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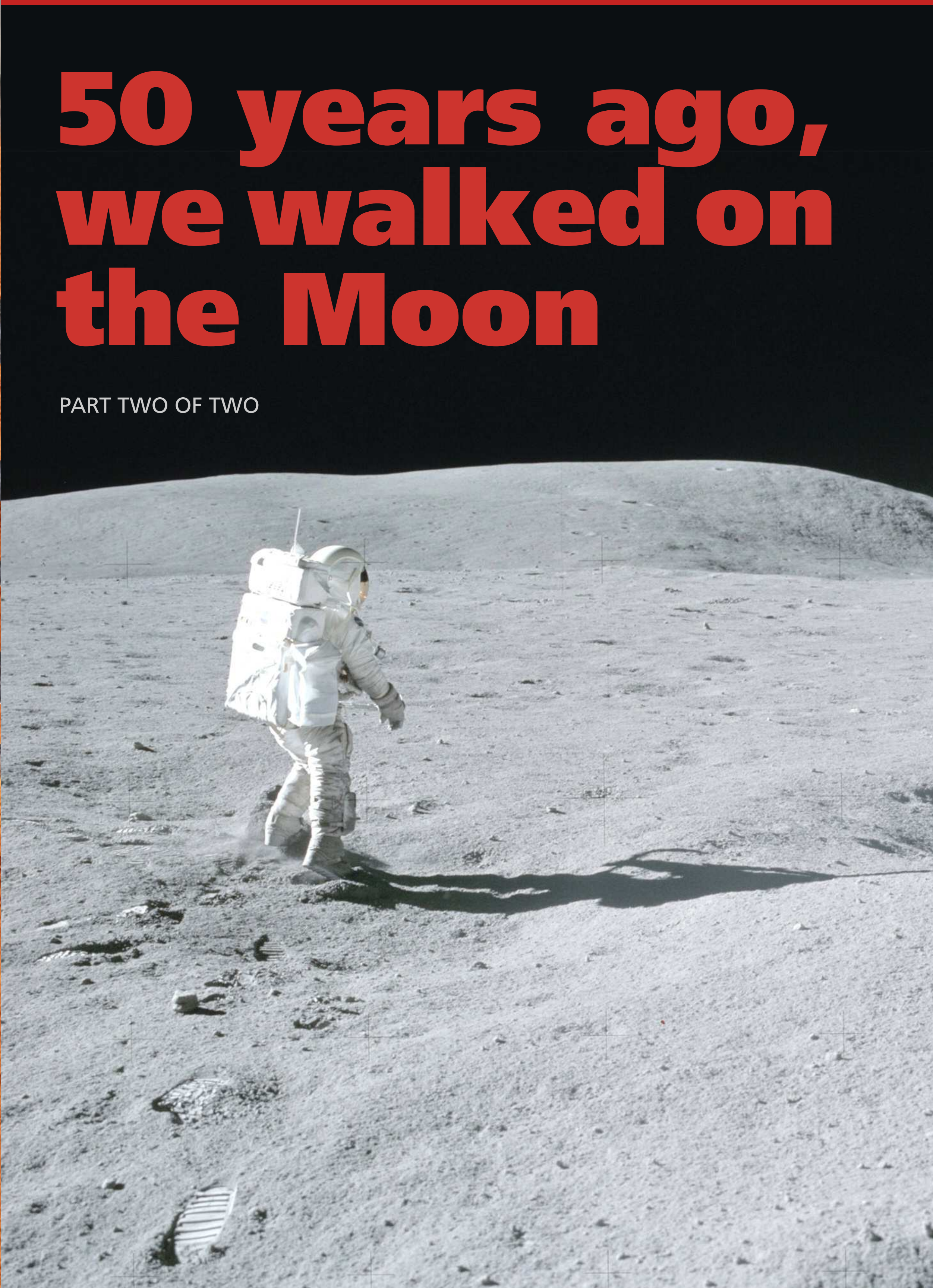
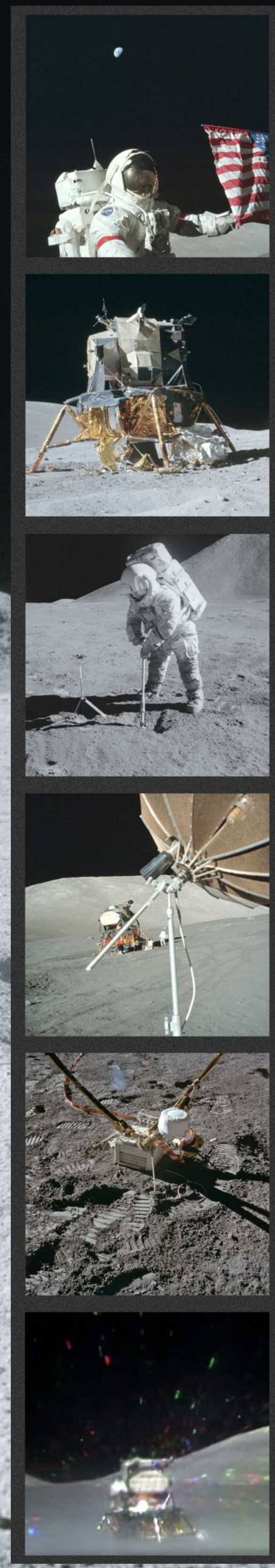


50 years ago, we walked on the Moon

PART TWO OF TWO



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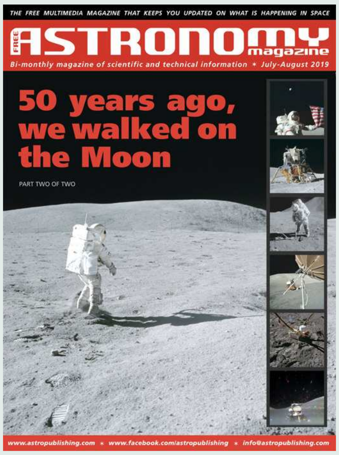

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SUMMARY

50 years ago, we walked on the Moon

(Part Two of Two)

by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

Let us continue and complete our contribution to the celebrations of the fiftieth anniversary of the conquest of the Moon, the first part of which was published in the May-June issue. The goal remains to highlight the reasons why NASA chose specific sites for the six human landings and the importance that these sites had, and still have, from the point of view of our gained knowledge of the geological evolution of the Moon.After sampling 'marine' territories and the Fra Mauro Formation, geologists were eager to direct the astronauts into a mountainous environment, but no such site had been sufficiently inspected to certify it for a landing. However, there was no shortage of reachable alternatives. In addition to the apparently volcanic structures of Marius Hills and Davy Rille, there was a system of dark-looking ridges and gullies in Mare Serenitatis, which Apollo 14 planned to visit before being redirected to Fra Mauro.

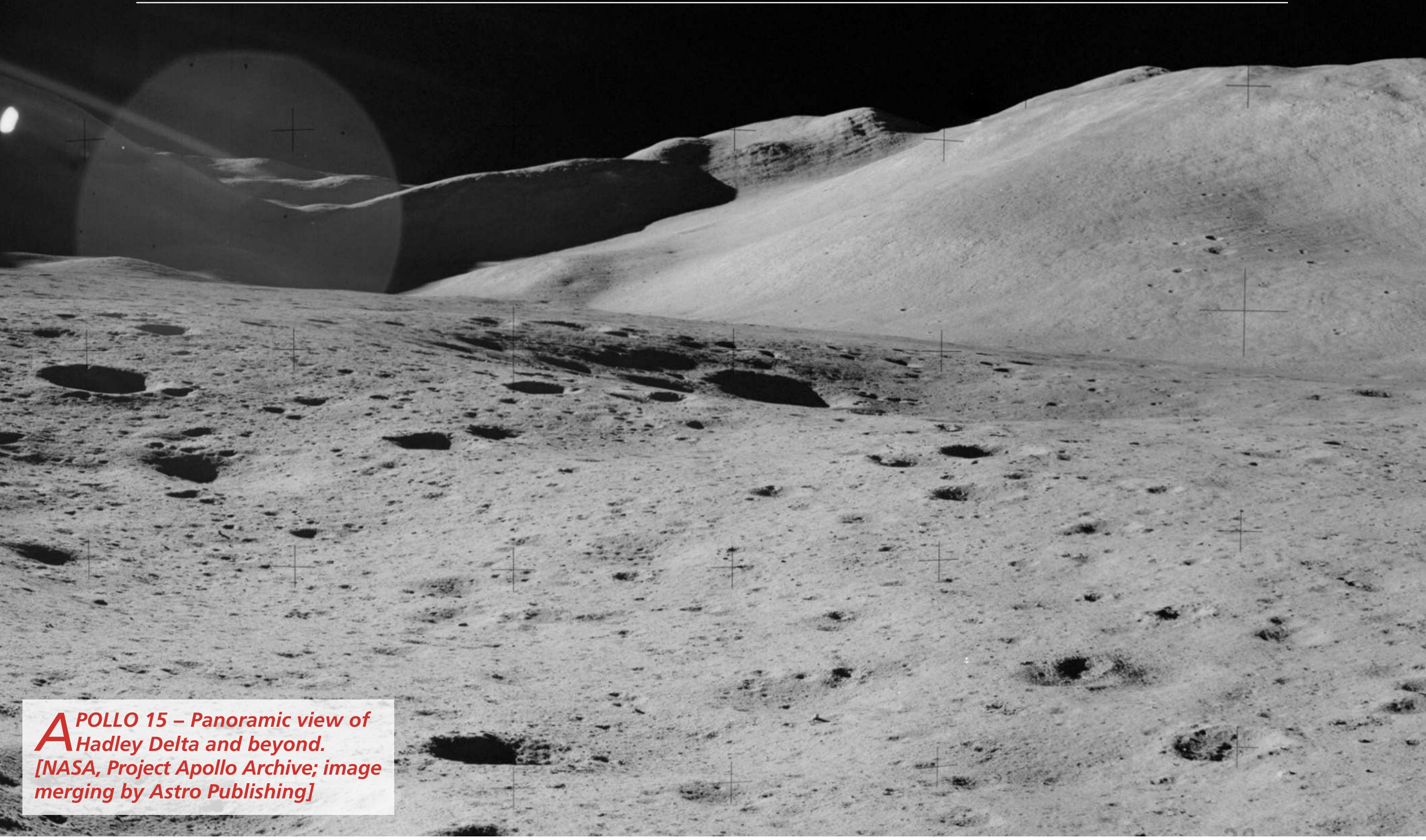
At first, Apollo 15 was supposed to be an 'H' mission (precision landing, with a stay of up-to two days on the Moon and including two extravehicular activities), but on September 2, 1970, it was decided to turn it into the first 'J' mission, able to stay longer on the Moon and with greater mobility on the surface. For this reason, a site with multiple structures was really needed to take advantage of the huge exploration potential offered by the Lunar Roving Vehicle (LRV). The favorite target was a new candidate: Hadley Rille, east of Mare Imbrium. Of the two existing types of lunar rilles, linear and sinuous, Hadley is one of the most impressive among the sinuous rilles. It starts in an

APOLLO 15 – Panoramic view of the Apollo 15 operational area. [NASA, Project Apollo Archive; image merging by Astro Publishing]

APOLLO 15 – David R. Scott at work next to the Lunar Roving Vehicle parked near Hadley Rille. [NASA, Project Apollo Archive]

APOLLO 15 – James B. Irwin, pilot of the lunar module, uses a scoop to dig a groove in the lunar soil. [NASA, Project Apollo Archive]

APOLLO 15 – David R. Scott at the Station 2 boulder. [NASA, Project Apollo Archive]

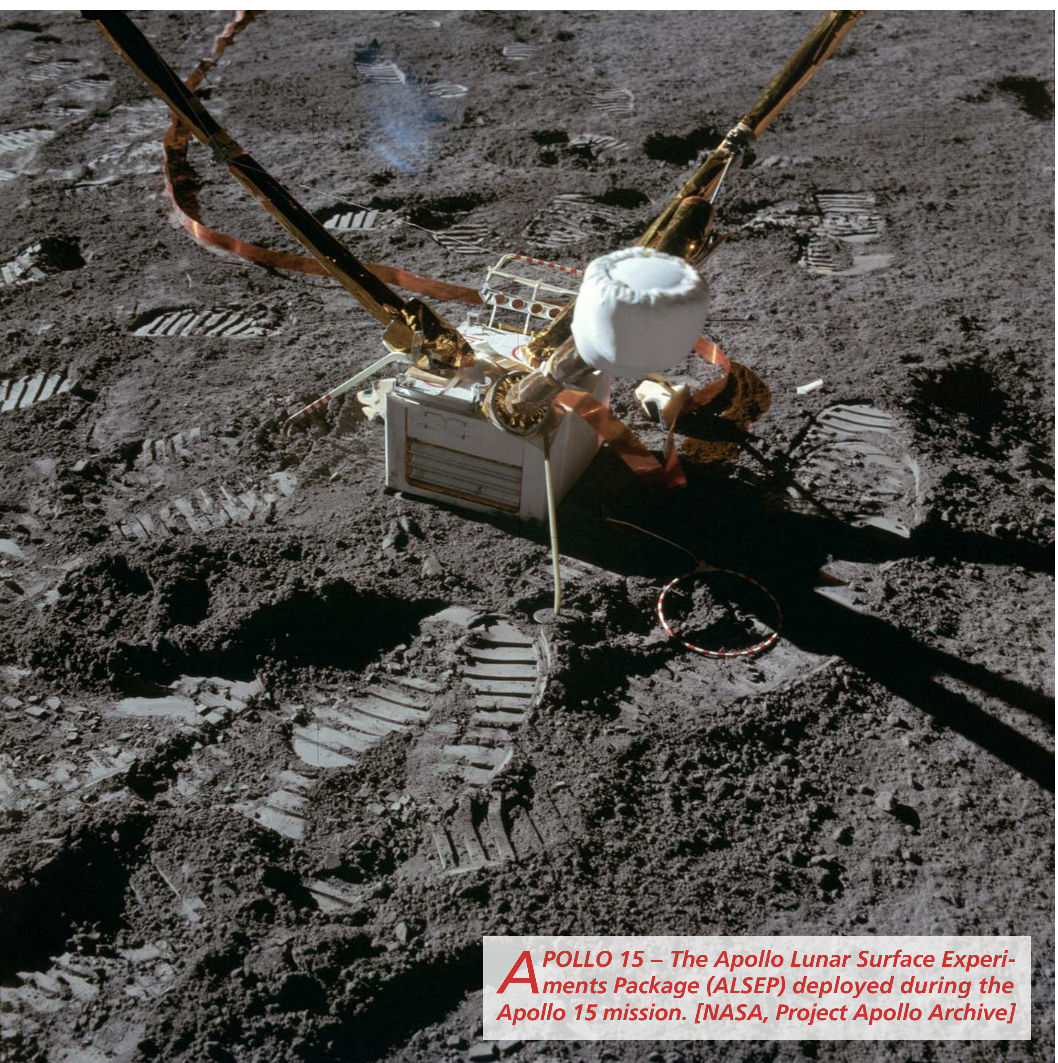


APOLLO 15 – Panoramic view of Hadley Delta and beyond. [NASA, Project Apollo Archive; image merging by Astro Publishing]

arched split in the basin in front of the Montes Apenninus, and then exploits a system of radial and peripheral fractures to head north for about 110 km, parallel to the seacoast. At the base of Mount Hadley Delta (a peak south of Mount Hadley) the rille touches Palus Putredinis before finally

APOLLO 15 – An astronaut at work near Hadley Rille. Bottom right, scenes of 'lunar life' during the Apollo 15 mission. [NASA, Project Apollo Archive]

APOLLO 15 – James B. Irwin makes the military salute standing near the unfolded US flag. [NASA, Project Apollo Archive]

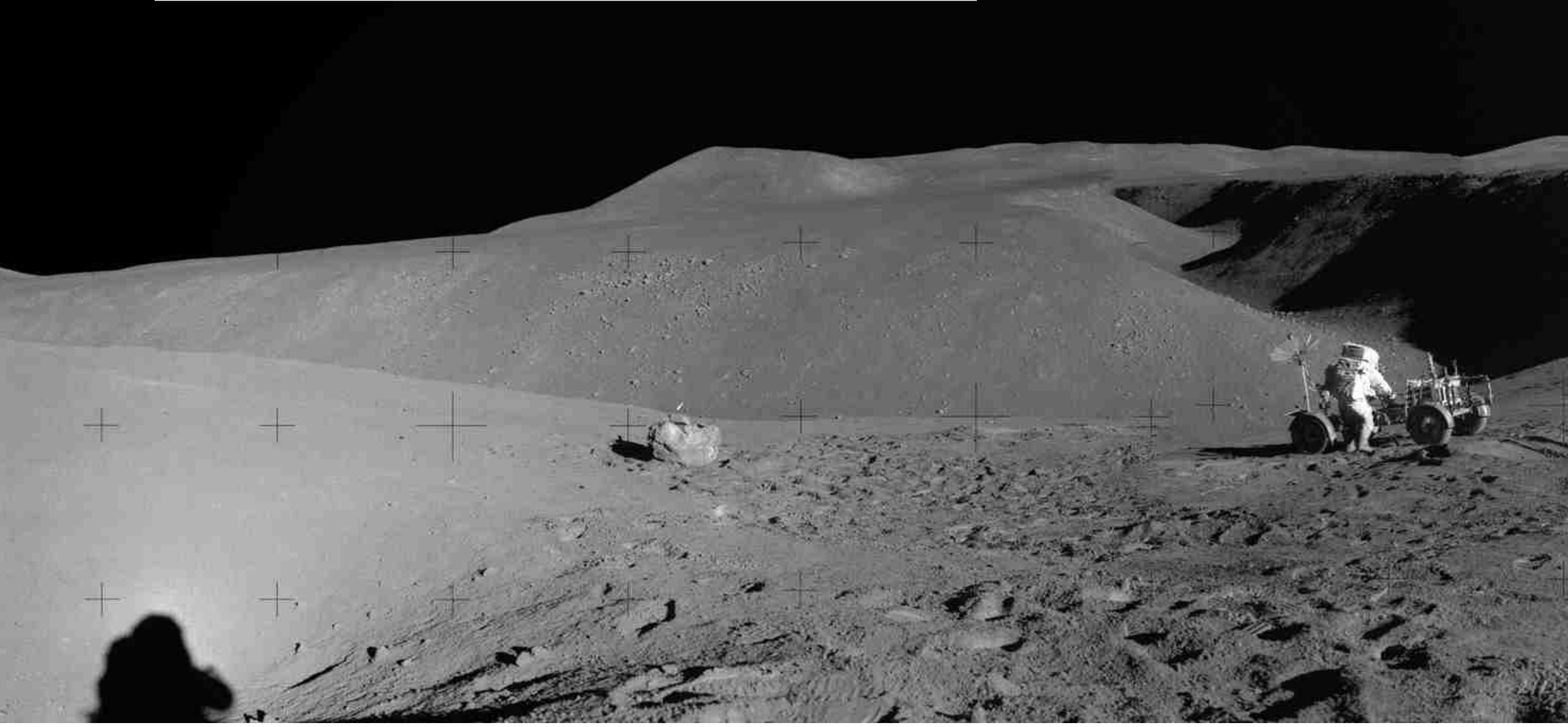


APOLLO 15 – The Apollo Lunar Surface Experiments Package (ALSEP) deployed during the Apollo 15 mission. [NASA, Project Apollo Archive]

running out. The Hadley-Apennine combination promised to be an optimal target for the study of the formation of Mare Imbrium, which in turn was the basis for the stratigraphic study of the Moon. But landing in this area would have been an operational challenge because it would have involved flying over the Apennine, whose peaks are among the highest on the near side of the Moon and would

APOLLO 15 – James B. Irwin works around the LRV. [NASA, Project Apollo Archive]

APOLLO 15 – Panoramic view of the edge of Hadley Rille. A high-resolution version of this image is available at https://www.astropublishing.com/moonscapes/A15_Hadley_Rille_panorama.pdf [NASA, Project Apollo Archive; image merging by Astro Publishing]

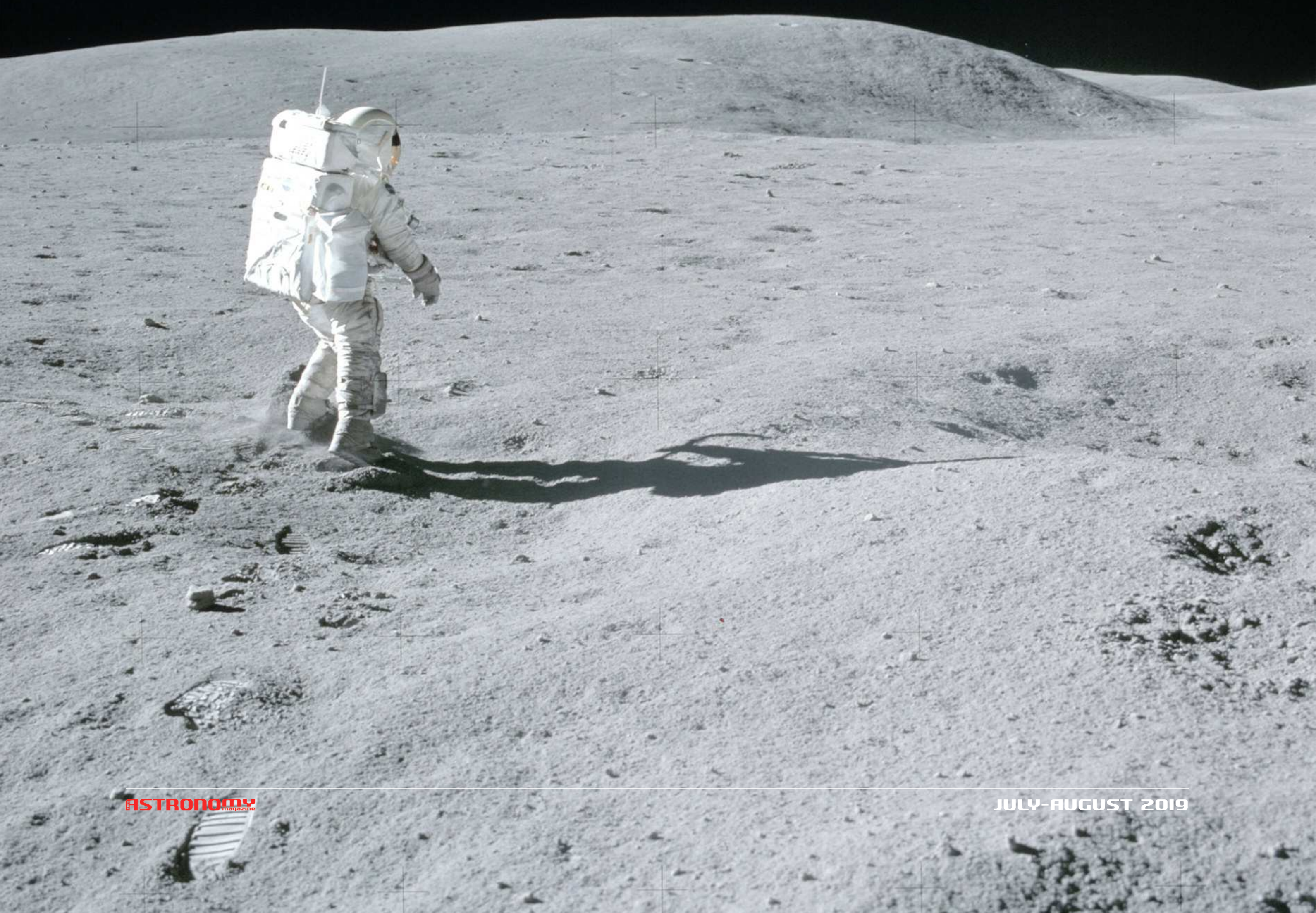


have required a descent twice as steep as previous missions to go down into the valley between two mountains and a rille. There was no space for a significant deviation from the trace of an ideal approach. It could not have been visited before, since it required that the site selection rules were softened.

