

**JUPITER:**  
Opposition at Last!

PAGE 48

**TEST REPORT:**  
QHYCCD's MiniCAM8

PAGE 72

**DIY:**  
Turn a Newton into a Cat

PAGE 76

# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JANUARY 2026

**TICKET TO RIDE:**  
**The New  
Lunar  
Economy**

Page 34



skyandtelescope.org

\$9.99US \$10.99CAN

A/A  
S  
0 1 >



7 12744 90661 5

# Fly Me to the Moon

National governments are ceding their monopoly over lunar exploration and inviting commercial enterprises to partner with them.

**T**he first human-made object to land on the surface of the Moon was the Soviet Luna 2 probe, which mission controllers intentionally crashed into Mare Imbrium in September 1959. Between then and early 2024, 30 more impact probes, landers, and other craft — six carrying people — have successfully completed their missions on the lunar surface.

All of these missions were “big government” enterprises, funded by the national space agencies of the U.S., the Soviet Union, China, Japan, and India. The Moon was once the exclusive domain of these kinds of space agencies. Recently, however, the focus has shifted to a new wave of smaller, more entrepreneurial ambitions. Private companies are now building and launching lunar landers, carrying scientific instruments and technology payloads for NASA, other governments, and even private customers.

This commercial revolution is transforming how human-kind explores — and maybe one day even settles — the surface of our closest neighbor in the solar system.

## The Road to Commercialization

The U.S. Apollo missions of the 1960s and '70s proved that humans could land on and return from the Moon. But after Apollo 17, NASA canceled the program; astronauts haven't returned for more than 50 years.

Some robotic missions followed over the subsequent decades. But the high cost and risk associated with lunar landings — even superpowers suffer occasional failures — have generally kept access to the lunar surface rare.

In the 2010s, however, a new commercial era began to take shape. As NASA and other space agencies sought to reduce costs and accelerate innovation, they contracted private companies for “lunar delivery services” — in other words, the agency would pay to fly instruments to the Moon on private rockets and spacecraft. Instead of building all of its own robotic landers or rovers, or purchasing them from the large, long-established aerospace contractors, NASA has started accepting rides from newer companies.

The pivotal moment came in 2018, when NASA created



**LIFTOFF** Firefly Aerospace's Blue Ghost lander launches from Kennedy Space Center aboard a SpaceX Falcon 9 rocket on January 15, 2025. Blue Ghost became the first commercial mission to successfully land on the Moon.

the Commercial Lunar Payload Services (CLPS) program, inviting companies with existing or emerging capabilities to bid for contracts. CLPS is a NASA initiative designed to foster competition, encourage innovation, and ultimately lower the cost of lunar exploration. The program issues “task orders” for specific missions, and both public and private companies bid to deliver payloads — ranging from scientific instruments to technology demonstrations — to various lunar locations.

This shift has manifested in other countries as well. Around the same time as NASA established CLPS (pronounced “clips”), two other entities initiated their first attempts at commercial lunar missions: the SpaceIL organization in Israel (propelled mostly by private philanthropy but also by the Israel Space Agency) and the publicly traded Japanese company ispace, working in collaboration with both the Japanese and Emirati space agencies. While neither of these missions was ultimately successful, they demonstrated that the push to enable cheaper, more frequent scientific access to the lunar surface is a truly global quest.

## Payloads Bring the Paychecks

Between 2019 and 2024, NASA awarded 13 CLPS mission contracts to seven different companies. Each of these contracts committed the company to delivering science payloads to specific areas of the Moon using their own commercial landers and/or rovers (see table on page 37). Some of these missions have already launched, some plan to soon, and some never will: Two of the companies have since terminated their contracts due to bankruptcy or other fundraising challenges.

Of the CLPS missions that *have* launched so far, three out of four have either partially or completely failed. These failures highlight the higher risks of relying on less-experienced and lower-cost commercial space entrepreneurs: Although “big government” contractors are sometimes late and over budget, their generally higher costs help to decrease risks, and they usually get the job done.

NASA chose 11 different landing sites — five near the south pole — for these initial CLPS missions. Planners based those choices on both the general goals of the lunar science community and specific goals for NASA’s Artemis program, intended to bring astronauts back to the Moon within the next decade. By focusing on the south polar region in particular, mission planners aim to use the robotic landers’ instruments to test the hypothesis that extractable quantities of water ice are sequestered in permanently shadowed regions there. If so, then those water-ice deposits could be a resource for future astronauts and settlers on the Moon (*S&T*: Jan. 2021, p. 34). Indeed, demonstrations of *in situ resource utilization* (ISRU) experiments — which do things like search for water ice or a variety of extractable metals — have been regularly included among the payloads selected for CLPS missions thus far.

