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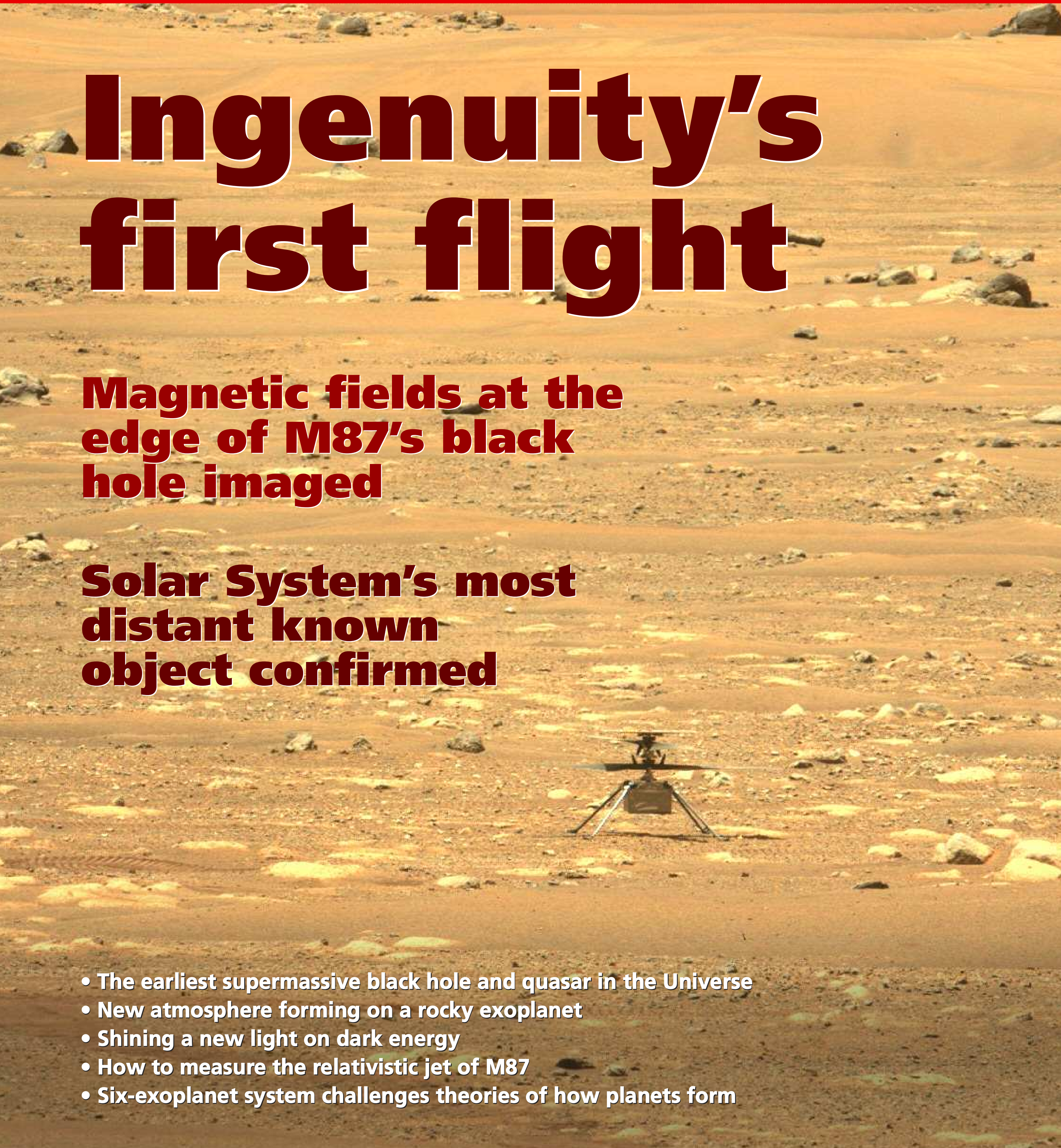

Ingenuity's first flight

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Solar System's most distant known object confirmed

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ASTRONOMY magazine

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Ingenuity's first flight

by Damian G. Allis
NASA Solar System Ambassador

In the background, a frame of the first video of NASA's Ingenuity Mars helicopter in flight. [NASA/JPL-Caltech/ASU/MSSS]

For 39 seconds this past April 19th, the Mars 2020 mission's Ingenuity helicopter performed the first demonstration of controlled, powered flight on another planet, including a 30-second hover three meters above where the Perseverance rover had deployed it on April 3rd. This first demonstration, recorded by both Ingenuity and Perseverance, is the first step in dramatically changing how we explore the red planet and beyond.

Flight by humans has a long history here on Earth. A cave painting on Muna Island in Indonesia that dates back to at least 9,000 B.C. depicts a *kaghati*, a kite whose design is still in use today by the island communities. Human flight also has a long, if sporadic, history, with recorded human flight by attachment to a kite dating back nearly two millennia in China, and a first human lift by hot air balloon recorded on October 19th, 1783 in Paris. The leap from simple flight to controlled, powered flight began on December 17, 1903 outside of Kitty Hawk, North Carolina, with the 12-second flight of the Wright Flyer by Orville Wright. With this first demonstration, and additional flights by both Orville and Wilbur Wright, the force of

This animation shows each step of the Ingenuity helicopter deploying from the belly of NASA's Perseverance Mars rover from March 26 to April 3, 2021. The final image shows the helicopter on the ground after the rover drove about 13 feet (4 meters) away. [NASA/JPL-Caltech]

The Ingenuity Mars Helicopter's carbon fiber blades can be seen in this video taken by the Mastcam-Z instrument aboard NASA's Perseverance Mars rover on April 8, 2021, the 48th Martian day, or sol, of the mission. The four blades are arranged into two 4-foot-long (1.2-meter-long) counter-rotating rotors that can spin at roughly 2,400 rpm. The video shows the blades performing a wiggle test before the actual spin-up to ensure they were working properly. [NASA/JPL-Caltech/ASU]

NASA's Ingenuity helicopter does a slow spin test of its blades on April 8, 2021, the 48th Martian day, or sol, of the mission. This image was captured by the Mastcam-Z on NASA's Perseverance Mars rover. [NASA/JPL-Caltech/ASU]

Members of NASA's Ingenuity helicopter team in the Space Flight Operations Facility at NASA's Jet Propulsion Laboratory prepare to receive the data downlink showing whether the helicopter completed its first flight on April 19, 2021. [NASA/JPL-Caltech]

wind – or the lack thereof – was no longer the factor determining where a vehicle could go.
Fast-forward to 2021, and remote-controlled drones with built-in hi-def cameras and batteries capable

In this video captured by NASA's Perseverance rover, the agency's Ingenuity Mars Helicopter took the first powered, controlled flight on another planet on April 19, 2021. [NASA/JPL-Caltech/ASU/MSSS]

of supporting 30 minutes or more of flight are both affordable and commonplace. The Ingenuity helicopter extends drone capabilities on Earth to Mars and to any other planets with a sufficiently thick atmosphere. For Ingenuity, successful operation requires a delicate balance of weight, battery size, internal heating, and propeller design to work at a surface

NASA's Ingenuity Mars Helicopter achieves powered, controlled flight for the first time on another planet, hovering for several seconds before touching back down on April 19, 2021. The image was taken by the left Navigation Camera, or Navcam, aboard the agency's Perseverance Mars rover from a distance of 210 feet (64 meters). [NASA/JPL-Caltech]

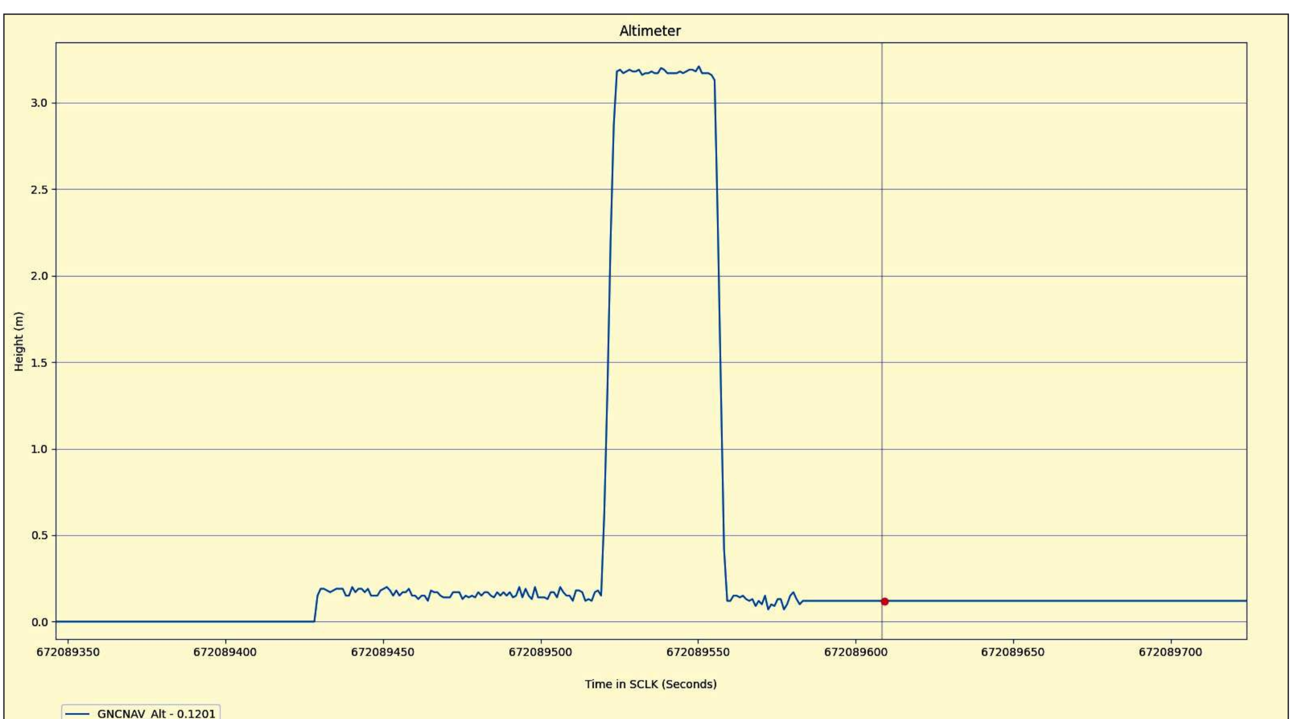
atmospheric pressure less than 1% that on Earth and to survive temperatures as low as -130°F (-90°C). The Perseverance landing and the Mars 2020 Mission were covered in detail in the March-April issue of this magazine. We mentioned then that an aerial vehicle on Mars was a solution to many issues that have complicated our exploration of the red planet, providing the same solution on Mars as has been implemented here on Earth for centuries.
The planning of Martian rover journeys has occurred either by humans receiving data about the local environment and programming in the next set of driving coordinates, or by the rovers having the ability to analyze and adjust headings and distances near-autonomously. In both cases, this planning can only be informed by as far as the onboard cameras could see. The combination of slow speed, need for planning the path forward from a limited visual range, and the wealth of measurement and collection being performed all were contributing reasons why the Opportunity rover, over 14 years of operation, only traveled 28 miles (45 km) from its landing site.

Members of NASA's Ingenuity helicopter team in the Space Flight Operations Facility at NASA's Jet Propulsion Laboratory react to data showing that the helicopter completed its first flight on April 19, 2021. [NASA/JPL-Caltech]

NASA's Ingenuity helicopter can be seen here taking off, hovering and then landing on the Martian surface on April 19, 2021. The Mastcam-Z imager aboard NASA's Perseverance Mars rover shot video of the helicopter's flight. The video is presented here in side-by-side formats that have both been enhanced to show a dust plume swirling during takeoff and again on landing. The view on the left uses motion filtering to show where dust was detected during liftoff and landing and the view on the right is enhanced with the motion filtering. Scientists use this image processing to detect dust devils as they pass by Mars rovers. An additional version of the video includes a timer that counts down until liftoff and then counts up until landing. A ghostly "cut-out" of the helicopter is visible in each side-by-side format; that's an artifact related to the digital processing. [NASA/JPL-Caltech/ASU/MSSS/SSI]

At a maximum speed of 10 m/s, Ingenuity's ability to image the entire Opportunity journey and return to the rover's starting position in under three hours would be limited only by the onboard power to complete the journey in a single flight. A considerable range of visual information between the short-range views of the rover cameras and the planet-scanning studies of the Mars Reconnaissance Orbiter can be filled in by drone, greatly improving both the internal path selection algorithms by

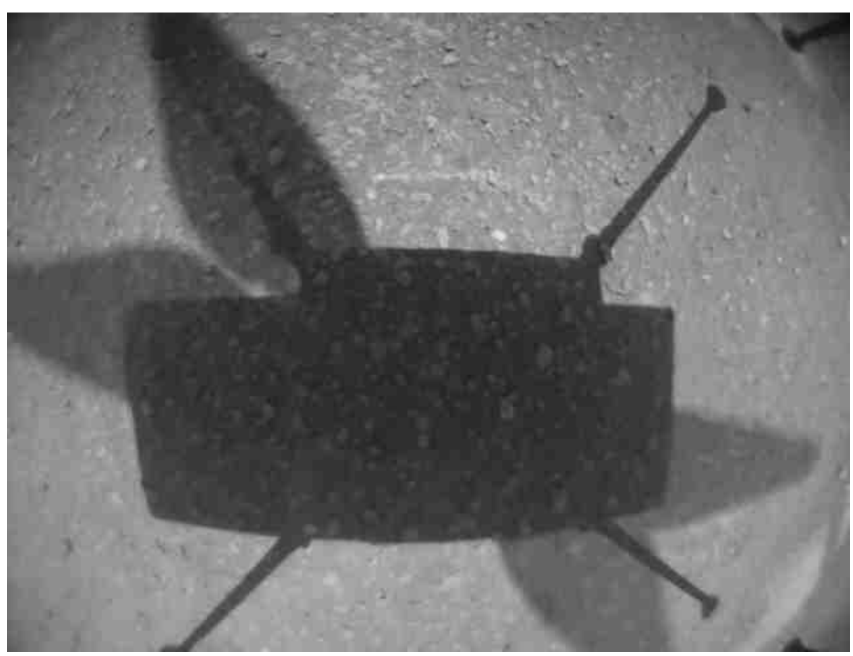
This altimeter chart shows data from the first flight of NASA's Ingenuity Mars Helicopter, which occurred on April 19, 2021. [NASA/JPL-Caltech]



ment on April 8th was successful, but a high-spin test on April 9th was cut short by a fault-detecting watchdog timer. With a software update submitted on April 12th, a high-spin test on the 17th paved the way for the historic take-off on the 19th. The care and concern in testing prior to first flight are for obvious reasons – any unsuccessful take-off or rough landing on Mars would require either delicate reorienting movements by a rover ill-equipped for such fine-motor control, or human intervention in the form of the most expensive drone recovery in history.

To paraphrase from another famous first, the first flight for Ingenuity was *"one small flight for (a) helicopter, one giant flight for Martian air travel."* And, for the second time during the Mars 2020 mission, the

NASA's Ingenuity Mars Helicopter took this shot while hovering over the Martian surface on April 19, 2021, during the first instance of powered, controlled flight on another planet. It used its navigation camera, which autonomously tracks the ground during flight. On the side, an enlargement that highlights details of the Martian soil underneath the shade. [NASA/JPL-Caltech]



autonomous rovers and the ability of those rovers to do much more meaningful discovery and analysis much more efficiently.

The next few rover missions themselves may benefit greatly from associated drones beyond just better imagery and path planning. Drones provide a means to quickly returning sample collections to a common location for analysis or eventual return to Earth for study. Designs capable of supporting more weight can also host spectroscopic equipment to pre-study areas prior to rover arrival. Drones also provide access to places rovers simply cannot yet go – sedimentary layers in tall cliffs, the walls of any ancient impact craters, or water-carved cervices that might hide the remnants of ancient ecosystems.

Like so many flights, this first demonstration was not without some delay. An initial slow-spin test after deploy-

contingency speech written for mission failure was ripped up during the live video feed. This time, it was JPL Project Manager MiMi Aung, exclaiming *"We can now say that human beings have flown a rotorcraft on another planet!"* ■

NORT

RAPIDO 450

ALTAZIMUTH NEWTONIAN TELESCOPE

- SCHOTT Supremax 33 optics
- optical diameter: 460 mm
- useful diameter: 450 mm
- focal ratio: f/4
- primary mirror thickness: 35 mm
- minor axis secondary mirror: 100 mm
- axial cell cooling system
- multi-fan removal of the mirror surface boundary layer
- carbon truss with self-centering conical couplings
- lateral supports (six) designed for altazimuth instruments
- zero deformations

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.

