SCIENTIFIC AMERICAN

Lost Worlds of the Dinosaurs

Sand Mafias

Quantum-Proof Encryption

The Milky Way's Secret History

New star maps reveal our galaxy's turbulent past

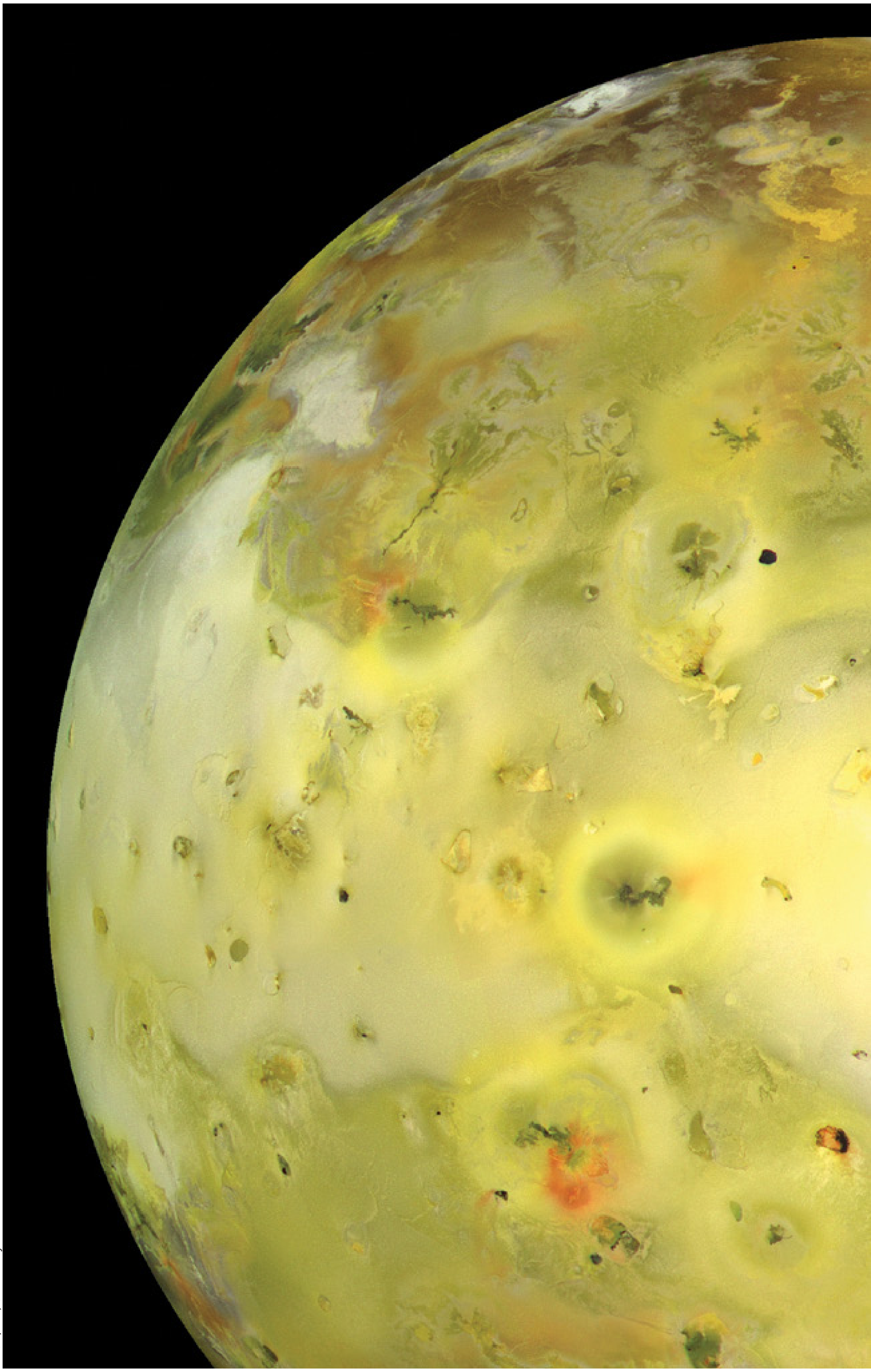
FEBRUARY 2024
SCIENTIFICAMERICAN.COM

ADVANCES

SPACE

Erupting Moon

What heats the prodigious volcanoes on Jupiter's fiery moon Io?



