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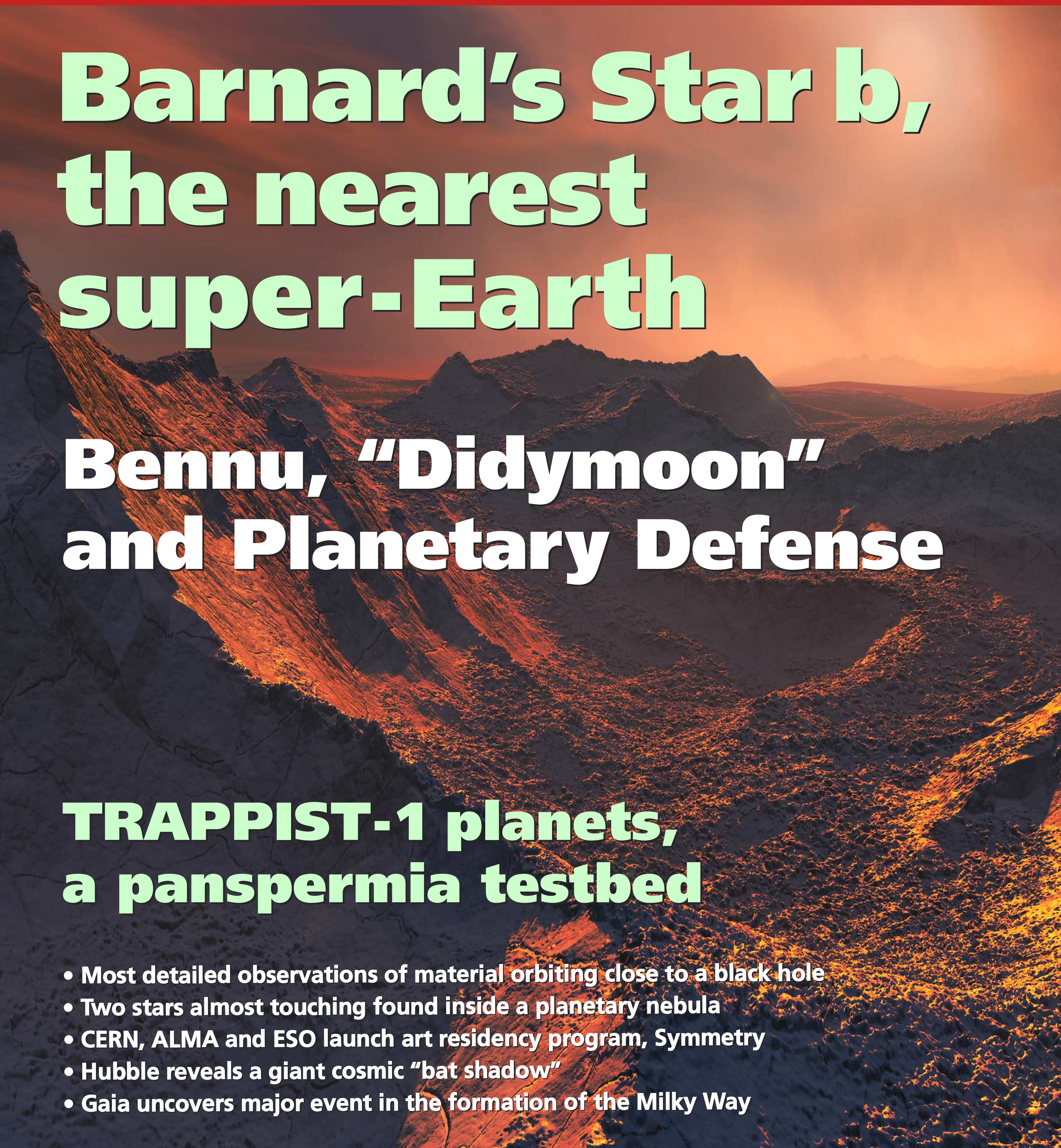

Barnard's Star b, the nearest super-Earth

Bennu, "Didymoon" and Planetary Defense

TRAPPIST-1 planets, a panspermia testbed

- Most detailed observations of material orbiting close to a black hole
- Two stars almost touching found inside a planetary nebula
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- Gaia uncovers major event in the formation of the Milky Way

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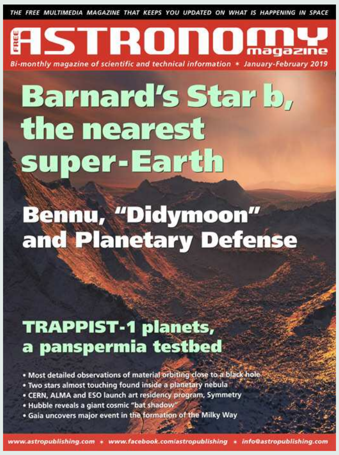

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SUMMARY

Barnard's Star b, the nearest super-Earth

by Michele Ferrara

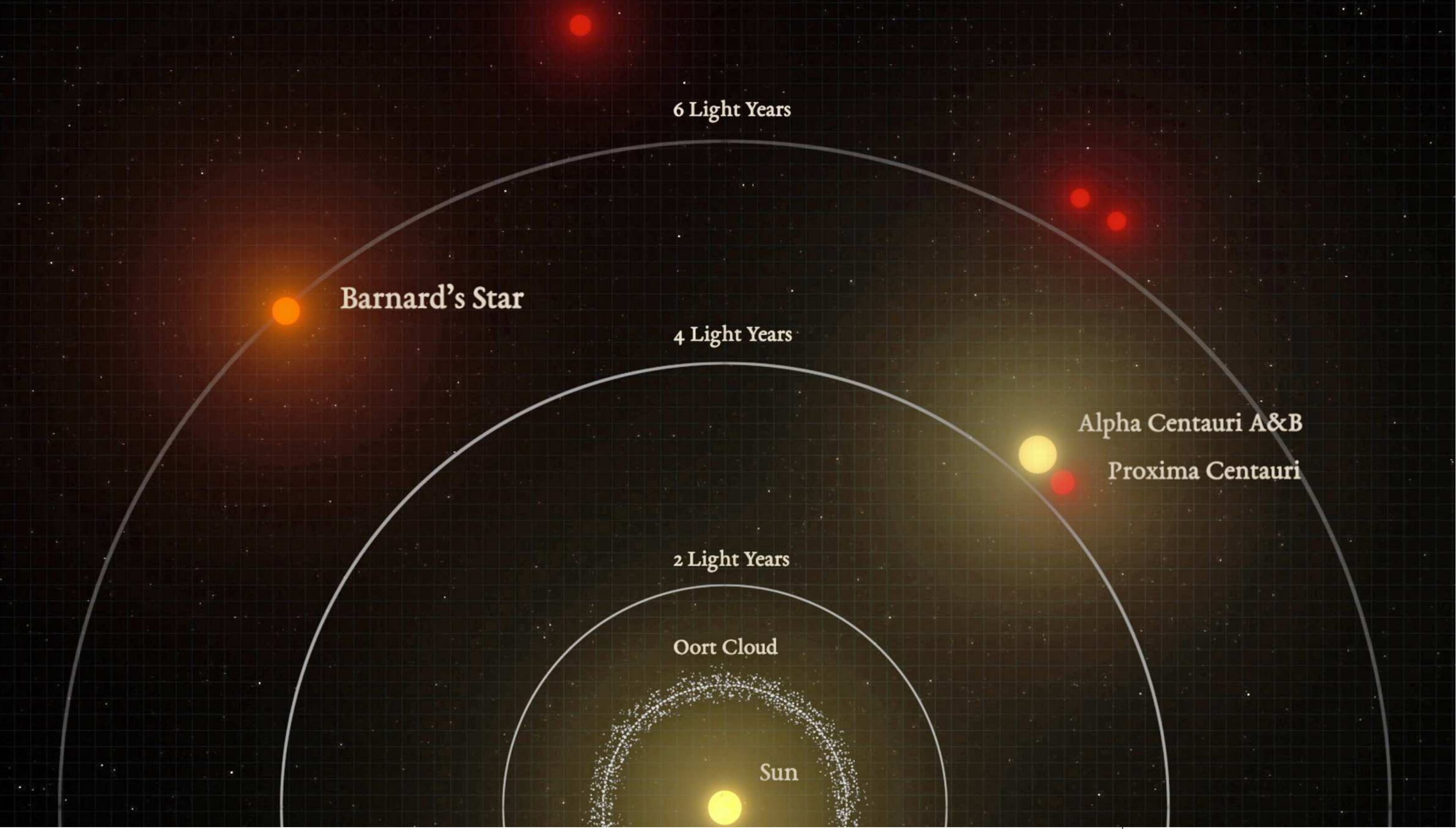
revised by Damian G. Allis
NASA Solar System Ambassador

Barnard's Star, which for over a century has held the record of the star with the fastest apparent motion in our night sky, houses a cold super-Earth that could soon be photographed directly. This planet is the second closest among the known extrasolar ones and one day it will perhaps become a destination for the first interstellar probes.

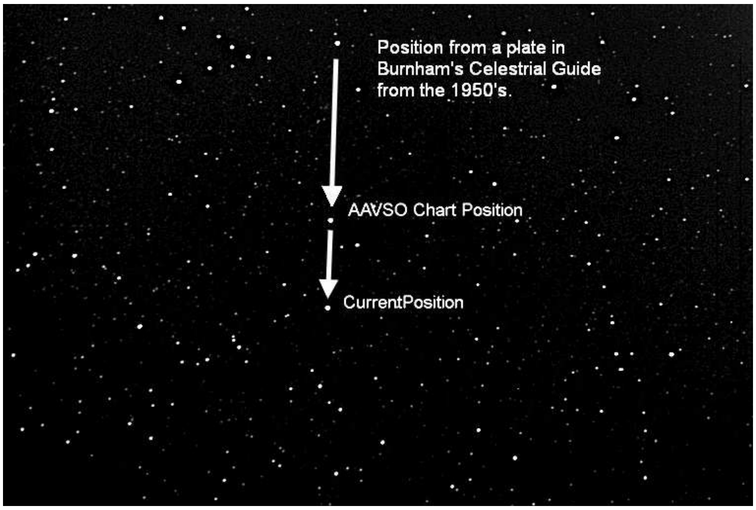
The nearest single star to the Sun hosts an exoplanet at least 3.2 times as massive as Earth — a so-called super-Earth. Data from a worldwide array of telescopes, including ESO's planet-hunting HARPS instrument, have revealed this frozen, dimly lit world. The newly discovered planet is the second-closest known exoplanet to the Earth and orbits the fastest moving star in our night sky. This image shows an artist's impression of the planet's surface. [ESO/M. Kornmesser]
On the right, a video from the ESOcast Light series introducing the discovery of Barnard's Star b. [ESO]

A little over a century ago, the American astronomer Edward Emerson Barnard, already famous for having discovered fifteen comets, measured the proper motion of a star of magnitude 9.5 in the constellation of Ophiuchus, obtaining a surprising value: 10.3 arcseconds per year. Barnard had discovered the fastest star in the night sky, so fast that it covers an angle the size of the full moon in 180 years.

Usually, the more an object appears to move quickly in the sky, the closer it is to the observer, and, in fact, that star is only 6 light years away. Only the components of the Alpha Centauri triple system are closer to the Sun.



The fast motion and the relative proximity of that star made Barnard even more famed, to the point that his name has since been indissolubly linked to the star.
Today we know that Barnard's Star is a typical red dwarf, considerably older than the Sun and therefore quieter than younger red dwarfs, whose surface often shows particularly severe flares. The last of these events at Barnard's Star occurred about twenty years ago and doubled the surface temperature.
In the decades following the discovery by Barnard, astrometry continued to be fundamental to the work on this star by many astronomers, who continued to measure the positions of the star on photographic plates in order to improve estimates of parallax and proper motion.
Among those astronomers was Peter van de Kamp, Dutch by birth and American by adoption, who was director of observatories and a university professor. In the late 1960s, van de Kamp became quite famous for announcing the discovery of a planet in orbit around Barnard's Star. Examining photographic plates taken between 1916 and 1962, the astronomer noticed small oscillations in the straight motion of the star, explainable with the presence of a body 1.6 times more massive than Jupiter, that from a distance of 4.4 AU pulled the star towards itself by rotating around it. The announcement of the discovery had a remarkable resonance because at that time the only known planets were those in our Solar System, and to tell the truth little was known even of them.
As usual, other astronomers went to work to verify the discovery, and in the 1970s it became clear that the anomalies found by van de Kamp were not attributable to a planet, but to a problem of the 24-inch refractor op-



Graphical representation of the relative distances between the nearest stars and the Sun. Barnard's Star is the second closest star system to the Sun and the nearest single star to our Solar System. On the left, the high apparent motion of V2500 Ophiuchi, or Barnard's Star, from the 1950s to 2018.

This wide-field image shows the surroundings of the red dwarf known as Barnard's Star in the constellation of Ophiuchus (the Serpent-Bearer). This picture was created from the material forming part of the Digitized Sky Survey 2. The center of the image shows Barnard's Star captured in three different exposures. The star is the fastest moving star in the night sky and its large apparent motion can be seen as its position changes between successive observations — shown in red, yellow and blue. [ESO/Digitized Sky Survey 2. Davide De Martin E – Red Dots]

tics with which the plates were taken: curiously, each time the objective lens was removed, cleaned and reassembled, the color-dependent image scale of the stellar images changed. It is for this reason that the same, presumed oscillations were then noticed also for many other stars, and it is again for this reason that van de Kamp and some of his collaborators were convinced they had already discovered other planetary systems, later proved as non-existent.
In spite of the evidence of equipment being responsible for the observed oscillations, van de Kamp advocated his discovery in specialized magazines until the 1980s. By this time, the precision of other radial velocity measurements had imposed for the mass of the alleged planet a much lower limit than that calculated by van de Kamp, insufficiently small to produce the observed effects. In short, that planet did not exist. However, the interest of astronomers in Barnard's Star has never diminished. Because of its proximity to our planet, it has continued to be a very studied object with astrometric, photometric and spectroscopic techniques.
The last two decades of data, gathered in seven prestigious observatories, have merged into a study linked to the Red Dots project (which in 2016 produced the discovery of Proxima Centauri b). This collective study has now made real the original illusion of van de Kamp through the discovery of a planet in orbit around Barnard's Star.
The achievement was realized thanks to the synergy of about sixty researchers, belonging to about thirty scientific institutes, who combined almost 800 measurements of radial velocities, all performed using high-resolution spectral lines of the star.

Let's open a brief parenthesis on this survey technique, to remind by summary how it works. Each star moves in the galaxy and, regardless of its real spatial trajectory, we can see it moving away or approaching (it rarely appears motionless). If the star moves away, the lines of the chemical elements visible in its spectrum will be slightly redshifted when compared to the reference lines produced in the laboratory. If the star approaches, the shift of the lines will be towards the blue. In any case, for each star, we can know the exact value of the displacement, which remains unchanged for millennia if in the meantime no mass intervenes to modify it. A planet orbiting a star can make the radial velocity oscillate significantly. The magnitude of the oscillation essentially depends on the mass of the star, the mass of the planet, the distance separating the two bodies, and their position with respect to the observer. The farther the planet moves from the straight line passing through the star and the observer, the lower the oscillation in the radial velocity of the star will be. An Earth-sized planet can displace a dwarf star no more than a few meters per second, an amount easily achieved by phenomena related to the magnetic activity of the star and the mass difference between the two objects. All of these radial velocity details underline that the search for non-transiting extrasolar planets requires high power instruments and very high-resolution spectroscopes, as well as long periods of observation. The large team of researchers mentioned above who discovered Barnard's Star b (led by Ignasi Ribas, Institut d'Estudis Espacials de Catalunya, IEEC, and Institut de Ciències de l'Espai, CSIC, Barcelona) worked based on this high-resolution radial velocity measurement method. The study started by reviewing archive data collected from the end of the last century through 2015. The database had suggested the presence of a potentially significant signal, with a period of about 230 days, but without a sufficient sampling to accurately characterize it. To confirm and understand the nature of that signal, the

In the background, an artistic view of Barnard's Star b seen from space. [ESO/M. Kornmesser]

This video shows Barnard's Star and its super-Earth. [ESO/M. Kornmesser]

research team undertook, from 2016 to 2017, a monitoring campaign with the spectrometer CARMENES (Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs) at the Observatorio de Calar Alto (Almería, Spain), collecting radial velocity measurements so precise as to detect differences of 1 m/s. These data have been integrated with equally accurate data gathered with other high-resolution spectrographs, such as ESO's HARPS and UVES, in Chile, and Telescopio Nazionale Galileo's HARPS-N, in the Canary Islands.

