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- Micronovae, a new kind of stellar explosions
- Supermassive black hole precursor detected
- The most distant galaxy candidate yet

The first image of Sagittarius A*

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Ingenuity at 29 flights and approaching winter

by Damian G. Allis
NASA Solar System Ambassador

As this issue goes online, the Mars 2020 Perseverance Rover and Ingenuity Helicopter will have spent 483 sols, or 496 Earth days, on Mars, of which Ingenuity will have been an active mission for 425 sols, or 437 Earth days. In that time, Ingenuity, or "Ginny" as it is more swiftly known, will have performed 29 powered flights, covered a total distance of 7.1 km (just over 4.4 miles, more than half the distance traversed by "Percy"), spent just under 55.5 total minutes in the thin Martian atmosphere, and defined a new era in the exploration of visited worlds beyond Earth.
Ingenuity now approaches an important stage in its mission – not one of distance, but instead of time. The northern hemisphere of Mars is currently in its late autumn and moving into winter – a time when the temperature at Jezero Crater, the mission target for Mars 2020 and the current location of Percy and Ginny, might drop to as low as -80 °C (-112 °F). Jezero Crater is in the northern hemisphere – but not by much. Due to both the obliquity and eccentricity

Jezero Crater formation by asteroid impact. At Jezero Crater, Perseverance should be able to access rocks that are as old as 3.6 billion years. [NASA/JPL-Caltech/MSSS]

This image of NASA's Ingenuity Mars Helicopter was taken by the Mastcam-Z instrument of the Perseverance rover on June 15, 2021, the 114th Martian day, or sol, of the mission. The location, "Airfield D" (the fourth airfield), is just east of the "Séítah" geologic unit. [NASA/JPL-Caltech/ASU/MSSS]

of its orbit, Martian northern winters tend to not be as brutally long and cold as those in the south, which is hopefully good news for Ginny's future. The lows expected to be experienced by Ingenuity are still a considerable drain not only on its battery. Because the energy drain from the onboard heaters used to keep electronics at a not-too-low temperature is too great for the battery to accommodate overnight, the lifetime of its electronics now risk a reduction that might, as one among several possible reasons, leave us with a dead helicopter by winter's end. The charge/drain cycle of its onboard battery, currently also dependent on the amount of dust covering the solar panels, not only affects onboard hardware, but also software – the constantly reset mission clock, unable to be maintained without the battery source, means that each reboot of Ingenuity's computer will be out-of-sync with that of its stably-powered Perseverance host computer, providing another potential operational obstacle in the long-term.

This image shows the remains of an ancient delta in Mars' Jezero Crater, which NASA's Perseverance Mars rover will explore for signs of fossilized microbial life. The image was taken by the High Resolution Stereo Camera aboard the ESA (European Space Agency) Mars Express orbiter. [ESA/DLR/FU-Berlin]

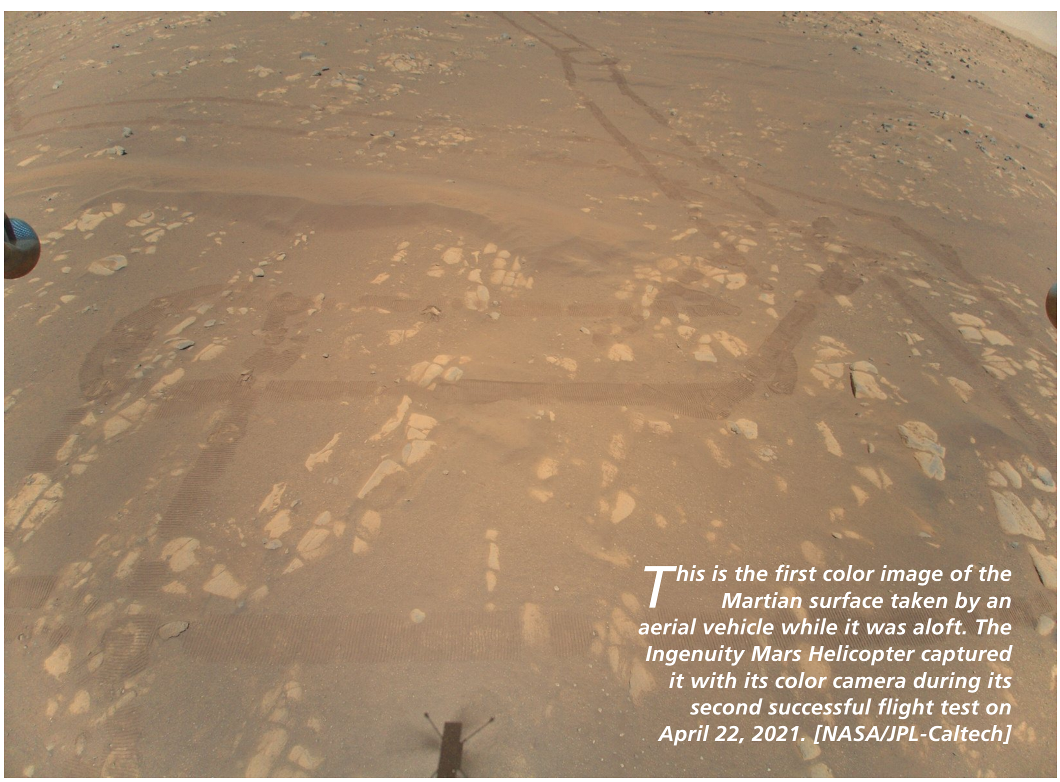
The sequence in which NASA's Perseverance Mars rover took 62 individual images with its WATSON camera, on April 6, 2021, before they were stitched together into a single selfie. [NASA/ JPL-Caltech/MSSS]

The current situation is discussed in great detail by Ingenuity Team Lead Teddy Tzanetos in the post "Ingenuity Adapts for Mars Winter Operations" on the NASA Ingenuity Mission Blog. All the technical issues and the many complexities that a Martian winter may bring to the mission aside, the takeaway quote from Tzanetos' analysis is simple – "each sol (Martian day) could be Ingenuity's last."

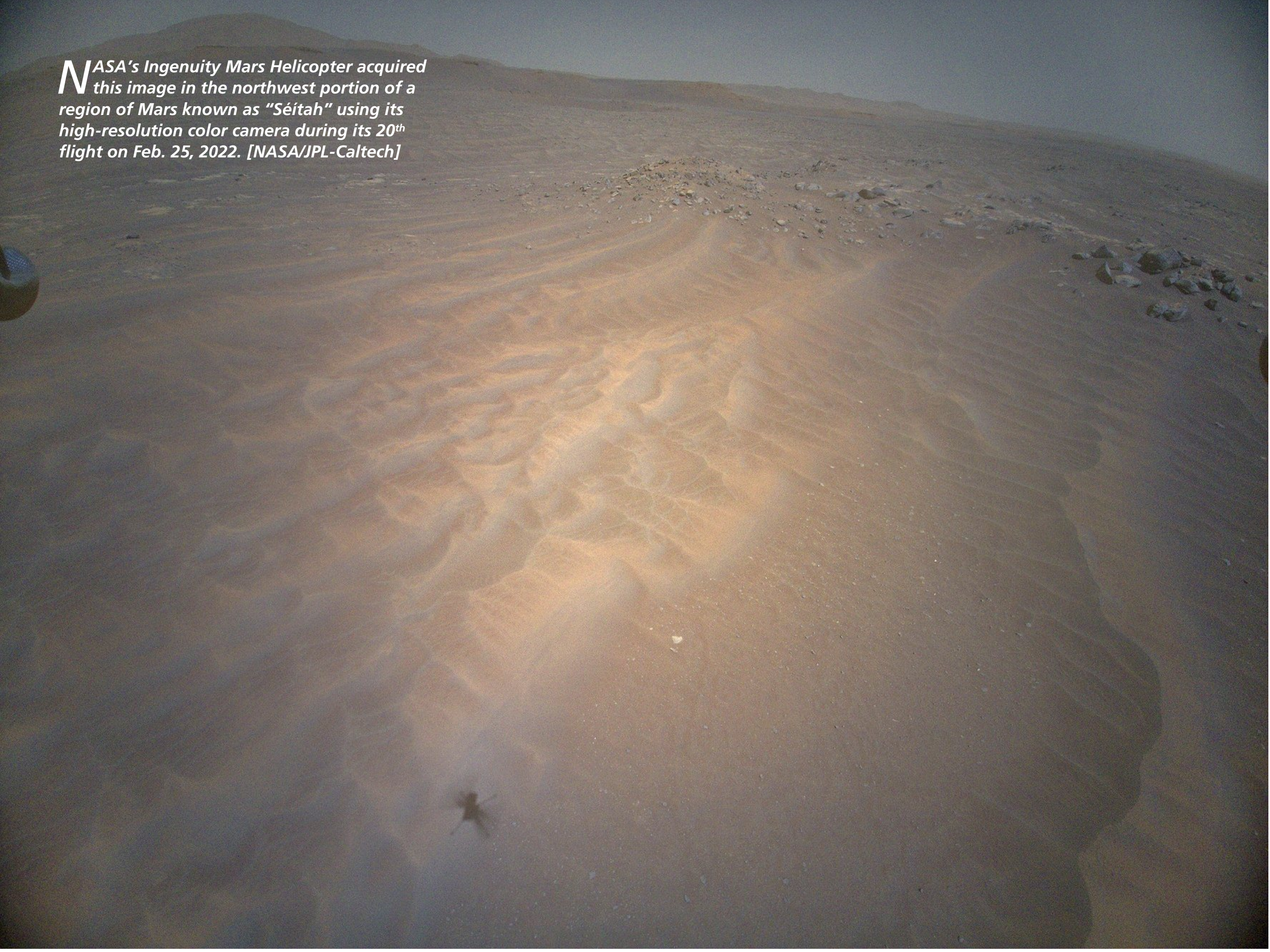
Despite the approaching difficult weather conditions ahead, optimism still abounds. Ingenuity is now 24 flights past its planned five-flight demonstration phase, has been actively participating in the Perseverance mission as the scout it is most qualified to be, and has had its mission extended through at least September 2022, when conditions on the ground will return to those that the onboard systems can compensate for to maintain reliable flight status. With winter and the expectation of dormancy arriving soon to its mission, this is an excellent time to account for the mission and report on its several highlights.

The first flight, taken on April 19, 2021, was covered in detail in the May-June 2021 issue of this magazine. At 39 seconds, of which 30 seconds was dedicated to hovering in place, this first example of controlled, powered flight lasted 27 seconds longer than the first powered flight here on Earth. In an action somewhere on the spectrum between sentimentality and a nod to history, the specification of Ingenuity's first flight zone as Wright Brothers Field (official airport code JZRO for Jezero Crater) also finds a small piece of fabric from Orville and Wilbur's original 1903 Wright Flyer (that made that first short flight) attached to the underside of Ingenuity (another piece having flown with Neil Armstrong and Buzz Aldrin on the Apollo 11 Eagle Lunar Lander as it touched down on the Moon in 1969).

The two additional flights in the initial demonstration phase included longer durations (39 and 52 seconds) and greater round-trip distances covered (4 meters and 100 meters). Flight 2 included rotations around the rotor axis (yawing) and images taken at stationary points.



This is the first color image of the Martian surface taken by an aerial vehicle while it was aloft. The Ingenuity Mars Helicopter captured it with its color camera during its second successful flight test on April 22, 2021. [NASA/JPL-Caltech]



NASA's Ingenuity Mars Helicopter acquired this image in the northwest portion of a region of Mars known as "Séítah" using its high-resolution color camera during its 20th flight on Feb. 25, 2022. [NASA/JPL-Caltech]

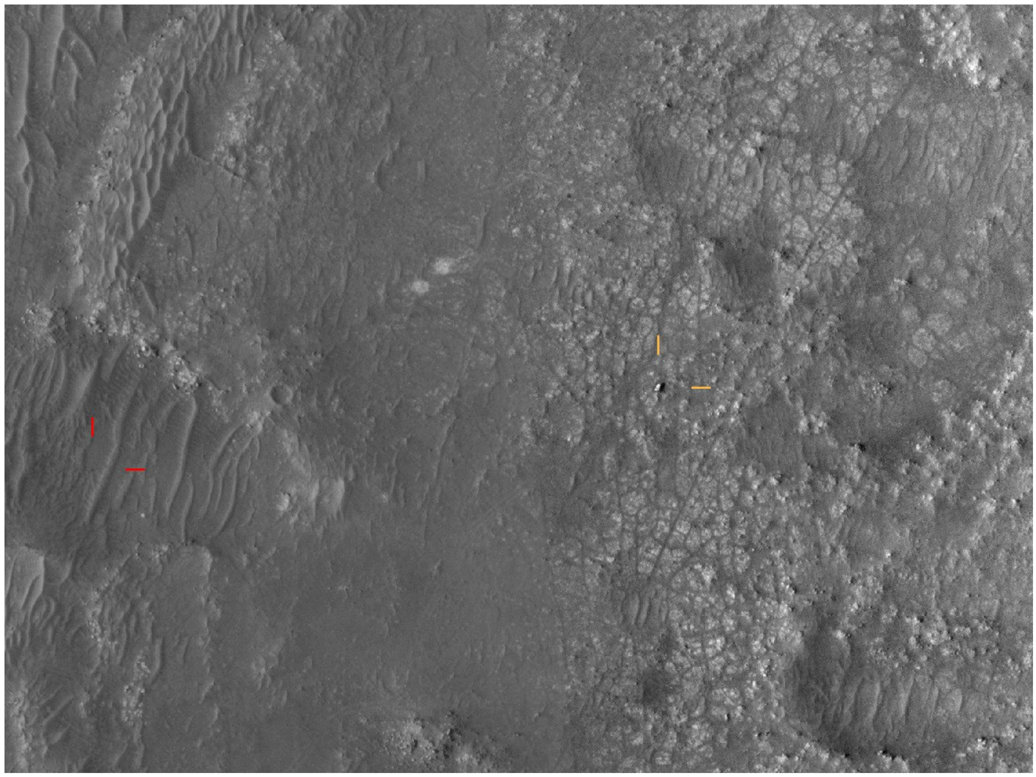
Flight 3 was a pure distance run, with Ingenuity covering in 52 seconds the distance the Sojourner rover from the Mars Pathfinder Mission covered in 83 sols.

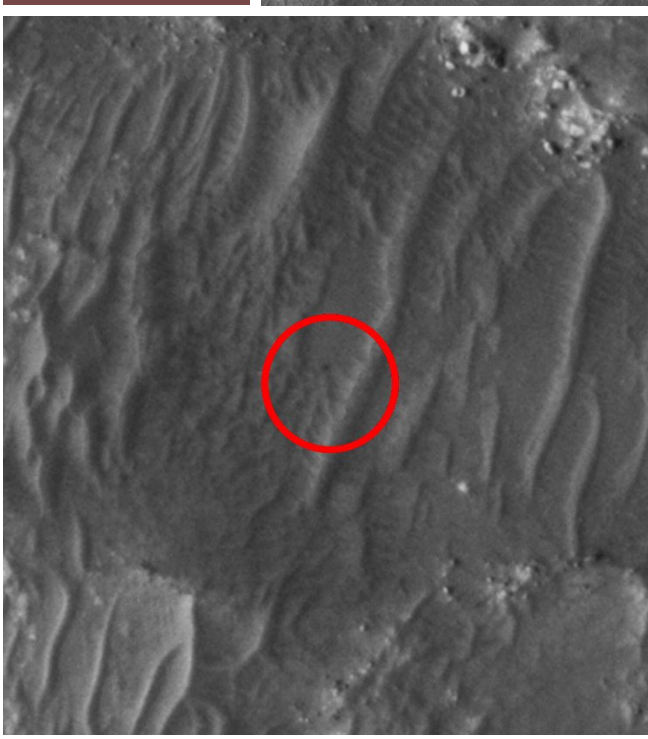
With these three successes behind it, the mission entered a brief transitional period from demonstration to operation. After resolving an onboard software problem that postponed its first attempt, Flight 4, famous for the video and audio Perseverance captured, included color images taken of the Martian surface at the farthest distance traveled during the nearly two-minute flight. Finally, with flight 5, Ginny landed at a different location 130 meters to the south of Wright Brothers Field – designated Airfield B.

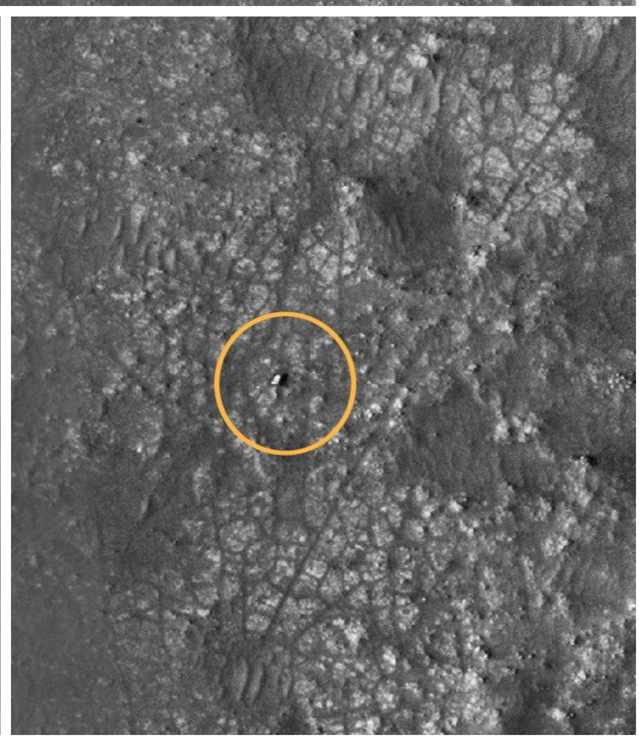
With hovering, flight, landing, imaging, and communications all in place, Ingenuity entered its operational demonstration phase with flight 6, where the helicopter was now charged with scouting terrain for Perseverance. With this change in phase also, ironically, came a reduction in Perseverance resources dedicated to monitoring Ingenuity's progress. As stated by Jennifer Trosper, JPL Deputy Project Manager for Perseverance, *"What we aren't going to be doing anymore, which took an enormous amount of time, is imaging the helicopter flights. That is what took away from our ability to continue with the* [Perseverance] *science mission in one way or another."* With its mission goal the search for signs of life somewhere in Mars' ancient past, it is difficult to argue the point. This is not to say that the two would not be in regular communication, nor ever very far from one another physically. The low-power monopole antennas on Ginny and Percy are only rated for communications at distances as far as 1 km, and Ginny-NASA communications rely on Percy's communication with the Mars Relay Network, which consists of NASA orbiters Mars Reconnaissance Orbiter, Mars Odyssey, and MAVEN, as well as ESA orbiters ExoMars Trace Gas Orbiter (TGO) and Mars Express.

