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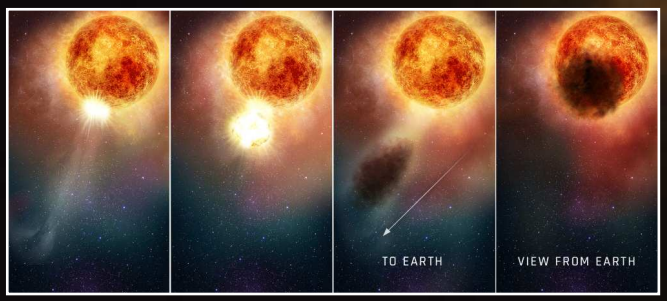
FREE ASTRONOMY magazine

Bi-monthly magazine of scientific and technical information ✶ September-October 2020

Betelgeuse

100 years of uncertainties

In the mind of ET



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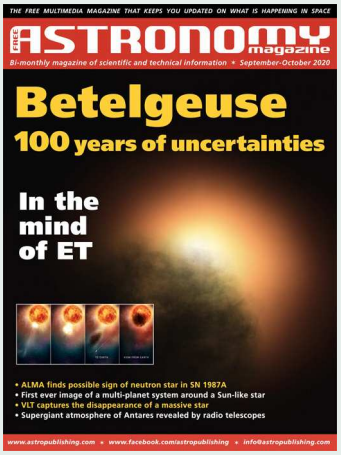

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SUMMARY

Betelgeuse – 100 years of uncertainties

by Michele Ferrara

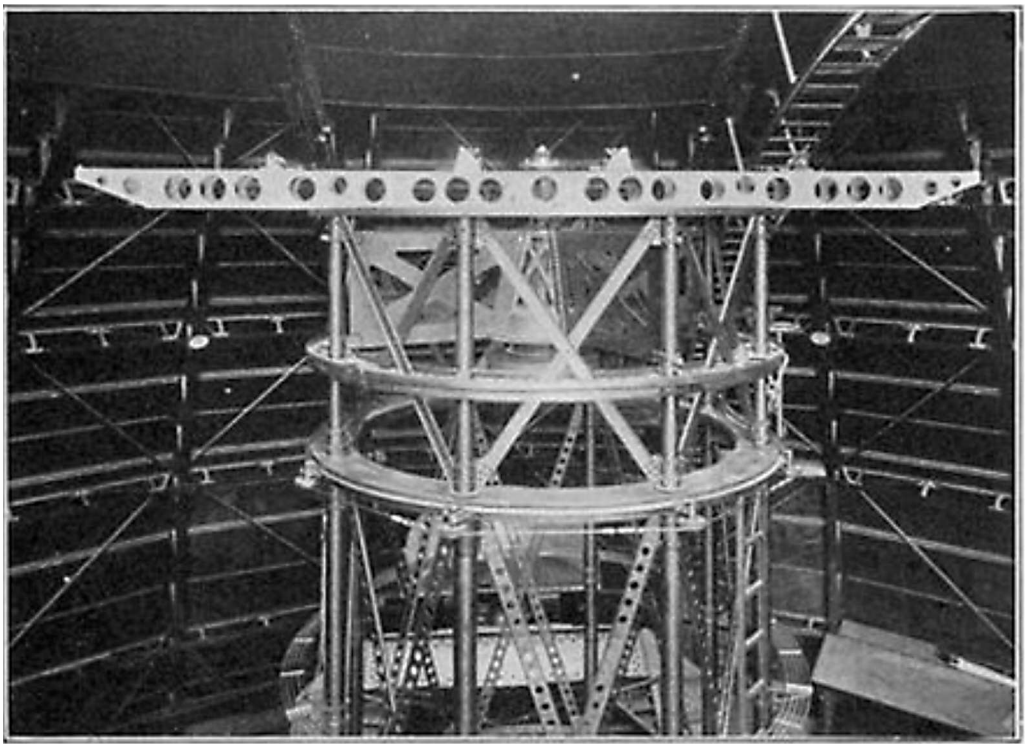
revised by Damian G. Allis
NASA Solar System Ambassador

The alpha star of the constellation Orion is perhaps the closest red supergiant to Earth and one of the most observed and studied variable stars in history. It still continues to surprise us and to hide valuable information that would be fundamental to our understanding of how such massive dying stars, whose diameter can exceed a billion kilometers before exploding as supernovae, evolve.

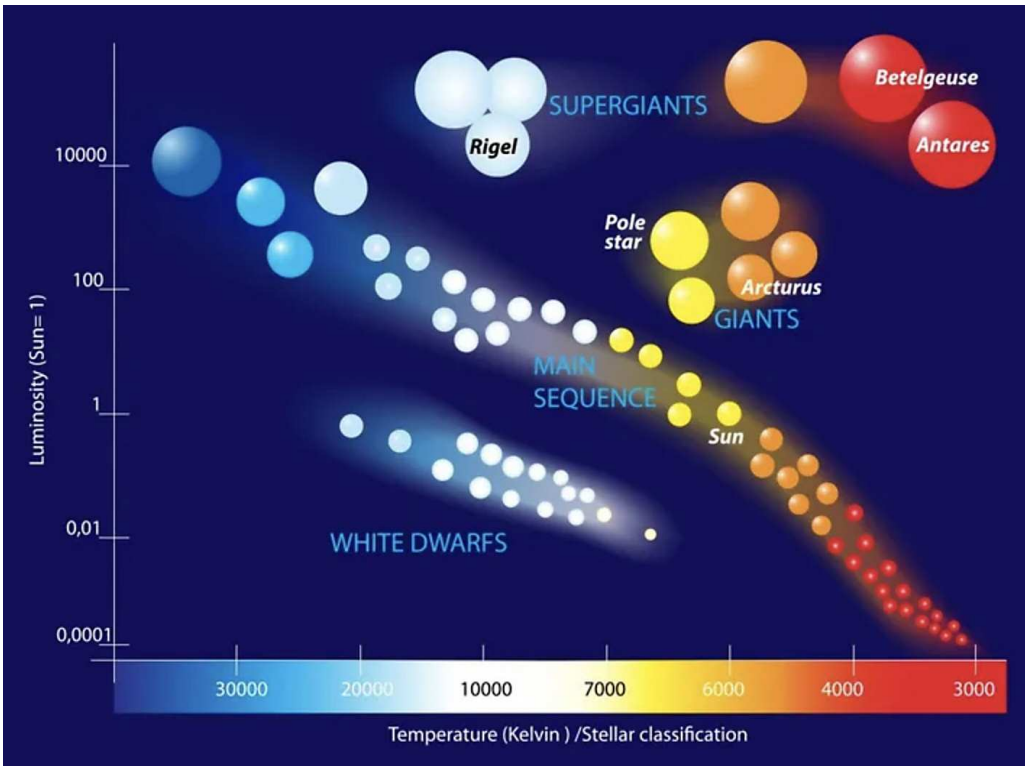
Exactly 100 years ago, the physicist Albert Abraham Michelson and the astronomer Francis Gladheim Pease were preparing the equipment for and setting up, on top of the Hooker Telescope at Mount Wilson Observatory, an experiment of interferometry. On 13 December 1920, they made the first measurement of Betelgeuse's angular diameter. Before that day, the only star whose real size was known was the Sun, because both its angular diameter and its distance could be calculated with relative ease. All other stars appeared point-like even in the most powerful telescopes and, although the distances to many were known, it was impossible to deter-

The unmistakable constellation Orion rises above the Swedish-ESO Submillimeter Telescope at La Silla Observatory. [Y. Beletsky (LCO)/ESO]

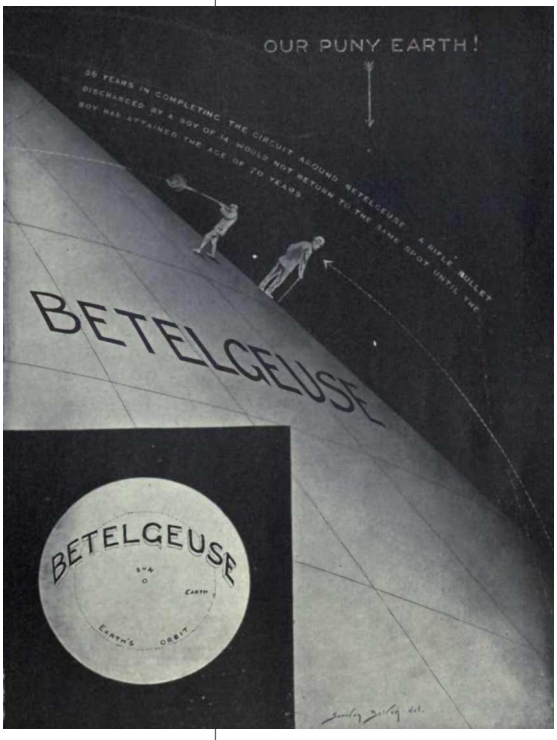
mine their physical diameters. Thanks both to the instrument and technique, developed primarily by Michelson, the two scientists obtained for the angular diameter of Betelgeuse the value of 47 mas (milliarcseconds) at the yellow-light wavelength of 5750 Å. This angular diameter measurement was valid only for a uniformly illuminated stellar disk. Since it was reasonable to assume that Betelgeuse, like the Sun, was also better characterized as darkening at the edge, Michelson and Pease adjusted their value by bringing it up to 55 mas. At that time, the parallax angle of Betelgeuse was estimated to be 0.018", but the two scientists did not know that this value was about four times larger than the actual one, resulting in their underestimation of the distance to the star: about 180 light-years. This, in turn, produced an underestimation of the star's size, which, nonetheless, turned out to be colossal: 450 million km in diameter. Placed at the center of our solar system, Betelgeuse would have



Albert A. Michelson (left) and Francis G. Pease were the first researchers to calculate the angular diameter of Betelgeuse. To do this, they installed an interferometer on top of the Hooker Telescope at Mount Wilson Observatory, visible on the side.



Virtual Hertzsprung-Russell diagram showing Betelgeuse's position with respect to other reference stars. Below, a curious illustration inserted in Hutchinson's Splendor of the Heavens, *which emphasizes the extraordinary size of Betelgeuse.*

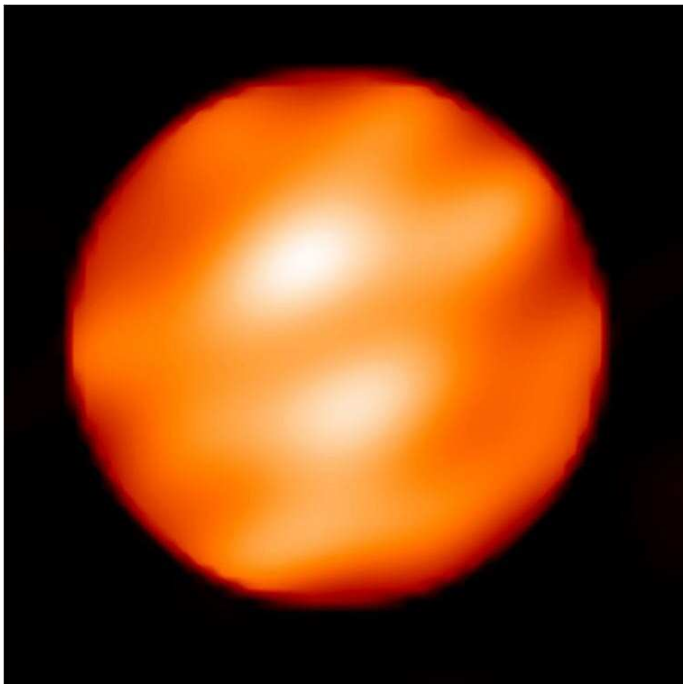


reached the orbit of Mars. To convey its enormousness, a curious illustration from the surface of Betelgeuse was inserted into a popular work of 1923, entitled *Hutchinson's Splendor of the Heavens*. It shows a 14-year-old boy on its surface firing a bullet from a rifle; behind him is a 70-year-old man who is about to be hit by the same bullet. The young and the old in this odd illustration are the same person – the bullet took 56 years to circle around Betelgeuse and return to its starting point. Today we know that that paradoxical suicide could not have taken place, as Betelgeuse is much larger than what Michelson and Pease calculated. In fact, the star is approximately as large as the orbit of Jupiter, although the diameter is still not known precisely. This is due to the fact that, despite a century of measurements, the distance to the star is still very uncertain.

About Betelgeuse, we know for sure that it is a red supergiant (more orange than red) near the end of its existence and that it will end with an explosion of a type II supernova (core collapse). In the modern star classification system, developed starting in the 1930s by William Morgan and Philip Keenan, Betelgeuse oscillates between the spectral classes M1 and M2Ia-Iab, betraying its nature as a variable star. This variability has been known since ancient times and is caused by the tumultuous reshuffling

of its outer layers over semi-regular periods – typical behavior of a very old and massive star. These jolts are a complication for anyone trying to accurately measure the physical properties of Betelgeuse.

As our understanding of stellar evolution progressed, astronomers realized that the turbulent activity of Betelgeuse should have caused a conspicuous loss of mass, quantifiable as one solar mass every 10,000 years. The gravitational attraction exerted on the outermost stellar layers is indeed so mild that the thrust of the convective cells that transport heat from the core towards the surface is sufficient to throw into outer space mat-



Above, a composite image of the star field around Betelgeuse. [ESO/Digitized Sky Survey 2. Ack D. De Martin] On the left, the first detailed image of Betelgeuse's surface, obtained in near-infrared by the IOTA interferometer at the Paris Observatory. The resolution is 9 mas. The differences in brightness are attributable to convective phenomena. [Haubois/Perrin (LESIA, Observatoire de Paris) 2010]

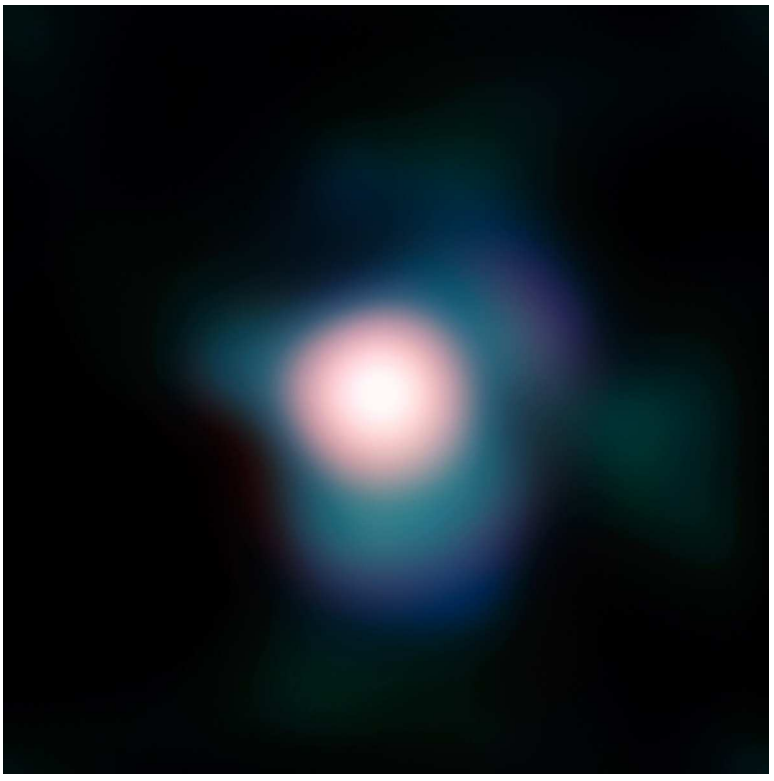
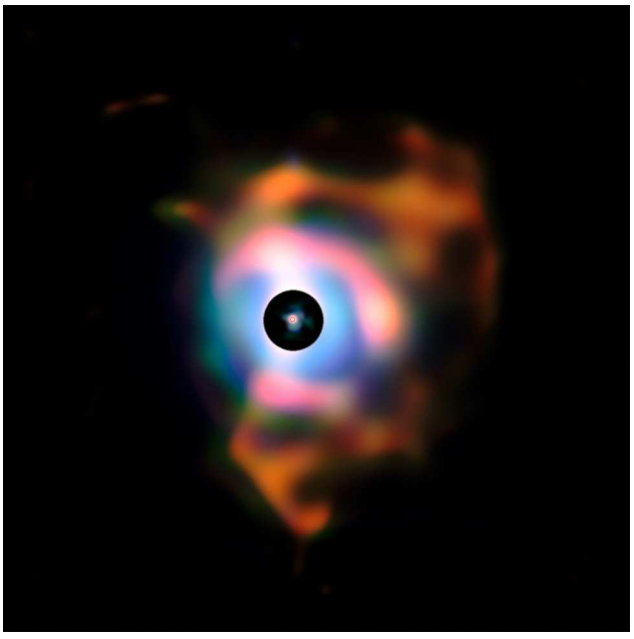
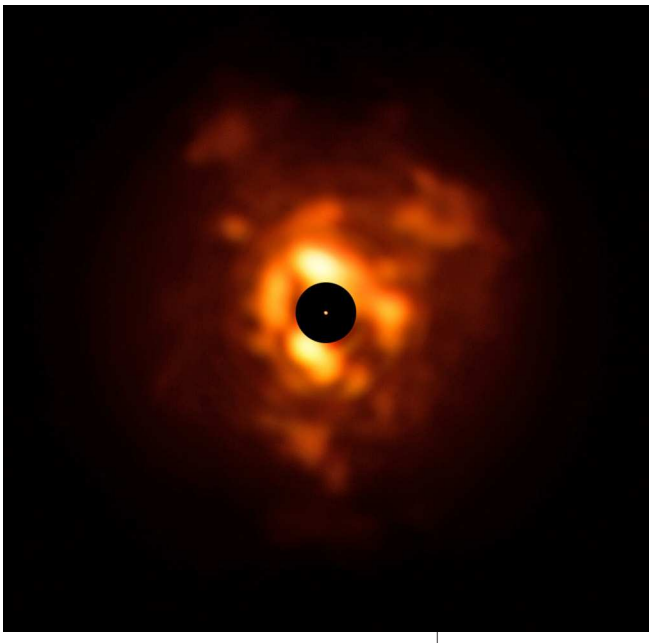


Image of Betelgeuse obtained in the near-infrared by the NACO instrument, which shows for the first time the mass ejection from the stellar surface. [ESO/P. Kervella] In the video below, a zooming in of the red supergiant. [ESO, P. Kervella, Digitized Sky Survey 2, and A. Fujii. Music by John Dyson from the CD Darklight]

ter which, at a given moment, constitutes the photosphere and the chromosphere. For several decades, astronomers had not been able to prove Betelgeuse's mass loss (also predicted by models of supernova progenitors). We had to wait for the new millennium and the development of revolutionary investigation techniques and instruments. The first confirmations that the mass-loss process was real came in mid-2009, thanks to two separate studies carried out with the ESO's Very Large Telescope. The first was conducted with the NACO instrument (installed on VLT's Unit Telescope 1) by a team of researchers led by Pierre Kervella (Observatoire de Paris). The team managed to obtain an image of Betelgeuse with a resolution of 37 mas, close to the theoretical limits of the instrument used. In the image, plumes of gas are visible rising on the surface of Betelgeuse and extending into outer space for at least six times the star's diameter. The asymmetrical appearance of the dispersed gas showed for the first time that Betelgeuse was not losing mass uniformly in all directions, suggesting that the sizes of the convective cells were remarkably large and that the more impressive plumes were the result of large-scale gas movements inside the star.

