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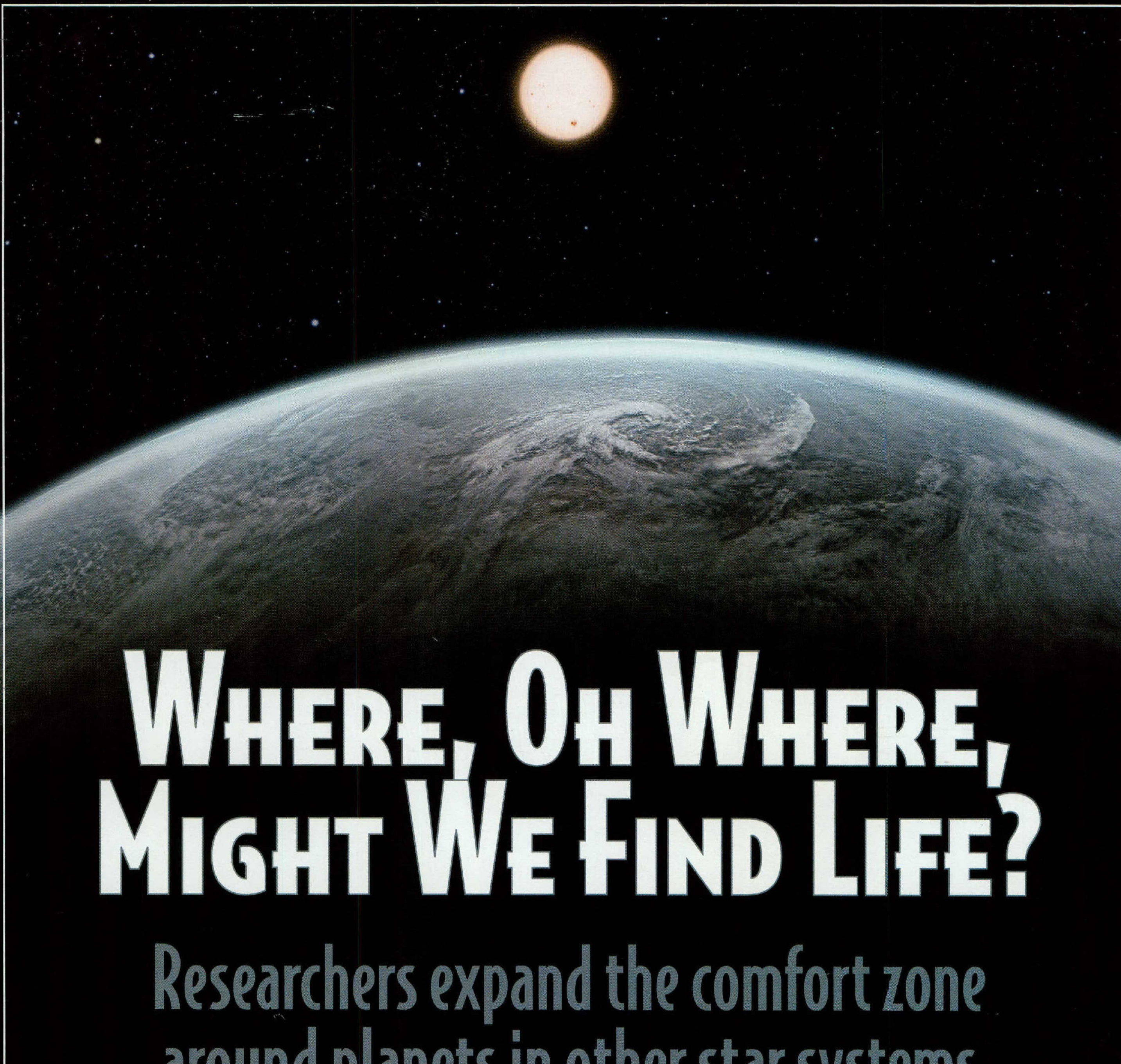
WAITING FOR 'THE CALL'
PAGE 4



WHERE, OH WHERE, MIGHT WE FIND LIFE?

Researchers expand the comfort zone around planets in other star systems

THE UNIVERSITY OF TEXAS AT AUSTIN McDONALD OBSERVATORY

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Features

Departments

ESO/M. KORNMESSER

On The Cover

An artist's impression depicts a 'super-Earth' orbiting the star HD 85512. The planet is at the edge of the star's habitable zone, which is the most comfortable distance from the star for Earth-like life.

This Page

An artist's concept shows six recently discovered galaxies (bright spots) enveloped in tendrils of gas near a supermassive black hole (brightest object). The black hole is surrounded by a disk of superhot gas that glows brightly, forming a quasar. Astronomers see the cluster as it looked when the universe was less than one billion years old, confirming that supermassive black holes formed quickly in the early universe.

Coming Up

We'll set you up for an entire year of skywatching with our 2021 Sky Almanac. It lets you know when to look for meteor showers, eclipses, close encounters, and many other beautiful events. And it highlights some of the most intriguing stars around — some alive, some dead.

MERLIN

Dear Merlin,

Why does the Moon look like it is sitting down the street from you sometimes?

Cynthia Y. Harris
Plainfield, Illinois

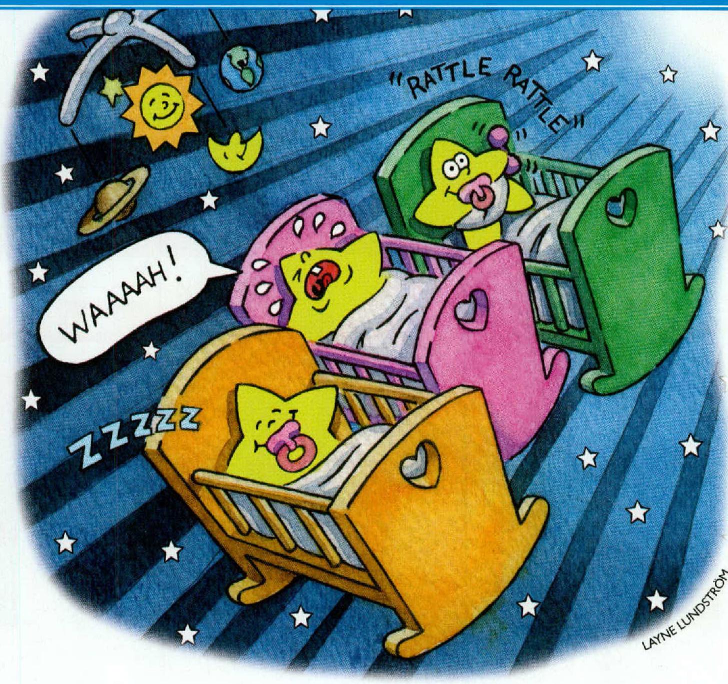
Merlin suggests that if you figure it out you notify all the leading scientific societies, because astronomers, psychologists, and others have been trying to find the answer for millennia.

First, let's rule out the obvious: Measurements of the Moon's angular size (how big it appears in the sky) show that it isn't any bigger when it's on the horizon than when it's higher in the sky. (Its apparent size does vary from month to month because the Moon's distance from Earth varies. But there's almost no variation in the Moon's size across a single night.)

That means the effect, known as the Moon illusion, is all in your head. But exactly why your brain sees a "bigger" Moon on the horizon — when it's just down the street — has been a point of contention.

Some studies suggest that your brain "sees" the horizon as farther away than the overhead point, so it perceives the horizon Moon as being larger. Others suggest that the brain compares the Moon to other objects along the horizon, such as buildings or trees. The brain sees fine detail in these objects, which makes the adjacent Moon seem larger. Conversely, when the Moon is higher there are no objects to which it may be compared, so it seems smaller.

Researchers have proposed a few other explanations over the years, but they all come back to the same general idea: It's all in your head.



Dear Merlin,

What is the catalyst for a big bunch of gas and dust to suddenly come together to form a star? What initiates that sort of action given that the gas and dust have just been hanging around for eons minding their own business?

Greg Walker
Irvine, California

The birth of a new star usually is triggered by another star.

Sometimes the trigger is the death of a star in a supernova explosion (the probable mechanism for the birth of the Sun and its family of planets). The shockwave from such a blast rams into nearby clouds of gas and dust, causing the clouds to collapse. As a cloud gets denser, it breaks apart into smaller clumps, each of which may collapse to form a star.

Other times, the trigger is a sibling star. Some of the newborn stars in a cluster are many times the mass of the Sun. Such stars are extremely hot, so they produce enormous amounts of radiation and strong winds of charged particles. The howling winds compress some of the surrounding gas and dust, causing it to collapse and give birth to new stars.

Individual stars aren't the only catalysts in creating new stars, though. If a cloud of gas and dust passes another large nebula or a star cluster, the gravity of the other object can squeeze the cloud, causing it to collapse and give birth to new stars. And the gravity of the entire galaxy can raise "tides" in a cloud, just like the ocean tides on Earth, again triggering the birth of stars.

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
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Dear Merlin,

As I understand it, meteor showers are caused by Earth passing through clouds of rocky debris. But how is it possible for the debris that makes these showers to be in the same place at the same time every year? The rocks must be orbiting the Sun on their own schedule. If so, how can Earth pass through these clouds at the same time year after year?

Keith Meldahl
Encinitas, California

Merlin would say that you have basically answered your own question: The debris does indeed orbit the Sun on its own schedule. It just happens that the schedule overlaps with Earth's.

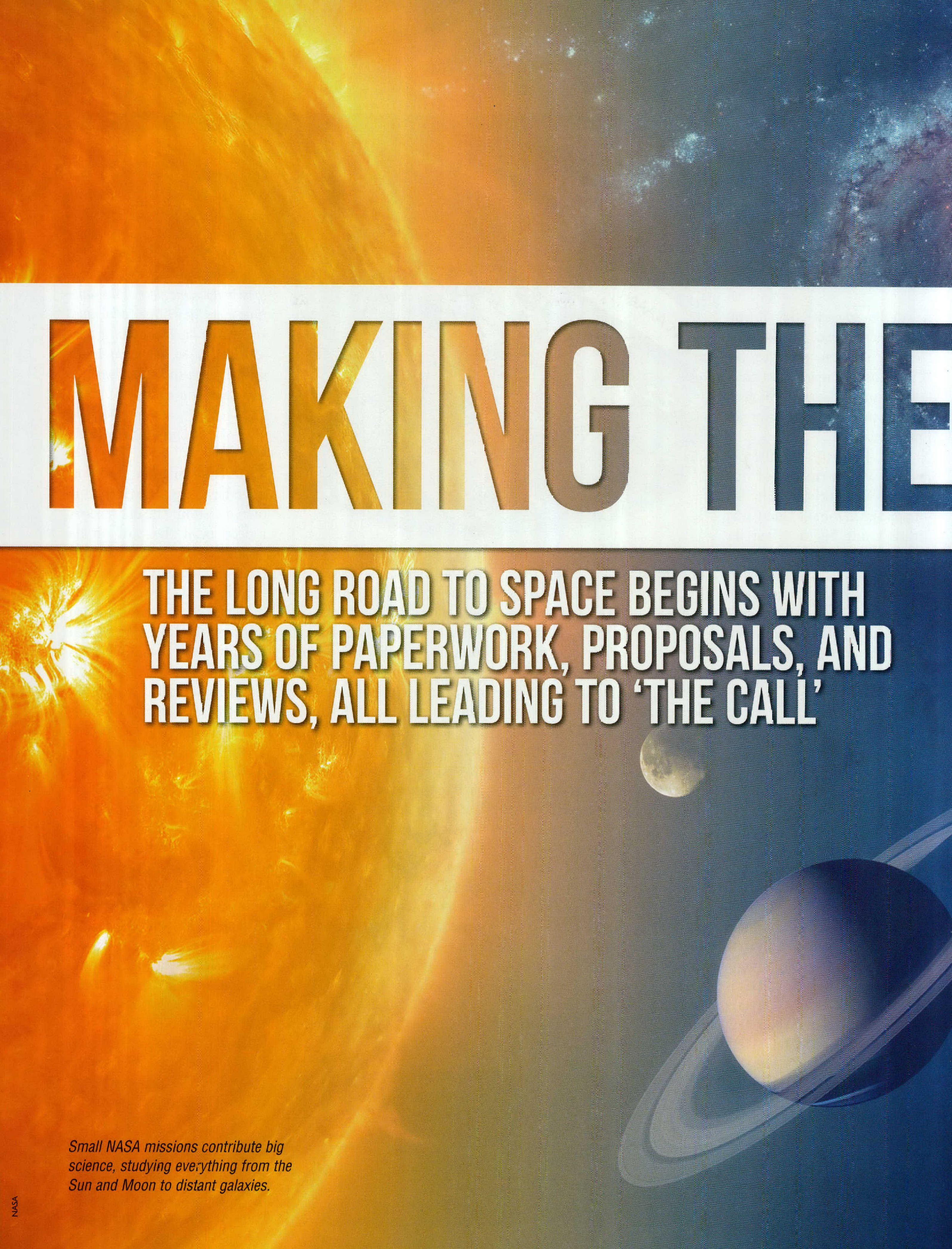
Meteor showers are spawned by comets and asteroids, which shed grains of rock and dirt as they orbit the Sun, leaving a trail behind them. A trail follows the same orbit as its parent body, although it spreads along the parent's entire orbital path.

