Astrophysicists calculate the likelihood that Earth was exposed to cold harsh interstellar clouds 2 million years ago

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Around two million years ago, Earth was a very different place, with our early human ancestors living alongside saber-toothed tigers, mastodons, and enormous rodents. And, depending on where they were, they may have been cold: Earth had fallen into a deep freeze, with multiple ice

ages coming and going until about 12,000 years ago.

Scientists theorize that ice ages occur for a number of reasons, including the planet's tilt and rotation, shifting plate tectonics, volcanic eruptions, and carbon dioxide levels in the atmosphere. But what if drastic changes like these are not only a result of Earth's environment, but also the sun's location in the galaxy?

In a new paper published in *Nature Astronomy,* lead author and astrophysicist Merav Opher—an astronomy professor at Boston University and fellow at Harvard Radcliffe Institute— found evidence that some two million years ago, the solar system encountered an interstellar cloud so dense that it could have interfered with the sun's solar wind. Opher and her co-authors believe this shows that the sun's location in space might shape Earth's history more than previously considered.

Our whole solar system is swathed in a protective plasma shield that emanates from the sun, known as the heliosphere. It's made from a constant flow of charged particles, called solar wind, that stretch well past Pluto, wrapping the planets in what NASA calls a "giant bubble."

It protects us from radiation and galactic rays that could alter DNA, and scientists believe it's part of the reason life evolved on Earth as it did. According to the latest paper, the cold cloud compressed the heliosphere in such a way that it briefly placed Earth and the other planets in the solar system outside of the heliosphere's influence.

"This paper is the first to quantitatively show there was an encounter between the sun and something outside of the solar system that would have affected Earth's climate," says Opher, who is an expert on the heliosphere.

Her models have quite literally shaped our scientific understanding of the heliosphere, and how the bubble is structured by the solar wind pushing up against the interstellar medium—which is the space in between stars and beyond the heliosphere in our galaxy. Her theory is that the heliosphere is shaped like a puffy croissant, an idea that shook the space physics community.

Now, she's shedding new light on how the heliosphere, and where the sun moves through space, could affect Earth's atmospheric chemistry.

"Stars move, and now this paper is showing not only that they move, but they encounter drastic changes," says Opher. She first discovered and began working on this study during a yearlong fellowship at Harvard Radcliffe Institute.

To study this phenomenon, Opher and her collaborators essentially looked back in time, using sophisticated computer models to visualize where the sun was positioned two million years in the past—and, with it, the heliosphere, and the rest of the solar system. They also mapped the path of the Local Ribbon of Cold Clouds system, a string of large, dense, very cold clouds mostly made of hydrogen atoms.

Their simulations showed that one of the clouds close to the end of that ribbon, named the Local Lynx of Cold Cloud, could have collided with the heliosphere.

If that had happened, says Opher, Earth would have been fully exposed to the interstellar medium, where gas and dust mix with the leftover atomic elements of exploded stars, including iron and plutonium.

Normally, the heliosphere filters out most of these radioactive particles. But without protection, they can easily reach Earth. According to the paper, this aligns with geological evidence that shows increased ^{60}Fe

(iron 60) and ^{244}Pu (plutonium 244) isotopes in the ocean, on the moon, Antarctic snow, and ice cores from the same time period. The timing also matches with temperature records that indicate a cooling period.

"Only rarely does our cosmic neighborhood beyond the solar system affect life on Earth," says Avi Loeb, director of Harvard University's Institute for Theory and Computation and co-author on the paper.

"It is exciting to discover that our passage through dense clouds a few million years ago could have exposed the Earth to a much larger flux of cosmic rays and hydrogen atoms. Our results open a new window into the relationship between the evolution of life on Earth and our cosmic neighborhood."

The outside pressure from the Local Lynx of Cold Cloud could have continually blocked out the heliosphere for a couple of hundred years to a million years, Opher says—depending on the size of the cloud. "But as soon as the Earth was away from the cold cloud, the heliosphere engulfed all the planets, including Earth," she says. And that's how it is today.

It's impossible to know the exact effect the cold clouds had on Earth—like if it could have spurred an ice age. But there are a couple of other cold clouds in the interstellar medium that the sun has likely encountered in the billions of years since it was born, Opher says. And it will likely stumble across more in another million years or so.

Opher and her collaborators are now working to trace where the sun was seven million years ago, and even further back. Pinpointing the location of the sun millions of years in the past, as well as the cold cloud system, is possible with data collected by the European Space Agency's Gaia mission, which is building the largest 3D map of the galaxy and giving an unprecedented look at the speed stars move.

"This cloud was indeed in our past, and if we crossed something that massive, we were exposed to the interstellar medium," Opher says. The effect of crossing paths with so much hydrogen and radioactive material is unclear, so Opher and her team at BU's SHIELD (Solar wind with Hydrogen Ion Exchange and Large-scale Dynamics) DRIVE Science Center are now exploring the effect it could have had on Earth's radiation, as well as the atmosphere and climate.

"This is only the beginning," Opher says. She hopes that this paper will open the door to much more exploration of how the solar system was influenced by outside forces in the deep past and how these forces have in turn shaped life on our planet.

More information: A possible direct exposure of the Earth to the cold dense interstellar medium 2–3 Myr ago, *Nature Astronomy* (2024). DOI: 10.1038/s41550-024-02279-8

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