In this video, we fly over the surface of Barnard's Star b. [ESO/M. Kornmesser]

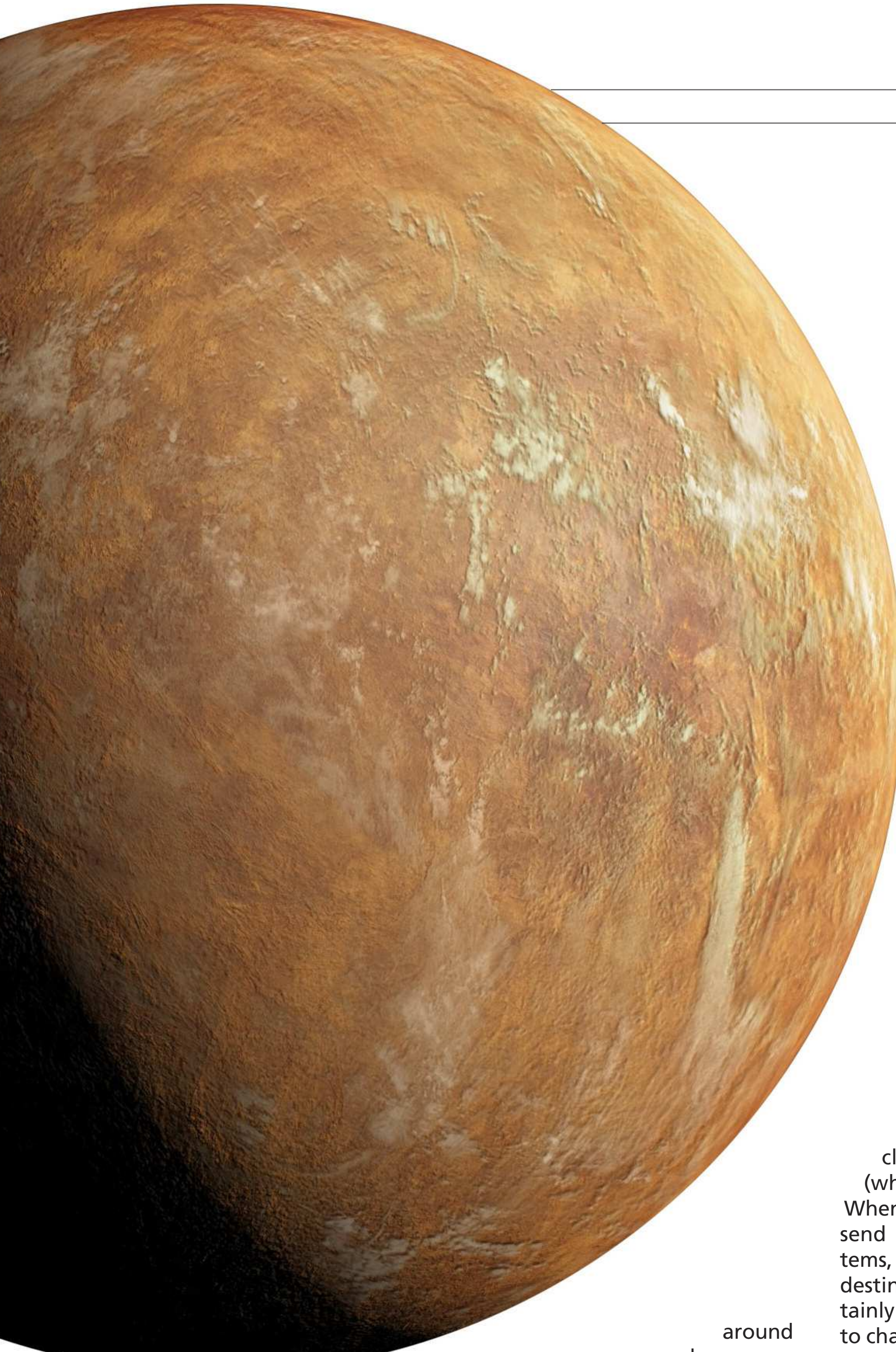
The combination of new measurements with the archive datasets clearly showed a signal with a periodicity of 233 days, and also revealed a fainter long-term modulation.

The 233-day periodicity originates from a variation in the radial velocity of just 1.2 m/s, a shift that could easily be produced by the photospheric activity. However, the researchers are 99% confident they can rule out this possibility because Barnard's Star shows an extremely low level of magnetic activity, a minimum X-ray flow, an imperceptible emission in H-alpha, and negligible chromospheric emission.

Independent photometric and spectroscopic monitoring has indicated a rotation period of the star of 140 ± 10 days, which leads the researchers to exclude the possibility that the 233-days signal is in any way related to surface structures, such as unexpectedly long-lasting active regions. The fact that the star is between 6 and 11 billion year old also favors a very mild magnetic activity, unable of producing persistent phenomena for decades.

For all these reasons, Ribas and colleagues have come to the conclusion that this signal is more easily explained if produced by a planetary companion, with a minimum mass of 3.2 Earth masses, placed on a low-eccentricity orbit, and with a semi-major axis greater than about 0.4 AU. This distance in the Barnard's Star system corresponds roughly to the so-called "snow line", where volatile elements such as water are present in the solid-state. A planet orbiting in this region would only receive 2% of the energy the Earth receives from the Sun and, accordingly, the surface temperature of Barnard's Star b should range between -150°C and -170°C. The predicted temperature of this planet is therefore not habitable for life as we know it, although this could possibly be mitigated by the presence of a thick atmosphere. The mass could also represent an additional hurdle: the calculated value of 3.2 Earth masses must be considered as a minimum limit, valid for a planet which, although non-transiting in front of and behind the disk, is very close to the visual line in the points of maximum approach and maximum distance from the observer. As the deviation from this line increases, the value of the mass grows at the same pace. In the most favorable of possible configurations, Barnard's Star b weighs a little more than three times that of Earth. For this reason, it falls into the category of super-Earths, the type of planet that is most frequently discovered in orbit

This animation shows the stars closest to the Sun and highlights the position of Barnard's Star. [ESO/L. Calçada/ Vladimir Romanyuk (spaceengine.org). Music: Astral Electronics]



mature star system, could question some aspects of planetary migration theories, which disadvantage the maintenance of a planet within its original orbit. It is, however, possible that Barnard's Star b has not migrated because not perturbed in its orbital motion either by the residual dust of the protoplanetary disk or by other orbiting planets. This does not exclude, in any way, that another planet may exist much farther away in this system, whose presence could be associated with the long-term modulation mentioned above. With reference to this possibility, the article published by the research team last November in Nature suggested the existence of a second planet with a minimum mass equal to 15 Earth masses in orbit at 4 AU from the star, but the existence of this second planet is just a hypothesis. On the contrary, the existence of Barnard's Star b is almost certain, which becomes the second exoplanet closest to us after Proxima Centauri b (which is more "similar" to the Earth). When the technology is mature enough to send probes to the nearest planetary systems, Barnard's Star b will be one of the first destinations; in the meantime, we will certainly be able to photograph it directly and to characterize it with sufficient precision. If it travels through the expected orbit, it should move away 220 milliarcseconds from its star, a sufficient angular distance to make it visible in the most powerful telescopes that will be available to astronomers in the imminent future. Although there is no hope of revealing biomarkers in its atmosphere, the direct study of Barnard's Star b will allow us to better understand a type of planet that, although common in the galaxy, is not present in our own Solar System. ■

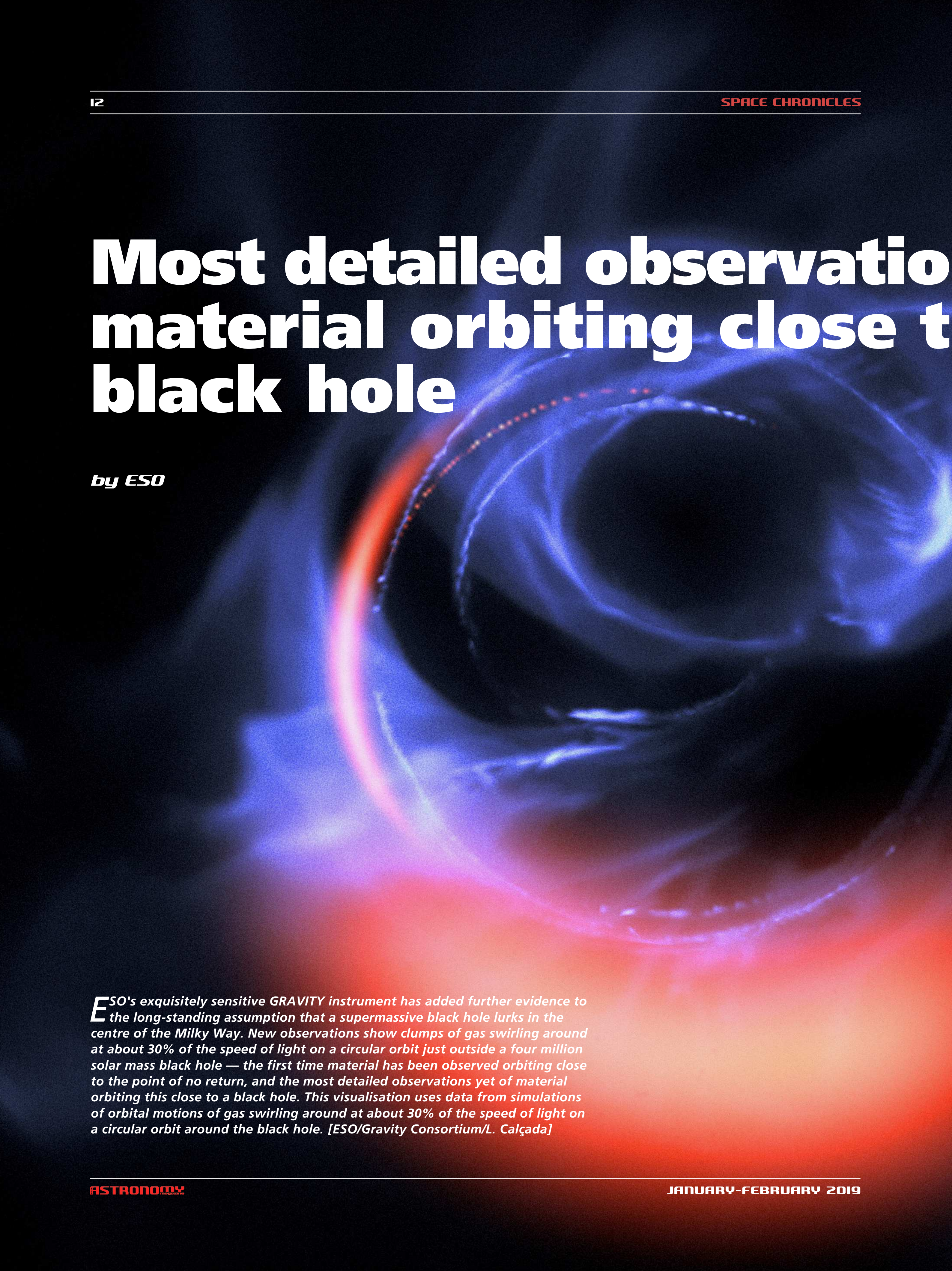
around low-mass stars, a scenario which gives credibility to the results of the Ribas team.

It is interesting to note that current theories of planetary formation predict that the snow-line is the most favorable distance for the birth of super-Earths. Discovering one of these planets in the orbit within which it most likely formed, and in such a

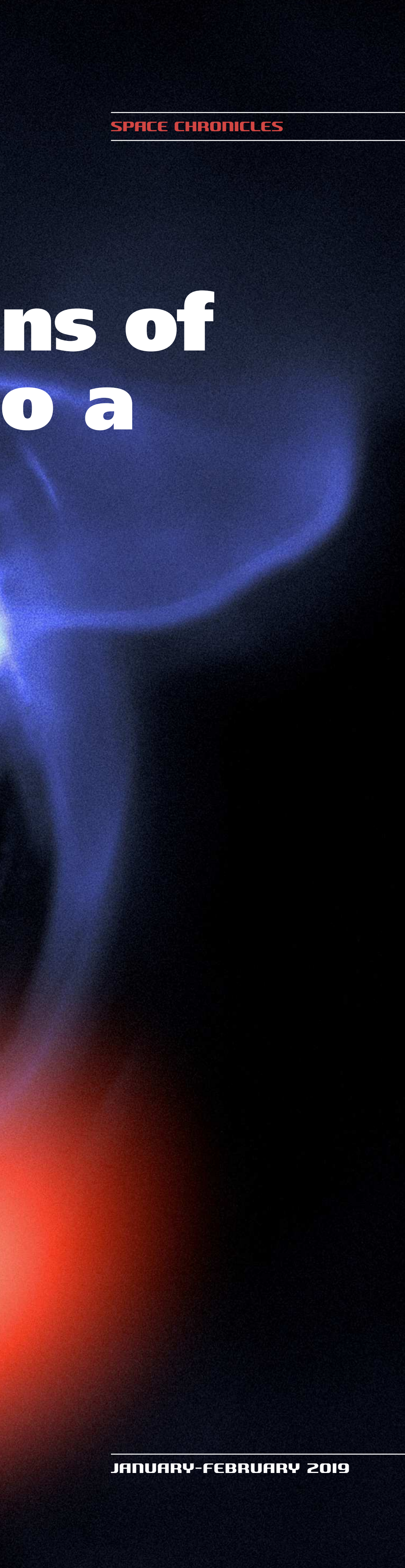
An artistic vision of Barnard's Star b, lit by the red light of the star. [IEEC/Science-Wave – Guillem Ramisa]

Most detailed observatio material orbiting close t black hole

by ESO

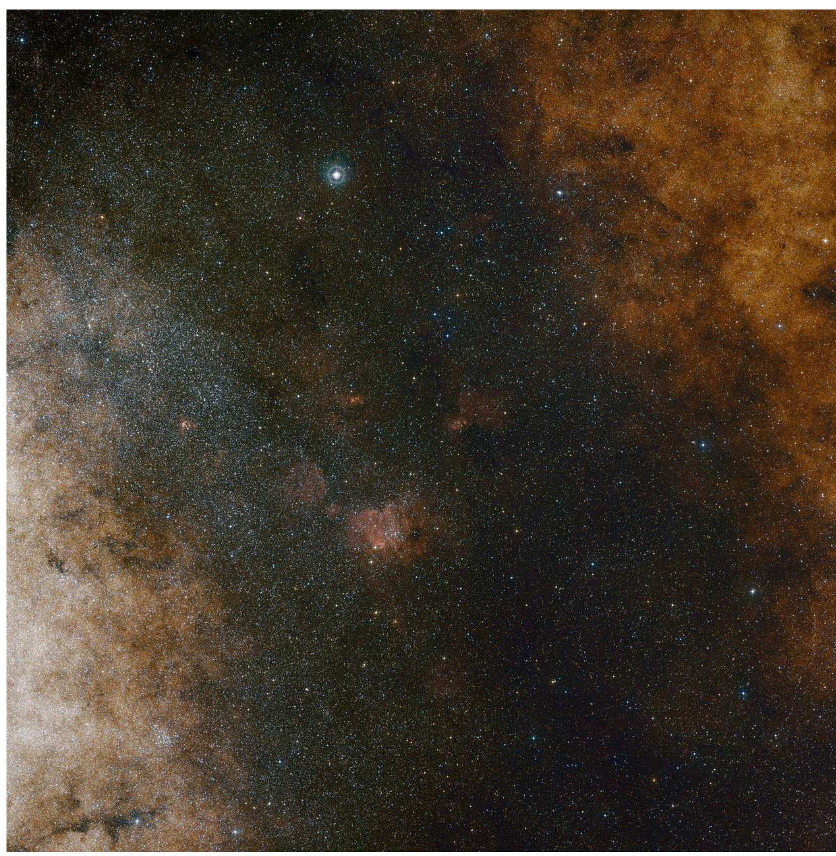


ESO's exquisitely sensitive GRAVITY instrument has added further evidence to the long-standing assumption that a supermassive black hole lurks in the centre of the Milky Way. New observations show clumps of gas swirling around at about 30% of the speed of light on a circular orbit just outside a four million solar mass black hole — the first time material has been observed orbiting close to the point of no return, and the most detailed observations yet of material orbiting this close to a black hole. This visualisation uses data from simulations of orbital motions of gas swirling around at about 30% of the speed of light on a circular orbit around the black hole. [ESO/Gravity Consortium/L. Calçada]



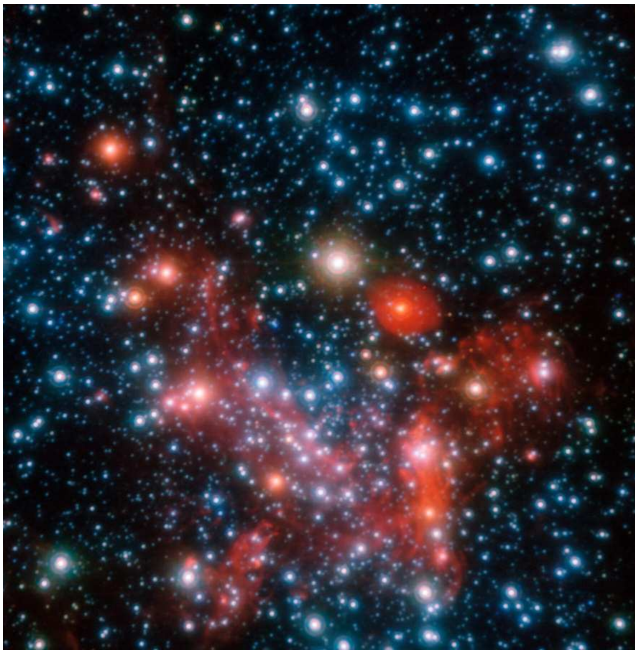
ESO’s GRAVITY instrument on the Very Large Telescope (VLT) Interferometer has been used by scientists from a consortium of European institutions, including ESO, to observe flares of infrared radiation coming from the accretion disc around Sagittarius A*, the massive object at the heart of the Milky Way. The observed flares provide long-awaited confirmation that the object in the centre of our galaxy is, as has long been assumed, a supermassive black hole. The flares originate from material orbiting very close to the black hole’s event horizon — making these the most detailed observations yet of material orbiting this close to a black hole.