NASA typically pays in the range of \$100 million for



◀ **GOOD EFFORT** The Resilience lander, made by Japanese company ispace, crashed on the Moon during its landing attempt.

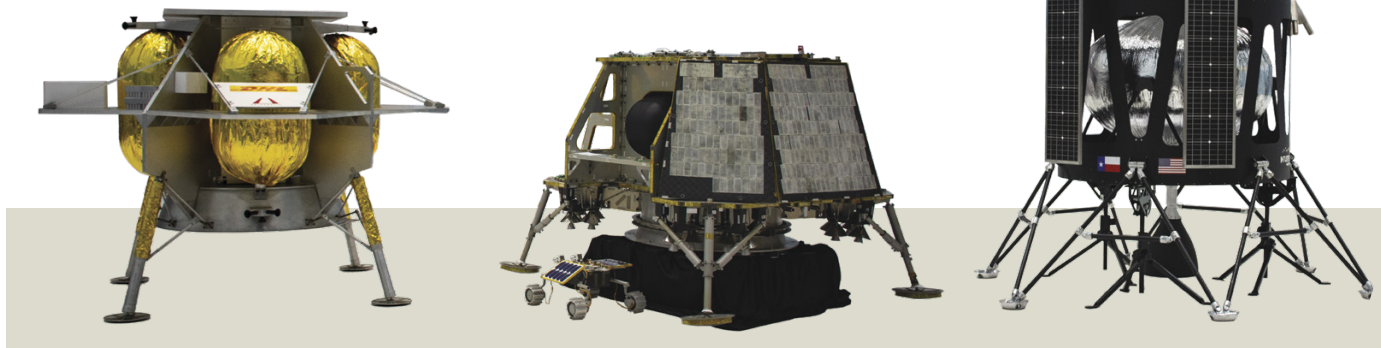
each lander, and it also pays for many of the science payloads, to the tune of approximately \$1 million/kg, or about \$2 million/lb. (That cost should drop as experience grows and competition intensifies.) Due to these budget constraints, the landers and the payloads that they can carry are relatively small compared with the typically larger and more costly traditional NASA spacecraft.

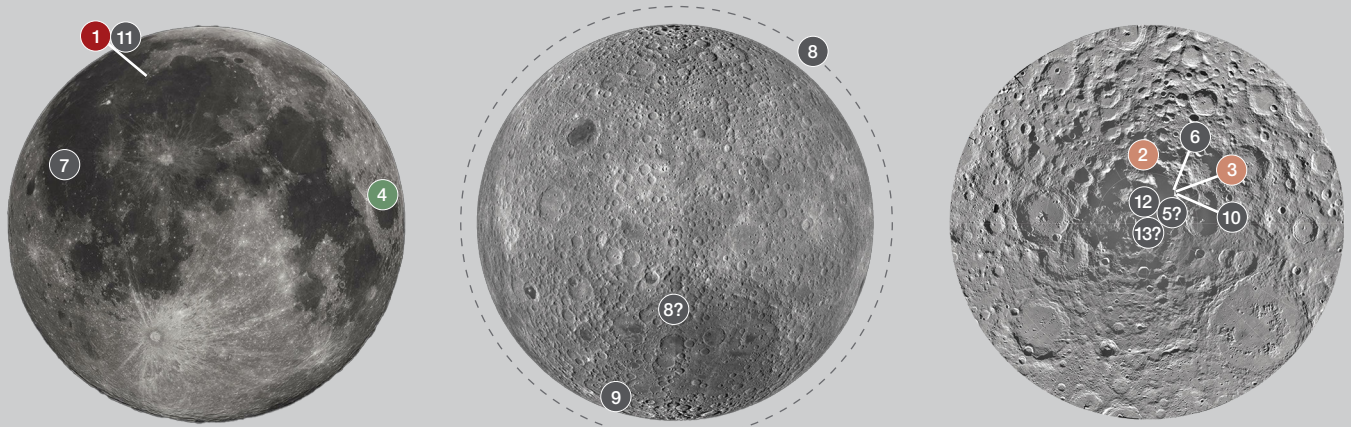
Still, advances in miniaturization and onboard computational capabilities are enabling even relatively small payloads to make important measurements, both for scientific research and for technology development. The results not only impact our understanding of lunar geology and composition but also inform future power, mobility, communications, precision landing, hazard avoidance, ISRU, and other engineering needs.