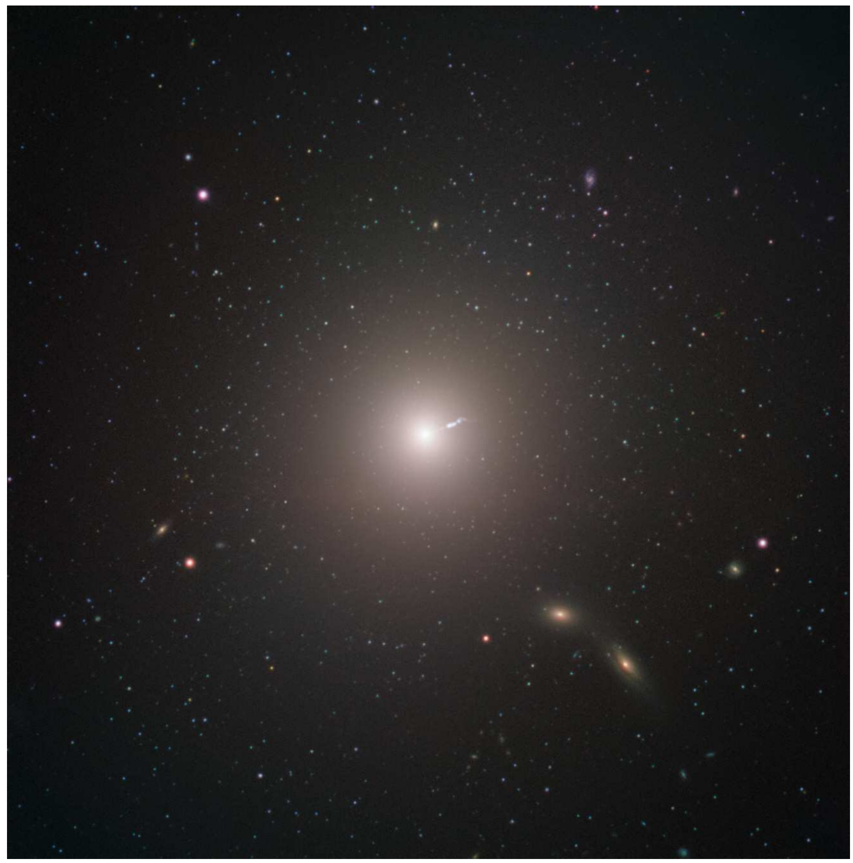
I N S T R U M E N T S - C O

Magnetic fields at the edge of M87's black hole imaged

by ESO - Bárbara Ferreira

This image shows the polarised view of the black hole in M87. The lines mark the orientation of polarisation, which is related to the magnetic field around the shadow of the black hole. [EHT Collaboration]

The Event Horizon Telescope (EHT) collaboration, who produced the first ever image of a black hole, revealed a new view of the massive object at the centre of the Messier 87 (M87) galaxy: how it looks in polarised light. This is the first time astronomers have been able to measure polarisation, a signature of magnetic fields, this close to the edge of a black hole. The observations are key to explaining how the M87 galaxy, located 55 million light-years away, is able to launch



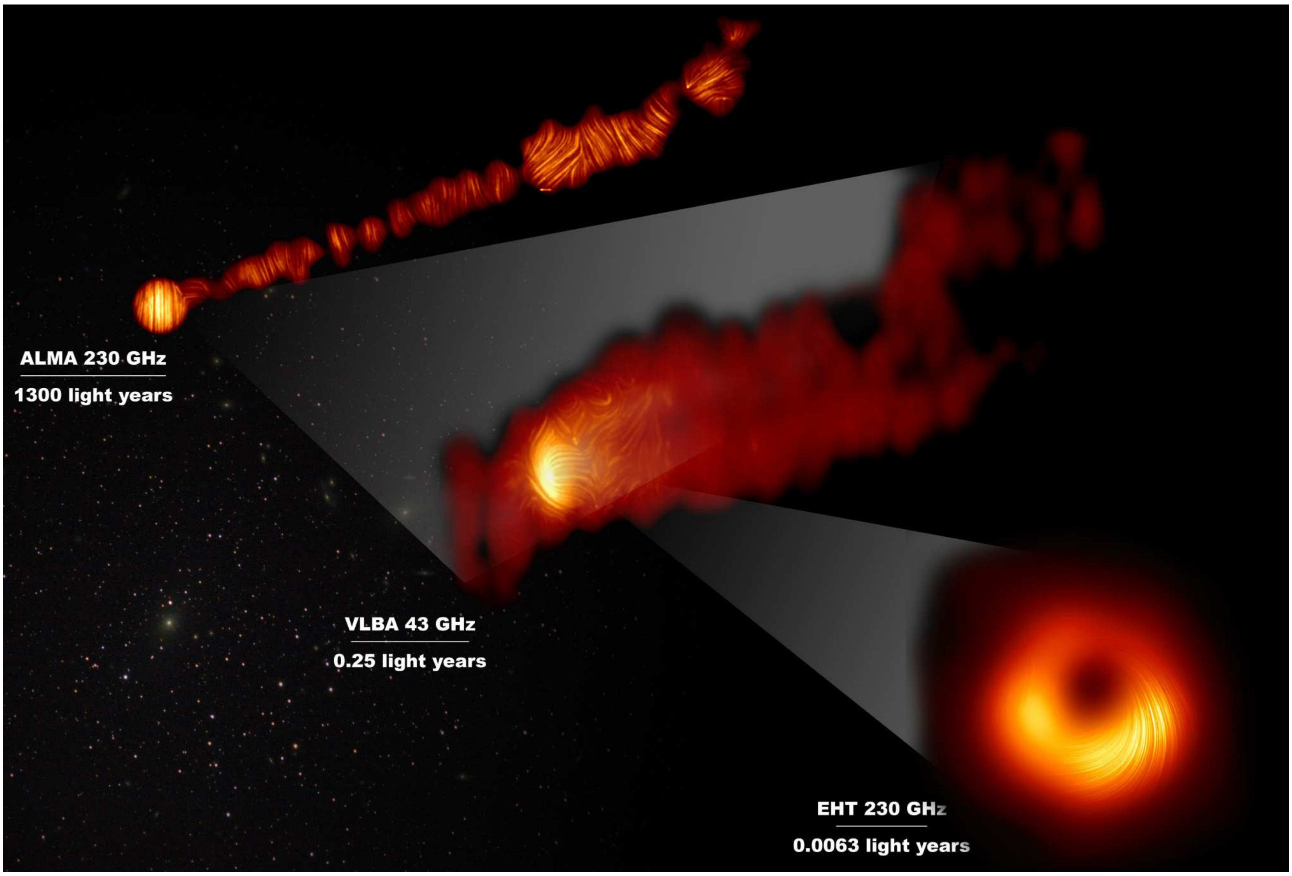
Messier 87 (M87) is an enormous elliptical galaxy located about 55 million light years from Earth, visible in the constellation Virgo. At double the mass of our own galaxy, the Milky Way, and containing as many as ten times more stars, it is amongst the largest galaxies in the local universe. [ESO]

energetic jets from its core. *"We are now seeing the next crucial piece of evidence to understand how magnetic fields behave around black holes, and how activity in this very compact region of space can drive powerful jets that extend far beyond the galaxy,"* says Monika Moś?cibrodzka, Coordinator of the EHT Polarimetry Working Group and Assistant Professor at Radboud University in the Netherlands.

On 10 April 2019, scientists released the first ever image of a black hole, revealing a bright ring-like structure with a dark central region — the black hole's shadow.

Since then, the EHT collaboration has delved deeper into the data on the supermassive object at the heart of the M87 galaxy collected in 2017. They have discovered that a significant fraction of the light around the M87 black hole is polarised.

"This work is a major milestone: the polarisation of light carries information that allows us to better understand the physics behind the image we saw in April 2019, which was not possible before," explains Iván Martí-Vidal, also Coordinator of the EHT Polarimetry Working Group and GenT Distinguished Researcher at the University of Valencia, Spain.



This composite image shows three views of the central region of the Messier 87 (M87) galaxy in polarised light. The galaxy has a supermassive black hole at its centre and is famous for its jets, that extend far beyond the galaxy. One of the polarised-light images, obtained with the Chile-based Atacama Large Millimeter/submillimeter Array (ALMA), in which ESO is a partner, shows part of the jet in polarised light. This image captures the part of the jet, with a size of 6000 light years, closer to the centre of the galaxy. The other polarised light images zoom in closer to the supermassive black hole: the middle view covers a region about one light year in size and was obtained with the National Radio Astronomy Observatory's Very Long Baseline Array (VLBA) in the US. The most zoomed-in view was obtained by linking eight telescopes around the world to create a virtual Earth-sized telescope, the Event Horizon Telescope or EHT. This allows astronomers to see very close to the supermassive black hole, into the region where the jets are launched. The lines mark the orientation of polarisation, which is related to the magnetic field in the regions imaged.The ALMA data provides a description of the magnetic field structure along the jet. Therefore the combined information from the EHT and ALMA allows astronomers to investigate the role of magnetic fields from the vicinity of the event horizon (as probed with the EHT on light-day scales) to far beyond the M87 galaxy along its powerful jets (as probed with ALMA on scales of thousand of light-years). The values in GHz refer to the frequencies of light at which the different observations were made. The horizontal lines show the scale (in light years) of each of the individual images. [EHT Collaboration; ALMA (ESO/NAOJ/NRAO), Goddi et al.; VLBA (NRAO), Kravchenko et al.; J. C. Algaba, I. Martí-Vidal]

He adds that *"unveiling this new polarised-light image required years of work due to the complex techniques involved in obtaining and analysing the data."* Light becomes polarised when it goes through certain filters, like the lenses of polarised sunglasses, or when it is emitted in hot regions of space where magnetic fields are present. In the same way that polarised sunglasses help us see better by reducing reflections and glare from bright surfaces, astronomers can sharpen their view of the region around the black hole by looking at how the light originating from it is polarised. Specifically, polarisation allows astronomers to map

This video summarises the discovery made by the Event Horizon Telescope (EHT) collaboration. [ESO]

the magnetic field lines present at the inner edge of the black hole. *"The newly published polarised images are key to understanding how the magnetic field allows the black hole to 'eat' matter and launch powerful jets,"* says EHT collaboration member Andrew Chael, a NASA Hubble Fellow at the Princeton Center for Theoretical Science and the Princeton Gravity Initiative in the US.

The bright jets of energy and matter that emerge from M87's core and extend at least 5000 light-years from its centre are one of the galaxy's most mysterious and energetic features. Most matter lying close to the edge of a black hole falls in. However, some of the surrounding particles escape moments before capture and are blown far out into space in the form of jets.

Astronomers have relied on different models of how matter behaves near the black hole to better understand this process. But they still don't know exactly how jets larger than the galaxy are launched from its central region, which is comparable in size to the Solar System, nor how exactly matter falls into the black hole. With the new EHT image of the black hole and its shadow in polarised light, astronomers managed for the first time to look into the region just outside the black hole where this interplay between matter flowing in and being ejected out is happening.

The observations provide new information about the structure of the magnetic fields just outside the black hole. The team found that only theoretical models featuring strongly magnetised gas can explain what they are seeing at the event horizon. *"The observations suggest that the magnetic fields at the black hole's edge are strong enough to push back on the hot gas and help it resist gravity's pull. Only the gas that slips through the field can spiral inwards to the event horizon,"* explains Jason Dexter, Assistant Professor at the University of Colorado Boulder, US, and Coordinator of the EHT Theory Working Group.

To observe the heart of the M87 galaxy, the collaboration linked eight telescopes around the world — including the northern Chile-based Atacama Large Millimeter/submillimeter Array (ALMA) and the Atacama Pathfinder EXperiment (APEX), in which the European Southern Observatory (ESO) is a partner — to create a virtual Earth-sized telescope, the EHT. The impressive resolution obtained with the EHT is equivalent to that needed to measure the length of a credit card on the surface of the Moon.

"With ALMA and APEX, which through their southern location enhance the image quality by adding geographical spread to the EHT network, European scientists were able to play a central role in the research," says Ciska Kemper, European ALMA Programme Scientist at ESO. *"With its 66 antennas, ALMA dominates the overall signal collection in polarised light, while APEX has been essential for the calibration of the image."*

"ALMA data were also crucial to calibrate, image and interpret the EHT observations, providing tight constraints on the theoretical models that explain how matter behaves near the black hole event horizon," adds Ciriaco Goddi, a scientist at Radboud University and Leiden Observatory, the Netherlands, who led an accompanying study that relied only on ALMA observations.

The EHT setup allowed the team to directly observe the black hole shadow and the ring of light around it, with the new polarised-light image clearly showing that the ring is magnetised.

The results have been published in two separate papers in *The Astrophysical Journal Letters* by the EHT collaboration. The research involved over 300 researchers from multiple organisations and universities worldwide.

"The EHT is making rapid advancements, with technological upgrades being done to the network and new observatories being added. We expect future EHT observations to reveal more accurately the magnetic field structure around the black hole and to tell us more about the physics of the hot gas in this region," concludes EHT collaboration member Jongho Park, an East Asian Core Observatories Association Fellow at the Academia Sinica Institute of Astronomy and Astrophysics in Taipei.

The earliest supermassive black hole and quasar in the Universe

by NOIRLab - Amanda Kocz

Quasars, which are powered by the feeding frenzies of colossal supermassive black holes, are the most energetic objects in the Universe. They occur when gas in the superheated accretion disk around a supermassive black hole is inexorably drawn inwards, shedding energy across the electromagnetic spectrum. The amount of electromagnetic radiation

An artist's impression of quasar J0313-1806 showing the supermassive black hole and the extremely high velocity wind. The quasar, seen just 670 million years after the Big Bang, is 1000 times more luminous than the Milky Way, and is powered by the earliest known supermassive black hole, which weighs in at more than 1.6 billion times the mass of the Sun. [NOIRLab/NSF/AURA/J. da Silva] emitted by quasars is enormous, with the most massive examples easily outshining entire galaxies. An international team of astronomers has announced the discovery of J0313-1806, the most distant quasar known to date. *"The most distant quasars are crucial for understanding how the earliest black holes formed and for understanding cosmic reionization — the last major phase transition of our Universe,"* said Xiaohui Fan, study co-author and Regents Professor of Astronomy at the University of Arizona.

J0313-1806 is seen more than 13 billion years ago. As the most distant quasar known, it is also the earliest, being fully formed only about 670 million years after the Big Bang. The new quasar is more than ten trillion times as luminous as our Sun — meaning that it pours out one thousand times more energy than the entire Milky Way Galaxy. The source of this quasar's power is a supermassive black hole 1.6 billion times as massive as the Sun — the earliest black hole currently known to exist in the Universe.

The presence of such a massive black hole so early in the Universe's history challenges theories of black hole formation as astronomers need to explain how it came into existence when it barely had the time to do so. Feige Wang, NASA Hubble fellow at the University of Arizona and lead author of the research paper, explains: *"Black holes created by the very first massive stars could not have grown this large in only a few hundred million years."*

The observations that led to this discovery were made using a variety of telescopes, including three National Science Foundation NOIRLab facilities — the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory, Gemini South, and Gemini North. Data from the Blanco Telescope, taken as part of the DESI Legacy Imaging Surveys, which are served to the astronomical community via the Astro Data Lab at NOIRLab's Community Science and Data Center (CSDC), helped to first identify J0313-1806, while Gemini South observations were used to confirm its identity as a quasar. High-quality spectra from two Maunakea observatories in Hawai'i — Gemini North and W. M. Keck Observatory — were used to measure the mass of the central supermassive black hole.

"The most distant quasars and earliest black holes are important markers in the history of the Universe," said Program Director Martin Still of the National Science Foundation. *"The researchers combined several of NSF's NOIRLab facilities to make this discovery."*

As well as weighing the monster black hole, the Gemini North and Keck Observatory observations uncovered an extremely fast outflow emanating from the quasar in the form of a high-velocity wind, which is traveling at 20% of the speed of light. *"The energy released by such an extreme high-velocity outflow is large enough to impact the star formation in the entire quasar host galaxy,"* said Jinyi Yang, Peter A. Strittmatter postdoctoral fellow of Steward Observatory at the University of Arizona. This is the earliest known example of a quasar sculpting the growth of its host galaxy, making J0313-1806 a promising target for future observations.

The galaxy hosting J0313-1806 is undergoing a spurt of star formation, producing new stars 200 times faster than the Milky Way. The combination of this intense star formation, the luminous quasar, and the high-velocity outflow make J0313-1806 and its host galaxy a promising natural laboratory for understanding the growth of supermassive black holes and their host galaxies in the early Universe.

"This would be a great target to investigate the formation of the earliest supermassive black holes," concluded Feige Wang. *"We also hope to learn more about the effect of quasar outflows on their host galaxy — as well as to learn how the most massive galaxies formed in the early Universe."*

This is CosmoView Episode 17 for press release noirlab2102: The earliest supermassive black hole and quasar in the Universe. [Images and Videos: NOIRLab/NSF/AURA/J. da Silva, ESO/M.Kornmesser, CTIO/D. Munizaga, International Gemini Observatory/Kwon O Chul. Music: Stellardrone - Comet Halley]