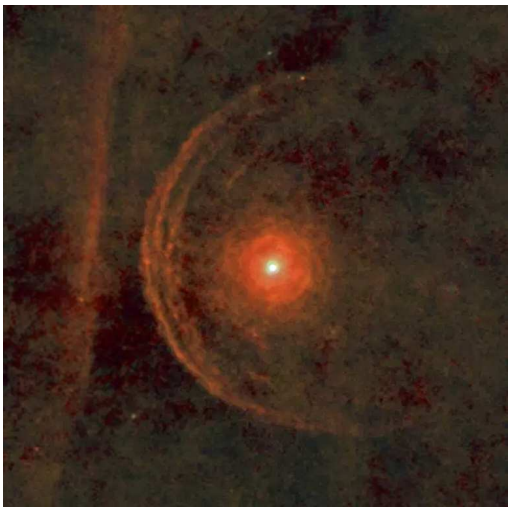
This scenario was confirmed by a team of researchers led by Keiichi Ohnaka (then at the Max Planck Institute for Radio Astronomy, Bonn), who observed Betelgeuse with the AMBER instrument in combination with the interferometer formed by three auxiliary telescopes of the VLT. This solution made it possible to produce images of the gases surrounding the star with a resolution four times greater than that of NACO. The team revealed vigorous vertical movements of the gas in different areas of the photosphere (the first time for a star other than the Sun). The larger convection cells were as large as the star itself, confirming that they were the engines of the huge mass ejections observed.



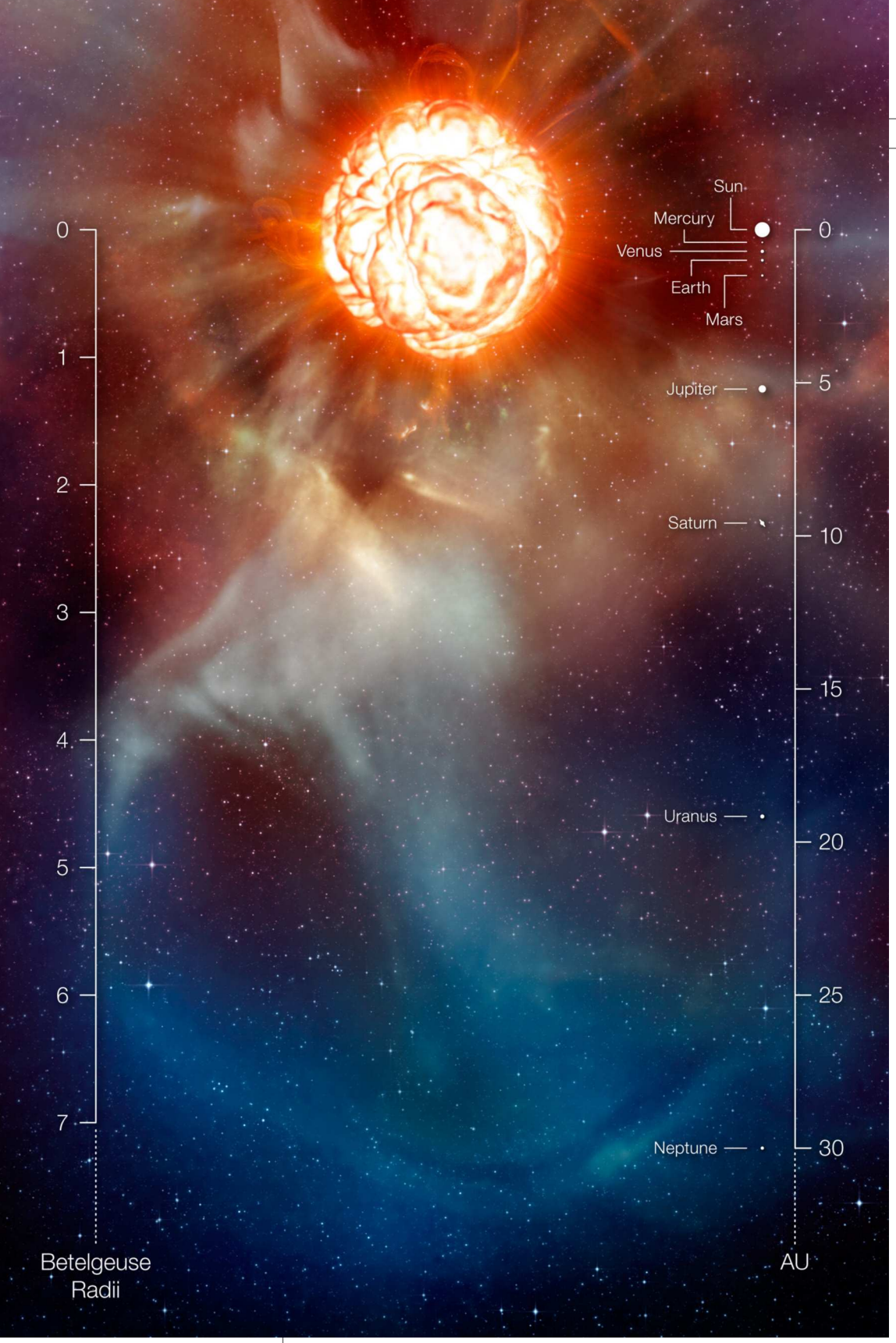


Two years after these first revelations, astronomers were able to verify that the material surrounding Betelgeuse extends far beyond the boundaries already identified. New images obtained in the mid-infrared by the VISIR instrument (installed on VLT's Unit Telescope 3) indeed showed an immense nebular structure, extended up to about 60 billion km from the star, equivalent to over two light-days. Those same images showed for the first time that the plumes previously observed near the photosphere are probably connected to the external nebular structure. The latter also has an asymmetrical shape, supporting the hypothesis according to which the star would not lose mass uniformly from the surface.

The environment surrounding Betelgeuse proved to be even more complex when, at the beginning of 2013, images obtained the year before in the far-infrared by Leen Decin (KU Leuven, Belgium) with ESA's Herschel Space Telescope were presented. In them, it is evident that the stellar winds



Images obtained by VISIR of the nebular structure surrounding Betelgeuse up to distances of tens of billions of km. The one on the left was taken in 2011; the one on the right during the recent light fall, in December 2019. The central regions of the two images have been obscured. Betelgeuse is indicated in the center. [ESO/P. Kervella/ M. Montargès et al., Acknowledgement Eric Pantin]
To the side, the arches preceding Betelgeuse, photographed by the Herschel Space Telescope. [ESA/ Herschel/PACS/L. Decin et al./University of Leuven]

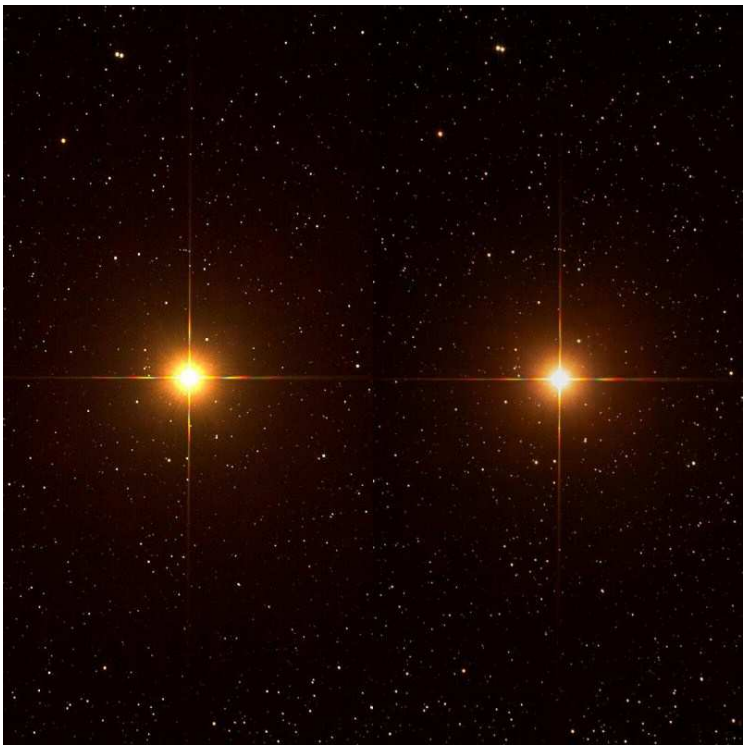


Infographic summarizing the gaseous and dusty structures surrounding Betelgeuse. [ESO/L. Calçada]

have impacted the surrounding interstellar medium, creating multiple arches in the direction that the star whizzes along at about 30 km/s. It is very likely that the material the arches are made from was expelled from Betelgeuse itself during paroxysmal events in its distant past. A linear structure is also visible in front of the arches, the nature of which is still uncertain. If it is material not related to the star's activity, it will be wiped out over the next 12,500 years unless Betelgeuse explodes first as a supernova.

To this already quite complicated situation, a further mystery was added in December 2016: the rotation of Betelgeuse around its axis was found to be 150 times faster than theory had predicted. Publisher of this disconcerting discovery in the *Monthly Notices of the Royal Astronomical Society* is the astronomer J. Craig Wheeler (University of Texas, Austin), who reported the results of observations made along with a group of his students.

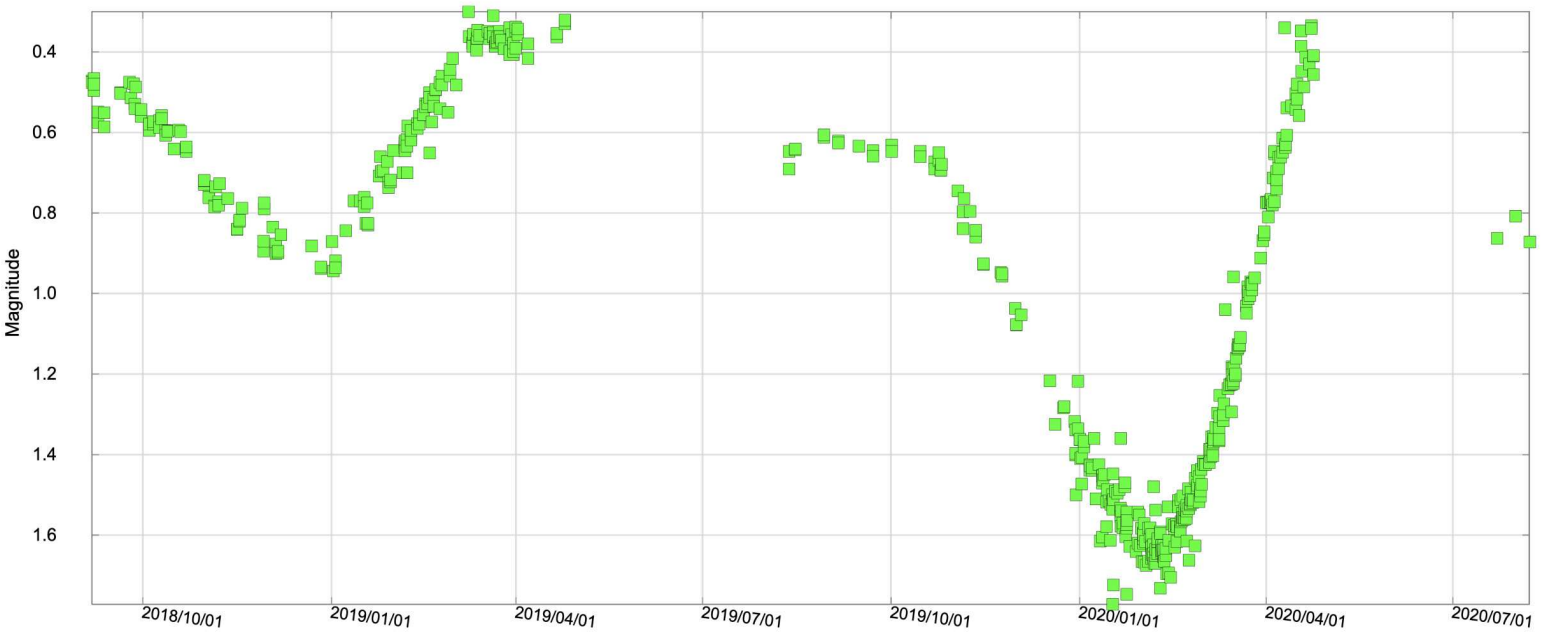
According to the principle of the conservation of angular momentum, when a very massive star (10-40 solar masses) turns into a red supergiant, its rotational speed must necessarily decrease, with the final speed inversely proportional to the diameter reached. Betelgeuse does not respect this principle and, to explain the anomaly, Wheeler suggested that, at the end of its expansion (about 100,000 years ago), the star may have engulfed a companion that orbited it at a distance similar to that which now separates the center of Betelgeuse from its photosphere.



Comparisons that highlight the different brightness of Betelgeuse before and during the extraordinary minimum. Left, two photos from February 2016 and 31 December 2019. [Brian Ottum/EarthSky] Below, two images taken with the VLT's SPHERE instrument in January 2019 and December 2019. [ESO/M. Montargès et al.]

The angular momentum of the orbital motion of the companion would be transferred to the outermost layers of the supergiant, accelerating its rotation. Wheeler calculated that, to justify Betelgeuse's current 15 km/s rotation speed, the mass of the destroyed star had to be comparable to that of the Sun. Also knowing that the loss of mass from a supergiant occurs at a typical speed of 10 km/s, Wheeler has come to speculate that the arches preceding Betelgeuse may have formed as a result of that dramatic event.

Parallel to the observations of the nebular structures surrounding Betelgeuse, attempts have obviously multiplied to measure the distance to the star through various techniques, all without reaching a common value. Indeed, even today, depending on the authoritative



Betelgeuse's V-band light curve, which compares the normal minimum at the beginning of 2019 with the extraordinary minimum at the beginning of 2020. [AAVSO] To the side, an image of Betelgeuse's lower chromosphere, taken in 2017 by the Atacama Large Millimeter/submillimeter Array (ALMA). The asymmetry in the distribution of temperatures is evident and is due to huge convection cells. [ALMA (ESO/NAOJ NRAO)/E. O'Gorman/P. Kervella]

sources we consult, we find distances between less than 500 and over 700 light-years. Not even the uncertainty about the crucial datum of the angular diameter has been eliminated: its value undoubtedly dropped in the last century, but the last sixteen years of measurements still produce results that oscillate between 42.3 and 44.3 mas.

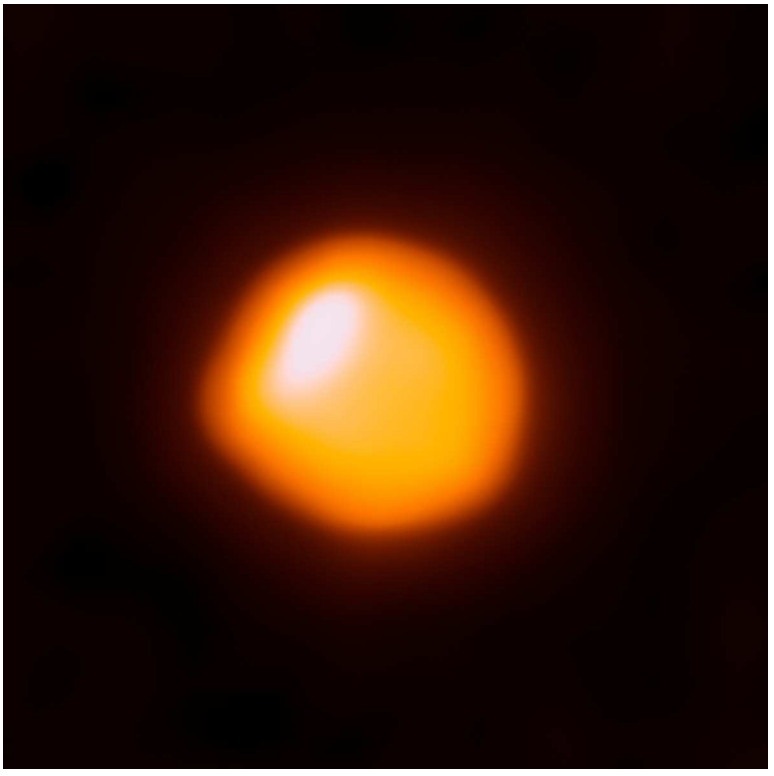
Note that these measures are also affected by the wavelengths chosen for the observations. It has been difficult to establish to what extent the brightness variations of Betelgeuse are due to surface phenomena, rather than to the expulsion of material which, once cooled, would obscure part of the photosphere.

