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Bi-monthly magazine of scientific and technical information ✶ January-February 2021

It will be difficult to find traces of life in the Martian subsoil

OSIRIS-REx set to return a feather from Bennu

Less eccentric orbits in the most crowded planetary systems

- A thermal ecosystem originating from the Chicxulub event
- Craters reveal Titan is still a dynamic world
- Cold Jupiters and super-Earths, a rather interesting combination
- Galaxies in the infant Universe were surprisingly mature

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The 2021 edition of one of our most popular products, the ESO Calendar, is now available and can be purchased from the online ESOshop and in the ESO Supernova Planetarium & Visitor Centre.

The calendar's cover features a spectacular starscape around the relatively unknown central object, Gum 15, a nebula in which stars are being born. The image also features one of the closest supernova remnants to Earth, which exploded between 11,000 and 12,300 years ago and is located 800 light-years away from our cosmic home.

For the month of March, the bright band of the Milky Way arcs above the ALMA antennas on the Chajnantor plateau. One of the closest stellar nurseries to Earth, the Orion Nebula, is the chosen image for July and the massive 3-tonne blank for the Extremely Large Telescope's (ELT) secondary mirror is the star of September. Finally, in December the viewer will feel they are speeding towards the centre of our galaxy, thanks to a clever photographic technique used on an observation of the Milky Way. These are just a few highlights, we invite you to view the individual pages of the ESO Calendar 2021 here.

The calendar has a total of 14 pages, and is available for 9.50 EUR in the ESOshop — but stock is limited so don't delay!

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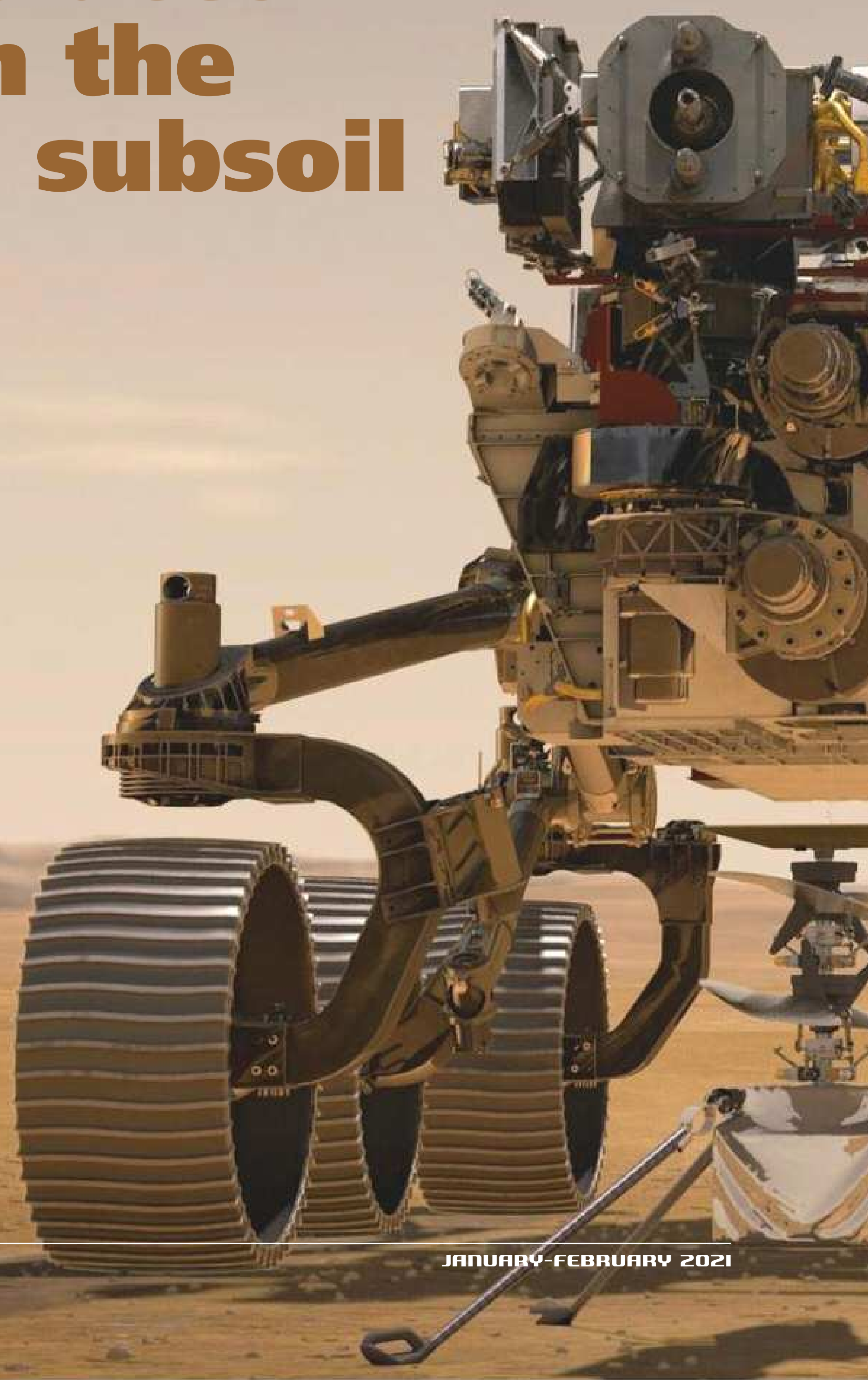
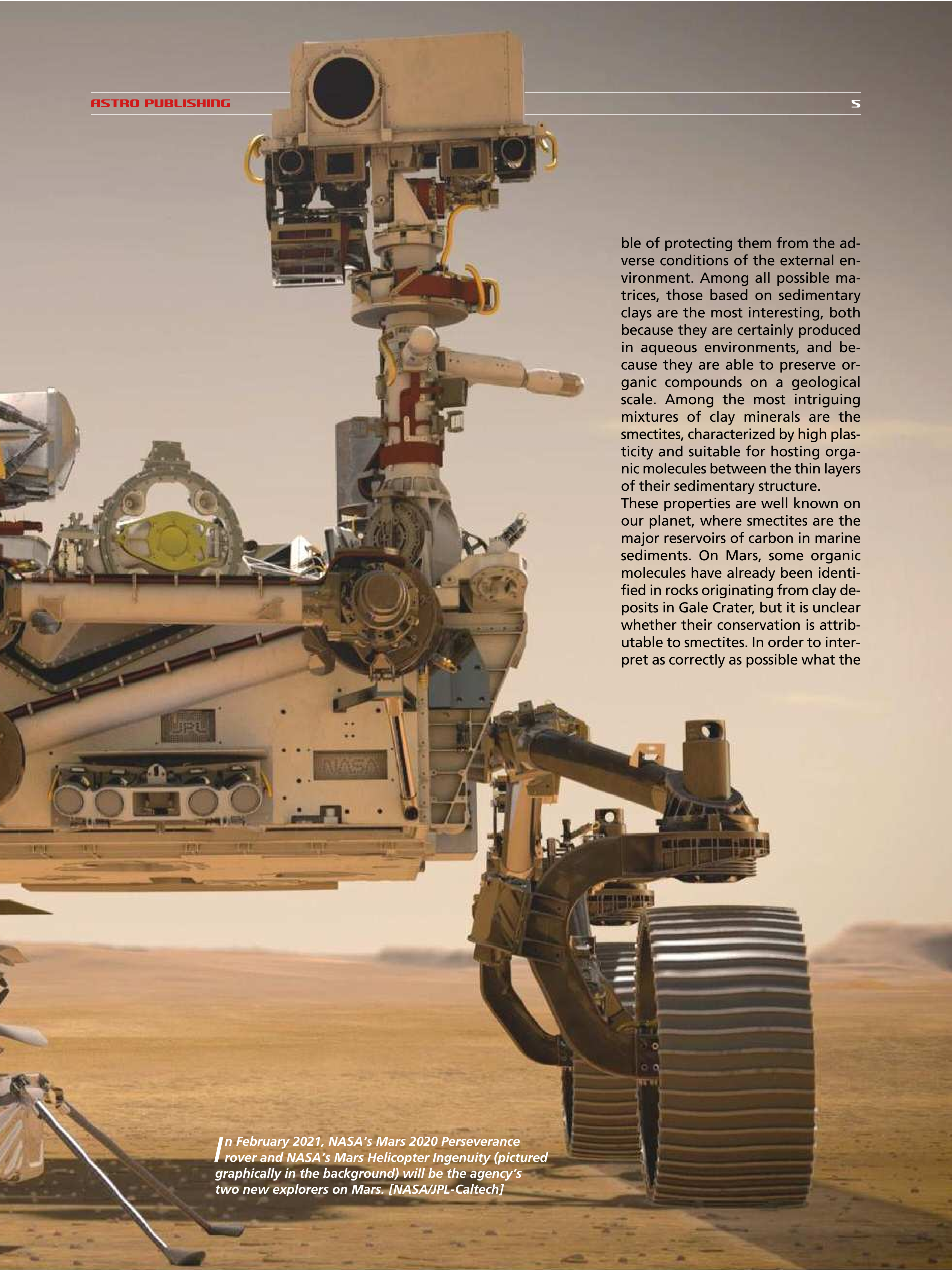
It will be difficult to find traces of life in the Martian subsoil

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador



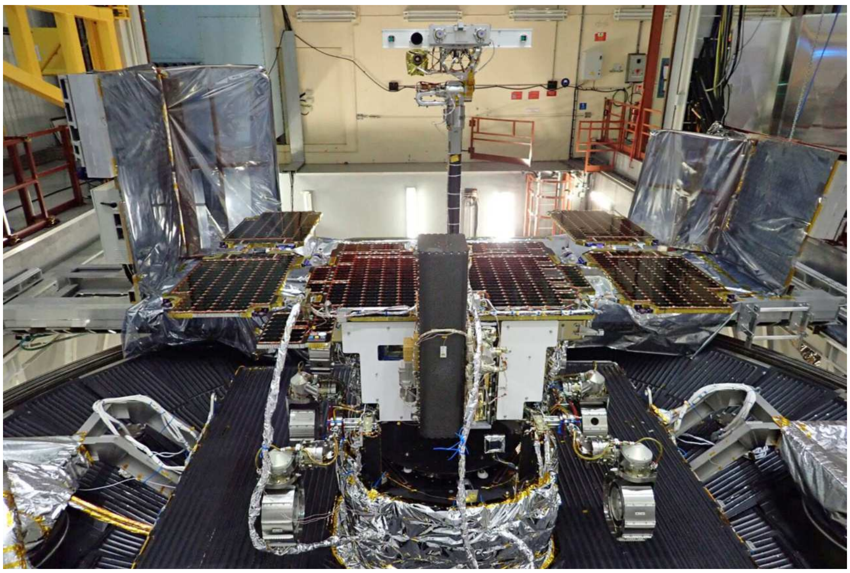
On February 18, 2021, NASA's Perseverance rover will land in Jezero Crater on Mars. On June 10, 2023, ESA's Rosalind Franklin rover will also land on the red planet in a region called Oxia Planum. Both rovers are equipped with scientific instruments that could allow them to determine if life existed on Mars or even if life is still present in microbial form. Both Jezero Crater and Oxia Planum are very promising sites from a biological point of view given the particular abundance of hydrated minerals that characterize them, produced in the first billion years by a rather lively hydrological system that may have supported life. The Martian atmosphere is no longer able to shield the extremely arid surface from ionizing radiation (especially UVC), meaning we can only hope to find traces of desiccated life preserved within mineral matrices capa-



ble of protecting them from the adverse conditions of the external environment. Among all possible matrices, those based on sedimentary clays are the most interesting, both because they are certainly produced in aqueous environments, and because they are able to preserve organic compounds on a geological scale. Among the most intriguing mixtures of clay minerals are the smectites, characterized by high plasticity and suitable for hosting organic molecules between the thin layers of their sedimentary structure.

These properties are well known on our planet, where smectites are the major reservoirs of carbon in marine sediments. On Mars, some organic molecules have already been identified in rocks originating from clay deposits in Gale Crater, but it is unclear whether their conservation is attributable to smectites. In order to interpret as correctly as possible what the

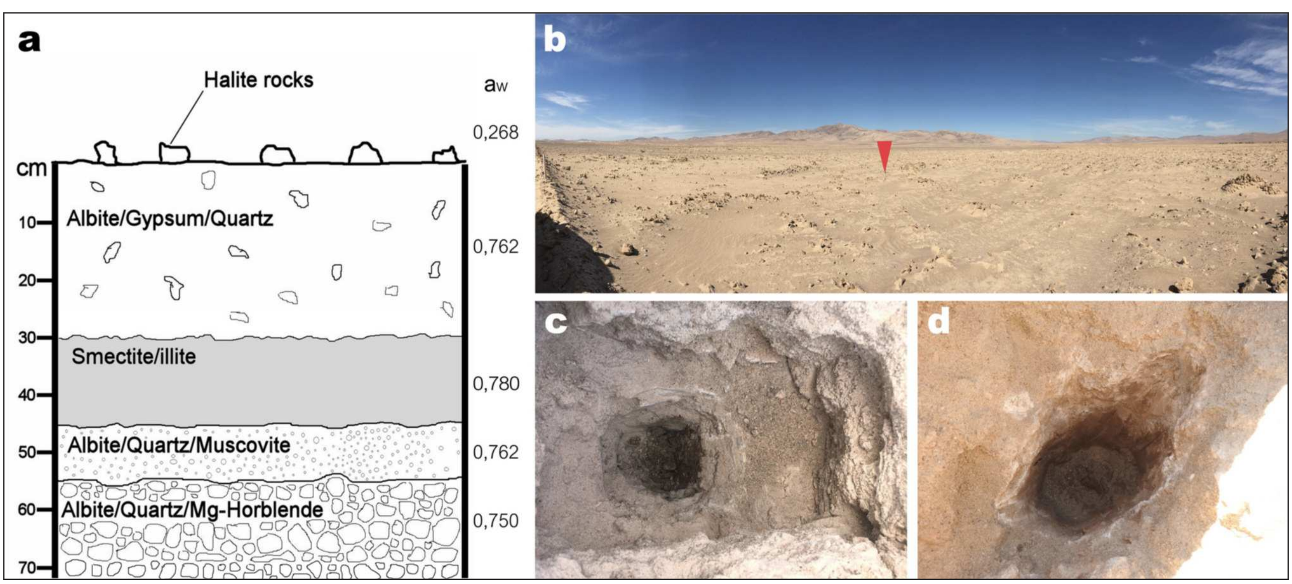
In February 2021, NASA's Mars 2020 Perseverance rover and NASA's Mars Helicopter Ingenuity (pictured graphically in the background) will be the agency's two new explorers on Mars. [NASA/JPL-Caltech]



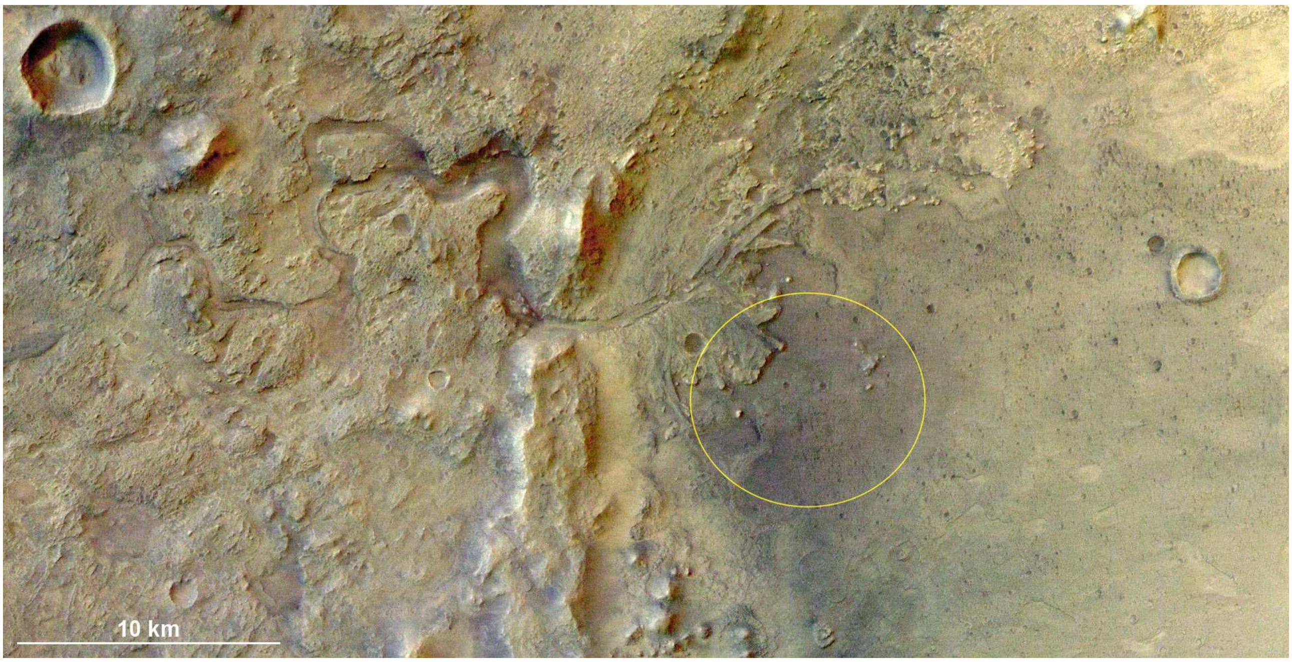
ESA's Rosalind Franklin rover completes environmental tests.

two rovers will discover during their missions, researchers are experimenting on Earth with different scenarios in which smectites are involved. To date, diametrically opposite results regarding their ability to host and protect organic compounds and microorganisms have been obtained. Let's take for example two studies published in the last few months in *Nature Scientific Reports*.

The first, carried out by a team led by Armando Azua-Bustos (Centro de Astrobiología, CSIC-INTA, Madrid), demonstrated that in the subsoil of a limited area of the arid core of the Atacama Desert, more precisely in the Yungay region, there are clay layers inhabited by microorganisms. That region is not only the driest place on Earth (less than 1 mm of annual rainfall) but it is also one of the most UV-exposed regions, as well as one of those regions with the most oxidized soil on Earth. For these reasons, it is considered a habitability analogue to conditions on Mars. It is no coincidence that the Yungay region was where experiments carried out on Mars by the Viking 1 and Viking 2 landers were reproduced in the first years of this century. Just as the Viking lander experiments results in many discussions and debates, the Yungan re-



Features of the Yungay site. (a) Diagram of the structure, composition and mean water activity of soil layers with depth. (b) General view of the sampled site. The red arrow marks the first pit from where samples were taken, seen in detail in (c). (d) Another pit dug 4 km away from the pit shown in (c). Pit dimensions are approximately 1 m length, 60 cm width and 60 cm depth. Both (c, d) show a clear color change between the lower wet clay-rich layer and the upper soil layers. [Nature Scientific Reports, A. Azua-Bustos et al.]