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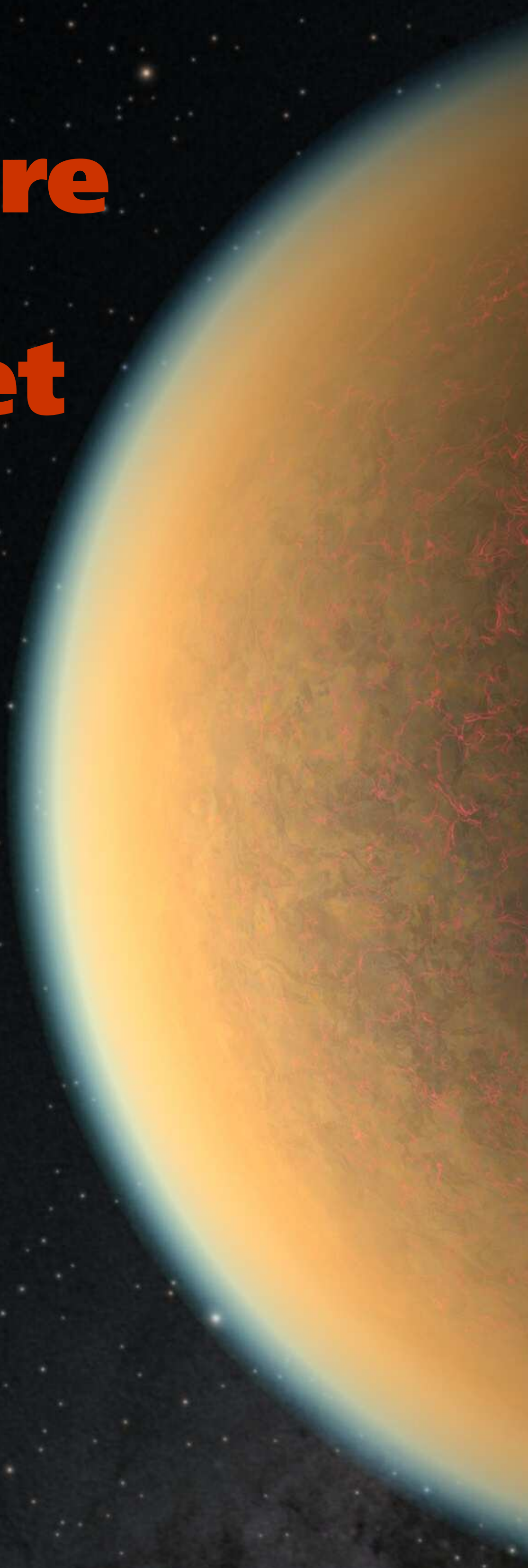
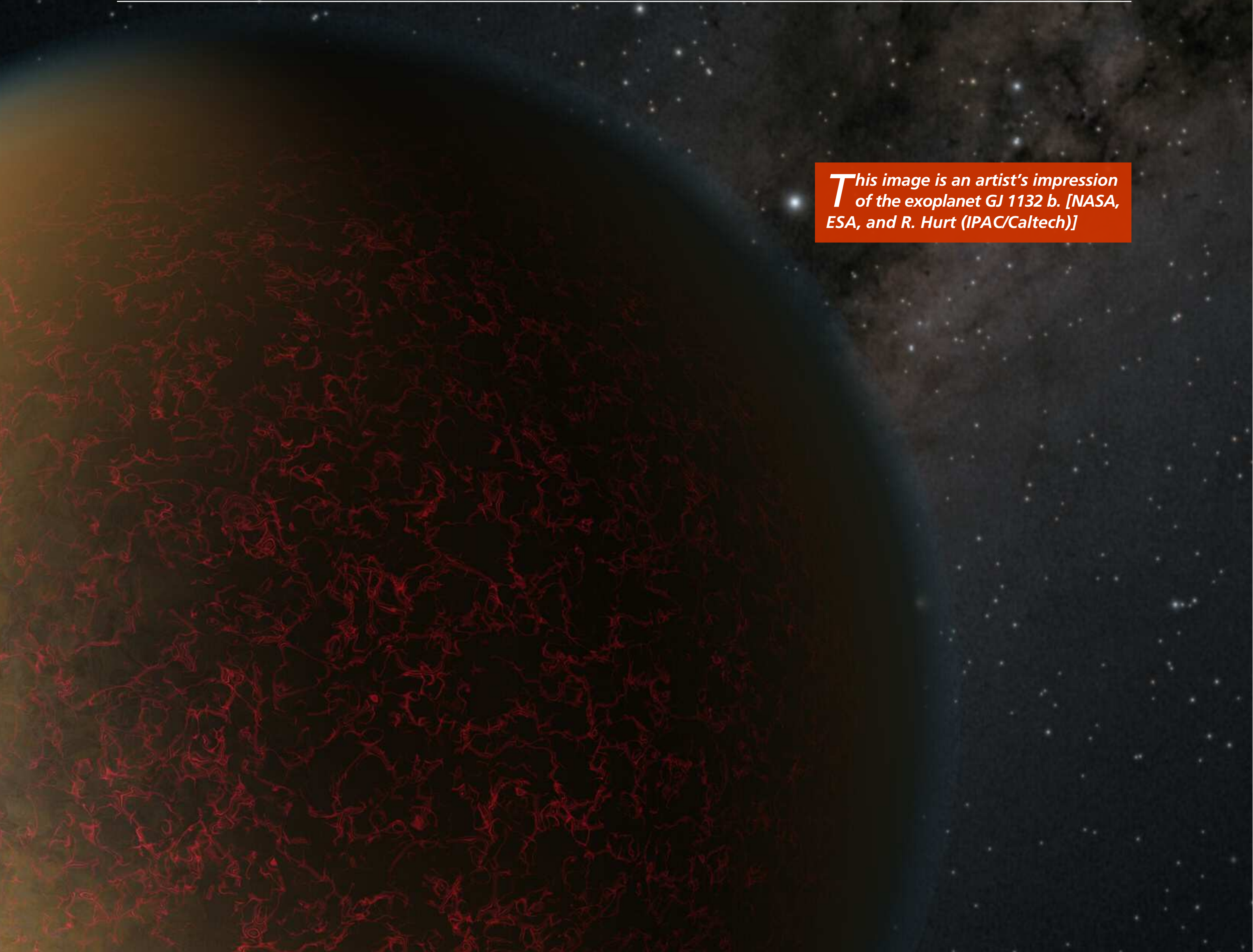
New atmosphere forming on a rocky exoplanet

by NASA/ESA - Bethany Downer



For the first time, scientists using the NASA/ESA Hubble Space Telescope have found evidence of volcanic activity reforming the atmosphere on a rocky planet around a distant star. The planet, GJ 1132 b, has a similar density, size, and age to those of Earth.
The planet GJ 1132 b appears to have begun life as a gaseous world with a thick blanket of atmosphere. Starting out at several times the radius of Earth, this so-called "sub-Neptune" quickly lost its primordial hydrogen and helium atmosphere, which was stripped away by the intense radiation from its hot, young star. In a short period of time, it was reduced to a bare core about the size of Earth.
To the surprise of astronomers, new observations from Hubble have uncovered a secondary atmosphere that has replaced the planet's first atmosphere. It is rich in hydrogen, hydrogen cyanide, methane and ammonia, and also has a hydrocarbon haze. Astronomers theorise that hydrogen from the original atmosphere was absorbed into the planet's molten magma mantle and is now being slowly released by volcanism to form a new atmosphere. This second atmosphere, which con-



This image is an artist's impression of the exoplanet GJ 1132 b. [NASA, ESA, and R. Hurt (IPAC/Caltech)]

tinues to leak away into space, is continually being replenished from the reservoir of hydrogen in the mantle's magma.

"This second atmosphere comes from the surface and interior of the planet, and so it is a window onto the geology of another world," explained team member Paul Rimmer of the University of Cambridge, UK. *"A lot more work needs to be done to properly look through it, but the discovery of this window is of great importance."*

"We first thought that these highly radiated planets would be pretty boring because we believed that they lost their atmospheres," said team member Raissa Estrela of the Jet Propulsion Laboratory at the California Institute of Technology in Pasadena, California, USA. "But we looked at existing observations of this planet with Hubble and realised that there is an atmosphere there."

"How many terrestrial planets don't begin as terrestrials? Some may start as sub-Neptunes, and they become terrestrials through a mechanism whereby light evaporates the primordial atmosphere. This process works early in a planet's life, when the star is hotter," said team leader Mark Swain of the Jet Propulsion

Pictured here is the region around the host star of the exoplanet GJ 1132 b. [ESA/Hubble, Digitized Sky Survey 2. Ack: Davide De Martin]

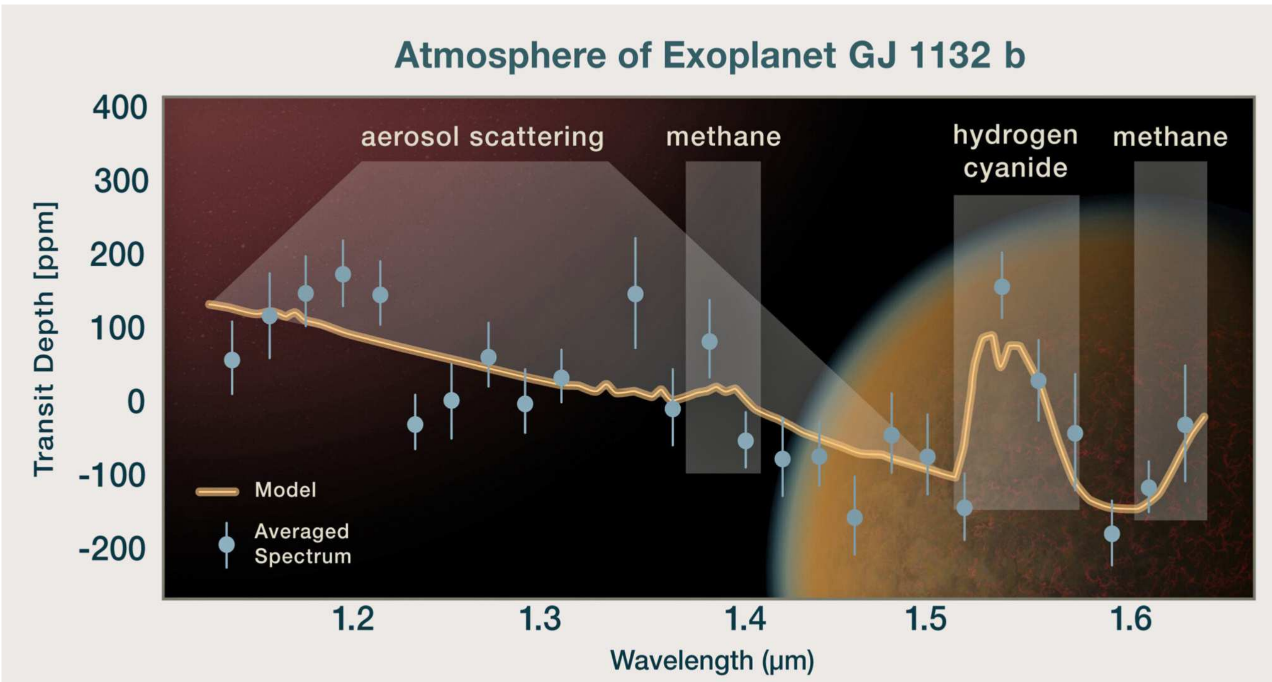
Laboratory. *"Then the star cools down and the planet's just sitting there. So you've got this mechanism that can cook off the atmosphere in the first 100 million years, and then things settle down. And if you can regenerate the atmosphere, maybe you can keep it."*

In some ways, GJ 1132 b has various parallels to Earth, but in some ways it is also very different. Both have similar densities, similar sizes, and similar ages, being about 4.5 billion years old. Both started with a hydrogen-dominated atmosphere, and both were hot before they cooled down. The team's work even suggests that GJ 1132 b and Earth have similar atmospheric pressure at the surface.

However, the planets' formation histories are profoundly different. Earth is not believed to be the surviving core of a sub-Neptune. And Earth orbits at a comfortable distance from our yellow dwarf Sun. GJ 1132 b is so close to its host red dwarf star that it completes an orbit the star once every day and a half. This extremely close proximity keeps GJ 1132 b tidally locked, showing the same face to its star at all times — just as our moon keeps one hemisphere permanently facing Earth.

"The question is, what is keeping the mantle hot enough to remain liquid and power volcanism?" asked

In this Space Sparks episode, ESA/Hubble summarises an exciting new discovery from the NASA/ESA Hubble Space Telescope. [Directed by: Bethany Downer and Nico Bartmann. Editing: Nico Bartmann. Web and technical support: Enciso Systems. Written by: Bethany Downer. Music: STAN DART – Organic Life (Music written and performed by STAN DART). Footage and photos: ESA/Hubble & NASA, R. Hurt (IPAC/Caltech)]



This plot shows the spectrum of the atmosphere of an Earth sized rocky exoplanet, GJ 1132 b, which is overlaid on an artist's impression of the planet. The orange line represents the model spectrum. In comparison, the observed spectrum is shown as blue dots representing averaged data points, along with their error bars. This analysis is consistent with GJ 1132 b being predominantly a hydrogen atmosphere with a mix of methane and hydrogen cyanide. The planet also has aerosols which cause scattering of light. This is the first time a so-called "secondary atmosphere," which was replenished after the planet lost its primordial atmosphere, has been detected on a world outside of our solar system. [NASA, ESA, and P. Jeffries (STScI)]

Swain. *"This system is special because it has the opportunity for quite a lot of tidal heating."*

The phenomenon of tidal heating occurs through friction, when energy from a planet's orbit and rotation is dispersed as heat inside the planet. GJ 1132 b is in an elliptical orbit, and the tidal forces acting on it are strongest when it is closest to or farthest from its host star.

At least one other planet in the host star's system also exerts a gravitational pull on the planet. The consequences are that the planet is squeezed or stretched by this gravitational "pumping." That tidal heating keeps the mantle liquid for a long time. A nearby example in our own Solar System is the Jovian moon, Io, which has continuous volcanism as a result of a tidal tug-of-war between Jupiter and the neighbouring Jovian moons.

The team believes the crust of GJ 1132 b is extremely thin, perhaps only hundreds of feet thick. That's much too feeble to support anything resembling volcanic mountains. Its flat terrain may also be cracked like an eggshell by tidal flexing. Hydrogen and other gases could be released through such cracks.

"This atmosphere, if it's thin — meaning if it has a surface pressure similar to Earth — probably means you can see right down to the ground at infrared wavelengths. That means that if astronomers use the James Webb Space Telescope to observe this planet, there's a possibility that they will see not the spectrum of the atmosphere, but rather the spectrum of the surface," explained Swain. *"And if there are magma pools or volcanism going on, those areas will be hotter. That will generate more emission, and so they'll potentially be looking at the actual geological activity — which is exciting!"*

"This result is significant because it gives exoplanet scientists a way to figure out something about a planet's geology from its atmosphere," added Rimmer. *"It is also important for understanding where the rocky planets in our own Solar System — Mercury, Venus, Earth and Mars, fit into the bigger picture of comparative planetology, in terms of the availability of hydrogen versus oxygen in the atmosphere."* ■

A distant galaxy dies as astronomers watch

by ESO - Bárbara Ferreira

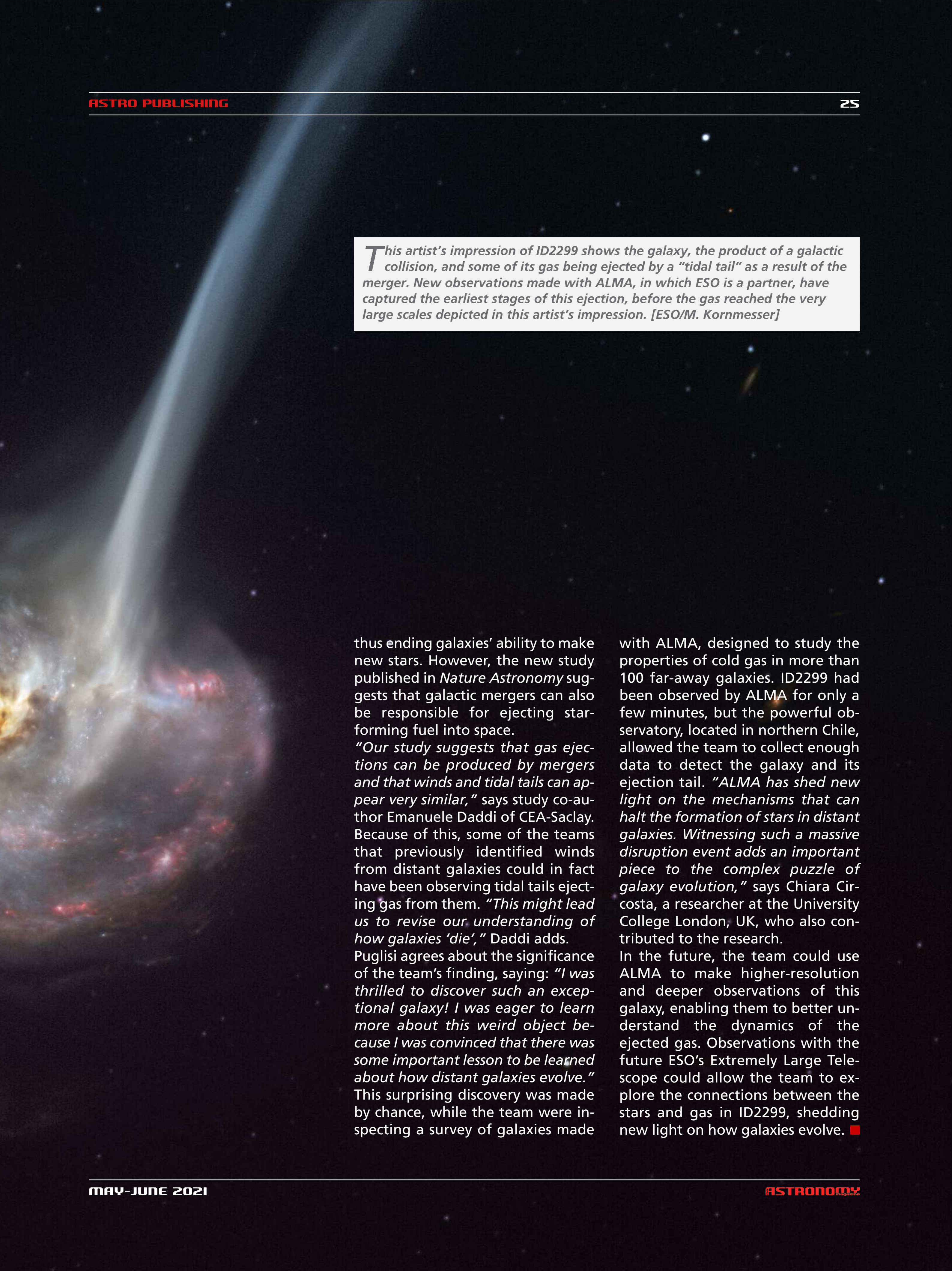
Galaxies begin to "die" when they stop forming stars, but until now astronomers had never clearly glimpsed the start of this process in a far-away galaxy. Using the Atacama Large Millimeter/submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, astronomers have seen a galaxy ejecting nearly half of its star-forming gas. *"This is the first time we have observed a typical massive star-forming galaxy in the distant Universe about to 'die' because of a massive cold gas ejection,"* says Annagrazia Puglisi, lead researcher on the new study, from the Durham University, UK, and the Saclay Nuclear Research Centre (CEA-Saclay), France.

The galaxy, ID2299, is distant enough that its light takes some 9 billion years to reach us; we see it when the Universe was just 4.5 billion years old.

The gas ejection is happening at a rate equivalent to 10,000 Suns per year, and is removing an astonishing 46% of the total cold gas from ID2299. Because the galaxy is also forming stars very rapidly, hundreds of times faster than our Milky Way, the remaining gas will be quickly consumed, shutting down ID2299 in just a few tens of million years.

The event responsible for the spectacular gas loss, the team believes, is a collision between two galaxies, which eventually merged to form ID2299.

The elusive clue that pointed the scientists towards this scenario was the association of the ejected gas with a "tidal tail". Tidal tails are elongated streams of stars and gas extending into interstellar space that result when two galaxies merge, and they are usually too faint to see in distant galaxies. However, the team managed to observe the relatively bright feature just as it was launching into space, and were able to identify it as a tidal tail. Most astronomers believe that winds caused by star formation and the activity of black holes at the centres of massive galaxies are responsible for launching star-forming material into space,



This artist's impression of ID2299 shows the galaxy, the product of a galactic collision, and some of its gas being ejected by a "tidal tail" as a result of the merger. New observations made with ALMA, in which ESO is a partner, have captured the earliest stages of this ejection, before the gas reached the very large scales depicted in this artist's impression. [ESO/M. Kornmesser]

thus ending galaxies' ability to make new stars. However, the new study published in *Nature Astronomy* suggests that galactic mergers can also be responsible for ejecting star-forming fuel into space.

