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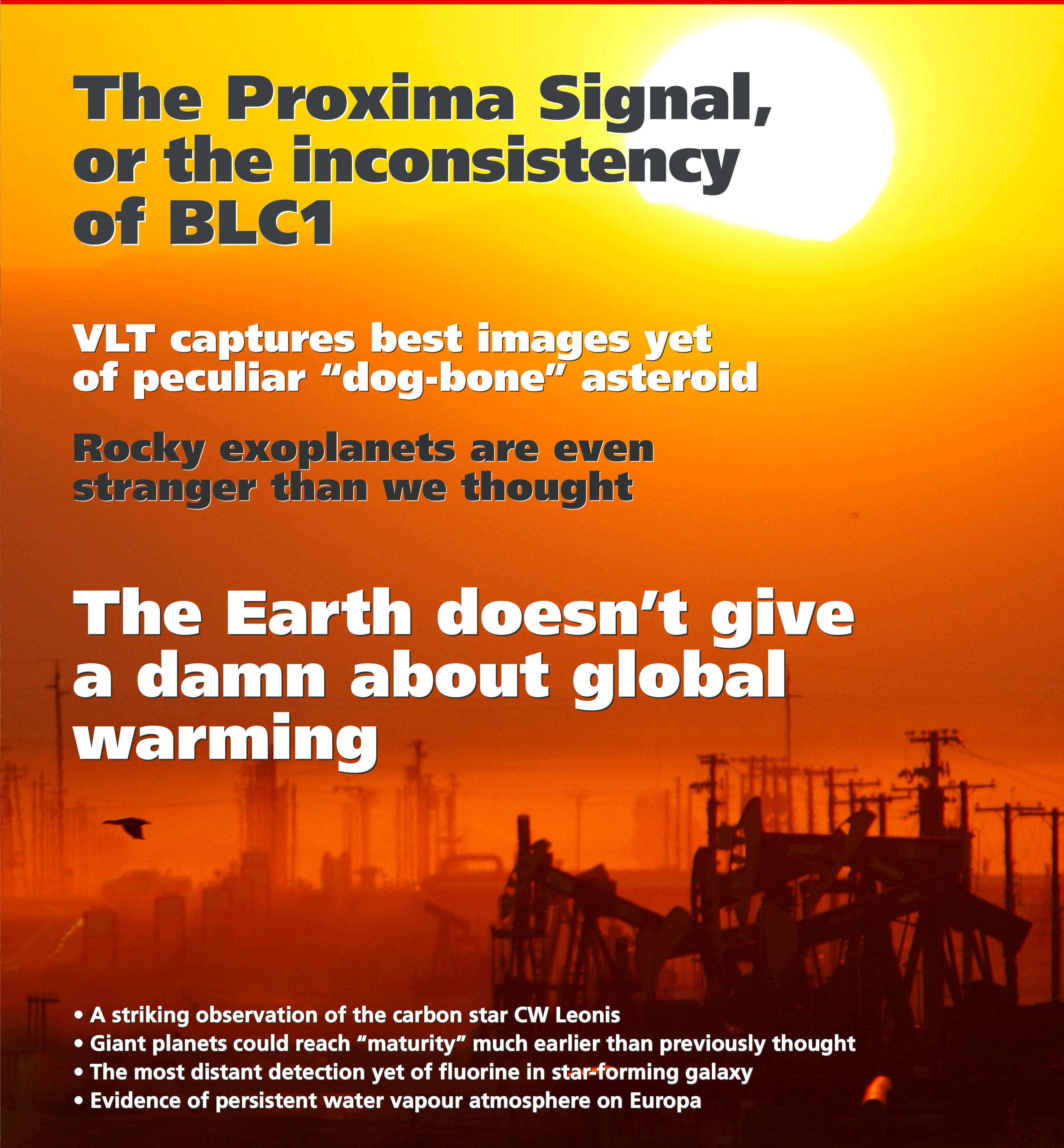
Bi-monthly magazine of scientific and technical information ✶ January-February 2022



The Proxima Signal, or the inconsistency of BLC1

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The Earth doesn't give a damn about global warming

- A striking observation of the carbon star CW Leonis
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- The most distant detection yet of fluorine in star-forming galaxy
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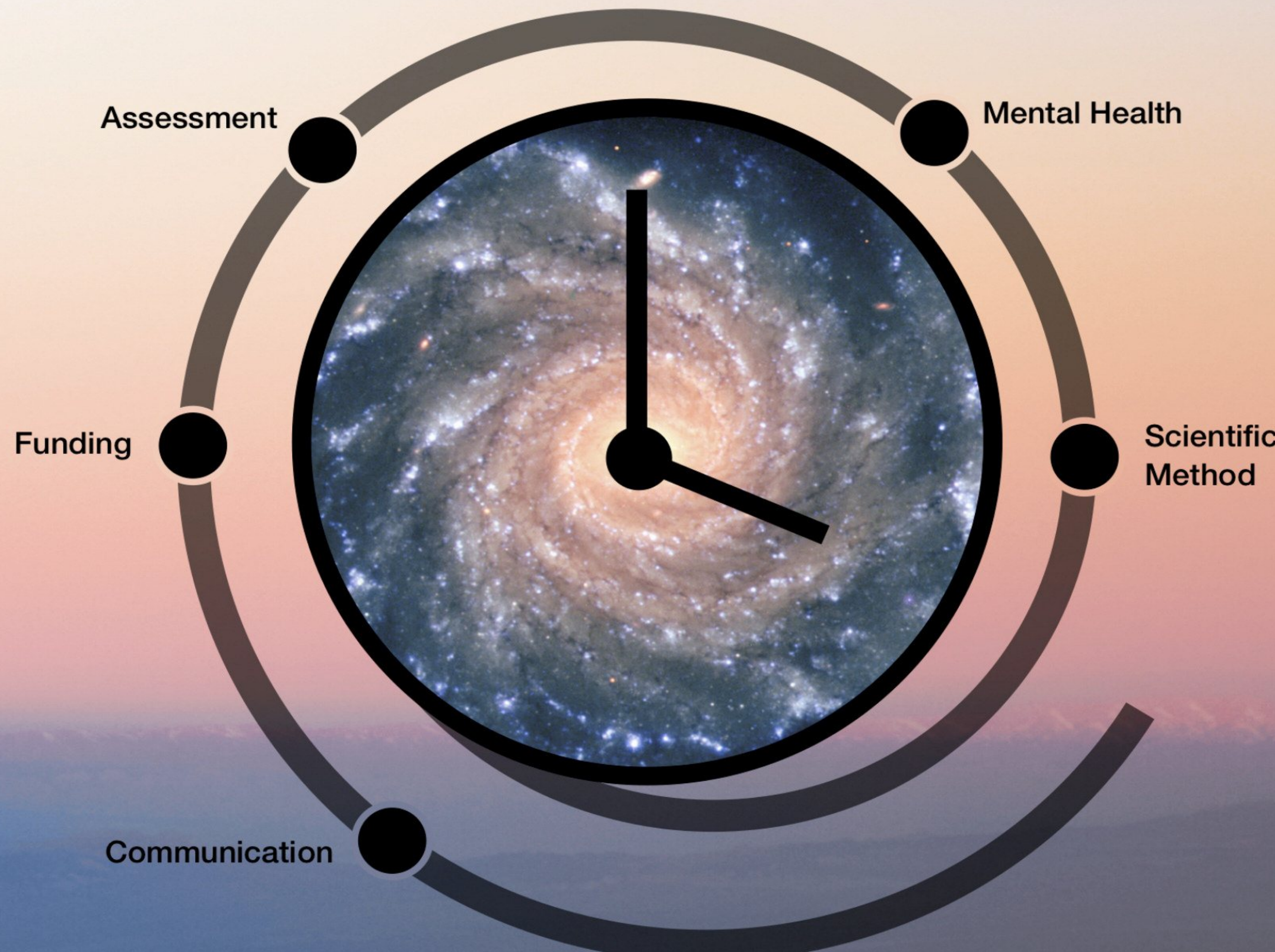

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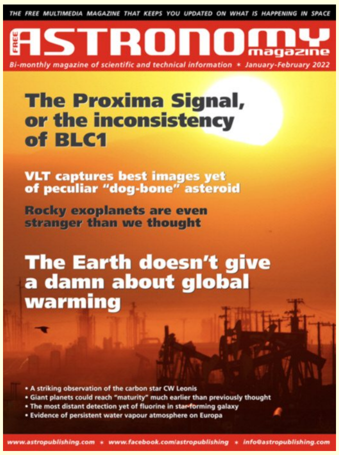

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4 *The Proxima Signal, or the inconsistency of BLC1*

14 *VLT captures best images yet of peculiar "dog-bone" asteroid*

18 *Plunging into the Fornax Cluster*

20 *A striking observation of the carbon star CW Leonis*

22 *Giant planets could reach "maturity" much earlier than previously thoughty*

24 *The most distant detection yet of fluorine in star-forming galaxy*

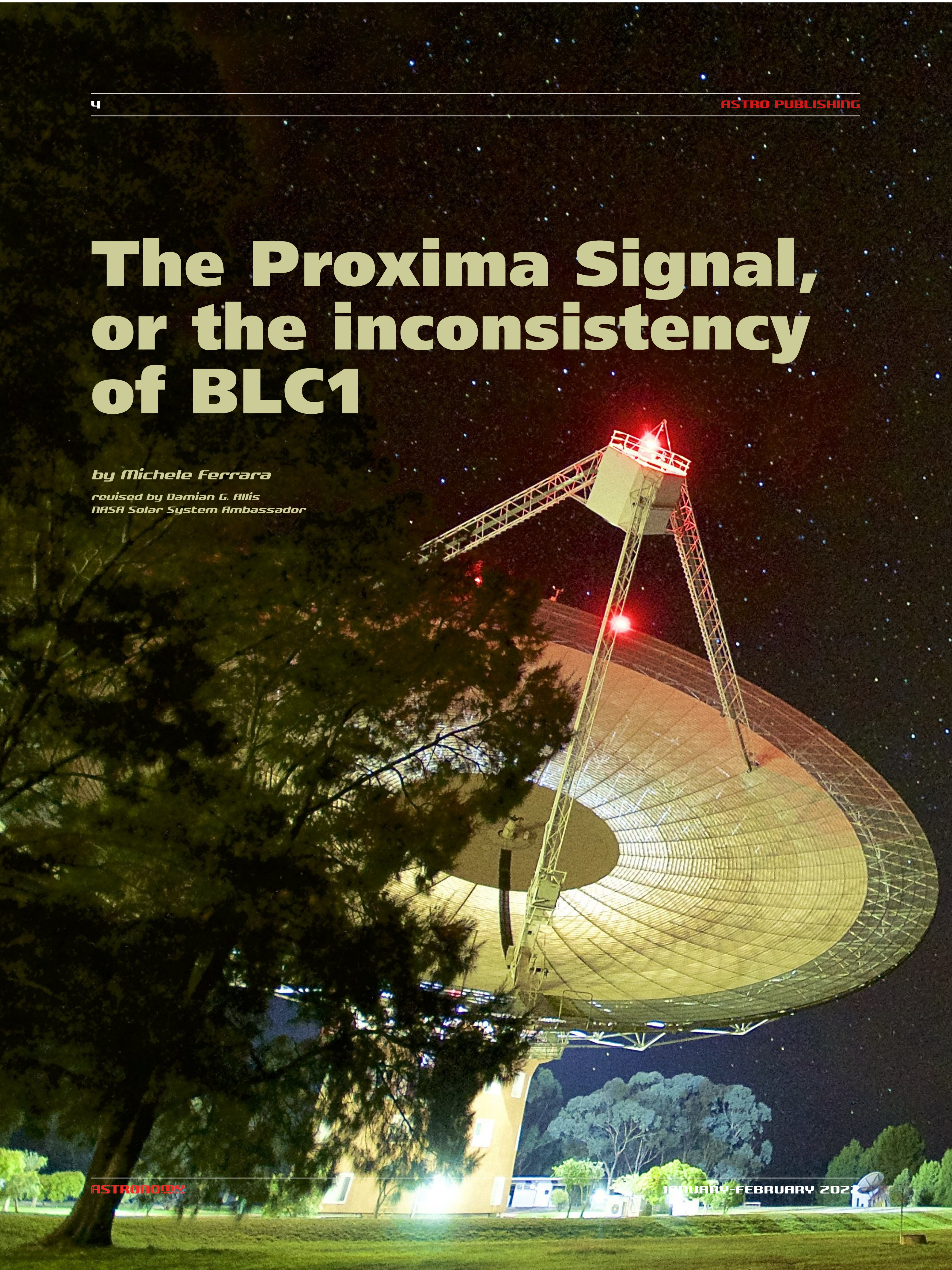
28 *The Earth doesn't give a damn about global warming*

36 *Evidence of persistent water vapour atmosphere on Europa*

40 *ALMA detects signs of water in a galaxy far, far away*

44 *VLT images some of the biggest asteroids in our Solar System*

50 *Rocky exoplanets are even stranger than we thought*



The Proxima Signal, or the inconsistency of BLC1

by Michele Ferrara

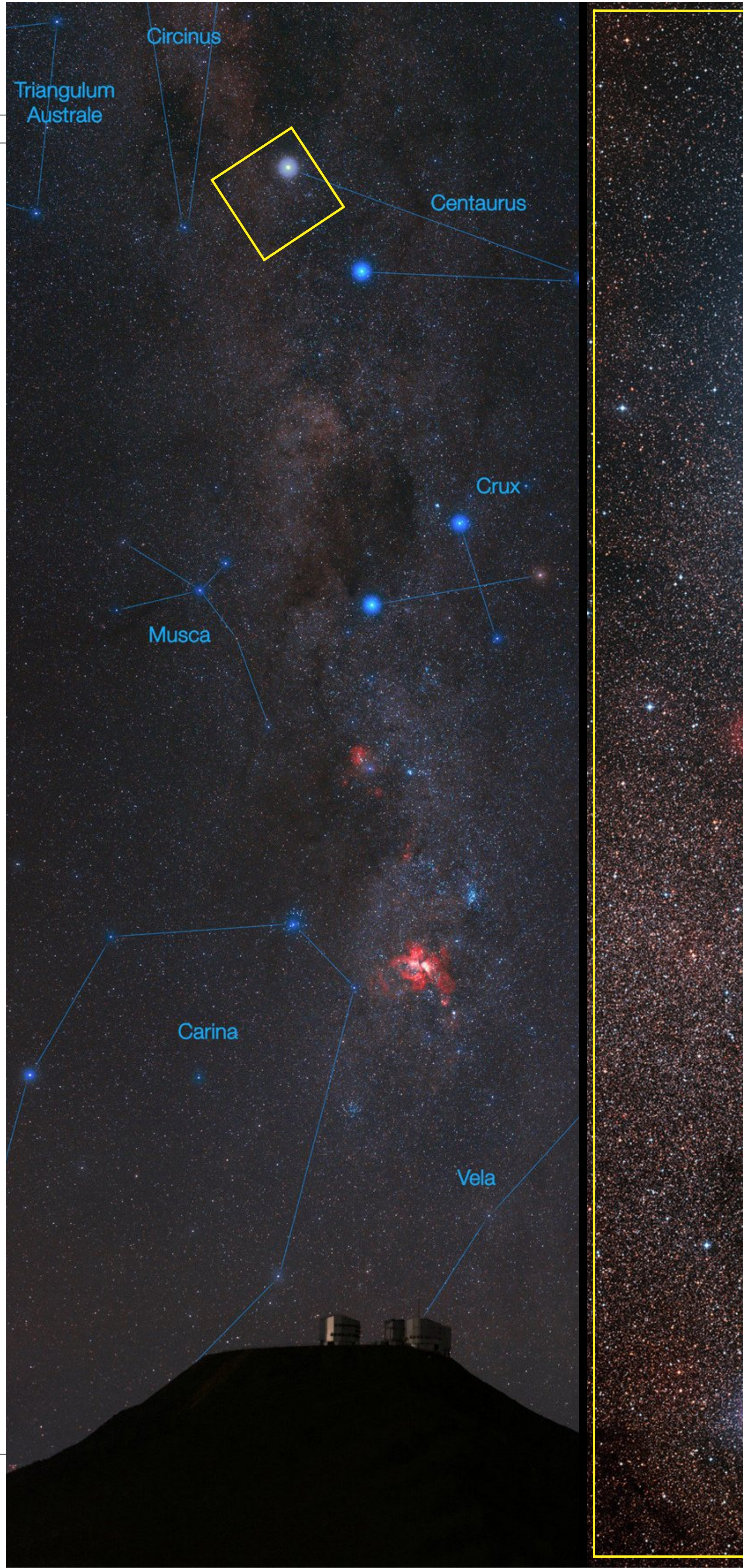
revised by Damian G. Allis
NASA Solar System Ambassador

In the background, the Parkes 64-Meter Radio Telescope, New South Wales, Australia, with the Milky Way on its right. [Daniel John Reardon] Above, a stunning time-lapse shows the Moon over Australia's observatory at Parkes. [CSIRO]

Two articles published last October 31 in *Nature Astronomy* dispelled any doubts about the terrestrial origin of a mysterious radio signal that seemed to come from the Proxima Centauri planetary system. The history and interpretation of that radio signal are quite interesting and deserving of our attention.

It all started in April 2019, when a graduate student from the University of Sydney, Andrew Zic, engaged in an observation program of Proxima Centauri, aimed at recording in different wavelengths the frequent flares that emanate from that star. Among the instruments used by Zic was the historic 64-meter-diameter Parkes Radio Telescope, operated by the Commonwealth Scientific and Industrial Research Organization (CSIRO) as part of the Australia Telescope National Facility (ATNF) radio telescope network. Since Proxima Centauri is a fundamental target of Breakthrough Listen, a program of Breakthrough Initiatives dedicated to the search for alien technosignatures (evidence of technologies attributable to extraterrestrial intelligences), some researchers involved in this project proposed to Zic and colleagues to join their efforts in radio observation of Proxima Centauri, with the plan to carry out SETI research in parallel with those studies of the stellar flares.

Between April and May 2019, some series of observations were carried out in the frequency range between 700 MHz and 4 GHz, with a resolution of just 3.81 Hz. This meant listening to about 800 million radio channels simultaneously and consequently recording a huge amount of data, which only specific automated procedures (search algorithms) could possibly process. A trainee from Breakthrough Listen, Shane Smith, was entrusted with the long work of "creaming off" the data. He found himself having to look for the proverbial "needle in the haystack," where the haystack was represented by over 4 million "hits," or frequency intervals with some radio emission. As always in these cases, the first thing done was to eliminate all those signals clearly produced by human technologies and which certainly could not have come from great distances beyond the Earth. This process involved the consideration of two main selection criteria. The first criterion was the determination of whether the frequency of a given signal varied over time. In fact, we can expect that a transmitter placed on a planet orbiting a star other than the Sun is either moving away from or approaching the radio telescope that picks up the signal here on Earth, meaning that the signal can be characterized as having a positive or negative radial acceleration (zero acceleration is instead typical of local sources moving in the same reference frame as the detector). The rotation of an exoplanet on its axis, as well as its orbital motion, can vary the frequency of the

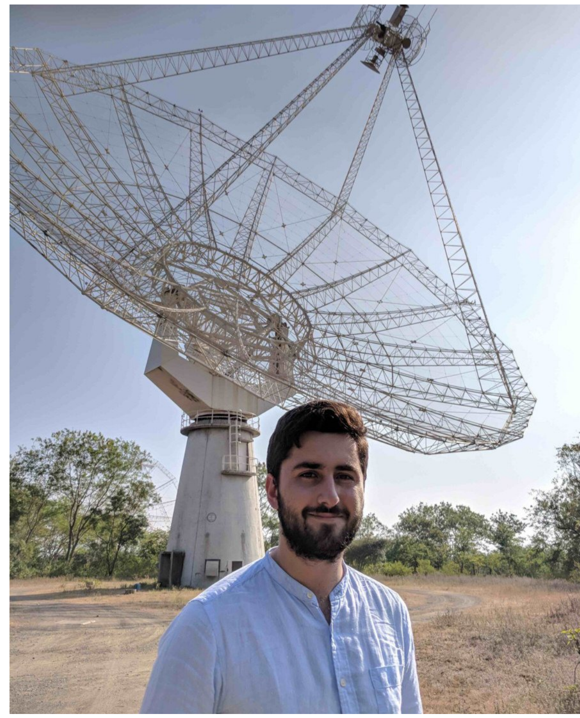


This image shows the star system closest to the Sun – the double star Alpha Centauri AB and its companion, the dim and distant Proxima Centauri. At the end of 2016, ESO signed an agreement with Breakthrough Initiatives to adapt the VLT instrumentation so that it could search for planets in the Alpha Centauri system, planets that could become the target of a launch of miniature space probes by Breakthrough Starshot Initiatives. [ESO/ B. Tafreshi (twanight.org)/Digitized Sky Survey 2. Acknowledgement: Davide De Martin/Mahdi Zamani]

