MIND THE GAP:
How Planets Are Built
PAGE 34

GALACTIC HULA-HOOP:
Hoag's Object
PAGE 57

OBSERVING:
A Cascade of Galaxies
PAGE 22

SKY & TELESCOPE

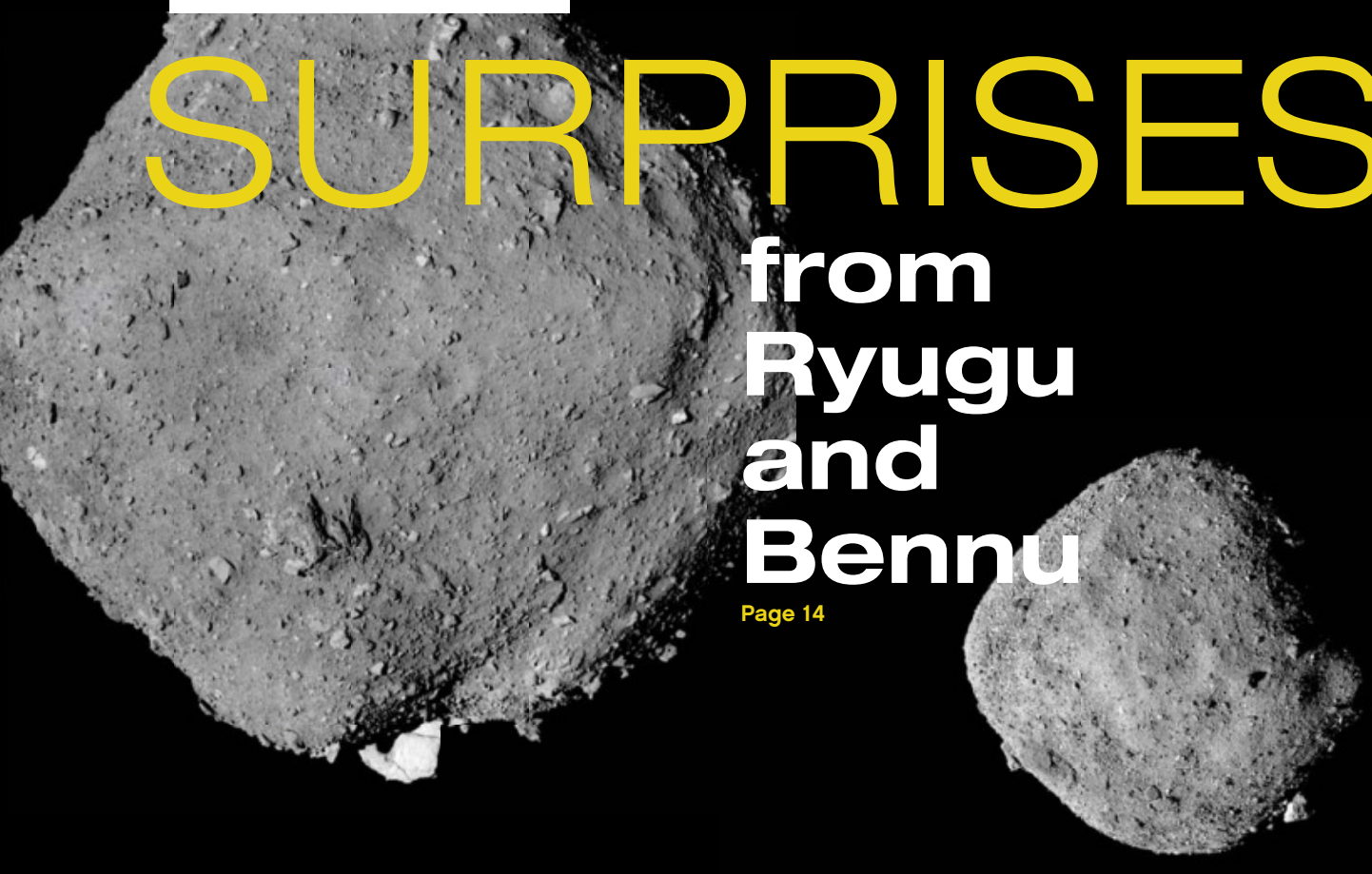
THE ESSENTIAL GUIDE TO ASTRONOMY

MAY 2020

ASTEROID RECON

SURPRISES from Ryugu and Bennu

Page 14



skyandtelescope.org

The Untimely End of Amateur CCDs?
Page 30

Mitchel's Mountains on Mars
Page 52

The Discovery of Jupiter's Moons
Page 60

Seventy-nine and Counting: Finding Jupit

The discovery of the Jovian satellites enhanced our understanding of the solar system and changed the course of history.

