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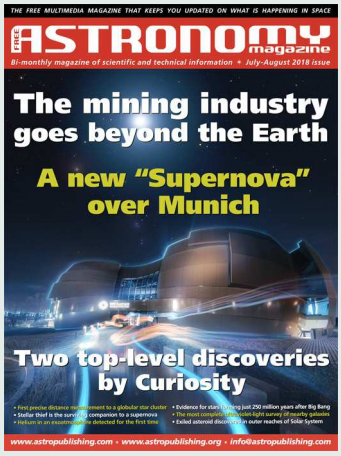

English edition of the magazine

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Publisher
Astro Publishing di Pirlo L.
Via Bonomelli, 106
25049 Iseo - BS - ITALY
email info@astropublishing.com

Internet Service Provider
Aruba S.p.A.
Via San Clemente, 53
24036 Ponte San Pietro - BG - ITALY

Advertising - Administration
Astro Publishing di Pirlo L.
Via Bonomelli, 106
25049 Iseo - BS - ITALY
email admin@astropublishing.com

SUMMARY

The mining industry goes beyond the Earth

Factor-Tech Magazine

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

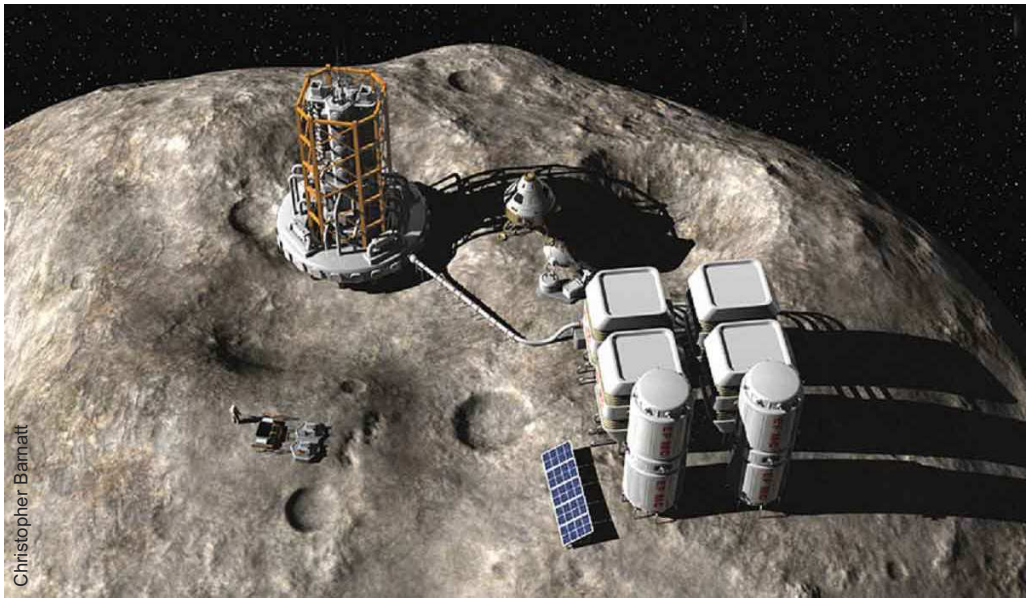
The colonization of near-space and beyond by mankind will require large quantities of raw materials from which to build habitats that will allow us to live without depending on Mother Earth. Asteroids can provide much of the necessary resources, and the mining industry is already looking towards that new frontier. However, the difficulties that must be overcome to turn asteroids into mines are considerable.

In the background, a hypothetical mining plant in action on the surface of a rocky body of the Solar System.

A major player in the upheaval of the Earth's ecosystem is undoubtedly the mining industry. The extraction and processing of underground resources inevitably involves pollution of the natural environment and, if the deposits are shallow, the scars left by man's work can last for millions of years. Even by minimizing the impact of those activities, a basic problem remains: mineral resources sooner or later will run out or become cost-prohibitive to obtain, and their availability and distribution

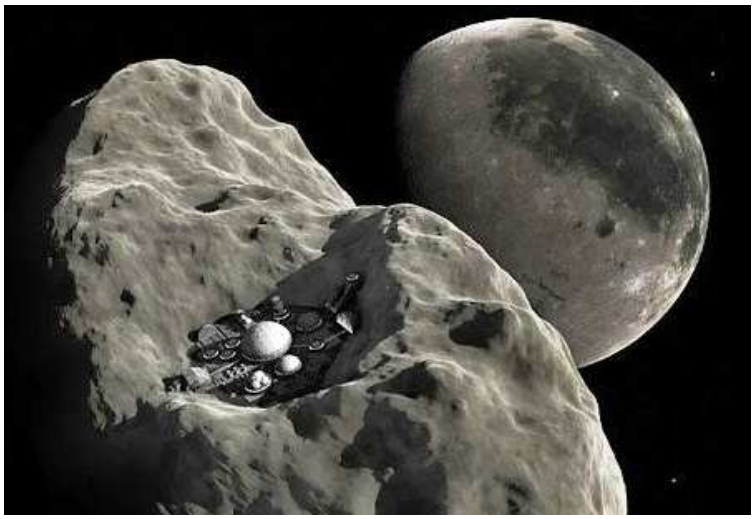
on the Earth's surface seem insufficient to meet our needs in the long run, especially if we consider the demographic increase expected in the coming decades - a real social time bomb.

The mining industry of the future will, therefore, have to make the necessary choice of extending its activities beyond the Earth. The resources closest to our planet are on the Moon, but the gravity of our satellite is a severe obstacle to the short-term exploitation of that wealth. A reasonable alternative is represented by asteroids with orbits similar to that of the Earth, the so-called Near-Earth Asteroids (NEAs), which are usually very small and therefore easy to approach. It is precisely on the NEAs that, for some years now, the attention of asteroid specialists and mining engineers has seriously focused. The idea of exploiting those small rocky bodies for their supply of raw materials that are scarce on Earth, or that are not convenient to transport from Earth, is decades old and was born at the same time as the idea of building colonies in space. However, the first attempt to concretely



Christopher Barnatt

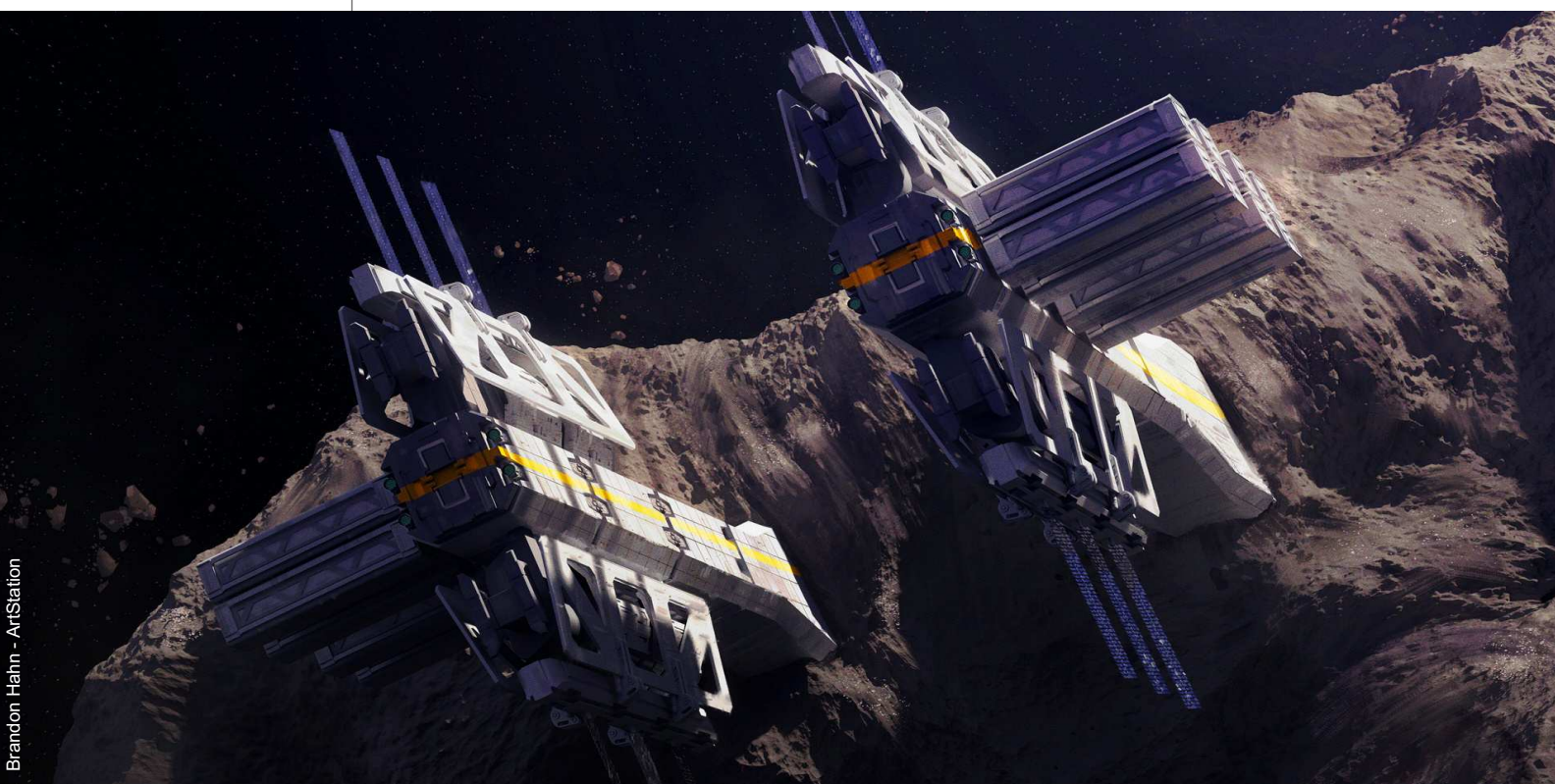
On this page and the following one, we see some fanciful creations of industrial plants dedicated to the extraction of raw materials from the surfaces of four hypothetical NEAs. One day we may see scenarios of this kind, but not in the immediate future.



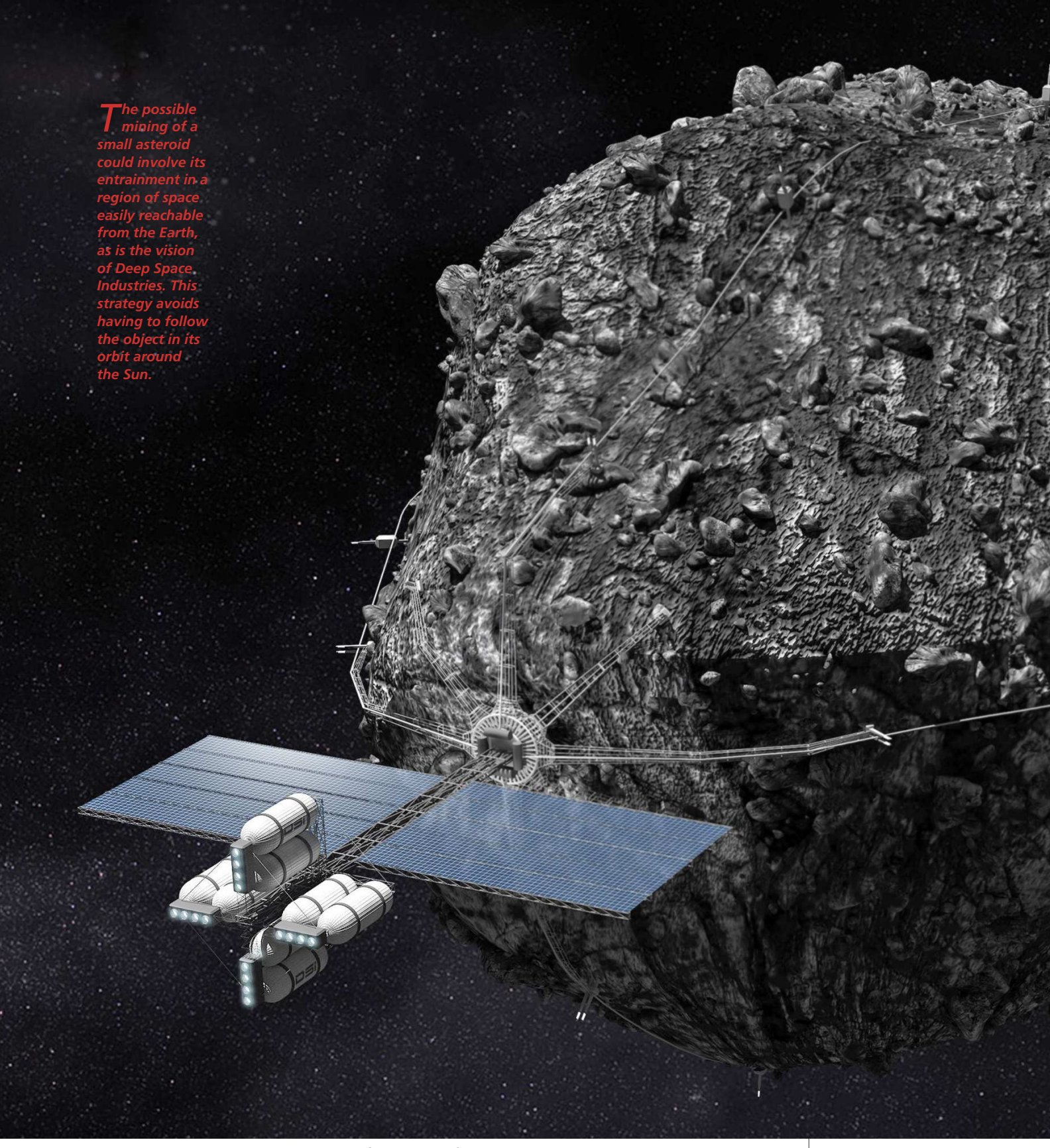
tackle the issue is recent, dating back only to September 2016, when dozens of scientists, technicians and entrepreneurs met in Luxembourg to outline the guidelines for what could be the beginning of the mining of NEAs. In particular, this group highlighted the main gaps in scientific and technical knowledge that need to be filled before pursuing NEA mining further.

The meeting, "Asteroid Science Intersections with In-Space Mine Engineering (ASIME) 2016," produced a white paper entitled "Answers to Questions from the Asteroid Miners," presented in September 2017 at the European Planetary Science Congress 2017 in Riga (Latvia) by JL Galache (formerly at the Minor Planet Center, Harvard-Smithsonian Center for Astrophysics, now Chief Technology Officer of Aten Engineering and a Deep Space Industries adviser) and first author Amara Graps (University of Bath, UK). The document deals with a series of arguments that point out the need to deepen the study of the properties of NEAs as an initial step towards the realization of the first successful mining missions.

Out of a total of over 750,000 identified asteroids, those that transit close to the Earth (less than 1.3 AU) number only about 17,000. Of all these, we only know the orbits with enough precision of a smaller number. With approximation, we only know some of the chemical-physical properties of a few dozen of all NEAs. This scarcity of information is due largely to two factors. The first is related to the purpose of the surveys dedicated to the discovery of potentially haz-



Brandon Hahn - ArtStation



The possible mining of a small asteroid could involve its entrainment in a region of space easily reachable from the Earth, as is the vision of Deep Space Industries. This strategy avoids having to follow the object in its orbit around the Sun.

ardous asteroids – the only goal of these surveys is to determine the orbits, and not the composition, of those objects. The second factor is that NEAs are generally discovered only when they are at their maximum brightness. Because their apparitions are very fleeting, there is usually no opportunity to observe the brightened NEAs long enough and deepen our knowledge of their chemical and surface properties before they become invisible to any telescope. Without spectroscopic observations, it is impossible


Deep Space Industries - Bryan Versteeg

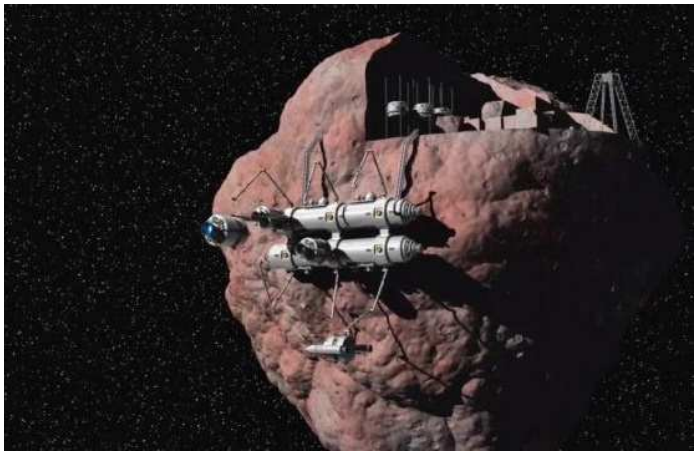
In the video above, a sample is taken from an asteroidal surface, according to Deep Space Industries.

to determine the mineralogical compositions of their surfaces. With knowledge of the orbit of a given asteroid, we can only hypothesize that it inherited its chemical elements from the early protoplanetary disk at that distance from the Sun, or that it has the same composition as other, better known, dynamically-comparable objects belonging to the same family or shared ancestor. Nonetheless, the level of uncertainty remains high. This has not been a major problem up to now, but becomes one as we plan the mining exploitation of those bodies, when it is essential to know in advance where to go digging and what we can expect to extract.

Since asteroids can be roughly divided into carbonaceous, siliceous and metallic categories, one can imagine that robotic miners will be exposed to very different characteristics depending on the surfaces they land on and drill into. Mining companies are particularly interested in metal asteroids because they are rich in iron and nickel.