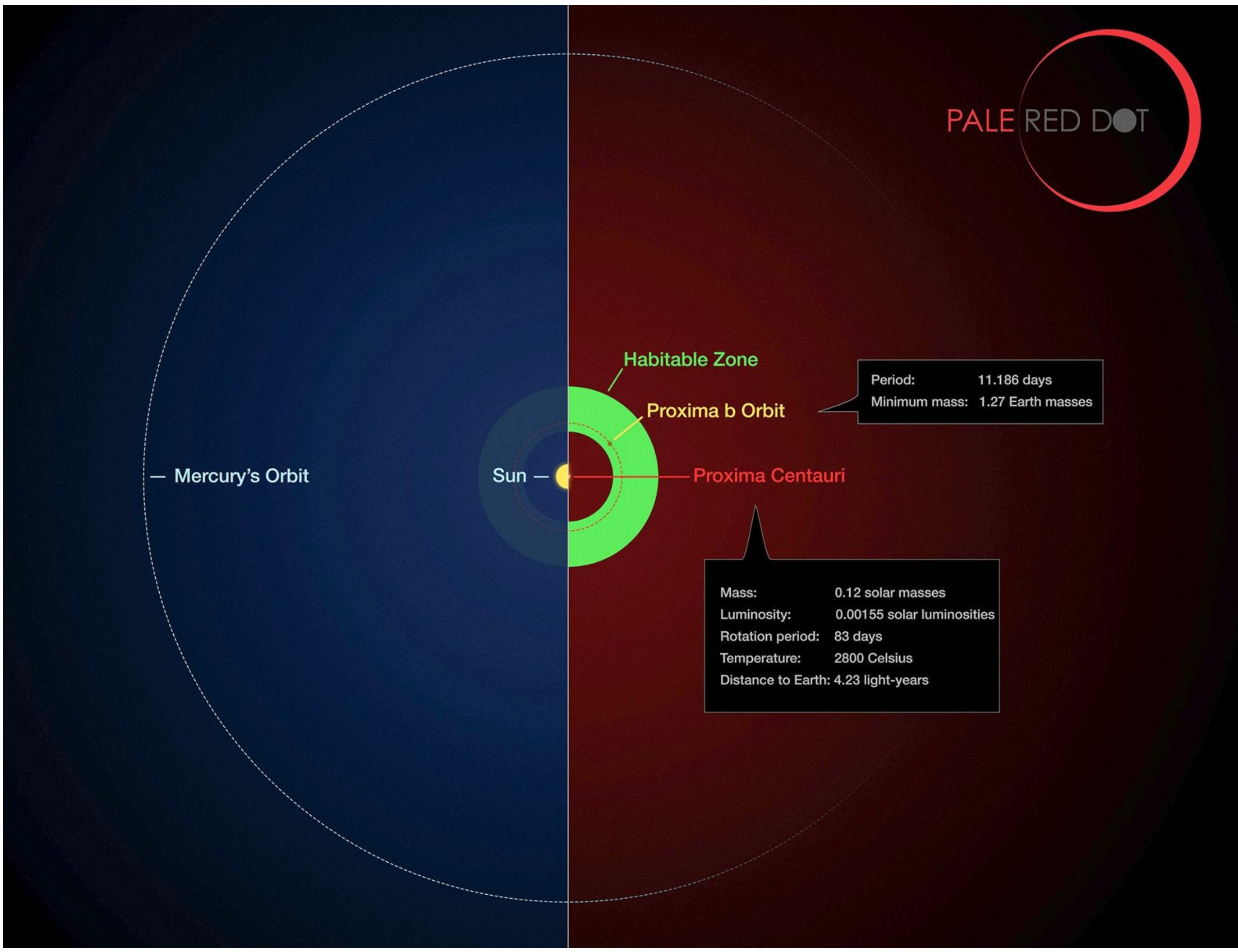

Alpha Centauri A&B
Proxima Centauri

signal due to the Doppler effect. For this reason, the first creaming off performed by the search algorithm applied by the Breakthrough Listen team concerned all signals inconsistent with a transmitter that might be placed on the surface of Proxima b, the only planet that we know exists in the habitable zone of Proxima Centauri.
The second selection criterion that was applied to the initial screening of the collected signals concerned the direction from which they came. If by pointing the radio telescope at a certain target we receive a signal, it is sufficient to point the instrument towards a different region of the sky to check and see if the signal persists, if it is perhaps weakened, or if it disappears completely. In the first case, it is almost certain that it is from a local source or is local interference; in the second case, the signal could come from the target or from a source that is prospectively close to it. A single radio telescope guarantees a rather low spatial resolution, and it is therefore not possible to precisely locate a source. As for the Parkes dish, the margin of uncertainty is as wide as half a full moon, and it is therefore necessary to move the antenna by more than half an angular degree to carry out the "ON-OFF" control of the signal sources. At the end of these first automated procedures, a few unidentified sources remained that required a "human" verification of their characteristics. Usually, these

Andrew Zic studies radio-continuum observations of pulsars, radio transients, and multi-wavelength stellar activity. Here he is pictured near the Antenna C2 of the Giant Metrewave Radio Telescope, located in the state of Maharashtra, India.

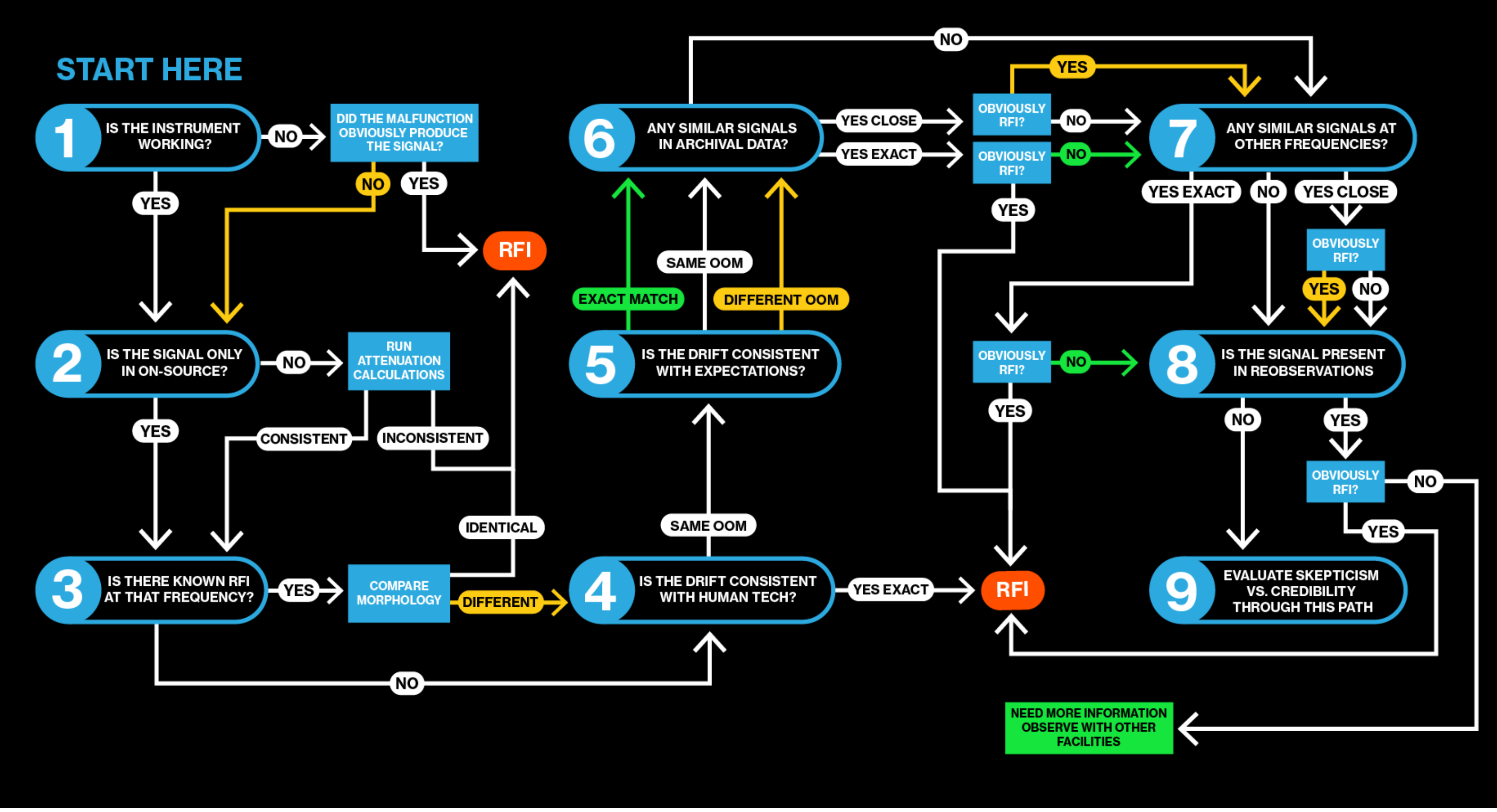


This artist's impression shows a view of the surface of the planet Proxima b orbiting the red dwarf star Proxima Centauri, the closest star to the Solar System. The double star Alpha Centauri AB also appears in the image to the upper-right of Proxima itself. Proxima b is a little more massive than the Earth and orbits in the habitable zone around Proxima Centauri, where the temperature is suitable for liquid water to exist on its surface. [ESO/M. Kornmesser]



This infographic compares Proxima b's orbit around Proxima Centauri with the same region of the Solar System. Proxima Centauri is smaller and cooler than the Sun and the planet orbits much closer to its star than Mercury. As a result it lies well within the habitable zone, where liquid water can exist on the planet's surface. [ESO]

are sources that in the "OFF target" position do not produce signals strong enough to be recognized by the search algorithms.
Even the transit of satellites and airplanes can generate interference that is not immediately recognizable, as can the simple passage near the antenna of vehicles and people equipped with electronic devices. When all reasonable sources have also been excluded, usually there is no signal left that can be interpreted as an alien technosignature. Instead, when Shane Smith completed the preliminary processing of the data acquired during the Proxima Centauri observations in 2020, he was faced with a signal that did not seem to be eliminated by any filter and which appeared to come from the region of the sky centered on Proxima Centauri. Being the first alien signal candidate recorded by the Breakthrough Listen program, it was called "BLC1."
The first in-depth verifications of BLC1 indicated that the signal had many of the characteristics we might expect from an alien technosignature. First, it became visible only when the radio telescope pointed towards Proxima Centauri. Moreover, it occupied a narrow band of frequencies (982 MHz), a typical property of an artificial source, whereas natural sources "transmit" over a wide range of frequencies. BLC1 also met the frequency variation requirement: on the only day the signal was recorded (April 29, 2019), its spectral position varied



A very complicated flowchart showing the method developed for verifying a signal-of-interest. For a more thorough explanation of the process, see https://seti.berkeley.edu/blc1/flowchart.html. [Flowchart graphics by Z. Sheikh]

slightly over a period of about 5 hours. As mentioned above, this is the expected behavior if the signal comes from the surface of another (moving) planet. In reality, this requirement is not stringent, as an artificial signal could also come from an apparently immobilized source in space in the short term, for example from a planet with an orbit perpendicular to our line of sight, or from a Lagrangian point of that orbit; in these cases there would be no Doppler effect. The length of the signal, nevertheless, made it possible to exclude satellites, airplanes and passing devices at a relatively short distance from the antenna.

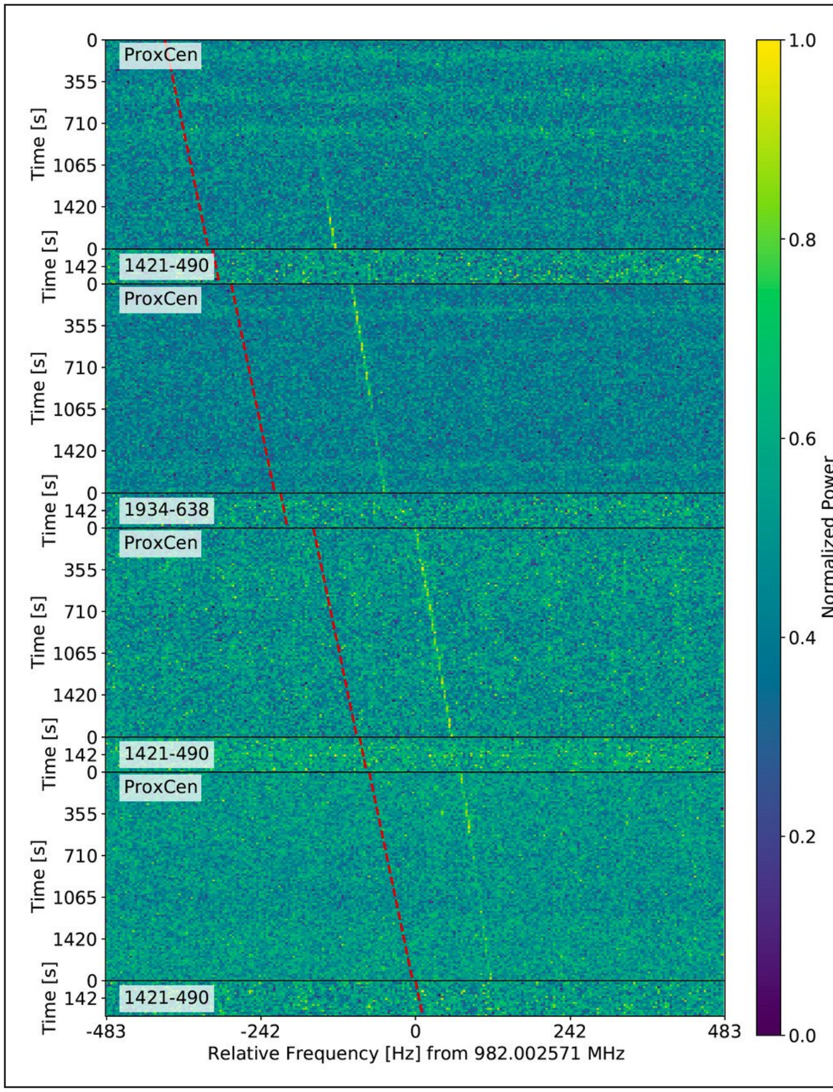
BLC1 did not appear to be either the result of a recognizable astrophysical phenomenon or a familiar interference of terrestrial origin. The only (reasonable) alternative to these two possibilities was that the signal had originated from occasional radio interference, capable of very faithfully mimicking what the researchers expected to discover. To test this hypothesis, Sofia Sheikh, of the Breakthrough Listen team at UC Berkeley, went to "dig" into a larger set of observational data, recorded with Parkes at different times. The new analysis highlighted the existence of about sixty signals that shared many characteristics with BLC1 but which, unlike the latter, also manifested themselves when the radio telescope was aimed at "OFF target." Here is how Sofia Sheikh commented on the results of her analysis: *"We can confidently say that these other signals are local to the telescope and human-generated. The signals are spaced at regular frequency intervals in the data, and these intervals appear to correspond to multiples of frequencies used by oscillators that are commonly used in various electronic devices. Taken together, this evidence suggests that the signal is interference from human technology, although we were unable to identify its specific source. The original signal found by Shane Smith is not obviously detected when the telescope is pointed away from Proxima Centauri – but given a haystack of millions of signals, the most likely explanation is still that it is a transmission from human technology that happens to be 'weird' in just the right way to fool our filters."*

We can therefore conclude that BLC1 was not a signal produced by an alien technology. To tell the truth, almost no one among the insiders has ever considered it an extraterrestrial technosignature. The reasons are more than one. First, Proxima Centauri is a red dwarf (type M5.5V) and, as known for stars of this class, often produces very high-power flares that overwhelm its planets with intense streams of radiation lethal to surface life (that is, life as we know it).

Another reason is the extreme improbability that two civilizations of

Sofia Sheikh is a radio astronomer and technosignature researcher working as a post-doctoral scholar with the Breakthrough Listen Project.

The BLC1 signal. Each panel in the plot is an observation towards Proxima Centauri ('ON source'), or towards a reference source ('OFF source'). BLC1 is the yellow drifting line and is only present when the telescope is pointed at Proxima Centauri. [Smith et al., Nature Astronomy]



the same technological level might exist simultaneously around two stars so close to each other. With our civilization as our only example, we cannot imagine how long other civilizations can and will produce technosignatures in the radio domain. However, we know that our galaxy is at least 13 billion years old (although at the beginning it was very different from how we perceive it today) and that humanity has been able to produce radio signals for only about a century. If we use the length of an Earth year to compare the age of the Milky Way to the time we've been able to produce radio signals, we see that we started producing radio signals just 0.2 seconds from the end of that year. Is it reasonable to assume that another technological civilization could be our contemporary, and that it is located on the nearest habitable zone exoplanet? From that probabilistic standpoint, this hypothesis is not reasonable, not even considering that having originated from distinct protostellar clouds, the Sun and Proxima Centauri were in the past certainly more distant than they are in our time. The timing of the coexistence of the two "radio civilizations" would nevertheless remain unlikely unless millions of technological civilizations exist in the Milky Way. If there were so many, it is likely that some of them would have already contacted us. Not having done so, however, it could also be the demonstration that truly intelligent life exists nowhere else in the universe...

The lesson that we can learn from the story of BLC1 is that we can certainly pick up sufficiently powerful alien radio signals with today's technology, although it does not seem so easy to recognize them in the ocean of interference that we ourselves produce. What is certain is that we use radio frequencies, and it is all our belief that any alien technological civilization must necessarily make the same choice to communicate with other worlds. To get an idea of how the main SETI programs are set up today, let's imagine that we are in a large stadium filled with fans who all support the home team at the top of their lungs, with the exception (perhaps) of one fan who supports the opposing team. What we try to do now is isolate the latter's voice without even knowing what he is saying and where he is sitting. Might there not be a more distinguishing aspect to the person we're trying to detect? Wouldn't it be less random to look for a different colored flag in the areas reserved for guests? ■

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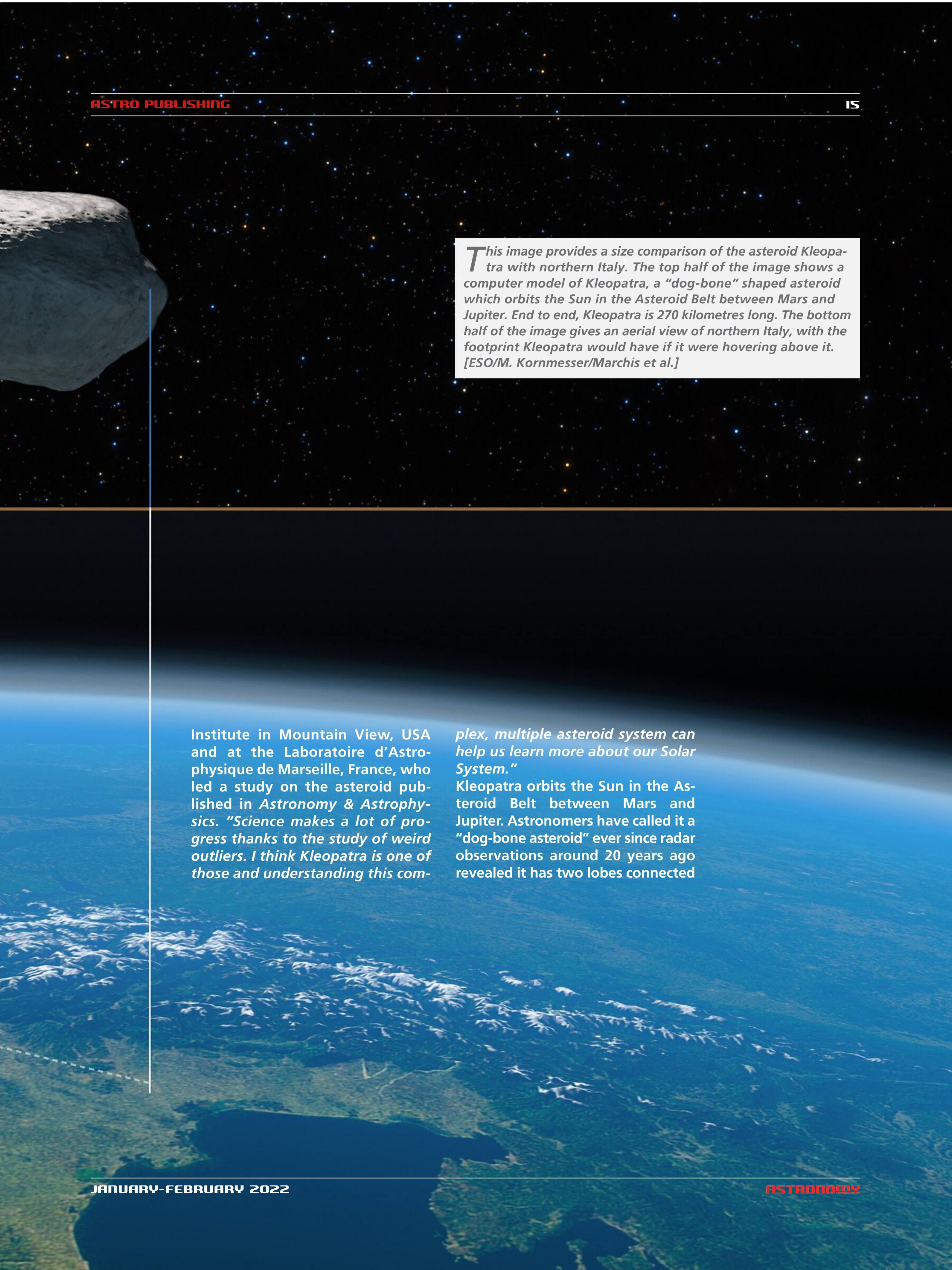
I N S T R U M E N T S - C O

