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Giant comet found in outer solar system

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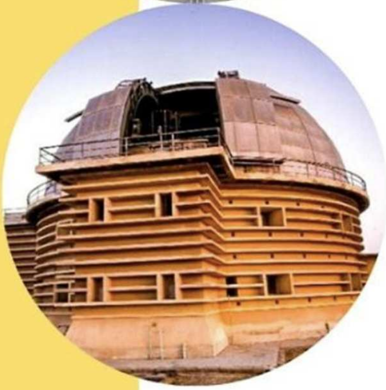

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ASTRONOMY magazine

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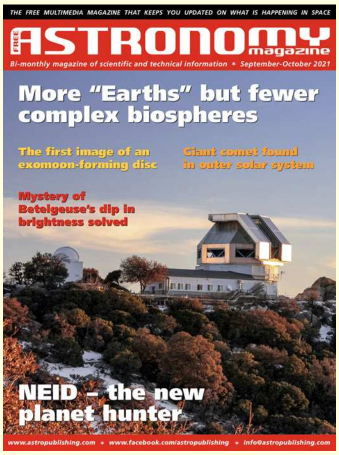

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More “Earths” but fewer complex biospheres

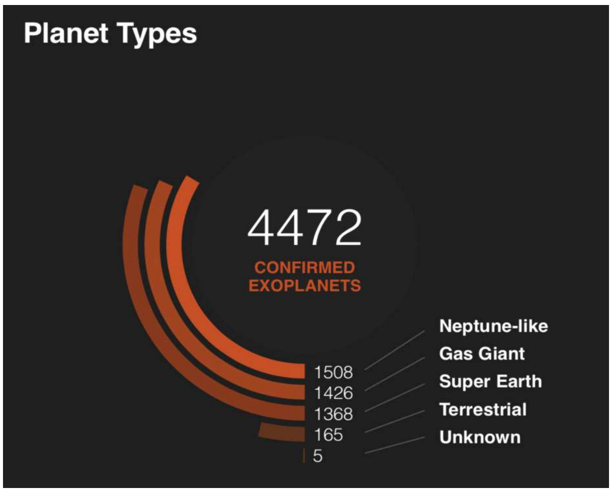
by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

This illustration depicts a planet partially hidden in the glow of its host star and a nearby companion star. After examining a number of binary stars, astronomers concluded that Earth-sized planets in many two-star systems may go unnoticed in transit research. The light from the second star makes it more difficult to detect changes in the host star’s light as the planet passes in front of it. [International Gemini Observatory/NOIRLab/NSF/AURA/J. da Silva (Spaceengine)]

In recent months, several published studies have significantly expanded what we know about Earth-sized planets and their potential capacity to host life as we know it. One of the biggest unknowns concerning Earth-like (but not necessarily habitable) planets is their number within the Milky Way. Current estimates are distributed over a very wide range that also varies depending on the type of the host star.

By considering stars slightly smaller to slightly larger than the Sun, we find estimates ranging from 0.02 to over one potentially habitable planet per system. It is difficult to determine which of these two extreme values is closest to reality, as the smaller planets are less easy to detect, especially with the most prolific method used by astronomers - transits across their stellar discs. A planet comparable in size to the Earth, seen as it transits in front of a star similar to the Sun, reduces the star's brightness by just about 1/10,000, a value that is close to the detection limits of the small space telescopes currently used in these types of observations. Being able to observe planets even a little smaller than the Earth does not, however, mean being able to make a reliable projection of the number of existing Earth-sized planets. In fact, we know



This chart, updated as of August 20, 2021, tracks the current number of known planet discoveries beyond our solar system, sorted by type. Confirmed exoplanets have been validated by multiple observations. [NASA]

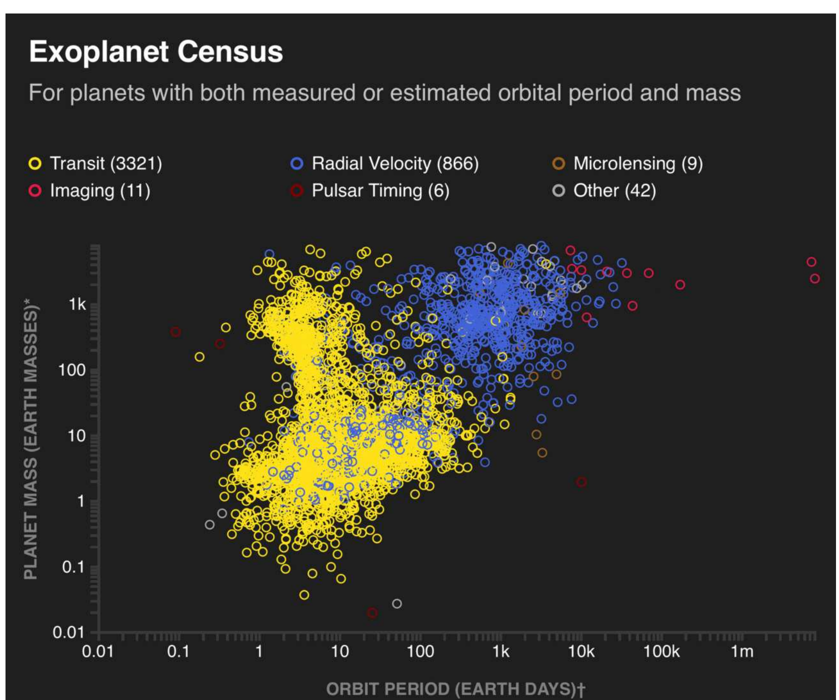
that at least half of all stars are in binary systems, containing a companion star to which a primary star is gravitationally linked. If the pair is far enough away from us as to be inseparable through the instrument observing them, then the combined light of the two stars could make imperceptible the transit of a planet otherwise visible if its host star were single. It is, therefore, likely that the number of Earth-sized planets is much higher than that estimated so far from the number of recorded transits.

For several years, astronomers have asked themselves two crucial questions: *"How many host stars are binary?"* and *"Are stars with planets equally likely to have a companion star or do companion stars affect the formation of planets?"*

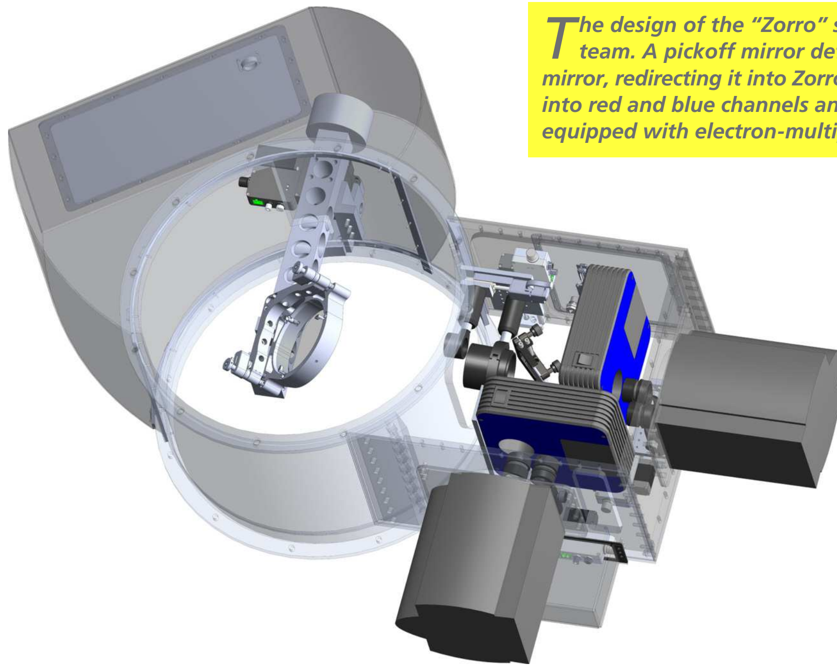
The first concrete answers to these questions came in 2014 from a team of researchers led by Elliott Horch (Southern Connecticut State University).

The team acquired images of over 600 stars with transits already observed by the Kepler Space Telescope, revealing 49 stellar companions within 1 arc second of the primary stars. To accomplish this feat, Horch and colleagues used a technique known as "speckle imaging" (devised in the 1960s and developed over the following decades) with the 3.5-meter WIYN and 8.1-meter Gemini North telescopes.

Speckle imaging consists of obtaining images of a small portion of the sky around a star with exposure times so short (a few hundredths of a second) that they freeze out the deleterious effects of atmospheric turbulence and reach the diffraction limit of the instrument used. The individual exposures are then combined and treated through software employing complex algorithms to provide a final image of the star and its possible companion with a better resolution than that achievable by the Hubble Space Telescope. Thanks to this technique, Horch's team was able to reveal companion stars up to 125 times fainter than the primaries, separated by just 0.05 arcseconds, equivalent in most cases to about 100 astronomical units (AU). Although based on a rather limited dataset and an only approximate characterization of the binary systems, this



This graph shows the exoplanets so far confirmed, divided according to the type of discovery method. As expected, the planets discovered thanks to transits in front of stellar disks have periods of revolution that are shorter on average, while most of those discovered through radial velocities have very significant masses. [NASA]

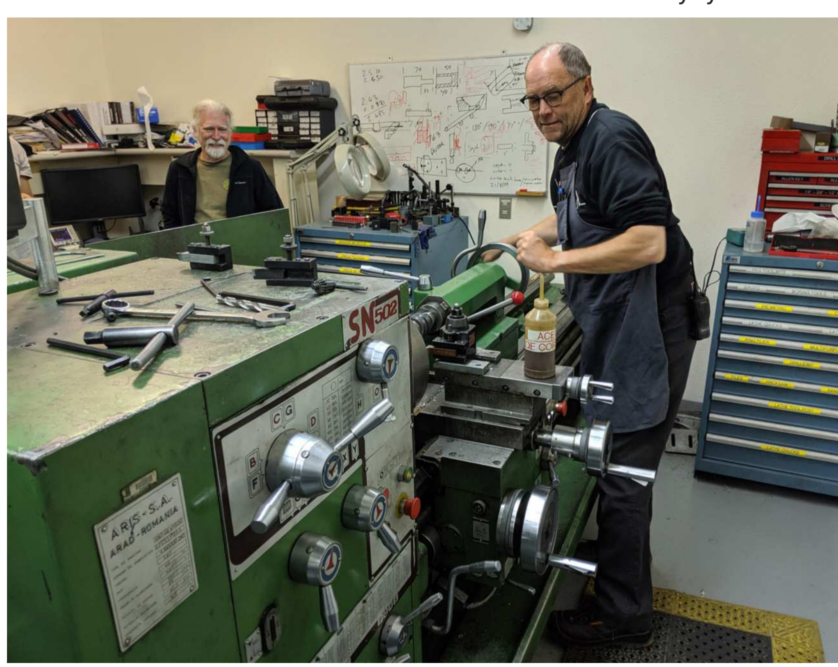


The design of the "Zorro" speckle imaging device used by Lester's team. A pickoff mirror deflects the light coming from the tertiary mirror, redirecting it into Zorro. Inside Zorro, the light is split by a dichroic into red and blue channels and their light is sent to respective cameras equipped with electron-multiplying CCDs. [Dr. Nic Scott/NASA Ames]

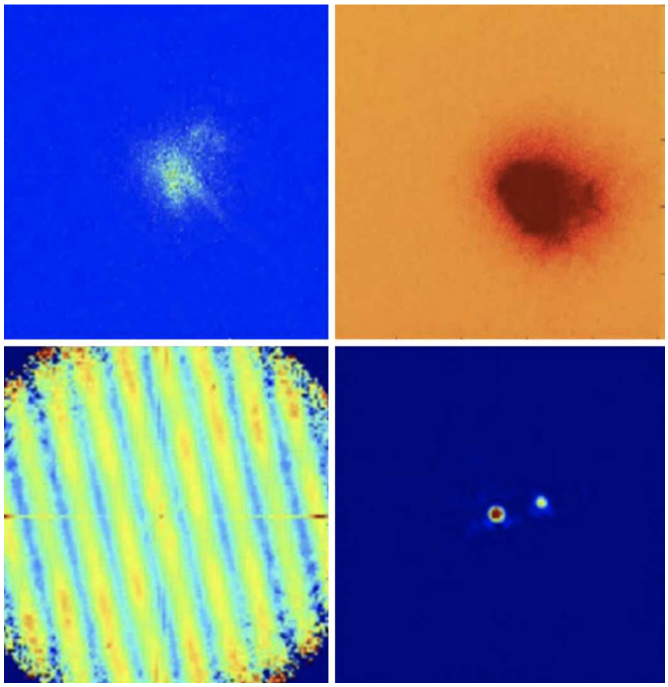
first study showed that double stars can host planets like single ones, provided that the two stars are far enough apart that they do not prevent the formation of the planets themselves. This first study was confirmation that there could be many more Earth-sized planets than those discovered up to that point.

In more recent years, this line of research has recorded several other contributions from various teams, including the most recent and significant one by Kathryn Lester (NASA Ames Research Center) and collaborators. This team employed speckle imaging with both Gemini (North and South) and WIYN telescopes to study over 500 candidate planet-hosting stars already observed by the Transiting Exoplanet Survey Satellite (TESS).

The researchers' ground-based observations reached angular resolutions between 20 milliarcseconds and 1.2 arcseconds, corresponding to spatial resolutions between just under 10 and about 500 AU, a much larger range than that of previous studies. This allowed the team to evaluate the influence a companion star can have on the formation, evolution and survival of planets. Theoretical studies have suggested that a stellar companion can distort the protoplanetary disk of the primary star (or vice versa), removing material from the formation of the planets. Later, the bulky presence can favor the migration of gas giants and eventually disperse smaller planets. Overall, fewer companion stars could be expected to be found at distances of less than 100 AU around stars with a planetary system, compared to pairs without planets. And so it was. Lester's team found that 73 stars in the sample examined with Gemini telescopes and 18 observed with WIYN are binary systems.



NASA machinist Emmett Quigley doing work on a part for the speckle instrument in Chile. Dr Steve Howell is in the background. [NASA]

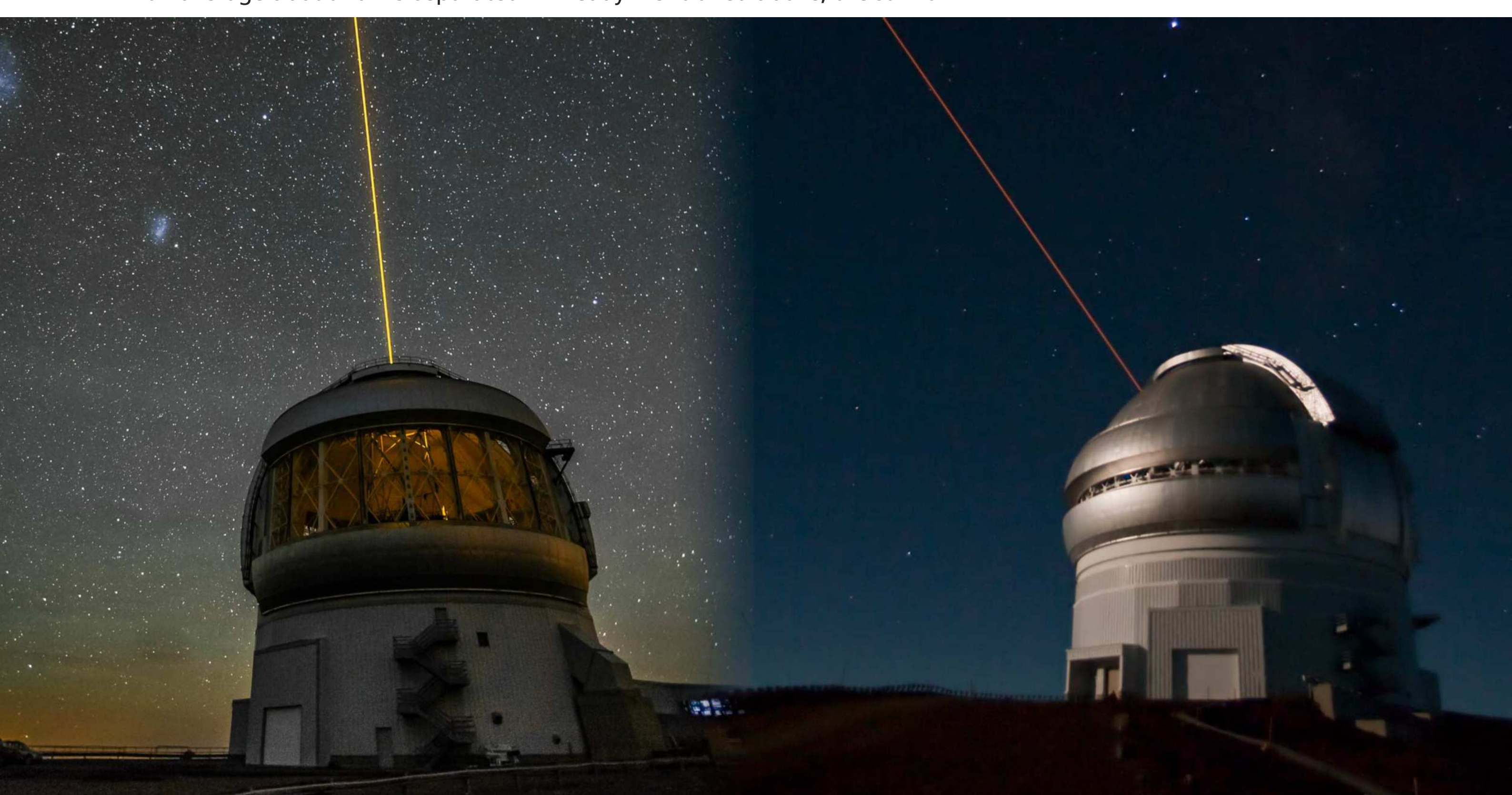


A single 60 msec speckle frame (top left), the integrated sum of 1,000 speckle frames (top right), the Fourier power spectrum (bottom left) and the resulting reconstructed diffraction-limited image (bottom right). Adapted from Scott and Howell (2018). [GeminiFocus, 2019]

After having identified and characterized the 92 pairs, the researchers were able to confirm that the average separation between the components is about 100 AU, while binary stars without planetary systems are on average about 40 AU separated. This does not necessarily mean that below 100 AU of separation no Earth-sized planets can form, but that we currently cannot observe them (by their transits across the stellar disc) precisely because, as already mentioned above, the sum of the light of the two stars excessively reduces the darkening due to transits. Not surprisingly, TESS has found both giant planets and planets similar in size to ours around single stars, while the latter seem much rarer in binary star systems.

