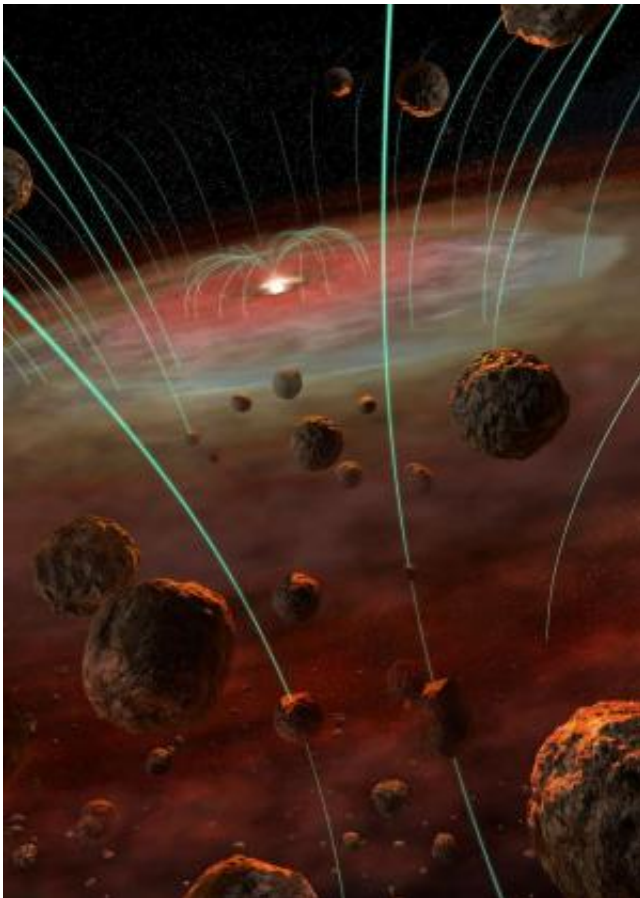


Magnetic fields frozen into meteorite grains tell a shocking tale of solar system birth

November 13 2014



Magnetic field lines (green) weave through the cloud of dusty gas surrounding the newborn Sun. In the foreground are asteroids and chondrules, the building blocks of chondritic meteorites. While solar magnetic fields dominate the region near the Sun, out where the asteroids orbit, chondrules preserve a record of varying local magnetic fields. Credit: Science

The most accurate laboratory measurements yet made of magnetic fields trapped in grains within a primitive meteorite are providing important clues to how the early solar system evolved. The measurements point to shock waves traveling through the cloud of dusty gas around the newborn Sun as a major factor in solar system formation.

The results appear in a paper published Nov. 13 in the journal *Science*. The lead author is graduate student Roger Fu of MIT, working under Benjamin Weiss; Steve Desch of Arizona State University's School of Earth and Space Exploration is a co-author of the paper.

"The measurements made by Fu and Weiss are astounding and unprecedented," says Desch. "Not only have they measured tiny magnetic fields thousands of times weaker than a compass feels, they have mapped the magnetic fields' variation recorded by the meteorite, millimeter by millimeter."

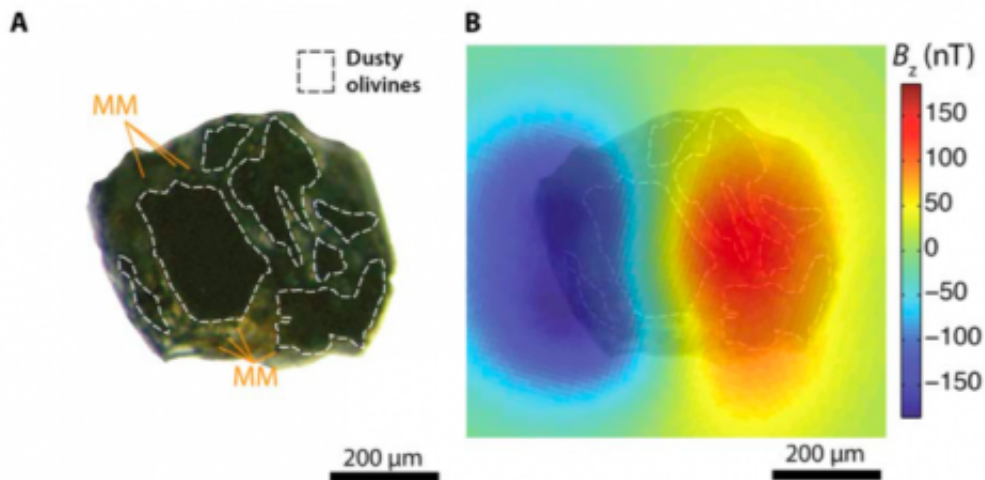
Construction debris

It may seem all but impossible to determine how the [solar system](#) formed, given it happened about 4.5 billion years ago. But making the solar system was a messy process, leaving lots of construction debris behind for scientists to study.

