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The background of the discovery of Pluto

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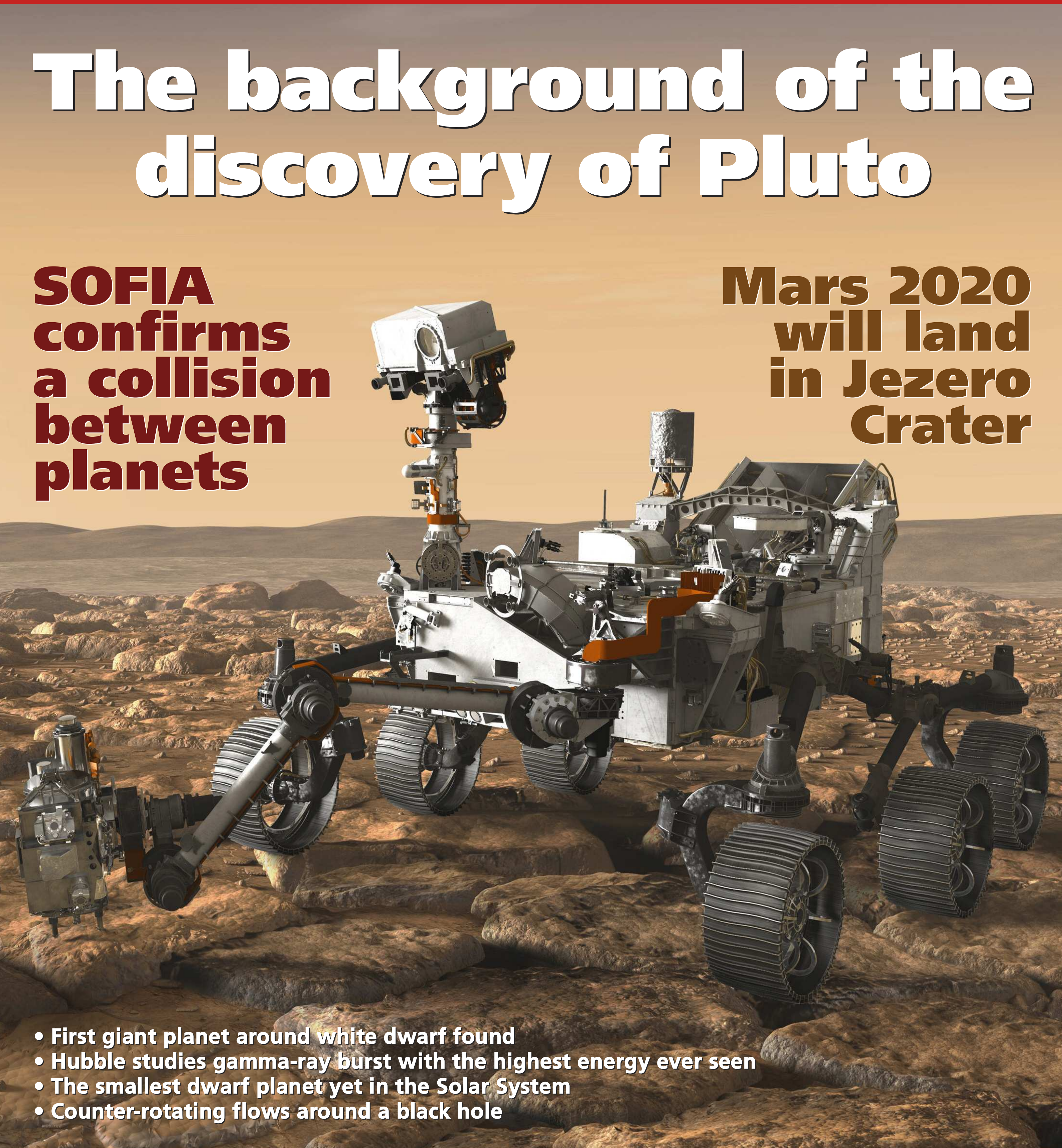

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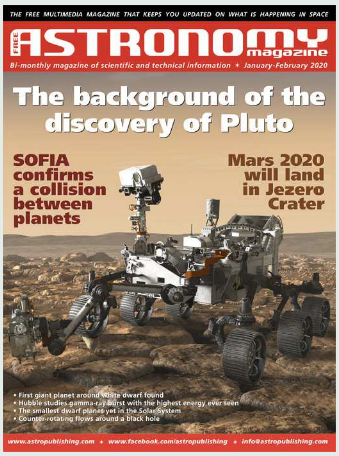

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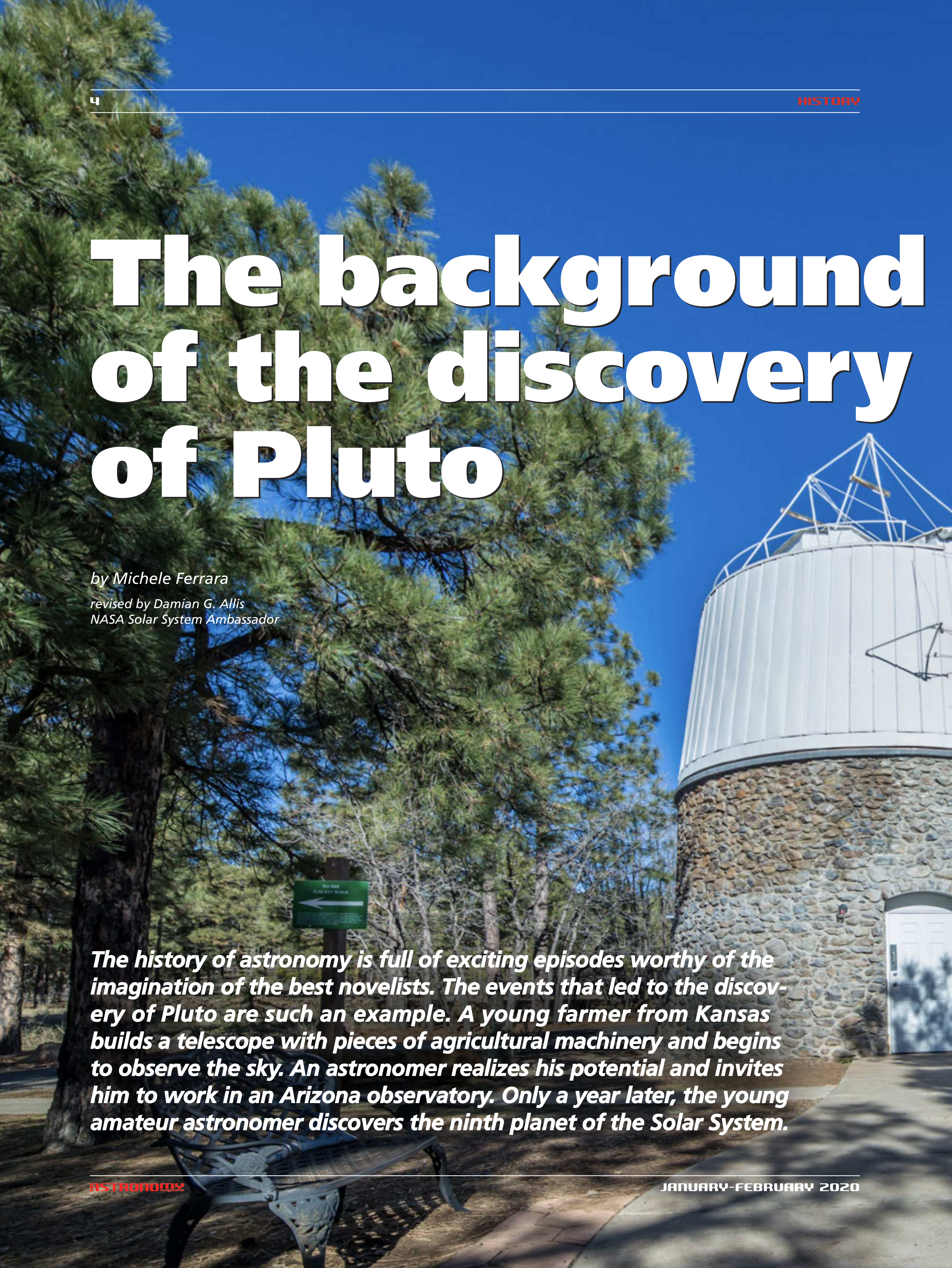
SUMMARY



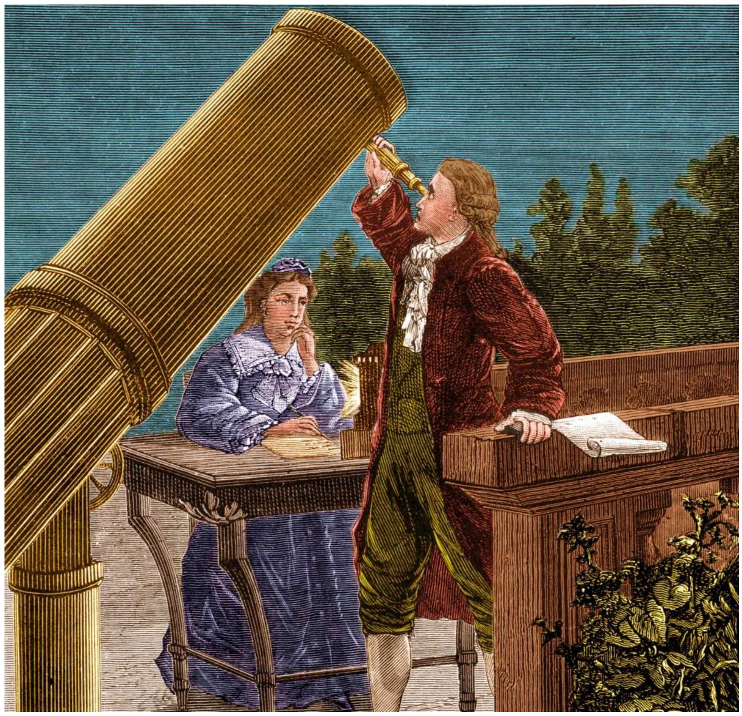
The background of the discovery of Pluto

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

The history of astronomy is full of exciting episodes worthy of the imagination of the best novelists. The events that led to the discovery of Pluto are such an example. A young farmer from Kansas builds a telescope with pieces of agricultural machinery and begins to observe the sky. An astronomer realizes his potential and invites him to work in an Arizona observatory. Only a year later, the young amateur astronomer discovers the ninth planet of the Solar System.

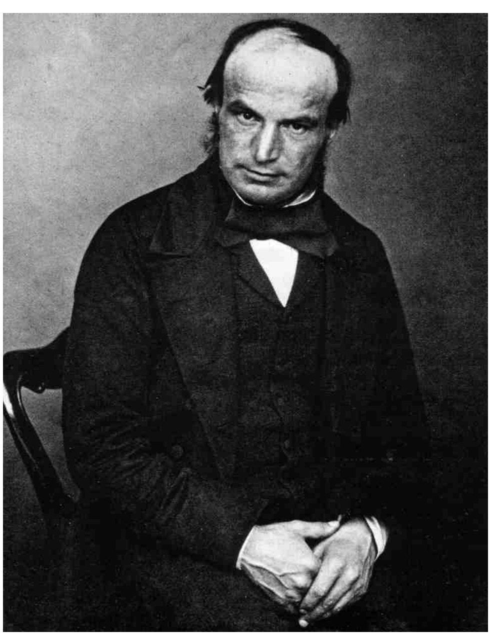
The 90th anniversary of the discovery of Pluto gives us the opportunity to briefly review the events that led to the chance identification of that planet. We will focus our attention on the decisive months that saw Clyde Tombaugh complete that feat, which actually started a century and a half earlier. The chain of events that led to the discovery of Pluto began, indeed, on March 13, 1781, when the great sky observer Frederick William Herschel noticed what seemed to him to be a new comet, but was found over the following months to instead be the seventh planet of the Solar System, Uranus.



The discoverer of Uranus, William Herschel, along with his sister Carolina, who played an important role in the results achieved by her brother. Below left, John Couch Adams and, on the right, Urbain Jean Joseph Le Verrier. These two brilliant mathematicians were able to calculate the position of Neptune in the sky, allowing for its discovery.

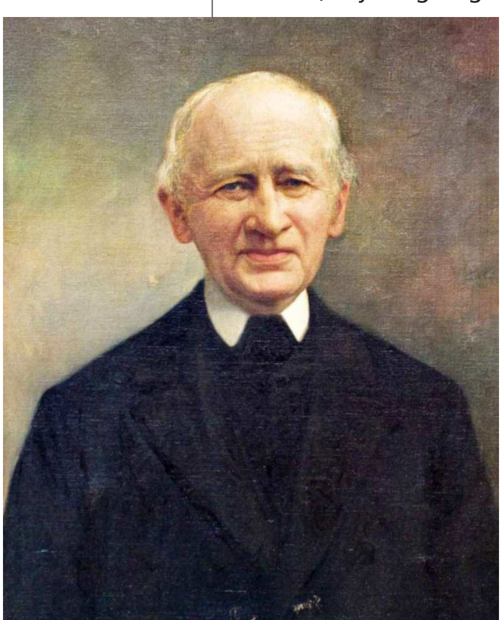
Astronomers accurately measured the slow motion of Uranus over subsequent years and realized that there was something strange, as the mathematically predicted positions did not coincide with the real ones. The planet's orbit was perturbed far beyond the gravitational effects attributable to Jupiter and Saturn.

The Leibniz-Newton laws did not admit disagreements of that kind, and it was unthinkable that Uranus was slightly offset with respect to the positions forecast through the already very precise calculations of the time. In the 1830s, the discrepancy came to be more than four times the diameter of the planet and astronomers could no longer avoid seeking the cause of that embarrassing situation. The dominant hypotheses went in two directions: either the Leibniz-Newton laws were not universally effective as believed, or there was another planet beyond Uranus' orbit, massive enough to gravitationally disrupt Uranus' motion.



On the right, the Astronomer Royal George Biddell Airy, who missed the opportunity to discover Neptune because of his arrogance, thus damaging Adams. Below, Johann Gottfried Galle, the official discoverer of Neptune. Actually, he had only the merit of pointing a telescope towards the point indicated by Le Verrier.

In theory, the orbit of the unknown planet could be calculated with relative precision exactly on the basis of the observed discrepancies. Some of the greatest experts in celestial mechanics took up the challenge and immersed themselves in very complex calculations which, as a result, should have provided the position in the sky of the hypothetical eighth planet. In the 1840s, one of the most exciting chapters of astronomy was about to be written, with the achievement of the greatest success of celestial mechanics.



Between 1843 and 1845, a young English mathematician, John Couch Adams, had developed the possible solution to the problem, managing to calculate the celestial coordinates that the unknown planet would have had on September 30, 1845.

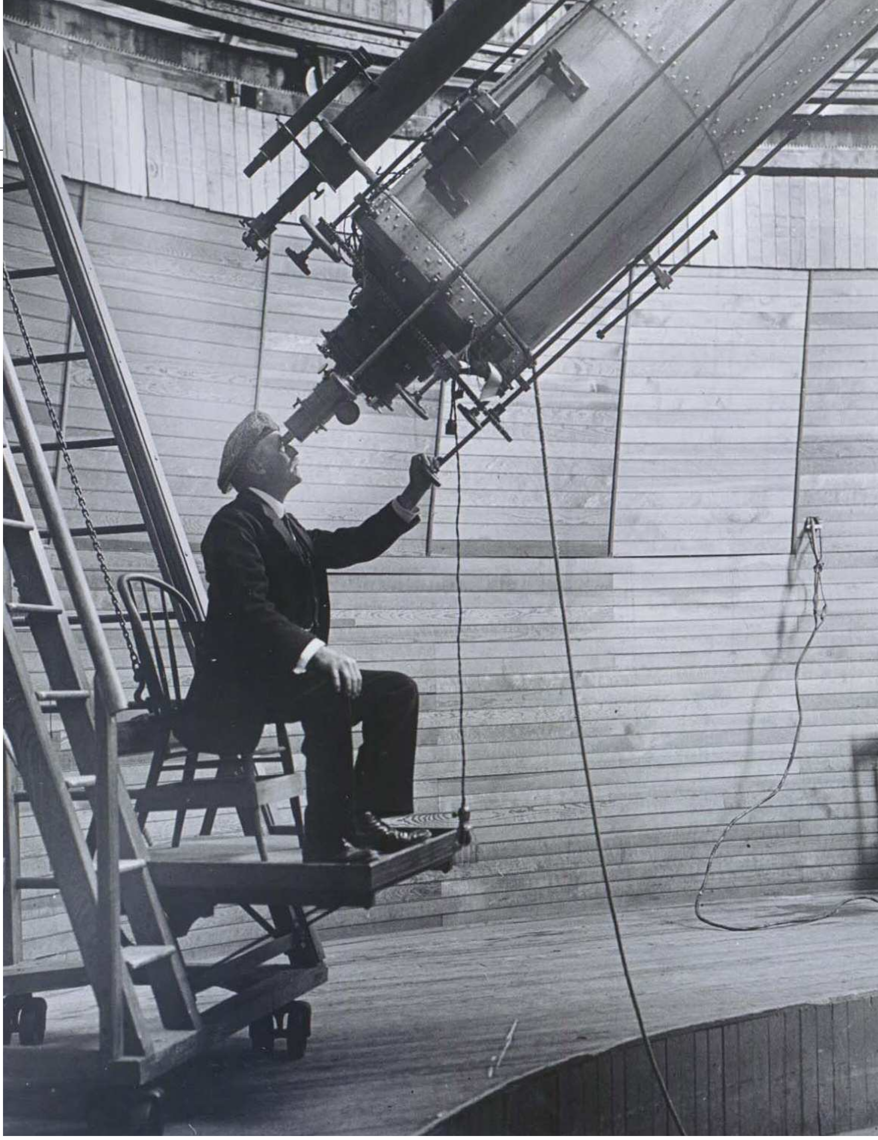
Adams informed the Astronomer Royal and director of the Greenwich Observatory, George Biddell Airy, of this possibility and unsuccessfully asked him to perform a telescopic check.

