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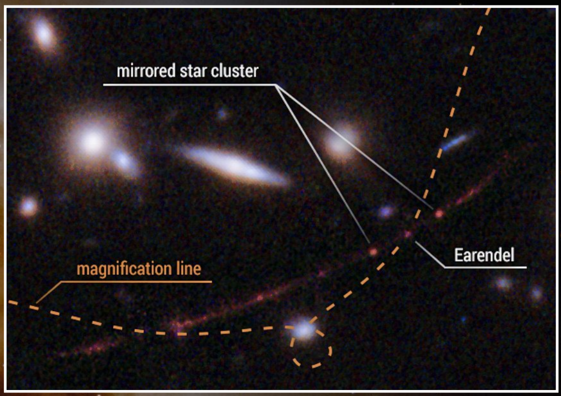
Earendel and the universe of the Population III



New planet discovered around Proxima Centauri

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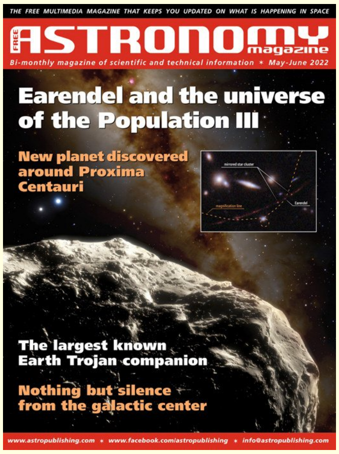

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Earendel and the universe of the Population III

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

In the first decades of the last century, astronomers realized that stars could essentially be divided into two populations based on the abundance of metals found in their spectra. It was Walter Baade, in the 1940s, who proposed the Spartan subdivision (still in use today, with some variations) into Population I stars and Population II stars, the former rich in metals (2-3% of the mass), the latter poor in metals (0.1% of the mass). Since the metallicity of the universe has increased with the passing of billions of years due to the production of metals in stellar nuclei and their subsequent spillage into space, it goes without saying that Population I stars are typically younger than those in Population II. The Sun, although not very young (4.6 billion years), belongs to Population I, which suggests that Population II stars must be older on average.

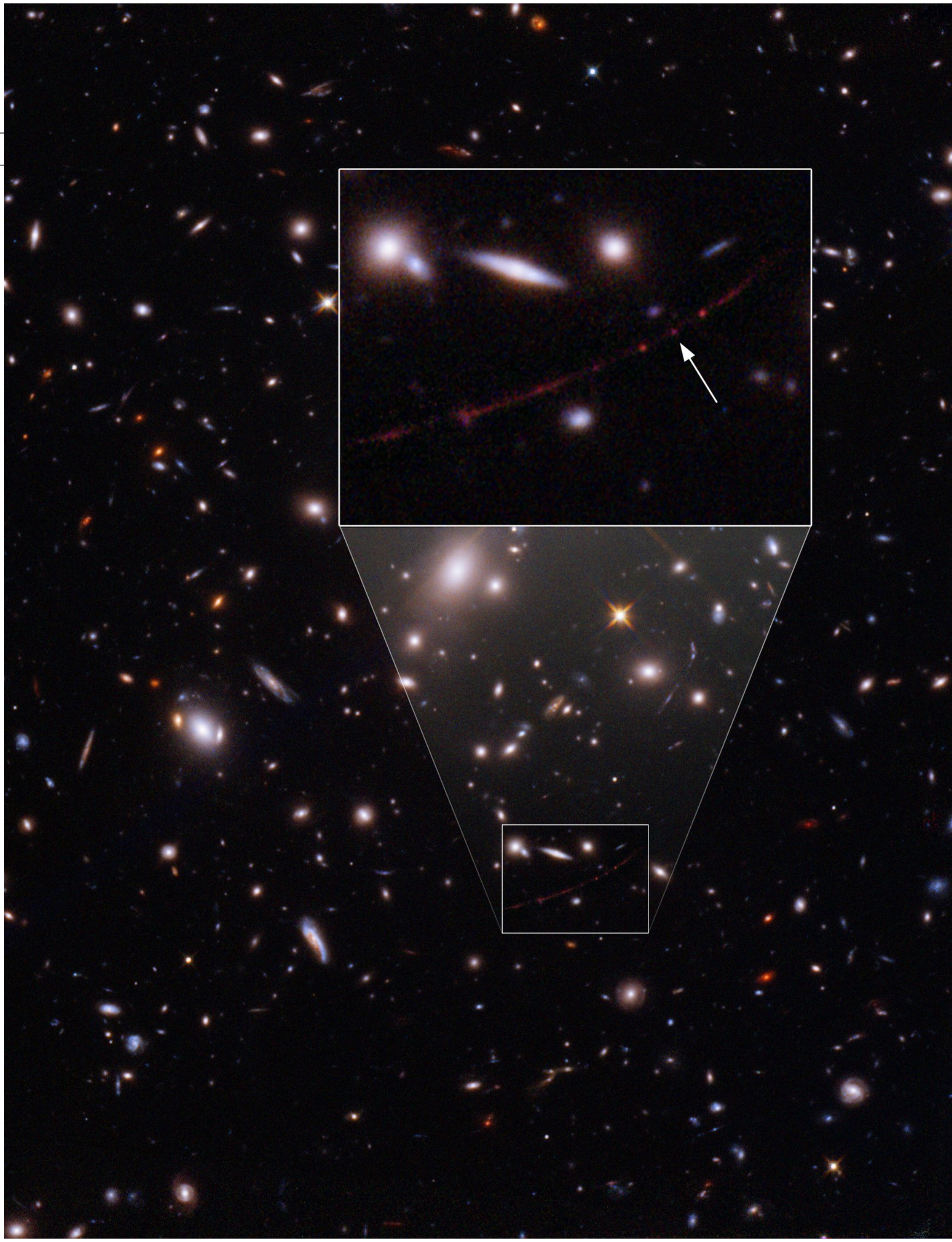
Observations from the Hubble Space Telescope, pictured here, allowed a team of researchers to discover what is now the most distant star in the universe, Earendel. Towards the end of this year, Hubble's successor, the Webb Space Telescope, will analyze the light from that star, and we will determine if Earendel belongs to the elusive Population III. [ESA/Hubble]

Today we know that many of them have existed for over 10 billion years and that some are almost as old as the universe itself. However, not even the oldest known stars can belong to the first generation of stars born in the universe. In fact, even if the metals of Population II are not very abundant, most of those metals still did not exist immediately after the Big Bang, when the universe was composed almost entirely of hydrogen and helium, with negligible traces of lithium and beryllium. It was to fill this gap that astronomers introduced a hypothetical third class of stars, Population III, whose chemical composition should mirror that of the primordial gas generated directly by the Big Bang.

While the search has been on for decades, no Population III stars have so far been observed with certainty. The most shared explanation by astronomers for this is that all Population III stars must have had enormous masses, at least 50-300 solar masses, since star formation models indicate that lower metallicity requires a greater initial mass for the

With this observation, the NASA/ESA Hubble Space Telescope has established an extraordinary new benchmark: detecting the light of a star that existed within the first billion years after the Universe's birth in the Big Bang (at a redshift of 6.2) — the most distant individual star ever seen. This sets up a major target for the NASA/ESA/CSA James Webb Space Telescope in its first year. [NASA, ESA, B. Welch (JHU), D. Coe and A. Pagan (STScI)]

stars. Those models also tell us that the larger the initial mass, the shorter the existence of the star. About Population III stars, their permanence in the so-called Main Sequence has probably not exceeded a few tens of millions of years. If we consider, as the most recent cosmological models indicate, that the first stars of the universe should have appeared between 100 and 250 million years after the Big Bang, the observation of Population III stars requires that we be able to reach the epoch when the universe was only about 300 million years old. Unfortunately, that era is hard to investigate because it is characterized by the final phase of the so-called reionization of the universe, which transitioned the universe from a state of transparency to a state in which the first objects became visible by emitting electromagnetic radiation. So far, the farthest object astronomers have been able to prove the existence of is a very remote galaxy called GN-z11, located in time about 400 million years after the Big Bang. Therefore, it seems unthinkable to be able to observe individual Population III stars. In these remote times, however, at least two scenarios might have occurred that could delay the extinction of those stars, making them reach epochs (distances) that can be investigated by current instruments. The first scenario predicts that, in the extreme peripheries of the first galaxies, there may have remained clouds of primordial gas not enriched by the metals expelled by supernova explosions typical of the innermost galactic regions. Population III stars may have grown in those clouds late enough that their light is still reaching us. The second scenario is predicted by some models describing the formation of those stars, according to which the clouds of hydrogen and helium that forged more massive stars might also have produced less massive stars with significantly longer life expectancies.

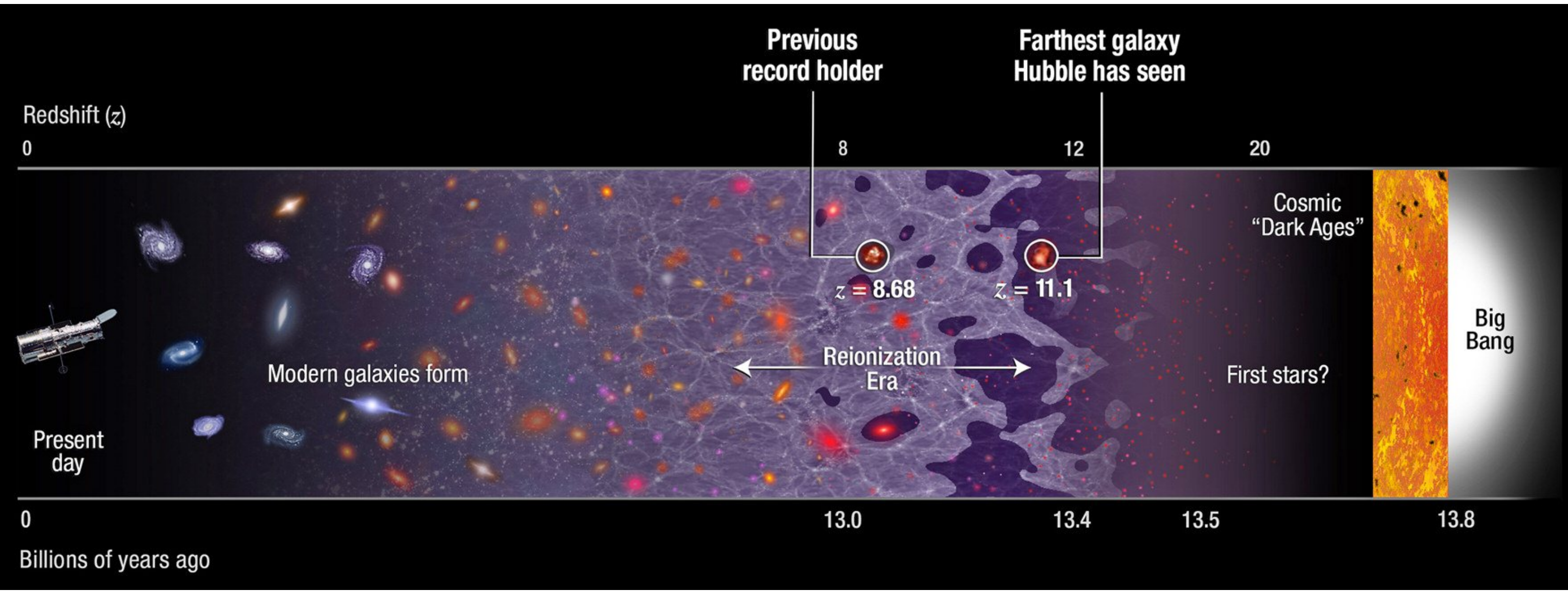


The star nicknamed Earendel (indicated here with an arrow) is positioned along a ripple in spacetime that gives it extreme magnification, allowing it to emerge into view from its host galaxy, which appears as a red smear across the sky. The whole scene is viewed through the distorted lens created by a massive galaxy cluster in the intervening space, which allows the galaxy's features to be seen, but also warps their appearance—an effect astronomers call gravitational lensing. The red dots on either side of Earendel are a star cluster that is mirrored on either side of the ripple, a result of the gravitational lensing distortion. The entire galaxy, called the Sunrise Arc, appears three times, and knots along its length are other mirrored star clusters. Earendel's unique position right along the line of most extreme magnification allows it to be detected, even though it is not a cluster. [NASA, ESA, B. Welch (JHU), D. Coe (STScI), A. Pagan (STScI)]

The two possible scenarios justify the efforts of different teams of astronomers in the search for Population III stars. Of all the teams active in this field, one particularly large group, led by Brian Welch (Department of Physics and Astronomy, Johns Hopkins University) and Dan Coe (Space Telescope Science Institute), may have recently hit the mark. In fact, at the end of March, an article entitled "A highly magnified star at redshift 6.2" was published in *Nature*, which refers to the discovery of a star located 12.9 billion light years from Earth, or in an epoch 900 million years after the Big Bang. This performance wipes out the previous record of the farthest star, set in 2018 at 9.4 billion light years, when the universe was about 4.4 billion years old.

The protagonist of both discoveries was the Hubble Space Telescope, with the decisive help of the phenomenon of gravitational lensing. Here is a statement from Welch about the most recent discovery: *"We almost didn't believe it at first, it was so much farther than the previous most distant, highest redshift star. Normally at these distances, entire galaxies look like small smudges, the light from millions of stars blending together. The galaxy hosting this star has been magnified and distorted by gravitational lensing into a long crescent that we named the Sunrise Arc."*

The discovery was made by examining data collected during Hubble's Reionization Lensing Cluster Survey (RELICS) program, coordinated by Coe, which includes images of 41 galaxy clusters that generate gravi-

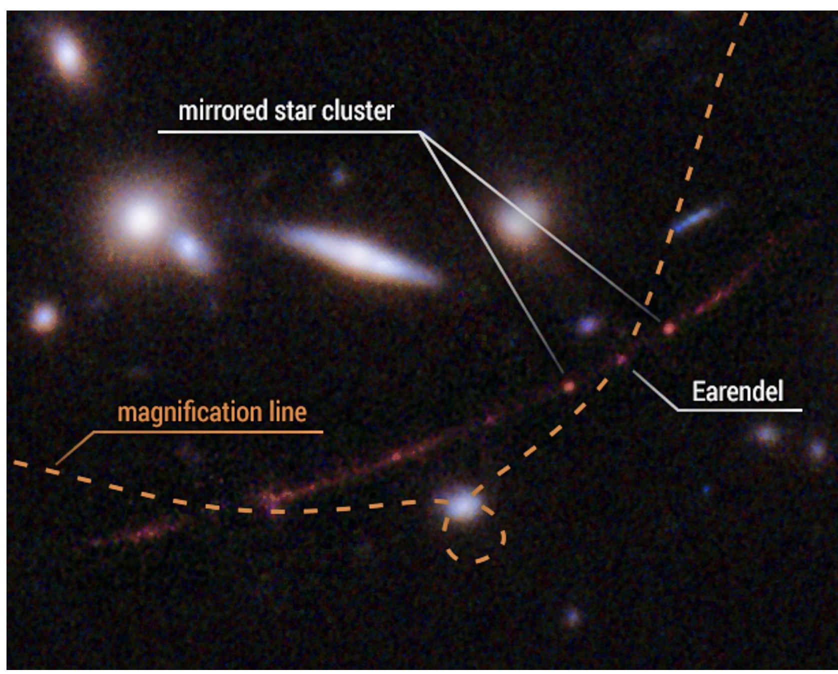


This graphic shows a timeline of the universe, stretching from the present day (left) all the way back to the Big Bang (right). The position of the record-breaking galaxy GN-z11 is shown not far from where the first stars began to form. The previous record holder's position is also identified. [NASA, ESA, P. Oesch and B. Robertson (University of California, Santa Cruz), and A. Feild (STScI)]

tational lenses. The attention of the researchers focused on a particular image of a remote galaxy, deformed in a 15" long arc (the aforementioned "Sunrise Arc") by the lensing produced by a galaxy cluster called WHL0137-08. After studying in detail the image of the galaxy (cataloged WHL0137-zD1), the team came to the conclusion that one of its most compact structures could only be a star, whose light is extremely intensified by the gravitational lens. The researchers decided to give that star an evocative name, Earendel, which in Old English (5th-12th century) means "morning star" or "rising light."

