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News from the TRAPPIST-1 system

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- Keck Observatory achieves first light with NIRES
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- SMBHs–host galaxies co-evolution deepened by ALMA

A WR star at the origin of the Solar System

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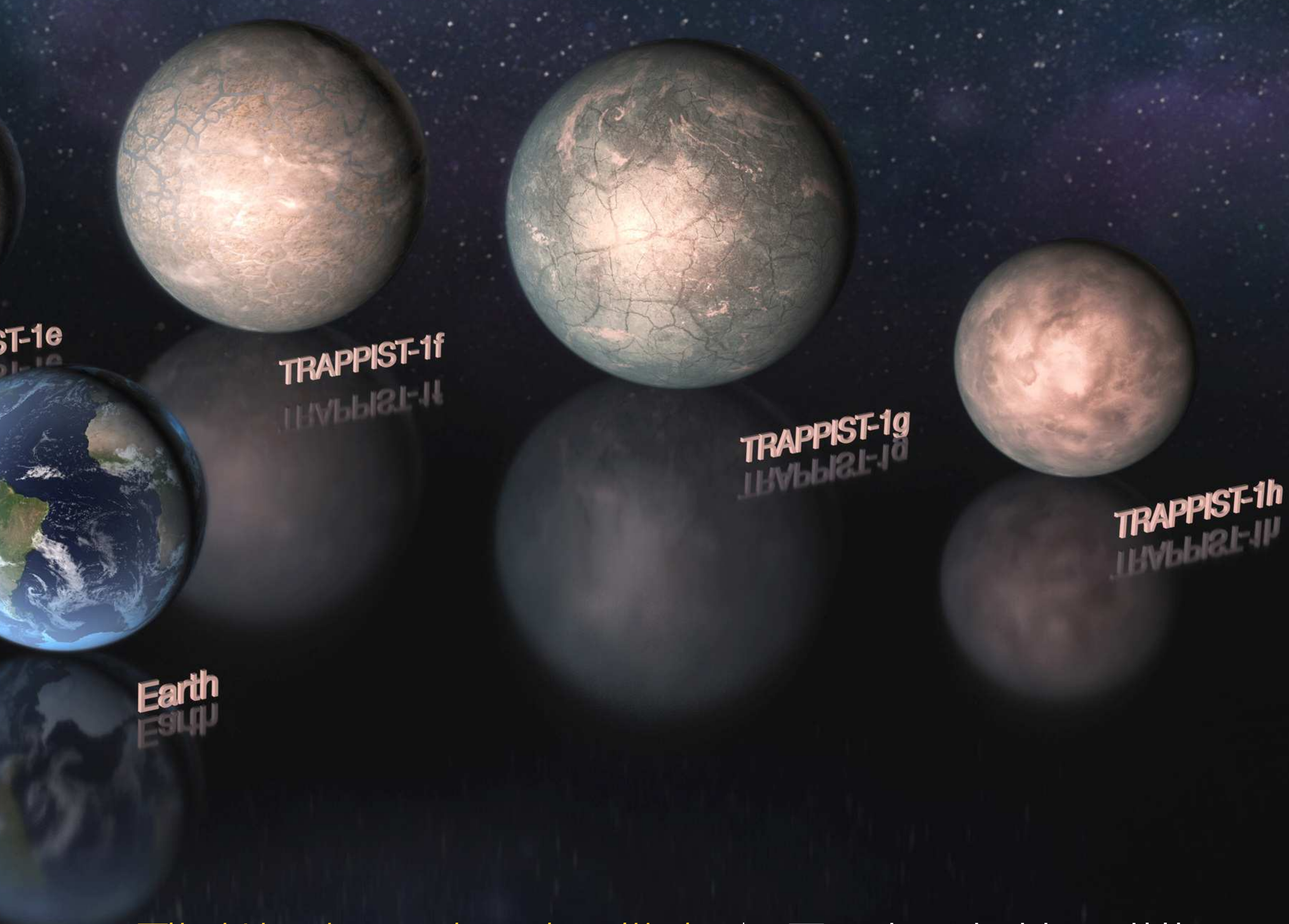
S U M M A R Y

News from the system

by Michele Ferrara

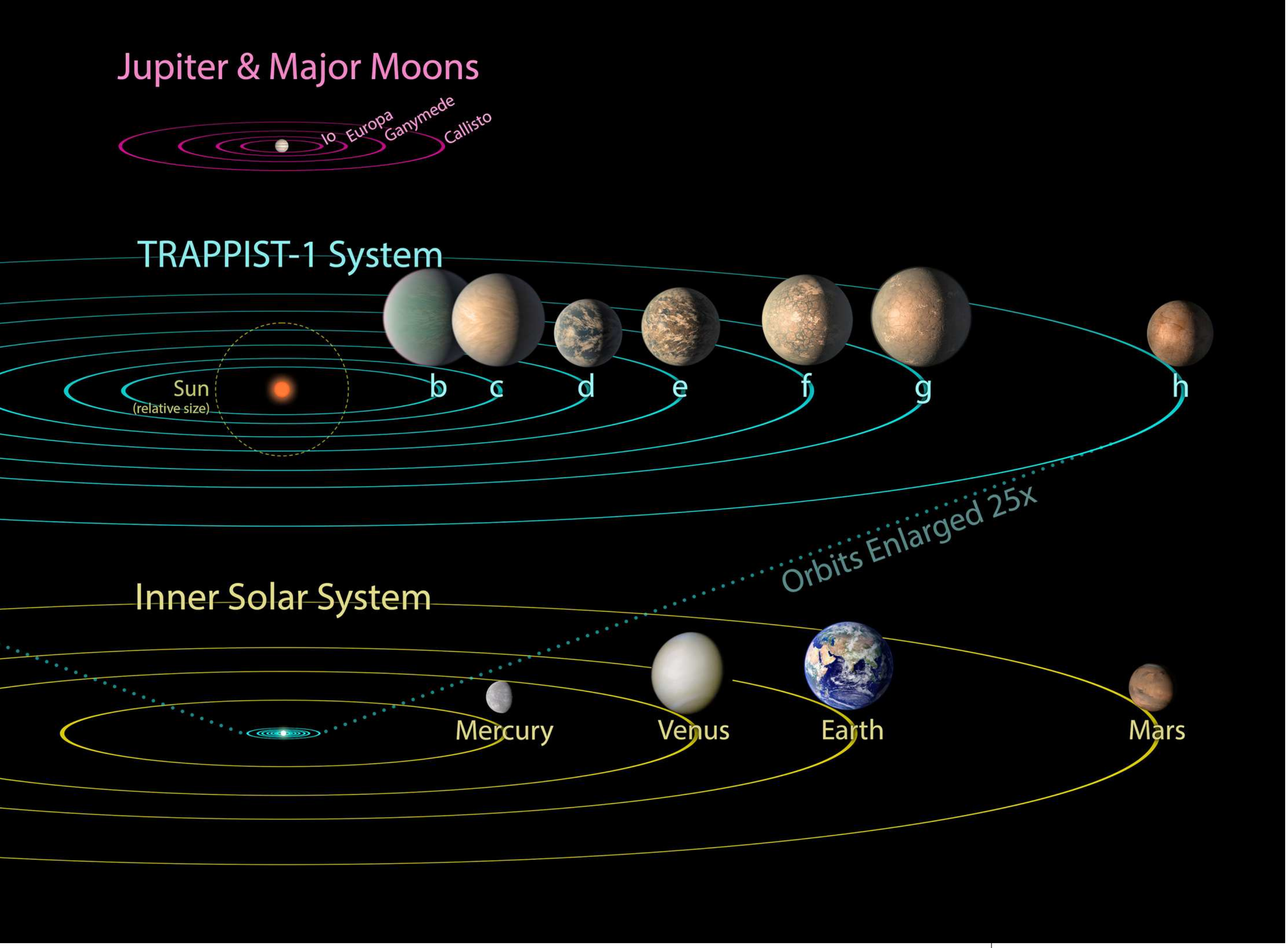
In the last year, many studies dedicated to the extraordinary TRAPPIST-1's planetary system have been realised and published. Sometimes, works published a short distance from one another have described antithetical scenarios, but as a whole, the efforts made by researchers portrayed the system as even more interesting.

TRAPPIST-1

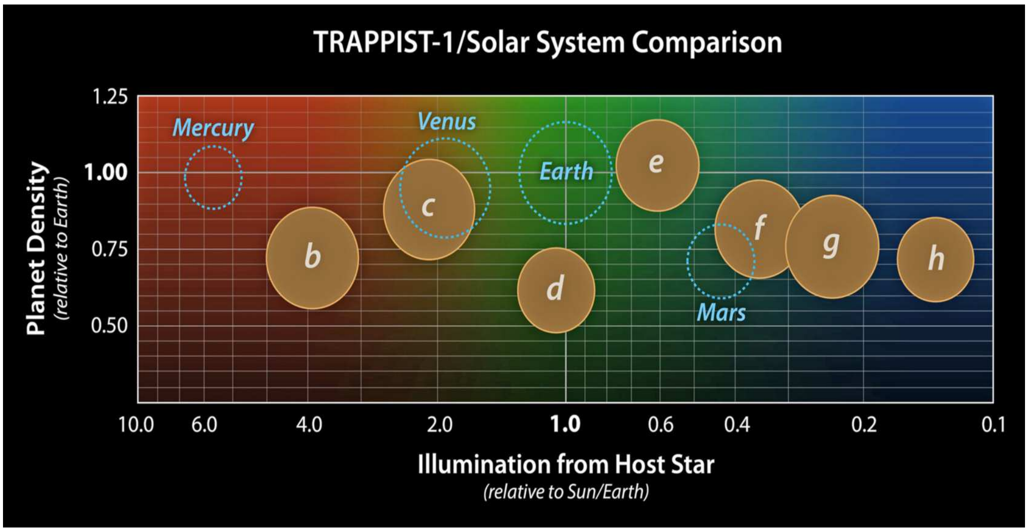


This artist's impression compares the seven planets orbiting the ultra-cool red dwarf star TRAPPIST-1 to the Earth at the same scale. New observations, when combined with very sophisticated analysis, have now yielded good estimates of the densities of all seven of the Earth-sized planets and suggest that they are rich in volatile materials, probably water. They are shown to the same scale but not in the correct relative positions. [ESO/M. Kornmesser]

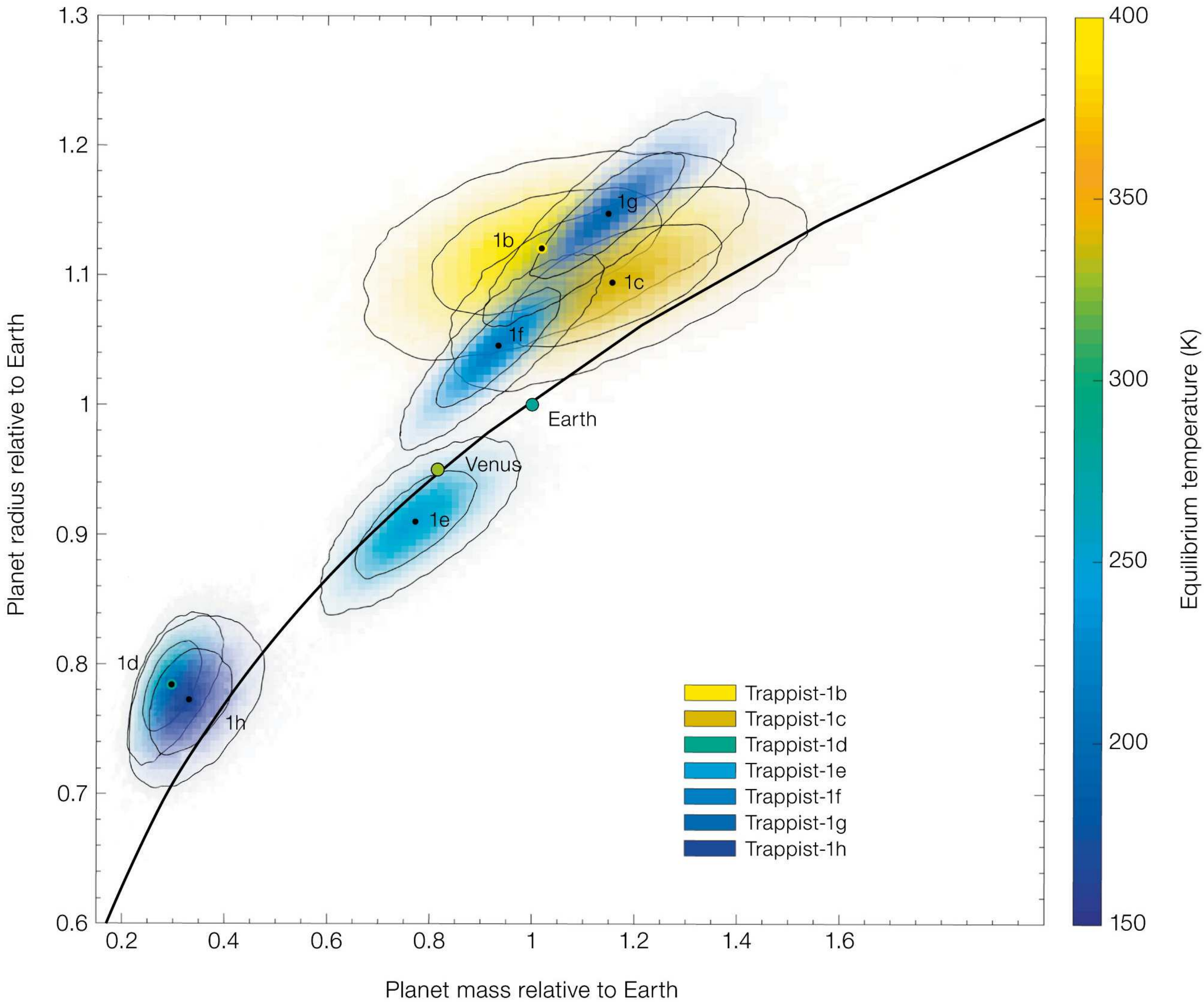
From time to time it is unavoidable to go back to talking about TRAPPIST-1, a decidedly dwarf and relatively cold star, around which there are as many as seven planets of a size comparable to that of Earth's. We had already talked about this system a couple of years ago (2016; 4), on the occasion of the discovery



of the first three planets. Then again a year ago (2017; 2), when we reported the discovery of the other four, and the possibility that above some water may exist and therefore an environment perhaps favourable to life as we know it. Now, we want to give an update on the leading news concerning the system in the last year, including the most recent and exciting studies published in specialised magazines.
We were left with uncertainties regarding the distance from the star of the outermost



This infographic compares the TRAPPIST-1 planetary system with the inner Solar System and the four Galilean moons of the planet Jupiter. Left, this diagram compares the masses and energy input of the seven TRAPPIST-1 planets, along with the properties of the four innermost Solar System planets. [NASA/JPL-Caltech]

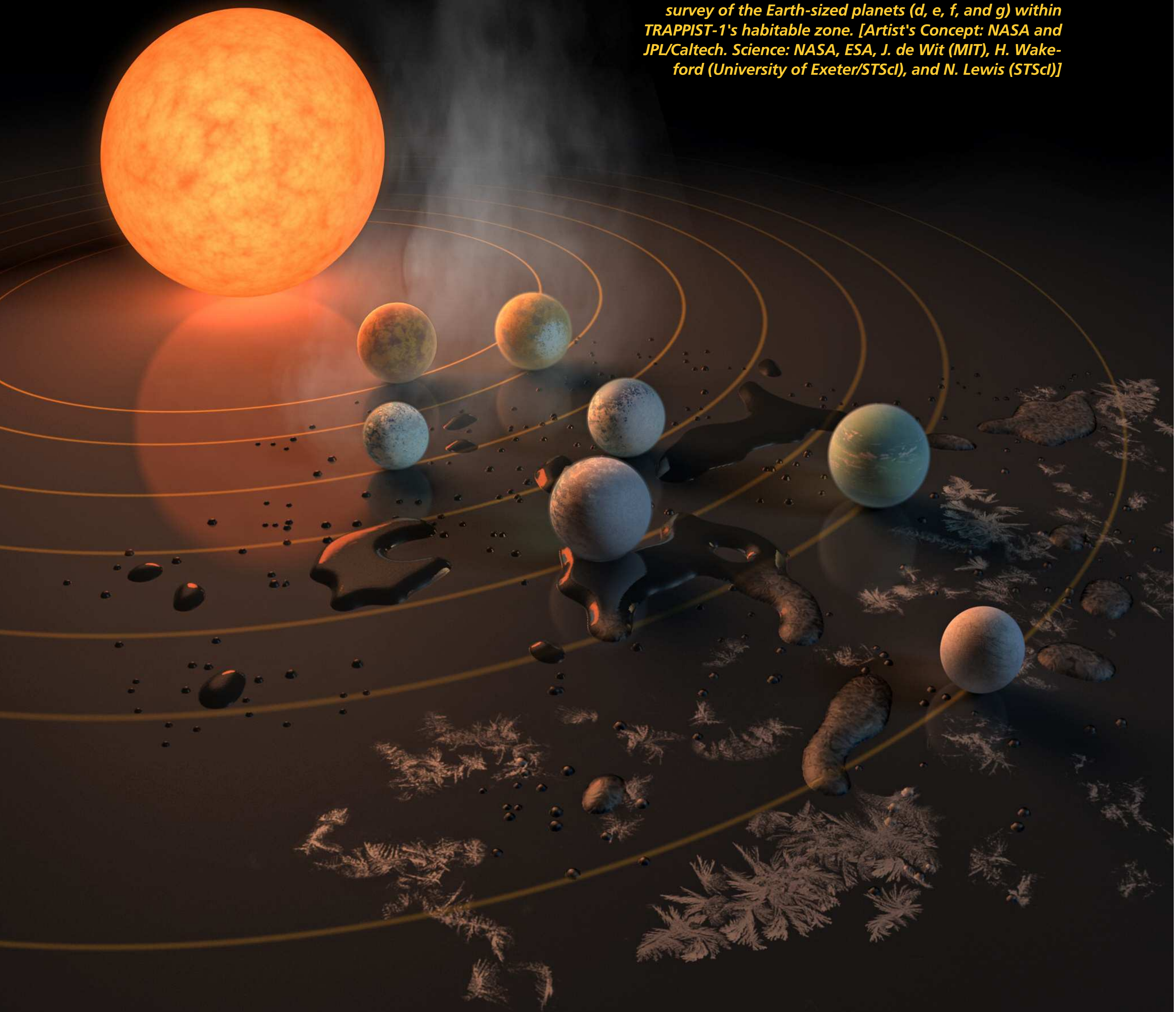


This diagram compares the sizes, masses and estimated temperatures of the TRAPPIST-1 planets with Solar System planets. The colours indicate temperatures and the black line matches the densities and composition of the terrestrial planets in the Solar System. Planets above the line are less dense and planets below are denser. [ESO/S. Grimm et al.]