Until then, to be certified, both the site and the approach from the east had to be documented in high resolution. The Hadley-Apennine area was photographed by a Lunar Orbiter only as a site of scientific interest, with a just-acceptable resolution of about 20 meters. However, it was the topography itself bordering Hadley-Apennine that made the area so appealing to scientists. The availability of a rille on a sea that had flooded a valley near a mountain range on the outskirts of Mare Imbrium made Apollo 15

APOLLO 16 – Panoramic view of the Apollo 16 landing site. A high-resolution version of this image is available at https://www.astropublishing.com/moonscapes/A16_LEM_Station_panorama.pdf [NASA, Project Apollo Archive; image merging by Astro Publishing]

the first multi-target mission. Sending a previous flight on such a rich site would have been wasteful, as the LRV was essential to exploiting such potential.
On Earth, the process of orogenesis is the result of plate tectonics, and it takes millions of years to create a mountain range. The lunar surface, conversely, is shaped by the bombardment of meteorites, and the mountains surrounding the impact basins were instantly lifted when the shock broke the crust, producing a series of crisscrossing radial and peripheral fissures. In this rapid-origin scenario, the formed mountains are unique, individual masses. The Apennine represents the southeastern edge of Mare Imbrium, with the steep slope facing the basin of this chain known as the Apennine Front. To appreciate the importance of this mountain range, it is necessary to consider its position between the basins of Imbrium and Serenitatis.
The Moon can be studied by stratigraphic analysis based on the superposition principle. This analysis shows that before the Imbrium



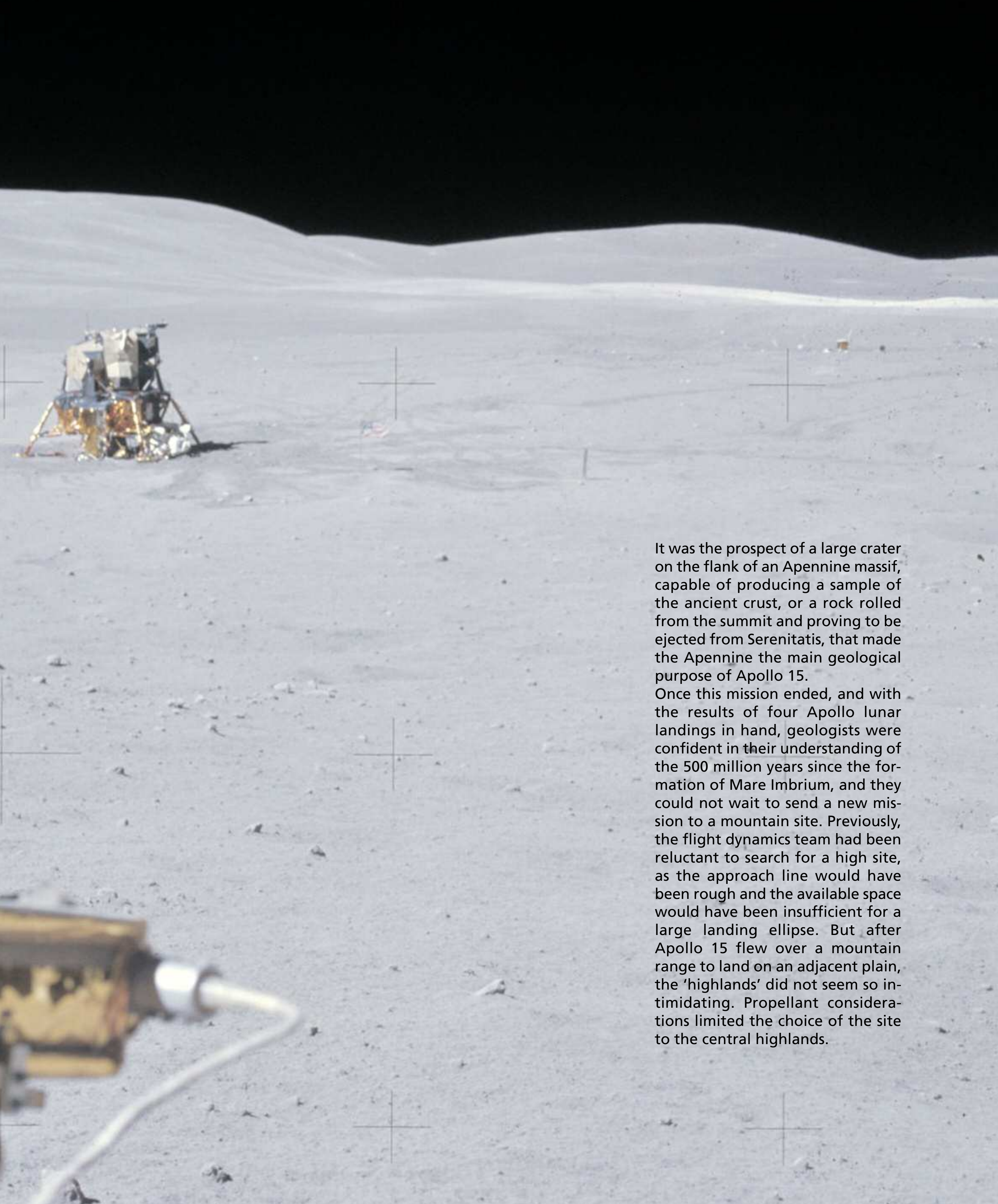
APOLLO 16 – Charles Duke walking in Plum Crater. [NASA, Project Apollo Archive]

APOLLO 16 – Astronauts collecting surface samples. [NASA, Project Apollo Archive]

APOLLO 16 – John W. Young posing beside the LRV. [NASA, Project Apollo Archive]

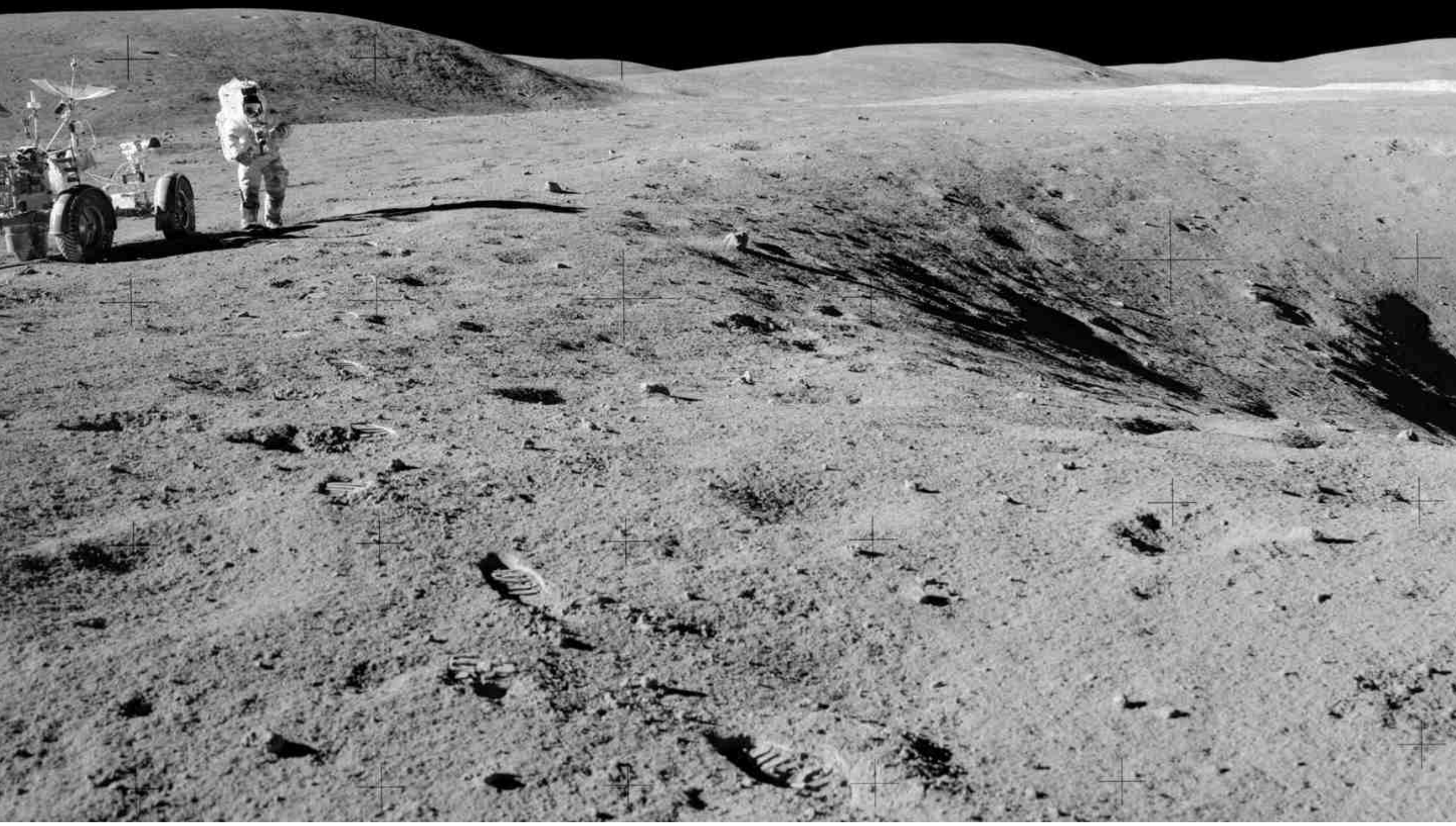
APOLLO 16 – Image taken aboard the LRV as the astronauts were heading to the lunar module. [NASA, Project Apollo Archive]

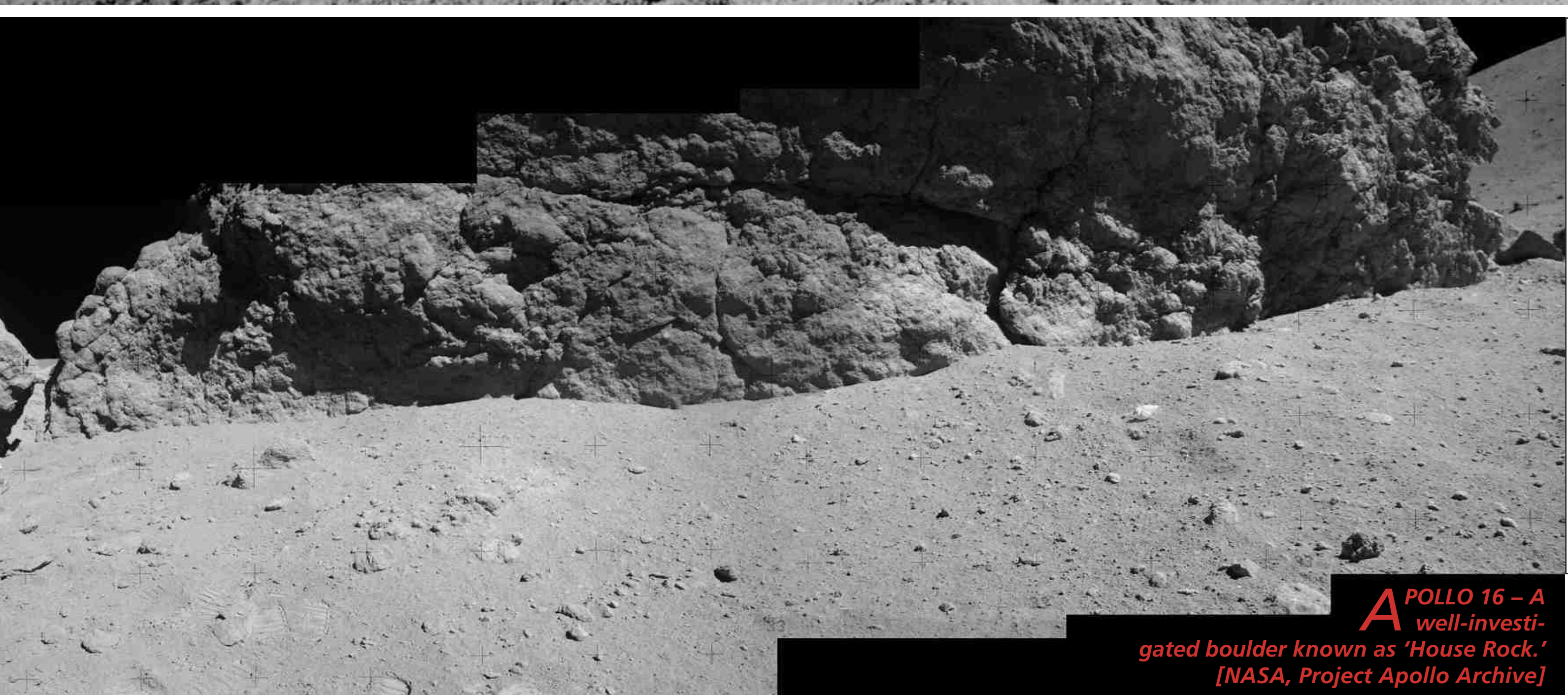
event, the land on which the Apennine was built was the inner part of the Serenitatis-equivalent of the Fra Mauro Formation. Therefore, there was a layer of Serenitatis ejecta deposited on the crust, later contaminated by the formation of Mare Imbrium, so that the underlying crustal blocks were exposed by the new event. It is possible that part of this material remained on the peaks, but it is likely that most of it slipped down, accumulating in the valleys. When an impact crater is formed, material dug from deeper underground is left at the edge of the crater itself. When a basin is formed, there is also a pulse of semi-melted material dug into the depths of the surface crust, and this material would have coated the Apennine. Fra Mauro rocks revealed that Imbrium was formed 3.85 billion years ago, but the Fra Mauro Formation only represented the ejecta of the crust.



It was the prospect of a large crater on the flank of an Apennine massif, capable of producing a sample of the ancient crust, or a rock rolled from the summit and proving to be ejected from Serenitatis, that made the Apennine the main geological purpose of Apollo 15.
Once this mission ended, and with the results of four Apollo lunar landings in hand, geologists were confident in their understanding of the 500 million years since the formation of Mare Imbrium, and they could not wait to send a new mission to a mountain site. Previously, the flight dynamics team had been reluctant to search for a high site, as the approach line would have been rough and the available space would have been insufficient for a large landing ellipse. But after Apollo 15 flew over a mountain range to land on an adjacent plain, the ‘highlands’ did not seem so intimidating. Propellant considerations limited the choice of the site to the central highlands.

APOLLO 16 – Panoramic view of Plum Crater. A high-resolution version of this image is available at https://www.astropublishing.com/moonscapes/A16_Plum_Crater_panorama.pdf
[NASA, Project Apollo Archive; image merging by Astro Publishing]





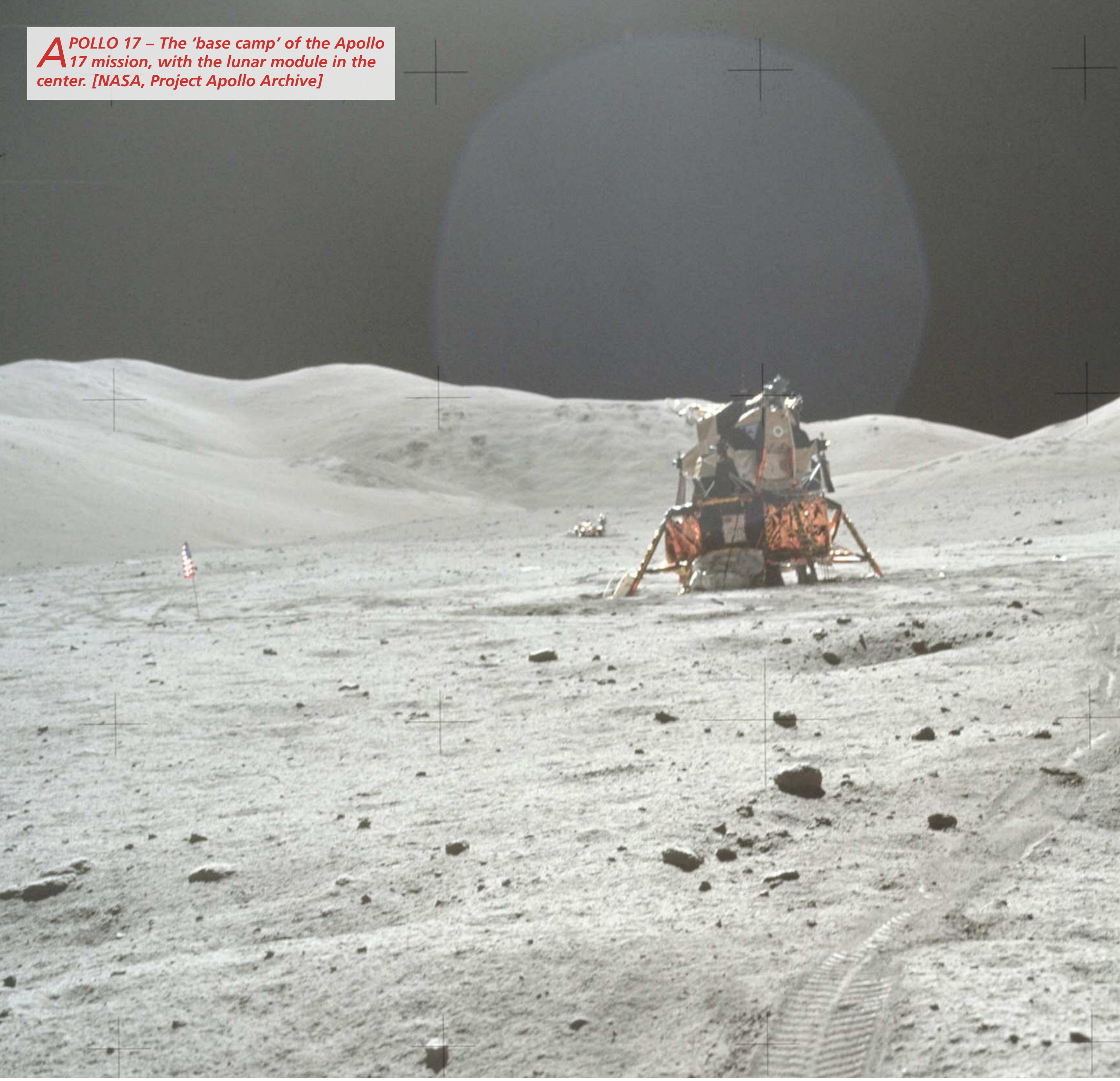
APOLLO 16 – A well-investigated boulder known as 'House Rock.'
[NASA, Project Apollo Archive]