With this transition to supporting the rover mission, flights became more of a means to an end than the experiments themselves. Flights 7 and 8 were used to reach Séítah, an ancient formation within Jezero Crater that served as the location of the first Perseverance science campaign. According to Kevin Hand, co-lead of the Perseverance exploratory phase of this region, Séítah (and the Crater Floor Fractured Rough region) *"was under at least 100 meters of water 3.8 billion years*

NASA's Perseverance Mars rover and Ingenuity helicopter were spotted on the surface of the Red Planet in this black-and-white image captured Feb. 26, 2022, by the HiRISE camera aboard NASA's Mars Reconnaissance Orbiter. The rover is viewed here sitting on fractured bedrock of the "Máaz" formation before its long drive to the Jezero Crater's delta. About 656 feet (200 meters) to the left is the Ingenuity helicopter, which is so small that it appears as a mere dot on the landscape. [NASA/JPL-Caltech/UArizona]







This image of Perseverance's backshell sitting upright on the surface of Jezero Crater was collected from an altitude of 26 feet (8 meters) by NASA's Ingenuity Mars Helicopter during its 26th flight at Mars on April 19, 2022. The tangle of cables seen streaming out from the top of the backshell, and coated with Martian dust on the surface, are high-strength suspension lines that connect the backshell to Perseverance's supersonic parachute (upper left). The backshell and parachute helped protect the rover in deep space and during its fiery descent toward the Martian surface. The shadow cast by Ingenuity is visible at the bottom left of the image. [NASA/JPL-Caltech] *ago,"* exactly the conditions ripe for the exploration of chemical and mineral signatures of anything that might have existed within the ancient river delta.

Flights 9 (July 5, 2021) through 18 (December 15, 2021) continued the survey of Séítah and established Airfields F through L, with the additional re-landing of Ingenuity to some prior Airfield locations in its travels. Flight 19 was not attempted until February 8, 2022 due to a significant dust storm at Jezero Crater that reduced incoming sunlight by 18% and lowered the local air density by 7%, affecting both the flight conditions and the ability of Ingenuity to recharge itself. The long wait to flight 19 was to provide ample time for clearing sensors and solar panels (both naturally in the thin Martian air and by performing mechanical tests to shake dust off of the copter), returning Ingenuity to its pre-storm charging status.

Flights 19 and 20 returned Ingenuity to near Wright Brothers Field, placing it for subsequent flights around the Jezero Crater river delta while Percy traversed a longer path on the ground.

Flights 21 through 29 were continued scouting missions of the river delta, during which Flight 25 on April 8th achieved both the farthest distance covered (709 meters) and the fastest speed (5.5 m/s) reached during the mission. Flight 26 on April 19th was noteworthy for the remarkable color photo of the entry-descent-landing (EDL) hardware that brought Percy and Ginny safely to the Martian surface. The wreckage snapshot included the Perseverance backshell landing capsule and parachute.

In both its capabilities and its design for extended use in such a hostile environment, Ingenuity is both a technical and scientific marvel. That said, all missions come with obstacles that require address, reconfiguration, and documentation to spare

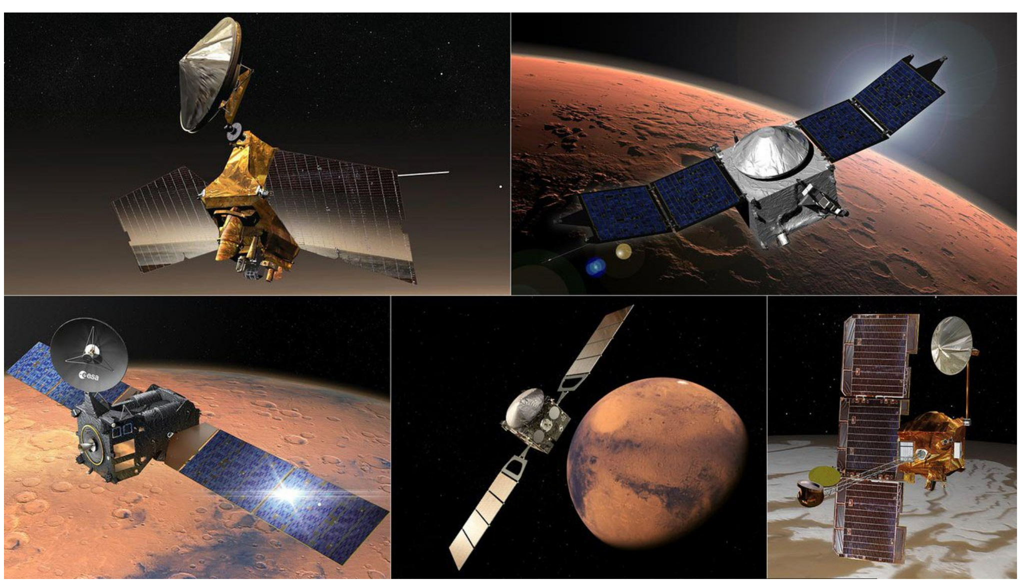
Video from the navigation camera aboard NASA's Ingenuity Mars Helicopter shows its record-breaking 25th flight on April 8, 2022. Covering 2,310 feet (704 meters) at a maximum speed of 12 mph (5.5 meters per second), it was the rotorcraft's longest and fastest flight to date. [NASA/JPL-Caltech]

future missions the same problems. Ingenuity has had its share of issues throughout the (so far) 425 sol mission, and we are fortunate that NASA is such a transparent organization as to make the public aware of things breaking and being fixed.

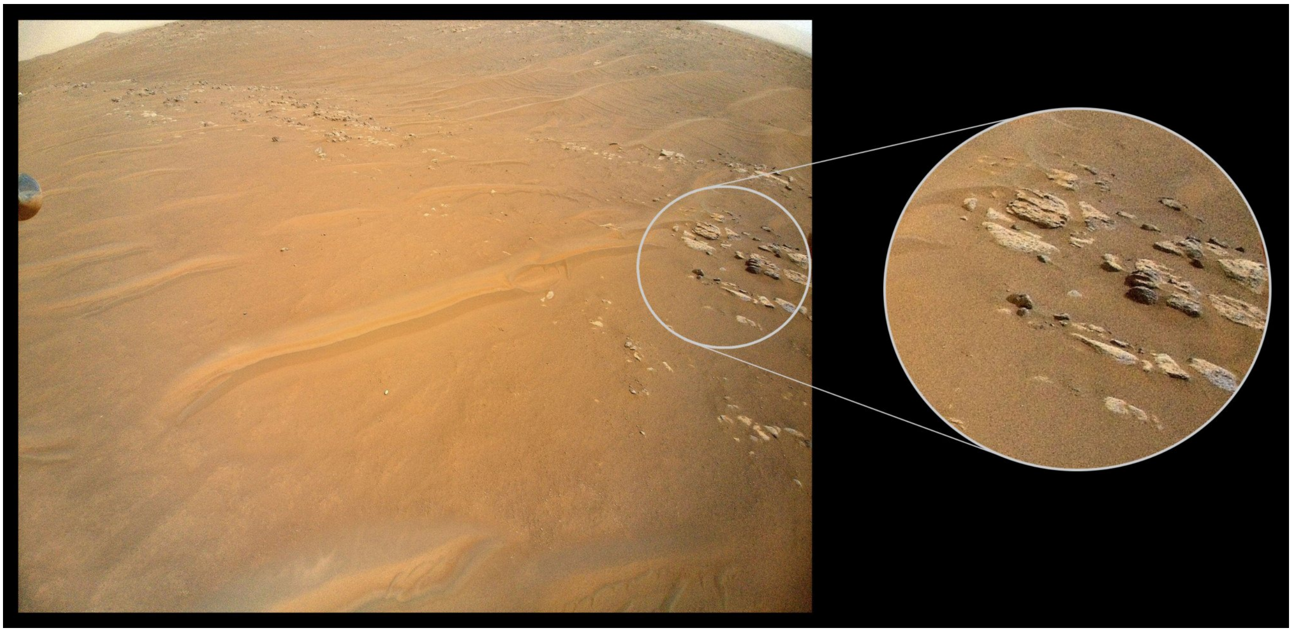
The first attempts at flights 4 and 7 failed due to reported software issues, during which the phrase "watchdog timer" (a simple software check of system and condition status) became one all Mars enthusiasts learned the meaning of. The time around September 18, 2021 (between successful flights 13 and 14) saw a test of increased rotor speed to obtain more lift in the colder and thinning atmosphere, but was canceled due to a servo motor issue. Resolution was delayed due to solar conjunction, when Mars was behind the Sun with respect to Earth. Flight 17 included a loss of communication between Percy and Ginny, ascribed to features on the Martian terrain that blocked signals (for which the limits of the antennas, the value of shorter distances between equipment, and greater consideration of surface features affecting line-of-sight very likely were part of flight analysis).

Flight 28 was, perhaps, the most disconcerting of the series, with days of lost communications to Percy, a dead inclinometer (a sensor composed of two accelerometers that determine, simply, which way is down in order to determine copter orientation), and Martian northern winter looming. Despite these issues, Flight 29 occurred successfully on June 11th and we now await word on any additional flights to be taken.

Whether it awakens from, or succumbs to, the upcoming Martian winter, Ingenuity has already exceeded expectations and marks the beginning of a great new chapter in planetary exploration. Plans for fu-



Five spacecraft currently in orbit about the Red Planet make up the Mars Relay Network to transmit commands from Earth to surface missions and receive science data back from them. Clockwise from top left: NASA's Mars Reconnaissance Orbiter (MRO), Mars Atmospheric and Volatile EvolutioN (MAVEN), Mars Odyssey, and the European Space Agency's (ESA's) Mars Express and Trace Gas Orbiter (TGO). [NASA/JPL-Caltech, ESA]



NASA's Ingenuity Mars Helicopter recently surveyed a ridgeline near the ancient river delta in Mars' Jezero Crater at request of the Perseverance rover's science team. On the left is the full image Ingenuity acquired of the ridgeline on April 23, 2022, during its 27th flight. The science team calls the line of rocky outcrops running from the upper left to middle right of the main image "Fortun Ridge." Enlarged at right is a close-up of one of the ridgeline's rocky outcrops. [NASA/JPL-Caltech]

ture Martian flight are already underway as part of sample collection and delivery for eventual return to Earth. In a solar system filled with gas giants, thick atmospheres, and moons containing surface and subsurface liquids, exploration requiring modes of travel beyond wheeled rovers are key to discovery. With a solid demonstration on Mars already in the proverbial history books, the NASA New Frontiers Program has set sights on a return to Saturn's moon Titan with the upcoming Dragonfly Mission. A proposed dual-quadcopter is scheduled to land on January 1, 2034 and fly through Titan's thick predominantly nitrogen atmosphere to explore this moon – a world rich in surface organic molecules and remarkably varied surface geology.

If alternative power supplies and equipment can be kept very light, the harsh realities of cold Martian winters might be avoided, enabling surveys, studies, or transportation around both hemispheres throughout the Martian year. If constrained to flight based on solar power, it is marvelous to think of swarms of robust solar helicopters migrating seasonally across the Martian hemispheres. This might keep the polar regions inaccessible to flying robots until technology catches up to our scientific curiosity, but it still leaves us a very large part of a very unexplored planet to discover. As always, the technology being incorporated into planetary missions is both older and more resilient than the state-of-the-art. How our efforts on Earth to improve solar panel, battery, and electronics efficiencies to accommodate global energy demands will play out in planetary missions remains to be seen. It should not go without mention that much of Ingenuity, including the communications hardware, batteries, cameras, and sensors, is completely off-the-shelf and available for purchase by anyone online. This helicopter, and the mission in general, might have looked a fair bit different with equipment only a generation or two older.

Flight 29 is in the books despite some technical and weather-related problems – but perhaps another flight opportunity will open soon before the long wait to northern Martian spring, when conditions will again be suitable for Ingenuity to warm up, wake up, and take to the skies. For those looking for the most up-to-date information, the Ingenuity Mission site (mars.nasa.gov/technology/helicopter/) has been a wealth of information about Ingenuity's activities and the trials and tribulations that come from being a first experiment on a world less forgiving of hardware than our own.

NORT

RAPIDO 450

ALTAZIMUTH NEWTONIAN TELESCOPE

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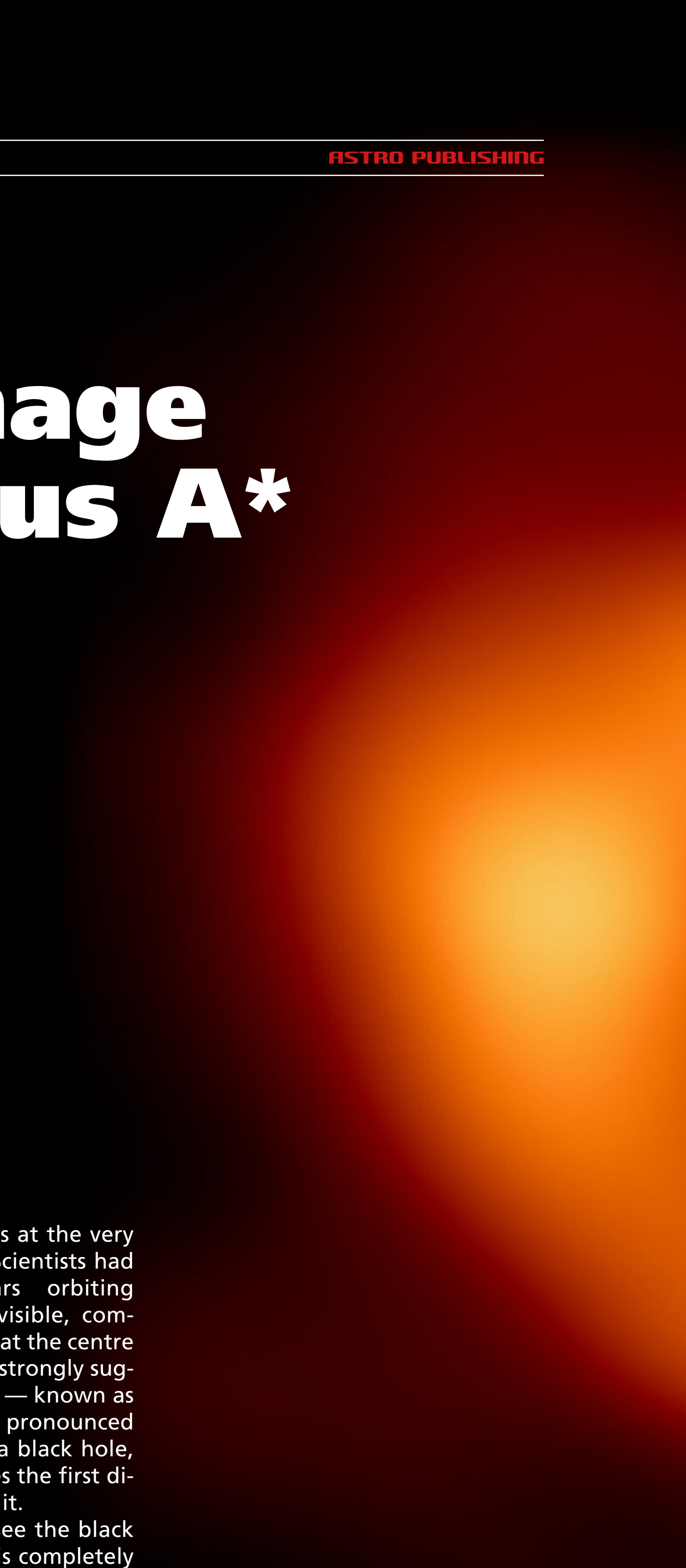
The NortheK Rapido 450 is designed to be disassembled into essential parts for transport in a small car. Each component is equipped with its own case, facilitating transport and assembly. The main element weighs 27 kg. Incorporated mechanical devices and the precise execution of each component allows for the collimation of the optics with extreme ease, maintaining collimation throughout an observation session while eliminating twisting and bending, regardless of the weight of the accessories used. The very thin primary optic allows for rapid acclimatization and ensures thermal stability throughout the night. Two bars equipped with sliding weights allow for the perfect balance of the telescope and accessories. On demand, it is also possible to modify the support to mount the telescope on an equatorial platform. This instrument is composed of aluminum, carbon and steel, each perfectly selected according to strict mechanical standards. It is undoubtedly the best altazimuth Newtonian on the market.

INSTRUMENTS - CO

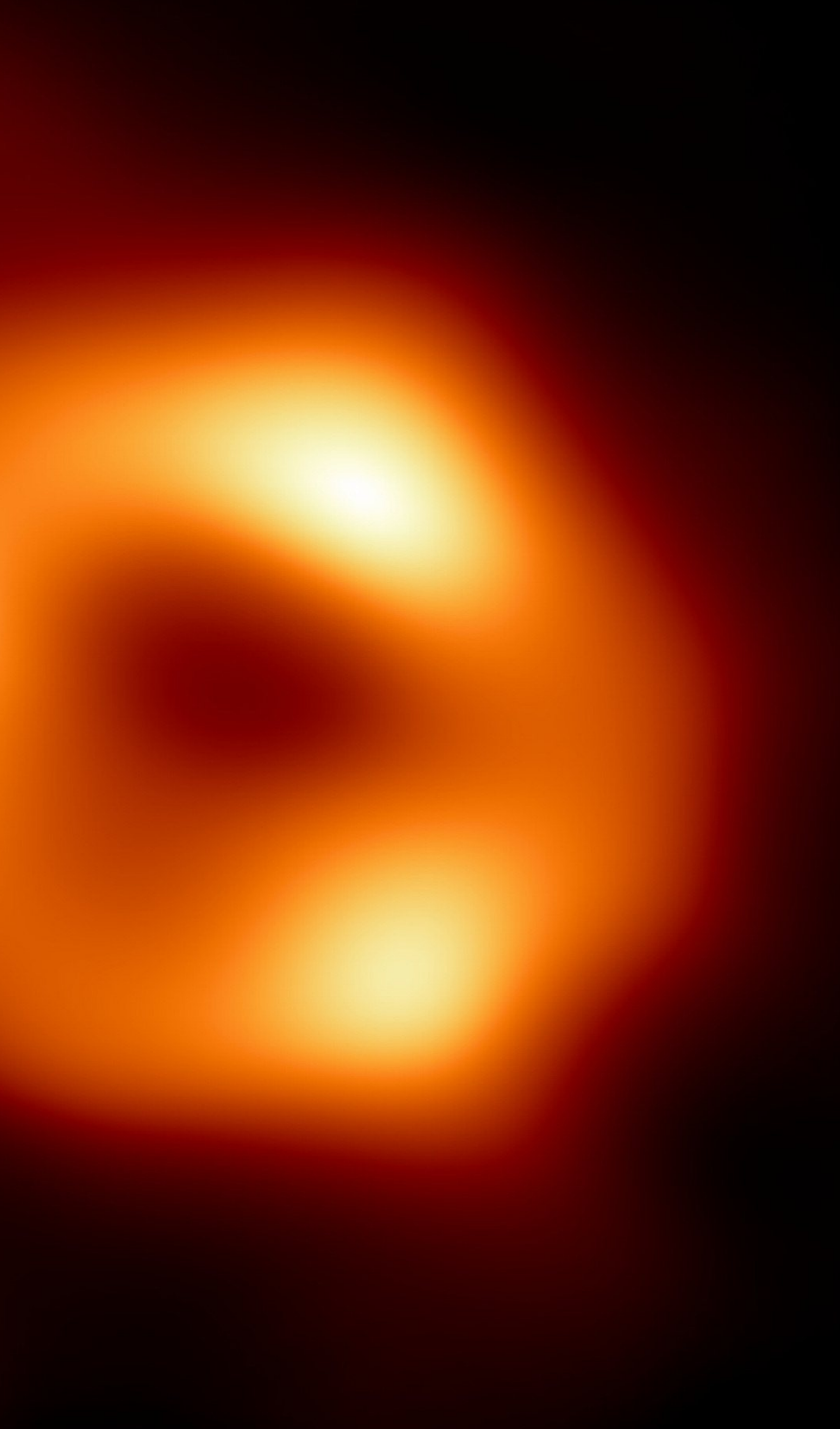
The first image of Sagittarius A*

by ESO - Bárbara Ferreira

At simultaneous press conferences around the world, including at the European Southern Observatory (ESO) headquarters in Germany, astronomers have unveiled the first image of the supermassive black hole at the centre of our own Milky Way galaxy. This result provides overwhelming evidence that the object is indeed a black hole and yields valuable clues about the workings of such giants, which are thought to reside at the centre of most galaxies. The image was produced by a global research team called the Event Horizon Telescope (EHT) Collaboration, using observations from a worldwide network of radio telescopes. The image is a long-anticipated look at the massive object that sits at the very centre of our galaxy. Scientists had previously seen stars orbiting around something invisible, compact, and very massive at the centre of the Milky Way. This strongly suggested that this object — known as Sagittarius A* (Sgr A*, pronounced "sadge-ay-star") — is a black hole, and the image provides the first direct visual evidence of it.
Although we cannot see the black hole itself, because it is completely



