LUNAR ORBITER

AUGUST 1966 - JANUARY 1968

an essay by

HAMISH LINDSAY

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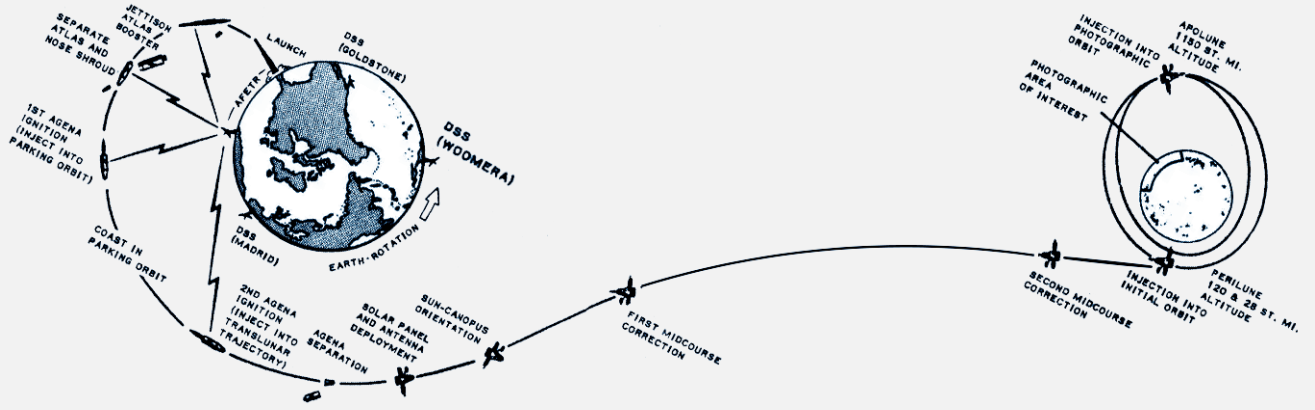
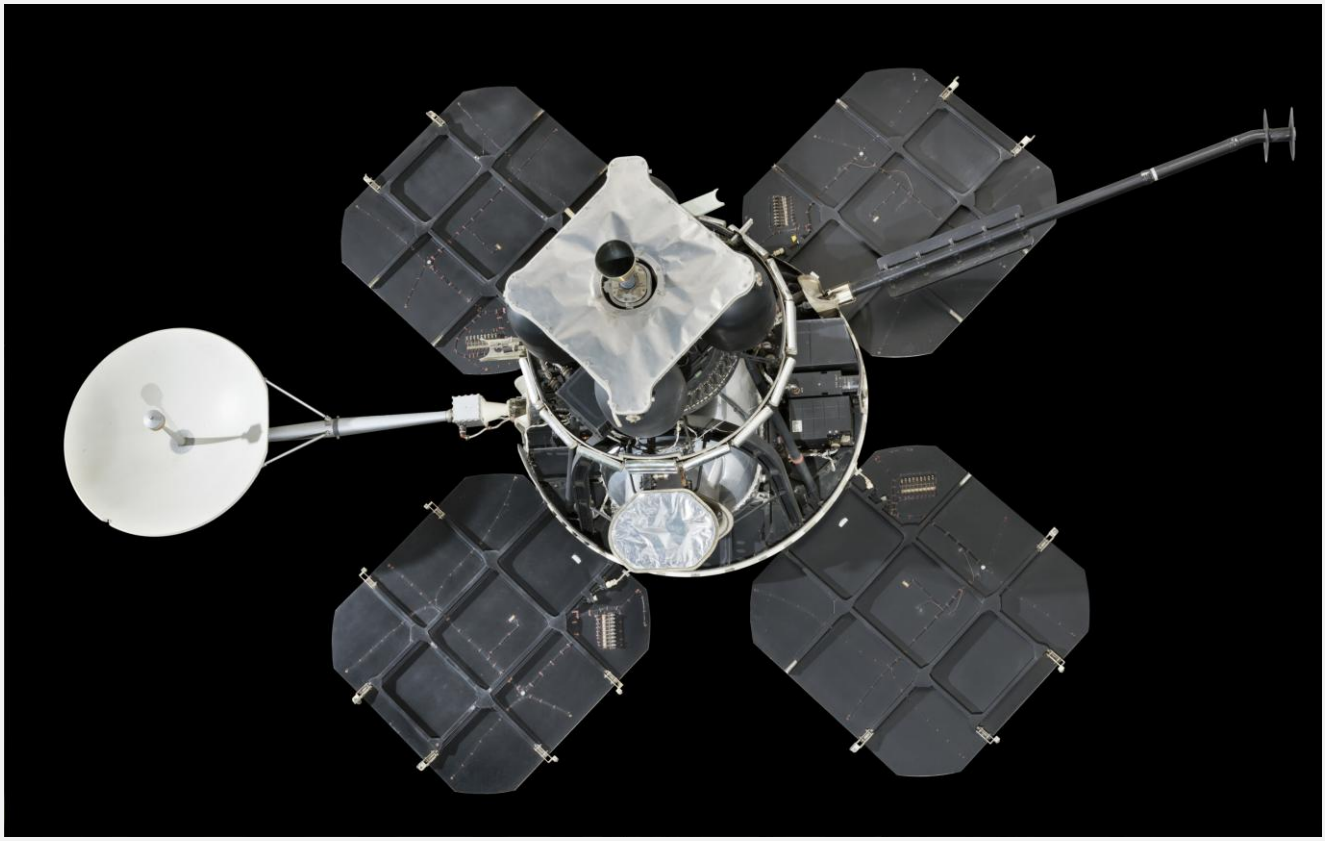
Extracted from content available on the
Honeysuckle Creek Tracking Station
website, developed by Colin Mackellar

www.honeysucklecreek.net

Click or scan the QR code below to see the website:

Above: Lunar Orbiter spacecraft during engineering testing. **Below:** Flight plan. Images: NASA





Lunar Orbiter engineering mock-up. Image: NASA/National Air and Space Museum

Lunar Orbiter

Before Surveyor and Apollo, the question was, what is the Moon made of?

- Would it support a spacecraft?
- What if it was made of fine powder which would swallow a whole spacecraft?
- What if it was made of a brittle foam rock that would be crushed by a spacecraft landing on it?
- What if the surface was honeycombed with caves just under the surface for the spacecraft to fall into?

These questions had to be answered before trusting to put a manned spacecraft down on the lunar surface.

With Ranger and Surveyor, the Lunar Orbiter program was part of three complementary programs to survey the Moon's surface and answer these questions, as well as select sites for the Apollo manned landings.

First, nine Ranger spacecraft headed straight for the lunar surface, taking TV pictures until impact on selected areas, with the last frame to main object of interest.

After sending 17,000 pictures back to Earth, the Ranger program ended in March 1965.

Then, headed by geologist Eugene Shoemaker, the Surveyor series of soft landings on the Moon's surface ferreted out the properties of the lunar surface, and found it was hard enough to support a spacecraft. 88,000 high-resolution pictures were taken by the seven Surveyor spacecraft, and the soil sampled with three chemical analyses. The last Surveyor signal was received on 10 January 1968.

