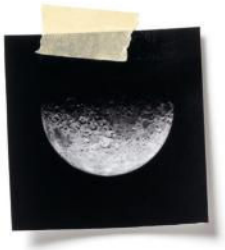
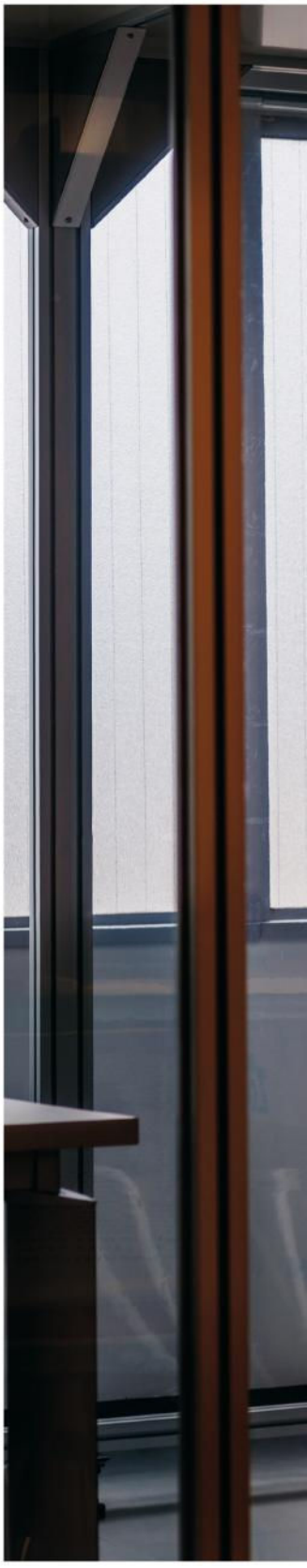

SELF-STYLED MESSIAHS
FASTEST SHARKS IN THE SEA
ARCHAEOLOGY BY SATELLITE
NATIONAL GEOGRAPHIC
THE SPACE ISSUE
THE NEXT MOON SHOT
IN ORBIT WITH SCOTT KELLY
VOYAGER, 40 YEARS LATER
BEST ECLIPSE IN A CENTURY
AUGUST 2017



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.

L
AP
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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.