In 1965, D.E. Wilhelms made a distinction between Fra Mauro's corrugated area and the gentle clear plains of the adjacent highland, producing a new map in which the latter was labeled as Cayley Formation. While the maria were effusive eruptions of a dark basalt rich in mafic silicates that produced low-viscosity lava capable of forming smooth plains, it was thought that 'highland basalt' was sufficiently enriched with silica to render it semi-viscous, with the result that, after oozing from fissures, it settled as isolated spots in low areas. When R.E. Eggleton mapped the clear hills near Descartes Crater, in the central highlands, he reported them as an atypical patch of the Fra Mauro Formation. Lacking evidence to the contrary, it was natural to consider these domic hills as extrusions of silica-rich rhyolite which, being viscous, had accumulated to become hills. Originally called 'Material of the Descartes Mountains', this hilly

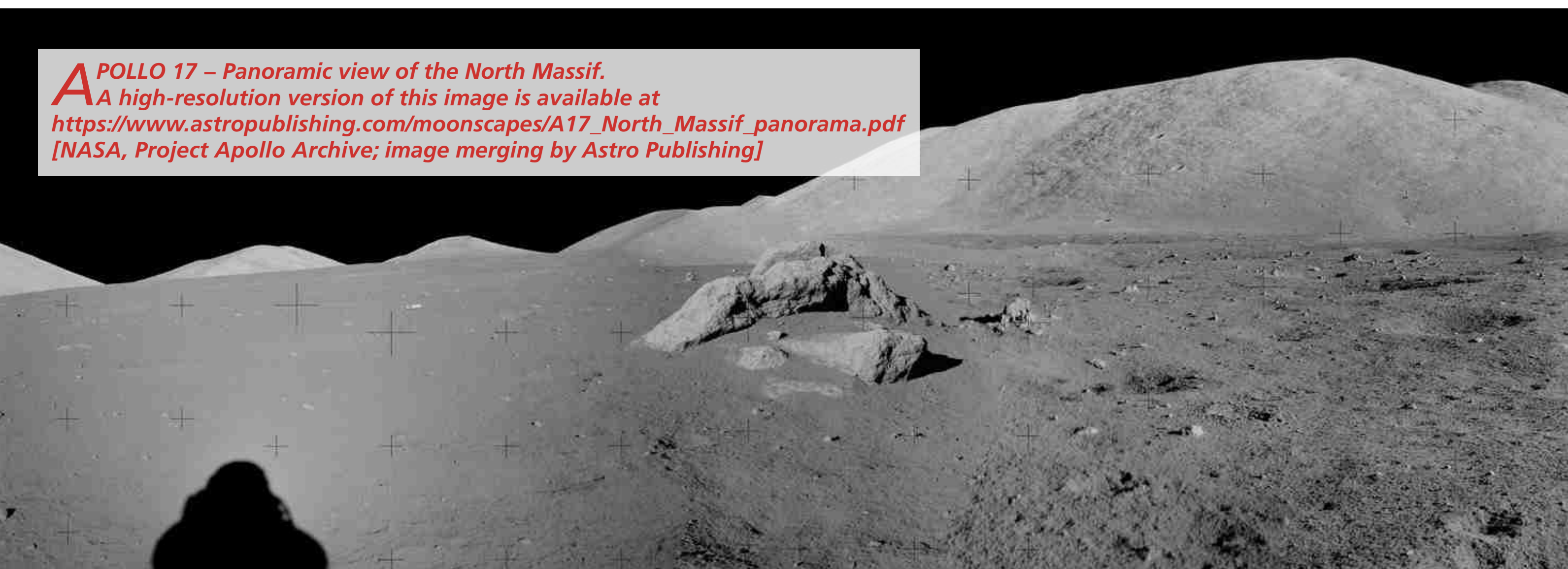
APOLLO 16 – Videos showing Thomas Mattingly and John Young having fun aboard the LRV. [NASA, Project Apollo Archive]

region was renamed Descartes Formation.
Petrologists have claimed that Apollo 16 should have landed on the Kant Plateau, as it resembled a primitive crustal block that, although cratered, did not seem masked by volcanism. But geologists rejected this idea precisely for this reason: they were looking for evidence of volcanism. They pointed out that just beyond the western slope of the highland there was the Descartes Formation and that a landing in one of the valleys that seemed wedged in the Cayley Formation would have allowed a single mission to sample both types of terrain.
The information provided by the direct observations of Apollo 16 upset the scientific logic surrounding the choice of the landing site. The Cayley Formation was certainly not a volcanic plain. The nature of Descartes Formation was uncertain because it was not clear whether it had been sampled. If Stone Mountain was of volcanic origin, it would have been masked by South Ray ejecta. Although the Smoky Mountain area was not sampled, nothing was observed in North Ray that looked volcanic. Apollo 16 results have suggested that there are probably few (if any) mountains of volcanic origin on the Moon.
Nearly three and a half years after the first lunar steps were taken by Armstrong and Aldrin, the Apollo 17 mission began.
The landing site was chosen already knowing that it would be the final mission. As the selection had taken place prior to the Apollo 16 flight, it was influenced by the extent to which crucial events in the lunar history had already been understood or were likely to be addressed by Apollo 16.
The target of Apollo 17 has, therefore, been hotly debated. Tycho, in the southern highlands, and Tsiolkovsky, on the far side of the Moon, were of special interest but were impractical from an operational point of view. The Humorum Basin, south of Oceanus Procellarum, is partially flooded, while Gassendi Crater, 93 km in diameter, stretches between the edge and the north shore of the internal mare. A landing in this crater would have allowed us to sample its central summit, to date the crater and probably to shed light on the surrounding basin. The choice of the last landing site was nevertheless motivated by the need to refine the timeframe in which the lunar heat engine had been active.
As the formation of Mare Imbrium was well-known, as was the awakening of the lavas that flooded most basins over the next 500 million years, the mission target was late volcanism. Marius Hills and Davy Rille did not deserve a 'J' mission, so the choice narrowed down to Gassendi and Alphonsus Craters, the latter 100 km in diameter, which seemed to have volcanoes inside and a 'dark cover' on the east edge of Serenitatis.
Although the Serenitatis Basin was not flooded by the lava until sometime later, it is thought that the process began before the start of the ascent in Imbrium. Obviously, Serenitatis was not flooded at one time. There were dark materials around the southeastern edge, and the general opinion was that it was significantly younger than the lighter shades in the middle. A visit to this area would have allowed us to sample both the old and younger soils.
Thanks to the experienced staff and the excellent performance of the equipment, all aspects of the final landing mission were conducted with competence, precision

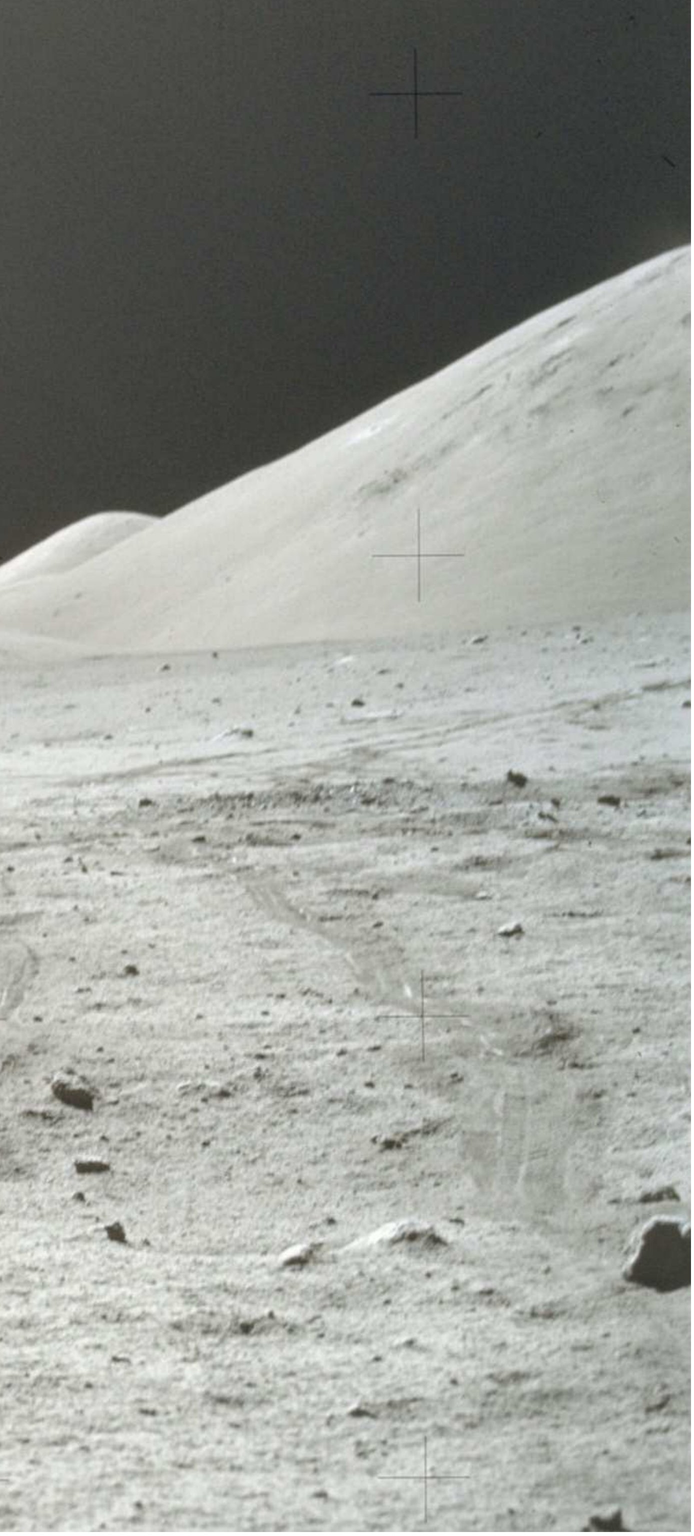
APOLLO 17 – Astronaut Eugene Cernan posing near the US flag, with the Earth in the background. [NASA, Project Apollo Archive]

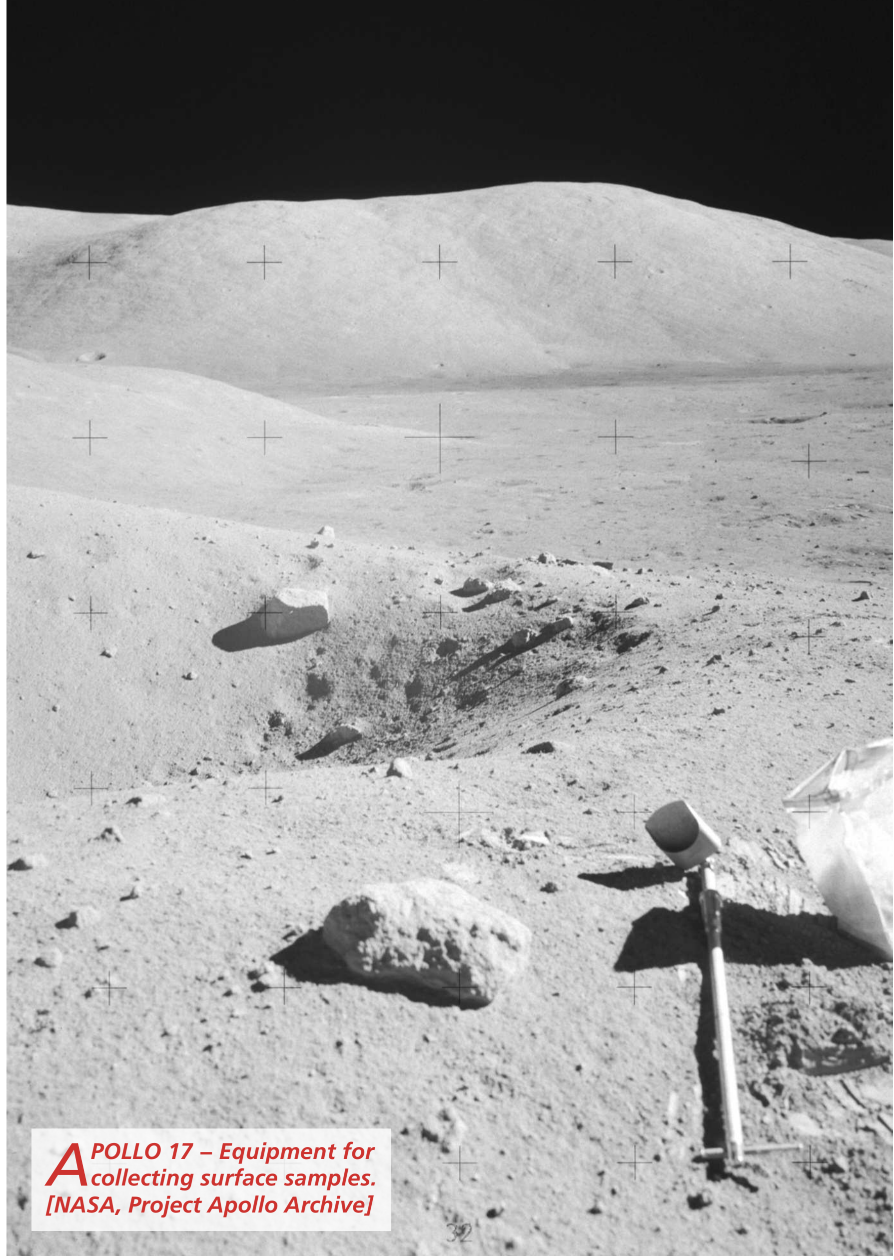


APOLLO 17 – The 'base camp' of the Apollo 17 mission, with the lunar module in the center. [NASA, Project Apollo Archive]

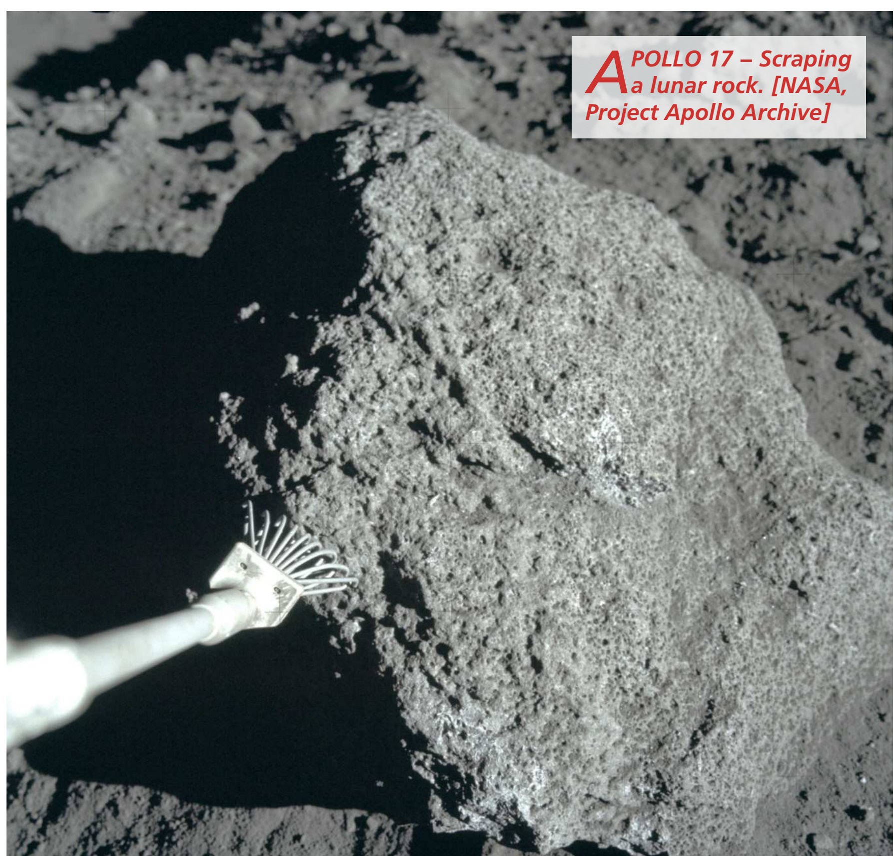


APOLLO 17 – Panoramic view of the North Massif.
A high-resolution version of this image is available at https://www.astropublishing.com/moonscapes/A17_North_Massif_panorama.pdf [NASA, Project Apollo Archive; image merging by Astro Publishing]





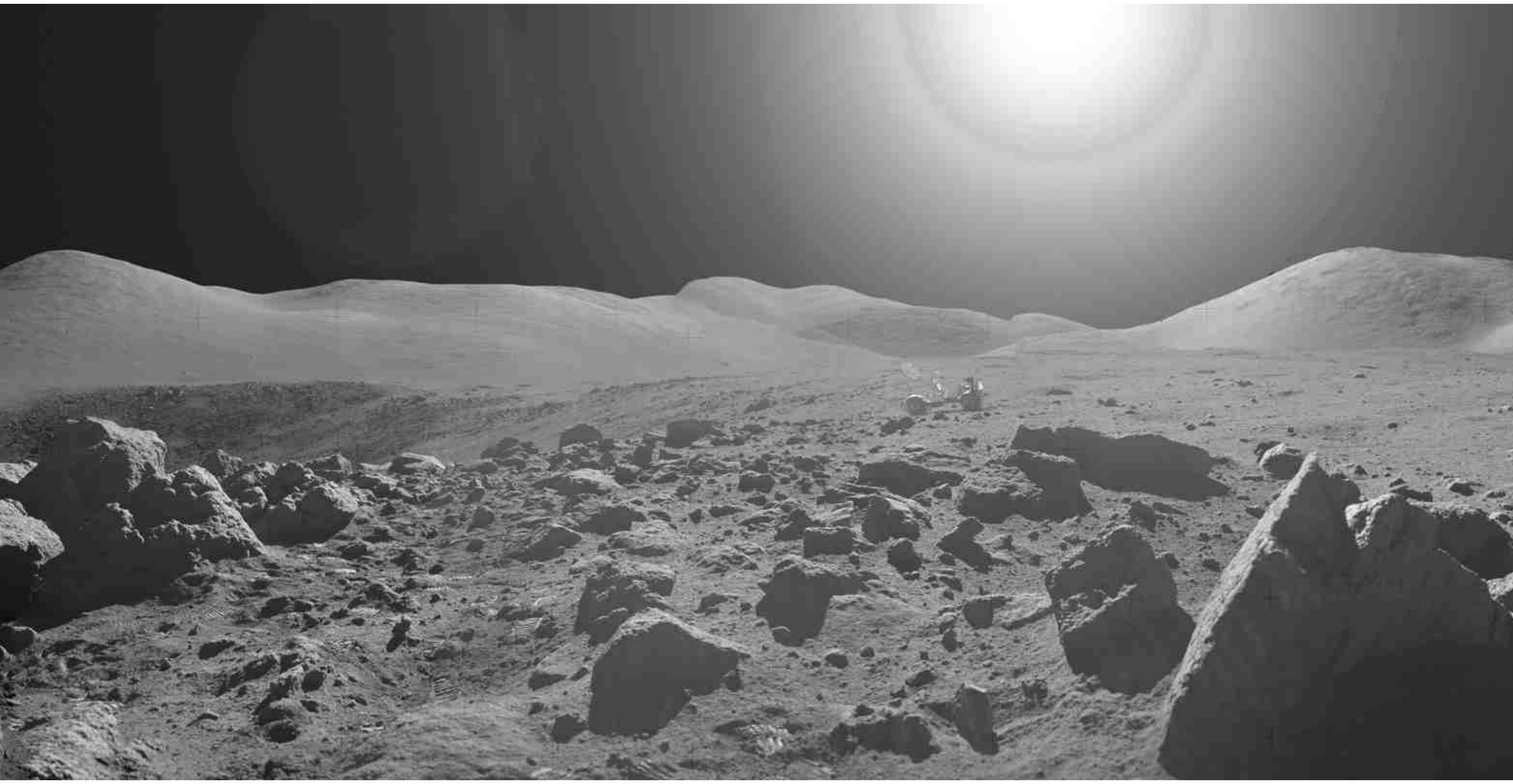
APOLLO 17 – Equipment for collecting surface samples. [NASA, Project Apollo Archive]



APOLLO 17 – Scraping a lunar rock. [NASA, Project Apollo Archive]

APOLLO 17 – 360° panoramic view of South and North massifs. The astronaut (below) heads for the LRV at the end of the second strip under the reflection of the Sun. A high-resolution version of this image is available at https://www.astropublishing.com/moonscapes/A17_South&North_Massifs_panorama360.pdf [NASA, Project Apollo Archive; image merging by Astro Publishing]

and relative ease. The basement turned out to be a lava flow. When the seismic charges deployed in the valley were remotely triggered, they revealed that the thickness of this material exceeded 2 km. Before the experiment on the electrical properties of the surface would overheat, it recorded data consistent with this result. The underlying pre-Serenitatis basement lies under the range of an impact.
Clearly, before the incorporation, the massifs rose almost 6 km above the original valley floor, and most of the Taurus Mountains ejecta are now submerged.
Apollo 17 was the last inhabited lunar mission. In NASA's initial plans, there were three further missions, 18, 19 and 20, which were