Perseverance rover landing ellipse in Jezero Crater, on the flat floor of the crater, just east of a dramatic ancient river delta. [ESA/DLR/FU Berlin/Emily Lakdawalla]

plication experiments were of consequence for also finding no trace of life – despite our knowledge of microbial life existing in this region.

The Azua-Bustos team only needed to dig up to 30 cm deep to discover a layer rich in smectite with a humidity of 78% (a phenomenon never observed before in that region), isolation from various external agents and, above all, inhabitation by at least 30 species of metabolically active microorganisms (bacteria and archaea). It is very unlikely that anything like this could exist on Mars, as its surface became barren billions of years earlier than the Atacama Desert. But it cannot be ruled out that the subsoil has retained evidence of the metabolism of microorganisms that proliferated during the Noachian era (between 4.1 and about 3.7 billion years ago). If so, the biomarkers identified by Azua-Bustos and colleagues in Yungay's smectite can provide detailed guidance on what to look for with Martian rovers.

Overall, the discovery made in the Atacama Desert authorizes some optimism, but the very restricted location of the habitats of those same microorganisms suggests that the search for similar scenarios on Mars could be extremely long and difficult.

According to another team of researchers, coordinated by Carolina Gil-Lozano (Centro de Astrobiología, CSIC-INTA, Madrid), discovering biomarkers in the Martian smectite layers could be impossible. This second team, which has members in common with the first team (quite bizarre, given the opposite conclusions of the research), conducted simulations with clay and amino acids to verify the possible degradation of biological material on Mars. If it is true that the sub-surface clay soils of that planet may have included and protected colonies of microorganisms, it is also true that any contact of those clays with acidic fluids may have thwarted any ability of those clays to retain traces of vital presences.

Previous studies had shown that the Martian surface of the distant past was affected by acidic fluids, probably waters rich in corrosive substances and with high salinity, residue of the evaporation of primordial seas. The new laboratory experiments conducted by the Gil-Lozano team use glycine (the simplest and most penetrating of the 20 ordinary amino acids) as a "lab rat" embedded in the clay to study what happens upon exposure. The team has shown that if this clay matrix is exposed to acidic fluids, the interlayer space is erased, transforming into a gel-like silica.

The optimism authorized by the first research is therefore reduced, as you can guess from a statement of Alberto Fairén (Centro de Astrobiología, CSIC-INTA, Madrid), second signatory of both researches: "*When clays are exposed to acidic fluids, layers collapse and organic matter cannot be preserved. Our results explain why the search for organic compounds on Mars is so difficult.*" ■

NORT

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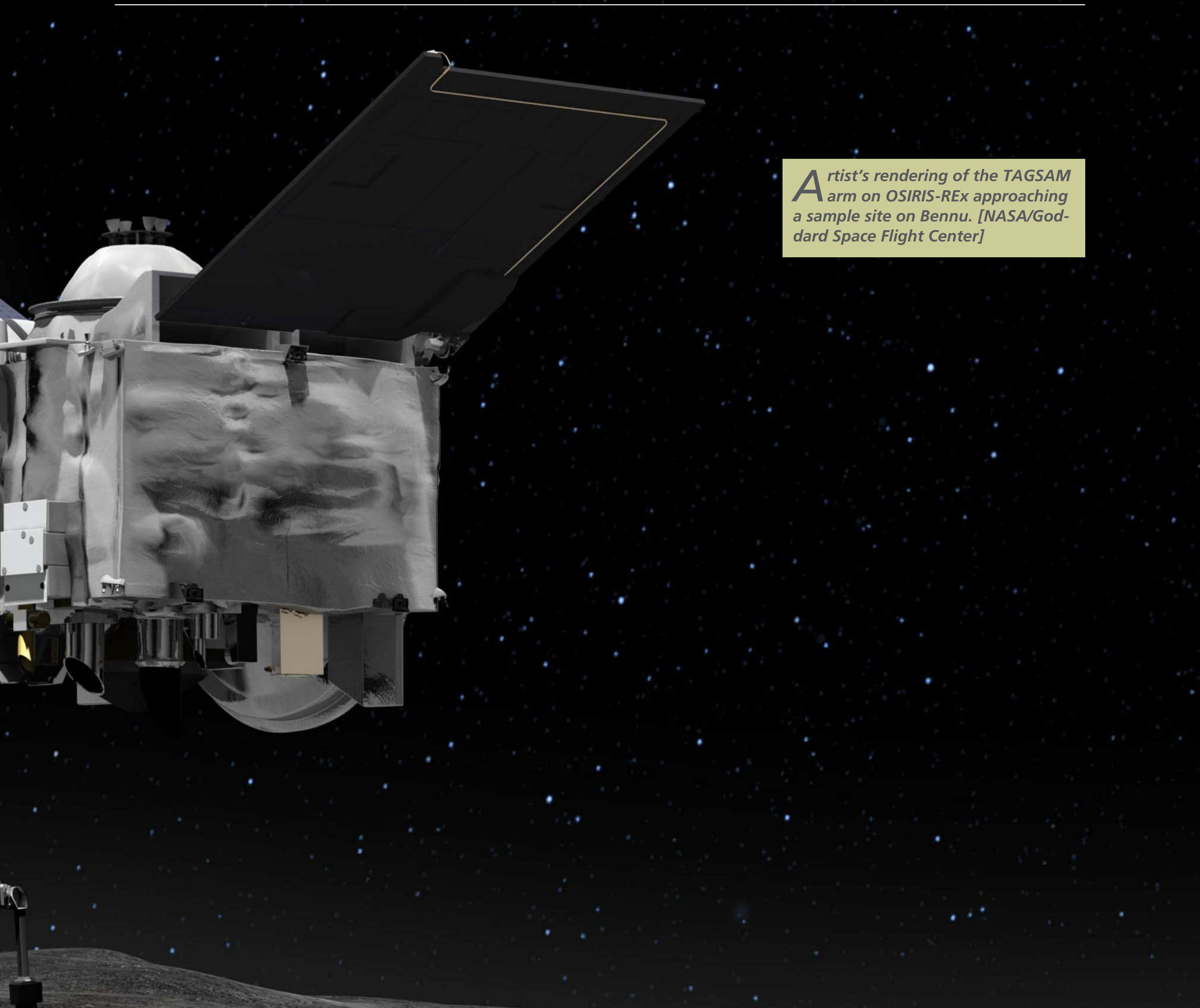
I N S T R U M E N T S - CO

OSIRIS-REx set to return a feather from Bennu

by Damian G. Allis
NASA Solar System Ambassador

The asteroid 101955 Bennu is both a window into the early history of our solar system and a potential risk to our civilization, making the multiple successes of the OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) mission important within and far beyond the scientific community. This mission has dramatically improved our understanding – and view – of this large asteroid as high-resolution cameras and detectors were trained on the Bennu surface for the discovery of a most-ideal sample collection site.

In terms of both history and possible calamity, it is easy to intertwine the science of the OSIRIS-REx mission to Bennu with the mythology surrounding the ancient Egyptian deities bearing (nearly) the same names. Some of the many aspects



Artist's rendering of the TAGSAM arm on OSIRIS-REx approaching a sample site on Bennu. [NASA/Goddard Space Flight Center]

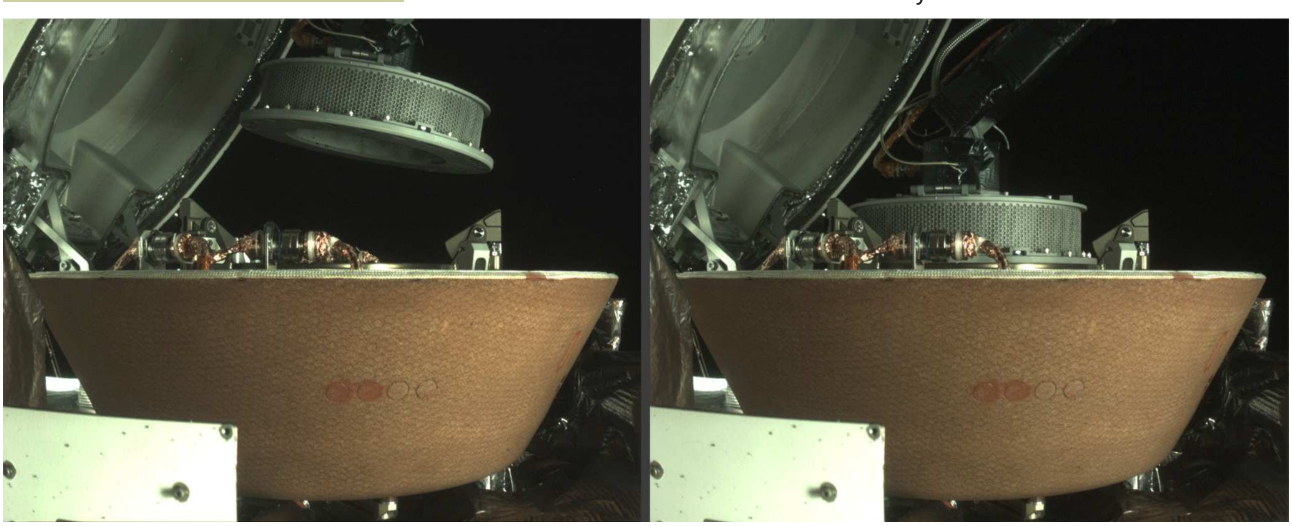
of existence represented by the god Osiris and great heron Bennu – life, fertility, death, rebirth, and creation itself – all are reflected as much in the evolution of stellar systems as they are in the immediate study of near-Earth asteroids. The cycle of "creation, life, death, and rebirth" is the story of our own solar system, for which the abundance of heavy elements that make up everything from the gas giants to the bulk of our own bodies is due to nucleosynthesis in ancient, almost unknowable stars. In the asteroid Bennu, we see an astronomical body created and largely unchanged from a time when the solar system was well on its way to its modern arrangement. The geology of Bennu is a story of the chaos of creation that came from the collisions of planetesimals and protoplanets as the slow accretion of

small bodies occurred within the gravitational grip of the Sun, also closely associated with the mythic bird. Fertility is represented by the abundance of organic materials and carbonaceous minerals responsible for Bennu's low albedo, yet another confirmation that the building blocks of life were already present and undergoing complex chemistry in the early solar system. Even the selection of the mythic name "Bennu" for the asteroid imparts a certain imagery to the story of the OSIRIS-REx mission, from its Phoenix-like launch on 8 September 2016, to its grand swooping gravitational assist by its terrestrial nest to speed the journey to Bennu on 22 September 2017, to its orbital perching around Bennu on 3 December 2018, to the stalking of its prey for so many months in search of an exposed and accessible patch of regolith. This long flight was re-

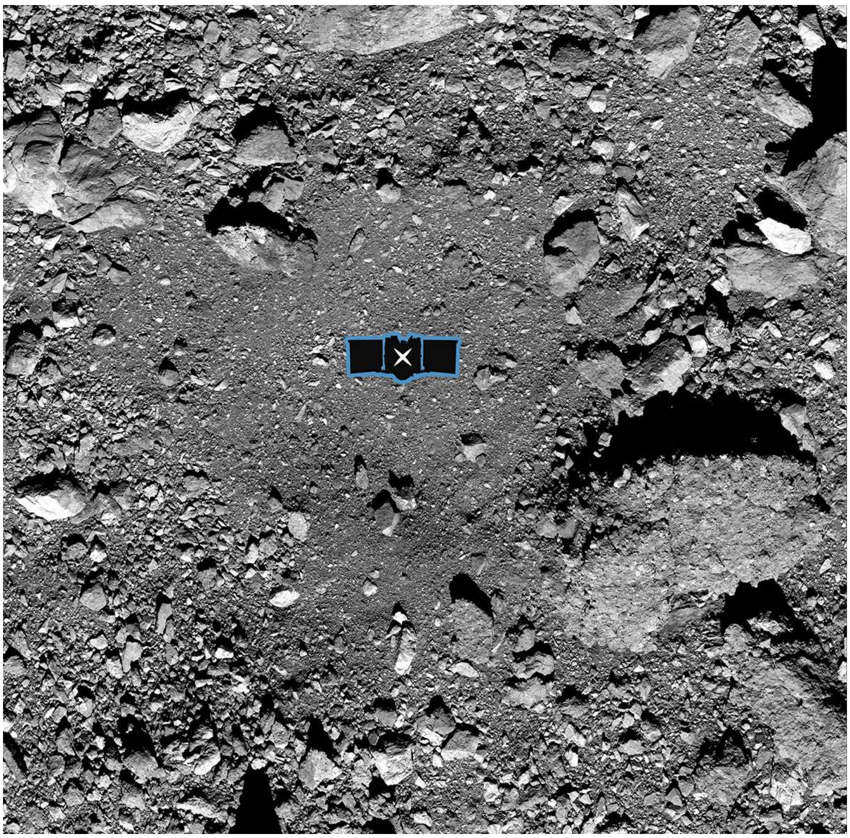
A mosaic of Bennu composed of twelve images taken from 24 km above its surface. [NASA/Goddard/University of Arizona]

warded on October 20, 2020, when the talon-like TAGSAM (Touch-and-Go Sample Acquisition Mechanism) arm collected somewhere between half and just-over a kilogram of regolith to safely stow and return to Earth on 24 September 2023 for exhaustive chemical and mineralogical analyses.
The regolith sampling from the "Nightingale" collection site was nearly flawless – flaps on the collector meant to keep the material contained were instead blocked open by a few too many large particles, resulting in a steady release of small particulates.
The secure stowing process of the remaining collection into the Sample Return Capsule (SRC) was completed on October 28th, with a heralding confirmation taking 18.5 light minutes to reach Earth from the mission's currently location.
Our knowledge of chemistry and geology, when combined with spectroscopic measurements of its surface, reveal a more complicated history for Bennu than simply an asteroid in near-Earth orbit. Certain minerals can only be formed under certain combinations of pressure, heat, and, in some cases, water.
When we observe certain minerals on asteroids, such as the carbonaceous materials detected on Bennu, for which that body's mass and composition are simply incapable of forming those minerals alone, we know that those minerals must have formed in some other environment. Bennu is a large, undisturbed body today, but it very likely originated from a catastrophic event for some much larger protoplanet very early in the formation of the solar system. By its composition and location, we can even estimate its origin – there is a very high probability that Bennu originated from a body that now constitutes either the Polana or Eulania families of asteroids in the inner asteroid belt. A key motivator for OSIRIS-REx was

NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) spacecraft unfurled its robotic arm Oct. 20, 2020, and in a first for the agency, briefly touched an asteroid to collect dust and pebbles from the surface for delivery to Earth in 2023. [NASA's Goddard Space Flight Center]



OSIRIS-REx collector head on the TAGSAM arm being stowed in the Sample Return Capsule (SRC). [NASA/Goddard/University of Arizona/Lockheed Martin]

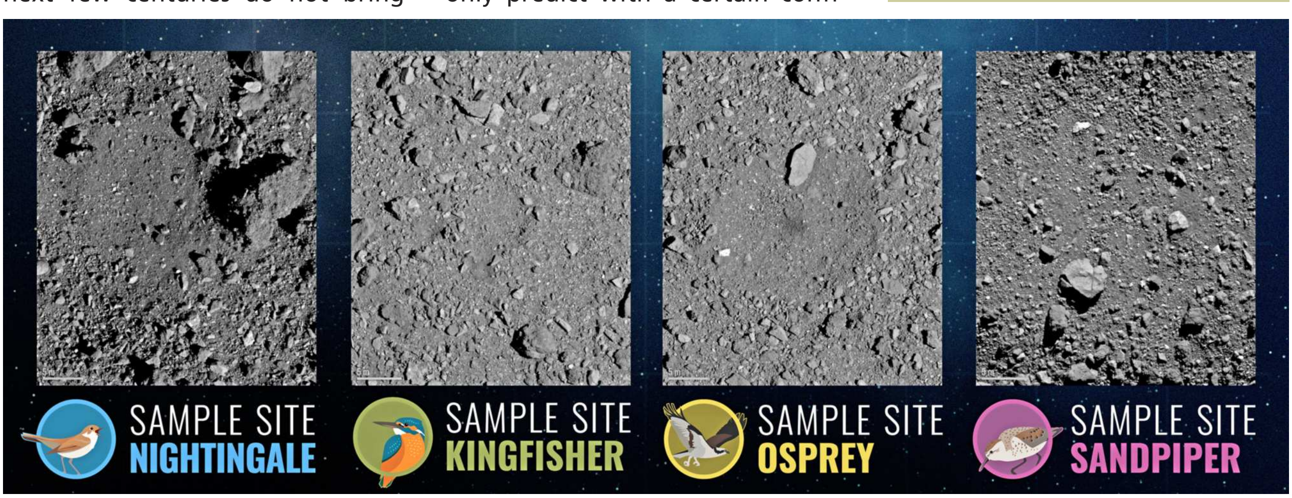


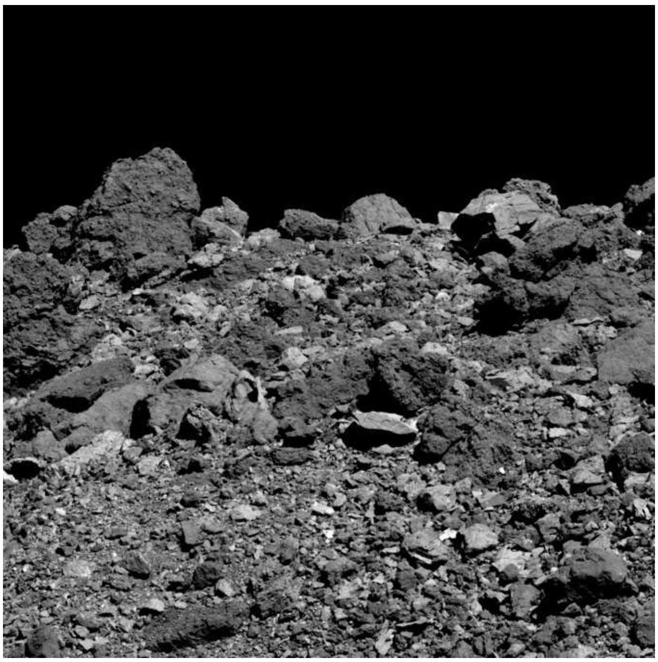
An image of the sample-collection site 'Nightingale' with a silhouette of the OSIRIS-REx spacecraft overlaid for scale. [NASA, Goddard and University of Arizona]

the focus of an article in the January-February 2019 issue. Bennu is a large near-Earth object (NEO) that crosses Earth's orbit regularly. While most of the predicted orbits in the next few centuries do not bring both objects into close-enough proximity to worry about a collision, there are a few instances where the two may come into uncomfortably close contact. Furthermore, we can only predict with a certain confidence level how the gravitational influence of Earth (or even more distant bodies) on these approaches will affect the future orbits of the much smaller Bennu. Any other factors that influence Bennu's orbit are details that we need to understand to improve our models to know if, at some point, we need to start planning in advance to avert a planet-wide disaster.