In October 1845 and also in the following months, a series of unlucky circumstances, worthy of a thriller plot, left Adams' forecast checks still pending, until finally they were openly hindered by Airy himself.

Meanwhile, in France, another great personality in celestial mechanics, Urbain Jean Joseph Le Verrier, had also set to work to identify the location of the unknown planet. His calculations yielded results very similar to those of Adams, and when, in

June 1846, Airy became aware of them, he did not care to inform Le Verrier of Adams' previous work. Incredibly, at the end of that same month, Le Verrier was willing to provide the celestial coordinates that would lead to the discovery of the hypothetical planet, but Airy refused them, justifying it by the fact that he was leaving for a trip to the continent. That journey began on August 10th, so the Astronomer Royal would have had plenty of time to point a telescope at the coordinates indicated by Le Verrier. Le Verrier received no better attention in his homeland, so he decided to turn to a young astronomer at the Berlin Observatory whom he had known previously, Johann Gottfried Galle. On September 23, 1846, immediately after receiving Le Verrier's request, Galle, together with Heinrich Louis d'Arrest, opened the dome of the Fraunhofer 9-inch refractor and aimed the instrument towards the area of the sky where the planet was supposed to be. After some initial difficulties with

Photographs of the construction of the first Flagstaff Observatory facility, commissioned by Percival Lawrence Lowell in 1894. [Lowell Observatory Archives]



Lowell at the eyepiece of the 24-inch Clark refractor, built in 1896 and housed in the great Mars Hill dome. Below, the same instrument as it appears today [Lowell Observatory Archives]

the reference atlases, the two astronomers saw one star too many. Observations at higher magnifications showed that the star was not point-like: the eighth planet of the Solar System had been discovered.

In the decades following the discovery of Neptune, astronomers realized that the perturbations of Uranus' orbit could not be entirely explained by the presence of the eighth planet and, therefore, they began to suspect that there was a ninth planet as well, even farther away than Neptune.

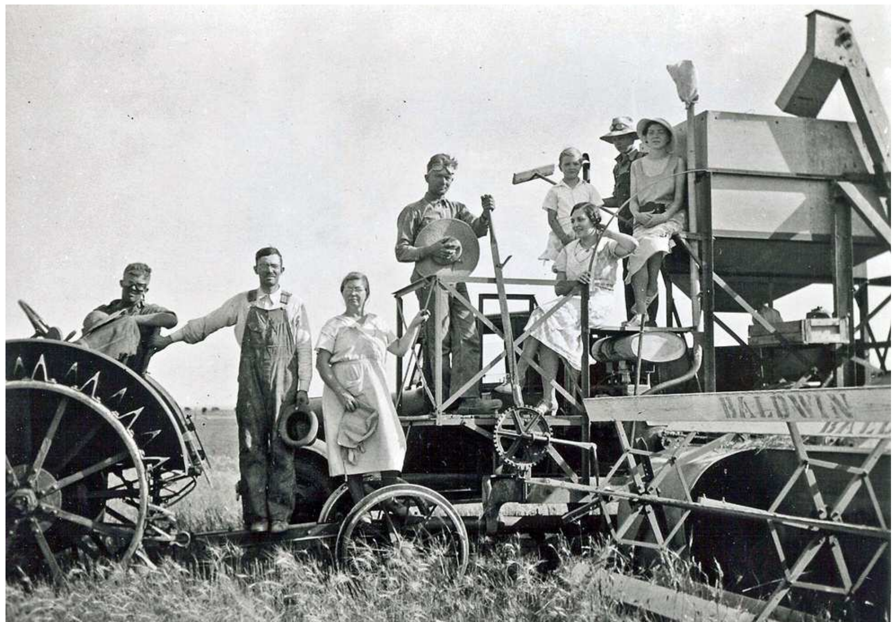
In the first decade of the 20th century, a wealthy American astronomer, Percival Lawrence Lowell

(already famous for questionable observations of Mars), decided to emulate Adams and Le Verrier, trying to calculate the position of what he called "Planet X". Assisted by a small circle of valid collaborators, including Carl Otto Lampland and the brothers Earl Charles Slipher and Vesto Melvin Slipher, Lowell began searching for the planet in the sky from his private observatory in Flagstaff, Arizona. If Planet X had existed, it would have been more likely to be found along what was called "Laplace's invariable plane", a band of sky within 0.5° from the orbital plane of Jupiter. Earl Slipher assiduously photographed that band with a 5-inch refractor, but on the 440 plates exposed for about 3 hours each there was no suspicious object. The only result of that first survey was the alleged discovery of two comets, which turned out to be non-existent, adding discredit to the figure of Lowell and his observatory.

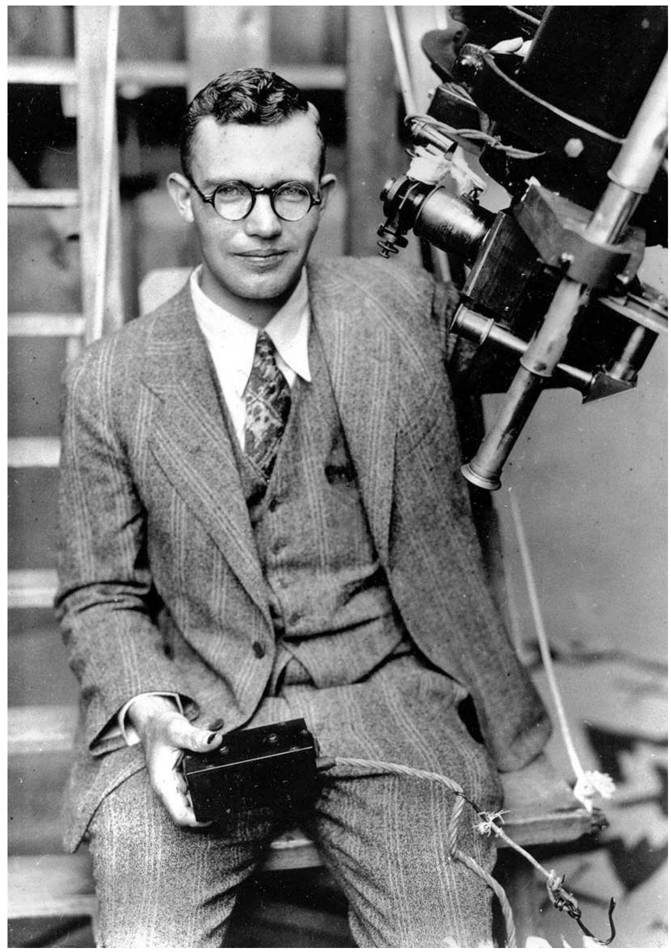
After the setback, the search for Planet X resumed with greater vigor when the observatory was equipped with a new 42-inch reflecting telescope that greatly accelerated image acquisition (seven minutes instead of three hours), but that, on the other hand, compared to 5-inch refractor, covered areas of the sky ten times smaller. Considering that any possible positions of Planet X provided by Lowell were approximate (to say the least), it was necessary to expose many hundreds of plates in large regions of the zodiacal constellations to have any hopes of a discovery. Comparing the positions of the stars contained in these plates to find suspicious movements would have been a very hard task without the invention (in 1904) of a new laboratory instrument – the blink comparator, a kind of microscope that allowed one to observe in rapid and continuous succession two photographic plates, highlighting, in the form of a flickering, every stellar-looking object that had moved in the interval between the exposures.

Lowell bought the blink from Zeiss in 1911 and the observatory team used it with plates taken by the 42-inch scope up until the following year without discovering anything particularly interesting.

Wanting to try new solutions, Lowell borrowed a 9-inch astrograph from the Sproul Observatory (Swarthmore, Pennsylvania) in 1912, hoping that the large field of that instrument would serve as a turning point in the hunt for the elusive planet. This third research campaign ended on November 12, 1916 with the death of Lowell, who therefore did not see his dream realized. In actual-



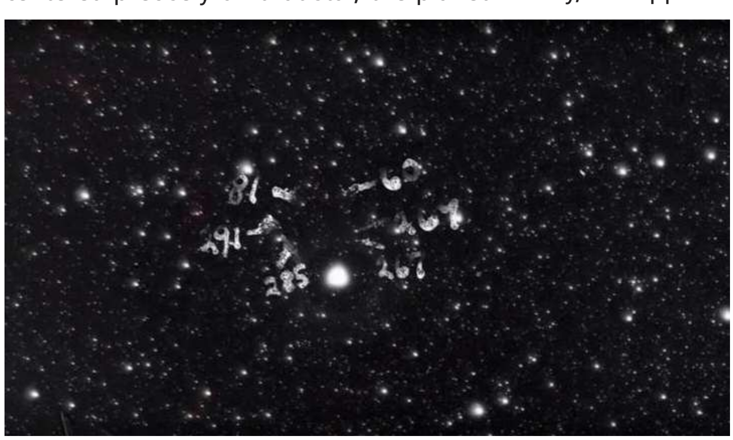
Clyde Tombaugh (second from left) at harvest time on the Tombaugh family farm in Kansas. Left to right: Charles, Clyde, Adella, Roy, Anita, Robert, Esther, Patsy. Beside, the young amateur astronomer next to the 9-inch telescope he built in 1928 at the age of 22. [Lowell Observatory Archives]



Clyde Tombaugh near the eyepiece of the 13-inch refractor used to discover Pluto. [Lowell Observatory Archives]

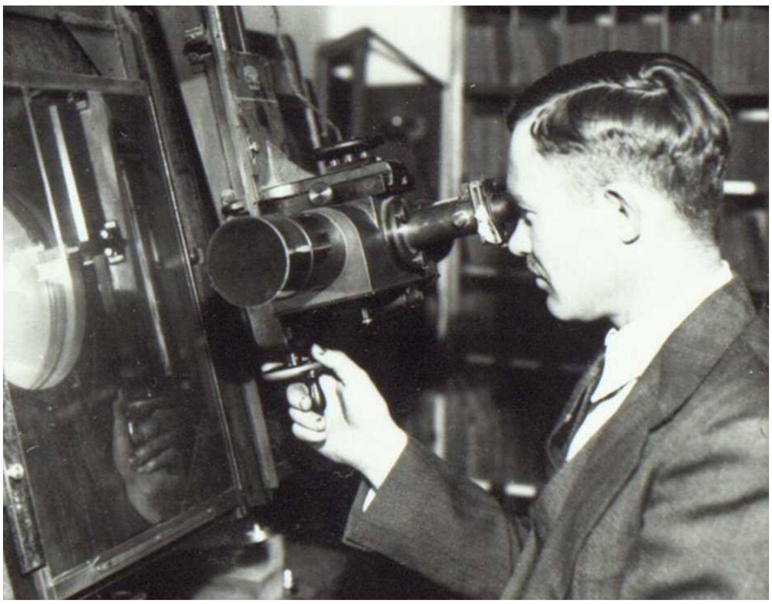
ity, Planet X was present near the edge of two plates exposed on March 19 and April 7, 1915, but no one noticed it. Without the spur of Lowell and with the First World War on its doorstep, the Flagstaff Observatory experienced a long, dark period.

Planet X hunting resumed in 1928 at the initiative of a nephew of Lowell, the politician and businessman Roger Lowell Putnam, and with the help of Lampland and the Slipher brothers. Thanks to new funds, the observatory was equipped with a 13-inch astrograph and the research team was expanded with the hiring of a young amateur astronomer from Kansas, Clyde Tombaugh, whose main task would be to examine the plates with the blink. In the spring of 1929, the enterprising amateur astronomer (he will become an astronomer seven years later) began his activity. According to Lowell's calculations, at that time, Planet X would have been hidden in the region of sky around Delta Geminorum. Before that season ended, several hundred plates had already been exposed, and on two of them, centered precisely on that star, the planet was there. Perhaps due to a hasty comparison in the blink, or more probably because at the time the planet was almost stationary, it happened that no one noticed its presence.

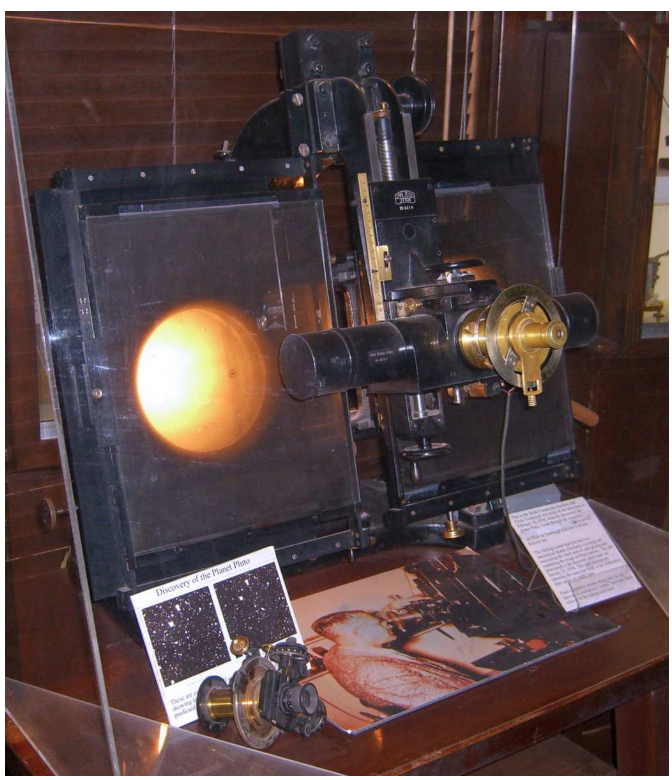


A plate exposed in December 1925 in which Pluto appears. The planet had been photographed on several occasions since 1909 but was first identified only in February 1930.

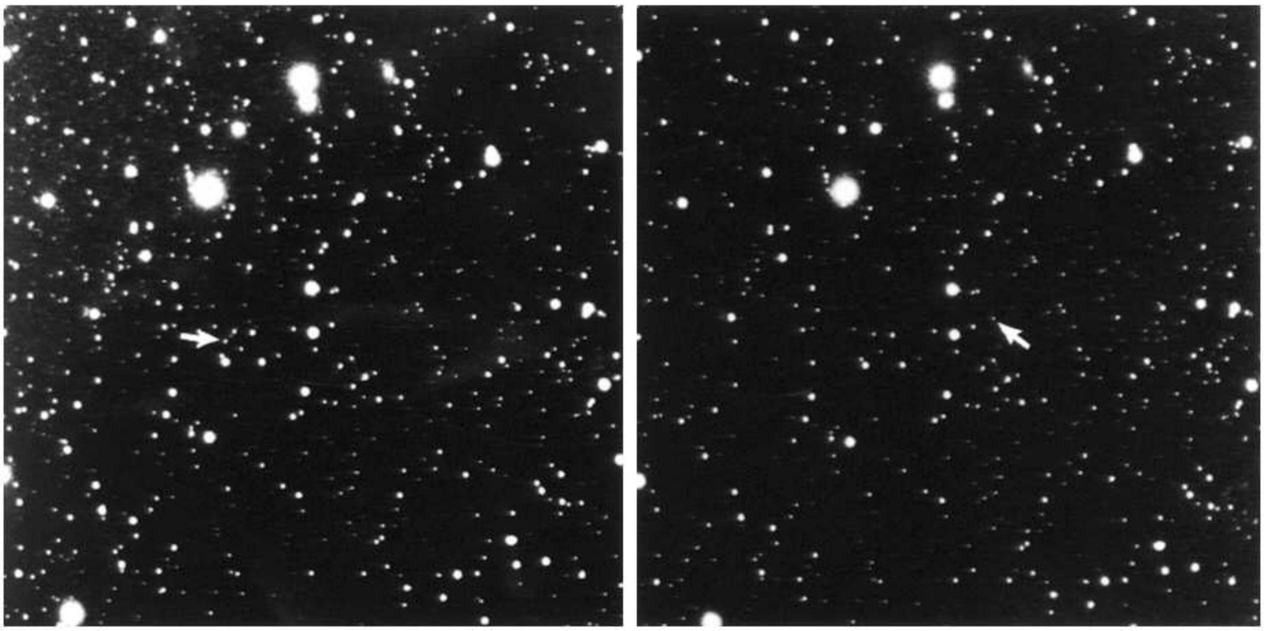
The new astrograph was so powerful (and probably the plates so sensitive) that a problem began to emerge: each image contained thousands of stars, and on each plate appeared up to dozens of objects flickering in the blink. Most were known asteroids, but there were also unknown asteroids, stationary meteors, defects



of the sensitive support, and other noises. Not knowing how Planet X might have appeared, it is clear that, if it had a stellar appearance, it would have been almost impossible to make the necessary checks on all those non-fixed objects. Frustrated by this situation and homesick for the remoteness of his land, Tombaugh became very sad, to the point that Lampland granted him a long vacation to spend with his family.
The fear of never seeing him return to Flagstaff was strong. Instead, in the autumn of 1929, Tombaugh returned to the observatory to restart, more motivated than ever, the search for Planet X.
To speed up his work he had thought to photograph the regions of the sky in opposition, where it was easier for him to estimate the distance of a body in motion, starting from the length of the path between one photographic exposure and the other. Lowell's prediction had now faded into the background, also due to previous failures, and Tombaugh had practically started his own research program. Between September and October 1929, the tenacious amateur astronomer photographed star fields in Aquarius, Pisces and Aries, while in November and December, he concentrated on the constellation Taurus. In January 1930, Tombaugh began to re-photograph the constellation Gemini, already photographed eight months earlier. Now, however, it was in opposition, and somewhere there should have been the Planet X yearned for by Lowell. It was therefore unavoidable to photograph



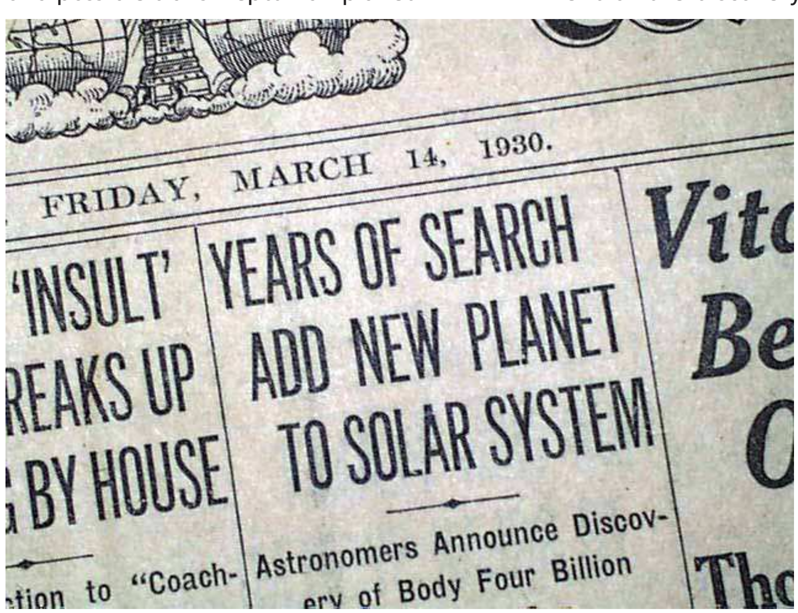
Clyde Tombaugh at work with the blink comparator which highlighted Pluto's motion in the sky. Below, the same instrument displayed today as a relic at the Flagstaff Observatory. [Lowell Observatory Archives]



January 23, 1930 January 29, 1930

Clyde Tombaugh's original images identifying Pluto in 1930. The tiny, faint dot moves very slightly relative to the background stars, but sufficiently so that we've been able to successfully reconstruct its orbit. [Lowell Observatory Archives] Alongside, the announcement of the discovery of Pluto given by the newspaper THE WORLD on March 14, 1930: "Years of search add new planet to Solar System', "Astronomers Announce Discovery of Body Four Billion Miles From Sun".

the entire region again. After the Last Quarter Moon, on 23 and 29 January, Tombaugh took two plates around Delta Geminorum, which he put in the blink only in mid-February. On those plates a stellar-looking object had moved at a speed compatible with that of a possible trans-Neptunian planet.