The Spacecraft

Built by the Boeing Aircraft Company and managed by NASA's Langley Research Center, Hampton, Virginia, the Lunar Orbiter spacecraft weighed 385 kilograms.

They were 1.7 metres tall and 1.5 metres in diameter at its base, without including the solar panels and the antennas.

With its solar panels and antennas extended, the spacecraft measured 3.7 metres across the panels and 5.6 metres to the ends of the antennas.

Lunar Orbiter engineering mock-up. Image: NASA/National Air and Space Museum

The spacecraft consisted of two sections:

The Main Equipment Deck with the camera system, radiation detectors, communication and orientation equipment. Two antennas poked out on opposite sides of the spacecraft, a high-gain dish antenna and a low gain omni antenna.

The Upper Module housed the propulsion system, which included a 45 kilogram thrust liquid propellant rocket engine, and nitrogen gas jets for attitude changes. Storage tanks for fuel were also mounted on this module.

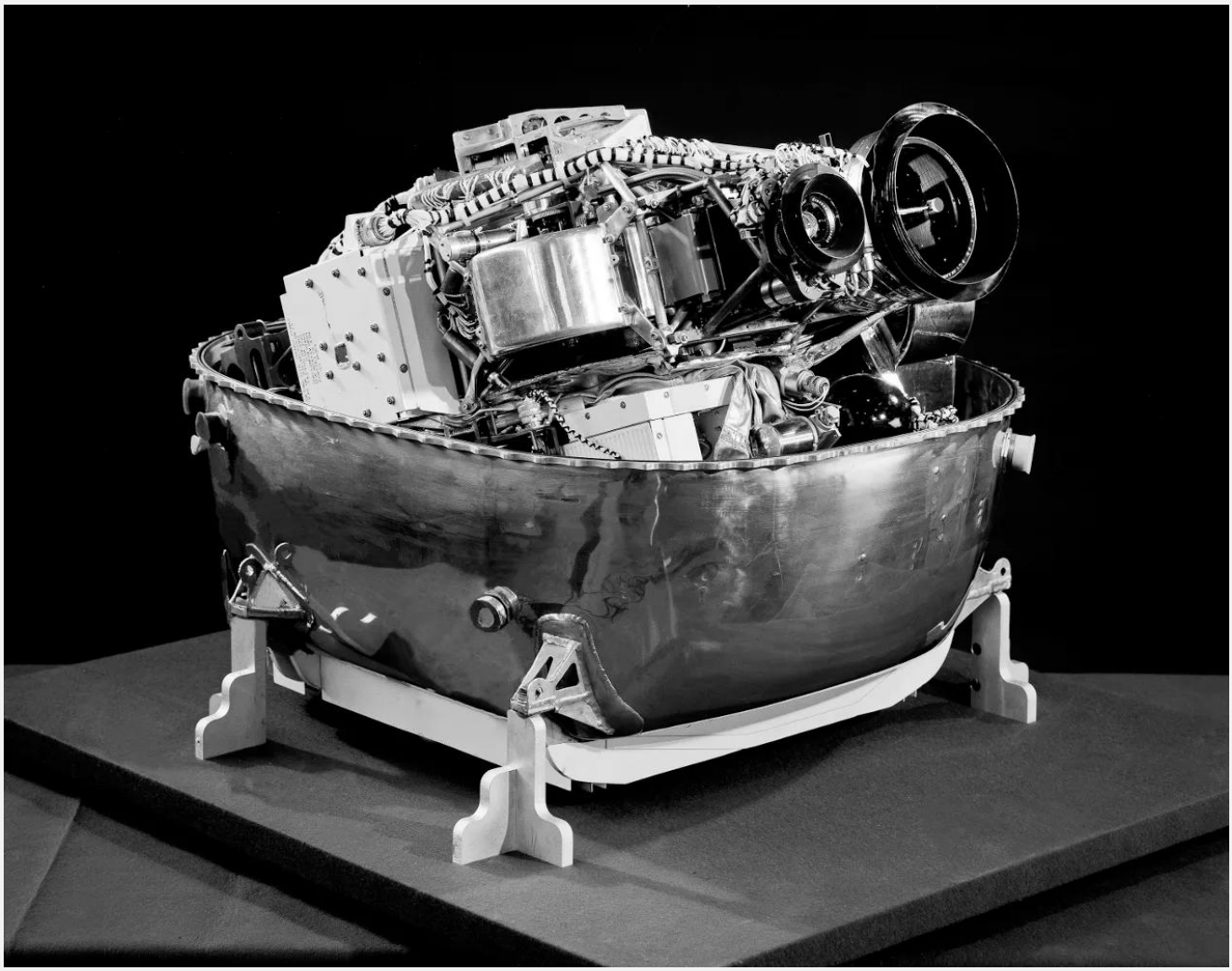
Electrical power was supplied by four solar arrays delivering 375 watts from 10,856 n/p solar cells which would directly run the spacecraft, and also charge the 12 ampere hour nickel-cadmium battery, used for Sun occultation periods.

The attitude control subsystem served as the navigator for Lunar Orbiter during an entire mission. Composed of Sun sensors, the Canopus sensor, the inertial reference unit, and the thrusters, the system controlled the spacecraft's attitude in space using the Sun, the star Canopus, and the Moon as references. The sun sensor was used to control pitch and yaw of the spacecraft, while the Canopus sensor controlled roll. When these were not visible, stability was provided by three gyroscopes.

Receiving and transmitting data to and from the spacecraft was the job of the communications subsystem, many of whose components had been flight-proven in the Ranger and the Mariner programs. This complex assembly could operate in four individual modes:

1) A tracking and ranging mode
2) A command mode
3) A low power mode
4) A high power mode.

The communications system could send and receive data simultaneously while also transponding velocity (doppler) and ranging signals for the Deep Space Network's tracking and ranging systems.



The Lunar Orbiter imaging system included two cameras, an 'in-space' 70mm film development lab, onboard scanning, and transmission systems. Image: NASA

The Lunar Orbiter Photographic System

Unlike the Ranger and Surveyor spacecraft, which transmitted images in real time, the Orbiters had a built-in film processing laboratory invented by Eastman Kodak called the Bimat process.