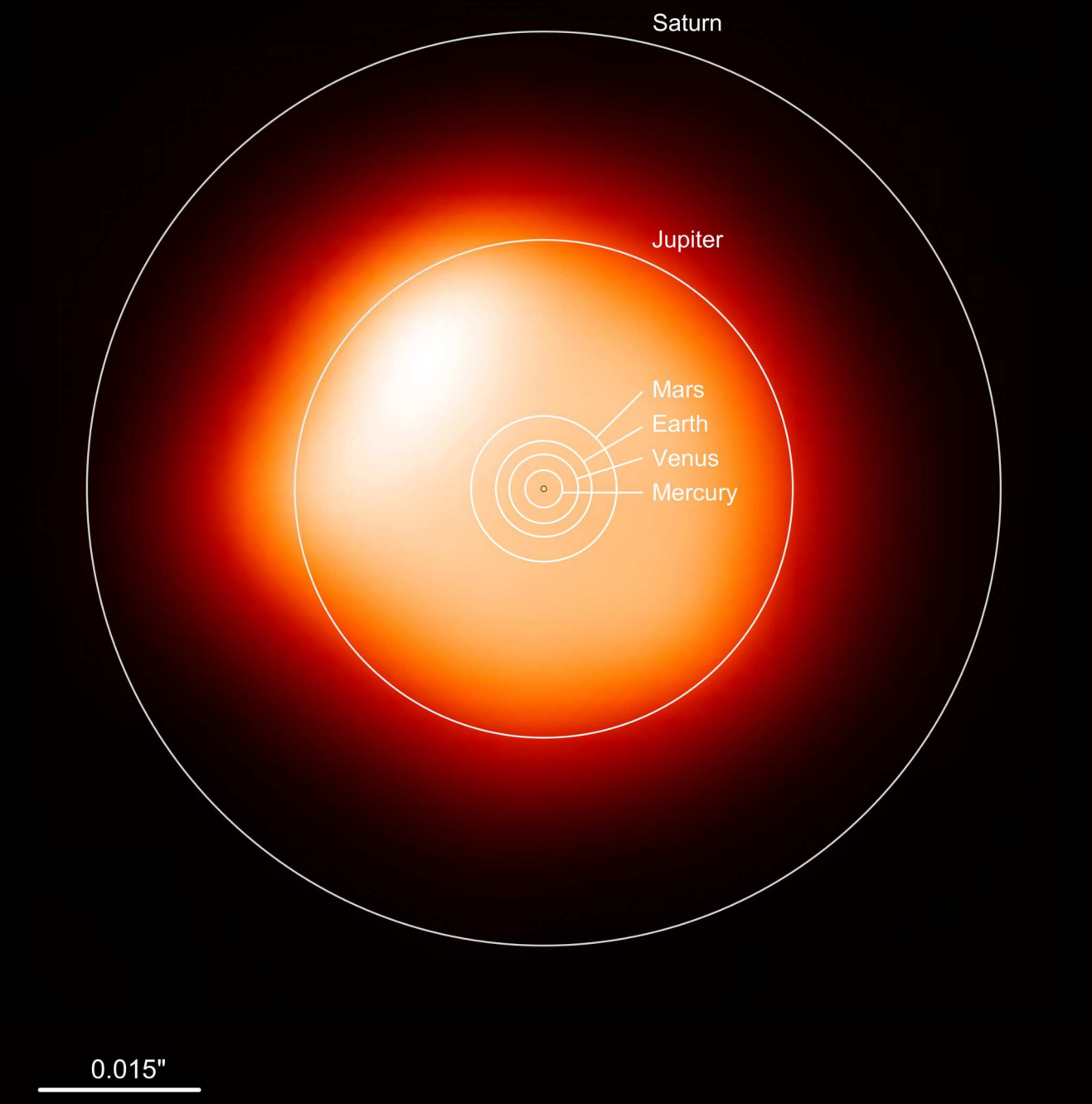
All these uncertainties have made Betelgeuse one of the most observed stars by astronomers and amateur astronomers.

This made it possible to grasp from the very beginning the extraordinary drop in brightness that began in the Autumn of 2019 and which once again highlighted how approximate our knowledge of this star is.

It all started in October, with a first dimming of light that still could have returned to normality – Betelgeuse has recorded oscillations between magnitudes +0.5 and +1.25, the latter value recorded between late 1926 and early 1927.

When, on December 19 of last year, the magnitude of Betelgeuse dropped to +1.29, it soon became clear that something

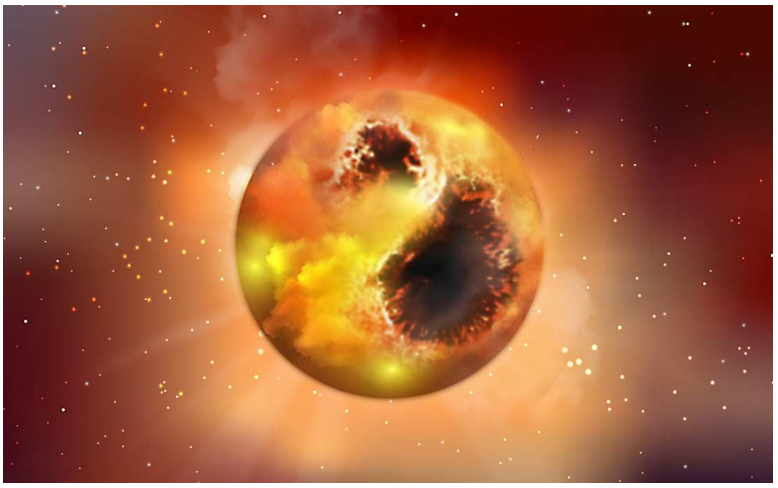




unusual was happening. The star continued to dim even into January of this year, ending the month at +1.62 – the same magnitude as Bellatrix, which is usually the third brightest star in Orion (Betelgeuse and Rigel alternate for first and second place). In practice, in just over four months, Betelgeuse had lost one magnitude, becoming 2.5 times less bright.

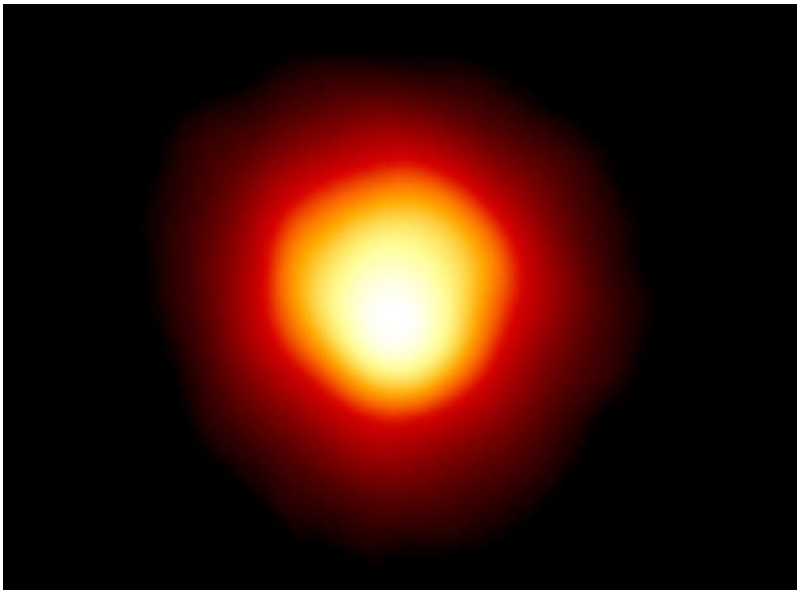
At the same time, its surface temperature dropped by 100-200 degrees, an unusual phenomenon for a star its size. In the absence of extraordinary photospheric phenomenologies, only an 8% reduction in stellar diameter could have account for a similar variation, yet a reduction of that magnitude would have been inexplicable. The first interpretations of Betelgeuse's strange photometric behavior began to circulate as early as last December. Among the most accredited, there were: the overlap of the minimums of the three known

If it were located at the center of our solar system, Betelgeuse would perhaps incorporate Jupiter and destabilize the orbit of Saturn. [ALMA(ESO/NAOJ/NRAO)/E. O'Gorman/P. Kervella]



Visual representation of Betelgeuse based on the knowledge acquired in the last decades. [MPIA graphics department]

cycles (100-180 days, 420 days, 5-6 years); the interposition of large quantities of dust and gases recently ejected from the star; the formation of a gigantic dark region on the photosphere, something like sunspots.
Initially, the most promoted hypothesis was that of the interposed material, with Kervella's team obtaining a new mid-infrared image with VISIR in December that clearly revealed the presence of relatively cold clouds most likely made of silicate and alumina dust, as well as gas.
Between March and May, Betelgeuse's light curve moved back towards normal values. This could have been interpreted as the dissolution of the intervening material, but once again reality was different. At the end of June, a study coordinated by Thavisha Dharmawardena (Max Planck Institute for Astronomy, Heidelberg) on several Betelgeuse observations made with ESO's Atacama Pathfinder Experiment telescope (APEX) definitively confirmed the stellar spot scenario. The reason is quite simple. APEX observes at submillimeter wavelengths, where an increase in the production of dust by the star would have translated into an increase in magnitude; instead, Betelgeuse had also faded in the APEX images, a fact that is explained by a decrease in the surface temperature on a large scale, i.e. through a conspicuous 50-70% darkening of the visible photosphere.
Problem solved? Not exactly. In mid-August, the first results of a three-year study conducted on Betelgeuse with the Hubble Space Telescope by Andrea Dupree (Center for Astrophysics – Harvard & Smithsonian, Cambridge) and a dozen of his collaborators were released.
The team monitored changes in temperature and plasma movements affecting the atmospheric layers overlying the photosphere. These are layers so hot (over 20,000 degrees Fahrenheit) that they

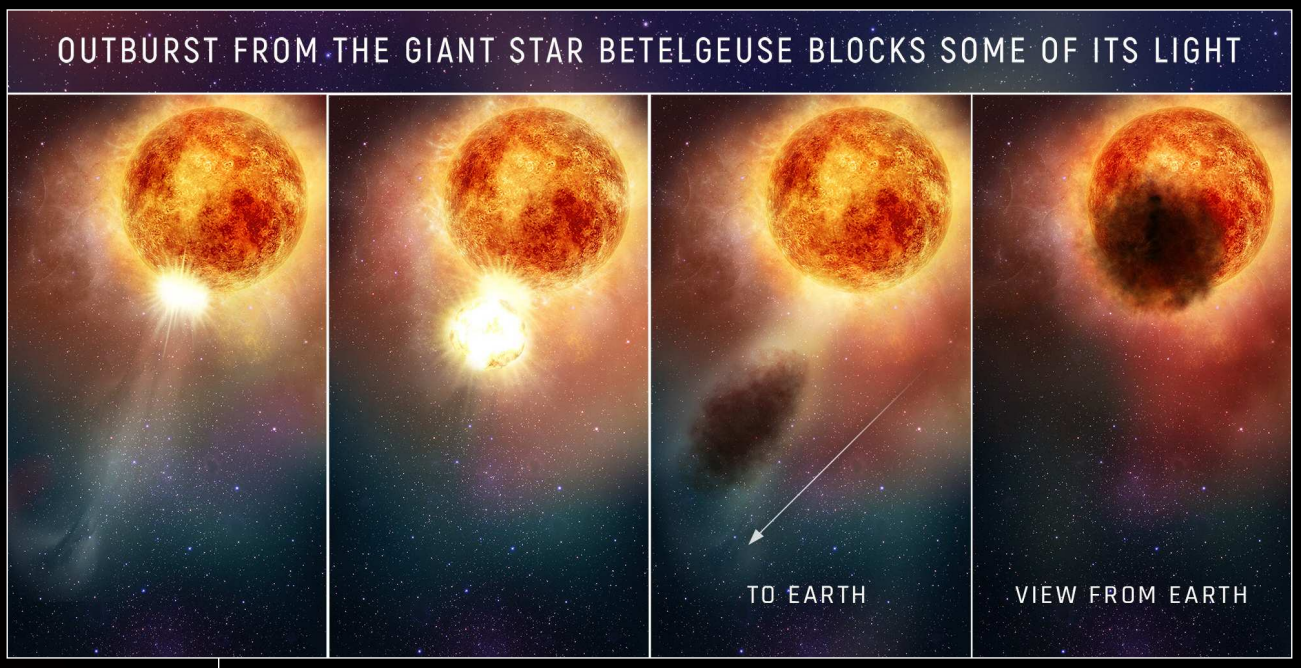


This is the first ultraviolet image of Betelgeuse made with the Hubble Space Telescope. A huge hot spot is visible that is hundreds of times larger than the Sun, with a temperature exceeding the surrounding surface temperature by at least 2000 Kelvin. [Andrea Dupree (Harvard-Smithsonian CfA), Ronald Gilliland (STScI), NASA/ESA]

emit light essentially in the ultraviolet, which Hubble manages to reach. Spectroscopic observations of the plasma in motion in Betelgeuse's atmosphere, started in January 2019 and continued over the following months, have re-proposed the scenario of the interposition of relatively cold material with rather convincing evidence. Between September and November 2019, Dupree's team recorded, in the southern hemisphere of the star, the dynamic evolution of an immense bubble of plasma that rose from the photosphere through the densest layers of the atmosphere. Along its path, the plasma had cooled more and more to form dust which, by blocking the light emitted by about a quarter of the visible photosphere, would then have been responsible for the deep minimum observed. Here is how Dupree describes the phenomenon: *"With Hubble, we see the material as it left the star's visible surface and moved out through the atmosphere, before the dust formed that caused the star [to] appear to dim. We could see the effect of a dense, hot region in the southeast part of the star moving outward. This material was two to four times more luminous than the star's normal brightness. And then, about a month later, the southern hemisphere of Betelgeuse dimmed conspicuously as the star grew fainter. We think it is possible that a dark cloud resulted from the outflow that Hubble detected. Only Hubble gives us this evidence of what led up to the dimming."* To follow the evolution of the bubble of plasma, the researchers used singly-ionized magnesium as a tracer, which made it possible to estimate the ascent rate of the material at about 200,000 miles per hour. The plasma crossed the atmosphere over many millions of miles before reaching a temperature sufficient to create grains of dust.

It is not clear which process produced that bubble of plasma, but according to Dupree its development was facilitated by the convective motions linked to the 420-day cycle with which the star appears to pulsate.

The scenario that emerged from the observations of Dupree's team, represented using an image of Betelgeuse taken at the end of 2019 by ESO's SPHERE instrument. [ESO, ESA/Hubble, M. Kornmesser]



Visual representation of what Dupree's team observed as described in this article. [NASA, ESA, and E. Wheatley (STScI)]

This cycle in fact continued normally during the fall of light in the visible, as demonstrated by another member of the team, Klaus Strassmeier (Leibniz-Institut für Astrophysik Potsdam, AIP, Germany). He used the STELLA robotic observatory (from STELLar Activity) in the Canary Islands, to measure the vertical velocity of the gas at the photospheric level during the pulsation cycle.

Betelgeuse was expanding as the bubble of plasma moved up through the convective cell, and so the two processes may be related. The stellar pulsation may have contributed to push the plasma towards the upper atmosphere. Dupree estimated that, over the course of this extraordinary three-month event, Betelgeuse lost twice as much material as it loses on average from the southern hemisphere, an amount that is 30 million times greater than that lost by the Sun at the same time.

This interpretation is consistent with Hubble's ultraviolet observations in February of this year, which showed a return to normal at those wavelengths, while in the visible the dust made the star's light increasingly faint. Only after the radiation pressure and stellar winds dispersed the dust did Betelgeuse's brightness return to typical values.

Now it will be necessary to understand how to reconcile the results from Dupree's team with those from Dharmawardena's team, both supported by valid arguments, but with antithetical scenarios at the base. Perhaps, the very latest (as we write this) news about the star's bright variations, followed from space by NASA's Solar and Terrestrial Relations Observatory (STEREO), will be useful in settling the issue. Observations made between the end of June and the beginning of August for five separate days show that Betelgeuse was weakening again, an unexpected behavior at such a short separation from the previous low. All that remains now is to wait for the return of the star in the night skies to try to understand something more.

