Galactic Observer

John J. McCarthy Observatory

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Image of the Earth combined with one of Jupiter's Great Red Spot from NASA's Juno spacecraft showing the size and depth of the cyclonic storm. Credit: JunoCam Image data: NASA/JPL-Caltech/SwRI/MSSS, JunoCam Image processing by Kevin M. Gill (CC BY)

December Astronomy Calendar and Space Exploration Almanac

November's Full Moon as it passed through Earth's shadow. The nearly 3-1/2-hour transit climaxed in an almost-Total-Lunar-Eclipse with 97% of the Moon within the umbra at mid-eclipse (4:03 AM EST). The portion of the Moon outside the umbra created a bright sliver of light on the limb near Tycho crater. The photo was taken through a C-11 telescope at prime focus with a Nikon D7200.

Photo: Bill Cloutier

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“Out the Window on Your Left”

It’s been more than 52 years since Neil Armstrong first stepped onto the moon’s surface and 49 years since Gene Cernan left the last footprint. As a nation founded on exploration and the conquest of new frontiers, today’s commitment to return to the moon has been as fleeting as the funding. But what if the average citizen had the means to visit our only natural satellite; what would they see out the window of their spacecraft as they entered orbit around the moon? This column may provide some thoughts to ponder when planning your visit (if only in your imagination).

For lunar observers, the sun rises on the Taurus-Littrow valley early in the morning on the 9th of December. A narrow opening in the rim of the Serenitatis Basin, the valley is enclosed on three sides by large, rounded mountains - the South, North, and East Massifs. It is also the landing site of Apollo 17 on December 11, 1972, the final lunar mission of the Apollo program.

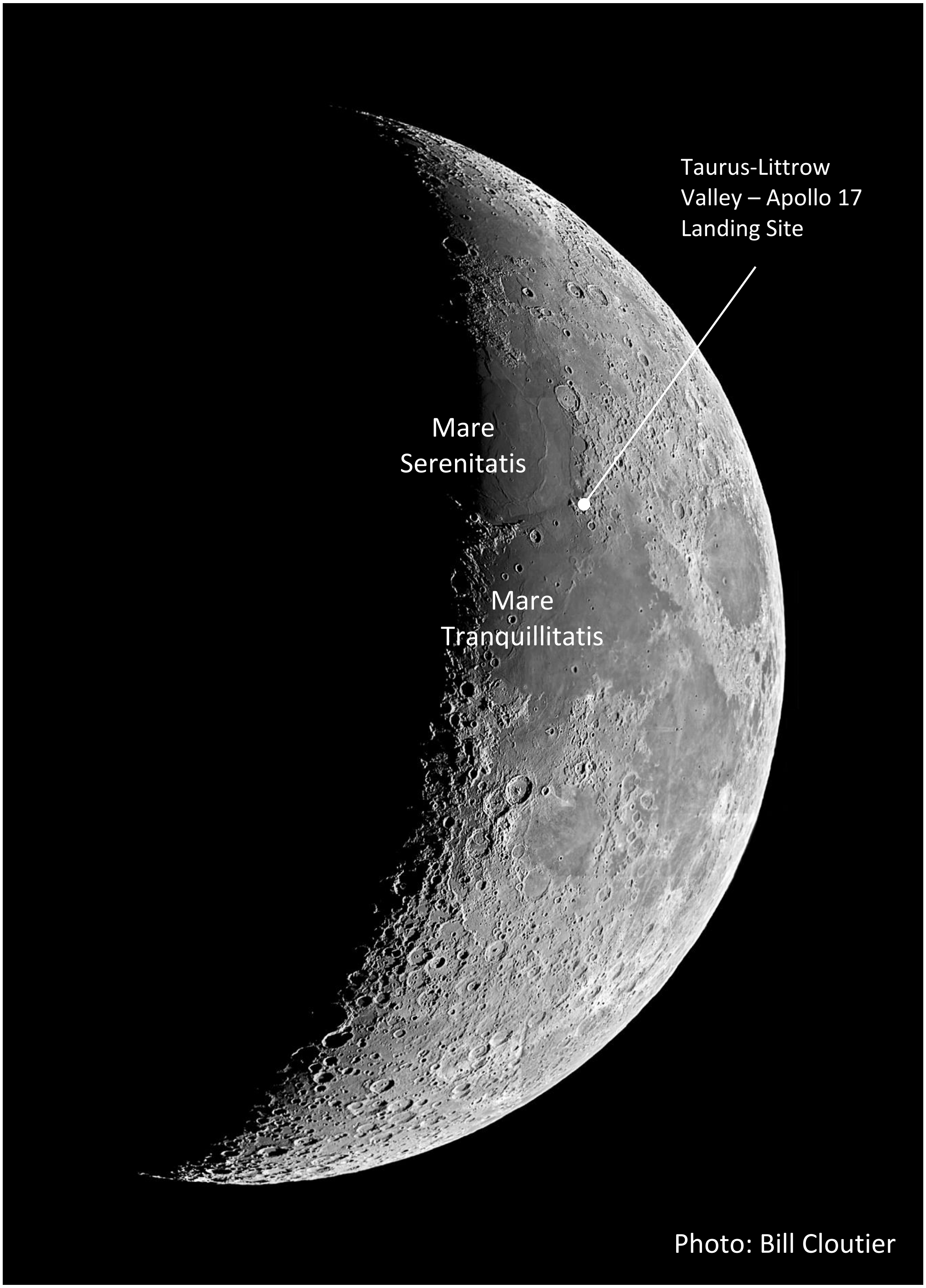
Multiple sites competed for the last mission, offering a variety of terrains, history and geology. Taurus-Littrow provided astronauts, including astronaut-geologist Harrison Schmitt, the opportunity to explore craters on the valley floor with dark halos that had been identified from orbit by earlier missions. The lunar module set down near one of these craters, designated Shorty.

It was on the rim of Shorty that Schmitt discovered a deposit of “orange soil.” The orange particles were later determined to be volcanic glass, likely produced by a volcanic vent or fire fountain. The glass formed 3.64 billion years ago from material that melted several hundred miles below the surface. The glass was then buried and later excavated by impacts.

Scientist-astronaut Harrison Schmitt stands next to a huge, split lunar boulder during the third Apollo 17 extravehicular activity at the Taurus-Littrow landing site. The Lunar Roving Vehicle can be seen in the background.
Image Credit: NASA/Eugene Cernan

Apollo 17 featured the most extensive lunar exploration of the program, with three moonwalks that each lasted more than seven hours. The crew collected the oldest known unshocked lunar rock (at least 4.2 billion years old) - suggesting that the Moon had, at one time, a magnetic field generated by a dynamo at its core. The astronauts took more than 2,000 photographs and collected about 243 pounds (110 kg) of soil and rock samples at 22 different sites.

Taurus Littrow



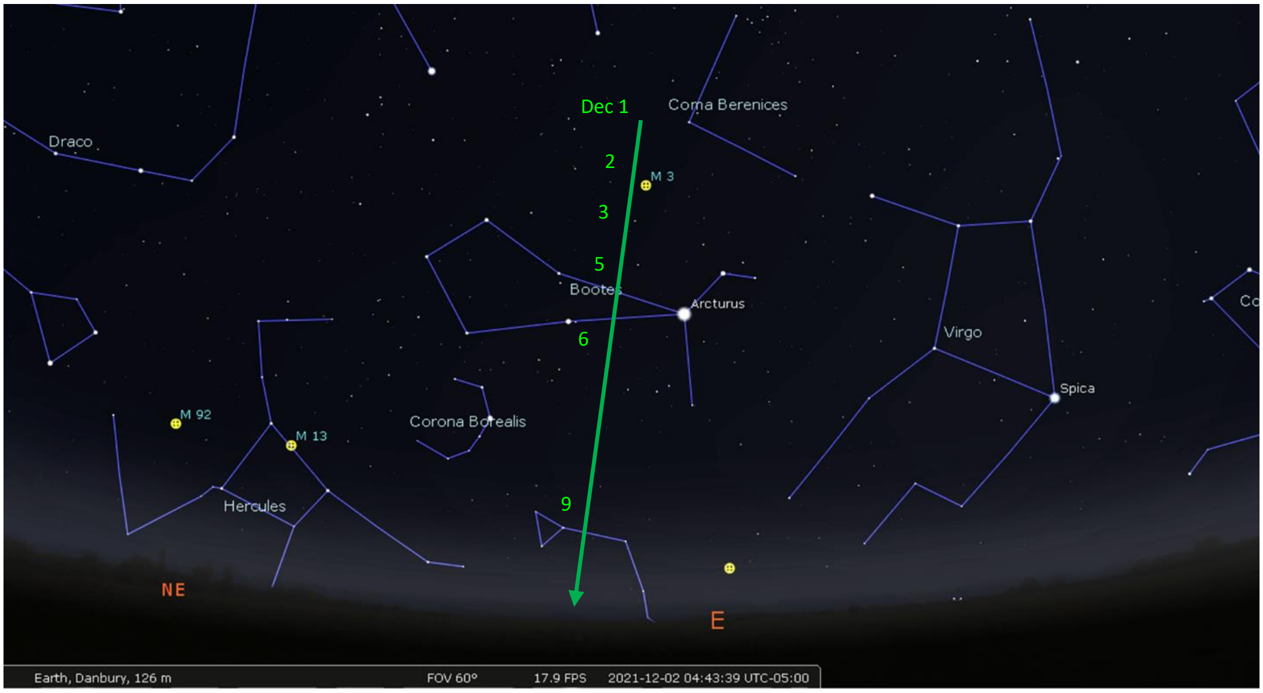
Comet Leonard

We haven't had a bright comet grace our skies in quite a while. Last summer, Comet NEOWISE (C/2020 F3) put on a nice appearance in the early morning before moving into the evening sky, but for most viewers NEOWISE was at the threshold of visibility without binoculars.

