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DIGGING MARS

What penetrating 5 meters could tell us about the history of the red planet and habitable worlds. PAGE 26

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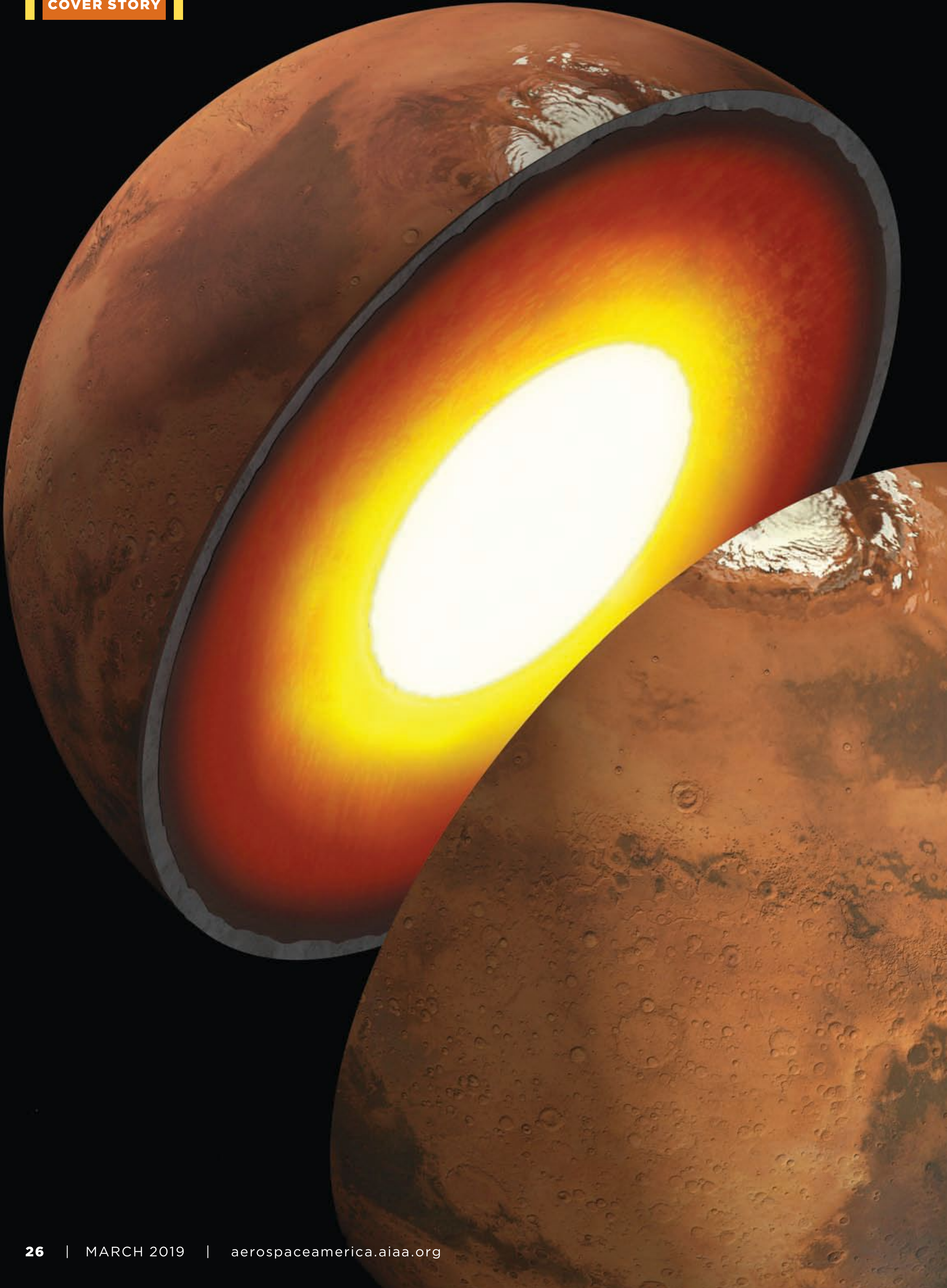


DIGGING INTO MARS

Every square meter of Mars has been photographed from orbit; its dirt has been scooped up and heated to reveal its constituent chemicals; rovers have driven for kilometers. The surface of Mars, though, has never been dug so deep. That is set to change. Cracking the surface of Mars could deliver readings that will upend tenets about planetary evolution.

