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Bi-monthly magazine of scientific and technical information ✶ May-June 2019

50 years ago, we walked on the Moon

PART ONE OF TWO

The EHT captures the first image of a black hole


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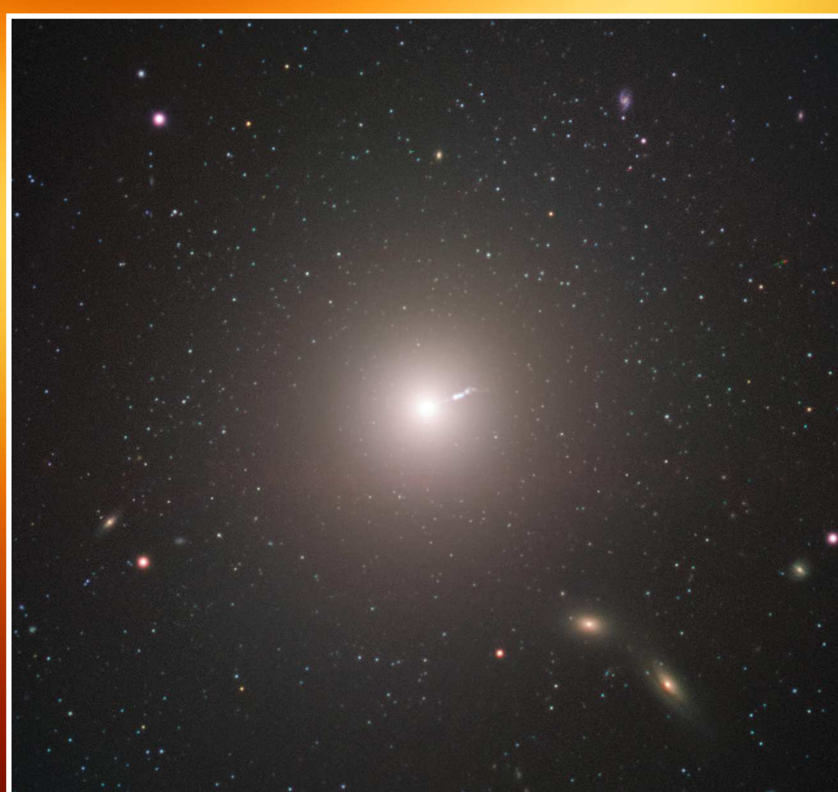
SUMMARY

IN THE SHADOW OF THE BLACK HOLE

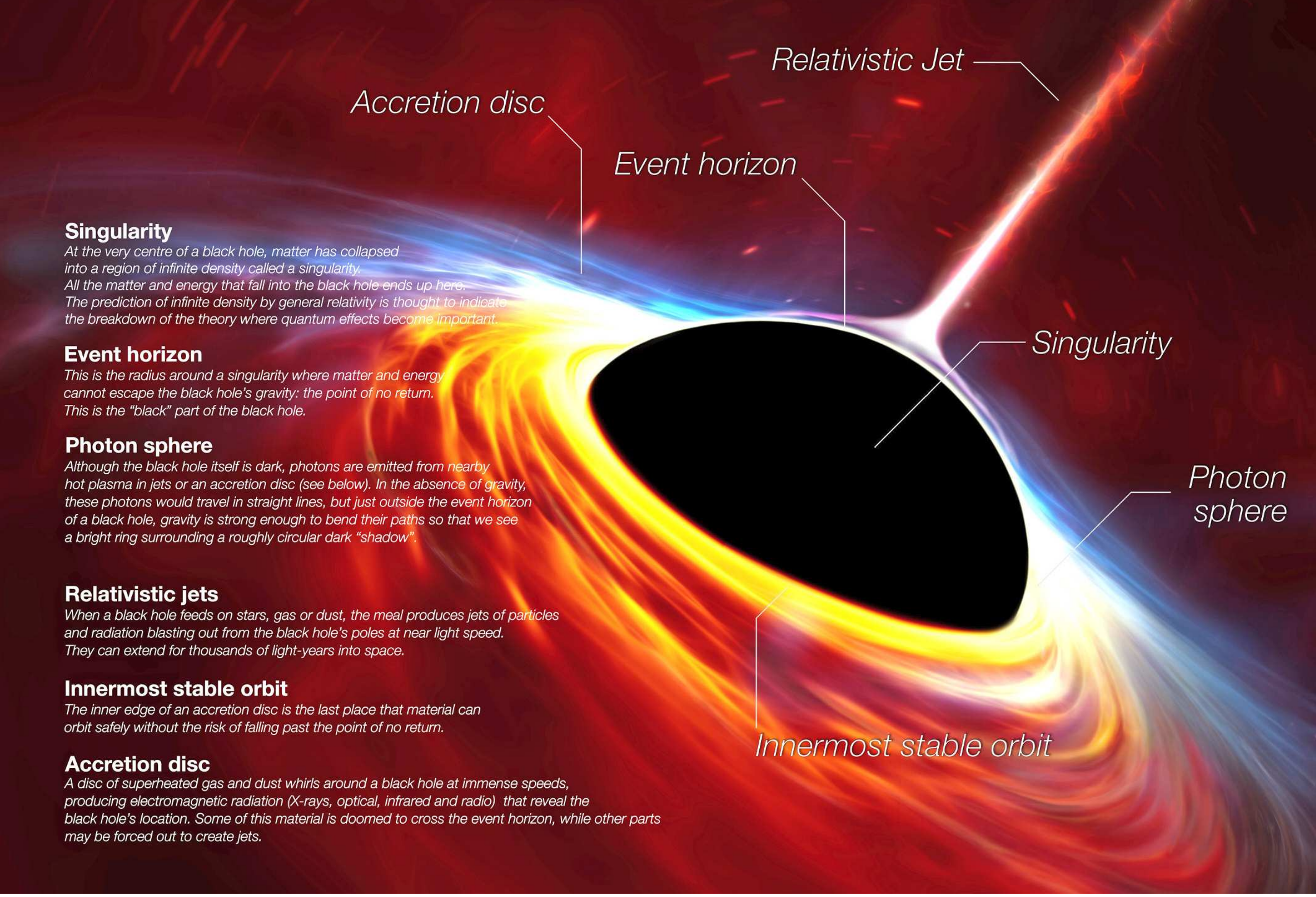
by ESO

The Event Horizon Telescope captures the first image of a black hole

This breakthrough was announced on April 10th in a series of six papers published in a special issue of *The Astrophysical Journal Letters*. The image reveals the black hole at the centre of Messier 87, a massive galaxy in the nearby Virgo galaxy cluster. This black hole resides 55 million light-years from Earth and has a mass 6.5 billion times that of the Sun. The shadow of a black hole is the closest we can come to an image of the black hole itself, a completely dark object from which light cannot escape.



Messier 87 (M87) is an enormous elliptical galaxy located about 55 million light years from Earth, visible in the constellation Virgo. At the center of this galaxy, the first black hole has been photographed. [ESO]



This artist's impression depicts a rapidly spinning supermassive black hole surrounded by an accretion disc. This thin disc of rotating material consists of the leftovers of a Sun-like star which was ripped apart by the tidal forces of the black hole. The black hole is labelled, showing the anatomy of this fascinating object. [ESO]

The black hole's boundary — the event horizon — is around 2.5 times smaller than the shadow it casts and measures just under 40 billion km across.

The EHT links telescopes around the globe to form an unprecedented Earth-sized virtual telescope. The EHT offers scientists a new way to study the most extreme objects in the Universe predicted by Einstein's general relativity during the centenary year of the historic experiment that first confirmed the theory.

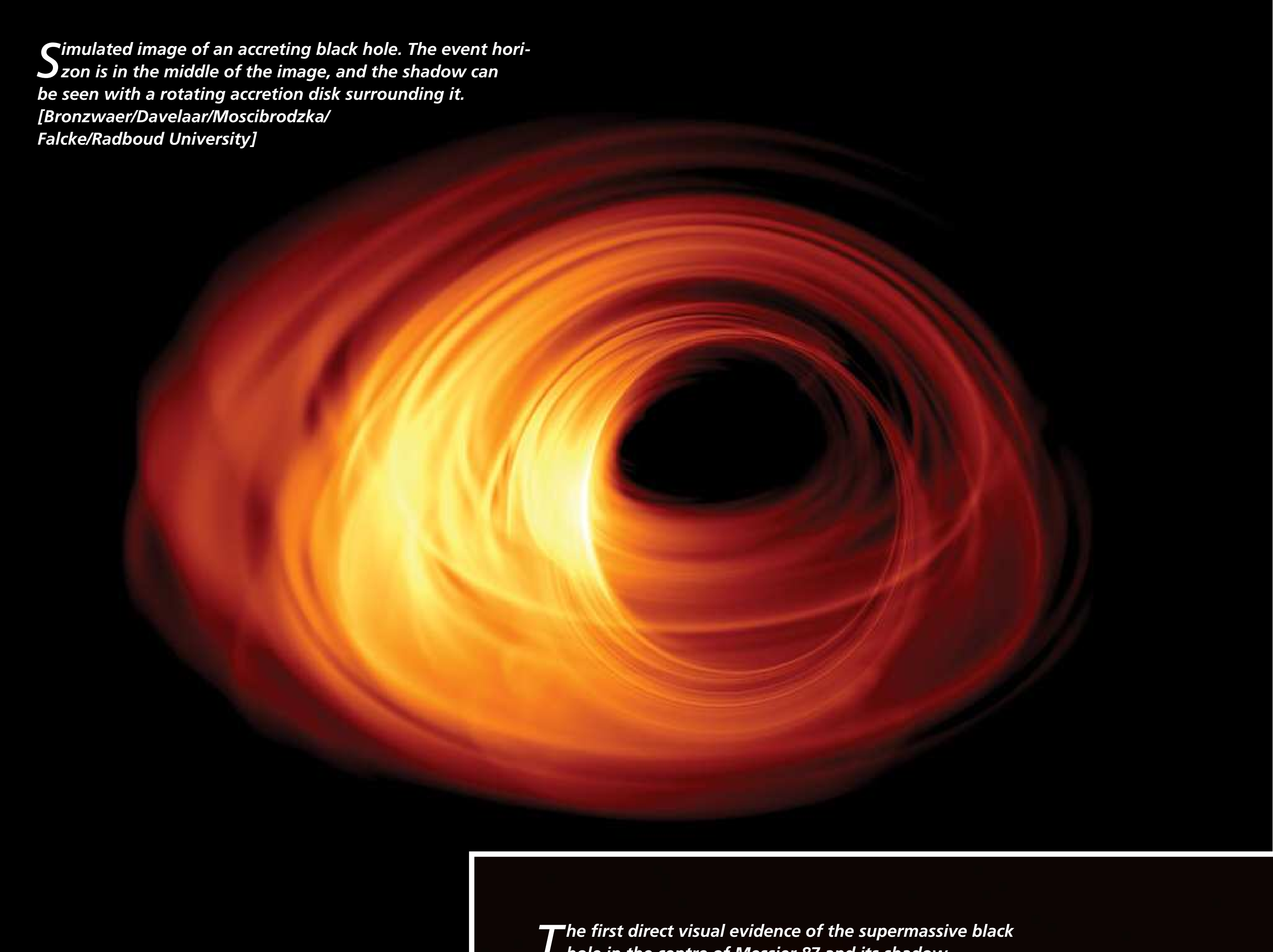
Although the telescopes are not physically connected, they are able to synchronize their recorded data with atomic clocks — hydrogen masers — which precisely time their observations. These observations were collected at a wavelength of 1.3 mm during a 2017 global campaign. Each telescope of the EHT produced enormous amounts of data — roughly 350 terabytes per day — which was stored on high-performance helium-filled hard drives. These data were flown to highly specialised supercomputers — known as correlators — at the Max Planck Institute for Radio Astronomy and MIT Haystack Observatory to be combined. They were then painstakingly converted into an image using novel computational tools developed by the collaboration.

"We have taken the first picture of a black hole," said EHT project director Sheperd S. Doeleman of the Center for Astrophysics | Harvard & Smithsonian. *"This is an extraordinary scientific feat accomplished by a team of more than 200 researchers."*

Black holes are extraordinary cosmic objects with enormous masses but extremely compact sizes. The presence of these objects affects their environment in extreme ways, warping spacetime and superheating any surrounding material.

"If immersed in a bright region, like a disc of glowing gas, we expect a black hole to create a dark region similar to a shadow — something predicted by Einstein's general relativity that we've never seen before," explained chair of the EHT Science Council Heino Falcke of Radboud University, the Netherlands. *"This shadow, caused by the gravitational bending and capture of light by the event horizon, reveals a lot about the nature of these fascinating objects and has allowed us to measure the enormous mass of M87's black hole."*

Multiple calibration and imaging methods have revealed a ring-like structure with a dark central region — the black hole's shadow — that persisted over multiple independent EHT observations.



Simulated image of an accreting black hole. The event horizon is in the middle of the image, and the shadow can be seen with a rotating accretion disk surrounding it. [Bronzwaer/Davelaar/Moscibrodzka/ Falcke/Radboud University]

"Once we were sure we had imaged the shadow, we could compare our observations to extensive computer models that include the physics of warped space, superheated matter and strong magnetic fields. Many of the features of the observed image match our theoretical understanding surprisingly well," remarks Paul T.P. Ho, EHT Board member and Director of the East Asian Observatory. *"This makes us confident about the interpretation of our observations, including our estimation of the black hole's mass."*

"The confrontation of theory with observations is always a dramatic moment for a theorist. It was a relief and a source of pride to realise that the observations matched our predictions so well," elaborated EHT Board member Luciano Rezzolla of Goethe Universität, Germany. Creating the EHT was a formidable chal-

The first direct visual evidence of the supermassive black hole in the centre of Messier 87 and its shadow. This image is very similar to the simulated one. [EHT Collaboration] lenge which required upgrading and connecting a worldwide network of eight pre-existing telescopes deployed at a variety of challenging high-altitude sites.

These locations included volcanoes in Hawai`i and Mexico, mountains in Arizona and the Spanish Sierra Nevada, the Chilean Atacama Desert, and Antarctica.

The EHT observations use a technique called very-long-baseline interferometry (VLBI) which synchronises telescope facilities around the world and exploits the rotation of our planet to form one huge, Earth-size telescope observing at a wavelength of 1.3 mm. VLBI allows the EHT to achieve an angular resolution of 20 micro-arcseconds — enough to read a newspaper in New York from a café in Paris. The telescopes contributing to this result were ALMA, APEX, the IRAM 30-meter telescope, the James Clerk Maxwell Telescope, the Large Millimeter Telescope Alfonso Serrano, the Submillimeter Array, the Submillimeter Telescope, and the South Pole Telescope.

Petabytes of raw data from the telescopes were combined by highly specialised supercomputers hosted by the Max Planck Institute for Radio Astronomy and MIT Haystack Observatory. European facilities and funding played a crucial role in this worldwide effort, with the participation of advanced European telescopes and the support from the European Research Council — particularly a 14 million euros grant for the BlackHoleCam project. Support from ESO, IRAM and the Max Planck Society was also key. *"This result builds on decades of European expertise in millimetre astronomy"*, commented Karl Schuster, Director of IRAM and member of the EHT Board. The construction of the EHT and the observations announced today represent the culmination of decades of observational, technical, and theoretical work. This example of global teamwork required close collaboration by researchers from around the world. Thirteen partner institutions worked together to create the EHT, using both pre-existing infrastructure and support from a variety of agencies. Key funding was provided by the US National Science Foundation (NSF), the EU's European Research Council (ERC), and funding agencies in East Asia. *"ESO is delighted to have significantly contributed to this result through its European leadership and pivotal role in two of the EHT's component telescopes, located in Chile — ALMA and APEX,"* commented ESO Director General Xavier Barcons. *"ALMA is the most sensitive facility in the EHT, and its 66 high-precision antennas were critical in making the EHT a success."*

"We have achieved something presumed to be impossible just a generation ago," concluded Doeleman. *"Breakthroughs in technology, connections between the world's best radio observatories, and innovative algorithms all came together to open an entirely new window on black holes and the event horizon."*

This video summarizes the historic feat of EHT researchers that have succeeded in getting the first direct visual evidence of a supermassive black hole and its shadow. [ESO]

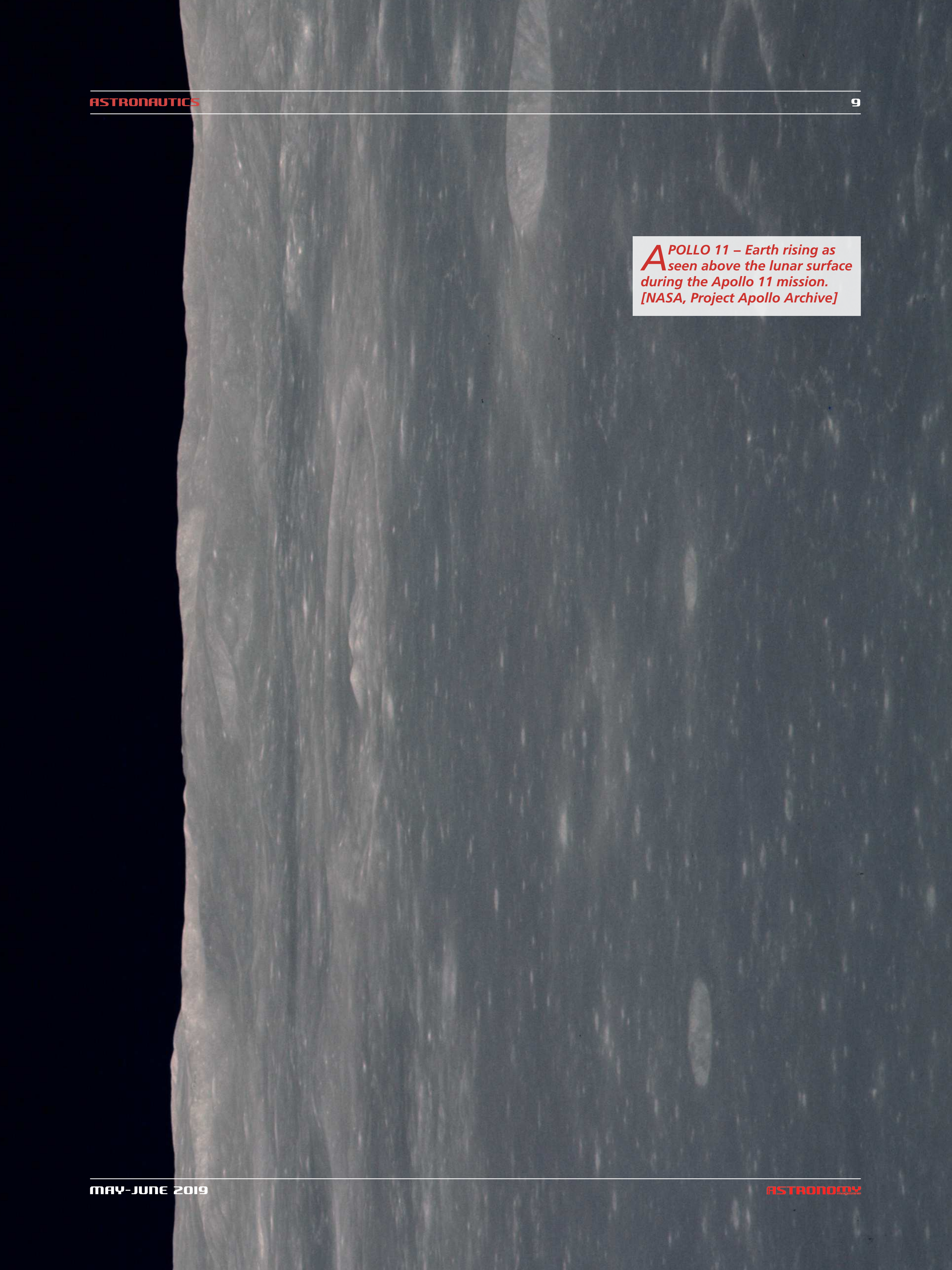
50 years ago, we walked on the Moon

(Part One of Two)