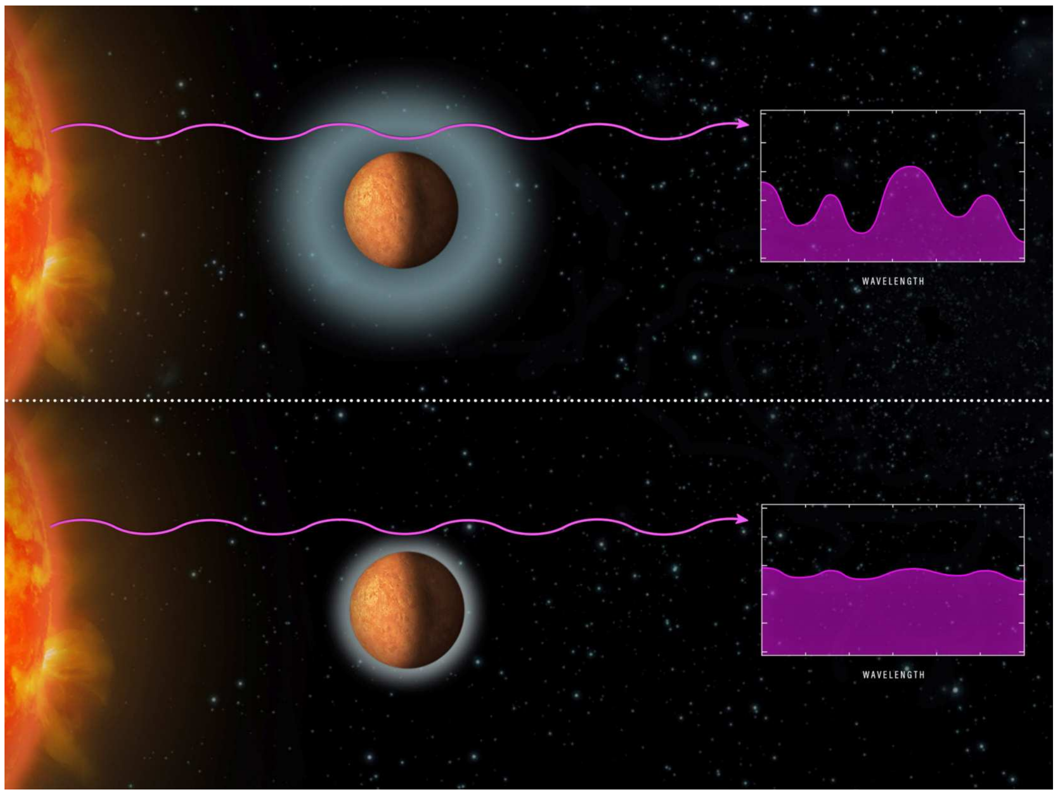
planet, TRAPPIST-1h, a fundamental parameter to understand whether liquid water can exist in that world (admitted and not granted that there is water). A team of researchers, led by Rodrigo Luger of the University of Washington, intervened to solve the problem. In an article published in *Nature Astronomy* last May, the team reports the results of processing the photometric data of TRAPPIST-1 collected by the Kepler space telescope between December 2016 and March 2017.

In this period, known as K2 Campaign 12, Kepler monitored the small star for 74 days, providing the longest, nearly continuous set of observations of TRAPPIST-1. This data allowed the researchers to study the mutual gravitational interactions between planets and to better characterise the individual orbits. The orbital period of TRAPPIST-1h was found to be 18.76 days, which corresponds to an average distance from the star of 9.27 million km, too excessive to suppose that liquid water can exist on that planet. Thus, the Luger team excluded the farthest planet from the TRAPPIST-1's habitable zone, after the two closest ones, TRAPPIST-1b and TRAPPIST-1c, had already been considered uninhabitable, not only for the maximum surface temperatures (higher than 100°C), but also because their rotation periods are surely synchronized with their revolution periods, which leads them to always expose the same hemisphere to the star radiation, with non-positive consequences.

At that point, many exoplanet specialists focused their attention on the four planets almost certainly orbiting in the habitable zone: TRAPPIST-1d, TRAPPIST-1e, TRAPPIST-1f



This artist's concept appeared on the Feb. 23, 2017, cover of the journal Nature announcing that the nearby star TRAPPIST-1, an ultra-cool dwarf, has seven Earth-sized planets orbiting it. Now, astronomers have used NASA's Hubble Space Telescope to conduct the first spectroscopic survey of the Earth-sized planets (d, e, f, and g) within TRAPPIST-1's habitable zone. [Artist's Concept: NASA and JPL/Caltech. Science: NASA, ESA, J. de Wit (MIT), H. Wakeford (University of Exeter/STScI), and N. Lewis (STScI)]

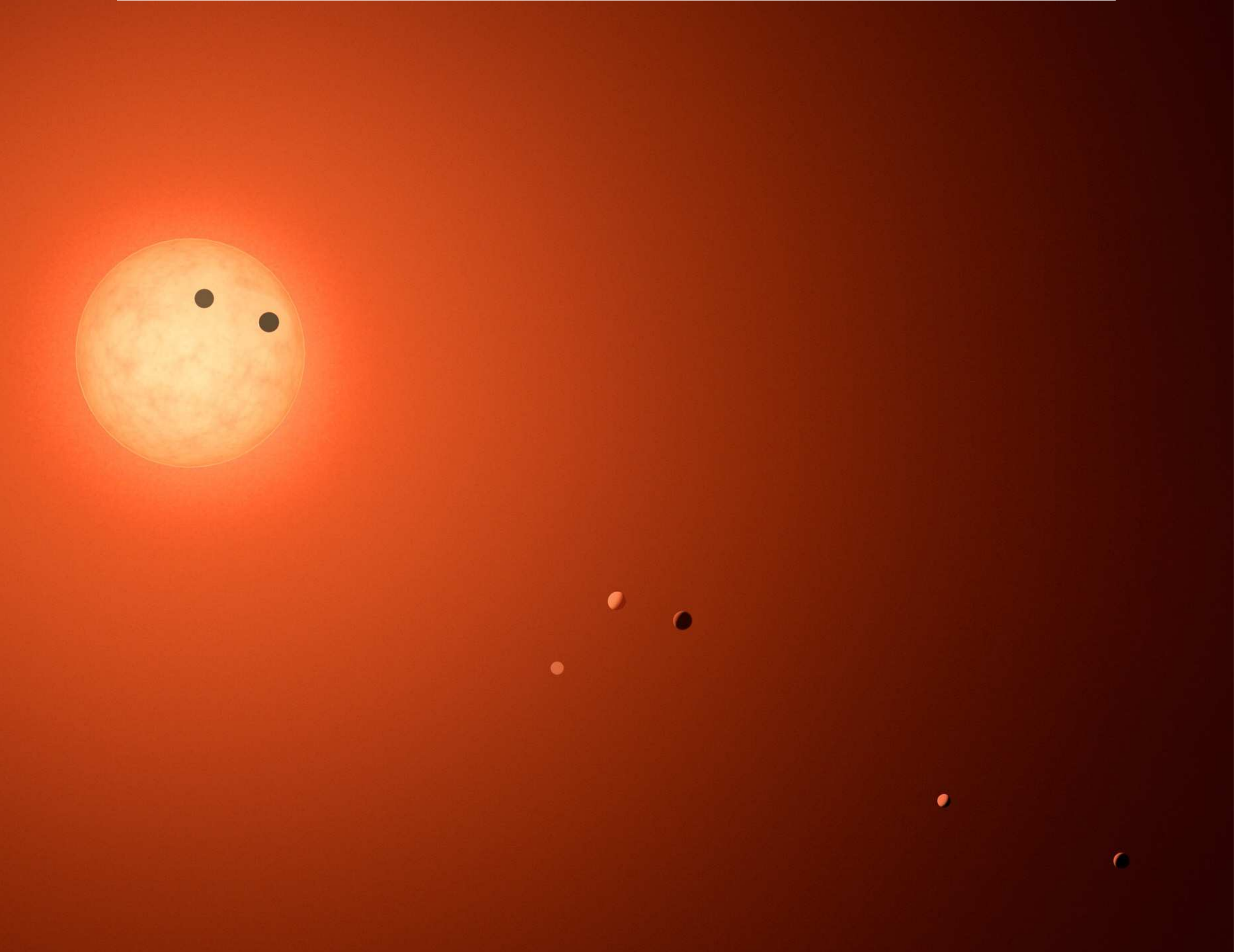


Astronomers used Hubble to analyze light from the nearby star TRAPPIST-1 that passed through the atmospheres of four Earth-sized planets in the star's habitable zone. This zone is a region at a distance from the star where liquid water, the key to life as we know it, could exist on the planet's surfaces. The astronomers were looking for the signatures of certain gases, including hydrogen, in the atmospheres that were imprinted on the starlight. The graphic at the top shows a model spectrum containing the signatures of gases the astronomers would expect to see if the exoplanets' atmospheres were puffy and dominated by primordial hydrogen from the distant worlds' formation. The Hubble Space Telescope observations, however, revealed that the planets do not have hydrogen-dominated atmospheres. The flat spectrum shown in the illustration at the bottom indicates that Hubble did not spot any traces of water or methane, which are abundant in hydrogen-rich atmospheres. The researchers concluded that the atmospheres are composed of heavier elements residing at much lower altitudes than could be measured by the Hubble observations. [NASA, ESA, and Z. Levy (STScI)]

and TRAPPIST-1g, about 3 to 7 million km away from the star. The enthusiasm generated by these potentially Earth-like planets, however, was somewhat lacking in the following months. Indeed, in June and July, two teams of researchers from Harvard-Smithsonian Center for Astrophysics (CfA) announced the results of two independent studies on the effects of red dwarf's stellar activity in the surrounding environment and therefore on the planets.

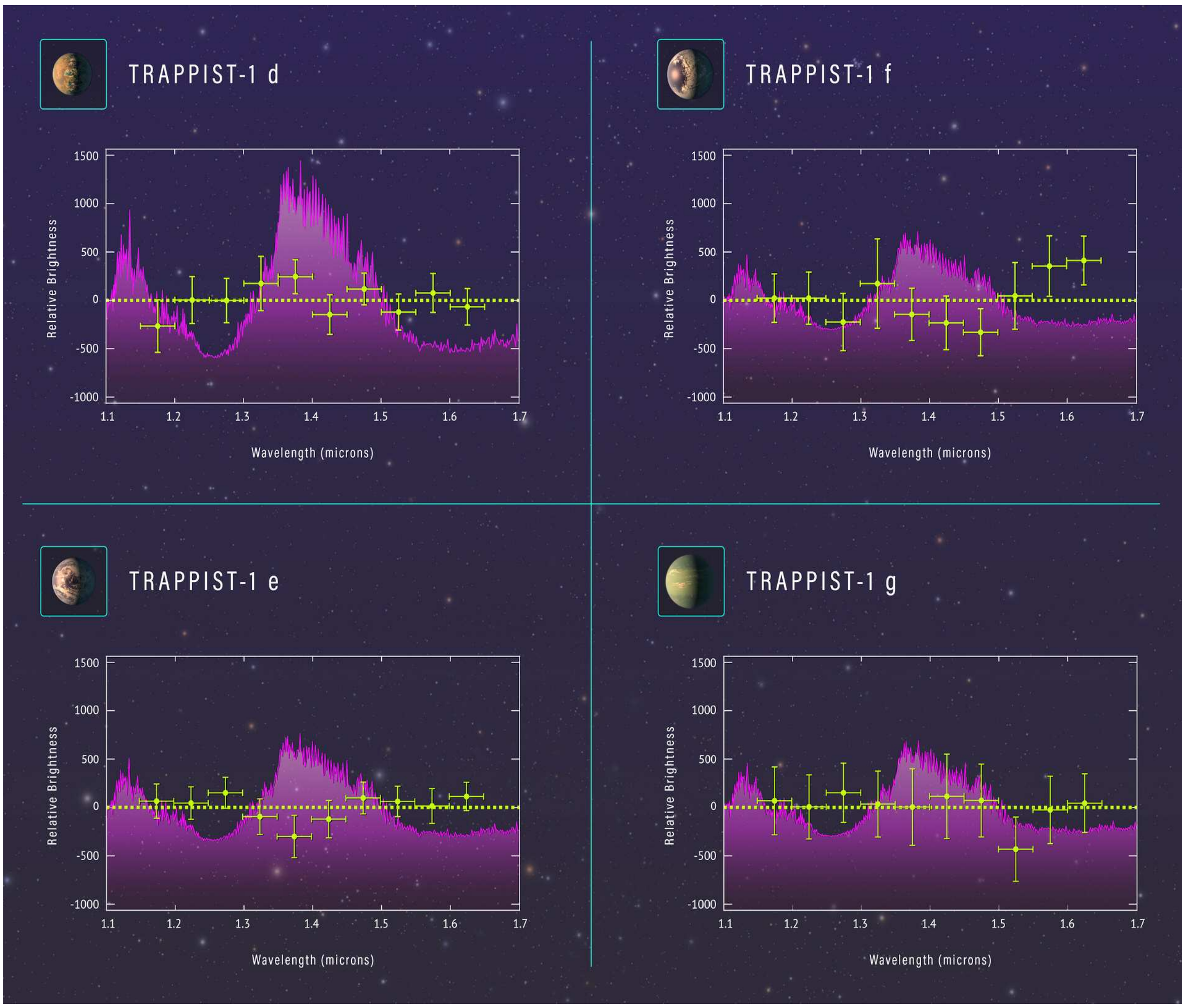
One of the two teams of researchers, led by Manasvi Lingam, focused on the consequences of TRAPPIST-1's ultraviolet radiation on the planetary system. As that radiation is much more intense than that from the Sun which hits the Earth, researchers came to the conclusion that the atmospheres of those worlds could be destroyed in a short time, astronomically speaking. This scenario, described in the *International Journal of Astrobiology*, obviously clashes with the possibility that the dwarf star's planetary system can accommodate life. Indeed, CfA researchers estimate that under those conditions, life has less than a 1% chance of appearing compared to the Earth.

The second CfA team, led by Cecilia Garraffo, and also attended by the University of Massachusetts, highlighted another deadly threat to those planets. Like the Sun, even TRAPPIST-1 pours copious amounts of high-energy particles into the surrounding space, but as the dwarf is much closer to its worlds, the stellar wind pressure that invests them is 1000 to 100,000 times greater than that exerted on the Earth by the solar wind. As the stellar wind carries with it the magnetic field associated with the particles, researchers claim (in an article in *The Astrophysical Journal Letters*) that this specific magnetic field can be directly connected to the magnetic fields of the individual planets. If this is the case, the flux of particles emitted all around by TRAPPIST-1 would continuously affect the atmospheres, which would gradually be eroded



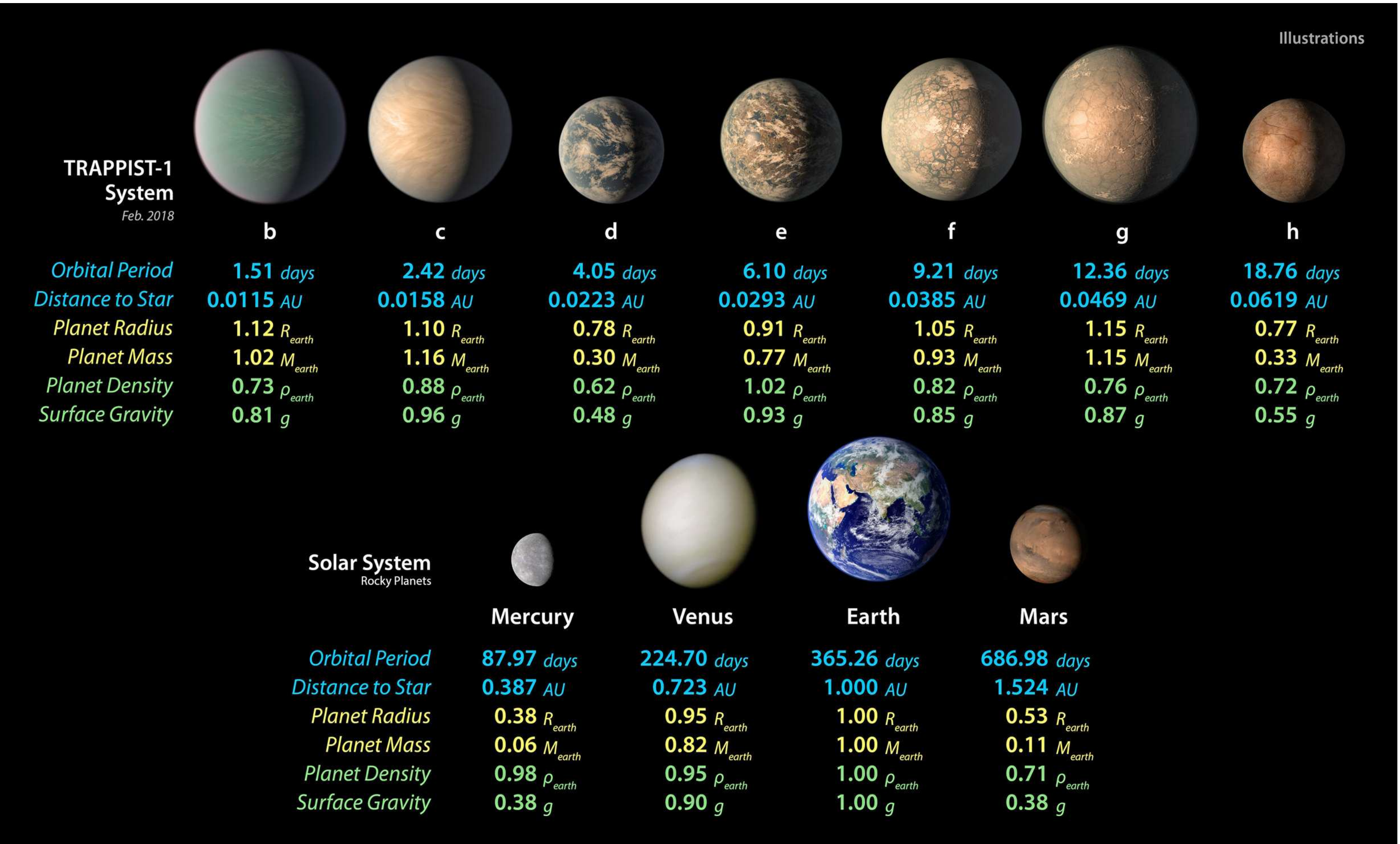
until complete evaporation. In short, the two CfA studies warn against easy enthusiasm, even if, as researchers themselves point out, their conclusions do not entirely exclude the possibility that life forms may exist around TRAPPIST-1 or other red dwarfs. Shortly after the publication of these works, near the middle of August last year, the results of another study conducted by Adam Burgasser (University of California, San Diego) and Eric Mamajek (NASA / JPL) were published in *The Astrophysical Journal*. The goal was to establish the TRAPPIST-1's age, a fundamental datum to understand the extent to which its planetary system can be hostile or favourable to life. To obtain a reliable estimate, the two researchers took into account some key parameters, such as the speed at which the dwarf orbits around the galactic centre (a speed that increases with age), its atmospheric composition (also the quantity of metals increases with age), and the number of harsh flares that occurred during the observation periods. All of the parameters considered indicate that the age of TRAPPIST-1 is significantly higher than that of the Sun and is likely between 5.4 and 9.8 billion years old. Such an advanced age affects both negatively and positively the possible habitability of those worlds. On the negative side, in such a long period of

