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Bi-monthly magazine of scientific and technical information ✶ November-December 2019

K2-18 b and the "streetlamp" paradox

Where the aliens don't come from

A flexible concept of the habitability of other worlds

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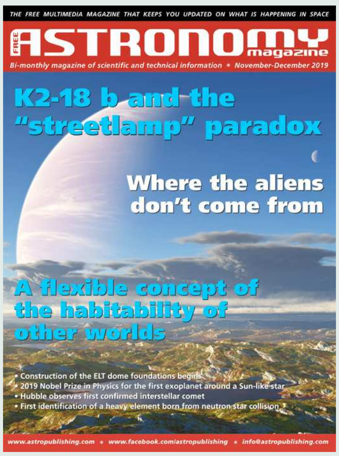

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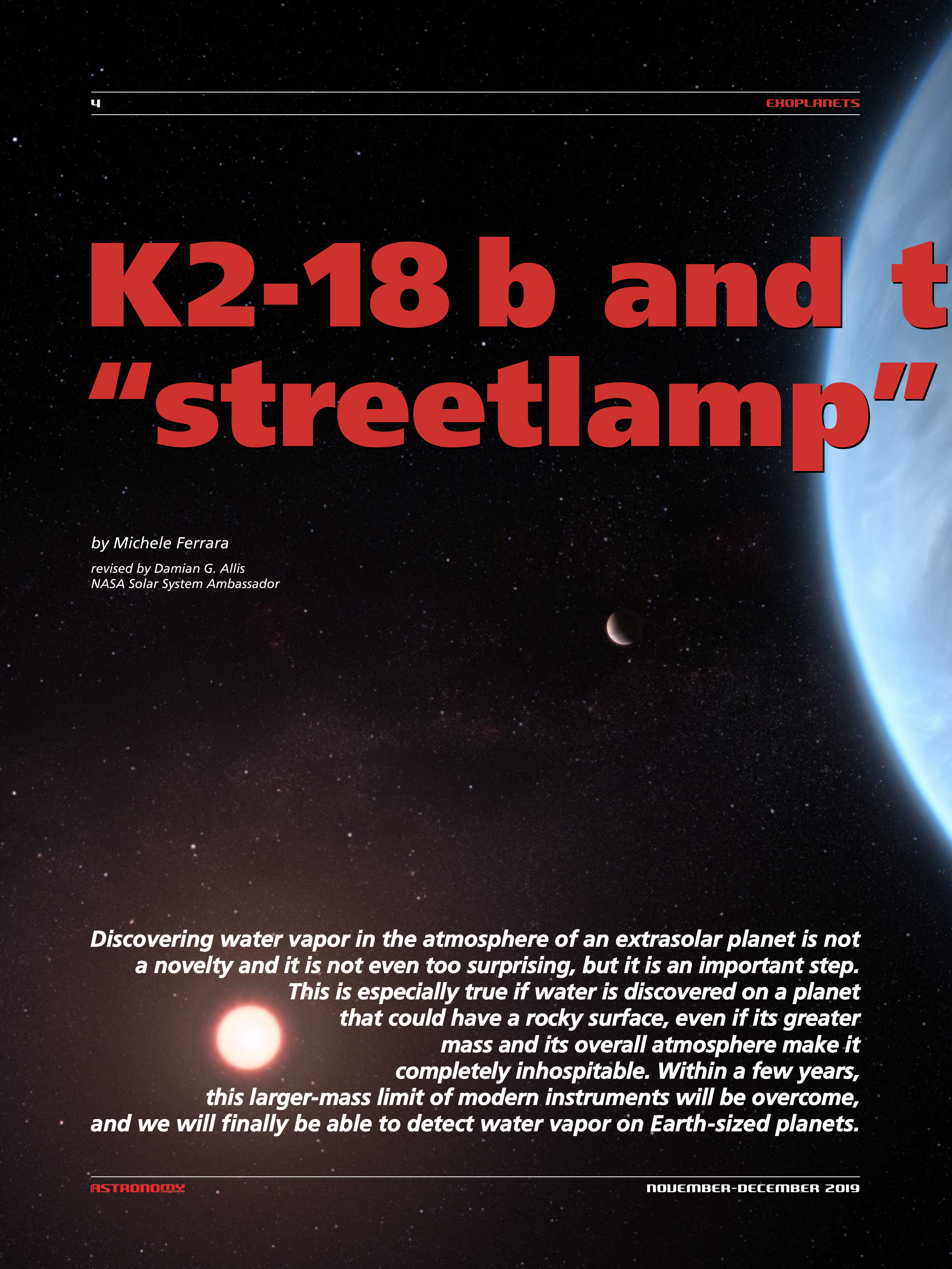
SUMMARY

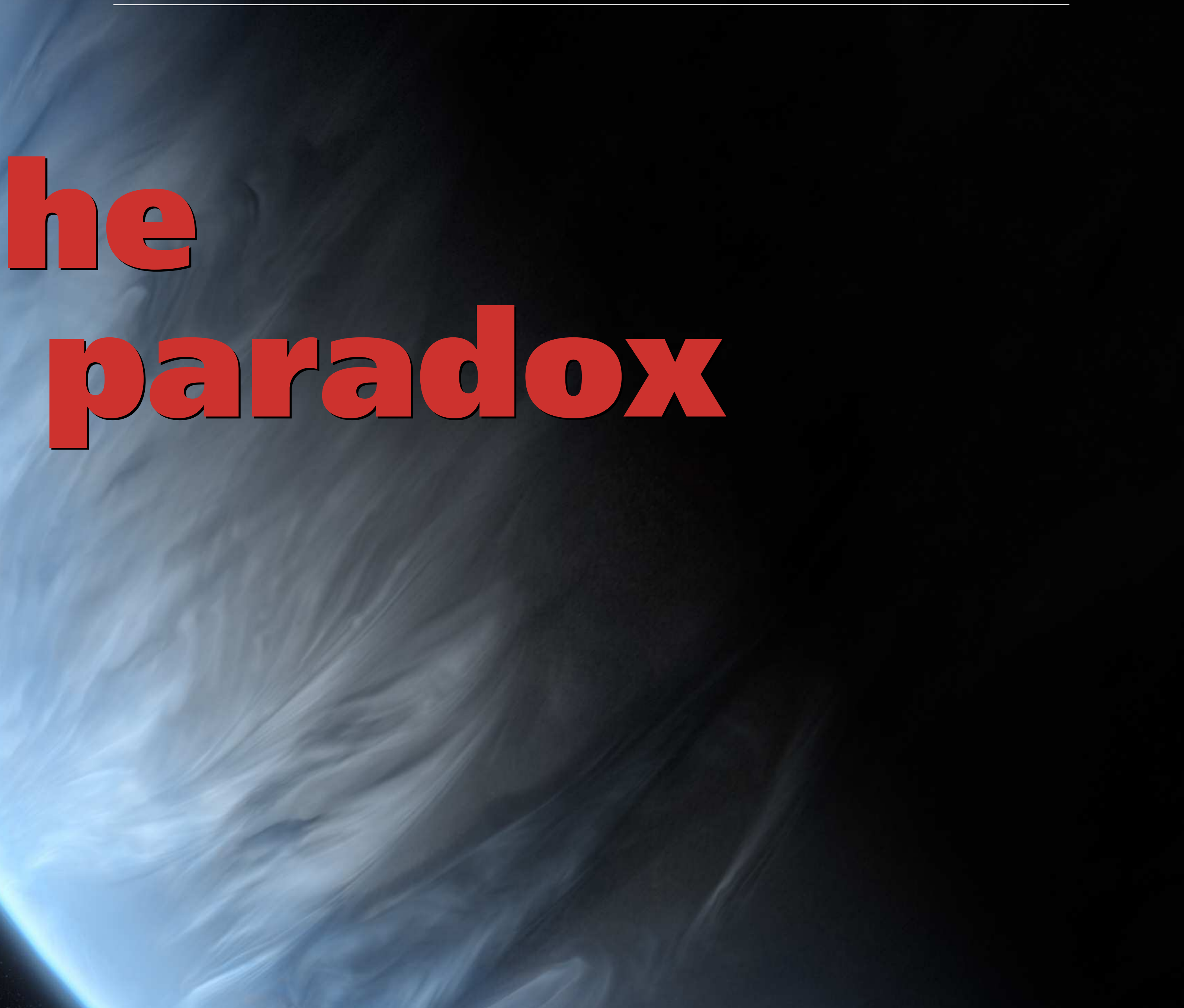


K2-18 b and t "streetlamp"

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

Discovering water vapor in the atmosphere of an extrasolar planet is not a novelty and it is not even too surprising, but it is an important step. This is especially true if water is discovered on a planet that could have a rocky surface, even if its greater mass and its overall atmosphere make it completely inhospitable. Within a few years, this larger-mass limit of modern instruments will be overcome, and we will finally be able to detect water vapor on Earth-sized planets.



he paradox

An imagined representation of planet K2-18 b, its star and the planet that accompanies them in the system. [ESA/Hubble, M. Kornmesser]

At night, under a streetlamp, there is a drunk who is looking for something. A policeman approaches and asks him what he has lost. *"I lost my house keys,"* the man replies, and they both start looking for them. After looking for a long time, the policeman asks the drunk if he is really sure he lost the keys there, and he is told: *"No, I think I lost them in the park." "But then, why are you looking for them here?" "Because there is more light here!"* This bizarre tale, taken up and adapted by various twentieth-century authors from a satirical tale of the thirteenth century, is today known as the "streetlamp" paradox. It is a type of observational distortion that consists of looking for something where it seems easier to find, even if if the researcher knows in advance that he will not find what he is looking for. At the very least from his efforts, he will show that it is not there.

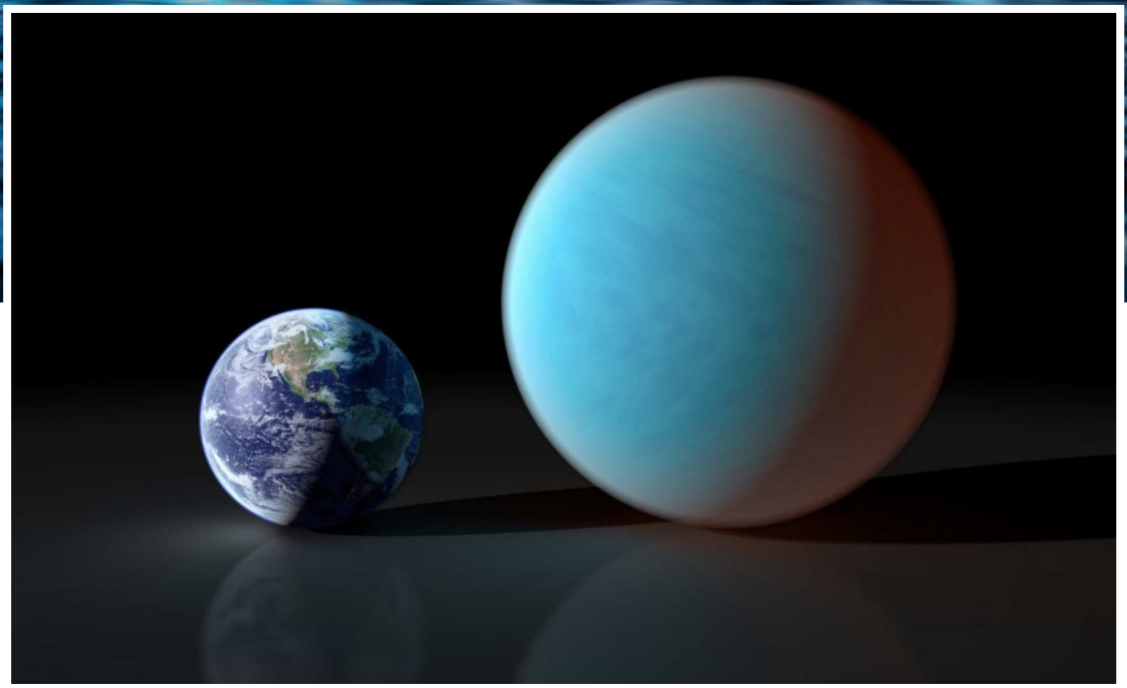
Astronomers looking for habitable exoplanets are today in the position of the

This illustration is a good example of how the mass media painted the super-Earth K2-18 b after learning of the discovery of water vapor in its atmosphere. Atmospheric gas was soon transformed into large expanses of surface water. [Harvard University]

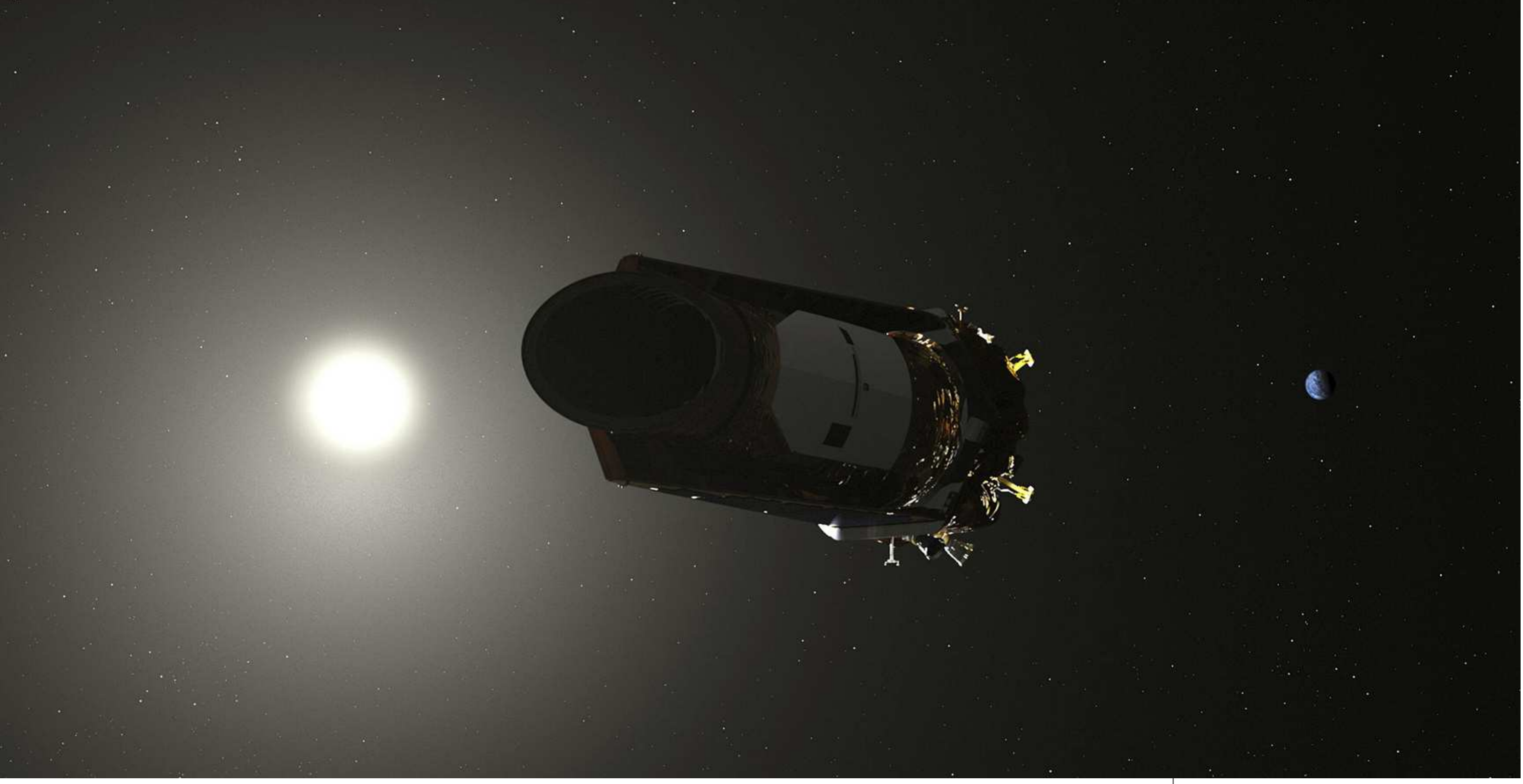
drunk, even if they are sober. They are, in fact, looking for water in the atmospheres of planets that, despite possessing essential characteristics for the sustainability of life as we know it, may still be planets with properties that make life difficult (not to say impossible) to exist. Those planets are the so-called "super-Earths," to which rather elastic conventions attribute masses between 2 and 10 Earth masses and diameters between 2 and 4 Earth diameters.

We know very little about super-Earths because we don't have any in our solar system, yet we know they are the most common planets in the galaxy. We know that it is relatively easy to discover them in transit in front of the disk of their stars when these stars are M-type dwarfs. We also know that these little stars hide non-negligible pitfalls, which make them perhaps totally unsuitable for hosting life on their planets.

