David et al., *Bull. Amer. Meteor. Soc.*, in press.) —RJF

Sound strategy for levitating and moving particles. Bounce a propagating sound wave off an acoustic mirror and the superposition of original and reflected waves may yield a standing pressure wave. A particle located in that pressure field will feel a force driving it to a position of stable equilibrium; indeed, an acoustic standing wave with sufficient amplitude can even suspend a particle against the action of gravity. Numerous researchers have used acoustic levitators

to study behaviors of liquid drops without the complications of a confining vessel. The problem with conventional levitators, though, is that the separation between the wave generator and the reflector must be resonantly tuned if a standing wave is to result. Now Marco Andrade of the Institute of Physics at the University of São Paulo, Brazil, and colleagues have demonstrated a device that can levitate particles—indeed, manipulate them—without the need for fine tuning. Their trap, based on a decades-old proposal by Charles Rey, is shown here suspending four polystyrene balls. It comprises a 10-mm-diameter cylindrical transducer (at the tops of the photos) that generates the sound, and a somewhat larger concave reflector. For the coaxial geometry shown on the left, the trapped balls remain at a fixed distance from the mirror even as the mirror–transducer separation varies from 50 mm to 100 mm. Moreover, as one misaligns the axes of the transducer and mirror (right photo), the balls will adjust their positions, remaining confined all the while. (M. A. B. Andrade, N. Pérez, J. C. Adamowski, *App. Phys. Lett.* **106**, 014101, 2015.) —SKB