OSIRIS-REx has provided invaluable information about the composition and orbital dynamics of Bennu, which alone might be sufficient to improve our models and make predictions for future close encounters. Well beyond the ability to measure the phenomenon in detail from Earth's surface, we have now studied another process occurring at Bennu that addresses yet another complicator to our prediction of the

The four TAGSAM approach sites selected after months of surface imaging and analysis. The sample was ultimately taken from Nightingale. [NASA/Goddard/U. of Arizona]





OSIRIS-REx sent back a treasure trove of images revealing an amazingly fragmented surface resembling a roughly spherical rock pile. In the shot on the left, captured 28 March 2020, the spacecraft provides an angled view of Bennu's equator and northern hemisphere as seen from an altitude of about 4 kilometres (2.5 miles). The field of view is 52 metres (170 feet) across. To put the scene in perspective, the largest boulder visible at upper left measures 14.5 metres (48 feet) across, or about the length of a large lorry, or tractor-trailer. The shot below, recorded 29 March 2020, shows a 48-metre-wide (157-foot-wide) field of view in Bennu's northern hemisphere with a wide range of rock sizes. For scale, the small rock resting atop the boulder at lower left measures 2.5 metres (8 feet) wide, or about the length of a horse. [NASA/Goddard/University of Arizona]

future orbits of Bennu and other NEOs. The broad-spectrum radiation from the Sun that is absorbed by Bennu is eventually released back into space in the form of thermal radiation – but not at the same time. Just as the solar radiation hitting Bennu imparts the slightest push against the pull of gravity, the release of thermal radiation from Bennu at a later time also effectively nudges Bennu in a slightly different direction, causing its orbit to drift by a few hundred meters per year. This phenomenon, known as the Yarkov-sky effect, is exceedingly small (for Bennu) compared to its 168 billion meter semi-major axis, but every phenomenon that changes an NEO's orbit is something that physicists must contend with, be that today or as the decades and centuries of this effect changes an orbit in unpredictable ways.

The presence of OSIRIS-REx at Bennu enabled the detection of yet another active phenomenon that might have been impossible from Earth with current technologies. The ejections of small particles from Bennu's surface have been detected on multiple occasions, promoting Bennu from "asteroid" to "active asteroid." While only approaching a few centimeters in size, the observation of ejection means that Bennu is still changing as a result of such factors solar heating and meteor impacts. While the change in orbit due to these random ejections might be infinitesimal, one might argue that no phenomenon is insignificant if it in any way affects the long-term odds of collision.

Our interest in Bennu goes well beyond the many important discoveries to be had about the chemistry and dynamics of the early solar system. We live in a time when the orbits of Bennu and Earth set the stage for many close encounters of these two bodies, with observation and prediction providing estimates of these encounters that are only reliable over many decades.

Bennu is not just a potential collision threat – it is currently the most likely object to impact with the Earth over, at least, the next few hundred years (estimates from NASA's Planetary Defense Coordination Office currently put these odds at 1/2700 in the second half of the 22nd century). As such, we want to know as much as possible about this threat, including both its composition and its orbit. ■

The ethereal remnant of a long dead star

by ESO

This ethereal remnant of a long dead star, nestled in the belly of The Whale, bears an uneasy resemblance to a skull floating through space. Captured in astounding detail by ESO's Very Large Telescope (VLT), the eerie Skull Nebula is showcased in this new image in beautiful bloodshot colours.
This planetary nebula is the first known to be associated with a pair of closely bound stars orbited by a third outer star.
Also known as NGC 246, the Skull Nebula lies about 1600 light-years away from Earth in the southern constellation of Cetus (The Whale). It formed when a Sun-like star expelled its outer layers in its old age, leaving behind its naked core — a white dwarf — one of two stars that can be seen at the very centre of NGC 246.
Even though this nebula has been known for centuries, only in 2014 did astronomers discover, using ESO's VLT, that the white dwarf and its companion are concealing a third star situated at the heart of the Skull Nebula. This star, which is not visible in this image, is a dim red dwarf that sits close to the white dwarf at about 500 times the distance between Earth and the Sun. The red and white dwarf stars orbit each other as a pair, and the outer star orbits the two dwarfs at a distance of around 1900 times the Earth-Sun separation. Collectively, these three stars establish NGC 246 as the first known planetary nebula with a hierarchical triple stellar system at its centre. Taken by the FORS 2 instrument on ESO's VLT in the Chilean Atacama Desert, this new image of the Skull Nebula intentionally captures light emitted in some narrow ranges of wavelengths — those associated with hydrogen and oxygen gas. Observations of light emitted by particular elements help reveal a wealth of information about an object's chemical and structural compositions. This new image of the Skull Nebula highlights where NGC 246 is rich or poor in hydrogen (shown in red) and oxygen (depicted in light blue).
This image was selected as part of the ESO Cosmic Gems programme, an outreach initiative to produce images of interesting, intriguing or visually attractive objects using ESO telescopes, for the purposes of education and public outreach. The programme makes use of telescope time that cannot be used for science observations. All data collected may also be suitable for scientific purposes, and are made available to astronomers through ESO's science archive.

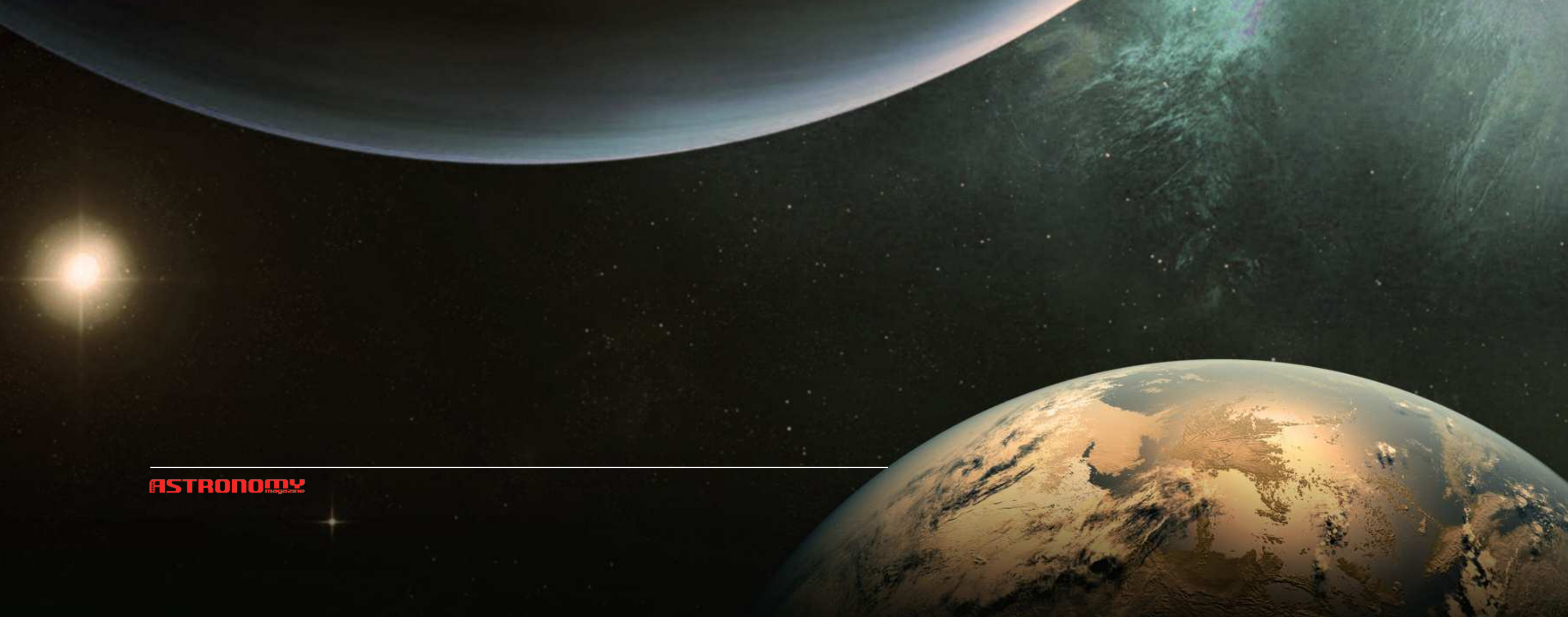
Captured in astounding detail by ESO's Very Large Telescope (VLT), the eerie Skull Nebula is showcased in this new image in beautiful pink and red tones. This planetary nebula, also known as NGC 246, is the first known to be associated with a pair of closely bound stars orbited by a third outer star. [ESO]

Less eccentric orbits in the most crowded planetary systems

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

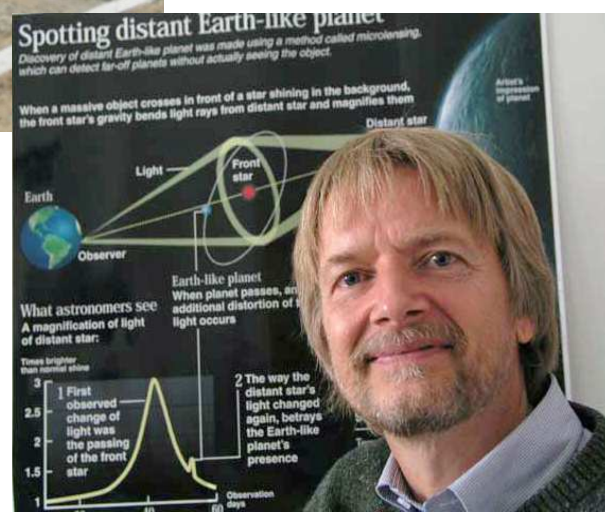
There are 3200 known planetary systems as of December 2020. These systems are home to at least 5700 detected planets, 4300 of which have been confirmed. Given the limitations of current research methods, we can reasonably assume that the number of planets hosted by those same systems is actually significantly higher – we simply do not have the resolution to observe them yet. Many planets may in fact be too small or too far away from their star to be discovered with any instrument available to astronomers today. Thousands of these worlds may currently be beyond our ability to observe them, but even assuming that there are twice as many of these worlds as there are detected ones (there are likely to be fewer), we find that planetary systems have on average less than half the number of planets contained in our own solar system. According to the results of available observations, most planetary systems are composed of only one or two planets. Having said that, it is inevitable to wonder if



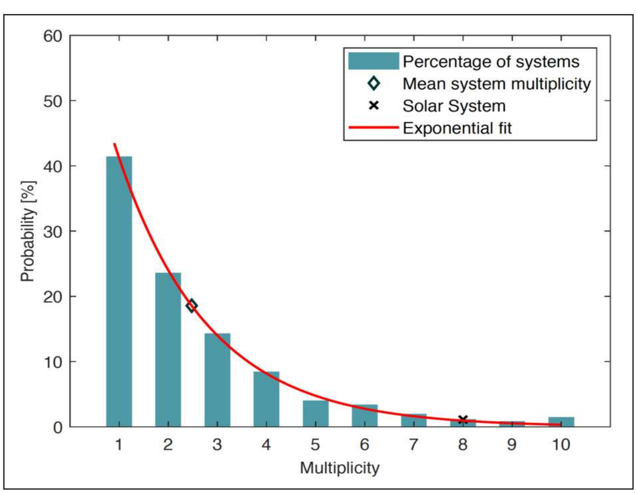
our solar system, with its eight planets, is an exception, and if this abundance may have played a role in the emergence of life on Earth. Back when the discoveries of new systems numbered only in the hundreds, it was observed that most exoplanets have orbits with an eccentricity value that is anything but negligible. In other words, their orbits are quite elongated, with many planets only passing through the habitable zone of their orbited star for a fraction of their year. Barring evolutionary paths that can accommodate extreme long freeze/short thaw cycles, this orbital elongation does not speak favorably for the habitability of those worlds. For as long as they have had orbital data to analyze from the first discovered exoplanets, astronomers have been trying to understand why planetary systems characterized by relatively eccentric orbits are so frequent and why those with orbits close to circularity are instead so rare.

A possible interpretation of the phenomenon was proposed in 2008, with the publication of a couple of works that identified the dynamic interaction between planets as a regulator of orbital eccentricity. Subsequent works have improved our knowledge of that process, which begins very early on with the formation of planetesimals within the protoplanetary discs. These building blocks of the protoplanets form on relatively circular orbits but begin to interact gravitationally with each other as they reach significant masses. The result is a dispersion of planetesimals on decidedly more eccentric orbits, which in astronomically short timespans cause collisions and aggregations that originate solid planets and the nuclei of gaseous ones. After the gas from the disk has been captured by the young planets or dispersed by stellar radiation, the dominant mechanism for determining the final eccentricities of the orbits are the planet-planet interactions themselves. It is easy to understand that if a system consists of only one planet, the initial eccentricity of its orbit from the sum of all of the early collisions during its formation will remain substantially unchanged and therefore high. As the number of planets increases, the interactions will become more and more frequent and the planets may either be expelled from the system or settle on different orbits. Since gravitational interactions cause planets to lose energy, more planets lead to more interactions, resulting in eventually more circular orbits.

The authors of the work discussed in the article: Nanna Bach-Møller and Uffe Gråe Jørgensen. [Niels Bohr Institute, University of Copenhagen]



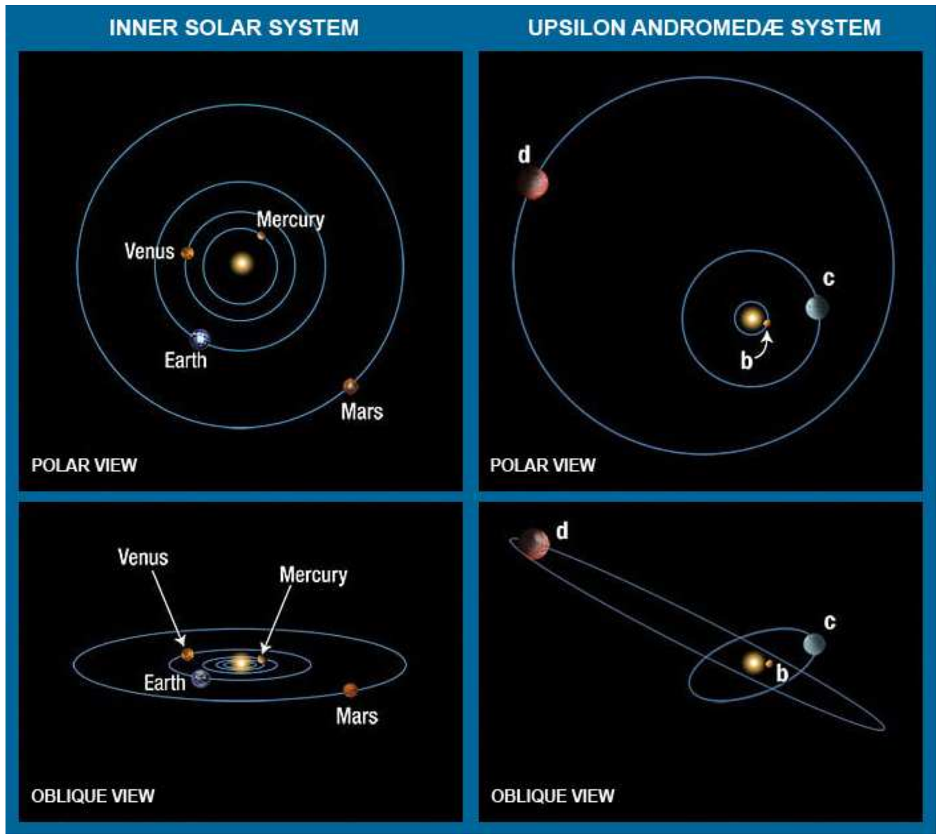
Is there a correlation between the multiplicity (number) of planets in a system and the final eccentricity of their orbits? This possibility was first evaluated in a 2014 paper (Davies et al.) and empirically tested in a 2015 paper (Limbach & Turner), taking over 400 exoplanets discovered by the radial velocity method as a reference sample. On that occasion, a strong correlation (or anti-correlation, if you prefer) was highlighted between multiplicity and eccentricity. A similar study presented in 2017 (Zinzi & Turrini) substantially confirmed that type of correlation, start-



The percentage of planetary systems with a given multiplicity. The probability fits to an exponential function. Mean multiplicity estimated to ~2.5. [Bach-Møller & Jørgensen] ing from a numerically smaller (about 250) but more diversified sample of planets in terms of discovery techniques, since it additionally included the planetary transits.

These first encouraging results spurred new works, such as the one published at the end of November in the *Monthly Notices of the Royal Astronomical Society* by Nanna Bach-Møller and Uffe Gråe Jørgensen (Niels Bohr Institute, University of Copenhagen). The two Danish researchers considered 1171 exoplanets in 895 systems and allowed for any method of discovery, a procedure that excluded bias in the results due to different populations of planets. Furthermore, unlike previous works, each system was treated as a unit, using the value of the mean orbital eccentricity in the analysis instead of considering each planet out of its own context. This choice is justified by the fact that multiplicity and potential planet-planet interactions are properties of the planetary system as a whole, rather than of individual planets. At the end of their analysis, Bach-Møller and Jørgensen confirmed the strong correlation between multiplicity and eccentricity, finding also that this correlation follows a power law for all multiplicities greater than one. In other words, in all planetary systems that have two or more planets (about 270 known systems) up to the maximum known today of eight confirmed planets (our system and the one of Kepler-90), the average value of eccentricity decreases in proportion to the increase in the number of planets. We therefore have the confirmation that our solar system is not atypical, but that it is simply at the limit of a scale that likely extends farther than we can demonstrate today. Let's consider, for example, the solar-type star HD 10180, which could host nine planets, six of which have already been confirmed. The only systems that seem to not respect the power law highlighted by the two researchers at the Niels Bohr Institute are those with only one (known) planet. From the 667 examined single-planet samples, a certain dispersion of the orbital eccentricity values was evident. According to Bach-Møller and Jørgensen, this could be due to the fact that many of those systems actually contain other undiscovered planets. Detecting additional planets in those systems to remove them from the single-planet sample set would therefore be an interesting target for more in-depth research to improve the observed trend.