The experience of terrestrial miners tells us that, where iron and nickel are present, gold and platinum can also often be found. According to Martin Elvis (Harvard-Smithsonian Center for Astrophysics), for a company to be profitable in light of the enormous investments needed to mine an asteroid, it must produce at least $1 billion, a threshold perhaps reachable if the asteroid has a diameter greater than 1 km and 10 parts per million or more of platinum. NEA composition is not the only factor, as the asteroid must also have orbital properties very favorable for a rendezvous, such as being able to be brought to a relative speed with respect to the Earth of less than 4.5 m/s.

How many NEAs do exist with these minimum requirements? According to an esti-

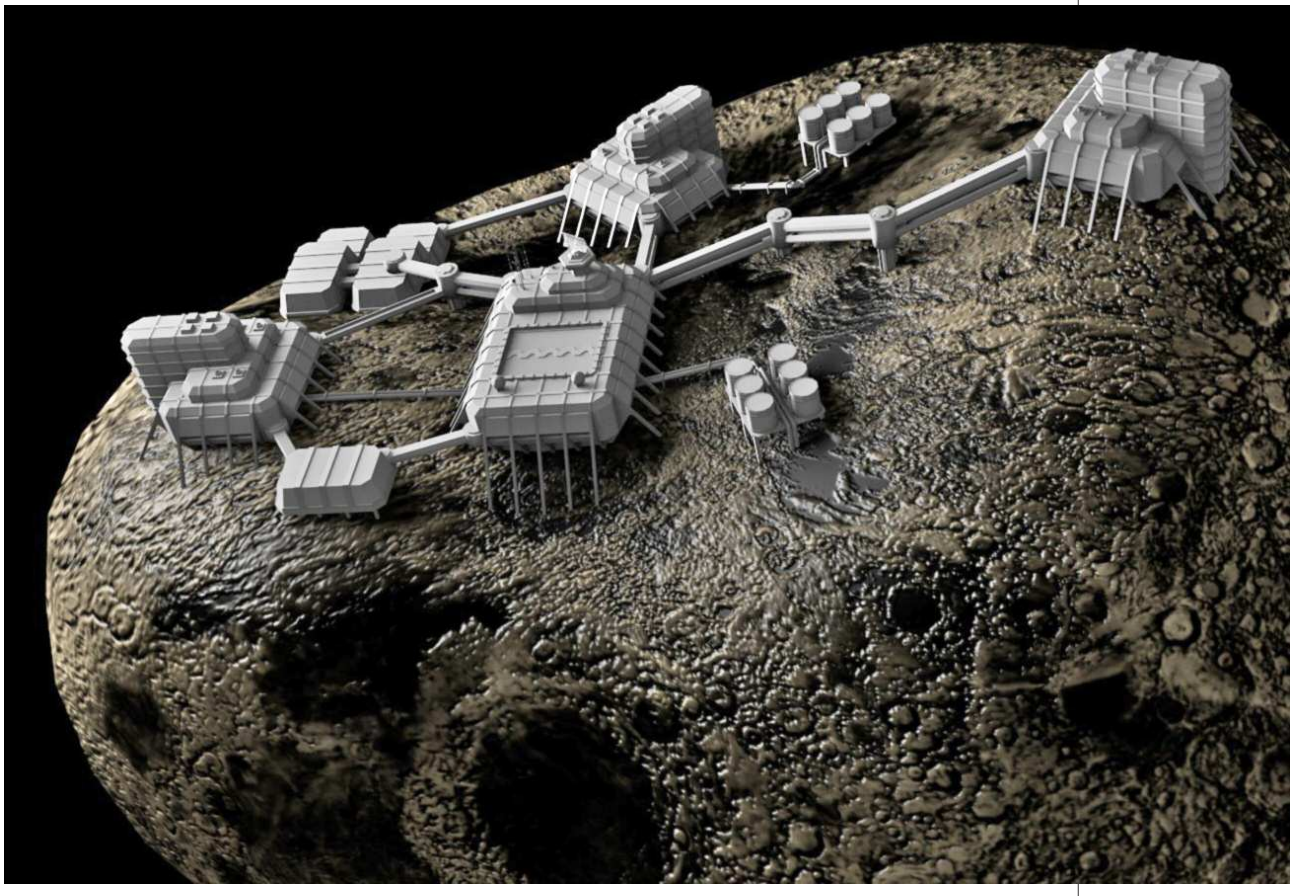


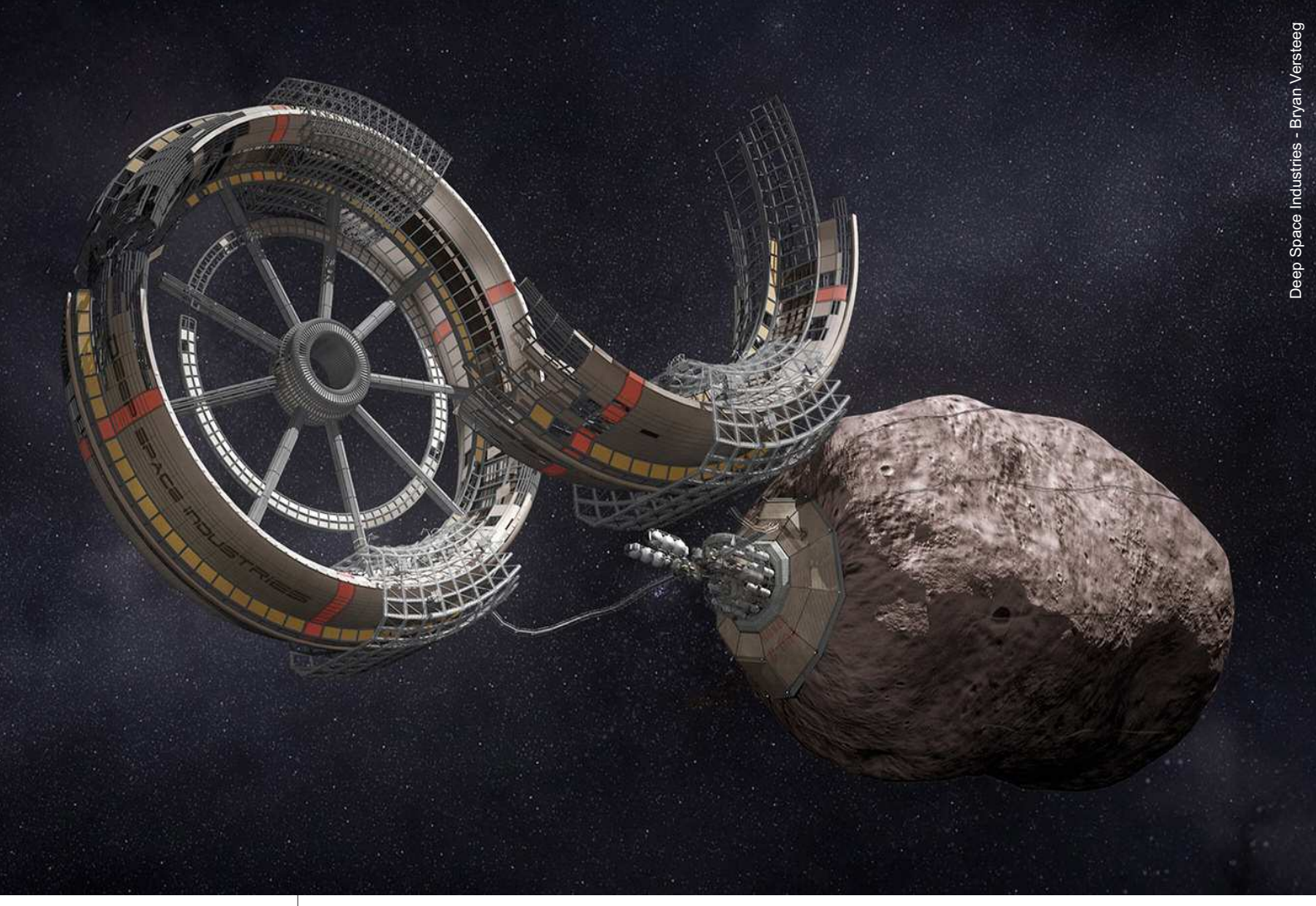
mate by Elvis, 4% of the 17,000 NEAs could be metallic – the same percentage of metallic meteorites that fall on the Earth compared to the total number of meteorites. This assessment (a possibly questionable estimate, based only on assumptions and probabilities) and other more stringent parameters led Elvis to say that the potentially profitable asteroids number just a dozen. Unfortunately, of this estimated dozen, we do not yet know where they are or what they may actually contain.

So the survey starts from scratch, the primary goal being to find that handful of NEAs in the multitude of those already discovered and the many still to be discovered.

To find them, researchers intend to organize a network of ground-based telescopes of a 2-3m class, able to perform spectrophotometric observations in the infrared – and

The models of mining facilities clinging to the two NEAs depicted on this page highlight the need to firmly anchor the structures to the surface. Indeed, due to the feeble gravity of these asteroids, the pressure exerted by the excavators could otherwise be sufficient to lift the plants off the surface.





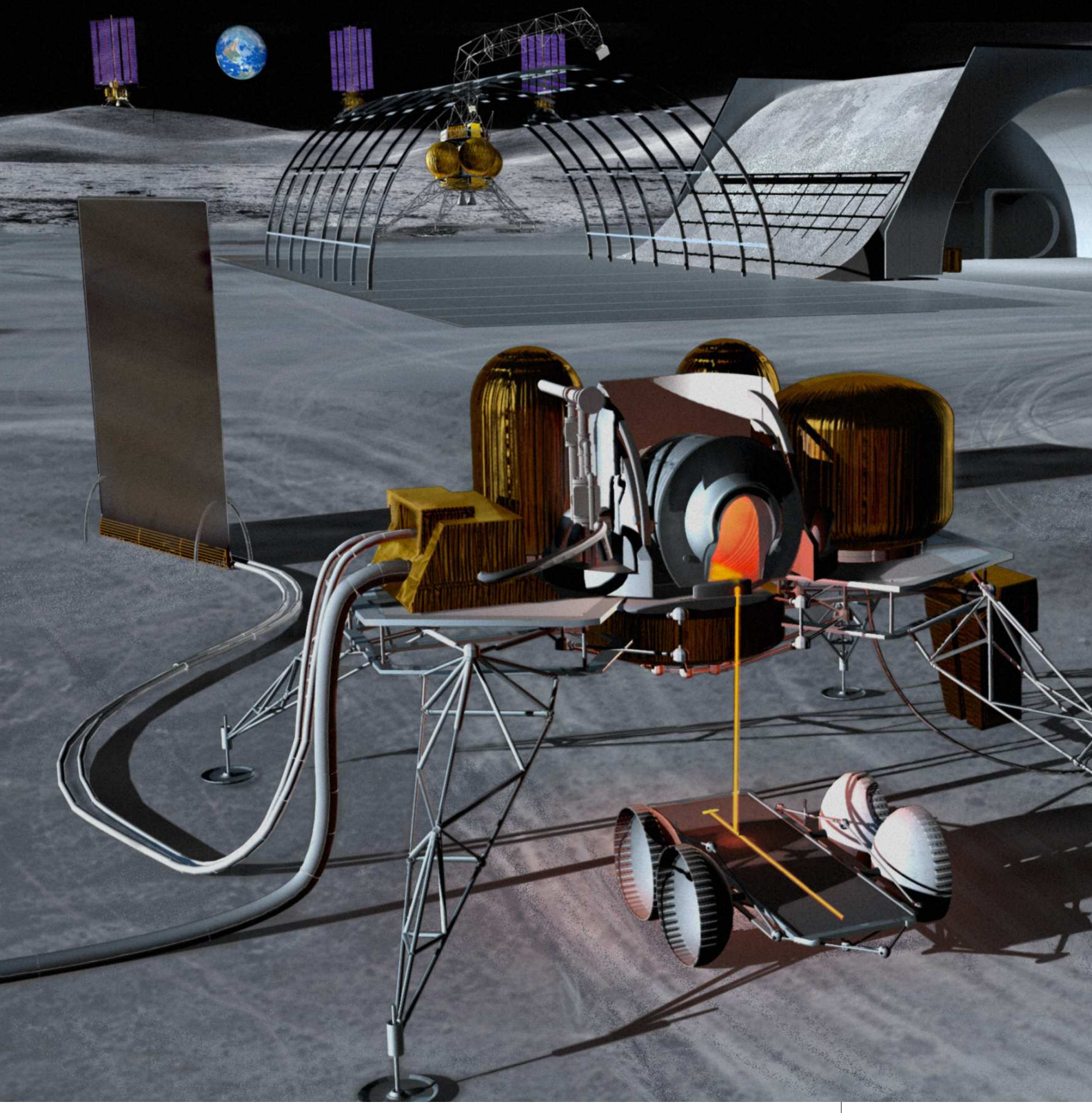
Deep Space Industries - Bryan Versteeg

Although very imaginative, this illustration highlights the need to develop in parallel with the space mining industry an "industry of transformation" and nearby use of resources extracted from asteroids. In this case, the raw materials obtained from a NEA are fashioned to give shape to a large spatial base.

also able to quickly alert seekers upon discovery. Asteroid Mining Corporation (Tarleton, Preston, UK), is also planning a small space telescope specifically designed for research and the spectroscopic study of NEAs, which should be launched into low-Earth orbit by 2020.

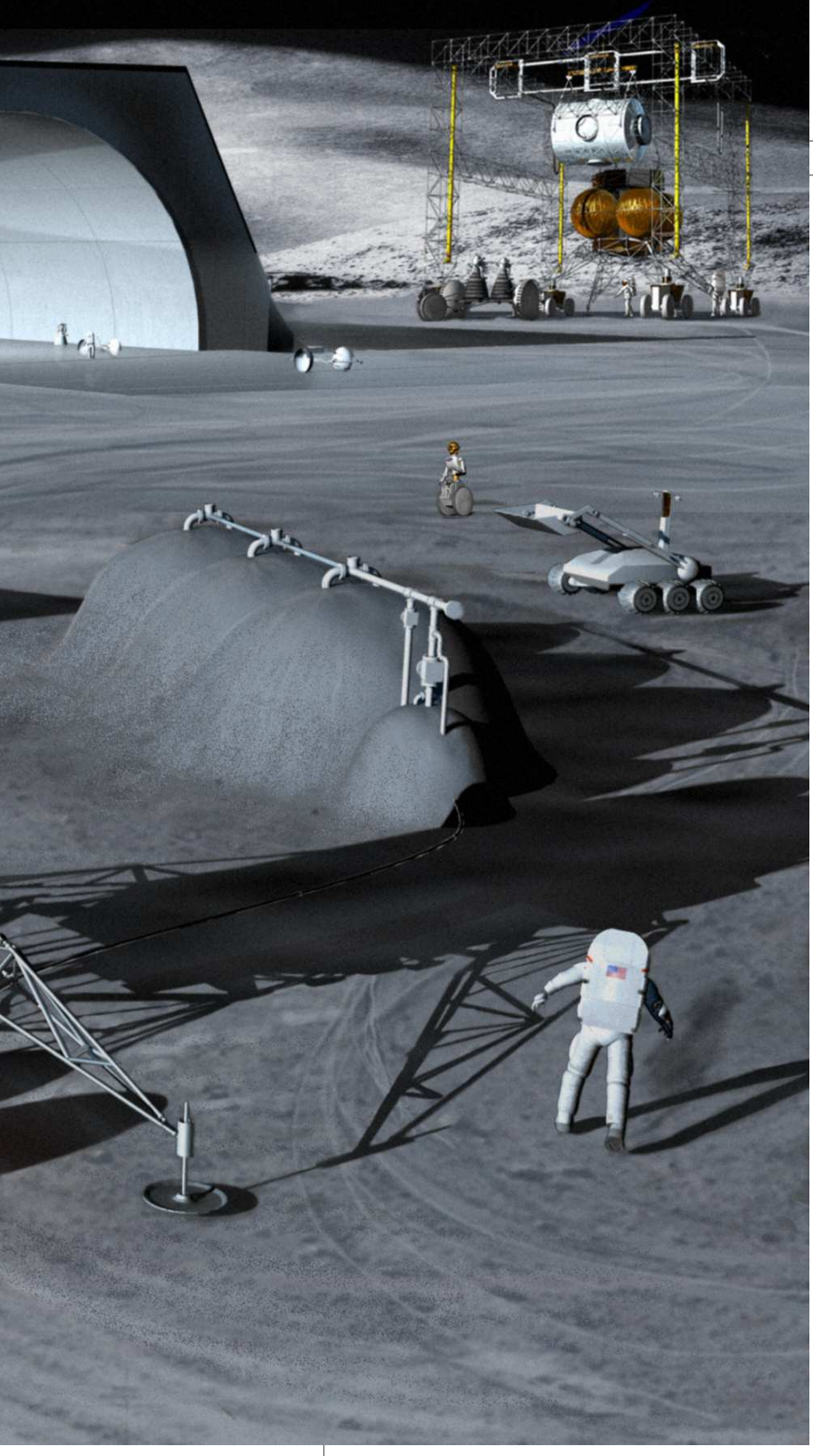
Whatever method of investigation is adopted, spectroscopic studies can only provide information on the outermost part of the asteroidal surfaces by measuring the NEA's reflected sunlight. It does not mean that the elements on the surface are representative of the mineralogy of the subsoil. This problem brings together, as a first approximation, all the asteroids, but it is particularly concrete for those orbiting closer to the Sun, such as NEAs, which are subjected more than others to the action of space weather and micrometeoritic bombardment. Consequently, we will not be able to avoid the more intensive second phase of study of these objects by landing probes directly on their surfaces. This further step will allow us to collect samples for subsequent chemical analysis either with on-board or sample-returned laboratories, and will also provide detailed images of the surfaces, useful for identifying possible landing sites. The close approach will be essential even to know the consistency of the regolith and the debris covering those surfaces, a feature almost impossible to describe today through remote observation. In this regard, the case of the Eros and Itokawa asteroids is emblematic: both are very similar in terms of spectrum and reflectivity when viewed from Earth, but they revealed very different surface materials when visited by NEAR Shoemaker and Hayabusa probes. Eros is covered with fine regolith, while rubble of a few centimeters in size is prevalent on the surface of Itokawa. In both cases, however, we do not know how deep these surface materials extend.