"Our study suggests that gas ejections can be produced by mergers and that winds and tidal tails can appear very similar," says study co-author Emanuele Daddi of CEA-Saclay. Because of this, some of the teams that previously identified winds from distant galaxies could in fact have been observing tidal tails ejecting gas from them. *"This might lead us to revise our understanding of how galaxies 'die',"* Daddi adds.

Puglisi agrees about the significance of the team's finding, saying: *"I was thrilled to discover such an exceptional galaxy! I was eager to learn more about this weird object because I was convinced that there was some important lesson to be learned about how distant galaxies evolve."*

This surprising discovery was made by chance, while the team were inspecting a survey of galaxies made with ALMA, designed to study the properties of cold gas in more than 100 far-away galaxies. ID2299 had been observed by ALMA for only a few minutes, but the powerful observatory, located in northern Chile, allowed the team to collect enough data to detect the galaxy and its ejection tail. *"ALMA has shed new light on the mechanisms that can halt the formation of stars in distant galaxies. Witnessing such a massive disruption event adds an important piece to the complex puzzle of galaxy evolution,"* says Chiara Circosta, a researcher at the University College London, UK, who also contributed to the research.

In the future, the team could use ALMA to make higher-resolution and deeper observations of this galaxy, enabling them to better understand the dynamics of the ejected gas. Observations with the future ESO's Extremely Large Telescope could allow the team to explore the connections between the stars and gas in ID2299, shedding new light on how galaxies evolve. ■

Shining a new light on dark energy

by NOIRLab - Amanda Kocz

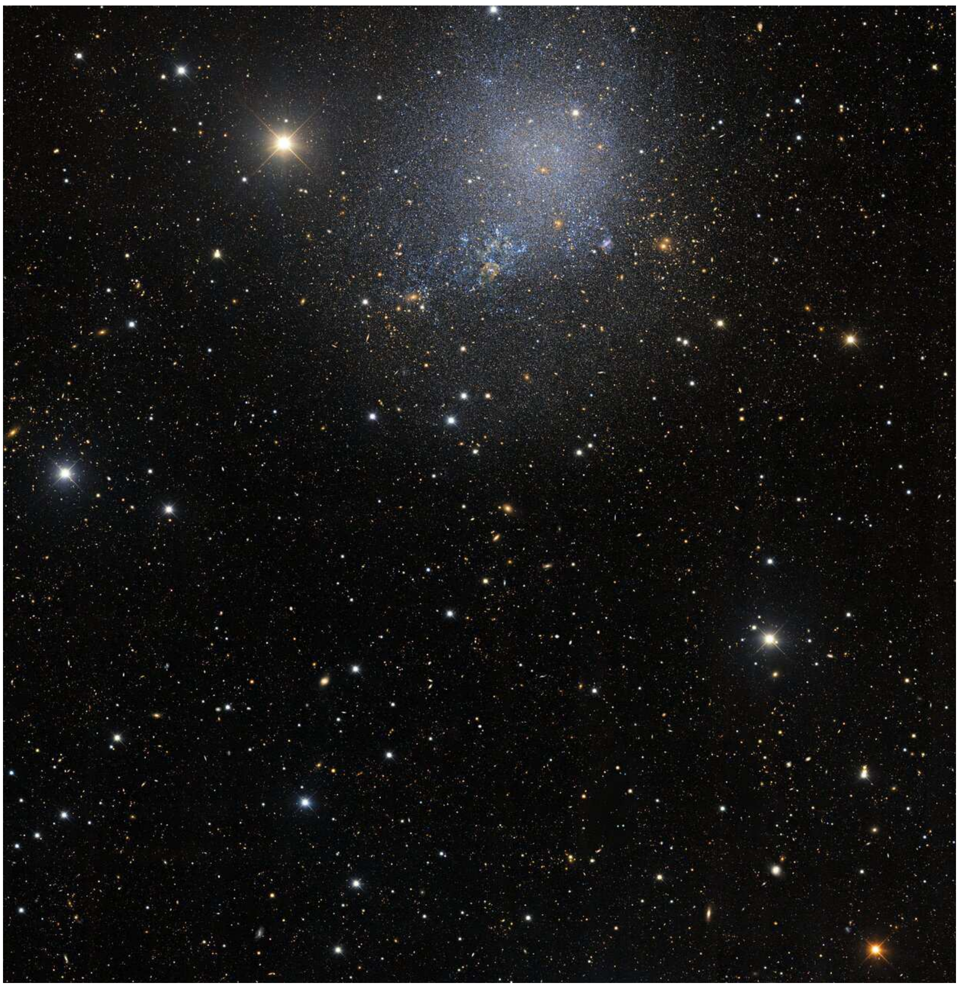
DR2 is the second release of images and object catalogs from the Dark Energy Survey (DES). It is the culmination of over half a decade of astronomical data collection and analysis, with the ultimate goal of understanding the accelerating expansion rate of the Universe and the phenomenon of dark energy that is thought to be responsible for the expansion. The Dark Energy Survey is a global collaboration that includes the Department of Energy's (DOE) Fermi National Accelerator Laboratory (Fermilab), the National Center for Supercomputing Applications (NCSA), and NSF's NOIRLab.

Including a catalog of nearly 700 million astronomical objects, DR2 builds on the 400 million objects cataloged with the Survey's previous data release (DR1), and also improves on it by refining calibration techniques, which, with the deeper combined images from DR2, leads to improved estimates of the amount and distribution of matter in the Universe. It is one of the largest astronomical catalogs released to date.

Astronomical researchers around the world can access these unprecedented data and mine them to make new discoveries about the Universe, complementary to the studies being carried out by the Dark Energy Survey collaboration.

One early result relates to the construction of a catalog of RR Lyrae pulsating stars, which tell scientists about the region of space beyond the edge of our Milky Way. In this area nearly devoid of stars, the mo-

This image shows unusual structures around NGC 474 characterized as tidal tails and shell-like structures made up of hundreds of millions of stars. These features are due to recent mergers (within the last billion years) or close interactions with smaller infalling dwarf galaxies. This image is an excerpt from the Dark Energy Survey, which has released a massive, public collection of astronomical data and calibrated images from six years of work. [DES/DOE/Fermilab/NCSA & CTIO/NOIRLab/NSF/AURA - Ack: Image processing: DES, Jen Miller (Gemini Observatory/NSF's NOIRLab), Travis Rector (University of Alaska Anchorage), Mahdi Zamani & Davide de Martin]



The irregular dwarf galaxy IC 1613 contains some 100 million stars and is a member of our Local Group of galaxies, which also includes our Milky Way, the Andromeda spiral galaxy, and the Magellanic Clouds. Also this image is an excerpt from the Dark Energy Survey. [DES/DOE/Fermilab/NCSA & CTIO/NOIRLab/NSF/AURA - Ack: Image processing: DES, Jen Miller (Gemini Observatory/NSF's NOIRLab), Travis Rector (University of Alaska Anchorage), Mahdi Zamani & Davide de Martin]

tion of the RR Lyrae stars hints at the presence of an enormous "halo" of invisible dark matter, which may provide clues to how our galaxy was assembled over the last 12 billion years. In another result, DES scientists used the extensive DR2 galaxy catalog, along with data from the LIGO gravitational wave experiment, to estimate the location of a black hole merger and, independent of other techniques, infer the value of the Hubble constant, a key cosmological parameter.

Combining their data with other surveys, DES scientists have also been able to generate a detailed map of the Milky Way's dwarf satellites, giving researchers insight into how our own galaxy was assembled and how it compares with cosmologists' predictions.

The detailed precision cosmology constraints based on the full six-year DES dataset will come out over the next two years.

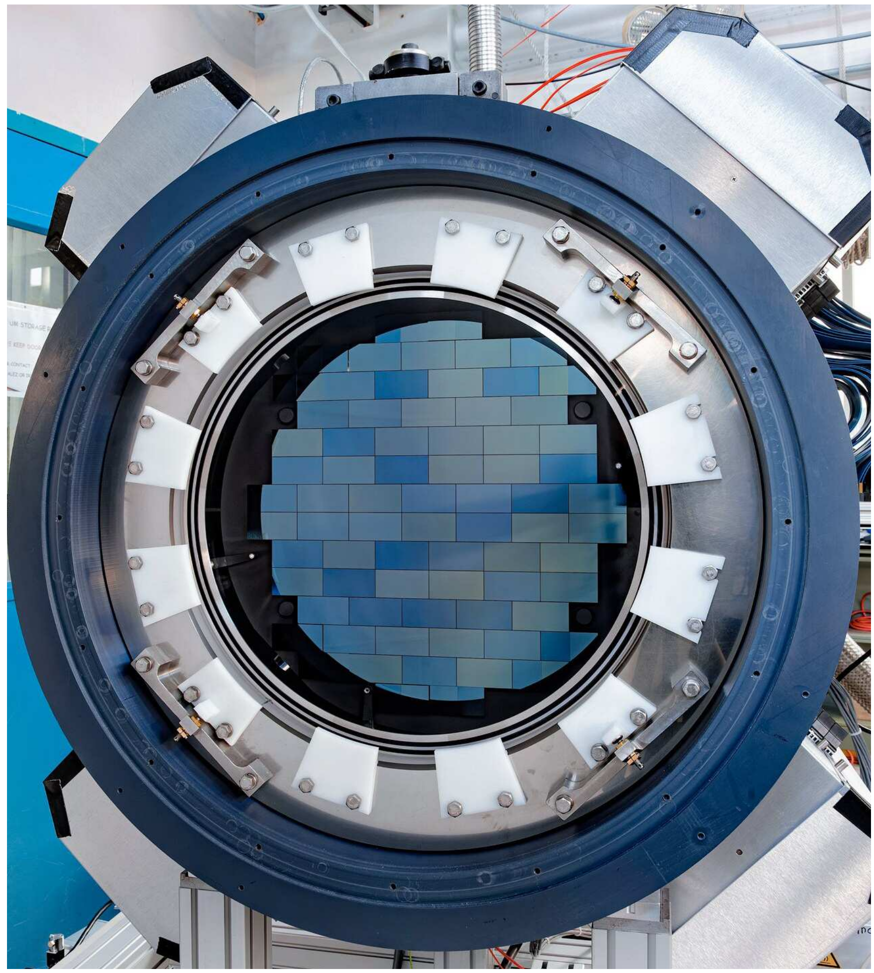
DES was conceived to map hundreds of millions of galaxies and to chart the size of the expanding Universe as it accelerates under the influence of dark energy. DES has produced the largest and most accurate dark matter map from galaxy weak lensing to date.

Covering 5,000 square degrees of the southern sky, the survey data enable many other investigations in addition to those targeting dark energy, covering a vast range of cosmic distances — from discovering new nearby Solar System objects to investigating the nature of the first star-forming galaxies in the early Universe.

"This is a momentous milestone. For six years, the Dark Energy Survey collaboration took pictures of distant celestial objects in the night sky. Now, after carefully checking the quality and calibration of the images captured by the Dark Energy Camera, we are releasing this second batch of data to the public," said DES Director Rich Kron of Fermilab and the University of Chicago. *"We invite professional and amateur scientists alike to dig into what we consider a rich mine of gems waiting to be discovered."*

The primary tool used to collect these images, the Dark Energy Camera (DECam), fabricated by DOE, is mounted on the National Science Foundation-funded Víctor M. Blanco 4-meter Telescope, part of the Cerro Tololo Inter-American Observatory

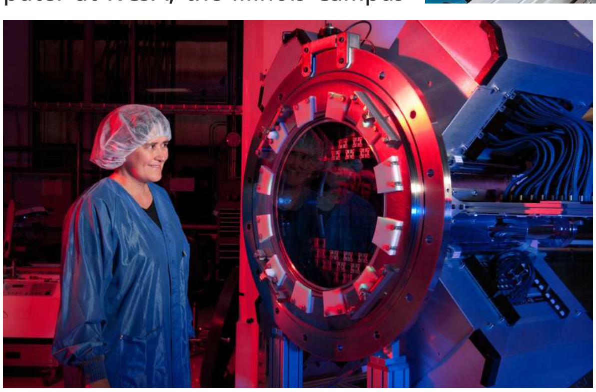
The Dark Energy Camera (DECam) focal plane consists of a science array of sixty-two 2048 x 4096 CCDs. Additionally, there are four 2048 x 2048 guider CCDs and eight 2048 x 2048 focus and alignment CCDs. The quantum efficiency of these LBNL-designed CCDs with their anti-reflective coating is red optimized to be more than 90% at 900 nm and more than 60% over the range of 400-1000 nm. The Dark Energy Survey CCDs were fabricated by Dalsa with further processing done by Lawrence Berkeley National Laboratory (Berkeley Lab). They were then packaged and tested by the Department of Energy's (DOE) Fermilab. DECam was fabricated by the DOE. [DES/DOE/LBNL/CTIO/NOIRLab/NSF/AURA/R. Hahn]



(CTIO) in the Chilean Andes, a Program of NSF's NOIRLab. Each week from 2013 to 2019, DECam collected thousands of images of the southern sky, unlocking a trove of potential cosmological insights.

Once captured, these images (and the large amount of data surrounding them) were transferred to NCSA for processing via the DES Data Management (DESDM) project.

Using the Blue Waters supercomputer at NCSA, the Illinois Campus



The Dark Energy Camera (DECam) focal plane compared with the size of a person. DECam was fabricated by the Department of Energy (DOE). [DES/DOE/LBNL/CTIO/NOIRLab/NSF/AURA/R. Hahn]

Cluster, and computational systems at Fermilab, NCSA prepares calibrated data products for research and public consumption. It took approximately four months to process one year's worth of data into a searchable, usable catalog. The DES DR2 is hosted at the Community Science and Data Center (CSDC), a Program of NSF's NOIRLab. CSDC provides software systems, user services, and development initiatives to connect and support the scientific missions of NOIRLab's telescopes, including the Blanco Telescope at CTIO.

"Because astronomical datasets today are so vast, the cost of handling them is prohibitive for individual researchers or most organizations," said Robert Nikutta, Project Scientist for Astro Data Lab at CSDC. *"CSDC provides open access to big astronomical datasets like DES DR2, and the necessary tools to explore and exploit them — then all it takes is someone from the community with a clever idea to discover new and exciting science."* ■

How to measure the relativistic jet of M87

by Aniceto Porcel & Miguel Sánchez
revised by Damian G. Allis
NASA Solar System Ambassador

This work describes spatial measurements made of the plasma jet emanating from the nucleus of the galaxy M87 and based on observations performed at the La Laguna Astronomical Observatory (OLA, Granada, Spain). With this work, apart from our interest in the study itself, we want to demonstrate that it is possible to undertake "apparently inaccessible" astronomical investigations and calculations with the aid of typical amateur instruments, with both telescope diameters and focal lengths far below those we find in professional observatories, but which nevertheless give good results when we are able to exploit the potential of our team for collecting and processing data.
The calculations we carried out to obtain the dimensions of the M87 jet are not complex; the main difficulty in this study was the isolation of the jet from the great brightness of the galaxy's core. Given the resolving power of the instruments used, there is a higher degree of uncertainty in the values we have obtained compared to result one might obtain by using higher-resolution equipment and more elaborate calculation techniques. However, as we shall see, our results are consistent with those considered to be the "established values" from observations with professional telescopes, including the Hubble Space Telescope (HST).

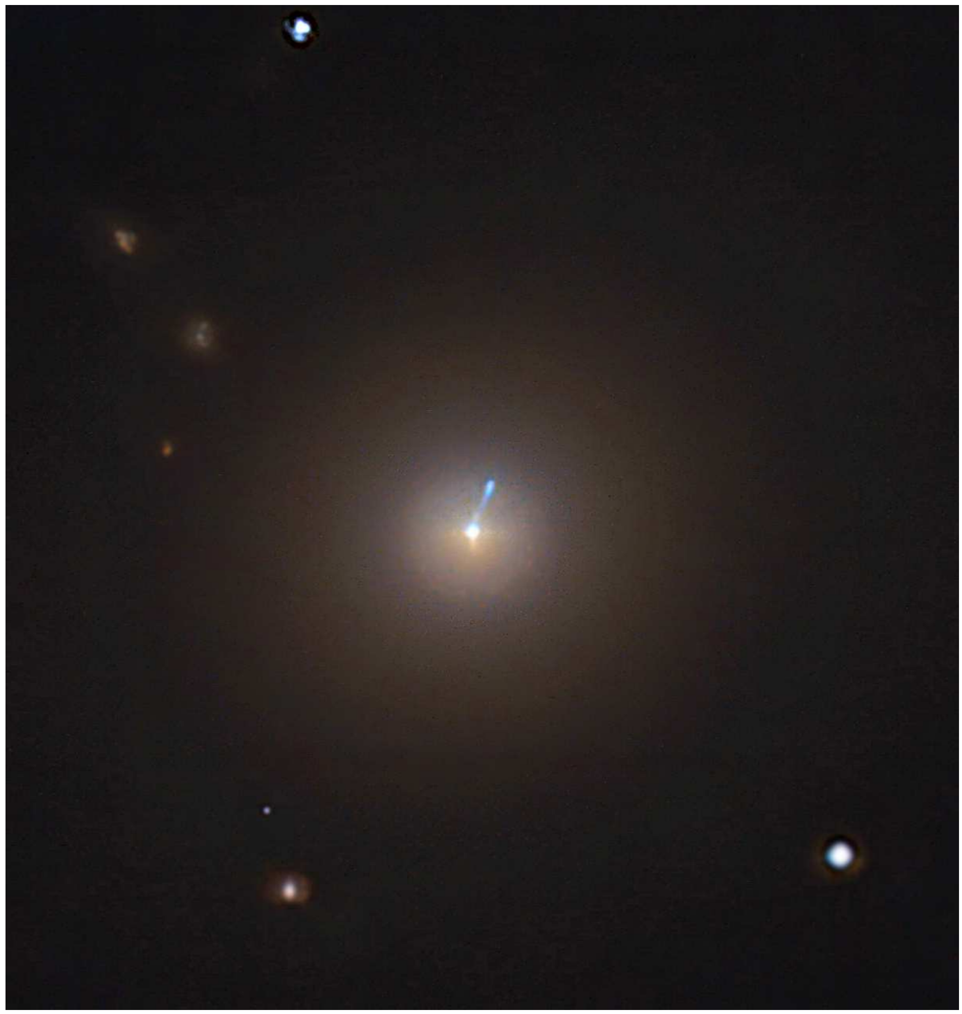
In March 2019 at the La Laguna Astronomical Observatory, we took a sequence of images of M87 to record the jet of matter that emanates outwards from its center. This plasma jet, or relativistic jet, was first identified in 1918 by astronomer Heber Curtis (Lick Observatory), but it was many years later before the details of the expulsion of matter were finally revealed.