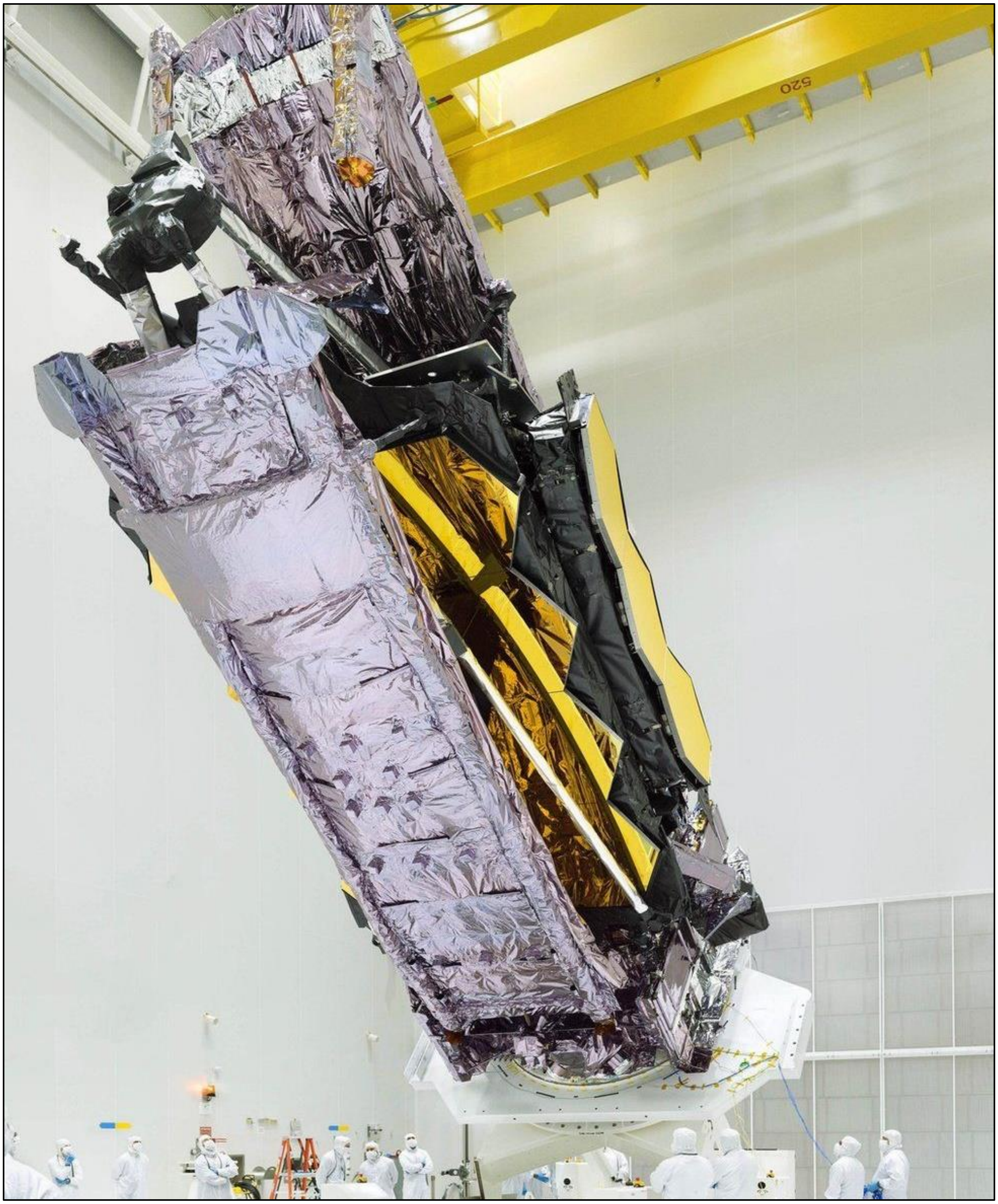
Comet NEOWISE in July 2020
Photo: Bill Cloutier

This year, Comet Leonard (C/2021 A1) is raising expectations. Discovered on January 3, 2021, at the Mount Lemmon Observatory in Arizona, the comet's closest approach to Earth occurs on December 12th when it will pass by at a distance of 21.7 million miles (34.9 million km). It comes much closer to Venus on the 18th before heading around the Sun (perihelion, or the closest point to the Sun is around January 3, 2022) and back out into the outer solar system, not to be seen again for another 80,000 years.

Start looking for Leonard in the morning sky during the first week of December. It will pass near the bright globular cluster M3 on December 2nd and 3rd. The red giant Arcturus provides a fine celestial signpost with Leonard in the constellation Boötes on the 5th and 6th. While the comet is brightening with each passing day, it's also moving very fast (traveling at 158,084 miles per hour or 254,412 km/h) relative to Earth. Leonard will transition to the evening sky by mid-month but stay close to the horizon, making viewing a challenge. There is a possibility that the comet could continue to brighten as it approaches the Sun, but observers in the southern hemisphere will have the better view.



Launch of the Next Generation Space Telescope



Removed from its transport container after a 16-day ocean voyage to French Guiana, the James Webb Space Telescope is readied to go through preflight checks before being placed in the payload fairing of an Ariane 5 rocket
Credit: NASA/Chris Gunn

The James Webb Space Telescope (Webb) is NASA's largest and most powerful space science telescope. The next generation space observatory will allow astronomers to look further back in time - to an era when the very first stars and galaxies formed over 13.5 billion years ago. The infrared telescope will also be used to study exoplanets located in the habitable zones of other stars and is capable of analyzing the chemical compositions of their atmospheres. Webb is scheduled to launch on December 22nd from Arianespace's ELA-3 launch complex at the Guiana Space Center, near the town of Kourou in French Guiana.

The Webb's observing location is approximately 1 million miles (1.5 million km) from Earth at Lagrange point (L2). The telescope will actually orbit L2, keeping it on the night side of Earth. This will ensure that its sunshield will block any light (and heat) from the Sun, Earth and Moon from falling on the telescope's optics and detectors. At L2, Webb will stay in touch with the Earth through NASA's Deep Space Network and its power-producing solar arrays will be in constant sunlight.

The telescope will ride to orbit on an Ariane rocket, with the rocket providing the thrust for the first 27 minutes. Small thrusters on the telescope will be used for a final boost and small corrections to its trajectory. The first of three critical course corrections, and the most time-critical, occurs between 12.5 and 20 hours after launch.

Webb will start transmitting telemetry data after the payload fairing separates, about 3 and a half minutes after launch. The telescope will be released from the rocket a half hour later with the solar array unfolding shortly thereafter. The high gain antenna is deployed at the 2-hour mark.

During the first week in space, the two sunshield pallets are brought into position (the supports for the sunshield), followed by the Deployable Tower Assembly. The sunshield's telescoping booms are then extended followed by the unfolding and tensioning of the five-layered, tennis-court-size shield, comprised of aluminum-coated Kapton membranes. There are 107 membrane release devises or restraints that need to be activated, as well as an elaborate system of motors, pulleys, and cables used to position the shield in its proper configuration.

The telescope is deployed during the second week, starting with the tripod holding the secondary mirror. Once in position, the mirror segments on each side of the primary mirror unfold, exposing all 18 mirrors segments to space (once deployed the 18 gold-plated hexagonal beryllium segments will create a mirror 21.3 feet or 6.5 meters across).

The journey to L2 takes about a month. Once the telescope reaches its destination it will go through a cooling period. It will take another month before the operating temperature of -380°F (40°K) is achieved and even longer for a cryocooler to lower the temperature for the Webb's mid-infrared instrument (MIRI) instrument to -447°F (7°K). Once the telescope reaches operating temperature, its Near-Infrared Camera (NIRCam) will be used to confirm (and adjust as needed) the alignment of the mirrors segments and the observatory's science instruments. To act as a single mirror, the 18 segments need to be aligned to within a fraction of a wavelength of near-infrared light. Alignment is scheduled to be completed four months after launch. The telescope's instruments will be calibrated during months five and six before the start of routine science operations.

NASA fun fact: "Webb is so sensitive it could theoretically detect the heat signature of a bumblebee at the distance of the Moon."

A Reckless Act

On November 15th, Russia destroyed one of its own non-operational satellites in a demonstration of a direct-ascent anti-satellite weapon. The target, COSMOS-1408, was a Soviet ELINT (Electronic and Signals Intelligence) Tselina-D satellite with an estimated mass of more than 4,800 pounds (2,200 kg). Within a day, the United States' 18th Space Control Squadron (operating out of the Vandenburg Space Force base) was tracking 1,500 individual pieces from the event.

Screenshot from simulation and visualization of Cosmos-1408 debris cloud
Credit: Hugh Lewis, University of Southampton, England

While any debris-creating event should be avoided, this act was particularly reckless with the satellite in a high-inclination orbit that passed within 60 miles (100 km) of the International Space Station (above the ISS), and less than 60 miles (100 km) below several commercial satellite constellations.

Reacting to the destruction of COSMOS-1408, NASA awakened the crew on the ISS and directed them to close the hatches to the radial modules on the station and proceed to their spacecraft docked at the station (providing a more robust shelter). The astronauts (and Russian cosmonauts) remained in their spacecraft for several passes of the debris cloud until the immediate danger had passed (the hatches to the modules attached to the ISS remained closed until the 17th).

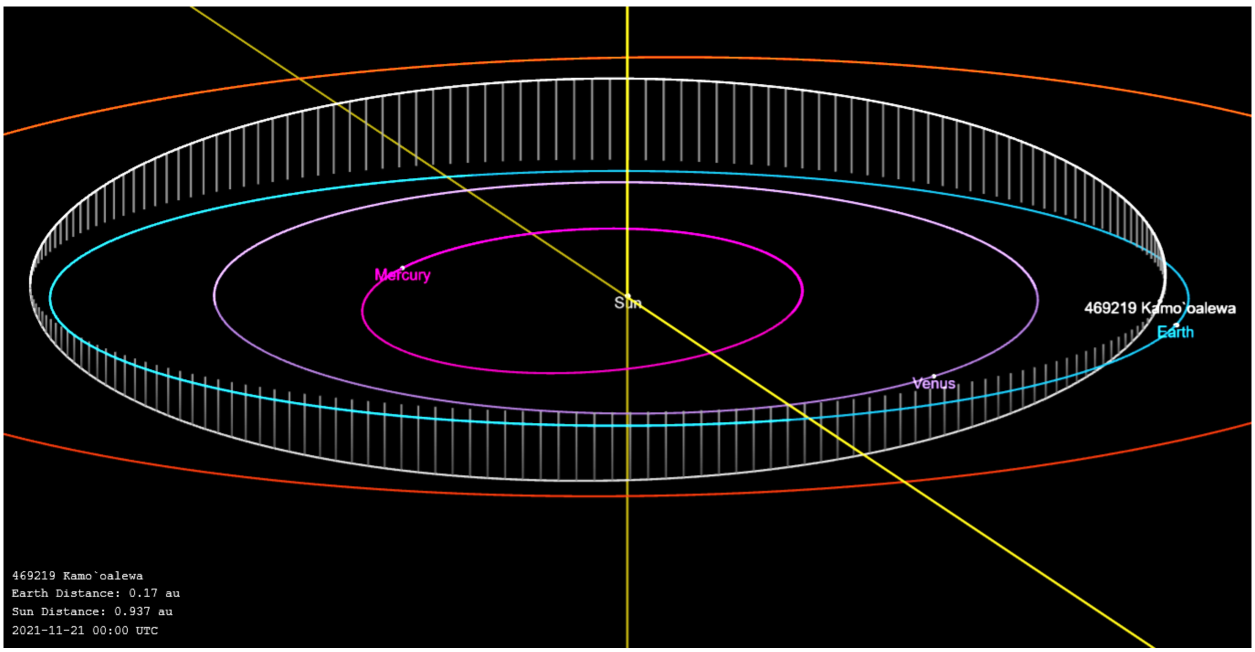
Based on some preliminary calculations, Hugh Lewis, a space debris expert, estimated that about half of the debris will reenter Earth's atmosphere and burn up within about a year, while the remaining fragments will continue to pose a hazard for 10 to 15 years, if not longer.