Without adequate knowledge of the properties and distribution of surface material, it is impossible to develop a strategy for landing and extracting resources. Because of the feeble gravity of NEAs, any activity practiced on them may have unpredictable effects even in the absence of information on the innermost structure of those asteroids: the presence of empty spaces or material not sufficiently sturdy to support mining operations can put mining activity at risk.



Having established that we know little or nothing about the chemical, physical and structural properties of asteroids important to mining operations, one wonders whether the investments that some companies are already making are justified. The answer can be affirmative or negative depending on how far in the future we want to look. If the goal is to colonize space, it will be unavoidable to resort, sooner or later, to resources offered in space (well beyond a handful of asteroids). However, it is implausible that this will happen in the near future. Companies that are moving today to create the preconditions for the mining industry of the future do this to secure a dominant position when the market finally opens. That said, one wonders if they are playing a little too early. In addition to the enormous technological and economic efforts that must be

In a distant future, human beings will massively exploit the resources of the lunar subsurface to build permanent bases, spaceports and fuel depots for interplanetary



travel. A scene like the one shown above could become a reality within a few decades. Meanwhile, at least part of the future mining industry will likely focus on NEAs.

made to select the ideal targets, to send a fleet of robotic machines to them, and to find and collect raw materials of various kinds for analysis, it will also be necessary to carry or build in space the industrial facilities needed to transform those materials into usable products. Transporting these last raw or already refined materials back to Earth is unthinkable – it would be uneconomical even in the cases of gold and platinum.

Accordingly, the products of space mining must be used in the construction of orbital stations, lunar bases, spaceships, fuel depots and more – and be implemented directly in space. This implies the development of an industry that is still pure "technology fiction": nothing that seems achievable within the next decade and probably not even the second decade to come. Very optimistically, Asteroid Mining Corporation proposes the solution of 3D printing metallic materials to build housing structures in space while managing to overcome the problem of the absence of gravity in the process. Even with the technology developed to build the infrastructure, it takes more than a metal structure to create a livable environment in space. If the mining phase were to be implemented too far in advance of the transformative infrastructure and colonization phases, the only reasonable destination for the raw materials is in storage in Earth orbit or at the Lagrangian point of the Earth-Moon system. This solution would not, however, repay the costs incurred to extract those raw materials.

There are not only huge technological and economic obstacles to overcome to start the space mining industry. There are also legal and international law issues to be addressed. To whom do the asteroids belong? Who has the right to exploit what?

The legislative void that characterizes the exploration and exploitation of space risks turning the race to the asteroids into a sort of "far west" without rules. The only international agreement on the subject is the Outer Space Treaty, a generic document on the principles governing the activities of nations in the exploration and use of cosmic space, including the Moon and other celestial bodies, signed more than half a century ago by the USA, USSR and UK, to which another hundred countries have subsequently joined. Obviously, that treaty is totally inadequate to manage scenarios that were not even remotely imaginable in the 1960s.

The mining industry will remain exclusively terrestrial for a long time yet to come until a great deal of science and legislation is addressed, and this is not good news for those envisioning the near-term population of near-space and beyond. ■

Too many massive stars in starburst galaxies

by ESO

Probing the distant Universe a team of scientists, led by University of Edinburgh astronomer Zhi-Yu Zhang, used the Atacama Large Millimeter/submillimeter Array (ALMA) to investigate the proportion of massive stars in four distant gas-rich starburst galaxies. These galaxies are seen when the Universe was much younger than it is now so the infant galaxies are unlikely to have undergone many previous episodes of star formation, which might otherwise have confused the results.

Zhang and his team developed a new technique — analogous to radiocarbon dating (also known as carbon-14 dating) — to measure the abundances of different types of carbon monoxide in four very distant, dust-shrouded starburst galaxies. They observed the ratio of two types of carbon monoxide containing different isotopes.

"Carbon and oxygen isotopes have different origins", explains Zhang. *"^{18}O is produced more in massive stars, and ^{13}C is produced more in low- to intermediate-mass stars."* Thanks to the new technique the team was able to peer through the dust in these galaxies and assess for the first time the masses of their stars. The mass of a star is the most important factor determining how it will evolve.

This artist's impression shows a dusty galaxy in the distant Universe that is forming stars at a rate much higher than in our Milky Way. New ALMA observations have allowed scientists to lift the veil of dust and see what was previously inaccessible — that such starburst galaxies have an excess of massive stars as compared to more peaceful galaxies. [ESO/M. Kornmesser]

Massive stars shine brilliantly and have short lives and less massive ones, such as the Sun, shine more modestly for billions of years. Knowing the proportions of stars of different masses that are formed in galaxies therefore underpins astronomers' understanding of the formation and evolution of galaxies throughout the history of the Universe. Consequently, it gives us crucial insights about the chemical elements available to form new stars and planets and, ultimately, the number of seed black holes that may coalesce to form the supermassive black holes that we see in the centres of many galaxies.

Co-author Donatella Romano from the INAF-Astrophysics and Space Science Observatory in Bologna explains what the team found: *"The ratio of ^{18}O to ^{13}C was about 10 times higher in these starburst galaxies in the early Universe than it is in galaxies such as the Milky Way, meaning that there is a much higher proportion of massive stars within these starburst galaxies."*

The ALMA finding is consistent with another discovery in the local Universe. A team led by Fabian Schneider of the University of Oxford, UK, made spectroscopic measurements with ESO's Very Large Telescope of 800 stars in the gigantic star-forming region 30 Doradus in the Large Magellanic Cloud in order to investigate the overall distribution of stellar ages and initial masses.

Schneider explained, *"We found around 30% more stars with masses more than 30 times that of the Sun than expected, and about 70% more than expected above 60 solar masses. Our results challenge the previously predicted 150 solar mass limit for the maximum birth mass of stars and even suggest that stars could have birth masses up to 300 solar masses!"* Rob Ivison, co-author of the new ALMA paper, concludes: *"Our findings lead us to question our understanding of cosmic history. Astronomers building models of the Universe must now go back to the drawing board, with yet more sophistication required."* ■

First precise distance measurement to a globular star cluster

by NASA/ESA

Astronomers using NASA's Hubble Space Telescope have for the first time precisely measured the distance to one of the oldest objects in the universe, a collection of stars born shortly after the big bang. This new, refined distance yardstick provides an independent estimate for the age of the universe. The new measurement also will help astronomers improve models of stellar evolution. Star clusters are the key ingredient in stellar models because the stars in each grouping are at the same distance, have the same age, and have the same chemical composition. They therefore constitute a single stellar population to study.

This stellar assembly, a globular star cluster called NGC 6397, is one of the closest such clusters to Earth. The new measurement sets the cluster's distance at 7,800 light-years away, with just a 3 percent margin of error. Until now, astronomers have estimated the distances to our galaxy's globular clusters by comparing the luminosities and colors of stars to theoretical models, and to the luminosities and colors of similar stars in the solar neighborhood. But the accuracy of these estimates varies, with uncertainties hovering between 10 percent and 20 percent. However, the new measurement uses straightforward trigonometry, the same method used by surveyors, and as old as ancient Greek science. Using a novel observational technique to measure extraordinarily tiny angles on the sky, astronomers managed to stretch Hubble's yardstick outside of the disk of our Milky Way galaxy. The research team calculated NGC 6397's age at 13.4 billion years old. *"The globular clusters are so old that if their ages and distances deduced from models are off by a little bit, they seem to be older than the age of the universe,"* said Tom Brown of the Space Telescope Science Institute (STScI) in Baltimore, Maryland, leader of the Hubble study. Accurate distances to globu-

This ancient stellar jewelry box, a globular cluster called NGC 6397, glitters with the light from hundreds of thousands of stars. Astronomers used the Hubble Space Telescope to gauge the distance to this brilliant stellar grouping, obtaining the first precise measurement ever made to an ancient globular cluster. The new measurement sets the cluster's distance at 7,800 light-years away, with just a 3 percent margin of error. NGC 6397 is one of the closest globular clusters to Earth. By measuring an accurate distance to NGC 6397, astronomers then calculated a precise age for the cluster. The cluster is 13.4 billion years old, which means it was born shortly after the big bang. NGC 6397 is one of about 150 globular clusters that orbit outside of our Milky Way galaxy's comparatively younger starry disk. These spherical, densely packed swarms of hundreds of thousands of stars are our galaxy's first homesteaders. The cluster's blue stars are near the end of their lives. These stars have used up their hydrogen fuel that makes them shine. Now they are converting helium to energy in their cores, which fuses at a higher temperature and appears blue. The reddish glow is from red giant stars that have consumed their hydrogen fuel and have expanded in size. The myriad small white objects include stars like our Sun. This image is composed of a series of observations taken from July 2004 to June 2005 with Hubble's Advanced Camera for Surveys. The research team used Hubble's Wide Field Camera 3 to measure the distance to the cluster. [NASA, ESA, and T. Brown and S. Casertano (STScI); acknowledgement: J. Anderson (STScI)]

This video zooms into a Hubble Space Telescope view of globular star cluster NGC 6397. [NASA, ESA, and G. Bacon (STScI)]

lar clusters are used as references in stellar models to study the characteristics of young and old stellar populations. *"Any model that agrees with the measurements gives you more faith in applying that model to more distant stars,"* Brown said. *"The nearby star clusters serve as anchors for the stellar models. Until now, we only had accurate distances to the much younger open clusters inside our galaxy because they are closer to Earth."* By contrast, about 150 globular clusters orbit outside of our galaxy's comparatively younger starry disk. These spherical, densely packed swarms of hundreds of thousands of stars are the first homesteaders of the Milky Way. The Hubble astronomers used trigonometric parallax to nail down the cluster's distance. This technique measures the tiny, apparent shift of an object's position due to a change in an observer's point of view. Hubble measured the apparent tiny wobble of the cluster stars due to Earth's motion around the Sun. To obtain the precise distance to NGC 6397, Brown's team employed a clever method developed by astronomers Adam Riess, a Nobel laureate, and Stefano Casertano of the STScI and Johns Hopkins University, also in Baltimore, to accurately measure distances to pulsating stars called Cepheid variables. These pulsating stars serve as reliable distance markers for astronomers to calculate an accurate expansion rate of the universe. With this technique, called "spatial scanning," Hubble's Wide Field Camera 3 gauged the parallax of 40 NGC 6397 cluster stars, making measurements every 6 months for 2 years. The researchers then combined the results to obtain the precise distance measurement. *"Because we are looking at a bunch of stars, we can get a better measurement than simply looking at individual Cepheid variable stars,"* team member Casertano said. The tiny wobbles of these cluster stars were only 1/100th of a pixel on the telescope's camera, measured to a precision of 1/3000th of a pixel. This is the equivalent to measuring the size of an automobile tire on the moon to a precision of one inch. The researchers say they could reach an accuracy of 1 percent if they combine the Hubble distance measurement of NGC 6397 with the upcoming results obtained from the European Space Agency's Gaia space observatory, which is measuring the positions and distances of stars with unprecedented precision. *"Getting to 1 percent accuracy will nail this distance measurement forever,"* Brown said. ■

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Ancient galaxy megamergers

by ESO

Using the Atacama Large Millimeter/submillimeter Array (ALMA) and the Atacama Pathfinder Experiment (APEX), two international teams of scientists led by Tim Miller from Dalhousie University in Canada and Yale University in the US and Iván Oteo from the University of Edinburgh, United Kingdom, have uncovered startlingly dense concentrations of galaxies that are poised to merge, forming the cores of what will eventually become colossal galaxy clusters. Peering 90% of the way across the observable Universe, the Miller team observed a galaxy protocluster named SPT2349-56. The light from this object began travelling to us when the Universe was about a tenth of its current age. The individual galaxies in this dense cosmic pileup are starburst galaxies and the concentration of vigorous star formation in such a compact region makes this by far the most active region ever observed in the young Universe. Thousands of stars are born there every year, compared to just one in our own Milky Way. The Oteo team discovered a similar megamerger formed by ten dusty star-forming galaxies, nicknamed a "dusty red core" because of its very red colour, by combining observations from ALMA and the APEX. Iván Oteo explains why these objects are unexpected: *"The lifetime of dusty starbursts is thought to be relatively short, because they consume their gas at an extraordinary rate. At any time, in any corner of the Universe, these galaxies are usually in the minority. So, finding numer-*

This artist's impression of SPT2349-56 shows a group of interacting and merging galaxies in the early Universe. Such mergers have been spotted using the ALMA and APEX telescopes and represent the formation of galaxies clusters, the most massive objects in the modern Universe. Astronomers thought that these events occurred around three billion years after the Big Bang, so they were surprised when the new observations revealed them happening when the Universe was only half that age! [ESO/M. Kornmesser]

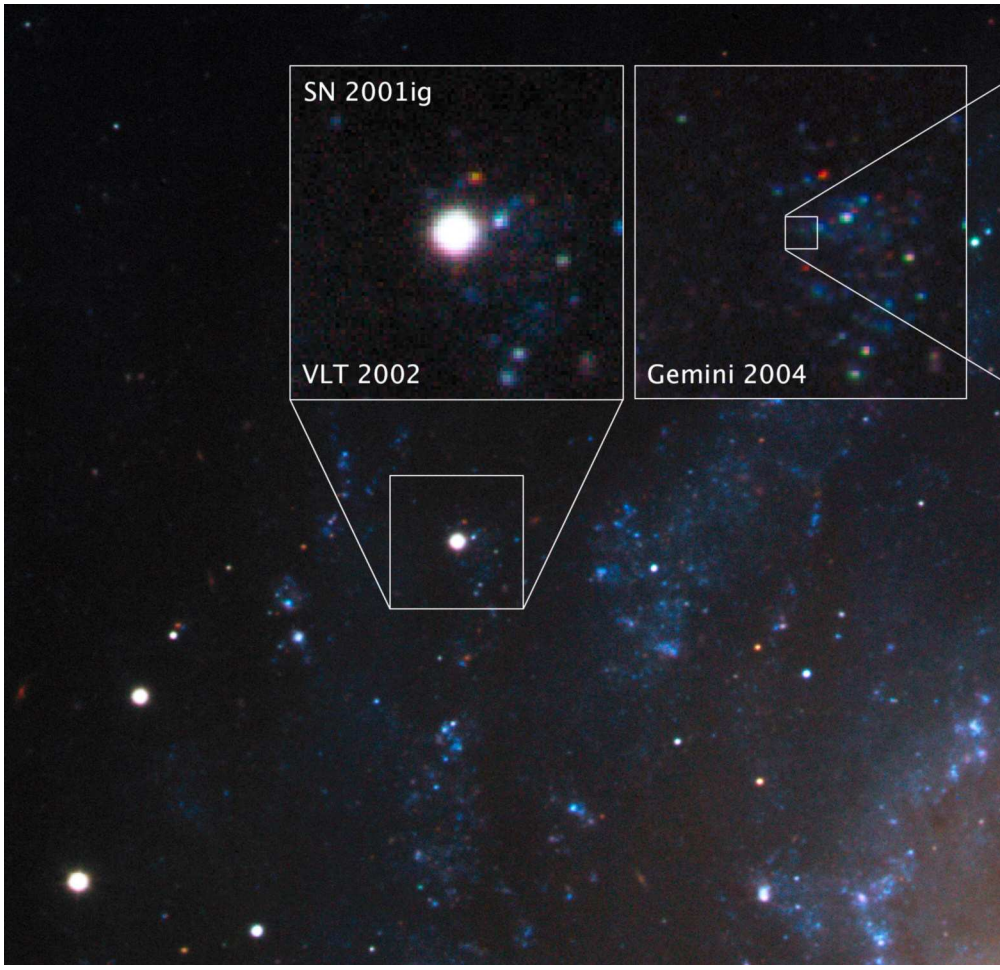
ous dusty starbursts shining at the same time like this is very puzzling, and something that we still need to understand." These forming galaxy clusters were first spotted as faint smudges of light, using the South Pole Telescope and the Herschel Space Observatory. Subsequent ALMA and APEX observations showed that they had unusual structure and confirmed that their light originated much earlier than expected — only 1.5 billion years after the Big Bang. The new high-resolution ALMA observations finally revealed that the two faint glows are not single objects, but are actually composed of fourteen and ten individual massive galaxies respectively, each within a radius comparable to the distance between the Milky Way and the neighbouring Magellanic Clouds.

"These discoveries by ALMA are only the tip of the iceberg. Additional observations with the APEX telescope show that the real number of star-forming galaxies is likely even three times higher. Ongoing observations with the MUSE instrument on ESO's VLT are also identifying additional galaxies," comments Carlos De Breuck, ESO astronomer. Current theoretical and computer models suggest that protoclusters as massive as these should have taken much longer to evolve. By using data from ALMA, with its superior resolution and sensitivity, as input to sophisticated computer simulations, the researchers are able to study cluster formation less than 1.5 billion years after the Big Bang.

"How this assembly of galaxies got so big so fast is a mystery. It wasn't built up gradually over billions of years, as astronomers might expect. This discovery provides a great opportunity to study how massive galaxies came together to build enormous galaxy clusters," says Tim Miller, a PhD candidate at Yale University and lead author of one of the papers. ■

Stellar thief is the surviving companion to a supernova

by NASA/ESA



Seventeen years ago, astronomers witnessed a supernova go off 40 million light-years away in the galaxy called NGC 7424, located in the southern constellation Grus, the Crane. Now, in the fading afterglow of that explosion, NASA's Hubble has captured the first image of a surviving companion to a supernova. This picture is the most compelling evidence that some supernovas originate in double-star systems.

