
SELF-STYLED MESSIAHS
FASTEST SHARKS IN THE SEA
ARCHAEOLOGY BY SATELLITE
NATIONAL GEOGRAPHIC
THE SPACE ISSUE
THE NEXT MOON SHOT
IN ORBIT WITH SCOTT KELLY
VOYAGER, 40 YEARS LATER
BEST ECLIPSE IN A CENTURY
AUGUST 2017

"ELEGANT"

- Owen D., Brooklyn, NY

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2017 Mazda CX-5 Grand Touring shown.

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AUGUST 2017 • VOL. 232 • NO. 2 • OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY

THE SPACE ISSUE

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On the Cover This composite image is of the Crab Nebula, a supernova remnant in the Milky Way galaxy, as viewed by the Herschel Space Observatory and the Hubble Space Telescope. *Photo by NASA, ESA*

Corrections and Clarifications
Go to *natgeo.com/corrections.*

PHOTO: DAN WINTERS

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NAT GEO WILD, BOOKS

A SHARKFEST FOR VIEWERS, READERS

All sorts of sharks invade the airwaves during Nat Geo WILD's annual SharkFest; broadcasts begin July 23 at 8/7c. And award-winning National Geographic photographer Brian Skerry offers dozens of his images of the powerful ocean predators in *Shark,* a new book available at *shopng.com* and wherever books are sold.

NAT GEO TRAVELER

INSPIRATION FOR EXPLORATION

Drive yourself wild on a South African safari, discover the wonders of Nepal, and uncover secrets for seeing the world's iconic places in the new issue of *Traveler.*

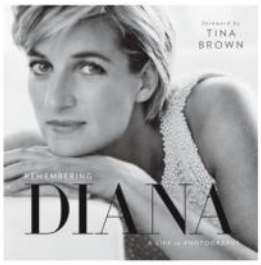
NAT GEO WILD

HEAR HISSING? THEY MAKE HOUSE CALLS.

Snake-catchers Simon Keys and Siouxsie Gillett retrieve venomous snakes that encroach on Durban, South Africa, and release them into the wild. Watch *Snake City* starting July 30 at 9/8c on Nat Geo WILD.

TELEVISION, BOOKS

'THE PEOPLE'S PRINCESS' REMEMBERED



To commemorate the 20th anniversary of the death of Diana, princess of Wales, National Geographic is airing the special *Diana: In Her Own Words* on August 14 at 9/8c and publishing the book *Remembering Diana: A Life in Photographs* (left), with foreword by Tina Brown. Find it at booksellers and *shopng.com.*

PHOTO: BRIAN SKERRY

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Oncilla
(Leopardus tigrinus)
Size:
Body length, 38 - 59 cm (15 - 23 inches); tail, 20 - 42 cm (7.8 - 16 inches)
Weight:
1.8 - 3.5 kg (4 - 8 lb)
Habitat:
Found across a broad range of habitats, generally in areas of dense cover
Surviving number:
Unknown

Photographed by Bruce Lyon

WILDLIFE AS CANON SEES IT

Discretion is the better part of valor. That's the motto the oncilla lives by, making itself scarce whenever larger cats are in the neighborhood. The little feline will even change its normal nocturnal habits and become active in the day to avoid running into ocelots, pumas and the like. The oncilla regularly goes on the prowl for birds, rodents, lizards and marsupials, but doesn't turn up its nose at eating plants. Prized for its soft, thick fur, this gorgeous cat is bedeviled by hunting as well as habitat loss and fragmentation.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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TALKING TOILETS WITH MATT DAMON

He's a famous, award-winning actor, producer, and screenwriter. But **Matt Damon,** 46, also is co-founder of Water.org, a nonprofit that promotes access to safe water and sanitation. I interviewed him in Washington, D.C., as he prepared to address leaders at the World Bank.

PHOTO: PARI DUKOVIC

THIS INTERVIEW WAS EDITED FOR LENGTH AND CLARITY.

Susan Goldberg: So let's have a conversation about poop.

Matt Damon: Great. With the group's name being Water.org, if we ever solve the access-to-clean-water side of water and sanitation, I wonder if the name would become [deleted].org...

SG: I can't print that! That's pretty funny though.

Seriously: In trying to report and photograph the story on sanitation that is in this issue [see page 94], it became clear that this is a hard thing to talk about for a lot of people.

MD: Yes. If you talk about something like cancer or AIDS, even if you're talking about the developing world, people in the developed world totally relate. We all have people who've battled one of those diseases, and it's instantly relatable. But something like this just isn't.

Maybe we'll have stories of grandparents or great-grandparents who were going to the outhouse, but this is a problem that largely has been solved in the developed world. We can't really relate to something like open defecation, which is a huge issue in the developing world.

SG: That's even hard for some people to say aloud. One of the things we really try to do in our story is to show the impact of the lack of sanitation; maybe then you can get people to rally around.

MD: It's hard to get people to comprehend the enormity of the problem—that 2.4 billion people lack adequate access to sanitation. More people have a cell phone than a toilet. You lose a kid under the age of five every 90 seconds because of lack of access to clean water and sanitation. Those two really go hand in hand.

SG: So what do you do?

MD: The first hurdle to clear is to get people to understand that it's an issue, and then the second is to try to make it easier to talk about. We can use humor. We had an idea of shooting a PSA [public service announcement] at some fabulous Hollywood celebrity's house and I'd

ask to use the bathroom and they'd go, Oh, no, we don't have bathrooms—we practice open defecation.
SG: Were there any celebrities you had in mind?
MD: I thought it would be funny if it were at Jimmy Kimmel's house. *[Editor's note: That line got a laugh because for nearly a decade Damon and talk show host Kimmel have pulled pranks on each other and pretended to be feuding.]*

SG: So the world is full of important causes, lots of things that you can spend your time and energy and money on. Why this mission?
MD: I started to look at issues of extreme poverty and wanted to get involved; water and sanitation just undergirded everything. It was just so massive, and I didn't hear anybody talking about it. It's just endlessly fascinating and vastly complex, and there's no kind of one silver bullet that's going to fix it.

SG: So where are you starting?
MD: I partnered with [engineer and social entrepreneur] Gary White, and we co-founded Water.org. It's basically using the concepts of microfinance and tilting it towards water and sanitation: We're providing loans for people to connect to a water utility or build a latrine for their house. We've now reached 5.5 million people, and we're going to hit 2.5 million [more] just this year.

SG: One of the things that our writer ran into in reporting the story was that there were so many cultural inhibitions—for example, that in parts of the world people liked going outside. They thought it was cleaner to go away from your house, to go off into a field.
MD: Yeah, if you don't have pipes to carry the waste away, then that's true. And so if you go to India, for instance, you'll find these giant fields where the entire community is practicing open defecation. But that is changing, and it's changing really rapidly, I think, in large part because of the young people.

SG: It's interesting you should mention young people. One of the places we went to report our story was Vietnam, and the problem is turning around because the kids are going to school and there are toilets in the school. And they're going home to their parents and saying, "This is what we should do."
MD: Yes, right, that's exactly right.

SG: One of the things I wonder about is this: The United Nations has said that by 2030 it is a goal that there not be open defecation. Do you think there's any way we could come close to that?
MD: Definitely by 2030.
SG: That's only 13 years.
MD: I know. But it's happening rapidly.

SG: You mentioned that in doing this work, you hear moving stories. What kind of stories are people telling you?
MD: Well, there was a 13-year-old girl, and my oldest was 13 at the time, so I really related to this kid. It was in Haiti, and we'd helped bring water to this village that hadn't had it. And this 13-year-old was no longer going to have to scavenge for water three to four hours every day.

I said, "What are you going to do with all this extra time? Are you going to have more time for homework?" And she looked at me and she goes, "I don't need more time for homework. I'm the smartest kid in my class." I knew she was telling the truth, so I was just like, "All right, hot shot, well what're you going to do with this extra time?" And she looked at me and she said, "I'm gonna play."

It just buckled me because kids shouldn't be burdened with these things. Those kids should be playing. That's what our kids think about, and it's what these kids should be thinking about.

***

Thank you for reading *National Geographic*.

Susan Goldberg, *Editor in Chief*

Writer Elizabeth Royte and photographer Andrea Bruce document sanitation problems in the developing world in the story "A Place to Go," on page 94 of this issue.

Visit *Water.org* to learn more about the organization's efforts to increase access to safe water and sanitation in the developing world.

'2.4 BILLION PEOPLE LACK ADEQUATE ACCESS TO SANITATION. MORE PEOPLE HAVE A CELL PHONE THAN A TOILET.'

MATT DAMON

VISIONS

United States
As summer temperatures soar, 96 fountains at the base of the Unisphere help visitors beat the heat in this long-exposure shot. The stainless steel globe in New York City's Flushing Meadows Corona Park—140 feet tall, 120 feet in diameter, 350 tons—is a lasting reminder of the 1964-65 World's Fair. Its rings symbolize three early orbital flights, heralding the dawn of the space age.

PHOTO: MATTHEW PILLSBURY, BENRUBI GALLERY

ASSIGNMENT: SPACE

We asked the Your Shot community to interpret the notion of "space." The images we received spanned the cosmic to the terrestrial.

Juan Carlos Osorio
Montclair, New Jersey

Osorio's daughter, Sophia, used to wear princess dresses. But one day she decided to dress as an astronaut instead. She donned her costume at Oheka Castle on Long Island, and Osorio had her hold these reflective balloons. "I wanted to have a picture of her happy childhood," he says.


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EXPLORE
SPACE

ARRAY OF LIGHT

By Catherine Zuckerman

Even on the starriest of nights, the human eye sees just a tiny fraction of the cosmos. So if the curve of the Big Dipper or the four points of the Southern Cross appear magnificent, consider how many more phenomena must exist out of view.

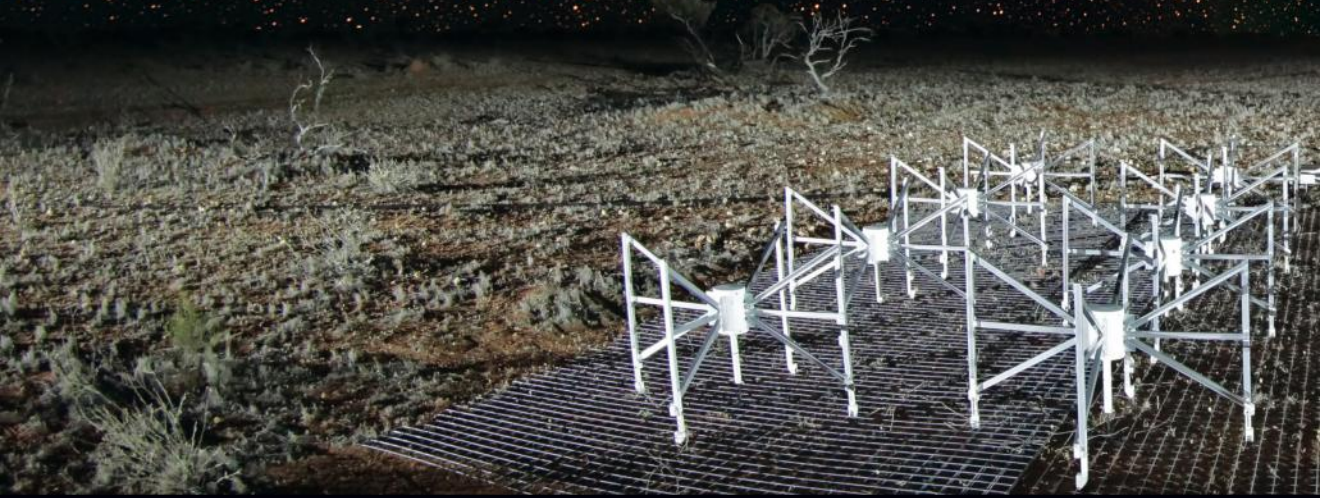
That prospect is what led astronomer Natasha Hurley-Walker to a radio telescope deep in the outback of Western Australia. The telescope, called the Murchison Widefield Array, is made up of thousands of antennas that see through celestial dust and detect "radio light"—revealing colors and objects in a spectrum not visible to humans, even with the aid of optical telescopes like Hubble. Stretched across nearly four square miles of desert, the antennas—cheaper to produce and maintain than typical dishes—look like "an army of mechanical spiders," she says.

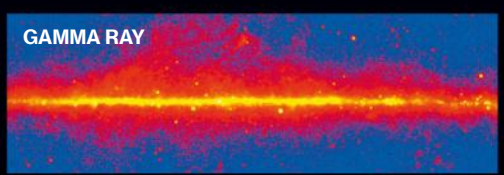
In the past four years, Hurley-Walker and a team of researchers—from the International Centre for Radio Astronomy Research in Perth as well as other institutions in Australia and New Zealand—have stitched together more than 40,000 images taken by the telescope.

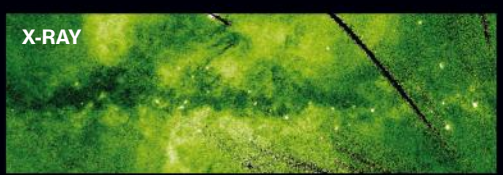
The result is a groundbreaking portrait of the entire southern sky. It exposes hundreds of thousands of galaxies millions of light-years away. And it shows in unobscured, blazing color the radio glow of the Milky Way, lit up with the remains of exploded stars and intense magnetic fields. This sweeping survey, says Hurley-Walker, "allows people to see the sky with radio eyes."

Her research is far from finished. Hurley-Walker is now working with an international team to develop a radio telescope many times bigger and more sensitive than the Murchison Widefield Array. Its technology could pick up fainter signals, which would unveil millions more galaxies and—if her wish comes true—"the birth of the very first stars."

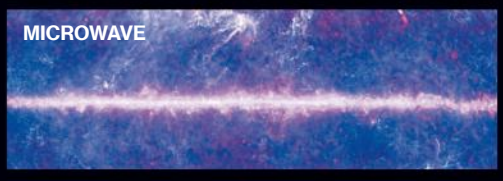
In this composite image, the Milky Way and radio galaxy Centaurus A glow in the southern night sky above a section of the Murchison Widefield Array telescope. Below, the center of the Milky Way is shown at various wavelengths.







PHOTOS: RADIO IMAGE BY NATASHA HURLEY-WALKER (ICRAR/CURTIN) AND THE GLEAM TEAM, MWA TILE AND LANDSCAPE BY JOHN GOLDSMITH, CELESTIAL VISIONS (COMPOSITE OF TWO IMAGES). BELOW, FROM LEFT: NASA/DOE/FERMI LAT COLLABORATION; ROSAT/CHROMOSCOPE; NICK RISINGER, SKYSURVEY; IRAS/NASA; C. CARREAU, ESA, HFI AND LFI CONSORTIA



WHERE STARDUST HIDES ON EARTH

By A. R. Williams

A Norwegian jazz musician and citizen scientist, Jon Larsen has figured out how to do something the experts thought was impossible—find specks of cosmic dust, called micrometeorites, amid the detritus of human habitation. Scientists look for these particles, which rain down constantly on Earth, in Antarctica and other pristine locations, but Larsen thought there should be a way to collect them in more populated places.

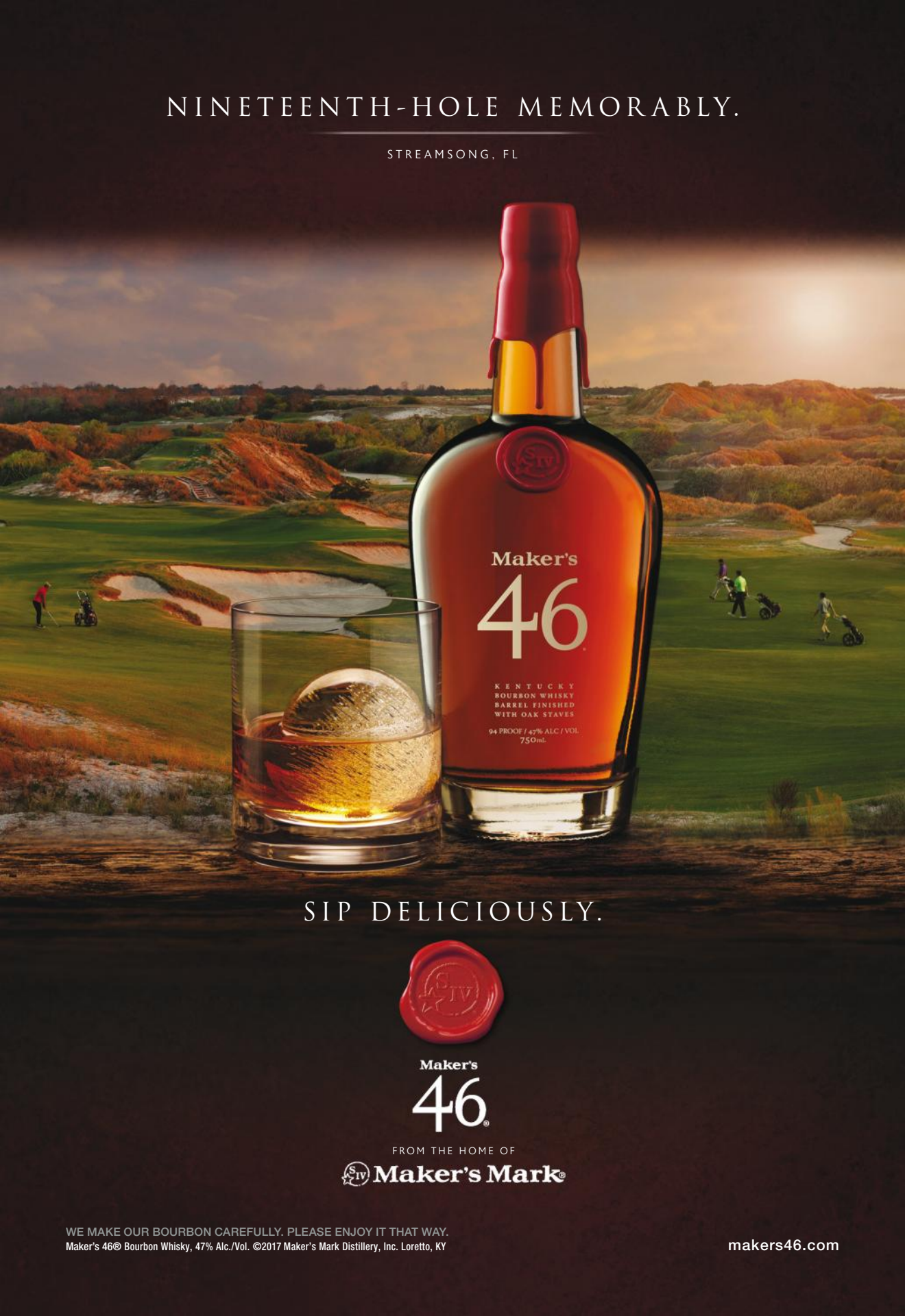
Some micrometeorites are real stardust—flecks from exploded stars. Others are likely created when asteroids collide and comets vaporize. Larsen learned to identify the unique features that take shape as the specks plummet through Earth's atmosphere, first melting and then solidifying. The examples shown here—from Larsen's new book, *In Search of Stardust*—exhibit swirling ridges, golden spots of iron-nickel metal and sulfide, and crystal pyramids of minerals, which formed during the journey.

Larsen was able to find micrometeorites by washing the sludge that had accumulated in open roof gutters, sifting it, and then using a magnet to extract particles from the remaining grit. After approaching many scientists, he finally persuaded Matthew Genge, a planetary scientist at Imperial College London, to examine 48 particles he had collected. Genge analyzed their composition and confirmed that Larsen had indeed managed to find extraterrestrial dust amid earthly debris. "Jon was the one staring down the microscope," says Genge, "going through hundreds of thousands of particles to find just one micrometeorite."

HOW SMALL?

Each particle is about 300 microns wide, roughly the width of a human hair. To capture tiny details, Larsen and colleague Jan Kihle shoot with varied focal lengths, taking one photo per micron. Software combines the images.

STACKED MICROSCOPE PHOTOS: JAN BRALY KIHLE AND JON LARSEN


NINETEENTH-HOLE MEMORABLY.
STREAMSONG, FL
Maker's
46
KENTUCKY
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IDENTITY CRISIS

The official name of the star above is now Betelgeuse, a word that's derived from Arabic. But it's had many other names – some of which are listed below.

- Al-mirzam (Arabic)
- Ardra (Sanskrit)
- Bed Elgeuze (spelling variation)
- Betel'gejze (spelling variation)
- Chak tulix (Mayan)
- Jed Algeuze (spelling variation)
- Kauluakoko (Hawaiian)
- Lak (Tibetan)
- Menkib al Gjauza (Arabic)
- Moroitch (Aboriginal Australian)
- Orionis Humerus Orient (Latin)
- Putara (Maori)

NAME THAT STAR

By Catherine Zuckerman

They may sound like characters from the pages of *Harry Potter,* but Alfirk and Grumium are actually the names of two stars in the universe. Along with 225 other unusual-sounding monikers, they're part of a new registry of official star names. The list was created by the International Astronomical Union, the group that authorizes the naming of celestial objects.

For millennia humans have relied on the stars to navigate seas and cultivate crops, says astronomer Eric Mamajek. Over time a single star could rack up dozens of names with various spellings and translations, many rooted in ancient Greek and Arabic. Astronomers assign alphanumeric designations to heavenly bodies, says Mamajek, but people like to use names for places: "You don't refer to your hometown by its zip code."

Mamajek hopes the new list will provide all stargazers a streamlined lexicon. Meanwhile, he and his team maintain an internal index of every name they find—at last count, about 3,500 for 950 stars.

PHOTO: ROGELIO BERNAL ANDREO (MOSAIC OF SOME 2,000 IMAGES)


NASA
ARMSTRONG

WELL SUITED FOR SPACE WORK

By Jeremy Berlin

On Earth, clothes make the man—and woman. In space, they're the key to survival. Whether helping astronauts enter Earth orbit, walk on the moon, pilot a space shuttle, or travel to Mars, space suits must serve several vital functions: provide oxygen, control temperature, permit movement, power communications, and protect against solar radiation.

But fashion is fickle, and technology grows apace. Space historian Roger Launius says the first suits were based on what jet pilots wore. Over time they've evolved into autonomous modules that help astronauts negotiate the inky expanse, gather samples, and work on the International Space Station.

Yet in some ways they've hardly changed. Now as then, a space suit is essentially a gas-filled, human-shaped covering. (Exceptions include the form-fitting suits Dava Newman is developing at MIT and the high-mobility models Pablo de León is designing at the University of North Dakota.)

Launius says a hard-shell suit is optimal but impractical. "So you've always had suits that can be pressurized, unpressurized, and folded up. The downside is that, when inflated, they look like the Stay Puft Marshmallow Man."

The next step: a suit that's easy to get into and out of. "We also need one for both zero gravity and a surface with some gravity, like Mars," says Launius. He concedes that those goals may be mutually exclusive. But why not shoot for the moon?

Neil Armstrong wore the classic suit at left on July 20, 1969, during his historic moonwalk. The Z-2 (above) is the newest prototype, with a bubble helmet, hard upper torso, rear-entry hatch, and *Tron*-inspired styling.

A SUIT FOR ALL MISSIONS

Mercury/Gemini
The first space suits were modified U.S. Navy jet-aircraft pressure suits. Neoprene-coated nylon lined the inside; aluminized nylon covered the exterior.

Apollo
Custom-tailored for a single lunar mission, with boots made for moonwalking, Apollo-era suits were the first equipped with a life-support system.

EMU
The Extravehicular Mobility Unit has been NASA's workhorse suit for some 30 years, allowing astronauts to function in Earth orbit and build the ISS.

Z-1, Z-2
These prototypes are being tested for use on the moon, asteroids, and Mars. They need to be lighter, more flexible, and more durable than previous suits.

PHOTOS: DAN WINTERS (LEFT); BILL STAFFORD AND ROBERT MARKOWITZ, NASA

CARL SAGAN IMAGINES MARS

By Natasha Daly

Carl Sagan spent his childhood immersed in Mars. The future scientist, an avid reader of Edgar Rice Burroughs's science fiction, would pass evenings lying in vacant lots, looking up at the sky and *"thinking* myself to that twinkling red place." He fantasized about Martians, their bodies a kaleidoscope of color—Burroughs's Mars had two more primary colors than Earth—with removable heads but decidedly human forms. "I didn't realize then the chauvinism of making people on another planet like us."

But in 1965 the first flyby mission to Mars returned photos of pristine rock—and nothing else. It was a gut punch. The *New York Times* declared Mars a dead planet. "The fanciful Martian megafauna," John Updike wrote many years later for this magazine, "were swept into oblivion." Sagan was undeterred: The photos were grainy and inconclusive and showed only one percent of the planet.

In 1967 Sagan wrote a feature story for *National Geographic* that explored the question that had occupied his thoughts as a child: Is there life on Mars? The piece included a rendering of a theoretical Martian, to which he gave serious attention. In correspondence with his editors, Sagan expressed dismay at an early draft of the art, saying the Martian resembled "a man dressed up in a turtle suit." He envisioned "a *benign* Martian vegetarian" with no eyes. "Let's have him find his way in the daytime by his little red tendrils and at night he will dig a hole."

