

**Hot Idea**

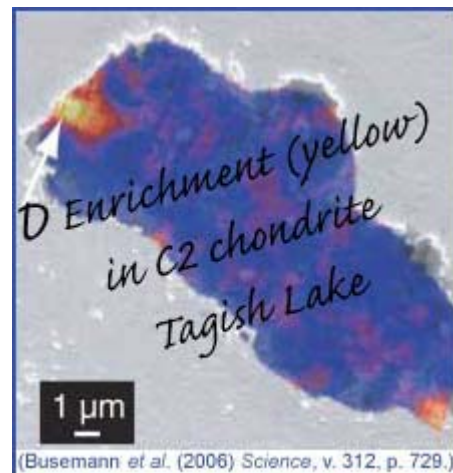
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# Interstellar Organic Matter in Meteorites

--- Carbonaceous chondrites contain organic compounds with high deuterium/hydrogen ratios, suggesting they formed in interstellar space.

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Organic compounds in carbonaceous [chondrites](#) contain microscopic regions with surprising enrichments in the ratios of deuterium (D) to hydrogen (H) and nitrogen-15 ( $^{15}\text{N}$ ) to nitrogen-14 ( $^{14}\text{N}$ ). Henner Busemann and his colleagues Andrea Young, Conel Alexander, Sujoy Mukhopadhyay, and Larry Nittler at the Carnegie Institution of Washington, and Peter Hoppe (Max-Planck-Institut für Chemie, Mainz, Germany) demonstrate that organic matter resistant to dissolution by strong acids carry significant [isotopic](#) anomalies. They suggest that these anomalies most likely formed in interstellar space before the solar system formed and survived the long journey from molecular cloud to protostellar disk to asteroids.

Reference:

- Busemann, H., A. F. Young, C. M. O'D. Alexander, P. Hoppe, S. Mukhopadhyay, and L. R. Nittler (2006) Interstellar chemistry recorded in organic matter from primitive meteorites. *Science*, v. 312, p. 727-730.

## Gunky Meteorites

Some carbonaceous chondrites smell. They contain [volatile](#) compounds that slowly give off chemicals with a distinctive organic aroma. Most types of carbonaceous chondrites (and there are lots of types) contain only about 2% organic compounds, but these are very important for understanding how organic compounds might have formed in the solar system. They even contain complex compounds such as amino acids, the building blocks of proteins.

The presence of amino acids certainly sounds like they could contain life. Maybe carbonaceous chondrites are crawling with micro-organisms. I was amazed when I first learned decades ago while still in graduate school that some meteorites contain amino acids. I admit I was a bit disappointed when I read that the amino acids have equal amounts of left- and right-handed molecules (a description of their symmetry, a property called chirality). Most biological amino acids on Earth have the same handedness, so the amino acids in carbonaceous chondrites formed inorganically. No wee creatures were involved. No big ones, either.

The organic compounds in carbonaceous are very important, however. They may represent the type of materials that seeded the Earth with organic molecules, producing a complex, smelly soup in which life arose. Most of