The orbits of some comets and asteroids cross Earth's orbit. When Earth passes through the path of one of those bodies it encounters the rocky debris, triggering a meteor shower. Most of these orbits are fairly stable over the short term, so Earth passes through the same paths at the same time each year, spawning such showers as the Leonids and Perseids.

However, the parent body and its trailing debris can be pushed by the Sun's radiation and winds, by the gravity of other planets, and by other factors. So over the centuries, an orbit can shift enough that Earth no longer passes through it, and the associated meteor shower comes to an end.

MAKING THE

THE LONG ROAD TO SPACE BEGINS WITH YEARS OF PAPERWORK, PROPOSALS, AND REVIEWS, ALL LEADING TO 'THE CALL'



Small NASA missions contribute big science, studying everything from the Sun and Moon to distant galaxies.

NASA

CUT

BY JASMIN FOX-SKELLY

On May 5, 2018, at 4:05 a.m., the InSight spacecraft launched from Vandenberg Air Force Base in California. More than six months later, it arrived at its destination, touching down in the Elysium Planitia region of Mars. In the two years since, the mission has revealed details about seismic activity on the Red Planet and about the processes that shaped the rocky planets of the inner solar system more than four billion years ago. However, the Mars mission had been in development for much longer than two years, and might never have happened at all.

"InSight went through many different configurations and was proposed numerous times before I even joined the team," says Suzanne Smrekar, deputy principal investigator of InSight at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

As well as large "flagship" missions, such as Perseverance, the Mars 2020 rover; the earlier Curiosity rover; and James Webb Space Telescope (JWST), which tackle bold exploration goals and can cost more than $2.5 billion, NASA also funds smaller scientific missions under the Explorer, Discovery, and New Frontiers programs. For these, budgets can vary from $165 million for a Small Explorer mission (SMEX) to $850 million for New Frontiers.

In each case, scientists must compete to be chosen, going through two brutal rounds of selection and spending years developing concepts for a mission that potentially could fall at the last hurdle. In 2010, for example, Insight was one of three Discovery finalists chosen from 28 original proposals to develop a detailed concept study. Only InSight was selected for development and launch.

"Getting the call was sort of surreal," says Smrekar. "There is so much at stake. They give you a two-hour window for the call, and I didn't hear until about an hour into that window. I was really sweating it! ... I was at home, and I knew it was going to be an emotionally overwhelming time no matter what. I knew I was going to need a moment to collect myself before sharing the news with the team."

While making the cut is an amazing moment, researchers must be prepared for the reality that most do not. Dealing with investing so much work into something that ultimately doesn't go ahead can be tough.

"I have definitely had my share of disappointments, as most have lost, and depending on the level of investment, it can be crushing" says Smrekar. "I was on a proposal in the first round of Discovery missions in the early '90s. ... I was also on a Mars Discovery proposal at some point, and have been on Venus lander proposals. It is a vast investment of energy. But, as they say for the lottery, 'If you don't play, you can't win!' It's similar for missions, as the payoff is enormous."

The art and the science of just how NASA chooses which missions to fund can sometimes seem like a mystery even to those who have submitted multiple proposals.

For each round of funding, NASA sends out an announcement of opportunity that gives researchers only a few months to submit a proposal — although most already have been working on the proposal for years. The proposal describes the science background behind the mission as well as how the scientists plan to conduct the mission, what instruments they plan to launch, what kind of data they expect to get back, how they expect to turn that data into science knowledge, and how they will build and operate the spacecraft and instruments. Two panels of reviewers then minutely examine each proposal.

"The first panel consists of scientists, who look at the merits of the science, how important it is, and how complementary it is to other planned missions," says Michael New, deputy associate administrator for research in NASA's Science Mission Directorate, who is a member of the leadership team responsible for making the final decisions. "They also look at the 'science of implementation,' which is basically asking whether the instruments and architecture can provide the data needed to actually achieve the science objectives of the mission. Those panels can be quite large. The last one I ran, which was one of the Discovery competitions, had 70 scientists evaluating over two dozen proposals."

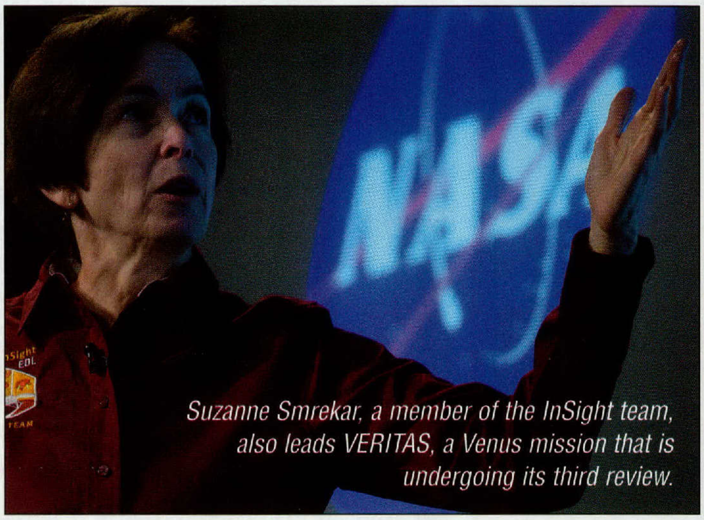
The second panel is a cost-evaluation team comprising a mixture of engineers, management specialists, cost estimators, and schedule analyzers. The team reviews the technical "nuts and bolts" of the proposal and considers whether the mission as proposed can be built and operated given the cost and schedule constraints.

After many months, the panels narrow the list to a few teams, which then are invited to perform a year-long concept study, known as phase A. At the end of that study, the team must submit a detailed concept review report justifying the importance of the science behind the mission, its technical feasibility, and its cost.

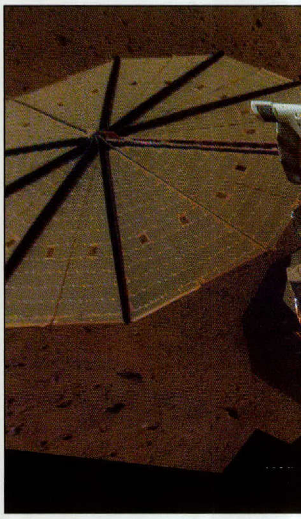
This then goes back to another evaluation team to review, consisting of scientists from all over the world, as well as engineers, cost estimators, schedule analyzers, and other space agency officials. A week or so later, 15 to 30 of these experts show up on the doorstep of the team, which then has 10 hours to answer questions and explain the project in more detail. Finally, the team must give a presentation to Thomas Zurbuchen, the associate administrator for science at NASA headquarters, who makes the final decision.

"The two key criteria for a mission to be selected are that it has to promise excellent science and be technically feasible," says New. "Usually there are several missions proposed that meet those criteria, so then we do begin to think about a variety of overall issues. For example, which targets have we not been to in a long time? Or which missions generate the most excitement? Sometimes it is a question of the workload of an institution — if one institution is already trying to juggle four or five missions, we might not give them another one."

Other boxes to tick include proposals that tap into NASA's wider goals and interests, or those that promise to study new targets that neither NASA nor other space agencies have current plans to investigate.



Suzanne Smrekar, a member of the InSight team, also leads VERITAS, a Venus mission that is undergoing its third review.



"To really stand out, you need to have clear, focused goals and objectives, you need to place those goals and objectives in an appropriate context, and you need to make sure that underneath all of the numbers and pictures, you are telling a great story," says New.

On the flip side of the coin, scientists who don't provide a narrative, or assume that reviewers at headquarters already know about their work, are at a disadvantage. "Some applicants try to bite off more than they can chew and cram too much science into a mission which is capped," says New.

Some scientists have enjoyed more luck than others. The Psyche mission — the first to explore a metal-rich asteroid, scheduled for launch in 2022 — was selected the first time it was proposed, in 2017. Out of five finalists, it was one of two missions given the green light in that round by the Discovery Program. (The other, Lucy, will study asteroids that share the orbit of Jupiter.)

"There have been a few times when a proposal has been accepted on its first attempt," says New. "However, most apply two or three times before being chosen. For big missions like the Discovery-class missions, the production of the proposal itself is quite expensive, costing on order of one to two million dollars, so most institutions will support a number of attempts."

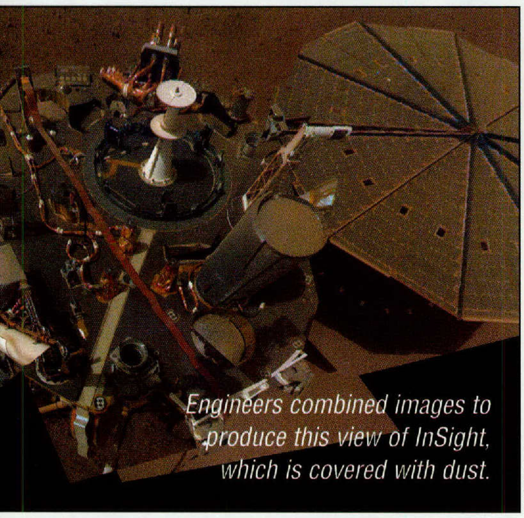
While Psyche enjoyed success the first time around, Lori Glaze, director of NASA's Planetary Science Division, has been the principal investigator (PI) for many proposals, but has made it to the semi-finals only once. "Writing a NASA mission proposal is one of the most intense and most rewarding things I've ever done in my career," says Glaze. "The proposal itself is hundreds of pages and requires a team of at least 75 scientists and engineers to prepare. The team has to be dedicated enough to work long hours for months to prepare the final product.

"However, because the chances of selection are so low, you always have to be prepared to not be selected. Leading a large NASA mission is very challenging and the leaders can't be quitters! All the PIs I know have worked long and hard and don't give up. They just keep trying. So, when they are finally selected for flight, it is an enormous accomplishment."

Another person who never gave up is Martin Weisskopf, project scientist for Chandra X-Ray Observatory and chief scientist for X-ray astronomy at NASA's Marshall Space Flight Center in Huntsville, Alabama. Weisskopf has been trying to get his Small Explorers Mission, the Imaging X-ray Polarimetry Explorer (IXPE), approved since the 1970s.

IXPE will study objects like black holes, which can heat the gases surrounding them to millions of degrees, producing X-rays. This radiation can be polarized, which means it's produced by atoms that vibrate in a particular direction.

After an almost 45-year wait, in autumn 2021 IXPE will launch three identical telescopes with cameras capable of measuring polarization, allowing scientists to answer fundamental questions



Engineers combined images to produce this view of InSight, which is covered with dust.

NASA/JPL (2)

about environments where gravitational, electric, and magnetic fields are at their limits.

"Polarization is a property of all electromagnetic waves, whether we're talking about radio waves, ultraviolet, infrared, or visible," says Weisskopf. "Measuring it gives us another way of answering questions like how do X-rays get produced near black holes and neutron stars? It can also help us measure the spin of stellar-mass black holes that are

ON THE HOTSEAT

NASA has selected four finalists for the next Discovery mission and two more for the next Small Explorer mission. Discovery teams receive $3 million, and SMEX teams $2 million, to prepare their proposals. The final selections will be made next year.