In light of what we have seen so far, it seems very unlikely that Betelgeuse is about to explode as a supernova, although astronomers believe this could happen within the next 100,000 years. Seeing Betelgeuse explode would be a grand event, but we would forever lose the familiar silhouette of one of the most beautiful constellations in the whole sky. ■

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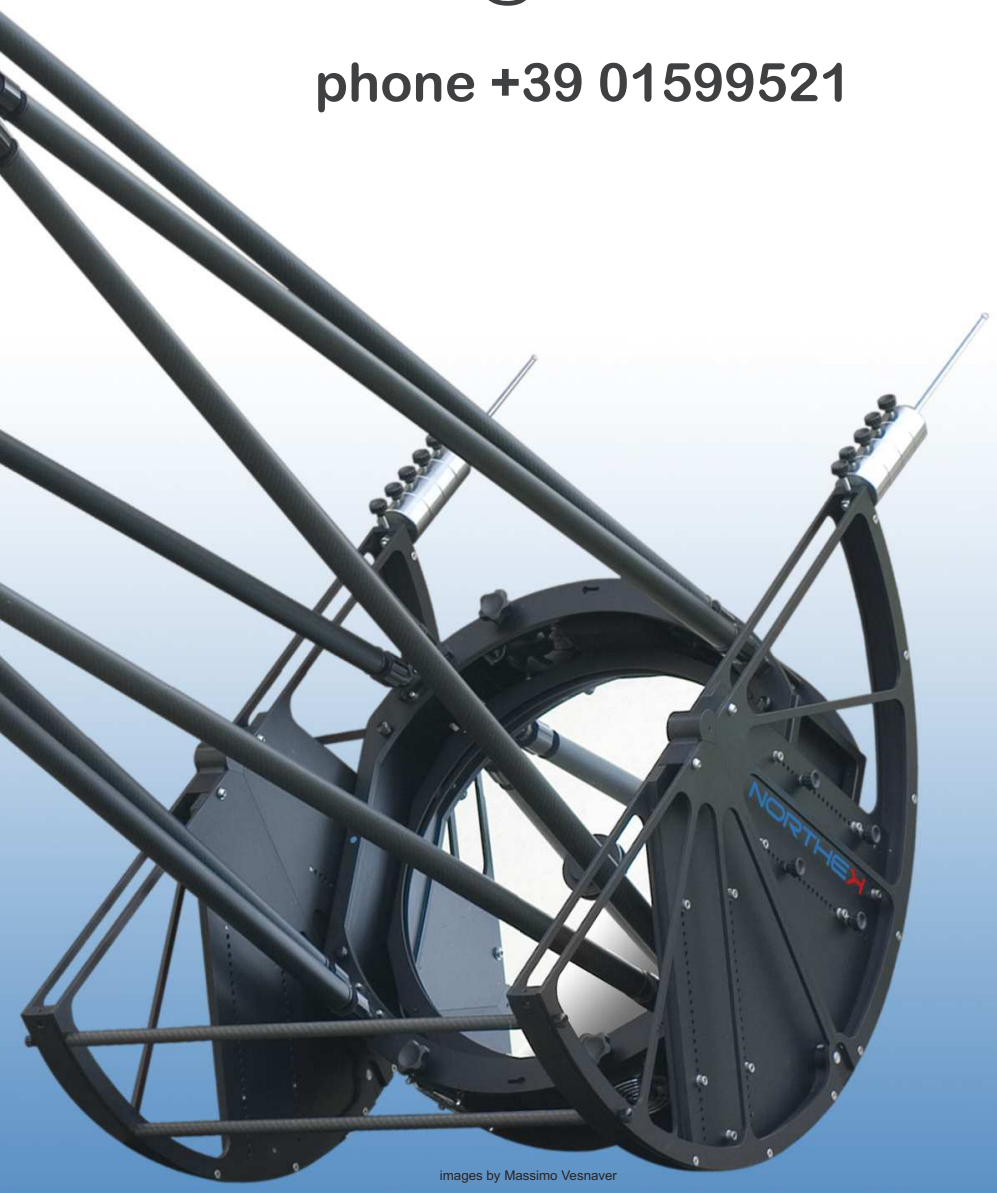


images by Massimo Vesnaver

M P O S I T E S - O P T I C S

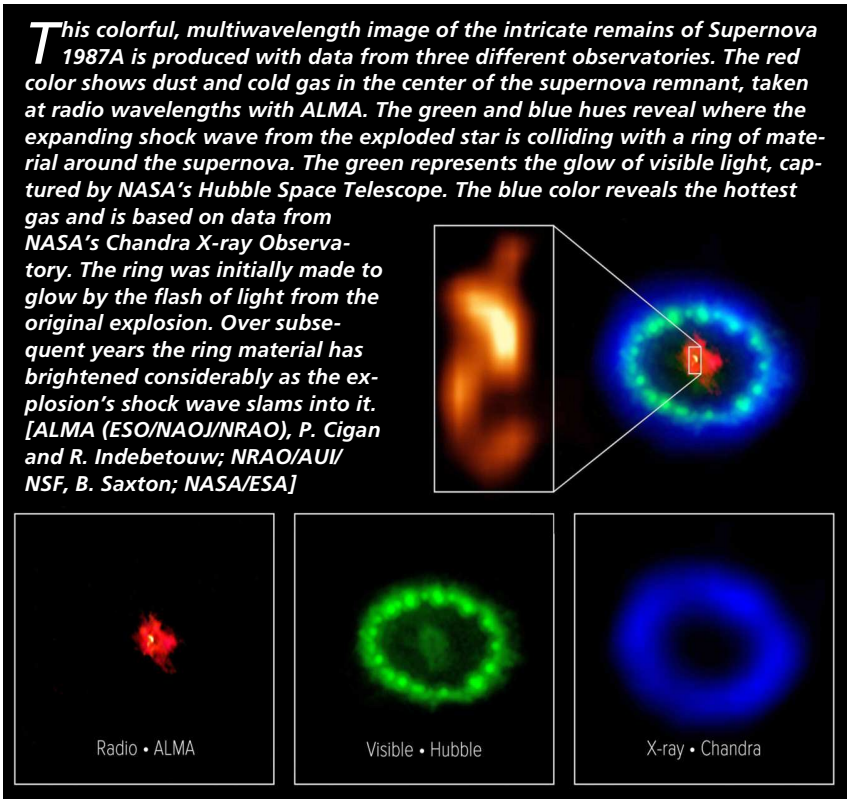
ALMA finds possible sign of neutron star in SN 1987A

by ALMA Observatory

Two teams of astronomers have made a compelling case in the 33-year-old mystery surrounding Supernova 1987A (SN 1987A). Based on observations of the Atacama Large Millimeter/submillimeter Array (ALMA) and a theoretical follow-up study, the scientists provide new insight for the argument that a neutron star is hiding deep inside the remains of the exploded star. This would be the youngest neutron star known to date. Ever since astronomers witnessed one of the brightest explosions of a star in the night sky, creating SN 1987A, they have been searching for a compact object that should have formed in the leftovers from the blast. Because particles known as neutrinos were detected on Earth on the day of the explosion (23 February 1987), astronomers expected that a neutron star had formed in the col-

This artist's illustration of Supernova 1987A shows the dusty inner regions of the exploded star's remnants (red), in which a neutron star might be hiding. This inner region is contrasted with the outer shell (blue), where the energy from the supernova is colliding (green) with the envelope of gas ejected from the star prior to its powerful detonation. [NRAO/AUI/NSF, B. Saxton]

lapsed center of the star. But when scientists could not find any evidence for that star, they started to wonder whether it subsequently collapsed into a black hole instead. For decades the scientific community has been eagerly awaiting a signal from this object that has been hiding behind a very thick cloud of dust. Recently, observations from the ALMA radio telescope provided the first indication of the missing neutron star after the explosion. Extremely high-resolution images revealed a hot "blob" in the dusty core of SN 1987A, which is brighter than its surroundings and matches the suspected location of the neutron star. *"We were very surprised to see this warm blob made by a thick cloud of dust in the supernova remnant,"* said Mikako Matsuura from Cardiff University and a member of the team that found the blob



This colorful, multiwavelength image of the intricate remains of Supernova 1987A is produced with data from three different observatories. The red color shows dust and cold gas in the center of the supernova remnant, taken at radio wavelengths with ALMA. The green and blue hues reveal where the expanding shock wave from the exploded star is colliding with a ring of material around the supernova. The green represents the glow of visible light, captured by NASA's Hubble Space Telescope. The blue color reveals the hottest gas and is based on data from NASA's Chandra X-ray Observatory. The ring was initially made to glow by the flash of light from the original explosion. Over subsequent years the ring material has brightened considerably as the explosion's shock wave slams into it. [ALMA (ESO/NAOJ/NRAO), P. Cigan and R. Indebetouw; NRAO/AUI/NSF, B. Saxton; NASA/ESA]

with ALMA. *"There has to be something in the cloud that has heated up the dust and which makes it shine. That's why we suggested that there is a neutron star hiding inside the dust cloud."*

Even though Matsuura and her team were excited about this result, they wondered about the brightness of the blob. *"We thought that the neutron star might be too bright to exist, but then Dany Page and his team published a study that indicated that the neutron star can indeed be this bright because it is so very young,"* said Matsuura.

Dany Page is an astrophysicist at the National Autonomous University of Mexico, who has been studying SN 1987A from the start. *"I was halfway through my PhD when the supernova happened,"* he said, *"it was one of the biggest events in my life that made me change the course of my career to try to solve this mystery. It was like a modern holy grail."*

The theoretical study by Page and his team, published in The Astrophysical Journal, strongly supports the suggestion made by the ALMA team that a neutron star is powering the dust blob.

"In spite of the supreme complexity of a supernova explosion and the extreme conditions reigning in the interior of a neutron star, the detection of a warm blob of dust is a confirmation of several predictions," Page explained. These predictions were the location and the temperature of the neutron star.

According to supernova computer models, the explosion has "kicked away" the neutron star from its birthplace with a speed of hundreds of kilometers per second (tens of times faster than the fastest rocket). The blob is exactly at the place where astronomers think the neutron star would be today. And the temperature of the neutron star, which was predicted to be around 5 million degrees Celsius, provides enough energy to explain the brightness of the blob.

Contrary to common expectations, the neutron star is likely not a pulsar. *"A pulsar's power depends on how fast it spins and on its magnetic field strength, both of which would need to have very finely tuned values to match the observations,"* said Page, *"while the thermal energy emitted by the hot surface of the young neutron star naturally fits the data."*

"The neutron star behaves exactly like we expected," added James Lattimer of Stony Brook University in New York, and a member of Page's research team. Lattimer has also followed SN 1987A closely, having published prior to SN 1987A predictions of a supernova's neutrino signal that subsequently matched the observations. *"Those neutrinos suggested that a black hole never formed, and moreover it seems difficult for a black hole to explain the observed brightness of the blob. We compared all possibilities and concluded that a hot neutron star is the most likely explanation."*

This neutron star is a 25 km wide, extremely hot ball of ultra-dense matter. A teaspoon of its material would weigh more than all the buildings within New York City combined. Because it can only be 33 years old, it would be the youngest neutron star ever found. The second youngest neutron star that we know of is located in the supernova remnant Cassiopeia A and is 330 years old.

Only a direct picture of the neutron star would give definite proof that it exists, but for that astronomers may need to wait a few more decades until the dust and gas in the supernova remnant become more transparent. ■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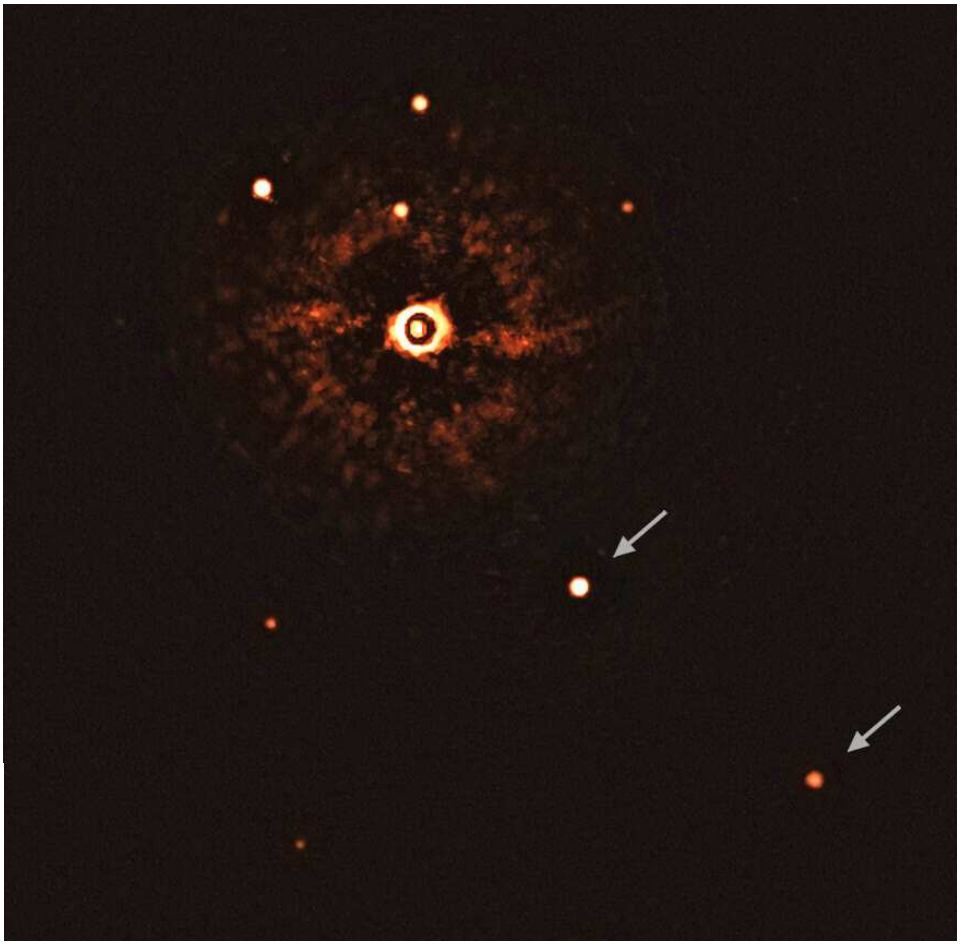
50 years ago, we walked on the Moon

First ever image of a multi-planet system around a Sun-like star

by ESO

Just a few weeks ago, ESO revealed a planetary system being born in a new, stunning VLT image. Now, the same telescope, using the same instrument, has taken the first direct image of a planetary system around a star like our Sun, located about 300 light-years away and known as TYC 8998-760-1.

"This discovery is a snapshot of an environment that is very similar to our Solar System, but at a much earlier stage of its evolution," says Alexander Bohn, a PhD student at Leiden University in the Netherlands, who led the new research published in *The Astrophysical Journal Letters*. *"Even though as-*



This image, captured by the SPHERE instrument on ESO's Very Large Telescope, shows the star TYC 8998-760-1 accompanied by two giant exoplanets, TYC 8998-760-1b and TYC 8998-760-1c. This is the first time astronomers have directly observed more than one planet orbiting a star similar to the Sun. The two planets are visible as two bright dots in the centre (TYC 8998-760-1b) and bottom right (TYC 8998-760-1c) of the frame, noted by arrows. Other bright dots, which are background stars, are visible in the image as well. By taking different images at different times, the team were able to distinguish the planets from the background stars. The image was captured by blocking the light from the young, Sun-like star using a coronagraph, which allows for the fainter planets to be detected. The bright and dark rings we see on the star's image are optical artefacts. [ESO/Bohn et al.]

tronomers have indirectly detected thousands of planets in our galaxy, only a tiny fraction of these exoplanets have been directly imaged," says co-author Matthew Kenworthy, Associate Professor at Leiden University, adding that *"direct observations are important in the search for environments that can support life."*
The direct imaging of two or more exoplanets around the same star is even more rare; only two such systems have been directly observed so far, both around stars markedly different from our Sun. The new ESO's VLT image is the first direct image of more than one exoplanet around a Sun-like star. ESO's VLT was also the first telescope to directly image an exoplanet, back in 2004, when it captured a speck of light around a brown dwarf, a type of 'failed' star. *"Our team has now been able to take the first image of two gas giant companions that are orbiting a young, solar analogue,"* says Maddalena Reggiani, a postdoctoral researcher from KU Leuven, Belgium, who also participated in the study. The two planets can be seen in the new image as two bright points of light distant from their parent star. By taking different images at different times, the team were able to distinguish these planets from the background stars.

The SPHERE instrument on ESO's Very Large Telescope has captured the first ever image of a young, Sun-like star accompanied by two giant exoplanets, located about 300 light-years away from Earth. This animation shows the orbits of the two exoplanets, compared with the size of Pluto's orbit. Note that the yellow circle does not represent Pluto's real orbit, but rather the size of the orbit, which is calculated based on the dwarf planet's average distance to the Sun. [ESO/L.Calçada/spaceengine.org]

PhD student Alex Bohn led the team that caught the first image of a multi-planet system around a Sun-like star. [Leiden University]

The two gas giants orbit their host star at distances of 160 and about 320 times the Earth-Sun distance. This places these planets much further away from their star than Jupiter or Saturn, also two gas giants, are from the Sun; they lie at only 5 and 10 times the Earth-Sun distance, respectively. The team also found the two exoplanets are much heavier than the ones in our Solar System, the inner planet having 14 times Jupiter's mass and the outer one six times. Bohn's team imaged this system during their search for young, giant planets around stars like our Sun but far younger. The star TYC 8998-760-1 is just 17 million years old and located in the Southern constellation of Musca (The Fly). Bohn describes it as a *"very young version of our own Sun."*
These images were possible thanks to the high performance of the SPHERE instrument on ESO's VLT in the Chilean Atacama desert. SPHERE blocks the bright light from the star using a device called coronagraph, allowing the much fainter planets to be seen. While older planets, such as those in our Solar System, are too cool to be found with this technique, young planets are hotter, and so glow brighter in infrared light. By taking several images over the past year, as well as using older data going back to 2017, the research team have confirmed that the two planets are part of the star's system.
Further observations of this system, including with the future ESO Extremely Large Telescope (ELT), will enable astronomers to test whether these planets formed at their current location distant from the star or migrated from elsewhere. ESO's ELT will also help probe the interaction between two young planets in the same system. Bohn concludes: *"The possibility that future instruments, such as those available on the ELT, will be able to detect even lower-mass planets around this star marks an important milestone in understanding multi-planet systems, with potential implications for the history of our own Solar System."* ■

Stars puffing off gas and dust yield new revelations

by NASA/ESA

As nuclear fusion engines, most stars live placid lives for hundreds of millions to billions of years. But near the end of their lives they can turn into crazy whirligigs, puffing off shells and jets of hot gas.

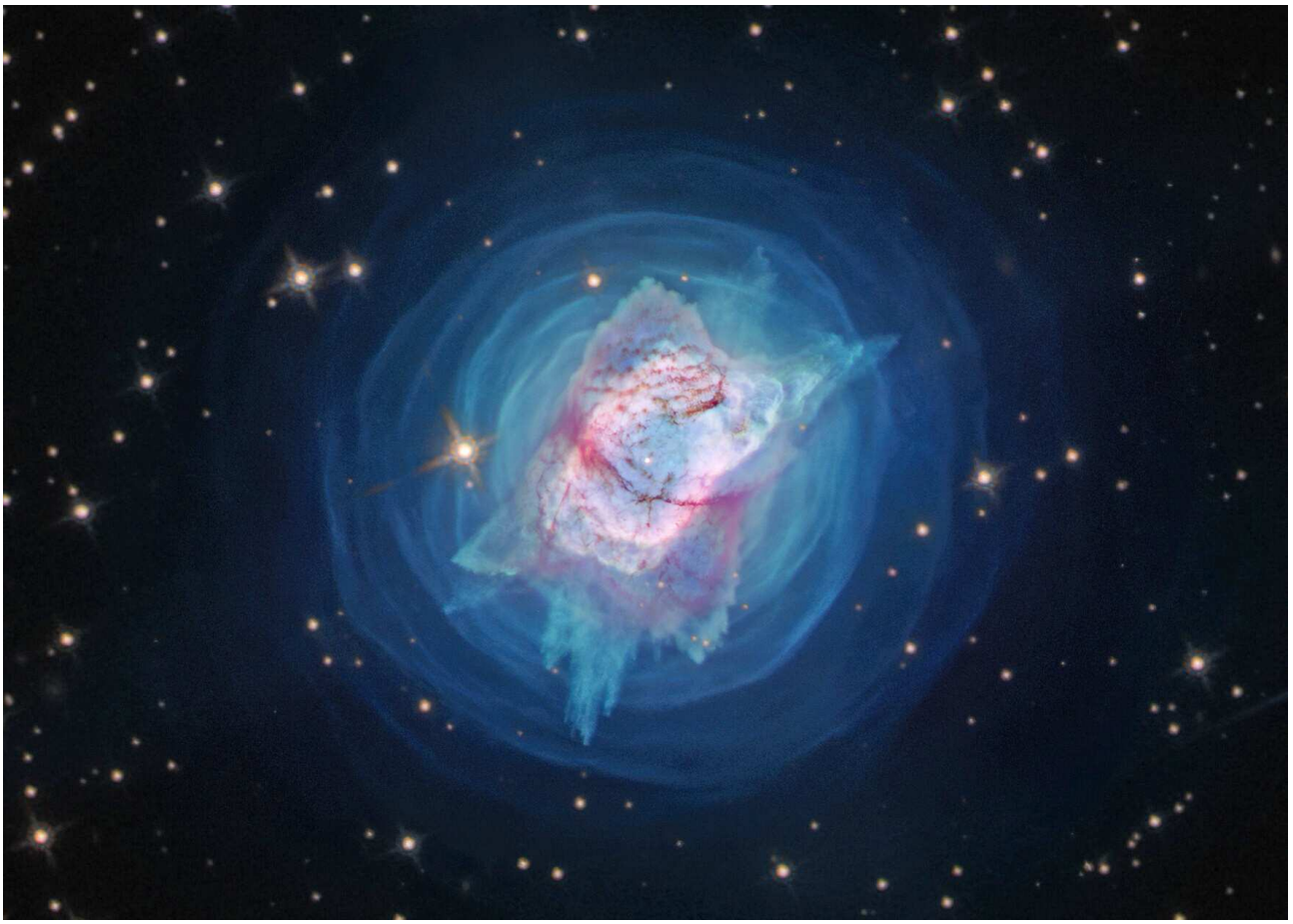
Astronomers have used Hubble to dissect such crazy fireworks happening in two planetary nebulae, NGC 6302 e NGC 7027. The researchers have found unprecedented levels of complexity and rapid changes in the jets and gas bubbles blasting off of the stars at the center of each nebula. Hubble is now allowing the researchers to converge on an understanding of the mechanisms underlying this chaos.