"We know that the majority of massive stars are in binary pairs," said Stuart Ryder from the Australian Astronomical Observatory (AAO) in Sydney, Australia and lead author of the study. *"Many of these binary pairs will interact and transfer gas from one star to the other when their orbits bring them close together."* The companion to the supernova's progenitor star was no innocent bystander to the explosion. It siphoned off almost all of the hydrogen from the doomed star's stellar envelope, the region that transports energy from the star's core to its atmosphere. Millions of years before the primary star went supernova, the companion's thievery created an instability in the primary star, causing it to episodically blow off a cocoon and shells of hydrogen gas before the catastrophe. The supernova, called SN 2001ig, is categorized as a Type IIb stripped-envelope supernova. This type of supernova is unusual because most, but not all, of the hydrogen is gone prior to the explo-

sion. This type of exploding star was first identified in 1987 by team member Alex Filippenko of the University of California, Berkeley.

How stripped-envelope supernovas lose that outer envelope is not entirely clear. They were originally thought to come from single stars with very fast winds that pushed off the outer envelopes. The problem was that when astronomers started looking for the primary stars from which supernovas were spawned, they couldn't find them for many stripped-envelope supernovas.

"That was especially bizarre, because astronomers expected that they would be the most massive and the brightest progenitor stars," explained team member Ori Fox of the Space Telescope Science Institute in Baltimore. *"Also, the sheer number of stripped-envelope supernovas is greater than predicted."* That fact led scientists to theorize that many of the primary stars were in lower-mass binary systems, and they set out to prove it.

Looking for a binary companion after a supernova explosion is no easy task. First, it has to be at a relatively close distance to Earth for Hubble to see such a faint star. SN 2001ig and its companion are about at that limit. Within that distance range, not many supernovas go off.

Even more importantly, astronomers have to know the exact position through very precise measurements.

In 2002, shortly after SN 2001ig exploded, scientists pinpointed the precise location of the supernova with the European Southern Observatory's Very Large Telescope (VLT) in Cerro Paranal, Chile. In 2004, they then followed up with the Gemini South Observatory in Cerro Pachón, Chile. This observation first hinted at the presence of a surviving binary companion.

Knowing the exact coordinates, Ryder and his team were able to focus Hubble on that location 12 years later, as the supernova's glow faded. With Hubble's exquisite resolution and ultraviolet capability, they were able to find and photograph the surviving companion — something only Hubble could do.

Prior to the supernova explosion, the orbit of the two stars around each other took about a year.

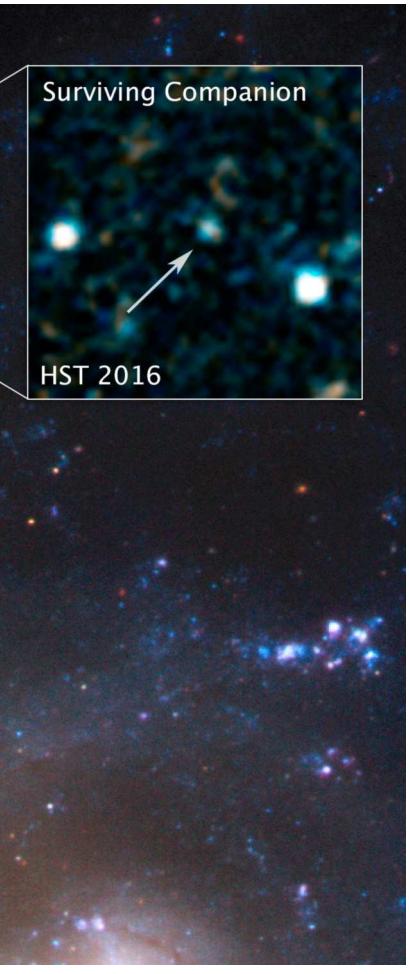
When the primary star exploded, it had far less impact on the surviving companion than might be thought. Imagine an avocado pit — representing the dense core of the companion star — embedded in a gelatin dessert — representing the star's gaseous envelope. As a shock wave passes through, the gelatin might temporarily stretch and wobble, but the avocado pit would remain intact. In 2014, Fox and his team used Hubble to detect the companion of another Type IIb supernova, SN 1993J. However, they captured a spectrum, not an image. The case of SN 2001ig is the first time a surviving companion has been photographed. *"We were finally able to catch the stellar thief, confirming our suspicions that one had to be there,"* said Filippenko.

Perhaps as many as half of all stripped-envelope supernovas have companions — the other half lose their outer envelopes via stellar winds. Ryder and his team have the ultimate goal of precisely determining how many supernovas with stripped envelopes have companions. Their next endeavor is to look at completely stripped-envelope supernovas, as opposed to SN 2001ig and SN 1993J, which were only about 90 percent stripped.

These completely stripped-envelope supernovas don't have much shock interaction with gas in the surrounding stellar environment, since their outer envelopes were lost long before the explosion.

Without shock interaction, they fade much faster. This means that the team will only have to wait two or three years to look for surviving companions.

In the future, they also hope to use the James Webb Space Telescope to continue their search. ■



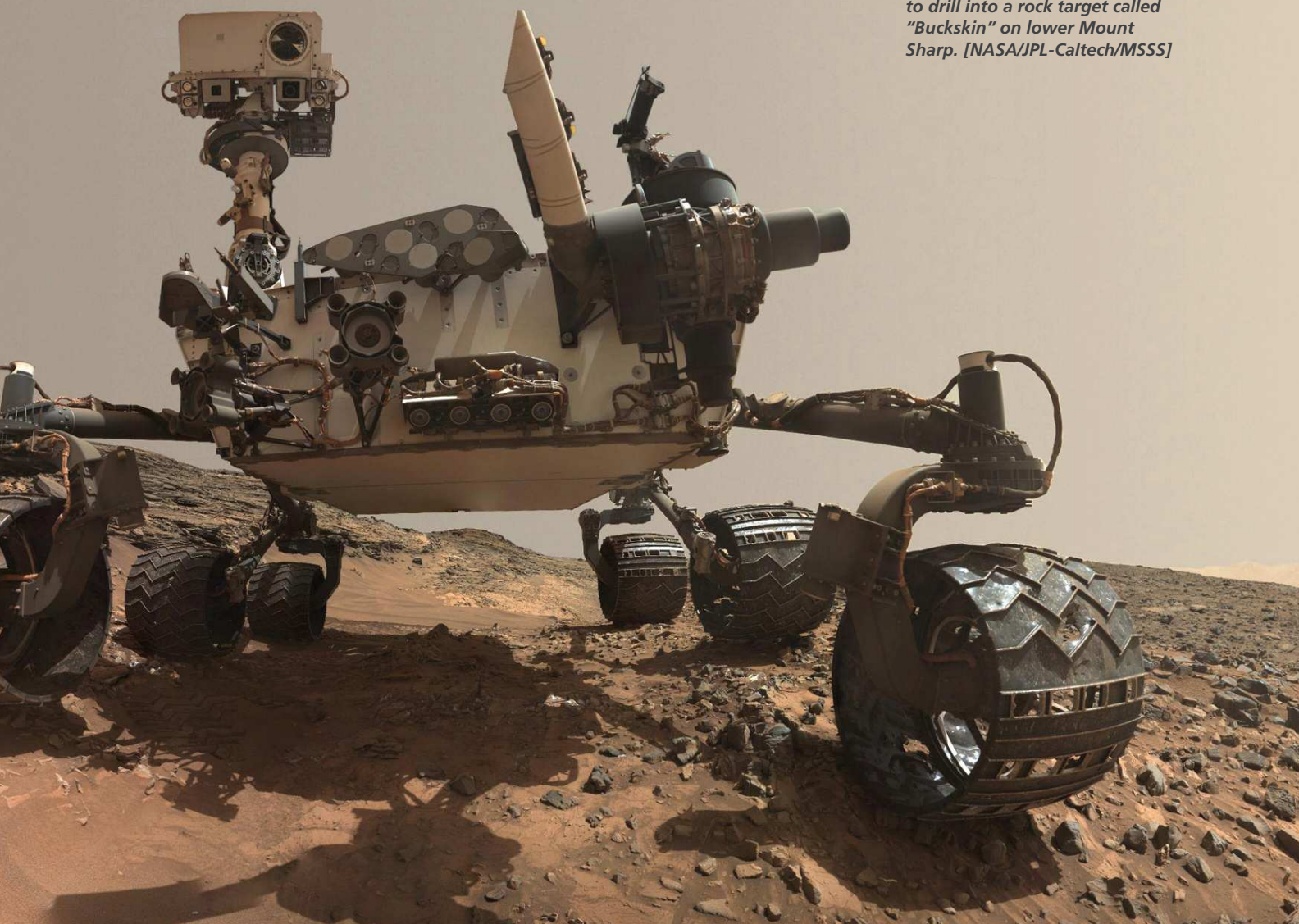
Shortly after SN 2001ig exploded, scientists photographed the supernova with the European Southern Observatory's Very Large Telescope (VLT) in 2002. Two years later, they followed up with the Gemini South Observatory, which hinted at the presence of a surviving binary companion. As the supernova's glow faded, scientists focused Hubble on that location in 2016. They pinpointed and photographed the surviving companion, which was possible only due to Hubble's exquisite resolution and ultraviolet sensitivity. Hubble observations of SN 2001ig provide the best evidence yet that some supernovas originate in double-star systems. [NASA, ESA, S. Ryder (Australian Astronomical Observatory), and O. Fox (STScI)]

Two top-level discoveries by Curiosity

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

The search for life on Mars produced exciting new results thanks to the work of NASA's Curiosity rover. The collected data reveal the presence of organic compounds on the surface of the planet and a mysterious seasonal variation in the concentration of methane in Gale Crater. A basis for these observations could involve biological or geochemical processes. What will the reality be?



This low-angle self-portrait of NASA's Curiosity Mars rover shows the vehicle at the site from which it reached down to drill into a rock target called "Buckskin" on lower Mount Sharp. [NASA/JPL-Caltech/MSSS]

Today, Mars is an inhospitable planet, but over 3 billion years ago it was much more similar to the conditions of our ancient Earth – the same conditions in which life here first developed. If, in those distant times, the martian surface had contained the necessary ingredients for life as we know it, then life would probably have appeared there as well. The most basic of those ingredients are water, energy, and more-or-less complex organic molecules, which in their structure can include carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur and other elements. Water certainly existed on Mars in the first billion years of the solar system. The energy of the Sun never failed and, in ancient times, even geothermal energy could have supplied the heat necessary to support any possible elementary form of martian life. So far, however, we have not had the certainty (beyond some controversial data) of the simultaneous presence of organic compounds. But now, an

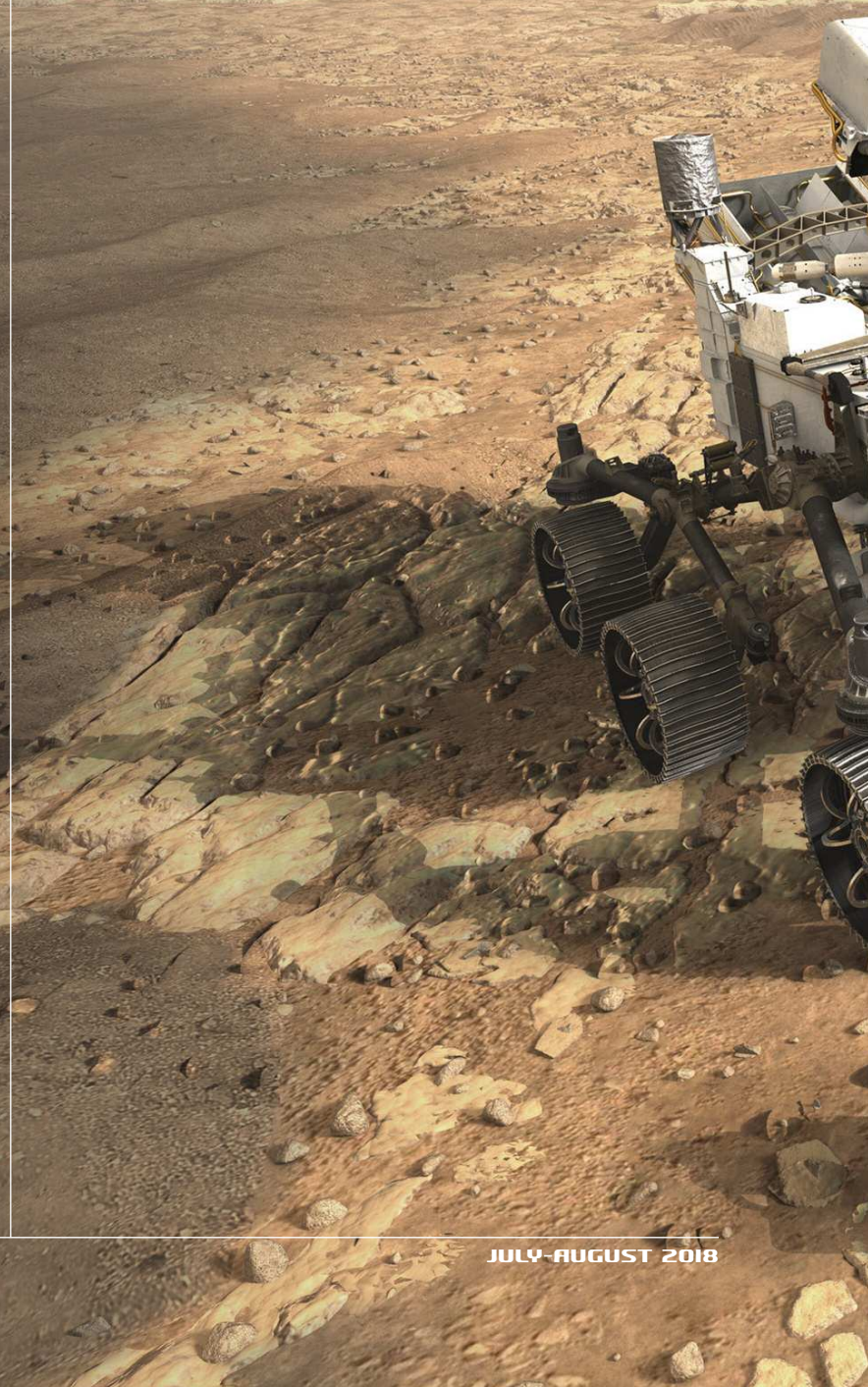
article published on June 8th in the prestigious *Science* magazine (first author Jen Eigenbrode, of NASA's Goddard Space Flight Center of Greenbelt, Maryland) confirms the presence of organic molecules on the surface of Mars. The discovery was made by NASA rover Curiosity, which identified those compounds in the powder produced by drilling holes in the clay sedimentary rocks of four different areas of Gale Crater. This large surface formation (154 km in diameter) originated over 3.5 billion years ago from the impact of a small asteroid; the depression created by the event was filled with water, turning it into a lake – this impact event produced the backdrop against which the sediments Curiosity has drilled into began to accumulate.

NASA chose Gale Crater as an operating area for Curiosity precisely because it was hoping to discover at least some complex organic molecules – the building blocks of life. The drilling of the rover reached a depth of 5 cm, pulverizing rock layers that settled at least 3 billion years ago. A special device transported the powder produced by the perforations into a small oven, where it was heated to temperatures between 500°C and 820°C (930 – 1500°F).

The gases produced by the heating of the powder were then analyzed by the SAM (Sample Analysis at Mars instrument suite) mass spectrometer, which revealed the presence of small organic molecules, present in the spectrometer as fragments of more complex organic molecules that were not completely vaporized upon heating. Researchers found that some of those fragments contained sulfur, an element which under certain conditions can protect organic material from solar radiation and from aggressive substances such as perchlorates, chemicals which are quite common on the martian surface. The results of the dust analysis also provided interesting information about the concentrations of organic molecules in the samples, which are on the order of 10 parts per million or more. This value coincides with the one obtained from the analysis of martian meteorites fallen on our planet and is about 100 times higher than the values provided by previous measurements.

The discovery of organic compounds on Mars, dating back to the times when the planet

This artist's concept depicts NASA's Mars 2020 rover exploring Mars. This mission is targeted for launch in July/August 2020 aboard an Atlas V-541 rocket from Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida. [NASA/JPL-Caltech]



could support life, is extremely interesting. We must stress that, although organic molecules are central to all life, they are not necessarily indicators of life; in fact, they can also be produced by non-biological processes.

Regardless of their origin, those organic compounds keep track of the processes and conditions present on the young Mars, and will, therefore, be useful for deepening our knowledge about the birth and evolution of that planet. This discovery by Curiosity is also a good omen for all the automatic missions already started or in preparation, which all have as a goal the search for traces of life on the red planet. In the absence of being able to identify organic compounds, those missions could likely not find anything.