FRIDAY, MARCH 14, 1930.

'INSULT' REAKS UP BY HOUSE

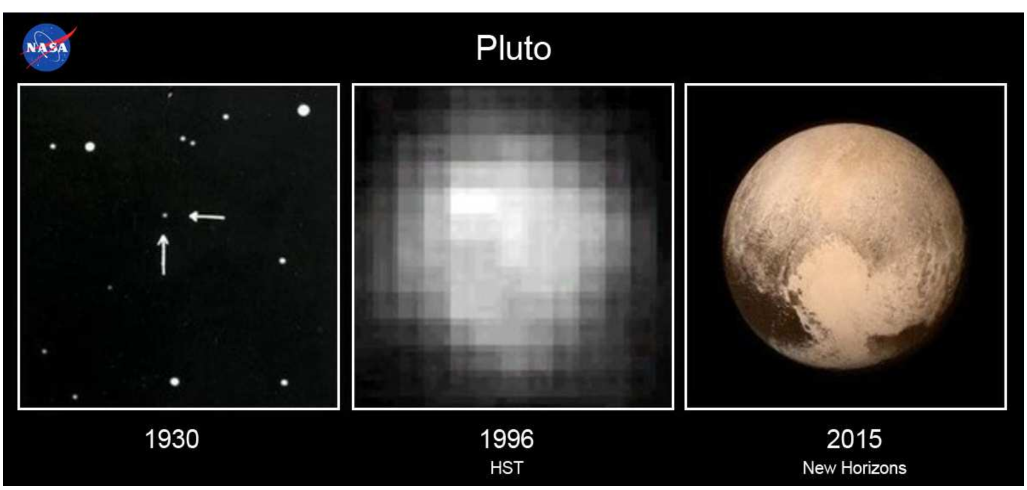
YEARS OF SEARCH ADD NEW PLANET TO SOLAR SYSTEM

Astronomers Announce Discovery of Body Four Billion

tion to "Coach-

Planet X had finally been captured. The days that followed the discovery were frantic. Mindful of the previous poor figures made by the observatory, Lampland, the Slipher brothers, and Tombaugh himself decided that before giving the announcement of the discovery it was essential to produce other images and observations. On 19 February, it was established that Tombaugh would continue to expose plates around Delta Geminorum with the 13-inch astrograph, while Lampland would use the 42-inch reflector to take higher magnification images centered on the planet in order to make accurate position measurements. Of course, the inten-

tion was to compute a temporary orbit. To contribute to this complex operation, Tombaugh quickly reviewed the plates taken both over the last year and in which the planet might have been present. That day, Lampland failed to calculate a satisfactory orbit, but foresaw the exact location where the planet would be found on the night between 19 and 20 February. At 11 P.M. on the 19th, defying bad weather conditions, Tombaugh began to expose a new plate.
After developing and putting it in the blink, he saw the planet exactly in the expected position. Lampland suggested making a contact copy on film of the planet-centered star field to have a manageable map for a direct visual comparison.
On the evening of the 20th, the weather conditions were favorable, and Lampland and Tombaugh, together with Vasto Slipher, aimed the 24-inch refractor, symbol of the observatory, towards the new planet. Theirs were the first eyes to knowingly observe Planet X. The understandable initial emotion soon turned into disappointment when the team realized that not even at the highest magnifications of that powerful refractor was it possible to distinguish even a hint of a planetary disc. The appearance remained stellar, meaning that the planet was not faint due to a very low albedo, as initially supposed, but because it was very small. Accordingly, its mass was not sufficient to explain the residual perturbations observed in Uranus' motion. The newly discovered planet could not therefore be the one forecast



Clyde Tombaugh in the 1950s, when he worked at the White Sands Missile Range in New Mexico. [Bettmann/Getty] On the left, the demonstration of how our vision of Pluto has changed from discovery to today.

In these two photos, the affection of an aged Clyde Tombaugh for astronomy is still alive. He died on 17 January 1997, and part of his ashes will travel beyond the Solar System on board the New Horizons probe.

by Lowell and, having found it right in the region of sky indicated by Lowell, its discovery may have only been an incredible coincidence.

In the days following the first direct observation, other plates were taken, the computation of the orbit was improved, and the team decided how and when to announce the discovery. The date of March 13 was chosen because it coincided with the 149th anniversary of the discovery of Uranus (which had, in a certain sense, instigated the subsequent events) and with the 75th anniversary of Lowell's birth. On March 13, 1930, Tombaugh and Vasto Slipher sent a telegram to the already famous Harlow Shapley, director of the Harvard College Observatory, in which, in addition to announcing the discovery, every relevant piece of information was provided. From that day and for another 76 years, our Solar System would have nine planets.

On the first day of May 1930, the Flagstaff Observatory team chose the name of the new planet from over one thousand proposals received. The choice fell on Pluto, the god of the underworld, proposed by a very young schoolgirl in Oxford.

Until recently, the story of Pluto after 1930 was only a little better known than the story before. For almost half a century after its discovery, Pluto remained a perfect unknown: except for the oddly inclined orbit and its 2:3 resonance with Neptune, and for the facts of being small and cold, nothing else was known. Diameter, mass and albedo were only imaginable. In 1978, however, there was a turning point with the discovery of Pluto's largest satellite, Charon, which allowed the mass and other major physical properties to be calculated more accurately. The rest is recent history. In 2006, after long and heated discussions, the International Astronomical Union downgraded Pluto to the rank of dwarf planet. In 2015, NASA's New Horizons mission revolutionized our vision of Pluto and its satellite system. The reader interested in the results of this mission may find it useful to read our articles *"Astonishing Pluto"* and *"The new face of Pluto's system"*.

First giant planet around white dwarf found

by ESO

Researchers using ESO's Very Large Telescope have, for the first time, found evidence of a giant planet associated with a white dwarf star. The planet orbits the hot white dwarf, the remnant of a Sun-like star, at close range, causing its atmosphere to be stripped away and form a disc of gas around the star. This unique system hints at what our own Solar System might look like in the distant future. *"It was one of those chance discoveries,"* says researcher Boris Gänsicke, from the University of Warwick in the UK, who led the study, published today in *Nature*. The team had inspected around 7000 white dwarfs observed by the Sloan Digital Sky Survey and found one to be unlike any other. By analysing subtle variations in the light from the star, they found traces of chemical elements in amounts that scientists had never before observed at a white dwarf. *"We knew*

This illustration shows the white dwarf WDJ0914+1914 and its Neptune-like exoplanet. Since the icy giant orbits the hot white dwarf at close range, the extreme ultraviolet radiation from the star strips away the planet's atmosphere. While most of this stripped gas escapes, some of it swirls into a disc, itself accreting onto the white dwarf. [ESO/M. Kornmesser]

that there had to be something exceptional going on in this system, and speculated that it may be related to some type of planetary remnant."

To get a better idea of the properties of this unusual star, named WDJ0914+1914, the team analysed it with the X-shooter instrument on ESO's Very Large Telescope in the Chilean Atacama Desert. These follow-up observations confirmed the presence of hydrogen, oxygen and sulphur associated with the white dwarf. By studying the fine details in the spectra taken by ESO's X-shooter, the team discovered that these elements were in a disc of gas swirling into the white dwarf, and not coming from the star itself.

"It took a few weeks of very hard thinking to figure out that the only way to make such a disc is the evaporation of a giant planet," says Matthias Schreiber from the University of Valparaiso in Chile, who com-

puted the past and future evolution of this system. The detected amounts of hydrogen, oxygen and sulphur are similar to those found in the deep atmospheric layers of icy, giant planets like Neptune and Uranus. If such a planet were orbiting close to a hot white dwarf, the extreme ultraviolet radiation from the star would strip away its outer layers and some of this stripped gas would swirl into a disc, itself accreting onto the white dwarf. This is what scientists think they are seeing around WDJ0914+1914: the first evaporating planet orbiting a white dwarf.

Combining observational data with theoretical models, the team of astronomers from the UK, Chile and Germany were able to paint a clearer image of this unique system. The white dwarf is small and, at a blistering 28,000 degrees Celsius (five times the Sun's temperature), extremely hot. By contrast, the planet is icy and large — at least twice as large as the star. Since it orbits the hot white dwarf at close range, making its way around it in just 10 days, the high-energy photons from the star are gradually blowing away the planet's atmosphere. Most of the gas escapes, but some is pulled into a disc swirling into the star at a rate of 3000 tonnes per second. It is this disc that makes the otherwise hidden Neptune-like planet visible.

"This is the first time we can measure the amounts of gases like oxygen and sulphur in the disc, which provides clues to the composition of exoplanet atmospheres," says Odette Toloza from the University of Warwick, who developed a model for the disc of gas surrounding the white dwarf.

"The discovery also opens up a new window into the final fate of planetary systems," adds Gänsicke.

Stars like our Sun burn hydrogen in their cores for most of their lives. Once they run out of this fuel, they puff up into red giants, becoming hundreds of times larger and engulfing nearby planets. In the case of the Solar System, this will include Mercury, Venus, and even Earth, which will all be consumed by the red-giant Sun in about 5 billion years.

Eventually, Sun-like stars lose their outer layers, leaving behind only a burnt-out core, a white dwarf. Such stellar remnants can still host planets, and many of these star systems are thought to exist in our galaxy. However, until now, scientists had never found evidence of a surviving giant planet around a white dwarf. The detection of an exoplanet in orbit around WDJ0914+1914, located about 1500 light years away in the constellation of Cancer, may be the first of many orbiting such stars.

According to the researchers, the exoplanet now found with the help of ESO's X-shooter orbits the white dwarf at a distance of only 10 million kilometres, or 15 times the solar radius, which would have been deep inside the red giant.

The unusual position of the planet implies that at some point after the host star became a white dwarf, the planet moved closer to it.

The astronomers believe that this new orbit could be the result of gravitational interactions with other planets in the system, meaning that more than one planet may have survived its host star's violent transition. *"Until recently, very few astronomers paused to ponder the fate of planets orbiting dying stars. This discovery of a planet orbiting closely around a burnt-out stellar core forcefully demonstrates that the Universe is time and again challenging our minds to step beyond our established ideas,"* concludes Gänsicke.

Artist's animation of the Sun becoming a red giant. [ESA/Hubble (M. Kornmesser & L. L. Christensen)]

This animation shows the white dwarf WDJ0914+1914 and its Neptune-like exoplanet. Since the icy giant orbits the hot white dwarf at close range, the extreme ultraviolet radiation from the star strips away the planet's atmosphere. While most of this stripped gas escapes, giving the planet a comet-like tail, some of it swirls into a disc, itself accreting onto the white dwarf. [ESO/M. Kornmesser]

Hubble studies gamma-ray burst with the highest energy ever seen

by NASA/ESA

Gamma-ray bursts are the most powerful explosions in the Universe. They emit most of their energy in gamma rays, light which is much more energetic than the visible light we can see with our eyes. In January 2019, an extremely bright and long gamma-ray burst (GRB) was detected by a suite of telescopes, including NASA's Swift and Fermi telescopes, as well as by the Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes.

Known as GRB 190114C, some of the light detected from the object had the highest energy ever observed: 1Tera electron volt (TeV) — about one trillion times as much energy per photon as visible light. Scientists have been trying to observe such very high energy emission from GRB's for a long time, so this detection is considered a milestone in high-energy astrophysics.

Previous observations revealed that to achieve this energy, material must be emitted from a collapsing star at 99.999% the speed of light. This material is then forced through the gas that surrounds the star, causing a shock that creates the gamma-ray burst itself. For the first time, scientists have observed extremely energetic gamma rays from this particular burst. Several ground- and space-based observatories have set out to study GRB 190114C.

European astronomers were provided observing time with the NASA/ESA Hubble Space Telescope to observe the gamma-ray burst, to study its environment and find out how this extreme emission is produced. *"Hubble's observations suggest that this particular burst was*

GRB 190114C according to an artist's impression. [ESA/Hubble, M. Kornmesser]

sitting in a very dense environment, right in the middle of a bright galaxy 5 billion light years away," explained one of the lead authors, Andrew Levan of the Institute for Mathematics, Astrophysics & Particle Physics Department of Astrophysics at Radboud University in the Netherlands. *"This is really unusual, and suggests that might be why it produced this exceptionally powerful light."*

Astronomers used the NASA/ESA Hubble Space Teleescope, together with the European Southern Observatory's Very Large Telescope and the Atacama Large Milimeter/submilimeter Array to study the host galaxy of this GRB. Hubble's Wide Field Camera 3 was instrumental in studying whether the environmental properties of the host system, which is composed of a close pair of interacting galaxies, might have contributed to the production of these very-high-energy photons. The GRB occurred within the nuclear region of a massive galaxy, a location that is rather unique. This is indicative of a denser environment than that in which GRBs are typically observed and could have been crucial for the generation of the very-high-energy photons that were observed.

"Scientists have been trying to observe very-high-energy emission from gamma-ray bursts for a long time," explained lead author Antonio de Ugarte Postigo of the Instituto de Astrofísica de Andalucía in Spain. *"This new observation is a vital step forward in our understanding of gamma-ray bursts, their immediate surroundings, and just how matter behaves when it is moving at 99.999% of the speed of light."* ■

Contract signed for ELT's mirror M5 cell structure

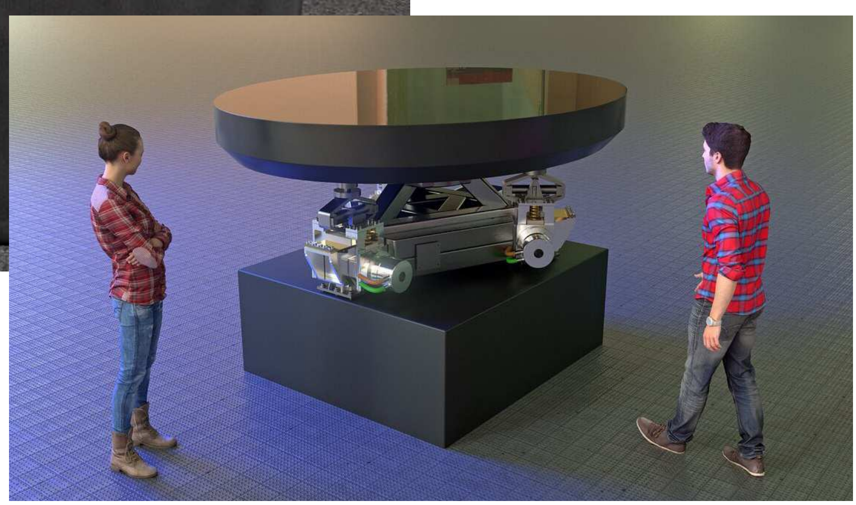
by ESO

ESO has signed a contract with SENER Aerospacial for the design and production of the support cell for the M5 mirror of the Extremely Large Telescope (ELT). SENER Aeroespacial will carry out the design, construction and verification of the cell for the M5 mirror, as well as its control system and auxiliary equipment. This complex mechanism has critical performances in terms of accuracy to ensure the stability of the flat elliptical mirror M5.

