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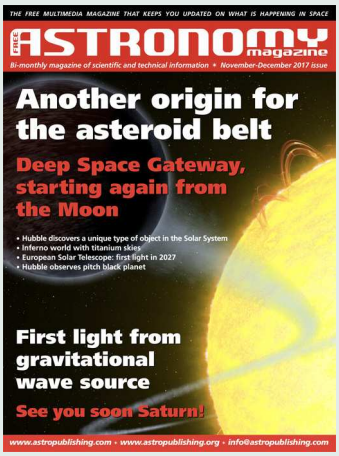
November-December 2017



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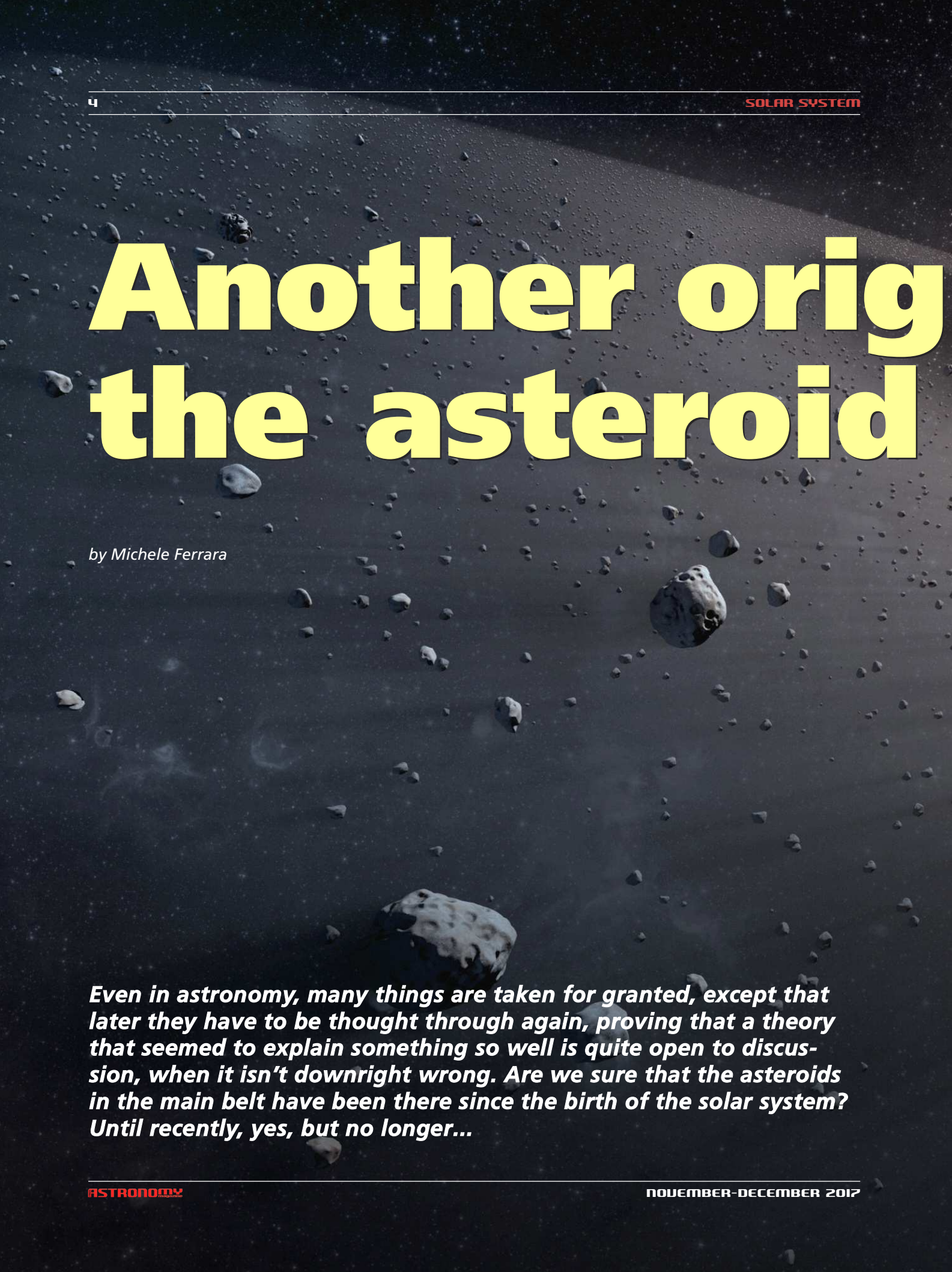
SUMMARY

Another orig the asteroid

by Michele Ferrara



Even in astronomy, many things are taken for granted, except that later they have to be thought through again, proving that a theory that seemed to explain something so well is quite open to discussion, when it isn't downright wrong. Are we sure that the asteroids in the main belt have been there since the birth of the solar system? Until recently, yes, but no longer...

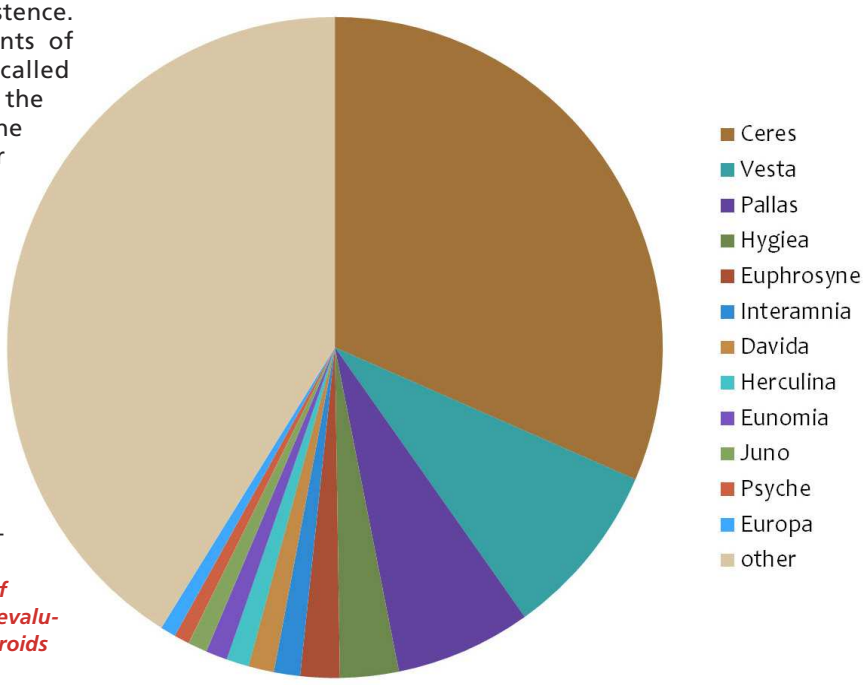
in for belt

Astronomy is definitely a science that is generous with plot twists, ones that can radically change our view of the cosmos. At times, the origin and nature of certain celestial bodies seem adequately explained by the commonly accepted theories, but then we discover that the reality may be something else altogether. The latest example of this is the main asteroid belt, the part of the solar system that contains about 1 million rocky structures larger than 1 km (for a total of

This illustration gives an idea of the possible appearance of the ring of planetesimals that produced the inner planets and the S-type asteroids. [NASA/JPL-Caltech]

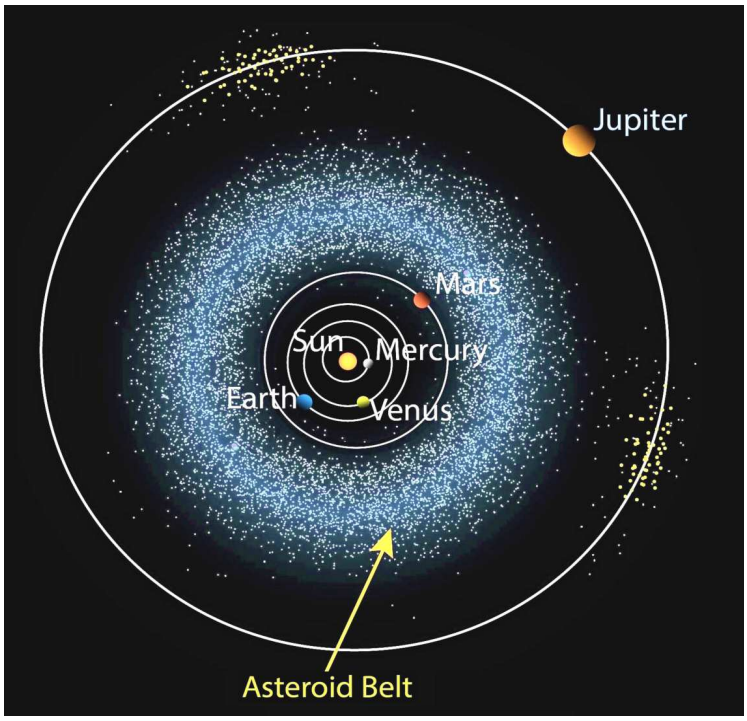
An imaginary scene in which a large planetesimal is growing by sweeping in smaller objects that cross its orbit.

less than a thousandth of Earth's mass), whose orbits are typically between those of Mars and Jupiter. In the nineteenth century, when astronomers realised that the first of these objects discovered were part of a real population (about 460 were discovered before 1900), the first hypotheses were presented to explain their existence. There were essentially two currents of thought on this: the asteroids (so called because they looked like stars, from the Greek asteroeidēs) could be either the remainders of a destroyed planet, or the building blocks of a planet that never formed. The first theory was advanced by Heinrich Wilhelm Olbers after he discovered the second (Pallas, in 1802) and fourth (Vesta, in 1807) objects in the main belt. Olbers predicted the existence of many other fragments of the hypothetical destroyed planet (called Phaeton). When the discoveries of new asteroids multiplied, his theory was reinforced, and it remained the leading theory for several decades. As time went by, however, nobody was able to find a valid reason why the supposed planet would have wound up in pieces. Astronomers thus started giving more credence to the theory of an aborted planet, whose formation would have been pre-



In this pie representing the total mass of the asteroids in the main belt, one can evaluate the importance of the 12 largest asteroids compared to all the rest.

On the right, an overview of the asteroid belt. Below, an animation that shows the orbital motions of over 100,000 of the asteroids observed by the Sloan Digital Sky Survey, with colors illustrating the compositional diversity measured by the SDSS five-color camera. The relative sizes of each asteroid are also illustrated. All main-belt asteroids and Trojan asteroids with orbits known to high precision are shown. The animation is rendered with a timestep of 3 days. The compositional gradient of the asteroid belt is clearly visible, with green Vesta-family members in the inner belt fading through the blue C-class asteroids in the outer belt, and the deep red Trojan swarms beyond that.The average orbital distances of Mercury, Venus, Earth, Mars, and Jupiter are illustrated with rings. [Alex H. Parker: alexharrison-parker.com - Music: Tamxr by LJ Kruzer (ljkruzer.co.uk)



vented and interrupted by Jupiter's growing mass, which was more than enough to throw that part of the solar system into disarray. This scenario gradually gained credibility during the twentieth century, but when the complexity of that population of asteroids became clearer in recent decades and it was determined that the planetary systems were characterised by an initial migration of the planets within them, the theory of the planet that failed to form began to show its weaknesses.

The best mathematical models, in fact, that explain the origin and evolution of the main asteroid belt are propped up by a rather forced assumption: that during the first 100 million years of its existence, the belt must have somehow lost at least 99% of its initial mass. The migration of the planets (Jupiter, essentially) and the resulting dynamic chaos, along with the collisional evolution of the asteroids, surely contributed to removing a significant mass from the belt, but explaining why that small fraction remained is a problem for which no elegant and wholly convincing solution exists. Among the least convinced are Sean N. Raymond (Université de Bordeaux, CNRS) and Andre Izidoro (Université de Bordeaux, CNRS, and Universidade Estadual Paulista), who proposed an alternative hypothesis last September in the magazine *Science Advances* on the origin of the main asteroid belt—one that is diametrically opposed to the classic one. The two researchers claim that at the dawn of the solar system that area was not more populated than today but, on the contrary, was completely empty. The hundreds of thousands

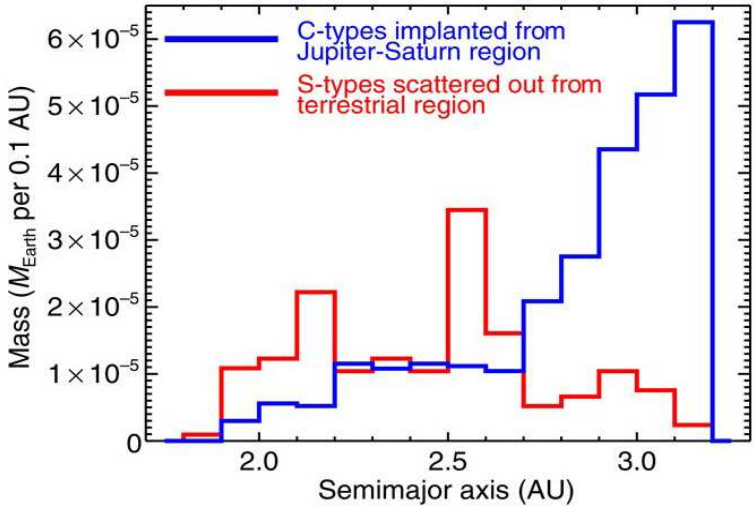
of asteroids that we see there today would have been added to the belt only during and after the planetary migration phase, when the planets were already in an advanced stage of formation. To support this apparently paradoxical scenario, Raymond and Izidoro offer arguments that, for the most part at least, seem quite convincing. The idea of an initially empty asteroid belt arose from a fact that has been established for decades: the innermost part of the belt is dominated by what are called S-type asteroids, particularly rich in silicates on their surfaces (and likely underground as well), while the outermost part of the belt is dominated by C-type asteroids, which feature an abundance of carbon. This rough division is actually

The collisional evolution of the asteroids, represented by the background illustration, is the mechanism by which the main belt was transformed beginning from its formation. This mechanism is still valid in Raymond and Izidoro's scenario. [NASA/JPL-Caltech]

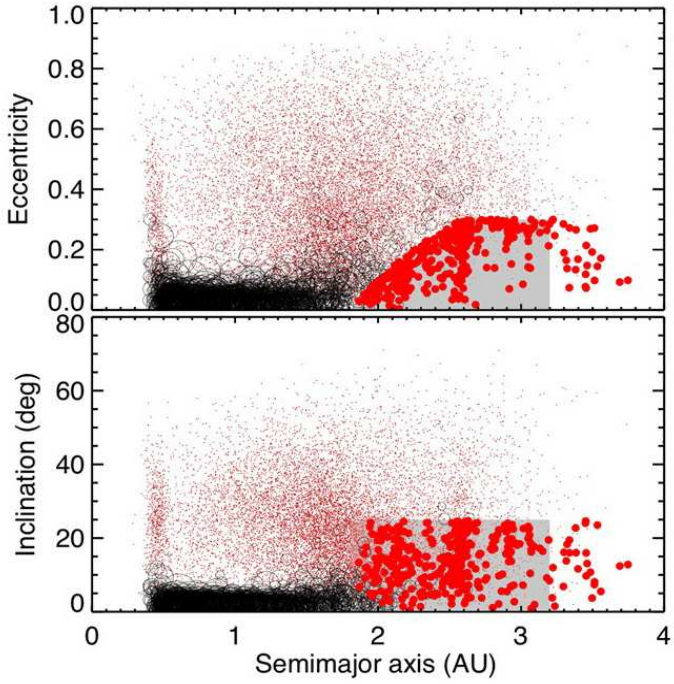
more complicated and profound. It is more complex because there are also other classes and subclasses (although less prominent than S and C), as well as a slight mixing of the classes in terms of their orbits. It is more profound because the predominance of certain surface elements indicates a different internal breakdown of minerals and thus a different location at the time they formed. The classic hypothesis, that the asteroids in the main belt had largely formed where they are still in orbit, substantially confirms that their differences in composition reflect the distribution of the elements that made up the gases and dust present in the protoplanetary disk at those distances from the protoSun. But according to Raymond and Izidoro, there are a couple of valid reasons to believe that the macroscopic differentiation between the S-type and C-type asteroids, as we see it today, cannot be a direct consequence of the original distribution of the matter in that area. The first reason is the current absence of dust in the main belt: if a planet had been about to be formed, in addition to what remains of the planetesimals (that is, the asteroids more or less shattered by mutual impacts), there should still be a significant amount of dust there, which is instead absent. The second reason is the fact that the rocky planets, the ones that in their mineralogical composition are the closest to the S-type asteroids,

were almost certainly formed in a very narrow, ring-shaped region in which the density of the matter was sufficient to create the planetesimals; nothing suggests that these conditions extended to the current asteroid belt. Perhaps the S-type asteroids originated in the inner parts of the protoplanetary disk and began to be thrust between the orbits of Mars and Jupiter by gravitational interactions with the embryos of the planets being formed.

