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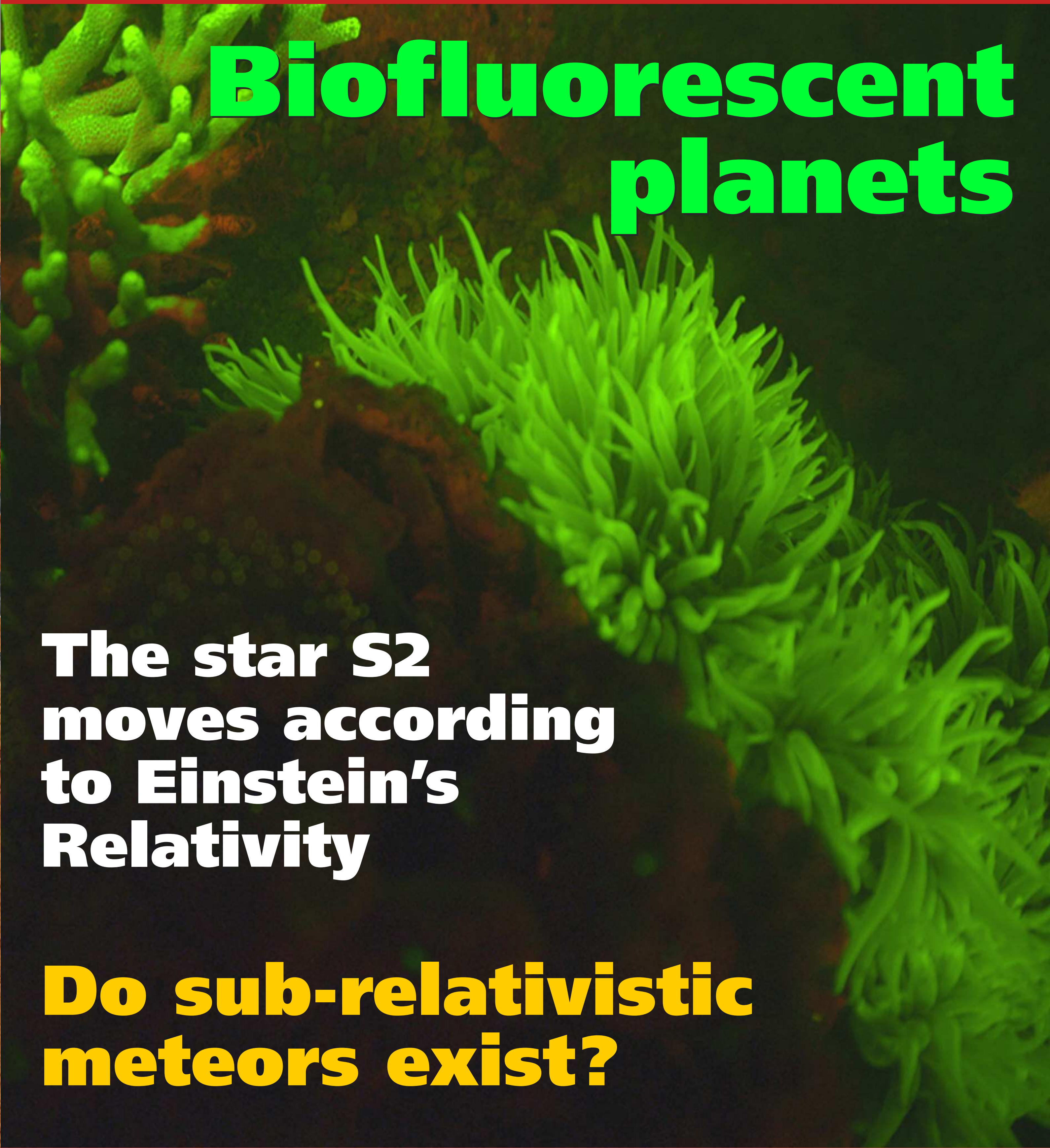

Biofluorescent planets

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Do sub-relativistic meteors exist?

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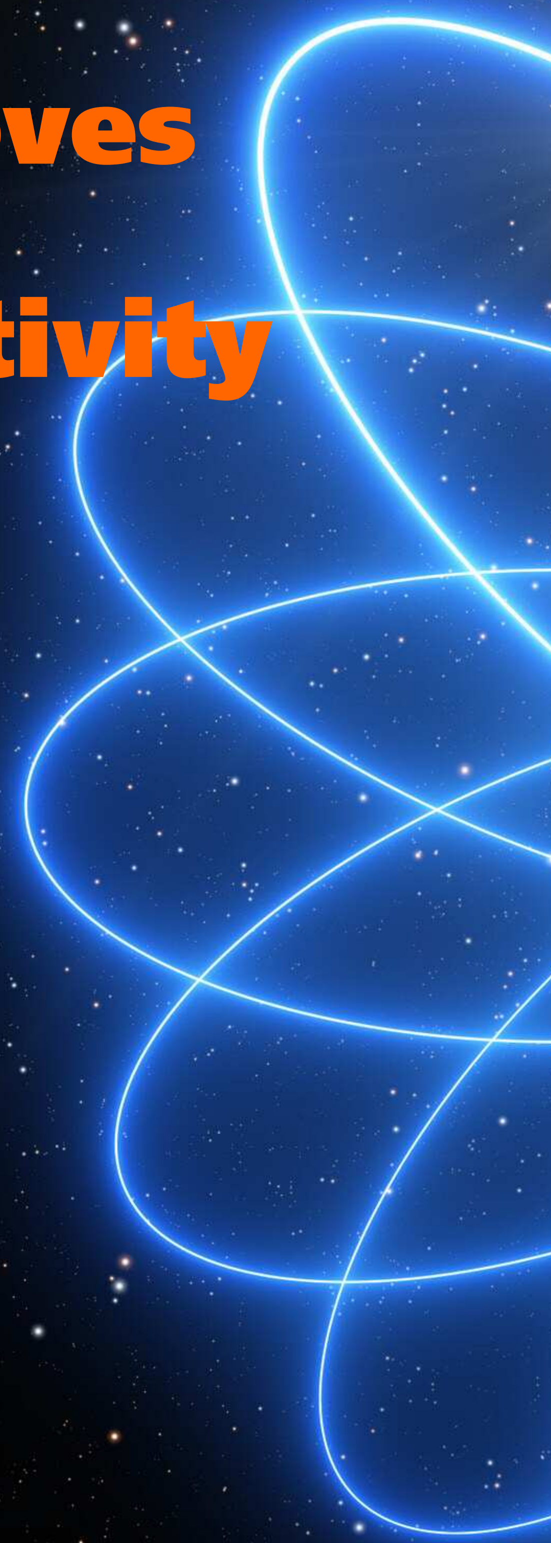
SUMMARY

The star S2 moves according to Einstein's Relativity

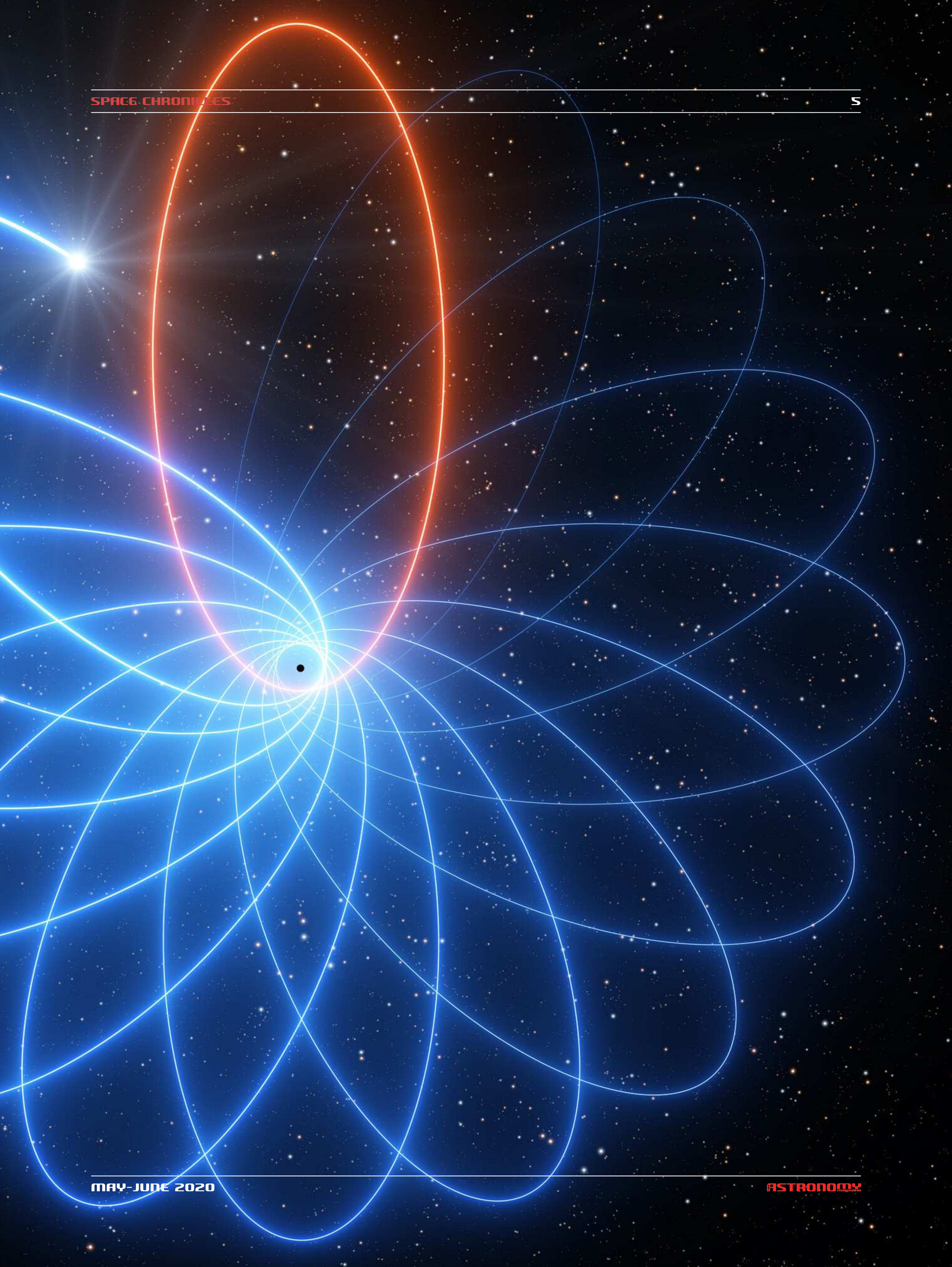
by ESO

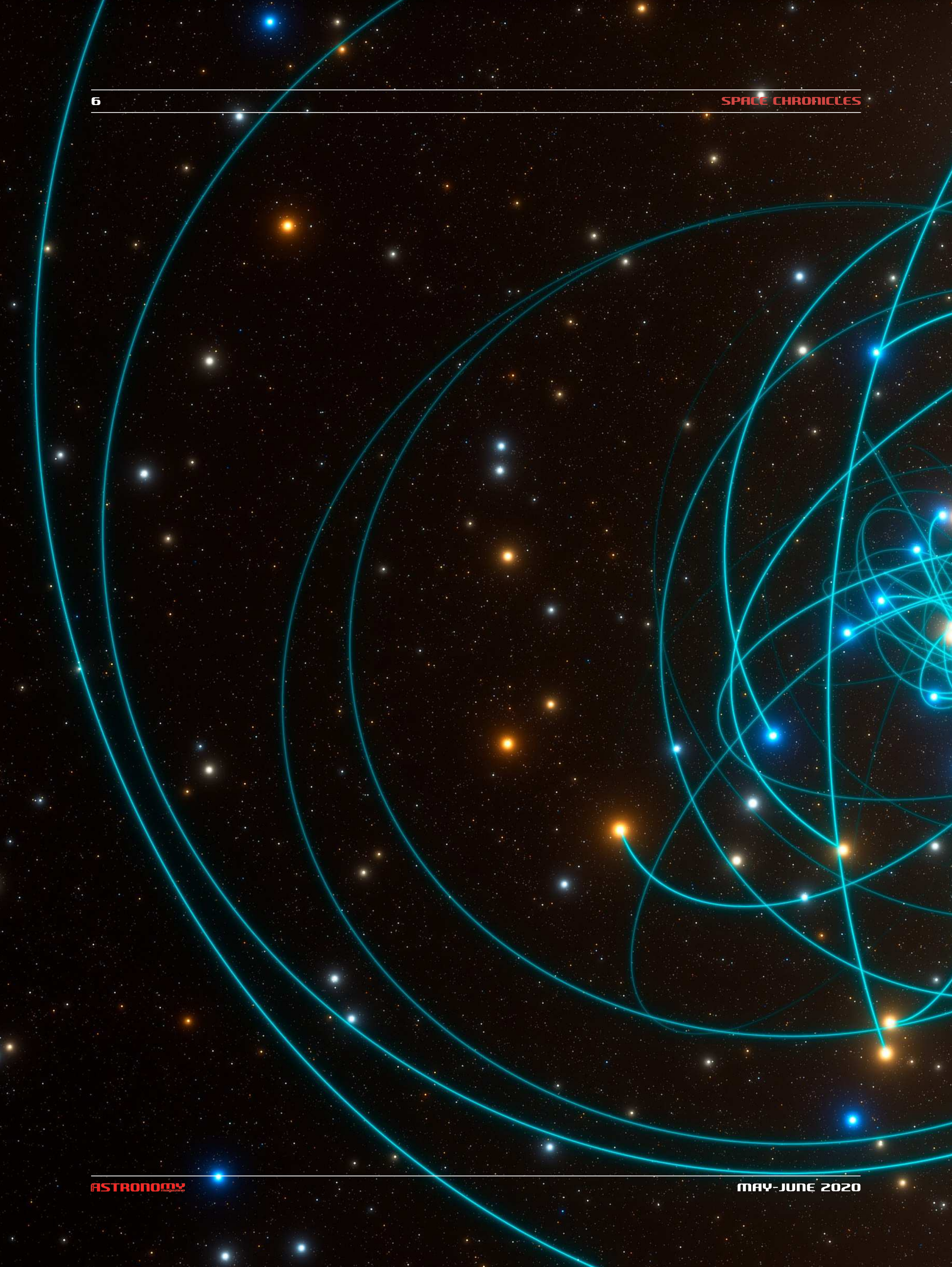
Observations made with ESO's Very Large Telescope (VLT) have revealed for the first time that a star orbiting the supermassive black hole at the centre of the Milky Way moves just as predicted by Einstein's general theory of relativity. Its orbit is shaped like a rosette and not like an ellipse as predicted by Newton's theory of gravity. This long-sought-after result was made possible by increasingly precise measurements over nearly 30 years, which have enabled scientists to unlock the mysteries of the behemoth lurking at the heart of our galaxy.

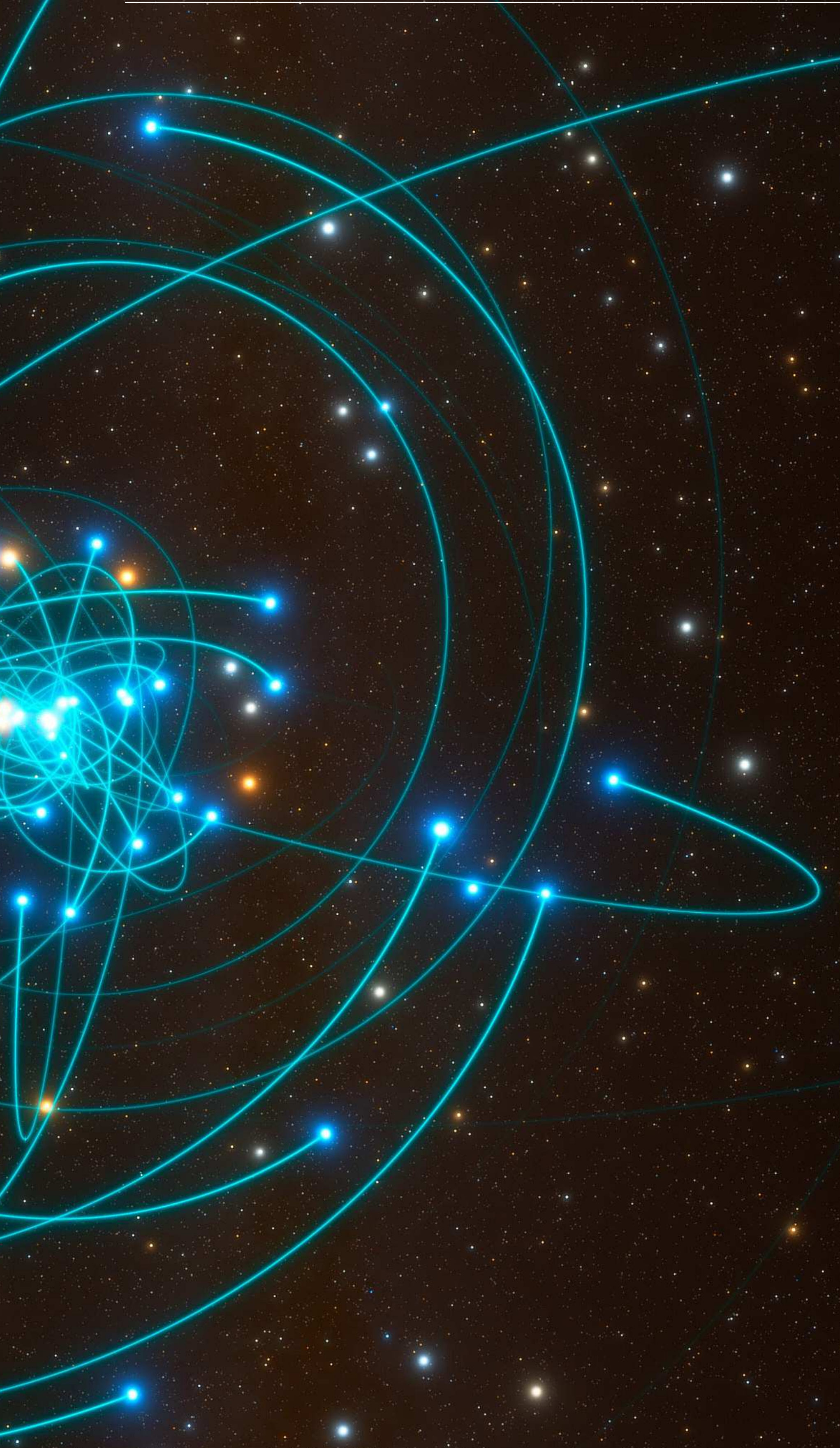
"Einstein's General Relativity predicts that bound orbits of one object around another are not closed, as in Newtonian Gravity, but precess forwards in the plane of motion. This famous effect — first seen in the orbit of the planet Mercury around the Sun — was the first evidence in favour of General Relativity. One hundred years later we have now detected the same effect in the motion of a star orbiting the compact radio source Sagittarius A at the centre of the Milky Way. This observational breakthrough strengthens the evidence that Sagittarius A* must be a supermassive black hole of 4 million times the mass of the Sun,"* says Reinhard Genzel, Director at the Max Planck Institute for



This artist's impression illustrates the precession of the star's orbit, with the effect exaggerated for easier visualisation. [ESO/L. Calçada]







This simulation shows the orbits of stars very close to the supermassive black hole at the heart of the Milky Way. One of these stars, named S2, orbits every 16 years and is passing very close to the black hole in May 2018. This is a perfect laboratory to test gravitational physics and specifically Einstein's general theory of relativity. [ESO/L. Calçada/spaceengine.org]

Extraterrestrial Physics (MPE) in Garching, Germany and the architect of the 30-year-long programme that led to this result.
Located 26 000 light-years from the Sun, Sagittarius A and the dense cluster of stars around it provide a unique laboratory for testing physics in an otherwise unexplored and extreme regime of gravity. One of these stars, S2, sweeps in towards the supermassive black hole to a closest distance less than 20 billion kilometres (one hundred and twenty times the distance between the Sun and Earth), making it one of the closest stars ever found in orbit around the massive giant. At its closest approach to the black hole, S2 is hurtling through space at almost three percent of the speed of light, completing an orbit once every 16 years. "After following the star in its orbit for over two and a half decades, our exquisite measurements robustly detect S2's Schwarzschild precession in its path around Sagittarius A*,"* says Stefan Gillessen of the MPE, who led the analysis of the measurements published today in the journal *Astronomy & Astrophysics*.
Most stars and planets have a non-circular orbit and therefore move closer to and further away from the object they are rotating around. S2's orbit precesses, meaning that the location of its closest point to the supermassive black hole changes with each turn, such that

This visible light wide-field view shows the rich star clouds in the constellation of Sagittarius (the Archer) in the direction of the centre of our Milky Way galaxy. The entire image is filled with vast numbers of stars — but far more remain hidden behind clouds of dust and are only revealed in infrared images. This view was created from photographs in red and blue light and forming part of the Digitized Sky Survey 2. The field of view is approximately 3.5 degrees x 3.6 degrees. [ESO and Digitized Sky Survey 2. Acknowledgment: Davide De Martin and S. Guisard]

the next orbit is rotated with regard to the previous one, creating a rosette shape. General Relativity provides a precise prediction of how much its orbit changes and the latest measurements from this research exactly match the theory. This effect, known as Schwarzschild precession, had never before been measured for a star around a supermassive black hole.

