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PARTICLES OF INTEREST

What can space dirt tell us about the origin of life on Earth?

STORY BY **MICHAEL SHAPIRO**
PHOTOS BY **ELYSE BUTLER**

There are a lot of sophisticated instruments at the Mauna Loa Observatory, but the high-volume air sampler isn't one of them. It's just a metal box on legs, with a snorkel sticking out the top and a whirring anemometer for measuring wind speed and direction. What it does is pretty simple, too: It sucks air through a filter. A vacuum cleaner, basically. Like most of the other tech at the observatory, operated by the National Oceanic and Atmospheric Administration, it was originally installed to take readings of atmospheric chemistry. But Hope Ishii is less interested in the atmosphere than what's falling through it.

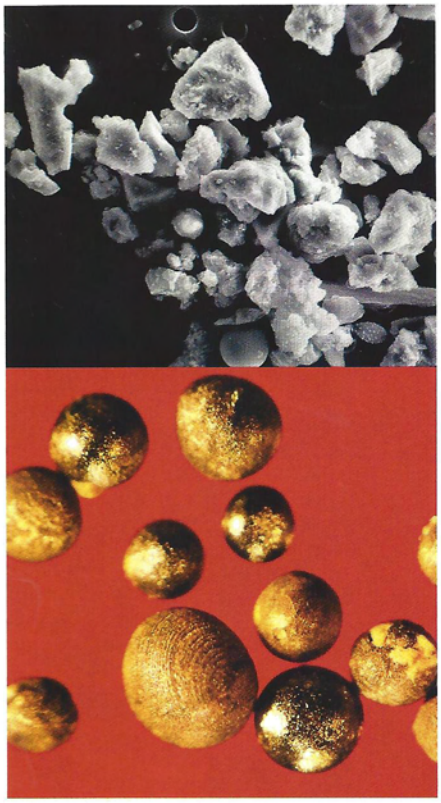
In the edgy, too-clear light at 11,141 feet, Ishii, an associate researcher at the University of Hawai'i's Institute of Geophysics & Planetology, is guiding an intern through what she calls a "royal-pain-in-the-butt moment": gingerly lifting a thin filter from the sampler and replacing it with a new one. Usually MLO techs would remove the filter and ship it to Ishii's lab at UH Mānoa, but today she's come in person to adjust the sampler because it's been sucking up too much Earth dirt, making it harder to find the "particles of interest" she's after: tiny meteorites older than the solar system itself.

Not that such particles are rare. About forty thousand *tons* of IDPs—interplanetary dust particles—fall to Earth every year. Space dust is everywhere, on everything. There might be some stuck to the sole of your shoe right now. You might have swallowed a four-billion-year-old grain of extraterrestrial dirt with your breakfast. But finding these minuscule particles—some less than a twentieth the width of a human hair—among ordinary dirt is a challenge. And even if you pluck one out, it's sure to be contaminated with terrestrial material. To collect the cleanest space dust, you need to grab it before it hits the ground.

That's one reason Ishii and research partner John Bradley came to Hawai'i last year. The husband-and-wife team are hardly new to the hunt: They met at Lawrence Livermore National Laboratory in California while collaborating on NASA's Stardust mission, which flew a probe through the tail of Comet Wild 2 in 2004—the first mission to bring material from beyond the moon back to Earth. Those samples contained IDPs left over from the formation of the solar system. But there was also *interstellar* material, a.k.a. "pre-solar grains," literal stardust from suns far older than our own.

Trawling for IDPs by spacecraft is

At top, intern Leanne Teodoro checks a filter in the high-volume air sampler at the Mauna Loa Observatory. The sampler vacuums up air at an altitude of eleven thousand feet in the hope of capturing interplanetary dust particles (IDPs) left over from the formation of the solar system. In their lab at the University of Hawai'i at Mānoa, John Bradley and Hope Ishii (seen with Teodoro at bottom left) use electron microscopy to find IDPs that may have been captured on the filter. On the opening page, micrometeorites (0.1 to 0.2 mm in diameter) collected from the deep sea.



Some forty thousand tons of space dust fall to Earth every year, but finding uncontaminated material—the "needle in a haystack that's in a haystack," says Bradley—is a challenge. At top, a sample collected at MLO seen under a focused ion beam microscope showing mineral grains and other terrestrial contaminants—and maybe some IDPs. Because deep-sea spherules (seen above) have undergone significant alteration, they offer different information about the early solar system than material collected at high altitude.

expensive. So is flying planes through the stratosphere, which yields slim returns on the investment. A snorkel on legs, though, is a bargain. But good luck finding a site where it'll collect enough IDPs to make it worth the effort. Ishii and Bradley tried the remote atoll of Kwajalein in the Marshall Islands, more than a thousand miles from the nearest continent. They had some success, but the samples were often contaminated with salt or with rust from the ships and planes that had sunk there during WWII. They tried Antarctica, but even the planet's last unspoiled wilderness was still a mote too dusty. High peaks like Mauna Loa are prime for collection, says Ishii, because of "down-mountain flow"; at night air flows earthward from the upper atmosphere, potentially carrying IDPs with it. This is true for all of the planet's high peaks, but Hawai'i's second-tallest mountain "is unique," says Bradley. "It's several thousand miles away from the nearest land mass, and it's high altitude. There aren't many places like that—Mauna Loa may be the *only*

accessible place on Earth right now where we can do this." And, bonus, there was already an air sampler at the observatory, sitting unused for a decade, which likely made the MLO Extraterrestrial Dust Collection Project possible. Given the sensitivities around putting new facilities in areas many Native Hawaiians regard as sacred, "this was an amazing stroke of luck," says Bradley. "We didn't install anything at all —we just walked in and were like, my God, we can collect dust here!"