DISCOVERY

DEEP ATMOSPHERE VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY, AND IMAGING PLUS (DAVINCI+)

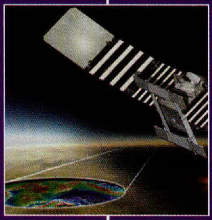
DAVINCI+ would analyze Venus' atmosphere to understand how it formed and evolved and to determine whether Venus ever had an ocean. It would measure the composition of the atmosphere all the way to the surface. The last U.S.-led mission to touch down on Venus was in 1978. DAVINCI was one of five finalists in the 2015 Discovery proposals.

IO VOLCANO OBSERVER (IVO)

Io, one of Jupiter's largest moons, is the most volcanically active body in the solar system. The gravity of Jupiter and its other large moons wage a constant tug-of-war inside Io, pulling and squeezing its interior. That heats the interior, creating the volcanoes. IVO would fly past Io several times to study that effect and learn more about the moon's volcanic activity.

TRIDENT

Trident would explore Triton, the largest moon of Neptune, the Sun's most distant major planet. Voyager 2 discovered erupting geysers and a thin atmosphere around Triton, which could have an ocean of liquid water beneath its icy crust. During a single fly-by, Trident would map Triton, study its active processes, and determine whether the ocean really exists.



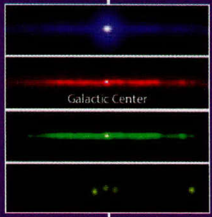
VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY (VERITAS)

VERITAS would use radar to peer through Venus' clouds and map the surface to determine the planet's geologic history and understand why Venus developed so differently from Earth. The orbiter's observations could confirm whether Venus has active volcanoes and other on-going processes and pinpoint active regions on the surface. It has been proposed in two previous cycles.

SMALL EXPLORER

EXTREME-ULTRAVIOLET STELLAR CHARACTERIZATION FOR ATMOSPHERIC PHYSICS AND EVOLUTION (ESCAPE)

ESCAPE would watch nearby stars for rapid, strong ultraviolet flares. That would help scientists determine how likely such flares are to strip the atmosphere from a rocky planet orbiting the star, affecting its suitability for life.



COMPTON SPECTROMETER AND IMAGER (COSI)

COSI would scan the Milky Way Galaxy for gamma rays from radioactive elements produced during stellar explosions. Astronomers would use those observations to map the recent history of star death and element production in the galaxy. COSI also would improve our understanding of how cosmic explosions produce gamma rays.

in binary systems, which will tell us how the black hole is interacting with the surrounding medium, and will give us an insight into the history of the evolution of the black hole."

During the first attempt, in the mid-2000s, a team worked for several years to flesh out the IXPE mission concept, including drafting a 1,000-page review report, so not being chosen was a bitter pill to swallow.

"It was very disappointing, as we thought that the case was very strong," says Weisskopf. "However, there was no question that having not been selected the first time helped us tremendously the second time, because effectively we already had a full draft of the proposal rather than starting from scratch.

"The amount of work that it takes to put together one of these proposals even for a small NASA mission is huge, and so having gone through that process already with everyone in the team, that was extremely useful, and the second proposal was much better than the first," Weisskopf says.

When it comes down to choosing between mission ideas, many factors can tip the scales toward one mission and away from another. Weisskopf says that this time his mission was successful because the team diligently demonstrated that it could do the job, deliver good science, and do so cheaply.

"I think that the reason our mission was chosen this time is that as well as the science being outstanding, our technical management and cost were extremely well justified and well presented — we presented strong evidence that we could do the job," he says. "At the technical and management cost meetings, we showed NASA working detectors, and demonstrated that these detectors could detect polarization just like we said they could."

Whatever the case, finally finding out that the mission had been accepted was, to Weisskopf, a "wonderful, great feeling." "We were ecstatic, we had a party, and then the real work started," he says.

Another mission that took a while to be greenlighted is Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx), which, when it launches in 2023, will scan the sky using state-of-the-art telescopes in both optical and near-infrared wavelengths. During the two-year mission, scientists will survey 300 million galaxies — including some so distant that their light has taken 10 billion years to reach Earth — looking for clues that will shine light on the birth of our universe, and the formation of galaxies and planetary systems. In particular, scientists will study inflation, the theory that the universe grew exponentially in the first fraction of a fraction of a second after the Big Bang. They also will search for traces of ice and organic molecules, thought to be the building blocks of life, in regions where new stars are forming.

SPHEREx began in 2012 after a NASA call to develop new ideas for a SMEX mission. Researchers led by James Brock, principal scientist at JPL, decided to combine three ideas into one proposal to maximize scientific impact, which was more easily said than done.

"Our idea was to study the birth of the universe, distant galaxies, and the icy materials that form on interstellar dust grains," says Brock. "These ideas shared the common theme of using near-infrared spectroscopy" — analyzing wavelengths of light that are just beyond the range of the human eye.

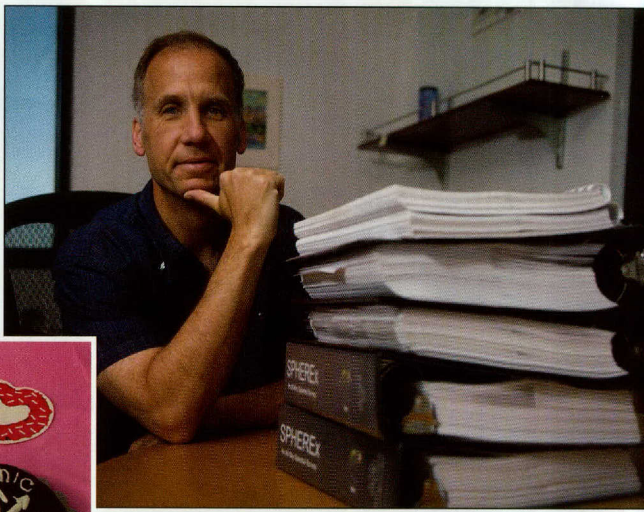
"The challenge was to figure out a way to do even one of these ideas within the very tight volume, mass, and cost constraints of a small satellite, as with an Explorer proposal. If you don't 'fit in the box' given by NASA, you will never be selected."

The proposal was selected to go into a competitive one-year study with two other mission concepts in 2015. It failed in that round, but succeeded two years later. "We produced a 900-page study report, endured an all-day site visit with NASA-appointed reviewers, and polished up our best case into a one-hour presentation," says Brock.

According to Brock, preparing for the dreaded all-day site visit can be the worst part of the process. JPL puts together a mock review board whose job is to provide a worst-case simulation of the real review. "Let's just say the mock panel is really good at channeling hostile, demanding, and obtuse reviewers," he says. "There are four practice sessions prior to the real thing, so you get to repeat what would be a very bad all-day experience over and over. In total, I've gone through eight days of mock reviews, plus two days of real reviews. The real reviews are much more pleasant."

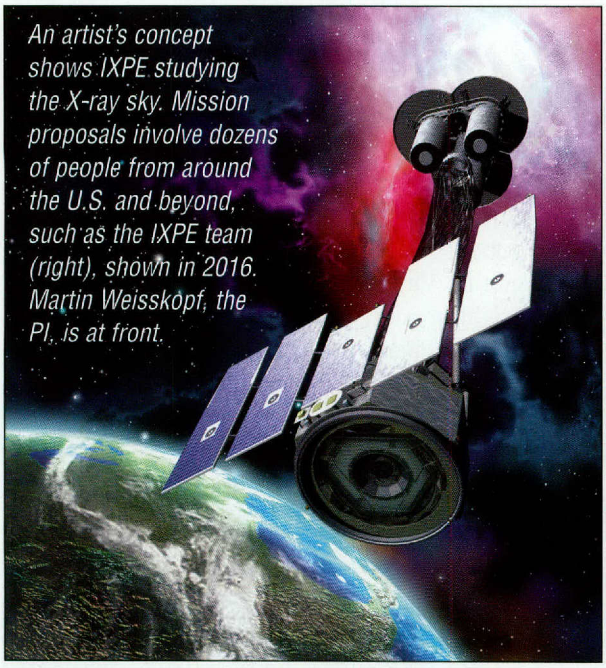
Despite all of this, in early 2017 the team received the disappointing news that SPHEREx had not been selected. In the final weeks of the scramble of submitting the SMEX proposal, the team submitted a similar proposal for a Medium Explorer-class mission. That mission went through the entire study process again, and was finally chosen, much to the team's delight.

"In February 2019 I received an invitation to a meeting at JPL and was surprised to walk into a room with Thomas Zurbuchen waiting for me with the President of Caltech and a



CALTECH (2)

James Bock with the full proposal for SPHEREx. The SPHEREx team celebrated the first anniversary of the mission's selection with cakes decorated in honor of its science themes (inset).



An artist's concept shows IXPE studying the X-ray sky. Mission proposals involve dozens of people from around the U.S. and beyond, such as the IXPE team (right), shown in 2016. Martin Weisskopf, the PI, is at front.

camera crew," says Brock. "That was a nice moment. Selection is only a step towards the ultimate goal of flying SPHEREx, but it meant we had finally crossed the start line."

The project is now in the detailed design phase, with researchers working through complete designs of the telescope, detectors, spacecraft, and science procedures. After this, construction will begin and instruments will be tested and then integrated with the spacecraft.

"To prepare for launch, we test everything as closely as possible to the way it will fly," says Brock. "This includes cooling down the entire telescope and detector system in a cryogenic vacuum chamber to check focus and sensitivity in a space-like environment."

So why does NASA put its researchers through such a grueling application and selection process? The agency wants to be confident that its missions will deliver excellent science and can be carried out on budget without the cost overruns that have plagued past missions. Overruns are a serious business, as they gobble up future proposal opportunities and curtail future science. Historically, the competitive approach has also worked to the overall benefit of science, according to the agency, as many of NASA's most powerful science missions have come from the Explorer, Discovery, and New Frontiers classes.

New Frontiers missions, for example, have included New Horizons, which flew past Pluto in 2015; Juno, which is orbiting Jupiter; and OSIRIS-REx, which was scheduled to gather samples from the surface of an asteroid in late October. And the list of Discovery missions includes craft that have visited the giant asteroids Ceres and Vesta, the Moon, Mars, and Mercury, along with the Kepler space telescope, which discovered thousands of exoplanets.

"When NASA first began doing PI-led missions in the early '90s, it was seen as a very revolutionary idea to trust the scientific community to come up with complete missions, and then trust the PI, who is almost always a scientist, to be responsible for all aspects of the mission's success," says Michael New. "However, this has paid dividends."

Ultimately, despite the difficulties and hardships, most scientists also support the rigorous selection process.

"Explorer selections are brutal, but the reward is rich, and since every proposal has to start afresh, it also prevents missions from shambling along year after year, with less and less scientific relevance as time goes by," says Brock. "So, overall, I am definitely a fan of the Explorers process, and have learned to appreciate the tough selections, though personally living the experience is painful at times."

Jasmin Fox-Skelly is a science writer in Cardiff, Wales, and a frequent contributor.

Resources

Internet

Explorers Program
explorers.gsfc.nasa.gov

Small Explorers Missions
explorers.gsfc.nasa.gov/smex.html

MidEx Missions
explorers.gsfc.nasa.gov/midex.html

Discovery Program
science.nasa.gov/solar-system/programs/discovery

New Frontiers Program
www.nasa.gov/planetarymissions/newfrontiers.html

IXPE
wwwastro.msfc.nasa.gov/ixpe/index.html

InSight
mars.nasa.gov/insight

Psyche
psyche.asu.edu

SPHEREx
spherex.caltech.edu

SPHEREx Review Process
www.caltech.edu/about/news/2700-pages-later-space-mission-born

SKY CALENDAR

by Alan MacRobert

November and December are all about the planets. Jupiter and Saturn stage a spectacular close encounter in the west as night falls, Venus and Mercury highlight the eastern sky as night fades, and Mars rolls along between them.

NOVEMBER 1-15

November's evening sky is famously on the dull side for showy stars and constellations but, boy, does it have planets this year.