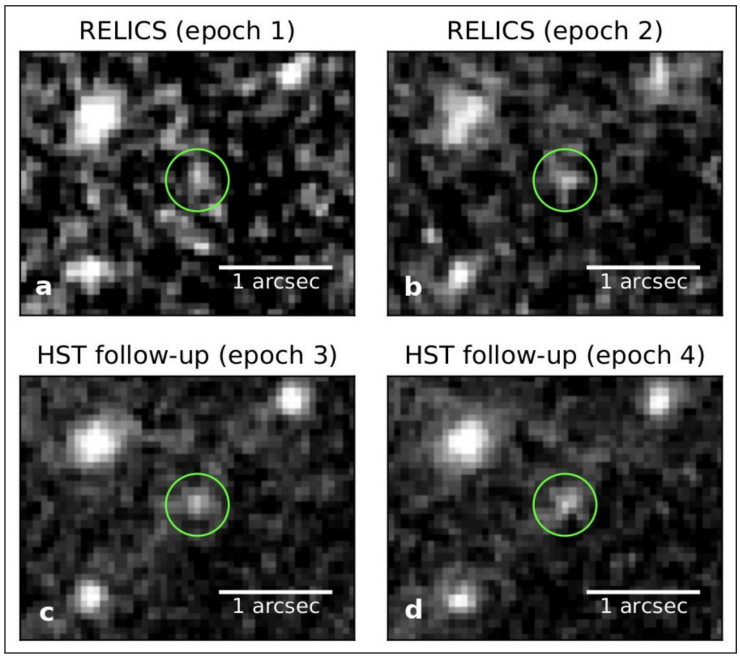
In most cases, gravitational lensing intensifies the light of remote objects by a few times, since the Earth-lens-remote object alignment is far from perfect; but the closer you get to optimal alignment, the greater the intensification of the light is (and, therefore, of the image). In Earendel's case, a particularly favorable alignment and the roughly point-like appearance of the star have meant that its brightness is intensified by thousands of times, making it observable with instruments that could never see it directly.

Although galaxy clusters deform space(time) in an inhomogeneous way that reflects the distribution of masses within them, there is still an intensification line or, more technically, a critical curve along which the lens effect is more pronounced. The farther an object is from the critical curve, the weaker its image appears to us - and the image is replicated in two or more copies. Multiple images occur on opposite sides of the critical curve. This is not the case with Earendel, which not only fits well into the Sunrise Arc, but is also likely to be found in the center of the critical curve path, since its image is not doubled. At most, it deviates from the critical curve by 0.1" and, there-



This detailed view highlights the star Earendel's position along a ripple in space-time (dotted line) that magnifies it and makes it possible for the star to be detected over such a great distance — nearly 13 billion light-years. Also indicated is a cluster of stars that is mirrored on either side of the line of magnification. The distortion and magnification are created by the mass of a huge galaxy cluster located in between Hubble and Earendel. The mass of the galaxy cluster is so great that it warps the fabric of space. Looking through that space is like looking through a magnifying glass — along the edge of the glass or lens, the appearance of things on the other side are warped as well as magnified. [Science: NASA, ESA, Brian Welch (JHU), Dan Coe (STScI). Image processing: NASA, ESA, Alyssa Pagan (STScI)]

fore, the two virtual images of the star are at least unresolved, if not perfectly superimposed (in a certain sense, the principle of this phenomenon recalls that of the Hartmann mask in photography).
Thanks to the favorable gravitational lensing, the intensification of Earendel's light reaches very high values: from at least 1,000 times to some tens of thousands of times. This wide range depends on the fact that near the critical curve (whose position can only be deduced approximately) the intensity of the light varies dizzyingly. Even if Earendel's light intensification factor were in the lower part of the considered range, it would still be a gigantic star (or alternatively a multiple system).



Lensed star variability across observations reveals that Earendel has remained consistently bright across 3.5 years of HST imaging. Panels a-d show WFC3/IR images of the lensed star (circled in green) across four epochs. Panels a and b show epochs 1 and 2 respectively (2016-06-07 and 2016-07-17), taken as part of RELICS. Panels c and d show follow-up Hubble imaging taken in epochs 3 and 4 respectively (2019-11-04 and 2019-11-27). [Welch et al.]

Before characterizing the star as such, Welch's team wanted to rule out that Earendel might be a star cluster, perhaps similar to the one that appears to be doubled along the Sunrise Arc, just before and just after the image of the star. The researchers ruled out this possibility by determining that the maximum radius of the patch of light corresponding to Earendel is fewer than 0.36 parsecs, so at most just over a light year. No known star cluster is that small: the tiniest has a radius of about 0.7 parsecs (2.3 light years).
By considering Earendel as a single star, the team calculated from its brightness an initial mass of between 40 and 500 solar masses, therefore typical of an OB spectral class star, with a maximum surface temperature of 60,000 K. Although these stars shine with a decidedly blue light in the contemporary universe, Earendel's light is so red-shifted by the expansion of the universe that the Hubble data is not decisive in determining whether or not Earendel is a Population III star. In fact, Hubble gives its best in ultraviolet and visible light, while the bright peak of Earendel is in infrared.
But Welch's team has already gotten some observation time with the new Webb Infrared Space Telescope to investigate the starlight towards the end of this year. One of the instruments that will be used is the NIRSpec (Near-Infrared Spectrograph), whose data will be decisive for defining the nature and chemical composition of Earendel.
A concluding reflection from Welch: *"Earendel existed so long ago that it may not have had all the same raw materials as the stars around us today. Studying Earendel will be a window in an era of the Universe that we are unfamiliar with, but that led to everything we do know. It's like we've been reading a really interesting book, but we started with the second chapter, and now we will have a chance to see how it all got started."* ■

This Space Sparks episode reveals how the NASA/ESA Hubble Space Telescope has established an extraordinary new benchmark. [Bethany Downer, Nico Bartmann, ESA, NASA]

NORT

RAPIDO 450

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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.
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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

New planet discovered around Proxima Centauri

by ESO - Bárbara Ferreira

A team of astronomers using the European Southern Observatory's Very Large Telescope (ESO's VLT) in Chile have found evidence of another planet orbiting Proxima Centauri, the closest star to our Solar System. This candidate planet is the third detected in the system and the lightest yet discovered orbiting this star. At just a quarter of Earth's mass, the planet is also one of the lightest exoplanets ever found.

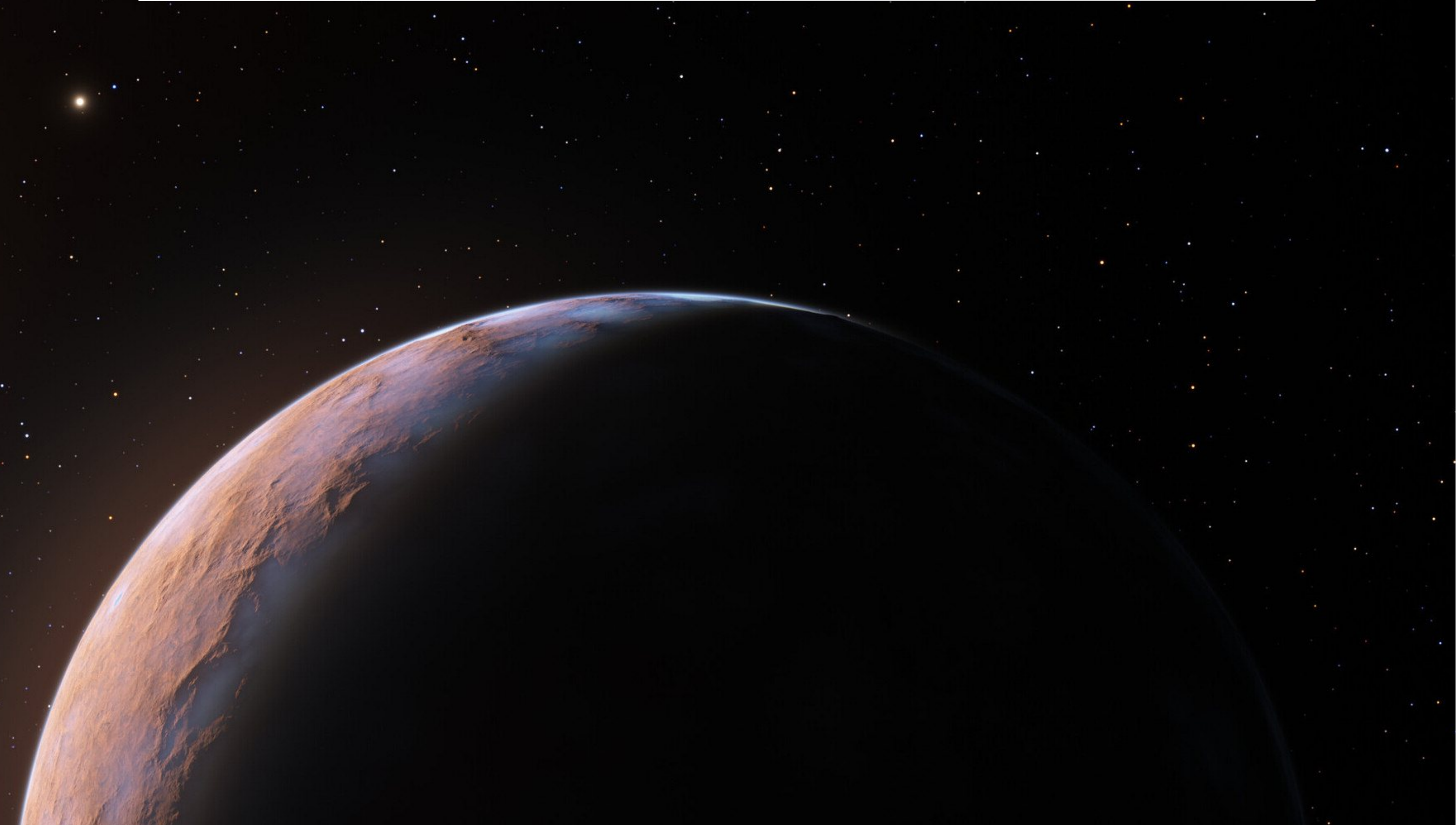
"The discovery shows that our closest stellar neighbour seems to be packed with interesting new worlds, within reach of further study and future exploration," explains João Faria, a researcher at the Instituto de Astrofísica e Ciências do Espaço, Portugal and lead author of the study published in *Astronomy & Astrophysics*.

Proxima Centauri is the closest star to the Sun, lying just over four light-years away. The newly discovered planet, named Proxima d, orbits Proxima Centauri at a distance of about four million kilometres, less than a tenth of Mercury's distance from the Sun. It orbits between the star and the habitable zone — the area around a star where liquid water can exist at the surface of a planet — and takes just five days to complete one orbit around Proxima Centauri.

The star is already known to host two other planets: Proxima b, a planet with a mass comparable to that of Earth that orbits the star every 11 days and is within the habitable zone, and candidate Proxima c, which is on a longer five-year orbit around the star.

Proxima b was discovered a few years ago using the HARPS instrument on ESO's 3.6-metre telescope. The discovery was confirmed in 2020 when scientists observed the Proxima system with a new instrument on ESO's VLT that had greater precision, the Echelle SPectrograph for Rocky Exoplanets and Stable

This artist's impression shows Proxima d, a planet candidate recently found orbiting the red dwarf star Proxima Centauri, the closest star to the Solar System. The planet is believed to be rocky and to have a mass about a quarter that of Earth. Two other planets known to orbit Proxima Centauri are visible in the image too: Proxima b, a planet with about the same mass as Earth that orbits the star every 11 days and is within the habitable zone, and candidate Proxima c, which is on a longer five-year orbit around the star. [ESO/L. Calçada]



Spectroscopic Observations (ESPRESSO). It was during these more recent VLT observations that astronomers spotted the first hints of a signal corresponding to an object with a five-day orbit. As the signal was so weak, the team had to conduct follow-up observations with ESPRESSO to confirm that it was due to a planet, and not simply a result of changes in the star itself. *"After obtaining new observations, we were able to confirm this signal as a new planet candidate,"* Faria says. *"I was excited by the challenge of detecting such a small signal and, by doing so, discovering an exoplanet so close to Earth."*

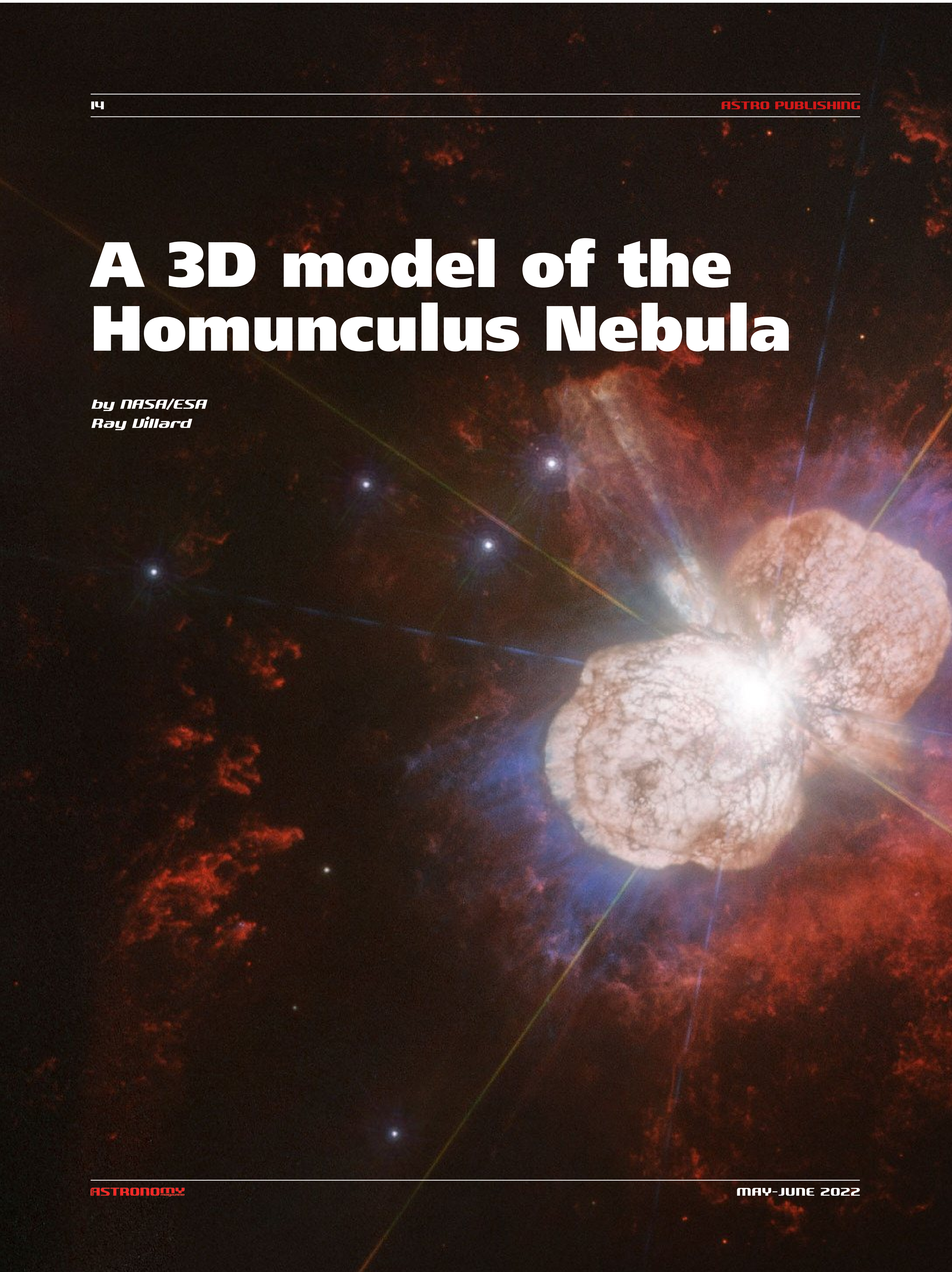
At just a quarter of the mass of Earth, Proxima d is the lightest exoplanet ever measured using the radial velocity technique, surpassing a planet recently discovered in the L 98-59 planetary system. The technique works by picking up tiny wobbles in the motion of a star created by an orbiting planet's gravitational pull. The effect of Proxima d's gravity is so small that it only causes Proxima Centauri to move back and forth at around 40 centimetres per second (1.44 kilometres per hour).

"This achievement is extremely important," says Pedro Figueira, ESPRESSO instrument scientist at ESO in Chile. *"It shows that the radial velocity technique has the potential to unveil a population of light planets, like our own, that are expected to be the most abundant in our galaxy and that can potentially host life as we know it."*

"This result clearly shows what ESPRESSO is capable of and makes me wonder about what it will be able to find in the future," Faria adds. ESPRESSO's search for other worlds will be complemented by ESO's Extremely Large Telescope (ELT), currently under construction in the Atacama Desert, which will be crucial to discovering and studying many more planets around nearby stars.

A 3D model of the Homunculus Nebula

by NASA/ESA
Ray Villard



Historical records do show that about 170 years ago Eta Carinae underwent an unusual outburst that made it one of the brightest stars in the southern sky. That explosion generated a structure of dust and gas known as the Homunculus Nebula. [NASA, ESA, Hubble; Processing & License: Judy Schmidt]

A new astronomical visualization from NASA's Universe of Learning showcases the multiwavelength emissions (from infrared light through X-rays) and three-dimensional structures surrounding Eta Carinae, one of the most massive and eruptive stars in our galaxy.

The video, *"Eta Carinae: The Great Eruption of a Massive Star,"* has been released on hubblesite.org and universe-of-learning.org.

Eta Carinae, or Eta Car, is famous for a brilliant and unusual outburst, called the "Great Eruption," observed in the 1840s. This briefly made it one of the brightest stars in the night sky, releasing almost as much visible light as a supernova explosion. The star survived the outburst, and slowly faded away for the next five decades. The primary cause of this brightness change is a small nebula of gas and dust, called the Homunculus Nebula, that was expelled during the blast, and has blocked the light of the star.