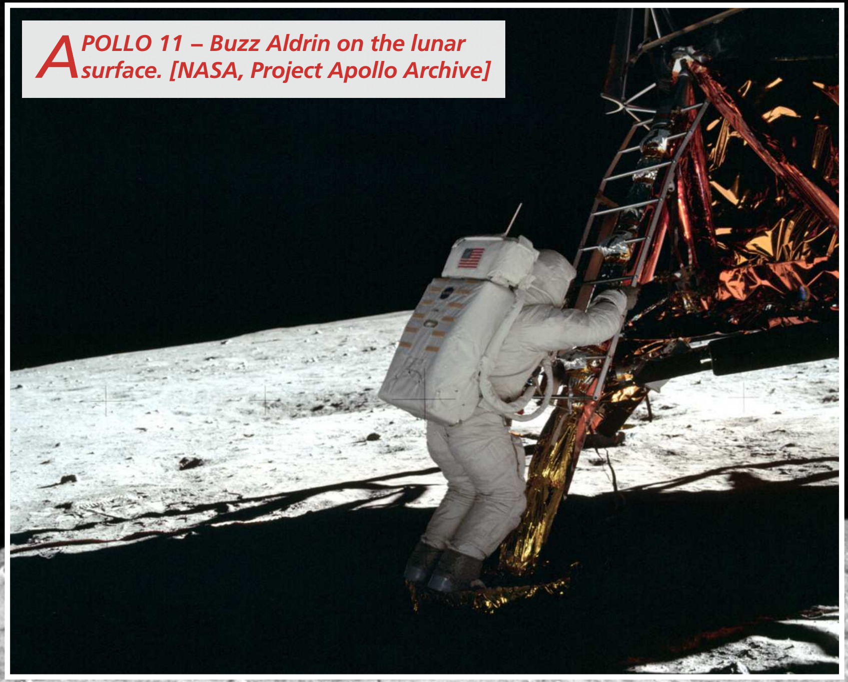
by Michele Ferrara

revised by Damian G. Allis
NASA Solar System Ambassador

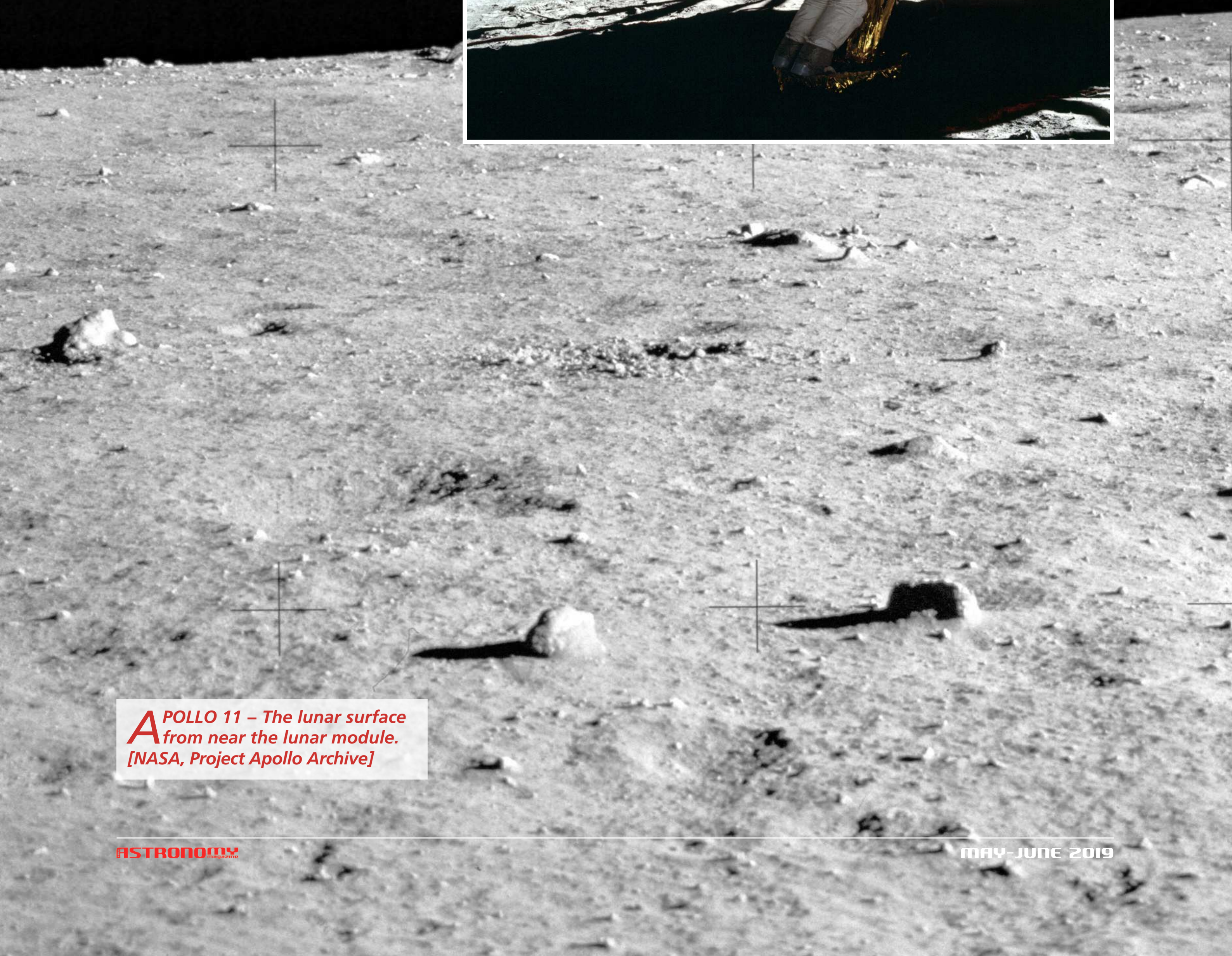
It is unavoidable. This year, all magazines dealing with astronomy and astronautics cannot help but devote considerable space to the fiftieth anniversary of the conquest of the Moon. In July and November 1969, Apollo 11 and Apollo 12 missions delivered the first men to walk on the surface of our natural satellite. Those first extraordinary results were replicated with the Apollo 14, 15, 16 and 17 missions. Before this, NASA gradually progressed through the Ranger, Surveyor, Mercury and Gemini programs, as well as the various test phases of the Apollo program, culminating with the general rehearsals of the Apollo 10 mission in May 1969. Although the topics that could be discussed with reference to those epic astronautical enterprises are almost unlimited, it is likely that most of the media will



APOLLO 11 – Earth rising as seen above the lunar surface during the Apollo 11 mission. [NASA, Project Apollo Archive] end up saying the same things, generalizing how it all happened at more-or-less every anniversary of the first lunar step taken by Neil Armstrong. We, therefore, want to try to differentiate ourselves, and will restrict our celebratory contribution to a very specific area – the path followed by NASA to choose the areas on which to land the lunar modules. Each mission had very specific tasks related to the

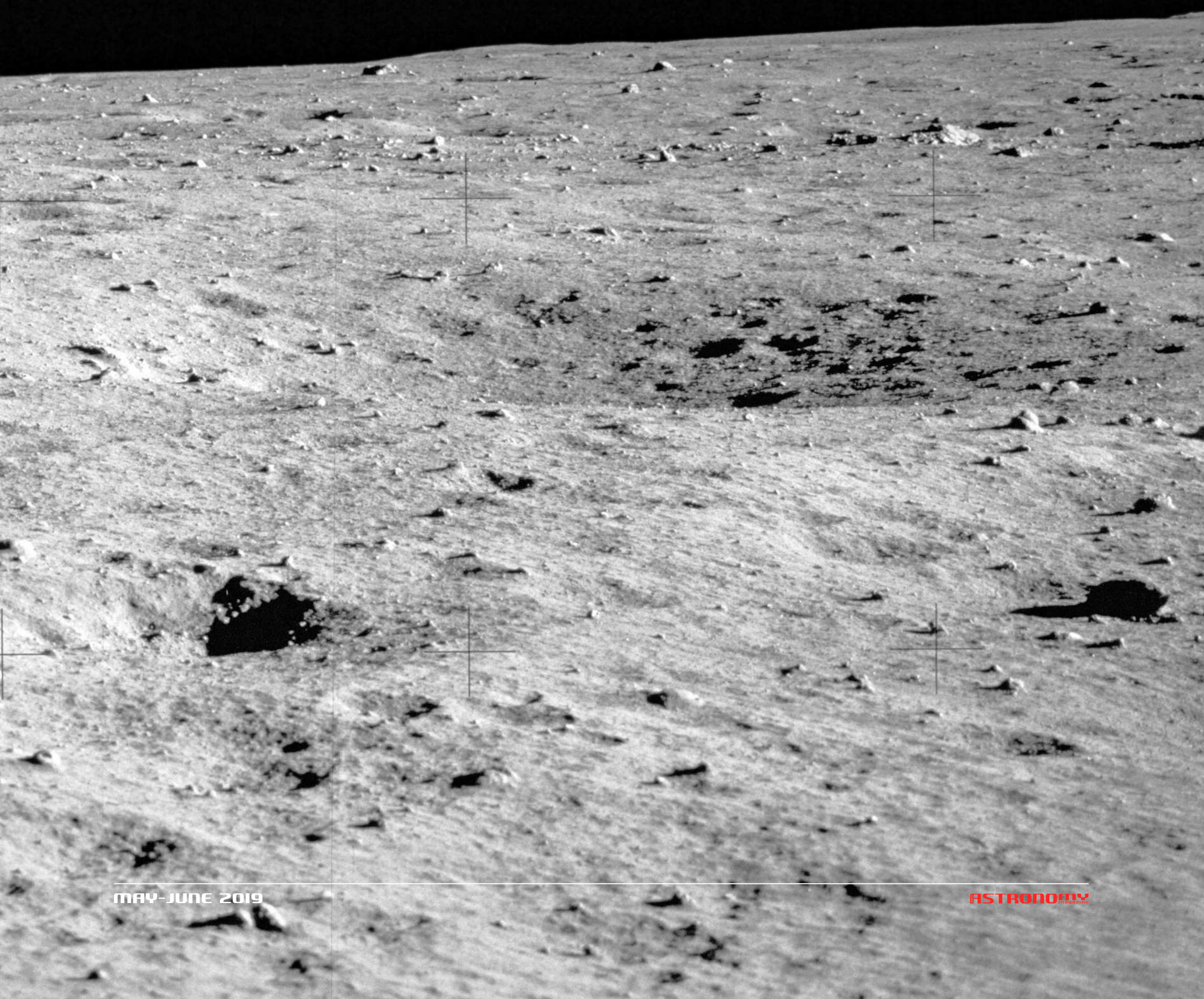


APOLLO 11 – Buzz Aldrin on the lunar surface. [NASA, Project Apollo Archive]



APOLLO 11 – The lunar surface from near the lunar module. [NASA, Project Apollo Archive]

uniqueness of the target regions. In this issue and the next, we will remember the missions and strategies that led scientists and engineers to select landing sites, an aspect of the conquest of the Moon often overlooked by the media, but which was of fundamental importance for the success of the Apollo Program. Images from the Project Apollo Archive, reworked in high resolution, complete this small contribution to the celebrations of the fiftieth anniversary.
A few years before John F. Kennedy formalized, in September 1962, the decision of the United States to send men to the Moon, NASA had already set up, in 1959, a program of studies of the lunar surface, known as the Ranger Program.
The aim was to launch a series of probes to the Moon capable of photographing the ground of our satellite, thus providing useful images to identify sites of particular interest for future landing missions with astronauts. The first two flights of the Ranger Program were launched in 1961 and were aimed at testing the basic systems of the spacecrafts in deep space. Sadly, the stages of the Agena rockets did not work properly and the spacecrafts eventually became unusable in orbit parking.



In spite of these early failures, the Jet Propulsion Laboratory (JPL) decided to launch a third spacecraft, charged with impacting the Moon, documenting the approach using a camera, and, a fraction of a second before the impact, ejecting a spherical capsule containing a seismometer able to withstand a hard landing. Unfortunately, the Ranger 3 Agena rocket gave a stronger thrust than expected and the spacecraft

missed the Moon by about 37,000 km. The next launch was more accurate – Ranger 4 did go on to impact the lunar surface, but the craft had been paralyzed by a system fault. The same issue occurred with Ranger 5, which. in addition. missed the Moon by nearly 800 km. In December 1962, the Ranger Program was at the risk of being canceled, with the best result being only an inactive spacecraft destroyed against the lunar surface. After a review of the spacecraft assembly procedures, NASA redefined the project's objectives, stating that future vehicles would carry nothing more than a camera

APOLLO 11 – Erection of the solar wind experiment. [NASA, Project Apollo Archive]

APOLLO 11 – Left, the lunar module and Earth. Right, the lunar module ladder and plaque. [NASA, Project Apollo Archive]

and would be charged with obtaining close-up images of the lunar surface so as to assess whether it could support the weight of a spaceship. At the time, there were still doubts about the thickness and consistency of the regolith, and it was feared that a spacecraft might sink after landing.
An ideal destination for the following missions was circumscribed by flight dynamics considerations. The initial framing should have matched the best telescopic photography available. The spacecraft had to make an almost vertical dive in order to superimpose successive images. To dive vertically, it was necessary to choose a target in the western hemisphere, but the dynamic constraints of the Apollo

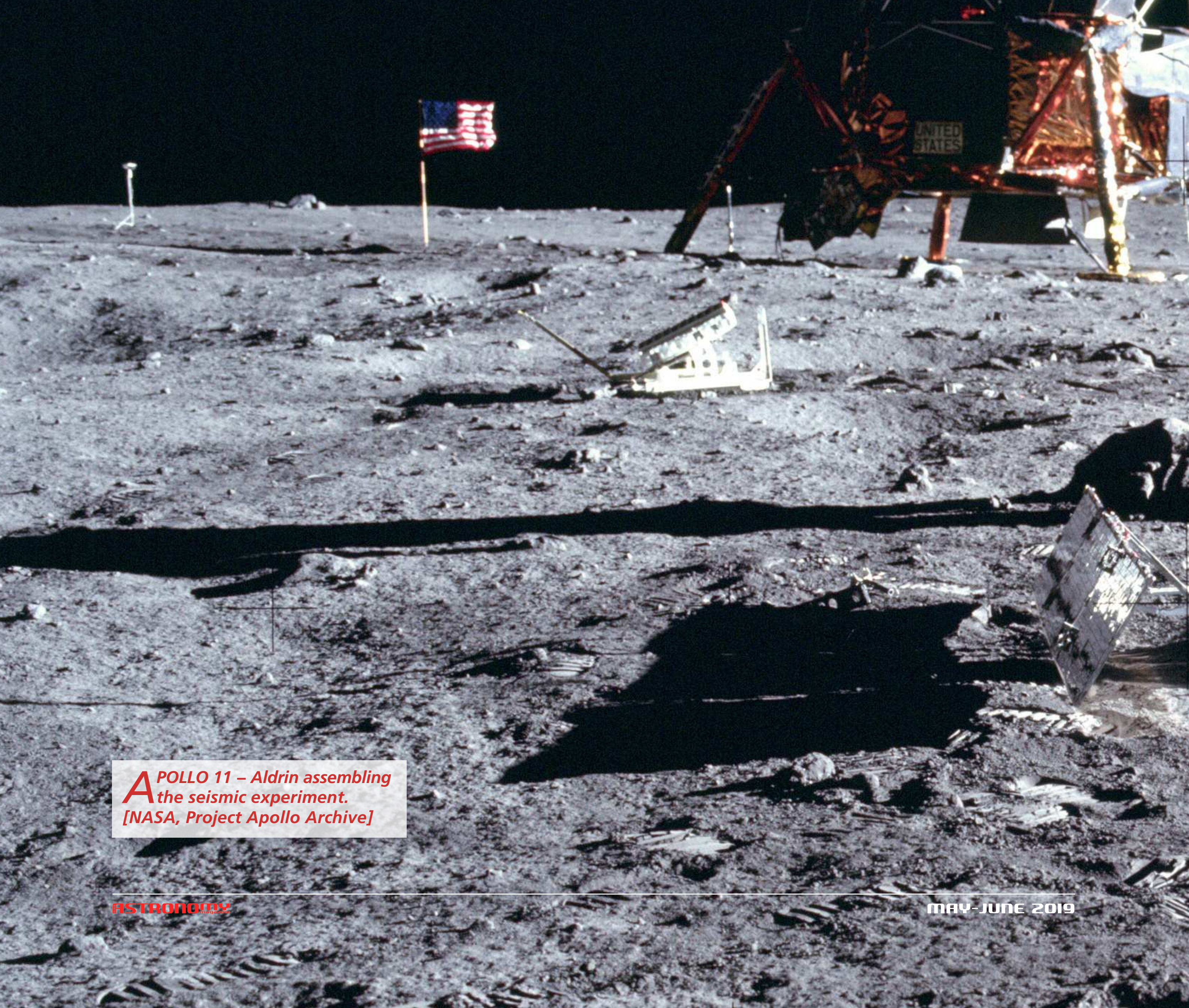
APOLLO 11 – The lunar surface beneath the lunar module. [NASA, Project Apollo Archive]

project favored sites in the eastern hemisphere (the right half for the terrestrial observer).
The missions resumed with the launch of Ranger 6. Its camera had been disabled by an electric arc, a problem that was not obvious until the system tried to start when the ship was close to its target in Mare Tranquillitatis.
The fate of this project changed at the end of July 1964, when Ranger 7 fell on an area at the border between Mare Nubium and Oceanus Procellarum. The last image showed details a few meters wide, which improved by a thousand times the resolution reached by the best telescopes. The ground appeared rather soft and rolling, devoid of the jagged structures often de-

APOLLO 11 – Color film of Neil Armstrong on the Moon (no sound). The video, made from color footage captured by a 35mm film camera mounted to the LM, shows Armstrong collecting samples near the LM. Although they are not individually high-quality photos like those taken by the medium-format Hasselblad, you can make out his face in his helmet for a brief moment as his glare visor is raised. [NASA] scribed in science fiction. The images also clearly showed flat and open spaces, as well as rocks and craters – an Apollo crew would have been able to maneuver in a safe place. A series of slightly accented ridges indicated that the sea was a solidified lava flow, and the presence of rocks implied that the surface would probably have supported a spacecraft.

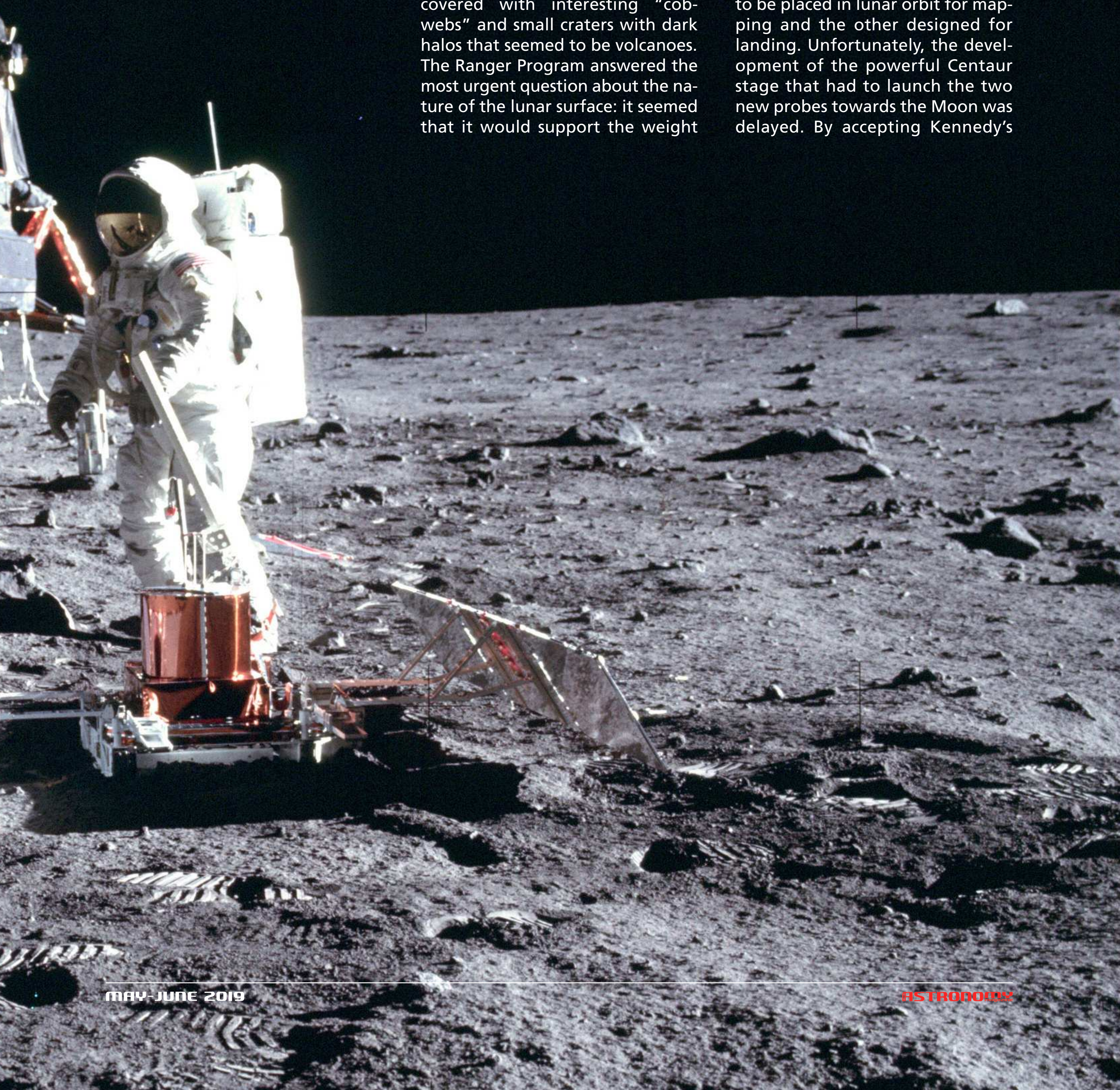
Thanks to the new knowledge acquired about this territory by Ranger 7, the International Astronomical Union, in August 1964, named the area Mare Cognitum (Known Sea).

In February 1965, Ranger 8 followed a low trajectory from the west, taking it over the central highlands of Mare Tranquillitatis. This trajectory increased the surface coverage, but it also caused a perceptible blurring in the final images.