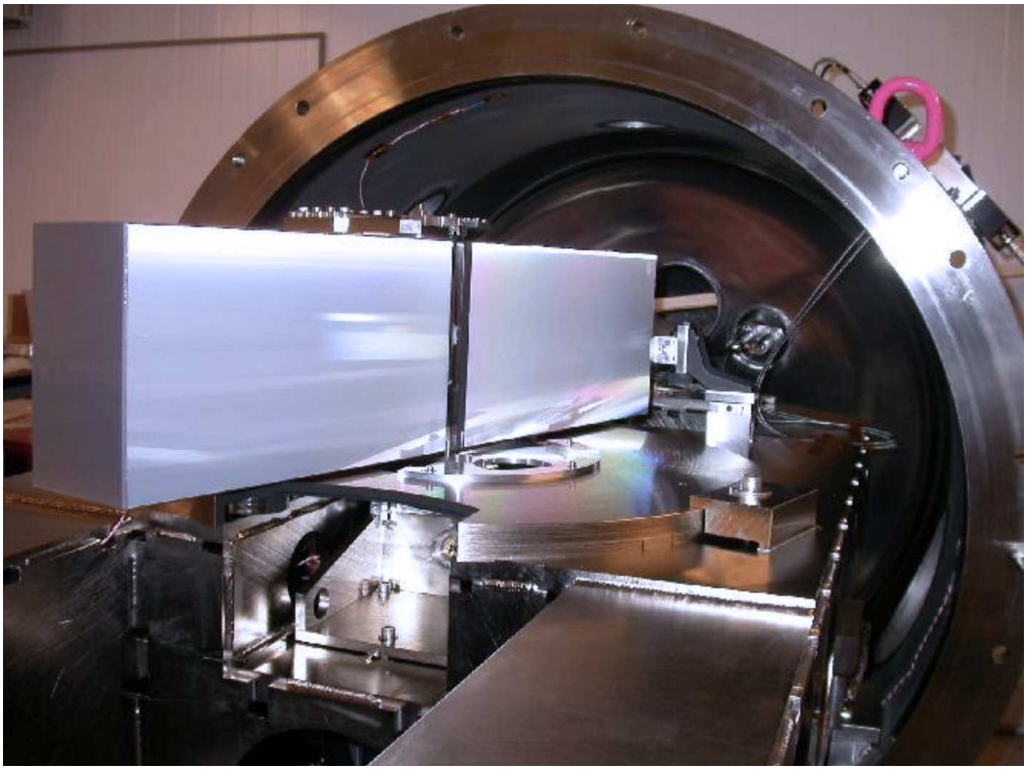
The positive and negative aspects of the search for potentially habitable planets around red dwarfs were sufficiently addressed in the previous issue of this magazine. Here, we want to understand why, although any terrestrial-like habitability on M dwarf super-Earths is unlikely, astronomers are today particularly involved in the search for water right in the atmospheres of these planets. The reason is simply stated: not even the most powerful telescopes currently operating in space or on the ground allow for the unequivocal recognition of the signature left by water molecules in the spectra of atmospheres around planets as small as the Earth (a little more, a little less), not even if these planets orbit around very small stars. The minimum threshold in this field of research is currently represented by the largest super-Earths, whose main atmospheric gases leave a signature (barely distinguishable in the best instruments) in the tiny fraction of stellar light



A comparison of the sizes of the Earth and a planet similar to K2-18 b. Defining the latter "the most similar to our own" is perhaps an excess of optimism. [NASA/JPL-Caltech/R. Hurt (SSC)]

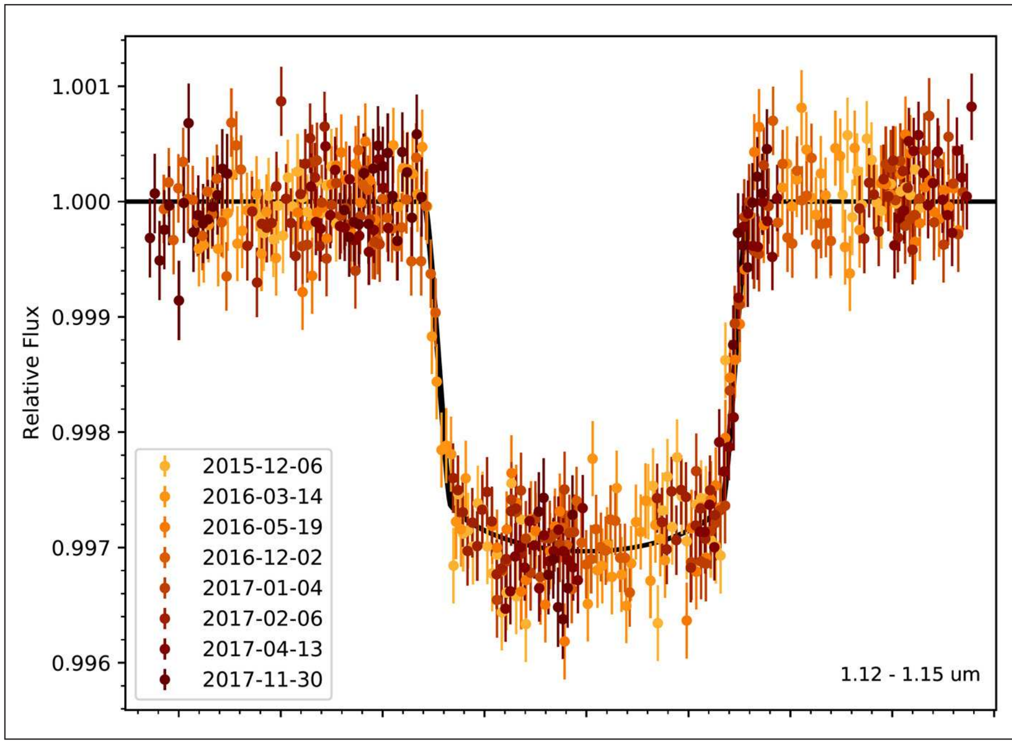


that goes through their atmospheres before reaching the observer. Not enough signal comes from Earth-like planetary atmospheres for astronomers to be able to distinguish signal from noise. It is, therefore, useless to look at these planets for the "house keys" (that is, a livable world). Not being able to do otherwise for the time being, astronomers are accordingly looking for the "keys" where there is more light. Even if they do not find Earth-like environments, they improve their skills as seekers, waiting for the "park" to become less dark. The best, technically-achievable result today is the discovery of water in the atmosphere of a super-Earth orbiting inside the habitable zone of a red dwarf. This very result was recently reported by two teams of researchers, leading to a kind of mass media sensationalism not entirely appropriate or warranted.

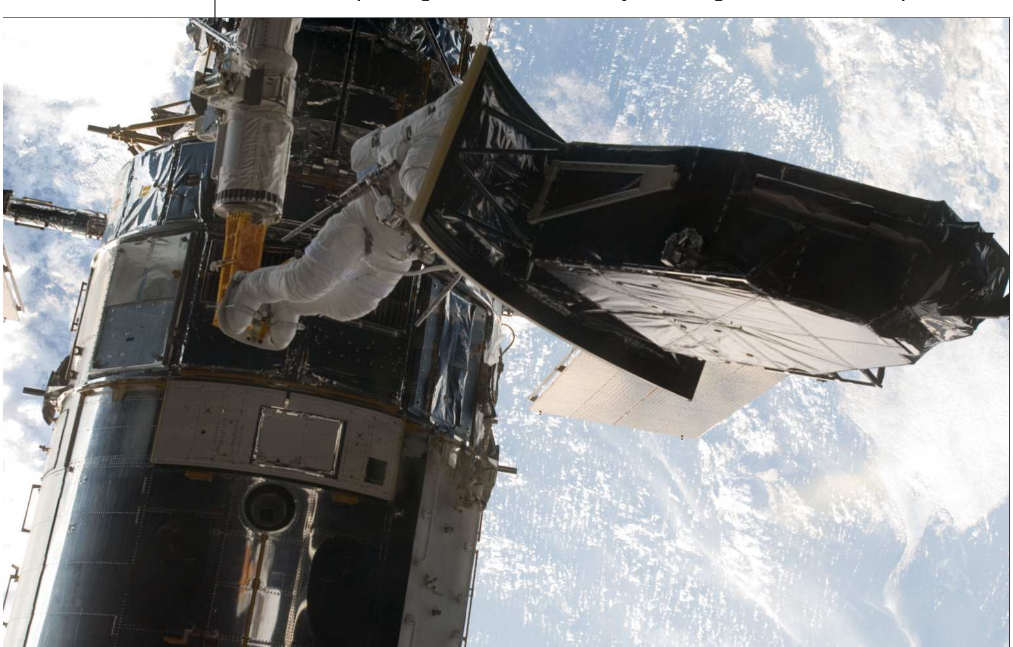


Two of the main protagonists in the twenty years-long history of exoplanets: the Kepler Space Telescope, the most prolific discoverer, and the HARPS spectrograph, the most precise validator. Together they have revolutionized extrasolar planetology. [NASA, ESO]

Below, the installation of Wide Field Camera 3 on the Hubble Space Telescope during Servicing Mission 4 in 2009. This is the instrument that, coupled with the STIS spectrograph, allowed researchers to investigate the atmospheric composition of K2-18 b. The graph on the right is the sum of all the photometric measurements made by WFC3 during the eight transits analyzed by the Tsiaras and Benneke teams. [NASA, B. Benneke et al.]



Before assessing the extent of the new discovery, we have to stress a few points that will help us give the discovery the right weight: 1) we have known for several years of large planets that show the presence of water vapor in their atmospheres, but these worlds are certainly inhospitable given, at the very least, their very high temperatures; 2) water is the second most common molecule in the universe after molecular hydrogen (H_2) and has even been recognized in the spectrum of the Sun, so it should not be surprising to find it in the atmosphere of a medium-sized planet orbiting inside the habitable zone of a star.



Given the above, the clamor around the discovery of water vapor in the atmosphere of super-Earth K2-18 b last September appears

to have been a bit excessive. As often happens when a scientific discovery becomes a media event, journalists lost control and K2-18 b soon became "the planet most similar to Earth yet discovered," despite the authors of the discovery being quick to point out that it is actually quite a bit different. To understand how different it is, it is sufficient to consider the main characteristics of the system that hosts it. K2-18 is a dwarf M3-type star almost 111 light-years away from Earth. Its mass is 40% that of the Sun, it has a diameter equivalent to four times that of Jupiter, a temperature of 3460 Kelvin (K), and a brightness that is just 2.7% that of the Sun. In 2015, the Kepler Space Telescope discovered the first known planet of this system, K2-18 b, the super-Earth in

If super-Earth K2-18 b has a rocky surface, an atmosphere not too thick, and maybe even a moon, its nights might resemble this imaginative view.

whose atmosphere water vapor has now been detected. In 2017, Kepler itself discovered a second super-Earth in the system, K2-18 c. K2-18 c turned out to be less interesting than the other, orbiting just 9 million km (0.06 AU) from the star and with a revolution period of 9 days, placing it far beyond the internal limit of the K2-18 habitable zone, which extends between 18 and 37.5 million km (0.12-0.25 AU). Even before the second planet was discovered, its outermost sibling had already attracted the attention of astronomers due to the fact that it is well-placed in the K2-18 habitable zone at about 21 million km (0.143 AU) and with a revolution period slightly smaller than 33 days. At that distance, the planet receives about 1440 W/m^2 from the star, a value very

similar to what the Earth receives from the Sun, 1370 W/m^2, albeit with a different spectral energy distribution. Models indicate that that level of irradiation can produce a surface temperature (a term sometimes ambiguous) between 200 K and 320 K, or between about -70 °C and +50 °C, practically the same measurable range on the Earth's surface (assuming also that the average albedo of K2-18 b is the same, i.e., about 0.3).

These assumptions prompted researchers to collect spectra of the K2-18 b atmosphere whenever the Hubble Space Telescope became available, the only instrument theoretically capable of collecting an infrared signal (1.1-1.7 μm) intense enough to allow the recognition of the most abundant molecules. The observations aimed to exploit the transits in front of the star disk to obtain the overall spectrum of the star together with the planet, from which one can then subtract the single out-of-transit star spectrum.

The two teams of researchers who worked on the complex data processing were led by Angelos Tsiaras (University College London) and Björn Benneke (Université de Montréal). Both teams analyzed eight K2-18 b transits recorded between 2015 and 2017. Benneke's team included in the process three observations from the Spitzer Space Telescope. The results of the long work of the two teams were published respectively in *Nature Astronomy* and *The Astronomical Journal*. The conclusions

This is another possible vision of the K2-18 b surface, especially if it is tidally locked, always displaying the same hemisphere to the star. On the left, Björn Benneke, leader of one of the two teams of researchers who discovered water vapor on K2-18 b. [Amélie Philibert]

On the right, Angelos Tsiaras, the leader of the other group of researchers involved in the discovery. [UCL Physics & Astronomy]

reached are essentially the same: the transmission spectrum of K2-18 b reveals a weak but statistically significant signature of water absorption at 1.4 µm.
By considering the low temperature of the planetary atmosphere, it is plausible to conclude that water vapor can condense into droplets and clouds, perhaps even causing precipitation of liquid water in the mid-atmosphere.
The positive notes end here, as the collected spectra and a comparison between atmospheric models indicate that the gaseous envelope surrounding K2-18 b is dominated by hydrogen, with a significant presence of helium – a highly toxic mixture for terrestrial-like life. Furthermore, we do not know the mass of the atmosphere and, consequently, not even its density and surface pressure. We know that the total mass of K2-18 b is equal to 8-9 Earth masses and that its diameter is between 2.3 and 2.7 times that of our planet (29,300-34,400 km) - the result is an average density between 2.5 and 4.5 g/cm^3.

The wide range of these values keeps open many different scenarios of how K2-18 b might actually be structured, from a rocky planet with an extended atmosphere to something similar to a mini-Neptune. In any case, we are very likely in the presence of an uninhabitable planet.
Even if K2-18 b had a solid surface with expanses of liquid water (the maximum we can hope for), the planet could have a high enough surface pressure and surface gravity to discourage any visitor.
A further negative feature of K2-18 b might be the possible synchronization of the revolution and rotation periods. This is not a rare event in billion-year-old red dwarf systems. The age of K2-18 is unknown, meaning its planets could be at a stage where they always show the same face to the star, subjecting one side to harmful surface and atmospheric conditions and causing planet-wide extremes related to the redistribution of accumulated heat.
Angelos Tsiaras is right when he states that: *"This is the only planet right now that we know outside the solar system that has the correct temperature to support water, it has an atmosphere, and it has water in it — making this planet the best candidate for habitability that we know right now."* But he is even more right when he states that: *"K2-18 b is not 'Earth 2.0' as it is significantly heavier and has a different atmospheric composition. However, it brings us closer to answering the fundamental question: Is the Earth unique?"* ■

Construction of the ELT

by ESO
Mariya Lyubenova

Construction is now underway of the foundation of ESO's Extremely Large Telescope (ELT) in the remote Chilean Atacama Desert. Once complete, the telescope will be the largest ground-based telescope in operation, weighing in at 3400 tonnes.

The ELT is a reflecting, fully-steerable telescope. The design includes a segmented primary mirror measuring 39.3 metres in diameter, a secondary mirror (4.2 metres in diameter) and a tertiary mirror (3.75 metres in diameter). The telescope will also feature groundbreaking adaptive optics technology that will help correct the distortions in Earth's at-

dome foundations begins

A detail of the work in progress on the construction site. [ESO]

mosphere, making the images sharper than those taken from space. The enclosure itself will be a classic dome shape and will be the telescope's first defence against the elements. The dome height comes in at nearly 74 metres from the ground and it will span 86 metres in diameter. Since the ELT is the largest telescope ever built to date — the question of where to put it was a very tricky one to answer.

Locations in Spain, Chile, Morocco and Argentina were tested, and finally, in April 2010, Cerro Armazones in Chile was selected. It was the ideal site thanks to a mixture of different geographical factors which set it above the rest — such as elevation, climate and the very dark skies of the Atacama Desert. The Chilean desert also has very little rainfall (100 mm annually on average), a median wind speed of 25 km/h and very little water vapour in the air, making it the perfect location for successful astronomy. ESO's Very Large Telescope (VLT) is only 23 km away meaning a lot of the infrastructure needed to build and maintain the ELT was already in place.

There are many questions the Universe has yet to answer and the ELT is well equipped to solve these mysteries. One of the ELT's biggest goals is to find and characterise the atmospheres of rocky exoplanets in habitable zones.

The ELT will also study star formation, metal enrichment, the physics of high redshift galaxies, cosmology and fundamental physics.

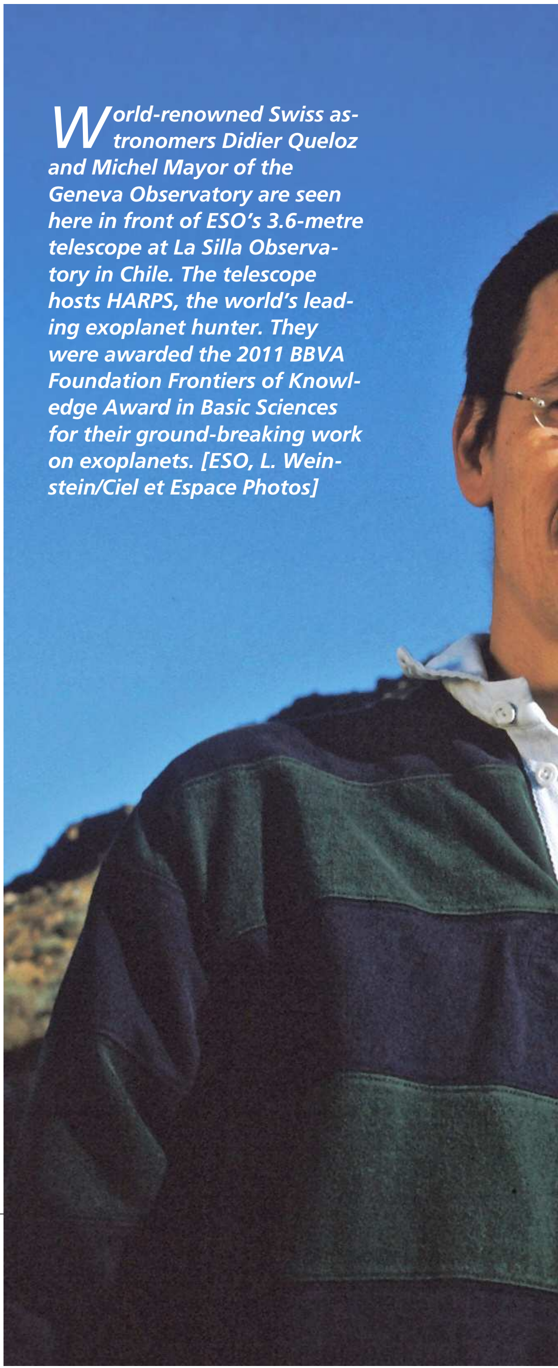
2019 Nobel Prize in Physics for the first exoplanet around a Sun-like star

by ESO

Bárbara Ferreira

Michel Mayor and Didier Queloz have been awarded the 2019 Nobel Prize in Physics for the discovery of the first exoplanet around a Sun-like star. Mayor, Professor Emeritus at Geneva University in Switzerland, and Queloz, Professor of Physics at the Cavendish Laboratory, Cambridge, UK, share the prize *"for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos"* with James Peebles, Albert Einstein Professor Emeritus of Science at Princeton University, US. *"ESO is really proud of the Nobel Prize in Physics awarded to Michel Mayor and Didier Queloz for having pioneered a new field in astronomy with the discovery of 51 Pegasi b and many more exoplanets after."* says ESO Director General Xavier Barcons. *"The partnership that ESO cultivates with research institutions in the Member States for the development of the most challenging instruments has been key to enable many of these discoveries. In particular HARPS on the ESO 3.6-metre telescope in La Silla Observatory and more recently ESPRESSO on the Very Large Telescope in Paranal are leading the world in radial-velocity searches of planets around stars outside the Solar System. ESO celebrates that two outstanding members of its scientific community, with very strong commitment to ESO, and very successful use of our facilities, have been given this well-deserved recognition."* The discovery of 51 Pegasi b, the first exoplanet ever found around a Sun-type star, was announced on 6 October 1995 by Mayor and Queloz, who detected it using the ELODIE spectrograph at the Observatoire de Haute-Provence in France. The discovery revolutionised astronomy, initiating an entirely new field and new instruments focused on finding and characterising exoplanets.