The results obtained by Lester's team confirmed those of Horch's team: an unspecified but not negligible number of "Earths" could hide in binary star systems. Here is how Lester commented on this conclusion: *"Since roughly 50% of stars are in binary systems, we could be missing the discovery and the chance to study a lot of Earth-like planets. Astronomers need to know whether a star is single or binary before they claim that no small planets exist in that system. If it is single, then we could say that no small planets exist. But if the host is in a binary, we would not know whether a small planet is hidden by the com-*

Gemini South on the summit of Cerro Pachón in Chile (left) and Gemini North on the summit of Maunakea in Hawai'i (right). [Gemini/NSF/AURA]



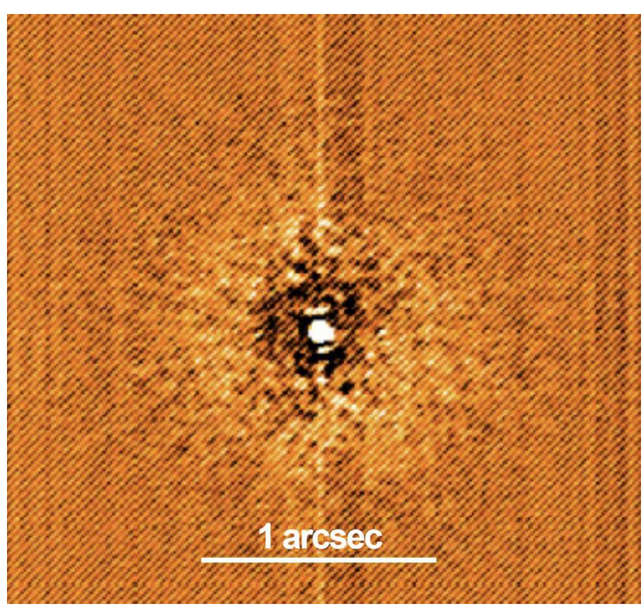
The WIYN telescope building against a sunset sky, with interior light on the telescope. It is owned and operated by the WIYN Consortium and is located at the Kitt Peak National Observatory. [Jean-Baptiste Faure]

panion star or does not exist at all. We would need more observations with a different technique to figure that out."

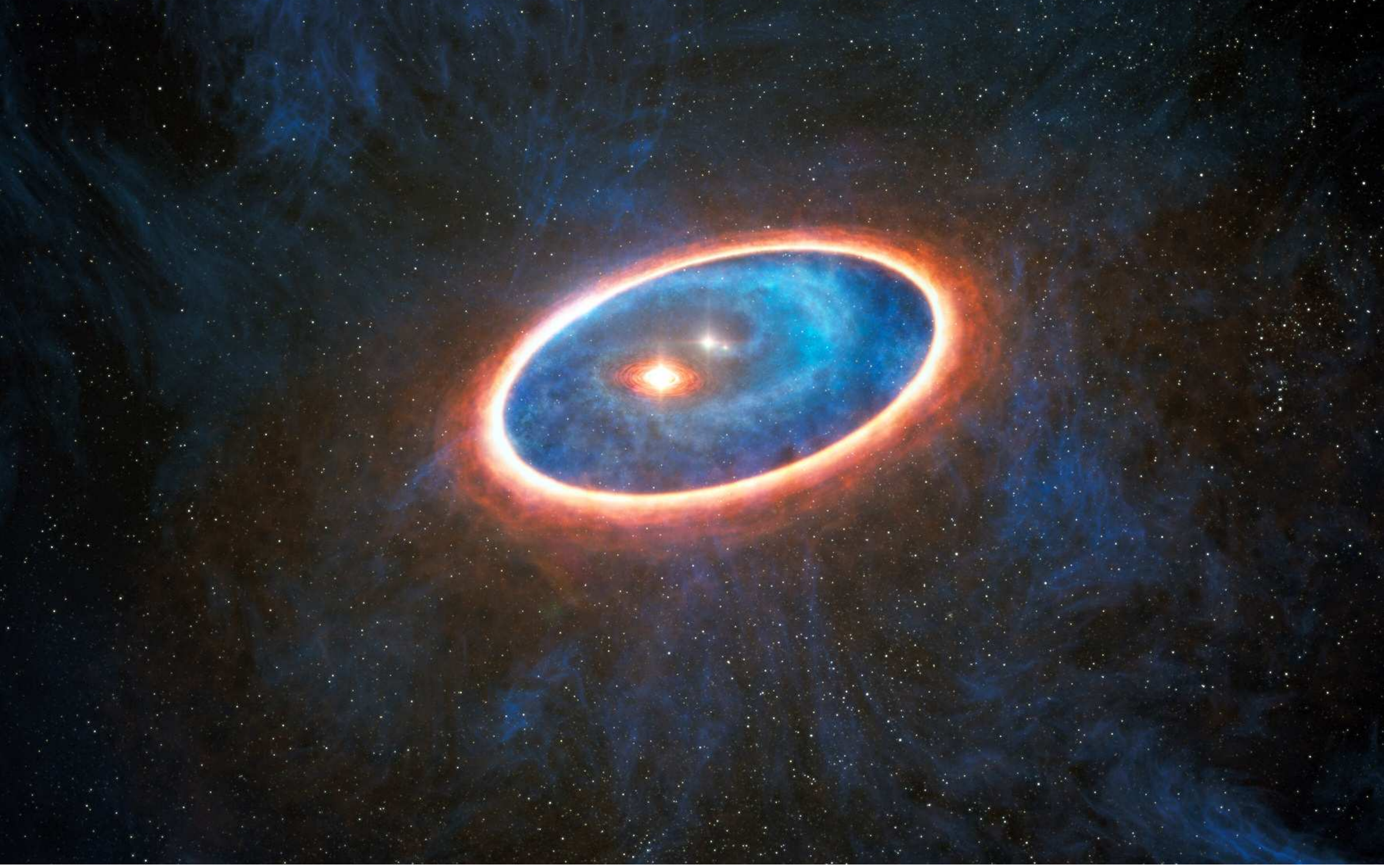
In light of all this, can we perhaps trust in the fact that if there are many more Earth-sized planets than previously believed, the number of potentially habitable planets increases proportionally? Apparently yes, but if by "habitable" we mean "something extremely similar to the Earth," then there is no need to be overly optimistic, especially after the publication at the end of June in the Monthly Notices of the Royal Astronomical Society of a study highlighting the criticalities of development of biospheres on other planets. The study was conducted by a team of researchers led by Giovanni Covone (University of Naples, Italy) and consists of an analysis of the known exoplanets and the conditions required so that an oxygen-based photosynthesis could develop on them, one capable of producing a complex Earth-like biosphere.

The prerequisites are, of course, that a given planet has a size and mass similar to Earth's and that it orbits in the habitable zone of its star, where liquid water can exist on the planetary surface. Only a small minority of planets, among the thousands confirmed so far, have these characteristics. According to Covone and colleagues, nowhere among this small minority exist the theoretical conditions to support an Earth-like biosphere through oxygenic photosynthesis, the process by which plants convert light and carbon dioxide into nutrients and oxygen.

The critical factor in this scenario is the stellar radiation necessary to support a large and complex biosphere on a given planet. According to the analysis conducted by the Covone team, only Kepler-442b (a rocky planet 17,000 km in diameter and twice the Earth's mass) comes close to re-

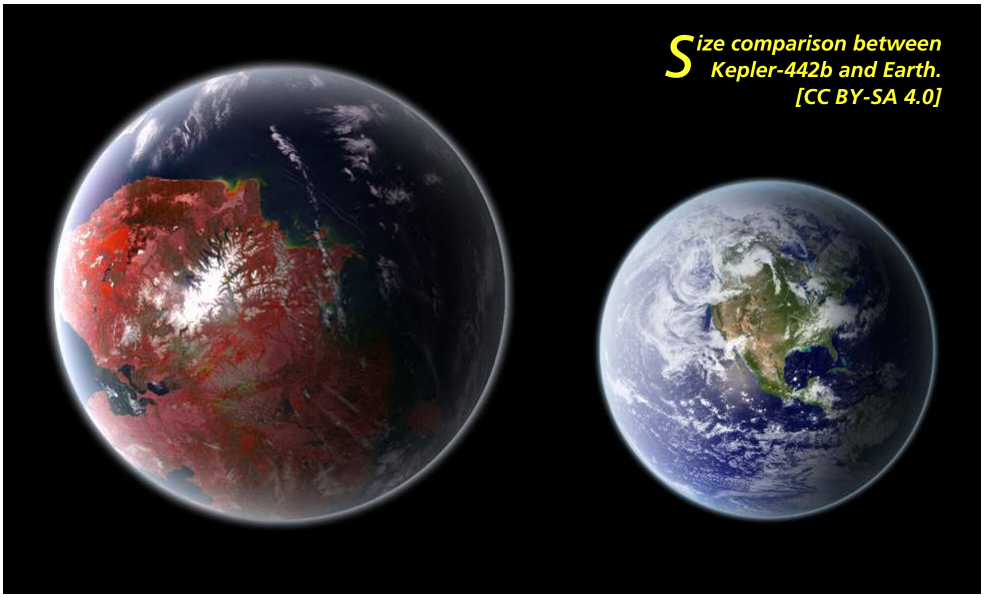


Kelt-25 as seen by Zorro. The Zorro observations show Kelt-25 has no stellar companions, thereby confirming the nature of the transiting giant planet KELT-25b. [Joey Rodriguez, Sam Quinn, and Josh Pepper (KELT-TESS); Steve Howell, Nic Scott, and Rachel Matson (NASA Ames)]

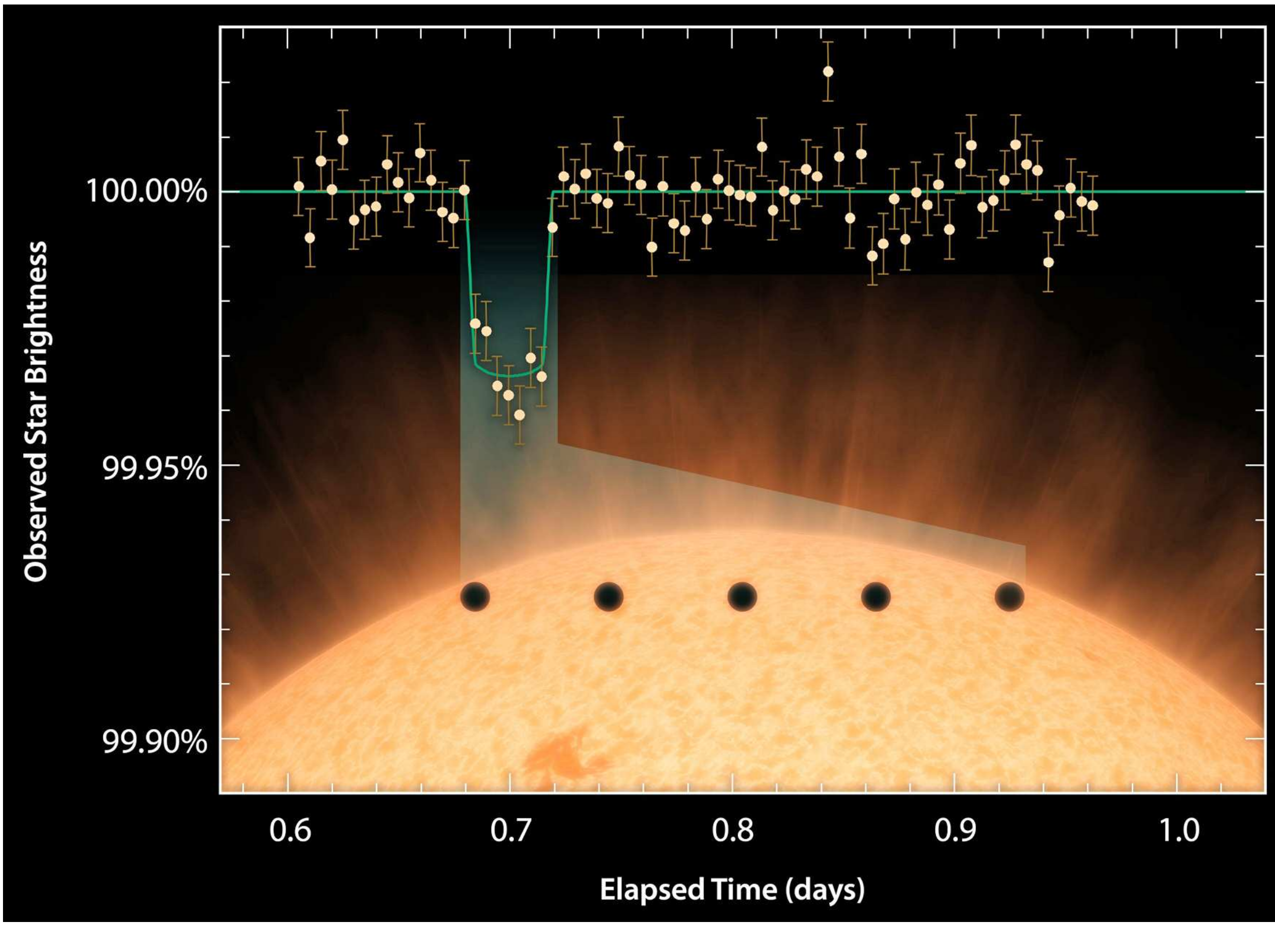


This artist's impression shows the dust and gas around the double star system GG Tauri-A. Seven years ago, researchers using ALMA detected gas in the region between two discs in this binary system. This may allow planets to form in the gravitationally perturbed environment of the binary. Half of Sun-like stars are born in binary systems, meaning that these findings will have major consequences in the hunt for exoplanets. [ESO/L. Calçada]

ceiving from its K5V spectral type star (diameter and mass 60% compared to the Sun) the radiation necessary to support an Earth-like biosphere. By calculating the amount of photosynthetically active radiation (light between 400 and 700 nanometers) that each planet receives from its star, the researchers found that stars with surface temperatures below one half that of the Sun cannot sustain an Earth-like biosphere, since they are unable to supply sufficient energy at the appropriate wavelengths. In less unfavorable cases (temperatures around 3000 Kelvin), oxygenic photosynthesis would still be possible, but plants would not be able to produce a biosphere like ours. It is easy to guess that the results obtained by the Covone team cut off all red dwarfs (spectral type M, with temperatures of about 2000-3000 Kelvin) from the possibility of feeding a complex biosphere – as if the frequent solar flares from these stars, which flood the surrounding planets with intense streams of X-ray and UV radiation, were not enough to preclude their possibility.

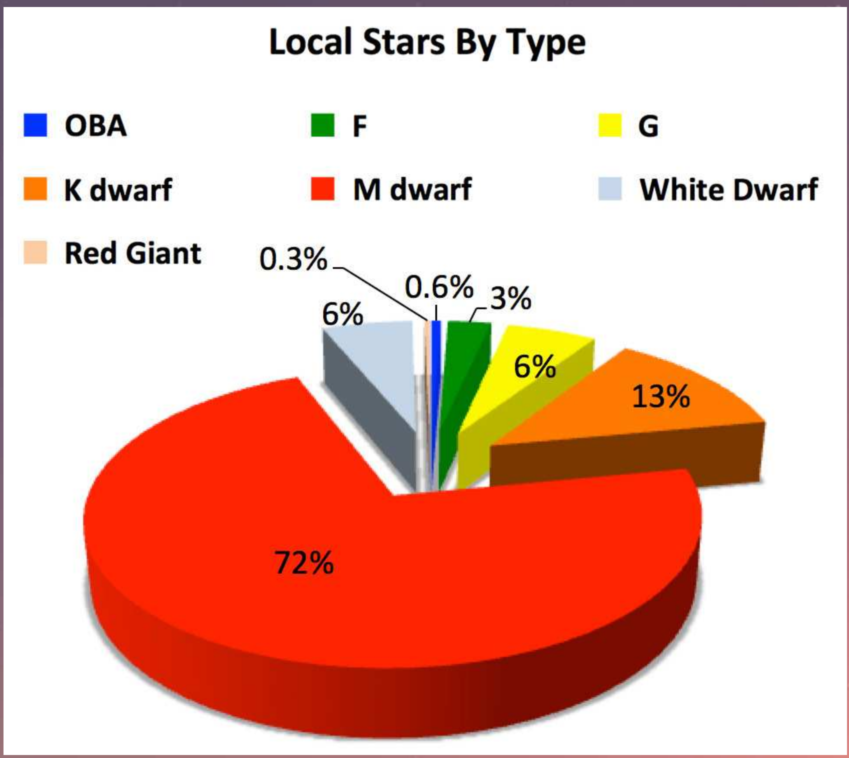


Size comparison between Kepler-442b and Earth. [CC BY-SA 4.0]



This plot captures one of the nearest rocky exoplanets, dubbed HD 219134b, in the act of passing in front of its star. The data were obtained in infrared light using the NASA Spitzer Space Telescope. By carefully measuring the brightness of the star over several hours, Spitzer easily detected the faint decrease in light that occurred when the planet's disk blocked a tiny portion of the star's light. Even though the planet is 1.6 times the size of Earth, it still only accounts for less than a 0.04% reduction in the total light from the star during its transit. [NASA/JPL-Caltech]

Conversely, the stars larger and hotter than the Sun (within certain limits) guarantee their eventual planets the radiation necessary to develop a biosphere, but often their existence is not long enough to allow for the evolution of complex life forms. In short, only stars between F5V and K5V spectral types offer the ideal conditions for the development of a biosphere like ours. Outside of this range, everything becomes more difficult. Nonetheless, even considering only these spectral types, we could have millions of biospheres in the Milky Way. But let us not delude ourselves that, by the law of large numbers, some of them are very similar to ours. In fact, the more scientists compare the Earth with other potentially habitable (by us) planets, the more we realize how unlikely the latter might actually be. In addition to orbiting at the right distance from their stars, these planets must have an atmosphere with the right density, pressure and composition. They must also have a magnetic field and, therefore, a rotating molten core, as well as plate tectonics and, therefore, continents on the surface. For life to evolve in the direction of high complexity, it is also essential that the host planet's rotation axis is as stable as possible for billions of years, a situation that has occurred on Earth thanks to the presence of the Moon. How many other planets have both a biosphere and an equally large natural satellite, originating from a fortuitous collision between proto-



Pie chart showing the fraction of local stars in the solar vicinity by spectral type, excluding brown dwarfs (L/T/Y dwarfs). Red giants and white dwarfs are treated as separate categories, and the OBA/F/G/K stars include dwarfs and subgiants. [Eric Mamajek]

planets? Even if this last requirement was met, it alone might not be enough, as the rotation axis, in addition to not oscillating excessively, also seems to need a certain inclination. This, at least, is what emerges in research presented in July at the Goldschmidt Geochemistry Virtual Conference. The authors, a team of researchers led by Stephanie Olson (Purdue University, Indiana) have developed a sophisticated model of the conditions required by Earth-like life to produce

oxygen. The model allows different parameters to be varied, showing how initial settings can affect the amount of oxygen produced by photosynthetic life. Curiously, the most interesting results came when the team modeled the orbital obliquity (or the inclination of the rotation axis) of a virtual planet.
Average values of this parameter lead in the oceans to an optimal production of oxygen (which is then transferred to the atmosphere) and nutrients for the sustenance of life.

Almost half a century ago, the creators of Star Wars imagined a life-sustaining planet, Tatooine, orbiting a pair of stars. Now, scientists have found new evidence that five known systems with multiple stars, Kepler-34, -35, -38, -64 and -413, are possible candidates for supporting life.

On the contrary, very low or very high values of the rotation axis inclination seem to limit the proliferation of life. The 23.5 degree inclination of the Earth's axis seems to be a confirmation of the validity of this latest study (the tilt of the axis varies between 22.1 and 24.5 degrees, during a cycle that averages about 40,000 years).
If confirmed, orbital obliquity becomes yet a further constraint in the search for complex life on other planets, adding to astronomers the difficulty of having to now derive the rotation axis inclination of an observed exoplanet before adding it to the candidate list.