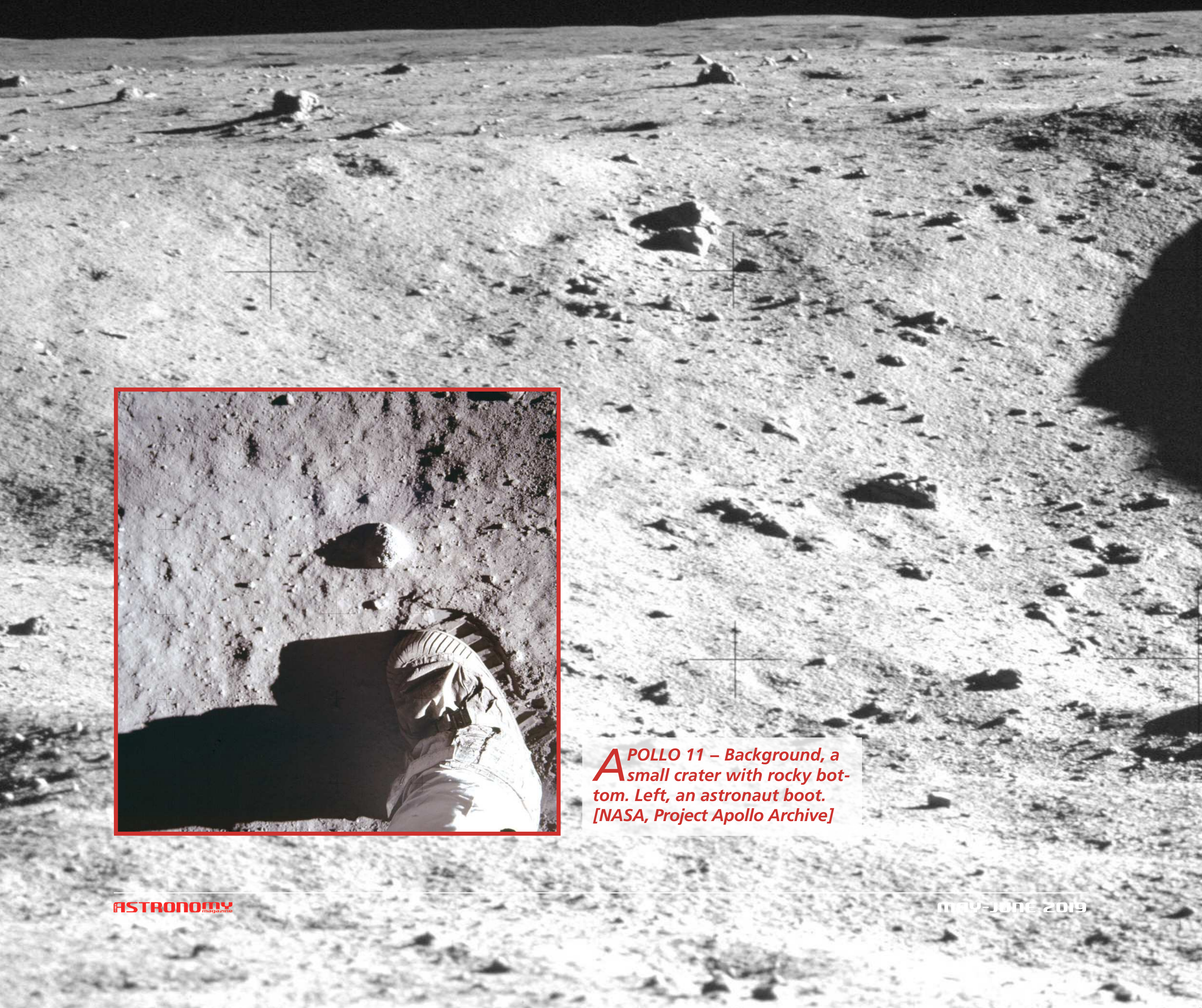


APOLLO 11 – Aldrin assembling the seismic experiment. [NASA, Project Apollo Archive]

After inspecting two sites in the sea, NASA left the Ranger 9 mission to scientists who, for the final impact in March 1965, chose Alphonsus, a crater 119 km in diameter, with a central peak and a flat floor covered with interesting "cobwebs" and small craters with dark halos that seemed to be volcanoes. The Ranger Program answered the most urgent question about the nature of the lunar surface: it seemed that it would support the weight of a spaceship. With this program completed, JPL began developing spacecraft for deep space missions. From May 1960, JPL also embarked on a much bolder project to develop two similar spacecraft, one to be placed in lunar orbit for mapping and the other designed for landing. Unfortunately, the development of the powerful Centaur stage that had to launch the two new probes towards the Moon was delayed. By accepting Kennedy's

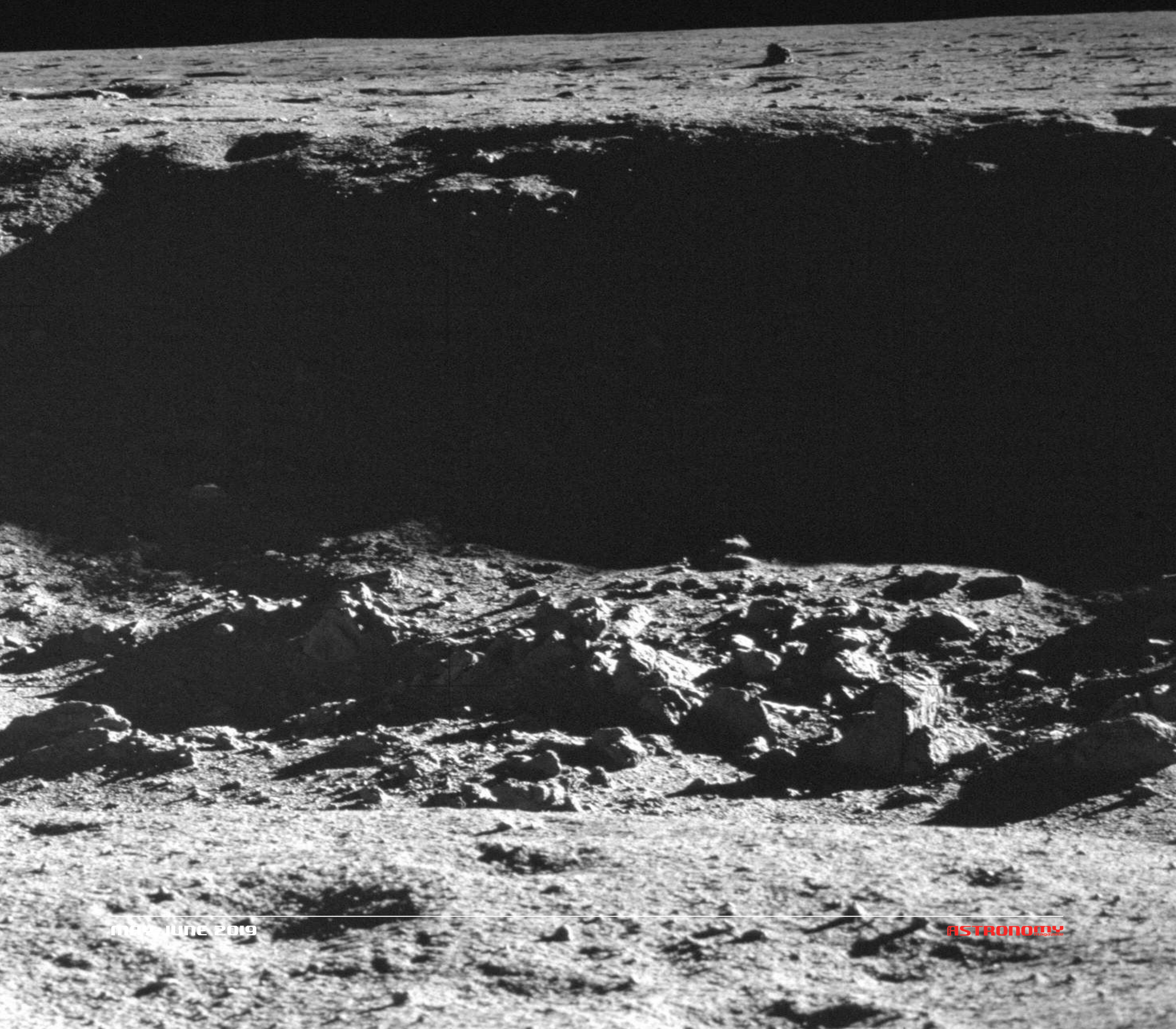


timescale for the Apollo program, NASA canceled the JPL mapper and ordered the Langley Research Center to develop a lightweight orbiter capable of traveling onboard an Atlas-Agena rocket. This new spacecraft was not supposed to produce a global map, but only to map predetermined sites as potential landing sites for Apollo. This project, called Lunar Orbiter, was launched in August 1963. Ranger had not yet proved its validity, but it was obvious that the development of an orbiter was not simply a matter of putting an engine together like one that might have been used to insert a Ranger into lunar orbit. While it is true that JPL's camera was ideal for recording a 20-minute dive that would have involved the destruction of the spacecraft, it is also true that it was able to provide the necessary high surface resolution only over the last seconds, when its field of view was extremely limited. To inspect large

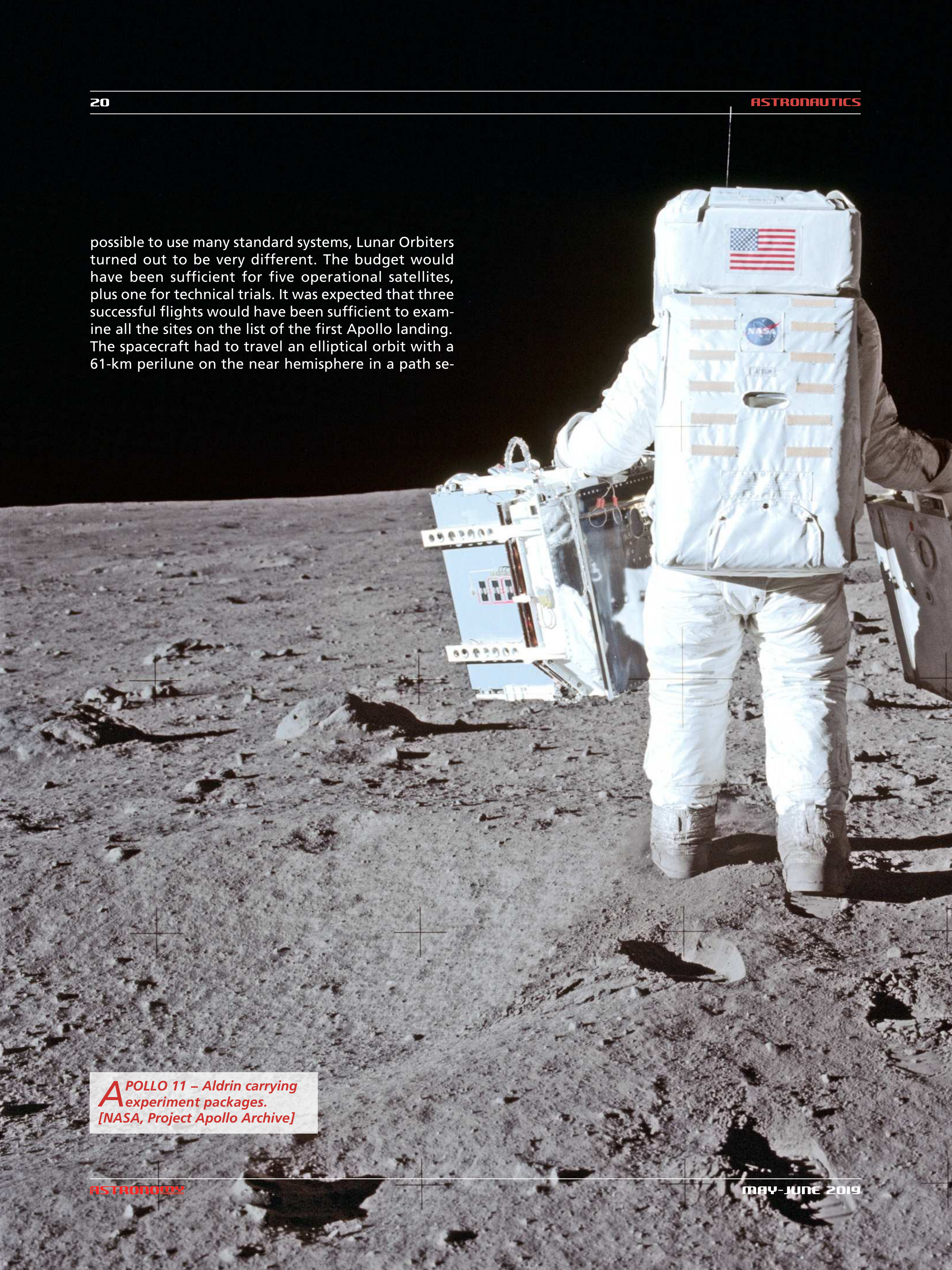


APOLLO 11 – Background, a small crater with rocky bottom. Left, an astronaut boot. [NASA, Project Apollo Archive] areas with sufficient resolution from an ideal altitude of about 65 km, the Lunar Orbiter should have exposed, developed and digitized by itself the films for transmission back to Earth. In addition, since the orbiter had to be lightweight, the camera would not have been protected from space radiation. Therefore, a very slow film was necessary, which meant that the camera had to be able to compensate for its own movements. Obviously, film stock would have been a limiting factor, but fortunately, NASA was able to use a special camera built by Kodak for a military reconnaissance satellite.

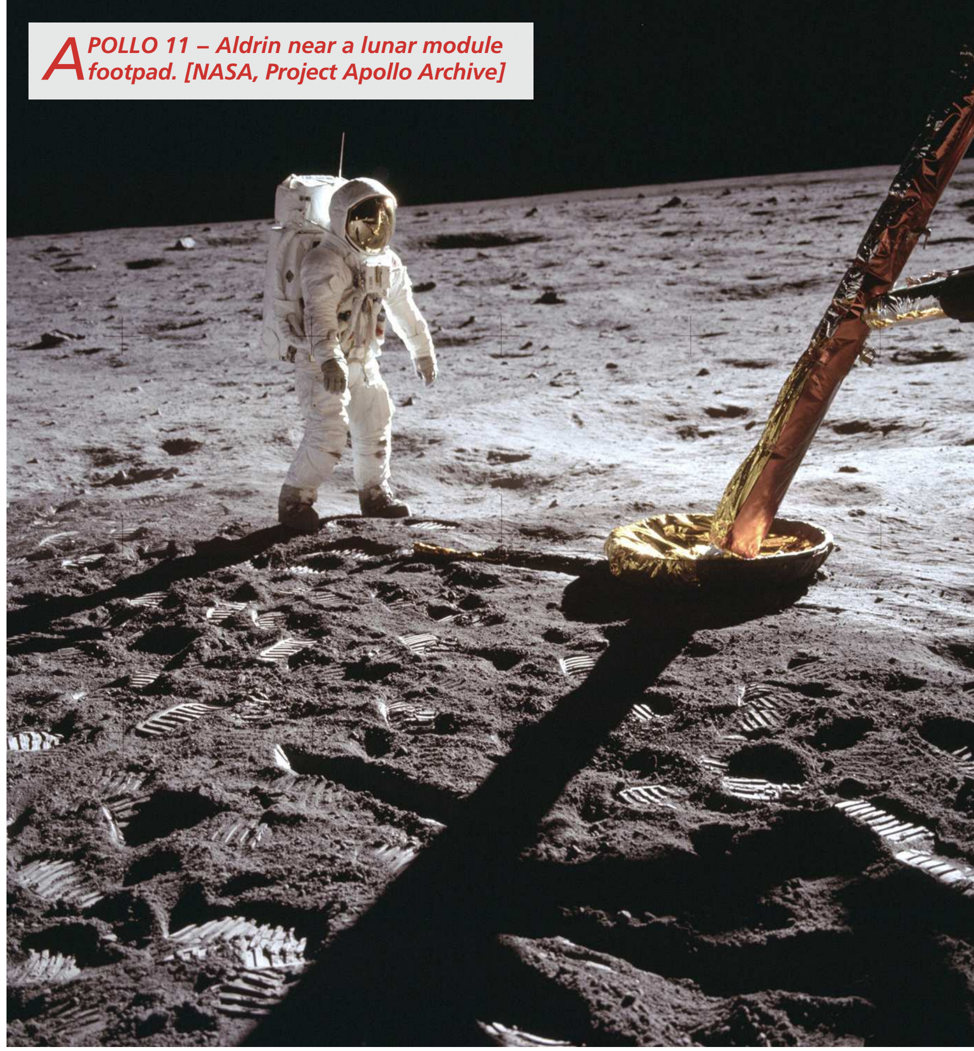
In December 1963, at the same time as the cancellation of the remaining Ranger missions, NASA signed the Lunar Orbiter contract with Boeing. Like Rangers, Lunar Orbiters would use three-axis stabilization, but the configuration of a spacecraft is closely related to its payload and, although it had been



possible to use many standard systems, Lunar Orbiters turned out to be very different. The budget would have been sufficient for five operational satellites, plus one for technical trials. It was expected that three successful flights would have been sufficient to examine all the sites on the list of the first Apollo landing. The spacecraft had to travel an elliptical orbit with a 61-km perilune on the near hemisphere in a path se-

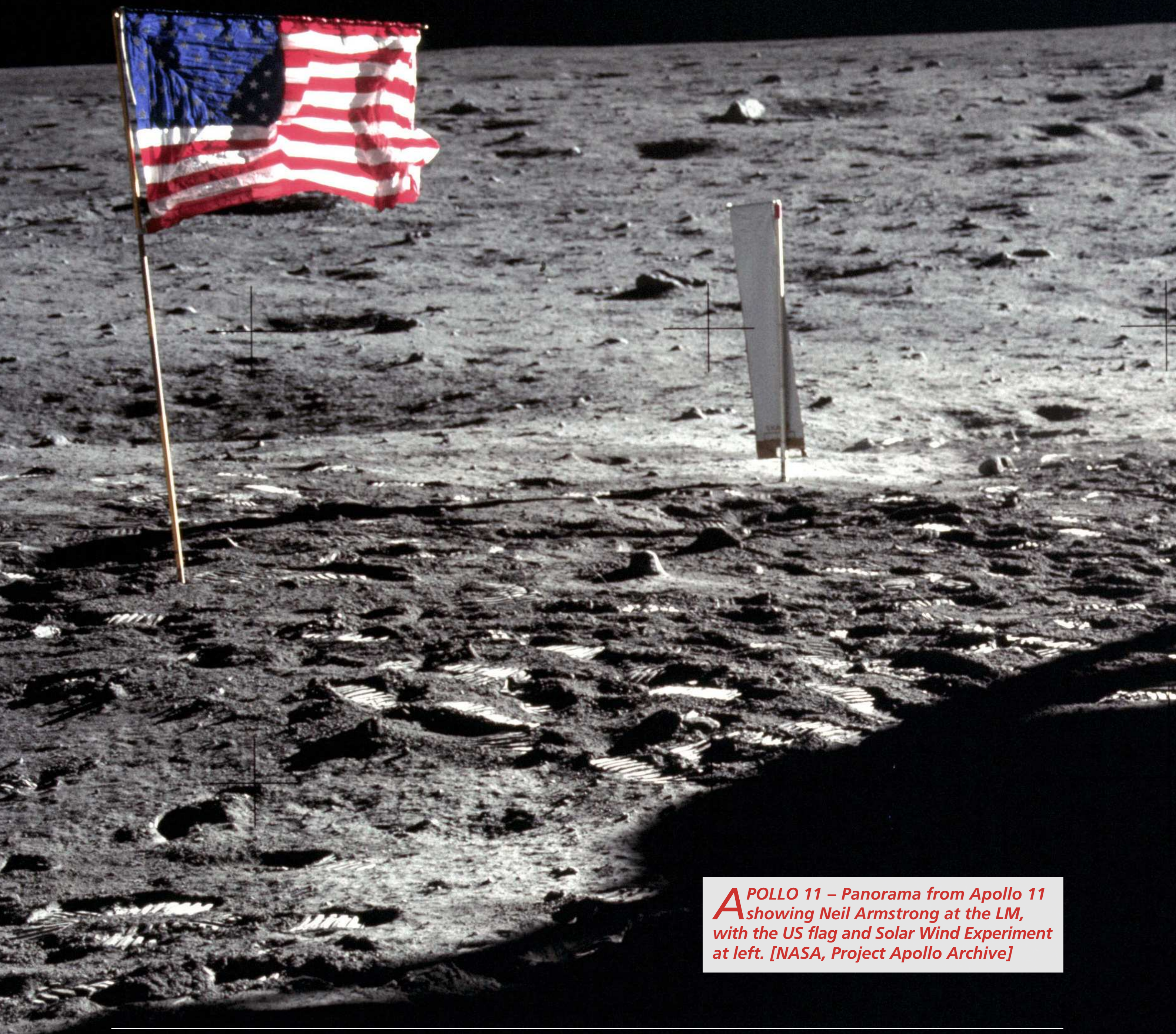


APOLLO 11 – Aldrin carrying experiment packages. [NASA, Project Apollo Archive] lected to allow it to take images at a low solar angle, allowing it to highlight the relief of the surface. With the orbit plane fixed in space, the point of perilune would have migrated towards more western longitudes during the rotation of the Moon and, after 10 days, the



APOLLO 11 – Aldrin near a lunar module footpad. [NASA, Project Apollo Archive]

APOLLO 11 – An iconic image: Aldrin photographed by Armstrong (visible in the visor). [NASA, Project Apollo Archive] point of perilune would have traveled the equatorial area where the candidate landing sites were located, documenting each in ideal lighting. In addition, since the sites were spread over a 300-km-wide strip, it was necessary to tilt the trajectory with respect to the lunar equator to pass on the sites close to the periphery of the strip. Indeed, it was decided to adopt an inclination of 11 degrees, with the perilune of the first orbiter located south of the equator, the second north and the third inclined as nec-

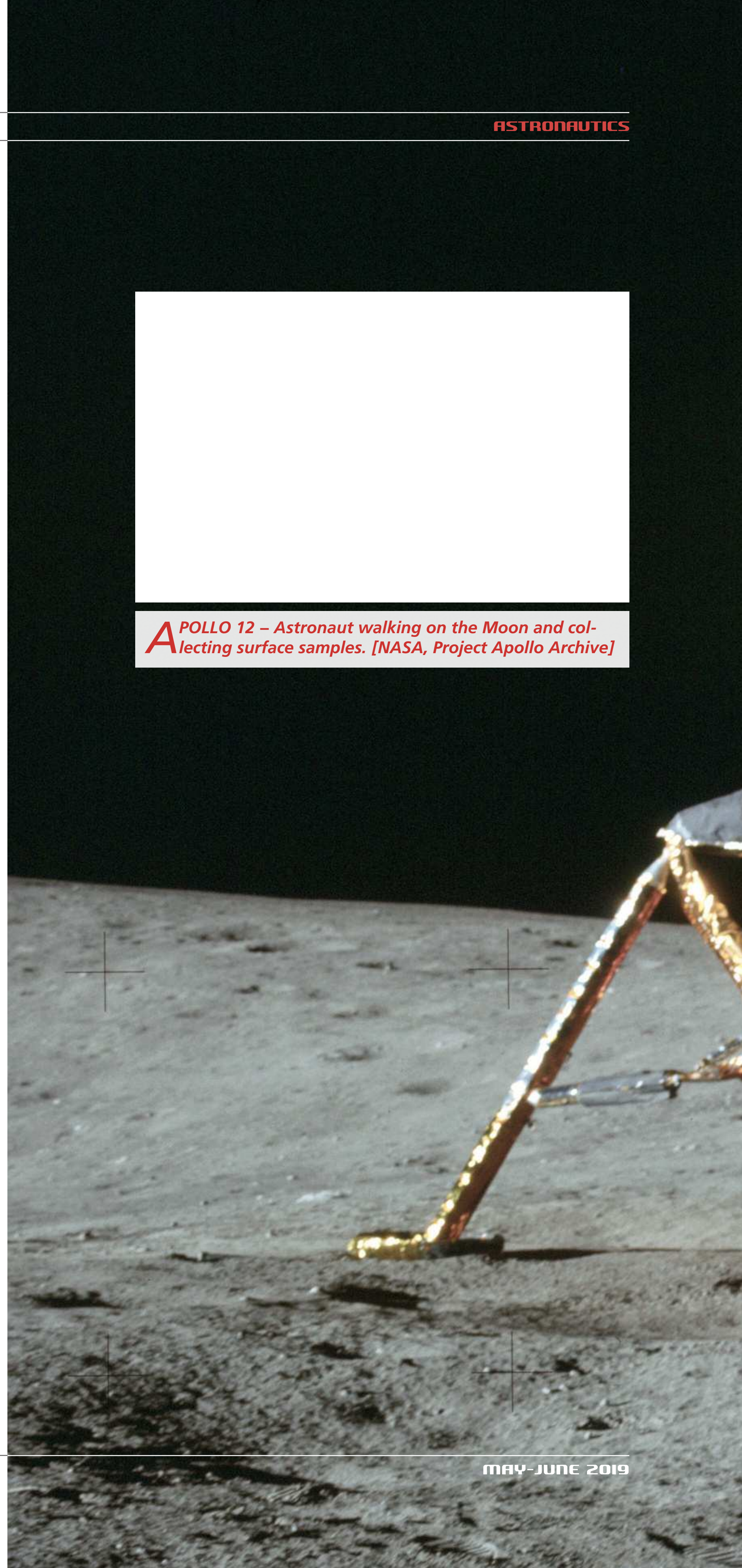


APOLLO 11 – Panorama from Apollo 11 showing Neil Armstrong at the LM, with the US flag and Solar Wind Experiment at left. [NASA, Project Apollo Archive]

essary to fill the gaps and make follow-up studies of the most interesting sites.