Artist's impression of the TRAPPIST-1 system, showcasing all seven planets in various phases. When a planet transits across the disk of the red dwarf host star, as two of the planets here are shown to do, it creates a dip in the star's light that can be detected from Earth. [NASA]



These spectra show the chemical makeup of the atmospheres of four Earth-size planets orbiting within or near the habitable zone of the nearby star TRAPPIST-1. The habitable zone is a region at a distance from the star where liquid water, the key to life as we know it, could exist on the planets' surfaces. To obtain the spectra, astronomers used the Hubble Space Telescope to collect light from TRAPPIST-1 that passed through the exoplanets' atmospheres as the alien worlds crossed the face of the star. The purple curves show the predicted signatures of gases such as water and methane that absorb certain wavelengths of light. These gases would be found in a puffy hydrogen-dominated atmosphere similar to gaseous planets such as Neptune. The Hubble results, noted by the green crosses, reveal no evidence of an extended atmosphere in three of the exoplanets (TRAPPIST-1d, f, and e). Additional observations are needed to rule out a hydrogen-dominated atmosphere for the fourth planet (TRAPPIST-1g). The evidence indicates that the atmospheres are more compact than could be measured by the Hubble observations. [NASA, ESA, and Z. Levy (STScI)]

time the mass of the star has surely managed to synchronise the rotation periods of all of the planets with their respective revolution periods, making the hemispheres facing the star too hot, and those in the shade too cold (without considering the powerful atmospheric winds that situation can generate). On the positive side, however, an old red dwarf produces less flares than a younger one, and it's, therefore, less devastating for any possible life forms living in the system. Moreover, if the planets are still where we see them



after billions of years (they have migrated there in remote times from more external orbits), it means that the system is stable, and we know well how stability is necessary for life to appear and evolve. However, the advanced TRAPPIST-1's age raises some doubts about the actual existence of atmospheres around its planets. Indeed, even neglecting the fateful scenario of magnetic fields, the extreme proximity of the whole system to the star and the exposure for several billion years to its radiation could have led to the boiling of the atmosphere. Researchers calculated that each of the five innermost planets might have lost, through evaporation, an average amount of water (if any) equivalent to a terrestrial ocean.

Only the two outer planets would have escaped that fate, but for other reasons, they are not less hostile. To be precise, there is no evidence to confirm the evaporation of atmospheres. On the contrary, the opposite seems to be true, and this is because despite those planets sizes being comparable to that of Earth's, they have lower average densities, which means that a significant part of their mass could be in a gaseous state. In other words, those planets are more than likely surrounded by a rather thick atmosphere.

Assuming that this scenario is realistic, we would have at least a couple of very positive effects: the dense atmospheres would be able to shield a relevant part of the harmful stellar radiation; furthermore, they would favour the global redistribution of

This infographic lists the main properties of the seven TRAPPIST-1 planets, along with the four innermost planets in the Solar System at the same scale. [NASA/JPL-Caltech/R. Hurt, T. Pyle (IPAC)] Left, this video takes the viewer on a quick trip from Earth to TRAPPIST-1 and its seven planets. The stars in the animation are accurately positioned as in reality. The artist's impression in this video is based on the known physical parameters for the planets and stars seen, and uses a vast database of objects in the Universe. [ESO/L. Calçada/spaceengine.org]

This video shows the TRAPPIST-1 system from the most distant planet (TRAPPIST-1h). In the video, the transits of two inner planets can be seen, with the large disc of TRAPPIST-1g transiting last. The artist's impression in this video is based on the known physical parameters for the planets and stars seen, and uses a vast database of objects in the Universe. [ESO/L. Calçada/spaceengine.org. Music: Johan B. Monell]

the heat accumulated in the hemispheres perpetually exposed towards the star. On the contrary, however, very dense atmospheres could easily trigger an irreversible greenhouse effect, similar to the one present on Venus.

Correct characterisation of the atmospheres is therefore essential to understand how much those planets can resemble ours, rather than Venus' or, conversely, Mars'. In this regard, the results of the first spectroscopic analysis of the planets "d", "e", "f" and "g", i.e. those that orbit in the TRAPPIST-1's habitable zone, were published in *Nature Astronomy* on 5 February. This new study, led by a team of astronomers from the Space Telescope Science Institute (STScI), revealed that at least the first three of those four planets are not surrounded by a puffy, particularly hydrogen-rich atmosphere, like that of a mini-Neptune. This is a good sign, as hydrogen is a greenhouse gas that makes the planets inhospitable. If in the atmospheres there is so little hydrogen not to be easily detectable, this increases the likelihood that heavier atoms and molecules are preponderant, like some potential biomarkers – more interesting for researchers – that could reveal the presence of life on those planets. But to confirm this, we have to wait until next year, when NASA's James Webb Space Telescope will become operational. In the meantime, we can try to understand which of the planets is less hostile to life. A large team of researchers, led by Simon Grimm (Universität Bern), went in this direction, and applied very complex models to all of the available data of TRAPPIST-1's planets, to define their densities with a precision never reached before. The results of this study, recently published on *Astronomy & Astrophysics*, suggest that all those planets may have retained water reserves equal to 5% of their mass, a huge amount if we consider that in the case of the Earth only 0.02% of the mass comes in the form of water. In the scenario that takes shape from Grimm's team's study, if TRAPPIST-1b and TRAPPIST-1c still have an atmosphere, water should be present in a vapour state, which would help make those worlds inhospitable. The outer planets, "f", "g" and "h", are perhaps a little too far from the star to ensure liquid water on the surface. The planets "d" and "e" are more interesting. The former is the lightest of the system, it has indeed only 30% of Earth's mass, and we do not know in what state the water (perhaps) present on it is. TRAPPIST-1e is instead the most promising planet: it is just a little smaller than the Earth, but it is slightly denser, features compatible with the presence of an iron core, a rocky surface alternating with expanses of water, and an atmosphere that is not necessarily thick.

In addition to the size, density and perhaps the consistency of the atmosphere, TRAPPIST-1e is comparable to Earth also for the amount of radiation it receives from its star. All of this, of course, does not mean habitability or presence of life, but we can bet that this planet will be one of Webb's first targets. ■

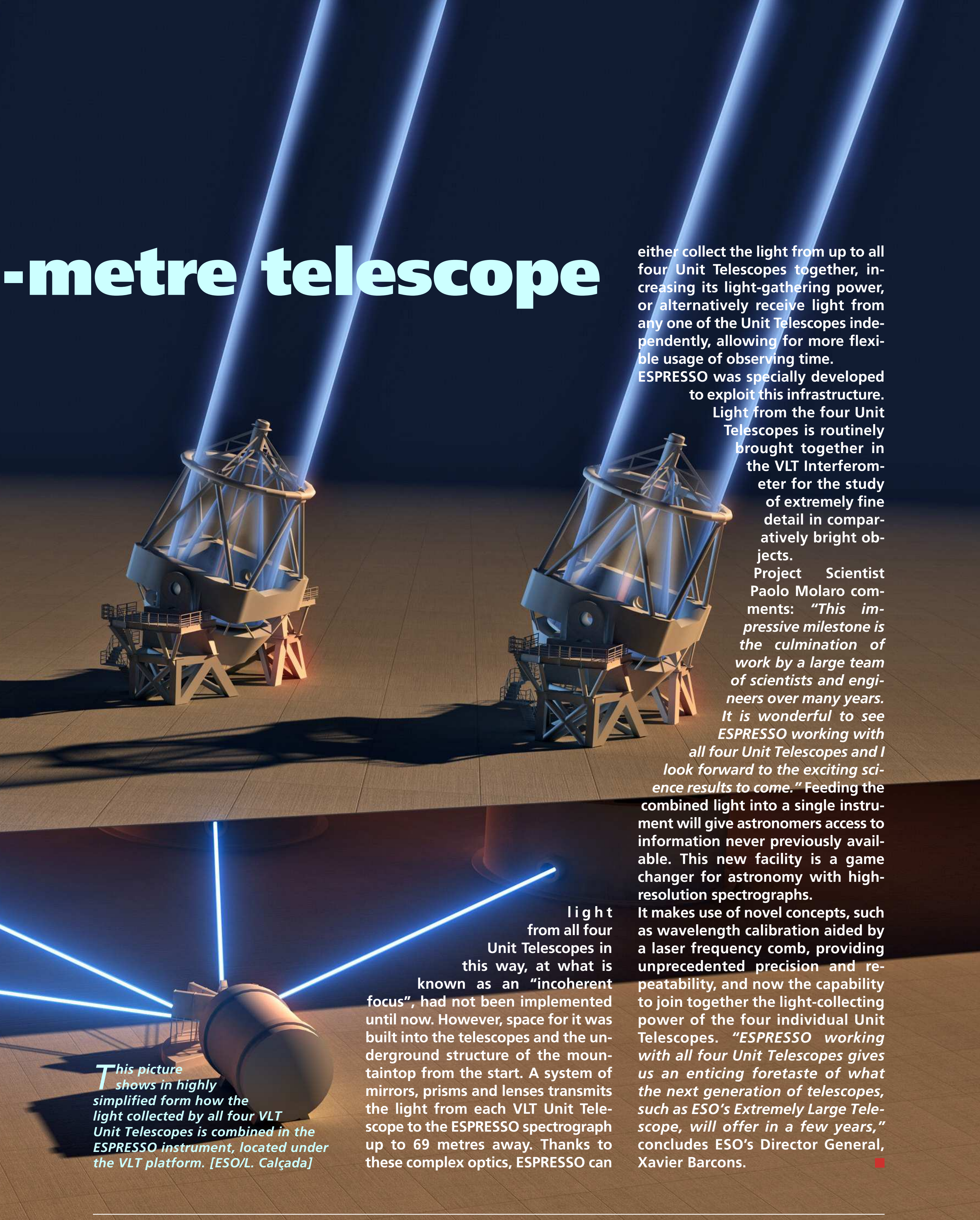
ESO's VLT working as 16 for first time

by ESO

One of the original design goals of ESO's Very Large Telescope (VLT) was for its four Unit Telescopes (UTs) to work together to create a single giant telescope. With the first light of the ESPRESSO spectrograph using the four-Unit-Telescope mode of the VLT, this milestone has now been reached.

After extensive preparations by the ESPRESSO consortium (led by the Astronomical Observatory of the University of Geneva, with the participation of research centres from Italy, Portugal, Spain and Switzerland) and ESO staff, ESO's Director General Xavier Barcons initiated this historic astronomical observation with the push of a button in the control room. ESPRESSO instrument scientist at ESO, Gaspare Lo Curto, explains the historical significance of this event: *"ESO has realised a dream that dates back to the time when the VLT was conceived in the 1980s: bringing the light from all four Unit Telescopes on Cerro Paranal together at an incoherent focus to feed a single instrument!"* When all four 8.2-metre Unit Telescopes combine their light-collecting power to feed a single instrument, the VLT effectively becomes the largest optical telescope in the world in terms of collecting area. Two of the main scientific goals of ESPRESSO are the discovery and characterisation of Earth-like planets and the search for possible variability of the fundamental constants of physics. The latter experiments in particular require the observation of distant and faint quasars, and this science goal will benefit the most from combining the light from all four Unit Telescopes in ESPRESSO. Both rely on the ultra-high stability of the instrument and an extremely stable reference light source. Due to the complexity involved, the combination of

-metre telescope



This picture shows in highly simplified form how the light collected by all four VLT Unit Telescopes is combined in the ESPRESSO instrument, located under the VLT platform. [ESO/L. Calçada]

light from all four Unit Telescopes in this way, at what is known as an "incoherent focus", had not been implemented until now. However, space for it was built into the telescopes and the underground structure of the mountaintop from the start. A system of mirrors, prisms and lenses transmits the light from each VLT Unit Telescope to the ESPRESSO spectrograph up to 69 metres away. Thanks to these complex optics, ESPRESSO can either collect the light from up to all four Unit Telescopes together, increasing its light-gathering power, or alternatively receive light from any one of the Unit Telescopes independently, allowing for more flexible usage of observing time.

ESPRESSO was specially developed to exploit this infrastructure. Light from the four Unit Telescopes is routinely brought together in the VLT Interferometer for the study of extremely fine detail in comparatively bright objects.

Project Scientist Paolo Molaro comments: *"This impressive milestone is the culmination of work by a large team of scientists and engineers over many years. It is wonderful to see ESPRESSO working with all four Unit Telescopes and I look forward to the exciting science results to come."* Feeding the combined light into a single instrument will give astronomers access to information never previously available. This new facility is a game changer for astronomy with high-resolution spectrographs.

It makes use of novel concepts, such as wavelength calibration aided by a laser frequency comb, providing unprecedented precision and repeatability, and now the capability to join together the light-collecting power of the four individual Unit Telescopes. *"ESPRESSO working with all four Unit Telescopes gives us an enticing foretaste of what the next generation of telescopes, such as ESO's Extremely Large Telescope, will offer in a few years,"* concludes ESO's Director General, Xavier Barcons.

Earliest galaxies spun like the Milky Way

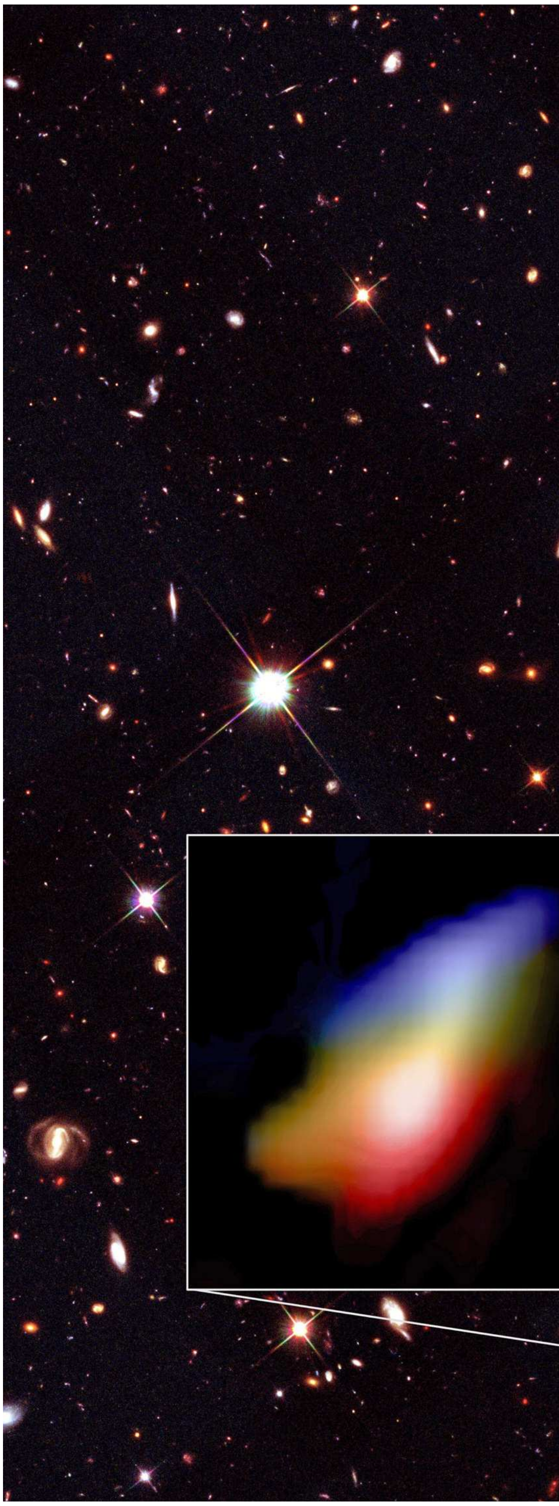
by ALMA Observatory

An international team led by Dr Renske Smit from the Kavli Institute of Cosmology at the University of Cambridge used the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile to open a new window onto the distant Universe, and have for the first time been able to identify normal star-forming galaxies at a very early stage in cosmic history with this telescope. The results are reported in the journal *Nature*, and were presented at the 231st meeting of the American Astronomical Society.

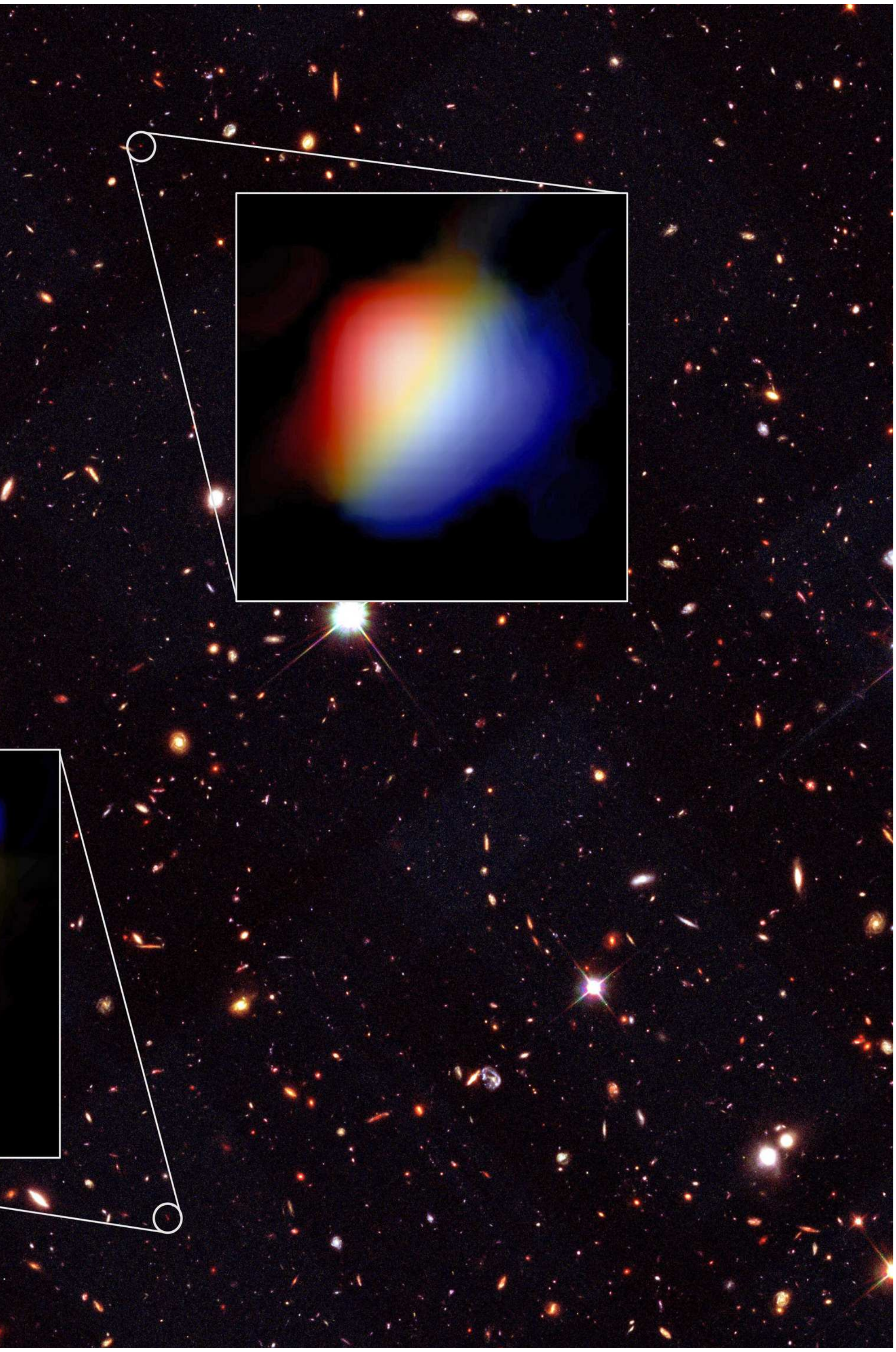
Light from distant objects takes time to reach Earth, so observing objects that are billions of light years away enables us to look back in time and directly observe the formation of the earliest galaxies. The Universe at that time, however, was filled with an obscuring 'haze' of neutral hydrogen gas, which makes it difficult to see the formation of the very first galaxies with optical telescopes.