Less than a week earlier, the ISS conducted a collision avoidance maneuver (which the Russian space agency arranged). Thrusters on the station raised its orbit about a mile (1.2 km) to avoid a remnant of a weather satellite destroyed by China in 2007 in a similar missile test. It was the 29th time that the ISS had to be moved to avoid debris that can travel at speeds up to 17,500 miles per hour (28,200 kph). According to the European Space Agency, anything larger than a third of an inch (1 cm) could penetrate the shields of the ISS's crew modules.

Earth's Quasi-Satellites – A Lunar Connection

Pluto was demoted by the International Astronomical Union (IAU), in part, because it failed to meet one of the three criteria established by the IAU in 2006 to be considered a planet – that the celestial body "has cleared the neighborhood around its orbit." In reality, orbits are messy, for example, all of the solar system's planets, except for Mercury and Saturn, have trojan asteroids sharing their orbits (asteroids at the Lagrange L4 and/or L5 positions).

Two Earth trojans have been discovered to date, but there are other bodies, known as quasi-satellites that, although faint and difficult to detect, come close to the Earth as they travel around the Sun. Astronomers have been using the Large Binocular Telescope (LBT) and the Lowell Discovery Telescope (LDT) to characterize one of the five known and most stable quasi-satellite - designated as (469219) Kamoʻoalewa. The diminutive body rotates with a period of less than 30 minutes. Its reflectance spectrum is consistent with a silicate body.



Orbital elements of Kamo'oalewa (in white) as generated by Jet Propulsion Laboratory's Small-Body Database

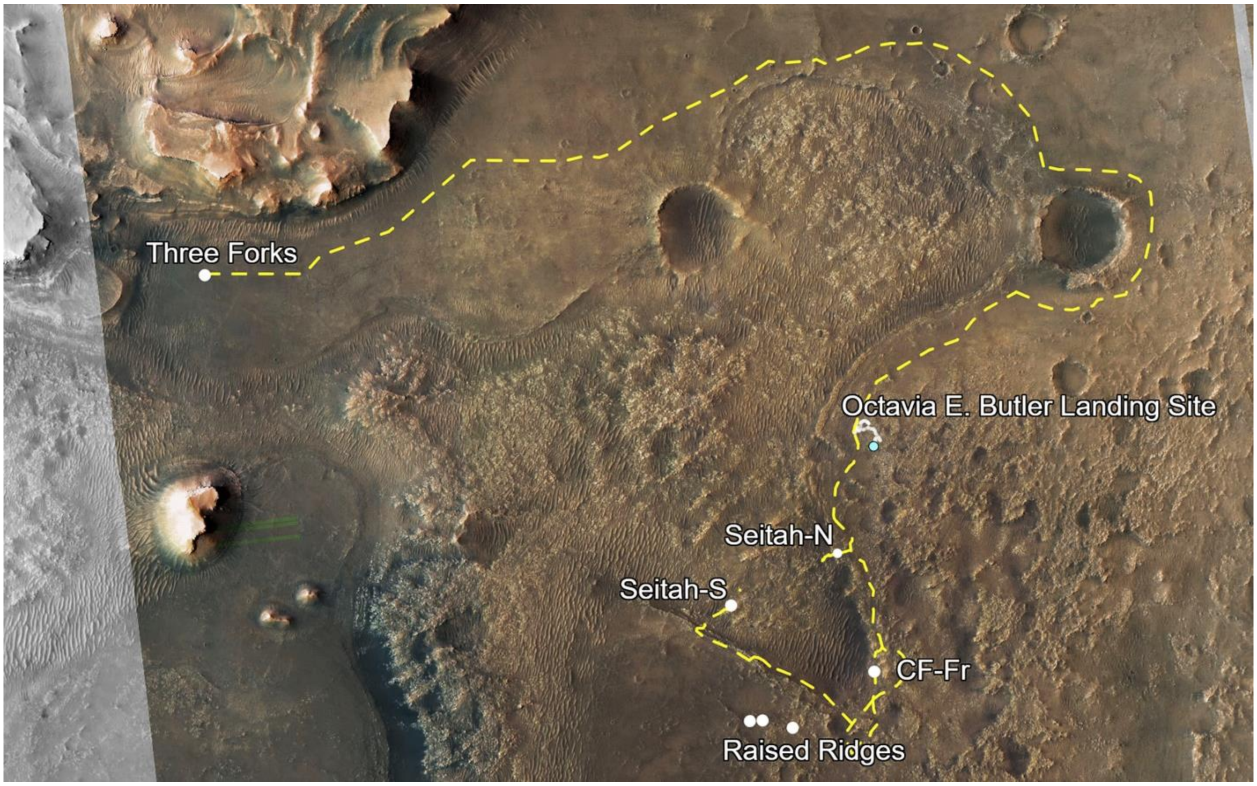
Several possibilities have been advanced as to Kamo'oalewa's origin, including: a captured near-Earth object (NEO); a member of an as-yet undiscovered quasi-stable population of Earth's trojan asteroids; or possibly an impact fragment or debris from the breakup of an NEO. Recent observations have advanced another possibility - an intriguing hypothesis that the quasi-satellite may be lunar ejecta.

While Kamo'oalewa's spectrum is indicative of a silicate-based composition, its reddening is beyond what is typically seen amongst asteroids in the inner solar system (spectrum "reddening" has been attributed to space weathering by the solar wind, cosmic ray irradiation, and meteoroid bombardment). It is analogous, however, to the highly space-weathered samples from the lunar highlands returned by missions like Apollo 14. A lunar origin for Kamoʻoalewa is further supported by its low relative velocity during its close approaches to Earth-Moon, as compared to NEOs with much higher velocities.

Return to Base

After a brief respite during solar conjunction (when the Sun is between Earth and Mars and communications are suspended), NASA's Ingenuity helicopter is back in the rarified air of the Red Planet. After a short hop to evaluate a higher rotor speed (the increase from 2,500 rpm for the first 13 flights to 2,700 rpm was necessitated by a seasonal decrease in air density), the diminutive rotorcraft completed its fifteenth flight on November 6th followed by another (sixteenth) on the 21st.

Ingenuity is working its way back to Wright Brothers Field, the site of the helicopter's first flight (it will take 4 to 7 fights). The 16th flight lasted almost 108 seconds and traversed 381 feet (116 meters) of horizontal distance. The helicopter traveled at a speed of about 3 mph (5 kph), at an altitude of 33 feet (10 meters). NASA's Perseverance rover is trailing behind. The helicopter and the rover are expected to work together as they make their way towards the delta's escarpment.



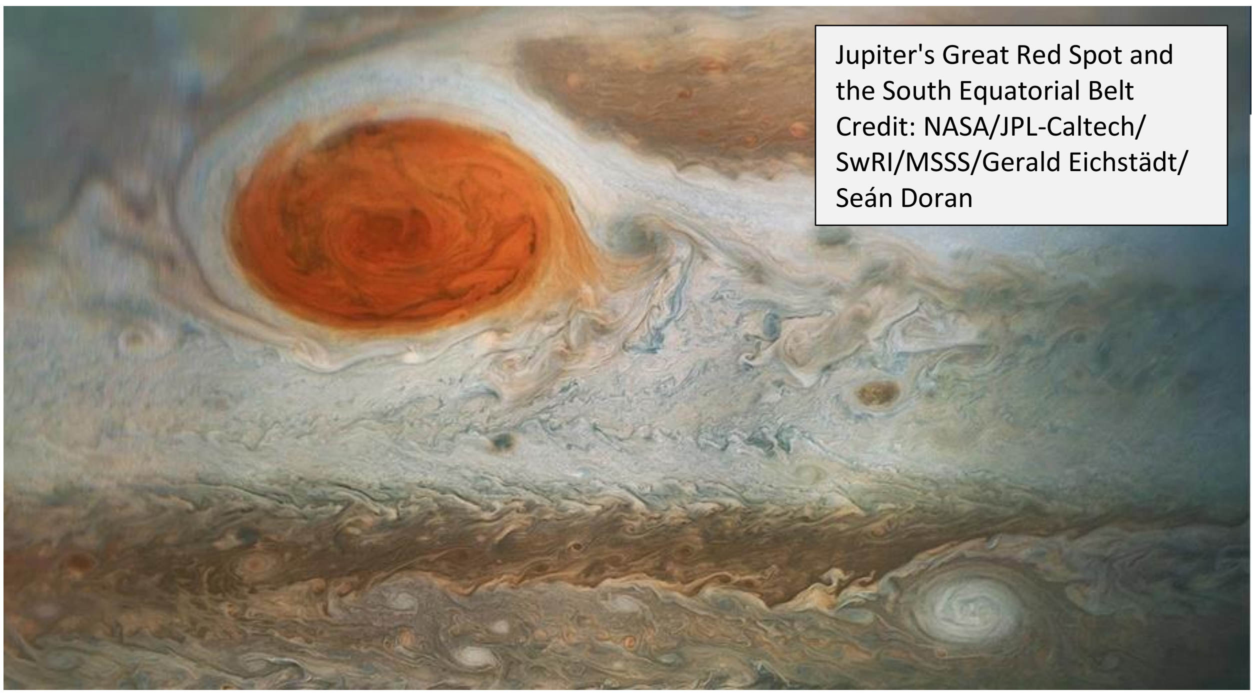
Travels (past and future) of NASA's Perseverance rover in Jezero Crater. In its first science campaign, the rover traveled as far as South Séítah before turning around and heading back to its landing site. Perseverance's second science campaign will target Jezero's river delta near Three Forks, driving north and then west from the landing site.
Credits: NASA/JPL-Caltech/University of Arizona

Ingenuity's navigation algorithm was designed for the level terrain of the airfield near the landing site. The Séítah area, with its raised ridges and rugged topography, poses a challenge for the helicopter with any change in the terrain height introducing heading errors. Flights are kept short to reduce the accumulation of errors over uneven ground. At some point, while the helicopter team waits for Perseverance to catch up, they are considering performing a flight software update to enable new navigation capabilities.