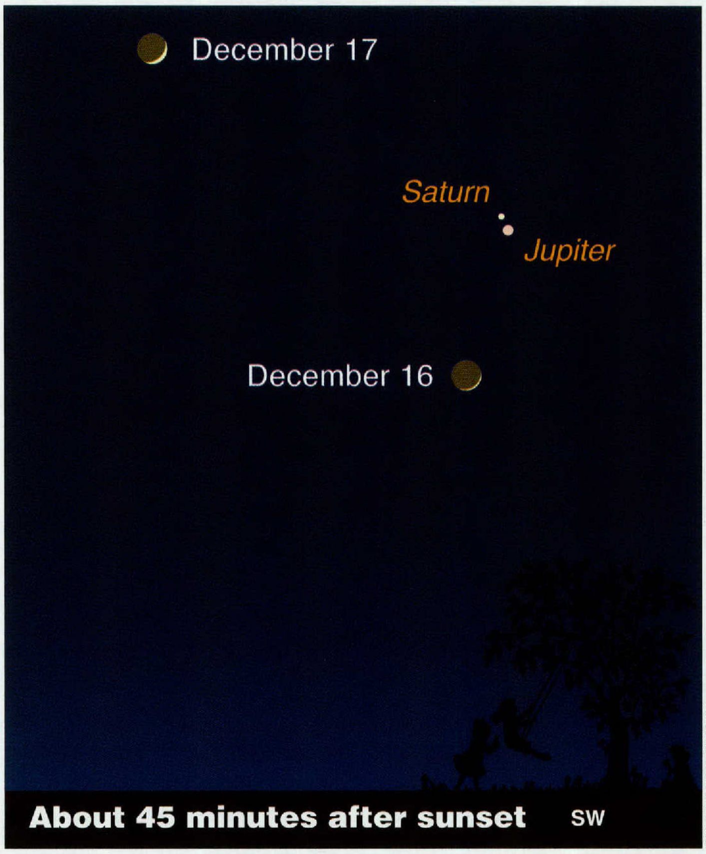
Jupiter and Saturn shine together in the southwest in late twilight and after nightfall. Jupiter is the first to come into view; it's the brightest point in the evening sky. As twilight deepens, look for fainter Saturn to Jupiter's upper left by the width of two or three fingers held at arm's length.

Keep an eye on those two; they're drawing closer together. They are five degrees apart on November 1, just two degrees on December 1, and a remarkably tight 0.1 degree from each other for their conjunction on December 21.

They stood nearly eight degrees apart at the beginning of fall. So what's going on?

Jupiter and Saturn are both long past their oppositions — long enough that, by the end of September, both had resumed their prograde (eastward) motion against the stars. However, Saturn is farther than Jupiter from both the Sun and Earth. Being farther from the Sun, it moves more slowly eastward along its orbit. And because Saturn is farther from Earth than Jupiter is, we see it undergo less apparent motion against the background of stars as Earth speeds along in its own orbit. The result is that all fall we see Jupiter move eastward on the starry background faster than Saturn does, so Jupiter catches up to it.

On the other side of the sky, meanwhile, Mars has been shouting for your attention. It's still almost Jupiter-bright several weeks after its October 13 opposition, and it's more colorful to boot. In a telescope, it's still unusually big, although it shrinks during the month.



At dawn, meanwhile, Venus and Mercury put on a show of their own in the east. Venus is the super-bold Morning Star, sinking lower in the east-southeast week by week. Down to its lower left as twilight gets under way, Mercury puts on its best dawn apparition of the year in mid- to late November.

Both planets are in Virgo. Spica, Virgo's brightest star (though no match for either planet), climbs out of the dawn glow to pass close to the left of Venus around mid-month.

NOVEMBER 16-30

Jupiter and Saturn continue to draw closer together in the southwest during and after dusk. The crescent Moon joins them on November 18 and 19.

High to the upper right of Jupiter and Saturn, by about three fists at arm's length, shines Altair. It's currently the leftmost star of the huge Summer Triangle. In fact, say what you will about November's starry dullness, the November heavens do offer some tasty leftovers from summer.

The other two stars of the Summer Triangle are bright Vega, shining about three fists to the right of Altair, and Deneb, more than two fists above Vega. Deneb is the head of the large Northern Cross and the tail of Cygnus, the swan. The shaft of the cross, which outlines the swan's long neck, extends to the lower left of Deneb.

Right along this centerline of Cygnus, if you have an even modestly dark sky, you can see one of the brightest stretches of the summer Milky Way. The Milky Way extends on to the lower left, passing below Altair and then down to the west-southwestern horizon.

In the other direction, the Milky Way runs to the right from Deneb and high across the north. It then drops through the W (or M) of Cassiopeia, through Perseus and Auriga, and finally to the east-northeastern horizon, where winter patterns are shouldering their way up.

The dimmest part of the November evening sky — the part that gave it its dull reputation — is the south. That's home to the Great Water region of Pisces, the fishes; Cetus, the whale or sea monster; Aquarius the water bearer, and Capricornus, the sea goat.

But shining bright and lonely below these is first-magnitude Fomalhaut. It's due south in early evening. It's the brightest star in another water constellation, Piscis Austrinus, the southern fish.

DECEMBER 1-15

The Jupiter-Saturn drama continues. As December opens, they're still modestly high in the southwest at nightfall. They are two degrees apart, which is the width of a finger at arm's

Meteor Watch

The Shower
Leonids

Named for the constellation Leo, the lion, which rises in the wee hours of the morning. Its most prominent star, Regulus, stands at the bottom of a pattern of stars that looks like a backward question mark.

Peak

Night of November 16

Notes

The Moon is just past new so it won't interfere with the shower, which should produce a peak of 12-15 meteors per hour.

The Shower
Geminids

Named for Gemini, the twins. This shower can produce some especially bright meteors, although its peak viewing time is shorter than that of many other showers. Expect a peak rate of 100 or more meteors per hour.

Peak

Night of December 13

Notes

The new Moon will be out of sight, providing dark skies for the shower's peak.

length. This unusual pair will catch notice by a lot of people who normally pay no attention to the sky. You can impress them with your knowledge of what the two dots are, and with the fact that while they may look close together, Saturn is almost twice as far away: Jupiter is 48 light-minutes from us (the distance light travels in 48 minutes) in early December, while Saturn is 88.

Mars? It's higher than ever, in the southeast to south, outshining anything else there. (It's in faint Pisces.) Even so, it's down to magnitude –0.9, a mere fifth of its brightness two months ago, when it peaked at magnitude –2.6.

With the arrival of December, the bright vanguards of winter take over the eastern sky. Brightest is Capella, in the northeast. Capella is part of the flattened pentagon of the five brightest stars of Auriga the charioteer. Capella is the pentagon's upper left corner. Above Auriga are Perseus, and even higher now, Cassiopeia.

Look to the right of Capella by roughly three fists at arm's length for the Pleiades, the catchiest star cluster in the sky: fingertip-sized and totaling magnitude 1.6 if you add up all of its stars.

Orange Aldebaran glares below the Pleiades, on the bottom edge of the much larger, but looser and dimmer, Hyades cluster.

And way below them, watch for Orion to rise.

DECEMBER 16-31

Jupiter and Saturn at last come to conjunction, shining 0.1 degree from each other on the evening of December 21. That's less than the width of a toothpick at arm's length! You may even have trouble resolving the pair if your vision is less than sharp, since Jupiter is 11 times brighter than Saturn, which is on Jupiter's right.

It's their first conjunction in 20 years and the closest since 1623, so this certainly is a time to bring out the telescope! The two giants easily fit together in a view magnified 100 times, which is quite enough to show Jupiter's disk and its four biggest moons, and Saturn's globe and rings. Unfortunately, you'll be looking very low in the southwest even in early twilight. The atmospheric seeing that low is guaranteed to be terrible, so don't expect anything in the way of planetary detail. Get your scope on them as early in twilight as you can.

Coincidentally, the winter solstice is also on December 21. By then, Orion clears the horizon in the east-southeast as twilight fades away. For those of us at mid-northern latitudes, that always means we're at the start of winter.

By 8 or 9 p.m., Orion strides high. His main stars form a misshapen rectangle, currently canted up on one corner, with the neat little three-star row of Orion's Belt in its center. The belt is more or less vertical. It will be horizontal when Orion walks down toward his departure in the sunsets of early spring — or, equivalently, if you look southwest around 4 or 5 a.m. now.

These evenings, follow the direction of Orion's Belt down by two fists. That spot won't clear the horizon until after about 7 or 8 p.m., depending on where you live. But that's where and when to watch for the rising of Sirius, the brightest star in the sky after the Sun.

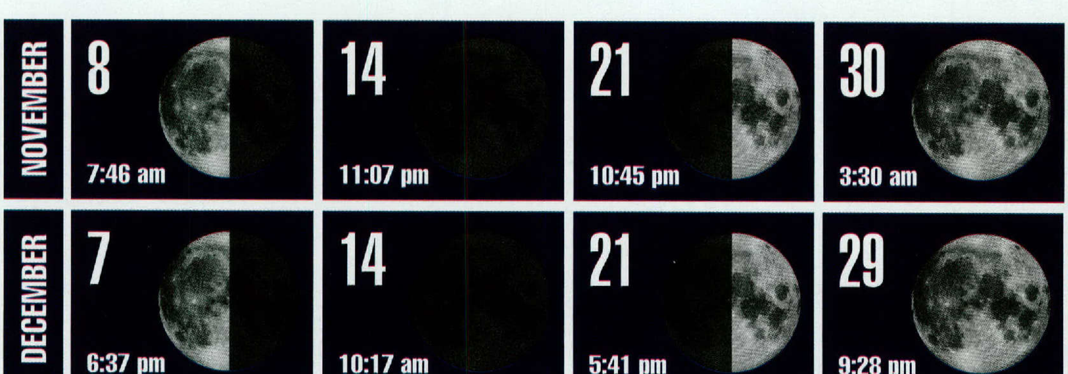
About 15 minutes before Sirius rises, a lesser star comes up barely to the right of Sirius' rising point: Beta Canis Majoris or Mirzam, a name that means "the announcer." What Mirzam announces is Sirius. You're not likely to mistake them; second-magnitude Mirzam is only a twentieth as bright as the sparkling king of stars when he makes his entry.

Alan MacRobert is a senior editor of Sky & Telescope.

A Bare Shadowing on the Moon

The full Moon will fade a bit in the wee hours of November 30 during a penumbral eclipse, as the Moon passes through the faint outer ring of Earth's shadow. None of the Moon will go completely dark. Instead, most of the lunar disk will take on a dusky appearance.

The eclipse begins at 1:32 a.m. CST, when the shadow first touches the Moon. It will peak at 3:44 a.m., when the penumbra will cover about 83 percent of the lunar diameter, and end at 5:53 a.m., when the Moon exits the penumbra.



Moon phase times are for the Central Time Zone.