VLT captures best images yet of peculiar "dog-bone" asteroid

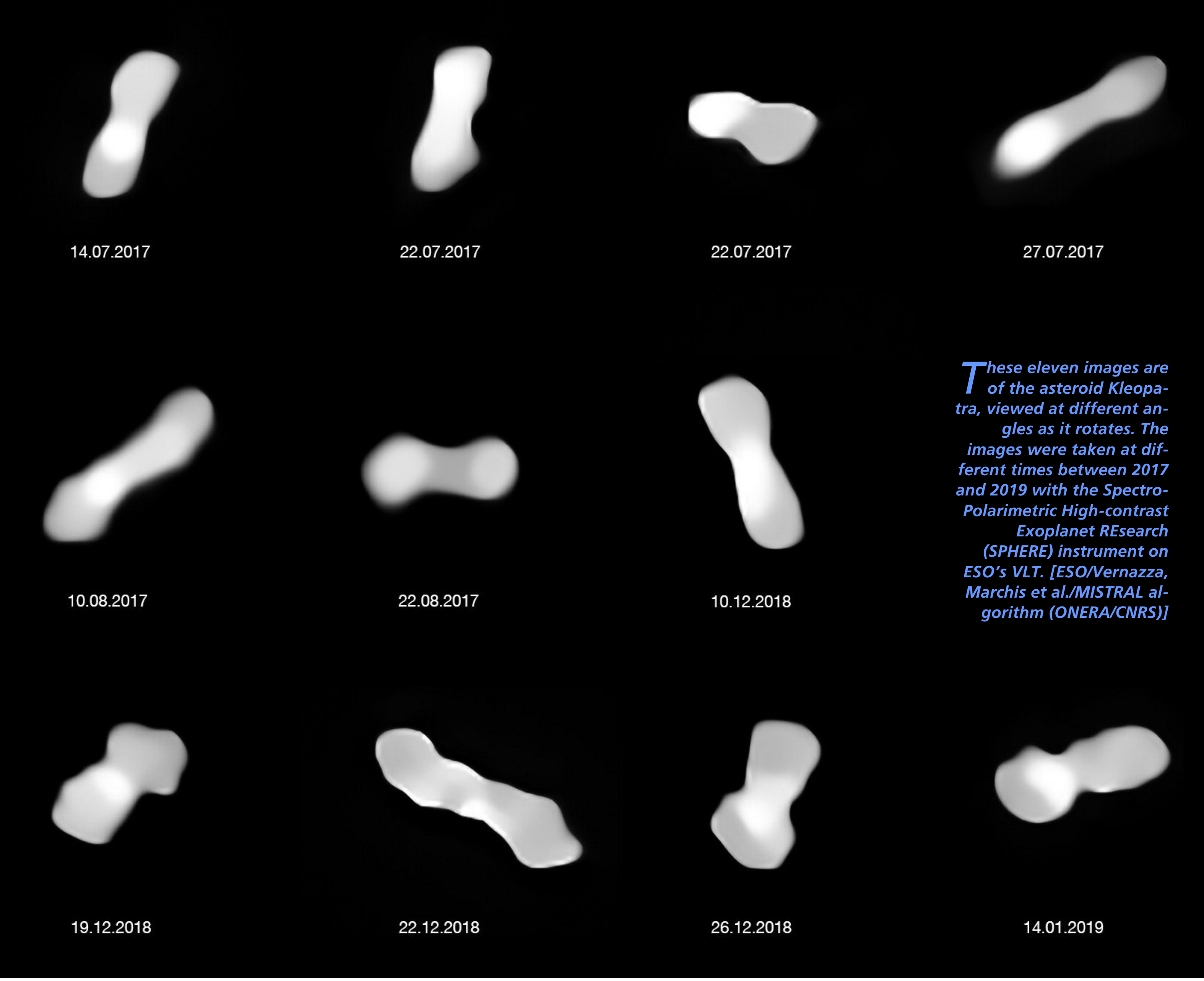
by ESO - Bárbara Ferreira

Using the European Southern Observatory's Very Large Telescope (ESO's VLT), a team of astronomers have obtained the sharpest and most detailed images yet of the asteroid Kleopatra. The observations have allowed the team to constrain the 3D shape and mass of this peculiar asteroid, which resembles a dog bone, to a higher accuracy than ever before.
Their research provides clues as to how this asteroid and the two moons that orbit it formed. *"Kleopatra is truly a unique body in our Solar System,"* says Franck Marchis, an astronomer at the SETI



This image provides a size comparison of the asteroid Kleopatra with northern Italy. The top half of the image shows a computer model of Kleopatra, a "dog-bone" shaped asteroid which orbits the Sun in the Asteroid Belt between Mars and Jupiter. End to end, Kleopatra is 270 kilometres long. The bottom half of the image gives an aerial view of northern Italy, with the footprint Kleopatra would have if it were hovering above it. [ESO/M. Kornmesser/Marchis et al.]

Institute in Mountain View, USA and at the Laboratoire d'Astrophysique de Marseille, France, who led a study on the asteroid published in *Astronomy & Astrophysics*. *"Science makes a lot of progress thanks to the study of weird outliers. I think Kleopatra is one of those and understanding this complex, multiple asteroid system can help us learn more about our Solar System."*
Kleopatra orbits the Sun in the Asteroid Belt between Mars and Jupiter. Astronomers have called it a "dog-bone asteroid" ever since radar observations around 20 years ago revealed it has two lobes connected



These eleven images are of the asteroid Kleopatra, viewed at different angles as it rotates. The images were taken at different times between 2017 and 2019 with the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument on ESO's VLT. [ESO/Vernazza, Marchis et al./MISTRAL algorithm (ONERA/CNRS)]

by a thick "neck". In 2008, Marchis and his colleagues discovered that Kleopatra is orbited by two moons, named AlexHelios and CleoSelene, after the Egyptian queen's children. To find out more about Kleopatra, Marchis and his team used snapshots of the asteroid taken at different times between 2017 and 2019 with the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument on ESO's VLT. As the asteroid was rotating, they were able to view it from different angles and to create the most accurate 3D models of its shape to date. They constrained the asteroid's dog-bone shape and its volume, finding one of the lobes to be larger

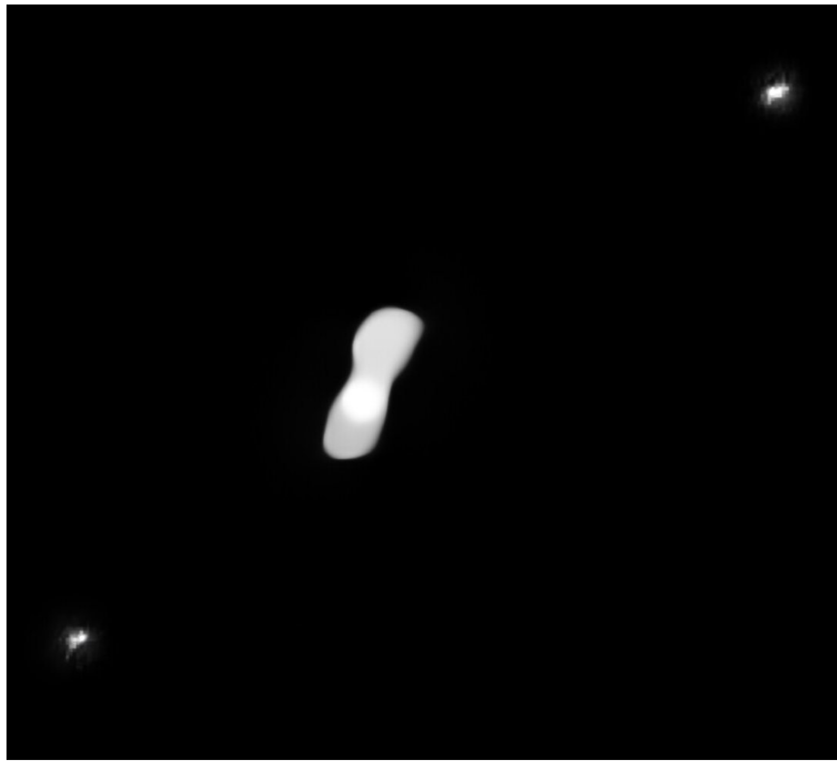
This animation shows where the orbit of the asteroid Kleopatra (in red) is in our Solar System. Kleopatra orbits the Sun in the Asteroid Belt, which is located between the orbits of Mars and Jupiter. [ESO/spaceengine.org] than the other, and determined the length of the asteroid to be about 270 kilometres or about half the length of the English Channel.

In a second study, also published in *Astronomy & Astrophysics* and led by Miroslav Brož of Charles University in Prague, Czech Republic, the team reported how they used the SPHERE observations to find the correct orbits of Kleopatra's two moons. Previous studies had estimated the orbits, but the new observations with ESO's VLT showed that the moons were not where the older data predicted them to be.

"This had to be resolved," says Brož. *"Because if the moons' orbits were wrong, everything was wrong, including the mass of Kleopatra."* Thanks to the new observations and sophisticated modelling, the team managed to precisely describe how Kleopatra's gravity influences the moons' movements and to determine the complex orbits of AlexHelios and CleoSelene. This allowed them to calculate the asteroid's mass, finding it to be 35% lower than previous estimates.

Combining the new estimates for volume and mass, astronomers were able to calculate a new value for the density of the asteroid, which, at less than half the density of iron, turned out to be lower than previously thought. The low density of Kleopatra, which is believed to have a metallic composition, suggests that it has a porous structure and could be little more than a "pile of rubble". This means it likely formed when material reaccumulated following a giant impact.

Kleopatra's rubble-pile structure and the way it rotates also give indications as to how its two moons could have formed. The asteroid rotates almost at a critical speed, the speed above which it would start to fall apart, and even small impacts may lift pebbles off its surface.



This processed image, based on observations taken in July 2017, shows the two moons of the asteroid Kleopatra (the central white object), AlexHelios and CleoSelene, which appear as two small white dots in the top-right and bottom-left corners of the picture. Kleopatra's moons are difficult to see in the raw images — which were taken with the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument on ESO's VLT — owing to glare around the asteroid, inherent to this kind of adaptive-optics observations. To achieve this view, the images of Kleopatra have been processed to remove the glare and reveal the moons. [ESO/Vernazza, Marchis et al./MISTRAL algorithm (ONERA/CNRS)]

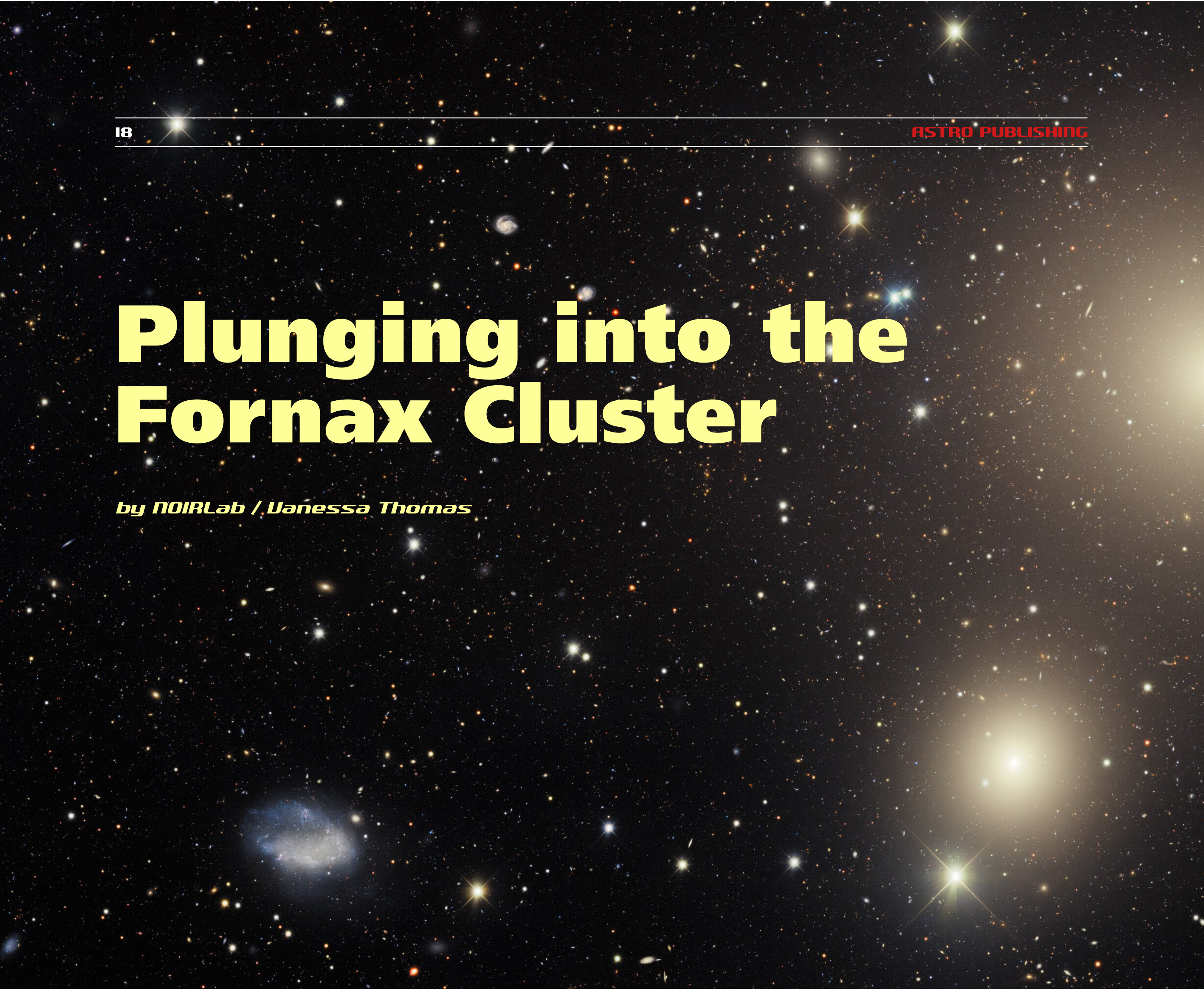
Marchis and his team believe that those pebbles could subsequently have formed AlexHelios and CleoSelene, meaning that Kleopatra has truly birthed its own moons.

The new images of Kleopatra and the insights they provide are only possible thanks to one of the advanced adaptive optics systems in use on ESO's VLT, which is located in the Atacama Desert in Chile.

Adaptive optics help to correct for distortions caused by the Earth's atmosphere which cause objects to appear blurred — the same effect that causes stars viewed from Earth to twinkle. Thanks to such corrections, SPHERE was able to image Kleopatra — located 200 million kilometres away from Earth at its closest — even though its apparent size on the sky is equivalent to that of a golf ball about 40 kilometres away. ESO's upcoming Extremely Large Telescope (ELT), with its advanced adaptive optics systems, will be ideal for imaging distant asteroids such as Kleopatra. *"I can't wait to point the ELT at Kleopatra, to see if there are more moons and refine their orbits to detect small changes,"* concluded Marchis.

Plunging into the Fornax Cluster

by NOIRLab / Vanessa Thomas



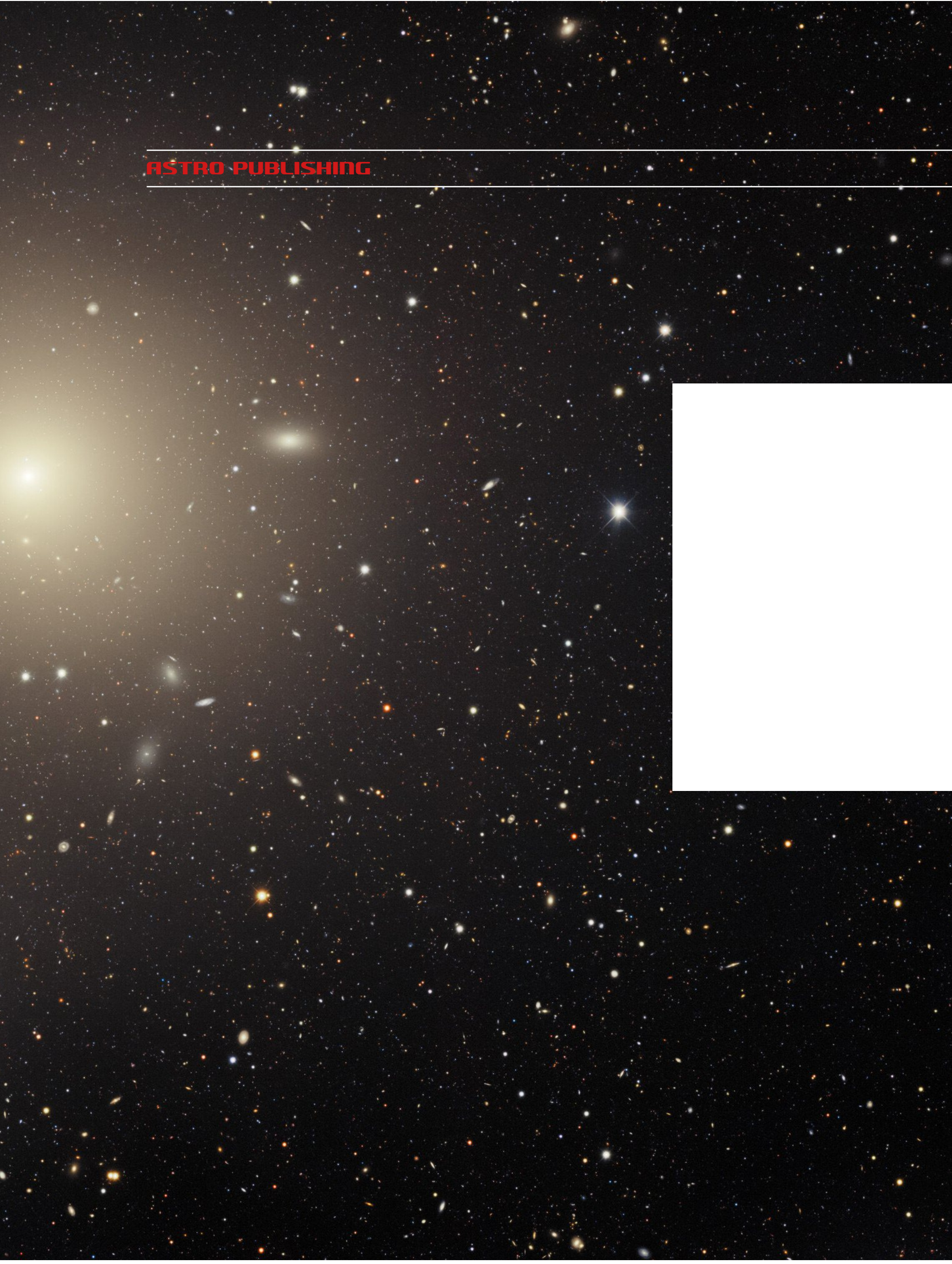
Members of the Fornax galaxy cluster fill this image from the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab. Appearing in the constellation Fornax (the Furnace), the Fornax Cluster is a relatively nearby galaxy cluster, only about 60 million light-years from Earth. Some foreground stars, which belong to our own Milky Way Galaxy, appear in the image as well. [CTIO/NOIRLab/DOE/NSF/AURA]

The denizens of the Fornax galaxy cluster populate this image from the Víctor M. Blanco 4-meter Telescope, located in Chile at Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab. The irregular galaxy lurking in the bottom left corner of this Dark Energy Survey image is NGC 1427A, and its headlong plunge into the heart of the Fornax Cluster over millions of years will eventually result in the galaxy's disruption.

The Fornax Cluster — which, as the name suggests, lies primarily in the constellation Fornax (the Furnace) — is a relatively nearby galaxy cluster, only about 60 million light-years from Earth. This means that it looms large in the night sky, stretching across an area more than 100 times larger than the full Moon.

With over 600 member galaxies, the Fornax Cluster is the second "richest" (most populous) galaxy cluster within 100 million light-years of our galaxy (after the much larger Virgo Cluster).

Two elliptical galaxies dominate the center of this image — visible as the two large patches of diffuse light with bright cores. Such galaxies usually contain much older stars than the more picturesque spiral galaxies, and they tend to be found in galaxy clusters such as the Fornax Cluster. These elliptical galaxies — which are named NGC 1399 and NGC 1404 — are among the brightest members of the Fornax Cluster and are inexorably being drawn together by the force of gravity. This interaction is stripping gas from NGC 1404, the lower elliptical galaxy in this image. In the bottom left corner of the image appears the irregular galaxy



A doomed galaxy falling into the core of the Fornax Cluster was captured by the Dark Energy Camera on the Víctor M. Blanco Telescope in Chile. The irregular galaxy NGC 1427A is plunging into the heart of the cluster at 2.2 million kilometers (or 1.3 million miles) per hour. Over millions of years, the galaxy will be ripped apart by gravitational interactions from the two largest galaxies in the image. Many colorful galaxies of various sizes and shapes paint the background of this image, appearing alongside nearby stars inside our own Milky Way. [CTIO/NOIRLab/NSF/AURA]

NGC 1427A. This ragged patch of light is a small, irregular collection of stars similar to the Large Magellanic Cloud. Similarly to NGC 1404, NGC 1427A is plunging toward the heart of the cluster at roughly 2.2 million kilometers (or 1.3 million miles) per hour. This headlong rush to destruction will eventually result in the galaxy being disrupted — pulled apart by gravitational interactions with other galaxies.