While some matter in the accretion disc — the belt of gas orbiting Sagittarius A* at relativistic speeds — can orbit the black hole safely, anything that gets too close is doomed to be pulled beyond the event horizon. The closest point to a black hole that material can orbit without being irresistibly drawn inwards by the im-



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

mense mass is known as the innermost stable orbit, and it is from here that the observed flares originate.
"It's mind-boggling to actually witness material orbiting a massive black hole at 30% of the speed of light," marvelled Oliver Pfuhl, a scientist at the MPE. *"GRAVITY's tremendous sensitivity has allowed us to observe the accretion processes in real time in unprecedented detail."* These measurements were only possible thanks to international collaboration and state-of-the-art instrumentation.
The GRAVITY instrument which made this work possible combines the light from four telescopes of ESO's VLT to create a virtual super-telescope 130 metres in diameter, and has already been used to probe the nature of Sagittarius A*. Earlier this year, GRAVITY and SINFONI, another instrument on the VLT, allowed the same team to accurately measure the close fly-by of the star S2 as it passed through the extreme gravitational field near Sagittarius A*, and for the first time revealed the effects predicted by Einstein's general relativity in such an extreme environment. During S2's close fly-by, strong infrared emission was also observed. *"We were closely monitoring S2, and of course we always keep an eye on Sagittarius A*,"* explained Pfuhl. *"During our observations, we were lucky enough to notice three bright flares from around the black hole — it was a lucky coincidence!"*
This emission, from highly energetic electrons very close to the black hole, was visible as three prominent bright flares, and exactly matches theoretical predictions for hot spots orbiting close to a black hole of four million solar masses. The flares are thought to originate from magnetic interactions in the very hot gas orbiting very close to Sagittarius A*.
Reinhard Genzel, of the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, Germany, who led the study, explained: *"This always was one of our dream projects but we did not dare to hope that it would become possible so soon."* Referring to the long-standing assumption that Sagittarius A* is a supermassive black hole, Genzel concluded that *"the result is a resounding confirmation of the massive black hole paradigm"*.



The central parts of our Galaxy, the Milky Way, as observed in the near-infrared with the NACO instrument on ESO's Very Large Telescope. By following the motions of the most central stars over more than 16 years, astronomers were able to determine the mass of the supermassive black hole that lurks there. [ESO/S. Gillessen et al.]

This video starts with a wide view of the Milky Way and then zooms into a visualization of data from simulations of orbital motions of gas swirling around at about 30% of the speed of light on a circular orbit around the supermassive black hole Sagittarius A*. [ESO/Gravity Consortium/L. Calçada/N. Risinger (skysurvey.org)]

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ALMA maps Europa's temperature

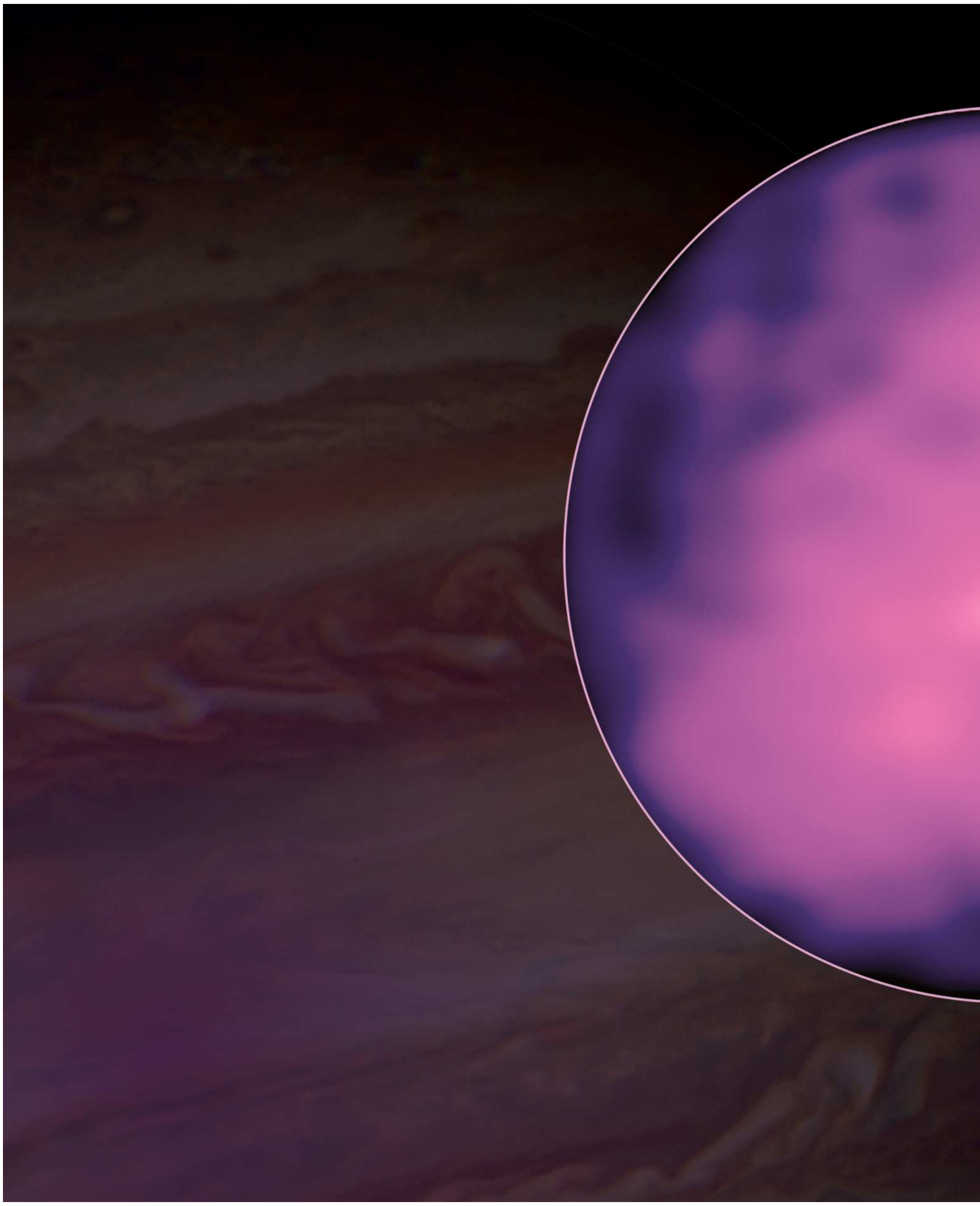
by ALMA Observatory

Jupiter's icy moon Europa has a chaotic surface terrain that is fractured and cracked, suggesting a long-standing history of geologic activity.

A new series of four images of Europa taken with the Atacama Large Millimeter/submillimeter Array (ALMA) has helped astronomers create the first global thermal map of this cold satellite of Jupiter. The new images have a resolution of roughly 200 kilometers, sufficient to study the relationship between surface thermal variations and the moon's major geologic features.

The researchers compared the new ALMA observations of Europa to a thermal model based on observations from the Galileo spacecraft. This comparison allowed them to analyze the temperature changes in the data and construct the first-ever global map of Europa's thermal characteristics. The new data also revealed an enigmatic cold spot on Europa's northern hemisphere.

"These ALMA images are really interesting because they provide the first global map of Europa's thermal



ALMA image of Jupiter's moon Europa. ALMA was able to map out thermal variations on its surface. Hubble image of Jupiter in the background. [ALMA (ESO/NAOJ/NRAO), S. Trumbo et al.; NRAO/AUI NSF, S. Dagnello; NASA/Hubble] *emission,"* said Samantha Trumbo, a planetary scientist at the California Institute of Technology and lead author on a paper published in *The Astrophysical Journal*. *"Since Europa is an ocean world with potential geologic activity, its surface temperatures are of great interest because they may constrain the locations and extents of any such activity."* Evidence strongly suggests that beneath its thin veneer of ice, Europa has an ocean of briny water in contact with a rocky core. Europa also has a comparatively young surface, only about 20 to 180 million years old, indicating that there are as-yet-unidentified thermal or geologic processes at work.

Unlike optical telescopes, which can only detect sunlight reflected by planetary bodies, radio and millimeter-wave telescopes like ALMA can detect the thermal "glow" naturally emitted by even relatively cold object in our Solar System, including comets, asteroids, and moons.

At its warmest, Europa's surface temperature never rises above minus 160 degrees Celsius (minus 260 degrees Fahrenheit).

"Studying Europa's thermal properties provides a unique means of understanding its surface," said Bryan Butler, an astronomer at the National Radio Astronomy Observatory in Socorro, New Mexico, and coauthor on the paper.

Series of 4 images of the surface of Europa taken with ALMA, enabling astronomers to create the first global thermal map of Jupiter's icy moon. [ALMA (ESO/NAOJ/NRAO), S. Trumbo et al.]

First light for SPECULOOS

by ESO

The telescopes of the SPECULOOS Southern Observatory gaze out into the stunning night sky over the Atacama Desert, Chile. [ESO/ P. Horálek]

The SPECULOOS Southern Observatory (SSO) has been successfully installed at the Paranal Observatory and has obtained its first engineering and calibration images — a process known as first light. After finishing this commissioning phase, this new array of planet-hunting telescopes will begin scientific operations, starting in earnest in January 2019.

SSO is the core facility of a new exoplanet-hunting project called Search for habitable Planets EClipsing ULtra-cOOl Stars (SPECULOOS), and consists of four telescopes equipped with 1-metre primary mirrors.

The telescopes — named Io, Europa, Ganymede and Callisto after the four Galilean moons of Jupiter — will enjoy pristine observing conditions at the Paranal site, which is also home to ESO's flagship Very Large Telescope (VLT). Paranal provides a near-perfect site for astronomy, with dark skies and a stable, arid climate. These telescopes have a momentous task — SPECULOOS aims to search for potentially habitable Earth-sized planets surrounding ultra-cool stars or brown dwarfs, whose planetary populations are still mostly unexplored. Only a few exoplanets have been found orbiting such stars, and even fewer lie within their parent star's habitable zone. Even though these dim stars are hard to observe, they are abundant — comprising about 15% of the stars in the nearby universe. SPECULOOS is designed to explore 1000 such stars, including the nearest, brightest, and smallest, in search of Earth-sized habitable planets.

"SPECULOOS gives us an unprecedented ability to detect terrestrial planets eclipsing some of our smallest and coolest neighbouring stars," elaborated Michaël Gillon of the University of Liège, principal investigator of the SPECULOOS project. *"This is a unique opportunity to uncover the details of these nearby worlds."*

SPECULOOS will search for exoplanets using the transit method, following the example of its prototype TRAPPIST-South telescope at ESO's La Silla Observatory. That telescope has been operational since 2011 and detected the famous TRAPPIST-1 planetary system. As a planet passes in front of its star it blocks some of the star's light — essentially causing a small partial eclipse — resulting in a subtle but detectable dimming of the star. Exoplanets with smaller host stars block more of their star's light during a transit, making these periodic eclipses much easier to detect than those associated with larger stars. Thus far, only a small fraction of the exoplanets detected by this method have been Earth-sized or smaller. However, the small size of the SPECULOOS target stars combined with the high sensitivity of its telescopes allows detection of Earth-sized transiting planets located in the habitable zone. These planets will be ideally suited for follow-up observations with large ground- or space-based facilities.

"The telescopes are kitted out with cameras that are highly sensitive in the near-infrared," explained Laetitia Delrez of the Cavendish Laboratory, Cambridge, a co-investigator in the SPECULOOS team. *"This radiation is a little beyond what human eyes can detect, and is the primary*

emission from the dim stars SPECULOOS will be targeting."

The telescopes and their brightly coloured mounts were built by the German company ASTELCO and are protected by domes made by the Italian manufacturer Gambato. The project will receive support from the two TRAPPIST 60-cm telescopes, one at ESO's La Silla Observatory and the other in Morocco.

The project will in due course also include the SPECULOOS Northern Observatory and SAINT-Ex, which are currently under construction in Tenerife, Spain, and at San Pedro Mártir, Mexico, respectively. There is also potential for an exciting future collaboration with the Extremely Large Telescope (ELT), ESO's future flagship telescope, currently under construction on Cerro Armazones.

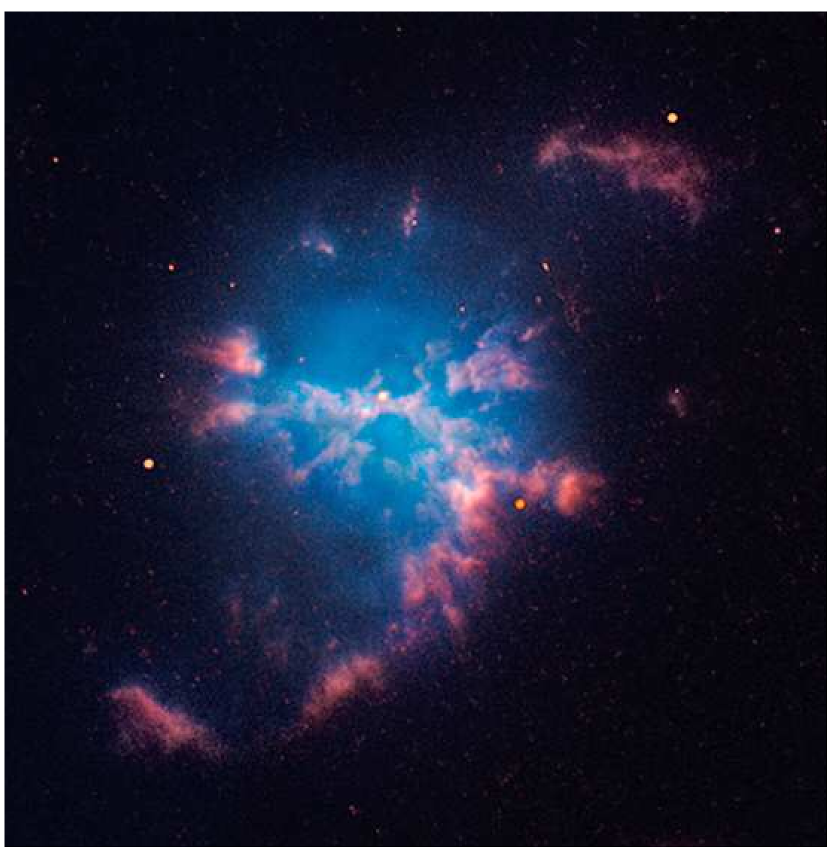
The ELT will be able to observe planets detected by SPECULOOS in unprecedented detail — perhaps even analysing their atmospheres. *"These new telescopes will allow us to investigate nearby Earth-like worlds in the Universe in greater detail than we could have imagined only ten years ago,"* concluded Gillon. *"These are tremendously exciting times for exoplanet science."*

Two stars almost touching found inside a planetary nebula

by IAC

An international team of astronomers, led by the Instituto de Astrofísica de Canarias (IAC) and Universidad de La Laguna (ULL) investigator David Jones, have discovered a binary system with an orbital period of just a little over three hours. The discovery, which involved several years of observing campaigns, is not only surprising due to the extremely short orbital period but also in that, due to their proximity to one another, the system may result in a nova explosion before the short-lived nebula has dissipated.

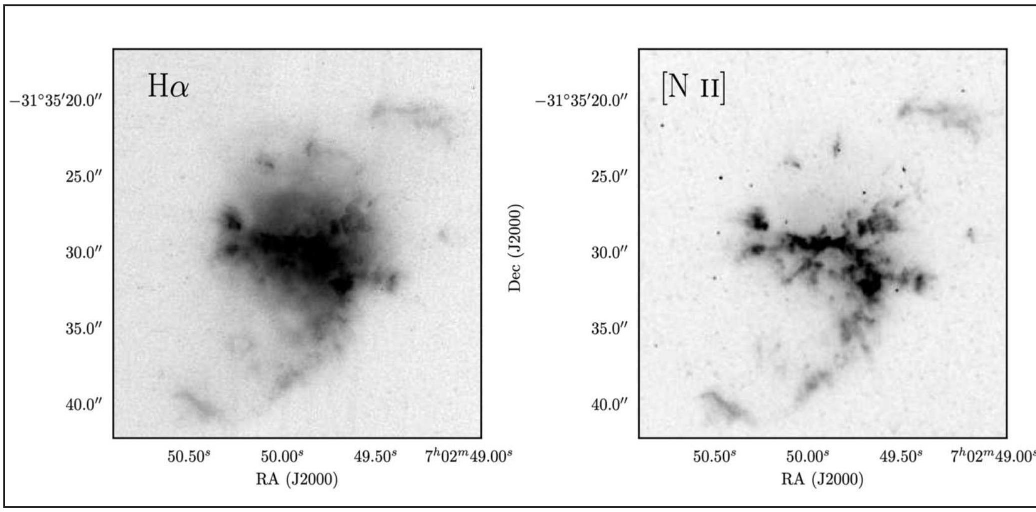
The results of the study were published in the prestigious scientific journal *Monthly Notices of the Royal Astronomical Society* (MNRAS).



