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SUMMARY

Twin spends in orbit

by Gonçalo Magalhães

In 1961, Yuri Gagarin was the first human ever to travel in space; in 1969, Neil Armstrong became the first human ever to walk on the Moon; with the construction of space stations in orbit during the last years of the 20th century, humans became able to spend consecutive days, weeks, even months living in space. Now that we dream about our next big step in space exploration, travelling to Mars, we must fully understand how the human body and mind are affected by the environment in space. NASA astronauts Scott and Mark Kelly are genetically identical twins and they will show us some answers.

340 days

Night Earth observation of Japan taken by Expedition 44 crewmember Scott Kelly, with a Soyuz Spacecraft connected to the Mini Research Module 1 (MRM1), and a Progress Spacecraft visible. [NASA]

Outer space has one of the harshest environments for human life. Although the International Space Station takes care of the most obvious problems – such as proper air pressure, temperature and a lack of oxygen – there are also the obstacles of microgravity and cosmic radiation, which, as we will see, come with lots to be concerned about.

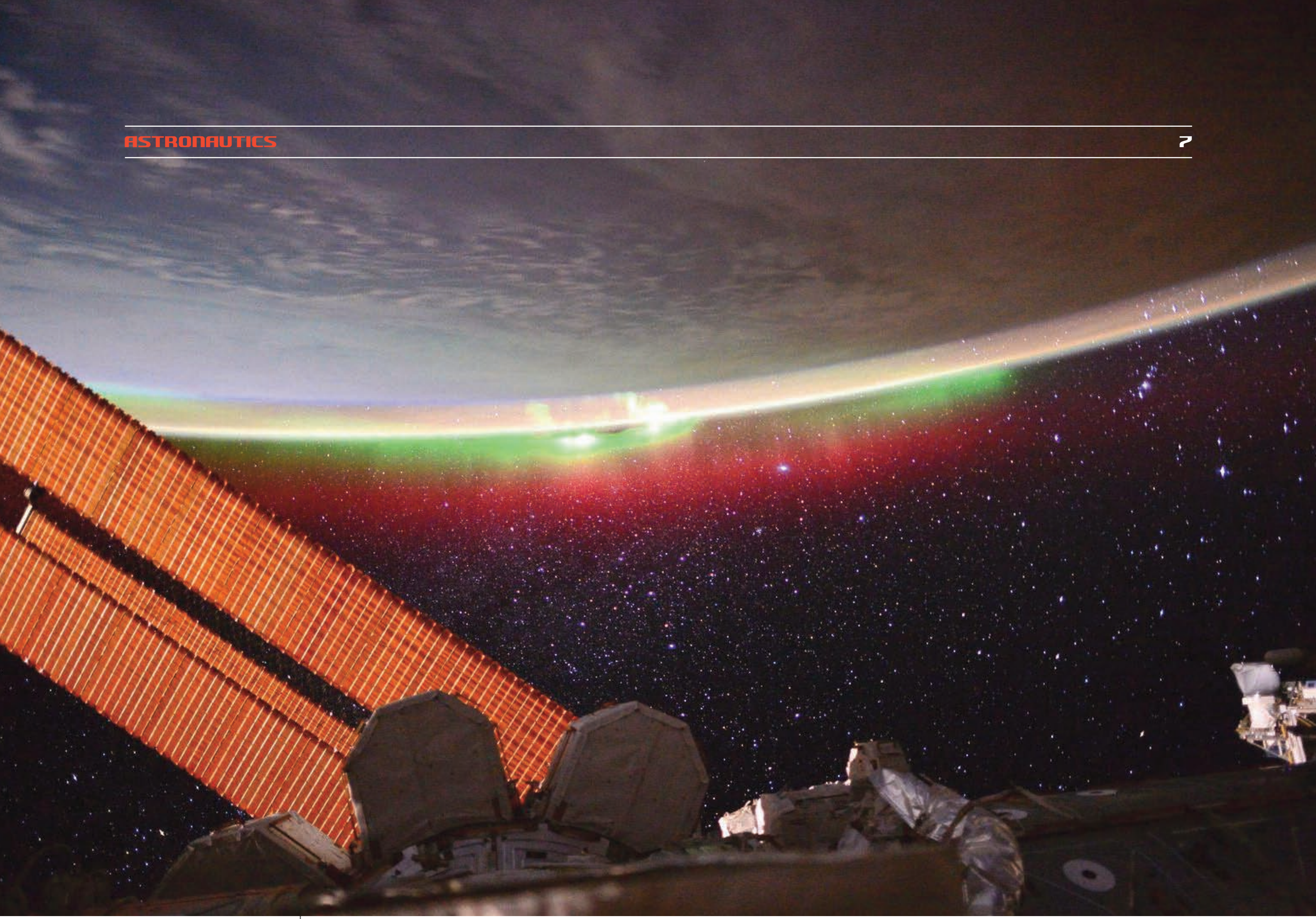
One could say that these problems aren't that important to address. However, human progress leads us to think that space exploration is the future. The increasingly possible upcoming trip to Mars is a great example of this advancement. But there is more to it than space technology. For a very long time, the United States of America and Russia were the only countries with major space programs, followed by the European Space Agency, created in 1975. But now, other countries like India and China have created their own space programs and the space exploration industry has attracted private sector companies like SpaceX, Orbital Sciences and SpaceDev. This has accelerated the race for cosmic supremacy.

The biggest problem that faces these great exploratory ambitions is the human body.

Our body is specifically designed for Earth's gravitational pull. When astronauts fly through space, they experience a near absence of gravity, known as microgravity. In an environment with less G-force, whether it's in space, on the Moon or eventually on Mars, the human body suffers various gradual changes: bones start getting brittle, the eyeballs lose their normal shape, hearts beat less efficiently, the legs lose muscle tone, and probably much more that we still don't know about. To fight these physical changes, astronauts must undertake a very strict exercise and dietary regimen.

However, it's not that easy to work out in space. Our normal training uses gravity, whether it is doing push-ups, lifting weights or running. One way astronauts can get exercise aboard the ISS is by running on a treadmill with strings pulling them against it. This is a small example of how hard it is to live in space, but there are many more difficulties, from eating to bathing and sleeping. It's not just the incredibly beautiful experience we are used to imagining. Whether it is a beautiful palace or the ISS, staying inside any house for an entire year is rough, and you settle into a routine in no time.

Identical twins, Scott and Mark Kelly, are the subjects of NASA's Twins Study. Scott (left) spent a year in space while Mark (right) stayed on Earth as a control subject. Researchers are looking at the effects of space travel on the human body. Left, Twins Study Investigators. [NASA]



Above, an image taken by Scott Kelly, from the International Space Station, on June 27, 2015. [NASA]. Below, a video that summarize the One-Year Mission and Twins Study. [CNN, NASA]

Besides the physical changes and difficulties that our bodies present, the astronauts in space get much more exposure to harmful solar radiation, since they don't have the atmosphere to protect them from this major hazard. This is such a significant danger that NASA established a limited period of time an astronaut can spend in space, mainly because of this exposure.

Regardless, we must be prepared to face the challenges of the space environment. Not only that, we need to know if such journeys are even possible for human beings. Most importantly, we should know what health consequences astronauts face when they spend a long, uninterrupted period in space.

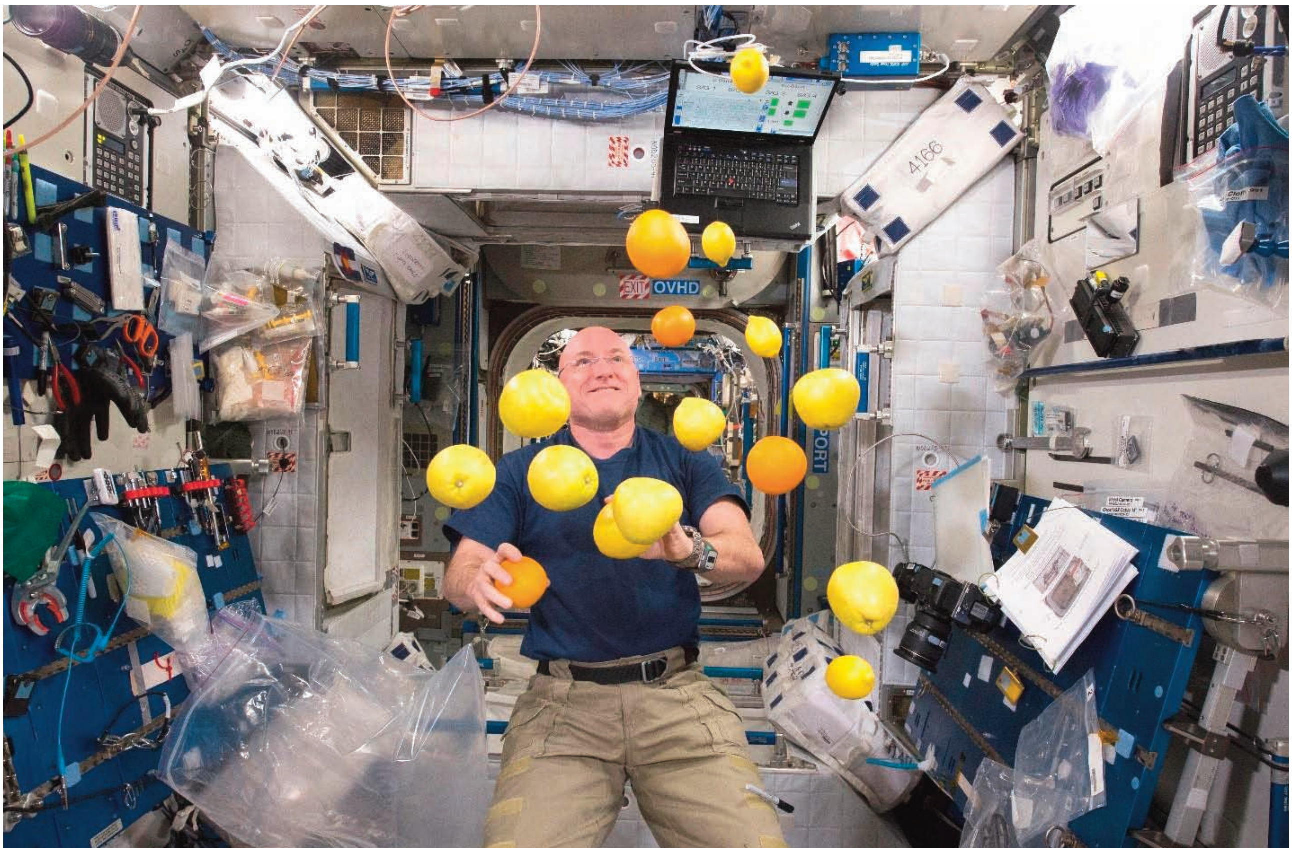
To explore these problems, years ago NASA announced a revolutionary study involving two twin astronauts, Mark and Scott Kelly. The study meant rocketing one of the twins to the International Space Station and leaving him there for about a year, while the other twin remained on Earth. Since they are genetically identical twins, this experiment should show us the genetic changes caused by the space environment, shedding light on how humans change when they leave our planet.

So, on March 27, 2015, NASA astronaut Scott Kelly and his Russian colleague Mikhail Kornienko rode a Russian Soyuz Rocket to

Scott Kelly posted this photo of a moonrise from the International Space Station to Twitter on July 17, 2015. Below, the famed astronaut speaks about his historic mission aboard the ISS during an event at the United States Capitol Visitor Center, in Washington. [NASA/ Bill Ingalls]

the ISS, where Kelly would live for the following 340 days, breaking the record for the longest consecutive time a US astronaut has spent in space. This mission was not going to be a major threat to Scott Kelly's wellbeing, since (for example) Russian astronaut Valery Polyakov had already spent 437 days aboard the Mir Space Station in the 1990s. Medicine, however, has made it easier to measure genetic changes since then. Although this incredible enterprise is known as a one-year mission, counting the preparation and results phases makes it in effect a three-year mission.

For an entire year before the launch, NASA's Scott Kelly and cosmonaut Mikhail Kornienko participated in various studies aimed at better understanding how the human body responds to long stints in space, and many samples of their bodily



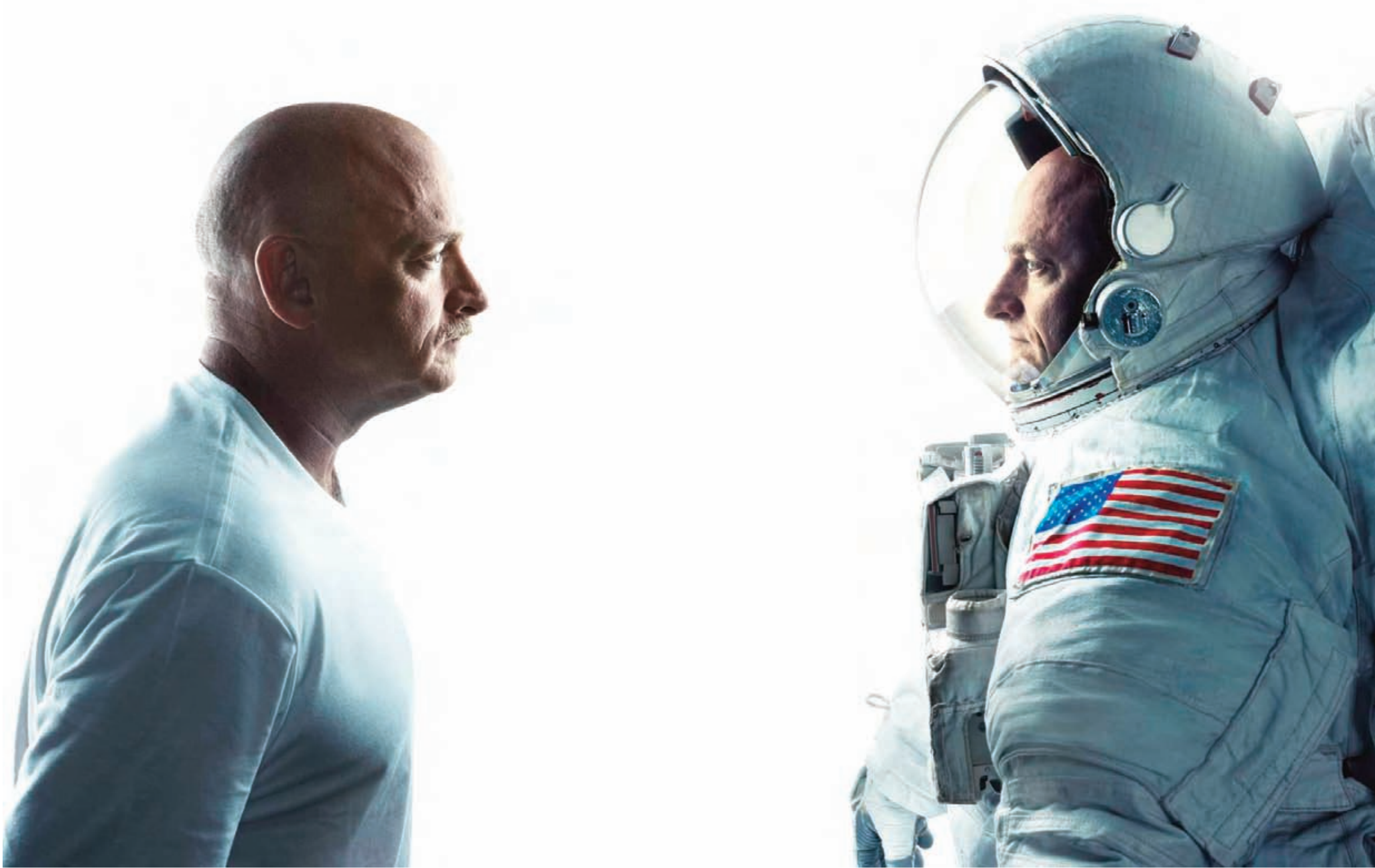
NASA Twins Study investigators are looking for metabolic changes in retired astronaut Scott Kelly and studying how it correlates to the food he ate during the One-Year Mission and Twins Study. He is photographed with oranges, lemons, and grapefruits floating around him on the International Space Station. [NASA]

fluids were collected for scientists to study. The Kelly brothers are the only set of astronaut twins who have flown in space, and both were selected by NASA in 1996. Mark Kelly was best known for commanding the second-to-last shuttle mission, with the Endeavour Space Shuttle, although he also commanded the Discovery in 2008. Scott Kelly was also an experienced NASA astronaut, but this one-year mission made him famous worldwide, not only because of his incredible journey, but also through his Twitter account, @StationCDRKelly, where he posted many stunning photos of our planet as seen from space or strange and funny moments aboard the ISS.

During Scott Kelly's journey aboard the ISS, almost 400 science studies were performed, with him acting as either a subject or a scientist. One of these studies was experiment Veg-01, in which the astronauts grew plants in space for the first time, specifically lettuce, which is an important step for space exploration, since plants will be a necessity if humans ever live on other planets. Many samples of Kelly's blood, urine, saliva and more were taken throughout his 340 days in space, along with samples from Kornienko. This will help determine whether the human changes mentioned above keep happening and getting worse or eventually stop upon achieving some sort of equilibrium. *"There's quite a bit of data for six months in orbit"*, says space-station program manager Mike Suffredini. *"But have we reached stasis at six months, or do things change at one year? Is there a knee in the curve we haven't reached yet?"* A very important aspect of any scientific experiment is having a control sample. That's why, when doing experiments with humans, it's such an incredible advantage to have an opportunity to experiment with genetically identical twins. In this one-year

mission, it was very important to have Mark Kelly on Earth as a control subject. *"The twins didn't come up when we were selecting crew for the mission"*, says Suffredini. *"But it occurred to us later that we had this ground-based truth in Mark."*
Scott Kelly and Mikhail Kornienko returned home on March 1, 2016. Since then, a team of researchers has been comparing biological samples taken from each twin before, during and after the one-year mission, resulting in an enormous set of data. An integrated database is being created with the results of various investigations and comparisons. This 'twins study' is quite different from the usual studies resulting in publication.
The results are normally published in scientific journals that kick off discussions of findings, but the results of this study are already being incorporated before publishing, and the data is being shared instead of the research being done individually.
"The beauty of this study is when integrating rich data sets of physiological, neurobehavioral and molecular information, one can draw correlations and see patterns," says Tejaswini Mishra, research fellow at Stanford University School of Medicine, who is creating the integrated database. *"No one has ever looked this deeply at a human subject and profiled them in this detail. Most researchers combine maybe two to three types of data but this study is one of the few that is collecting many different types of data and an unprecedented amount of information."* As individual researchers integrate the data and reach conclusions about various aspects, the summarized compilation is taking shape and we get ever closer to a very accurate and complete view of how the human body changes during space flight. The joint summary publication is planned for later in 2017, to be followed by research articles by the investigators. However, many conclusions are already being released at the Investigators' Workshop in Galveston, Texas, where preliminary research results were presented in late January. In the Biochemi-

Scott and Mark Kelly were part of a bold experiment to see how the human body fared after a year in space. [NASA]



Galveston Odyssey Academy student Sophia George won 'Best in Show' for her portrayal of Omics in artwork. Below, Perla Zuniga won 2nd Place with her portrayal of the Kelly Twins as two in one: the spaceman and the Earthling. [NASA]

cal Profile investigation, there appeared to be a decline in bone formation during the second half of Scott Kelly's mission.

