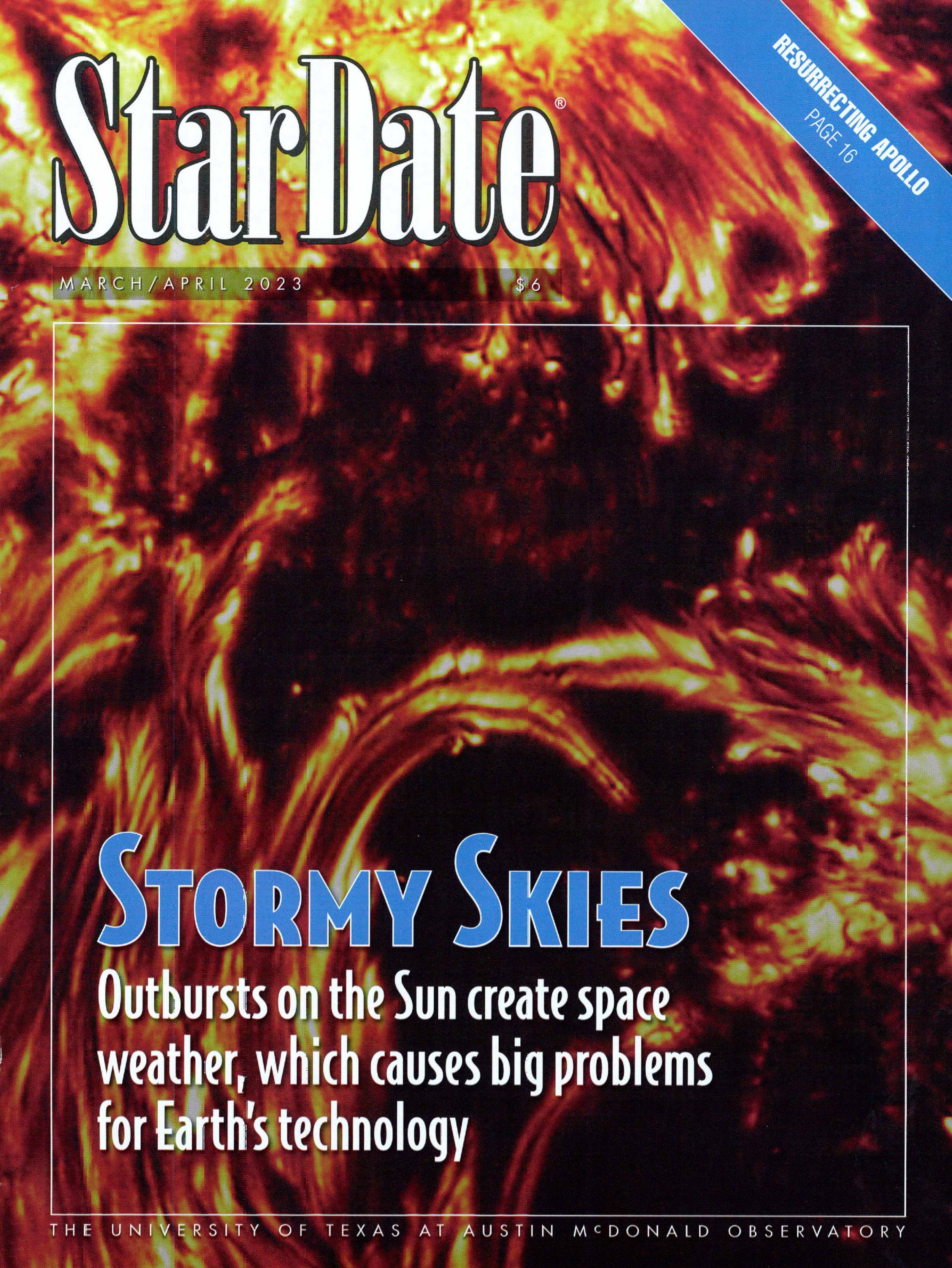


StarDate®

MARCH/APRIL 2023 $6

RESURRECTING APOLLO
PAGE 16

STORMY SKIES

Outbursts on the Sun create space weather, which causes big problems for Earth's technology

THE UNIVERSITY OF TEXAS AT AUSTIN McDONALD OBSERVATORY

For information about *StarDate* or other programs of the McDonald Observatory Education and Outreach Office, contact us at 512-471-5285. For subscription orders only, call 800-STARDATE.

StarDate (ISSN 0889-3098) is published bimonthly by the McDonald Observatory Education and Outreach Office, The University of Texas at Austin, 2515 Speedway C1402, Austin, TX 78712. © 2023 The University of Texas at Austin. Annual subscription rate is $30 in the United States. Subscriptions may be paid for using credit card or money orders. The University of Texas cannot accept checks drawn on foreign banks. Direct all correspondence to StarDate, The University of Texas at Austin, 2515 Speedway C1402, Austin, TX 78712, or call 512-471-5285. POSTMASTER: Send change of address to StarDate, The University of Texas at Austin, 2515 Speedway C1402, Austin, TX 78712. Periodicals Postage Paid at Austin, TX. StarDate is a registered trademark of The University of Texas McDonald Observatory.

Visit StarDate Online at stardate.org or on:

McDonald Observatory
The University of Texas at Austin

- StarDate
- StarDate Magazine
- Frank N. Bash Visitors Center

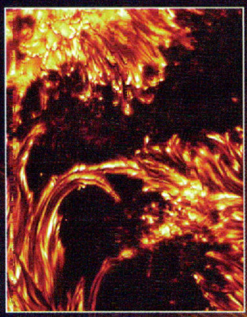
StarDate 50 1973-2023

StarDate®

MARCH/APRIL • Vol. 51, No. 2

Features

Departments



NOIRLAB/NSF/AURA

On The Cover

A dark magnetic storm roils the surface of the Sun. Such storms can unleash torrents of particles and radiation that can turn out the lights here on Earth.

This Page

Stars shine through a veil of dust in this James Webb Space Telescope view of the Chamaeleon I Nebula, which is about 630 light-years away. The nebula is giving birth to new stars.

NASA/ESA/CSA

Coming in May

We'll tell you about some exciting research taking place at McDonald Observatory, and about plans for growing food on the Moon and Mars.

MERLIN

Dear Merlin,

If one were living on the equator of Mars, what would the range of temperatures be during a Martian year?

Mark Finley
Austin

Like many things in life, it depends. In general, though, you could expect to see highs of about 70 degrees Fahrenheit (20 C) at noon on summer days, and lows of minus-100 degrees Fahrenheit or colder (-75 C) on winter nights.

The range is so great because the Martian atmosphere is only 0.7 percent as dense as Earth's, so there's a much thinner "blanket" to absorb heat during the day or retain it at night. Temperatures are a bit higher at lower elevations because the atmospheric pressure is a bit higher. And dust storms can add to the insulating properties of the atmosphere, making conditions warmer still.

Several Mars landers, including the current Perseverance rover, have carried weather stations. They have landed at various latitudes and elevations. They've recorded air temperatures as high as 95 degrees Fahrenheit (35 C) and as low as about minus-175 (-115 C).

Dear Merlin,

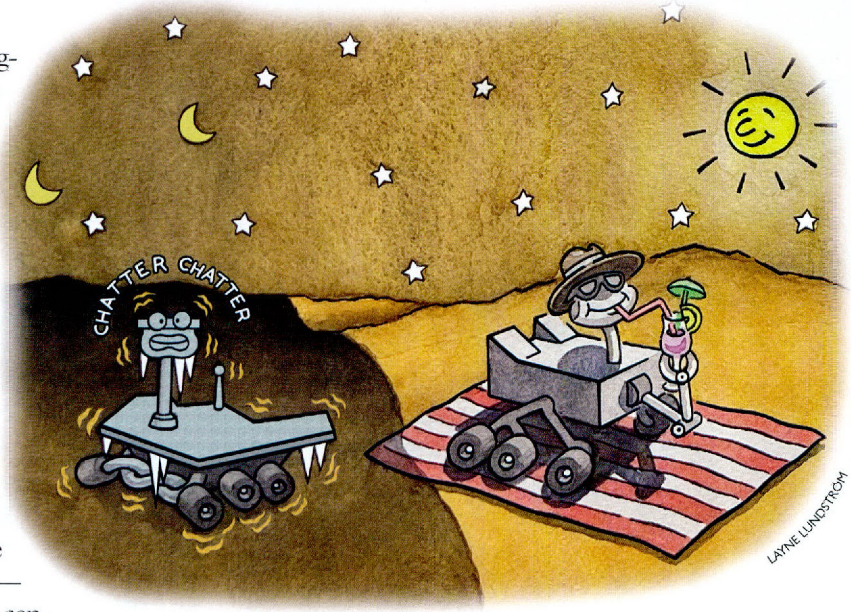
Recently you answered a question about day length, but I would like you to expand a bit on the subject. How did people hundreds of years ago figure this out? How have we established the length of a day and a second with such precision today?

Joe Lacchia
Sebastopol, California

Ancient peoples were much more clever and observant than people today give them credit for. They paid careful attention to the motions of the Sun, Moon, and stars. Watching those motions for a long time—years, decades, or even centuries—and averaging them out yielded highly accurate accountings of the length of the day and year and the cycles of the Moon. Such measurements were important for timing the planting and harvesting of crops, conducting religious ceremonies, coronating kings, and many other events.

Today, of course, scientists have highly precise and accurate instruments for measuring the passage of time—down to billionths or trillionths of a second. Such precision is critical for many scientific applications, the performance of GPS systems, and much more.

Among other things, those measurements have revealed that the length of Earth's day isn't constant; earthquakes, tsunamis, hurricanes, and other big events can cause it to speed up or slow down by a fraction of a second. In addition, the overall length of a day is increasing—by roughly .0023 seconds per century—thanks to gravitational interactions between Earth and the Moon.



Dear Merlin,

Is it possible that the Big Bang could have been a breach from another universe into an already existing space, which already had components in their rightful place? Could mapping this material along with dark energy pinpoint the age of our universe?

Dan Dougherty
Fresno, California

A breach from another universe? Not exactly, although it could have been spawned by other universes, cosmologists say. Into an already existing universe, with all of its stars and galaxies in place? Nope.

Many theorists suggest our universe is only one of many—perhaps an infinite number. Under some scenarios, a collision between universes could trigger the birth of a new universe in a Big Bang. Such a universe would expand and form its own matter, energy, and even laws of physics, so it wouldn't balloon into an existing universe. From its expansion rate and other factors, astronomers already know the age of our universe: 13.8 billion years.

Dear Merlin,

There is talk about mining the Moon for resources. Given that the Moon is critical to our orbit and stability, ocean tides, and other factors, has any consideration been given to the effect that less Moon mass would have regarding any of the above? Would removing significant ice from the Moon's poles to make rocket fuel have a similar effect?

Donna Hartness
Leicester, Massachusetts

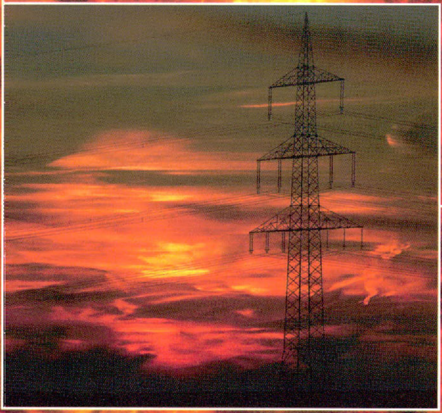
Worry not, dear friend. In the first place, much of the initial lunar mining (if it happens at all) would be to support colonies—building habitats, for example—so all of that mass would stay on the Moon. And even if lunar material is shipped to Earth or elsewhere in the solar system on a massive scale, it likely would take many millennia of heavy effort to have any measurable effect on the Moon's mass.

Merlin is unable to send personal replies. Answers to many astronomy questions are available through our web site:
stardate.org/astro-guide

SEND QUESTIONS TO
Merlin
StarDate
University of Texas at Austin
2515 Speedway, Stop C1402
Austin, TX 78712
stardatemerlin@gmail.com
stardate.org/magazine

HOW'S THE WEATHER UP THERE?

Space weather can cause big problems here on Earth, so scientists are working hard to develop better forecasts.