For similar reasons, it can be conjectured that the C-type asteroids also arose elsewhere, preferably in an area closer to the giant planets, which would explain their abundance of carbon. To test their hypothesis, the two researchers launched a series of long simulations on a supercomputer (each of which ran for months), to create a model of the young solar system and test a possible alternative origin for the asteroids in the belt. The starting configuration of the simulations entailed the formation of terrestrial planets beginning with a dissipating gaseous ring (totally re-



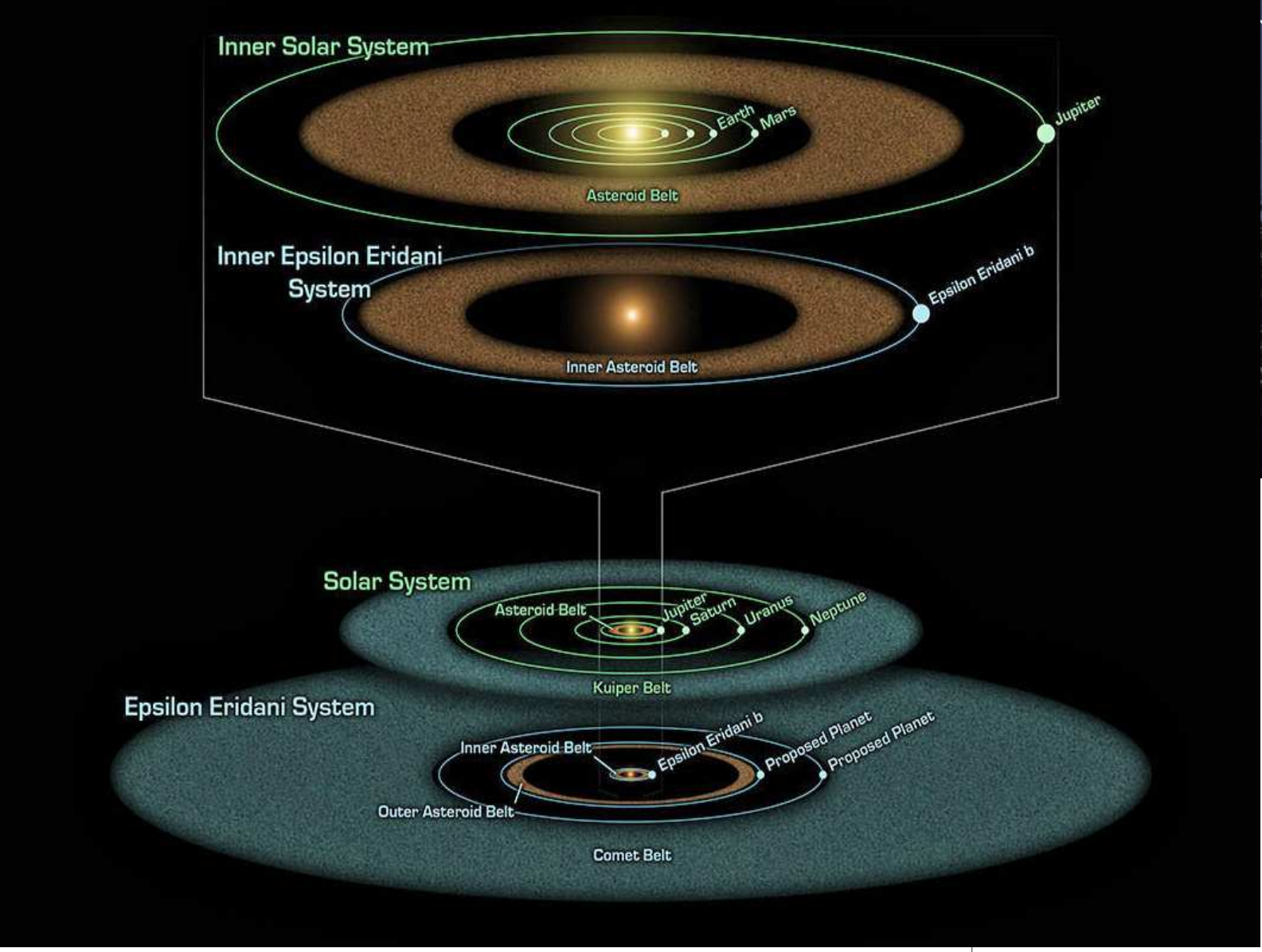
Above, a representation of a theoretical planetesimal that is held back by the gas collected by Jupiter. This mechanism could be behind the origin of the C-type asteroids. [Erik Wernquist]
At left, the radial distribution is shown for the virtual asteroids (100 km in diameter) added by the simulations in stable orbits in the main belt. [S.N. Raymond, and A. Izidoro]



On the right, semimajor axis–eccentricity and inclination distribution of S-type asteroids implanted from the terrestrial planet region. All planetesimals from the end of the simulations are shown, and the implanted ones are solid. The shaded region represents the main asteroid belt, defined here as having perihelion distance q > 1.8 AU, eccentricity e < 0.3, and inclination i < 25°. [S.N. Raymond, and A. Izidoro] Below, Sean N. Raymond, first author of the new study.

moved in 2 million years), with the external presence of a virtual Jupiter and Saturn in low-eccentricity orbits, held together by a 3:2 resonance, with Jupiter 5.4 AU from the Sun. The inner area of planetary formation included 2 to 2.5 Earth masses, distributed between 0.7 and 1 AU, or 0.7 and 1.5 AU (each simulation had different initial configurations). Those masses were divided between 50 and 100 planetary embryos, in addition to a cluster of 2000-5000 100-km-sized planetesimals. The planetary embryos made up between 75% and 90% of the total mass.

The gravitational disturbance due to the growth of the virtual rocky objects gradually dispersed the ring outwards, and in this scenario Mars would be a large embryo expelled from the ring (following gravitational interactions with its peers) and thus deprived of a way to gain further mass. The simulations Raymond and Izidoro ran finally produced Earth-like planets broadly resembling the real ones in our solar system, and the eccentricities and inclinations of their orbits are consistent with the real ones. It is doubtless a good starting point to test what could have happened to the planetesimals from the ring that were still in circulation after the planetary formation. The researchers observed that their virtual masses were disseminated in orbits that intersect the area now occupied by the main asteroid belt (but initially empty in the simulations). Simple transits of planetesimals in that area would not, however, have prevented the Sun's gravity from attracting those objects, sooner or later making them slam into the young, rocky planets. But the simulations indicate that if the belt had been repeatedly crossed by a planetary embryo as well, it could have



This diagram compares our solar system with that of Epsilon Eridani, whose structures are similar, as both have belts of asteroids and comets.

raised the perihelion of the orbits of the planetesimals in transit in its vicinity. Jupiter could then have done the rest, reducing the eccentricity of those orbits and trapping the planetesimals within dangerous planetary resonances, whose transience (the planetary migration was at its end) could nevertheless have allowed the planetesimals to become stabilised in relatively peaceful final orbits. The planetesimals that survived the formation of the terrestrial planets in the ring and were rerouted into the belt would comprise the S-type population, whose mineralogy is similar to that of the inner planets (from Mercury to Mars). According to what the two authors of the study stated in *Science Advances*, their simulations placed within the inner part of the belt a mass of planetesimal from 3 to 4 times larger than the total actual mass of the S-type asteroids present today, a proportion compatible with the mechanisms for depleting the belt used in the classic theory. The simulations by Raymond and Izidoro also provide a rather convincing scenario for the origin of the outermost part of the asteroid belt (more than 2.7 AU from the Sun), the one dominated by the C-type population, whose total mass is roughly triple of that of the S-types. In this case, the growth of Jupiter and Saturn would have destabilised a large number of planetesimals, distributed mainly between 4 and 9 AU from the Sun. The gas attracted by the planets in those areas of the solar system would have put the brakes on the orbital motion of the planetesimals, encouraging their relocation in orbits closer to the Sun and especially in the outer part of the belt. Altogether, the new scenario proposed by Raymond and Izidoro is definitely intriguing and shows that our knowledge of the origin of the main asteroid belt is not as solid as we previously believed.

Rather than being the traces of a planet that never formed between Mars and Jupiter, those asteroids would be a by-product of the formation of the terrestrial planets and the gaseous planets. ■

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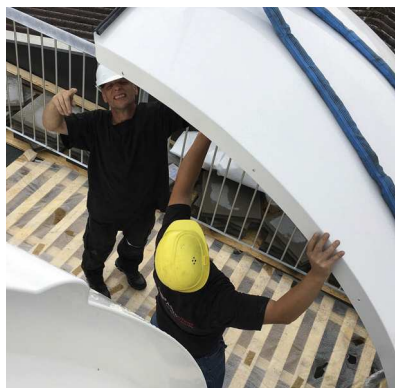

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ESO telescopes light from gravi wave source

by ESO

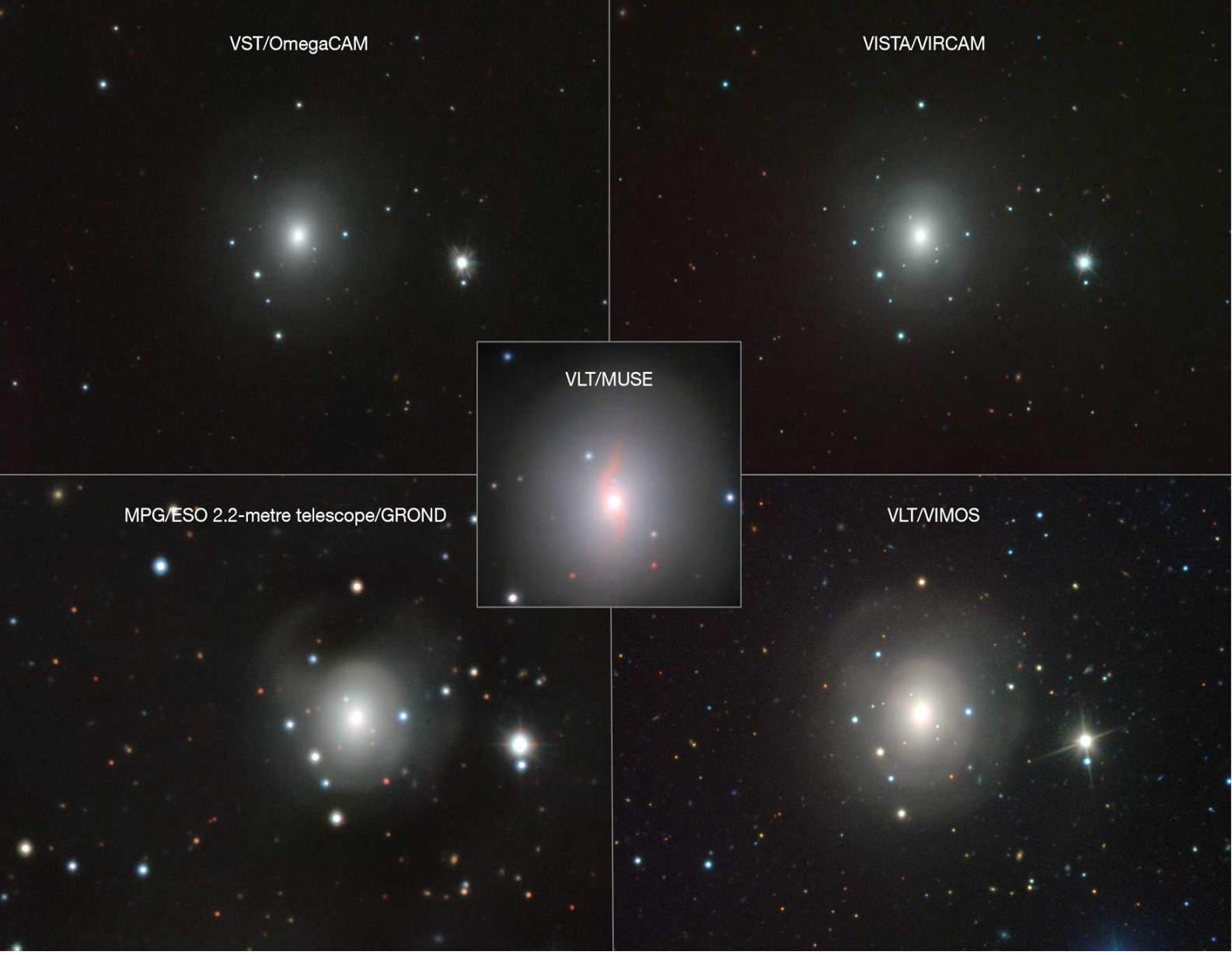
For the first time ever, astronomers have observed both gravitational waves and light (electromagnetic radiation) from the same event, thanks to a global collaborative effort and the quick reactions of both ESO's facilities and others around the world.

On 17 August 2017 the NSF's Laser Interferometer Gravitational-Wave Observatory (LIGO) in the United States, working with the Virgo Interferometer in Italy, detected gravitational waves passing the Earth. This event, the fifth ever detected, was named GW170817. About two seconds later, two space observatories, NASA's Fermi Gamma-ray Space Telescope and ESA's INTErnational Gamma Ray Astrophysics Laboratory (INTEGRAL), detected a short gamma-ray burst from the same area of the sky. The LIGO–Virgo observatory network positioned the source within a large region of the southern sky, the size of several hundred full Moons and containing millions of stars. As night fell in Chile many telescopes peered at this patch of sky, searching for new sources.

observe first tational

These included ESO's Visible and Infrared Survey Telescope for Astronomy (VISTA) and VLT Survey Telescope (VST) at the Paranal Observatory, the Italian Rapid Eye Mount (REM) telescope at ESO's La Silla Observatory, the LCO 0.4-meter telescope at Las Cumbres Observatory, and the American DECam at Cerro Tololo Inter-American Observatory.

This artist's impression shows two tiny but very dense neutron stars at the point at which they merge and explode as a kilonova. Such a very rare event is expected to produce both gravitational waves and a short gamma-ray burst, both of which were observed on 17 August 2017 by LIGO–Virgo and Fermi/INTEGRAL respectively.
Subsequent detailed observations with many ESO telescopes confirmed that this object, seen in the galaxy NGC 4993 about 130 million light-years from the Earth, is indeed a kilonova. Such objects are the main source of very heavy chemical elements, such as gold and platinum, in the Universe.
[ESO/L. Calçada/M. Kornmesser]



This composite shows images of the galaxy NGC 4993 from several different ESO telescopes and instruments. They all reveal a faint source of light close to the centre. This is a kilonova, the explosion resulting from the merger of two neutron stars. This merger produced both gravitational waves, detected by LIGO–Virgo, and gamma rays, detected by Fermi and INTEGRAL in space. [VLT/VIMOS. VLT/MUSE, MPG/ESO 2.2-metre telescope/GROND, VISTA/VIRCAM, VST/OmegaCAM]

The Swope 1-metre telescope was the first to announce a new point of light. It appeared very close to NGC 4993, a lenticular galaxy in the constellation of Hydra, and VISTA observations pinpointed this source at infrared wavelengths almost at the same time. As night marched west across the globe, the Hawaiian island telescopes Pan-STARRS and Subaru also picked it up and watched it evolve rapidly.

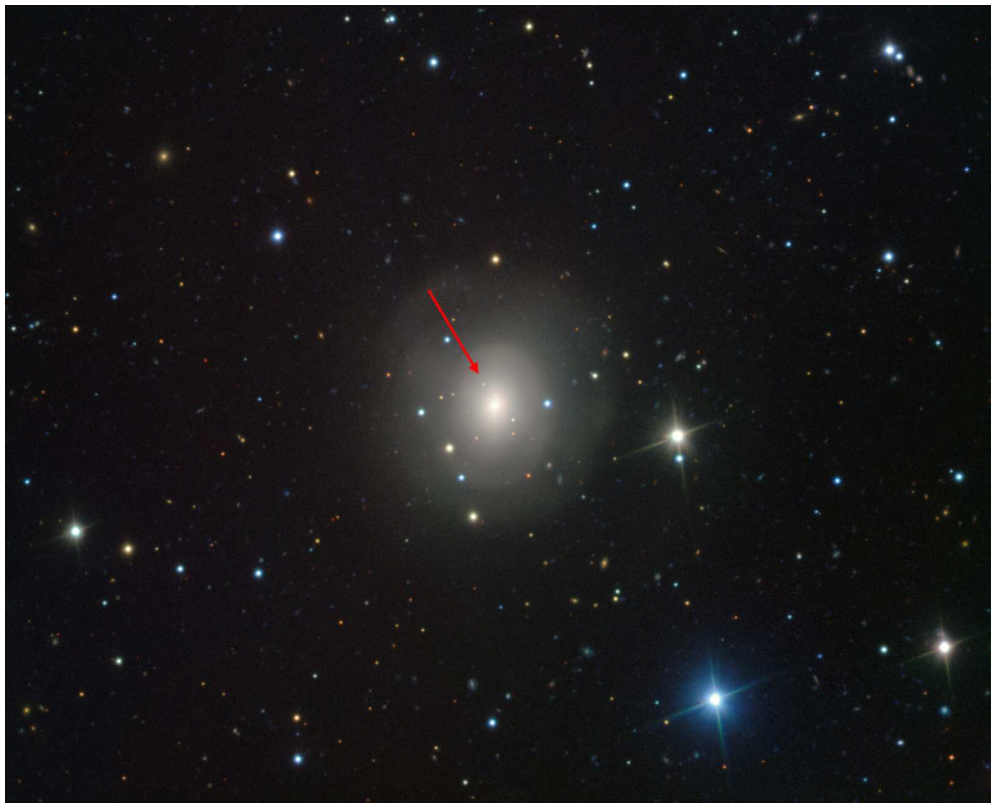
"There are rare occasions when a scientist has the chance to witness a new era at its beginning," said Elena Pian, astronomer with INAF, Italy, and lead author of one of the *Nature* papers. *"This is one such time!"* ESO launched one of the biggest ever "target of opportunity" observing campaigns and many ESO and ESO-partnered telescopes observed the object over the weeks following the detection. ESO's Very Large Telescope (VLT), New Technology Telescope (NTT), VST, the MPG/ESO 2.2-metre telescope, and the Atacama Large Millimeter/submillimeter Array (ALMA) all observed the event and its after-effects over a wide range of wavelengths. About 70 observatories around the world also observed the event, including the NASA/ESA Hubble Space Telescope. Distance estimates from both the gravitational wave data and other observations agree that GW170817 was at the same distance as NGC 4993, about 130 million light-years from Earth. This makes the source both the closest gravitational wave event detected so far and also one of the closest gamma-ray burst sources ever seen.

The ripples in spacetime known as gravitational waves are created by moving masses, but only the most intense, created by rapid changes in the speed of very massive objects, can currently be detected. One such event is the merging of neutron stars, the extremely dense, collapsed cores of high-mass stars left behind

after supernovae. These mergers have so far been the leading hypothesis to explain short gamma-ray bursts.

An explosive event 1000 times brighter than a typical nova — known as a kilonova — is expected to follow this type of event. The almost simultaneous detections of both gravitational waves and gamma rays from GW170817 raised hopes that this object was indeed a long-sought kilonova and observations with ESO facilities have revealed properties remarkably close to theoretical predictions.

Kilonovae were suggested more than 30 years ago but this marks the first confirmed observation. Following the merger of the two neutron stars, a burst of rapidly expanding radioactive heavy chemical elements left the kilonova, moving as fast as one-fifth of the speed of light. The colour of the kilonova shifted from very blue to very red over the next few days, a faster change than that seen in any other observed stellar explosion.



This image from the VIMOS instrument on ESO's Very Large Telescope at the Paranal Observatory in Chile shows the galaxy NGC 4993, about 130 million light-years from Earth. The galaxy is not itself unusual, but it contains something never before witnessed, the aftermath of the explosion of a pair of merging neutron stars, a rare event called a kilonova (indicated with the arrow). This merger also produced gravitational waves and gamma rays, both of which were detected by LIGO–Virgo and Fermi/INTEGRAL respectively. [ESO]

"When the spectrum appeared on our screens I realised that this was the most unusual transient event I'd ever seen," remarked Stephen Smartt, who led observations with ESO's NTT as part of the extended Public ESO Spectroscopic Survey of Transient Objects (ePESSTO) observing programme. *"I had never seen anything like it. Our data, along with data from other groups, proved to everyone that this was not a supernova or a foreground variable star, but was something quite remarkable."*

Spectra from ePESSTO and the VLT's X-shooter instrument suggest the presence of caesium and tellurium ejected from the merging neutron stars. These and other heavy elements, produced during the neutron star merger, would be blown into space by the subsequent kilonova. These observations pin down the formation of elements heavier than iron through nuclear reactions within high-density stellar objects, known as r-process nucleosynthesis, something which was only theorised before. *"The data we have so far are an amazingly close match to theory. It is a triumph for the theorists, a confirmation that the LIGO–VIRGO events are absolutely real, and an achievement for ESO to have gathered such an astonishing data set on the kilonova,"* adds Stefano Covino, lead author of one of the Nature Astronomy papers.