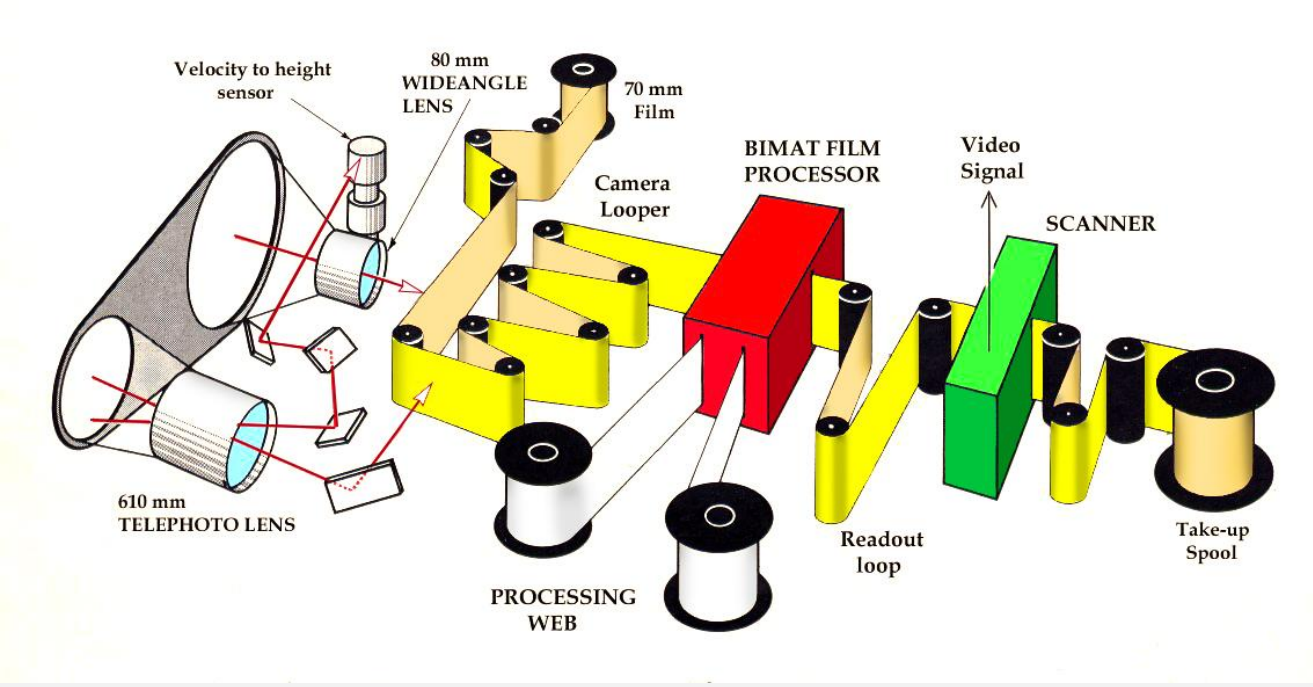
This system did away with a cumbersome television payload and used a film system instead. Film had an advantage over the television of those days as far as its ability to obtain higher resolution photographs.

Besides eliminating the need for liquids and their storage containers, the Bimat system did away with the necessity of an extra fixing step while producing photographic negatives having normal, high-quality physical and image characteristics. This greatly simplified the problems involved in materials handling while making the whole process fully automatic. Moreover, every part of the film enjoyed fresh chemicals, which made the resulting negatives more consistent and uniform.

Bimat would not leave any crystalline deposit on the film after separation, and lamination of the two materials would not result in any damage to the emulsion layer. In addition, the position of the equipment would not affect processing of the film, a factor which made the Bimat process ideally suited to work in a space environment.

The Orbiter photographic system was built by Eastman Kodak, and used a dual lens system to focus the images on to a single roll of 70 mm film with room for 212 dual frames. It was a 79- metre length of unperforated Kodak special high-definition aerial film, Type SO-243, with a very slow aerial exposure index of 1.6.

It was extremely fine grained with a high resolving power, and highly resistant to fogging at the levels of radiation expected in space. The film storage cassette was specially shielded against ionising radiation from solar flares. Along one edge of the film was a thin band of pre-exposed data



A schematic of the Bimat film image, processing and scanning system.
Image: NASA. Enhanced by Hamish Lindsay and Glen Nagle

containing calibrated resolving power charts and grey scales which were read out with each image for later comparison and interpretation, as well as helping estimate slope angles of the lurain from measuring film densities.

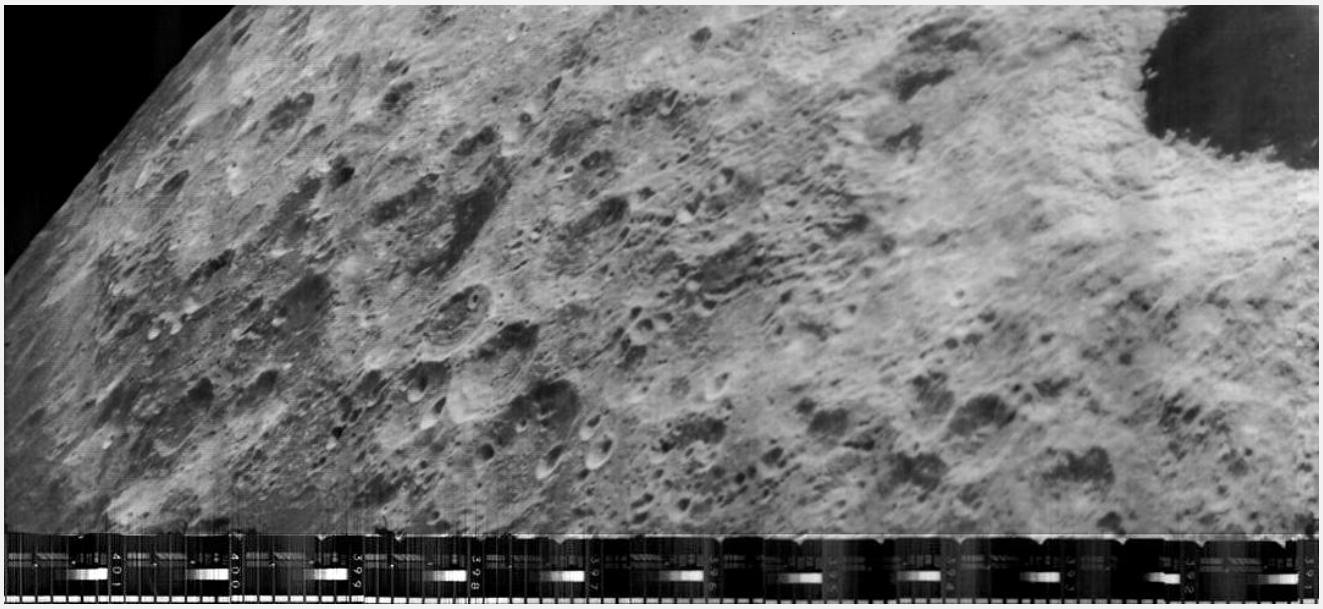
The camera lenses viewed the lunar surface through a quartz window that was protected by a lifting flap opened by a command from the Earth for each photographic pass. The German Schneider Xenotar wide-angle lens had a focal length of 80 mm with a fixed aperture of f5.6 and a between-lens shutter giving 1/25, 1/50 or 1/100 second exposures. The 610 mm telephoto lens was a f5.6 Paxoramic specially designed and made for the spacecraft by Pacific Optical Company. Weighing less than 7.3 kilograms, it had its own focal plane shutter offering the same exposure times as the wide-angle shutter. The two shutters operated simultaneously, so each exposure produced two images, the telephoto lens taking about 5% of the area of the wide angle lens, but at a resolution 8 times better.