In the Genome Sequencing investigation, researchers are looking more closely to see if some sort of 'space gene' could have been activated while Kelly was in space. Also, results from Andy Feinberg, who studies how the environment regulates gene expression, could indicate genes that are more sensitive to a changing environment, whether on Earth or in space. The overall results of this study are highly anticipated and are expected to be very enlightening. *"Both the universe and the human body are complicated systems and we are studying something hard to see,"* says Chris Mason, associate professor at the Department of Physiology and Biophysics at Weill Cornell Medical College. *"It's like having a new flashlight that illuminates the previously dark gears of molecular interactions. It is a more comprehensive way to conduct research."*

This study will be an important key factor in the international effort to reach Mars. *"There is no doubt, the learnings from integrating our data will be priceless,"* says Emmanuel Mignot, director of the Center for Sleep Science and Medicine at Stanford University School of Medicine.

As NASA officials say, the orchestra is only warming up. Much data is yet to be analysed and lots of results are awaiting publication and discussion. Indeed, as humankind gets closer to conquering new worlds, our limitations continue to be surpassed. One can only imagine what amazing mysteries will be unravelled thanks to this incredible study.

New insights into "ocean worlds" in our Solar System

by NASA

This illustration shows Cassini diving through the Enceladus plume in 2015. New ocean world discoveries from Cassini and Hubble will help inform future exploration and the broader search for life beyond Earth. [NASA/JPL-Caltech]

Two veteran NASA missions are providing new details about icy, ocean-bearing moons of Jupiter and Saturn, further heightening the scientific interest of these and other "ocean worlds" in our Solar System and beyond.

The findings are presented in papers recently published by researchers with NASA's Cassini mission to Saturn and Hubble Space Telescope.

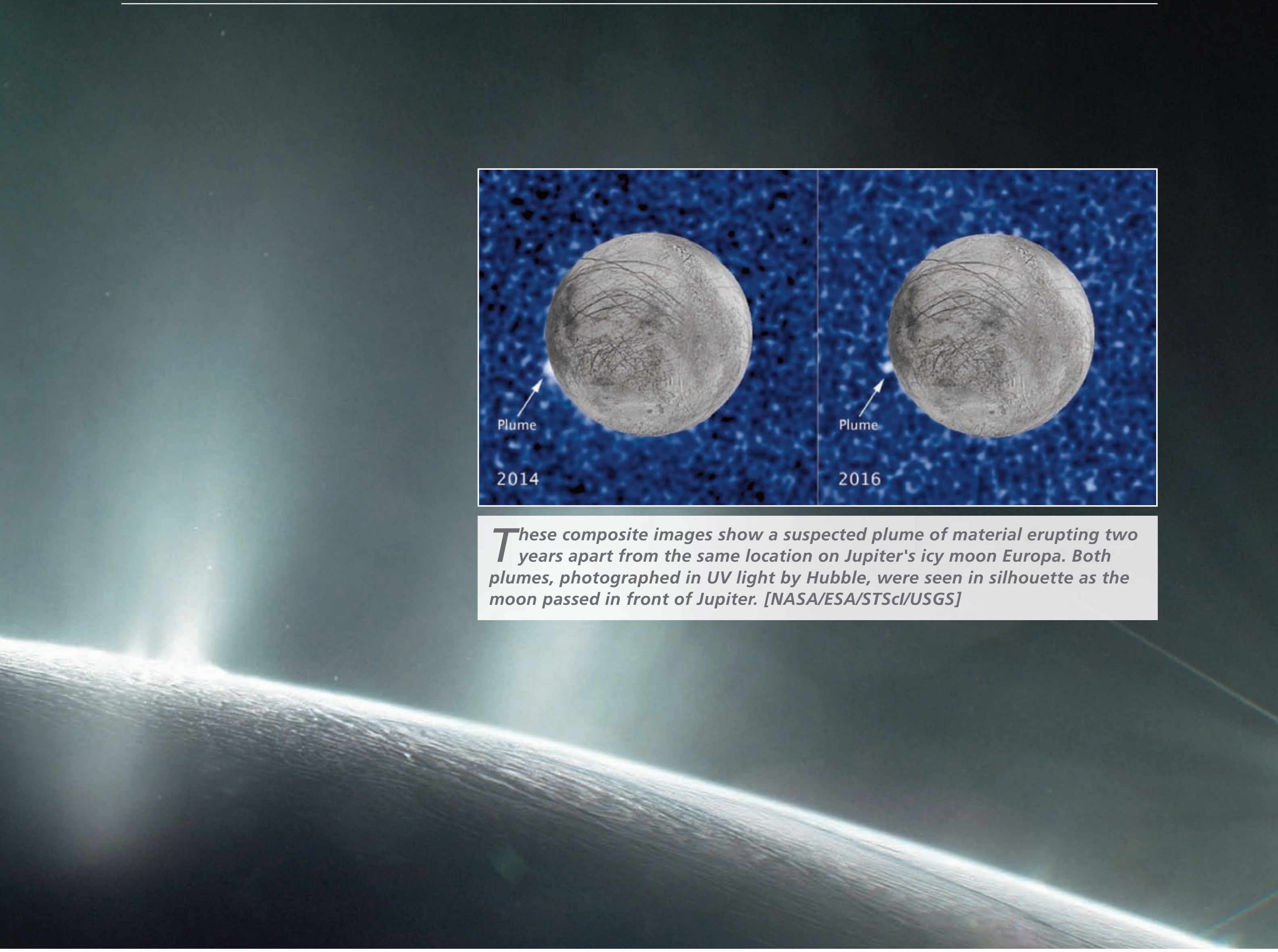
In the papers, Cassini scientists announce that a form of chemical energy that life can feed on appears to exist on Saturn's moon Enceladus, and Hubble researchers report additional evidence of plumes erupting from Jupiter's moon Europa.

"This is the closest we've come, so far, to identifying a place with some of the ingredients needed for a habitable environment," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate at Headquarters in Washington. *"These results demonstrate the interconnected nature of NASA's science missions that are getting us closer to answering whether we are indeed alone or not."*

The paper from researchers with the Cassini mission, published in the journal *Science*, indicates hydrogen gas, which could potentially provide a chemical energy source for life, is pouring into the subsurface ocean of Enceladus from hydrothermal activity on the seafloor.

The presence of ample hydrogen in the moon's ocean means that microbes – if any exist there – could use it to obtain energy by combining the hydrogen with carbon dioxide dissolved in the water. This chemical reaction, known as "methanogenesis" because it produces methane as a byproduct, is at the root of the tree of life on Earth, and could even have been critical to the origin of life on our planet.

Life as we know it requires three primary ingredients: liquid water; a source of energy for metabolism; and the right chemical ingredients,



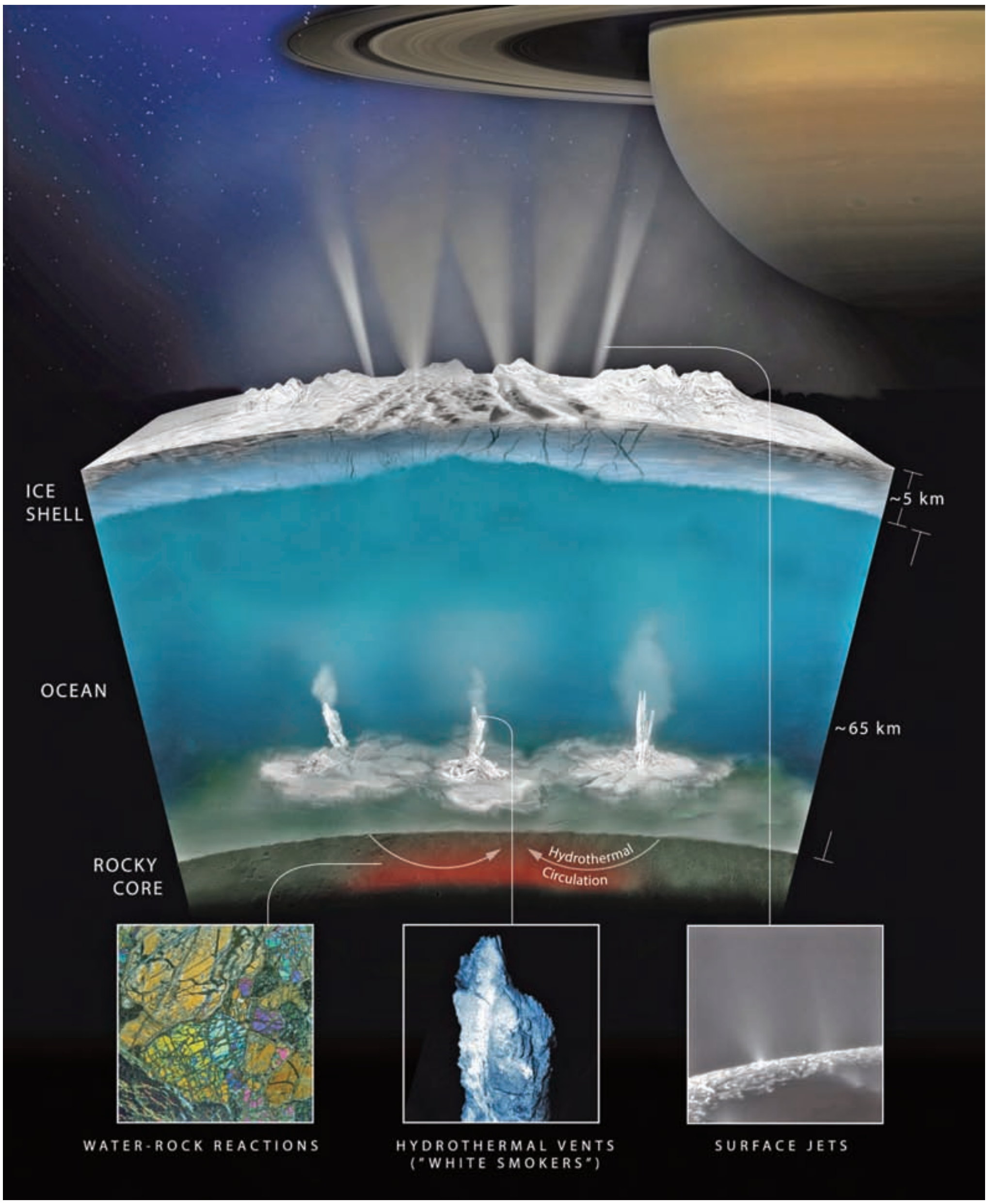
These composite images show a suspected plume of material erupting two years apart from the same location on Jupiter's icy moon Europa. Both plumes, photographed in UV light by Hubble, were seen in silhouette as the moon passed in front of Jupiter. [NASA/ESA/STScI/USGS]

primarily carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur. With this finding, Cassini has shown that Enceladus – a small, icy moon a billion miles farther from the Sun than Earth – has nearly all of these ingredients for habitability. Cassini has not yet shown phosphorus and sulfur are present in the ocean, but scientists suspect them to be, since the rocky core of Enceladus is thought to be chemically similar to meteorites that contain the two elements.

"Confirmation that the chemical energy for life exists within the ocean of a small moon of Saturn is an important milestone in our search for habitable worlds beyond Earth," said Linda Spilker, Cassini project scientist at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

The Cassini spacecraft detected the hydrogen in the plume of gas and icy material spraying from Enceladus during its last, and deepest, dive through the plume on Oct. 28, 2015. Cassini also sampled the plume's composition during flybys earlier in the mission. From these observations scientists have determined that nearly 98 percent of the gas in the plume is water, about 1 percent is hydrogen and the rest is a mixture of other molecules including carbon dioxide, methane and ammonia. The measurement was made using Cassini's Ion and Neutral Mass Spectrometer (INMS) instrument, which sniffs gases to determine their composition. INMS was designed to sample the upper atmosphere of Saturn's moon Titan. After Cassini's surprising discovery of a towering plume of icy spray in 2005, emanating from hot cracks near the south pole, scientists turned its detectors toward the small moon.

Cassini wasn't designed to detect signs of life in the Enceladus plume – indeed, scientists didn't know the plume existed until after the spacecraft arrived at Saturn.

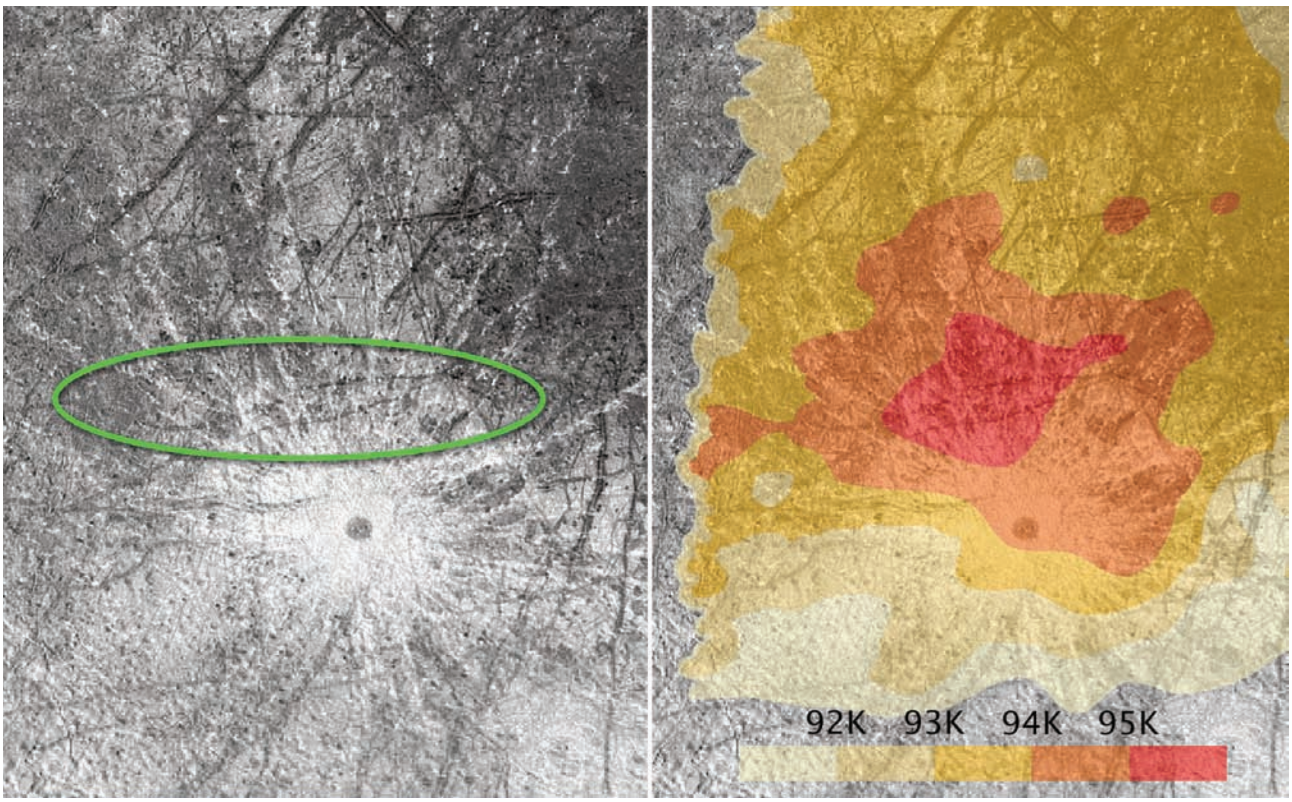


This graphic illustrates how Cassini scientists think water interacts with rock at the bottom of the ocean of Saturn's icy moon Enceladus, producing hydrogen gas. [NASA/JPL-Caltech]

"Although we can't detect life, we've found that there's a food source there for it. It would be like a candy store for microbes," said Hunter Waite, lead author of the Cassini study. The new findings are an independent line of evidence that hydrothermal activity is taking place in the Enceladus ocean. Previous results, published in March 2015, suggested hot water is interacting with rock beneath the sea; the new findings support that conclusion and add that the rock appears to be reacting chemically to produce the hydrogen. The paper detailing new Hubble Space Telescope findings, published in *The Astrophysical Journal Letters*, reports on observations of Europa from 2016 in which a probable plume of material was seen erupting from the moon's surface at the same location where Hubble saw evidence of a plume in 2014. These images bolster evidence that the Europa plumes could be a real phenomenon, flaring up intermittently in the same region on the moon's surface.

The newly imaged plume rises about 62 miles (100 kilometers) above Europa's surface, while the one observed in 2014 was estimated to be about 30 miles (50 kilometers) high. Both correspond to the location of an unusually warm region that contains features that appear to be cracks in the moon's icy crust, seen in the late 1990s by NASA's Galileo spacecraft. Researchers speculate that, like Enceladus, this could be evidence of water erupting from the moon's interior.

"The plumes on Enceladus are associated with hotter regions, so after Hubble imaged this new plume-like feature on Europa, we looked at that location on the Galileo thermal map.



The green oval highlights the plumes Hubble observed on Europa. The area also corresponds to a warm region on Europa's surface. The map is based on observations by the Galileo spacecraft. [NASA/ESA/STScI/USGS]

We discovered that Europa's plume candidate is sitting right on the thermal anomaly," said William Sparks of the Space Telescope Science Institute in Baltimore, Maryland. Sparks led the Hubble plume studies in both 2014 and 2016. The researchers say if the plumes and the warm spot are linked, it could mean water being vented from beneath the moon's icy crust is warming the surrounding surface. Another idea is that water ejected by the plume falls onto the surface as a fine mist, changing the structure of the surface grains and allowing them to retain heat longer than the surrounding landscape.

For both the 2014 and 2016 observations, the team used Hubble's Space Telescope Imaging Spectrograph (STIS) to spot the plumes in ultraviolet light. As Europa passes in front of Jupiter, any atmospheric features around the edge of the moon block some of Jupiter's light, allowing STIS to see the features in silhouette.

Sparks and his team are continuing to use Hubble to monitor Europa for additional examples of plume candidates and hope to determine the frequency with which they appear.

NASA's future exploration of ocean worlds is enabled by Hubble's monitoring of Europa's putative plume activity and Cassini's long-term investigation of the Enceladus plume. In particular, both investigations are laying the groundwork for NASA's Europa Clipper mission, which is planned for launch in the 2020s.

"If there are plumes on Europa, as we now strongly suspect, with the Europa Clipper we will be ready for them," said Jim Green, Director of Planetary Science, at NASA Headquarters.

Hubble's identification of a site which appears to have persistent, intermittent plume activity provides a tempting target for the Europa mission to investigate with its powerful suite of science instruments. In addition, some of Sparks' co-authors on the Hubble Europa studies are preparing a powerful ultraviolet camera to fly on Europa Clipper that will make similar measurements to Hubble's, but from thousands of times closer. And several members of the Cassini INMS team are developing an exquisitely sensitive, next-generation version of their instrument for flight on Europa Clipper.