Smit and her colleagues used ALMA to observe two small newborn galaxies, as they existed just 800 million years after the Big Bang. By analyzing the spectral 'fingerprint' of the far-infrared light collected by ALMA, they were able to establish the distance to the galaxies and, for the first time, see the internal motion of the gas that fueled their growth.

"Until ALMA, we've never been able to see the formation of galaxies in such de-



A video simulation of rotating disc. [R. Crain (LJMU) and J. Geach (U.Herts)]



Data visualization – Hubble Telescope image of the night sky where the galaxies were found and two zoomed in panels of the ALMA data. [Hubble (NASA/ESA), ALMA (ESO/NAOJ/NRAO), P. Oesch (University of Geneva) and R. Smit (University of Cambridge)]

tail, and we've never been able to measure the movement of gas in galaxies so early in the Universe's history," said co-author Dr Stefano Carniani, from Cambridge's Cavendish Laboratory and Kavli Institute of Cosmology.

The researchers found that the gas in these newborn galaxies swirled and rotated in a whirlpool motion, similar to our own galaxy and other, more mature galaxies much later in the Universe's history. Despite their relatively small size – about five times smaller than the Milky Way – these galaxies were forming stars at a higher rate than other young galaxies, but the researchers were surprised to discover that the galaxies were not as chaotic as expected.

"In the early Universe, gravity caused gas to flow rapidly into the galaxies, stirring them up and forming lots of new stars – violent supernova explosions from these stars also made the gas turbulent," said Smit, who is a Rubicon Fellow at Cambridge, sponsored by the Netherlands Organization for Scientific Research. *"We expected that young galaxies would be dynamically 'messy', due to the havoc caused by exploding young stars, but these mini-galaxies show the ability to retain order and appear well regulated. Despite their small size, they are already rapidly growing to become one of the 'adult' galaxies like we live in today."*

The data from this project on small galaxies paves the way for larger studies of galaxies during the first billion years of cosmic time.

3D journey through the Orion Nebula

by NASA/ESA

This image showcases both the visible-light and the infrared-light visualizations of the Orion Nebula. This view from the movie sequence looks down the "valley" leading to the star cluster at the far end. The left side of the image shows the visible-light visualization, which fades to the infrared visualization on the right. These two contrasting models derive from observations by the Hubble and Spitzer space telescopes. [NASA, ESA, F. Summers, G. Bacon, Z. Levay, J. DePasquale, L. Frattare, M. Robberto and M. Gennaro (STScI), and R. Hurt (Caltech/IPAC)]

Astronomers and visualization specialists from NASA's Universe of Learning program have combined visible and infrared vision of the Hubble and Spitzer space telescopes to create an unprecedented, three-dimensional, fly-through view of the picturesque Orion Nebula, a nearby star-forming region. Viewers experience this nearby stellar nursery "close up and personally" as the new digital visualization ferries them among newborn stars, glowing clouds heated by intense radiation, and tadpole-shaped gaseous envelopes surrounding protoplanetary disks.

Using actual scientific imagery and other data, combined with Hollywood techniques, a team at the Space Telescope Science Institute in Baltimore, Maryland, and the Caltech/IPAC in Pasadena, California, has created the best and most detailed multi-wavelength visualization yet of this photogenic nebula. The fly-through enables people to experience and learn about the universe in an exciting new way.

The three-minute movie, which shows the Orion Nebula in both visible and infrared light, was released to the public Thursday, Jan. 11. It is available to planetariums and other centers of informal learning worldwide to help audiences explore fundamental questions in science such as, "How did we get here?"

"Being able to fly through the nebula's tapestry in three dimensions gives people a much better sense of what the universe is really like," explained the Space Telescope Science Institute's visualization scientist Frank Summers, who led the team that developed the movie. *"By adding depth and structure to the amazing images, this fly-through helps elucidate the universe for the public, both educating and inspiring,"* added Summers.

"Looking at the universe in infrared light gives striking context for the more familiar visible-light views. This movie provides a uniquely immersive chance to see how new features appear as we shift to wavelengths of light normally invisible to our eyes," said Robert Hurt, lead visualization scientist at IPAC. One of the sky's brightest nebulas, the Orion Nebula is visible to the naked eye. It appears as the middle "star" in the sword of the constellation Orion, the Hunter, and is located about 1,350 light-years away. At only 2 million years old, the nebula is an ideal laboratory for studying young stars and stars that are still forming. It offers a glimpse of what might have happened when the Sun was born 4.6 billion years ago.

This visualization is an excerpt from a longer sequence that explores the Orion Nebula using both visible and infrared light. Two correlated computer models were created based on visible-light observations from the Hubble Space Telescope and infrared-light observations from the Spitzer Space Telescope. [NASA, ESA, F. Summers, G. Bacon, Z. Levay, J. DePasquale, L. Hustak, L. Frattare, M. Robberto and M. Gennaro (STScI), and R. Hurt (Caltech/IPAC) - Acknowledgement: R. Gendler]

The three-dimensional video provides a look at the fantastic topography of the nebula. A torrent of ultraviolet radiation and stellar winds from the massive, central stars of the Trapezium star cluster have carved out a cavernous bowl-like cavity in the wall of a giant cloud of cold molecular hydrogen laced with dust. Astronomers and visualizers worked together to make a three-dimensional model of the depths of this cavernous region, like plotting mountains and valleys on the ocean floor. Colorful Hubble and Spitzer images were then overlaid on the terrain.

The scientific visualization video takes the viewer on a breathtaking flight through the nebula, following the contours of the gas and dust. By toggling between the Hubble and Spitzer's views, the movie shows strikingly different details of the Orion Nebula.

Hubble sees objects that glow in visible light, which are typically in the thousands of degrees. Spitzer is sensitive to cooler objects with temperatures of just hundreds of degrees. Spitzer's infrared vision pierces through obscuring dust to see stars embedded deep into the nebula, as well as fainter and less massive stars, which are brighter in the infrared than in visible light. The new visualization helps people experience how the two telescopes provide a more complex and complete picture of the nebula.

The visualization is one of a new generation of products and experiences being developed by the NASA's Universe of Learning program. The effort combines a direct connection to the science and scientists of NASA's Astrophysics missions with attention to audience needs to enable youth, families, and lifelong learners to explore fundamental questions in science, experience how science is done, and discover the universe for themselves.

The three-dimensional interpretation is guided by scientific knowledge and scientific intuition.

Starting with the two-dimensional Hubble and Spitzer images, Summers and Hurt worked with experts to analyze the structure inside the nebula. They first created a visible-light surface, and then an underlying structure of the infrared features.

To give the nebula its ethereal feel, Summers wrote a special rendering code for efficiently combining the tens of millions of semi-transparent elements of the gas. The customized code allows Summers to run this and other visualizations on desktop workstations, rather than on a supercomputing cluster.

The other components of the nebula were isolated into image layers and modeled separately. These elements included stars, protoplanetary disks, bow shocks, and the thin gas in front of the nebula called "the veil." After rendering, these layers and the gaseous nebula are brought back together to create the visualization.

The three-dimensional structures serve as scientifically reasonable approximations for imagining the nebula. *"The main thing is to give the viewer an experiential understanding, so that they have a way to interpret the images from telescopes,"* explained Summers. *"It's a really wonderful thing when they can build a mental model in their head to transform the two-dimensional image into a three-dimensional scene."*

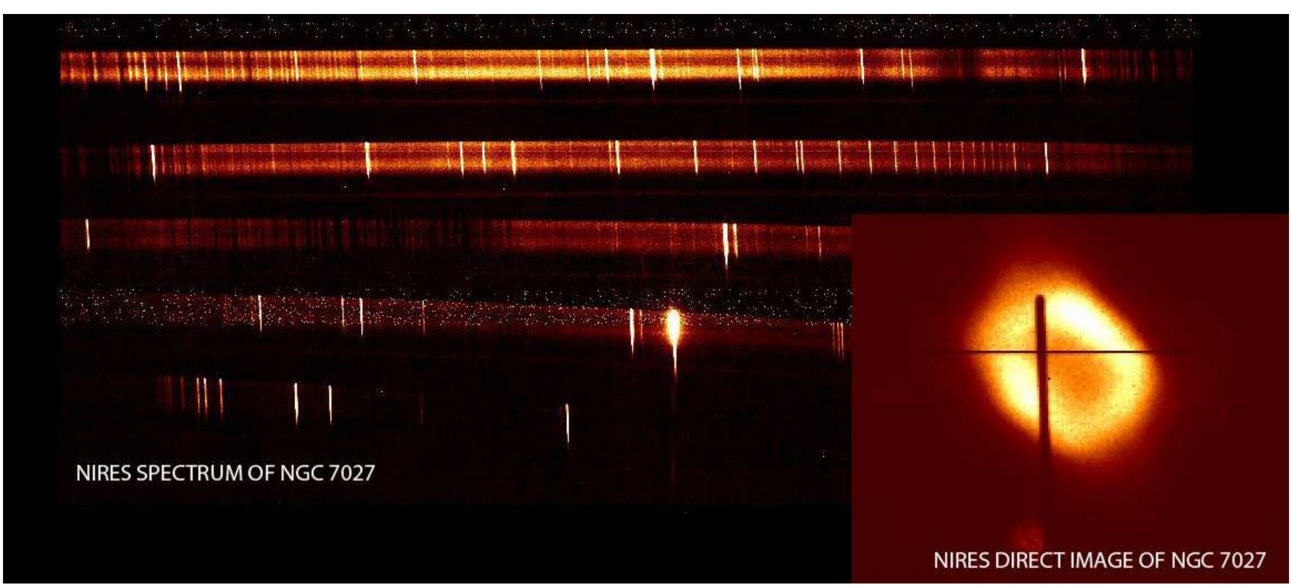
This movie demonstrates the power of multi-wavelength astronomy. It helps audiences understand how science is done — how and why astronomers use multiple regions of the electromagnetic spectrum to explore and learn about our universe. It is also whetting astronomers' appetites for what they will see with NASA's James Webb Space Telescope, which will show much finer details of the deeper, infrared features.

Keck Observatory achieves first light with NIRES

by Keck Observatory

Astronomers at W. M. Keck Observatory have successfully met a major milestone after capturing the very first science data from Keck Observatory's newest instrument, the Caltech-built Near-Infrared Echellette Spectrometer (NIRES). The Keck Observatory-Caltech NIRES team just completed the instrument's first set of commissioning observations and achieved "first light" with a spectral image of the planetary nebula NGC 7027.

"The Keck Observatory continually strives to provide instrumentation that meets the high aspirations of our scientific community and responds to changing scientific needs," said Keck Observatory Director Hilton Lewis. *"NIRES is expected to be one of the most efficient single-object, near-infrared spectrographs on an eight to ten-meter telescope, designed to study explosive, deep sky phenomena such as supernovae and gamma ray bursts, a capability that is in high demand."*



The "first-light" image from NIRES is of NGC 7027, a planetary nebula. The NIRES spectrum shows the near-IR spectrum of this nebula dominated by emission lines of hydrogen and helium. The direct image shows NBC 7027 in the K' filters at 2.2 microns. [W. M. Keck Observatory]

"The power of NIRES is that it can cover a whole spectral range simultaneously with one observation," said Keith Matthews, the instru-

NIRES arrived at Keck Observatory from Caltech on April 17 and was installed on Keck II on September 28. This long-awaited instrument is perfectly suited for time domain astronomy follow-up observations of targets identified by new surveys that are designed to find transients and exotic objects. [W. M. Keck Observatory]

ment's principal investigator and a chief instrument scientist at Caltech. *"It's a cross-dispersed spectrograph that works in the infrared from where the visual cuts off out to 2.4 microns where the background from the thermal emission gets severe."* Matthews developed the instrument with the help of Tom Soifer, the Harold Brown Professor of Physics, Emeritus, at Caltech and member of the Keck Observatory Board of Directors, Jason Melbourne, a former postdoctoral scholar at Caltech, and University of Toronto Department of Astronomy and Astrophysics Professor Dae-Sik Moon, who is also associated with Dunlap Institute, and started working on NIRES with Matthews and Soifer when he was a Millikan postdoctoral fellow at Caltech about a decade ago.

Because NIRES will be on the telescope at all times, its specialty will be capturing Targets of Opportunity (ToO) – astronomical objects that unexpectedly go 'boom.' This capability is now more important than ever, especially with the recent discovery, announced October 16, of gravitational waves caused by the collision of two neutron stars. For the first time in history, astronomers around the world detected both light and gravitational waves of this event, triggering a new era in astronomy.

"NIRES will be very useful in this new field of 'multi-messenger' astronomy," said Soifer. *"NIRES does not have to be taken off of the telescope, so it can respond very quickly to transient phenomena. Astronomers can easily turn NIRES to the event and literally use it within a moment's notice."*

With its high-sensitivity, NIRES will also allow astronomers to observe extremely faint objects found with the Spitzer and WISE infrared space telescopes. Such ancient objects, like high-redshift galaxies and quasars, can give clues about what happened just after the Big Bang. *"NIRES is yet another revolutionary Keck Observatory instrument developed by Keith and Tom; they built our very first instrument, NIRC, which was so sensitive it could detect the equivalent of a single candle flame on the Moon,"* said Lewis. *"Keith and Tom also developed its successor, NIRC2, and Keith was key to the success of MOSFIRE. They are instrumentation pioneers, and we are grateful to them and the entire NIRES team for helping Keck Observatory continue to advance our technological capabilities."*

NIRES Principal Investigator Keith Matthews of Caltech (left) with W. M. Keck Observatory Director Hilton Lewis (right) after successfully achieving "first light" with a spectral image of planetary nebula NGC 7027.

A Wolf-Rayet origin of the

by Michele Ferrara

We know the way many structures in the universe evolved following their origin, but in many cases we have not yet understood which phenomenon produced the origin itself. This is the case with our Solar System, for which the dominant thinking is that it was born because of a shock wave from a supernova compressing a cloud of dust and gas. A recent study, however, has shown that the triggering cause could be different.

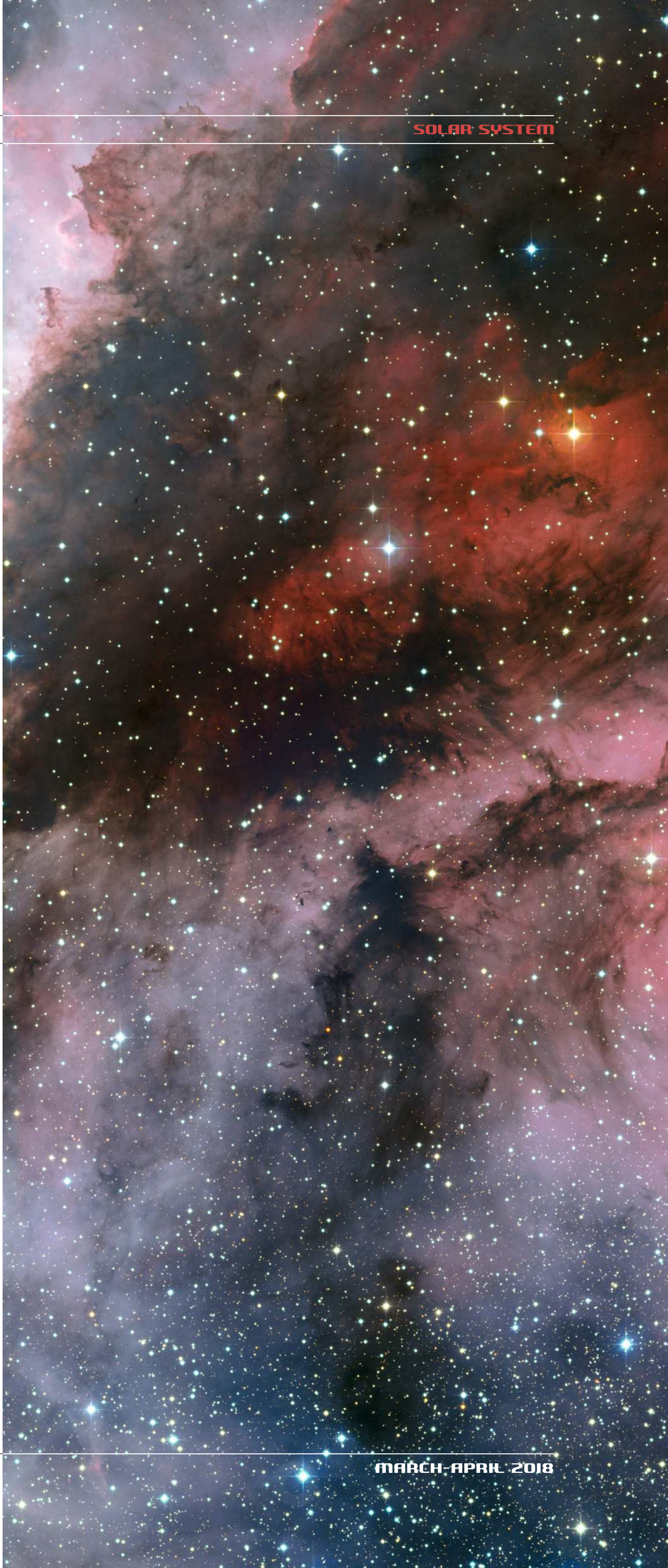
star at the Solar System

The Bubble Nebula (NGC 7635) is about 8000 light years from Earth and originated from the brilliant Wolf-Rayet star visible to the left of its centre. [NASA, ESA, Hubble Heritage Team]

