Cosmic twist offers insight into gas giant mysteries

An unexpected object in space is helping scientists probe the hidden atmosphere chemistry of Jupiter, Saturn and worlds beyond

By Kim Baptista, ASU News
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Why has silicon, one of the most common elements in the universe, gone largely undetected in the atmospheres of Jupiter and Saturn and gas planets like them around other stars?

A new study recently published in Nature using observations from NASA's James Webb Space Telescope sheds new light on this question by focusing on a peculiar object that astronomers discovered by chance in 2020 and called "The Accident."

The Accident is a brown dwarf, a ball of gas that falls somewhere between a planet and a star. What sets it apart, even from its hard-to-classify peers, is a puzzling combination of features — some usually found only in young brown dwarfs and others only in the oldest ones.

Because of those features, it slipped past typical detection methods before being discovered five years ago by a citizen scientist participating in Backyard Worlds: Planet 9, the program that lets people around the globe look for new discoveries in data from NASA's now-retired NEOWISE (Near-Earth Object Wide Field Infrared Survey Explorer), which was managed by NASA's Jet Propulsion Laboratory in Southern California.

The Accident is so faint and odd that researchers needed NASA's most powerful space observatory, Webb, to study its atmosphere. Among several surprises, they found evidence of a molecule that they couldn't initially identify.

It turned out to be a simple silicon molecule called silane (SiH_4). Researchers have long expected — but been unable — to find silane not only in our solar system's gas giants, but also in the thousands of atmospheres belonging to brown dwarfs and to the gas giants around other stars. The Accident is the first such object where this molecule has been identified.

Michael Line, an associate professor in Arizona State University's School of Earth and Space Exploration, led the painstaking process of identifying the molecule.

“We searched for a wide range of candidate molecules, but only silane consistently matched the specific features we saw in the Webb data,” co-author Line said. “That moment of realization was exhilarating — I love the thrill of discovery in the treasure trove of JWST observations of distant worlds.”

Scientists are fairly confident that silicon exists in Jupiter and Saturn’s atmospheres but that it is hidden: Bound to oxygen, silicon forms oxides such as quartz that can seed clouds bearing a resemblance to dust storms on Earth. If this is the case, such clouds would sink far beneath lighter layers of water vapor and ammonia clouds, until any silicon-containing molecules are deep in the atmosphere, invisible even to the spacecraft that have studied Jupiter and Saturn up close.

Some researchers have also posited that lighter molecules of silicon, like silane, should be found higher up in these atmospheric layers, left behind like traces of flour on a baking table. The absence of these molecules everywhere but in a single, peculiar brown dwarf hints at unique chemical processes in these environments.

“Sometimes it’s the extreme objects that help us understand what’s happening in the average ones,” said Jacqueline Faherty, a researcher at the American Museum of Natural History in New York City, and lead author on the new study.

A happy accident

Located about 50 light-years from Earth, The Accident likely formed 10 billion to 13 billion years ago, making it one of the oldest brown dwarfs ever discovered. The universe is about 14 billion years old, and at the time that The Accident developed, the cosmos contained mostly hydrogen and helium, with trace amounts of other elements, including silicon. Over eons, elements like carbon, nitrogen and oxygen formed in the cores of stars, so planets and stars that formed more recently possess more of those elements.

Webb’s observations of The Accident confirm that silane can form in brown dwarf and planetary atmospheres. The fact that silane seems to be missing in other brown dwarfs and gas giant planets suggests that when oxygen is available, it bonds with silicon at such a high rate and so easily that virtually no silicon is left over to bond with hydrogen and form silane.

So why is silane in The Accident?

The study authors surmise it is because far less oxygen was present in the universe when the ancient brown dwarf formed, resulting in less oxygen in its atmosphere to gobble up all the silicon. The available silicon would have bonded with hydrogen instead, resulting in silane. Line noted that silane has additional relevance beyond brown dwarfs.

“Silane is also predicted to be a byproduct of atmosphere-interior interactions in sub-Neptune-type planets with vast magma oceans hidden beneath thick atmospheres,” he said. “By understanding the conditions under which silane can arise in hydrogen-rich worlds like brown dwarfs, we gain critical context for how and when it might appear in the more observationally challenging atmospheres of exoplanets.”

“The Accident is a sort of laboratory experiment run by nature,” said JPL’s Peter Eisenhardt, project scientist for the WISE (Wide-field Infrared Survey Explorer) mission, which was later repurposed as NEOWISE. “We can’t change the atmospheres of Jupiter or Saturn, but these objects show us what those planets might look like with different conditions — in this case, what happens when a planet or a brown dwarf forms with essentially no oxygen.”