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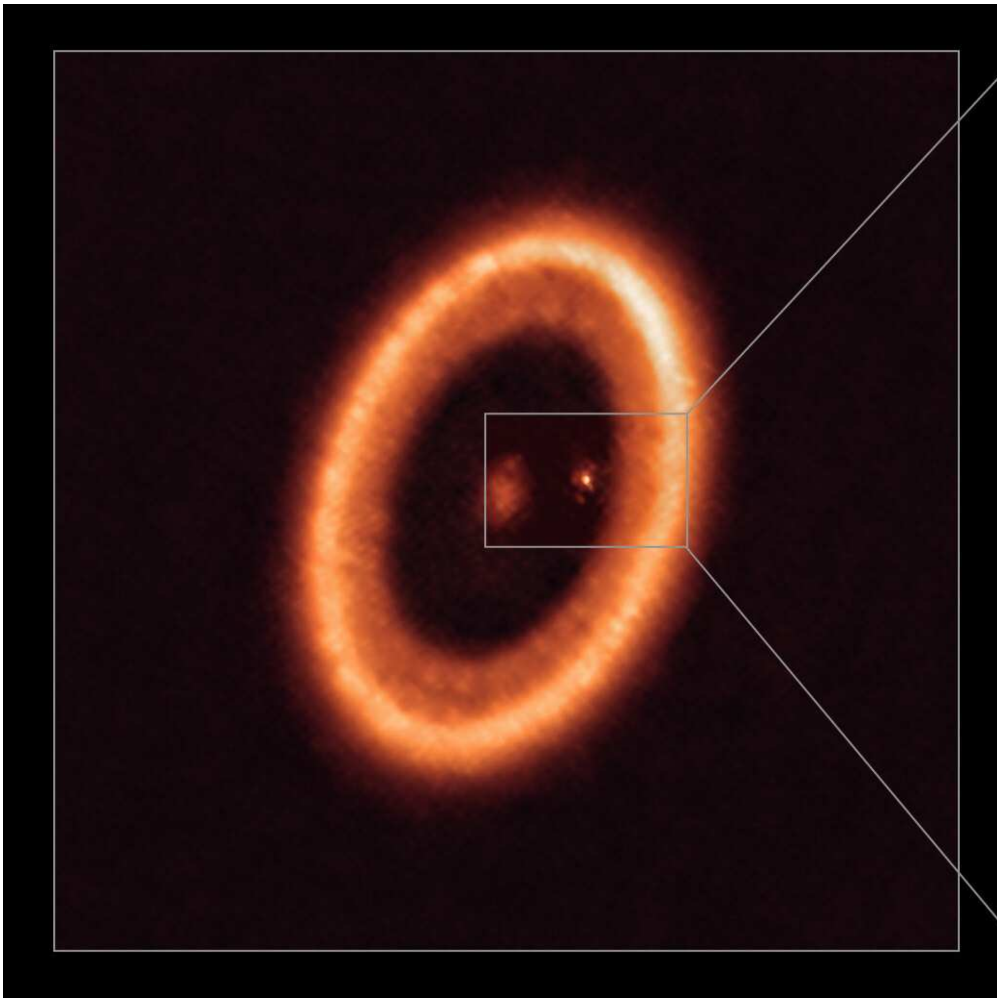
I N S T R U M E N T S - C O

The first clear image of an exomoon-forming disc

by ESO - Bárbara Ferreira

Using the Atacama Large Millimetre/submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, astronomers have unambiguously detected the presence of a disc around a planet outside our Solar System for the first time. The observations will shed new light on how moons and planets form in young stellar systems. *"Our work presents a clear detection of a disc in which satellites could be forming,"* says Myriam Benisty, a researcher at the University of Grenoble, France, and at the University of Chile, who led the new research published in *The Astrophysical Journal Letters*.



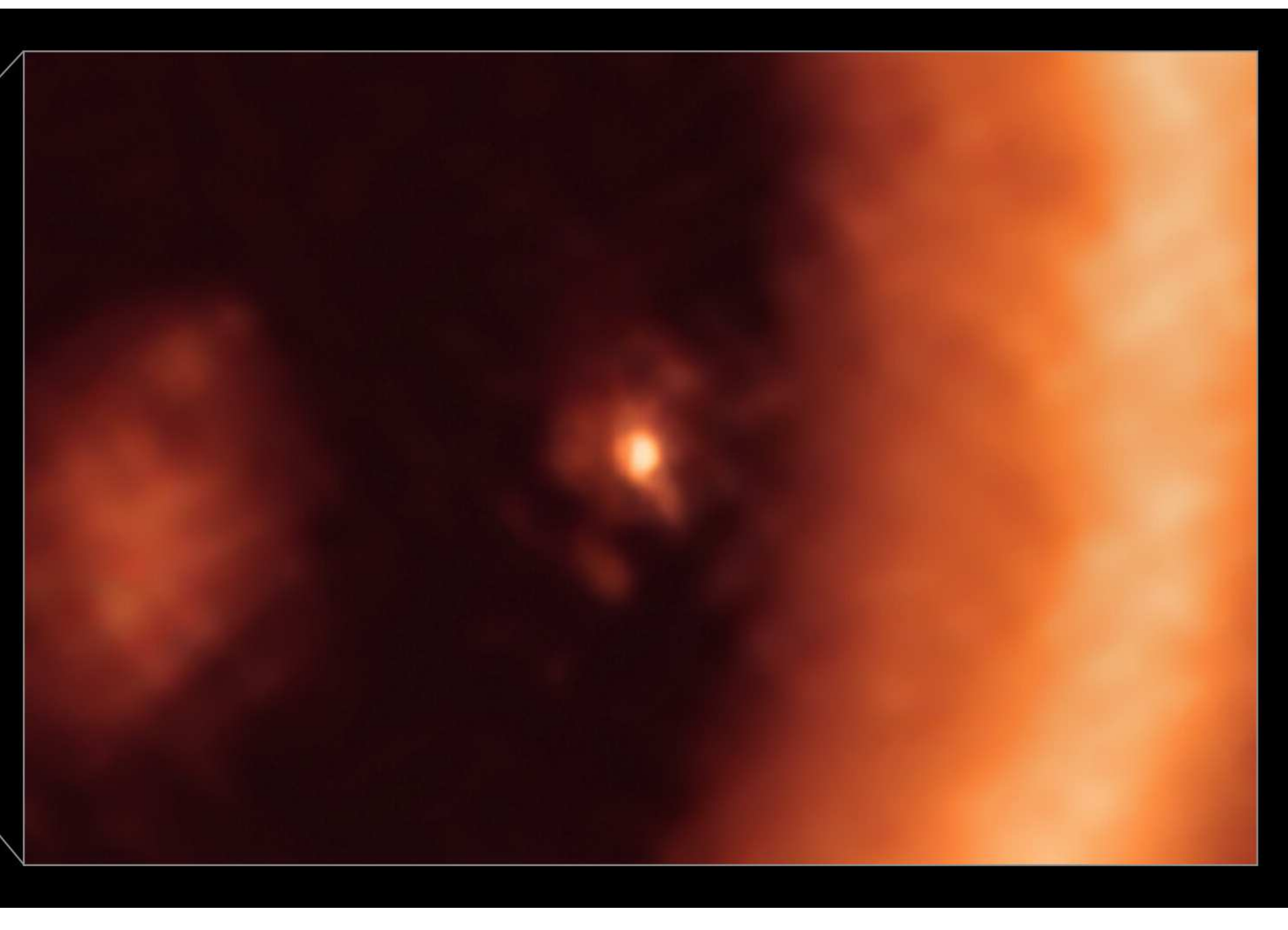
This image, taken with the Atacama Large Millimeter/submillimeter Array (ALMA), in which ESO is a partner, shows wide (left) and close-up (right) views of the moon-forming disc surrounding PDS 70c, a young Jupiter-like planet nearly 400 light-years away. The close-up view shows PDS 70c and its circumplanetary disc centre-front, with the larger circumstellar ring-like disc taking up most of the right-hand side of the image. The star PDS 70 is at the centre of the wide-view image on the left. [ALMA (ESO/NAOJ/NRAO)/Benisty et al.]

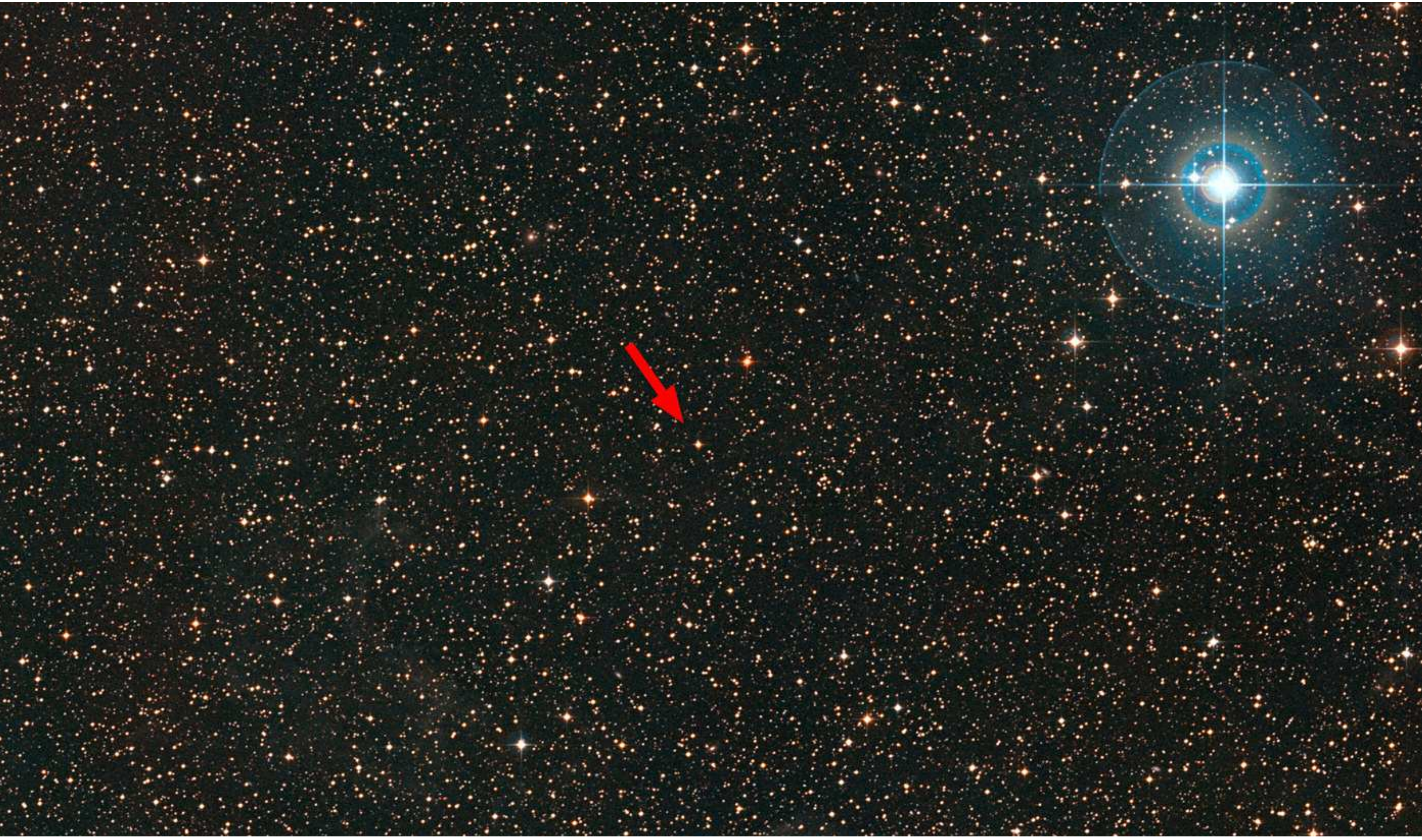
"Our ALMA observations were obtained at such exquisite resolution that we could clearly identify that the disc is associated with the planet and we are able to constrain its size for the first time," she adds. The disc in question, called a circumplanetary disc, surrounds the exoplanet PDS 70c, one of two giant, Jupiter-like planets orbiting a star nearly 400 light-years away. Astronomers had found hints of a "moon-forming" disc around this exoplanet before but, since they could not clearly tell the disc apart from its surrounding environment, they could not confirm its detection — until now.

In addition, with the help of ALMA, Benisty and her team found that the disc has about the same diameter as the distance from our Sun to the Earth and enough mass to form up to three satellites the size of the Moon.

But the results are not only key to finding out how moons arise. *"These new observations are also extremely important to prove theories of planet formation that could not be tested until now,"* says Jaehan Bae, a researcher from the Earth and Planets Laboratory of the Carnegie Institution for Science, USA, and author on the study.

Planets form in dusty discs around young stars, carving out cavities as they gobble up material from this circumstellar disc to grow. In this process, a planet can acquire its own circumplanetary disc, which contributes to the growth of the planet by regulating the amount of material falling onto it. At the same time, the gas and dust in the circumplanetary disc can come together into progressively larger bodies through multiple collisions, ultimately leading to the birth of moons. But astronomers do not yet fully understand the details of these processes. *"In short, it is still unclear when,*





The sky around the faint orange dwarf star PDS 70 (center of image). The bright blue star in the upper right is χ Centauri. [ESO/Digitized Sky Survey 2. Acknowledgement: Davide De Martin]

where, and how planets and moons form," explains ESO Research Fellow Stefano Facchini, also involved in the research.

"More than 4000 exoplanets have been found until now, but all of them were detected in mature systems. PDS 70b and PDS 70c, which form a system reminiscent of the Jupiter-Saturn pair, are the only two exoplanets detected so far that are still in the process of being formed," explains Miriam Keppler, researcher at the Max Planck Institute for Astronomy in Germany and one of the co-authors of the study. *"This system therefore offers us a unique opportunity to observe and study the processes of planet and satellite formation,"* Facchini adds. PDS 70b and PDS 70c, the two planets making up the system, were first discovered using ESO's Very Large Telescope (VLT) in 2018 and 2019 respectively, and their unique nature means they have been observed with other telescopes and instruments many times since. The latest high resolution ALMA observations have now allowed astronomers to gain further insights into the system. In addition to confirming the detection of the circumplanetary disc around PDS 70c and studying its size and mass, they found that PDS 70b does not show clear evidence of such a disc, indicating that it was starved of dust material from its birth environment by PDS 70c. An even deeper understanding of the planetary system will be achieved with ESO's Extremely Large Telescope (ELT), currently under construction on Cerro Armazones in the Chilean Atacama desert. *"The ELT will be key for this research since, with its much higher resolution, we will be able to map the system in great detail,"* says co-author Richard Teague, a researcher at the Center for Astrophysics | Harvard & Smithsonian, USA. In particular, by using the ELT's Mid-infrared ELT Imager and Spectrograph (METIS), the team will be able to look at the gas motions surrounding PDS 70c to get a full 3D picture of the system. ■

Using ALMA, a team of astronomers have unambiguously detected a moon-forming disc around a distant planet for the first time. The planet is a Jupiter-like gas giant, hosted in a system still in the process of being formed. The result promises to shed new light on how moons and planets form in young stellar systems. This video summarises the discovery. [ESO]

Giant comet found in outer solar system

by NOIRLab - Amanda Kocz

A giant comet has been discovered by two astronomers following a comprehensive search of data from the Dark Energy Survey (DES). The comet, which is estimated to be 100–200 kilometers across, or about 10 times the diameter of most comets, is an icy relic flung out of the Solar System by the migrating giant planets in the early history of the Solar System. This comet is quite unlike any other seen before and the huge size estimate is based on how much sunlight it reflects.

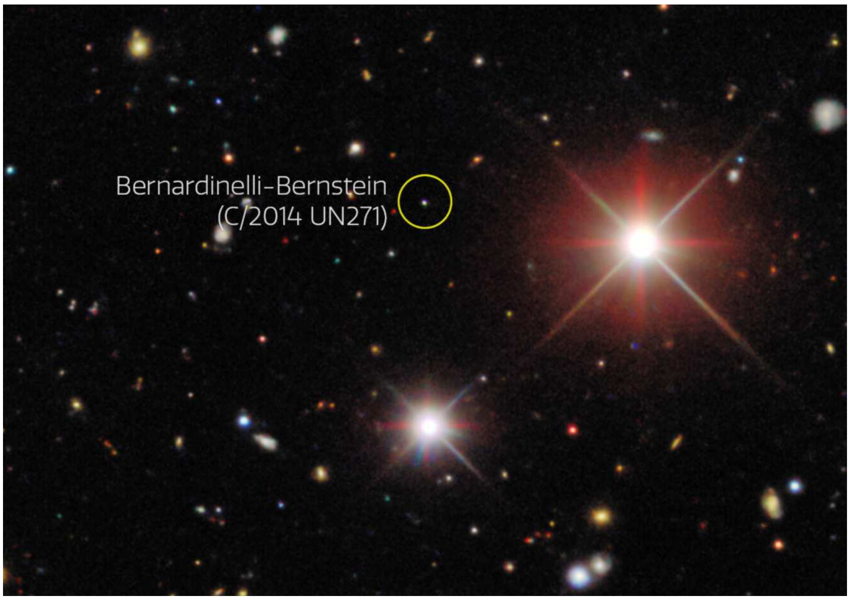
This illustration shows the distant Comet Bernardinelli-Bernstein as it might look in the outer Solar System. Comet Bernardinelli-Bernstein is estimated to be about 1,000 times more massive than a typical comet, making it arguably the largest comet discovered in modern times. It has an extremely elongated orbit, journeying inward from the distant Oort Cloud over millions of years. It is the most distant comet to be discovered on its incoming path. [NOIRLab/NSF/AURA/J. da Silva (Spaceengine)]

Pedro Bernardinelli and Gary Bernstein, of the University of Pennsylvania, found the comet — named Comet Bernardinelli-Bernstein (with the designation C/2014 UN_{271}) — hidden among data collected by the 570-megapixel Dark Energy Camera (DECam) mounted on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile. The analysis of data from the Dark Energy Survey is supported by the Department of Energy (DOE) and the National Science Foundation (NSF), and the DECam science archive is curated by the Community Science and Data Center (CSDC) at NSF's NOIRLab. CTIO and CSDC are Programs of NOIRLab.

One of the highest-performance, wide-field CCD imagers in the world, DECam was designed specifically for the DES and operated by the DOE and NSF between 2013 and 2019. DECam was funded by the DOE and was built and tested at DOE's Fermilab. At present DECam is used for programs covering a huge range of science. DES was tasked with mapping 300 million galaxies across a 5,000-square-degree area of the night sky, but during its six years of observations it also observed many comets and trans-Neptunian objects passing through the surveyed field. A trans-Neptunian object, or TNO, is an icy body that resides in our Solar System beyond the orbit of Neptune.

Bernardinelli and Bernstein used 15–20 million CPU hours at the National Center for Supercomputing Applications and Fermilab, employing sophisticated identification and tracking algorithms to identify over 800 individual TNOs from among the more than 16 billion individual sources detected in 80,000 exposures taken as part of the DES. Thirty-two of those detections belonged to one object in particular — C/2014 UN_{271}.

Comets are icy bodies that evaporate as they approach the warmth of the Sun, growing their coma and tails. The DES images of the object in 2014–2018 did not show a typical comet tail, but within a day of the announcement of its discovery via the Minor Planet Center, astronomers using the Las Cumbres Observatory network took fresh images of Comet Bernardinelli-Bernstein which revealed that it has grown a coma in the past 3 years, making it officially a comet.