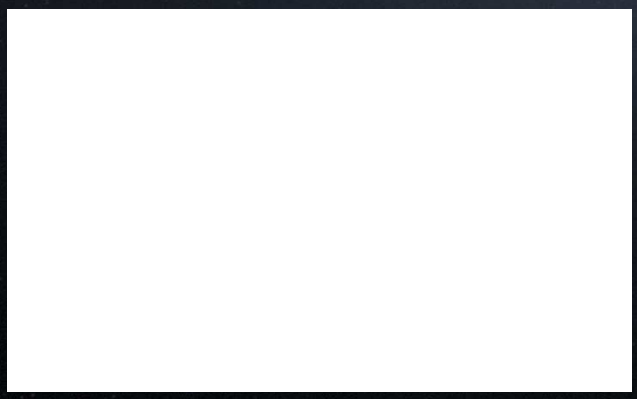
"ESO's great strength is that it has a wide range of telescopes and instruments to tackle big and complex astronomical projects, and at short notice. We have entered a new era of multi-messenger astronomy!" concludes Andrew Levan, lead author of one of the papers. ■

Hubble discovers a unique type of object in the Solar System

by NASA/ESA

With the help of the NASA/ESA Hubble Space Telescope, a German-led group of astronomers have observed the intriguing characteristics of an unusual type of object in the asteroid belt between Mars and Jupiter: two asteroids orbiting each other and exhibiting comet-like features, including a bright coma and a long tail. This is the first known binary asteroid also classified as a comet.

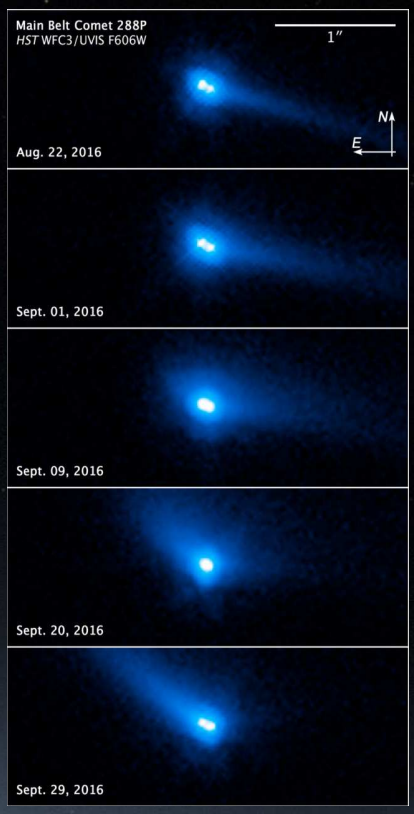
The research has been recently presented in a paper published in the journal *Nature*.



This artist's animation shows the binary main-belt comet 288P. From a distance the comet-like features of the system can clearly be seen: among them, the bright coma surrounding both components of the system and the long tail of dust and water pointing away from the Sun. Only a closer look reveals the two components of the system: two asteroids circling each other on an eccentric orbit. [ESA/Hubble, L. Calçada, M. Kornmesser]

In September 2016, just before the asteroid 288P made its closest approach to the Sun, it was close enough to Earth to allow astronomers a detailed look at it using the NASA/ESA Hubble Space Telescope. The images of 288P revealed that it was actually not a single object, but two asteroids of almost the same mass and size, orbiting each other at a distance of about 100 kilometres. That discovery was in itself an important find; because they orbit each other, the masses of the objects in such systems can be measured. But the observations also revealed ongoing activ-

The artist's impression in the background shows the binary asteroid 288P, located in the main asteroid belt between the planets Mars and Jupiter. The object is unique as it is a binary asteroid which also behaves like a comet. The comet-like properties are the result of water sublimation, caused by the heat of the Sun. The orbit of the asteroids is marked by a blue ellipse. [ESA/Hubble, L. Calçada]



This set of Hubble Space Telescope photos reveals two asteroids orbiting each other that have comet-like features. These include a bright halo of material, called a coma, and a long tail of dust. The asteroid pair, called 2006 VW139/288P, was observed in September 2016 just before the asteroid made its closest approach to the Sun. The photos revealed ongoing activity in the binary system. [NASA, ESA, and J. Agarwal (Max Planck Institute for Solar System Research)]

ity in the binary system. *"We detected strong indications of the sublimation of water ice due to the increased solar heating — similar to how the tail of a comet is created,"* explains Jessica Agarwal (Max Planck Institute for Solar System Research, Germany), the team leader and main author of the research paper. This makes 288P the first known binary asteroid that is also classified as a main-belt comet.

Understanding the origin and evolution of main-belt comets — asteroids orbiting between Mars and Jupiter that show comet-like activity — is a crucial element in our understanding of the formation and evolution of the whole Solar System. Among the questions main-belt comets can help to answer is how water came to Earth. Since only a few objects of this type are known, 288P presents itself as an extremely important system for future studies. The various features of 288P — wide separation of the two components, near-equal component size, high eccentricity and comet-like activity — also make it unique among the few known wide asteroid binaries in the Solar System. The observed activity of 288P also reveals information about its past, notes Agarwal: *"Surface ice cannot survive in the asteroid belt for the age of the Solar System but can be protected for billions of years by a refractory dust mantle, only a few metres thick."* From this, the team concluded that 288P has existed as a binary system for only about 5000 years. Agarwal elaborates on the formation scenario: *"The most probable formation scenario of 288P is a breakup due to fast rotation. After that, the two fragments may have been moved further apart by sublimation torques."*

The fact that 288P is so different from all other known binary asteroids raises some questions about whether it is not just a coincidence that it presents such unique properties.

As finding 288P included a lot of luck, it is likely to remain the only example of its kind for a long time. *"We need more theoretical and observational work, as well as more objects similar to 288P, to find an answer to this question,"* concluded Agarwal. ■

5th ESO Astronomy Winter Camp

Participants of the 4th ESO Astronomy Camp hosted by ESO and Sterrenlab at the Astronomical Observatory of the Aosta Valley, located in Saint Barthélemy. [L. Polo]

ESO and its Science Outreach Network are collaborating with the science education event organiser Sterrenlab and the Astronomical Observatory of the Autonomous Region of the Aosta Valley (OAVdA) to arrange the fifth ESO Astronomy Camp on the topic of Distances in the Universe. The camp will take place from Tuesday 26 December 2017 to Monday 1 January 2018 in the Aosta Valley, Italy.

The camp will explore the theme of Distances in the Universe through several astronomical sessions, including lectures, hands-on activities, and nighttime observations with the telescopes and instruments at the observatory. Social activities, winter sports and excursions will contribute to making the camp a memorable experience for the participants. ESO and OAVdA will be responsible for the scientific programme of the ESO Astronomy Camp, and will provide lecturers and material together with several other partners. The registration fee of €500 covers full-board accommodation at the hostel in Saint Barthélemy, supervision by professional staff, all astronomical and leisure activities, materials, excursions, internal transport and insurance. Bus transport between the observatory and the airport of Milan Malpensa will be provided. The fee does not include travel costs between the student's home and Milan Malpensa.

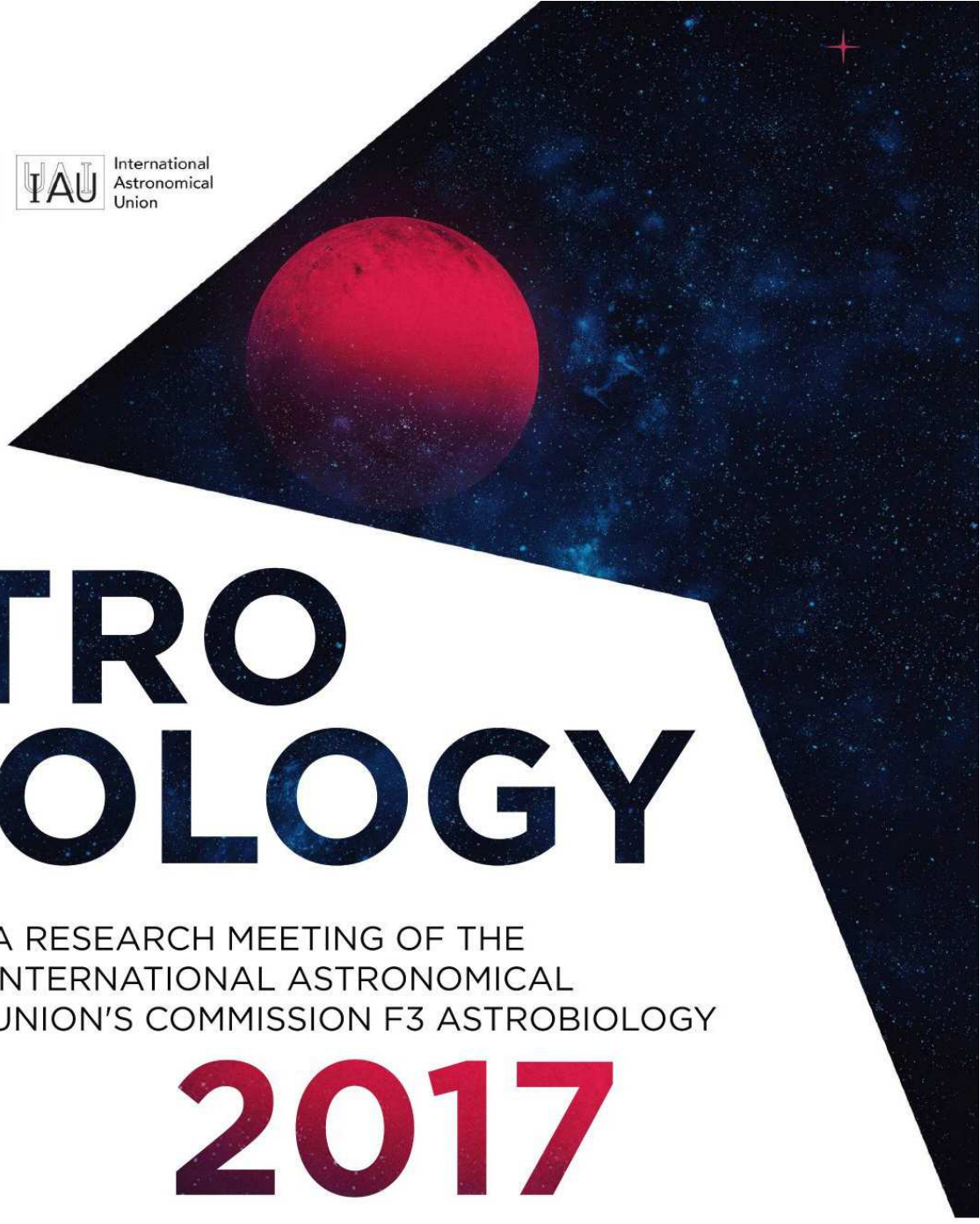
The Astronomical Observatory of the Autonomous Region of the Aosta Valley. [OAVDA, Fondation Clément Fillietroz]

The camp will accommodate a maximum of 56 secondary school students aged between 16 and 18 (born in the years 1999–2001) from the ESO Member States and additional ESO Science Outreach Network countries. A limited number of places will be available to students from other countries. The applicant with the best entry from one of ESO's Member States, will win a bursary offered by ESO that will cover the complete cost of the camp including transport.

Several national partners will also provide support to the best applications from a student residing in their respective countries. The selection criteria and other instructions for participation are given on the Camp web page. ■

ASTROBIOLOGY
COYHAIQUE - CHILE 2017

IAU International Astronomical Union



ASTRO BIOLOGY

A RESEARCH MEETING OF THE
INTERNATIONAL ASTRONOMICAL
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See you soon Saturn!

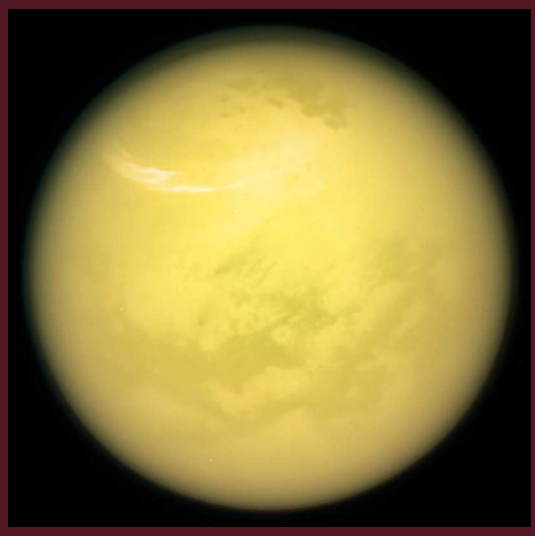
by NASA

Last September, after a 7 years travel and 13 years of zooming around Saturn and its many moons, NASA's Cassini spacecraft crashed into Saturn, ending a successful two-decade mission. NASA currently has no missions on the books to return to Saturn, although three proposals later this year are expected to be submitted to the space agency. The final selection is planned for May 2019 for launch by the end of 2025. In the meantime, let's enjoy some of the most spectacular images taken by Cassini.

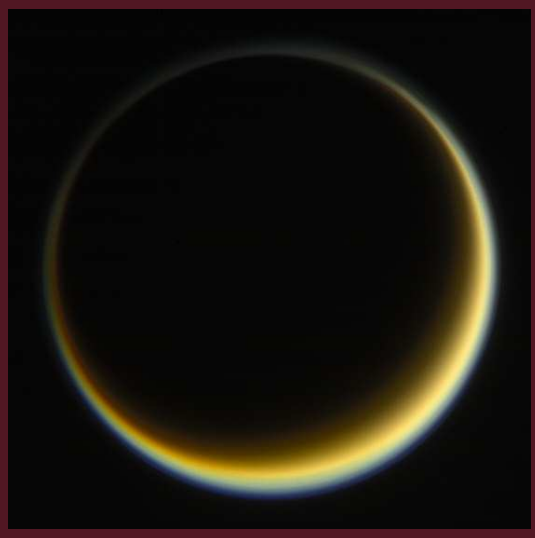
Saturn's night side

Stunning views like this image of Saturn's night side are only possible thanks to our robotic emissaries like Cassini. Until future missions are sent to Saturn, Cassini's image-rich legacy must suffice. Because Earth is closer to the Sun than Saturn, observers on Earth only see Saturn's day side. With spacecraft, we can capture views (and data) that are simply not possible from Earth, even with the largest telescopes. The image was taken in visible light with the wide-angle camera on NASA's Cassini spacecraft on June 7, 2017. The view was obtained at a distance of approximately 1.21 million kilometers from Saturn. The Cassini spacecraft ended its mission on Sept. 15, 2017. [NASA/JPL/Space Science Institute]

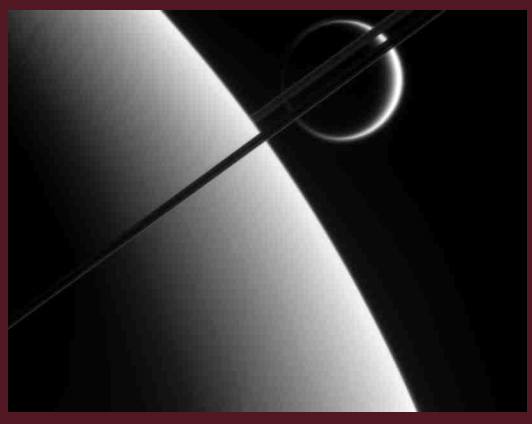
TITAN



These view was obtained with the Cassini spacecraft narrow-angle camera on March 21, 2017, at a distance of approximately 986,000 kilometers from Titan. [NASA/JPL/Space Science Institute]

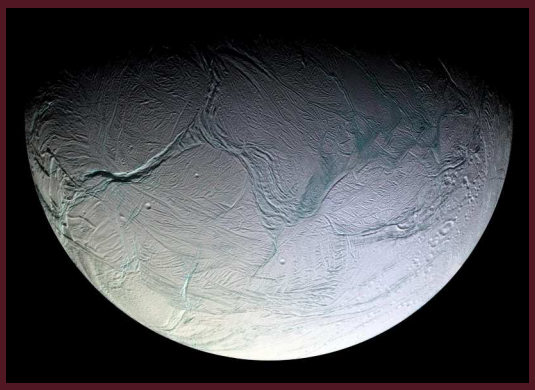


On May 29, 2017, NASA's Cassini looks toward the night side of Saturn's moon Titan in a view that highlights the extended, hazy nature of the moon's atmosphere. [NASA/JPL/Space Science Institute]

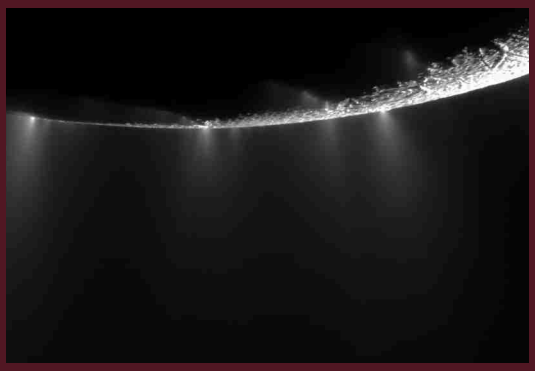


This view was taken on May 10, 2006 from above the ringplane and looks toward the unlit side of the rings, at a distance of approximately 2.9 million kilometers from Saturn and 4.1 million kilometers from Titan. [NASA/JPL/Space Science Institute]