Brown dwarfs are often easier to study than gas giant exoplanets because the light from a faraway planet is typically drowned out by the star it orbits, while brown dwarfs generally fly solo. And the lessons scientists learn from these objects extend to all kinds of planets, including ones outside our solar system that might feature potential signs of habitability.

“To be clear, we’re not finding life on brown dwarfs,” Faherty said. “But at a high level, by studying all of this variety and complexity in planetary atmospheres, we’re setting up the scientists who are one day going to have to do this kind of chemical analysis for rocky, potentially Earth-like planets. It might not specifically involve silicon, but they’re going to get data that is complicated and confusing and doesn’t fit their models, just like we are. They’ll have to parse all those complexities if they want to answer those big questions.”

Press release written by Calla Cofield at Jet Propulsion Laboratory and Christine Pulliam at Space Telescope Science Institute with contributions from Kim Baptista at Arizona State University.

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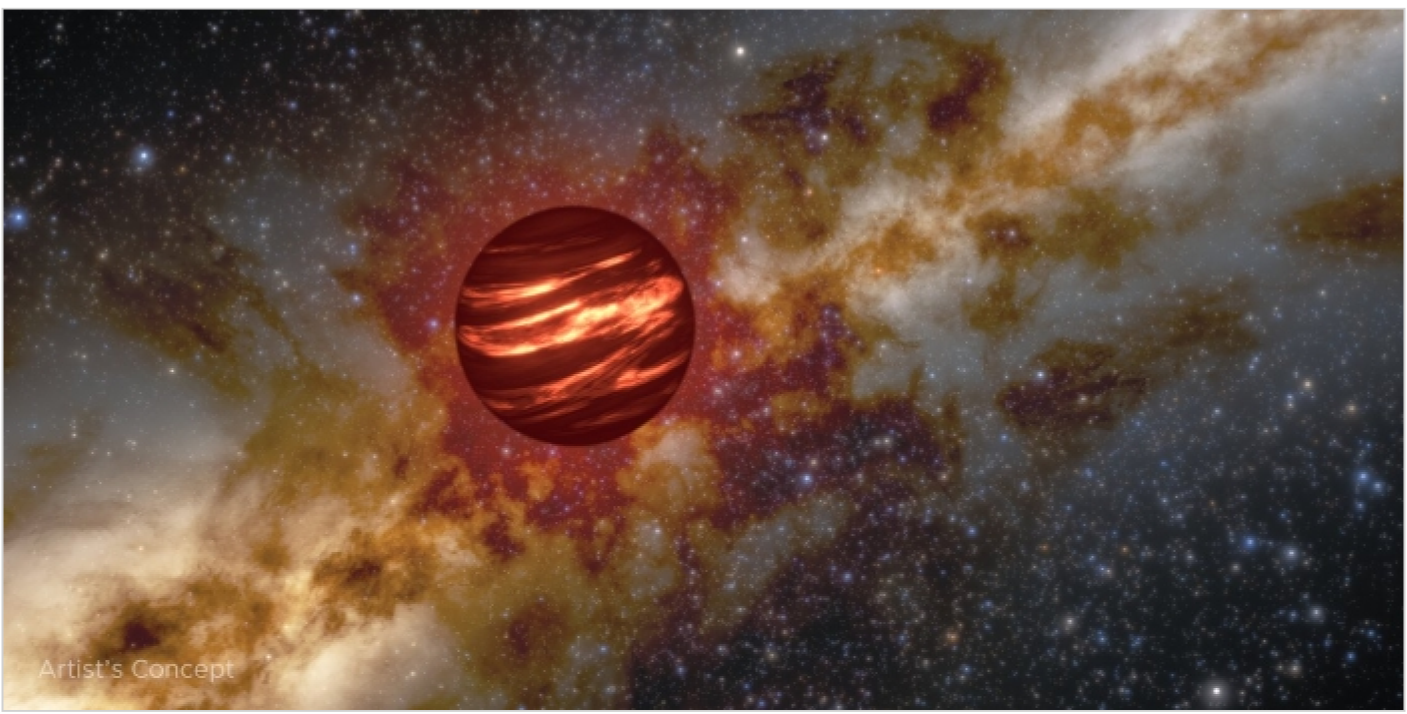
Main image



An artist’s concept shows a brown dwarf — an object larger than a planet but not massive enough to kick-start fusion in its core like a star. Brown dwarfs are hot when they form and may glow like this one, but over time they get closer in temperature to gas giant planets like Jupiter. Credit: NOIRLab/NSF/AURA/R. Proctor