The space telescope has imaged these objects before, but not for many years and never before with the Wide Field Camera 3 instrument across its full wavelength range — making observations in near-ultraviolet to near-infrared light. *"These new multi-wavelength Hubble observations provide the most comprehensive view to date of both of these spectacular nebulae,"* said Joel Kastner of the Rochester Institute of Technology, Rochester, New York, leader of the new study. *"As I was downloading the resulting images, I felt like a kid in a candy store."* The new Hubble images reveal in vivid detail how both nebulae are splitting themselves apart on extremely short timescales — allowing astronomers to see changes over the past couple of decades. In particular, Hubble's broad multi-wavelength views of each nebula are helping the researchers to trace the

This image from the NASA/ESA Hubble Space Telescope depicts NGC 6302, commonly known as the Butterfly Nebula. NGC 6302 lies within our Milky Way galaxy, roughly 3800 light-years away in the constellation of Scorpius. The glowing gas was once the star's outer layers, but has been expelled over about 2200 years. The butterfly shape stretches for more than two light-years, which is about half the distance from the Sun to the nearest star, Proxima Centauri. New observations of the object have found unprecedented levels of complexity and rapid changes in the jets and gas bubbles blasting off of the star at the centre of the nebula. [NASA, ESA, and J. Kastner (RIT)]

histories of shock waves in them. Such shocks are typically generated when fresh, fast stellar winds slam into and sweep up more slowly expanding gas and dust ejected by the star in its recent past, generating bubble-like cavities with well-defined walls. Researchers suspect that at the heart of each nebula were two stars orbiting around each other. Evidence for such a central "dynamic duo" comes from the bizarre shapes of these nebulas. Each has a pinched, dusty waist and polar lobes or outflows, as well as other, more complex symmetrical patterns. A leading theory for the generation of such structures in planetary nebulae is that the mass-losing star is one of two stars in a binary system. The two stars orbit one another closely enough that they eventually interact, producing a gas disc around one or both stars. The disc then launches jets that inflate polar-directed lobes of outflowing gas. Another, related, popular hypothesis is that the smaller star of the pair may merge with its bloated, more rapidly evolving stellar companion. This very short-lived "common envelope" binary star configuration can also generate wobbling jets, forming the trademark bipolar outflows commonly seen in planetary nebulae.

However, the suspect companion stars in these planetary nebulae have



This image from the NASA/ESA Hubble Space Telescope depicts NGC 7027, or the "Jewel Bug" nebula. The object had been slowly puffing away its mass in quiet, spherically symmetric or perhaps spiral patterns for centuries — until relatively recently when it produced a new cloverleaf pattern. New observations of the object have found unprecedented levels of complexity and rapid changes in the jets and gas bubbles blasting off of the star at the centre of the nebula. [NASA, ESA, and J. Kastner (RIT)]

not been directly observed. Researchers suggest this may be because these companions are next to, or have already been swallowed by, far larger and brighter red giant stars. NGC 6302, commonly known as the Butterfly Nebula, exhibits a distinct S-shaped pattern seen in reddish-orange in the image on the previous page. Imagine a lawn sprinkler spinning wildly, throwing out two S-shaped streams. In this case it is not water in the air, but gas blown out at high speed by a star. And the "S" only appears when captured by the Hubble camera filter that records near-infrared emission from singly ionised iron atoms. This iron emission is indicative of energetic collisions between both slow and fast winds, which is most commonly observed in active galactic nuclei and supernova remnants. *"This is very rarely seen in planetary nebulae,"* explained team member Bruce Balick of the University of Washington in Seattle. *"Importantly, the iron emission image shows that fast, off-axis winds penetrate far into the nebula like tsunamis, obliterating former clumps in their paths and leaving only long tails of debris."*

The above image of NGC 7027, which resembles a jewel bug, indicates that it had been slowly puffing away its mass in quiet, spherically symmetric or perhaps spiral patterns for centuries — until relatively recently. *"Something recently went haywire at the very centre, producing a new cloverleaf pattern, with bullets of material shooting out in specific directions,"* Kastner explained. ■

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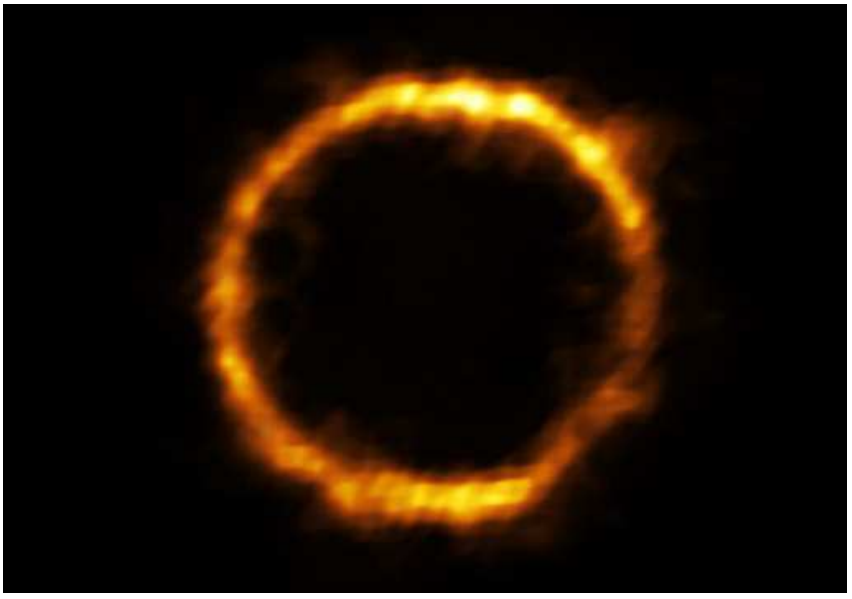
ALMA sees most distant Milky Way look-alike

by ESO

Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA), in which the European Southern Observatory (ESO) is a partner, have revealed an extremely distant and therefore very young galaxy that looks surprisingly like our Milky Way. The galaxy is so far away its light has taken more than 12 billion years to reach us: we see it as it was when the Universe was just 1.8 billion years old. It is also surprisingly unchaotic, contradicting theories that all galaxies in the early Universe were turbulent and unstable.

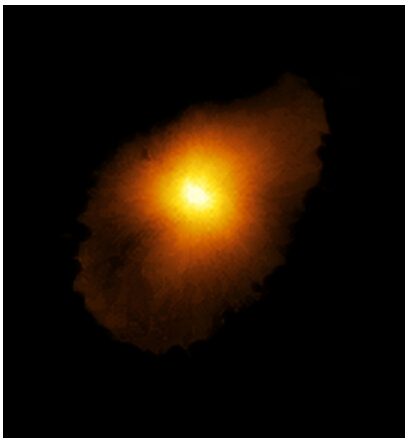
This unexpected discovery challenges our understanding of how galaxies form, giving new insights into the past of our Universe.

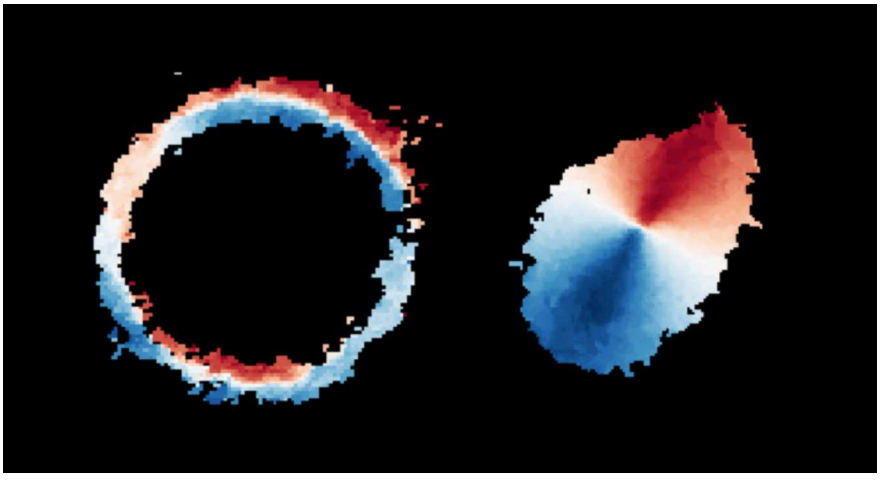
"This result represents a breakthrough in the field of galaxy formation, showing that the structures that we observe in nearby spiral galaxies and in our Milky Way were already in place 12 billion years ago," says Francesca Rizzo, PhD student from the Max Planck Institute for Astrophysics in Germany, who led the research published in *Nature*. While the galaxy the astronomers studied, called SPT0418-47, doesn't appear to have spiral arms, it has at least two features typical of our Milky Way: a rotating disc and a bulge, the large group of stars packed tightly around the galactic centre. This is the first time a bulge has been seen this early in the history of the Universe, making SPT0418-47 the most distant Milky Way look-alike.



Astronomers using ALMA, in which the ESO is a partner, have revealed an extremely distant galaxy that looks surprisingly like our Milky Way. The galaxy, SPT0418-47, is gravitationally lensed by a nearby galaxy, appearing in the sky as a near-perfect ring of light. [ALMA (ESO/NAOJ/NRAO), Rizzo et al.]

"The big surprise was to find that this galaxy is actually quite similar to nearby galaxies, contrary to all expectations from the models and previous, less detailed, observations," says co-author Filippo Fraternali, from the Kapteyn Astronomical Institute, University of Groningen in





The galaxy SPT0418-47 is gravitationally lensed by a nearby galaxy, appearing in the sky as a near-perfect ring of light. The research team reconstructed the distant galaxy's true shape and the motion of its gas (right) from the ALMA data using a new computer modelling technique. The observations indicate that SPT0418-47 is a disc galaxy with a central bulge and the material in it rotates around the centre. Gas moving away from us is shown in red, while gas moving in the direction of the observer is shown in blue. [ALMA (ESO/NAOJ/NRAO), Rizzo et al.]

the Netherlands. In the early Universe, young galaxies were still in the process of forming, so researchers expected them to be chaotic and lacking the distinct structures typical of more mature galaxies like the Milky Way.

Studying distant galaxies like SPT0418-47 is fundamental to our understanding of how galaxies formed and evolved. This galaxy is so far away we see it when the Universe was just 10% of its current age because its light took 12 billion years to reach Earth. By studying it, we are going back to a time when these baby galaxies were just beginning to develop. Because these galaxies are so far away, detailed observations with even the most powerful telescopes are almost impossible as the galaxies appear small and faint. The team overcame this obstacle by using a nearby galaxy as a powerful magnifying glass — an effect known as gravitational lensing — allowing ALMA to see into the distant past in unprecedented detail. In this effect, the gravitational pull from the nearby galaxy distorts and bends the light from the distant galaxy, causing it to appear misshapen and magnified.

The gravitationally lensed, distant galaxy appears as a near-perfect ring of light around the nearby galaxy, thanks to their almost exact alignment. The research team reconstructed the distant galaxy's true shape and the motion of its gas from the ALMA data using a new computer modelling technique. *"When I first saw the reconstructed image of SPT0418-47 I could not believe it: a treasure chest was opening,"* says Rizzo.

"What we found was quite puzzling; despite forming stars at a high rate, and therefore being the site of highly energetic processes, SPT0418-47 is the most well-ordered galaxy disc ever observed in the early Universe," stated co-author Simona Vegetti, also from the Max Planck Institute for Astrophysics. *"This result is quite unexpected and has important implications for how we think galaxies evolve."* The astronomers note, however, that even though SPT0418-47 has a disc and other features similar to those of spiral galaxies we see today, they expect it to evolve into a galaxy very different from the Milky Way, and join the class of elliptical galaxies, another type of galaxies that, alongside the spirals, inhabit the Universe today. This unexpected discovery suggests the early Universe may not be as chaotic as once believed and raises many questions on how a well-ordered galaxy could have formed so soon after the Big Bang.

This ALMA finding follows the earlier discovery announced in May of a massive rotating disc seen at a similar distance. SPT0418-47 is seen in finer detail, thanks to the lensing effect, and has a bulge in addition to a disc, making it even more similar to our present-day Milky Way than the one studied previously.

Future studies, including with ESO's Extremely Large Telescope, will seek to uncover how typical these 'baby' disc galaxies really are and whether they are commonly less chaotic than predicted, opening up new avenues for astronomers to discover how galaxies evolved. ■

In the mind of ET

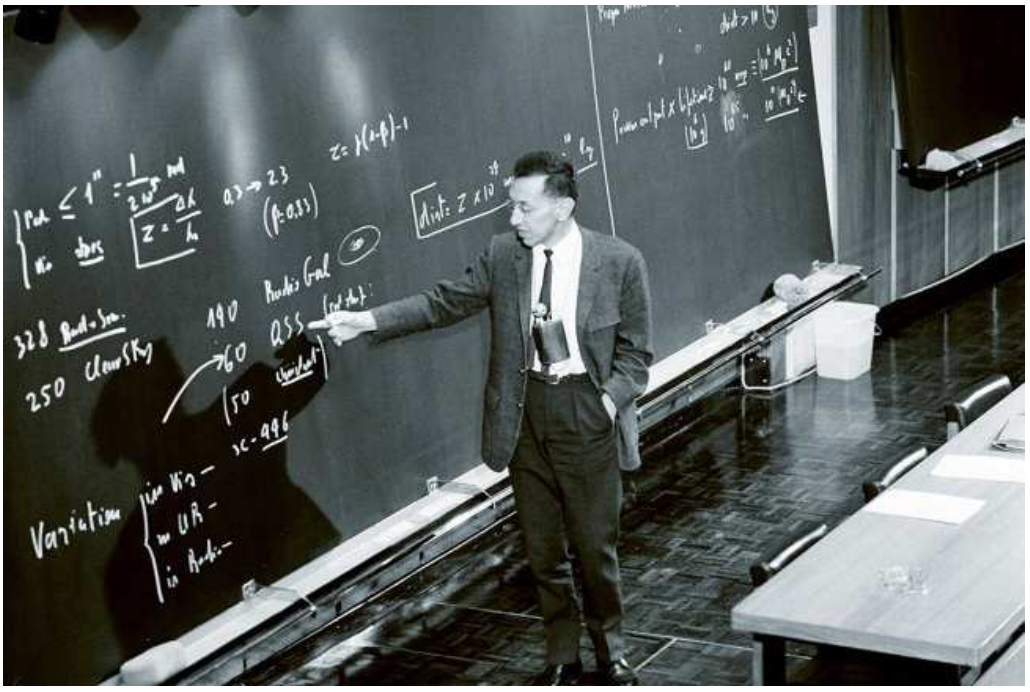
by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

The search for traces of other life in our own solar system is experiencing a remarkable boost, and the automatic missions already started or close to launch could produce some significant evidence in the coming years. Finding those traces would mean very little compared to direct contact with another technological civilization, but the achievement of this further goal depends only minimally on our own will.

Adam Frank, a professor of physics and astronomy at the University of Rochester in New York, recently received a grant from NASA for a SETI research project. At first glance it might not seem to be fascinating news, but since such a grant has not been awarded for more than twenty years, it may be useful to understand what has changed in the meantime.

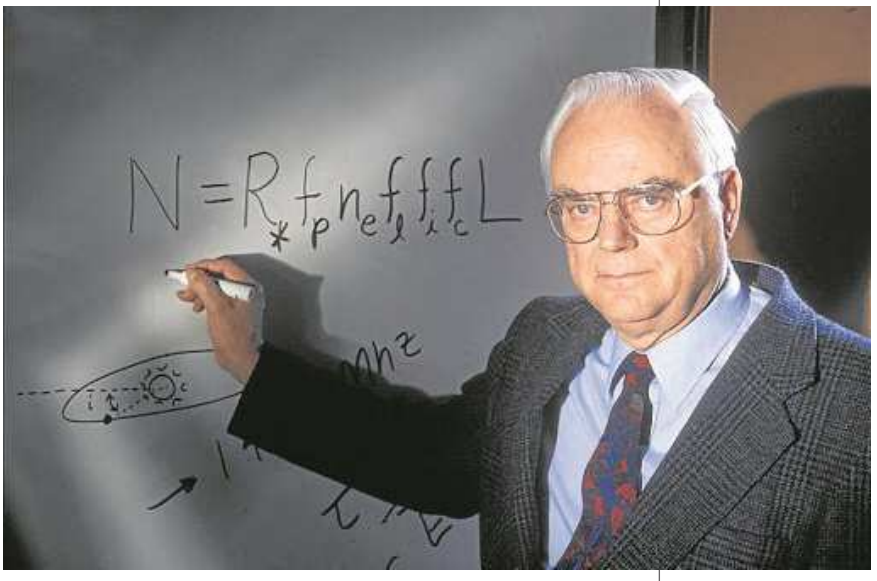
Let's start with SETI, which stands for Search for Extraterrestrial Intelligence. We can define it as a collective term that includes all those scientific researchers aimed at discovering evidence of evolved civilizations beyond the Earth. Although the SETI Institute



Physicist Giuseppe Cocconi was one of the first scientists to propose SETI strategies. [CERN] Below, astronomer Frank Drake and his famous formula, which allows us to estimate the number of technological civilizations in our galaxy.