Observations using NASA's Hubble Space Telescope and Chandra X-ray Observatory reveal the details in visible, ultraviolet, and X-ray light. Astronomers and artists at the Space Telescope Science Institute (STScI) in Baltimore, Maryland have developed three-dimensional models to represent the hourglass shape of the Homunculus and the clouds of glowing gas that encompass it. The result is a stunning tour of the nested emissions that brings the 2D images to 3D life.

"The team did such an amazing job representing the volumetric layers that viewers can immediately and intuitively comprehend the complex structure around Eta Car," said Frank Summers, principal visualization scientist at STScI and project lead. *"We can not only tell the story of the Great Eruption, but also showcase the resulting nebula in 3D."*

Eta Carinae, or Eta Car, is famous for a brilliant and unusual outburst, called the "Great Eruption," observed in the 1840s. This visualization presents the story of that event and examines the resulting multiwavelength emissions and three-dimensional structures surrounding Eta Car today. Massive stars are known to have major outbursts. Eta Car, one of the most massive stars known, expelled about 10% of its mass in the Great Eruption, creating a small nebula, called the Homunculus Nebula, around it. Images taken in different wavelengths of light reveal different structures, each providing more information about the outbursts of Eta Car. For this visualization, astronomers and artists have used NASA observations to model both the close-up and wide views of this massive and eruptive star. The Hubble Space Telescope and the Chandra X-ray Observatory have observed the nested layers of gas and dust around Eta Car using visible, ultraviolet, and X-ray light, as well as in the Hydrogen alpha emission line. The Spitzer Space Telescope provides a larger view of the Carina Nebula, along with Eta Car's dominant position within this star-forming region. This visualization is presented by the AstroViz Project of NASA's Universe of Learning. Viewers gain appreciation for how the observations from two centuries ago connect to the resulting structures seen today. Full 360-degree 3D views help to assemble a complete mental model that aids interpretation of the NASA observations. Eta Car serves as a notable example of the outbursts in the dying stages of massive stars. [Visualization: NASA, ESA, Joseph Olmsted (STScI), Dani Player (STScI), Leah Hustak (STScI), Alyssa Pagan (STScI), Joseph DePasquale (STScI), Greg T. Bacon (STScI), Frank Summers (STScI), Robert L. Hurt (IPAC). Image: NASA, ESA, STScI, NASA-JPL, Caltech, CXC, ESO, NOAO, AURA, NSF, Akira Fujii , Jon A. Morse (BoldlyGo Institute), Nathan Smith (University of Arizona), SM4 ERO Team. Music: Joseph DePasquale (STScI)]

In addition, Eta Car is extremely bright at infrared wavelengths, and its radiation impacts the much larger Carina Nebula where it resides. Working with NASA's Spitzer Space Telescope observations, the team was able to place Eta Car in context of the dazzling infrared view of the star-forming region.

"Spitzer's infrared image lets us peer through the dust that obscures our view in visible light to reveal the intricate details and extent of the Carina Nebula around this brilliant star," commented Robert Hurt, lead visualization scientist at Caltech/IPAC and team member.

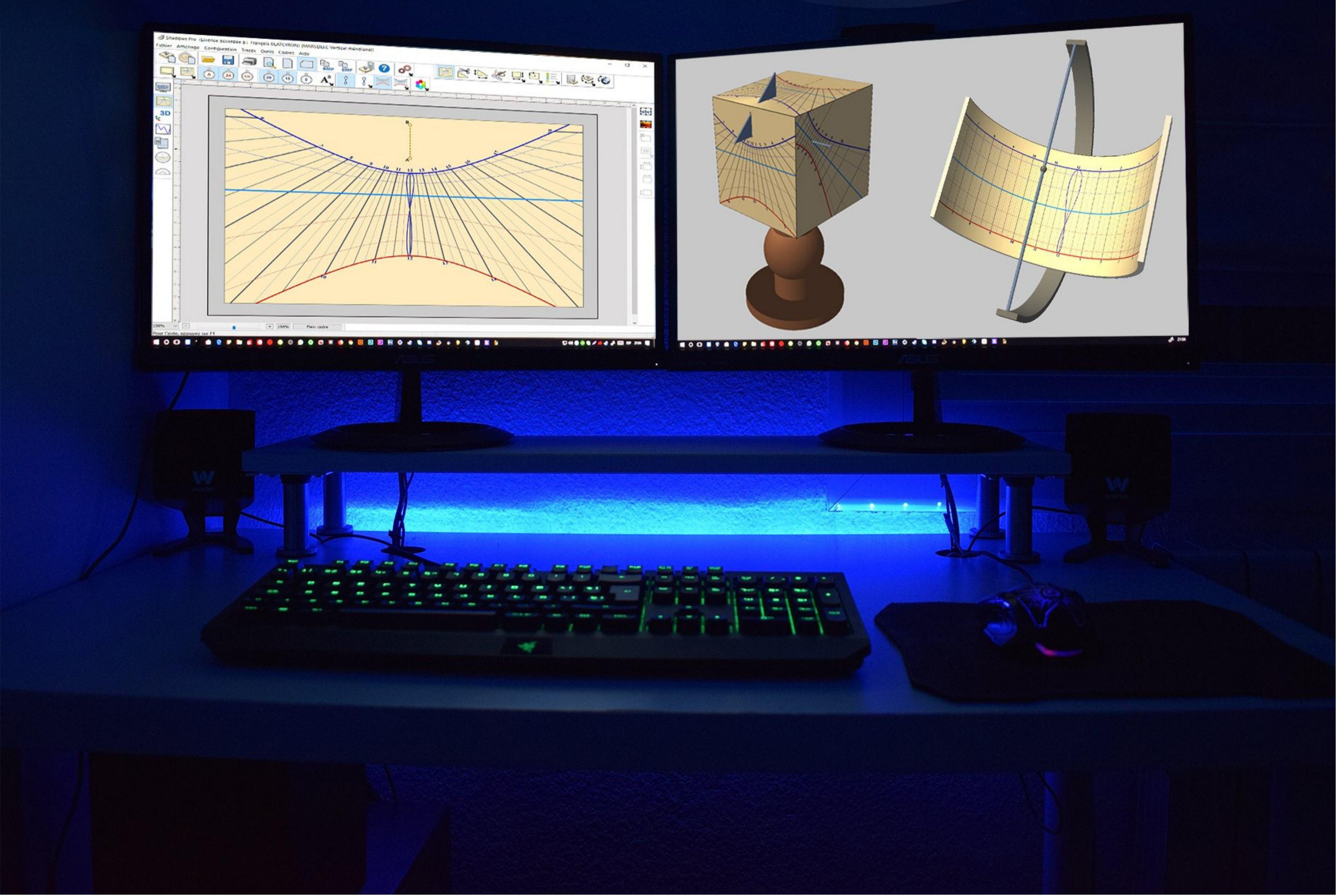
Extending the goals of NASA's Universe of Learning, the visualization assets promote learning beyond the video sequence. *"We can take these models like the one for Eta Car and use them in 3D printing and augmented reality programs,"* noted Kim Arcand, visualization lead scientist at the Chandra X-ray Center in Cambridge, Massachusetts. *"This means more people can put their hands on the data – literally and virtually – and this makes for better learning and engagement."*

Eta Carinae is one of the most massive stars known. These exceptional stars are prone to outbursts during their lives. They will end their lives by collapsing into a black hole, probably accompanied by a supernova explosion.

Eta Car is one of the nearest and best studied examples for learning about the energetic life and death of very massive stars.

NASA's Universe of Learning is part of the NASA Science Activation program.

The Science Activation program connects NASA science experts, real content and experiences, and community leaders in a way that activates minds and promotes deeper understanding of our world and beyond. Using its direct connection to the science and the experts behind the science, NASA's Universe of Learning provides resources and experiences that enable youth, families, and lifelong learners to explore fundamental questions in science, experience how science is done, and discover the universe for themselves. ■



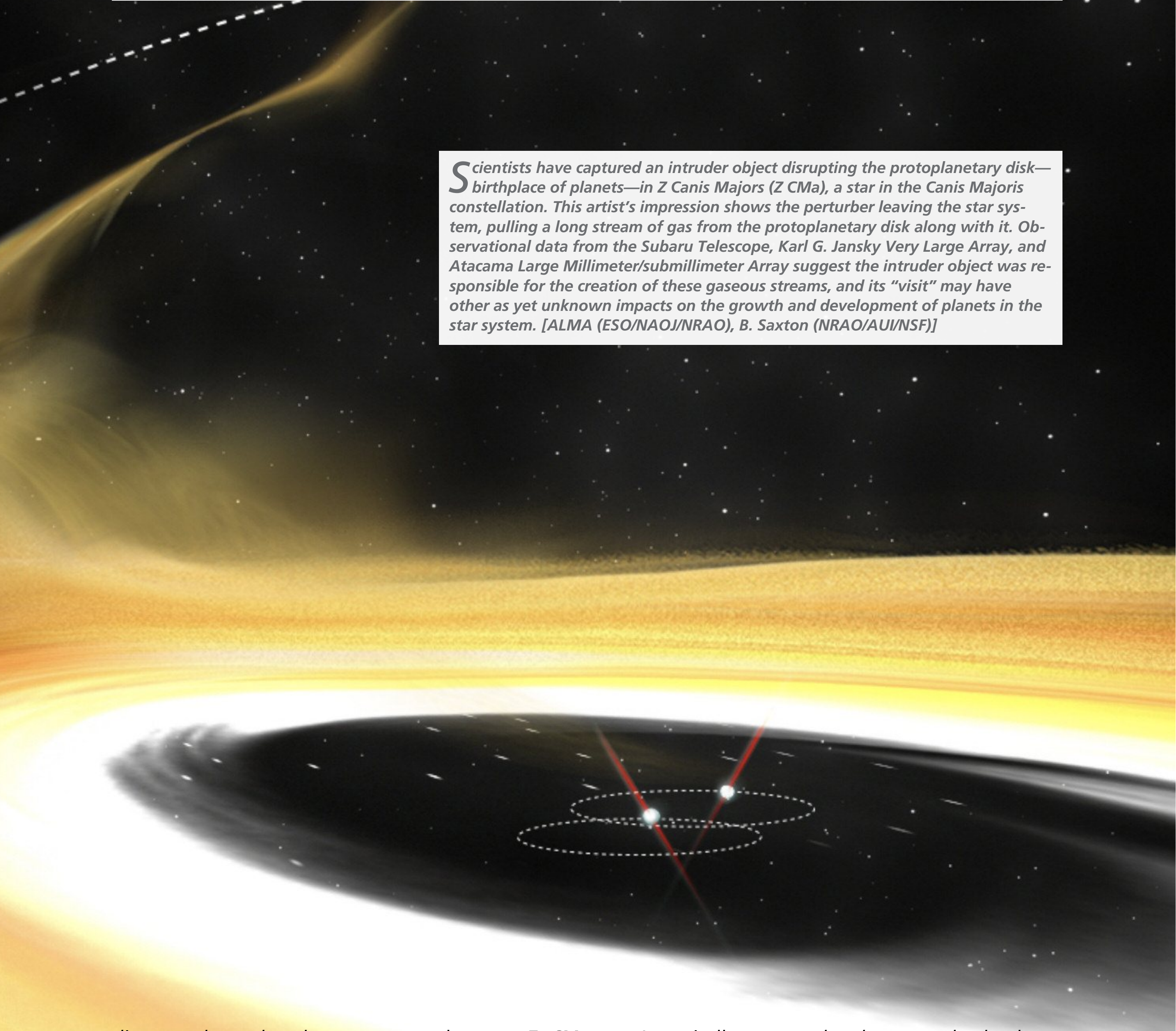
A rarely detected stellar flyby event

by ALMA Observatory
Bárbara Ferreira

Scientists using the Atacama Large Millimeter/submillimeter Array (ALMA) and the Karl G. Jansky Very Large Array (VLA) made a rare detection of a likely stellar flyby event in the Z Canis Majoris (Z CMa) star system. An intruder—not bound to the system—object came in close proximity to and interacted with the environment surrounding the binary protostar, causing the formation of chaotic, stretched-out streams of dust and gas in the disk surrounding it.

While such intruder-based flyby events have previously been witnessed with some regularity in computer simulations of star formation, few convincing direct observations have ever been made, and until now, the events have remained largely theoretical.

"Observational evidence of flyby events is difficult to obtain because these events happen fast and it is difficult to capture them in action. What we have done with our ALMA Band 6 and VLA observations is equivalent to capturing lightning striking a tree," said Ruobing Dong, an astronomer at the University of Victoria in Canada and the principal investigator on the new study. *"This*

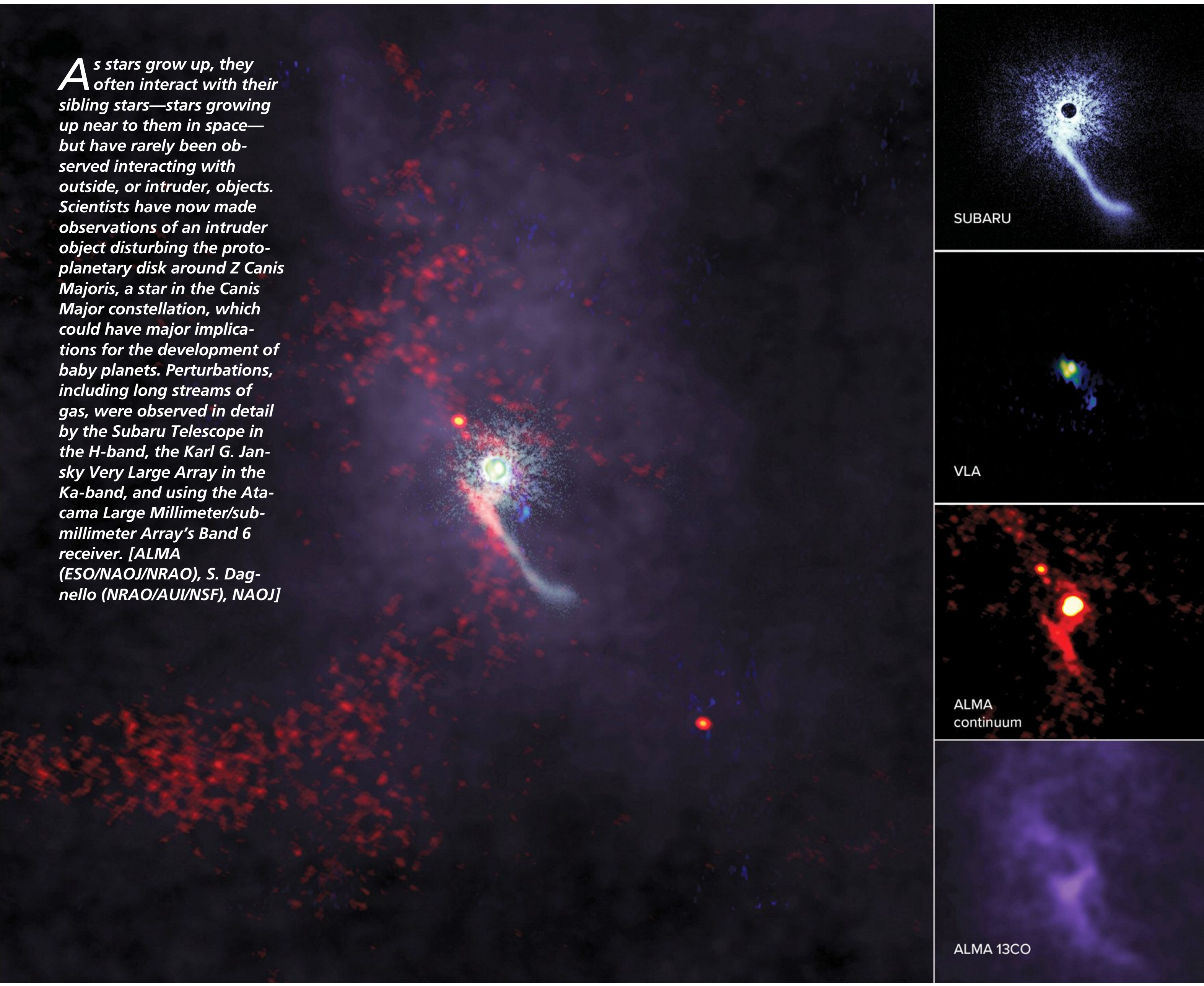


Scientists have captured an intruder object disrupting the protoplanetary disk—birthplace of planets—in Z Canis Majors (Z CMa), a star in the Canis Majoris constellation. This artist's impression shows the perturber leaving the star system, pulling a long stream of gas from the protoplanetary disk along with it. Observational data from the Subaru Telescope, Karl G. Jansky Very Large Array, and Atacama Large Millimeter/submillimeter Array suggest the intruder object was responsible for the creation of these gaseous streams, and its "visit" may have other as yet unknown impacts on the growth and development of planets in the star system. [ALMA (ESO/NAOJ/NRAO), B. Saxton (NRAO/AUI/NSF)]

discovery shows that close encounters between young stars harboring disks do happen in real life, and they are not just theoretical situations seen in computer simulations. Prior observational studies had seen flybys, but hadn't been able to collect the comprehensive evidence we were able to obtain of the event at Z CMa."