The study with ESO's VLT also helps scientists learn more about the vicinity of the supermassive black hole at the centre of our galaxy. *"Because the S2 measurements follow General Relativity so well, we can set stringent limits on how much invisible material, such as distributed dark matter or possible smaller black holes, is present around Sagittarius A*. This is of great interest for understanding the formation and evolution of supermassive black holes,"* say Guy Perrin and Karine Perraut, the French lead scientists of the project.

This result is the culmination of 27 years of observations of the S2 star using, for the best part of this time, a fleet of instruments at ESO's VLT, located in the Atacama Desert in Chile. The number of data points marking the star's position and velocity attests to the thoroughness and accuracy of the new research: the team made over 330 measurements in total, using the GRAVITY, SINFONI and NACO instruments. Because S2 takes years to orbit the supermassive black hole, it was crucial to follow the star for close to three decades, to unravel the intricacies of its orbital movement.

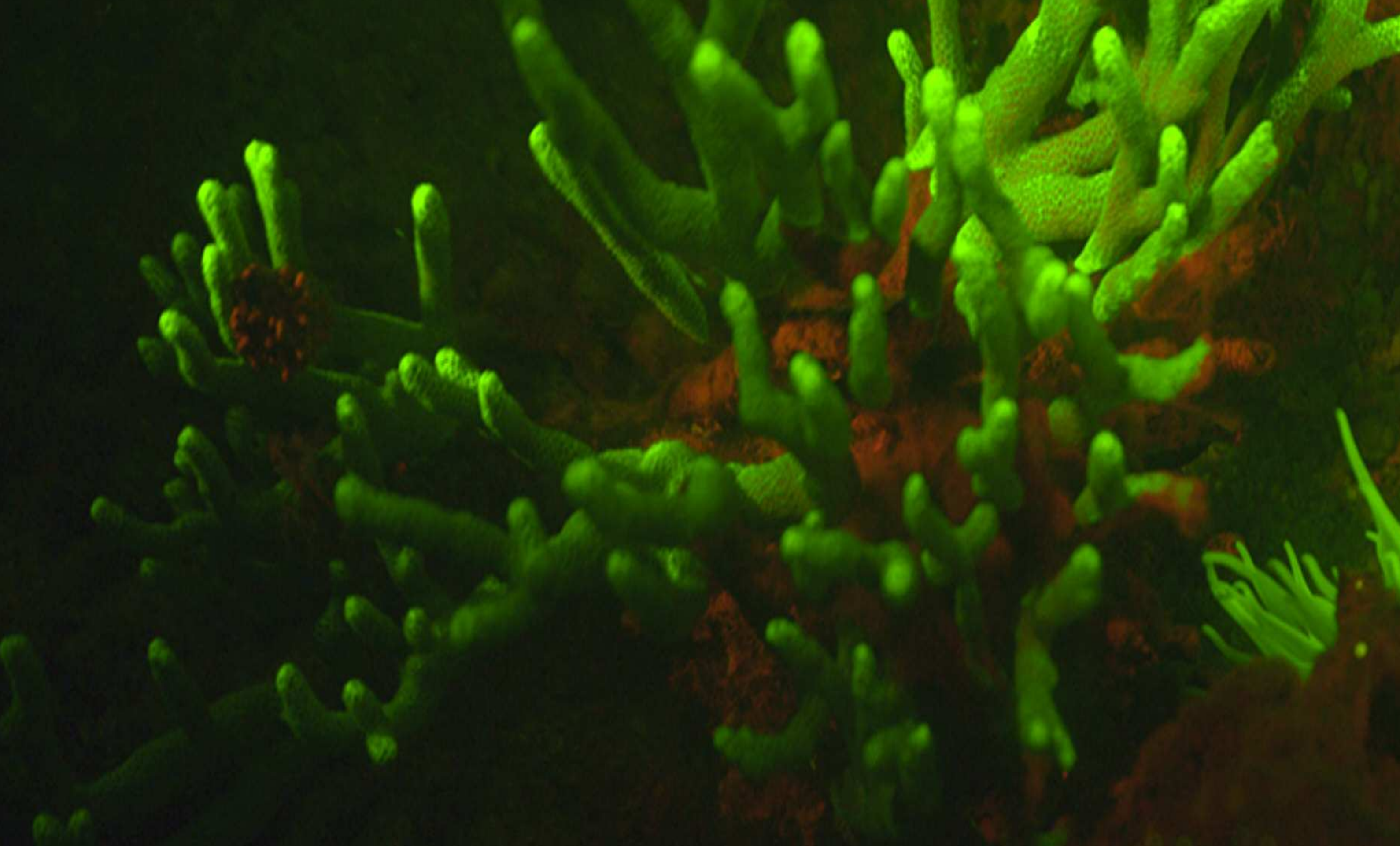
The research was conducted by an international team led by Frank Eisenhauer of the MPE with collaborators from France, Portugal, Germany and ESO. The team make up the GRAVITY collaboration, named after the instrument they developed for the VLT Interferometer, which combines the light of all four 8-metre VLT telescopes into a super-

This schematic illustration shows S2's orbit around Sagitarius A, the supermassive black hole at the centre of the Milky Way. The precession movement is exaggerated for easier viewing. [ESO/L. Calçada]*

telescope (with a resolution equivalent to that of a telescope 130 metres in diameter). The same team reported in 2018 another effect predicted by General Relativity: they saw the light received from S2 being stretched to longer wavelengths as the star passed close to Sagittarius A*. *"Our previous result has shown that the light emitted from the star experiences General Relativity. Now we have shown that the star itself senses the effects of General Relativity,"* says Paulo Garcia, a researcher at Portugal's Centre for Astrophysics and Gravitation and one of the lead scientists of the GRAVITY project.

With ESO's upcoming Extremely Large Telescope, the team believes that they would be able to see much fainter stars orbiting even closer to the supermassive black hole. *"If we are lucky, we might capture stars close enough that they actually feel the rotation, the spin, of the black hole,"* says Andreas Eckart from Cologne University, another of the lead scientists of the project. This would mean astronomers would be able to measure the two quantities, spin and mass, that characterise Sagittarius A* and define space and time around it. *"That would be again a completely different level of testing relativity,"* says Eckart.

This zoom video sequence starts with a broad view of the Milky Way. We then dive into the dusty central region to take a much closer look. There lurks a 4-million solar mass black hole, surrounded by a swarm of stars orbiting rapidly. We first see the stars in motion, thanks to 26 years of data from ESO's telescopes. We then see an even closer view of one of the stars, known as S2, passing very close to the black hole in May 2018. The final part shows a simulation of the motions of the stars. [ESO/GRAVITY Collaboration]



Biofluorescent planets

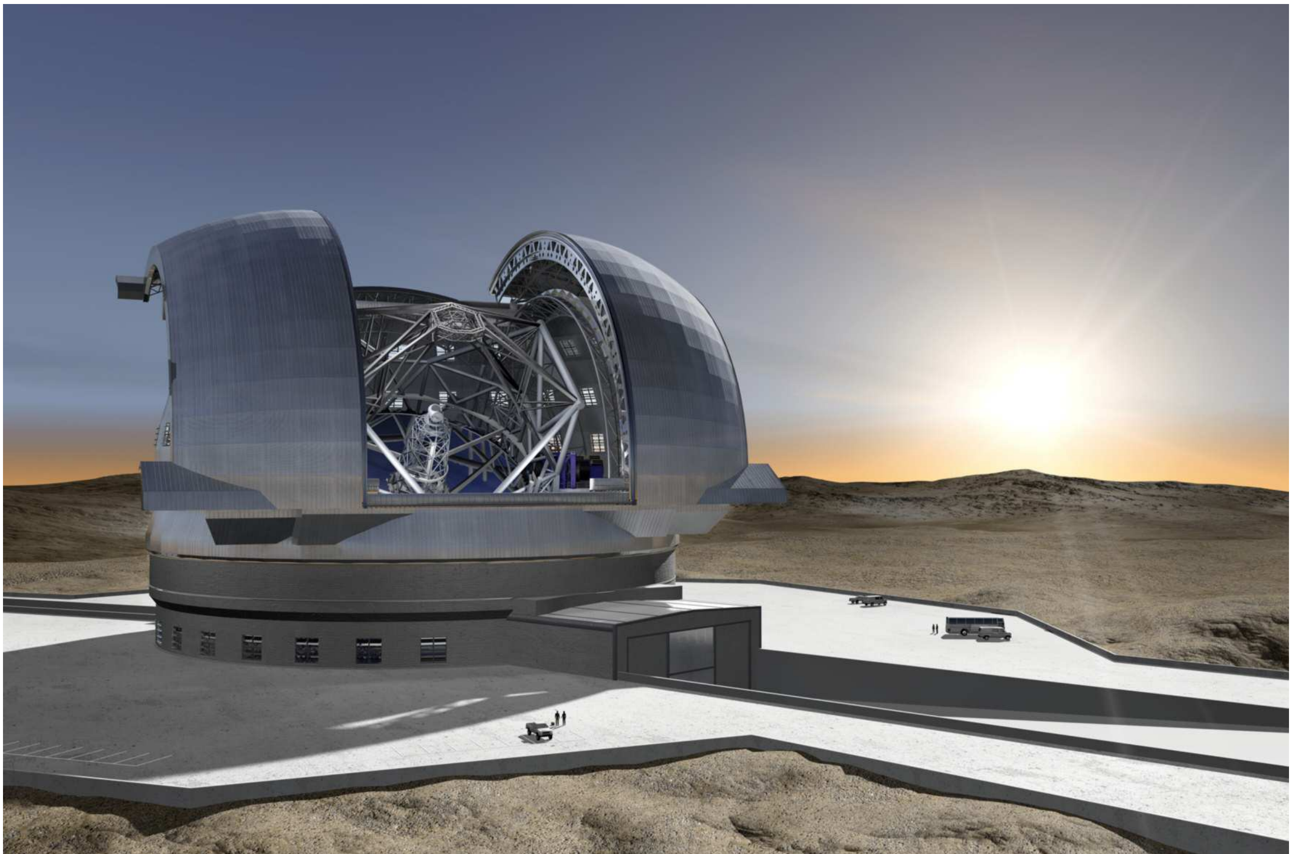
by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

The closest potentially habitable rocky exoplanets all orbit around red dwarfs. These types of stars are particularly suitable for hosting Earth-sized planets, but they are also characterized by surface phenomena very harmful to life as we know it. Some organisms, however, may be able to adapt to intense stellar radiation and also be detectable from the Earth thanks to the fascinating chemistry of biofluorescence.

According to two Cornell University researchers, fluorescent organisms similar to these could cover the shallow ocean floors of planets orbiting the habitable zones of some red dwarfs.

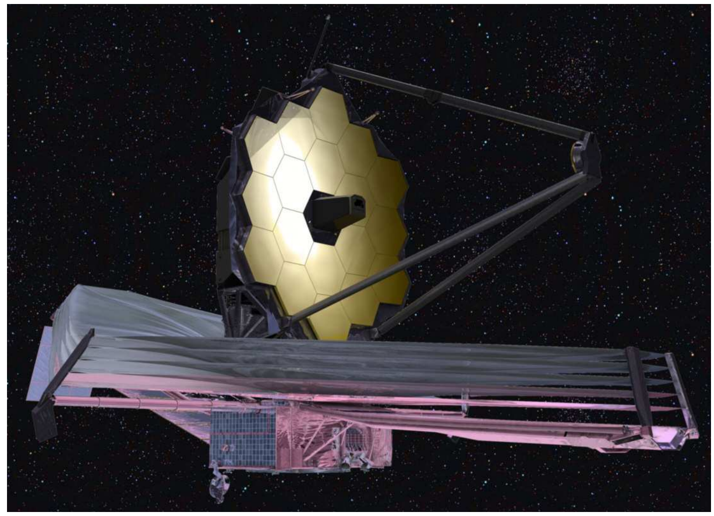
When the next generation of supertelescopes (the Extremely Large Telescope and James Webb Space Telescope first among them) are completed and become operational, it will finally be possible to observe and study the first potentially habitable exoplanets directly. For this reason, some teams of astrobiologists are currently engaged in modeling the most



favorable scenarios in order to define the most promising targets in the search for life beyond Earth. Knowing what to look for and where it is most likely to be found will allow us to make the most of both the time and the telescopes that will be assigned to these observations, excluding *a priori* targets that offer fewer chances of successful discovery.

Today, only a handful of known exoplanets are of astrobiological interest. The numbers do increase, and others will be added to this list thanks to the TESS (Transiting Exoplanets Survey Satellite) mission, which has so far identified nearly 1800 exoplanet candidates, of which only about 40 have been officially confirmed. Dozens of exoplanets as big as Earth are expected to be discovered during this mission, with some of them in orbit in the habitable zone of their stars. Other exoplanets will be found directly by ground-based telescopes and added to the growing list. Which of these new worlds will be studied first by the upcoming super-telescopes? Definitely those closest to our Solar System – the easiest ones to separate from their stars. Better still are those nearby systems where the stars are both smaller than the Sun and not very bright, allowing the reflected light coming from their planets to emerge more distinctly. If we consider the surroundings of the Sun, say up to a distance of 5 parsecs (16.3 light-years), we find about 50 star systems, composed of over 70 stars, of which most are red dwarfs (also called M stars). For reasons related to their formation and evolution, these small stars are very likely to host rocky planets in their habitable zones. It is, therefore, not surprising that most of the potentially habitable planets closest to us are in orbit around red dwarfs. In recent years, astronomers have repeatedly discussed the usefulness of looking for indicators of possible life (biosignatures) in the light of these planets.

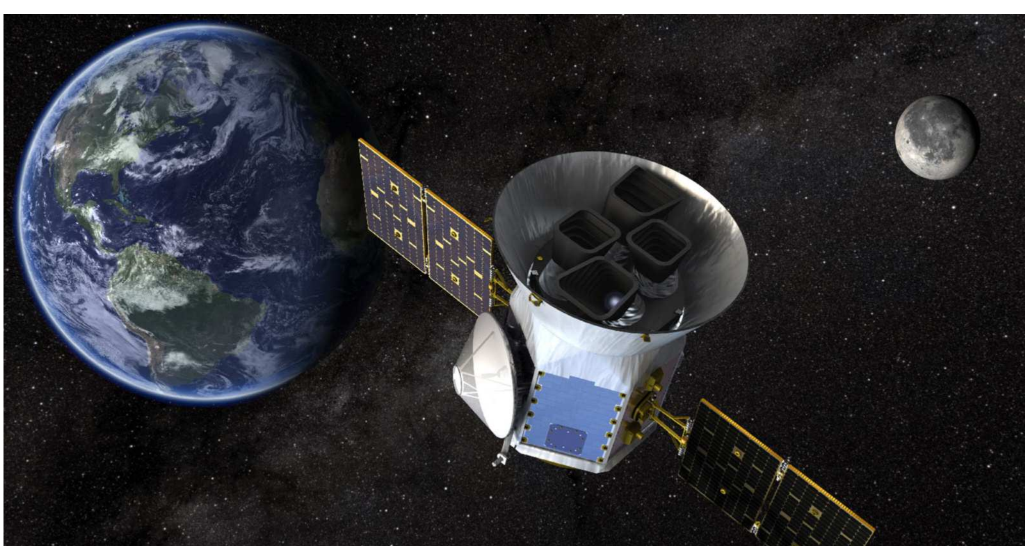
Graphical representation of the structure of the Extremely Large Telescope. When this gigantic instrument enters service (perhaps in 2025), it will be the flagship telescope in the search for life on other planets. [ESO/H. Zodet]