In the hierarchy of the sky, Jupiter has always enjoyed a front-row seat. With its prominence exceeded only by the Moon, Venus, and occasionally Mars, Jupiter is usually the third brightest object in the night sky. It's little wonder that the Romans named it the king of the gods.

On January 7, 1610, Jupiter's eminence surged when Galileo Galilei aimed his newly built telescope at it and observed what at first appeared to be three nearby stars hugging the regal planet. Then, on January 11th, he saw four. Documenting the first planetary moons other than our own, Galileo vaulted to lasting fame. The discovery of these four worlds was one of the most momentous turning points in astronomical history, challenging the established belief that Earth was the center of Creation around which all heavenly bodies revolved. Suddenly there was another system — one in which our planet didn't occupy the exclusive focus of the firmament.

In March 1610, Galileo published his findings in a pamphlet, *Sidereus nuncius* (*The Starry Messenger*), an account of his observations of Jupiter's satellites, the mountains and craters of the Moon, and the myriad stars visible in his telescope. His immediate intent was to honor his patron, Cosimo II de Medici, the Grand Duke of Tuscany, by naming the four satellites the "Medicean Stars." It wasn't until the mid-1800s that they were officially named Io, Europa, Ganymede, and Callisto, all characters from myths associated with Jupiter. Simon Marius proposed this nomenclature following a suggestion by fellow German astronomer Johannes Kepler (best known for determining that the planets describe elliptical orbits around the Sun — an accomplishment that ranks as one of the greatest intellectual achievements in history).

However, digging deeper, it's apparent that Marius deserves credit for more than just the naming of