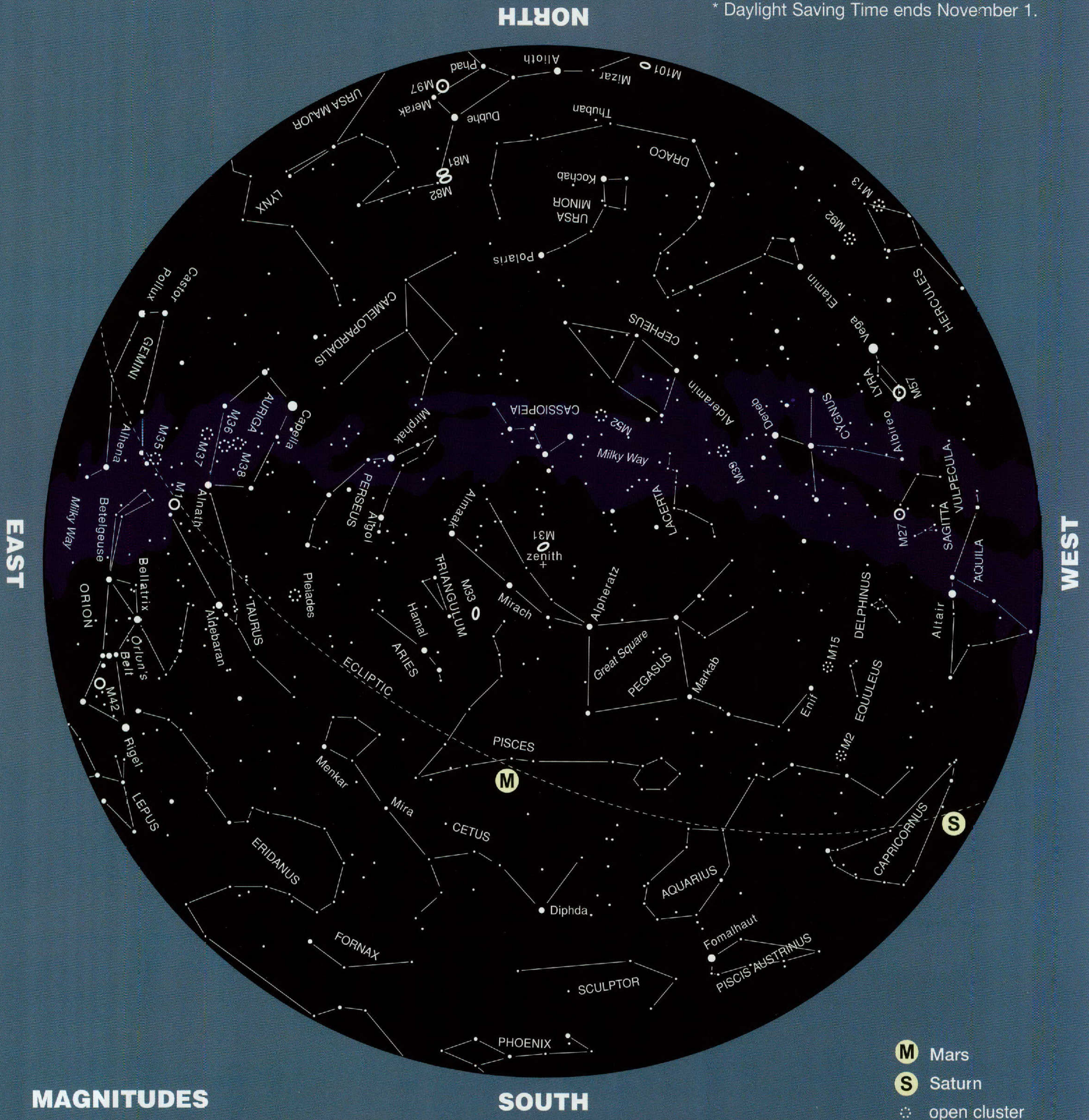
NOVEMBER

How to use these charts:

1. Determine the direction you are facing.
2. Turn the chart until that direction is at the bottom.

October 20	**11 p.m.**
November 5	**9 p.m.***
November 20	**8 p.m.**

* Daylight Saving Time ends November 1.



M Mars
S Saturn
open cluster
globular cluster
nebula
planetary nebula
galaxy

MAGNITUDES

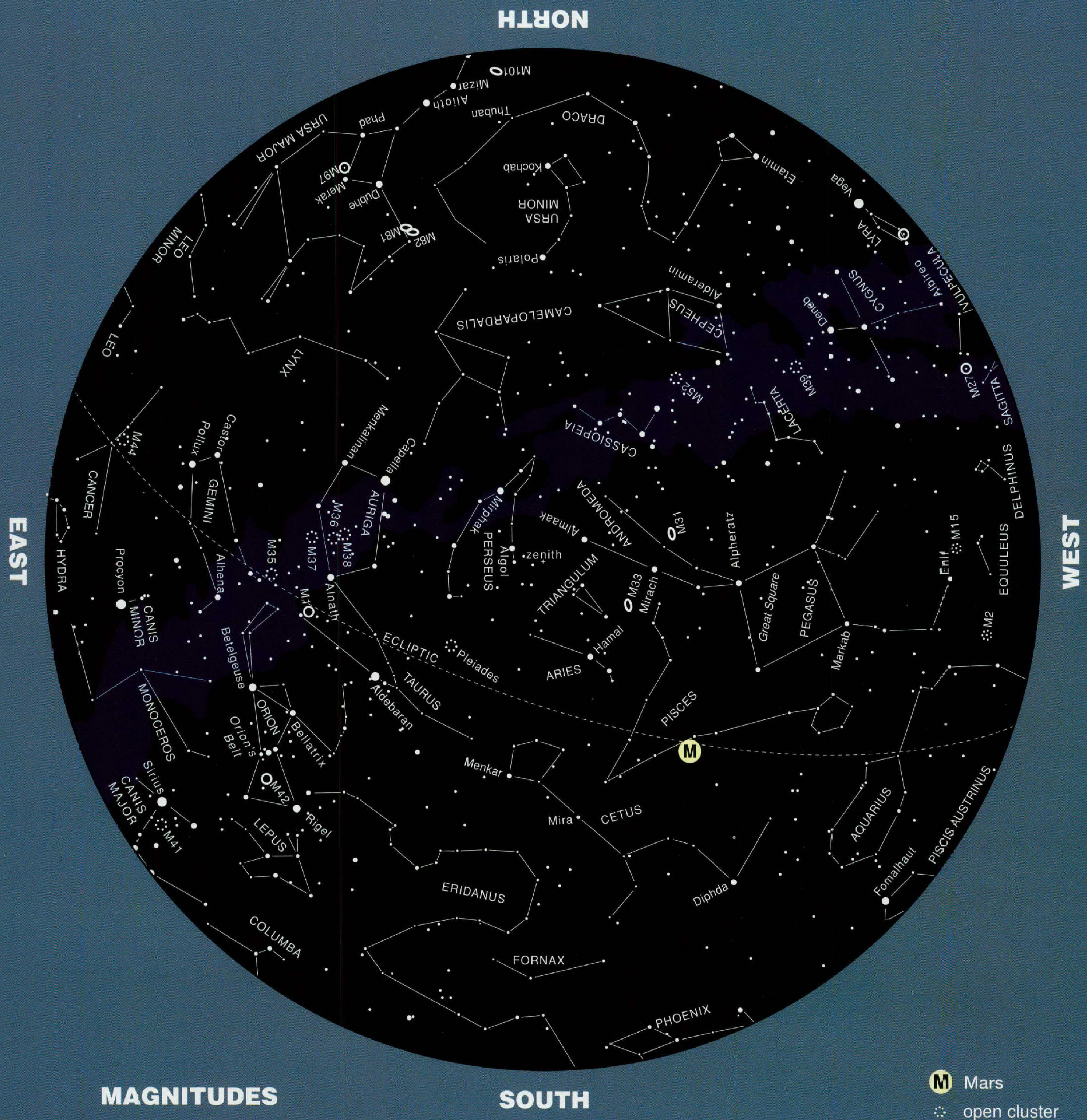
- 0 and brighter
- 1
- 2
- 3
- 4 and fainter

DECEMBER

How to use these charts:

1. Determine the direction you are facing.
2. Turn the chart until that direction is at the bottom.

November 20	**11 p.m.**
December 5	**10 p.m.**
December 20	**9 p.m.**



MAGNITUDES

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

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

Mesmerizing Mars

Recalling centuries of enthusiasm for the Red Planet

While studying radio waves in his Colorado laboratory in 1899, Nikola Tesla heard from Mars. In a magazine article two years later, Tesla reported that he decoded a message that could have come only from Mars. The message: "One, two, three."

Tesla wasn't the only person of his era interested in communications between Earth and Mars. In the 19th and early 20th centuries, scientists and quacks alike proposed schemes for talking with Martians: carving letter-shaped ditches in the Sahara, filling them with kerosene, and setting them ablaze; using mirrors atop the Eiffel Tower to reflect sunlight toward the Red Planet; carrying a radio receiver in a hot-air balloon to listen for communiques.

Marc Hartzman recounts these and many other ideas in *The Big Book of Mars*, a frothy parfait that layers science and exploration with concepts of the planet and its possible inhabitants in popular culture, all topped with copious illustrations.

Much of the enthusiasm for Mars over the last century-plus was fed by Percival Lowell's concept of giant canals sustaining a dying planet by carrying water from the polar ice caps. Astronomers looked for evidence of Martian life, authors pondered its nature in such volumes as H.G. Wells' *The War of the Worlds*, and spiritualists tried to capitalize by communing with Martians.

Hartzman shows that the enthusiasm didn't abate much after the first Mars probes showed a world bereft of canals or other evidence of life. Mars remained a hot topic in books, movies, television, and other media. The 2015 film "The Martian," for example, earned more than $600 million at the box office. And today, as Elon Musk and other billionaire entrepreneurs prepare to dispatch their own missions to Mars, the Red Planet remains as vital in the American imagination as ever, drawing us into its mysteries.

The Big Book of Mars
From Ancient Egypt to The Martian, A Deep-Space Dive Into Our Obsession With the Red Planet
By Marc Hartzman
Quirk Books, $24.99
www.quirkbooks.com/book/big-book-mars#

NASA/JPL/USGS

All the Ways to Kill the Universe

"In about five billion years, the Sun will …. engulf the orbit of Mercury and perhaps Venus, and leave the Earth a charred, lifeless, magma-covered rock," writes astrophysicist and cosmologist Katie Mack in *The End of Everything (Astrophysically Speaking)*. The assistant professor of physics at North Carolina State University is more interested in how the entire universe will end, though, and that gets complicated.

While not everyone agrees how the universe will end, experts do agree that it will. Mack outlines each scenario, along the way explaining in surprisingly clear terms a bunch of complex concepts — electroweak theory, Planck Time, the Hubble Constant, redshift/blueshift, deSitter Equilibrium, Chandrasekhar Limit, Cepheid variables, and more.

The scenarios, vastly simplified:

BIG CRUNCH. Given the universe started with a Big Bang and is expanding, one theory involves it turning around and coming back on itself, ending in a (truly) catastrophic implosion.

HEAT DEATH. Accelerated expansion never stops, black holes and ordinary matter — stars, planets, gas, and dust— all disappear. It's the Second Law of Thermodynamics, which states that in any isolated system, total entropy (chaos) can only increase and eventually, the universe is empty, expanding space.

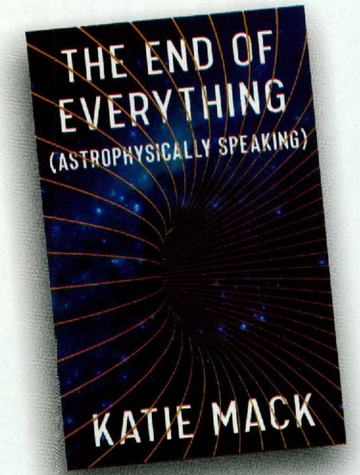
BIG RIP. Not a pretty picture. At some point, Earth drifts away from the Sun, then explodes. Molecules crack open, then the centers of atoms. The fabric of space itself rips apart — fortunately, though, not for something like another 200 billion years, if ever.

VACUUM DECAY. Starts with a bubble of true vacuum that expands and obliterates everything; "quick, clean, painless, and capable of destroying absolutely everything." It could happen at any minute, but extremely unlikely for many trillions of years. Except for tiny black holes, but — well, you'll have to read the book.

BOUNCE. The weirdest one yet, involving gravitational waves, with scientists still working out lots of theoretical details. (Insert mind-blown emoji here!)

"It's still rather rare to find papers in the physics literature that examine our ultimate fate with the same rigor and depth as they do our origins," Mack says. "But studies of both ends of the timeline help us … examine the principles of our physical theories. Beyond the insight they might provide into our future or past, they can help us understand the fundamental nature of reality itself."

However it all ends, we're just a blip. Enjoy it while you can.



The End of Everything
(Astrophysically Speaking)
By Katie Mack
Scribner; $26 (hardcover)
Available as ebook, audio CD
www.astrokatie.com/book

Tuning in the Cosmos

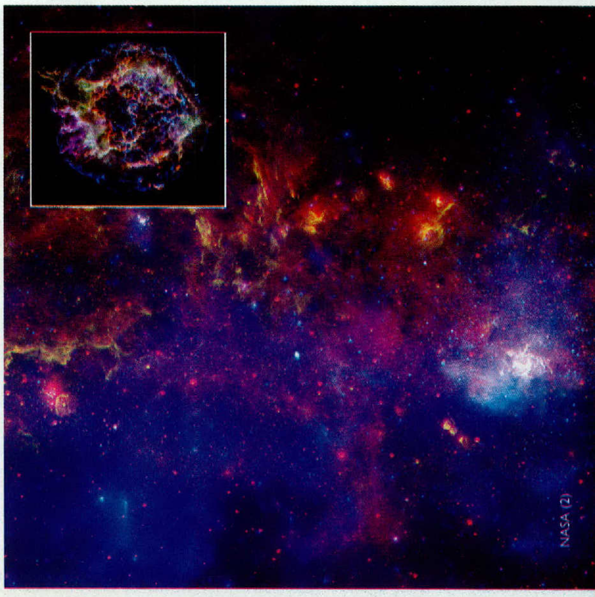
Project converts observations of the universe to melodies

The center of the Milky Way Galaxy (image, right) is beautiful to see, and thanks to a NASA project it's also beautiful to hear. Researchers have used a technique called sonification to convert images of the galaxy's heart and other objects into mini-symphonies. Each note represents a star or a mote of gas or dust seen in visible light, infrared, or X-rays.