ADD/PIXABAY

THATBALDGUY/PIXABAY

STARLINK

NASA/SDO

BY KRISTEN POPE

On February 3, 2022, SpaceX launched 49 Starlink satellites. By nine days later, 38 of them had been knocked from the sky, victims of a storm on the Sun. In October and November of 2003, powerful solar storms disrupted radio communications around the globe, damaged satellites, and forced airlines to shift flights away from polar routes. And on March 13, 1989, a storm knocked out power for six million customers in Quebec and caused minor outages and fluctuations from Wisconsin to Virginia.

These are far from the only examples of the damaging effects of space weather—interactions between outbursts from the Sun and Earth's magnetic field and atmosphere. Many storms have disrupted power systems, damaged or destroyed satellites, blacked out high-frequency radio transmissions, and scrambled Global Positioning System (GPS) signals. In earlier eras, they ignited fires in telegraph stations and brought trains to a halt.

As we become increasingly reliant on technology, the disruptions could become even more severe: The most powerful solar storms could trigger months-long blackouts and cause trillions of dollars in damages. That makes it critical for us to understand space weather, improve the forecasting, and prepare for future storms.

KENT MILLER/NPS

A powerful solar flare erupts from the upper right edge of the Sun in this image from a satellite. Insets, from left: Space weather events can black out power grids, disrupt aviation communications and cause airlines to divert flights, knock down satellites (including 38 launched on this SpaceX rocket), and create brilliant auroras.

Space weather is triggered by the Sun, even though it's 93 million miles (150 million km) from Earth.

As the Sun rotates, layers of superheated gas at and below its surface turn at different rates. That creates an electrical dynamo, which generates an intense magnetic field. Over an average period of about 11 years, the lines of magnetic force become twisted and tangled. Where the lines overlap, they create dark storms on the surface known as sunspots. The twisted lines sometimes snap like rubber bands, creating solar flares—brilliant outbursts of energy that can be as powerful as 10 million 100-megaton hydrogen bombs. They also produce eruptions of charged particles known as coronal mass ejections (CMEs), along with holes in the Sun's outer atmosphere that allow streamers of the solar wind to flow into the solar system unimpeded.

Energy from the flares can heat Earth's outer atmosphere, causing it to expand. They also energize lower layers of the atmosphere, preventing high-frequency radio waves from reflecting off higher layers. X-rays can penetrate deep enough into the atmosphere to zap passengers in high-altitude airliners flying over the north pole, boosting their risk of developing cancer and other afflictions.

Electrically charged particles from the solar wind and CMEs can zip through orbiting satellites, damaging their sensitive electronics and even knocking them out completely. In addition, Earth's magnetic field funnels the particles toward the surface, where they can create currents in the ground that can knock out power grids and other electrical equipment, weaken oil pipelines, and create other havoc.

The National Oceanic and Atmospheric Administration (NOAA) tracks space weather and issues alerts of potential events, known as geomagnetic storms. Much like hurricane categories, the alerts rate the severity of space weather events, with one for the lowest-level events and five representing extreme events. The warnings can help agencies that operate satellites, power grids, and other infrastructure take actions to protect their equipment.

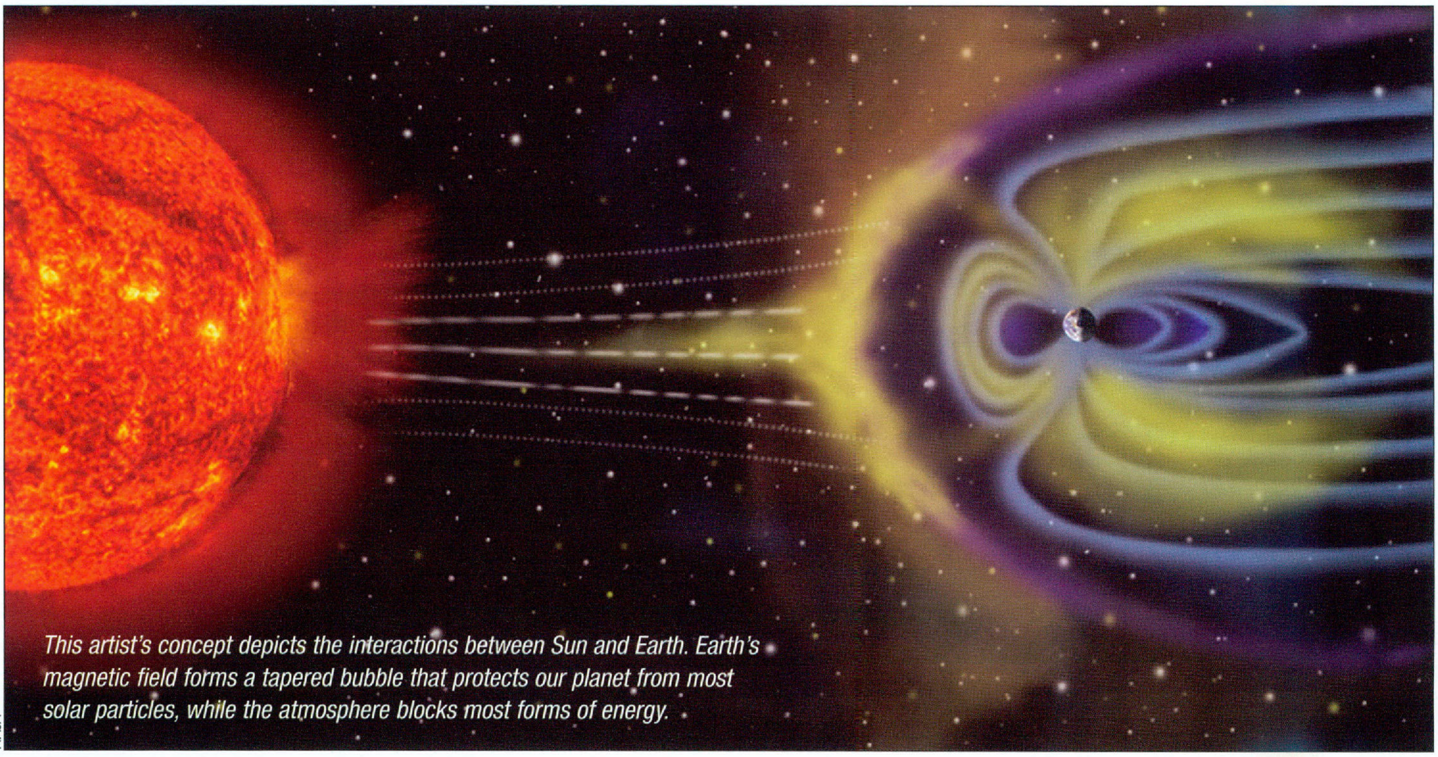
The threat is severe enough that the government even advises individuals to prepare for potential disruptions caused by these storms in the same way they do for hurricanes or winter storms: maintain an emergency kit, have a family communication plan, and keep a car's gas tank at last half full, among other measures.

Not all of the effects of space weather are dangerous, though. In fact, some can be quite beautiful. Electrons caught in Earth's magnetic field ram into atoms and molecules high in the atmosphere, causing them to glow, forming the colorful, shimmering curtains of light known as the aurora borealis and australis—the northern and southern lights. During intense storms, they can spread far beyond their normal range. In the northern hemisphere, they've been seen as far south as Texas, Florida, and even Mexico.

The largest solar flare ever seen also was the first ever seen. On September 1, 1859, British astronomers Richard Carrington and Richard Hodgson were independently studying the Sun by using telescopes to project a large image on a sheet. Both men were looking at a dark sunspot when they saw a bright flash of light—a solar flare. A likely CME sent electrons screaming toward Earth at several million miles per hour—far faster than the typical solar wind. And they hit with a fury.

Over the following couple of days, skywatchers observed brilliant aurorae as far south as the Caribbean. Reports from New England said the northern lights were bright enough to read by, while gold miners in Colorado awakened by the light thought it was dawn and began cooking breakfast. Telegraph service was disrupted, and electrical fires were ignited in some offices.

Recent studies have suggested that if a Carrington Event-level storm were to hit us today, it could cause up to $2 trillion in damages and knock out power grids



This artist's concept depicts the interactions between Sun and Earth. Earth's magnetic field forms a tapered bubble that protects our planet from most solar particles, while the atmosphere blocks most forms of energy.

NASA

for days, weeks, or even months.

"This was a huge event, and, if it had been today, it could have had quite a substantial impact to not only communications, satellites in space and orbiting the Earth, but also potentially our power grid," says C. Alex Young, associate director for science in the Heliophysics Science Division at NASA's Goddard Space Flight Center in Maryland.

There's evidence of even stronger storms in earlier centuries. Analysis of tree rings and Antarctic ice cores had revealed particularly high levels of radioactive isotopes in the years 774-775 and 993-994, perhaps created by especially powerful space weather events.

And we've seen the effects of strong storms many times in the past few decades.

In early February 2022, for example, 49 Starlink satellites, which are designed to bring Internet service to parts of the globe where it's not currently available, were launched into low Earth orbit as planned. They were scheduled to spend the following few days raising their altitude. The day after they were launched, however, a storm hit, causing the outer atmosphere to expand, increasing drag; 38 satellites were pulled back to Earth and burned up during entry.

In 1967, a geomagnetic storm hit during a time of immense Cold War tensions. "[T]he May 1967 storm was nearly one with ultimate societal impact," wrote Delores Knipp, a research professor at the University of Colorado, and colleagues in an article in the journal *Space Weather*. They described the storm as a "colossal solar radio burst causing radio interference" at multiple frequencies. It was classified as an extreme storm, with strong X-rays. "As a magnetospheric disturbance, the 25-26 May event ranks near the top in the record books," the authors wrote.

"When the Sun became wildly noisy, produced huge solar radio bursts that we basically had not seen or had not recorded before, there was great concern that this indicated that the Eastern Bloc was trying to do something that would perhaps distract from what was going on," Knipp says. "The generals at the time had in their playbook that this was something that could be expected at the outset of an attack, and so discussions were going on at NORAD that this was a precursor to some kind of attack. I think we can now be fairly certain that the Eastern Bloc thought exactly the same thing."

The Air Weather Service notified NORAD of the storm and disaster was averted. After the "near incident," many realized the necessity of incorporating real-time space weather in military decision-making.

Two CMEs hit Earth on August 4, 1972, during the Vietnam War. They appear to have triggered the detonations of numerous sea mines in a harbor near Hai Phong, North Vietnam. These magnetic-influence sea mines (called Destructors) had been placed by the U.S. Navy about three months earlier.

A spectacular aurora "bright enough to cast shadows" in southern Britain followed, and dayside radio blackouts occurred. Scientists later noted the storm fit the categorization of a Carrington-class event in many ways. The storm also caused issues with the power grid in parts of the United States and Canada, and distrupted phone service in Illinois and other states.

On March 13, 1989, a large storm hit Quebec, knocking out power for nine hours. In 2003, the "Halloween storms," which occurred over more than two weeks, caused a number of impacts, including problems with communications, navigation systems, and satellites, and the FAA issued a radiation alert for planes traveling polar routes. Sweden's power grid suffered several failures as well.

Today, the impacts could be even more severe. Solar flares can affect the radio systems airlines use to talk to air traffic control, so it's important for the aviation industry to track them.

Electrical currents created by space weather can affect power systems. The most intense storms—similar to the Carrington Event or the earlier mega-eruptions—could knock out most of the American power grid.

If electric companies know a storm is coming, however, they can take steps to protect transformers, change the routing of electricity, bring additional resources online, keep careful watch over the system, and even shut things down if there's a problem. "Better to have a brownout than a blackout," says Douglas Biesecker, chief scientist for upcoming space weather missions for the National Environmental Satellite, Data, and Information Service. "[There are] definite actions the power grid can take to keep the lights on."

Geomagnetic storms also affect the accuracy of GPS systems. While Biesecker says your car's GPS navigation likely won't be too seriously affected by small shifts in accuracy—if it tells a driver to turn right in 95 feet instead of 100 feet, the driver will be able to figure it out—other types of GPS systems require exactness.

Farmers using precision agriculture, for example, rely on GPS coordinates to control tractors, identify weeds and apply herbicide, plant crops, apply fertilizer, and to water their crops. Surveying for road construction also requires precision—

More Problems from Solar Storms

Storms on the Sun not only create space weather, they can influence the weather in Earth's atmosphere as well, from off-season typhoons in the western Pacific Ocean to ice storms in northern Canada.

Scientists first proposed a link between storms on the Sun and storms on Earth decades ago, and studies since then have supported the idea. Two recent ones show links with off-season typhoons, and with winter storms in many parts of the globe.