This is the first image of Sgr A, the supermassive black hole at the centre of our galaxy. It's the first direct visual evidence of the presence of this black hole. It was captured by the Event Horizon Telescope (EHT), an array which linked together eight existing radio observatories across the planet to form a single "Earth-sized" virtual telescope. The telescope is named after the event horizon, the boundary of the black hole beyond which no light can escape. [EHT Collaboration]*

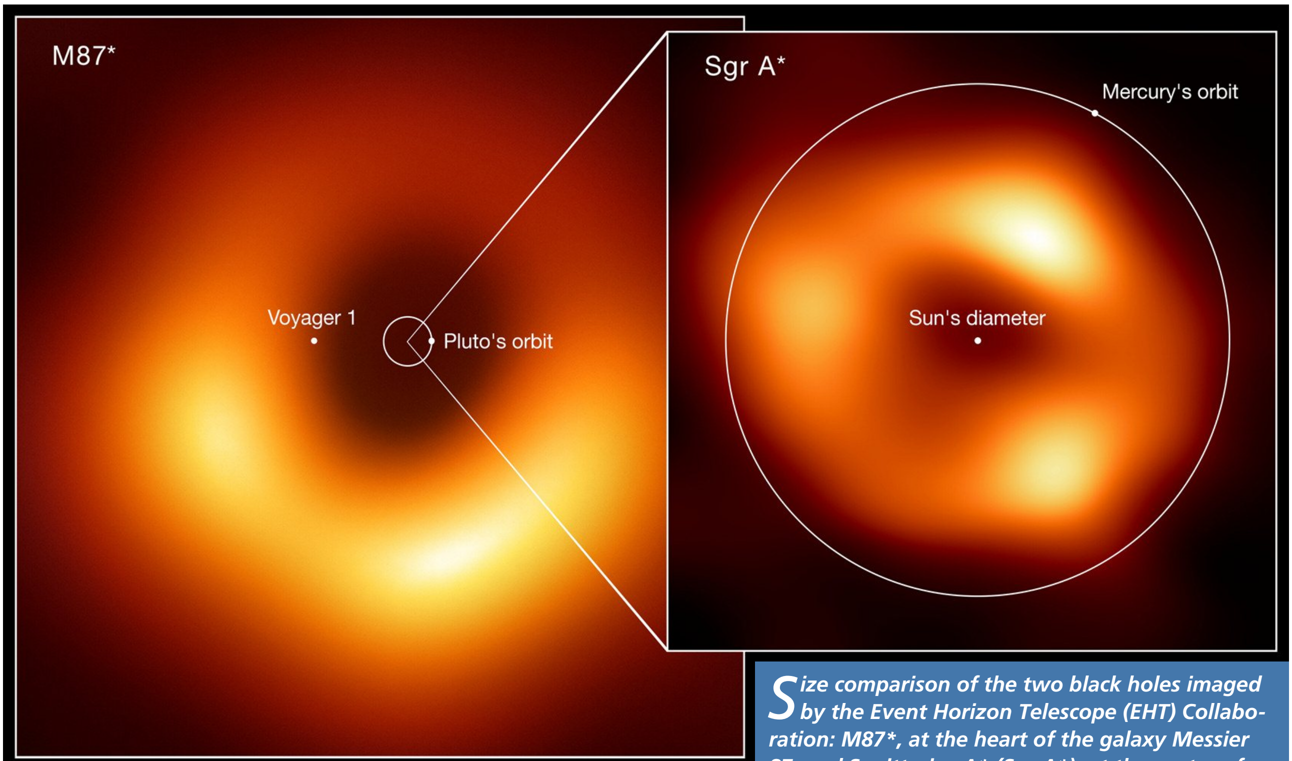


dark, glowing gas around it reveals a telltale signature: a dark central region (called a shadow) surrounded by a bright ring-like structure. The new view captures light bent by the powerful gravity of the black hole, which is four million times more massive than our Sun.

"We were stunned by how well the size of the ring agreed with predictions from Einstein's Theory of General Relativity," said EHT Project Scientist Geoffrey Bower from the Institute of Astronomy and Astrophysics, Academia Sinica, Taipei. *"These unprecedented observations have greatly improved our understanding of what happens at the very centre of our galaxy, and offer new insights on how these giant black holes interact with their surroundings."* The EHT team's results are being published in a special issue of *The Astrophysical Journal Letters*.

Because the black hole is about 27,000 light-years away from Earth, it appears to us to have about the same size in the sky as a doughnut on the Moon. To image it, the team created the powerful EHT, which linked together eight existing radio observatories across the planet to form a single "Earth-sized" virtual telescope. The EHT observed Sgr A* on multiple nights in 2017, collecting data for many hours in a row, similar to using a long exposure time on a camera.

In addition to other facilities, the EHT network of radio observatories includes the Atacama Large Millimeter/submillimeter Array (ALMA) and the Atacama Pathfinder EXperiment (APEX) in the Atacama Desert in Chile, co-owned and co-operated by ESO on behalf of its member states in Europe. Europe also contributes to the EHT observations with other radio observatories — the IRAM 30-meter telescope in Spain and, since 2018, the NOrthern



Size comparison of the two black holes imaged by the Event Horizon Telescope (EHT) Collaboration: M87*, at the heart of the galaxy Messier 87, and Sagittarius A* (Sgr A*), at the centre of the Milky Way. The image shows the scale of Sgr A* in comparison with both M87* and other elements of the Solar System such as the orbits of Pluto and Mercury. Also displayed is the Sun's diameter and the current location of the Voyager 1 space probe, the furthest spacecraft from Earth. M87*, which lies 55 million light-years away, is one of the largest black holes known. While Sgr A*, 27,000 light-years away, has a mass roughly four million times the Sun's mass, M87* is more than 1000 times more massive. Because of their relative distances from Earth, both black holes appear the same size in the sky. [EHT collaboration (acknowledgment: Lia Medeiros, xkcd)]

Extended Millimeter Array (NOEMA) in France — as well as a supercomputer to combine EHT data hosted by the Max Planck Institute for Radio Astronomy in Germany.
Moreover, Europe contributed with funding to the EHT consortium project through grants by the European Research Council and by the Max Planck Society in Germany.
"It is very exciting for ESO to have been playing such an important role in unravelling the mysteries of black holes, and of Sgr A in particular, over so many years,"* commented ESO Director General Xavier Barcons. *"ESO not only contributed to the EHT observations through the ALMA and APEX facilities but also enabled, with its other observatories in Chile, some of the previous breakthrough observations of the Galactic centre."*
The EHT achievement follows the collaboration's 2019 release of the first image of a black hole, called M87*, at the centre of the more distant Messier 87 galaxy.
The two black holes look remarkably similar, even though our galaxy's black hole is more than a thousand times smaller and less massive than M87*. *"We have two completely different types of galaxies and two very different black hole masses, but close to the edge of these black holes they look amazingly similar,"* says Sera Markoff, Co-Chair of the EHT Science Council and a professor of theoretical astrophysics at the University of Amsterdam, the Netherlands. *"This tells us that General Relativity governs these objects up close, and any differences we see further away must be due to differences in the material that surrounds the black holes."* This achievement was considerably more difficult than for M87*, even though Sgr A* is much closer to us. EHT scientist Chi-kwan ('CK') Chan, from Steward Observatory and Department of Astronomy and the Data Science Institute of the University of Arizona, USA, explains: *"The gas in the vicinity of the black holes moves at the same speed — nearly as fast as light*

— around both Sgr A and M87*. But where gas takes days to weeks to orbit the larger M87*, in the much smaller Sgr A* it completes an orbit in mere minutes. This means the brightness and pattern of the gas around Sgr A* were changing rapidly as the EHT Collaboration was observing it — a bit like trying to take a clear picture of a puppy quickly chasing its tail."*

The researchers had to develop sophisticated new tools that accounted for the gas movement around Sgr A*.

While M87* was an easier, steadier target, with nearly all images looking the same, that was not the case for Sgr A*.

A global map showing the radio observatories that form the Event Horizon Telescope (EHT) network used to image the Milky Way's central black hole, Sagittarius A. The telescopes highlighted in yellow were part of the EHT network during the observations of Sagittarius A* in 2017. These include the Atacama Large Millimeter/submillimeter Array (ALMA), the Atacama Pathfinder EXperiment (APEX), IRAM 30-meter telescope, James Clark Maxwell Telescope (JCMT), Large Millimeter Telescope (LMT), Submillimeter Array (SMA), Submillimetere Telescope (SMT) and South Pole Telescope (SPT). Highlighted in blue are the three telescopes added to the EHT Collaboration after 2018: the Greenland Telescope, the NOrthern Extended Millimeter Array (NOEMA) in France, and the UArizona ARO 12-meter Telescope at Kitt Peak. [ESO/M. Kornmesser]*

The image of the Sgr A* black hole is an average of the different images the team extracted, finally revealing the giant lurking at the centre of our galaxy for the first time. The effort was made possible through the ingenuity of more than 300 researchers from 80 institutes around the world that together make up the EHT Collaboration.

In addition to developing complex tools to overcome the challenges of imaging Sgr A*, the team worked rigorously for five years, using supercomputers to combine and analyse their data, all while compiling an unprecedented library of simulated black holes to compare with the observations.

Scientists are particularly excited to finally have images of two black holes of very different sizes, which offers the opportunity to understand how they compare and contrast. They have also begun to use the new data to test theories and models of how gas behaves around supermassive black holes.

This process is not yet fully understood but is thought to play a key role in shaping the formation and evolution of galaxies.

"Now we can study the differences between these two supermassive black holes to gain valuable new clues about how this important process works," said EHT scientist Keiichi Asada from the Institute of Astronomy and Astrophysics, Academia Sinica, Taipei. *"We have images for two black holes — one at the large end and one at the small end of supermassive black holes in the Universe — so we can go a lot further in testing how gravity behaves in these extreme environments than ever before."*

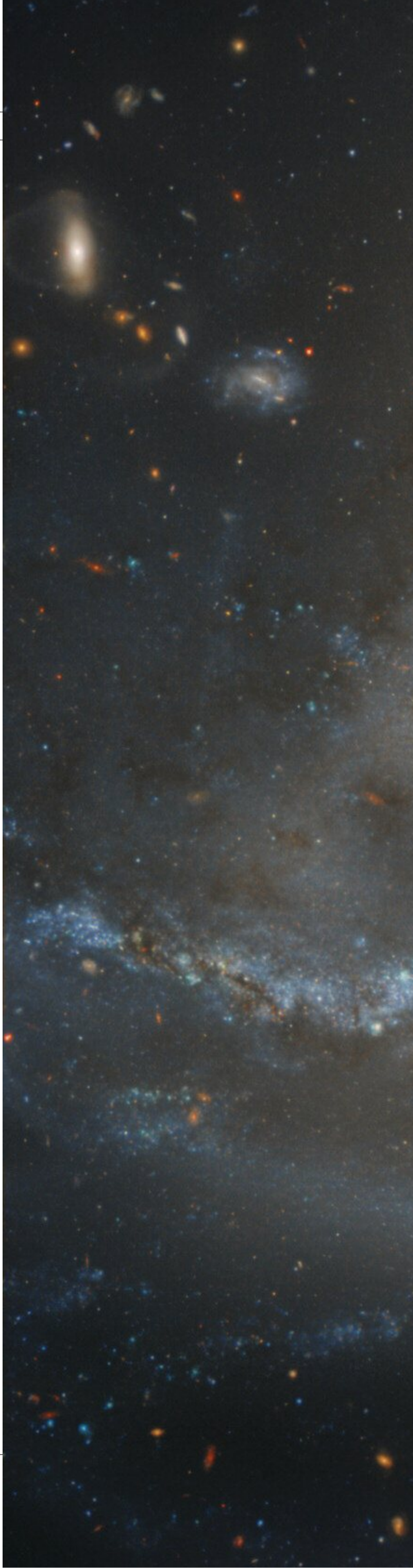
Progress on the EHT continues: a ma- jor observation campaign in March 2022 included more telescopes than ever before. The ongoing expansion of the EHT network and significant technological upgrades will allow scientists to share even more impressive images as well as movies of black holes in the near future.

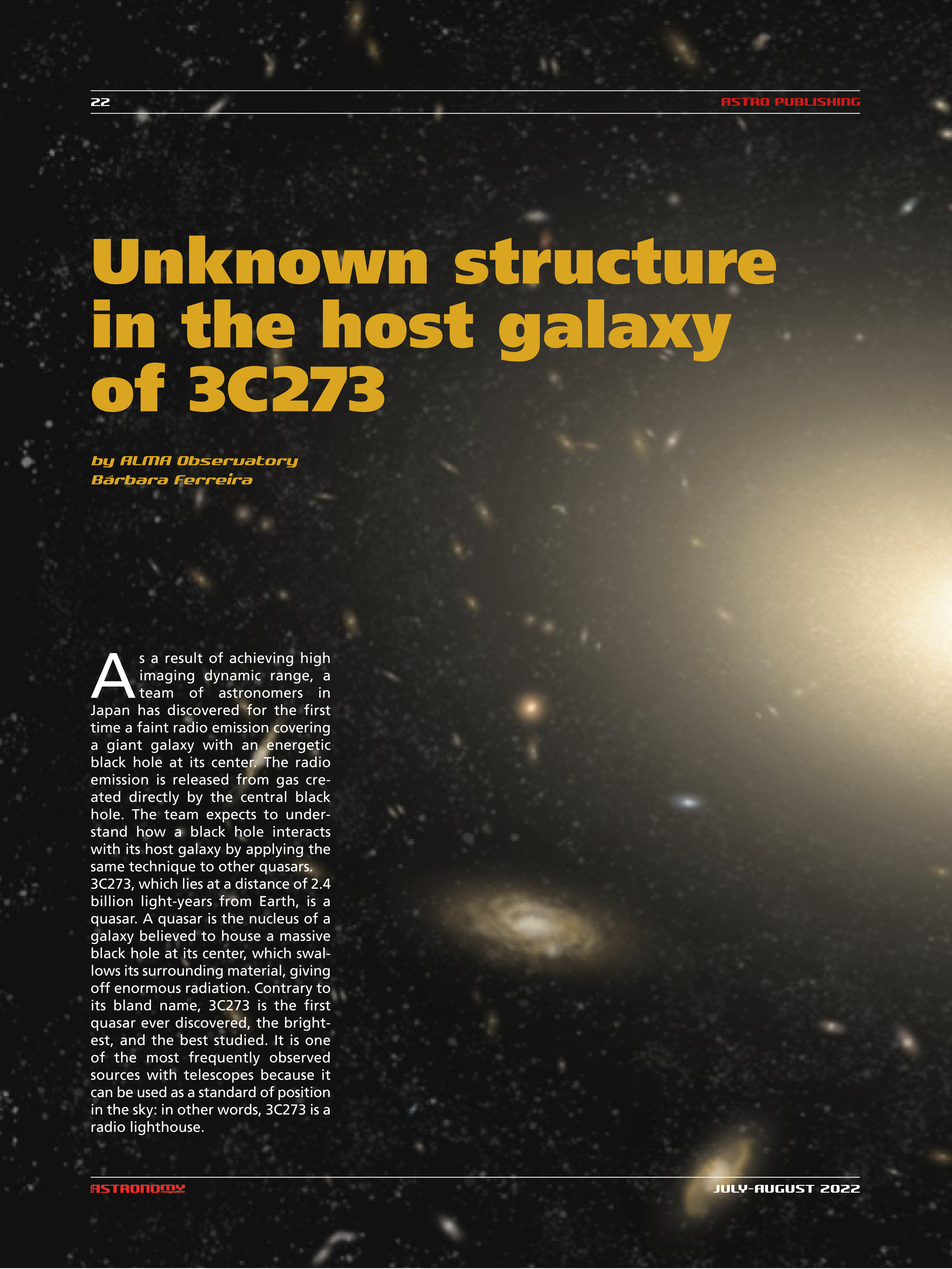
An extra large galactic arm

by NOIRLab
Amanda Kocz

This impressive image shows the strangely lopsided spiral galaxy NGC 772, which lies over 100 million light-years from Earth in the constellation Aries. Captured by the Gemini North telescope in Hawai'i, one half of the international Gemini Observatory, a Program of NSF's NOIRLab, the image shows NGC 772's overdeveloped spiral arm, which stretches across toward the left-hand edge of the frame. This extra large arm is due to one of NGC 772's unruly neighbors, the dwarf elliptical galaxy NGC 770. The tidal interactions between NGC 772 and its diminutive companion have distorted and stretched one of the spiral galaxy's arms, giving it the lopsided appearance seen in this image. NGC 772 also lacks a bright central bar. Other spiral galaxies such as the Andromeda Galaxy or our own Milky Way exhibit prominent central bars — large, linear structures composed of gas, dust, and countless stars. Without a bar, NGC 772's spiral arms sweep out directly from the bright center of the galaxy. The galaxy's unusual appearance has earned it the distinction of appearing in the Atlas of Peculiar Galaxies, a careful curation by astronomer Halton Arp of some of the weird and wonderful galaxies populating the Universe. The 338 galaxies in the Atlas are a rogues' gallery of strange and unusual galaxy shapes chosen to provide astronomers with a catalog of odd galaxy structures. Entries in the Atlas of Peculiar Galaxies include galaxies boasting trailing tidal tails, rings, jets, detached segments, and a host of other structural idiosyncrasies. NGC 772 is included as Arp 78. While NGC 772's peculiarities dominate this image, there is also a menagerie of galaxies lurking in the background. The bright smears and smudges littering this image are distant galaxies — some of the closer examples can be resolved into characteristic spiral shapes. Every direction on the sky that astronomers have pointed telescopes toward contains a rich carpet of galaxies, with an estimated 2 trillion galaxies in total in our observable Universe. ■