The final painting (above) satisfied Sagan, his years of study evident in the details: The creature's spindly limbs suit Mars's low gravity; its glass-like shield blocks ultraviolet radiation. The art was a paean to the Martian imaginings of Sagan's youth. In 1996, shortly before his death, Sagan recorded a message to future Mars explorers: "Whatever the reason you're on Mars is, I'm glad you're there. And I wish I was with you."

GO FURTHER

Read Carl Sagan's "Mars: A New World to Explore" in the December 1967 issue of *National Geographic* by visiting *archive.nationalgeographic.com.*

'LET'S HAVE [THE MARTIAN] FIND HIS WAY IN THE DAYTIME BY HIS LITTLE RED TENDRILS AND AT NIGHT HE WILL DIG A HOLE.'

CARL SAGAN IN A LETTER TO HIS EDITOR, 1967

PAINTING: DOUGLAS S. CHAFFEE

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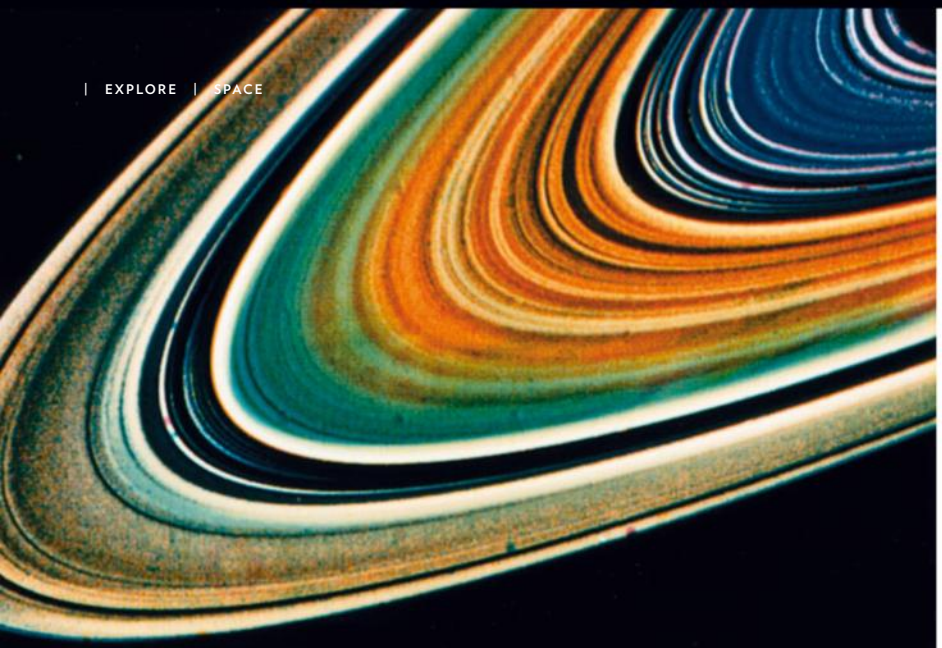
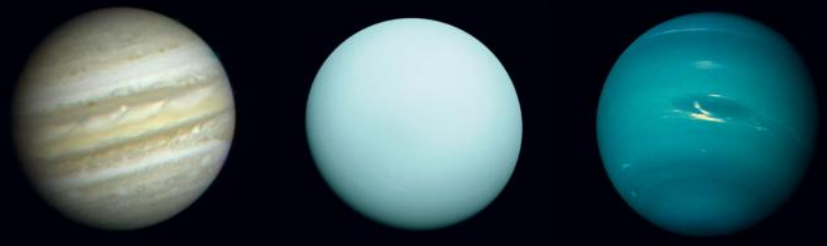


FANTASTIC VOYAGE

DEEP IN SPACE, TWO INTREPID TRAVELERS TURN 40



Launched in August and September 1977, NASA's twin Voyager spacecraft have opened up new worlds for exploration, including Saturn (top) and Jupiter, Uranus, and Neptune (above, left to right).

By Timothy Ferris

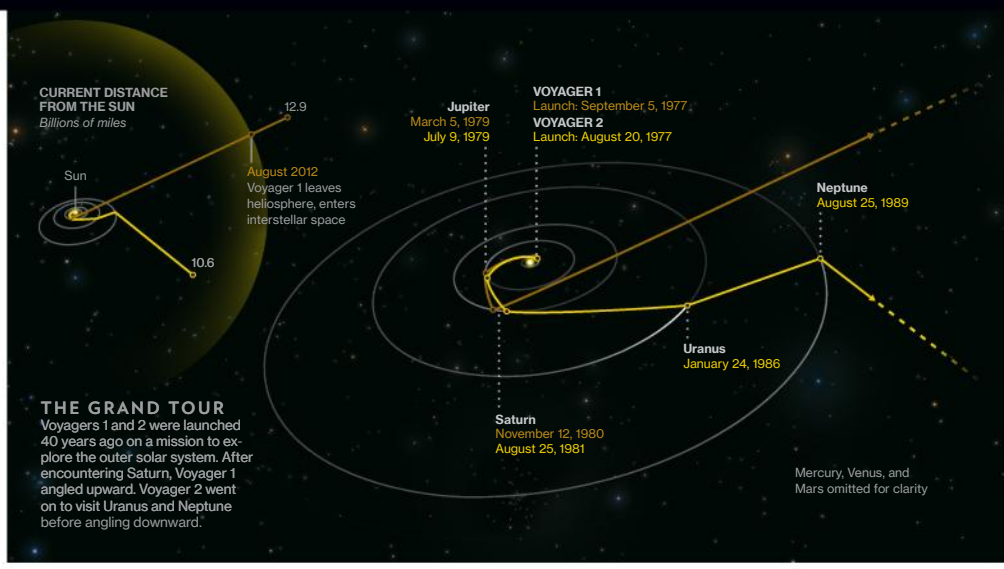
Insofar as we esteem the creations tha
last—Homer's *Odyssey,* the bridge sti
standing, enduring love—let us no
praise the twin Voyager space probes
launched 40 years ago and currentl
departing the solar system to drift fo
ever among the stars.

Each about the size and weight of
subcompact automobile, the Voyager
epitomize 1970s high tech. Their com
puters are weaker than those in today'
digital watches, their analog TV camera
more primitive than the ones that sho
Laverne & Shirley. But they made histor
at every planet they reconnoitered—
confirming, as Voyager chief scientis
Ed Stone put it, that "nature is muc
more inventive than our imaginations.

Jupiter, which looks serene through
telescope, was shown by Voyager to hav
hundreds of raging hurricanes, a glow
ing aurora at the north pole, and thre
thin rings. Saturn's rings, previousl
countable on the fingers of one hand
turned out to include thousands of ring
lets and seemingly braided component
that theorists had assumed were im
possible. ("We thought we knew it all,
said astronomer Brad Smith. "Ha!"
Active volcanoes, formerly found onl
on Earth, turned up in abundance o
Jupiter's satellite Io and, astoundingly
on Neptune's Triton, where nitroge
geysers were observed erupting at 4
degrees above absolute zero on th
Kelvin scale. Two of the solar system'
most promising environments for find
ing alien life—Jupiter's icy moon Europ
and Saturn's Enceladus—were unveile
by the Voyager mission. Their cores pal
pitated and heated by tidal interaction
Europa and Enceladus appear to sustai
vast, briny oceans beneath the ice, wher
living organisms might thrive.

A big-science endeavor that con
sumed some 10,000 work-years, th
mission has been described as "one o
the greatest voyages of exploration eve
conducted by our species."

Yet it almost didn't happen.



The prospect of a "grand tour" of the outer planets emerged in 1965 from the musings of an aeronautics graduate student named Gary Flandro, then working part-time at NASA's Jet Propulsion Laboratory in Southern California, the world's preeminent center for interplanetary exploration. At age six, Flandro had been given *Wonders of the Heavens*, a book that showed the planets lined up like stepping-stones. "I thought about how neat it would be to go all the way through the solar system and pass each one of those outer planets," he recalled.

Assigned at JPL to envision possible missions beyond Mars, Flandro plotted the future positions of Jupiter, Saturn, Uranus, and Neptune with paper and pencil. He found that they would align in such a way that a spacecraft could tap the planets' orbital momentum to slingshot from one to the next, gaining enough velocity to visit all four planets within 10 or 12 years rather than the decades such a venture would require otherwise. The mission launch window would open for a matter of months in the late 1970s, then close for another 175 years.

It was an ambitious idea at a time when the apex of interplanetary exploration was Mariner 4 shooting 21 grainy photos as it flew past Mars. No probe had ever functioned for anything close to a decade in space. None had the intelligence to manage complex planetary encounters at vast distances without constant human hand-holding. Playing crack-the-whip past multiple planets might work in theory but had never been attempted in practice. "I was told, 'This is impossible; stop wasting my time,'" Flandro recalled.

NASA swallowed hard and proposed a grand tour mission anyway, but Congress rejected it, instead approving a cheaper, stripped-down version that would venture out no farther than Saturn.

The JPL spacefarers responded in the tradition of the hardiest explorers of earlier epochs. They cheerfully agreed to the plan, assured one another that Congress didn't really understand the situation, and quietly went to work designing and building two tough, smart spacecraft capable of going all the way to Neptune. Any "life limiting" flaws in the probes' design were weeded out. The sun sensors in their navigation systems were boosted so they could function out where the sun gets dim. Fuel-saving techniques were developed to keep the mission viable long after it was supposed to end. "We just did it and didn't talk about it," recalled William Pickering, JPL's director at the time.

A Voyager spacecraft undergoes testing at JPL in November 1976, nine months before its launch. Originally built to last five years and explore Jupiter, Saturn, and their moons, the Voyagers are now far beyond Pluto and still sending scientific information back to Earta.

The ruse worked. Once Voyager had proved to be both a scientific cornucopia and a globally popular emissary to the great beyond, Congress funded the extended mission that JPL had surreptitiously been managing all along.

The Voyagers paved the way for the Jupiter orbiter Galileo and the Saturn orbiter Cassini that followed, which spent years gathering photos and data before being ordered to incinerate themselves in the planets' upper atmospheres to ensure that they'd never impact and contaminate a possibly life-harboring moon. Now the Voyagers as well are nearing the end of their scientific life. Their weakening radio signals, currently reporting on the surprisingly complex plasma bubble that surrounds the sun and marks the designated boundary between the solar system and interstellar space, are expected to fall silent around 2030, when the Voyagers' plutonium-powered electrical generators finally falter.

Thereafter the Voyagers will function more as time capsules than spaceships. With that eventuality in mind, JPL attached to each probe a copy of the "golden record" that contains music, photographs, and sounds of Earth for the benefit of any extraterrestrials who might intercept it someday. The records should remain playable for at least a billion years before succumbing to erosion from micrometeorites and the high-velocity subatomic particles called cosmic rays.

That's a long time. A billion years ago, the most complex forms of life on Earth were the tidewater mats of cyanobacteria called stromatolites. A billion years from now, the brightening sun shall have begun boiling off Earth's oceans. Yet the Voyagers will still be out there somewhere, emissaries of a species that dispatched them without hope of return.

Timothy Ferris, the producer of Voyager's golden record, wrote on dark matter in the January 2015 issue. Story produced in partnership with HHMI Tangled Bank Studios.

PHOTO: JOHN GREGOIRE, NASA/JPL. ALL OTHER IMAGES, NASA/JPL
GRAPHIC: MATTHEW TWOMBLY. SOURCE: NASA/JPL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| EXPLORE | SPACE
THE FARTHEST
VOYAGER IN SPACE
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Sun coverage
Portion of sun covered by moon
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90%
UMBRA
100%
90%
75%
THE DARKEST ARC
The sun will be totally obscured by the moon in the approximately 70-mile-wide shadow called the umbra. Outside this track, in the penumbra, viewers should see a partial eclipse.
WHAT YOU MIGHT SEE
The sun's corona – the dramatic, outermost atmosphere made of plasma and superheated to an unknown temperature – is believed to be several million degrees Fahrenheit. It's visible to the naked eye only during a total solar eclipse, inside the umbral shadow.
SUN ILLUSTRATION IS NOT TO SCALE. THE SUN IS 400 TIMES AS LARGE AS THE MOON AND 400 TIMES FARTHER FROM EARTH THAN SHOWN ON MAP. LOCAL DAYLIGHT SAVING TIME GIVEN.
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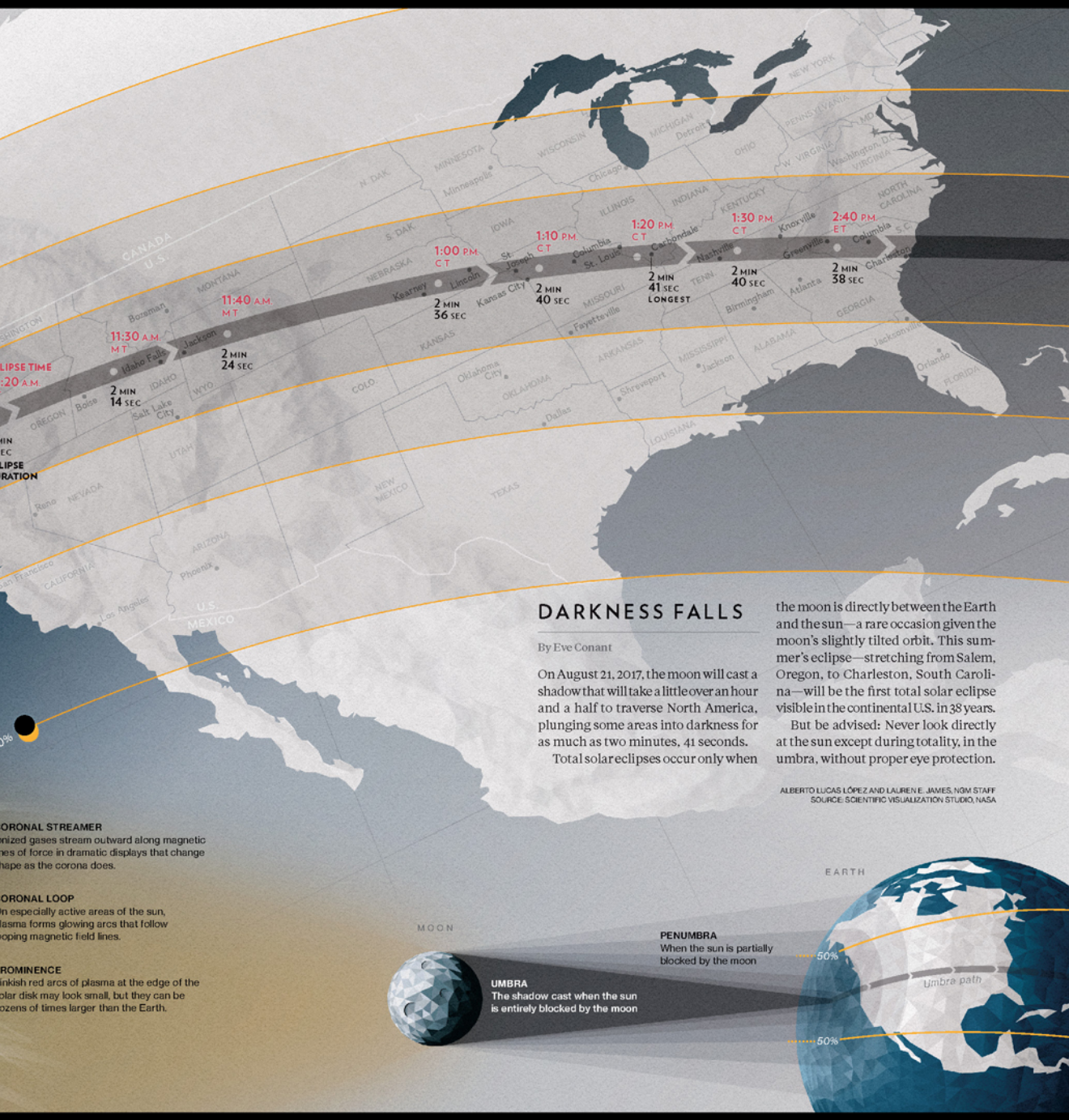


DARKNESS FALLS

By Eve Conant

On August 21, 2017, the moon will cast a shadow that will take a little over an hour and a half to traverse North America, plunging some areas into darkness for as much as two minutes, 41 seconds.

Total solar eclipses occur only when the moon is directly between the Earth and the sun—a rare occasion given the moon's slightly tilted orbit. This summer's eclipse—stretching from Salem, Oregon, to Charleston, South Carolina—will be the first total solar eclipse visible in the continental U.S. in 38 years.

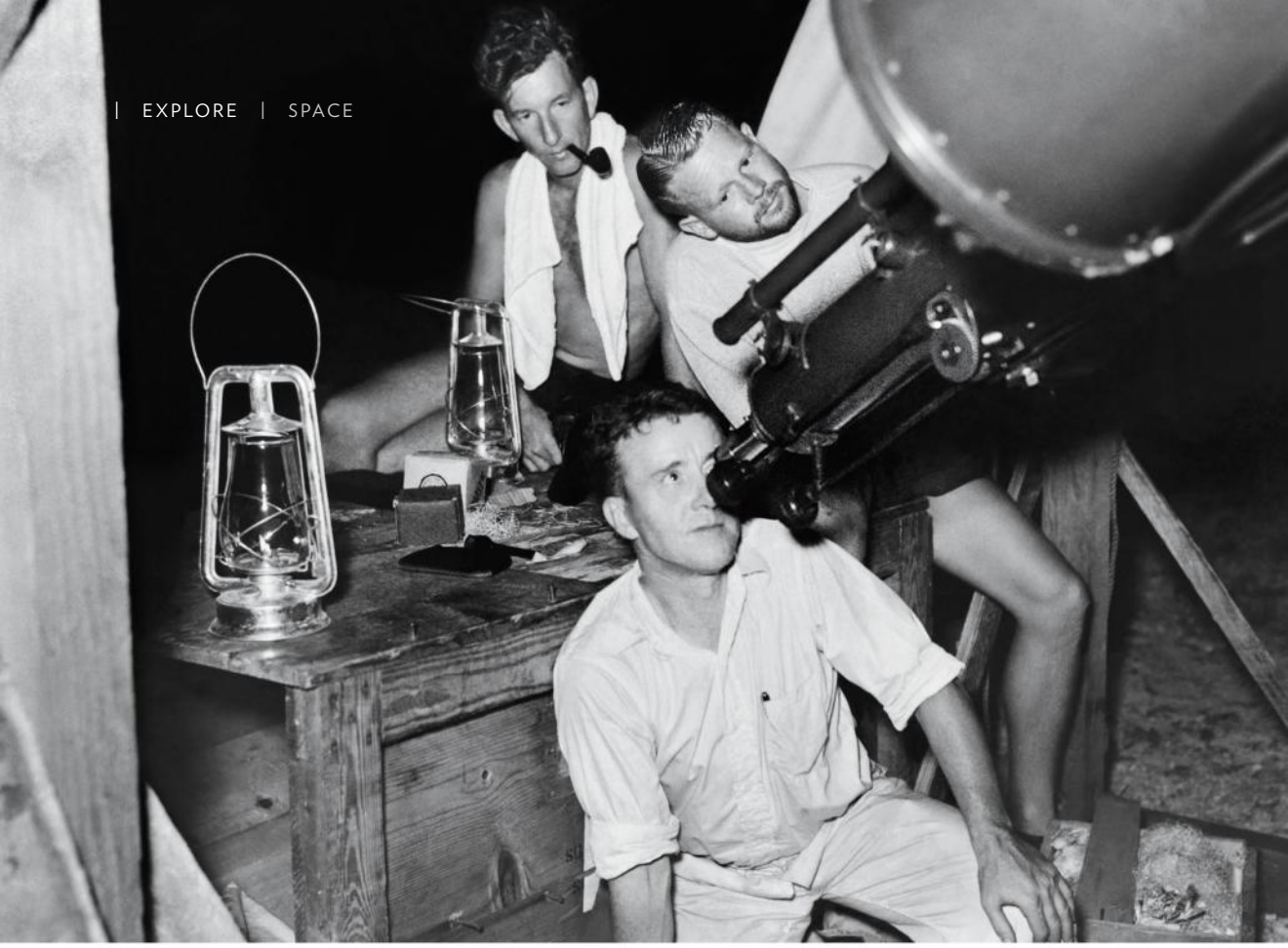
But be advised: Never look directly at the sun except during totality, in the umbra, without proper eye protection.

ALBERTO LUCAS LÓPEZ AND LAUREN E. JAMES, NGM STAFF
SOURCE: SCIENTIFIC VISUALIZATION STUDIO, NASA

ORONAL STREAMER
nized gases stream outward along magnetic nes of force in dramatic displays that change hape as the corona does.

ORONAL LOOP
n especially active areas of the sun, lasma forms glowing arcs that follow oping magnetic field lines.

ROMINENCE
inkish red arcs of plasma at the edge of the olar disk may look small, but they can be ozens of times larger than the Earth.



ECLIPSED BY WAR

By Nina Strochlic

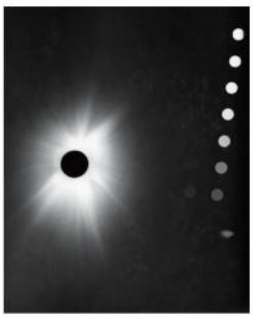
"The weather is absolutely perfect," announced an NBC broadcaster from an uninhabited Pacific atoll on June 8, 1937. Minutes later the moon blocked the sun—beginning what reports called the longest total eclipse in 1,238 years.

Isolated Canton Island was the best place to observe the eclipse's seven-minute arc across the sky, and a National Geographic–U.S. Navy expedition had hauled 22,000 pounds of equipment from Washington, D.C., to Honolulu and then 1,900 miles into the Pacific Ocean to be there. The 13-person team of scientists and photographers marked their mission's success with a large concrete monument embedded with two American flags. Nearby, a scientific expedition sponsored by Britain displayed the Union Jack.

The friendly rivalry soon became a diplomatic issue. Canton had no shade or permanent drinking water, but it was perfectly situated for refueling planes between Hawaii and Australia. In August, Britain sent two officials to set up a base and asked the United States to remove its marker. Instead, President Franklin Roosevelt claimed the island and dispatched three Hawaiian "colonists" to live there.

As World War II loomed, Japan viewed Britain's tolerance of the encroachment "as evidence of Anglo-American cooperation," according to media reports. Sure enough, the U.S. and U.K. did agree to control the island jointly and to prevent the Japanese from using it. The U.S. military built an airstrip and installed over a thousand men. Though the Japanese occasionally staged submarine and bomber attacks, Canton survived the war largely unscathed.

The U.S. finally left the island in 1976. Three years later Canton joined the Republic of Kiribati and was renamed Kanton. A few years ago only two dozen people remained. Soon the island might return to its uninhabited state.



To see the total eclipse of 1937, an American expedition set up camp on barren Canton Island. The team's presence, alongside a rival viewing party, provoked a tug-of-war for the Pacific island, which the *Christian Science Monitor* described as ideal "for somebody who doesn't care about shade or drinking water, and who likes solitude."

PHOTOS: RICHARD H. STEWART (TOP); F. K. RICHTMYER (ABOVE); NATIONAL GEOGRAPHIC CREATIVE (BOTH)

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NATIONAL GEOGRAPHIC

If you purchased RUST-OLEUM 2X spray paint Products, a class action Settlement may affect your rights.

A proposed class action Settlement has been reached concerning Rust-Oleum marketing practices regarding certain Products. The case, *White v. Rust-Oleum Corp.*, Case No. 16AC-CC00533, is pending in Cole County Circuit Court, Missouri.

What is this about?

The lawsuit claims that certain Rust-Oleum 2X spray paint Products were improperly labeled as providing twice the coverage of competing brands. As part of the Settlement, Defendant Rust-Oleum Corp. has agreed to stop this marketing practice and provide payments for customers. Rust-Oleum denies any wrongdoing.

Who is a Settlement Class Member?

You may be an eligible Settlement Class Member if you purchased (in the U.S., for personal use and not for resale) between December 12, 2011 and May 30, 2017, any Rust-Oleum 2X spray paint Products, including: Painter's Touch Ultra Cover 2X spray paint, Painter's Touch 2X Ultra Cover spray paint, PaintPlus Ultra Cover 2X spray paint, American Accents Ultra Cover 2X spray paint, and American Accents 2X Ultra Cover spray paint. A complete list of Products is found on the website below.

What are the Benefits?

Settlement Class Members without Proof of Purchase may elect a Benefit of $1.00 per Unit purchased, up to $3.00 per Household for Tier 1 Claims; or $1.50 per Unit, up to $6.00 per Household for Tier 2 Claims, if willing to provide additional information. Proof of Purchase is required to obtain a refund of more than $6.00 per Household. Payments may be less depending on a number of factors. There is also injunctive relief. Visit the website for details.

What are my rights?