The contract was signed on 29 November 2019 at ESO's headquarters in Garching bei München in Germany by ESO's Director General Xavier Barcons and the General Di-

At a ceremony at ESO Headquarters in Garching, Germany on 29 November 2019, ESO signed a contract with SENER Aerospacial for the design and production of the cell for the M5 mirror of the Extremely Large Telescope (ELT). The contract was signed by ESO's Director General Xavier Barcons and the General Director of SENER Aeroespacial José Julián Echevarría. [ESO]

rector of SENER Aeroespacial José Julián Echevarría. The ceremony was also attended by the Vice-Consul of Spain in Munich María Gonzalo Villanueva, representatives from the Spanish Centre for the Development of Industrial Technology, the Spanish Ministry of Science, Innovation and Universities, as well as by staff members of ESO and SENER Aeroespacial. With a primary mirror of 39-metre diameter, the ELT will be equipped with five mirrors in total. Two of them – M4 and M5 – form part of the adaptive optics system of the telescope. Their unique synergy will allow the ELT to take extremely high-quality and sharp images.



This image shows a rendering of the M5 mirror and cell support structure that will be used on ESO's Extremely Large Telescope (ELT). Designed and manufactured by SENER Aerospacial , the support cell structure will have critical performances in terms of accuracy to ensure the stability of the flat elliptical mirror M5. [SENER Aerospacial/ESO/L. Calçada]

Although the M5 mirror will be the smallest mirror on the telescope (2.7 by 2.2 metres), it will be the largest tip-tilt stabilised mirror in the world. The M5 cell includes a fast tip-tilt system for image stabilisation that will compensate perturbations caused by the telescope mechanisms, wind vibrations, and atmospheric turbulence. The ELT, which was approved for construction in 2014 by the ESO Council, is currently under construction on Cerro Armazones in the Chilean Atacama desert. The telescope will reside very close to ESO's Paranal Observatory where ESO's current flagship telescope the Very Large Telescope (VLT) is located. First light of the ELT is scheduled to take place in 2025.
Once built it will be humanity's biggest eye on the sky.

SOFIA confirms collision betwe planets

by Michele Ferrara

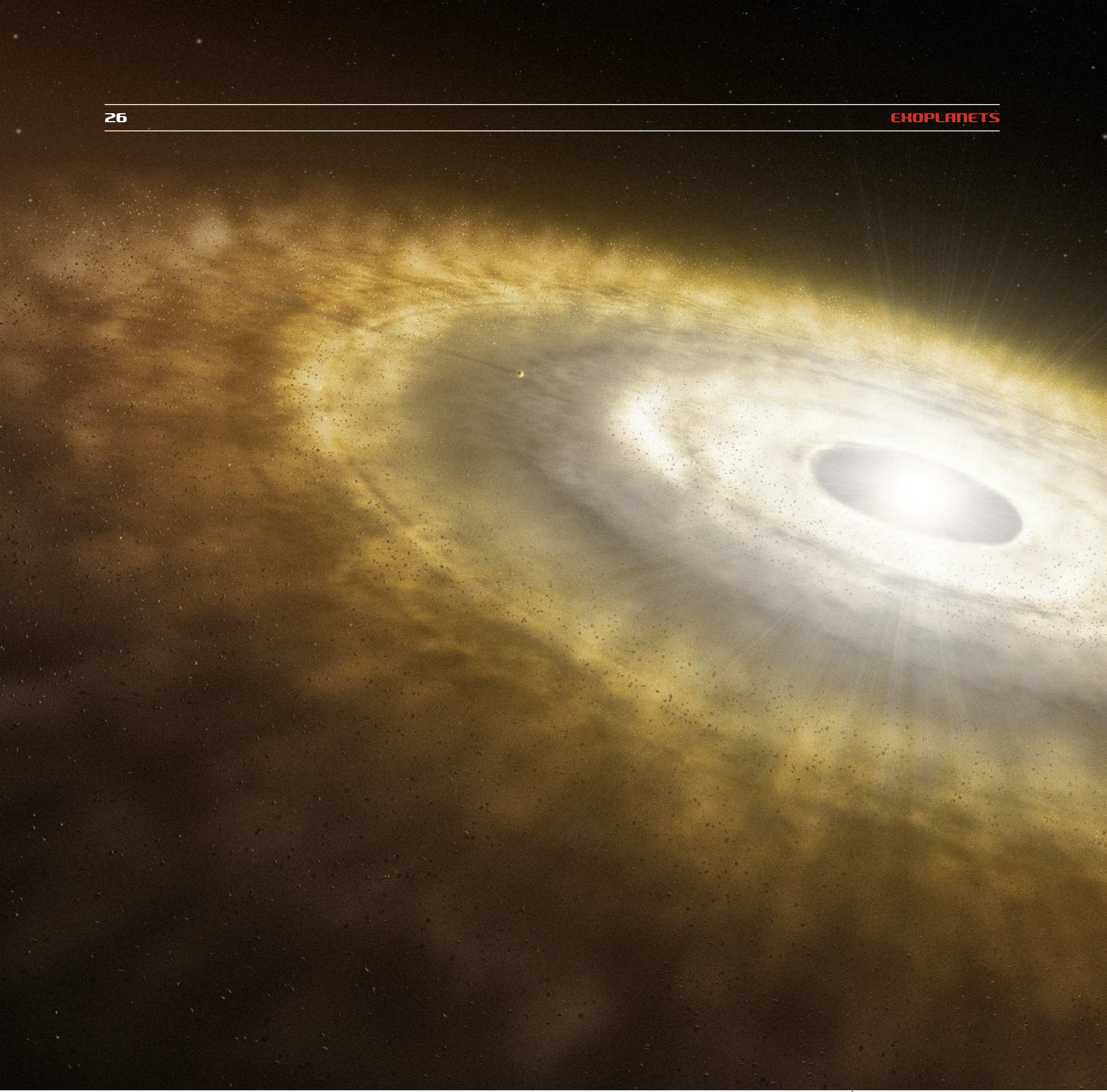
revised by Damian G. Allis
NASA Solar System Ambassador

Collisions between planets do not only occur in novels and science fiction movies. Astronomers have discovered that one of these catastrophic events occurred not too many years ago in a planetary system relatively close to us. Events of this kind also occurred in our solar system shortly after its formation, but the new findings indicate that planetary collisions can occur even in mature planetary systems.

A graphical representation of a catastrophic collision between two rocky exoplanets in the planetary system BD +20 307, which reduced both bodies to dusty debris. [NASA/SOFIA/Lynette Cook]

a
en

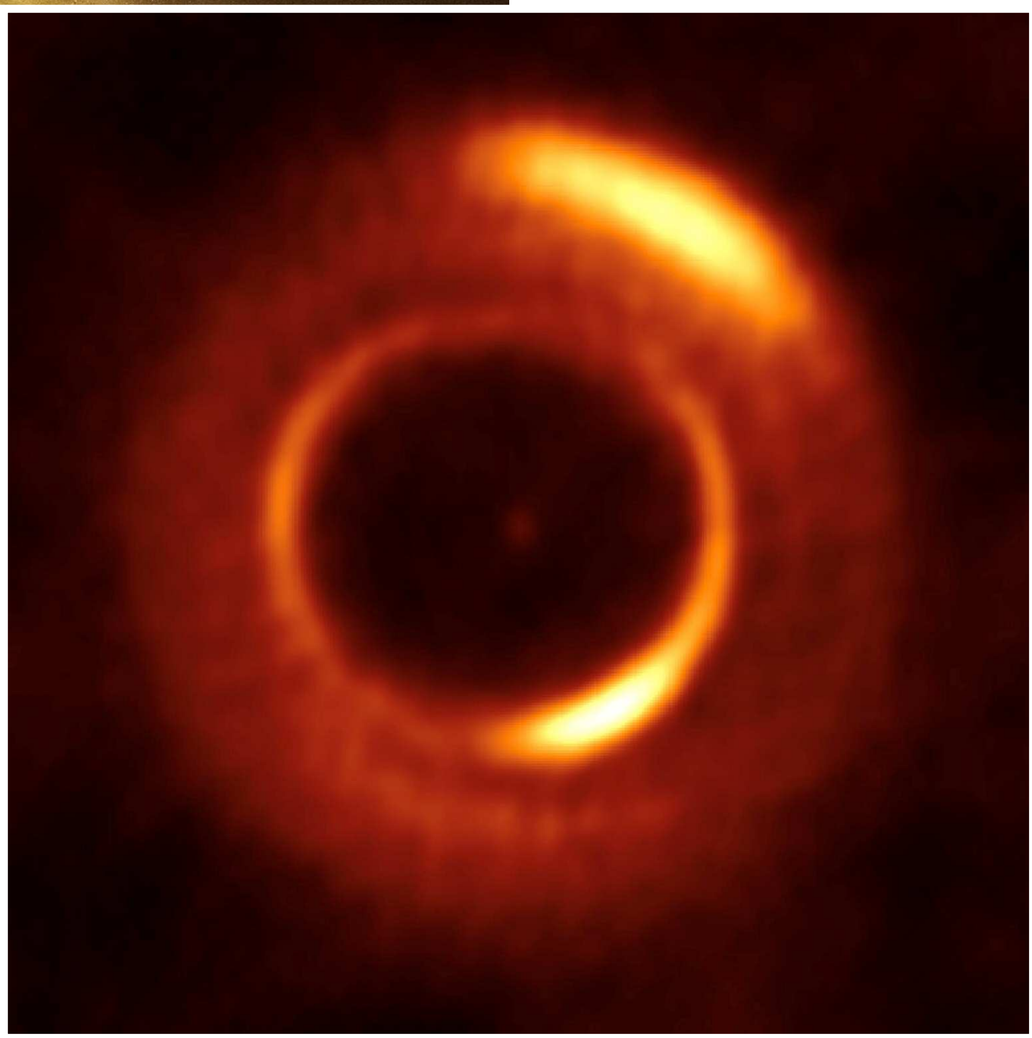
Nearly 400 light-years from Earth, in the constellation Aries, there is a very closely spaced star system, a so-called "spectroscopic binary," which has attracted the attention of astronomers for over a decade. That system is known as BD +20 307 and is composed of two solar-type stars orbiting around their common center-of-mass in 3.4 days. They are so close together that they could almost be considered a single star for the purposes of the existence and orbital stability of any planets.



Between 2004 and 2007, when BD +20 307 was still considered a single star, astronomers observed it in the infrared with highly sensitive instruments – including Keck and Gemini North in Hawaii, as well as the Spitzer space telescope.
The data collected showed the existence of a large disk of dusty debris around the star. The disk appeared unusually warm and, therefore, was brilliant in the infrared, but its presence and its temperature could only be explained by assuming that the star was extremely young, perhaps just a few million years old. In fact, it is normal to observe disks of debris and dust around younger stars, as their planetary system is still in formation. Only after tens or hundreds of millions of years, that scattered material runs out after being raked up by the formed planets, consumed by the star, confined to the periphery of the system, or dispersed by stellar radiation pressure.

A fantasy illustration of a protoplanetary disk. These types of structures are transitory and usually remain observable until the complete formation of a planetary system. [ESO/L. Calçada]

However, the idea astronomers had about a young BD +20 307 turned out to be incorrect at the beginning of 2008, when new observations of that star showed that in reality it was a binary system with an age of at least one billion years, if not even several billion years. At that point, it was evident that if the stars were surrounded by a dusty disk, that disk could only have been generated by a relatively recent event, considering that its temperature is around 420 K (almost 150° C), higher than the average for these structures. In the BD +20 307 system, the set of debris and dust that astronomers observed may have been generated solely through a couple of mechanisms: the colli-



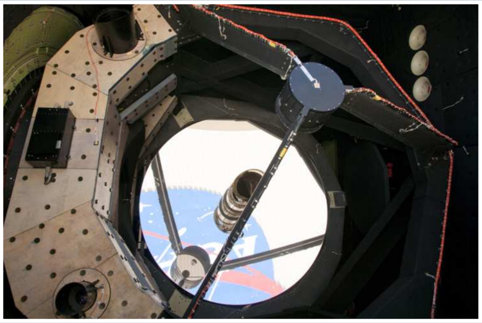
The protoplanetary disk surrounding the young star MWC 758. A similar structure was unexpectedly discovered around BD +20 307. [ALMA (ESO/NAOJ/NRAO)/Dong et al.]

sion between rocky planets within 1 AU of the stars, or the overheating of an ancient belt of cold dust caused either by its sliding towards the stars or by an increase in the flow of radiation emitted by one or both the stars themselves.

To find out the cause of that abnormal excess of infrared radiation, in 2011-2012, astronomers conducted further studies of BD +20 307 with the Herschel space telescope, and then again in 2015 with the airborne telescope SOFIA (acronym of Stratospheric Observatory for Infrared Astronomy). SOFIA is a 2.7-meter-diameter telescope housed inside a modified Boeing 747 and equipped with various scientific instruments working at infrared wavelengths. In particular, the observations carried out with the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST) provided the key to understanding the origin of the material surrounding BD +20 307.

The data collected by this instrument, in fact, showed an increase of approximately 10% in the infrared emissions between 8.8 and 12.5 microns in the last ten years, as compared to the first Spitzer measurements. Such significant growth in such a short timeframe is well

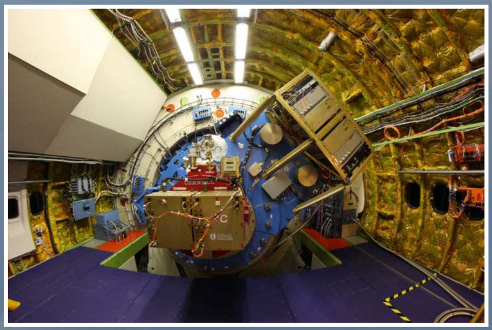
The SOFIA flying observatory, with the open tailgate that reveals the 2.7-meter-diameter telescope for infrared astronomy. With this instrument, the remnants of a collision between planets have been observed. [DLR/NASA]



On the left, a video presentation of SOFIA. At right, the mirror of the telescope housed in the fuselage of the Boeing 747. [DLR/NASA] suited to the scenario of a catastrophic planetary collision, whose fragments would continue to impact each other at each orbit, thereby increasing the amount of debris and dust. Heated by the pair of stars, this material would be directly responsible for the increased flow of infrared radiation, and only when the average size of the dust particles becomes so small as to make their heating negligible can we expect a decline in infrared light.

Data collected by SOFIA have merged into a study on BD +20 307 by Maggie Thompson (University of California, Santa Cruz), Alycia Weinberger (Carnegie Institution of Washington) and other researchers, whose results were published in *The Astrophysical Journal*. Here is what the authors write in their scientific paper: *"Typical debris disks*

Beside, the focal plane of the telescope, where the scientific instruments are placed. In the rightmost picture, you can see the Faint Object Infrared Camera used to investigate the dust of BD +20 307. [DLR/NASA]

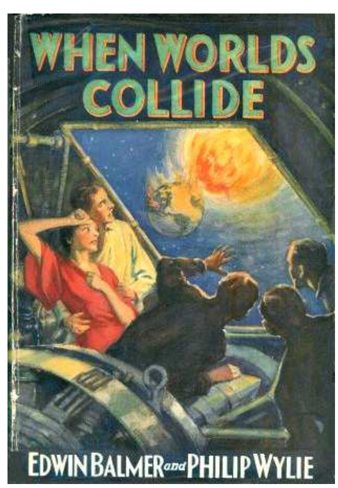


include leftover planetesimals and are thought to evolve through collisions or evaporation of solid bodies, ranging from small planetesimal to protoplanet/planet-sized. Just like the Solar System's Kuiper Belt located beyond the orbit of Neptune, most debris disks contain low-temperature dust (≤ 100 K) orbiting far from the host star. However, there exists a small class of known stars with unusually warm, dusty debris disks that serve as a key sample to probe in order to understand cascade models and extreme collisions that likely lead to the final configurations of planetary systems.
Collisional cascade, a process in which larger planetesimals in the disk collide and are continually broken up into smaller objects can explain most debris disks.
In a collisional cascade, small debris disks with warm dust do not last for very long because once the dust has reached a small enough size, removal mechanisms operate quickly, such as radiation pressure that blows the dust out of the system or Poynting-Robertson drag that causes dust particles to fall into the star."
BD +20 307, therefore, represents a rare opportunity to study the catastrophic collisions that probably occur in many planetary systems in the phases following their formation, perhaps simultaneously with the phenomenon of orbital migration.
According to the authors of the study: *"If the origin of the copious amount of warm dust orbiting BD +20 307 is an extreme collision between planetary-sized bodies, then this system may help unlock clues into planetary systems around binary stars, along with providing a glimpse into catastrophic collisions occurring late in a planetary system's history. Understanding BD +20 307 and other systems like it with extremely dusty debris disks could advance our knowledge of catastrophic collisions, the effects of binary stars on debris disks and the evolution of planetary systems."*
Indeed, the knowledge of systems like BD +20 307 can help us to trace the history of other star systems that are more interesting to us, such as the triple one of Alpha Centauri, where we know some planets exist. But the study of the collisional evolution of planetary systems can also be useful to bet-

The two main protagonists of the discovery of shattered planets around the double star BD +20 307: Maggie Thompson (with the pretty Rocket) on the left and Alycia Weinberger below.

Collisions between planets like the one that occurred in the BD +20 307 system also occurred in our own solar system, but not at such a late age. The most probable of these collisions (depicted above) gave rise to the Moon. [Gemini Observatory/ Lynette Cook] On the right, the cover of the first science fiction novel that described an impact between planets.

ter understand some catastrophic events that certainly occurred in our own solar system, which led to the formation of the Moon (as a consequence of an impact between the proto-Earth and a Mars-sized planet), the overturning of Uranus' rotation axis, and the probable expulsion of a gas giant. It is therefore clear that prolonged observations over time of hot dusty debris around solar-type mature stars is not only fundamental for understanding the evolution of those extrasolar systems, but it is also useful for describing with greater precision the evolutionary framework of our own solar system. If future observations of BD +20 307 reinforce the hypothesis of a clash between planets, once again science will have surpassed science fiction, which before could only imagine such a kind of event as in the novel *When Worlds Collide*, written in 1932 by Edwin Balmer and Philip Wylie, who tell about the clash between the Earth and a planet arrived from who knows where. Although decidedly imaginative in the plot, and even a bit naive in detail, that novel must have left its mark, as it was adapted for the big screen in 1951.