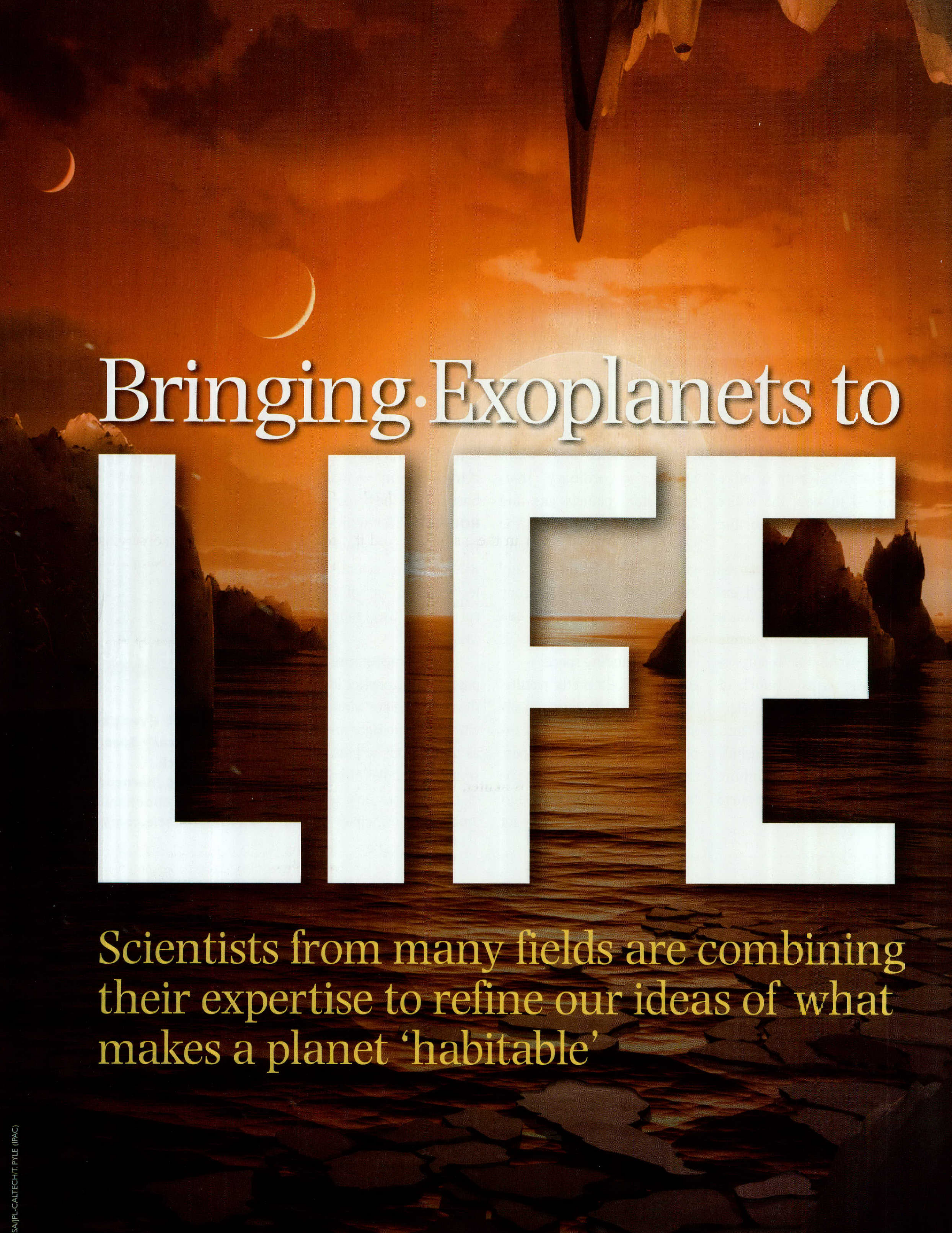
The sonifications are produced by converting digital data from space telescopes into sound. Each "soundscape" is the equivalent of scanning across a picture of the selected object, providing a new way to appreciate the beauty of the universe, NASA says. Users may listen to the entire symphony or isolate specific instruments, which represent the different wavelengths of light.

In addition to the galactic center, the project has produced sonic versions of an exploded star known as Cassiopeia A (inset) and M16, a nebula that contains the famous "pillars of creation" — towering clouds of gas and dust that are giving birth to new stars.

chandra.si.edu/photo/2020/sonify



NASA (2)



Bringing Exoplanets to LIFE

Scientists from many fields are combining their expertise to refine our ideas of what makes a planet 'habitable'

NASA/JPL-CALTECH/T. PYLE (IPAC)

Ice at the north pole of TRAPPIST-1f melts under the heat of its nearby star, a red dwarf, in this artist's impression. The planet lies inside the habitable zone, where temperatures are just right for liquid water. Three other planets in the system line up to the upper left of the star.

BY CHRISTIAN FOGERTY

A paradox lies at the core of more than 20 years of exoplanet observations: We are both alone and not alone. Many, if not most, of the 20 billion or so Sun-like stars in our galaxy may host rocky planets inside the habitable zone, the distance from a star where temperatures are just right for liquid water to exist on a planet's surface. Many of these extraplanetary systems — planetary systems outside our own — also have giant planets similar to Jupiter and Saturn orbiting at greater distances than the rocky planets.

Upon closer inspection, though, many of these systems are completely alien. Some of their stars spin at odd angles, others have planets with backwards orbits, and many of the stars are completely unlike the Sun. This begs the question: Could life exist in these systems? And if so, what would it look like?

In a galaxy teeming with planets, opportunities for life abound. To capture the diversity of these opportunities, though, scientists say they must think beyond the traditional notions of habitability and take a "systems" approach. By looking at planetary habitability as much more than whether a planet is at a certain distance from its star, one can start to imagine life on worlds where the rotational axis is akilter, two suns beam through a hazy atmosphere of methane, or one hemisphere receives perpetual sunlight while the other remains in perpetual darkness.

Astrobiology — the study of life on other planets — must integrate the expertise of geoscientists, astronomers, microbiologists, and others to imagine these alternate realities. Researchers at the new Center for Planetary Systems Habitability (CPSH) at the University of Texas at Austin are among the scientists from many fields working to tackle these questions and new ones that pop up along the way. Their guiding questions focus not only on what makes life arise in the first place, but also what allows it to persist through changes across environmental, planetary, and galactic scales.

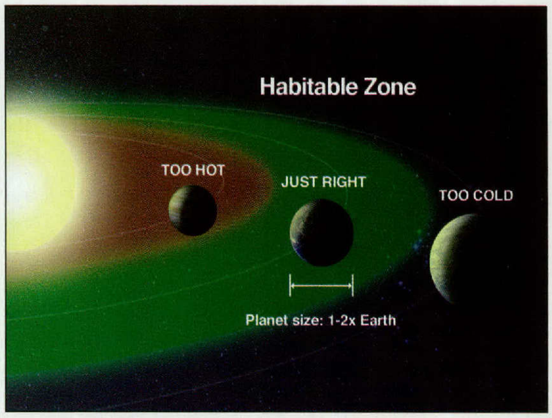
By combining forces across disciplines, researchers are working together to answer these questions and gear up for future observatories, such as the space-based James Webb Space Telescope (JWST) and the Giant Magellan Telescope, which is under construction in Chile.

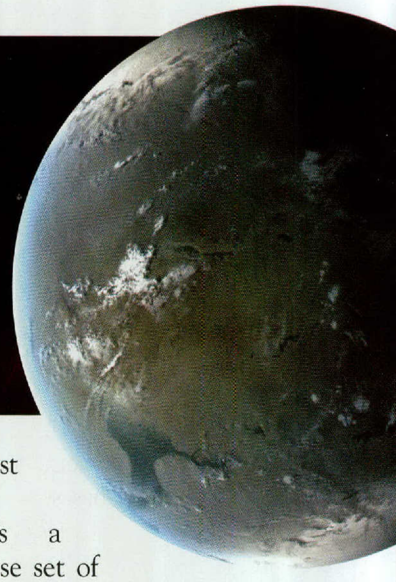
Bill Cochran, astronomer and co-director of CPSH, has been observing exoplanets for decades. He took part in the explosion of exoplanet discoveries made with NASA's highly successful Kepler space telescope, which revealed hundreds of rocky planets out of the more than 4,000 exoplanets currently known.

"I'm really excited to start applying new models to the exoplanets we've been discovering and trying to characterize them," says Cochran, "How is a planet around this type of star similar to and different from Earth? How could a planet like that sustain life?"

One researcher in the center, Cynthia Froning, applies her expertise in stellar astrophysics to the most common class of stars in the galaxy: M dwarfs, also known as red dwarfs. These small, cool stars shine at only a fraction of the Sun's brilliance, but they far outnumber any other class, so they're prime targets for many exoplanet searches.

Froning is the principal investigator of a project to characterize the environments around M dwarfs and better understand the radiation to which the rocky planets around them are exposed. M dwarfs emit much of their radiation in the infrared — wavelengths that are too long for the human eye to see and that are largely blocked by Earth's atmosphere. JWST is designed to observe in the infrared. "Where we are going to be looking when JWST launches is heavily biased towards these lower-mass stars," Froning says.





A star's habitable zone would provide the most comfortable home for Earth-like life (left). Many M-dwarf stars (lower left) produce powerful flares and other magnetic storms, zapping their planets with X-rays and other radiation as shown in this artist's concept. An artist's concept depicts the possible appearance of Kepler-62f, which orbits inside the habitable zone of an M dwarf.

Even though red dwarfs are the most common stars in the universe, much about them remains unknown. The way they interact with planetary atmospheres and whether life can persist around them is a mystery, for example.

Solving the latter requires scientists to expand the notion of what habitability can be. For example, photosynthesis as we know it functions through the visible light from the Sun, but no one is certain how it would work under the longer-wavelength light from a red dwarf. Other questions include, how could life withstand the intense radiation of a young star as it rips away ozone layers and vital atmospheric elements such as nitrogen and oxygen? And how could life on rocky planets that orbit closer to their stars than Mercury, the closest of the Sun's major planets, survive in these conditions?

Some of the most common planets in M dwarf systems are tidally locked, which means that the same hemisphere always faces the star, while the other hemisphere remains in perpetual darkness. These planets often orbit at distances that are much closer to their star than Mercury is from the Sun. A recent study posits that these kinds of planets could generate enough dust in their atmospheres to shield them from potentially life-destroying stellar radiation. On the planet's star-facing side, the dust would cool the surface by reflecting energy from the star. Circulated dust could warm the nightside enough to keep liquid water stable.

The closest extraplanetary system orbits our closest stellar neighbor, Proxima Centauri, which is just 4.2 light-years away. It consists of an M-dwarf star and two known planets, including one that was reported just this year and confirmed by University of Texas astronomers Fritz Benedict and Barbara McArthur. And one of the best-known extraplanetary systems, TRAPPIST-1, is 40 light-years away and consists of seven small, rocky planets orbiting an M dwarf. Astronomers will observe these systems with future space- and ground-based telescopes. Their observations, which will show changes in the star's light as a planet passes directly in front of it, will allow scientists to calculate each planet's mass, size, density, and other characteristics. Today, theorists are churning out scenarios for what this scrutiny might reveal.

Scientists at the University of Washington's Virtual Planetary Laboratory (VPL), for example, are at the forefront of this kind of modeling. Rory Barnes, an astrobiologist with VPL, led the development of a software package, known as VPlanet, and plans to enhance it by integrating observations and models made by other researchers, including those at CPSH. "It's basically a synthesis of other models in science, and we developed a way to link them all together," says Barnes. "It has stellar astrophysics, geophysics, atmospheric science, orbital dynamics, galactic effects, all linked together."