BY AMANDA MILLER | agmiller@outlook.com

When Apollo astronauts first bored into the moon to take temperature readings below the surface, they established an important fact: The moon is hard. Jagged particles scattered by asteroid strikes are tightly packed by seismic vibrations, and there is no wind or water to loosen the particles or smooth them out.

Nevertheless, the men on the moon made it work. Drills in hand, the Apollo 15 and Apollo 17 astronauts just had to push harder.

That wasn't the case on the Comet 67P/Churyumov-Gerasimenko, where the European Space Agency crash landed its robotic Philae spacecraft in a crevice in 2014 after an 11-year flight. The team commanded Philae to deploy a drill, undamaged as far as anyone could tell, but the drill still couldn't crack the surface.

"We were very naïve at this point," recalls Tilman Spohn, a member of the international team of scientists and engineers who designed Philae's drill.

Now, Spohn, a planetary geophysicist and director of the Institute of Planetary Research at DLR, the German Aerospace Center, will have another chance to crack the surface of a celestial body, this time Mars. He is the principal investigator for a package of instruments that arrived at Mars in November aboard NASA's InSight lander as part of the $800 million mission. This package includes a titanium tube with a bullet-shaped tip that is attempting to hammer — not drill — itself as deeply as 5 meters below the surface to learn, among other things, how much heat Mars sheds to its at-

mosphere. No one has ever gone that deep. The Viking 1 lander dug 22 centimeters down in the 1970s. NASA's Phoenix lander reached 18 cm in 2000.

Just as on the comet, there are no guarantees. The device, nicknamed the Mole, could hit a rock too big to work around before it gets very far, or the Mole's science team could discover that the dirt is denser than suggested by photos from the Mars Reconnaissance Orbiter, spectroscopy from the Mars Global Surveyor and analysis by other landers.

But if all goes as hoped over the next few months, scientists will begin to gather data that could help solve some of the great geophysical mysteries of Mars, including details about its core and what happened to its water — facts that could help exoplanet hunters as well.

For some, the water question is particularly pertinent. "Ultimately, why are people so fascinated with Mars? Because they know it had liquid water on the surface at one point and that the environment could have supported life," says Sue Smrekar, a planetary geophysicist at the NASA-funded Jet Propulsion Laboratory who is trying to find out why Venus, Earth and Mars all evolved differently. Smrekar is also the deputy principal investigator for the InSight mission.

▼ A prototype of the Mole on the Heat Flow and Physical Properties Package burrows into simulated regolith in a screenshot from a NASA video. The orange-colored tape represents the science tether that is embedded with temperature sensors. NASA

At this writing, the InSight lander — short for Interior Exploration using Seismic Investigations, Geodesy and Heat Transport — is robotically setting out devices on the surface that will make a host of geophysical observations.

Digging for heat flow

When planners at JPL put out an informal call in 2006 for ways to bore into the surface of Mars, they soon realized that a conventional drill would be too big and heavy to transport on a small lander and too difficult to run remotely, recalls InSight principal investigator Bruce Banerdt of JPL, a planetary geophysicist. A drill's motor would need to stay on the surface. To drill 5 meters down, the bit had to be 5 meters long.

Engineers at DLR were already working on a so-called "mole" digging device, but with a future comet mission in mind. That said, it was similar to a device that had reached Mars aboard the British lander Beagle 2 in 2003. Unfortunately, that spacecraft never communicated with Earth after landing.

The 40-centimeter-long titanium tube that would become today's "Mole" — picture a cylindrical cigar humidor about three cigars long — would sink deeper into the dirt with each blow of a hammer housed inside it. To generate a thump, an electric motor would draw the hammer upward to compress a spring. Upon release, the hammer would strike a cylinder that then would bounce off another spring coiled inside the bullet-shaped tip, tapping the tip and tube a little farther into the dirt.