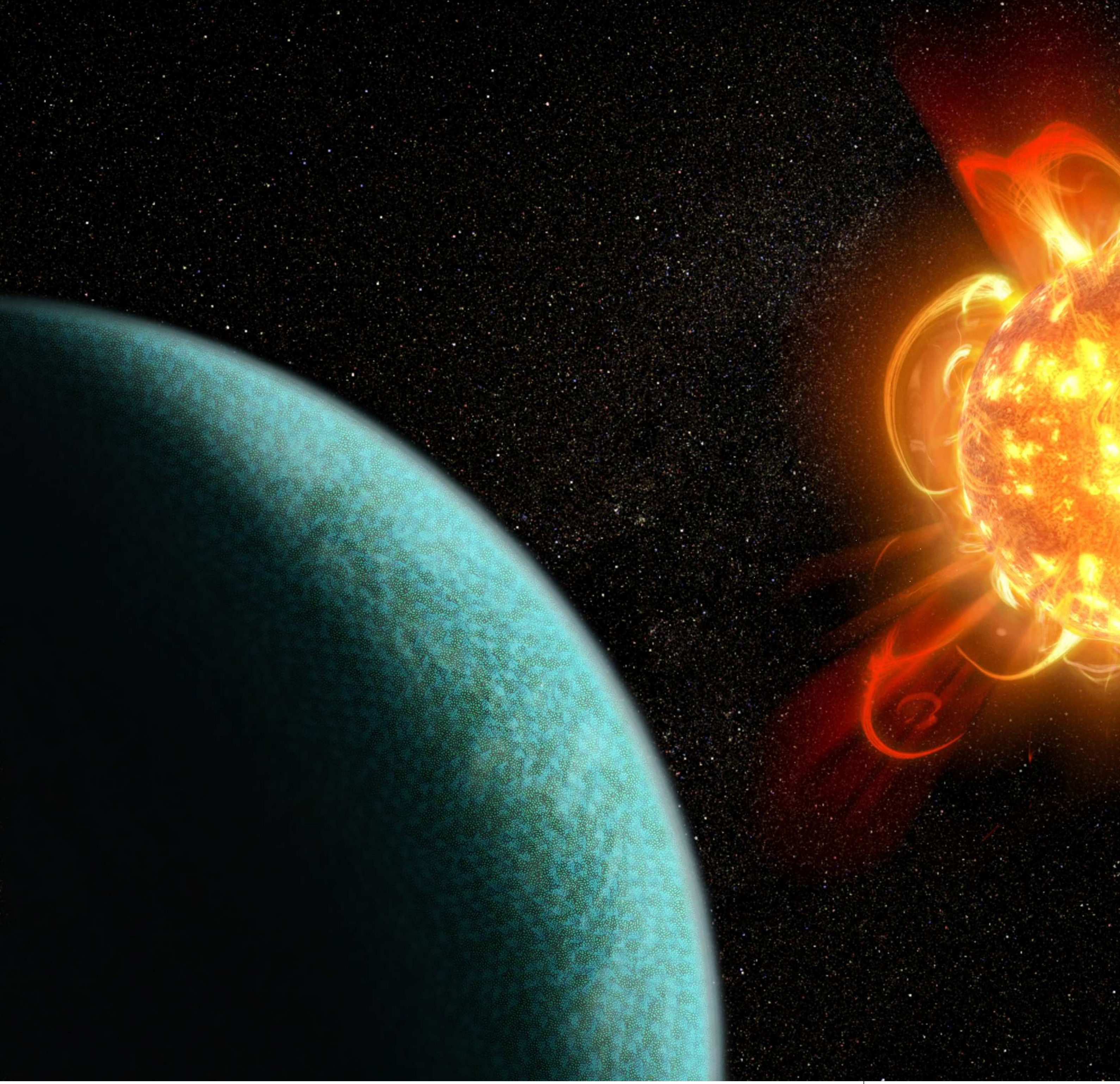
The James Webb Space Telescope, slated to launch in March 2021, will be the most powerful instrument available in the search from space of biosignatures originating in other planetary systems. [NASA]

It is, in fact, known that red dwarfs show violent surface activity for several billion years after their birth, an activity that manifests itself with frequent flares that pour high-energy UV radiation (in addition to less abundant X-rays) into their surrounding space, well beyond their habitable zones. As red dwarfs age, explosive activity decreases significantly but remains, on average, higher than that of the Sun. We know very little about the atmospheres of planets orbiting red dwarfs, but we can infer that the intense and prolonged stellar radiation can erode them so deeply as to generate a surface environment totally unsuitable for the appearance of life as we know it. We cannot, however, ever rule out the existence of lifeforms able to adapt to those environments inhospitable to us.

Among those who support this hypothesis are Lisa Kaltenegger and Jack T. O'Malley-James (Carl Sagan Institute, Cornell University, Ithaca NY). For some years now, these two researchers have developed a very tantalizing hypothesis (published in several articles in the *Monthly Notices of the Royal Astronomical Society*), according to which planets might exist around red dwarfs with lifeforms capable of defending themselves from UV rays that reach the surface, and these defense mechanisms could possibly be used by us to recognize their existence from Earth. When, about 3.9 billion years ago, the processes that led to the appearance of life began on our planet, UV fluxes reaching the ground were more intense than those which typically reach the habitable zones of red dwarfs. Nonetheless, life blossomed. If we add to this that, according to recent studies, UV radiation would be necessary for prebiotic chemistry, the work



The Transiting Exoplanets Survey Satellite, the successor to the Kepler Space Telescope, has the task of discovering new candidate Earth-sized planets orbiting the habitable zones of their stars. [NASA]

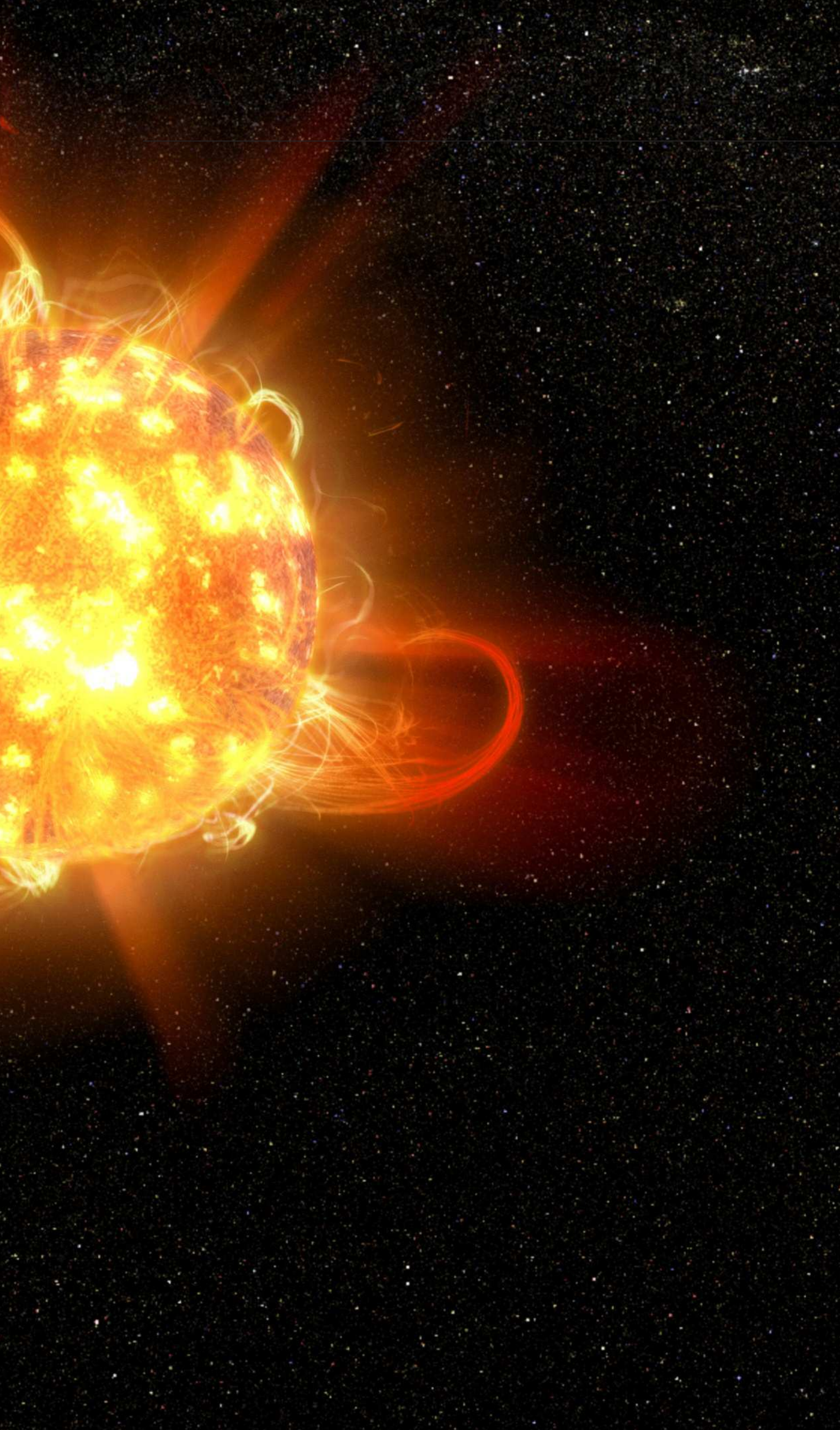


of the two Cornell researchers becomes even more relevant. We already know that lifeforms would be able to survive and perhaps proliferate in a hostile environment, such as that on Mars (where UV rays continuously hit the surface), simply by sheltering under rocks or within the ravines along the surface. That said, such lifeforms are not remotely detectable.

What Kaltenegger and O'Malley-James propose is something different – something visible from Earth.

Let's suppose that, in the habitable zones of some nearby red dwarfs, there are planets that have managed to maintain a sufficiently thick atmosphere (observations go in this direction) to prevent possible surface oceans from evaporating completely. In this case, there could be aquatic lifeforms that defend themselves from UV rays just by remaining immersed and reacting through biofluorescence to that part of the incoming radiation not shielded by the water. Biofluorescence is a mechanism by which

In this illustration, flares from a red dwarf activate the biofluorescence of lifeforms that cover the shallow ocean floors of a planet, elevating the planet-star contrast. [adapted from NASA image]



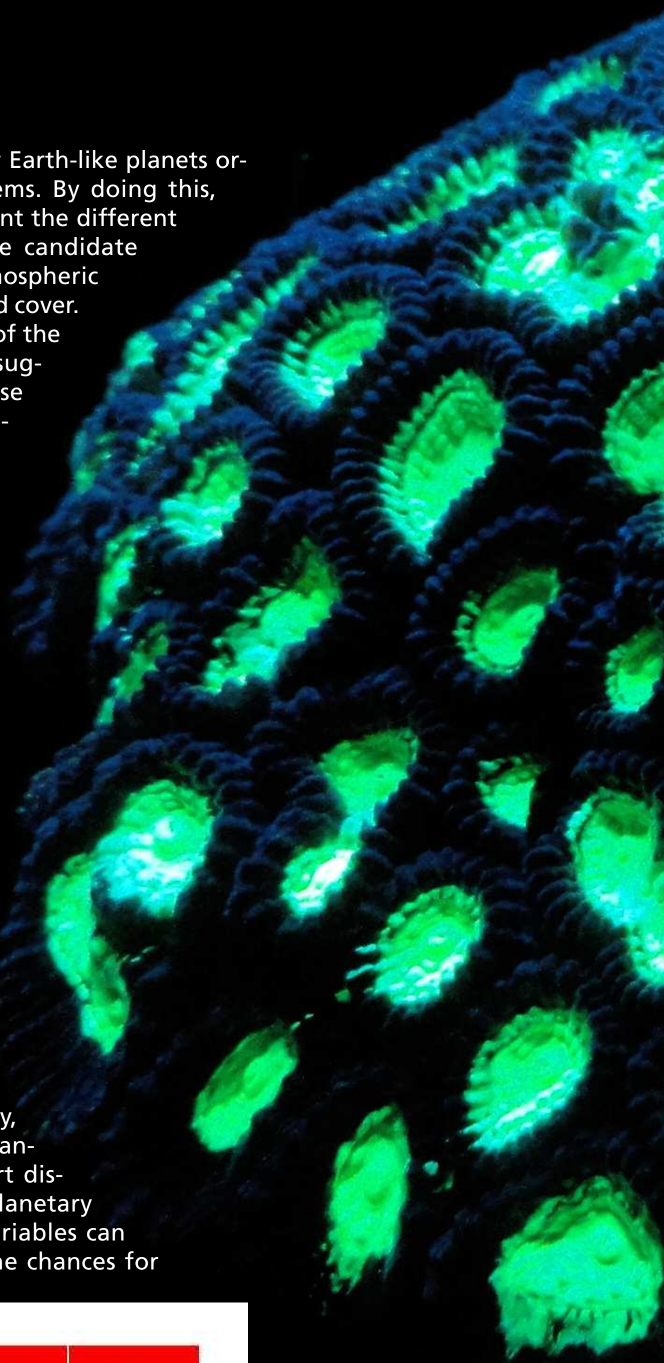
Right, Lisa Kaltenegger and Jack T. O'Malley-James, the two researchers from the Carl Sagan Institute who, for some years, have been considering the possibility of discovering fluorescent extraterrestrial life.

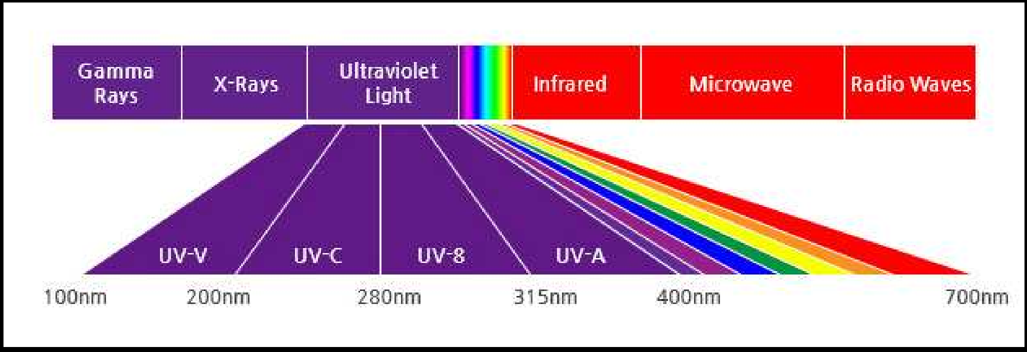
certain organisms prevent or mitigate the harmful effects caused by the most energetic radiation that reaches the Earth's surface. To do this, these organisms use particular proteins and pigments as anti-UV screens. The task of these biological screens is to absorb UV light and to almost instantly re-emit radiation at longer wavelengths, dissipating any residual energy in the form of heat. In an aquatic environment with shallow waters, biofluorescence might also play a crucial role in keeping the planets of the red dwarfs inhabited, even if their atmospheres have been depleted by stellar activity. Very extensive colonies of biofluorescent organisms could defend against UV fluxes produced by stellar flares through the production of visible radiation, thus causing a temporary increase in the brightness of the planetary surface.

Since biofluorescence would solely be correlated with UV fluxes triggered by solar flares and independent of the visible light fluxes from the star, the planet-star contrast could increase significantly in the visible spectrum compared to any non-biofluorescent state. On the emerged surface of the Earth, the biofluorescence of vegetation produces an effect that can be detected from orbit but is too weak to be recognized from another planetary system. More interesting is the biofluorescence produced in shallow ocean floors by corals and organisms in symbiosis with them. The fluorescence efficiency of these aquatic biological structures is much higher than that of surface vegetation (some coral species re-emit more than 70% of the incident radiation) and high-resolution observations from orbit can distinguish the signals they emit. However, these are fractions of a percentage point of the total signal emitted by all atmospheric and surface biosignatures. This does not rule out that, on an Earth-like planet orbiting the habitable zone of a particularly active red dwarf, fluorescent lifeforms can proliferate and spread to the point of producing a signal observable from another planetary system.

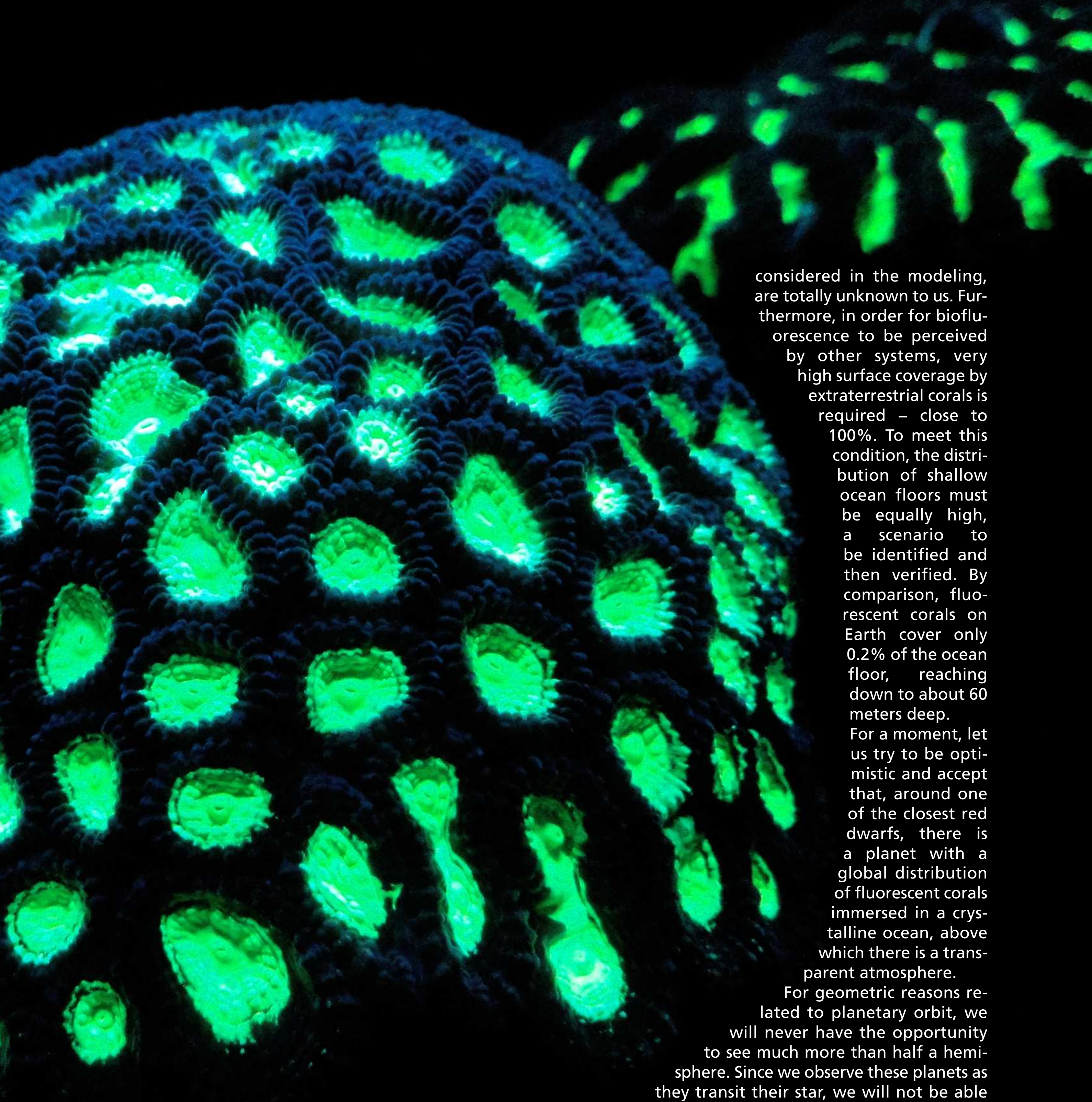
Kaltenegger and O'Malley-James investigated this possibility, modeling many scenarios based essentially on what we know about the fluorescence in coral structures and about the planets of some of the closest red dwarfs: Proxima Centauri, Ross 128, TRAPPIST-1, and LHS 1140. The two researchers used the emission and absorption properties of fluorescent proteins and pigments of common corals to create spectra and color models for Earth-like planets orbiting in these systems. By doing this, they took into account the different characteristics of the candidate planet's surface, atmospheric absorption, and cloud cover.