Ancient stardust sheds light on the first stars

by ESO

An international team of astronomers, led by Nicolas Laporte of University College London, have used the Atacama Large Millimeter/submillimeter Array (ALMA) to observe A2744_YD4, the youngest and most remote galaxy ever seen by ALMA. They were surprised to find that this youthful galaxy contained an abundance of interstellar dust — dust formed by the deaths of an earlier generation of stars.

Follow-up observations using the X-shooter instrument on ESO's Very Large Telescope confirmed the enormous distance to A2744_YD4. The galaxy appears to us as it was when the Universe was only 600 million years old, during the period when the first stars and galaxies were forming. This time corresponds to a redshift of z=8.38, during the epoch of reionisation.

"Not only is A2744_YD4 the most distant galaxy yet observed by ALMA," comments Nicolas Laporte, *"but the detection of so much dust indicates early supernovae must have already polluted this galaxy."*

Cosmic dust is mainly composed of silicon, carbon and aluminium, in grains as small as a millionth of a centimetre across.

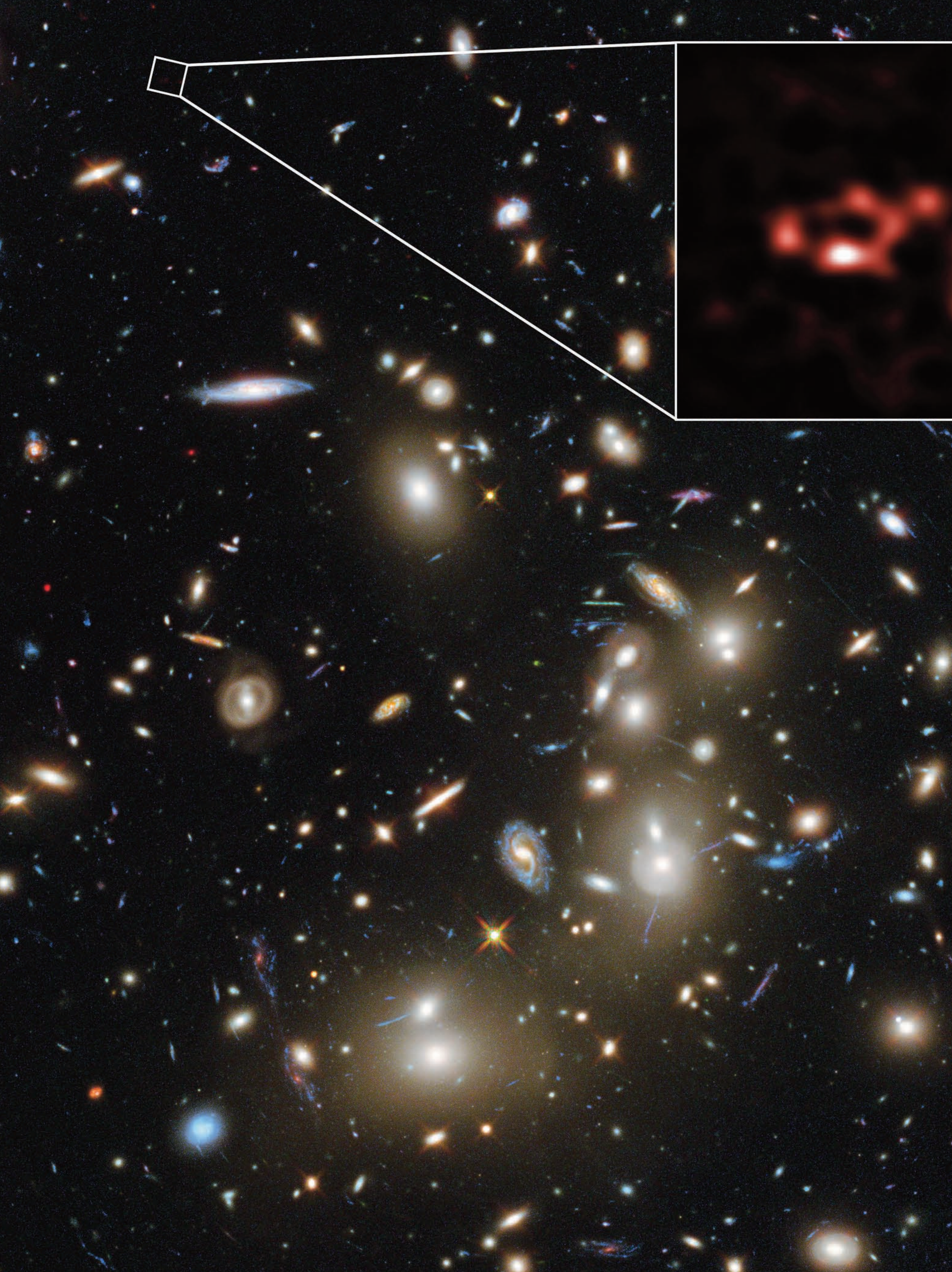
The chemical elements in these grains are forged inside stars and are scattered across the cosmos when the stars die, most spectacularly in supernova explosions, the final fate of short-lived, massive stars. Today, this dust is plentiful and is a key building block in the formation of stars, planets and complex molecules; but in the early Universe — before the first generations of stars died out — it was scarce.

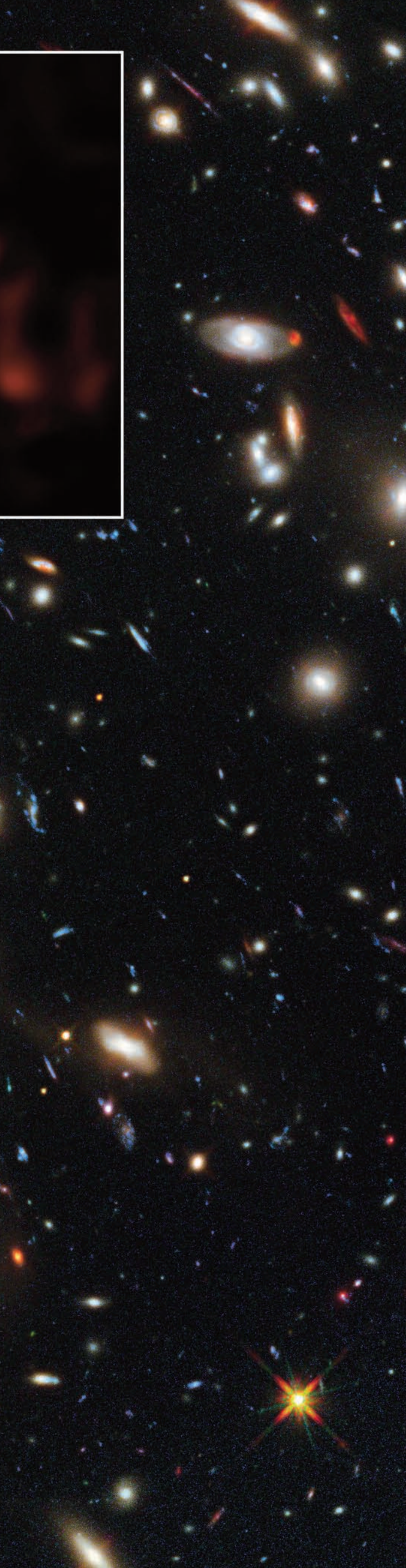
The observations of the dusty galaxy A2744_YD4 were made possible because this galaxy lies behind a massive galaxy cluster called Abell 2744. Because of a phenomenon called gravitational lensing, the cluster acted like a giant cosmic "telescope" to magnify the more distant A2744_YD4 by about 1.8 times, allowing the team to peer far back into the early Universe.

The ALMA observations also detected the glowing emission of ionised oxygen from A2744_YD4. This is the most distant, and hence earliest, detection of oxygen in the Universe, surpassing another ALMA result from 2016.

The detection of dust in the early Universe provides new informa-

This artist's impression shows what the very distant young galaxy A2744_YD4 might look like. Observations using ALMA have shown that this galaxy, seen when the Universe was just 4% of its current age, is rich in dust. Such dust was produced by an earlier generation of stars and these observations provide insights into the birth and explosive deaths of the very first stars in the Universe. [ESO/M. Kornmesser]





This image is dominated by a spectacular view of the rich galaxy cluster Abell 2744 from the NASA/ESA Hubble Space Telescope. But, far beyond this cluster, and seen when the Universe was only about 600 million years old, is a very faint galaxy called A2744_YD4. New observations of this galaxy with ALMA, shown in red, have demonstrated that it is rich in dust. [ALMA (ESO/NAOJ/NRAO), NASA, ESA, ESO and D. Coe (STScI)/J. Merten (Heidelberg/Bologna)]

tion on when the first supernovae exploded and hence the time when the first hot stars bathed the Universe in light. Determining the timing of this "cosmic dawn" is one of the holy grails of modern astronomy, and it can be indirectly probed through the study of early interstellar dust.

The team estimates that A2744_YD4 contained an amount of dust equivalent to 6 million times the mass of our Sun, while the galaxy's total stellar mass — the mass of all its stars — was 2 billion times the mass of our Sun. The team also measured the rate of star formation in A2744_YD4 and found that stars are forming at a rate of 20 solar masses per year — compared to just one solar mass per year in the Milky Way. This rate means that the total mass of the stars formed every year is equivalent to 20 times the mass of the Sun.

"This rate is not unusual for such a distant galaxy, but it does shed light on how quickly the dust in A2744_YD4 formed," explains Richard Ellis (ESO and University College London), a co-author of the study. *"Remarkably, the required time is only about 200 million years — so we are witnessing this galaxy shortly after its formation."*

This means that significant star formation began approximately 200 million years before the epoch at which the galaxy is being observed. This provides a great opportunity for ALMA to help study the era when the first stars and galaxies "switched on" — the earliest epoch yet probed. Our Sun, our planet and our existence are the products — 13 billion years later — of this first generation of stars. By studying their formation, lives and deaths, we are exploring our origins.

"With ALMA, the prospects for performing deeper and more extensive observations of similar galaxies at these early times are very promising," says Ellis.

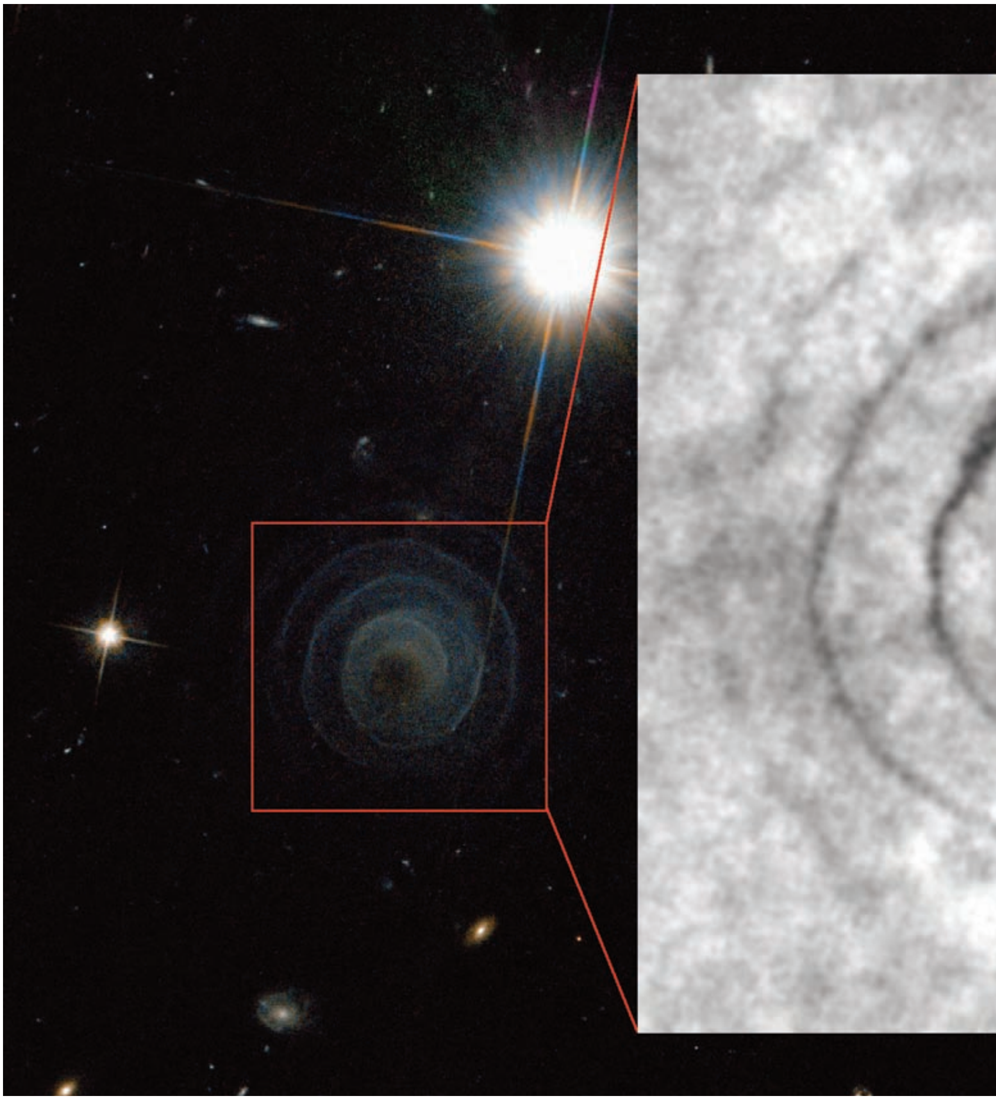
And Laporte concludes: *"Further measurements of this kind offer the exciting prospect of tracing early star formation and the creation of the heavier chemical elements even further back into the early Universe."*

This artist's impression shows what the very distant young galaxy A2744_YD4 might look like and how supernovae explosions, the deaths of very massive and brilliant stars, polluted it with dust. ALMA observations of this galaxy, seen when the Universe was just 4% of its current age, are providing insights into the birth and explosive deaths of the very first stars in the Universe. [ESO/M. Kornmesser]

ALMA adds a new dimension to a HST result

by ALMA Observatory

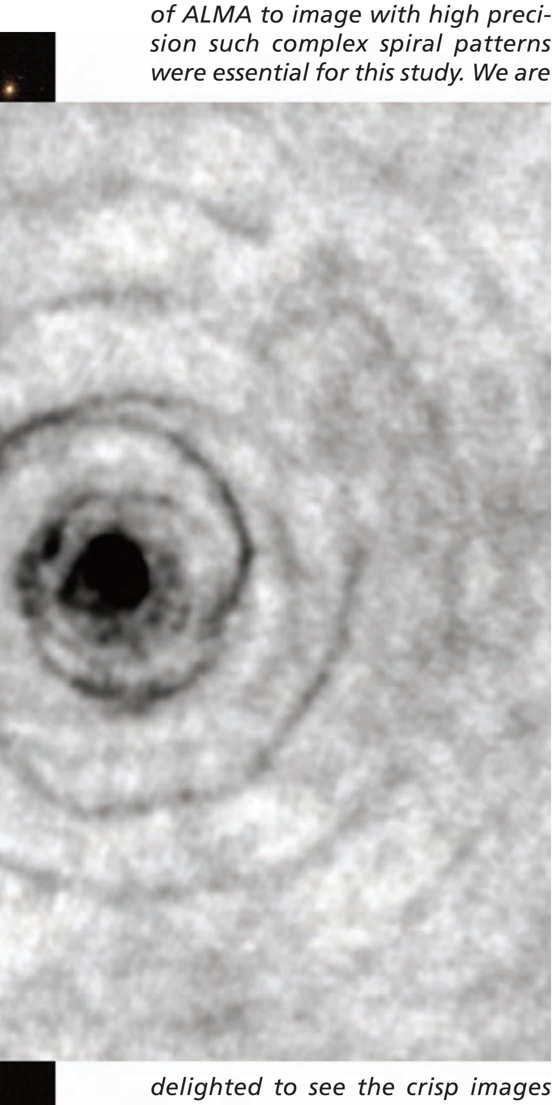
An international team of astronomers, led by Hyosun Kim in Academia Sinica Institute of Astronomy and Astrophysics (ASIAA, Taiwan), has found a way of deriving the orbital shape of binary stars that have orbital periods too long to be directly measured. This new technique was possible thanks to an observation toward the old star LL Pegasi (also known as AFGL 3068) using the state-of-the-art telescope, the Atacama Large Millimeter/submillimeter Array (ALMA). *"It is exciting to see such a beautiful spiral-shell pattern in the sky. Our observations have revealed the exquisitely ordered three-dimensional geometry of this spiral-shell pattern, and we have produced a very satisfying theory to account for its details,"* says Hyosun Kim.
The new ALMA images reveal the detailed features of spiral-shell pattern imprinted in the gas material continuously ejected from LL Pegasi. A comparison of this observation with computer simulations led the team, for the first time, to the conclusion that a binary system with a



HST image of LL Pegasi publicized in 2010 (left). [ESA/NASA & R. Sahai] Right, ALMA image of LL Pegasi. [ALMA (ESO/NAOJ/NRAO) / Hyosun Kim et al.]

highly elliptical orbit is responsible for its morphology of gas distribution. In particular, the bifurcation of the spiral-shell pattern, which is clearly visible in the ALMA images, is a unique characteristic of elliptical binaries. This quintessential object opens a new window on the nature of central binaries through the repetitive patterns that reside far from the star at distances of a few thousand the stellar radii.

"The exquisite sensitivity and ability of ALMA to image with high precision such complex spiral patterns were essential for this study. We are



delighted to see the crisp images translated into rich results and their implications in binary research," says Alfonso Trejo (ASIAA, Taiwan), a co-author of the study. Binaries in elliptical orbits for stars in late stellar evolutionary phases may be ubiquitous over an extensive period range. Many planetary nebulae (stars that are in the next stage of stellar evolution) consist of nearly spherical structures in the outer part and highly-asymmetric structures in the inner part. Near-spherical patterns include those appearing like spirals, shells, and arcs, while highly non-spherical features are bipolar- or multipolar-like. The coexistence of such geometrically distinct structures is enigmatic because it hints at the simultaneous presence of both wide and close binary interactions. This phenomenon has been attributed to the binary stars with elliptical orbits. As indicated by the current research, the orbital parameters of central binaries can be obtained by a careful inspection of the outer recurrent patterns, which hint at the origin of the transition from the near-spherical to asymmetric structures.

LL Pegasi is a mass-losing giant star with a size of 200 times or more that of the Sun. Among the stellar

Visualizing the ALMA image cube of LL Pegasi. Each frame of the video shows the molecular gas material surround-ing LL Pegasi for a different line-of-sight velocity. This velocity, advancing 1 km/s per frame, is given at the top-right corner. The field size is 20,000 times the distance between the Sun and the Earth. [ALMA (ESO/NAOJ/NRAO) / Hyosun Kim et al.]

3D visualization of the molecular gas material surrounding LL Pegasi. First as it appears to the Hubble Space Telescope, and then as it appears in the emis- sion from molecules, as observed with ALMA. The numerical model appears beside the nebula, and both the model and the image are rotated to display the excellent three-dimensional agreement. [Hyosun Kim et al. / I-Ta Hsieh (ASIAA)]

evolutionary phases, it is currently on the asymptotic giant branch, which reflects the future of the Sun a few billion years from now. This star was spotlighted about ten years ago due to a picture of an almost-perfect spiral taken with the Hubble Space Telescope.