In the beginning—about 4.6 billion years ago—there was no sun. But the void was hardly empty; it was filled with nebulae of dust and gas. The latest theory holds that gravitational waves generated by the violent deaths of nearby stars pushed these nebulae together. As they condensed, gravity took over: They collapsed on themselves and started spinning, flattening out like a pancake. As this "presolar disk" rotated, most of its material—99.8 percent by some estimates—was drawn toward its center to form a bulge, or "proto-sun." Over some 50 million years the proto-sun's temperature and pressure increased until its atoms started fusing, igniting the star we know and bask under. As this occurred the rest of the solar system formed from material trapped by the sun's gravity: comets, asteroids and, through accretion over time, the planets and moons. The infant sun burped intense radiation—again and again—blowing out to space the leftover presolar material and leaving behind the larger bodies orbiting around it in a relative vacuum. The whole process was relatively fast in cosmic terms—about 100 million years from start to finish.

We know some of this origin story by studying the composition of IDPs, in particular the most primitive ones from the earliest days of the solar system. Those come from comets. "Comets formed really far from the young sun, where it was extremely cold," says Ishii. "So anything in those comets has been kept in cold storage. They're like time capsules from the beginning of the solar system." Cometary particles returned by Stardust, for example, provided hard evidence of the going hypothesis that gravitational waves from dying stars likely kick-started our own sun's formation.

Much can also be learned from studying rocky IDPs from asteroids called carbonaceous chondrites—you've seen the larger chunks if you've ever visited a planetarium or a mineral shop. But those don't tell us as

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much about the early solar system as their nanoscale cousins. "Asteroids that failed to come together into really large bodies have changed less, so they tell us more about what the conditions were like," Ishii says. "This is one way we can understand planet-building—by looking at the leftovers that didn't make it into a planet."

Such research helps to flesh out chapters one and two of this genesis story: how the sun formed and how the solar system developed. But chapters three and four are just now being drafted, and they are arguably more exciting: how Earth got its water and how life began. Here again IDPs offer tantalizing clues. Samples from Stardust contained evidence of extraterrestrial water and organic molecules, including one essential precursor for life: the amino acid glycine. Today it's well known that water ice is common throughout the solar system, but how oceans of liquid water got to a hot, rocky body like Earth isn't understood. "The early Earth was very hot, and there was almost no water, so something had to deliver the water and organic materials," says Ishii. "Some of it could have come from within the planet itself, from ices on the dust that formed the Earth. Some of it was probably delivered by comets and asteroids. People argue about what fraction comes from each—how much from the Earth and how much from asteroids and comets." By analyzing the water carried here by IDPs, scientists aim to answer that "big question," Ishii says, as well as what she calls "the biggest driving question": Where did the building blocks of life come from?

Back in their lab in a basement at UH Mānoa, Bradley is showing me an electron microscope image of a black speck he calls "very exciting"—what he suspects is an IDP from a filter recently sent from MLO.

"Sorry," I say. "All I see is a dot."

"It's a very black dot, so it's likely to be high in organics." Ishii shoots a glance at Bradley and chuckles. "We get excited about these things."

"Why should *you* be excited?" Bradley asks me. "Let me introduce you to your atomic and molecular ancestors. That's what it basically—and probably—is. We are literally stardust. I've read recently that in the next twenty-five years, people living today will know how life on Earth got started." He gestures toward the now much more exciting dot on the screen. "My money is on these things."

And not just his money. Dominating

Ishii and Bradley's lab is "the Titan," a twelve-foot-tall rectangular monolith. In terms of sophistication, it's as far from a high-volume air sampler as you can get. UH's new, $10 million transmission electron microscope is one of only four of its kind in the United States. It's so powerful it can distinguish a single *atom* and so sensitive that sound waves from mere nearby conversation can distort its readings. Ishii and Bradley use it, along with a focused ion beam microscope and a scanning electron microscope, to determine which specks from a given filter are in fact IDPs—as opposed to terrestrial dirt, industrial aerosols or, as one impressively large and tantalizing specimen turned out to be, bug poop. It can also analyze an IDP's chemical and physical composition. With this tool, which Bradley calls a "quantum leap for technology in Hawai'i," Ishii and Bradley are building an archive of material from which other researchers can draw to search for organic molecules, because the primary thing that prevents us from answering the question of where the components for life originated is that there isn't enough material to study—yet.

So Bradley and Ishii will continue to tweak the high-volume air sampler up at MLO, adding a timer so that it collects during peak down-mountain flows and especially whenever Earth passes through a comet's tail—a phenomenon that we Earthlings experience as meteor showers. It's only a matter of time before that material is collected—within a decade, Ishii predicts. "If we can get enough organics to do higher-fidelity, higher-resolution analysis," she says, "then we can say a lot more about what's being delivered to Earth now and what may have been delivered in its early history."

"We are intimately connected to dirt," muses Bradley. "Across the universe, floating between the stars, and something happened to some of that dirt that kicked off a process that led to us. But ultimately we trace everything back to that." I ask Bradley to hypothesize about what we're likely to learn from this research—something many scientists are reluctant to do without hard data or qualifying language, but he doesn't hedge.

"I think we'll find that the key molecules required for the evolution of life on Earth came from space," Bradley says, then adds: "And that's important, because if it happened around this star, it happens around many stars all the time. If it happened here, it happened everywhere." HH