"We realized it could pull down temperature sensors on a cable," Banerdt says.

That was important because the team wanted to record the temperature at various depths as they dug into Mars. Today, these readings, called the thermal gradient study, are half of what's required to calculate the heat flow at InSight's landing site, meaning the rate by which heat is conducted from the interior of Mars to the surface and into the atmosphere.

To gather the balance, the scientists will periodically command the Mole, during its dig down, to warm itself to a specific temperature, and time how long it takes to reach that temperature.

The heat flow results could test some key predictions about the evolution of Mars, such as how hot Mars was when it formed. Spohn estimates that about 10 percent of the heat flowing just below the surface of Mars comes from the planet's core. Scientists also want to see if their heat flow prediction for Mars is correct. They expect the average heat flow just below the surface to be about a quarter of Earth's. For starters, Mars is about half the diameter of Earth, and on top of that, most of the volcanic activity on Mars took place early in its evolution.

The interior heat data could have implications for planet hunting by shedding light on the characteristics of planets that are most likely to be habitable, meaning capable of supporting some form of life. "Is it just a matter of how close a planet is to its star? Or is it more subtle? Would the interior makeup of a planet have implications for its habitability? This is cutting-edge discussion in planetary science these days," Spohn says.

If Mars has water

Only 20 years ago, people on Earth still thought planets got their water delivered by comets.

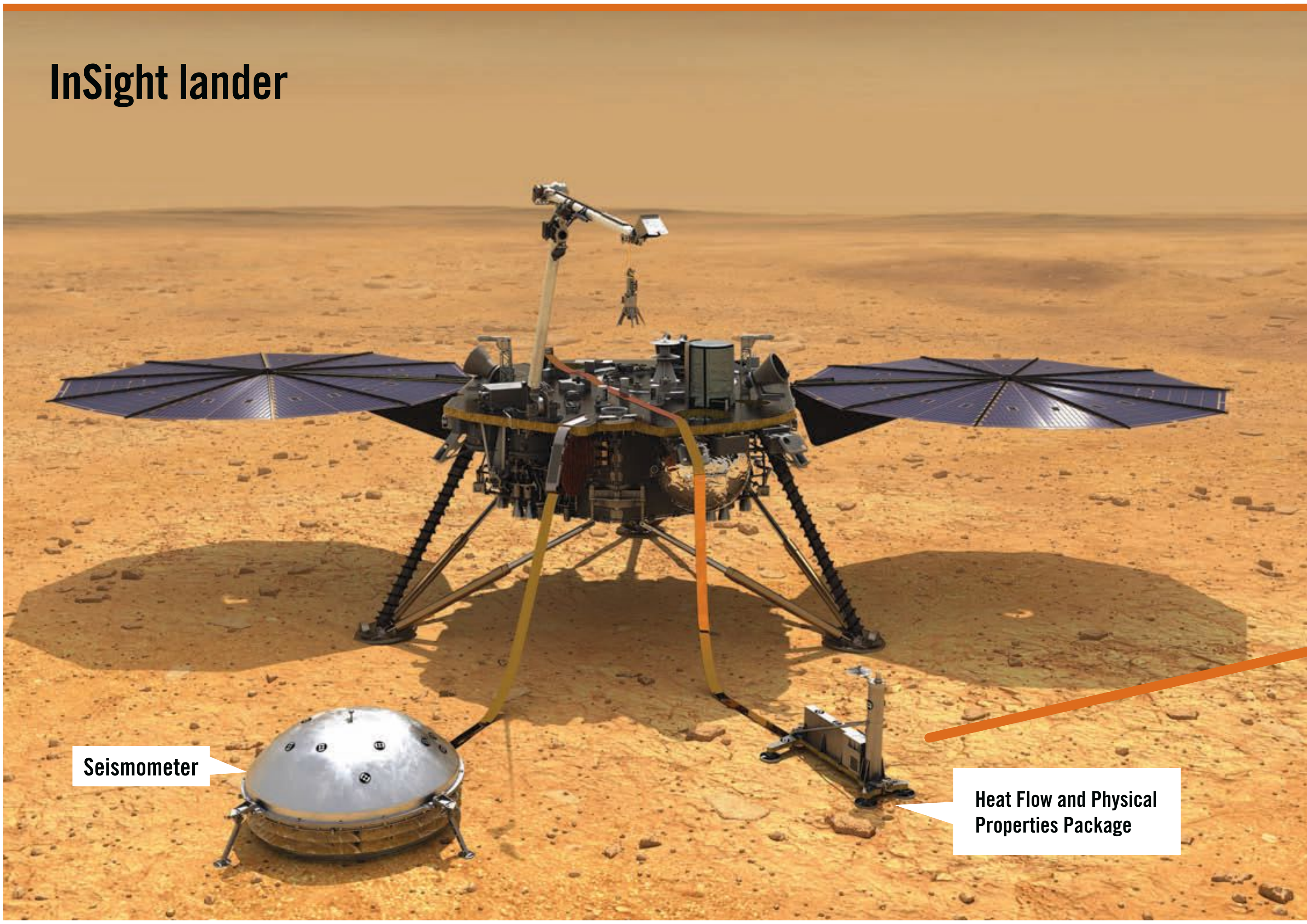
"Now we understand that most of a planet's water comes from the inside," Smrekar says. Geophysicists think most of Mars' volcanic activity happened in just the first 50 million years of its evolution, or "a blink of an eye," as Smrekar puts it. She wonders if a single volcanic eruption could've freed the water that flowed on the surface for the next 1 billion to 2 billion years.