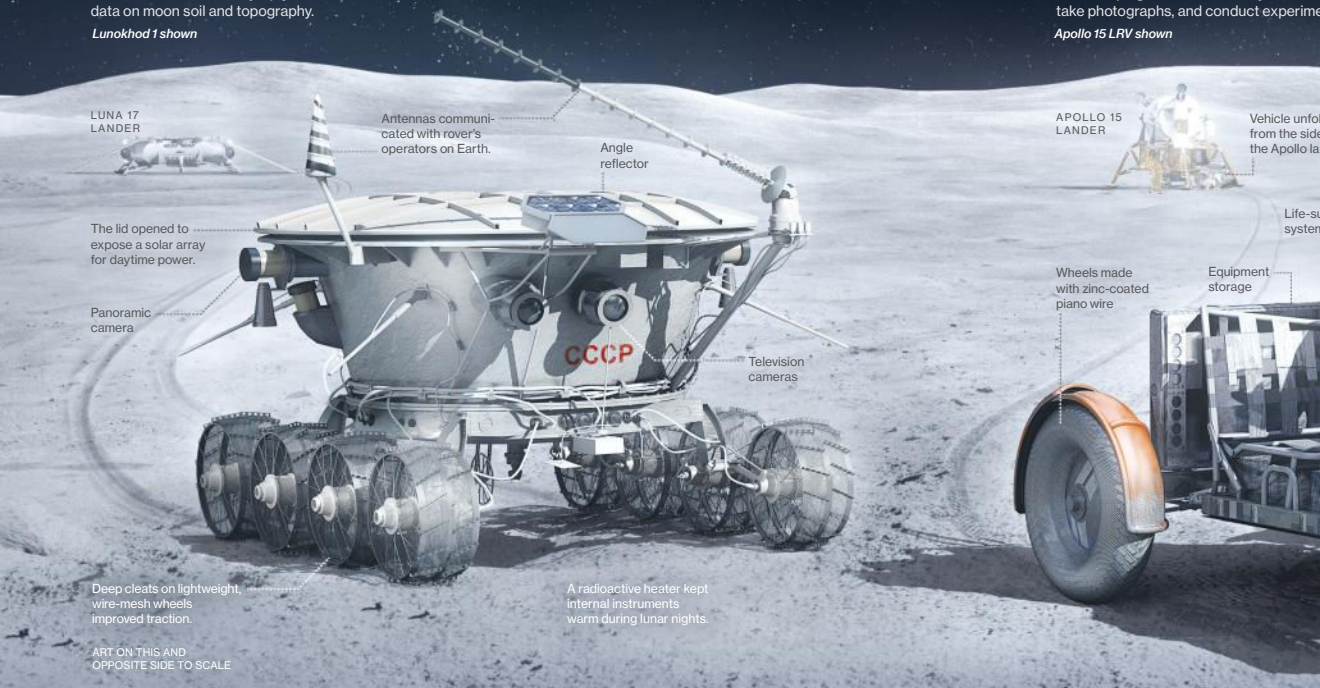
Lunokhod 1 shown

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

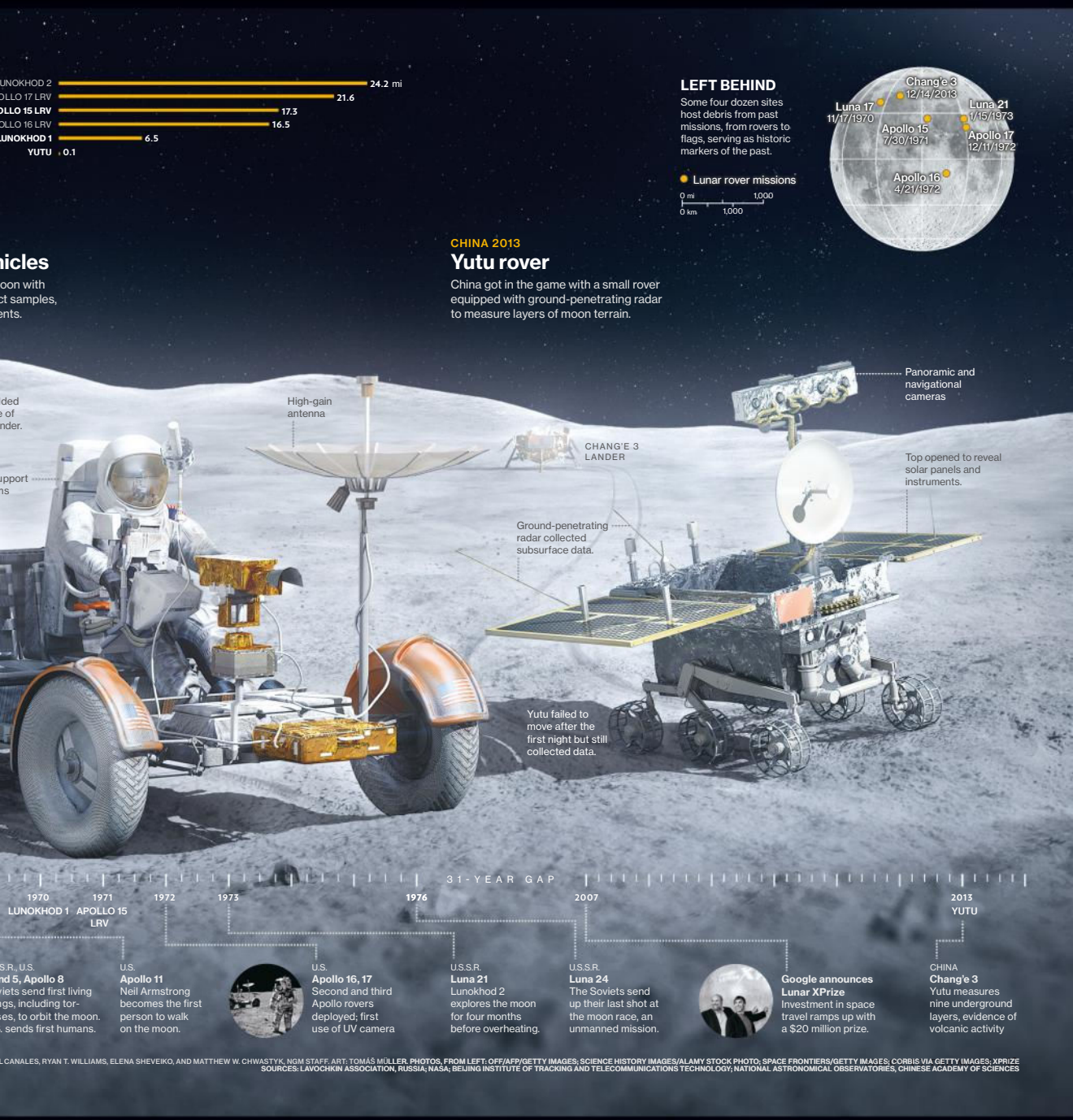
U.S.S.R.
Luna 9, 10
First soft lunar landing; first artificial satellite to orbit the moon