ENCELADUS

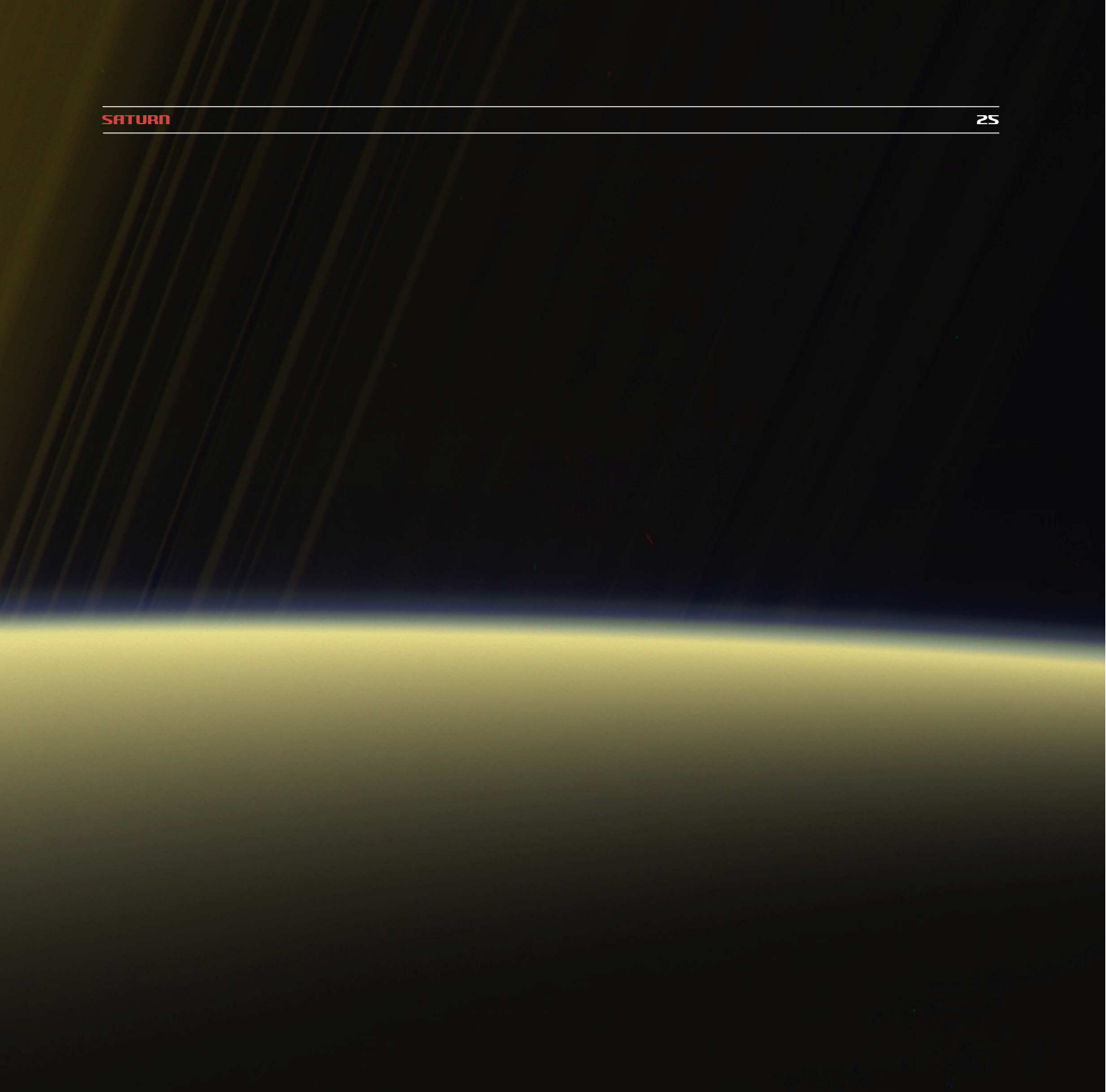


Craters and cratered terrains are rare in this view of the southern region of Enceladus. Instead, the surface is replete with fractures, folds, and ridges, all hallmarks of remarkable tectonic activity for a relatively small world. [NASA/JPL/Space Science Institute]



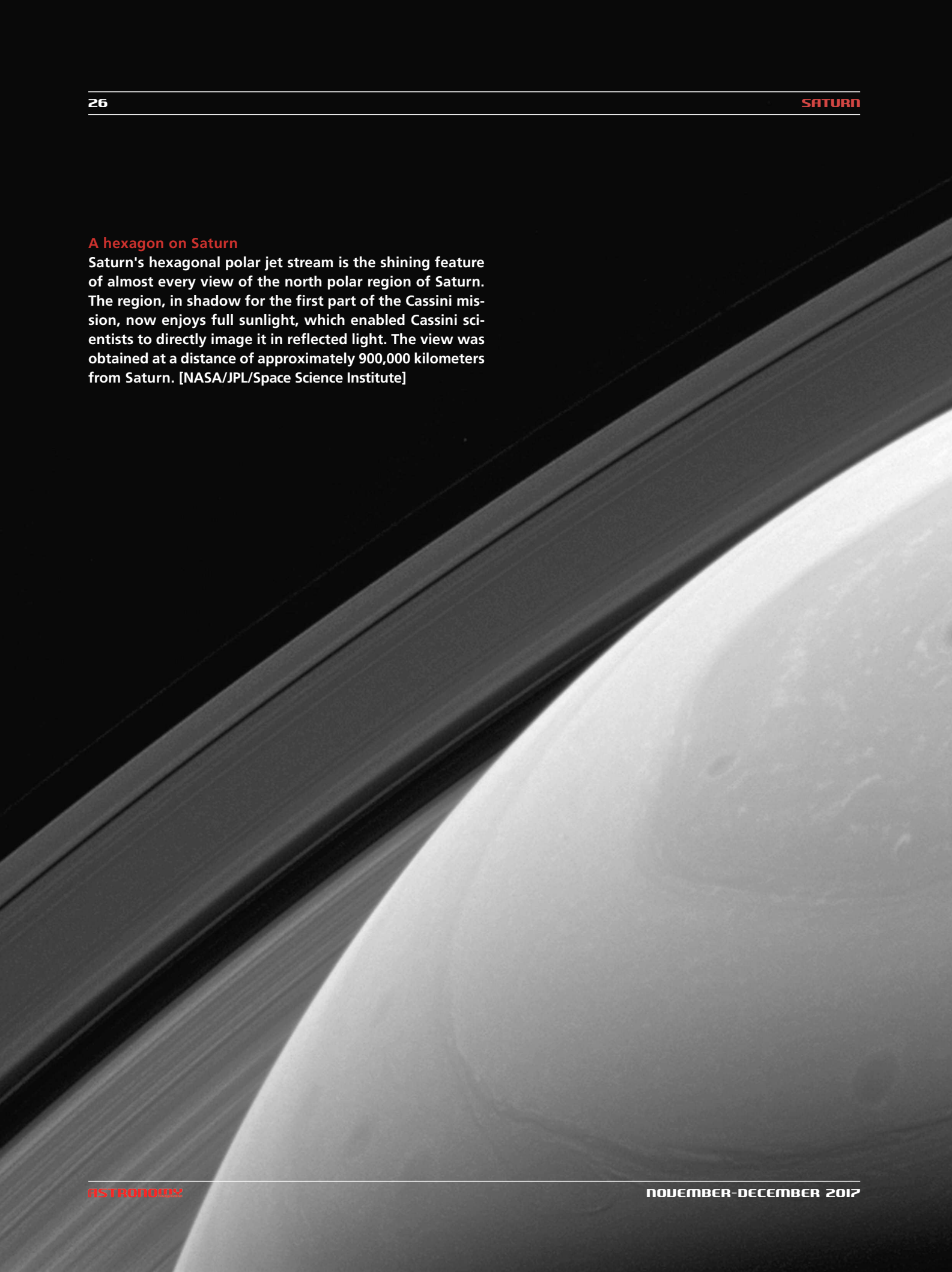
Dramatic plumes, both large and small, spray water ice and vapor from many locations along the famed "tiger stripes" near the south pole of Saturn's moon Enceladus. The tiger stripes are four prominent, approximately 135-kilometer-long fractures that cross the moon's south polar terrain. This two-image mosaic is one of the highest resolution views acquired by Cassini during its imaging survey of the geyser basin capping the southern hemisphere of Saturn's moon Enceladus. It clearly shows the curvilinear arrangement of geysers, erupting from the fractures. [NASA/JPL/Space Science Institute]

Saturn's active, ocean-bearing moon Enceladus sinks behind the giant planet in a farewell portrait from NASA's Cassini spacecraft. This view of Enceladus was taken by NASA's Cassini spacecraft on Sept. 13, 2017. It is among the last images Cassini sent back. [NASA/JPL/Space Science Institute]



Haze on the horizon

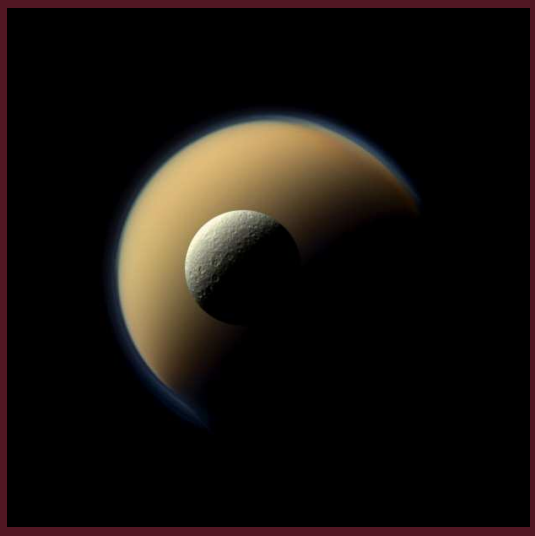
This false-color view from NASA's Cassini spacecraft gazes toward the rings beyond Saturn's sunlit horizon. Along the limb (the planet's edge) at left can be seen a thin, detached haze. The haze vanishes toward the right side of the scene. This view is a false-color composite made using images taken in red, green and ultra-violet spectral filters. The images were obtained using the Cassini spacecraft narrow-angle camera on July 16, 2017, at a distance of about 1.25 million kilometers from Saturn. Image scale is about 7 kilometers per pixel on Saturn. [NASA/JPL/Space Science Institute]



A hexagon on Saturn

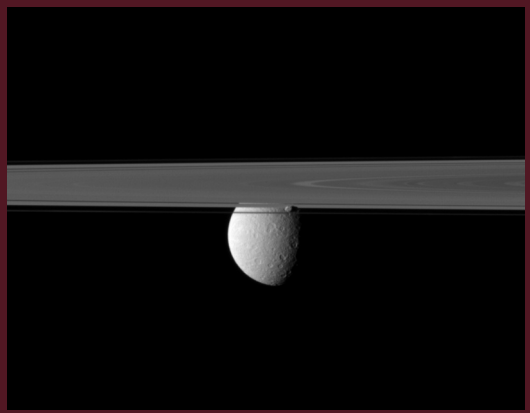
Saturn's hexagonal polar jet stream is the shining feature of almost every view of the north polar region of Saturn. The region, in shadow for the first part of the Cassini mission, now enjoys full sunlight, which enabled Cassini scientists to directly image it in reflected light. The view was obtained at a distance of approximately 900,000 kilometers from Saturn. [NASA/JPL/Space Science Institute]

RHEA



Saturn's largest and second largest moons, Titan and Rhea, appear to be stacked on top of each other in this true-color scene from NASA's Cassini spacecraft. [NASA/JPL/Space Science Institute]

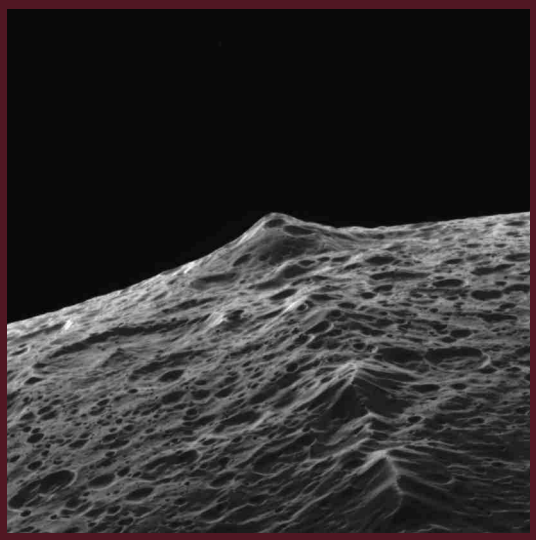
Cassini looks over the heavily cratered surface of Rhea during the spacecraft's flyby of the moon on March 10, 2012. [NASA/JPL/Space Science Institute]



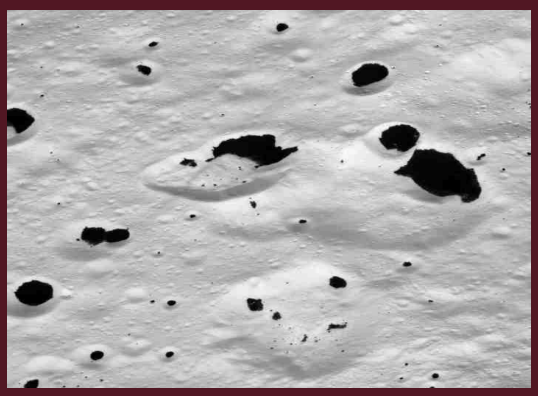
Saturn's rings and small moon Prometheus obscure the Cassini spacecraft's view of the planet's second largest moon, Rhea. Prometheus, which orbits in the Roche Division between the main rings and the thin F ring, can be seen just below the center of the image, in front of Rhea. [NASA/JPL/Space Science Institute]

IAPETUS

The brightest hemisphere of Iapetus. The prominent basin on the southern trailing side is Engelier. [NASA/JPL/Space Science Institute]



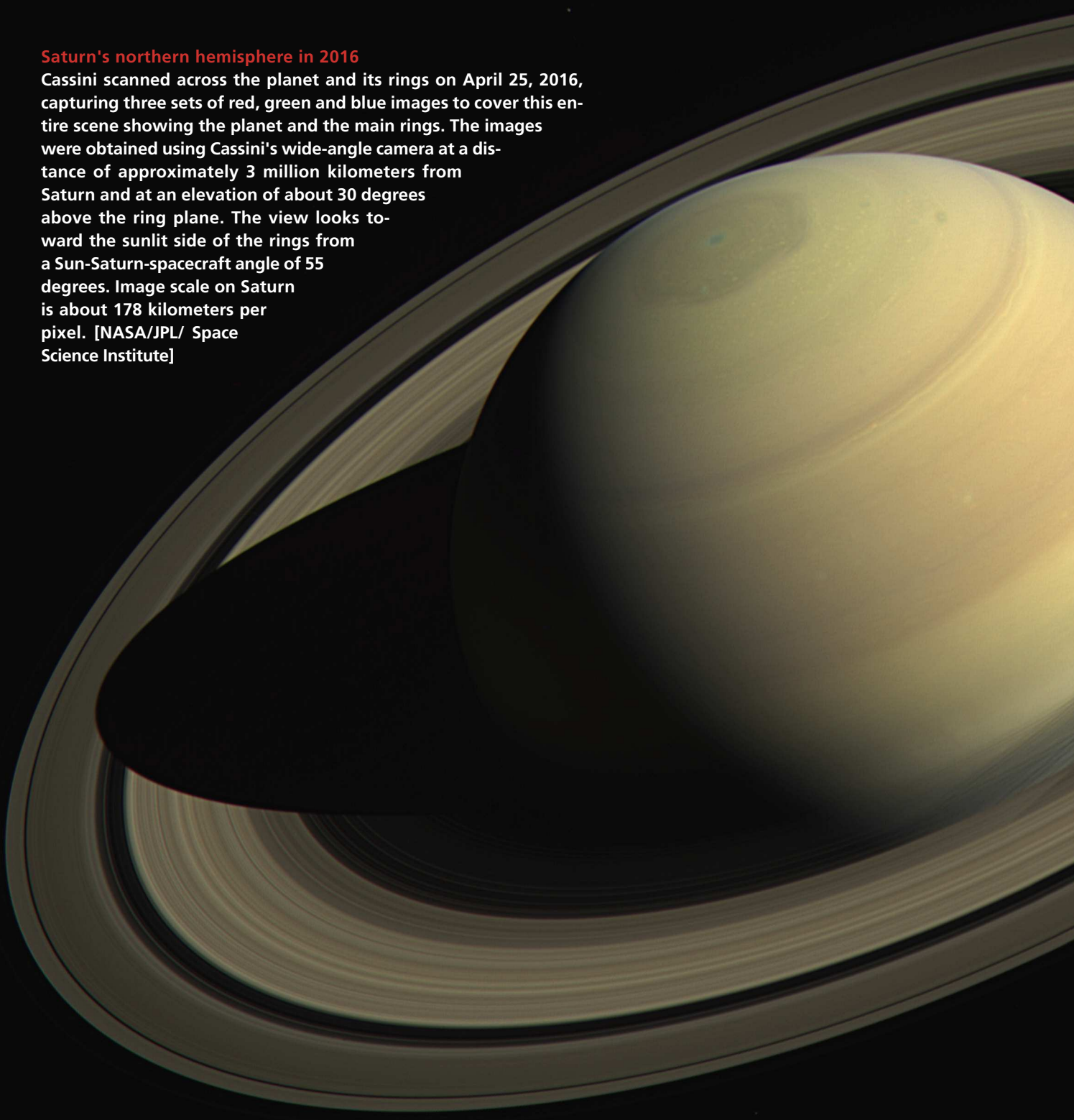
The equatorial ridge that runs along the center of Cassini Regio, about 1,300 km long, 20 km wide, and 13 km high. This prominent bulge gives Iapetus a walnut-like appearance. [NASA/JPL/Space Science Institute]



Dark material splatters the walls and floors of craters in the surreal, frozen wastelands of Iapetus. This image shows terrain in the transition region between the moon's dark leading hemisphere and its bright trailing hemisphere. [NASA/JPL/Space Science Institute]

Southern color

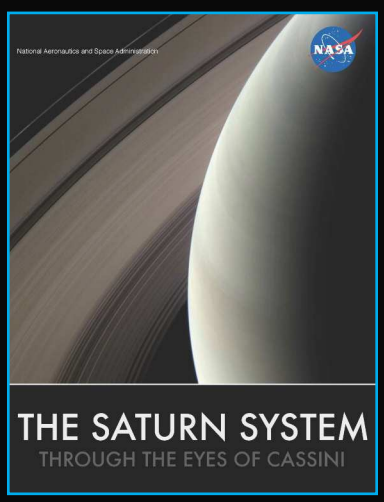
The Cassini spacecraft samples a bit of Saturn's southern hemisphere along with a spread of the planet's main rings. Working outward from the planet, the C, B, and A rings are visible in this natural color image. The rings have been brightened relative to the planet to enhance their visibility. The images were acquired with the Cassini spacecraft wide-angle camera on April 23, 2009 at a distance of approximately 1 million kilometers from Saturn. Image scale is 58 kilometers per pixel. [NASA/JPL/Space Science Institute]



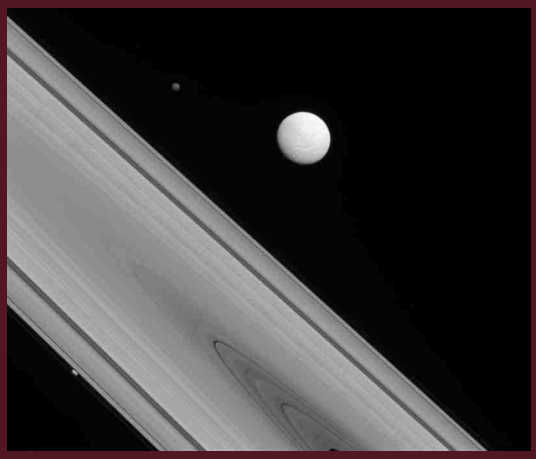
Saturn's northern hemisphere in 2016
Cassini scanned across the planet and its rings on April 25, 2016, capturing three sets of red, green and blue images to cover this entire scene showing the planet and the main rings. The images were obtained using Cassini's wide-angle camera at a distance of approximately 3 million kilometers from Saturn and at an elevation of about 30 degrees above the ring plane. The view looks toward the sunlit side of the rings from a Sun-Saturn-spacecraft angle of 55 degrees. Image scale on Saturn is about 178 kilometers per pixel. [NASA/JPL/ Space Science Institute]

This free NASA e-Book celebrates Saturn as seen through the eyes of the Cassini spacecraft.