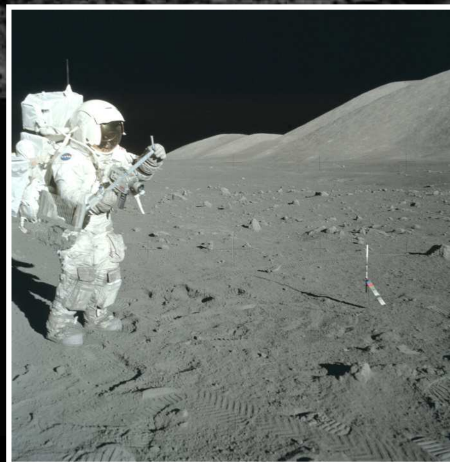


canceled for various reasons, including budget cuts needed to fund the Skylab program and, less usefully, the war in Vietnam.
The Apollo 20 mission was canceled immediately after the success of Apollo 12, while Apollo 18 and 19 were canceled after the misadventure of Apollo 13, still at the apex of public interest in the conquest of the Moon. This invalidates a fairly widespread thesis, according to which it was the growing disinterest of US taxpayers towards that type of space activity that decreed its premature conclusion.
When NASA decided to abandon Apollo 20, the mission hardware was only partially built. On the contrary, the hardware for Apollo 18 and 19 was ready and these two

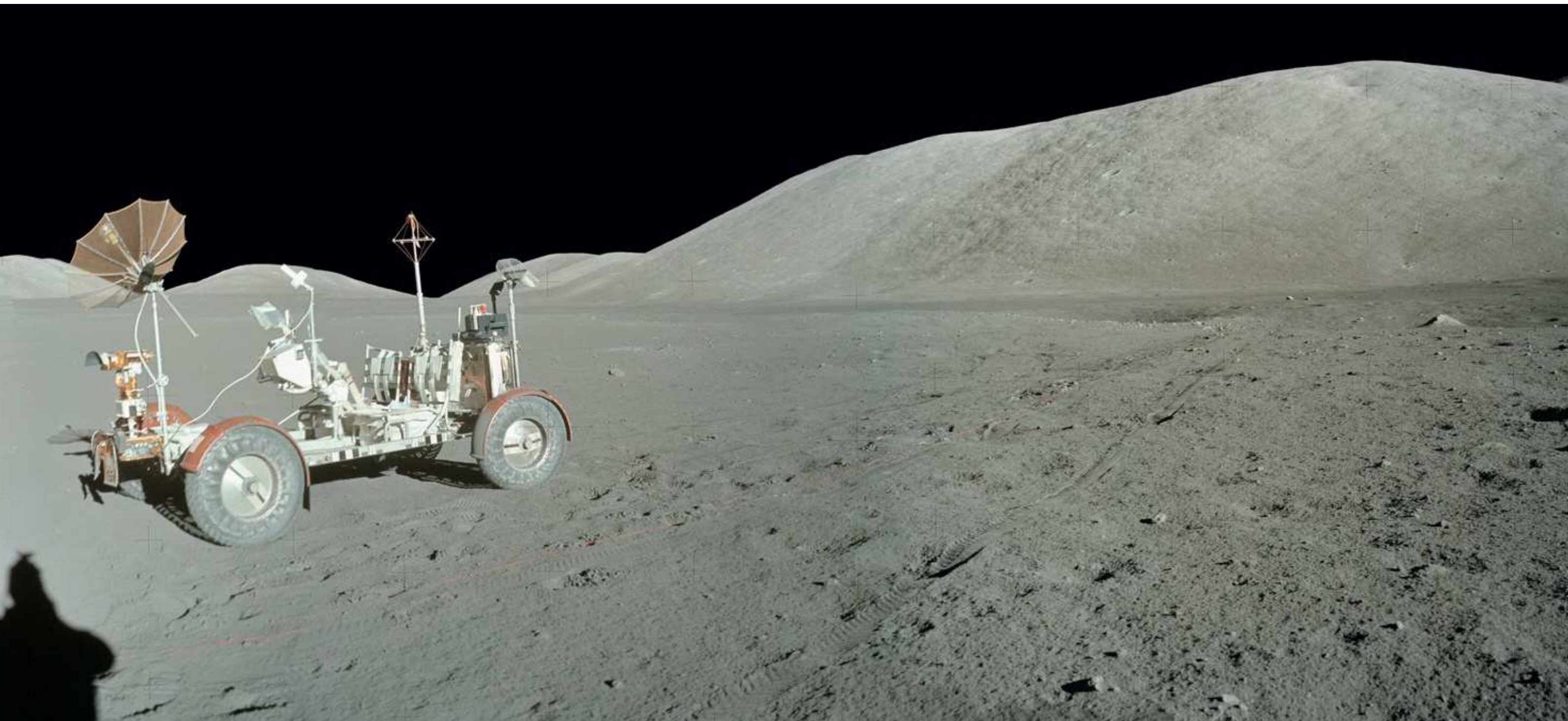
missions could have been implemented with a relatively modest economic effort, significantly increasing the scientific production of the whole program. Instead of sending man back to the Moon, the hardware for these missions had been partly converted for other space programs and partly used to adorn parking lots of NASA centers and museum rooms in different cities. At that time, such a waste was not immediately felt, as it was widely believed that within

APOLLO 17 – A close-up of Shorty Crater. [NASA, Project Apollo Archive]

APOLLO 17 – Panoramic view of South and North massifs. In the foreground, Harrison Schmitt stretches out to open the solar panels of the SEP transmitter. A high-resolution version of this image is available at https://www.astropublishing.com/moonscapes/A17_South&North_Massifs.pdf [NASA, Project Apollo Archive; image merging by Astro Publishing]



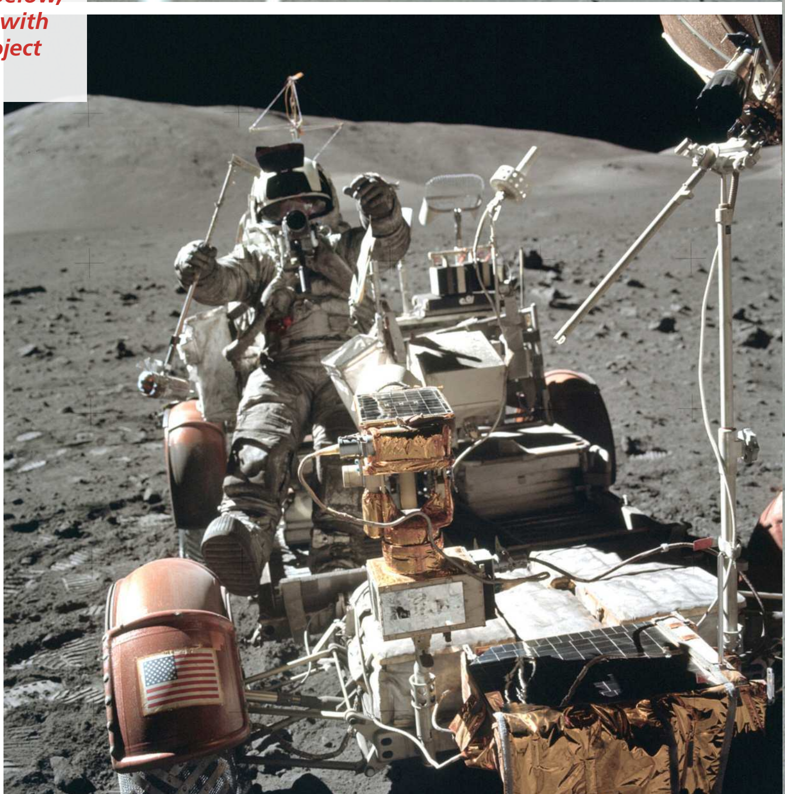
APOLLO 17 – Scientist-astronaut Harrison H. Schmitt collects lunar samples at Station 1. [NASA, Project Apollo Archive]



a few years it would have been possible to send astronauts to Mars and that going back to the Moon would have been a simple routine. Instead, 50 years after the epic adventure of Apollo 11, we are still waiting to find out who will land where and when.

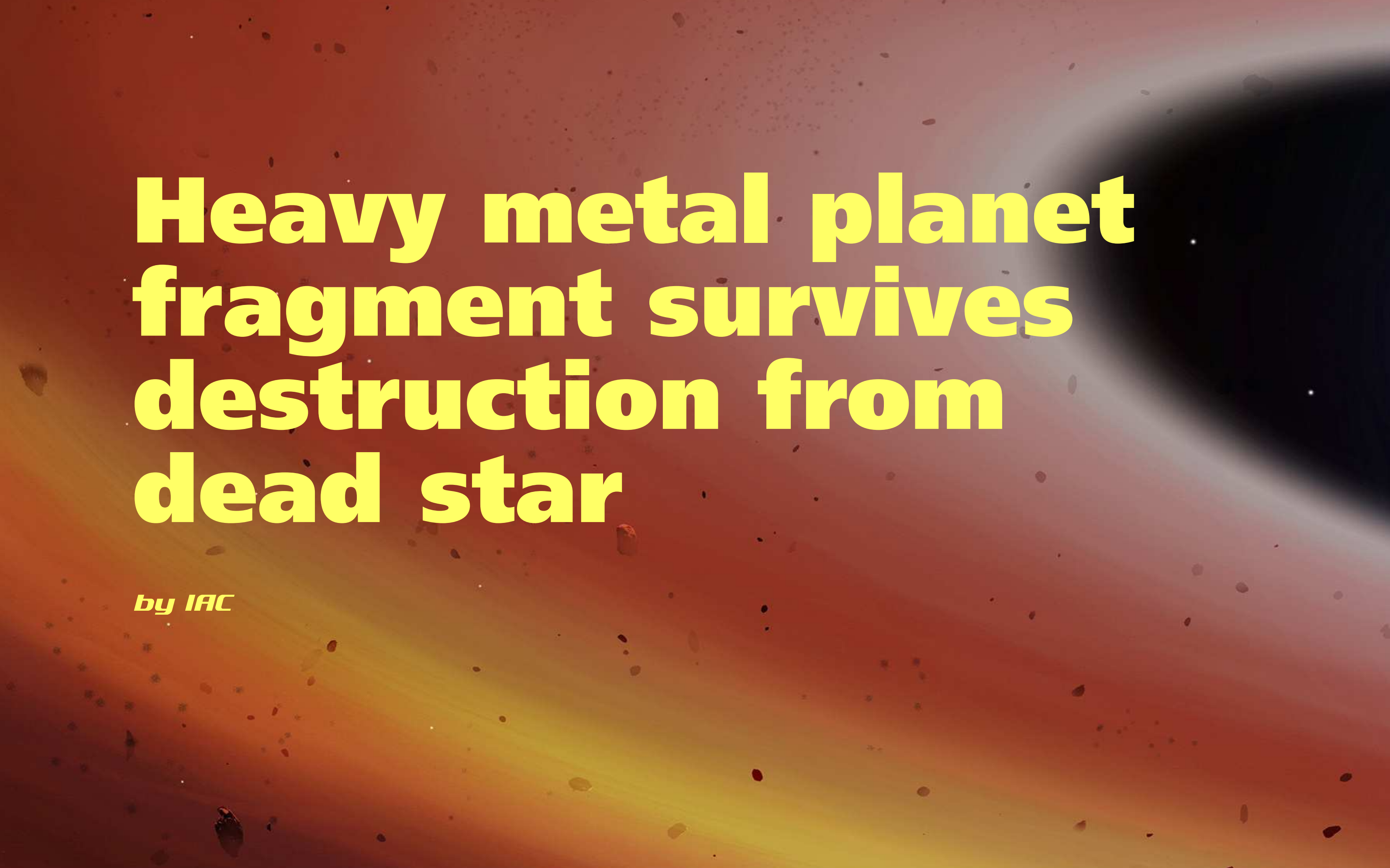
In recent decades, governments and private space agencies have presented many landing projects

APOLLO 17 – Above, a view from the Lunar Roving Vehicle (LRV) Traverse. The Station Surface Electrical Properties (SEP) Experiment is towards the lunar module. Below, exploration scenes with the LRV. [NASA, Project Apollo Archive]



for the Moon and Mars (with their subsequent colonization), projects that promptly disappeared into thin air due to budget cuts, technical unfeasibility, and other causes. In the current state of things, the most optimistic return to the Moon of a crew is scheduled for 2024 as part of the Artemis program, which initially proposes to send two astronauts to explore the lunar south pole, paving the way for a future sustainable stay in this region, hypothesized feasible since 2028. NASA's administrator, Jim Bridenstine, illustrated the latest developments of the Artemis program in person on May 23rd, following statements of the President and the Vice President of the United States, about the will and need to return as soon as possible to trample the lunar soil, statements accompanied by the allocation to NASA of an extra budget of 1.6 billion dollars in fiscal year 2020 in addition to the 21 billion dollars already allocated. Evidently, the competition with the exuberant Chinese astronautics is providing the right stimuli for a new space race. ■

APOLLO 17 – In the above video, the farewell to the Moon: the last lift-off of a lunar module. Below, the LRV imaged during the second extravehicular activity (EVA) 2 of the Apollo 17 mission. [NASA, Project Apollo Archive]



Heavy metal planet fragment survives destruction from dead star

by IAC

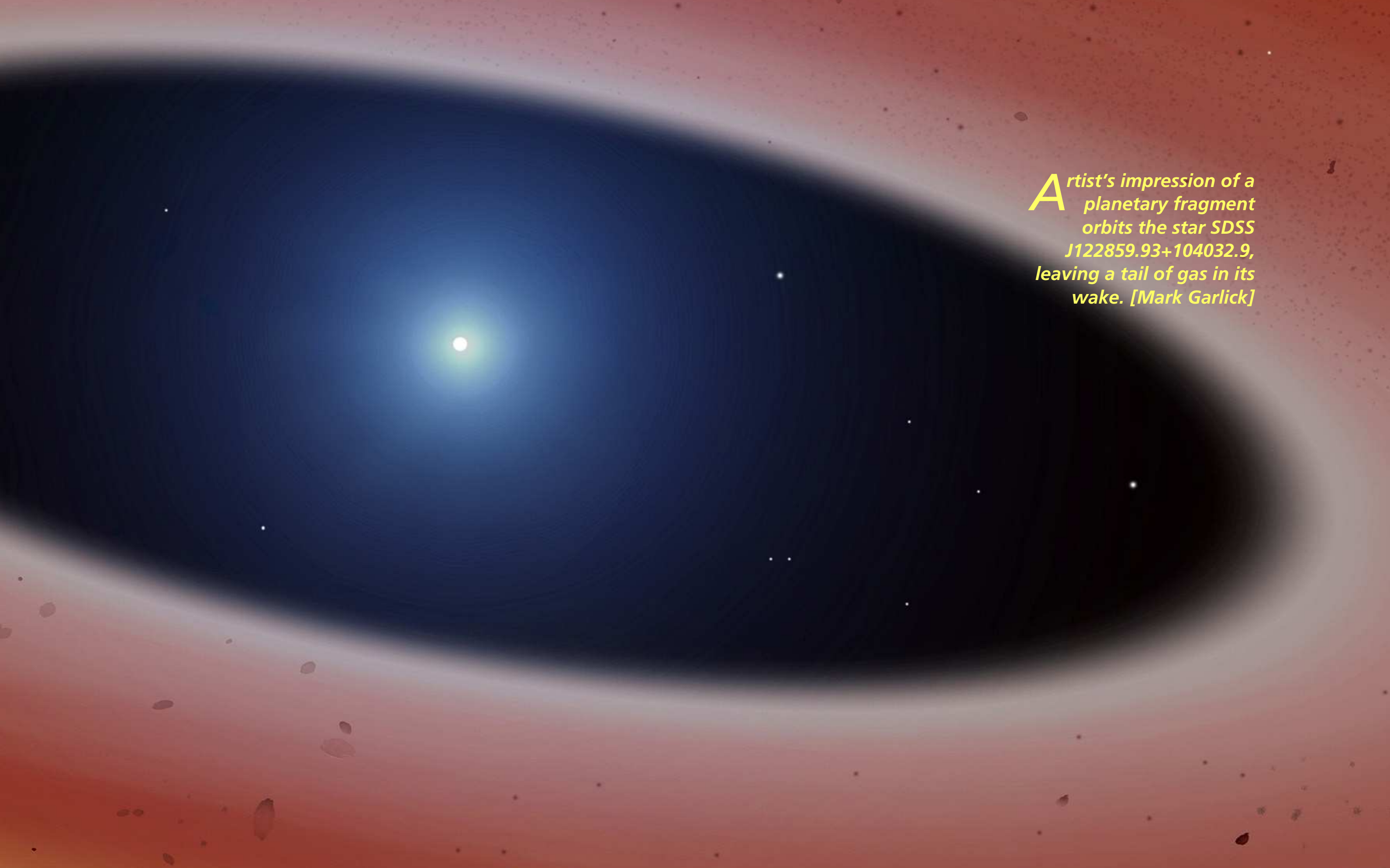
A fragment of a planet that has survived the death of its star has been discovered in a disc of debris formed from destroyed planets which the star ultimately consumes. The discovery was made by a group of astronomers led by the University of Warwick and involving research staff from the IAC and ULL. The iron and nickel rich planetesimal survived a system-wide cataclysm that followed the death of its host star, SDSS J122859.93+104032.9.

Believed to have once been part of a larger planet, its survival is all the more astonishing as it orbits closer to its star than previously thought possible, going around it once every two hours. As reported in the journal Science, is the first time that scientists have used spectroscopy to discover a solid body in orbit around a white dwarf, using subtle variations in the emitted light to identify additional gas that the planetesimal is generating.

Using OSIRIS spectrograph, installed in the Gran Telescopio Canarias (GTC), situated in the Roque de los Muchachos Observatory (Garafía, La Palma), the scientists studied a debris disc orbiting a white dwarf 410 light years away formed by the disruption of rocky bodies composed of elements such as iron, magnesium, silicon, and oxygen – the four key building blocks of the Earth and most rocky bodies. Within that disc they discovered a ring of gas streaming from a solid body, like a comet's tail. This gas could either be generated by the body itself or by evaporating dust as it collides with small debris within the disc.

The astronomers estimate that this body has to be at least a kilometer in size, but could be as large as a few hundred kilometres in diameter, comparable to the largest asteroids known in the solar system.