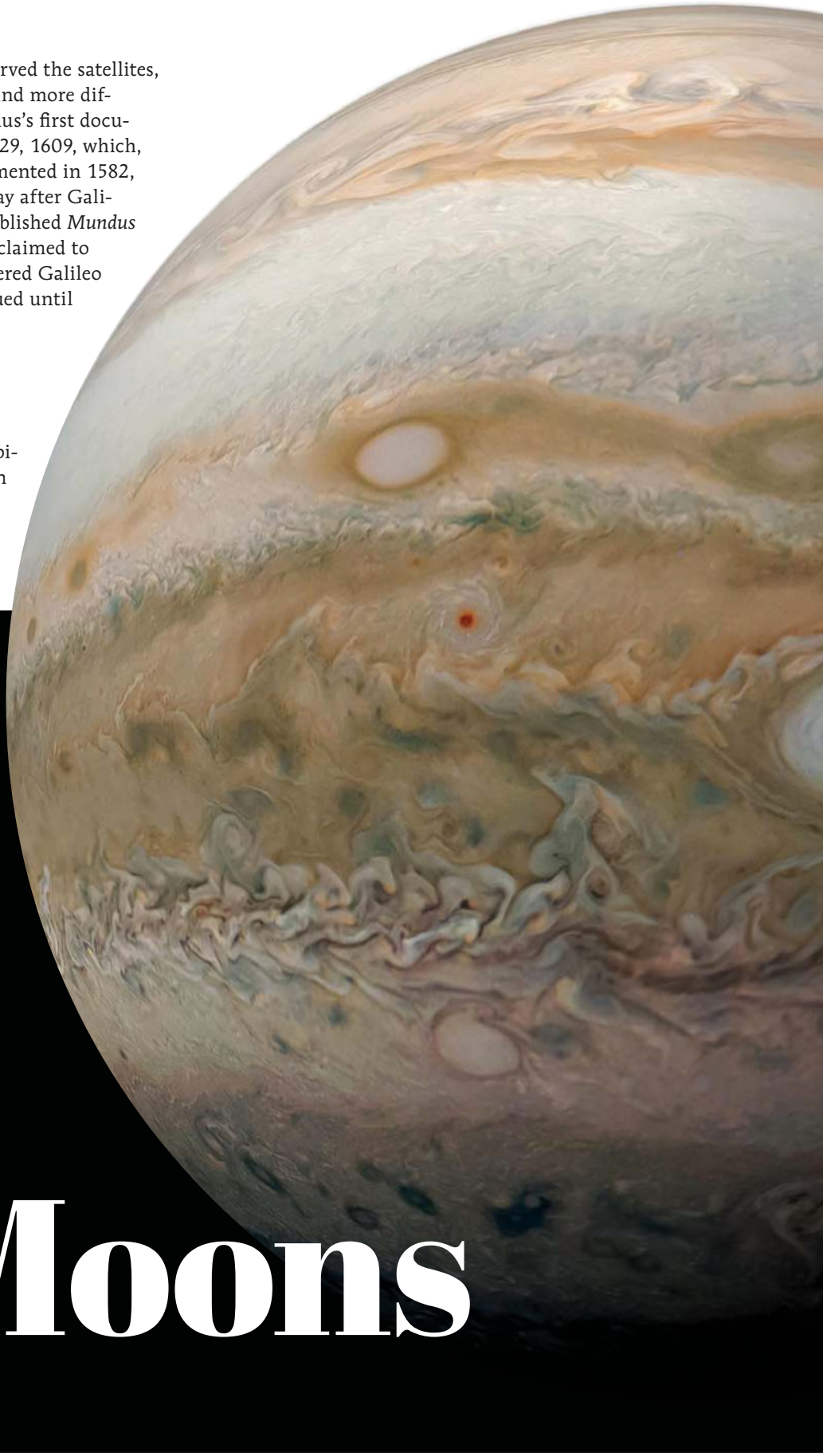
CALLISTO, EUROPA: NASA / JPL / DLR; GANYMEDE: NASA / JPL

the moons. In fact, he independently observed the satellites, but records of his work are less complete and more difficult to verify than those of Galileo. Marius's first documented observations are dated December 29, 1609, which, after adjusting for calendar reform implemented in 1582, translates to January 8, 1610 — just one day after Galileo's first observations! In 1614 Marius published *Mundus Iovialis* (*The World of Jupiter*) in which he claimed to have observed the satellites first. This angered Galileo and triggered a bitter conflict that continued until Marius's death in 1625.

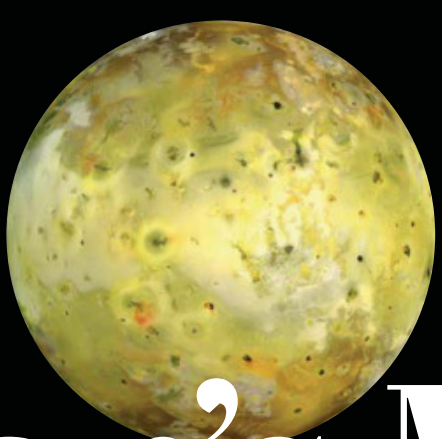
Through the Looking Glass

As anyone who observes Jupiter regularly knows, the four Galilean satellites aren't always all visible. They can hide behind Jupiter's disk or traverse through eclipse within the planet's shadow. This happens most often for Io and Europa, which never journey far from the planet. Ganymede

IO: NASA / JPL / UNIVERSITY OF ARIZONA; JUPITER: NASA / JPL-CALTECH / SWRI / MSSS / KEVIN M. GILL



◀▼ **GALILEO'S MOONS** This composite family portrait shows (from left to right) Callisto, Ganymede, Europa, Io, and Jupiter. The individual images were recorded by these spacecraft: Galileo (Ganymede, Europa, and Io), Voyager 2 (Callisto), and Juno (Jupiter). Images not to scale.



er's Moons

and Callisto, on the other hand, are almost always visible. The Galilean moons have orbits that are virtually perfectly circular and, consequently, veer as far to the east of Jupiter as they do to the west. Although the four moons orbit in nearly the same plane aligned with Jupiter's equator, from our Earthly perspective we usually view the Jovian system from slightly above or below the planet's equator, so the satellites rarely appear strung out in a straight line.