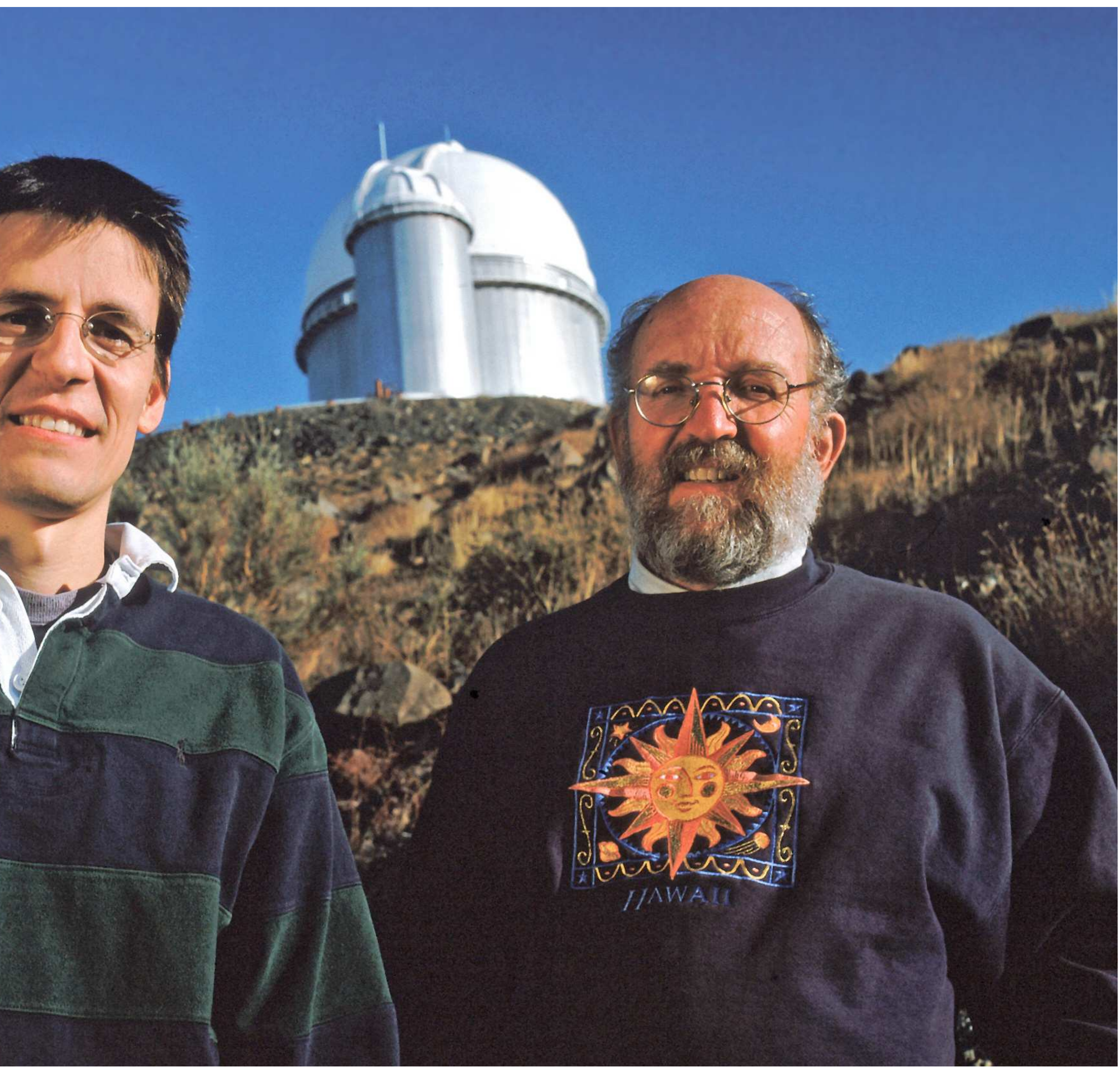
The success of ELODIE led to the construction of CORALIE, an improved version of ELODIE mounted on the 1.2-metre Swiss Euler Telescope at ESO's La Silla Observatory in Chile. The knowledge gained from building and operating these two instruments was put in the development of HARPS, the High Accuracy Radial velocity Planet Searcher, which began operations in 2003. The light from 51 Pegasi b was also observed by HARPS, which performed the first-ever spectroscopic detection of



World-renowned Swiss astronomers Didier Queloz and Michel Mayor of the Geneva Observatory are seen here in front of ESO's 3.6-metre telescope at La Silla Observatory in Chile. The telescope hosts HARPS, the world's leading exoplanet hunter. They were awarded the 2011 BBVA Foundation Frontiers of Knowledge Award in Basic Sciences for their ground-breaking work on exoplanets. [ESO, L. Weinstein/Ciel et Espace Photos]

visible light reflected off an exoplanet. Mayor and Queloz were instrumental in developing the revolutionary radial velocity technique that is still used to search for exoplanets today. This method looks for tiny backwards and forwards motion of the central star, due to the changing direction of the gravitational pull from an (unseen) orbiting exoplanet. If the star is moving towards us, its spectrum is blueshifted, and redshifted correspondingly when it moves away from us. By looking for regular shifts in the spectrum of the star — and so measuring any velocity changes — any periodic effects due to the influence of a companion can be seen.

Both Mayor and Queloz have longstanding collaborations with ESO and have been involved with the organisation's governing and advisory bodies. They are very experienced observers, having participated in hundreds of observing runs at ESO with a variety of instruments. In 1996, ESO commemorated Mayor and Queloz's groundbreaking 1995 paper by placing it in a time capsule that is still buried in the wall of the VLT enclosure. It is a testament to the rigour and determination of their work that their discovery is being recognised with a Nobel Prize in Physics over twenty years later. ■



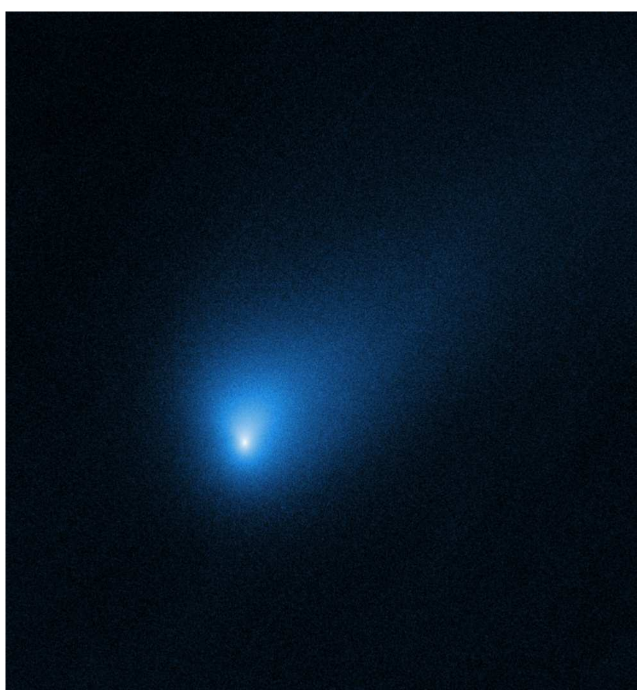
Hubble observes first confirmed interstellar comet

by NASA/ESA

On 12 October 2019, the NASA/ESA Hubble Space Telescope provided astronomers with their best look yet at an interstellar visitor — Comet 2I/Borisov — which is believed to have arrived here from another planetary system elsewhere in our galaxy. This observation is the sharpest view ever of the interstellar comet. Hubble reveals a central concentration of dust around the solid icy nucleus.

Comet 2I/Borisov is only the second such interstellar object known to have passed through our Solar System. In 2017, the first identified interstellar visitor, an object dubbed 'Oumuamua, swung within 38 million kilometres of the Sun before racing out of the Solar System.

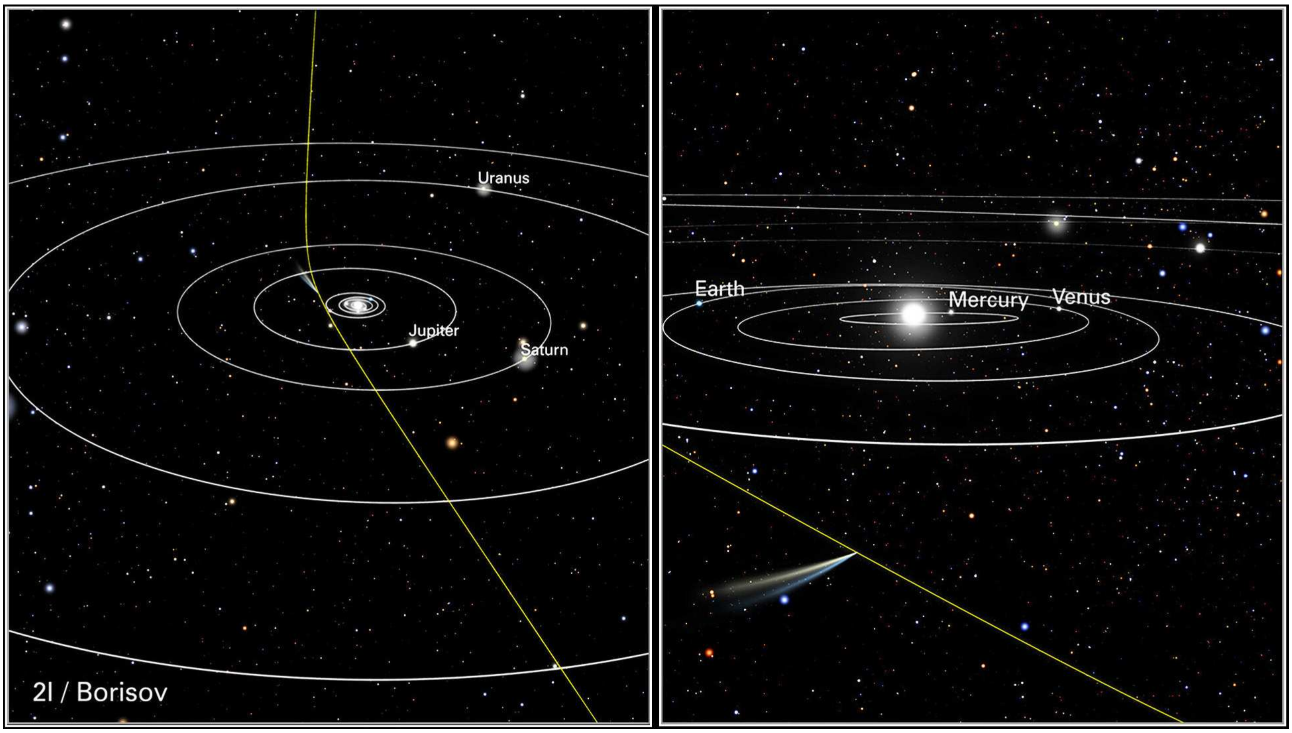
"Whereas 'Oumuamua looked like a bare rock, Borisov is really active, more like a normal comet. It's a puzzle why these two are so different," explained David Jewitt of UCLA, leader of the Hubble team who observed the comet. As the second interstellar object found to enter our Solar System, the comet provides various invaluable insights. For example, it offers clues to the chemical composition, structure, and dust characteristics of a planetary building block presumably forged in an alien star system a long time ago and far away. *"Because another star system could be quite different from our own, the comet could have experienced significant changes during its long interstellar journey. Yet its properties are very similar to those of the Solar System's building blocks, and this is very remarkable,"* said Amaya Moro-Martin of the Space Telescope Science Institute in Baltimore, Maryland.



On 12 October 2019, the NASA/ESA Hubble Space Telescope observed Comet 2I/Borisov at a distance of approximately 420 million kilometres from Earth. The comet is believed to have arrived here from another planetary system elsewhere in our galaxy. [NASA, ESA, D. Jewitt (UCLA)]

Hubble photographed the comet at a distance of approximately 420 million kilometres from Earth. The comet is travelling toward the Sun and will make its closest approach to the Sun on 7 December, when it will be twice as far from the Sun as Earth. It is also following a hyperbolic path around the Sun, and is currently blazing along at the extraordinary velocity of over 150,000 kilometres per hour. By the middle of 2020, the comet will be on its way back into interstellar space where it will drift for millions of years before maybe one day approaching another star system.

Crimean amateur astronomer Gennady Borisov first discovered the comet on 30 August 2019. After a week of observations by amateur and professional astronomers all over the world, the



This illustration shows the path of comet 2I/Borisov through our Solar System. This visitor came from interstellar space along a hyperbolic trajectory. It is only the second known intruder to zoom through our Solar System (the interstellar object 'Oumuamua was detected in 2017). As the graphic shows, the comet's straight path across interstellar space is slightly deflected by the gravitational pull of our Sun. The comet is travelling so fast, at over 150,000 kilometres per hour, it will eventually leave the Solar System. The panel on the right shows the comet's position relative to Earth when the NASA/ESA Hubble Space Telescope observed it on 12 October 2019, when it was 420 million kilometres from Earth. [NASA, ESA, J. Olmsted, F. Summers (STScI)]

International Astronomical Union's Minor Planet Center computed an orbit for the comet which showed that it came from interstellar space. Until now, all catalogued comets have come either from a ring of icy debris at the periphery of our Solar System, called the Kuiper belt, or from the Oort cloud, a shell of icy objects which is thought to be in the outermost regions of our Solar System, with its innermost edge at about 2000 times the distance between the Earth and the Sun.

An animation of Comet 2I/Borisov. [NASA, ESA, D. Jewitt (UCLA)]

2I/Borisov and 'Oumuamua are only the beginning of the discoveries of interstellar objects paying a brief visit to our Solar System.

There may be thousands of such interstellar objects here at any given time; most, however, are too faint to be detected with present-day telescopes. Observations by Hubble and other telescopes have shown that rings and shells of icy debris encircle young stars where planet formation is underway. A gravitational interaction between these comet-like objects and other massive bodies could hurtle them deep into space where they go adrift among the stars.

Future Hubble observations of 2I/Borisov are planned through January 2020, with more being proposed. ■

Where the aliens

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

The messy movement of people and opinions that is ufology does not need assistance in appearing laughable. The congeries of anecdotal experiences that compose all evidence within the field deprive ufology of actual credibility. And yet, a minimum of scientific rigor and a legitimate vision capable of crossing the boundaries of our atmosphere would be enough to distinguish the possible from the impossible. Three controversial videos provided by the US Navy give us the opportunity to reflect on the subject.

In the background, an imaginative extraterrestrial landscape, flooded with light by a star other than the Sun, which gives the vegetation a color very unusual to us.

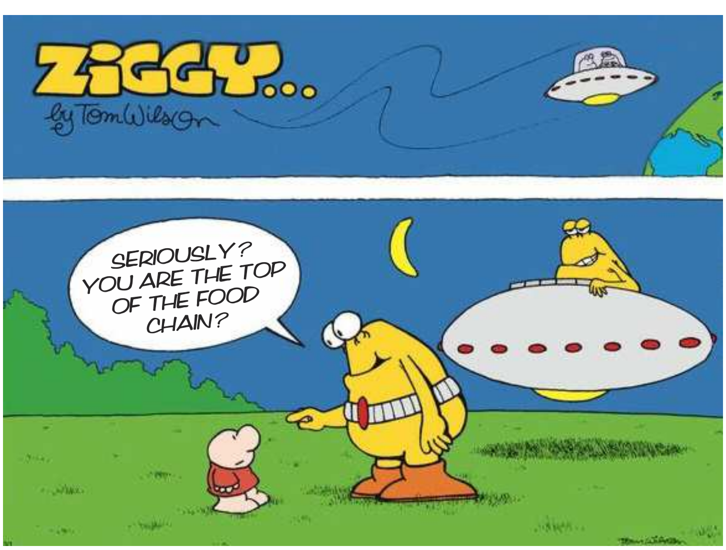
don't come from

In the second half of September, spokesperson Joseph Gradisher of the United States Navy confirmed the authenticity of three videos recorded by fighter pilots, in which small, indistinct shapes appear that move at speeds similar to those of the planes. The videos had been in the public domain for several months but, not having resonated with interest on the web to that point, it was as if they didn't exist at all. It is not clear who authorized the declassification of the material, but it is clear that someone had an interest in making it known for reasons that themselves remain unknown. The first publication of the three videos took place between 2017 and 2018 on the initiative of an authoritative newspaper, *The New York Times* (NYT), and a much less authoritative association

that we will not cite here. The oldest video dates back to 2004 from the skies near San Diego (California) and involved a recording of a US Navy fighter plane and an unidentified atmospheric phenomenon, or UAP, an acronym that indicates those manifestations that previously were generically defined as UFOs. Since UAP also includes "not objects," the term "phenomena" was preferred as an alternative descriptor.