These galactic jet-shaped structures are not unusual. The idea of capturing this one from OLA started as a challenge when we saw that our first images showed a small prominence indicating its presence, and we wondered if it was possible to improve on that result.

The first images recorded on March 9, 2019 were archived for further processing. On April 10, just a month later, the media announced with considerable fanfare that the Event Horizon Telescope (EHT) team had captured the first image of a black hole. Quite fortuitously, the imaged black hole was the one at the center of M87, and the jet we were trying to observe in our images has long been the clearest evidence of what that galaxy hosts at its core. The coincidence was exciting: while we were trying to capture and measure the jet of highly-collimated matter emerging from the core of M87, an international team of astronomers was concretizing the first visual evidence of the very black hole that caused it. In truth, it has long been

Image of the M87 field taken from OLA on 9 March 2019. [M. Sánchez (SAG), A. Porcel (SAG/OLA)]

In the background, the black hole-powered jet of electrons and sub-atomic particles that streams from the center of M87. [NASA and The Hubble Heritage Team (STScI/AURA)] thought that the M87 jet was the result of a black hole, even though it nor any other black hole had been seen directly. For decades, black holes had only been a theory supported by indirect observational evidence, such as through their gravitational influence and by the jets of matter ejected at very high speeds from galactic nuclei. It is not easy to record this structure using the equipment available at OLA, not so much for the weakness and thinness of the jet, but mainly due to the great brightness of the M87 core, which saturates the pixels imaging the center of the galaxy, hiding the fine details in that region. In the images and in the first treatments, the plasma jet appears only as a small swelling or spike that only indicated its faint presence or, perhaps, showed it to be just a bit more prominent. The integration times had to be calculated carefully. Likewise, the choice of filters to be used and their characteristics were important – we were trying to record true color using the LRGB color palette. Subsequently, we verified that the jet, being bluish, would have required an increase in the integrations of the blue filter (B), but ignorance of this made us assign identical exposure times to each filter. We also did exposures in Hα, knowing (or almost knowing) that they would not provide any extra information. As they would likely worsen our signal-to-noise ratio, which became evident in the processing, we ultimately discarded the Hα data.



The jet of M87. Forced processing to isolate the plasma jet from the galaxy core makes the field stars appear with strange edges and halos. 10” f/3.9 Newtonian telescope, SBIG ST-8300M CCD camera, 8.3 megapixel KAF-8300 sensor, 5.4x5.4 μ (3326x2504 pixels), German equatorial mount EQ-8. [M. Sánchez (SAG), A. Porcel (SAG/OLA)]

The images were acquired with the help of the software programs Maxim DL, Astrotortilla, EQMOD and Cartes du Ciel. Each of the produced FITS (Flexible Image Transport System) files was initially processed with Avis FITS Viewer (AvisFV) to reduce the brightness of the galaxy’s core until the plasma jet was exposed.
Image stacking was performed with DeepSkyStacker (DSS), including luminance (L) in the red (R+L) channel and independent green (G) and blue (B) channels. The color (RGB) montage was done with Photoshop, where it was reworked to recalibrate color, brightness and contrast. The IRIS program was used for the spatial measurements of the jet.
The final image of the M87 field is an LRGB stacking in the following proportions: L 3×300", R 3×300", G 3×300", B 3×300"; 12 shots of 300

seconds; total exposure of 3,600 seconds (1 hour).
After enjoying the jet as seen in these images, we asked ourselves: *"What if we used them to measure the size of the jet? Would we get measurements similar to the accepted ones?"*
Taking as known the distance to M87 (53 million light-years) and by being able to calculate the apparent size of the jet in arcseconds from our exposures, we calculated the jet size by applying basic trigonometry.
We know that, using the tangent formula, we can relate the angle and the two catheti, which is just what we needed in our case:

$$tan\theta = \frac{d}{D}$$

Because the angle is so small, the tangent can be approximated as the angle itself:

$$tan\theta \approx \theta$$

And by transforming the angle from radians to arcseconds we get:

$$\theta_{arcseconds} = 206265\frac{d}{D}$$

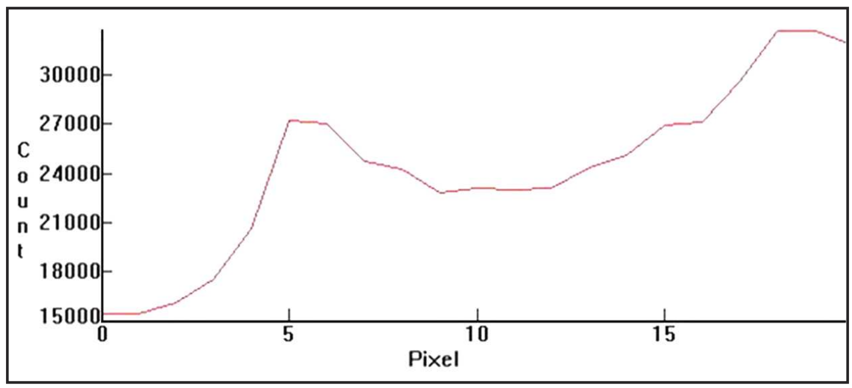
With D known – 5×10^{23} m (53 million light-years converted into meters) – we simply had to calculate how many arcseconds the jet occupies in the sky.
To do this, we first needed to know the resolution of our camera/telescope set, which is given by the following formula:

$$R\ (arcseconds\ per\ pixel) = \frac{206 \times size\ of\ the\ pixel\ \ (\mu)}{focal\ length\ \ (mm)}$$

In our case:

$$R = \frac{206 \times 5.4}{1000} = 1.11 arcsecpix$$

Now we just had to measure how many pixels the jet occupied in our image, from the center of the galaxy to the edge of the jet, using the "Slice" tool of the IRIS program. This gave us 16 ± 1 pixels.



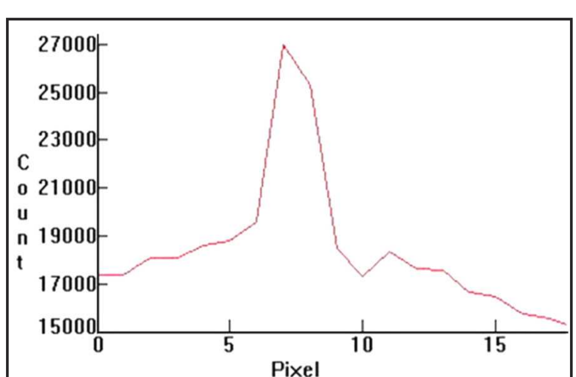
By multiplying our R by 16, we get about 17.8 arcseconds, which we then substitute in the formula discussed above to get *d*:

$$d = \frac{17.8 \times 5 \times 10^{23}}{206265} = 4.3 \times 10^{19} m$$

which is:

4,542 ± 285 light-years
(1,392.6 ± 87.4 pcs)
of length.

Even taking 3 ± 1 pixels for the width of the jet:



we get the value:

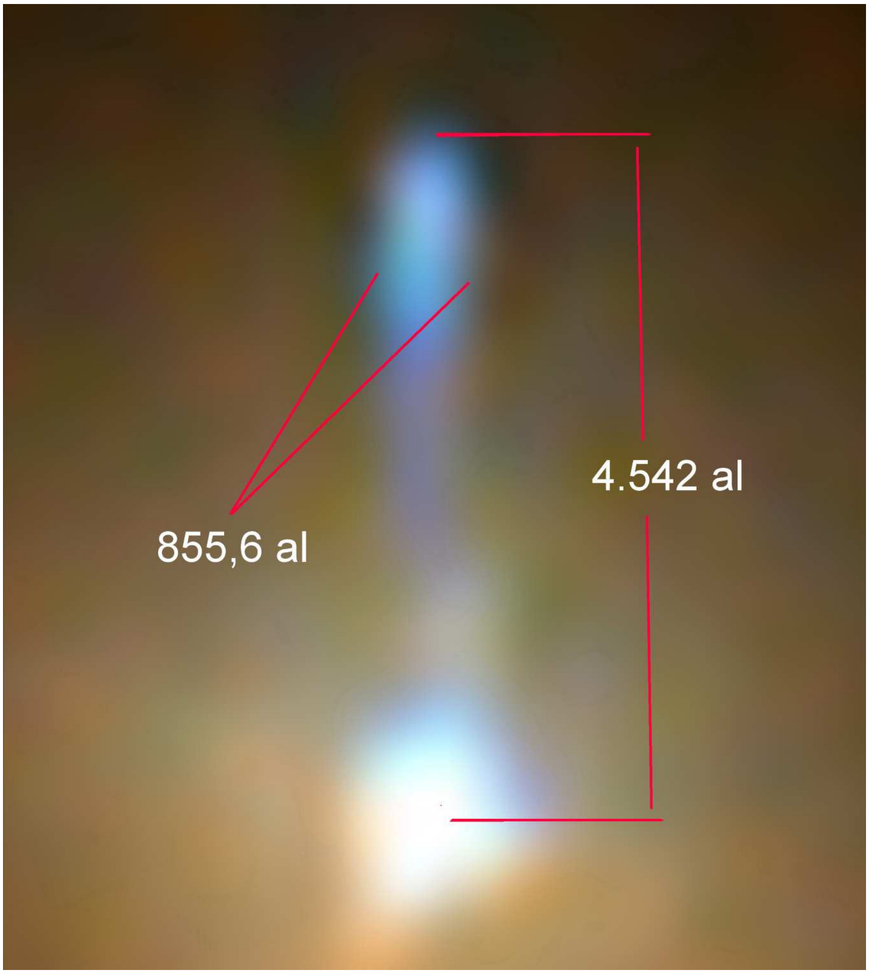
855.6 ± 285 light-years
(262.3 ± 87.4 pcs)
wide.

The accepted value for the jet is about 5,000 light-years, or about 20 arcseconds, placing our calculation within reasonable margins.

Conclusions
Jets are structures that exhibit very interesting properties and exist in amazing conditions due to their extreme nature and properties.
Knowing more about them yields a greater understanding about quasars, radio galaxies, active galaxies and black holes. In the case of the M87 jet, whose spatial dimensions we have studied, we believe we have obtained results comparable with official data using far more modest equipment.
Our calculations show a plasma jet length of approximately 4,542 light-years, compared to the approximately 5,000 light-years calculated by observatories with greater resolving power or located outside of the Earth's atmosphere. Similarly, we obtained the value of 855.6 light-years for the width of the jet,

which is a combination of the highly collimated central relativistic jet (much smaller in width) and the envelope of non-relativistic material surrounding it.
We measured the size of an object located 53 million light-years from Earth, with an error of less than 500 light-years. The difference between our values and the official ones may be due to the fact that we likely were not capturing the

The jet of M87. OLA, 9 March 2019. [M. Sánchez (SAG), A. Porcel (SAG/OLA)]



The La Laguna Astronomical Observatory is a structure dedicated to astronomical observation, research and dissemination in collaboration with the Sociedad Astronómica Granadina.

very end of the jet in our images, a region that is perhaps more nebulous than the rest.
It is evident that it is possible to obtain measurements that correspond to professionally-obtained values with amateur instruments.
This has opened our minds in two respects: firstly, and contrary to what one might think, it is relatively easy to find examples of mathematics applied to astronomical observations made by amateurs, which can be extrapolated to educational centers or astronomical associations in the form of a laboratory exercise, where students or participants can experience firsthand how to gather evidence (images), extract data and apply theory to see how what sometimes appears to us as something unattainable can actually be reproducible and verifiable by ourselves. Secondly, it shows us that if these kinds of observations are done rigorously, anyone can do good science, which is extremely motivating. ■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Most distant quasar with powerful radio jets discovered

by ESO - Bárbara Ferreira

With the help of the European Southern Observatory's Very Large Telescope (ESO's VLT), astronomers have discovered and studied in detail the most distant source of radio emission known to date. The source is a "radio-loud" quasar — a bright object with powerful jets emitting at radio wavelengths — that is so far away its light has taken 13 billion years to reach us.

The discovery could provide important clues to help astronomers understand the early Universe.

Quasars are very bright objects that lie at the centre of some galaxies and are powered by supermassive black holes. As the black hole consumes the surrounding gas, energy is released, allowing astronomers to spot them even when they are very far away.

The newly discovered quasar, nicknamed P172+18, is so distant that light from it has travelled for about 13 billion years to reach us: we see it as it was when the Universe was just around 780 million years old. While more distant quasars have been discovered, this is the first time astronomers have been able to identify the telltale signatures of radio jets in a quasar this early on in the history of the Universe. Only about 10% of quasars — which astronomers classify as "radio-loud" — have jets, which shine brightly at radio frequencies.

P172+18 is powered by a black hole about 300 million times more massive than our Sun that is consuming gas at a stunning rate. *"The black hole is eating up matter very rapidly, growing in mass at one of the highest rates ever observed,"* explains astronomer Chiara Mazzucchelli, Fellow at ESO in Chile, who led the discovery together with Eduardo Bañados of the Max Planck Institute for Astronomy in Germany.

The astronomers think that there's a link between the rapid growth of supermassive black holes and the powerful radio jets spotted in quasars like P172+18. The jets are thought to be capable of disturbing the gas around

This artist's impression shows how the distant quasar P172+18 and its radio jets may have looked. To date (early 2021), this is the most distant quasar with radio jets ever found and it was studied with the help of ESO's Very Large Telescope. It is so distant that light from it has travelled for about 13 billion years to reach us: we see it as it was when the Universe was only about 780 million years old. [ESO/M. Kornmesser]

the black hole, increasing the rate at which gas falls in. Therefore, studying radio-loud quasars can provide important insights into how black holes in the early Universe grew to their supermassive sizes so quickly after the Big Bang. *"I find it very exciting to discover 'new' black holes for the first time, and to provide one more building block to understand the primordial Universe, where we come from, and ultimately ourselves,"* says Mazzucchelli.

P172+18 was first recognised as a faraway quasar, after having been previously identified as a radio source, at the Magellan Telescope at Las Campanas Observatory in Chile by Bañados and Mazzucchelli. *"As soon as we got the data, we inspected it by eye, and we knew immediately that we had discovered the most distant radio-loud quasar known so far,"* says Bañados.

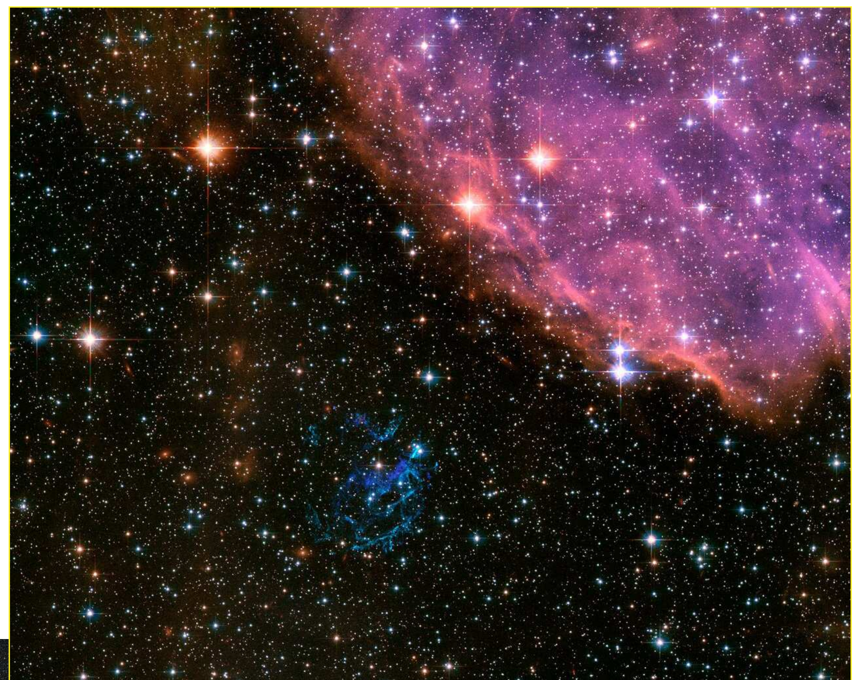
However, owing to a short observation time, the team did not have enough data to study the object in detail. A flurry of observations with other telescopes followed, including with the X-shooter instrument on ESO's VLT, which allowed them to dig deeper into the characteristics of this quasar, including determining key properties such as the mass of the black hole and how fast it's eating up matter from its surroundings. Other telescopes that contributed to the study include the National Radio Astronomy Observatory's Very Large Array and the Keck Telescope in the US. While the team are excited about their discovery, appeared in *The Astrophysical Journal*, they believe this radio-loud quasar could be the first of many to be found, perhaps at even larger cosmological distances. *"This discovery makes me optimistic and I believe — and hope — that the distance record will be broken soon,"* says Bañados.

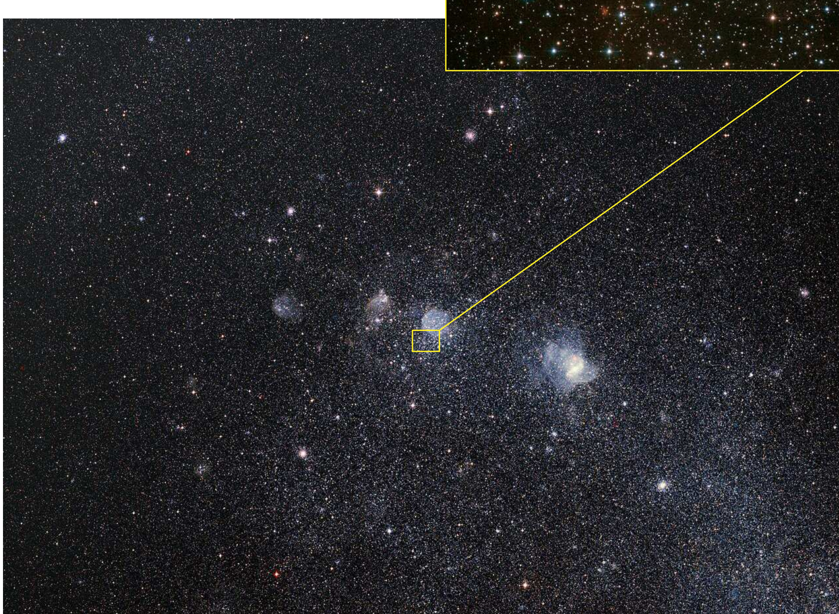
Observations with facilities such as ALMA, in which ESO is a partner, and with ESO's upcoming Extremely Large Telescope (ELT) could help uncover and study more of these early-Universe objects in detail.