An image obtained with the Hubble Space Telescope of the planetary nebula M3-1, the central star of which is actually a binary system with one of the shortest orbital periods known. [David Jones / Daniel López - IAC]

Planetary nebulae are the glowing shells of gas and dust ejected from Sun-like stars towards the ends of their lives. *"In many cases, we see that the ejection is driven by the interaction between the progenitor star and a close companion, and this leads to the vast array of elaborate shapes and structures we see in the nebulae"*, explains Jones.

The study focused on the planetary nebula M3-1, a firm candidate to have been the product of a binary system due to its spectacular jets, which are typically formed by the interaction of two stars. According to Brent Miszalski, a researcher at the SALT telescope in South Africa and co-author of the work, *"We knew it had to contain a binary, that's why we decided to study the system to try to understand the relationship between the stars and the nebula they have formed"*. The observations quickly confirmed the researchers' suspicions. *"When we began observing it was immediately clear that it was, indeed, a binary. Moreover, the brightness of the system was changing very quickly and this could mean a rather short orbital period"*, says Henri Boffin, a researcher at the European Southern Observatory (ESO) in Germany. In fact, the study revealed the separation between the stars to be, approximately, 160,000 kilometers, or less than half the distance between the Moon and the Earth.



HST archival imagery of M 3-1 showing its remarkable filamentary nucleus and extended jet-like structures. [Jones et al.]

After various observing campaigns in Chile with ESO's Very Large Telescope (VLT) and New Technology Telescope (NTT), the researchers had enough data to work out the properties of the binary system, like the masses, temperatures and sizes of both stars. *"To our surprise, we discovered that the two stars were quite big and that, as they are so close to one another, it is very likely that they will begin to interact again in just another few thousand years perhaps resulting in nova explosion"* adds Paulina Sowicka, PhD student at the Nicolas Copernicus Astronomical Center in Poland.

The result contradicts current theories of binary stellar evolution which predict that, upon forming the planetary nebula, the two stars should take quite a long time before beginning to interact again. By the time they do, the nebula should have dispersed and should no longer be visible. However, a nova explosion in 2007, known as Nova Vul 2007, was found to be inside another planetary nebula, putting into question the models. *"In the case of M3-1, we have found a candidate to experience a similar evolution. Given that the stars are almost touching, they shouldn't take too long before interacting again and, perhaps, producing another nova inside a planetary nebula"*, concludes Jones.

This animation shows the orbits of the almost touching stars inside the planetary nebula M3-1. [Jones et al.]

Bennu, “Didy and Planetary

by Michele Ferrara

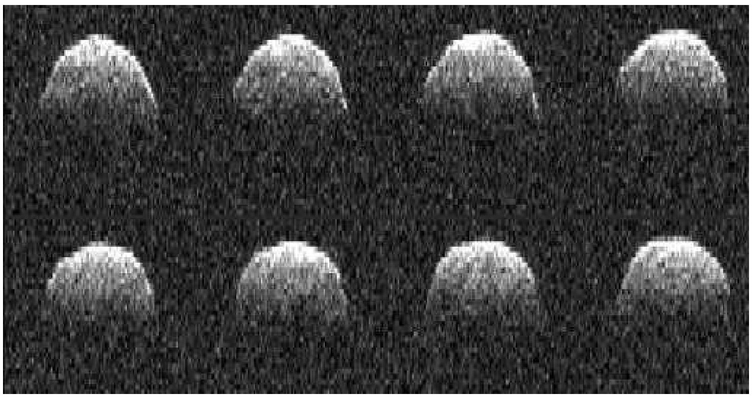
revised by Damian G. Allis
NASA Solar System Ambassador

moon" Defense

The OSIRIS-REx probe reached its goal, the asteroid Bennu, and entered its scientific phase. This mission, together with the Hayabusa2 probe around the asteroid Ryugu and other missions in an advanced phase of design, are expressions of the will to defend our planet from possible collisions with the rocky bodies that periodically cross Earth's orbit. We are still far from a global coordination of these initiatives, but the first steps have moved us in the right direction.

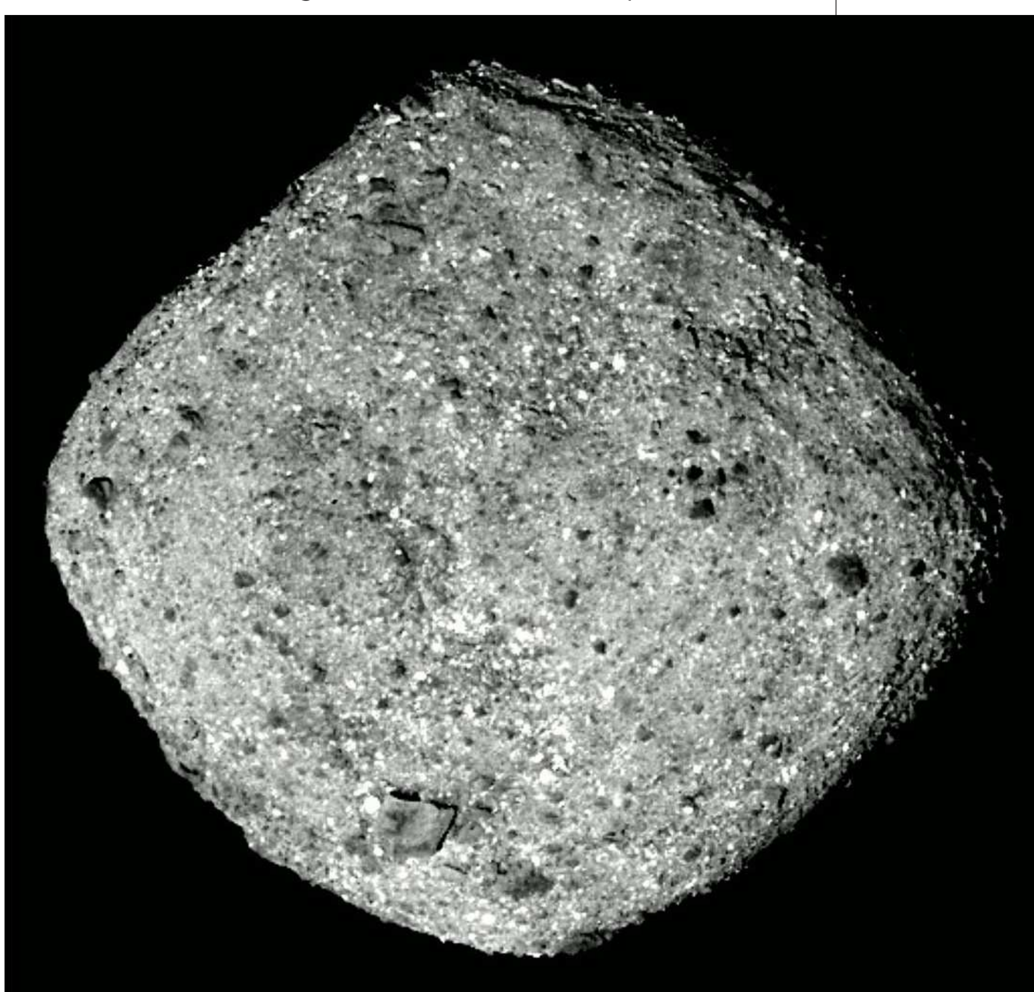
In the background, a depiction of the meteoroid 2018 LA, which disintegrated on June 6th, 2018 in the atmosphere above Botswana just 4 days after its discovery. [NASA/ JPL-Caltech]

On December 3rd, after traveling over two years and more than two billion kilometers, NASA's OSIRIS-REx probe (Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) finally reached the asteroid Bennu. This mission is almost a photocopy of the Japanese probe Hayabusa2 at the asteroid Ryugu and, incredibly, the two asteroids even appear at first sight very similar to each other. After arriving near the asteroid, OSIRIS-REx started a series of approach maneuvers, which at the end of December ended with its insertion into operational orbit, just over 1 km above the Bennu surface. The probe then conducted a preliminary survey of the Bennu surface structures from a polar orbit. Bennu has a diameter of only 492 meters,



A series of radar images of the asteroid Bennu, recorded in September 1999 by the Goldstone's Deep Space Network antenna. Despite the poor resolution, the shape is already recognizable, as confirmed (below) by the OSIRIS-REx probe. [NASA/JPL-Caltech/Goddard/University of Arizona]

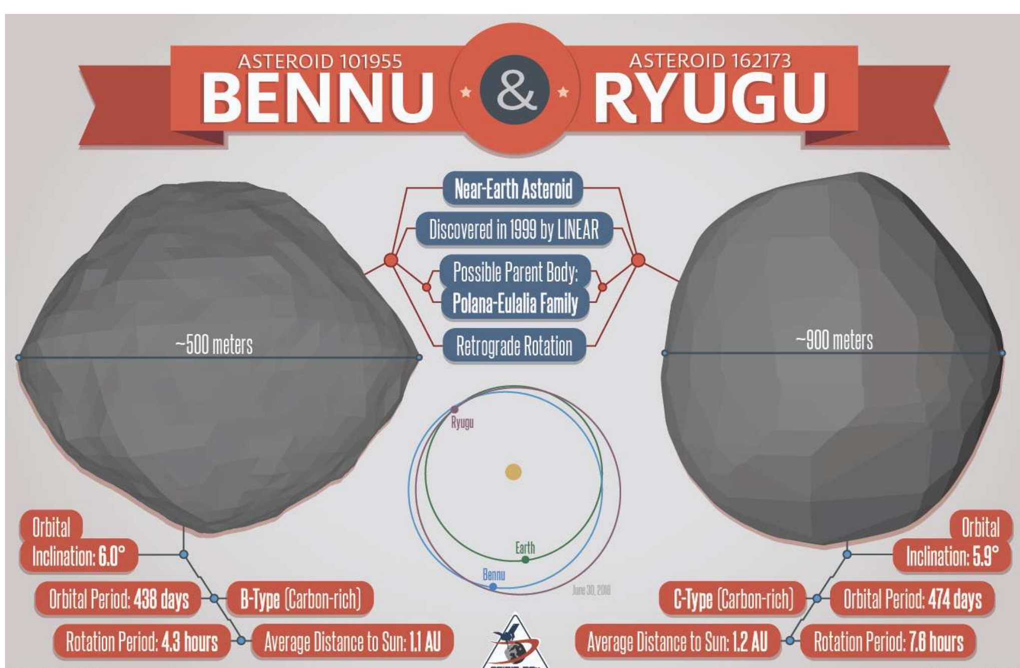
making it the smallest body ever orbited by a probe. The scientific objectives of this first phase are to improve the estimates of the physical properties and the rotational period of Bennu, and to create a more precise model of its shape. By examining the images and the data gathered with a suite of five scientific instruments, mission technicians will be able to select the most suitable site for collecting the only sample of debris and regolith scheduled from the mission. This will happen in about a year, after which the collected sample, weighing at least 60 grams, will be brought back to our planet, where it is expected to land in Utah in September, 2023. The goals of the laboratory analysis of the material taken from Bennu are the same as those of the Hayabusa2 mission.



Researchers expect to get information about the composition and initial conditions of our Solar System, and to understand if and how the primeval material brought to Earth by asteroids may have contributed to enriching our planet with the organic compounds from which life was established.

The in-depth study of Bennu (as well as that of Ryugu) has another remarkable goal – to understand the compactness of its internal structure by accurately measuring its mass, thus offering us insights into a possible weakness of this type of potentially dangerous, Earth-crossing asteroid. We know of almost two thousand small asteroids that, in the not too distant future (astronomically speaking), could threaten our planet. One of the most worrying is Bennu. It is no coincidence that NASA has chosen it as a subject to be studied carefully in the two years of planned scientific activity.

From a dynamic point of view, researchers are particularly interested in non-gravitational forces – the less predictable ones – that move the asteroid. The most relevant of these forces is known as the "Yarkovsky effect," which consists of a small push that the asteroid gives to itself when, by rotating on its axis, it releases from its night-side hemisphere the heat accumulated when that hemisphere was exposed to solar radiation. However small the push may be, any variation of orbital parameters that may unexpectedly result are amplified over the long run by gravitational perturbations produced by the planets and other massive bodies. The more the asteroid's position is projected into the future, the more the margin of error attributable to gravitational perturbations increases – and that



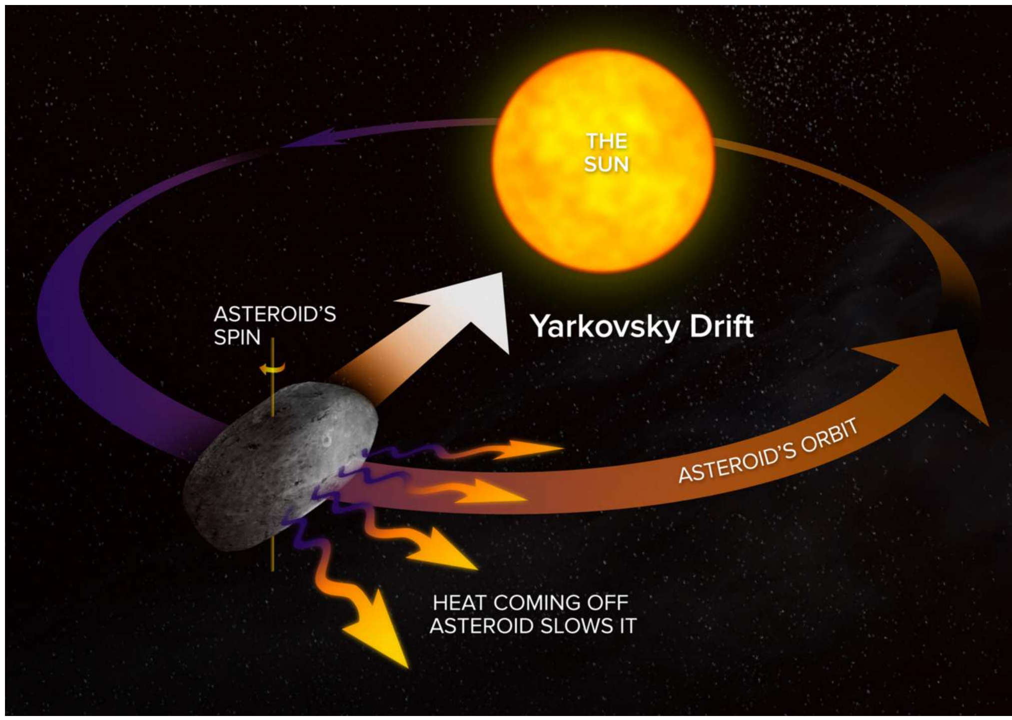
A sequence of images taken by the OSIRIS-REx probe that shows Bennu in a complete rotation from a distance of about 80 km. The PolyCam probe camera obtained 36 frames of 2.2 milliseconds over a period of 4 hours and 18 minutes. [NASA's Goddard Space Flight Center/University of Arizona] Alongside, a comparison of the asteroids Bennu and Ryugu. [NASA] position becomes even more uncertain if other forces less quantifiable than the gravitational ones are acting on the motion of the asteroid. In this context, the Yarkovsky effect is decidedly difficult to quantify, as its intensity and efficiency depend on the reflectivity, composition, distribution, and the structure of the surface material.

It is evident that only in situ studies of individual types of surface can provide comprehensive information, making such missions as OSIRIS-Rex of great importance.

This render shows OSIRIS-REx touching asteroid Bennu with the Touch-And-Go Sample Arm Mechanism or TAGSAM. [NASA's Goddard Space Flight Center] On the left, in mid-2020, the OSIRIS-REx probe will use its TAGSAM device to lift and collect a sample of loose material from the surface of the asteroid. That material will reach Earth in 2023 to be studied. [NASA/Goddard/ University of Arizona]

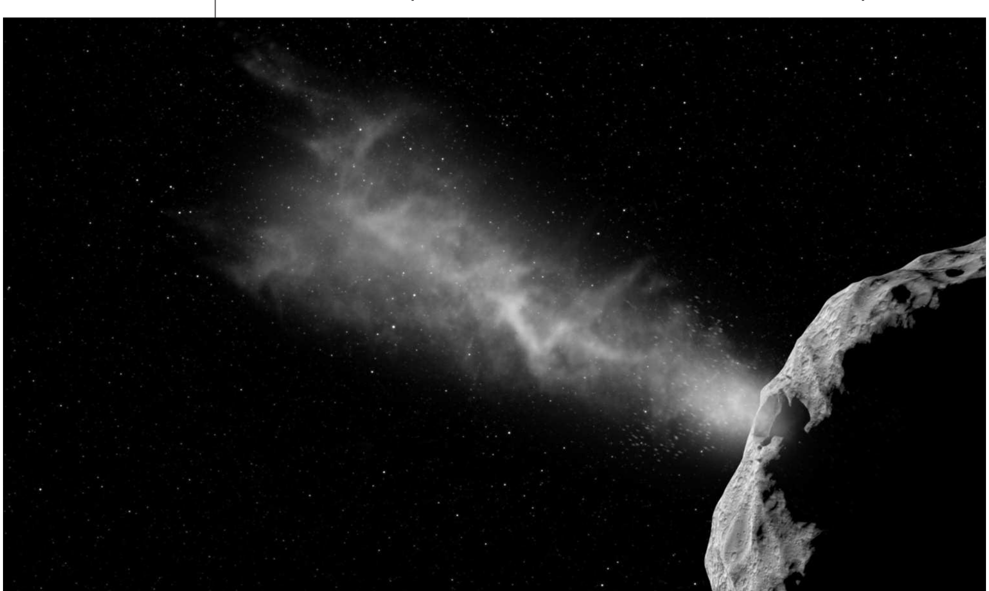
By means of mathematical simulations, astronomers have already calculated how the orbit of Bennu will change in the future, taking into account the gravitational perturbations it will suffer from the Sun, the planets, the Moon, and other asteroids. A rough estimate of the Yarkovsky effect was also included in the calculation. The results of the simulations say that in 2054, 2060, 2080 and 2135, Bennu will pass at a distance of less than 7.5 million km from the Earth. At each close encounter, the asteroid's trajectory will be influenced by the mass of our planet and the mass of the Moon. This makes the position of the asteroid quite uncertain after its close encounter in 2060, when Bennu will be about twice the distance of the Moon away within a window of space 30 km wide.