This image from the Dark Energy Survey (DES) is composed of some of the discovery exposures showing Comet Bernardinelli-Bernstein collected by the 570-megapixel Dark Energy Camera (DECam) mounted on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile. These images show the comet in October 2017, when it was 25 au away [Dark Energy Survey/ DOE/ FNAL/DECam/CTIO/ NOIRLab/ NSF/AURA/P. Bernardinelli & G. Bernstein (UPenn)/DESI Legacy Imaging Surveys. – Acknowledgement: T.A. Rector (University of Alaska Anchorage/NSF's NOIRLab), M. Zamani (NSF's NOIRLab) & J. Miller (NSF's NOIRLab)]

Its current inward journey began at a distance of over 40,000 astronomical units (au) from the Sun — in other words 40,000 times farther from the Sun than Earth is, or 6 trillion kilometers away (3.7 trillion miles or 0.6 light-years — 1/7 of the distance to the nearest star). For comparison, Pluto is 39 au from the Sun, on average. This means that Comet Bernardinelli-Bernstein originated in the Oort Cloud of objects, ejected during the early history of the Solar System. It could be the largest member of the Oort Cloud ever detected, and it is the first comet on an incoming path to be detected so far away.
Comet Bernardinelli-Bernstein is currently much closer to the Sun. It was first seen by DES in 2014 at a distance of 29 au (4 billion kilometers or 2.5 billion miles, roughly the distance of Neptune), and as of June 2021, it was 20 au (3 billion kilometers or 1.8 billion miles, the distance of Uranus) from the Sun and currently shines at magnitude 20. The comet's orbit is perpendicular to the plane of the Solar System and it will reach its closest point to the Sun (known as perihelion) in 2031, when it will be around 11 au away (a bit more than Saturn's distance from the Sun) — but it will get no closer. Despite the comet's size, it is currently predicted that skywatchers will require a large amateur telescope to see it, even at its brightest.
"We have the privilege of having discovered perhaps the largest comet ever seen — or at least larger than any well-studied one — and caught it early enough for people to watch it evolve as it approaches and warms up," said Gary Bernstein. *"It has not visited the Solar System in more than 3 million years."*
Comet Bernardinelli-Bernstein will be followed intensively by the astronomical community, including with NOIRLab facilities, to understand the composition and origin of this massive relic from the birth of our own planet. Astronomers suspect that there may be many more undiscovered comets of this size waiting in the Oort Cloud far beyond Pluto and the Kuiper Belt. These giant comets are thought to have been scattered to the far reaches of the Solar System by the migration of Jupiter, Saturn, Uranus, and Neptune early in their history.
"This is a much needed anchor on the unknown population of large objects in the Oort Cloud and their connection with early migration of the ice/gas giants soon after the Solar System was formed," said NOIRLab astronomer Tod Lauer.
"These observations demonstrate the value of long-duration survey observations on national facilities like the Blanco telescope," says Chris Davis, National Science Foundation Program Director for NOIRLab. *"Finding huge objects like Comet Bernardinelli-Bernstein is crucial to our understanding of the early history of our Solar System."*
It is not yet known how active and bright it will become when it reaches perihelion. However, Bernardinelli says that Vera C. Rubin Observatory, a future Program of NOIRLab, *"will continuously measure Comet Bernardinelli-Bernstein all the way to its perihelion in 2031, and probably find many, many others like it,"* allowing astronomers to characterize objects from the Oort Cloud in much greater detail. ■

Science in School aims to promote inspiring science teaching by encouraging communication between teachers, scientists, and everyone else involved in European science education. **Science in School** is published by EIROforum, a collaboration between eight European intergovernmental scientific research organisations, of which ESO is a member. The journal addresses science teaching both across Europe and across disciplines: highlighting the best in teaching and cutting-edge research.
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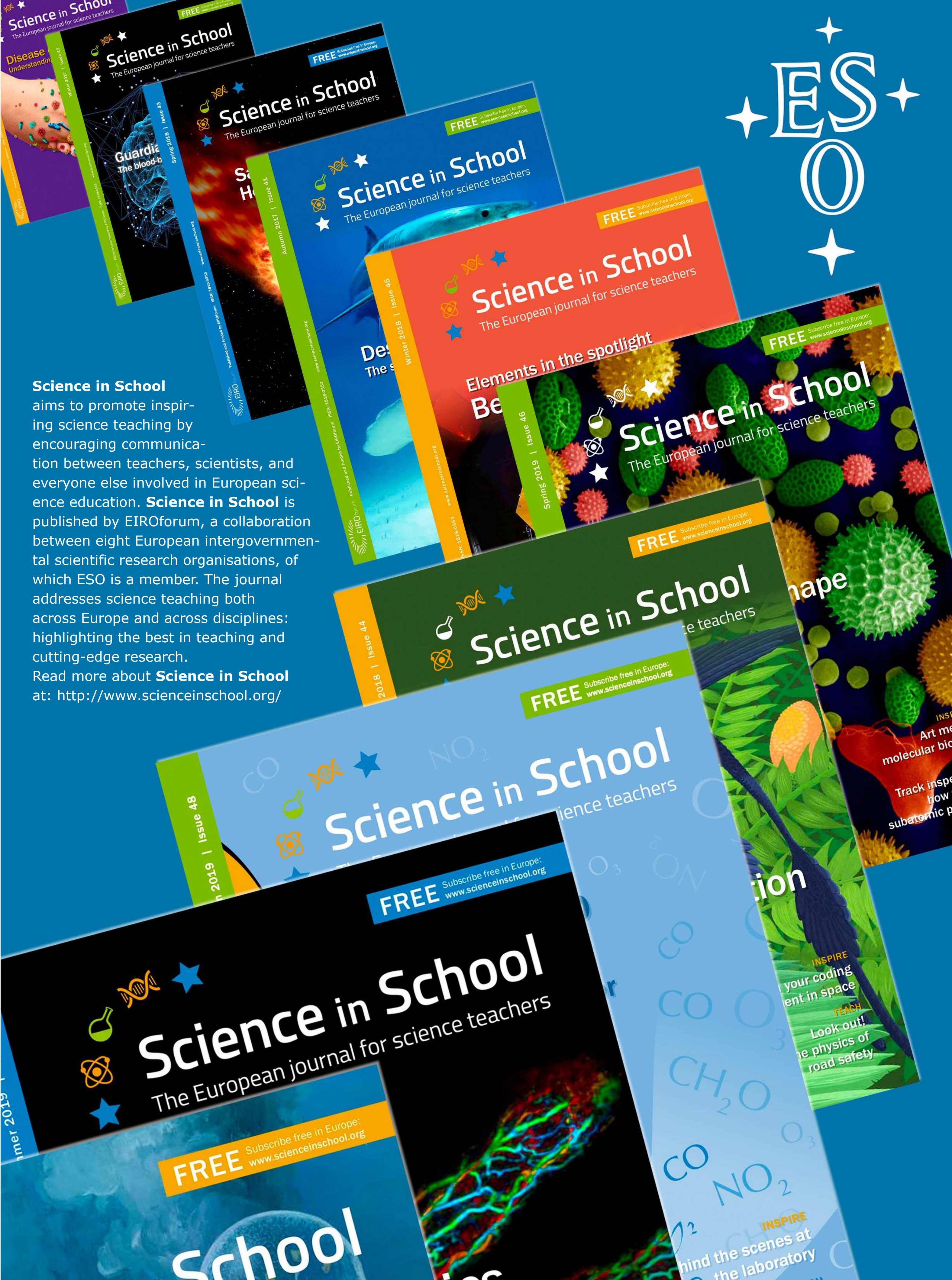
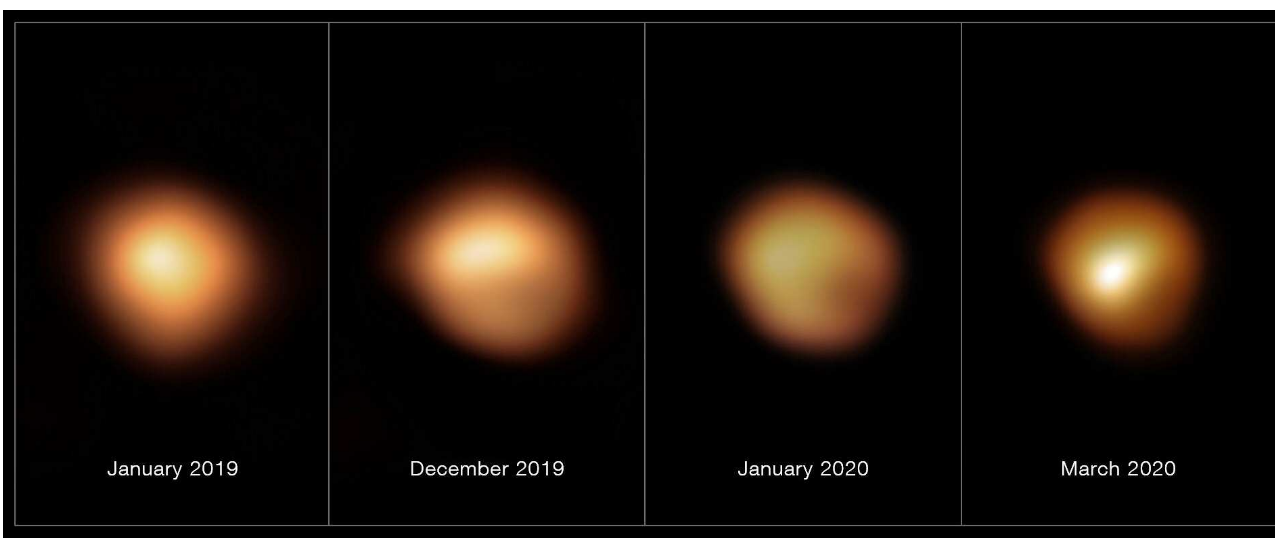


Mystery of Betelgeuse's dip in brightness solved

by ESO - Bárbara Ferreira



These images, taken with the SPHERE instrument on ESO's Very Large Telescope, show the surface of the red supergiant star Betelgeuse during its unprecedented dimming, which happened in late 2019 and early 2020. The image on the far left, taken in January 2019, shows the star at its normal brightness, while the remaining images, from December 2019, January 2020, and March 2020, were all taken when the star's brightness had noticeably dropped, especially in its southern region. The brightness returned to normal in April 2020. [ESO/M. Montargès et al.]

Betelgeuse's dip in brightness — a change noticeable even to the naked eye — led Miguel Montargès and his team to point ESO's VLT towards the star in late 2019. An image from December 2019, when compared to an earlier image taken in January of the same year, showed that the stellar surface was significantly darker, especially in the southern region. But the astronomers weren't sure why.

The team continued observing the star during its Great Dimming, capturing two other never-before-seen images in January 2020 and March 2020. By April 2020, the star had returned to its normal brightness.

"For once, we were seeing the appearance of a star changing in real time on a scale of weeks," says Montargès, from the Observatoire de Paris, France, and KU Leuven, Belgium. The images now published are the only ones we have that show Betelgeuse's surface changing in brightness over time. In their new study, published in *Nature*, the team revealed that the mysterious dim-

ming was caused by a dusty veil shading the star, which in turn was the result of a drop in temperature on Betelgeuse's stellar surface.

Betelgeuse's surface regularly changes as giant bubbles of gas move, shrink and swell within the star. The team concludes that some time before the Great Dimming, the star ejected a large gas bubble that moved away from it. When a patch of the surface cooled down shortly after, that temperature decrease was enough for the gas to condense into solid dust.

"We have directly witnessed the formation of so-called stardust," says Montargès, whose study provides evidence that dust formation can occur very quickly and close to a star's surface. *"The dust expelled from cool evolved stars, such as the ejection we've just witnessed, could go on to become the building blocks of terrestrial planets and life,"* adds Emily Cannon, from KU Leuven, who was also involved in the study.

Rather than just the result of a dusty outburst, there was some speculation online that Betelgeuse's drop in brightness could signal its imminent death in a spectacular supernova explosion.

A supernova hasn't been observed in our galaxy since the 17th century, so present-day astronomers aren't entirely sure what to expect from a star in the lead-up to such an event. However, this new research confirms that Betelgeuse's Great Dimming was not an early sign that the star was heading towards its dramatic fate. Witnessing the dimming of such a recognisable star was exciting for professional and amateur astronomers alike, as summed up by Cannon: *"Looking up at the stars at night, these tiny, twinkling dots of light seem perpetual. The dimming of Betelgeuse breaks this illusion."*

This animation combines four real images of the red supergiant star Betelgeuse, the first taken in January 2019 and the others taken in December 2019, January 2020 and March 2020, during the star's unprecedented dimming. All images, which allow us to resolve the surface of the star, were taken with the SPHERE instrument on ESO's Very Large Telescope. [ESO/M. Montargès et al./L. Calçada]

The team used the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument on ESO's VLT to directly image the surface of Betelgeuse, alongside data from the GRAVITY instrument on ESO's Very Large Telescope Interferometer (VLTI), to monitor the star throughout the dimming. The telescopes, located at ESO's Paranal Observatory in Chile's Atacama Desert, were a *"vital diagnostic tool in uncovering the cause of this dimming event,"* says Cannon.

"We were able to observe the star not just as a point but could resolve the details of its surface and monitor it throughout the event," Montargès adds.

Montargès and Cannon are looking forward to what the future of astronomy, in particular what ESO's Extremely Large Telescope (ELT), will bring to their study of Betelgeuse, a red supergiant star.

"With the ability to reach unparalleled spatial resolutions, the ELT will enable us to directly image Betelgeuse in remarkable detail," says Cannon. *"It will also significantly expand the sample of red supergiants for which we can resolve the surface through direct imaging, further helping us to unravel the mysteries behind the winds of these massive stars."* ■

This artist's animation shows a close-up view of Betelgeuse's irregular surface — with its giant, dynamic gas bubbles — and distant stars dotting the background. As the "virtual camera" rotates from right to left we see a dusty clump, which condensed from gas released by the star, obscuring the southern region of Betelgeuse from different vantage points. [ESO/L. Calçada]

Hubble inspects a contorted spiral galaxy

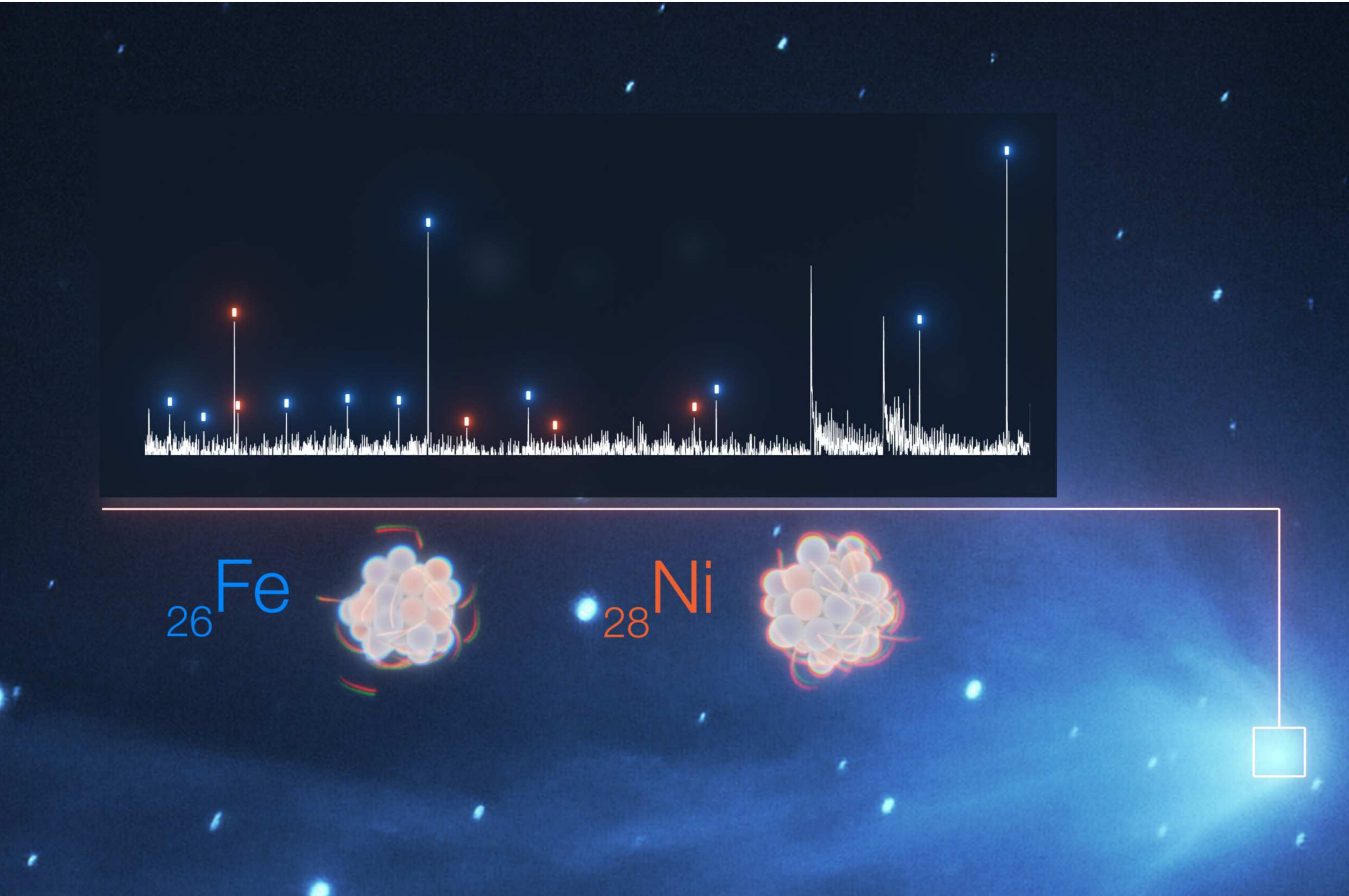
by NASA/ESA - Bethany Downer

This spectacular image from the NASA/ESA Hubble Space Telescope shows the trailing arms of NGC 2276, a spiral galaxy 120 million light-years away in the constellation of Cepheus. At first glance, the delicate tracery of bright spiral arms and dark dust lanes resembles countless other spiral galaxies.

A closer look reveals a strangely lopsided galaxy shaped by gravitational interaction and intense star formation. The interaction of NGC 2276 with the intracluster medium — the superheated gas lying between the galaxies in galaxy clusters — has ignited a burst of star formation along one edge of the galaxy. This wave of star formation is visible as the bright, blue-tinged glow of newly formed massive stars towards the left side of this image, and gives the galaxy a strangely lopsided appearance. NGC 2276's recent burst of star formation is also related to the appearance of more exotic inhabitants — black holes and neutron stars in binary systems. On the other side of the galaxy from this burst of new stars, the gravitational attraction of a smaller companion is pulling the outer edges of NGC 2276 out of shape. This interaction with the small lens-shaped galaxy NGC 2300 has distorted the outermost spiral arms of NGC 2276, giving the false impression that the larger galaxy is orientated face-on to Earth. NGC 2276 is by no means the only galaxy with a strange appearance. The Atlas of Peculiar Galaxies — a catalogue of unusual galaxies published in 1966 — contains a menagerie of weird and wonderful galaxies, including spectacular galaxy mergers, ring-shaped galaxies, and other galactic oddities.

As befits an unusually contorted galaxy, NGC 2276 has the distinction of being listed in the Atlas of Peculiar Galaxies twice — once for its lopsided spiral arms and once for its interaction with its smaller neighbour NGC 2300.

ESA/Hubble & NASA, P. Sell
Acknowledgement: L. Shatz



Heavy metal vapours unexpectedly found in comets

by ESO - Bárbara Ferreira

A new study by a Belgian team using data from the European Southern Observatory's Very Large Telescope (ESO's VLT) has shown that iron and nickel exist in the atmospheres of comets throughout our Solar System, even those far from the Sun. A separate study by a Polish team, who also used ESO data, reported that nickel vapour is also present in the icy interstellar comet 2I/Borisov. This is the

The detection of the heavy metals iron (Fe) and nickel (Ni) in the fuzzy atmosphere of a comet are illustrated in this image, which features the spectrum of light of C/2016 R2 (PANSTARRS) on the top left superimposed to a real image of the comet taken with the SPECULOOS telescope at ESO's Paranal Observatory. Each white peak in the spectrum represents a different element, with those for iron and nickel indicated by blue and orange dashes, respectively. Spectra like these are possible thanks to the UVES instrument on ESO's VLT, a high-resolution spectrograph that spreads the line so much they can be individually identified. In addition, UVES remains sensitive down to wavelengths of 300nm. Most of the important iron and nickel lines appear at wavelengths of around 350nm, meaning that the capabilities of UVES were essential in making this discovery. [ESO/L. Calçada, SPECULOOS Team/E. Jehin, Manfroid et al.]