The overdeveloped spiral arm of the galaxy NGC 772, which was created by tidal interactions with an unruly neighbor, dominates this observation made by astronomers using the Gemini North telescope located near the summit of Maunakea in Hawai'i. [International Gemini Observatory/NOIRLab/NSF/AURA. Image processing: T.A. Rector (University of Alaska Anchorage), J. Miller (Gemini Observatory/NSF's NOIRLab), M. Zamani & D. de Martin]



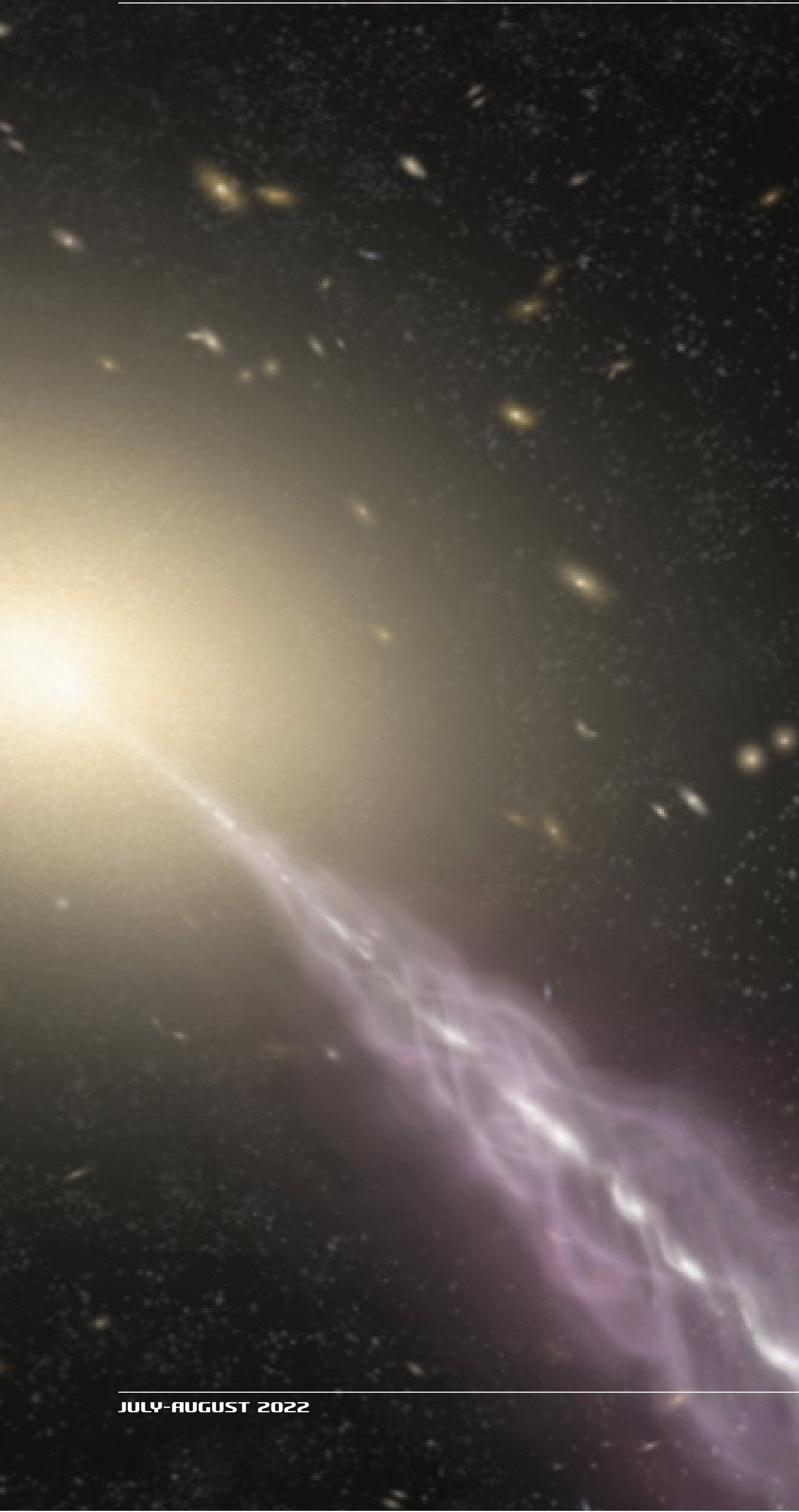


Unknown structure in the host galaxy of 3C273

by ALMA Observatory
Bárbara Ferreira

As a result of achieving high imaging dynamic range, a team of astronomers in Japan has discovered for the first time a faint radio emission covering a giant galaxy with an energetic black hole at its center. The radio emission is released from gas created directly by the central black hole. The team expects to understand how a black hole interacts with its host galaxy by applying the same technique to other quasars.

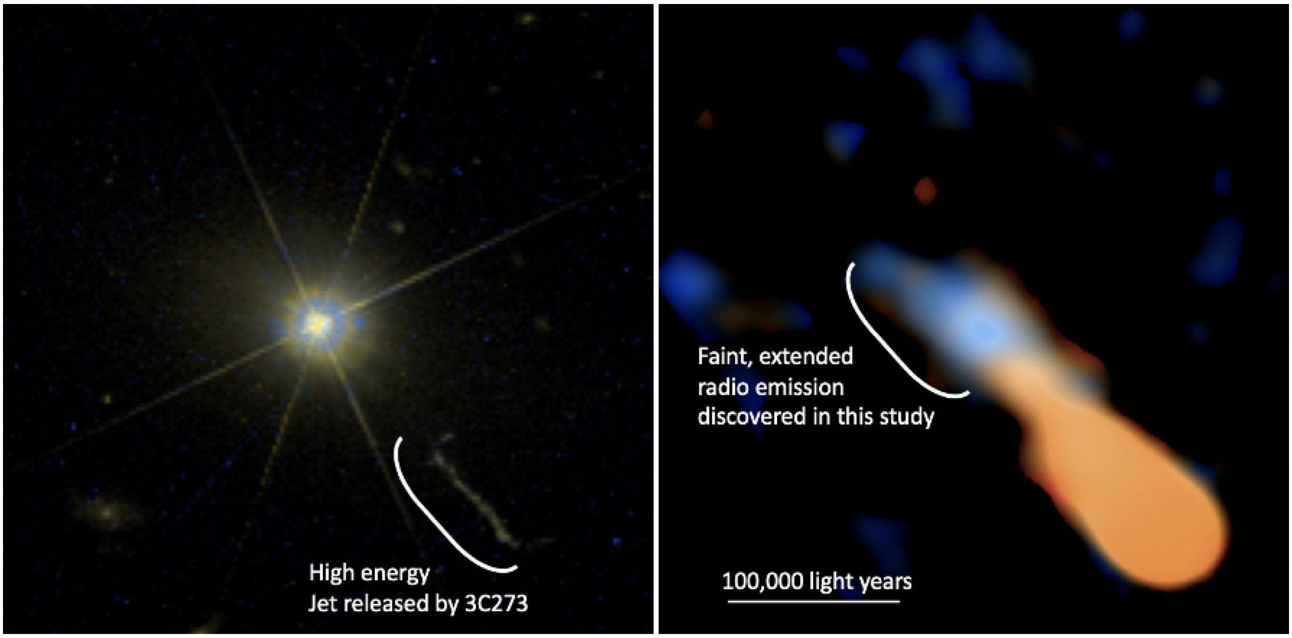
3C273, which lies at a distance of 2.4 billion light-years from Earth, is a quasar. A quasar is the nucleus of a galaxy believed to house a massive black hole at its center, which swallows its surrounding material, giving off enormous radiation. Contrary to its bland name, 3C273 is the first quasar ever discovered, the brightest, and the best studied. It is one of the most frequently observed sources with telescopes because it can be used as a standard of position in the sky: in other words, 3C273 is a radio lighthouse.



When you see a car's headlight, the dazzling brightness makes it challenging to see the darker surroundings. The same thing happens to telescopes when you observe bright objects. Dynamic range is the contrast between the most brilliant and darkest tones in an image. You need a high dynamic range to reveal both the bright and dark parts in a telescope's single shot. ALMA can regularly attain imaging dynamic ranges up to around 100, but commercially available digital cameras would typically have a dynamic range of several thousands. Radio telescopes aren't very good at seeing objects with significant contrast.

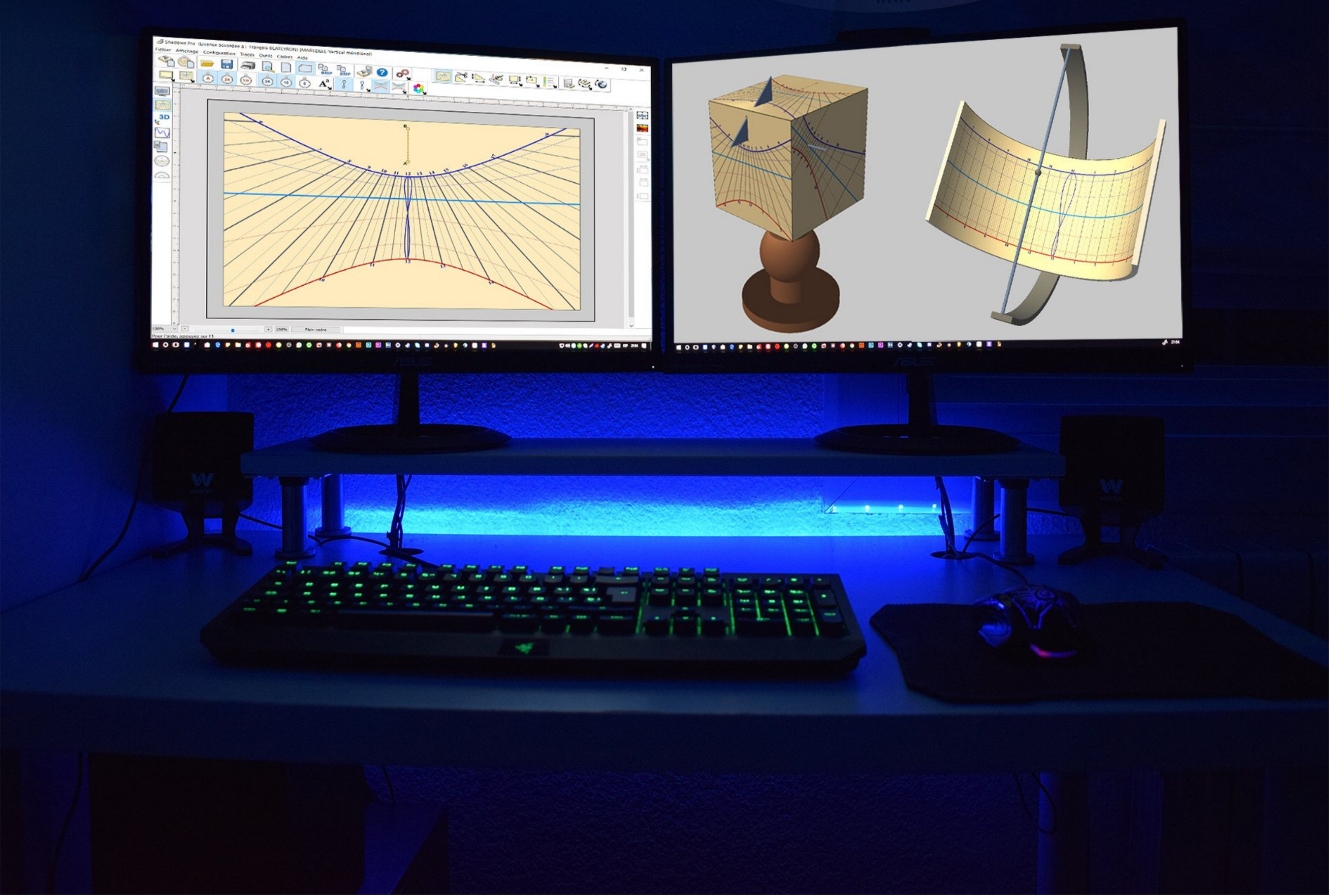
3C273 has been known for decades as the most famous quasar, but knowledge has been concentrated on its bright central nuclei, where most radio waves come from. However, much less has been known about its host galaxy itself because the combination of the faint and diffuse galaxy with the 3C273 nucleus required such high dynamic ranges to detect. The research team used a technique called self-calibration to reduce the leakage of radio waves from 3C273 to the galaxy, which used 3C273 itself to correct for the effects of Earth's atmospheric fluctuations on the telescope system. They reached an imaging dynamic range of 85000, an ALMA record for extragalactic objects. As a result of achieving high imaging dynamic range, the team discovered the faint radio emission extending for tens of thousands of light-years over the host galaxy of 3C273. Radio emission around quasars typically suggests synchrotron emission, which comes from highly energetic events like bursts of star formation or ultra-fast

Artist's impression of a giant galaxy with a high-energy jet. [ALMA (ESO/NAOJ/NRAO)]



Quasar 3C273 observed by the Hubble Space Telescope (left). The exceeding brightness results in radial leaks of light created by light scattered by the telescope. At the lower right is a high-energy jet released by the gas around the central black hole. Radio image of 3C273 (right) observed by ALMA, showing the faint and extended radio emission (in blue-white color) around the nucleus. The bright central source has been subtracted from the image. The same jet as the image on the left can be seen in orange. [Komugi et al., NASA/ESA Hubble Space Telescope]

jets emanating from the central nucleus. A synchrotron jet exists in 3C273 as well, seen in the lower right of the images. An essential characteristic of synchrotron emission is its brightness changes with frequency, but the faint radio emission discovered by the team had constant brightness irrespective of the radio frequency. After considering alternative mechanisms, the team found that this faint and extended radio emission came from hydrogen gas in the galaxy energized directly by the 3C273 nucleus. This is the first time that radio waves from such a mechanism are found to extend for tens of thousands of light-years in the host galaxy of a quasar. Astronomers had overlooked this phenomenon for decades in this iconic cosmic lighthouse. So why is this discovery so important? It has been a big mystery in galactic astronomy whether the energy from a quasar nucleus can be strong enough to deprive the galaxy's ability to form stars. The faint radio emission may help to solve it. Hydrogen gas is an essential ingredient in creating stars, but if such an intense light shines on it that the gas is disassembled (ionized), no stars can be born. To study whether this process is happening around quasars, astronomers have used optical light emitted by ionized gas. The problem working with optical light is that cosmic dust absorbs the light along the way to the telescope, so it is difficult to know how much light the gas gives off. Moreover, the mechanism responsible for giving off optical light is complex, forcing astronomers to make a lot of assumptions. The radio waves discovered in this study come from the same gas due to simple processes and are not absorbed by dust. Using radio waves makes measuring ionized gas created by 3C273's nucleus much easier. In this study, the astronomers found that at least 7% of the light from 3C273 was absorbed by gas in the host galaxy, creating ionized gas amounting to 10-100 billion times the sun's mass. However, 3C273 had a lot of gas just before the formation of stars, so as a whole, it didn't look like star formation was strongly suppressed by the nucleus. *"This discovery provides a new avenue to studying problems previously tackled using observations by optical light,"* says Shinya Komugi, an associate professor at Kogakuin University and lead author of the study published in *The Astrophysical Journal*. *"By applying the same technique to other quasars, we expect to understand how a galaxy evolves through its interaction with the central nucleus."* ■



The first direct evidence for an interstellar black hole

by NASA/ESA
Bethany Downer

Astronomers estimate that 100 million black holes roam among the stars in our Milky Way galaxy, but they have never conclusively identified an isolated black hole. Following six years of meticulous observations, the NASA/ESA Hubble Space Telescope has, for the first time ever, provided direct evidence for a lone black hole drifting through interstellar space by a precise mass measurement of the phantom object. Until now, all black hole masses have been inferred statistically or through interactions in

This is an artist's impression of a black hole drifting through our Milky Way galaxy. The black hole is the crushed remnant of a massive star that exploded as a supernova. The surviving core is several times the mass of our Sun. The black hole traps light because of its intense gravitational field. The black hole distorts the space around it, which warps images of background stars lined up almost directly behind it. This gravitational "lensing" effect offers the only telltale evidence for the existence of lone black holes wandering our galaxy, of which there may be a population of 100 million. The Hubble Space Telescope goes hunting for these black holes by looking for distortion in starlight as the black holes drift in front of background stars. [ESA/Hubble, Digitized Sky Survey, Nick Risinger (skysurvey.org), N. Bartmann]

binary systems or in the cores of galaxies. Stellar-mass black holes are usually found with companion stars, making this one unusual.

The newly detected wandering black hole lies about 5,000 light-years away, in the Carina-Sagittarius spiral arm of our galaxy. However, its discovery allows astronomers to estimate that the nearest isolated stellar-mass black hole to Earth might be as close as 80 light-years away. The nearest star to our solar system, Proxima Centauri, is a little over 4 light-years away.

Black holes roaming our galaxy are born from rare, monstrous stars (less than one-thousandth of the galaxy's stellar population) that are at least 20 times more massive than our Sun. These stars explode as supernovae, and the remnant core is crushed by gravity into a black hole. Because the self-detonation is not perfectly symmetrical, the black hole may get a kick, and go careening through our galaxy like a blasted cannonball.

Telescopes can't photograph a wayward black hole because it doesn't emit any light. However, a black hole warps space, which then deflects and amplifies starlight from anything that momentarily lines up exactly behind it.