Much exoplanet modeling is done through a technique that determines the habitable zones of different star types. By modeling how starlight would travel through a one-dimensional column of a planet's atmosphere, scientists can simulate what chemicals are in the atmosphere and the temperature of the planet's surface. Even from these relatively simple models, scientists have gleaned a rich variety of planetary environments. They predict that some surfaces could be covered with ocean, while others could be all forest or desert.

"There's a very precise set of parameters that could create something like Earth," says Jack Madden, an astrophysicist at Cornell University. "But there's also a wide set of parameters that can create something that we think could host life."

As an exoplanet modeler, Madden studies how different planet surfaces affect their atmospheres and, thus, what they might look like to future telescopes.

It turns out that slightly tweaking parameters such as the reflectance of a planet can dramatically alter such fundamental properties as atmospheric composition and heat circulation. This creates a wide spectrum of possible planets.

As long as a budding planetary system contains the right ingredients for life, there is always a chance. The main ingredients are sources of energy, "bioessential" elements such as carbon and nitrogen, and liquid water. It turns out that the first two are common, but the third may be rare. Although water is the third most common molecule in the universe, the range of temperature and pressure required for it to remain in its liquid phase is narrow. Nevertheless, when we look at Earth, life is everywhere, even in extreme locales where liquid water is lacking. It could be that the microorganisms that live in these environments, known as extremophiles, are common.

Even on planets with dangerous surface environments, microbial life might be able to survive beneath the surface. For many of the planets orbiting young M dwarfs, in fact, these subsurface environments could be the most realistic homes for life. "Most astronomers would say that microbial life is the most dominant form of life out there," says Barnes. "But that's just speculation until we go find it."

Some of the most important sources of energy for rocky planets are radioactive isotopes — unstable versions of elements that decay into more stable forms by releasing particles and energy. As they decay, they can release heat for billions of years. Recent research conducted by CPSH astrophysicist Stella Offner and her colleagues has shown that one of these isotopes, aluminum-26, can form through the acceleration of high-energy particles called cosmic rays around different types of stars. "What we showed was that you don't need supernovae [exploding stars] to create this, and that may mean that the conditions and chemistry that happen in our solar system are more common than we might expect," Offner says.

Offner also studies multi-star systems, where two or more stars orbit each other. Many of these systems consist of pairs of Sun-like stars, and so far, 23 of them have been spotted with planets. Half of these planets lie in the habitable zone. So if anything lives on these planets, it has an interesting sky to enjoy — like something out of "Star Wars."

"Think of it like two light bulbs orbiting each other and then you have an orbiting planet," says Brendan Bowler, an astronomer with CPSH. "If the planet were stationary, for example, you would have one star getting bigger and one getting smaller." In this case, the conditions for life might be time dependent, appearing and disappearing as the stars move relative to the planets.

Roughly half of all Sun-like stars are in binary or multi-star systems. Some of these stars orbit each other closer than the Earth-Sun distance of 93 million miles (150 million km), while some have been observed with separations up to 20 times greater. In both cases, the intense shifts in radiation that the planets would experience might preclude any possibility of life. Additionally, only gas-giant planets have been found in these systems. But all is not lost — future observatories could detect smaller rocky planets upon which hardy microbes might thrive even under these intense changes.

Bowler uses telescopes at the Keck Observatory in Hawaii to scrutinize extrasolar systems across the galaxy. He specializes in taking direct pictures of exoplanets, which are rare. Other planet-finding methods are more indirect — astronomers deduce the existence of a planet based on how it influences its star. These methods account for the great majority of successful detections so far, but direct imaging is a goal of many researchers, Bowler says. "Right now, with direct imaging we are sensitive to planets at wide separations, and [to] giant planets," he says. "To get to the end goal of smaller planets, we need to transition to space-based telescopes that observe planets in the optical" — wavelengths visible to the eye.

Although the observations are skewed toward giant planets for now, studying them can reveal a great deal about planetary habitability. To understand more about how giant planets relate to the latter, Bowler studies how they migrate — a planet may be born far from its star, but move closer later on, for example.

And by looking at systems of different ages, he can piece together a story of how they evolve, and the influence giant planets have on habitability. This story tells us that no object is free from the gravitational influence of giant planets, but this isn't necessarily a bad thing. Jupiter, for example, may have scattered asteroids and comets away from Earth early in the solar system's history, keeping our planet from experiencing too many catastrophic impacts. Bowler's findings suggest that giant planets across the galaxy might play this same role.

Additionally, moons for these giant planets are expected to be common. The exomoons would provide opportunities for life on their own, even at distances far outside a star's traditional habitable zone. Tidal friction from the immense gravitational influence of a giant planet creates a consistent source of internal heat. This energy may turn what would otherwise be dead, frozen worlds into dynamic ones. Moons around the giant planets in our own solar system, such as Europa and Enceladus, contain subsurface oceans where microbes could survive off the energy from vents that spew hot, nutrient-rich water. "You just need heating of a moon from interactions it has with its giant planet," Bowler says. "Once you start that process, then the potential for habitability really opens up."

Astronomers are awaiting the launch of JWST, as well as the completion of the Giant Magellan Telescope and other ground-based telescopes to reveal the sky at unprecedented resolution.

Succeeding telescopes should see exoplanets at new wavelengths and at closer distances to their stars. Many of the mission concepts under development for these telescopes are focused on habitability. Two of them are being designed to directly image Earth-like exoplanets in optical wavelengths and look for biosignatures — evidence of life, such as oxygen in the atmosphere.

"These questions get at the pinnacle of what it means to be human," says Bowler. "We're at the very, very beginning of this."

Christian Fogerty is a science writer based in Austin.

Resources

Internet

Center for Planetary Systems Habitability
habitability.utexas.edu

Warm welcome: finding habitable planets
exoplanets.nasa.gov/what-is-an-exoplanet/how-do-we-find-habitable-planets

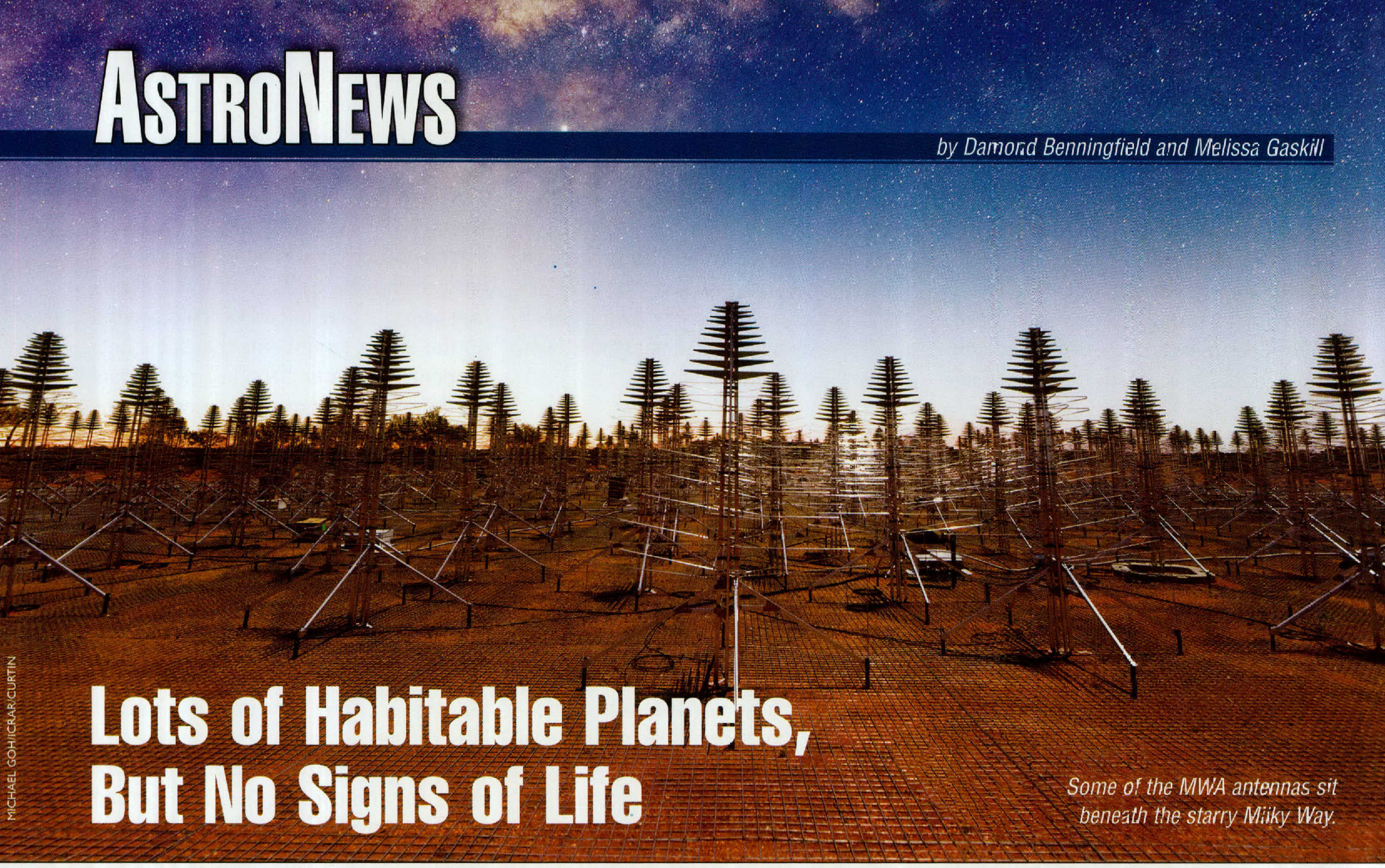
Habitable Exoplanets Catalog
phl.upr.edu/projects/habitable-exoplanets-catalog

Virtual Planetary Laboratory
depts.washington.edu/naivpl/content/welcome-virtual-planetary-laboratory

James Webb Space Telescope and Exoplanets
www.jwst.nasa.gov/content/science/origins.html

Giant Magellan Telescope: The Search for Life
www.gmto.org/the-search-for-life

by Damond Benningfield and Melissa Gaskill



MICHAEL GOH/ICRAR/CURTIN

Some of the MWA antennas sit beneath the starry Milky Way.

Lots of Habitable Planets, But No Signs of Life

Earth is the only comfortably habitable planet in our solar system, but a recent report shows that some stars might support as many as seven Earth-like planets.

Astronomers studying the nearby star system TRAPPIST-1 (see page 16), which has three Earth-sized planets in its habitable zone (the distance from the star where temperatures are just right for liquid water), began to wonder just how many such planets a system could have. They simulated planets of various sizes and tested how the planets interacted with each other over millions of years. The simulations showed that some types of stars could have as many as seven planets in the habitable zone, but only if the star didn't have a giant planet like Jupiter, the largest planet in our own solar system. More than seven and the planets would bunch too close together, destabilizing their orbits.

The model also showed that stars similar to the Sun could support up to six planets in the habitable zone. The shapes of the orbits of our fellow planets is one reason our solar system currently has only one water-bearing planet. The size of Jupiter is another. With two-and-a-half times the mass of the other planets combined, it disturbs their orbits and limits their habitability.

With so many possibly hospitable worlds, it might seem we would have found signs of other life out there by now. But the deepest and broadest low-frequency radio search for alien technologies to date, covering 10 million stars in the constellation Vela, found no signs of other civilizations.

The Murchison Widefield Array (MWA) telescope in Western Australia searched for powerful radio emissions at frequencies similar to FM radio. These emissions could indicate the presence of an intelligent civilization. According to a paper in *Publications of the Astronomical Society of Australia*, though, the search turned up empty.

Of course, the universe is huge. The researchers likened the amount of space they scanned to examining a part of the ocean the size of a backyard swimming pool to search for life in Earth's seas. The Square Kilometre Array, a $2 billion telescope planned for Western Australia and South Africa, will be 50 times more sensitive than MWA and able to survey billions (as opposed to millions) of star systems for technosignatures. The search for intelligent life goes on. **MG**

Living in the Clouds?

The surface of Venus is hellish. The temperature is hot enough to melt lead, the pressure is the equivalent of a depth of about two-thirds of a mile in Earth's oceans, and the atmosphere is made almost entirely of carbon dioxide. It's not a place for a holiday getaway.