The presence of a spiral surrounding an old star had never been reported before the discovery of this object. *"This unusually ordered system opens the door to understanding how the orbits of such systems evolve with time, since each winding of the spiral samples a different orbit in a different period,"* says Mark Morris (UCLA, USA), a co-author of the study.

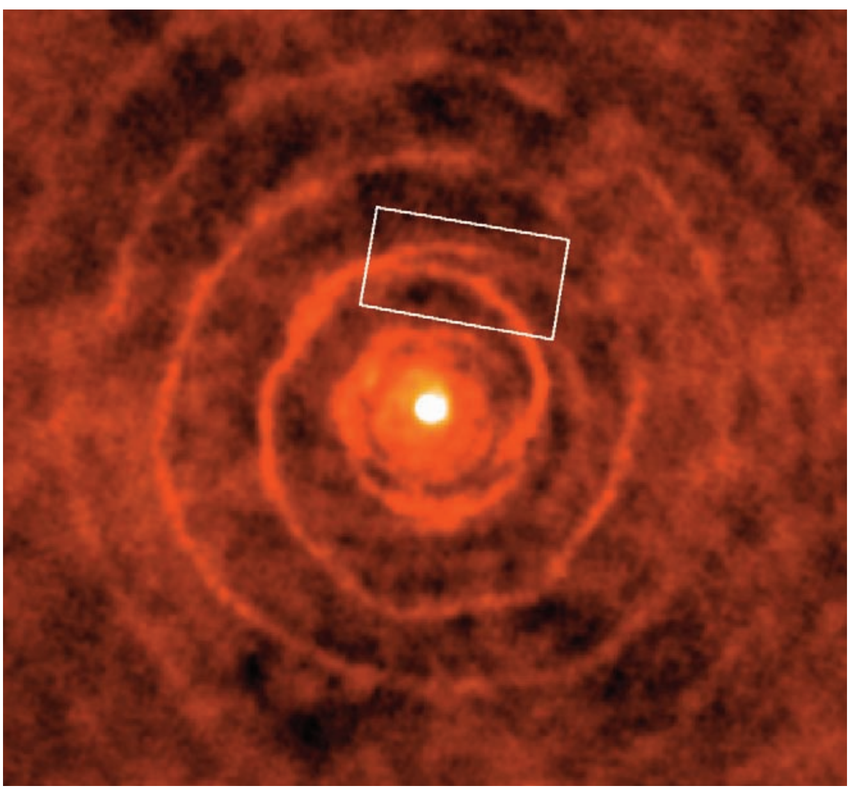
Zooming into the old star LL Pegasi in the constellation of Pegasus. [Hyosun Kim (ASIAA)]

The regularity of the pattern was quite surprising, leading to being considered as a binary system in a circular orbit. It is now equally striking that this best-characterized, unambiguous, and complete spiral is influenced by an elliptical-orbit binary.

"While the HST image shows us the beautiful spiral structure, it is a 2D projection of a 3D shape, which becomes fully revealed in the ALMA data," says Raghvendra Sahai (JPL, USA), a co-author of the study. The new ALMA images reveal the spatiokinematic information of dense molecular gas in the spiral-shell pattern, unveiling the dynamics of the mass loss from the giant star modulated by its orbital motion.

"The interval of spiral arms yields the orbital period of LL Pegasi to be about 800 years, at which the binary motion can be barely detected even with continuous observations over several human lifetimes. Decoding the spiral-shell pattern is a clever way to trace back the history of orbital motion," adds Sheng-Yuan Liu (ASIAA, Taiwan), a co-author of the study.

"By putting this striking spiral-shell on display, nature has left us some clear messages. Deciphering those messages to determine the dynamics of the central stars is the challenge that astronomers are facing," remarks Hyosun Kim.



An international team of astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have unraveled the elliptical nature of the binary orbit of the old star LL Pegasi and its companion. The figure shows the composite image of molecular gas around LL Pegasi. By comparing this gas distribution depicted in exquisite detail by ALMA with theoretical simulations, the team concluded that the bifurcation of the spiral-shell pattern (indicated by a white box) is resulted from a highly elliptical binary system. [ALMA (ESO/NAOJ/NRAO) / Hyosun Kim et al.]

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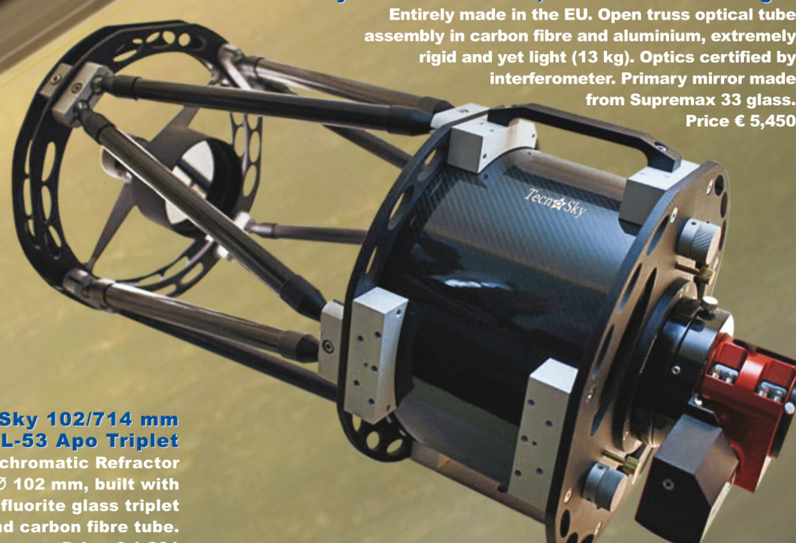

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Image: Saturn by NASA

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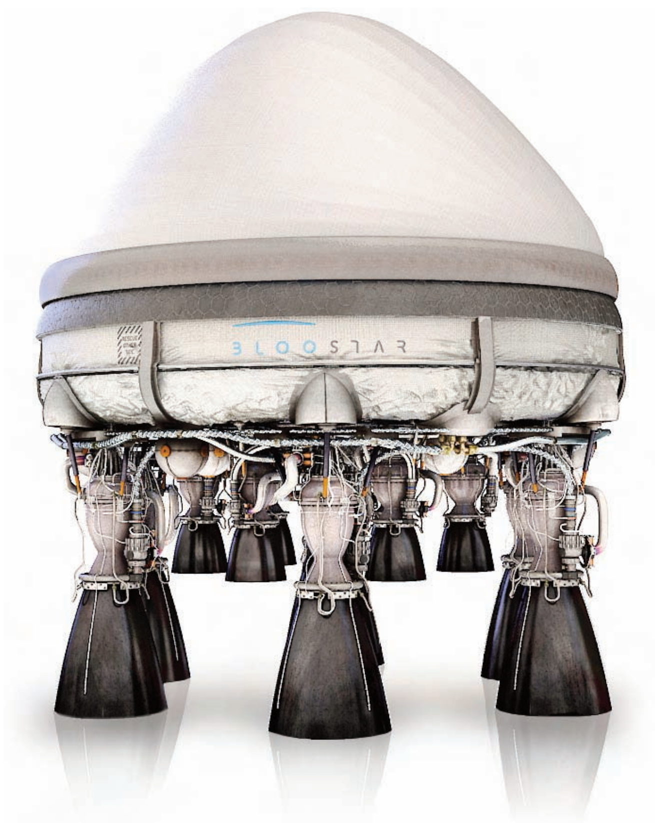
Bloostar: space at your fingertips

by Michele Ferrara

Private companies are intensifying the race to space, and there are already about thirty of them with aerospace programmes that have started up or are in development. One of them, Zero 2 Infinity, is perfecting an interesting system to put small satellites into orbit using a hybrid carrier rocket that combines a high-altitude balloon and a small three-stage rocket.

When sending an object into space, the tallest hurdle by far to be overcome is Earth's gravitational force. It does not make much difference whether the object must escape our planet's pull, remain in orbit around it or if it simply will make a brief suborbital flight. In any case, the object must be brought high enough to perform its mission. And that is exactly the problem.
Launching a load into space from the Earth's surface is an extremely wasteful operation: the cost of transport may total tens of thousands of dollars per kilogramme. On average, about 90% of the mass that takes off from a surface launchpad is squandered within the first few minutes: the fuel is burned, the carrier rocket is discarded, the troposphere is polluted: all this to take the remaining 10% (or less) to its destination.
More effective solutions have been around for recovering at least some of the stages of the carrier rockets in order to reuse them

Render of Bloostar rocket launcher moments before its ignition hanging from the balloon gondola. [Zero 2 Infinity]

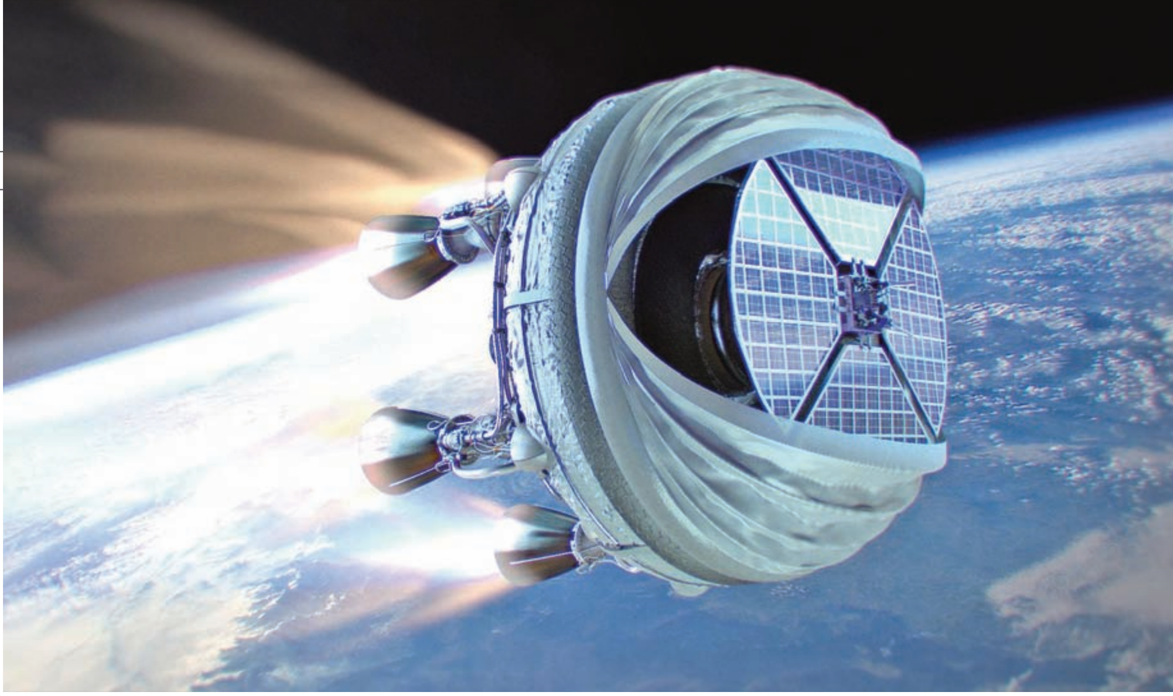


(the so-called Reusable Launch System), but these solutions have not been perfected and are mostly applicable to light payloads, meaning small satellites, headed for low orbits. If the goal is essentially to transport small satellites, another trail was, in fact, blazed around the middle of the last century, one that allows a payload to be launched with a carrier rocket of reduced power and size, brought to a high altitude using a balloon capable of reaching the stratosphere. It is, in short, a kind of flying launchpad.

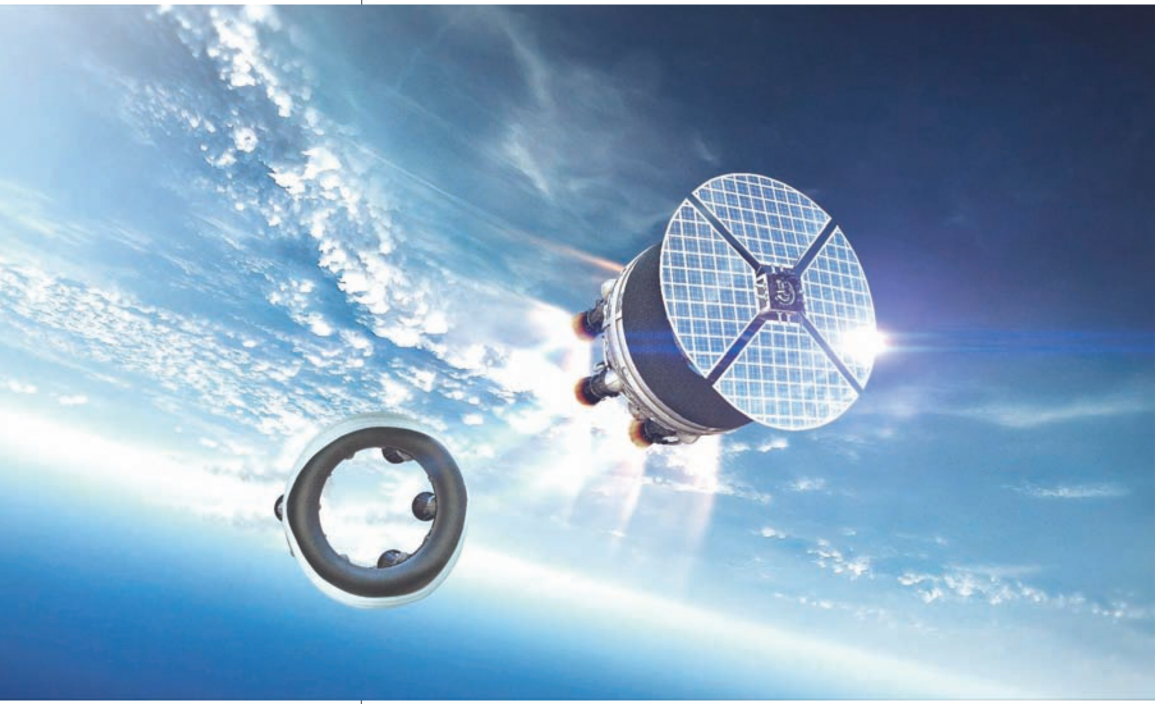
This solution was tried during the decade that led to the first real space mission (Sputnik), when a probe called Deacon was repeatedly launched into suborbital flight. It has been about 60 years since those early attempts, and now the idea of a rockoon (a portmanteau of the words 'rocket' and 'balloon') has come to the fore again, thanks to the Spanish aerospace company Zero 2 Infinity.

Founded in 2009 by Jose Mariano Lopez-Urdiales (the current CEO), this Barcelona-based company specialises in the high-altitude transport of scientific instruments using these balloons and the recording of data from these journeys. Using a system called the 'near-space balloon platform', in May 2016, Zero 2 Infinity successfully carried into the stratosphere – 28 km high – the first satellite made by the Aistech company (also located near Barcelona). That mission was essentially a test of the solutions and instrumentation the two companies used, but for Zero 2 Infinity it was also an important step towards implementing its Bloostar project. Defined as a 'short-cut into orbit', Bloostar is a hybrid carrier rocket that launches small

Left, side view of Bloostar with its fairing closed. Below, the three stages of the rocket and the platform that will host the payload. [Zero 2 Infinity]



Right, Bloostar fairing opening before first stage separation. [Zero 2 Infinity]



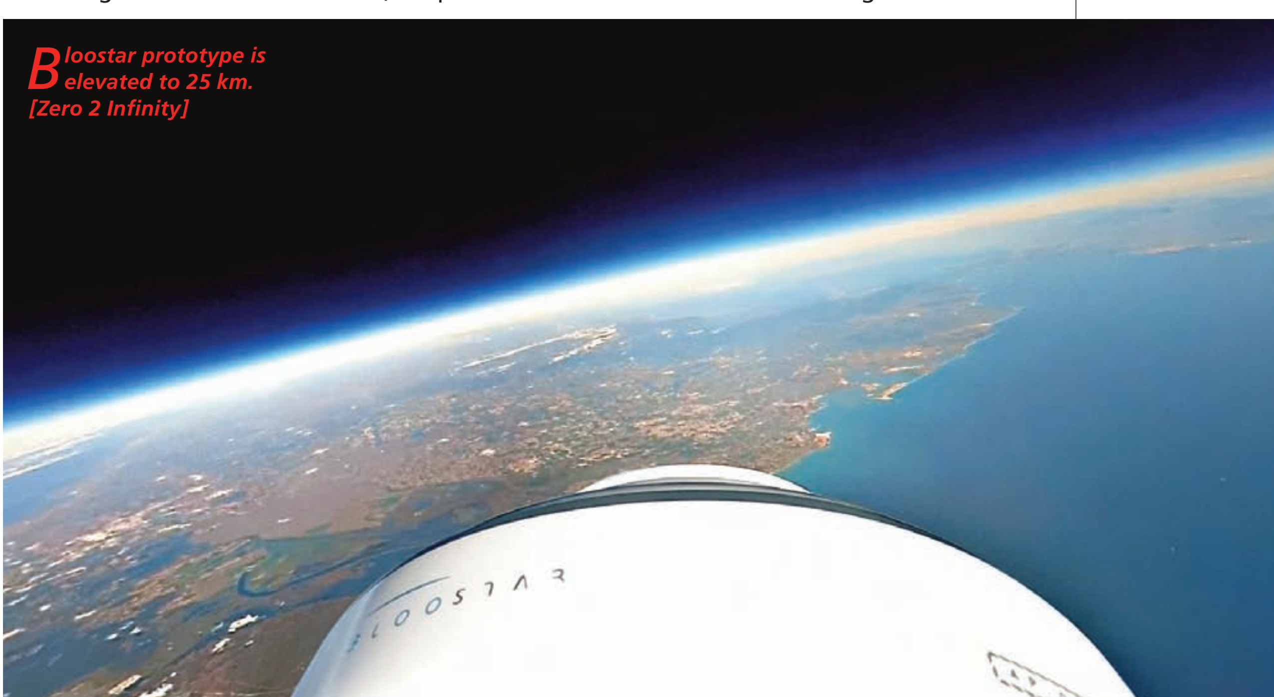
satellites (up to about 100 kg), consisting of a stratospheric balloon designed to take a special kind of 3-stage rocket to a maximum height of 40 km, where it then must thrust the payload into its orbit. For a given weight carried, this launch system has obvious benefits over the traditional rocket that departs from a launchpad on the ground: it saves a lot of propellant; the sizes of the rocket stages are significantly reduced; it is no longer necessary to construct and manage a classic launchpad; most of the components of the hy-

Above, Bloostar first stage separation. Side, last stage with satellite. [Zero 2 Infinity]

Scheme of the ascent profile for the Bloostar system. [Zero 2 Infinity]

brid carrier rocket can be reused within a short time; and the pollution of the air we breathe is reduced to nearly zero.