The most optimistic of the modeled scenarios suggests that, in the case of a transparent atmosphere, active biofluorescence could produce a temporary increase in visible spectrum brightness of two orders of magnitude over the planetary brightness during the non-fluorescing state. All this, however, is provided that the entire surface is covered by a biosphere characterized by highly-efficient fluorescent processes – an idealized scenario that is highly unlikely to be observed in reality, at least among exoplanets at relatively short distances from our planetary system. Countless variables can negatively impact the chances for





Spectral diagram showing the different types of UV rays and the colors visible to us. Aquatic fluorescent life reacts to the former by emitting visible light almost instantly.



An example of coral fluorescence, by which proteins absorb near-UV and blue light and re-emit light at longer wavelengths. [Monterey Bay Aquarium, California]

promising scenarios. We do not know, for example, whether biofluorescence can develop in biospheres other than our own on Earth, and we can only speculate on the existence of extraterrestrial coral structures. Even assuming their existence, the fluorescence efficiency of proteins and pigments of terrestrial corals depends on the environments in which they live, environments that, for planets around the red dwarfs considered in the modeling, are totally unknown to us. Furthermore, in order for biofluorescence to be perceived by other systems, very high surface coverage by extraterrestrial corals is required – close to 100%. To meet this condition, the distribution of shallow ocean floors must be equally high, a scenario to be identified and then verified. By comparison, fluorescent corals on Earth cover only 0.2% of the ocean floor, reaching down to about 60 meters deep.

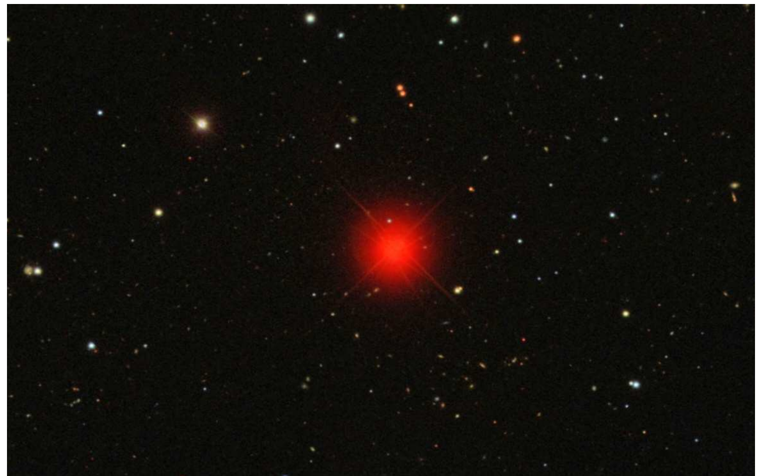
For a moment, let us try to be optimistic and accept that, around one of the closest red dwarfs, there is a planet with a global distribution of fluorescent corals immersed in a crystalline ocean, above which there is a transparent atmosphere.

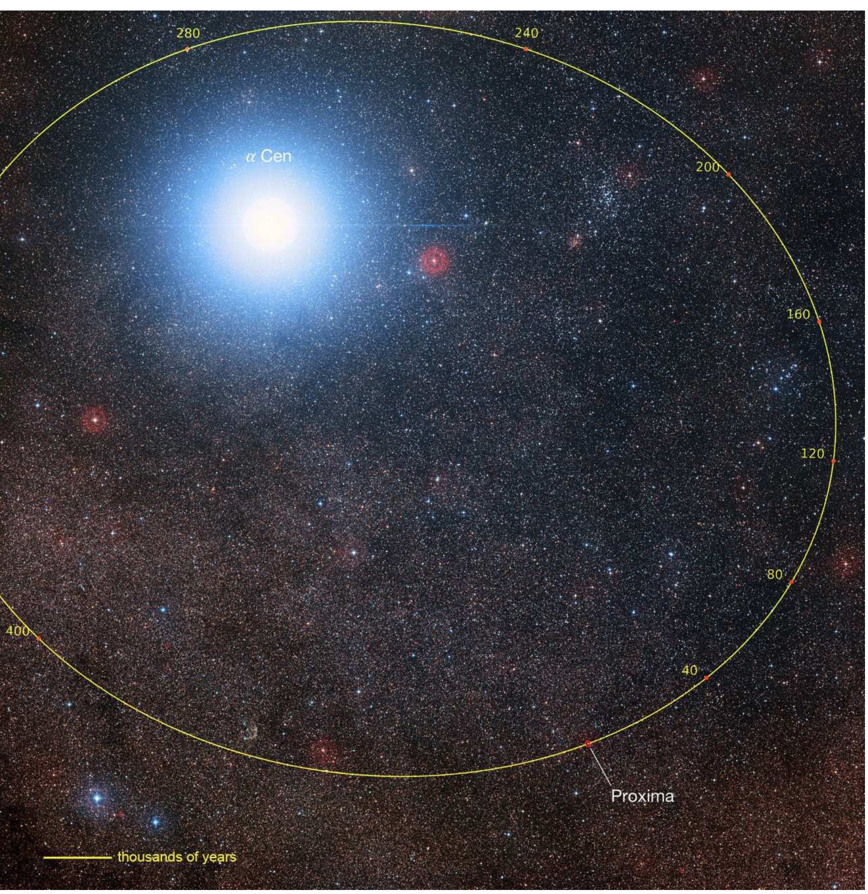
For geometric reasons related to planetary orbit, we will never have the opportunity to see much more than half a hemisphere. Since we observe these planets as they transit their star, we will not be able to see the surplus of light due to the biosphere either during the transit or half an orbit later, when the planet is either completely hidden or too close to the star to be observed separately. We can, in fact, hope to capture the light of the corals only near the maximum elongations of the planet – when only half of the lit hemisphere is facing us. According to the calculations of Kaltenegger and O'Malley-James, once biofluorescence is triggered by the UV radiation, the entire process might last a few hours, but the maximum peak (the reaction associated with the peak of the flare) would last only about a quarter of an hour, too short a time to hope to record an event that started with the planet near the conjunctions with the star.

Now that it is clear that we will be able to observe only half of the planetary hemisphere or a little more, it is necessary that the red dwarf be particularly active in order to have a greater chance of observing biofluorescence. Among those examined by the Cornell researchers, only Proxima Centauri and TRAPPIST-1 are considered active enough to guarantee at least some daily flares. Considering that only a small fraction of these flares will pour any UV flux on the part of the planetary surface visible from time to time from the Earth and that it is also not foreseeable when this might happen, it will not be easy for researchers to obtain with ELT and Webb a sufficient amount of time-telescope to observe the hypothetical biological signal.

Even while we want to be overly optimistic about the possibility of observing biofluorescence from exoplanets, there is an evolutionary characteristic of red dwarfs that poses a perhaps insurmountable challenge.

When these little stars go through their slow pre-main sequence phase, which can last up-to about 2 billion years, they are much brighter and warmer than they will be after reaching the main sequence, and this is because they are still contracting under their own gravity (a process that heats the core). Therefore, the planets we see today orbiting in the habitable zones of Proxima Centauri (almost 5 billion years), Ross 128 (about 10 billion years), TRAPPIST-1 (about 8 billion years),





Ross 128 above) and Proxima Centauri (with its orbit around Alpha Centauri, on the left) are two red dwarfs that host potentially habitable planets. They could be interesting targets to test the hypothesis of Kaltenegger and O'Malley-James. [Sloan Digital Sky Survey, P. Kervella (CNRS/U. of Chile/ Observatoire de Paris/LESIA), ESO/ DSS2, D. De Martin/M. Zamani]

The other two red dwarfs taken into consideration in the Kaltenegger and O'Malley-James models: LHS 1140 (in the center of the image on the right) and TRAPPIST-1 (below). [ESO, Sloan Digital Sky Survey]

LHS 1140 (over 5 billion years), and many other red dwarfs have all been subjected to extreme conditions in their first billion years, probably sufficient to make the planets sterile forever.

Let's add that, inevitably, the innermost planets of the aged red dwarfs have rotation and orbital periods tidally locked and, therefore, are always presenting the same hemisphere to their star, with easily imaginable consequences. That situation makes the prospects for finding any lifeforms unlikely, but it is true that exploiting biofluorescence may be the only way to discover life around the red dwarfs, which account for about 75 percent of known stars. We end with the conclusions of Kaltenegger and O'Malley-James, as reported in their article Lessons from early Earth: UV surface radiation should not limit the habitability of active M star systems: *"While a multitude of factors ultimately determine an individual planet's habitability, our results demonstrate that high UV radiation levels may not be a limiting factor. The compositions of the atmospheres of our nearest habitable exoplanets are currently unknown; however, if the atmospheres of these worlds resemble the composition of Earth's atmosphere through geological time, UV surface radiation would not be a limiting factor to the ability of these planets to host life. Even for planets with eroded or anoxic atmospheres orbiting active, flaring M stars the surface UV radiation in our models remains below that of the early Earth for all cases modelled. Therefore, rather than ruling these worlds out in our search for life, they provide an intriguing environment for the search for life and even for searching for alternative biosignatures that could exist under high-UV surface conditions."*

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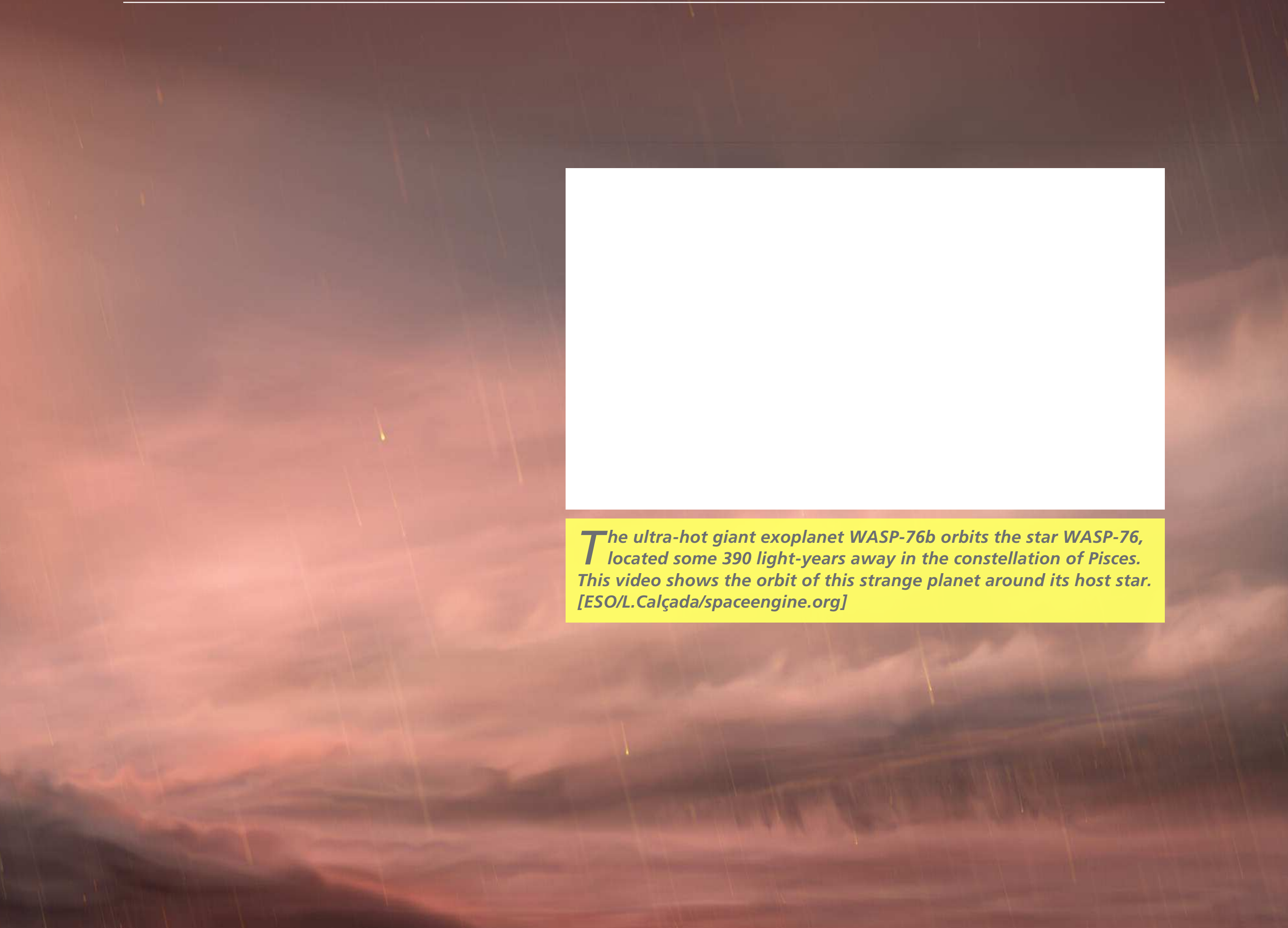
I N S T R U M E N T S - C O

ESO telescope observes exoplanet where it rains iron

by ESO

Researchers using ESO's Very Large Telescope (VLT) have observed an extreme planet where they suspect it rains iron. The ultra-hot giant exoplanet has a day side where temperatures climb above 2400 degrees Celsius, high enough to vaporise metals.
Strong winds carry iron vapour to the cooler night side where it condenses into iron droplets. *"One could say that this planet gets rainy in the evening, except it rains iron,"* says David Ehrenreich, a professor at the University of Geneva in Switzerland. He led a study, published today in the journal *Nature*, of this exotic exoplanet. Known as WASP-76b, it is located some 640 light-years away in the constellation of Pisces.
This strange phenomenon happens because the 'iron rain' planet only ever shows one face, its day side, to its parent star, its cooler night side remaining in perpetual darkness. Like the Moon on its orbit around the Earth, WASP-76b is 'tidally locked': it takes as long to rotate around its axis as it does to go around the star.
On its day side, it receives thousands of times more radiation from its parent star than the Earth does from the Sun. It's so hot that molecules separate into atoms, and metals like iron evaporate into the atmosphere. The extreme temperature difference between the day and night sides results in vigorous winds that bring the iron vapour from the ultra-hot day side to the cooler night side, where temperatures decrease to

This illustration shows a night-side view of the exoplanet WASP-76b. The ultra-hot giant exoplanet has a day side where temperatures climb above 2400 degrees Celsius, high enough to vaporise metals. Strong winds carry iron vapour to the cooler night side where it condenses into iron droplets. To the left of the image, we see the evening border of the exoplanet, where it transitions from day to night. [ESO/M. Kornmesser]



The ultra-hot giant exoplanet WASP-76b orbits the star WASP-76, located some 390 light-years away in the constellation of Pisces. This video shows the orbit of this strange planet around its host star. [ESO/L.Calçada/spaceengine.org]

around 1500 degrees Celsius. Not only does WASP-76b have different day-night temperatures, it also has distinct day-night chemistry, according to the new study. Using the new ESPRESSO instrument on ESO's VLT in the Chilean Atacama Desert, the astronomers identified for the first time chemical variations on an ultra-hot gas giant planet.

They detected a strong signature of iron vapour at the evening border that separates the planet's day side from its night side. *"Surprisingly, however, we do not see the iron vapour in the morning,"* says Ehrenreich. The reason, he says, is that *"it is raining iron on the night side of this extreme exoplanet."*

"The observations show that iron vapour is abundant in the atmosphere of the hot day side of WASP-76b," adds María Rosa Zapatero Osorio, an astrophysicist at the Centre for Astrobiology in Madrid, Spain, and the chair of the ESPRESSO science team. *"A fraction of this iron is injected into the night side owing to the planet's rotation and atmospheric winds. There, the iron encounters much cooler environments, condenses and rains down."*

This result was obtained from the very first science observations done with ESPRESSO, in September 2018, by the scientific consortium who built the instrument: a team from Portugal, Italy, Switzerland, Spain and ESO.

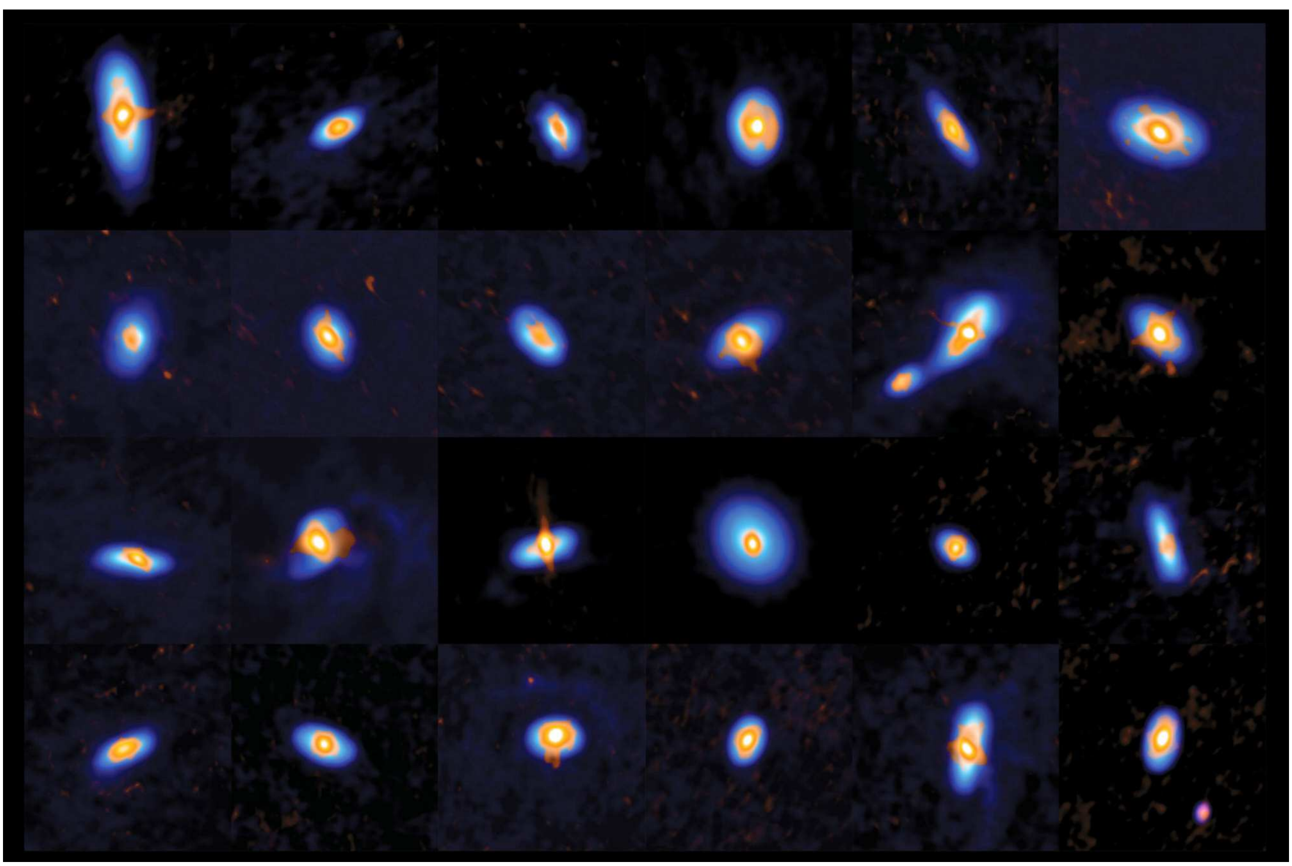
ESPRESSO — the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations — was originally designed to hunt for Earth-like planets around Sun-like stars. However, it has proven to be much more versatile. *"We soon realised that the remarkable collecting power of the VLT and the extreme stability of ESPRESSO made it a prime machine to study exoplanet atmospheres,"* says Pedro Figueira, ESPRESSO instrument scientist at ESO in Chile. *"What we have now is a whole new way to trace the climate of the most extreme exoplanets,"* concludes Ehrenreich.