NASA/JPL/University of Arizona

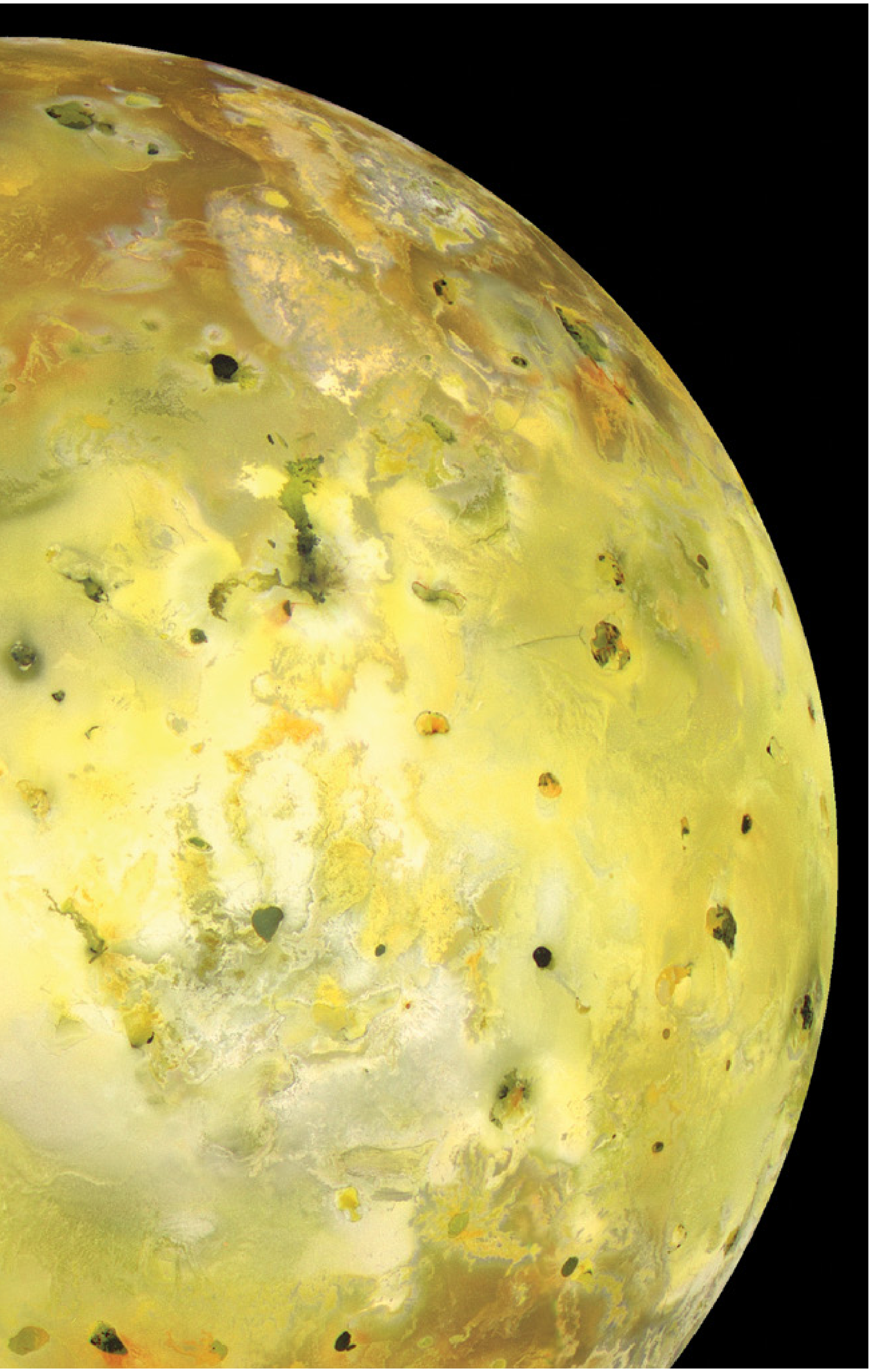
SCIENTISTS CAN SAY two things with certainty about Io. First, this moon of Jupiter is the most volcanic object in the known universe. Its surface is festooned with so many lava-spewing calderas that it resembles an oven-baked cheese pizza; its glowing rivers of molten rock stretch sinuously from horizon to horizon, and its endless eruptions spray towering arcs of matter into the vacuum of space.