White dwarfs are the remains of stars like our sun that have burnt all their fuel and shed their outer layers, leaving behind a dense core which slowly cools over time. This star has shrunk so dramatically that the planetesimal orbits within its sun's original radius. Evidence suggests that it was once part of a larger body further out in its solar system and is likely to have been a planet torn apart as the star began its cooling process. Lead author, Christopher Manser, a Research Fellow in the Department of Physics, said: *"The star would have originally been about two solar masses, but now the white dwarf is only 70% of the mass of our Sun. It is also very small – roughly the size of the Earth – and this makes the star, and in*



Artist's impression of a planetary fragment orbits the star SDSS J122859.93+104032.9, leaving a tail of gas in its wake. [Mark Garlick]

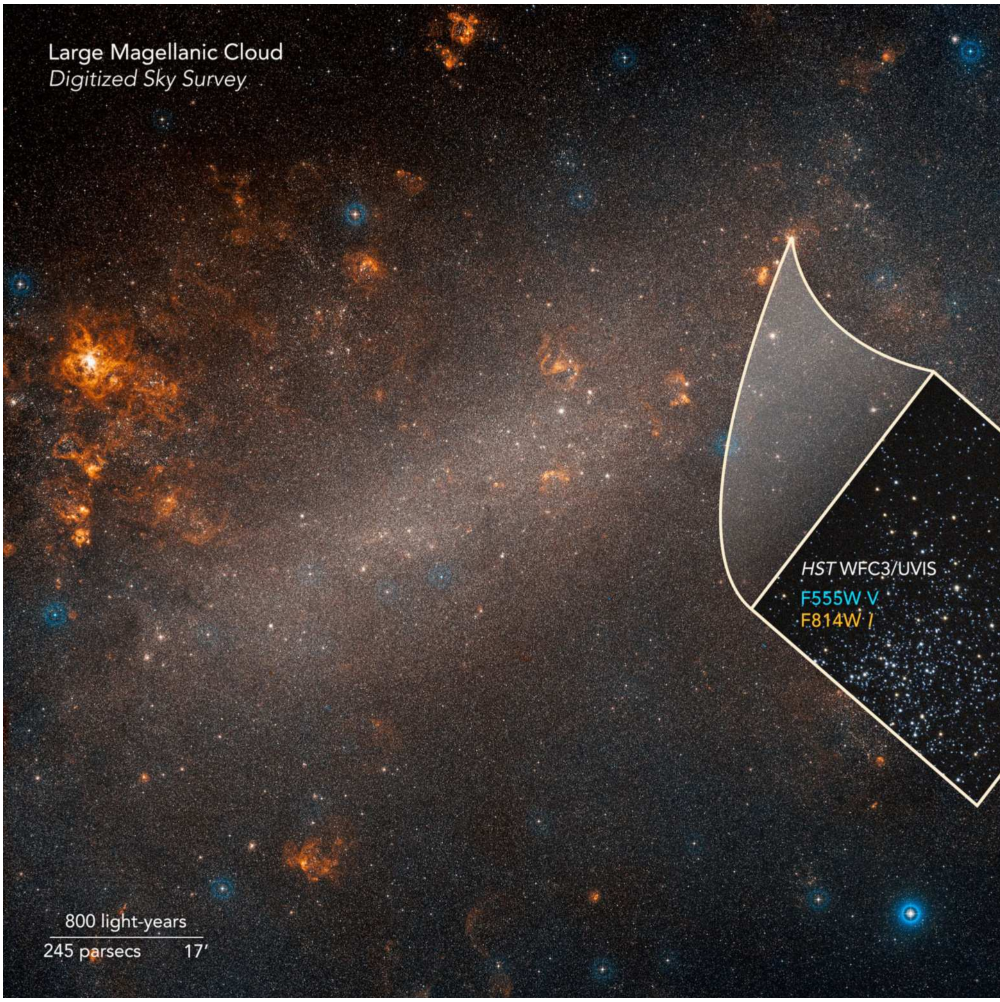
general all white dwarfs, extremely dense". The white dwarf's gravity is so strong – about 100,000 times that of the Earth's – that a typical asteroid would be ripped apart by gravitational forces if it passed too close. Professor Boris Gaensicke, co-author from the Department of Physics, added: *"The planetesimal we have discovered is deep into the gravitational well of the white dwarf, much closer to it than we would expect to find anything still alive. That is only possible because it must be very dense and/or very likely to have internal strength that holds it together, so we propose that it is composed largely of iron and nickel"*. And he explained: *"If it was pure iron it could survive where it lives now, but equally it could be a body that is rich in iron but with internal strength to hold it together, which is consistent with the planetesimal being a fairly massive fragment of a planet core. If correct, the original body was at least hundreds of kilometres in diameter because it is only at that point planets begin to differentiate – like oil on water – and have heavier elements sink to form a metallic core."* The discovery offers a hint as to what planets may reside in other solar systems, and a glimpse into the future of our own. Christopher Manser said: "As stars age they grow into red giants, which 'clean out' much of the inner part of their planetary system. In our Solar System, the Sun will expand up to where the Earth currently orbits, and will wipe out Earth, Mercury, and Venus. Mars and beyond will survive and will move further out. The general consensus is that 5-6 billion years from now, our Solar System will be a white dwarf in place of the Sun, orbited by Mars, Jupiter, Saturn, the outer planets, as well as asteroids and comets. Gravitational interactions are likely to happen in such remnants of planetary systems, meaning the bigger planets can easily nudge the smaller bodies onto an orbit that takes them close to the white dwarf, where they get shredded by its enormous gravity".

Disparity in Hubble Constant calculations is not a fluke

by NASA/ESA

Astronomers using NASA's Hubble Space Telescope say they have crossed an important threshold in revealing a discrepancy between the two key techniques for measuring the universe's expansion rate. The recent study strengthens the case that new theories may be needed to explain the forces that have shaped the cosmos. A brief recap: The universe is getting bigger every second. The space between galaxies is stretching, like dough rising in the oven. But how fast is the universe expanding? As Hubble and other telescopes seek to answer this question, they have run into an intriguing difference between what scientists predict and what they observe.

Hubble measurements suggest a faster expansion rate in the modern universe than expected, based on how the universe appeared more than 13 billion years ago.



A ground-based telescope's view of the Large Magellanic Cloud, a satellite galaxy of our Milky Way. The inset image, taken by the Hubble Space Telescope, reveals one of many star clusters scattered throughout the dwarf galaxy. [NASA, ESA, A. Riess (STScI/JHU), and Palomar Digitized Sky Survey]

These measurements of the early universe come from the European Space Agency's Planck satellite. This discrepancy has been identified in scientific papers over the last several years, but it has been unclear whether differences in measurement techniques are to blame, or whether the difference could result from unlucky measurements.

Measurements of today's expansion rate do not match the rate that was expected based on how the Universe appeared shortly after the Big Bang over 13 billion years ago. Using new data from the NASA/ESA Hubble Space Telescope, astronomers have significantly lowered the possibility that this discrepancy is a fluke. [NASA/ESA]

The latest Hubble data lower the possibility that the discrepancy is only a fluke to 1 in 100,000. This is a significant gain from an earlier estimate, less than a year ago, of a chance of 1 in 3,000. These most precise Hubble measurements to date bolster the idea that new physics may be needed to explain the mismatch.

"The Hubble tension between the early and late universe may be the most exciting development in cosmology in decades," said lead researcher and Nobel laureate Adam Riess of the Space Telescope Science Institute (STScI) and Johns Hopkins University, in Baltimore, Maryland. *"This mismatch has been growing and has now reached a point that is really impossible to dismiss as a fluke. This disparity could not plausibly occur just by chance."* Scientists use a "cosmic distance ladder" to determine how far away things are in the universe. This method depends on making accurate measurements of distances to nearby galaxies and then moving to galaxies farther and farther away, using their stars as milepost markers. Astronomers use these values, along with other measurements of the galaxies' light that reddens as it passes through a stretching universe, to calculate how fast the cosmos expands with time, a value known as the Hubble constant. Riess and his SH0ES (Supernovae H0 for the Equation of State) team have been on a quest since 2005 to refine those distance measurements with Hubble and fine-tune the Hubble constant.

In this new study, astronomers used Hubble to observe 70 pulsating stars called Cepheid variables in the Large Magellanic Cloud. The observations helped the astronomers "rebuild" the distance ladder by improving the comparison between those Cepheids and their more distant cousins in the galactic hosts of supernovas. Riess's team reduced the uncertainty in their Hubble constant value to 1.9% from an earlier estimate of 2.2%. As the team's measurements have become more precise, their calculation of the Hubble constant has remained at odds with the expected value derived from observations of the early universe's expansion. Those measurements were made by Planck, which maps the cosmic microwave background, a relic afterglow from 380,000 years after the big bang.

The measurements have been thoroughly vetted, so astronomers cannot currently dismiss the gap between the two results as due to an error in any single measurement or method. Both values have been tested multiple ways.

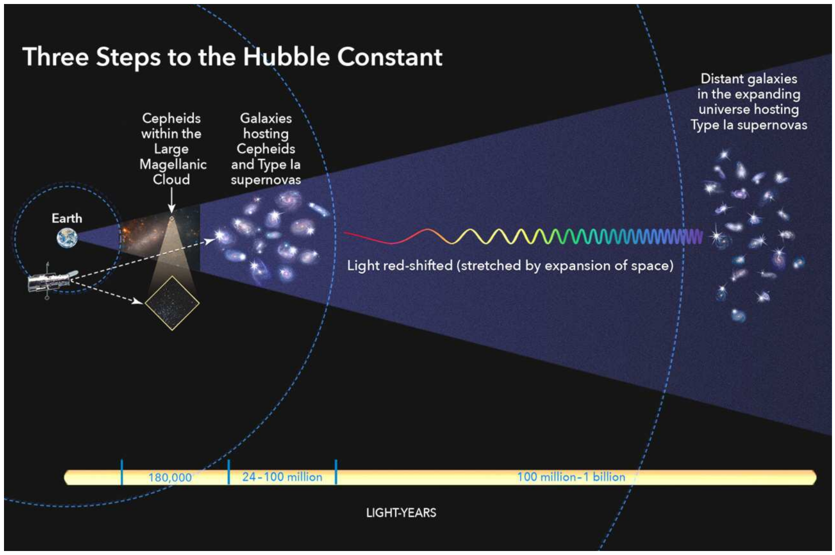
"This is not just two experiments disagreeing," Riess explained. *"We are measuring something fundamentally different. One is a measurement of how fast the universe is expanding today, as we see it. The other is a prediction based on the physics of the early universe and on measurements of how fast it ought to be expanding. If these values don't agree, there becomes a very strong likelihood that we're missing something in the cosmological model that connects the two eras."*

Astronomers have been using Cepheid variables as cosmic yardsticks to gauge nearby intergalactic distances for more than a century. But trying to harvest a bunch of these stars was so time-consuming as to be nearly unachievable.

So, the team employed a clever new method, called DASH (Drift And Shift), using Hubble as a "point-and-shoot" camera to snap quick images of the extremely bright pulsating stars, which eliminates the time-consuming need for precise pointing.

"When Hubble uses precise pointing by locking onto guide stars, it can only observe one Cepheid per each 90-minute Hubble orbit around Earth. So, it would be very costly for

the telescope to observe each Cepheid," explained team member Stefano Casertano, also of STScI and Johns Hopkins. *"Instead, we searched for groups of Cepheids close enough to each other that we could move between them without recalibrating the telescope pointing. These Cepheids are so bright, we only need to observe them for two seconds. This technique is allowing us to observe a dozen Cepheids for the duration of one orbit. So, we stay on gyroscope control and keep 'DASHing' around very fast."* The Hubble astronomers then combined their result with another set of observations, made by the Araucaria Project, a collaboration between astronomers from institutions in Chile, the U.S., and Europe.



This illustration shows the three basic steps astronomers use to calculate how fast the universe expands over time, a value called the Hubble constant. All the steps involve building a strong "cosmic distance ladder," by starting with measuring accurate distances to nearby galaxies and then moving to galaxies farther and farther away. This "ladder" is a series of measurements of different kinds of astronomical objects with an intrinsic brightness that researchers can use to calculate distances. [NASA, ESA, and A. Feild (STScI)]

This group made distance measurements to the Large Magellanic Cloud by observing the dimming of light as one star passes in front of its partner in eclipsing binary-star systems. The combined measurements helped the SH0ES Team refine the Cepheids' true brightness. With this more accurate result, the team could then "tighten the bolts" of the rest of the distance ladder that extends deeper into space.

The new estimate of the Hubble constant is 74 kilometers (46 miles) per second per megaparsec. This means that for every 3.3 million light-years farther away a galaxy is from us, it appears to be moving 74 kilometers (46 miles) per second faster, as a result of the expansion of the universe.

The number indicates that the universe is expanding at a 9% faster rate than the prediction of 67 kilometers (41.6 miles) per second per megaparsec, which comes from Planck's observations of the early universe, coupled with our present understanding of the universe.

One explanation for the mismatch involves an unexpected appearance of dark energy in the young universe, which is thought to now comprise 70% of the universe's contents. Proposed by astronomers at Johns Hopkins, the theory is dubbed "early dark energy," and suggests that the universe evolved like a three-act play.

Astronomers have already hypothesized that dark energy existed during the first seconds after the big bang and pushed matter throughout space, starting the initial expansion. Dark energy may also be the reason for the universe's accelerated expansion today. The new theory suggests that there was a third dark-energy episode not long after the big bang, which expanded the universe faster than astronomers had predicted. The existence of this "early dark energy" could account for the tension between the two Hubble constant values, Riess said. Another idea is that the universe contains a new subatomic particle that travels close to the speed of light. Such speedy particles are collectively called "dark radiation" and include previously known particles like neutrinos, which are created in nuclear reactions and radioactive decays.

Yet another attractive possibility is that dark matter (an invisible form of matter not made up of protons, neutrons, and electrons) interacts more strongly with normal matter or radiation than previously assumed.

But the true explanation is still a mystery. Riess doesn't have an answer to this vexing problem, but his team will continue to use Hubble to reduce the uncertainties in the Hubble constant. Their goal is to decrease the uncertainty to 1%, which should help astronomers identify the cause of the discrepancy.

Hubble captures rare active asteroid

by NASA/ESA

Thanks to an impressive collaboration bringing together data from ground-based telescopes, all-sky surveys and space-based facilities — including the Hubble Space Telescope — a rare self-destructing asteroid called 6478 Gault has been observed. Clear images from the NASA/ESA Hubble Space Telescope have provided researchers with new insight into asteroid Gault's unusual past.

The object is 4–9 kilometres wide and has two narrow, comet-like tails of debris that tell us that the asteroid is slowly undergoing self-destruction. Each tail is evidence of an active event that released material into space.

Gault was discovered in 1988. However, this observation of two debris tails is the first indication of the asteroid's instability. This asteroid one of only a handful to be caught disintegrating by a process known as a YORP torque. When sunlight heats an asteroid, the infrared radiation that escapes from its warmed surface carries off both heat and momentum. This creates a small

The asteroid 6478 Gault is seen with the Hubble Space Telescope, showing two narrow, comet-like tails of debris that tell us that the asteroid is slowly undergoing self-destruction. The bright streaks surrounding the asteroid are background stars. The Gault asteroid is located between the orbits of Mars and Jupiter. [NASA, ESA, K. Meech and J. Kleyna (University of Hawaii), O. Hainaut (European Southern Observatory)]

force that can cause the asteroid to spin faster. If this centrifugal force eventually overcomes gravity, the asteroid becomes unstable. Landslides on the object can release rubble and dust into space, leaving behind a tail of debris, as seen here with asteroid Gault.

"This self-destruction event is rare" explained Olivier Hainaut (European Southern Observatory, Germany). *"Active and unstable asteroids such as Gault are only now being detected by means of new survey telescopes that scan the entire sky, which means asteroids such as Gault that are misbehaving cannot escape detection any more."* Astronomers estimate that among the 800,000 known asteroids that occupy the Asteroid Belt between Mars and Jupiter, YORP disruptions occur roughly once per year. The direct observation of this activity by the Hubble Space Telescope has provided astronomers with a special opportunity to study the composition of asteroids. By researching the material that this unstable asteroid releases into space, astronomers can get a glimpse into the history of planet formation in the early ages of the Solar System.

Understanding the nature of this active and self-destructive object has been a collaborative effort involving researchers and facilities around the world. The asteroid's debris tail was first detected by the University of Hawai i/NASA ATLAS (Asteroid Terrestrial-Impact Last Alert System) telescopes in the Hawaiian Islands on 5 January 2019. Upon review of archival data from ATLAS and UH/NASA Pan-STARRS (Panoramic Survey Telescope and Rapid Response System), it was found that the object's larger tail of debris had been observed earlier in December 2018. Shortly thereafter, in January 2019, a second, shorter tail was seen by various telescopes, including the Isaac Newton, William Herschel, and ESA OGS Telescopes in La Palma and Tenerife, Spain; the Himalayan Chandra Telescope in India; and the CFHT in Hawai i. Subsequent analysis of these observations suggested that the two events that produced these debris trails occurred around 28 October and 30 December 2018, respectively. These tails will only be visible for only a few months, after which the dust will have dispersed into interplanetary space.

Follow-up observations were then made by various ground-based telescopes. These data were used to deduce a two-hour rotation period for Gault, which is very close to the critical speed at which material will begin to tumble and slide across the asteroid's surface before drifting off into space.

"Gault is the best 'smoking-gun' example of a fast rotator right at the two-hour limit", explained lead author Jan Kleyna (University of Hawai i, USA). *"It could have been on the brink of instability for 10 million years. Even a tiny disturbance, like a small impact from a pebble, might have triggered the recent outbursts."*

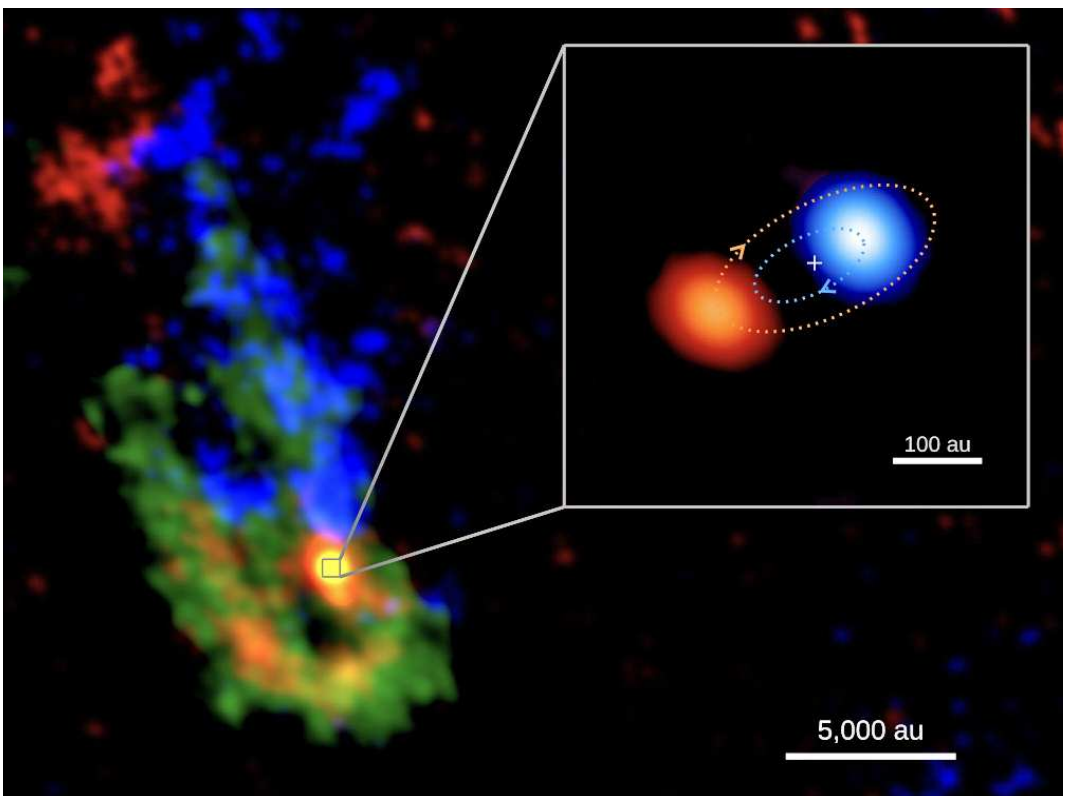
Hubble's sharp imaging provided valuable detail regarding the asteroid's activity. From the narrow width of the streaming tails, researchers inferred that the release of material took place in short episodes lasting from a few hours to a couple of days.