Hubble pinpoints supernova blast

by NASA/ESA
Bethany Downer

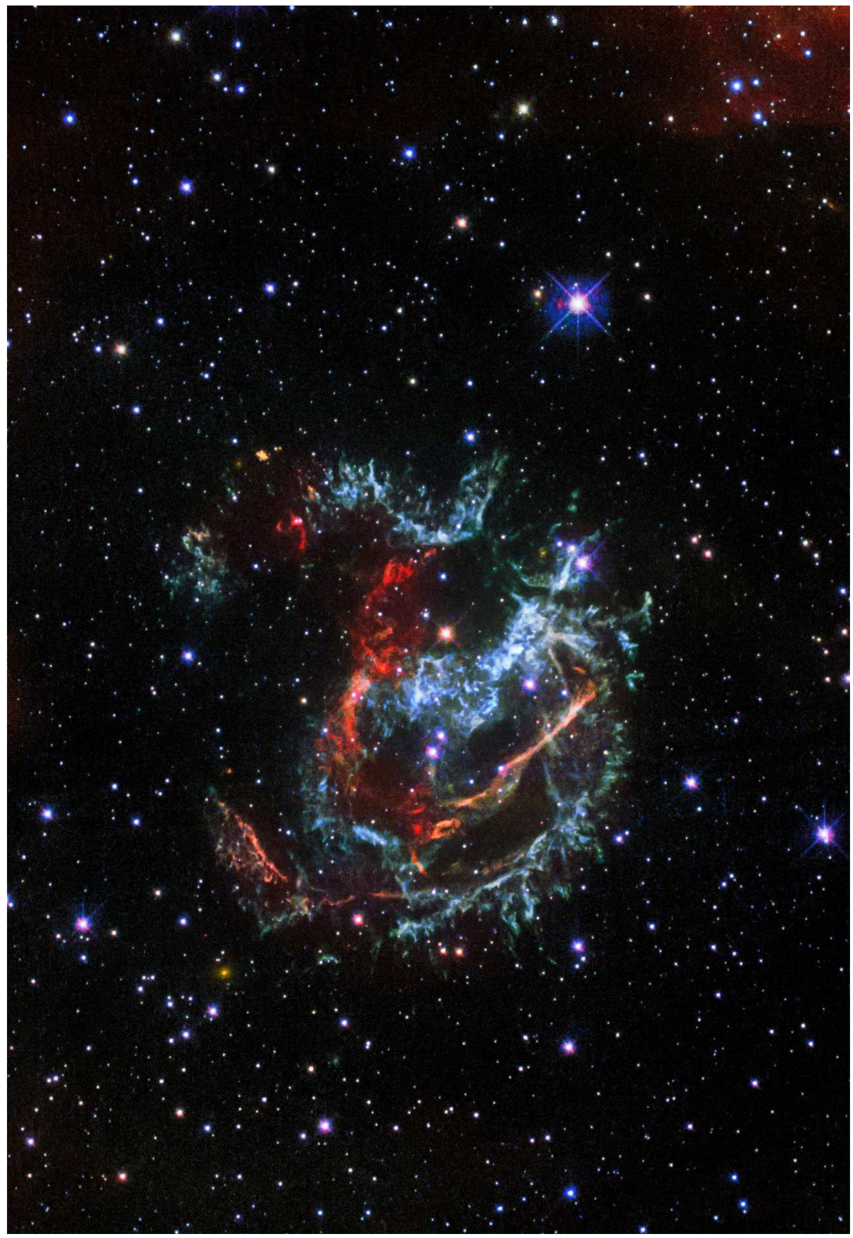
The NASA/ESA Hubble Space Telescope has observed the supernova remnant named 1E 0102.2-7219. Researchers are using Hubble's imagery of the remnant object to wind back the clock on the expanding remains of this exploded star in the hope of understanding the supernova event that caused it 1700 years ago. The featured star that exploded long ago belongs to the Small Magellanic Cloud, a satellite galaxy of our Milky Way located roughly 200,000 light-years away. The doomed star left behind an expanding, gaseous corpse — a supernova remnant — known as 1E 0102.2-7219.





Because the gaseous knots in this supernova remnant are moving at different speeds and directions from the supernova explosion, those moving toward Earth are colored blue in this composition and the ones moving away are shown in red.
This new Hubble image shows these ribbons of gas speeding away from

Left: pictured here is the region of sky around the supernova remnant 1E 0102.2-7219. [ESA/Hubble, Digitized Sky Survey 2. Acknowledgement: Davide De Martin]
Top: Hubble's Distant View of the Supernova Remnant 1E 0102.2-7219 in 2006. [NASA, ESA and the Hubble Heritage Team (STScI/AURA)]



Featured in this Hubble image is an expanding, gaseous corpse — a supernova remnant — known as 1E 0102.2-7219. It is the remnant of a star that exploded long ago in the Small Magellanic Cloud, a satellite galaxy of our Milky Way located roughly 200,000 light-years away. [NASA, ESA, and J. Banovetz and D. Milisavljevic (Purdue University)]

the explosion site at an average speed of 3.2 million kilometers per hour. At that speed, you could travel to the Moon and back in 15 minutes.

Researchers have studied the Hubble archive looking for visible-light images of the supernova remnant and they have analysed the data to calculate a more accurate estimate of the age and centre of the supernova blast.

According to their new estimates, light from this blast arrived at Earth 1700 years ago, during the decline of the Roman Empire. This supernova would only have been visible to inhabitants of Earth's southern hemisphere. Unfortunately, there are no known records of this titanic event. Earlier studies proposed explosion dates of 2,000 and 1,000 years ago, but this new analysis is believed to be more robust.

To pinpoint when the explosion occurred, researchers studied the tadpole-shaped, oxygen-rich clumps of ejecta flung out by this supernova blast. Ionised oxygen is an excellent tracer because it glows brightest in visible light. By using Hubble's powerful resolution to identify the 22 fastest moving ejecta clumps, or knots, the researchers determined that these targets were the least likely to have been slowed down by passage through interstellar material. They then traced the knots' motion backward until the ejecta coalesced at one point, identifying the explosion site. Once that was known, they could calculate how long it took the speedy knots to travel from the explosion centre to their current location.

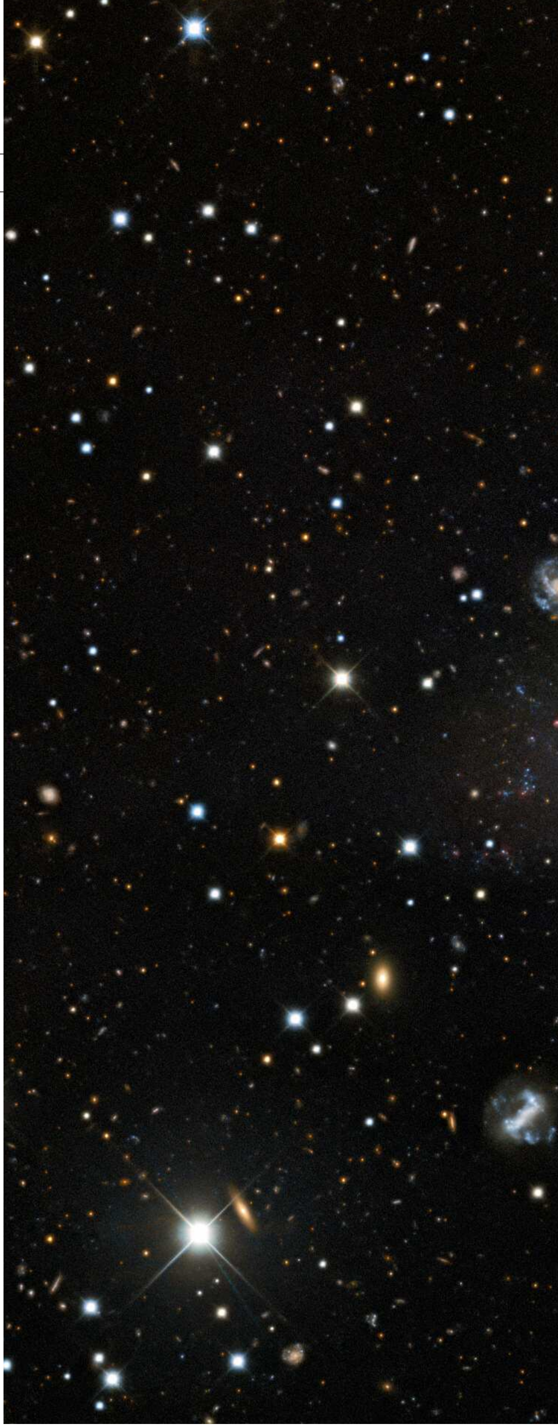
Hubble also measured the speed of a suspected neutron star — the crushed core of the doomed star — that was ejected from the blast. Based on the researchers' estimates, itmust be moving at more than 3 million kilometres per hour from the centre of the explosion to have arrived at its current position. The suspected neutron star was identified in observations with the European Southern Observatory's Very Large Telescope in Chile, in combination with data from NASA's Chandra X-ray Observatory.

Deep dive into a galaxy cluster

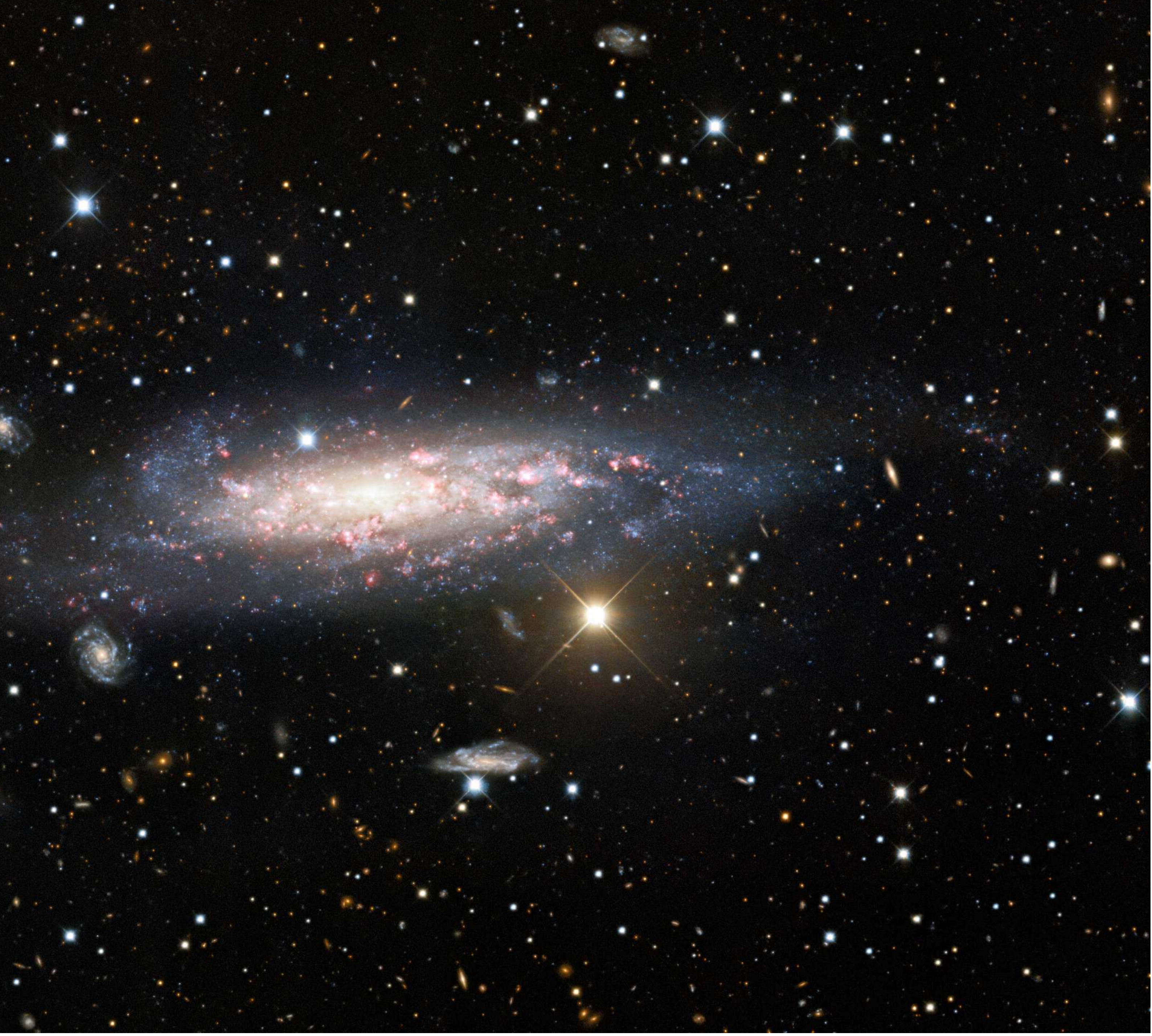
by NOIRLab - Amanda Kocz

Astronomers refer to observations as "deep" when they are taken with very long exposure times. Just as with photography, this gathers more light, revealing distant, fainter objects.
Deeper exposures let astronomers look deeper into the Universe — hence the name. This particular deep image (right) was taken with a 70-minute exposure with the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a Program of NSF's NOIRLab, and captures the spiral galaxy NGC 1003.
NGC 1003 lies over 30 million light-years from Earth in the direction of the constellation Perseus. While it makes for a spectacular sight, it is only one of many galaxies captured in this image. Upon closer inspection, other galaxies can also be seen strewn throughout the image, with everything from delicate spiral galaxies to hundreds of fuzzy, red ellip-

A stunning long-exposure observation lasting 70 minutes from the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a Program of NSF's NOIRLab, reveals the spiral galaxy NGC 1003 in glorious detail. NGC 1003 resides in front of a galaxy cluster — a vast collection of galaxies bound together by gravity. The long exposure time of this deep observation allowed these usually overlooked red background cluster galaxies to be captured. [KPNO/NOIRLab/NSF/AURA - Ack: M.T. Patterson (New Mexico State University) - Image processing: Travis Rector (University of Alaska Anchorage), Mahdi Zamani & Davide de Martin]



Zooming on NGC 1003 for press release noirlab2101: Deep Dive into a Galaxy Cluster. [KPNO/NOIRLab/NSF/AURA, S. Brunier/Digitized Sky Survey 2, E. Slawik. Image Processing: Travis Rector (University of Alaska Anchorage), Mahdi Zamani & Davide de Martin]



tical galaxies lurking in the background. The long exposure time of this deep observation — arguably the deepest image of NGC 1003 ever captured — allowed these usually overlooked background cluster galaxies to be captured in breathtaking detail.

Deep images such as this one have had an important role in shaping our understanding of the Universe. In 1995, the Hubble Space Telescope famously observed a tiny, nondescript patch of sky for 10 days to create the Hubble Deep Field. The observations revealed thousands of distinct galaxies, showing that our Universe is a surprisingly crowded place.

While the Hubble team deliberately avoided bright galaxies for their observation, this ground-based observation is littered with galaxies of all shapes and sizes — a spectacular backdrop for this portrait of NGC 1003. As well as revealing the host of background galaxies, the long exposure time of this observation allowed the researchers to capture the faint outer reaches of NGC 1003, which are threaded through with bright tendrils of stars. Equally eye-catching is the bright heart of the galaxy, which is surrounded by clouds of dense dust.

NGC 1003 resides in front of a galaxy cluster — a vast collection of galaxies bound together by gravity. These structures are among the most massive in the known Universe, and outweigh the Sun by a factor of a thousand trillion.

Just as stars can be grouped into clusters, and these star clusters into galaxies, galaxies themselves form clusters and even superclusters — building up the large-scale structure of our Universe. ■

Six-exoplanet system challenges theories of how planets form

by ESO - Bárbara Ferreira

The first time an ESO team observed TOI-178, a star some 200 light-years away in the constellation of Sculptor, they thought they had spotted two planets going around it in the same orbit. However, a closer look revealed something entirely different.

"Through further observations we realised that there were not two planets orbiting the star at roughly the same distance from it, but rather multiple planets in a very special configuration," says Adrien Leleu from the Université de Genève and the University of Bern, Switzerland, who led a new study of the system published in *Astronomy & Astrophysics*.