For example, at an altitude of 46 kilometres the wide-angle lens covered an area of 31.5 kilometres by 37.3 kilometres with a resolution of 7.3 metres. In the centre of the same footprint the telephoto lens covered an area of 4.2 kilometres by 16.4 kilometres with a resolution of 0.9 of a metre.

To cover larger areas photographs were overlapped, either by successive exposures along the flight path, or on successive orbits. Stereoscopic pictures could be produced if required, for instance to determine the slope of a hillside.

With the spacecraft speeding over the lurain at 6,920 kilometres per hour, taking pictures at around the perilune regions with shutter speeds of 1/25, 1/50, or 1/100 of a second dictated by the slow film speed, would result in blurred images, so there was a mechanism to compensate for the motion. It sensed the velocity to height ratio of the spacecraft by measuring the apparent motion of a small portion of the lunar surface viewed through the telephoto lens, and applied the necessary corrections to the speed of the film past the aperture during exposure.

The exposed film was developed using the Bimat technique invented by Kodak. Housed in a pressurised and temperature controlled unit, the process pressed the exposed film against a web, or roll with a gelatine layer that had been soaked in a solution that developed and fixed the film in one step. The film was then dried by passing it over a heated drum, before being fed into a flying-spot scanner to be read a frame at a time. Here the image could be converted to electronic signals by the scanner upon command from the ground, then the film stored on to a take-up reel.



The film was pre-exposed with calibrated resolving power charts and grey scales which were used for later comparison and interpretation. Image: NASA

The line-scanning device consisted of a cathode-ray tube with a rotating anode having a high-intensity spot of light. One complete scan, or raster, took up 2.54 millimetres of film and the full 60 millimetres width, these being the strips visible in the pictures.

This process was repeated 286 times for each millimetre of film scanned. It took a 5 micron light beam 22 seconds to do 17,000 horizontal scans to produce one band of an image.

Photographic data was transmitted in a different way to telemetry data. The spacecraft had two antennas that operated in the S-band at the frequency of 2295 Mhz.

When photographic data was transmitted to the tracking stations, the spacecraft operated in the high-power mode, and transmitted the signal via the one metre diameter parabolic high-gain antenna.

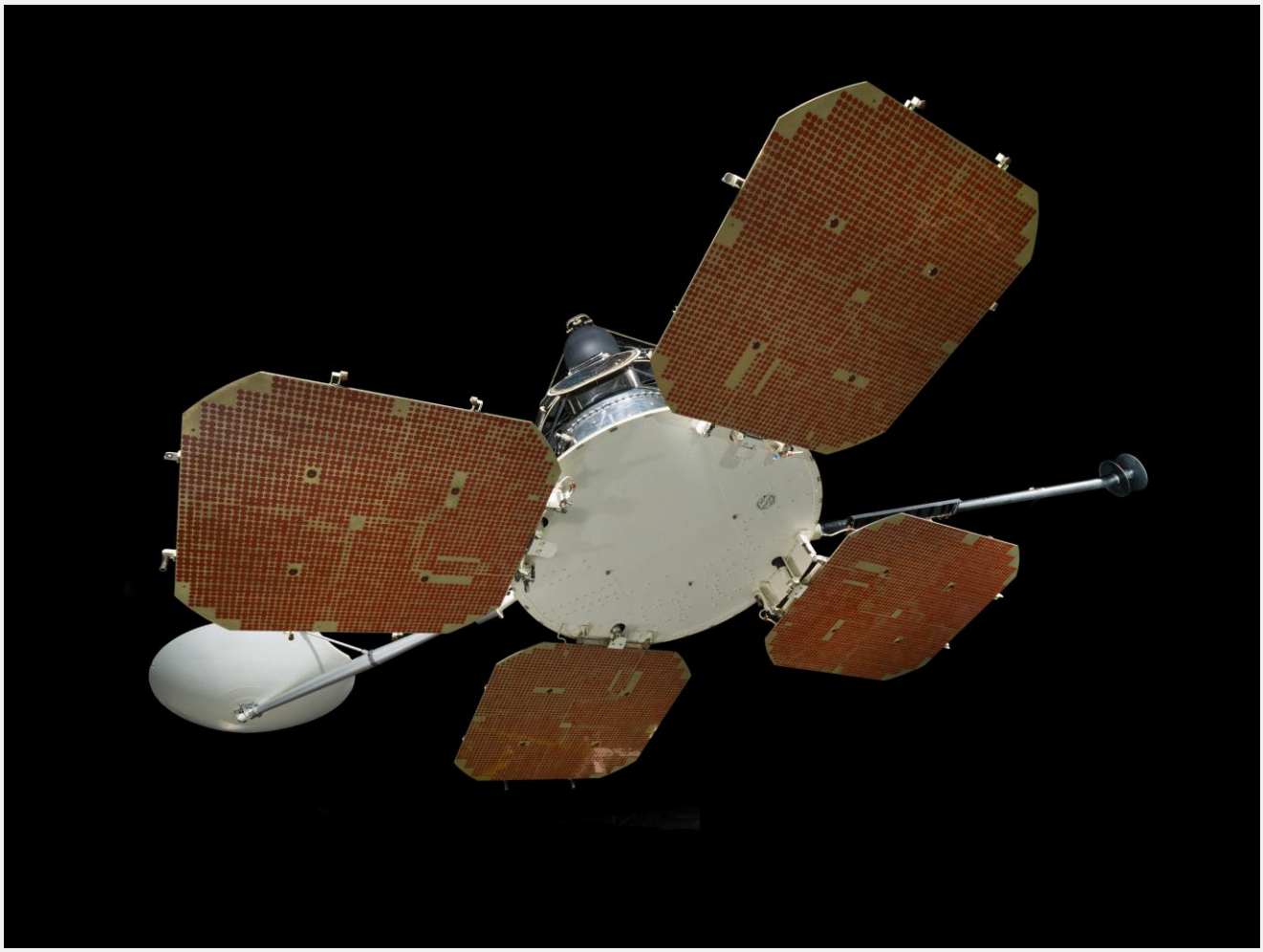
Simultaneous transmission of photographic and telemetry data was carried out as follows:

- The 50-bit/second telemetry data train was phase modulated onto a 30khz subcarrier, which was then combined with the video data that had been transformed to a vestigial sideband signal. That signal was created by amplitude modulating the data on a 310khz subcarrier by means of a double balanced modulator. This suppressed the carrier and produced two equal sidebands.
- An appropriate filter was then superimposed on the double sideband spectrum, essentially eliminating the upper sideband.
- Since the missing subcarrier must be reinserted on the ground for the proper detection of the vestigial sideband signal, provision for deriving such a subcarrier signal was made by transmitting a pilot tone of 38–75khz. That pilot tone was exactly one-eighth of the original 310khz subcarrier frequency, and was derived from the same crystal oscillator. Multiplying the received pilot tone by 8 in the ground equipment provides a proper subcarrier for reinsertion.