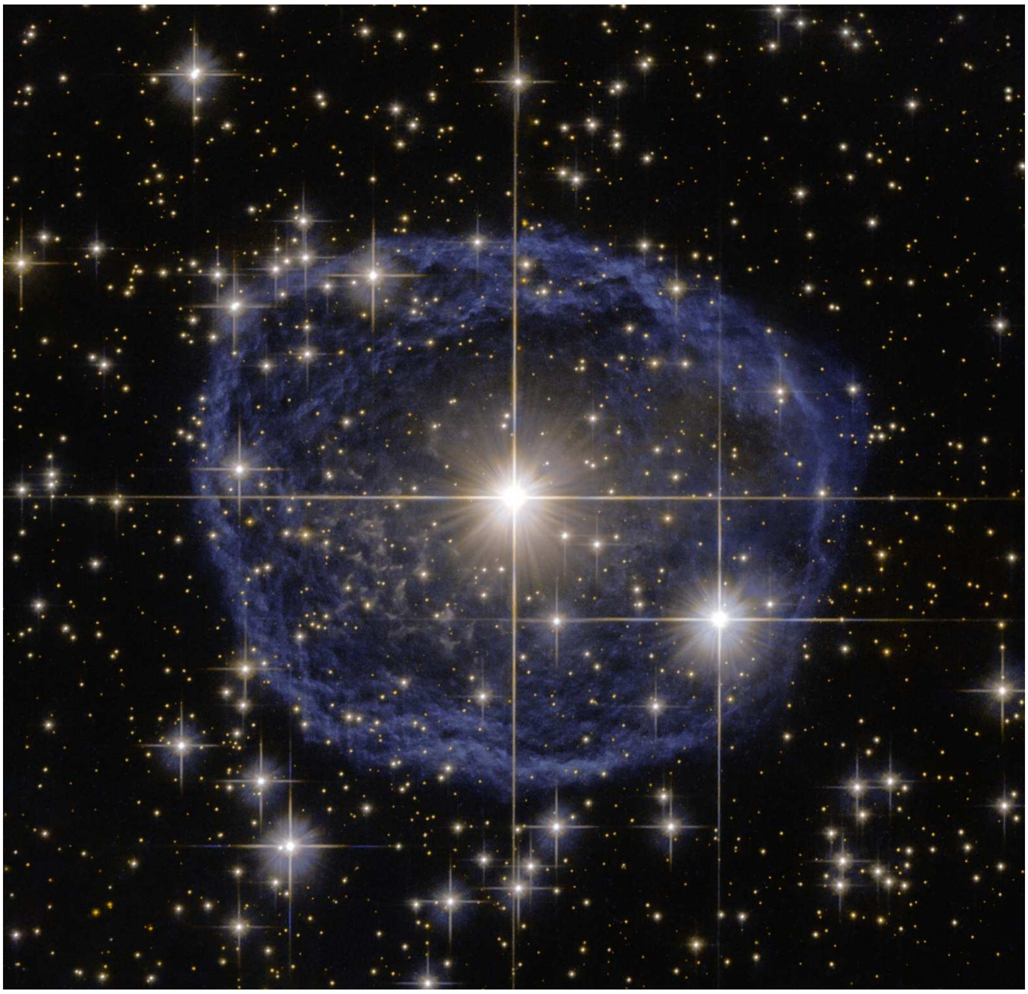
We know a lot about the evolution of the Solar System from its birth to today. Some processes we understand in detail, others are only broad outlines, but all in all, we have a sufficiently clear framework. Conversely, we know very little about the mechanism that triggered the formation of the Sun and all the bodies that orbit around it. The predominant hypothesis has it that an interstellar cloud of dust and gas was hit by the shock wave from a supernova, with consequent compression of the material. The higher density regions therefore began to attract other matter gravitationally until reaching concentrations and temperature levels sufficient to trigger thermonuclear reactions. Thus a cluster of stars was born, one of which was the Sun. Then, the different proper motions of individual stars helped to disperse the cluster relatively quickly, and the Sun continued alone its path around the centre of the galaxy.

That the explosion of a supernova really triggered the birth of the Solar System is not an established truth. Indeed, though that mechanism is effective in destabilizing a cloud of interstellar material, and it is certainly the most widespread mechanism in our galaxy, it is not the only blueprint for powering the formation of new stars. Moreover, in the specific case of our Solar System, a birth due to a supernova is questionable because of a specific peculiarity: the anomalous initial abundance of two specific radioisotopes, aluminium-26 (^{26}Al) and iron-60 (^{60}Fe). These two elements are widespread in the galaxy in constant average ratios with respect to their stable forms, ^{27}Al and ^{56}Fe, and supernova explosions are helpful in keeping the ratios constant, as they pour these radioisotopes, along with many other elements, into interstellar space. These elements, generically called 'metals', end up enriching the hydrogen clouds that are mainly scattered in the galactic disk. Whenever new stars and planetary systems form under the impulse of a supernova, in a cloud enriched with metals, they inherit from the interstellar medium the $^{26}Al/^{27}Al$ and $^{60}Fe/^{56}Fe$ ratios typical of the galaxy.

When the two radioisotopes combine with other elements to form complex structures, in that specific scenario the ratios with respect to the stable isotopes begin to change due to their decay, ending in the complete disappearance of the radioisotopes. Aluminium-26 has a half-life of about 700,000 years, while iron-60 has a half-life of about 1.5 million years. Therefore, the only way we have to verify their presence and their abundances at the Solar System's time zero is by studying the isotopic variations in their decay products. Meteorites are the ideal subjects on which



This image of part of the Carina Nebula shows in its centre a Wolf-Rayet star (WR 22) whose powerful winds are thinning the gases that surround it, up to more than 2 parsecs away. In some cases, WRs can sweep regions of space larger than 10 parsecs. [ESO]

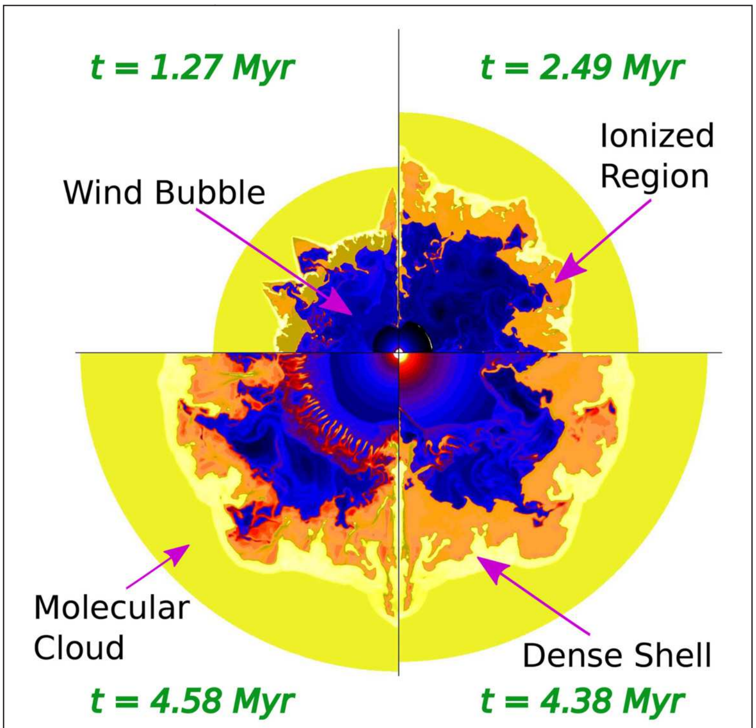


A delicate blue nebula triggered around 20,000 years ago by the Wolf-Rayet star (WR 31a) visible at its centre. Our Solar System could have been born in a mass concentration like those distributed in the shell of this bubble. [ESA/Hubble & NASA, Judy Schmidt]

to perform that kind of analysis because their mineralogical structure has remained substantially unaltered since the birth of the Solar System. And it is precisely through studying the decay products of the two radioisotopes in question that researchers have on several occasions reached an unexpected conclusion: the $^{26}Al/^{27}Al$ ratio, being 1 atom of the first element to every 20,000 atoms of the second element, is 17 times higher than the corresponding average value in the galaxy; but the $^{60}Fe/^{56}Fe$ ratio is 1 atom of the first element to every 50 million atoms of the second element, a value much lower than the galactic average. These differences undermine the supernova hypothesis as a trigger for the formation of our Solar System. The progenitor of a supernova, typically a very massive star, produces ^{26}Al in the outer layers and expels it into space through the powerful winds driven by the pressure of the radiation. Radioisotope ^{60}Fe is, however, produced in the innermost regions and released during the supernova phase.

It would, therefore, be reasonable to expect that, after the explosion of a supernova, a localised surplus of ^{26}Al would coincide with a surplus of ^{60}Fe (with respect to the galactic mean value). Instead, ^{60}Fe seems to be almost absent at the very beginning of the Solar System.

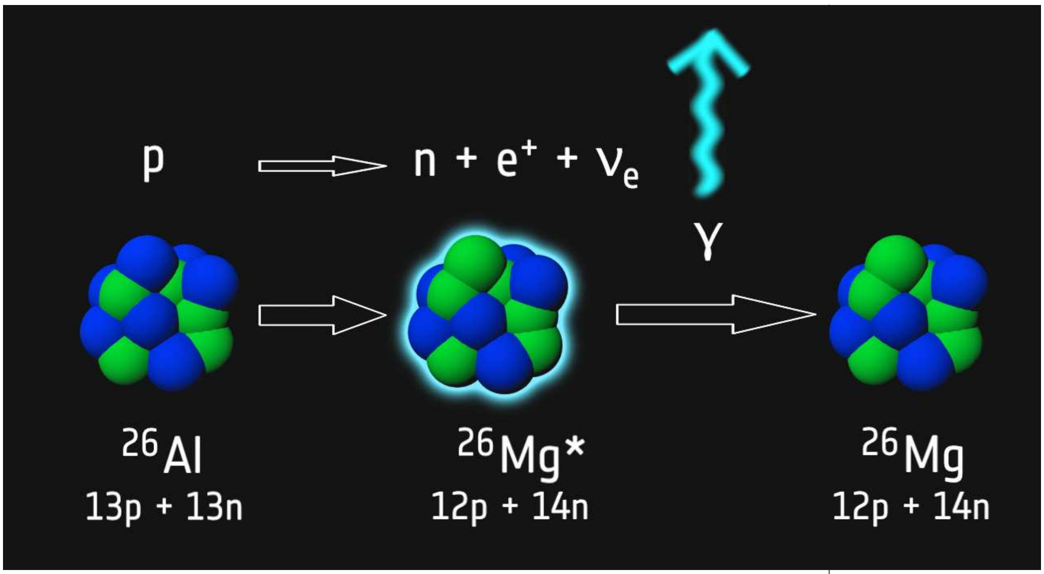
What if it was not a supernova that triggered the birth of the Solar System? Is there



Graphic simulation of the evolution of a bubble of dust and gases around a WR of 40 solar masses, in successive periods, starting from the upper left quadrant (t = 1.27 million years from the beginning of the stellar activity). Blue represents the wind-driven bubble, and ochre is the region ionised by the star, with the thick shell further out. [V. Dwarkadas et al.]

another scenario that leads to the same result but that can also explain the anomaly of the two radioisotopes? Maybe so. In an article recently published in *The Astrophysical Journal*, a team of researchers from the universities of Chicago and Clemson led by Vikram Dwarkadas has put forward an alternative hypothesis, which no longer sees the Solar System born from a supernova's shock wave crashing into an interstellar cloud, but from the gravitational collapse of part of a bubble of material ejected by a Wolf-Rayet star (WR).
This type of star is very rare, gigantic (40-50 times more massive than the Sun) and has very high surface temperatures, from 30,000°C to 200,000°C. These features place them at the top of the list of the brightest stars in the universe. The very high temperature generates very powerful stellar winds (1000-2000 km/s) which, during the short life of WRs, sweep away their outer layers, leaving uncovered the red-hot innermost layers where helium is abundant. The material blown away by the stellar wind forms a giant bubble (up to tens of light-years long), which over time is enriched by the elements just produced in the outer stellar layers, including ^{26}Al. Researchers have calculated that the impetuous WR stellar winds can expel up to half of the stellar mass over a period of hundreds of thousands of years.
By processing observations made by various teams of researchers, Dwarkadas and his colleagues calculated that the average amount of ^{26}Al transferred to the shell of the bubble from a WR is equal to the mass of 3 Earths. They also determined the medium that carries the radioisotopes in that external environment. If the atoms of ^{26}Al darted freely through the bubble, they would not be effectively captured by the shell material. For this to happen, the atoms must 'cling' to something more voluminous. We have known for decades that WRs can have infrared emissions attributable to the

This animation shows how stellar winds can, over millions of years, produce bubbles inside the envelope of material that surrounds a giant star. A team from the University of Chicago claims that the Solar System could have formed within one of these bubbles. [V. Dwarkadas and D. Rosenberg]



This diagram shows the decay of ^{26}Al: a proton decays into a neutron, releasing a positron and a neutrino as by-products; ^{26}Al is thus transformed into ^{26}Mg, magnesium with higher energy than in its ground state; finally, the magnesium is transformed into its stable form, ^{26}Mg, emitting a gamma photon with energy of 1.8 MeV, a frequency that in the galaxy is related to the presence of the most massive stars. [ESA]*

presence of dust located a relatively short distance from the photosphere. That dust is made up of grains with sizes between about 0.3 and 2 microns, and the Dwarkadas team has shown that larger grains can overcome the severe environmental conditions that surround WRs, and can, therefore, reach the shell of the enormous bubble unharmed. In the model proposed by the team, the ^{26}Al atoms launched into space are deposited on the dust grains they intercept along the way, and together with these, after an average journey of about ten parsecs, travelled in about 20,000 years, they reach the densest regions of the shell, where their speed slows to zero. Since the length of the journey is much shorter than the half-life of ^{26}Al, we can expect the average velocities of that isotope in the space dominated by WRs to be much lower than those of the stellar winds, which would demonstrate the accumulation of the metal in the shell, and indeed this is the case. When, due to gravitational instability, a part of the shell collapses into a centre of mass capable of spawning a new solar system, the system will contain more ^{26}Al than the galactic average, but it will certainly not show an excess of ^{60}Fe, an element that remains in the WR's core and that will not necessarily be released if the star is instantly transformed into a black hole without going through the supernova phase.

In conclusion, the Sun and our entire planetary system (including us) could be the offspring of a WR. Dwarkadas and his colleagues estimate that from 1% to 16% of all solar-type stars could be produced from those giant stars. ■

Vikram V. Dwarkadas, Research Associate Professor in the Department of Astronomy and Astrophysics at the University of Chicago, is the first author of the new study proposing a WR star as a trigger for the birth of our Solar System. [The University of Chicago]

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Odd behaviour of star reveals lonely black hole hiding in giant star cluster

by ESO

Globular star clusters are huge spheres of tens of thousands of stars that orbit most galaxies. They are among the oldest known stellar systems in the Universe and date back to near the beginning of galaxy growth and evolution. More than 150 are currently known to belong to the Milky Way. One particular cluster, called NGC 3201 and situated in the southern constellation of Vela (The Sails), has now been studied using the MUSE instrument on ESO's Very Large Telescope in Chile. An international team of astronomers has found that one of the stars in NGC 3201 is behaving very oddly — it is being flung backwards and forwards at speeds of several hundred thousand kilometres per hour, with the pattern repeating every 167 days. Lead author Benjamin Giesers (Georg-August-Universität Göttingen, Germany) was intrigued by the star's behaviour: *"It was orbiting something that was completely invisible, which had a mass more than four times the Sun — this could only be a black hole! The first one found in a globular cluster by directly observing its gravitational pull."* The relationship between

Background and video: astronomers using ESO's MUSE instrument on the Very Large Telescope in Chile have discovered a star in the cluster NGC 3201 that is behaving very strangely. It appears to be orbiting an invisible black hole with about four times the mass of the Sun — the first such inactive stellar-mass black hole found in a globular cluster. This important discovery impacts on our understanding of the formation of these star clusters, black holes, and the origins of gravitational wave events. This artist's impression shows how the star and its massive but invisible black hole companion may look, as they orbit each other in the rich heart of the globular star cluster. [ESO/L. Calçada/spaceengine.org] black holes and globular clusters is an important but mysterious one. Because of their large masses and great ages, these clusters are thought to have produced a large number of stellar-mass black holes — created as massive stars within them exploded and collapsed over the long lifetime of the cluster. In the absence of continuous star formation, as is the case for globular clusters, stellar-mass black holes soon become the most massive objects present. Generally, stellar-mass black holes in globular clusters are about four times as massive as the surrounding low-mass stars. Recent theories have concluded that black holes form a dense nucleus within the cluster, which then becomes detached from the rest of the globular material. Movements at the centre of the cluster are then thought to eject the majority of black holes, meaning only a few would survive after a billion years.

ESO's MUSE instrument provides astronomers with a unique ability to measure the motions of thousands of far away stars at the same time. With this new finding, the team have for the first time been able to detect an inactive black hole at the heart of a globular cluster — one that is not currently swallowing matter and is not surrounded by a glowing disc of gas. They could estimate the black hole's mass through the movements of a star caught up in its enormous gravitational pull. From its observed properties the star was determined to be about 0.8 times the mass of our Sun, and the mass of its mysterious counterpart was calculated at around 4.36 times the Sun's mass — almost certainly a black hole.

Recent detections of radio and X-ray sources in globular clusters, as well as the 2016 detection of gravitational-wave signals produced by the merging of two stellar-mass black holes, suggest that these relatively small black holes may be more common in globular clusters than previously thought.