Beneath the Jovian Clouds

NASA's Juno spacecraft entered into a polar orbit around Jupiter in 2016. The spacecraft completed its prime mission in July and is now in an extended phase of the mission. Assuming its systems remain healthy, the orbiter is expected to carry on in its exploration of the gas giant and largest moons through September 2025, with the potential of 42 orbits being added to the mission.

Recently, a number of papers have been published that describe what researchers have learned from the data collected by Juno's instruments over the first 37 flybys on the inner workings of the Jovian atmosphere. Using Juno's microwave radiometer (MWR), which can probe into and beneath multiple layers of the upper atmosphere, researchers have found that the planet's cyclones are warmer on top with lower atmospheric densities than at the bottom. Anticyclones, rotating in the opposite direction, including the Great Red Spot, are colder at the top but warmer at the bottom.

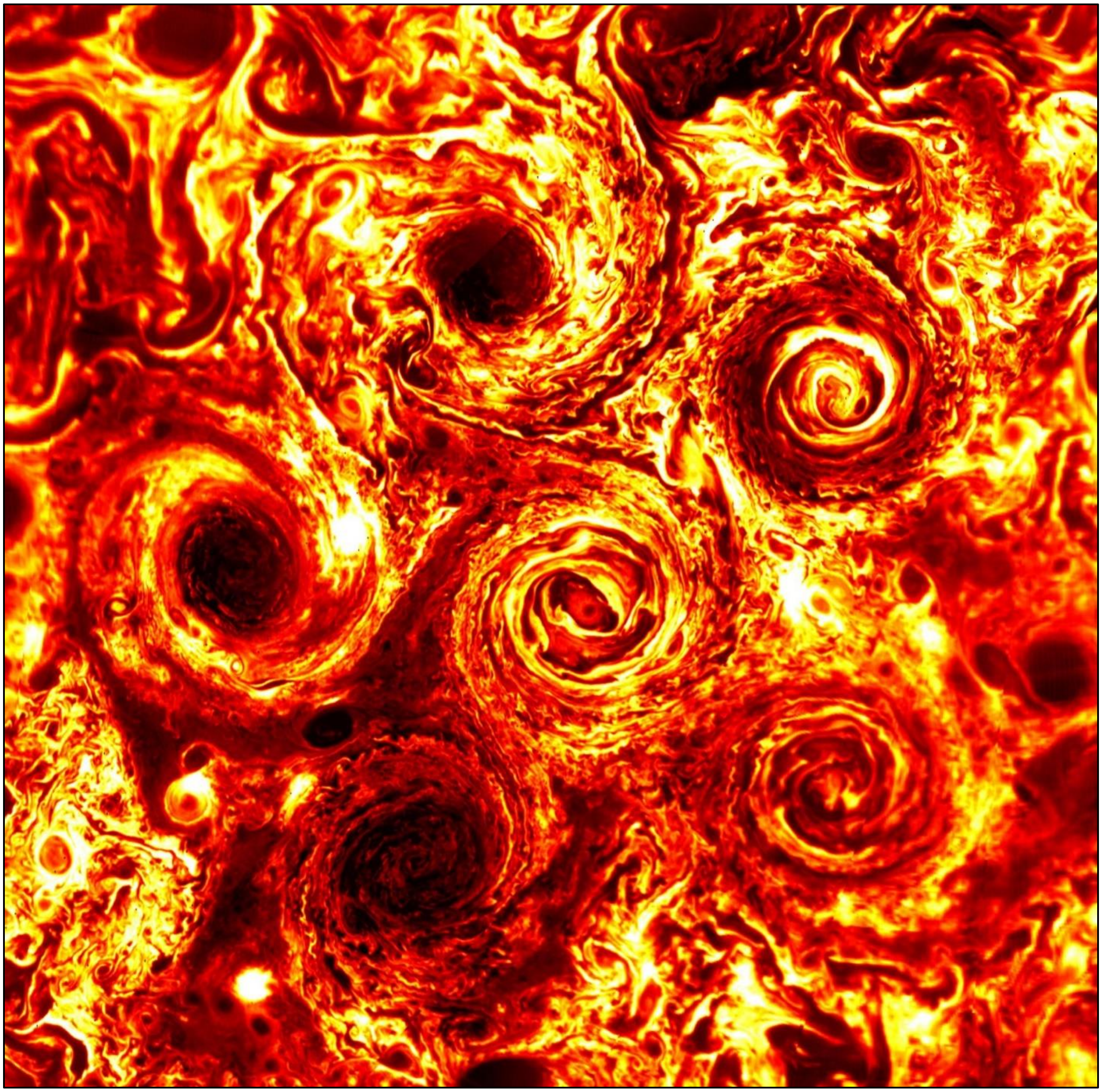


Jupiter's Great Red Spot and the South Equatorial Belt
Credit: NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt/Seán Doran

The atmospheric storms extend farther into the planet's atmosphere than was expected, with some reaching 60 miles (100 kms) or more below the cloud deck. More surprising was that the storms extended deeper into the atmosphere than where clouds form and sunlight penetrates (water and sunlight are integral to the formation of storms on Earth). The Great Red Spot extends more than 200 miles (350 km) below Jupiter's cloud tops, but the rising and falling jet streams that power the long-lasting storm reach as deep as 1,800 miles (3,000 km). The anticyclone has also been observed to be shrinking in size, since first observed, with its winds increasing.

Dark belts and light zones give Jupiter a banded appearance, noticeable in even the smallest of Earth-bound telescopes. Juno's MWR found that the cloud tops in the belts are warmer and/or devoid of ammonia gas while the opposite was observed in the zones. However, as the pressure increases, somewhere around a depth of 28 to 50 miles (45 – 80 km) from the top of the clouds, a transition occurs where the zones appear warmer than the belts. This well-defined transitional boundary, dubbed the "Jovicline," (a nod to science fiction author Arthur C. Clarke who first used the term), while unexplained, may be temperature driven or somehow associated with the abundance and circulation of ammonia.

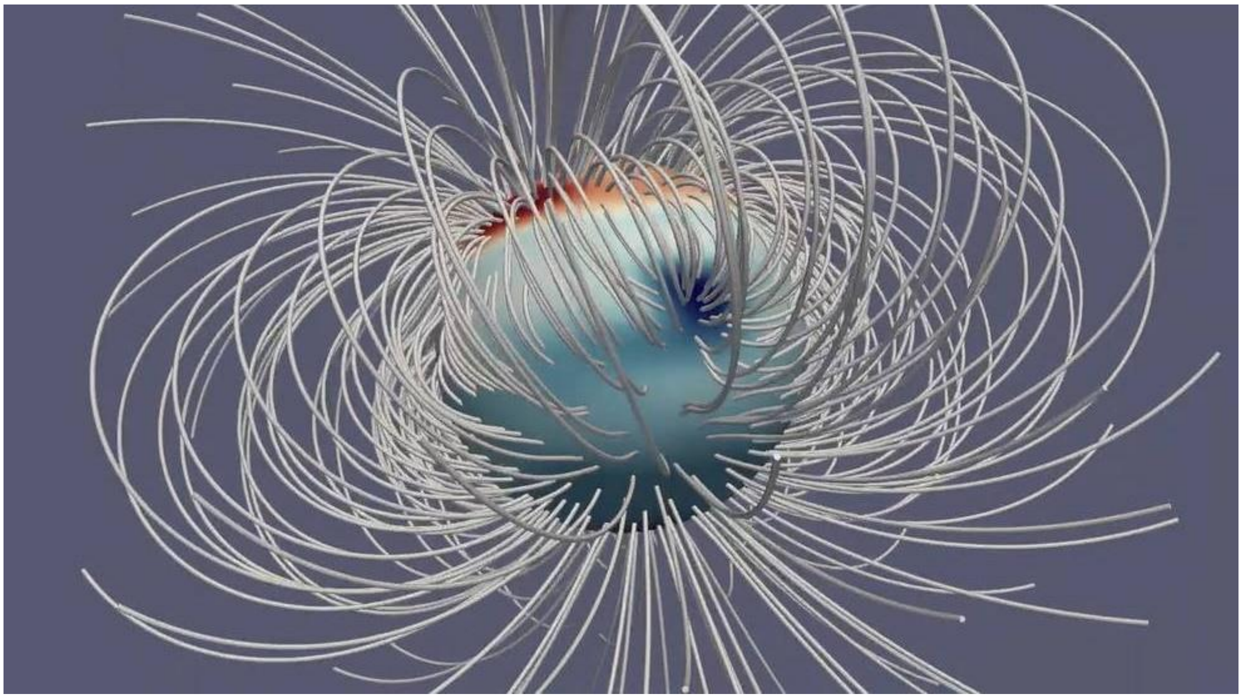
Other Jovian revelations reported by researchers include polar cyclones in equilibrium, an ill-defined core and a very unconventional magnetic field.



Infrared image of Jupiter's south pole and its six cyclones (five surrounding a central vortex
Credit: NASA/JPL-Caltech/SwRI/ASI/INAF/JIRAM

Juno had discovered giant cyclonic storms at both of Jupiter's poles, eight at the north pole and six at the south. The storms were arranged in an octagonal pattern in the north and a hexagonal pattern in the south, with central vortices. Now after five years of observation, and using the spacecraft's Jovian Infrared Auroral Mapper (JIRAM), researches have concluded that the central vortex is the key to the longevity of this arrangement, blocking the outlying storms from moving any closer to the poles. Unable to migrate any farther north, the bordering cyclones slowly oscillate about an equilibrium position, maintaining their relative location to each other and the pole.

Earth's magnetic field is believed to be generated by the churning of electrically conductive fluids (molten iron) in the planet’s outer core. The invisible field lines generated by this dynamo resemble that of a bar magnet, spreading outward from the north pole before returning to the south pole. In the case of Jupiter, researchers believe that the conductive fluid is liquid metallic hydrogen, created by the intense pressure deep within the atmosphere. The arrangement of the gas giant’s fields lines, however, are much different than our, and other planets. Jupiter’s magnetic field radiates from a high-latitude band near the north pole as compared to a more concentrated point on Earth, and it returns to two points on the planet, rather than one – a point near the equator dubbed “the Great Blue Spot” (not related to the “Great Red Spot”), as well as the south pole.



Jupiter’s magnetic field lines color coded red for positive and blue for negative, and the “Great Blue Spot” – one of two south magnetic poles
Credit: NASA/JPL-Caltech/Harvard/Moore et al.