At the same time, planetary scientists wonder whether liquid water is still waiting below the surface. Recording how much warmer Mars gets over those first few meters could help human explorers estimate how deep they will need to dig to reach the zero Celsius point where liquid water could exist.

But for now, the InSight team has only asked NASA's permission to dig as far as 5 meters into Mars, a much shallower depth than Banerdt would expect to find water.

"One of the things we had to worry about was [the surrounding regolith] getting warm enough to melt ice and form water," Banerdt says. "That's a big concern to the planetary protection people — contaminating the surface by incubating things," he says, referring to microorganisms that, despite precautions, might happen to hitch a ride from Earth.

At NASA's Office of Planetary Protection, the job is to make sure people explore the solar system re-



sponsibly, partly to try to keep planets as pristine as possible for more study. The Mole is designed to dig only as deeply as it needs to — 3 meters to 5 meters, according to scientists, to get good data.

"It's already really cold," Banerdt says — around minus 30 or minus 40 degrees Celsius. "So we're only heating it up a little bit."

Testing the Mole

The InSight team feels reasonably confident that they won't suffer a Philae-like disappointment.

To prove the design, they filled a 5-meter-deep tube at DLR with simulated Mars regolith. The engineers did that for various mixtures, given that no one can know for sure the composition of the regolith that the Mole will encounter. Similar tests were done at JPL, but in only a 2-meter-deep, dirt-filled tube. The advantage was that engineers could pump the air down to Mars-like pressures and temperatures.

The Mole scientists think InSight's flat Elysium Planitia landing site will prove to be most like the fine quartz sand in their testing, with rocks making up only a small percentage — 5 percent at worst.