You have the right to file a Claim, Opt-Out, Object, or do nothing. To receive a payment, you must submit a Claim online or by mail. Your Claim must be submitted online or postmarked by October 16, 2017. Or, you may Opt-Out. You will not receive a payment, but you will keep your right to pursue a separate lawsuit against the Defendant about these claims. Your request to Opt-Out must be postmarked by August 28, 2017. Finally, you may object to the Settlement. You must submit an Objection in writing. Complete information and instructions are available on the Settlement Website. Your Objection must be received by August 28, 2017. If you do nothing, you will receive no payment and have no right to sue later for the claims released by the Settlement.

The Court will hold a Fairness Hearing in the Circuit Court of Cole County, Missouri, 301 E High Street, Jefferson City, MO 65101, in the courtroom of the Honorable Jon E. Beetem, Division One, on September 12, 2017, at 9:00 a.m., to decide whether to approve the Settlement and to award attorneys' fees and expenses of $1,740,000, and up to $5,000 as a Class Representative Service Award to each of two Class Representatives. The Fee and Expense Award and the Class Representative Service Award are to be paid by the Defendant and do not reduce the recovery by the class in any way. All briefs and materials filed in support of the Settlement and the Fee and Expense Award will be made available on the Settlement Website. You may attend this hearing, but you do not have to.

Payment will be made to the Settlement Class only if the Court approves the Settlement and all appeals are resolved. Please be patient. If the Settlement does not become effective, the Action will continue. You still have the right to make a Claim or file an Objection now and Opt-Out from the Action later if the Settlement does not become effective.

For more information, please visit www.SprayPaintSettlement.com, or contact the Settlement Administrator at 1-855-486-7348 or by writing to Spray Paint Settlement, c/o Heffler Claims Group, P.O. Box 58788, Philadelphia, PA 19102-8788, or contact Class Counsel at Steelman, Gaunt & Horsefield, 901 Pine Street, Suite 110, Rolla, MO 65401.

1-855-486-7348
www.SprayPaintSettlement.com

MISSION INTO THE HEAT OF THE SUN

By Rachel Hartigan Shea

NASA has embarked on many successful missions—from rocketing astronauts to the moon to launching the first spacecraft to reach interstellar space. But it hasn't yet sent a mission to the sun. The deterrent? Our nearest star's searing heat.

The surface of the sun is 10,000°F, but its outer atmosphere—the corona—soars to some 3.5 million degrees Fahrenheit. "This temperature inversion is a big mystery that no one has been able to explain," says Nicola Fox, project scientist for the Parker Solar Probe, the NASA mission that aims to finally get close to the sun.

The mission is made possible now by a shield constructed from a carbon-carbon composite, which will keep the probe's instruments safe in the 70-degree range. Launching as early as July 31, 2018, the probe will make 24 orbits of the sun. It will get within four million miles of the star with the gravitational assist of seven Venus flybys. That's close enough to find answers to the sun's other big mystery: what creates the solar wind, the charged particles that accelerate from the sun and wreak havoc on Earth's electrical systems.

"We see the sun every day, but we don't know much about it," says Fox. "The sun is the last major place for us to go."

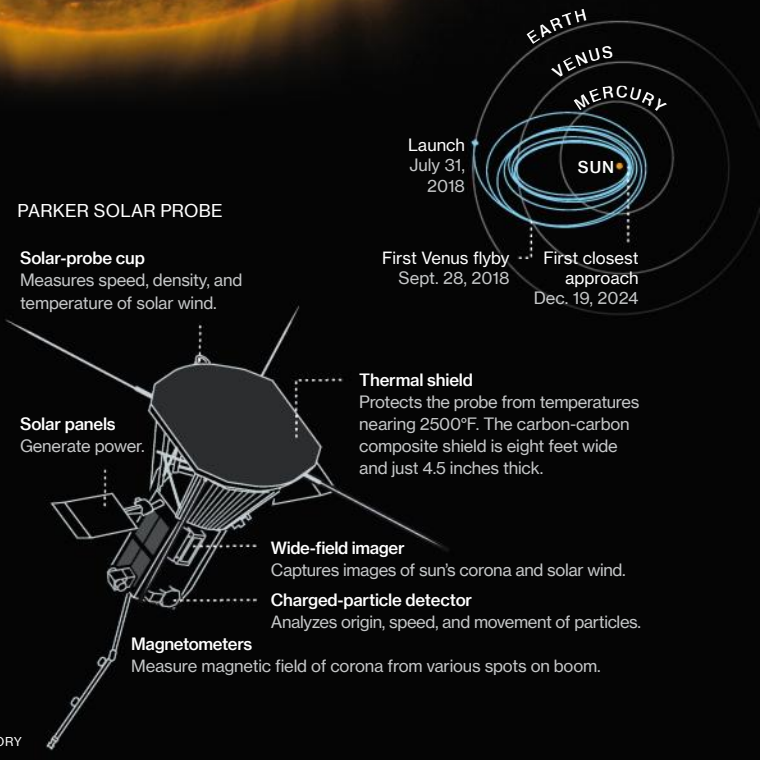
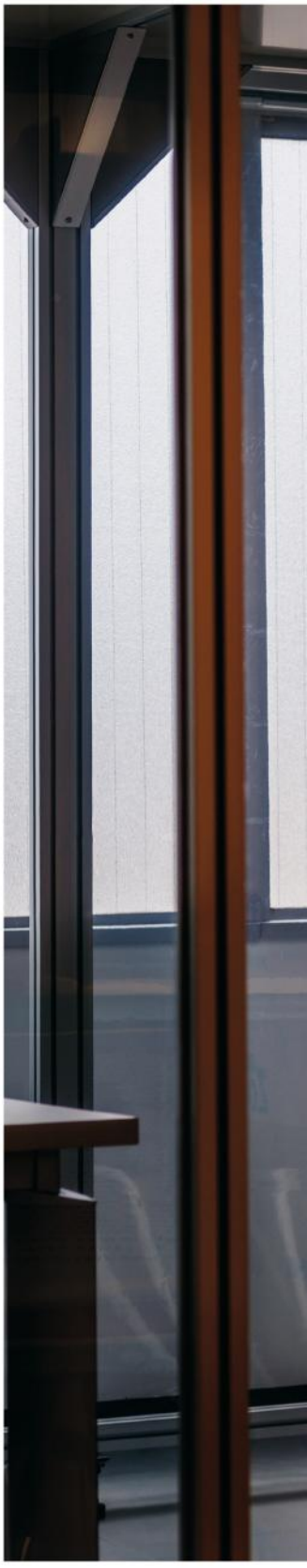


PHOTO: NASA/SDO. GRAPHIC: DAISY CHUNG, NGM STAFF
SOURCE: JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

Scientists, visionaries, evangelists, dreamers:



Team Hakuto, Japan Sorato, the rover built by the Japanese team competing for the Google Lunar XPrize, sits in a Tokyo clean room. A $20 million prize will go to the first privately funded group to land a craft that travels 500 meters on the moon and beams images and video back to Earth – a small step toward potentially giant economic rewards beckoning from the moon, and beyond.

LEFT: FROM *FULL MOON* BY MICHAEL LIGHT, 1999; ORIGINAL BY NASA; PHOTO BY MARK THIESSEN, NGM STAFF

Synergy Moon Technician Erik Reedy ponders rocket design at Interorbital Systems (IOS), backer of this international team. IOS's goal: to be the lowest cost launch provider in the private space industry.


Shoot for
the moon.

By Sam Howe Verhovek
Photographs by Vincent Fournier

Again.

The youthful Indian engineers took their seats, a bit nervously, in a makeshift conference room inside a cavernous former car-battery warehouse in Bangalore. Arrayed in front of them were several much older men and women, many of them gray-haired luminaries of India's robust space program. The first Asian space agency to send an orbiter to Mars, it also nearly tripled a previous world record by launching 104 satellites into orbit in a single mission this past February. The object of everyone's attention was a small rolling device barely the size of a microwave oven.

TeamIndus, India Weighing in at just under 17 pounds – but carrying the pride and hopes of a nation on its spindly frame – the Indian team's rover, code-named ECA, undergoes testing in Bangalore. A large helium balloon attached to it simulates the moon's gravity, which is one-sixth that of Earth.

The members of the young crew explained their plans to blast the device into space aboard a rocket late this year, position it into lunar orbit nearly a quarter million miles away, guide it to a landing on the moon, and send it roaming across the harsh lunar landscape. The engineers of TeamIndus said their company would do all of this on a shoestring budget, probably $65 million, give or take, the vast majority of it raised from private investors.

A prominent Mumbai investor, Ashish Kacholia, who has put more than a million dollars into the firm, sat at the back of the room, transfixed by the discussion. It somehow combined the intense, rapid-fire questions of a doctoral thesis defense with the freewheeling, everybody's-shouting, laughter-punctuated atmosphere of the Lok Sabha, India's boisterous lower house of parliament. Kacholia hardly needed to be here all day to check up on this particular investment of his—far from his largest—but he stayed just to hear the erudite dialogue on selenocentric (moon-centered) orbit projections, force modeling, apogee and perigee, and the basis for how "the kids" drew up the error covariance matrix.

"It's thrilling, really," Kacholia explained. "You've got these 25-, 28-year-olds up there defending their calculations, all their work, in front of a thousand years of the nation's collective aerospace experience and wisdom." His friend S. K. Jain, also a well-known Indian investor, nodded in vigorous agreement. "These kids are firing up the whole imagination of India," he commented. "They're saying to everyone, Nothing is impossible."

Nearly 50 years after the culmination of the first major race to the moon, in which the United States and the Soviet Union spent fantastic amounts of public money in a bid to land the first humans on the lunar surface, an intriguing new race to our nearest neighbor in space is unfolding—this one largely involving private capital and dramatically lower costs. The most immediate reward, the $20 million Google Lunar XPrize (or GLXP) will be awarded to one of five finalist teams from around the world. They're the first ever privately funded teams to attempt landing a traveling vehicle on the moon that can transmit high-quality imagery back to Earth.

The competition is modeled explicitly after the great innovation-spurring prize races of the early years of aviation, most notably the Orteig Prize, which Charles Lindbergh won in 1927 when he flew the *Spirit of St. Louis* nonstop from New York to Paris.

Like the quest for the Orteig Prize, the competition for the Lunar XPrize involves national prestige. Teams from Israel, Japan, and the U.S., plus one multinational group, are vying for the honor along with India; a cavalcade of other nations participated on the 16 teams that survived into the semifinal stage last year.

Almost as diverse as their countries of origin is the range of approaches and commercial partnerships involved in solving the three basic problems at hand—launching from Earth, landing on the moon, and then going mobile to gather and transmit data. To meet the last challenge, three teams plan to deploy variants of a traditional rover, while the other two intend to use their landing craft to make one giant leap for private enterprise: They will "hop" the required minimum of 500 meters on the moon rather than drive across the lunar surface.

As with many early aviation prizes, whichever team prevails almost surely will spend much more to win the prize than it gets back in prize money, though all the teams hope the global publicity and "brand enhancement" of victory will eventually make their investment pay off handsomely.

AT ITS CORE, this new sprint to space poses a question that would have been laughable in the Cold War era of the 1960s, when the U.S. was willing to spend more than 4 percent of its federal budget to beat its superpower foe to the moon: Can someone actually make money venturing out into the great beyond? To a demonstrably wide range of entrepreneurs, scientists, visionaries, evangelists, dreamers, eccentrics, and possible crackpots involved in the burgeoning space industry, the answer is an enthusiastic yes.

President John F. Kennedy famously urged America in 1962 to "choose to go to the moon

in this decade and do the other things, not because they are easy, but because they are hard." Today Bob Richards, founder and CEO of Moon Express, the American team, offers a different, if consciously cheeky, rationale. "We choose to go to the moon," he says, "because it is profitable!"

Whether Richards is correct about that, and if so, just when it might prove true, is wildly unclear. Setbacks are the norm in the space business, and realistically, many companies will make their early money mainly from government contracts, not private customers. Nonetheless, Richards predicts that the world's first trillionaire will be a space entrepreneur, perhaps one who mines the lunar soil for helium-3, a gas that's rare on Earth but plentiful on the moon and an excellent potential fuel source for nuclear fusion—a holy grail of energy technology that scientists have been trying to master for decades. Or a huge fortune may be minted from the asteroids and other near-Earth objects, where robotic technology could help mine vast amounts of gold, silver, platinum, titanium, and other prized elements bound up in them.

"There are $20 trillion checks up there, just waiting to be cashed!" says Peter Diamandis, a physician and engineer who is co-founder of Planetary Resources, a company backed by *Avatar* director James Cameron and several tech billionaires. Planetary Resources also acquired the company Asterank in 2013. Asterank's website offers scientific data and projects the economic value of mining more than 600,000 asteroids.

Diamandis is also founder and executive chairman of the XPrize Foundation, which has sponsored several other award competitions designed to push the boundaries of invention and technology in fields as diverse as artificial intelligence, mathematics, energy, and global health. The whole thrust of the Lunar XPrize competition, says Chanda Gonzales-Mowrer, a senior director at the foundation, is to help pave the way to "a new era of affordable access to the moon and beyond."

Just as the worldwide acclaim for Lindbergh's bravura feat sparked huge interest in civil aviation, the lunar competition is intended to fire

Think a Lunar XPrize ($20 million for first place and $5 million for second) would give a nice boost to your bank account? There are a few things you'll need to do:

Launch

before December 31, 2017

Land

a spacecraft on the moon's surface

Travel

500 meters on the moon

Talk

to Earth, using video and images

U.S. XPrize noncontenders dream big too. Astrobotic Technology is building lunar landers such as Griffin (above) in a Pittsburgh warehouse that once was a steel-stamping plant. The firm pledges to "make the moon accessible to the world," selling MoonMail space, starting at $460, on its charter journey.

Germany The Audi Lunar Quattro rover (right), built by PT Scientists, sits on soil heated to 250°F and under 1,000-watt lights that mimic lunar conditions. This rover isn't an XPrize contender, but it may deliver payloads of "personal, commercial, educational, scientific, or technological value" to the lunar surface.

Superpower Rivalry

Beginning in the 1950s, the Soviet Union and the U.S. deployed massive budgets to be first to the moon, then spent more to leapfrog each other in exploring its surface. Four decades after that race quieted, China made its first foray.

ROVING THE MOON

The first rovers and human-driven lunar roving vehicles (LRVs) to traverse the surface of the moon traveled significant distances collecting data.

U.S.S.R. 1970-73

Lunokhod rovers

The first successful robotic lunar rover, remotely controlled from Russia by a joystick, collected data on moon soil and topography.

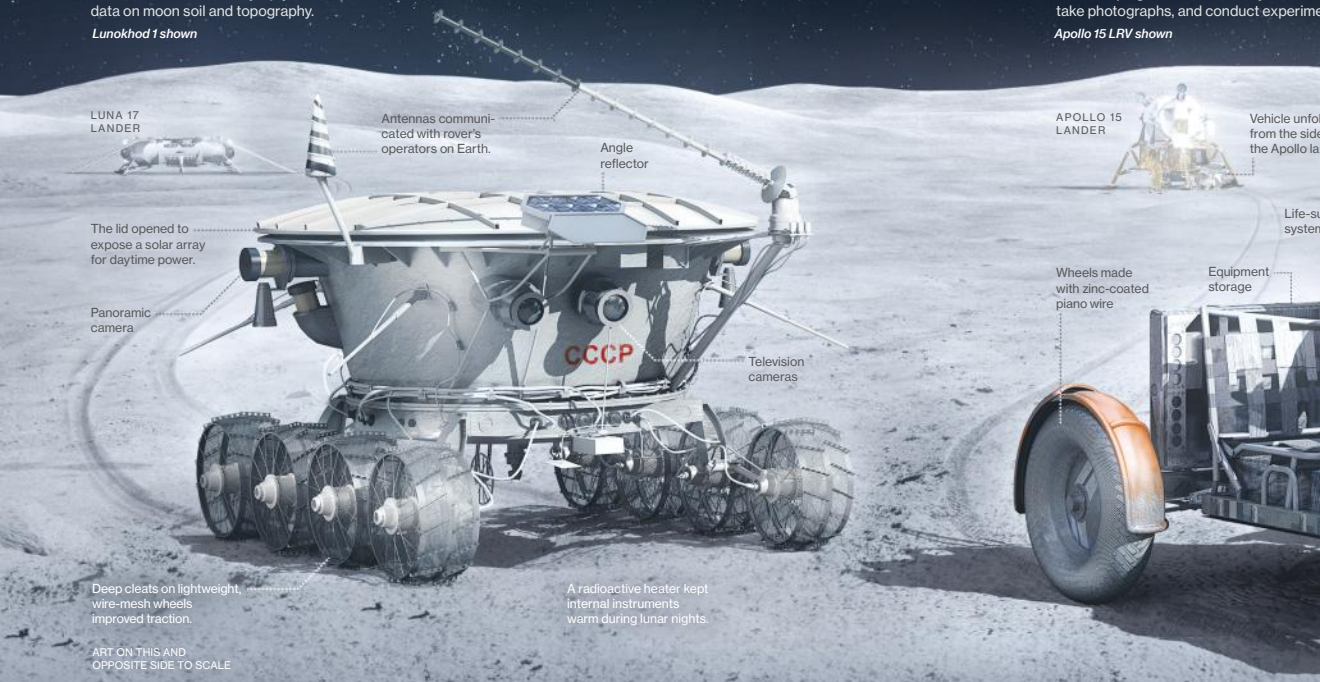
Lunokhod 1 shown

U.S. 1971-72

Apollo lunar roving veh

Three Apollo missions sent men to the m
LRVs, helping them travel widely to collec
take photographs, and conduct experime

Apollo 15 LRV shown



ART ON THIS AND OPPOSITE SIDE TO SCALE

TIGHT CONTEST

The battle for supremacy was a close one, with the governments of the U.S.S.R. and the U.S. alternating victories in the race to explore the moon.

1957

U.S.S.R.
Sputnik
First artificial satellite is launched into Earth's orbit.

1959

U.S.S.R.
Luna 1, 2, 3
First lunar flyby; crash landing; and probe

1961

U.S.
JFK speech
John F. Kennedy directs the U.S. to land "a man on the moon" by decade's end.

1966

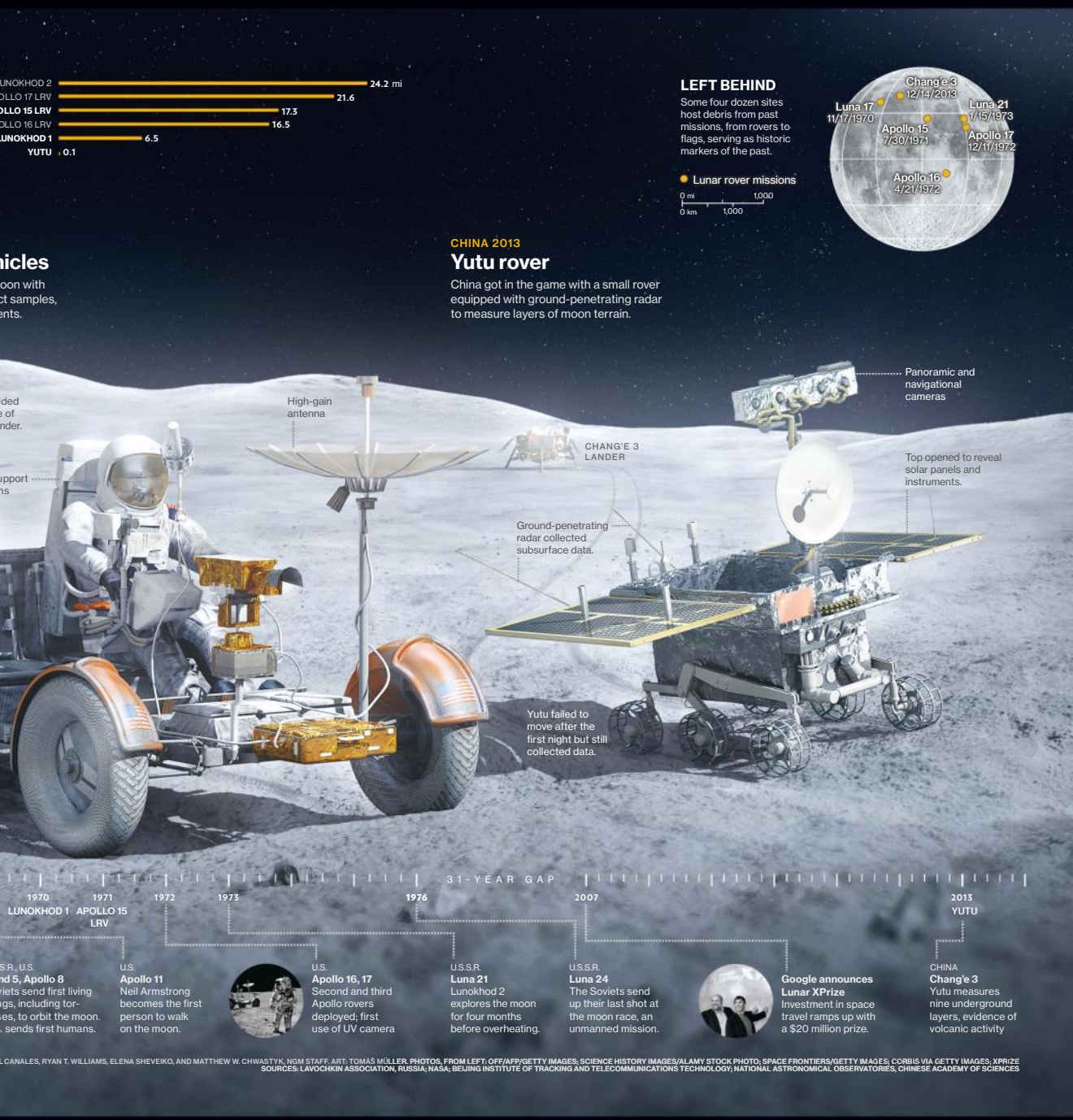
U.S.S.R.
Luna 9, 10
First soft lunar landing; first artificial satellite to orbit the moon

1968

1969

U.S.
Zo
Sov
thir
tois
U.S.

MANUE



L CANALES, RYAN T. WILLIAMS, ELENA SHEVEIKO, AND MATTHEW W. CHWASTYK, NGM STAFF. ART: TOMÁS MÜLLER. PHOTOS, FROM LEFT: OFF/AFP/GETTY IMAGES; SCIENCE HISTORY IMAGES/ALAMY STOCK PHOTO; SPACE FRONTIERS/GETTY IMAGES; CORBIS VIA GETTY IMAGES; XPRIZE
SOURCES: LAVOCHKIN ASSOCIATION, RUSSIA; NASA; BEIJING INSTITUTE OF TRACKING AND TELECOMMUNICATIONS TECHNOLOGY; NATIONAL ASTRONOMICAL OBSERVATORIES, CHINESE ACADEMY OF SCIENCES

Privatizing the Race

Propelled in part by Google's Lunar XPrize, today's moon race involves private groups from multiple countries. To win, a team must land a spacecraft, have it travel 500 meters, and send back high-res images and video.

RISE OF THE SPACE ENTREPRENEURS

The number of commercial space companies is soaring. The space industry as a whole generated more than $250 billion in revenue in 2016.

The Finalists

After a dangerous descent and tricky landing, the teams that have made all deadlines and remain in the race plan to either "hop" or rove the required distance. In the future the race will be for the moon's resources.

CAMERA NUMBER · APPROX. WEIGHT · BUDGET ESTIMATE

The Indian lander will also deliver Hakuto's rover.

Airbags will protect Synergy Moon's lander as it hits the surface.

Moon Express / MX-1E

This U.S. team is aiming not just to reach the moon but also to eventually mine it for resources such as helium-3 and precious metals.

12 · 496 LBS · $10 MIL

Team / *Craft*

TeamIndus / ECA

The largest rover hails from engineers in India's "Silicon Valley" and was tested in rock quarry dust. The team also is under contract to land the Japanese rover.

3 · 16.5 LBS · $65 MIL

Hakuto / SORATO

The Japanese rover has a 3-D sensor to detect obstacles. In future missions the team hopes to search for lava tubes that could become the first moon colonies.

4 · 8.8 LBS · $10 MIL

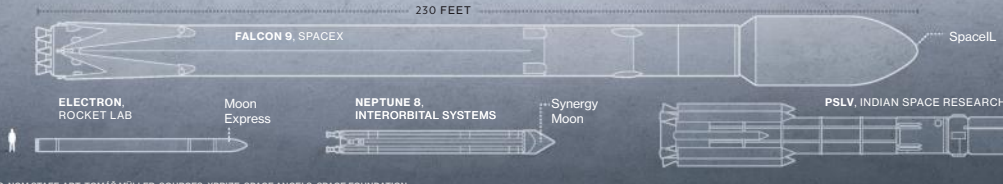
Synergy Moon / TESLA

This international team formed by previous competitors includes artists. Its rover is the smallest, based on a commercially available military surveillance bot.

1 · 1.5 LBS · $15 MIL

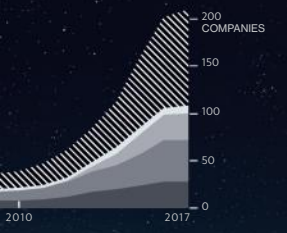
REACHING THE MOON

It can cost tens of millions to launch a rocket out of Earth's atmosphere at 18,000 miles an hour. Teams are contracting with companies for rockets they hope can take them the distance.