Giesers concludes: *"Until recently, it was assumed that almost all black holes would disappear from globular clusters after a short time and that systems like this should not even exist! But clearly this is not the case — our discovery is the first direct detection of the gravitational effects of a stellar-mass black hole in a globular cluster. This finding helps in understanding the formation of globular clusters and the evolution of black holes and binary systems — vital in the context of understanding gravitational wave sources."* ■

Researchers catch supermassive black hole burping – twice

by NASA/ESA

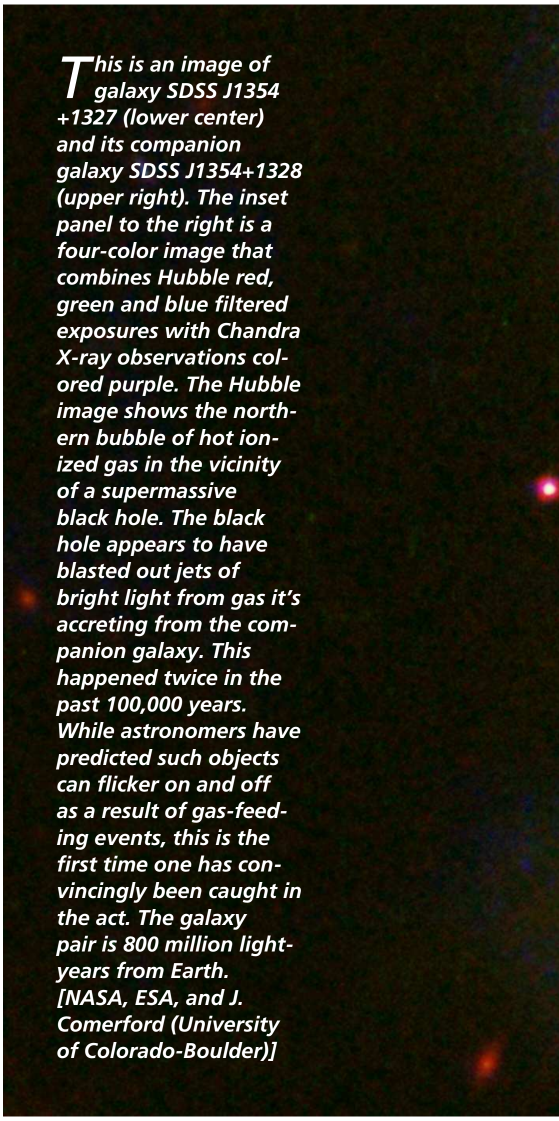
Astronomers have caught a supermassive black hole in a distant galaxy snacking on gas and then "burping" — not once, but twice. The galaxy under study, called SDSS J1354+1327 (J1354 for short), is about 800 million light-years from Earth. The team used observations from NASA's Hubble Space Telescope, the Chandra X-ray Observatory, as well as the W.M. Keck Observatory in Mauna Kea, Hawaii, and the Apache Point Observatory (APO) near Sunspot, New Mexico.

Chandra detected a bright, point-like source of X-ray emission from J1354, a telltale sign of the presence of a supermassive black hole millions or billions of times more massive than our Sun. The X-rays are produced by gas heated to millions of degrees by the enormous gravitational and magnetic forces near the black hole. Some of this gas will fall into the black hole, while a portion will be expelled in a powerful outflow of high-energy particles.

By comparing X-ray images from Chandra and visible-light (optical) images from Hubble, the team determined that the black hole is located in the center of the galaxy, the expected address for such an object. The X-ray data also provide evidence that the supermassive black hole is embedded in a heavy veil of dust and gas.

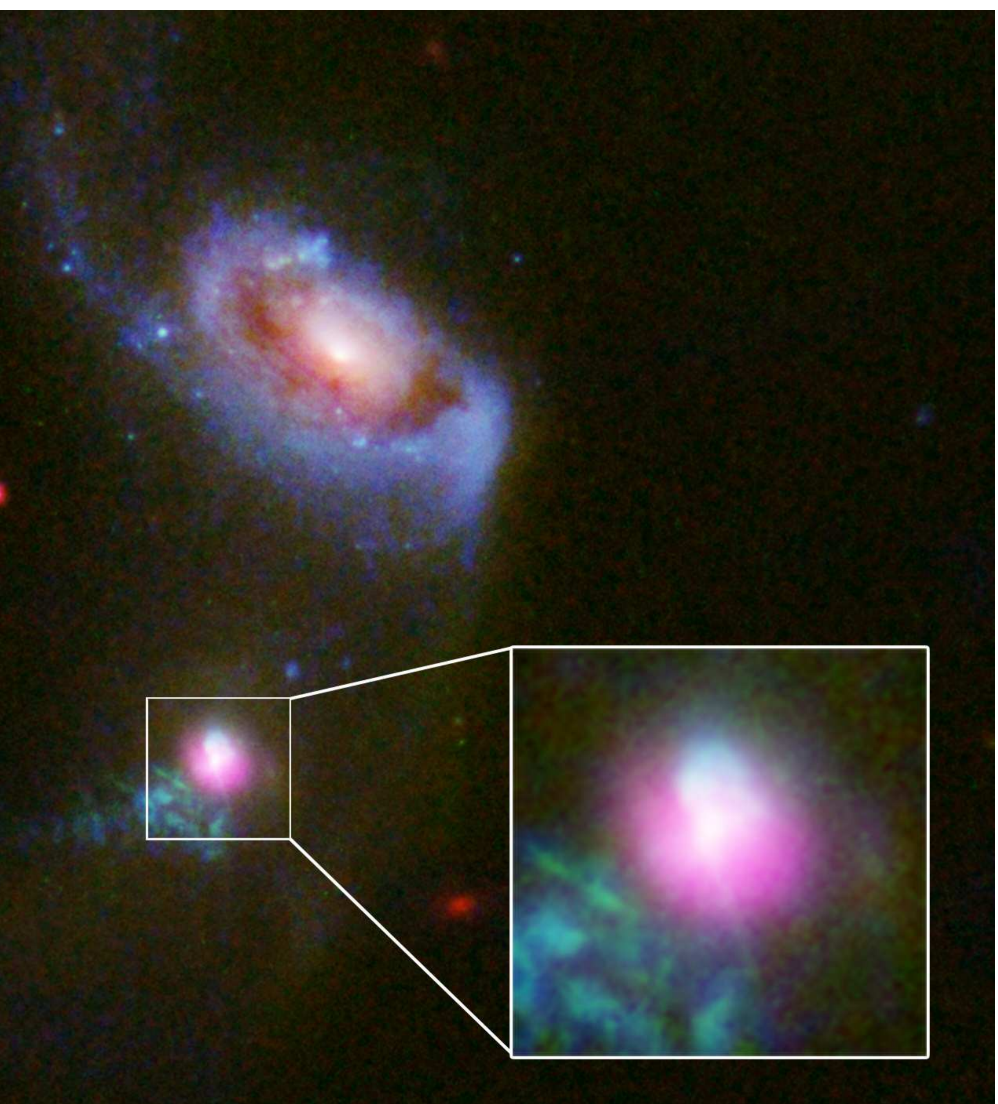
The results indicate that in the past, the supermassive black hole in J1354 appears to have consumed, or accreted, large amounts of gas while blasting off an outflow of high-energy particles. The outflow eventually switched off then turned back on about 100,000 years later. This is strong evidence that accreting black holes can switch their power output off and on again over timescales that are short compared to the 13.8-billion-year age of the universe. *"We are seeing this object feast, burp, and nap, and then feast and burp once again, which theory had predicted,"* said Julie Comerford of the University of Colorado (CU) at Boulder's Department of Astrophysical and Space Science, who led the study. *"Fortunately, we happened to observe this galaxy at a time when we could clearly see evidence for both events."*

So why did the black hole have two separate meals? The answer lies in



This is an image of galaxy SDSS J1354+1327 (lower center) and its companion galaxy SDSS J1354+1328 (upper right). The inset panel to the right is a four-color image that combines Hubble red, green and blue filtered exposures with Chandra X-ray observations colored purple. The Hubble image shows the northern bubble of hot ionized gas in the vicinity of a supermassive black hole. The black hole appears to have blasted out jets of bright light from gas it's accreting from the companion galaxy. This happened twice in the past 100,000 years. While astronomers have predicted such objects can flicker on and off as a result of gas-feeding events, this is the first time one has convincingly been caught in the act. The galaxy pair is 800 million light-years from Earth. [NASA, ESA, and J. Comerford (University of Colorado-Boulder)] a companion galaxy that is linked to J1354 by streams of stars and gas produced by a collision between the two galaxies. The team concluded that clumps of material from the companion galaxy swirled toward the center of J1354 and then were eaten by the supermassive black hole. The team used optical data from Hubble, Keck, and APO to show that electrons had been stripped from atoms in a cone of gas extending some 30,000 light-years south from the galaxy's center. This stripping was likely caused by a burst of radiation from the vicinity of the black hole, indicating that a feasting event had occurred.

To the north they found evidence for a shock wave, similar to a sonic boom, located about 3,000 light-years from the black hole. This suggests that a burp occurred after a different clump of gas had been consumed roughly 100,000 years later. *"This galaxy really caught us off guard,"* said CU Boulder doctoral student Rebecca Nevin, a study co-author who used data from APO to look at the velocities and intensities of light from the gas and stars in J1354. *"We were able to show that the gas from the northern part of the galaxy was consistent with an advancing edge of a shock wave, and the gas from the south was consistent with an older outflow from the black hole."*



Our Milky Way galaxy's supermassive black hole has had at least one burp. In 2010, another research team discovered a Milky Way belch using observations from the orbiting Fermi Gamma-ray Observatory to look at the galaxy edge on.

Astronomers saw gas outflows dubbed "Fermi bubbles" that shine in the gamma-ray, X-ray, and radio wave portion of the electromagnetic spectrum.

"These are the kinds of bubbles we see after a black hole feeding event," said CU postdoctoral fellow Scott Barrows. *"Our galaxy's supermassive black hole is now napping after a big meal, just like J1354's black hole has in the past. So we also expect our massive black hole to feast again, just as J1354's has."*

Other co-authors on the new study include postdoctoral fellow Francisco Muller-Sanchez of CU Boulder, Jenny Greene of Princeton University, David Pooley from Trinity University, Daniel Stern from NASA's Jet Propulsion Laboratory in Pasadena, California, and Fiona Harrison from the California Institute of Technology.

A paper on the subject was published in a recent issue of *The Astrophysical Journal* and is available online. Comerford presented the team's findings in a January 11th, 2018 press briefing at the 231st meeting of the American Astronomical Society held in Washington D.C.

Giant bubbles on red giant star's surface

by ESO

This colourful image shows the sky around the bright pair of stars π1 Gruis (centre-right, very red) and π2 Gruis (centre-left, bluish-white). Just right of centre the bright spiral galaxy IC 5201 is also visible and many other fainter galaxies are scattered across this wide-field image from the Digitized Sky Survey 2. [ESO/Digitized Sky Survey 2]

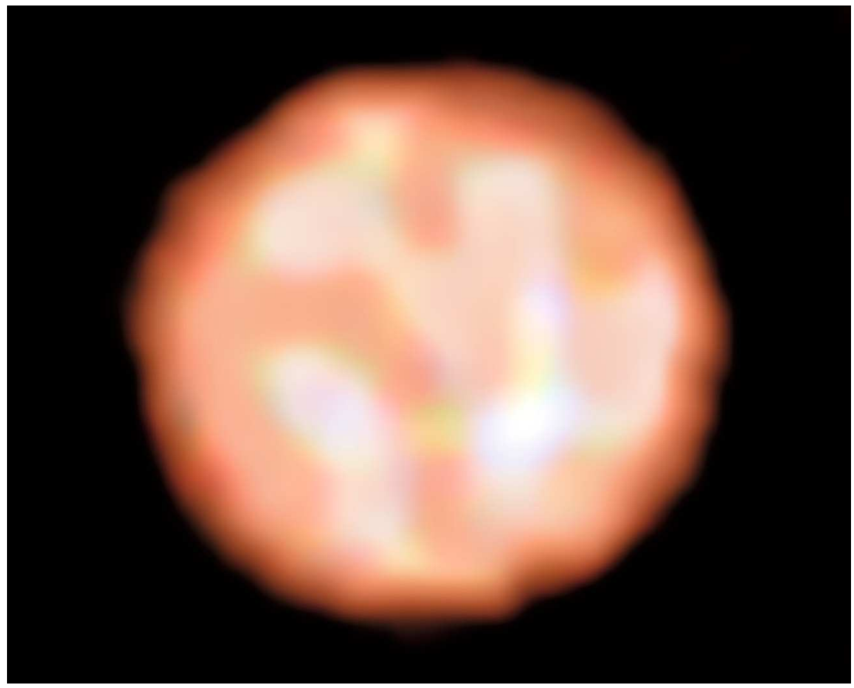
Located 530 light-years from Earth in the constellation of Grus (The Crane), π1 Gruis is a cool red giant. It has about the same mass as our Sun, but is 350 times larger and several thousand times as bright. Our Sun will swell to become a similar red giant star in about five billion years.

An international team of astronomers led by Claudia Paladini (ESO) used the PIONIER instrument on ESO's Very Large Telescope to observe π1 Gruis in greater detail than ever before. They found that the surface of this red giant has just a few convective cells, or granules, that are each about 120 million kilometres across — about a quarter of the star's diameter. Granules are patterns of convection currents in the plasma of a star. As plasma heats up at the centre of the star it expands and rises to the surface, then cools at the outer edges, becoming darker and more dense, and descends back to the centre. This process continues for billions of years and plays a major role in many astrophysical processes including energy transport, pulsation, stellar wind and dust clouds on brown dwarfs. Just one of these granules would extend from the Sun to beyond Venus. The surfaces — known as photospheres — of many giant stars are obscured by dust, which hinders observations. However, in the case of π1 Gruis, although dust is present far from the star, it does not have a significant effect on the new infrared observations.

π1 Gruis is one of the brightest members of the rare S class of stars that was first defined by the American astronomer Paul W. Merrill to group together stars with similarly unusual spectra. π1 Gruis, R Andromedae and R Cygni became prototypes of this type. Their unusual spectra is now known to be the result of the "s-process" or "slow neutron capture process" — responsible for the creation of half the elements heavier than iron.

When π1 Gruis ran out of hydrogen to burn long ago, this ancient star ceased the first stage of its nuclear fusion programme. It shrank as it ran out of energy, causing it to heat up to over 100 million degrees. These extreme temperatures fueled the star's next phase as it began to fuse helium into heavier atoms such as carbon and oxygen. This intensely hot core then expelled the star's outer layers, causing it to balloon to hundreds of times larger than its original size. The star we see today is a variable red giant. Until now, the surface of one of these stars has never before been imaged in detail. By comparison, the Sun's photosphere contains about two million convective cells, with typical diameters of just 1500 kilometres. The vast size differences in the convective cells of these two stars can be explained in part by their varying surface gravities. π1 Gruis is just 1.5 times the mass of the Sun but much larger, resulting in a much lower surface gravity and just a few, extremely large, granules.

While stars more massive than eight solar masses end their lives in dramatic supernovae explosions, less massive stars like this one gradually expel their outer layers, resulting in beautiful planetary nebulae. Previous studies of π1 Gruis found a shell of material 0.9 light-years away from the central star, thought to have been ejected around 20,000 years ago. This relatively short period in a star's life lasts just a few tens of thousands of years – compared to the overall lifetime of several billion – and these observations reveal a new method for probing this fleeting red giant phase. ■



Astronomers using ESO's Very Large Telescope have directly observed granulation patterns on the surface of a star outside the Solar System — the ageing red giant π1 Gruis. This remarkable new image from the PIONIER instrument reveals the convective cells that make up the surface of this huge star. Each cell covers more than a quarter of the star's diameter and measures about 120 million kilometres across. [ESO]

This sequence takes the viewer towards the southern constellation of Grus (The Crane). We zoom in on the pair of stars π1 Gruis (red) and π2 Gruis (bluish-white), and the bright spiral galaxy IC 5201 is also visible. The final shot shows a very detailed view of the surface of the red giant star π1 Gruis from the PIONIER instrument on the VLT Interferometer. [ESO/Digitized Sky Survey 2/N. Risinger (skysurvey.org) Music: Astral Electronic]

Outflow in ultraluminous infrared galaxy observed

by ALMA Observatory

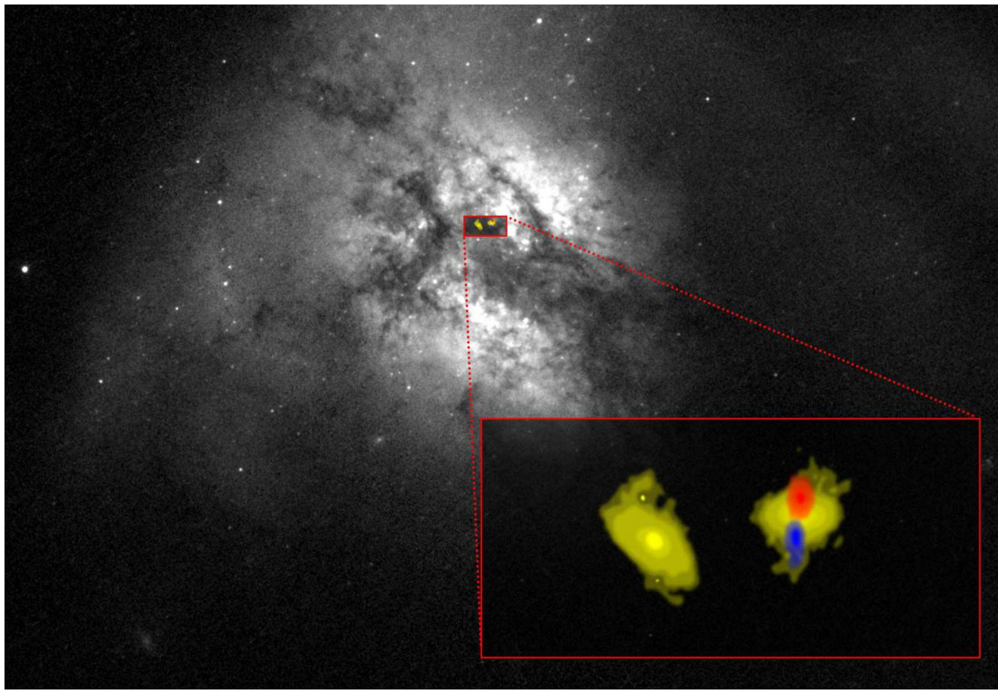
Astronomers using the Atacama Large Millimeter/ submillimeter Array (ALMA) observed for the first time an outflow emerging from one of the nuclei in Arp 220, the closest Ultraluminous Infrared Galaxy to Earth resulting from the collision of two galaxies which are now in the process of merging. Although this object has been extensively studied, its compactness and obscuration have been a challenge for astronomers until now: ALMA observed the outflow from one of its nuclei in three dimensions (velocity and 2D spatial information). The results of this research appeared in *The Astrophysical Journal Letters.*

The presence of an outflow has been previously detected in Arp 220. However, this is the first time it has been imaged and its kinematics and morphological characteristics determined.