Galileo's telescopes were optically poor by today's standards — his observations we can accomplish with modern binoculars. Indeed, under favorable conditions, Galileo's satellite worlds are bright enough to be discerned with the unaided eye were it not for their proximity to Jupiter and its overpowering luminosity. Ganymede, at magnitude 4.6 and a diameter of 5,262 kilometers, is the brightest and largest, while 4,821-km-diameter Callisto is the dimmest at magnitude 5.7. Europa has a diameter of only 3,122 km, making it the smallest of the four, but its relatively high albedo allows it to shine at magnitude 5.3. Closest to Jupiter in distance is magnitude-5.0 Io, which spans 3,643 km.

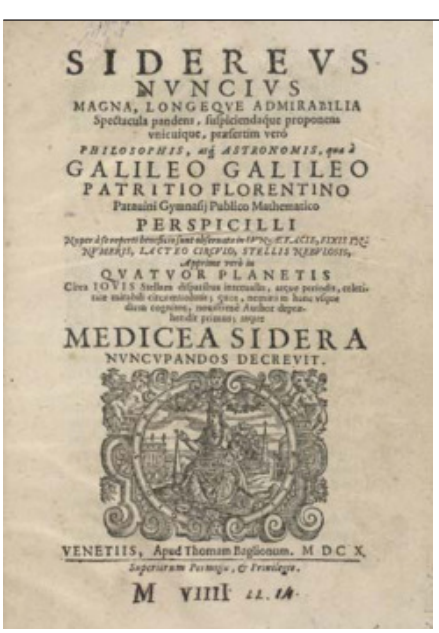
Are there any confirmed naked-eye sightings of the Jovian moons? There is one recorded pre-telescopic observation from the 4th century BC. Chinese astronomer Gan De recorded "a small reddish star" next to Jupiter, which the 20th-century Chinese astronomer and historian Xi Zezong has interpreted as a possible sighting of Ganymede. This magazine has received a few reports over the years, but the very nature of such observations makes them difficult to verify.

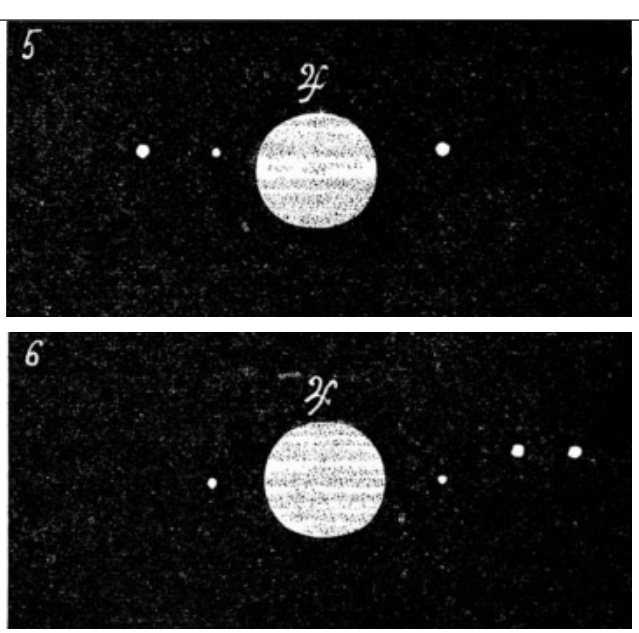
◀ **BY ANY OTHER NAME** In a bid to curry favor, Galileo initially named the four new Jovian moons Cosmica Sidera ("Cosimo's stars"), but Cosimo de Medici graciously suggested he refer to the newly discovered objects simply as Medicea Sidera ("the Medician stars"). In this illustration, Galileo is depicted showing Cosimo the Jovian moons.