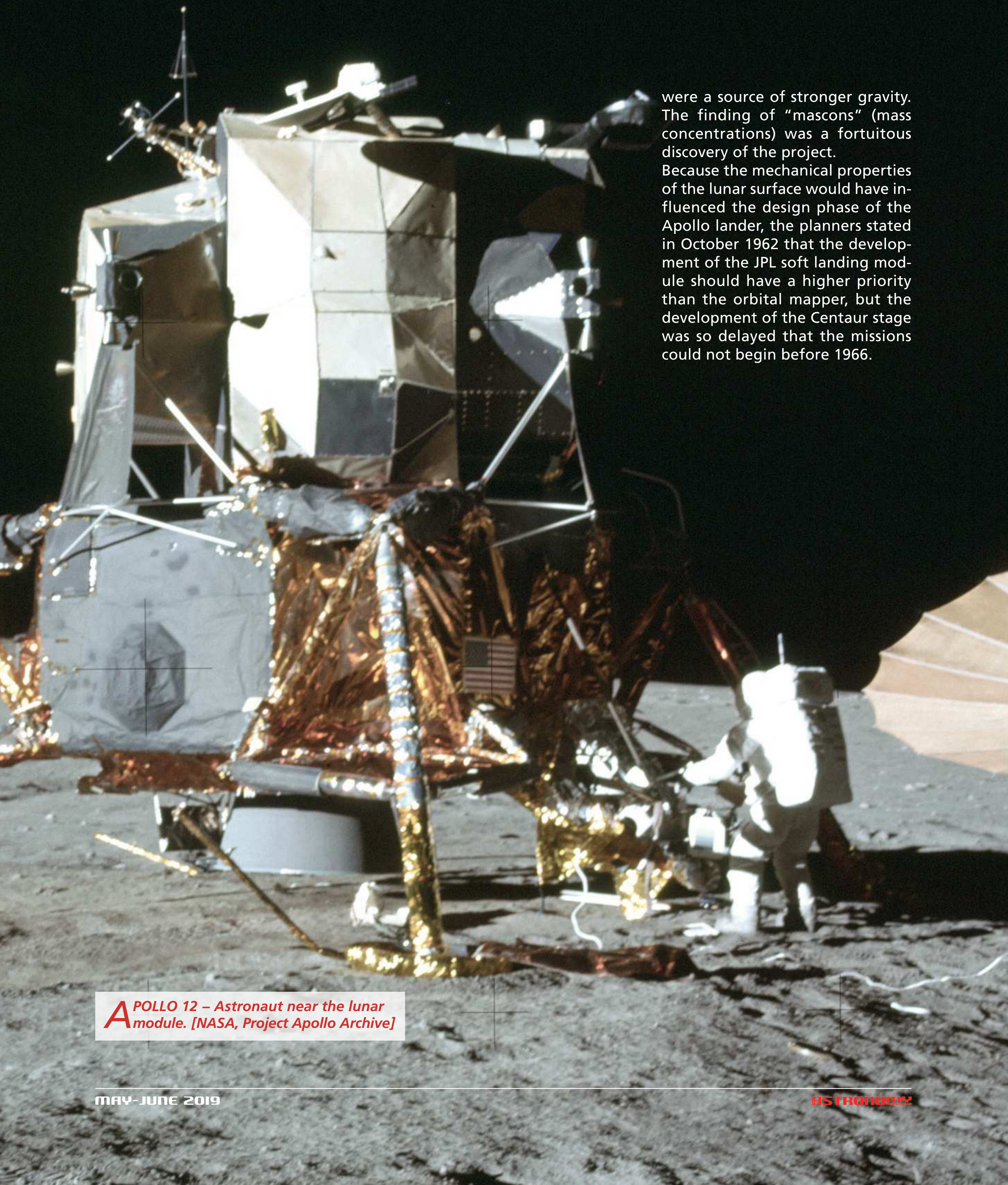
Lunar Orbiter 1 was launched on 10 August 1966 and entered lunar orbit on 14 August. In mapping mode, it had to take four narrow frames for each wide-angle image, so that the sequences contiguously covered the surface – but a motion compensator malfunction blurred the images taken up-close. Although the flight controllers considered an increase of the perilune to reduce blurring and map the entire Apollo destination area with a resolution of about 30 meters, it was decided to document the planned sites at a lower resolution. On August 29, Lunar Orbiter 1 photographed the ninth potential landing site on its target list, completing its main mission. The spacecraft transmitted the telemetry for another two months to assess the degradation of its systems, then was deorbited to clear the path for its successor, which entered service on 18 November. In addition to inspecting the eleven remaining candidate sites, Lunar Orbiter 2 was able to photograph a number of secondary sites that, while not im-

mediately of interest to Apollo selectors, were of scientific interest. In addition to its targets, Lunar Orbiter 2 had taken high-resolution images of the best sites of its predecessor. With all the candidate sites documented, the US Geological Survey produced terrain maps for Apollo designers.
In addition to photographing the most promising sites from different angles to facilitate stereoscopic studies for detailed topographic analysis, the next mission, the one of Lunar Orbiter 3, mapped approach routes. After achieving the project's goal using the first three spacecrafts, NASA left the remaining vehicles to scientists, who decided to fly them into near-polar orbits at higher altitudes for more general mapping.
In just one year, Lunar Orbiters not only fulfilled their purpose of probing sites likely to be Apollo's first landing locations, but they also returned the first clear views of the opposite hemisphere, significantly advanced knowledge of the regional geology of the near hemisphere, and identified more features of sites that could have been visited during subsequent missions. The Lunar Orbiter program had been a remarkable success. Even after they had finished shooting, the spacecrafts gave a glimpse of the lunar interior. Although Lunar Orbiter 1 was deorbited before the arrival of its successor, it was noted that its orbit had been disturbed, which meant that the Moon's gravitational field was inhomogeneous. To investigate the matter further, the subsequent spacecrafts were not deorbited until their attitude-control propellant was almost exhausted. By exploiting vehicles in both equatorial and polar orbits, it was possible to map the gravitational field in sufficient detail to reveal that the seas flooded by lava

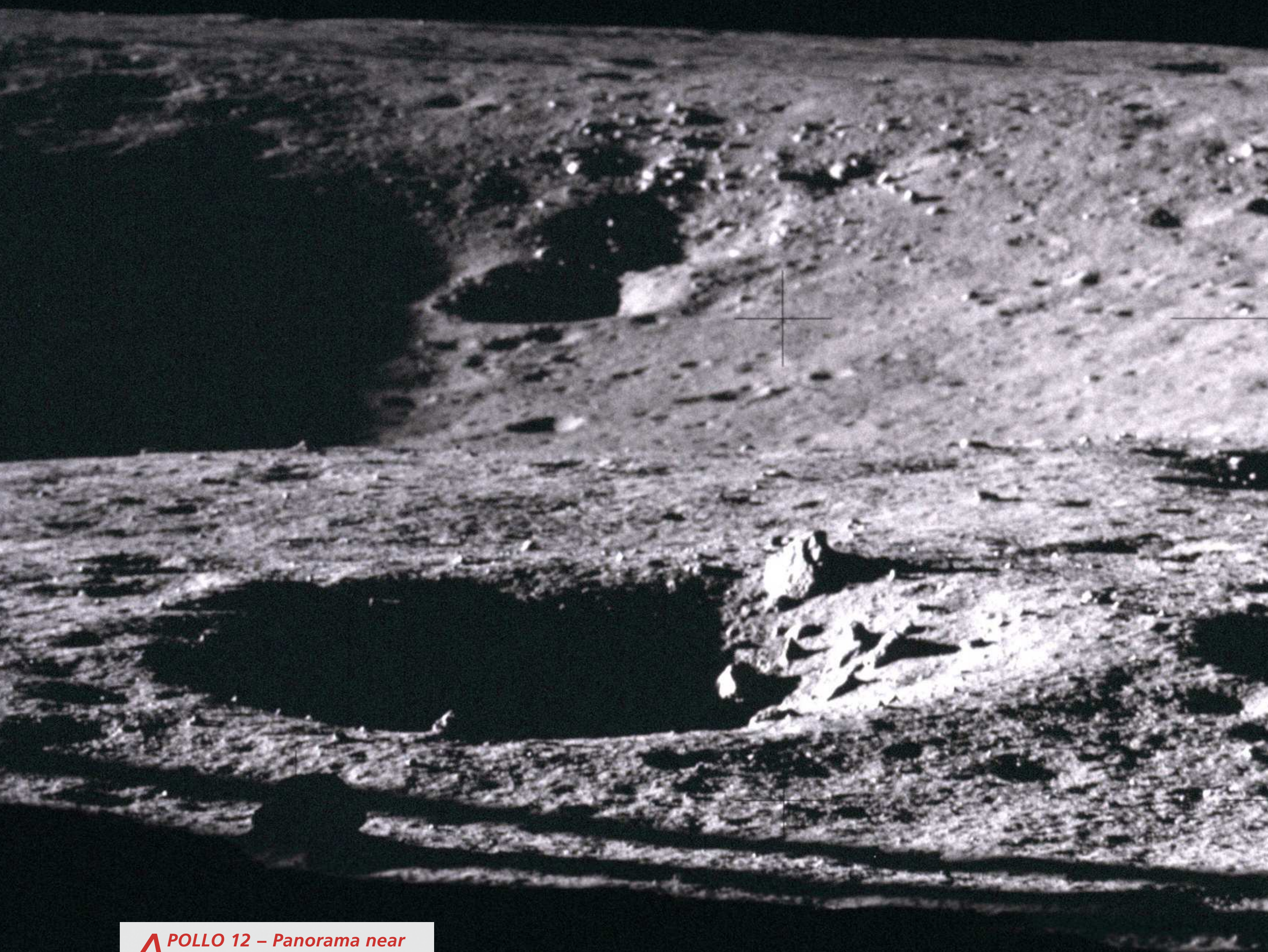


APOLLO 12 – Astronaut walking on the Moon and collecting surface samples. [NASA, Project Apollo Archive] were a source of stronger gravity. The finding of "mascons" (mass concentrations) was a fortuitous discovery of the project.

Because the mechanical properties of the lunar surface would have influenced the design phase of the Apollo lander, the planners stated in October 1962 that the development of the JPL soft landing module should have a higher priority than the orbital mapper, but the development of the Centaur stage was so delayed that the missions could not begin before 1966.

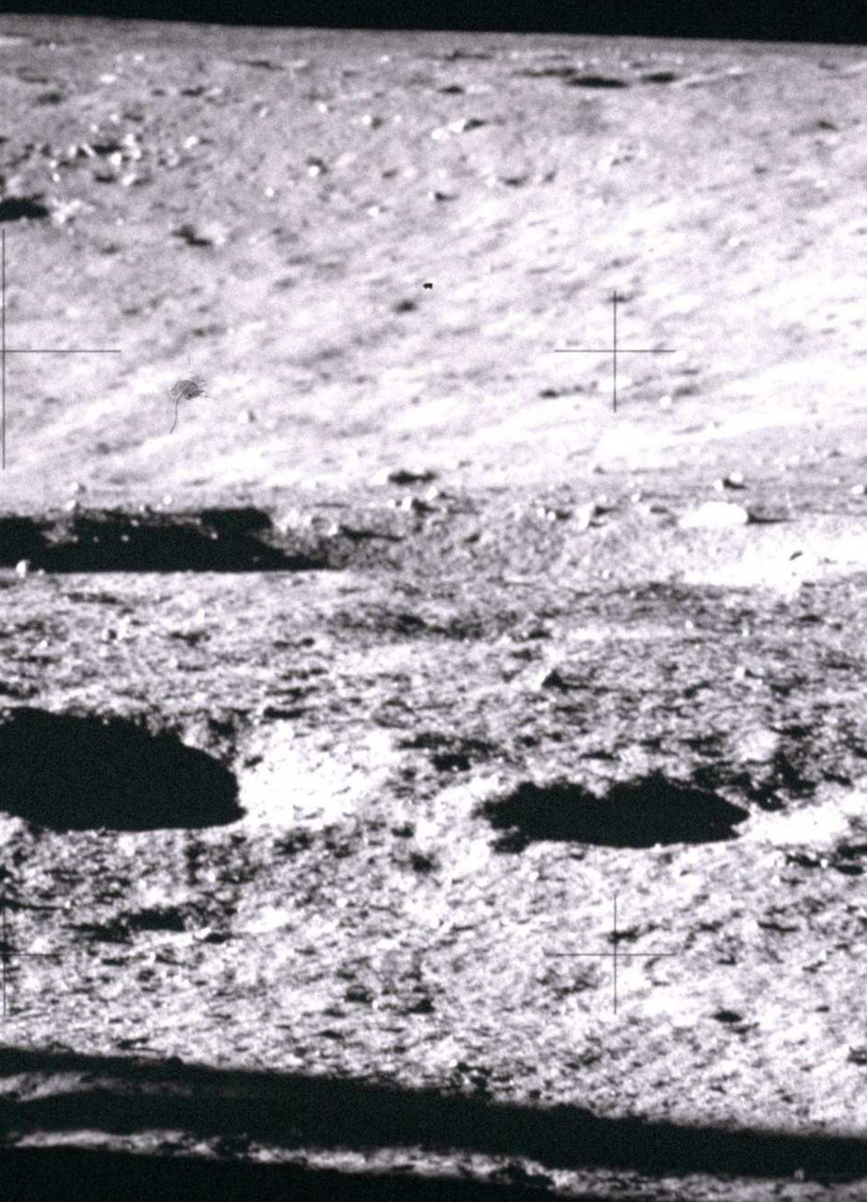


APOLLO 12 – Astronaut near the lunar module. [NASA, Project Apollo Archive]

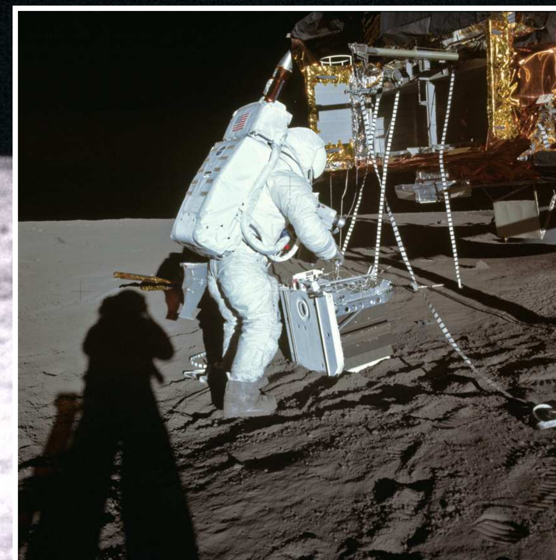


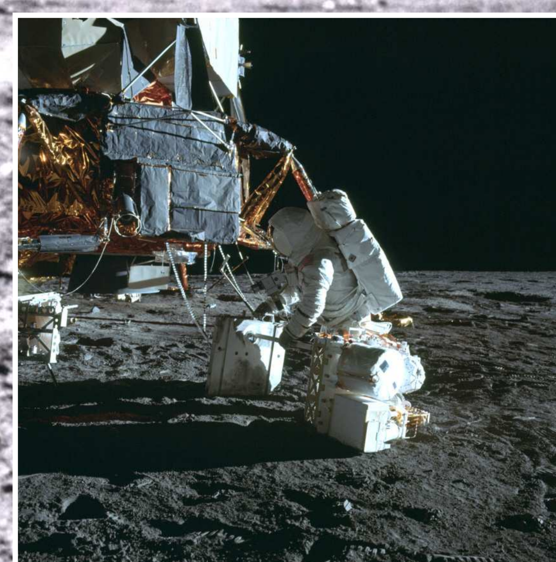
APOLLO 12 – Panorama near the lunar module. [NASA, Project Apollo Archive]

The designers faced the same dilemma as their Apollo counterpart – namely, where to direct the first mission. For security reasons, they were forced to choose a "marine" site. Indeed, this corresponded to the objective of characterizing the surface in the Apollo landing area.
When Surveyor 1 was launched on May 30, 1966, technicians hoped not to see a replica of the initial problems that had affected the Ranger series. Fortunately, the spacecraft safely landed inside Flamsteed, a crater on which a breach was opened by Oceanus Procellarum. As was the case for the later Ranger missons, the only instrument onboard was a camera. A multitude of small craters and rocks were visible, but the site was basically flat with a monotonous horizon. The spacecraft continued to transmit panoramas to document the appearance of the surface under different light and, at sunset, it went into hibernation for the two-week lunar night. To everyone's surprise, not only did it wake up when the



APOLLO 12 – Right and below, ALSEP (Apollo Lunar Surface Experiments Package) removal from the lunar module. [NASA, Project Apollo Archive]





Sun returned, but it did so every morning for the rest of the year. Having succeeded in the first attempt, there was bewilderment when, in September 1966, Surveyor 2 was lost due to a correction of its trajectory around the Moon.

In April 1967, Surveyor 3 landed in a crater 220 meters in diameter in Oceanus Procellarum, bouncing several times before stopping. The inner wall appeared covered with small craters, one of which had dug large blocks of rock, indicating that the regolith on the surface was not many meters thick. In addition to a camera, this lander had an arm equipped with a shovel to investigate the mechanical properties of the surface material, to dig small trenches, to inspect the near subsurface, and to roll rocks to determine the degree of selectivity of their erosion. Unlike its predecessor, Surveyor 3 survived only one lunar night. More unlucky was Surveyor 4, for which contact was lost several minutes before landing.

After sampling two western seas and failing to reach a site on the

APOLLO 12 – Astronaut at work with the ALSEP package. [NASA, Project Apollo Archive]

meridian, JPL sent Surveyor 5 to sample a sea in the eastern hemisphere. The probe landed in Mare Tranquillitatis, about 22 km away from the A3 site that had passed the Lunar Orbiter inspection and that had been shortlisted for the first Apollo landing. Surveyor 5 also landed in a crater, this time on a slope of 20 degrees. Instead of a shovel, it carried an instrument to study the chemical composition of the regolith. After taking a single reading, the probe activated its thrusters to "jump" a little lower down the slope to sample a second patch of regolith. The results indicated calcium, silicon, oxygen, aluminum and magnesium. This implied the existence of basalt, but the high ratio of iron-to-titanium suggested that it was slightly different from its terrestrial counterpart. Surveyor 6 was instead sent to Sinus Medii (among Mare Insularum and Mare Vaporum) to replace the science of its lost predecessors and landed without issue on November 10, 1967. The results of the chemical analysis indicated an iron-rich basalt.

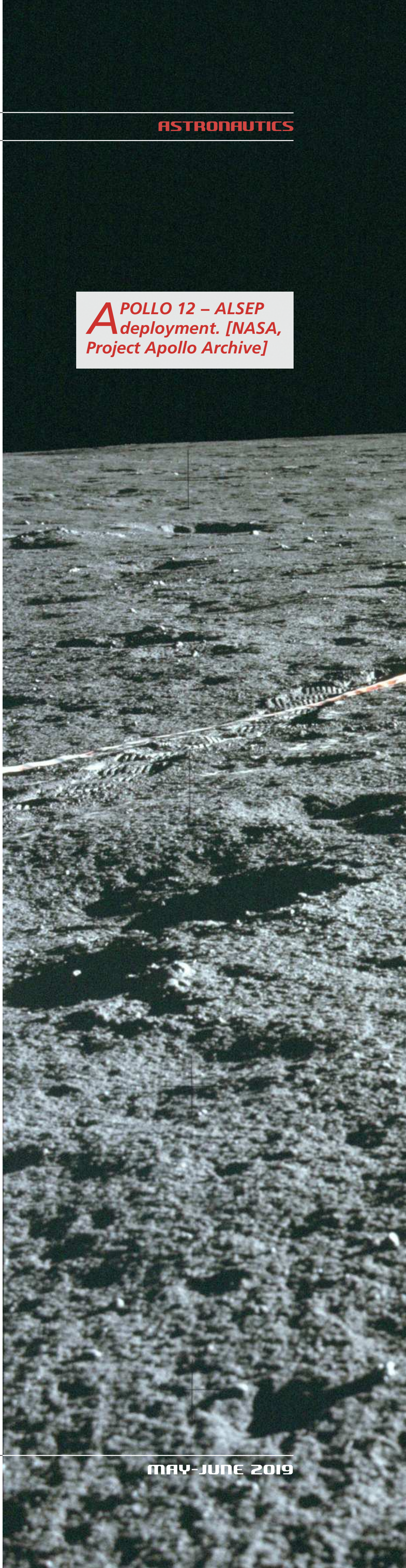
As we have seen, the goal of the Lunar Orbiter program was to pinpoint possible landing sites for Apollo. Since there was not enough film to search for other sites, technicians focused on those that seemed suitable based on telescopic studies. Possible sites for the first lunar landing were studied by the Apollo Site Selection Board for over two years. The thirty original candidate sites located on the near hemisphere, less than 45 degrees from the meridian and 5 degrees from the equator, were reduced to three by operational factors.