This video starts by showing an animation of comet C/2016 R2 (PANSTARRS), which was done using real images taken by the SPECULOOS telescope at ESO's Paranal Observatory. The video then zooms in on a blue comet. In a new study done with the UVES instrument on ESO's Very Large Telescope, a team has spotted heavy metal atoms in the inner atmosphere of the comet, a discovery illustrated at the end of the video. There we see the spectrum of the comet and in particular the iron (Fe, blue) and nickel (Ni, orange) lines, marking the presence of the two elements in the atmosphere of the comet. [ESO/L. Calçada/M. Kornmesser, SPECULOOS Team/E. Jehin, Manfroid et al.]

first time heavy metals, usually associated with hot environments, have been found in the cold atmospheres of distant comets.

"It was a big surprise to detect iron and nickel atoms in the atmosphere of all the comets we have observed in the last two decades, about 20 of them, and even in ones far from the Sun in the cold space environment," says Jean Manfroid from the University of Liège, Belgium, who lead the new study on Solar System comets published in *Nature*.

Astronomers know that heavy metals exist in comets' dusty and rocky interiors. But, because solid metals don't usually "sublimate" (become gaseous) at low temperatures, they did not expect to find them in the atmospheres of cold comets that travel far from the Sun. Nickel and iron vapours have now even been detected in comets observed at more than 480 million kilometres from the Sun, more than three times the Earth-Sun distance.

The Belgian team found iron and nickel in comets' atmospheres in approximately equal amounts. Material in our Solar System, for example that found in the Sun and in meteorites, usually contains about ten times more iron than nickel. This new result therefore has implications for astronomers' understanding of the early Solar System, though the team is still decoding what these are.

"Comets formed around 4.6 billion years ago, in the very young Solar System, and haven't changed since that time. In that sense, they're like fossils for astronomers," says study co-author Emmanuel Jehin, also from the University of Liège.

While the Belgian team has been studying these "fossil" objects with ESO's VLT for nearly 20 years, they had not spotted the presence of nickel and iron in their atmospheres until now. *"This discovery went under the radar for many years,"* Jehin says.

The team used data from the Ultraviolet and Visual Echelle Spectrograph (UVES) instrument on ESO's VLT, which uses a technique called spectroscopy, to analyse the atmospheres of comets at different distances from the Sun. This technique allows astronomers to reveal the chemical makeup of cosmic objects: each chemical element leaves a unique signature — a set of lines —

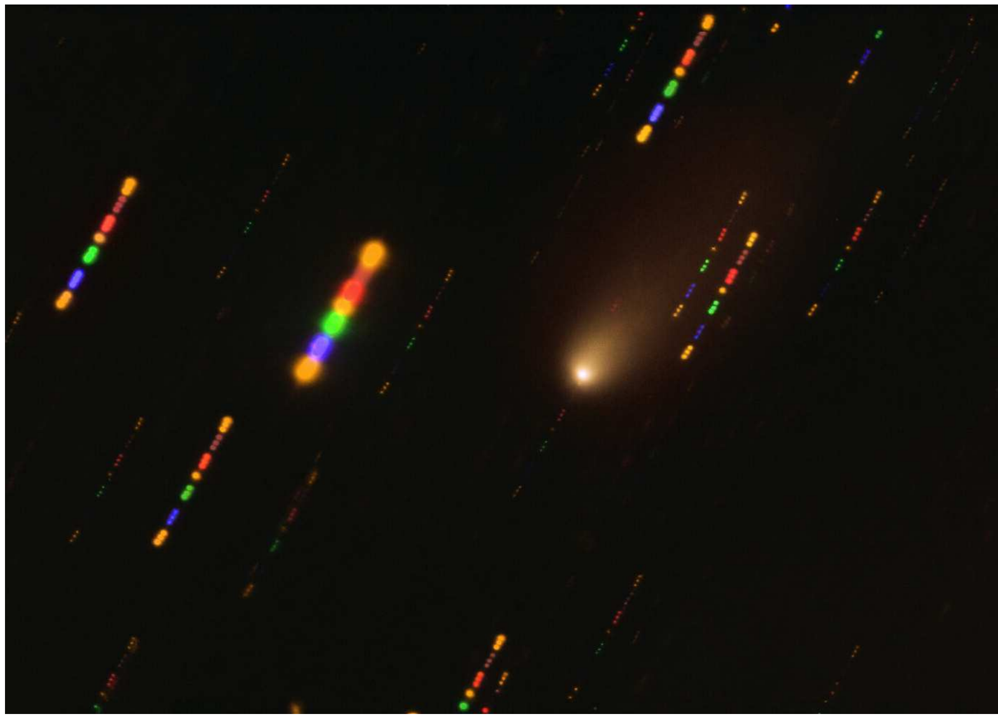
in the spectrum of the light from the objects.

The Belgian team had spotted weak, unidentified spectral lines in their UVES data and on closer inspection noticed that they were signalling the presence of neutral atoms of iron and nickel.

A reason why the heavy elements were difficult to identify is that they exist in very small amounts: the team estimates that for each 100 kg of water in the comets' atmospheres there is only 1 g of iron, and about

This image features a comet located in the outer reaches of the Solar System: comet C/2016 R2 (PANSTARRS). As its name suggests, the comet was discovered in 2016 by the Pan-STARRS telescopes in Hawai'i. The new image seen here was captured by a project based at ESO's Paranal Observatory in Chile named the Search for habitable Planets EClipsing ULtra-cOOl Stars – or SPECULOOS for short. This comet is particularly exciting because of the rare compounds and molecules that scientists have detected in its coma: carbon monoxide and nitrogen ions. These compounds give the comet distinctive blue emission lines — so much so that it is nicknamed "the blue comet". This shy comet only orbits the Sun once every 20,000 years, its most recent approach being in May 2018. This image was taken over a period of time as the telescope tracked the comet's motion; the bright streaks of light in the background are faraway stars, but the comet and its gaseous coma are all in focus, a testament to the tracking power of SPECULOOS. [ESO/SPECULOOS Team/E. Jehin]

This image was taken with the FORS2 instrument on ESO's Very Large Telescope in late 2019, when comet 2I/Borisov passed near the Sun. Since the comet was travelling at breakneck speed, around 175,000 kilometres per hour, the background stars appeared as streaks of light as the telescope followed the comet's trajectory. The colours in these streaks give the image some disco flair and are the result of combining observations in different wavelength bands, highlighted by the various colours in this composite image. [ESO/ O. Hainaut]



the same amount of nickel. *"Usually there is 10 times more iron than nickel, and in those comet atmospheres we found about the same quantity for both elements. We came to the conclusion they might come from a special kind of material on the surface of the comet nucleus, sublimating at a rather low temperature and releasing iron and nickel in about the same proportions,"* explains Damien Hutsemékers, also a member of the Belgian team from the University of Liège.

Although the team aren't sure yet what material this might be, advances in astronomy — such as the Mid-infrared ELT Imager and Spectrograph (METIS) on ESO's upcoming Extremely Large Telescope (ELT) — will allow researchers to confirm the source of the iron and nickel atoms found in the atmospheres of these comets.

The Belgian team hope their study will pave the way for future research. *"Now people will search for those lines in their archival data from other telescopes,"* Jehin says. *"We think this will also trigger new work on the subject."*

Another remarkable study published in *Nature* shows that heavy metals are also present in the atmosphere of the interstellar comet 2I/Borisov. A team in Poland observed this object, the first alien comet to visit our Solar System, using the X-shooter spectrograph on ESO's VLT when the comet flew by about a year and a half ago. They found that 2I/Borisov's cold atmosphere contains gaseous nickel.

"At first we had a hard time believing that atomic nickel could really be present in 2I/Borisov that far from the Sun. It took numerous tests and checks before we could finally convince ourselves," says study author Piotr Guzik from the Jagiellonian University in Poland. The finding is surprising because, before these two studies, gases with heavy metal atoms had only been observed in hot environments, such as in the atmospheres of ultra-hot exoplanets or evaporating comets that passed too close to the Sun.

2I/Borisov was observed when it was some 300 million kilometres away from the Sun, or about twice the Earth-Sun distance.

Studying interstellar bodies in detail is fundamental to science because they carry invaluable information about the alien planetary systems they originate from. *"All of a sudden we understood that gaseous nickel is present in cometary atmospheres in other corners of the Galaxy,"* says co-author Michał Drahus, also from the Jagiellonian University.

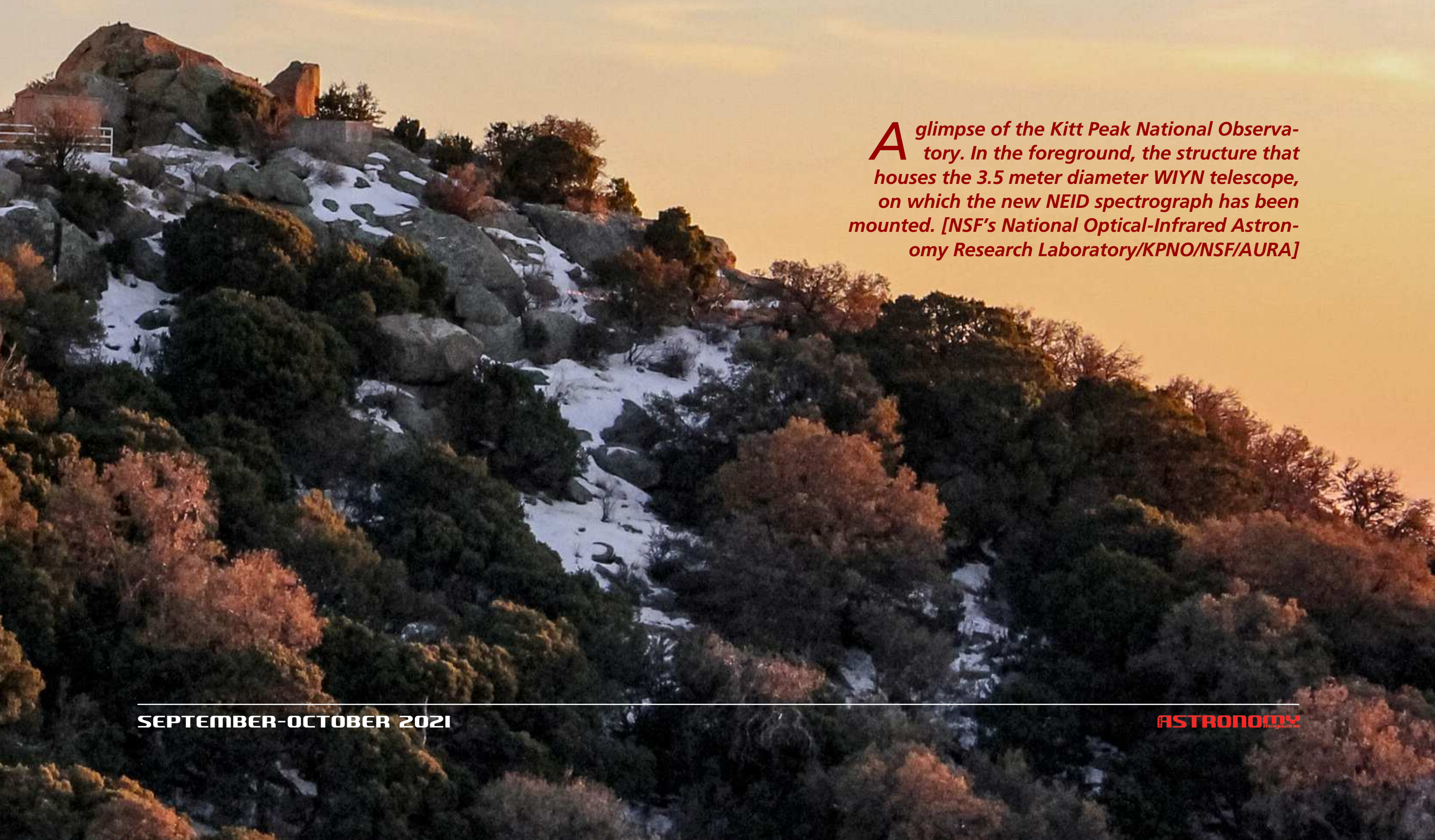
The Polish and Belgian studies show that 2I/Borisov and Solar System comets have even more in common than previously thought. *"Now imagine that our Solar System's comets have their true analogues in other planetary systems — how cool is that?"* Drahus concludes.

NEID – the new planet hunter

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

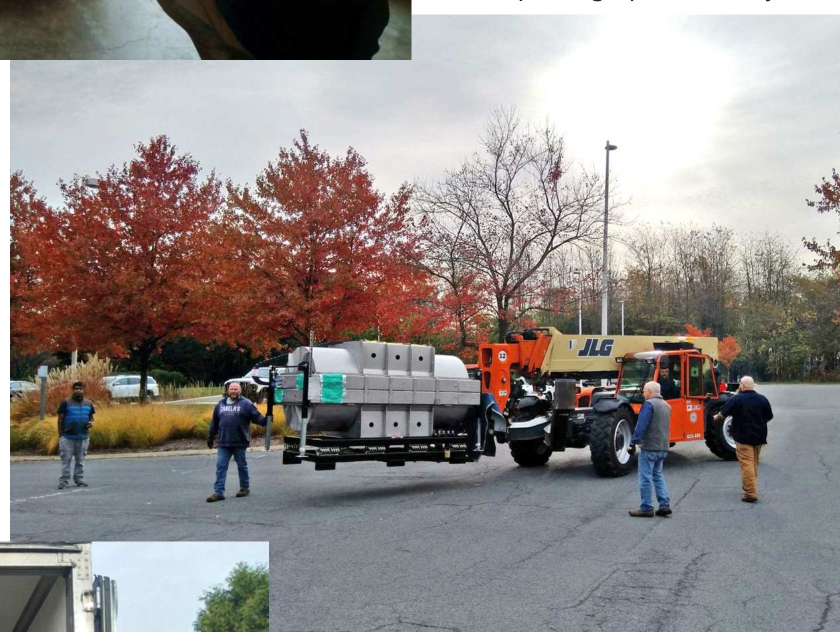
In astronomy, high speeds are the norm. With just local examples, let's take the orbital speed of the Earth, almost 30 km/s, or the speed with which the entire solar system moves around the Milky Way center, about 230 km/s. Astronomers can measure such rapid displacements with relative ease and they can do so with all the stars approaching or moving away from us (radial velocity). But with what maximum precision are astronomers able to measure those speeds? The answer is to within less than 1 m/s. To get an idea of how small a displacement this is, measured in the spectra of objects tens or hundreds of light years away, we must consider that these are stars with diameters of hundreds of thousands or millions of kilometers. Further, the surfaces of these stars can be affected by local and global phenomena that develop at speeds well above a few m/s, phenomena that can be erroneously interpreted as a translation in space of the entire star. For example, a star subject to a pulsation that causes it to periodically expand and contract at a speed of a few m/s appears to approach and move away from us with a period equal to that



A glimpse of the Kitt Peak National Observatory. In the foreground, the structure that houses the 3.5 meter diameter WIYN telescope, on which the new NEID spectrograph has been mounted. [NSF's National Optical-Infrared Astronomy Research Laboratory/KPNO/NSF/AURA]

plane containing the axis of our line of sight.
The similarity at low radial speeds of the effects produced by stellar activity and those produced by a planetary system is the main difficulty that planet hunters face – only a precise characterization of the star and long periods of observation allow them to distinguish false signals generated by stellar activity from the gravitational interactions attributable to any orbiting planets. What is worse is that the most interesting planets, i.e. those of terrestrial size orbiting in the habitable zone of their stars, gravitationally attract their star by less than 0.5 m/s, a limit that is rarely reached by the best spectrographs and only under

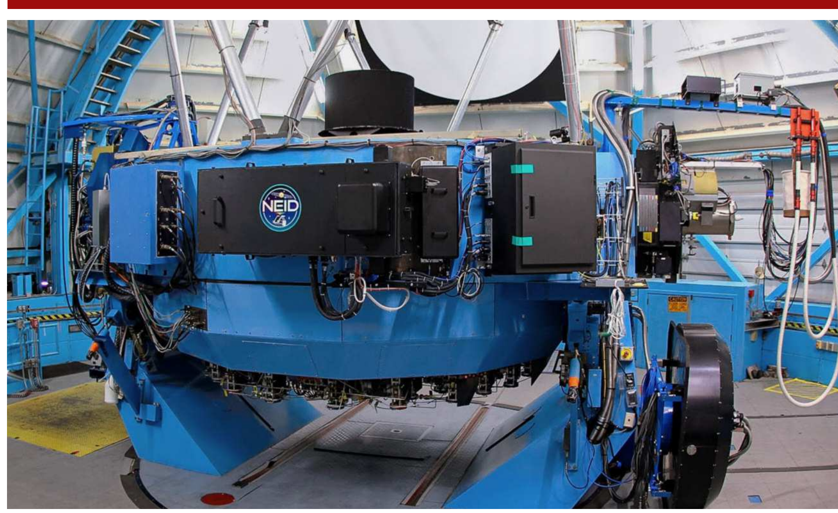
of the pulsation, when instead the geometric center of the star has not changed speed and direction in space. By inverting the order of the addends, the sum does not change, but the substance does change, which produces the observed variation in radial velocity. If a non-variable star cyclically approaches and recedes from us, what we observe is very similar to the effect of a moderate pulsation, but in this case it is the result of one or more masses in orbit around the star – probably planets with orbits more or less in a



Steps in the transfer of NEID to the truck that took it to Kitt Peak National Observatory for installation on the WIYN telescope. As with the acronym NEID, the acronym WIYN is also difficult to understand - it stands for "(University of) Wisconsin, Indiana, Yale, and NOAO (consortium)," where NOAO stands for "National Optical Astronomy Observatory." [NSF's National Optical-Infrared Astronomy Research Lab./KPNO/NSF/AURA]

particularly favorable conditions of stability of both the instruments and the light sources.
For the continuous search for Earth-sized planets (discoveries and verifications), something even more precise is therefore needed, such as NEID, a new spectrograph installed on the WIYN telescope at Kitt Peak National Observatory in Arizona. NEID is a very unguessable acronym that stands for "NN-EXPLORE Exoplanet Investigations with Doppler Spectroscopy", where NN-EXPLORE stands for the "NASA-NSF Exoplanet Observational Research Program."
Conceived as part of a partnership between NASA and the National Science Foundation, the NEID project began to take shape in 2016, when researchers at Penn State University were awarded a $10 million