Perturbations, or disturbances, like those at Z CMa aren't typically caused by intruders, but rather by sibling stars growing up together in space. Hauyu Baobab Liu, an astronomer at the Institute of Astronomy and Astrophysics at Academia Sinica in Taiwan and a co-author on the paper, said, *"Most often, stars do not form in isolation. The twins, or even triplets or quadruplets, born together may be gravitationally attracted and, as a result, closely approach each other. During these moments, some material on the stars' protoplanetary disks may be stripped off to form extended gas streams that provide clues to astronomers about the history of past stellar encounters."*

Nicolás Cuello, an astrophysicist and Marie Curie Fellow at Université Grenoble Alpes in France and a co-



As stars grow up, they often interact with their sibling stars—stars growing up near to them in space—but have rarely been observed interacting with outside, or intruder, objects. Scientists have now made observations of an intruder object disturbing the protoplanetary disk around Z Canis Majoris, a star in the Canis Major constellation, which could have major implications for the development of baby planets. Perturbations, including long streams of gas, were observed in detail by the Subaru Telescope in the H-band, the Karl G. Jansky Very Large Array in the Ka-band, and using the Atacama Large Millimeter/submillimeter Array's Band 6 receiver. [ALMA (ESO/NAOJ/NRAO), S. Dagnello (NRAO/AUI/NSF), NAOJ]

author on the paper added that in the case of Z CMa, it was the morphology, or structure, of these streams that helped scientists to identify and pinpoint the intruder. *"When a stellar encounter occurs, it causes changes in disk morphology – spirals, warps, shadows, etc. – that could be considered as flyby fingerprints. In this case, by looking very carefully at Z CMa's disk, we revealed the presence of several flyby fingerprints."*

These fingerprints not only helped scientists to identify the intruder, but also led them to consider what these interactions might mean for the future of Z CMa and the baby planets being born in the system, a process that so far has remained a mystery to scientists. *"What we now know with this new research is that flyby events do occur in nature and that they have major impacts on the gaseous circumstellar disks, which are the birth cradles of planets, surrounding baby stars,"* said Cuello. *"Flyby events can dramatically perturb the circumstellar disks around participant stars, as we've seen with the production of long streamers around Z CMa."*

Liu added, *"These perturbers not only cause gaseous streams but may also impact the thermal history of the involved host stars, like Z CMa. This can lead to such violent events as accretion outbursts, and also impact the development of the overall star system in ways that we haven't yet observed or defined."*

Dong said that studying the evolution and growth of young star systems throughout the galaxy helps scientists to better understand our own Solar System's origin. *"Studying these types of events gives a window into the past, including what might have happened in the early development of our own Solar System, critical evidence of which is long since gone. Watching these events take place in a newly forming star system provides us with the information needed to say, 'Ah ha! This is what may have happened to our own Solar System long ago.' Right now, VLA and ALMA have given us the first evidence to solve this mystery, and the next generations of these technologies will open windows on the Universe that we have yet only dreamed of."* ■

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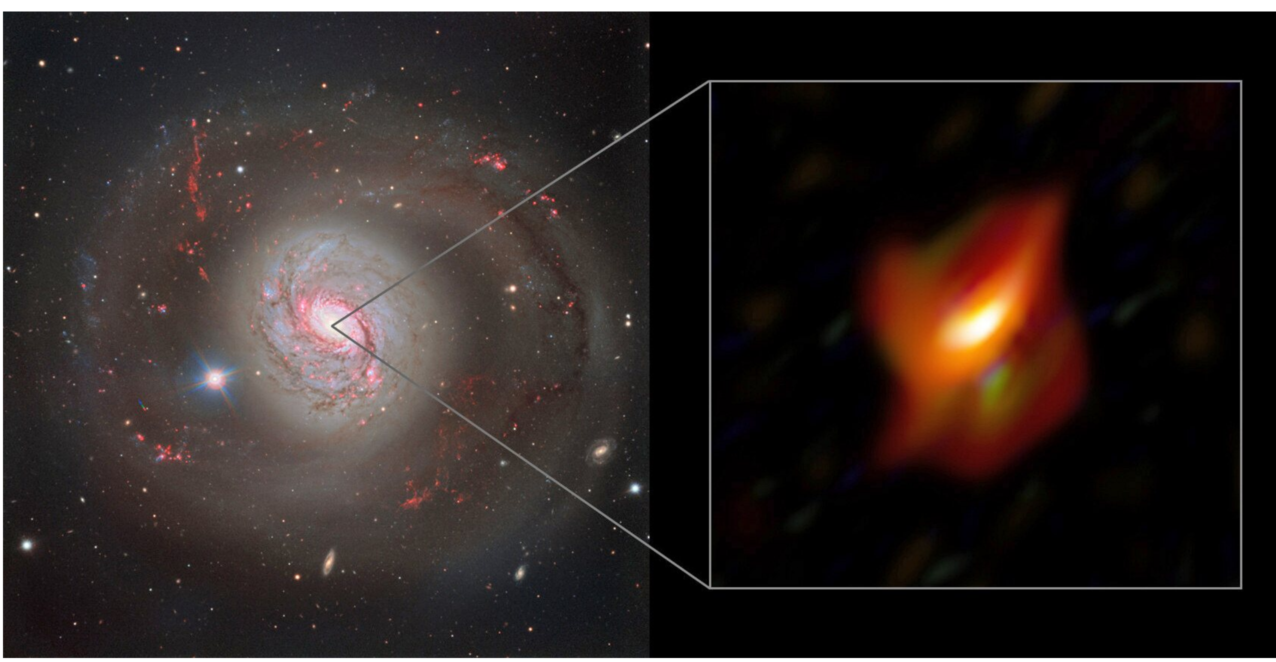
Supermassive black hole caught hiding in a ring of cosmic dust

by ESO - Bárbara Ferreira

The European Southern Observatory's Very Large Telescope Interferometer (ESO's VLTI) has observed a cloud of cosmic dust at the centre of the galaxy Messier 77 that is hiding a supermassive black hole. The findings have confirmed predictions made around 30 years ago and are giving astronomers new insight into "active galactic nuclei", some of the brightest and most enigmatic objects in the universe.

Active galactic nuclei (AGNs) are extremely energetic sources powered



The left panel of this image shows a dazzling view of the active galaxy Messier 77 captured with the FOcal Reducer and low dispersion Spectrograph 2 (FORS2) instrument on ESO's Very Large Telescope. The right panel shows a blow-up view of the very inner region of this galaxy, its active galactic nucleus, as seen with the MATISSE instrument on ESO's Very Large Telescope Interferometer. [ESO/Jaffe, Gámez-Rosas et al.]

by supermassive black holes and found at the centre of some galaxies. These black holes feed on large volumes of cosmic dust and gas. Before it is eaten up, this material spirals towards the black hole and huge amounts of energy are released in the process, often outshining all the stars in the galaxy.

Astronomers have been curious about AGNs ever since they first spotted these bright objects in the 1950s. Now, thanks to ESO's VLTI, a team of researchers, led by Violeta Gámez Rosas from Leiden University in the Netherlands, have taken a key step towards understanding how they work and what they look like up close. The results are published in *Nature*.

By making extraordinarily detailed observations of the centre of the galaxy Messier 77, also known as NGC 1068, Gámez Rosas and her team detected a thick ring of cosmic dust and gas hiding a supermassive black hole. This discovery provides vital evidence to support a 30-year-old theory known as the Unified Model of AGNs.

Astronomers know there are different types of AGN. For example, some release bursts of radio waves while others don't; certain AGNs shine brightly in visible light, while others, like Messier 77, are more subdued. The Unified Model states that despite their differences, all AGNs have the same basic structure: a supermassive black hole surrounded by a thick ring of dust.

According to this model, any difference in appearance between AGNs results from the orientation at which we view the black hole and its thick ring from Earth. The type of AGN we see depends on how much the ring obscures the black hole from our view point, completely hiding it in some cases.

Astronomers had found some evidence to support the Unified Model before, including spotting warm dust at the centre of Messier 77. However, doubts remained about whether this dust could completely hide a black hole and hence explain why this AGN shines less brightly in visible light than others.

"The real nature of the dust clouds and their role in both feeding the black hole and determining how it looks when viewed from Earth have been central questions in AGN studies over the last three decades," explains Gámez Rosas. *"Whilst no single result will settle all the questions we have, we have taken a major step in understanding how AGNs work."*

The observations were made possible thanks to the Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) mounted on ESO's VLTI, located in Chile's Atacama Desert. MATISSE combined infrared light collected by all four 8.2-metre telescopes of ESO's Very Large Telescope (VLT) using a technique called interferometry. The team used MATISSE to scan the centre of Messier 77, located 47 million light-years away in the constellation Cetus.

Active galactic nuclei (AGNs) are extremely energetic sources powered by supermassive black holes. This short video provides insights into these peculiar objects by showcasing a new discovery on the AGN at the centre of the Messier 77 galaxy. [ESO]

"MATISSE can see a broad range of infrared wavelengths, which lets us see through the dust and accurately measure temperatures. Because the VLTI is in fact a very large interferometer, we have the resolution to see what's going on even in galaxies as far away as Messier 77. The images we obtained detail the changes in temperature and absorption of the dust clouds around the black hole," says co-author Walter Jaffe, a professor at Leiden University.

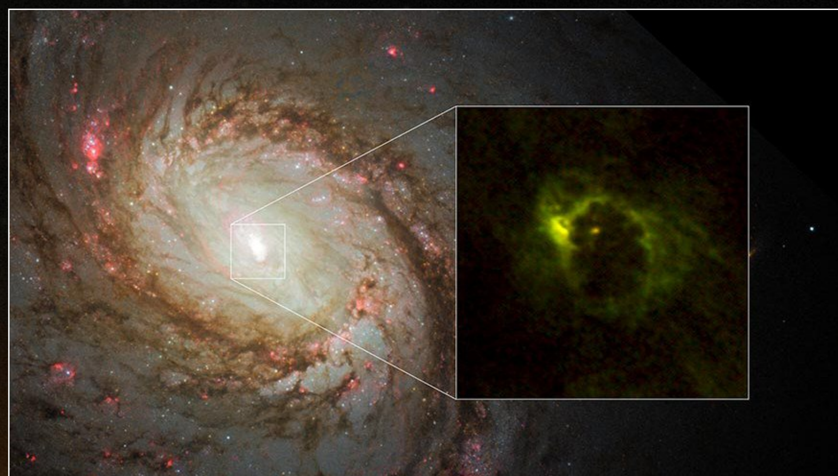
Combining the changes in dust temperature (from around room temperature to about 1200 °C) caused by the intense radiation from the black hole with the absorption maps, the team built up a detailed picture of the dust and pinpointed where the black hole must lie. The dust — in a thick inner ring and a more extended disc — with the black hole positioned at its centre supports the Unified Model.

The team also used data from the Atacama Large Millimeter/submillimeter Array, co-owned by ESO,

and the National Radio Astronomy Observatory's Very Long Baseline Array to construct their picture.

"Our results should lead to a better understanding of the inner workings of AGNs," concludes Gámez Rosas. *"They could also help us better understand the history of the Milky Way, which harbours a supermassive black hole at its centre that may have been active in the past."* The researchers are now looking to use ESO's VLTI to find more supporting evidence of the Unified Model of AGNs by considering a larger sample of galaxies.

The background illustration shows what the core of Messier 77 might look like. As other active galactic nuclei, the central region of Messier 77 is powered by a black hole that is surrounded by a thin accretion disc, which itself is surrounded by a thick ring or torus of gas and dust. In the case of Messier 77, this thick ring completely obscures our view of the supermassive black hole. This active galactic nucleus is also believed to have jets, as well as dusty winds, that flow out of the region around the black hole perpendicularly to the accretion disc around it. [ESO/M. Kornmesser and L. Calçada]



This composite image shows the central region of the barred spiral galaxy Messier 77. The NASA/ESA Hubble Space Telescope imaged the distribution of stars. ALMA revealed the distribution of gas in the very center of the galaxy. ALMA imaged a horseshoe-like structure with a radius of 700 light-years and a central compact component with a radius of 20 light-years. The latter is the gaseous torus around the AGN. Red color indicates emission from formyl ions and green indicates hydrogen cyanide emission. [ALMA/ESO/NAOJ/NRAO/Imanishi et al./NASA/ESA/Hubble/A. van der Hoeven]

Team member Bruno Lopez, the MATISSE Principal Investigator at the Observatoire de la Côte d'Azur in Nice, France, says: *"Messier 77 is an important prototype AGN and a wonderful motivation to expand our observing programme and to optimise MATISSE to tackle a wider sample of AGNs."* ESO's Extremely Large Telescope (ELT), set to begin observing later this decade, will also aid the search, providing results that will complement the team's findings and allow them to explore the interaction between AGNs and galaxies.

The largest known Earth Trojan companion

by NOIRLab
Vanessa Thomas

In this illustration, the asteroid 2020 XL_5 is shown in the foreground in the lower left. The two bright points above it on the far left are Earth (right) and the Moon (left). The Sun appears on the right. [NOIRLab/NSF/AURA/J. da Silva/Spaceengine. Ack.: M. Zamani (NSF's NOIRLab)]

Using the 4.1-meter SOAR (Southern Astrophysical Research) Telescope on Cerro Pachón in Chile, astronomers led by Toni Santana-Ros of the University of Alicante and the Institute of Cosmos Sciences of the University of Barcelona observed the recently discovered asteroid 2020 XL_5 to constrain its orbit and size. Their results confirm that 2020 XL_5 is an Earth Trojan — an asteroid companion to Earth that orbits the Sun along the same path as our planet does — and that it is the largest one yet found.

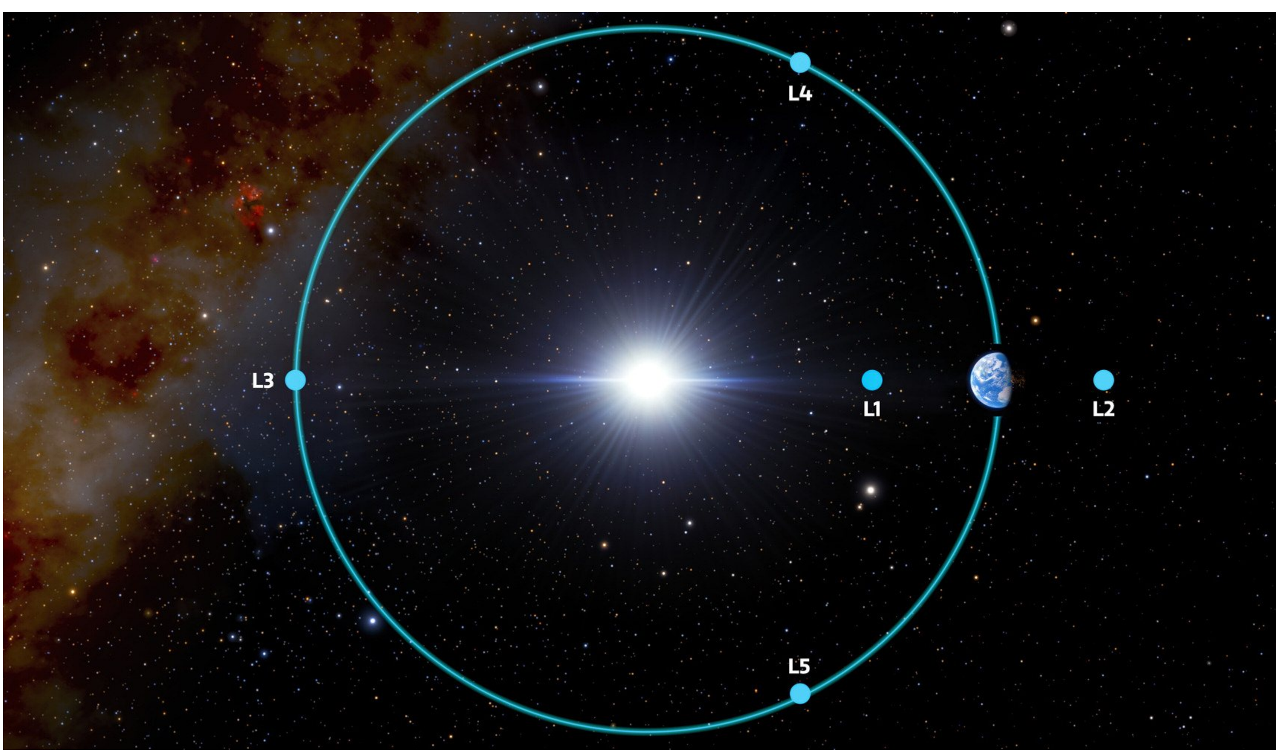
"Trojans are objects sharing an orbit with a planet, clustered around one of two special gravitationally balanced areas along the orbit of the planet known as Lagrange points," says Cesar Briceño of NSF's NOIRLab, who is one of the authors of a paper published in *Nature Communications* reporting the results, and who helped make the observations with the SOAR Telescope at Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab, in March 2021.