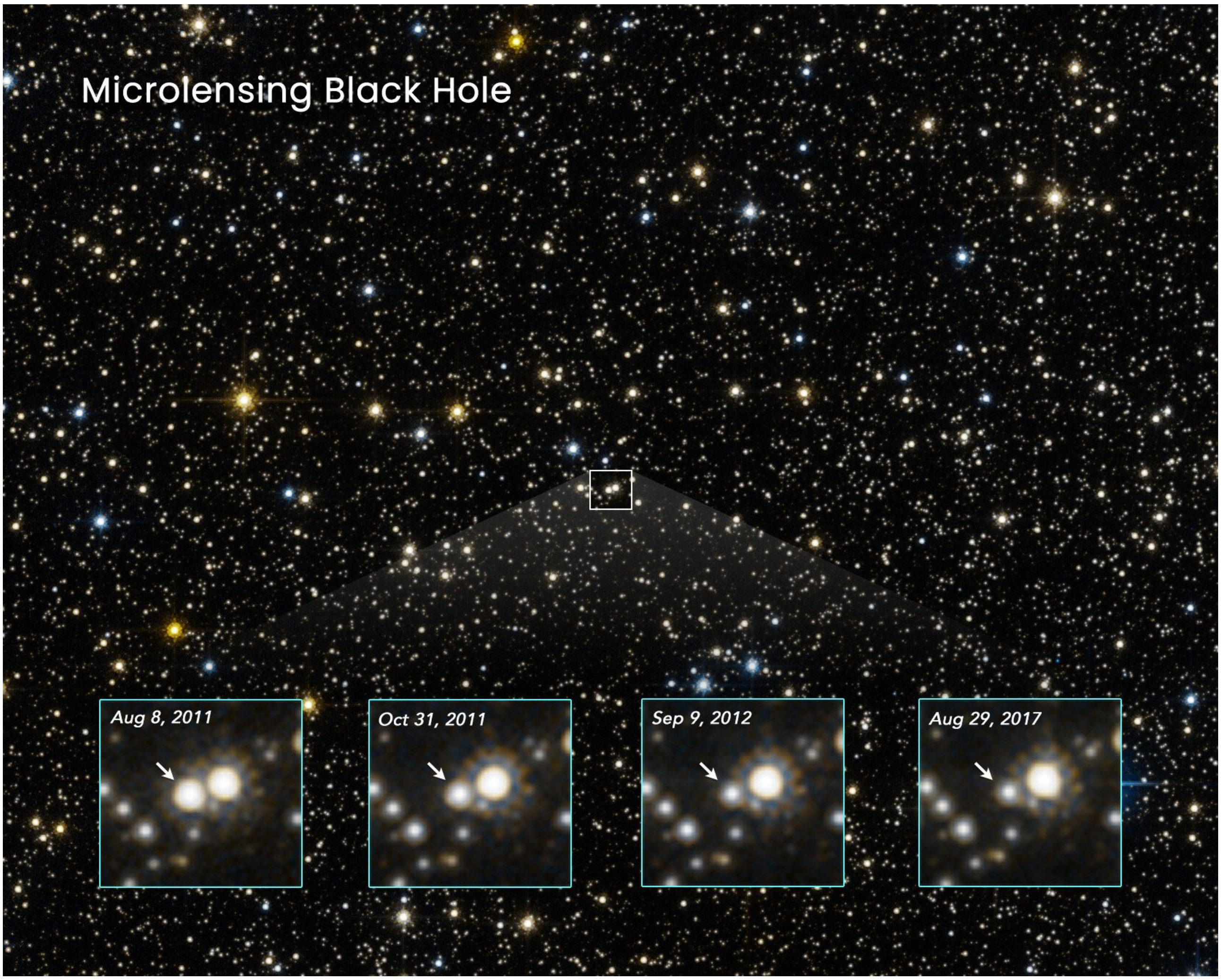
Ground-based telescopes, which monitor the brightness of millions of stars in the rich star fields toward the central bulge of our Milky Way, look for a tell-tale sudden brightening of one of them when a massive object passes between us and the star. Then Hubble follows up on the most interesting such events.

Two teams used Hubble data in their investigations — one led by Kailash Sahu of the Space Telescope Science Institute in Baltimore, Maryland; and the other by Casey Lam of the University of California, Berkeley. The teams' results differ slightly, but both suggest the presence of a compact object.

The warping of space due to the gravity of a foreground object passing in front of a star located far behind it will momentarily bend and amplify the light of the background star as it passes in front of it. Astronomers use the phenomenon, called gravitational microlensing, to study stars and exoplanets in the approximately 30,000 events seen so far inside our galaxy.

The signature of a foreground black hole stands out as unique among other microlensing events. The very intense gravity of the black hole will stretch out the duration of the lensing event for over 200 days.

Also, if the intervening object was instead a foreground star, it would cause a transient color change in the



The star-filled sky in this NASA/ESA Hubble Space Telescope photo lies in the direction of the Galactic centre. The light from stars is monitored to see if any change in their apparent brightness is caused by a foreground object drifting in front of them. The warping of space by the interloper would momentarily brighten the appearance of a background star, an effect called gravitational lensing. One such event is shown in the four close-up frames at the bottom. The arrow points to a star that momentarily brightened, as first captured by Hubble in August 2011. This was caused by a foreground black hole drifting in front of the star, along our line of sight. The star brightened and then subsequently faded back to its normal brightness as the black hole passed by. Because a black hole doesn't emit or reflect light, it cannot be directly observed. But its unique thumbprint on the fabric of space can be measured through these so-called microlensing events. Though an estimated 100 million isolated black holes roam our galaxy, finding the telltale signature of one is a needle-in-a-haystack search for Hubble astronomers. [NASA, ESA, K. Sahu (STScI), J. DePasquale (STScI)]

starlight as measured because the light from the foreground and background stars would momentarily be blended together. But no color change was seen in the black hole event.

Next, Hubble was used to measure the amount of deflection of the background star's image by the black hole. Hubble is capable of the extraordinary precision needed for such measurements. The star's image was offset from where it normally would be by about a milliarcsecond. That's equivalent to measuring the height of an adult human lying on the surface of the moon from the Earth.

This astrometric microlensing technique provided information on the mass, distance, and velocity of the black hole. The amount of deflection by the black hole's intense warping of space allowed Sahu's team to estimate that it weighs seven solar masses.

Lam's team reports a slightly lower mass range, meaning that the object may be either a neutron star or a black hole. They estimate that the mass of the invisible compact object is between 1.6 and 4.4 times that of the Sun. At the high end of this range the object would be a black hole; at the low end, it would be a neutron star. *"As much as we would like to say it is definitively a black hole, we must report all allowed solutions. This includes both lower mass black holes and possibly even a neutron star,"* said Jessica Lu of the Berkeley team. "*Whatever it is, the object is the first dark stellar remnant discovered wandering through the galaxy, unacompanied by another star"* Lam added.

This was a particularly difficult measurement for the team because there is another bright star that is extremely close in angular separation to the source star. *"So it's like trying to measure the tiny motion of a firefly next to a bright light bulb,"* said Sahu. *"We had to meticulously subtract the light of the nearby bright star to precisely measure the deflection of the faint source."*

Sahu's team estimates the isolated black hole is traveling across the galaxy at 160,000 kilometres per hour (fast enough to travel from Earth to the Moon in less than three hours). That's faster than most of the other neighbouring stars in that region of our galaxy.

"Astrometric microlensing is conceptually simple but observationally very tough," said Sahu. *"Microlensing is the only technique available for identifying isolated black holes."*

Following six years of meticulous observations, the NASA/ESA Hubble Space Telescope has provided, for the first time ever, clear evidence for a lone black hole drifting through interstellar space. This is the first time the mass of an isolated black hole has been measured. This video summarizes the discovery. [ESA/Hubble, ESA, NASA, STScI, Digitized Sky Survey, Nick Risinger (skysurvey.org)]

When the black hole passed in front of a background star located 19,000 light-years away in the galactic bulge, the starlight coming toward Earth was amplified for a duration of 270 days as the black hole passed by. However, it took several years of Hubble observations to follow how the background star's position appeared to be deflected by the bending of light by the foreground black hole.

The existence of stellar-mass black holes has been known since the early 1970s, but all of their mass measurements — until now — have been in binary star systems. Gas from the companion star falls into the black hole and is heated to such high temperatures that it emits X-rays. About two dozen black holes have had their masses measured in X-ray binaries through their gravitational effect on their companions. Mass estimates range from 5 to 20 solar masses. Black holes detected in other galaxies by gravitational waves from mergers between black holes and companion objects have been as high as 90 solar masses.

"Detections of isolated black holes will provide new insights into the population of these objects in the Milky Way," said Sahu. He expects that his programme will uncover more free-roaming black holes inside our galaxy. But it is a needle-in-a-haystack search. The prediction is that only one in a few hundred microlensing events are caused by isolated black holes.

In his 1916 paper on general relativity, Albert Einstein predicted that his theory could be tested by observing the offset in the apparent position of a background star caused by the Sun's gravity. This was tested by a collaboration led by astronomers Arthur Eddington and Frank Dyson during a solar eclipse on 29 May 1919. Eddington and his colleagues measured a background star being offset by 2 arc seconds, validating Einstein's theories. These scientists could hardly have imagined that over a century later this same technique would be used — with a then-unimaginable thousandfold improvement in precision — to look for black holes across our galaxy. ■

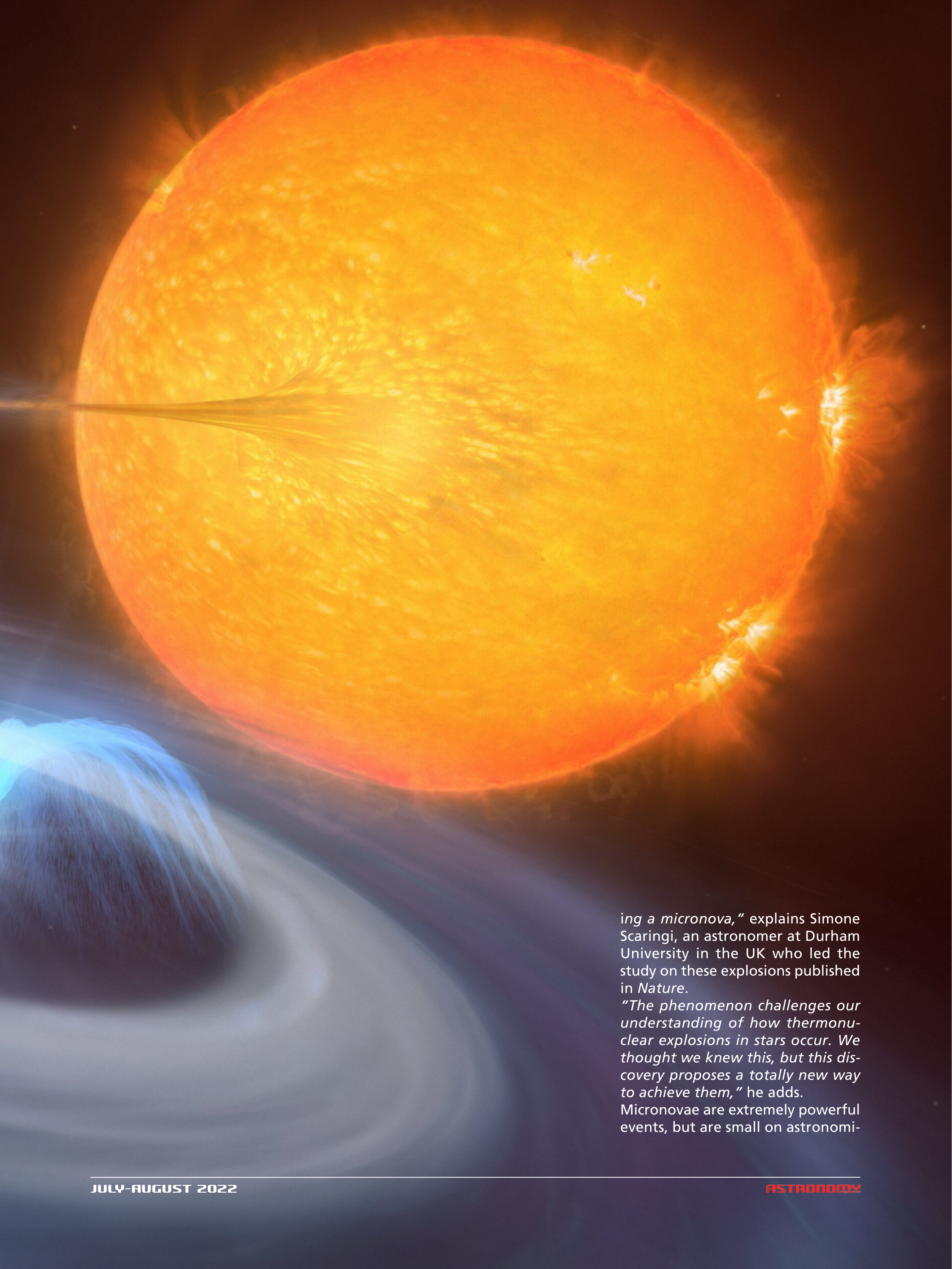
Micronovae, a new kind of stellar explosions

by ESO - Bárbara Ferreira

A team of astronomers, with the help of the European Southern Observatory's Very Large Telescope (ESO's VLT), have observed a new type of stellar explosion — a micronova. These outbursts happen on the surface of certain stars, and can each burn through around 3.5 billion Great Pyramids of Giza of stellar material in only a few hours.

"We have discovered and identified for the first time what we are call-

This artist's impression shows a two-star system where micronovae may occur. The blue disc swirling around the bright white dwarf in the centre of the image is made up of material, mostly hydrogen, stolen from its companion star. Towards the centre of the disc, the white dwarf uses its strong magnetic fields to funnel the hydrogen towards its poles. As the material falls on the hot surface of the star, it triggers a micronova explosion, contained by the magnetic fields at one of the white dwarf's poles. [ESO/M. Kornmesser, L. Calçada]



ing a micronova," explains Simone Scaringi, an astronomer at Durham University in the UK who led the study on these explosions published in *Nature*.

"The phenomenon challenges our understanding of how thermonuclear explosions in stars occur. We thought we knew this, but this discovery proposes a totally new way to achieve them," he adds.

Micronovae are extremely powerful events, but are small on astronomi-

The illustration on the background shows a two-star system, with a white dwarf (in the foreground) and a companion star (in the background), where micronovae may occur. The white dwarf steals materials from its companion, which is funneled towards its poles. As the material falls on the hot surface of the white dwarf, it triggers a micronova explosion, contained at one of the star's poles. [Mark Garlick (http://www.markgarlick.com/)]

cal scales; they are much less energetic than the stellar explosions known as novae, which astronomers have known about for centuries. Both types of explosions occur on white dwarfs, dead stars with a mass about that of our Sun, but as small as Earth.

A white dwarf in a two-star system can steal material, mostly hydrogen, from its companion star if they are close enough together. As this gas falls onto the very hot surface of the white dwarf star, it triggers the hydrogen atoms to fuse into helium explosively. In novae, these thermonuclear explosions occur over the entire stellar surface.

"Such detonations make the entire surface of the white dwarf burn and shine brightly for several weeks," explains co-author Nathalie Degenaar, an astronomer at the University of Amsterdam, the Netherlands.

Micronovae are similar explosions that are smaller in scale and faster, lasting just several hours. They occur on some white dwarfs with strong magnetic fields, which funnel material towards the star's magnetic poles. *"For the first time, we have now seen that hydrogen fusion can also happen in a localised way. The hydrogen fuel can be contained at the base of the magnetic poles of some white dwarfs, so that fusion only happens at these magnetic poles,"* says Paul Groot, an astronomer at Radboud University in the Netherlands and co-author of the study.

"This leads to micro-fusion bombs going off, which have about one millionth of the strength of a nova explosion, hence the name micronova," Groot continues.

Although 'micro' may imply these events are small, do not be mistaken: just one of these outbursts can burn through about 20,000,000 trillion kg, or about 3.5 billion Great Pyramids of Giza, of material.

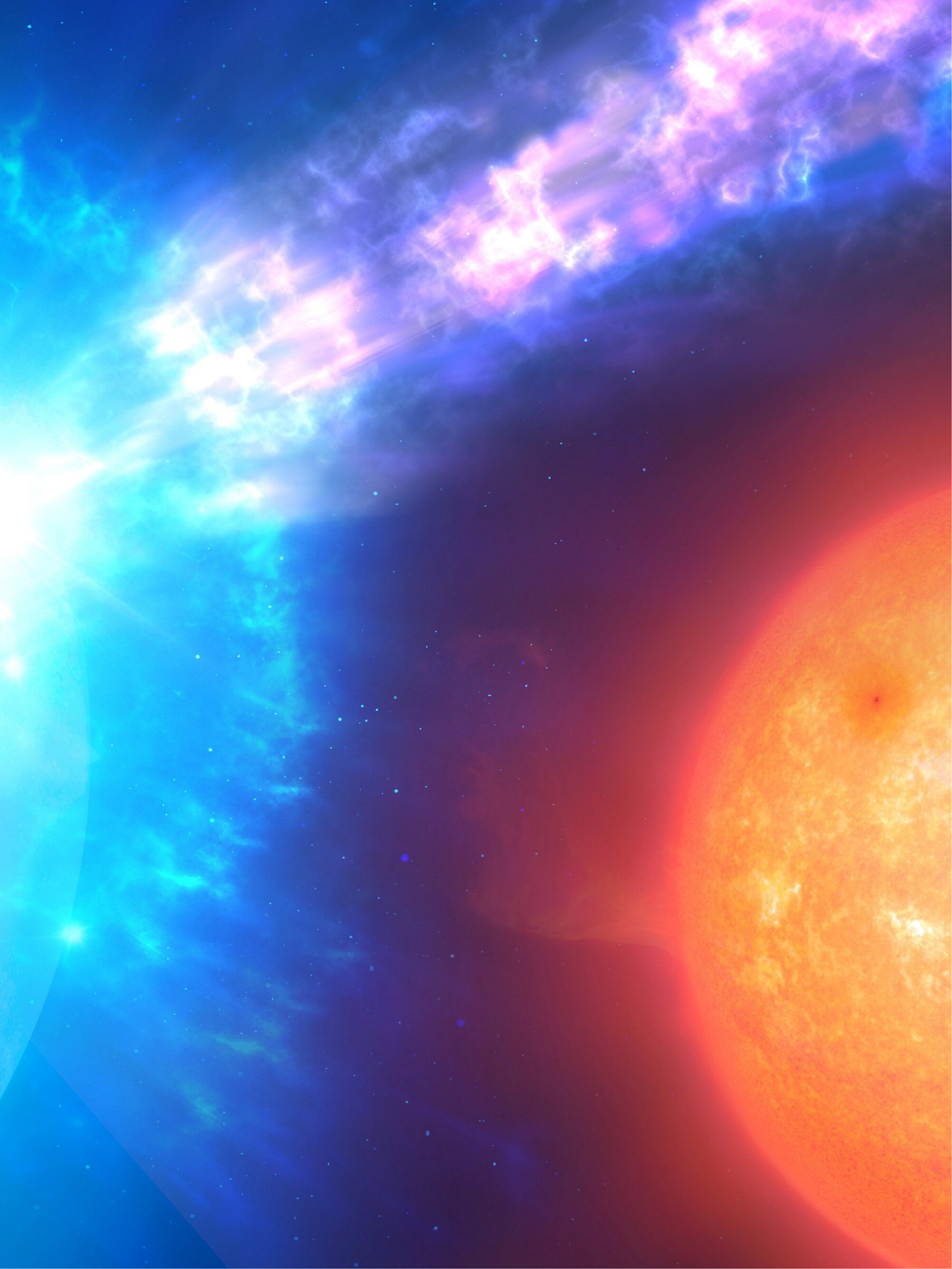
These new micronovae challenge astronomers' understanding of stellar explosions and may be more abundant than previously thought. *"It just goes to show how dynamic the Universe is. These events may actually be quite common, but because they are so fast they are difficult to catch in action,"* Scaringi explains.

Astronomers have discovered a new type of explosion occurring on white dwarf stars in two-star systems. This video summarises the discovery. [Mark Garlick (http://www.markgarlick.com/)]

The team first came across these mysterious micro-explosions when analysing data from NASA's Transiting Exoplanet Survey Satellite (TESS). *"Looking through astronomical data collected by NASA's TESS, we discovered something unusual: a bright flash of optical light lasting for a few hours. Searching further, we found several similar signals,"* says Degenaar. The team observed three micronovae with TESS: two were from known white dwarfs, but the third required further observations with the X-shooter instrument on ESO's VLT to confirm its white dwarf status.