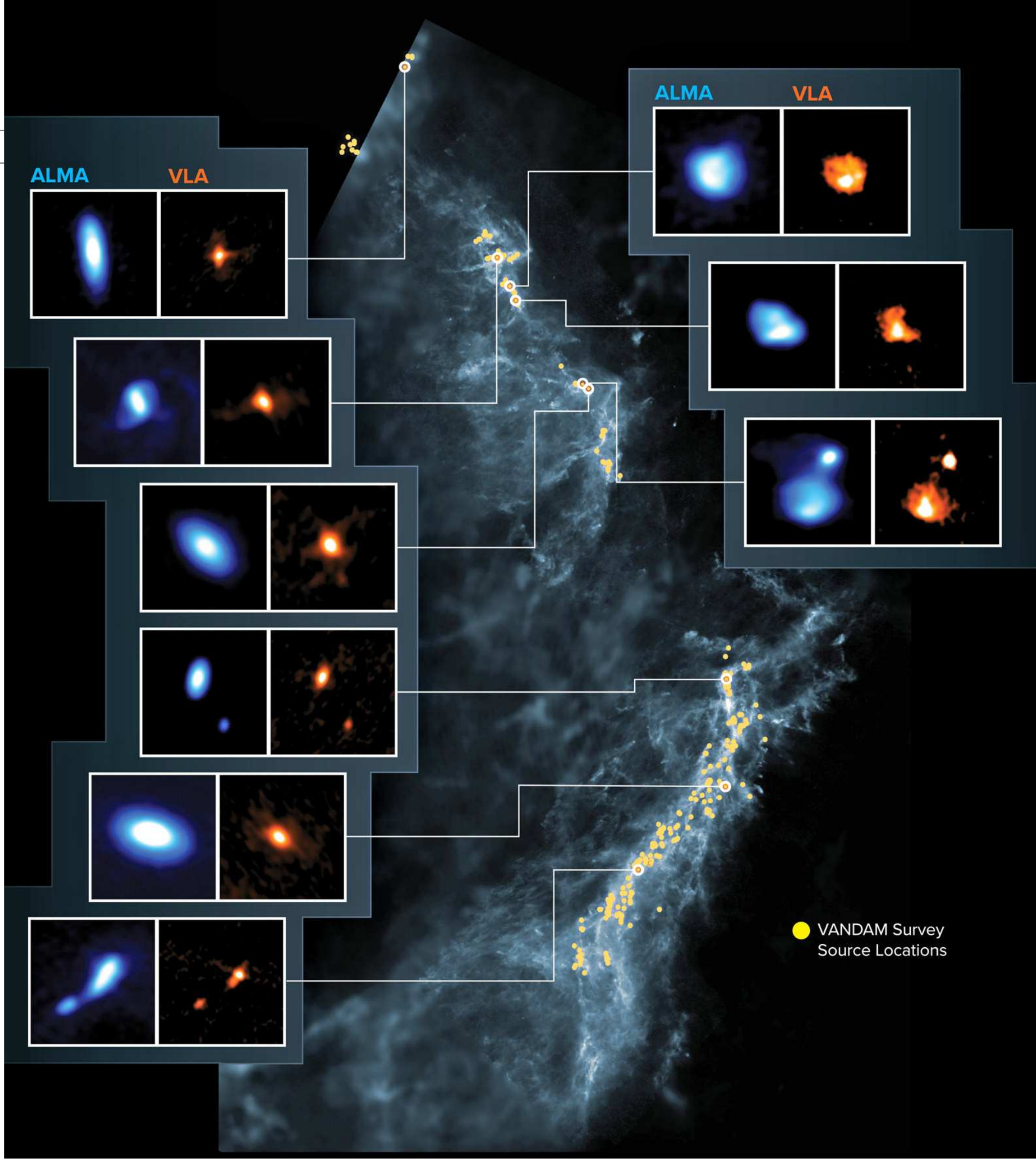
How newborn stars prepare for the birth of planets

by ALMA Observatory

An international team of astronomers used two of the most powerful radio telescopes in the world to create more than three hundred images of

ALMA and the VLA observed more than 300 protostars and their young protoplanetary disks in Orion. This image shows a subset of stars, including a few binaries. The ALMA and VLA data compliment each other: ALMA sees the outer disk structure (visualized in blue), and the VLA observes the inner disks and star cores (orange). [ALMA (ESO/NAOJ/NRAO), J. Tobin; NRAO/AUI/NSF, S. Dagnello; Herschel/ESA]





This image shows the Orion Molecular Clouds, the target of the VANDAM survey. Yellow dots are the locations of the observed protostars on a blue background image made by Herschel. Side panels show nine young protostars imaged by ALMA (blue) and the VLA (orange). [ALMA (ESO/NAOJ/NRAO), J. Tobin; NRAO/AUI/NSF, S. Dagnello; Herschel/ESA]

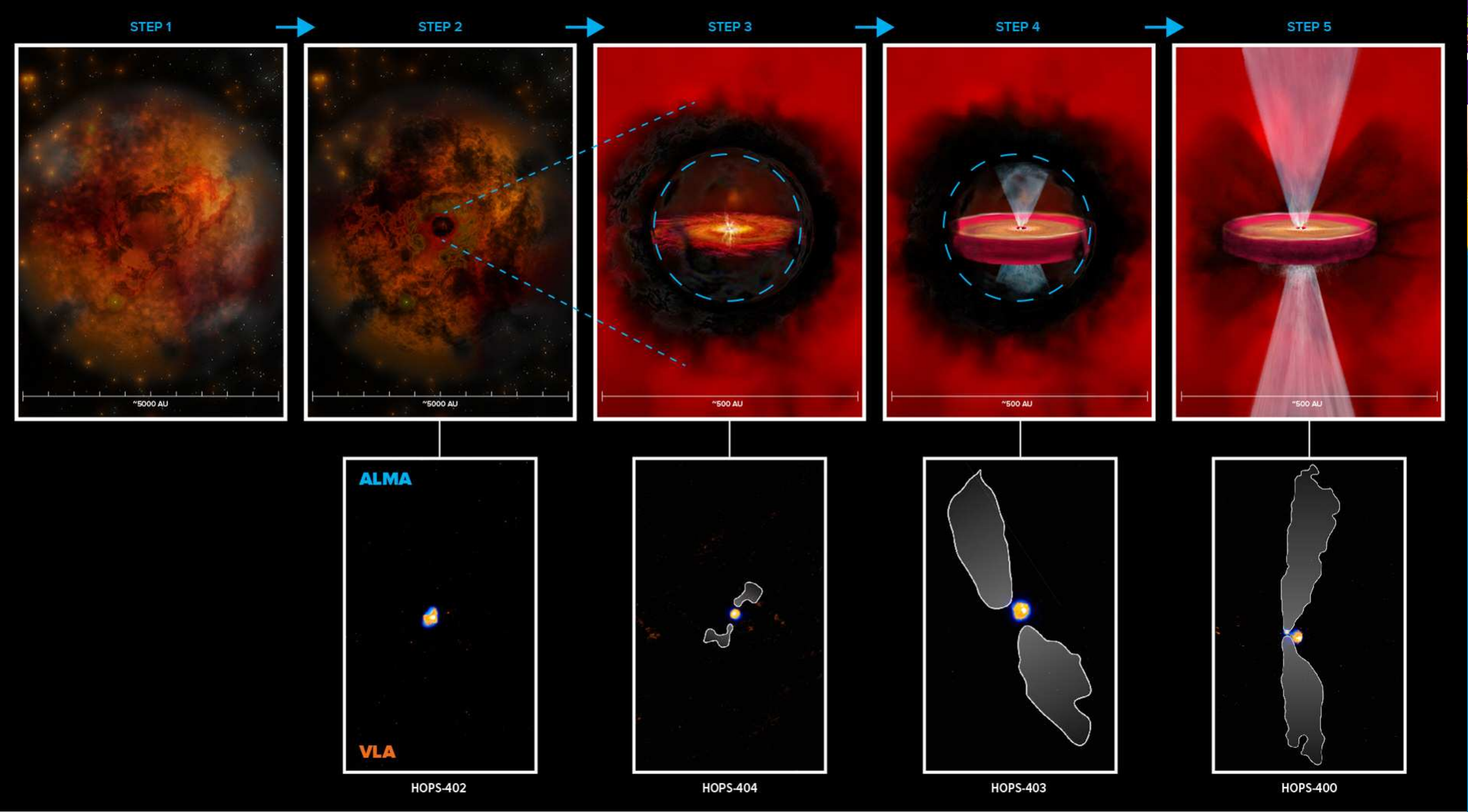
planet-forming disks around very young stars in the Orion Clouds. These images reveal new details about the birthplaces of planets and the earliest stages of star formation. Most of the stars in the Universe are accompanied by planets. These planets are born in rings of dust and gas, called protoplanetary disks. Even very young stars are surrounded by these disks. Astronomers want to know exactly when these disks start to form, and what they look like. But young stars are very faint, and there are dense clouds of dust and gas surrounding them in stellar nurseries. Only highly sensitive radio telescope arrays can spot the tiny disks around these infant stars amidst the densely packed material in these clouds. For this new research, astronomers pointed both the Atacama Large Millimeter/submillimeter Array (ALMA) and the National Science Foundation's Karl G. Jansky Very Large Array (VLA) to a region in space where many stars are born: the Orion Molecular Clouds. This survey, called VLA/ALMA Nascent Disk and Multiplicity (VANDAM), is the largest survey of young stars and their disks to date.

Very young stars, also called protostars, form in clouds of gas and dust in space. The first step in the formation of a star is when these dense clouds collapse due to gravity. As the cloud collapses, it begins to spin – forming a flattened disk around the protostar. Material from the disk continues to feed the star and make it grow. Eventually, the leftover material in the disk is expected to form planets.

Many aspects about these first stages of star formation, and how the disk forms, are still unclear. But this new survey provides some missing clues as the VLA and ALMA peered through the dense clouds and observed hundreds of protostars and their disks in various stages of their formation.

"This survey revealed the average mass and size of these very young protoplanetary disks," said John Tobin of the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia, and leader of the survey team. *"We can now compare them to older disks that have been studied intensively with ALMA as well."*

What Tobin and his team found, is that very young disks can be similar



This schematic shows a proposed pathway (top row) for the formation of protostars, based on four very young protostars (bottom row) observed by VLA (orange) and ALMA (blue). Step 1 represents the collapsing fragment of gas and dust. In step 2, an opaque region starts to form in the cloud. In step 3, a hydrostatic core starts to form due to an increase in pressure and temperature, surrounded by a disk-like structure and the beginning of an outflow. Step 4 depicts the formation of a class 0 protostar inside the opaque region, that may have a rotationally supported disk and more well-defined outflows. Step 5 is a typical class 0 protostar with outflows that have broken through the envelope (making it optically visible), an actively accreting, rotationally supported disk. In the bottom row, white contours are the protostar outflows as seen with ALMA. [ALMA (ESO/NAOJ/NRAO), N. Karnath; NRAO/AUI/NSF, B. Saxton and S. Dagnello]

in size, but are on average much more massive than older disks. *"When a star grows, it eats away more and more material from the disk. This means that younger disks have a lot more raw material from which planets could form. Possibly bigger planets already start to form around very young stars."*

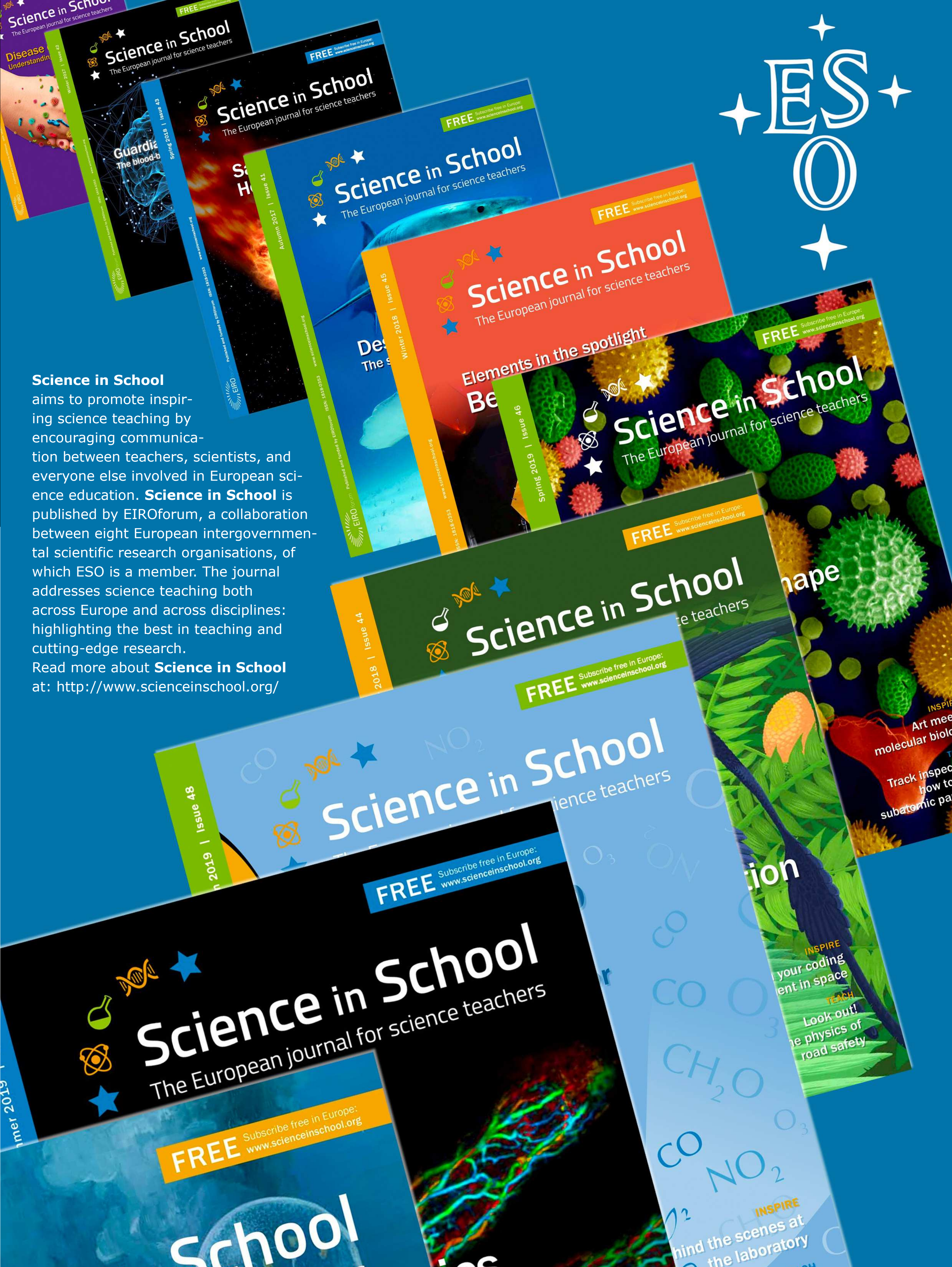
Among hundreds of survey images, four protostars looked different than the rest and caught the scientists' attention. *"These newborn stars looked very irregular and blobby,"* said team member Nicole Karnath of the University of Toledo, Ohio (now at SOFIA Science Center). *"We think that they are in one of the earliest stages of star formation and some may not even have formed into protostars yet."*

It is special that the scientists found four of these objects. *"We rarely find more than one such irregular object in one observation,"* added Karnath, who used these four infant stars to propose a schematic pathway for the earliest stages of star formation. *"We are not entirely sure how old they are, but they are probably younger than ten thousand years."*

To be defined as a typical (class 0) protostar, stars should not only have a flattened rotating disk surrounding them, but also an outflow – spewing away material in opposite directions – that clears the dense cloud surrounding the stars and makes them optically visible. This outflow is important, because it prevents stars from spinning out of control while they grow. But when exactly these outflows start to happen, is an open question in astronomy.