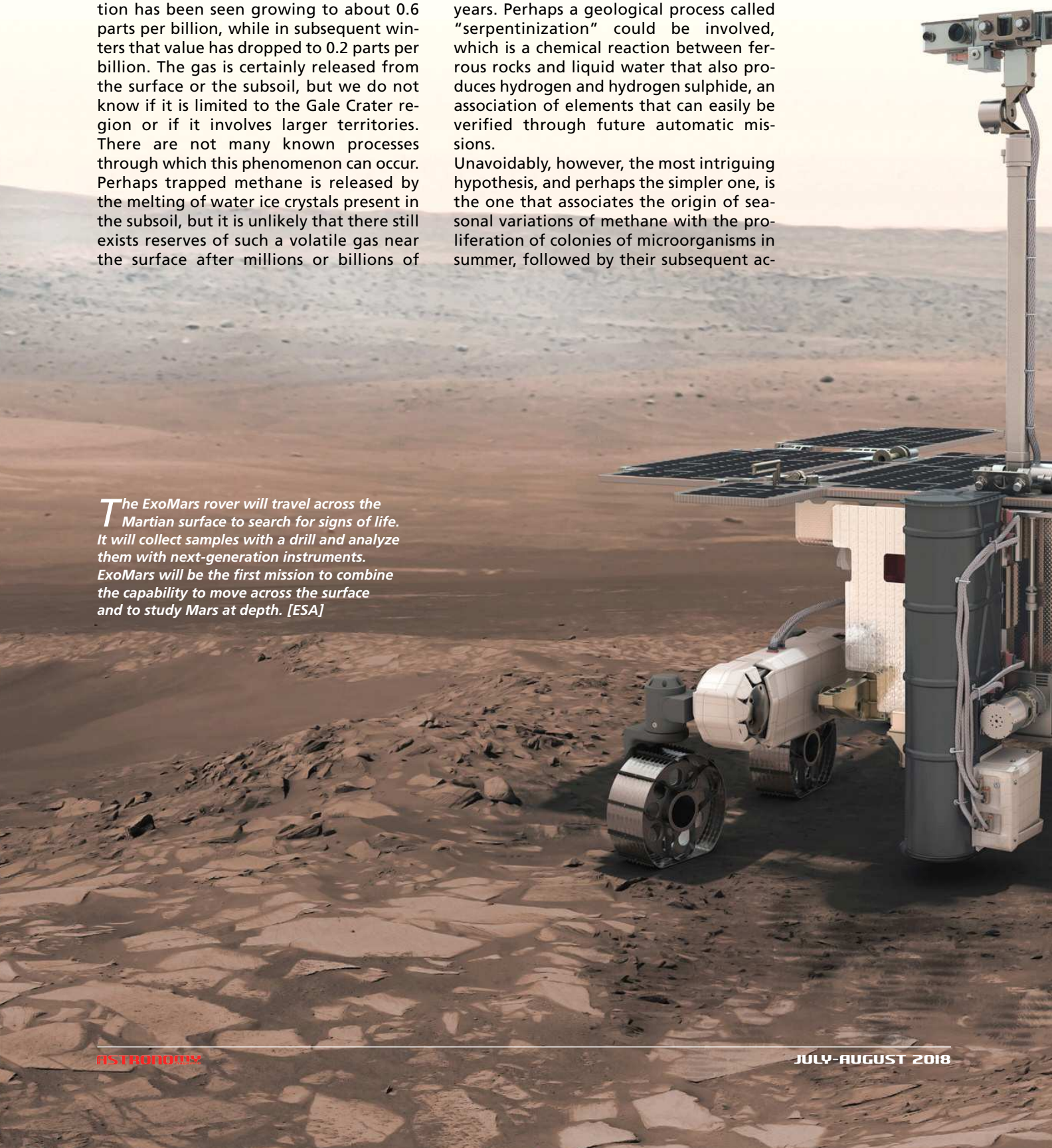
As the title of this article notes, the NASA rover has also made another important discovery thanks to the accumulation of years of analysis of the martian atmosphere. The discovery concerns methane, the simplest organic molecule.

For some years now, we've known that this gas is present in the martian atmosphere and is revealed on a regional scale in the form of large and unpredictable plumes occurring through unknown processes. If not a more-or-less constant supply, methane can remain in the atmosphere of Mars for a few centuries at most; therefore, if we still observe it today, this means that there is a mechanism that can renew it continuously – or at least periodically. At the base of that mechanism, there could be essentially chemical and/or biological processes. On Earth, life forms produce more methane than abiotic reactions, and the same thing could happen on Mars. So far, however, the dynamics of the martian methane seemed not very compatible with possible biological activities. This situation could substantially change in light of a second article, also published in *Science* on June 8th (first author Christopher R. Webster, NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California), in which it is shown that there is a seasonal variation in the abundance of atmospheric methane.

The researchers reached this conclusion by analyzing the data collected over 5 years by the Tunable Laser Spectrometer, an instrument of SAM. Every summer, the methane concentra-

tion has been seen growing to about 0.6 parts per billion, while in subsequent winters that value has dropped to 0.2 parts per billion. The gas is certainly released from the surface or the subsoil, but we do not know if it is limited to the Gale Crater region or if it involves larger territories. There are not many known processes through which this phenomenon can occur. Perhaps trapped methane is released by the melting of water ice crystals present in the subsoil, but it is unlikely that there still exists reserves of such a volatile gas near the surface after millions or billions of years. Perhaps a geological process called "serpentinization" could be involved, which is a chemical reaction between ferrous rocks and liquid water that also produces hydrogen and hydrogen sulphide, an association of elements that can easily be verified through future automatic missions.

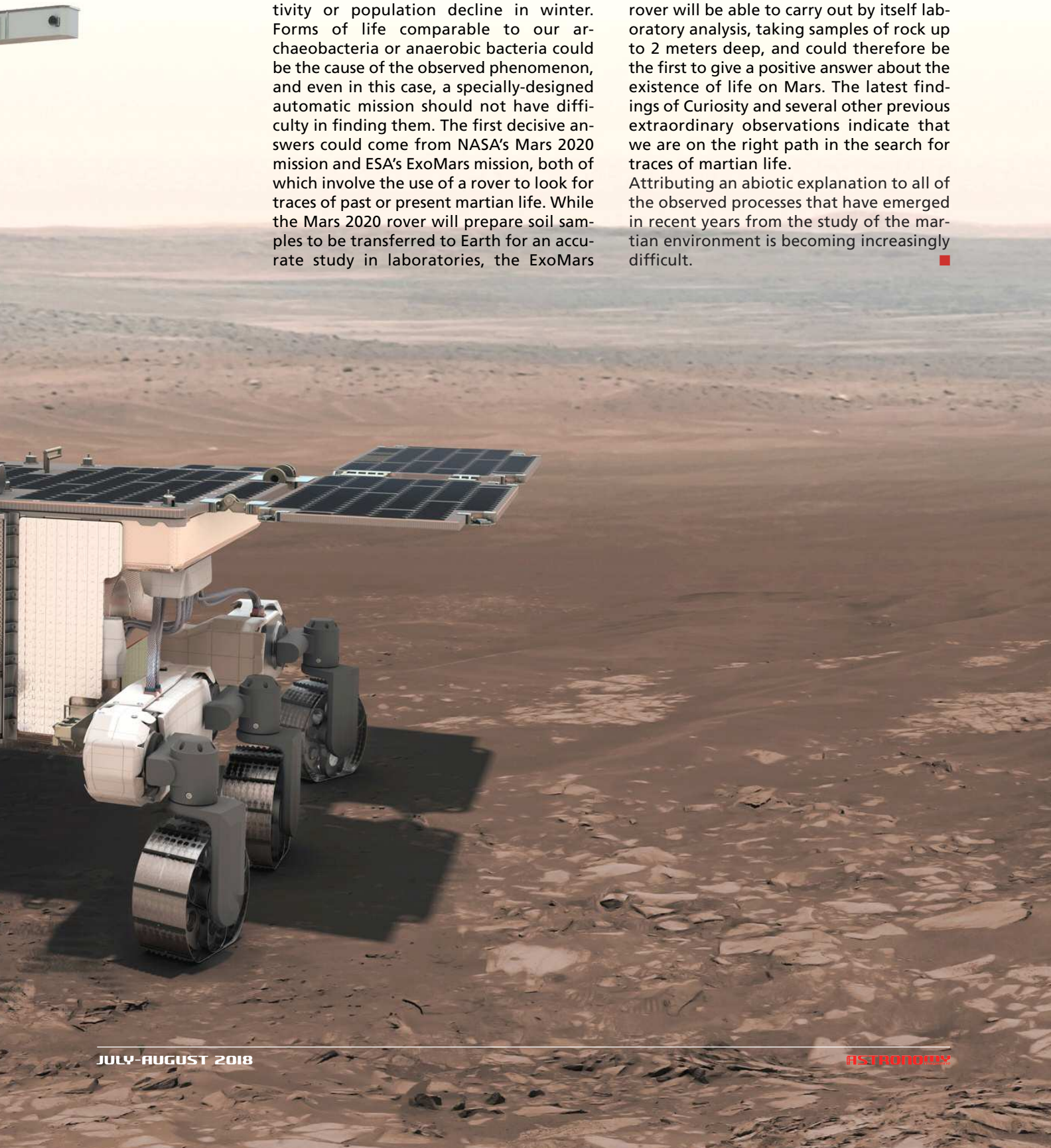
Unavoidably, however, the most intriguing hypothesis, and perhaps the simpler one, is the one that associates the origin of seasonal variations of methane with the proliferation of colonies of microorganisms in summer, followed by their subsequent ac-



The ExoMars rover will travel across the Martian surface to search for signs of life. It will collect samples with a drill and analyze them with next-generation instruments. ExoMars will be the first mission to combine the capability to move across the surface and to study Mars at depth. [ESA]

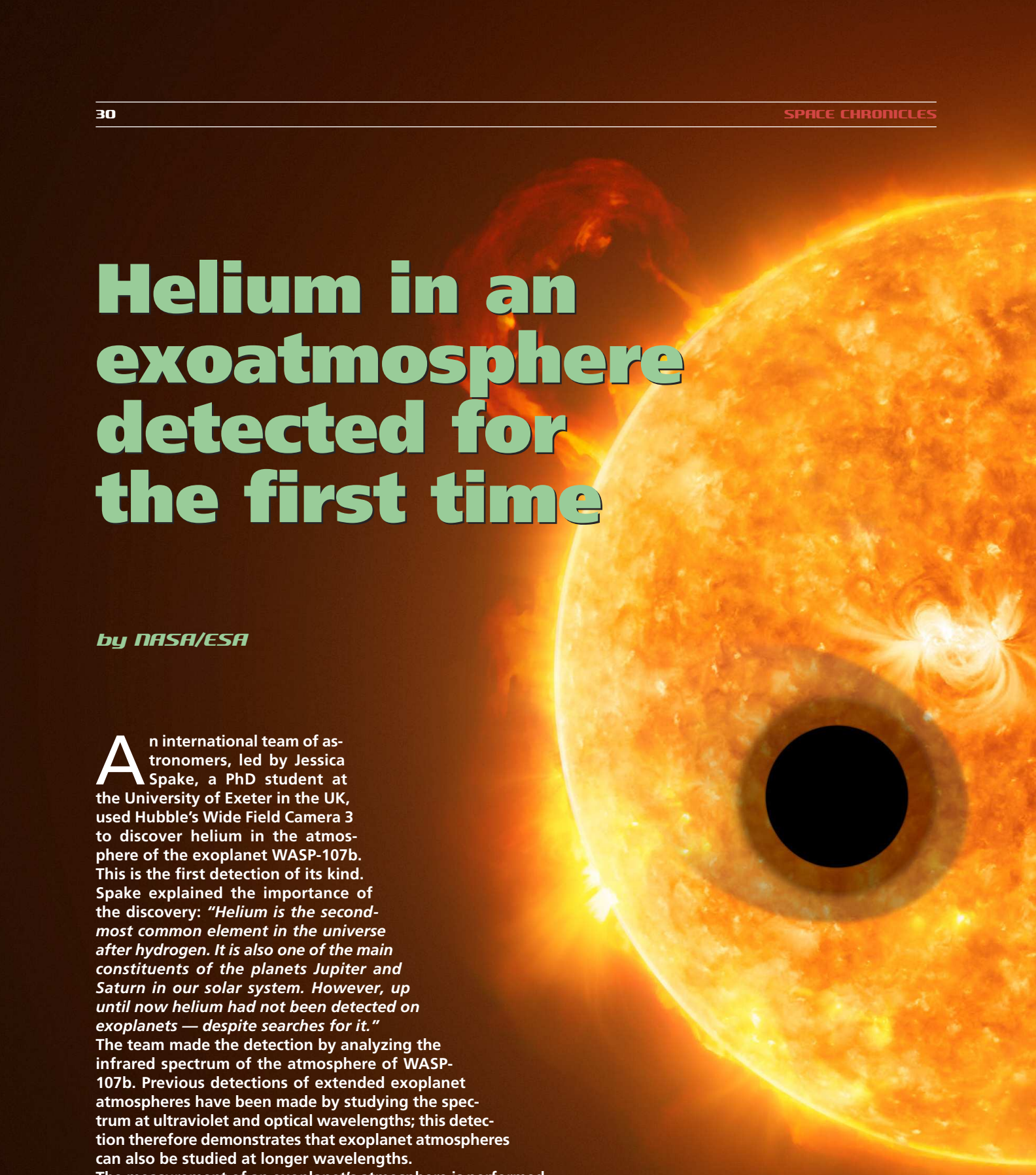
tivity or population decline in winter. Forms of life comparable to our archaeobacteria or anaerobic bacteria could be the cause of the observed phenomenon, and even in this case, a specially-designed automatic mission should not have difficulty in finding them. The first decisive answers could come from NASA's Mars 2020 mission and ESA's ExoMars mission, both of which involve the use of a rover to look for traces of past or present martian life. While the Mars 2020 rover will prepare soil samples to be transferred to Earth for an accurate study in laboratories, the ExoMars rover will be able to carry out by itself laboratory analysis, taking samples of rock up to 2 meters deep, and could therefore be the first to give a positive answer about the existence of life on Mars. The latest findings of Curiosity and several other previous extraordinary observations indicate that we are on the right path in the search for traces of martian life.

Attributing an abiotic explanation to all of the observed processes that have emerged in recent years from the study of the martian environment is becoming increasingly difficult. ■



Helium in an exoatmosphere detected for the first time

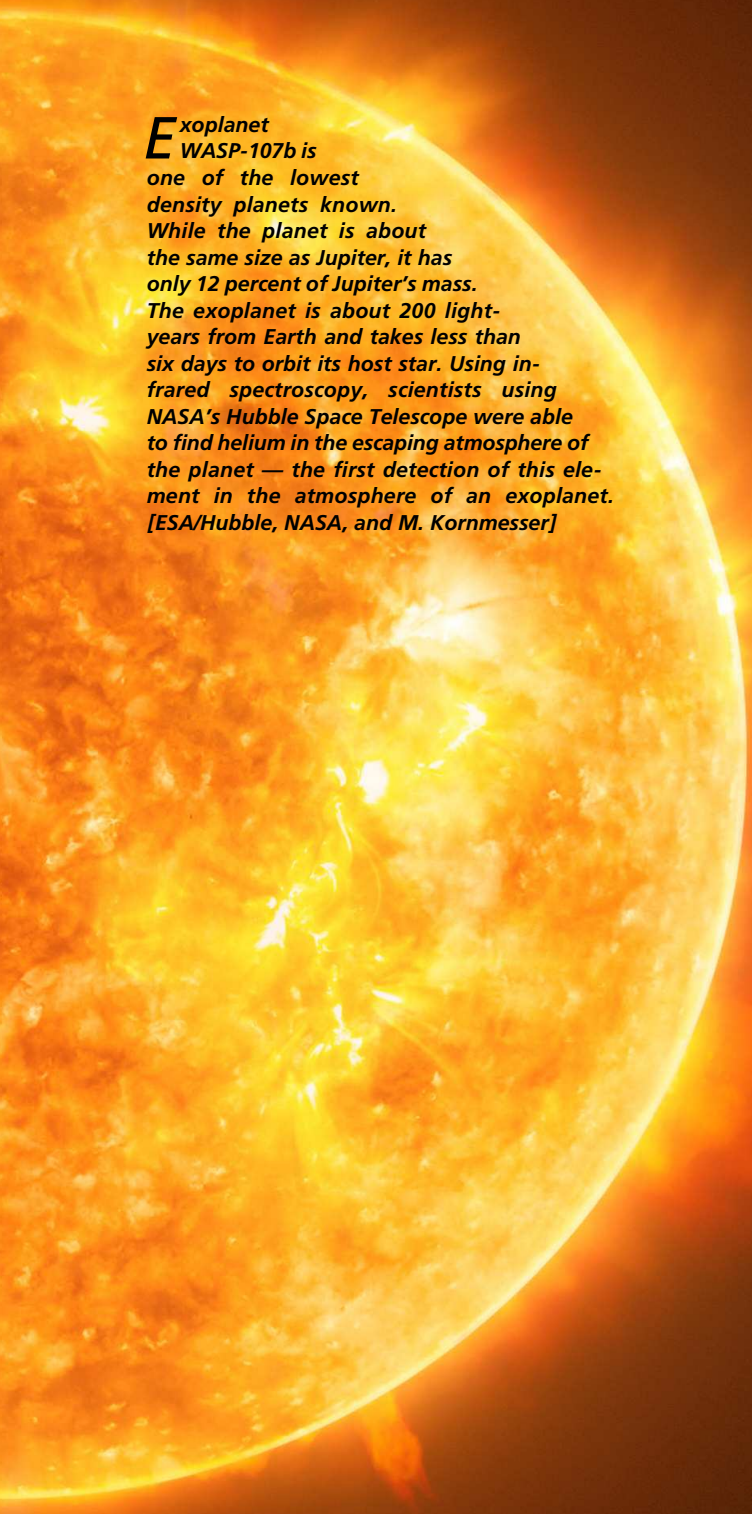
by NASA/ESA



An international team of astronomers, led by Jessica Spake, a PhD student at the University of Exeter in the UK, used Hubble's Wide Field Camera 3 to discover helium in the atmosphere of the exoplanet WASP-107b. This is the first detection of its kind. Spake explained the importance of the discovery: *"Helium is the second-most common element in the universe after hydrogen. It is also one of the main constituents of the planets Jupiter and Saturn in our solar system. However, up until now helium had not been detected on exoplanets — despite searches for it."*

The team made the detection by analyzing the infrared spectrum of the atmosphere of WASP-107b. Previous detections of extended exoplanet atmospheres have been made by studying the spectrum at ultraviolet and optical wavelengths; this detection therefore demonstrates that exoplanet atmospheres can also be studied at longer wavelengths.