The 2004 video was published in December 2017 in a NYT report on the US Defense Department's "Advanced Aerospace Threat Identification Program," specifically launched to study the numerous UAP cases being registered and to prevent any dangers to military and civilian aviation. The other two videos were published in 2018 in similar ways, but even these did not have great resonance until the recent official confirmation of their authenticity by the US Navy.

Beyond the belated and unmotivated enthusiasm that arose due to the revival of the news last September, the videos reveal nothing new about objects or phenomena (punctually blurred or grainy or amorphous) that appear on radar screens or in aircraft imaging devices. Anyone who asked Gradisher for his opinion on the possible nature of these phenomena was told that *"The frequency of incursions has increased since the advents of drones and quadcopters,"* a clear reference to a terrestrial origin.

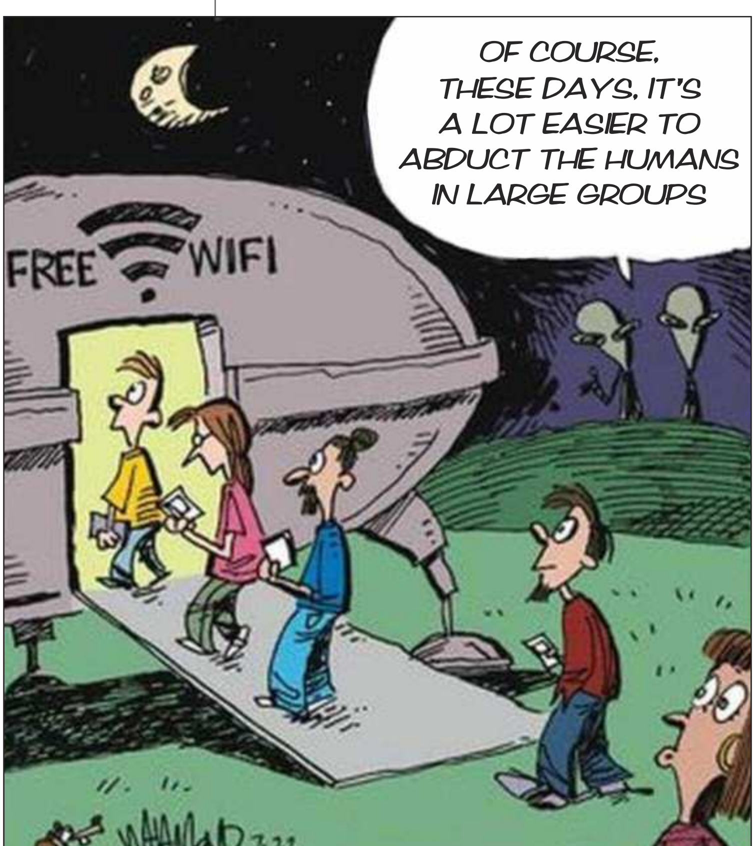


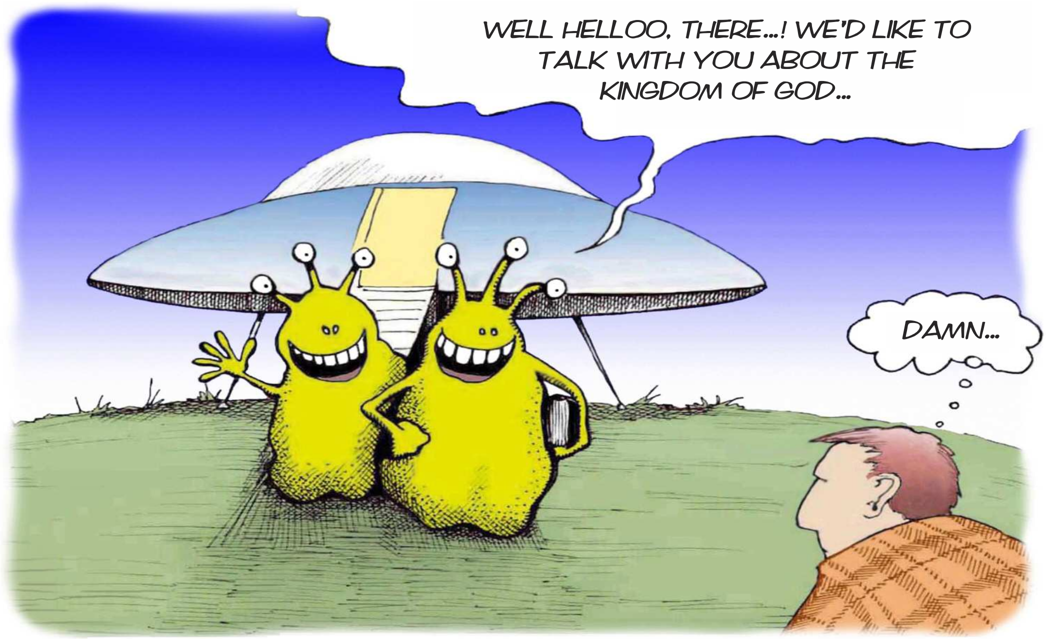
Commenting on images that show nothing definitive is the official pastime of ufology, so everyone has been freed to hypothesize on alien presences, secret weapons, political conspiracies, and any other unprovable scenario.

We prefer here to take the science beyond the atmosphere – where almost everyone in ufology usually stops – to see if it is reasonable to believe that even a small number of the reported UAPs are a product of extraterrestrial visitors. To do this seriously, we must start from two fundamental, hardly questionable assumptions: 1) in the Milky Way, there are probably hundreds of billions of planets, and it is, therefore, likely that life appeared on some of them as well as on Earth; 2) the repeated experimental validations of Einsteinian Relativity confirm that the speed of light is an insurmountable limit, this because the energy necessary to accelerate a mass grows exponentially with speed, becoming infinite (therefore greater than that of the whole Universe) at the speed of light.

This second assumption seems to us rather solid given the state of modern physics, but obviously those who think differently can support their alternative theories at the appropriate locations.

Given that the speed of light cannot be overcome by any technological civilization regardless of its location, let us try to evaluate the probability that aliens will visit us, appar-



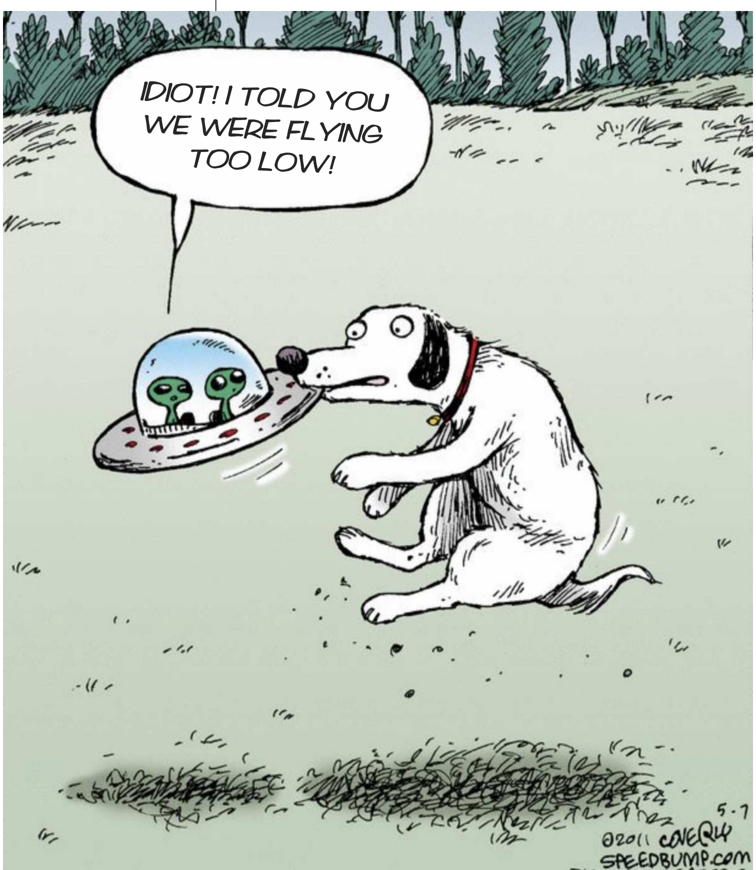


ently both incessantly and with a great variety of different spaceships and, assumedly, crews. Whatever path you want to take to investigate the issue, an empirical approach is inevitable, but we will do our best to offer an objective point of view.

Let us begin by evaluating how many technological civilizations can exist simultaneously with us in the Milky Way. A starting point to predicting this number based on some approximations is by the adoption of the Drake Equation, for which we will attribute values to its variables as conservatively as possible. If we do not decide to deny the existence of extraterrestrial life *a priori*, we find that other technological civilizations could exist that can communicate using electromagnetic radiation. Their number is probably less than ten if we are particularly strict with the variables of the Drake Equation – and we must be strict if we want to give credibility to the evaluation.

Given that we earthlings have dealt with telecommunications for only a very short time, it is likely that other extant technological civilizations are more advanced than us. They may be theoretically capable of performing interstellar journeys, but they are certainly capable of sending powerful sig-

nals towards other planetary systems. Although we have been listening to the sky for 60 years now (starting from Frank Drake's Project Ozma), we have yet to record non-natural signals of clear extraterrestrial origin. An alien civilization that wanted to make itself heard could easily overcome the listening limits of those who are less technologically gifted. Accordingly, if we have not yet received messages, it is because the

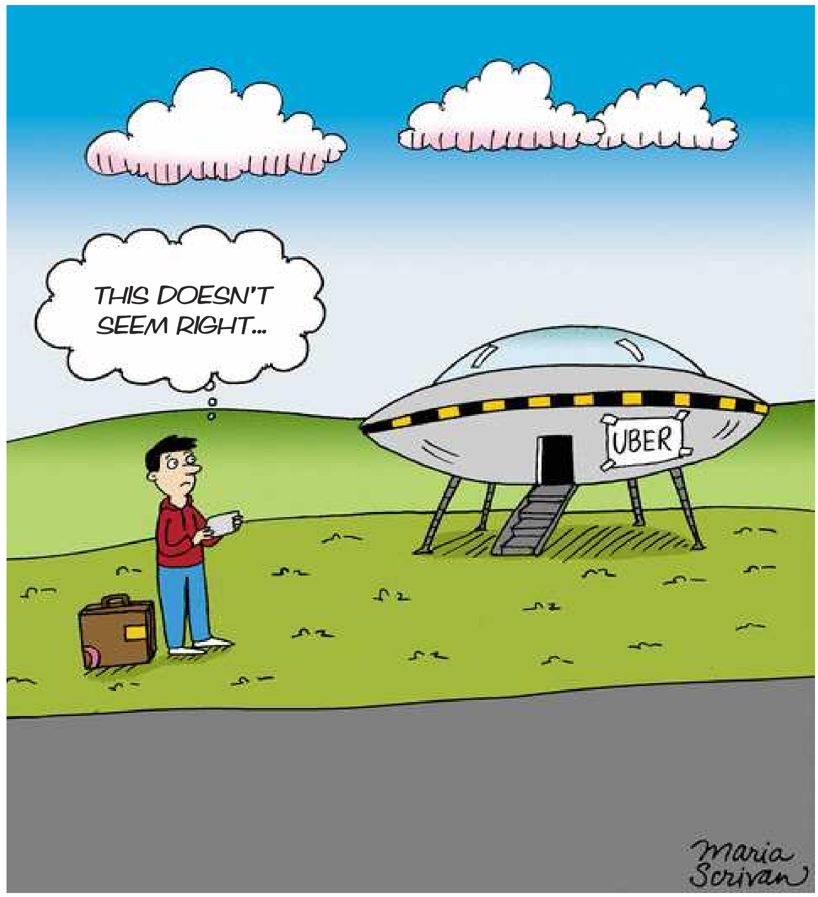


aliens either do not want to communicate with us (which would make the raids in our atmosphere meaningless), or because their signals have not yet reached the Earth due to the enormous distances that separate any planetary civilizations from each other. This second hypothesis is far more relevant – for instance, we ourselves, in 1974, sent a message to the M13 globular cluster that will reach its destination in about 25,000 years. A handful of civilizations scattered through-

out the Milky Way might be separated by tens of thousands of light-years, making the silence that currently surrounds us understandable. It might even be more strange to not have already received signals sent in the past by civilizations much older than our own and, perhaps, already disappeared.

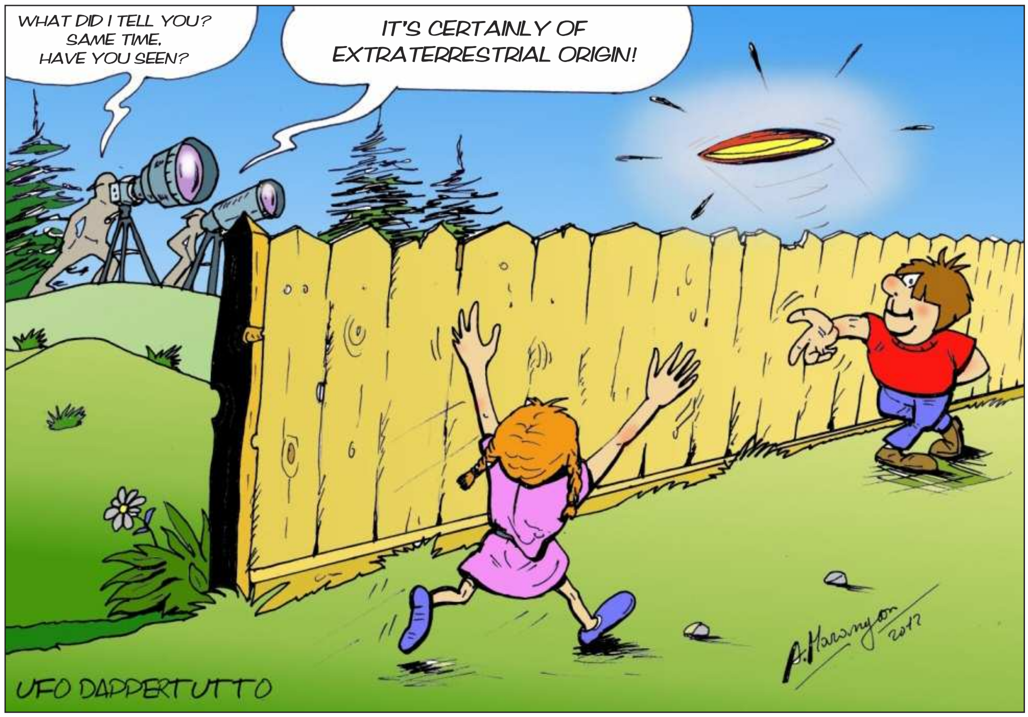
If the average distance between civilizations is so high as to make even the exchange of messages highly unlikely, it goes without

saying that hypothesizing interstellar travel aimed at fleeting close encounters is absurd. Let's see why, taking as an example a hypothetical technological civilization, developed in a planetary system just 200 light-years from us (we want to be extremely optimistic). The beings that make up that civilization represent the culmination of the evolution of life on that planet, they have probably overcome all the struggles for survival that existence entails, including planetary conflicts, natural catastrophes and adversities of every kind. Having finally reached high levels of social and scientific awareness, the Gotha of that planet decides to start an exploratory mission to another planet, about 200 light-years away, in whose atmosphere the markers that indicate the beginning of possible industrialization are increasing. The other planet is obviously the Earth, which the aliens see as it was in the early nineteenth century. However advanced that alien civilization might be, even the fastest of their spaceships take many centuries to reach the Earth, which means dedicating entire generations to that mission, both on the mother planet and onboard the spaceships (if inhabited). After all these efforts, without telling us and without

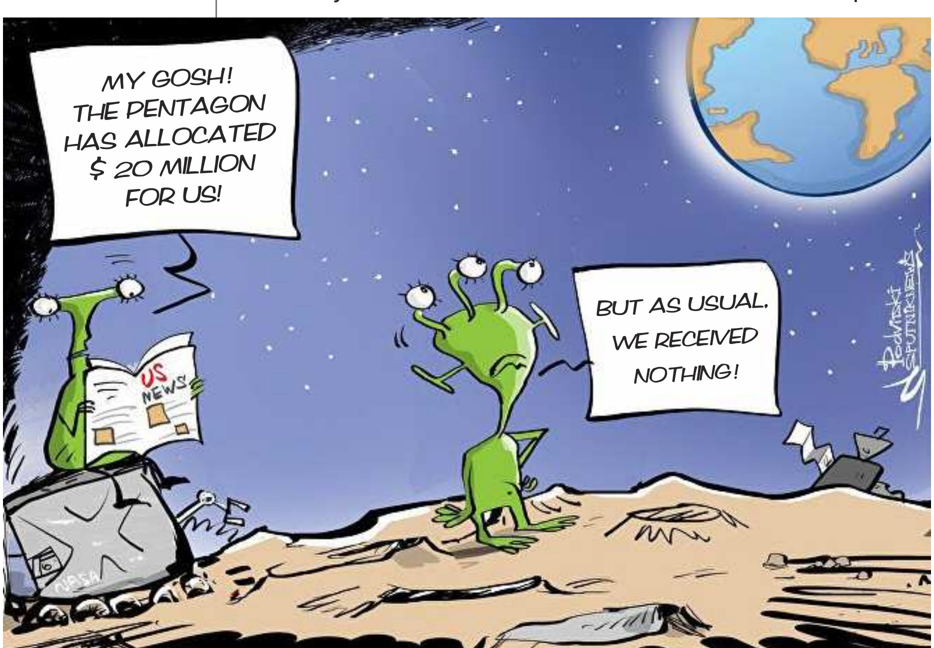


knowing exactly what awaits them here, the aliens finally arrive and what do they do? They start playing with our planes and, once they land on the surface (let's give a little satisfaction even to contactees), instead of going to meet the top representatives of science and politics, they introduce themselves to the first stranger who passes by and maybe abducts them.