Several planets in the Solar System are known to have Trojan asteroids, but 2020 XL_5 is only the second known Trojan asteroid found near Earth. Observations of 2020 XL_5 were also made with the 4.3-meter Lowell Discovery Telescope at Lowell Observatory in Arizona and by the European Space Agency's 1-meter Optical Ground Station in Tenerife in the Canary Islands.

Discovered on 12 December 2020 by the Pan-STARRS1 survey telescope in Hawai'i, 2020 XL_5 is much larger than the first Earth Trojan discovered, called 2010 TK_7. The researchers found that 2020 XL_5 is about 1.2 kilometers (0.73 miles) in diameter, about three times as wide as the first (2010 TK_7 is estimated to be less than 400 meters or yards across).

Astronomers have confirmed the existence of the second known Earth Trojan asteroid and found that it is much bigger than the first. This video summarizes the discovery. [Images and Videos: CTIO/NOIRLab/NSF/AURA/J. da Silva/Spaceengine, ESO/M. Kornmesser, SOAR/J. P. Burgos. Image Processing: M. Zamani (NSF's NOIRLab). Music: Stellardrone - A Moment of Stillness]

When 2020 XL_5 was discovered, its orbit around the Sun was not known well enough to say whether it was merely a near-Earth asteroid crossing our orbit, or whether it was a true Trojan. SOAR's measurements were so accurate that Santana-Ros's team was then able to go back and search for 2020 XL_5 in archival images from 2012 to 2019 taken as part of the Dark Energy Survey using the Dark Energy Camera (DECam) on the Víctor M. Blanco 4-meter Telescope located at CTIO in Chile. With almost 10 years of data on hand, the team was able to vastly improve our understanding of the asteroid's orbit. Although other studies have



Lagrange points are places in space where the gravitational forces of two massive bodies, such as the Sun and a planet, balance out, making it easier for a low-mass object (such as a spacecraft or an asteroid) to orbit there. This diagram shows the five Lagrange points for the Earth-Sun system. (The size of Earth and the distances in the illustration are not to scale.) [NOIRLab/NSF/AURA/J. da Silva. Ack.: M. Zamani (NSF's NOIRLab)]

supported the Trojan asteroid's identification, the new results make that determination far more robust and provide estimates of the size of 2020 XL_5 and what type of asteroid it is. *"SOAR's data allowed us to make a first photometric analysis of the object, revealing that 2020 XL_5 is likely a C-type asteroid, with a size larger than one kilometer,"* says Santana-Ros. A C-type asteroid is dark, contains a lot of carbon, and is the most common type of asteroid in the Solar System.

This graphic shows where the Earth Trojan asteroid 2020 XL_5 would appear in the sky from Cerro Pachón in Chile as the asteroid orbits the Earth-Sun Lagrange point 4 (L4). The arrows show the direction of its motion. The SOAR Telescope appears in the lower left. The asteroid's apparent magnitude is around magnitude 22, beyond the reach of anything but the largest telescopes. [NOIRLab/NSF/AURA/J. da Silva]

The findings also showed that 2020 XL_5 will not remain a Trojan asteroid forever. It will remain stable in its position for at least another 4000 years, but eventually it will be gravitationally perturbed and escape to wander through space.

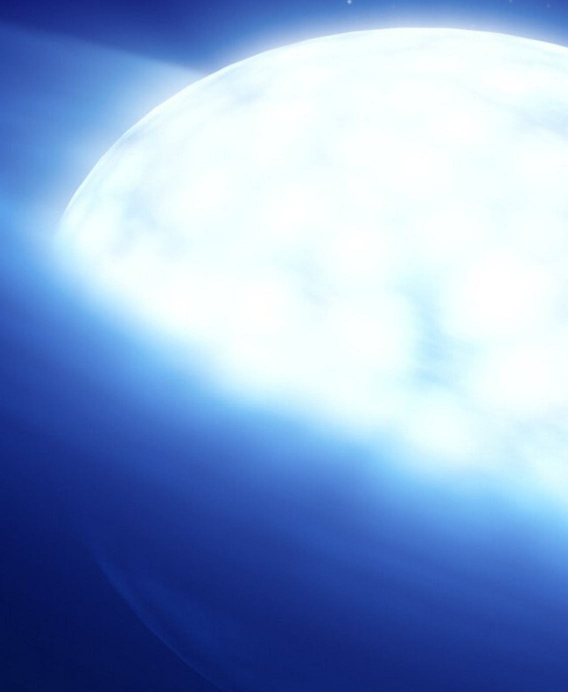
2020 XL_5 and 2010 TK_7 may not be alone — there could be many more Earth Trojans that have so far gone undetected as they appear close to the Sun in the sky. This means that searches for, and observations of, Earth Trojans must be performed close to sunrise or sunset, with the telescope pointing near the horizon, through the thickest part of the atmosphere, which results in poor seeing conditions. SOAR was able to point down to 16 degrees above the horizon, while many 4-meter (and larger) telescopes are not able to aim that low.

"These were very challenging observations, requiring the telescope to track correctly at its lowest elevation limit, as the object was very low on the western horizon at dawn," says Briceño.

Nevertheless, the prize of discovering Earth Trojans is worth the effort of finding them. Because they are made of primitive material dating back to the birth of the Solar System and could represent some of the building blocks that formed our planet, they are attractive targets for future space missions.

"If we are able to discover more Earth Trojans, and if some of them can have orbits with lower inclinations, they might become cheaper to reach than our Moon," says Briceño. *"So they might become ideal bases for an advanced exploration of the Solar System, or they could even be a source of resources."* ■

"Closest black hole" system found to contain no black hole



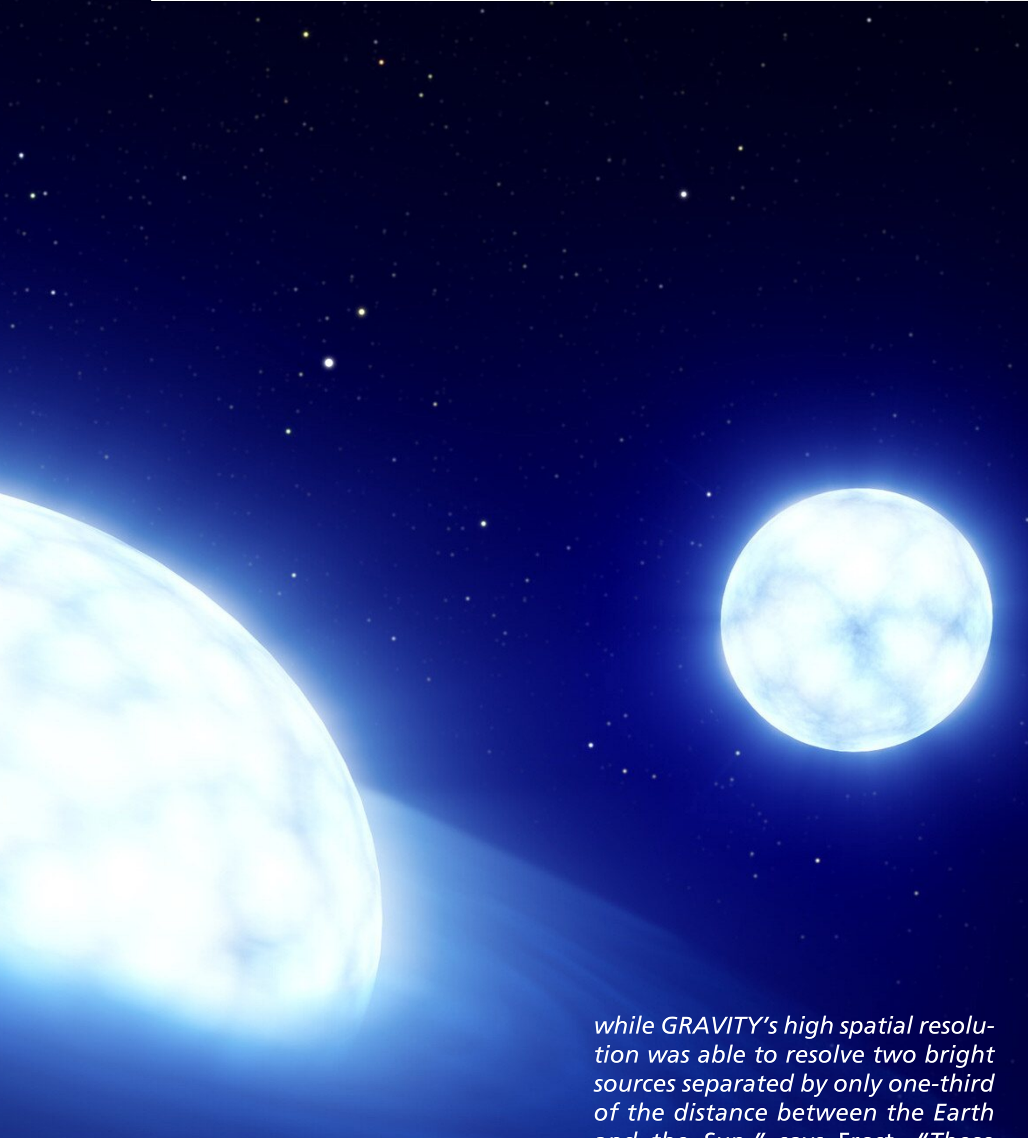
by ESO - Bárbara Ferreira

In 2020 a team led by European Southern Observatory (ESO) astronomers reported the closest black hole to Earth, located just 1000 light-years away in the HR 6819 system. But the results of their study were contested by other researchers, including by an international team based at KU Leuven, Belgium. In a paper, these two teams have united to report that there is in fact no black hole in HR 6819, which is instead a "vampire" two-star system in a rare and short-lived stage of its evolution. The original study on HR 6819 received significant attention from both the press and scientists. Thomas Rivinius, a Chile-based ESO astronomer and lead author on that paper, was not surprised by the astronomy community's reception to their discovery of the black hole. *"Not only is it normal, but it should be that results are scrutinised,"* he says, *"and a result that makes the headlines even more so."*

Rivinius and his colleagues were convinced that the best explanation for the data they had, obtained with the MPG/ESO 2.2-metre telescope, was that HR 6819 was a triple system, with one star orbiting a black hole every 40 days and a second star in a much wider orbit. But a study led by Julia Bodensteiner, then a PhD student at KU Leuven, Belgium, proposed a different explanation for the same data: HR 6819 could also be a system with only two stars on a 40-day orbit and no black hole at all. This alternative scenario would require one of the stars to be "stripped", meaning that, at an earlier time, it had lost a large fraction of its mass to the other star.

"We had reached the limit of the existing data, so we had to turn to a different observational strategy to decide between the two scenarios proposed by the two teams," says KU Leuven researcher Abigail Frost, who led the new study published in *Astronomy & Astrophysics*.

To solve the mystery, the two teams worked together to obtain new, sharper data of HR 6819 using ESO's Very Large Telescope (VLT) and Very Large Telescope Interferometer (VLTI). *"The VLTI was the only facility that would give us the decisive data we needed to distinguish between the two explanations,"* says Dietrich Baade, author on both the original HR 6819 study and the new Astronomy & Astrophysics paper. Since it made no sense to ask for the same observation twice, the two teams joined forces, which allowed them to pool their resources and knowledge to find the true nature



New research using data from ESO's Very Large Telescope and Very Large Telescope Interferometer has revealed that HR 6819, previously believed to be a triple system with a black hole, is in fact a system of two stars with no black hole. [ESO/L. Calçada]

of this system. *"The scenarios we were looking for were rather clear, very different and easily distinguishable with the right instrument,"* says Rivinius. *"We agreed that there were two sources of light in the system, so the question was whether they orbit each other closely, as in the stripped-star scenario, or are far apart from each other, as in the black hole scenario."*

To distinguish between the two proposals, the astronomers used both the VLTI's GRAVITY instrument and the Multi Unit Spectroscopic Explorer (MUSE) instrument on ESO's VLT.

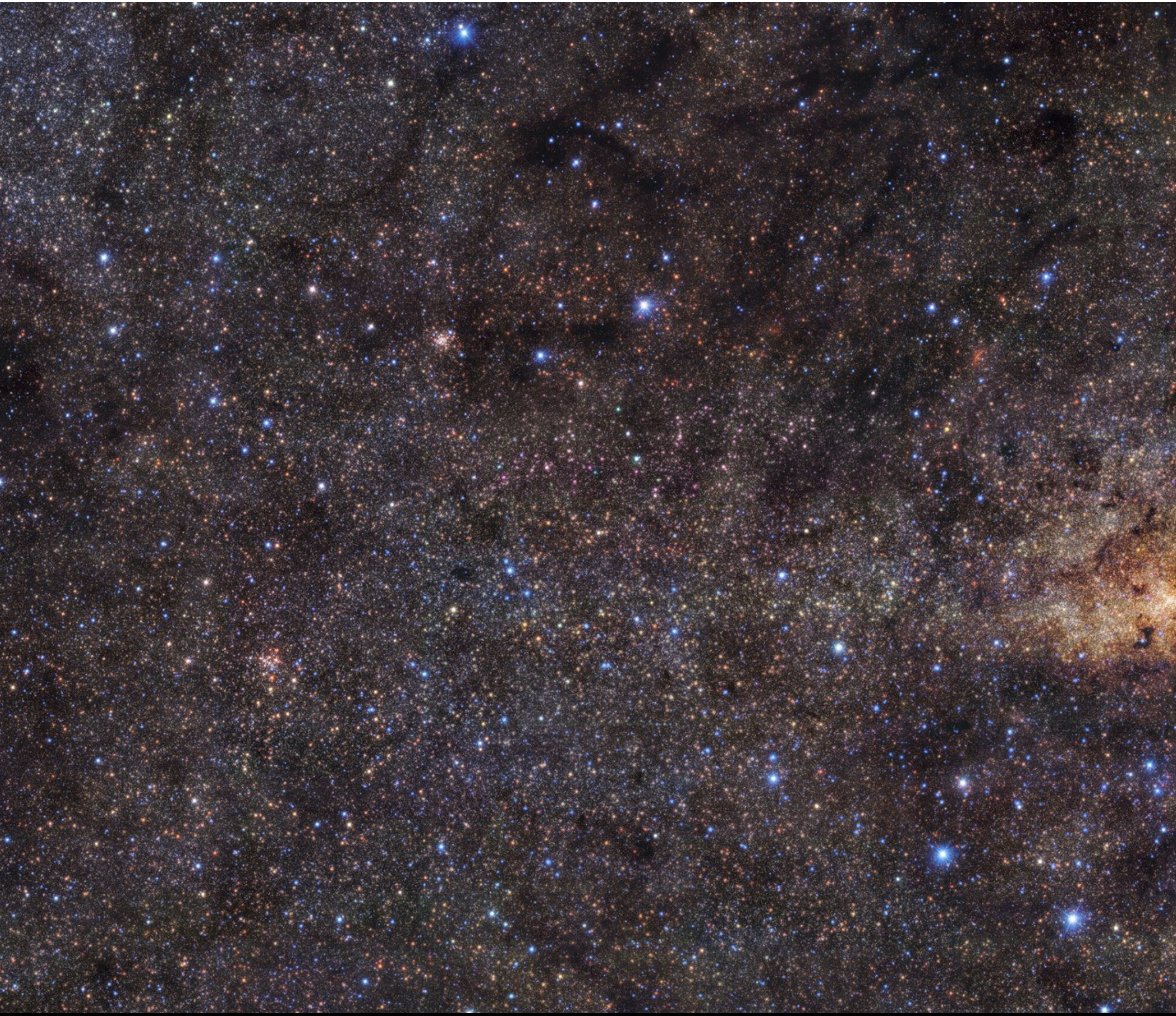
"MUSE confirmed that there was no bright companion in a wider orbit, while GRAVITY's high spatial resolution was able to resolve two bright sources separated by only one-third of the distance between the Earth and the Sun," says Frost. *"These data proved to be the final piece of the puzzle, and allowed us to conclude that HR 6819 is a binary system with no black hole."*

"Our best interpretation so far is that we caught this binary system in a moment shortly after one of the stars had sucked the atmosphere off its companion star. This is a common phenomenon in close binary systems, sometimes referred to as 'stellar vampirism' in the press," explains Bodensteiner, now a fellow at ESO in Germany and an author on the new study. *"While the donor star was stripped of some of its material, the recipient star began to spin more rapidly."*

"Catching such a post-interaction phase is extremely difficult as it is so short," adds Frost. *"This makes our findings for HR 6819 very exciting, as it presents a perfect candidate to study how this vampirism affects the evolution of massive stars, and in turn the formation of their associated phenomena including gravitational waves and violent supernova explosions."*

The newly formed Leuven-ESO joint team now plans to monitor HR 6819 more closely using the VLTI's GRAVITY instrument. The researchers will conduct a joint study of the system over time, to better understand its evolution, constrain its properties, and use that knowledge to learn more about other binary systems.