The measurement of an exoplanet's atmosphere is performed when the planet passes in front of its host star. A tiny portion of the star's light passes through the exoplanet's atmosphere, leaving detectable fingerprints in the spectrum of the star. The larger the



Exoplanet WASP-107b is one of the lowest density planets known. While the planet is about the same size as Jupiter, it has only 12 percent of Jupiter's mass. The exoplanet is about 200 light-years from Earth and takes less than six days to orbit its host star. Using infrared spectroscopy, scientists using NASA's Hubble Space Telescope were able to find helium in the escaping atmosphere of the planet — the first detection of this element in the atmosphere of an exoplanet. [ESA/Hubble, NASA, and M. Kornmesser]

amount of an element present in the atmosphere, the easier the detection becomes.

"The strong signal from helium we measured demonstrates a new technique to study upper layers of exoplanet atmospheres in a wider range of planets," said Spake. *"Current methods, which use ultraviolet light, are limited to the closest exoplanets. We know there is helium in the Earth's upper atmosphere and this new technique may help us to detect atmospheres around Earth-sized exoplanets — which is very difficult with current technology."*

WASP-107b is one of the lowest density planets known: While the planet is about the same size as Jupiter, it has only 12 percent of Jupiter's mass. The exoplanet is about 200 light-years from Earth and takes less than six days to orbit its host star.

The amount of helium detected in the atmosphere of WASP-107b is so large that its upper atmosphere must extend tens of thousands of miles out into space. This also makes it the first time that an extended atmosphere has been discovered at infrared wavelengths.

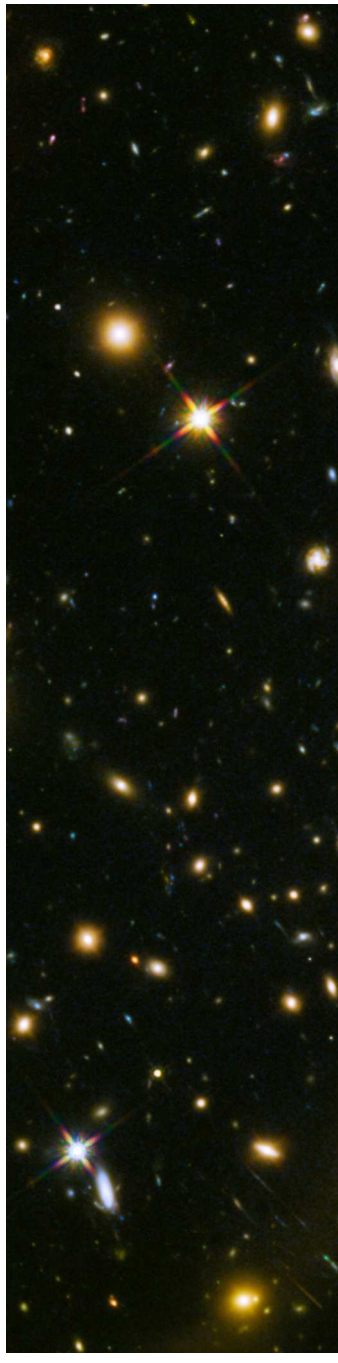
Since its atmosphere is so extended, the planet is losing a significant amount of its atmospheric gases into space — between about 0.1 percent to 4 percent of its atmosphere's total mass every billion years.

Stellar radiation has a significant effect on the rate at which a planet's atmosphere escapes. The star WASP-107 is highly active, supporting the atmospheric loss. As the atmosphere absorbs radiation it heats up, so the gas rapidly expands and escapes more quickly into space.

As far back as the year 2000, it was predicted that helium would be one of the most readily-detectable gases on giant exoplanets, but until now, searches were unsuccessful. David Sing, co-author of the study also from the University of Exeter, concluded: *"Our new method, along with future telescopes such as NASA's James Webb Space Telescope, will allow us to analyze atmospheres of exoplanets in far greater detail than ever before."* ■

Evidence for stars forming just 250 million years after Big Bang

by ESO



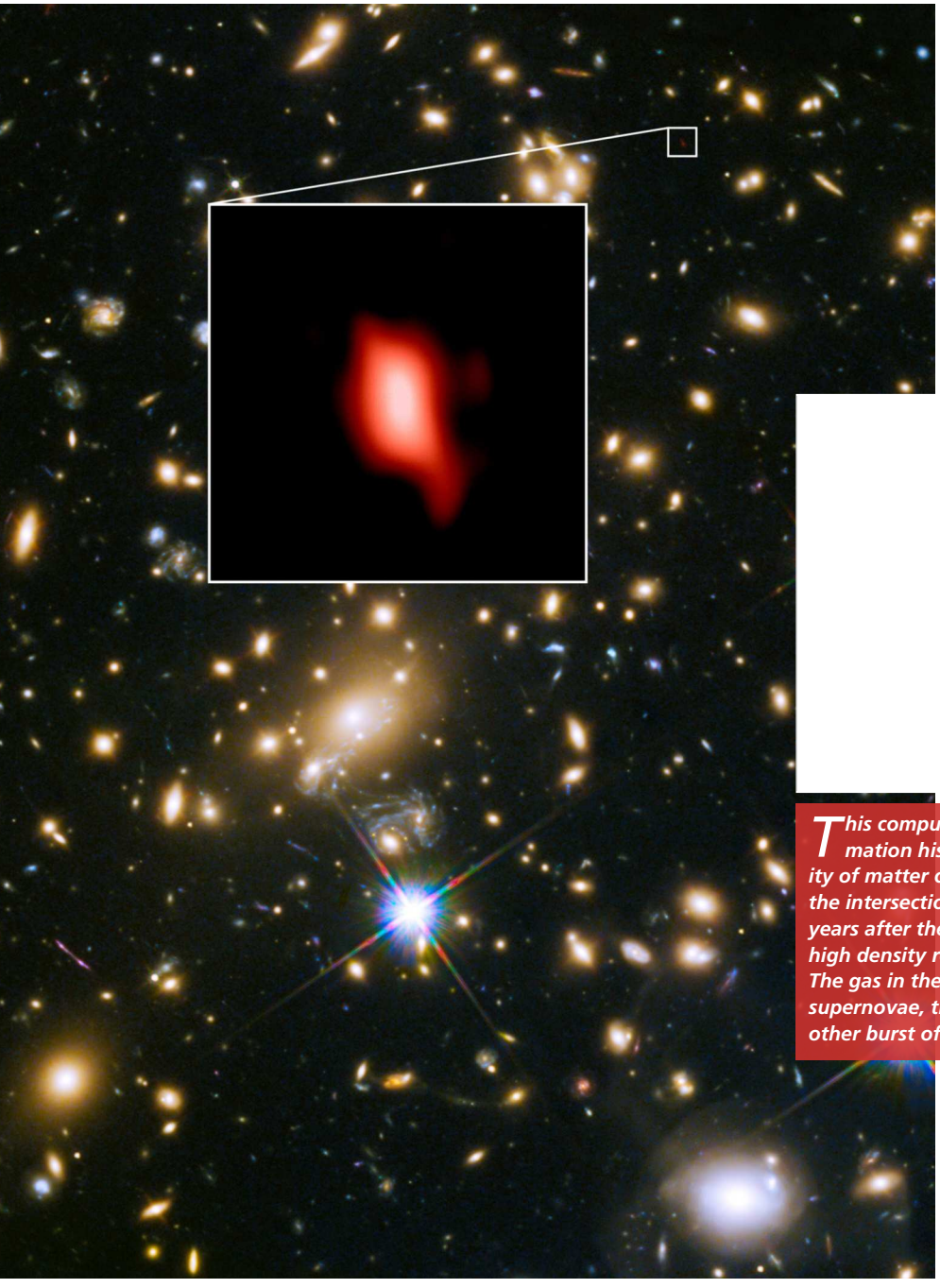
This image shows the galaxy cluster MACS J1149.5+2223 taken with the NASA/ESA Hubble Space Telescope; the inset image is the very distant galaxy MACS1149-JD1, seen as it was 13.3 billion years ago and observed with ALMA. Here, the oxygen distribution detected with ALMA is depicted in red. [ALMA (ESO/NAOJ/NRAO), NASA/ESA Hubble Space Telescope, W. Zheng (JHU), M. Postman (STScI), the CLASH Team, Hashimoto et al.]

An international team of astronomers used ALMA to observe a distant galaxy called MACS1149-JD1. They detected a very faint glow emitted by ionised oxygen in the galaxy. As this infrared light travelled across space, the expansion of the Universe stretched it to wavelengths more than ten times longer by the time it reached Earth and was detected by ALMA. The team inferred that the signal was emitted 13.3 billion years ago (or 500 million years after the Big Bang), making it the most distant oxygen ever detected by any telescope. The presence of oxygen is a clear sign that there must have been even earlier generations of stars in this galaxy.

"I was thrilled to see the signal of the distant oxygen in the ALMA data," says Takuya Hashimoto, the lead author of the new paper and a researcher at both Osaka Sangyo University and the National Astronomical Observatory of Japan. *"This detection pushes back the frontiers of the observable Universe."* In addition to the glow from oxygen picked up by ALMA, a weaker signal of hydrogen emission was also detected by ESO's Very Large Telescope (VLT). The distance to the galaxy determined from this observation is consistent with the distance from the oxygen observation. This makes MACS1149-JD1 the most distant galaxy with a precise distance measurement and the most distant galaxy ever observed with ALMA or the VLT.

"This galaxy is seen at a time when the Universe was only 500 million years old and yet it already has a population of mature stars," explains Nicolas Laporte, a researcher at University College London (UCL) in the UK and second author of the new paper. *"We are therefore able to use this galaxy to probe into an earlier, completely uncharted period of cosmic history."*

For a period after the Big Bang there was no oxygen in the Universe; it was created by the fusion processes of the first stars and then released when these stars died. The detection of oxygen in MACS1149-JD1 indicates that these earlier generations of stars had been already



This computer graphics movie shows the probable star formation history in the galaxy MACS1149-JD1. The self-gravity of matter creates filamentary structures and the density at the intersections of the filaments increases. Around 200 million years after the Big Bang, active star formation ignites in the high density regions, which leads to the formation of galaxies. The gas in the galaxy is blown off by active stellar wind and supernovae, then the gas returns to the galaxy and causes another burst of star formation. [ALMA (ESO/NAOJ/NRAO)]

formed and expelled oxygen by just 500 million years after the beginning of the Universe.

But when did this earlier star formation occur? To find out, the team reconstructed the earlier history of MACS1149-JD1 using infrared data taken with the NASA/ESA Hubble Space Telescope and the NASA Spitzer Space Telescope. They found that the observed brightness of the galaxy is well-explained by a model where the onset of star formation corresponds to only 250 million years after the Universe began.

The maturity of the stars seen in MACS1149-JD1 raises the question of when the very first galaxies emerged from total darkness, an epoch astronomers romantically term "cosmic dawn".

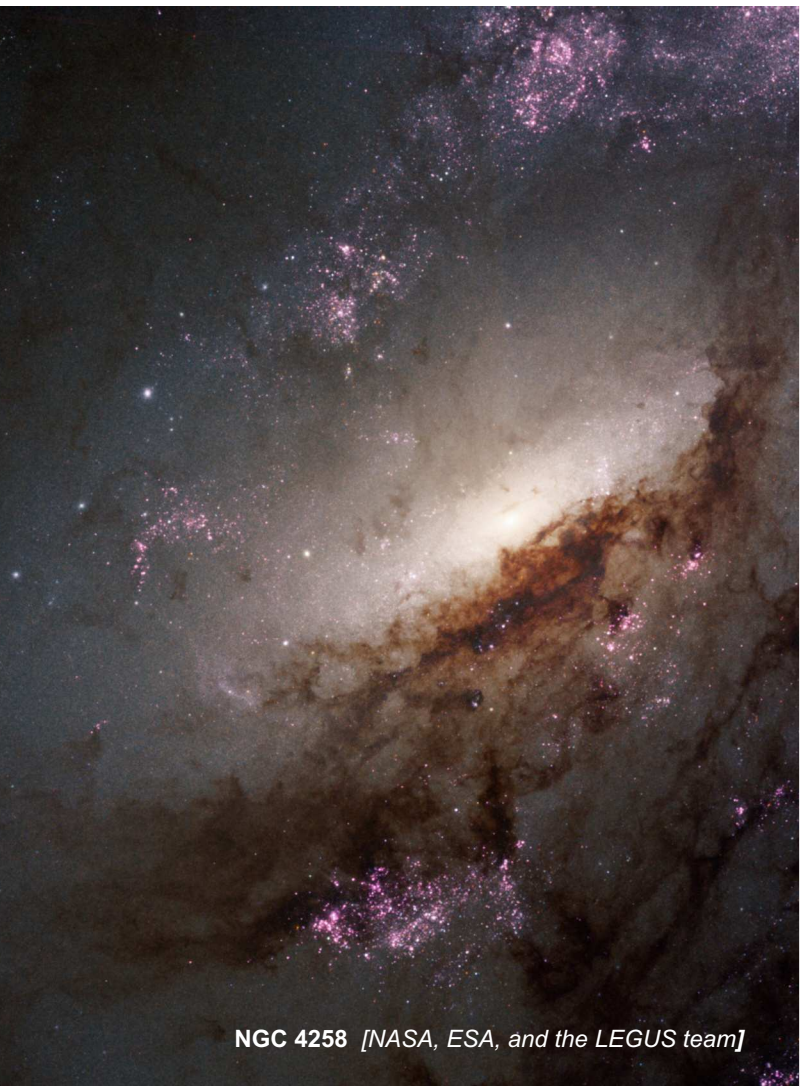
By establishing the age of MACS 1149-JD1, the team has effectively demonstrated that galaxies existed earlier than those we can currently directly detect. Richard Ellis, senior astronomer at UCL and co-author of the paper, concludes: *"Determining when cosmic dawn occurred is akin to the Holy Grail of cosmology and galaxy formation. With these new observations of MACS1149-JD1 we are getting closer to directly witnessing the birth of starlight! Since we are all made of processed stellar material, this is really finding our own origins."* ■

The most complete ultraviolet-light survey of nearby galaxies

by NASA/ESA

Capitalizing on the unparalleled sharpness and spectral range of NASA's Hubble Space Telescope, an international team of astronomers is releasing the most comprehensive, high-resolution ultraviolet-light survey of nearby star-forming galaxies. The researchers combined new

UGC 5340 *[NASA, ESA, and the LEGUS team]*



NGC 4258 *[NASA, ESA, and the LEGUS team]*

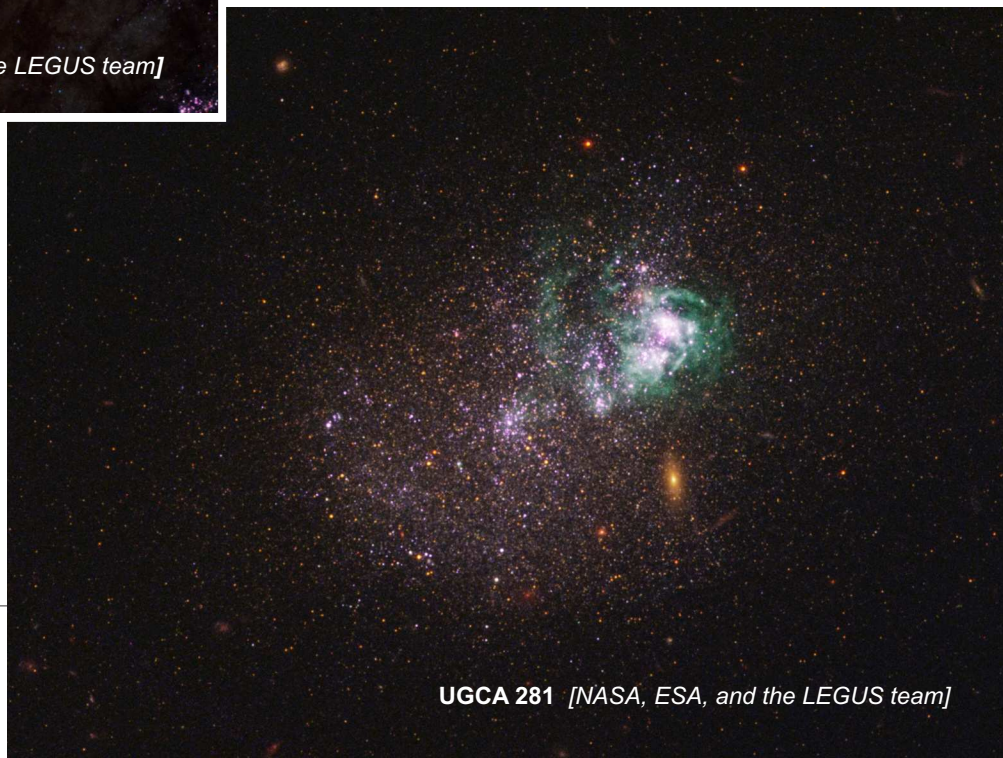
Hubble observations with archival Hubble images for 50 star-forming spiral and dwarf galaxies in the local universe, offering a large and extensive resource for understanding the complexities of star formation and galaxy evolution.