Lunar Orbiter photographic data was never encoded; instead, data was transmitted as frequency-modulated analogue signals. All other data from the spacecraft were encoded and sent on the subcarrier frequency as described above.

The temperature control subsystem protected all of the spacecraft's other subsystems from the extreme temperature variations of the deep space environment. Heat from the Sun could warm external parts of the spacecraft to 120°C while areas not exposed to solar radiation would cool down to -160°C.

These extremes were beyond the temperature levels most components could endure. The temperature control system established an environment ranging from + 2°C to +30°C for the operation of all subsystems.



The four solar panels and two protruding antennas of a Lunar Orbiter spacecraft.
Image: NASA/National Air and Space Museum

A few components were exposed to direct sunlight: the four solar panels, the two antennas, and the bottom of the equipment deck. The solar panels were designed to withstand temperature variations of 160°C to +120°C without cracking or buckling from severe expansion and contraction over a long period of time.

The Lunar Orbiter program gets underway

The Lunar Orbiter program began in June 1962 when NASA's Office of Manned Space Flight submitted a formal list of requirements for data of the Moon's surface to choose the Apollo landing sites. The list gave the Office of Lunar and Planetary Programs its first opportunity to compare the objectives of its lunar programs with preliminary Apollo needs. It re-examined the mission objectives of the Surveyor Lander and acknowledged that Ranger data alone would not meet the Apollo requirements.

NASA selected a design proposed by The Boeing Co. of Seattle, Washington. Although this choice was criticized because it involved a relatively complex and costly camera and spacecraft configuration, NASA Headquarters was convinced that the Boeing design was the one that would best meet the requirements of the mission.

Five Lunar Orbiter missions were launched from 1966 to 1967; all were successful. 99% of the Moon's surface was photographed with a resolution of 60 metres or better.

The first three missions were dedicated to imaging 20 potential lunar landing sites, selected from Earth-based observations. These were flown at low inclination orbits.

The fourth and fifth missions were devoted to broader scientific objectives and were flown in high altitude polar orbits. Lunar Orbiter 4 photographed the entire nearside and 95% of the farside, and Lunar Orbiter 5 completed the farside coverage and acquired medium (20 metre) and high (2 metre) resolution images of 36 pre-selected areas.

A total of 1,950 photographs were taken, and some 40 candidate sites for Surveyor and Apollo landings were identified. Models for study were made from the images of the lunar surface.

An initial elliptical orbit of 193 kilometres by 1,850 kilometres was chosen so the spacecraft would spend more time in the sun to make maximum use of solar power, and reduce the amount by which the velocity of the spacecraft would have to be modified in the manoeuvres near the Moon. Then the Orbiters were sent into low orbits to take sharp, close-up pictures of the lunar surface. They also supplied information on the Moon's size, shape, gravitational field, micrometeoroid impacts, and radiation.

The greater part of the photography was done near perilune to achieve a balance between the required photographic resolution and to cover the maximum area. The Sun's illumination of the ground had to be taken into account to bring out details by the use of shadows and highlights. The optimum sun angle was determined to be 10° to 30° above the local horizon. Sunrise, rather than sunset, was selected for photography so the spacecraft was travelling into sunlight to recharge the batteries to supply the power for processing the film after shooting.

Honeysuckle Creek Station Director Don Gray, has memories of Lunar Orbiter at DSS41, Island Lagoon,

"Lunar Orbiter was quite a different concept. We went through all the same sort of preparation to get ready for the mission as with Ranger, but it was the first of the long duration missions, because instead of crash landing onto the lunar surface, it was new to us to have this continuous sort of a mission. It was also the first time we had American contractors on site performing part of the mission function.

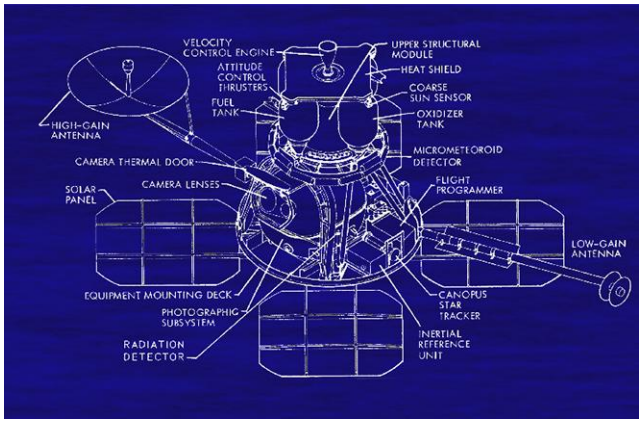
The film was developed directly on the station. The nature of this film was interesting – it came out in thin strips of film which had to be mosaiced to get the full picture. This was one of the first times that the Earth was photographed from space with a Moon horizon, a grainy black and white picture, nothing like the beautiful pictures that later came from Apollo, but it was very exciting in its time.

Although it wasn't the first time the back of the Moon had been seen, the Russians had done that, but it was the first time it had been mapped.