The typhoons are in the western Pacific, near the Philippines and New Guinea. When the Sun is especially active, there's an increase in the number of off-season typhoons. In addition, the typhoons are more likely to occur right after a solar storm reaches Earth. The Sun may trigger the typhoons by adding energy to the upper atmosphere, disrupting the normal circulation patterns.

The other study found a link between solar storms and massive winter storms on Earth. In particular, it found that ice storms in Canada either broke out or grew stronger when jolts of solar wind hit Earth. Those blasts may create big waves in the upper atmosphere. The waves then transfer energy to the lower levels of the atmosphere, heating them and triggering a series of events that intensifies storms at the surface.

small errors could affect the alignment or smoothness of the finished roadway.

In space, astronauts lack protection from Earth's atmosphere, so preparing for storms is especially important. Most of the time, the International Space Station is deep enough in Earth's magnetic field to be shielded from space weather, but stronger storms can penetrate far enough to harm space travelers. They sometimes must take refuge in the most heavily shielded parts of the station or in the craft that shuttle them to and from orbit. And if an extreme CME is on the way they can return to Earth.

Future travelers to the Moon would be completely outside Earth's magnetic field, and might be too far away to return home in an emergency. (The August 1972 event occurred just weeks after an Apollo mission; had it been underway during the storm, the three astronauts could have been bombarded with harmful levels of radiation.)

Permanent lunar habitats, however, might be covered with lunar rocks and dirt to screen the radiation and particles. And designers are working on shielded spaces aboard future Mars-bound craft.

The Space Weather Prediction Center (SWPC) is the primary agency in charge of forecasting space weather. It uses Earth- and space-based systems to monitor sunspots and "active" regions, where the roiling gases at the surface are hotter and more turbulent than normal. Scientists analyze the size and complexity of these systems, which drive space weather. They watch for solar flares, CMEs, and coronal holes that are sources of high-speed solar wind. They analyze the probability of various types of events, and input their findings into computer models to produce forecasts. Short-term forecasts are issued several times a day, with daily long-term forecasts covering up to 27 days (the period of the Sun's rotation).

SWPC sends forecasts to satellite and electrical grid operators, emergency communications systems, airlines, and even people who work with pigeons.

Yes, pigeons. This includes people who race pigeons, plus those who release doves at weddings. "We occasionally get calls from pigeon racers because even during below-minor storm levels ... pigeons can get lost," says Rob Steenburgh, acting lead in SWPC's Space Weather Forecast Office. "They use the Earth's magnetic field to navigate, and when the magnetic field is disrupted it throws them off."

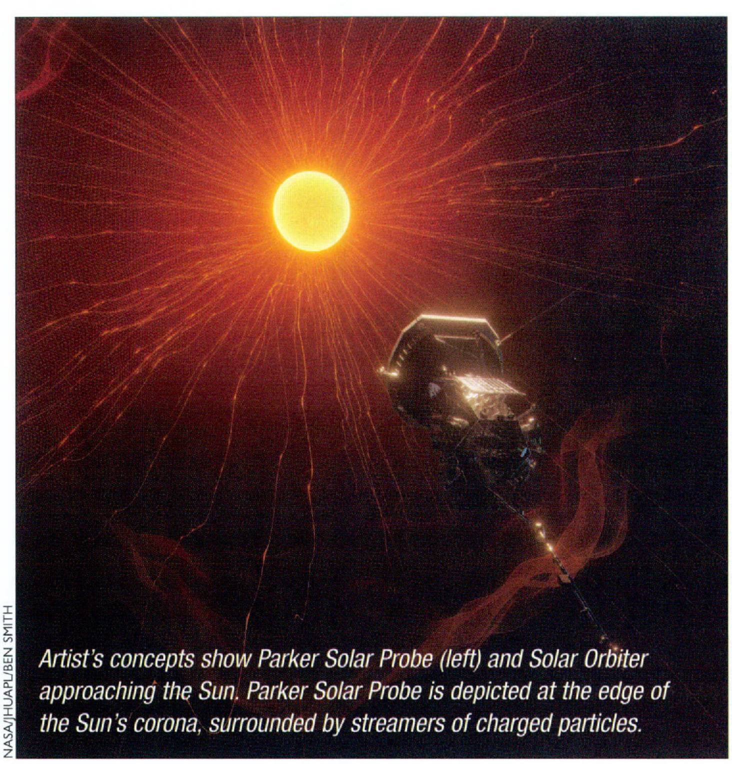
Customers use the forecasts to prepare for upcoming events. "That gives the people we serve a time to prepare, kind of like when you have a hurricane watch out you can board up the windows," Steenburgh says. "The power grid can take measures to mitigate the impacts of a geomagnetic storm."

Michael Stevens, an astrophysicist with Harvard-Smithsonian Center for Astrophysics, has worked with Voyager, Wind, and DSCOVR missions, and is a co-investigator with Parker Solar Probe. He says forecasting space weather can be a challenge: "With space we don't have very many weather stations. We only have a few spacecraft that we've launched out into space, so it's a much scrappier enterprise."

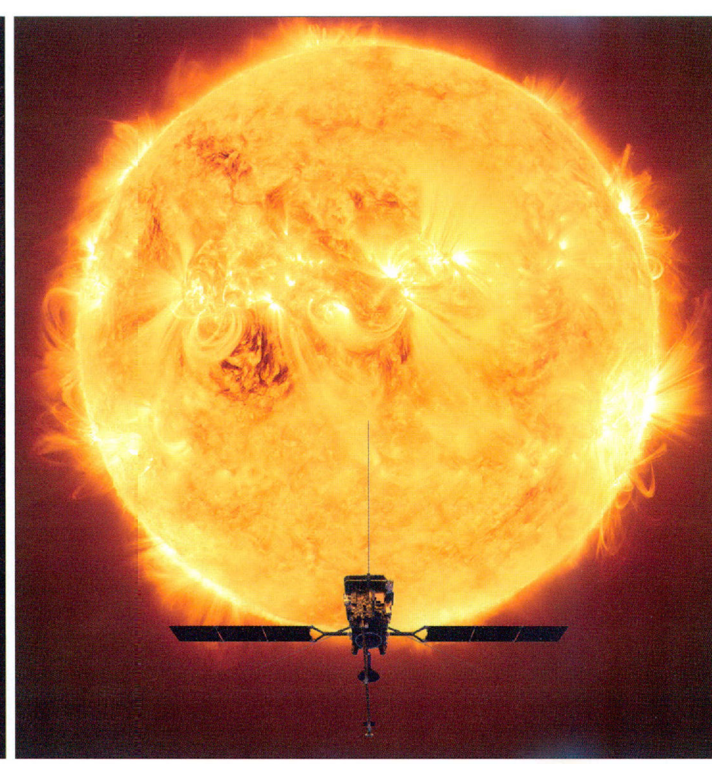
Forecasting actually extends much farther into the future—all the way through the next solar cycle. Each cycle lasts roughly 11 years (although the period can vary by several years), with a distinct peak in sunspots and other activity (solar maximum) and a low point (solar minimum). And no two cycles are alike. The most recent cycle, which ended in 2019, was one of the calmest on record, with periods of days or weeks with no sunspots at all. The current cycle, which is expected to peak in 2025, is forecast to be relatively quiet as well.

"Predicting the solar cycle is in a sense very different than the day-to-day prediction that the Space Weather Prediction Center is doing," Biesecker says.

These predictions rely on historical observations of the Sun. Biesecker points out the types of data collected today are very different from those collected when



NASA/JHUAPL/BEN SMITH



ESA/ATG MEDIALAB

Artist's concepts show Parker Solar Probe (left) and Solar Orbiter approaching the Sun. Parker Solar Probe is depicted at the edge of the Sun's corona, surrounded by streamers of charged particles.

scientists first began tracking the solar cycle, in 1755. The only common data set is the sunspot count. Knowing how the Sun may act in a few years is important for people doing things like preparing to launch satellites several years down the road, so researchers can plan ahead for the conditions they are likely to encounter.

Steenburgh, who was a meteorologist for 20 years before joining SWPC in 2007, says the biggest challenge in forecasting space weather is the lack of data. "As a weather forecaster, I was spoiled with all these observations," he says. "I like to tell people it's kind of like if you had one surface weather observation of temperature, pressure, humidity, and winds in Tokyo, and then you were asked to make a forecast for Philadelphia three days later with only that information. And it's not much of a stretch—we don't have a lot of information out there."

Getting the highest-quality data—and more of it—is a top priority for forecasters.

"A model is only as good as the data that goes into it," Biesecker says. "We're focused on the next generation of satellites and making sure that we are providing the highest availability and best quality data that we can."

New spacecraft are venturing out to learn more about the Sun, studying its magnetic field, its hot outer atmosphere (the corona), and more. Both ground-based and space-based telescopes are using a technique called helioseismology to probe deep below the Sun's surface, showing us the regions where the magnetic field is generated and even providing rough views of storms on the far side of the Sun.

The two most recent space missions are Parker Solar Probe (PSP) and Solar Orbiter. PSP is designed to fly through the corona, where much of the Sun's magnetic activity is generated or directed out into space. Launched in 2018, PSP has already passed far closer to the Sun than any previous spacecraft—5.3 million miles (8.5 million km). It's scheduled to make its closest approaches, just 3.8 million miles (6.1 million km), in late 2024 through 2025.


Violent Magnetic Storm Disrupts Short-Wave Radio Communication

MAGNETIC TREMORS EXPECTED TO PASS WITHIN 48 HOURS

SUNSPOT CREDITED WITH RAIL TIE-UP

New York Central Signal System Put Out of Service by Play of Northern Lights.

Space weather created headlines as far back as the 1930s.

"We're having a lot of fun with Parker Solar Probe," Stevens says. "Depending on how you define the Sun, Parker Solar Probe is skimming the Sun, skimming through the corona of the Sun, every time it makes an encounter."

Solar Orbiter is a collaboration between the European Space Agency and NASA, and, while it won't snuggle quite as close to the Sun as PSP, its instruments are gathering valuable data, including taking pictures of areas near the poles, which will provide insight into the Sun's magnetism.

Several other spacecraft are watching the Sun as well, including Solar Dynamics Observatory, STEREO, ACE, SOHO, and others. However, some of these are older and not all of their instruments are still working. Scientists also use other instruments to gather data, including weather stations on other spacecraft.

"It's like the golden age," Steenburgh says. "I couldn't have made the jump at a more exciting time, I think. So just watching how this has evolved has been fantastic, but we still have a lot of work to do. I want my forecast numbers to be better, we all do, we want to do the best we can. And that's a serious responsibility that we have, and everything we do is directed towards providing actionable space weather information for society."

Kristen Pope is a freelance writer and editor who frequently writes about science.

Resources

Internet

Space Weather Impacts
metoffice.gov.uk/weather/learn-about/space-weather/impacts

Space Weather Prediction Center
spaceweather.gov

Ready! Space Weather
ready.gov/space-weather

Carrington Event
history.com/news/a-perfect-solar-superstorm-the-1859-carrington-event

May 1967 Solar Storm
agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016SW001423

Parker Solar Probe
parkersolarprobe.jhuapl.edu

Solar Orbiter
esa.int/Science_Exploration/Space_Science/Solar_Orbiter

by Alan MacRobert

Brilliant Planets Go Their Own Ways

March begins with Venus and Jupiter, the brightest objects in the night sky other than the Moon, forming a dazzling pair in the west at nightfall, but they quickly separate, with Jupiter disappearing in the sunset by month's end. Venus, on the other hand, climbs higher, sliding near the shoulder of the bull, represented by the Pleiades star cluster, a third of the way through April. The Moon teams up with Venus and the bull's orange eye, the star Aldebaran, later on.

MARCH 1-15

Take one look low in the west in late twilight, and you'll know why Venus got its name as the Evening Star. As in, *the* evening star. It's by far the brightest starlike point when it's visible at all, the one you see first—and never mind that it's really a planet.

Venus has been slowly creeping up out of the sunset afterglow for two months now, and it's only getting higher. It will continue to gain altitude into May, shining down from a more and more impressively commanding position.

And right now it has a companion! Jupiter, the second-brightest pinpoint, has been closing in on it from above for several months. On March 1, they finally reach their close conjunction in the western twilight, shining only one-half degree apart—about the width of a pencil held at arm's length.