From the absence of excess dust in the immediate vicinity of the asteroid, they concluded that the asteroid's activity was not caused by a collision with another massive object. Researchers hope that further observations will provide even more insight into this rare and curious object. ■

Witnessing the birth of a massive binary star system

by ALMA Observatory

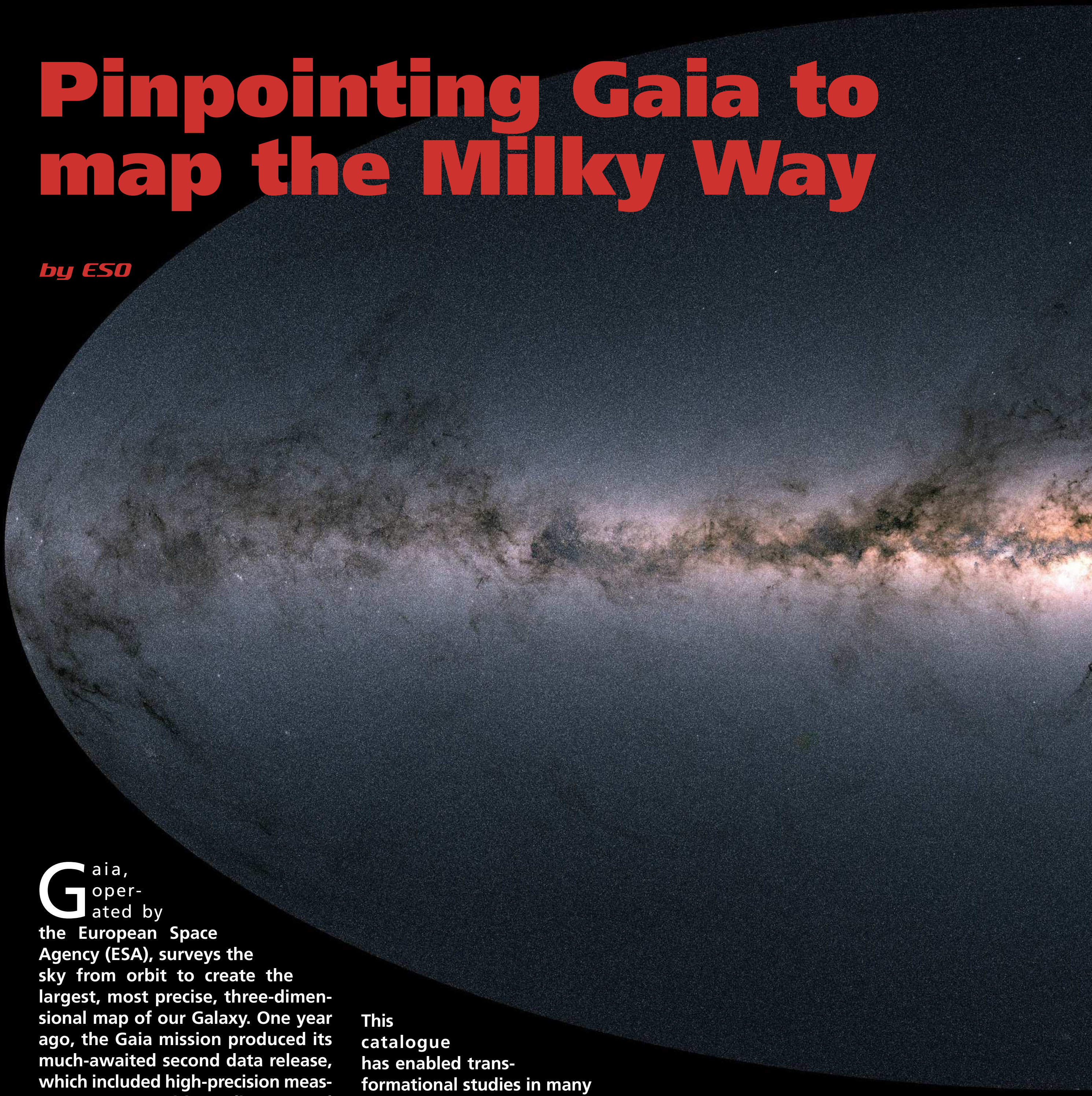
Scientists from the RIKEN Cluster for Pioneering Research in Japan, the Chalmers University of Technology in Sweden, and the University of Virginia in the USA and collaborators used the Atacama Large Millimeter/submillimeter Array (ALMA) to observe a molecular cloud that is collapsing to form two massive protostars that will eventually become a binary star system. While it is known that most massive stars



ALMA's view of the IRAS-07299 star-forming region and the massive binary system at its center. The background image shows dense, dusty streams of gas (shown in green) that appear to be flowing towards the center. Gas motions, as traced by the methanol molecule, that are towards us are shown in blue; motions away from us in red. The inset image shows a zoom-in view of the massive forming binary, with the brighter, primary protostar moving toward us is shown in blue and the fainter, secondary protostar moving away from us shown in red. The blue and red dotted lines show an example of orbits of the primary and secondary spiraling around their center of mass (marked by the cross).

possess orbiting stellar companions it has been unclear how this comes about – for example, are the stars born together from a common spiraling gas disk at the center of a collapsing cloud, or do they pair up later by chance encounters in a crowded star cluster.
Understanding the dynamics of forming binaries has been difficult because the protostars in these systems are still enveloped in a thick cloud of gas and dust that prevents most light from escaping.
Fortunately, it is possible to see them using radio waves, as long as they can be imaged with sufficiently high spatial resolution.
In the current research, published in *Nature Astronomy*, the researchers led by Yichen Zhang of the RIKEN Cluster for Pioneering Research and Jonathan C. Tan at the Chalmers University, and the University of Virginia, used ALMAto observe, at high spatial resolution, a star-forming region known as IRAS07299-1651, which is located 1.68 kiloparsecs, or about 5,500 light years, away.
The observations showed that already at this early stage, the cloud contains two objects, a massive "primary" central star and another "secondary" forming star, also of high mass. For the first time, the research team was able to use these observations to deduce the dynamics of the system.
The observations showed that the two forming stars are separated by a distance of about 180 astronomical units — a unit approximately the distance from the Earth to the Sun. Hence, they are quite far apart. They are currently orbiting each other with a period of at most 600 years and have a total mass at least 18 times that of our Sun.
According to Zhang, *"This is an exciting finding because we have long been perplexed by the question of whether stars form into binaries during the initial collapse of the star-forming cloud or whether they are created during later stages. Our observations clearly show that the division into binary stars takes place early on, while they are still in their infancy."* Another finding of the study was that the binary stars are being nurtured from a common disk fed by the collapsing cloud and favoring a scenario in which the secondary star of the binary formed as a result of fragmentation of the disk originally around the primary. This allows the initially smaller secondary protostar to "steal" infalling matter from its sibling and eventually they should emerge as quite similar "twins". Tan adds, *"This is an important result for understanding the birth of massive stars. Such stars are important throughout the universe, not least for producing, at the ends of their lives, the heavy elements that make up our Earth and are in our bodies."*
Zhang concludes, *"What is important now is to look at other examples to see whether this is a unique situation or something that is common for the birth of all massive stars."* ■

Movie composed of images taken by ALMA showing the gas streams, as traced by the methanol molecule, with different line-of-sight color-coded velocities, around the massive binary protostar system. The grey background image shows the overall distribution, from all velocities, of dust emission from the dense gas streams.

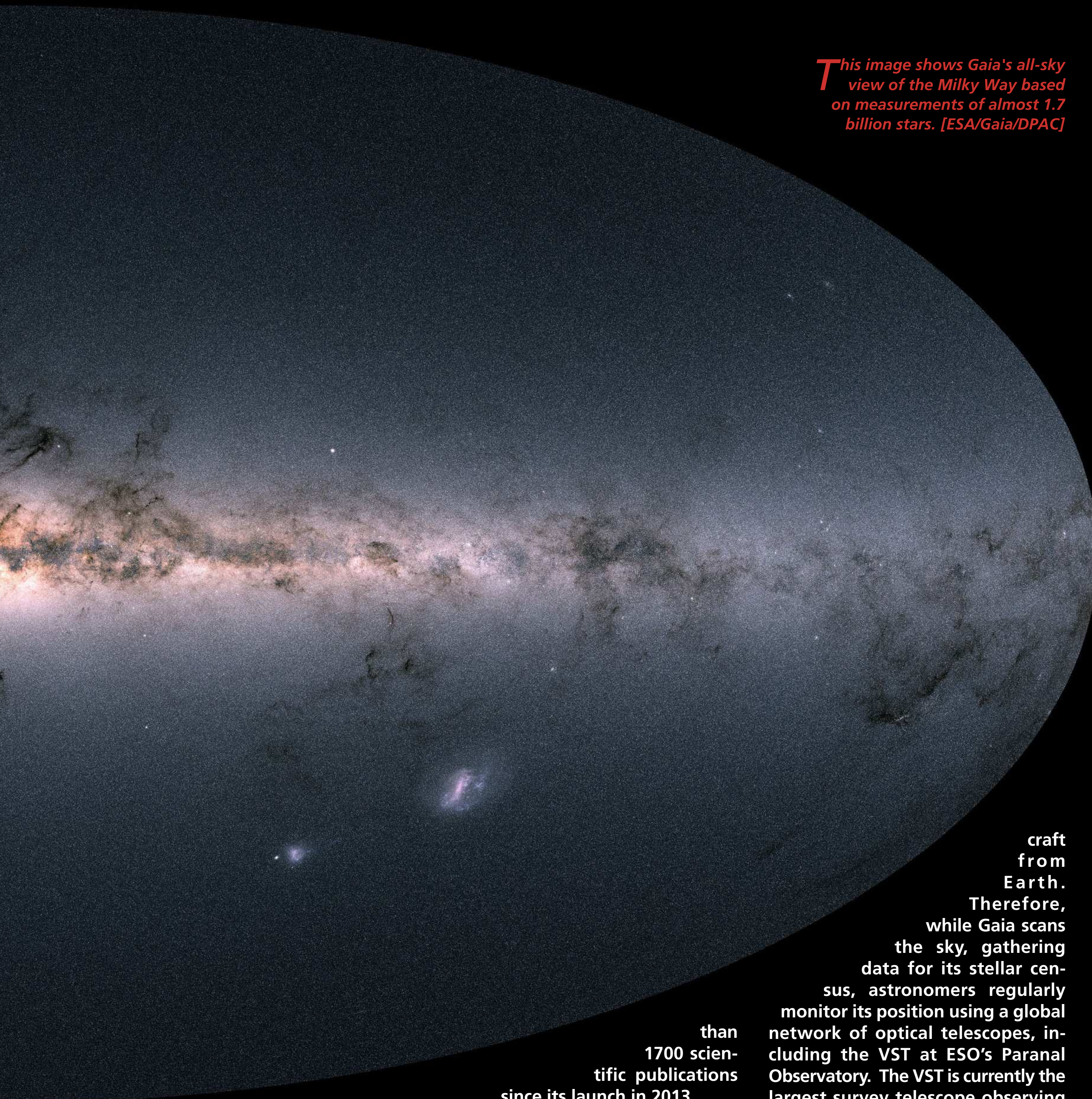


Pinpointing Gaia to map the Milky Way

by ESO

Gaia, operated by the European Space Agency (ESA), surveys the sky from orbit to create the largest, most precise, three-dimensional map of our Galaxy. One year ago, the Gaia mission produced its much-awaited second data release, which included high-precision measurements — positions, distance and proper motions — of more than one billion stars in our Milky Way galaxy.

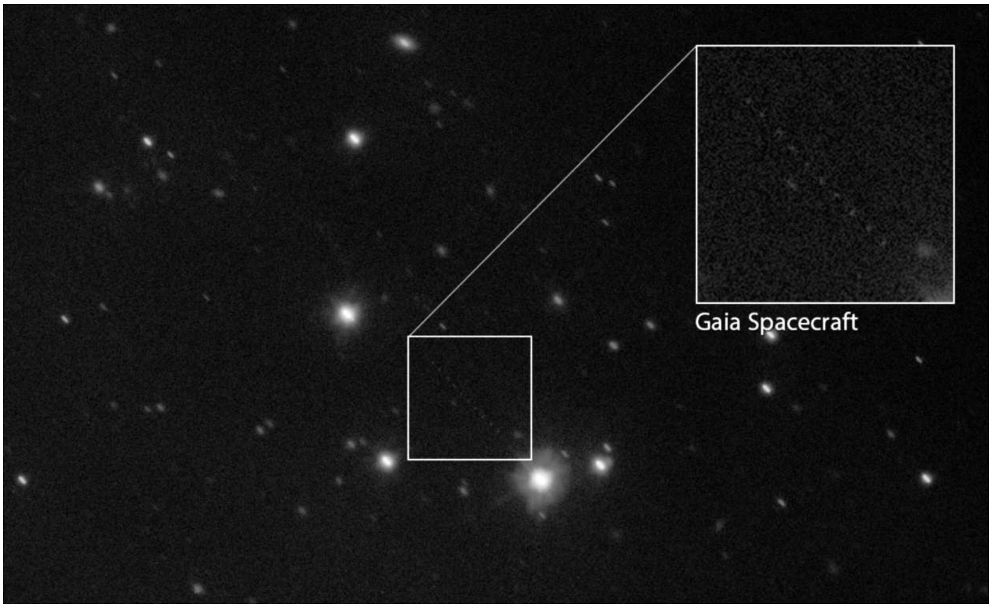
This catalogue has enabled transformational studies in many fields of astronomy, addressing the structure, origin and evolution the Milky Way and generating more



This image shows Gaia's all-sky view of the Milky Way based on measurements of almost 1.7 billion stars. [ESA/Gaia/DPAC]

than 1700 scientific publications since its launch in 2013.

In order to reach the accuracy necessary for Gaia's sky maps, it is crucial to pinpoint the position of the spacecraft from Earth. Therefore, while Gaia scans the sky, gathering data for its stellar census, astronomers regularly monitor its position using a global network of optical telescopes, including the VST at ESO's Paranal Observatory. The VST is currently the largest survey telescope observing the sky in visible light, and records Gaia's position in the sky every second night throughout the year.



This image, a composite of several observations captured by ESO's VLT Survey Telescope (VST), shows the space observatory Gaia as a faint trail of dots across the lower half of the star-filled field of view. These observations were taken as part of an ongoing collaborative effort to measure Gaia's orbit and improve the accuracy of its unprecedented star map. The position of Gaia is shown in this annotated image. [ESO]

"Gaia observations require a special observing procedure," explained Monika Petr-Gotzens, who has coordinated the execution of ESO's observations of Gaia since 2013. *"The spacecraft is what we call a 'moving target', as it is moving quickly relative to background stars — tracking Gaia is quite the challenge!"*

"The VST is the perfect tool for picking out the motion of Gaia," elaborated Ferdinando Patat, head of the ESO's Observing Programmes Office. *"Using one of ESO's first-rate ground-based facilities to bolster cutting-edge space observations is a fine example of scientific cooperation."*

"This is an exciting ground-space collaboration, using one of ESO's world-class telescopes to anchor the trailblazing observations of ESA's billion star surveyor," commented Timo Prusti, Gaia project scientist at ESA.

The VST observations are used by ESA's flight dynamics experts to track Gaia and refine the knowledge of the spacecraft's orbit.

Painstaking calibration is required to transform the observations, in which Gaia is just a speck of light among the bright stars, into meaningful orbital information. Data from Gaia's second release was used to identify each of the stars in the field of view, and allowed the position of the spacecraft to be calculated with astonishing precision — up to 20 milliarcseconds.

"This is a challenging process: we are using Gaia's measurements of the stars to calibrate the position of the Gaia spacecraft and ultimately improve its measurements of the stars," explains Timo Prusti. *"After careful and lengthy data processing, we have now achieved the accuracy required for the ground-based observations of Gaia to be implemented as part of the orbit determination,"* says Martin Altmann, lead of the Ground Based Optical Tracking (GBOT) campaign at the Centre for Astronomy of Heidelberg University, Germany. The GBOT information will be used to improve our knowledge of Gaia's orbit not only in observations to come, but also for all the data that have been gathered from Earth in the previous years, leading to improvements in the data products that will be included in future releases. ■

This video summarizes how ESO's VLT Survey Telescope (VST) helps map our galaxy, by tracking Gaia in motion as a faint series of dots trailing across the night sky. [ESO]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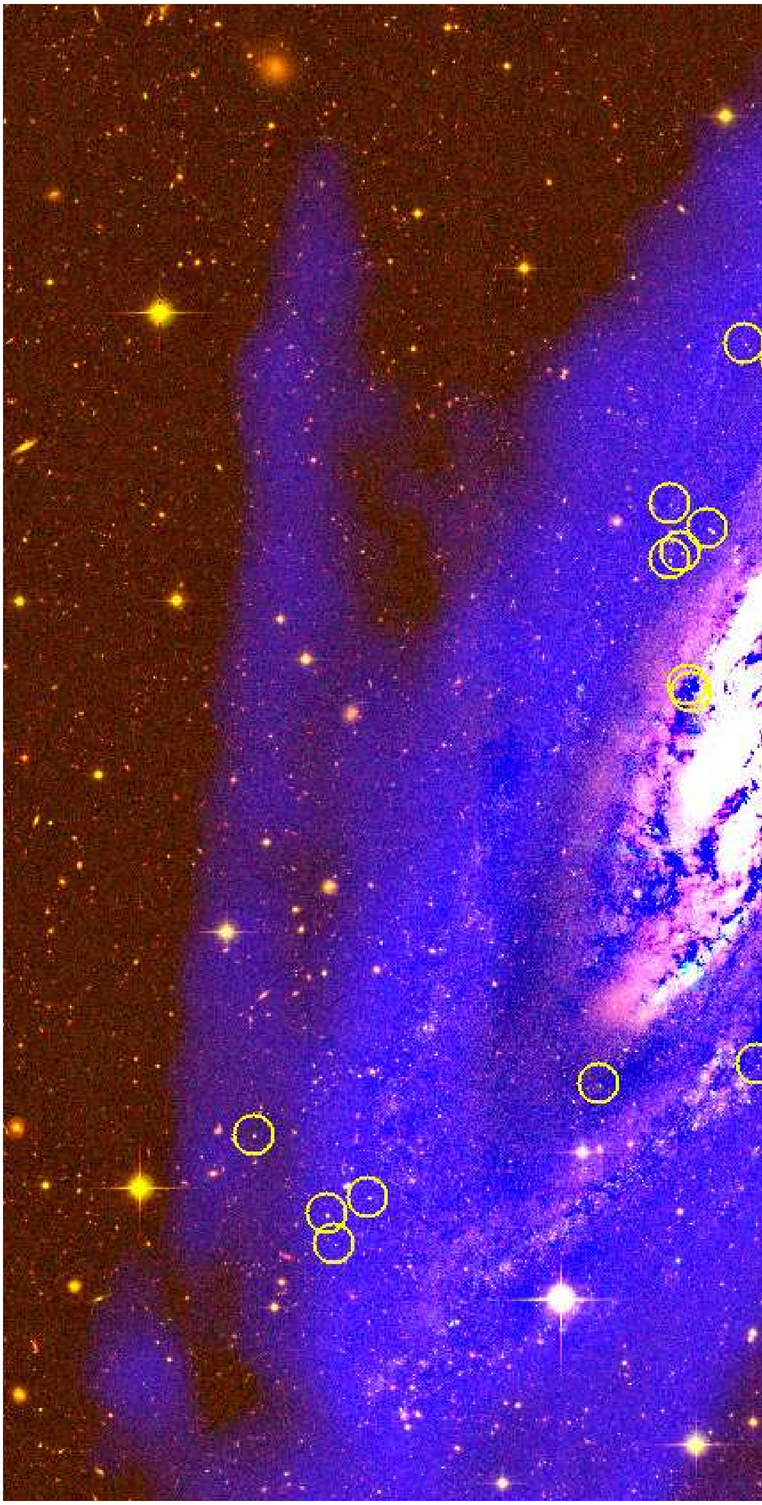
A system of globular clusters in the disc of a galaxy

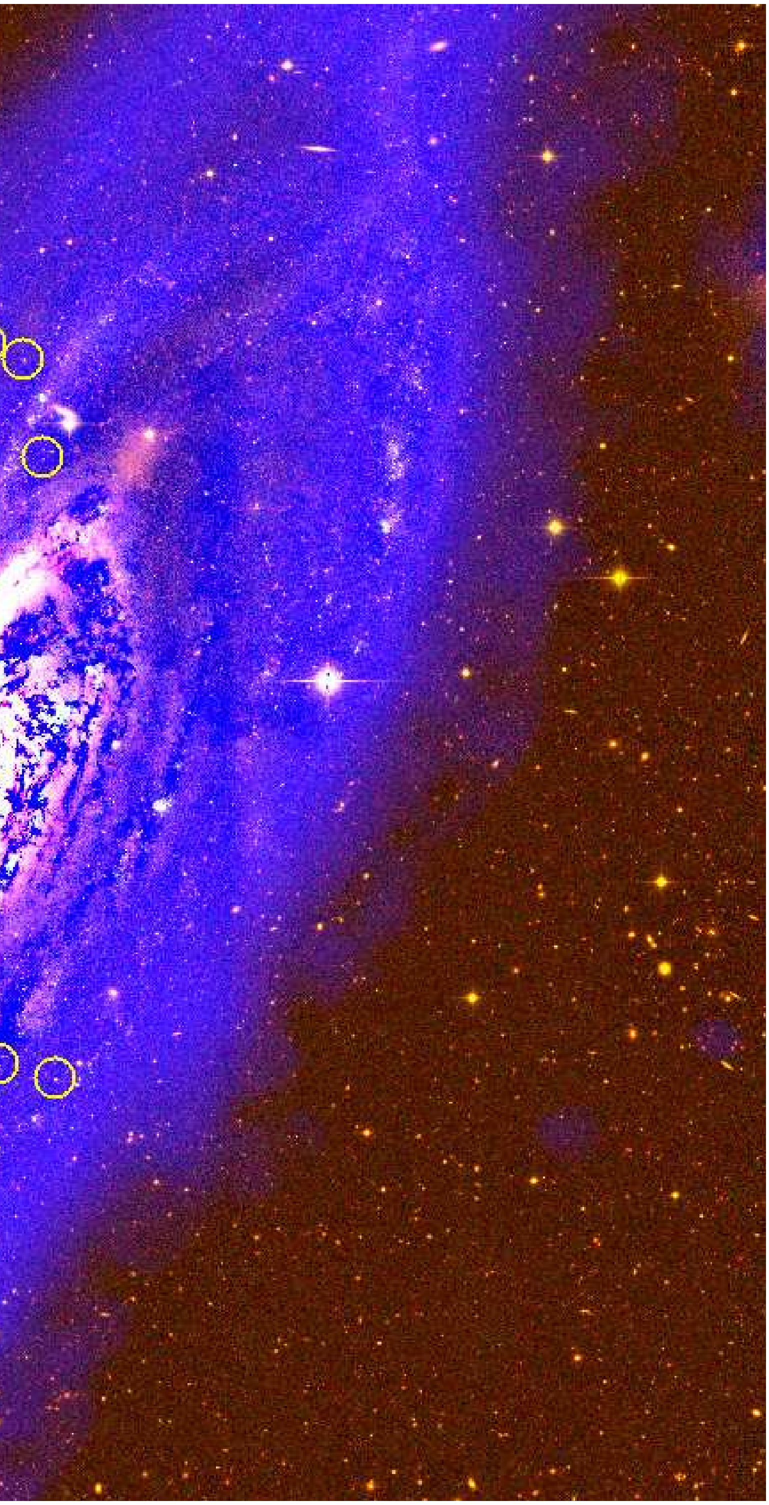
by IAC



Globular clusters are clusters of between a hundred thousand and a million stars, whose components have all roughly the same age, and have similar chemical composition. They are very old objects, formed some 11,500 million years ago, 2,300 million years after the Big Bang. These clusters are normally found in large galaxies, distributed in their halos, in a spherical conformation around their centres. An international piece of research, led by a group from the National Autonomous University of Mexico (UNAM) and carried out with the OSIRIS instrument on the Gran Telescopio Canarias (GTC) has discovered in the spiral galaxy Messier 106 (also known as M106, and NGC 4258) globular clusters which, instead of being distributed in a sphere, appear to be arranged in a disc aligned with the disc of gas in the galaxy and rotating at approximately the same velocity at this disc.