Regardless of this anomaly, the researchers were able to estimate that the probability of a system consisting of eight or more planets is close to 1%, a value in good agreement with other recent predictions made through analysis based on independent arguments. In conclusion, in the Milky Way, there could be at least a billion systems similar to ours, each with one or more planets likely placed in the habitable zone – a very interesting perspective from an astrobiological point of view. ■



This simple comparison between our inner solar system and the Upsilon Andromedæ system gives an idea of how different the orbits of the planets may appear depending on the observer's position, a further complication for those who study them. [NASA, ESA and A. Feild (STScI)]

ALMA shows volcanic impact on Io's atmosphere

by ALMA Observatory

New radio images from the Atacama Large Millimeter/submillimeter Array (ALMA) show for the first time the direct effect of volcanic activity on the atmosphere of Jupiter's moon Io.
Io is the most volcanically active moon in our solar system. It hosts more than 400 active volcanoes, spewing out sulfur gases that give Io its yellow-white-orange-red colors when they freeze out on its surface. Although extremely thin (about a billion times thinner than Earth's atmosphere), Io's atmosphere can teach us something about volcanic activity and the interior of that exotic moon, and what is happening beneath its colorful crust. Previous research has shown that Io's atmosphere is dominated by sulfur dioxide gas, ultimately sourced from volcanic activity. *"However, it is not known which process drives the dynamics in Io's atmosphere,"* said Imke de Pater of the University of Califor-

Composite image showing Jupiter's moon Io in radio (ALMA), and optical light (Voyager 1 and Galileo). The ALMA images of Io show for the first time plumes of sulfur dioxide (in yellow) rise up from its volcanoes. Jupiter is visible in the background (Cassini image). [ALMA (ESO/NAOJ/NRAO), I. de Pater et al.; NRAO/AUI NSF, S. Dagnello; NASA]

This video shows images of Jupiter's moon Io in radio (made with ALMA), and optical light (made with Voyager 1 and Galileo missions). The ALMA images were taken when Io passed into Jupiter's shadow in March 2018 (eclipse), and from Jupiter's shadow into the sunlight in September 2018. These radio images for the first time show plumes of sulfur dioxide (in yellow) rise up from the volcanoes on Io. [ALMA (ESO/NAOJ/NRAO), I. de Pater et al.; NRAO/AUI NSF, S. Dagnello; NASA]

nia, Berkeley. *"Is it volcanic activity, or gas that has sublimated (transitioned from solid to gaseous state) from the icy surface when Io is in sunlight?"* To distinguish between the different processes that give rise to Io's atmosphere, a team of astronomers used ALMA to make snapshots of the moon when it passed in and out of Jupiter's shadow (they call this an "eclipse"). *"When Io passes into Jupiter's shadow, and is out of direct sunlight, it is too cold for sulfur dioxide gas, and it condenses onto Io's surface. During that time we can only see volcanically-sourced sulfur dioxide. We can therefore see exactly how much of the atmosphere is impacted by volcanic activity,"* explained Statia Luszcz-Cook from Columbia University, New York. Thanks to ALMA's exquisite resolution and sensitivity, the astronomers could, for the first time, clearly see the plumes of sulfur dioxide (SO_2) and sulfur monoxide (SO) rise up from the volcanoes. Based on the snapshots, they calculated that active volcanoes directly produce 30-50 percent of Io's atmosphere.

The ALMA images also showed a third gas coming out of volcanoes: potassium chloride (KCl). *"We see KCl in volcanic regions where we do not see SO_2 or SO,"* said Luszcz-Cook. *"This is strong evidence that the magma reservoirs are different under different volcanoes."*

Io is volcanically active due to a process called tidal heating. Io orbits Jupiter in an orbit that is not quite circular and, like our Moon always faces the same side of Earth, so does the same side of Io always face Jupiter. The gravitational pull of Jupiter's other moons Europa and Ganymede causes tremendous amounts of internal friction and heat, giving rise to volcanoes such as Loki Patera, which spans more than 200 kilometers (124 miles) across. *"By studying Io's atmosphere and volcanic activity we learn more about not only the volcanoes themselves, but also the tidal heating process and Io's interior,"* added Luszcz-Cook.

A big unknown remains the temperature in Io's lower atmosphere. In future research, the astronomers hope to measure this with ALMA. *"To measure the temperature of Io's atmosphere, we need to obtain a higher resolution in our observations, which requires that we observe the moon for a longer period of time. We can only do this when Io is in sunlight since it does not spend much time in eclipse,"* said de Pater. *"During such an observation, Io will rotate by tens of degrees. We will need to apply software that helps us make unsmeared images. We have done this previously with radio images of Jupiter made with ALMA and the Very Large Array (VLA)."* ■

New light shed on small-scale concentrations of dark matter

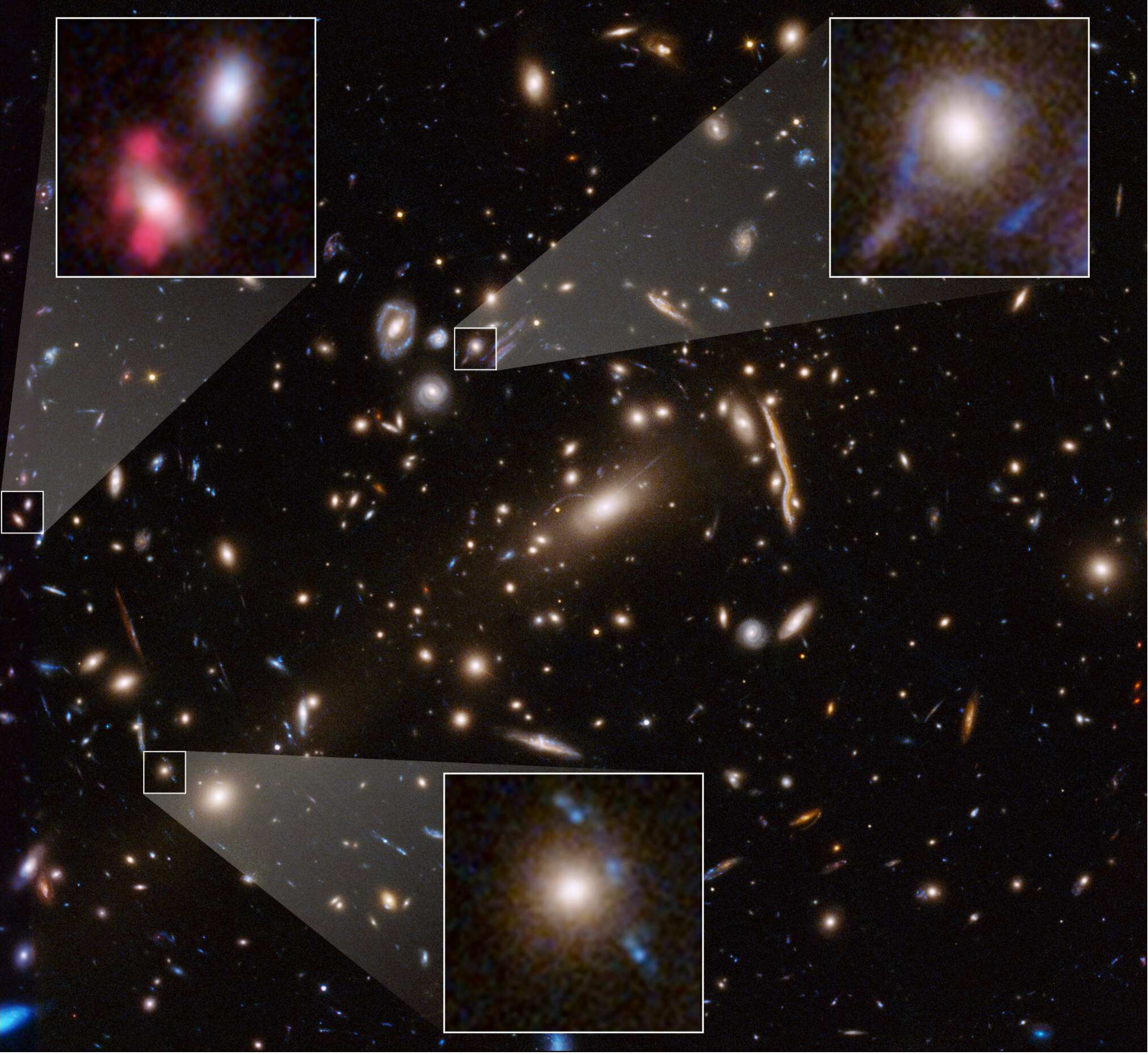
by NASA/ESA

Observations by the NASA/ESA Hubble Space Telescope and the European Southern Observatory's Very Large Telescope (VLT) in Chile have found that something may be missing from the theories of how dark matter behaves. This missing ingredient may explain why researchers have uncovered an unexpected discrepancy between observations of the dark matter concentrations in a sample of massive galaxy clusters and theoretical computer simulations of how dark matter should be distributed in clusters. The new findings indicate that some small-scale concentrations of dark matter produce lensing effects that are 10 times stronger than expected. Dark matter is the invisible glue that keeps

This NASA/ESA Hubble Space Telescope image shows the massive galaxy cluster MACSJ 1206. Overlaid on the image are small-scale concentrations of dark matter (represented in this artist's impression in blue). [NASA, ESA, G. Caminha (University of Groningen), M. Meneghetti (Observatory of Astrophysics and Space Science of Bologna), P. Natarajan (Yale University), the CLASH team, and M. Kornmesser (ESA/Hubble)]

stars, dust, and gas together in a galaxy. This mysterious substance makes up the bulk of a galaxy's mass and forms the foundation of our Universe's large-scale structure. Because dark matter does not emit, absorb, or reflect light, its presence is only known through its gravitational pull on visible matter in space. Astronomers and physicists are still trying to pin down what it is.

Galaxy clusters, the most massive and recently assembled structures in the Universe, are also the largest repositories of dark matter. Clusters are composed of individual member galaxies that are held together largely by the gravity of dark matter. *"Galaxy clusters are ideal laboratories in which to study whether the numerical simulations of the*



Universe that are currently available reproduce well what we can infer from gravitational lensing," said Massimo Meneghetti of the INAF-Observatory of Astrophysics and Space Science of Bologna in Italy, the study's lead author. *"We have done a lot of testing of the data in this study, and we are sure that this mismatch indicates that some physical ingredient is missing either from the simulations or from our understanding of the nature of dark matter,"* added Meneghetti. *"There's a feature of the real Universe that we are simply not capturing in our current theoretical models,"* added Priyamvada Natarajan of Yale University in Connecticut, one of the senior theorists on the team. *"This could signal a gap in our current un-*

Embedded within the cluster MACSJ 1206 are the distorted images of distant background galaxies, seen as arcs and smeared features. These distortions are caused by the dark matter in the cluster, whose gravity bends and magnifies the light from faraway galaxies, an effect called gravitational lensing. This phenomenon allows astronomers to study remote galaxies that would otherwise be too faint to see. Astronomers measured the amount of gravitational lensing caused by this cluster to produce a detailed map of the distribution of dark matter in it. Dark matter is the invisible glue that keeps stars bound together inside a galaxy and makes up the bulk of the matter in the Universe. [NASA, ESA, G. Caminha (University of Groningen), M. Meneghetti (Observatory of Astrophysics and Space Science of Bologna), P. Natarajan (Yale University), and the CLASH team]

This video shows an artist's impression of the phenomenon of gravitational lensing. [ESA/Hubble and M. Kornmesser]

derstanding of the nature of dark matter and its properties, as these exquisite data have permitted us to probe the detailed distribution of dark matter on the smallest scales."

The distribution of dark matter in clusters is mapped by measuring the bending of light — the gravitational lensing effect — that they produce. The gravity of dark matter concentrated in clusters magnifies and warps light from distant background objects. This effect produces distortions in the shapes of background galaxies which appear in images of the clusters. Gravitational lensing can often also produce multiple images of the same distant galaxy.

The higher the concentration of dark matter in a cluster, the more dramatic its light-bending effect. The presence of smaller-scale clumps of dark matter associated with individual cluster galaxies enhances the level of distortions. In some sense, the galaxy cluster acts as a large-scale lens that has many smaller lenses embedded within it.

Hubble's crisp images were taken by the telescope's Wide Field Camera 3 and Advanced Camera for Surveys. Coupled with spectra from the European Southern Observatory's Very Large Telescope (VLT), the team produced an accurate, high-fidelity, dark-matter map.

By measuring the lensing distortions astronomers could trace out the amount and distribution of dark matter. The three key galaxy clusters, MACS J1206.2-0847, MACS J0416.1-2403, and Abell S1063, were part of two Hubble surveys: The Frontier Fields and the Cluster Lensing And Supernova survey with Hubble (CLASH) programs.

To the team's surprise, in addition to the dramatic arcs and elongated features of distant galaxies produced by each cluster's gravitational lensing, the Hubble images also revealed an unexpected number of smaller-scale arcs and distorted images nested near each cluster's core, where the most massive galaxies reside. The researchers believe the nested lenses are produced by the gravity of dense concentrations of matter inside the individual cluster galaxies.

Follow-up spectroscopic observations measured the velocity of the stars orbiting inside several of the cluster galaxies to therby pin down their masses.

"The data from Hubble and the VLT provided excellent synergy," shared team member Piero Rosati of the Università degli Studi di Ferrara in Italy, who led the spectroscopic campaign. *"We were able to associate the galaxies with each cluster and estimate their distances."*

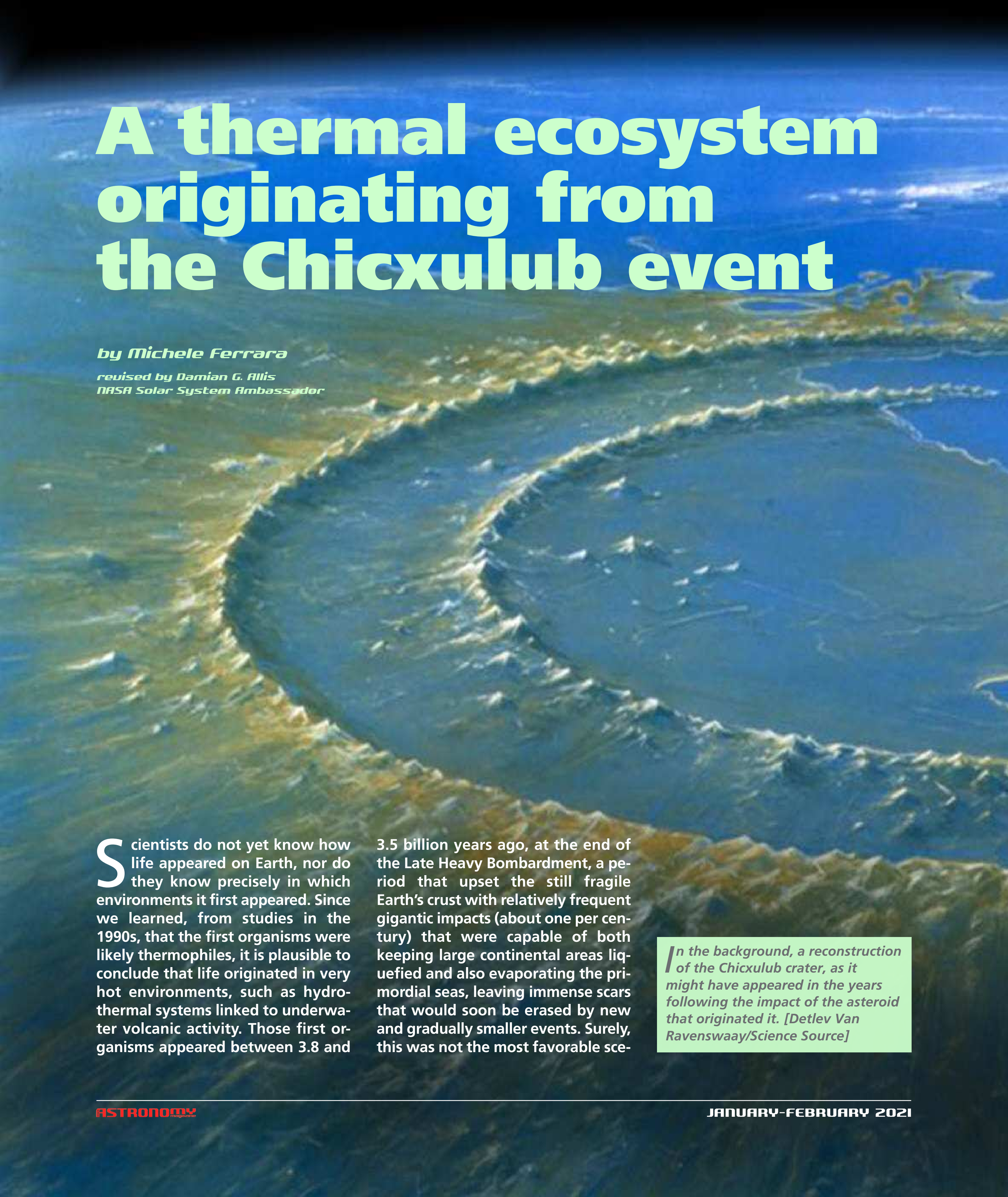
"The speed of the stars gave us an estimate of each individual galaxy's mass, including the amount of dark matter," added team member Pietro Bergamini of the INAF-Observatory of Astrophysics and Space Science in Bologna, Italy.

By combining Hubble imaging and VLT spectroscopy, the astronomers were able to identify dozens of multiply imaged, lensed, background galaxies. This allowed them to assemble a well-calibrated, high-resolution map of the mass distribution of dark matter in each cluster.

The team compared the dark-matter maps with samples of simulated galaxy clusters with similar masses, located at roughly the same distances. The clusters in the computer model did not show any of the same level of dark-matter concentration on the smallest scales — the scales associated with individual cluster galaxies. *"The results of these analyses further demonstrate how observations and numerical simulations go hand in hand"*, said team member Elena Rasia of the INAF-Astronomical Observatory of Trieste, Italy.

"With advanced cosmological simulations, we can match the quality of observations analysed in our paper, permitting detailed comparisons like never before," added Stefano Borgani of the Università degli Studi di Trieste, Italy.