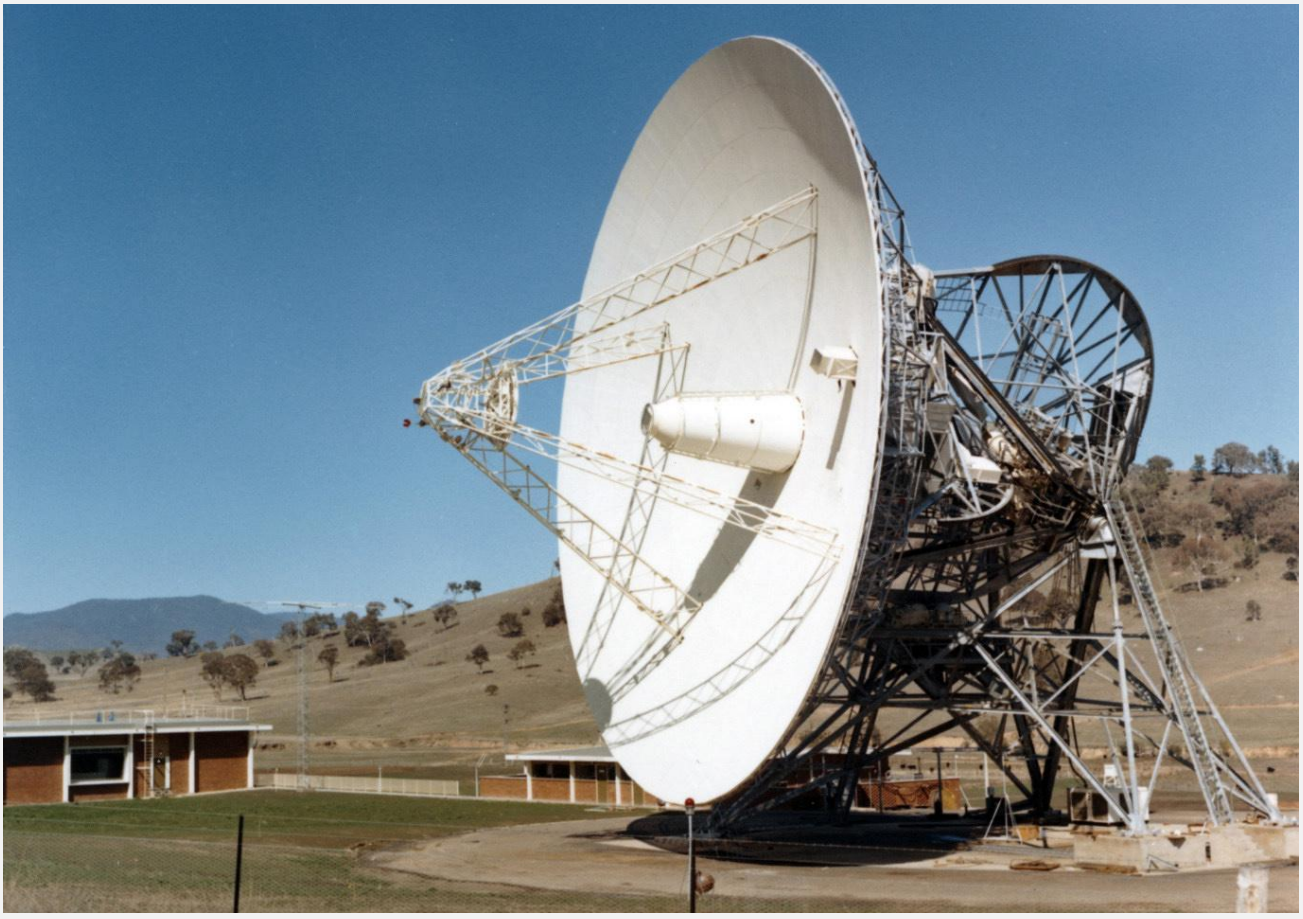
NASA had sent out a public relations officer with the first Lunar Orbiter mission, and he was responsible for releasing any pictures to the press. However, the same pictures were in fact Boeing's responsibility to provide to NASA as mission data, so hanging up drying around the darkroom you would find these pictures from Lunar Orbiter. This Boeing guy had a habit of whipping them off, and the next thing you knew it would appear in the Adelaide Advertiser. People had spent days looking for this print, and then there it was in the newspaper.

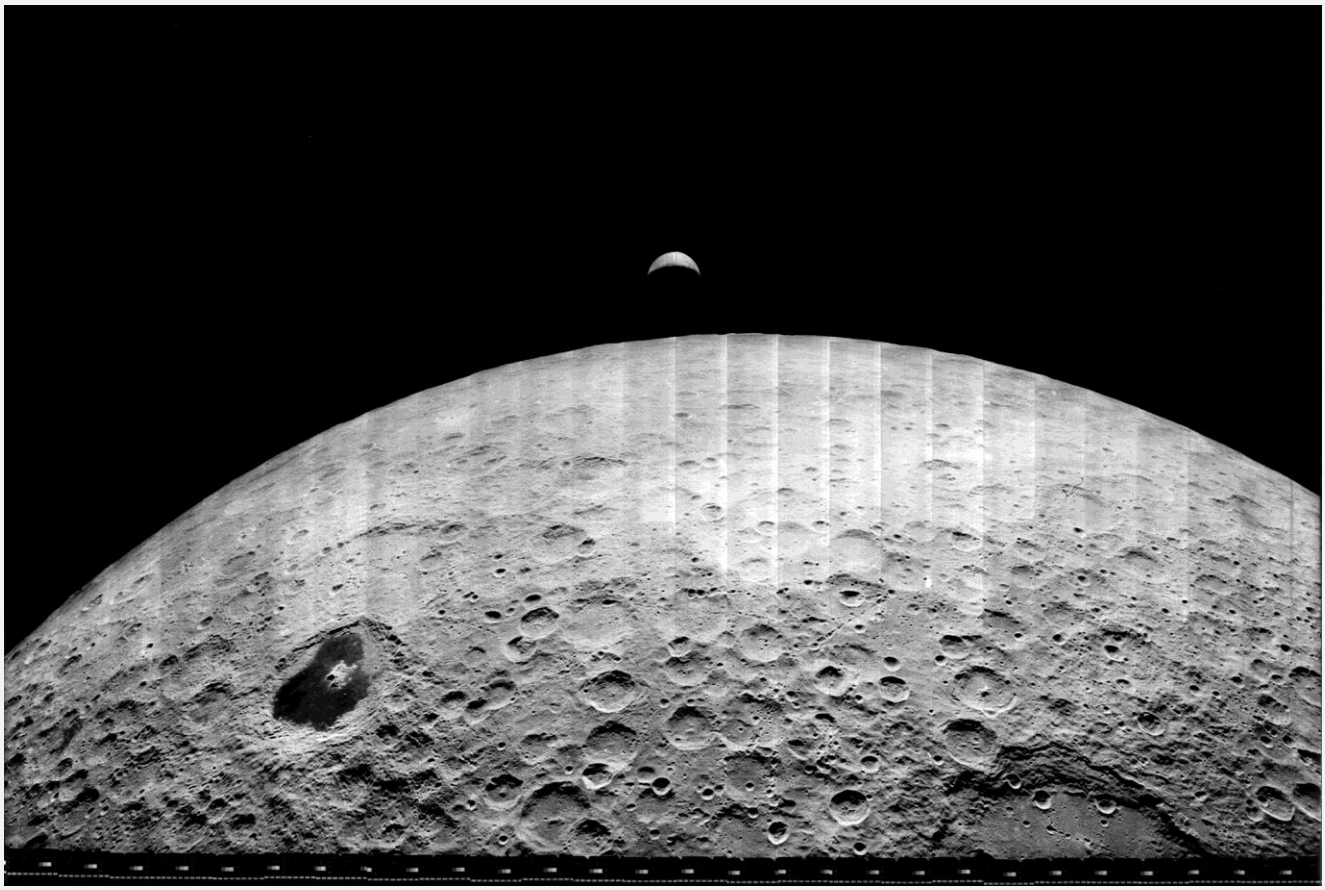
All the original film was all immediately packed in very large, refrigerated containers and shipped back in special shipments within 24 hours to America. The only real time data that was sent back was the health of the spacecraft. The mission data was just too large to go over the cables and links that existed round the world in those days."

When we first became operational at Honeysuckle Creek in 1967 we often used the Lunar Orbiters for tracking experience and engineering exercises such as adjusting the antenna sub-reflector. We were never scheduled to track the Lunar Orbiters for recovering data; that was the role of the Deep Space Network, with Australia's 26 metre diameter antennas at DSS41, Island Lagoon, in the desert at Woomera, a prime site for the mission. DSS42 at Tidbinbilla was also scheduled to track the Orbiters.



Above: Deep Space Station 41 (DSS41) at Island Lagoon, South Australia.
Images: (above) Photo: Ed von Renouard. (below) Preserved: Les Whaley. Scan: Mike Dinn
Below: Deep Space Station 42 (DSS42) at Tidbinbilla, Canberra, Australian Capital Territory.