INFORMATION ACCURATE AS OF MAY 2017 AND SUBJECT TO CHANGE

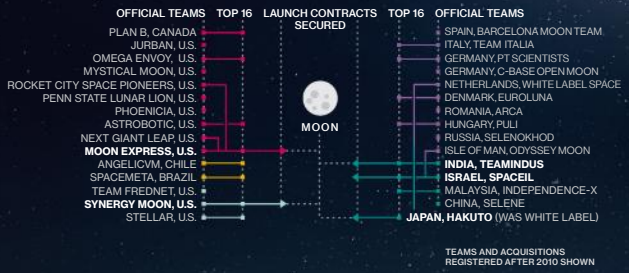
MANUEL CANALES, RYAN T. WILLIAMS, AND DAISY CHUNG, NGM STAFF. ART: TOMÁŠ MÜLLER. SOURCES: XPRIZE; SPACE ANGELS; SPACE FOUNDATION

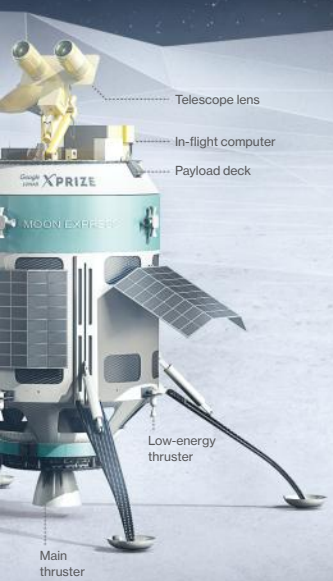


COMPETING FOR THE FUTURE

More than two dozen teams signed up to compete for the XPrize after it was announced in 2007. As of print date, five remain.

- NORTH AMERICA
- SOUTH AMERICA
- EUROPE
- ASIA
- INTERNATIONAL

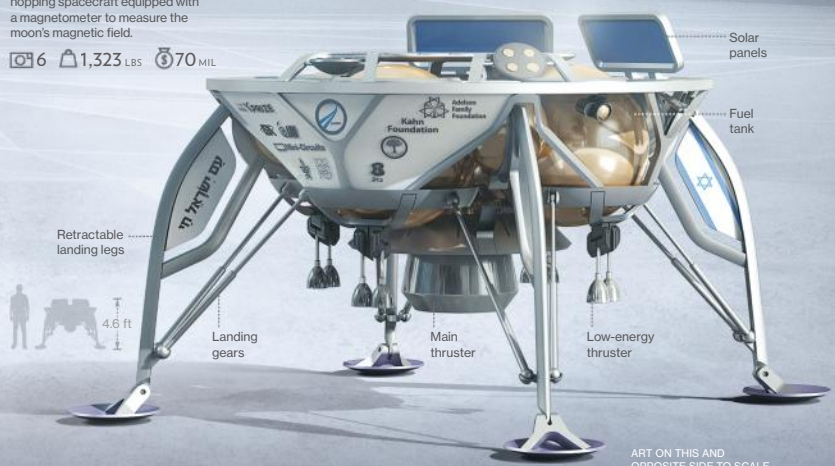




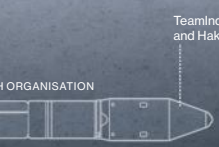
SpaceIL / SPACEIL

The nonprofit Israeli team has a hopping spacecraft equipped with a magnetometer to measure the moon's magnetic field.

6 | 1,323 LBS | 70 MIL

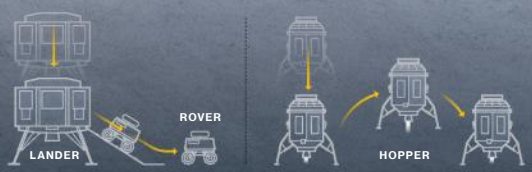


ART ON THIS AND OPPOSITE SIDE TO SCALE



ROVERS VS. HOPPERS

Three of the teams are modernizing existing rover technology to traverse the moon's surface after landing. Two aim to use landers that will hop across the landscape with the help of thrusters.



public imagination about private space pioneers, who already are ferrying cargo to the International Space Station and deploying satellites, orbital rocketry, and test modules. Soon the crafts may be carrying passengers: Virgin Galactic, which billionaire founder Richard Branson calls "the world's first commercial spaceline," says it's gearing up to take passengers on brief space tours in which they will experience weightlessness and awe-inspiring views of Earth. SpaceX founder Elon Musk announced in February that his company would fly two as yet unnamed private citizens around the moon in late 2018 aboard its *Dragon* spacecraft. Two months later Amazon founder Jeff Bezos said he'd be selling a billion dollars in stock a year to fund Blue Origin, his own commercial and space tourism enterprise.

THERE ARE PLENTY OF REASONS to be skeptical about how soon these firms will actually be carrying private customers to space; after all, a 2014 crash of Virgin Galactic's prototype passenger spacecraft set that company's effort back by several years. And while the Lunar XPrize competition appears to be coming to a head, there are plenty of obstacles to contend with: the possibility of a missed deadline, failure of prelaunch rocket tests, to name just two. Plus, the impact of the race on the public imagination could well prove limited. For one thing it simply lacks the human drama and suspense of the 1969 moon landing and safe return of men to Earth, a feat that began an era of human exploration on the lunar surface that wound up lasting a mere three years. Unmanned lunar rovers have been around for decades now: When China landed Yutu in 2013, it became the third nation to put a rover on the moon.

So, really, then: What's the big deal?

"What's new is that the cost of getting to space is dropping, and it is doing so dramatically," explains John Thornton, the chief executive at Astrobotic, a Pittsburgh-based firm whose aim is to "make the moon accessible to the world" with logistical services that involve carrying everything from experiments for universities to MoonMail for customers who just want to leave a tiny something on the lunar surface—a note, a photo, a lock of hair from a deceased loved one.

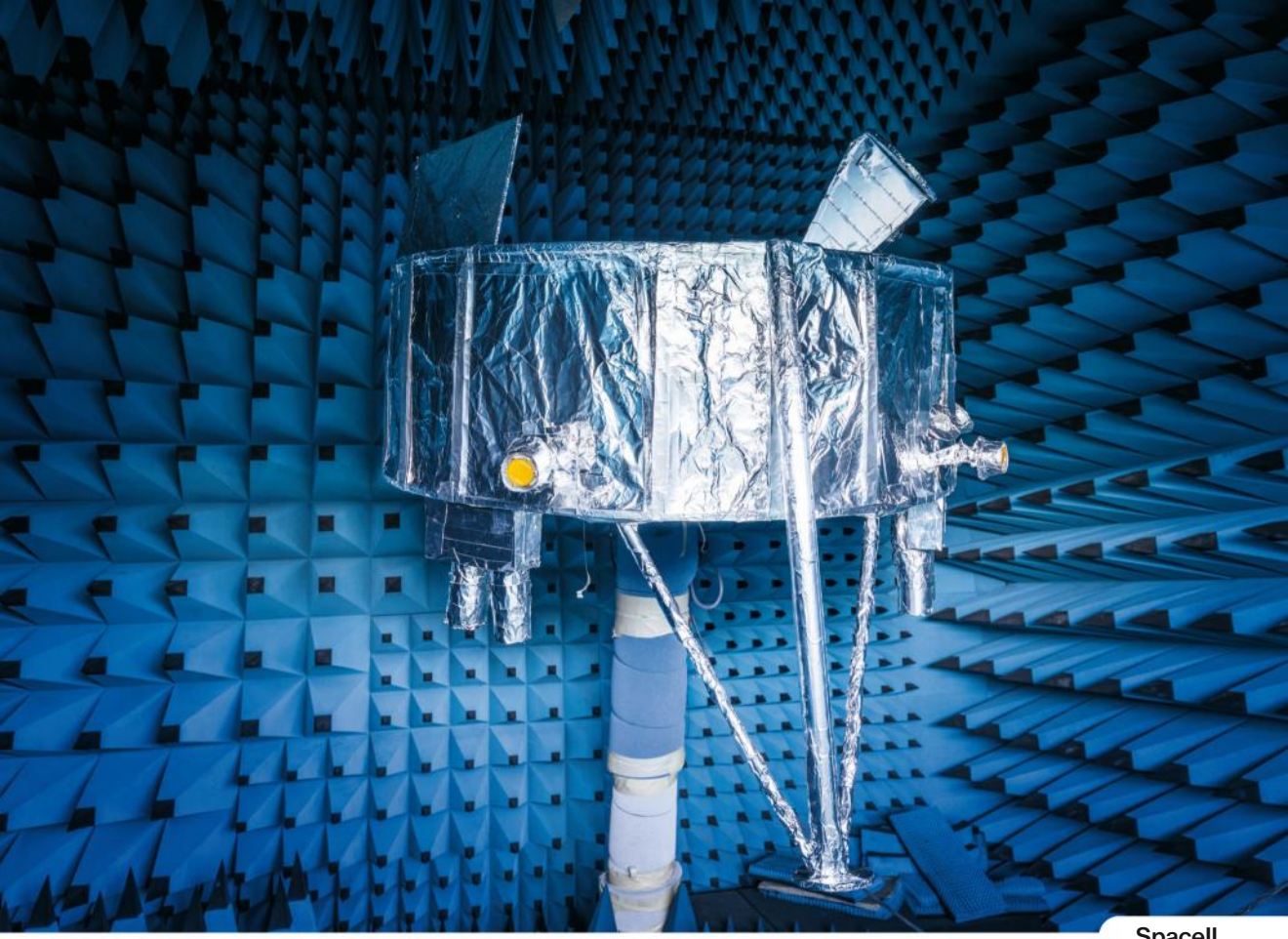
"A company like ours can do the math and show investors that we really do have a feasible plan to make money," Thornton says. "Not many years ago, that would have been science fiction."

If the race to put a man on the moon was the equivalent of building one of those giant, room-size, prodigiously expensive mainframe computers in the early days of high technology, today's race is analogous to a different era of computing: the race to put an affordable computer on everyone's desktop or, a few years later, in everyone's telephone. Today computers are so tiny—and the batteries that power them so compact—that we can reach the moon with increasingly smaller and decreasingly expensive devices. Rather than golf cart–size rovers on the moon, the next generation of machines exploring, mapping, and even mining the lunar landscape may well be the size of a child's Tonka truck. More than anything else, that's the driving factor behind today's space economy.

"Think micro-rovers and miniature CubeSats," says William L. "Red" Whittaker, legendary roboticist at Carnegie Mellon University and a pioneer in both rover and self-driving automobile technology. "It's astonishing what's going on. Small is the next big thing. Very small."

The physics of human spaceflight remain more complex—we are growing neither smaller nor more compact, so it still takes plenty of fuel to get us up there—but these advances could

SpaceIL, Israel **A partial model of the lander SpaceIL rests in an anechoic, or echo-free, chamber (top) that absorbs electromagnetic waves, enabling engineers to test how its antennas will transmit and receive data while on the moon. Elsewhere at SpaceIL's facility near Tel Aviv, a thermal vacuum chamber creates the same intense heat the lander would encounter during the moon's daytime, which is equivalent to the continuous sunlight of 14 Earth days.**



SpaceIL

SpaceIL, Israel Wearing her official space suit costume at team headquarters in Tel Aviv, Yuval Klinger, 7, is enthusiastically tracking the Israeli organization's progress — and contemplating whether spacefaring may be a part of her future career plans. She is far from alone in her interest. "We wanted all kids in Israel to be heads-up about this," says SpaceIL's leader, Eran Privman. "We want these kids to be able to explain to their parents what's going on."

Moon Express

herald a smaller, nimbler, cheaper way to get people back on the moon and far beyond.

In fact, some in the space industry say the moon may one day be less the object of our journey than a sort of giant Atlanta airport that we'll have to go through on our way to somewhere else, where both the engineering and the economics of blasting off from a place with only one-sixth the gravity of Earth will make a lunar hub the ideal way station in exploring the universe.

Water, now locked in the form of ice at the lunar poles, would be both lifeblood and fuel source: water to drink, water to irrigate crops, and water to be split into oxygen and hydrogen, the former for us to breathe and the latter to power our spacecraft beyond this lunar base. Again, whether that will prove true, and if so, when, is unknowable. But what is known now is that the first destination of the emerging space industry is obvious: the moon.

TO WITNESS A TEST MISSION of Team Hakuto—Japan's entry in the Lunar XPrize competition—I traveled last September to a remote, windswept region of western Japan known as the Tottori Sand Dunes. For days, ferocious and very un-moonlike rain whipping off the Sea of Japan pelted the coast, drowning out proper conditions for testing a lunar rover. In a nearby youth hostel, team leader Takeshi Hakamada and his colleagues were getting restless. Dressed in spiffy gray jackets with a rabbit logo (Hakuto is a mythological white rabbit in Japanese folktales) and tossing back energy drinks, they kept fine-tuning software that carefully mimicked the communications delay of 2.5 seconds between Earth and the moon, nearly a quarter million miles away.

Then abruptly one evening the skies cleared and stars emerged. Amid a crackle of walkie-talkies, Hakamada's team carted an impressive array of laptops, tablets, and sensors through a wooded clearing and out onto the dunes. Then came—literally with white-glove treatment—a pair of roving robots designed to work mostly in tandem when they're on the moon, but partly independently, which is where Hakamada's profit-making idea comes in.

Team Hakuto's entry features a four-wheel rover—dubbed Sorato by the crew, after a song by a Japanese alternative rock band—which in future missions beyond XPrize will be tethered to a separate, two-wheel tilting robot. Both units are made largely of very lightweight, strong, carbon fiber components. Hakamada, a thin, thoughtful man with a mop of unruly hair, who has been a space geek since he saw his first *Star Wars* movie as an elementary school student, said the smaller robot can be lowered deep into fissures, lava tubes, and caves. It will gather vital data on such spots, which could serve an essential function one day as temporary habitats for future lunar bases, shielding arriving humans for a period of time while more permanent digs are constructed.

The Tokyo-based company Hakamada runs, iSpace, plans to leverage Japanese advances in technology miniaturization to probe, photograph, map, and model the moon in much higher detail than can be seen in the photos and soil-testing results from earlier lunar rover missions.

"We are not in this just to win a prize, although that would be nice," Hakamada told me shortly before the test run. "We are in this to demonstrate to the world that we have a viable technology that can produce important information that people will be willing to pay for."

With wheels that each look a bit like an old-fashioned waterwheel, the main rover reached a "drop point" on the dunes, a stand-in for the harsh lunar surface. It's hitching a late December launch with the Indian Space Research

Moon Express, U.S. **Cape Canaveral is home base for the team building the MX-1E lander. A pocket-size model of the craft takes center stage on a conference table (top) during a lunch-and-learn session. Outside, team members take a break from the ongoing battery of tests to position their prototype (bottom) for a photo session. Says Moon Express CEO Bob Richards: "What's trending now is our shift to a spacefaring species, perhaps as significant as the transition of amphibians from the oceans to the land."**

Organisation, the government agency whose rocket will be carrying TeamIndus's lunar rover as well. (To win the XPrize, a team must be launched by December 31, 2017, but can complete its mission in early 2018.)

It was quiet out on the Tottori Dunes as the clock neared midnight, the roar of the sea muffled by the bluffs. Hakuto's tiny rover looked a bit forlorn out on the sandy simulacrum (a simulation of the lunar surface). Hakamada and his crew coordinated a series of computer-entered commands through the lunar time lag, and suddenly the rover clicked to life, cutting cleanly through the sand, traveling just a few inches per second. It correctly sensed and navigated around several hazards placed in its path. This ability will be critical on the moon, where a large enough rock or ditch could scuttle a whole mission.

"The rover did great," Hakamada said later, beaming like a proud new father. In fact, he explained, his confidence in its performance was no longer his biggest challenge. "We believe that the biggest problem for space innovation now is really not technology itself but the entrepreneurship involved. To open new markets in space, you have to convince people this is for real—and thus defy all those old stereotypes about how only big government agencies can undertake this sort of exploration.

"That's what's great about this race," he added. "Whoever wins will show it can be done."

A FEW STEPS from the Atlantic Ocean, on a giant patch of Florida scrubland visited by alligators, sea turtles, and the occasional bobcat, Cape Canaveral's Space Launch Complex (SLC) 17 appears at first glance to be a relic. From 1957 to 2011, the site was used for both Thor and Delta rocket launches, the former for the country's first ballistic missiles, the latter for satellites and solar system probes and for closer observation of the sun itself.

On a pleasant March evening this year, the only sound at SLC-17 was a slight breeze from the sea whistling through the rusting towers of the complex. But behind a locked door in a former maintenance shed, the prototype vehicle belonging to the first U.S. company to receive government approval for a space mission beyond Earth orbit was ready to hit the beach—on its way, ultimately, to the moon.

To Bob Richards, once an assistant to famed astrophysicist Carl Sagan and now head of Moon Express, the beauty of the company's MX-1E lander design is its dual-purpose utility. "There's no need for a rover at all if your landing craft can provide the same function," Richards told me. In fact, he added, the Google Lunar XPrize is too often misconstrued as a rover competition.

"The greatest challenge of the GLXP is to land on the moon," he said. "Rovers can't land on the moon themselves, and in fact the term 'rover' doesn't appear in competition rules at all, just a requirement to accomplish mobility of at least 500 meters."

Thus was born the idea of hopping to victory by bouncing along with the help of thrusters. After an initial rocket launch to low-Earth orbit, the MX-1E—a single-stage robotic spacecraft that is shaped and sized more than a bit like R2-D2 of *Star Wars* fame—will blast away using a super-high-test hydrogen peroxide as its main propellant to travel at bullet speed on course for its lunar goal. After establishing lunar orbit, Moon Express's vehicle will eventually achieve what engineers euphemistically call a "soft landing": Aided by reverse thrust, the vertical descent will nonetheless be violent enough to require cushioning by a flexible landing-leg system capable of absorbing the blow and springing back with

Team Hakuto, Japan **Kyoko Yonezawa reflects on the team's progress as the launch deadline draws ever nearer. The plan is for Sorato, the Japanese rover, to hitch a ride to the moon aboard TeamIndus's rocket and lander – and wait for the rovers to fight to the finish on the lunar surface. National pride and the optimism of youth have made the quest for the XPrize a huge story in Japan. Team leader Takeshi Hakamada says: "We're not in this just to win, although that would be nice."**


GOOGLE LUNAR XPRIZE
OFFICIAL TEAM

Team Hakuto, Japan Members of the Japanese media assemble on the remote Tottori Sand Dunes to see Sorato undergo field tests. They look on as Hakamada carries the rover to a sandy test bed that simulates the moon's surface. "We want to demonstrate to the world that we have a viable technology," he says.

enough life to take on the next stage of the mission. With a small amount of fuel remaining, the MX-1E will take off on a big hop—or, perhaps, a series of smaller hops—to travel the required distance to win the XPrize.

With his TED Talk–worthy profundities and an industry reputation (not always a positive one) for the gift of gab, Richards makes it all sound so brilliantly achievable that you're tempted to invest. But there are arguments for holding on to your wallet—for one thing, Moon Express is currently slated for launch not with a proven carrier such as SpaceX, with its Falcon rocket lines, but instead with Rocket Lab, a U.S.-based company whose launch site at the Mahia Peninsula on the North Island of New Zealand opened this past September.

Testing is just beginning this year, meaning that the firm will be on a very aggressive timetable to achieve the XPrize's stipulation of an actual launch by the end of the year. Previous milestone deadlines have been extended, but XPrize says it is committed to wrapping up the competition soon. Thus it could conceivably end with no winner, though a foundation official insists it "really, really wants someone to win."

The other team aiming to hop the distance needed to win is based in a small complex of industrial buildings on the outskirts of Tel Aviv. Its leader is hardly less evangelistic than Richards.

"Our vision is to re-create an 'Apollo effect' here in Israel, to really inspire a rising generation of kids to excel in science and technology," said Eran Privman, a national hero and the CEO of SpaceIL, whose eclectic résumé includes combat experience as a pilot in the Israeli Air Force; a doctorate in computer science and neuroscience from Tel Aviv University; and a range of research, development, and executive posts for several major technology companies in Israel. He was referring to the impact the Apollo space programs had on youth in the 1960s and '70s, when the enterprise's successful missions inspired many of the founders of today's leading high-tech companies.

ROUGHLY THE SIZE of a small refrigerator but more circular in shape—a bit like a flying saucer—SpaceIL's lander is expected to weigh 1,323 pounds when it detaches from a SpaceX Falcon 9 rocket, though about two-thirds of that weight will be fuel used up by the time it is ready to land. With some residual spring action in its legs similar to the MX-1E's, it will use the little fuel left to hop the nearly one-third of a mile set by the XPrize rules.

The Israeli effort began in late 2010 as "three crazy guys with not a lot of money but with the thought that it would be really cool to land a robot on the moon." That's how co-founder Yariv Bash described the beginning to me during a visit to the testing lab for the lander's main computer. They struggled down to the wire to meet an initial competition deadline requiring them to show plans for a landing strategy and at least $50,000 in assets.

"We asked anybody we could for money," Bash recalled. "It got to where I was asking my wife for money in my sleep." While short on capital, the group was not short on know-how: Bash is an electronics and computer engineer who once headed R and D efforts for Israeli intelligence forces. ("You know Q in the James Bond movies?" Bash asked me with a wink. "It was a bit like that.")

Their initial designs were far smaller—one as small as a two-liter soda bottle—than the lander they are assembling with parts from around the world this summer. And rather than a for-profit enterprise, SpaceIL has wound up as the only nonprofit in the remaining field of XPrize competitors, with generous funding from two

TeamIndus, India **A concept mocked up in foam for a video (top) echoes a prototype of the rover ECA, now ready for testing in a Bangalore lab (bottom). Engineers discuss the challenges of translunar injection, the propulsive minuet that must be exquisitely choreographed in order to achieve a successful landing. "If she goes too fast, she'll slam into the moon," explains one. "Too slow, and this turns into a slingshot Mars mission" – another way of saying ECA would be forever lost in space.**

TeamIndus

TeamIndus, India With ECA at rest, engineer Lakshman Murthy takes a break. The hundred-plus members of the team hope for dividends far greater than prize money. “There are superbright kids out there in the cities and in the remote parts of the nation,” says Sheelika Ravishankar (nicknamed “Jedi Master” by the team). “We need them to know anything is possible. We need to reach them.”


TEAM
INDUS

Wait. There's more.

Lunar XPrize finalists that land can compete for a pot of up to $4 million more for additional heroics on the moon.

Visit and transmit from a historic lunar site:

$1-4 million

Travel five kilometers:

$2 million

Survive and transmit on two lunar days:

$2 million

Provide proof of the presence of water:

$4 million

well-known billionaires, technology entrepreneur Morris Kahn and casino magnate Sheldon Adelson. Its mission now is essentially twofold—to win the prize, of course, but also to educate and inspire a new generation of potential tech leaders in a country often referred to as Start-up Nation.

As in India, national pride is clearly on the line here. Virtually every school in Israel now has a teaching unit about the SpaceIL effort, and schoolkids will be closely following the mission once it blasts off for the moon, hoping theirs will become the first country ever to send a privately funded mission to explore the lunar surface.

"We wanted all kids in Israel to be heads-up about this," said Privman, adding with a laugh: "We want these kids to be able to explain to their parents what's going on."

Enough with the hopping already. Hakuto, TeamIndus, and a California-based international consortium known as Synergy Moon all plan to use a separate, wheeled rover to gather data, which points up an arguable loophole in the rules: Hakuto could win by subcontracting out both launch and landing, only needing to deploy its Sorato rover to achieve victory. Gonzales-Mowrer, the XPrize race director, says that would be just fine: "We wanted teams to come up with various approaches to accomplishing the mission," she explains. From a financing point of view, the main threshold is simply that competitors must show XPrize judges that at least 90 percent of their money comes from nongovernment sources.

"It's been fun to watch the teams network with each other and with outside providers to drive down the cost," she said. "In that sense, the ultimate goal of this competition has already been achieved."

IF THERE IS TO BE a giant Walmart—or perhaps an Ikea—for spacefaring ventures someday, then Interorbital Systems, the primary company behind the Synergy Moon consortium, is determined to fill that role. It aims to be "the lowest cost launch provider in the commercial space industry," says its co-founder and CEO, Randa Relich Milliron. To do this, she explains, it will build rockets in modular, standardized units;

use off-the-shelf components wherever possible, including industrial irrigation tubes and microcontrollers; and experiment with lower cost fuels such as turpentine as propellants.

In her office at the Mojave Air & Space Port in the California desert, a hundred miles or so north of downtown Los Angeles, Milliron pointed with pride to the company brochure, which offers a do-it-yourself TubeSat Personal Satellite Kit for around $16,000, a price that "Includes Free Launch!" and could drop to $8,000 for high school or college students. Customers will assemble the tube (there is also a more expensive CubeSat available) and outfit it with whatever small additional gear they can fit, such as a camera for tracking migratory animals from orbit or sensors that can monitor weather conditions. The company plans to launch the personal satellites into orbit 192 miles above the Earth, a sufficient height to allow them to operate from three weeks to two months, depending on solar activity, after which the devices will burn up safely after reentering the atmosphere.