Astronomers, including those of this team, look forward to continuing to probe dark matter and its mysteries in order to finally pin down its nature. ■



A thermal ecosystem originating from the Chicxulub event

by Michele Ferrara

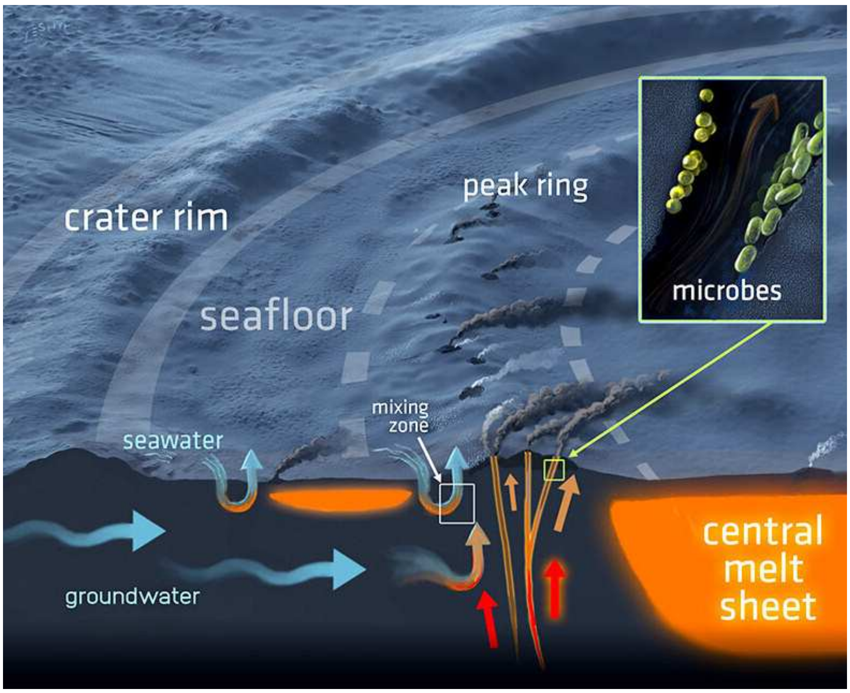
revised by Damian G. Allis
NASA Solar System Ambassador

Scientists do not yet know how life appeared on Earth, nor do they know precisely in which environments it first appeared. Since we learned, from studies in the 1990s, that the first organisms were likely thermophiles, it is plausible to conclude that life originated in very hot environments, such as hydrothermal systems linked to underwater volcanic activity. Those first organisms appeared between 3.8 and 3.5 billion years ago, at the end of the Late Heavy Bombardment, a period that upset the still fragile Earth's crust with relatively frequent gigantic impacts (about one per century) that were capable of both keeping large continental areas liquefied and also evaporating the primordial seas, leaving immense scars that would soon be erased by new and gradually smaller events. Surely, this was not the most favorable sce-

In the background, a reconstruction of the Chicxulub crater, as it might have appeared in the years following the impact of the asteroid that originated it. [Detlev Van Ravenswaay/Science Source]

nario for the emergence and, even less, the proliferation of life; but some studies conducted in recent decades have indicated that those catastrophic events may have created, precisely at the impact sites, the ideal conditions for the biochemical processes that transformed organic compounds into life.
The main proponent of this scenario is David Kring (Lunar and Planetary Institute), who developed the im-

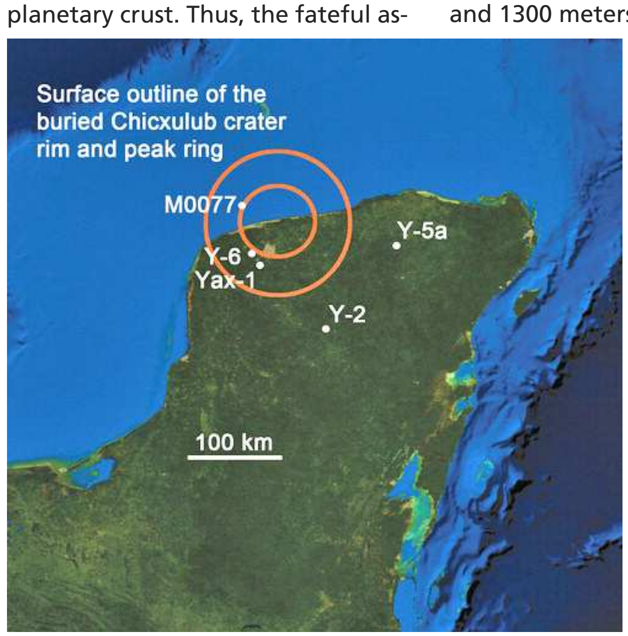
In this video, a reconstruction of the Chicxulub event, which 66 million years ago led to the mass extinction that marked the end of the Cretaceous, the last period of the Mesozoic era. The extinction involved 75% of the living species on Earth. [SCI Discovery Science]



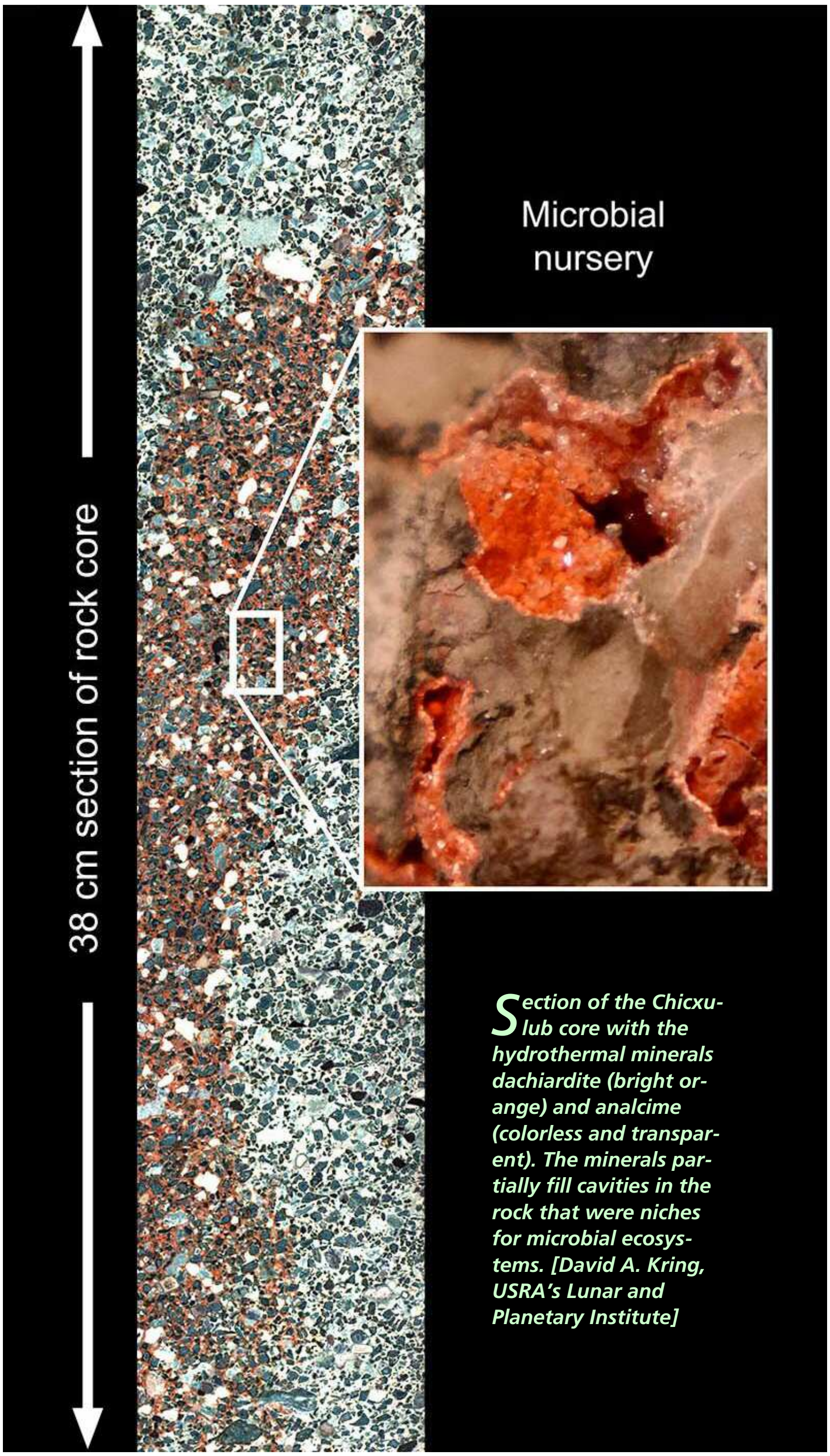
A three-dimensional cross-section of the hydrothermal system in the Chicxulub impact crater and its seafloor vents. The system has the potential for harboring microbial life. [Victor O. Leshyk, Lunar and Planetary Institute]

pact origin of life (or "impact-origin") hypothesis by studying the Chicxulub crater. This approximately 180 km-diameter structure, buried partly beneath the Gulf of Mexico and partly under the present Yucatán Peninsula, is the best-preserved peak ring impact basin on Earth. In the early 1990s, Kring and his colleague William Boynton were studying rock samples extracted from the crater to correlate that structure to the mass extinction event that involved the dinosaurs. In addition to confirming that link, the analysis of some minerals suggested the possible existence of a hydrothermal system associated with the crater that was generated following the impact.

In subsequent years, other similar studies conducted by several researchers on other impact craters have highlighted how hydrothermal activity could be a common consequence of impact heating in hydrous planetary crust. Thus, the fateful asteroid bombardment may have actually created potential crucibles for prebiotic chemistry, as well as habitats for the evolution of primeval life. Perhaps not incidentally, the end of the Late Heavy Bombardment coincides with what is currently the most ancient evidence of life on Earth. A series of subsequent studies carried out in the first decade of this century in the Chicxulub crater confirmed, mainly thanks to the core drilling of two of its areas between the outer rim and the peak ring, that a vast hydrothermal system was created following the impact that is similar to those typical of underwater volcanic areas. To explore the crater in even more detail, two major research programs (the International Continental Scientific Drilling Program and the International Ocean Discovery Program) funded the 2016 drilling of a section of the Chicxulub peak ring, where thermal evolution models placed a high rate of hydrothermal activity. The operation brought to the surface 15 tons of rock from under the ocean floor, excavated between 600 and 1300 meters deep.



Location of the Chicxulub crater relative to the Yucatán Peninsula. The white dots indicate the drilling sites of various scientific expeditions. The one marked M0077 indicates the 2016 drilling, which made it possible to discover traces of microbial activity in the hydrothermal system formed by the asteroid impact. [Astrobiology magazine]



Section of the Chicxulub core with the hydrothermal minerals dachiardite (bright orange) and analcime (colorless and transparent). The minerals partially fill cavities in the rock that were niches for microbial ecosystems. [David A. Kring, USRA's Lunar and Planetary Institute]

Since then, several teams of researchers have had the opportunity to analyze those rock samples.
Recently, one of the teams, composed of Kring, Martin Whitehouse (Swedish Museum of Natural History) and Martin Schmieder (Neu-Ulm University, Germany), has taken the decisive potential step towards confirming the impact-origin hypothesis. The three researchers discovered in the rock samples tiny spherules of pyrite (FeS_2), just 10 microns in diameter, produced by a microbial ecosystem that proliferated in the streams of water laden with chemical compounds that crossed the rocky ravines. The presence of these microscopic sulfur formations, called framboids (due to their vague resemblance to raspberries, *framboises* in French), can be associated with the activity of organisms that transform sulfate ions (SO_4^{2-}) into sulfide (S^{2-}), drawing from the process the energy necessary for their survival.
It seems that the porous structure of the Chicxulub crater may have offered a habitat, if not actually given rise, to colonies of thermophilic organisms capable of transforming to their advantage sulfur compounds transported by water within a hydrothermal system. From the stratification of sediments containing the signatures of those chemical processes, the researchers were able to estimate that the organisms' activity persisted for at least 2.5 million years after the impact.
This important discovery, published in *Astrobiology* at the end of October, suggests that the asteroidal impacts that occurred between the late Hadean and the upper Archean may have created the ideal environmental conditions for the birth and initial evolution of life on our planet. ■

The last moments of a star devoured by a black hole

by ESO

Using telescopes from the European Southern Observatory (ESO) and other organisations around the world, astronomers have spotted a rare blast of light from a star being ripped apart by a supermassive black hole.

The phenomenon, known as a tidal disruption event, is the closest such flare recorded to date at just over 215 million light-years from Earth, and has been studied in unprecedented detail. The research is published in *Monthly Notices of the Royal Astronomical Society.*

"The idea of a black hole 'sucking in' a nearby star sounds like science fiction. But this is exactly what happens in a tidal disruption event," says Matt Nicholl, a lecturer and Royal Astronomical Society research fellow at the University of Birmingham, UK, and the lead author of the new study. But these tidal disruption events, where a star experiences

This illustration depicts a star (in the foreground) experiencing spaghettification as it's sucked in by a supermassive black hole (in the background) during a 'tidal disruption event'. In a new study, done with the help of ESO's Very Large Telescope and ESO's New Technology Telescope, a team of astronomers found that when a black hole devours a star, it can launch a powerful blast of material outwards. [ESO/M. Kornmesser]

what's known as spaghettification as it's sucked in by a black hole, are rare and not always easy to study. The team of researchers pointed ESO's Very Large Telescope (VLT) and ESO's New Technology Telescope (NTT) at a new flash of light that occurred last year close to a supermassive black hole, to investigate in detail what happens when a star is devoured by such a monster.

Astronomers know what should happen in theory. *"When an unlucky star wanders too close to a supermassive black hole in the centre of a galaxy, the extreme gravitational pull of the black hole shreds the star into thin streams of material,"* explains study author Thomas Wevers, an ESO Fellow in Santiago, Chile, who was at the Institute of Astronomy, University of Cambridge, UK, when he conducted the work. As some of the thin strands of stellar material fall into the black hole during this spaghettification process, a bright flare of energy is released, which astronomers can detect.

Although powerful and bright, up to now astronomers have had trouble investigating this burst of light, which is often obscured by a curtain of dust and debris. Only now have

astronomers been able to shed light on the origin of this curtain.
"We found that, when a black hole devours a star, it can launch a powerful blast of material outwards that obstructs our view," explains Samantha Oates, also at the University of Birmingham. This happens because the energy released as the black hole eats up stellar material propels the star's debris outwards.
The discovery was possible because the tidal disruption event the team studied, AT2019qiz, was found just a short time after the star was ripped apart. *"Because we caught it early, we could actually see the curtain of dust and debris being drawn up as the black hole launched a powerful outflow of material with velocities up to 10,000 km/s,"* says Kate Alexander, NASA Einstein Fellow at Northwestern University in the US. *"This unique 'peek behind the curtain' provided the first opportunity to pinpoint the origin of the obscuring material and follow in real time how it engulfs the black hole."*
The team carried out observations of AT2019qiz, located in a spiral galaxy in the constellation of Eridanus, over a 6-month period as the flare grew in luminosity and then faded away. *"Several sky surveys discovered emission from the new tidal disruption event very quickly after the star was ripped apart,"* says Wevers. *"We immediately pointed a suite of ground-based and space telescopes in that direction to see how the light was produced."*
Multiple observations of the event were taken over the following months with facilities that included X-shooter and EFOSC2, powerful instruments on ESO's VLT and ESO's NTT, which are situated in Chile. The prompt and extensive observations in ultraviolet, optical, X-ray and radio light revealed, for the first time, a direct connection between the material flowing out from the star and the bright flare emitted as it is devoured by the black hole. "*The observations showed that the star had roughly the same mass as our own Sun, and that it lost about half of that to the monster black hole, which is over a million times more massive,"* says Nicholl, who is also a visiting researcher at the University of Edinburgh.
The research helps us better understand supermassive black holes and how matter behaves in the extreme gravity environments around them. The team say AT2019qiz could even act as a 'Rosetta stone' for interpreting future observations of tidal disruption events. ESO's Extremely Large Telescope (ELT), planned to start operating this decade, will enable researchers to detect increasingly fainter and faster evolving tidal disruption events, to solve further mysteries of black hole physics. ■

This animation depicts a star experiencing spaghettification as it's sucked in by a supermassive black hole during a 'tidal disruption event'. In a new study, done with the help of ESO's Very Large Telescope and ESO's New Technology Telescope, a team of astronomers found that when a black hole devours a star, it can launch a powerful blast of material outwards. [ESO/M. Kornmesser]

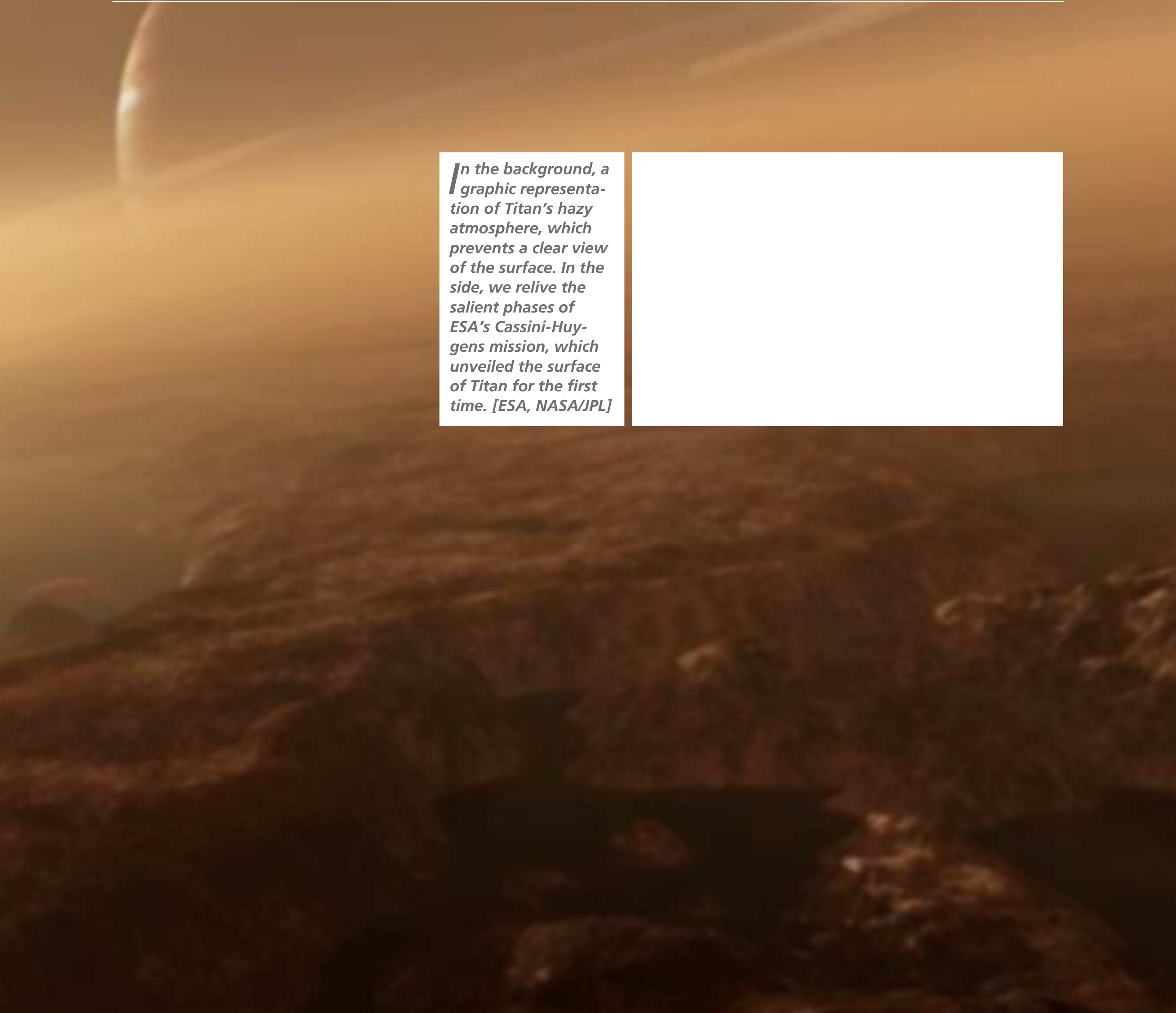
This video sequence zooms in on the galaxy where the AT2019qiz tidal disruption event is taking place. This phenomenon, a blast of light from a star being ripped apart by a supermassive black hole, has been studied by ESO telescopes. [ESO/Digitized Sky Survey 2/N. Risinger (skysurvey.org). Music: Astral Electronics]

Craters reveal Titan is still a dynamic world

by ESA

Using data from the international Cassini-Huygens mission to Saturn and Titan, scientists have found that there are two distinct types of craters on Saturn's largest moon Titan that are still being shaped by erosion. Titan has a dense atmosphere, a subsurface ocean, and a surface adorned with mountains, lakes, dunes, and many other Earth-like features. It is also scarred with impact craters, although relatively few compared to other moons of Saturn. It is thought that erosion has obscured most of the craters on Titan, similar to what has happened on Earth. Not only does studying Titan's craters reveal the geomorphological processes on the moon, but the craters give an insight into the subsurface composition as they carve out a small pocket in the surface. Anezina Solomonidou and colleagues have recently published a paper in *Astronomy & Astrophysics* which performs a detailed analysis of nine prominent craters on Titan. Analysing craters is a key way to study Titan's interior and the atmospheric influence on the surface.