Flying over the too-easy irony of committing a civilization's resources to crop circles and cattle mutilation (we leave this task to the cartoons that accompany the text), we find it more useful to go back to the point where the aliens infer the beginning of our industrialization. Since their discovery of our 200-year-old industrialization only

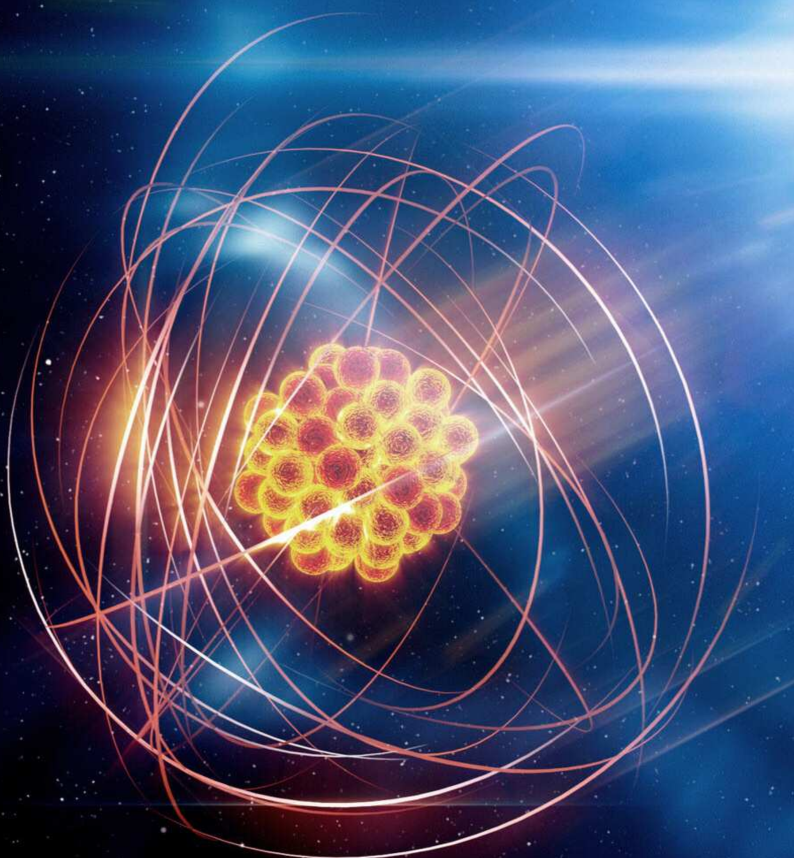


takes place "today" with the arrival of 200-year-old spectral signatures, they cannot already be here, because in reality they still have yet to take off. Possible civilizations placed at even greater distances could, at most, realize that there is life developing on Earth, but that probably no species has developed enough to become technological. So why go there, with all the sacrifices the journey entails? Summing up, those who see in, at least, a part of the UAPs the incursions of aliens must necessarily claim that they come from stars very close to us, a possibility that in the coming years the new telescopes that will become operational will be able to definitively exclude. It is infinitely unlikely that there is another technological civilization just around the corner to our house. So, if the laws of physics will not be revolutionized, in the next decade the acronyms UAP, UFO and their analogues may refer to everything except extraterrestrial visitors. In the meantime, everyone is free to continue believing in fairy tales. ■

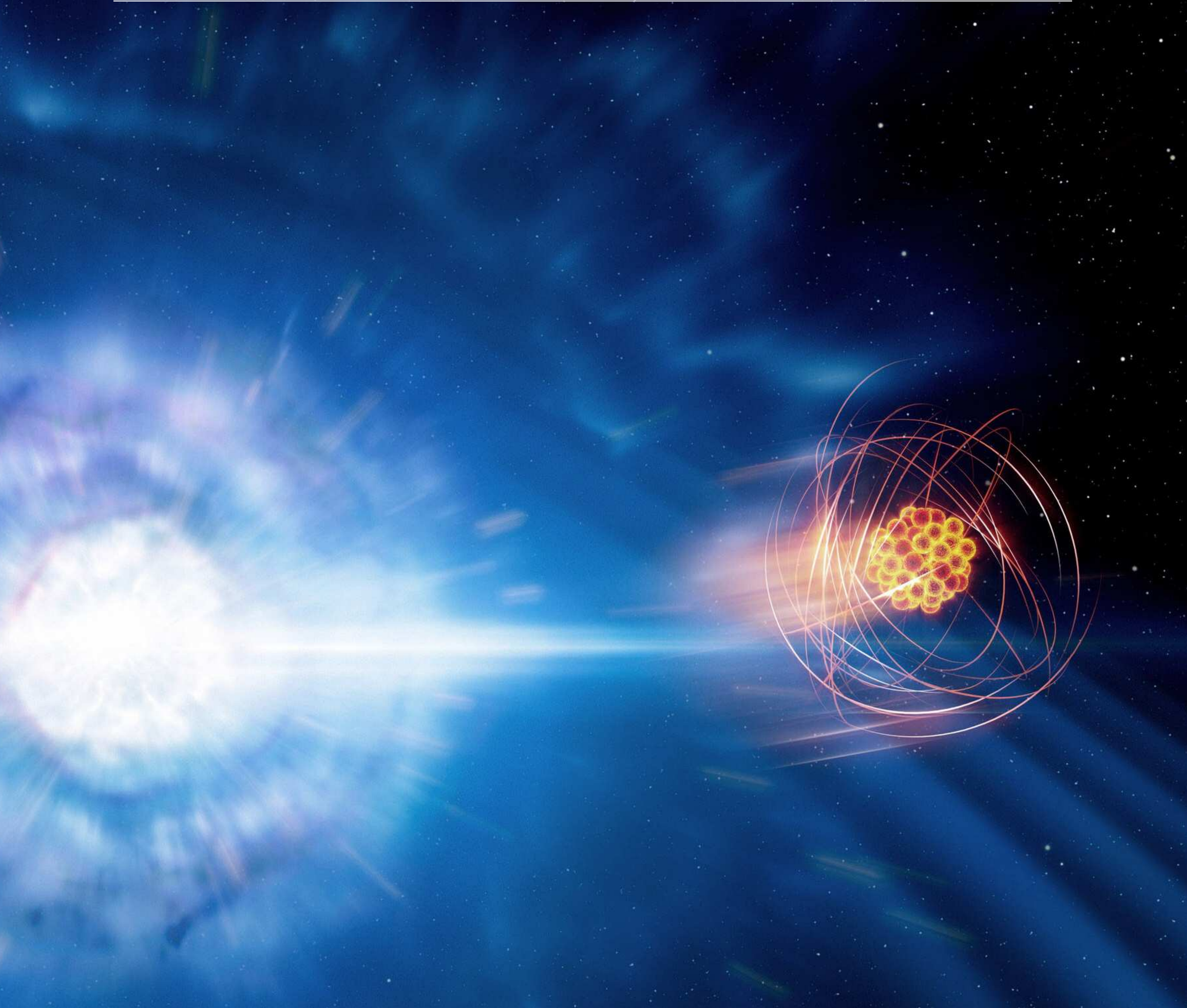


First identification of a heavy element born from neutron star collision

by ESO



In 2017, following the detection of gravitational waves passing the Earth, ESO pointed its telescopes in Chile, including the VLT, to the source: a neutron star merger named GW170817. Astronomers suspected that, if heavier elements did form in neutron star collisions, signatures of those elements could be detected in kilonovae, the explosive aftermaths of these mergers. This is what a team of European re-



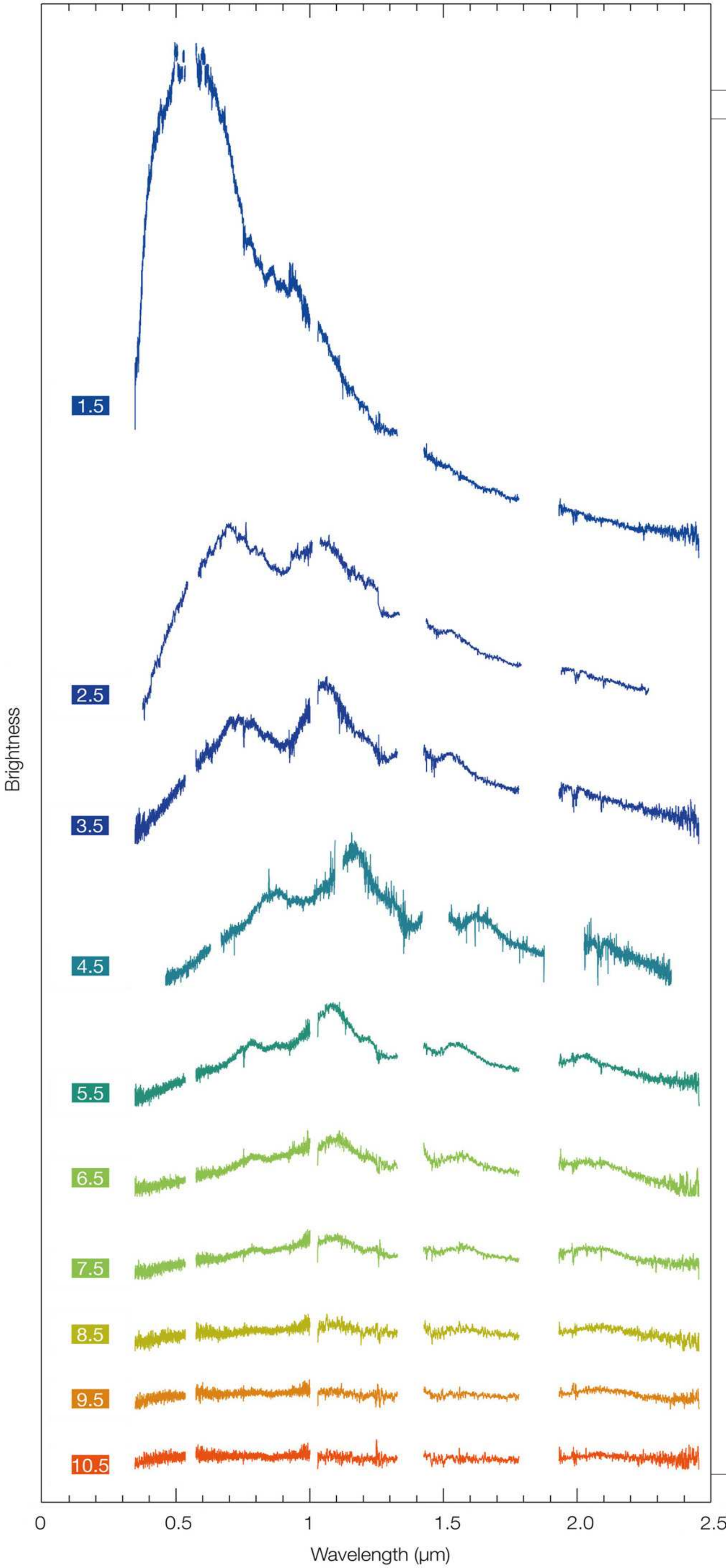
searchers has now done, using data from the X-shooter instrument on ESO's VLT.

Following the GW170817 merger, ESO's fleet of telescopes began monitoring the emerging kilonova explosion over a wide range of wavelengths. X-shooter in particular took a series of spectra from the ultraviolet to the near infrared.

Initial analysis of these spectra suggested the presence of heavy elements in the kilonova, but astronomers could not pinpoint individual elements until now.

"By reanalysing the 2017 data from the merger, we have now identified the signature of one heavy element in this fireball, strontium, proving that the collision of neutron stars creates this element in the Universe," says the study's lead author Darach Watson from the University of Copenhagen in Denmark.

A team of European researchers, using data from the X-shooter instrument on ESO's Very Large Telescope, has found signatures of strontium formed in a neutron-star merger. This artist's impression shows two tiny but very dense neutron stars at the point at which they merge and explode as a kilonova. In the foreground, we see a representation of freshly created strontium. [ESO/L. Calçada/M. Kornmesser]



This montage of spectra taken using the X-shooter instrument on ESO's Very Large Telescope shows the changing behaviour of the kilonova in the galaxy NGC 4993 over a period of 12 days after the explosion was detected on 17 August 2017. Each spectrum covers a range of wavelengths from the near-ultraviolet to the near-infrared and reveals how the object became dramatically redder as it faded. [ESO/E. Pian et al./S. Smartt & ePESSTO]

On Earth, strontium is found naturally in the soil and is concentrated in certain minerals. Its salts are used to give fireworks a brilliant red colour.

Astronomers have known the physical processes that create the elements since the 1950s. Over the following decades they have uncovered the cosmic sites of each of these major nuclear forges, except one. *"This is the final stage of a decades-long chase to pin down the origin of the elements,"* says Watson. *"We know now that the processes that created the elements happened mostly in ordinary stars, in supernova explosions, or in the outer layers of old stars. But, until now, we did not know the location of the final, undiscovered process, known as rapid neutron capture, that created the heavier elements in the periodic table."*

Rapid neutron capture is a process in which an atomic nucleus captures neutrons quickly enough to allow very heavy elements to be created. Although many elements are produced in the cores of stars, creating elements heavier than iron, such as strontium, requires even hotter environments with lots of free neutrons. Rapid neutron capture only occurs naturally in extreme environments where atoms are bombarded by vast numbers of neutrons. *"This is the first time that we can directly*

This wide-field image generated from the Digitized Sky Survey 2 shows the sky around the galaxy NGC 4993. This galaxy was the host to a merger between two neutron stars, which led to a gravitational wave detection, a short gamma-ray burst and an optical identification of a kilonova event. [ESO and Digitized Sky Survey 2]

associate newly created material formed via neutron capture with a neutron star merger, confirming that neutron stars are made of neutrons and tying the long-debated rapid neutron capture process to such mergers," says Camilla Juul Hansen from the Max Planck Institute for Astronomy in Heidelberg, who played a major role in the study. Scientists are only now starting to better understand neutron star mergers and kilonovae. Because of the limited understanding of these new phenomena and other complexities in the spectra that the VLT's X-shooter took of the explosion, astronomers had not been able to identify individual elements until now. *"We actually came up with the idea that we might be seeing strontium quite quickly after the event. However, showing that this was demonstrably the case turned out to be very difficult. This difficulty was due to our highly incomplete knowledge of the spectral appearance of the heavier elements in the periodic table,"* says University of Copenhagen researcher Jonatan Selsing, who was a key author on the paper. The GW170817 merger was the fifth detection of gravitational waves, made possible thanks to the NSF's Laser Interferometer Gravitational-Wave Observatory (LIGO) in the US and the Virgo Interferometer in Italy. Located in the galaxy NGC 4993, the merger was the first, and so far the only, gravitational wave source to have its visible counterpart detected by telescopes on Earth.

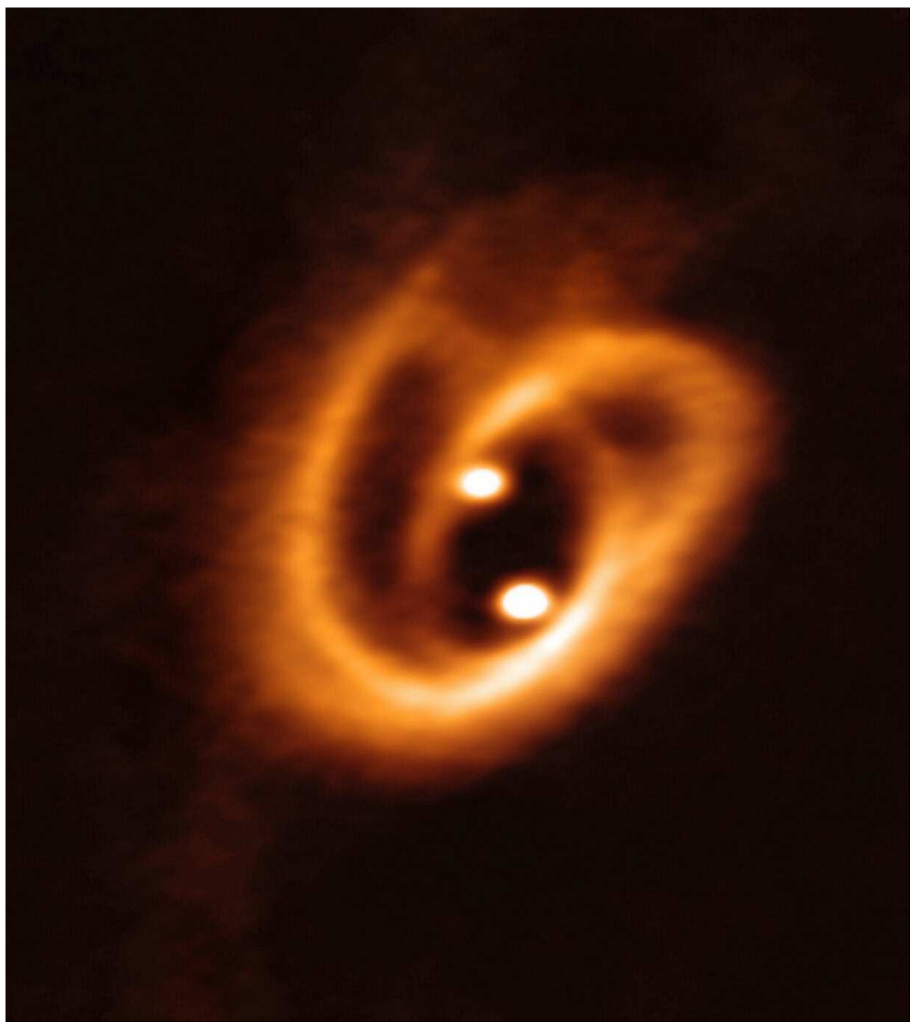
With the combined efforts of LIGO, Virgo and the VLT, we have the clearest understanding yet of the inner workings of neutron stars and their explosive mergers. ■

This artist's impression shows two tiny but very dense neutron stars merging and exploding as a kilonova. Such objects are the main source of very heavy chemical elements, such as gold and platinum, in the Universe. The detection of one element, strontium (Sr), has now been confirmed using data from the X-shooter instrument on ESO's Very Large Telescope. [ESO/L. Calçada]