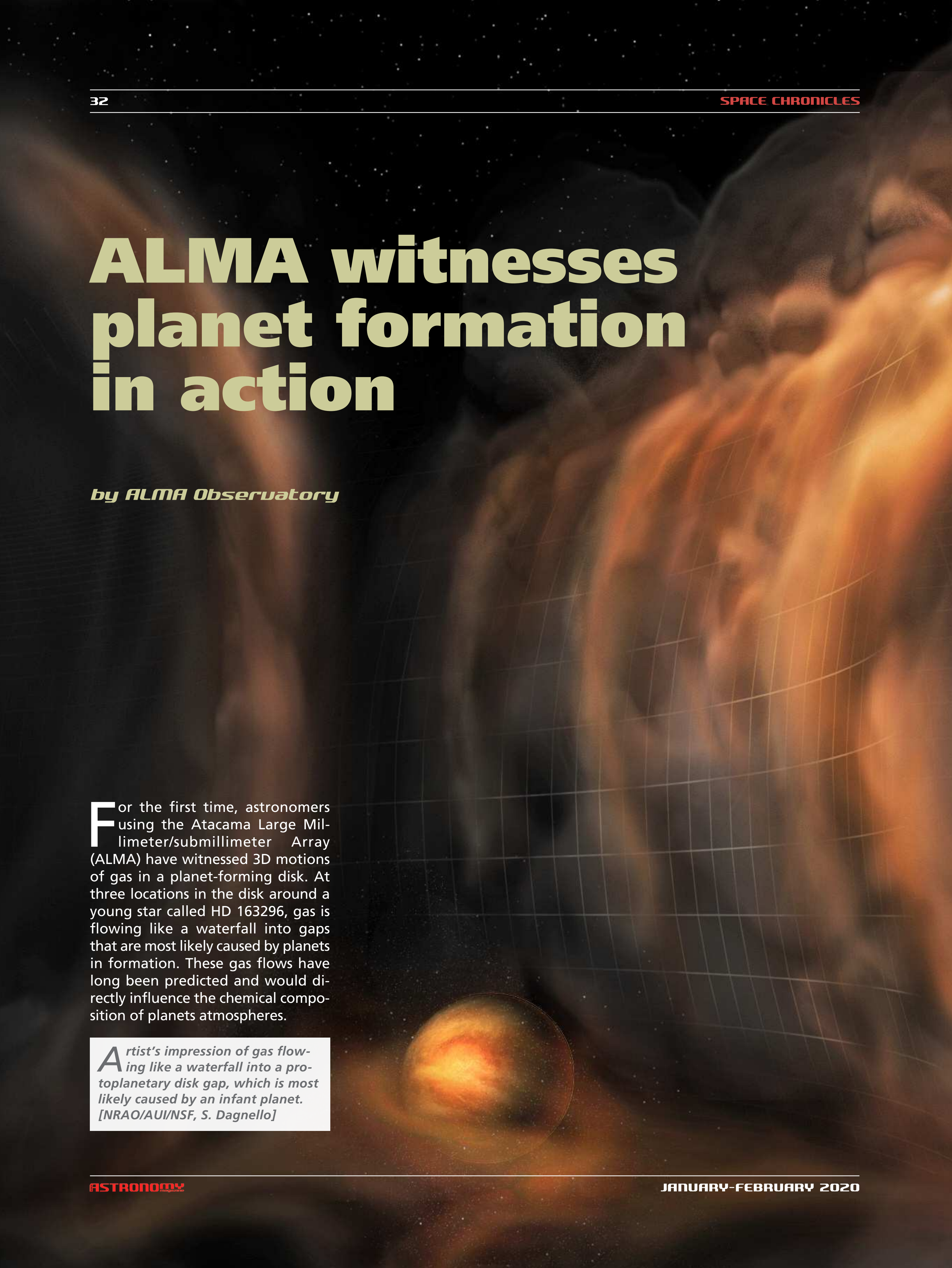


Curiously, in 1999, the alternative metal band Powerman 5000 re-used the title *When Worlds Collide* for its "masterpiece," thus demonstrating that there may be more disturbing things than the collision of planets... ■

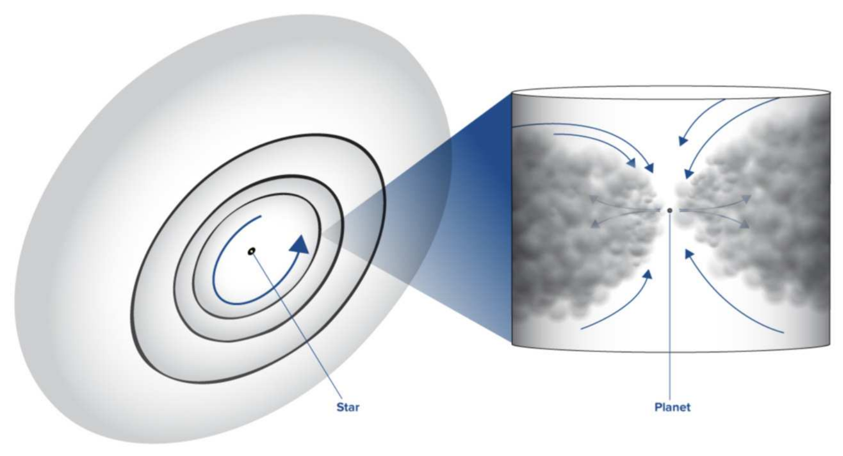
ALMA witnesses planet formation in action

by ALMA Observatory

For the first time, astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have witnessed 3D motions of gas in a planet-forming disk. At three locations in the disk around a young star called HD 163296, gas is flowing like a waterfall into gaps that are most likely caused by planets in formation. These gas flows have long been predicted and would directly influence the chemical composition of planets atmospheres.



Artist's impression of gas flowing like a waterfall into a protoplanetary disk gap, which is most likely caused by an infant planet. [NRAO/AUI/NSF, S. Dagnello]



Scientists measured the motion of gas (arrows) in a protoplanetary disk in three directions: rotating around the star, towards or away from the star, and up- or downwards in the disk. The inset shows a close-up of where a planet in orbit around the star pushes the gas and dust aside, opening a gap. [NRAO/AUI/NSF, B. Saxton]

The birthplaces of planets are disks made out of gas and dust. Astronomers study these so-called protoplanetary disks to understand the processes of planet formation. Beautiful images of disks made with ALMA show distinct gaps and ring features in the dust, which may be caused by infant planets.

To get more certainty that planets cause these gaps, and to get a complete view of planetary formation, scientists study the gas in the disks in addition to dust. Ninety-nine percent of a protoplanetary disk's mass is gas, of which carbon monoxide (CO) is the brightest component, and ALMA can observe it.

Last year, two teams of astronomers demonstrated a new planet-hunting technique using this gas. They measured the velocity of CO gas rotating in the disk around the young star HD 163296. Localized disturbances in the movements of the gas revealed three planet-like patterns in the disk. In this new study, lead author Richard Teague from the University of Michigan and his team used new high-resolution ALMA data from the Disk Substructures at High Angular Resolution Project (DSHARP) to study the gas's velocity in more detail. *"With the high-fidelity data from this program, we were able to measure the gas's velocity in three directions instead of just one,"* said Teague. *"For the first time, we measured the motion of the gas in every possible direction. Rotating around, moving towards or away from the star, and up or downwards in the disk."*

Teague and his colleagues saw the gas moving from the upper layers towards the middle of the disk at three different locations. *"What most likely happens is that a planet in orbit around the star pushes the gas and dust aside, opening a gap,"* Teague explained. *"The gas above the gap then collapses into it like a waterfall, causing a rotational flow of gas in the disk."*

This is the best evidence to date that there are indeed planets forming around HD 163296. But astronomers cannot say with one hundred percent certainty that planets cause the gas flows. For example, the star's

This animation shows the computer simulation of how the gas flows in the disk as a result of three planets in formation. [ALMA (ESO/NAOJ/NRAO), J. Bae; NRAO/AUI/NSF, S. Dagnello]

magnetic field could also cause disturbances in the gas. *"Right now, only direct observation of the planets could rule out the other options. But, the patterns of these gas flows are unique, and very likely, only planets can cause them,"* said coauthor Jaehan Bae of the Carnegie Institution for Science, who tested this theory with a computer simulation of the disk. The location of the three predicted planets in this study correspond to the results from last year. Their positions probably are at 87, 140, and 237 AU (An astronomical unit – AU – is the average distance from the Earth to the Sun). The closest planet to HD 163296 is calculated to be half the mass of Jupiter, the middle planet is Jupiter-mass, and the farthest planet is twice as massive as Jupiter.

Gas flows from the surface towards the midplane of the protoplanetary disk have been predicted since the late nineties. But this is the first time that astronomers observed them. Besides being useful to detect infant planets, these flows can also shape our understanding of how gas giant planets obtain their atmospheres.

"Planets form in the middle layer of the disk, the so-called midplane. This is a cold place, shielded from radiation from the star," Teague explained. *"We think that the gaps caused by planets bring in warmer gas from the more chemically active outer layers of the disk and that this gas will form the atmosphere of the planet."*

Teague and his team did not expect that they would be able to see this phenomenon. *"The disk around HD 163296 is the brightest and biggest disk we can see with ALMA,"* said Teague. *"But it was a big surprise to see these gas flows so clearly. The disks appear to be much more dynamic than we thought."*

"This gives us a much more complete picture of planet formation than we ever dreamed," said coauthor Ted Bergin of the University of Michigan. *"By characterizing these flows, we can determine how planets like Jupiter are born and characterize their chemical composition at birth. We might be able to use this to trace the birth location of these planets, as they can move during formation."* ■

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Hubble captures a dozen sunburst arc doppelgangers

by NASA/ESA

This new image from the NASA/ESA Hubble Space Telescope shows an astronomical object whose image is multiplied by the effect of strong gravitational lensing. The galaxy, nicknamed the Sunburst Arc, is almost 11 billion light-years away from Earth and has been lensed into multiple images by a massive cluster of galaxies 4.6 billion light-years away.

The mass of the galaxy cluster is large enough to bend and magnify the light from the more distant galaxy behind it. This process leads not only to a deformation of the light from the object, but also to a multiplication of the image of the lensed galaxy.

In the case of the Sunburst Arc the lensing effect led to at least 12 images of the galaxy, distributed over four major arcs. Three of these arcs are visible in the top right of the image, while one counterarc is visible in the lower left — partially obscured by a bright foreground star within the Milky Way.

Hubble uses these cosmic magnifying glasses to study objects otherwise too faint and too small for even its extraordinarily sensitive instruments. The Sunburst Arc is no exception, despite being one of the brightest gravitationally lensed galaxies known.

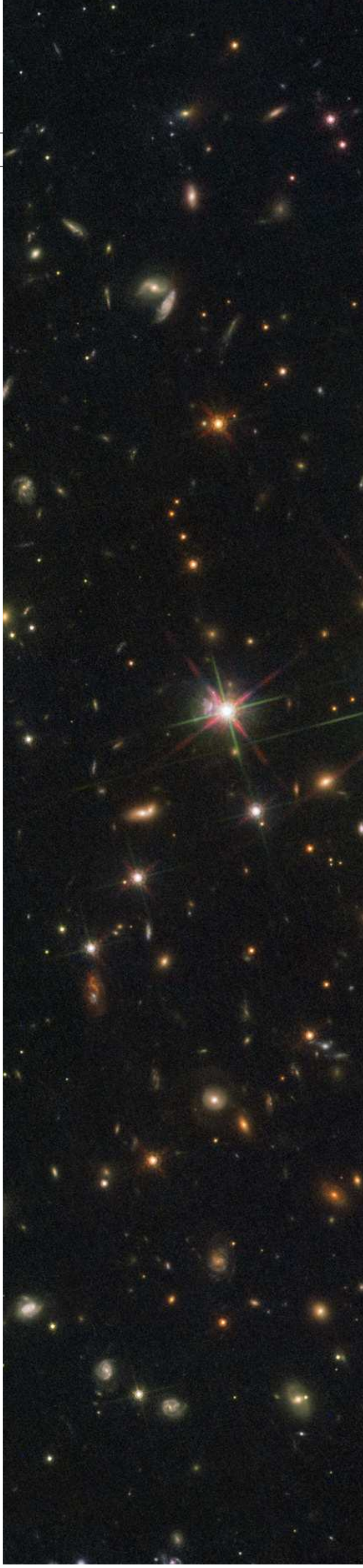
The lens makes various images of the Sunburst Arc between 10 and 30 times brighter. This allows Hubble to view structures as small as 520 light-years across — a rare detailed observation for an object that distant. This compares reasonably well with star forming regions in galaxies in the local Universe, allowing astronomers to study the galaxy and its environment in great detail.

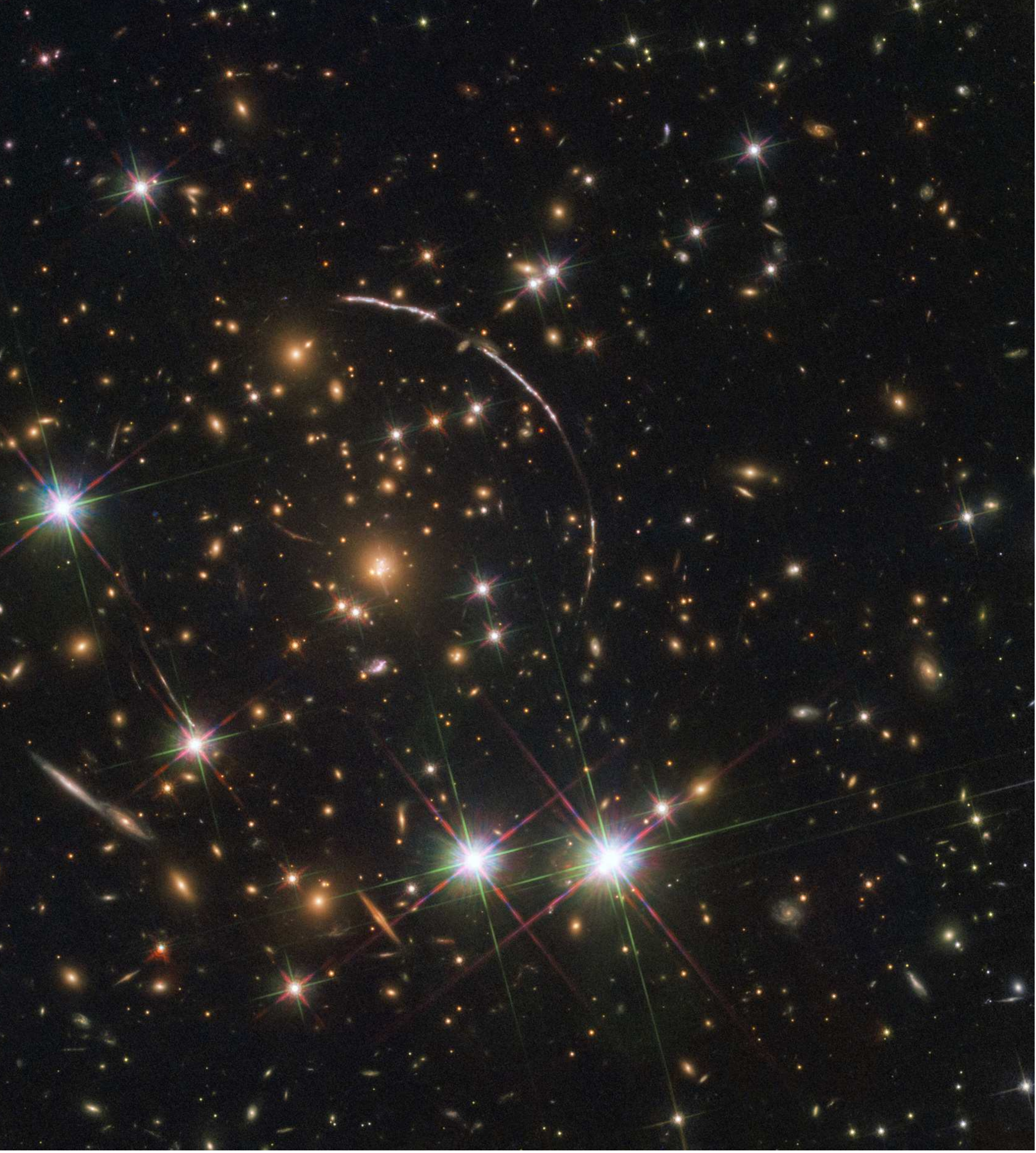
Hubble's observations showed that the Sunburst Arc is an analogue of galaxies which existed at a much earlier time in the history of the Universe: a period known as the epoch of reionisation — an era which began only 150 million years after the Big Bang.

The epoch of reionisation was a key era in the early Universe, one which ended the "dark ages", the epoch before the first stars were created when the Universe was dark and filled with neutral hydrogen.

Once the first stars formed, they started to radiate light, producing the high-energy photons required to ionise the neutral hydrogen.

This converted the intergalactic matter into the mostly ionised form in which it exists today. However, to ionise intergalactic hydrogen, high-energy radiation from these early stars would have had to escape their host galaxies without first being absorbed by interstellar matter. So far only a small number of galaxies have been found to "leak" high-energy photons into deep space. How this light escaped from the early galaxies remains a mystery.





The analysis of the Sunburst Arc helps astronomers to add another piece to the puzzle — it seems that at least some photons can leave the galaxy through narrow channels in a gas rich neutral medium. This is the first observation of a long-theorised process. While this process is unlikely to be the main mechanism that led the Universe to become reionised, it may very well have provided a decisive push.