The planet's clouds may be a different matter. In September, astronomers reported finding phosphine in the middle layers of the clouds, where temperatures and pressures are much more Earth-like. On Earth, the compound is produced only by living organisms and by industrial processes.

Scientists have suggested since the 1960s that microbes could live in the Venusian clouds. More recently, orbiting spacecraft have detected dark patches of material inside the clouds that could be "mats" of microscopic organisms.

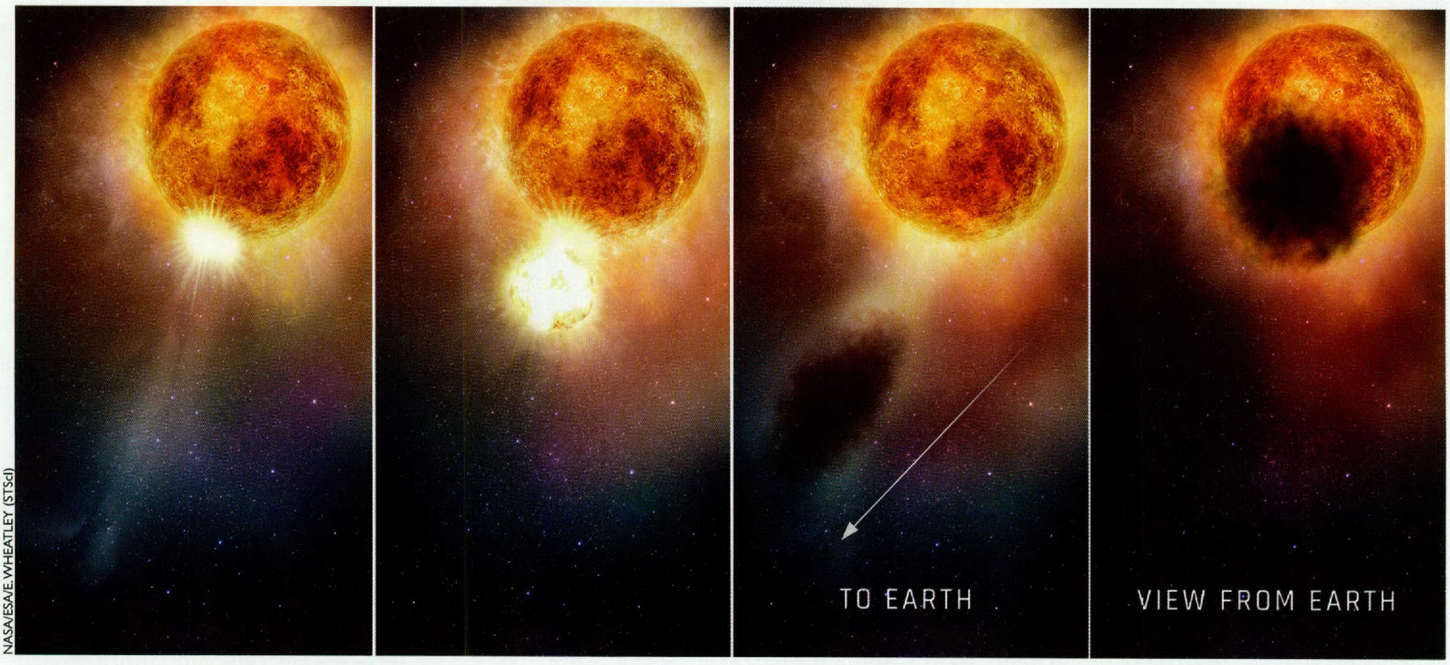
The Breakthrough Initiative, which made the discovery using radio telescopes in Hawaii and Chile, will fund follow-up observations to try to determine the origin of the phosphine.

Death from a Dying Star

You don't have to get too close to an exploding star for it to ruin your day. A recent study, for example, says that one or more exploding stars about 65 light-years from Earth could have caused a mass extinction roughly 360 million years ago. Some fish and other animals survived, but most organisms died off.

According to the study, a massive star exploded as a supernova, flooding Earth with radiation and destroying its protective ozone layer. The supernova later bathed our planet in cosmic rays, which are heavy particles accelerated to near the speed of light. The combination created both a long decline in life, over a period of a few hundred thousand years, and a shorter "pulse" of extinctions.

Researchers say that debris from the explosion might be found in terrestrial rock layers from the time of the die-off. In particular, even tiny amounts of plutonium or certain other radioactive elements would confirm that Earth was zapped by an exploding star. **DB**



NASA/ESA/E. WHEATLEY (STScI)

Hot gas erupts from the surface of Betelgeuse then cools to form a cloud of dark dust. The final panel shows how the outburst looked from Earth.

Cleaning Up After a Supergiant

Studies say Betelgeuse's 'big fade' caused by either dust or spots

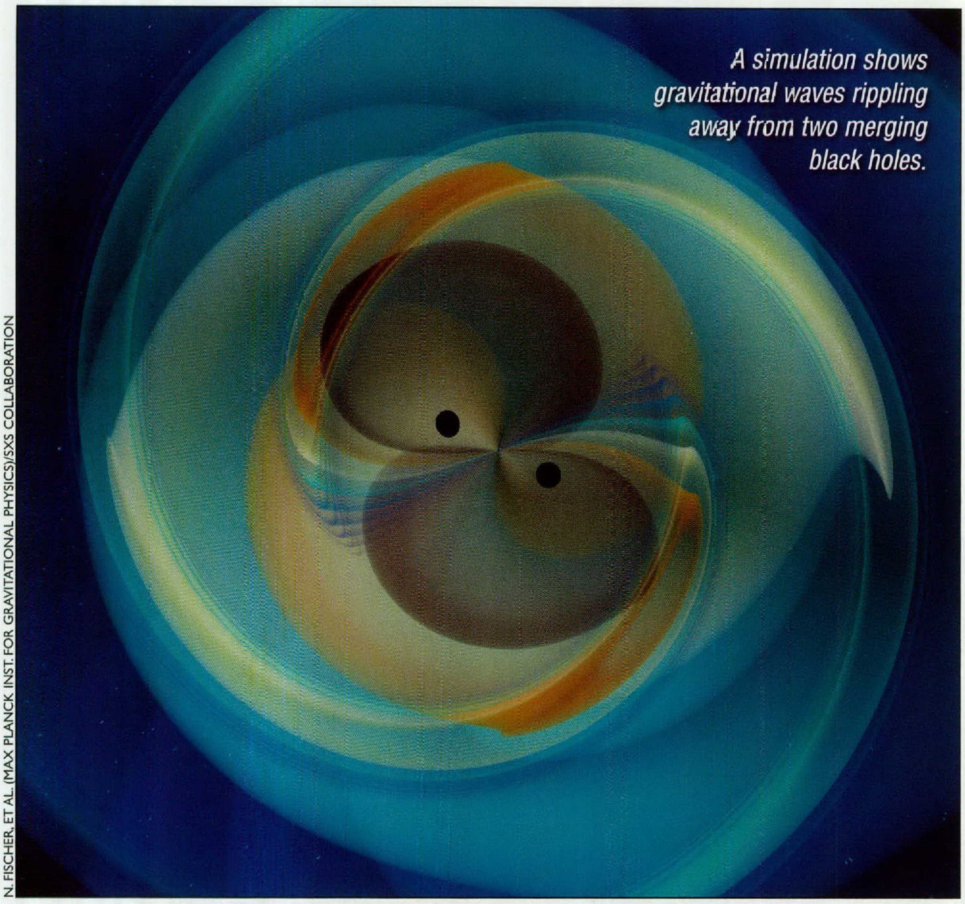
Betelgeuse fades and brightens on a regular schedule — once every 420 days — as its surface puffs in and out like a beating heart. The change in brightness is fairly small, so it's hard to notice without sensitive instruments. But from October 2019 to April 2020, the supergiant dimmed to about 40 percent of its normal luster — a change that was easily visible to the unaided eye.

Scientists have devised conflicting theories to explain the dramatic change.

One possibility: A dust cloud blocked its light. From September through November of 2019, Hubble Space Telescope captured signs of hot, dense material moving away from Betelgeuse's surface and into its thin, extended atmosphere. The blob of material might have been superhot gas from a giant bubble that rose to the star's surface as part of its normal cycle of pulsations. As the blob of gas moved away from Betelgeuse it cooled and condensed, forming a dust cloud that blocked light from about a quarter of the star's surface.

But a second team of astronomers observed a 20 percent dimming in some radio wavelengths that they say is not compatible with the presence of dust. Instead, they suggest the dimming was caused by gigantic cool spots, similar to sunspots, that covered 50 to 70 percent of Betelgeuse's surface.

Betelgeuse, which marks the shoulder of Orion the hunter, sits at a relatively close 725 light-years from Earth, meaning it dimmed around the year 1300 and the event only just reached us. The star will end its life as a supernova, a titanic blast that would be bright enough to see during the day. **MG**



N. FISCHER, ET AL. (MAX PLANCK INST. FOR GRAVITATIONAL PHYSICS)/SXS COLLABORATION

A simulation shows gravitational waves rippling away from two merging black holes.

Whipping Up a Mid-Sized Black Hole

Scientists say they are more than a little puzzled by the merger of two giant black holes that was observed last year. The mass of the combined black holes is in a range that has seldom been seen and never confirmed. And at least one of the original black holes appears to lie in a "forbidden zone" — a mass that shouldn't be possible.

The merger produced a small pulse of gravitational waves — ripples in space and time that were seen by observatories in the United States and Europe on May 21, 2019. The pulse lasted about one-tenth of a second. From the characteristics of the waves, scientists deduced that the pulse was created about seven billion years ago, when the universe was just half of its present age.

In a pair of papers published in early September, a team of about 1,300 scientists reported that the pulse, known as GW 190521, likely was created by the merger of black holes that were roughly 85 and 66 times the mass of the Sun. The merged black hole was about 142 times the Sun's mass; the remainder of the original mass was radiated away as gravitational waves.

The merged object is an intermediate-mass black hole (IMBH). Astronomers have reported several black holes in this range, but most of those findings have not been confirmed. The discovery team says that makes GW 190521 the most solid discovery of an IMBH to date.

One or both of the original black holes may be even harder to explain. Each of them likely formed from the collapse of a giant star. Yet current theories suggest that instead of collapsing to form black holes, stars from roughly 65 to 120 times the mass of the Sun should blast themselves apart in titanic explosions. That "represents a challenge for current astrophysical formation scenarios," the team writes in one of the papers. It could, in fact, mean that the two merging black holes each formed from the mergers of less-massive black holes, the team adds.

The brevity of the pulse of gravitational waves means it's possible that GW 190521 isn't an IMBH, although it's by far the most likely explanation. Still, "other interpretations are possible, adding to the exceptional nature of this event," the team wrote. **DB**

Dark Matter Gets 'Blobby'

Dark matter may be concentrated in denser blobs than astronomers had expected, according to a study published in September. Astronomers discovered heavy concentrations of dark matter inside individual galaxies that are members of giant galaxy clusters — up to 10 times more dark matter than expected.

Dark matter produces no detectable energy (hence the name). Astronomers detect it through its gravitational pull on the visible matter around it. Studies suggest it accounts for roughly seven times more mass than the stars, planets, and other forms of matter we can see. Physicists say dark matter likely consists of heavy particles, but every experiment designed to detect them has come up empty.

Much dark matter is concentrated in galaxy clusters, which can contain hundreds of individual galaxies. The gravity of that dark matter acts like a lens, distorting and magnifying the view of galaxies that lie behind a cluster.

The recent study, using Hubble Space Telescope and a ground-based telescope in Chile, found unusually strong lensing effects within the clusters. They are caused by "blobs" of dark matter that correspond to the locations of individual galaxies. That doesn't match models of how dark matter works, which suggest it is likely to concentrate at the center of a cluster. The study shows there's still a lot of work to be done to explain the nature and behavior of dark matter. **DB**

An artist's concept shows giant lightning storms in the atmosphere of Jupiter, the solar system's largest planet. While the lightning on Earth comes from clouds made of water, a recent study found that some lightning on Jupiter may come from clouds containing both water and ammonia. The clouds may generate slushy ammonia-rich hailstones called mushballs.