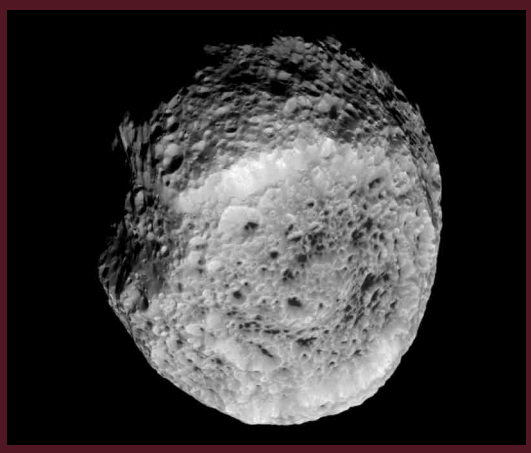
https://saturn.jpl.nasa.gov/resources/7777/?category=images



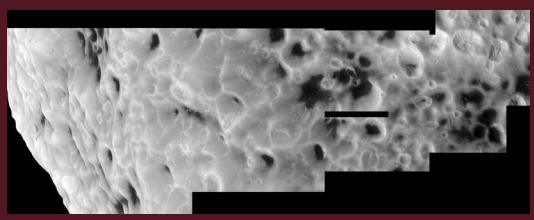
HYPERION



The Cassini spacecraft captures a rare family photo of three of Saturn's moons that couldn't be more different from each other! As the largest of the three, Tethys (image center) is round and has a variety of terrains across its surface. Meanwhile, Hyperion (to the upper-left of Tethys) is the "wild one" with a chaotic spin and Prometheus (lower-left) is a tiny moon that busies itself sculpting the F ring. [NASA/JPL/Space Science Institute]



The Cassini spacecraft looks at Saturn's highly irregular moon Hyperion in this view from the spacecraft's flyby of the moon on Aug. 25, 2011. Hyperion, 270 kilometers across, has an irregular shape, and it tumbles through its orbit: that is, it does not spin at a constant rate or in a constant orientation. [NASA/JPL/Space Science Institute]



This high-resolution Cassini mosaic shows that Hyperion truly has a surface different from any other in the Saturn system. Features within the dark terrain, including a 200-meter-wide impact crater surrounded by rays to the right of center and numerous bright-rimmed craters, indicate that the dark material may be only tens of meters thick with brighter material beneath. [NASA/JPL/Space Science Institute]

European Solar Telescope: first light in 2027

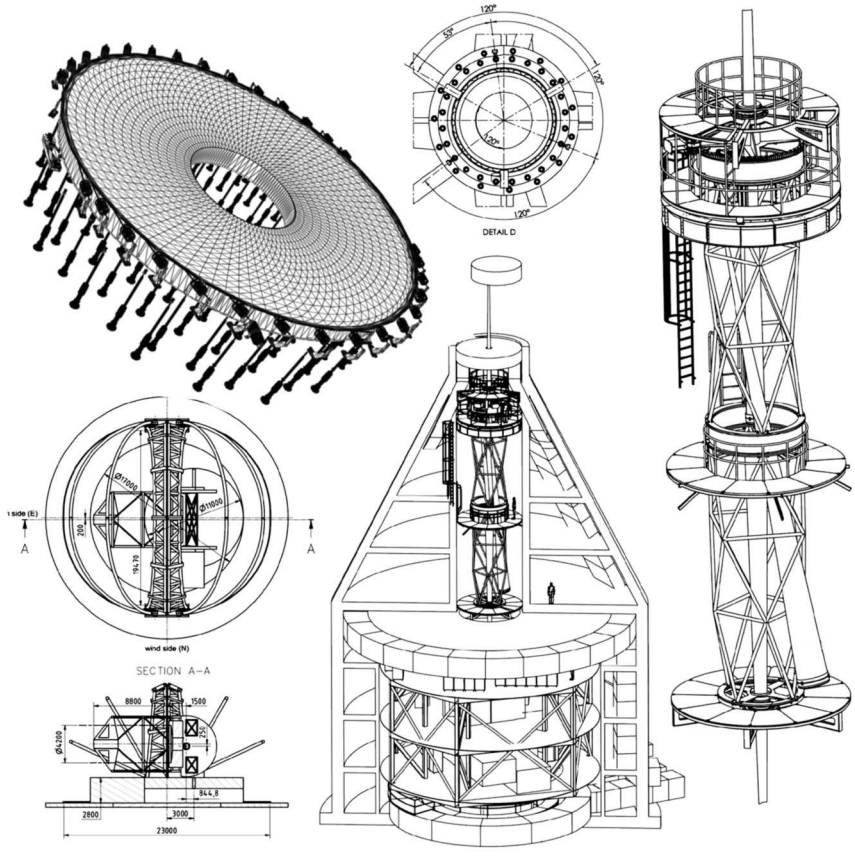
by IAC

Although it will be installed in the Canary Islands (Spain), the Accademia Nazionale dei Lincei in Rome has hosted on Oct. 5, 2017 the first European presentation of the European Solar Telescope (EST) in the frame of the preparatory phase for its construction. This infrastructure will be the largest European telescope to observe the Sun. The construction is expected to start in 2021, and first light is planned for 2027. The project is included in the Roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) since 2016 and involves 21 scientific and in-

dustrial institutions from 15 different European countries. European astronomers have studied the Sun for centuries. Starting with Galileo Galilei, many solar physicists have helped unravel its secrets with the most advanced instrumentation at their disposal. Thanks to those efforts we now know the structure and composition of our star. However, some important questions remain unanswered. Among them is the role played by solar magnetic fields, which are thought to be responsible for the most energetic processes happening in the solar atmosphere. To address these questions, a next-generation telescope is needed. EST will have a 4-meter primary mirror and an advanced adaptive optics system – a technology designed to reduce the image distortions caused by the Earth's turbulent atmosphere. Thus, EST will be able to distinguish structures on the solar surface as small as 30 kilometers.

3D model of the future European Solar Telescope (EST). [Gabriel Pérez Díaz, IAC (SMM)]

3D model of the future European Solar Telescope (EST). [Gabriel Pérez Díaz, IAC (SMM)]. On the right, a few sketches of the structure of the EST. [IAC]



Thanks to its large mirror, EST will also excel in delivering accurate measurements of solar magnetic fields, surpassing by far the capabilities of any existing solar telescope. The main goal of EST is to investigate the structure, dynamics, and energetics of the lower solar atmosphere, where magnetic fields continually interact with the plasma and magnetic energy is sometimes released in powerful explosions.
The event at the Accademia Nazionale dei Lincei is a presentation at European level of a project set to be the cornerstone of European solar physics in the coming decades.

Left to right: Daniele Gallieni (A.D.S. international), Manolo Collados (Instituto de Astrofísica de Canarias, IAC), Fabio Manni (SRS Engineering), Francesca Zuccarello (Università di Catania), Ilaria Ermolli (Instituto Nazionale di Astrofisica), Francesco Berrilli (Università di Roma Tor Vergata) y Salvo Guglielmino (Università di Catania).

The event was attended by researchers related to it and representatives of the Italian industry.
Manolo Collados, coordinator of the EST and researcher at the Instituto de Astrofísica de Canarias (IAC), presented the project, stating that: *"EST will combine the best of the current solar telescopes and will greatly improve their capacities"*.
EST is promoted by the European Association for Solar Telescopes (EAST), which includes around 500 researchers from 15 European countries. Spain participates through the IAC, coordinator of the project and responsible for several work packages, and the Instituto de Astrofísica of Andalucía (IAA-CSIC), who manages the entire communication package and has collaborated in its scientific and technological aspects from its origins.
The telescope will be located in one of the two observatories in the Canary Islands: the Teide Observatory (Izaña, Tenerife) or the Roque de los Muchachos Observatory (Garafía, La Palma), to benefit from the magnificent conditions for observation of the Canary skies. ■

In the two videos here above we can see a presentation of the European Solar Telescope project and the making of a scale model. [IAC]

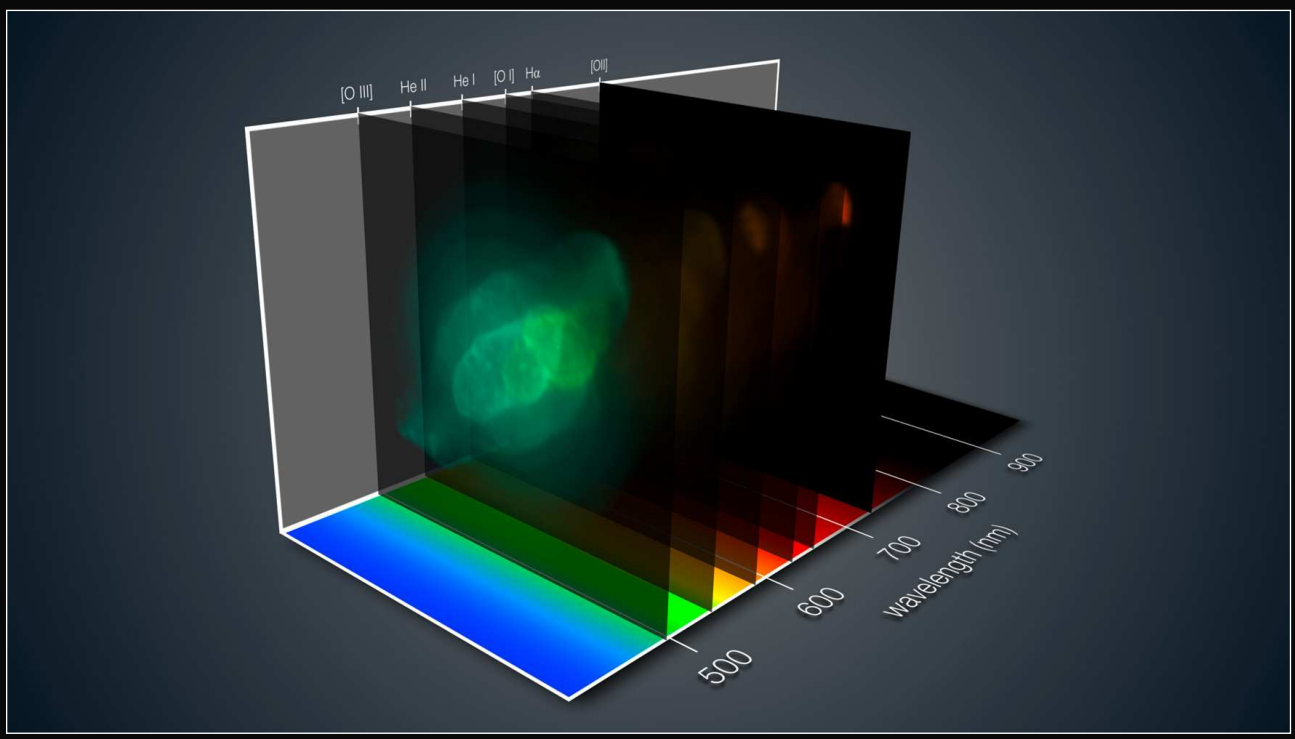
The strange structures of the Saturn Nebula

by ESO

The Saturn Nebula is located approximately 5000 light years away in the constellation of Aquarius (The Water Bearer). Its name derives from its odd shape, which resembles everyone's favourite ringed planet seen edge-on.

But in fact, planetary nebulae have nothing to do with planets. The Saturn Nebula was originally a low-mass star, which expanded into a red giant at the end of its life and began to shed its outer layers. This material was blown out by strong stellar winds and energised by ultraviolet radiation from the hot stellar core left behind, creating a circumstellar nebula of dust and brightly-coloured hot gas. At the heart of the Saturn Nebula lies the doomed

The spectacular planetary nebula NGC 7009, or the Saturn Nebula, emerges from the darkness like a series of oddly-shaped bubbles, lit up in glorious pinks and blues. This colourful image was captured by the powerful MUSE instrument on ESO's Very Large Telescope (VLT), as part of a study which mapped the dust inside a planetary nebula for the first time. [ESO/J. Walsh]



This view shows how the MUSE instrument on ESO's Very Large Telescope gives a three-dimensional depiction of the Saturn Nebula. For each part of this spectacular nebula, the light has been split up into its component colours — revealing in detail the chemical and physical properties of each pixel. During the subsequent analysis the astronomer can move through the data and study different views of the object at different wavelengths, just like tuning a television to different channels at different frequencies. [ESO/J. Walsh]

star, visible in this image, which is in the process of becoming a white dwarf. In order to better understand how planetary nebulae are moulded into such odd shapes, an international team of astronomers led by Jeremy Walsh from ESO used the Multi Unit Spectroscopic Explorer (MUSE) to peer inside the dusty veils of the Saturn Nebula. MUSE is an instrument installed on one of the four Unit Telescopes of the Very Large Telescope at ESO's Paranal Observatory in Chile. It is so powerful because it doesn't just create an image, but also gathers information about the spectrum — or range of colours — of the light from the object at each point in the image.

The team used MUSE to produce the first detailed optical maps of the gas and dust distributed throughout a planetary nebula.

The resulting image of the Saturn Nebula reveals many intricate structures, including an elliptical inner shell, an outer shell, and a halo. It also shows two previously imaged streams extending from either end of the nebula's long axis, ending in bright ansae (Latin for "handles").

Intriguingly, the team also found a wave-like feature in the dust, which is not yet fully understood.

Dust is distributed throughout the nebula, but there is a significant drop in the amount of dust at the rim of the inner shell, where it seems that it is being destroyed. There are several potential mechanisms for this destruction. The inner shell is essentially an expanding shock wave, so it may be smashing into the dust grains and obliterating them, or producing an extra heating effect that evaporates the dust.

Mapping the gas and dust structures within planetary nebulae will aid in understanding their role in the lives and deaths of low mass stars, and it will also help astronomers understand how planetary nebulae acquire their strange and complex shapes.

But MUSE's capabilities extend far beyond planetary nebulae.

This sensitive instrument can also study the formation of stars and galaxies in the early Universe, as well as map the dark matter distribution in galaxy clusters in the nearby Universe. ■

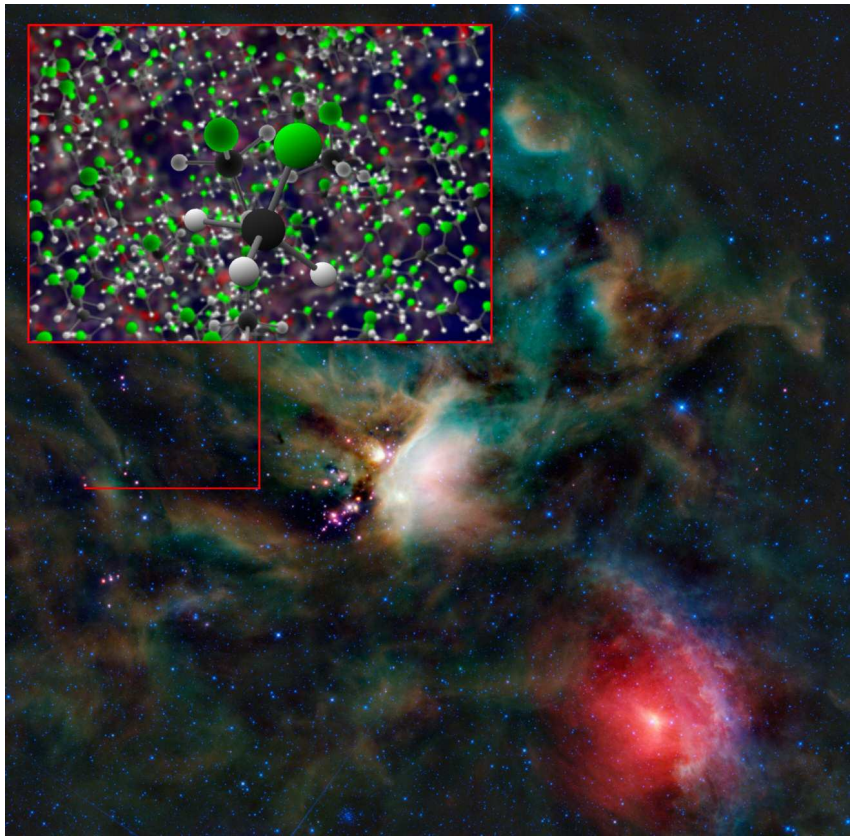
ALMA and Rosetta detect Freon-40 in space

by ESO

Using data captured by ALMA in Chile and from the ROSINA instrument on ESA's Rosetta mission, a team of astronomers has found faint traces of the chemical compound Freon-40 (CH_3Cl), also known as methyl chloride and chloromethane, around both the infant star system IRAS 16293-2422, about 400 light-years away, and the famous comet 67P/Churyumov-Gerasimenko (67P/C-G) in our own Solar System. The new ALMA observation is the first detection ever of a stable organohalogen in interstellar space.

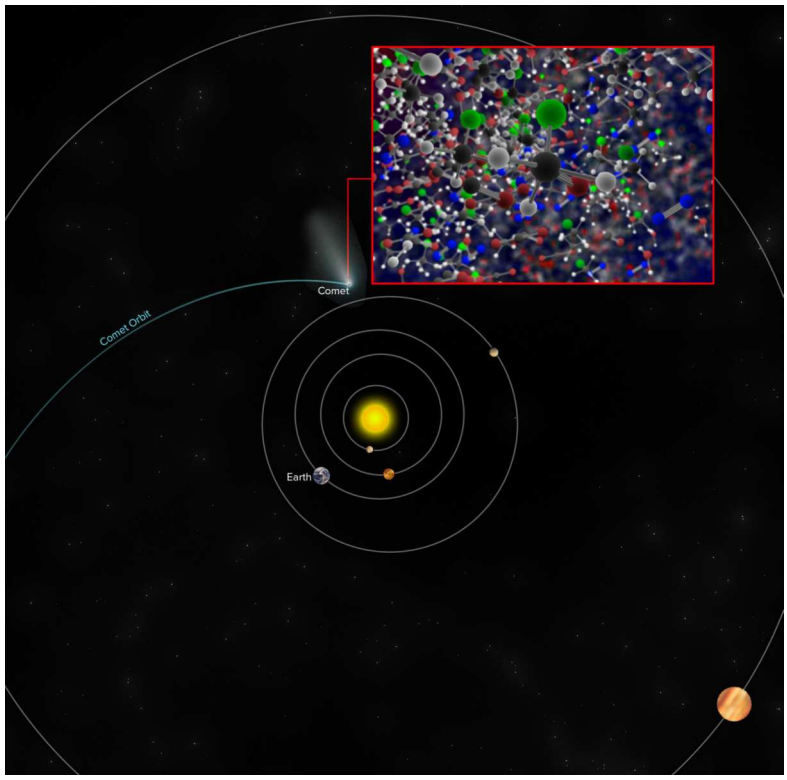
Organohalogens consist of halogens, such as chlorine and fluorine, bonded with carbon and sometimes other elements. On Earth, these compounds are created by some biological processes — in organisms ranging from humans to fungi — as well as by industrial processes such as the production of dyes and medical drugs.

This new discovery of one of these compounds, Freon-40, in places that must predate the origin of life, can be seen as a disappointment, as earlier research had suggested that these molecules could indicate the presence of life.