Importantly, these commercial providers realize that although the funding from government programs such as NASA’s CLPS is substantial, it is still often not enough to cover expenses for the design, manufacture, test, launch, and operations of their missions. Thus, to earn some profit for their investors (or at least break even), many have to accommodate additional payloads from paying international, commercial, or even private customers.

Some of these other hosted payloads have been scientific, engineering, or technological in nature. Others have been artistic or cultural, such as a (miniature) art museum on the Moon, delivered to the lunar surface by the IM-1 Odysseus lander in 2024. In the commercial lunar sector, landers and rovers are not only primarily tools for scientific and technological advancement, but they are also vehicles for showcasing humanity’s artistic and cultural heritage, extending our

▼ **MOON DREAMERS** NASA selected these three commercial landers as the first CLPS carriers. Unfortunately, none of the projects succeeded: Astrobotic’s Peregrine (*left*) failed to reach the Moon, OrbitBeyond (*center*) terminated its contract only two months after being chosen, and Intuitive Machines’ Odysseus lander tipped over once it reached the surface. Models appear approximately to scale; Odysseus is roughly twice the height of an adult.





## NASA Companies Awarded CLPS Mission Contracts

Company	Mission Name	Award Date	Landing Date	Intended or Actual Landing Site	Notes/Status	Map Number
Astrobotic Technology (Pittsburgh, PA)	Peregrine-1	May 2019	Jan. 2024	Oceanus Procellarum, near the Gruithuisen domes	Propellant leak prevented landing attempt carrying five CLPS payloads	1
Intuitive Machines (Houston, TX)	IM-1 (Odysseus)	May 2019	Feb. 2024	Malapert A Crater near the lunar south pole	Nova-C lander tipped over after landing, limiting six CLPS payloads to only partial success	2
OrbitBeyond (Bridgewater, NJ)	Z-01	May 2019	—	Within Mare Imbrium	Terminated its contract in July 2019 due to “internal corporate challenges”	N/A
Masten Space Systems (Mojave, CA)	XL-1	Apr. 2020	—	Haworth Crater near the lunar south pole	Filed for bankruptcy in July 2022; contract terminated by NASA	N/A
Intuitive Machines	IM-2 (Athena)	Oct. 2020	Mar. 2025	Mons Mouton region near the lunar south pole	Nova-C lander tipped over after landing, limiting the CLPS payloads to only partial success	3
Firefly Aerospace (Austin, TX)	Blue Ghost 1	Feb. 2021	Mar. 2025	Near Mons Latreille in Mare Crisium	Fully successful deployment of 10 CLPS payloads	4
Blue Origin (Kent, WA)	Blue Moon MK1 Pathfinder	July 2024	Late 2025?	TBD near the lunar south pole	Will test future human landing technologies and might deliver a CLPS payload	5
Astrobotic Technology	Griffin-1	June 2020	Late 2025?	Nobile Crater region near the lunar south pole	Was to carry NASA’s VIPER rover, will carry commercial rover and CLPS payloads instead	6
Intuitive Machines	IM-3	Nov. 2021	Early 2026?	Reiner Gamma region in Oceanus Procellarum	Will carry four payload packages from NASA, ESA, and Korea	7
Firefly Aerospace	Blue Ghost 2	Mar. 2023	2026?	TBD on the lunar farside	Will deliver both a science/communications orbiter and a lander with CLPS payloads	8
Draper Laboratory (Cambridge, MA)	Apex 1.0	July 2022	Late 2026?	In Schrödinger Basin on the lunar farside	Will carry three CLPS payloads plus other commercial payloads	9
Intuitive Machines	IM-4	Aug. 2024	2027?	Mons Mouton region near the lunar south pole	Will carry NASA and ESA science payloads	10
Firefly Aerospace	Blue Ghost 3	Dec. 2024	2028?	Oceanus Procellarum, near the Gruithuisen domes	Will deliver six NASA CLPS payloads	11
Firefly Aerospace	Blue Ghost 4	July 2025	2029?	Haworth Crater rim, south pole region	Will carry two rovers and three science payloads	12
Blue Origin	Blue Moon MK1	Sept. 2025	Late 2027	TBD, near the lunar south pole	Will carry NASA’s VIPER rover	13

● Failed after launch    
 ● Launched, partially succeeded    
 ● Never launched    
 ● Fully successful    
 ● Planned

MAP LOCATIONS SOURCES: NASA, FIREFLY AEROSPACE; NEAR-SIDE AND FAR-SIDE IMAGES: NASA, LRO / JAPAN AGENCY; SOUTH POLE IMAGE: NASA / JPL / USGS

reach beyond Earth and leaving a legacy for future generations to explore.