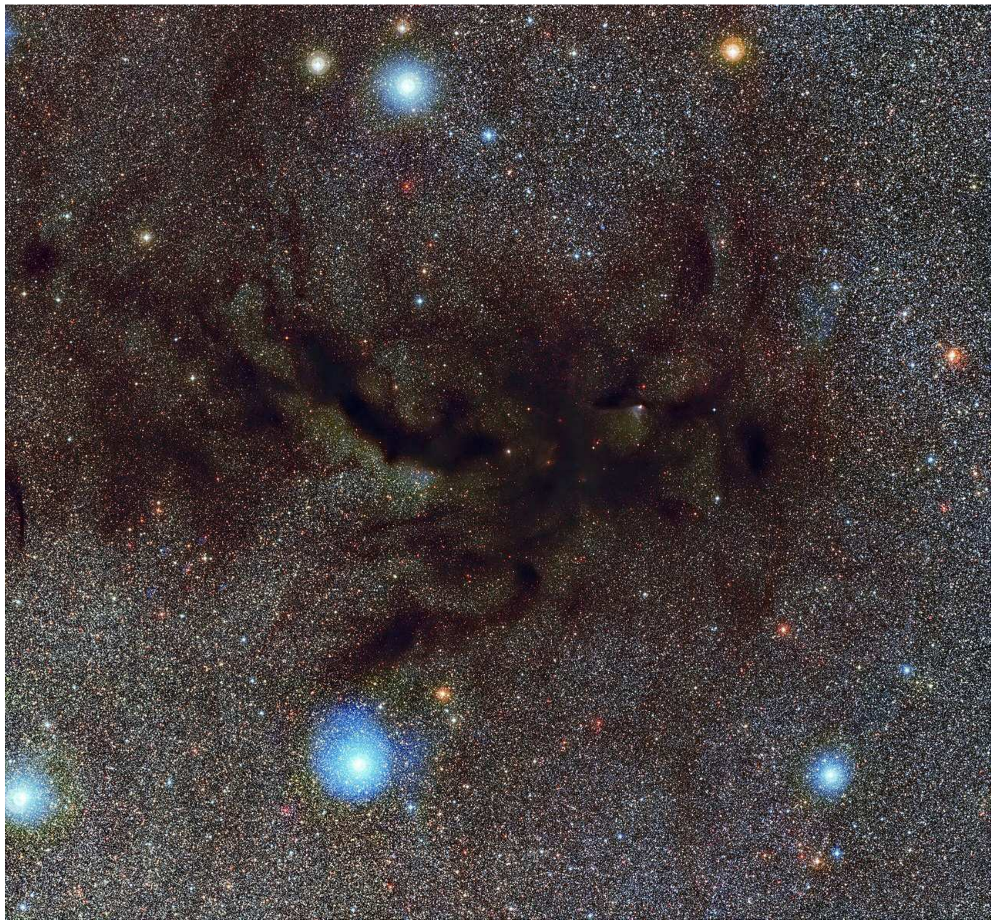
A cosmic pretzel

by ESO

Astronomers using ALMA have obtained an extremely high-resolution image showing two disks in which young stars are growing, fed by a complex pretzel-shaped network of filaments of gas and dust. Observing this remarkable phenomenon sheds new light on the earliest phases of the lives of stars and helps astronomers determine the conditions in which binary stars are born. The two baby stars were found in the [BHB2007] 11 system – the youngest member of a small stellar cluster in the Barnard 59 dark nebula, which is part of the clouds of interstellar dust called the Pipe nebula. Previous observations of this binary system showed the outer structure. Now, thanks to the high resolution of the Atacama Large Millimeter/submillimeter Array (ALMA) and an international team of astronomers led by scientists from the Max Planck Institute for Extraterrestrial Physics (MPE) in Germany, we can see the inner structure of this object. *"We see two compact sources that we interpret as circumstellar disks around the two young stars,"* explains Felipe Alves from MPE who led the study. A circumstellar disk is the ring of dust and gas that surrounds a young star. The star accrete matter from the ring to grow bigger. *"The size of each of these disks is similar to the asteroid belt*



The Atacama Large Millimeter/submillimeter Array (ALMA) captured this unprecedented image of two circumstellar disks, in which baby stars are growing, feeding with material from their surrounding birth disk. The complex network of dust structures distributed in spiral shapes remind of the loops of a pretzel. These observations shed new light on the earliest phases of the lives of stars and help astronomers determine the conditions in which binary stars are born. [ALMA (ESO/NAOJ/NRAO), Alves et al.]



This picture shows Barnard 59, part of a vast dark cloud of interstellar dust called the Pipe Nebula. This new and very detailed image of what is known as a dark nebula was captured by the Wide Field Imager on the MPG/ESO 2.2-metre telescope at ESO's La Silla Observatory. [ESO]

in our Solar System and the separation between them is 28 times the distance between the Sun and the Earth," notes Alves. The two circumstellar disks are surrounded by a bigger disk with a total mass of about 80 Jupiter masses, which displays a complex network of dust structures distributed in spiral shapes – the pretzel loops. *"This is a really important result,"* stresses Paola Caselli, managing director at MPE, head of the Centre of Astrochemical Studies and co-author of the study. *"We have finally imaged the complex structure of young binary stars with their feeding filaments connecting them to the disk in which they were born. This provides important constraints for current models of star formation."* The baby stars accrete mass from the bigger disk in two stages. The first stage is when mass is transferred to the individual circumstellar disks in beautiful twirling loops, which is what the new ALMA image showed. The data analysis also revealed that the less-massive but brighter circumstellar disk — the one in the lower part of the image — accretes more material. In the second stage, the stars accrete mass from their circumstellar disks. *"We expect this two-level accretion process to drive the dynamics of the binary system during its mass accretion phase,"* adds Alves. *"While the good agreement of these observations with theory is already very promising, we will need to study more young binary systems in detail to better understand how multiple stars form."*

This artistic animation shows two circumstellar disk orbiting each other and accreting gas and dust for their surrounding cloud. [ESO/L. Calçada]

VISTA unveils a new image of the Large Magellanic Cloud

by ESO

The Large Magellanic Cloud, or LMC, is one of our nearest galactic neighbors, at only 163,000 light-years from Earth. With its sibling the Small Magellanic Cloud, these are among the nearest dwarf satellite galaxies to the Milky Way. The LMC is also the home of various stellar conglomerates and is an ideal laboratory for astronomers to study the processes that shape galaxies. ESO's VISTA telescope, has been observing these two galaxies for the last decade. The image presented today is the result of one of the many surveys that astronomers have performed with this telescope. The main goal of the VISTA Magellanic Clouds (VMC) Survey has been to map the star formation history of the Large and Small Magellanic Clouds, as well as their three-dimensional structures.

VISTA was key to this image because it observes the sky in near-infrared wavelengths of light. This allows it to see through clouds of dust that obscure parts of the galaxy. These clouds block a large portion of visible light but are transparent at the longer wavelengths VISTA was built to observe. As a result, many more of the individual stars populating the centre of the galaxy are clearly visible. Astronomers analysed about 10 million individual stars in the Large Magellanic Cloud in detail and determined their ages using cutting-edge stellar models. They found that younger stars trace multiple spiral arms in this galaxy.

For millennia, the Magellanic Clouds have fascinated people in the Southern Hemisphere, but they were largely unknown to Europeans until the Age of Discovery. The name we use today harkens back to the explorer Ferdinand Magellan, who 500 years ago began the first circumnavigation of the Earth. The records the expedition brought back to Europe revealed many places and things to Europeans for the first time. The spirit of exploration and discovery is ever more live today in the work of astronomers around the world, including the VMC Survey team whose observations led to this stunning image of the LMC.

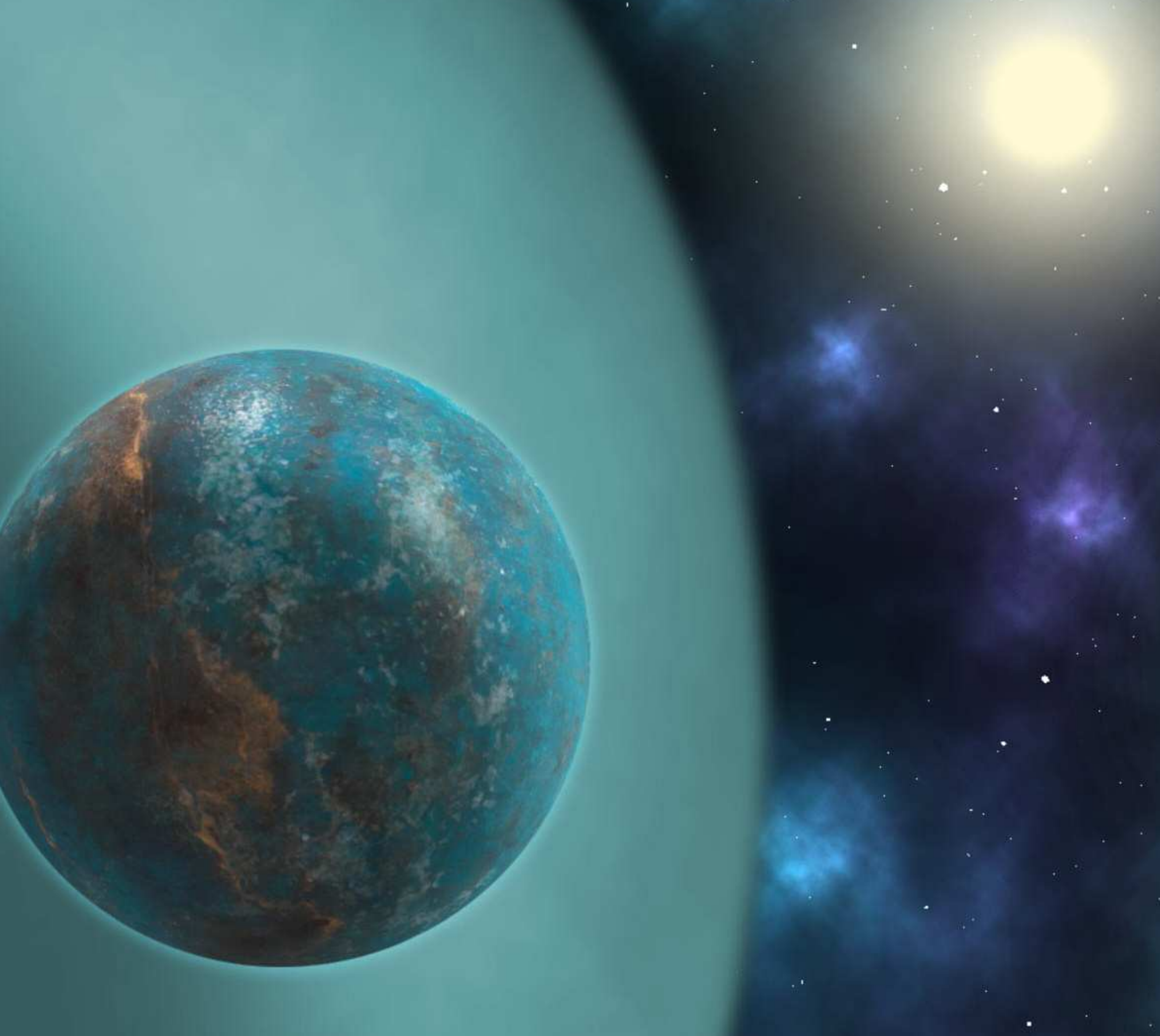
ESO's VISTA telescope reveals a remarkable image of the Large Magellanic Cloud, one of our nearest galactic neighbours. VISTA has been surveying this galaxy and its sibling the Small Magellanic Cloud, as well as their surroundings, in unprecedented detail. This survey allows astronomers to observe a large number of stars, opening up new opportunities to study stellar evolution, galactic dynamics, and variable stars. [ESO/VMC Survey]

A flexible concept of the habitability of other worlds

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

Science fiction has described uncountable possible extraterrestrial environments and imaginable forms of alien life. But there is also the unimaginable, that is, all that is not conditioned by our knowledge. When we think of a habitable world, we inevitably transfer to it a few things familiar to us, but some scenarios could be entirely inconceivable to us and our idea of habitability may prove to be very limited.



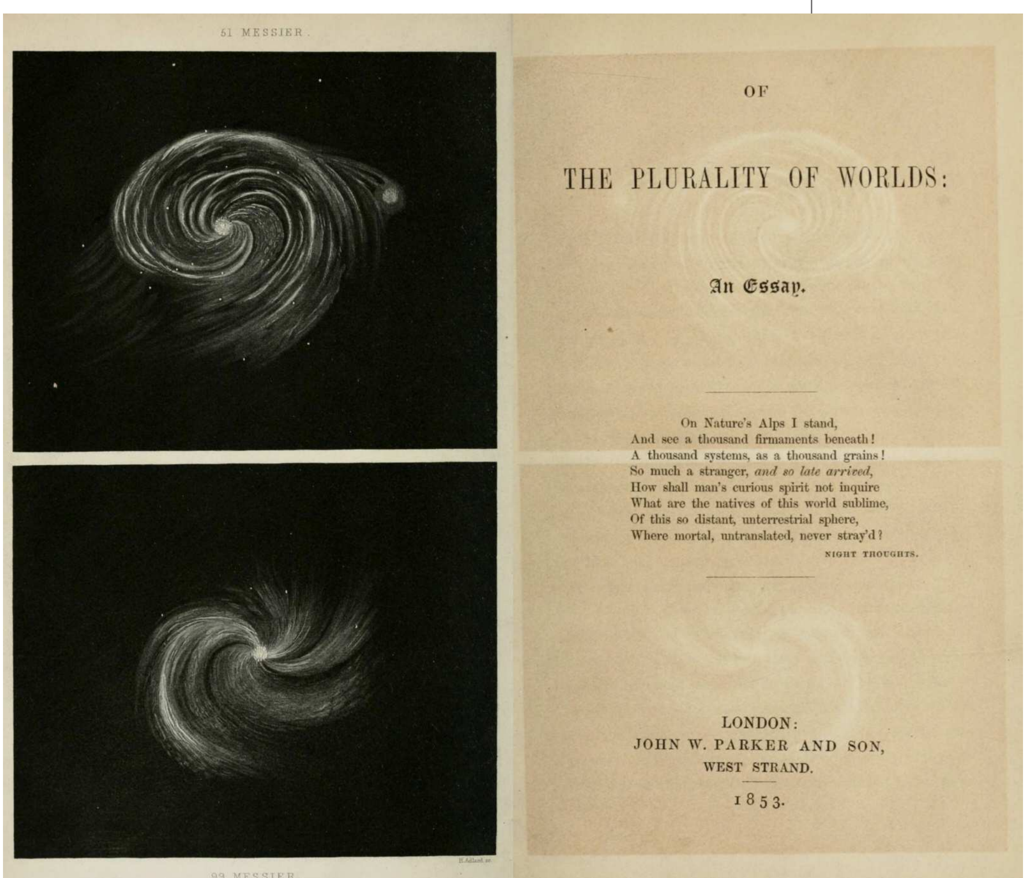
A hypothetical superhabitable world could be an Earth-sized moon orbiting a gas giant, a scenario like the one depicted here.

The search for Earth-like planets has been a significant theme in astronomy for several years now, and will become increasingly dominant in the near future. Perhaps it is not too far-fetched to imagine that, in a few decades, astronomy research will be divided into two major sectors: planetology on one side and "all the rest" on the other. Something similar already happened in the 70s-80s, when the exploration of the planets of our own Solar System stole the show from all the other branches of astronomy, the latter limited by instruments much more akin to those of forty years prior than those of forty years later. At that time, scientists could only speculate on the existence of planets around other stars. Today, we know that there are certainly thousands of

It is clear that these scenarios are extremely different – nevertheless, they are sometimes confused. It is understandable that "habitable zone" does not automatically mean "habitability." In fact, there are a number of factors that determine whether a world can be habitable or not. The fact of orbiting in the habitable zone of a star is only one of them, and it is not even an essential factor, because there can exist worlds capable of hosting life even outside the habitable zone of a star.
Although the concept of habitability related to circumstellar space seems to belong to modern science, it has no very recent origin. The first mention of a "temperate zone of the Solar System" dates back to 1853 and is found in the essay *Of the plurality of worlds*, by the eclectic English Reverend William Whewell.

On the left, a portrait of William Whewell, the philosopher-scientist who first mentioned in an essay (frontispiece below) the temperate zone of the Solar System.

them at relatively short distances from the Sun and that there are probably billions of them in the whole Milky Way, a small percentage of which could host life as we know it. This last phrase, dutifully repeated as a mantra in all astrobiology texts, leads us to the concept of "habitability," a term that appears to be very precise, but that when applied to extrasolar planets takes on an elasticity that makes it, to say the least, vague. What do we mean by "habitable planet"? Perhaps a copy of the Earth, where humans could live without encountering excessive adaptation difficulties? Or a planet on which at least some forms of terrestrial life, perhaps the simplest, could proliferate? Or again, a planet that simply orbits in the habitable zone of a star?