"With help from ESO's Very Large Telescope, we found that all these optical flashes were produced by white dwarfs," says Degenaar. *"This observation was crucial in interpreting our result and for the discovery of micronovae,"* Scaringi adds.

The discovery of micronovae adds to the repertoire of known stellar explosions. The team now want to capture more of these elusive events, requiring large scale surveys and quick follow-up measurements. *"Rapid response from telescopes such as the VLT or ESO's New Technology Telescope and the suite of available instruments will allow us to unravel in more detail what these mysterious micronovae are,"* Scaringi concludes.



The Drake equation doubles

by Michele Ferrara

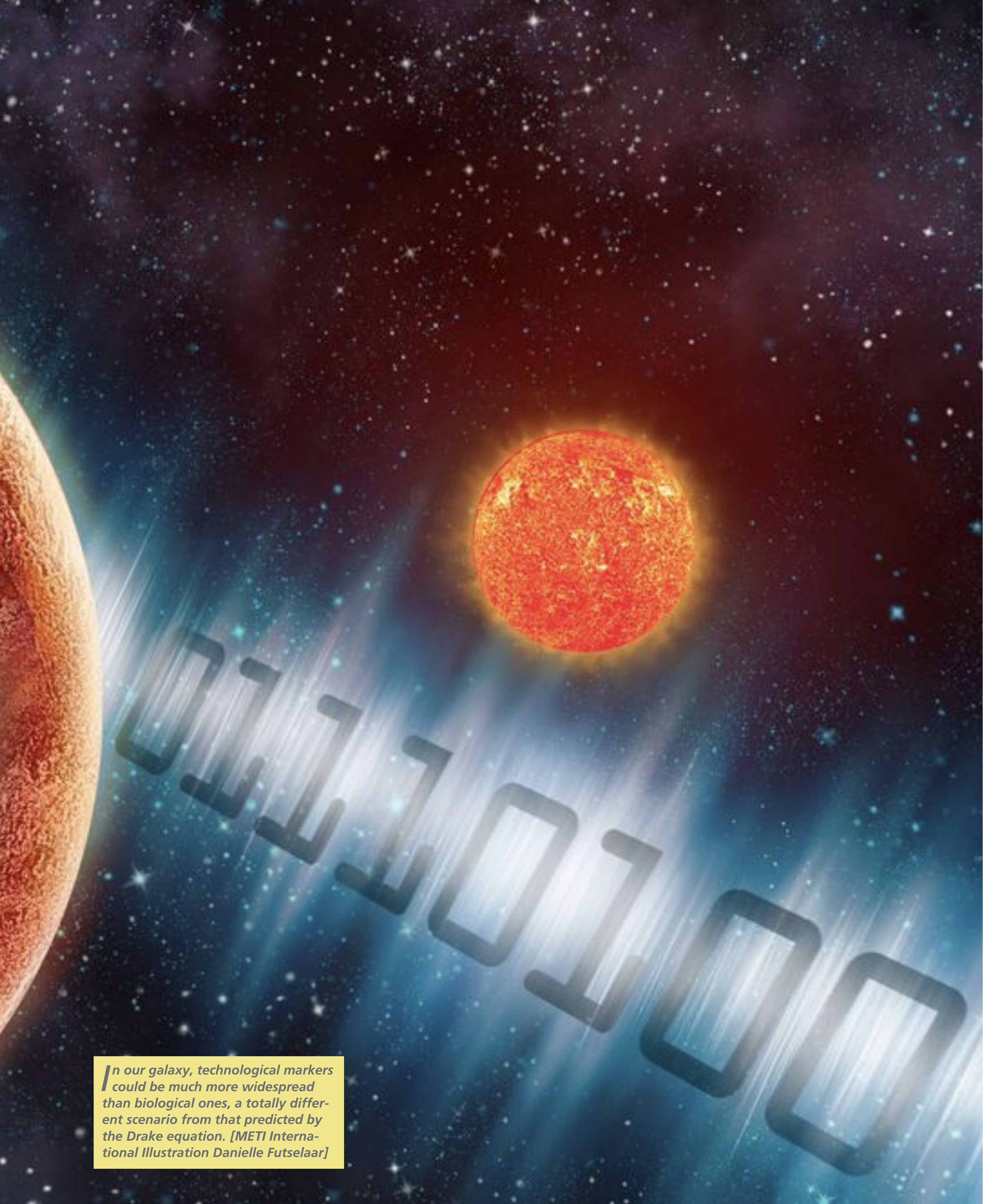
revised by Damian G. Allis
NASA Solar System Ambassador

In the early 1960s, astronomer Frank Drake proposed an equation designed to provide an estimate of the number of planets inhabited by intelligent species capable of communicating with the homologous species of other planets. That equation, still discussed today, is expressed in the following form:

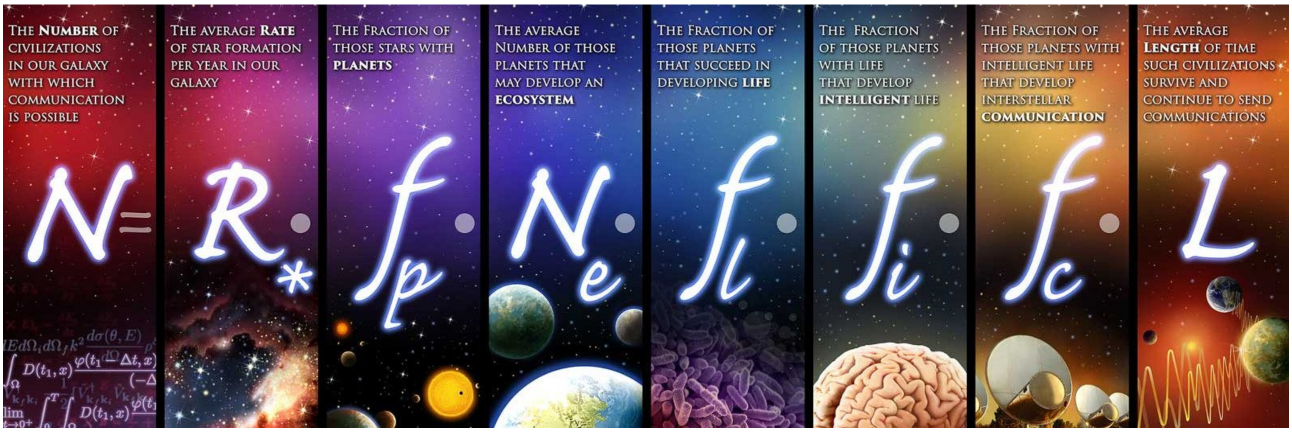
$$N = R_* f_p n_p f_l f_i f_c L$$

where **N** is the value searched, R_* the star formation rate of our galaxy, f_p the fraction of stars with planets, n_p the number of habitable planets per star, f_l the fraction of those planets that developed life, f_i the fraction of the latter on which there is intelligent life, and f_c the fraction of planets where intelligent life is able to communicate through technology. Finally, we have **L**, a most controversial term, which accounts for the average time during which a technological civilization sends detectable signals, consequently providing an estimate of the number of communicative species at any given time.

Beyond some questionable aspects, the Drake equation has a remarkably visionary quality. Consider that, when it was formulated, only R_* was barely known, while all the other terms had to assume the existence of exoplanets, the first of which was only discovered thirty years after the drawing up of the equation. It was probably that predictive ability that kept it in vogue until today, despite the many radical transformations that astronomical research has brought to our understanding of the cosmos.



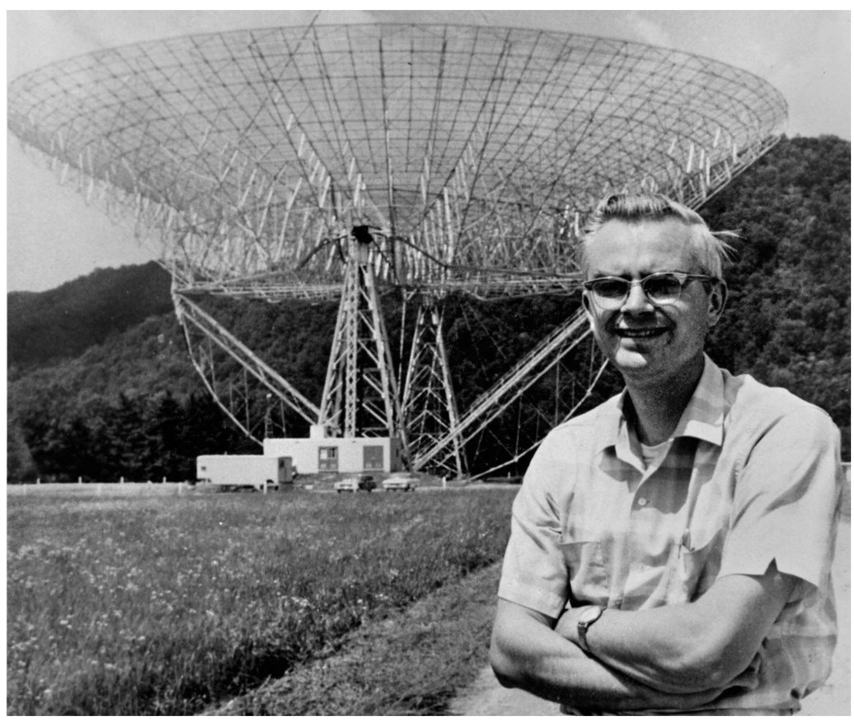
In our galaxy, technological markers could be much more widespread than biological ones, a totally different scenario from that predicted by the Drake equation. [METI International Illustration Danielle Futselaar]



The Drake equation represented in graphic and photographic form, to make all the terms included in it more intuitive.

However, in recent times, some terms of the Drake equation have begun to prove insufficient to correctly represent the weight that the biological and technological contributions may have on the discovery of extraterrestrial life. A careful examination of the subject was published last March in *The Astrophysical Journal Letters*, signed by six of the most famous researchers working in this field: Jason Wright, Jacob Haqq-Misra, Adam Frank, Ravi Kopparapu, Manasvi Lingam and Sofia Sheikh. The authors questioned the aspects of the equation related to the recognition of the effects of any technologies used by possible extraterrestrial intelligences. These effects are generically referred to as technosignatures. In the original formulation, the Drake equation implies that within our galaxy technosignatures must necessarily be less relevant than biosignatures, those that indicate the presence of non-technological life. This is evident by considering that f_c is a fraction of f_i. According to Wright and colleagues, the opposite may be true, although an objective and quantitative comparison between the relative abundances of yet undiscovered technosignatures and biosignatures is not possible.

The main reason why the Drake equation tends to underestimate the weight of technosignatures is because in the early 1960s there was a widespread belief that if there were alien civilizations, we would only discover them by picking up their radio signals, a single type of technosignature. Today we are aware that technosignatures can come in many forms and that the technologies that produce them can



In 1961, at the first meeting on the search for extraterrestrial intelligence (SETI), Frank Drake proposed his equation to assist in searching for alien life as a way to stimulate scientific discussion. In this picture, Drake poses in front of the National Radio Astronomy Observatory Green Bank. [NRAO] spread far beyond their origin in space, time and scope. In practice, the Drake equation cannot represent all of this. To bridge the gap, Wright and colleagues propose two new "Drake-like" equations.

The first variant is:

$$\mathbf{N(bio) = R_* f_p n_p f_l L_b}$$

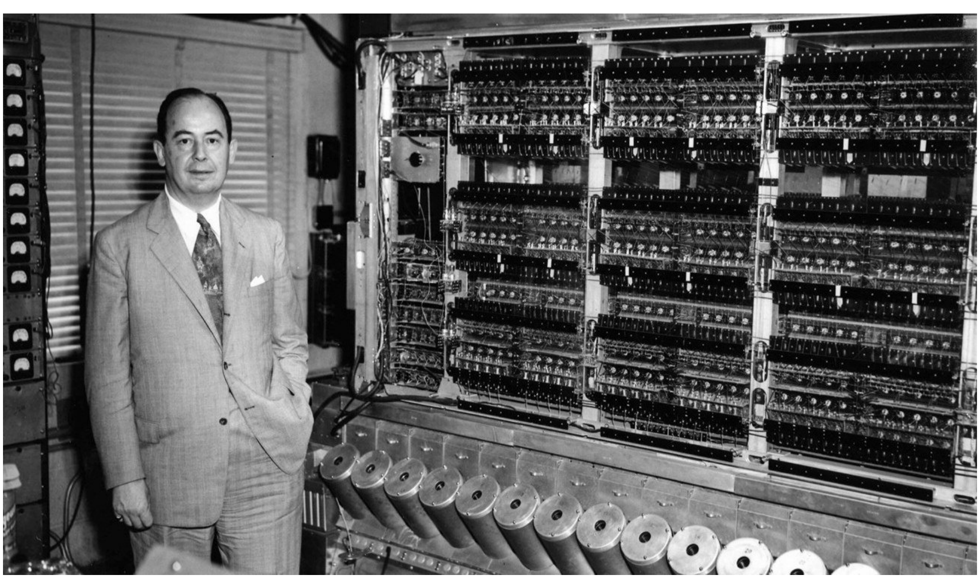
and is designed to estimate the number of planets with biosignatures detectable from Earth with current instruments and based on today's knowledge. The term $\mathbf{f_l}$ is here interpreted as the fraction of planets that develop biospheres comparable to ours, while $\mathbf{L_b}$ is the average time during which a biosphere is detectable.

The second variant is:

$$\mathbf{N(tech) = R_* f_p n_p f_l f_t L_t}$$

and provides an estimate of the number of planets with technosignatures, as we can expect based on our experiences. Here, $\mathbf{f_t}$ expresses the fraction of planets hosting intelligent life that produce technosignatures and is the equivalent of $f_i f_c$ in the canonical form of the equation. $\mathbf{L_t}$, on the other hand, is the time during which the technosignatures remain detectable.
If the evolution of life on Earth were the galactic standard and the technological level reached by humanity were the highest in the Milky Way, we could say that N(bio)>N(tech). However, the researchers rightly point out that although technology originates from biology, it can also exist regardless of the latter in various forms that the original equation does not capture. We can take the example of a technology resistant enough to survive the biosphere that created it and capable of producing technosigna-

Frank Drake speaking at Cornell University in Schwartz Auditorium, 19 October 2017. More than sixty years have passed since this astronomer proposed his famous equation, which still today generates discussions among astrobiologists. [Amalex5]



John Von Neumann, an eclectic and controversial genius of the twentieth century, is the father of the Theory of Self-Reproducing Automata, according to which, in the future, machines could replicate themselves regardless of the existence of human beings. This would allow them to spread across the galaxy in astronomically short times.

Jason Wright, is an associate professor of astronomy and astrophysics at The Pennsylvania State University poses for a portrait in the Davey Lab building on the Penn State campus on March 14, 2019. [Eric Firestine, Special to Penn-Live]

tures without technological life and even without a biosphere (Dyson spheres or other megastructures). Another example is a technological civilization that colonizes sterile worlds by creating technospheres. This will likely happen in our own solar system, when humanity has permanent installations on the Moon, Mars and beyond: a single biosphere (the Earth) in the face of two or more technospheres. Wright and colleagues go even further with the imagining, considering self-replicating technologies that spread across the galaxy regardless of technological life (a nearly century-old idea, attributable to John von Neumann).

Aside from the more daring scenarios, there are already more planets in our own solar system with technosignature sources than there are planets characterized by biosignatures. Of the latter there is only one, ours, while in the calculation of the former we must add to Earth three other planets – Venus, Mars and Jupiter – which are currently visited by terrestrial technological devices that produce technosignatures (radio waves) certainly weak but theoretically detectable by alien technologies.

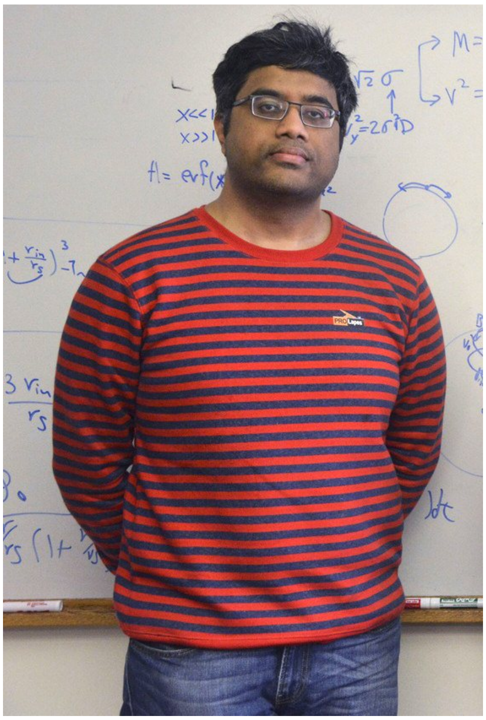
Jacob Haqq-Misra is a Senior Research Investigator at Blue Marble Space Institute of Science. [Penn State University]

Wright and colleagues estimate that if spreading technology across the galaxy is part of any civilization's evolutionary path, the Drake equation could go as far as underestimating N(tech) by ten billion times in some extreme scenarios. Obviously, it is not possible to make precise estimates and projections of galactic technosignature abundances based on the only example of a technological civilization that we know of.

Nevertheless, it is reasonable to expect that the values of N(tech) and N(bio) are strongly conditioned by L_t and L_b, respectively. Based on our experiences, we can think that L_t must be much smaller than L_b. In fact, the Earth hosts life that has been producing biosignatures for billions of years, while the first prominent technosignatures date back to only a few centuries ago.

Adam Frank speaks to an audience of Rochester community members. He was awarded the 2021 Carl Sagan Medal for excellence in public communication in planetary science. [University of Rochester / J. Adam Fenster]

Since its original formulation, the biggest unknown in the Drake equation has been the duration of a communicative civilization, paradoxically the only unknown of which we ourselves are the only known example.



Manasvi Lingam is a member of the Department of Aerospace, Physics and Space Sciences, Florida Institute of Technology. [Photo by Mia B. Frothingham]

The arbitrary average value initially attributed to L_c was around 10,000 years, perhaps even optimistic considering that the apex of the so-called "Cold War" was reached at the very beginning of the 1960s, when the use of nuclear weapons seemed close. After 60 years, the same scenario and threat has returned, "enriched" by a pandemic and the beginning of a climatic upheaval, whose developments we cannot predict. These are just some of the threats that, in extreme cases, could plunge humanity to a pre-technological level. Fortunately, there are no concrete reasons to believe that our civilization is representative of all possible alien civilizations existing in the galaxy. If there are others, they could aspire to longevity immeasurably greater than ours.

Suppose, however, that humanity comes to its senses as soon as possible and is able to fully exploit the vital time span that the Sun guarantees to the Earth, then another 1-2 billion years. Today, as well as in that distant future, L_t remains smaller than L_b because both are linked to a specific planet, on which biology has a much longer history than technology. Long before the Sun, in its red giant phase, engulfs the Earth, humanity will have already moved elsewhere, and having an almost infinite future ahead, it could happen that at some point L_t becomes greater than L_b. It can be deduced that if technosignatures are not already in excess compared to biosignatures today, they will probably be in the future.