Even a minute inaccuracy in the current forecasts could be dangerously amplified in the following encounters, and this window of uncertainty only grows with time. In 2080, this window will be 14,000 km wide, which is all-in-all reassuring; but for the encounter of 2135, the uncertainty in the position of Bennu reaches 160,000 km and, since this crossing will be closest to Earth in the coming centuries, it is inferable that an uncertainty of that magnitude is not reassuring at all, especially if we consider that the Yarkovsky effect for this specific asteroid could be significantly different from the estimated one. This is why it is



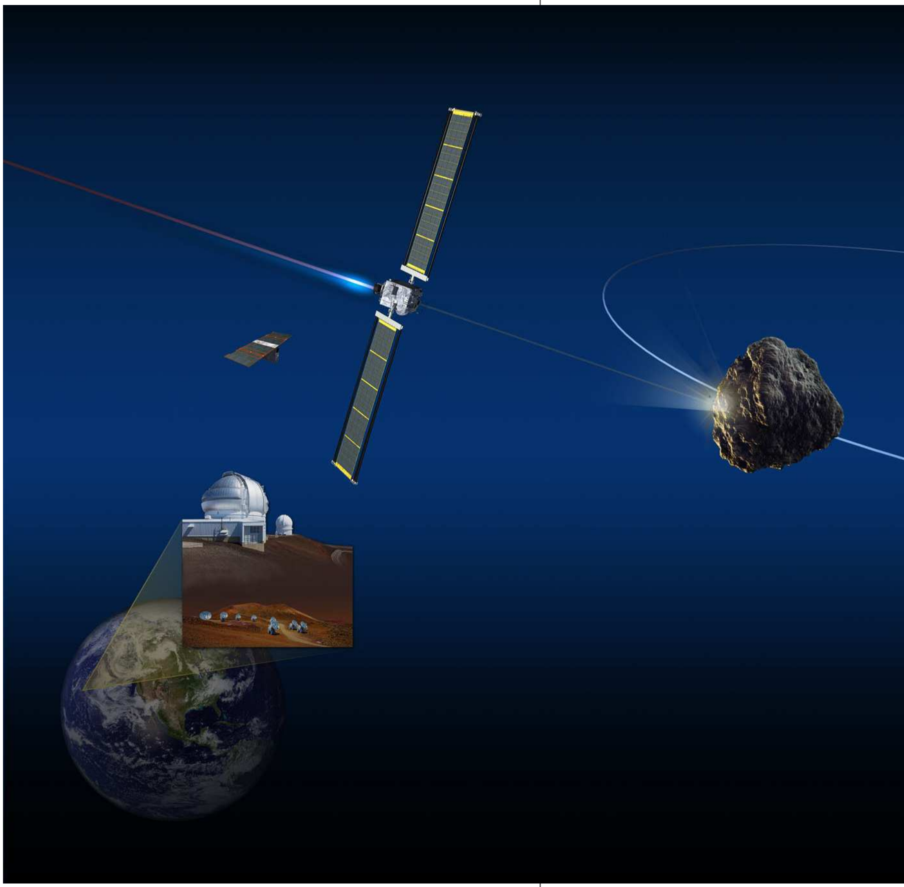
The Yarkovsky effect is the change in the orbit of an asteroid due to the thermal heat it releases. This effect can help scientists to study the orbits of various asteroids and even predict if any of them come dangerously close to our planet. [Alexandra Bolling, NRAO/AUI/NSF] Below, natural or induced emissions of heat or volatile elements from the surface of an asteroid produce small variations in the orbital velocity that should not be underestimated. [ESA – Science Office]

so important to accurately know Bennu's energy balance and to precisely trace its orbit by following the radio signals that OSIRIS-REx will send to our antennas for the next few years. Astronomers have calculated that, since Bennu was discovered (1999), the Yarkovsky effect has shifted its orbit by almost 6 km towards the Sun. This may seem a negligible quantity, but over the centuries, and with the possible amplification made by gravitational perturbations, that modest amount could hide a real threat. It is worth acknowledging that, if an asteroid half a kilometer in diameter and 40 million tons of weight (like Bennu) should ever fall to Earth, it would release an energy comparable to 80,000 of the atomic bombs dropped on Hiroshima, causing destruction on a continental scale with heavy consequences for the whole planet.

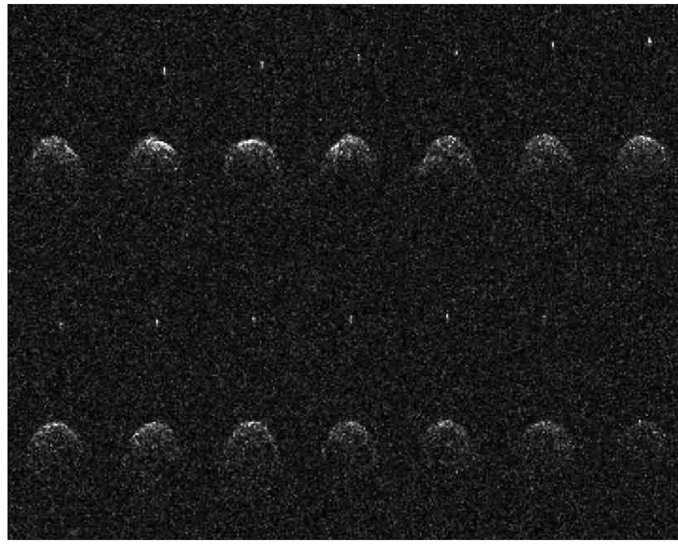


Experts at the Center for Near-Earth Object Studies (CNEOS) at NASA's Jet Propulsion Laboratory forecast that, in the second half of the next century, more precisely in 2175 and 2196, Bennu will approach the Earth close enough to have 1-in-2700 chance of hitting it. Although the chances of collision appear rather remote with our current models, the Yarkovsky effect on Bennu could alter the probabilities and increase significantly the chances after the OSIRIS-REx mission results are included in the models. The reduction in the uncertainty of the future positions of Bennu (and other potentially dangerous asteroids) is crucial for us to know to ignore, or to plan for, possible collisions with our planet. Unlike what happens in science fiction movies, we cannot destroy an asteroid by means of nuclear warheads – neither the small asteroids nor, much less, the large ones. The only concrete defense is to appropriately modify the orbit of the asteroid many decades or centuries before the date of the possible impact, letting the gravitational perturbations of the major bodies act successively in our favor. The earlier one intervenes to change an orbit, the less energy is then required to modify that orbit. Planetary defense programs have been in testing for several years, the purposes of which are to test orbital path deviation techniques for small asteroids. In short, scientists plan to give those objects a very precise push, hitting them with spacecraft launched at very high speeds, possibly even strengthening the thrust with the explosion of nuclear warheads. One of these programs is NASA's Double Asteroid Redirection Test (DART), a space mission (derived from the Asteroid Impact and Deflection Assessment, now canceled) in the final design and assembly phase.

Its goal is to crash a spacecraft into the unofficially named "Didymoon," the small moon of the asteroid 65803 Didymos. The DART mission should take place in 2022 or 2024. The spacecraft is, in fact, an impactor with a mass of 500 kg, equipped with navigation instruments only.

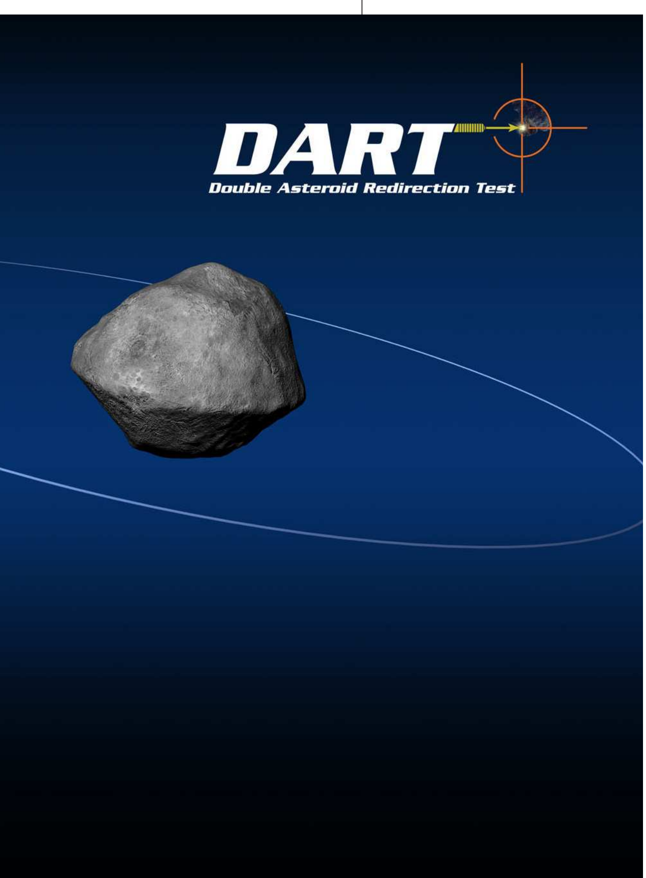


On the left, an animation that illustrates how NASA's DART (Double Asteroid Redirection Test) aims and strikes the smaller element of the binary asteroid Didymos, to demonstrate how a kinetic impact can potentially redirect an asteroid as part of the planetary defense program. Below, a poster of the DART mission concept. [NASA/JHUAPL]



Fourteen Arecibo radar images of the near-Earth asteroid Didymos and its moon, taken in November 2003. The photometric data indicate that Didymos is a binary system and radar images clearly show the secondary body. [National Science Foundation]

Didymos is a small asteroid 780 meters in diameter, separated by just 1.1 km from Didymoon, whose diameter does not exceed 160 meters. Even though this binary system periodically approaches the Earth's orbit up to a fraction of an astronomical unit, it does not fall into the category of Potentially Hazardous Asteroids, and therefore any intervention on its orbit will not make it more threatening in the future.
The effects the DART experiment will produce will be small but important. The mission's designers predict that the spacecraft will hit Didymoon centrally at a speed of 6 km/s and will modify the orbital velocity of the little asteroid by about half a millimeter per second, which will result in a variation of the orbital period around Didymos of about ten minutes. This variation will have repercussions on the orbit of the binary system around the Sun (today taking 770 days), with the result being that the orbital velocity will change by about 0.4 mm/s. It is a seemingly insignificant value, but in reality exceeds that attributable to the Yarkovsky effect.



If projected over the period of a century, this impact will produce a spatial positioning difference of over one million km!
The aftermath of the DART experiment will be followed by ground-based optical and radio telescopes, and it will be possible to prove that the threat posed by potentially dangerous asteroids can be mitigated by intervening well in advance on their orbits. Here are two comments from researchers directly involved in the project. The first one by Tom Statler, program scientist for DART at NASA Headquarters: *"A binary asteroid is the perfect natural laboratory for this test. The fact that Didymoon is in orbit around Didymos makes it easier to see the results of the impact"*. The second one by Andy Cheng, of the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland and DART investigation co-lead: *"DART is a critical step in demonstrating we can protect our planet from a future asteroid impact. Since we don't know that much about their internal structure or composition, we need to perform this experiment on a real asteroid. With DART, we can show how to protect Earth from an asteroid strike with a kinetic impactor by knocking the hazardous object into a different flight path that would not threaten the planet"*.
DART will be only a first, shy step towards the realization of international programs of planetary defense, but it is a good start to be able to prevent the only non-terrestrial natural catastrophe that can be avoided with modern technology.

A call for the cold

by ESA

Carmen working in the Concordia laboratory. [ESA/IPEV/PNRA–Filippo Cali Quaglia]

Concordia station. [ESA/IPEV/PNRA–C. Possnig]

As the Northern hemisphere starts to feel the cold winter approaching, research stations in Antarctica are emerging from their long dark winter and awaiting the arrival of fresh supplies after living months in isolation.

A truly unique experience, ESA is calling medical research doctors to spend a year on the ice conducting researching into how humans adapt to living in extreme environments – as a stand-in to spaceflight. Do you have what it takes?

The French-Italian Concordia research station in Antarctica has to deal with temperatures as low as –80°C, no sunlight for four months and no access at all during the winter, it is one of the most remote and isolated human outposts.

Its unique location and extreme conditions offer ESA the chance to research how humans adapt to living far away from home – similar to an outpost in space or on another planet.

ESA's current research doctor in the South, Carmen Possnig, is acting much like an astronaut on the International Space Station running experiments for researchers in more comfortable but less interesting environments and recording the data for analysis.

The team of up to 15 people who live in Concordia throughout the winter started to prepare for the arrival of the "summer scientists" in November. After months of living on their own, now the research station hosts around 80 scientists who flock to Concordia to check equipment, setup sensors and run experiments for a few weeks.

Carmen will be replaced by Danish medical doctor Nadja Albertsen who is preparing for her stay in the South and learning about the experiments she will run at ESA's astronaut centre in Cologne, Germany, and at the centres of the organisations that own and run Concordia station, French Polar Institute IPEV and Italian Polar Institute PNRA.

Nadja will be taking over research such as how isolation changes people's brains and blood pressure, and search for extremophiles that might be able to survive the extreme cold.

ESA's Jennifer Ngo-Anh, responsible for science in space for Human and Robotic Exploration, explains, *"the work done by our medical doctor in Antarctica is indispensable to be prepared for long exploration missions beyond our moon".*

"The environment is tough and the experience will be no walk in the park, but you will have done your part to further human exploration of our Solar System and I guarantee you will never forget it."

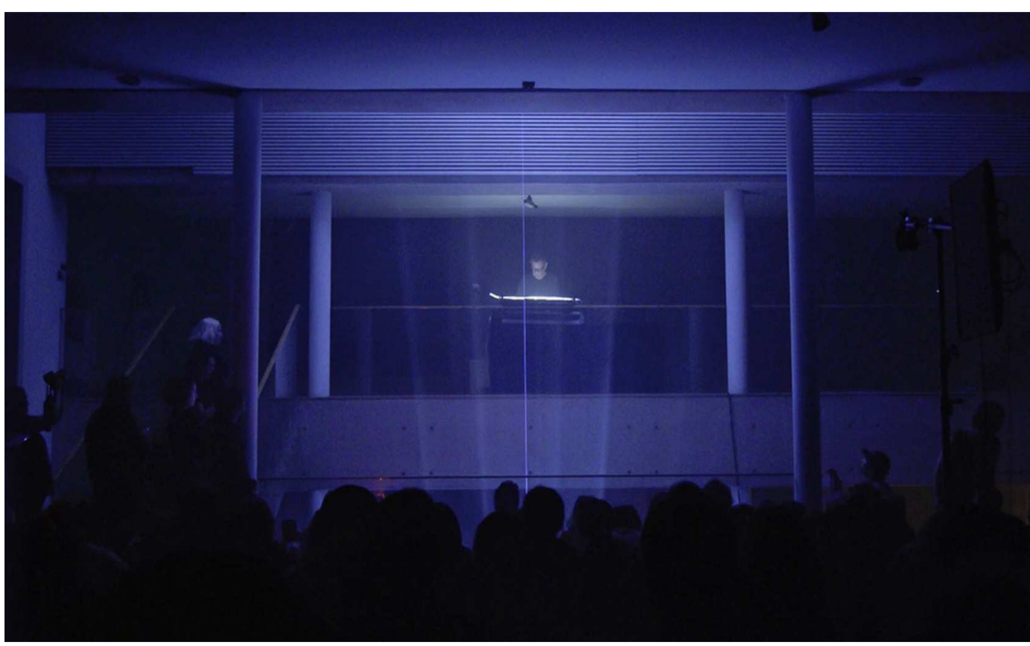
Are you interested in the adventure of a lifetime or know somebody who might be? ESA is looking for the next research doctor, who will travel to Concordia in 2019 to run experiments in this unique setting. A medical degree and an ESA member state nationality is required.

Concordia reaching for the stars. [ESA/IPEV/PNRA–B. Healey]

CERN, ALMA and ESO launch art residency program, Symmetry

by ALMA Observatory

The Symmetry program was launched to foster interdisciplinary exchange between artists and scientists working or living in Chile and Switzerland. It combines the residency of two artists in three of the most fascinating scientific research centers in the world: the Large Hadron Collider, CERN, in Geneva, Switzerland, and the astronomic observatories in Chile: ALMA and the VLT in Cerro Paranal.



