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Marauding Moons Spell Disaster for Some Planets

Roughly half of all stars have planets orbiting them, scientists currently believe. And surely many have moons, too, if our own solar system is any indication (only Mercury and Venus lack them).

Now a researcher has shown that the presence of a moon might be a planetary liability: It may escape the gravitational tug of its host planet only to crash back into it, potentially obliterating any life present. Such a marauding moon would leave an observational fingerprint—copious amounts of dust produced in the impact—that would glow in infrared light and be detectable with astronomical instruments, the researcher suggested. These results were published in *Monthly Notices of the Royal Astronomical Society* (bit.ly/marauding-moons).

Theory suggests that moons in other solar systems, as suggested in this artist's illustration, might occasionally collide with their host planets. Credit: iStock.com/dottedhipp

Moons Across the Milky Way

Astronomers think that solar systems are born from spinning clouds of gas and dust. Over time, that primordial material coalesces into larger bodies, which go on to collide with one another, forming planets and moons.

According to that traditional picture, moons should be commonplace, said Joan Najita, an astronomer at the National Optical-Infrared Astronomy Research Laboratory in Tucson, Ariz., not involved in the new research. "A moonlike object seems like a pretty natural outcome."

Several years ago, motivated by the notion that exomoons ought to be prevalent in the Milky Way as well as puzzling observations of excess infrared emission around some middle-aged stars, Brad Hansen began thinking about how the presence of a moon might affect its host planet.

"A moonlike object seems like a pretty natural outcome."

But Hansen, a planetary scientist at the University of California, Los Angeles, wasn't thinking about run-of-the-mill effects of moons, such as the tides they induce on a watery planet. Instead, he was curious about the possibility of a collision between a moon and its host planet and the likelihood that such an event, were it to occur, might be detectable with large research telescopes.

The Retreat of the Moon

The orbit of our own Moon is changing, albeit very slowly; every year, the Moon moves about 4 centimeters (1.5 inches) farther away from Earth. Gravitational forces are the culprit—the Moon tugs on Earth gravitationally, causing the planet to bulge toward the Moon, and because the rotation of our planet moves that bulge ahead of the Moon by roughly 10°, our satellite essentially feels an extra pull forward. The Moon consequently speeds up and, according to the tenets of orbital mechanics, moves outward in its orbit. At the same time, Earth's rotational period is also slowing down because of conservation of angular momentum. "The Moon is spiraling out just because it's extracting angular momentum from the spin of the Earth," Hansen said.

Hypothetically, the Moon's orbit will continue to enlarge, and Earth's rotational period will continue to slow in tandem for tens of billions of years. (That's notwithstanding, of course, other more pressing cosmic eventualities, such as the death of the Sun and its probable engulfment of Earth in roughly 5 billion years.) But moons orbiting planets that are substantially closer to their host stars could undergo a much different course of evolution, Hansen calculated.

With an eye toward determining the long-term outcomes of planetary systems containing moons, Hansen modeled a solar system containing a single spinning rocky planet up to 10 times the mass of Earth with a rocky moon that ranged in mass from 1 to 10 times the mass of Earth's Moon. In various model scenarios, he assumed that the planet was anywhere from 0.2 to 0.8 astronomical unit from its host star. For comparison, Earth orbits the Sun at a distance of 1.0 astronomical unit, or roughly 150 million kilometers (93 million miles).

Crossing a Boundary

Hansen modeled the gravitational interactions of the moon, planet, and star in each planetary system. He found that for planets orbiting between roughly 0.4 and 0.8 astronomical unit from their host stars, their moons tended to spiral outward, just as our own Moon is doing.

But when Hansen modeled the long-term evolution of those out-spiraling moons, he found that some of them traveled so far from their host planet that they ended up crossing an invisible boundary: the edge of a volume of space known as the Hill sphere. Within a planet's Hill sphere, an orbiting object primarily feels that planet's gravity and is therefore gravitationally bound to it. The Moon and all of our planet's artificial satellites are within Earth's Hill sphere, which extends roughly 1.5 million kilometers (900,000 miles) into space.

A moon that journeys beyond a planet's Hill sphere is no longer bound to that planet—instead, it now orbits the star in its planetary system. However, it's still in proximity to its erstwhile host, which makes for a gravitationally unstable situation, said Hansen.

Hallmark of a Cataclysm?

Hansen showed that such moons overwhelmingly went on to collide with their host planets several hundreds of millions or even a billion years after the formation of the planetary system. Such collisions would, in all likelihood, be catastrophic impacts, he estimated, and they'd release copious amounts of dust. That material would then be heated by starlight to temperatures of several hundred kelvins and would accordingly begin to glow in the infrared. That makes sense, said Najita. "It sounds quite plausible."