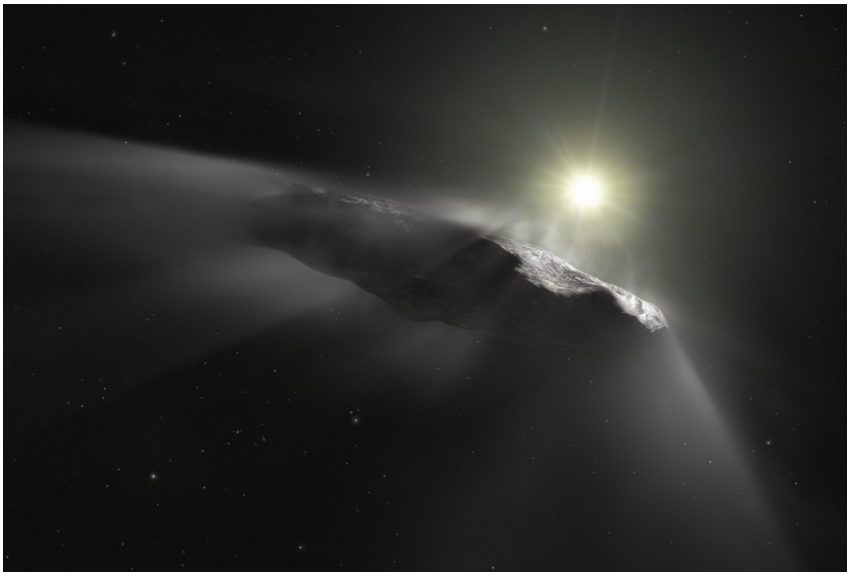
Anyway, we cannot rule out that humanity as a whole becomes so stupid as to annihilate itself, unleashing a nuclear war, creating lethal viruses or irreparably compromising the ecosystem. If this happens within a very short geologically time, another technological civilization could evolve after a pause of a few million years, a new civilization that would still have an immense time at its disposal to spread its technology throughout the galaxy, hopefully without making the same mistakes as ours. Curiously, just as we cannot quantify the L_t/L_b ratio for the future, we cannot quantify it for the past. In fact, although our civilization is having an indelible impact on geological records (in a word: Anthropocene), in millions of years the causes of the changes we are responsible for will not be distinguishable from the effects of natural processes and phenomena. If there had existed on Earth a technological civilization before ours, perhaps tens of millions of years ago, the chances of finding direct evidence of its passage would be feeble. We would be more likely to detect indirect evidence, such as anomalies in the chemical composi-

Ravi Kumar Kopparapu is a research scientist at NASA Goddard Space Flight Center, Greenbelt, MD.

Sofia Z. Sheikh is an NSF-ASCEND Postdoctoral Fellow at the SETI Institute, working on technosignature searches with the Allen Telescope Array.

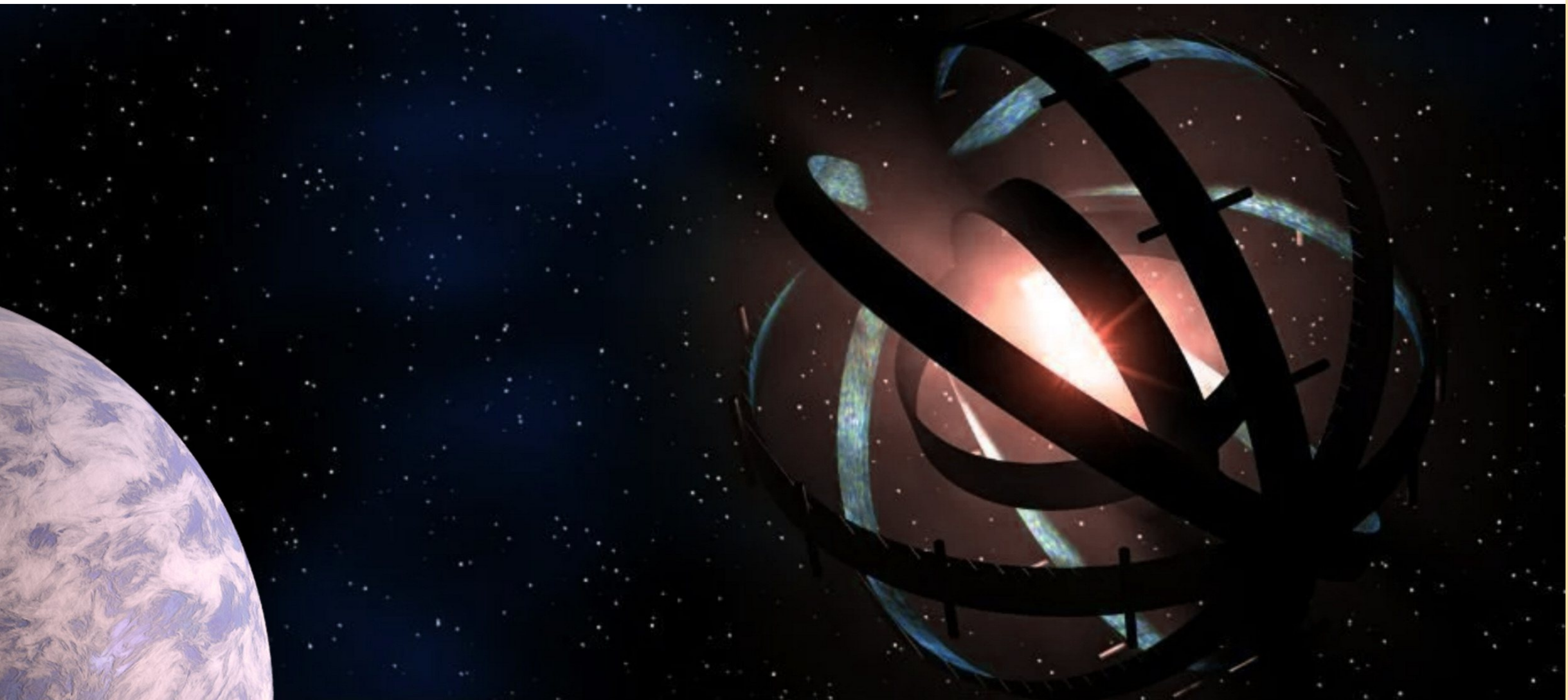
tion or isotope ratios of sediments, but we could not rule out natural causes behind such anomalies. However, the existence of a previous terrestrial civilization remains more of a thought experiment than a realistic hypothesis.
Regardless of the relative abundances of the two markers of life in the cosmos, both the search for bio and techno are hampered by the problem of the ambiguity of their recognition. Wright and colleagues highlight two main forms of ambiguity: nature and the significance of the detected marker. Biosignatures suffer more from this because the potentially life-related molecules recognizable today in the atmospheres of planets other than Earth can easily arise from natural processes. Let's think about the recent cases of methane on Mars or phosphine on Venus. On the other hand, some technosignatures detectable even at great distances, such as very narrow-band radio signals, are decidedly less ambiguous, since no known natural source can generate them.

A megastructure, such as the Dyson sphere pictured here, would be capable of generating technosignatures visible at great distances in the galaxy, revealing the presence of an alien technological civilization even in the absence of radio communications. [Capnhack.com]



At this point, it is easy to understand why astrobiologists prefer to look for an anomalous signal in a large star field that likely contains thousands or millions of planets, rather than struggling to isolate the spectrum of a single planet, looking for molecules that today could not be associated with certainty to the presence of life. In this astrobiological context, the variants proposed by Wright and colleagues will be useful in developing the discussion on the implications of some properties of technological life that differ fundamentally from those of non-technological life.

Interstellar spacecraft can be detectable from hundreds to thousands of light years away through various forms of radiation. The asteroid `Oumuamua (illustrated here) has shown that we can even receive visits from objects from other planetary systems. [ESA/Hubble, NASA, ESO, M. Kornmesser]



Galactic ballet captured by DECam

by NOIRLab
Amanda Kocz

The barred spiral galaxy NGC 1512 (left) and its diminutive neighbor NGC 1510 were captured in this observation from the Víctor M. Blanco 4-meter Telescope. As well as revealing the intricate internal structure of NGC 1512, this image shows the wispy outer tendrils of the galaxy stretching out and appearing to envelop its tiny companion. The starry stream of light that connects the two galaxies is evidence of the gravitational interaction between them — a stately and graceful liaison that has been going on for 400 million years. NGC 1512 and NGC 1510's gravitational interaction has affected the rate of star formation in both galaxies as well as distorting their shapes. Eventually, NGC 1512 and NGC 1510 will merge into one larger galaxy — a drawn-out example of galactic evolution. These interacting galaxies lie in the direction of the constellation of Horologium in the southern celestial hemisphere and are around 60 million light-years from Earth. The wide field of view of this observation shows not only the intertwined galaxies, but also their star-studded surroundings. The frame is populated with bright foreground stars within the Milky Way and is set against a backdrop of even more distant galaxies.

The image was taken with one of the highest-performance wide-field imaging instruments in the world, the Dark Energy Camera (DECam). This instrument is perched atop the Víctor M. Blanco 4-meter Telescope and its vantage point allows it to collect starlight reflected by the telescope's 4-meter-wide (13-foot-wide) mirror, a massive, aluminum-coated and precisely shaped piece of glass roughly the weight of a semi truck.
After passing through the optical innards of DECam — including a corrective lens nearly a meter (3.3 feet) across — starlight is captured by a grid of 62 charge-coupled devices (CCDs). These CCDs are similar to the sensors found in ordinary digital cameras but are far more sensitive, and allow the instrument to create detailed images of faint astronomical objects such as NGC 1512 and NGC 1510.
Large astronomical instruments such as DECam are custom-built masterpieces of optical engineering, requiring enormous effort from astronomers, engineers, and technicians before the first images can be captured. Funded by the US Department of Energy (DOE) with contributions from international partners, DECam was built and tested at DOE's Fermilab, where sci-

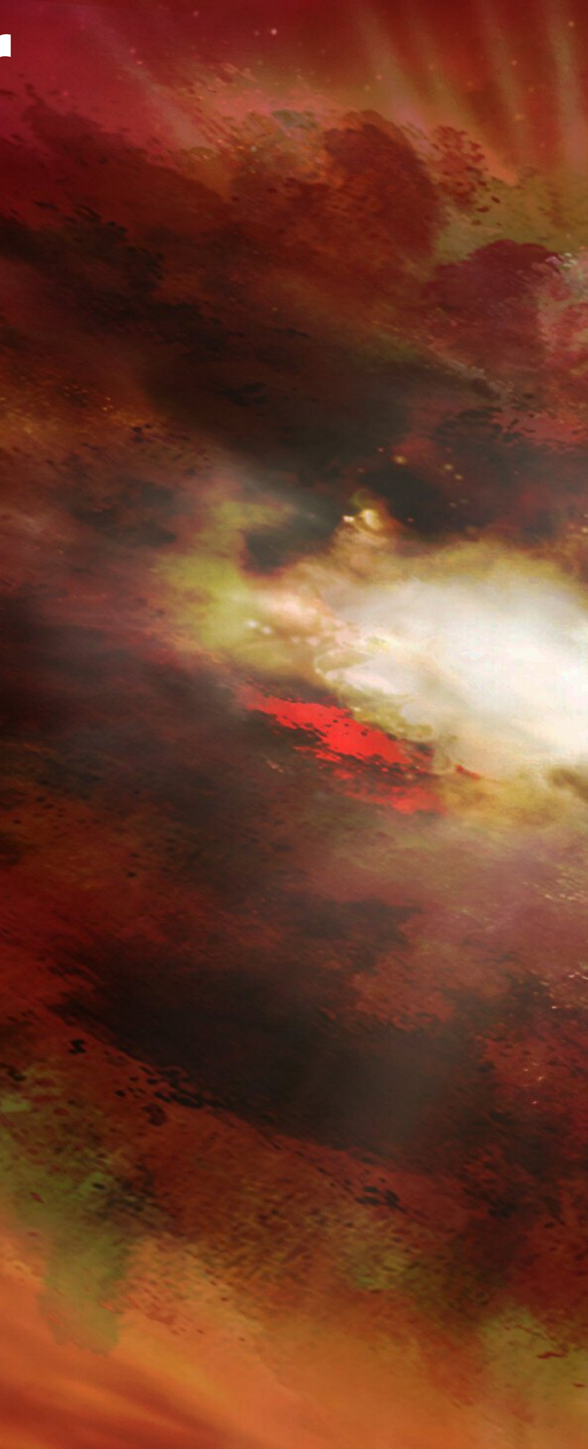
entists and engineers built a 'telescope simulator' — a replica of the upper segments of the Víctor M. Blanco 4-meter Telescope — that allowed them to thoroughly test DECam before shipping it to Cerro Tololo in Chile.

DECam was created to conduct the Dark Energy Survey (DES), a six-year observing campaign (from 2013 to 2019) involving over 400 scientists from 25 institutions in seven countries. This international collaborative effort set out to map hundreds of millions of galaxies, detect thousands of supernovae, and discover delicate patterns of cosmic structure — all to provide much-needed details of the mysterious dark energy that is accelerating the expansion of the Universe. Today DECam is still used for programs by scientists from around the world continuing its legacy of cutting-edge science.

The interacting galaxy pair NGC 1512 and NGC 1510 take center stage in this image from the Dark Energy Camera, a state-of-the art wide-field imager on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory, a Program of NSF's NOIRLab. NGC 1512 has been in the process of merging with its smaller galactic neighbor for 400 million years, and this drawn-out interaction has ignited waves of star formation and warped both galaxies. [Dark Energy Survey/DOE/FNAL/DECam/CTIO/NOIRLab/NSF/AURA. Image processing: T.A. Rector (University of Alaska Anchorage/NSF's NOIRLab), J. Miller (Gemini Observatory/NSF's NOIRLab), M. Zamani & D. de Martin (NSF's NOIRLab)]

Supermassive black hole precursor detected

by NASA/ESA
Bethany Downer



Astronomers have struggled to understand the emergence of supermassive black holes in the early Universe ever since these objects were discovered at distances corresponding to a time only 750 million years after the Big Bang. Rapidly growing black holes in dusty, early star-forming galaxies are predicted by theories and computer simulations but until now they had not been observed.

Now, however, astronomers have reported the discovery of an object — which they name GNz7q — that is believed to be the first such rapidly growing black hole to be found in the early Universe.

Archival Hubble data from the Advanced Camera for Surveys helped the team study the compact ultraviolet emission from the black hole's accretion disc and to determine that GNz7q existed just 750 million years after the Big Bang.

"Our analysis suggests that GNz7q is the first example of a rapidly-growing black hole in the dusty core of a starburst galaxy at an epoch close to the earliest super massive black hole known in the Universe," explains Seiji Fujimoto, an astronomer at the Niels Bohr Institute of the University of Copenhagen in Denmark and lead author of the paper describing this discovery. *"The object's properties across the electromagnetic spectrum are in excellent agreement with predictions from theoretical simulations."*

Current theories predict that supermassive black holes begin their lives in the dust-shrouded cores of vigorously star-forming "starburst" galaxies before expelling the surrounding gas and dust and emerging as extremely luminous quasars. Whilst they are extremely rare, examples of both dusty starburst galaxies and luminous quasars have been detected in the early Universe. The team believes that GNz7q could be the "missing link" between these two classes of objects.

Artist's impression of GNz7q, the first such rapidly growing black hole to be found in the early Universe. [ESA/Hubble, N. Bartmann]

"GNz7q provides a direct connection between these two rare populations and provides a new avenue towards understanding the rapid growth of supermassive black holes in the early days of the Universe," continued Fujimoto. *"Our discovery is a precursor of the supermassive black holes we observe at later epochs."*

Whilst other interpretations of the team's data cannot be completely ruled out, the observed properties of GNz7q are in strong agreement with theoretical predictions.

GNz7q's host galaxy is forming stars at the rate of 1600 solar masses of stars per year and GNz7q itself appears bright at ultraviolet wavelengths but very faint at X-ray wavelengths.

The team have interpreted this — along with the host galaxy's brightness at infrared wavelengths — to suggest that GNz7q is harbors a rapidly growing black hole still obscured by the dusty core of its accretion disc at the center of the star-forming host galaxy.

As well as GNz7q's importance to the understanding of the origins of supermassive black holes, this discovery is noteworthy for its location in the Hubble GOODS North field, one of the most highly scrutinised areas of the night sky.

"GNz7q is a unique discovery that was found just at the centre of a famous, well-studied sky field — showing that big discoveries can often be hidden just in front of you," commented Gabriel Brammer, another astronomer from the Niels Bohr Institute of the University of Copenhagen and a member of the team behind this result. *"It's unlikely that discovering GNz7q within the relatively small GOODS-N survey area was just 'dumb luck' rather the prevalence of such sources may in fact be significantly higher than previously thought."*

Finding GNz7q hiding in plain sight was only possible thanks to the uniquely detailed, multi-wavelength datasets available for GOODS-North. Without this richness of data GNz7q would have been easy to overlook, as it lacks the distinguishing features usually used to identify quasars in the early Universe.

The team now hopes to systematically search for similar objects using dedicated high-resolution surveys and to take advantage of the NASA/ESA/CSA James Webb Space Telescope's spectroscopic instruments to study objects such as GNz7q in unprecedented detail.