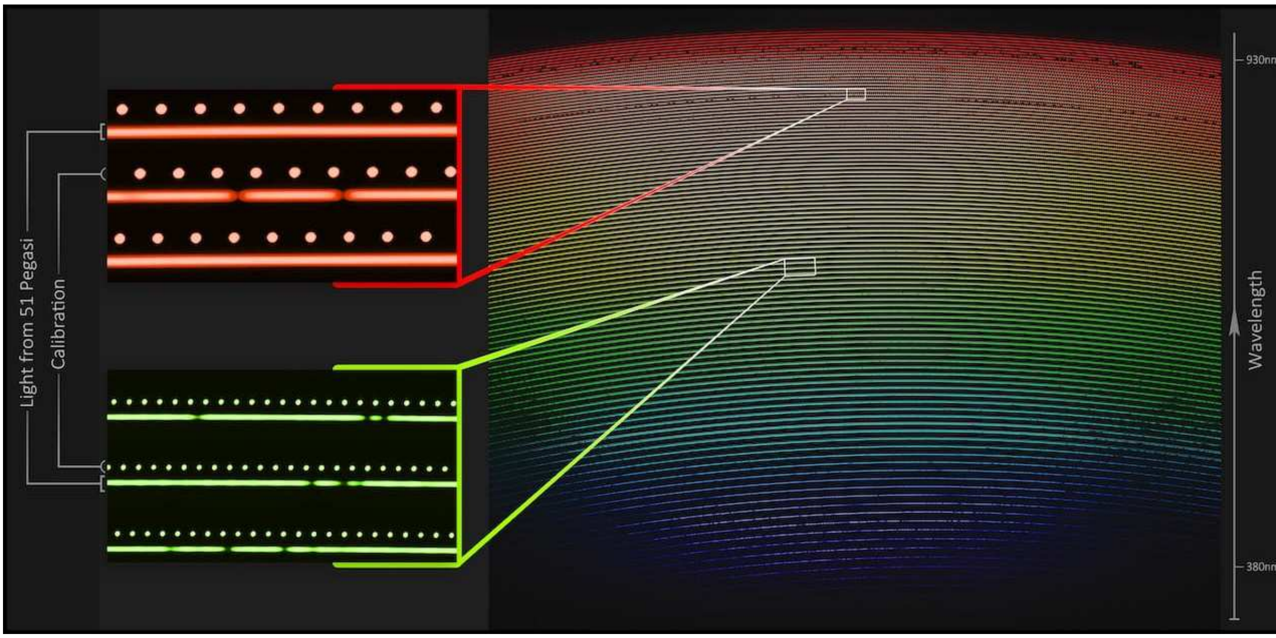
The NEID instrument, mounted on the 3.5 meter WIYN telescope at the Kitt Peak National Observatory. This state-of-the-art spectrometer has officially started its scientific mission of discovering new exoplanets. [NSF's National Optical-Infrared Astronomy Research Laboratory/KPNO/NSF/AURA]



NEID Project Scientist Jason Wright at the Press Release at AAS 235, announcing the first light for NEID. [American Astronomical Society]

contract to build the instrument. The ultimate goal was to build and operate the most accurate spectrograph ever, as Jason Wright, associate professor of astronomy and astrophysics, and NEID Project Scientist at Penn State, pointed out: *"NEID will be more stable than any existing spectrograph, allowing astronomers around the world to make the precise measurements of the motions of nearby, Sun-like stars. Our team will use NEID to discover and measure the orbits of rocky planets at the right distances from their stars to host liquid water on their surfaces."*
NEID was installed on the WIYN telescope in October 2019 and the "commissioning" phase began immediately afterwards. This phase is a period that precedes the scientific activity of an instrument, during which a team of scientists and technicians solves all the problems that may arise when moving from simulations to action in the field. The NEID team spent many long nights over the winter of 2019 and into 2020 to test the spectrograph. Operations were already well underway when, in March 2020, everything was stopped due to the pandemic, when all activities at Kitt Peak were suspended. While the WIYN telescope was turned off for eight months, the NEID team took advantage of this forced pause to make some small tweaks to the spectrograph in response to minimal problems that had been identified at the beginning of the testing.
Due to the shutdown, but above all due to the modifications and interventions on the instrument, the commissioning phase was restarted in November 2020, with many more nights dedicated to fine-tuning the WIYN-NEID system. Between December 2020 and April 2021, several experiments were conducted to establish the reliability, precision and limitations of NEID and its associ-

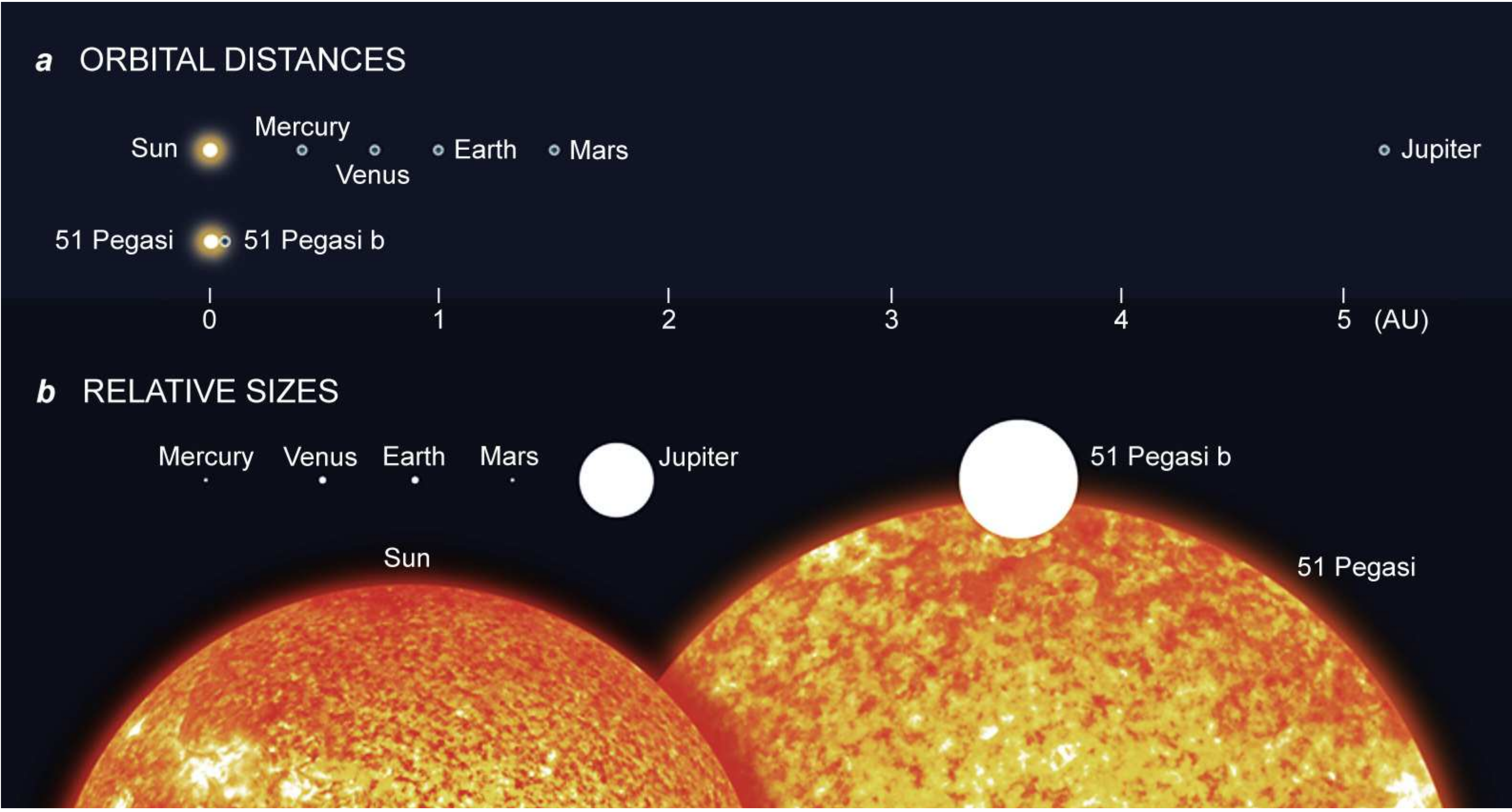
This video summarizes the NEID project and the expectations of astronomers who will search and study exoplanets with the new spectrograph. [NSF's National Optical-Infrared Astronomy Research Laboratory/KPNO/NSF/AURA]



The "first light" spectrum of 51 Pegasi as captured by NEID on the WIYN telescope with a blowup of a small section of the spectrum. The right panel shows the light from the star, highly dispersed by NEID, from short wavelengths (bluer colors) to long wavelengths (redder colors). The colors shown, which approximate the true color of the starlight at each part of the image, are included for illustrative purposes only. The region in the small white box in the right panel, when expanded (left panel), shows the spectrum of the star (longer dashed lines) and the light from the wavelength calibration source (dots). Deficits of light (dark interruptions) in the stellar spectrum are due to stellar absorption lines – "fingerprints" of the elements that are present in the atmosphere of the star. By measuring the subtle motion of these features, to bluer or redder wavelengths, astronomers can detect the "wobble" of the star produced in response to its orbiting planet. [Guðmundur Kári Stefánsson/Princeton University/Penn State/NSF's National Optical-Infrared Astronomy Research Laboratory/KPNO/AURA]

ated subsystems. Much of the on-sky time was dedicated to the usual Doppler observations of stable stars to probe the spectrometer's limiting velocity measurement precision. At the same time, the NEID team also conducted some unusual tests that saw the instrument used in non-ideal operations to verify its performance in sub-optimal working conditions. For example, the radial velocities of stars prospectively too close to the Moon or too low on the horizon were measured, and observations were made with the telescope primary mirror partially covered by the observatory dome. Even under such adverse conditions, NEID

Souvenir photo of the NEID team. [NSF's NOIRLab/KPNO/NSF/AURA]



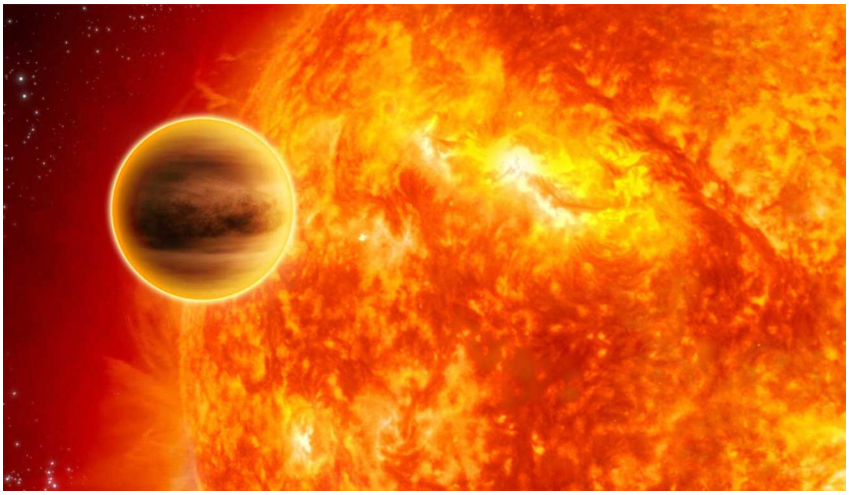
The planetary systems of the Sun and 51 Pegasi. In the solar system, gas-giant planets, such as Jupiter, orbit far from the Sun. In 1995, Mayor and Queloz reported the discovery of 51 Pegasi b, a gas-giant planet that is much closer to its host star than Mercury is to the Sun. The orbital distances of the planets are given in astronomical units. The sizes of all objects are shown approximately to scale. [Nature]

has reached levels of precision comparable to those of the best existing spectrographs.

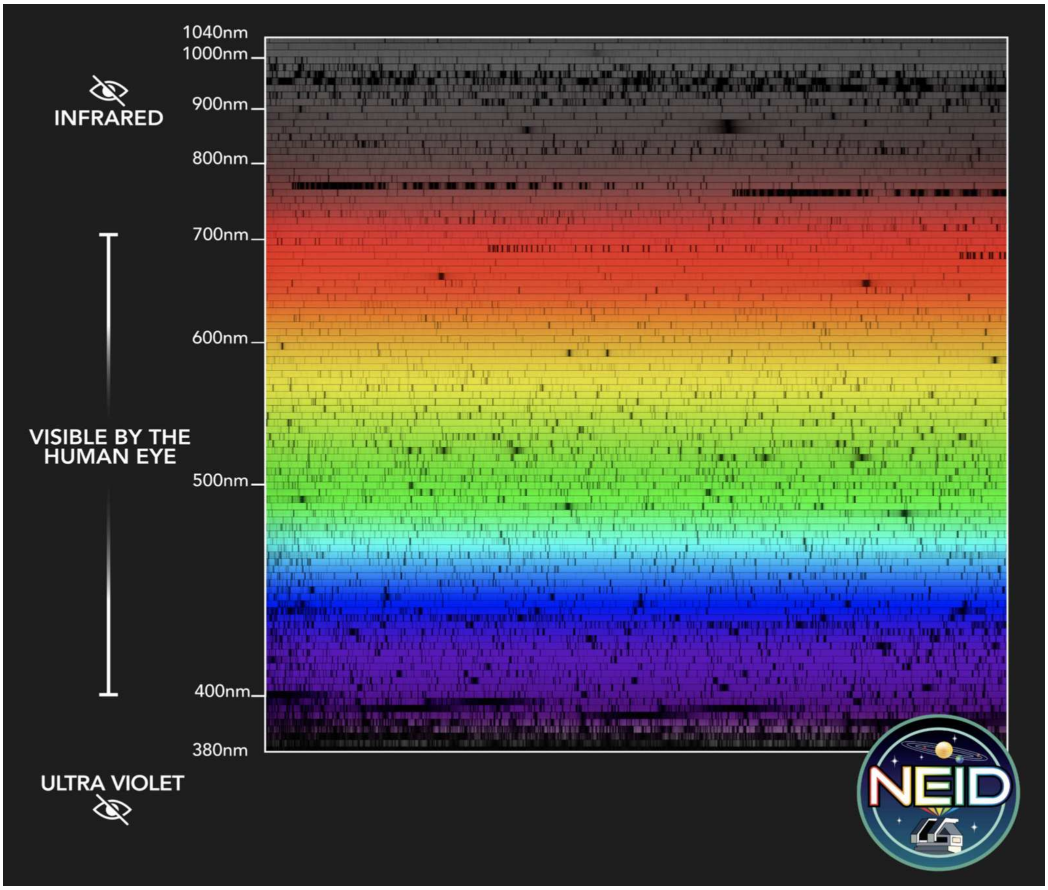
As pointed out by the NEID team: *"Our measurements of stable stars consistently show variability less than 1 meter per second. This on-sky stability reflects a combination of noise sources, including the instrument, statistical fluctuations (so-called 'photon noise'), and the star's inherent atmospheric variability. Thus, while it is hard to pin down an exact number, we are assured that NEID's instrument-limited measurement precision is significantly better than 1 meter per second."*

Jason Wright comments: *"In the last decade, the state of the art has been roughly 1 m/s. NEID is expected to reach 0.3 m/s, pushing the envelope to higher precision. When we combine future NEID observations with data from spacecraft, things will really get interesting, and we will be able to learn what planets are made of. We will know the planet's density, which is a clue to understanding how much of an atmosphere the planet has; is it gaseous like Saturn, an ice giant like Neptune, rocky like Earth, or something in between — a super-Earth or sub-Neptune?"*

However, reaching an accuracy of about 0.3 m/s in the measurement of radial velocities does not mean easily discovering other Earths around stars as large as the Sun, but it will certainly be possible to discover them around slightly smaller stars. Let us consider that Jupiter attracts the Sun to itself at a speed of 13 m/s, a value that for Earth drops to just over 0.08 m/s – just 8 cm/s – not exactly close to the theoretical



51 Pegasi b, also called "Dimidium", was the first exoplanet discovered orbiting a star similar to the Sun. This breakthrough discovery in 1995 confirmed that planets like Earth might exist elsewhere in the universe, even though 51 Pegasi b itself is actually a "hot Jupiter," something extremely different from Earth. Despite this, its discovery earned its discoverers a belated Nobel Prize (in 2019). [NASA/JPL-Caltech]



An image of the spectroscopic observations of the Sun made by NEID. NEID's spectral coverage extends significantly redder and bluer than the limits of human vision, enabling it to observe many critical spectral lines. NEID's design enables high spectral resolution, large wavelength coverage, and exquisite stability. [Dani Zemba, Guðmundur Stefánsson, and the NEID Team]

25 cm/s reachable by NEID with a single observation. Nevertheless, by suitably combining a good number of observations, it is possible to overcome that limit and recognize planet-star systems more similar to ours. To be able to do this, it is essential that the NEID measurements remain stable during the entire expected period of operation, at least five years. For this purpose, its optics are kept at a stable temperature within a thousandth of a degree!

In the long commissioning phase of NEID, the so-called "first light" was obviously also taken. The researchers chose the symbolic star 51 Pegasi, the first Sun-like star around which, in 1995, a planet was discovered. This measurement was an easy task for the new spectrograph, as the orbiting planet has a mass equal to about half that of Jupiter.

Now that NEID has become fully operational and 60% of the WIYN telescope's observation time has been booked in conjunction with the spectrograph, researchers are expecting great results. We are not referring only to the NEID team, as the instrument is, unlike other spectrographs of its capabilities, available to the entire international astronomical community regardless of the home scientific institution.

"I can't wait to see the results we and our colleagues around the world will produce over the next few years, from discovering new, rocky planets, to measuring the compositions of exoplanetary atmospheres, to measuring the shapes and orientations of planetary orbits, to characterization of the physical processes of these planets' host stars," said Jason Wright.

But NEID will not "just" observe distant stars, it will also observe the Sun through a small solar telescope that the NEID team has specially developed, as stated by Eric Ford, professor of astronomy and astrophysics and director of Penn State's Center for Exoplanets and Habitable Worlds: *"Thanks to the NEID solar telescope funded by the Heising-Simons Foundation, NEID won't sit idle during the day. Instead, it will carry out a second mission, collecting a unique dataset that will enhance the ability of machine learning algorithms to recognize the signals of low-mass planets during the nighttime."*

NEID, therefore, also marks the return of solar observations to Kitt Peak, which was suspended in 2017 when renovations began on the historic Dunn Solar Telescope. ■

VLT and ALMA reveal stunning features of nearby galaxies

by ESO - Bárbara Ferreira

Astronomers know that stars are born in clouds of gas, but what sets off star formation, and how galaxies as a whole play into it, remains a mystery. To understand this process, a team of researchers has observed various nearby galaxies with powerful telescopes on the ground and in space, scanning the different galactic regions involved in stellar births. *"For the first time we are resolving individual units of star formation over a wide range of locations and environments in a sample that well represents the different types of galaxies,"* says Eric Emsellem, an astronomer at ESO in Germany and lead of the VLT-based observations conducted as part of the Physics at High Angular resolution in Nearby GalaxieS (PHANGS) project. *"We can directly observe the gas that gives birth to stars, we see the young stars themselves, and we witness their evolution through various phases."*

Image of the nearby galaxy NGC 4303 obtained by combining observations taken by the Multi-Unit Spectroscopic Explorer (MUSE) on ESO's Very Large Telescope (VLT) and the Atacama Large Millimeter/submillimeter Array (ALMA), in which ESO is a partner. NGC 4303 is a spiral galaxy, centered on a bar of stars and gas, located approximately 55 million light-years from Earth in the constellation Virgo. [ESO/ALMA (ESO/NAOJ/NRAO)/PHANGS]

NGC 4254 is a grand-design spiral galaxy located approximately 45 million light-years from Earth in the constellation Coma Berenices. Instrumentation and technical features of the image similar to those of NGC 4303. [ESO/ALMA (ESO/NAOJ/NRAO)/PHANGS]

Emsellem, who is also affiliated with the University of Lyon, France, and his team have now released their latest set of galactic scans, taken with the Multi-Unit Spectroscopic Explorer (MUSE) instrument on ESO's VLT in the Atacama Desert in Chile. They used MUSE to trace newborn stars and the warm gas around them, which is illuminated and heated up by the stars and acts as a smoking gun of ongoing star formation.