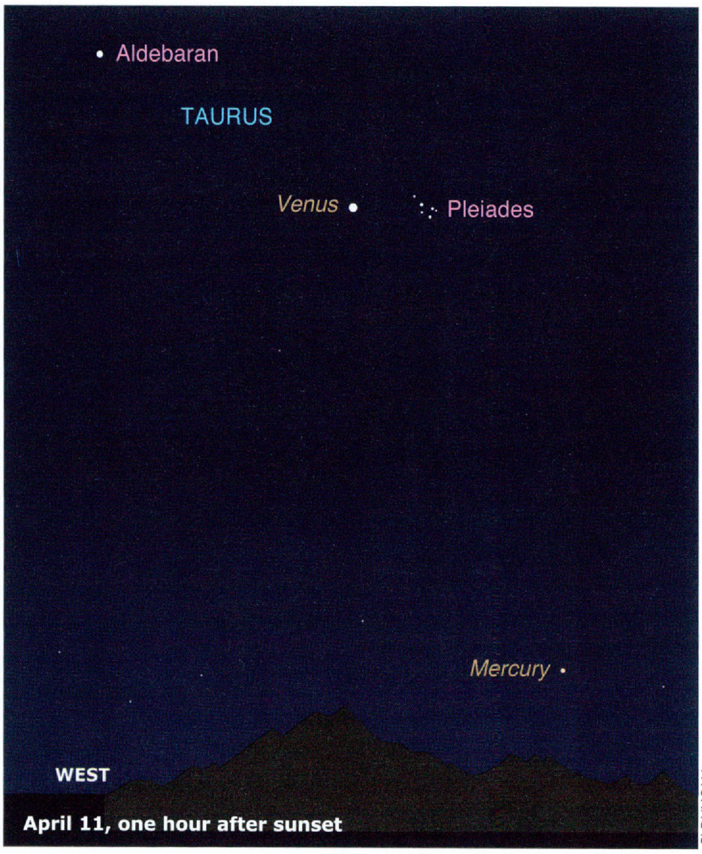
Think photo opportunity! Find a spot with some nice foreground, set your phone or camera on something solid, turn off the flash, zoom way in, and snap. And maybe come back for several evenings to catch their changing configuration as Jupiter drops lower into the twilight.

The third-brightest point in the evening sky is Sirius, the brightest actual star. It sparkles at its highest in the south in late twilight and after dark, then moves lower to the southwest as evening advances.

Look to the upper right of Sirius for the constellation Orion, and to the upper left of Sirius for Procyon. Sirius, Procyon, and Orion's bright shoulder star, orange Betelgeuse, form the big Winter Triangle.

And high above Orion after dark, almost straight overhead depending on your latitude, is the third planet of these evenings, Mars. It's much diminished from the brave blaze it presented when at opposition last December, more comparable now to Betelgeuse and to lesser Aldebaran, which is more directly below Mars and closer to it. Both Betelgeuse and Aldebaran are Mars-colored.

Not really sure which is the planet? Run a line from Sirius through Betelgeuse and extend it on, and in early March you hit Mars.



April 11, one hour after sunset

MARCH 16-31

Venus continues to creep higher in the west during and after dusk, and it's brightening slightly, too. Jupiter drops below it and is lost in the sunset by the end of the month.

But do take a last look for Jupiter on March 27, just above the due-western horizon while twilight is still bright. Try about 30 minutes after sunset. You're likely to need binoculars unless your air happens to be remarkably clear. On that date, Jupiter has another conjunction, this time with Mercury, which luckily is not too much fainter than Jupiter at the time. Look for it a bit more than one degree to Jupiter's right—about a finger width.

And Mars? It's still high overhead just after dusk, growing fainter in the distance as it crawls eastward against the stars. Mars is moving quite out of alignment with Sirius and Betelgeuse now, as it passes from the constellation Taurus, its home since last August, into Gemini.

The waxing Moon shines near Jupiter on March 22, Venus on the 23rd and 24th, then Mars on the 27th and 28th.

No other naked-eye planet adorns the night. But the sky is full of stars that are changing with the season. Face south soon after dark. The whole sky to the right is full of the bright array of traditional winter stars: Orion and his family, including his trailing dogs: Canis Major with brilliant Sirius (to the lower left of Orion), and Canis Minor, sporting Procyon, high over Sirius.

To the left are the milder stars associated with spring: Leo with his leading light, Regulus; dim, straggling Hydra, the water snake; challenging Coma Berenices, the hair of Queen Berenices; and, higher in the northeast, Ursa Major, with the obvious Big Dipper.

APRIL 1-15

Jupiter has dropped away into the sunset; lesser Mercury takes its place low above the western horizon in twilight. Starting from Venus, look for Mercury far down and a bit to the right.

Venus itself, meanwhile, is doing one of its loveliest things: pairing up with the Pleiades. This most striking of star clusters descends toward Venus from above day by day in early April, then passes to the right of Venus by a finger width or two on April 9-11. Here's another photo opportunity, but take longer exposures or shoot later in the dusk to catch these fainter stars. The six brightest Pleiads, forming a tiny dipper shape, are third and fourth magnitude.

Definitely bring the binoculars—they'll make Venus a blaze and expand your visible Pleiades population to a few dozen. In reality, the cluster contains more than 1,000 confirmed members, most of them dim orange and red dwarfs, some sprawling quite far out, and an estimated 250 even smaller, darker brown dwarfs. The whole swarm is 440 light-years away. Its brightest region is about 10 light-years wide.

Meanwhile, the brightest point on the opposite side of the sky is the Spring Star, Arcturus. It's the Alpha of the constellation Boötes the herdsman. His other main stars lie to the left of Arcturus in a shape like a long, narrow, bent kite lying on its side, about two fists at arm's length from end to end. The head of the kite, on the left, is bent upward. Arcturus, on the right, is the point where the tail would be tied on. Maybe you can make out the faint stars to the upper right of Arcturus that some call the kite's tail.

The Big Dipper hangs high to the upper left of Arcturus. It's turned to dump April showers now, with its handle to the lower right and its upside-down bowl to the upper left. The Big Dipper isn't technically a spring pattern—it can be seen all or most of the night all around the year, at least from the latitudes of the northern U.S. But the warm-weather months are when it's highest and most prominent.

In the evenings of late fall, the dipper will scoop up water in the northwest to dump again next spring.

APRIL 16-30

I think of late April and early May evenings as Arch-of-Spring time. The Arch of Spring, spanning the western sky in late twilight and after dark, is what remains of the enormous Winter Hexagon, which is beginning to set.

Look high in the west for the arch's top two stars, Pollux and Castor. Pollux is a little brighter than Castor and it shows a detectable orange tint, while Castor is pure white.

Mars is moving below them from night to night, faded now to about the equal of Pollux. The waxing crescent Moon hangs with Mars on April 25, then above Pollux and Castor on the 26th.

Procyon shines to the lower left of Pollux, marking the left end of the arch.

Farther to the lower right of Castor are second-magnitude Menkalinan and then brilliant Capella, the arch's right end.

Watch the whole pattern descend and set through the coming hours and weeks. Remember: When it comes to the turning of the stars and constellations, one hour later is the same as two weeks later.

Below the arch shines Venus, distractingly bright. The crescent Moon poses between Venus and the Pleiades on April 22, then above Venus the following night.

Orion, way off to the arch's left, is far along in his own spring descent. He tilts to the right as he walks downward at this time of year, turning his three-star belt horizontal. As ever, Orion's Belt points more or less toward Aldebaran in one direction, currently the right, and brilliant Sirius in the other direction, currently left. But their days are numbered.

Leo, the springtime lion, is standing high in the south at nightfall. His forefoot is Regulus, the brightest star in the area. Leo's mane and head are marked by the Sickle of Leo, a backward question mark of stars that extends upward from Regulus. Well to the left of this is a long triangle: Leo's rear end and tail.

Whenever Leo stands horizontal in the south, the Big Dipper is approaching its highest stance way up in the north. And that means the dipper's pointer stars point down. They're the two stars forming the end of the dipper's bowl. All night and all year, whatever their orientation, they point to Polaris, the North Star, standing essentially motionless through all the starry changes as Earth turns.

Alan MacRobert is a senior editor of Sky & Telescope *magazine.*

Meteor Watch

The Shower
Lyrids

Peak
Night of April 22

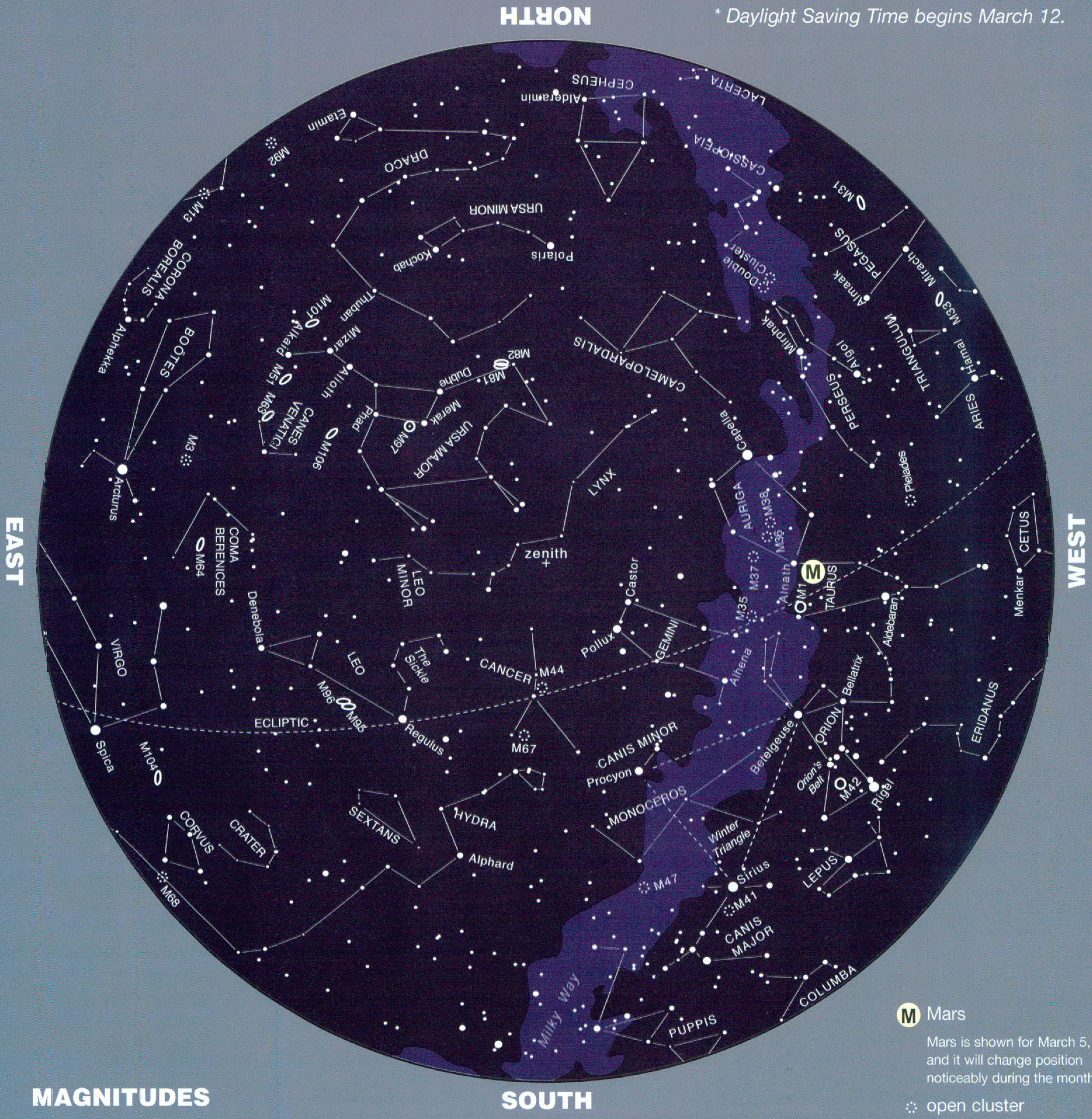
Notes
The Lyrids are modest, with perhaps a dozen meteors per hour at best. The Moon sets by about 11 p.m., so it won't interfere with the light show.

MARCH

How to use these charts:
1. Determine the direction you are facing.
2. Turn the chart until that direction is at the bottom.

February 20 11 p.m.
March 5 10 p.m.
March 20 8 p.m.*

** Daylight Saving Time begins March 12.*



M Mars

Mars is shown for March 5, and it will change position noticeably during the month.