First, the flight dynamics research team insisted that the site should be located east of the lunar meridian in order to allow more space to the west for one or two sufficiently lighted backup sites, in case the launch had been postponed by several days. The launch window for a particular site opened only once a month and it was thought that it was better to visit a secondary site a few days later than to wait a month for the optimal site to reappear. This required that the primary candidate site was in the eastern hemisphere. The landing time was to be right after local dawn on the site, as the Sun had to be placed very low on the horizon to project a shadow sufficient to indicate the topography of the surface. Since the rotation of the Moon is synchronized with its orbital period around the Earth, it rotates once a month and the Sun crosses the lunar sky at a speed of 12 degrees in 24 hours, requiring the backup sites to be spaced apart 12 degrees in longitude so that the lighting was correct for each day of delay in the launch. On the other hand, the main site should not have been too far to the east, as this would not have allowed enough time, after crossing the limb, to check the navigation before starting the powered descent.

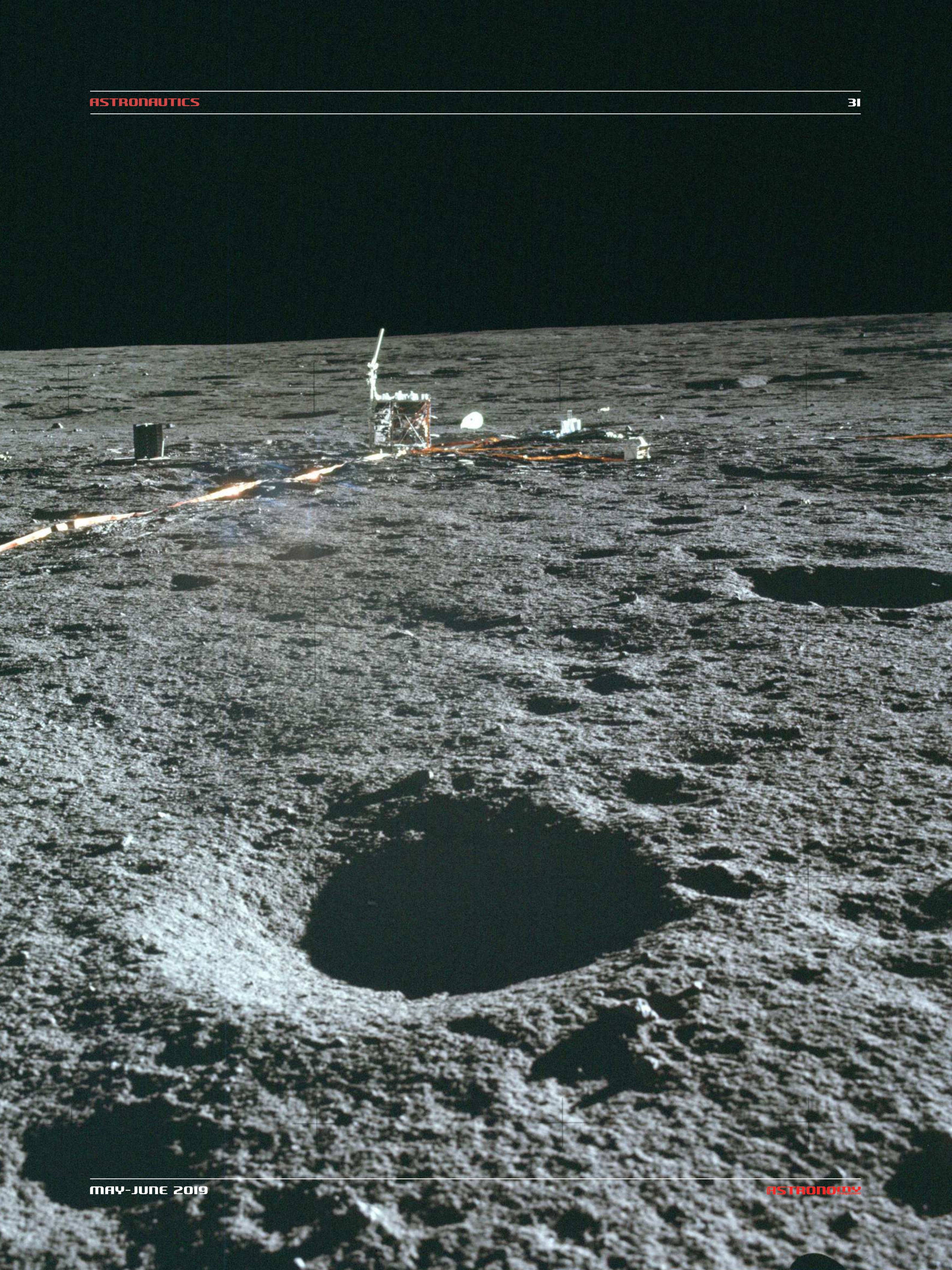
Second, the landing site had to be in a narrow band within 5 degrees of latitude from the lunar equator. A site at higher latitude would have involved a trajectory with greater propellant consumption, and the propellant economy was a priority for the first landing. In addition, not only should all considered sites be flat to minimize the need for maneuvering to avoid obstacles in the final phase of the descent, but the approaching ground needed to be level so as not to complicate the task of the landing radar.

These safety constraints limited the first landing to one of the eastern maria on the equator, establishing the main landing site in Mare Tranquillitatis or Mare Fecunditatis, the

backup site on the meridian and the reserves in the western hemisphere. Mare Fecunditatis was too far to the east to provide a comfortable margin for the final navigation update, leaving Apollo 11 assigned to Mare Tranquillitatis, where two useful sites were located. The trajectory of Apollo 8 (launched on December 21, 1968, when the Surveyor and Lunar Orbiter programs were almost a year past completion) was programmed to visualize the easternmost site, ALS-1, under ideal lighting. Apollo 10, on the other hand, performed a flyby of ALS-2 and reported it was generally appropriate, even though the furthest part of the landing ellipse was approximate.
A number of factors determined the launch windows for a lunar landing mission. These considerations included the lighting conditions at the time of launch, the launch pad azimuth, the geometry of translunar injection, the elevation angle of the Sun at the lunar landing site, the number and location of lunar landing sites, and the lighting conditions during the return to Earth. The time of a lunar landing was determined by the position of the site and the acceptable range of elevation angles of the Sun, which spanned from 5 to 14 degrees in an east-west direction. Under these conditions, the visible shadows of the craters would have helped the crew to recognize the topographic features.
The number of launch opportunities from Earth for a given lunar month was equal to the number of candidate landing sites. The launch time was mainly determined by the allowed variation in launchpad azimuth and by the position of the Moon at the arrival of the spacecraft. The spacecraft had to be launched on an orbital plane containing the position of the Moon and its antipode at the arrival of the spacecraft. A launch pad azimuth variation of 34 degrees allowed a launch period of four and a half hours. This period was called the "daily launch window", the timeframe in which the launch direction was within the required range to intercept the Moon. Every day, two launch windows were open: one was available for translunar injection out of Earth's orbit near the Pacific Ocean; the other was near the Atlantic Ocean.
The opportunity of injection over the Pacific Ocean was privileged because it generally allowed a daytime launch.
Apollo 11 demonstrated the lunar module's ability to land on the Moon, but the fact that it was moved away from the established site was embarrassing. The flight technicians developed a simple method to correct the disturbances of the mascons and were certain that it would have worked to reduce the size of the target ellipse. In addition, they decided to reduce the requirement from two backup sites to one.
There were five main sites in the shortlist for the first landing. The ALS-1 and ALS-2 sites, located east of Mare Tranquillitatis, were supported by ALS-3 in Sinus Medii, leaving ALS-4 and ALS-5 in Oceanus Procellarum as reserves in case of a prolonged launch delay. It would have been natural to send Apollo 12 to one of these sites, but the conservative constraints imposed during the first landing had led to the selection of open sites, and geologists were eager to sample the ejecta from a large-enough crater. Indeed, even prior to the Apollo 11 flight, landing site selectors established a list of craters for this eventuality. In principle, it had to be a simple matter of reviewing the sites rejected for the first landing



APOLLO 12 – ALSEP deployment. [NASA, Project Apollo Archive]

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because of the unpleasant proximity of a crater.

Although a number of strategic sites were identified near ALS-5, they were rather insignificant. A site in the large crater Hipparchus was considered insufficiently documented. The corrugated terrain north of the Fra Mauro crater was rejected as too demanding. The relaxation of the operational constraints made it possible to restore ALS-6. This was in the Flamsteed Ring, the big crater almost completely flooded by a lava flow from Oceanus Procellarum.

Moreover, the fact that ALS-6 was not far from where Surveyor 1 had landed prompted the flight dynamics team to propose it as a destination because positioning at a short distance from another spacecraft would have been a powerful demonstration of precision.

Unfortunately, since this site was so west, it had no backup site. But there was another spacecraft in the eastern part of Oceanus Procellarum that could have easily represented a backup to the west. It was a site selected for Surveyor 3, then discarded because it was too rough for Apollo, but eventually renamed ALS-7. In addition to exploring the most favorable sites for the first landing of Apollo, the Lunar Orbiter photographed many characteristic sites.

Nevertheless, this program was so focused on locating open sites for the first landing that the coverage of more difficult sites was too superficial to be certified. It was clear, therefore, that if Apollo had exploited the relaxation of the flight dynamics constraints, the early missions would have to search out-of-area sites for their successors.

Once the accuracy of the location had been demonstrated, it would have been possible to assign more specific targets rather than generic areas. Apollo 12 had to open this door. The choice of ALS-7 for Apollo 12 would allow it to scour Fra Mauro, the region of Descartes and Davy Rille, a chain of craters

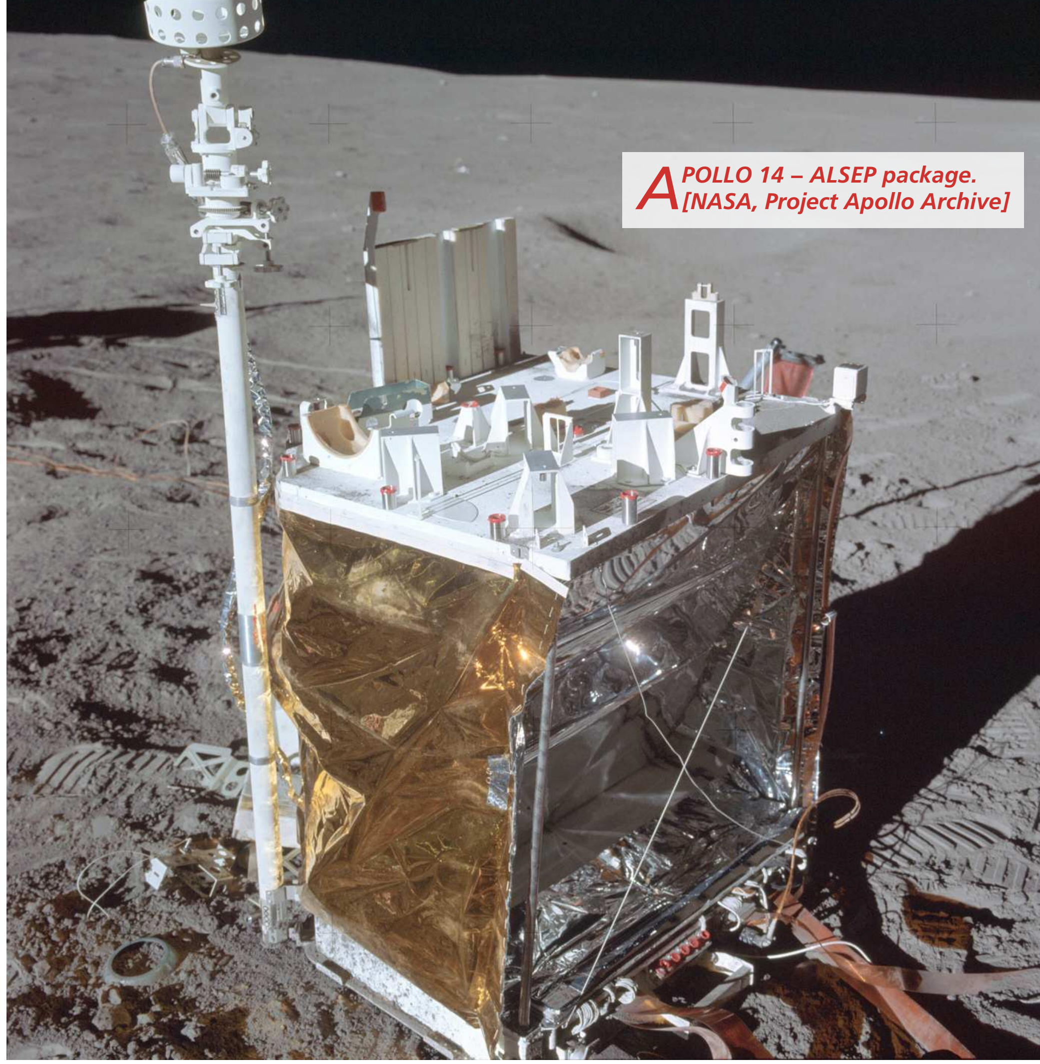
APOLLO 14 – View from west of the lunar module looking east. [NASA, Project Apollo Archive] considered by some as volcanic mouths along a geological fault. After making a precise landing with Apollo 12, the flight dynamics team felt confident enough to reduce the target ellipse and allow the next mission to aim for a smaller site on more rugged terrain.

Since an inclined orbit is more wasteful than an equatorial one, the thresholds of the propellant had been increased to escape the confinement of the equatorial zone. In addition, the need for a backup site had been eliminated. From that moment, the delay in the launch of a maximum of three days would have been remedied by landing with a less favorable Sun angle. This relaxation of the constraints, however, did not “open” the Moon, because the high latitude sites were still out of reach. Still, these relaxations offered an appreciated degree of flexibility. It was the narrowing of the target ellipse and the rejection of the requirement that the landing site should be free of reliefs that allowed for the consideration of more interesting sites.

Some geologists proposed to land inside a large crater like Hipparcus or Censorinus, but the preferences were for the territory to the north of Fra Mauro crater. In 1962, E. M. Cordonnier and R. J. Hackman published a stratigraphic study of Mare Imbrium. In extending this map, R. E. Eggleton decided to indicate the peripheral wavy ground as Imbrium ejecta and named it the Fra Mauro Formation. Although it was a single unit, it was divided into isolated areas on the periphery of the basin.

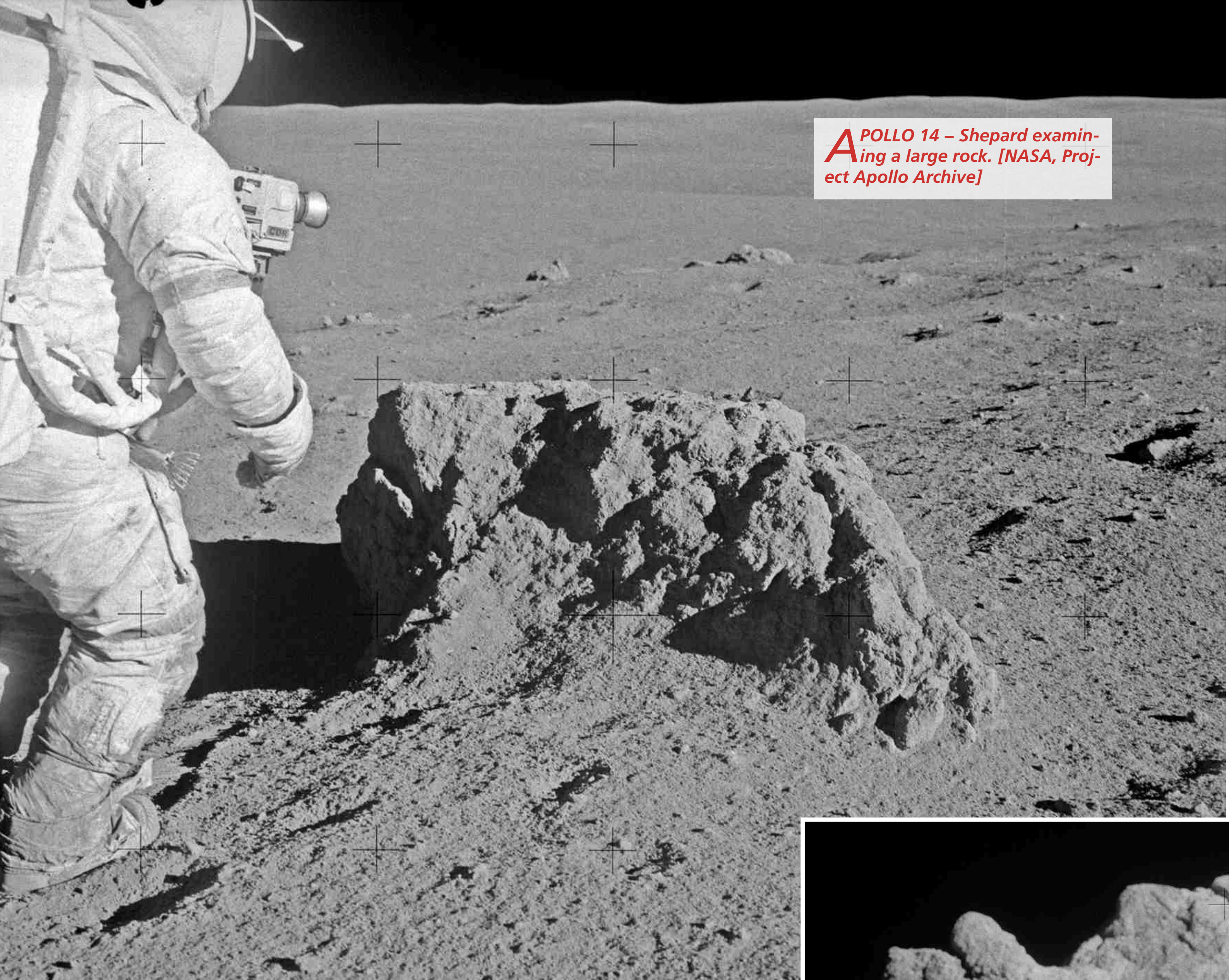
At the time, the understanding of the first lunar history was based on how the Imbrium ejecta had spread over thousands of kilometers, carving furrows. Dating Imbrium was the most important item on the

APOLLO 14 – Alan Shepard on the lunar surface from the lunar module looking NW. [NASA, Project Apollo Archive]



APOLLO 14 – ALSEP package. [NASA, Project Apollo Archive]

APOLLO 14 – Laser reflector. [NASA, Project Apollo Archive]

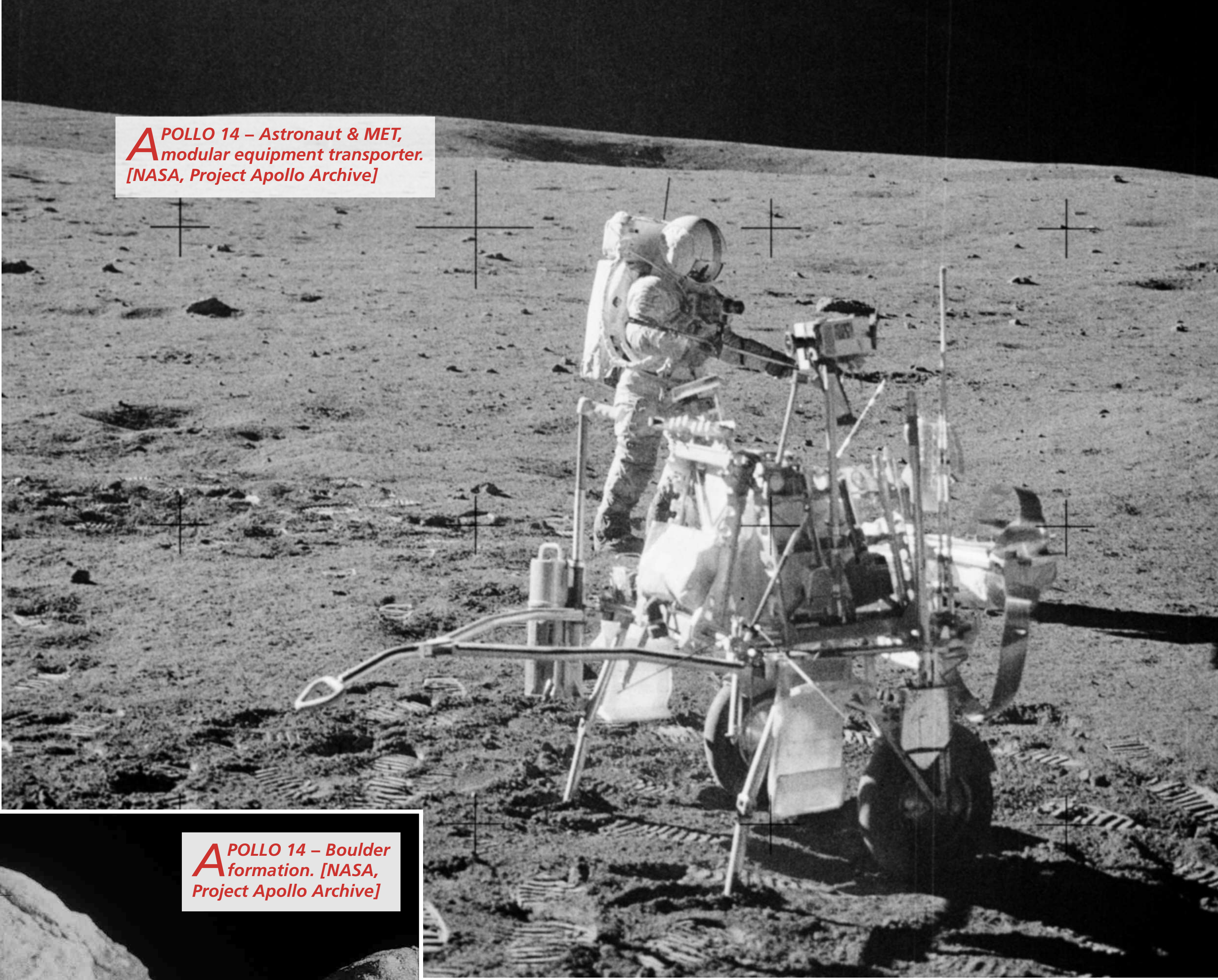


APOLLO 14 – Shepard examining a large rock. [NASA, Project Apollo Archive]

agenda, as many other structures would have been fixed over time. It was not just a question of knowing the Moon. The lunar basins indicated that the young Solar System was a very dynamic environment. If the Moon had been bombarded, the Earth would have suffered as well. Studying the Moon would have provided an idea about the ancient history of our planet.

