

An origin story for a family of oddball meteorites

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Most meteorites that have landed on Earth are fragments of planetesimals, the very earliest protoplanetary bodies in the solar system. Scientists have thought that these primordial bodies either completely

melted early in their history or remained as piles of unmelted rubble.

But a family of meteorites has befuddled researchers since its discovery in the 1960s. The diverse fragments, found all over the world, seem to have broken off from the same primordial body, and yet the makeup of these meteorites indicates that their parent must have been a puzzling chimera that was both melted and unmelted.

Now researchers at MIT and elsewhere have determined that the parent body of these rare meteorites was indeed a multilayered, differentiated object that likely had a liquid [metallic core](#). This core was substantial enough to generate a [magnetic field](#) that may have been as strong as Earth's magnetic field is today.

Their results, published in the journal *Science Advances*, suggest that the diversity of the earliest objects in the solar system may have been more complex than scientists had assumed.

"This is one example of a planetesimal that must have had melted and unmelted layers. It encourages searches for more evidence of composite planetary structures," says lead author Clara Maurel, a graduate student in MIT's Department of Earth, Atmospheric, and Planetary Sciences (EAPS). "Understanding the full spectrum of structures, from nonmelted to fully melted, is key to deciphering how planetesimals formed in the early solar system."

Maurel's co-authors include EAPS professor Benjamin Weiss, along with collaborators at Oxford University, Cambridge University, the University of Chicago, Lawrence Berkeley National Laboratory, and the Southwest Research Institute.

Oddball irons

The solar system formed around 4.5 billion years ago as a swirl of super-hot gas and dust. As this disk gradually cooled, bits of matter collided and merged to form progressively larger bodies, such as planetesimals.

The majority of meteorites that have fallen to Earth have compositions that suggest they came from such early planetesimals that were either of two types: melted, and unmelted. Both types of objects, scientists believe, would have formed relatively quickly, in less than a few million years, early in the solar system's evolution.

If a planetesimal formed in the first 1.5 million years of the solar system, short-lived radiogenic elements could have melted the body entirely due to the heat released by their decay. Unmelted planetesimals could have formed later, when their material had lower quantities of radiogenic elements, insufficient for melting.

There has been little evidence in the meteorite record of intermediate objects with both melted and unmelted compositions, except for a rare family of meteorites called IIE irons.

"These IIE irons are oddball meteorites," Weiss says. "They show both evidence of being from primordial objects that never melted, and also evidence for coming from a body that's completely or at least substantially melted. We haven't known where to put them, and that's what made us zero in on them."



X-ray experiments at Berkeley Lab's Advanced Light Source helped scientists to establish that the parent planetesimal of rare meteorites, like the one shown here, had a molten core, a solid crust, and a magnetic field similar in strength to the Earth's magnetic field. Credit: Carl Agee/Institute of Meteoritics, University of New Mexico; background edited by MIT News

Magnetic pockets

Scientists have previously found that both melted and unmelted IIE meteorites originated from the same ancient planetesimal, which likely had a solid crust overlying a liquid mantle, like Earth. Maurel and her colleagues wondered whether the planetesimal also may have harbored a metallic, melted core.

"Did this object melt enough that material sank to the center and formed a metallic core like that of the Earth?" Maurel says. "That was the missing piece to the story of these meteorites."

The team reasoned that if the planetesimal did host a metallic core, it could very well have generated a magnetic field, similar to the way Earth's churning liquid core produces a magnetic field. Such an ancient field could have caused minerals in the planetesimal to point in the direction of the field, like a needle in a compass. Certain minerals could have kept this alignment over billions of years.

Maurel and her colleagues wondered whether they might find such minerals in samples of IIE meteorites that had crashed to Earth. They obtained two meteorites, which they analyzed for a type of iron-nickel mineral known for its exceptional magnetism-recording properties.

The team analyzed the samples using the Lawrence Berkeley National Laboratory's Advanced Light Source, which produces X-rays that interact with mineral grains at the nanometer scale, in a way that can reveal the minerals' magnetic direction.

Sure enough, the electrons within a number of grains were aligned in a similar direction—evidence that the parent body generated a magnetic field, possibly up to several tens of microtesla, which is about the strength of Earth's magnetic field. After ruling out less plausible sources, the team concluded that the magnetic field was most likely produced by a liquid metallic core. To generate such a field, they estimate the core must have been at least several tens of kilometers wide.

Such complex planetesimals with mixed composition (both melted, in the form of a liquid core and mantle, and unmelted in the form of a solid crust), Maurel says, would likely have taken over several million years to form—a formation period that is longer than what scientists had

assumed until recently.

But where within the parent body did the meteorites come from? If the magnetic field was generated by the parent body's core, this would mean that the fragments that ultimately fell to Earth could not have come from the core itself. That's because a liquid core only generates a magnetic field while still churning and hot. Any minerals that would have recorded the ancient field must have done so outside the core, before the core itself completely cooled.

Working with collaborators at the University of Chicago, the team ran high-velocity simulations of various formation scenarios for these meteorites. They showed that it was possible for a body with a liquid core to collide with another object, and for that impact to dislodge material from the core. That material would then migrate to pockets close to the surface where the meteorites originated.

"As the body cools, the meteorites in these pockets will imprint this magnetic field in their minerals. At some point, the magnetic field will decay, but the imprint will remain," Maurel says. "Later on, this [body](#) is going to undergo a lot of other collisions until the ultimate collisions that will place these meteorites on Earth's trajectory."

Was such a complex planetesimal an outlier in the early [solar system](#), or one of many such differentiated objects? The answer, Weiss says, may lie in the asteroid belt, a region populated with primordial remnants.

"Most bodies in the [asteroid belt](#) appear unmelted on their surface," Weiss says. "If we're eventually able to see inside asteroids, we might test this idea. Maybe some asteroids are melted inside, and bodies like this planetesimal are actually common."

More information: Meteorite evidence for partial differentiation and

protracted accretion of planetesimals, *Science Advances* (2020). DOI: 10.1126/sciadv.aba1303

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