"When we study the astrobiological potential of an ocean-bearing world



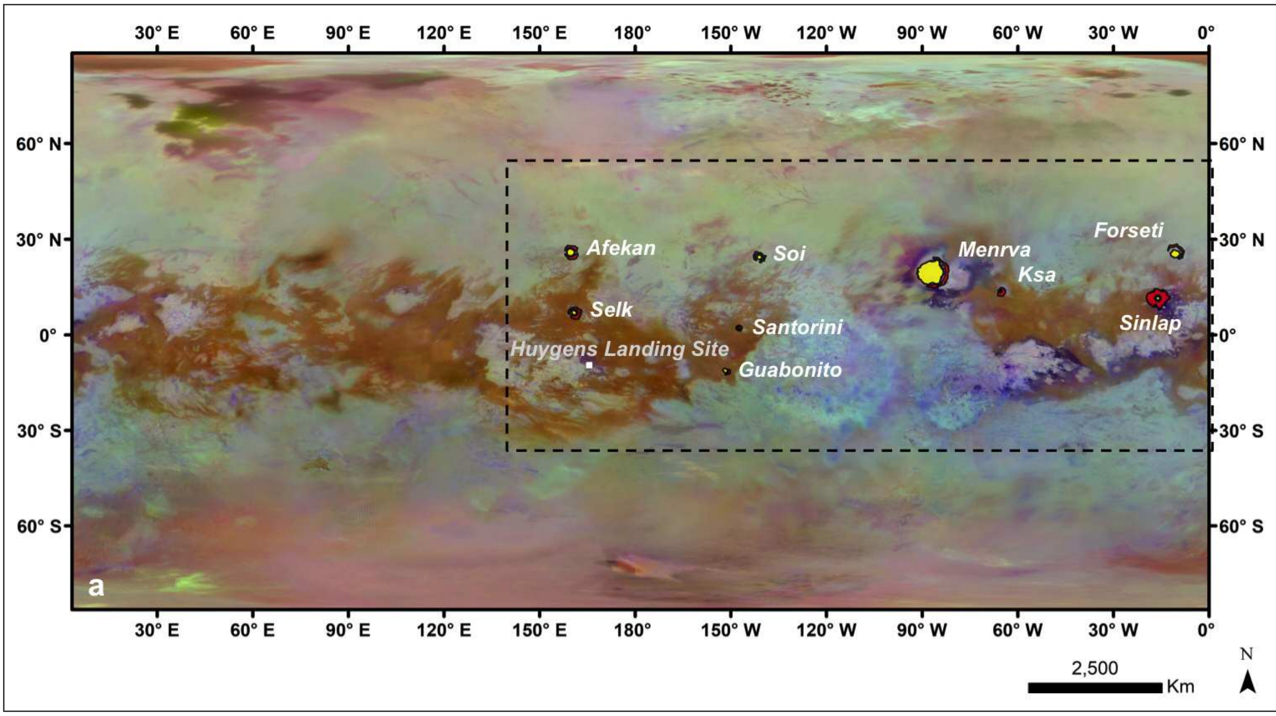
In the background, a graphic representation of Titan's hazy atmosphere, which prevents a clear view of the surface. In the side, we relive the salient phases of ESA's Cassini-Huygens mission, which unveiled the surface of Titan for the first time. [ESA, NASA/JPL]

like Titan, it is vital to look for pathways for organic material, for example mixtures that contain important elements, like carbon," says Anezina. *"These can be recognizable at the surface and in the atmosphere after being transported from the subsurface ocean, which is the most likely habitable environment, and vice versa. Impact craters are one of the few geologic features that expose material from the interior, providing a rare opportunity to understand the subsurface composition of Titan."*

Six of the craters in the study are located in the equatorial dune fields and three in the midlatitude plains. They used data from two instruments on the Cassini orbiter; the Visual and Infrared Mapping Spectrometer (VIMS) and RADAR, along with information provided by the Huygens Titan lander.

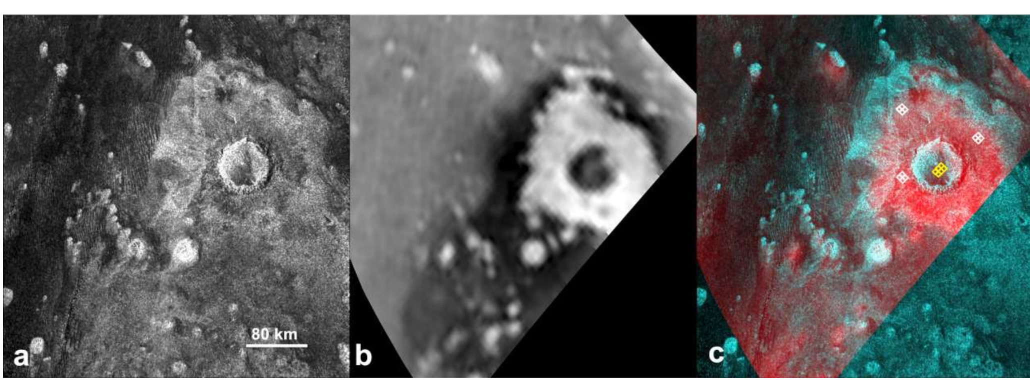
RADAR obtained microwave emissivity data – which is a measure of how effective a surface is at emitting energy – and could probe the surface to depths of tens of centimetres revealing details on the subsurface composition.

Areas with lower emissivity on Titan are thought to indicate water ice,

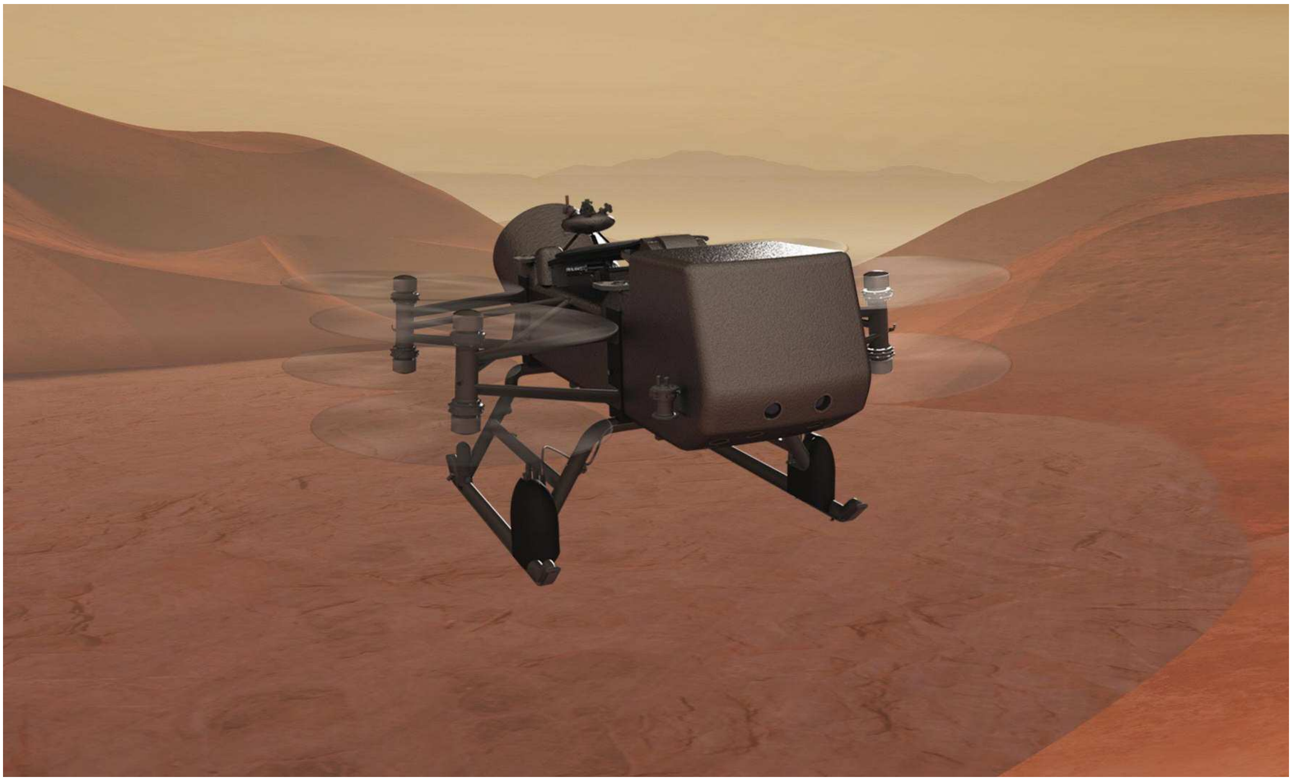


An annotated VIMS RGB colour image showing the nine dune and plain impact craters on Titan from the recent study of crater composition and evolution. The yellow sections indicate the crater floors and the red sections are the ejecta blankets. Menrva is the largest crater, and Selk will be visited by NASA's Dragonfly mission in 2034. [Solomonidou et al. (2020); background map: Le Mouélic et al. (2019)]

while higher emissivity indicates an organic-rich layer. The VIMS data can be used to look at the thin 'veil' that covers the surface. Using VIMS to study the surface of Titan requires an understanding of the methane absorption and haze in the atmosphere, which was provided by the Huygens data and the use of a radiative transfer code. The team then used a new mixing model to study the chemical composition of the crater floors and ejecta blankets (i.e. material thrown out of the crater area during the impact). The results showed that the dune craters and the plain craters have two different types of composition. The plain craters have a mix of organics and are enriched with water ice, whereas the dune craters have mainly organic material and no water ice. Both types of craters have



Sinlap is thought to be the youngest crater on Titan. The RADAR image of Sinlap is shown in (a), the VIMS image in (b), and the two are combined in (c) with yellow areas selecting the crater floor and white areas the ejecta blanket. The data from these areas were used in a recent study of crater composition and evolution on Titan. [Solomonidou et al. (2020)]



L'atterrisseur Dragonfly de la NASA au-dessus de la surface de Titan, la lune principale de Saturne. Profitant de l'atmosphère dense de ce satellite, Dragonfly sera équipé de moteurs à hélices qui lui permettront de se déplacer dans les airs, à la recherche de sites potentiellement intéressants. L'un de ceux-ci sera le cratère Selk. Décollage de la mission prévu en 2027, arrivée sur Titan en 2034. [Johns Hopkins APL]

been altered compositionally showing two different evolution routes.

The VIMS data show a difference in abundances between the crater floors and ejecta blankets for the dune craters, which is in contrast to the RADAR data. This suggests that there is a difference in the surface layer between the floor and ejecta that doesn't affect the subsurface composition. It is possible that this is due to the dune craters becoming infilled with a fine layer of sand sediment.

The composition of craters and ejecta is generally the same for the plain craters, which the authors say suggests that the plain craters are being "cleaned" of sediment. This could be caused by fluvial erosion, and agrees with previous assumptions that more rain falls in the higher latitudes of Titan.

There are two craters which are exceptions to the rule: Menrva and Sinlap. Menrva, is the largest crater on Titan at around 425 kilometres across, which means it intersects both the dunes and the plains.

Sinlap is thought to be the youngest crater and while it is located in the dune region, it has signs of water ice and doesn't display the same characteristics of a dune crater and couldn't be classified into either of the two groups.

It is possible that the dune craters originally had exposed water ice which was then covered with organic material, and Sinlap's younger age means that this process is still occurring. Erosion is thought to occur quite quickly with even the younger craters covered by a thin layer of organic material.

"Titan seems to have a compositional latitudinal dependence that is also reflected in the impact craters as well," says Anezina. *"This latitudinal dependence seems to unveil many of Titan's secrets, showing us that the surface is actively connected with atmospheric processes and possibly with internal ones."*

Further investigation of Titan's craters will be possible in the future when NASA's Dragonfly lander mission visits Selk, one of the dune craters. The mission is due to launch in 2027 and arrive at Titan in 2034 to study several sites on the moon. ■

VLT spots galaxies trapped in the web of a SMBH

by ESO

With the help of ESO's Very Large Telescope (VLT), astronomers have found six galaxies lying around a supermassive black hole when the Universe was less than a billion years old. This is the first time such a close grouping has been seen so soon after the Big Bang and the finding helps us better understand how supermassive black holes, one of which exists at the centre of our Milky Way, formed and grew to their enormous sizes so quickly. It supports the theory that black holes can grow rapidly within large, web-like structures which contain plenty of gas to fuel them.

"This research was mainly driven by the desire to understand some of the most challenging astronomical objects — supermassive black holes in the early Universe. These are extreme systems and to date we have had no good explanation for their existence," said Marco Mignoli, an astronomer at the National Institute for Astrophysics (INAF) in Bologna, Italy, and lead author of the new research published in *Astronomy & Astrophysics*.

The new observations with ESO's VLT revealed several galaxies surrounding a supermassive black hole, all lying in a cosmic "spider's web" of gas extending to over 300 times the size of the Milky Way. *"The cosmic web filaments are like spider's web threads,"* explains Mignoli. *"The galaxies stand and grow where the filaments cross, and streams of gas — available to fuel both the galaxies and the central supermassive black hole — can flow along the filaments."*

The light from this large web-like structure, with its black hole of one billion solar masses, has travelled to us from a time when the Universe was only 0.9 billion years old. *"Our work has placed an important piece in the largely incomplete puzzle that is the formation and growth of such extreme, yet relatively abundant, objects so quickly after the Big Bang,"* says co-author Roberto Gilli, also an astronomer at INAF in Bologna, referring to supermassive black holes. The very first black holes,

This artist's impression shows the central black hole and the galaxies trapped in its gas web. The black hole, which together with the disc around it is known as quasar SDSS J103027.09+052455.0, shines brightly as it engulfs matter around it. [ESO/L. Calçada]

thought to have formed from the collapse of the first stars, must have grown very fast to reach masses of a billion suns within the first 0.9 billion years of the Universe's life. But astronomers have struggled to explain how sufficiently large amounts of "black hole fuel" could have been available to enable these objects to grow to such enormous sizes in such a short time. The new-found structure offers a likely explanation: the "spider's web" and the galaxies within it contain enough gas to provide the fuel that the central black hole needs to quickly become a supermassive giant.

But how did such large web-like structures form in the first place? Astronomers think giant halos of mysterious dark matter are key. These large regions of invisible matter are thought to attract huge amounts of gas in the early Universe; together, the gas and the invisible dark matter form the web-like structures where galaxies and black holes can evolve. *"Our finding lends support to the idea that the most distant and massive black holes form and grow within massive dark matter halos in large-scale structures, and that the absence of earlier detections of such structures was likely due to observational limitations,"* says Colin Norman of Johns Hopkins University in Baltimore, US, also a co-author on the study.

The galaxies now detected are some of the faintest that current telescopes can observe. This discovery required observations over several hours using the largest optical telescopes available, including ESO's VLT. Using the MUSE and FORS2 instruments on the VLT at ESO's Paranal Observatory in the Chilean Atacama Desert, the team confirmed the link between four of the six galaxies and the black hole. *"We believe we have just seen the tip of the iceberg, and that the few galaxies discovered so far around this supermassive black hole are only the brightest ones,"* said co-author Barbara Balmaverde, an astronomer at INAF in Torino, Italy. These results contribute to our understanding of how supermassive black holes and large cosmic structures formed and evolved. ESO's Extremely Large Telescope, currently under construction in Chile, will be able to build on this research by observing many more fainter galaxies around massive black holes in the early Universe using its powerful instruments.