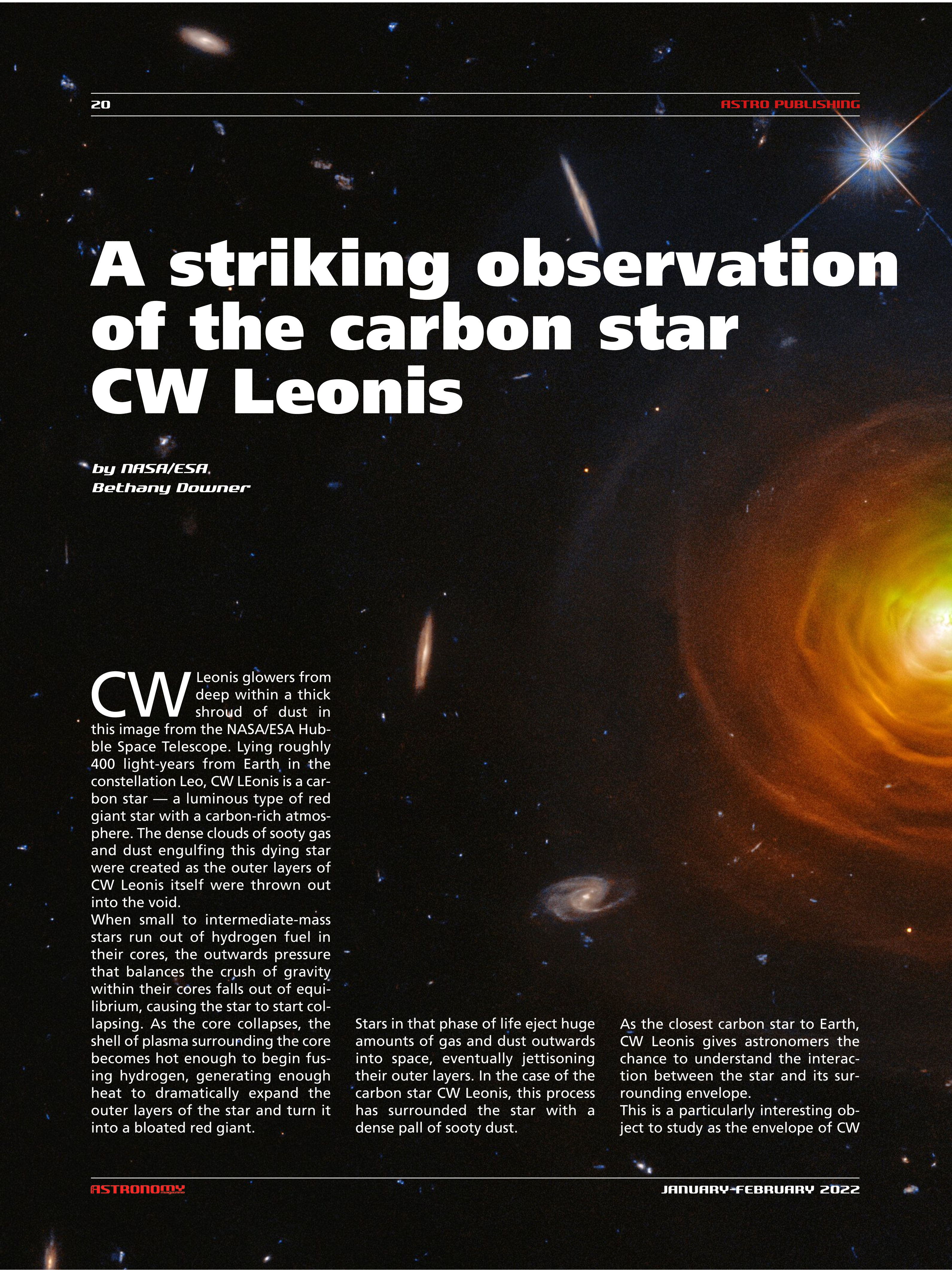
As with most astronomical observations, this image shows not only the intended target but also a menagerie of objects both close to home and at tremendous distances. The image is dotted with interloping objects from within our own Milky Way — bright stars with diffraction spikes. At the other extreme, distant galaxies provide a colorful backdrop to this image: some are recognizable as spiral galaxies, while others are mere smudges.

Despite appearing tiny in this image, each of the distant galaxies contains billions of stars.

This image was captured by the 570-megapixel Dark Energy Camera (DECam), one of the highest-performance, wide-field imagers in the world, as part of the Dark Energy Survey. Funded by the US Department of Energy (DOE) and built and tested at DOE's Fermilab, DECam was operated by DOE and the National Science Foundation (NSF) between 2013 and 2019. Among its many accomplishments, DECam observations have helped astronomers discover nearly 300 previously unknown dwarf galaxies in the Fornax Cluster.

At present DECam is used for programs covering a huge range of science. Like other survey instruments, DECam captures images of large swaths of the night sky, allowing astronomers to understand structures in the Universe at large scales.

Telescope surveys also help identify intriguing astronomical objects worthy of follow-up observation; the most powerful telescopes can only study a minute portion of the night sky at any given time, so astronomers often use surveys to find objects that are interesting enough to observe in detail.



A striking observation of the carbon star CW Leonis

by NASA/ESA
Bethany Downer

CW Leonis glowers from deep within a thick shroud of dust in this image from the NASA/ESA Hubble Space Telescope. Lying roughly 400 light-years from Earth in the constellation Leo, CW LEonis is a carbon star — a luminous type of red giant star with a carbon-rich atmosphere. The dense clouds of sooty gas and dust engulfing this dying star were created as the outer layers of CW Leonis itself were thrown out into the void.

When small to intermediate-mass stars run out of hydrogen fuel in their cores, the outwards pressure that balances the crush of gravity within their cores falls out of equilibrium, causing the star to start collapsing. As the core collapses, the shell of plasma surrounding the core becomes hot enough to begin fusing hydrogen, generating enough heat to dramatically expand the outer layers of the star and turn it into a bloated red giant. Stars in that phase of life eject huge amounts of gas and dust outwards into space, eventually jettisoning their outer layers. In the case of the carbon star CW Leonis, this process has surrounded the star with a dense pall of sooty dust. As the closest carbon star to Earth, CW Leonis gives astronomers the chance to understand the interaction between the star and its surrounding envelope.

This is a particularly interesting object to study as the envelope of CW

CW Leonis glowers from deep within a thick shroud of dust in this image from the NASA/ESA Hubble Space Telescope. Lying roughly 400 light-years from Earth in the constellation Leo, CW Leonis is a carbon star — a luminous type of red giant star with a carbon-rich atmosphere. The dense clouds of sooty gas and dust engulfing this dying star were created as the outer layers of CW Leonis itself were thrown out into the void. [ESA/Hubble & NASA, T. Ueta, H. Kim]

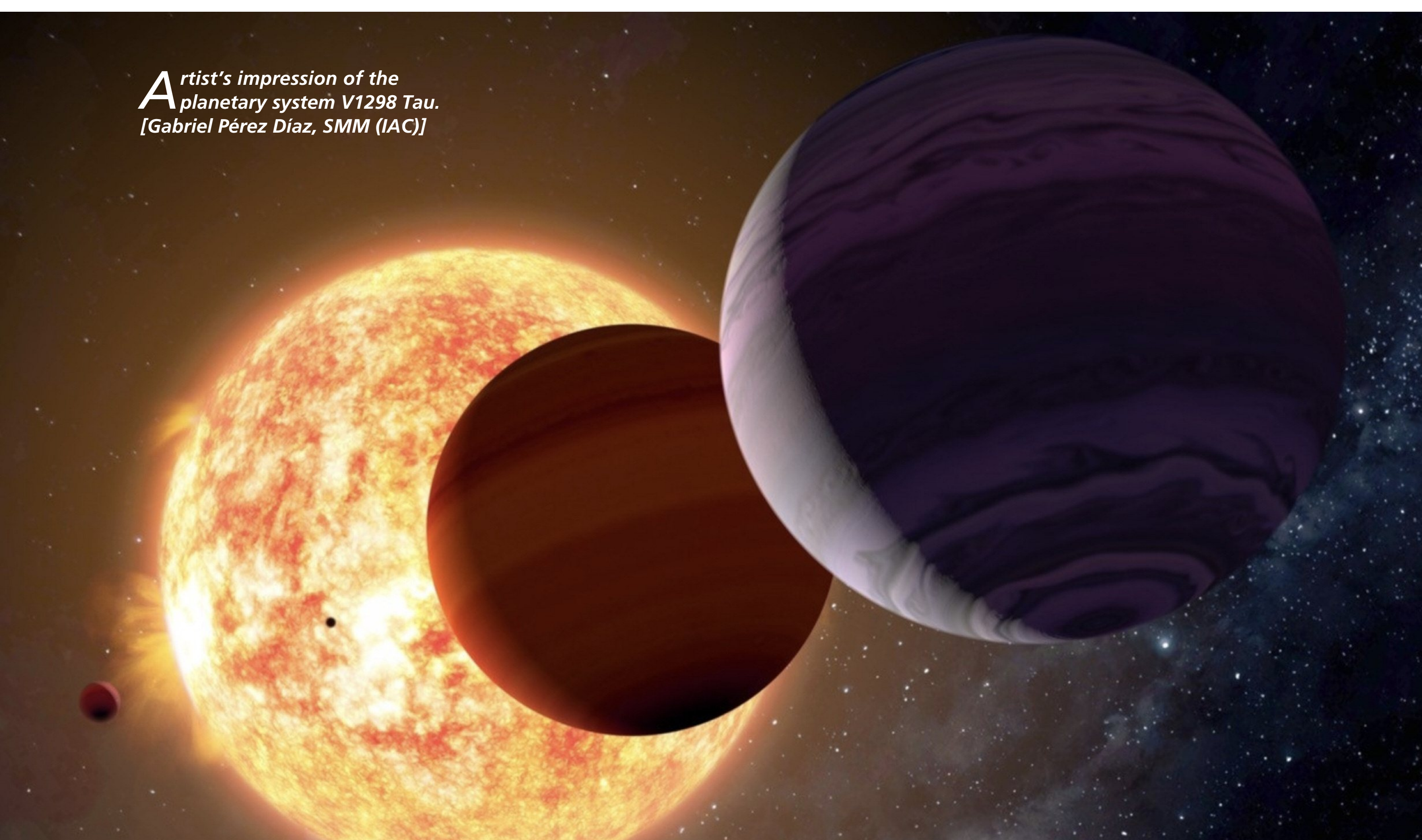
Leonis is relatively turbulent, with a complex inner structure that astronomers believe may be sculpted by a nearby companion star.
The bright beams of light radiating outwards from CW Leonis are one of the most intriguing parts of this image, as they've changed in brightness within a 15 year period — an incredibly short span of time in astronomical terms.
Astronomers speculate that gaps in the shroud of dust surrounding CW Leonis may allow these beams of starlight to pierce through and illuminate dust further from the star. However the exact cause of the dramatic changes in their brightness is as yet unexplained.
Detailed Hubble observations of CW Leonis taken over the last two decades also show the expansion of ring-like threads of ejected material around the star — CW Leonis's sloughed-off outer layers.
This image incorporates observations from 2011 and 2016 by one of Hubble's workhorse instruments, the Wide Field Camera 3. CW Leonis is brightest in the red filters, R and I, and therefore the simmering orange colour pervading the centre of the image well represents the real colour of the star.

Zoom into CW Leonis. [ESA/Hubble, NASA, Dark Energy Survey/DOE/FNAL/NOIRLab/NSF/AURA, Digitized Sky Survey 2, E. Slawik, N. Risinger, M. Zamani]

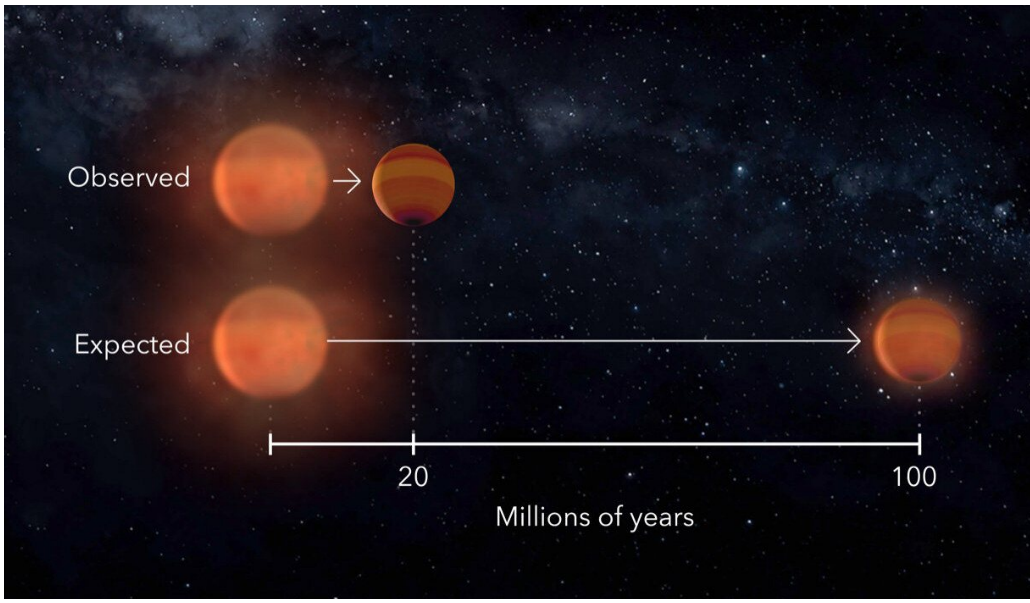
Giant planets could reach "maturity" much earlier than previously thought

by IAC - Outreach Unit

An international team of scientists, in which researchers from the Instituto de Astrofísica de Canarias (IAC) participate together with other institutions from Spain, Italy, Germany, Belgium, UK, and Mexico, has been able to measure the masses of the giant planets of the V1298 Tau system, just 20 million year old. Masses for such young giant planets had not been obtained previously, and this is the first evidence that these objects have already reached their final size at very early stages of their evolution. For this study they have used radial velocity measurements from the HARPS-N spectrographs, at the Roque de los Muchachos Observatory (ORM), and CARMENES, at the Calar Alto Observatory. The results



Artist's impression of the planetary system V1298 Tau. [Gabriel Pérez Díaz, SMM (IAC)]



Comparison of the expected and observed contraction time for the planets in the V1298 Tau system. [Gabriel Pérez Díaz, SMM]

are published in the journal *Nature Astronomy*. The study, led by the IAC researcher Alejandro Suárez Mascareño, reports the measurement of the masses of two giant planets that orbit the young solar-type star V1298 Tau. They were discovered in 2019 by a team lead by Trevor David (JPL) using data from NASA's Kepler space telescope, which allowed the measurement of their sizes, slightly smaller than Jupiter, and of their orbital periods, 24 and 40 days for V1298 Tau b and e, respectively.

"The characterization of very young planets is extraordinarily difficult," says Alejandro Suárez Mascareño, first author of the publication. The parent stars have very high levels of activity and until very recently it was unthinkable to even try. And he adds: *"Only thanks to the combination of detections made with space telescopes, combined with intense radial velocity campaigns from Earth-based observatories and the use of the most advanced analysis techniques, it was possible to begin to see what is happening in such early stages of the evolution of planetary systems."* In fact, for the new measurements of the planetary masses, it was necessary to separate the signals generated by these planets from the signal generated by the star's activity, almost ten times larger.

The study shows that the masses and radii of the planets V1298 Tau b and c are surprisingly similar to those of the giant planets of the Solar System or in other old extra-solar systems. These measurements, which are the first to be obtained of such young giant planets, allow us to test current ideas about the formation of planetary systems. *"For many years, theoretical models have indicated that giant planets begin their evolution as bodies with a larger size, and later they contract over hundreds millions or even billions of years,"* explains Víctor J. Sánchez Béjar, researcher at the IAC and co-author of the work. *"We now know that they can actually reach a size similar to that of the planets in the Solar System in a very short time,"* he notes.

The study of young systems gives researchers clues about what happened during the infancy of our solar system. *"We still do not know if V1298 Tau is a normal case and its evolution is similar to that of most planets or if we are facing an exceptional case; if this were the normal scenario, it would mean that the evolution of planets like Jupiter and Saturn could have been very different from what we think,"* comments Nicolas Lodieu, a researcher at the IAC and also a co-author of the work. The results of this work thus help to build a more solid idea of the early evolution of planetary systems like ours.

To achieve the measurement of these masses, the study has required a significant observational effort and the collaboration of multiple observatories and institutions from different countries. It has been necessary to combine radial velocity measurements from various instruments such as the high-resolution HARPS-N ultrastable spectrograph, installed at the Roque de los Muchachos Observatory's Telescopio Nazionale Galileo (TNG); the CARMENES high resolution spectrograph, installed at the Calar Alto observatory; the HERMES spectrograph, installed on the Mercator telescope, also at the ORM; and the SES spectrograph, installed in the STELLA telescope at the Teide Observatory. Observations taken from the Las Cumbres Observatory, a network of telescopes located around the world, have been used to continuously monitor the variations of the star's activity. ■

The most distant detection yet of fluorine in star-forming galaxy

by ESO - Bárbara Ferreira

A new discovery is shedding light on how fluorine — an element found in our bones and teeth as fluoride — is forged in the Universe. Using the Atacama Large Millimeter/submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, a team of astronomers have detected this element in a galaxy that is so far away its light has taken over 12 billion years to reach us. This is the first time fluorine has been spotted in such a distant star-forming galaxy.

“We all know about fluorine because the toothpaste we use every day contains it in the form of fluoride,” says Maximilien Franco from the University of Hertfordshire in the UK, who led the new study, published in *Nature Astronomy*. Like most elements around us, fluorine is created inside stars but, until now, we did not know exactly how this element was produced. *“We did not even know which type of stars produced the majority of fluorine in the Universe!”*

Franco and his collaborators spotted fluorine (in the form of hydrogen fluoride) in the large clouds of gas of the distant galaxy NGP–190387, which we see as it was when the Universe was only 1.4 billion years old, about 10% of its current age. Since stars expel the elements they form in their cores as they reach the end of their lives, this detection implies that the stars that created fluorine must have lived and died quickly.

The team believes that Wolf–Rayet stars, very massive stars that live only a few million years, a blink of the eye in the Universe’s history, are the most likely production sites of fluorine. They are needed to explain the amounts of hydrogen fluoride the team spotted, they say. Wolf–Rayet stars had been suggested as possible sources of cosmic fluorine before, but astronomers did not know until now how important they were in producing this element in the early Universe.

“We have shown that Wolf–Rayet stars, which are among the most massive stars known and can explode violently as they reach the

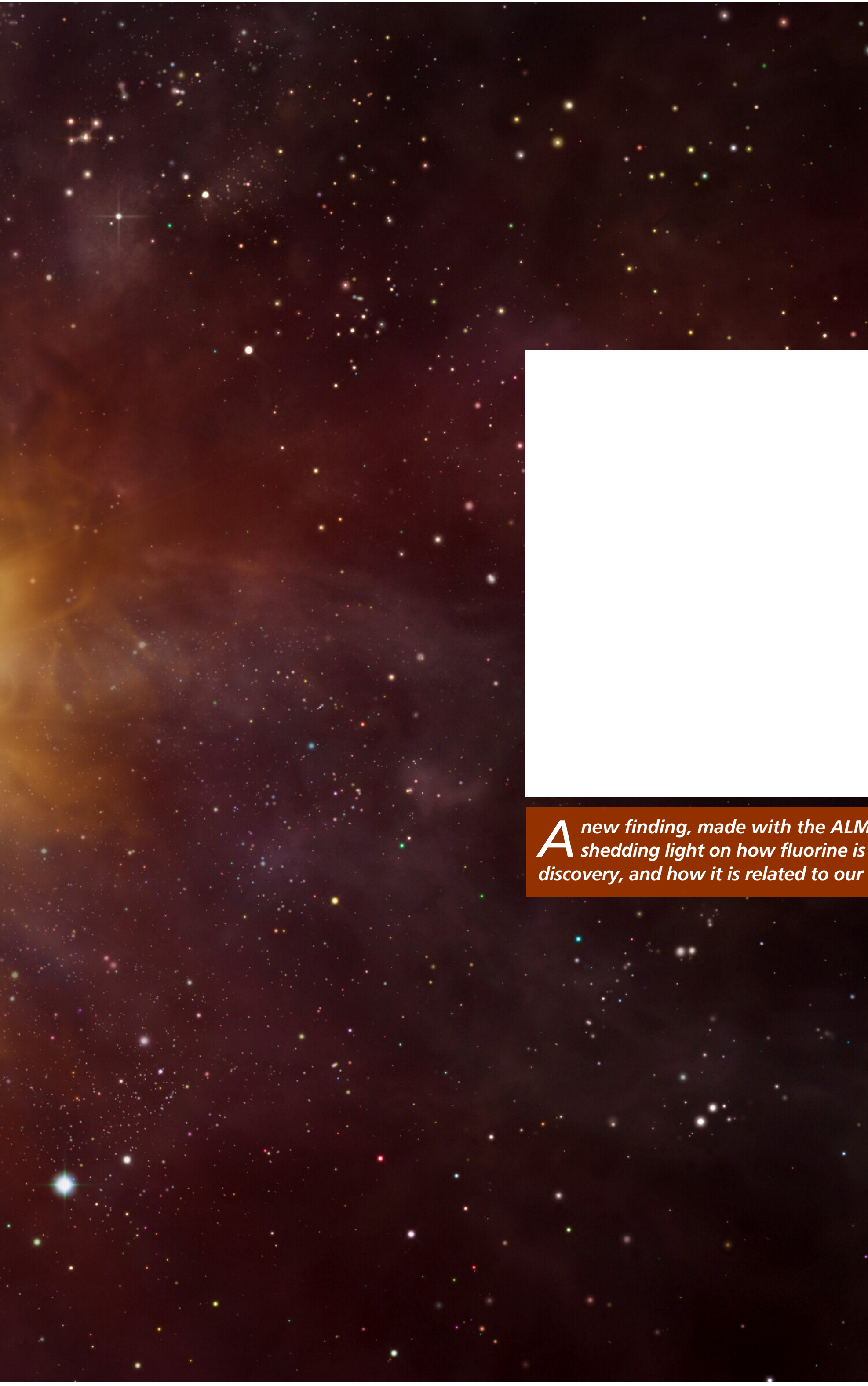
This artist’s impression shows NGP–190387, a star-forming, dusty galaxy that is so far away its light has taken over 12 billion years to reach us. [ESO/M. Kornmesser]

This artist's impression shows the bright core of a Wolf–Rayet star surrounded by a nebula of material which has been expelled by the star itself. Wolf–Rayet stars are hot and massive with lifespans of a few million years. They are thought to end in dramatic supernova explosions, ejecting the elements forged in their cores into the cosmos. [ESO/L. Calçada]

end of their lives, help us, in a way, to maintain good dental health!" jokes Franco.