OF

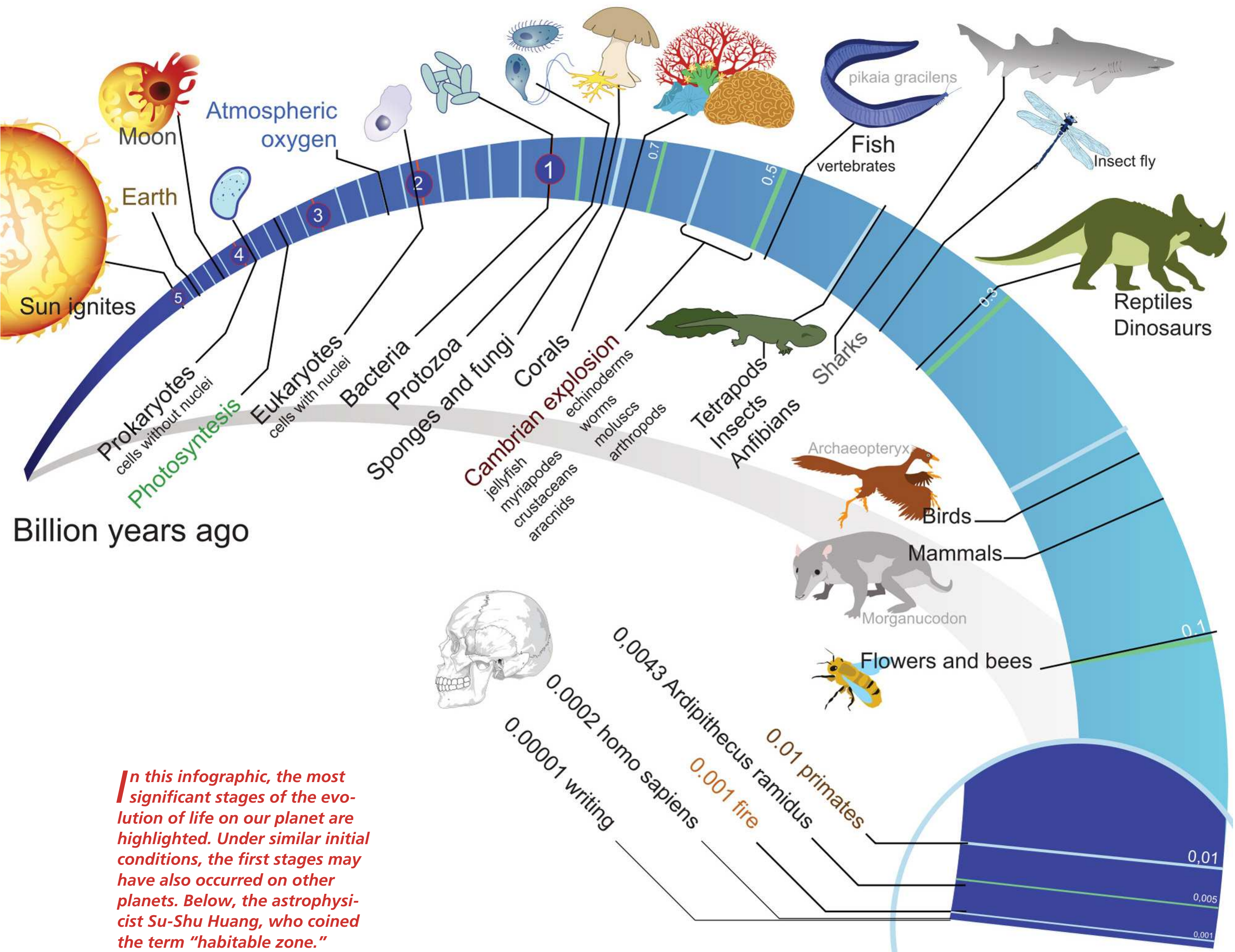
THE PLURALITY OF WORLDS:

An Essay.

On Nature's Alps I stand,
And see a thousand firmaments beneath!
A thousand systems, as a thousand grains!
So much a stranger, *and so late arrived*,
How shall man's curious spirit not inquire
What are the natives of this world sublime,
Of this so distant, unterrestrial sphere,
Where mortal, untranslated, never stray'd?

NIGHT THOUGHTS.

LONDON:
JOHN W. PARKER AND SON,
WEST STRAND.
1853.



In this infographic, the most significant stages of the evolution of life on our planet are highlighted. Under similar initial conditions, the first stages may have also occurred on other planets. Below, the astrophysicist Su-Shu Huang, who coined the term "habitable zone."

Even at that time, it was clear that the natural starting point for characterizing the habitability of a world is the calculation of the energy received from its star. A little over a century later, an American astrophysicist of Chinese descent, Su-Shu Huang, proposed at a conference of the Astronomical Society of the Pacific the term "habitable zone" to define the region around the star where liquid water can exist on the surface of planets within it. Huang considered a fundamental factor to establish the duration of the habitability of planets, namely, the time of permanence of the associated stars in the main sequence. Indeed, the more this time is extended, the greater the chance that life may appear and evolve.

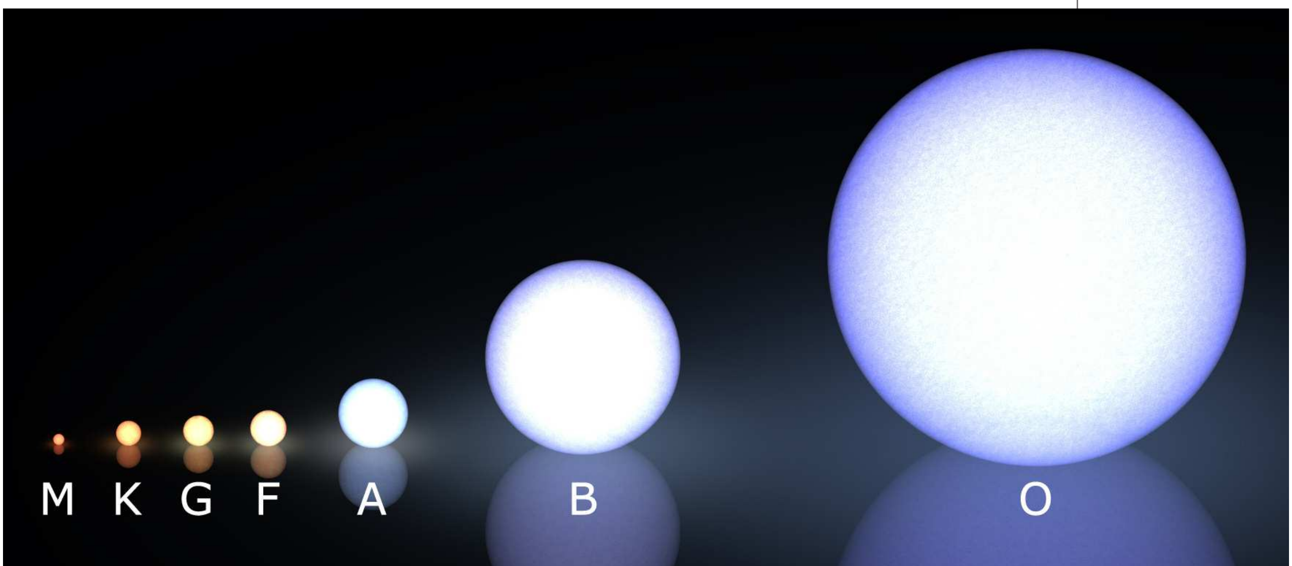
The fossil and chemical indicators tell us that life on Earth appeared about one billion years after the formation of the planet, and that, to reach an important biodiversity comparable to the current one, terrestrial life took another 3 billion years to evolve. It is possible that this timing is also valid for other planetary systems, but the clear dependency is on the type of star, which may not necessarily be identical to the Sun. Appreciably more massive stars have a permanence time in the main sequence shorter than that necessary for life to transform the environment that hosts them, at least up to being detectable by other worlds.

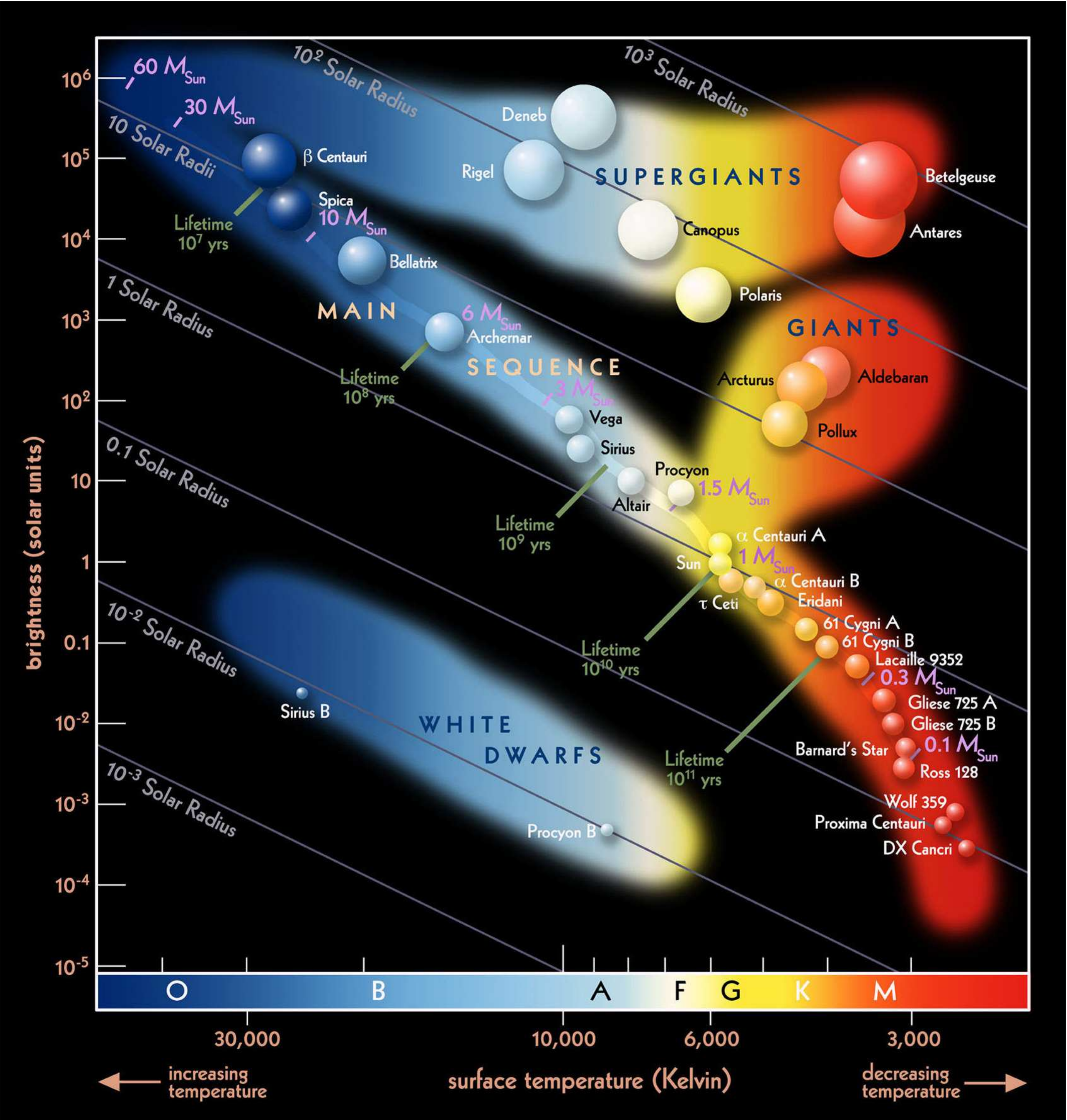

Therefore, even if a star just 1.5 times more massive than the Sun (the F-type upper mass limit) can remain stable for about 4 billion years, that still may not be sufficient to develop an Earth-type biosphere. On the contrary, significantly less massive stars, such as K-type stars (from 0.45 to 0.8 solar masses), can guarantee a habitable zone for tens of billions of years, allowing the development of life forms perhaps unimaginable. Planets and large moons orbiting these stars are likely to fall into the category of so-called "superhabitable worlds," an expression coined in 2013 by René Heller (Max Planck Institute for Solar System Research) and John Armstrong (Weber State University), to indicate those planetary bodies that, due to their physical and dynamic features, can be even more habitable than the Earth.

Because of our inveterate anthropocentrism, we take for granted that Earth is the best place in the universe to live. This is true only for the living species on our planet, which over billions of years have evolved by adapting to any available habitats, sometimes even transforming entire ecosystems to their own advantage. It is therefore unlikely to find another planet that is equally well-suited to us. But this does not mean that the Earth is the "best" possible planet for other potential forms of life: if Earth had had other physical and dynamic features, perhaps life would have been even more luxuriant and diversified.

Still, in 2013, a team of researchers led by astrobiologist Ravi Kumar Kopparapu (NASA Goddard Space Flight Center) calculated that the habitable zone around stars very similar to the Sun extends, on average, between 0.99 and 1.7 astronomical units (in literature, we also find markedly different values). This is to say that the Earth orbits very close to

René Heller and John Armstrong, the first astronomers to propose the concept of "superhabitable worlds." Below, a comparison of the average sizes of stars of different spectral classes. The Sun is a G-type star, while K-type stars are those believed to offer the best conditions for habitability.





The Hertzsprung-Russell diagram. Terrestrial life can evolve for billions of years only in the lower part of the main sequence.

the inner limit – any closer and a runaway greenhouse effect would be activated. Such an inner position in the habitable zone will result in our planet becoming unlivable long before the Sun completes its transit through the main sequence. Indeed, our star will gradually become hotter, and researchers estimate that within 1-2 billion years the oceans will evaporate.

Another Earth, a little less close to another Sun, would already be superhabitable. It would be even more so if it had a larger surface area than our planet, with even more surface water collected in a greater number

of lakes, seas and oceans, on average less deep than ours. It goes without saying that, in order to have a larger surface, a planet must be bigger and therefore more massive – but there is obviously a limit to the size. Planets more massive than the Earth develop much higher pressures at the mantle level, which increases viscosity, hampering (or making impossible) plate tectonics, a geological process essential to the redistribution of continents and oceans, and to the regen-

eration of substances essential to life. A study carried out a few years ago (Noack and Breuer, 2011) suggests that plate tectonics is active within planets between 1 and 5 Earth masses, and is particularly efficient near 2 Earth masses; beyond this value, the crustal movements start to slow down. A planet twice as massive as Earth, orbiting in the habitable zone of a star like our own or smaller, would probably be superhabitable. Moreover, the superficial gravity could be identical to what we experience daily if that planet had a diameter 1.4 times that of the Earth.

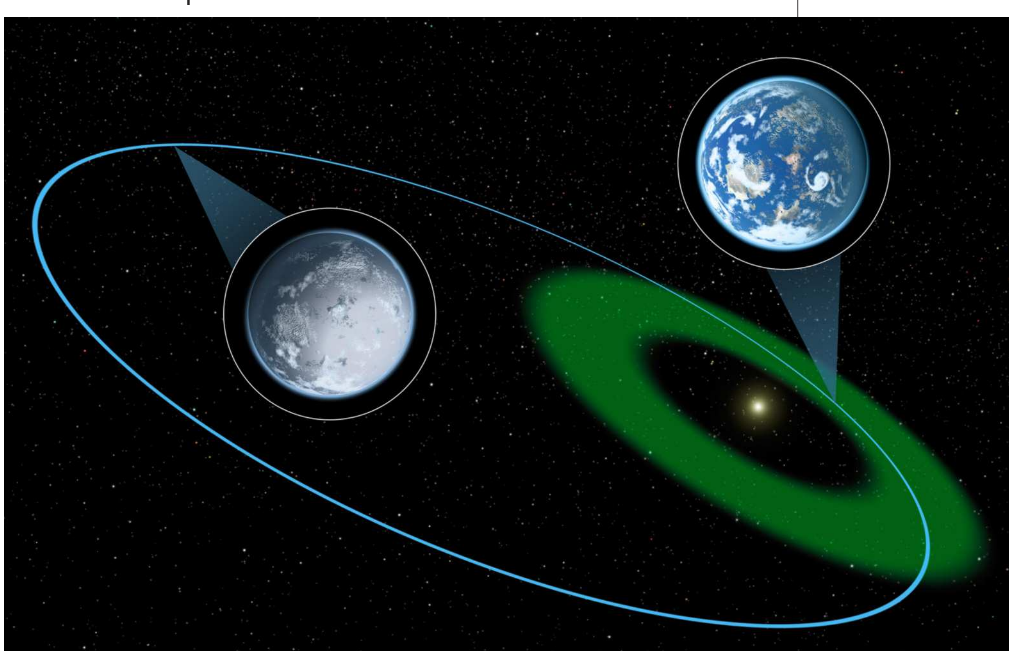
According to Heller and Armstrong, the rotating core of a planet of that size would also

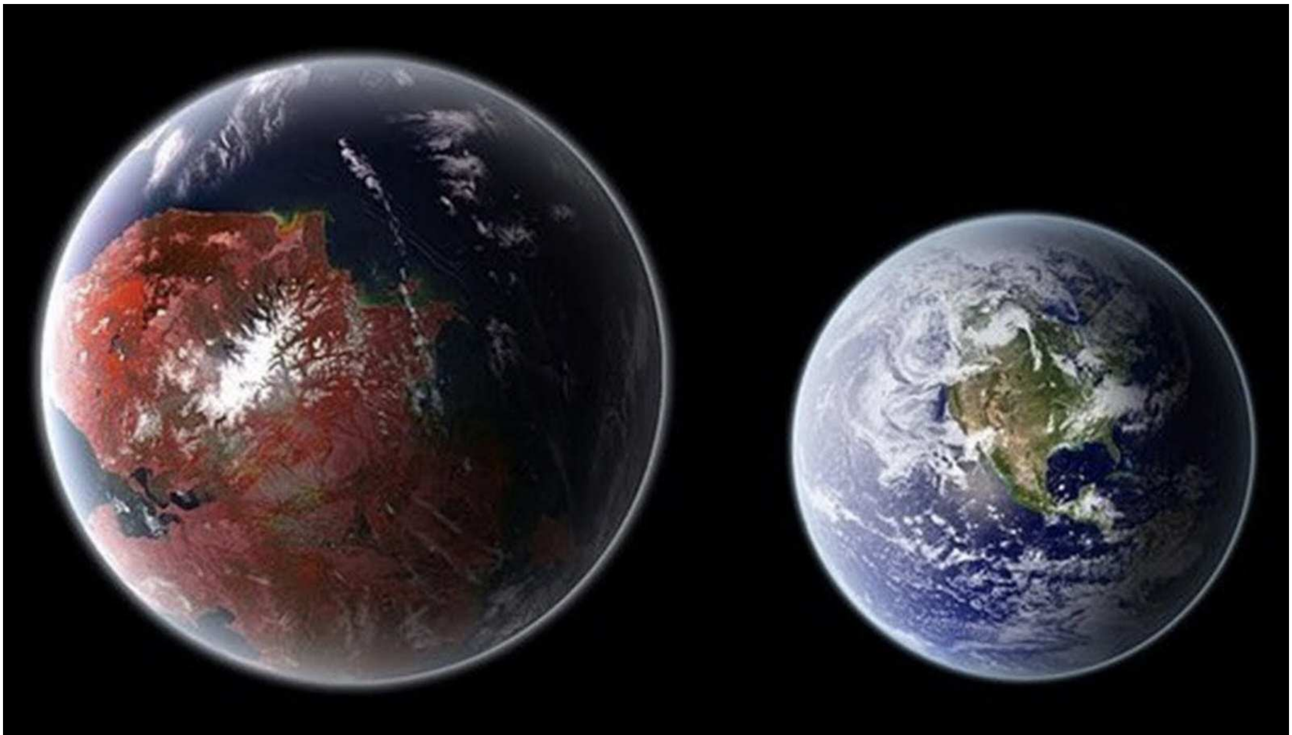
A hypothetical terrestrial-type landscape on a gas giant's moon. These planets have their own habitable zone, which in particular cases can be complementary with or independent of the stellar one. In the video to the side, the process of plate tectonics, considered essential to the evolution of life.