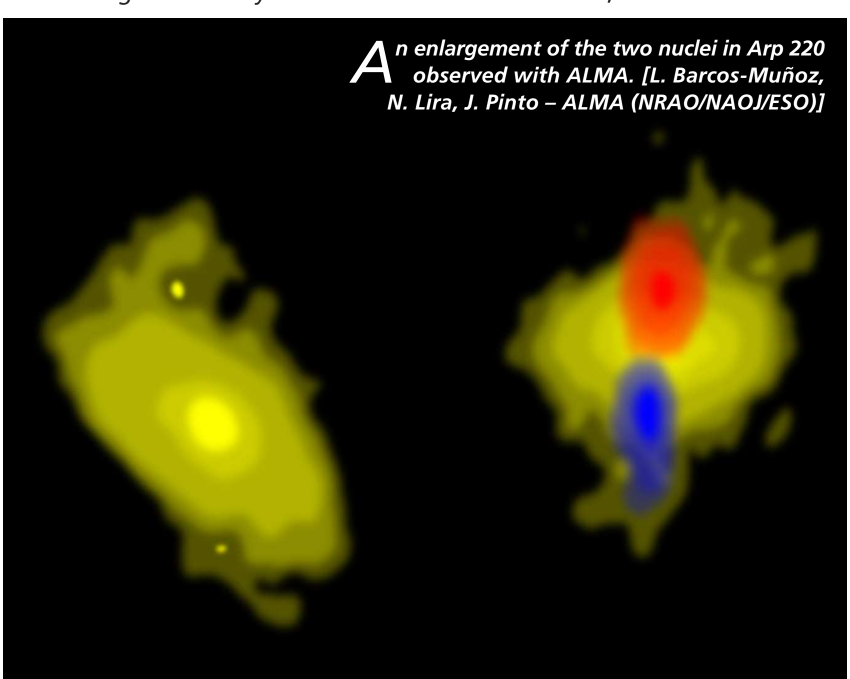
The flow is collimated, instead of the wide-angle morphology that is usually observed. With this discovery, it is possible now to start studying extragalactic outflows at 100 pc scales, giving the opportunity to research

Arp 220 appears to be a single, odd-looking galaxy, but is in fact a nearby example of the aftermath of a collision between two spiral galaxies. It is the brightest of the three galactic mergers closest to Earth, about 250 million light-years away in the constellation of Serpens, the Serpent. [NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)]

ALMA image of Arp 220 cores over HST image of Arp 220. The two cores (yellow), obscured by dust on visible wavelengths, are observed by ALMA. The research team detected a bipolar outflow from the western nucleus and measured its velocity. In red, the North section of the outflow, particles are moving away from Earth. In blue, the South section of the outflow, particles are moving towards Earth. [L. Barcos-Muñoz, N. Lira, J. Pinto – ALMA (NRAO/NAOJ/ESO) / Hubble Space Telescope – (NASA/ESA)]



feedback processes in these deeply embedded galaxy nuclei. *"ALMA's observation wavelength, combined with its high sensitivity and resolution, allowed us to observe inside this very compact and dust obscured galaxy nucleus,"* explained Loreto Barcos-Muñoz, an NRAO Postdoctoral Fellow at ALMA observatory, and Principal Investigator of this research. *"We confirmed the presence of an outflow and obtained a detailed image of its morphology and its velocity at the same time."*



An enlargement of the two nuclei in Arp 220 observed with ALMA. [L. Barcos-Muñoz, N. Lira, J. Pinto – ALMA (NRAO/NAOJ/ESO)]

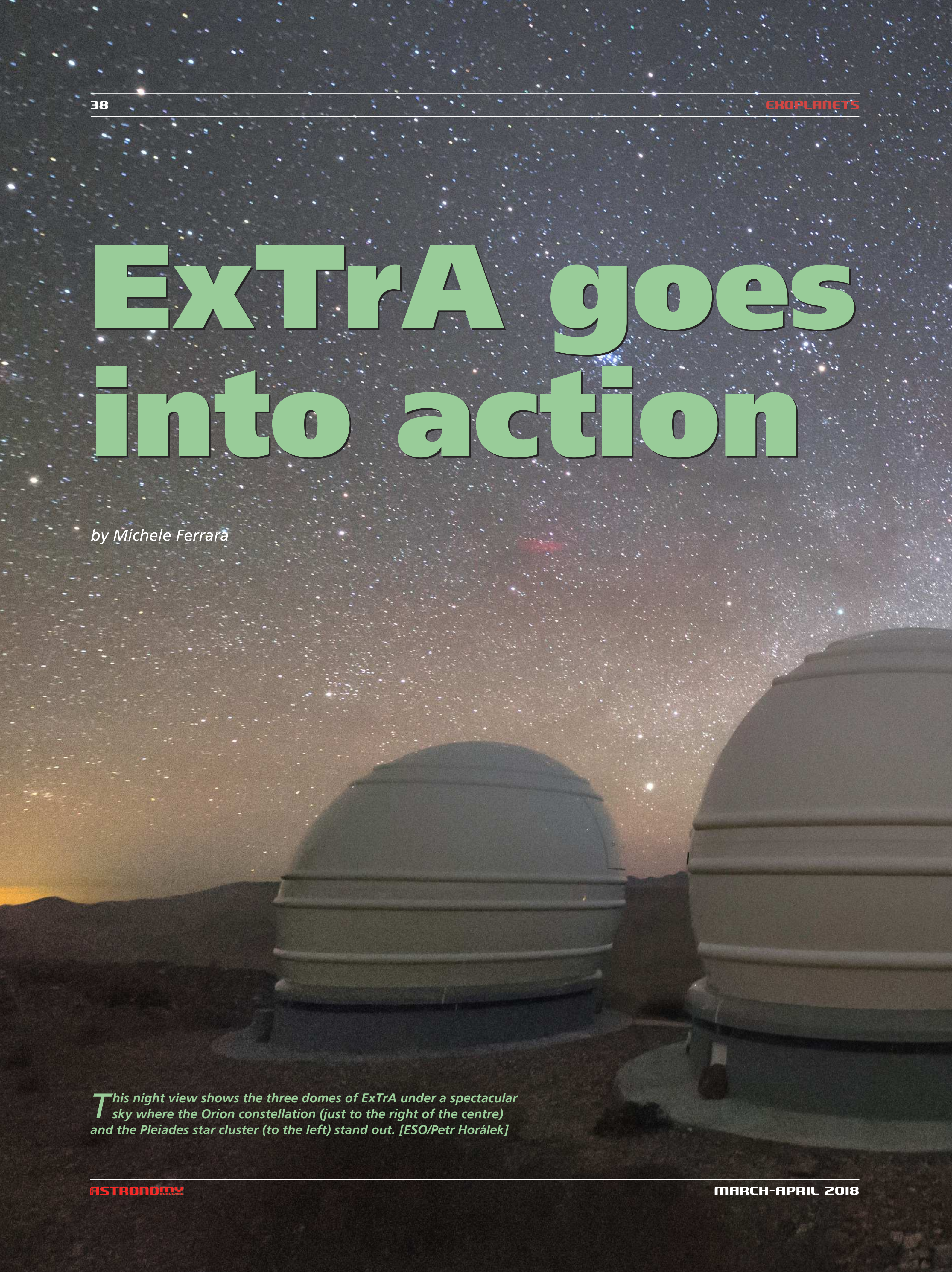
The new ALMA observations reveal a bipolar, fast, collimated outflow emerging from the western nucleus of Arp 220. The material transported from the core through the flows has a maximum speed of 840 km/s.

According to Loreto Barcos-Muñoz, possible explanations for this outflow could be energy from supernovae and momentum transfers, radiation pressure feedback, and a central AGN. Another finding that surprised the team of astron-omers is that the outflow is brighter in HCN than in CO, while the opposite is the norm for most extragalactic outflows detected to date.

Further observations are needed to determine the origin of this behavior, but this discovery challenges the current knowledge about extragalactic outflow gas properties.

ExTrA goes into action

by Michele Ferrara



This night view shows the three domes of ExTrA under a spectacular sky where the Orion constellation (just to the right of the centre) and the Pleiades star cluster (to the left) stand out. [ESO/Petr Horálek]

A strategic instrument has become operative in the search for Earth-like planets orbiting red dwarf stars located at relatively short distances from us. Its name is ExTrA. From the ground, it will be able to discover planets as small as other telescopes can detect from space, and it will help to compile a list of astrobiologically interesting atmospheres to be investigated thoroughly using the super telescopes already in an advanced phase of construction.

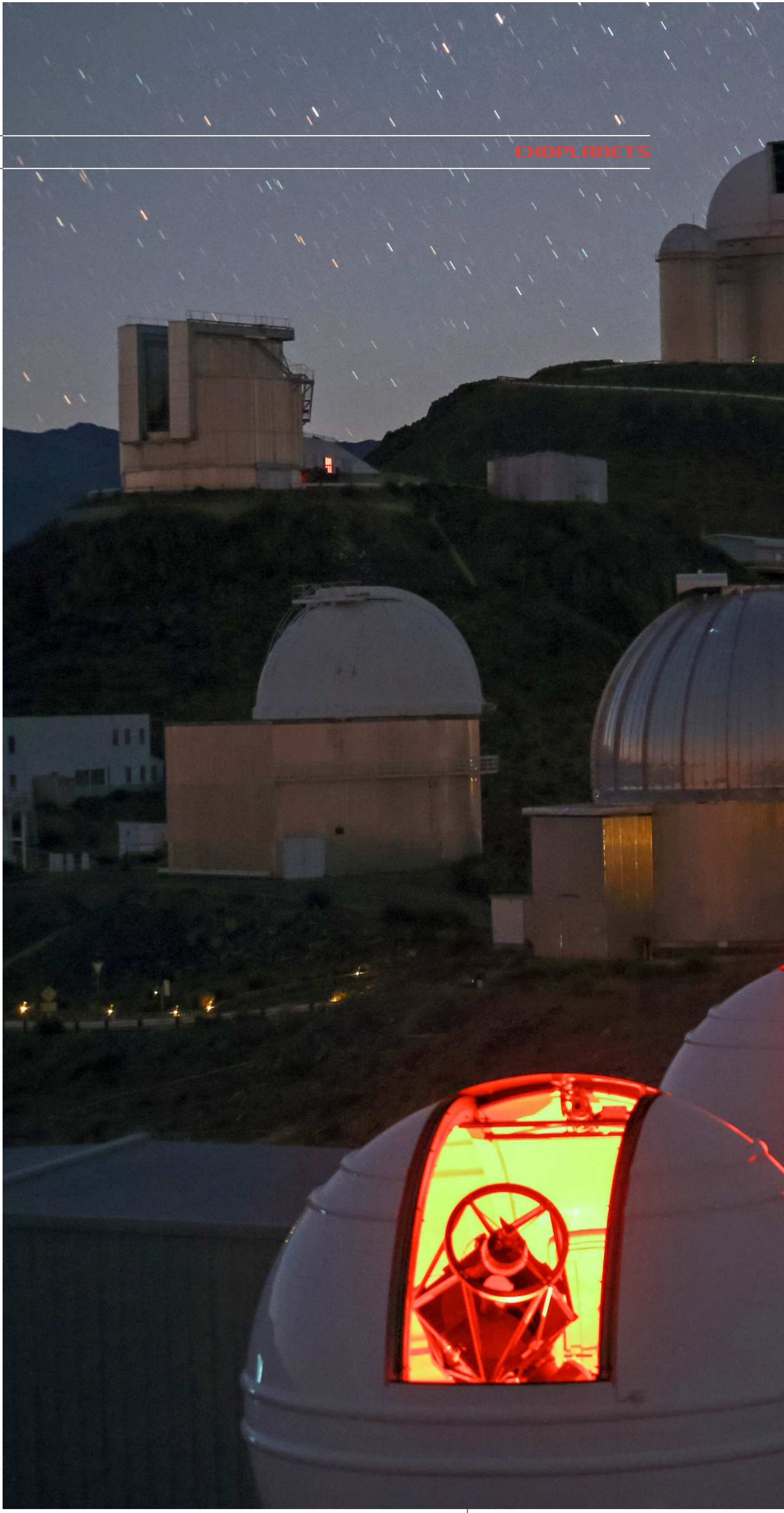
A sign of the great vitality of astronomical research is the number of new instruments that recently became operational. The latest one to have produced its 'first light' is called ExTrA, an acronym for Exoplanets in Transit and their Atmospheres that leaves no doubt about its mission. This instrument, designed by French researchers from the Université Grenoble Alpes and the French National Centre for Scientific Research (CNRS) and funded by the European Research Council and the Agence National de la Recherche, is composed of three Ritchey-Chrétien telescopes, 60 cm in diameter, f/8, equipped with two-lens field correctors. The telescopes are housed in three independent domes at the European Southern Observatory's La Silla Observatory in Chile.

The light collected by the mirrors, rather than being focused directly into a CCD camera, is transferred through optical fibre beams to a low-resolution multi-object spectrograph and then recorded by a sensor.

The reasons why French researchers adopted this innovative solution will be clearer after we explain what the ExTrA targets are and the problems involved in studying them.

The mission of the new instrument is to monitor hundreds of M-type red dwarf stars, looking for temporary and very slight drops in brightness, typical of planets transiting the discs of stars.

If the physical properties of a star are known with an excellent amount of confidence, a transit can provide information on the planet's size, its orbit and, if it has an atmosphere, the composition of that atmosphere. The atmosphere itself filters a very small portion of starlight, adding the fingerprints of the molecules that compose it. Under optimal conditions, it is possible to recognise the nature of those fingerprints using spectroscopy and then to characterise the planet's atmosphere with reasonable certainty. If the spectrum of a star is known with precision, the planetary atmosphere



Overview of the ExTrA project. Astronomers now have a new instrument for searching for potentially habitable worlds. [ESO]

can theoretically be studied both when it passes in front of the star's disc and when it passes behind it. In the second case, the very weak spectrum produced by the planet

The three illuminated domes of ExTrA in the foreground, with numerous other structures belonging to the Chilean observatory La Silla in the background. [ESO/Emmanuela Rimbaud]

does not add to that of the star, as happens in all the out-of-transit orbital positions. Using the instruments currently available to researchers, the only configuration that, in the most favourable cases, can analyse a planet's atmosphere is its transit across the star's disc. This is because of the high signal-to-noise ratio (S/N) required for the spectroscopic examination. Per unit of observing time and for a given planetary size,

better S/N ratios are achieved with stars that appear brighter, meaning those that are closer to us (on average). This implies that the atmospheres of thousands of extrasolar planets discovered around very distant stars, such as the ones monitored by the Kepler space telescope, are currently out of reach for a detailed spectroscopic investigation.
It follows that if we want to discover terrestrial-like atmospheres and even potential biomarkers inside them, we must look for planets transiting in front of close stars. Because the S/N ratio improves as the star size decreases, our best chance of discovering planets is surveys of databases containing M-type red dwarfs, the most common stars in the galaxy and relatively abundant in the part of the galaxy near the Sun.
Calculations tell us that Earth-sized planet that passes in front of a red dwarf with a diameter one-tenth that of the Sun will eclipse 0.8% of the star's surface.

ExTrA telescopes at the ESO Observatory in La Silla, Chile, will search for and study Earth-sized planets in orbit around nearby red dwarfs.
The innovative design of ExTrA allows a higher sensitivity than previous tools. Here we see one of the three ExTrA telescopes inside its dome. [ESO/Petr Horálek]

A planet of the same diameter, on the other hand, transiting a larger, solar-type star's disc produces an eclipse about a hundred times less evident. This is another reason we cannot examine in detail the at-

Three short time-lapse video sequences of the ExTrA instrument under the La Silla sky. [ESO/Petr Horálek]

mospheres of most exoplanets discovered so far; indeed, they were mainly searched around stars similar to the Sun because they are considered (for several good reasons) the most likely to host planets like our own. Nonetheless, an increasing number of rocky planets have recently been discovered around nearby red dwarfs: our readers will surely remember, for example, the famous case of Proxima Centauri b (2016; 5). To ease their discovery, there is not only the favourable S/N ratio but also the frequency with which the planets transit. Indeed, the lesse massive the star, the smaller the stable orbits, and therefore the higher the chances of observing transits, including those of planets orbiting in the habitable zone of those dwarf stars. It is estimated that, compared to a solar-type star, planetary transits on a red dwarf are 4 to 10 times more frequent. Also, at an equal distance from the star, a planet of mass 'x' produces larger variations in the radial velocity of a red dwarf than in a star similar to the Sun, and the chance of calculating 'x' depends on the magnitude of those variations. When the mass of a planet is known, you may then have a rough idea of the kind of atmosphere that surrounds it.

With the most powerful ground-based telescopes, especially those that will become operational in the imminent future, it will finally be possible to accurately characterise that atmosphere. From the above it is clear that if we want, within a few years, to throw the first glimpse into an exoatmosphere potentially conducive to life as we know it, we must necessarily focus on the nearest red dwarfs, discovering new Earth-sized rocky planets and drawing up a list of possible candidates for follow-up atmospheric analysis. This is exactly the task entrusted to ExTrA. Although ExTrA is certainly not the first instrument used in this type of research, it is the first one with optical and electronic solutions that allow it to counteract the main limitations afflicting telescopes operating on the ground.

As mentioned, the photometric variations produced by a planetary transit in the light curve of a red dwarf are, in the most favourable cases, measurable in fractions of one-hundredth of a magnitude.

One can therefore easily imagine how detrimental the movements of air masses in our atmosphere are to measurements. But it's not just a matter of seeing because when the signal you want to highlight is so small, any inaccuracy in the instruments can produce 'noise' greater than the signal sought. It is no coincidence that no ground-based instrument has yet been able to discover exoplanets with diameters less than twice that of the Earth.

Even given an instrument that does not introduce noise into the measurements and

that does not disperse any of the useful signal, all the limitations imposed by our atmosphere remain. The two most significant of these are the efficiency with which humidity in the air breaks down infrared radiation from the red dwarfs (which are particularly bright in that domain of the electromagnetic spectrum); and the atmosphere's chromatic absorption, which unpredictably unbalances the colours of the comparison stars with respect to the target star, distorting the photometric measurements.

So far, researchers have tackled these problems by making observations from particularly dry sites with low air humidity, and by using narrow band-pass filters. If the first solution helps in some way, the second one thwarts it, because in this specific case the quality of the photometry improves with the reduction of the filter bandwidth.

But the more you tighten the band, the more the light signal weakens, and the larger the telescope diameter must be to obtain a readable S/N ratio. To get around all these obstacles, the ExTrA designers have developed a new method that, in a sense, assigns the task of narrow band-pass filters to the aforementioned low-resolution multi-object spectrograph (R~200), that covers the range 0.85-1.55 microns of the near infrared, in which there is the peak of sensitivity of the CCD camera joined with the instrument. This solution offers the double advantage of collecting much more incoming radiation and of being able to tune the colours of the target star and its comparison stars in specific spectral channels, solving the problem of stellar chromatism. By suitably managing individual channels, the bandwidth, the focusing of stars and the recording of the signal via CCD, the French team can produce light curves with a photometric accuracy of 0.02% for measurement, and with a high S/N ratio.