One of the infant stars in this study, called HOPS 404, has an outflow of only two kilometers (1.2 miles) per second (a typical protostar-outflow of 10-100 km/s or 6-62 miles/s). *"It is a big puffy sun that is still gathering a lot of mass, but just started its outflow to lose angular momentum to be able to keep growing,"* explained Karnath. *"This is one of the smallest outflows that we have seen and it supports our theory of what the first step in forming a protostar looks like."*

The exquisite resolution and sensitivity provided by both ALMA and the VLA were crucial to understand both the outer and inner regions of protostars and their disks in this survey. While ALMA can examine the dense dusty material around protostars in great detail, the images from the VLA made at longer wavelengths were essential to understand the inner structures of the youngest protostars at scales smaller than our solar system. *"The combined use of ALMA and the VLA has given us the best of both worlds,"* said Tobin. *"Thanks to these telescopes, we start to understand how planet formation begins."*



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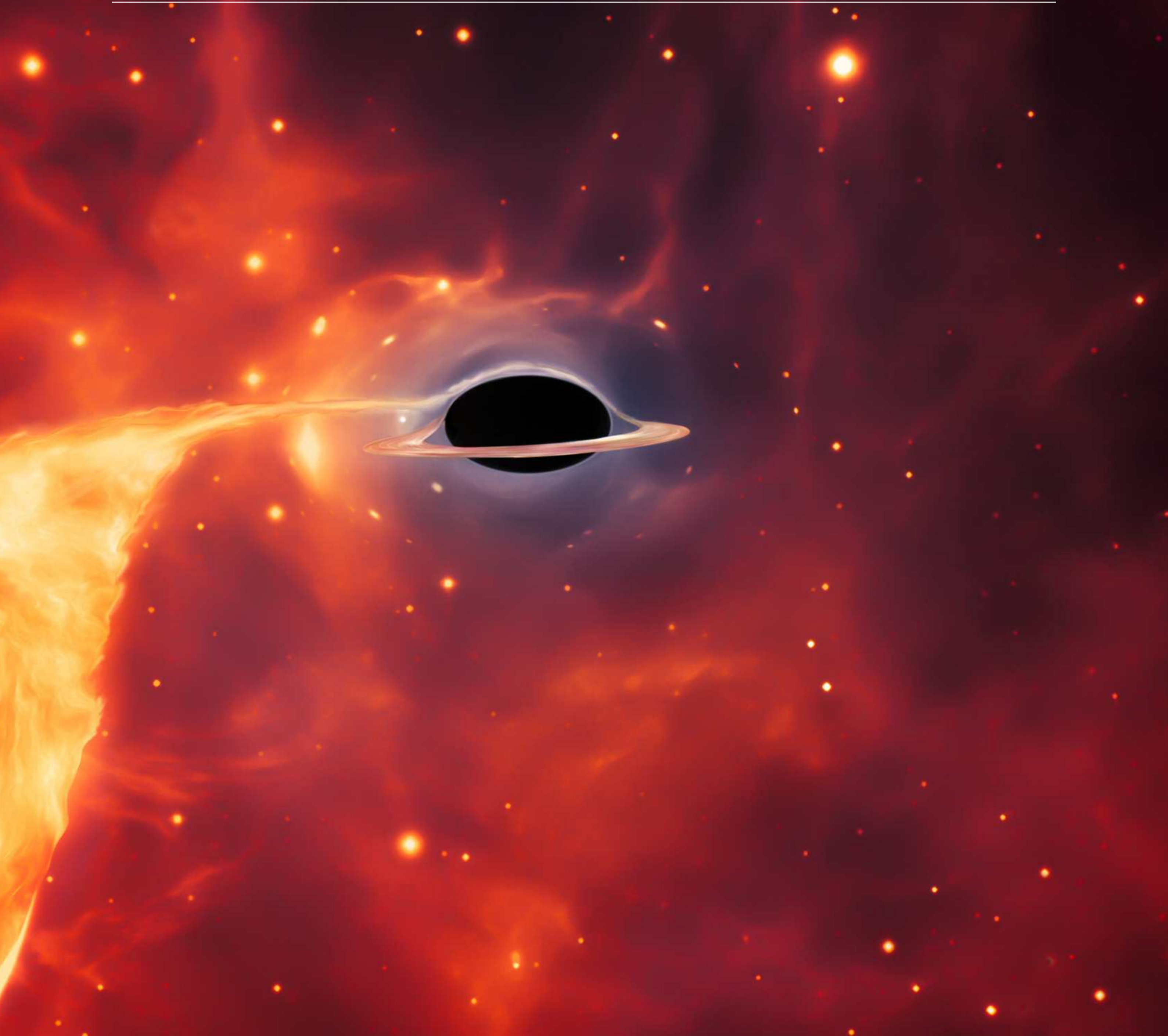
The best evidence for elusive mid-size black hole

by NASA/ESA

New data from the NASA/ESA Hubble Space Telescope have provided the strongest evidence yet for mid-sized black holes in the Universe. Hubble confirms that this "intermediate-mass" black hole dwells



This artist's impression depicts a star being torn apart by an intermediate-mass black hole (IMBH), surrounded by an accretion disc. This thin, rotating disc of material consists of the leftovers of a star which was ripped apart by the tidal forces of the black hole. [ESA/Hubble, M. Kornmesser]

inside a dense star cluster. Intermediate-mass black holes (IMBHs) are a long-sought "missing link" in black hole evolution. There have been a few other IMBH candidates found to date. They are smaller than the supermassive black holes that lie at the cores of large galaxies, but larger than stellar-mass black holes formed by the collapse of massive stars. This new black hole is over 50,000 times the mass of our Sun.

IMBHs are hard to find. *"Intermediate-mass black holes are very elusive objects, and so it is critical to carefully consider and rule out alternative explanations for each candidate. That is what Hubble has allowed us to do for our candidate,"* said Dacheng Lin of the University

of New Hampshire, principal investigator of the study.

Lin and his team used Hubble to follow up on leads from NASA's Chandra X-ray Observatory and the European Space Agency's X-ray Multi-Mirror Mission (XMM-Newton), which carries three high-throughput X-ray telescopes and an optical monitor to make long uninterrupted exposures providing highly sensitive observations.

Wide-field image around the field of J2150–0551 (ground-based view), in which an intermediate-mass black hole named 3XMM J215022.4–055 108 has been detected. [NASA, ESA, Digitized Sky Survey 2. Acknowledgement: Davide De Martin]

"Adding further X-ray observations allowed us to understand the total energy output," said team member Natalie Webb of the Université de Toulouse in France. *"This helps us to understand the type of star that was disrupted by the black hole."*

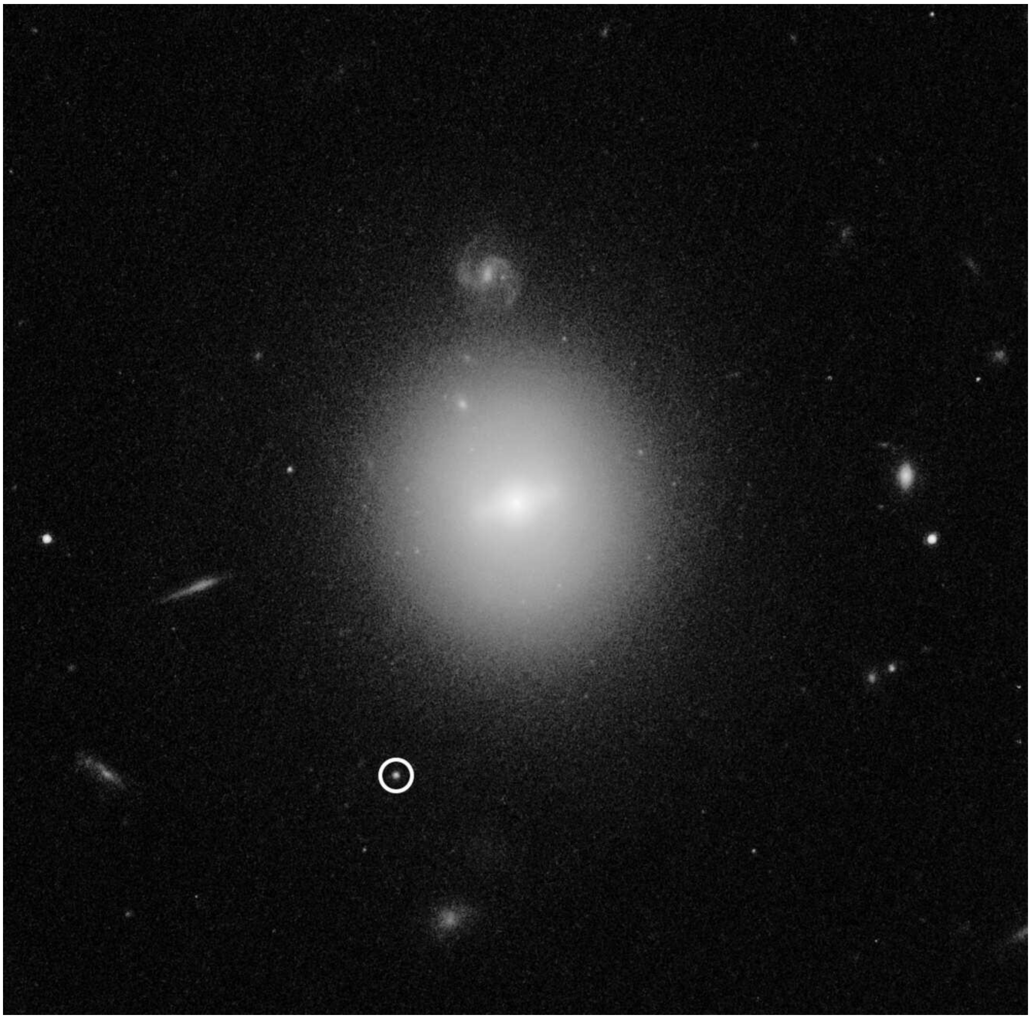
In 2006 these high-energy satellites detected a powerful flare of X-rays, but it was not clear if they originated from inside or outside of our galaxy. Researchers attributed it to a star being torn apart after coming too close to a gravitationally powerful compact object, like a black hole.

This is an animation of a rare and exotic intermediate-mass black hole at the centre of a star cluster, similar to the one thought to be at the centre of globular cluster Messier 15. Studying these unusual black holes could tell us about how such objects grow and evolve within both star clusters and galaxies. [NASA, ESA, and M. Kornmesser]

Surprisingly, the X-ray source, named 3XMM J215022.4–055108, was not located in the centre of a galaxy, where massive black holes normally reside. This raised hopes that an IMBH was the culprit, but first another possible source of the X-ray flare had to be ruled out: a neutron star in our own Milky Way galaxy, cooling off after being heated to a very high temperature. Neutron stars are the extremely dense remnants of an exploded star. Hubble was pointed at the X-ray source to resolve its precise location.

Deep, high-resolution imaging confirmed that the X-rays emanated not from an isolated source in our galaxy, but instead in a distant, dense star cluster on the outskirts of another galaxy — just the sort of place astronomers expected to find evidence for an IMBH. Previous Hubble research has shown that the more massive the galaxy, the more massive its black hole. Therefore, this new result suggests that the star cluster that is home to 3XMM J215022.4–055108 may be the stripped-down core of a lower-mass dwarf galaxy that has been gravitationally and tidally disrupted by its close interactions with its current larger galaxy host.

IMBHs have been particularly difficult to find because they are smaller and less active than supermassive black holes; they do not have readily available sources of fuel, nor do they have a gravitational pull that



This Hubble Space Telescope image identified the location of an intermediate-mass black hole (IMBH), weighing over 50,000 times the mass of our Sun (making it much smaller than the supermassive black holes found in the centres of galaxies). The location of the black hole, named 3XMM J215022.4– 055108, is indicated by the white circle. This elusive type of black hole was first identified via a telltale burst of X-rays emitted by hot gas from a star as it was captured and destroyed by the black hole. Hubble was needed to pinpoint the black hole's location in visible light. Hubble's deep, high-resolution imaging shows that the black hole resides inside a dense cluster of stars that is far beyond our Milky Way galaxy. The star cluster is in the vicinity of the galaxy at the centre of the image. Much smaller images of distant background galaxies appear sprinkled around the image, including a face-on spiral just above the central foreground galaxy. This photo was taken with Hubble's Advanced Camera for Surveys. [NASA, ESA, and D. Lin (University of New Hampshire)]

is strong enough for them to be constantly drawing in stars and other cosmic material and producing the tell-tale X-ray glow. Astronomers therefore have to catch an IMBH red-handed in the relatively rare act of gobbling up a star. Lin and his colleagues combed through the XMM-Newton data archive, searching hundreds of thousands of sources to find strong evidence for this one IMBH candidate.

Once found, the X-ray glow from the shredded star allowed astronomers to estimate the black hole's mass.

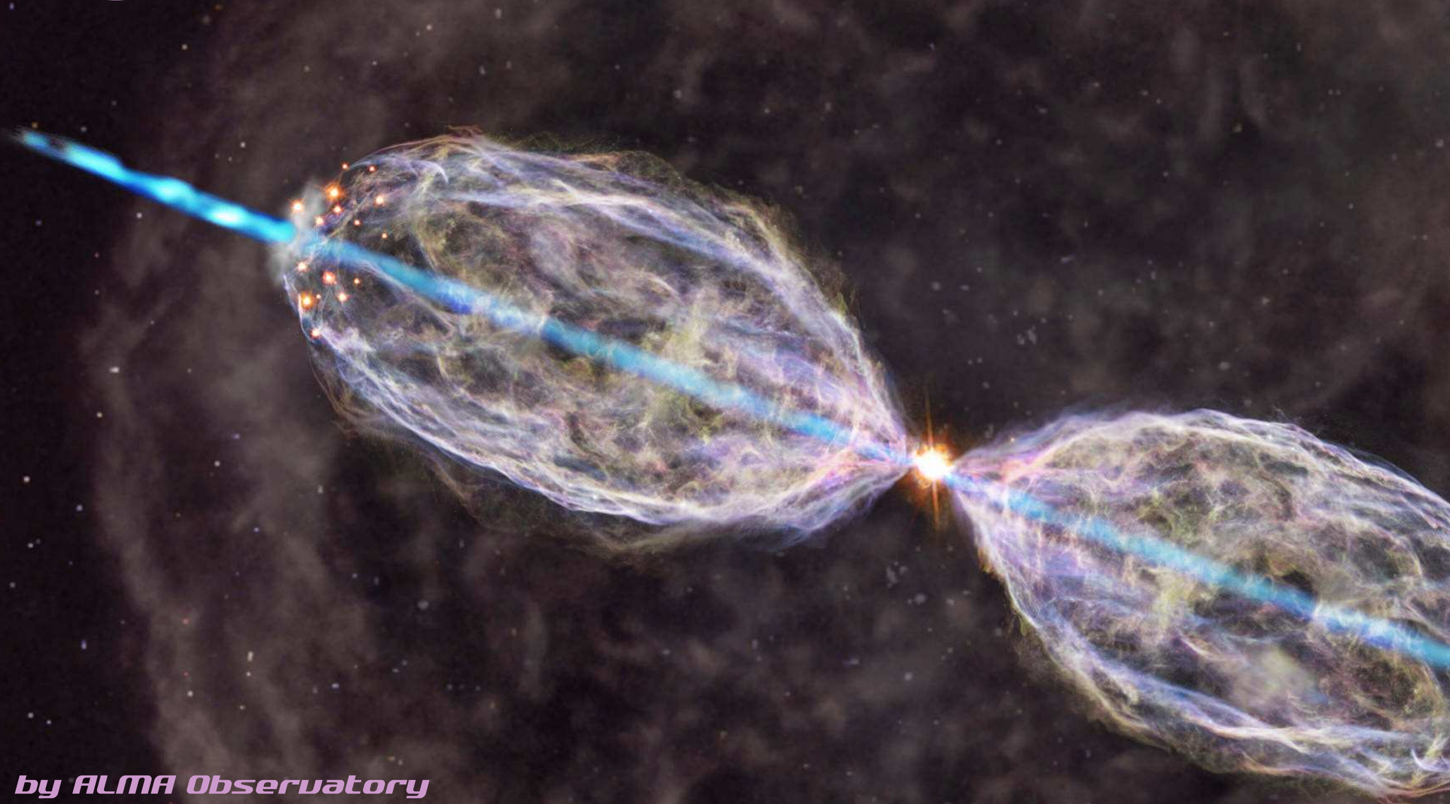
Confirming one IMBH opens the door to the possibility that many more lurk undetected in the dark, waiting to be given away by a star passing too close.

Lin plans to continue this meticulous detective work, using the methods his team has proved successful.

"Studying the origin and evolution of the intermediate mass black holes will finally give an answer as to how the supermassive black holes that we find in the centres of massive galaxies came to exist," added Webb.

Black holes are one of the most extreme environments humans are aware of, and so they are a testing ground for the laws of physics and our understanding of how the Universe works. Does a supermassive black hole grow from an IMBH? How do IMBHs themselves form? Are dense star clusters their favoured home? With a confident conclusion to one mystery, Lin and other black hole astronomers find they have many more exciting questions to pursue. ■

ALMA spots metamorph aged star



by ALMA Observatory

An international team of astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) captured the very moment when an old star first starts to alter its environment. The star has ejected high-speed bipolar gas jets which are now colliding with the surrounding material; the age of the observed jet is estimated to be less than 60 years. These are key features to understand how the complex shapes of planetary nebulae are formed. Sun-like stars evolve to puffed-up Red Giants in the final stage of their lives. Then, the star expels gas to form a remnant called a planetary nebula. There is a wide variety in the shapes of planetary nebulae; some are spherical, but others are bipolar or show complicated structures. Astronomers are interested in the origins of this variety, but the thick dust and gas expelled by an old star obscure the system and make it difficult to investigate the inner-workings of the process. To tackle this problem, a team of astronomers led by Daniel Tafoya in Chalmers University of Technology, Sweden, pointed ALMA at W43A, an old star system in the constellation Aquila, the Eagle.

Thanks to ALMA's high resolution, the team obtained a very detailed view of the space around W43A. *"The most notable structures are its small bipolar jets,"* says Tafoya, the lead author of the research paper

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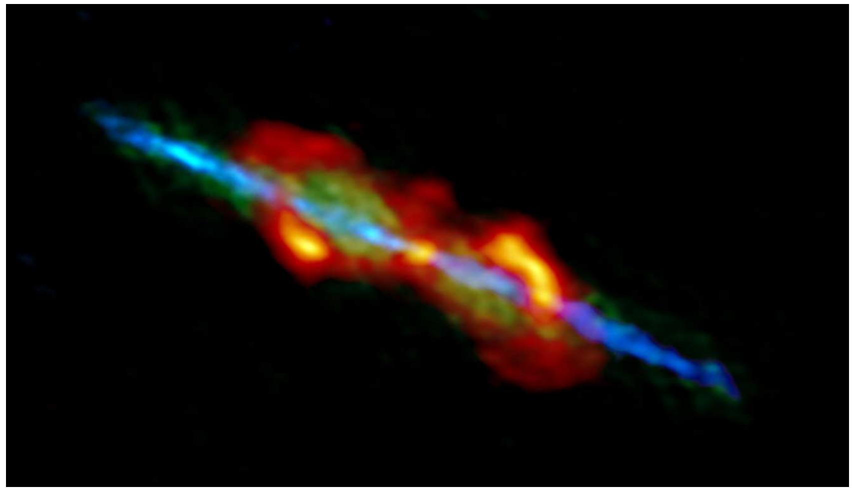

ALMA image of the old star system W43A. The high velocity bipolar jets ejected from the central aged star are seen in blue, low velocity outflow is shown in green, and dusty clouds entrained by the jets are shown in orange. [ALMA (ESO/NAOJ/NRAO), Tafoya et al.]

Artist's impression of W43A based on the ALMA observation results. Diffuse spherical gas was emitted from the star in the past. W43A has just started ejecting bipolar jets which entrain the surrounding material. Bright spots in radio emissions from water molecules are distributed around the interface of the jets and the diffuse gas. [NAOJ]

published by *The Astrophysical Journal Letters*. The team found that the velocity of the jets is as high as 175 km per second, which is much higher than previous estimations. Based on this speed and the size of the jets, the team calculated the age of the jets to be less than a human lifespan. *"Considering the youth of the jets compared to the overall lifetime of a star, it is safe to say we are witnessing the 'exact moment' that the jets have just started to shove through the surrounding gas,"* explains Tafoya. *"When the jets carve through the surrounding material in some 60 years, a single person can watch the progress in their life."*
In fact, the ALMA image clearly maps the distribution of dusty clouds entrained by the jets, which is telltale evidence that it is impacting on the surroundings.
The team assumes that this entrainment is the key to form a bipolar-shaped planetary nebula. In their scenario, the aged star originally ejects gas spherically and the core of the star loses its envelope. If the star has a companion, gas from the companion pours onto the core of the dying star, and a portion of this new gas forms the jets. Therefore, whether or not the old star has a companion is an important factor to determine the structure of the resulting planetary nebula.
"W43A is one of the peculiar so called 'water fountain' objects," says Hiroshi Imai at Kagoshima University, Japan, a member of the team.
"Some old stars show characteristic radio emissions from water molecules. We suppose that spots of these water emissions indicate the interface region between the jets and the surrounding material. We named them 'water fountains,' and it could be a sign that the central source is a binarity system launching a new jet."
"There are only 15 'water fountain' objects identified to date, despite the fact that more than 100 billion stars are included in our Milky Way Galaxy," explains José Francisco Gómez at Instituto de Astrofísica de Andalucía, Spain. *"This is probably because the lifetime of the jets is quite short, so we are very lucky to see such rare objects."* ■

Do sub-relativis meteors exist?