Second, no one really knows the depth of this flashy orb's fiery plumbing. Are Io's volcanoes fed from reservoirs just underneath its crust, or does the heat well up from some far deeper source, near the moon's metallic core? Solving this mystery could also help reveal how Io's lunar sibling Europa and other icy moons manage to harbor vast, potentially habitable liquid-water oceans despite the outer solar system's sunlight-starved chill. Now the authors of a new study in *Nature Astronomy* think they have an answer: they're placing their bets on "heat engines" buried not too far below Io's surreal surface.

"Research like this provides invaluable insights into the diversity of volcanic activity and the interior heating of other worlds," says California Institute of Technology planetary scientist Anna Gülcher, who was not part of the new study. The work helps to winnow down researchers' models of where and how heat arises within otherwise frozen alien moons.

In a way, Io's internal heat can be traced to the presence of Europa and its other nearest neighboring moon, Ganymede: the two bend Io's orbit around Jupiter into an oval

COLOR WORDS SHOW A BILINGUAL BONUS P. 10
BACTERIA REMEMBER PAST SWARMS P. 14
DEEPWATER CORAL IN UNEXPECTED PERIL P. 16



that brings the hypervolcanic moon swooping closer to and then farther from the gas giant's wrenching gravitational grip. This movement raises tidal forces within Io that squeeze the moon's geological guts, generating enormous amounts of magma-making frictional heat. The question is where within Io that heating is concentrated—and, by proxy, where Europa's and other oceanic moons' tidal heating may originate as well.

Glimpses from NASA's Juno spacecraft have helped fill in views of Io's volcanic hotspots, letting scientists gather clues. These infrared images "are showing things nobody has ever seen before," says study co-author Ashley Davies, a volcanologist and planetary scientist at NASA's Jet Propulsion Laboratory. In particular, they reveal considerably more volcanic heat coming from Io's lower latitudes and equatorial expanses than from its comparatively lukewarm poles. This distribution suggests Io's tidal heating is concentrated not at great depths but higher up, closer to the crust.

"We have been wanting to have this data set for decades, and it's finally here," says Caltech planetary scientist Katherine de Kleer, who was not part of the new study. "The models [have differed] as to where the melting is mostly occurring—whether it's down at the core-mantle boundary or whether it's close to the surface."

Finding out which of these models works best demanded a global map of Io's erupting volcanoes. But existing maps remained incomplete, especially near Io's polar regions, because no spacecraft has been exclusively dedicated to investigating the moon.

Juno came to the rescue in 2016, when it entered a polar orbit of Jupiter. Taking advantage of this novel perspective, scientists used the spacecraft's Jovian Infrared Auroral Mapper (JIRAM) instrument—designed primarily to investigate Jupiter's magnetic field and polar auroras—to get a prolonged peek at Io's poles.

In the new study, the authors surveyed 266 volcanic hotspots across the moon. This map showed that Io's lower latitudes were emitting 60 percent more volcanic heat per unit area than the poles. The best explanation of this dichotomy is that Io's tidal heating is mostly happening at shallow depths, either within a puttylike upper mantle or within a partly or fully molten ocean of rock just below the crust.

"I'm kind of leaning toward a magma ocean," Davies says. But evidence is not clear-cut: the erupting volcanoes' positions don't perfectly match any heating hypothesis. "Io's going to be a lot more complicated," he adds.