As for the search for black holes, the team remains optimistic. *"Stellar-mass black holes remain very elusive owing to their nature,"* says Rivinius. *"But order-of-magnitude estimates suggest there are tens to hundreds of millions of black holes in the Milky Way alone,"* Baade adds. It is just a matter of time until astronomers discover them. ■

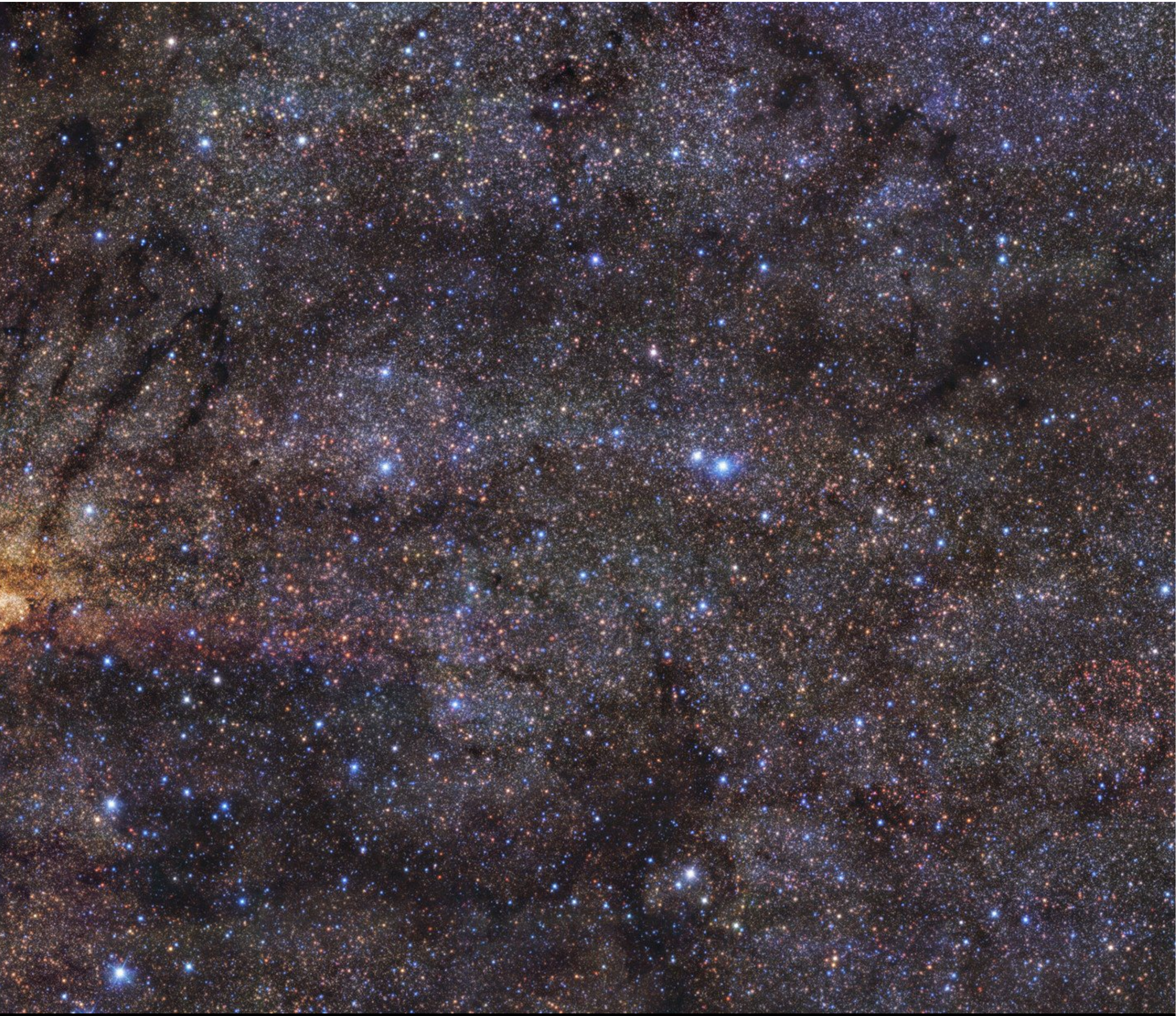


Nothing but silence from the galactic center

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

Chenoa Tremblay (Commonwealth Scientific and Industrial Research Organization) and two of her collaborators recently published in *The Astrophysical Journal* a new report of their low-frequency radio observations in the search for alien technosignatures, signals that can only be produced through non-terrestrial technologies. The target of this umpteenth SETI attempt was the region of the galactic center, more precisely a 200-square-degree wide area of sky centered on Sagittarius A*, the Milky Way's supermassive black hole. The intentions of the small team were certainly the best, but there were all of the right conditions to obtain, once again, inconclusive results.



Taken with the HAWK-I instrument on ESO's Very Large Telescope (VLT) in the Chilean Atacama Desert, this extraordinary image shows the central region of the Milky Way at an angular resolution of 0.2 arc seconds. It is towards this area, densely populated with stars, that a team of researchers pointed the Murchison Widefield Array in an attempt to record alien signals. Nestled in the center of the image is Sagittarius A, the Milky Way's supermassive black hole, whose presence conditioned every aspect of the evolution of our galaxy from the very beginning. [ESO/Nogueras-Lara et al.]*

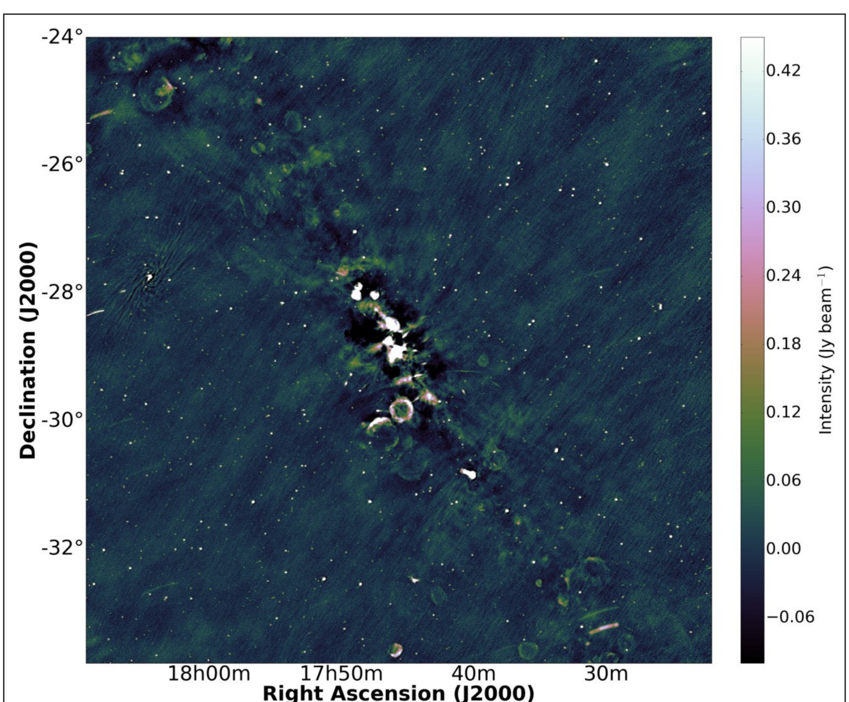
As happened for previous similar research coordinated by Tremblay, the instrument used was the Murchison Widefield Array (MWA), this time tuned to a frequency of 155 MHz, far enough away from commercial radio frequencies to avoid most of the interference of local origin. As stated by the authors of the research, the choice of the galactic center as a target was dictated solely by the fact that the stellar density is greater in that direction than in any other direction and, apparently, the chances of success are higher: *"We don't know where to look or not look to improve our chances because we haven't discovered another technological civilization yet. In the search for extraterrestrial intelligence, it makes sense to cast our net wide. The galactic center is a prime SETI target, as the line of sight has the largest integrated count of galactic stars than any other direction."*

This point of view is rather questionable, both because there are much more specific targets than a congeries of stars in which to look for technosignatures, and because a "wide net" does not appear more reasonable than any other option. Precisely because no alien signal has

This video sequence zooms into the Hubble Space Telescope view of the galactic core. Hubble's infrared vision pierced the dusty heart of our Milky Way to reveal more than half a million stars at its core. Except for a few blue foreground stars, the stars are part of the Milky Way's nuclear star cluster, the most massive and densest stellar cluster in our galaxy. Located about 27,000 light-years away, this region is so packed with stars that it is equivalent to having a million suns crammed into the volume of space between us and our closest stellar neighbor, Alpha Centauri, 4.3 light-years away. At the very hub of our galaxy, this star cluster surrounds the Milky Way's central supermassive black hole, which is about 4 million times the mass of our Sun. [NASA, ESA, and G. Bacon (STScI)]

been recorded so far, we do not know which net is more suitable. Even the radio frequency chosen for the search was completely arbitrary, and if it is true that it offers a good angular resolution (75 arc seconds), it is also true that it is decidedly exclusive. In addition, the radio telescope remained "listening" for just two nights, producing 7 hours of data in total. This is an almost insignificant time coverage and presupposes a continuous transmission of signals by aliens.

In contrast to these research weaknesses, Tremblay and colleagues bring some arguments supporting their choice to aim into the heap in the direction of the galactic center. For example, theoretical studies conducted in 2011 and 2015 by Michael Gowanlock (Northern Arizona University) and other researchers indicated that towards the innermost parts of our galaxy, even within 1 kpc (1 kiloparsec = 3,260 light years) of Sagittarius A*, the number of planets potentially capable of hosting complex life should be greater than anywhere else. Similar scenarios also emerged from more recent studies, which see the high density of the galactic center as a strong point in the search for technosignatures. In the field framed by MWA, there were over 3 million stars and 144 known planetary systems; however, the instrument recorded only silence, excluding the inevitable human radio interference. Maybe this environment is not as hospitable as someone assumed? Tremblay herself points out that there are also negative aspects in making observations in the direction of the galactic center: *"The high density of stars within the galactic center means that cataclysmic events such as stellar supernovae and magnetar flares are more likely to impact exoplanets, potentially destroying any life on their surface. With so many stars*



Continuum image of the Galactic Plane in ICRS Coordinates as viewed by the MWA at 155 MHz. ICRS (International Celestial Reference System) is the current standard celestial reference system adopted by the International Astronomical Union. [Pawsey Supercomputing Centre]

An outlook of the Eastern Hex at sunset, part of the Murchison Widefield Array's Phase 2 compact configuration. [Kim Steele, Curtin University]

in the densely packed galactic center, stellar flybys are more likely. Those are bad news for life, let alone civilization. They can disrupt protoplanetary disks and interfere in the planet formation process."

If these were the only contraindications in the search for technosignatures in the galactic center, all SETI programs would point in that direction. The reality is far worse. Both Gowanlock and Tremblay's team seem to underestimate a decisive presence in the evolution of our galaxy: Sagittarius A*, that supermassive black hole surprisingly placed at the center of the star field framed by MWA. Several studies have shown that that monstrous object of 4.2 million solar masses has gone through periods of intense activity, during which it devoured enormous quantities of matter and emitted very intense streams of X-Ray and UV radiation. These episodes have occurred quite frequently (on an astronomical scale) in the history of the Milky Way and have lasted for up to tens of millions of years. A work published in *Nature* in 2017, authored by Amedeo Balbi and Francesco Tombesi (University of Rome 'Tor Vergata'), showed that the radiation released by Sagittarius A* in those episodes was more than enough to annihilate all forms of life (as we know it) within a radius of 7 kpc, stripping Earth-like planets of much of their atmospheres. Only at distances greater than 7 kpc might life have enjoyed relatively safe and stable habitats, capable of favoring its development in ever more advanced forms, up to the possible emergence of a technological civilization. This is our case. The Earth is in fact 8.2 kpc (26,700 light years) from Sagittarius A*, therefore just 4,000 light years outside the critical radius, which means that looking for technosignatures in the direction of Sagittarius A* can only make sense if one hopes to find them in the first 4,000 light years from Earth. This distance is 15% of that investigated by Tremblay's team, and if we consider that stellar density increases significantly near the galactic center, we find that of the 3 million stars theoretically observed, only a small part is at a safe-enough distance from Sagittarius A*. Of these, we know that only about 20% can offer the conditions necessary for the lasting evolution of life. On balance, it was extremely unlikely that those 7 hours of "listening" could lead to the discovery of technosignatures. It is much more likely to win the Mega Millions lottery jackpot! Fatally, even this umpteenth SETI study could only end with the usual sad statement: *"No plausible technosignatures are detected."*

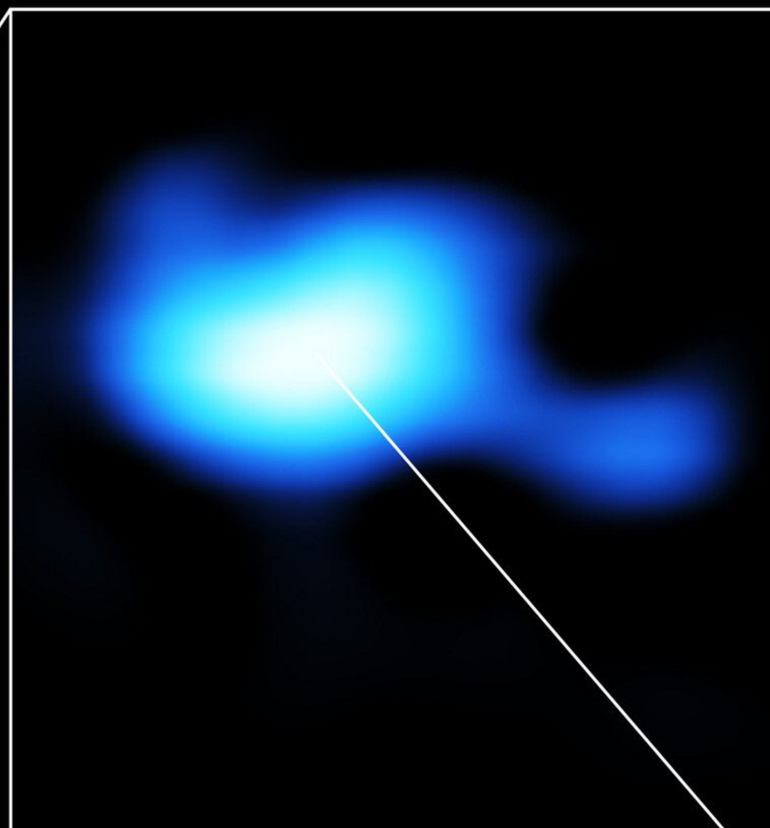
Chenoa Tremblay is the researcher who in recent years has led several series of observations in the radio domain in search for technosignatures of alien origin. The last session targeted the galactic center. [Pawsey Supercomputing Centre]

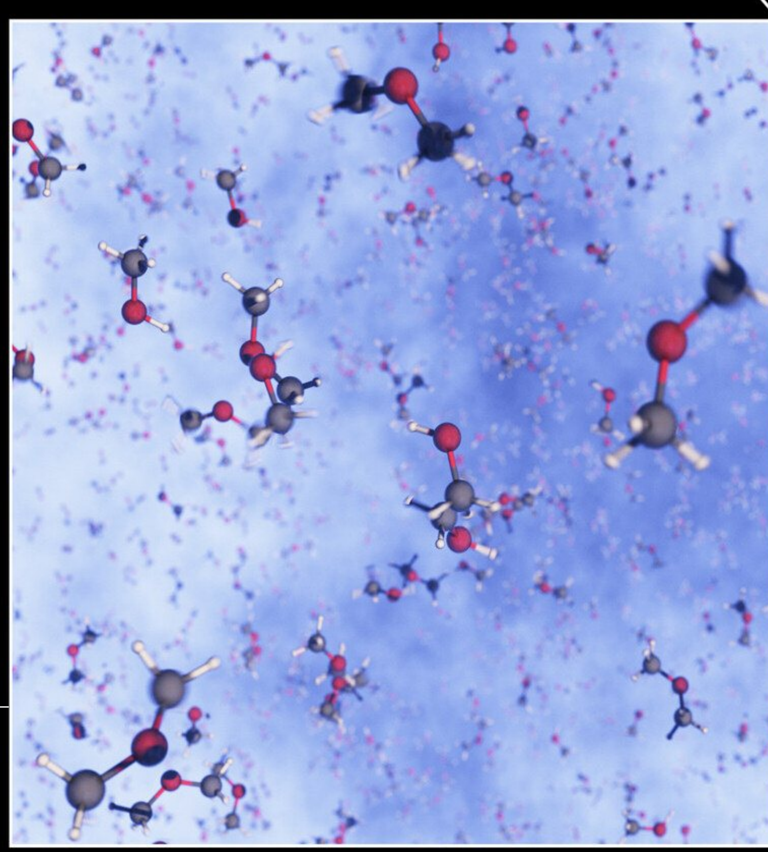
Largest molecule yet in a planet-forming disc discovered