Organohalogen methyl chloride (Freon-40) discovered by ALMA around the infant stars in IRAS 16293-2422. These same organic compounds were discovered in the thin atmosphere surrounding Comet 67P/C-G by the ROSINA instrument on ESA's Rosetta space probe. [B. Saxton (NRAO/AUI/NSF); NASA/JPL-Caltech/UCLA]

"Finding the organohalogen Freon-40 near these young, Sun-like stars was surprising," said Edith Fayolle, a researcher with the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts in the USA, and lead author of the new paper. *"We simply didn't predict its formation and were surprised to find it in such significant concentra-*



Approximate location of Comet 67P/Churyumov–Gerasimenko when the ROSINA instrument on ESA's Rosetta space probe discovered traces of Freon-40 (methyl chloride), the same molecule detected by ALMA around the IRAS 16293-2422 star-forming region. [B. Saxton (NRAO/AUI/NSF)]

tions. It's clear now that these molecules form readily in stellar nurseries, providing insights into the chemical evolution of planetary systems, including our own."

Exoplanet research has gone beyond the point of finding planets — more than 3000 exoplanets are now known — to looking for chemical markers that might indicate the potential presence of life. A vital step is determining which molecules could indicate life, but establishing reliable markers remains a tricky process. *"ALMA's discovery of organohalogens in the interstellar medium also tells us something about the starting conditions for organic chemistry on planets. Such chemistry is an important step toward the origins of life,"* adds Karin Öberg, a co-author on the study. *"Based on our discovery, organohalogens are likely to be a constituent of the so-called 'primordial soup', both on the young Earth and on nascent rocky exoplanets."*

This suggests that astronomers may have had things around the wrong way; rather than indicating the presence of existing life, organohalogens may be an important element in the little-understood chemistry involved in the origin of life.

Co-author Jes Jørgensen from the Niels Bohr Institute at University of Copenhagen adds: *"This result shows the power of ALMA to detect molecules of astrobiological interest toward young stars on scales where planets may be forming.*

Using ALMA we have previously found precursors to sugars and amino acids around different stars.

The additional discovery of Freon-40 around Comet 67P/C-G strengthens the links between the pre-biological chemistry of distant protostars and our own Solar System."

The astronomers also compared the relative amounts of Freon-40 that contain different isotopes of chlorine in the infant star system and the comet — and found similar abundances.

This supports the idea that a young planetary system can inherit the chemical composition of its parent star-forming cloud and opens up the possibility that organohalogens could arrive on planets in young systems during planet formation or via comet impacts. *"Our results shows that we still have more to learn about the formation of organohalogens,"* concludes Fayolle. *"Additional searches for organohalogens around other protostars and comets need to be undertaken to help find the answer."* ■

This video summarizes the discovery of Freon-40 around both IRAS 16293-2422 and comet 67P/C-G. [ESO]

Deep Space Ga starting again the Moon

by Michele Ferrara

Graphical depiction of a small housing module docking with the energy and propulsion segment that would be a start to the Deep Space Gateway near the Moon. [Spaceflight Insider]

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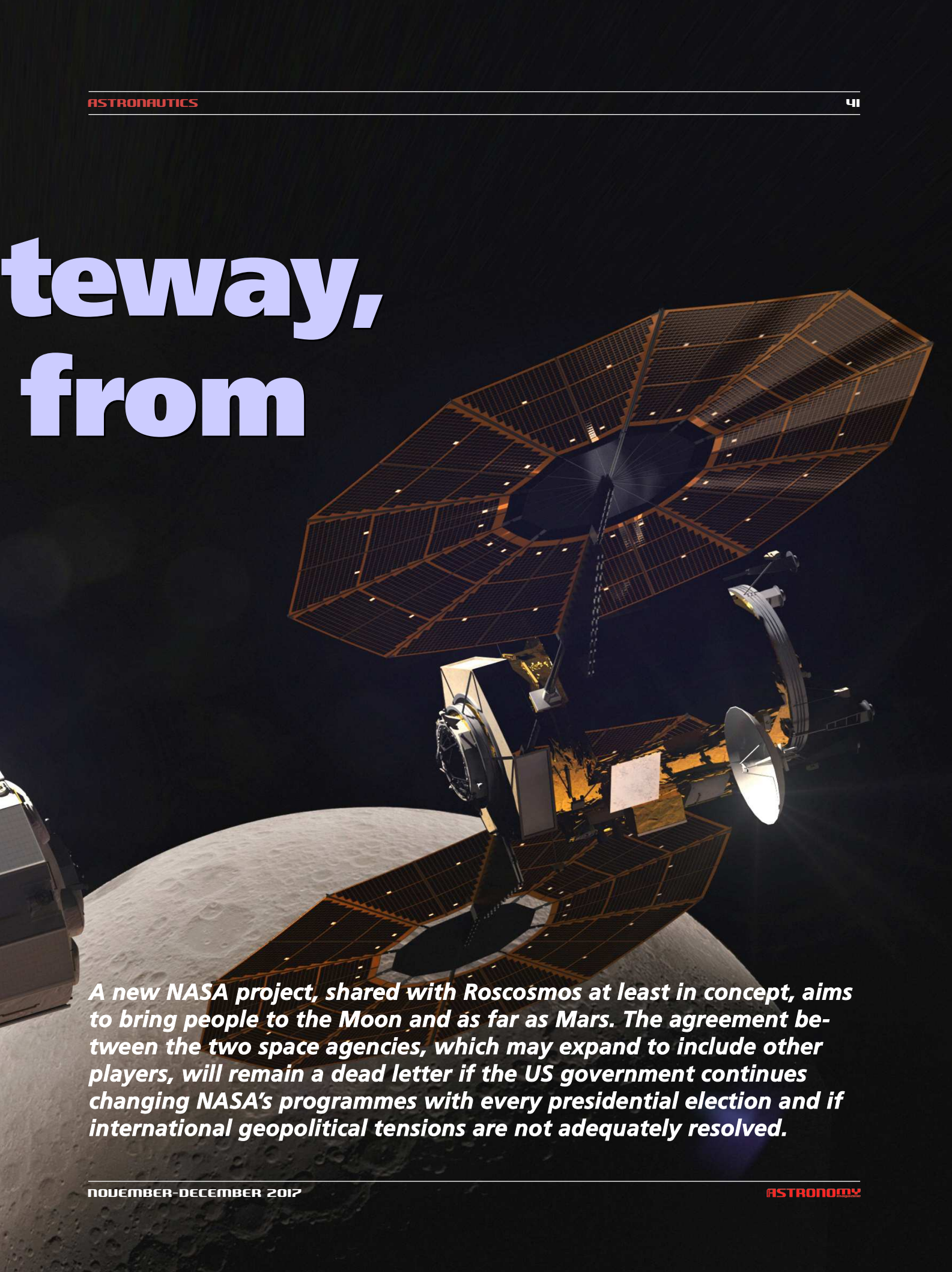
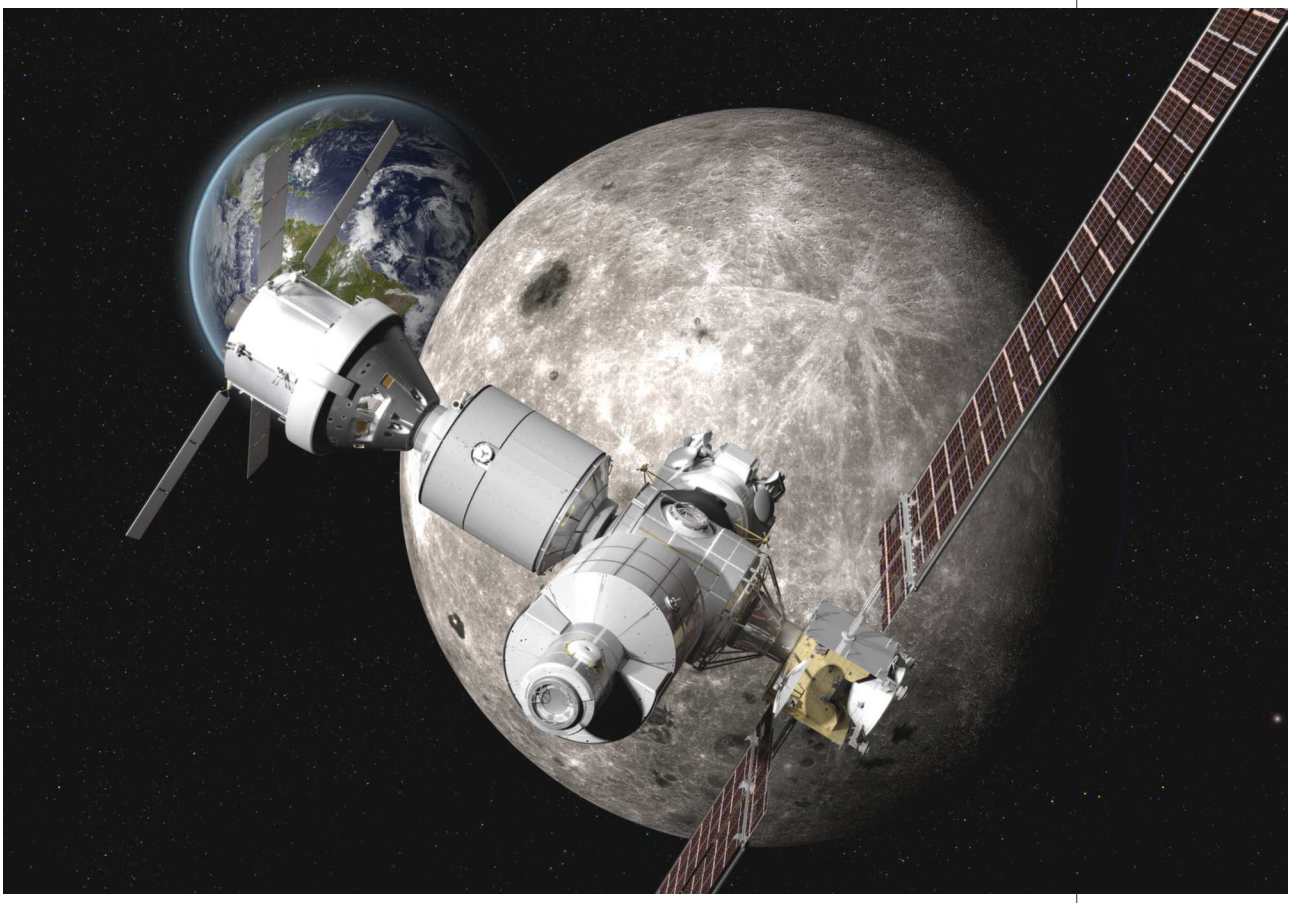
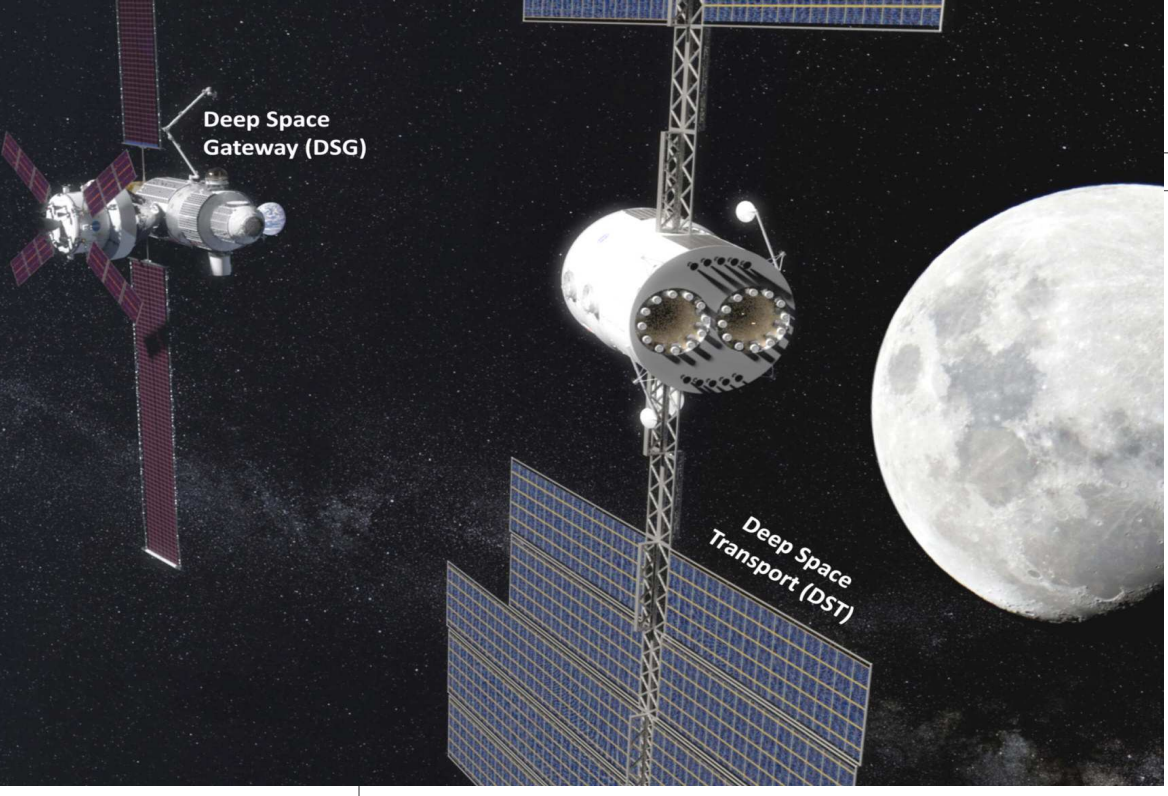


A new NASA project, shared with Roscosmos at least in concept, aims to bring people to the Moon and as far as Mars. The agreement between the two space agencies, which may expand to include other players, will remain a dead letter if the US government continues changing NASA's programmes with every presidential election and if international geopolitical tensions are not adequately resolved.

How many times have we heard, even from authoritative sources, that human missions to Mars were and are imminent? Too many, no doubt, and every time our hopes have been in vain. Until recently, 2020 (or even 2018) was thought to be the year to conquer the red planet, but it has become clear that this will not happen, so the departure date for Mars will be delayed even more. Indeed, as far as NASA is concerned, that date has already been moved to somewhere between 2030 and 2040 because of the US space agency's new strategy: first build a space station near the Moon, and then go to Mars. It is difficult not to feel perplexed by such an idea, since for years everything needed to launch a mission to the red planet from Earth's orbit has been in existence. Why go near the Moon to duplicate all the experiments already done in Earth's orbit? To understand this, we must go back almost three years, specifically to March 2015, when the Russian space agency Roscosmos announced that it would cooperate with NASA in building a new space station near the Earth to replace the International Space Station, which will not be funded beyond 2024 unless plans are revised. A lot has changed since that promising statement: some geopolitical situations have chilled US-Russian relations, and a new US president was elected who, freshly installed in office on 20 January, appointed a new NASA administrator. As strange as it may seem, NASA's priorities, rather than being tied to the invariable, vital and unquestionable importance of meeting certain space goals, change with the presidents and the administrations they appoint. During the years of the younger Bush, for example, the priority was to set foot again on the surface of the Moon by 2020; with Obama, the

On this page and the next, portrayals of the Deep Space Gateway space station and the Deep Space Transport Vehicle in operation near the Moon. [Boeing, NASA]

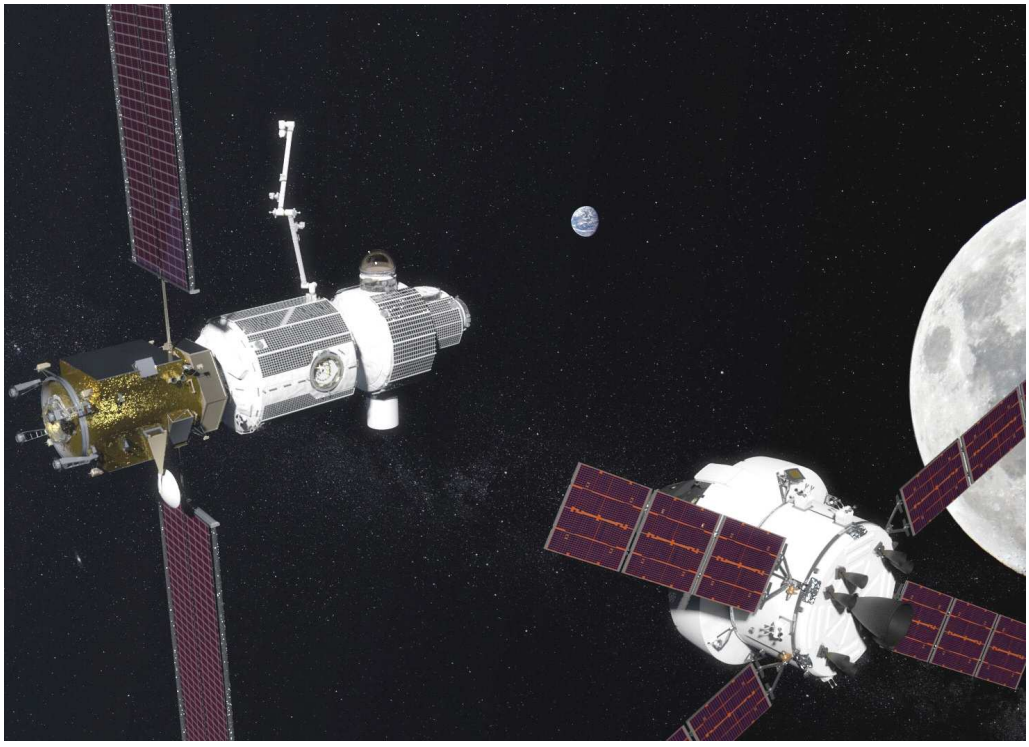




goal seemed to be to reach Mars, but then it was downsized to simply capturing an asteroid or even merely some surface samples from one; now, with Trump, there are no more human missions to the asteroids, but rather new interest in the Moon, with Mars in second place. All this happens because there is no longer any real competition to conquer space, and the only nation that could relight that flame, China, is just now discovering the pitfalls of outer space.

During the 1960s, fortunately, the governments of the superpowers were much more motivated to achieve certain goals. The US-USSR rivalry in the space race was crucial in reaching the Moon.