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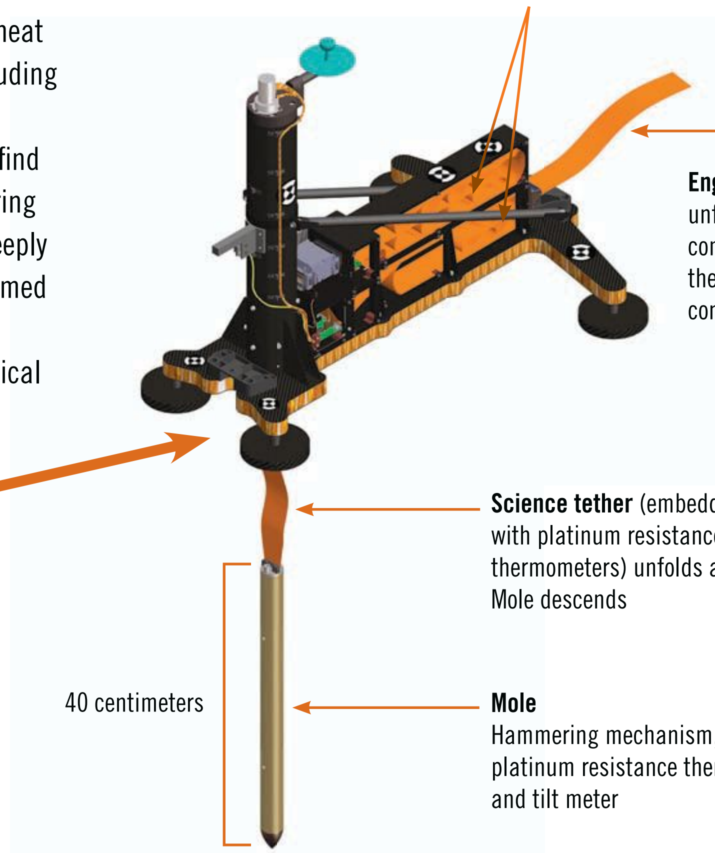
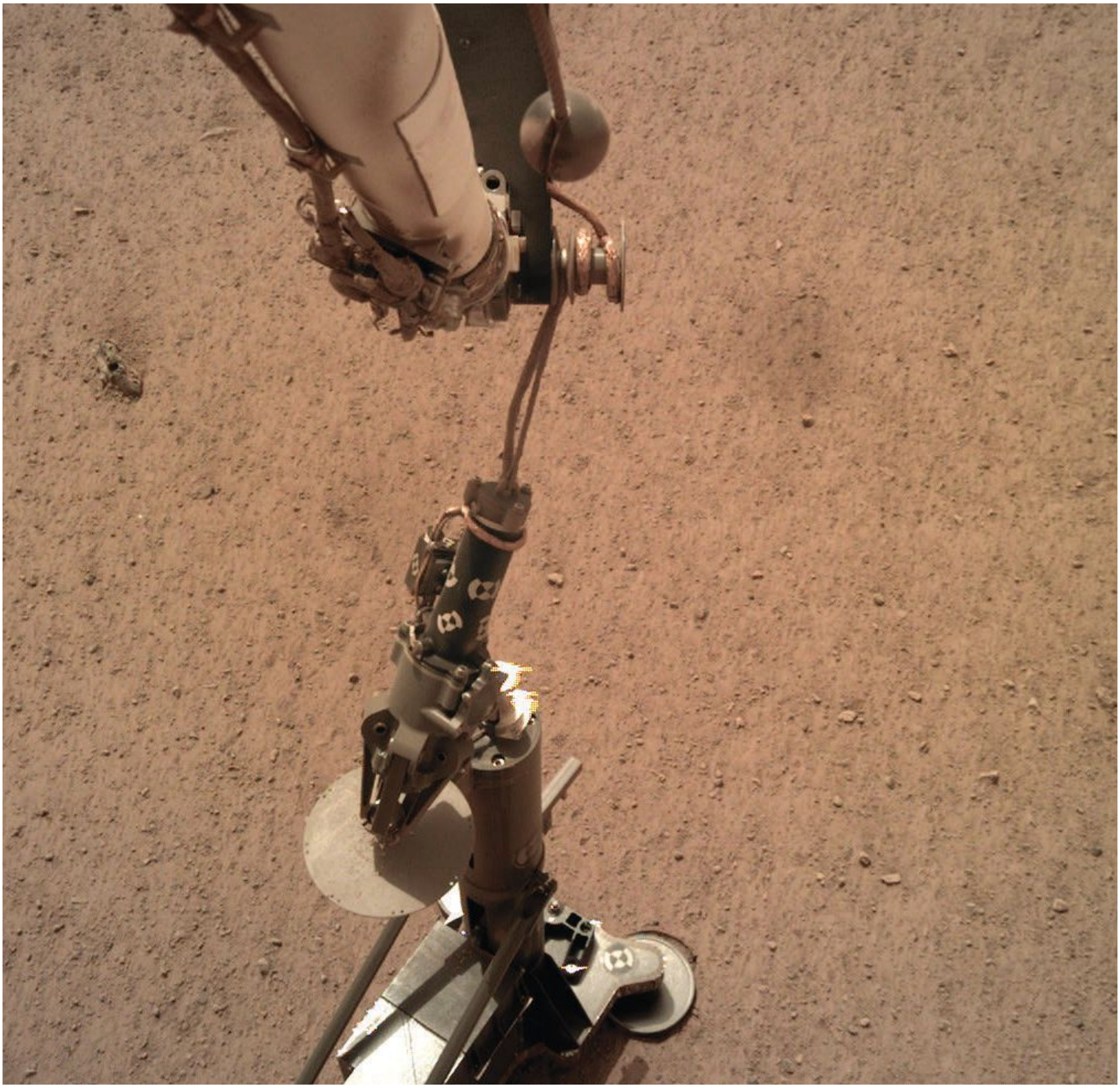
Digging for answers