- open cluster
- globular cluster
- nebula
- planetary nebula
- galaxy

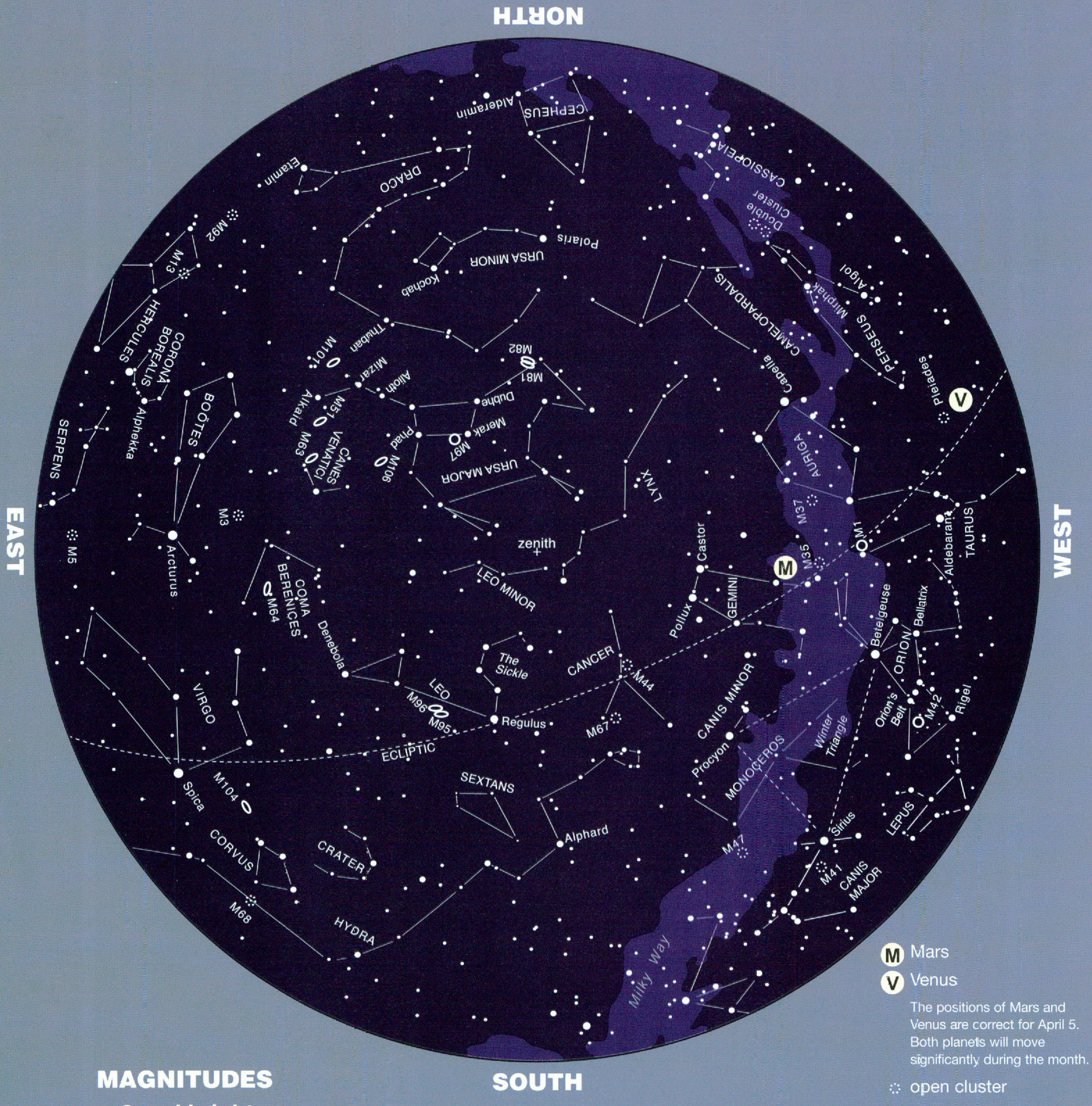
MAGNITUDES

- 0 and brighter
- 1
- 2
- 3
- 4 and fainter

APRIL

How to use these charts:
1. Determine the direction you are facing.
2. Turn the chart until that direction is at the bottom.

March 20	**11 p.m.**
April 5	**10 p.m.**
April 20	**9 p.m.**



MAGNITUDES

- 0 and brighter
- 1
- 2
- 3
- 4 and fainter

M Mars
V Venus

The positions of Mars and Venus are correct for April 5. Both planets will move significantly during the month.

- open cluster
- globular cluster
- nebula
- planetary nebula
- galaxy

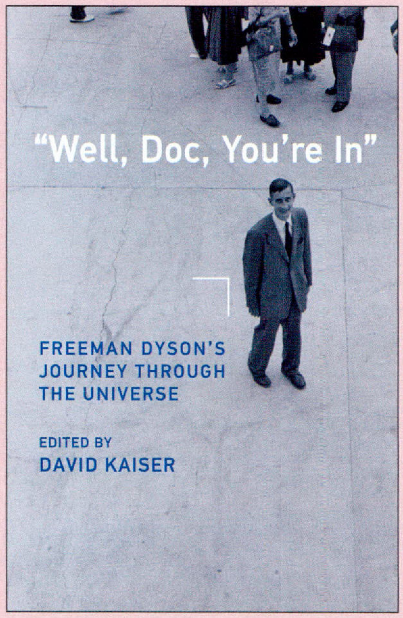
Hopping from Pond to Pond

Freeman Dyson climbed towers in the dark, brought light to many areas of science and technology

Freeman Dyson described himself as a frog among birds. While birds soar high above the landscape, taking in the big picture, frogs burrow into the mud, seeing all the details and solving problems one at a time. "As a happily hopping frog, Dyson loved to switch academic fields," according to *"Well, Doc, You're In": Freeman Dyson's Journey Through the Universe,* "often achieving some early signature successes, sometimes jumping to an unfashionable, faraway pool that didn't look very fertile in the eyes of his colleagues."

Dyson hopped into just about every pool in 20th- and early 21st-century science: particle physics, quantum mechanics, space exploration, extraterrestrial intelligence, the origin of life, genetic engineering, and others, making critical contributions to many. He also designed a nuclear reactor and a nuclear rocket and devised a concept that's one of the most popular in science fiction: the Dyson sphere.

Dyson's life and times are well described in *"Well, Doc, You're In,"* a collection of tales by historians, friends, and fellow scientists edited by David Kaiser, a professor of the history of science at MIT. While some of the science can be dense, the overall story is entrancing and easy to follow.



"Well, Doc, You're In"
Freeman Dyson's Journey Through the Universe
Edited by David Kaiser
The MIT Press, 2022
$29.95, hardcover
mitpress.mit.edu/9780262047340/well-doc-youre-in

Dyson was born in 1923, in England. At age 16, he read a book on number theory (he had to translate it from Russian, which required him to learn Russian first), leading to his lifelong love of mathematics. At Winchester College, he won top marks each of his three years, earning small cash awards that he had to spend on books.

He enrolled at a practically deserted Cambridge University in 1941. During the blacked-out nights, he and a friend free-climbed the town's walls and towers. He then worked for Britain's bomber command, tackling tedious problems in bomber formations. His conclusions were ignored, giving him a lifelong distrust of large bureaucracies and small bureaucrats.

After the war, Dyson studied the weirdness of quantum physics, reconciling different models by three of the giants of the field and earning an invitation to visit the Institute for Advanced Studies in Princeton, New Jersey, the home of Albert Einstein. (He later became a member and spent most of his career there.)

In 1955, he joined General Atomics, in California, where he helped design a nuclear reactor for academic and commercial uses. It sold like crazy, and many are still in use today. He also worked on a project that would have used a series of nuclear explosions to accelerate a 4,000-ton spacecraft to the outer solar system. Although the engineering was sound, neither NASA nor the military was interested, so the concept died.

He returned to Princeton after that and leapt into new ponds. He wrote a book about the origins of life, for example, and urged Congress to not restrict genetic engineering research.

In 1960, he developed the concept for the Dyson sphere. He suggested that an advanced civilization could capture huge amounts of energy by dismantling a planet and constructing a ring around its star. The structure would radiate enough infrared energy to be detected by space telescopes. Astronomers continue to search for them today, while sci-fi writers incorporate them into new stories.

These and many other contributions made Freeman Dyson one of the scientific giants of the past century. As one of the book's authors notes: "Dyson was the original 'star child,' an intellect whose own odyssey reached far beyond its earthly manifestation."

THE MIT PRESS (2)

SOFIA is towed to its new home after landing at Davis-Monthan Air Force Base in Tucson. Inset: SOFIA at work, with the telescope door open.

RAMON PURCELL; NASA (INSET)

Retired Airborne Observatory Donated to Tucson Museum

NASA has donated its recently retired airborne infrared observatory, SOFIA, to the Pima Air & Space Museum (PASM) in Tucson. The modified Boeing 747 airliner carried an infrared telescope aloft to study the sky from Earth's stratosphere. It was grounded in September and arrived in Tucson in December.

PASM Executive Director Scott Marchand says visitors will be able to tour inside the jet once NASA completes its decommissioning, sometime from April to June. Marchand expects the telescope structure to remain in the aircraft for public viewing. Scientists are removing the telescope's mirror, which will be replaced with a blank.

The museum will conduct tours inside the jet a couple of days per week. PASM also plans to create a small indoor exhibit dedicated to SOFIA.

SOFIA was a partnership between NASA and the German Space Agency. During eight years of research, starting in 2014, it observed the heavens about 1,000 hours per year.

Some of the telescope's achievements include the discovery of water on the sunlit portion of the Moon, the first detection of the earliest type of molecule to form in the universe, studies of the atmospheres of Pluto and its big moon Charon, and secrets of star formation hidden inside massive clouds of gas and dust.

Pima Air & Space Museum
pimaair.org

Real Science from Your Own Back Yard

Got a telescope? If so, you could help astronomers look for planets around other stars or monitor changes in light pollution in your own neighborhood.

In NASA's project Exoplanet Watch, backyard astronomers take their own telescope images to help find planets around other stars. The project provides software and guides participants in converting their images into measurements that could reveal a planet passing in front of a target star.

No telescope? You can still help. Exoplanet Watch will supply raw data from a robotic telescope network that you can help process and then submit.

In addition to training, Exoplanet Watch explains how astronomers find and explore exoplanets, offers a chance to be listed as a co-author on a scientific paper, and provides tools to connect Exoplanet Watch participants.

Globe at Night is another project where data from your back yard can help astronomers. The project is run by the National Optical Infrared Laboratory.

With the Globe at Night app on a smartphone, the user enters the time, date, and location. The app then offers several star maps. You then select which view most closely matches what you see in the sky with your unaided eye.

Scientists recently published results of 50,000 observations from Globe at Night participants gathered from 2006 to 2022. They showed that skyglow, or light pollution, is growing rapidly worse, and it's increasing faster than satellite data alone would indicate.