Earth’s magnetic field has a negative polarity near its north geographical pole and a positive polarity near its south pole. Its magnetic field is evenly distributed, with no part favoring one pole or another. At Jupiter, there is a concentration of the field in the northern hemisphere.

Jupiter’s unconventional magnetic field may be related to another discovery – concerning its unusual interior. Planetary scientists had expected Juno’s observations to settle a question on the planet’s origin and evolution, either as a ball of essentially almost-pure hydrogen and helium, similar to the Sun, or as a ball of gas with a solid core of heavier elements or rock, similar to the terrestrial planets. Juno did detect a core, but instead of solid/concentrated, it’s a mushy construct that is spread across nearly half of the planet’s interior.

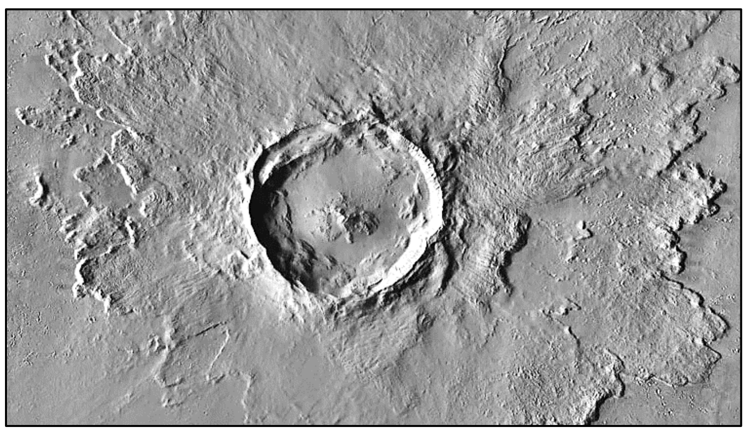
Juno’s discoveries are challenging conventional views and theories on planetary formation, not just within our solar system, but around other stars. It appears that the more we learn about planet-building, the more there is to learn.

Shergottites – Meteorites from Mars

Meteorites that have been determined to have come from Mars (gases trapped inside these extraterrestrial rocks are in the exact proportions as gases in the Martian atmosphere, as measured by the Viking landers) are generally one of three types or families of achondrites, with Shergottites being the most numerous (more than 80% of all Martian meteorites). Shergottites are further categorized into three subgroups in accordance with their relative abundance of light, rare-earth elements such as Lanthanum, Cesium, and Praseodymium.

Meteorites from Mars (or the Moon) are comprised of material excavated from the surface as a result of a relatively energetic impact (powerful enough to eject the material into space). Once in space, the material is subject to the gravitational forces of nearby bodies and can migrate far from its point of origin, for example, until it comes under the influence of another body like Earth. Shergotty, the first member of the family, was an 11-pound (5 kg) meteorite that was seen to fall at Sherghati, in the Gaya district, Bihar, India on August 25, 1865.

The time a rocky body spends in space can be measured by its exposure to cosmic radiation. Scientists noticed that a number of "depleted shergottites" had similar ejection ages (around 1.1 million years), suggesting a common impact event and location. In searching for that point of origin, Australian researchers at Curtin University compiled a database of 90 million impact craters, while also considering the surface geology, age of the terrain around the craters, crystallization ages of the meteoritic material, and the chemical and mineralogical properties of the depleted shergottites.



Tooting crater
Credit: NASA

As described in a recent paper published in *Nature Communications*, the crater-modeling algorithm identified Tooting crater as the most likely source of the depleted shergottites ejected 1.1 million years ago. The 17-mile (27.2 km) diameter crater is located in the Tharsis volcanic province, not far from the solar system's largest volcano, Olympus Mons. Its age is estimated to be about 1 million years, with the age of the surrounding surface estimated at 308 ± 41 million years.

The McCarthy Observatory has an extensive collection of meteoritic specimens, including historic finds and falls, as well as meteorites from both Mars and the Moon.

The collection includes a meteorite classified as a depleted shergottite – Dar al Gani 475 (image of the 0.866 mg part slice on left). The meteorite was found in Libya in 1998. Radiogenic analysis indicates that the basalt crystalized about 475 million years, was exposed to cosmic rays for 1 million years, and lay on the sands of the Sahara for 40-80 thousand years.

Apollo 8 – Lookback

1968 was a year of turmoil. The United States was entangled in a war that even the Secretary of Defense concluded could not be won and he resigned from office. The My Lai massacre was one of many atrocities of the Vietnam War perpetrated by both sides during this year. Major U.S. cities were the target of race riots and anti-war protests. Chicago police violently clashed with protesters at the Democratic National Convention and civil rights leader Martin Luther King and presidential candidate Robert Kennedy were assassinated in 1968. To many Americans, the only heartening event in this otherwise horrific year was the reading from the Book of Genesis by the crew of Apollo 8 as they orbited the Moon on Christmas Eve.

The race to beat the Soviets to the Moon took a dramatic turn in 1968 and saw the United States take its first lead by year's end. Apollo 7 was launched in October 1968 into Earth orbit. A week or so later, the Soviets launched two Soyuz space craft into Earth orbit (one manned and one unmanned for a planned rendezvous). In November, another unmanned Zond flew around the Moon and photographed the unseen far side. The United States expected that the Soviets would attempt another moon shot in early December when the launch window for the Baikonur space center in Kazakhstan reopened (a Zond stood poised on the launching pad). Curiously, the opportunity passed without any activity. Cosmonaut Alexei Leonov would later attribute the Soviet's loss of initiative and resolve to the premature death of Sergei Korolev, the "Chief Designer" of the Soviet space program as well as the design complexities of their Moon rocket (the N1).

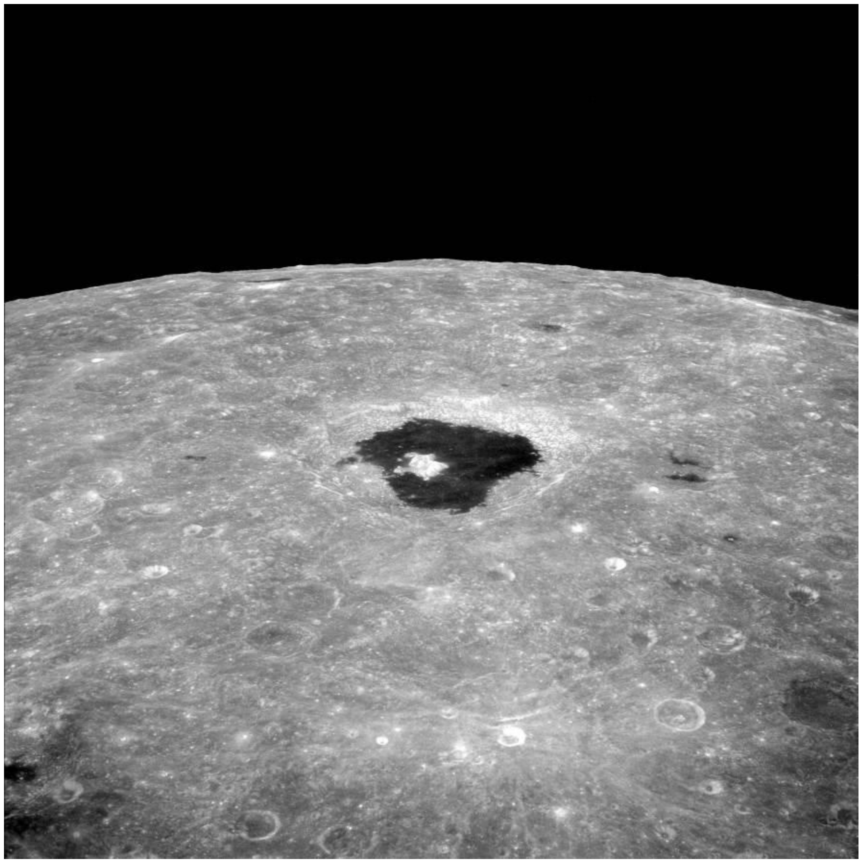
While Apollo 7 had been a successful maiden voyage of the completely redesigned command module (after the Apollo 1 fire), the United States had yet to leave Earth orbit. NASA's original plan was to launch a series of increasingly complex missions to near-Earth orbit before attempting a lunar excursion. Development of the lunar lander was behind schedule and violent vibrations in the Saturn rocket's main stage needed to be corrected before NASA felt confident of sending men to the Moon. However, the apparent progress by the Soviets threatened to upstage the United States once again. It was a proposal by a quiet engineering genius, George Low, (Manager of the Apollo Spacecraft Program Office) to send the Apollo 8 command module alone into lunar orbit that would ultimately place the United States in a position to achieve President Kennedy's goal to land a man on the Moon and safely return him to Earth by the end of the decade.

Apollo 8 was launched on December 21st under the command of Frank Borman with astronauts William Anders and Jim Lovell (Lovell replaced Michael Collins on the original team; Collins, who required back surgery, would go on to be the Command Module Pilot for Apollo 11). The launch was scheduled so that the crew would arrive at the Moon as the Sun was rising on the Sea of Tranquility. With the Sun low in the sky, the astronauts could photograph potential landing sites and resolve surface detail that would otherwise be washed out in the glare from a higher Sun.

The crew of Apollo 8 was the first to ride the three stage Saturn V rocket, with the explosive energy of an atomic bomb (the Saturn V had only been launched twice before – both unmanned). The night before the launch, the astronauts were visited by Charles Lindbergh. During the visit, it was discussed that the engines on the Saturn V would burn 10 times the amount of fuel every second that Lindbergh had used to fly nonstop from New York to Paris.

The Apollo 8 astronauts were also the first humans to leave Earth orbit and pass through the Van

Allen radiation belts that extend up to 15,000 miles from Earth. To accomplish the mission, Apollo 8 had to cross the 240,000-mile void between the Earth and the Moon with sufficient precision so as to intercept the Moon (traveling at 2,300 miles an hour through space) just 69 miles above the lunar surface. By successfully doing so, the astronauts were the first humans to witness the rising of the Earth above the Moon's horizon (Earthrise). They would also be the first to return to Earth and reenter the atmosphere at a speed of 25,000 miles an hour.



Apollo 8's view of Tsiolkovsky crater with its lava covered floor on the Moon's far side. Credit: NASA

The highlight of the mission, to many, was the broadcast from the Apollo 8 command module during the ninth orbit of the Moon. After a brief introduction of the crew and their general impressions of the lunar landscape, William Anders said that the crew had a message for all those on Earth. The astronauts took turns reading from the book of Genesis, the story of creation. Frank Borman closed the broadcast with: "And from the crew of Apollo 8, we close with: Good night, Good luck, a Merry Christmas, and God bless all of you, all you on the good Earth." It is estimated that a quarter of Earth's population saw the Christmas Eve transmission.