"This has never been seen before, it is one of those totally unexpected and surprising findings which occur in science," explains Rosa Amelia González Lópezlira a researcher at the Instituto de Radioastronomía y Astrofísica (IRyA-UNAM), who has led this work. *"The way these clusters move, and their distribution is similar to the discs of galaxies during the period of maximum star formation rate, some 10,000 million years ago, which is known as 'cosmic noon', so that we think that the disc of clusters in M106 could be a remnant from that epoch"*

The data obtained with the OSIRIS instrument, on the GTC at the Roque de los Muchachos Observatory have been of key importance, above all to confirm the candidates for



False color image of M106. The figure combines neutral hydrogen data taken using the Westerbrook Synthesis Radio Telescope (WSRT) in blue, with optical images obtained with the (CFHT) in green and red. The yellow circles highlight the observed globular clusters, which are arranged on a disk that rotates in phase and at the same speed as the neutral gas. [Divakara Mayya (INAOE)]

globular clusters and to distinguish them from other apparent point sources such as stars, and distant galaxies. To do that one needs to take spectra to show that each cluster has a coeval population of old stars and really belongs to the galaxy under study.

For Divakara Mayya, a researcher at the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), the second author of the article *"The observations with the GTC and OSIRIS are essential for the success of the study, because the objects are quite far away, and so they need exposures of more than one hour with the largest optical-infrared telescope in the world to be able to extract the relevant information from the spectra. The OSIRIS instrument (Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy) is a multi-object spectrograph built at the Instituto de Astrofísica de Canarias (IAC) in collaboration with Mexico, which is capable of observing several objects at a time."*

"To have this capacity for multiplexing, that is to obtain several spectra simultaneously, is fundamental for this type of studies, and it is offered on three of the current instruments on the GTC, covering the optical and the infrared" explains Antonio Cabrera, head of scientific operations on the GTC. For this work, 23 candidate globular clusters in two fields were observed.

This article is one result from a wider project which will study the systems of globular clusters in nine spiral galaxies within a radius of 52 million light years, in order to look into the relation between the number of globular clusters and the mass of the central black hole in spiral galaxies. *"This relation if very tight for elliptical galaxies, but it is not so clear in spiral galaxies, such as the Milky Way,"* comments researcher Lopezlira. *"The nine galaxies which we plan to study have good estimates of the masses of their central black holes, and lie at distances where we can make good studies of their globular clusters."*

This recent study confirms that there is a correlation between the number of globular clusters and the mass of the central black hole in M106 and proves the accuracy of the photometric method used at the GTC. *"Studies of this type in more spiral galaxies can clarify the role of the different hypotheses proposed for galaxy assembly, and that of the globular clusters and central black holes"* claims the first author of the work.

Radio emissions from dust particles in MACS0416_Y1

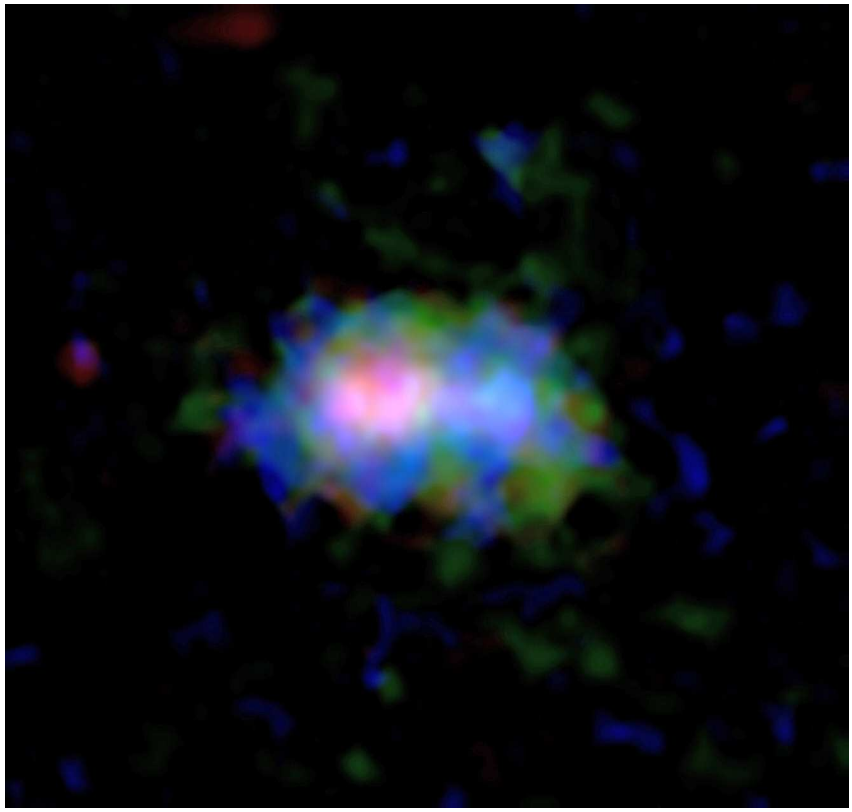
by ALMA Observatory

Researchers have detected a radio signal from abundant interstellar dust in MACS0416_Y1, a galaxy 13.2 billion light-years away in the constellation Eridanus. Standard models can't explain this much dust in a galaxy this young, forcing us to rethink the history of star formation. Researchers now think MACS0416_Y1 experienced staggered star formation with two intense starburst periods 300 million and 600 million years after the Big Bang with a quiet phase in between. Stars are the main players in the Universe, but they are supported by the unseen backstage stagehands: stardust and gas. Cosmic clouds of dust and gas are the sites of star formation and masterful storytellers of the cosmic history.

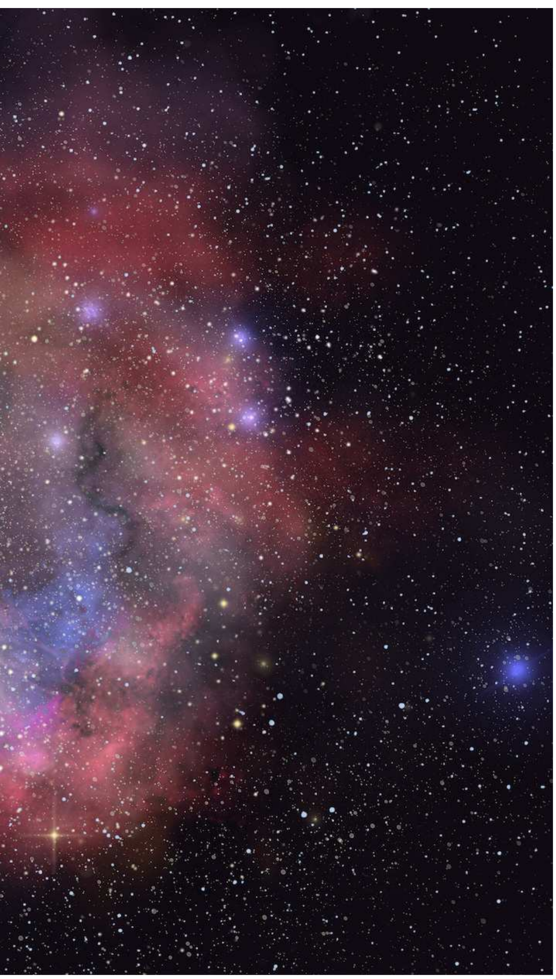
"Dust and relatively heavy elements such as oxygen are disseminated by the deaths of stars," said Yoichi Tamura, an associate professor at Nagoya University and the lead author of the research paper. *"Therefore, a detection of dust at some point in time indicates that a number of stars have already formed and died well before that point."* Using ALMA (Atacama Large Millimeter/submillimeter Array), Tamura

Artist's impression of the distant galaxy MACS0416_Y1. Based on the observations with ALMA and HST, researchers assume that this galaxy contains stellar clusters with a mix of old and young stars. The clouds of gas and dust are illuminated by starlight. [National Astronomical Observatory of Japan] and his team observed the distant galaxy MACS0416_Y1. Because of the finite speed of light, the radio waves we observe from this galaxy today had to travel for 13.2 billion years to reach us. In other words, they provide an image of what the galaxy looked like 13.2 billion years ago, which is only 600 million years after the Big Bang.

The astronomers detected a weak but telltale signal of radio emissions from dust particles in MACS0416_Y1. The Hubble Space Telescope, the Spitzer Space Telescope, and the European Southern Observatory's Very Large Telescope have observed the light from stars in the galaxy; and



ALMA and Hubble Space Telescope (HST) image of the distant galaxy MACS0416_Y1. Distribution of dust and oxygen gas traced by ALMA are shown in red and green, respectively, while the distribution of stars captured by HST is shown in blue. [ALMA (ESO/NAOJ/NRAO), NASA/ESA Hubble Space Telescope, Tamura, et al.]



from its color they estimate the stellar age to be 4 million years.

"It ain't easy," said Tamura half-lost in a moonage daydream. *"The dust is too abundant to have been formed in 4 million years. It is surprising, but we need to hang onto ourselves. Older stars might be hiding in the galaxy, or they may have died out and disappeared already."*

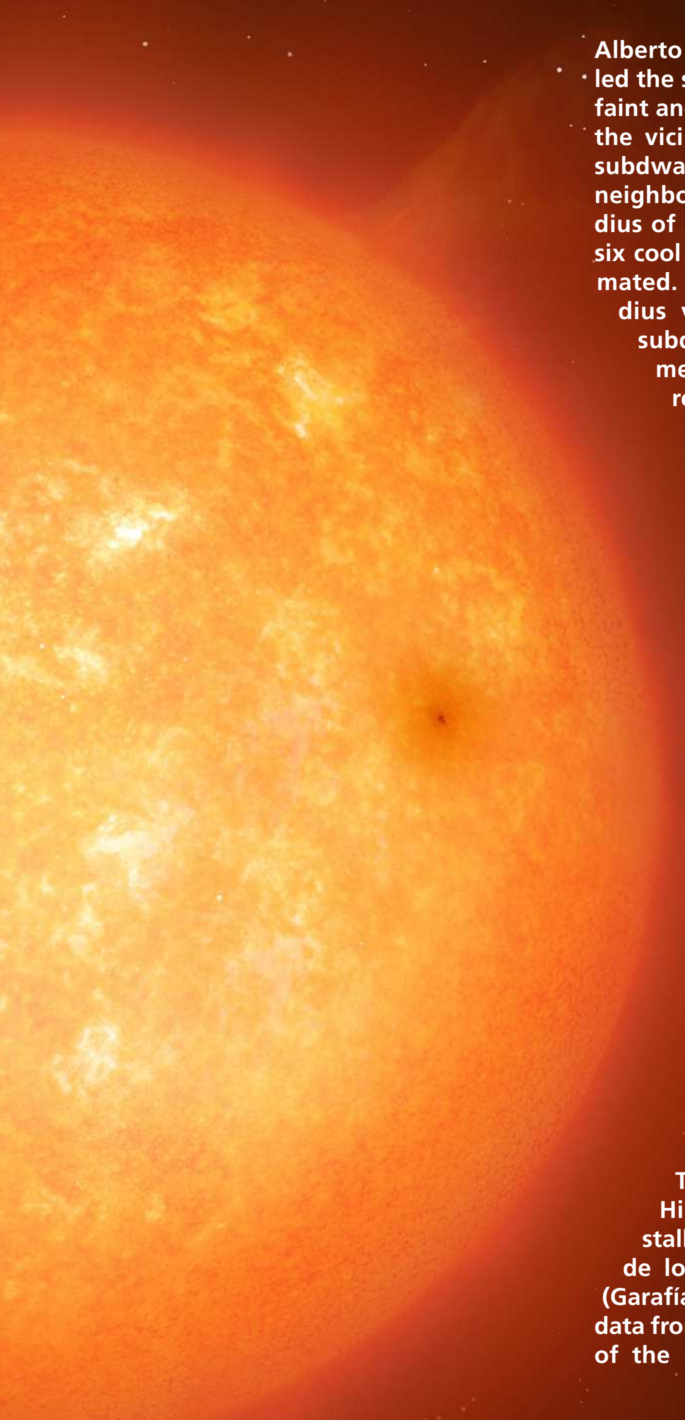
"There have been several ideas proposed to overcome this dust budget crisis," said Ken Mawatari, a researcher at the University of Tokyo. *"However, no one is conclusive. We made a new model which doesn't need any extreme assumptions diverging far from our knowledge of the life of stars in today's Universe. The model well explains both the color of the galaxy and the amount of dust."* In this model, the first burst of star formation started at 300 million years and lasted 100 million years. After that, the star formation activity went quiet for a while and then restarted at 600 million years. The researchers think ALMA observed this galaxy at the beginning of its second generation of star formation. *"Dust is a crucial material for planets like Earth,"* explains Tamura. *"Our result is an important step forward for understanding the early history of the Universe and the origin of dust."*

HiPERCAM reveals new details about the oldest stars in the Milky Way

by IAC

An international team, led by a researcher from the Universitat Politècnica de Catalunya - BarcelonaTech (UPC) and the Institute of Space Studies of Catalonia (IEEC), has measured for the first time the stellar parameters of a very old kind of stars, known as cool subdwarf stars, in our Galaxy, the Milky Way. Cool subdwarfs are stars like our Sun, but of smaller mass and radius, which formed during the beginning of the Milky Way and, therefore, carry important information about its structure and chemical evolution. The work has been done in collaboration with researchers from the University of Sheffield and the National Astronomical Observatories, Chinese Academy of Sciences, and the results are published in the journal *Nature Astronomy*. When the Milky Way formed, the first stars were mainly composed of hydrogen. Heavier elements than hydrogen and helium are considered as metals in astronomy and their presence determines the metallicity of a star.

As time passed and stars died, the content of such metals in the Milky Way and in the new stars born increased. Therefore, old stars have lower metallicity than younger ones. *"Since old stars can reveal important information about the structure and the chemical evolution of the Milky Way, it is essential for astronomers to determine their most basic stellar parameters such as masses and radii"*, explains the researcher from the UPC and IEEC



Artist's impression of an eclipsing binary system composed by a cool subdwarf (yellow) and a white dwarf (white). [Mark Garlick]

Alberto Rebassa Mansergas, who led the study. Because old stars are faint and they are relatively rare in the vicinity of the Sun, few cool subdwarfs are known in our solar neighbourhood. Currently, the radius of only 88 and the masses of six cool subdwarfs have been estimated. However, no mass and radius values for the same cool subdwarf had been accurately measured, leaving the theoretical studies for such stars untested until now. In their work, the researchers have found the first cool subdwarf in an eclipsing binary system, a system where two stars orbit one another, in this case, a cool subdwarf and a white dwarf.

"Eclipsing binaries offer the opportunity to measure directly the masses and radii of the two components with unprecedented precision", argues Rebassa Mansergas.

Until now scientists did not have a camera powerful enough to get accurate measurements of stellar components such as mass and radius.

Thanks to the use of the HiPERCAM instrument installed in the GTC, in the Roque de los Muchachos Observatory (Garafía, La Palma), combined with data from the X-Shooter instrument of the Unit 2 telescope of ESO's Very Large Telescope (VLT), in Chile, the researchers were able to accurately measure the system for the first time.

The article is the first to be published using HiPERCAM data. According to Vikram Dhillon, an astrophysicist at the University of Sheffield, an IAC affiliate researcher and one of those responsible for the HiPERCAM project: *"Our measurement of the mass and radius of this ancient star confirms a key prediction of the theory of stellar structure and demonstrates the unique capabilities of our new camera HiPERCAM on the 10.4m Gran Telescopio Canarias"*.

This camera can take one picture every millisecond, unlike other cameras that normally only take one picture every few minutes. Thanks to its high capture speed, HiPERCAM makes it possible to study in unprecedented detail objects with rapid variations in brightness due to phenomena such as eclipses and explosions.

"The observations with HiPERCAM in GTC have allowed to obtain the curves of light of this object in up to 5 filters simultaneously with an unprecedented precision, thanks to the telescope light collecting capacity. The HiPERCAM/GTC combination opens an extraordinary door to the study of objects with temporal variability, providing a very high temporal resolution and covering a range of magnitudes unattainable for other telescopes", explains Antonio Cabrera, head of scientific operations at the GTC.

With these values, together with the temperature and the luminosity of the cool subdwarf star also obtained from the observations, the authors were able to validate, for the first time, the theoretical relations between the mass, radius, luminosity, and temperature for the oldest stars in our Galaxy. ■

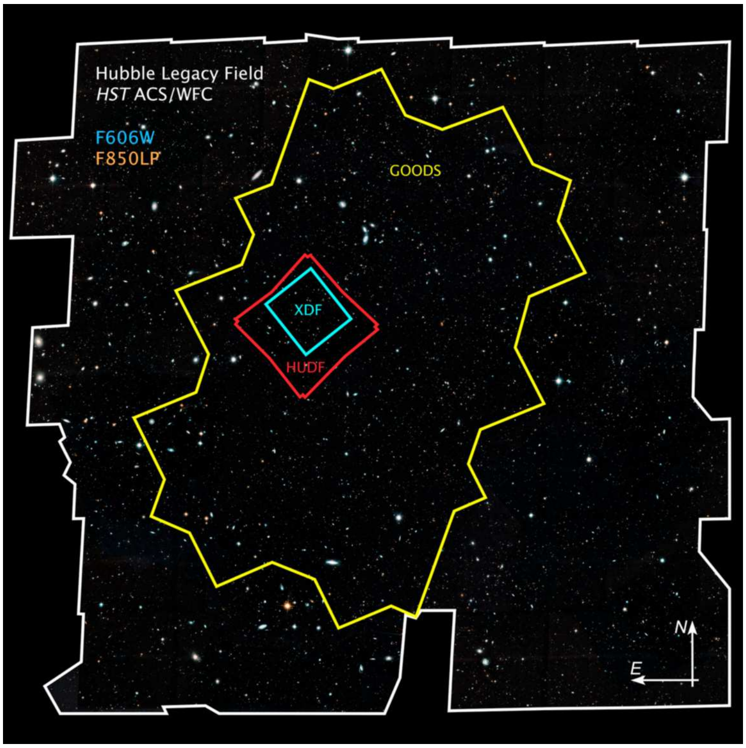
Hubble assembles wide view of the distant Universe

by NASA/ESA

Astronomers have put together the largest and most comprehensive "history book" of galaxies into one single image, using 16 years' worth of observations from NASA's Hubble Space Telescope.

The deep-sky mosaic, created from nearly 7,500 individual exposures, provides a wide portrait of the distant Universe, containing 265,000 galaxies that stretch back through 13.3 billion years of time to just 500 million years after the big bang. The faintest and farthest galaxies are just one ten-billionth the brightness of what the human eye can see.

The universe's evolutionary history is also chronicled in this one sweeping view. The portrait shows how galaxies change over time, building themselves up to become the giant galaxies seen in the nearby universe. This ambitious endeavor, called the Hubble Legacy Field, also combines observations taken by several Hubble deep-field surveys, including the eXtreme Deep Field (XDF), the deepest view of the universe.



This image shows the sizes and locations within the Hubble Legacy Field of the two areas that Hubble first studied in this region, the Great Observatories Origins Deep Survey (GOODS) and the Hubble Ultra Deep Field (HUDF), along with the deepest image ever taken by Hubble, the eXtreme Deep Field (XDF). [NASA, ESA, G. Illingworth and D. Magee (University of California, Santa Cruz), K. Whitaker (University of Connecticut), R. Bouwens (Leiden University), P. Oesch (University of Geneva), and the Hubble Legacy Field team]

The wavelength range stretches from ultraviolet to near-infrared light, capturing the key features of galaxy assembly over time.