Moving Heaven and Earth

As is well known, Galileo's discoveries and the inevitable implication that Earth no longer occupied a special place in the cosmos prompted consternation within the formidable Catholic establishment. In the early decades of the 16th century, Nicolaus Copernicus labored over a lengthy exposé on heliocentricity, a Sun-centered scenario that opposed the prevailing Earth-centered model that the ancient Greeks, particularly Aristotle and later Ptolemy had promulgated. Heliocentrism also contradicted Catholic dogma, and as such was considered heresy. Copernicus's ideas are spelled out in detail in a six-part book, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), issued at the time of his death in 1543.

While Copernicus was hesitant about publishing his ideas, Galileo was confident his own observations had conclusively verified that the universe was not Earth-centered. He traveled to Rome in 1611 and invited ecclesiastical authorities to view Jupiter through his telescope. Some readily accepted the valid-


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, nec non ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.



◀◀ **A NEW VIEW** In 1610, Galileo published *Sidereus nuncius* (*The Starry Messenger*), the title page from which is reproduced here. This slender volume contained his pioneering telescopic observations, including drawings of Jupiter's satellites. Although a scientific triumph, *Sidereus nuncius* also set Galileo on a collision course with the Church.

◀ **NEW MOONS** Galileo's drawings depicting Jupiter's four largest moons first appeared in *Sidereus nuncius*. His efforts provided important observational support for the Copernican model of a Sun-centered solar system.

GALILEO AND COSIMO DE MEDICI: CHRONICLE / ALAMY STOCK PHOTO; SIDEREUS NUNCIUS: PUBLIC DOMAIN / WIKIMEDIA COMMONS; JOVIAN MOON DRAWINGS: SPL / SCIENCE SOURCE

ity of what appeared to be a miniature analog to the solar system. Others struggled to find reasons to deny what was clearly obvious, appealing to the word of Scripture, which espoused a centralized, motionless Earth. Still others conjectured that the instrument was faulty and didn't portray reality.

However, Jesuit priest and astronomer Christopher Clavius was an early endorser of Galileo's assertions. Clavius was also responsible for much of the analysis behind the 1582 reform of the calendar, which more accurately synchronized it with the length of the year, thus keeping holy days (particularly Easter) in step with the seasons. Ironically, Clavius adhered to the geocentric view, yet he didn't turn a blind eye to the reality presented by Galileo's telescope.

◀ GALILEO'S NEMESIS Simon Marius not only gave the Galilean moons the names they now bear, but he also proved to be a thorn in the great scientist's side by claiming to have discovered the satellites first and publishing a book to bolster his assertion.

Galileo's observations and scientific musings triggered years of dispute with the Church, resulting in his eventual trial and subsequent lifetime house arrest. Multiple factors played a part in this outcome, including the overt bluntness of the books Galileo authored, coupled with his sometimes abrasive personality. Teaching and writing about Copernicanism was forbidden, and *Revolutions* was placed on the "Index" — a list of books Catholics were prohibited from reading.

Down-to-Earth Matters

While Galileo's observations ultimately validated a Sun-centered view, observations of Jupiter's moons contributed to other advancements of the era, particularly for determining longitude, essential for navigation and cartography.

Although latitude is easy to reckon by measuring the altitude of stars above the horizon, no equivalent technique existed for determining longitude. In the 1670s Danish astronomer Ole Rømer devised a method of calculating longitude by timing the eclipses of Jupiter's satellites. He made his observations from Uraniborg, Tycho Brahe's observatory near Copenhagen, in concert with Giovanni Domenico Cassini, who documented the same events from Paris. By comparing their results the two could calculate the difference in longitude between the two locations. Although a valid procedure, it proved unworkable from the deck of a ship navigating turbulent oceans. Many other scientists and inventors toiled over the puzzle using various means, but it wasn't until the late 1700s when John Harrison and others built accurate chronometers that a truly reliable method for determining longitude at sea existed.