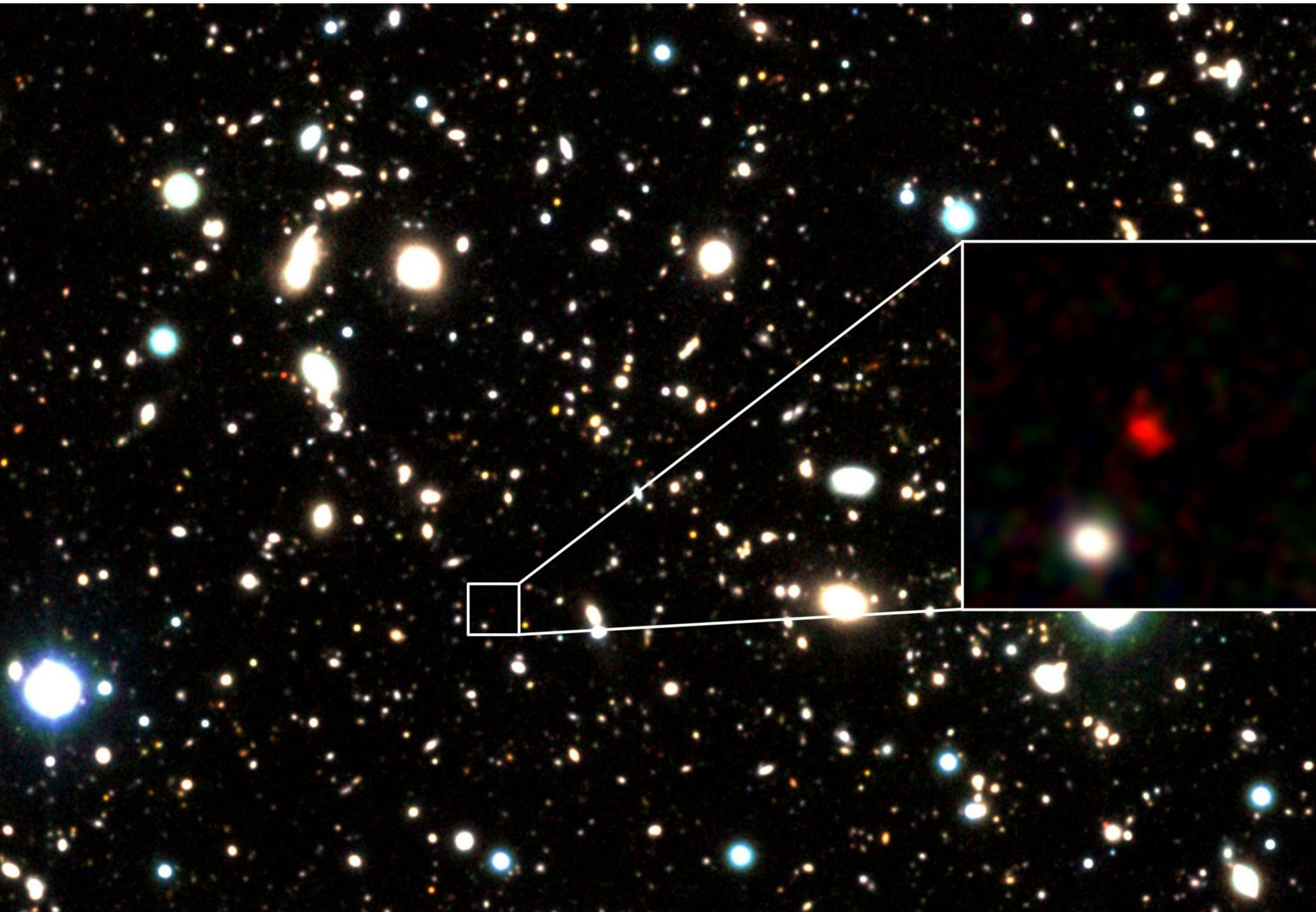
"Fully characterising these objects and probing their evolution and underlying physics in much greater detail will become possible with the James Webb Space Telescope." concluded Fujimoto. *"Once in regular operation, Webb will have the power to decisively determine how common these rapidly growing black holes truly are."*

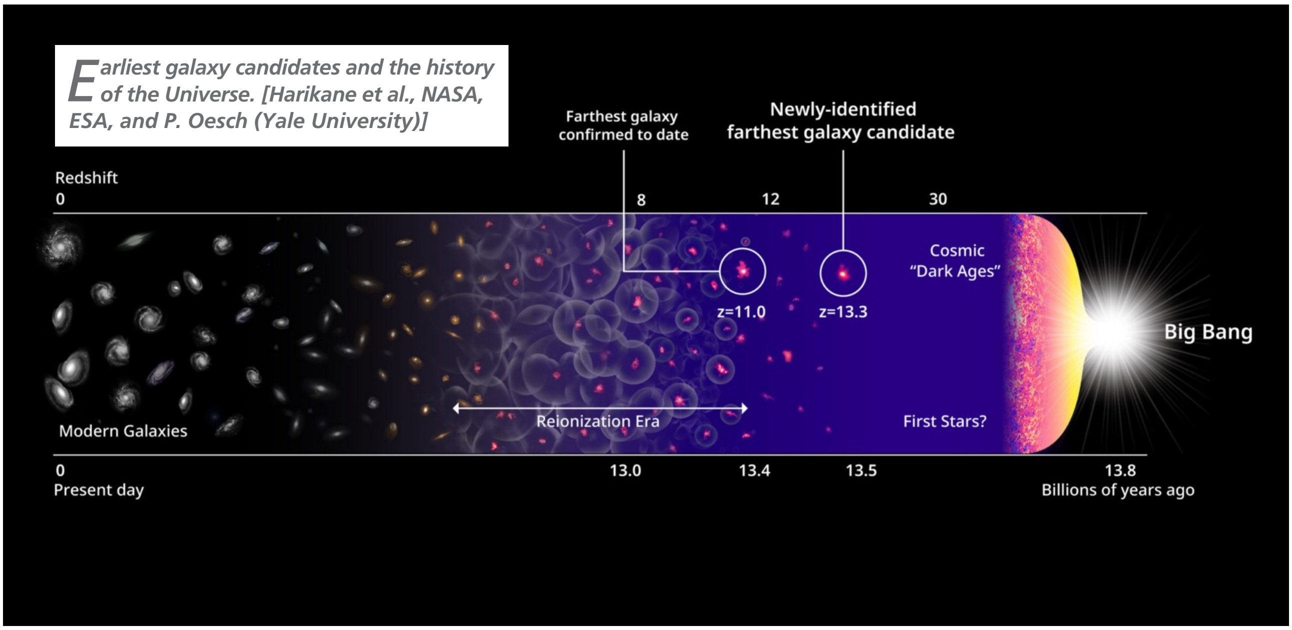
The most distant galaxy candidate yet

by ALMA Observatory
Bárbara Ferreira

An international astronomer team has discovered the most distant galaxy candidate to date, named HD1, which is about 13.5 billion light-years away. This discovery implies that bright systems like HD1 existed as early as 300 million years after the Big Bang. This galaxy candidate is one of the James Webb Space Telescope (JWST) targets launched late last year. If observations with the JWST confirm its exact distance, HD1 will be the most distant galaxy ever recorded.

Three-color image of HD1, the most distant galaxy candidate to date, created using data from the VISTA telescope. The red object in the center of the zoom-in image is HD1. [Harikane et al.]





Earliest galaxy candidates and the history of the Universe. [Harikane et al., NASA, ESA, and P. Oesch (Yale University)]

To understand how and when galaxies formed in the early Universe, astronomers look for distant galaxies. Because of the finite speed of light, it takes time for the light from distant objects to reach Earth. The light we see from an object 1 billion light-years away left that object 1 billion years ago and had to travel for 1 billion years to reach us. Thus studying distant galaxies lets us look back in time.

The current record holder for the most distant galaxy is GN-z11, a galaxy 13.4 billion light-years away discovered by the Hubble Space Telescope. However, this distance is about the limit of Hubble's detection capabilities.

HD1, a candidate object for the earliest/most-distant galaxy, was discovered from more than 1,200 hours of observation data taken by the Subaru Telescope, VISTA Telescope, UK Infrared Telescope, and Spitzer Space Telescope. *"It was tough work to find HD1 out of more than 700,000 objects,"* says Yuichi Harikane, who discovered HD1. *"HD1's red color matched the expected characteristics of a galaxy 13.5 billion light-years away surprisingly well, giving me some goosebumps when I found it."*

The team conducted follow-up observations using the Atacama Large Millimeter/submillimeter Array (ALMA) to confirm HD1's distance. Akio Inoue, a professor at Waseda University, who led the ALMA observations, says, *"We found a weak signal at the frequency where an oxygen emission line was expected. The significance of the signal is 99.99%. If this signal is real, this is evidence that HD1 exists 13.5 billion light-years away, but we cannot be sure without a significance of 99.999% or more."*

HD1 is very bright, suggesting that bright objects already existed in the Universe only 300 million years after the Big Bang.

HD1 is hardly explained with current theoretical models of galaxy formation. Observational information on HD1 is limited, and its physical properties remain a mystery. It is thought to be a very active star-forming galaxy, but it might be an active black hole. Either possibility makes it a fascinating object. In recognition of its astronomical importance, HD1 was selected as a target for the Cycle 1 observations by the James Webb Space Telescope, launched last year. Yuichi Harikane, who is leading these observations, says, *"If the spectroscopic observation confirms its exact distance, HD1 will be the most distant galaxy ever recorded, 100 million light-years further away than GN-z11. We are looking forward to seeing the Universe with the James Webb Space Telescope."* ■

Here's why Uranus and Neptune are different colors

by NOIRLab
Amanda Kocz

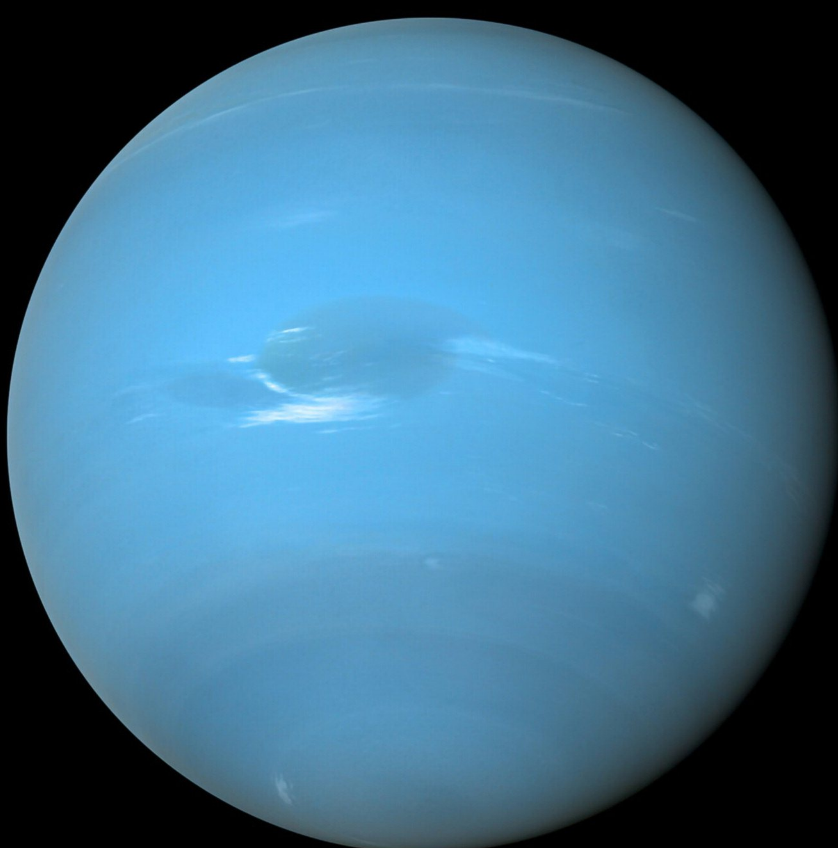
Neptune and Uranus have much in common — they have similar masses, sizes, and atmospheric compositions — yet their appearances are notably different. At visible wavelengths Neptune has a distinctly bluer color whereas Uranus is a pale shade of cyan. Astronomers now have an explanation for why the two planets are different colors.

New research suggests that a layer of concentrated haze that exists on both planets is thicker on Uranus than a similar layer on Neptune and 'whitens' Uranus's appearance more than Neptune's. If there were no haze in the atmospheres of Neptune and Uranus, both would appear almost equally blue.

This conclusion comes from a model that an international team led by Patrick Irwin, Professor of

NASA's Voyager 2 spacecraft captured these views of Uranus (on the left) and Neptune (on the right) during its flybys of the planets in the 1980s. [NASA/JPL-Caltech/B. Jónsson]

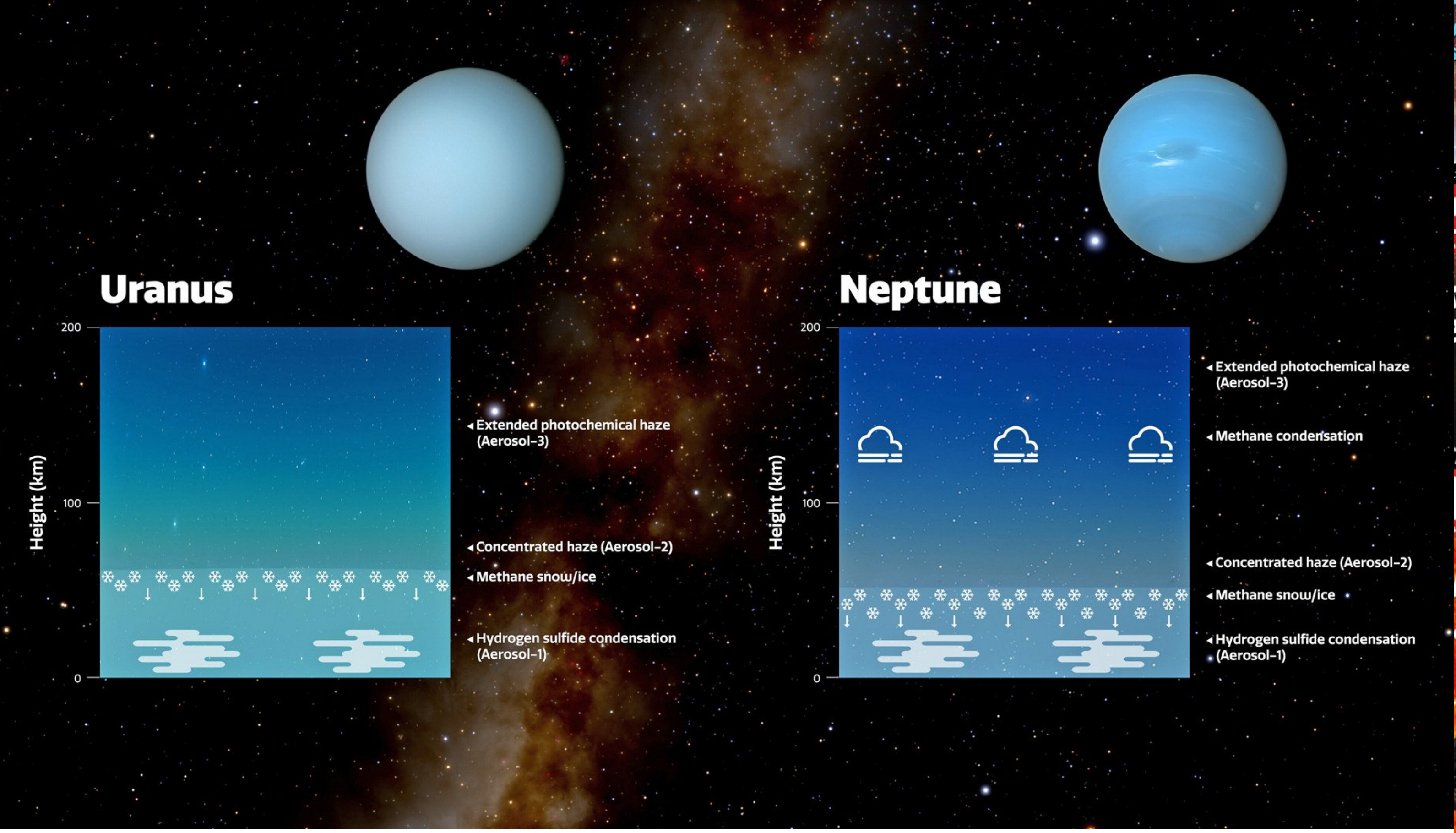
Astronomers may now understand why the similar planets Uranus and Neptune are different colors. Using observations from the Gemini North telescope, the NASA Infrared Telescope Facility, and the Hubble Space Telescope, researchers have developed a single atmospheric model that matches observations of both planets. The model reveals that excess haze on Uranus builds up in the planet's stagnant, sluggish atmosphere and makes it appear a lighter tone than Neptune. [Images and Videos: International Gemini Observatory/NOIRLab/ NSF/AURA/J. da Silva/NASA /JPL-Caltech /B. Jónsson, J. Pollard, E. Mastroianni, ESA/Hubble, M.Kornmesser. Image Processing: M. Zamani (NSF's NOIRLab). Music: Stellardrone – Airglow]



Planetary Physics at Oxford University, developed to describe aerosol layers in the atmospheres of Neptune and Uranus. Previous investigations of these planets' upper atmospheres had focused on the appearance of the atmosphere at only specific wavelengths. However, this new model, consisting of multiple atmospheric layers, matches observations from both planets across a wide range of wavelengths. The new model also includes haze particles within deeper layers that had previously been thought to contain only clouds of methane and hydrogen sulfide ices.

"This is the first model to simultaneously fit observations of reflected sunlight from ultraviolet to near-infrared wavelengths," explained Irwin, who is the lead author of a paper presenting this result in the *Journal of Geophysical Research*: *Planets. "It's also the first to explain the difference in visible color between Uranus and Neptune."*

The team's model consists of three layers of aerosols at different heights. The key layer that affects the colors is the middle layer, which is a layer of haze particles (referred to in the paper as the Aerosol-2 layer) that is thicker on Uranus than on Neptune. The team suspects



This diagram shows three layers of aerosols in the atmospheres of Uranus and Neptune, as modeled by a team of scientists led by Patrick Irwin. The height scale on the diagram represents the pressure above 10 bar. The deepest layer (the Aerosol-1 layer) is thick and composed of a mixture of hydrogen sulfide ice and particles produced by the interaction of the planets' atmospheres with sunlight. The key layer that affects the colors is the middle layer, which is a layer of haze particles (referred to in the paper as the Aerosol-2 layer) that is thicker on Uranus than on Neptune. Above both of these layers is an extended layer of haze (the Aerosol-3 layer) similar to the layer below it but more tenuous. On Neptune, large methane ice particles also form above this layer. [International Gemini Observatory/NOIRLab/NSF/AURA, J. da Silva/NASA /JPL-Caltech /B. Jónsson]

that, on both planets, methane ice condenses onto the particles in this layer, pulling the particles deeper into the atmosphere in a shower of methane snow. Because Neptune has a more active, turbulent atmosphere than Uranus does, the team believes Neptune's atmosphere is more efficient at churning up methane particles into the haze layer and producing this snow. This removes more of the haze and keeps Neptune's haze layer thinner than it is on Uranus, meaning the blue color of Neptune looks stronger.

"We hoped that developing this model would help us understand clouds and hazes in the ice giant atmospheres," commented Mike Wong, an astronomer at the University of California, Berkeley, and a member of the team behind this result. *"Explaining the difference in color between Uranus and Neptune was an unexpected bonus!"*

To create this model, Irwin's team analyzed a set of observations of the planets encompassing ultraviolet, visible, and near-infrared wavelengths (from 0.3 to 2.5 micrometers) taken with the Near-Infrared Integral Field Spectrometer (NIFS) on the Gemini North telescope near the summit of Maunakea in Hawai'i — which is part of the international Gemini Observatory, a Program of NSF's NOIRLab — as well as archival data from the NASA Infrared Telescope Facility, also located in Hawai'i, and the NASA/ESA Hubble Space Telescope.

The NIFS instrument on Gemini North was particularly important to this result as it is able to provide spectra — measurements of how bright an object is at different wavelengths — for every point in its field of view. This provided the team with detailed measurements of how reflective both planets' atmospheres are across both the full disk of the planet and across a range of near-infrared wavelengths. *"The Gemini observatories continue to deliver new insights into the nature of our planetary neighbors,"* said Martin Still, Gemini Program Officer at the National Science Foundation. *"In this experiment, Gemini North provided a component within a suite of ground- and space-based facilities critical to the detection and characterization of atmospheric hazes."*

The model also helps explain the dark spots that are occasionally visible on Neptune and less commonly detected on Uranus. While astronomers were already aware of the presence of dark spots in the atmospheres of both planets, they didn't know which aerosol layer was causing these dark spots or why the aerosols at those layers were less reflective.

The team's research sheds light on these questions by showing that a darkening of the deepest layer of their model would produce dark spots similar to those seen on Neptune and perhaps Uranus. ■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