In order to safely return to Earth, the main engine had to be restarted on the far side of the Moon (out of contact with the Earth). If successful, Apollo 8 would reappear from behind the Moon at a predetermined time. As predicted, the spacecraft re-emerged on time, and when voice contact was regained, astronaut Jim Lovell would announce: "Please be informed, there is a Santa Claus." It was Christmas Day. Apollo 8 would return safely to the Earth two days later, splashing down in the Pacific Ocean shortly before sunrise. The astronauts and the capsule were recovered by the aircraft carrier USS Yorktown.

Following the success of Apollo 8, the Soviet Moon program fell further behind with catastrophically unsuccessful launches of their N1 booster in February and again in July of 1969. An unmanned, sample return mission attempted to upstage the Apollo 11 landing, but Luna 15 crashed into Mare Crisium shortly before Armstrong and Aldrin were scheduled to lift off from the Moon. The Soviets officially cancelled their Moon program in the early 1970s.

Purchasing a Telescope

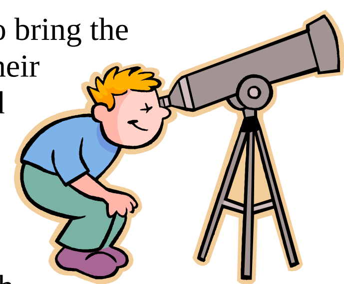
During the holidays it's not uncommon to see parents and grandparents carrying around a telescope that they just picked up at the mall or warehouse store for their budding astronomer. Unfortunately, too many of these thoughtful gifts end up in a basement or attic after one or two uses. All too often, telescope manufacturers prey on consumer's expectations, which are often out of line with the capabilities of the product, resulting in frustration and disillusionment. However, even a crudely constructed telescope can be coaxed to produce acceptable images, if the observer understands the limitations of his or her instrument.

There is no perfect telescope for everyone. An inexpensive, mass-produced telescope that gets carted out of the house and set up every clear night, stimulates the users' imagination and encourages them to push the instrument's capabilities to its limits is far more valuable than the most highly crafted optical masterpiece that spends its nights in a closet.

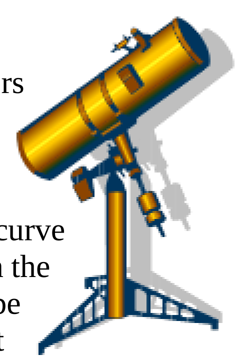
There are several types of telescopes available to the general consumer. Each has advantages and disadvantages, and with a little education, a consumer can find a telescope that fits his or her needs and lifestyle. Again, if you don't use it, a telescope is about as useful as a garden gnome and not as cute.

Types of Telescopes

There are three basic types of telescopes: refractors, reflectors and compound or catadioptric telescopes.



Refractors have been around for 400 years and use a series of lenses to bring the light rays from distant objects to focus. They are highly regarded for their unobstructed and high-contrast images. The optical tubes are sealed and generally more rugged than other designs. As such, the optics rarely need to be adjusted (realigned) which makes the refractor a good choice as a travel telescope. Refractors are an excellent choice for planetary and lunar viewing and for double stars, but generally do not have the large light gathering capacity needed for faint objects such as nebula and galaxies. The disadvantages of refractors include: the potential for different wavelengths of light to diverge from a common focus as they pass through the glass (producing color "fringing" around bright objects), the position of the eyepiece at the rear of the optical tube (requiring the telescope to be mounted fairly high off the ground for comfortable viewing), the closed tube that can take some time to cool down, and the price (highest cost per inch of aperture of the basic telescopes designs).



Reflectors have been around for almost as long as refractors, but use mirrors instead of lenses to bring light to the observer's eye. A large mirror located at the closed end of the optical tube reflects light back up the tube to a smaller mirror mounted near the open end and out to an eyepiece. Mirrors are much easier and less expensive to manufacture than lenses with only an optical curve required on the front of the mirror. With mirrors, the light never passes through the glass, so there is no divergence of the light rays. However, since the optical tube is open to the atmosphere, mirrors will require periodic cleaning, adjustment and, eventually, recoating. Reflectors offer the best value, particularly for larger apertures.

The most popular compound or catadioptric telescopes combine a large, rear spherical mirror with a front corrector lens to create a very compact optical tube. Companies such as Meade and Celestron built their businesses on the Schmidt-Cassegrain design. While generally more expensive than reflectors, the compound telescope offers a very portable alterative for large aperture telescopes. Disadvantages include cool down time (since the optical tubes are sealed), and a relatively large secondary mirror that degrades the image of high contrast objects (planets or the Moon). The front corrector plate is also susceptible to dew formation although this can be managed with a dew shield or corrector plate heater.

There are several terms that are used in the sales promotion of telescopes. Some of the common ones are discussed below:

Aperture

Aperture refers to the size of the largest lens or mirror in the telescope, for example, the primary mirror in an 8-inch reflector is 8-inches in diameter. As a general rule, bigger is better, as light gathering and resolution increase with the size of the optics. However, as with everything else, there are other considerations that limit the practical size of a particular instrument. Alvan Clark & Sons figured the 40-inch lens for the Yerkes Observatory's refractor, delivering the lens in 1897. More than 100 years later, it is still the world's largest working refractor. Why? The weight of the glass and the complexities in supporting a large lens by its edge and the absorption of light passing through the glass were factors; however, the refractor was ultimately done in by Sir Isaac Newton when he built the first reflecting telescope in 1668. Mirrors, unlike lenses, can be completely supported from the back. Since light does not pass through the glass, reflected images do not suffer from "chromatic aberration." Today single mirrors are routinely produced with diameters exceeding 28 feet and telescopes are constructed combining multiple mirrors to achieve even larger light gathering capabilities. So what size is good for you? Before you answer, you may want to consider:

- Are you planning on setting up your telescope in a permanent installation, e.g., backyard observatory, or will you be moving it in and out of your home every time you plan on observing? If the latter, then weight, portability and ease of set up are important considerations. Due to its size and weight, my telescope saw very little use until I invested in a wheeled platform that allows me to easily roll the fully assembled telescope in and out of my garage in minutes.

- Are you planning on taking your telescope on the road, with you on vacation or planning to travel some distance to find truly dark skies or observe a "once in a lifetime event?" Whether by train, plane or automobile, care must be taken to protect your telescope and ensure that it arrives at its destination in working order (mechanically and optically). If this is important to you, a smaller and simpler design such as a refractor may be a good choice.

- What are you interested in looking at? Spectacular views of the Sun, Moon and planets can be acquired with a relatively modest instrument. However, if your passion is hunting down the more elusive and distant residents of the Milky Way Galaxy or exploring other galaxies far, far, away, it will require a much larger aperture to capture those meager photons.

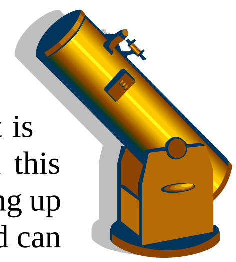
Magnification

Magnification is likely the most overrated measure of a telescope's capabilities. Magnification is a function of the eyepiece placed in the path of the incoming light and in front of the observer's eye; the observer can change the magnification by simply selecting a different eyepiece. As such, it shouldn't be a criterion in selecting a telescope.

The limiting useful magnification is approximately 50 times the diameter of the objective lens or primary mirror. For example, a small refracting telescope with a 4-inch objective lens can be pushed to a magnification of 200 times; however, only under the best observing conditions and, in general, only on bright objects such as the Moon and planets. Most astronomers prefer the views that lower magnification provides with a wider field and brighter image. So, the next time you are captured by the stunning views of the universe on the packaging of a modest instrument, remember that the potential of most telescopes is rarely realized, particularly if you reside in the light polluted skies of the northeast. A higher power eyepiece magnifies not only the telescope's intended target but also the side-effects of living under 20 miles of Earth's atmosphere.

Mounts

While generally not at the top of the list as far as features, the telescope's mounting system and construction is key to its ease of use and the stability of the image. A poorly designed mount or one with flimsy construction can be just as frustrating to deal with as poor optics. An altitude-azimuth or alt-az mount is the simplest type of telescope mount and generally the easiest to set up. In this arrangement, the mount allows the telescope to move left and right while pivoting up and down. It is commonly found on Dobsonian* telescopes, is user friendly and can be mechanized to track celestial objects across the sky.



Another common mount design is the equatorial mount. In this design, one axis is aligned with the celestial pole, requiring only the movement around this axis to follow objects across the sky. It is the easiest configuration for tracking and is generally preferred for astrophotography. Some alt-az mounts can be converted to an equatorial configuration with the addition of an "equatorial wedge." Equatorial mounts, however, can be heavier than their alt-az counterparts.

Go-To

Essentially a computer controlled pointing system, "go-to" allows the user to select an object from a data base and command the drive motors on the mount to move the telescope to the object's location in the sky. This presupposes that the telescope user has properly set up the telescope and successfully navigated through the alignment process (a process by which the telescope's computer determines where it's pointed, the local time, and its position on the Earth). Most "go-

* Dobsonian telescopes are reflectors on a simple, swivel mount. They offer a low-cost solution for those on a limited budget with aperture fever (an insatiable desire for a larger telescope).

to" telescopes come with a large database, some of which can be modified (supplemented) by the user. While "go-to" capability is extremely convenient and can take you to thousands of objects in its database in a blink of an eye, it doesn't necessarily mean that you will be able to see the object. Depending upon the size of your telescope (see Aperture), many objects in these databases are just too dim to see with the equipment provided. CCD cameras are much more sensitive than your eye and can accumulate light for long durations. So, if you are planning on using your telescope primarily as a camera lens, then some of the disadvantage of a small aperture can be overcome. However, if you plan on doing most of your observing at the eyepiece, you may want to consider spending the money on a larger aperture rather than on "go-to" electronics.

What to Do

If you are seriously considering acquiring a telescope, a little bit of research can go a long way in enjoying your final purchase. If possible, try to observe through the telescope(s) that you are considering. Check out product reviews in trade magazines such as Sky & Telescope and Astronomy and on their websites. Contact reputable dealers and visit trade shows such as the Northeast Astronomical Forum where you can pick the brains of industry experts. When the McCarthy Observatory reopens - attend an open house. When the skies are clear, up to a dozen telescopes can be found on the premises (including refractors, reflectors, a Dobsonian, and several Schmidt–Cassegrains). Compare the same celestial objects through different scopes, talk to the owners about portability, ease of setup and operation.