The names of the artists who will participate in the first version of the Symmetry residency program were announced at the "Fourth Meeting of Art, Science and Digital Culture" held in the Museum of Visual Arts (MAVI) in Santiago, Chile. In the image, visual concert by Carlos Cabezas, Chilean musician, founder of the band Electrodomésticos, who presented the result of his residency at ALMA. [Benjamin Matte, CChV]

Symmetry will invite one artist from Chile and one artist from Switzerland to a shared residency in each country. The experience seeks to connect artists with the community of physicists and engineers to further delve into the challenges of contemporary science through advanced technologies that explore and observe nature. *"I am proud to launch Symmetry, which I am sure it will make a significant contribution to the current challenges in interdisciplinary thinking, by fostering deep conversations and dialog between artists and scientists in Chile and Switzerland,"* says Mónica Bello, Head of Arts at CERN.

Artist Laura Couto Rosado with scientific partner James Beacham at CERN. [Sophia Elizabeth Bennett/CERN]

In this first version, 8 artists from each country were invited to present their portfolios, which were reviewed by members of the participating institutions to select the final candidates to form part of this Residency: Nicole L'Huillier from Chile and Alan Bogana from Switzerland. The announcement of the selected artists was made at the 4th Meeting of Art, Science and Digital Culture in the Museum of Visual Arts (MAVI), in Santiago, Chile. The Minister of Culture, Art and Heritage, Consuelo Valdés, who participated in the event and supports the initiative, highlighted the alliances behind this project and revealed that: *"We are convinced that the dialogue between art, science and culture it will nourish us of significant experiences for the cultural development for which we all work"*.

Selected artists will visit the remote Chajnantor Plateau in the northern Chilean Andes, where 66 antennas from the ALMA radio telescope are located, and also the Very Large Telescope, an Observatory located in Cerro Paranal near Antofagasta. In Switzerland, the artists will be guest residents at CERN in Geneva.

"I am very pleased that the VLT and ALMA are part of this initiative, because art and science raise the spirits and remind us of the importance of treasuring the dimension of creativity, curiosity and discovery that, in a sense, defines us as humans and therefore should never be forgotten," adds Claudio Melo, Representative of the European Southern Observatory (ESO) in Chile.

In the image, the Minister of Culture of Chile talks with the director of the Arts at CERN program, Monica Bello. [Benjamin Matte, CChV]

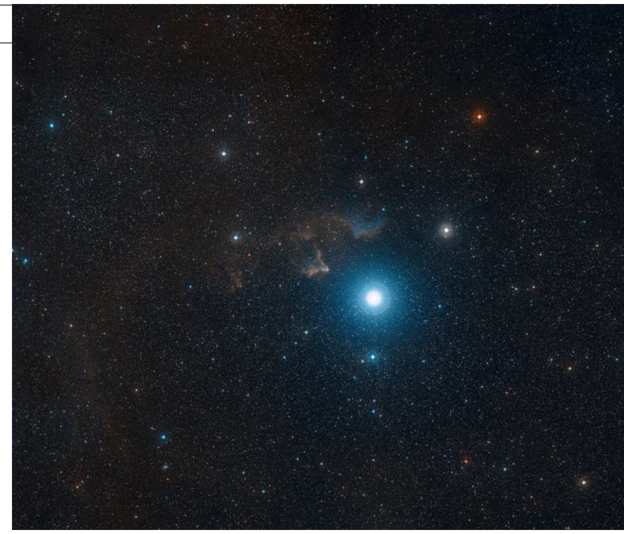
Symmetry is a collaboration between Arts at CERN, ALMA, ESO and the Chilean Corporation of Video and Electronic Arts, made possible by support from the Swiss Arts Council Pro Helvetia and the Chilean Ministry of Cultures, Art and Heritage through its New Media Area.

"The shared residency of two artists in two of the most extraordinary research centers in the fields of astronomy and particle physics will enable us to expand and explore the connections between new creative forms," indicates Enrique Rivera, Director of the Chilean Corporation of Video and Electronic Arts.

The ghost of Cassiopeia

by NASA/ESA

IC 63 — nicknamed the Ghost Nebula — is about 550 light-years from Earth. The nebula is classified as both a reflection nebula — as it is reflecting the light of a nearby star — and as an emission nebula — as it releases hydrogen-alpha radiation. Both effects are caused by the gigantic star Gamma Cassiopeiae. The radiation of this star is also slowly causing the nebula to dissipate. [ESA/Hubble, NASA]



This image shows the sky around the nebula IC 63, nicknamed the Ghost Nebula. It was created from images forming part of the Digitized Sky Survey 2. The field of view is dominated by the bright star Gamma Cassiopeiae, which is having a profound influence on IC 63. [ESA/Hubble, NASA, Digitized Sky Survey 2]

Also known as the ghost of Cassiopeia, IC 63 is being shaped by radiation from a nearby unpredictably variable star, Gamma Cassiopeiae, which is slowly eroding away the ghostly cloud of dust and gas. The constellation of Cassiopeia, named after a vain queen in Greek mythology, forms the easily recognisable "W" shape in the night sky. The central point of the W is marked by a dramatic star: here is Gamma Cassiopeiae.

The remarkable Gamma Cassiopeiae is a blue-white subgiant variable star that is surrounded by a gaseous disc. This star is 19 times more massive and 65,000 times brighter than our Sun. It also rotates at the incredible speed of 1.6 million kilometres per hour — more than 200 times faster than our parent star. This frenzied rotation gives it a squashed appearance. The fast rotation causes eruptions of mass from the star into a surrounding disk. This mass loss is related to the observed brightness variations.

The radiation of Gamma Cassiopeiae is so powerful that it even affects IC 63, sometimes nicknamed the Ghost Nebula, that lies several light years away from the star. IC 63 is visible in this image taken by the NASA/ESA Hubble Space Telescope. The colours in the eerie nebula showcase how it is affected by the powerful radiation from the distant star. The hydrogen within IC 63 is being bombarded with ultraviolet radiation from Gamma Cassiopeiae, causing its electrons to gain energy which they later release as hydrogen-alpha radiation — visible in red in this image. This hydrogen-alpha radiation makes IC 63 an emission nebula, but we also see blue light in this image. This is light from Gamma Cassiopeiae that has been reflected by dust particles in the nebula, meaning that IC 63 is also a reflection nebula.

This colourful and ghostly nebula is slowly dissipating under the influence of ultraviolet radiation from Gamma Cassiopeiae.

However, IC 63 is not the only object under the influence of the mighty star. It is part of a much larger nebulous region surrounding Gamma Cassiopeiae that measures approximately two degrees on the sky — roughly four times as wide as the full Moon.

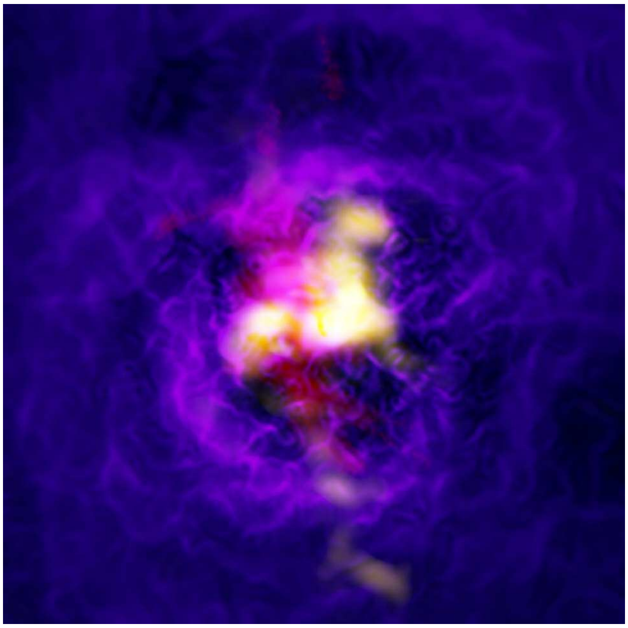
This region is best seen from the Northern Hemisphere during autumn and winter. Though it is high in the sky and visible all year round from Europe, it is very dim, so observing it requires a fairly large telescope and dark skies.

From above Earth's atmosphere, Hubble gives us a view that we cannot hope to see with our eyes. This photo is possibly the most detailed image that has ever been taken of IC 63, and it beautifully showcases Hubble's capabilities.

ALMA and MUSE detect galactic fountain

by ESO

A mere one billion light-years away in the nearby galaxy cluster known as Abell 2597, there lies a gargantuan galactic fountain. A massive black hole at the heart of a distant galaxy has been observed pumping a vast spout of cold molecular gas into space, which then rains back onto the black hole as an intergalactic deluge. The in- and outflow of such a vast cosmic fountain has never before been observed in combination, and has its origin in the innermost 100,000 light-years of the brightest galaxy in the Abell 2597 cluster. *"This is possibly the first system in which we find clear evidence for both cold molecular gas inflow toward the black hole and outflow or uplift from the jets that the black hole launches,"* explained Grant Tremblay of the Harvard-Smithsonian Center for Astrophysics and former ESO Fellow, who led this study. *"The supermassive black hole at the centre of this giant galaxy acts like a mechanical pump in a fountain."*
Tremblay and his team used ALMA to track the position and motion of molecules of carbon monoxide within the nebula. These cold molecules, with temperatures as low as minus 250–260°C, were found to be falling inwards to the black hole. The team also used data from the MUSE instrument on ESO's Very Large Telescope to track warmer gas — which is being launched out of the black hole in the form of jets.
"The unique aspect here is a very detailed coupled analysis of the source using data from ALMA and MUSE," Tremblay explained. *"The two facilities make for an incredibly powerful combination."*
Together these two sets of data form a complete picture of the process; cold gas falls towards the black hole, igniting the black hole and causing it to launch fast-moving jets of incandescent plasma into the void. These jets then spout from the black hole in a spectacular galactic fountain. With no hope of escaping the galaxy's gravitational clutches, the plasma cools off, slows down, and eventually rains back down on the black hole, where the cycle begins anew.
This unprecedented observation could shed light on the life cycle of galaxies. The team speculates that this process may be not only common, but also essential to understanding galaxy formation. While the inflow and outflow of cold molecular gas have both previously been detected, this is the first time both have been detected within one system, and hence the first evidence that the two make up part of the same vast process.
Abell 2597 is found in the constellation Aquarius, and is named for its inclusion in the Abell catalogue of rich clusters of galaxies.
The catalogue also includes such clusters as the Fornax cluster, the Hercules cluster, and Pandora's cluster.



Composite image of the Abell 2597 galaxy cluster showing the fountain-like flow of gas powered by the supermassive black hole in the central galaxy. The yellow is ALMA data showing cold gas. The red is data from the MUSE instrument on ESO's Very Large Telescope showing the hot hydrogen gas in the same region. The blue-purple is the extended hot, ionized gas as imaged by the Chandra X-ray Observatory. The yellow ALMA data shows infalling material and the red MUSE data shows material launched in a vast spout by the black hole. [ALMA (ESO/NAOJ/NRAO), Tremblay et al.; NRAO/AUI/NSF, B. Saxton; NASA/Chandra; ESO/VLT]

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revised by Damian G. Allis
NASA Solar System Ambassador

"Once all our attempts to obtain living matter from inanimate matter are vain, it seems to me to be part of a fully correct scientific procedure to ask oneself whether life has in fact ever had an origin, if it is not as old as the matter itself, and if spores could not have been transported from one planet to another and took root where they found fertile ground." Hermann von Helmholtz

The planets of TRAPPIST-1, represented in this illustration, constitute a dynamically perfect system for testing the concept of panspermia. If life can move from one planet to another, it is very likely that it could do it inside systems like this. [NASA]

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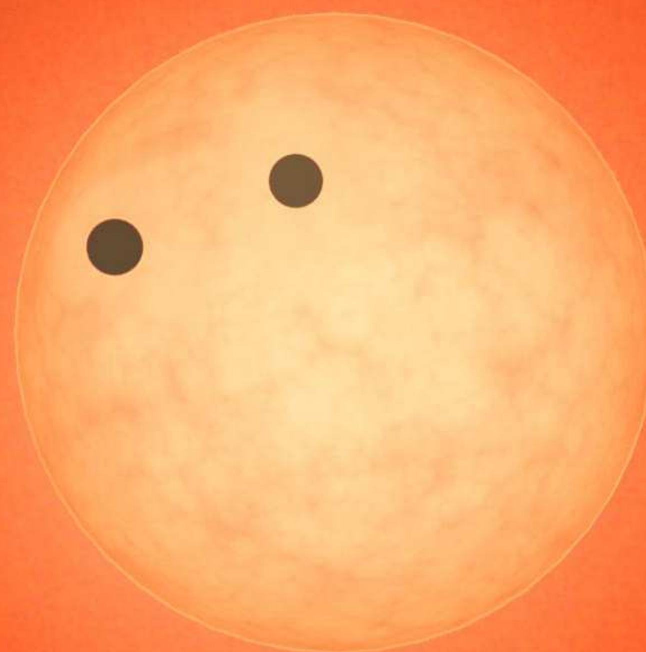
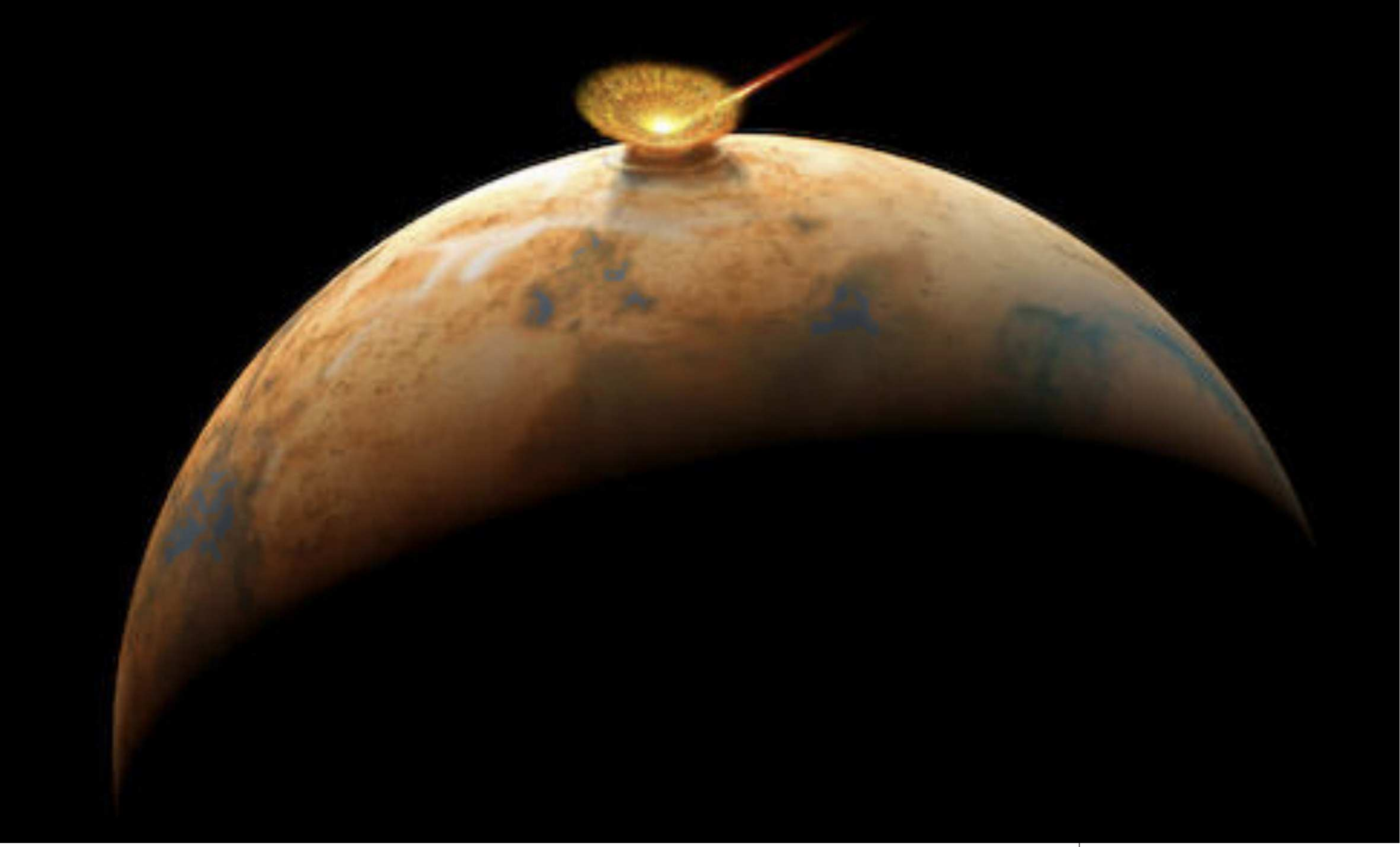


About the diffusion of life in the universe, we have only one certainty: it is present on our planet. Any region of the Earth, even the most inhospitable, pullulates with life. Chemistry, biology and paleontology have discovered a great deal about current and past forms of life on our planet. However, in spite of great scientific and technological progress in the last decades, we still do not know how and when the first living organisms appeared.

Since the pioneering laboratory experiments of Stanley Miller and Harold Urey in the 1950s, nothing has substantially changed: biochemists know how to produce amino acids and proteins necessary for life; they know how to do it by simulating the likely terrestrial environment billions of years ago, but no scientist has so far managed to take the decisive step of transforming complex organic molecules into self-replicating living organisms. This apparent inability to generate life here on Earth beginning from its fundamental building blocks has repeatedly reinvigorated the panspermia hypothesis, according to which life has spread in the cosmos through "seeds" transported by interstellar dust, meteoroids and comets of various sizes. Perhaps the young Earth did not have the necessary requisites to generate life,



but it was nonetheless suitable for hosting species from outside. As we do not know the environment in which that "adopted" life may have been born, we are not able to recreate it in the laboratory.