The poles are also volcanically active, which implies that some tidal heating is occurring at greater depths. "There's probably some degree of melting happening everywhere," de Kleer says. Weirdly, the north pole is emitting more than twice the volcanic heat per unit area of Io's southernmost reaches. It's unclear why; Davies posits that a geological barrier below the south pole—perhaps a thicker crust or some other heat-resistant tectonic structure—inhibits the flow of hot rock to the surface.

Although these results may be the closest anyone can get to an x-ray of the ultravolcanic orb, they still contain huge uncertainties. Researchers cannot even be sure that the pattern of Io's volcanic thermal emissions is a reliable proxy for the moon's heat flow. "Magma will come to the surface where it can, even if that isn't directly over the melting source," says Tracy Gregg, a planetary volcanologist at the University at Buffalo, who was not part of the study.

And this map of Io's volcanic hotspots cannot be set in stone (molten or otherwise). Some volcanoes stay active for a long time, whereas others have short-lived paroxysms. Its ever-changing fiery face is "the delightful thing about Io," says Jani Radebaugh, a planetary geologist at Brigham Young University, who was not part of the study. "There is no way we can ever be done mapping all the volcanism."

Future pictures of the volcanic hotspots might look much different from this one, potentially supporting a different conclusion. For now, however, this thermal snapshot broadly aligns with past research. And as Juno continues its daring flybys, we will spy even more volcanic outbursts. "This is the purest form of discovery you can imagine," Davies says. "It's an absolute thrill to see these things." *—Robin George Andrews*

Thinking in Color

Becoming bilingual can change the way people think

PSYCHOLINGUISTICS Like the ancient Greek of Homer's time, the Tsimane' language has no set word for the parts of the color spectrum English speakers call "blue." Although Tsimane' does name a number of more subjective hues (think "aquamarine" or "mauve" in English), its speakers—the Tsimane' people of Bolivia—reliably agree on just three main color categories: blackish, reddish and whitish.

But bilingualism is reworking the Tsimane' tricolor rainbow, researchers recently reported in *Psychological Science*—offering a rare, real-time glimpse into how learning a second language can change how people think about abstract concepts and fuel language evolution. The data show Tsimane' speakers who also speak Spanish are borrowing the concepts of—but not the Spanish words for—new color categories such as blue, green and yellow.

"You could have imagined that they could have just started calling things *amarillo* and *azul*" (the Spanish words for yellow and blue), says lead author Saima Malik-Moraleda, a cognitive neuroscientist at Harvard University and the Massachusetts Institute of Technology. But instead "they're repurposing their own Tsimane' color words."

Malik-Moraleda and her colleagues asked 152 people who spoke Tsimane' or Spanish, or both, to name and sort a set of 84 differently colored chips. Bilingual participants sorted the colors into narrower categories in both languages. For example, to describe blue and green chips in Tsimane', they chose two hazy Tsimane' color terms, *yụshñus* and *shandyes,* and repurposed them as distinct, consistent labels for their freshly acquired color concepts. But monolingual Tsimane' speakers used these words interchangeably for bluish and greenish colors.

These results add to the evidence that the languages we speak affect how we slice up the rainbow into color categories. The new study documented this effect in real time as a language evolved; other work in languages such as Greek and Welsh has relied on historical evidence to study this transition after the fact, says psycholinguist Panos Athanasopoulos of Lund University in Sweden. "What they're showing is the end process of this conceptual restructuring" associated with bilingualism, he says.

Although the results reflect changes in how bilingual people talk about the world, they do not reveal whether these speakers actually perceive colors differently than monolingual people do. Psycholinguistics evidence suggests the language we speak can subtly influence how our brains process what we see. Testing whether bilingual Tsimane' speakers' use of color terms reflects a difference in how they experience color—that is, whether their brains react to color differently than those of monolingual people—would be a fascinating follow-up, Athanasopoulos says.

"To me personally, I feel like it shows the beauty of language learning," Malik-Moraleda says. Even without borrowing words, it can "transform your own concepts in your native language." *—Elise Cutts*

Illustrations by Thomas Fuchs