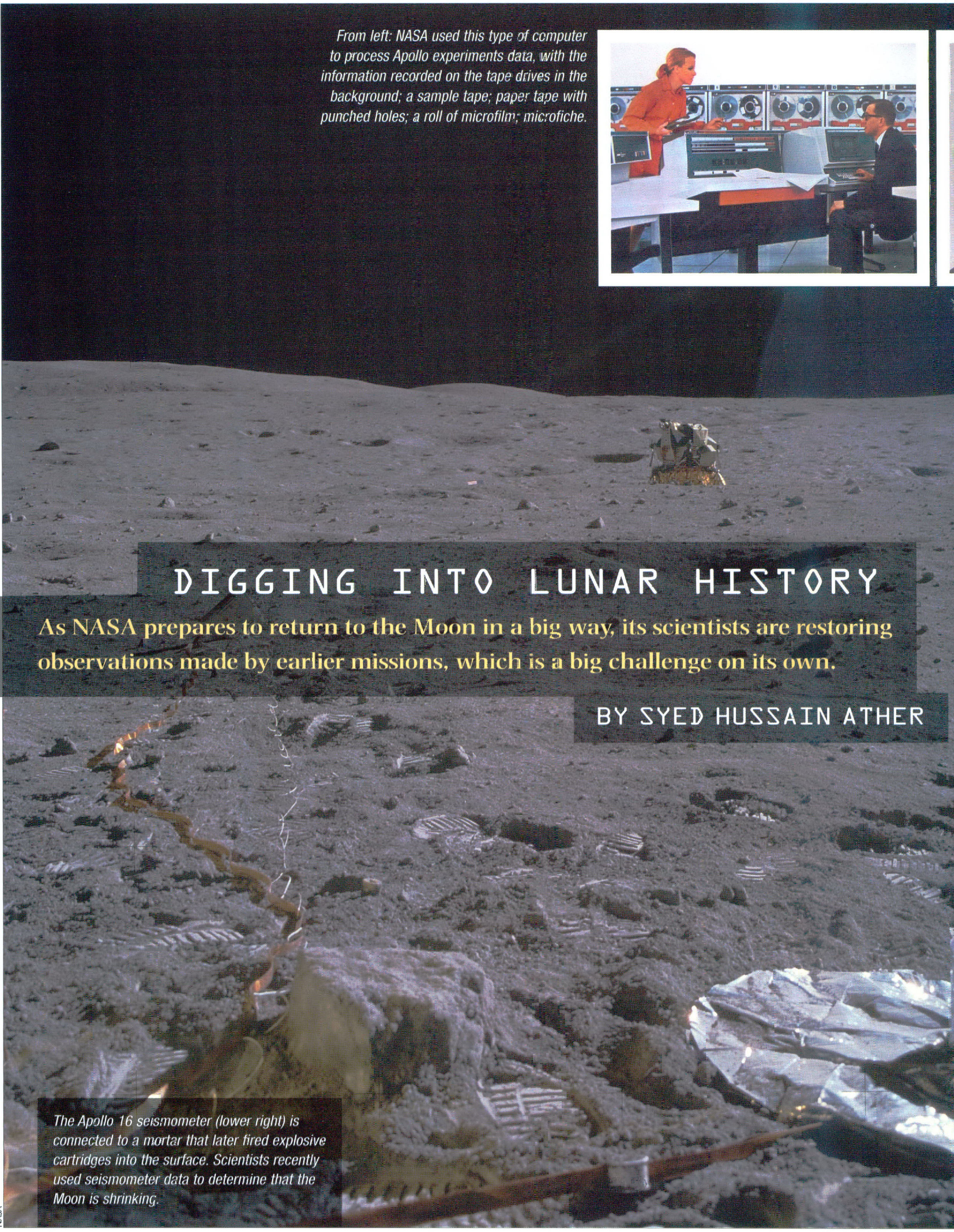
The project found that the loss of visible stars reported by Globe at Night shows an almost 10 percent increase in sky brightness per year over the past decade, much higher than the two percent suggested by satellite data.

Though light pollution is a well-known problem, it hasn't been tracked well on a global scale. Globe at Night seeks to fill in the blanks. **RJ**

Exoplanet Watch
exoplanets.nasa.gov/exoplanet-watch

Globe at Night
www.globeatnight.org

From left: NASA used this type of computer to process Apollo experiments data, with the information recorded on the tape drives in the background; a sample tape; paper tape with punched holes; a roll of microfilm; microfiche.



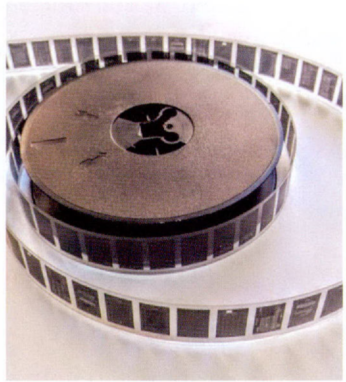
DIGGING INTO LUNAR HISTORY

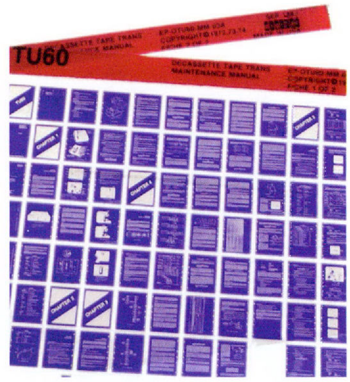
As NASA prepares to return to the Moon in a big way, its scientists are restoring observations made by earlier missions, which is a big challenge on its own.

BY SYED HUSSAIN ATHER

The Apollo 16 seismometer (lower right) is connected to a mortar that later fired explosive cartridges into the surface. Scientists recently used seismometer data to determine that the Moon is shrinking.

NASA





The Moon is shrinking. In the past few hundred million years, as its interior cooled its diameter decreased by about 150 feet (50 meters). That's caused the brittle crust to crack and form cliffs that can be miles long and dozens of feet high. And the process appears to be continuing today, creating fresh crackles and pops that reverberate throughout the Moon, suggesting that our satellite world is still geologically active.

Scientists announced that discovery in 2019, but it was based largely on observations made a half century earlier, by seismometers placed on the lunar surface by Apollo astronauts. The instruments recorded hundreds of moonquakes, produced by everything from space rocks slamming into the lunar surface to the pull of Earth's gravity rattling the Moon's interior. The shrinking produces shallow quakes, but it took modern computers to tease out the discovery.

It also took a robust archive of data from the Apollo missions, which hasn't been easy to maintain. Many observations were recorded on magnetic tapes or other obsolete media, some have been damaged or lost, and many others didn't have good descriptions of how, when, or where they were recorded—key details needed for an accurate interpretation.

The problem isn't unique to the Apollo data. The United States has been launching science missions to Earth orbit and beyond since its very first satellite, Explorer 1, in January 1958. Hundreds have followed, studying everything from the planets and moons of our own solar system to the most distant galaxies and quasars. Those early observations can tell today's scientists how the targets have changed over the decades, helping them develop a more complete understanding of almost every type of object in the universe.

As with the Apollo observations, though, many of those early peeks at the universe are difficult to recover. Turning them into useful information is like an archaeological expedition: Scientists must dig up the original data, clean it, then translate it from a language that probably hasn't been used in decades.

The Apollo missions and their robotic precursors have been high priorities for data preservation efforts, especially over the past decade and a half, as NASA has intensified plans for returning astronauts to the Moon.

"If we're going to go back to the Moon, we want to know what the environment is like," says David Williams, an astronomer at NASA's Goddard Space Flight Center in Maryland. "If we are going to do experiments, we want to do them better."

The data from many early experiments have not been fully explored. Early robotic missions, for example, were designed primarily to pave the way for Apollo, identifying good landing sites and confirming that it was safe to touch down. Scientists skimmed through the mission results, but often lacked the funding to dig deeper. In addition, improvements in computer technology and analytic techniques have made it possible to find details in the observations that 1960s and '70s scientists missed.

"As the power of computers changes, so does the paradigm," says Williams. With these new ways of studying space data, for example, evidence of hydroxyl—a form of water—was found on the Moon's surface. "It was assumed there was no water on the Moon at all, and now we know there is water on the Moon, and these things changed with the computing ability and new ways of thinking."

In the early 2000s, planetary scientists began reprocessing the images obtained by the five Lunar Orbiter missions of the 1960s. Each craft flew low over the lunar surface, snapping high-resolution images to help Apollo planners find good landing sites. The images were recorded on film, processed in an on-board photo lab, then scanned in strips and beamed to Earth. Technicians used computers to produce final images, which clearly showed the seams between strips.

The modern project reprocessed those images, removing the strips and sharpening the overall quality. It wasn't easy, however. The originals were preserved on 1,500 magnetic tapes, which had been stored in a NASA scientist's garage for two decades. Reading the tapes required a specialized drive that was used only by NASA and a few other government agencies, but had been out of service for decades. Technicians, who set up shop in a former McDonald's next door to NASA's Ames Research Center in Silicon Valley, had to track down and rehabilitate the drives, then reprocess all of the images. The first one was released in 2005, and the completed set wasn't handed over to NASA until 2017.

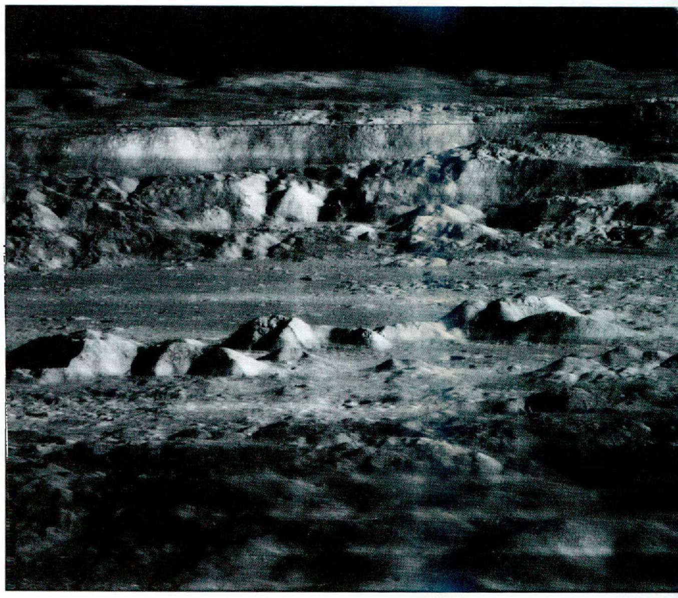
The new images are being put to work to identify changes in the lunar surface over the past half-century. "Scientists are comparing newly acquired high-resolution images from the Lunar Reconnaissance Orbiter Camera to find new craters formed on the Moon since the Apollo era," says Mark Robinson, a professor of Earth and space exploration at Arizona State University. This tells us how often large space rocks slam into the lunar surface, which can quantify possible risks to future human explorers.

Most of the lunar data preservation effort, however, has focused on the information recorded by instruments left on the Moon by the Apollo lunar landing missions. Five of the six Apollo crews deployed an Apollo Lunar Surface Experiments Package (ALSEP). These nuclear-powered stations included seismometers as well as instruments for measuring the Moon's magnetic and gravitational fields, the solar wind, impacts by microscopic space rocks, the Moon's internal temperature, and even the few particles that make up the Moon's vanishingly thin atmosphere. Some of the instruments operated until 1977—five years after the last Apollo mission.

Much of the ALSEP data was not properly archived, however, and some of the archived data became outmoded or lacked appropriate documentation to help researchers understand the observations.

To correct those flaws, in 2003 NASA launched the Lunar Data Project (LDP).

It gathered observations from the NASA Space Science Data Coordinated Archive (NSSDCA), the storage depot for data from many space missions, and analyzed them with the Planetary Data System (PDS) Lunar Data Node, which puts relevant, scientifically important data into accessible digital forms for researchers and missions planners.



A Lunar Orbiter photograph of Copernicus Crater, with the original at left and the reprocessed version at right.

The experiments themselves had their own issues with collected data, such as the effects of dust on the Lunar Dust Detector Experiment. "Despite what you think of when you look at the Moon and see this bright white thing, it's very dark and absorptive," and covered with a fine, powdery dust, Williams says. "It was getting on instruments. The dust on the Moon has got lots of hooks and sharp edges. It catches onto the space suits, for one thing. ... It was rubbing against them and kind of damaging the joints. It was like they had a scouring powder in the joints."

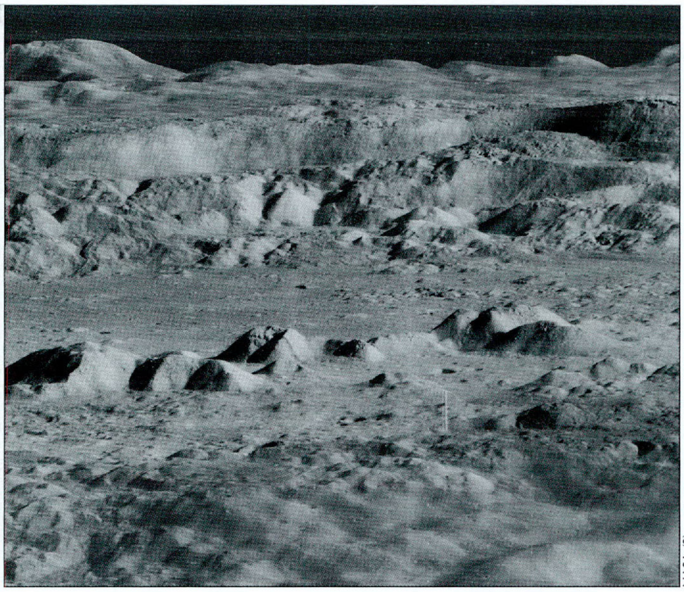
In addition, dust grains can be levitated by electric charges imparted by particles of the solar wind. "You'd see dust appearing on these surfaces in the morning or in the evening or overnight," Williams says. "That's one thing that was important for understanding how the lunar environment might affect astronauts and equipment. ... If you have a lunar rover, let's say, and it has a radiator to make sure it doesn't overheat, and the radiator gets dust on it by whatever mechanism, then you're driving around and the radiator is absorbing heat, suddenly you might have a problem with your rover."