by ESO - Bárbara Ferreira

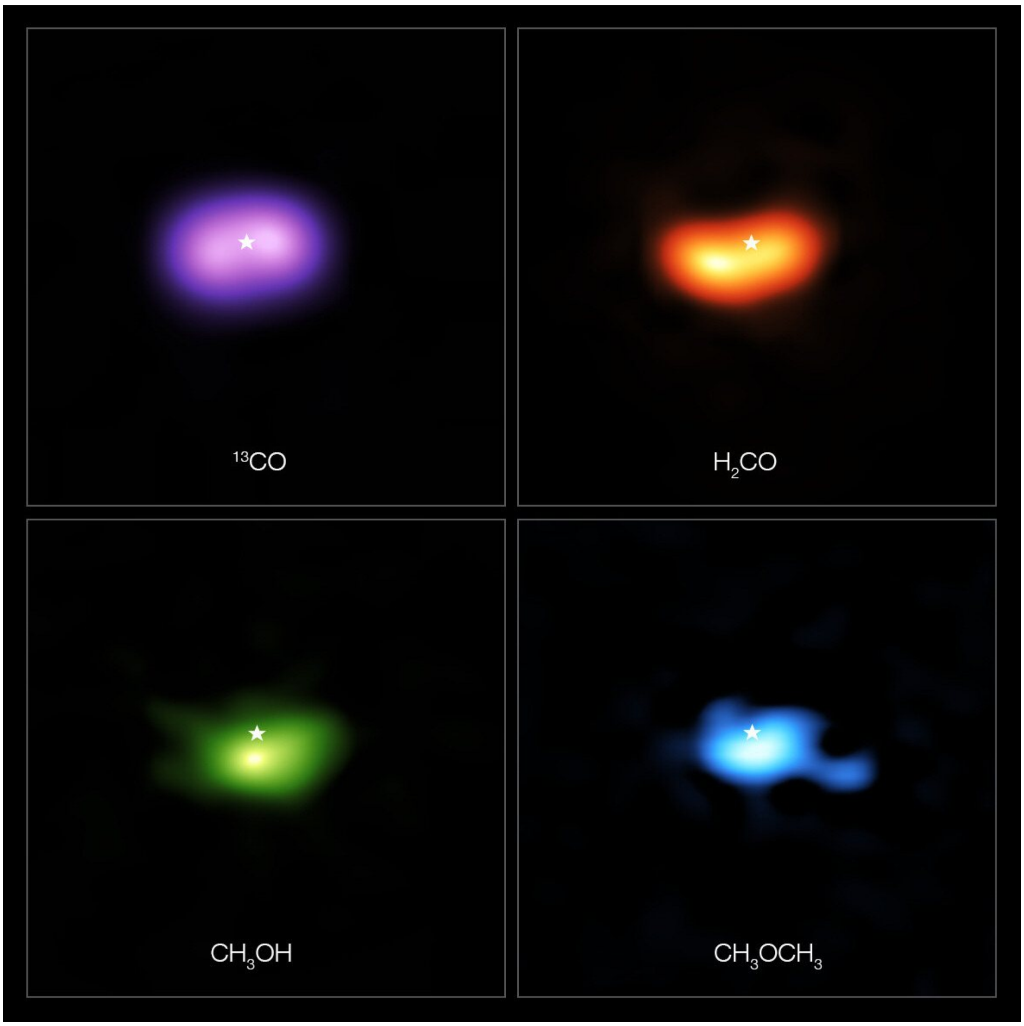
Using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, researchers at Leiden Observatory in the Netherlands have for the first time detected dimethyl ether in a planet-forming disc. With nine atoms, this is the largest molecule identified in such a disc to date. It is also a precursor of larger organic molecules that can lead to the emergence of life. *"From these results, we can learn more about the origin of life on our planet and therefore get a better idea of the potential for life in other planetary systems. It is very exciting to see how these findings fit into the bigger picture,"* says Nashanty Brunken, a Master's student at Leiden Observatory, part of Leiden University, and lead author of the study published in *Astronomy & Astrophysics*.

Dimethyl ether is an organic molecule commonly seen in star-forming clouds, but had never before been found in a planet-forming disc. The researchers also made a tentative detection of methyl formate, a complex molecule similar to dimethyl ether that is also a building block for even larger organic molecules.





This composite image features an artistic impression of the planet-forming disc around the IRS 48 star, also known as Oph-IRS 48. The disc contains a cashew-nut-shaped region in its southern part, which traps millimetre-sized dust grains that can come together and grow into kilometre-sized objects like comets, asteroids and potentially even planets. Recent observations with the Atacama Large Millimeter/submillimeter Array (ALMA) spotted several complex organic molecules in this region, including dimethyl ether, the largest molecule found in a planet-forming disc to date. The emission signaling the presence of this molecule (real observations shown in blue) is clearly stronger in the disc's dust trap. A model of the molecule is also shown in this composite. [ESO/L. Calçada, ALMA (ESO/NAOJ/NRAO)/A. Pohl, van der Marel et al., Brunken et al.]

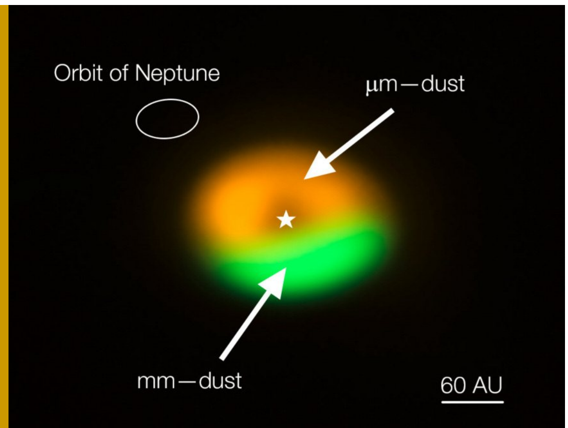


These images from the Atacama Large Millimeter/submillimeter Array (ALMA) show where various gas molecules were found in the disc around the IRS 48 star, also known as Oph-IRS 48. The disc contains a cashew-nut-shaped region in its southern part, which traps millimetre-sized dust grains that can come together and grow into kilometre-sized objects like comets, asteroids and potentially even planets. Recent observations spotted several complex organic molecules in this region, including formaldehyde (H_2CO; orange), methanol (CH_3OH; green) and dimethyl ether (CH_3OCH_3; blue), the last being the largest molecule found in a planet-forming disc to date. The emission signaling the presence of these molecules is clearly stronger in the disc's dust trap, while carbon monoxide gas (CO; purple) is present in the entire gas disc. The location of the central star is marked with a star in all four images. The dust trap is about the same size as the area taken up by the methanol emission, shown on the bottom left. [ALMA (ESO/NAOJ/NRAO)/A. Pohl, van der Marel et al., Brunken et al.]

"It is really exciting to finally detect these larger molecules in discs. For a while we thought it might not be possible to observe them," says co-author Alice Booth, also a researcher at Leiden Observatory.

The molecules were found in the planet-forming disc around the young star IRS 48 (also known as Oph-IRS 48) with the help of ALMA, an observatory co-owned by the European Southern Observatory (ESO). IRS 48, located 444 light-years away in the constellation Ophiuchus, has been the subject of numerous studies because its disc contains an asymmetric, cashew-nut-shaped "dust trap". This region, which likely formed as a result of a newly born planet or small companion star located between the star and the dust trap, retains large numbers of millimetre-sized dust grains that can come together and grow into kilometre-sized objects like comets, asteroids and potentially even planets.

Many complex organic molecules, such as dimethyl ether, are thought to arise in star-forming clouds, even before the stars themselves are born. In these cold environments, atoms and simple molecules like carbon monoxide stick to dust grains, forming an ice layer and undergoing chemical reactions, which result in more complex molecules. Researchers recently discovered that the dust trap in the IRS 48 disc is also an ice reservoir, harbouring dust grains covered with this ice rich in complex mole-



Annotated image from the Atacama Large Millimeter/submillimeter Array (ALMA) showing the dust trap in the disc that surrounds the system Oph-IRS 48. The dust trap provides a safe haven for the tiny dust particles in the disc, allowing them to clump together and grow to sizes that allow them to survive on their own. The green area is the dust trap, where the bigger particles accumulate. The size of the orbit of Neptune is shown in the upper left corner to show the scale. [ALMA (ESO/NAOJ/NRAO)/Nienke van der Marel]

cules. It was in this region of the disc that ALMA has now spotted signs of the dimethyl ether molecule: as heating from IRS 48 sublimates the ice into gas, the trapped molecules inherited from the cold clouds are freed and become detectable.

"What makes this even more exciting is that we now know these larger complex molecules are available to feed forming planets in the disc," explains Booth. *"This was not known before as in most systems these molecules are hidden in the ice."* The discovery of dimethyl ether suggests that many other complex molecules that are commonly detected in star-forming regions may also be lurking on icy structures in planet-forming discs. These molecules are the precursors of prebiotic molecules such as amino acids and sugars, which are some of the basic building blocks of life.

How do the ingredients for life end up on planets? The discovery of the largest molecule ever found in a planet-forming disc is providing clues. [ESO]

By studying their formation and evolution, researchers can therefore gain a better understanding of how prebiotic molecules end up on planets, including our own. *"We are incredibly pleased that we can now start to follow the entire journey of these complex molecules from the clouds that form stars, to planet-forming discs, and to comets. Hopefully with more observations we can get a step closer to understanding the origin of prebiotic molecules in our own Solar System,"* says Nienke van der Marel, a Leiden Observatory researcher who also participated in the study.

This video zooms in on the Oph-IRS 48 system, a star surrounded by a planet-forming disc that contains a dust trap. This trap allows dust particles to grow and spawn bigger bodies. [ALMA (ESO/NAOJ/NRAO)/Nick Risinger (skysurvey.org)/Digitized Sky Survey 2/S. Guisard (www.eso.org/~sguisard)]

Future studies of IRS 48 with ESO's Extremely Large Telescope (ELT), currently under construction in Chile and set to start operations later this decade, will allow the team to study the chemistry of the very inner regions of the disc, where planets like Earth may be forming. ■

Two mini-Neptunes that are transforming into super-Earths

by NASA/ESA
Ray Villard

Exoplanets come in shapes and sizes that are not found in our solar system. These include small gaseous planets called mini-Neptunes and rocky planets several times Earth's mass called super-Earths.

Now, astronomers have identified two different cases of "mini-Neptune" planets that are losing their puffy atmospheres and likely transforming into super-Earths. Radiation from the planets' stars is stripping away their atmospheres, driving the hot gas to escape like steam from a pot of boiling water. The new findings help paint a picture of how exotic worlds like these form and evolve, and help explain a curious gap in the size distribution of planets found around other stars.

Mini-Neptunes are smaller, denser versions of the planet Neptune in our solar system, and are thought to consist of large rocky cores surrounded by thick blankets of gas. In the new studies, a team of astronomers used NASA's Hubble Space Telescope to look at two mini-Neptunes orbiting HD 63433, a star located 73 light-years away. And they used the W. M. Keck Observatory in Hawaii to study one of two mini-

In this artistic animation, the mini-Neptune TOI 560.01 is shown transforming into a super-Earth. The planet is about 2.8 times the size of Earth and has a puffy atmosphere, made up of mostly hydrogen and helium. Observations with the W. M. Keck Observatory in Hawaii revealed that helium is escaping from the planet. Scientists say that the planet could lose the vast majority of its atmosphere after several hundred million years, leaving behind a type of large rocky planet called a super-Earth. [Adam Makarenko (Keck Observatory)]

Neptune planets in the star system called TOI 560, located 103 light-years away.
Their results show that atmospheric gas is escaping from the innermost mini-Neptune in TOI 560, called TOI 560.01 (also known as HD 73583b), and from the outermost mini-Neptune in HD 63433, called HD 63433c. This suggests that they could be turning into super-Earths.
"Most astronomers suspected that young, mini-Neptunes must have evaporating atmospheres," said Michael Zhang, lead author of both studies and a graduate student at Caltech. *"But nobody had ever caught one in the process of doing so until now."*
The study also found, surprisingly, that the gas around TOI 560.01 was escaping predominantly toward the star.
"This was unexpected, as most models predict that the gas should flow away from the star," said professor of planetary science Heather Knutson of Caltech, Zhang's advisor and a co-author of the study. *"We still have a lot to learn about how these outflows work in practice."*
Since the first exoplanets orbiting sun-like stars were discovered in the mid-1990s, thousands of other exoplanets have been found. Many of these orbit close to their stars, and the smaller, rocky ones generally fall into two groups: the mini-Neptunes and super-Earths. The super-Earths are as large as 1.6 times the size of Earth (and occasionally as large as 1.75 times the size of Earth), while the mini-Neptunes are between 2 and 4 times the size of Earth. Planets of these types are not found in our solar system. In fact, few planets with sizes between these two ranges have been detected around other stars.

In the background, an artwork of the mini-Neptune TOI 560.01, located 103 light-years away in the Hydra constellation. The planet, which orbits closely to its star, is losing its puffy atmosphere and may ultimately transform into a super-Earth. [Adam Makarenko (Keck Observatory)]

One possible explanation for this size-gap is that the mini-Neptunes are transforming into the super-Earths. The mini-Neptunes are theorized to be cocooned by primordial atmospheres made of hydrogen and helium. The hydrogen and helium are left over from the formation of the central star, which is born out of clouds of gas. If a mini-Neptune is small enough and close enough to its star, stellar X-rays and ultraviolet radiation can strip away its primordial atmosphere over a period of hundreds of millions of years, scientists theorize. This would then leave behind a rocky super-Earth with a substantially smaller diameter (which could, in theory, still retain a relatively thin atmosphere similar to that surrounding our planet Earth).
The astronomers were able to detect the escaping atmospheres by watching the mini-Neptunes cross in front of, or transit, their host stars. The planets cannot be seen directly but when they pass in front of their stars as seen from our point of view on Earth, telescopes can look for absorption of starlight by atoms in the planets' atmospheres. In the case of the mini-Neptune TOI 560.01, the researchers found signatures of helium. For the star system HD 63433, the team found signatures of hydrogen in the outermost planet they studied, called HD 63433c, but not the inner planet, HD 63433b.
"The inner planet may have already lost its atmosphere," explained Zhang.
"The speed of the gases provides the evidence that the atmospheres are escaping. The observed helium around TOI 560.01 is moving as fast as 20 kilometers per second, while the hydrogen around HD 63433c is moving as fast as 50 kilometers per second. The gravity of these mini-Neptunes is not strong enough to hold on to such fast-moving gas. The extent of the outflows around the planets also indicates escaping atmospheres; the cocoon of gas around TOI 560.01 is at least 3.5 times as large as the radius of the planet, and the cocoon around HD 63433c is at least 12 times the radius of the planet."
Future observations of other mini-Neptunes should reveal if TOI 560.01 is an anomaly or whether an inward-moving atmospheric outflow is more common.
"As exoplanet scientists, we've learned to expect the unexpected," Knutson said. *"These exotic worlds are constantly surprising us with new physics that goes beyond what we observe in our solar system."*

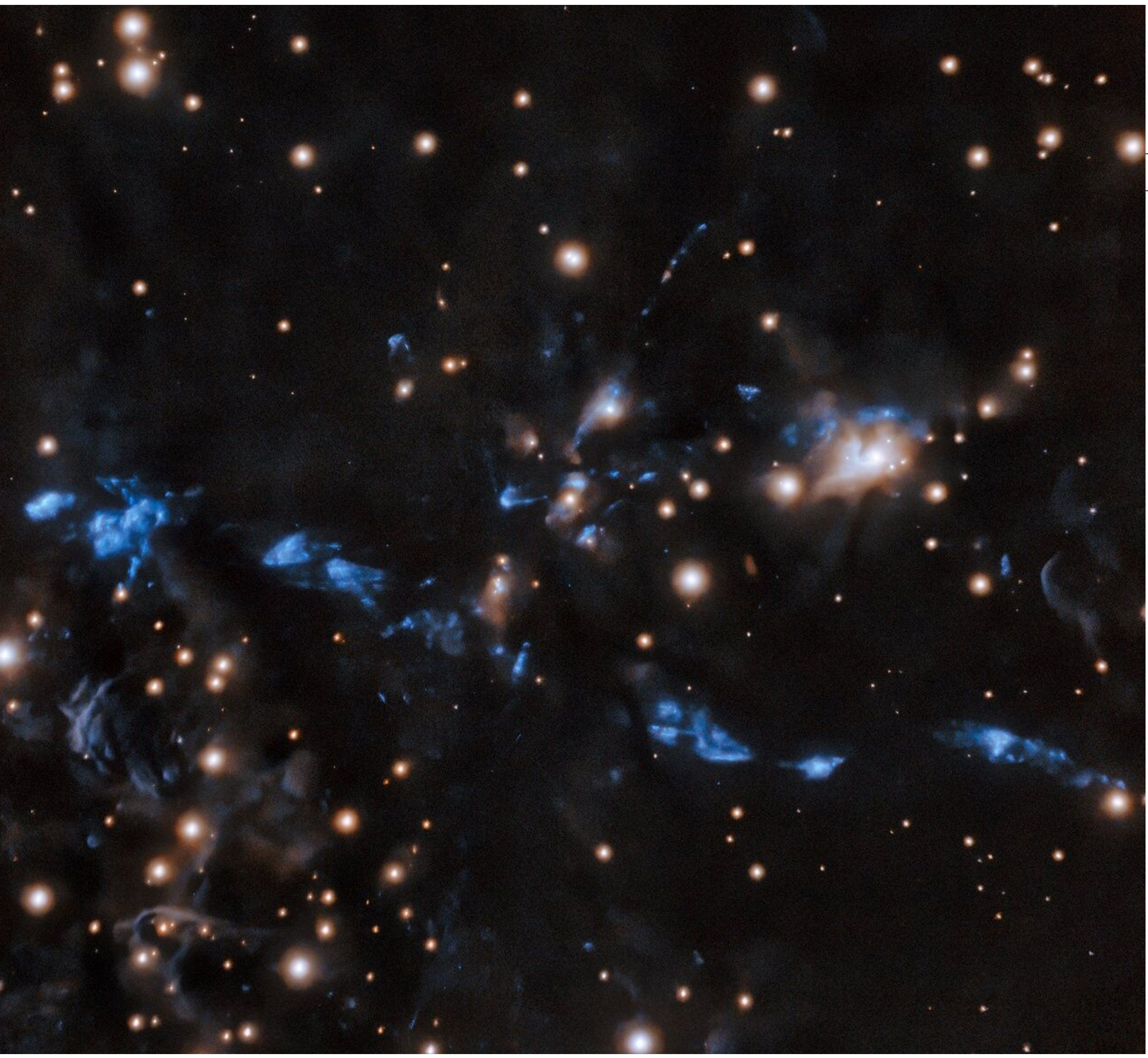
Sidewinding young stellar jets spied by Gemini South

by NOIRLab
Vanessa Thomas

Young stellar jets are a common by-product of star formation and are thought to be caused by the interplay between the magnetic fields of rotating young stars and the disks of gas surrounding them. These interactions eject twin torrents of ionized gas in opposite directions, such as those pictured in two images captured by astronomers using the Gemini South telescope on Cerro Pachón on the edge of the Chilean Andes. Gemini South is one half of the international Gemini Observatory, a Program of NSF's NOIRLab, that comprises twin 8.1-meter optical/infrared telescopes on two of the best observing sites on the planet. Its counterpart, Gemini North, is located near the summit of Maunakea in Hawai'i.