There are also significant economic and strategic motivations at work. ISRU experiments and technology maturation are important for the sustainability of future lunar settlements. Water ice, for example, could be mined and split into hydrogen and oxygen for life support or rocket propellant, literally fueling a potential transformation in what is currently Earth-based space transportation economics by enabling on-the-ground propellant manufacturing, instead of requiring us to ship fuel to the Moon. Future, more capable commercial missions, based on early pathfinders like those in the CLPS program, could also deliver habitats, power systems, and other infrastructure needed for long-term human presence.

The political confrontation that played out in the 1960s “space race” between the U.S. and USSR has been replaced in some ways by an economic competition between the systems of government represented by the U.S. and other western nations and those of China and Russia. As this competition continues, space — and the Moon in particular — is seen by some as the ultimate high ground upon which America is keen to establish a foothold before rivals can claim key resources or strategic sites.

## 2025: A Banner Year

This past year has seen an exciting surge in lunar activity: Several notable missions from the first few years of NASA’s CLPS selections launched or landed, and Japan’s ispace made a second attempt to safely touch down on the Moon. These companies are each having to navigate the immense technical

challenges of lunar landings, often with tighter budgets and less institutional experience than government agencies.

The results have been mixed. The Intuitive Machines IM-2 Athena lander launched on February 26th and then performed a successful slow descent to a site near the lunar south pole on March 6th. But it tipped over upon landing, completing only a small fraction of its intended science measurements before it lost power and died.

The ispace Resilience mission, meanwhile, carrying a small rover from Luxembourg as well as scientific and cultural payloads from Japan, Taiwan, and the United Nations, launched without mishap on January 15th but then crashed onto the surface of Mare Frigoris on June 5th because of a landing-system error.

Both of these commercial teams will be back for future attempts, they say: Not only did they collect important telemetry and other data, but they also amassed a large number of engineering and operational “lessons learned” by coming so close to success.

These failures join several that came before them: Until 2025, there had never been a fully successful commercial landing on the Moon. This fact might sound disparaging, but remember that it took NASA several attempts just to successfully *hit* the Moon with one of the Ranger impact probes back in the 1960s.

Happily, Firefly Aerospace broke the pattern of failures, achieving a triumphant landing only a few days before Athena’s tilted touchdown. Firefly’s Blue Ghost 1 lander, carrying 10 NASA CLPS payloads, successfully launched on January 15th from Kennedy Space Center and performed a perfect soft



**SHAKY FOOTING** Intuitive Machines’ Athena lander reached the lunar surface in March 2025 but tipped over after landing. It took this image of itself on its side, with NASA’s drilling experiment visible between the two lander legs.

landing on the lava plains of Mare Crisium on March 2nd.

Traditional big-ticket NASA spacecraft typically allocate only around 10% or less of their total mass to scientific instruments. But twice that was devoted to science and technology payloads on Firefly’s Blue Ghost. The instruments acquired spectacular data that scientists and engineers are going to be digging into for years. These include pictures of Earth interacting with the solar wind as well as measurements of radiation levels on the lunar surface, of how much the temperature decreases below the surface, and of how rough lunar dust is and how well it sticks to surfaces.

Successful technology experiments in turn included a demo of using Earth GPS signals for navigation on the Moon, a novel soil-collection and analysis system, an electrical dust-shielding system, and images and videos of the effects of the lander’s rocket plume on the lunar surface. The lander also deployed a retroreflector mirror system, so that Earth-based lasers can track the slowly increasing distance between us and the Moon.

Blue Ghost 1 operated for two weeks, surviving and thriving under the harsh sunlight before succumbing to the freezing lunar night — an expected fate for landers or rovers relying on solar power for their energy and survival, as all CLPS craft have so far.

Several other missions are planned for later in 2025, although of course their actual launch and landing dates are always subject to change, based on not only the status of launch vehicles but also the vagaries of both governmental and private funding.

For example, Astrobotic’s Griffin lander is set to attempt a payload delivery to the Nobile Crater region of the lunar south pole. Griffin is larger than the company’s previous craft, Peregrine, which failed shortly after launch in early 2024. Griffin was initially intended to carry NASA’s large VIPER rover, designed to map the locations of water ice and other resources. When NASA postponed VIPER for budgetary reasons (*S&T*: Nov. 2024, p. 8), Astrobotic pivoted to potentially delivering other CLPS payloads plus a different but similarly sized rover developed by another space startup, Venturi Astrolab. That vehicle, called the “Flexible Logistics and Exploration Lunar Innovation Platform” (FLIP) rover, is intended to pave the way for a larger lunar rover that the company is planning for the future (*S&T*: June 2025, p. 11).