Since then, the more or less constant collaboration and sharing of expertise between the major space agencies in the world have certainly produced benefits, but none of it has carried astronauts further than 450 km from our planet's surface. Aside from the projects in the pipeline, today the scenario is roughly the following: the ISS's days are numbered; the 2015 announcement of a new US-Russian space station is not being pursued; the Chinese dream of going to the Moon has suffered various setbacks, and little is known about the development of their plan for an Earth-orbiting space station; India initially had a space program, which was sus-



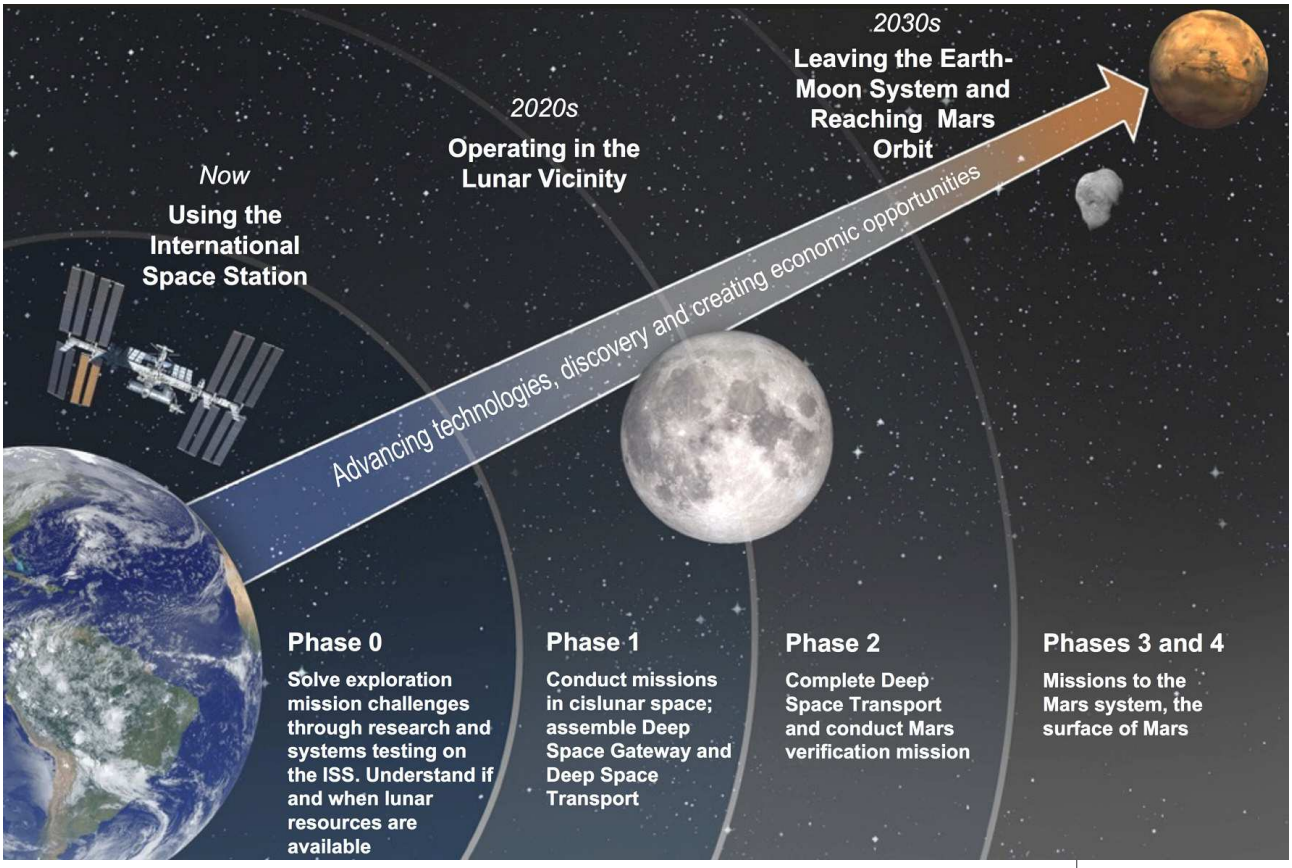
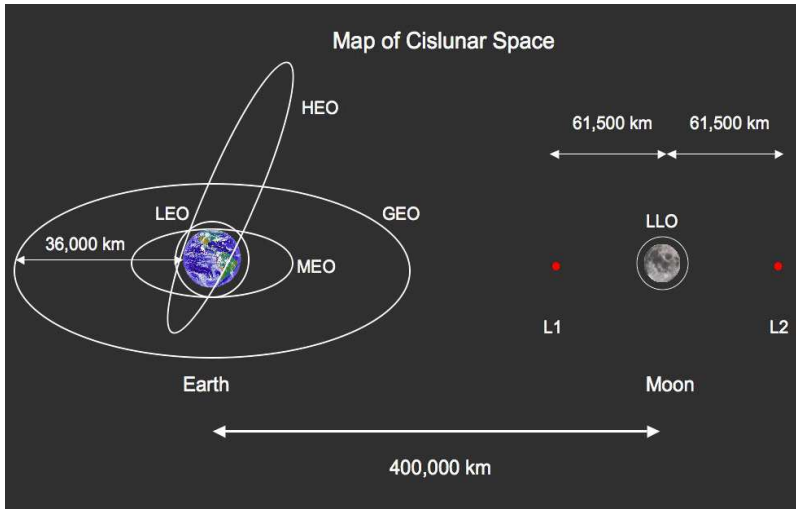


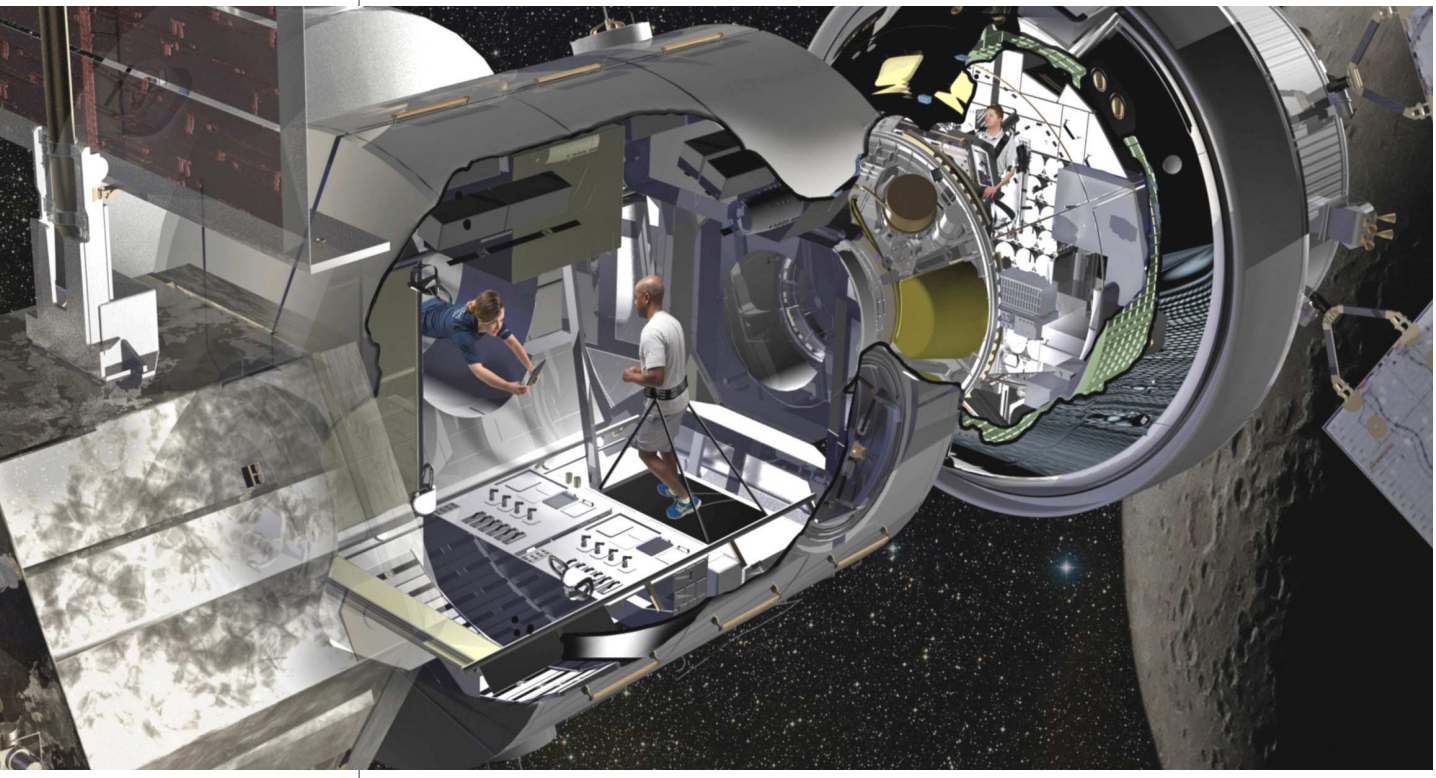
Diagram of the new strategy to reach Mars, chosen by NASA and shared by Roscosmos. The current phase is Phase 0, and for now there is only an agreement on the intention to possibly proceed further. [NASA]

pended and then relaunched without any particular ambitions, while all the other government space agencies are limited to at most sending astronauts and supplies to the ISS, stirring up often unjustified enthusiasms since going into orbit is no longer a novelty and even the docking manoeuvre is nothing new. As if this weren't enough, even today it isn't terribly rare to see space missions threatened by the explosion of a typical carrier rocket, whose functioning principle is more than 80 years old. In this less-than-exhilarating scenario, it is inevitable that news of the possible construction of a space station near the Moon would attract attention from the mass media. But what aroused special interest was a joint announcement from NASA and Roscosmos in late September, according to which the two space agencies will work together on the project known as the Deep Space Gateway. The idea is to build a space station in a cislunar position, meaning in the Lagrangian point L1 of the Earth-Moon system, which allows relatively easy access to lunar and terrestrial orbits with a minimum change in velocity, with considerable advantages for transporting goods and people from one celestial body to the other. In addition to being a place to experience all the conditions that astronauts may encounter during a journey towards Mars, the Deep Space Gateway will act as an outpost for lunar landing missions as well as missions to intermediate destinations such as nearby asteroids. The Deep Space Gateway will therefore be a sort of spaceport, where space vehicles and crews will arrive and depart for different kinds of missions. To assemble the new space station, NASA will use a powerful carrier rocket called the Space Launch System, integrated with the Orion Multi-Purpose Crew Vehicle, a small spacecraft (5 metres in diameter, 3.3 metres high) capable of hosting four astro-

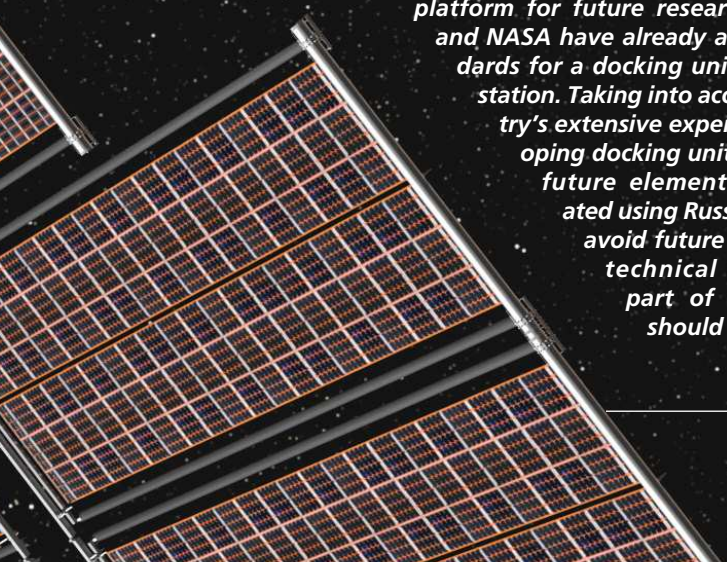
At right, a schematic display of the cislunar space. Below, a possible scene from life inside the housing module of the cislunar space station. [Lockheed Martin]

nauts. Exemplars of both the carrier and the spacecraft are currently in production and will be used in the first two missions, one of which should launch during the 2020s. The basic structure of the Deep Space Gateway will include the Gateway Power-Propulsion Module, which will be used to generate electricity on the space station; the Cislunar Habitation Module, which will be used for long periods of residence on board the space station; the Gateway Logistics Module, which will be used for experiments and logistics; and the Gateway Airlock Module, a compensation chamber that will be used to perform extravehicular activities. The propulsion system will mainly use electricity for orbital corrections. In a second phase, likely to be years after the completion of the DSG, the plan is to create the Deep Space Transport, a reusable vehicle with electrical and chemical propulsion, specially designed for crewed missions towards Mars.





To assemble and launch a space vehicle into lunar orbit would surely have advantages over the other more 'earthly' solutions, but there is the risk that something unforeseen could always push the first human mission to Mars further away. On the other hand, the openness that NASA immediately showed towards the other international space flight entities, which it asked for collaboration and sharing of experiences, cannot help but be favourable to the achievement of the Deep Space Gateway. Robert Lightfoot, acting administrator at NASA's headquarters in Washington, noted when the project was introduced: *"I envision different partners, both international and commercial, contributing to the gateway and using it in a variety of ways with a system that can move to different orbits to enable a variety of missions. The gateway could move to support robotic or partner missions to the surface of the Moon, or to a high lunar orbit to support missions departing from the gateway to other destinations in the solar system"*. And Igor Komarov, Director



This scene shows Boeing's idea for the Deep Space Transit Vehicle, which will be used to carry the astronauts from the space station to the Moon and towards Mars. [Boeing]

General of Roscosmos, upon the signing of the joint declaration with NASA on 27 September, at the 68th International Astronautical Congress in Adelaide, Australia, said: *"We understand that we are key players and we have to work on these missions together. The station will be a serious platform for future research. Roscosmos and NASA have already agreed on standards for a docking unit of the future station. Taking into account the country's extensive experience in developing docking units, the station's future elements will be created using Russian designs. To avoid future problems over technical cooperation, part of the standards should be unified, for a possibility for various countries to work on their craft and dock to the international lunar station"*. Today, we cannot imagine what progress may be spurred by the broad agreement in Adelaide between the two biggest space agencies on our planet. We note, however, that Roscosmos and NASA have as yet only shown willingness to work together on a future cislunar space station, which does not oblige either party to build the spaceport. Also, as we have seen, the election of a new US president would be enough to reshuffle the deck and give top priority to other projects. ■

Hubble observes pitch black planet

by NASA/ESA

Using the Space Telescope Imaging Spectrograph (STIS) on the NASA/ESA Hubble Space Telescope, an international team led by astronomers at McGill University, Canada, and the University of Exeter, UK, have measured how much light the exoplanet WASP-12b reflects — its albedo — in order to learn more about the composition of its atmosphere. The results were surprising, explains lead author Taylor Bell, a Master's student in astronomy at McGill University who is affiliated with the Institute for Research on Exoplanets: *"The measured albedo of WASP-12b is 0.064 at most. This is*

This artist's impression shows the exoplanet WASP-12b, an alien world as black as fresh asphalt, orbiting a star like our Sun. Scientists were able to measure its albedo, the amount of light the planet reflects. The results showed that the planet is extremely dark at optical wavelengths. [NASA, ESA, and G. Bacon (STScI)]

an extremely low value, making the planet darker than fresh asphalt!" This makes WASP-12b two times less reflective than our Moon which has an albedo of 0.12. Bell adds: *"The low albedo shows we still have a lot to learn about WASP-12b and other similar exoplanets."* WASP-12b orbits the Sun-like star WASP-12A, about 1400 light-years away, and since its discovery in 2008 it has become one of the best studied exoplanets. With a radius almost twice that of Jupiter and a year of just over one Earth day, WASP-12b is categorised as a hot Jupiter.

Because it is so close to its parent star, the gravitational pull of the star has stretched WASP-12b into an egg shape and raised the surface temperature of its daylight side to 2600 degrees Celsius.

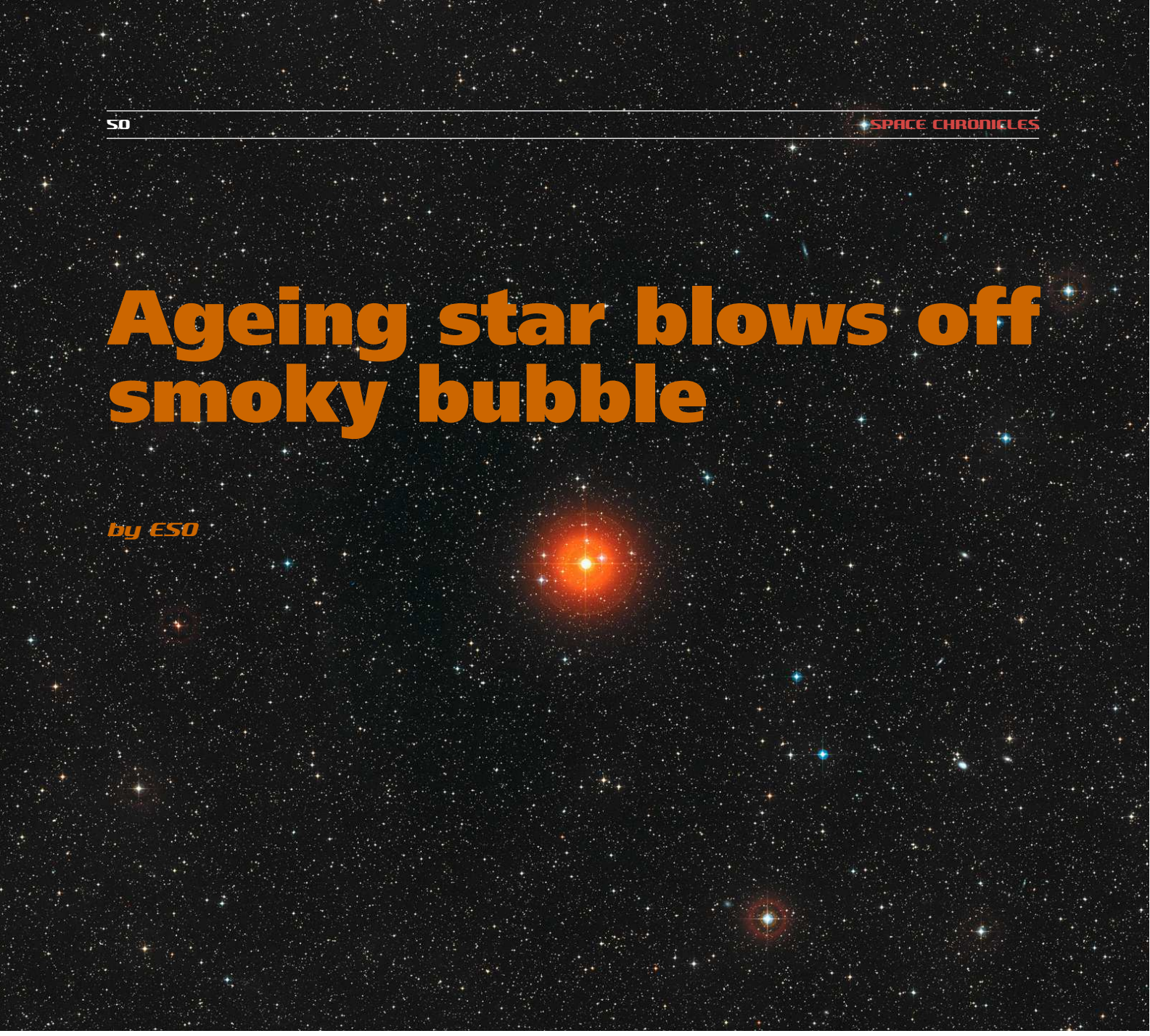
The high temperature is also the most likely explanation for WASP-12b's low albedo. *"There are other hot Jupiters that have been found to be remarkably black, but they are much cooler than WASP-12b. For those planets, it is suggested that things like clouds and alkali metals are the reason for the absorption of light, but those don't work for WASP-12b because it is so incredibly hot,"* explains Bell.