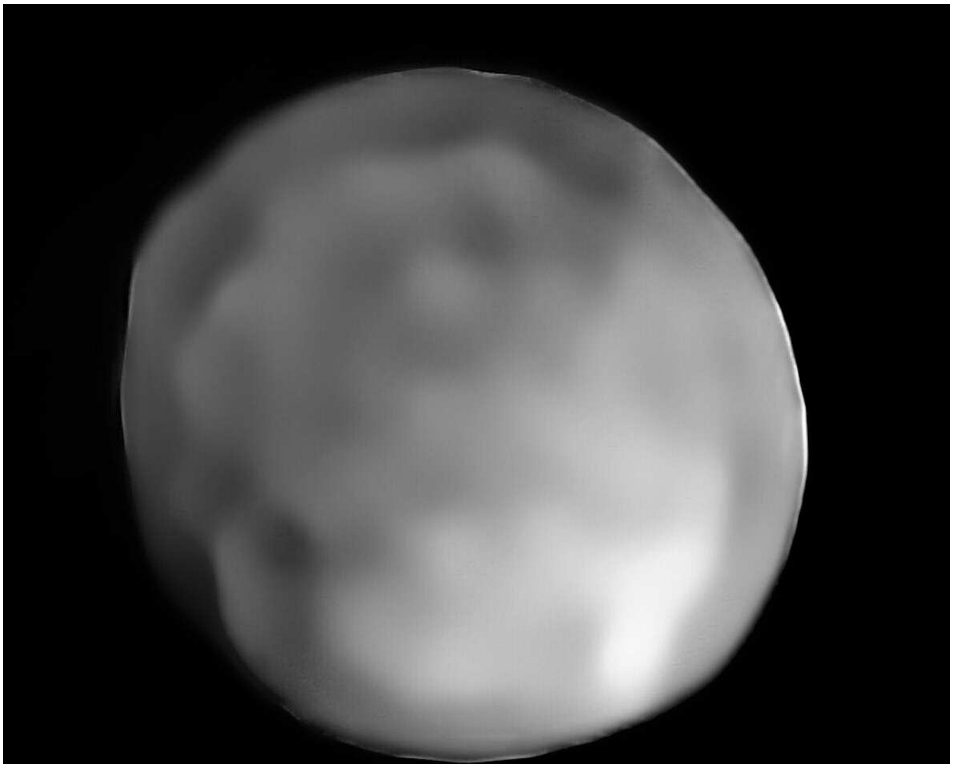
The smallest dwarf planet yet in the Solar System

by ESO

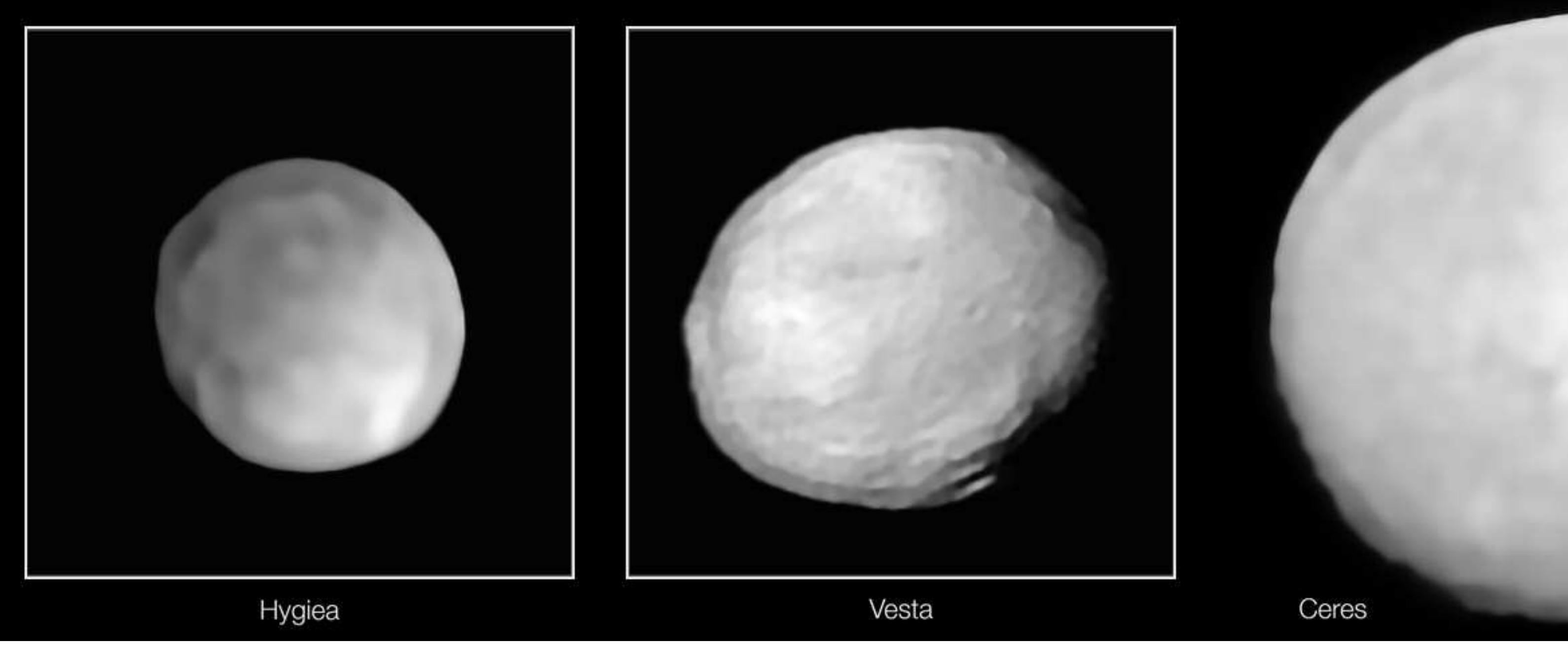
Astronomers using ESO's SPHERE instrument at the Very Large Telescope (VLT) have revealed that the asteroid Hygiea could be classified as a dwarf planet. The object is the fourth largest in the asteroid belt after Ceres, Vesta and Pallas. For the first time, astronomers have observed Hygiea in sufficiently high resolution to study its surface and determine its shape and size. They found that Hygiea is spherical, potentially taking the crown from Ceres as the smallest dwarf planet in the Solar System.

As an object in the main asteroid belt, Hygiea satisfies right away three of the four requirements to be classified as a dwarf planet: it orbits around the Sun, it is not a moon and, unlike a planet, it has not cleared the neighbourhood around its orbit. The final requirement is that it has enough mass for its own gravity to pull it into a roughly spherical shape. This is what VLT observations have now revealed about Hygiea.

"Thanks to the unique capability of the SPHERE instrument on the VLT, which is one of the most powerful imaging systems in the world, we could resolve Hygiea's shape, which turns out to be nearly spherical," says lead researcher Pierre Vernazza from the Laboratoire d'Astrophysique de Marseille in France. *"Thanks to these images, Hygiea may be reclassified as a dwarf planet, so far the smallest in the Solar System."* The team also used the SPHERE observations to constrain Hygiea's size, putting its diameter at just over 430 km.



This is what VLT observations have now revealed about Hygiea. [ESO/P. Vernazza et al./ MISTRAL algorithm (ONERA/CNRS)]



New observations with ESO's SPHERE instrument on the Very Large Telescope have revealed that the surface of Hygiea lacks the very large impact crater that scientists expected to see on its surface. Since it was formed from one of the largest impacts in the history of the asteroid belt, they were expecting to find at least one large, deep impact basin, similar to the one on Vesta (bottom right in the central panel). The new study also found that Hygiea is spherical, potentially taking the crown from Ceres as the smallest dwarf planet in the Solar System. The team used the SPHERE observations to constrain Hygiea's size, putting its diameter at just over 430 km, while Ceres is close to 950 km in size. [ESO/P. Vernazza et al., L. Jorda et al./MISTRAL algorithm (ONERA/CNRS)]

Pluto, the most famous of dwarf planets, has a diameter close to 2400 km, while Ceres is close to 950 km in size. Surprisingly, the observations also revealed that Hygiea lacks the very large impact crater that scientists expected to see on its surface, the team report in the study published today in *Nature Astronomy*.

Hygiea is the main member of one of the largest asteroid families, with close to 7000 members that all originated from the same parent body. Astronomers expected the event that led to the formation of this numerous family to have left a large, deep mark on Hygiea.

"This result came as a real surprise as we were expecting the presence of a large impact basin, as is the case on Vesta," says Vernazza.

Although the astronomers observed Hygiea's surface with a 95% coverage, they could only identify two unambiguous craters. *"Neither of these two craters could have been caused by the impact that originated the Hygiea family of asteroids whose volume is comparable to that of a 100 km-sized object. They are too small,"* explains study co-author Miroslav Brož of the Astronomical Institute of Charles University in Prague, Czech Republic.

The team decided to investigate further. Using numerical simulations, they deduced that Hygiea's spherical shape and large family of asteroids are likely the result of a major head-on collision with a large projectile of diameter between 75 and 150 km. Their simulations show this violent impact, thought to have occurred about 2 billion years ago, completely shattered the parent body. Once the left-over pieces reassembled, they gave Hygiea its round shape and thousands of companion asteroids. *"Such a collision between two large bodies in the asteroid belt is unique in the last 3–4 billion years,"* says Pavel Ševeček, a PhD student at the Astronomical Institute of Charles University who also participated in the study.

Studying asteroids in detail has been possible thanks not only to advances in numerical computation, but also to more powerful telescopes.

"Thanks to the VLT and the new generation adaptive-optics instrument SPHERE, we are now imaging main belt asteroids with unprecedented resolution, closing the gap between Earth-based and interplanetary mission observations," Vernazza concludes. ■

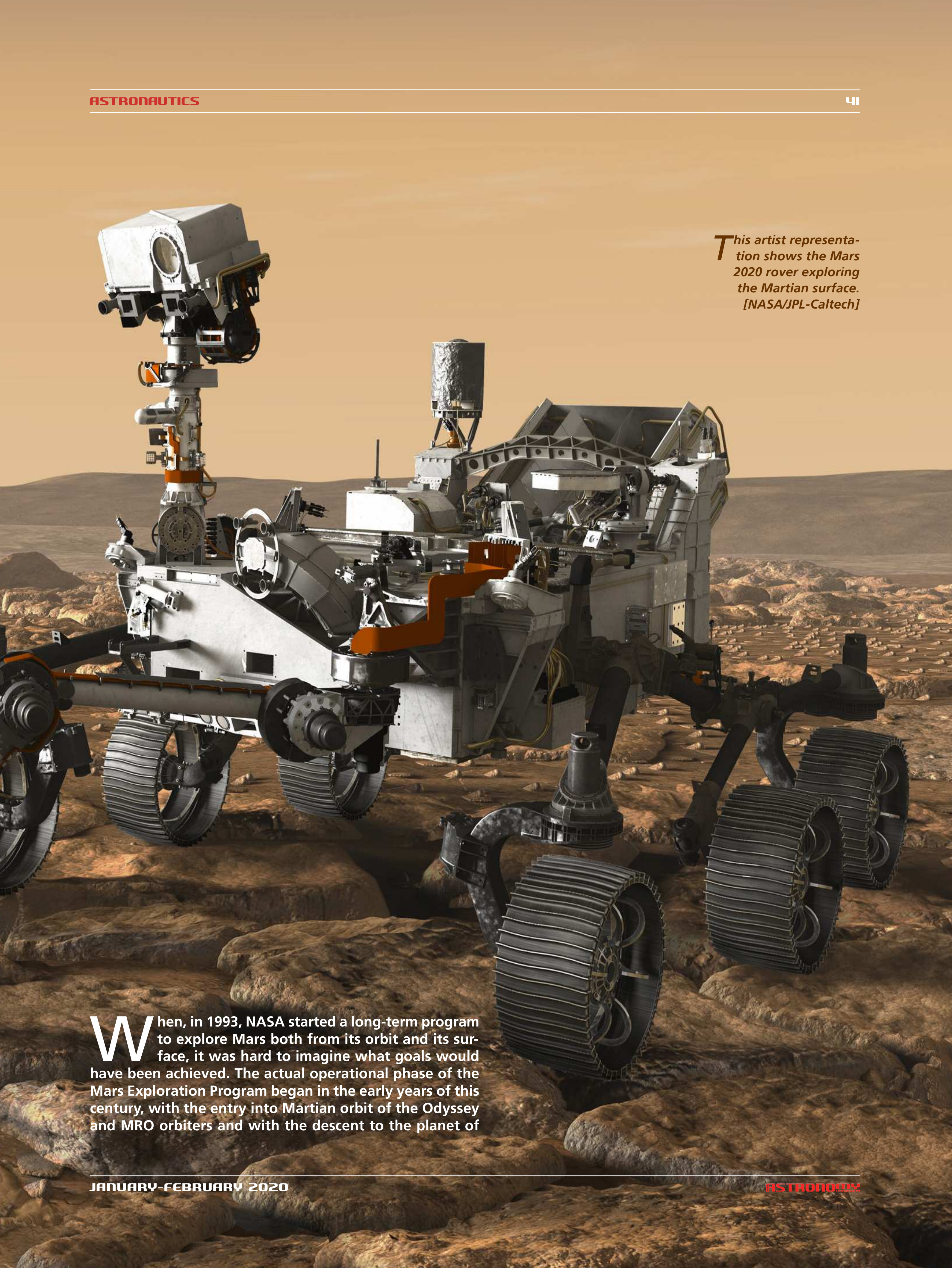
Computational simulation of the fragmentation and reassembly that led to the formation of Hygiea and its family of asteroids, following an impact with a large object. While changes in the shape of Hygiea occur after the impact, the dwarf-planet candidate eventually acquires a round shape. [P. Ševeček/Charles University]

Mars 2020 will land in Jezero Crater

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

While waiting to see the ESA's ExoMars 2020 mission rover in action, let's get ready for the next NASA mission, Mars 2020, which will see a rover hunt for traces of possible fossil life inside an impact crater that, billions of years ago, housed a lake into which a river delta poured. The conditions for epochal discoveries are there, we just have to be patient.



This artist representation shows the Mars 2020 rover exploring the Martian surface. [NASA/JPL-Caltech]

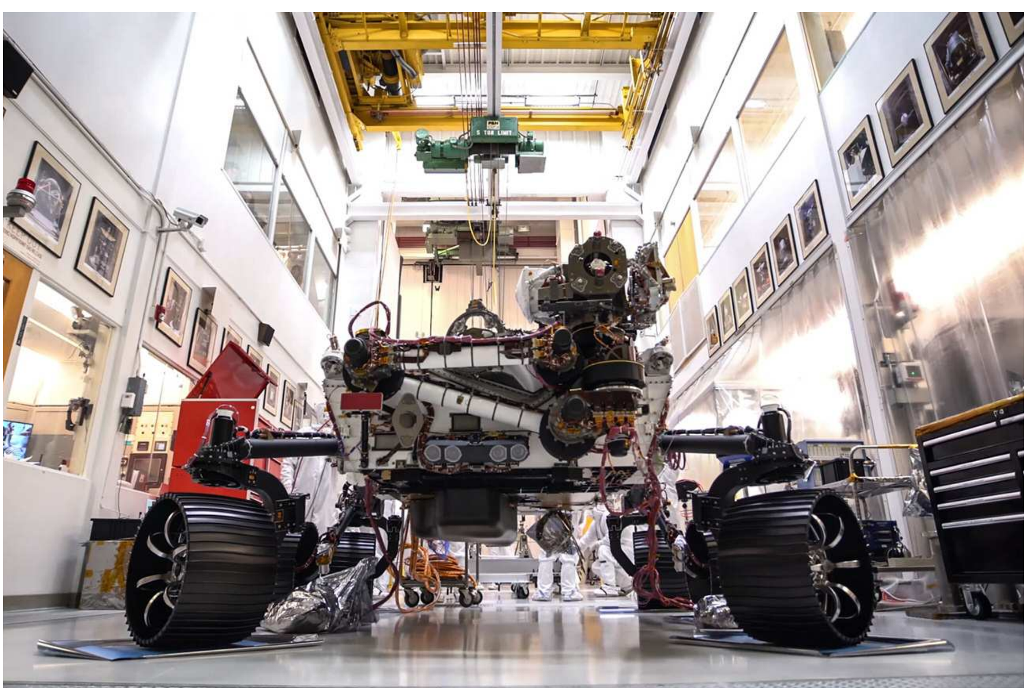
When, in 1993, NASA started a long-term program to explore Mars both from its orbit and its surface, it was hard to imagine what goals would have been achieved. The actual operational phase of the Mars Exploration Program began in the early years of this century, with the entry into Martian orbit of the Odyssey and MRO orbiters and with the descent to the planet of

the Spirit and Opportunity rovers. Subsequently, other protagonists were added: Curiosity, MAVEN and InSight. All of these missions have revolutionized our knowledge of the red planet, and they have shown us a much more dynamic and fascinating world than previously believed.

The goals of the Mars Explorer Program are essentially four. The first goal is to understand if Mars ever hosted life and, if it did, to verify if life is still present there. The fact that, in the first billion years of the Solar System, Earth and Mars were much more similar to one another than they are today does authorize moderate optimism. However, none of the Mars missions so far carried out have had technology suitable to give a definitive answer to this issue, and therefore the first goal has yet to be achieved.