On the Earth, recordings of this period are lacking, because the crust is recycled by plate tectonics. The Moon, for its part, is so quiescent that its face has remained virtually unchanged for billions of years. The task was to find, in the corrugated soil, a crater with a clear access line from the east, providing a landing point a few kilometers away and having a sharp rim. A cavity 400 meters in diameter was chosen, located 35 km north of Fra Mauro. Since this was exactly the type of terrain that was avoided during the search for safe sites, selectors ran the risk of certifying a site for which they had only four high-resolution photographs taken by Lunar Orbiter 3 for scientific interest. However, as it was located on the east coast of Oceanus Procellarum, the site was well lit during the Apollo 12 mission and it was possible to obtain new images.

In December 1969, Fra Mauro was confirmed as the landing site for Apollo 13. Given its shape, the crater to be sampled was called Cone. The best terrain for a landing was the relatively flat plain about 1



APOLLO 14 – Astronaut & MET, modular equipment transporter. [NASA, Project Apollo Archive]

APOLLO 14 – Boulder formation. [NASA, Project Apollo Archive]

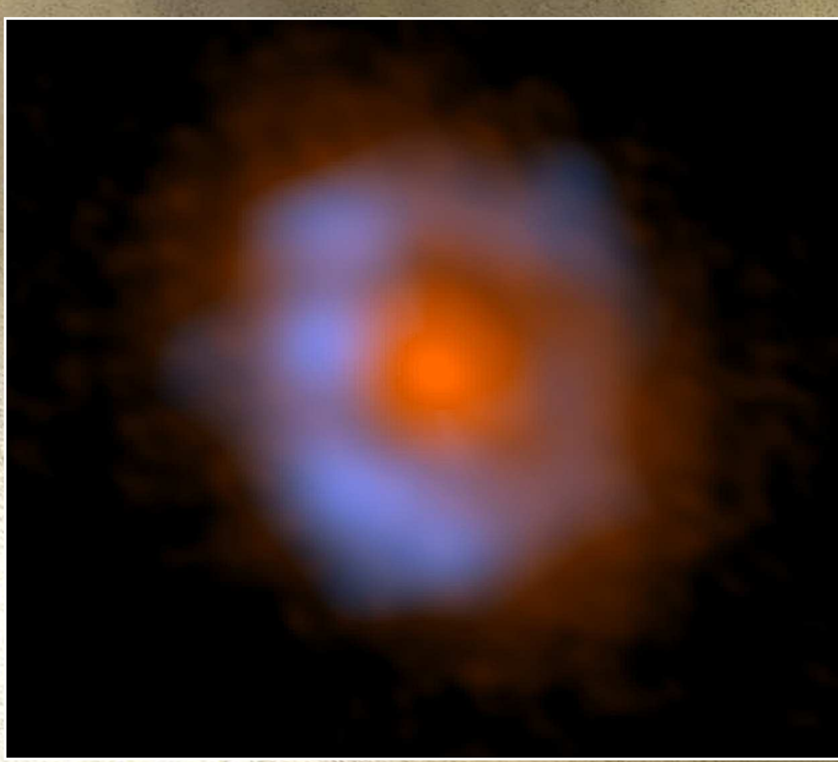
km west of the crater, but as it was too close to the edge of the Cone debris field, it was decided to go down twice as far as the crater. Cone was so vital to the geological objectives that there would be little merit for a landing beyond walking distance from the crater. Given the importance of the Fra Mauro Formation, whose sampling was assigned to Apollo 13 (a mission that lost its chance to land on the Moon), this site was reassigned to Apollo 14, which became the third successful lunar landing.

Although the main targets of Apollo 14 were the same as Apollo 13, steps were taken for returning a considerably larger quantity of lunar material and scientific data than in the past.

An innovation that allowed an increase in the exploration range of the lunar surface and in the quantity of material collected was the supply of a folding two-wheeled trolley, the Modular Equipment Transporter (MET), for the transportation of tools, cameras, a portable magnetometer and lunar samples. An investigation into the cause of the Apollo 13 cryogenic oxygen tank failure resulted in three major modifications to the Apollo 14 cryogenic oxygen storage system and feed systems. The internal construction of the oxygen tanks was modified, a third oxygen tank was added, and an auxiliary battery was installed. These changes were also incorporated into all subsequent spacecraft. ■

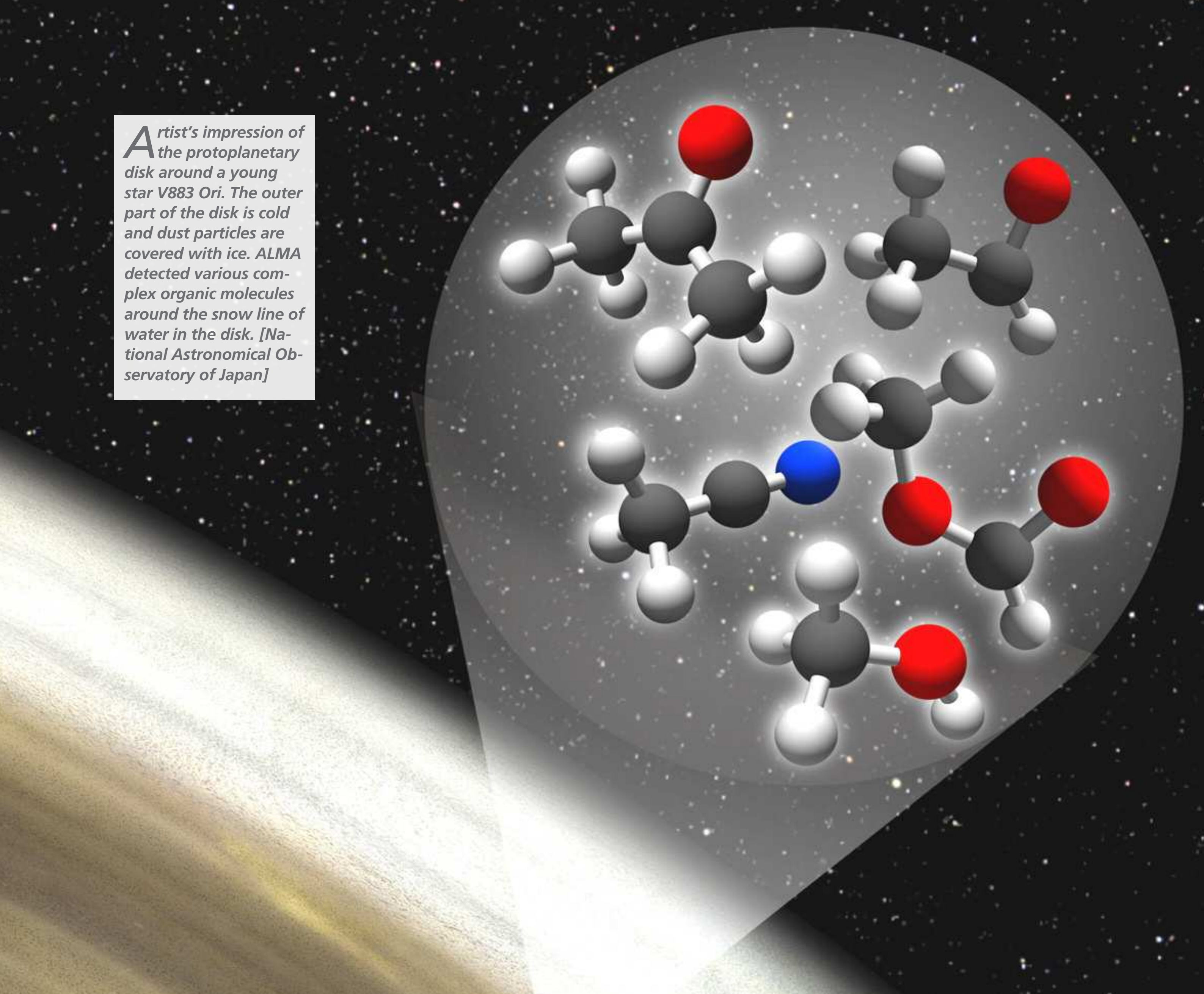
Retreating snow line reveals organic molecules around young star

by ALMA Observatory



False-color image of V883 Ori taken with ALMA. The distribution of dust is shown in orange and the distribution of methanol, an organic molecule, is shown in blue. [ALMA (ESO/NAOJ/NRAO), Lee et al.]

Astronomers using ALMA have detected various complex organic molecules around the young star V883 Ori. A sudden outburst from this star is releasing molecules from the icy compounds in the planet forming disk. The chemical composition of the disk is similar to that of comets in the modern Solar System. Sensitive ALMA observations enable astronomers to reconstruct the evolution of organic molecules from the birth of the Solar System to the objects we see today. The research team led by Jeong-Eun Lee (Kyung Hee University, Korea) used the Atacama Large Millimeter/ submillimeter Array to detect complex organic molecules including methanol



Artist's impression of the protoplanetary disk around a young star V883 Ori. The outer part of the disk is cold and dust particles are covered with ice. ALMA detected various complex organic molecules around the snow line of water in the disk. [National Astronomical Observatory of Japan]

(CH_3OH), acetone (CH_3COCH_3), acetaldehyde (CH_3CHO), methyl formate (CH_3OCHO), and acetonitrile (CH_3CN). This is the first time that acetone was unambiguously detected in a planet forming region or protoplanetary disk.

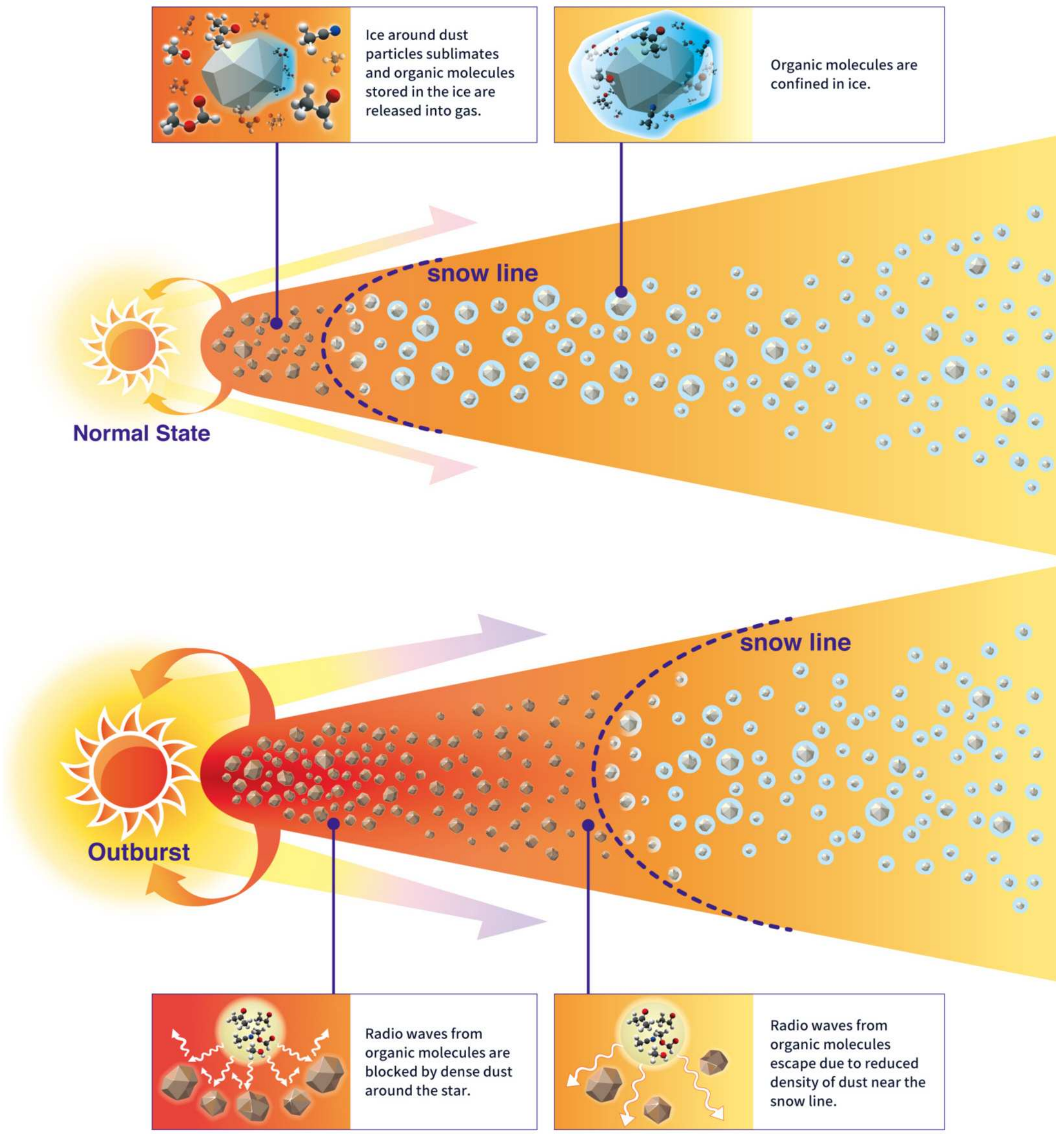
Various molecules are frozen in ice around micrometer-sized dust particles in protoplanetary disks. V883 Ori's sudden flare-up is heating the disk and sublimating the ice, which releases the molecules into gas. The region in a disk where the temperature reaches the sublimation temperature of the molecules is called the "snow line."

The radii of snow lines are about a few astronomical units (au) around normal young stars, however, they are enlarged almost 10 times around bursting stars.

"It is difficult to image a disk on the scale of a few au with current telescopes," said Lee. *"However, around an outburst star, ice melts in a wider area of the disk and it is easier to see the distribution of molecules. We are interested in the distribution of complex organic molecules as the building blocks of life."*

Ice, including frozen organic molecules, could be closely related to the origin of life on planets. In our Solar System, comets are the focus of attention because of their rich icy compounds. For example, the European Space Agency's legendary comet explorer Rosetta found rich organic chemistry around the comet Churyumov-Gerasimenko.

Comets are thought to have been formed in the outer colder region of the proto-Solar System, where the molecules were contained in ice.



Schematic illustration of the composition of protoplanetary disks in normal state and outburst phase. V883 Ori is experiencing an FU Orionis outburst and the increase in disk temperature pushes the snow line outward, causing various molecules contained in ice to be released into gas. [National Astronomical Observatory of Japan]

Probing the chemical composition of ice in protoplanetary disks is directly related to probing the origin of organic molecules in comets, and the origin of the building blocks of life.

Thanks to ALMA's sharp vision and the enlarged snow line due to the flare-up of the star, the astronomers obtained the spatial distribution of methanol and acetaldehyde. The distribution of these molecules has a ring-like structure with a radius of 60 au, which is twice the size of Neptune's orbit.

The researchers assume that inside of this ring the molecules are invisible because they are obscured by thick dusty material, and are invisible outside of this radius because they are frozen in ice.

"Since rocky and icy planets are made from solid material, the chemical composition of solids in disks is of special importance. An outburst is a unique chance to investigate fresh sublimates, and thus the composition of solids," says Yuri Aikawa at the University of Tokyo, a member of the research team.

V883 Ori is a young star located at 1300 light-years away from the Earth. This star is experiencing a so-called FU Orionis type outburst, a sudden increase of luminosity due to a bursting torrent of material flowing from the disk to the star.

These outbursts last only on the order of 100 years, therefore the chance to observe a burst is rather rare. However, since young stars with a wide range of ages experience FU Ori bursts, astronomers expect to be able to trace the chemical composition of ice throughout the evolution of young stars.

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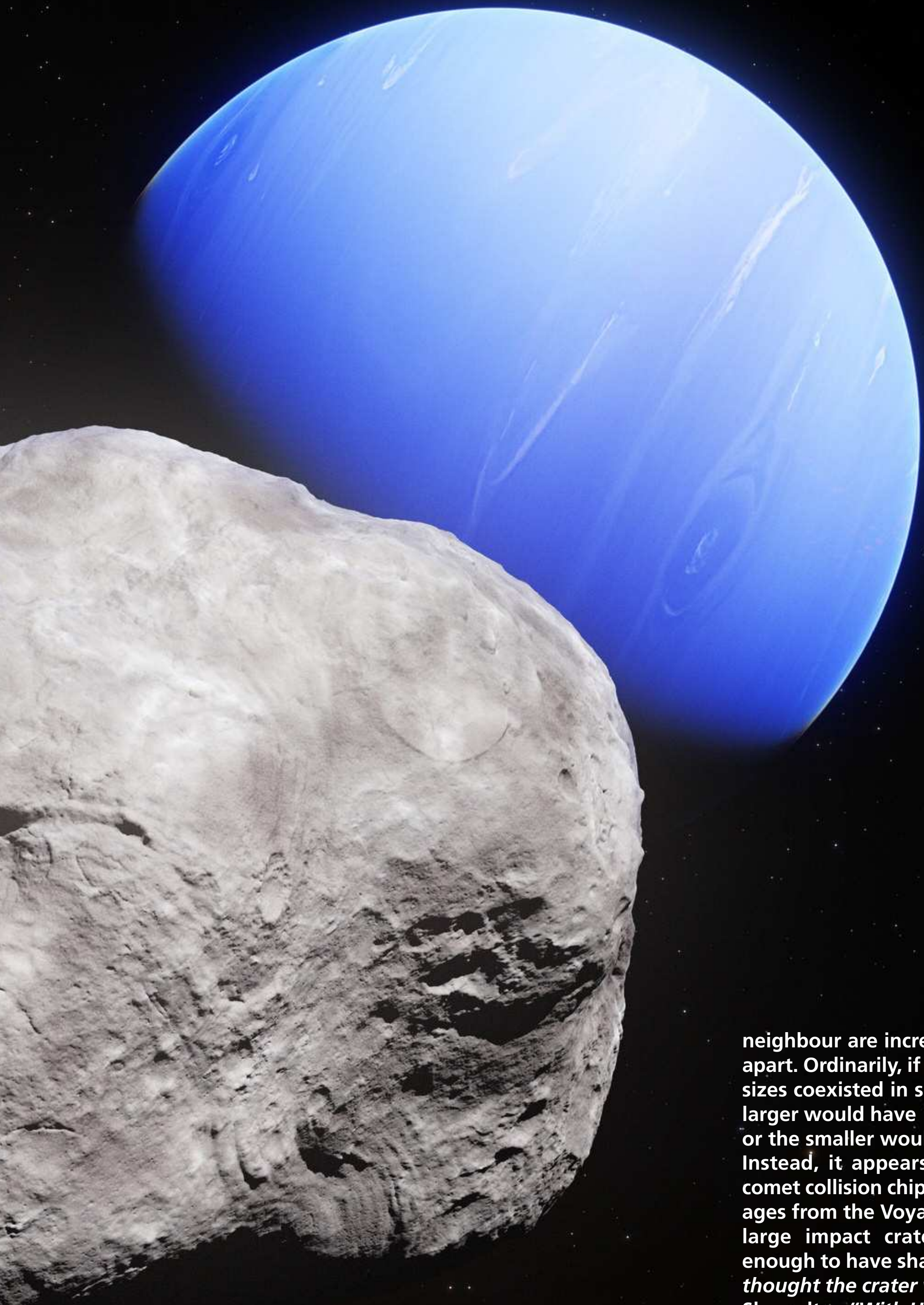
Hubble helps uncover origin of Neptune's smallest moon Hippocamp

by NASA/ESA

A team of astronomers, led by Mark Showalter of the SETI Institute, have used the NASA/ESA Hubble Space Telescope to study the origin of the smallest known moon orbiting the planet Neptune, discovered in 2013.
"The first thing we realised was that you wouldn't expect to find such a tiny moon right next to Neptune's biggest inner moon," said Mark Showalter. The tiny moon, with an estimated diameter of only about 34 km, was named Hippocamp and is likely to be a fragment from Proteus, Neptune's second-largest moon and the outermost of the inner moons. Hippocamp, formerly known as S/2004 N 1, is named after the sea creatures of the same name from Greek and Roman mythology. The orbits of Proteus and its tiny

This artist's animation shows how the smallest known moon of Neptune, now named Hippocamp, might look close up. In the animation the camera rotates once around the tiny moon, showing first the distant Sun and at the end the planet Neptune, which the moon is orbiting. [ESA/Hubble, L.Calçada]