According to the astrobiologist Ravi Kumar Kopparapu, here photographed during an interview with CBS, the Earth orbits almost in the inner edge of the habitable zone of the Sun. Below is shown the case of a planet with an orbit that only partially enters the habitable zone of its star.

more efficiently generate a magnetic field than that produced by the Earth's core, protecting the surface from cosmic and stellar rays. This shielding, together with a foreseeably thicker atmosphere, would allow for the less-threatened diffusion of life compared to the same proliferation that happened on Earth. In this regard, however, we must point out that, according to some researchers, biodiversity on our planet has been promoted by mutations occurring in certain organisms following peaks of space radiation. If things really went that way, a magnetosphere and an atmosphere that are too protective could hinder the sudden appearance of new species.

Just as there is an upper limit to the size of a planet for it to be habitable, does a lower limit perhaps exist? Of course it does, and according to recent work by Constantin Arnscheidt (Harvard University) and colleagues, that limit approaches just 3% of the Earth's mass in the case where the atmosphere is subjected to a greenhouse effect that expands it enough to balance heat absorption and radiation. It is clear that we are consid-





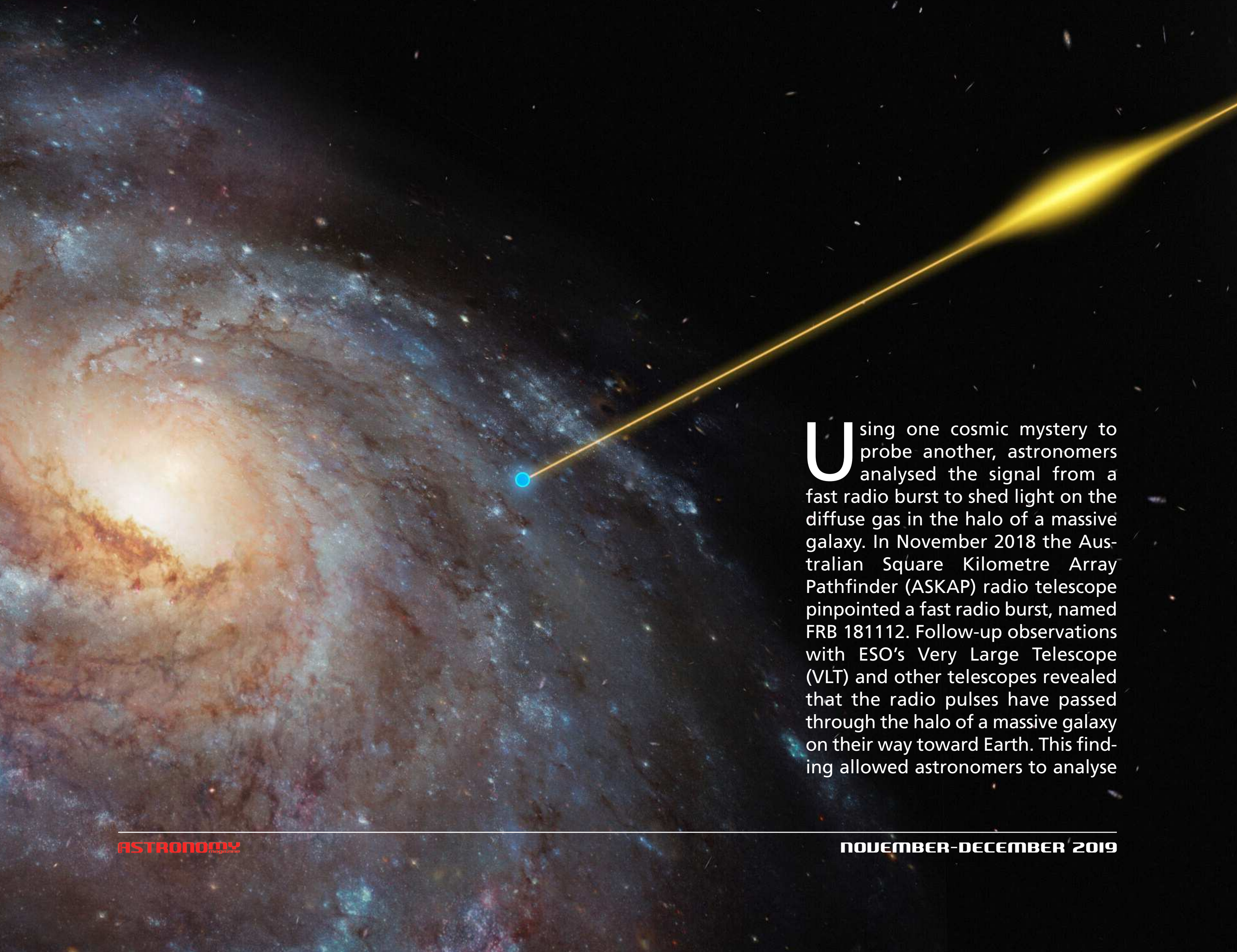
A planet twice as massive as Earth, 40% larger by volume and placed at the right distance from its solar-type star, could offer life forms more hospitable conditions than those found on Earth.

ering an extreme case under such conditions, showing clearly how the concept of "habitability" may be very loosely tied to that of "habitable zone." Other borderline cases are represented by planets in remarkable elliptical orbits, which, although moving mainly outside the habitable zone, could be heated by tidal forces exerted by their star. But the most interesting scenario is perhaps that of the great moons, which can be habitable regardless of their location in the habitable zone of a star thanks largely to the heat produced by the gravitational tides driven by their planet. Imagine a moon as big as Earth in orbit around a planet the size of Jupiter, both about 1 AU from a Sun-like star. If the moon moves in an orbit as wide as at least 20 times the planet's radius, it is the star that provides it with all the energy needed to be habitable. The relevance of the planet as a source of reflected starlight, residual thermal emission, and even tidal heating for providing energy to drive surface processes on the moon is, in this scenario, marginal. However, if we move the moon to an orbit closer to the planet, the thermal contributions of the latter, combined with those of the star, can become significant enough to make the moon uninhabitable. If we now imagine pushing the system into increasingly distant regions of the stellar habitable zone, we find locations where the closely-placed moon will once again be habitable due to the decreasing supply of stellar heat. In extreme cases, even a moon-planet system located outside the habitable zone can offer habitable conditions if the two bodies are close enough to each other to keep water liquid on the surface of the moon. In a sense, gas giants away from the habitable stellar zone have their own planetary habitable zone.

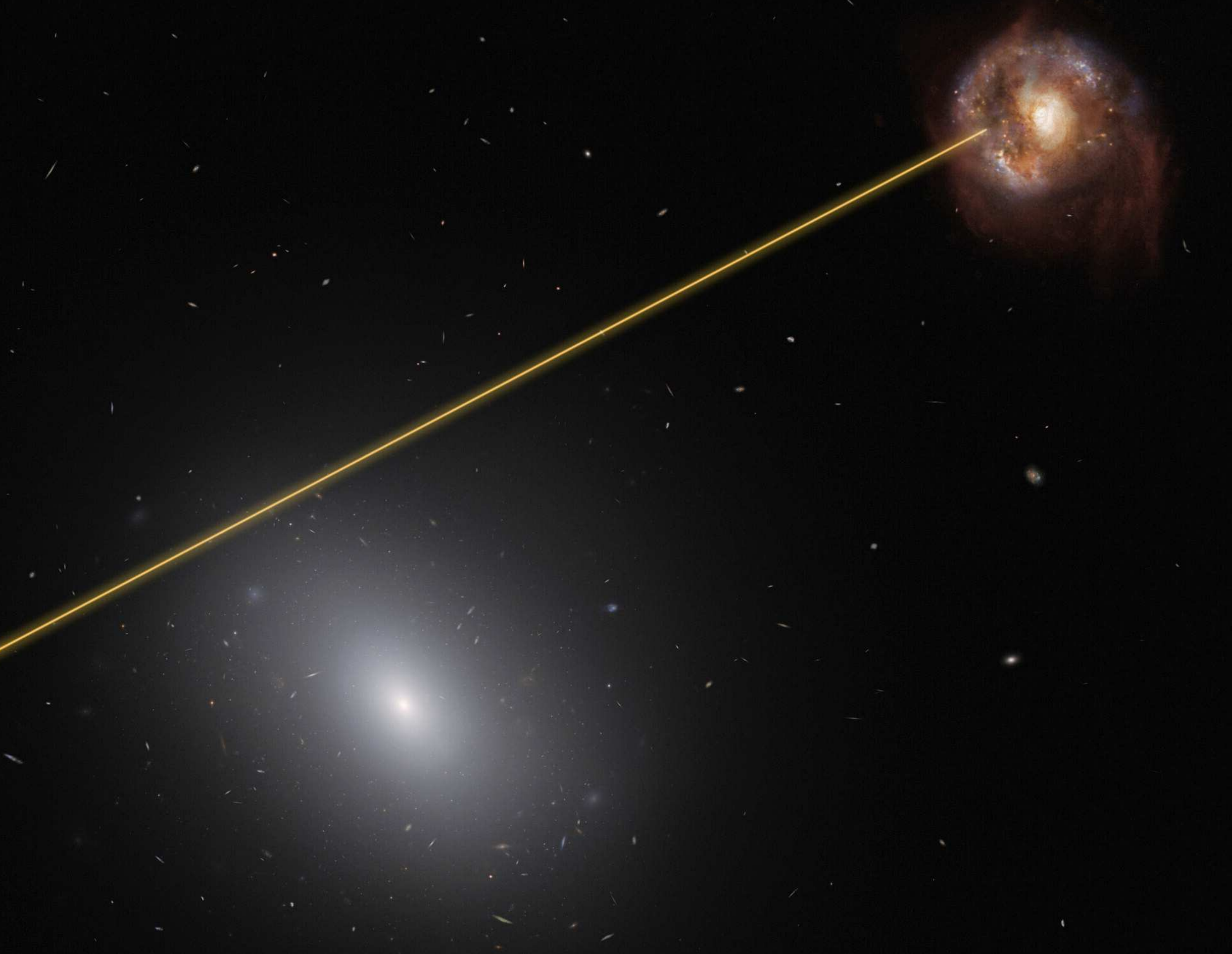
From the different scenarios so far presented (and they are just some of those possible), all the elasticity within the concept of habitability emerges, both when used to define a circumstellar region and to label a planet. The existence of superhabitable worlds and life forms far more advanced than terrestrial ones is likely. Despite this, the yearning to find something very similar to our reality is still irresistible. ■

Enigmatic radio burst illuminates a galaxy's tranquil halo

by ESO



Using one cosmic mystery to probe another, astronomers analysed the signal from a fast radio burst to shed light on the diffuse gas in the halo of a massive galaxy. In November 2018 the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope pinpointed a fast radio burst, named FRB 181112. Follow-up observations with ESO's Very Large Telescope (VLT) and other telescopes revealed that the radio pulses have passed through the halo of a massive galaxy on their way toward Earth. This finding allowed astronomers to analyse

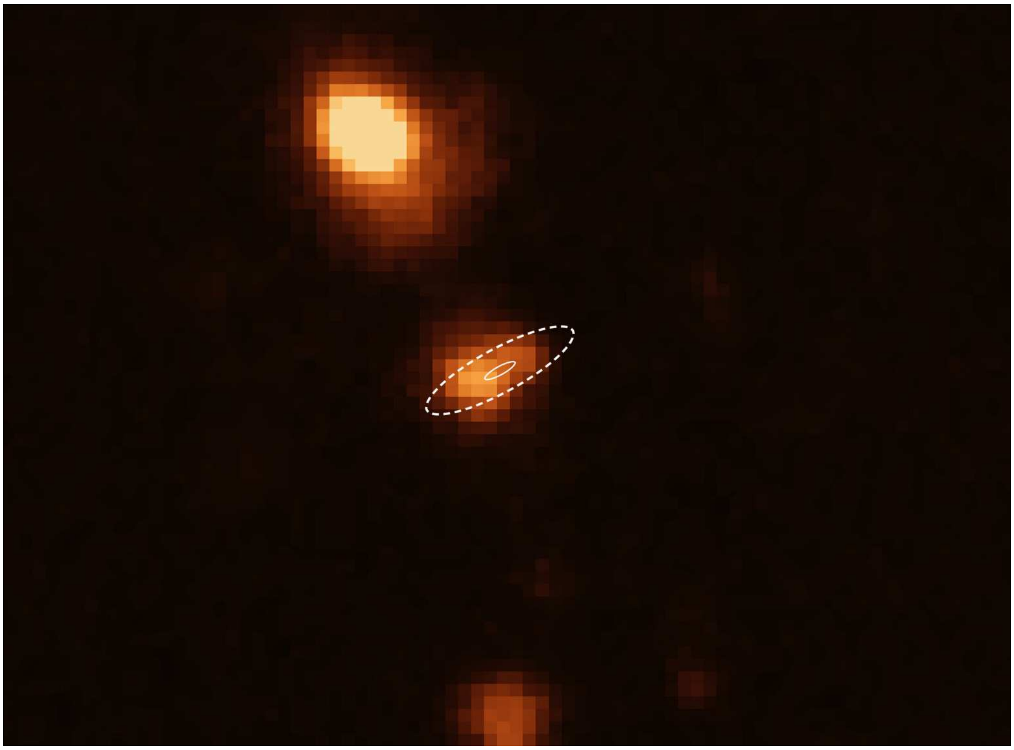


the radio signal for clues about the nature of the halo gas. *"The signal from the fast radio burst exposed the nature of the magnetic field around the galaxy and the structure of the halo gas. The study proves a new and transformative technique for exploring the nature of galaxy halos,"* said J. Xavier Prochaska, professor of astronomy and astrophysics at the University of California Santa Cruz and lead author of a paper presenting the new findings published today in the journal *Science*.

Astronomers still don't know what causes fast radio bursts and only recently have been able to trace some of these very short, very bright radio signals back to the galaxies in which they originated. *"When we overlaid the radio and optical images, we could see straight away that the fast radio burst pierced the halo of this coincident foreground galaxy and, for the first time, we had a direct way of investigating the otherwise invisible matter surrounding this galaxy,"* said coauthor Cherie Day, a PhD student at Swinburne University of Technology, Australia.

A galactic halo contains both dark and ordinary – or baryonic – matter

This artist's impression represents the path of the fast radio burst FRB 181112 traveling from a distant host galaxy to reach the Earth. FRB 181112 was pinpointed by the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope. Follow-up observations with ESO's Very Large Telescope (VLT) revealed that the radio pulses have passed through the halo of a massive galaxy on their way toward Earth. This finding allowed astronomers to analyse the radio signal for clues about the nature of the halo gas. [ESO/M. Kornmesser]



Soon after the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope pinpointed a fast radio burst, named FRB 181112, ESO's Very Large Telescope (VLT) took this image and other data to determine the distance to its host galaxy (FRB 181112 location indicated by the white ellipses). The analysis of these data revealed that the radio pulses have passed through the halo of a massive galaxy (at the top of the image) on their way toward Earth. [ESO/X. Prochaska et al.]

that is primarily in the form of a hot ionised gas. While the luminous part of a massive galaxy might be around 30 000 light years across, its roughly spherical halo is ten times larger in diameter. Halo gas fuels star formation as it falls towards the centre of the galaxy, while other processes, such as supernova explosions, can eject material out of the star-forming regions and into the galactic halo. One reason astronomers want to study the halo gas is to better understand these ejection processes which can shut down star formation.

"This galaxy's halo is surprisingly tranquil," Prochaska said. *"The radio signal was largely unperturbed by the galaxy, which is in stark contrast to what previous models predict would have happened to the burst."*

The signal of FRB 181112 was comprised of a few pulses, each lasting less than 40 microseconds (10 000 times shorter than the blink of an eye). The short duration of the pulses puts an upper limit on the density of the halo gas because passage through a denser medium would broaden the duration of the radio signal. The researchers calculated that the density of the halo gas must be less than 0.1 atoms per cubic centimeter (equivalent to several hundred atoms in a volume the size of a child's balloon).

"Like the shimmering air on a hot summer's day, the tenuous atmosphere in this massive galaxy should warp the signal of the fast radio burst. Instead we received a pulse so pristine and sharp that there is no signature of this gas at all," said coauthor Jean-Pierre Macquart, an astronomer at the International Center for Radio Astronomy Research at Curtin University, Australia.

The study found no evidence of cold turbulent clouds or small dense clumps of cool halo gas. The fast radio burst signal also yielded information about the magnetic field in the halo, which is very weak—a billion times weaker than that of a refrigerator magnet.

At this point, with results from only one galactic halo, the researchers cannot say whether the low density and low magnetic field strength they measured are unusual or if previous studies of galactic halos have overestimated these properties.

Prochaska said he expects that ASKAP and other radio telescopes will use fast radio bursts to study many more galactic halos and resolve their properties.

"This galaxy may be special," he said. *"We will need to use fast radio bursts to study tens or hundreds of galaxies over a range of masses and ages to assess the full population."*

Optical telescopes like ESO's VLT play an important role by revealing how far away the galaxy that played host to each burst is, as well as whether the burst would have passed through the halo of any galaxy in the foreground.

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