The Bloostar rocket consists of a series of engines running on liquid propellant, in an arrangement of concentric tori, coupled centrally to the payload. Each torus works as a traditional rocket stage, but much less thrust is required, as the carrier rocket begins from an altitude that has already left behind 95% of the atmosphere's mass. The smaller sizes of the rocket stages are also an

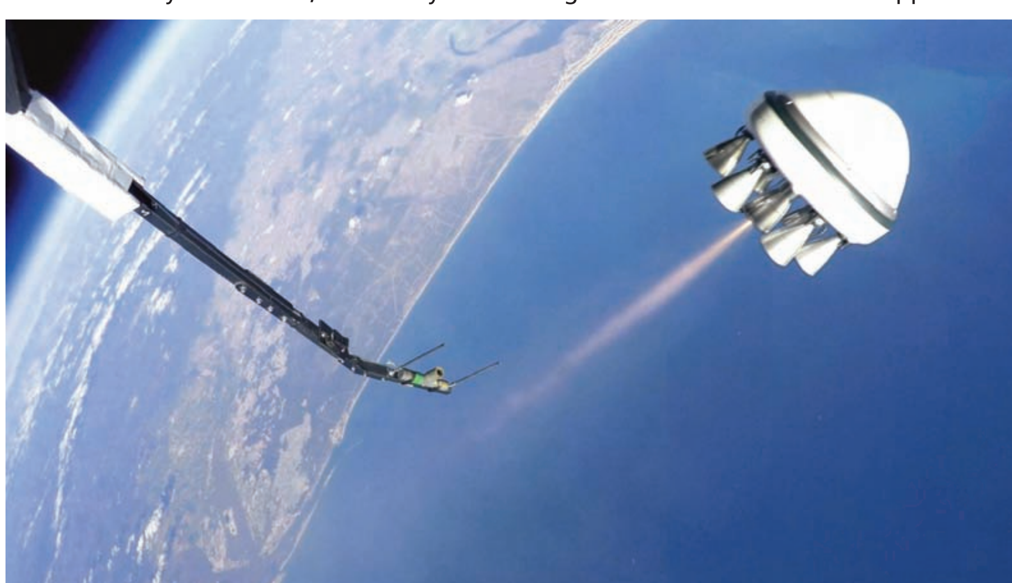


Bloostar prototype is elevated to 25 km. [Zero 2 Infinity]

Above, Bloostar is reaching 25 km. Below, ignition close up. [Zero 2 Infinity]

advantage in terms of their recovery and reuse, as their modest mass reduces the damage caused by friction with the atmosphere during re-entry. Furthermore, being able to ignite the engines in an environment with very rarefied air, above any turbulence, allows the payload to be aimed precisely at the target orbit, up to a maximum altitude of 600 km.

On March 1 of this year, Zero 2 Infinity successfully tested a Bloostar prototype, launching the first rocket from the upper atmo-



Left, Bloostar ignites at 25 km, before flying away (below). [Zero 2 Infinity]

sphere, about 25 km up. Company officials say that the goals for this test included assessing the telemetry systems under conditions like those in space, which it did successfully. In addition to this, the company tried to control the ignition and stabilise the rocket, to monitor the launch sequence, to open the parachute and to recover the carrier rocket from the ocean. Having met these objectives as well, Zero 2 Infinity is now the only aerospace company able to offer a reliable rockoon system to put small satellites into orbit in the near future.

Bloostar's first commercial launch is expected in 2019. In 2018, it will begin true orbital testing. For the test flight this March, the rockoon's trip began off the coast of continental Spain, but for payload launching, the Bloostar missions will begin in the sea near the Canary Islands, where the geographical location is more favourable to the successful orbiting of the satellites it will carry. Zero 2 Infinity will handle the rocket igni-

Here is an amazing video that illustrates the Bloostar concept. [Zero 2 Infinity]

Right, video of the first flight test of Bloostar. Below, Jose Mariano Lopez-Urdiales, the CEO and founder of Zero 2 Infinity, stands near the Bloon module. [Zero 2 Infinity]

tion operations, the release of the payloads, their introduction into orbit, and the rockoon recovery.

The artificial satellite industry welcomed the Bloostar experimentation, enough so that Zero 2 Infinity has already racked up more than 250 million dollars in letters of intent for future launches.

Under these conditions, it is quite likely that the Barcelona aerospace company will form a stable part of the market for small launchers, because, while it is true that Bloostar has a limit in payload mass, it is also true that satellite miniaturisation is increasing, and now with small payloads of minimal weight it is possible to attain data and images previously only accessible to satellites having significant tonnage. In addition to the greatly reduced costs in comparison to traditional carrier rockets, the Bloostar system will also offer a greater launch frequency and shorter reservation times. What is more, it can transport the satellites without needing to fold up any of their component parts to fit the capacity of the hold. With traditional carrier rockets, more than one satellite in the past was compromised to some degree by a failure to unfold solar panels or certain scientific instruments. Bloostar is warding off this danger, because its satellites can be released in their final configuration.

As we await future developments of the Zero 2 Infinity rockoons, it may be of interest to note that this is not the only field of business this company is operating in. Zero 2 Infinity also offers services for testing the reliability of satellites and scientific instruments under different environmental conditions, and it is also developing a space tourism programme that anticipates carrying people on board the stratospheric balloons to an altitude of 36 km, not far from ‘black sky’, where one can view the Earth in its entirety and see its fragility and uniqueness against the depths of the cosmos. The space tourists will stay in a special cabin called Bloon, which was already tested last January with very satisfactory results. ■

Stars born in winds from supermassive black holes

by ESO

A UK-led group of European astronomers used the MUSE and X-shooter instruments on the Very Large Telescope (VLT) at ESO's Paranal Observatory in Chile to study an ongoing collision between two galaxies, known collectively as IRAS F23128-5919, that lie around 600 million light-years from Earth. The group observed the colossal winds of material — or outflows — that originate near the supermassive black hole at the heart of the pair's southern galaxy, and have found the first clear evidence that stars are being born within them. Stars are forming in the outflows at a very rapid rate; the astronomers say that stars totalling around 30 times the mass of the Sun are being created every year. This accounts for over a quarter of the total star formation in the entire merging galaxy system.

Such galactic outflows are driven by the huge energy output from the active and turbulent centres of galaxies. Supermassive black holes lurk in the cores of most galaxies, and when they gobble up matter they also heat the surrounding gas and expel it from the host galaxy in powerful, dense winds. The expulsion of gas through galactic outflows leads to a gas-poor environment within the galaxy, which could be why some galaxies cease forming new stars as they age. Although these outflows are most likely to be driven by massive central black holes, it is also possible that the winds are powered by supernovae in a starburst nucleus undergoing vigorous star formation.

"Astronomers have thought for a while that conditions within these outflows could be right for star formation, but no one has seen it actually happening as it's a very difficult observation," comments team leader Roberto Maiolino from the University of Cambridge. "Our results are exciting because they show unambiguously that stars are being created inside these outflows."

The group set out to study stars in the outflow directly, as well as the gas that surrounds them. By using two of the world-leading VLT spectroscopic instruments, MUSE and X-shooter, they could carry out a very detailed study of the properties of the emitted light to determine its source. Radiation from young stars is known to cause nearby gas clouds to glow in a particular way.

The extreme sensitivity of X-shooter allowed the team to rule out other possible causes of this illumination, including gas shocks or the active nucleus of the galaxy.

Artist's impression of a galaxy forming stars within powerful outflows of material blasted out from supermassive black holes at its core. Results from ESO's Very Large Telescope are the first confirmed observations of stars forming in this kind of extreme environment. The discovery has many consequences for understanding galaxy properties and evolution. [ESO/M. Kornmesser]

The group then made an unmistakable direct detection of an infant stellar population in the outflow. This was achieved through the detection of signatures characteristic of young stellar populations and with a velocity pattern consistent with that expected from stars formed at high velocity in the outflow. These stars are thought to be less than a few tens of millions of years old, and preliminary analysis suggests that they are hotter and brighter than stars formed in less extreme environments such as the galactic disc.

As further evidence, the astronomers also determined the motion and velocity of these stars.

The light from most of the region's stars indicates that they are travelling at very large velocities away from the galaxy centre — as would make sense for objects caught in a stream of fast-moving material.

Co-author Helen Russell (Institute of Astronomy, Cambridge, UK) expands: *"The stars that form in the wind close to the galaxy centre might slow down and even start heading back inwards, but the stars that form further out in the flow experience less deceleration and can even fly off out of the galaxy altogether."*

The discovery provides new and exciting information that could better our understanding of some astrophysics, including how certain galaxies obtain their shapes; how intergalactic space becomes enriched with heavy elements; and even from where unexplained cosmic infrared background radiation may arise.

Maiolino is excited for the future: *"If star formation is really occurring in most galactic outflows, as some theories predict, then this would provide a completely new scenario for our understanding of galaxy evolution."*

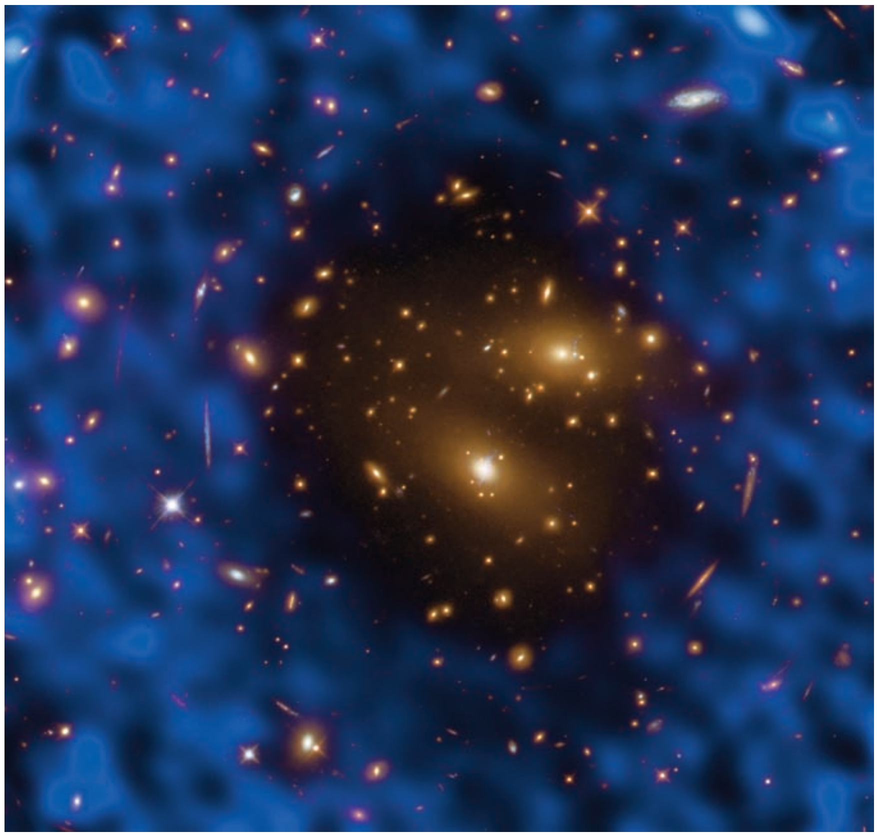
ALMA confirms ability to see a "cosmic hole"

by ALMA Observatory

Researchers using the Atacama Large Millimeter/submillimeter Array (ALMA) successfully imaged a radio "hole" around a galaxy cluster 4.8 billion light-years away from the Earth. This is the highest resolution image ever taken of such a hole caused by the Sunyaev-Zel'dovich effect (SZ effect). The image proves ALMA's high capability to investigate the distribution and temperature of gas around galaxy clusters through the SZ effect.

A research team led by Tetsu Kitayama, a professor at Toho Univer-

This cluster of galaxies, RX J1347.5–1145, was observed by the NASA/ESA Hubble Space Telescope as part of the Cluster Lensing and Supernova survey with Hubble (CLASH). The cluster is one of most massive known galaxy clusters in the Universe. [ESA/Hubble, NASA] sity, Japan, used ALMA to investigate the hot gas in a galaxy cluster. The hot gas is an essential component to understand the nature and evolution of galaxy clusters. Even though the hot gas does not emit radio waves detectable with ALMA, the gas scatters the radio waves of the Cosmic Microwave Background and makes a "hole" around the galaxy cluster. Cosmic Microwave Background (CMB) radio waves come from every direction. When CMB radio waves pass through the hot gas in a galaxy cluster, the radio waves interact with high-energy electrons in the hot gas and gain energy. As a result, the CMB radio waves shift to higher energy. Observing from the Earth, the CMB in the original energy range has less intensity near the galaxy cluster. This is called the "Sunyaev-Zel'dovich effect," first proposed by Rashid Sunyaev and Yakov Zel'dovich in 1970.



The image shows the measurement of the SZ effect in the galaxy cluster RX J1347.5-1145 taken with ALMA (blue). The background image was taken by the Hubble Space Telescope. A "hole" caused by the SZ effect is seen in the ALMA observations. [ALMA (ESO/NAOJ/NRAO), Kitayama et al., NASA/ESA Hubble Space Telescope]

The team observed the galaxy cluster RX J1347.5-1145, known among astronomers for its strong SZ effect and which has been observed many times with radio telescopes. For example, the Nobeyama 45-m Radio Telescope, operated by the National Astronomical Observatory of Japan, has revealed an uneven distribution of the hot gas in this galaxy cluster, which was not seen in X-ray observations.

To better understand the unevenness, astronomers need higher resolution observations. But relatively smooth and widely-distributed objects, such as the hot gas in galaxy clusters, are difficult to image with high-resolution radio interferometers.

To overcome this difficulty, ALMA utilized the Atacama Compact Array, also known as the Morita Array, the major Japanese contribution to the project.

The Morita Array's smaller diameter antennas and the close-packed antenna configuration provide a wider field of view.

By using the data from the Morita Array, astronomers can precisely measure the radio waves from objects subtending a large angle on the sky.

With ALMA, the team obtained an SZ effect image of RX J1347.5-1145, with twice the resolution and ten times better sensitivity than previous observations. This is the first image of the SZ effect with ALMA. The ALMA SZ image is consistent with the previous observations and better illustrates the pressure distribution of hot gas. It proves that ALMA is highly capable of observing the SZ effect and clearly shows that a gigantic collision is ongoing in this galaxy cluster.

"It was nearly 50 years ago that the SZ effect was proposed for the first time," explains Kitayama.

"The effect is pretty weak, and it has been tough to image the effect with high resolution. Thanks to ALMA, this time we made a long-awaited breakthrough to pave a new path to probe the cosmic evolution."

Search for stellar survivor of a supernova explosion

by ESA/NASA

A group of astronomers used Hubble to study the remnant of the Type Ia supernova explosion SNR 0509-68.7 — also known as N103B. The supernova remnant is located in the Large Magellanic Cloud, just over 160,000 light-years from Earth. In contrast to many other supernova remnants N103B does not appear to have a spherical shape but is strongly elliptical. Astronomers assume that part of material ejected by the explosion hit a denser cloud of interstellar material, which slowed its speed. The shell of expanding material being open to one side supports this idea. The relative proximity of N103B allows astronomers to study the life cycles of stars in another galaxy in great detail. And probably even to lift the veil on questions surrounding this type of supernova. The predictable luminosity of Type Ia supernovae means that astronomers can use them as cosmic standard candles to measure their distances, making them useful tools in studying the cosmos. Their exact nature, however, is still a matter of debate. Astronomers suspect Type Ia supernovae occur in binary systems in which at least one of the stars in the pair is a white dwarf.

There are currently two main theories describing how these binary systems become supernovae.

Studies like the one that has provided the new image of N103B — that involve searching for remnants of past explosions — can help astronomers to finally confirm one of the two theories.

One theory assumes that both stars in the binary are white dwarfs. If the stars merge with one another it would ultimately lead to a supernova explosion of type Ia.

The second theory proposes that only one star in the system is a white dwarf, while its companion is a normal star. In this theory material from the companion star is accreted onto the white dwarf until its mass reaches a limit, leading to a dramatic explosion.

In that scenario, the theory indicates that the normal star should survive the blast in at least some form. However, to date no residual companion around any type Ia supernova has been found.

Astronomers observed the N103B supernova remnant in a search for such a companion. They looked at the region in H-alpha — which highlights regions of gas ionised by the radiation from nearby stars — to locate supernova shock fronts.

They hoped to find a star near the centre of the explosion which is indicated by the curved shock fronts. The discovery of a surviving companion would put an end to the ongoing discussion about the origin of type Ia supernova. And indeed they found one can-

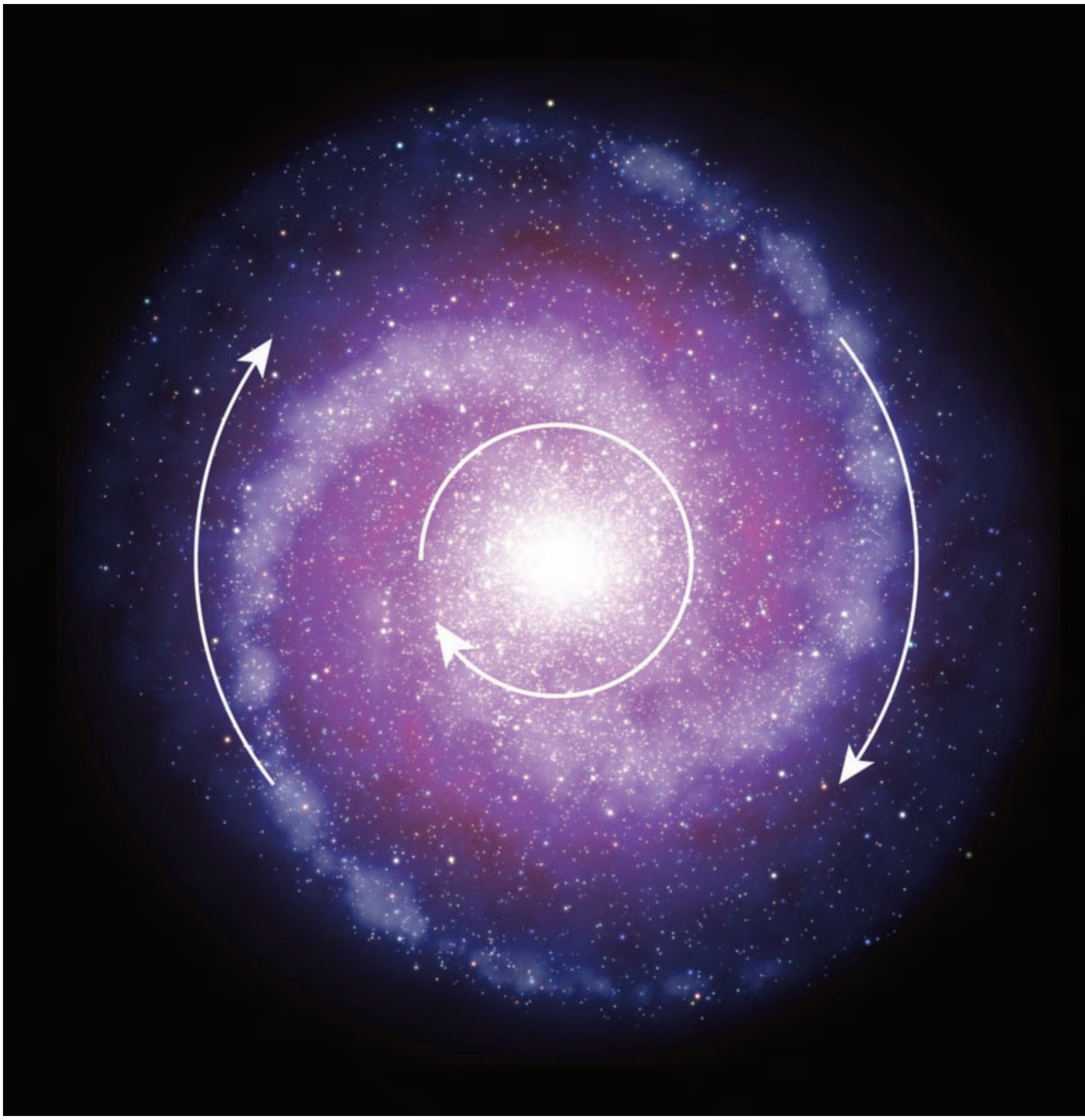
This video starts with a wide-field view of the night sky, as seen from the ground, displaying the Large and the Small Magellanic Clouds. It zooms in on the Large Magellanic Cloud, a satellite galaxy of the Milky Way, and onto the star cluster NGC 1850. Just next to the bright cluster Hubble observed the supernova remnant N103B. In the remnant of this supernova astronomers hope to find the surviving star of a supernova explosion. [ESA/Hubble, Nick Risinger (skysurvey.org), R. Gendler & ESO]

This image, taken with the Hubble Space Telescope, shows the supernova remnant SNR 0509-68.7, also known as N103B. The orange-red filaments visible in the image show the shock fronts of the supernova explosion. These filaments allow astronomers to calculate the original centre of the explosion. The filaments also show that the explosion is no longer expanding as a sphere, but is elliptical in shape. Astronomers assume that part of material ejected by the explosion hit a denser cloud of interstellar material, which slowed its speed. The gas in the lower half of the image and the dense concentration of stars in the lower left are the outskirts of the star cluster NGC 1850. [ESA/Hubble, NASA]

didate star that meets the criteria — for star type, temperature, luminosity and distance from the centre of the original supernova explosion. This star has approximately the same mass as the Sun, but it is surrounded by an envelope of hot material that was likely ejected from the pre-supernova system. Although this star is a reasonable contender for N103B's surviving companion, its status cannot be confirmed yet without further investigation and a spectroscopic confirmation. The search is still ongoing.