Milliron and her husband, Roderick, have been working on and off for more than 20 years to get the company—and its rockets—off the ground. It's safe to say that several remaining and former competitors in the GLXP race admire their pluck but doubt their chances. Even if they reach the moon with one of their DIY rockets, their plan to use a customized "throwbot" as their roving device on the moon has also raised eyebrows. (Throwbots, throwable robots, are frequently used by the military, police, and firefighters to provide video "eyes" in a location too dangerous to enter, such as a terrorist hideout, a suspected meth lab, or a burning building.)

Even so, the couple and a small crew of employees press on in their warehouse set amid the large, military-issue sheds and Quonset huts that make up the spaceport side of the dusty desert complex—the other side of the runway is a giant "boneyard," where commercial airliners such as old Boeing 747s and DC-10s have come to die, parked for good and waiting to be cut up for scrap.

The Millirons say their initial launches will be from a barge at an ocean site off the California coast. With a humble budget they decline to quantify publicly, but with grand dreams they describe expansively, it is hard to know exactly what to make of them or of the Synergy Moon entry in the space race, which their firm essentially anchors. The team does have a verified launch contract, although it appears to be essentially with itself, since it's the only entrant in the race planning to do all the things needed to win—launching, landing, roving, and transmitting—on its own.

"Sometimes we feel like renegades or outcasts, building these rockets by ourselves," said Randa Milliron on a tour of Interorbital's workshop. "But that's the whole point, really. We are disrupters. We are out to show the world this can all be done at truly radically lower costs."

From this Mojave Desert outpost to the Atlantic shore at Cape Canaveral, from the outskirts of Tel Aviv to the Japanese sand dunes and a Bangalore warehouse, all five teams are forging ahead on their respective missions. Each is driven to win—but each is also surprisingly friendly with its competitors. Over the past several years, even as the number of teams officially dwindled from 29 to 16 and down to the five remaining at time of writing, one of them has hosted an annual summit meeting for everyone else, as well as XPrize Foundation officials, with each leader offering a frank presentation on successes and setbacks to date. Alliances have formed, such as an agreement between TeamIndus and Hakuto to share a ride on the Indian space agency's rocket and the Indus lander, essentially duking it out once they reach the moon. An industry is being born.

"There's really a 'Yes We Can' theme going on here," says Rahul Narayan, the charismatic leader of the 112 members working for TeamIndus. "This is the time. How it will all evolve, exactly, I don't know. I'm not sure anyone knows. But this is the time." □

Journalist **Sam Howe Verhovek** is based in Seattle and is the author of *Jet Age: The Comet, the 707, and the Race to Shrink the World.* **Vincent Fournier** is a French artist and photographer living in Paris. In this issue, they both make their first appearance in *National Geographic* magazine.

A Moon Museum

As a private lunar industry nears liftoff, preservationists seek to protect the landing sites that are the legacy of the first space race.

AT THE ABANDONED CAMPSITE, occupied for less than a day, the visitors left much behind: sophisticated instruments and part of the ship that carried them on this first-of-its-kind voyage, but simpler things as well—scoops and scales, canisters and brackets, two pairs of boots. The expendable trash of a successful mission, too heavy to carry home, lies exactly where it was tossed.

On the Earth-facing side of the moon 48 years later, undisturbed by wind or water, development or war, Tranquility Base is still tranquil.

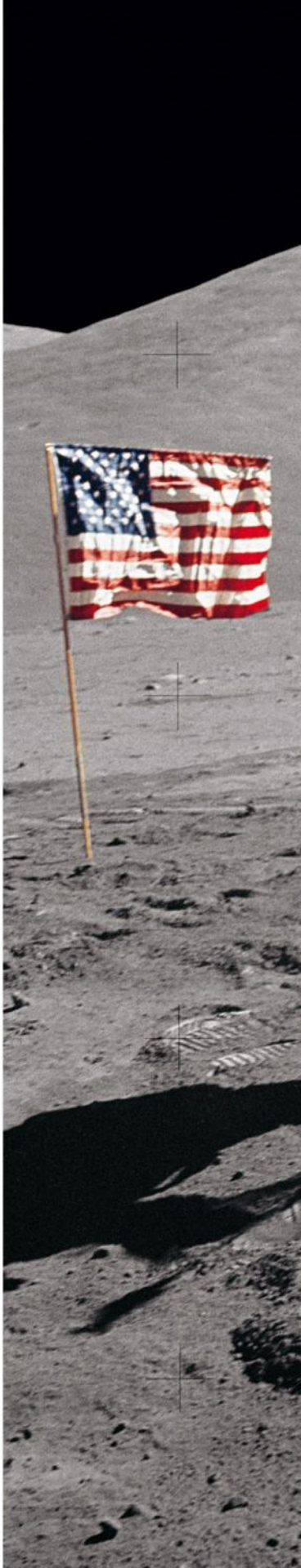
"It's like an archaeologist's dream," says Beth O'Leary, of New Mexico State University, one of several preservationists who consider this pristine time capsule as deserving of protection as any archaeological site on Earth.

The Google Lunar XPrize has offered a four-million-dollar bonus for close-up footage of an Apollo landing site. While the organizers and teams have pledged caution, O'Leary and others also worry about those who will follow—landing, rolling, or hopping their robots dangerously close to objects of immeasurable value to posterity.

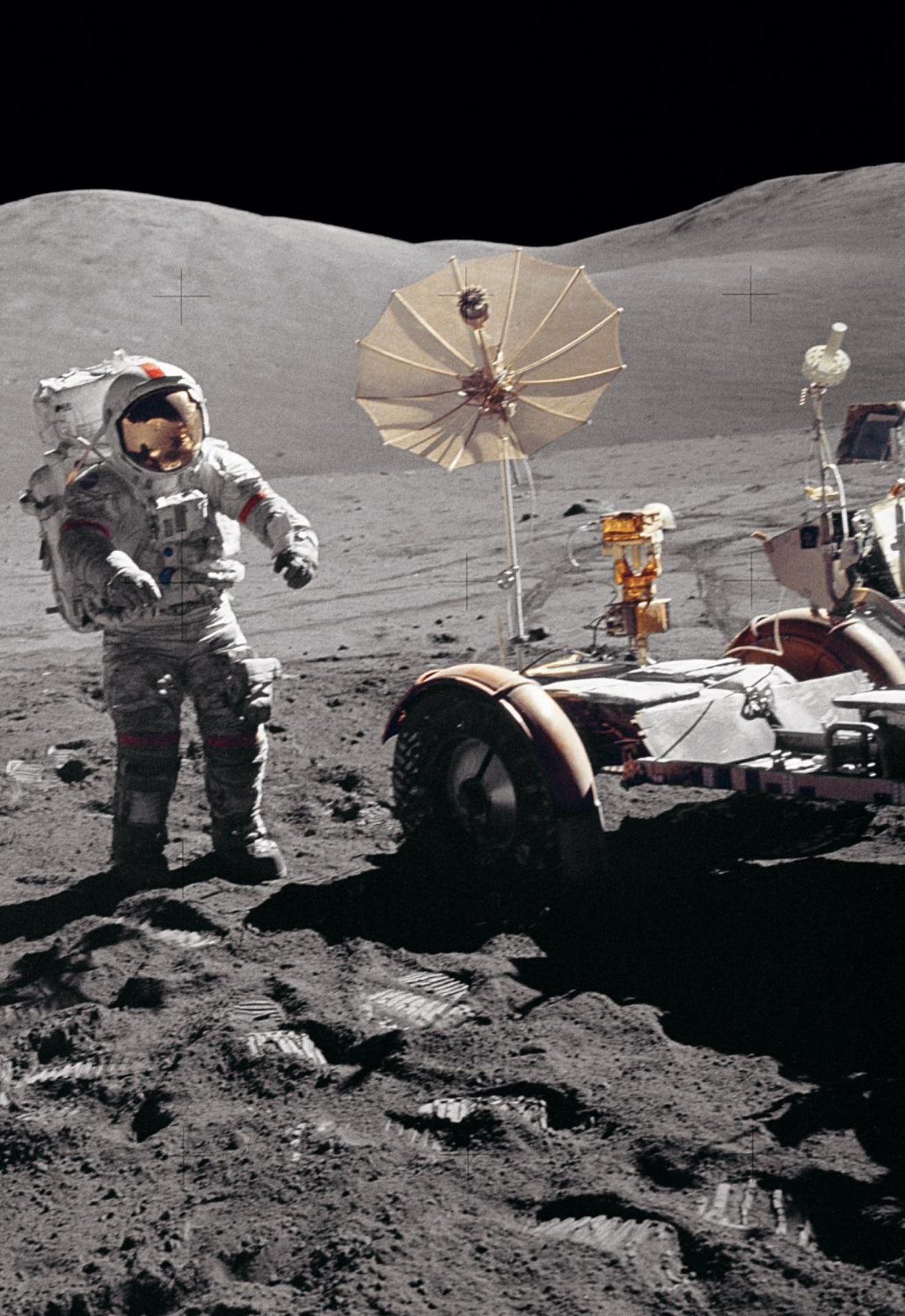
O'Leary and colleagues have secured historic recognition from two states, California and New Mexico, for the objects at Tranquility Base, but federal officials have balked at granting the same for any Apollo site, wary that such a move might be interpreted as a claim on the moon itself. The UN's Outer Space Treaty, which has governed exploration and use of the moon since 1967, forbids any country from claiming sovereignty over it.

Protection, if it comes at all, will likely require sponsorship from multiple nations, including the growing number of countries whose probes have left their own physical traces on the moon.

—Brad Scriber



In 2011 NASA made a nonbinding request that no craft land within a 1.2-mile buffer around the six Apollo sites. The agency still owns the rovers and other artifacts, but space law gives it no standing to protect iconic footprints such as those made by the last moonwalker, Gene Cernan (right), who said in 1972, "God willing...we shall return, with peace and hope for all mankind."

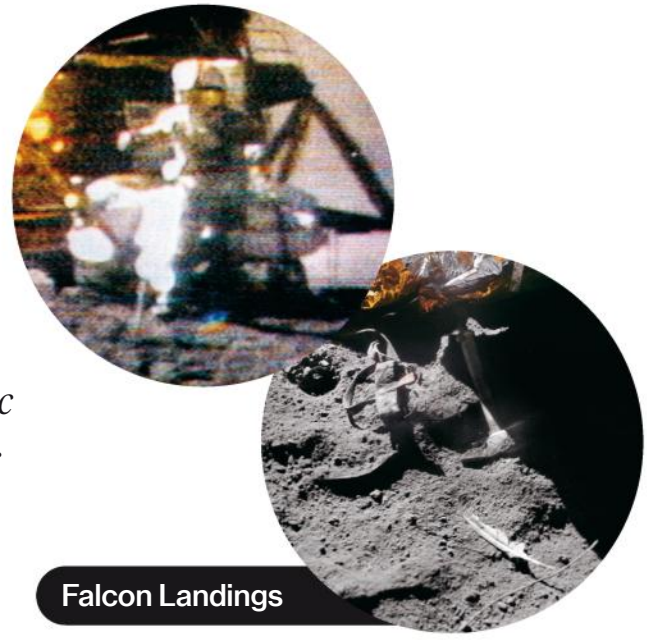


Namesakes

Charles Duke never reached what Apollo 16 dubbed Dot Crater, for his wife, Dorothy, or Cat Crater, an acronym for sons Charles and Tom, but he did leave behind a backyard portrait. Decades of exposure have likely faded the image, but perhaps the signatures on the reverse are still legible, along with the inscription that identifies the group as the family of astronaut Duke from planet Earth.

More Than Exploration

Dropped onto moondust, some Apollo artifacts are a record of human nature: traces of scientific curiosity, nostalgia, and whimsy.



Falcon Landings

"How 'bout that?... Mr. Galileo was correct," declared Apollo 15 commander David Scott with feigned surprise after testing that moon-gazing scientist's law: Without air friction, objects of any weight fall at the same speed. As cameras rolled, Scott released a falcon feather from his left hand and a rock hammer a thousand times as heavy from his right. They hit the ground simultaneously. Three days prior, an understanding of this principle had helped the crew descend safely to the surface in their lunar module, the *Falcon.*

The Fallen

Only 12 men have walked on the moon, but it took the best technological efforts of the 20th century's two dueling superpowers to get them there. Countless people contributed; some lost their lives. "Fallen Astronaut," a 3.3-inch aluminum sculpture, memorializes 14 astronauts and cosmonauts who died in the space race. David Scott placed the stylized spacefarer and a plaque with their names on the moon's surface during the Apollo 15 mission. The next year Paul Van Hoeydonck revealed himself as the artist in an interview with Walter Cronkite during the Apollo 16 launch. A plan to sell replicas of the statue entangled the memorial in a years-long controversy about profiting from moon missions.

Swing and Pitch

Their work nearly complete, the Apollo 14 astronauts turned to sport. Alan Shepard had attached a six iron to the handle of a soil-sampling tool and, after a few attempts, hit two golf balls, with one landing in a crater a short distance away. Edgar Mitchell followed up with a "javelin" throw, hurling the staff of a solar wind collector just past the ball. Both of the objects were visible (forefront) from the window of the lander as the pair prepared to leave the moon.

ALL PHOTOS: NASA

This Japanese spacecraft delivered nearly five tons of hardware and supplies to the space station in 2015. Lit up on Earth below, the Nile River flows into the eastern part of the Mediterranean Sea.

Space Odyssey

Astronaut Scott Kelly reflects on his yearlong journey aboard the International Space Station in this exclusive excerpt from his memoir, Endurance.


HTV5

For 340 consecutive days Scott Kelly was a living, breathing science experiment. Kelly (below, in a selfie taken on the space station with a view of Earth) was monitored to help researchers understand how the body reacts and adapts to the harsh conditions in space – with an eye toward future exploration of the solar system. After three space walks, 5,440 orbits around Earth, and some 144 million miles aboard the space station, he returned home in March 2016. Here he discloses the physical – and emotional – challenges of long-term space travel.

Looking down at the planet

from 200 miles in space, I feel as though I know the Earth in an intimate way most people don't—the coastlines, terrains, mountains, and rivers. Some parts of the world, especially in Asia, are so blanketed by air pollution that they appear sick, in need of treatment or at least a chance to heal. The line of our atmosphere on the horizon looks as thin as a contact lens over an eye, and its fragility seems to demand our protection. One of my favorite views of Earth is of the Bahamas (above), a large archipelago with a stunning contrast from light to dark colors. The vibrant deep blue of the ocean mixes with a much brighter turquoise, swirled with something almost like gold, where the sun bounces off the shallow sand and reefs. Whenever new crewmates come up to the International Space Station, I always make a point of taking them to the Cupola—a module made entirely of windows looking down on Earth—to see the Bahamas. That sight always reminds me to stop and appreciate the view of Earth I have the privilege of experiencing.

Sometimes when I'm looking out the window it occurs to me that everything

ALL PHOTOS: NASA

that matters to me, every person who has ever lived and died (minus our crew of six) is down there. Other times, of course, I'm aware that the people on the station with me are the whole of humanity for me now. If I'm going to talk to someone in the flesh, look someone in the eye, ask someone for help, share a meal with someone, it will be one of the five people up here with me.

This is my fourth mission to space, my second to the ISS, and I've been here for three weeks now. I'm getting better at knowing where I am when I first wake up, but I'm often still disoriented about how my body is positioned. I'll wake up convinced that I'm upside down, because in the dark and without gravity, my inner ear just takes a random guess on the position of my body in the small space. When I turn on a light, I have a sort of visual illusion that the room is rotating rapidly as it reorients itself around me, though I know it's actually my brain readjusting in response to new sensory input.

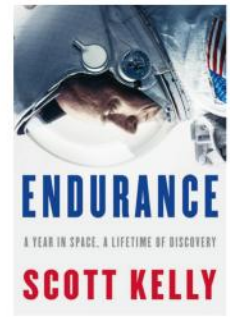
My crew quarters are just barely big enough for me and my sleeping bag, two laptops, some clothes, toiletries, photos of Amiko (my longtime girlfriend) and my daughters, a few paperback books. Without getting out of my sleeping bag, I wake up one of the two computers attached to the wall and look at my schedule. Much of today is to be taken up with one long task labeled DRAGON CAPTURE.

THE STATION IS SOMETIMES DESCRIBED as an object: "The International Space Station is the most expensive object ever created." "The ISS is the only object whose components were manufactured by different countries and assembled in space." That much is true. But when you live inside the station for days and weeks and months, it doesn't feel like an object. It feels like a place, a very specific place with its own personality and its own unique characteristics. It has an inside and an outside and rooms upon rooms, each of which has different purposes, its own equipment and hardware, and its own feeling and smell, distinct from the others. Each module has its own story and its own quirks.

From the outside the ISS looks like a number of giant empty soda cans attached to each other end to end. Roughly the size of a football field, the station is made up of five modules connected the long way—three American and two Russian. More modules, including ones from Europe and Japan as well as the United States, are connected as offshoots to port and starboard, and the Russians have three that are attached "up" and "down" (we call these directions zenith and nadir). Between my first time visiting the space station and this mission, it has grown by seven modules, a significant proportion of its volume. This growth is not haphazard but reflects an assembly sequence that had been planned since the beginning of the space station project in the 1990s.

Whenever visiting vehicles are berthed here for a time, there is a new "room," usually on the Earth-facing side of the station; to get into one of them I have to turn "down" rather than left or right. Those rooms get roomier as we get the cargo unpacked, then get smaller again as we fill them with trash. Not that we need the space—especially on the U.S. side, the station feels quite spacious, and in fact we can lose each other in here easily. But the appearance of extra rooms—and then their disappearance after we set them loose—is a strange feature most homes don't have.

Since before the space shuttle was retired, NASA has been contracting with private companies to develop spacecraft capable of supplying the station with cargo and, at some point in the future, new crews. The most successful private company so far has been Space Exploration Technologies, better known as SpaceX, which produces the *Dragon* spacecraft. Yesterday a *Dragon* launched



from a pad at Cape Canaveral. Since then *Dragon* has been in orbit a safe 10 kilometers from us. This morning our aim is to capture it with the space station's robot arm and attach it to the docking port on the station. The process of grappling a visiting vehicle is a bit like playing a video game that tests hand-eye coordination, except that it involves real equipment worth hundreds of millions of dollars. Not only could an error cause us to lose or damage the *Dragon* and the millions of dollars' worth of supplies on board, but a slip of the hand could easily crash the visiting vehicle into the station. An accident with a resupply ship has happened before, when a cargo spacecraft struck the old Russian space station Mir, though its crew was lucky enough not to have been killed by decompression when the *Progress* crashed into its hull.

These uncrewed spacecraft are the only way we can get supplies from Earth. The Russian *Soyuz* spacecraft has the capability to send three humans to space, but there is almost no room left over for anything else. SpaceX has had a lot of success so far with their *Dragon* spacecraft and Falcon rocket, and in 2012 they became the first private company to reach the ISS. Since then they have become one of our regular suppliers, along with the Russian *Progress* and Orbital ATK's *Cygnus,* and they hope to be ready to fly astronauts on the *Dragon* in the next few years. If they can pull that off, they will be the first private company to carry human beings to orbit, and that launch will be the first time astronauts leave Earth from the United States since the space shuttle was retired in 2011.

Right now *Dragon* is carrying 4,300 pounds of supplies we need. There is food, water, and oxygen; spare parts and supplies for the systems that keep us alive; health care supplies like needles and vacuum tubes for drawing our blood, sample containers, medications; clothing and towels and washcloths, all of which we throw away after using them as long as we can. *Dragon* will also be carrying new science experiments for us to carry out, as well as new samples to keep the existing ones going. Notable among the science experiments is a small population of live mice for a study we will be carrying out on how weightlessness affects bone and muscle. Each resupply spacecraft also carries small care packages from our families, which we always look forward to, and precious supplies of fresh food that we enjoy for just a few days, until it runs out or goes bad. Fruits and vegetables seem to rot much faster here than on Earth. I'm not sure why, and seeing the process makes me worry that the same thing is happening to my own cells.

We are especially looking forward to this *Dragon*'s arrival because another resupply rocket exploded just after launch back in October 2014. That one was a *Cygnus* flown by another private contractor, U.S.-based Orbital ATK. The station is always supplied far beyond the needs of the current crew, so there was no immediate danger of running out of food or oxygen when those supplies were lost. Still, this was the first time a rocket to resupply the ISS had failed in years, and it destroyed millions of dollars' worth of equipment. The loss of vital supplies like food and oxygen made everyone think harder about what would happen if a string of failures were to occur. A few days after the explosion, an experimental space plane being developed by Virgin Galactic crashed in the Mojave Desert, killing the copilot. These failures were unrelated, of course, but the timing made it feel as though a string of bad luck might be catching up with us after years of success.

BACK IN MY CREW QUARTERS I get dressed while reading and clicking through emails. Getting dressed is a bit of a hassle when you can't "sit" or

"stand," but I've gotten used to it. The most challenging thing is putting on my socks—without gravity to help me bend over, I'm using only core strength and flexibility to pull my legs up to my chest. It's not a challenge to figure out what to wear, since I wear the same thing every day: a pair of khaki pants with lots of pockets and strips of Velcro across the thighs, crucial when I can't put anything "down." I have decided to experiment with how long I can make my clothes last, the idea of going to Mars in the back of my mind. Can a pair of underwear be worn four days instead of just two? Can a pair of socks last a month? Can a pair of pants last six months? I aim to find out. I put on my favorite black T-shirt and a sweatshirt that, because it's flying with me for the third time, has to be the most traveled piece of clothing in the history of clothing.

Dressed and ready for breakfast, I open the door to my quarters. As I push against the back wall to float myself out, I accidentally kick loose a paperback book: *Endurance: Shackleton's Incredible Voyage,* by Alfred Lansing. I brought this book with me on my previous flight as well, and sometimes I flip through it after a long day on the station and reflect on what these explorers went through almost exactly a hundred years before. They were stranded on

Fruits and vegetables seem to rot much faster here than on Earth. I'm not sure why, and seeing the process makes me worry that the same thing is happening to my own cells.

ice floes for months at a time, forced to kill their dogs for food, and nearly froze to death in the biting cold. They hiked across mountains that had been considered impassable by explorers who were better equipped and not half-starved. Most remarkable, not a single member of the expedition was lost.

When I try to put myself in their place, I think the uncertainty must have been the worst thing. They must have wondered if they could survive, and that doubt must have been worse than the hunger and the cold. When I read about their experiences, I think about how much harder they had it than I do. Sometimes I'll pick up the book specifically for that reason. If I'm inclined to feel sorry for myself because I miss my family or because I had a frustrating day or because the isolation is getting to me, reading a few pages about the Shackleton expedition reminds me that even if I have it hard up here in some ways, I'm certainly not going through what they did. It's all about perspective. I tuck the book back in with a few other personal items. Maybe I'll read a few pages before I go to sleep tonight.

DRAGON IS NOW IN ITS ORBIT 10 kilometers away from us, matching our speed of 17,500 miles per hour. We can see its light blinking at us on the external cameras. Soon SpaceX ground control in Hawthorne, California, will move it to within 2.5 kilometers, then 1.2 kilometers, then 250 meters, then 30 meters, then 10 meters. At each stopping point, teams on the ground will check *Dragon*'s systems and evaluate its position before calling "go" or "no go" to move on to the next stage. Inside of 250 meters we will get involved by monitoring the approach, making sure the vehicle stays within a safe corridor, is

Kelly was safely tethered to the space station during this seven-hour, 48-minute space walk to reconfigure a cooling unit in November 2015. Mere layers of a space suit shielded him from radiation and other hazards of space.

behaving as expected—and that we are ready to abort if required. Once it's close enough, my crewmate Samantha Cristoforetti will grapple it with the station's robot arm. This is a glacially slow and deliberate process, and this is one of the many things that's very different between movies and real life. In the films *Gravity* and *2001: A Space Odyssey,* a visiting spacecraft zips up to a space station and locks onto it; then a hatch pops open and people pass through, all over the course of about 90 seconds. In reality we operate with the knowledge that one spacecraft is always a potentially fatal threat to another—a bigger threat the closer it gets—and so we move slowly and deliberately.

Samantha will operate the robot arm from the robotics workstation in the Cupola. Terry Virts, the only other American on board, will be her backup, and I will be helping out with the approach and rendezvous procedures. Terry and I squeeze into the Cupola with Samantha, watching the data screen over her shoulder that shows the speed and position of *Dragon*.

Like me, Terry was a test pilot before joining NASA—in his case, with the Air Force. His call sign is Flanders, after the lovably square character

An unusual and unmistakable smell hits me. Slightly burned, slightly metallic. It reminds me of the smell of sparklers on the Fourth of July: the smell of space.

Ned Flanders on *The Simpsons*. Terry has the positive attributes of Ned Flanders—optimism, enthusiasm, friendliness—and none of the negative ones. I've found him to be consistently competent, and I appreciate that as a leader he is a consensus builder rather than an authoritarian. Since I've been up here, he has always been respectful of my previous experience, always open to suggestions about how to do things better rather than getting defensive or competitive. He loves baseball, so there is always a game on somewhere on the station, especially when the Astros or the Orioles are playing. I've gotten used to the rhythm of the nine-inning games marking time for a few hours of our workdays.