Lunar Orbiter 1 – Frame 1117 – The Earth above the lunar horizon. Image: NASA

Mission Fact Box

Launch
Launch Complex - 13 Cape Kennedy/Canaveral
Wednesday, 10 August 1966
1526:00 US EDT / 1926:00 UTC
[Thursday, 11 August 1966, 0526:00 AEST]

Spacecraft
Rocket: Atlas SLV-3 Agena-D
Probe: *Lunar Orbiter 1*

Primary mission
Apollo landing site survey

Images returned
207 – 18-29 August 1966

Lunar orbital data
Closest approach: 40.5 kilometres
Periselene: 189.1 to 40.5 kilometres
Aposelene: 1,866.8 kilometres
Inclination: 12°
Period: 3 hours 28 minutes 6 seconds
Orbits: 547 revolutions over 76 days

Lunar Impact
29 October 1966, 1329:06 UTC
Near Mandel'shtam Crater, 6.35°N 160.72°E

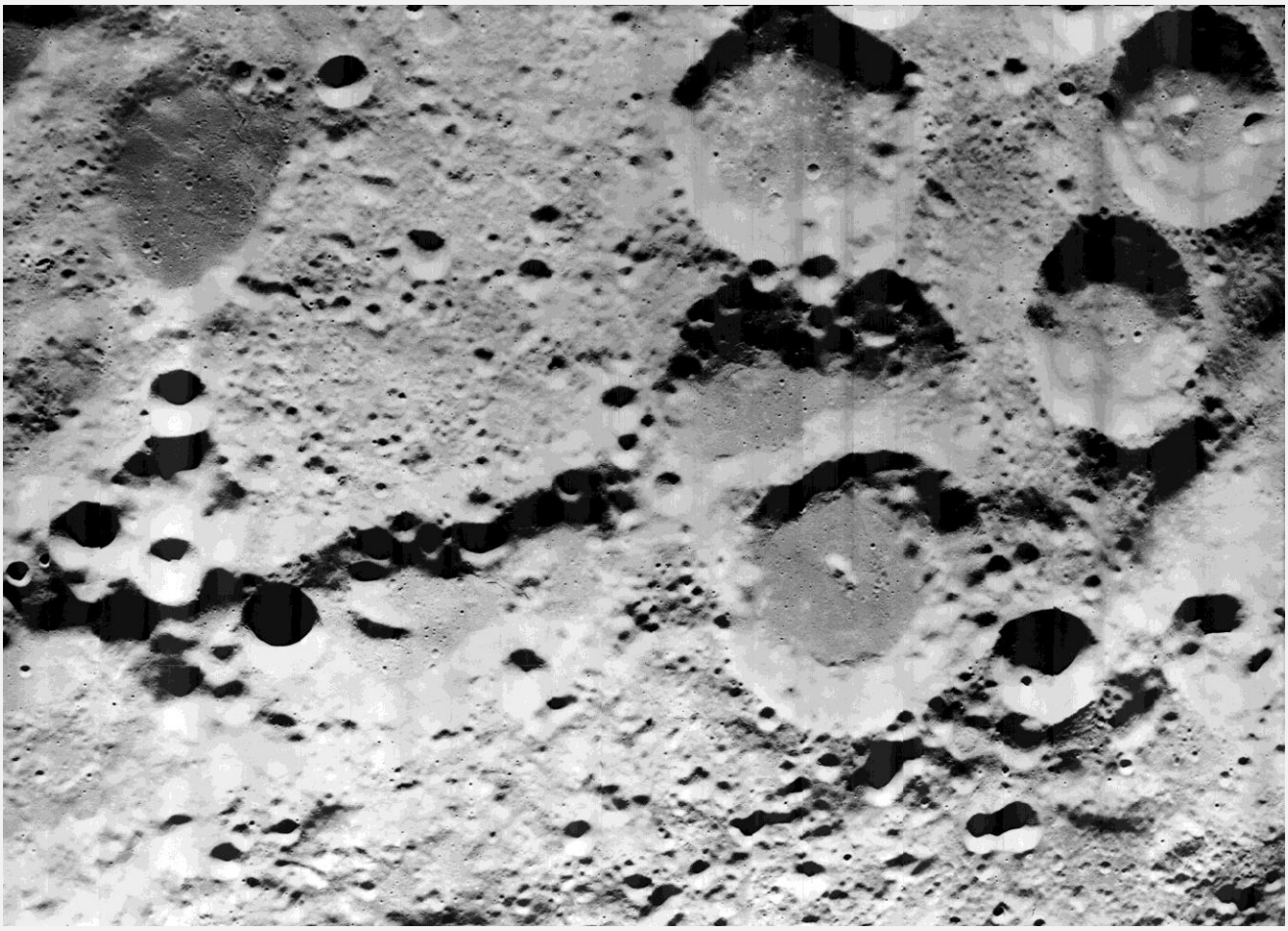
Lunar Orbiter I

Lunar Orbiter I was launched from Cape Kennedy Launch Complex 13 at 1526 EDT on 10 August 1966, the Atlas-Agena D launch vehicle injecting the spacecraft into its planned 90-hour trajectory to the Moon. A midcourse correction manoeuvre was made at 2000 EDT the next day. A faultless de-boost manoeuvre on 14 August achieved the desired initial elliptic orbit around the Moon, and one week later the spacecraft was commanded to make a transfer manoeuvre to place it in a final close-in elliptic orbit of the Moon.

During the photo-acquisition phase of the flight from 18 to 29 August, Lunar Orbiter I photographed the 9 selected primary potential Apollo landing sites, including the one in which Surveyor I landed; 7 other potential Apollo landing sites; the east limb of the Moon; and 11 areas on the far side of the Moon. It also took photos of the Earth, giving man the first view of Earth-rise from the Moon.