The project, called the Legacy ExtraGalactic UV Survey (LEGUS), has amassed star catalogs for each of the LEGUS galaxies and cluster catalogs for 30 of the galaxies, as well as images of the galaxies themselves. The data provide detailed information on young, massive stars and star clusters, and how their environment affects their development. *"There has never before been a star cluster and a stellar catalog that included observations in ultraviolet light,"* explained survey leader Daniela Calzetti of the University of Massachusetts, Amherst. *"Ultraviolet light is a major tracer of the youngest and hottest star populations, which astronomers need to derive the ages of stars and get a complete stellar history. The synergy of the two catalogs combined offers an unprecedented potential for understanding star formation."*

How stars form is still a vexing question in astronomy. *"Much of the light we get from the universe comes from stars, and yet we still don't understand many aspects of how stars form,"* said team member Elena Sabbi of the Space Telescope Science Institute in Baltimore, Maryland. *"This is even key to our existence — we know life wouldn't be here if we didn't have a star around."*

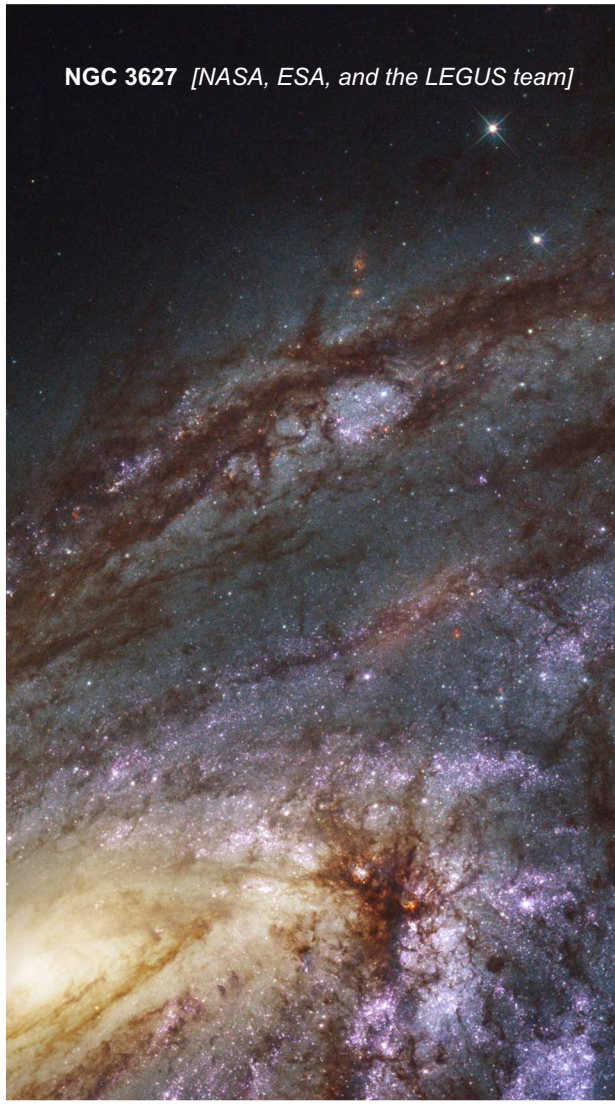
The research team carefully selected the LEGUS targets from among 500 galaxies, compiled in ground-based surveys, located between 11 million and 58 million light-years from Earth. Team members chose the galaxies based on their mass, star-formation rate, and abundances of elements that are heavier than hydrogen and helium. The catalog of ultraviolet objects collected by NASA's Galaxy Evolution Explorer (GALEX) spacecraft also helped lay the path for the Hubble study.

The team used Hubble's Wide Field Camera 3 and the Advanced Camera for Surveys over a one-year period to snap visible- and ultraviolet-light images of the



UGCA 281 *[NASA, ESA, and the LEGUS team]*

NGC 3368 *[NASA, ESA, and the LEGUS team]*



NGC 3627 *[NASA, ESA, and the LEGUS team]*

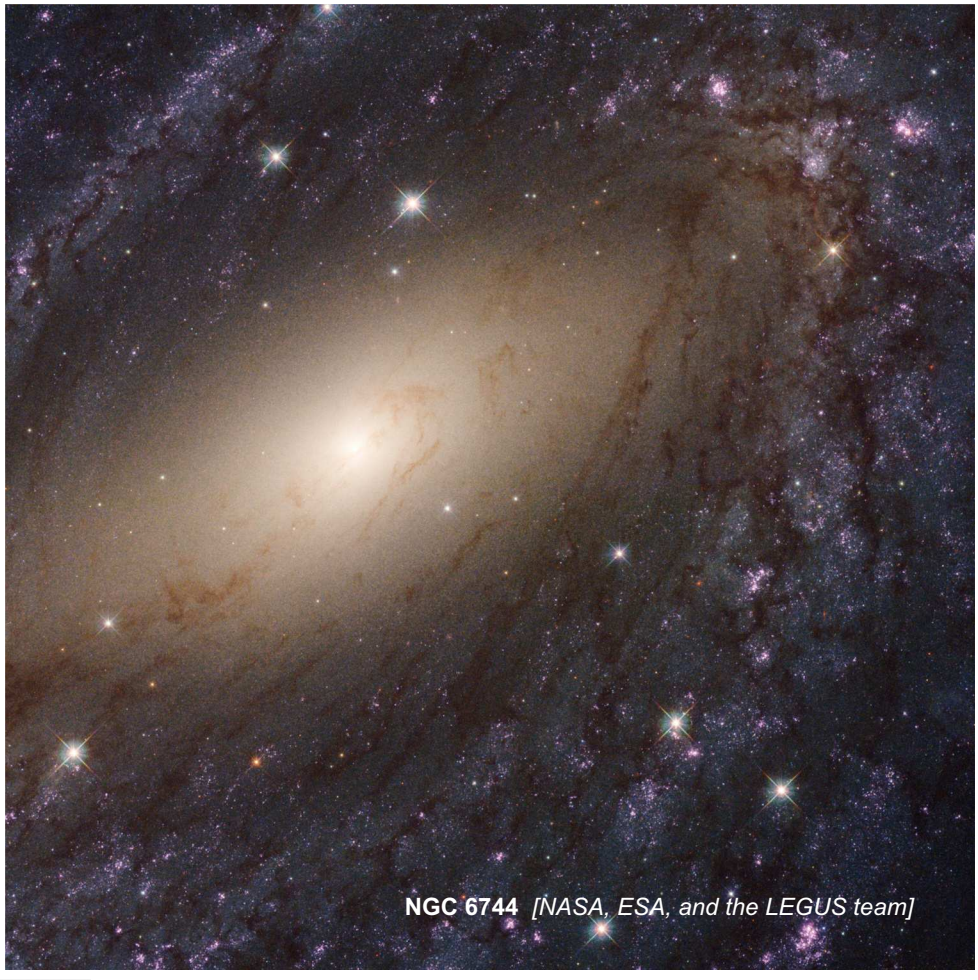
said. *"It's a very orderly structure, whether it's spiral arms or rings, and that's particularly true with the youngest stellar populations."*

On the other hand, there are multiple competing theories to connect the individual stars in individual star clusters to these ordered structures. *"By seeing galaxies in very* galaxies and their most massive young stars and star clusters. The researchers also added archival visible-light images to provide a complete picture. The star cluster catalogs contain about 8,000 young clusters whose ages range from 1 million to roughly 500 million years old. These stellar groupings are as much as 10 times more massive than the largest clusters seen in our Milky Way galaxy.

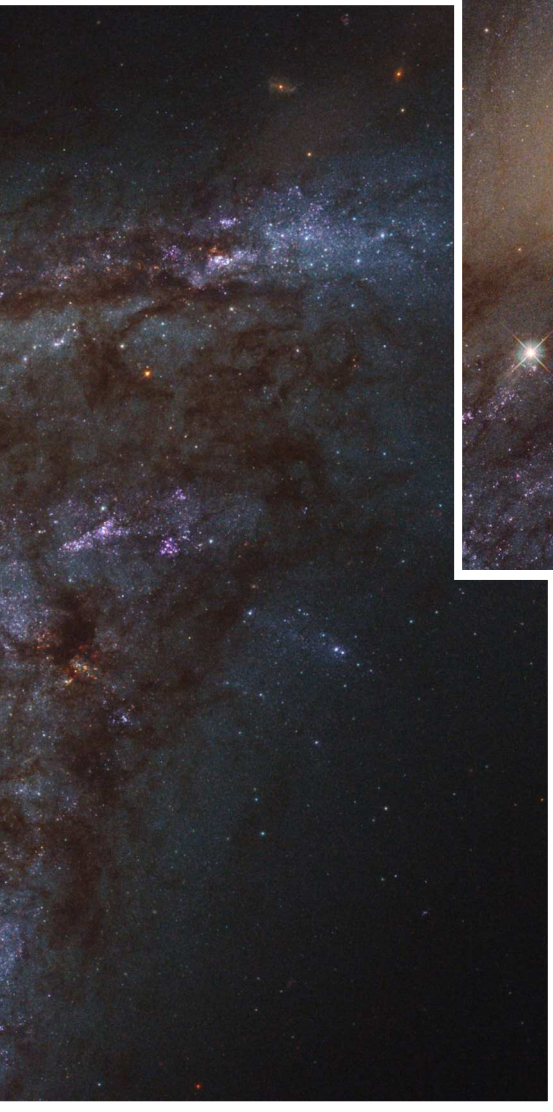
The star catalogs comprise about 39 million stars that are at least five times more massive than our Sun. Stars in the visible-light images are between 1 million and several billion years old; the youngest stars, those between 1 million and 100 million years old, shine prominently in ultraviolet light. The Hubble data provide all of the information to analyze these galaxies, the researchers explained. *"We also are offering computer models to help astronomers interpret the data in the star and cluster catalogs,"* Sabbi said. *"Researchers, for example, can investigate how star formation occurred in one specific galaxy or a set of galaxies. They can correlate the properties of the galaxies with their star formation. They can derive the star-formation history of the galaxies. The ultraviolet-light images may also help astronomers identify the progenitor stars of supernovas found in the data."*

One of the key questions the survey may help astronomers answer is the connection between star formation and the major structures, such as spiral arms, that make up a galaxy. *"When we look at a spiral galaxy, we usually don't just see a random distribution of stars,"* Calzetti

fine detail — the star clusters — while also showing the connection to the larger structures, we are trying to identify the physical parameters underlying this ordering of stellar populations within galaxies. Getting the final link between gas and star formation is key for understanding galaxy evolution."



NGC 6744 *[NASA, ESA, and the LEGUS team]*



Team member Linda Smith of the European Space Agency (ESA) and the Space Telescope Science Institute, added: *"We're looking at the effects of the environment, particularly with star clusters, and how their survival is linked to the environment around them."*

The LEGUS survey will also help astronomers interpret views of galaxies in the distant universe, where the ultraviolet glow from young stars is stretched to infrared wavelengths due to the expansion of space. *"The data in the star and cluster catalogs of these nearby galaxies will help pave the way for what we see with NASA's upcoming infrared observatory, the James Webb Space Telescope, developed in partnership with ESA and the Canadian Space Agency (CSA),"* Sabbi said.

Webb observations would be complementary to the LEGUS views. The space observatory will penetrate dusty stellar cocoons to reveal the infrared glow of infant stars, which cannot be seen in visible- and ultraviolet-light images. *"Webb will be able to see how star formation propagates over a galaxy,"* Sabbi continued. *"If you have information on the gas properties, you can really connect the points and see where, when, and how star formation happens."* ■

A new "Superno

On 26 April 2018, the ESO Supernova Planetarium & Visitor Centre was officially inaugurated, and its doors opened to the public from 28 April. The centre, located at ESO Headquarters in Garching, Germany, provides visitors with an immersive experience of astronomy in general, along with ESO-specific scientific results, projects, and technological breakthroughs.

va" over Munich

This spectacular evening picture, taken a few days before the opening, shows a conjunction of the planet Venus with the young crescent Moon in the background. [ESO/P. Horálek]

by European Southern Observatory

The ESO Supernova Planetarium & Visitor Centre is a cooperation between the European Southern Observatory (ESO) and the Heidelberg Institute for Theoretical Studies (HITS). The building is a donation from the Klaus Tschira Stiftung (KTS), a foundation that promotes natural sciences, mathematics and computer science. ESO will run the facility.

Having developed the idea for an exciting and innovative new building for astronomy education and public outreach, the late Klaus Tschira, then Managing Director of the Klaus Tschira Stiftung and the Heidelberg Institute for Theoretical Studies, started discussing options with ESO for

Opening poster for the ESO Supernova Planetarium & Visitor Centre, which opened in April 2018. Join us at Garching-Forschungzentrum to explore the Universe from here on Earth! [ESO]

hosting the facility. In December 2013, ESO officially accepted the donation of the facility. The striking building was designed by the architects Bernhardt + Partner. It resembles a close binary star system with one star transferring mass to its companion. This leads to the heavier star exploding as a supernova, briefly shining as bright as all the stars in a galaxy combined. The centre — aptly named the ESO Supernova — similarly shines brightly, to generate enthusiasm and passion for astronomy in the young and not-so-young alike. At the heart of the ESO Supernova is a digital planetarium that offers an immersive experi-

This trailer presents the ESO Supernova Planetarium & Visitor Centre, a new cutting-edge astronomy centre for the public. The ESO Supernova — which is free to enter — has the largest tilted planetarium in Germany, Austria and Switzerland and a captivating 2200 m² interactive astronomical exhibition. More information about the ESO Supernova Planetarium and Visitor Centre can be found online. [ESO. Images and footage: ESO/P. Horálek, Architekten Bernhardt + Partner (www.bp-da.de). Music: Johan B. Monell (www.johanmonell.com)]

ence through the use of state-of-the-art visualisation techniques. The planetarium screens many different shows and other cultural events. Visitors can pick from different planetarium shows, ranging from the award-winning *The Secrets of Gravity* animated film about Albert Einstein's discoveries to the giant-screen documentary adventure *Hidden Universe*.

For school classes, the ESO Supernova also offers specially designed planetarium shows — such as *A Tour of the Solar System* and *The Skies Above Us* — and workshops specially tailored to the curriculum. The programme for visitor groups is aimed at children in kindergarten, primary school and all secondary schools.

For teachers, the ESO Supernova offers special teacher training.

The ESO Supernova also hosts an interactive astronomical exhibition where visitors can explore and examine real astronomical artefacts and conduct experiments to get an idea of what it means to be an astronomer, to work in science, and to discover the mysteries of the Universe. The first permanent exhibition is *The Living Universe*, which covers the broad topic of life in the Universe.

Highlights include: a 40-meter image of the night sky (arguably the largest in the world), a meteorite and a mirror segment from the future Extremely Large Telescope that visitors can touch, a hands-on station where visitors can build their own telescope and athletic visitors can even take a ride on a bicycle that travels at the speed of light! The exhibition can be experienced independently or as part of a guided tour.

The seminar rooms on the top floor house space for lectures, workshops and conferences, while *The Void* on the ground floor is a central area with a unique and beautiful star-roof.

The ESO Supernova is open each week between 9:00 and 17:00, Wednesdays to Fridays, and between 12:00 and 17:00 on Saturdays and Sundays. Free tickets can be

This picture shows the ribbon being cut in front of the entrance to the centre by Beate Spiegel, Managing Director of the Klaus Tschira Stiftung, and ESO's Director General, Xavier Barcons. From left to right those present are Gesa Schönberger, Managing Director of HITS, Tania Johnston, ESO Supernova Coordinator, Beate Spiegel, Xavier Barcons and Axel Müller, from the architects Bernhardt + Partner. [ESO/H. Zodet]

In the background, the reception area of the ESO Supernova Planetarium & Visitor Centre including the shop, the partners wall and the models of Jupiter and Saturn hanging overhead. On the side and the following page, view from inside the planetarium, which opened its doors to the public on Saturday 28 April 2018. The building is open five days a week and features planetarium screenings, tours and a permanent exhibition in both German and English. The 25-degree tilted planetarium dome does not just give the audience the sensation of watching the Universe, but of being immersed in it. All of ESP's 'fulldome' planetarium materials are free and open access. [ESO/P. Horálek]

booked online and printed out after arrival at the centre. All content is provided in both English and German and is completely free of charge in 2018. More information, including the programme and details about planning a visit, are available on the website https://supernova.eso.org/. Visitors can sign up for the Public Newsletter and follow @ESOSupernovaDE in German on Facebook and/or Twitter, or @ESOSupernova in English on Facebook and/or Twitter. Media representatives can also sign up to receive news, while educators have the option to receive a dedicated Education Newsletter. Donations for and partnerships with the ESO Supernova are welcome. The spaces are also available for rent. ■

SPHERE reveals fascinating zoo of discs around young stars

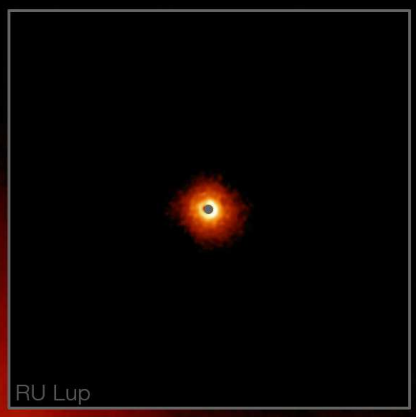
by ESO

The SPHERE instrument on ESO's Very Large Telescope (VLT) in Chile allows astronomers to suppress the brilliant light of nearby stars in order to obtain a better view of the regions surrounding them. This collection of new SPHERE images is just a sample of the wide variety of dusty discs being found around young stars.