Dark matter less influential in galaxies in early Universe

by ESO

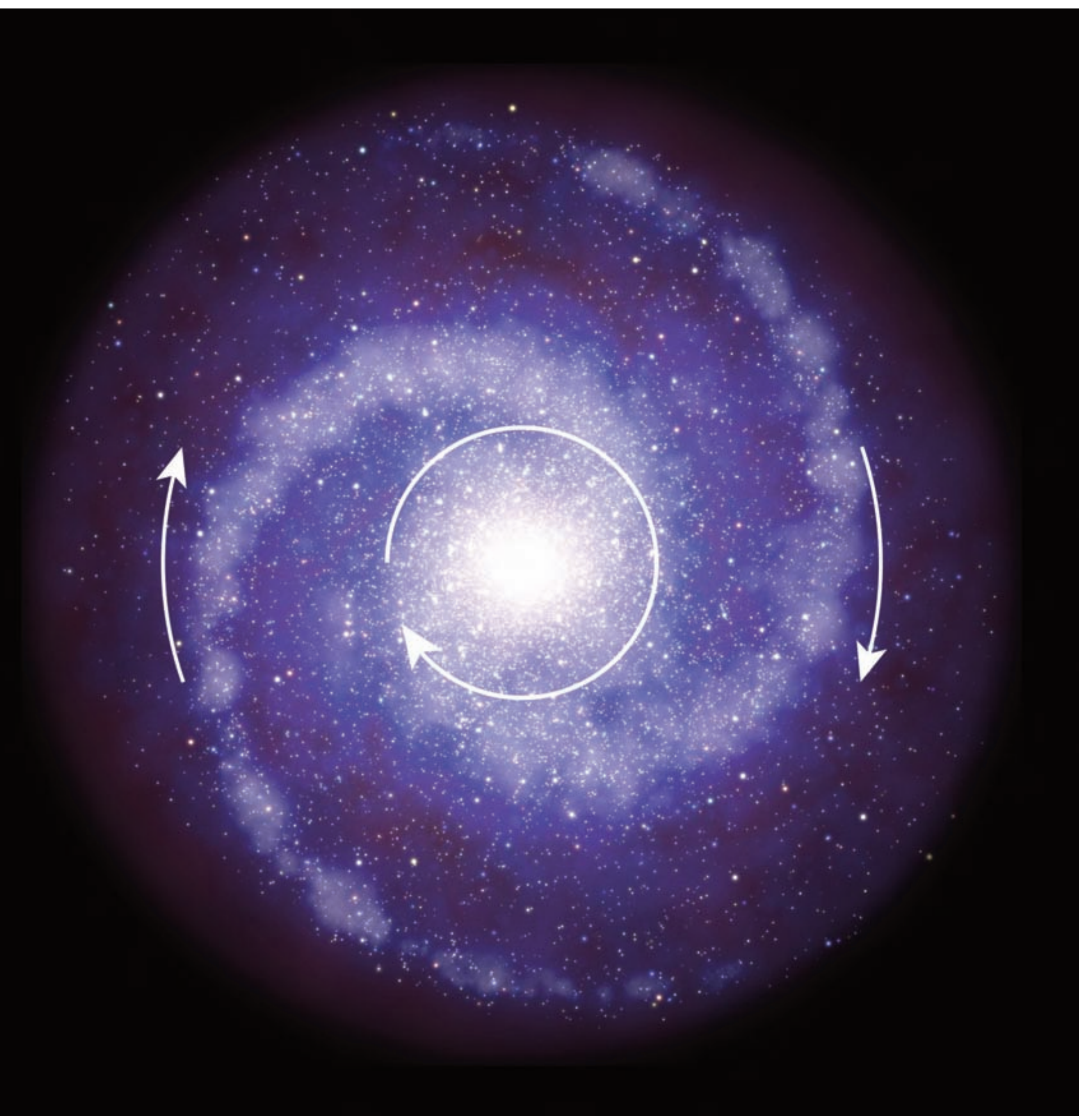


We see normal matter as brightly shining stars, glowing gas and clouds of dust. But the more elusive dark matter does not emit, absorb or reflect light and can only be observed via its gravitational effects. The presence of dark matter can explain why the outer parts of nearby spiral galaxies rotate more quickly than would be expected if only the normal matter that we can see directly were present.

Now, an international team of astronomers led by Reinhard Genzel at the Max Planck Institute for Extraterrestrial Physics in Garching, Germany have used the KMOS and SINFONI instruments at ESO's Very Large Telescope in Chile to measure the rotation of six massive, star-forming galaxies in the distant Universe, at the peak of galaxy formation 10 billion years ago.

What they found was intriguing: unlike spiral galaxies in the modern Universe, the outer regions of these distant galaxies seem to be rotating more slowly than regions closer to the core — suggesting

Schematic representation of rotating disc galaxies in the early Universe (right) and the present day (left). Observations with ESO's Very Large Telescope suggest that such massive star-forming disc galaxies in the early Universe were less influenced by dark matter (shown in red), as it was less concentrated. As a result the outer parts of distant galaxies rotate more slowly than comparable regions of galaxies in the local Universe. [ESO/L. Calçada]



there is less dark matter present than expected.

"Surprisingly, the rotation velocities are not constant, but decrease further out in the galaxies," comments Reinhard Genzel, lead author of the *Nature* paper. *"There are probably two causes for this. Firstly, most of these early massive galaxies are strongly dominated by normal matter, with dark matter playing a much smaller role than in the Local Universe. Secondly, these early discs were much more turbulent than the spiral galaxies we see in our cosmic neighbourhood."*

Both effects seem to become more marked as astronomers look further and further back in time, into the early Universe. This suggests that 3 to 4 billion years after the Big Bang, the gas in galaxies had already efficiently condensed into flat, rotating discs, while the dark matter halos surrounding them were much larger and more spread out. Apparently it took billions of years longer for dark matter to condense as well, so its dominating effect is only seen on the rotation velocities of galaxy discs today.

This explanation is consistent with observations showing that early galaxies were much more gas-rich and compact than today's galaxies.

The six galaxies mapped in this study were among a larger sample of a hundred distant, star-forming discs imaged with the KMOS and SINFONI instruments at ESO's Very Large Telescope at the Paranal Observatory in Chile. In addition to the individual galaxy measurements described above, an average rotation curve was created by combining the weaker signals from the other galaxies. This composite curve also showed the same decreasing velocity trend away from the centres of the galaxies. In addition, two further studies of 240 star forming discs also support these findings. Detailed modelling shows that while normal matter typically accounts for about half of the total mass of all galaxies on average, it completely dominates the dynamics of galaxies at the highest redshifts.

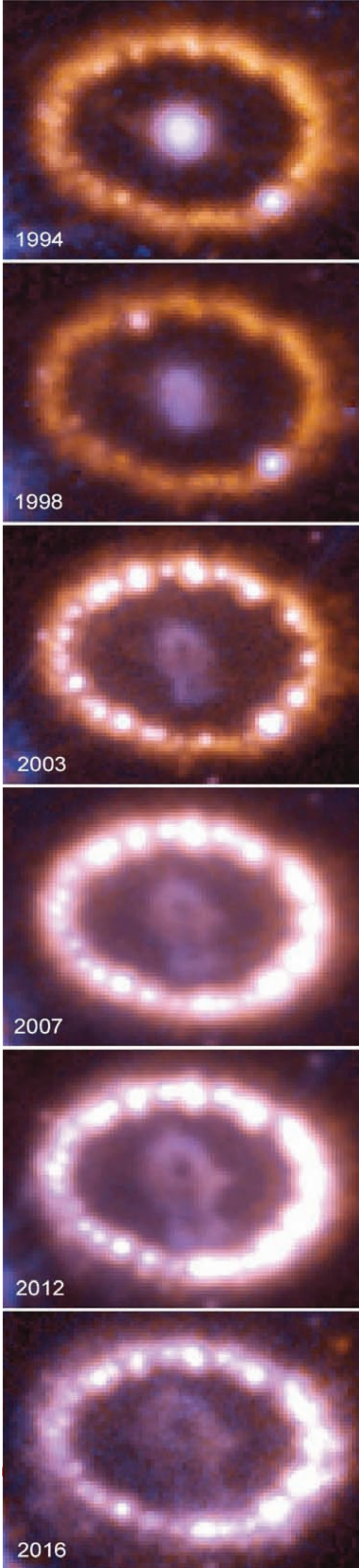
A supernova that is still in the news

by Krishna Bharadwaj

To commemorate the 30th anniversary of SN 1987A, new images, time-lapse movies, a data-based animation based on work led by Salvatore Orlando at INAF-Osservatorio Astronomico di Palermo, Italy, and a three-dimensional model are being released. By combining data from NASA's Hubble Space Telescope and Chandra X-ray Observatory, as well as the international Atacama Large Millimeter/submillimeter Array (ALMA), astronomers – and the public – can explore SN 1987A like never before. [NASA]

3 decades ago, on February 24, 1987, astronomers Ian Shelton and Oscar Duhalde discovered one of the brightest supernovae ever recorded by humans. Supernova 1987A, with an apparent magnitude of +2.9, was observed at about 163,000 light years away from Earth in the Large Magellanic Cloud, at the outskirts of the Tarantula Nebula. Supernova 1987A blazed with the power of 100 million suns, becoming visible to the naked eye, which made it a worldwide sensation, stimulating

This Hubble Space Telescope image shows Supernova 1987A within the Large Magellanic Cloud, a neighboring galaxy to our Milky Way. [NASA, ESA, R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation), and M. Mutchler and R. Avila (STScI)]



The sequence on the left, taken between 1994 and 2016 by NASA's Hubble Space Telescope, chronicles the brightening of a ring of gas around an exploded star. [NASA, ESA, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation), and P. Challis (Harvard-Smithsonian Center for Astrophysics)]

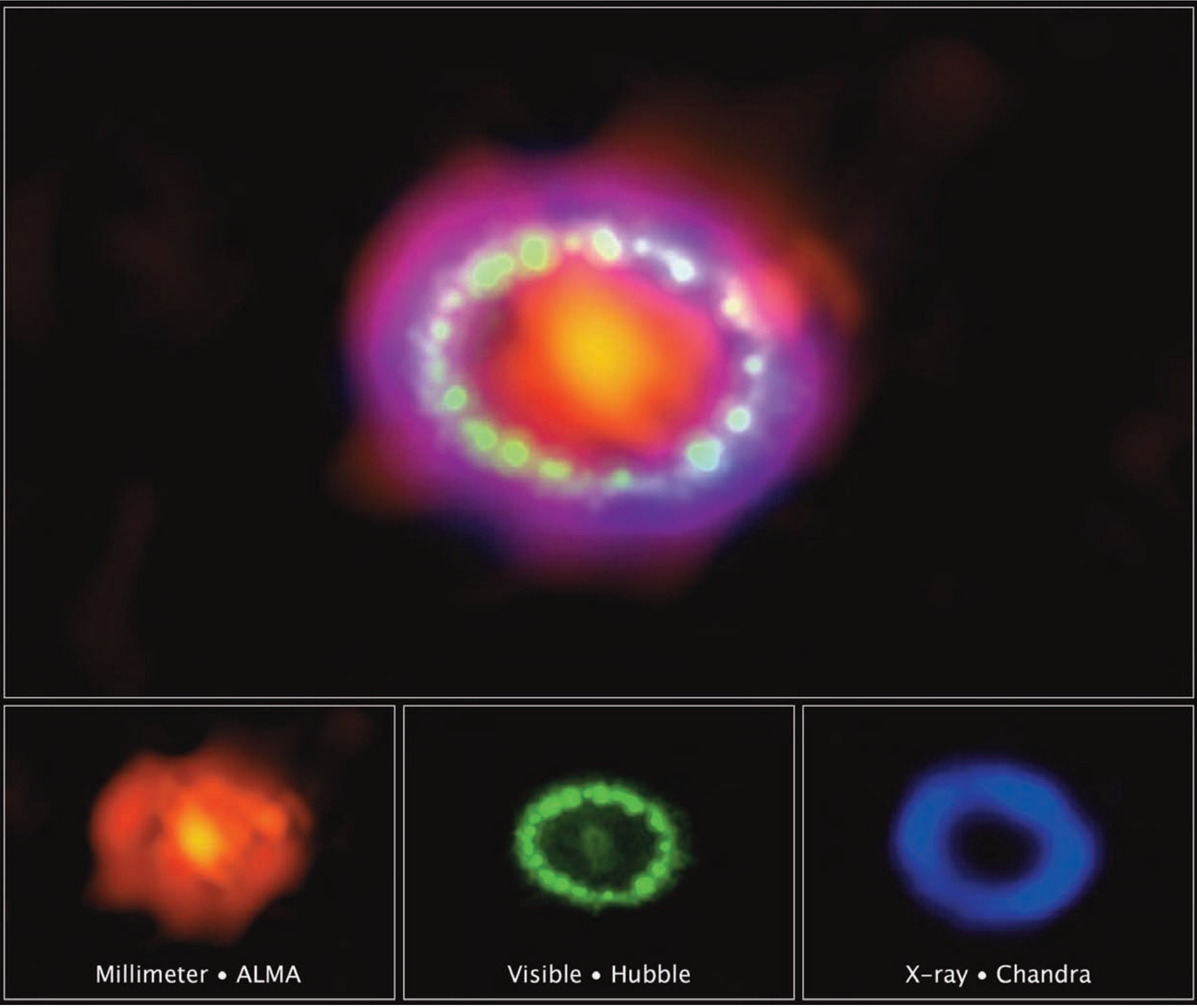
the interest of researchers and astronomy enthusiasts. Being one of the nearest supernovae to have been recorded, SN 1987A was and is still the best opportunity for astronomers to study the phases before and after the death of a star.

"The 30 years' worth of observations of SN 1987A are important because they provide insight into the last stages of stellar evolution," said Robert Kirshner of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, and the Gordon and Betty Moore Foundation in Palo Alto, California.

The Hubble telescope has been observing supernova 1987A since 1990 and has produced hundreds of images along with the Chandra telescope, which was deployed in 1999, and the ALMA telescope has been gathering high-resolution millimetre and sub-millimetre data on SN 1987A since its inauguration in 2013.

Besides Hubble and Chandra, whose focus is on the relatively warm debris, Herschel Observatory has its attention on the cold dust scattered by the supernova. As pointed up by NASA: *"The latest data from these*

This video begins with a nighttime view of the Small and Large Magellanic clouds, satellite galaxies of our Milky Way. It then zooms into a rich star-birth region in the Large Magellanic Cloud. Nestled between mountains of red-colored gas is the odd-looking structure of Supernova 1987A, the remnant of an exploded star that was first observed in February 1987. The site of the supernova is surrounded by a ring of material that is illuminated by a wave of energy from the outburst. Two faint outer rings are also visible. All three rings existed before the explosion as fossil relics of the doomed star's activity in its final days. [NASA, ESA, and G. Bacon (STScI)]



Astronomers combined observations from three different observatories to produce this colorful, multiwavelength image of the intricate remains of Supernova 1987A. The red color shows newly formed dust in the center of the supernova remnant, taken at submillimeter wavelengths by the Atacama Large Millimeter/submillimeter Array (ALMA) telescope in Chile. 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 slammed into it. Supernova 1987A resides 163,000 light-years away in the Large Magellanic Cloud, where a firestorm of star birth is taking place. The ALMA, Hubble, and Chandra images at the bottom of the graphic were used to make up the multiwavelength view. [NASA, ESA, and A. Angelich (NRAO)]

powerful telescopes indicate that SN 1987A has passed an important threshold. The supernova shock wave is moving beyond the dense ring of gas produced late in the life of the pre-supernova star when a fast outflow or wind from the star collided with a slower wind generated in an earlier red giant phase of the star's evolution. What lies beyond the ring is poorly known at present, and depends on the details of the evolution of the star when it was a red giant."

"The details of this transition will give astronomers a better understanding of the life of the doomed star, and how it ended," said Kari Frank of Penn State University who led the latest Chandra study of SN 1987A. Studies by Hubble have revealed that the gas surrounding the supernova glows in visible light and has a diameter of a light year. Astronomers estimate that the gas must have been around for at least 20,000 years before the supernova outburst.