1968

1969

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

MANUE



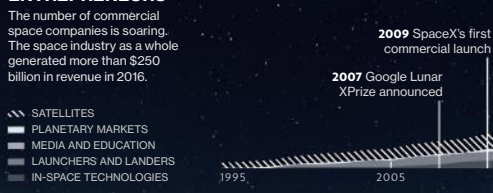
L CANALES, RYAN T. WILLIAMS, ELENA SHEVEIKO, AND MATTHEW W. CHWASTYK, NGM STAFF. ART: TOMÁS MÜLLER. PHOTOS, FROM LEFT: OFF/AFP/GETTY IMAGES; SCIENCE HISTORY IMAGES/ALAMY STOCK PHOTO; SPACE FRONTIERS/GETTY IMAGES; CORBIS VIA GETTY IMAGES; XPRIZE
SOURCES: LAVOCHKIN ASSOCIATION, RUSSIA; NASA; BEIJING INSTITUTE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

Team *Craft*

TeamIndus / ECA

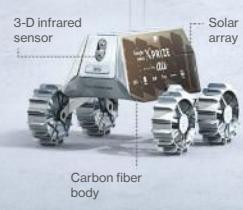
The largest rover hails from engineers in India's "Silicon Valley" and was tested in rock quarry dust. The team also is under contract to land the Japanese rover.

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.

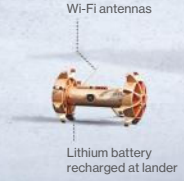
4 · 8.8 LBS · 10 MIL



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.

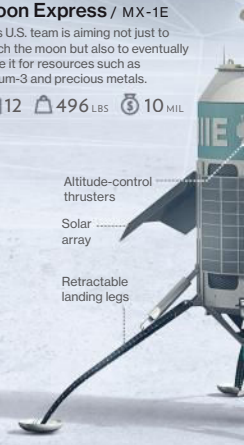
1 · 1.5 LBS · 15 MIL



Moon Express / MX-1E

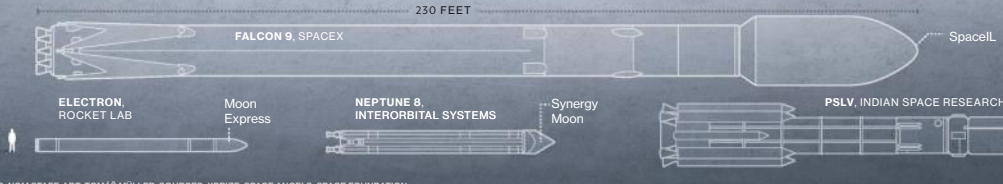
This U.S. team is aiming not just to reach the moon but also to eventually mine it for resources such as helium-3 and precious metals.