Among the most useful pieces of debris are the oldest, most primitive and least altered type of meteorites, called the chondrites (KON-drites). Chondrite meteorites are pieces of asteroids, broken off by collisions, that have remained relatively unmodified since they formed at the birth of the solar system. They are built mostly of small stony grains, called chondrules, barely a millimeter in diameter.

Chondrules themselves formed through quick melting events in the dusty gas cloud - the solar nebula - that surrounded the young sun. Patches of

the solar nebula must have been heated above the melting point of rock for hours to days. Dustballs caught in these events made droplets of molten rock, which then cooled and crystallized into chondrules.



An optical photomicrograph of one of the chondrules in the study shows (in outline) dusty olivine rock crystals with magnetic iron-bearing minerals. The areas marked 'MM' have contaminating minerals, which were removed. The image at right shows the magnetic field around the chondrule. Red denotes a magnetic field coming out of the screen, blue going into the screen. The chondrule behaves as a tiny bar magnet recording the strength of the magnetic field in the solar nebula gas. The orientation of the magnetic field differs among the chondrules in the same meteorite, indicating magnetization took place before the chondrules came together to make the meteorite. Credit: Fu et al./Science

Tiny magnets

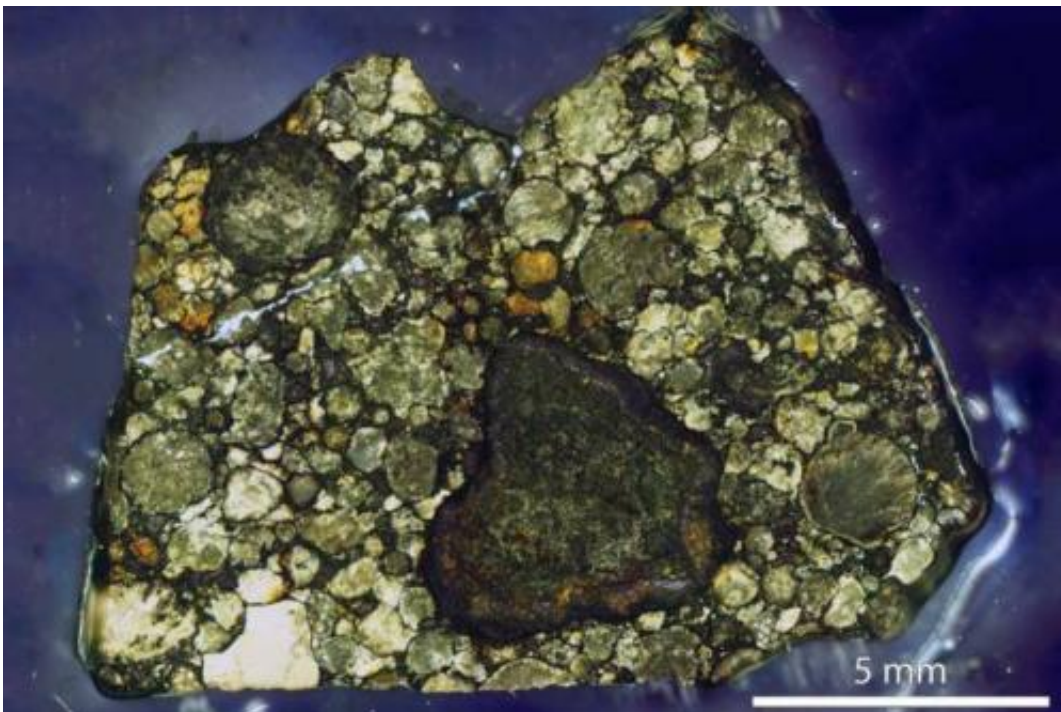
As chondrules cooled, iron-bearing minerals within them became magnetized like bits on a hard drive by the local [magnetic field](#) in the gas. These magnetic fields are preserved in the chondrules even down to

the present day.