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

Estimates produced from satellite data and extrapolations from meteor falls indicate that, every day, a few to a few hundred tons of dust and rock enter the Earth's atmosphere from outer space. Nobody knows the precise amount, but it is assumed that all of that material formed in our own Solar System and therefore moves at a relatively slow speed. But is it really so?

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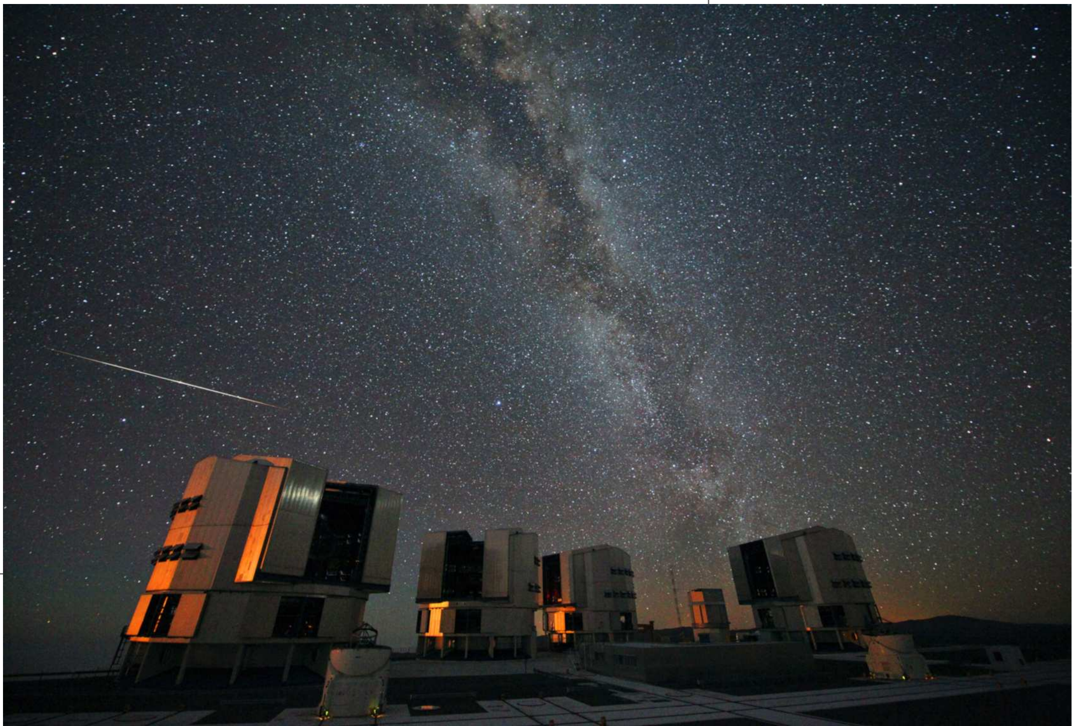
Meteor showers are certainly one of the best-known phenomena in the night sky. It is difficult to imagine that there are people who, in their lifetime, have not seen at least one "falling star" (but, sadly, those people probably do exist). The tradition of "making a wish" when a meteor is seen

While waiting for someone to photograph a sub-relativistic meteor, we present a running series of the most spectacular images of ordinary meteors, captured in the night skies of some famous astronomical observatories. Let's start with this one, taken in 2015 at ESO La Silla, which shows a multitude of different objects, including Comet Lovejoy. [P. Horálek/ESO]

falling is quite widespread, and it is by now a custom for amateur associations to organize public events on the occasion of the peaks of the most famous meteor showers.
Although they are familiar to almost everyone, and although astronomers and meteorologists know nearly everything about this phenomenon, there may be an exotic type of meteor that so far no one has ever seen: the sub-relativistic meteor. As you can guess from the name, the original meteoric material would travel through interstellar space at very high speed, measurable in non-negligible fractions of the speed of light (the conditional here is a must). Occasionally, very small agglomerations of this material would strike the atmosphere of our planet, producing effects different from those typically generated by ordinary meteors.

A bright meteor rushes over the Atacama Large Millimeter/sub-millimeter Array. [ESO/C. Malin, 2014] On the left, two Perseids in the vibrant sky of the Himalayan Chandra Telescope at 4500 meters elevation. The light from Mars is reflected in the dome. [Chirag Upreti, 2018] Below, another Perseid, captured this time in the night sky above the four Very Large Telescope domes. [ESO/ S. Guisard, 2010]



On the right, many Geminids photographed above the Teide Observatory, Tenerife, Canary Islands. [Flickr/StarryEarth, 2013] Below, a shower of Geminids, the sum of five hours of many exposures. In the foreground, the two principal domes of the Las Campanas Observatory. [Yuri Beletsky, Carnegie, TWAN, 2015]

This bizarre possibility was recently discussed in a paper published in The Astrophysical Journal by Amir Siraj and Abraham Loeb (Department of Astronomy, Harvard University, Cambridge, MA). The two researchers developed a hydrodynamic and radiative model to determine whether it is possible to detect sub-relativistic meteors generated by solid particles 1 mm in size or larger. The assumptions in Siraj and Loeb's study are reasonable based on the results of previous work. Back in the middle of the last century, Lyman Spitzer theoretically demonstrated that the radiation pressure of a supernova could accelerate dust grains to relativistic speeds. In the early 1970s, Satio Hayakawa had suggested that particles of such dust could be responsible for ultrahigh-energy cosmic rays. In the decades that have followed, other researchers further developed these topics, studying the processes that influence the origin and survival of relativistic dust, all the way to showing that, in our galaxy, there may exist dust grains that move at nearly the speed of light. We also have the certainty that, in the past, the Earth has been targeted by matter fired by the explosion of relatively close supernovae. Evidence of this is found in the enrichment of iron-60, discovered at the end of the last century in rocks within the depths of the Pacific Ocean. This radioactive iron isotope is formed in nature by the explosion of supernovae, has a half-life of 2.6 million years, and decays into cobalt-60 (which in turn decays much more rapidly into nickel-60). The abundance of iron-60 found in the first 2 cm of the ocean floor, corresponding to the last 13.4 million years, suggests that a supernova could have exploded less than 100 light-years away from Earth in the last 5 million years. It is estimated that, in the geological period covered by that thin layer of crust, twenty supernovae may have exploded within 1000 light-years of Earth. Although no other event has left clear traces, this frequency, extrapolated to the entire Milky Way, makes acceptable the hypothesis that interstellar space is crossed by a non-negligible quantity of very small agglomerations of matter endowed with sub-relativistic speeds. The value of the speed depends, of course, on the mass of matter accelerated by a given supernova. Currently, we do not know if, in the ejecta rain that supernovae pour into interstellar space, there are also solid particles more massive than the dust grains. In their study, Siraj and Loeb are optimistic in this regard, relying on the fact that concentrations of low-density ejecta have been observed in the remnants of several supernovae, which could at least in part be made up of the tiny solid bodies considered in the study.

The two researchers estimate that if just 0.01% of the dust ejected from a supernova were contained in particles measurable in millimeters, we could expect to observe, on average, one sub-relativistic meteor per month. This estimate takes into account the average supernovae rate estimated for the Milky Way (~1 every 50 years), the average mass of dust released by a supernova (~0.1 solar masses), and our distance from the galactic center (~26,000 light-years).

Siraj and Loeb have applied their model to hypothetical sub-relativistic meteoroids with diameters between 1 mm and 100 mm, which enter the atmosphere perpendicular to the surface and produce effects essentially starting from a height of 10 km. The researchers' goal was to track the evolution of the plasma generated by sub-relativistic meteors in order to determine what type of signal they might produce, then provide astronomers with information on what to look for. The results indicate that a large part of a meteoroid's energy would be released into the upper atmosphere and would feed the adiabatic expansion of a

A Perseid shower in the sky over the National Astronomical Observatory of Japan, the sum of images taken with the Moon illuminating the horizon. [NAOJ, 2017]

boiling plasma cylinder. In other words, the exceptionally high speed of the meteoroid would cause the column of air being passed through by the meteor to be instantly ionized along its entire length, but the surrounding pressure from the rest of the atmosphere would thermally isolate this column. There would, therefore, be no heat exchange with the gas outside the plasma cylinder, as is the case in ordinary meteors. Being much slower (20-30 km/s), ordinary meteors move slowly enough to allow cold air (ions and electrons again united) to reset behind them before the end of the glowing phenomenon. It is for this reason that we can appreciate the movement of the meteors through the sky.

In the case of sub-relativistic meteors, however, the speeds would be hundreds of times faster (thousands of km/s), the result being an instantaneous manifestation of the boiling plasma phenomenon along the entire meteor trajectory without the possibility of recognizing its beginning and end in the atmosphere. According to Siraj and Loeb, the duration of the event should not exceed one-tenth millisecond, but on the other hand, the brightness would be very high, comparable at least to that of a typical fire-

A swarm of Lyrids photographed above some structures of the Las Campanas Observatory, with the dome of the Optical Gravitational Lensing Experiment (OGLE) telescope in the foreground. [Y. Beletsky, Carnegie, TWAN, 2017] Alongside, several Geminids captured at the Kitt Peak National Observatory. In the foreground, the open dome of the Bok Telescope; just behind the dome of the Mayall telescope. [David A. Harvey, 2010]

A brilliant fireball photographed "near" the domes of the Observatoire de Saint-Véran, in the French Alps, near the Italian border, at almost 3000 meters elevation. [Mikael De Ketelaere, 2019] Below, the sum of many images showing a storm of over fifty Geminids above the Xinglong Observatory, China. [Steed Yu and NightChina.net]

ball. Potentially, the human eye can observe such a rapid and bright phenomenon, but no evidence of such an event has been recorded thus far.

The two researchers predict that a global network of several hundred small ultrafast optical detectors separated by distances of up to 1000 km (with a surface area of just 1 cm^2 each) would be sufficient to reveal any sub-relativistic meteors produced by 1 mm diameter particles. Even the shock wave generated in the atmosphere could be recorded with the help of infrasound microphones. A part of the structures necessary for this research already exist and it would be possible to implement their experimental design, but going beyond the theoretical phase might not be so simple. Indeed, there seem to be some critical issues in the conclusions reached by Siraj and Loeb.

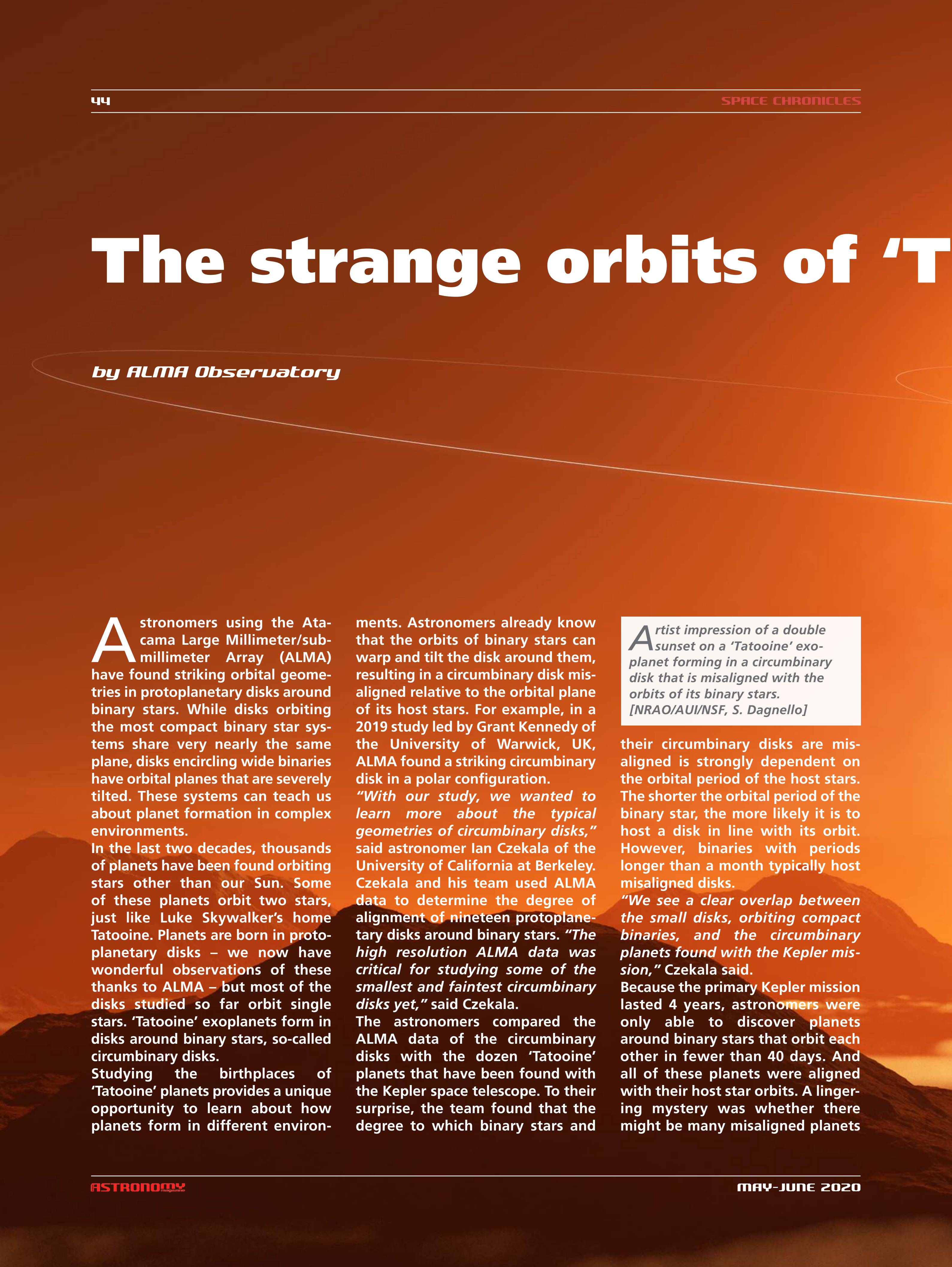
A first doubt concerns the extrapolation to macroscopic dimensions of phenomena that we know today only take place at the microscopic level, and therefore are based on different theoretical models. In this particular instance, iron-60 atoms, dust grains, and agglomerations of matter as large as a grain of sand can all be accelerated at extreme speeds by a supernova. That said, they remain very distant from one another on the size scale, with differences measurable in millions of times both in mass and in volume. To suggest that a grain of sand behaves like a grain of dust or an atom when subjected to the thrust of the explosion and radi-

A bright, green-toned meteor photographed above the La Silla Observatory, Chile. By magnifying the meteor wake, you can easily notice its sinuous shape, produced by the rotation of the meteoroid during the fall. [ESO/B. Tafreshi (twanight.org)]

ation pressure of a supernova is only a working hypothesis or little more.
A second doubt concerns the preservation of sub-relativistic speed by the grains with diameters on the order of 1 mm or larger. These grains would be mainly produced in the central regions of the galaxy, where the density of the interstellar medium exceeds by thousands of times the average density of one atom per cm^3 adopted to establish the potential frequency of sub-relativistic meteors. The doubt arises because a body of a certain mass, moving at very high speed in a medium, slows down significantly by coming into contact with a total mass of matter comparable to its own. Consequently, since only bodies of very small mass can be accelerated at relativistic or sub-relativistic speeds, and since these bodies decelerate rather quickly through a medium with relatively high density, the prediction of observing an average sub-relativistic meteor per month appears quite optimistic.
Another point of Siraj and Loeb's hypothesis that does not seem convincing is the apparent brightness of the sub-relativistic meteors. Their calculations show that if the progenitor body had a diameter of 1 mm, it could generate about a billion photons of visible light in 0.1 milliseconds, a much higher flow than that coming from the brightest stars in the sky. In the case of a meteoroid with a diameter of 10 mm, the brightness of the meteor produced could exceed 10 million times that of Vega. Finally, a body placed at the maximum limit of the size scale considered by the researchers, 100 mm, would produce a Sun-like flash.
To our knowledge, no one has ever reported observations of this kind – and one would imagine a record of such an event existing, considering that even the weakest flashes of light would still be much brighter than Venus.
And what about the atmospheric traces left by the passage of hyper-fast meteors? The authors of the study don't address this topic, but we can imagine that, for at least a few seconds or perhaps for a longer time, the section of the atmosphere affected by the phenomenon would be noticeably altered.

The strange orbits of ‘T

by ALMA Observatory



Artist impression of a double sunset on a ‘Tatooine’ exoplanet forming in a circumbinary disk that is misaligned with the orbits of its binary stars. [NRAO/AUI/NSF, S. Dagnello]

Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have found striking orbital geometries in protoplanetary disks around binary stars. While disks orbiting the most compact binary star systems share very nearly the same plane, disks encircling wide binaries have orbital planes that are severely tilted. These systems can teach us about planet formation in complex environments.

In the last two decades, thousands of planets have been found orbiting stars other than our Sun. Some of these planets orbit two stars, just like Luke Skywalker’s home Tatooine. Planets are born in protoplanetary disks – we now have wonderful observations of these thanks to ALMA – but most of the disks studied so far orbit single stars. ‘Tatooine’ exoplanets form in disks around binary stars, so-called circumbinary disks.

Studying the birthplaces of ‘Tatooine’ planets provides a unique opportunity to learn about how planets form in different environments. Astronomers already know that the orbits of binary stars can warp and tilt the disk around them, resulting in a circumbinary disk misaligned relative to the orbital plane of its host stars. For example, in a 2019 study led by Grant Kennedy of the University of Warwick, UK, ALMA found a striking circumbinary disk in a polar configuration.

***“With our study, we wanted to learn more about the typical geometries of circumbinary disks,”* said astronomer Ian Czekala of the University of California at Berkeley. Czekala and his team used ALMA data to determine the degree of alignment of nineteen protoplanetary disks around binary stars. *“The high resolution ALMA data was critical for studying some of the smallest and faintest circumbinary disks yet,”* said Czekala.**

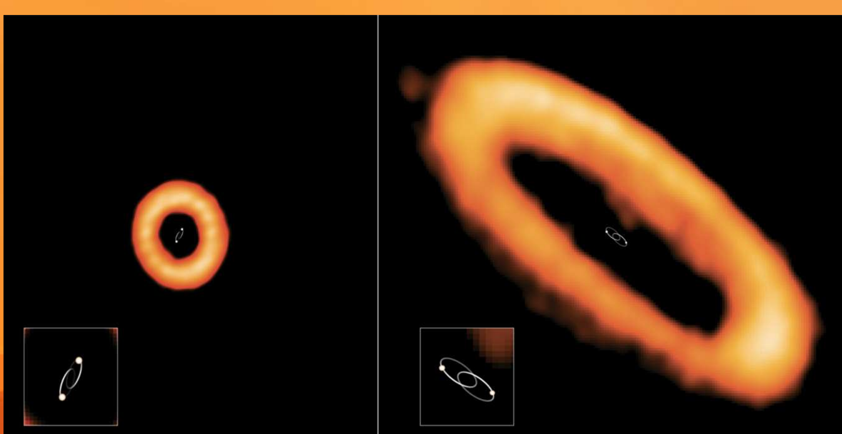
The astronomers compared the ALMA data of the circumbinary disks with the dozen ‘Tatooine’ planets that have been found with the Kepler space telescope. To their surprise, the team found that the degree to which binary stars and their circumbinary disks are misaligned is strongly dependent on the orbital period of the host stars. The shorter the orbital period of the binary star, the more likely it is to host a disk in line with its orbit. However, binaries with periods longer than a month typically host misaligned disks.