12 · 496 LBS · 10 MIL



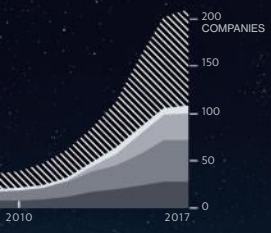
REACHING THE MOON

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

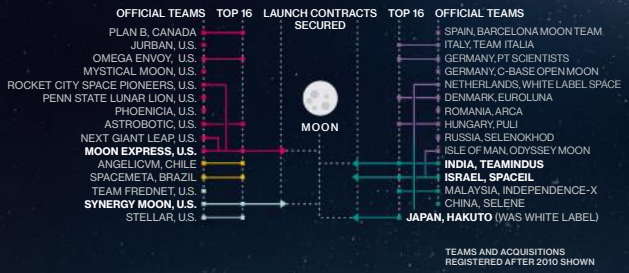
MANUEL CANALES, RYAN T. WILLIAMS, AND DAISY CHUNG, NGM STAFF. ART: TOMÁŠ MÜLLER. SOURCES: XPRIZE; SPACE ANGELS; SPACE FOUNDATION



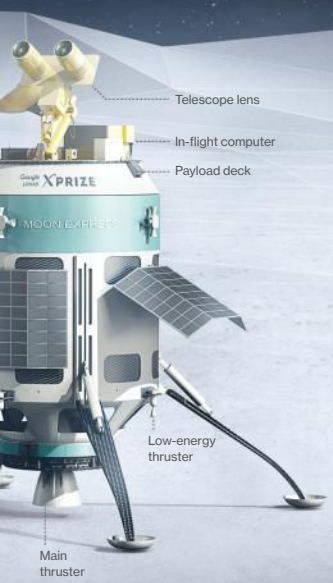
COMPETING FOR THE FUTURE

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



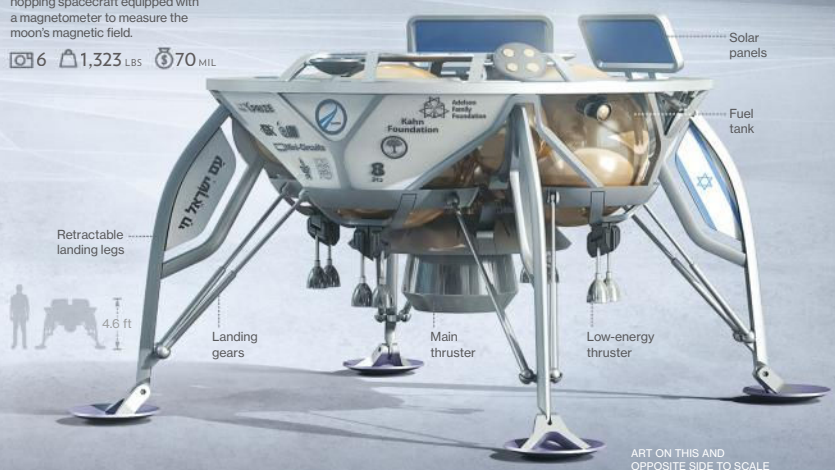
TEAMS AND ACQUISITIONS REGISTERED AFTER 2010 SHOWN



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



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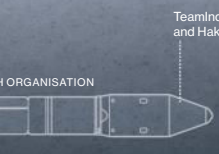
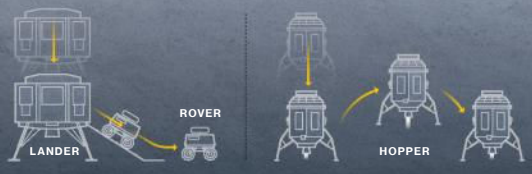


ROVERS VS. HOPPERS

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.