Besides these stars, other scenarios for how fluorine is produced and expelled have been put forward in the past. An example includes pulsations of giant, evolved stars with masses up to few times that of our Sun, called asymptotic giant branch stars. But the team believes these scenarios, some of which take billions of years to occur, might not fully explain the amount of fluorine in NGP–190387.

"For this galaxy, it took just tens or hundreds of millions of years to have fluorine levels comparable to those found in stars in the Milky Way, which is 13.5 billion years old. This was a totally unexpected result," says Chiaki Kobayashi, a professor at



A new finding, made with the ALMA observatory, in which ESO is a partner, is shedding light on how fluorine is forged in the Universe. Find out more in this discovery, and how it is related to our dental hygiene, in this video summary. [ESO]

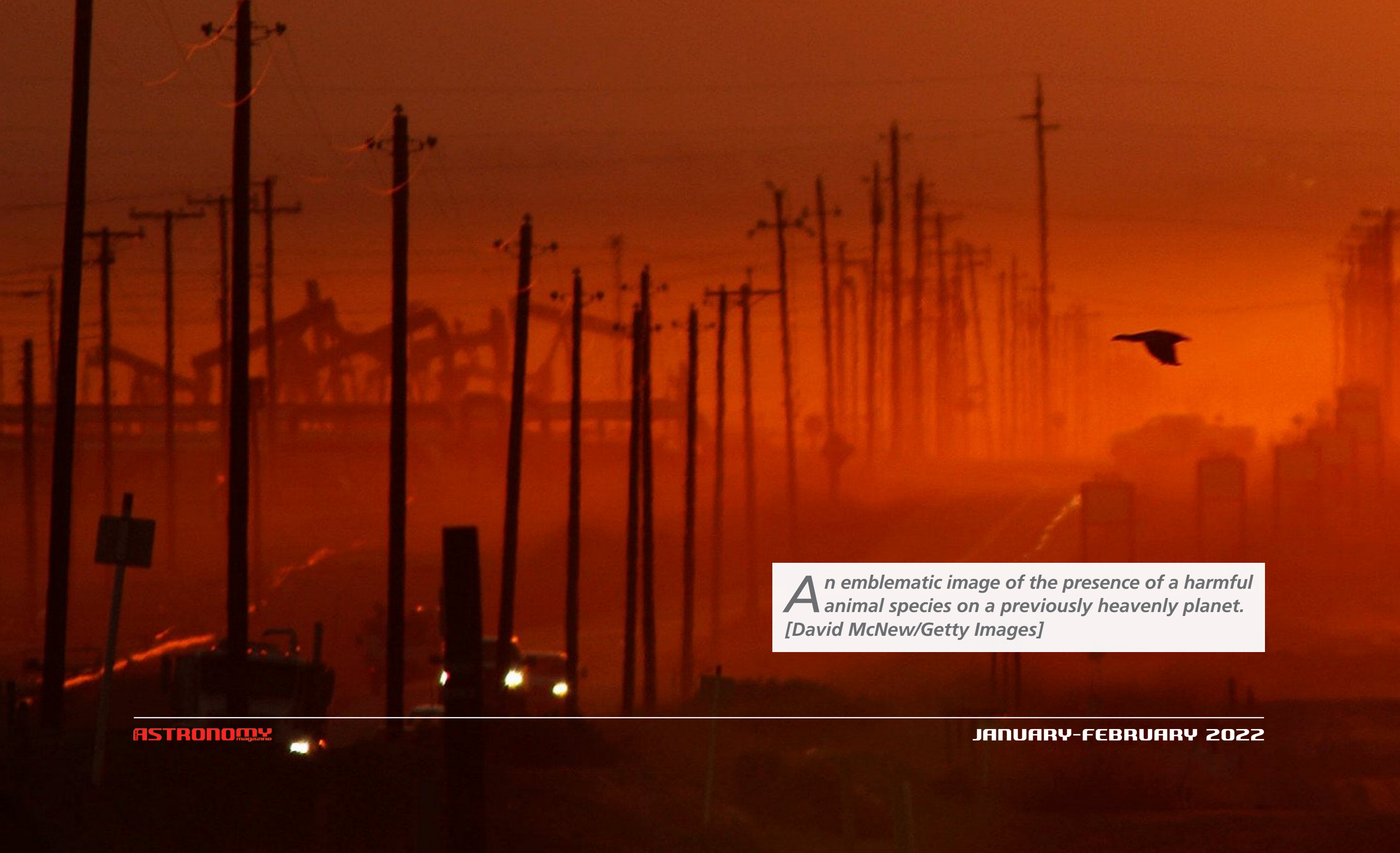
the University of Hertfordshire. *"Our measurement adds a completely new constraint on the origin of fluorine, which has been studied for two decades."*
The discovery in NGP–190387 marks one of the first detections of fluorine beyond the Milky Way and its neighbouring galaxies. Astronomers have previously spotted this element in distant quasars, bright objects powered by supermassive black holes at the centre of some galaxies. But never before had this element been observed in a star-forming galaxy so early in the history of the Universe.
The team's detection of fluorine was a chance discovery made possible thanks to the use of space and ground-based observatories. NGP–190387, originally discovered with the European Space Agency's Herschel Space Observatory and later observed with the Chile-based ALMA, is extraordinarily bright for its distance. The ALMA data confirmed that the exceptional luminosity of NGP–190387 was partly caused by another known massive galaxy, located between NGP–190387 and the Earth, very close to the line of sight. This massive galaxy amplified the light observed by Franco and his collaborators, enabling them to spot the faint radiation emitted billions of years ago by the fluorine in NGP–190387.
Future studies of NGP–190387 with the Extremely Large Telescope (ELT) — ESO's new flagship project, under construction in Chile and set to start operations later this decade — could reveal further secrets about this galaxy. *"ALMA is sensitive to radiation emitted by cold interstellar gas and dust,"* says Chentao Yang, an ESO Fellow in Chile. *"With the ELT, we will be able to observe NGP–190387 through the direct light of stars, gaining crucial information on the stellar content of this galaxy."* ■

The Earth doesn't give a damn about global warming

by Michele Ferrara

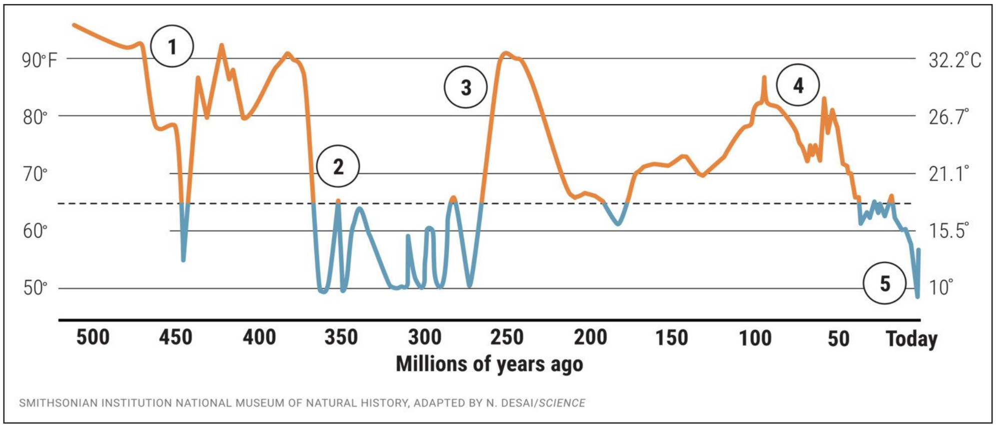
revised by Damian G. Allis
NASA Solar System Ambassador

To what extent is the increase in greenhouse gas levels in the atmosphere attributable to human activities? Nobody knows exactly and, depending on the time frames considered and the economic interests at stake, the estimates vary incredibly from a few percentage points to 100%. The contradictions in the data are there for all to see, and it is likely that the answer lies somewhere in between. It is established that, since the beginning of the industrial revolution (second half of the 1700s), the concentration of atmospheric carbon dioxide (CO_2, the most famous but not the most dangerous greenhouse gas) has grown by 48% (NASA). Likely, this value also includes a greater contribution by the main natural sources of atmospheric carbon dioxide: degassing of the oceans, decomposition of biomass, volcanic activity, forest and wood fires, respiration of organisms, alteration of carbonate



An emblematic image of the presence of a harmful animal species on a previously heavenly planet. [David McNew/Getty Images]

rocks by weathering, and more. However, the contribution of natural sources is generally offset by processes such as chlorophyll photosynthesis, direct absorption into the oceans, creation of soil and peat, and so on. The dynamic interchange between the geosphere, hydrosphere, atmosphere, and biosphere, known as the "carbon cycle," is the basis for the amount of carbon dioxide present in the atmosphere at any given time. Today, around 410 parts per million (ppm) of CO_2 are measured in the atmosphere, or 0.041% of the total atmospheric composition. In the last 800,000 years, which include glaciations and interglacial periods, characterized respectively by less and more atmospheric CO_2, the values of this gas have never exceeded the threshold of 300 ppm. In the 60s of the last century, human activities had already raised that threshold to 320 ppm, but it is only in the last six decades that we have significantly contributed to the abundance of CO_2, a growth that in geological terms can be defined as instantaneous. The last time the CO_2 concentration reached levels comparable to the current ones was more than three million years ago, during the so-called "mid-Pliocene Warm Period" (mPWP). At that time, average temperatures exceeded those of the pre-industrial era by 2-3 °C and sea levels were at least 7-10 meters higher than they are today.

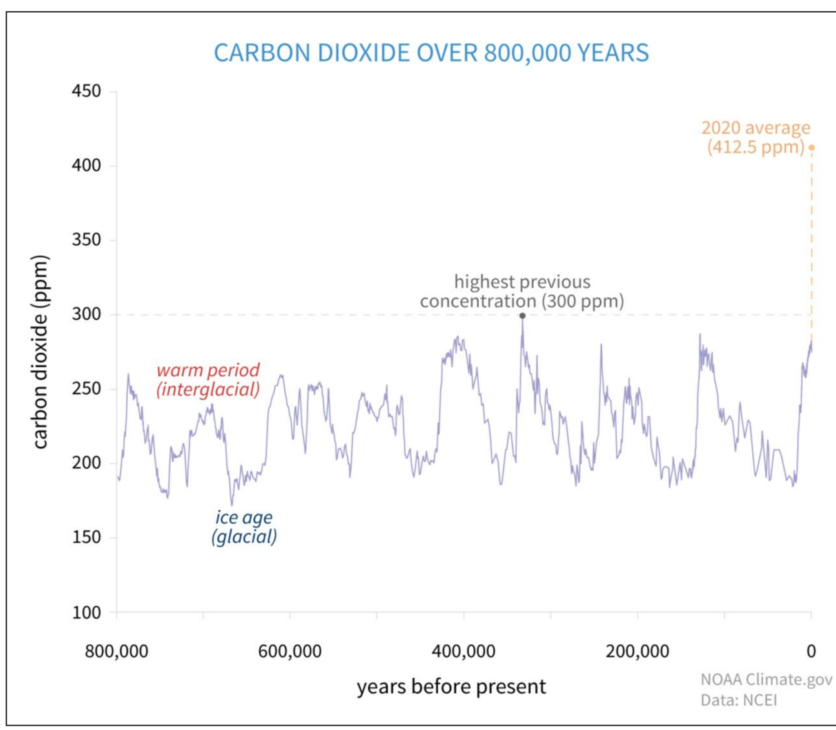


Preliminary results from a Smithsonian Institution project led by Scott Wing and Paul Huber, showing Earth's average surface temperature over the past 500 million years. For most of the time, global temperatures appear to have been too warm (red portions of line) for persistent polar ice caps. The most recent 50 million years are an exception. A preliminary global temperature curve shows that marine life diversified in extreme heat (1) before land-based plants absorbed carbon dioxide (CO_2) and polar ice caps formed (2). Volcanoes and erosion swung CO_2 levels up and down (3), but mammals evolved in a warm period (4). Now, humans are rapidly warming the climate again (5). Image adapted from the Smithsonian National Museum of Natural History.

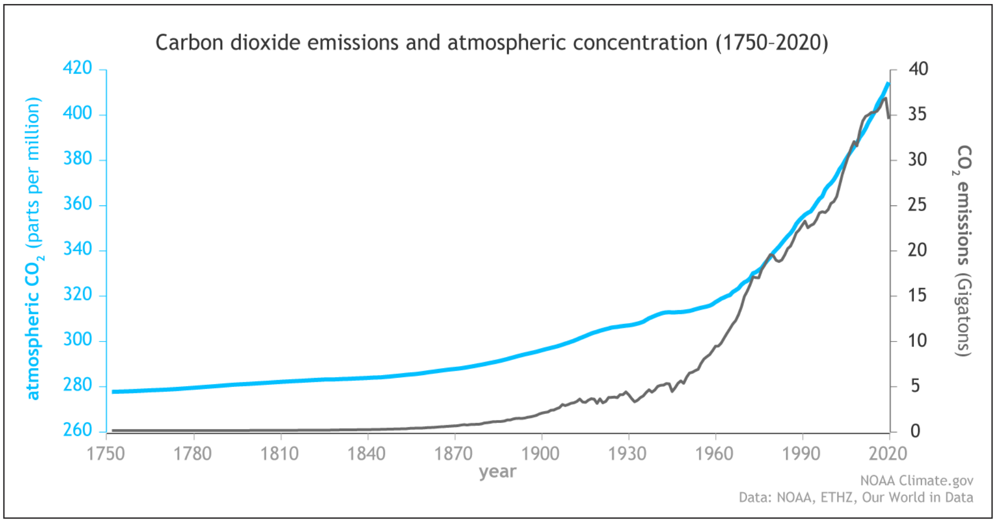
This should be a real warning for humanity, which risks experiencing similar scenarios within one or two centuries if the release of CO_2 into the atmosphere is not significantly reduced.

Although the phenomenon has been known for a long time, global warming seems to have become a problem only recently, due to the exacerbation of some meteorological phenomena that affect people, their assets, and their economic activities with greater violence than in the past.

Those phenomena are the normal and predictable consequences of the increased energy accumulated in the troposphere. Compared to the pre-industrial average values, today we measure an average surface temperature higher than 1.5 °C above previous stable values, with the goal to contain the increase to within 2 °C in the next decades to avoid reaching the notorious "point of no return." This expression, too often interpreted as "the end of the world," essentially concerns only mankind because the biosphere, as a whole, would be minimally affected by global warming that were to continue at current rates, even up to and exceeding the levels of the mPWP. Almost all animal and plant



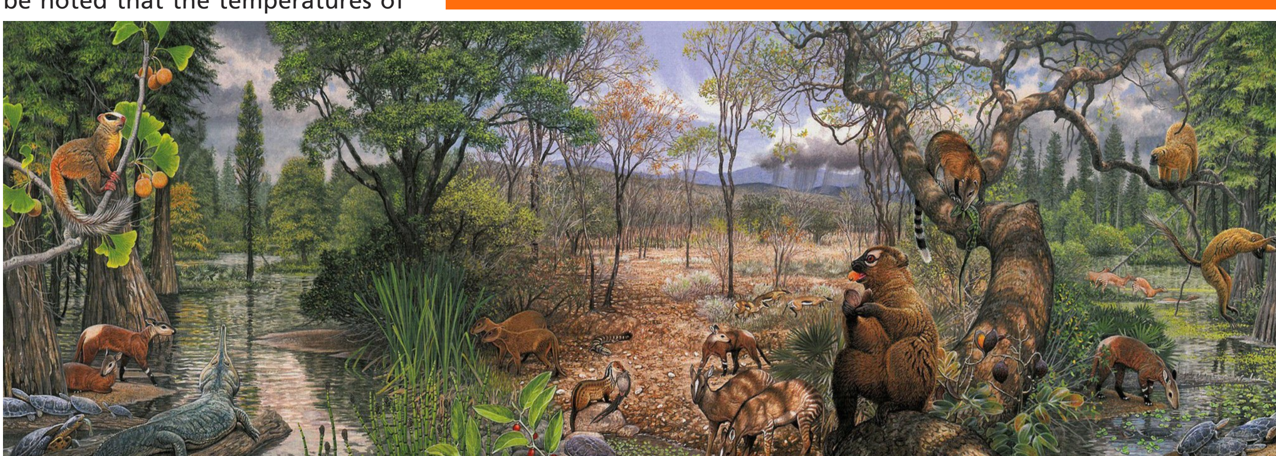
Global atmospheric carbon dioxide concentrations (CO_2) in parts per million (ppm) for the past 800,000 years. The peaks and valleys track ice ages (low CO_2) and warmer interglacials (higher CO_2). During these cycles, CO_2 was never higher than 300 ppm. On the geologic time scale, the increase (orange dashed line) looks virtually instantaneous. Graph by NOAA (climate.gov) based on data from Lüthi, et al., 2008, via the NOAA NCEI Paleoclimatology Program.

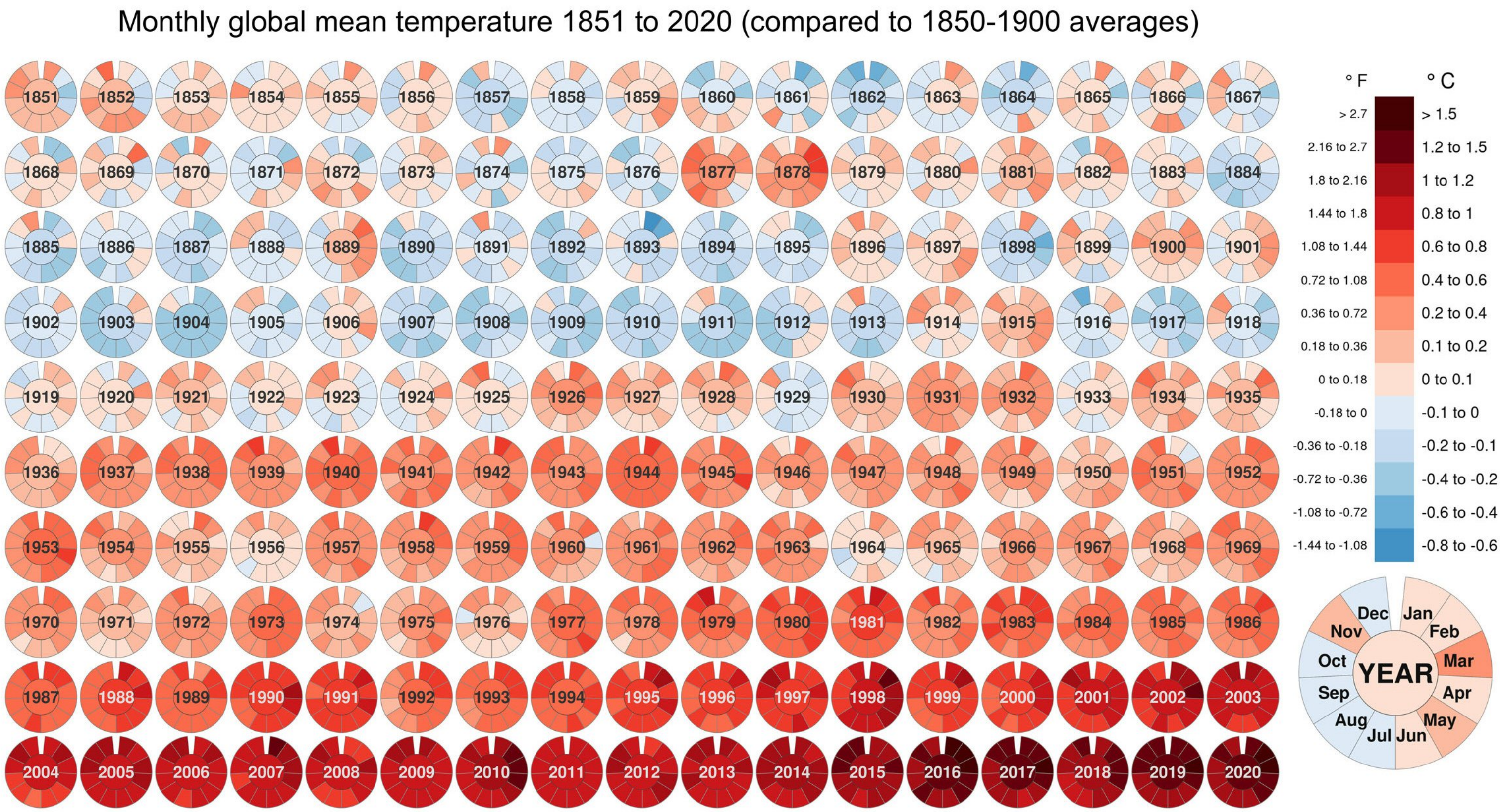


The amount of carbon dioxide in the atmosphere (blue line) has increased along with human emissions (gray line) since the start of the Industrial Revolution in 1750. Emissions rose slowly to about 5 billion tons per year in the mid-20th century before skyrocketing to more than 35 billion tons per year by the end of the century. NOAA (climate.gov) graph, adapted from original by Dr. Howard Diamond (NOAA ARL). Atmospheric CO_2 data from NOAA and ETHZ. CO_2 emissions data from Our World in Data and the Global Carbon Project.