In theory, ExTrA should allow the discovery of planets with a minimum diameter approximately the same as the Earth's radius. This new method of research also has the great advantage of being much cheaper than the classical methods. ■

In the foreground, one of the domes housing the ExTrA telescopes. The size of the entrance is a clue to the small size of these structures: the telescope inside takes up almost all the available space. [ESO/Petr Horálek]

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The archaeology of our Milky Way's ancient hub probed by Hubble

by NASA/ESA

For many years, astronomers had a simple view of our Milky Way's central hub, or bulge, as a quiescent place composed of old stars, the earliest homesteaders of our galaxy. However, because the inner Milky Way is such a crowded environment, it has always been a challenge to disentangle stellar motions to probe the bulge in detail. Now, a new analysis of about 10,000 normal Sun-like stars in the bulge reveals that our galaxy's hub is a dynamic environment of stars of various ages zipping around at different speeds, like travelers bustling about a busy airport. This conclusion is based on nine years' worth

Previous page: the vast edge-on stretch of our home galaxy, the Milky Way, is seen intersecting the night sky above the silhouetted Rocky Mountains in this photograph. The Milky Way noticeably widens at lower right. This wider area is the central hub, or bulge, of our galaxy. Peering into a very narrow region of the core, astronomers used the Hubble Space Telescope to study the compositions and motions of 10,000 Sun-like stars, as seen in the inset Hubble image. The analysis reveals that our galaxy's bulge is an unexpectedly dynamic environment of stars of various ages zipping around at different speeds, like travelers bustling about a busy airport. The study yields important new clues to the complexity of the central bulge and our Milky Way's evolution over billions of years. The Hubble image is a composite of exposures taken in near-infrared and visible light with Hubble's Wide Field Camera 3. The observations are part of two Hubble surveys: the Galactic Bulge Treasury Program and the Sagittarius Window Eclipsing Extrasolar Planet Search. The center of our galaxy is 26,000 light-years away. [NASA, ESA, and Z. Levay (STScI)]

of archival data from NASA's Hubble Space Telescope. The Hubble study of this complicated, chaotic heart of our Milky Way may provide new clues to the evolution of our galaxy, said researchers.

The research team, led by Will Clarkson of the University of Michigan-Dearborn, found that the motions of bulge stars are different, depending on a star's chemical composition. Stars richer in elements heavier than hydrogen and helium have less disordered motions, but are orbiting around the galactic center faster than older stars that are deficient in heavier elements.

"There are many theories describing the formation of our galaxy and central bulge," said Annalisa Calamida of the Space Telescope Science Institute, Baltimore, Maryland, a member of the Hubble research team. *"Some say the bulge formed when the galaxy first formed about 13 billion years ago. In this case, all bulge stars should be old and share a similar motion. But others think the bulge formed later in the galaxy's lifetime, slowly evolving after the first generations of stars were born. In this scenario, some of the stars in the bulge might be younger, with their chemical composition enriched in heavier elements expelled from the death of previous generations of stars, and they should show a different motion compared to the older stars. The stars in our study are showing characteristics of both models. Therefore, this analysis can help us in understanding the bulge's origin."*

The astronomers divided the stars by their chemical compositions and then compared the motions of each group. They determined the stars' chemical content by studying their colors and divided them in two main groups according to their heavy-element (iron) abundance. The chemically enriched stars are moving twice as fast as the other population.

"By analyzing nine years' worth of data in the archive and improving our analysis techniques, we have made a clear, robust detection of the differences in the motion for chemically deficient and chemically enriched Sun-like stars," Clarkson said. *"We hope to continue our analysis, which will allow us to make a three-dimensional chart of the rich chemical and dynamical complexity of the populations in the bulge."*

The astronomers based their analysis on Advanced Camera for Surveys and Wide Field Camera 3 data from two Hubble surveys: the Wide Field Camera 3 Galactic Bulge Treasury Program and the Sagittarius Window Eclipsing Extrasolar Planet Search. Sets of spectra from the European Southern Observatory's Very Large Telescope in Chile were used to help estimate the chemical compositions of stars.

Currently, only Hubble has sharp enough resolution to simultaneously measure the motions of thousands of Sun-like stars at the the galaxy bulge's distance from Earth.

The center of our galaxy is about 26,000 light-years away. *"Before this analysis, the motions of these stars was not known,"* said team member Kailash Sahu of the Space Telescope Science Institute. *"You need a long time baseline to accurately measure the positions and the motions of these faint stars."*

The team studied Sun-like stars because they are so abundant and easily within Hubble's reach. Previous observations looked at brighter, aging red giant stars, which are not as plentiful because they represent a brief episode in a star's lifetime. *"Hubble gave us a narrow, pencil-beam view of the galaxy's core, but we are seeing thousands more stars than those spotted in earlier studies,"* Calamida said. The Milky Way's bulge is roughly one-tenth the diameter of our pancake-shaped galaxy. *"We next plan to extend our analysis to do additional observations along different sight-lines, which will allow us to make a three-dimensional probe of the rich complexity of the populations in the bulge,"* Clarkson added.

The researchers said that this work is also an important pathfinder for NASA's James Webb Space Telescope to probe the archaeology of the Milky Way. Scheduled for launch in 2019, Webb is expected to more deeply probe stellar populations in the Milky Way bulge. The research team presented its findings Thursday, Jan. 11, at the 231st meeting of the American Astronomical Society in Washington, D.C. ■

First ELT main mirror segments successfully cast

by ESO

The 39-metre-diameter primary mirror of ESO's Extremely Large Telescope will be by far the largest ever made for an optical-infrared telescope. Such a giant is much too large to be made from a single piece of glass, so it will consist of 798 individual hexagonal segments, each measuring 1.4 metres across and about 5 centimetres thick. The segments will work together as a single huge mirror to collect tens of millions of times as much light as the human eye. Marc Cayrel, head of ELT optomechanics at ESO, was pre-

The first hexagonal segments for the main mirror of ESO's Extremely Large Telescope (ELT) are shown being successfully cast by the German company SCHOTT at their facility in Mainz. These segments will form parts of the ELT's 39-metre main mirror, which will have 798 segments in total when completed. The ELT will be the largest optical telescope in the world when it sees first light in 2024. [SCHOTT/ESO]

The SCHOTT team that successfully casted the first ELT main mirror segments. [SCHOTT/ESO]

sent at the first castings: *"It was a wonderful feeling to see the first segments being successfully cast. This is a major milestone for the ELT!"* As with the telescope's secondary mirror blank, the ELT main mirror segments are made from the low-expansion ceramic material Zerodur© from SCHOTT.
Zerodur© was originally developed for astronomical telescopes in the late 1960s. It has an extremely low coefficient of thermal expansion, meaning that even in the case of large temperature fluctuations, the material does not expand. Chemically, Zerodur© is very resistant and can be polished to a high standard of finish.
The actual reflective layer, made of aluminium or silver, is usually vaporised onto the extremely smooth surface shortly before a telescope is put into operation and at regular intervals afterwards.
Many well-known telescopes with Zerodur© mirrors have been operating reliably for decades, including ESO's Very Large Telescope in Chile.
ESO has awarded this German company with contracts to manufacture the blanks of the first four ELT mirrors (known as M1 to M4, with M1 being the primary mirror).
The first segment castings are important as they allow the engineers at SCHOTT to validate and optimise the manufacturing process and the associated tools and procedures. The casting of the first six segments is a major milestone, but the road ahead is long — in total more than 900 segments will need to be cast and polished (798 for the main mirror itself, plus a spare set of 133). When fully up to speed, the production rate will be about one segment per day. After casting, the mirror segment blanks will go through a slow cooling and heat treatment sequence and will then be ground to the right shape and polished to a precision of 15 nanometres across the entire optical surface. The shaping and polishing will be performed by the French company Safran Reosc, which will also be responsible for additional testing. ■

This video shows the fusion of the first ELT main mirror segments. [SCHOTT AG]

SMBHs–host galaxies co-evolution deepened by ALMA

by ALMA Observatory

Using the Atacama Large Millimeter/submillimeter Array (ALMA) to observe an active galaxy with a strong ionized gas outflow from the galactic center, astronomers have obtained a result making themselves even more puzzled: an unambiguous detection of carbon monoxide (CO) gas associated with the galactic disk. However, they have also found that the CO gas which settles in the galaxy is not affected by the strong ionized gas outflow launched from the galactic center.

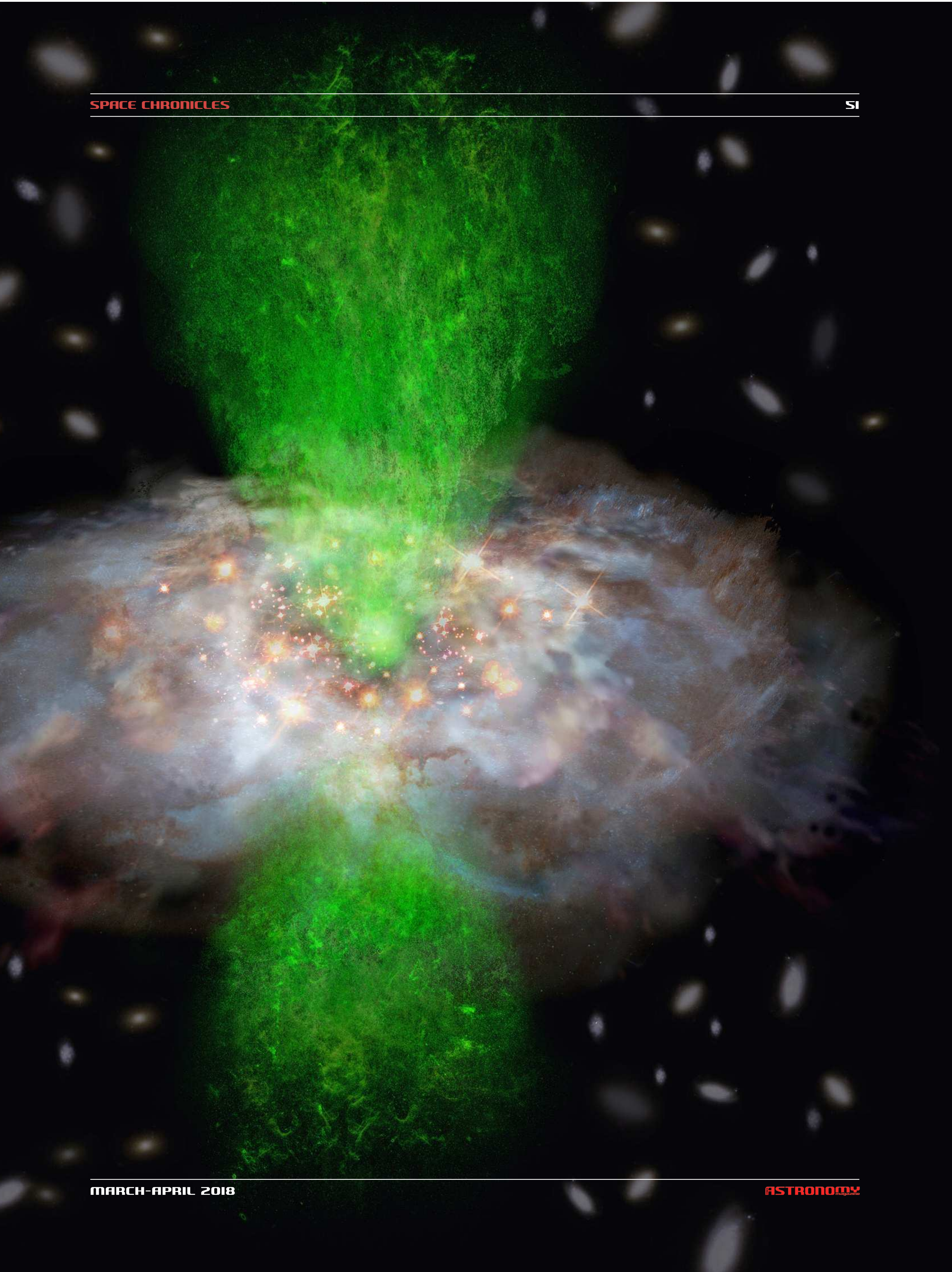
According to a popular scenario explaining the formation and evolution of galaxies and supermassive black holes, radiation from galactic centers, where supermassive black holes are, can significantly influence the molecular gas (such as CO) and the star formation activities of the galaxies.

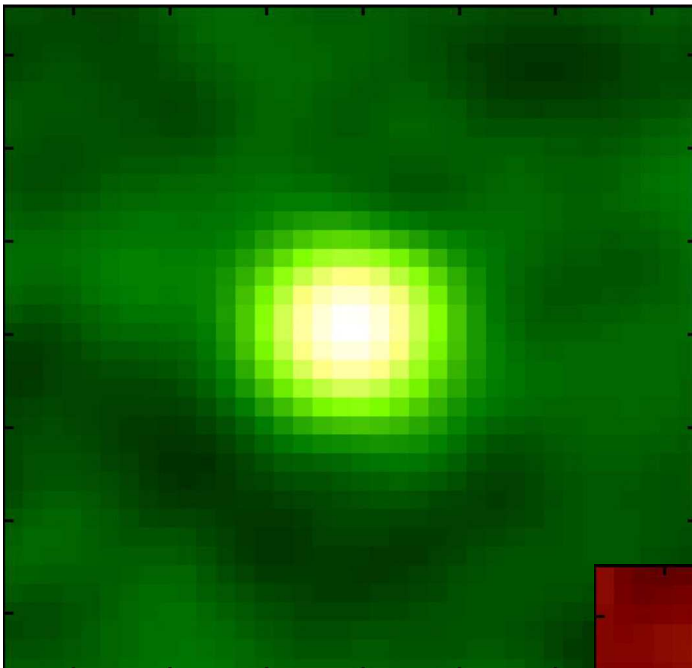
ALMA result shows that the ionized gas outflow driven by the supermassive black hole does not necessarily affect its host galaxy. This result *"has made the co-evolution of galaxies and supermassive black holes more puzzling,"* explains Dr. Yoshiki Toba from the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA, Taiwan), and main author of this research. *"The next step is looking into more data of this kind of galaxies. That is crucial for understanding the full picture of the formation and evolution of galaxies and supermassive black holes"*.

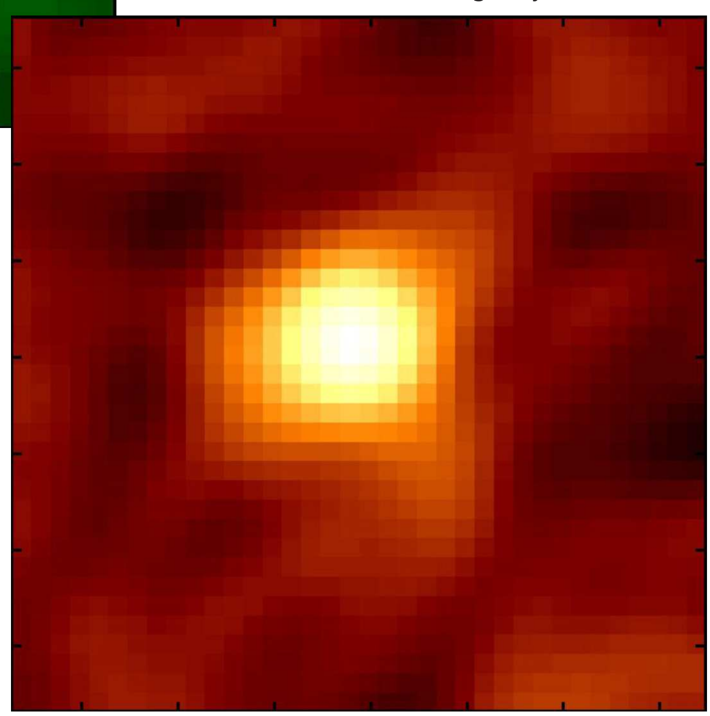
Answering the question *"How did galaxies form and evolve during the 13.8-billion-year history of the universe?"* has been one top issue in modern astronomy. Studies already revealed that almost all massive galaxies harbor a supermassive black hole at their centers. In recent findings, studies further showed the tight correlation between the mass of black holes and those of their host galaxies. This correlation suggests that supermassive black holes and their host galaxies have evolved together and they closely interacted each other as they grew, as known as the co-evolution of galaxies and supermassive black holes.

The gas outflow driven by a supermassive black hole at the galactic center recently has become the focus of attention as it possibly is playing a key role in the co-evolution of galaxies and black holes. A widely accepted idea has described this phenomenon as the intense radiation from the galactic

A schematic view of the fact that an ionized gas outflow (green) driven by the central supermassive black hole does not affect the star formation of its host galaxy. This situation may occur if the ionized gas is outflowing perpendicularly to the molecular gas. [ALMA (ESO/NAOJ/NRAO)]







Emission from carbon monoxide (green) and cold dust (red) in WISE1029 observed by ALMA. The image size is 3 square arcsecond. [ALMA (ESO/NAOJ/NRAO), Toba et al.]

center in which is the supermassive black hole ionizes the surrounding gas, even affecting the molecular gas that is the ingredient of star formation. The strong radiation activates or suppresses the star formation of galaxies. However, *"we astronomers do not understand the real relation between the activity of supermassive black holes and star formation in galaxies,"* says Tohru Nagao, Professor at Ehime University. *"Therefore, many astronomers including us are eager to observe the real scene of the interaction between the nuclear outflow and the star-forming activities, for revealing the mystery of the co-evolution."* Astronomers believe that DOGs harbor actively growing supermassive black holes in their nuclei. In particular, one DOG (WISE1029 +0501, hereafter WISE1029) is outflowing gas ionized by the intense radiation from its supermassive black hole. WISE1029 is known as an extreme case concerning ionized gas outflow, and this particular factor has motivated the researchers to see what happens to its molecular gas. By making use of ALMA's outstanding sensitivity which is excellent in investigating properties of molecular gas and star-forming activities in galaxies, the team conducted their research by observing the CO and the cold dust of galaxy WISE1029. After detailed analysis, surprisingly they found, there is no sign of significant molecular gas outflow. Furthermore, star-forming activity is neither activated nor suppressed. This indicates that a strong ionized gas outflow launched from the supermassive black hole in WISE1029 neither significantly affect the surrounding molecular gas nor the star formation.

There have been many reports saying that the ionized gas outflow driven by the accretion power of a supermassive black hole has an enormous impact on surrounding molecular gas. However, it is a rare case that there is no close interaction between ionized and molecular gas as the researchers are reporting this time. Yoshiki and its team's result suggests that the radiation from a supermassive black hole does not always affect the molecular gas and star formation of its host galaxy.

While their result is making the co-evolution of galaxies and supermassive black holes more puzzling, Yoshiki and his team are exciting about revealing the full picture of the scenario. He says that *"understanding such co-evolution is crucial for astronomy. By collecting statistical data of this kind of galaxies and continuing in more follow-up observations using ALMA, we hope to reveal the truth."*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