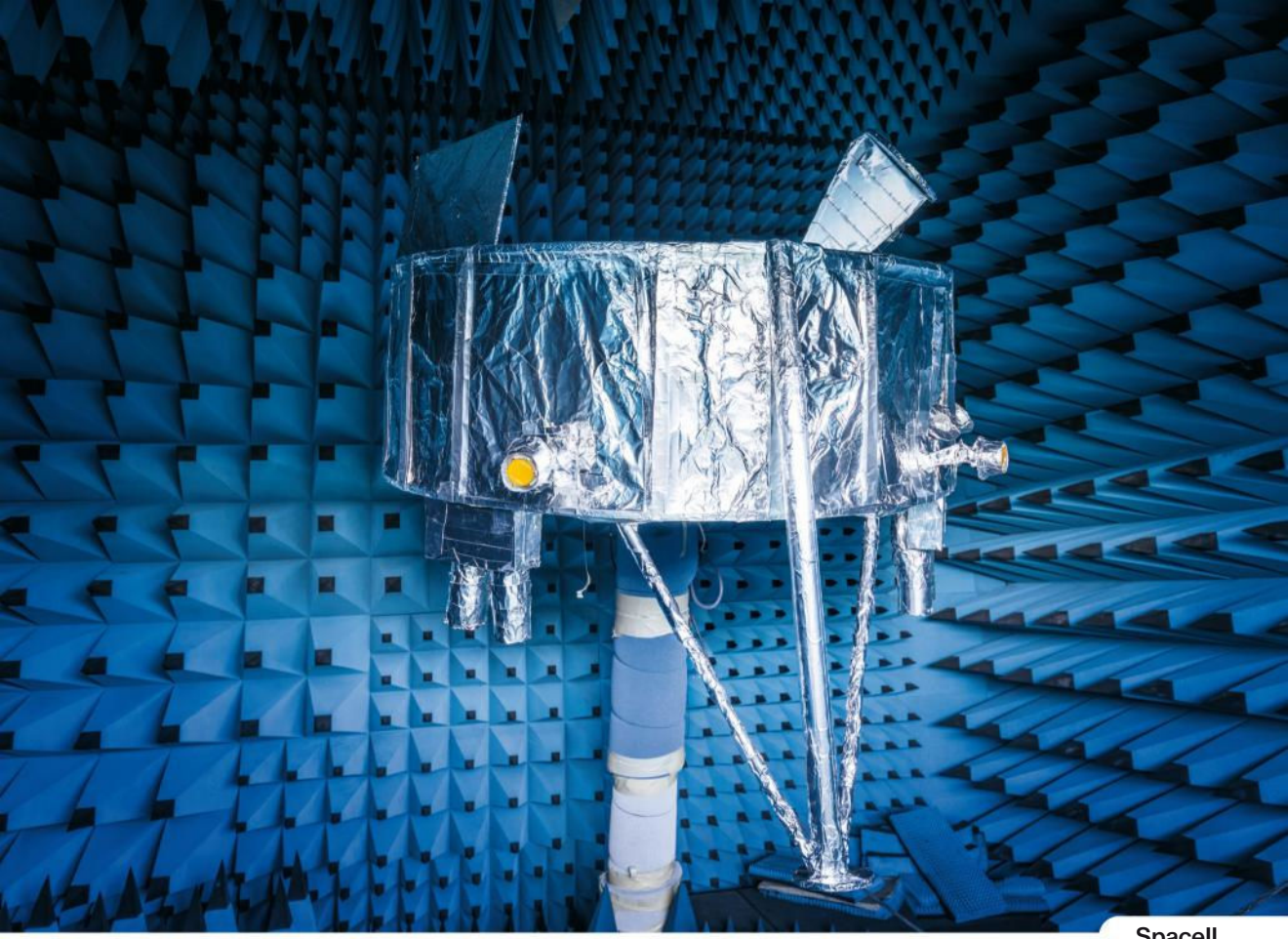
"A company like ours can do the math and show investors that we really do have a feasible plan to make money," Thornton says. "Not many years ago, that would have been science fiction."

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.