species would adapt gradually, changing habits and behaviors. Our ancestors of the Upper Paleolithic (from 35,000 to 12,000 years ago) would certainly not have complained about a few more degrees of higher temperature, while for "Homo Technologicus" an average of half a degree Celsius more per century is already a drama. It should be noted that the temperatures of the mPWP were no more than sweet warmth when compared to those of previous, much warmer periods, during which life proliferated anyway and everywhere. In the last 100 million years, for example, there were at least two long heat peaks, the first of which, called the Cretaceous Thermal Maximum (CTM), occurred around 92 million years ago, while the second, known as the Paleocene-Eocene Thermal Maximum (PETM), manifested itself around 55 million years ago. The geological records from those periods tell us that during the CTM, atmospheric carbon dioxide levels certainly rose over 1000 ppm and possibly even over 2000 ppm. At those levels, average surface temperatures must have been at least 5 to perhaps more than 8 degrees Celsius higher than in the pre-industrial era (in 1750, the average temperature was close to 14 °C or 57 °F; today it is around 15.5 °C or 60 °F). Even during the CTM, sea levels were 50 to 100 me-

Depiction of living biota during the Paleocene-Eocene Thermal Maximum, which occurred around 55 million years ago. Geological and paleontological evidence tells us that life on Earth proliferated wonderfully at that time, although average surface temperatures were over 5 °C higher than today. [National Geographic, Aldo Chiappe]

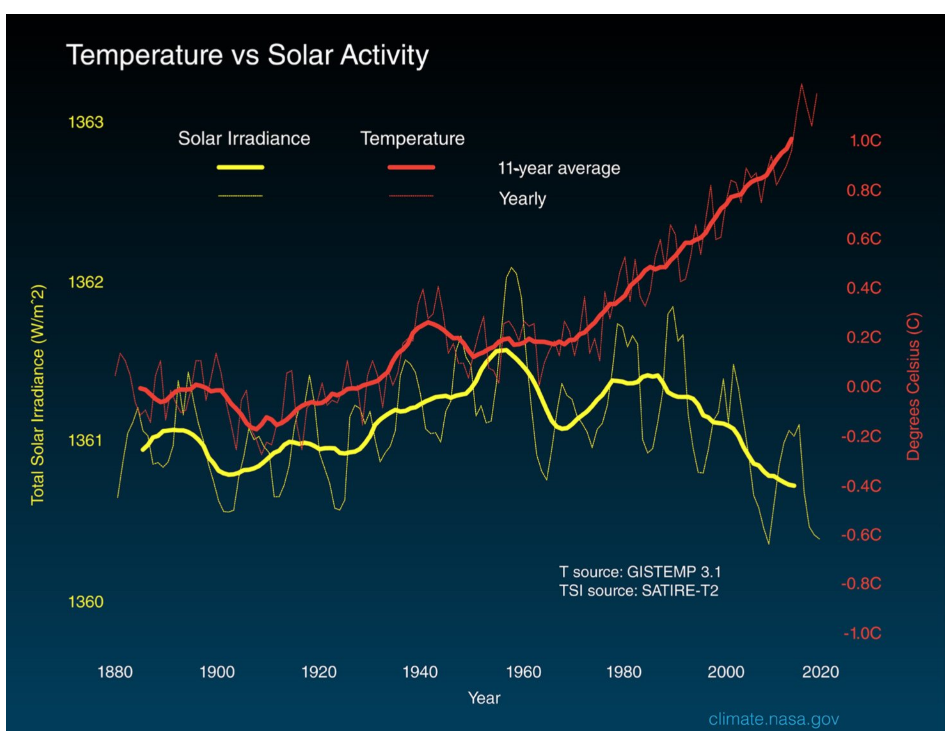




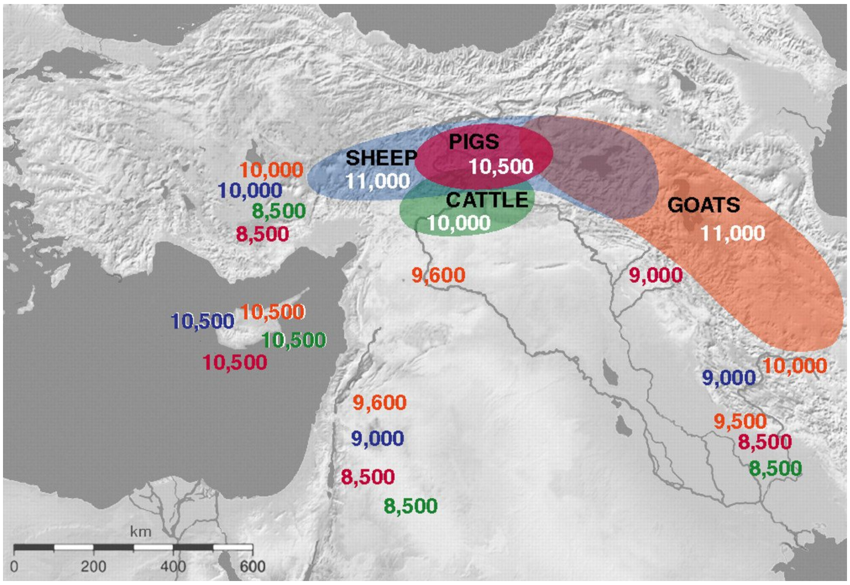
In this global temperature graph, climate data scientist Neil R. Kaye breaks down how monthly average temperatures have changed over nearly 170 years. Temperature values have been benchmarked against pre-industrial averages. [Data: HadCRUT5 - Created by: Neil R. Kay]

ters higher than they are today. In that hot period, there was also much more oxygen in the atmosphere (about 30% versus the current 21%), the ice was completely melted even at the poles, the dinosaurs dominated the world, and the land was covered with lush forests and was rich in evergreen tropical plants. About ten million years after the extinction of the large reptiles, the PETM began, characterized by still-high levels of atmospheric carbon dioxide and with average temperatures on the

This graph compares global surface temperature changes (red line) and the Sun's energy that Earth receives (yellow line) in watts (units of energy) per square meter since 1880. The lighter/thinner lines show the yearly levels while the heavier/thicker lines show the 11-year average trends. Eleven-year averages are used to reduce the year-to-year natural noise in the data, making the underlying trends more obvious. The amount of solar energy that Earth receives has followed the Sun's natural 11-year cycle of small ups and downs with no net increase since the 1950s. Over the same period, global temperature has risen markedly. It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century. [NASA/JPL-Caltech]

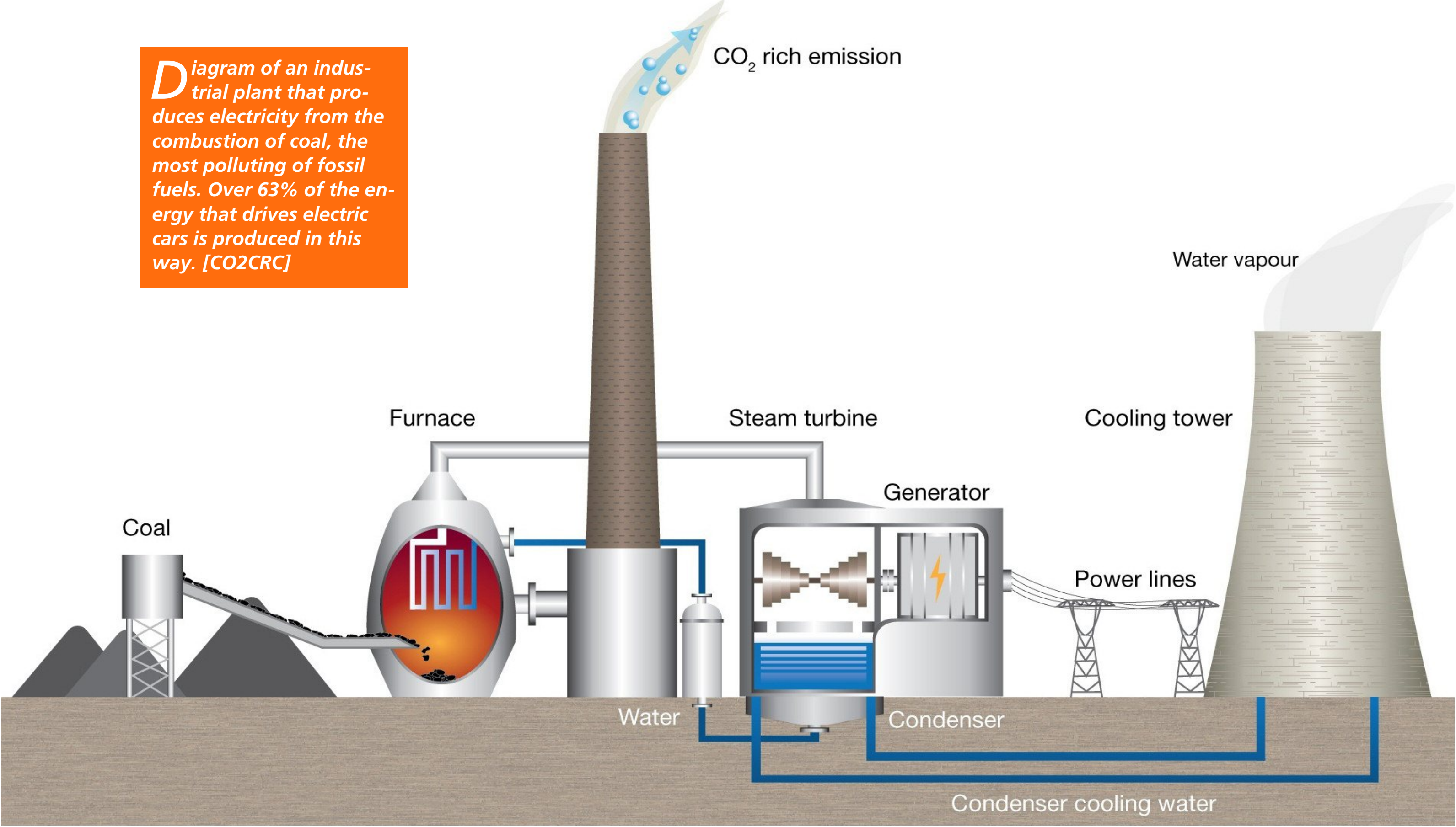


ground and sea levels only slightly lower than those of the CTM.
While the CTM lasted for millions of years, the PETM lasted "only" about 200,000 years. By considering the Earth's climatological history, we realize that the current geological epoch, the Holocene (second epoch of the Quaternary period, after the Pleistocene), which began 11,700 years ago, is, in fact, characterized by unusually cold average temperatures. Geologists consider our epoch as an interglacial period included in the current ice age, which began about 2.5 million years ago with the Pleistocene.
Technically, we are living in an ice age. Why, then, is global warming of just 1.5 °C in two and a half centuries so worrying? The reasons are different, but almost all of them are linked to the fact that, starting about 11,000 years ago, humans became more and more resident, linking all the activities necessary for



This map represents the spread of herding in the Fertile Crescent, between 11,000 and 8,500 years ago. In the same period and in the same regions, agriculture also spread. The two practices made the human being resident and, therefore, more vulnerable to climate change. Legend: orange, goats (Capra hircus); blue, sheep (Ovis aries); green, cattle (Bos taurus); fuchsia, pigs (Sus scrofa).

Diagram of an industrial plant that produces electricity from the combustion of coal, the most polluting of fossil fuels. Over 63% of the energy that drives electric cars is produced in this way. [CO2CRC]



The Earth Overshoot Day marks the date when humanity's demand for ecological resources and services in a given year exceeds what the Earth can regenerate in that year. In 2021, that date was July 29. The infographic shows what the Overshoot Days would have been if the entire world population had burned resources at the rate of the populations of the nations indicated.

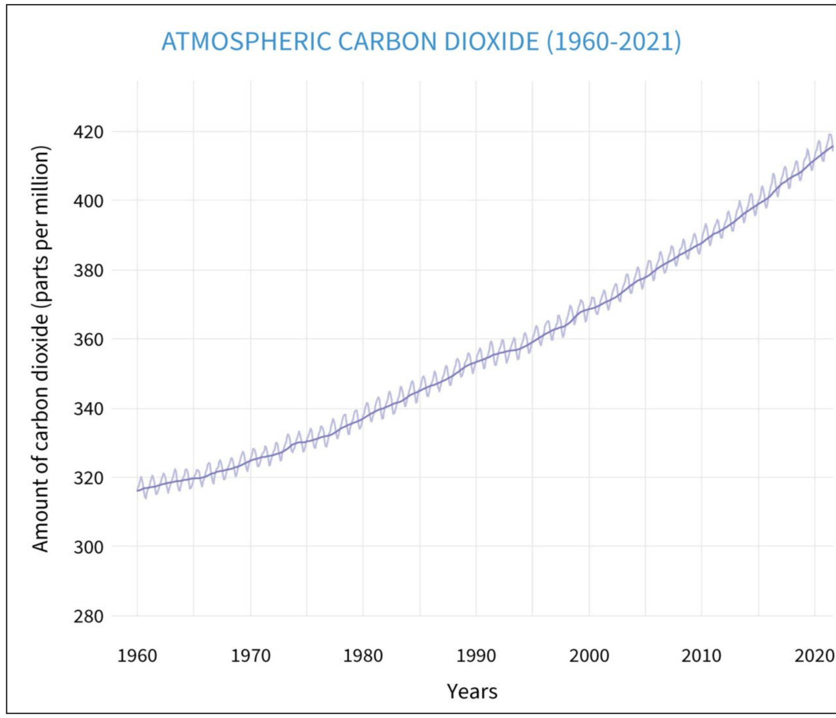
their existence to well-defined territories. Since we stopped following our prey in their periodic migrations and began to take advantage of the fruits made available innately, preferring instead the "certainties" offered by agriculture, stock rearing and industry, we have begun to suffer more and more from climatic phenomena, which are gradually becoming extremes precisely as a consequence of those practices and activities associated with them, directly or indirectly polluting and co-responsible for the increase in atmospheric carbon dioxide levels.

As obvious as they may be, the solutions proposed to tackle global warming are either poorly applicable or impracticable in the near future. Two simple examples should be quite illuminating:

1) Replacing fossil fuels with renewable sources – essentially with electricity. Great idea, but it is a pity that, in 2020, over 63.3% of global electricity production took place by burning fossil fuels (64.8% in 2000, so practically no progress in the last 20 years), and that part of the remaining 36.7% includes nuclear, methane (a potent greenhouse gas) and low, but not zero, carbon-content fuels. Consequently, when the ecologist on duty recharges his green car, he has already given his contribution of CO_2 even before starting the electric motor (and we avoid dwelling on the damage caused to the environment by the supplying of raw materials necessary for the manufacture of rechargeable batteries).

2) Exploiting the only unlimited, renewable, and spread all over the planet source to produce electricity – the Sun. If we consider that the world's electricity consumption amounts to approximately 24,000 billion kilowatt-hours/year and that a good one-square-meter solar panel produces, with average values of solar radiation, about 200 kilowatt-hours/year, it would be necessary to cover an area as large as Pennsylvania with solar panels to give up all the most polluting forms of energy. Currently, only about 3% of the

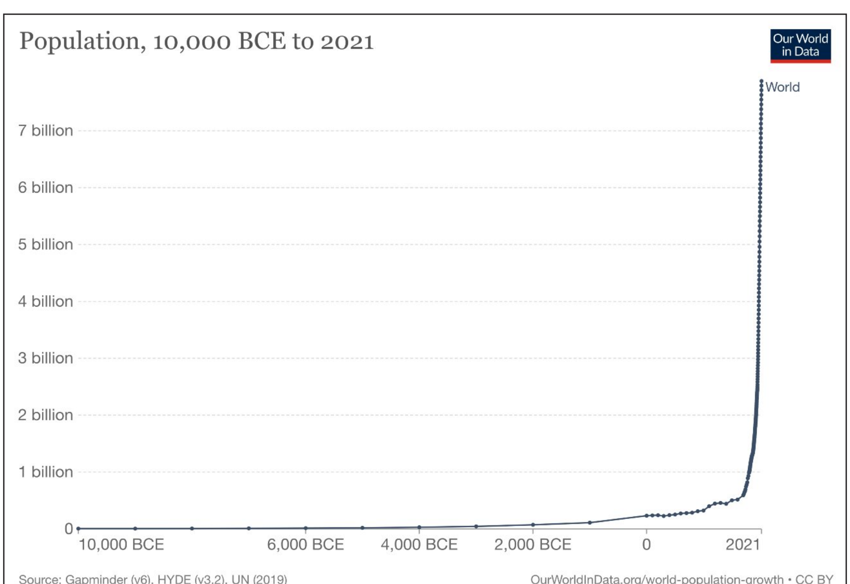
The modern record of atmospheric carbon dioxide levels began with observations recorded at Mauna Loa Observatory in Hawaii. This graph shows the station's monthly average carbon dioxide measurements since 1960 in parts per million (ppm). The seasonal cycle of highs and lows (small peaks and valleys) is driven by summertime growth and winter decay of Northern Hemisphere vegetation. The long-term trend of rising carbon dioxide levels is driven by human activities. NOAA (climate.gov) image, based on data from the NOAA Global Monitoring Lab.



electricity produced in a year comes from photovoltaics. It is understandable that in the short term (decades) it will be impossible to counteract global warming, regardless of the willingness of the various governments to share the provisions of the Intergovernmental Panel on Climate Change. There is also the possibility, currently controversial, that the climate system will continue by inertia to fuel global warming, even if emissions were to be eliminated today. It could take centuries before natural balances are restored.

However, one thing is certain: global warming has grown and will continue to grow in tandem with the exploitation of our planet's resources, an exploitation that is closely related to population growth.

In the year 1700 (just before the beginning of the industrial era), there were 600 million human beings. A hundred years later, there were already a billion. In 1960, the year in which global warming began to spike, the world population numbered 2.5 billion. Now (end of 2021), one step away from our "point of no return," we have exceeded 7.9 billion. In 2050, we will most likely reach 10 billion. By considering that we already consume the resources of 1.7 Earths in a year, how many billions of individuals must humanity reach before cannibalism becomes inevitable?



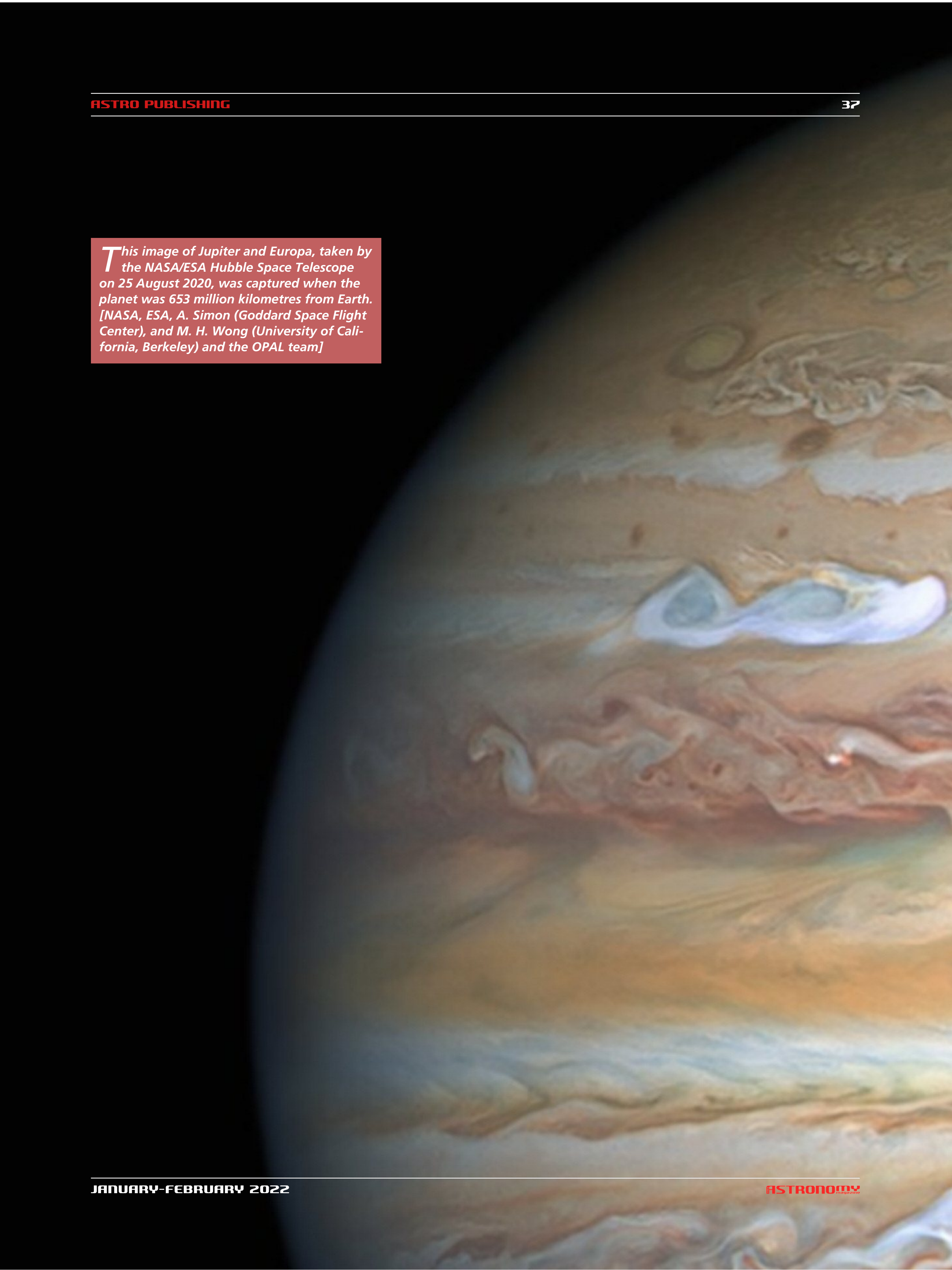
The graph shows the growing number of people living on our planet over the past 12,000 years. A frightening increase: the world population today is nearly two thousand times larger than it was 12 millennia ago, when it amounted to about 4 million people, half of the current population of London.