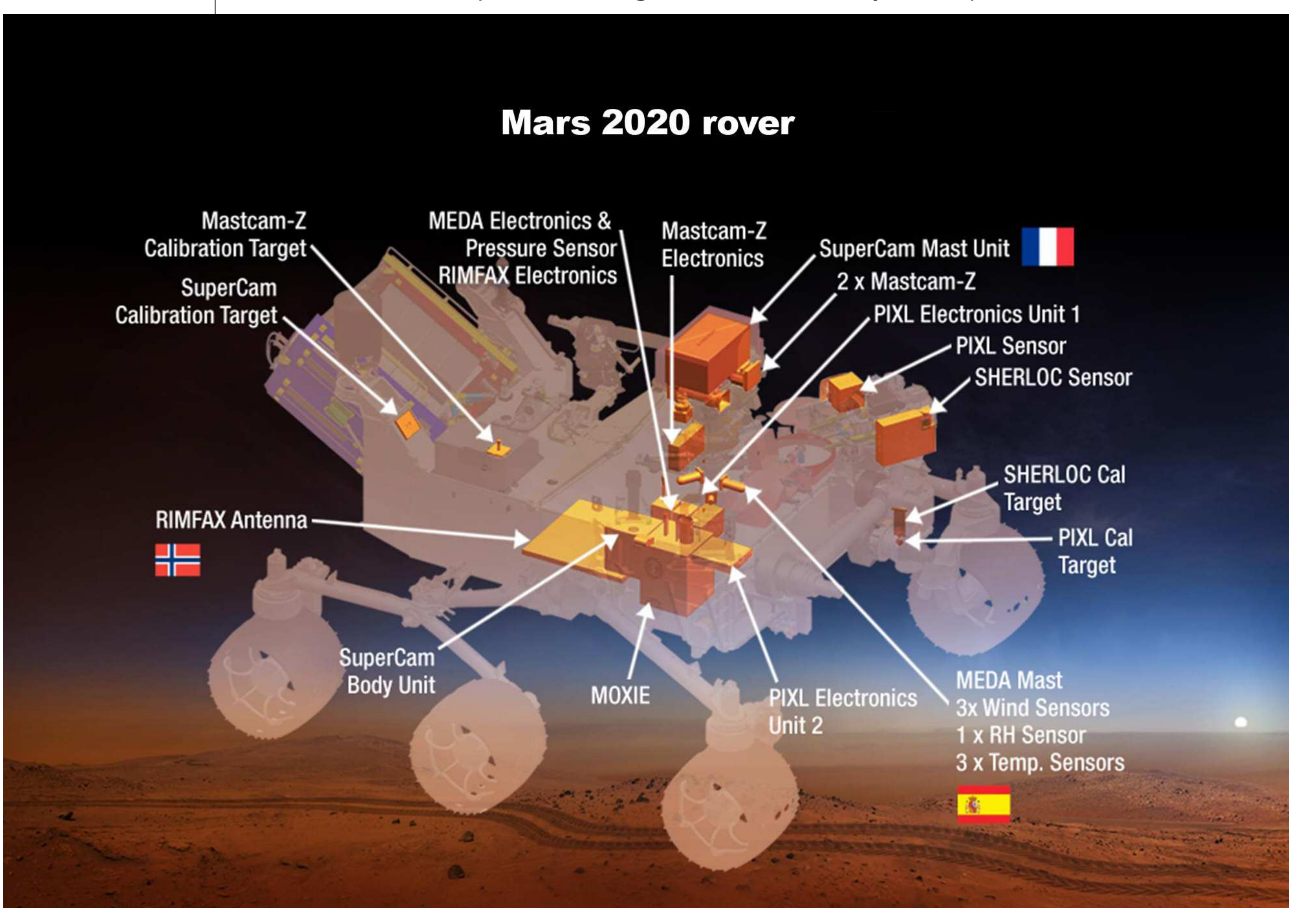
At least partially already achieved are the second goal, which concerns the understanding of the history and processes of the Martian climate, and the third goal, which aims to understand the origin and evolution of the planet as a geological system. The fourth and final goal is to set the conditions

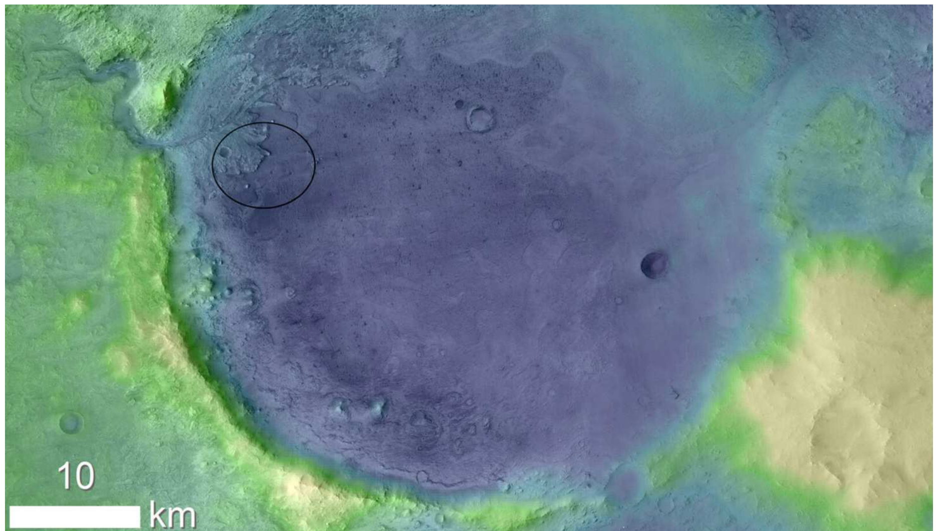
The Mars 2020 rover during the final setup and in the Martian environment simulator. [NASA/JPL-Caltech]



In the diagram below, some instruments with which the Mars 2020 rover will analyze the surface of Jezero Crater are highlighted. [NASA/ JPL-Caltech]

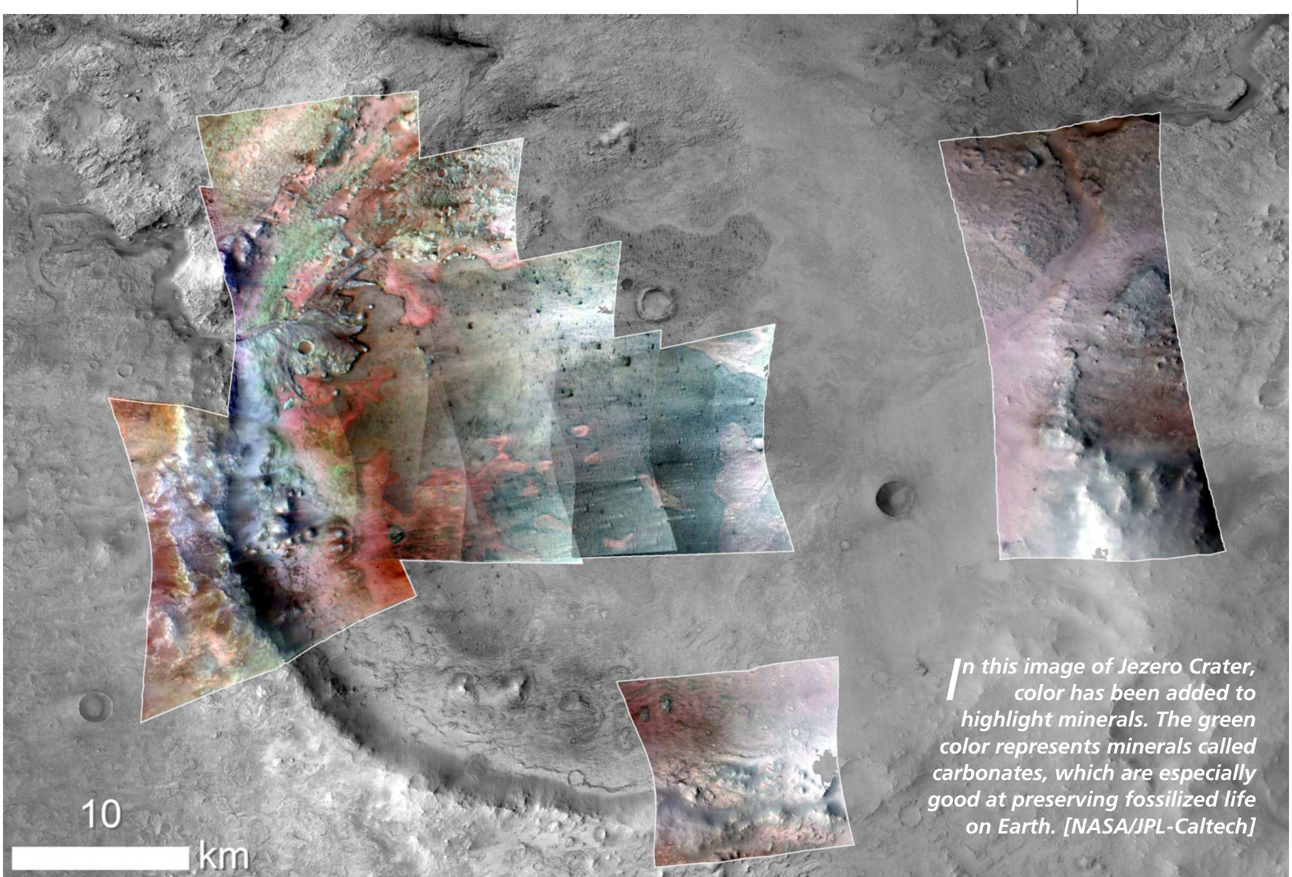
for the human exploration of Mars, taking advantage of the technological experience gained through robotic missions.
Regardless of the levels of climate and geology knowledge that will be attained in the coming years, it is easy to predict that the timing of the human exploration of Mars will be determined by the results obtained within the first goal of the exploration program.
Until we have very convincing clues of the possible absence of life on Mars, it is unlikely that astronauts will be sent to perform activities that machines can already do with lower costs, fewer risks and in less time. If instead, in the near future, a robot discovers fossil traces of possible biological activities, human mission planning would then undergo a rapid acceleration.
The next Mars Exploration Program mission, temporarily called Mars 2020, could be discriminating in this regard. It will be launched next July and will reach its destination in February 2021. The protagonist will be a new rover, derived from the Curiosity project (with which it will share many components), but further developed and equipped with cutting-edge research instruments, including a core drill and a small helicopter similar to a drone.
The substantial difference between the Curiosity rover and the one for Mars 2020 is the fact that the latter, through the SHERLOC spectrometer (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals), will be able to both identify a series of biosignatures typical of microbial life and to assess the conditions of habitability in the history of the planet.



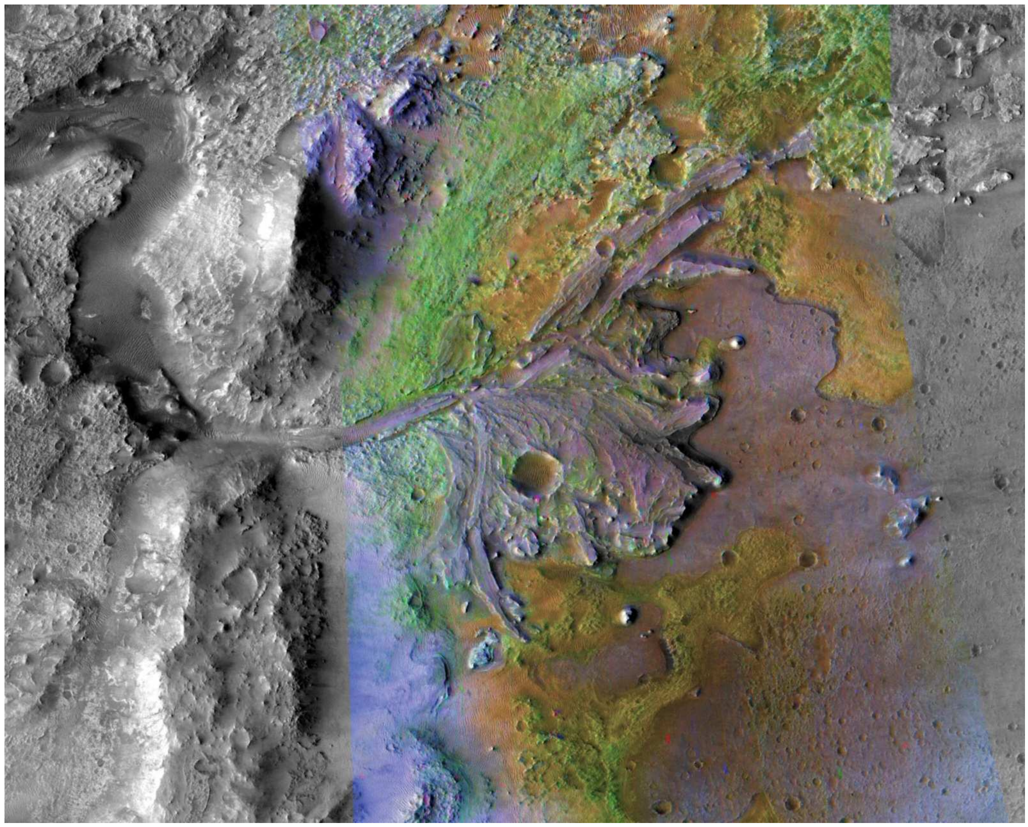


In this image of the Jezero crater, the landing site of the NASA Mars 2020 mission, the lightest colors represent a greater elevation. The oval indicates the landing ellipse, where the rover will touch the Martian soil. [NASA/JPL-Caltech]

To take full advantage of the new rover's capabilities, part of the mission team has spent the last five years searching for the ideal landing site, the one that more than any other may have previously been an optimal habitat for possible forms of elementary life. The selection was carried out by analyzing the data recorded by the CRISM (Compact Reconnaissance Imaging Spectrometers for Mars) instrument onboard the MRO. The attentions of the selectors have focused on the weak spectral



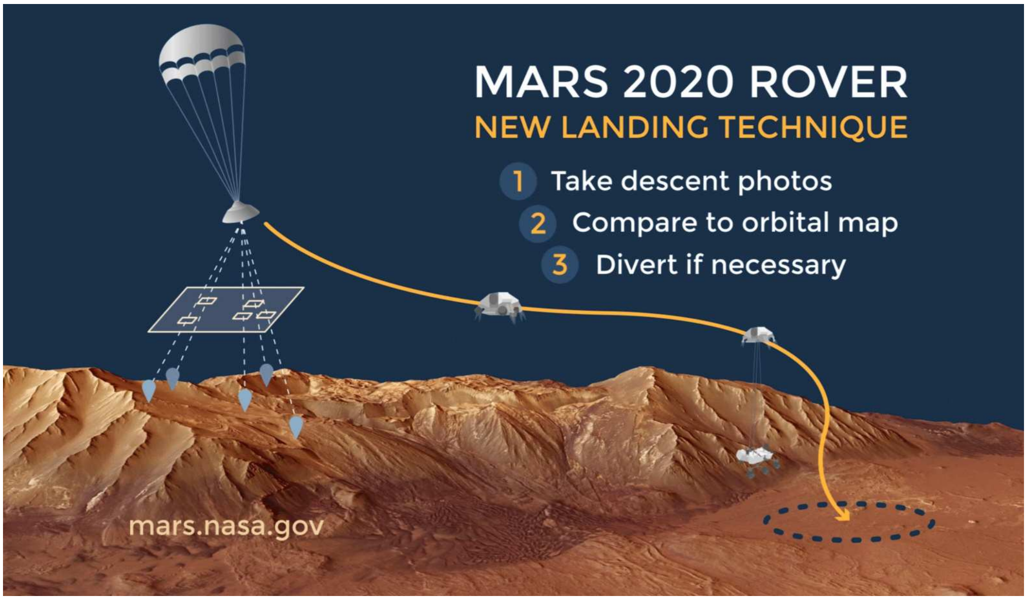
In this image of Jezero Crater, color has been added to highlight minerals. The green color represents minerals called carbonates, which are especially good at preserving fossilized life on Earth. [NASA/JPL-Caltech]



On ancient Mars, water carved channels and transported sediments to form fans and deltas within lake basins. Examination of spectral data acquired from orbit show that some of these sediments have minerals that indicate chemical alteration by water. Here in the Jezero Crater delta, sediments contain clays and carbonates. [NASA/JPL/JHUAPL/MSSS/Brown University] Below, a false-color image of Jezero Crater shows the edge of an ancient river delta where researchers have spied hydrated silica, a mineral that's especially good at preserving microfossils and other signs of past life. [NASA]

signatures of hydrated silica deposits (a typical clay compound) and carbonate deposits (minerals formed by the interaction between water and carbon dioxide). These minerals are very effective at preserving biosignatures and microfossils. As a result, a rover capable of analyzing the soil and subsoil of sites in which hydrated silica and carbonates abound is more likely to recognize clues of past life.

In the final stages of landing site selection, the mission team and the planetary science community considered over 60 candidates, concluding that the most promising destination for the Mars 2020 rover is Jezero Crater. This 28-mile-wide crater is located on the western edge of Isidis Planitia, a huge impact basin visible just north of the Martian equator. In that part of Isidis Planitia are some of the oldest and scientifically interesting geological structures on the planet. Observations made by the orbiters suggest that the Jezero Crater depression was, in very remote times, occupied by a lake into which a delta flowed. Thus, the lake may have collected and preserved organic molecules and potential traces of microbial life present in both the water and



Mars 2020 has major new technologies that improve entry, descent, and landing, as highlighted in this animation. [NASA] Below, this artist's concept depicts NASA's Mars 2020 rover at work on the surface of Mars. [NASA/JPL-Caltech]

debris that spilled into the crater. Here is what Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate, said in this regard: *"The landing site in Jezero Crater offers geologically rich terrain, with landforms reaching as far back as 3.6 billion years old, that could potentially answer important questions in planetary evolution and astrobiology. Getting samples from this unique area will revolutionize how we think about Mars and its ability to harbor life."* According to the mission team, there are at least five different types of rock in Jezero Crater that may represent interesting targets to sample, simply because they include hydrated silica and carbonates. *"Using a technique we developed that helps us find rare, hard-to-detect mineral phases in data taken from orbiting spacecraft, we found two outcrops of hydrated silica within Jezero crater. We know from Earth that this mineral phase is exceptional at preserving microfossils and other biosignatures, so that makes these outcrops exciting targets*

This artist concept and the side video show the Mars Helicopter, a small, autonomous rotorcraft that will travel with NASA's Mars 2020 rover mission to demonstrate the viability and potential of heavier-than-air vehicles on the red planet. [NASA/JPL-Caltech]

for the rover to explore," added Jesse Tarnas, a Ph.D. student at Brown University and the study's lead author.