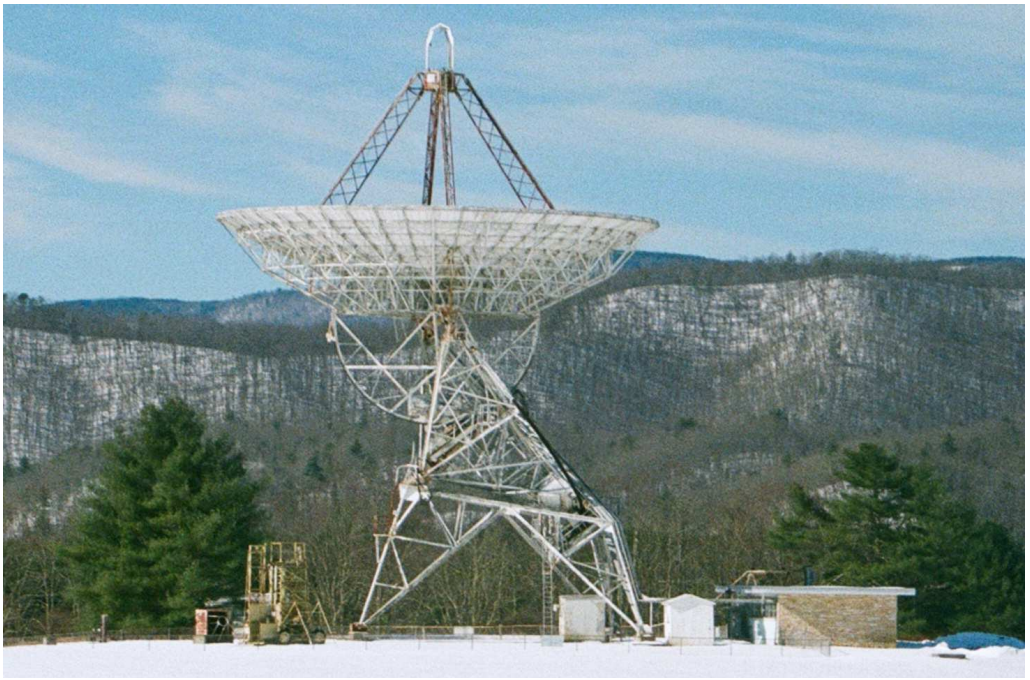
(which includes the Carl Sagan Center) was founded in 1984, it represents only a small part of the SETI world. In fact, it numbers less than 100 scientists, while thousands of others have dedicated themselves to similar research at hundreds of other institutes. Historically, the birth of SETI dates back to 1960, the year in which the astronomer Frank Drake started Project Ozma, which planned to use the Green Bank 26-meter radio telescope (West Virginia) to "listen" for possible messages from Tau Ceti and Epsilon Eridani stars. Drake was probably inspired by a theoretical work of the previous year, performed by Philip Morrison and Giuseppe Cocconi, who suggested that any extraterrestrial civilizations could use radio signals to communicate with us. To tell the truth, this idea was not very original - in fact, it had already been proposed in the early 1900's by Guglielmo Marconi, Lord Kelvin and David Peck Todd, who proposed to use radio waves to contact a possible Martian civilization.

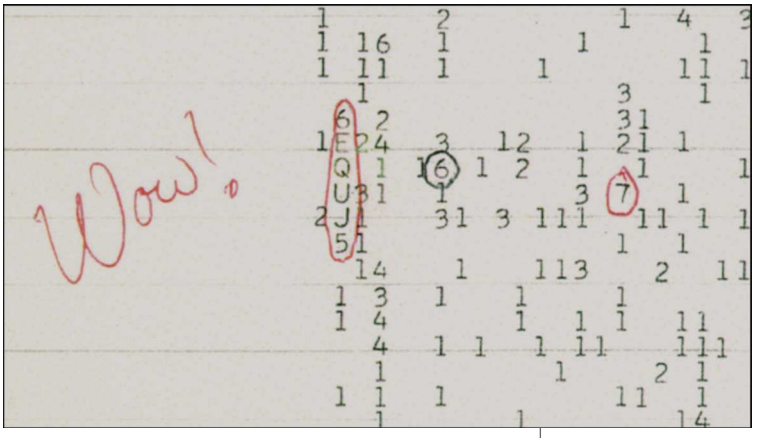
The search for artificial radio signals from space has been the cornerstone of all SETI projects, at least until the invention and development of the laser, which was immediately considered an alternative technology that an extraterrestrial civilization could choose to communicate with in the visible spectrum rather than the radio spectrum. It is quite evident that SETI projects have al-



Tau Ceti and Epsilon Eridani were the main targets of Frank Drake's Project Ozma. At that time, no extrasolar planets were known. We now know that both stars have a planetary system. [Palomar Observatory]
Here on the side, Green Bank's Howard Tatel Radio Telescope, the instrument used for the Project Ozma. [NRAO]

ways been characterized and conditioned by an underlying anthropocentrism. Not surprisingly, the location of hypothetical alien civilizations in space and the solutions by which they could choose to communicate with us have curiously changed with the progress of our own scientific and technological knowledge. Despite this, no alien signals have ever been recorded in the 60 years since Drake's pioneering research, not even



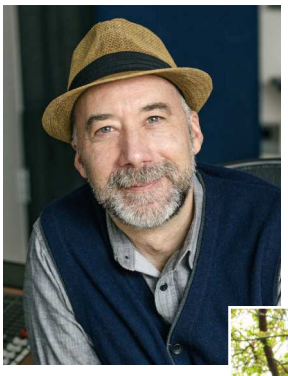


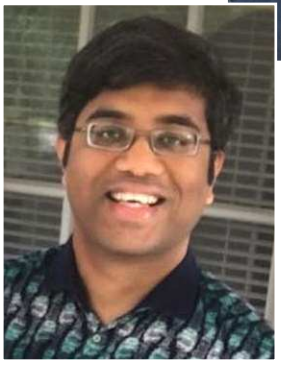
On the left, the astronomer Carl Sagan, promoter of SETI and inspiration for the film Contact, starring Jodie Foster, of whom we see an iconic image below. [Cosmos/ Discovery] Above, the famous 72-second "Wow signal" from 1977. For a long time, it was reputed to be a possible alien message. In 2017, astronomers determined that it was generated by hydrogen expelled from a passing comet. [Big Ear Radio Observatory and North American AstroPhysical Observatory (NAAPO)]

when, in 1971, SETI benefited from NASA's first contribution, Project Cyclops, consisting of a network of large radio telescopes that, for a couple of years, looked for radio signals from stars up to 1,000 light-years away. NASA's last remarkable contribution was the expensive Microwave Observing Project, which reached its peak in the early 1990s, only to be canceled in late 1992.

Since then, only private moneylenders have contributed to the SETI initiatives, and these funders have not always given the necessary relevance to the scientific aspects of the research. The "spectacularization" of privately-funded SETI projects, combined with the total absence of positive results, has undoubtedly contributed to diverting public funding towards a new interdisciplinary science that has developed extraordinarily in recent decades: astrobiology. Instead of looking for improbable alien messages, astrobiology investigates the origin, evolution and distribution of life in the solar system, in the Milky Way and beyond. Over time, this basic difference has produced a real dichotomy between astrobiology and SETI, although the latter is actually an ultimate ramification of the former. Its greater proximity to alien issues has often made people perceive SETI as something closer to ufology than to astrobiology, and this has certainly

The team of the new SETI project funded by NASA. Top to bottom: Adam Frank, Avi Loeb, Jason Wright, Jacob-Haqq Misra, Manasvi Lingam.





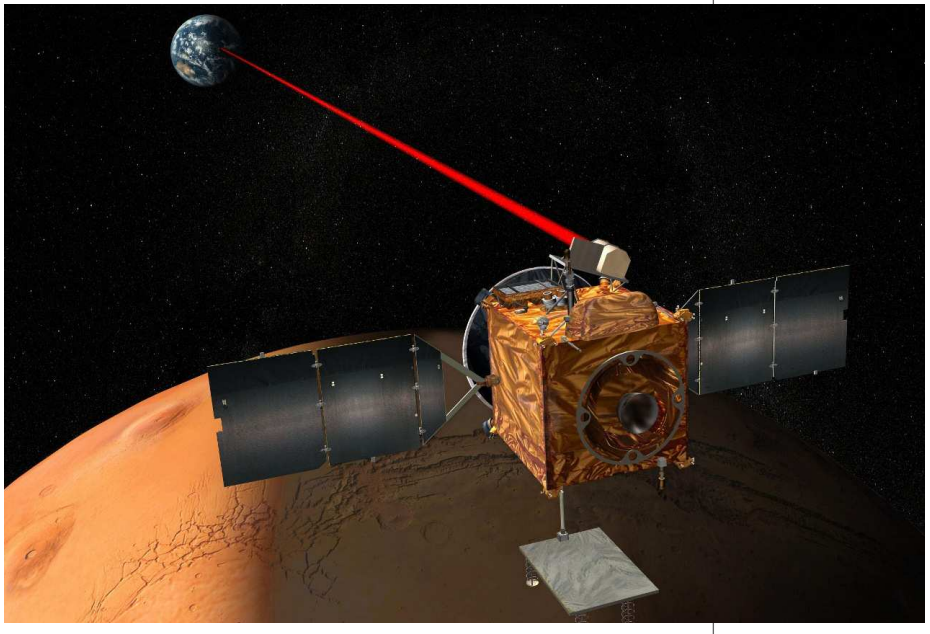
not facilitated the awarding of public funds. Until a few years ago, most astrobiologists considered the search for fossil microbial traces on Mars as a priority (perhaps the most we can aspire to find in our solar system), as opposed to the search for signals sent by extraterrestrial intelligences. That said, discovering traces of life a stone's throw from home would not tell us much about how widespread it is in the Milky Way and in the universe. However, since we became aware that millions of other potentially habitable planets could exist (a few dozen of which have already been discovered and confirmed), the attention of a growing number of researchers has also turned well beyond the borders of our solar system. Discovering life indicators in the Milky Way has now become a priority as well. In this endeavor, the distinction between astrobiology and SETI appears truly inappropriate - both have the same final objective, with the difference being that astrobiology essentially seeks biosignatures, which can include elementary life forms, while SETI specializes in the search for technosignatures, which result from highly evolved life forms. It is exactly in this context that the project by Frank and his collaborators (Avi Loeb, Harvard University; Jason Wright, Pennsylvania State University; Jacob-Haqq Misra, international nonprofit organization Blue Marble Space; Manasvi Lingam, Florida Institute of Technology) is placed. Called "Characterizing Atmospheric Technosignatures", the project is aimed at the search for indicators of technological activities, in particular expanses of solar panels and atmospheric pollutants of non-natural origin. "SETI has always faced the challenge of figuring out where to look. Which stars do you point your telescope at and look for signals? Now we know where to look. We have thousands of exoplanets including planets in the habitable zone where life can form. The game has changed," Frank explained. While Loeb added: "My hope is that, using this grant, we will quantify new ways to probe signs of alien technological civilizations that are similar or much more advanced to our own."

Technosignatures taken into consideration by Frank's team reflect or absorb light at typical wavelengths which, if present, will be recognizable in the spectra of the nearest exoplanets and observed through next-generation telescopes. Since the time allotted to researchers on the world's largest telescopes is particularly valuable, it is a must to know in advance where to look and for what.

The news of the NASA grant for this new SETI project has been welcomed with general satisfaction, yet quite a few criticisms have also been raised regarding the technological targets chosen by the team, typically terrestrial and contemporary, and

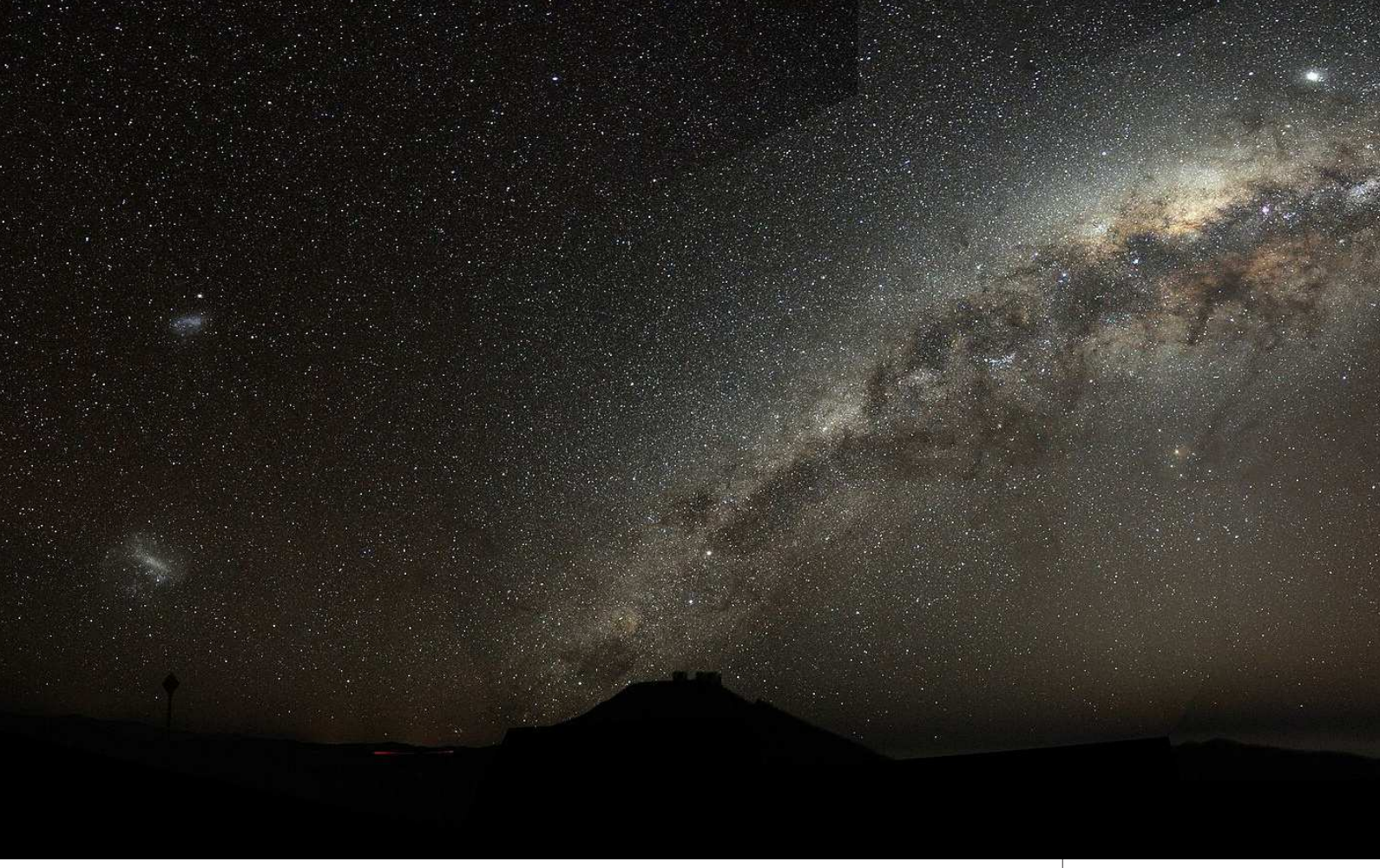
The Extreme Light Infrastructure for Nuclear Physics (ELI-NP) is currently the most powerful laser in the world: it can generate light pulses with a power of up to 10 petawatts and keep them generated for a few hours. Despite its extraordinary performance, we are still very far from being able to use laser techniques to communicate with alien civilizations. At most, we can use them to communicate with satellites, as in the illustration below. [Thales, NASA-JPL]

therefore with a strong anthropocentric flavor. The choice of those targets is based, more or less, on the following essential assumptions: regardless of how many forms life can take, it can only be the result of the same physical and chemical principles, as well as any technology used by any civilization. This means that researchers can take advantage of what has been learned on Earth to imagine what may have happened elsewhere. Despite this logic, focusing the search for technosignatures on solar panels and atmospheric pollutants does not seem to be a winning strategy. It is true that, for each planetary system, its star is the most powerful energy generator, and that harnessing that energy with photovoltaic systems is an interesting possibility. Nonetheless, our own experience as Earthlings teaches us that this particular way does not appear decisive, as there are more efficient alternatives, such as nuclear fusion and hydrogen combustion. A more advanced civilization than ours might have optimized the collection of stellar energy and disseminated solar panels across a planetary surface, but it could also have chosen more efficient and less bulky solutions. Not even the idea of looking for atmospheric pollutants enjoys great consensus, because it would be desirable that any civilization, having reached a certain maturity, would stop polluting the air it breathes. We are all with Frank when he explains that: "Our job is to say, this wavelength band is where you might see certain types of pollutants, this wavelength band is where you would see sunlight reflected off