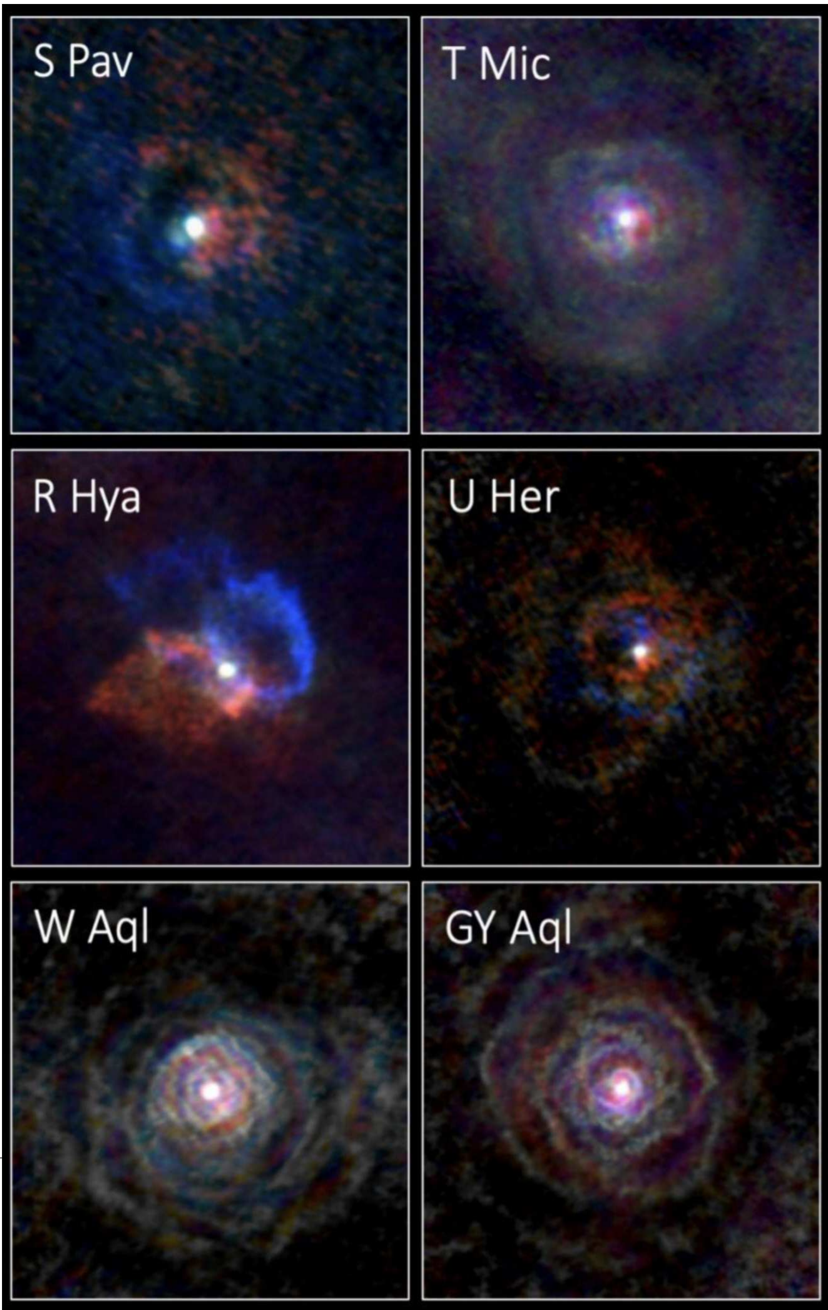
Astronomers capture stellar winds in unprecedented detail

by ALMA Observatory

Astronomers used the Atacama Large Millimeter/submillimeter Array (ALMA) to observe a set of stellar winds around aging stars and present an explanation for the mesmerizing shapes of planetary nebulae. Contrary to common consensus, the team found that stellar winds are not spherical but have a form similar to that of planetary nebulae. The team concludes that interaction with an accompanying star or exoplanet shapes both the stellar winds and planetary nebulae.

Dying stars swell and cool to eventually become red giants. They produce stellar winds, flows of particles that the star expels, which causes them to lose mass. Because detailed observations were lacking, astronomers have always assumed that these winds were spherical, like the stars they surround. As the star evolves further, it heats up again, and the stellar radiation causes the expanding ejected layers of stellar material to glow, forming a planetary nebula.

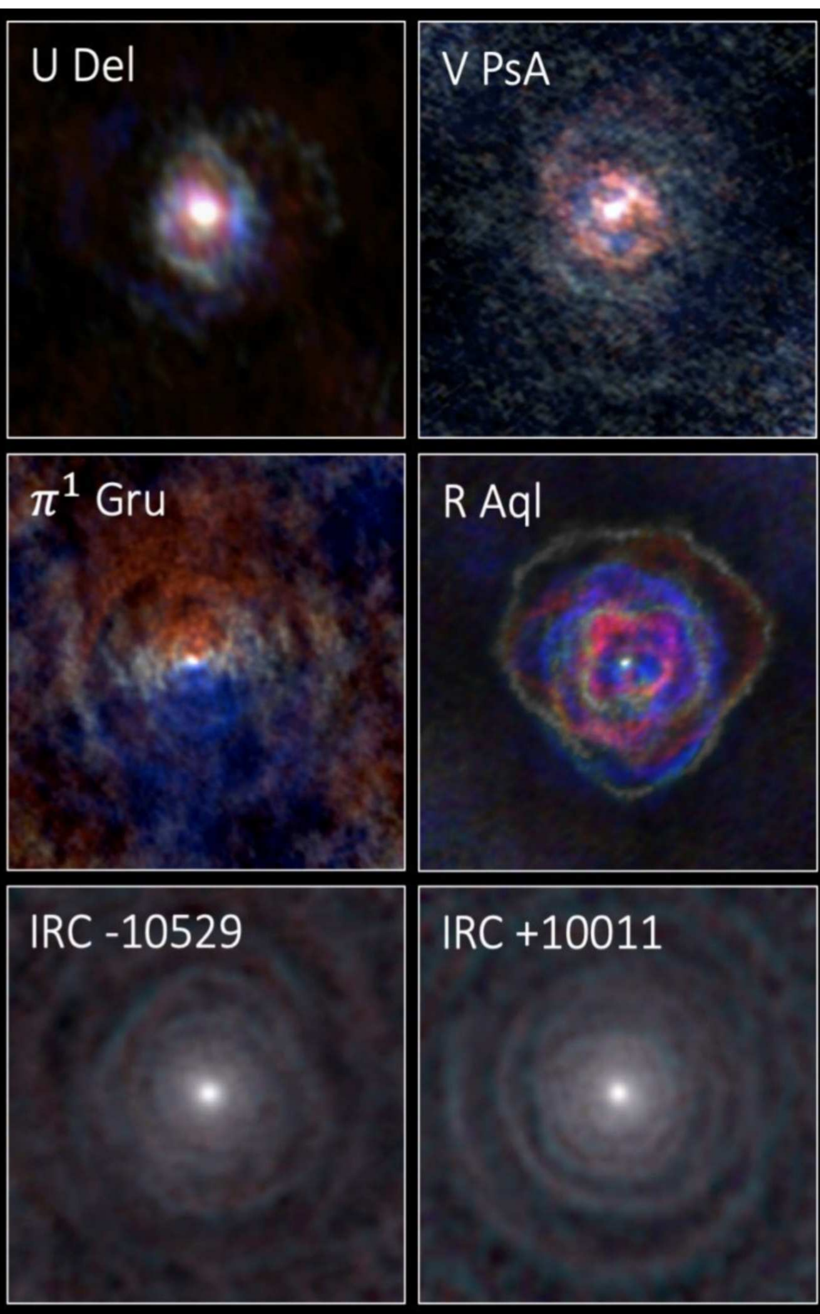
For centuries, astronomers were in the dark about the extraordinary variety of colorful shapes observed in planetary nebulas. The nebulae all seem to have a certain symmetry but are rarely round. *"The Sun – which will ultimately become a red giant – is as round as a billiard ball, so we wondered: how can such a star produce all these different shapes?"* says corresponding author Leen Decin (KU Leuven).



This image gallery of stellar winds around cool ageing stars shows a variety of morphologies, including disks, cones, and spirals. The blue color represents material that is coming towards you; red is material that is moving away from you. [L. Decin, ESO/ALMA, ATOMIUM Large Program]

Her team observed stellar winds around cool red giant stars with the ALMA observatory in Chile, the world's largest radio telescope. For the first time, they gathered an extensive, detailed collection of observations. Each of them made using the same method, crucial to compare the data, and exclude biases directly.

What the astronomers saw surprised them. *"We noticed these winds are anything but symmetrical or round,"* Professor Decin says. *"Some of them are quite similar in shape to planetary nebulae."* The researchers could even identify different categories of shapes. *"Some stellar winds were disk-shaped, others contained spirals, and we identified cones in a third group."* This is a clear indication that the shapes weren't created randomly. The team realized that other low-mass stars or even heavy planets in the dying star's vicinity were causing the different patterns. These companions are too small and dim to detect directly. *"Just like how a spoon that you stir in a cup of coffee with some milk can create a spiral pattern, the companion sucks material towards it as it revolves around the star and shapes the stellar wind,"* Decin explains.



The team put this theory into models, and indeed: the shape of the stellar winds can be explained by the companions surrounding them. The rate at which the cool evolved star is losing its mass due to the stellar wind is an important parameter.

Up until now, calculations about the evolution of stars were based on the assumption that aging Sun-like stars have spherical stellar winds. *"Our findings change a lot. Since the complexity of stellar winds was not accounted for in the past, any previous mass-loss rate estimate of old stars could be wrong by up to a factor of 10."* The team is now doing further research to see how this might impact calculations of other crucial characteristics of stellar and galactic evolution.

The study also helps envision what the Sun might look like when it dies in 7000 million years. *"Jupiter or even Saturn – because they have such a big mass – are going to influence whether the Sun spends its last millennia at the heart of a spiral, a butterfly, or any of the other entrancing shapes we see in planetary nebulae today,"* Decin notes. *"Our calculations now indicate that a weak spiral will form in the stellar wind of the old dying Sun."*

"We were very excited when we explored the first images," says co-author Miguel Montargès (KU Leuven). *"Each star, which was only a number before, became an individual by itself. Now, to us, they have their own identity. This is the magic of having high-precision observations: stars are no longer just points anymore."*

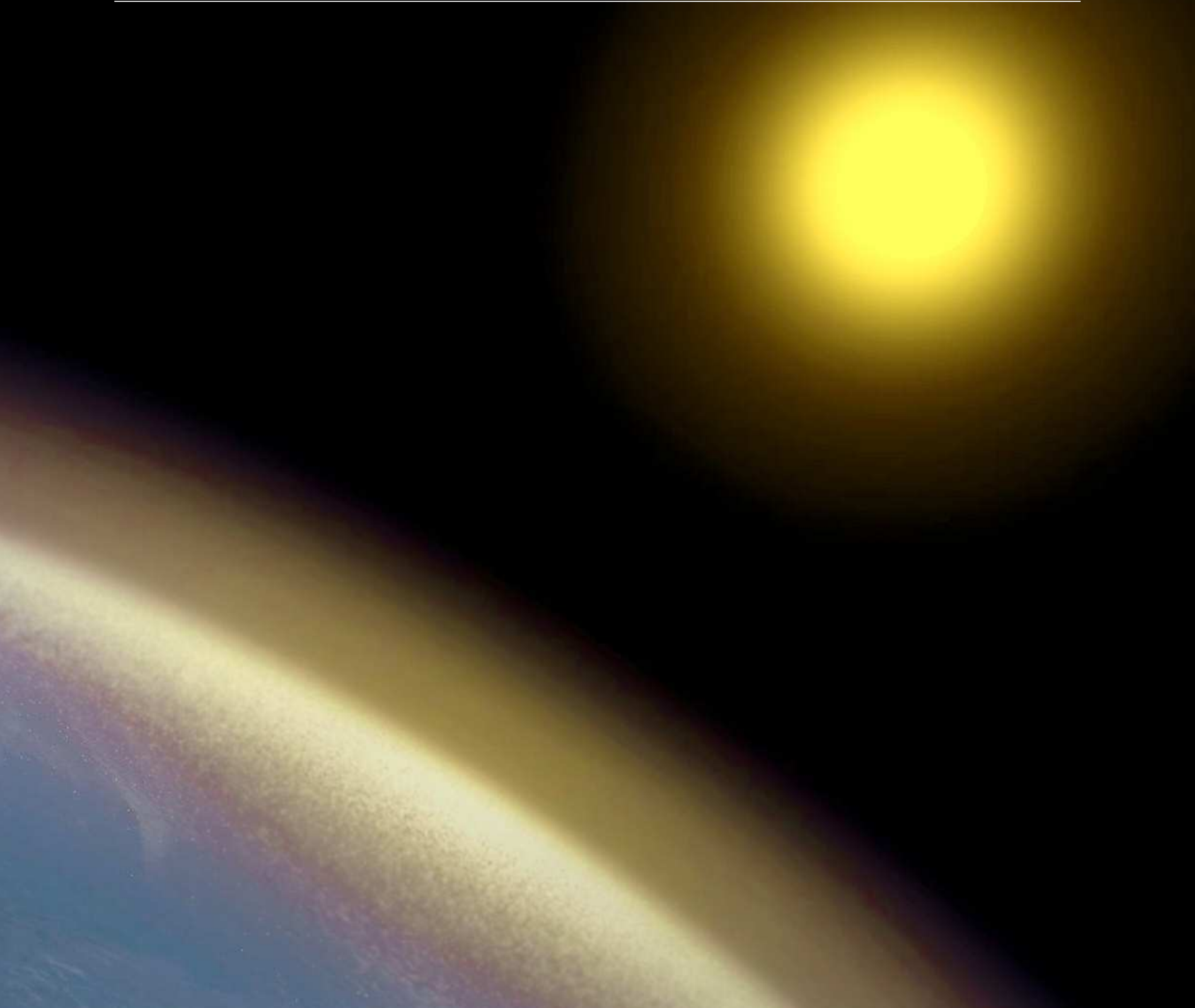
The study is part of the ATOMIUM project, which aims to learn more about the physics and chemistry of old stars. *"Cool aging stars are considered boring, old and simple, but we now prove that they are not: they tell the story of what comes after. It took us some time to realize that stellar winds can have the shape of rose petals (see, for example, the stellar wind of R Aquilae). But, as Antoine de Saint-Exupéry said in his book Le Petit Prince: 'C'est le temps que tu as perdu pour ta rose, qui fait ta rose si importante' – 'It's the time you spent on your rose that makes your rose so important,'"* Decin concludes.

Cold Jupiters and super-Earths, a rather interesting combination

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

Simulations with supercomputers are tools of primary importance in astronomy, allowing us to analyze the evolution of phenomena that instrumental and temporal limits do not permit us to study directly. The results of the simulations, virtual scenarios based on physics models that should represent a reality not yet confirmed, are inevitably dependent on the "ingredients" of the simulations themselves. Starting from a basic knowledge of a given phenomenon and applying a well-structured algorithm to its evolution are essential requirements for launching a promising simulation. The higher the precision of the algorithm's so-called "input data", the more realistic the scenario produced by the simulation. In particularly favorable cases, a simulation can generate so much information that the result itself can be analyzed in detail, as if it were a non-virtual reality. For example, consider simulations of the entire universe, or at less ambitious scales, simulations of planetary systems. In the latter context, a recent work by astronomers from the Max Planck Institute for Astronomy (MPIA) in Heidelberg, the University of Bern, and the University of Arizona deserves to be mentioned.
The study, coordinated by Martin Schlecker (MPIA), had among its ob-



jectives an understanding of how recurrent the configurations that include both a rocky planet similar to the Earth (or a little more massive) and a gas giant as large as Jupiter are within the planetary systems of solar-type stars.

For several years, scientists have suspected that, in our planetary system, Jupiter played an important role in maintaining life on our planet.

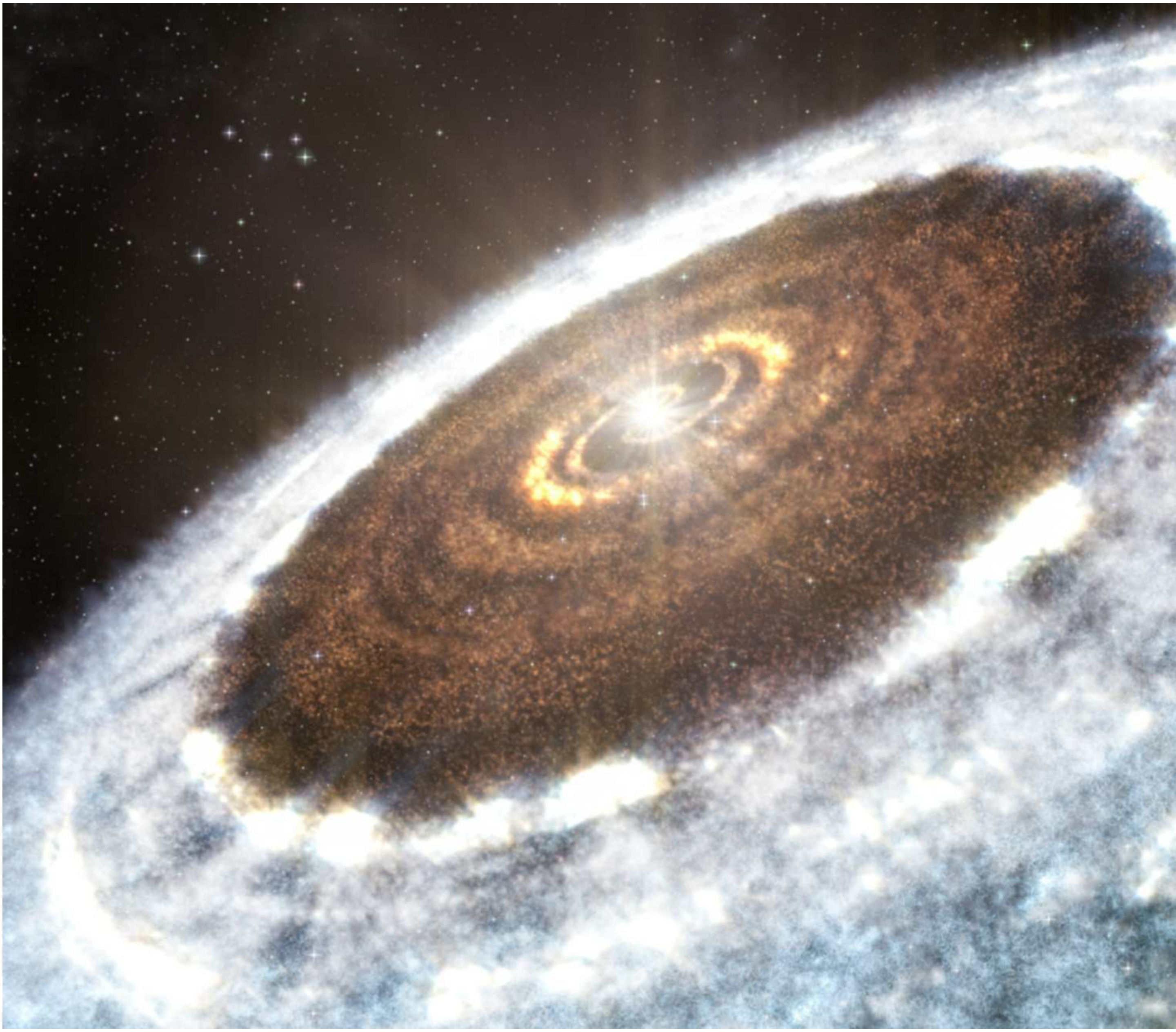
Its presence beyond the so-called "snow line" would have prevented many asteroids and comets from traveling potentially dangerous orbits, considerably reducing the number of their catastrophic collisions with the Earth. It goes without saying that it would be interesting to understand if this combination of planets, orbiting solar-type stars, is purely coincidental or if it is instead a scenario common to a significant number of extrasolar systems.