Samantha is one of the few women to have served as a fighter pilot in the Italian Air Force, and she is unfailingly competent in everything technical. She is also friendly and quick to laugh, and among her many other qualifications to fly in space, she has a rare talent for language. She has native-level fluency in English and Russian (the two official languages of the ISS) as well as French, German, and her native Italian. She is also working on learning Chinese.

For some people who hope to fly in space, language can be a challenge. We all have to be able to speak a second language (I've been studying Russian for years, and my cosmonaut crewmates speak English much better than I speak Russian), but the European and Japanese astronauts have the added burden of learning two languages if they don't already speak English or Russian. For Samantha this wasn't a problem. In fact her Russian and English are both so good that she sometimes acts as an interpreter between cosmonauts and astronauts if we have to talk about something nuanced or complicated.

David Saint-Jacques, a Canadian astronaut at Mission Control in Houston, will talk us through the capture process, announcing *Dragon*'s position as it moves, controlled from the ground through each of its preplanned stops.

"Dragon is inside the 200-meter keep-out sphere," David says. The keep-out sphere is an imaginary radius boundary around the station, meant to protect us from accidental collisions. "The crew now has the authority to issue an abort." This means that we can shut down the process ourselves if we lose contact with Houston or if *Dragon* is outside the corridor.

"Houston, capture conditions are confirmed. We're ready for *Dragon* capture," Terry replies.

At 10 meters we inhibit the station's thrusters to prevent any unintended jolts. Samantha takes control of the robotic arm, using her left hand to control the arm's translation (in, out, up, down, left, right) and her right hand to control its rotation (pitch, roll, and yaw).

Samantha reaches out with the robot arm, watching a monitor that offers a view from a camera on the "hand," or end effector, of the arm, as well as two other video monitors showing data describing *Dragon*'s position and speed. She can also look out the big windows to see what she's doing. She moves the arm out away from the station—very slowly and deliberately. Closing the space between the two spacecraft inch by inch, Samantha never wavers or goes off course. On the center screen the grapple fixture on *Dragon* grows larger. She makes precise adjustments to keep the spacecraft and the robot arm perfectly lined up.

The arm creeps out slowly, slowly. It's almost touching the *Dragon*.

Samantha pulls the trigger. "Capture," she says.

Perfect.

The process of pressurizing the space between the *Dragon* and the station (the "vestibule") takes several hours and is important to do correctly. The danger that *Dragon* poses to the station is not over. A mistake in vestibule outfitting could cause depressurization—our air venting out into space. So Samantha and I work through the steps one by one.

We wait to open the ISS hatch that leads to the *Dragon* until the next morning. When Samantha slides it out of the way, an unusual and unmistakable smell hits me. Slightly burned, slightly metallic. This time it reminds me of the smell of sparklers on the Fourth of July: the smell of space. After a series of procedures we eventually open *Dragon*'s hatch, and our care packages are clearly marked and easily accessible, as are the mice and the fresh food. Terry and I distribute the packages to everyone, feeling a bit like Santa Claus.

I FINALLY OPEN MY care package in the privacy of my crew quarters. Inside is a poem and some chocolates from Amiko (she knows I crave sweets when I'm in space, though on Earth I don't have much of a sweet tooth); a pair of shoelaces for my workout shoes with toggle ties, because it's hard to tie laces without gravity; a bottle of Frank's hot sauce; a picture from my identical twin brother, Mark, showing twin redhead little boys giving the finger to the camera, with a note on the back that reads, "Hope the WCS is working up there!" (WCS stands for waste collection system, a space toilet); and a card from my daughters, Charlotte and Samantha, their distinctive handwritings gouged into the heavy paper by a black pen.

I put everything away, eat a piece of the chocolate, check my email again. I hang in my sleeping bag for a while, thinking about my kids, wondering how they are doing with me being gone. Then I go to sleep. □

Warriors to the Rescue

Trailblazing indigenous communities in northern Kenya are working together to save orphaned elephants.

It's feeding time for hungry orphans at the Reteti Elephant Sanctuary in northern Kenya. Established last year, the refuge is staffed by local Samburus, whose goal is to return their young charges to the wild.

STORY AND PHOTOGRAPHS BY **AMI VITALE**

From afar, the cries of a baby elephant in distress seem almost human. Drawn by the sounds, young Samburu warriors, long spears in hand, thread their way toward a wide riverbed, where they find the victim. The calf is half-submerged in sand and water, trapped in one of the hand-dug wells that dot the valley. Only its narrow back can be seen—and its trunk, waving back and forth like a cobra.

As recently as a year ago, the men likely would have dragged the elephant out before it could pollute the water and would have left it to die. But this day they do something different: Using a cell phone, ubiquitous even in remotest Kenya, they send a message to Reteti Elephant Sanctuary, about six miles away. Then they sit and wait.

Reteti lies within a 975,000-acre swath of thorny scrubland in northern Kenya known as the Namunyak Wildlife Conservation Trust—part of the ancestral homeland of the Samburu people. Namunyak is supported and advised by the Northern Rangelands Trust, a local organization that works with 33 community conservancies to boost security, sustainable development, and wildlife conservation. The region includes the Turkana, Rendille, Borana, and Somali, as well as the Samburu—ethnic groups that have fought to the death over the land and its resources. Now they're working together to strengthen their communities and protect the estimated 6,000 elephants they live, sometimes uneasily, alongside.

The riverbed that the Samburu men have come to looks dry and unyielding, but just below the surface is water. Elephants can smell water, and Samburu families, guided by elephants' scrapings, have dug narrow wells to reach the cold, clean, mineral-rich elixir. Each family maintains a particular well, which can be as much as 15 feet deep. While drawing water, Samburus sing a rhythmic chant praising their cattle, luring the animals to the life-giving source. During the dry months (February, March, September, and October) the Samburu deepen their "singing wells," and elephants, desperate to drink, come to the wells too. Sometimes they lose their footing and fall in.

Samburu warriors found this baby trapped in a hand-dug well. Here Lkalatian Lopeta (right), a Samburu wildlife ranger, and Reteti staffers guard the two-week-old at night, hoping that her mother and the rest of the herd will come back for her. But 36 hours later they hadn't, and the elephant was weakening fast from dehydration. So the team bundled her up, hoisted her into a truck, and drove her to the sanctuary. Dubbed Kinya, she was given loving care – but even with all the coddling, she died weeks later.

THE WARRIORS don't have to wait long before a Reteti rescue team arrives, led by Joseph Lolngojine and Rimland Lemojong, both Samburu. The men quickly dig out the sides of the well, widening its mouth so that two of them can step in and slip a harness under the elephant's belly. Then the rescuers, grunting with the effort, hoist the elephant into the sunlight.

Now comes another wait, this time much longer. The hope is that the herd will return here to

drink and that the baby, reunited with its mother and family, will be safe. But after 36 tense hours it's clear that this isn't going to happen. The elephant, swaddled in blankets, is lifted into the vehicle and driven to the sanctuary.

Nestled within the crook of a half-moon-shaped ridge, the Reteti elephant orphanage was established in 2016 by local Samburus. Funding has come from Conservation International, San Diego Zoo Global, and Tusk UK. The Kenya Wildlife Service and the Northern Rangelands Trust provide ongoing support. The first rescued elephant, named Suyian, arrived on September 25. The sanctuary's more than 20 elephant keepers are Samburus, all intent on returning their charges, under a dozen as of now, to the wild.

As soon as the weakened baby arrives, Sasha Dorothy Lowuekuduk, who prepares elephant food at Reteti, readies a half-gallon bottle of special formula. Lolngojine, the sanctuary's veterinary technician, examines the calf and smears antibiotic ointment on any cuts. It's decided that the elephant, a female, should be named Kinya, after the well of her misfortune.

At Reteti heartbreak is a looming specter. Like many calves who become separated from their mothers, Kinya, whose rescue was so hard won, didn't make it. "It's so sad that Kinya died," Lemojong says. "We all worked hard to make sure Kinya should get a second chance to live." □

NGM MAPS

Above: Mathew Mutinda, a vet with the Kenya Wildlife Service, crouches over 18-month-old Mugie, still sedated after his rescue. His mother had been shot and killed as a result of conflict with people. Mugie was flown to an airstrip near the sanctuary, then driven to Reteti. Below: Mike Learka reaches for a bottle of formula while Naomi Leshongoro (at right) empties one into a hungry mouth.

Above: A feel-good dirt bath is just the thing in the heat of the day. A coating of soil helps protect sensitive elephant skin by acting as both sunscreen and insect repellent. Below: Leshongoro gentles orphaned Pokot with the hand of experience: She had cared for and released five young elephants into the wild before Reteti opened last year. A mother herself, Leshongoro views these big babies as her own children.

THESE MEN SAY THEY'RE THE SECOND COMING OF JESUS CHRIST. THEIR DISCIPLES AGREE.

MESSIAH COMPLEX

MOSES HLONGWANE

ALSO KNOWN AS
The King of Kings, The Lord of Lords, Jesus

In Eshowe, South Africa, Moses Hlongwane preaches to his flock during his own wedding ceremony—an event he says marks the beginning of the End of Days. Moses says that God identified him as the Messiah during a dream in 1992. At the time Moses was working as a jewelry salesman. Since then, he's preached in Eshowe, Johannesburg, and other cities in the region. Moses has about 40 disciples.

INRI

(PRECEDING PAGES)

Near Brasília, Brazil, followers of INRI (Iesus Nazarenus Rex Iudaeorum: Jesus of Nazareth, King of the Jews) push their messiah around on a rolling pedestal. A dozen disciples—most of them women—live full-time with the celibate 69-year-old in his walled compound, which is protected with barbed wire and electrical fencing. INRI takes his name from the initials that Pontius Pilate inscribed on Christ's cross. His awakening came in 1979.

Story and Photographs by Jonas Bendiksen

'SURELY I AM COMING SOON.'

The Bible's penultimate verse, prophesying the return of Jesus Christ, has always fascinated me. When is "soon"? And who is "I"? For the past three years I've followed seven men who claim to be the Second Coming of Christ (five are shown here). By immersing myself in their revelations and spending time with their disciples, I've tried to produce images that illustrate the human longing for faith, meaning, and salvation.

Religion is somewhat mysterious to me, probably because I wasn't raised with it in Norway. But I've always enjoyed reading Scripture, and over the past decade or so my interest in it has grown. I've found myself coming back, again and again, to that mysterious line—a promise that Christianity has been waiting nearly 2,000 years to be fulfilled.

If Christ were to come back to complete his work today, I've thought, what would he think of the world we've created? And what would we think of him? With these thoughts tumbling around in my head, I decided to start looking for messiahs.

I found them the way you find everything these days: through Google. You might think there'd be more people who claim to be Christ. But while many can be called prophets, gurus, or spiritual leaders, only a few meet what I consider the minimum criteria: consistent revelations, years of scriptural records, a following of disciples.

Each of these men is unique. The communities that surround them are too. For most people, belief in a higher power is an abstract thing. But for these disciples—most of whom seem highly intelligent; none appear to be brainwashed or crazy—it's tangible. They can touch their belief.

Wherever I went, I tried to keep an open mind and submerge myself in their reality. One thing I was struck by is how extremely consistent several of these messiahs are. The New Testament is full of contradictions, but each of these men has a narrative that sort of reconciles those inconsistencies. In some ways they're more coherent than the Scripture we have.

I know a lot of people will dismiss these men as fakers or lunatics. But I've always thought that a fundamental part of the Abrahamic religions—Judaism, Christianity, Islam—involves the coming of a messiah. Those faiths may disagree about identity and timing, but I think they agree on the basic premise. So if one accepts that, why couldn't it be one of these guys?

For me this project has been more about asking questions than finding answers. I hope it will get people to do the same—to think about belief and who has the power to define it. □

AS TOLD TO JEREMY BERLIN

VISSARION

ALSO KNOWN AS
The Christ of Siberia

In an off-the-grid Russian village called Obitel Rassveta ("abode of dawn"), Vissarion sits in the living room of a disciple. Born Sergei Torop, he had a revelation around the time the Soviet Union collapsed that he was Jesus Christ reborn. Founder of the Church of the Last Testament, he now has at least 5,000 followers; many of them live with him in several utopian eco-villages in the Siberian woods. They've built their own schools, churches, and society. Vissarion's proclamations have been published in 16 tomes titled *The Last Testament*.

VISSARION'S FOLLOWERS

These disciples, all vegetarians, share a communal Christmas lunch in Cheremshanka, one of the community's five villages. Christmas here falls on January 14—Vissarion's birthday. Celebrations start on the 12th, with a daylong pilgrimage through all of the villages. On Christmas Day thousands of followers gather and ascend to a mountain altar above Obitel Rassveta, after which Vissarion greets the crowd and delivers a short sermon.


TANZANIA

JESUS OF KITWE

ALSO KNOWN AS
Parent Rock of the World, Mr. Faithful, Mr. Word of God

Jesus of Kitwe walks around a marketplace in the town of Ndola, Zambia, proclaiming the arrival of the Messiah and the End of Days. When he's not sermonizing, the 43-year-old man named Bupete Chibwe Chishimba wears street clothes, drives a taxi, and lives with his wife and five children in neighboring Kitwe, a copper-mining city with more than half a million inhabitants. This Jesus says he received a revelation from God when he was 24. Shortly after this image was taken, a crowd of churchgoing Christians accused him of blasphemy. When the crowd began to threaten violence, Jesus of Kitwe left in a hurry.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JESUS MATAYOSHI

ALSO KNOWN AS
The Only God

Atop a van in Tokyo, Jesus Matayoshi delivers a fiery sermon as part of his campaign for a seat in the House of Councillors, instructing opponents to commit suicide and threatening hellfire upon transgressors. During two weeks of campaigning in 2016—he's run in many elections over the past two decades—he drove around Tokyo, spreading his message. Many people ignored him, but he did garner 6,114 votes. Mitsuo Matayoshi was born in Okinawa in 1944. In 1997 he founded the World Economic Community Party, which bases its policies on his identity as Jesus Christ reborn. Jesus Matayoshi says his goal is to bring about the End of Days via the democratic political process, eventually occupying the post of United Nations secretary-general and instituting the will of God on Earth.

Jonas Bendiksen's book *The Last Testament* will be published in September 2017 by Aperture/GOST.

Nearly a billion people, more than half of them in India, defecate outdoors every day. The result: millions of deaths and disease-stunted lives. The problem isn't just a lack of toilets—it's a lack of toilets that people want to use.

A Place to Go

INDIA A farmer in Peepli Khera heads into a sugarcane field to defecate, carrying a container of water to rinse with. In his village, north of Delhi, only one family has a toilet. The others go in the fields – men on one side of the village, women on the other.

By Elizabeth Royte
Photographs by Andrea Bruce

At 65, Moolchand, bandy-legged and white-haired, has no problem rising for his predawn hunts. In fact he revels in them.

"I hide along the lane with my flashlight," he says in a low, excited voice, gesturing down the main road of Gaji Khedi village, in India's Madhya Pradesh state. "And I look for people walking with a lota."

A lota is a water container, traditionally made of brass but these days more often of plastic. Spied outdoors in the early morning, it all but screams that its owner is headed for a field or roadside to move his or her bowels—the water is for rinsing.

"I give chase," Moolchand continues. "I blow my whistle, and I dump out their lota. Sometimes I take it away and burn it." Moolchand sees himself as defending a hard-won honor: The district has declared his village "open defecation free." "People get angry and shout at me when I stop them," he says. "But the government has given villagers lots of help to construct a toilet, so there is no excuse."

Defecating in the open is as old as humankind. As long as population densities were low and the earth could safely absorb human wastes, it caused few problems. But as more people gathered in towns and cities, we gradually learned the link between hygiene and health and, in particular, the importance of avoiding contact with feces. Today open defecation is on the decline worldwide, but nearly 950 million people still routinely practice it. Some 569 million of them live in India. Walk along its train tracks or rural roads, and you will readily encounter the evidence.

In 2015 the United Nations called for an end to open defecation by 2030. It's not impossible to make great strides: Vietnam, for example, has all but eliminated the practice over the past few decades. Achieving the global milestone, number six on the UN's list of Sustainable Development Goals, would radically improve public health: Diseases caused by poor sanitation and unsafe water kill more children, some 1.4 million per year, than measles, malaria, and AIDS combined. It also would help alleviate poverty and hunger and improve education. Sick kids miss school, and so do menstruating girls whose schools lack a clean and safe toilet.

India has been grappling with the problem since before it won independence from Great Britain in 1947. "Sanitation is more important than independence," Mahatma Gandhi said, urging his compatriots to clean up their act. To some extent they have: The percentage of Indians who defecate in the open has declined substantially in recent decades. But with the population growing rapidly, census data suggest that most Indians now live in places where they are more exposed to others' feces, not less.

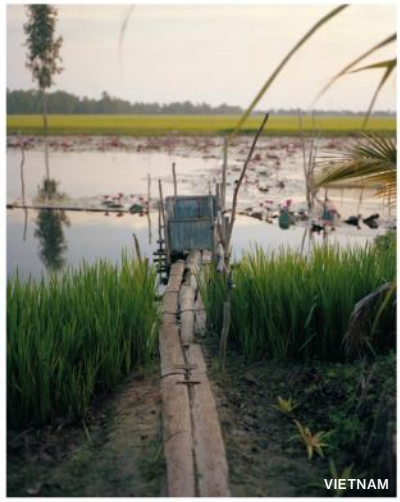
The current prime minister, Narendra Modi, campaigned with the slogan "toilets before temples." In 2014, before the UN set its 2030 goal, Modi declared his intention to end open defecation in India more than a decade earlier, by October 2, 2019—Gandhi's 150th birthday. He allotted more than $40 billion for a latrine-building and behavior-change blitz called Swachh Bharat Abhiyan (Clean India Mission), for which the

Around the World, the Same Need

Pit latrines are a simple alternative to open defecation, but even they aren't easy to implement across a whole country. Haiti, for example, lacks the resources to emulate the success of Vietnam, where the government built millions of toilets – including indoor ones (second row, left). In India, latrines often offend deep notions of purity and caste. Many go unused.


INDIA


HAITI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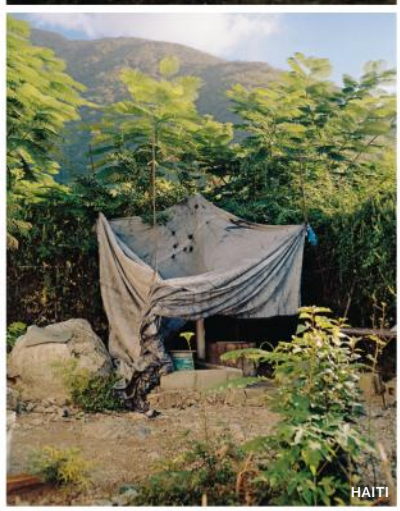
HAITI

INDIA At a community toilet complex in Safeda Basti, one of Delhi's many slums, women wait their turn for the single functioning latrine – while covering their noses against the smell of feces left by someone who couldn't wait. Many people skip the hassle of city-run facilities altogether and do their business in rubble-strewn lots.


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5

INDIA Baby, a 10-year-old girl in Safeda Basti, is severely underweight. Diarrhea and malnutrition are endemic in the slum, says health worker Balram Yadare, "so children aren't progressing at the level they should." Toilets are scarce here, and the water supply for handwashing is intermittent.

World Bank threw in another $1.5 billion in loans.

Modi aims to build more than 100 million new toilets in rural areas alone by 2019. Whether he'll succeed is one question; whether the toilets will make much difference is another. Indian governments have been building low-cost latrines for at least 30 years. Millions of these simple, freestanding structures dot the countryside, but many are crumbling. And many more are used to shelter small animals or to store tools, bikes, and grain—while their owners head out into the fields with their lotas. In India deep-seated attitudes may present an even bigger barrier to improving sanitation than a lack of pipes and pits.

IN THE SIDE YARD OF EVERY mud-plastered home in the hamlet of Jawda, several hours southwest of Moolchand's village, stands a spanking-new concrete outhouse the size of a large phone booth, painted salmon pink. Inside, a white ceramic squat pan funnels waste—sluiced by water from a bucket or lota—through a pipe into a four-foot-deep pit. The brick-walled pit is designed to collect feces while allowing liquids to seep into the earth. A small pool of water cradled in a U-shaped bend in the pipe helps contain smells and block insects from the pit. Flies breeding and feeding on feces are one of the main vehicles delivering infectious organisms back to humans; one gram of feces can contain 10 million viruses, one million bacteria, and 1,000 parasitic cysts. They infect us through tiny openings in our skin or by contaminating food and water.

The health toll in India is staggering. Diarrhea kills over 117,000 children under age five each year. Millions more struggle on with chronically infected intestines that don't absorb nutrients and medicines well. The misery cycles on: Underweight women give birth to underweight babies, who are more vulnerable to infections, more likely to be stunted, and less able to benefit from vaccines. In 2016, 39 percent of Indian children under age five were stunted.

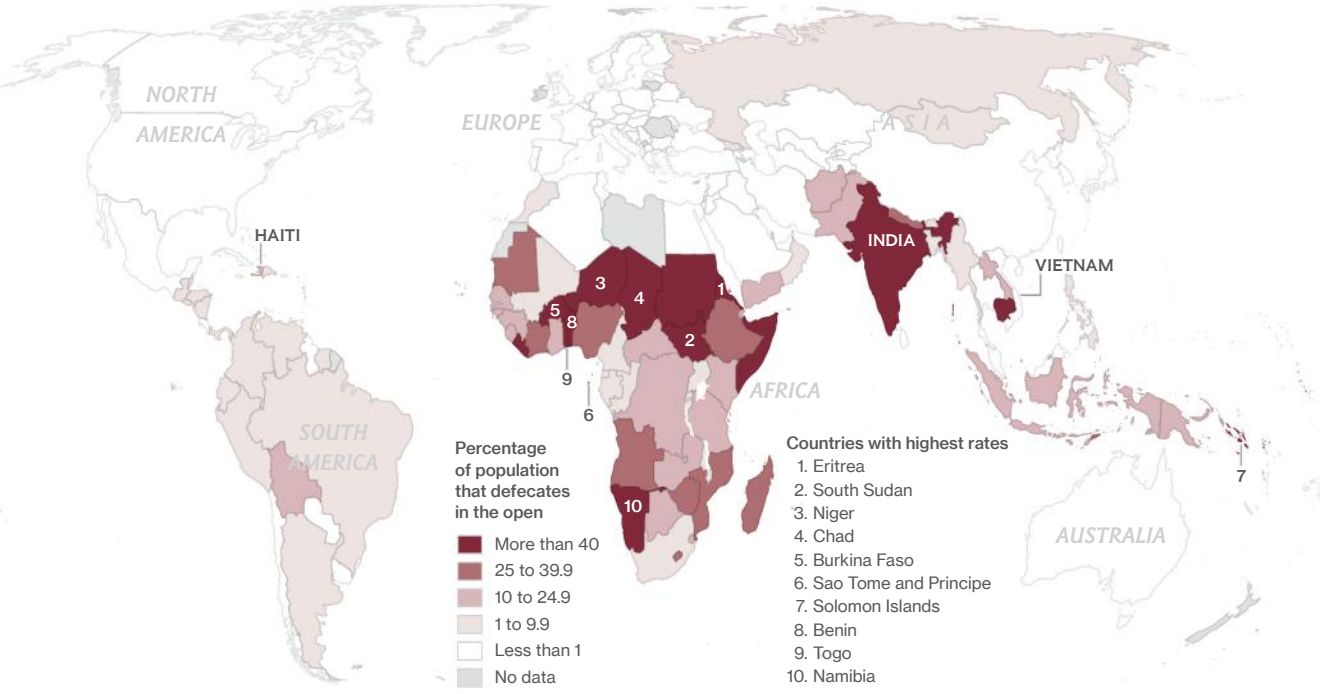
The Swachh Bharat mission offers each household about $190 to construct a pit latrine—far more than other developing nations spend. In Jawda, however, nobody uses the latrines. "It's for washing clothes or bathing," says a woman in a pink-and-black sari, resting on a rope-strung cot in the shade. "We have a lot of open space. Why shouldn't we use that?" Grassy fields dotted with wildflowers surround her village.

In surveys done throughout rural northern India, where open defecation is more prevalent than in the south, people express a keen preference for relieving themselves outdoors. It's healthier, they say. It's natural and even virtuous. Many rural Indians consider even the most immaculate latrine religiously polluting; a toilet near the home seems more unclean to them than answering the call of nature 200 yards away. Flies, however, can travel more than a mile.

The children in Jawda know, from visits by community health workers, that toilets are a boon for health. A girl nuzzling a tawny goat explains with great precision how flies and fingers can transfer feces from the field to food and water, sickening villagers. "But if the toilet pits are small," her mother interrupts, "we'll have this filth near us. And if we get sick, we have no money to cure ourselves."