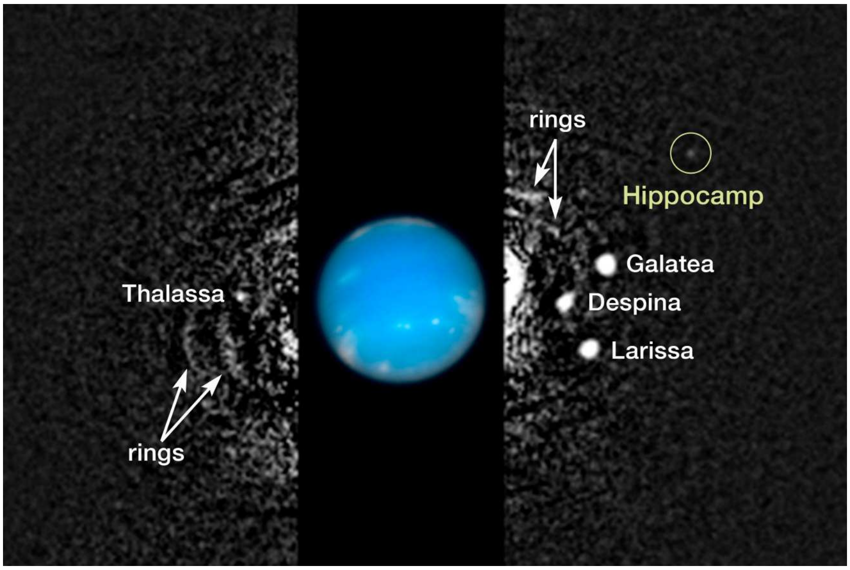


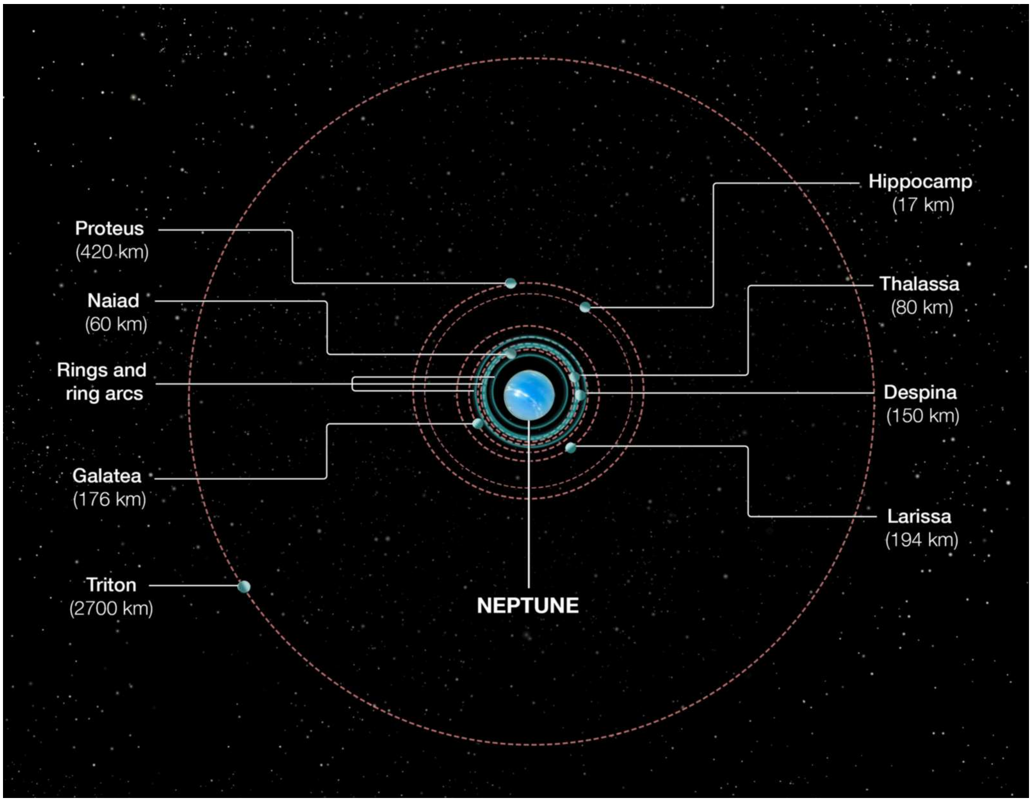
This artist's impression shows the outermost planet of the Solar System, Neptune, and its small moon Hippocamp. Hippocamp was discovered in images taken with the NASA/ESA Hubble Space Telescope. Whilst the images taken with Hubble allowed astronomers to discover the moon and also to measure its diameter, about 34 kilometres, these images do not allow us to see surface structures. [ESA/Hubble, NASA, L. Calçada]

neighbour are incredibly close, at only 12,000 km apart. Ordinarily, if two satellites of such different sizes coexisted in such close proximity, either the larger would have kicked the smaller out of orbit or the smaller would crash into the larger one.
Instead, it appears that billions of years ago a comet collision chipped off a chunk of Proteus. Images from the Voyager 2 probe from 1989 show a large impact crater on Proteus, almost large enough to have shattered the moon. *"In 1989, we thought the crater was the end of the story,"* said Showalter. *"With Hubble, now we know that a little piece of Proteus got left behind and we see it today as Hippocamp."*

Hippocamp is only the most recent result of the turbulent and violent history of Neptune's satellite system. Proteus itself formed billions of years ago after a cataclysmic event involving Neptune's satellites. The planet captured an enormous body from the Kuiper belt, now known to be Neptune's largest moon, Triton. The sudden presence of such a massive object in orbit tore apart all the other satellites in orbit at that time. The debris from shattered moons re-coalesced into the second generation of natural satellites that we see today. Later bombardment by comets led to the birth of Hippocamp, which can therefore be considered a third-generation satellite. *"Based on estimates of comet populations, we know that other moons in the outer Solar System have been hit by comets, smashed apart, and re-accreted multiple times,"* noted Jack Lissauer of NASA's Ames Research Center, California, USA, a coauthor of the new research. *"This pair of satellites provides a dramatic illustration that moons are sometimes broken apart by comets."*

This composite image shows the location of Neptune's moon Hippocamp, formerly known just as S/2004 N 1, orbiting the giant planet Neptune, about 4.8 billion kilometres from Earth. [NASA, ESA, and M. Showalter (SETI Institute)]





This diagram shows the orbital positions of Neptune's inner moons, which range in size from 17 to 420 kilometres in diameter. The outer moon Triton was captured from the Kuiper belt many billions of years ago. [NASA, ESA, and A. Feild (STScI)]

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ALMA differentiates two birth cries from a single star

by ALMA Observatory

Astronomers have unveiled the enigmatic origins of two different gas streams from a baby star. Using ALMA, they found that the slow outflow and the high speed jet from a protostar have misaligned axes and that the former started to be ejected earlier than the latter.

The origins of these two flows have been a mystery, but these observations provide telltale signs that these two streams were launched from different parts of the disk around the protostar.

Stars in the Universe have a wide range of masses, ranging from hundreds of times the mass of the Sun to less than a tenth of that of the Sun. To understand the origin of this variety, astronomers study the formation process of the stars, that is the aggregation of cosmic gas and dust. Baby stars collect the gas with their gravitational pull, however, some of the material is ejected by the protostars. This ejected material forms a stellar birth cry which provides clues to understand the process of mass accumulation.

Yuko Matsushita, a graduate student at Kyushu University and her team used ALMA to observe the detailed structure of the birth cry from the baby star MMS5/OMC-3 and found two different gaseous flows: a slow outflow and a fast jet. There have been a handful of examples with two flows seen in radio waves, but MMS5/OMC-3 is exceptional. *"Measuring the Doppler shift of the radio waves, we can estimate the speed and lifetime of the gas flows,"* said Matsushita, the lead author of the research paper that appeared in *The Astrophysical Journal*. *"We found that the jet and outflow were launched 500 years and 1300 years ago, respectively. These gas streams are quite young."*

More interestingly, the team found that the axes of the two flows are misaligned by 17 degrees. The axis of the flows can be changed over

Artist's impression of the baby star MMS5/OMC-3. ALMA observations identified two gas streams from the protostar, a collimated fast jet and a wide-angle slow outflow, and found that the axes of the two gas flows are misaligned. [NAOJ]

ALMA image of the protostar MMS5/OMC-3. The protostar is located at the center and the gas streams are ejected to the east and west (left and right). The slow outflow is shown in orange and the fast jet is shown in blue. It is obvious that the axes of the outflow and jet are misaligned. [ALMA (ESO/NAOJ/NRAO), Matsushita et al.]

long time periods due to the precession of the central star. But in this case, considering the extreme youth of the gas streams, researchers concluded that the misalignment is not due to precession but is related to the launching process. There are two competing models for the formation mechanism of the protostellar outflows and jets.

Some researchers assume that the two streams are formed independently in different parts of the gas disk around the central baby star, while others propose that the collocated jet is formed first, then it entrains the surrounding material to form the slower outflows.

Despite extensive research, astronomers had not yet reached a conclusive answer.

A misalignment in the two flows could occur in the 'independent model,' but is difficult in the 'entrainment model.' Moreover, the team found that the outflow was ejected considerably earlier than the jet. This clearly backs the 'independent model.'

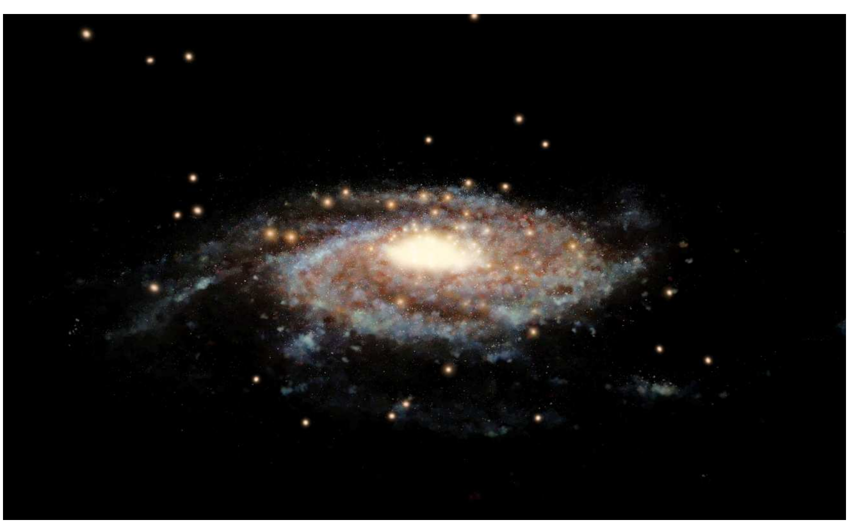
"The observation well matches the result of my simulation,"* said Masahiro Machida, a professor at Kyushu University. A decade ago, he performed pioneering simulation studies using a supercomputer operated by the National Astronomical Observatory of Japan. In the simulation, the wide-angle outflow is ejected from the outer area of the gaseous disk around a protostar, while the collimated jet is launched independently from the inner area of the disk. Machida continues, *"An observed misalignment between the two gas streams may indicate that the disk around the protostar is warped."

"ALMA's high sensitivity and high angular resolution will enable us to find more and more young, energetic outflow-and-jet-systems like MMS 5/OMC-3,"* said Satoko Takahashi, an astronomer at the National Astronomical Observatory of Japan and the Joint ALMA Observatory and co-author of the paper. *"They will provide clues to understand the driving mechanisms of outflows and jets. Moreover studying such objects will also tell us how the mass accretion and ejection processes work at the earliest stage of star formation."

Hubble & Gaia accurately weigh the Milky Way

by NASA/ESA

The mass of the Milky Way is one of the most fundamental measurements astronomers can make about our galactic home. However, despite decades of intense effort, even the best available estimates of the Milky Way's mass disagree wildly. Now, by combining new data from the European Space Agency (ESA) Gaia mission with observations made with the NASA/ESA Hubble Space Telescope, astronomers have found that the Milky Way weighs in at about 1.5 trillion solar masses within a radius of 129,000 light-years from the galactic centre. Previous estimates of the mass of the Milky Way ranged from 500 billion to 3 trillion times the mass of the Sun. This huge uncertainty arose primarily from the different methods used for measuring the distribution of dark matter — which makes up about 90% of the mass of the galaxy. *"We just can't detect dark matter directly,"* explains Laura Watkins (European Southern Observatory, Germany), who led the team performing the analysis. *"That's what leads to the present uncertainty in the Milky Way's mass — you can't measure accurately what you can't see!"*



This artist's impression shows a computer generated model of the Milky Way and the accurate positions of the globular clusters used in this study surrounding it. Scientists used the measured velocities of these 44 globular clusters to determine the total mass of the Milky Way, our cosmic home. [ESA/Hubble, NASA, L. Calçada]

Given the elusive nature of the dark matter, the team had to use a clever method to weigh the Milky Way, which relied on measuring the velocities of globular clusters — dense star clusters that orbit the spiral disc of the galaxy at great distances.

"The more massive a galaxy, the faster its clusters move under the pull of its gravity" explains N. Wyn Evans (University of Cambridge, UK). *"Most previous measurements have found the speed at which a cluster is approaching or receding from Earth, that is the velocity along our line of sight. However, we were able to also measure the sideways motion of the clusters, from which the total velocity, and consequently the galactic mass, can be calculated."*

The group used Gaia's second data release as a basis for their study. Gaia was designed to create a precise three-dimensional map of astronomical objects throughout the Milky Way and to track their motions. Its second data release includes measurements of globular clusters as far as 65,000 light-years from Earth.
"Global clusters extend out to a great distance, so they are considered the best tracers astronomers use to measure the mass of our galaxy," said Tony Sohn (Space Telescope Science Institute, USA), who led the Hubble measurements.
The team combined these data with Hubble's unparalleled sensitivity and observational legacy.
Observations from Hubble allowed faint and distant globular clusters, as far as 130,000 light-years from Earth, to be added to the study. As Hubble has been observing some of these objects for a decade, it was possible to accurately track the velocities of these clusters as well. *"We were lucky to have such a great combination of data,"* explained Roeland P. van der Marel (Space Telescope Science Institute, USA). *"By combining Gaia's measurements of 34 globular clusters with measurements of 12 more distant clusters from Hubble, we could pin down the Milky Way's mass in a way that would be impossible without these two space telescopes."*
Until now, not knowing the precise mass of the Milky Way has presented a problem for attempts to answer a lot of cosmological questions. The dark matter content of a galaxy and its distribution are intrinsically linked to the formation and growth of structures in the Universe. Accurately determining the mass for the Milky Way gives us a clearer understanding of where our galaxy sits in a cosmological context.

This globular cluster, NGC 4147, seen with the NASA/ESA Hubble Space Telescope, was one of many which were used by astronomers to measure the total mass of the Milky Way. NGC 4147 is located about 60,000 light-years from Earth in the northern constellation of Coma Berenices (the Berenice's hair). [ESA/Hubble & NASA, T. Sohn et al.]

This video highlights the new estimate of the mass of our home galaxy the Milky Way by Hubble & Gaia. [NASA/ESA]

Hiding black hole found

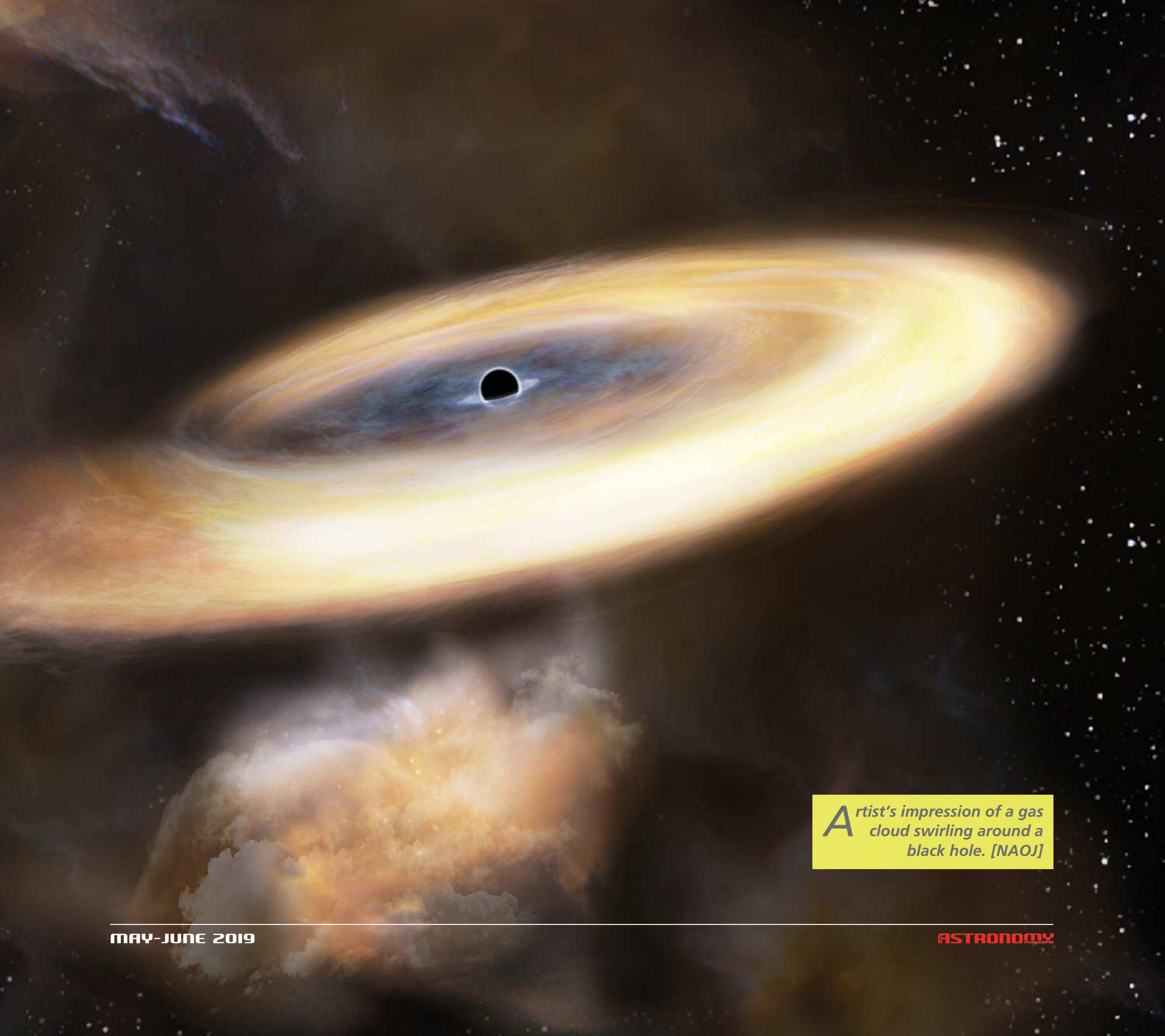
by ALMA Observatory

Astronomers have detected a stealthy black hole from its effects on an interstellar gas cloud. This intermediate mass black hole is one of over 100 million quiet black holes expected to be lurking in our galaxy. These results provide a new method to search for other hidden black holes and help us understand the growth and evolution of black holes.

Black holes are objects with such strong gravity that everything, including light, is sucked in and cannot escape. Because black holes do not emit light, astronomers must infer their existence from the effects their gravity produce in other objects. Black holes range in mass from about 5 times the mass of the Sun to supermassive black holes millions of times the mass of the Sun. Astronomers think that small black holes merge and gradually grow into large ones, but no one has [almost] ever found an intermediate mass, hundreds or thousands of times the mass of the Sun.

A research team led by Shunya Takekawa at the National Astronomical Observatory of Japan noticed HCN–0.009–0.044, a gas cloud moving strangely near the center of

the Galaxy 25,000 light-years away from Earth in the constellation Sagittarius. They used ALMA (Atacama Large Millimeter/submillimeter Array) to perform high resolution observations of the cloud and found that it is swirling around an invisible massive object.
Takekawa explains, *"Detailed kinematic analyses revealed that an enormous mass, 30,000 times that of the Sun, was concentrated in a region much smaller than our Solar System. This and the lack of any observed object at that location strongly suggests an intermediate-mass black hole. By analyzing other anomalous clouds, we hope to expose other quiet black holes."*
Tomoharu Oka, a professor at Keio University and coleader of the team, adds, *"It is significant that this intermediate mass black hole was found only 20 light-years from the supermassive black hole at the Galactic center. In the future, it will fall into the supermassive black hole; much like gas is currently falling into it. This supports the merger model of black hole growth."*



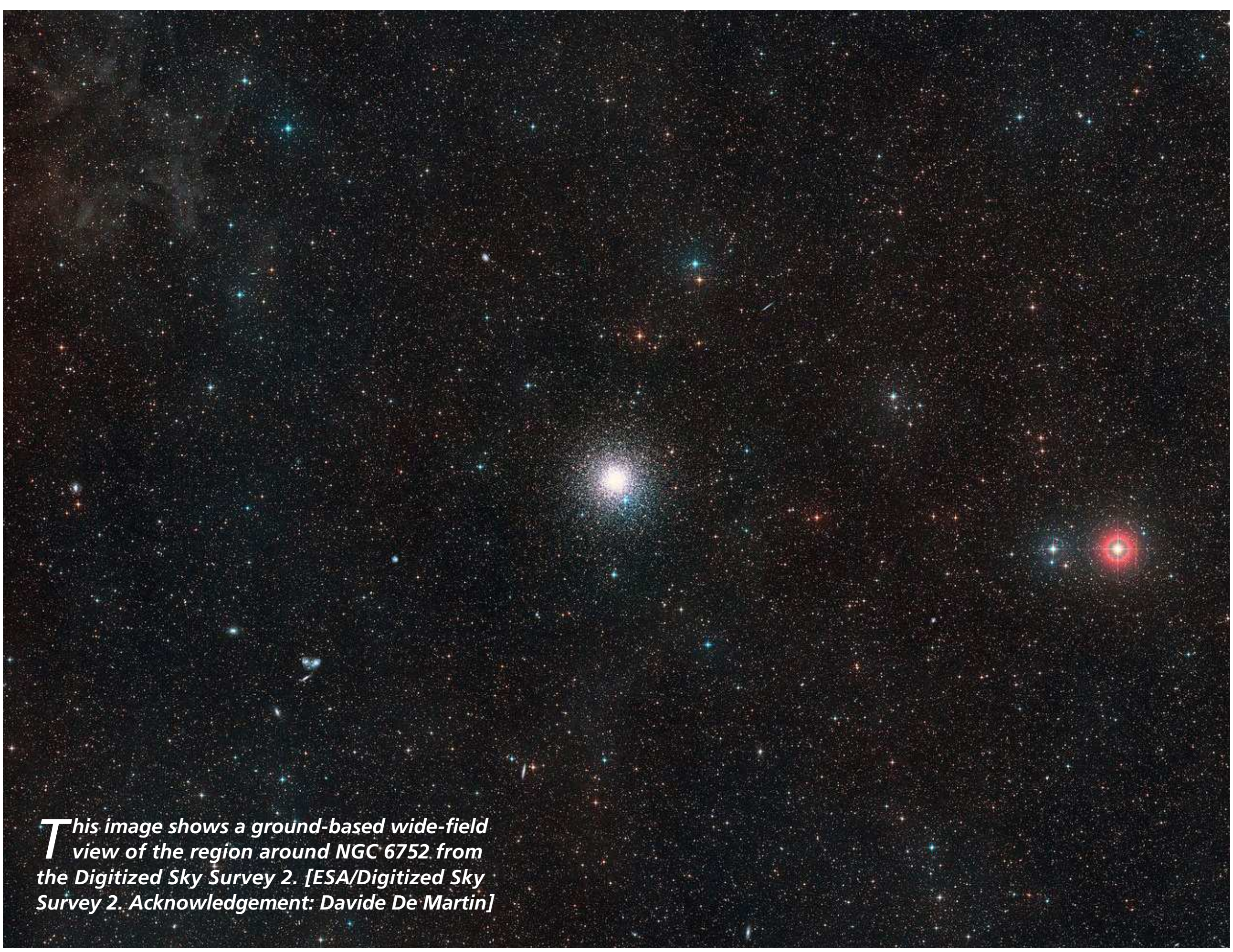
Artist's impression of a gas cloud swirling around a black hole. [NAOJ]