Evidence of persistent water vapour atmosphere on Europa

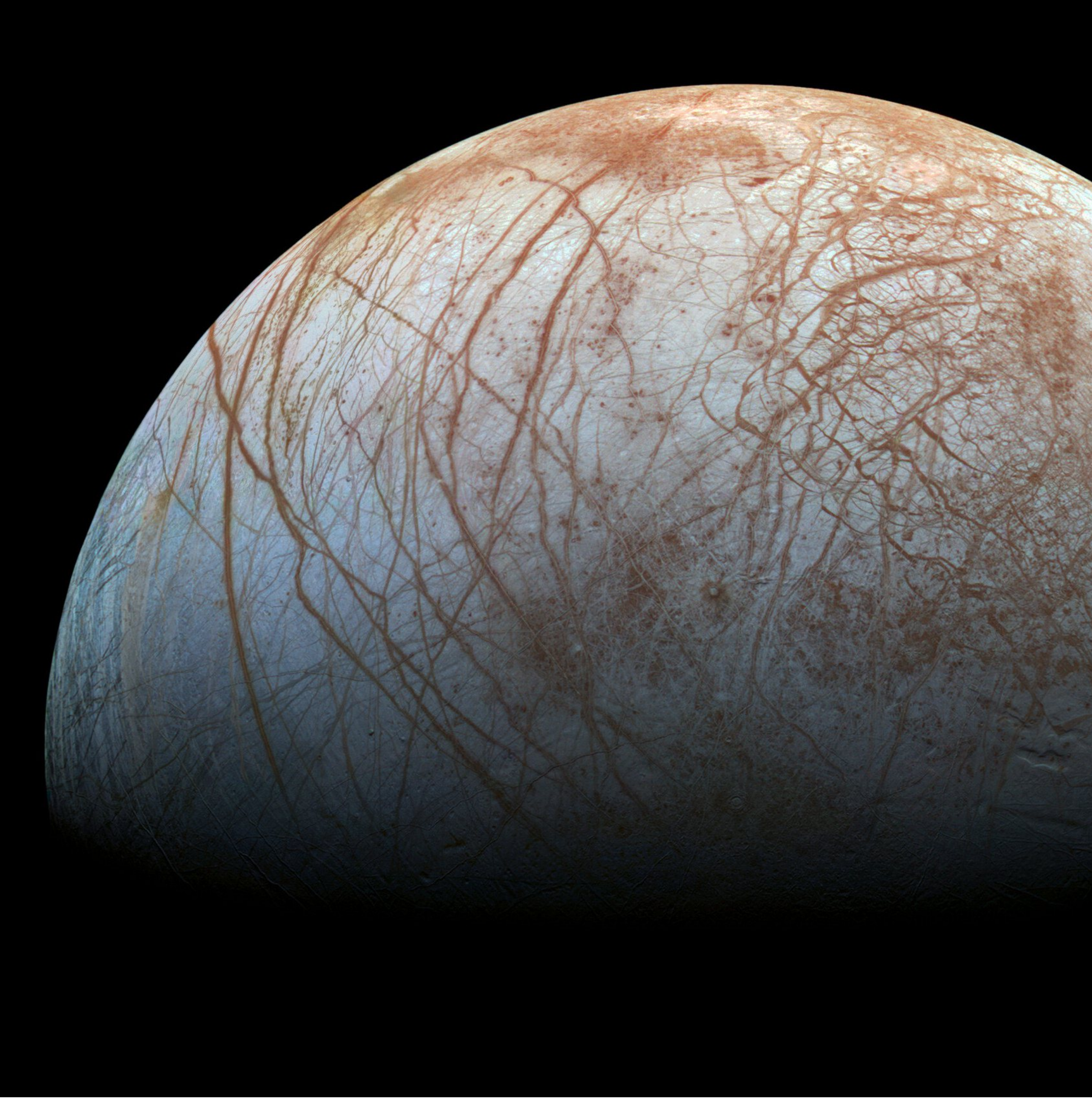
by NASA/ESA
Bethany Downer

Observations by the NASA/ESA Hubble Space Telescope recently revealed water vapour in the atmosphere of Ganymede, one of Jupiter's moons. A new analysis of archival images and spectra has now revealed that water vapour is also present in the atmosphere of Jupiter's icy moon Europa. The analysis found that a water vapour atmosphere is present only on one hemisphere of the moon. This result advances our understanding of the atmospheric structure of icy moons, and helps lay the groundwork for upcoming science missions which will explore Jupiter's icy moons.
Europa — one of Jupiter's 79 moons — is both the sixth closest moon to Jupiter and the sixth largest moon in the Solar System. It is an icy orb larger than the dwarf planet Pluto

Watch this Space Sparks episode to learn about how an astronomer has found evidence of water in Europa's trailing atmosphere. [ESA/Hubble, NASA, N. Bartmann, JPL-Caltech, SwRI, MSSS, J. da Silva]



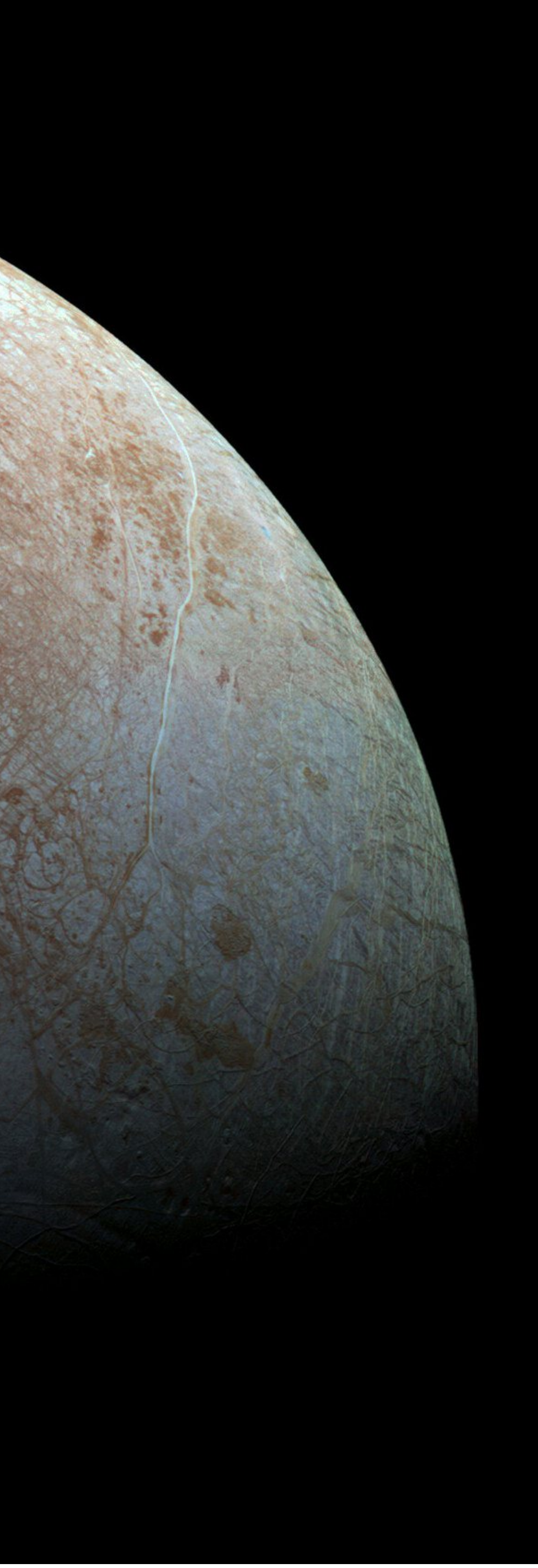
This image of Jupiter and Europa, taken by the NASA/ESA Hubble Space Telescope on 25 August 2020, was captured when the planet was 653 million kilometres from Earth. [NASA, ESA, A. Simon (Goddard Space Flight Center), and M. H. Wong (University of California, Berkeley) and the OPAL team]



with a smooth, icy surface scarred by cracks and fissures. The surface of the moon is a bleak environment with an average temperature of −170 °C and only a tenuous atmosphere. However, astronomers suspect that Europa harbours a vast ocean underneath its icy surface, which some scientists speculate could host extraterrestrial life. Now, for the first time, an astronomer has discovered evidence for persistent water vapour in the atmosphere of Europa. Using a technique that recently resulted in the discovery of water vapour in the atmosphere of Jupiter's moon Ganymede, an astronomer has found evidence of water in Europa's trailing hemisphere — the portion of the moon that is always opposite to its direction of motion.

The asymmetric distribution of water vapour was predicted by previous studies based on computer simulations, but had not previously been detected observationally.

"The observation of water vapour on Ganymede and on the trailing side of Europa advances our under-



The puzzling, fascinating surface of Jupiter's icy moon Europa. The scene shows the stunning diversity of Europa's surface geology. Long, linear cracks and ridges crisscross the surface, interrupted by regions of disrupted terrain where the surface ice crust has been broken up and refrozen into new patterns. This global color view consists of images acquired by the Galileo Solid-State Imaging (SSI) experiment on the spacecraft's first and fourteenth orbits through the Jupiter system, in 1995 and 1998, respectively. Image scale is 1 mile (1.6 kilometers) per pixel. North on Europa is at right. [NASA/JPL-Caltech/SETI Institute]

standing of the atmospheres of icy moons," commented Lorenz Roth of the KTH Royal Institute of Technology in Stockholm, Sweden, the author of this study. *"The detection of a stable H_2O abundance on Europa is surprising because the surface temperatures are so low."*

To make this discovery, Roth delved into archival Hubble datasets, selecting ultraviolet observations of Europa from 1999, 2012, 2014 and 2015 while the moon was at various orbital positions. These observations were all taken with one of Hubble's most versatile instruments — the Space Telescope Imaging Spectrograph (STIS).

These ultraviolet STIS observations allowed Roth to determine the abundance of oxygen — one of the constituents of water — in Europa's atmosphere, and by interpreting the strength of emission at different wavelengths he was able to infer the presence of water vapour.

Previous observations of water vapour on Europa have been associated with transient plumes erupting through the ice, analogous to geysers here on Earth but more than 100 kilometres high.

The phenomena seen in these plume studies were apparently transient inhomogeneities or blobs in the atmosphere. The new results, however, show similar amounts of water vapour to be present spread over a larger area in observations spanning from 1999 to 2015.

This suggests the long-term presence of a water vapour atmosphere on Europa's trailing hemisphere. Despite the presence of water vapour on Europa's trailing hemisphere there is no indication of H_2O on the leading hemisphere of Europa.

Space scientists working to understand these icy moons will soon be able to benefit from a close-up view. ESA's JUpiter ICy moons Explorer (JUICE) mission is being prepared for a tour of Ganymede, Callisto and Europa, Jupiter's three largest icy moons. JUICE is the first large-class mission in ESA's Cosmic Vision 2015–2025 programme and is expected to launch in 2022 and arrive at Jupiter in 2031. The probe will carry an advanced suite of instruments — the most powerful remote sensing payload ever flown to the outer Solar System — and will spend at least three years making detailed observations of the Jovian system. Europa will also be visited by a NASA mission, Europa Clipper, which will perform a series of flybys of the moon and investigate its habitability, as well as selecting a landing site for a future mission.

"This result lays the groundwork for future science based on upcoming missions to the Jovian moons," concluded Roth. *"The more we can understand about these icy moons before spacecraft like JUICE and Europa Clipper arrive, the better use we can make of our limited observing time within the Jovian system."*

This discovery and the insights from upcoming missions such as JUICE will improve our understanding of potentially habitable environments in the Solar System. Understanding the formation and evolution of Jupiter and its moons also helps astronomers gain insights into Jupiter-like exoplanets around other stars. Combined with observations from space telescopes such as the upcoming NASA/ESA/CSA James Webb Space Telescope, this could help astronomers determine if life could emerge in Jupiter-like exoplanetary systems elsewhere in the universe. ■

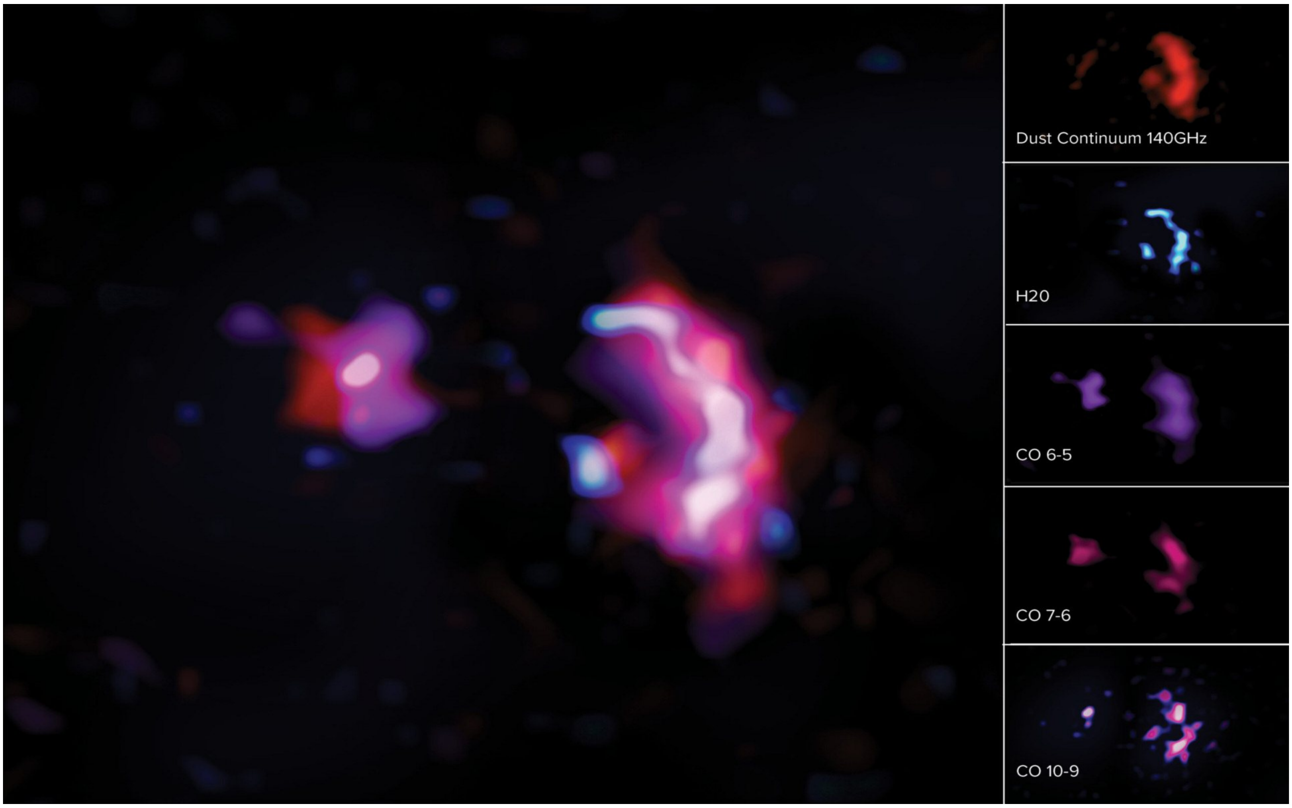
ALMA detects signs of water in a galaxy far, far away

by ALMA Observatory
Nicolás Lira

Water has been detected in the most massive galaxy in the early Universe, according to new observations from the Atacama Large Millimeter/submillimeter Array (ALMA). Scientists studying SPT0311-58 found H_2O, along with carbon monoxide in the galaxy, which is located nearly 12.88 billion light years from Earth. Detection of these two molecules in abundance suggests that the molecular Universe was going strong shortly after the elements were forged in early stars. The new research comprises the most detailed study of molecular gas content of a galaxy in the early Universe to date and the most distant detection of H_2O in a regular star-forming galaxy.

This artist's conception shows the dust continuum and molecular lines of carbon monoxide and water seen in the pair of galaxies known as SPT0311-58. ALMA data reveals abundant CO and H_2O in the larger of the two galaxies, indicating that the molecular Universe was going strong shortly after the elements were initially forged. [ALMA (ESO/ NAOJ/NRAO)/S. Dagnello (NRAO)]

The research is published in *The Astrophysical Journal*.
SPT0311-58 is actually made up of two galaxies, and was first seen by ALMA scientists in 2017 at its location, or time, in the Epoch of Reionization. This epoch occurred at a time when the Universe was just 780 million years old—roughly 5-percent of its current age—and the first stars and galaxies were being born.
Scientists believe that the two galaxies may be merging, and that their rapid star formation is not only using up their gas, or star-forming fuel, but that it may eventually evolve the pair into massive elliptical galaxies like those seen in the Local Universe.
"Using high-resolution ALMA observations of molecular gas in the pair of galaxies known collectively as SPT0311-58 we detected both water and carbon monoxide molecules in the larger of the two galaxies. Oxygen and carbon, in particular, are first-generation elements, and in the molecular forms of carbon monoxide and water, they are critical to life as we know it," said Sreevani Jarugula, an astronomer at the University of Illinois and the principal investigator on the new research. *"This galaxy is the most massive galaxy currently known at high redshift, or the time when the Universe was still very young. It has more gas and dust compared to other galaxies in the early Universe, which gives us plenty of potential opportunities to observe abundant molecules and to better understand how these life-creating elements impacted the development of the early Universe."*
Water, in particular, is the third most abundant molecule in the Universe after molecular hydrogen and carbon monoxide. Previous studies of galaxies in the local and early Universe have correlated water emission and the far-infrared emission from dust. *"The dust absorbs the ul-*



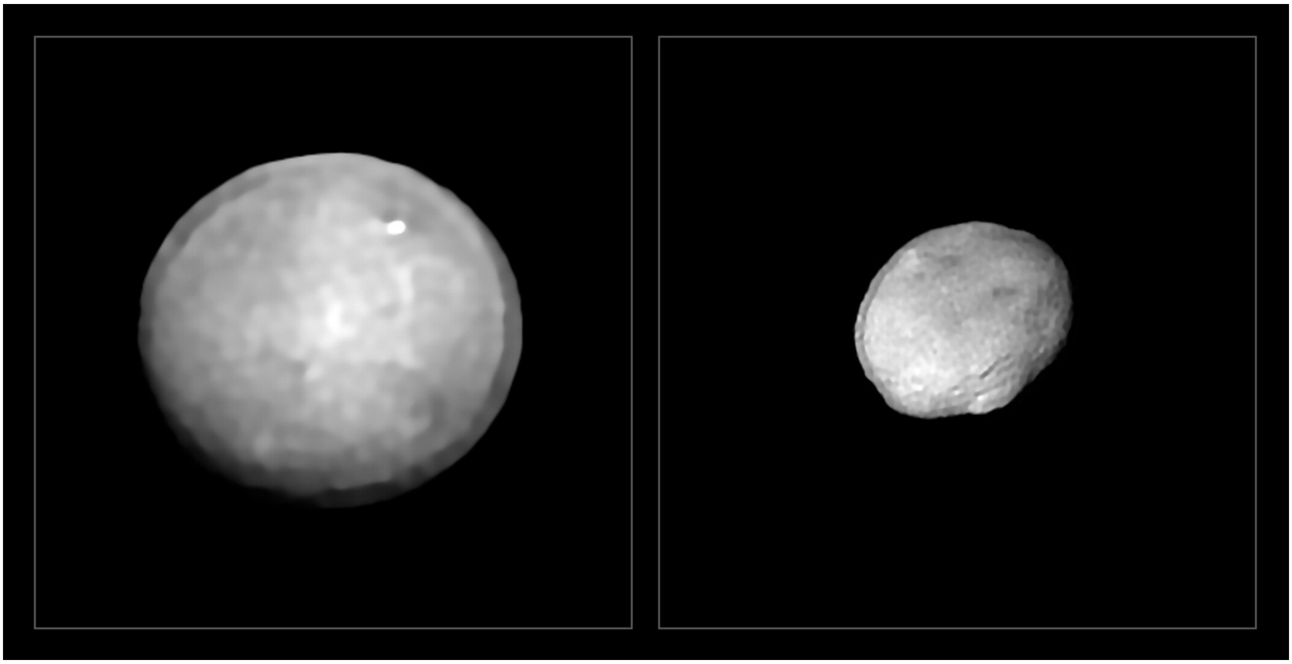
These science images show the molecular lines and dust continuum seen in ALMA observations of the pair of early massive galaxies known as SPT0311-58. On left: A composite image combining the dust continuum with molecular lines for H_2O and CO. On right: The dust continuum seen in red (top), molecular line for H_2O shown in blue (2nd from top), molecular line transitions for carbon monoxide, CO(6-5) shown in purple (middle), CO(7-6) shown in magenta (second from bottom), and CO(10-9) shown in pinks and deep blue (bottom). [ALMA (ESO/NAOJ/NRAO)/S. Dagnello (NRAO)]

traviolet radiation from the stars in the galaxy and re-emits it as far-infrared photons," said Jarugula. *"This further excites the water molecules, giving rise to the water emission that scientists are able to observe. In this case, it helped us to detect water emission in this massive galaxy. This correlation could be used to develop water as a tracer of star formation, which could then be applied to galaxies on a cosmological scale."*
Studying the first galaxies to form in the Universe helps scientists to better understand the birth, growth, and evolution of the Universe, and everything in it, including the Solar System and Earth. *"Early galaxies are forming stars at a rate thousands of times that of the Milky Way,"* said Jarugula. *"Studying the gas and dust content of these early galaxies informs us of their properties, such as how many stars are being formed, the rate at which gas is converted into stars, how galaxies interact with each other and with the interstellar medium, and more."*
According to Jarugula, there's plenty left to learn about SPT0311-58 and the galaxies of the early Universe. *"This study not only provides answers about where, and how far away, water can exist in the Universe, but also has given rise to a big question: How has so much gas and dust assembled to form stars and galaxies so early in the Universe? The answer requires further study of these and similar star-forming galaxies to get a better understanding of the structural formation and evolution of the early Universe."*
"This exciting result, which shows the power of ALMA, adds to a growing collection of observations of the early Universe," said Joe Pesce, astrophysicist and ALMA Program Director at the National Science Foundation. *"These molecules, important to life on Earth, are forming as soon as they can, and their observation is giving us insight into the fundamental processes of a Universe very much different from today's."* ■