The new MUSE images are now being combined with observations of the same galaxies taken with ALMA and released.

ALMA, which is also located in Chile, is especially well suited to mapping cold gas clouds — the parts of galaxies that provide the raw material out of which stars form. By combining MUSE and ALMA images astronomers can examine the galactic regions where star formation is happening, compared to where it is expected to happen, so as to better understand what triggers, boosts or holds back the birth of new stars. The resulting images are stunning, offering a spectacularly colourful insight into stellar nurseries in our neighbouring galaxies.

"There are many mysteries we want to unravel," says Kathryn Kreckel from the University of Heidelberg in Germany and PHANGS team member. *"Are stars more often born in specific regions of their host galaxies — and, if so, why? And after stars are born how does their evolution influence the formation of new generations of stars?"*

Astronomers will now be able to answer these questions thanks to the wealth of MUSE and ALMA data the PHANGS team have obtained. MUSE collects spectra — the "bar codes" astronomers scan to unveil the properties and nature of cosmic objects — at every single location within its field of view, thus providing much richer information than traditional instruments.

For the PHANGS project, MUSE observed 30,000 nebulae of warm gas and collected about 15 million spectra of different galactic regions. The ALMA observations, on the other hand, allowed astronomers to map around 100,000 cold-gas regions across 90 nearby galaxies, producing an unprecedentedly sharp atlas of stellar nurseries in the close Universe.

NGC 3627 is a spiral galaxy located approximately 31 million light-years from Earth in the constellation Leo. Instrumentation and technical features of the image similar to those of NGC 4303. [ESO/ALMA(ESO/NAOJ/NRAO)/PHANGS]

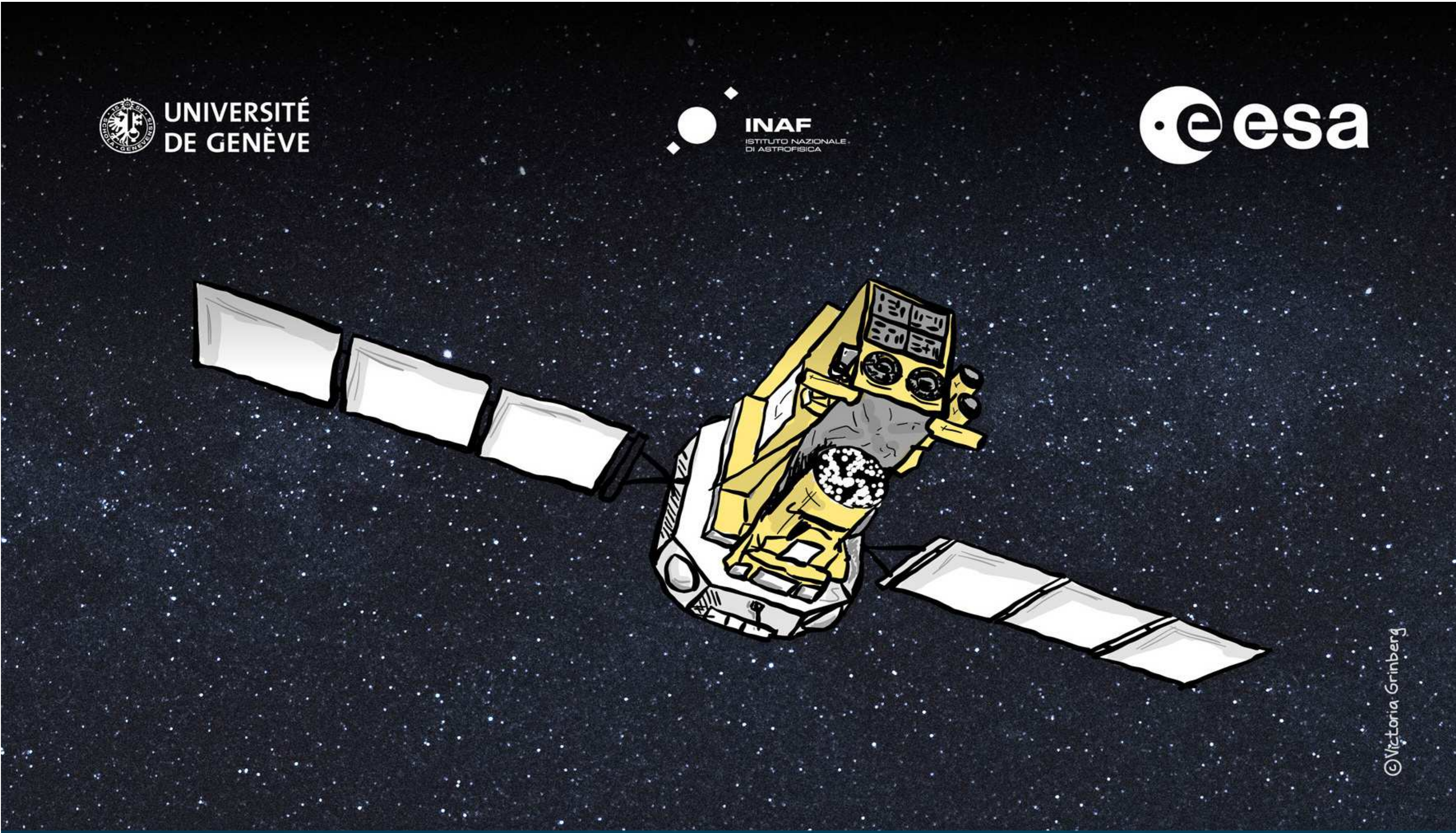
In addition to ALMA and MUSE, the PHANGS project also features observations from the NASA/ESA Hubble Space Telescope. The various observatories were selected to allow the team to scan our galactic neighbours at different wavelengths (visible, near-infrared and radio), with each wavelength range unveiling distinct parts of the observed galaxies. *"Their combination allows us to probe the various stages of stellar birth — from the formation of the stellar nurseries to the onset of star formation itself and the final destruction of the nurseries by the newly born stars — in more detail than is possible with individual observations,"* says PHANGS team member Francesco Belfiore from INAF-Arcetri in Florence, Italy. *"PHANGS is the first time we have been able to assemble such a complete view, taking images sharp enough to see the individual clouds, stars, and nebulae that signify forming stars."*

NGC 1300 is a spiral galaxy, with a bar of stars and gas at its centre, located approximately 61 million light-years from Earth in the constellation Eridanus. Instrumentation and technical features of the image similar to those of NGC 4303. [ESO/ALMA(ESO/NAOJ/NRAO)/PHANGS]

The work carried out by the PHANGS project will be further honed by upcoming telescopes and instruments, such as NASA's James Webb Space Telescope. The data obtained in this way will lay further groundwork for observations with ESO's future Extremely Large Telescope (ELT), which will start operating later this decade and will enable an even more detailed look at the structures of stellar nurseries.

"As amazing as PHANGS is, the resolution of the maps that we produce is just sufficient to identify and separate individual star-forming clouds, but not good enough to see what's happening inside them in detail," pointed out Eva Schinnerer, a research group leader at the Max Planck Institute for Astronomy in Germany and principal investigator of the PHANGS project, under which the new observations were conducted. *"New observational efforts by our team and others are pushing the boundary in this direction, so we have decades of exciting discoveries ahead of us."*

NGC 1087 is a spiral galaxy located approximately 80 million light-years from Earth in the constellation Cetus. Instrumentation and technical features of the image similar to those of NGC 4303. [ESO/ALMA(ESO/NAOJ/NRAO)/PHANGS]



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The most precise look at the Universe's evolution

by NOIRLab - Amanda Kocz

New results from the Dark Energy Survey (DES) use the largest-ever sample of galaxies observed over nearly one-eighth of the sky to produce the most precise measurements to date of the Universe's composition and growth. DES images the night sky using the 570-megapixel Dark Energy Camera on the National Science Foundation's Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile, a Program of NSF's NOIRLab. One of the most powerful digital cameras in the world, the Dark Energy Camera was

Ten areas in the sky were selected as "deep fields" that the Dark Energy Camera imaged several times during the survey, providing a glimpse of distant galaxies and helping determine their 3D distribution in the cosmos. The image is teeming with galaxies — in fact, nearly every single object in this image is a galaxy. Some exceptions include a couple of dozen asteroids as well as a few handfuls of foreground stars in our own Milky Way. [Dark Energy Survey/DOE/FNAL/DECam/CTIO/NOIRLab/NSF/AURA. Ack.: T.A. Rector (University of Alaska Anchorage/NSF's NOIRLab), M. Zamani (NSF's NOIRLab) & D. de Martin (NSF's NOIRLab)]

designed specifically for DES. It was funded by the Department of Energy (DOE) and was built and tested at DOE's Fermilab.
Over the course of six years, from 2013 to 2019, DES used 30% of the time on the Blanco Telescope and surveyed 5,000 square degrees — almost one-eighth of the entire sky — in 758 nights of observation, cataloging hundreds of millions of objects. The results of the survey draw on data from the first three years — 226 million galaxies observed over 345 nights — to create the largest and most precise maps yet of the distribution of galaxies in the Universe at relatively recent epochs. The DES data were processed at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign.
"NOIRLab is a proud host for and member of the DES collaboration," said Steve Heathcote, CTIO Associate Director. *"Both during and after the survey, the Dark Energy Camera has been a popular choice for community and Chilean astronomers."*
At present the Dark Energy Camera is used for programs covering a huge range of science including cosmology. The Dark Energy Camera science archive, including DES Data Release 2 on which these results are based, is curated by the Community Science and Data Center (CSDC), a Program of NSF's NOIRLab. CSDC provides software systems, user serv-

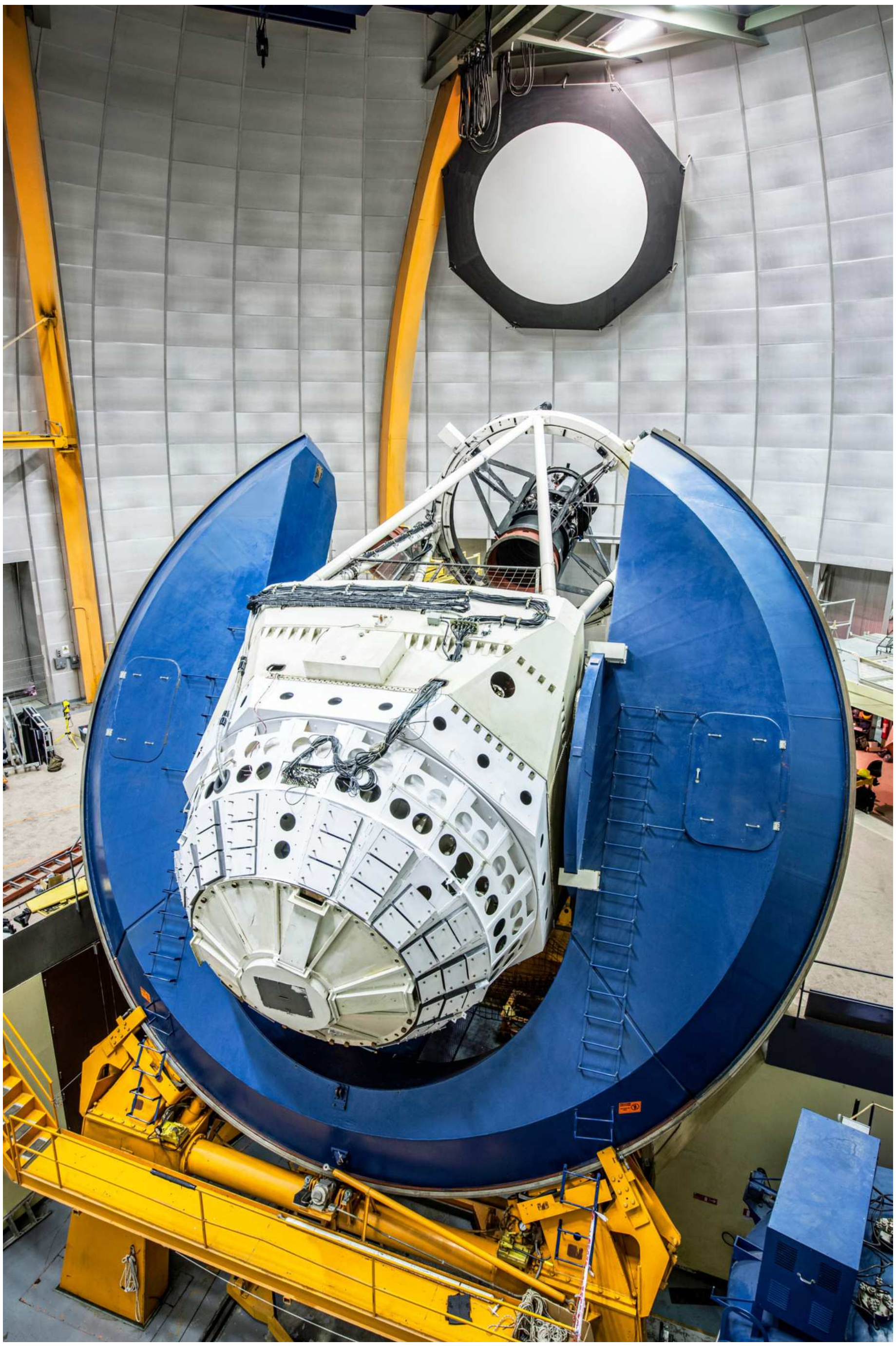
ices, and development initiatives to connect and support the scientific missions of NOIRLab's telescopes, including the Blanco telescope at CTIO.

Since DES studied nearby galaxies as well as those billions of light-years away, its maps provide both a snapshot of the current large-scale structure of the Universe and a view of how that structure has evolved over the past 7 billion years.

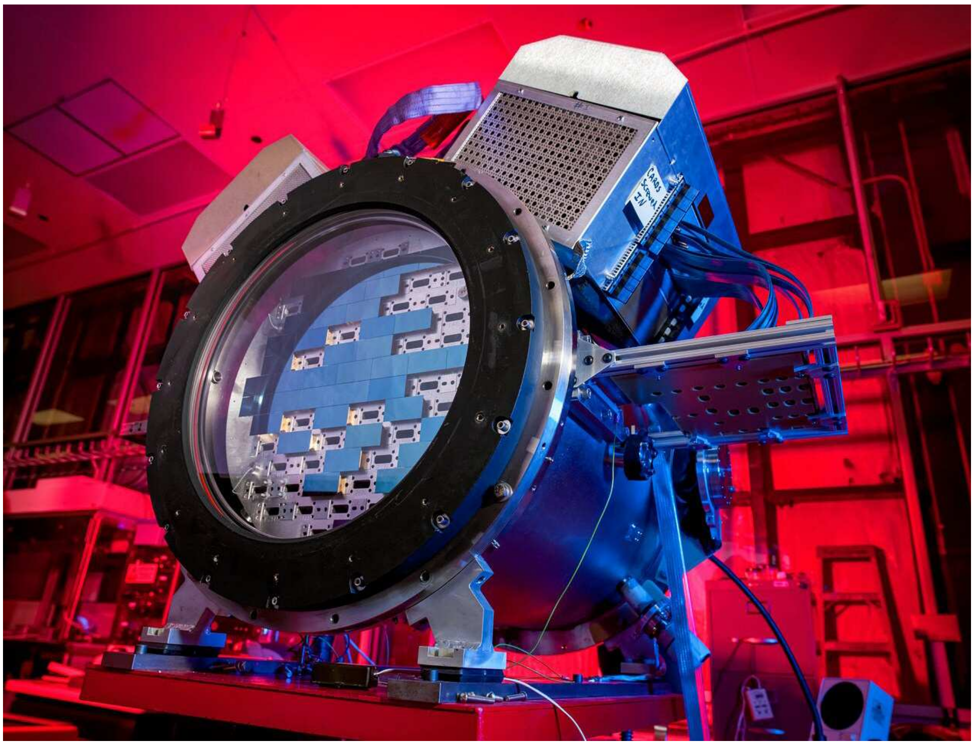
Ordinary matter makes up only about 5% of the Universe. Dark energy, which cosmologists hypothesize drives the accelerating expansion of the Universe by counteracting the force of gravity, accounts for about 70%. The last 25% is dark matter, whose gravitational influence binds galaxies together. Both dark matter and dark energy remain invisible. DES seeks to illuminate their nature by studying how the competition between them shapes the large-scale structure of the Universe over cosmic time.

To quantify the distribution of dark matter and the effect of dark energy, DES relied mainly on two phenomena. First, on large scales galaxies are not distributed randomly throughout space but rather form a weblike structure that is due to the gravity of dark matter. DES measured how this cosmic web has evolved over the history of the Universe. The galaxy clustering that forms the cosmic web in turn revealed regions with a higher density of dark matter.

Second, DES detected the signature of dark matter through weak gravitational lensing. As light from a distant galaxy trav-



This image shows an immersive view from inside the dome of the Víctor M. Blanco 4-meter Telescope at the Cerro Tololo Inter-American Observatory (CTIO), a Program of NSF's NOIRLab. The Dark Energy Survey photographed the night sky using the 570-megapixel Dark Energy Camera on the Blanco. [DOE/FNAL/DECam/R. Hahn/CTIO/NOIRLab/NSF/AURA]



The Dark Energy Survey camera (DECam) at the SiDet clean room. The Dark Energy Camera was designed specifically for the Dark Energy Survey. It was funded by the Department of Energy (DOE) and was built and tested at DOE's Fermilab. [DOE/ FNAL/ DECam/R. Hahn/ CTIO/NOIRLab/NSF/AURA]

els through space, the gravity of both ordinary and dark matter in the foreground can bend its path, as if through a lens, resulting in a distorted image of the galaxy as seen from Earth. By studying how the apparent shapes of distant galaxies are aligned with each other and with the positions of nearby galaxies along the line of sight, DES scientists were able to infer the clumpiness of the dark matter in the Universe.

To test cosmologists' current model of the Universe, DES scientists compared their results with measurements from the European Space Agency's orbiting Planck observatory. Planck used light known as the cosmic microwave background to peer back to the early Universe, just 400,000 years after the Big Bang. The Planck data give a precise view of the Universe 13 billion years ago, and the standard cosmological model predicts how the dark matter should evolve to the present.

Combined with earlier results DES provides the most powerful test of the current best model of the Universe to date, and the results are consistent with the predictions of the standard model of cosmology. However, hints remain from DES and several previous galaxy surveys that the Universe today is a few percent less clumpy than predicted.

Ten regions of the sky were chosen as "deep fields" that the Dark Energy Camera imaged repeatedly throughout the survey. Stacking those images together allowed the scientists to glimpse more distant galaxies. The team then used the redshift information from the deep fields to calibrate the rest of the survey region.