Scientists want to know how much heat flows from the Martian interior, including how quickly the dirt, called regolith, warms up as one probes deeper. To find out, a titanium tube with a hammering mechanism inside will plunge as deeply as 5 meters. Scientists have nicknamed the device the Mole. It is part of the InSight lander's Heat Flow and Physical Properties Package, or HP^3.



Sources: Artist's rendering at left, NASA; diagram above, German Aerospace Center, DLR



Prior to the Mole's deployment, Banerdt told me he thought the Mole had a 75 percent to 80 percent chance of reaching 5 meters. That probability came close to a prior estimate, which assumed the Mole could get past rocks up to 15 centimeters in diameter or those oriented with their surfaces at a 45-degree angle to the Mole's path.

Before the landing, members of the Mole's team analyzed the likelihood of reaching 5 meters. The 80 percent chance assumes a "less conservative assumption" than one that showed a 41 percent chance of digging down the full 5 meters, they wrote in the article, "The Heat Flow and Physical Properties Package (HP^3) for the InSight Mission," published last August in Springer Space Science Reviews.

The Mole may have to do as many as 10,000 to 30,000 hammer strokes to get down to the ideal 5-meter depth, but it doesn't have to make it all the way to 5 meters. If the Mole digs only as deep as 3 meters, that should produce the desired temperature readings, with one important adjustment. The team will need to take measurements for a much longer period to account for daily and seasonal temperature fluctuations aboveground that extend down below.

Scientists would need just a couple of Earth months' worth of data to calculate the heat flow if the Mole makes it to 5 meters. Or they may need the full duration of the mission, about two Earth years, Spohn says, if the Mole digs down only 3 meters.

▲ The claw on the InSight lander's robotic arm grasps the handle on the Heat Flow and Physical Properties Package and places the instrument on the Mars dirt. A camera on the lander shot a series of these images on Feb. 12.
NASA

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— **Sue Smrekar,** NASA-funded Jet Propulsion Laboratory

Burrowing was set to begin by late February, with the box that contained the Mole acting as an anchor to keep the self-hammering tube from bouncing off the surface before friction from the regolith takes hold. The hammering could last through March or even into April, if the Mole is able to go deep.

Instrument deployment had fallen behind schedule in January after a few attempts to robotically stow InSight's claw-like grapple, the robotic arm and grapple having already placed another of InSight's instruments, its seismometer, out on the surface.

Could there be regolith surprises?

To come up with their best educated guess as to the ground's composition at InSight's landing site — hoping the dirt proves neither too rocky nor too dense — the researchers looked at photos from the Mars Reconnaissance Orbiter, examining the sides of ridges for clues to what's beneath. The Mars Global Surveyor's spectroscopy data characterized heat emissions from the surface, suggesting its mineral composition. Plus the team took into account the consistency of those scoops of regolith picked up by past Mars probes.

Slight as Mars' atmosphere may be — about 1 percent of the density of Earth's — the red planet's thin covering does give it windy weather. The Mole should have an easier time burrowing through the smooth, weathered Martian sands than it would mitigating the sharp, super-compacted substrate Apollo astronauts encountered on the moon.

If there is trouble, Spohn thinks densely packed regolith — more so than expected — could be as likely as a big rock to stymie the Mole's progress. ★