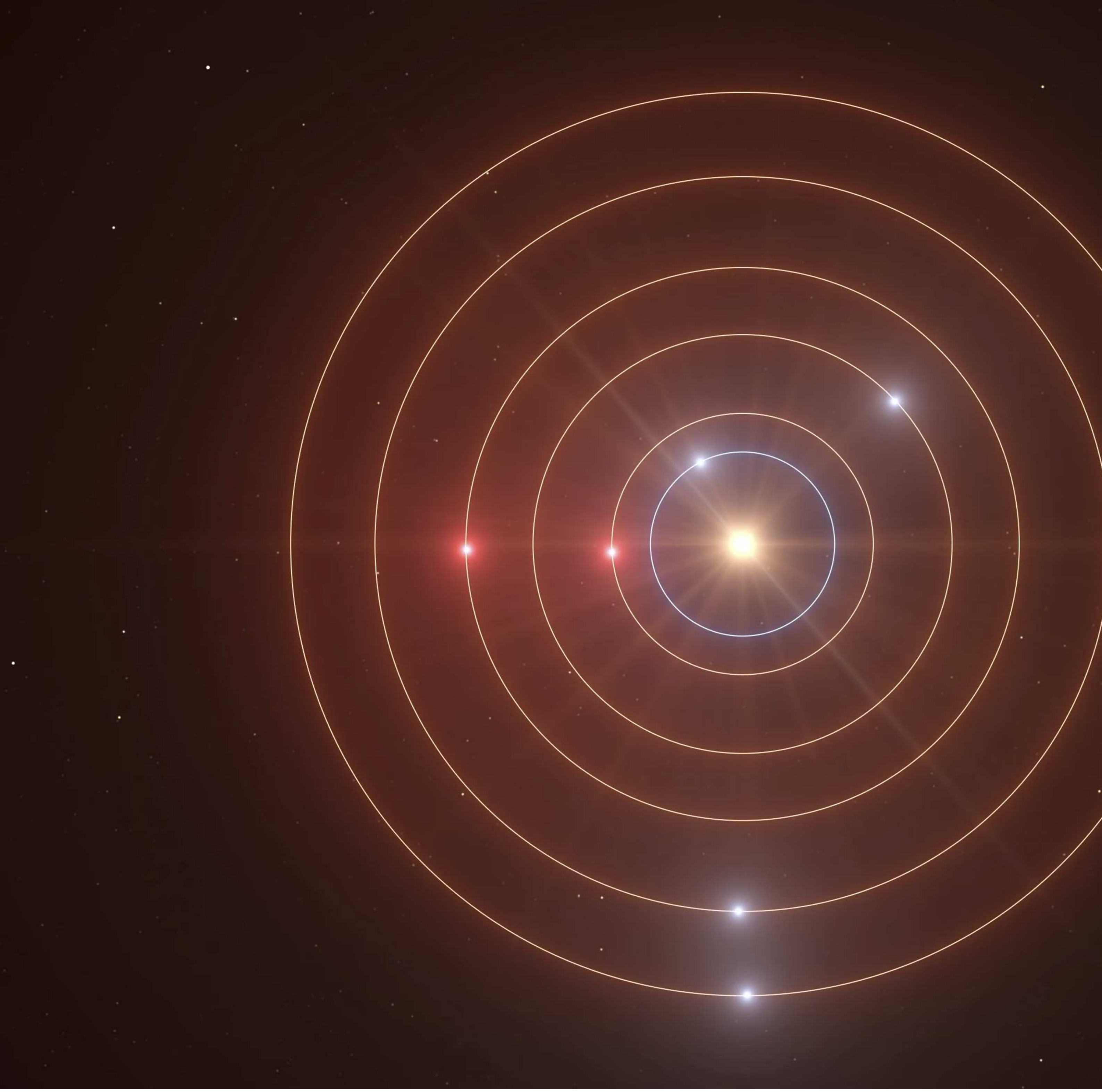
The new research has revealed that the system boasts six exoplanets and that all but the one closest to the star are locked in a rhythmic dance as they move in their orbits. In other words, they are in resonance. This means that there are patterns that repeat themselves as the planets go around the star, with some planets aligning every few orbits. A similar resonance is observed in the orbits of three of Jupiter's moons: Io, Europa and Ganymede. Io, the closest of the three to Jupiter, completes four full orbits around Jupiter for every orbit that Ganymede, the furthest away, makes, and two full orbits for every orbit Europa makes.

The five outer exoplanets of the TOI-178 system follow a much more complex chain of resonance, one of the longest yet discovered in a system of planets. While the three Jupiter moons are in a 4:2:1 resonance, the five outer planets in the TOI-178 system follow a 18:9:6:4:3 chain: while the second planet from the star (the first in the resonance

This artist's impression shows the view from the planet in the TOI-178 system found orbiting furthest from the star. New research by Adrien Leleu and his colleagues with several telescopes, including ESO's Very Large Telescope, has revealed that the system boasts six exoplanets and that all but the one closest to the star are locked in a rare rhythm as they move in their orbits. But while the orbital motion in this system is in harmony, the physical properties of the planets are more disorderly, with significant variations in density from planet to planet. This contrast challenges astronomers' understanding of how planets form and evolve. This artist's impression is based on the known physical parameters for the planets and the star seen, and uses a vast database of objects in the Universe. [ESO/L. Calçada/spaceengine.org]

chain) completes 18 orbits, the third planet from the star (second in the chain) completes 9 orbits, and so on. In fact, the scientists initially only found five planets in the system, but by following this resonant rhythm they calculated where in its orbit an additional planet would be when they next had a window to observe the system.

More than just an orbital curiosity, this dance of resonant planets provides clues about the system's past. *"The orbits in this system are very well ordered, which tells us that this system has evolved quite gently since its birth,"* explains co-author Yann Alibert from the University of Bern. If the system had been significantly disturbed earlier in its life, for example by a giant impact, this fragile configuration of orbits would not have survived.



Artist's representation of the orbits of the planets in the TOI-178 system. [ESO/L. Calçada]

But even if the arrangement of the orbits is neat and well-ordered, the densities of the planets *"are much more disorderly,"* says Nathan Hara from the Université de Genève, Switzerland, who was also involved in the study. *"It appears there is a planet as dense as the Earth right next to a very fluffy planet with half the density of Neptune, followed by a planet with the density of Neptune. It is not what we are used to."*

In our Solar System, for example, the planets are neatly arranged, with the rocky, denser planets closer to the central star and the fluffy, low-density gas planets farther out. *"This contrast between the rhythmic harmony of the orbital motion and the disorderly densities certainly challenges our understanding of the formation and evolution of planetary systems,"* says Leleu.

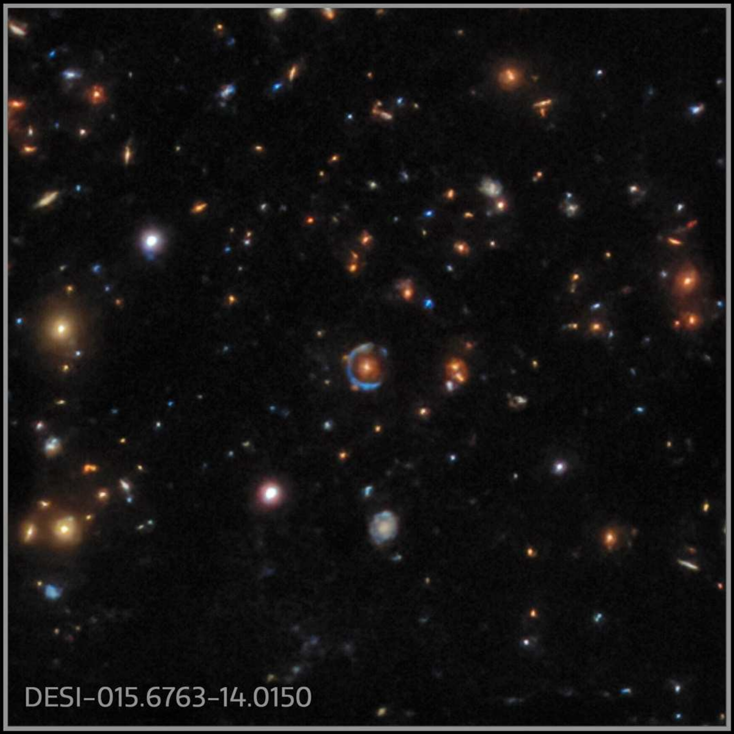
To investigate the system's unusual architecture, the team used data from the European Space Agency's CHEOPS satellite, alongside the ground-based ESPRESSO instrument on ESO's VLT and the NGTS and

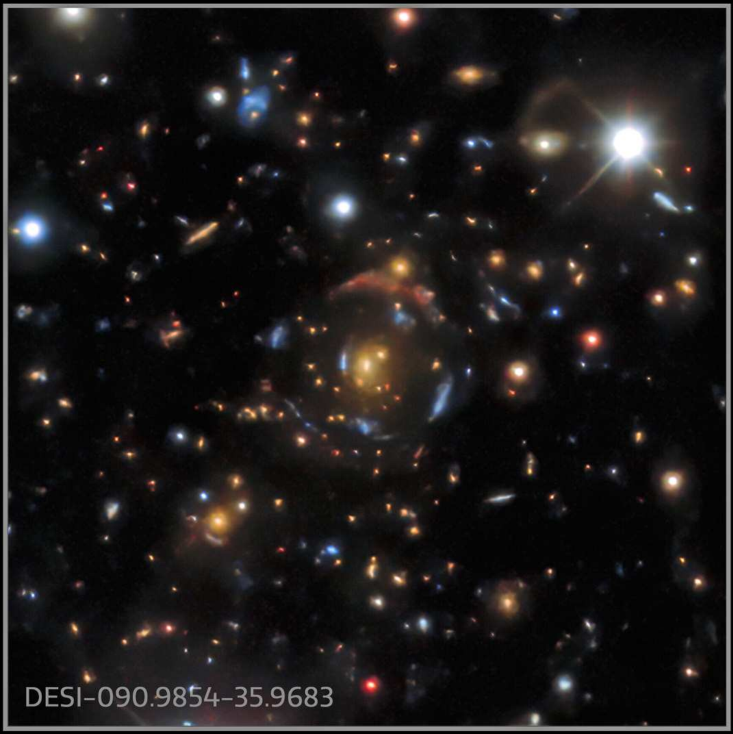
This animation shows a representation of the orbits and movements of the planets in the TOI-178 system. New research by Adrien Leleu and his colleagues with several telescopes, including ESO's Very Large Telescope, has revealed that the system boasts six exoplanets and that all but the one closest to the star are locked in a rare rhythm as they move in their orbits (represented in orange). In other words, they are in resonance. This means that there are patterns that repeat themselves rhythmically as the planets go around the star, with some planets aligning every few orbits. In this artist's animation, the rhythmic movement of the planets around the central star is represented through a musical harmony, created by attributing a note (in the pentatonic scale) to each of the planets in the resonance chain. This note plays when a planet completes either one full orbit or one half orbit; when planets align at these points in their orbits, they ring in resonance. [ESO/L. Calçada]

SPECULOOS, both sited at ESO's Paranal Observatory in Chile. Since exoplanets are extremely tricky to spot directly with telescopes, astronomers must instead rely on other techniques to detect them. The main methods used are imaging transits — observing the light emitted by the central star, which dims as an exoplanet passes in front of it when observed from the Earth — and radial velocities — observing the star's light spectrum for small signs of wobbles which happen as the exoplanets move in their orbits. The team used both methods to observe the system: CHEOPS, NGTS and SPECULOOS for transits and ESPRESSO for radial velocities.

By combining the two techniques, astronomers were able to gather key information about the system and its planets, which orbit their central star much closer and much faster than the Earth orbits the Sun. The fastest (the innermost planet) completes an orbit in just a couple of days, while the slowest takes about ten times longer. The six planets have sizes ranging from about one to about three times the size of Earth, while their masses are 1.5 to 8 times the mass of Earth. Some of the planets are rocky, but larger than Earth — these planets are known as Super-Earths. Others are gas planets, like the outer planets in our Solar System, but they are much smaller — these are nicknamed Mini-Neptunes.

Although none of the six exoplanets found lies in the star's habitable zone, the researchers suggest that, by continuing the resonance chain, they might find additional planets that could exist in or very close to this zone. ESO's Extremely Large Telescope (ELT), which is set to begin operating this decade, will be able to directly image rocky exoplanets in a star's habitable zone and even characterise their atmospheres, presenting an opportunity to get to know systems like TOI-178 in even greater detail.





Doubling the number of known gravitational lenses

by NOIRLab - Amanda Kocz

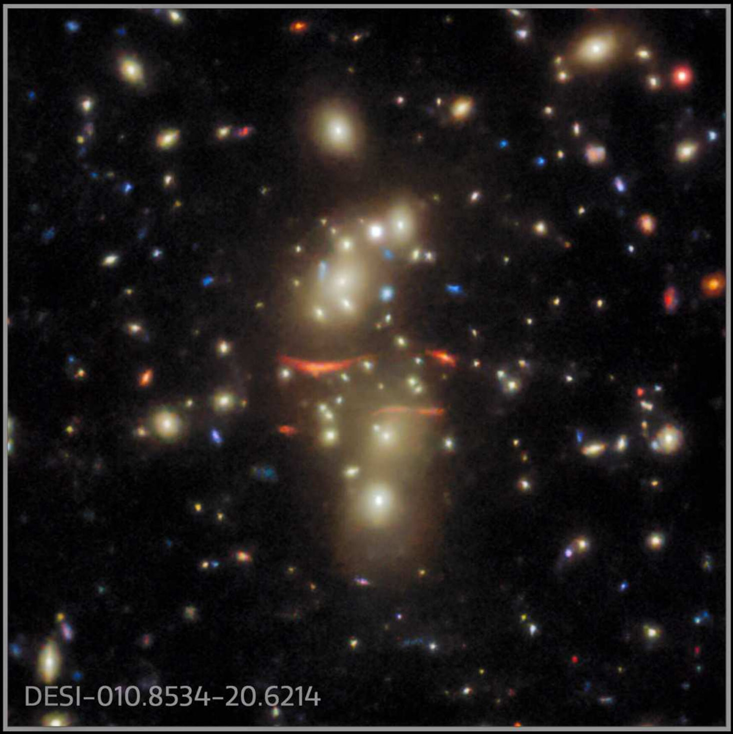
Astronomers hunting for gravitational lenses utilized machine learning to inspect the vast dataset known as the DESI Legacy Imaging Surveys, uncovering 1,210 new lenses. The data were collected at Cerro Tololo Inter-American Observatory (CTIO) and Kitt Peak National Observatory (KPNO), both Programs of the National Science Foundation's NOIRLab. The ambitious DESI Legacy Imaging Surveys just had its ninth and final data release.

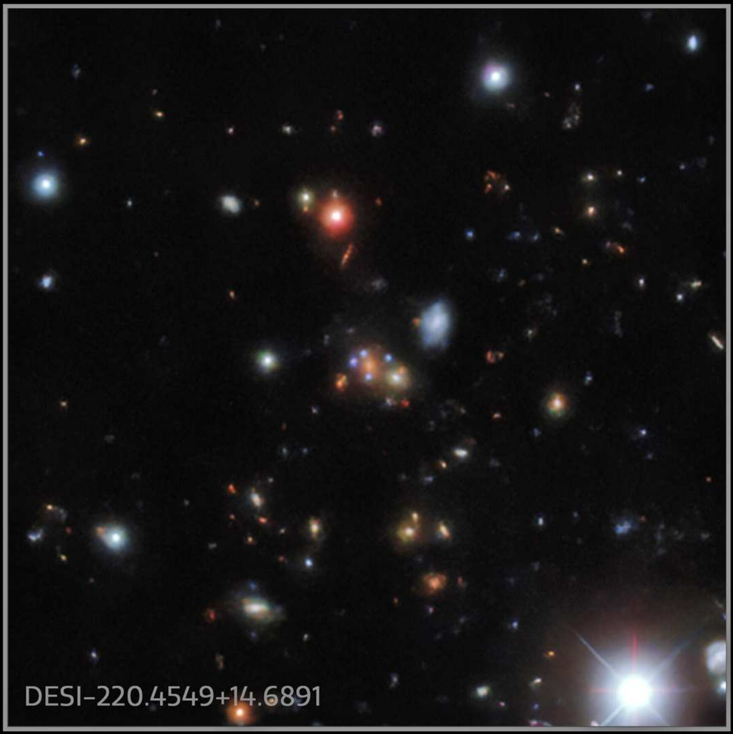
Discussed in scientific journals since the 1930s, gravitational lenses are products of Einstein's General Theory of Relativity. The theory says that a massive object, such as a cluster of galaxies, can warp spacetime. Some scientists, including Einstein, predicted that this warping of spacetime might be observable, as a stretching and distortion of the light from a background galaxy by a foreground cluster of galaxies.

The lenses typically appear in images as arcs and streaks around foreground galaxies and galaxy clusters. Only 1 in 10,000 massive galaxies are expected to show evidence of strong gravitational lensing, and locating them is not easy. Gravitational lenses allow astronomers to explore the most profound questions of our Universe, including the nature of dark matter and the value of the Hubble constant, which defines the expansion of the Universe. A major limitation of the use of gravitational lenses until now has been the small number of them known.

"A massive galaxy warps the spacetime around it, but usually you don't notice this effect. Only when a galaxy is hidden directly behind a giant galaxy is a lens possible to see," notes the lead author of the study, Xiaosheng Huang from the University of San Francisco. *"When we started this project in 2018, there were only about 300 confirmed strong lenses."*

"As a co-leader in the DESI Legacy Surveys, I realized this would be the perfect dataset to search for gravitational lenses," explains study co-author David Schlegel of Lawrence Berkeley National Laboratory (LBNL). *"My colleague Huang had just finished teaching an undergraduate class on machine learning at the University of San Francisco, and together we realized this was a perfect opportunity to apply those techniques to a search for gravitational lenses."*





Examples of gravitational lenses found in the DESI Legacy Survey data. [DESI Legacy Imaging Surveys/ LBNL/DOE & KPNO/CTIO/NOIRLab/ NSF/AURA]

The lensing study was possible because of the availability of science-ready data from the DESI Legacy Imaging Surveys, which were conducted to identify targets for DESI's operations, and from which the ninth and final dataset has just been released. These surveys comprise a unique blend of three projects that have observed a third of the night sky: the Dark Energy Camera Legacy Survey (DECaLS), observed by the DOE-built Dark Energy Camera (DECam) on the Víctor M. Blanco 4-meter Telescope at CTIO in Chile; the Mayall z-band Legacy Survey (MzLS), by the Mosaic3 camera on the Nicholas U. Mayall 4-meter Telescope at KPNO; and the Beijing-Arizona Sky Survey (BASS) by the 90Prime camera on the Bok 2.3-meter Telescope, which is owned and operated by the University of Arizona and located at KPNO.

"We designed the Legacy Surveys imaging project from the ground up as a public enterprise, so that it could be used by any scientist," said study co-author Arjun Dey, from NSF's NOIRLab. *"Our survey has already yielded more than a thousand new gravitational lenses, and there are undoubtedly many more awaiting discovery."*

The DESI Legacy Imaging Surveys data are served to the astronomical community via the Astro Data Lab at NOIRLab's Community Science and Data Center (CSDC).

"Providing science-ready datasets for discovery and exploration is core to our mission," said CSDC Director Adam Bolton. *"The DESI Legacy Imaging Surveys is a key resource that can be used for years to come by the astronomy community for investigations like these."*

To analyze the data, Huang and team used the National Energy Research Scientific Computer Center's (NERSC) supercomputer at Berkeley Lab. *"The DESI Legacy Imaging Surveys were absolutely crucial to this study; not just the telescopes, instruments, and facilities but also data reduction and source extraction,"* explains Huang. *"The combination of the breadth and depth of the observations is unparalleled."*

With the huge amount of science-ready data to work through, the researchers turned to a kind of machine learning known as a deep residual neural net. Neural nets are computing algorithms that are somewhat comparable to a human brain and are used for solving artificial intelligence problems. Deep neural nets have many layers that collectively can decide whether a candidate object belongs to a particular group. In order to be able to do this, however, the neural nets have to be trained to recognize the objects in question.