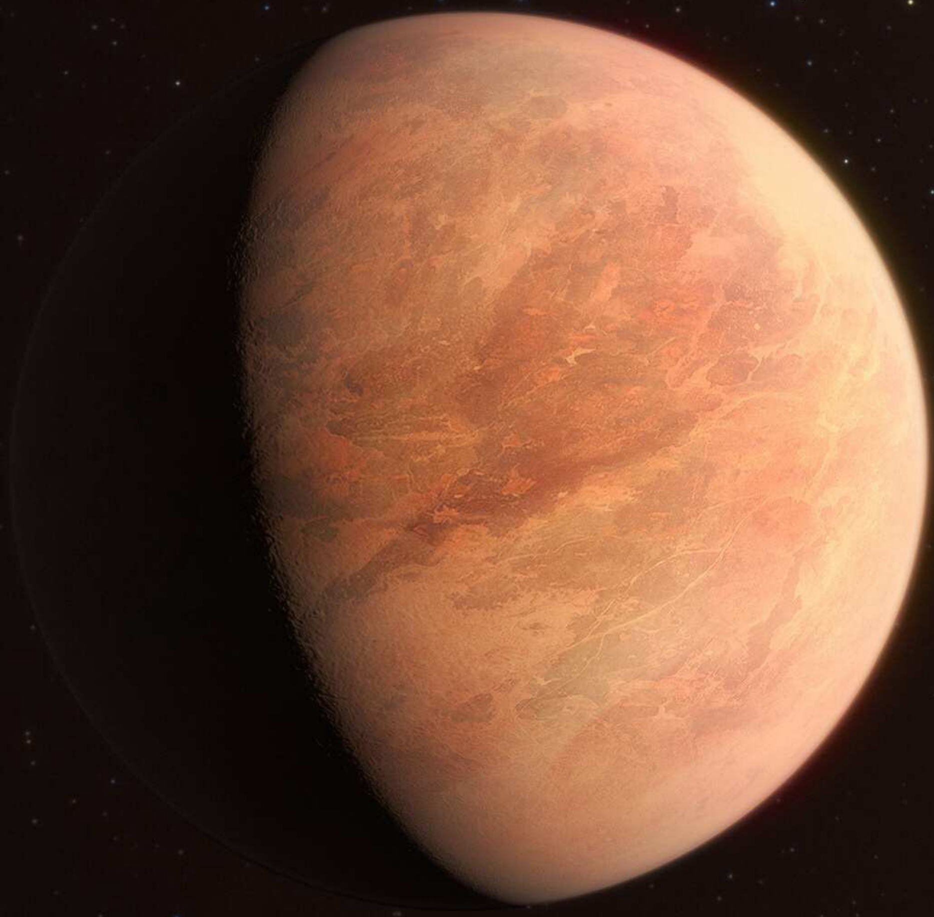
This and other advancements in measurements and modeling, coupled with a threefold increase in data compared to the first year, enabled the team to pin down the density and clumpiness of the Universe with unprecedented precision. DES concluded its observations of the night sky in 2019. With the experience gained from analyzing the first half of the data, the team is now prepared to handle the complete dataset. The final DES analysis is expected to paint an even more precise picture of the dark matter and dark energy in the Universe. The DES collaboration consists of over 400 scientists from 25 institutions in seven countries.

"The collaboration is remarkably young. It's tilted strongly in the direction of postdocs and graduate students who are doing a huge amount of this work," said DES Director and spokesperson Rich Kron, who is a Fermilab and University of Chicago scientist. *"That's really gratifying. A new generation of cosmologists are being trained using the Dark Energy Survey."*

The methods developed by the team have paved the way for future sky surveys such as the Rubin Observatory Legacy Survey of Space and Time. *"DES shows that the era of big survey data has well and truly begun,"* notes Chris Davis, NSF's Program Director for NOIRLab. *"DES on NSF's Blanco telescope has set the scene for the remarkable discoveries to come with Rubin Observatory over the coming decade."* ■

L 98-59, a rather interesting system

by ESO - Bárbara Ferreira



A team of astronomers have used the European Southern Observatory's Very Large Telescope (ESO's VLT) in Chile to shed new light on planets around a nearby star, L 98-59, that resemble those in the inner Solar System. Amongst the findings are a planet with half the mass of Venus — the lightest exoplanet ever to be measured using the radial velocity technique — an ocean world, and a possible planet in the habitable zone. *"The planet in the habitable zone may have an atmosphere that could protect and support life,"* says María Rosa Zapatero Osorio, an as-

This artist's impression shows L 98-59b, one of the planets in the L 98-59 system 35 light-years away. The system contains four confirmed rocky planets with a potential fifth, the furthest from the star, being unconfirmed. [ESO/M. Kornmesser]

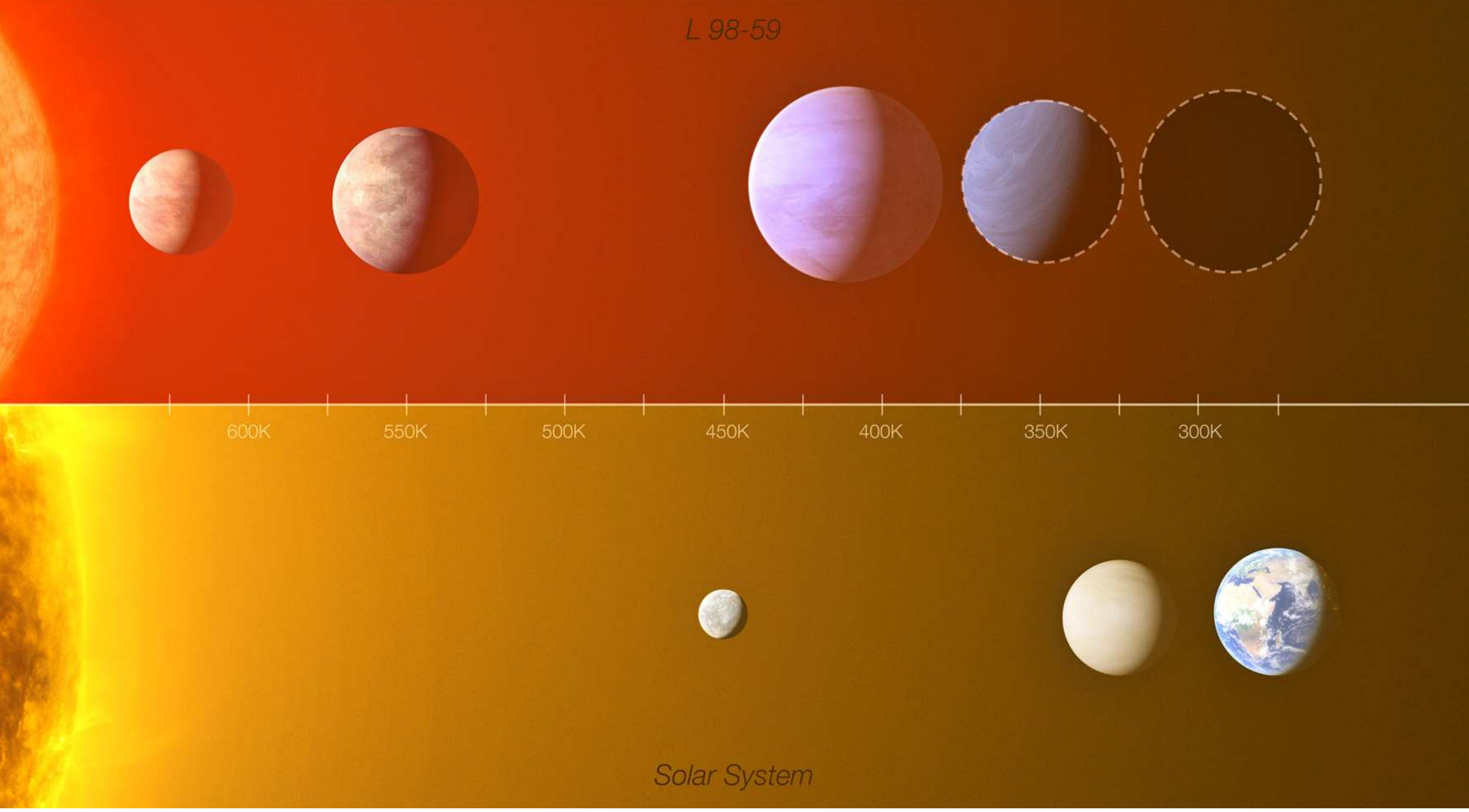
tronomer at the Centre for Astrobiology in Madrid, Spain, and one of the authors of the study published in *Astronomy & Astrophysics*.

The results are an important step in the quest to find life on Earth-sized planets outside the Solar System. The detection of biosignatures on an exoplanet depends on the ability to study its atmosphere, but current telescopes are not large enough to achieve the resolution needed to do this for small, rocky planets. The newly studied planetary system, called L 98-59 after its star, is an attractive target for future observations of exoplanet atmospheres. Its orbits a star only 35 light-years away and has now been found to host rocky planets, like Earth or Venus, which are close enough to the star to be warm.

With the contribution of ESO's VLT, the team was able to infer that three of the planets may contain water in their interiors or atmospheres. The two planets closest to the star in the L 98-59 system are probably dry, but might have small amounts of water, while up to 30% of the third planet's mass could be water, making it an ocean world.

Furthermore, the team found "hidden" exoplanets that had not previously been spotted in this planetary system. They discovered a fourth planet and suspect there is a fifth, in a zone at the right distance from the star for liquid water to exist on its surface. *"We have hints of the presence of a terrestrial planet in the habitable zone of this system,"* explains Olivier Demangeon, a researcher at the Instituto de Astrofísica e Ciências do Espaço, University of Porto in Portugal and lead author of the new study.

The study represents a technical breakthrough, as astronomers were able to determine, using the radial velocity method, that the innermost



This infographic shows a comparison between the L 98-59 exoplanet system (top) with part of the inner Solar System (Mercury, Venus and Earth), highlighting the similarities between the two. [ESO/L. Calçada/M. Kornmesser (Ack.: O. Demangeon)]

planet in the system has just half the mass of Venus. This makes it the lightest exoplanet ever measured using this technique, which calculates the wobble of the star caused by the tiny gravitational tug of its orbiting planets.

The team used the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations (ESPRESSO) instrument on ESO's VLT to study L 98-59. *"Without the precision and stability provided by ESPRESSO this measurement would have not been possible,"* says Zapatero Osorio. *"This is a step forward in our ability to measure the masses of the smallest planets beyond the Solar System."*

The astronomers first spotted three of L 98-59's planets in 2019, using NASA's Transiting Exoplanet Survey Satellite (TESS). This satellite relies on a technique called the transit method — where the dip in the light coming from the star caused by a planet passing in front of it is used to infer the properties of the planet — to find the planets and measure their sizes. However, it was only with the addition of radial velocity measurements made with ESPRESSO and its predecessor, the High Accuracy Radial velocity Planet Searcher (HARPS) at the ESO La Silla 3.6-metre telescope, that Demangeon and his team were able to find extra planets and measure the masses and radii of the first three. *"If we want to know what a planet is made of, the minimum that we need is its mass and its radius,"* Demangeon explains.

The team hopes to continue to study the system with the forthcoming NASA/ESA/CSA James Webb Space Telescope (JWST), while ESO's Extremely Large Telescope (ELT), under construction in the Chilean Atacama Desert and set to start observations in 2027, will also be ideal for studying these planets. *"The HIRES instrument on the ELT may have the power to study the atmospheres of some of the planets in the L 98-59 system, thus complementing the JWST from the ground,"* says Zapatero Osorio. *"This system announces what is to come,"* adds Demangeon. *"We, as a society, have been chasing terrestrial planets since the birth of astronomy and now we are finally getting closer and closer to the detection of a terrestrial planet in the habitable zone of its star, of which we could study the atmosphere."* ■

A team of astronomers have used ESO's Very Large Telescope in Chile to shed new light on planets around a nearby star that resemble those in the inner Solar System. This video summarises what they found about the planetary system, called L 98-59. [ESO]

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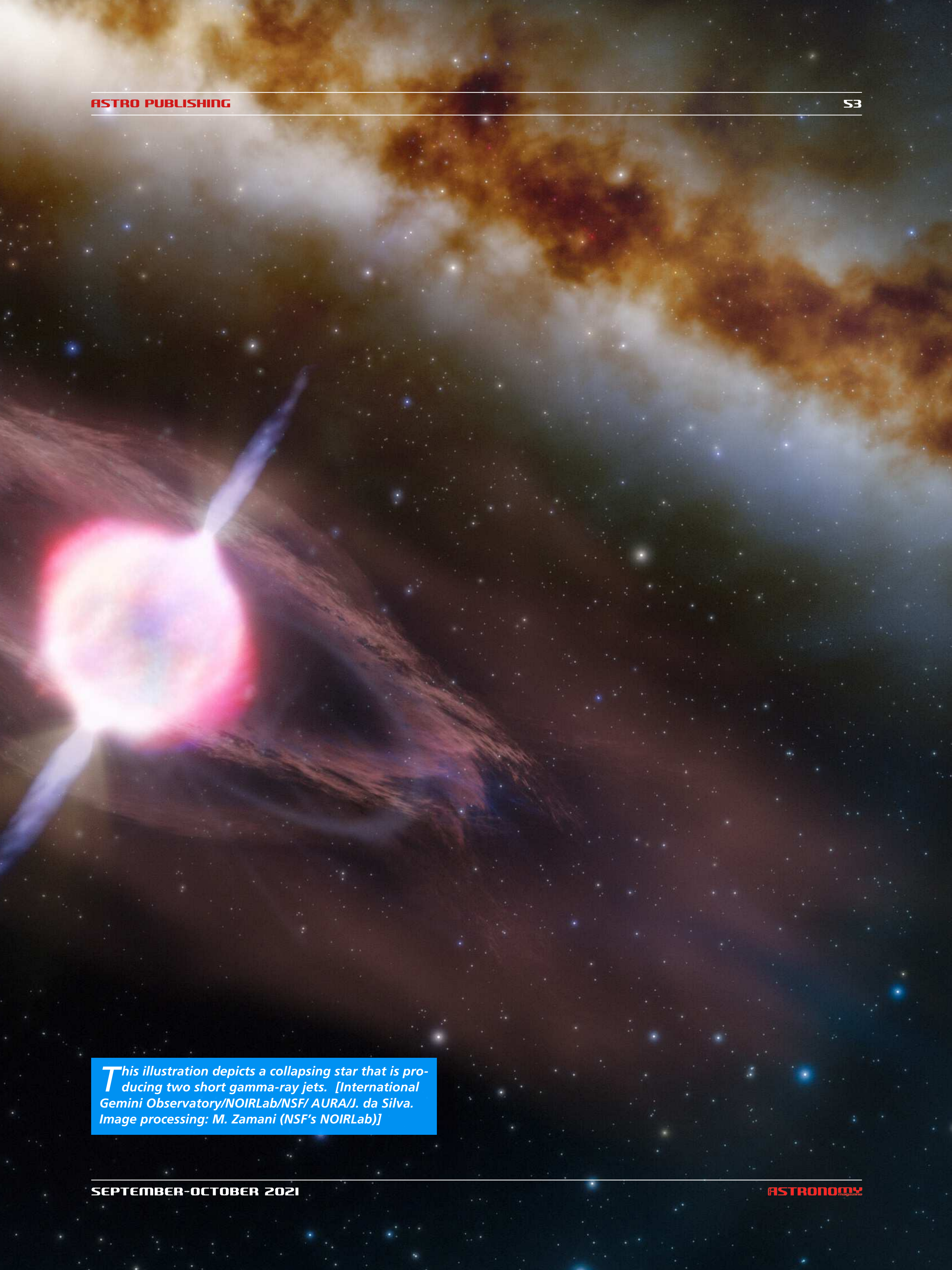
Astronomers uncover briefest supernova-powered gamma-ray burst

by NOIRLab - Amanda Kocz

Astronomers have discovered the shortest-ever gamma-ray burst (GRB) caused by the implosion of a massive star. Using the international Gemini Observatory, a Program of NSF's NOIRLab, astronomers identified the cause of this 0.6-second flurry of gamma rays as a supernova explosion in a distant galaxy.

GRBs caused by supernovae are usually more than twice as long, which suggests that some short GRBs might actually be imposters — supernova-produced GRBs in disguise. Gamma-ray bursts (GRBs) are among the brightest and most energetic events in the Universe, but scientists are still figuring out exactly what causes these fleeting events. Astronomers divide GRBs into two broad categories based on their duration. Short GRBs blaze into life in less than two seconds and are thought to be caused by the merging of binary neutron stars. Those that last longer are classified as long GRBs, and have been associated with supernova explosions caused by the implosions of massive stars. However, the recent discovery of the shortest-ever GRB produced during a supernova shows that GRBs don't fit neatly into the boxes astronomers have created for them.



This illustration depicts a collapsing star that is producing two short gamma-ray jets. [International Gemini Observatory/NOIRLab/NSF/ AURA/J. da Silva. Image processing: M. Zamani (NSF's NOIRLab)]

Using the Gemini North telescope in Hawai'i, astronomers identified the cause of a surprisingly short burst of gamma rays. The source was a supernova explosion, which usually produces a long gamma-ray burst (GRB). Astronomers now think that this and many other short GRBs are actually supernova-produced GRBs in disguise. They suspect these GRBs look shorter because their gamma-ray jets aren't strong enough to completely escape the collapsing star. [Images and Videos: International Gemini Observatory/NOIRLab/NSF/AURA/J. da Silva/NASA/Goddard Space Flight Center. Image Processing: M. Zamani (NSF's NOIRLab). Music: Stellardrone - Airglow]

"This discovery represents the shortest gamma-ray emission caused by a supernova during the collapse of a massive star," commented Tomás Ahumada, who led this research and is a PhD candidate at the University of Maryland and astronomer at NASA's Goddard Space Flight Center. *"It lasted for only 0.6 seconds, and it sits on the brink between a successful and a failed gamma-ray burst."*

The team believes that this and some other supernova-related GRBs are appearing short because the jets of gamma rays that emerge from the collapsing star's poles aren't strong enough to completely escape the star — almost failing to produce a GRB — and that other collapsing stars have such weak jets that they don't produce GRBs at all.

This discovery could also help explain an astronomical mystery. Long GRBs are associated with a specific type of supernova (called Type Ic-BL). However, astronomers observe many more of these supernovae than long GRBs.

This discovery of the shortest GRB associated with a supernova suggests that some of these supernova-caused GRBs are masquerading as short GRBs thought to be created by neutron-star mergers, and are therefore not getting counted as the supernova kind.

"Our discovery suggests that, since we observe many more of these supernovae than long gamma-ray bursts, most collapsing stars fail to produce a GRB jet that breaks through the outer envelope of the collapsing star," explained Ahumada. *"We think this event was effectively a fizzle, one that was close to not happening at all."*

The team was able to determine that this GRB — identified as GRB 200826A — originated from a supernova explosion thanks to the imaging capabilities of the Gemini Multi-Object Spectrograph on Gemini North in Hawai'i. The researchers used Gemini North to obtain images of the GRB's host galaxy 28, 45, and 80 days after the GRB was first detected on 26 August 2020 by a network of observatories that included NASA's Fermi Gamma-ray Space Telescope. Gemini's observations allowed the team to spot the tell-tale rise in energy that signifies a supernova, despite the blast's location in a galaxy 6.6 billion light-years away.

"This was a complicated endeavor as we needed to separate the light of an already faint galaxy from the light of a supernova," said Ahumada. *"Gemini is the only ground-based telescope that can do follow-up observations like this with a flexible-enough schedule to let us squeeze in our observations."* This result shows that classifying GRBs based solely on their duration may not be the best approach, and that additional observations are needed to determine a GRB's cause. *"We were originally hunting for merging neutron stars, which are thought to produce short gamma-ray bursts,"* added Ahumada. *"Once we discovered GRB 200826A, however, we realized that this burst was more likely to be caused by a collapsing star's supernova, which was a surprise!"*

"The Gemini observatories continue to shed new light on the nature of these incredible explosions occurring across the distant Universe," said Martin Still, Gemini Program Officer at NSF. *"Dedicated instrumentation arriving for use over the next decade will maintain Gemini's leadership in the follow-up of these awe-inspiring cosmic events."* ■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