VLT images some of the biggest asteroids in our Solar System

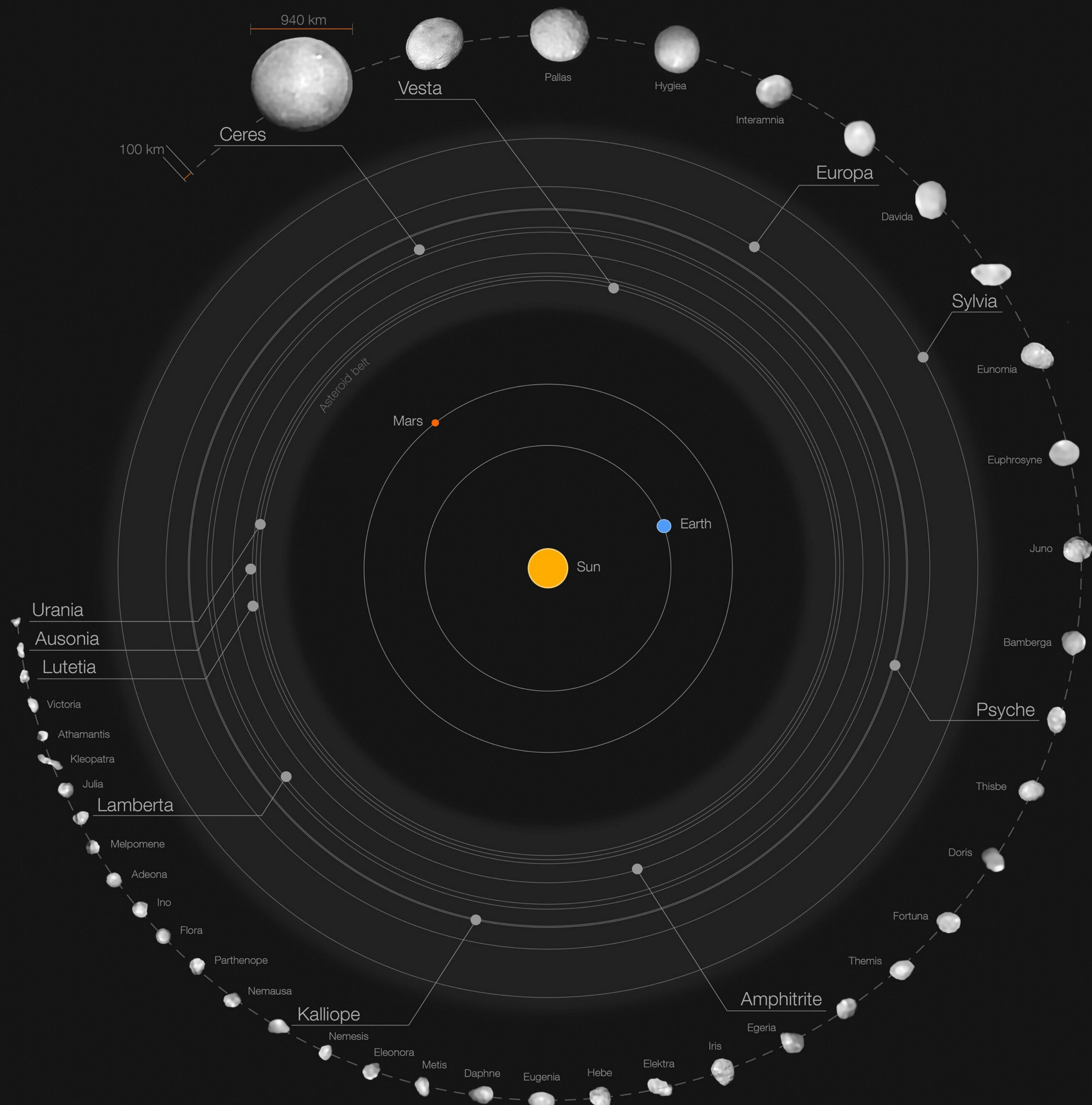
by ESO - Bárbara Ferreira

Using the European Southern Observatory's Very Large Telescope (ESO's VLT) in Chile, astronomers have imaged 42 of the largest objects in the asteroid belt, located between Mars and Jupiter. Never before had such a large group of asteroids been imaged so sharply. The observations reveal a wide range of peculiar shapes, from spherical to dog-bone, and are helping astronomers trace the origins of the asteroids in our Solar System. The detailed images of these 42 objects are a leap forward in exploring asteroids, made possible thanks to ground-based telescopes, and contribute to answering the ultimate



These images have been captured with the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument on ESO's Very Large Telescope as part of a programme that surveyed 42 of the largest asteroids in our Solar System. They show Ceres and Vesta, the two largest objects in the asteroid belt between Mars and Jupiter, approximately 940 and 520 kilometres in diameter. These two asteroids are also the two most massive in the sample. [ESO/Vernazza et al./MISTRAL algorithm (ONERA/CNRS)]

MEET 42 ASTEROIDS IN OUR SOLAR SYSTEM



This poster shows 42 of the largest objects in the asteroid belt, located between Mars and Jupiter (orbits not to scale). The images in the outermost circle of this infographic have been captured with the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument on ESO's Very Large Telescope. The asteroid sample features 39 objects larger than 100 kilometres in diameter, including 20 larger than 200 kilometres. [ESO/M. Kornmesser/Vernazza et al./MISTRAL algorithm (ONERA/CNRS)]

The asteroids presented here, 42 of the largest in our Solar System, were imaged with the European Southern Observatory's Very Large Telescope. The orbits are not to scale.

Astronomers have used the ESO's Very Large Telescope in Chile to image 42 of the biggest main-belt asteroids. Meet some of the 42 in this video summarising the discovery! [ESO]

question of life, the Universe, and everything. *"Only three large main belt asteroids, Ceres, Vesta and Lutetia, have been imaged with a high level of detail so far, as they were visited by the space missions Dawn and Rosetta of NASA and the European Space Agency, respectively,"* explains Pierre Vernazza, from the Laboratoire d'Astrophysique de Marseille in France, who led the asteroid study published in *Astronomy & Astrophysics*. *"Our ESO observations have provided sharp images for many more targets, 42 in total."*

The previously small number of detailed observations of asteroids meant that, until now, key characteristics such as their 3D shape or density had remained largely unknown. Between 2017 and 2019, Vernazza and his team set out to fill this gap by conducting a thorough survey of the major bodies in the asteroid belt.

Most of the 42 objects in their sample are larger than 100 km in size; in particular, the team imaged nearly all of the belt asteroids larger than 200 kilometres, 20 out of 23.

The two biggest objects the team probed were Ceres and Vesta, which are around 940 and 520 kilometres in diameter, whereas the two smallest asteroids are Urania and Ausonia, each only about 90 kilometres. By reconstructing the objects' shapes, the team realised that the observed asteroids are mainly divided into two families. Some are almost perfectly spherical, such as Hygiea and Ceres, while others have a more peculiar, "elongated" shape, their undisputed queen being the "dog-bone" asteroid Kleopatra.

By combining the asteroids' shapes with information on their masses, the team found that the densities change significantly across the sample. The four least dense asteroids studied, including Lamberta and Sylvia, have densities of about 1.3 grams per cubic centimetre, approximately the density of coal. The highest, Psyche and Kalliope, have densities of 3.9 and 4.4 grammes per cubic centimetre, respectively, which is higher than the density of diamond (3.5 grammes per cubic centimetre). This large difference in density suggests the asteroids' composition varies significantly, giving astronomers important clues about their origin. *"Our observations provide strong support for substantial migration of these bodies since their formation. In short, such tremendous variety in their composition can only be understood if the bodies originated across distinct regions in the Solar System,"* explains Josef Hanuš of the Charles University, Prague, Czech Republic, one of the authors of the study. In particular, the results support the theory that the least dense asteroids formed in the remote regions beyond the orbit of Neptune and migrated to their current location.

These findings were made possible thanks to the sensitivity of the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument mounted on ESO's VLT. *"With the improved capabilities of SPHERE, along with the fact that little was known regarding the shape of the largest main belt asteroids, we were able to make substantial progress in this field,"* says co-author Laurent Jorda, also of the Laboratoire d'Astrophysique de Marseille.

Astronomers will be able to image even more asteroids in fine detail with ESO's upcoming Extremely Large Telescope (ELT), currently under construction in Chile and set to start operations later this decade. *"ELT observations of main-belt asteroids will allow us to study objects with diameters down to 35 to 80 kilometres, depending on their location in the belt, and craters down to approximately 10 to 25 kilometres in size,"* says Vernazza. *"Having a SPHERE-like instrument at the ELT would even allow us to image a similar sample of objects in the distant Kuiper Belt. This means we'll be able to characterise the geological history of a much larger sample of small bodies from the ground."* ■

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Hubble gives unprecedented, early view of a supernova

by NASA/ESA / Ann Jenkins

Like a witness to a violent death, NASA's Hubble Space Telescope recently gave astronomers an unprecedented, comprehensive view of the first moments of a star's cataclysmic demise. Hubble's data, combined with other observations of the doomed star from space- and ground-based telescopes, may give astronomers an early warning system for other stars on the verge of blowing up.

"We used to talk about supernova work like we were crime scene investigators, where we would show up after the fact and try to figure out what happened to that star," explained Ryan Foley of the University of California, Santa Cruz, the leader of the team that made this discovery. *"This is a different situation, because we really know what's going on and we actually see the death in real time."*

The supernova, called SN 2020fqv, is in the interacting Butterfly Galaxies, which are located about 60 million light-years away in the constellation Virgo. It was discovered in April 2020 by the Zwicky Transient Facility at the Palomar Observatory in San Diego, California.

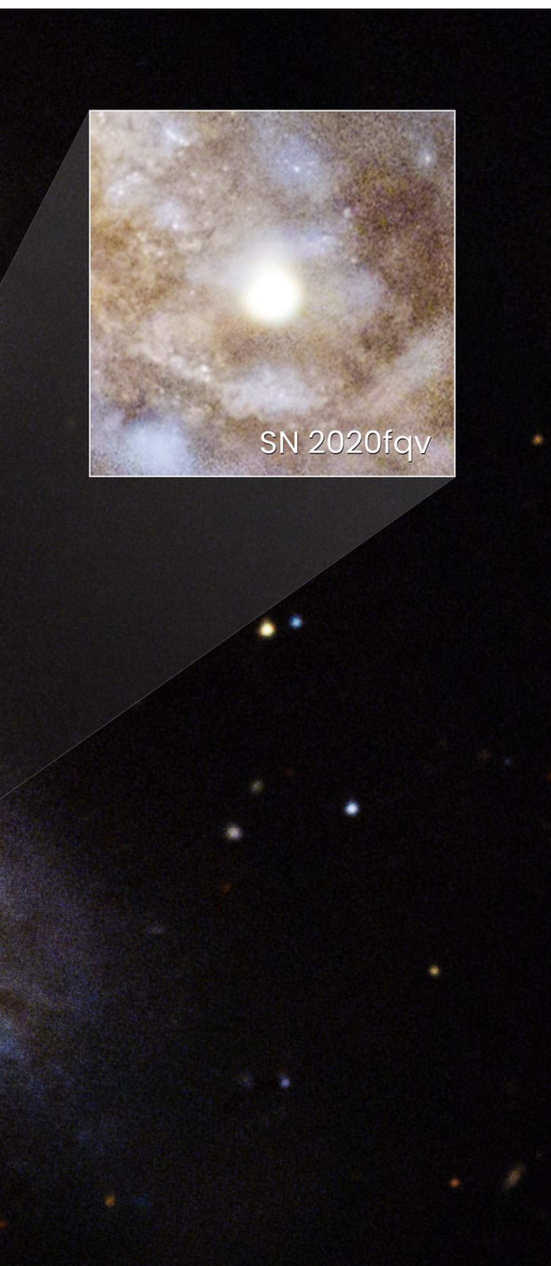
Astronomers realized that the supernova was simultaneously being observed by the Transiting Exoplanet Survey Satellite (TESS), a

Supernova 2020fqv in NGC 4568. [NASA, ESA, Ryan Foley (UC Santa Cruz)]

NASA satellite designed primarily to discover exoplanets, with the ability to detect an assortment of other phenomena. They quickly trained Hubble and a suite of ground-based telescopes on it.

Together, these observatories gave the first holistic view of a star in the very earliest stage of destruction. Hubble probed the material very close to the star, called circumstellar material, mere hours after the explosion.

This material was blown off the star in the last year of its life. These observations allowed astronomers to understand what was happening to the star just before it died.



"We rarely get to examine this very close-in circumstellar material since it is only visible for a very short time, and we usually don't start observing a supernova until at least a few days after the explosion," explained Samaporn Tinyanont, lead author on the study's paper published in the *Monthly Notices of the Royal Astronomical Society*. *"For this supernova, we were able to make ultra-rapid observations with Hubble, giving unprecedented coverage of the region right next to the star that exploded."*

The team looked at Hubble observations of the star going back to the 1990s. TESS provided an image of the system every 30 minutes starting several days before the explosion, through the explosion itself, and continuing for several weeks. Hubble was used again starting only hours after astronomers first detected the explosion. And from studying the circumstellar material with Hubble, the scientists gained an understanding of what was happening around the star in the previous decade. By combining all of this information, the team was able to create a multi-decade look at the star's final years.

"Now we have this whole story about what's happening to the star in the years before it died, through the time of death, and then the aftermath of that," said Foley. *"This is really the most detailed view of stars like this in their last moments and how they explode."*

Tinyanont and Foley called SN 2020fqv "the Rosetta Stone of supernovas." The ancient Rosetta Stone, which has the same text inscribed in three different scripts, helped experts learn to read Egyptian hieroglyphs.

In the case of this supernova, the science team used three different methods to determine the mass of the exploding star. These included comparing the properties and the evolution of the supernova with theoretical models; using information from a 1997 archival Hubble image of the star to rule out higher-mass stars; and using observations to directly measure the amount of oxygen in the supernova, which probes the mass of the star. The results are all consistent: around 14 to 15 times the mass of the Sun. Accurately determining the mass of the star that explodes in a supernova is crucial to understanding how massive stars live and die.

"People use the term 'Rosetta Stone' a lot. But this is the first time we've been able to verify the mass with these three different methods for one supernova, and all of them are consistent," said Tinyanont. *"Now we can push forward using these different methods and combining them, because there are a lot of other supernovas where we have masses from one method but not another."*

In the years before stars explode, they tend to become more active. Some astronomers point to the red supergiant Betelgeuse, which has recently been belching significant amounts of material, and they wonder if this star will soon go supernova. While Foley doubts Betelgeuse will imminently explode, he does think we should take such stellar outbursts seriously.

"This could be a warning system," said Foley. *"So if you see a star start to shake around a bit, start acting up, then maybe we should pay more attention and really try to understand what's going on there before it explodes. As we find more and more of these supernovas with this sort of excellent data set, we'll be able to understand better what's happening in the last few years of a star's life."* ■

Rocky exoplanets are even stranger than we thought

by NOIRLab / Vanessa Thomas

Astronomers have discovered thousands of planets orbiting stars in our galaxy — known as exoplanets. However, it's difficult to know what exactly these planets are made of, or whether any resemble Earth. To try to find out, astronomer Siyi Xu of NSF's NOIRLab partnered with geologist Keith Putirka of California State University, Fresno, to study the atmospheres of what are known as polluted white dwarfs. These are the dense, collapsed cores of once-

Rocky debris, the pieces of a former rocky planet that has broken up, spiral inward toward a white dwarf in this illustration. Studying the atmospheres of white dwarfs that have been "polluted" by such debris, a NOIRLab astronomer and a geologist have identified exotic rock types that do not exist in our Solar System. The results suggest that nearby rocky exoplanets must be even stranger and more diverse than previously thought. [NOIRLab/NSF/AURA/J. da Silva]

By studying the atmospheres of stellar remnants called white dwarfs, two scientists discovered types of rocks not found in our Solar System. This video summarises the discovery. [NOIRLab/NSF/AURA/J. da Silva/NASA's Goddard Space Flight Center/Scott Wiessinger/ESO/M. Kornmesser]

normal stars like the Sun that contain foreign material from planets, asteroids, or other rocky bodies that once orbited the star but eventually fell into the white dwarf and "contaminated" its atmosphere.

By looking for elements that wouldn't naturally exist in a white dwarf's atmosphere (anything other than hydrogen and helium), scientists can figure out what the rocky planetary objects that fell into the star were made of.

Putirka and Xu looked at 23 polluted white dwarfs, all within about 650 light-years of the Sun, where calcium, silicon, magnesium, and iron had been measured with precision using the W. M. Keck Observatory in Hawai'i, the Hubble Space Telescope, and other observatories. The scientists then used the measured abundances of those elements to reconstruct the minerals and rocks that would form from them. They found that these white dwarfs have a much wider range of compositions than any of the inner planets in our Solar System, suggesting their planets had a wider variety of rock types. In fact, some of the compositions are so unusual that Putirka and Xu had to create new names (such as "quartz pyroxenites" and "periclase dunites") to classify the novel rock types that must have existed on those planets.

"While some exoplanets that once orbited polluted white dwarfs appear similar to Earth, most have rock types that are exotic to our Solar System," said Xu. *"They have no direct counterparts in the Solar System."*

Putirka describes what these new rock types might mean for the rocky worlds they belong to. *"Some of the rock types that we see from the white dwarf data would dissolve more water than rocks on Earth and might impact how oceans are developed,"* he explained. "*Some rock types might melt at much lower temperatures and produce thicker crust than Earth rocks, and some rock types might be weaker, which might facilitate the development of plate tectonics."*

Earlier studies of polluted white dwarfs had found elements from rocky bodies, including calcium, aluminum, and lithium. However, Putirka and Xu explain that those are minor elements (which typically make up a small part of an Earth rock) and measurements of major elements (which make up a large part of an Earth rock), especially silicon, are needed to truly know what kind of rock types would have existed on those planets. In addition, Putirka and Xu state that the high levels of magnesium and low levels of silicon measured in the white dwarfs' atmospheres suggest that the rocky debris detected likely came from the interiors of the planets — from the mantle, not their crust. Some previous studies of polluted white dwarfs reported signs that continental crust existed on the rocky planets that once orbited those stars, but Putirka and Xu found no evidence of crustal rocks. However, the observations do not completely rule out that the planets had continental crust or other crust types. *"We believe that if crustal rock exists, we are unable to see it, probably because it occurs in too small a fraction compared to the mass of other planetary components, like the core and mantle, to be measured,"* Putirka stated.

According to Xu, the pairing of an astronomer and a geologist was the key to unlocking the secrets hidden in the atmospheres of the polluted white dwarfs. *"I met Keith Putirka at a conference and was excited that he could help me understand the systems that I was observing. He taught me geology and I taught him astronomy, and we figured out how to make sense of these mysterious exoplanetary systems."* ■

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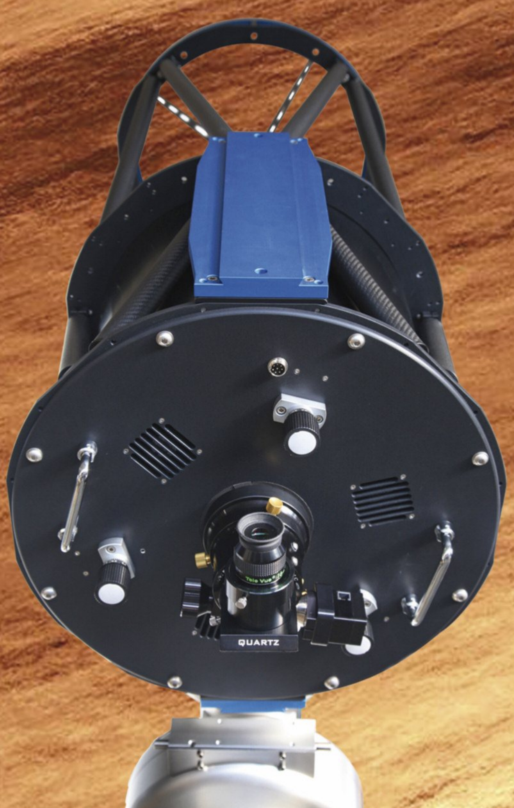
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