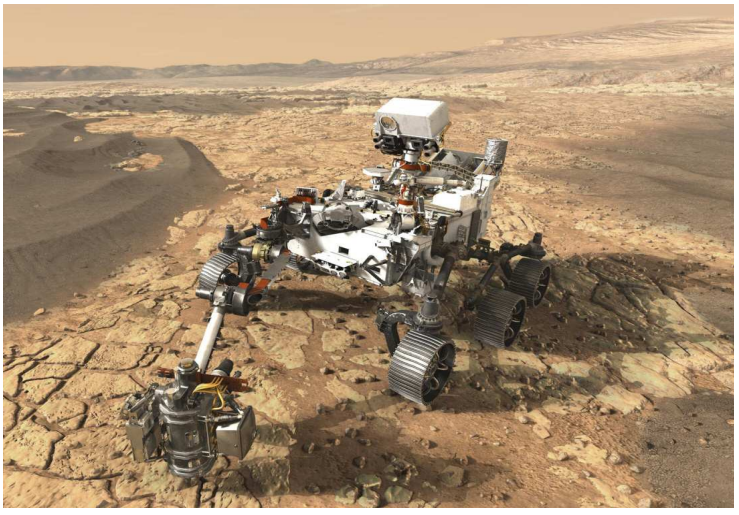
Artificial lights lit in the nighttime hemisphere of an imaginary alien planet. The search for technosignatures in the Milky Way also contemplates this scenario. [David A. Aguilar/ Harvard-Smithsonian Center for Astrophysics]

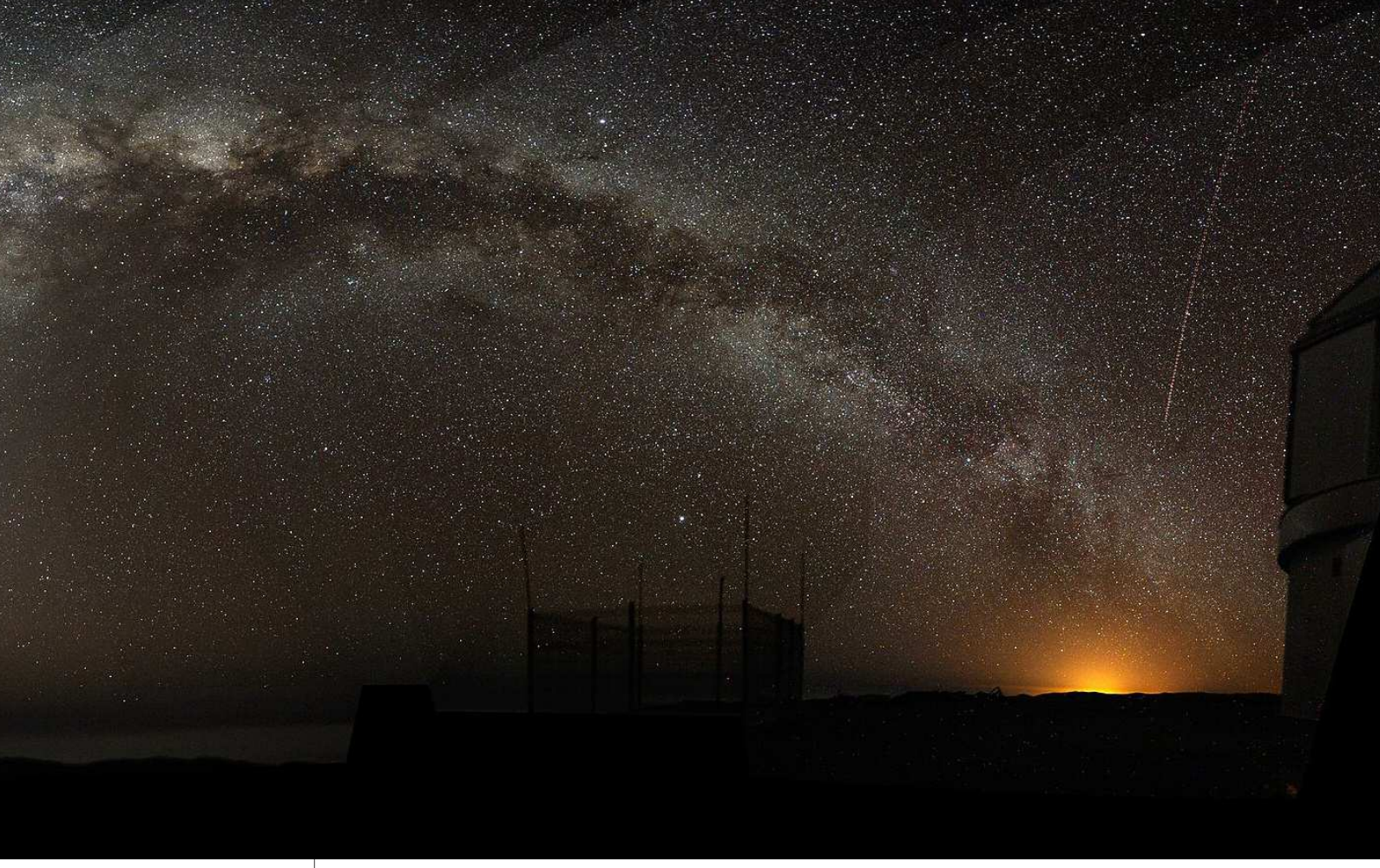
solar panels. This way, astronomers observing a distant exoplanet will know where and what to look for if they're searching for technosignatures," but the database that this survey promises to produce could ultimately be useful only to recognize the presence of any technological civilizations identical to our current one. Considering that we have been polluting the atmosphere in an evident way for about two centuries, and hoping that this will end by the end of this century (a deadline by which we could also have optimized energy production), we can assume that a civilization like ours would be recognizable by Frank's team within a time span of just 3-4 centuries, after which it might become invisible to us. It is difficult to fathom that a technological civilization could theoretically evolve slowly over millennia or even millions of years for us to have a large window within which to identify them. The same can be said for other technosignatures, such as the planetary heat surplus expected in the presence of a technological civilization or the artificial lighting of the nighttime hemisphere. Within certain limits, these technosignatures could be revealed by the large telescopes under construction or about to become operational. But even in these cases, it would be reasonable to expect that a mature civilization knows how not to waste heat and how not to disperse into space artificial lighting destined for the ground.



The Milky Way arching through the night sky. Composite panorama created at the Paranal Observatory, Chile. At first glance it doesn't look like it, but the stars of our galaxy are so numerous that, in order to find another technological civilization, it would be necessary to aim at hundreds of millions of stars with our instruments. [Bruno Gilli/ESO] Alongside, the Mars 2020 Mission rover, one of the best chances we have for discovering traces of extraterrestrial life in the coming years. [NASA/JPL-Caltech]

It goes around and around - one has the impression that each SETI project is thought to find our analogues. Apparently, we just cannot get into the mind of ET. One of the reasons why we might not succeed is to be found in the strategies of many SETI projects, which appear to be losers at the start, as they underestimate the capabilities of the hypothetical technological civilizations they would like to discover. We expect, for example, that these civilizations are identifiable regardless of their will, and that they send messages blindly through interstellar space. We also expect that those messages are not sent continuously but instead occasionally, as sending them would be energetically expensive. You see, we are all of this! Someone will certainly remember the questionable message launched in 1974 by the Arecibo Radio Telescope towards the globular cluster M13, about 25,000 light-years away. A civilization more evolved than ours would have enough knowledge of the worlds that surround it to know, with good approximation, if and where other civilizations developed and, based on the evolutionary levels on these worlds, it would know if and how to attempt a contact. The reduced number of targets would allow for the optimization of energy consumption to sustain a continuous signal and, therefore, maximize the chances of success. Sending a continuous signal should be a priority for ET, because this would also allow a civilization like ours, which is unable to "listen" for long periods to a given target, to





The video below introduces NASA's Europa Clipper mission to Europa, the Jovian moon that houses an ocean below its frozen surface. Life could exist in the waters of that ocean. [NASA/JPL-Caltech]

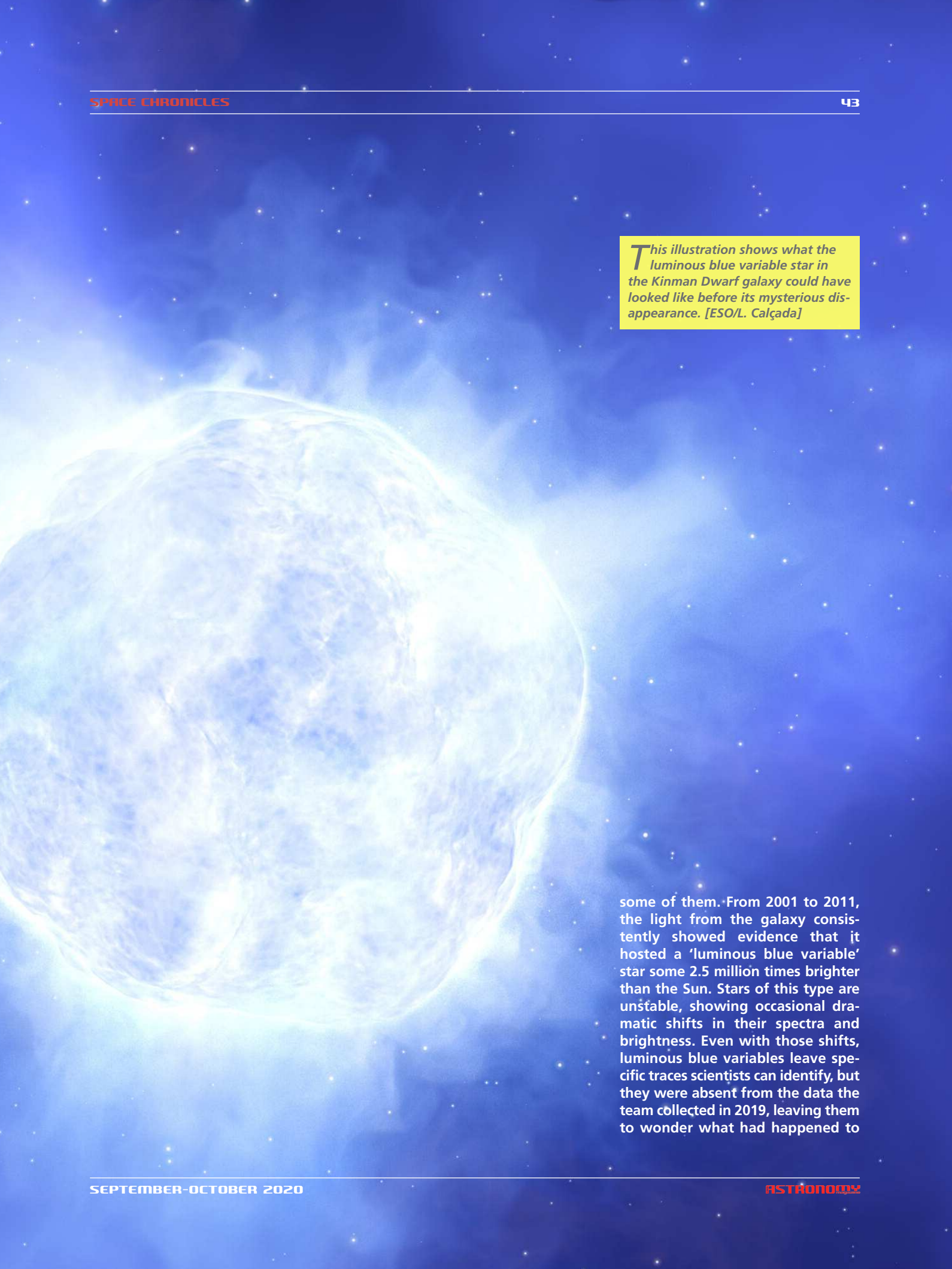
have some minimal chance of receiving the message. In this regard, we must remember that the instruments used in the various SETI projects have aimed their targets only for periods between less than a minute and less than an hour a day. It is true that even such short periods may be enough to record a continuously repeated signal, but only if two essential conditions are met: (1) ET wants to communicate with us; (2) we aim at the right star. Even if we want to be optimistic about the first condition, the real problem is the second. Very few people truly realize how many stars there are in our galaxy, and it doesn't help much to say that there are "a few hundred billion." To provide some perspective - if there were 1000 technological civilizations in the Milky Way (a number perhaps disproportionate, given that the most conservative estimates range from one to a few dozen), in order to receive a message repeated continuously by one of them, we would have to plan to aim at, on average, from 100 to 400 million stars. So far, all SETI projects have targeted a few thousand stars overall. So, let us not be surprised if nothing has been found so far and if government agencies prefer to allocate taxpayers' money to missions to Mars and Europa.

Leaving aside all the problems related to SETI, let's suppose we have the lucky fortune of picking up a real alien signal. After what has been said above, it is very likely that it is intended for us and that it was sent by a relatively close and certainly more advanced civilization than ours, as we are not currently able to do the same. How do we behave? What reasoning did ET have (or do) before sending it? Do we have to answer? What consequences could our response have? ■

VLT captures the disappearance of a massive star

by ESO

Using the European Southern Observatory's Very Large Telescope (VLT), astronomers have discovered the absence of an unstable massive star in a dwarf galaxy. Scientists think this could indicate that the star became less bright and partially obscured by dust. An alternative explanation is that the star collapsed into a black hole without producing a supernova. *"If true,"* says team leader and PhD student Andrew Allan of Trinity College Dublin, Ireland, *"this would be the first direct detection of such a monster star ending its life in this manner."* Between 2001 and 2011, various teams of astronomers studied the mysterious massive star, located in the Kinman Dwarf galaxy, and their observations indicated it was in a late stage of its evolution. Allan and his collaborators in Ireland, Chile and the US wanted to find out more about how very massive stars end their lives, and the object in the Kinman Dwarf seemed like the perfect target. But when they pointed ESO's VLT to the distant galaxy in 2019, they could no longer find the telltale signatures of the star. *"Instead, we were surprised to find out that the star had disappeared!"* says Allan, who led a study of the star published in *Monthly Notices of the Royal Astronomical Society*. Located some 75 million light-years away in the constellation of Aquarius, the Kinman Dwarf galaxy is too far away for astronomers to see its individual stars, but they can detect the signatures of



This illustration shows what the luminous blue variable star in the Kinman Dwarf galaxy could have looked like before its mysterious disappearance. [ESO/L. Calçada]

some of them. From 2001 to 2011, the light from the galaxy consistently showed evidence that it hosted a 'luminous blue variable' star some 2.5 million times brighter than the Sun. Stars of this type are unstable, showing occasional dramatic shifts in their spectra and brightness. Even with those shifts, luminous blue variables leave specific traces scientists can identify, but they were absent from the data the team collected in 2019, leaving them to wonder what had happened to

the star. *"It would be highly unusual for such a massive star to disappear without producing a bright supernova explosion,"* says Allan. The group first turned the ESPRESSO instrument toward the star in August 2019, using the VLT's four 8-metre telescopes simultaneously. But they were unable to find the signs that previously pointed to the presence of the luminous star. A few months later, the group tried the X-shooter instrument, also on ESO's VLT, and again found no traces of the star.

"We may have detected one of the most massive stars of the local Universe going gently into the night," says teammember Jose Groh, also of Trinity College Dublin. *"Our discovery would not have been made without using the powerful ESO 8-metre telescopes, their unique instrumentation, and the prompt access to those capabilities following the recent agreement of Ireland to join ESO."* Ireland became an ESO member state in September 2018. The team then turned to older data collected using X-shooter and the UVES instrument on ESO's VLT, located in the Chilean Atacama desert, and telescopes elsewhere. *"The ESO Science Archive Facility enabled us to find and use data of the same object obtained in 2002 and 2009,"* says Andrea Mehner, a staff astronomer at ESO in Chile who participated in the study. *"The comparison of the 2002 high-resolution UVES spectra with our observations obtained in 2019 with ESO's newest high-resolution spectrograph ESPRESSO was especially revealing, from both an astronomical and an instrumentation point of view."*

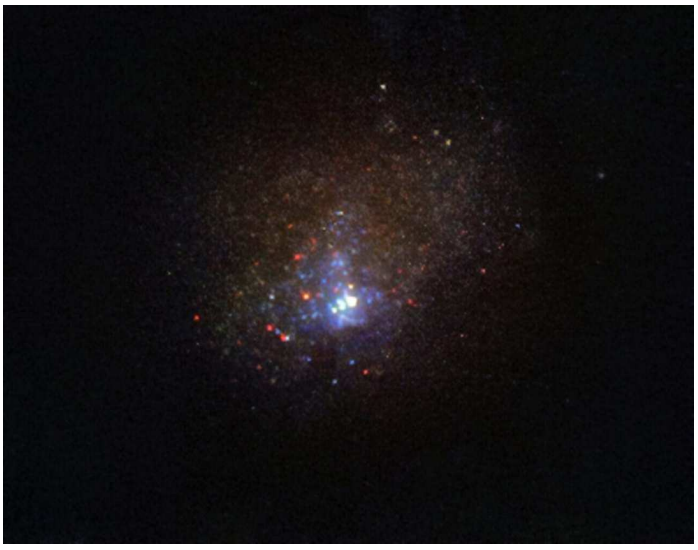


Image of the Kinman Dwarf galaxy, also known as PHL 293B, taken with the NASA/ESA Hubble Space Telescope's Wide Field Camera 3 in 2011, before the disappearance of the massive star. Located some 75 million light-years away, the galaxy is too far away for astronomers to clearly resolve its individual stars, but in observations done between 2001 and 2011, they detected the signatures of the massive star. These signatures were not present in more recent data. [NASA, ESA/Hubble, J. Andrews (U. Arizona)]

The old data indicated that the star in the Kinman Dwarf could have been undergoing a strong outburst period that likely ended sometime after 2011. Luminous blue variable stars such as this one are prone to experiencing giant outbursts over the course of their life, causing the stars' rate of mass loss to spike and their luminosity to increase dramatically.

Based on their observations and models, the astronomers have suggested two explanations for the star's disappearance and lack of a supernova, related to this possible outburst. The outburst may have resulted in the luminous blue variable being transformed into a less luminous star, which could also be partly hidden by dust. Alternatively, the team says the star may have collapsed into a black hole, without producing a supernova explosion. This would be a rare event: our current understanding of how massive stars die points to most of them ending their lives in a supernova.