***“We see a clear overlap between the small disks, orbiting compact binaries, and the circumbinary planets found with the Kepler mission,”* Czekala said.**

Because the primary Kepler mission lasted 4 years, astronomers were only able to discover planets around binary stars that orbit each other in fewer than 40 days. And all of these planets were aligned with their host star orbits. A lingering mystery was whether there might be many misaligned planets

atooine' planetary disks

that Kepler would have a hard time finding. *"With our study, we now know that there likely isn't a large population of misaligned planets that Kepler missed, since circumbinary disks around tight binary stars are also typically aligned with their stellar hosts,"* added Czekala. Still, based on this finding, the astronomers conclude that misaligned planets around wide binary stars should be out there and that it would be an exciting population to search for with other exoplanet-finding methods like direct imaging and microlensing. (NASA's Kepler mission used the transit method, which is one of the ways to find a planet.)



Two examples of aligned and misaligned protoplanetary disks around binary stars (circumbinary disks), observed with ALMA. Binary star orbits are added for clarity. Left: in star system HD 98800 B, the disk is misaligned with inner binary stars. The stars are orbiting each other (in this view, towards and away from us) in 315 days. Right: in star system AK Sco, the disk is in line with the orbit of its binary stars. The stars are orbiting each other in 13.6 days. [ALMA (ESO/NAOJ/NRAO), I. Czekala and G. Kennedy; NRAO/AUI/NSF, S. Dagnello]

Czekala now wants to find out why there is such a strong correlation between disk (mis)alignment and the binary star orbital period. *"We want to use existing and coming facilities like ALMA and the next generation Very Large Array to study disk structures at exquisite levels of precision,"* he said, *"and try to understand how warped or tilted disks affect the planet formation environment and how this might influence the population of planets that form within these disks."*

"This research is a great example of how new discoveries build on previous observations," said Joe Pesce, National Science Foundation Program Officer for NRAO and ALMA. *"Discerning trends in the circumbinary disk population was only made possible by building on the foundation of archival observational programs undertaken by the ALMA community in previous cycles."*

The impact of satellite constellations on astronomical observations

by ESO

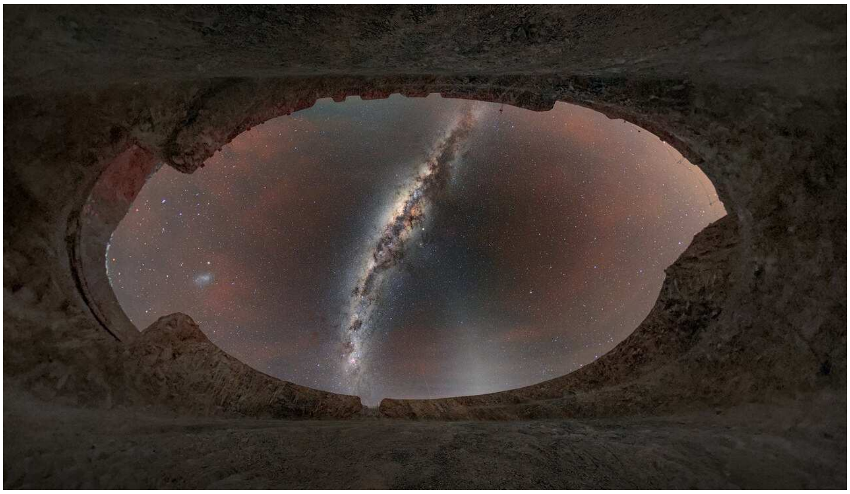
Astronomers have recently raised concerns about the impact of satellite mega-constellations on scientific research. To better understand the effect these constellations could have on astronomical observations, ESO commissioned a scientific study of their impact, focusing on observations with ESO telescopes in the visible and infrared but also considering other observatories. The study, which considers a total of 18 representative satellite constellations under development by SpaceX, Amazon, OneWeb and others, together amounting to over 26 thousand satellites, has now been accepted for publication in *Astronomy & Astrophysics*.

The study finds that large telescopes like ESO's Very Large Telescope (VLT) and ESO's upcoming Extremely Large Telescope (ELT) will be "moderately affected" by the constellations under development. The effect is more pronounced for long exposures (of about 1000 s), up to 3% of which could be ruined during twilight, the time between dawn and sunrise and between sunset and dusk. Shorter exposures would be less impacted, with fewer than 0.5% of observations of this type affected. Observations conducted at other times during the night would also be less affected, as the satellites would be in the shadow of the Earth and therefore not illuminated. Depending on the science case, the impacts could be lessened by making changes to the operating schedules of ESO telescopes, though these changes come at a cost. On the industry side, an effective step to mitigate impacts would be to darken the satellites.

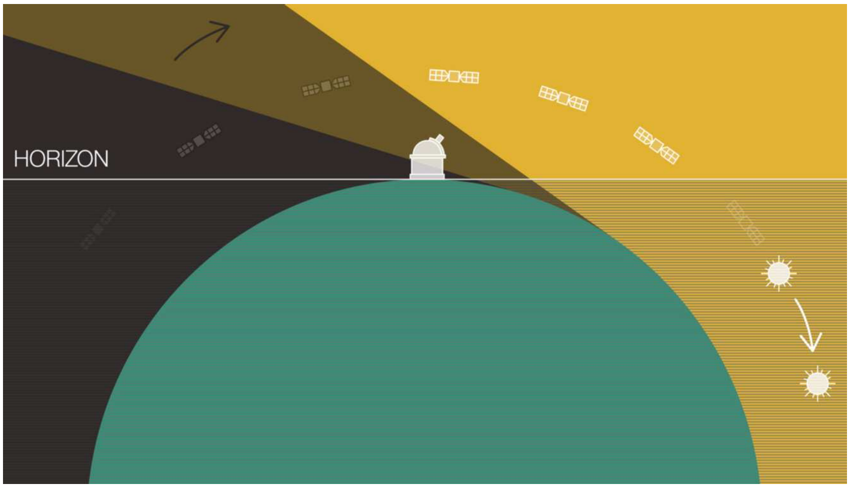
The study also finds that the greatest impact could be on wide-field surveys, in particular those done with large telescopes. For example, up to 30% to 50% of exposures with the US National Science Foundation's Vera C. Rubin Observatory (not an ESO facility) would be "severely affected", depending on the time of year, the time of night, and the simplifying assumptions of the study. Mitigation techniques that could be applied on ESO telescopes would not work for this observatory although other strategies are being actively explored. Further studies are required to fully understand the scientific implications of this loss of observational data and complexities in their analysis. Wide-field survey telescopes like the Rubin Observatory can scan large parts of the sky quickly, making them crucial to spot short-lived phenomena like supernovae or potentially dangerous asteroids. Because of their unique capability to generate very large data sets and to find observation targets for many other observatories, astronomy communities and funding agencies in Europe and else-

This annotated image shows the night sky at ESO's Paranal Observatory around twilight, about 90 minutes before sunrise. The blue lines mark degrees of elevation above the horizon. A new ESO study looking into the impact of satellite constellations on astronomical observations shows that up to about 100 satellites could be bright enough to be visible with the naked eye during twilight hours (magnitude 5–6 or brighter). The vast majority of these, their locations marked with small green circles in the image, would be low in the sky, below about 30 degrees elevation, and/or would be rather faint. Only a few satellites, their locations marked in red, would be above 30 degrees of the horizon — the part of the sky where most astronomical observations take place — and be relatively bright (magnitude of about 3–4). For comparison, Polaris, the North Star, has a magnitude of 2, which is 2.5 times brighter than an object of magnitude 3. The number of visible satellites plummets towards the middle of the night when more satellites fall into the shadow of the Earth, represented by the dark area on the left of the image. Satellites within the Earth's shadow are invisible. [ESO/Y. Beletsky/L. Calçada] where have ranked wide-field survey telescopes as a top priority for future developments in astronomy.

Professional and amateur astronomers alike have also raised concerns about how satellite mega-constellations could impact the pristine views of the night sky. The study shows that about 1600 satellites from the constellations will be above the horizon of an observatory at mid-latitude, most of which will be low in the sky — within 30 degrees of the horizon. Above this — the part of the sky where most astronomical observations take place — there will be about 250 constellation satellites at any given time. While they are all illuminated by the Sun at sunset and sunrise, more and more get into the shadow of the Earth toward the middle of the night. The ESO study assumes a brightness for all of these satellites. With this assumption, up to about 100 satellites could be bright enough to be visible with the naked eye during twilight hours, about 10 of which would be higher than 30 degrees of elevation. All these numbers plummet as the night gets darker and the satellites fall into the shadow of the Earth. Overall, these new satellite constellations would about double the number of satellites visible in the night sky to the naked eye above 30 degrees.



This image shows the night sky above the construction site of ESO's Extremely Large Telescope, which is planned to start operating in late 2025. A laser guide from the nearby Very Large Telescope is seen in the background. [ESO/M. Zamani]



This 2D diagram illustrates that an observer at mid-latitude would see only a fraction of the constellation satellites orbiting the Earth. To be visible, satellites need to be above the observer's horizon and be illuminated by the Sun. Most satellites would be below the horizon and/or hidden by the Earth's shadow which, for a given observer, covers increasingly more of the sky as night advances. [ESO/L. Calçada]

These numbers do not include the trains of satellites visible immediately after launch. Whilst spectacular and bright, they are short lived and visible only briefly after sunset or before sunrise, and — at any given time — only from a very limited area on Earth.

The ESO study uses simplifications and assumptions to obtain conservative estimates of the effects, which may be smaller in reality than calculated in the paper. More sophisticated modelling will be necessary to more precisely quantify the actual impacts. While the focus is on ESO telescopes, the results apply to similar non-ESO telescopes that also operate in the visible and infrared, with similar instrumentation and science cases.

Satellite constellations will also have an impact on radio, millimetre and submillimetre observatories, including the Atacama Large Millimeter/submillimeter Array (ALMA) and the Atacama Pathfinder Experiment (APEX). This impact will be considered in further studies.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ALMA and Rosetta map the journey of phosphorus

by ESO

Phosphorus, present in our DNA and cell membranes, is an essential element for life as we know it. But how it arrived on the early Earth is something of a mystery. Astronomers have now traced the journey of phosphorus from star-forming regions to comets using the combined powers of ALMA and the European Space Agency's probe Rosetta. Their research shows, for the first time, where molecules containing phosphorus form, how this element is carried in comets, and how a particular molecule may have played a crucial role in starting life on our planet.

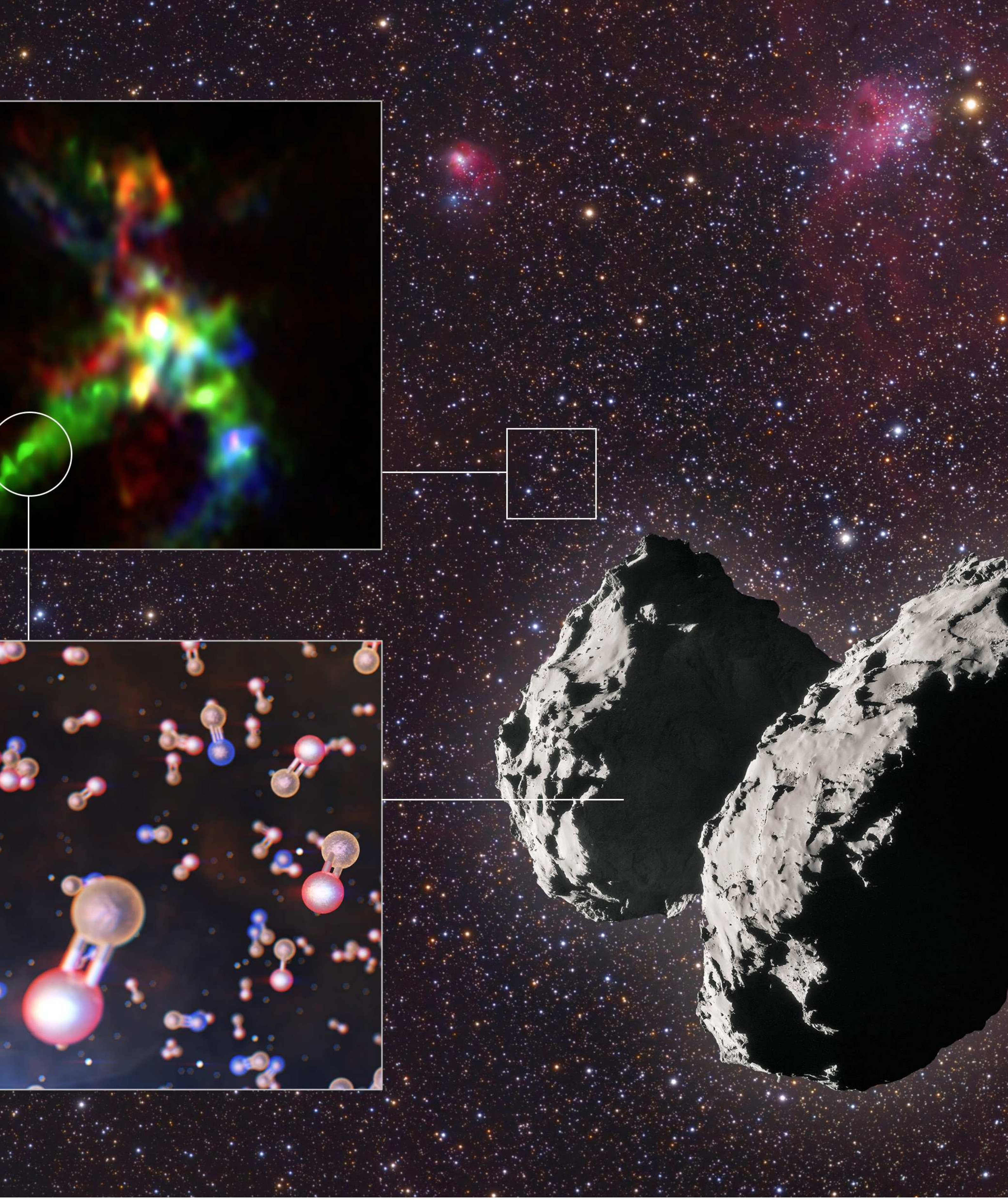
"Life appeared on Earth about 4 billion years ago, but we still do not know the processes that made it possible," says Víctor Rivilla, the lead author of a new study published today in the journal *Monthly Notices of the Royal Astronomical Society*. The new results from the Atacama Large Millimeter/Submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, and from the ROSINA instrument on board Rosetta, show that phosphorus monoxide is a key piece in the origin-of-life puzzle.

With the power of ALMA, which allowed a detailed look into the star-forming region AFGL 5142, astronomers could pinpoint where phosphorus-bearing molecules, like phosphorus monoxide, form. New stars and planetary systems arise in cloud-like regions of gas and dust in between stars, making these interstellar clouds the ideal places to start the search for life's building blocks.

The ALMA observations showed that phosphorus-bearing molecules are created as massive stars are formed. Flows of gas from young massive stars open up cavities in interstellar clouds. Molecules containing phosphorus form on the cavity walls, through the combined action of shocks and radiation from the infant star. The astronomers have also shown that phosphorus monoxide is the most abundant phosphorus-bearing molecule in the cavity walls.

After searching for this molecule in star-forming regions with ALMA, the European team moved on to a Solar System object: the now-

This infographic shows the key results from a study that has revealed the interstellar thread of phosphorus, one of life's building blocks. [ALMA (ESO/NAOJ/NRAO), Rivilla et al.; ESO/L. Calçada; ESA/Rosetta/NAVCAM; Mario Weigand, www.SkyTrip.de]



This wide-field view shows the region of the sky, in the constellation of Auriga, where the star-forming region AFGL 5142 is located. This view was created from images forming part of the Digitized Sky Survey 2. [ESO/Digitized Sky Survey 2]

famous comet 67P/Churyumov–Gerasimenko. The idea was to follow the trail of these phosphorus-bearing compounds. If the cavity walls collapse to form a star, particularly a less-massive one like the Sun, phosphorus monoxide can freeze out and get trapped in the icy dust grains that remain around the new star. Even before the star is fully formed, those dust grains come together to form pebbles, rocks and ultimately comets, which become transporters of phosphorus monoxide.

ROSINA, which stands for Rosetta Orbiter Spectrometer for Ion and Neutral Analysis, collected data from 67P for two years as Rosetta orbited the comet. Astronomers had found hints of phosphorus in the ROSINA data before, but they did not know what molecule had carried it there. Kathrin Altwegg, the Principal Investigator for Rosina and an author in the new study, got a clue about what this molecule could be after being approached at a conference by an astronomer studying star-forming regions with ALMA: *"She said that phosphorus monoxide would be a very likely candidate, so I went back to our data and there it was!"*

This first sighting of phosphorus monoxide on a comet helps astronomers draw a connection between star-forming regions, where the molecule is created, all the way to Earth. *"The combination of the ALMA and ROSINA data has revealed a sort of chemical thread during the whole process of star formation, in which phosphorus monoxide plays the dominant role,"* says Rivilla, who is a researcher at the Arcetri Astrophysical Observatory of INAF, Italy's National Institute for Astrophysics.

"Phosphorus is essential for life as we know it," adds Altwegg. *"As comets most probably delivered large amounts of organic compounds to the Earth, the phosphorus monoxide found in comet 67P may strengthen the link between comets and life on Earth."*

This intriguing journey could be documented because of the collaborative efforts between astronomers. *"The detection of phosphorus monoxide was clearly thanks to an interdisciplinary exchange between telescopes on Earth and instruments in space,"* says Altwegg.

Leonardo Testi, ESO astronomer and ALMA European Operations Manager, concludes: *"Understanding our cosmic origins, including how common the chemical conditions favourable for the emergence of life are, is a major topic of modern astrophysics.*

While ESO and ALMA focus on the observations of molecules in distant young planetary systems, the direct exploration of the chemical inventory within our Solar System is made possible by ESA missions, like Rosetta. The synergy between world leading ground-based and space facilities, through the collaboration between ESO and ESA, is a powerful asset for European researchers and enables transformational discoveries like the one reported in this paper." ■

This video starts by showing a wide-field view of a region of the sky in the constellation of Auriga. It then zooms in to show the star-forming region AFGL 5142, recently observed with ALMA. [ALMA (ESO/NAOJ/NRAO), Rivilla et al.; Mario Weigand, www.SkyTrip.de; ESO/Digitized Sky Survey 2; Nick Risinger (skysurvey.org).]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