December Nights

Nights in December are not to be missed. While the often frigid and turbulent atmosphere can be frustrating for astronomers, the reflection of shimmering starlight (or moonlight) off a snow-covered landscape can be truly magical. The bright stars of the winter sky glow with color from orange to yellow to brilliant blue-white. A star-filled sky in December is unsurpassed in grandeur.

Sunrise and Sunset (New Milford, CT)

Sun	Sunrise	Sunset
December 1st (EST)	07:01	16:21
December 15th	07:13	16:22
December 31st	07:19	16:31

Astronomical and Historical Events

1st Kuiper Belt Object 386723 (2009 YE7) at Opposition (49.792 AU)
1st History: launch of Soviet satellite Sputnik 6 and two dogs: Pchelka and Mushka (1960)
2nd Aten Asteroid 2010 TK7 (Earth Trojan) closest approach to Earth (0.224 AU)
2nd Apollo Asteroid *10563 Izhdubar* closest approach to Earth (1.233 AU)
2nd History: Soviet Mars 3 lander became the first spacecraft to attain a soft landing on Mars, only to fail after 110 seconds (1971)
2nd History: launch of the Hayabusa 2 spacecraft to the asteroid *162173 Ryugu* from the Tanegashima Space Center, Japan (2014)
2nd History: dedication of the John J. McCarthy Observatory in New Milford, CT (2000)

Astronomical and Historical Events (continued)

2nd History: launch of SOHO solar observatory (1995)
2nd History: launch of space shuttle Endeavour (STS-61), first servicing of the Hubble Space Telescope, including the installation of corrective optics and new solar panels (1993)
2nd History: Pioneer 11 spacecraft makes its closest approach to Jupiter; encounter redirects the spacecraft to Saturn and an escape trajectory out of the solar system (1974)
2nd History: touchdown of Soviet Mars 3 lander: communications were lost with the lander, the first spacecraft to touch down on the Red Planet, after 20 seconds possibly due to raging dust storm (1971)
3rd Kuiper Belt Object 2006 QH181 at Opposition (83.679 AU)
3rd History: NASA spacecraft OSIRIS-REx arrives at asteroid *Bennu* (2018)
3rd History: Pioneer 10 spacecraft makes its closest approach to Jupiter; first space probe to fly through the asteroid belt and to an outer planet (1973)
3rd History: discovery of Jupiter's moon *Himalia* by Charles Perrine (1904)
4th New Moon
4th Moon at perigee (closest distance from Earth at 221,701 miles or 356,793 km)
4th Kuiper Belt Object 145453 (2005 RR43) at Opposition (39.052 AU)
4th History: launch of space shuttle Endeavour (STS-88), first International Space Station construction flight, including the mating of the Unity and Zarya modules (1998)
4th History: launch of the Pathfinder spacecraft to Mars (1996)
4th History: Pioneer Venus 1 enters orbit, first of two orbiters (and probes) to conduct a comprehensive investigation of the atmosphere of Venus (1978)
4th History: launch of Gemini 7 with astronauts Frank Borman and Jim Lovell, spending almost 14 days in space (1965)
4th History: launch of Little Joe 2 rocket, test flight for the Mercury capsule and first U.S. animal flight with Sam, a Rhesus monkey (1959)
6th History: recovery of Hayabusa 2's sample return capsule containing material from the asteroid Ryugu (2020)
6th History: Japanese spacecraft Akatsuki enters around Venus five years after unsuccessful first attempt and main engine failure (2015)
7th Jupiter Trojan *1437 Diomedes* at Opposition (4.058 AU)
7th Kuiper Belt Object 2018 VG18 at Opposition (122.622 AU)
7th History: launch of the Jason-1 satellite to measure ocean surface topography from the Vandenberg Air Force Base, California (2001)
7th History: arrival of the Galileo space probe at Jupiter (1995)
7th History: launch of Apollo 17 with astronauts Ronald Evans, Harrison Schmitt (first scientist – geologist) and Eugene Cernan (last man on the Moon – so far) (1972)
8th Scheduled launch of a Russian Soyuz spacecraft with the next expedition crew to the International Space Station from the Baikonur Cosmodrome, Kazakhstan
8th History: launch of the Chinese Chang'e 4 spacecraft to the far side of the Moon from the Xichang, China launch site (2018)
8th History: Dragon spacecraft, launched by SpaceX into low-Earth orbit, is recovered in the Pacific Ocean: first time a spacecraft recovered by a commercial company (2010)
8th History: Japanese spacecraft IKAROS becomes the first to successfully demonstrate solar sail technology in interplanetary space during a Venus flyby (2010)
8th History: discovery of asteroid *5 Astraea* by Karl Hencke (1845)
9th Kuiper Belt Object 229762 G!kun||'homdima at Opposition (40.353 AU)

Astronomical and Historical Events (continued)

9th Kuiper Belt Object *148780 Altjira* at Opposition (45.104 AU)
9th History: Pioneer Venus 2 enters orbit, second of two orbiters (and probes) to conduct a comprehensive investigation of the atmosphere of Venus (1978)
10th First Quarter Moon
10th History: launch of the X-ray Multi-Mirror Mission (XMM-Newton), the largest scientific satellite built in Europe and one of the most powerful (1999)
10th History: launch of Helios 1 (also known as Helios A) into solar orbit; joint venture by Federal Republic of Germany and NASA to study the Sun (1974)
10th History: launch of the Boeing X-37B Orbital Test Vehicle 1 (unmanned space plane) from the Cape Canaveral Air Force Station (2012)
11th Second Saturday Stars – Open House at the McCarthy Observatory (7:00 pm)
11th Comet 19P/Borrelly closest approach to Earth (1.175 AU)
11th Apollo Asteroid *4660 Nereus* near-Earth flyby (0.026 AU)
12th C/2021 A1 (Leonard) closest approach to Earth
12th Apollo Asteroid *4486 Mithra* closest approach to Earth (2.631 AU)
12th Centaur Object 2015 KJ153 at Opposition (8.743 AU)
12th Kuiper Belt Object 145451 (2005 RM43) at Opposition (36.826 AU)
12th Kuiper Belt Object 470443 (2007 XV50) at Opposition (46.058 AU)
12th History: discovery of Saturn moons *Fornjot*, *Farbauti*, *Aegir*, *Bebhionn*, *Hati* and *Bergeimi*r by Scott Sheppard, et al's (2004)
12th History: discovery of Saturn moons *Hyrrokkin* by Sheppard/Jewitt/Kleyna (2004)
12th History: launch of Uhuru, the first satellite designed specifically for X-ray astronomy (1970)
12th History: launch of Oscar, first amateur satellite (1961)
13th Geminids meteor shower peak
13th Aten Asteroid 2019 XQ1 near-Earth flyby (0.036 AU)
13th Apollo Asteroid *4341 Poseidon* closest approach to Earth (0.332 AU)
13th Aten Asteroid 2014 BA3 closest approach to Earth (1.069 AU)
13th Kuiper Belt Object 2004 XR190 at Opposition (55.956 AU)
13th History: flyby of Asteroid 4179 *Toutatis* by the Chang'e 2 spacecraft, China’s second lunar probe (2012)
13th History: discovery of Saturn’s moons *Fenrir* and *Bestla* by Scott Sheppard, et al's (2004)
13th History: launch of Pioneer 8, third of four identical solar orbiting, spin-stabilized spacecraft (1967)
13th History: Mt. Wilson’s 100-inch telescope used to measure the first stellar diameter (Betelgeuse); measured by Francis Pease and Albert Michelson (1920)
13th History: first light of Mt. Wilson’s 60-inch telescope (1908)
14th History: landing of China’s Chang'e 3 Moon lander on Mare Imbrium (2013)
14th History: flyby of Mars by Japan’s Nozomi spacecraft after an attempt to achieve orbit fails (2003)
14th History: creation of the Canadian Space Agency (1990)
14th History: flyby of Venus by Mariner 2; first spacecraft to execute a successful encounter with another planet, finding cool cloud layers and an extremely hot surface (1962)
14th History: Weston meteorite fall: first documented fall in the United States (1807); best coordinates for the fall are based upon investigative research conducted by Monty Robson, Director of the McCarthy Observatory, published in 2009

Astronomical and Historical Events (continued)

14th History: birth of Tycho Brahe, Danish astronomer noted for his observational skills, the precision of his observations, and the instruments he developed; builder of the Uraniborg and Stjenborg observatories on the Swedish island of Ven (1546)
15th Aten Asteroid 2004 YC near-Earth flyby (0.045 AU)
15th History: launch of Soviet spacecraft, Vega 1 to Venus and then to Comet Halley (1984)
15th History: landing of Soviet spacecraft Venera 7 on the surface of Venus (1970)
15th History: discovery of Saturn's moon *Janus* by Audouin Dollfus (1966)
15th History: launch of Gemini 6 with astronauts Walter Schirra and Thomas Stafford (1965)
15th History: Gemini 6 and 7 execute the first manned spacecraft rendezvous (1965)
16th Centaur Object *54598 Bienor* at Opposition (13.041 AU)
16th History: launch of Pioneer 6, the first of four identical solar orbiting, spin-stabilized spacecraft (1965)
17th Moon at apogee (furthest distance from Earth at 252,476 miles or 406,321 km)
17th Aten Asteroid 163899 (2003 SD220) near-Earth flyby (0.036 AU)
17th Plutino 307463 (2002 VU130) at Opposition (38.362 AU)
17th History: Project Mercury publicly announced (1958)
17th History: Wright Brothers' first airplane flight, Kitty Hawk, North Carolina (1903)
18th Full Moon (Cold Moon)
18th Centaur Object *8405 Asbolus* at Opposition (22.928 AU)
18th Plutino 84922 (2003 VS2) at Opposition (35.801 AU)
18th History: discovery of Saturn's moon *Epimetheus* by Richard Walker (discovery shared with Stephen Larson and John Fountain) (1966)
19th History: launch of the Gaia spacecraft from French Guiana to survey more than one billion stars in an effort to chart the chart the evolution of the Milky Way galaxy (2013)
19th History: launch of space shuttle Discovery (STS-103), third servicing of the Hubble space telescope including the installation of new gyroscopes and computer (1999)
19th History: launch of Mercury-Redstone 1A; first successful flight and qualification of the spacecraft and booster (1960)
20th Kuiper Belt Object *19521 Chaos* at Opposition (40.223 AU)
20th History: launch of the Active Cavity Radiometer Irradiance Monitor satellite (ACRIMSAT); designed to measure Sun's total solar irradiance (1999)
20th History: Ames Research Center founded as the second National Advisory Committee for Aeronautics (NACA) laboratory at Moffett Federal Airfield in California (1939)
20th History: founding of the Mt. Wilson Observatory (1904)
21st Winter Solstice at 10:59 am EST (15:59 UT)
21st Scheduled launch of a SpaceX Dragon 2 cargo-carrying spacecraft to the International Space Station from the Kennedy Space Center, Florida
21st Apollo Asteroid 2016 YY10 near-Earth flyby (0.025 AU)
21st Aten Asteroid 2017 XQ60 near-Earth flyby (0.035 AU)
21st Apollo Asteroid *1981 Midas* closest approach to Earth (2.260 AU)
21st History: launch of the Soviet spacecraft Vega 2 to Venus, continued on to Comet Halley (1984)
21st History: landing of Soviet spacecraft Venera 12 on the surface of Venus, found evidence of thunder and lightning in the atmosphere (1978)
21st History: launch of Apollo 8 with astronauts Frank Borman, Jim Lovell and William Anders, first to circumnavigate the Moon (1968)