These discs are wildly different in size and shape — some contain bright rings, some dark rings, and some even resemble hamburgers. They also differ dramatically in appearance depending on their orientation in the sky — from circular face-on discs to narrow discs seen almost edge-on.

SPHERE's primary task is to discover and study giant exoplanets orbiting

This spectacular image from the SPHERE instrument on ESO's Very Large Telescope shows the dusty disc around the young star IM Lupi in finer detail than ever before. [ESO/H. Avenhaus et al./DARTT-S collaboration]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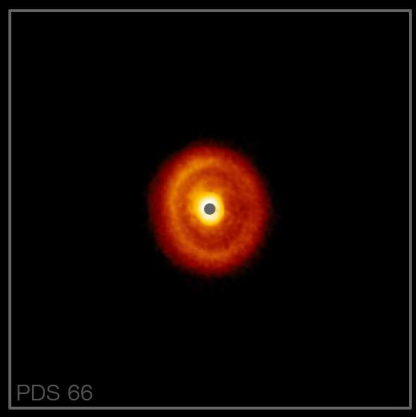
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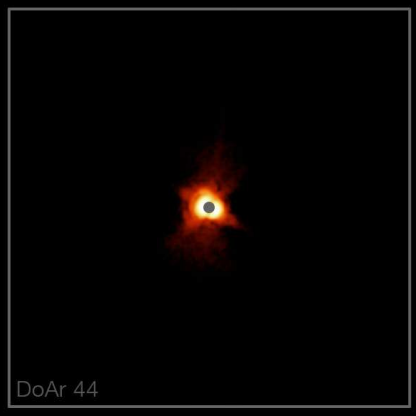
New images from the SPHERE instrument on ESO's Very Large Telescope are revealing the dusty discs surrounding nearby young stars in greater detail than previously achieved. They show a bizarre variety of shapes, sizes and structures, including the likely effects of planets still in the process of forming. [ESO/H. Avenhaus et al./E. Sissa et al./DARTT-S and SHINE collaborations]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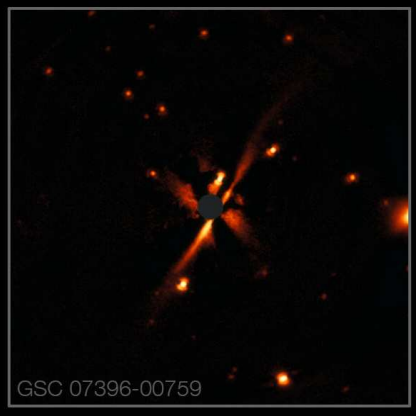
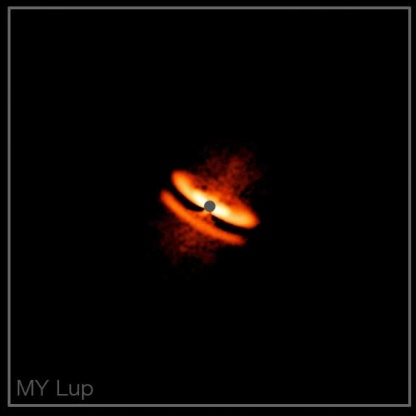

GSC 07396-00759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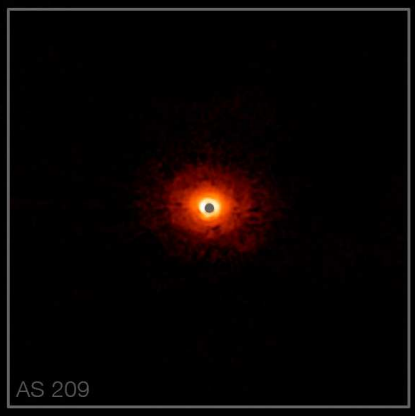
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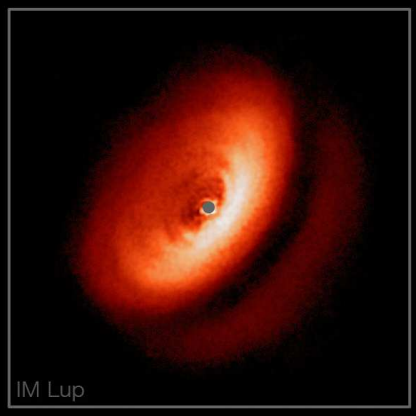
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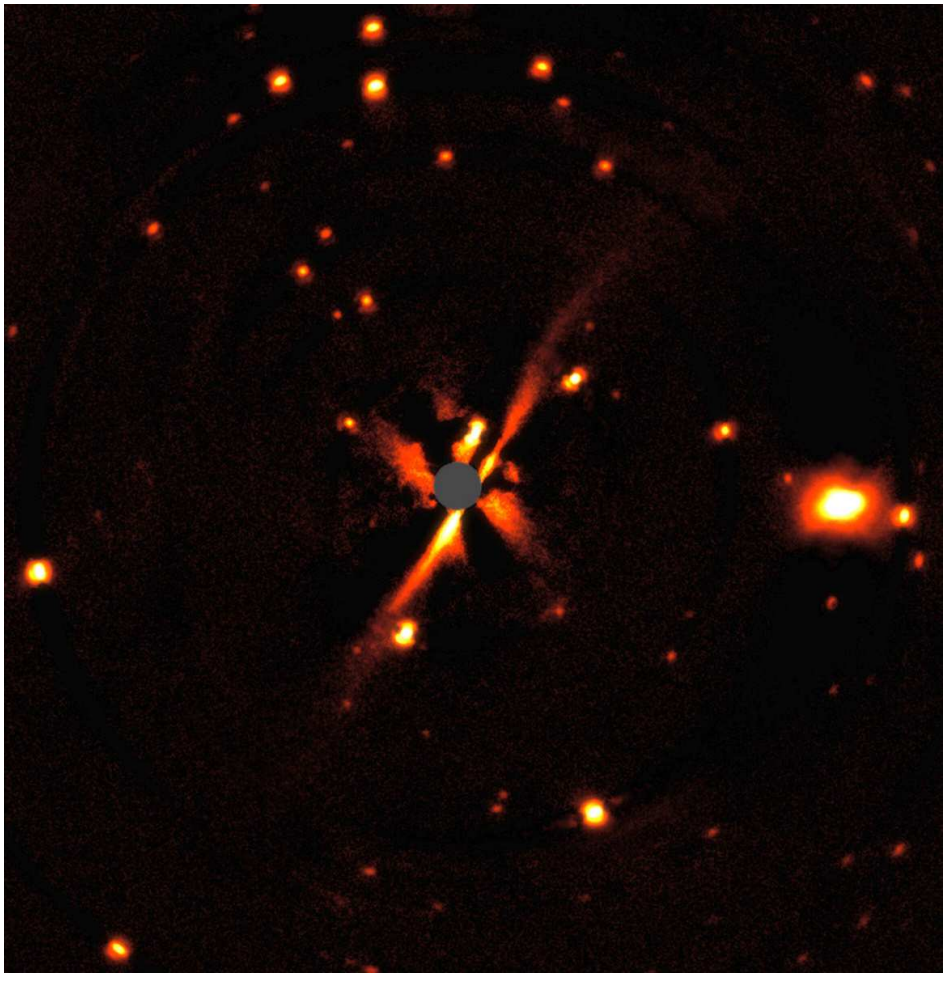

This SPHERE observation is the discovery of an edge-on disc around the star GSC 07396-00759, which is a member of a multiple star system included in the DARTTS-S sample. Oddly, this new disc appears to be more evolved than the gas-rich disc around the T Tauri star in the same system, although they are the same age. The disc extends from the lower-left to the upper-right and the central grey region shows where the star was masked out. [ESO/E. Sissa et al.]

nearby stars using direct imaging. But the instrument is also one of the best tools in existence to obtain images of the discs around young stars — regions where planets may be forming. Studying such discs is critical to investigating the link between disc properties and the formation and presence of planets.

Many of the young stars shown here come from a new study of T Tauri stars, a class of stars that are very young (less than 10 million years old) and vary in brightness. The discs around these stars contain gas, dust, and planetesimals — the building blocks of planets and the progenitors of planetary systems. These images also show what our own Solar System may have looked like in the early stages of its formation, more than four billion years ago. Most of the images presented were obtained as part of the DARTTS-S (Discs ARound T Tauri Stars with SPHERE) survey. The distances of the targets ranged from 230 to 550 light-years away from Earth. For comparison, the Milky Way is roughly 100000 light-years across, so these stars are, relatively speaking, very close to Earth. But even at this distance, it is very challenging to obtain good images of the faint reflected light from discs, since they are outshone by the dazzling light of their parent stars.

Another new SPHERE observation is the discovery of an edge-on disc around the star GSC 07396-00759, found by the SHINE (SpHere INfrared survey for Exoplanets) survey. This red star is a member of a multiple star system also included in the DARTTS-S sample but, oddly, this new disc appears to be more evolved than the gas-rich disc around the T Tauri star in the same system, although they are the same age.

This puzzling difference in the evolutionary timescales of discs around two stars of the same age is another reason why astronomers are keen to find out more about discs and their characteristics. Astronomers have used SPHERE to obtain many other impressive images, as well as for other studies including the interaction of a planet with a disc, the orbital motions within a system, and the time evolution of a disc.

The new results from SPHERE, along with data from other telescopes such as ALMA, are revolutionising astronomers' understanding of the environments around young stars and the complex mechanisms of planetary formation. ■

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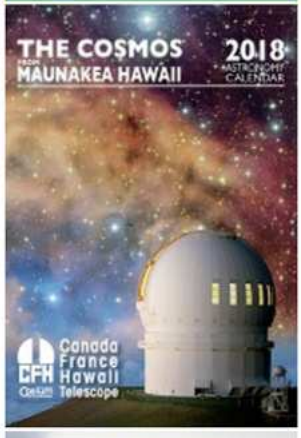

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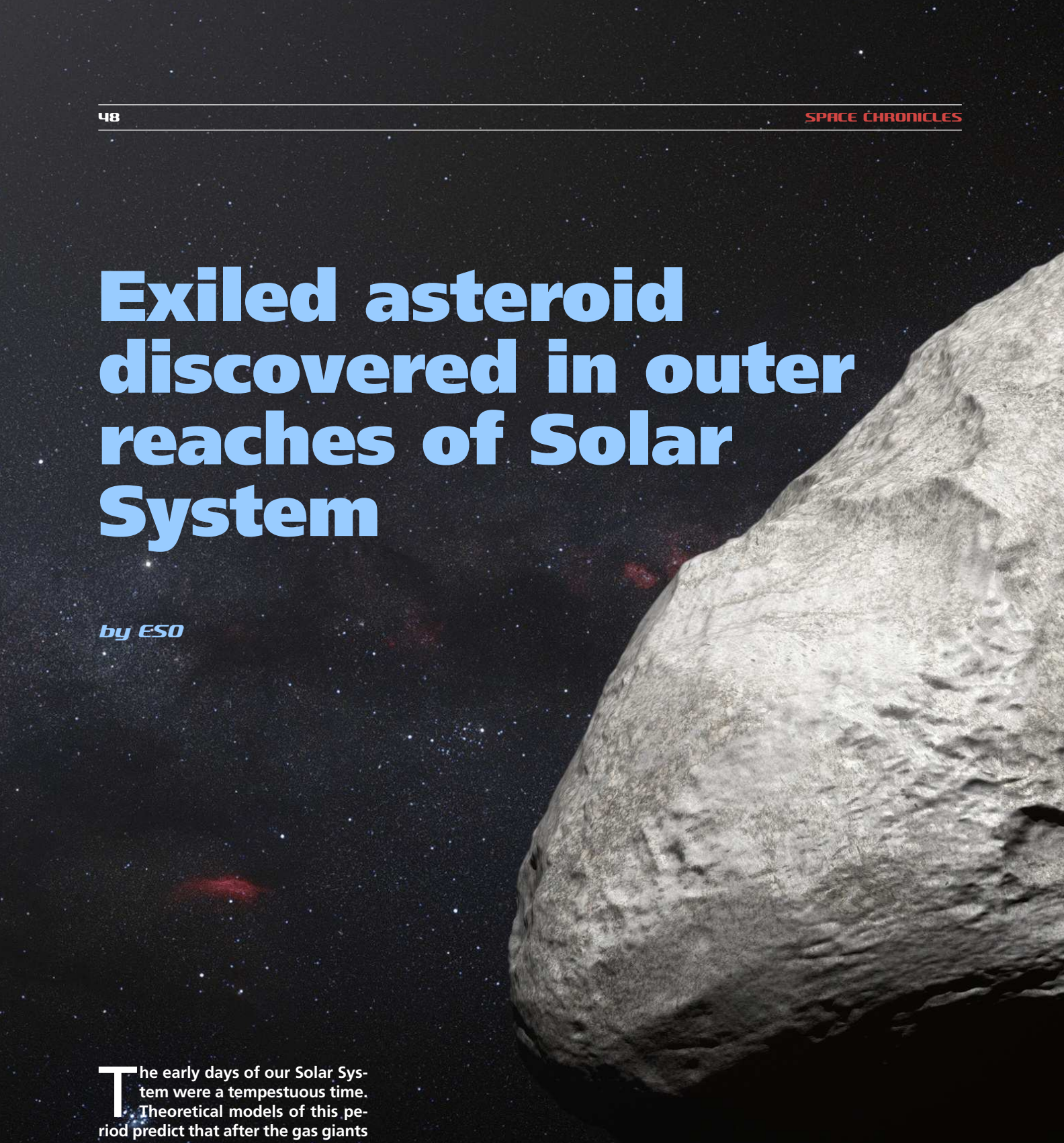
Exiled asteroid discovered in outer reaches of Solar System

by ESO



This artist's impression shows the exiled asteroid 2004 EW_{95}, the first carbon-rich asteroid confirmed to exist in the Kuiper Belt and a relic of the primordial Solar System. This curious object likely formed in the asteroid belt between Mars and Jupiter and must have been transported billions of kilometres from its origin to its current home in the Kuiper Belt. [ESO/M. Kornmesser]

The early days of our Solar System were a tempestuous time. Theoretical models of this period predict that after the gas giants formed they rampaged through the Solar System, ejecting small rocky bodies from the inner Solar System to far-flung orbits at great distances from the Sun. In particular, these models suggest that the Kuiper Belt — a cold region beyond the orbit of

Neptune — should contain a small fraction of rocky bodies from the inner Solar System, such as carbon-rich asteroids, referred to as carbonaceous asteroids.

Now, a recent paper has presented evidence for the first reliably-observed carbonaceous asteroid in the Kuiper Belt, providing strong support for these theoretical models of our Solar System's troubled youth.

After painstaking measurements from multiple instruments at ESO's Very Large Telescope (VLT), a small team of astronomers led by Tom Seccull of Queen's University Belfast in the UK was able to measure the composition of the anomalous Kuiper Belt Object 2004 EW_{95}, and thus determine that it is a carbonaceous asteroid. This suggests that it originally formed in the inner Solar System and must have since migrated outwards. Other inner Solar System objects have previously been detected in the outer reaches of the Solar System, but this is the first carbonaceous asteroid to be found far from home in the Kuiper Belt. The peculiar nature of 2004 EW_{95} first came to light during routine observations with the NASA/ESA Hubble Space Telescope by Wesley Fraser,

an astronomer from Queen's University Belfast who was also a member of the team behind this discovery. The asteroid's reflectance spectrum — the specific pattern of wavelengths of light reflected from an object — was different to that of similar small Kuiper Belt Objects (KBOs), which typically have uninteresting, featureless spectra that reveal little information about their composition. *"The reflectance spectrum of 2004 EW_{95} was clearly distinct from the other observed outer Solar System objects,"* explains lead author Seccull. *"It looked enough of a weirdo for us to take a closer look."* The team observed 2004 EW_{95} with the X-Shooter and FORS2 instruments on the VLT. The sensitivity of these spectrographs allowed the team to obtain more detailed measurements of the pattern of light reflected from the asteroid and thus infer its composition. However, even with the impressive light-collecting power of the VLT, 2004 EW_{95} was still difficult to observe.

Though the object is 300 kilometres across, it is currently a colossal four billion kilometres from Earth, making gathering data from its dark, carbon-rich surface a demanding scientific challenge.

"It's like observing a giant mountain of coal against the pitch-black canvas of the night sky," says co-author Thomas Puzia from the Pontificia Universidad Católica de Chile.

"Not only is 2004 EW_{95} moving, it's also very faint," adds Seccull. *"We had to use a pretty advanced data processing technique to get as much out of the data as possible."*

Two features of the object's spectra were particularly eye-catching and corresponded to the presence of ferric oxides and phyllosilicates.

The presence of these materials had never before been confirmed in a KBO, and they strongly suggest that 2004 EW_{95} formed in the inner Solar System.

Seccull concludes: *"Given 2004 EW_{95}'s present-day abode in the icy outer reaches of the Solar System, this implies that it has been flung out into its present orbit by a migratory planet in the early days of the Solar System."*

"While there have been previous reports of other 'atypical' Kuiper Belt Object spectra, none were confirmed to this level of quality," comments Olivier Hainaut, an ESO astronomer who was not part of the team. *"The discovery of a carbonaceous asteroid in the Kuiper Belt is a key verification of one of the fundamental predictions of dynamical models of the early Solar System."* ■

This short video shows an artist's impression of 2004 EW_{95}, the first carbon-rich asteroid confirmed to exist in the Kuiper Belt and a relic of the primordial Solar System. The video shows a fly-by of the enigmatic asteroid as it tumbles through the icy outer reaches of the Solar System due to past interactions with migrating planets. [ESO/M. Kornmesser]

The red line in this animation shows the orbit of 2004 EW_{95}, with the orbits of other Solar System bodies shown in green for comparison. [ESO/L. Calçada]

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