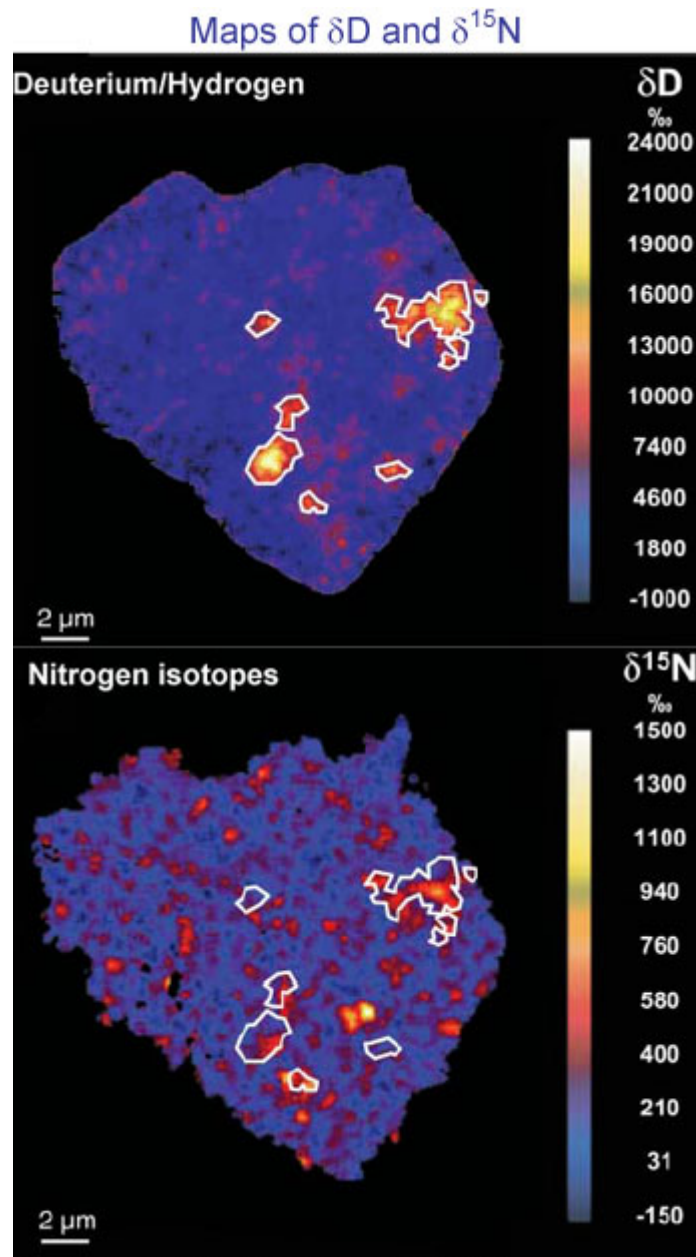
the studies of organic compounds in carbonaceous chondrites have focused on the origin of organics to the early Earth and on the processes in the cloud of gas and dust from which the solar system formed (the [solar nebula](#) or protoplanetary disk). Now, advanced instrumentation allows cosmochemists to investigate the origin of the carbonaceous gunk, and it appears that at least some of it formed in interstellar space before the Sun formed. It is presolar organic matter.

The Murchison carbonaceous chondrite (a CM chondrite), shown on the left, was the first meteorite in which unambiguous evidence for organic compounds, including amino acids, was found. It fell in Australia in 1969.

## Searching for Presolar Organic Compounds

**H**enner Busemann and his colleagues concentrated their work on CR chondrites. These are carbonaceous chondrites that contain metallic iron and appear to be primitive (relatively unaltered since their parent asteroid formed). Previous research on CR chondrites hinted that they have unusual deuterium/hydrogen ratios. (Deuterium is an isotope of hydrogen. Its nucleus contains a proton and a neutron; hydrogen's nucleus contains only a proton.) The team analyzed samples using two different ion microprobes (see [PSRD](#) article: [Ion Microprobe](#)) capable of making images of the distribution of hydrogen and nitrogen isotopes. They studied two types of samples. One type was extracted by using a highly acidic solution of cesium fluoride and hydrochloric acid. This procedure dissolves everything but insoluble organic matter, which is nicknamed IOM. The other material was small chips of the dark, fine-grained matrix of the chondrites.

 The results are quite startling. Instead of the modest enrichments in deuterium/hydrogen (D/H) observed in bulk analyses of meteorites, Busemann and his coworkers found very high values of D/H, higher than even observed in interplanetary dust particles. (The D/H ratio is expressed as delta D ( $\delta D$ ), a measure of the deviation in the D/H ratio from a terrestrial standard.) The highest values were found in pure separates of insoluble organic matter. Tiny spots in two of the meteorite organic separates record the highest values ever measured in meteoritic material. See maps below.



Maps of  $\delta D$  (a measure of the deviation of the D/H ratio from Earth values) and  $\delta^{15}N$  (the deviation in the nitrogen-15 to nitrogen-14 ratio compared to Earth values). Both scales are in parts per thousand (10 parts per thousand is 1 percent) also known as parts per mil and indicated with this symbol ‰. Hot spots (outlined in white) for  $\delta D$  do not correspond to those for nitrogen. These maps are in a sample of insoluble organic matter extracted from the CR chondrite EET 92042.