The jet in the first image, named MHO 2147, is roughly 10,000 light-years from Earth, and lies in the galactic plane of the Milky Way, close to the boundary between the constellations Sagittarius and Ophiuchus. MHO 2147 snakes across a starry backdrop in the image — an appropriately serpentine appearance for an object close to Ophiuchus. Like many of the 88 modern astronomical constellations, Ophi-

The sinuous young stellar jet, MHO 2147, meanders lazily across a field of stars in this image captured from Chile by the international Gemini Observatory, a Program of NSF's NOIRLab. The stellar jet is the outflow from a young star that is embedded in an infrared dark cloud. Astronomers suspect its sidewinding appearance is caused by the gravitational attraction of companion stars. These crystal-clear observations were made using the Gemini South telescope's adaptive optics system, which helps astronomers counteract the blurring effects of atmospheric turbulence. [International Gemini Observatory/NOIRLab/NSF/AURA. Ack.: Image processing: T.A. Rector (University of Alaska Anchorage/NSF's NOIRLab), M. Zamani (NSF's NOIRLab) & D. de Martin (NSF's NOIRLab)]



The knotted young stellar jet, MHO 1502, is captured in this image from Chile by the international Gemini Observatory, a Program of NSF's NOIRLab. The stellar jet is embedded in an area of star formation known as an HII region. The bipolar jet is composed of a chain of knots, suggesting that its source, thought to be two stars, has been intermittently emitting material. These crystal-clear observations were made using the Gemini South telescope's adaptive optics system, which helps astronomers counteract the blurring effects of atmospheric turbulence. [International Gemini Observatory/NOIRLab/NSF/AURA. Ack.: Image processing: T.A. Rector (University of Alaska Anchorage/NSF's NOIRLab), M. Zamani (NSF's NOIRLab) & D. de Martin (NSF's NOIRLab)]

uchus has mythological roots — in ancient Greece it represented a variety of gods and heroes grappling with a serpent. MHO 1502, the jet pictured in the second image, is located in the constellation of Vela, approximately 2000 light-years away. Most stellar jets are straight but some can be wandering or knotted. The shape of the uneven jets is thought to be related to a characteristic of the object or objects that created them. In the case of the two bipolar jets MHO 2147 and MHO 1502, the stars which created them are obscured from view.

In the case of MHO 2147, this young central star, which has the catchy identifier IRAS 17527-2439, is embedded in an infrared dark cloud — a cold, dense region of gas that is opaque at the infrared wavelengths represented in this image. The sinuous shape of MHO 2147 is caused because the direction of the jet has changed over time, tracing out a gentle curve on either side of the central star. These almost unbroken curves suggest that MHO 2147 has been sculpted by continuous emission from its central source. Astronomers found that the changing direction (precession) of the jet may be due to the gravitational influence of nearby stars acting on the central star. Their observations suggest that IRAS 17527-2439 could belong to a triple star system separated by more than 300 billion kilometers (almost 200 billion miles).

MHO 1502, on the other hand, is embedded in a totally different environment — an area of star formation known as an HII region. The bipolar jet is composed of a chain of knots, suggesting that its source, thought to be two stars, has been intermittently emitting material.

These detailed images were captured by the Gemini South Adaptive Optics Imager (GSAOI), an instrument on the 8.1-meter-diameter Gemini South telescope. Gemini South is perched on the summit of Cerro Pachón, where dry air and negligible cloud cover provide one of the best observing sites on the planet. Even atop Cerro Pachón, however, atmospheric turbulence causes the stars to blur and twinkle. GSAOI works with GeMs, the Gemini Multi-Conjugate Adaptive Optics System, to cancel out this blurring effect using a technique called adaptive optics. By monitoring the twinkling of natural and artificial guide stars up to 800 times a second, GeMs can determine how atmospheric turbulence is distorting Gemini South's observations. A computer uses this information to minutely adjust the shape of deformable mirrors, canceling out the distortions caused by turbulence. In this case, the sharp adaptive optics images have made it possible to recognize more details in each knot of the young stellar jets than in previous studies. ■

Artificial Intelligence for Science and Operations in Astronomy

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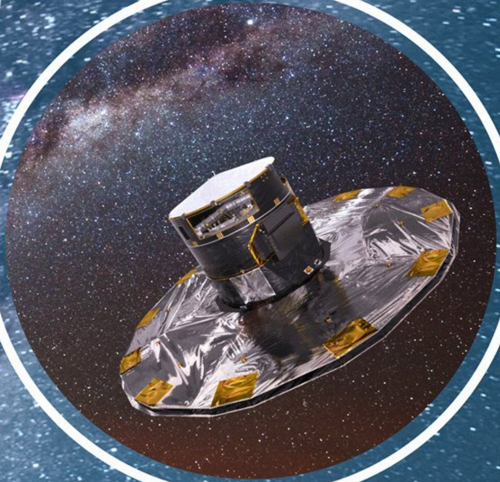

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ESO telescopes help uncover largest group of rogue planets yet

by ESO - Bárbara Ferreira

Rogue planets are elusive cosmic objects that have masses comparable to those of the planets in our Solar System but do not orbit a star, instead roaming freely on their own. Not many were known until now, but a team of astronomers, using data from several European Southern Observatory (ESO) telescopes and other facilities, have just discovered at least 70 new rogue planets in our galaxy. This is the largest group of rogue planets ever discovered, an important step towards understanding the origins and features of these mysterious galactic nomads.

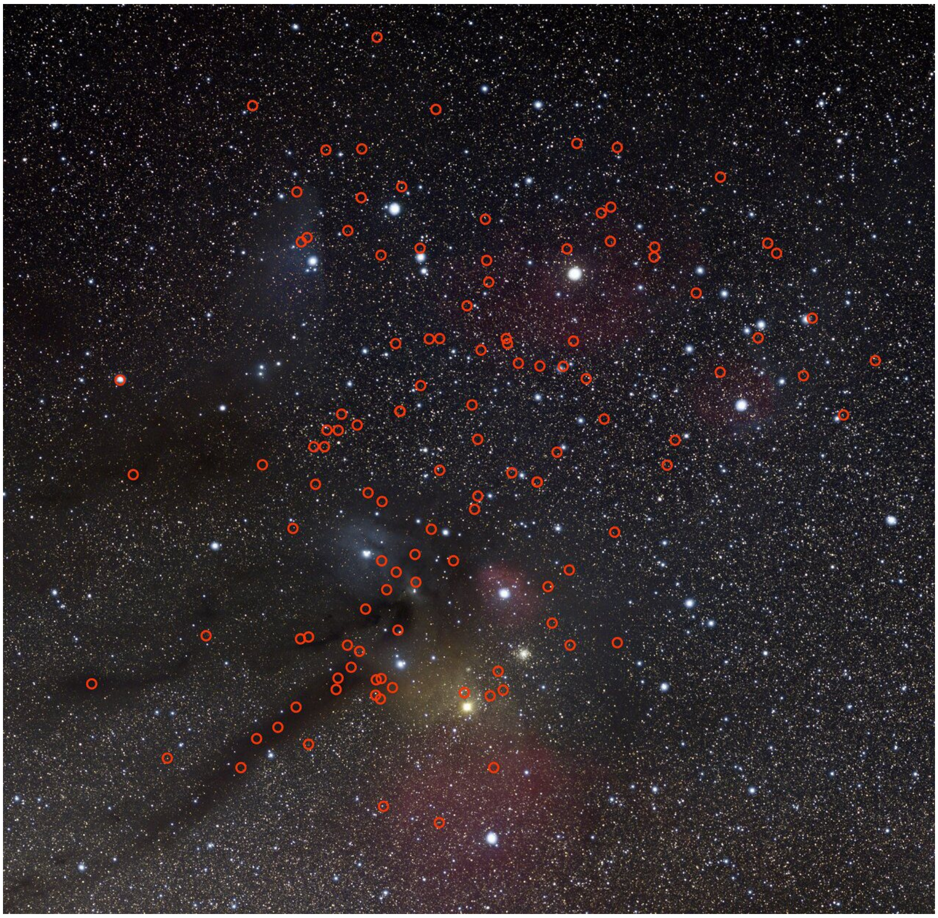
"We did not know how many to expect and are excited to have found so many," says Núria Miret-Roig, an astronomer at the Laboratoire d'Astrophysique de Bordeaux, France and the University of Vienna, Austria, and the first author of the new study published in *Nature Astronomy*.

This artist's impression shows an example of a rogue planet with the Rho Ophiuchi cloud complex visible in the background. Rogue planets have masses comparable to those of the planets in our Solar System but do not orbit a star, instead roaming freely on their own. [ESO/M. Kornmesser/S. Guisard]

Rogue planets, lurking far away from any star illuminating them, would normally be impossible to image. However, Miret-Roig and her team took advantage of the fact that, in the few million years after their formation, these planets are still hot enough to glow, making them directly detectable by sensitive cameras on large telescopes. They found at least 70 new rogue planets with masses comparable to Jupiter's in a star-forming region close to our Sun, located within the Scorpius and Ophiuchus constellations.

To spot so many rogue planets, the team used data spanning about 20 years from a number of telescopes on the ground and in space. *"We measured the tiny motions, the colours and luminosities of tens of millions of sources in a large area of the sky,"* explains Miret-Roig. *"These measurements allowed us to securely identify the faintest objects in this region, the rogue planets."*

The team used observations from ESO's Very Large Telescope (VLT), the Visible and Infrared Survey Telescope for Astronomy (VISTA), the VLT Survey Telescope (VST) and the MPG/ESO 2.2-metre telescope located in Chile, along with other facilities. *"The vast majority of our data come from ESO observatories, which were absolutely critical for this study. Their wide field of view and unique sensitivity were keys to our success,"* explains Hervé Bouy, an astronomer at the Laboratoire d'Astrophysique de Bordeaux, France, and project leader of the new research. *"We used tens of thousands of wide-field images from ESO facilities, corresponding to hundreds of hours of observations, and literally tens of terabytes of data."*



This image shows the locations of 115 potential rogue planets, highlighted with red circles, recently discovered by a team of astronomers in a region of the sky occupied by Upper Scorpius and Ophiucus. Rogue planets have masses comparable to those of the planets in our Solar System, but do not orbit a star and instead roam freely on their own. The exact number of rogue planets found by the team is between 70 and 170, depending on the age assumed for the study region. This image was created assuming an intermediate age, resulting in a number of planet candidates in between the two extremes of the study. [ESO/N. Risinger (skysurvey.org)]

The team also used data from the European Space Agency's Gaia satellite, marking a huge success for the collaboration of ground- and space-based telescopes in the exploration and understanding of our Universe. The study suggests there could be many more of these elusive, starless planets that we have yet to discover. *"There could be several billions of these free-floating giant planets roaming freely in the Milky Way without a host star,"* Bouy explains.

By studying the newly found rogue planets, astronomers may find clues to how these mysterious objects form. Some scientists believe rogue planets can form from the collapse of a gas cloud that is too small to lead to the formation of a star, or that they could have been kicked out from their parent system. But which mechanism is more likely remains unknown. Further advances in technology will be key to unlocking the mystery of these nomadic planets. The team hopes to continue to study them in greater detail with ESO's forthcoming Extremely Large Telescope (ELT), currently under construction in the Chilean Atacama Desert and due to start observations later this decade. *"These objects are extremely faint and little can be done to study them with current facilities,"* says Bouy. *"The ELT will be absolutely crucial to gathering more information about most of the rogue planets we have found."*

Astronomers have used ESO telescopes to detect at least 70 rogue planets in our Milky Way, the largest group to date. Learn more about these elusive cosmic nomads in this video summarising the discovery! [ESO]

ESO

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A 'space triangle' spawned by a galaxy collision

by NASA/ESA
Bethany Downer

A spectacular head-on collision between two galaxies, known as Arp 143, has fueled the unusual triangular-shaped star-formation frenzy as captured by the NASA/ESA Hubble Space Telescope.

The interacting galaxy duo Arp 143 contains the distorted, star-forming spiral galaxy NGC 2445, at right, along with its less flashy companion, NGC 2444, at left. Their frenzied collision takes place against the tapestry of distant galaxies, of which some can be seen through the interacting pair.

Astronomers suggest that the two galaxies passed through each other, igniting the uniquely shaped firestorm of star formation in NGC 2445, where thousands of stars are bursting into life. This galaxy is awash with new stars because it is rich in gas, the raw material from which stars are made. However, it hasn't yet escaped the gravitational clutches of its partner at left. The pair is waging a cosmic tug-of-war, which NGC 2444 appears to be winning. That galaxy has pulled gas from NGC 2445, forming the oddball triangle of newly minted stars.

NGC 2444 is also responsible for yanking strands of gas from its partner, stoking the streamers of young, blue stars that appear to form a bridge between the two galaxies. These streamers are among the first in what appears to be a wave of star formation that started on the galaxy's outskirts and continued inward. Researchers estimate the streamer stars were born between 50 million and 100 million years ago. But these infant stars are being left behind as NGC 2445 continues to pull slowly away from NGC 2444.

Stars no older than one million to two million years old are forming closer to the centre of NGC 2445. Hubble's keen vision reveals some individual stars, the brightest and most massive in the galaxy. Most of the brilliant blue clumps are groupings of stars and the pink blobs are

Hubble's Observation of Arp 143. [NASA, ESA, STScI, and J. Dalcanton (Center for Computational Astrophysics/Flatiron Inst., UWashington)]

glowing gas clouds enshrouding young, massive star clusters.
Although most of the action is happening in NGC 2445, it doesn't mean the other member of the interacting pair has escaped unscathed. The gravitational tussle has stretched NGC 2444 into an odd shape, yanking gas far from the galaxy. NGC 2444 contains old stars and no new starbirth because it lost its gas long ago, well before this galactic encounter. Aside from the star formation in NGC 2445, another interesting feature that Hubble has uncovered is the dark filaments of gas in the starburst galaxy's bright core. Those features may have been formed by outbursts of material. Radio observations reveal a powerful source in the core that may be spearheading the outbursts. The radio source may have been produced by intense star formation or a black hole gobbling up material flowing into the centre.
It's not uncommon for star formation to occur in the cores of galaxies, driven by interactions. Plenty of gas from galactic encounters flows into

This image shows a wide-field view around Arp 143. [ESA/Hubble, Digitized Sky Survey 2. Acknowledgement: Davide De Martin]

the centre, which can trigger the birth of new stars. Outflows from these stars can drive material out, but the dust created by these outbursts blankets the core and other regions throughout NGC 2445, making it difficult for Hubble to study in visible light. However, the NASA/ESA/CSA James Webb Space Telescope will have the infrared vision to peer through the dust covering these regions to reveal the young star clusters that are hidden from view in visible-light images. In this way, Hubble and Webb will provide the full census of stars in NGC 2445. The census will help astronomers answer questions such as what the star-formation rate is, how long it takes for stars to form, and whether the starburst in NGC 2445 is fading or just heating up.

Studying young, massive star clusters still embedded in their dust and gas cocoons is important for understanding how star formation affects the evolution of galaxies. Massive stars that explode as supernovae enrich their environment with chemical elements heavier than hydrogen and helium. The Arp 143 system is listed in a compendium of 338 unusual-looking interacting galaxies called the *Atlas of Peculiar Galaxies* published in 1966 by astronomer Halton Arp. ■

Zoom into Arp 143. [NASA, ESA, STScI, and J. Dalcanton (Center for Computational Astrophysics/Flatiron Institute, UWashington)]


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