A new galaxy in the cosmic neighbourhood

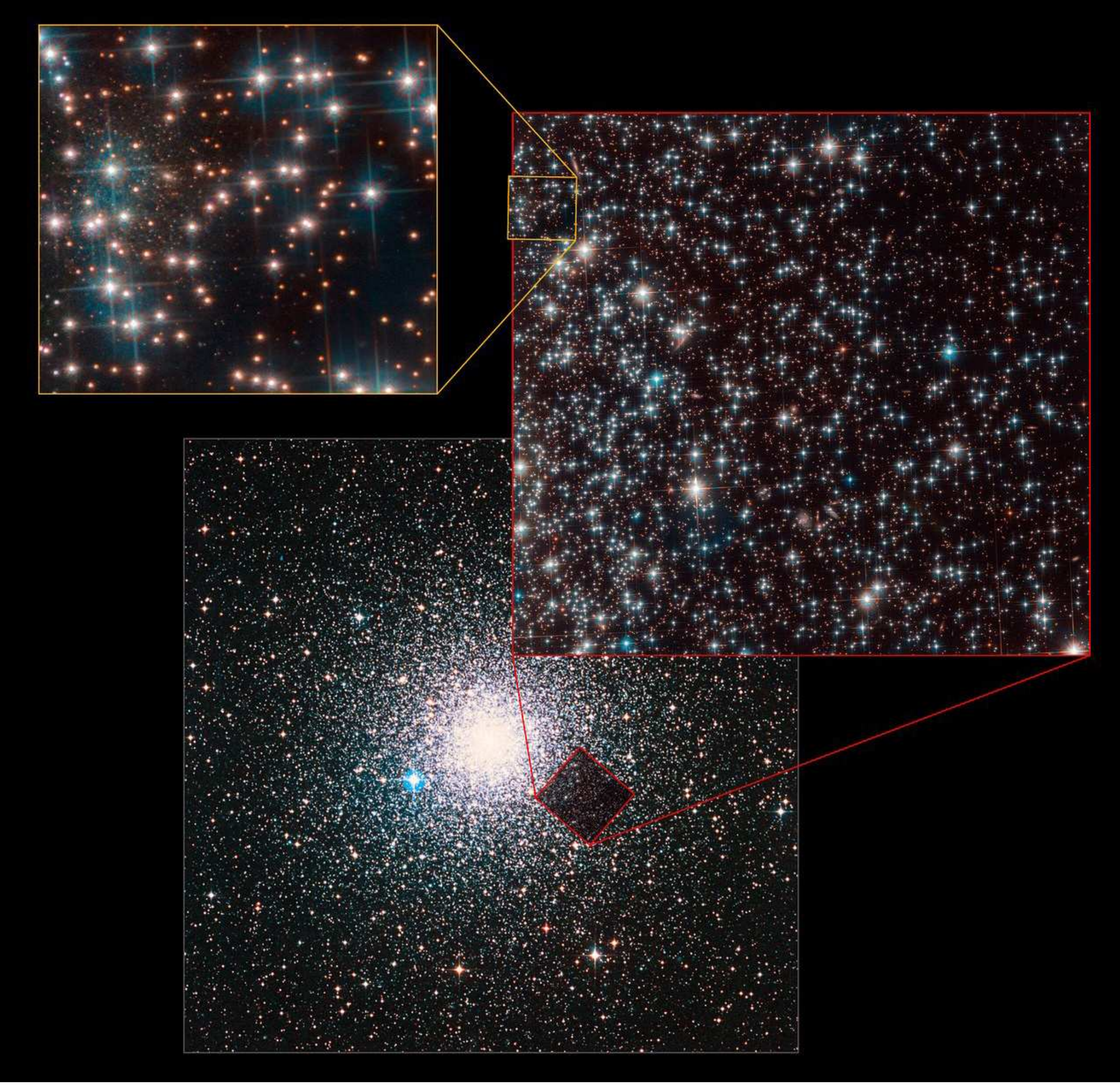
by NASA/ESA

An international team of astronomers recently used the NASA/ESA Hubble Space Telescope to study white dwarf stars within the globular cluster NGC 6752. The aim of their observations was to use these stars to measure the age of the globular cluster, but in the process they made an unexpected discovery.

In the outer fringes of the area observed with Hubble's Advanced Camera for Surveys a compact collection of stars was visible. After a careful analysis of their brightnesses



This image shows a ground-based wide-field view of the region around NGC 6752 from the Digitized Sky Survey 2. [ESA/Digitized Sky Survey 2. Acknowledgement: Davide De Martin]



and temperatures, the astronomers concluded that these stars did not belong to the cluster — which is part of the Milky Way — but rather they are millions of light-years more distant. Our newly discovered cosmic neighbour, nicknamed Bedin 1 by the astronomers, is a modestly sized, elongated galaxy. It measures only around 3000 light-years at its greatest extent — a fraction of the size of the Milky Way. Not only is it tiny, but it is also incredibly faint. These properties led astronomers to classify it as a dwarf spheroidal galaxy.

This computer animation, using real astronomical data from the NASA/ESA Hubble Space Telescopes and from ground-based telescopes, allows us to fly through the globular cluster NGC 6752 and shows the newly discovered dwarf galaxy Bedin 1 behind it. [ESA/Hubble, M. Kornmesser]

Dwarf spheroidal galaxies are defined by their small size, low-luminosity, lack of dust and old stellar populations. 36 galaxies of this type are already known to exist in the Local Group of Galaxies, 22 of which are satellite galaxies of the Milky Way.

While dwarf spheroidal galaxies are not uncommon, Bedin 1 has some notable features. Not only is it one of just a few dwarf spheroidals that have a well established distance but it is also extremely isolated. It lies about 30 million light-years from the Milky Way and 2 million light-years from the nearest plausible large galaxy host, NGC 6744. This makes it possibly the most isolated small dwarf galaxy discovered to date.

From the properties of its stars, astronomers were able to infer that the galaxy is around 13 billion years old — nearly as old as the Universe itself. Because of its isolation — which resulted in hardly any interaction with other galaxies — and its age, Bedin 1 is the astronomical equivalent of a living fossil from the early Universe.

The discovery of Bedin 1 was a truly serendipitous find. Very few Hubble images allow such faint objects to be seen, and they cover only a small area of the sky. Future telescopes with a large field of view, such as the WFIRST telescope, will have cameras covering a much larger area of the sky and may find many more of these galactic neighbours. ■

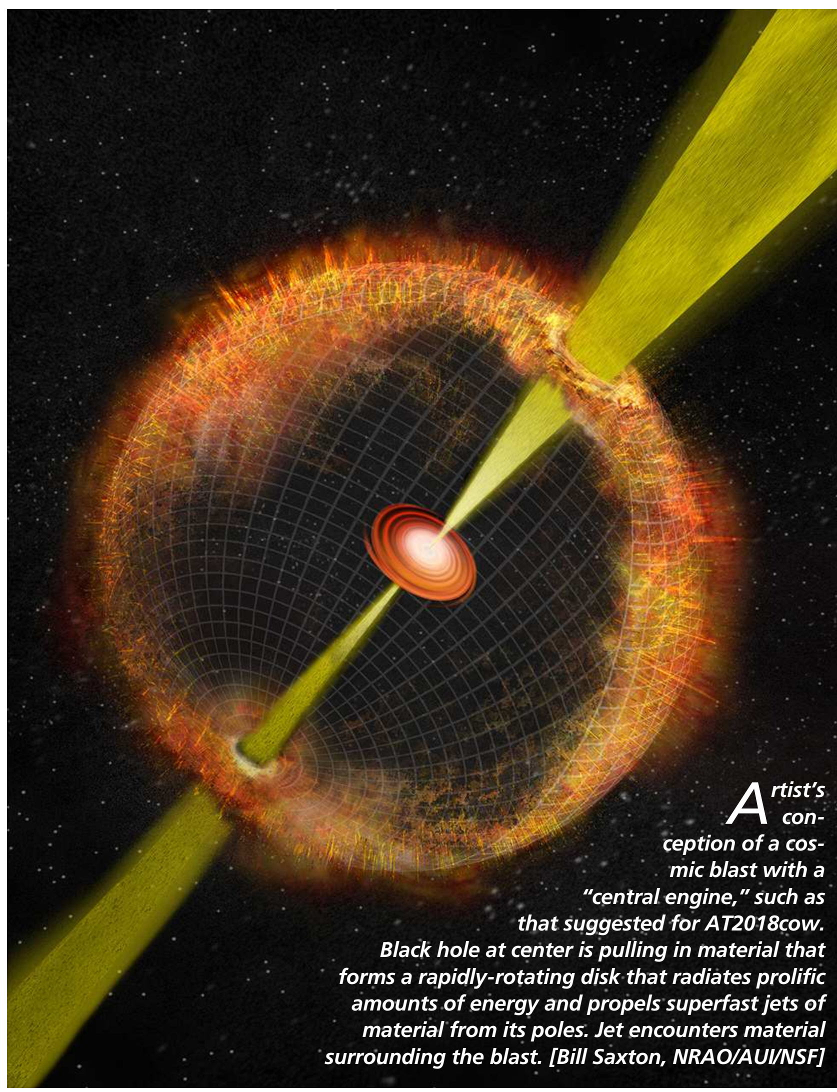
Astronomers study mysterious new type of cosmic blast

by ALMA Observatory

When astronomers discovered a cosmic explosion in a galaxy nearly 200 million light-years from Earth last June 16, they soon realized it was something different. While still debating the details, scientists now believe they may have gotten their first glimpse of the birth of a powerful phenomenon seen throughout the Universe.

The explosion was discovered by the ATLAS all-sky survey system in Hawaii, and immediately got the attention of astronomers. First, it was unusually bright for a supernova explosion — a common source of such outbursts. In addition, it brightened, then faded, much faster than expected.

Half a year later, *"despite being one of the most intensely studied cosmic events in history, watched by astronomers all over the world, we still don't know what it is,"* said Anna Ho, of Caltech, who led a team using the Atacama Large Millimeter/submillimeter Array (ALMA), in Chile, among other telescopes. The object, dubbed AT2018cow, *"heralds a new class of energetic cosmic blasts,"* Ho added. The explosion's unusual characteristics *"were enough to get everybody excited,"* said Raffaella Margutti, of Northwestern University, who led a



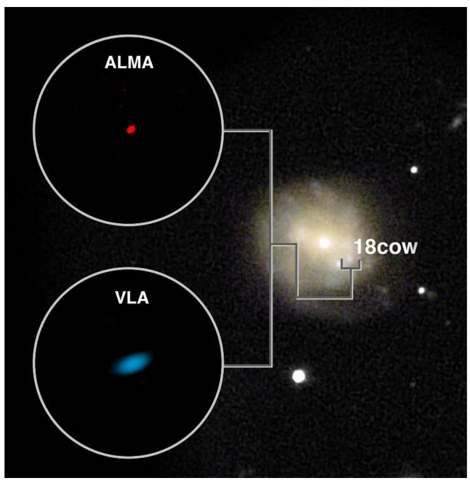
Artist's conception of a cosmic blast with a "central engine," such as that suggested for AT2018cow. Black hole at center is pulling in material that forms a rapidly-rotating disk that radiates prolific amounts of energy and propels superfast jets of material from its poles. Jet encounters material surrounding the blast. [Bill Saxton, NRAO/AUI/NSF] team that used telescopes ranging from gamma rays to radio waves, including the National Science Foundation's Karl G. Jansky Very Large Array (VLA), to study the object. *"In addition, AT2018cow's distance of 200 million light-years, is nearby, by astronomical standards, making it an excellent target for study,"* Margutti said.

Astronomers presented their findings about the object at the American Astronomical Society's meeting in Seattle, Washington.

After watching the object and measuring its changing characteristics with a worldwide collection of ground-based and orbiting telescopes, scientists still are not sure exactly what it is, but they have two leading explanations. It may be, they suspect, either a very unusual supernova, or the shredding of a star that passed too close to a massive black hole, called a Tidal Disruption Event (TDE).

Researchers are quick to point out, however, that the object's characteristics don't match previously-seen examples of either one. *"If it is a supernova, then it is unlike any supernova we have ever seen,"* Ho said. The object's range of colors, or spectrum, she said, *"doesn't look like a supernova at all."* In addition, it was brighter in millimeter waves — those seen by ALMA — than any other supernova. It also differs from previously-seen Tidal Disruption Events.

"It's off-center in its host galaxy," Deanne Coppejans, of Northwestern University, said, meaning it can't be a star shredded by the supermassive black hole at the galaxy's center. *"If it's a TDE, then we need an intermediate mass black hole to do the shredding, and those are expected to form in stellar clusters,"* Kate Alexander, an Einstein Fellow at Northwestern, added. The problem with that, she pointed out, is that AT2018cow appears to be inside a high-density interstellar medium, which *"is difficult to reconcile with the density of gas in stellar clusters."*



ALMA and VLA images of the mysterious new type of cosmic blast, AT2018cow at left. Visible-light image of outburst in its host galaxy at right. Images not to same scale. Images of the blast itself do not indicate its size, but are the result of its brightness and the characteristics of the telescopes. [Sophia Dagnello, NRAO/AUI/NSF; R. Margutti, W.M. Keck Observatory; Ho, et al.]

Most of the researchers agree that AT2018cow's behavior requires a central source of ongoing energy unlike those of other supernova explosions. The best candidate, they said, is a black hole that is drawing material from its surroundings. The inflowing material forms a rotating disk around the black hole and that disk radiates prolific amounts of energy. This is the type of "central engine" that powers quasars and radio galaxies throughout the Universe as well as smaller examples such as microquasars.

When a star much more massive than the Sun ceases thermonuclear fusion and collapses of its own gravity, producing a "normal" supernova explosion, no such central engine is produced. However, in the extreme cases called hypernovas, which produce gamma ray bursts, such a central engine produces the superfast jets of material that generate the gamma rays. That engine, however is very short-lived, lasting only a matter of seconds.

If such a central engine powered AT2018cow, it lasted for weeks, making this event distinct from the collapse-induced explosions of supernovas and the more-energetic such explosions that produce gamma ray bursts. In the case of a TDE, the "engine" would come to life as the black hole drew in material from the star shredded by its gravitational pull.

Alternatively, the "engine" resulting from a supernova explosion might be a rapidly-rotating neutron star with an extremely powerful magnetic field — a magnetar.

"We know from theory that black holes and neutron stars form when a star dies, but we've never seen them right after they are born. Never," Margutti said.

"This is very exciting, since it would be the first time that astronomers have witnessed the birth of a central engine," Ho said.

However, because of AT2018cow's strange behavior, the verdict still is unclear, the scientists said.

The central energy source could be a powerful shock wave hitting a dense shell of material at the object's core. Either the strange supernova or the TDE explanation still is viable, Ho's team said.

The astronomers look forward to more work on AT2018cow and to more objects like it.

"During the first few weeks, this object was very bright at millimeter wavelengths, so that means that, with ALMA now available, we may be able to find and study others," Ho said. *"The peak strength of the radio emission starts at ALMA wavelengths, and only moved to VLA wavelengths after a few weeks,"* she added. ■

Liberal sprinkling of salt discovered around a young star

by ALMA Observatory

A team of astronomers and chemists using the Atacama Large Millimeter/submillimeter Array (ALMA) has detected the chemical fingerprints of sodium chloride (NaCl) and other similar salty compounds emanating from the dusty disk surrounding Orion Source I, a massive, young star in a dusty cloud behind the Orion Nebula.

"It's amazing we're seeing these molecules at all," said Adam Ginsburg, a Jansky Fellow of the National Radio Astronomy Observatory (NRAO) in Socorro, New Mexico, and lead author of a paper accepted for publication in *The Astrophysical Journal*. *"Since we've only ever seen these compounds in the sloughed-off outer layers of dying stars, we don't fully know what our new discovery means. The nature of the detection, however, shows that the environment around this star is very unusual."* To detect molecules in space, astronomers use radio telescopes to search for their chemical signatures – telltale spikes in the spread-out spectra of radio and millimeter-wavelength light. Atoms and molecules emit these signals in several ways, depending on the temperature of their environments.

The new ALMA observations contain a bristling array of spectral signatures – or transitions, as astronomers refer to them – of the same molecules. To create such strong and varied molecular fingerprints, the temperature differences where the molecules reside must be extreme, ranging anywhere from 100 kelvin to 4,000 kelvin (about -175 Celsius to 3700 Celsius).

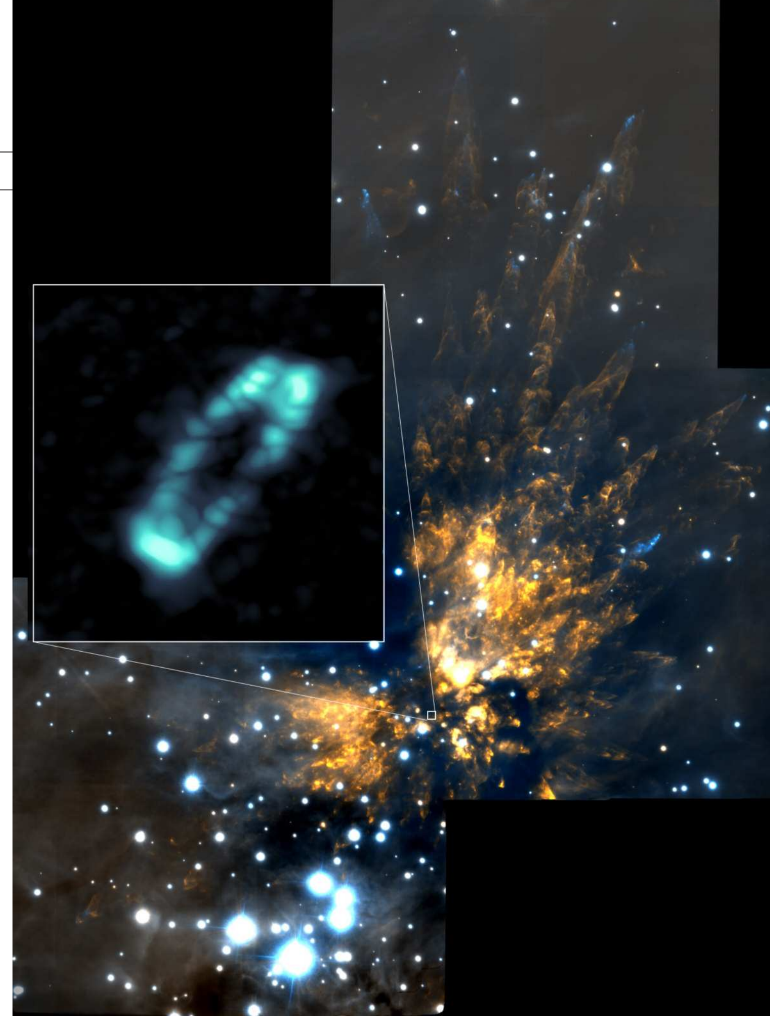
Artist impression of Orion Source I, a young, massive star about 1,500 light-years away. New ALMA observations detected a ring of salt — sodium chloride, ordinary table salt — surrounding the star. This is the first detection of salts of any kind associated with a young star. The blue region (about 1/3 the way out from the center of the disk) represents the region where ALMA detected the millimeter-wavelength "glow" from the salts. [NRAO/AUI/NSF; S. Dagnello]

An in-depth study of these spectral spikes could provide insights about how the star is heating the disk, which would also be a useful measure of the luminosity of the star.

"When we look at the information ALMA has provided, we see about 60 different transitions – or unique fingerprints – of molecules like sodium chloride and potassium chloride coming from the disk. That is both shocking and exciting," **said Brett McGuire, a chemist at the NRAO in Charlottesville, Virginia, and co-author on the paper.**

The researchers speculate that these salts come from dust grains that collided and spilled their contents into the surrounding disk.

Their observations confirm that the salty regions trace the location of the circumstellar disk.



ALMA image of the salty disk surrounding the young, massive star Orion Source I (blue ring). It is shown in relation to the Orion Molecular Cloud 1, a region of explosive starbirth. The background near infrared image was taken with the Gemini Observatory. [ALMA (NRAO/ESO/NAOJ); NRAO/AUI/NSF; Gemini Observatory/AURA]

"Usually when we study protostars in this manner, the signals from the disk and the outflow from the star get muddled, making it difficult to distinguish one from the other," said Ginsburg. *"Since we can now isolate just the disk, we can learn how it is moving and how much mass it contains. It also may tell us new things about the star."*

The detection of salts around a young star is also of interest to astronomers and astrochemists because some of constituent atoms of salts are metals – sodium and potassium. This suggests there may be other metal-containing molecules in this environment. If so, it may be possible to use similar observations to measure the amount of metals in star-forming regions. *"This type of study is not available to us at all presently. Free-floating metallic compounds are generally invisible to radio astronomy,"* noted McGuire.

The salty signatures were found about 30 to 60 astronomical units (AU, or the average distance between the Earth and the Sun) from the host stars.

Based on their observations, the astronomers infer that there may be as much as one sextillion (a one with 21 zeros after it) kilograms of salt in this region, which is roughly equivalent to the entire mass of Earth's oceans.

"Our next step in this research is to look for salts and metallic molecules in other regions. This will help us understand if these chemical fingerprints are a powerful tool to study a wide range of protoplanetary disks, or if this detection is unique to this source," said Ginsburg. *"In looking to the future, the planned Next Generation VLA would have the right mix of sensitivity and wavelength coverage to study these molecules and perhaps use them as tracers for planet-forming disks."*

Orion Source I formed in the Orion Molecular Cloud I, a region of explosive starbirth previously observed with ALMA. *"This star was ejected from its parent cloud with a speed of about 10 kilometers per second around 550 years ago,"* said John Bally, an astronomer at the University of Colorado and co-author on the paper. *"It is possible that solid grains of salt were vaporized by shock waves as the star and its disk were abruptly accelerated by a close encounter or collision with another star. It remains to be seen if salt vapor is present in all disks surrounding massive protostars, or if such vapor traces violent events like the one we observed with ALMA."* ■

New ALMA observations show there is ordinary table salt in a not-so-ordinary location: 1,500 light-years from Earth in the disk surrounding a massive young star. [ALMA (NRAO/ESO/NAOJ); NRAO/AUI/NSF; Gemini Observatory/AURA]

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