Nitrogen also shows isotopic anomalies in the insoluble organic matter, but the locations of these are almost always different from those showing deuterium anomalies. These isotopic differences suggest that they formed in different environments in interstellar space (or possibly in the outer fringes of the solar system).

### A Long Journey Through Space and Time

No matter how this isotopically anomalous organic matter formed, Busemann and his colleagues have shown that such material survived their long journey from interstellar space into the solar nebula (the Sun's protoplanetary disk), then into a carbonaceous asteroid. It was not even affected by processes that operated inside the asteroid, such as those driven by migrating water. Busemann and coworkers point out that the preservation of the anomalous areas, small though they are, shows that organic matter was not completely



homogenized when the solar system formed. This is consistent with preservation of other types of interstellar grains in chondrites and interplanetary dust particles (see **PSRD** articles: [Silicate Stardust in Meteorites](#), [A New Type of Stardust](#), and [Moving Stars and Shifting Sands of Presolar History](#).)

How did these interesting isotopic anomalies form? One idea is that they originated in cold interstellar clouds. Another is that they formed in the fringes of the protoplanetary disk. In either case, the environment was very cold (about 10 Kelvin) and reactions between ions and molecules or reactions on the frigid surfaces of grains can cause isotopic fraction. Busemann and his colleagues favor an interstellar origin because infrared and ultraviolet spectra of insoluble organic matter is similar to spectra taken of the interstellar medium. They also point out that other types of presolar grains survived formation of the solar system, so why shouldn't at least some organic matter? On the other hand, they are less sure of how the nitrogen anomalies formed. Current theory cannot explain the high  $\delta^{15}\text{N}$  in any astrophysical environment. Its formation probably does not involve the same chemical processes that led to enrichments in deuterium.

### Star Formation Region IC 1396



(Courtesy of Canada-France-Hawaii Telescope/J.-C. Cuillandre/Coelum.)

Interstellar clouds such as IC 1396 may be the birthplace of isotopically anomalous organic matter in primitive chondrites. The solar system most likely formed in an environment like this. For more information about interstellar clouds, see an [article](#) by University of Hawaii scientists Karen Meech and Eric Gaidos. For more information about organics in the interstellar medium, see [article](#) from the Jet Propulsion Lab. For more images see [Hawaiian Starlight](#). [These links will open in a new window.]

These detailed studies of organic matter in carbonaceous chondrites have important implications for the origin of asteroids, too. Busemann points out that organic molecules are much more fragile than silicates, oxides, and other presolar grains found in meteorites. If heated too much organic compounds break down. This indicates that the asteroids that gave rise to carbonaceous chondrites (at least the types rich in organic compounds) either formed in regions of the protoplanetary disk that were always cold or in places where the temperature had dropped enough to assure survival of the organics. Busemann and his colleagues speculate that the organic matter could have been transported into the asteroid belt from much farther out in the solar system, where temperatures were colder. This kind of transport is consistent with the presence of crystalline silicates in comets (see **PSRD** article: [Cosmochemistry from Nanometers to Light Years.](#))

This study, like all studies of presolar grains in meteorites and interplanetary dust particles, bridges the gap between astronomy and cosmochemistry. The meteorites contain a wide variety of presolar materials that exist in molecular clouds or in star-forming regions--little pieces of the clouds examined by powerful telescopes.

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## Additional Resources

LINKS OPEN IN A NEW WINDOW.

- Busemann, H., A. F. Young, C. M. O'D. Alexander, P. Hoppe, S. Mukhopadhyay, and L. R. Nittler (2006) Interstellar chemistry recorded in organic matter from primitive meteorites. *Science*, v. 312, p. 727-730.
- Clayton, D. D. (1997) Moving Stars and Shifting Sands of Presolar History. *Planetary Science Research Discoveries*. <http://www.psrд.hawaii.edu/July97/Stardust.html>
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- Taylor, G. J. (2004) Silicate Stardust in Meteorites. *Planetary Science Research Discoveries*. <http://www.psrд.hawaii.edu/June04/silicatesMeteorites.html>
- Taylor, G. J. (2006) Cosmochemistry from Nanometers to Light Years. *Planetary Science Research Discoveries*. <http://www.psrд.hawaii.edu/Jan06/protoplanetary.html>



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