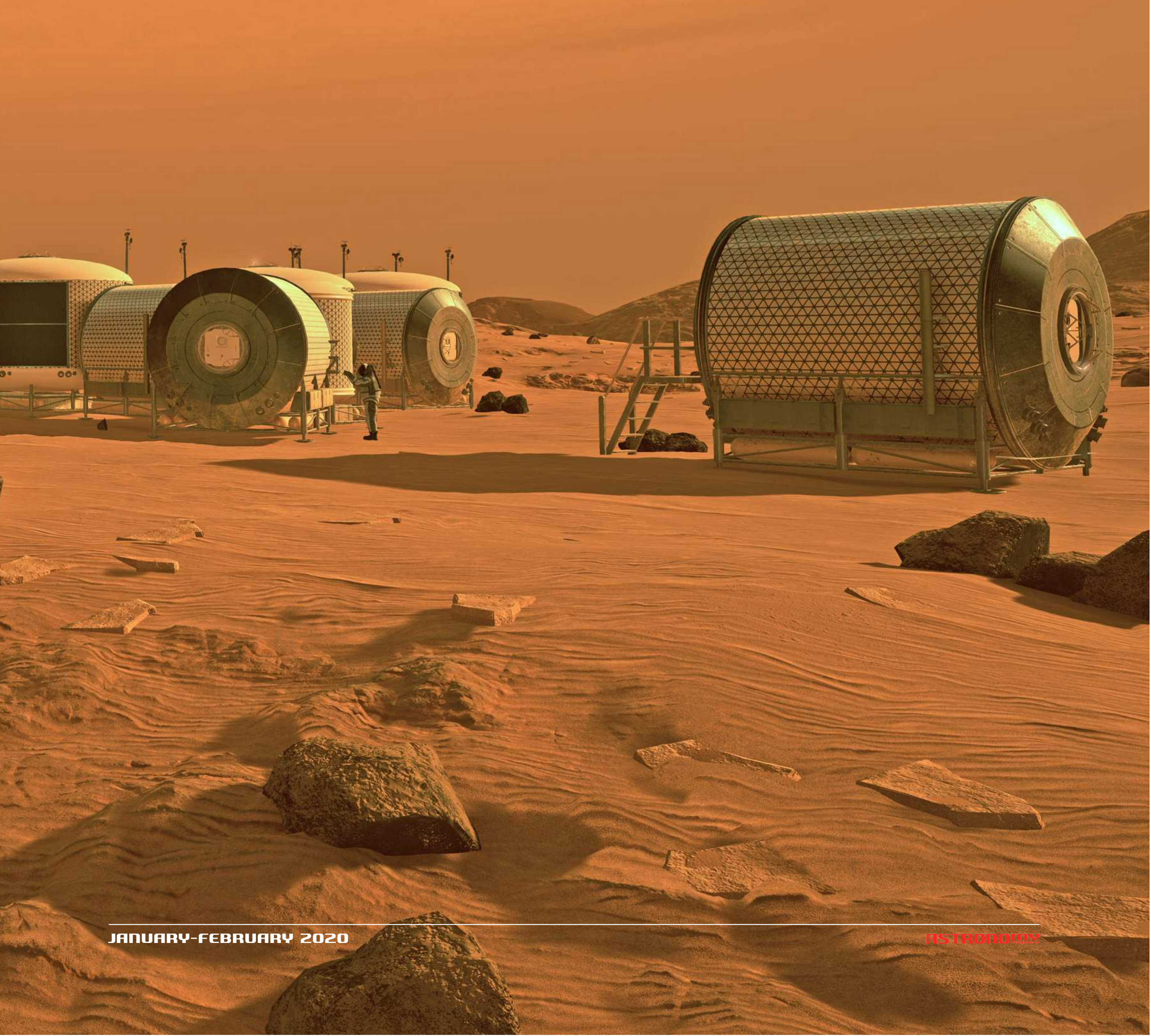
Among the hydrated silica deposits known today, there is one that should be easily accessible to the rover, being at low elevation in the river delta. Given the position of this deposit, it is possible that it is part of the bottommost layer of the delta itself, an ideal scenario for the preservation of any clues of past life, as recalled by Jack Mustard, a professor at Brown and study co-author: *"The material that forms the bottom layer of a delta is sometimes the most productive in terms of preserving biosignatures. So if you can find that bottomset layer, and that layer has a lot of silica in it, that's a double bonus."*

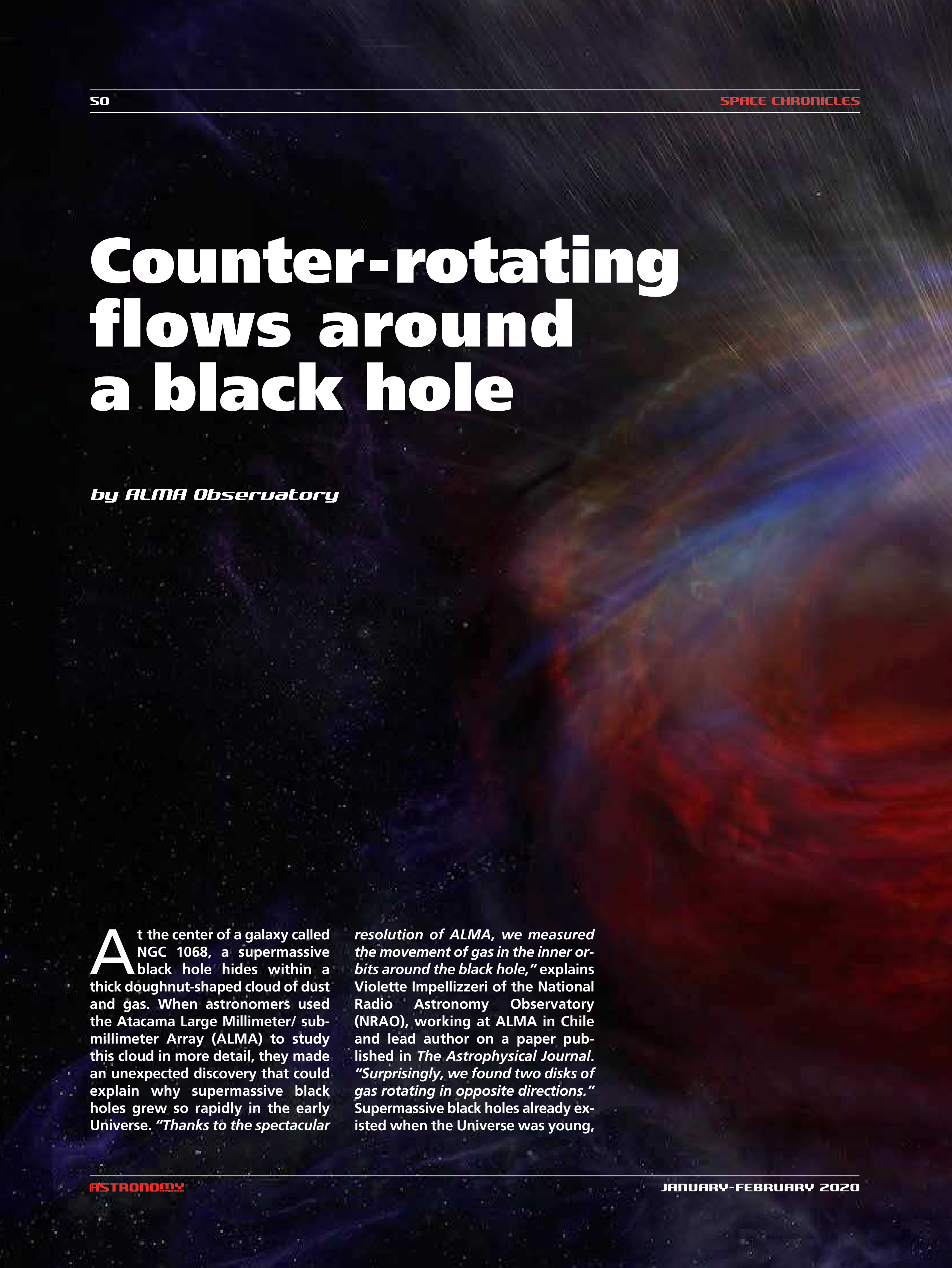
Carbonate distribution is equally interesting. A recent work published in November in the journal *Icarus* (Briony H.N. Horgan et al., 2019) highlighted concentrations of carbonates that seem to draw shorelines within Jezero Crater, as if to indicate the level of water that filled the crater for a long period of time. On our planet, scenar-

ios like this (carbonates, shallow water, sunlight) were the basis for the development of many life forms, whose fossil relics have been found precisely in deposits comparable to those within the inner edge of Jezero Crater.
Even if the Martian carbonates do not contain traces of fossil life, their close study will be useful for understanding how the planet passed from having expanses of surface water and a thick atmosphere to being the frozen desert it is today. If it were possible to study carbonates at different elevations, we would be able to understand how the interaction between water and carbon dioxide has changed over time. In this sense, carbonates are a kind of time capsule, and opening this capsule will reveal much more about why and over what amount of time Mars became so dry.

An imaginary scene showing astronauts and settlements on Mars. The Mars 2020 rover will carry many new technologies that will make future human exploration easier and safer. [NASA]

The landing of the Mars 2020 rover in Jezero Crater, however, will not occur with the relative ease of Curiosity rover in Gale Crater. In fact, the region of Jezero is much rougher terrain and requires a higher precision than that of any previous EDL (entry, descent, landing) phase. Nevertheless, recent technological advances allow for landings in an area 50% smaller than the one requested by Curiosity at the time, and therefore it is possible to approach more demanding sites without excessive risk. Furthermore, the landing device of the new rover is equipped with an instrument called Terrain Relative Navigation, which will assess the presence of unexpected obstacles (rocks, cliffs, fractures, etc.) at different altitudes and will independently make the necessary corrections to the trajectory for a safe landing. ■





Counter-rotating flows around a black hole

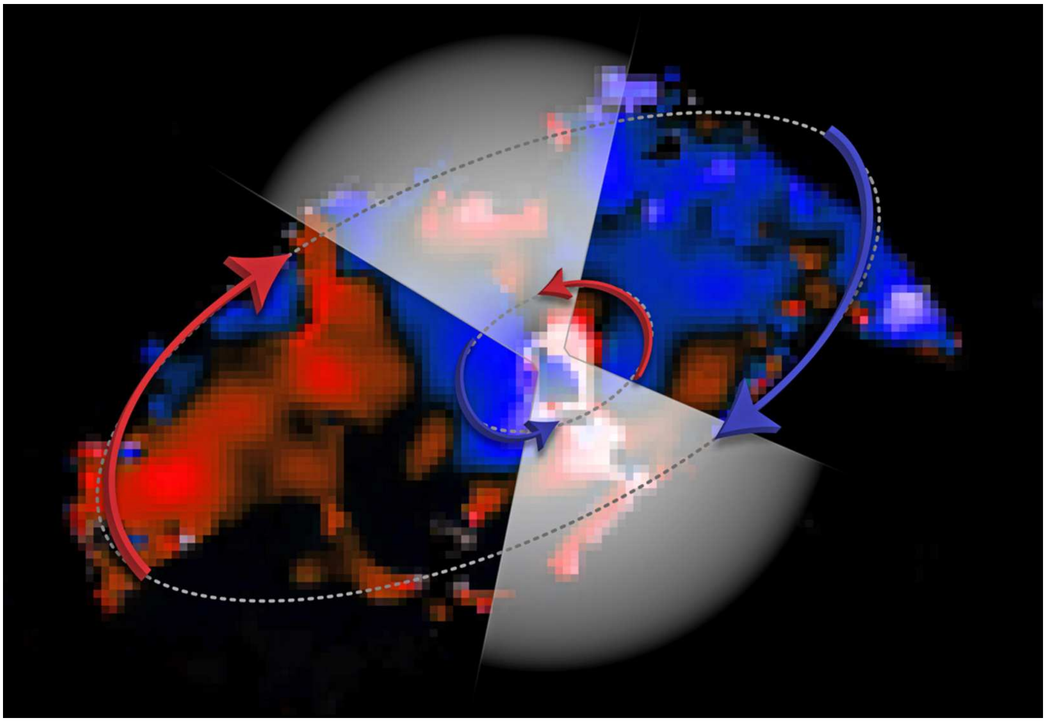
by ALMA Observatory

At the center of a galaxy called NGC 1068, a supermassive black hole hides within a thick doughnut-shaped cloud of dust and gas. When astronomers used the Atacama Large Millimeter/ submillimeter Array (ALMA) to study this cloud in more detail, they made an unexpected discovery that could explain why supermassive black holes grew so rapidly in the early Universe. *"Thanks to the spectacular resolution of ALMA, we measured the movement of gas in the inner orbits around the black hole,"* explains Violette Impellizzeri of the National Radio Astronomy Observatory (NRAO), working at ALMA in Chile and lead author on a paper published in *The Astrophysical Journal*. *"Surprisingly, we found two disks of gas rotating in opposite directions."* Supermassive black holes already existed when the Universe was young,

just a billion years after the Big Bang. But how these extreme objects, whose masses are up to billions of times the mass of the Sun, had time to grow so fast, is an outstanding question among astronomers.

Artist impression of the heart of galaxy NGC 1068, which harbors an actively feeding supermassive black hole, hidden within a thick doughnut-shaped cloud of dust and gas. ALMA discovered two counter-rotating flows of gas around the black hole. The colors in this image represent the motion of the gas: blue is material moving toward us, red is moving away. [NRAO/AUI/NSF, S. Dagnello]

This new ALMA discovery could provide a clue. *"Counter-rotating gas streams are unstable, which means that clouds fall into the black hole faster than they do in a disk with a single rotation direction,"* said Impellizzeri. *"This could be a way in which a black hole can grow rapidly."*



ALMA image showing two disks of gas moving in opposite directions around the black hole in galaxy NGC 1068. The colors in this image represent the motion of the gas: blue is material moving toward us, red is moving away. The white triangles are added to show the accelerated gas that is expelled from the inner disk – forming a thick, obscuring cloud around the black hole. [ALMA (ESO/NAOJ/NRAO), V. Impellizzeri; NRAO/AUI/NSF, S. Dagnello]

NGC 1068 (also known as Messier 77) is a spiral galaxy approximately 47 million light-years from Earth in the direction of the constellation Cetus. At its center is an active galactic nucleus, a supermassive black hole that is actively feeding itself from a thin, rotating disk of gas and dust, also known as an accretion disk.

Previous ALMA observations revealed that the black hole is gulping down material and spewing out gas at incredibly high speeds. This gas that gets expelled from the accretion disk likely contributes to hiding the region around the black hole from optical telescopes.

Impellizzeri and her team used ALMA's superior zoom lens ability to observe the molecular gas around the black hole. Unexpectedly, they found two counter-rotating disks of gas. The inner disk spans 2-4 light-years and follows the rotation of the galaxy, whereas the outer disk (also known as the torus) spans 4-22 light-years and is rotating the opposite way.

"We did not expect to see this, because gas falling into a black hole would normally spin around it in only one direction," said Impellizzeri. *"Something must have disturbed the flow because it is impossible for a part of the disk to start rotating backward all on its own."*

Counter-rotation is not an unusual phenomenon in space. *"We see it in galaxies, usually thousands of light-years away from their galactic centers,"* explained co-author Jack Gallimore from Bucknell University in Lewisburg, Pennsylvania. *"The counter-rotation always results from the collision or interaction between two galaxies. What makes this result remarkable is that we see it on a much smaller scale, tens of light-years instead of thousands from the central black hole."* The astronomers think that the backward flow in NGC 1068 might be caused by gas clouds that fell out of the host galaxy, or by a small passing galaxy on a counter-rotating orbit captured in the disk.

At the moment, the outer disk appears to be in a stable orbit around the inner disk. *"That will change when the outer disk begins to fall onto the inner disk, which may happen after a few orbits or a few hundred thousand years. The rotating streams of gas will collide and become unstable, and the disks will likely collapse in a luminous event as the molecular gas falls into the black hole. Unfortunately, we will not be there to witness the fireworks,"* said Gallimore. ■

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Is it Pac-Man trying to swallow the Moon or a fortuitous photo of one of our VLT Auxiliary telescopes on the cover of the 2020 ESO Calendar? The calendar, which is available in the ESOshop, has 12 images — a selection of our best photos of the cosmos and our telescopes against the stunning Chilean landscape — which will accompany you throughout the year.

For the month of March, you can enjoy the breathtaking Milky Way over the site of the biggest eye on the sky, ESO's Extremely Large Telescope. Just imagine what this place will look like in 2025 when the giant, 40-metre class telescope is ready to uncover some of the mysteries of the Universe that can only be tackled with a facility of this size.

The month of July brings you a composite image of the phases of the 2019 Total Solar Eclipse from ESO's La Silla Observatory in Chile, a celestial show we were lucky to witness during the observatory's 50^{th} anniversary.

In September you can marvel at the first picture of a black hole, made possible thanks to a truly global collaboration, while December brings you a colourful and wispy view of cloud Sharpless 2-296 — the "wings" of the Seagull Nebula — carrying you into the holiday season. You can view the individual pages of the calendar here https://www.eso.org/public/usa/products/calendars/?search=cal2020

Also, marked for each month, are the dates of the lunar phases.

The calendar measures 43 × 43 centimetres and has 14 pages, with a cardboard back. It is available in the ESOshop https://www.eso.org/public/usa/shop/product/calendar_2020 for 9.50 euros.

ESO Calendar 2020

European Southern Observatory