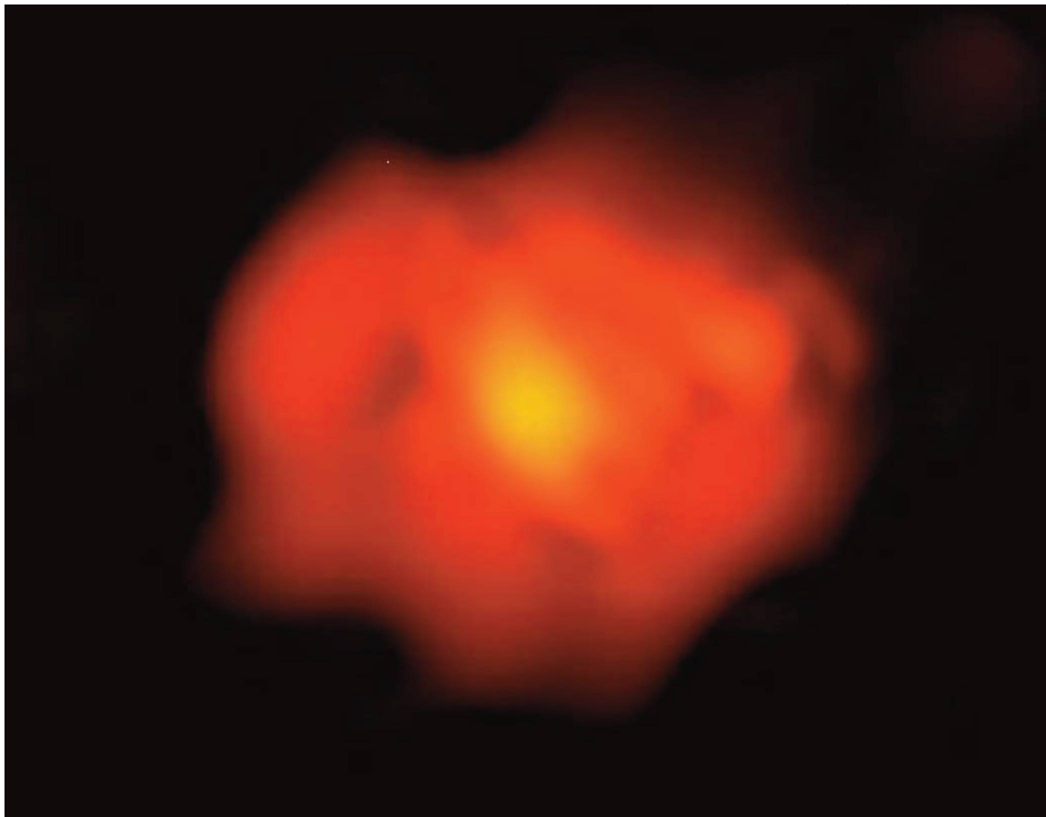


Image of the intricate remains of Supernova 1987A taken in submillimeter wavelengths by the Atacama Large Millimeter/submillimeter Array (ALMA) telescope in Chile. The red color shows newly formed dust in the center of the supernova remnant. [NASA, ESA, and A. Angelich (NRAO)]

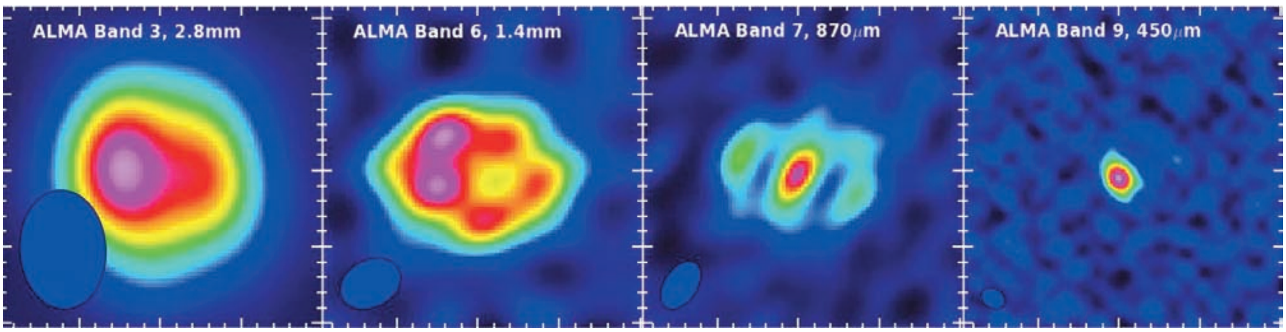
The ring of gas glows due to the late burst of ultraviolet rays during the explosion. Powerful supernovae such as SN 1987A stir up surrounding gases rich in elements like carbon, oxygen, nitrogen and iron, leading to the formation of new stars and planets which might in time sustain life.

The subsequent stars, forged with heavy elements, further disperse the gases throughout the galaxy in the supernova phase of their respective lives.

A detailed study of SN 1987A therefore provides an insight into the early stages of dispersal, which are very crucial in understanding the life cycle of the star.

"A supernova remnant cools quickly, so within a few years the heavy elements formed in the star can form mole-

This time-lapse video sequence of Hubble Space Telescope images reveals dramatic changes in a ring of material around the exploded star Supernova 1987A. The images, taken from 1994 to 2016, show the effects of a shock wave from the supernova blast smashing into the ring. The ring begins to brighten as the shock wave hits it. The ring is about one light-year across. [NASA, ESA, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation), and P. Challis (Harvard-Smithsonian Center for Astrophysics)]



The first spatially resolved submillimeter continuum observations of SN 1987A, obtained with the Atacama Large Millimeter/Submillimeter Array (ALMA). Top row: continuum images of SN 1987A in ALMA bands 3, 6, 7, and 9 (2.8 mm, 1.4 mm, 870 μm and 450 μm respectively). The spatial resolution is marked by dark-blue ovals. In band 9 it is 0.33x0.25", 15% of the diameter of the equatorial ring. At bands 7, 6, and 3 the beams are 0.69x0.42", 0.83x0.61", and 1.56x1.12", respectively. At long wavelengths, the emission is a torus associated with the supernova shock wave; shorter wavelengths are dominated by the inner supernova ejecta. [R. Indebetouw et al.]

cules and condense into dust, turning the remnant into a veritable dust factory," said Remy Indebetouw of the National Radio Astronomy Observatory in Charlottesville, Virginia. *"ALMA is now able to see this newly formed dust directly, and ongoing studies will help us understand how it forms and how supernovae seed interstellar space with the raw material for new planetary systems."*

The SN 1987A star is classified as a core-collapse type of star, and these stars generally end up becoming neutron stars. However, an absence of X-rays and gamma-rays has prompted researchers to reconsider the original theory that the star was of the core-collapse type, hinting at the possibility of the star evolving into a black hole.

SN 1987A took the world of science by storm and has left us with a more sophisticated understanding of the life cycle of stars. Though SN 1987A is a supernova outside of our galaxy, it is celebrated as one of the few celestial events of that type visible to the naked eye. The mere fact that we are observing and studying the supernova as it was 163,000 years ago is astounding. We humans are so confined and limited in our understanding, and yet it seems that our insignificant consciousness is all the universe has to marvel at its beauty.

This scientific visualization, using data from a computer simulation, shows Supernova 1987A, as the luminous ring of material we see today. [NASA, ESA, and F. Summers and G. Bacon (STScI); Simulation Credit: S. Orlando (INAF-Osservatorio Astronomico di Palermo)]

Protostar blazes bright, reshaping its stellar nursery

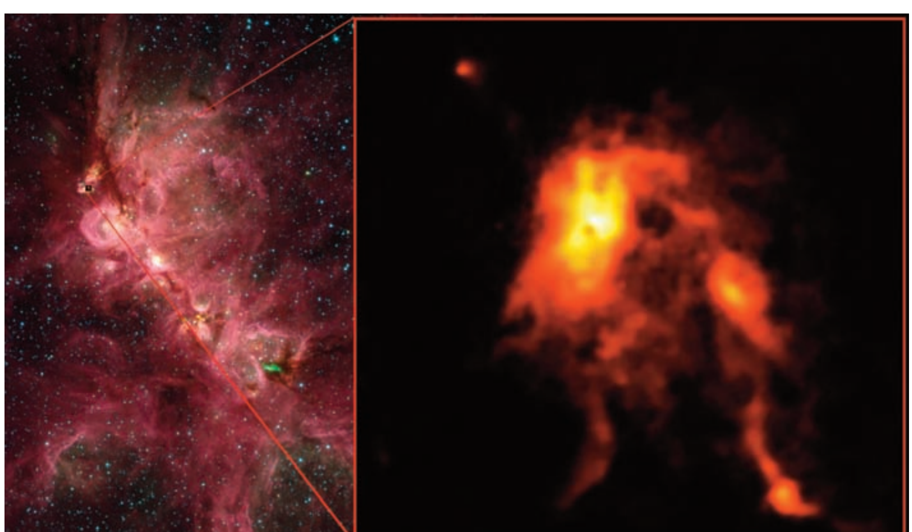
by ALMA Observatory

A massive protostar, deeply nestled in its dust-filled stellar nursery, recently roared to life, shining nearly 100 times brighter than before. This outburst, apparently triggered by an avalanche of star-forming gas crashing onto the surface of the star, supports the theory that young stars can undergo intense growth spurts that reshape their surroundings. Astronomers made this discovery by comparing new observations from the Atacama Large Millimeter/submillimeter Array (ALMA) with earlier observations from the Submillimeter Array (SMA) in Hawaii. *"We were amazingly fortunate to detect this spectacular transformation of a young, massive star,"* said Todd Hunter, an astronomer at the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia, USA, and lead author on a paper published in *The Astrophysical Journal Letters*. *"By studying a dense star-forming cloud with both ALMA and the SMA, we could see that something dramatic had taken place, completely changing a stellar nursery over a surprisingly short period of time."*

In 2008, before the era of ALMA, Hunter and his colleagues used the SMA to observe a small but active portion of the Cat's Paw Nebula (also known as NGC 6334), a star-forming complex located about 5500 light-years from Earth in the direction of the southern constellation Scorpius. This nebula is similar in many respects to its northern cousin, the Orion Nebula, which is also brimming with young stars, star clusters, and dense cores of gas that are on the verge of becoming stars.

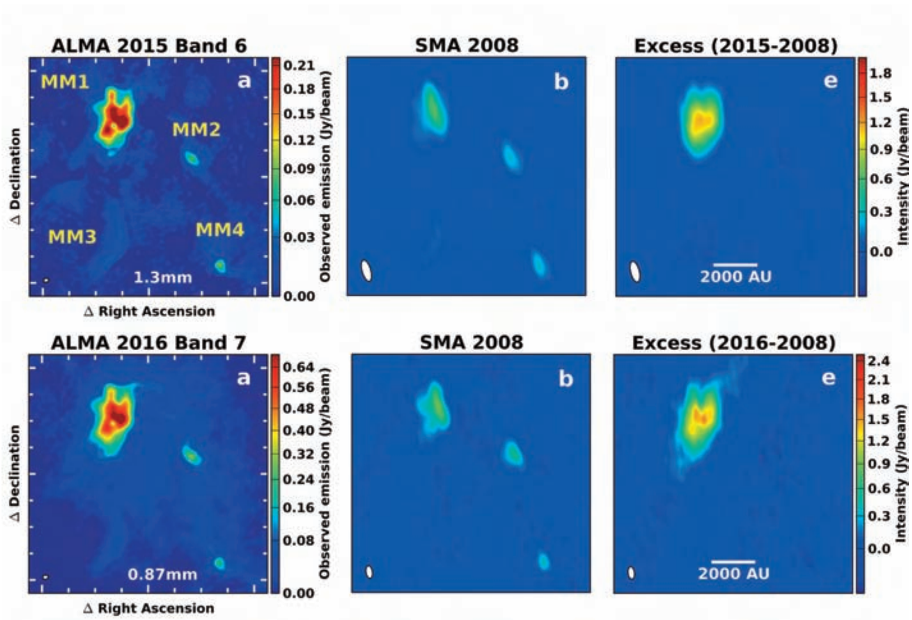
The Cat's Paw Nebula, however, is forming stars at a faster rate.

The initial SMA observations of this portion of the nebula, dubbed NGC 6334I, revealed what appeared to be a typical protocluster: a dense cloud of dust and gas harboring several still-growing stars. Young stars form in these tightly packed regions when pockets of gas become so dense that they begin to collapse under their own gravity. Over time, disks of dust and gas form around these nascent stars and funnel material onto their surfaces helping them grow. This process, however, may not be entirely slow and



Inside the Cats's Paw Nebula as seen in an infrared image from NASA's Spitzer Space Telescope (left), ALMA discovered that an infant star is undergoing an intense growth spurt, shining nearly 100 brighter than before and reshaping its stellar nursery (right). [ALMA (ESO/NAOJ/NRAO), T. Hunter; C. Brogan, B. Saxton (NRAO/AUI/NSF); NASA Spitzer]

steady. Astronomers now believe that young stars can also experience spectacular growth spurts, periods when they rapidly acquire mass by gorging on star-forming gas.
The new ALMA observations of this region, taken in 2015 and 2016, reveal that dramatic changes occurred toward a portion of the protocluster called NGC 6334I-MM1 in the years since the original SMA observations. This region is now about four times brighter at millimeter wavelengths, meaning that the central protostar is nearly 100 times more luminous than before.
The astronomers speculate that leading up to this outburst, an uncommonly large clump of material was drawn into the star's accretion disk, creating a logjam of dust and gas. Once enough material accumulated, the logjam burst, releasing an avalanche of gas onto the growing star. This extreme accretion event greatly increased the star's luminosity, heating its surrounding dust. It's this hot, glowing dust that the astronomers observed with ALMA.
Though similar events have been observed in infrared light, this is the first time that such an event has been identified at millimeter wavelengths. To ensure that the observed changes were not the result of differences in the telescopes or simply a data-processing error, Hunter and his colleagues used the ALMA data as a model to accurately simulate what the SMA – with its more modest capabilities – would have seen if it conducted similar operations in 2015 and 2016.
By digitally subtracting the actual 2008 SMA images from the simulated images, the astronomers confirmed that there was indeed a significant and consistent change to one member of the protocluster.
"Once we made sure we were comparing the two sets of observations on an even playing field, we knew that we were witnessing a very special time in the growth of a star," said Crystal Brogan, also with the NRAO and co-author on the paper.
Further confirmation of this event came from complementary data taken by the Hartebeesthoek Radio Astronomy Observatory in South Africa. This single-dish observatory was monitoring the radio signals from masers in the same region. Masers are the naturally occurring cosmic radio equivalent of lasers.
They are powered by a variety of energetic processes throughout the universe, including outbursts from rapidly growing stars.
The data from the Hartebeesthoek observatory reveal an abrupt and dramatic spike in maser emission from this region in early 2015, only a few months before the first ALMA observation. Such a spike is precisely what astronomers would expect to see if there were a protostar undergoing a major growth spurt.
"These observations add evidence to the theory that star formation is punctuated by a sequence of dynamic events that build up a star, rather than a smooth continuous growth," concluded Hunter. *"It also tells us that it is important to monitor young stars at radio and millimeter wavelengths, because these wavelengths allow us to peer into the youngest, most deeply embedded star-forming regions. Catching such events at the earliest stage may reveal new phenomena of the star-formation process."*



Comparing observations by two different millimeter-wavelength telescopes, ALMA and the SMA, astronomers noted a massive outburst in a star-forming cloud. Because the ALMA images are more sensitive and show finer detail, it was possible to use them to simulate what the SMA could have seen in 2015 and 2016. By subtracting the earlier SMA images from the simulated images, astronomers could see that a significant change had taken place in MM1 while the other three millimeter sources (MM2, MM3, and MM4) are unchanged. [ALMA (ESO/NAOJ/NRAO); SMA, Harvard/Smithsonian CfA]

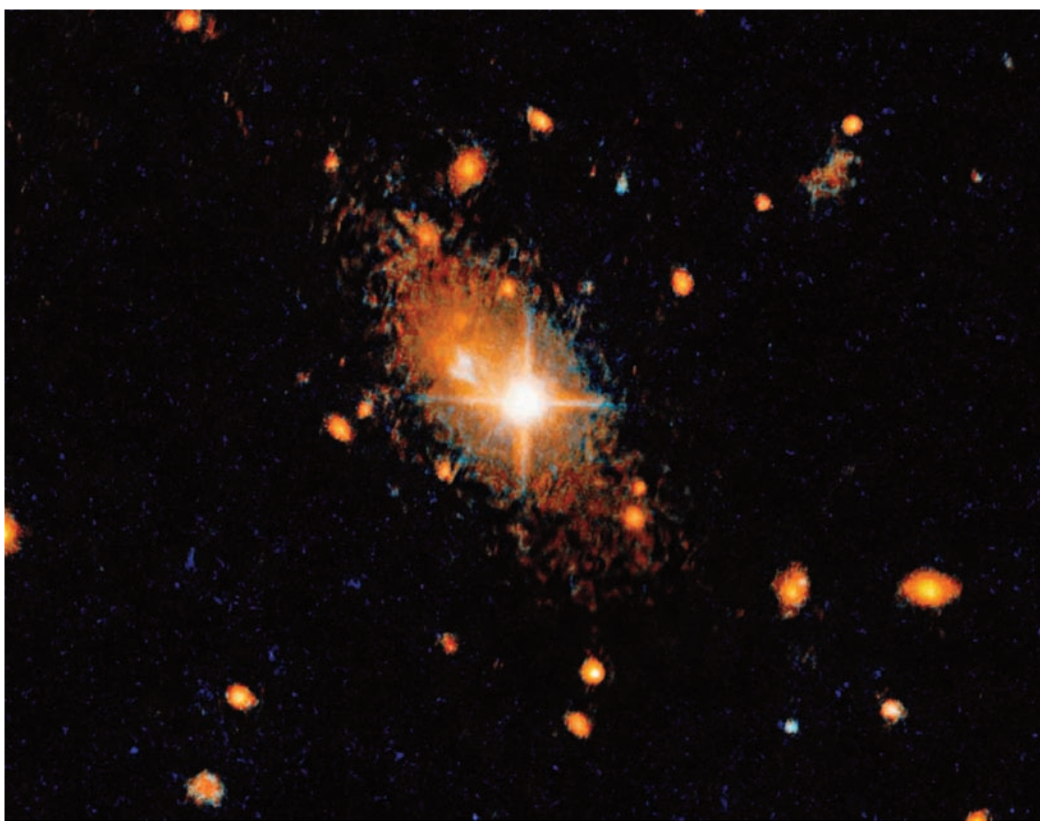
Supermassive black hole kicked out of galactic core

by ESA/NASA

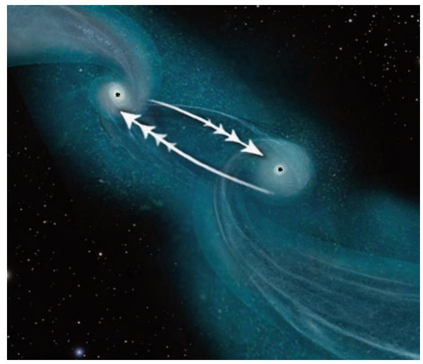
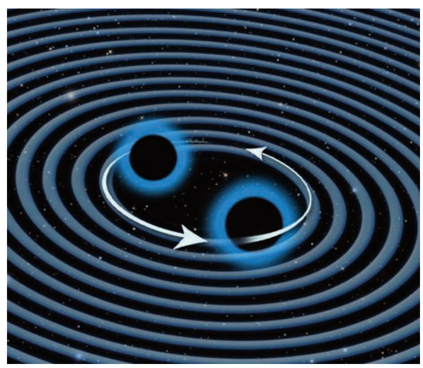
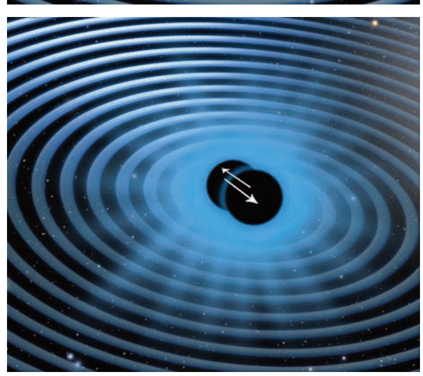
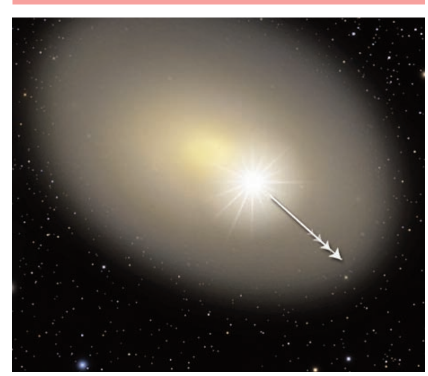
Though several other suspected runaway black holes have been seen elsewhere, none has so far been confirmed.