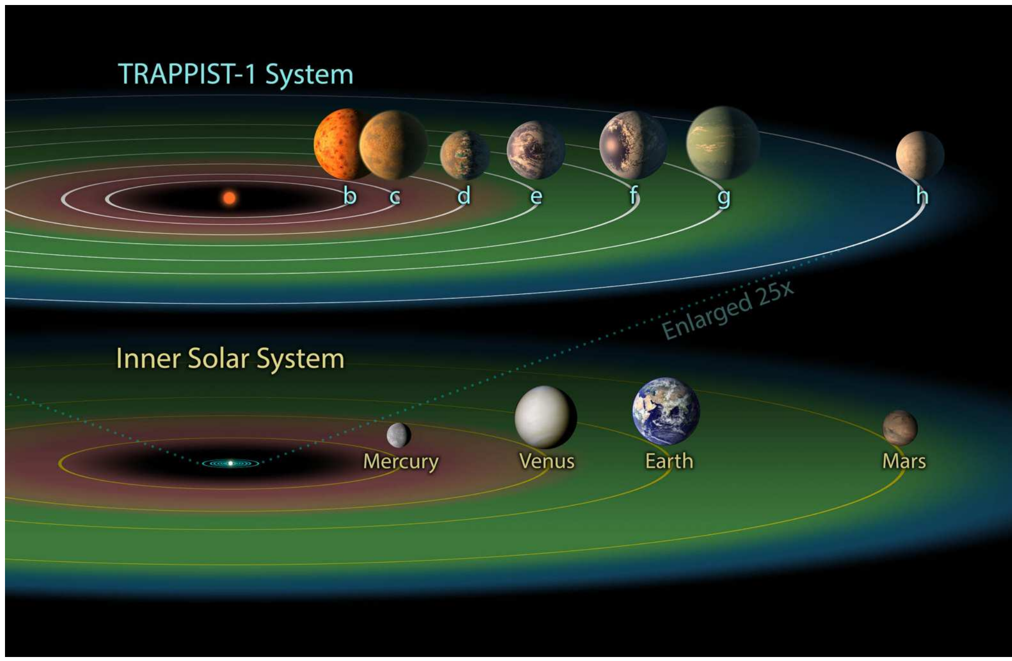
This is evidently a hypothesis of convenience, a solution that does not solve the problem, but instead transfers it to unknown times and places. The concept of panspermia is, however, interesting because, from a theoretical point of view, life could certainly move from one celestial body to another.

This idea dates back to 25 centuries ago. The first to spread the notion was Anaxagoras, a philosopher of ancient Greece and very careful observer of celestial phenomena. One must wait until the 19th century to see the proposition of panspermia in a more scientific context, then further strengthened in the following century, mainly thanks to two giants of astronomy – Fred Hoyle and Chandra Wickramasinghe. In the 1970s, they hypothesized that interstellar dust could contain organic molecules (a hypothesis then verified) and that forms of elementary life are continuously entering the atmosphere (a hypothesis never verified). More recently, in 2009, Stephen Hawking also came out in support of panspermia as a possible explanation for the spread of living organisms between planets and solar systems.

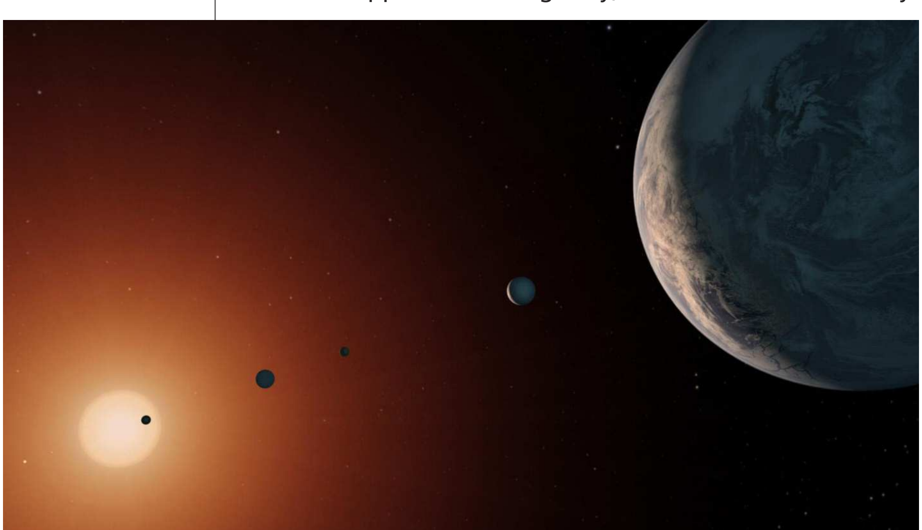
In October 2017, with the discovery of `Oumuamua, we received confirmation that a meteoroid (or a cometoid) can actually travel from one planetary system to another, and these wandering objects might exist in the billions of bil-

The impact of an asteroid on a young Mars could have thrown many rocks into space, perhaps containing colonies of extremophile bacteria, which continued to proliferate for decades. When part of those rocks fell to Earth, the surviving bacteria found a hospitable environment to conquer. [NASA]

As this graphic shows, the TRAPPIST-1 system is so compact that it can be easily contained inside the orbit of Mercury. The green areas highlight the habitable zones of the two systems. Below, the TRAPPIST-1 system seen from its outermost planet, TRAPPIST-1h. [NASA]

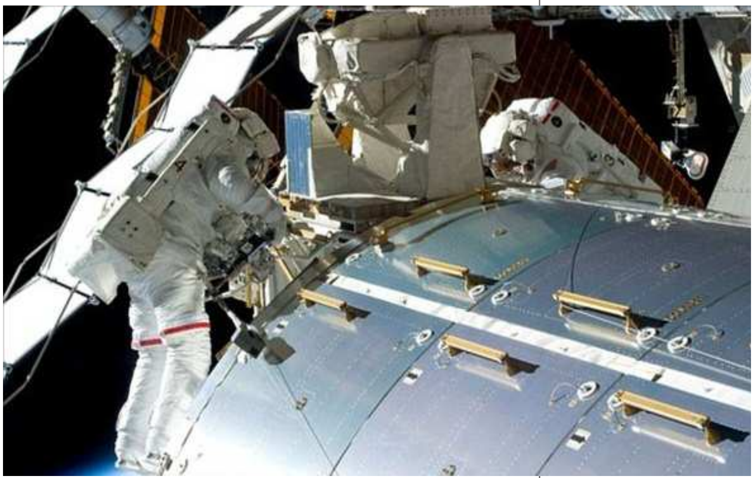


lions of members within our galaxy. If panspermia were a consolidated reality, the universe could be teeming with life and our most distant ancestors could have been extraterrestrials – two non-negligible consequences. Nevertheless, there are many arguments against panspermia. Interstellar space is so vast that astronomers calculated a collision between two single stars has never happened in our galaxy; it does not seem much more likely that a meteoroid with a vital load can fall right on a hospitable planet after an interstellar journey of hundreds of thousands or millions of years. Even the most basic colonies of bacteria and the simplest spores we know cannot remain viable for such long periods of time. Moreover, in order for meteoroids to be able to transport these organisms, it is necessary that the planet hosting those forms of life suffers heavy-enough asteroid impacts to throw rock fragments beyond the escape velocity of the planet's gravity well. This presupposes the existence of at least an asteroid belt and a period of intense bombardment triggered by planetary migration. We do not know within how many planetary systems this has happened, so we cannot even remotely estimate the average number of meteoroids expelled by a typical planetary system - this also because we know almost nothing about the architecture and evolutionary history of extrasolar systems.

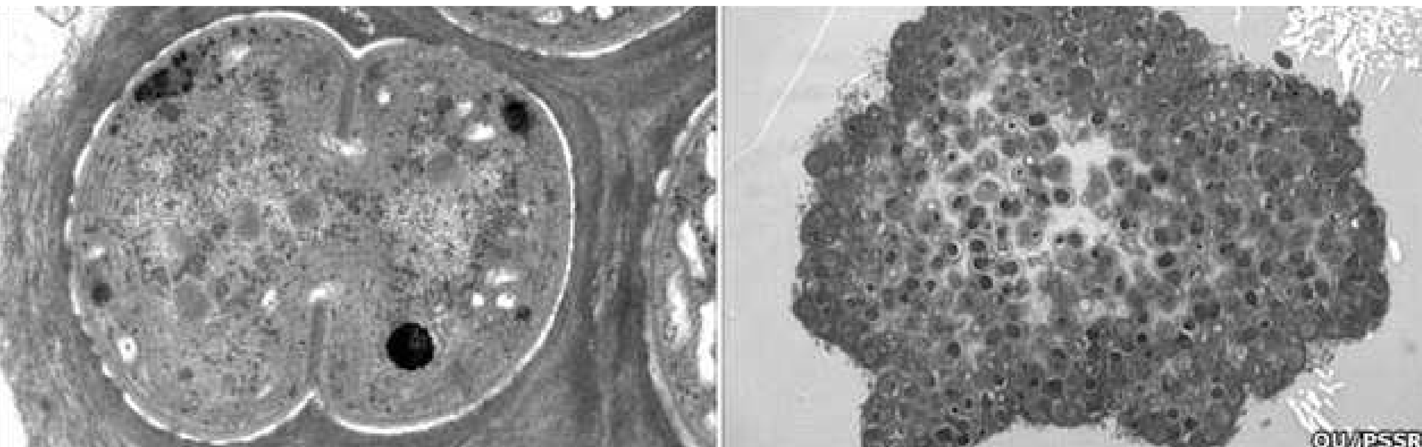


Simulations indicate that most peripheral rocks thrown into space reach temperatures below 100°C.
On might conclude that the trauma of the fall to Earth seems impossible to overcome, either for the piece of rock or for the organisms it might contain. However, various studies have shown that entry into the atmosphere occurs at speeds between 12 and 20 km/s, and the friction produced creates a melting crust around the meteoroid which prevents any penetration of the excessive heating beyond the first few millimeters. This would protect the hypothetical organisms from overheating during this critical atmospheric entry phase. Finally, the impact with the ground for something like a single-celled organism is less violent than we might imagine at first sight, since the speed has already fallen to a few tens of meters per second. In fact, a meteorite may even remain intact if it impacts a soft soil or the water.
We do not know to what extent the models of this process are applicable to other planetary systems, also because the three phases of panspermia have always been modeled and simulated separately from each other,

The uncertainties about what may have happened elsewhere beyond our Solar System have prompted researchers to focus on panspermia within "our home", in particular on the possibility that life has come to Earth from Mars (or vice versa). We know that in the first billion years, the Red Planet could host elementary forms of life. We also know that between 4.1 and 3.8 billion years ago, the rocky planets suffered an intense asteroid bombardment. Finally, we know that numerous meteorites originating from Martian rocks thrown into space during that bombing (and more recently too) have ended up plunging to Earth.
The whole process has been scrutinized by scientists with sufficient precision, and although there is no evidence that terrestrial life descends from Martian organisms, the proximity between the orbits of the two planets allows the three phases of panspermia, i.e. initial expulsion, interplanetary travel and final fall, to be surmountable obstacles. Mathematical models and experiments in the laboratory and in low Earth orbit have shown that extremophile bacteria and spores are able to withstand violent accelerations and decelerations, as well as prolonged exposure to solar and cosmic radiation.
It may seem strange that something survives the energy triggered by an asteroid collision on Mars, but we have to imagine that the land adjacent to the point of impact takes off from simple recoil and the only trauma organisms have to overcome is acceleration.



Between 2008 and 2010, a colony of extremophile bacteria called Gloecapsa, taken from the cliffs of Beer, in Devon, UK (pictured left), was placed outside the International Space Station (below), only protected by the rocks that housed it. Returned to Earth after 553 days, the rock samples still contained a large number of viable bacteria. [NASA, Open University]



A photo of the bacteria colony surviving the experiment called OU-20, which lasted a year and a half outside the ISS. Below, Professor Charles Cockell, from the Open University, with a sample of rock impregnated with the bacteria protagonists of the OU-20 experiment. [NASA, Open University]

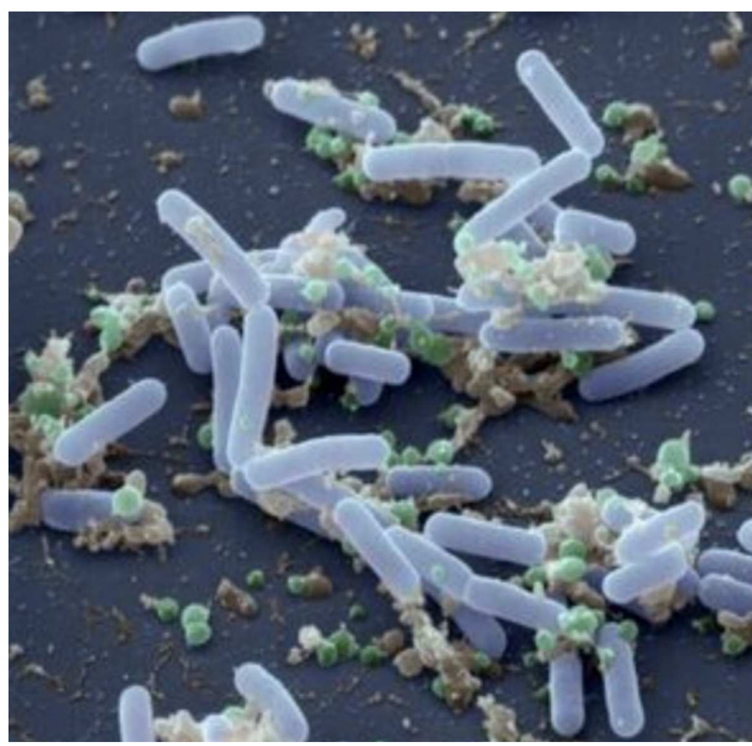
and the outcome of each of them depends on numerous varying factors.
Only recently, researchers attempted to merge the various solutions into a single model, however unavoidably generic. A push in this direction has been from the discovery, between 2015 and 2017, of seven planets in orbit around the red dwarf TRAPPIST-1. This system has awakened the interest in panspermia, because its planets are all comparable in size to Earth (from 0.77 to 1.14 times the Earth's diameter) and five of them also have masses comparable to that of Earth. But the most interesting feature of the TRAPPIST-1 system is represented by the orbits of the planets, very close to each other and decidedly coplanar. The semimajor axes range from 1.73 million km for the innermost planet, TRAPPIST-1b, to 9.27 million km for the outermost planet, TRAPPIST-1h. The planets graze each other at distances between 2 and 6 times the Earth-Moon distance!
Despite being so close to their star, TRAPPIST-1 is so weak an energy source that some of its planets orbit in its habitable zone, making this system theoretically ideal for carrying out panspermia studies, as highlighted in a work published at the end of October in Astrobiology Magazine with the title "Dynamical and biological panspermia constraints within multi-planet exosystems".

In this paper, a small team of researchers led by Dimitri Veras (University of Warwick, Coventry) proposes the unification and extension to other planetary systems of panspermia models based on our Solar System. Here is how Veras commented on this: *"Equations regarding the physics of impact have already been established and used for Solar System applications, so we converted those for use in a general extra-solar system." "Usually, the dynamics of panspermia is studied with numerical simulations, however, these can be slow to run and must be tailored to an individual system." "Alternatively, analytics are much faster to use and are general enough to be applicable to a wide variety of systems."*

And analytics are certainly applicable to the TRAPPIST-1 system, for which it would be possible to calculate with approximation the likelihood life has been shared among several planets given assumptions about certain physical and chemical properties of each planet, information that is currently out of our reach. At the moment, the equations produced by Veras' team are just a tool that

Imaginative representation of a glimpse of the surface of a habitable TRAPPIST-1 planet. In an environment of this kind, any elementary form of life from a nearby planet could easily proliferate. [NASA]
On the side, the astrophysicist Dimitri Veras, first author of a recent work on panspermia in extrasolar systems. [University of Warwick, Coventry]

in the future will help other researchers to establish whether, from the dynamic point of view, panspermia is possible in multiple planetary systems.
In a system structured like TRAPPIST-1 it is very probable that elementary forms of life are able to move from one planet to another, because the interplanetary journey of the material in which they could take shelter would be quite short, on average.
Note that stellar and cosmic radiation exposure is the worst threat to the panspermia hypothesis.
The experiments conducted so far tell us that colonies of extremophile bacteria exposed to outer space in low Earth orbit can survive well over a year if sheltered by the rock. Under ideal conditions of protection, a very large colony can probably survive for decades or centuries. What if there were extraterrestrial forms of life able to survive in space for millennia? In the TRAPPIST-1 system, the three phases of panspermia could occur within a few weeks or months, ensuring the integrity of the vital load. Unfortunately, the more those planets are studied, the less they seem hospitable to life as we know it. The greatest unknown concerns the existence and consistency of atmospheres, as well as the presence of land. According to a study by researchers from Arizona State University and Vanderbilt University, between 20% and 50% of the mass of TRAPPIST-1 planets would consist of water (Earth = 0.2%). The deep global oceans that, in this case, would cover the planetary surfaces would inhibit the geochemical cycles necessary to maintain an atmosphere and would instead favor the "snowball" effect.
Since there are no better candidates, we just have to wait for new discoveries. Finding any evidence of life, even as a fossil, on Mars that shares chemical similarities with life on Earth, or recognizing identical biomarkers in the atmospheres of two exoplanets of the same extrasolar system, could lend support to the panspermia hypothesis, and our conception of the diffusion of life in the cosmos would radically change. ■



On the right, some specimens of Bacillus pumilus. Microorganisms of this type can form endospores – tough, dormant, and non-reproductive structures that allow it to survive harsh conditions and extreme environments. The tough shells of the endospores provide the organism with the means to protect its genetic material from cosmic radiation and other factors. [Science Photo Library]

Hubble reveals a giant cosmic "bat shadow"

by NASA/ESA

This image, taken with the NASA/ESA Hubble Space Telescope shows the Serpens Nebula, a stellar nursery about 1300 light-years away. Within the nebula, in the upper right of the image, a shadow is created by the protoplanetary disc surrounding the star HBC 672. While the disc of debris is too tiny to be seen even by Hubble, its shadow is projected upon the cloud in which it was born. In this view, the feature — nicknamed the Bat Shadow — spans approximately 200 times the diameter of our own Solar System. [NASA, ESA, and STScI]

The NASA/ESA Hubble Space Telescope has captured part of the wondrous Serpens Nebula, lit up by the star HBC 672. This young star casts a striking shadow — nicknamed the Bat Shadow — on the nebula behind it, revealing telltale signs of its otherwise invisible protoplanetary disc.