Better understanding the characteristics of the dust, how it's distributed, how that distribution changes during the lunar day (which lasts 28 Earth days), and other details can help designers produce better space suits and other equipment for NASA's Artemis astronauts, who are scheduled to make their first trips to the Moon later this decade. It can also help scientists design better instruments for a fleet of robotic orbiters, landers, and rovers planned for the next few years, which will, in turn, provide both better basic knowledge of the lunar surface and more guidance for later crews of astronauts.

Data preservation isn't a new concern. In a 1990 report, the General Accounting Office chastised NASA for data storage, processing, and analysis protocols that were sloppy, inefficient, or worse.

"Currently, hundreds of thousands of tapes containing space science data are stored under deplorable conditions," the report said. "[NASA] has not performed an agencywide inventory of its magnetic tapes and, consequently, does not know what data are retained, or may have been lost. ... Without the allocation of adequate resources to improve the tape storage and archival facilities, the continuing deterioration of the magnetic tapes may result in the permanent loss of irreplaceable space science data."

During the early space program, NASA spent billions developing its missions, dispatching them to far-away locations, and gathering stacks of information from them. Yet it barely thought about archiving those observations for future generations, and spent



NASA (2)

almost nothing on it. In part, that was because, while data storage technology was changing rapidly, the pace was nothing compared to the present day, in which a medium can appear, gain popularity, then be supplanted by a new one almost overnight.

That lack of vision has created big headaches for today's researchers.

"The data were on various media—typically millimeter tapes, microfilms, and even hardcopies in some cases," says Stephanie McLaughlin, a data scientist at NSSDCA. Most media tend to degrade over the years, McLaughlin noted, raising concerns not just about preserving older observations but about having anything left to preserve.

Then, of course, there is the problem of deciphering the older formats. "We used to have the ability to copy the microfilm. Now we don't even have that ability anymore," Williams says.

The data also need context—a picture of a rock on the Moon doesn't mean much if scientists don't know anything about it. So researchers put great effort into creating documentation, or metadata, describing the data itself, with references, mission and instrument descriptions, contact information, and related details.

"When you're looking at a magnetic tape, it's just bits [ones and zeroes]. You have no context, no idea, you don't even know how long each number is," Williams says. "Maybe it's six digits? Maybe it's eight digits? For that, you would need documentation explaining the formatting. A lot of times we didn't have that."

In the case of the Lunar Ejecta and Meteorites Experiment on Apollo 17, which measured impacts by tiny space rocks, results were recorded on four-by-four grids, with keys on the grid. However, "we don't know which point on the grid is being referred to by the data," Williams says. "Some of the data we have doesn't make any sense."

Struggles with data analysis also were found with Apollo 15 and 17 heat flow experiments, in which astronauts drilled pairs of holes in the surface, then dropped thermometers into each hole. Scientists used those readings to measure how heat flowed through the lunar surface, revealing details about the rocks and dust. "When we did the heat flow experiment, the documentation had two different numbering schemes that didn't match up," Williams says. "That made it a little hard to figure out which thermostat was measuring which temperature."

Recent work by a group of researchers led by Seiichi Nagihara at Texas Tech University has shown promising results in recovering lost data from the Apollo experiments. The team retrieved 400 missing tapes from ALSEP archives, processed them, and made digital copies available through the Lunar and Planetary Institute in Houston.

McLaughlin says there are similar efforts to read Apollo data recovered from the National Archives and Records Administration. Scientists could clean or resolve the electronic data, scrub them to restore lost parts, fix errors in translation, or deal with data that aren't thoroughly documented. "Sometimes, the documentation would not be as thorough as we would've liked it," McLaughlin says. "We'd call out fields or columns that we were unsure about."

The Apollo Digital Image Archive has been preserving original film products—from 35-millimeter slides to 16-millimeter movies—and posting them for the world to see. "The scans are digital, so as long as digital archives remain, the scans will be fine," notes Robinson.

Both NASA and its scientists seem to have learned from these lessons. The space agency requires missions to include preliminary data storage and retention plans from the beginning of the mission-planning process. The teams must develop and document detailed plans that explain how data files will be produced and archived. They also must specify which data repositories they will use, and outline details for each instrument the mission will carry. These efforts should address some of the overall problems of media deterioration and missing or incomplete documentation.

Keeping careful track of changing technology should allow mission teams to update their archives as needed, making their observations available to scientists decades into the future. "Nothing is on the media for more than 10 years before it's put onto something new," Williams says. "The idea is that all these data will be available forever."

Syed Hussain Ather is a PhD student in medical science at the University of Toronto, specializing in computational neuroscience.

RESOURCES

INTERNET

MoonViews
moonviews.com

Shrinking Moon May Be Generating Moonquakes
nasa.gov/press-release/goddard/2019/moonquakes

Lunar Data Project
nssdc.gsfc.nasa.gov/planetary/lunar/lunar_data/

Digitizing the Surveyor Lander Imaging Dataset
lpl.arizona.edu/sic/surveyor

by Rebecca Johnson and Damond Benningfield

Europe's 'Juicy' Mission is Jupiter Bound

The Juno spacecraft snapped this close-range view of Ganymede in 2021.

The European Space Agency (ESA) is set to dispatch a new mission to Jupiter in April from its spaceport in French Guiana.

One of the major goals of Jupiter Icy Moons Explorer (JUICE) is "to explore ... the habitability around a giant planet," said Olivier Witasse, JUICE Project Scientist at ESA, in a video. "Habitability means that we would like to see whether, around Jupiter, there are places where life could have started. And to explore that, we need to find a place with internal energy, and with liquid water.

"Inside the icy moons, which are Europa, Callisto, and Ganymede, we have good reason to believe that there is, in fact, more liquid water there, inside the surface, than on all Earth," Witasse said.

JUICE is scheduled to make almost three dozen close passes by these moons, all of which are suspected of having massive oceans of liquid water deep below their icy surfaces, before settling into orbit around Ganymede.

The mission aims to learn how far down the oceans begin, how deep they are, and whether they contain salt or fresh water (or perhaps both). Scientists want to understand how features on the surfaces, and past or present geological activity, relate to the oceans.

Ganymede is the spacecraft's primary target. It is the largest moon in the solar system—larger even than the planet Mercury. It's the only moon to generate its own magnetic field. In fact, only two other rocky bodies in the solar system do this, and one has life: Earth.

JUICE will study Ganymede's rotation, gravity, shape, interior structure, magnetic field, and composition, and probe its icy surface with radar to a depth of about six miles (nine km). It also will study the water vapor and particles in the moon's thin atmosphere to better understand how Ganymede interacts with Jupiter's magnetic field and radiation belts.

One of the other target moons, Europa, has a young and active surface; it may even spray plumes of water into space. It's considered one of the best possible habitats for life in the solar system. It could be infiltrated by hot, mineral-rich water from vents on the ocean floor, providing all the basic ingredients for life: water, energy, and the right chemical elements. JUICE will study Europa's surface and probe below it with radar, studying the composition of the crust and the ocean.

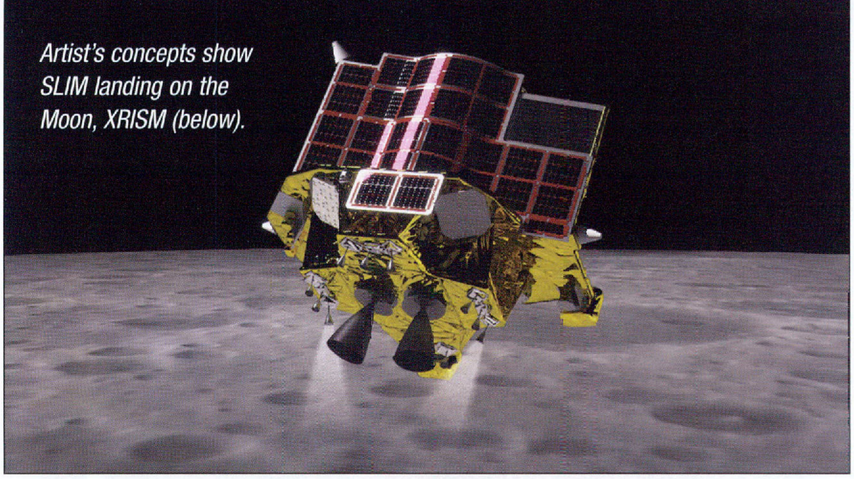
The third target, Callisto, isn't geologically active. Its surface is at least a billion years old. This ancient surface gives JUICE the opportunity to learn about the early environment of the Jovian system.

In addition to these big moons, JUICE will seek to understand how Jupiter's complex environment has shaped its moons, and what effect the moons have had on the environment. Finally, results from JUICE will help scientists use Jupiter to better understand what other giant worlds across the cosmos are like—how they formed, and how they evolve.

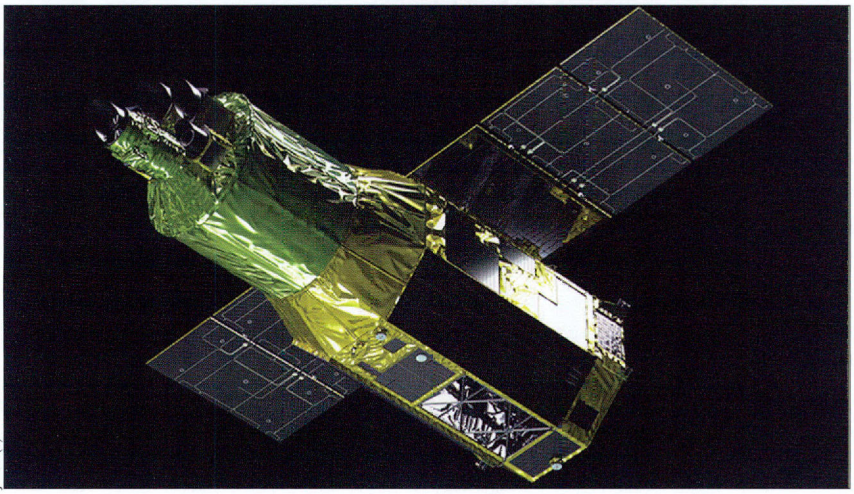
To accomplish these goals, the spacecraft carries 10 cameras, spectrographs, and other instruments that will probe Jupiter and its moons across different wavelengths, including ultraviolet, visible, infrared, and radio waves.

After launching as early as April 5, JUICE will fly past Earth multiples times, and Venus once, to get extra gravitational "kicks" to propel it to its destination. It will arrive at Jupiter in July 2031, then tour the Jupiter system for three years before entering orbit around Ganymede in late 2034.

It is the first of two Jupiter missions in the works. NASA plans to launch Europa Clipper in October 2024, with arrival in 2030. It will make close flybys of Europa, looking for evidence of conditions suitable for life. **RJ**



Artist's concepts show SLIM landing on the Moon, XRISM (below).



JAXA (2)

Japan Preps Missions to Explore Moon, X-Ray Universe

The Japan Aerospace Exploration Agency (JAXA), is planning to launch two space missions on a single rocket this spring or early summer—a lunar lander and an X-ray telescope.

The Smart Lander for Investigating the Moon (SLIM) is Japan's first lunar lander. After two to three weeks orbiting the Moon, it is expected to make a pinpoint landing near Marius Hills Hole, the entrance to a lunar lava tube discovered by a Japanese orbiter.

SLIM will operate on the surface for several days, measuring the composition of surface minerals and deploying a tiny rover. The mission will serve as a technology demonstrator for future missions to the Moon and planets with smaller, lighter spacecraft, including lunar sample-return missions.

The X-ray telescope is XRISM (X-ray Imaging and Spectroscopy Mission). It will carry two instruments. One will study X-rays from cosmic targets for clues to their chemical make-up, temperature, and motion. A camera, called Xtend, will take images at low X-ray energy levels.

From its vantage point in low Earth orbit, the telescope will use the two instruments to study such problems as how chemical elements were produced in the universe, how clusters of galaxies formed, and the nature of dark matter, a mysterious form of matter that produces no detectable energy on its own but reveals its presence through its gravitational pull on the visible matter around it. It will target galaxies and galaxy clusters, the remnants of exploded stars, and the environments around neutron stars and black holes.