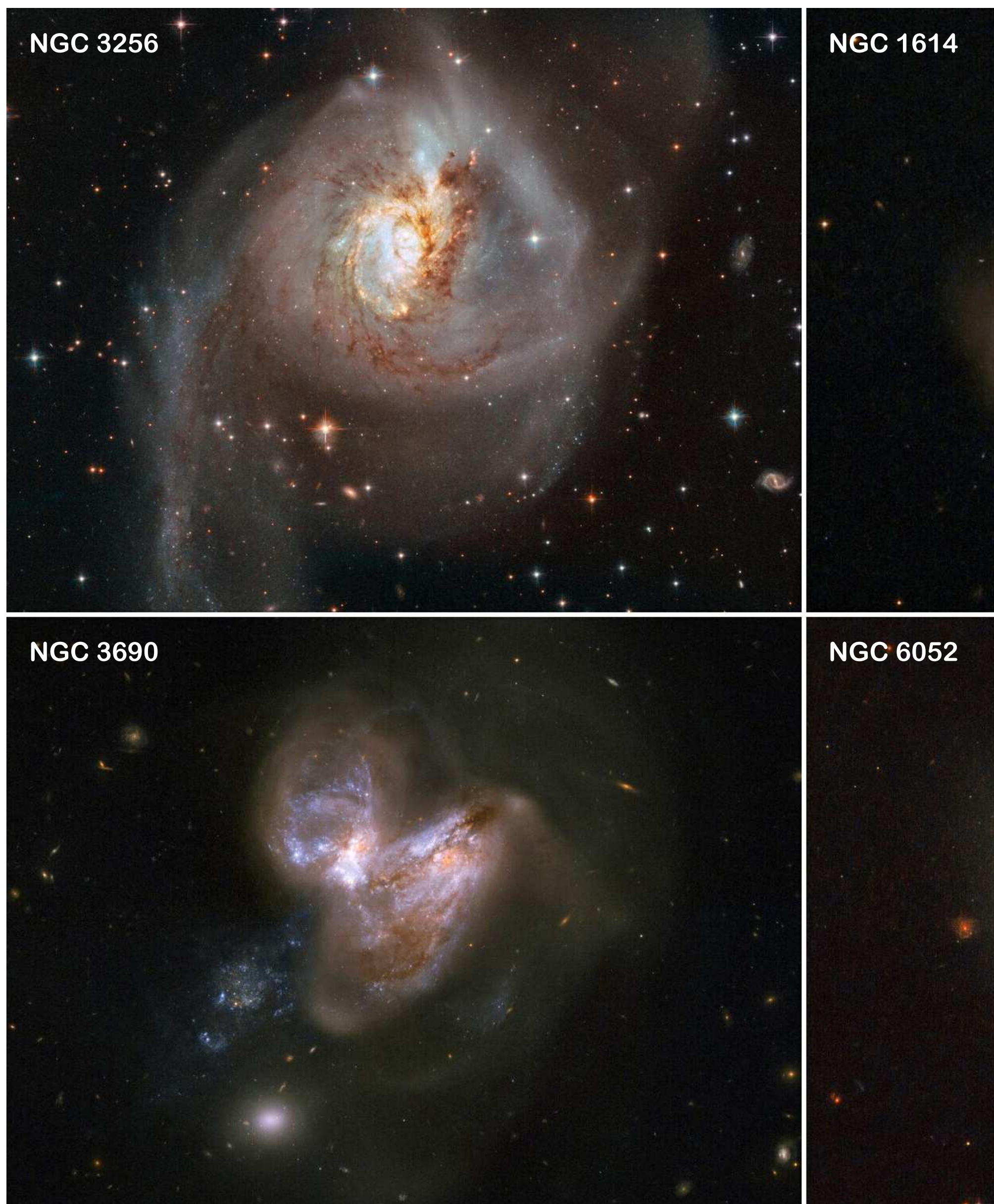
With the large number of lens candidates now on hand, researchers can make new measurements of cosmological parameters such as the Hubble constant. The key will be to detect a supernova in the background galaxy, which, when lensed by a foreground galaxy, will appear as multiple points of light. Now that astronomers know which galaxies show evidence for strong lensing, they know where to search.

New facilities such as the Vera C. Rubin Observatory (currently under construction in Chile and operated by NOIRLab) will monitor objects like these as part of its mission, allowing any supernova to be measured rapidly by other telescopes.

Undergraduate students played a significant role in the project from its beginning. University of California student Andi Gu said, *"My role on the project has helped me develop several skills which I believe to be key for my future academic career."*

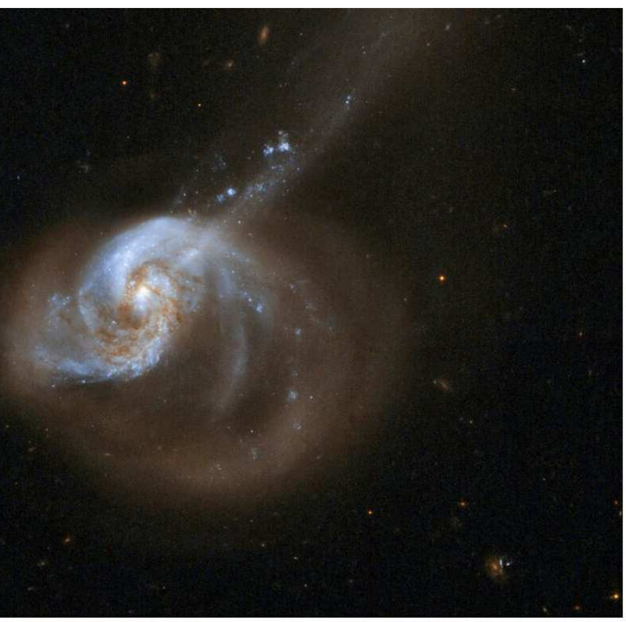
Hubble showcases six galaxy mergers

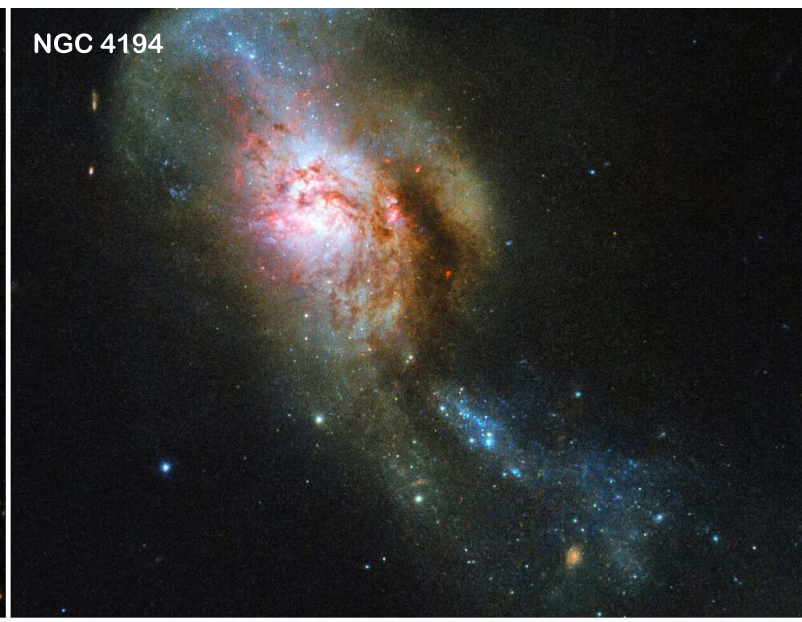
by NASA/ESA
Bethany Downer

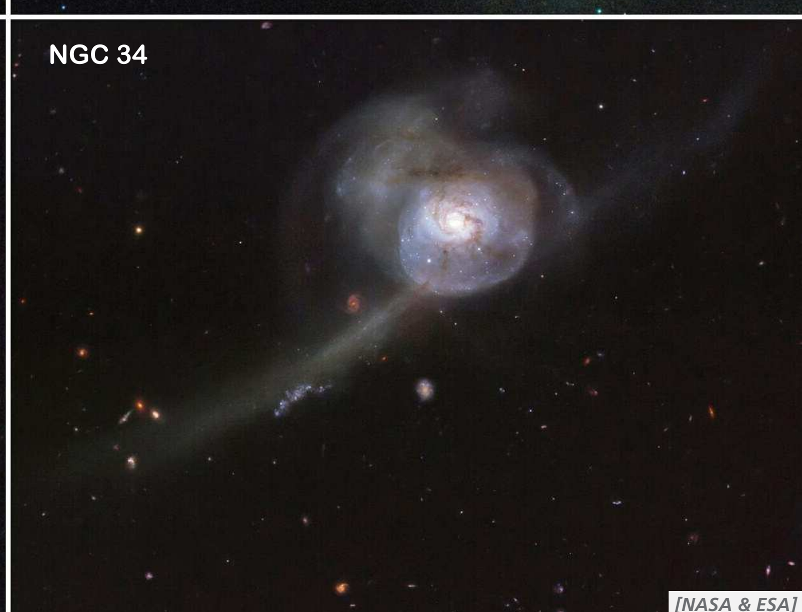


To celebrate a new year, the NASA/ESA Hubble Space Telescope has published a montage of six beautiful galaxy mergers. Each of these merging systems was studied as part of the recent HiPEEC survey to investigate the rate of new star formation within such systems. These interactions are a key aspect of galaxy evolution and are among the most spectacular events in the lifetime of a galaxy.
It is during rare merging events that galaxies undergo dramatic changes in their appearance and in their stellar content. These systems are excellent laboratories to trace the formation of star clusters under extreme physical conditions.
The Milky Way typically forms star clusters with masses that are 10 thousand times the mass of our Sun. This doesn't compare to the masses of the star clusters forming in colliding galaxies, which can reach millions of times the mass of our Sun.
These dense stellar systems are also very luminous. Even after the collision, when the resulting galactic system begins to fade into a more quiescent phase, these very massive

star clusters will shine throughout their host galaxy, as long-lasting witnesses of past merging events.
By studying the six galaxy mergers shown here, the Hubble imaging Probe of Extreme Environments and Clusters (HiPEEC) survey has investigated how star clusters are affected during collisions by the rapid changes that drastically increase the rate at which new stars are formed in these galaxies. Hubble's capabilities have made it possible to resolve large star-forming "knots" into numerous compact young star clusters. Hubble's ultraviolet and near-infrared observations of these systems have been used to derive star cluster ages, masses, and extinctions and to analyse the star formation rate within these six merging galaxies.
The HiPEEC study reveals that the star cluster populations undergo large and rapid variations in their properties, with the most massive clusters formed towards the end of the merger phase.





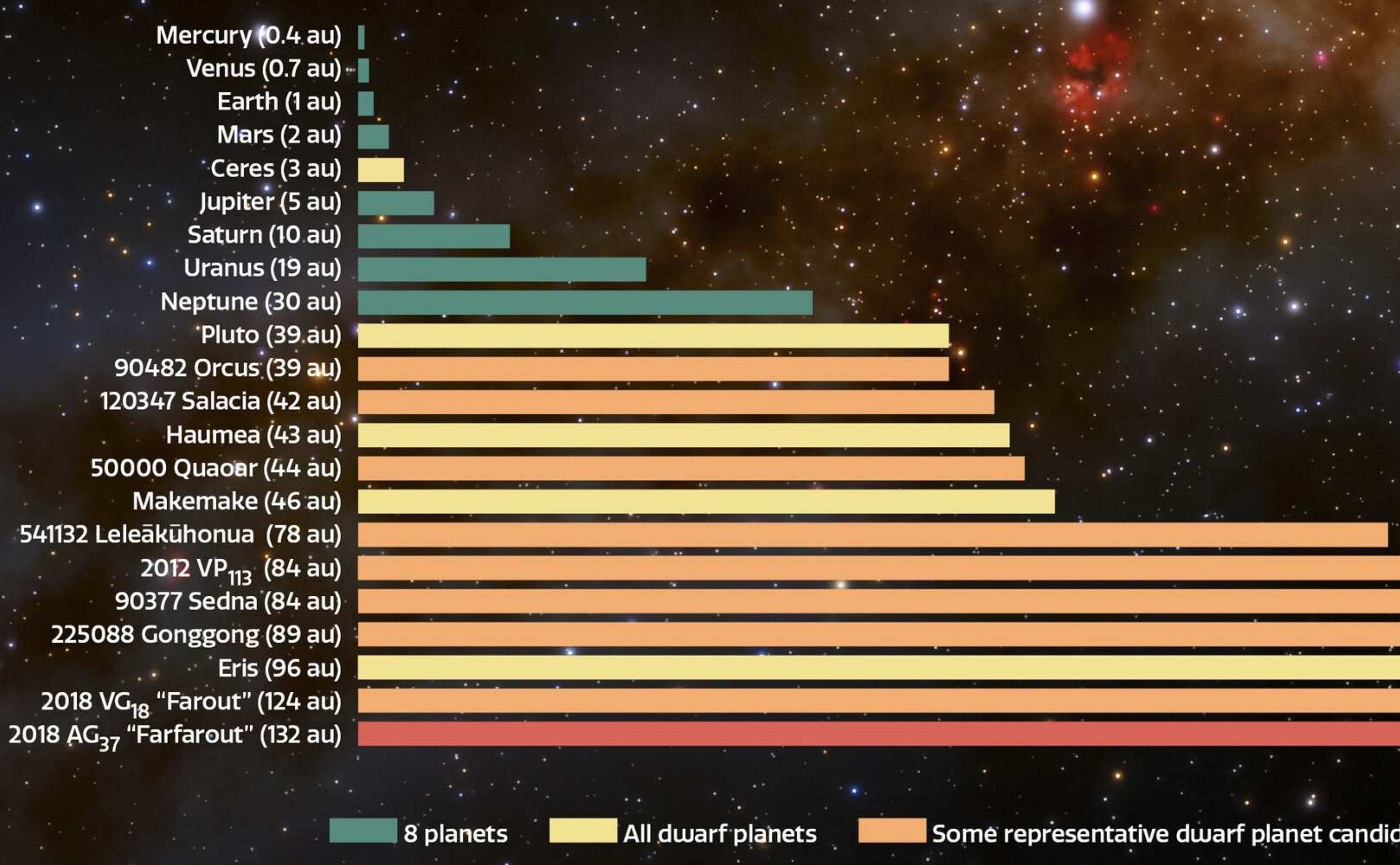


[NASA & ESA]

Solar System's most distant known object confirmed

by NOIRLab - Amanda Kocz

With the help of the international Gemini Observatory, a Program of NSF's NOIRLab, and other ground-based telescopes, astronomers have confirmed that a faint object discovered in 2018 and nicknamed "Farfarout" is indeed the most distant object yet found in our Solar System.



It was first spotted in January 2018 by the Subaru Telescope, located on Maunakea in Hawai'i. Its discoverers could tell it was very far away, but they weren't sure exactly how far. They needed more observations.

"At that time we did not know the object's orbit as we only had the Subaru discovery observations over 24 hours, but it takes years of observations to get an object's orbit around the Sun," explained co-discoverer Scott Sheppard of the Carnegie Institution for Science. "All we knew was that the object appeared to be very distant at the time of discovery."

Sheppard and his colleagues, David Tholen of the University of Hawai'i and Chad Trujillo of Northern Arizona University, spent the next few years tracking the object with the Gemini North telescope (also on Maunakea in Hawai'i) and the

This illustration depicts the most distant object yet found in our Solar System, nicknamed "Farfarout," in the lower right. In the lower left, a graph shows the distances of the planets, dwarf planets, candidate dwarf planets, and Farfarout from the Sun in astronomical units (au). One au is equal to Earth's average distance from the Sun. Farfarout is 132 au from the Sun. [NOIRLab/NSF/AURA/J. da Silva]

These discovery images of Farfarout (2018 AG_{37}) were taken with the Subaru Telescope on the nights of 15 and 16 January 2018 Universal Time (UT). By comparing the images with each other, it is possible to see that Farfarout (marked by blue horizontal lines) moves while the background stars and galaxies do not. [S. Sheppard]

Carnegie Institution for Science's Magellan Telescopes in Chile to determine its orbit. They have now confirmed that Farfarout currently lies 132 astronomical units (au) from the Sun, which is 132 times farther from the Sun than Earth is. (For comparison, Pluto is 39 au from the Sun, on average.)

Farfarout is even more remote than the previous Solar System distance record-holder, which was discovered by the same team and nicknamed "Farout." Provisionally designated 2018 VG_{18}, Farout is 124 au from the Sun. However, the orbit of Farfarout is quite elongated, taking it 175 au from the Sun at its farthest point and around 27 au at its closest, which is inside the orbit of Neptune. Because its orbit crosses Nep- tune's, Farfarout could provide insights into the history of the outer Solar System.

"Farfarout was likely thrown into the outer Solar System by getting too close to Neptune in the distant past," said Trujillo. *"Farfarout will likely interact with Neptune again in the future since their orbits still intersect."*

Farfarout is very faint. Based on its brightness and distance from the Sun, the team estimates it to be about 400 kilometers (250 miles) across, putting it at the low end of possibly being designated a dwarf planet by the International Astronomical Union (IAU).

The IAU's Minor Planet Center in Massachusetts announced that it has given Farfarout the provisional designation 2018 AG_{37}. The Solar System's most distant known member will receive an official name after more observations are gathered and its orbit becomes even more refined in the coming years.

"Farfarout takes a millennium to go around the Sun once," said Tholen. *"Because of this, it moves very slowly across the sky, requiring several years of observations to precisely determine its trajectory."*

Farfarout's discoverers are confident that even more distant objects remain to be discovered on the outskirts of the Solar System, and that its distance record might not stand for long.

"The discovery of Farfarout shows our increasing ability to map the outer Solar System and observe farther and farther towards the fringes of our Solar System," said Sheppard. *"Only with the advancements in the last few years of large digital cameras on very large telescopes has it been possible to efficiently discover very distant objects like Farfarout. Even though some of these distant objects are quite large — the size of dwarf planets — they are very faint because of their extreme distances from the Sun. Farfarout is just the tip of the iceberg of objects in the very distant Solar System."*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