In the background a super-Earth is represented, a planet more than twice the size of Earth, but which may still be habitable if it orbits in the temperate region of its star. [Amanda Smith]

According to observations (which are limited in scope by various factors), systems with a "cold Jupiter" quite far away from its star also quite often contain a super-Earth in

the temperate orbital region. The opposite is less frequent, in the sense that it is somewhat common to find super-Earths (and to a lesser extent also Earths) in systems where a relatively cold gas giant is missing or has not yet been discovered.
Schlecker's team tried to add insights into this rough picture by simulating the evolution of 1000 planetary systems around solar-like stars. Starting from different initial conditions of gas and dust masses, disk sizes, and the positions of planetary embryos, the researchers traced the development of those systems over

In this hypothetical protoplanetary disk, the so-called "snow line" is highlighted, the distance from the star beyond which water freezes, determining the outer limit of the habitable zone. [A. Angelich (NRAO/AUI/NSF)/ALMA (ESO/NAOJ/NRAO)]

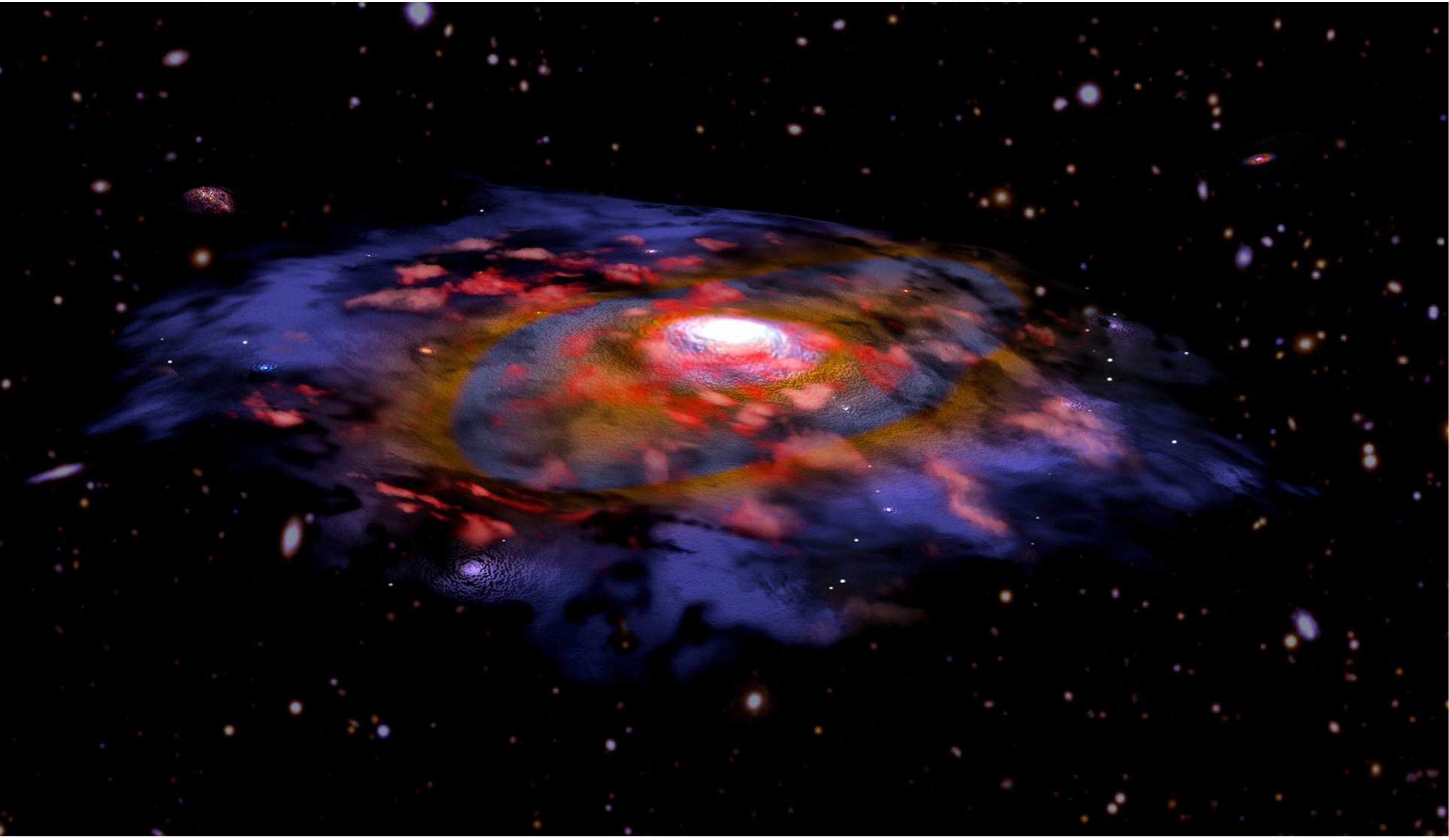


periods of billions of years, obtaining planets of different sizes, masses and compositions in different orbits around their central stars.
The results of the simulations did not agree with the trends from the observational data, instead predicting a reduction in the frequency of

cold Jupiter/super-Earth pairs in planetary systems. If the presence of a large planet like Jupiter does improve the chances for life on the inner super-Earths of a solar system, then this predicted reduction is not comforting from an astrobiological point of view. Although the researchers have taken into consideration super-Earths instead of Earths (only because they are more numerous, easier to discover and therefore statistically more relevant), from the point of view of habitability, the difference between the two is not great, making the end result an overall lower predicted number of total solar systems more likely to host a more protected, life-hosting planet.
The reasons why observations and simulations do not match may be manifold, ranging from a discrimination attributable, to the current methods of searching for exoplanets, to an approximate formulation of the theories concerning the migration of gaseous planets towards the innermost regions of their systems.
Leaving out some controversial aspects of the simulations performed by Schlecker and colleagues, an interesting fact has nevertheless emerged: the planetary systems in which there are a cold Jupiter and at least one super-Earth appear to originate from particularly massive protoplanetary disks. In medium-mass discs (and even more so in low-mass ones), there is not enough material in the innermost and temperate regions to form super-Earths, nor is there enough material beyond the snow line to form gas giants. Super-Earths with relatively high percentages of ice and a thick atmosphere are more likely to form beyond the snow line and, not being hindered by the presence of a gas giant in an inner orbit, these super-Earths are free to migrate towards more temperate regions.

Martin Schlecker (Max Planck Institute for Astronomy), the lead author of the study discussed in this article [MPIA]

It is interesting to note that (virtual) super-Earths and Earths that form in the habitable zone have a percentage of water/ice and an atmospheric mass significantly lower than those of similar planets that migrated in from outside. It is therefore probable that when the simultaneous presence of a cold Jupiter and a super-Earth (or Earth) is found (in reality), the latter is of the “arid” type, therefore similar to our planet and hence potentially more compatible with life as we know it.
When instruments such as the James Webb Space Telescope and the Extremely Large Telescope become operational in the next few years, it will be possible to more accurately assess the role of cold Jupiters in the habitability of planetary systems and understand just how much our Jupiter may have protected life on Earth. ■



Galaxies in the infant Universe were surprisingly mature

by ALMA Observatory

Massive galaxies were already much more mature in the early universe than previously expected. This was shown by an international team of astronomers who studied 118 distant galaxies with the Atacama Large Millimeter/submillimeter Array (ALMA). Most galaxies formed when the universe was still very young. Our own galaxy, for example, likely started forming 13.6 billion years ago, in our 13.8 billion-year-old universe. When the universe was only ten percent of its current age (1-1.5 billion years after the Big Bang), most of the galaxies experienced a "growth spurt". During this time, they built up most of their stellar mass and other properties, such as dust, heavy element content, and spiral-disk shapes, that we see in today's galaxies. Therefore, if we want to learn how galaxies like our Milky Way formed, it is important to study this epoch.

Artist's illustration of a galaxy in the early universe that is very dusty and shows the first signs of a rotationally supported disk. In this image, the red color represents gas, and blue/brown represents dust as seen in radio waves with ALMA. Many other galaxies are visible in the background, based on optical data from VLT and Subaru. [B. Saxton NRAO/AUI/ NSF, ESO, NASA/STScI; NAOJ/Subaru]

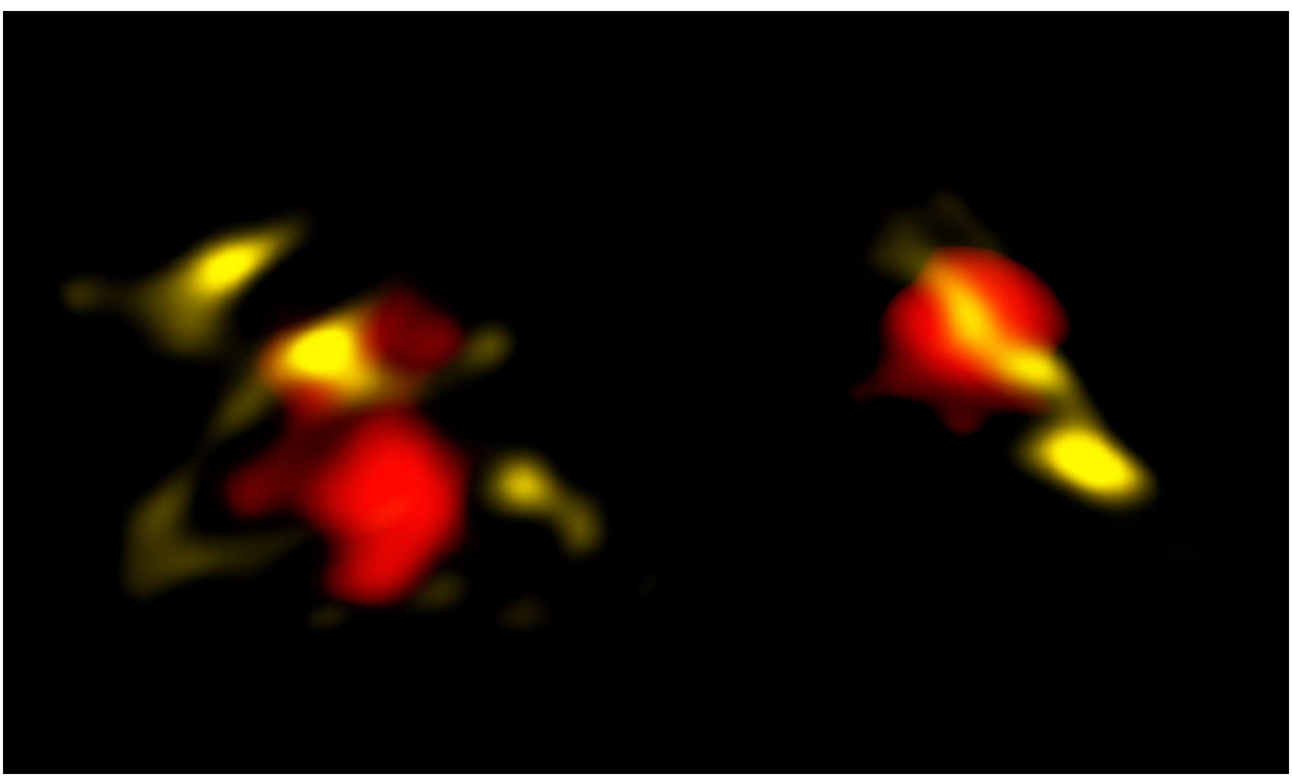
In a survey called ALPINE (the ALMA Large Program to Investigate C+ at Early Times), an international team of astronomers studied 118 galaxies experiencing such a "growth spurt" in the early universe. *"To our surprise, many of them were much more mature than we had expected,"* said Andreas Faisst of the Infrared Processing and Analysis Center (IPAC) at the California Institute of Technology (Caltech).

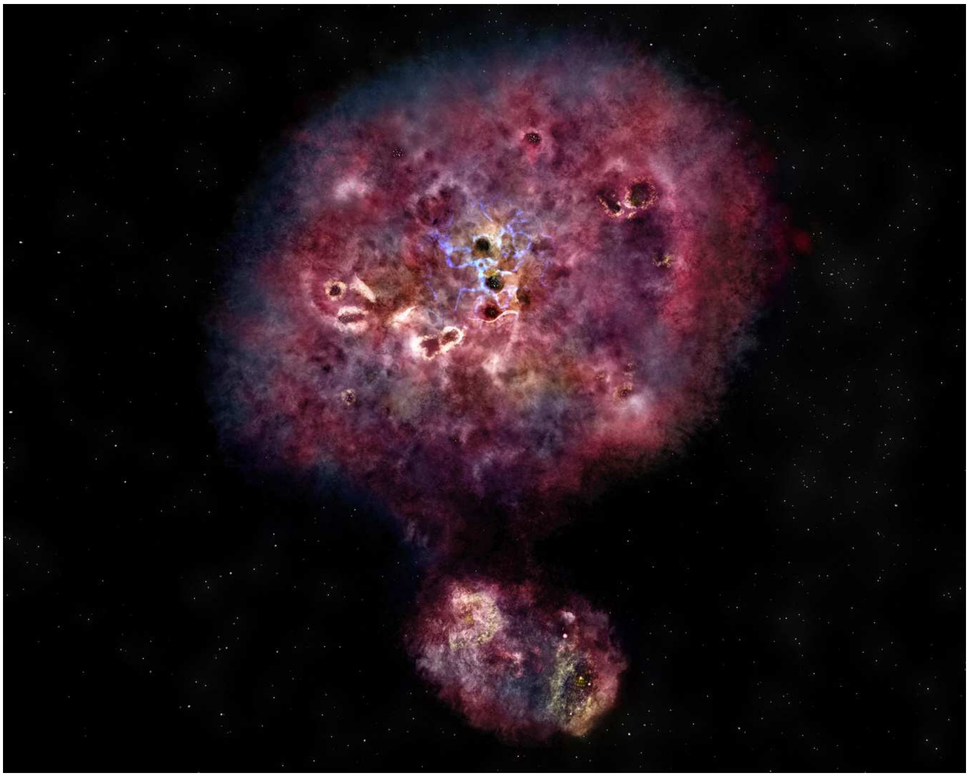
Galaxies are considered more "mature" than "primordial" when they contain a significant amount of dust and heavy elements. *"We didn't expect to see so much dust and heavy elements in these distant galaxies,"* said Faisst. Dust and heavy elements (defined by astronomers as all elements heavier than hydrogen and helium) are considered to be a byproduct of dying stars. But galaxies in the early universe have not had much time to build stars yet, so astronomers don't expect to see much dust or heavy elements there either. *"From previous studies, we understood that such young galaxies are dust-poor,"* said Daniel Schaerer of the University of Geneva in Switzerland. *"However, we find around 20 percent of the galaxies that assembled during this early epoch are already very dusty and a significant fraction of the ultraviolet light from newborn stars is already hidden by this dust,"* he added.

Many of the galaxies were also considered to be relatively grown-up because they showed diversity in their structures, including the first signs of rotationally supported disks – which may later lead to galaxies with a spiral structure as is observed in galaxies such as our Milky Way. Astronomers generally expect that galaxies in the early universe look like train wrecks because they often collide. *"We see many galaxies that are colliding, but we also see a number of them rotating in an orderly fashion with no signs of collisions,"* said John Silverman of the Kavli Institute for the Physics and Mathematics of the Universe in Japan.

ALMA has spotted very distant galaxies before, such as MAMBO-9 (a very dusty galaxy) and the Wolfe Disk (a galaxy with a rotating disk).

These are two of the galaxies in the early universe that ALMA observed in radio waves. The galaxies are considered more "mature" than "primordial" because they contain large amounts of dust (yellow). ALMA also revealed the gas (red), which is used to measure the obscured star-formation and motions in the galaxies. [B. Saxton NRAO/AUI/ NSF, ALMA (ESO/NAOJ/ NRAO), equipo de ALPINE]





Artist's impression of what the MAMBO-9 galaxy would look like in visible light. The galaxy is very dusty and has yet to build most of its stars. [NRAO/AUI/NSF, B. Saxton]

But it was hard to say whether these discoveries were unique, or whether there were more galaxies like them out there.
ALPINE is the first survey that enabled astronomers to study a significant number of galaxies in the early universe, and it shows that they might evolve faster than expected. But the scientists don't yet understand how these galaxies grew up so fast, and why some of them already have rotating disks.
Observations from ALMA were crucial for this research because the radio telescope can see the star formation that is hidden by dust and trace the motion of gas emitted from star-forming regions. Surveys of galaxies in the early universe commonly use optical and infrared telescopes. These allow the measurement of the unobscured star formation and stellar masses. However, these telescopes have difficulties measuring dust, obscured regions, where stars form, or the motions of gas in these galaxies. And sometimes they don't see a galaxy at all. *"With ALMA we discovered a few distant galaxies for the first time. We call these Hubble-dark as they could not be detected even with the Hubble telescope,"* said Lin Yan of Caltech.
To learn more about distant galaxies, the astronomers want to point ALMA at individual galaxies for a longer time. *"We want to see exactly where the dust is and how the gas moves around. We also want to compare the dusty galaxies to others at the same distance and figure out if there might be something special about their environments,"* added Paolo Cassata of the University of Padua in Italy, formerly at the Universidad de Valparaíso in Chile.
ALPINE is the first and largest multi-wavelength survey of galaxies in the early universe. For a large sample of galaxies the team collected measurements in the optical (including Subaru, VISTA, Hubble, Keck, and VLT), infrared (Spitzer), and radio (ALMA).
Multi-wavelength studies are needed to get the full picture of how galaxies are built up. *"Such a large and complex survey is only possible thanks to the collaboration between multiple institutes across the globe,"* said Matthieu Béthermin of the Laboratoire d'Astrophysique de Marseille in France. ■

A short video explaining the result of the research. [B. Saxton NRAO/AUI/NSF]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