Future studies are needed to confirm what fate befell this star. Planned to begin operations in 2025, ESO's Extremely Large Telescope (ELT) will be capable of resolving stars in distant galaxies such as the Kinman Dwarf, helping to solve cosmic mysteries such as this one. ■

This video starts by showing a wide-field view of a region of the sky in the constellation of Aquarius. It then zooms in to show the Kinman Dwarf galaxy, where a mysterious luminous blue variable star disappeared. The end of the video shows an artistic animation of what the star could have looked like before it disappeared. [ESO/L. Calçada, Digitized Sky Survey 2, N. Risinger (skysurvey.org), NASA, ESA/Hubble, J. Andrews (U. Arizona) Music: Konstantino Polizois]

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

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Hubble watches the "flapping" of cosmic bat shadow

by NASA/ESA

The young star HBC 672 is known by its nickname of Bat Shadow because of its wing-like shadow feature. The NASA/ESA Hubble Space Telescope has now observed a curious "flapping" motion in the shadow of the star's disc for the first time. The star resides in a stellar nursery called the Serpens Nebula, about 1300 light-years away. The Hubble Space Telescope captured a striking observation of the fledgling star's unseen, planet-forming disc in 2018. This disc casts a huge shadow across a more distant cloud in a star-forming region — like a fly wandering into the beam of a flashlight shining on a wall.

Now, astronomers have serendipitously observed the Bat Shadow's "flapping". This may have been caused by a planet pulling on the disc and warping it. *"You have a star that is surrounded by a disc, and the disc is not like Saturn's rings — it's not flat. It's puffed up. And so that means that the light from the star, if it goes straight up, can continue straight up — it's not blocked by anything. But if it tries to go along the plane of the disc, it doesn't get out, and it casts a shadow,"* explained lead author Klaus Pontoppidan, an astronomer at the Space Telescope Science Institute (STScI) in Baltimore, USA, whose team have published these results.

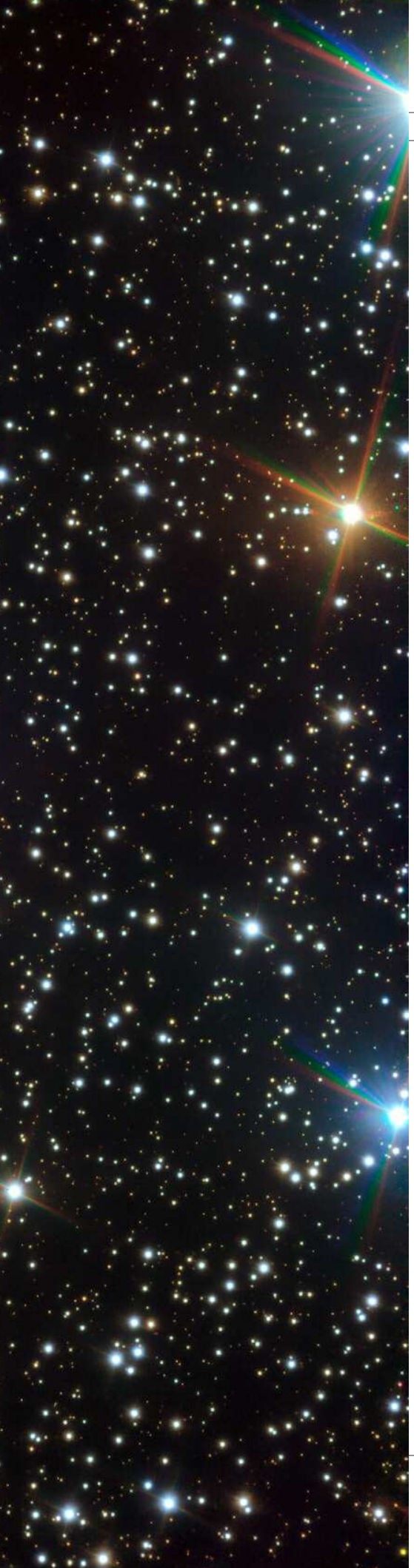
This "flapping" finding was also a surprise. Pontoppidan and his team observed the shadow in several filters over a period of 13 months. When they combined the old and new images, the shadow appeared to have moved.

The shadow is so large — about 200 times the diameter of our Solar System — that light doesn't travel instantaneously across it. In fact, it takes about 45 days for the light to travel from the star out to the best defined edge of the shadow.

Pontoppidan and his team calculate that a planet warping the disc would orbit its star in no fewer than 180 days. They estimate that it would be about the same distance from its star as Earth is from the Sun.

Pontoppidan's team also suggest the disc must be flared, with an angle that increases with distance — like a trumpet. This shape of its two peaks and two dips would explain the "flapping" of the shadow. The team also speculates that a planet is embedded in the disc, inclined to the disc's plane. If it's not a planet, a less likely explanation is a lower-mass stellar companion orbiting HBC 672 outside the plane of the disc. Pontoppidan and his team doubt this is the case, based on the thickness of the disc. There is also no current evidence for a binary companion. The disc is a circling structure of gas, dust, and rock, and is too small and too distant to be seen, even by Hubble. However, based on the projected shadow, scientists do know that its height-to-radius ratio is 1:5. ■

This image shows only the feature which was nicknamed the Bat Shadow. It is the shadow of a protoplanetary disc orbiting the star in the centre of the image. [NASA, ESA, K. Pontoppidan]



Stunning space butterfly captured by VLT

by ESO

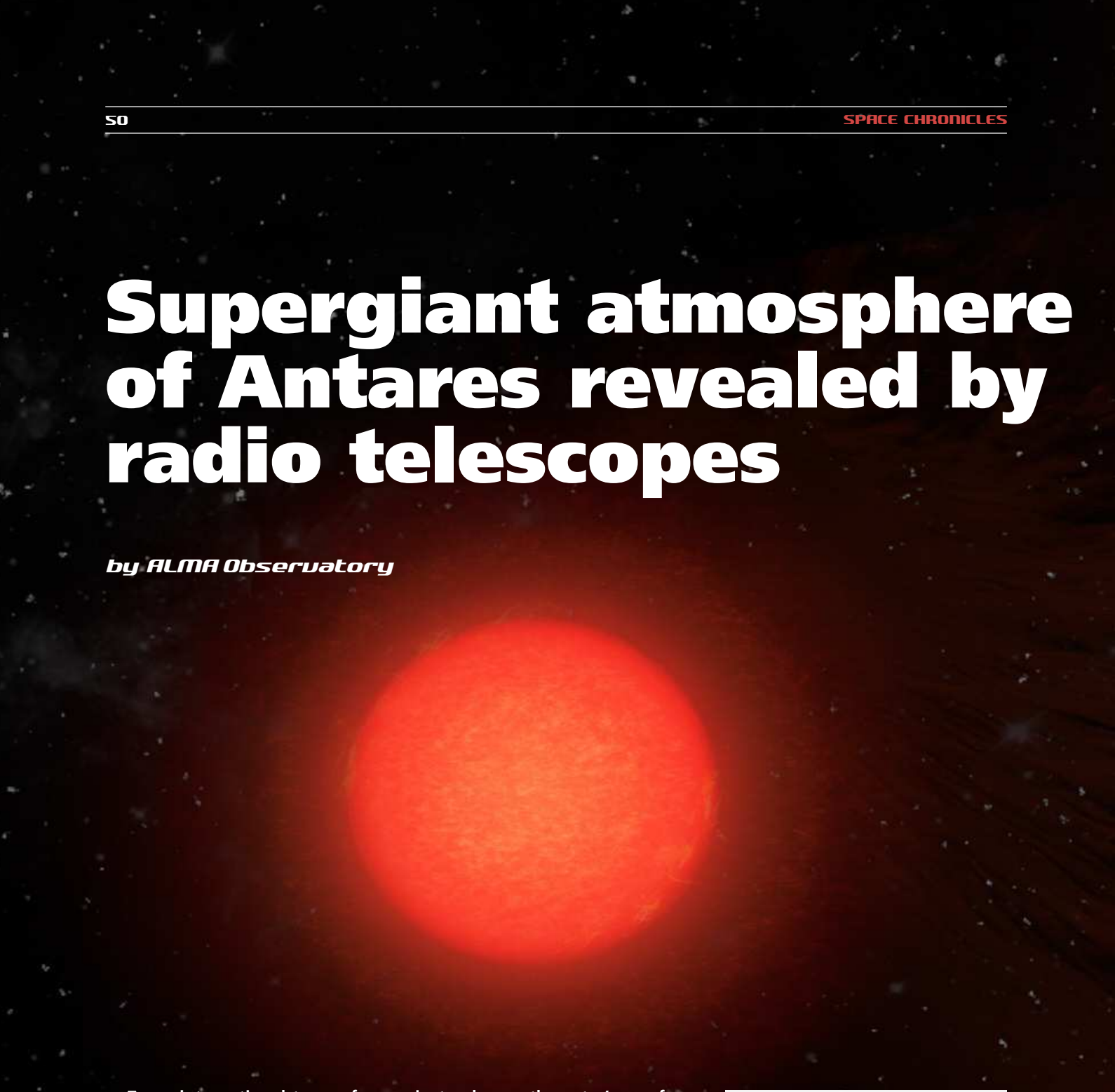
Resembling a butterfly with its symmetrical structure, beautiful colours, and intricate patterns, this striking bubble of gas — known as NGC 2899 — appears to float and flutter across the sky in this new picture from ESO's Very Large Telescope (VLT). This object has never before been imaged in such striking detail, with even the faint outer edges of the planetary nebula glowing over the background stars.

NGC 2899's vast swathes of gas extend up to a maximum of two light-years from its centre, glowing brightly in front of the stars of the Milky Way as the gas reaches temperatures upwards of ten thousand degrees. The high temperatures are due to the large amount of radiation from the nebula's parent star, which causes the hydrogen gas in the nebula to glow in a reddish halo around the oxygen gas, in blue.

This object, located between 3000 and 6500 light-years away in the Southern constellation of Vela (The Sails), has two central stars, which are believed to give it its nearly symmetric appearance. After one star reached the end of its life and cast off its outer layers, the other star now interferes with the flow of gas, forming the two-lobed shape seen here. Only about 10–20% of planetary nebulae display this type of bipolar shape. Astronomers were able to capture this highly detailed image of NGC 2899 using the FORS instrument installed on UT1 (Antu), one of the four 8.2-metre telescopes that make up ESO's VLT in Chile. Standing for FOcal Reducer and low dispersion Spectrograph, this high-resolution instrument was one of the first to be installed on ESO's VLT and is behind numerous beautiful images and discoveries from ESO. FORS has contributed to observations of light from a gravitational wave source, has researched the first known interstellar asteroid, and has been used to study in depth the physics behind the formation of complex planetary nebulae. This image was created under the ESO Cosmic Gems programme, an outreach initiative to produce images of interesting, intriguing or visually attractive objects using ESO telescopes, for the purposes of education and public outreach. The programme makes use of telescope time that cannot be used for science observations. All data collected may also be suitable for scientific purposes, and are made available to astronomers through ESO's science archive. ■

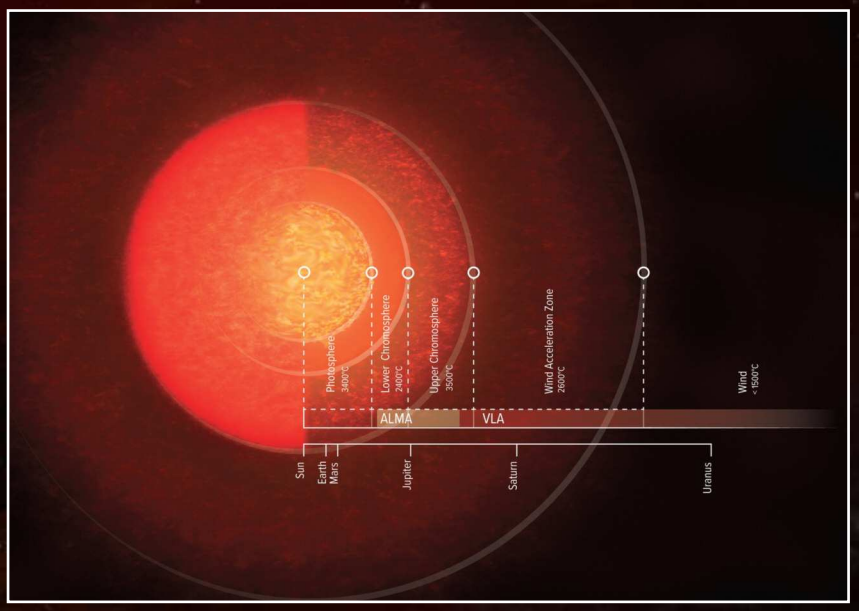
Supergiant atmosphere of Antares revealed by radio telescopes

by ALMA Observatory



An international team of astronomers has created the most detailed map yet of the atmosphere of the red supergiant star Antares. The unprecedented sensitivity and resolution of both the Atacama Large Millimeter/submillimeter Array (ALMA) and the National Science Foundation's Karl G. Jansky Very Large Array (VLA) revealed the size and temperature of Antares' atmosphere from just above the star's surface, throughout its chromosphere, and all the way out to the wind region. Red supergiant stars, like Antares and its more well-known cousin Betelgeuse, are huge, relatively cold stars at the end of their lifetime. They are on their way to run out of fuel, collapse, and become supernovae. Through their vast stellar winds, they launch heavy elements into space, thereby playing an important role in providing the essential building blocks for life in the universe. But it is a mystery how these enormous winds are launched. A detailed study of the atmosphere of Antares, perhaps the closest supergiant star to Earth, provides a crucial step towards an

Artist impression of red supergiant star Antares. [NRAO/AUI/NSF, S. Dagnello]

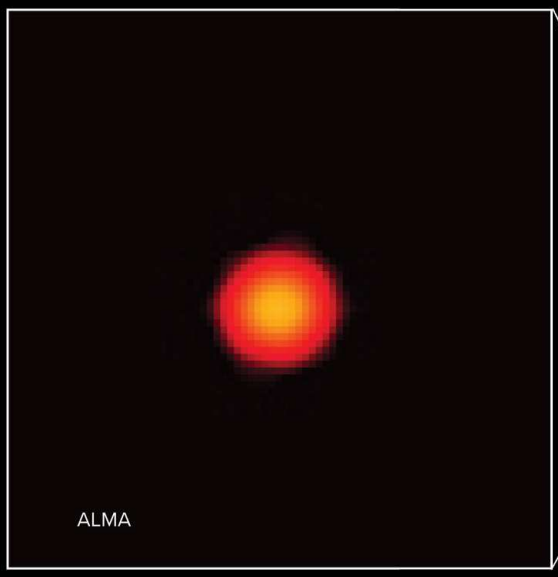


Graphic scheme of the atmosphere of Antares. As seen with the naked eye (up until the photosphere), Antares is around 700 times larger than our sun, big enough to fill the solar system beyond the orbit of Mars (Solar System scale shown for comparison). But ALMA and VLA showed that its atmosphere, including the lower and upper chromosphere and wind zones, reaches out 12 times farther than that. [NRAO/AUI/NSF, S. Dagnello]

answer. The ALMA and VLA map of Antares is the most detailed radio map yet of any star, other than the Sun. ALMA observed Antares close to its surface (its optical photosphere) in shorter wavelengths, and the longer wavelengths observed by the VLA revealed the star's atmosphere further out. As seen in visible light, Antares' diameter is approximately 700 times larger than the Sun. But when ALMA and the VLA revealed its atmosphere in radio light, the supergiant turned out to be even more gigantic.

"The size of a star can vary dramatically depending on what wavelength of light it is observed with," explained Eamon O'Gorman of the Dublin Institute for Advanced Studies in Ireland and lead author of the study published in *Astronomy & Astrophysics*. *"The longer wavelengths of the VLA revealed the supergiant's atmosphere out to nearly 12 times the star's radius."*

The radio telescopes measured the temperature of most of the gas and plasma in Antares' atmosphere. Most noticeable was the temperature in the chromosphere. This is the region above the star's surface that is heated up by magnetic fields and shock waves created by the vigorous roiling convection at the stellar surface – much like the bubbling



Radio images of Antares with ALMA and the VLA. ALMA observed Antares close to its surface in shorter wavelengths, and the longer wavelengths observed by the VLA revealed the star's atmosphere further out. In the VLA image a huge wind is visible on the right, ejected from Antares and lit up by its smaller but hotter companion star Antares B. [ALMA (ESO/NAOJ/NRAO), E. O'Gorman; NRAO/AUI/NSF, S. Dagnello]

motion in a pot of boiling water. Not much is known about chromospheres, and this is the first time that this region has been detected in radio waves.

Thanks to ALMA and the VLA, the scientists discovered that the star's chromosphere extends out to 2.5 times the star's radius (our Sun's chromosphere is only 1/200th of its radius). They also found that the temperature of the chromosphere is lower than previous optical and ultraviolet observations have suggested. The temperature peaks at 3,500 degrees Celsius (6,400 degrees Fahrenheit), after which it gradually decreases. As a comparison, the Sun's chromosphere reaches temperatures of almost 20,000 degrees Celsius. *"We found that the chromosphere is 'lukewarm' rather than hot, in stellar temperatures,"* said O'Gorman. *"The difference can be explained because our radio measurements are a sensitive thermometer for most of the gas and plasma in the star's atmosphere, whereas past optical and ultraviolet observations were only sensitive to very hot gas and plasma."*

"We think that red supergiant stars, such as Antares and Betelgeuse, have an inhomogeneous atmosphere," said co-author Keiichi Ohnaka of the Universidad Católica del Norte in Chile who previously observed Antares' atmosphere in infrared light. *"Imagine that their atmospheres are a painting made out of many dots of different colors, representing different temperatures. Most of the painting contains dots of the lukewarm gas that radio telescopes can see, but there are also cold dots that only infrared telescopes can see, and hot dots that UV telescopes see. At the moment we can't observe these dots individually, but we want to try that in future studies."*

In the ALMA and VLA data, astronomers for the first time saw a clear distinction between the chromosphere and the region where winds start to form. In the VLA image, a huge wind is visible, ejected from Antares and lit up by its smaller but hotter companion star Antares B. *"When I was a student, I dreamt of having data like this,"* said co-author Graham Harper of the University of Colorado, Boulder. *"Knowing the actual sizes and temperatures of the atmospheric zones gives us a clue of how these huge winds start to form and how much mass is being ejected."*

"Our innate understanding of the night sky is that stars are just points of light. The fact we can map the atmospheres of these supergiant stars in detail, is a true testament to technological advances in interferometry. These tour de force observations bring the universe close, right into our own backyard," said Chris Carilli of the National Radio Astronomy Observatory, who was involved in the first observations of Betelgeuse at multiple radio wavelengths with the VLA in 1998. ■

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