"Now that we have gone wider than in previous surveys, we are harvesting many more distant galaxies in the largest such dataset ever produced by Hubble," said Garth Illingworth of the University of California, Santa Cruz, leader of the team that assembled the image. *"This one image contains the full history of the growth*

Astronomers developed a mosaic of the distant Universe, called the Hubble Legacy Field, that documents 16 years of observations from the Hubble Space Telescope. The image contains more than 200,000 galaxies that stretch back through 13.3 billion years of time to just 500 million years after the Big Bang. [NASA, ESA, G. Illingworth and D. Magee (University of California, Santa Cruz), K. Whitaker (University of Connecticut), R. Bouwens (Leiden University), P. Oesch (University of Geneva), and the Hubble Legacy Field team]

of galaxies in the universe, from their time as 'infants' to when they grew into fully-fledged 'adults.' No image will surpass this one until future space telescopes are launched." *"We've put together this mosaic as a tool to be used by us and by other astronomers,"* Illingworth added. *"The expectation is that this survey will lead to an even more coherent, in-depth, and greater understanding of the universe's evolution in the coming years."* The image yields a huge catalog of distant galaxies. *"Such exquisite high-resolution measurements of the numerous galaxies in this catalog enable a wide swath of extragalactic study,"* said catalog lead researcher Katherine Whitaker of the University of Connecticut, in Storrs. *"Often, these kinds of surveys have yielded unanticipated discoveries which have had the greatest impact on our understanding of galaxy evolution."*

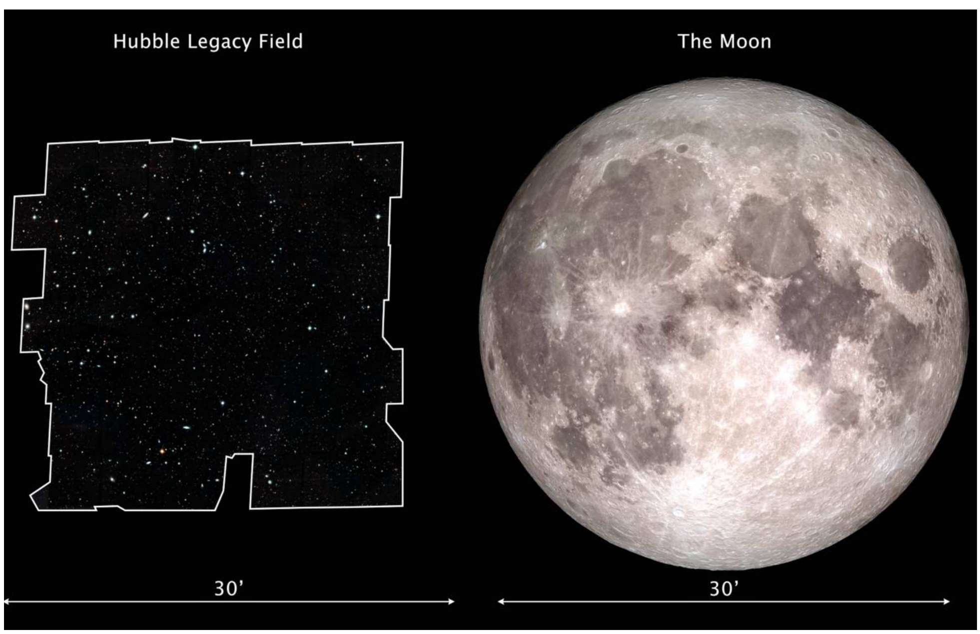
Galaxies are the "markers of space," as astronomer Edwin Hubble once described them a century ago. Galaxies allow astronomers to trace the expansion of the universe, offer clues to the underlying physics of the cosmos, show when the chemical elements originated, and enable the conditions that eventually led to the appearance of our solar system and life.

This wider view contains about 30 times as many galaxies as in the previous deep fields. The new portrait, a mosaic of multiple snapshots, covers almost the width of the full Moon. The XDF, which penetrated deeper into space than this wider view, lies in this region, but it covers less than one-tenth of the full Moon's diameter. The Legacy Field also uncovers a zoo of unusual objects. Many of them are the remnants of galactic "train wrecks," a time in the early universe when small, young galaxies collided and merged with other galaxies.

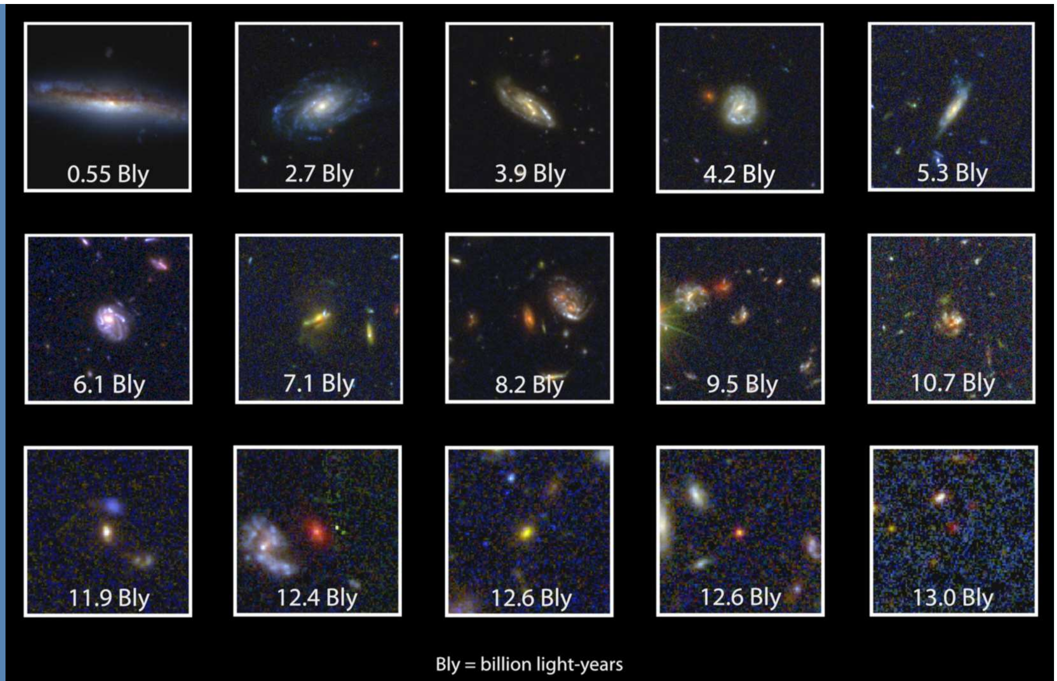
Assembling all of the observations was an immense task. The image comprises the collective work of 31 Hubble programs by different teams of astronomers. Hubble has spent more time on this tiny area than on any other region of the sky, totaling more than 250 days, representing nearly three-quarters of a year. *"Our goal was to assemble all 16 years of exposures into a legacy image,"* explained Dan Magee, of the University of California, Santa Cruz, the team's data processing lead. *"Previously, most of these exposures had not been put together in a consistent way that can be used by any researcher. Astronomers can select the data in the Legacy Field they want and work with it immediately, as opposed to having to perform a huge amount of data reduction before conducting scientific analysis."*

This video explores the detail of the Hubble Legacy Field. [NASA, ESA, G. Illingworth and D. Magee (University of California, Santa Cruz), K. Whitaker (University of Connecticut), R. Bouwens (Leiden University), P. Oesch (University of Geneva), and the Hubble Legacy Field team. Music: James Creasey]

The image, along with the individual exposures that make up the new view, is available to the worldwide astronomical community through the Mikulski Archive for Space Telescopes (MAST). MAST, an online database of astronomical data from Hubble and other NASA mis-



This graphic compares the dimensions of the Hubble Legacy Field on the sky with the angular size of the Moon. [Hubble Legacy Field Image: NASA, ESA, and G. Illingworth and D. Magee (University of California, Santa Cruz); Moon Image: NASA, GSFC, and Arizona State University]



This graphic reveals close-up images of 15 galaxies from the 265,000 galaxies in the Hubble Legacy Field. The galaxies are scattered across time, from 550 million years ago to 13 billion years ago. Their light is just arriving at Earth now, after crossing space for all those years. This collection of images allows astronomers to look back in time to see galaxies when they were very young, in the earliest epochs of the universe. The universe is 13.8 billion years old. The top panel of snapshots shows mature "adult" galaxies; the middle panel shows galaxies in their "teenage" years when they are growing and changing dramatically; and the bottom panel shows small, youthful galaxies. [NASA, ESA, G. Illingworth and D. Magee (University of California, Santa Cruz), K. Whitaker (University of Connecticut), R. Bouwens (Leiden University), P. Oesch (University of Geneva), and the Hubble Legacy Field team]

sions, is located at the Space Telescope Science Institute in Baltimore, Maryland.

The Hubble Space Telescope has come a long way in taking ever deeper "core samples" of the distant universe. After Hubble's launch in 1990, astronomers debated if it was worth spending a chunk of the telescope's time to go on a "fishing expedition" to take a very long exposure of a small, seemingly blank piece of sky. The resulting Hubble Deep Field image in 1995 captured several thousand unseen galaxies in one pointing.

The bold effort was a landmark demonstration and a defining proof-of-concept that set the stage for future deep field images. In 2002, Hubble's Advanced Camera for Surveys went even deeper to uncover 10,000 galaxies in a single snapshot. Astronomers used exposures taken by Hubble's Wide Field Camera 3 (WFC3), installed in 2009, to assemble the eXtreme Deep Field snapshot in 2012. Unlike previous Hubble cameras, the telescope's WFC3 covers a broader wavelength range, from ultraviolet to near-infrared.

This new image mosaic is the first in a series of Hubble Legacy Field images. The team is working on a second set of images, totaling more than 5,200 Hubble exposures, in another area of the sky. In the future, astronomers hope to broaden the multiwavelength range in the legacy images to include longer-wavelength infrared data and high-energy X-ray observations from two other NASA Great Observatories, the Spitzer Space Telescope and Chandra X-ray Observatory.

The vast number of galaxies in the Legacy Field image are also prime targets for future telescopes. *"This will really set the stage for NASA's planned Wide Field Infrared Survey Telescope (WFIRST),"* Illingworth said. *"The Legacy Field is a pathfinder for WFIRST, which will capture an image that is 100 times larger than a typical Hubble photo. In just three weeks' worth of observations by WFIRST, astronomers will be able to assemble a field that is much deeper and more than twice as large as the Hubble Legacy Field."*

In addition, NASA's upcoming James Webb Space Telescope will allow astronomers to push much deeper into the legacy field to reveal how the infant galaxies actually grew. Webb's infrared coverage will go beyond the limits of Hubble and Spitzer to help astronomers identify the first galaxies in the universe. ■

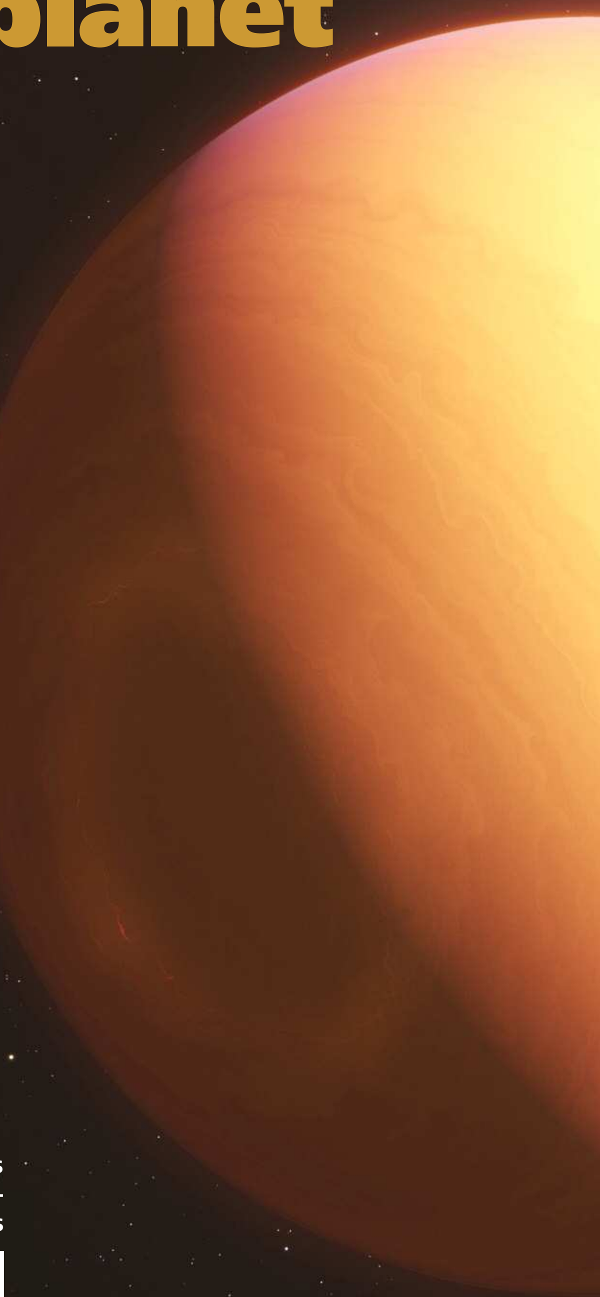
GRAVITY breaks new ground in exoplanet imaging

by ESO

The GRAVITY instrument on ESO's Very Large Telescope Interferometer (VLTI) has made the first direct observation of an exoplanet using optical interferometry. This method revealed a complex exoplanetary atmosphere with clouds of iron and silicates swirling in a planet-wide storm. The technique presents unique possibilities for characterising many of the exoplanets known today.

This result was announced today in a letter in the journal Astronomy and Astrophysics by the GRAVITY Collaboration, in which they present observations of the exoplanet HR-8799e using optical interferometry. The exoplanet was discovered in 2010 orbiting the young main-sequence star HR8799, which lies around 129 light-years from Earth in the constellation of Pegasus.

Today's result, which reveals new characteristics of HR8799e, required an instrument with very high resolution and sensitivity. GRAVITY can use ESO's VLT's four unit telescopes to work together to mimic a single larger telescope using a technique known as interferometry. This creates a super-telescope — the VLTI — that collects



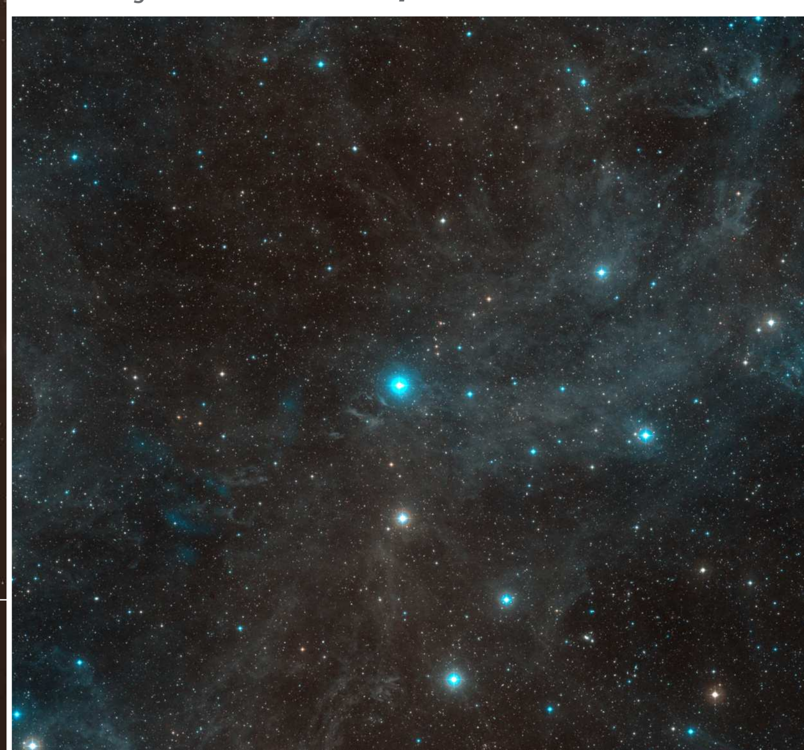
This artist's impression shows the observed exoplanet, which goes by the name HR8799e. [ESO/L. Calçada]

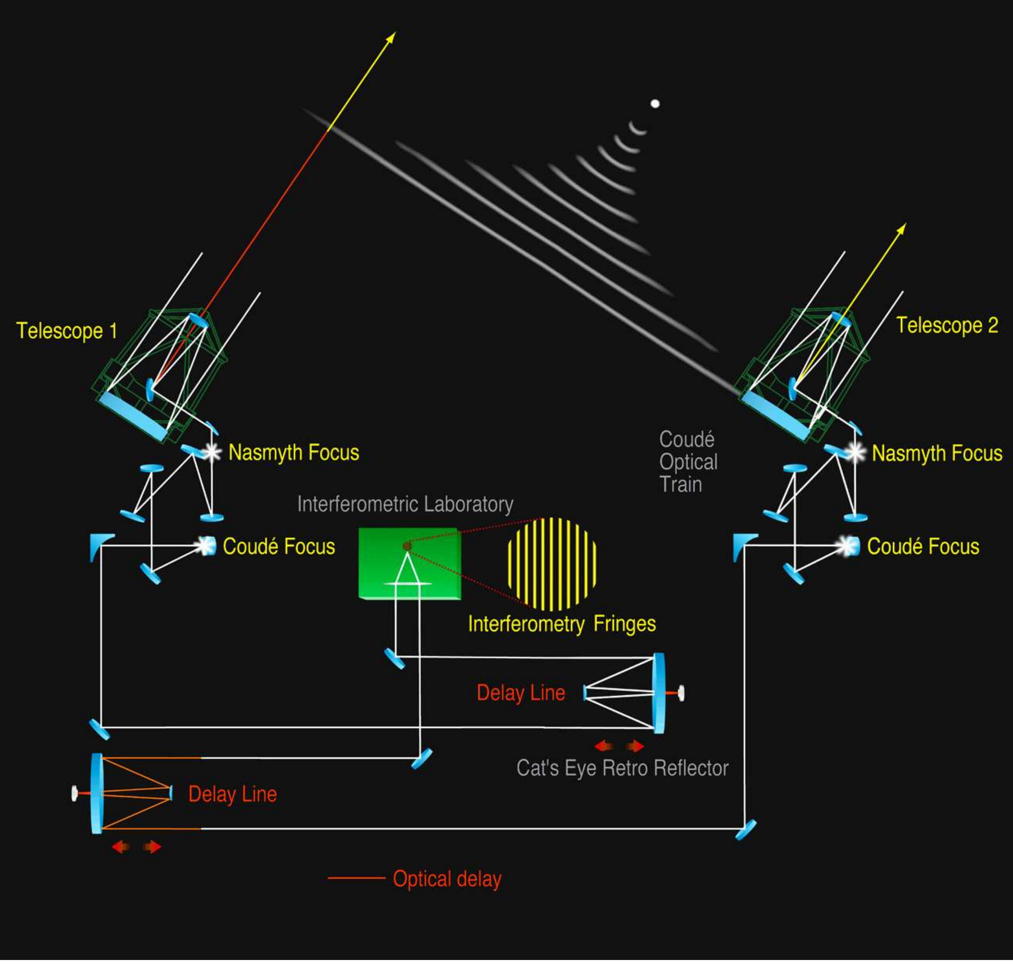
and precisely disentangles the light from HR8799e's atmosphere and the light from its parent star.

HR8799e is a 'super-Jupiter', a world unlike any found in our Solar System, that is both more massive and much younger than any planet orbiting the Sun. At only 30 million years old, this baby exoplanet is young enough to give scientists a window onto the formation of planets and planetary systems. The exoplanet is thoroughly inhospitable — leftover energy from its formation and a powerful greenhouse effect heat HR8799e to a hostile temperature of roughly 1000 °C.

This is the first time that optical interferometry has been used to reveal details of an exoplanet, and the new technique furnished an exquisitely detailed spectrum of unprecedented quality — ten times more detailed than earlier observations. The team's measurements were able to reveal the composition of HR-8799e's atmosphere — which contained some surprises.

This wide-field image shows the surroundings of the young star HR8799 in the constellation of Pegasus. This picture was created from material forming part of the Digitized Sky Survey 2. [ESO/Digitized Sky Survey 2. Acknowledgement: Davide de Martin]





Schematic lay-out of the VLT Interferometer. The light from a distant celestial objects enters two of the VLT telescopes and is reflected by the various mirrors into the Interferometric Tunnel, below the observing platform on the top of Paranal. Two Delay Lines with moveable carriages continuously adjust the length of the paths so that the two beams interfere constructively and produce fringes at the interferometric focus in the laboratory. [ESO]

"Our analysis showed that HR8799e has an atmosphere containing far more carbon monoxide than methane — something not expected from equilibrium chemistry," explains team leader Sylvestre Lacour researcher CNRS at the Observatoire de Paris - PSL and the Max Planck Institute for Extraterrestrial Physics. *"We can best explain this surprising result with high vertical winds within the atmosphere preventing the carbon monoxide from reacting with hydrogen to form methane."*

The team found that the atmosphere also contains clouds of iron and silicate dust. When combined with the excess of carbon monoxide, this suggests that HR-8799e's atmosphere is engaged in an enormous and violent storm.

"Our observations suggest a ball of gas illuminated from the interior, with rays of warm light swirling through stormy patches of dark clouds," elaborates Lacour. *"Convection moves around the clouds of silicate and iron particles, which disaggregate and rain down into the interior. This paints a picture of a dynamic atmosphere of a giant exoplanet at birth, undergoing complex physical and chemical processes."*

This result builds on GRAVITY's string of impressive discoveries, which have included breakthroughs such as last year's observation of gas swirling at 30% of the speed of light just outside the event horizon of the massive Black Hole in the Galactic Centre.

It also adds a new way of observing exoplanets to the already extensive arsenal of methods available to ESO's telescopes and instruments — paving the way to many more impressive discoveries.

The video on the side summarizes the first direct observation of an exoplanet using optical interferometry. [ESO]

The above footage consists of 7 images of HR 8799 taken with the Keck Telescope over 7 years. The video was made by Jason Wang, data was reduced by Christian Marois, and the orbits were fit by Quinn Konopacky. Bruce Macintosh, Travis Barman, and Ben Zuckerman assisted in the observations. [J. Wang et al.]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