Perhaps these marauding moons could explain why some middle-aged stars show a significant excess of infrared emission, Hansen postulated. Planetary systems should be generally pretty settled places—in terms of giant impacts—after 100 million or so years, he said, so spotting what's likely a lot of dust is puzzling. Maybe astronomers are seeing the hallmarks of a cataclysm in dust-enshrouded star systems, Hansen hypothesized.

But there are other ways to explain particularly dusty stars, said Carl Melis, an astronomer at the University of California, San Diego not involved in the research who studies stars that show excess infrared emission. Melis and his colleagues have suggested that collisions between planets, not between planets and moons, are responsible for creating the dust visible around some stars. One way to discriminate between those two scenarios, he said, is to look for planets orbiting those stars. Consistently finding several planets would lend credence to his hypothesis, he said, but finding only one would bolster Hansen's viewpoint. "It's very testable."

By **Katherine Kornei** (@KatherineKornei), Science Writer

Ice Cores Record Long-Ago Seasons in Antarctica

To many, the Antarctic Ice Sheet is a blank, frozen wasteland. But to those who study Earth's past climate, it contains a wealth of information. Gas bubbles trapped in ancient ice preserve long-ago atmospheres, and chemical changes in the ice trace fluctuations in Earth's temperature.

Climate scientists have used these "ice core diaries" to reconstruct long-term trends in Earth's temperature, such as the comings and goings of ice ages. But so far, it has been difficult to obtain long-term records of a hot-and-cold pattern that is more familiar to us: the seasonal cycle.

Ice doesn't reveal its secrets easily.

In January, a team of scientists presented a seasonal temperature record dating back 11,000 years. The ice revealed a connection between intense solar radiation and hot summers in Antarctica.

"[This] is the first record of its kind," said Tyler Jones, a polar climatologist at the University of Colorado Boulder's Institute of Arctic and Alpine Research (INSTAAR) and lead author of the study (bit.ly/ice-core-temps). Seasonal temperature data help researchers understand Antarctica's natural rhythm, which is critical for anticipating the region's responses to warming.

Temperatures in the Time of Mammoths

Researchers can infer past temperatures by measuring the ratios between isotopes—atoms with the same number of protons but different numbers of neutrons. Because hydrogen is a main constituent of water, paleoclimatologists often focus on the ratio between common hydrogen and its heavier sibling, deuterium: The warmer the regional average temperature was when the ice formed, the higher the deuterium concentration is.

By measuring the relative abundances of common hydrogen and deuterium along 3,405 meters (11,171 feet) of the West Antarctic Ice Sheet Divide core (WDC), Jones and his coauthors reconstructed temperatures into the early Holocene, a time when humans were just starting to develop agriculture and mammoths still roamed Siberia and North America.

The data showed that summer temperatures in West Antarctica were higher when the region received a more intense dose of sunlight. This deceptively simple observation is connected to Milankovitch cycles, a major tenet of climate science. According to Milankovitch theory, the amount of sunlight reaching Earth's surface—which depends on Earth's rotation and orbit around the Sun—drives long-term climate change. The study validated the link between sunlight and climate on a seasonal scale: Intensely sunny summers lead to warm temperatures that can potentially trigger large-scale melting of ice.

Deciphering Ice Core Diaries

Ice doesn't reveal its secrets easily. To construct a continuous temperature record, the scientists needed to be reasonably sure the ice core didn't contain any significant gaps: A long period without snowfall can create gaps in the information stored inside.

Zeroing in on seasonal cycles requires ice deposited in different seasons to be distinguishable within the ice core. Imagine trying to identify the layers of a tiered cake 11,000 feet tall—a challenging task in any case, but impossible if the layers are too thin to be differentiated. The WDC was ideal for seasonal measurements because its ice accumulated quickly, producing annual layers 10–50 centimeters (4–20 inches) thick.

The researchers measured water isotopes at 5-millimeter (0.2-inch) intervals along the ice core. Because each of those intervals represented several weeks' worth of ice, the resulting temperature record resolved seasonal changes. The researchers compared the data with the amount of sunlight that reached the pole, determined using numerical models.

Even an ideal ice core can be difficult to decipher, though. The researchers had to account for uneven snowfall between seasons, sporadic storms, and natural diffusion of water particles in ice. Correcting for diffusion and natural noise was a long-haul effort that required "working through a mountain of modeling and statistical considerations," said Jones, who began contributing to the project as a doctoral student in