XRISM will provide a bridge between current aging X-ray telescope missions and those of the future, including the European Space Agency's Athena mission and NASA's Lynx X-ray Observatory. **RJ**

On the Border

New object blurs boundaries between giant planets, brown dwarfs

A recently discovered planet in a star system 130 light-years away is on the border—the dividing line between a giant planet and a brown dwarf. Future studies may help astronomers refine that dividing line while better understanding how both classes of objects form and evolve.

HD 206893c is the third member of its system. The central star is bigger and heavier than the Sun. The star has a distant companion known as a brown dwarf—an object that's more massive than a planet but not massive enough to shine as a true star.

Observations by Gaia—a mission that's plotting the locations and motions of more than a billion stars—hinted at the presence of the third member. A team led by Sasha Hinkley of the University of Exeter in England used the Very Large Telescope in Chile to track down the second companion and even snap its picture.

Precise measurements revealed that HD 206893c orbits about 325 million miles from the star and is slightly larger and about 12.7 times more massive than Jupiter, the giant of our own solar system. That puts it on the border line between a giant planet and a brown dwarf—roughly 13 times Jupiter's mass.

Although astronomers have classified HD 206893c as a planet, it is much brighter than most giant planets. That suggests the planet is "fusing" deuterium, a heavy form of hydrogen, in its core—a characteristic of low-mass brown dwarfs. "That may help us refine what's a brown dwarf or an exoplanet," Hinkley said at a press conference in January.

Hinkley also said the discovery suggests "there's a coming Gaia revolution," as astronomers use the space telescope's observations of additional star systems to track down and photograph potentially thousands of exoplanets. **DB**

Mars Stays Active

Boulder slides, quakes show continued churning below the surface

Mars isn't dead yet. A volcanic region on the planet appears to have stayed active for the past 500 million years, and it's still producing tremors in the Martian surface. In the meantime, the largest marsquake yet recorded, generated in a separate volcanic province, rippled through Mars in May.

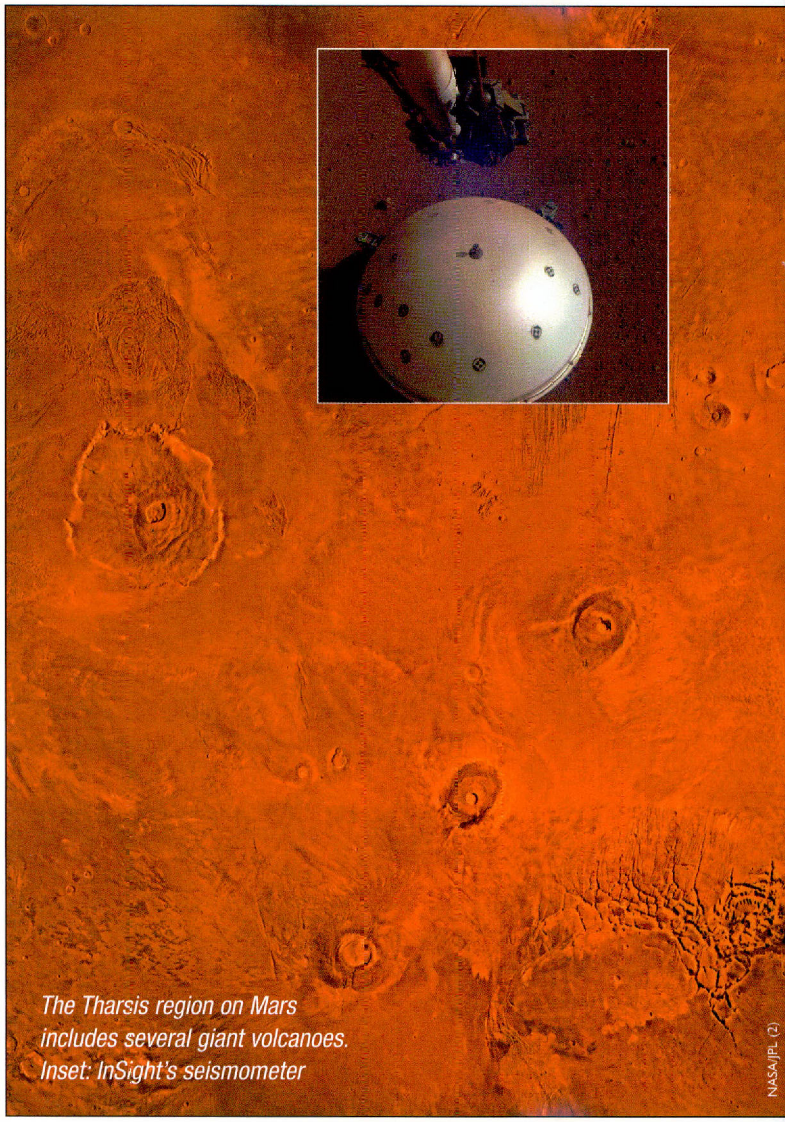
Tharsis is the largest volcanic region on Mars. It contains several giant volcanoes, including some of the largest in the solar system, plus hundreds of smaller volcanoes and many related features.

The volcanoes started about four billion years ago, and many of them have continued to build until fairly recently. Scientists don't see any eruptions today, but there's evidence that some of the volcanoes may have erupted within the past hundred thousand years or so.

A recent study found evidence of continuing activity below the surface there. Images reveal big boulder slides on the flanks of some of the volcanoes and other structures, which could have been triggered by volcanic activity. In addition, the recently expired InSight lander, which listened for marsquakes, recorded activity in the region.

A research team says that probably means there are still pockets of molten rock below some Tharsis volcanoes. Motions within those pockets trigger marsquakes and may create new volcanic features at the surface.

Another team reported that InSight recorded its most powerful quake on May 4, about 1,200 miles (2,000 km) from its landing site, in another volcanic region, Cerberus Fossae. The quake reverberated for 10 hours, compared to no more than an hour for the other temblors recorded by InSight. Scientists continue to study the seismic waves from the quake to learn more about Mars's interior, its geologic processes, and the region in which the quake was generated. **DB**



The Tharsis region on Mars includes several giant volcanoes. Inset: InSight's seismometer

NASA/JPL (2)

Universe Didn't Wait to Make Galaxies

The universe was churning out galaxies within a few hundred million years of the Big Bang, pushing the beginnings of galaxy formation earlier than most astronomers had expected, according to some of the first observations by James Webb Space Telescope (JWST).

Its first images revealed 87 galaxies that appear to have formed just 200 million to 400 million years after the Big Bang, which occurred 13.8 billion years ago. Astronomers are using other JWST observations to confirm those ages.

Haojing Yan, an astronomer at the University of Missouri-Columbia, said that if even a small fraction of the ages are confirmed, the previous picture of early galaxy formation must be revised. "We're on a very promising track," Yan said in a press conference in January.

In a second study, scientists compared JWST images of 850 galaxies that are at least nine billion light-years away to those snapped by Hubble Space Telescope. (JWST sees much deeper into the universe, and its instruments are sensitive to the wavelengths at which we observe these distant galaxies.)

Team members analyzed the pairs of images by hand, and found that the JWST pictures showed much more detail in the most distant galaxies. Many of them were disks, like our own Milky Way Galaxy, while others were well-defined balls, known as spheroids. This tells us that galaxies were pulling themselves together when the universe was quite young.

"Nobody knew what we would see when we looked at these galaxies with JWST," said Jayhan Kartaltepe, of Rochester Institute of Technology, during the January press conference. "The surprise was to see so many of them."

The initial images covered a tiny portion of the sky, so astronomers expect to find many more early galaxies as JWST surveys more of the universe. "This is only the beginning," said Kartaltepe. **DB**

McDonald Observatory's Stellar Supporters

McDonald Observatory's education and outreach initiatives provide many entry points to astronomy for stargazers of all ages, including virtual and in-person astronomy field trips, K-12 summer teacher workshops, Live-from-McDonald broadcasts on YouTube, and StarDate magazine and radio programs.

We are grateful to Friends of McDonald Observatory members, individual donors, and organizations for their support of education and outreach programming. It means the Universe to us!

FOUNDATIONS & ENDOWMENTS

The Abell-Hanger Foundation
The Albert and Ethel Herzstein Charitable Foundation
The Alfred S. Gage Foundation
The Bill and Alice Wright Endowment for Education & Outreach
The Carl B. and Florence E. King Foundation
The Carolyn Frost Keenan and Charlie Gaines Educational Endowment for McDonald Observatory
The Cynthia and George Mitchell Foundation
The Fash Foundation
The Harry W. Bass Jr. Foundation
The Helen Greathouse Charitable Trust
The Hugh Gragg Educational Endowment
The Lynn Lyles Brill Education & Outreach Endowment
The Leopold Tedesco Educational Endowment
The Mary Ann Rankin Endowment for UTeach Workshops
The Mary Kay Hemenway Outreach & Education Endowment
The MESA Engineering Education Endowment in honor of David L. Lambert
The Meyer Levy Charitable Foundation
The National Science Foundation
The Pam and Rom Welborn McDonald Observatory Endowment for Education Excellence
The Permian Basin Area Foundation
The Semmes Foundation
The Stillwater Foundation

INDIVIDUAL DONORS

Helen Alexander
Camilla Bennett
William Dicks
Jerry and Jody DePriest
Ed and Lisa De Reyes
Meredith Dreiss and David Brown
Mark Hart
Mary J Hickok
John M Lents
Gene Puhrmann
Donald and Melissa Reid
Jan Shurtleff
Paul Teten and Virginia Holbrook
Steven Yanagisawa

FRIENDS OF MCDONALD OBSERVATORY ORION CIRCLE AND ORION CIRCLE SUPERNOVA MEMBERS

James and Kathy Albers
Jana Baker
Jeff Beauchamp
Terry and Kiki Boeck
Christina Boswell
Tom and Carol Brayshaw
Chris and Sara Bunch
Julia Bustamante
Dee Cianciolo
Paul Cockreham
Jim and Michelle Connor
Thomas Copeland
John Cotton and Carol Jordan
Kevin and Diane Dahl
Jonathan Dahm
Anya Darrow
Dennis Dickerson
Thomas and Joell Doneker
Meredith Dreiss and David Brown
Emily Burch and James Dunagin
John Dykema
Jim and Carolyn Estes
Alan Eynon
Kathy Ferguson-Grosskopf
Charles Finger
Andrea Gastaldo
Amy Gurley
Dennis Haley
Sherman Hart
Deborah Hulse
Charles Hummel
Rashid Syed and Sumbul Husain
Jim Johnson and Coleen Quinn
Karen Johnston
Phillip and Karen Kelton
John Robert Kilgore
Katherine Kiolbassa Spalding
Katie Kizziar and Jimmy Crooks
Jeff and Gail Kodosky
Natalie Lake
Chad Lanier
Chadwick Lee
Jerry Lemon
Joan Lewis
William Lewis
Melaney Linton
Jack and Carolyn Long
Gus and Mary Lott
James and Marilynn Machin
Royden and Sue Marsh
Wanda McGarry
Ryan and Jenn Merket
James and Barbara Mobley
David Monyak
Willa Moore
Stanley and Kathryn Novey
James Phillips
John and Sherry Roan
Jay Roberts
A. John and Dee Rush
Augustus Rush
Brian and Tracy Shawn
Dirk Schroetter
Amy Simpson
Eric Smith
Randy Smith
Jason Soll
Rick Stephens
Xavier and Linda Stokes
Joseph and Sallie Tarride
Alethea Taylor
Roy and Dale Truitt
James Turner
Charles and Valera Walters
Christopher Webster
John Weeldreyer
Jane Wetzel
John and Mary Whisenhunt
Candace Williams
Laramie and Donna Winczewski
Robert Wright

Donate or become a member today!
mcdonaldobservatory.org/support

Regions of dense, cold gas and dust are giving birth to many new stars in NGC 346, a huge stellar nursery about 200,000 light-years away in the Small Magellanic Cloud, a companion galaxy to the Milky Way. The colder regions, colored in orange in this infrared view from James Webb Space Telescope, are where new stars are born. As the stars form, they heat and blow away the surrounding material, forming long streamers of hot gas (pink) and creating big cavities and pillars. More stars are being born in the pillars.

NASA/ESA/CSA/OLIVIA C. JONES (UK ATC)/GUIDO DE MARCHI (ESTEC)/MARGARET MEIXNER (USRA)