The Serpens Nebula, located in the tail of the Serpent (Serpens Cauda) about 1300 light-years away, is a reflection nebula that owes most of its sheen to the light emitted by stars like HBC 672 — a young star nestled in its dusty folds. In this image the NASA/ESA Hubble Space Telescope has exposed two vast cone-like shadows emanating from HBC 672.

This animation compares the appearance of the Serpens Nebula as seen from the ground — with the Very Large Telescope of the European Southern Observatory, and from space — with the NASA/ESA Hubble Space Telescope. Both instruments used detectors and filters observing in the near-infrared to gather their data. [NASA, ESA/Hubble, ESO]

These colossal shadows on the Serpens Nebula are cast by the protoplanetary disc surrounding HBC 672. By clinging tightly to the star the disc creates an imposing shadow, much larger than the disc — approximately 200 times the diameter of our own Solar System. The disc's shadow is similar to that produced by a cylindrical lamp shade. Light escapes from the top and bottom of the shade, but along its circumference, dark cones of shadow form.

The disc itself is so small and far away from Earth that not even Hubble can detect it encircling its host star. However, the shadow feature — nicknamed the Bat Shadow — reveals details of the disc's shape and nature. The presence of a shadow implies that the disc is being viewed nearly edge-on.

Whilst most of the shadow is completely opaque, scientists can look for colour differences along its edges, where some light gets through. Using the shape and colour of the shadow, they can determine the size and composition of dust grains in the disc.

The whole Serpens Nebula, of which this image shows only a tiny part, could host more of these shadow projections. The nebula envelops hundreds of young stars, many of which could also be in the process of forming planets in a protoplanetary disc.

Although shadow-casting discs are common around young stars, the combination of an edge-on viewing angle and the surrounding nebula is rare. However, in an unlikely coincidence, a similar looking shadow phenomenon can be seen emanating from another young star, in the upper left of the image.

These precious insights into protoplanetary discs around young stars allow astronomers to study our own past. The planetary system we live in once emerged from a similar protoplanetary disc when the Sun was only a few million years old. By studying these distant discs we get to uncover the formation and evolution of our own cosmic home. ■

Gaia uncovers major event in the formation of the Milky Way

by ESA

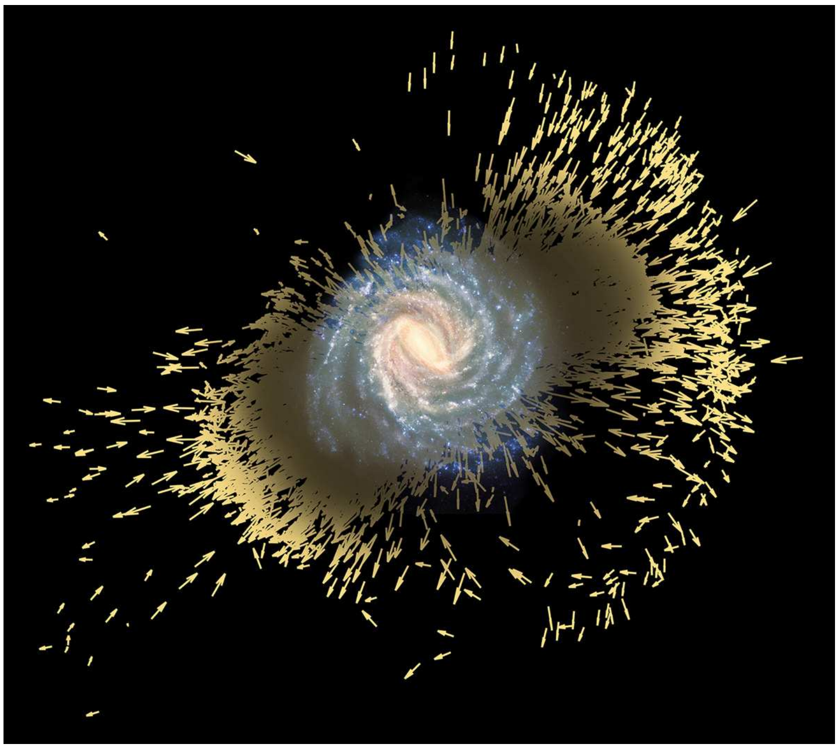
ESA's Gaia mission has made a major breakthrough in unravelling the formation history of the Milky Way.

Instead of forming alone, our Galaxy merged with another large galaxy early in its life, around 10 billion years ago. The evidence is littered across the sky all around us, but it has taken Gaia and its extraordinary precision to show us what has been hiding in plain sight all along.

Gaia measures the position, movement and brightness of stars to unprecedented levels of accuracy.

Using the first 22 months of observations, a team of astronomers led by Amina Helmi, University of Groningen, The Netherlands, looked at seven million stars – those for which the full 3D positions and velocities are available – and found that some 30,000 of them were part of an 'odd collection' moving through the Milky Way. The observed stars in particular are currently passing by our solar neighbourhood. We are so deeply embedded in this collection that its stars surround us almost completely, and so can be seen across most of the sky.

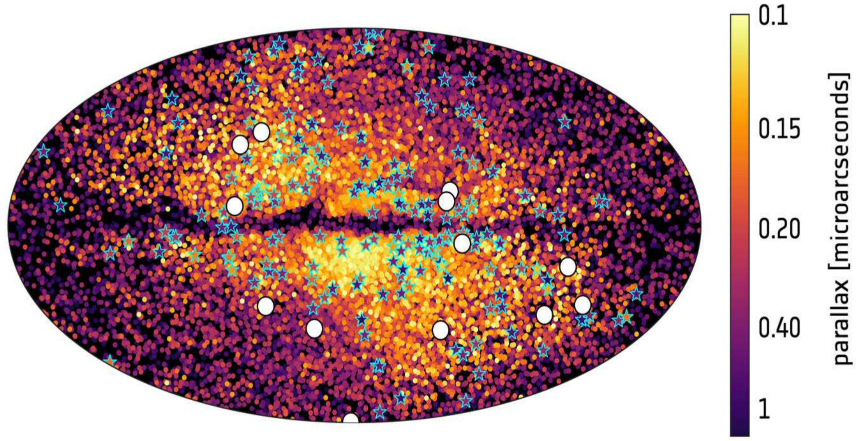
Even though they are interspersed with other stars, the stars in the collection stood out in the Gaia data



Two artist's impression of the merger between the Gaia-Enceladus galaxy and our Milky Way, which took place during our Galaxy's early formation stages, 10 billion years ago. [ESA (artist's impression and composition); Koppelman, Villalobos and Helmi (simulation); NASA/ESA/Hubble (galaxy image)]

because they all move along elongated trajectories in the opposite direction to the majority of the Galaxy's other hundred billion stars, including the Sun.
They also stood out in the so-called Hertzsprung-Russell diagram – which is used to compare the colour and brightness of stars – indicating that they belong to a clearly distinct stellar population. The sheer number of odd-moving stars involved intrigued Amina and her colleagues, who suspected they might have something to do with the Milky Way's formation history and set to work to understand their origins.
In the past, Amina and her research group had used computer simulations to study what happens to stars when two large galaxies merge. When she compared those to the Gaia data, the simulated results matched the observations. *"The collection of stars we found with Gaia has all the properties of what you would expect from the debris of a galactic merger,"* says Amina.
In other words, the collection is what they expected from stars that were once part of another galaxy and have been consumed by the Milky Way. The stars now form most of our Galaxy's inner halo – a diffuse component of old stars that were born at early times and now surround the main bulk of the Milky Way known as the central bulge and disc.
The galactic disc itself is composed of two parts. There is the thin disc, which is a few hundred light years deep and contains the pattern of spiral arms made by bright stars. And there is the thick disc, which is a few thousand light years deep. It contains about 10–20 percent of the Galaxy's stars yet its origins have been difficult to determine.
According to the team's simulations, as well as supplying the halo stars, the accreted galaxy could also have disturbed the Milky Way's pre-existing stars to help form the thick disc.
"We became only certain about our interpretation after complementing the Gaia data with additional information about the chemical composition of stars, supplied by the ground-based APOGEE survey," says Carine Babusiaux, Université Grenoble Alpes, France, and second author of the paper.
Stars that form in different galaxies have unique chemical compositions that match the conditions of the home galaxy. If this star collection was indeed the remains of a galaxy that merged with our own, the stars should show an imprint of this in their composition. And they did.
The astronomers called this galaxy Gaia-Enceladus after one of the Giants in ancient Greek mythology, who was the offspring of Gaia, the Earth, and Uranus, the Sky. *"According to the legend, Enceladus was buried*

All-sky distribution of an 'odd collection' of stars detected in the second data release of ESA's Gaia mission. These stars move along elongated trajectories in the opposite direction to the majority of our Milky Way's other hundred billion stars and have a markedly different chemical composition, indicating that they belong to a clearly distinct stellar population. [ESA/Gaia/DPAC; A. Helmi et al 2018]



under Mount Etna, in Sicily, and responsible for local earthquakes. Similarly, the stars of Gaia-Enceladus were deeply buried in the Gaia data, and they have shaken the Milky Way, leading to the formation of its thick disc," explains Amina.

Even though no more evidence was really needed, the team also found hundreds of variable stars and 13 globular clusters in the Milky Way that follow similar trajectories as the stars from Gaia-Enceladus, indicating that they were originally part of that system. Globular clusters are groups of up to millions of stars, held together by their mutual gravity and orbiting the centre of a galaxy. The fact that so many clusters could be linked to Gaia-Enceladus is another indication that this must have once been a big galaxy in its own right, with its own entourage of globular clusters.

Further analysis revealed that this galaxy was about the size of one of the Magellanic Clouds – two satellite galaxies roughly ten times smaller than the current size of the Milky Way. Ten billion years ago, however, when the merger with Gaia-Enceladus took place, the Milky Way itself was much smaller, so the ratio between the two was more like four to one. It was therefore clearly a major blow to our Galaxy.

"Seeing that we are now starting to unravel the formation history of the Milky Way is very exciting," says Anthony Brown, Leiden University, The Netherlands, who is a co-author of the paper and also chair of the Gaia Data Processing and Analysis Consortium Executive.

Since the very first discussions about building Gaia 25 years ago, one of the mission's key objectives was to examine the various stellar streams in the Milky Way, and reconstruct its early history. That vision is paying off. *"Gaia was built to answer such questions,"* says Amina. *"We can now say this is the way the Galaxy formed in those early epochs. It's fantastic. It's just so beautiful and makes you feel so big and so small at the same time."*

"By reading the motions of stars scattered across the sky, we are now able to rewind the history of the Milky Way and discover a major milestone in its formation, and this is possible thanks to Gaia," concludes Timo Prusti, Gaia project scientist at ESA.

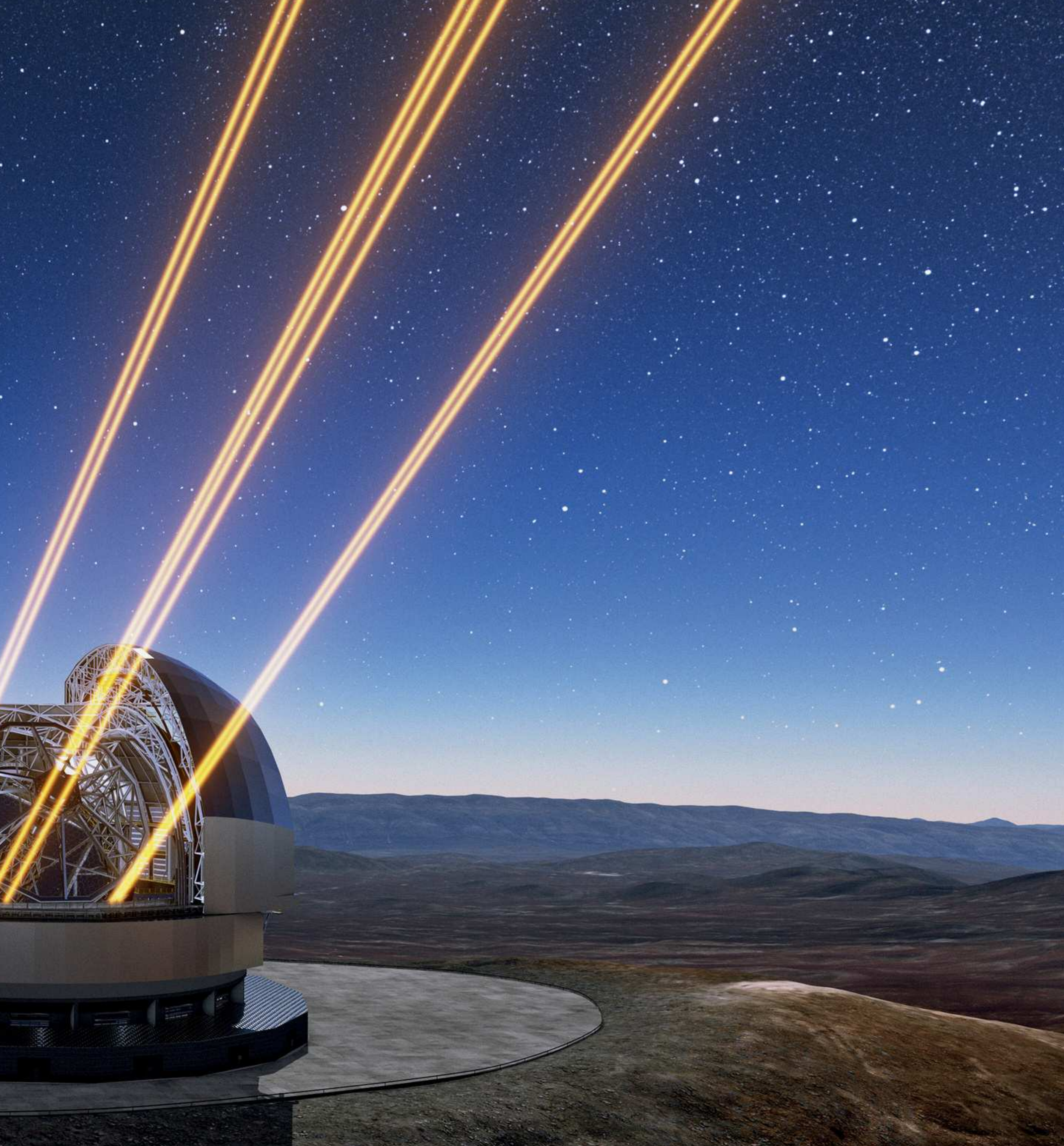
Computer simulation of the merger between a galaxy like the young Milky Way, whose stars are shown in cyan, and a smaller galaxy, indicated in red. [Koppelman, Villalobos & Helmi, Kapteyn Astronomical Institute, University of Groningen, The Netherlands]

ESO Calendar 2019

European Southern Observatory

www.eso.org/public/usa/shop/product/calendar_2019/

One of our most popular products, the ESO Calendar, is now available in its 2019 incarnation, and can be purchased from the ESO online shop and in the ESO Supernova Planetarium & Visitor Centre. The calendar's cover features an artist's impression of the forthcoming Extremely Large Telescope (ELT), the world's biggest eye on the sky. Inside, the calendar is packed with spectacular images of the cosmos as well as photographs of ESO's telescopes against the backdrop of the striking Chilean landscapes. 2019's ESO calendar contains some beautiful highlights. For the month of April, the bright band of the Milky Way arcs



above Antu, one of the four Unit Telescopes of ESO's Very Large Telescope. The spectacular barred spiral galaxy, NGC 1398, is the chosen image for July and a beautiful sunset over Paranal, taken from Cerro Armazones (the site for the ELT) is featured in August. Finally, for December, three telescopes situated at ESO's La Silla Observatory in Chile are shown gazing up at the spellbinding night sky. This long-exposure shot captures the apparent motion of the stars as they sweep out circular trails across the Chilean sky. The calendar has a total of 14 pages, and is available for 10.00 EUR in the ESOshop — but stock is limited so don't delay!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