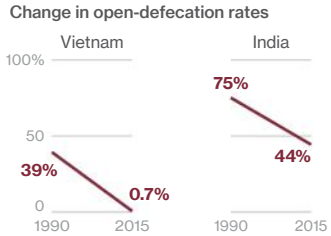
IN KHARGONE DISTRICT, in southwestern Madhya Pradesh, I walk through the unpaved streets of a hamlet with Nikhil Srivastav, a policy researcher affiliated with the Research Institute for Compassionate Economics (RICE). Led by two Americans, Diane Coffey and Dean Spears, the nonprofit deploys both American and Indian researchers to study the well-being of India's poor, with an emphasis on children. Trailed by barefoot kids, Srivastav and I step over a thin, smelly stream, in which rat-tailed maggots tumble, and into a neatly swept compound. There we meet Jagdish, a retired tour-bus driver who recently spent 50,000 rupees (about $780) to dig a latrine seven feet deep, instead of the government-recommended four, and finish its superstructure with blue dolphin tiles.

But Jagdish doesn't make much use of this beautiful chamber. "It's for my wife and daughter-in-law," he says. Like many of his neighbors, Jagdish prefers to walk uphill into the bush to perform his daily ablutions. In rural India it's

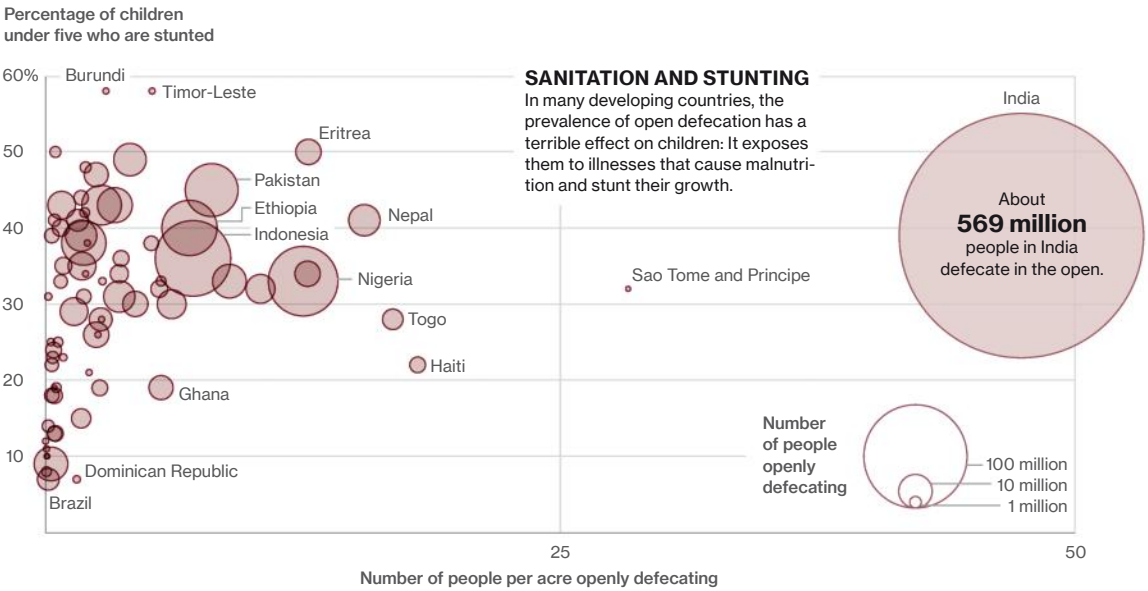


Cleaning Up an Unsanitary World

The percentage of people defecating in the open air declined worldwide from 1990 to 2015, with the most dramatic reductions in some of the least developed countries. Yet nearly 950 million people still practice this public health hazard – a challenge augmented by population growth.



MAKING GAINS
Vietnam has nearly eradicated open defecation. UN statistics based on toilet construction show India has made progress too – but some experts dispute the extent, arguing in part that many of the latrines that have been built go unused.



SANITATION AND STUNTING
In many developing countries, the prevalence of open defecation has a terrible effect on children: It exposes them to illnesses that cause malnutrition and stunt their growth.

JASON TREAT AND MATTHEW W. CHWASTYK, NGM STAFF; KELSEY NOWAKOWSKI

SOURCES: WHO/UNICEF JOINT MONITORING PROGRAMME FOR WATER SUPPLY AND SANITATION; SANGITA VYAS, RESEARCH INSTITUTE FOR COMPASSIONATE ECONOMICS

INDIA North of Bhopal, community organizer Santoshi Tiwari leads villagers through a farm field dotted with human waste. She explains how flies carry fecal germs to food and drink, offers to help them build toilets – and tries to shame them for their unsanitary habits.

considered the manly thing to do. Patriarchal advertisements indirectly reinforce that notion, imploring men to build toilets, not for the health of the whole family, but to protect their wives and daughters from sexual harassment out in the bush and from the shame of lifting their saris outdoors. One campaign encourages brides to reject grooms whose assets don't include a toilet.

And yet, as I saw in Jawda, many rural women ignore these messages and still head outdoors themselves. These women and girls may be reluctant to break with tradition or may feel cooped up inside a latrine, especially one they lack the tools or inclination to clean. Some may also prize the opportunity to get together with their girlfriends. Open defecation, as strange as this may sound to Westerners, offers young women a welcome break from their domestic confines and the oversight of in-laws and husbands.

Jagdish is proud of his latrine, which he built with Swachh Bharat funding and his own savings. His only regret is not digging his pit even

deeper. "Fifteen feet would have been better," he says. Pit latrines have a huge drawback, you see: They fill up. And rather than empty a pit with a shovel or hire a pump truck—or easier still, dig a new latrine, which is standard procedure in other nations—rural Indians, especially in northern India, often opt to build no latrine at all.

Three years ago RICE researchers collected data on latrine use by more than 22,000 rural Indians. The team discovered that 40 percent of households with toilets had at least one member who continued to defecate outdoors; that people with government-funded toilets were twice as likely to defecate in the open as those who built their own; and that families without any toilet at all said they couldn't afford to build the type they'd actually use. RICE found that privately constructed pit latrines were four to five times larger than the 50 cubic feet recommended by the World Health Organization. "That's the size used all over the world," Srivastav says, "and a family of six won't fill it for five years." Indians' ideal pit latrine was larger still: up to 1,000 cubic feet—larger than many Indians' living space.

Why this obsession with size? "A smaller soak pit will fill up in five months," Jagdish explains, erroneously. "Then I'd have to call a Dalit"—a low-caste person—"to empty it."

"Couldn't you do this on your own?" Srivastav asks. Jagdish shakes his head.

"There would be objections from the community," he says. "You'd be ostracized for cleaning your own house."

That pronouncement points to an answer to the great puzzle of Indian sanitation. Why are India's open-defecation rates so much higher than those in other developing nations, when India is richer, has higher literacy rates, and has more access to water? What sets India apart, at least according to RICE, are rural Indians' beliefs about purity, pollution, and caste.

For thousands of years Dalits—formerly known as Untouchables—have been forbidden from drinking at the same wells, worshipping at the same temples, or even wearing shoes in the presence of upper castes. Modern laws against such discrimination are rarely enforced, and poverty and violence still compel Dalits to do the nation's dirty work. They clear carcasses from roads, placentas from birthing rooms, and human waste from pits and open sewers. Meanwhile higher caste Indians retain their status and supposed superiority in part by avoiding any association with such degrading labors.

In recent years, however, Dalits struggling for equality have begun to shun the sorts of jobs historically used to justify their oppression. And so the cost of emptying a pit latrine has risen as demand for the service has outstripped the supply of willing workers. Given this fraught social and economic landscape, it's no wonder that some rural Indians save enough money to build

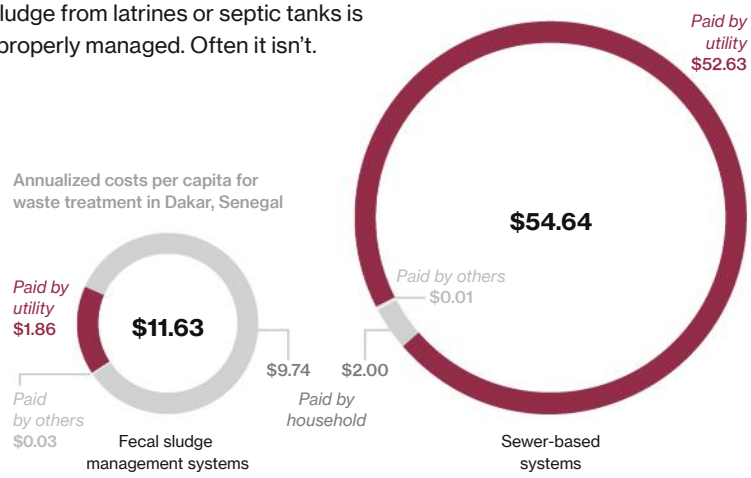
INDIA After charities spent $28,000 to install a sewer line in Safeda Basti, 62 households constructed and connected private toilets, some of them on rooftops (bottom left). Without other plumbing, however, most residents must still haul water for flushing and handwashing from taps in the street.

The High Price of Modern Hygiene

Sewers connected to treatment plants are the best way of removing the hazard of human waste, especially in cities. But they're costly to build and maintain. Collecting sludge from latrines or septic tanks is an alternative – if the sludge is properly managed. Often it isn't.

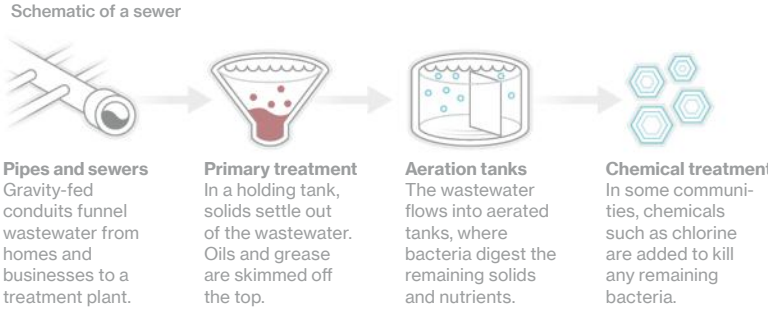
A PRIVATE BURDEN

In Dakar, Senegal, sewer systems were found to be nearly five times more expensive than collecting and managing fecal sludge. The latter method, however, costs more for households, which are responsible for their own latrines or septic tanks.



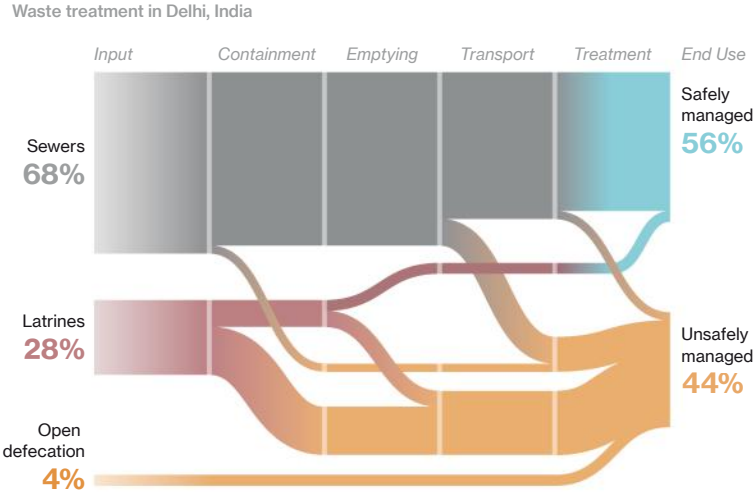
AFTER THE FLUSH

Sewer systems require a huge investment in infrastructure to connect all users. The process varies, but each toilet in an urban area must be connected to large underground mains, which then feed into large wastewater treatment plants.



OVERFLOWING CITIES

Sewers aren't guarantees: In Delhi only 56 percent of waste is safely managed, because sewers leak and nearly a third of the booming city isn't connected. Many latrines empty into open drains, and 4 percent of residents – some 700,000 – defecate outdoors.



JASON TREAT, NGM STAFF; KELSEY NOWAKOWSKI

SOURCES: LINDA STRANDE, SWISS FEDERAL INSTITUTE OF AQUATIC SCIENCE AND TECHNOLOGY (EAWAG); EMILY C. RAND, WORLD BANK; CENTRE FOR SCIENCE AND ENVIRONMENT, NEW DELHI

a latrine pit so big they'll never have to empty it. Or that hundreds of millions of them—most of whom could afford a simple latrine—choose to conduct their business in the great outdoors.

GLOBALLY MOST PEOPLE who defecate outdoors live in rural areas. But in India the number of urban slum dwellers who do so is on the rise, as the population increases and villagers migrate to cities that are lacking in toilets, to say nothing of sewer pipes and treatment plants. Today 157 million people in Indian cities—37 percent of the urban population—lack a safe and private toilet. It's a crisis and an opportunity, says Pragya Gupta of WaterAid India, a charity that works on sanitation: "It's easier to do behavior change in slums because the need is right there, in your face."

Gupta and I are visiting Safeda Basti, a slum in East Delhi's Geeta Colony. The narrow streets bustle with commerce, jousting children, and women washing dishes in the open doorways of ramshackle homes. Laundry hangs from electrical wires, and toddlers crawl just inches from open drains. Lacking household toilets, people either relieve themselves in rubbish-strewn lots or queue up at a nearby community toilet complex.

I ask a group of women about the benefits of such facilities, expecting to hear about convenience, privacy, and safety. Instead I learn they're universally reviled. "We have to stand in a long line because there aren't enough toilets," a mother says, "so our kids are late to school." "People fight," her neighbor chimes in. "Girls are harassed at night." The squat pans are dirty, faucets broken, soap absent. "We feel suffocated indoors," a young woman says. Some complexes don't have roofs, a misery during the monsoon, and some lack electricity. As if that weren't bad enough, the complexes charge a few rupees per day and close between 11 p.m. and 4 or 5 a.m. At night, people in need do what they must.

Batting away flies, I follow a street drain that grows wider as it nears a fetid canal at the colony's edge. Eventually it will pour into the Yamuna River, a tributary of the Ganges. Drains such as this one collect wastewater from cooking and cleaning, but they also fill with litter, food scraps, and the urine and feces of children who can't make it as far as the toilets. In stagnant reaches, methane bubbles up through the gray-green water, and the stench of rotten eggs—hydrogen sulfide—wafts into homes. With so many people so close together and so much fecal matter in play, it's not surprising to learn from a local health worker that the colony's major medical problems are diarrhea and worms.

In other Delhi slums, street drains overflow during heavy rains, and water rises to mid-calf and rushes onto floors where residents sleep. Visiting several of these places, I hear one constant refrain: "We want a sewer, and we want our own toilets"—an aspirational leap over government-built latrines. But many slums are too crowded or structurally unsound for sewer lines, and the government is reluctant to provide services to residents it considers illegal, on land that may be slated for private development.

So where's the hope? Hacking their way through thickets of interdepartmental bureaucracy, WaterAid India and the Centre for Urban and Regional Excellence, a Delhi-based nonprofit, recently raised $28,000 to install a small, shallow sewer line in one of Safeda Basti's alleys. The pipe, which drops into a trunk line on the slum's border, was completed in 2015. Within months 62 households installed latrines, some atop their roofs, that emptied into the new sewer—subtracting 300 people from the crowds at the toilet complex.

All of a sudden seemingly intractable cultural taboos had fallen away: It was OK to live near a toilet. The way Gupta describes it, the sanitation challenge in Indian cities is roughly the opposite of the one in the countryside. Changing behavior in the city is relatively easy; building infrastructure—and maintaining it—are hard.

FOR BEZWADA WILSON, a Delhi-based human rights activist who works to uplift Dalits, the flush toilet is the only path to social emancipation. "India has electricity and roads," he says. "We deliver natural gas. And when it comes to drains and sewers, the government doesn't have

HAITI In Port-au-Prince, Exilien Cenat stands above the hole in a communal outhouse. Working at night to avoid public scorn, he empties the pit with his hands and a bucket, collects the waste in bags, and dumps the bags into ditches or canals. Flush toilets and sewers would be a more sanitary solution, but they're simply too expensive.

HAITI Outside the town of Dame-Marie, residents bathe, wash clothes, and collect drinking water in streams. But they also defecate nearby, and storms sluice waste into the water. After Hurricane Matthew hit in 2016, the area suffered a resurgence of cholera, a bacterial disease that spreads when infected feces contaminate water and food.

HAITI It took Fritznel Xavier's parents six hours to carry the vomiting teenager to the cholera treatment center in Jérémie. Stabilized with intravenous fluids, Fritznel survived but returned to a village that lacks adequate toilets. Cholera most frequently afflicts the young and the old. In Haiti it sickened tens of thousands in 2016.

the money?" He shakes his head, incredulous. Even in rural areas Wilson doesn't see the point in promoting pit latrines. "More latrines will only lead to more coerced manual cleaning," he says.

Besides being expensive, however, flush toilets and sewers require running water, which many parts of India still don't have. As the country develops, such amenities may become universal—but that day is surely decades away. In the meantime millions more children will have died. The question is how best to reduce that number.

Technology can help. Waterless, solar-powered toilets that are under development will sterilize the waste they collect, making it safe to use on crops or as charcoal. A cheaper, simpler solution, available now, involves composting latrines that have two pits spaced about a yard apart. After the first pit fills, waste is diverted into the second pit. Long before it fills, the contents of the first pit dry out, pathogens die, and the crumbly remains—high in nitrogen, phosphorus, and potassium—can be safely applied to farm fields.

But the pit still does have to be excavated—and that has sharply limited the spread of twin-pit latrines in India. "Villagers say, 'No matter how dry it is, it's still poop,'" RICE's Srivastav says. "'Removing it will make me untouchable. People will not want to share a hookah with me.'"

For RICE's Diane Coffey, that prejudice is the nub of India's problem. Teaching people that ordinary pits take years to fill, not months, is important, she says; so are affordable pumps that would make emptying pits more hygienic and less disgusting. But the most important thing India can do to stop open defecation, Coffey says, is "to confront casteist ideas that make internationally normal latrine pits unacceptable." Emptying a latrine is never pleasant, she and Dean Spears write in their book, *Where India Goes*. But in other nations it's at least not "a symbol of generations of oppression and humiliation."

Parameswaran Iyer, India's secretary of drinking water and sanitation, acknowledges the role that caste plays in sanitation. "But the Swachh Bharat mission is actually helping to break down barriers," he insists, "because a village can't become open defecation free if different sections aren't ODF. The entire community is in it together." Iyer turns toward a hand-numbered sign on his office wall. "You see that?" he asks. "One hundred thousand is the number of villages that are ODF today." Just 540,000 to go, I note, three years before Modi's deadline.

Iyer remains undaunted. The government rewards certified ODF villages by moving them to the front of the line for road or drinking-water improvements, he says. It has launched an advertising campaign that exalts Swachh Bharat mascots, like the 106-year-old woman in Chhattisgarh state who sold seven goats to build two toilets. It has enlisted cricket and Bollywood stars to exhort people to use the new latrines. On the subject of emptying them, the ads are silent.

Meanwhile villages keen on ODF status are taking action against violators—Moolchand chasing furtive lota-carriers is just one example. In some villages, watch committees post photographs of violators on the Internet or shame them on the radio. Village leaders may even jail offenders or fine them 500 rupees—more than twice what a farmhand earns in a day—while district leaders may cut off government rations of rice, wheat, sugar, oil, or kerosene.

All these measures are beginning to have an impact, Iyer says. "Even if there are centuries of old habits and beliefs, I think they are changing a little. The momentum has picked up."

That may be true, but critics say the government's analysis of the remaining challenge is too rosy. Citing UN statistics, it says that the open-defecation rate declined from 75 to 44 percent of the population between 1990 and 2015. But that estimate reflects only the number of latrines that have been constructed—not the

VIETNAM In the southern village of Vinh Xuyen, Phham Thi Lan washes her son with pond water beside the family latrine, which drops nutrients into their fish farm. Recycling feces this way is an old practice that's better than open defecation and can be done safely – but separating waste from drinking and bathing water is imperative.

number that are actually used, consistently, by every family member.

EARLY ONE MORNING IN A VILLAGE north of Bhopal, more than a hundred people gather in an open area, where Santoshi Tiwari, a sharp-tongued field-worker with Samarthan, a regional nonprofit, tells them to sit down, close their mouths, and listen. First she asks what they're proudest of in their village. The temple, they say. And what gives them the most shame? The human waste along the roads.

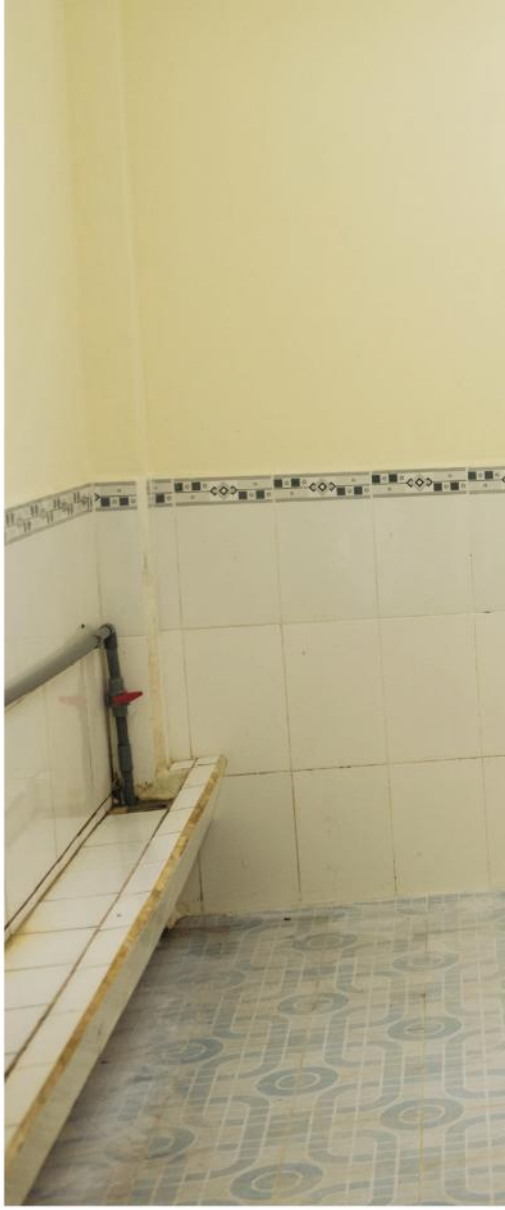
Like a Pied Piper, Tiwari then leads the villagers past their temple and into a recently plowed field, where she suddenly halts. "What is this?" she demands, pointing toward the ground.

A few wags offer variants on the technical term. Tiwari asks if the excrement can be identified—by man, woman, child, or caste. "It's from the lower caste," a woman says, "because this is a lower caste area." Tiwari moves on: How many people live here? About 1,500, a young man shouts. Tiwari explains that each person daily produces more than half a pound of feces, which means the village annually produces around 300,000 pounds. The crowd murmurs, and Tiwari leads them in a round of mocking applause.

Now she turns serious. She explains how feces circulate through the village on the legs of flies, in water, and in dust. She opens a bottle of water, pours some into a plastic cup, and sips. Then she plucks a long hair from her head, draws it through the pile at her feet, and swirls the filthy strand in her water cup. The crowd steps backward; their faces contort with disgust. "Would you drink this water?" Tiwari asks, proffering the cup. "This is just one hair," she adds. "Flies have six legs."

Triggering disgust—by mapping and quantifying feces and dipping tainted hairs in drinking water—is the hallmark of "community-led total sanitation," an approach that has been credited with reducing open defecation in places not plagued by caste division. Today's gathering is an opening salvo: Sensing commitment, Tiwari promises to return to help residents navigate the paperwork for the government subsidy, purchase bricks, and train masons to build pits. Settling who will empty them is beyond her brief, as is what happens to the sludge—a long-standing problem India scarcely has begun to address. But even if the sludge is merely dumped in some far-off ditch, it poses less of a health threat than individual piles of feces on nearby roads and fields.

Samarthan and other aid groups promote twin-pit latrines and the harmless fertilizer they



Elizabeth Royte has written books on trash and water, and her last article for *National Geographic* was on food waste. **Andrea Bruce** focuses on people living in the aftermath of war; she photographed Damascus for the March 2014 issue.

VIETNAM Indoor plumbing in newer schools has helped whittle Vietnam's open-defecation rate from 39 percent in 1990 to almost zero today. Even young students, like this five-year-old in Ben Tre city, act as sanitation ambassadors, bringing home lessons on toilet use and handwashing to share with their families.

yield. After Tiwari's presentation I ask a village elder, a non-Dalit, what he'd do after his pit was full. "It will be like mud, so we'll have no problem emptying it ourselves," he says. I want to believe him. But many others, in supposedly ODF villages, have told me they'll call a Dalit.

Back in the center of the village, Tiwari reminds her audience of the link between feces and diarrheal illness and calculates that the village spends tens of thousands of rupees a year on medicine. "You are enriching the doctors," she squawks. "Imagine how you could improve your house or your roads with that money." Tiwari appeals to their dignity. She shames them for spending rupees on mobile phones, or a thousand kinds of funeral foods, instead of on toilets.