The daylight side of WASP-12b is so hot that clouds cannot form and alkali metals are ionised. It is even hot enough to break up hydrogen molecules into atomic hydrogen which causes the atmosphere to act more like the atmosphere of a low-mass star than like a planetary atmosphere. This leads to the low albedo of the exoplanet. To measure the albedo of WASP-12b the scientists observed the exoplanet in October 2016 during an eclipse, when the planet was near full phase and passed behind its host star for a time. This is the best method to determine the albedo of an exoplanet, as it involves directly measuring the amount of light being reflected. However, this technique requires a precision ten times greater than traditional transit observations. Using Hubble's Space Telescope Imaging Spectrograph the scientists were able to measure the albedo of WASP-12b at several different wavelengths. *"After we measured the albedo we compared it to spectral models of previously suggested atmospheric models of WASP-12b"*, explains Nikolay Nikolov (University of Exeter, UK), co-author of the study. *"We found that the data match neither of the two currently proposed models."* The new data indicate that the WASP-12b atmosphere is composed of atomic hydrogen and helium.

WASP-12b is only the second planet to have spectrally resolved albedo measurements, the first being HD 189733b, another hot Jupiter. The data gathered by Bell and his team allowed them to determine whether the planet reflects more light towards the blue or the red end of the spectrum. While the results for HD 189733b suggest that the exoplanet has a deep blue colour, WASP-12b, on the other hand, is not reflecting light at any wavelength. WASP-12b does, however, emit light because of its high temperature, giving it a red hue similar to a hot glowing metal. *"The fact that the first two exoplanets with measured spectral albedo exhibit significant differences demonstrates the importance of these types of spectral observations and highlights the great diversity among hot Jupiters,"* concluded Bell. ■

Ageing star blows off smoky bubble

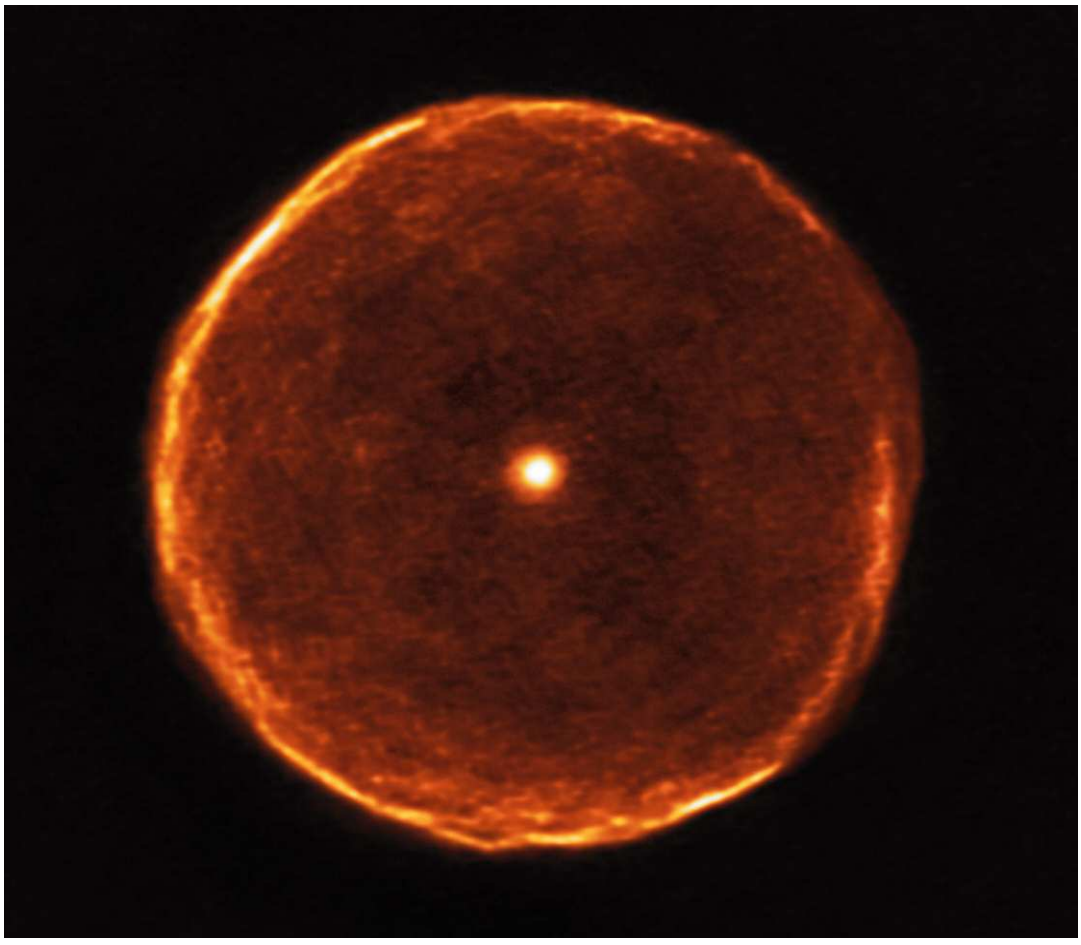
by ESO



In the faint southern constellation of Antlia (The Air Pump) the careful observer with binoculars will spot a very red star, which varies slightly in brightness from week to week. This very unusual star is called U Antliae and new observations with the Atacama Large Millimeter/submillimeter Array (ALMA) are revealing a remarkably thin spherical shell around it. U Antliae is a carbon star, an evolved, cool and luminous star of the asymptotic giant branch type. Around 2700 years ago, U Antliae went through a short period of rapid mass loss. During this period of only a few hundred years, the material making up the shell seen in the new ALMA data was ejected at high speed. Examination of this shell in further detail also shows some evidence of thin, wispy gas clouds known as filamentary substructures.

This spectacular view was only made possible by the unique ability to create sharp images at multiple wavelengths that is provided by the ALMA radio telescope, located on the Chajnantor Plateau in Chile's Atacama Desert. ALMA can see much finer structure in the U Antliae shell than has previously been possible. The new ALMA data are not just a single image; ALMA produces a three-dimensional dataset (a data cube) with each slice being observed at a slightly different wavelength. Because of the Doppler Effect, this means that different slices of the data cube show images of gas moving at different speeds

This image from the Digitized Sky Survey 2 shows the very red carbon star U Antliae and its surroundings. [ESO, Digitized Sky Survey 2. Acknowledgement: Davide De Martin]



This ALMA image reveals much finer structure in the U Antliae shell than has previously been possible. Around 2700 years ago, U Antliae went through a short period of rapid mass loss. During this period of only a few hundred years, the material making up the shell seen in the new ALMA data was ejected at high speed. Examination of this shell in further detail also shows some evidence of thin, wispy clouds known as filamentary substructures. [ALMA (ESO/ NAOJ/ NRAO)/F. Kerschbaum]

towards or away from the observer. This shell is also remarkable as it is very symmetrically round and also remarkably thin.

By displaying the different velocities we can cut this cosmic bubble into virtual slices just as we do in computer tomography of a human body. Understanding the chemical composition of the shells and atmospheres of these stars, and how these shells form by mass loss, is important to properly understand how stars evolve in the early Universe and also how galaxies evolved.

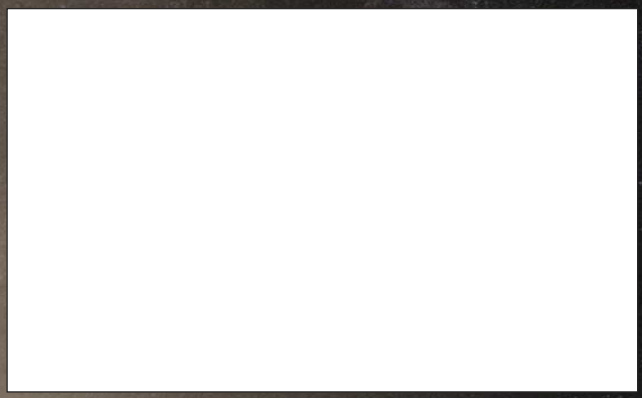
Shells such as the one around U Antliae show a rich variety of chemical compounds based on carbon and other elements. They also help to recycle matter, and contribute up to 70% of the dust between stars. ■

Astronomers have used ALMA to capture a strikingly beautiful view of a delicate bubble of expelled material around the exotic red star U Antliae. These observations will help astronomers to better understand how stars evolve during the later stages of their life-cycles. This short podcast takes a look at this important new result and what it means. [ESO]

Inferno world with titanium skies

by ESO

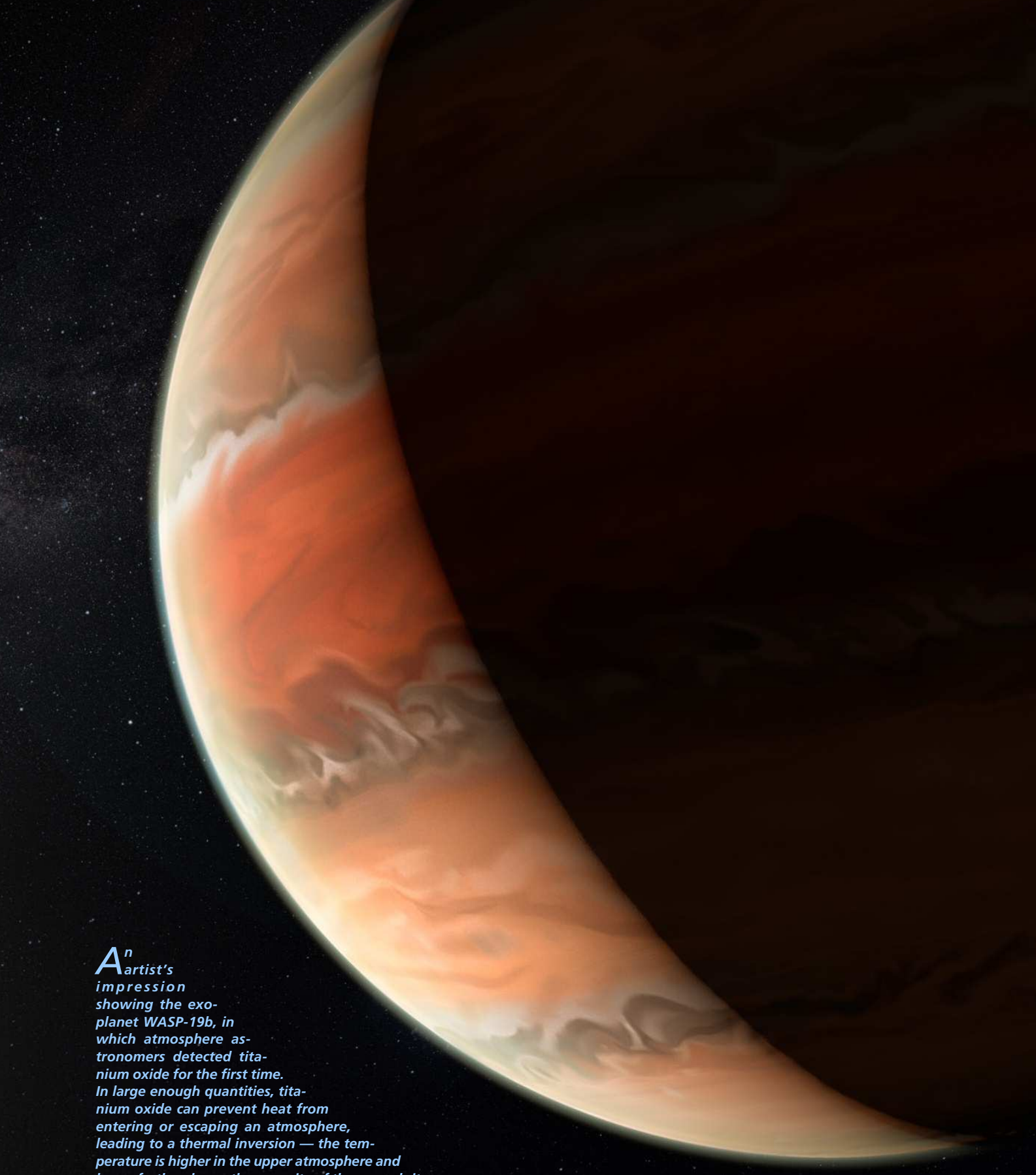
A team of astronomers led by Elyar Sedaghati, an ESO fellow and recent graduate of TU Berlin, has examined the atmosphere of the exoplanet WASP-19b in greater detail than ever before.



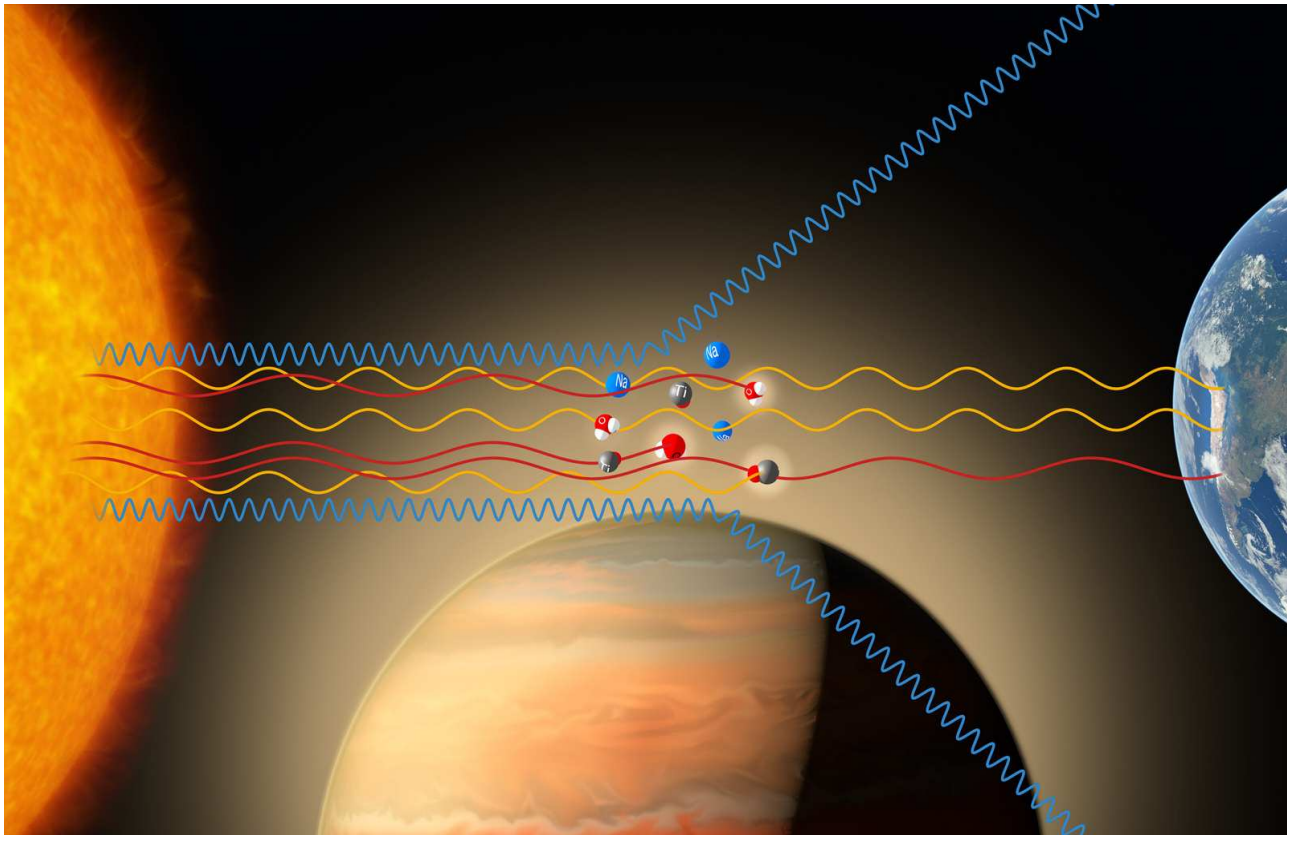
This remarkable planet has about the same mass as Jupiter, but is so close to its parent star that it completes an orbit in just 19 hours and its atmosphere is estimated to have a temperature of about 2000 degrees Celsius. As WASP-19b passes in front of its parent star, some of the starlight passes through the planet's atmosphere and leaves subtle fingerprints in the light that eventually reaches Earth.

By using the FORS2 instrument on the Very Large Telescope the team was able to carefully analyse this light and deduce that the atmosphere contained small amounts of titanium oxide, water and traces of sodium, alongside a strongly scattering global haze. *"Detecting such molecules is, however, no simple feat,"* explains Elyar Sedaghati, who spent 2 years as ESO student to work on this project. *"Not only do we need data of exceptional quality, but we also need to perform a sophisticated analysis. We used an algorithm that explores many millions of spectra spanning a wide range of chemical compositions, temperatures, and cloud or haze properties in order to draw our conclusions."*

Titanium oxide is rarely seen on Earth. It is known to exist in the atmospheres of cool stars. In the atmospheres of hot planets like WASP-19b, it acts as a heat absorber. If present in large enough quantities, these molecules prevent



An artist's impression showing the exoplanet WASP-19b, in which atmosphere astronomers detected titanium oxide for the first time. In large enough quantities, titanium oxide can prevent heat from entering or escaping an atmosphere, leading to a thermal inversion — the temperature is higher in the upper atmosphere and lower further down, the opposite of the normal situation. [ESO/M. Kornmesser] – Previous page, flying from the Earth to the star WASP-19 in the constellation Vela. [ESO/http://spaceengine.org. Music: John Dyson]



As WASP-19b passes in front of its parent star, some of the starlight passes through the planet's atmosphere and leaves subtle fingerprints in the light that eventually reaches Earth. By using the FORS2 instrument on the Very Large Telescope the team was able to carefully analyse this light and deduce that the atmosphere contained small amounts of titanium oxide, water and traces of sodium, alongside a strongly scattering global haze. [ESO/M. Kornmesser]

heat from entering or escaping through the atmosphere, leading to a thermal inversion — the temperature is higher in the upper atmosphere and lower further down, the opposite of the normal situation. Ozone plays a similar role in Earth's atmosphere, where it causes inversion in the stratosphere.

"The presence of titanium oxide in the atmosphere of WASP-19b can have substantial effects on the atmospheric temperature structure and circulation." explains Ryan MacDonald, another team member and an astronomer at Cambridge University, United Kingdom. *"To be able to examine exoplanets at this level of detail is promising and very exciting."* adds Nikku Madhusudhan from Cambridge University who oversaw the theoretical interpretation of the observations.

The astronomers collected observations of WASP-19b over a period of more than one year. By measuring the relative variations in the planet's radius at different wavelengths of light that passed through the exoplanet's atmosphere and comparing the observations to atmospheric models, they could extrapolate different properties, such as the chemical content, of the exoplanet's atmosphere.

This new information about the presence of metal oxides like titanium oxide and other substances will allow much better modeling of exoplanet atmospheres. Looking to the future, once astronomers are able to observe atmospheres of possibly habitable planets, the improved models will give them a much better idea of how to interpret those observations.

"This important discovery is the outcome of a refurbishment of the FORS2 instrument that was done exactly for this purpose," adds team member Henri Boffin, from ESO, who led the refurbishment project. *"Since then, FORS2 has become the best instrument to perform this kind of study from the ground."* ■

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