After relocating to Paris in 1672 to become Cassini's assistant, Rømer continued to observe Jupiter's satellites, which led him to conjecture that the speed of light is finite. This position was counter to the prevailing view that light propagated instantaneously from a source. Both he and Cassini recognized that as Earth and Jupiter move apart in their respective orbits, the interval between eclipses of the satellites increases, and when they approach each other, it decreases. Rømer primarily monitored Io, which, being closest to Jupiter, orbits more frequently and therefore provides more data points. His conclusion was that a finite speed of light accounted for the observed differences, although at the time methods sufficiently accurate for determining the speed of light were unavailable.

More and More Moons

In 1892, American astronomer E. E. Barnard discovered Jupiter's first post-Galilean satellite. Barnard detected the dim little moon (listed at magnitude 14.1) with the newly commissioned 36-inch refractor at Lick Observatory on Mount Hamilton in California. This was to be the last visual discovery of a planetary satellite. At 167 km in diameter, Amalthea (as it was formally named in 1976) is only 3% percent the size

▶ COPERNICAN REVOLUTION Polish astronomer Nicolaus Copernicus is credited with having first described a heliocentric solar system in detail in his book *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), published in 1543, the year of his death.

of Ganymede, and orbits much nearer to Jupiter than its four larger siblings do. Consequently, Amalthea is a virtually impossible target through amateur telescopes, regardless of size or quality — Jupiter is roughly 6 million times brighter than Amalthea, but only about 1,500 times brighter than the Galilean moons.

Jupiter's sixth satellite, Himalia, was discovered in 1904 by Charles Dillon Perrine on photographic plates taken with the 36-inch Crossley reflector telescope at Lick Observatory. Although slightly fainter than Amalthea, Himalia orbits far from Jupiter's overpowering brightness and is more easily visible. Nevertheless, at least a 10-inch telescope and optimal viewing conditions are required for this 14.2-magnitude object. Additionally, one would need to separate it from the multitudes of nearby field stars of similar appearance. Perrine also discovered Jupiter's seventh moon, Elara, a year later.

In subsequent decades, discoveries trickled in, but the dam finally broke in 2000 when highly sensitive ground-based detection methods came online. The vast majority of Jupiter's currently known, 79 satellites have been discovered in the past two decades, mostly by a team lead by Scott S. Sheppard at the Carnegie Institution for Science. These are tiny objects, generally only a few kilometers in diameter. However, in 2019 Sheppard's team announced the discovery of 20 new satellites orbiting Saturn, bringing the ringed planet's total to 82, thus crowning it the reigning moon king — at least for now.

◀ **BIG GLASS** It's easy to imagine how stunned Galileo would have been had he been able to utilize the Lick Observatory's 36-inch behemoth telescope. This refractor was the instrument E. E. Barnard used to make the last visual discovery of a planetary satellite.

But of all the satellites orbiting Jupiter the only ones that we can accurately describe as "worlds" are the four Galileo discovered. In the 1970s, Io, Europa, Ganymede, and Callisto returned to the forefront of scientific interest as the Pioneer, Voyager, and Galileo spacecraft returned scores of detailed close-up photographs of each one. These images established the distinct personalities of the Galilean moons. Io is a multicolored volcanic wonderland; Ganymede features grooved water-ice terrain; Callisto's ancient surface is pockmarked with impact craters; and Europa is a world covered with a water-ice crust encasing a silicate rock surface, sporting the smoothest surface of any solar system body. Could there be an ocean residing beneath Europa's surface — one that might harbor primitive microorganisms? Enthusiastic scientists are discussing plans for satellite missions to learn more about this exciting world. What began with a small spyglass more than 400 years ago continues unabated to this day.

■ **MIKE WITKOSKI** volunteers at Muddy Run Observatory (located approximately 100 miles west of Philadelphia), where the Galilean satellites are a big hit on public viewing nights.

LICK REFRACTOR: PUBLIC DOMAIN / WIKIMEDIA COMMONS; EUROPA CLIPPER BASE IMAGE: NASA / JPL-CALTECH / SETI INSTITUTE; EUROPA CLOSE-UP: NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

MYSTERY MOON What lurks below the intricate icy surface of Europa? The proposed Europa Clipper orbiter is designed to help scientists find out. The launch date of the mission, however, is still "TBD."