The chondrule grains whose magnetic fields were mapped in the new study came from a meteorite named Semarkona, after the place in India where it fell in 1940. It weighed 691 grams, or about a pound and a half.

The scientists focused specifically on the embedded magnetic fields captured by "dusty" olivine grains that contain abundant iron-bearing minerals. These had a magnetic field of about 54 microtesla, similar to the magnetic field at Earth's surface, which ranges from 25 to 65 microtesla.

Coincidentally, many previous measurements of meteorites also implied similar field strengths. But it is now understood that those measurements detected magnetic minerals contaminated by Earth's magnetic field, or even from hand magnets used by meteorite collectors.



Magnified image of the section of the Semarkona meteorite used in this study. Chondrules are millimeter sized, light-colored objects. Credit: MIT Paleomagnetism Laboratory

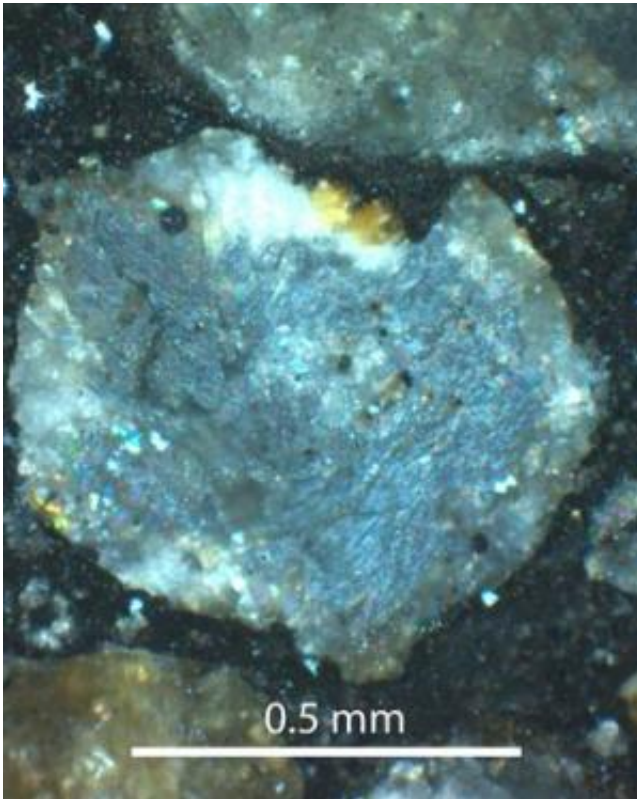
"The new experiments," Desch says, "probe magnetic minerals in chondrules never measured before. They also show that each chondrule is magnetized like a little bar magnet, but with 'north' pointing in random directions."

This shows, he says, they became magnetized before they were built into the meteorite, and not while sitting on Earth's surface.

Shocks and more shocks

"My modeling for the heating events shows that shock waves passing through the solar nebula is what melted most chondrules," Desch explains. Depending on the strength and size of the shock wave, the background magnetic field could be amplified by up to 30 times.

He says, "Given the measured [magnetic field strength](#) of about 54 microtesla, this shows the background field in the nebula was probably in the range of 5 to 50 microtesla."



Microscope image of a single chondrule from the Semarkona meteorite used in this study. Textured, light-blue regions represent concentrations of dusty olivine, which carry a recording of ancient magnetic fields from the protoplanetary disk. Credit: MIT Paleomagnetism Laboratory

There are other ideas for how chondrules might have formed, some involving magnetic flares above the solar nebula, or passage through the sun's magnetic field. But those mechanisms require stronger magnetic fields than what is measured in the Semarkona samples.

This reinforces the idea that shocks melted the chondrules in the [solar nebula](#) at about the location of today's asteroid belt, which lies some two to four times farther from the sun than Earth now orbits.

Desch says, "This is the first really accurate and reliable measurement of

the magnetic field in the gas from which our planets formed."

More information: "Solar nebula magnetic fields recorded in the Semarkona meteorite" *Science*, 2014. [www.sciencemag.org/lookup/doi/... 1126/science.1258022](http://www.sciencemag.org/lookup/doi/10.1126/science.1258022)

Provided by Arizona State University

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