She tries every argument. Then, after an hour-long harangue, Tiwari asks, "Should this change?" "Yes!" the crowd shouts. "Who will end open defecation?" she screams. A hundred hands shoot skyward. □

BOLT FROM THE BLUE

Can the shortfin mako, the fastest shark in the ocean, outswim our appetite?

A shortfin mako flashes in front of an intruder, introducing itself as a force to be reckoned with in waters off the coast of New Zealand.

By Glenn Hodges
Photographs by Brian Skerry

Zane Grey made his name writing adventure novels about the American West, but his real love wasn't gunslinging or cowpoking; it was deep-sea fishing. He held 14 world records for catching saltwater fish, including the first billfish over 1,000 pounds landed with a rod and reel, a marlin he caught in Tahiti in 1930. But nothing compared to the shortfin makos he encountered off the coast of New Zealand in 1926.

The first mako Grey got on the line was a 258-pounder, and when he reeled it to the side of the boat, "quickly I learned something about mako!" he wrote in his book *Tales of the Angler's Eldorado, New Zealand*. "He put up a terrific battle, broke one gaff, soaked us through with water, and gave no end of trouble." Once the shark was landed, Grey marveled at its build—streamlined, muscular, with a head like a bullet. "I had never seen its like," he wrote. "Every line of this mako showed speed and power."

But it was the 1,200-pounder that the captain of his boat battled that led to almost mythical superlatives. After a long fight in which the mako "leapt prodigiously and made incredible runs," the shark bit through the leader and escaped. "I was terrified," the captain told Grey. "It seemed that mako filled the whole sky. He was the most savage and powerful brute I ever saw, let alone had on a line!"

Almost a century later, shortfin makos still have a herculean reputation among fishermen, who love them for their fight and their meat in equal measure. But a century of fishing appears to have taken a toll. Shortfin makos—which are distinguished from their much rarer cousins, longfin makos, by, among other things, their shorter pectoral fins (in this article, "makos" will refer to shortfin makos)—are eagerly targeted by recreational fishermen and frequently caught as bycatch by commercial long-liners. Their meat rivals swordfish in quality, and their fins are prized in Asia for shark fin soup, a combination that has put makos under significant pressure. But how much pressure, and to what ultimate effect, is uncertain. Scientists have no clear idea how many makos there are in the Earth's oceans, and most of the data on catch and mortality rates come from commercial fishing operations, which famously tend to underreport catches. So biologists studying makos are trying to fill in some huge knowledge gaps.

In the summer of 2015 I was invited to join a mako-tagging operation off the Maryland coast with scientists trying to bridge some of those gaps. I thought it would go like this: We catch big makos; they put on the kind of show that Zane Grey saw; and I get great color for this story. Instead, I learned firsthand that Mark Twain was right about seasickness ("At first you are so sick you are afraid you will die, and then you are so sick you are afraid you won't") and was woozily indifferent when the

VIDEO

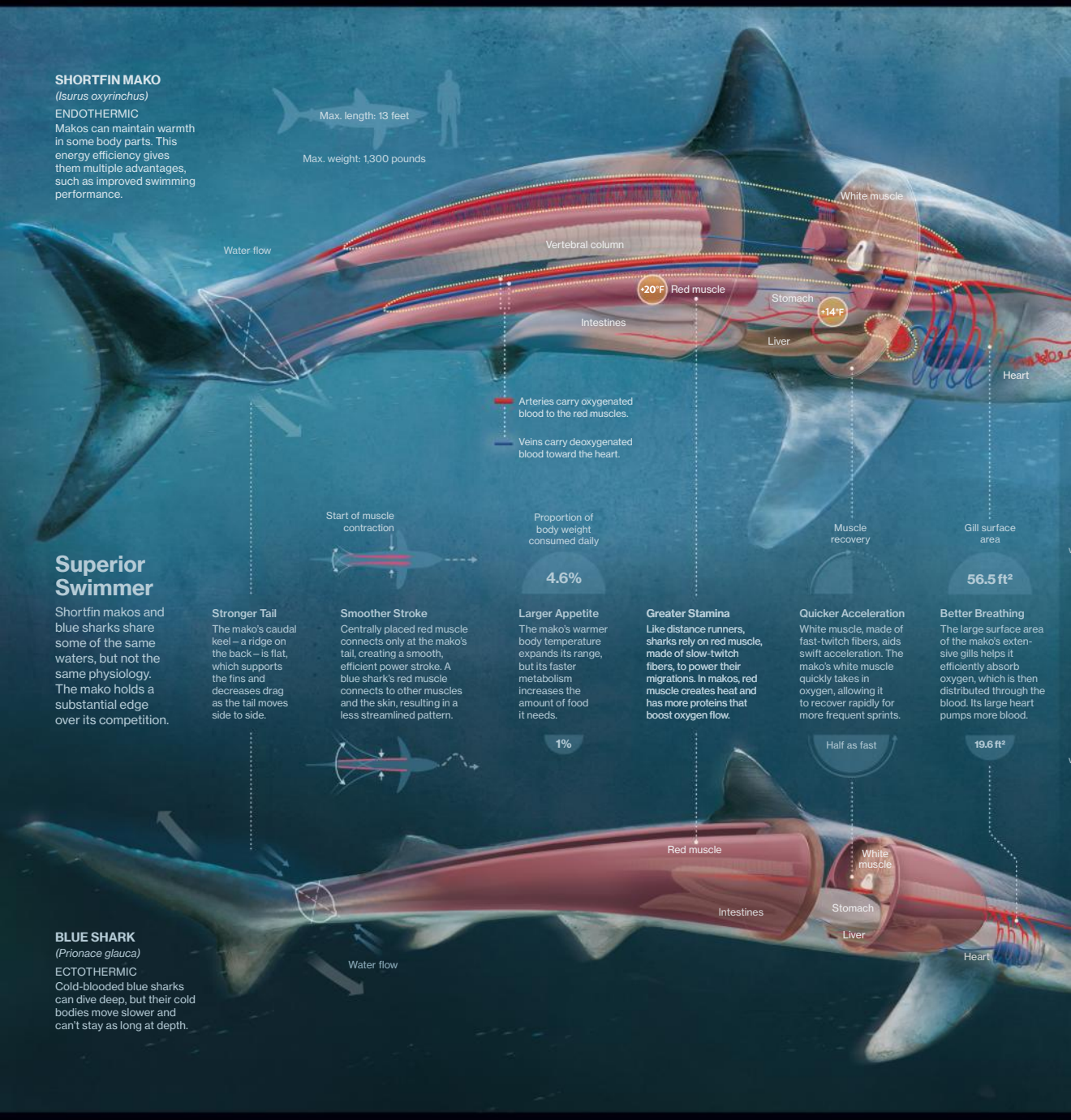
Go underwater and glide alongside mako sharks in action at *ngm.com/Aug2017.*

SHARK WEEK ON NAT GEO

Tune in to Nat Geo WILD's annual SharkFest, starting Sunday, July 23, at 8/7 central.

"Torpedoes with teeth." That's how photographer Brian Skerry describes shortfin makos. "That conical nose just pierces through the ocean." Though mature females can exceed 1,300 pounds, the sharks remain fast enough to ambush speedy tuna.

A diver keeps close tabs on a juvenile mako off the coast of San Diego, in an area where the sharks are known to give birth. Mature females bear as few as four young every three years.


SHORTFIN MAKO
(Isurus oxyrinchus)
ENDOTHERMIC
Makos can maintain warmth in some body parts. This energy efficiency gives them multiple advantages, such as improved swimming performance.
Max. length: 13 feet
Max. weight: 1,300 pounds
Water flow
Vertebral column
White muscle
+20°F
Red muscle
Stomach
+14°F
Intestines
Liver
Heart
Arteries carry oxygenated blood to the red muscles.
Veins carry deoxygenated blood toward the heart.
Start of muscle contraction
Proportion of body weight consumed daily
4.6%
Muscle recovery
Gill surface area
56.5 ft²
Superior Swimmer
Shortfin makos and blue sharks share some of the same waters, but not the same physiology. The mako holds a substantial edge over its competition.
Stronger Tail
The mako's caudal keel – a ridge on the back – is flat, which supports the fins and decreases drag as the tail moves side to side.
Smoother Stroke
Centrally placed red muscle connects only at the mako's tail, creating a smooth, efficient power stroke. A blue shark's red muscle connects to other muscles and the skin, resulting in a less streamlined pattern.
Larger Appetite
The mako's warmer body temperature expands its range, but its faster metabolism increases the amount of food it needs.
Greater Stamina
Like distance runners, sharks rely on red muscle, made of slow-twitch fibers, to power their migrations. In makos, red muscle creates heat and has more proteins that boost oxygen flow.
Quicker Acceleration
White muscle, made of fast-twitch fibers, aids swift acceleration. The mako's white muscle quickly takes in oxygen, allowing it to recover rapidly for more frequent sprints.
Better Breathing
The large surface area of the mako's extensive gills helps it efficiently absorb oxygen, which is then distributed through the blood. Its large heart pumps more blood.
1%
Half as fast
19.6 ft²
Red muscle
White muscle
Intestines
Stomach
Liver
Heart
Water flow
BLUE SHARK
(Prionace glauca)
ECTOTHERMIC
Cold-blooded blue sharks can dive deep, but their cold bodies move slower and can't stay as long at depth.

Ultimate Hunter

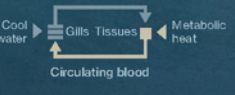
Though not as big as great whites or tiger sharks, shortfin makos are among the most versatile marine predators, built to race and range. Able to hit 35 miles an hour while chasing prey, they're the fastest sharks over short distances. Because they can maintain the temperature of key body parts, they venture into depths and latitudes too cold for most other shark species.

The heat advantage

Three heat-exchange systems allow the mako to retain heat in the red muscle, liver and digestive organs, and the eyes and brain.

More Heat

All sharks lose heat in their gills, but the mako's unique arrangement of veins and arteries allows transfer of heat between warm and cool blood, trapping heat around viscera and red muscle and pumping warm blood to the brain.



Mouthful of Weapons

Like all sharks, makos have teeth optimized for their prey. Needle-like teeth allow them to grab and hold some of the ocean's fastest targets – tuna, swordfish, and other sharks.

The fastest shark (miles an hour)

*TOP SWIMMING SPEEDS ARE APPROXIMATIONS. NO RELIABLE MAXIMUMS HAVE BEEN RECORDED IN THE WILD.

FERNANDO G. BAPTISTA AND MATTHEW W. CHWASTYK, NGM STAFF, LAWSON PARKER, SHIZUKA AOKI

SOURCES: DIEGO BERNAL, UNIVERSITY OF MASSACHUSETTS DARTMOUTH; KENNETH J. GOLDMAN, ALASKA DEPARTMENT OF FISH AND GAME; GUZMAN DIEZ, AZTI, MARINE RESEARCH DIVISION; MALCOLM FRANCIS, NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH; IUCN, FISHERIES AND AQUACULTURE DEPARTMENT, FAO

Three sharks is a crowd for makos, which tend to be solitary and highly migratory, sometimes crossing the waters of more than a dozen countries. One shark tagged near New Zealand, where mako populations are robust, traveled 11,600 miles in a year.

fishermen on board reeled in two small makos, neither of which put up much of a fight. So I decided to try again—this time with a seasickness patch—in Rhode Island later in the summer. And that's when I saw what I really needed to see.

On each trip I accompanied scientists affiliated with the Guy Harvey Research Institute, which has been tagging and tracking makos in the Atlantic Ocean and Gulf of Mexico since 2008, with the primary objective of studying the sharks' movement patterns. Makos in the western North Atlantic are highly migratory, traveling northward during the warmer months and then south as winter approaches. The excursions off Maryland's coast in May were a resounding success: Over two weeks, 12 makos were fitted with satellite transmitters. By contrast, the Rhode Island excursions in August were a resounding failure: one week, zero makos. But that contrast offered a clue as to what might be happening with makos in the Atlantic.

To pick up on the clue, you have to know one of the first things you learn when you're fishing for makos: They share territory with blue sharks. The two species are kind of like lions and hyenas, coexisting in the same areas as they pursue different feeding strategies. Shortfin makos are the fastest sharks in the ocean, capable of reaching 35 miles an hour as they chase down speedy prey such as bluefish and tuna, and sport fishermen love their power. Blue sharks, on the other hand, are relatively laconic and focus on slower prey, like squid. Catching them is like, in one fisherman's words, "reeling in a barn door," and their meat is not nearly as good to eat as a mako's. So you can guess which one is the lion in the analogy and which is the hyena. Everyone wants to bag the lion.

On our second day out of Narragansett, Rhode Island, as we hauled yet another blue shark to the side of the boat, I finally took note of the obvious.

"It seems like all the blue sharks have hooks in their mouths," I said. Brad Wetherbee, the marine ecologist from the University of Rhode Island who was there to tag any makos we caught, said, "Yup. Every one we've brought back to the boat so far has had a hook in it."

Removing a hook from a shark's mouth can be dangerous, so fishermen just cut the leaders and leave the hooks to rust away. And because the fishermen are after makos, they're much more likely to release blue sharks. "I've never seen a mako with a hook," the ship's mate, Lucas Berg, told me our first day out. "People don't ever let them go. But we've caught blue sharks with four hooks in their mouth."

The fishing pressures on makos are intense, Wetherbee explained. The ones we were trying to catch swim northward up the Atlantic coast in the summer, and between everyday recreational fishing and the dozens of shark-fishing tournaments held between Maryland and Rhode Island, it's a perilous journey for the sharks. "A lot of them have been weeded out by the time they get up here," Wetherbee said.

"Is the catch rate sustainable?" I asked him. Makos, like many sharks, are especially vulnerable to overfishing because of their small litters and high age of sexual maturity. (One study suggests that female makos don't reach maturity until around 15 years old or later, but these figures are not definitive. Biologists agree more research is needed.)

"We don't know," he said. "These are far-ranging, international sharks—some of our [tagged] makos have gone into the waters of at least 17 different countries—and there's not enough data for management agencies to come up with a good estimate of whether the population is going up or down or staying the same. There's probably some number of mako sharks that would be fine to catch and kill. But we don't know if it's 100, or 1,000, or 100,000."

According to the National Marine Fisheries Service, which regulates fishing in U.S. waters, makos are being fished at a sustainable level. This assessment is based largely on catch figures supplied by commercial long-liners to the international organization that regulates fishing for tuna and other pelagic fish in the Atlantic, and those figures show a relatively consistent harvest over recent years, suggesting that mako populations are stable. But the figures are an imprecise measure. The catch is recorded in metric tons, and basic information

■ **Society Grant** Your National Geographic Society membership helped fund this project.

like the number of sharks caught, and the size and sex of those sharks, can be missing. On top of that, many catches go unreported, leading scientists to question the reliability of both the data and the stock assessments.

What Wetherbee and his team do know is that the sharks they're tagging are not faring well. The tags they use—about the size of a Zippo lighter, mounted on the dorsal fin—send signals to satellites every time the sharks surface, allowing researchers to create detailed maps of their movements. When the signals start coming from land, they know the sharks have been caught. "We've tagged 49 makos, and 11 have been killed," Wetherbee told me. (Within a month, that number had increased to 12.) I said that seemed like a lot, and he agreed: The sample size is small, but the catch rate is troubling.

Back on land, I called Mahmood Shivji, the Nova Southeastern University scientist who leads the tagging project. "What amazes me," he said, "is that it's a vast ocean out there and these animals move a lot, and yet these tagged animals are running into fishing hooks to the tune of 25 percent. No shark fishery can sustain a 25 percent removal every year."

AFTER MY SEASICK CRUISE, I returned to the Maryland shore for Mako Mania, an annual shark-fishing tournament held at the Bahia Marina in Ocean City. This Mako Mania should not be confused with the Mako Mania tournament in Point Pleasant, New Jersey—or, for that matter, with the Mako Fever tournament in New Jersey or the Mako Rodeo tournament, also in New Jersey, or with any of the other 65 or so U.S. tournaments that include prizes for pelagic sharks like makos, threshers, and tiger sharks. After *Jaws* hit theaters in 1975, tournaments popped up along the eastern seaboard, and ever since, summer has not been a good time to be a shark in the North Atlantic.

I arrived at the marina just as the first sharks were being brought to the docks. It was a festive scene—hundreds of people eating and drinking and cheering for the anglers and their kills. Next to me a woman and a young boy watched as a 282-pound mako—the winner in the mako category, it turned out—was hoisted to be weighed. The anglers pulled up the snout for photographs, and the woman turned to the boy and said, "This is really cool, right?" The boy nodded silently, transfixed by the shark's bloody grimace.

Sport fishermen love the mako's power. It's able to jump 10 to 15 feet on the line, and its meat is among the tastiest of all sharks.

As the sharks continued rolling in—147-pound mako, 466-pound thresher, 500-pound thresher, 174-pound mako—I talked with the tournament's organizer, Shawn Harman. "What's more fun than seeing sharks?" he asked, surveying the cheering crowd. When we got to some of the knottier questions about the controversy over "kill tournaments," as critics call them (versus "no kill" or "catch and release" tournaments, which are rare but do exist), he explained that his tournament was not like those of old—back in the 1970s and '80s, when the sharks would pile up on the docks and go wholesale into the Dumpster afterward. Here, the only sharks brought to the dock were threshers and makos, the best tasting sharks in the ocean, with minimum sizes and a catch limit of one fish per boat per day. (Over the course of three days, 16 sharks were brought to the dock to be weighed.) "Nobody's wantonly killing fish here. Everyone here eats what they kill."

I asked him where I might find mako on the menu, to see what it tastes like, and he fetched a fillet from one of the sharks just brought in, had it blackened, and served it to me on a bun with wasabi mayo. It was delicious—as good as any billfish I'd ever had.

But the tasty sandwich and the festivity of the scene could not entirely conceal the problematic nature of the event. Later in the day, one of the fishermen told me that a 500-pound thresher shark brought in earlier had been pregnant, and when it was gutted, the tournament staff tried

A mako prowls near a drifting clump of kelp off the San Diego coast. Such patches of floating kelp anchor miniature ecosystems, with larger fish preying on smaller fish and makos at the top of the food chain.

to hide the pups from the crowd. Threshers, like makos, are considered "vulnerable" by the International Union for Conservation of Nature, and though killing the pregnant females of vulnerable species may be legal, it makes for bad publicity.

I asked Harman about the pregnant shark. He denied the story, so I asked one of the guys cleaning the fish, and he said yes, there had been three or four pups, each two to three feet long. I went back to Harman to ask him why he denied it. He got a little flustered and told me he was afraid of being the "bad guy" in the story. "We're following the law, according to what the law says is sustainable," he said. "If they make it illegal, we'll stop."

This juvenile mako "came in hot," says Skerry, and destroyed part of his camera's housing. Though makos rarely attack humans, the human threat to the sharks is substantial. In 2007 they were classified as vulnerable because of overfishing.

THE CAPTAINS OF THE BOATS I went out in for those tagging operations in Maryland and Rhode Island are both longtime shark fishermen. They are not reflexively against the capture and killing of fish, and they are not squeamish about what deep-sea fishing entails. But both men have qualms about how sharks are being fished.

Mark Sampson, the Maryland captain, started a prominent shark-fishing tournament in Ocean City in 1981 and ran it for more than three decades. But he became increasingly concerned about the conservation of shark populations, so he made his size limits more restrictive to reduce the number of sharks caught. He also insisted that anglers use "circle hooks," which, in contrast to conventional "J-hooks," don't lodge in a shark's stomach when swallowed and result in fewer unnecessary killings. Some fishermen balked, participation declined, and because of the higher size limits, he said, "we had days in our tournament where not a single shark was brought back to the dock.

"That's not the recipe for a successful tournament, because people want to see those fish being brought in and weighed," Sampson said. He shuttered his tournament in 2014, and he doesn't accept charters for anglers who want to use his boat to participate in other shark tournaments.

Charlie Donilon, the Rhode Island captain, has run shark-fishing charters since 1976. Where Sampson is quiet and circumspect, Donilon is talkative and emotional, and on one of those days in August when we were on the boat waiting for the fish to bite, he told me about the time a client reeled in a mako that refused to go gently.

"I threw a harpoon in it, then I hit it with a flying gaff, and then tied it down to a side cleat, and the thing is scratching and blasting blood everywhere, and it's all being recorded by the client. The guy sent me the video, and I watched it with my wife, and she asked, 'Does that bother you?'"

It did, he said, and he started trying to persuade his customers to release the sharks they caught. "I'd tell people, a 100-pound mako is just a tot, just a kid, because they have the potential to grow to 1,000 pounds or more. So I'd really like to let it go, because it's an immature fish." But since almost all the makos they catch out there are juveniles, it stopped making sense to even ask the anglers. So in 2015 Donilon instituted a catch-and-release

policy, no exceptions. His business has taken a hit. "I'm way off what I used to be," he said.

Donilon accepts the loss of business because it doesn't seem to him that the fishing is sustainable, no matter what the government says. "The sharks we tag, there's like a gantlet they have to go through coming up the coast. They've got to go through Maryland, New Jersey, Long Island, Massachusetts—and everyone in the world is out there fishing," he said. "They've got to be at least 15 years old in order to reproduce, the females. Now what are the odds of that shark making it up here 15 times without being caught? Pretty slim."

I thought of all the blue sharks we'd seen with hooks in their mouths, and it seemed to me he was right: pretty slim. Although most of the tagging study's casualties had been killed by commercial fishermen in international waters—not by recreational fishermen—the Fisheries Service's statistics attribute the majority of the mako kills in the U.S. to recreational fishermen. So who is fishing too much, and where? Empirically, it's still too soon to say. But Donilon, at least, doesn't need to wait for more data to render his verdict.

"I did my share of killing," he said one afternoon on the boat. "You know how there might be a guy in Africa who used to be a poacher, and he used to kill all the lions…" And as he said this, his eyes teared up and his voice started quivering, and finally he choked out a half whisper: "You've got to give back. We just take, take all the time…" □

Glenn Hodges wrote about oceanic whitetip sharks in the August 2016 issue. Photographer **Brian Skerry** has been named the Rolex National Geographic Explorer of the Year for 2017.

Parasitic copepods cling to the fin of a shortfin mako. They feed on different parts of the shark's body, eating everything from mucus and blood to upper layers of skin.

ANCIENT SITES AS SEEN FROM SPACE

By A. R. Williams

Archaeology isn't always a dirty job. Sometimes it means sitting at a computer and studying satellite images one by one to see if they show traces of long-lost ruins or threats to ancient sites. National Geographic Fellow Sarah Parcak, a pioneer of what's been called space archaeology, has screened plenty of those images herself. But she wondered if volunteers might be able to help.

In January she launched a crowdsourcing experiment that allowed volunteers to be virtual sleuths in the archaeologically rich country of Peru. Dubbed GlobalXplorer, the project was set up as a game using images from a company called DigitalGlobe that covered some hundred thousand square miles of farms, towns, and countryside. The response was huge. "We got more than 45,000 users and 10 million image views," Parcak said in April, near the end of the project. "Which is a little bonkers."

Identifying signs of looting, encroachment, or a potential discovery involved a learning curve, I found out. I played for weeks before I realized that the faint threads streaking across an occasional image were power lines and the little white beans strewn across some fields could be livestock. I don't know if I made any big discoveries in the 15,000 images I viewed, but other volunteers must have.

"The crowd was really, really good at finding things," said Parcak. "In one small area alone, just north of Lima, the users found almost 3,000 archaeological features." An initial review turned up very few false positives. The results were so encouraging that Parcak has plans to begin surveying another country.

These are some of the satellite pictures that GlobalXplorer volunteers considered.

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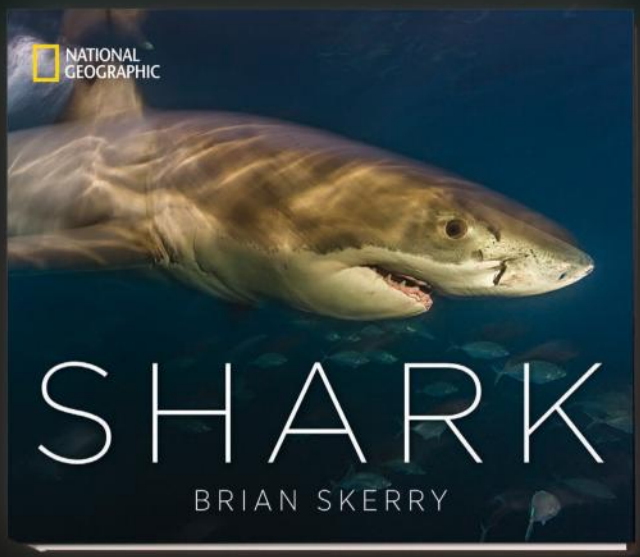

This magnificent collection of award-winning photographer Brian Skerry's best shark images illustrates the beauty and the power of these feared and revered creatures. Over the past four decades, Skerry has braved ocean depths and the jaws of predatory giants to capture the most remarkable photographs of sharks around the world. His personal reflections on his interactions with sharks demonstrate the crucial impact these top predators have on their environments and their importance to the health of the oceans.

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