Another potential 2025 CLPS achievement could be the launch and landing of Blue Origin’s Blue Moon MK1 Pathfinder lander. Pathfinder is a prototype for the Blue Moon lander, which Jeff Bezos and his Blue Origin colleagues plan to use to carry NASA cargo and astronauts down to the lunar surface on the Artemis V mission early in the 2030s. Blue Moon Pathfinder will launch on the company’s New Glenn rocket and deliver a NASA CLPS imaging payload designed to study the effects of rocket exhaust on the ground at the landing site. It will also test the 3D-printed BE-7 engine and some of the cargo-delivery capabilities planned for Blue’s future human-rated landers.

## Examples of Recent Artistic and Cultural Payloads

Lander	Payload	Notes/Status
Peregrine 1	Artwork: “The Lunar Codex” and “MoonArk” projects preserve digital and analog forms of art, literature, music, and other cultural artifacts, including goat DNA	Launched, but lander flew by the Moon without landing
Odysseus	Sculptures and digital art/music: Several artists provided physical and digital artwork and musical compositions in a radiation-proof container on the lunar surface, intended to represent Earth’s diverse cultures preserved in the first “art museum” on the lunar surface	Reached surface successfully, although lander tipped over
Resilience	Time capsule: UNESCO created a coin-size digital memory disk, “Memory Disc V3,” designed to preserve humanity’s linguistic diversity and cultural heritage for millions of years	“Hard landed” on the lunar surface

## Toward a Lunar Economy?

The commercial lunar-lander revolution is well under way. What began as government monopolies driven by the Cold War is now a competitive, innovative marketplace, with private companies hired to deliver science, technology, and infrastructure to the Moon.

The rest of this decade is likely to be just as interesting as this past year. At the time this article went to press, there were still seven additional active NASA CLPS missions contracted for landings in 2026 and beyond, as well as many other commercial efforts from companies and agencies outside of the U.S. These missions are scheduled to deliver dozens of science, engineering, and technology-demonstration payloads to diverse and interesting locations on the Moon.

Add to that the promise of the planned Artemis III, IV, and V human lunar-landing missions (currently scheduled for late 2028 and early 2030) — both of which involve and leverage significant entrepreneurial space systems and capabilities — and the result is stacking up to be an extremely busy and exciting time on the Moon.

Of course, landing on the Moon remains a formidable challenge. Companies face the same technical hurdles as government agencies — navigation, propulsion, a harsh thermal environment — but often with fewer resources and lower heritage hardware. The early commercial successes and failures, especially those that have struggled to land in rugged or bouldery terrain, have highlighted several must-haves for going forward: the need for active hazard avoidance or other autonomous onboard landing smarts; the need for more

robust communications and navigation systems that can work even when landings don't go perfectly; and of course the need to survive as long as possible in the harsh lunar environment, where radiation, abrasive dust, and huge temperature swings between day and night are all trying to kill spacecraft. Still, every mission, successful or not, incrementally advances the state of the art and brings the dream of routine lunar access for all stakeholders — both government and commercial — closer to reality.

In the meantime, many of the existing lunar space companies, and many more new ones, are working on larger landers capable of delivering heavier and more complex payloads, including habitats and rovers. NASA's next phase of CLPS ("CLPS 2.0") envisions delivery of essential infrastructure such as power sources, habitats, and mobility systems to support long-term exploration and eventual settlement. Eventually, perhaps, ISRU will move from demonstration to operational scale, with commercial propellant production and storage facilities on the horizon.

If current trends continue into the future, then as launch and operation costs drop and reliability improves, more international agencies and private companies could very well

seek routine lunar access for science, commerce, and even tourism purposes.

Still, for now, national governments remain the key customers and regulators. Along with the United Nations and other global agencies working under existing and new treaties, these space agencies will need to cooperate to fill gaps in international law and to ensure fair access to lunar resources.

In short, in just the next few decades, we could see the emergence of a true lunar economy, one that could reshape not only how we explore space but also how we live and work on Earth and beyond. As competition intensifies and technologies mature, the Moon could soon become a bustling hub of scientific discovery, resource prospecting and extraction, and even human activity — a stepping stone to the rest of the solar system.

■ Contributing Editor **JIM BELL** is a professor of astronomy and planetary science at Arizona State University. He's been involved in more than a dozen NASA missions to the Moon, Mars, and asteroids, is a past president of The Planetary Society, and enjoys writing popular-science books and articles about space exploration.



**SUCCESS** Firefly's Blue Ghost lander safely touched down on the Moon with its 10 payloads. It casts its shadow here shortly after arrival, with Earth on the horizon.