Now astronomers using the Hubble Space Telescope have detected a supermassive black hole, with a mass of one billion times the Sun's, being kicked out of its parent galaxy. *"We estimate that it took the equivalent energy of 100 million supernovae exploding simultaneously to jettison the black hole,"* describes Stefano Bianchi, co-author of the study, from the Roma Tre University, Italy.

The images taken by Hubble provided the first clue that the galaxy, named 3C186, was unusual. The images of the galaxy, located 8 billion light-years away, revealed a bright quasar, the energetic signature of an active black hole, located far from the galactic core. *"Black holes reside in the cen-*



The galaxy 3C186, located about 8 billion years from Earth, is most likely the result of a merger of two galaxies. This is supported by arc-shaped tidal tails, usually produced by a gravitational tug between two colliding galaxies, identified by the scientists. The merger of the galaxies also led to a merger of the two supermassive black holes in their centres, and the resultant black hole was then kicked out of its parent galaxy by the gravitational waves created by the merger. The bright, star-like looking quasar can be seen in the centre of the image. Its former host galaxy is the faint, extended object behind it. [NASA, ESA, and M. Chiaberge (STScI/ESA)]

This illustration shows how two supermassive black holes merged to form a single black hole which was then ejected from its parent galaxy. Panel 1: Two galaxies are interacting and finally merging with each other. The supermassive black holes in their centres are attracted to each other. Panel 2: As soon as the supermassive black holes get close they start orbiting each other, in the process creating strong gravitational waves. Panel 3: As they radiate away gravitational energy the black holes move closer to each other over time and finally merge. Panel 4: If the two black holes do not have the same mass and rotation rate, they emit gravitational waves more strongly along one direction. When the two black holes finally collide, they stop producing gravitational waves and the newly merged black hole then recoils in the opposite direction to the strongest gravitational waves and is shot out of its parent galaxy. [NASA, ESA/Hubble, and A. Feild/STScI]

tres of galaxies, so it's unusual to see a quasar not in the centre," recalls team leader Marco Chiaberge, ESA-AURA researcher at the Space Telescope Science Institute, USA.

The team calculated that the black hole has already travelled about 35,000 light-years from the centre, which is more than the distance between the Sun and the centre of the Milky Way. And it continues its flight at a speed of 7.5 million kilometres per hour. At this speed the black hole could travel from Earth to the Moon in three minutes. As the black hole cannot be observed directly, its mass and speed were determined via spectroscopic analysis of its surrounding gas.

Although other scenarios to explain the observations cannot be excluded, the most plausible source of the propulsive energy is that this supermassive black hole was given a kick by gravitational waves unleashed by the merger of two massive black holes at the centre of its host galaxy. This theory is supported by arc-shaped tidal tails identified by the scientists, produced by a gravitational tug between two colliding galaxies.

According to the theory presented by the scientists, 1-2 billion years ago two galaxies — each with central, massive black holes — merged. The black holes whirled around each other at the centre of the newly-formed elliptical galaxy, creating gravitational waves that were flung out like water from a lawn sprinkler. The black holes get closer over time as they radiate away gravitational energy. As the two black holes did not have the same mass and rotation rate, they emitted gravitational waves more strongly along one direction.

When the two black holes finally merged, the anisotropic emission of gravitational waves generated a kick that shot the resulting black hole out of the galactic centre.

"If our theory is correct, the observations provide strong evidence that supermassive black holes can actually merge," explains Stefano Bianchi on the importance of the discovery. *"There is already evidence of black hole collisions for stellar-mass black holes, but the process regulating supermassive black holes is more complex and not yet completely understood."*

The researchers are lucky to have caught this unique event because not every black hole merger produces imbalanced gravitational waves that propel a black hole out of the galaxy. The team now wants to secure further observation time with Hubble, in combination with the Atacama Large Millimeter/submillimeter Array (ALMA) and other facilities, to more accurately measure the speed of the black hole and its surrounding gas disc, which may yield further insights into the nature of this rare object. ■

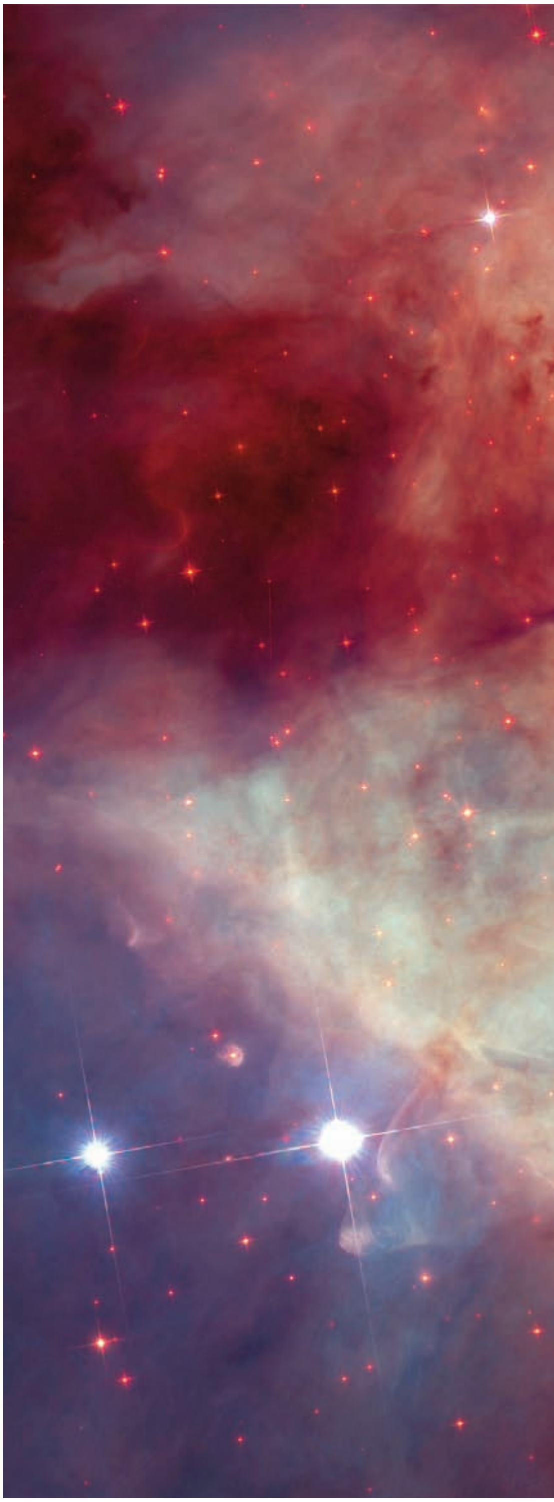
Runaway star yields clues to breakup of multiple-star system

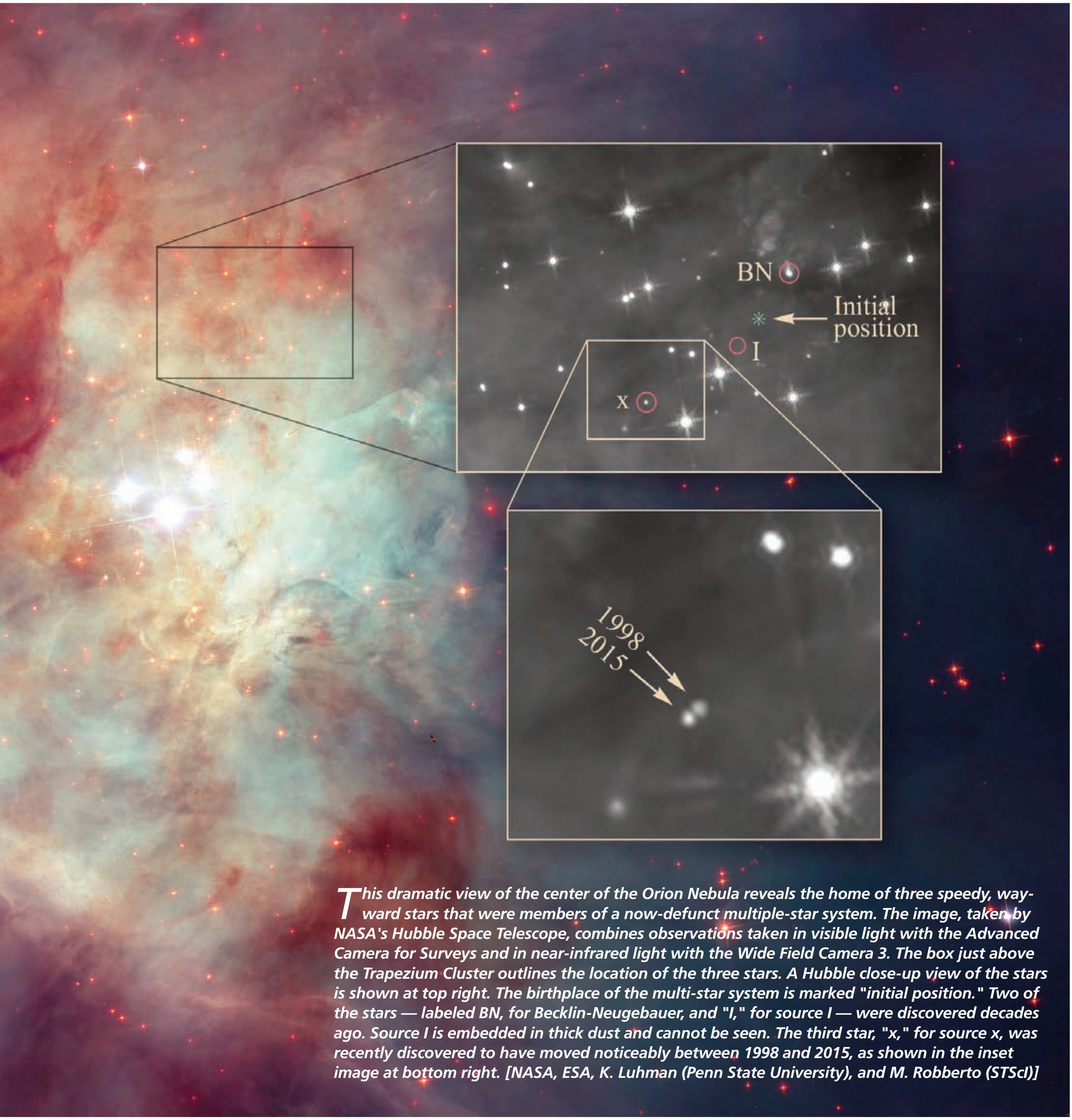
by NASA

As British royal families fought the War of the Roses in the 1400s for control of England's throne, a grouping of stars was waging its own contentious skirmish — a star wars far away in the Orion Nebula. The stars were battling each other in a gravitational tussle, which ended with the system breaking apart and at least three stars being ejected in different directions.

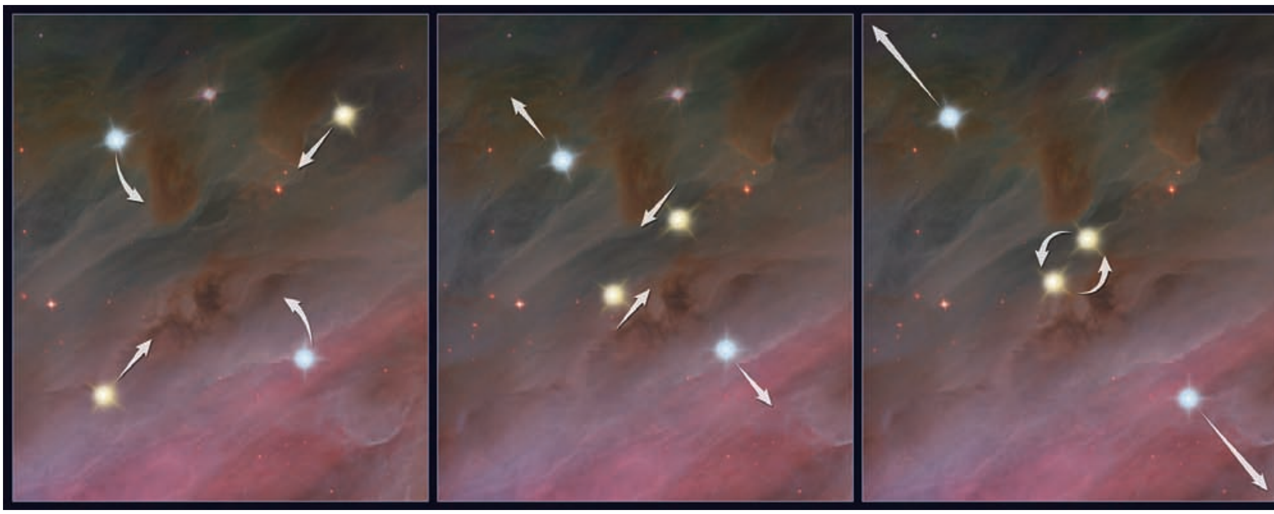
The speedy, wayward stars went unnoticed for hundreds of years until, over the past few decades, two of them were spotted in infrared and radio observations, which could penetrate the thick dust in the Orion Nebula. The observations showed that the two stars were traveling at high speeds in opposite directions from each other. The stars' origin, however, was a mystery. Astronomers traced both stars back 540 years to the same location and suggested they were part of a now-defunct multiple-star system. But the duo's combined energy, which is propelling them outward, didn't add up. The researchers reasoned there must be at least one other culprit that robbed energy from the stellar toss-up. Now NASA's Hubble Space Telescope has helped astronomers find the final piece of the puzzle by nabbing a third runaway star. The astronomers followed the path of the newly found star back to the same location where the two previously known stars were located 540 years ago. The trio reside in a small region of young stars called the Kleinmann-Low Nebula, near the center of the vast Orion Nebula complex, located 1300 light-years away.

"The new Hubble observations provide very strong evidence that the three stars were ejected from a multiple-star system," said lead researcher Kevin Luhman of Penn State University in University Park, Pennsylvania. *"Astronomers had previously found a few other examples of fast-moving stars that trace back to multiple-star systems, and therefore were likely ejected. But these three stars are the youngest examples of such ejected stars. They're probably only a few hundred thousand years old. In fact, based on infrared images, the stars are still young enough to have disks*





This dramatic view of the center of the Orion Nebula reveals the home of three speedy, wayward stars that were members of a now-defunct multiple-star system. The image, taken by NASA's Hubble Space Telescope, combines observations taken in visible light with the Advanced Camera for Surveys and in near-infrared light with the Wide Field Camera 3. The box just above the Trapezium Cluster outlines the location of the three stars. A Hubble close-up view of the stars is shown at top right. The birthplace of the multi-star system is marked "initial position." Two of the stars — labeled BN, for Becklin-Neugebauer, and "I," for source I — were discovered decades ago. Source I is embedded in thick dust and cannot be seen. The third star, "x," for source x, was recently discovered to have moved noticeably between 1998 and 2015, as shown in the inset image at bottom right. [NASA, ESA, K. Luhman (Penn State University), and M. Robberto (STScI)]



This three-frame illustration shows how a grouping of stars can break apart, flinging the members into space. The first panel shows four members of a multiple-star system orbiting each other. In the second panel, two of the stars move closer together in their orbits. In the third panel, the closely orbiting stars eventually either merge or form a tight binary. This event releases enough gravitational energy to propel all of the stars in the system outward. [NASA, ESA, and Z. Levy (STScI)]

of material leftover from their formation." All three stars are moving extremely fast on their way out of the Kleinmann-Low Nebula, up to almost 30 times the speed of most of the nebula's stellar inhabitants.

Based on computer simulations, astronomers predicted that these gravitational tugs-of-war should occur in young clusters, where newborn stars are crowded together. *"But we have not observed many examples, especially in very young clusters,"* Luhman said. *"The Orion Nebula could be surrounded by additional fledging stars that were ejected from it in the past and are now streaming away into space."*

The team's results have been published in the March 20, 2017 issue of *The Astrophysical Journal Letters*.

Luhman stumbled across the third speedy star, called "source x," while he was hunting for free-floating planets in the Orion Nebula as a member of an international team led by Massimo Robberto of the Space Telescope Science Institute in Baltimore, Maryland.

The team used the near-infrared vision of Hubble's Wide Field Camera 3 to conduct the survey. During the analysis, Luhman was comparing the new infrared images taken in 2015 with infrared observations taken in 1998 by the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). He noticed that source x had changed its position considerably, relative to nearby stars over the 17 years between Hubble images, indicating the star was moving fast, about 130,000 miles per hour.

The astronomer then looked at the star's previous locations, projecting its path back in time. He realized that in the 1470s source x had been near the same initial location in the Kleinmann-Low Nebula as two other runaway stars, Becklin-Neugebauer (BN) and "source I."

BN was discovered in infrared images in 1967, but its rapid motion wasn't detected until 1995, when radio observations measured the star's speed at 60,000 miles per hour. Source I is traveling roughly 22,000 miles per hour. The star had only been detected in radio observations; because it is so heavily enshrouded in dust, its visible and infrared light is largely blocked. *"The three stars were most likely kicked out of their home when they engaged in a game of gravitational billiards,"* Luhman said. What often happens when a multiple system falls apart is that two of the member stars move close enough to each other that they merge or form a very tight binary. In either case, the event releases enough gravitational energy to propel all of the stars in the system outward. The energetic episode also produces a massive outflow of material, which is seen in the NICMOS images as fingers of matter streaming away from the location of the embedded source I star. Future telescopes, such as the James Webb Space Telescope, will be able to observe a large swath of the Orion Nebula. By comparing images of the nebula taken by the Webb telescope with those made by Hubble years earlier, astronomers hope to identify more runaway stars from other multiple-star systems that broke apart. ■

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