Astronomical and Historical Events (continued)

21st History: launch of Luna 13, Soviet moon lander (1966)
22nd Ursids Meteor Shower peak
22nd Scheduled launch of the James Webb Space Telescope (JWST) from the ELA-3 launch site in Kourou, French Guiana
22nd History: first asteroid (323 *Brucia*) discovered using photography (1891)
23rd Amor Asteroid *52387 Huitzilopochtli* closest approach to Earth (0.849 AU)
23rd History: discovery of Saturn's moon *Rhea* by Giovanni Cassini (1672)
24th Aten Asteroid 2016 TR54 near-Earth flyby (0.043 AU)
24th Centaur Object 154783 (2004 PA44) at Opposition (22.020 AU)
24th History: inaugural of ESA's Ariane 1 rocket and first artificial satellite carried by an ESA rocket (1979)
24th History: the largest and best recorded meteorite fall in British history over the Leicestershire village of Barwell (1965)
24th History: Deep Space Network created (1963)
24th History: Jean-Louis Pons born into a poor family with only basic education, took post at observatory at Marseilles as concierge, went on to become most successful discover of comets (discovered or co-discovered 37 comets, 26 bear his name) (1761)
24th History: inaugural launch of the Arianne rocket, Europe's attempt to develop a cost-effective launcher to serve the commercial market (1979)
25th Plutino 15875 (1996 TP66) at Opposition (29.179 AU)
25th History: European Space Agency's Mars Express spacecraft enters orbit around Mars (2003)
25th History: landing of Soviet spacecraft Venera 11 on Venus, second of two identical spacecraft (1978)
26th Last Quarter Moon
26th Kuiper Belt Object 78799 (2002 XW93) at Opposition (44.998 AU)
26th History: launch of Soviet space station Salyut 4 from Baikonur Cosmodrome; third Soviet space station and second space station devoted primarily to civilian objectives; deorbited in 1977 (1974)
27th Apollo Asteroid 2018 AH near-Earth flyby (0.030 AU)
27th History: discovery of the ALH84001 Martian meteorite in the Allan Hills, Far Western Icefield, Antarctica, made famous by the announcement of the discovery of evidence for primitive Martian bacterial life (1984)
27th History: Johannes Kepler born, German mathematician and astronomer who postulated that the Earth and planets travel about the sun in elliptical orbits, developed three fundamental laws of planetary motion (1571)
28th Amor Asteroid *4957 Brucemurray* closest approach to Earth (1.786 AU)
29th Apollo Asteroid 2017 AE3 near-Earth flyby (0.025 AU)
30th Centaur Object *60558 Echeclus* at Opposition (10.138 AU)
30th Plutino 55638 (2002 VE95) at Opposition (29.715 AU)
30th Plutino 2005 TV189 at Opposition (31.827 AU)
30th History: flyby of Jupiter by Cassini spacecraft on mission to Saturn (2000)
30th History: discovery of Uranus' moon *Puck* by Stephen Synnott (1985)
30th History: Army Air Corp Captain Albert William Stevens takes first photo showing the Earth's curvature (1930)
31st Plutino 2002 XV93 at Opposition (37.280 AU)

Astronomical and Historical Events (continued)

31st History: GRAIL-A, lunar gravity mapping spacecraft enters orbit (2011)

Commonly Used Terms

- Apollo: a group of near-Earth asteroids whose orbits also cross Earth's orbit; Apollo asteroids spend most of their time outside Earth orbit.
- Aten: a group of near-Earth asteroids whose orbits also cross Earth's orbit, but unlike Apollos, Atens spend most of their time inside Earth orbit.
- Atira: a group of near-Earth asteroids whose orbits are entirely within Earth's orbit
- Centaur: icy planetesimals with characteristics of both asteroids and comets
- Kuiper Belt: region of the solar system beyond the orbit of Neptune (30 AUs to 50 AUs) with a vast population of small bodies orbiting the Sun
- Opposition: celestial bodies on opposite sides of the sky, typically as viewed from Earth
- Plutino: an asteroid-sized body that orbits the Sun in a 2:3 resonance with Neptune
- Trojan: asteroids orbiting in the 4th and 5th Lagrange points (leading and trailing) of major planets in the Solar System

References on Distances

- the apparent width of the Moon (and Sun) is approximately one-half a degree (½°), less than the width of your little finger at arm's length which covers approximately one degree (1°); three fingers span approximately five degrees (5°)
- 1 astronomical unit (AU) is the distance from the Sun to the Earth or approximately 93 million miles

International Space Station and Starlink Satellites

Visit www.heavens-above.com for the times of visibility and detailed star charts for viewing the International Space Station and the bright flares from Iridium satellites.

Solar Activity

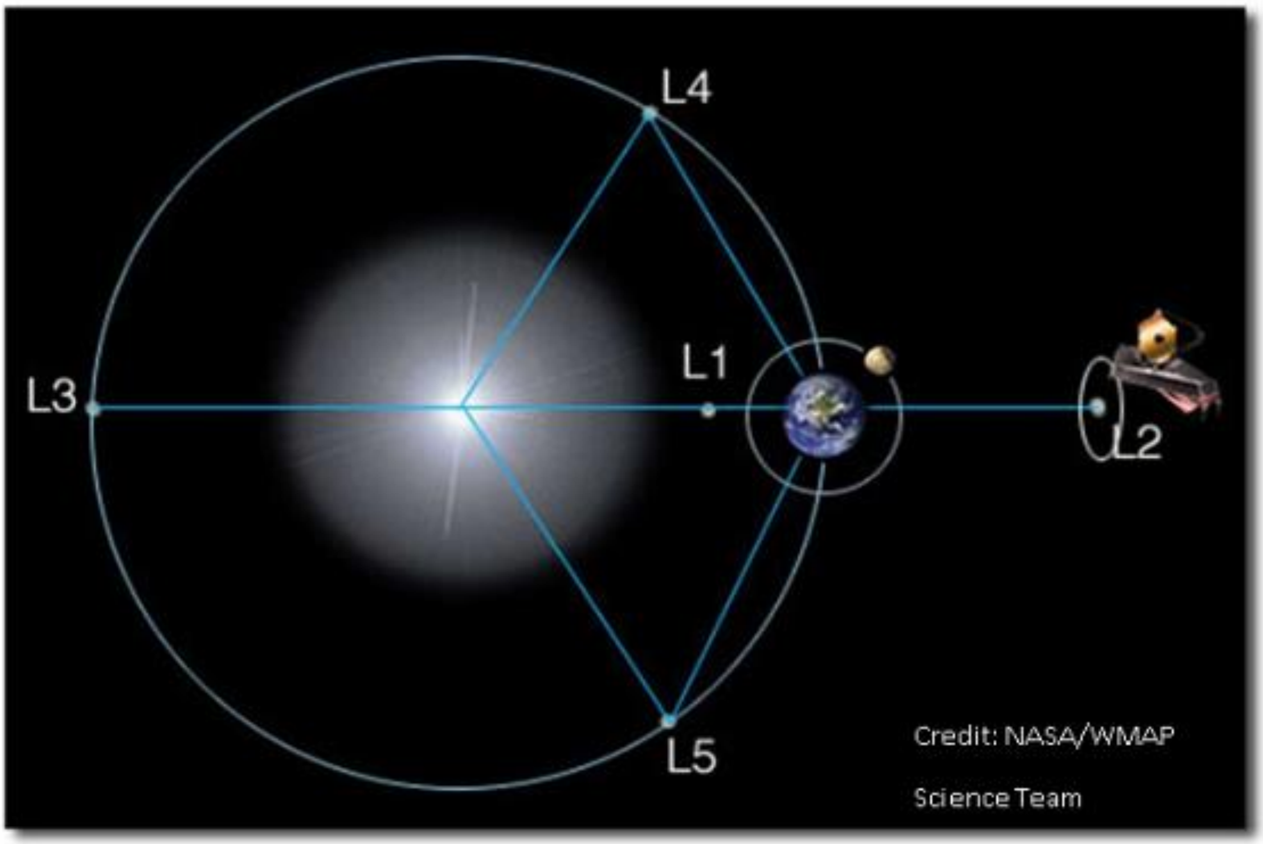
For the latest on what's happening on the Sun and the current forecast for flares and aurora, check out www.spaceweather.com

NASA's Global Climate Change Resource

Vital Signs of the Planet: https://climate.nasa.gov/

Lagrange Points

Five locations discovered by mathematician Joseph Lagrange where the gravitational forces of the Sun and Earth (or other large body) and the orbital motion of the spacecraft are balanced, allowing the spacecraft to hover or orbit around the point with minimal expenditure of energy. The L2 point (and future location of the James Webb telescope) is located 1.5 million kilometers beyond the Earth (as viewed from the Sun).



Mars – Mission Websites

Mars 2020 (Perseverance rover): https://mars.nasa.gov/mars2020/

Mars Helicopter (Ingenuity): https://mars.nasa.gov/technology/helicopter/

Mars Science Laboratory (Curiosity rover): https://mars.nasa.gov/msl/home/

Mars InSight (lander): https://mars.nasa.gov/insight/

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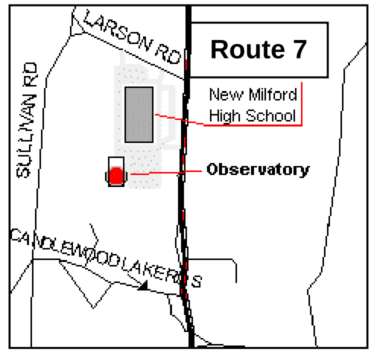

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