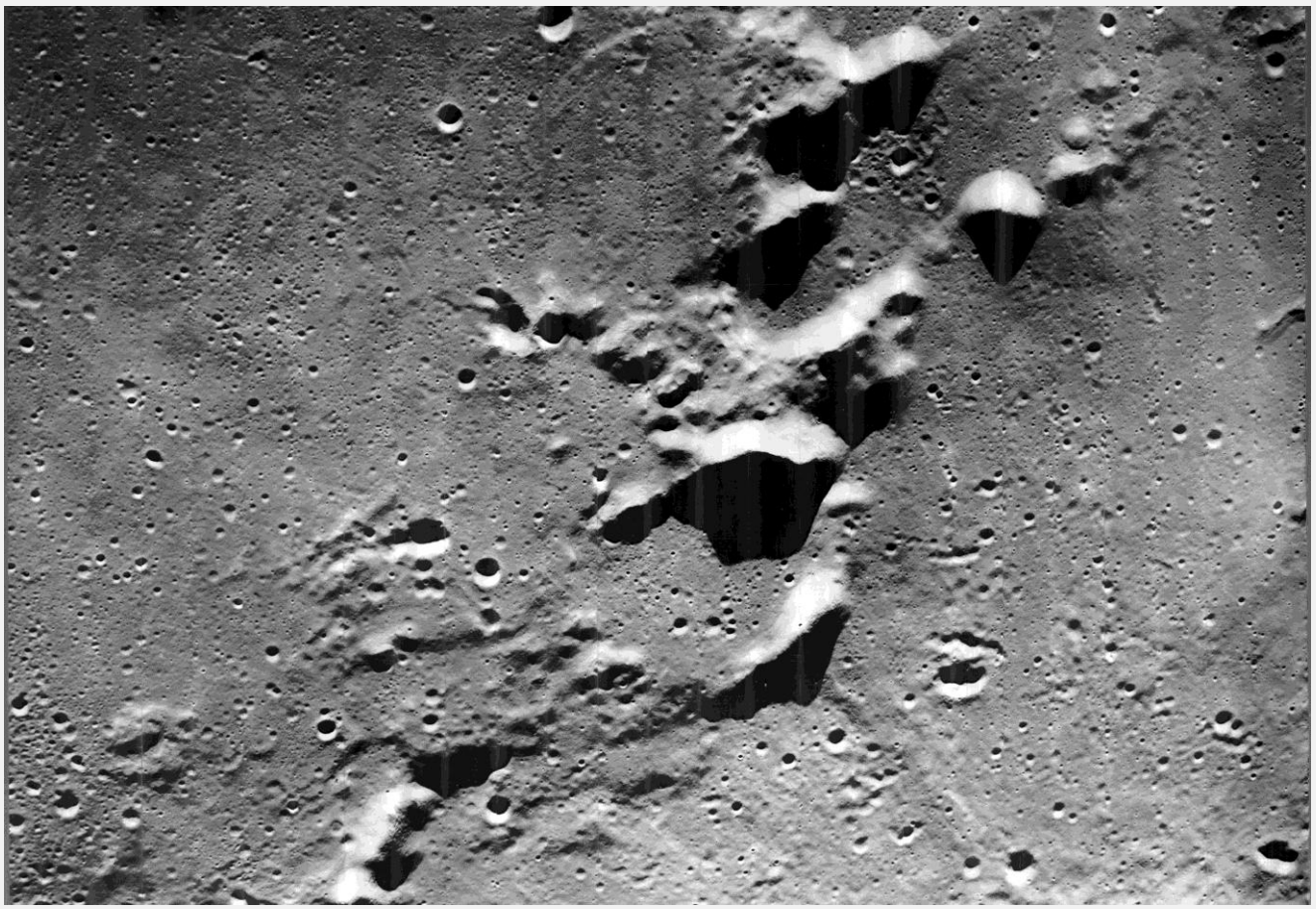
A total of 207 frames (sets of medium- and high-resolution pictures) were taken, 38 while the spacecraft was in initial orbit, the remainder while it was in the final close-in orbit.

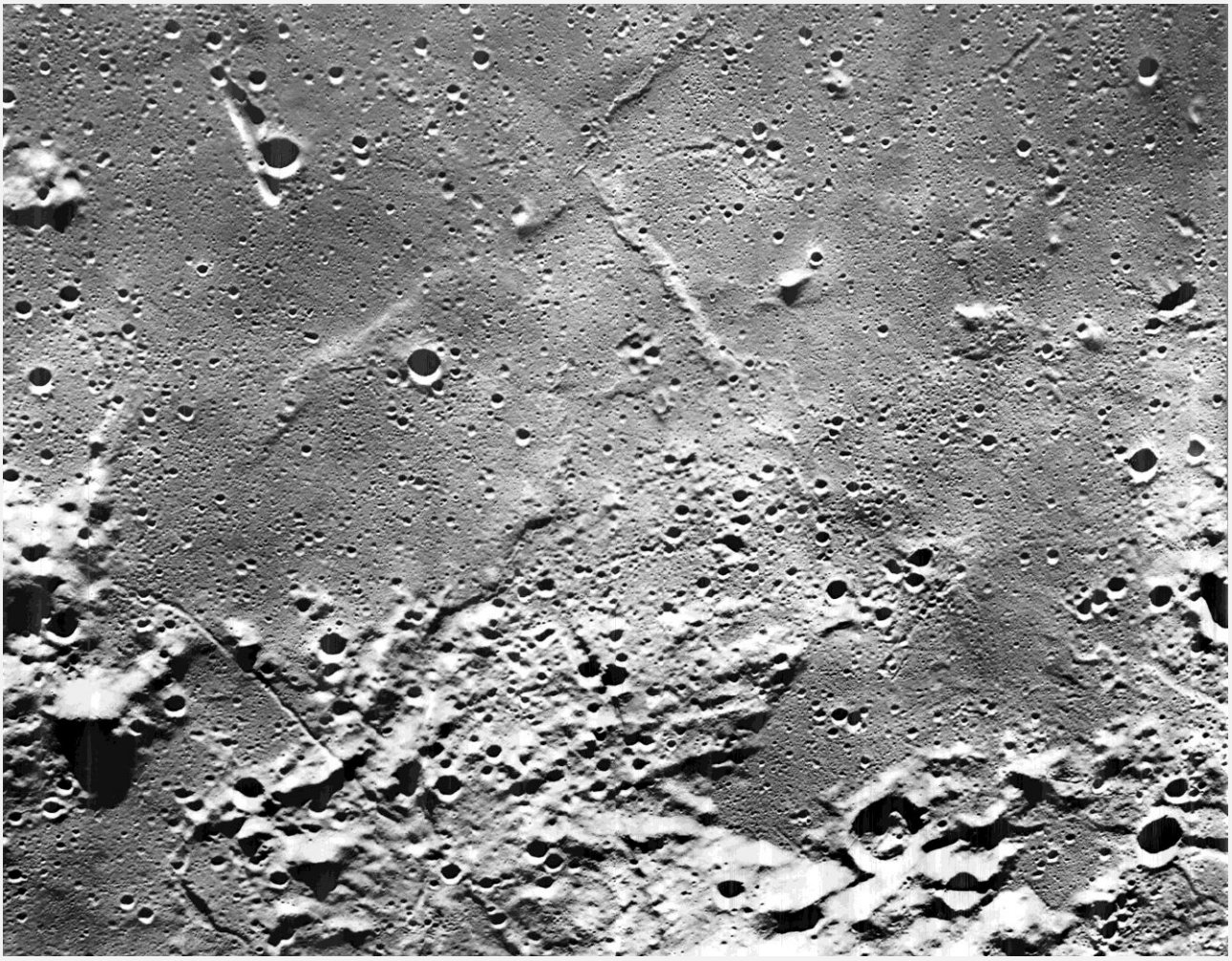
Launch of the Atlas SLV-3 Agena-D rocket carrying *Lunar Orbiter 1*. Image: NASA



Above: Overlapping craters, Jenkins (top), Schubert X, and Nobili. On right: Craters Schubert (top) and Back. Images: NASA

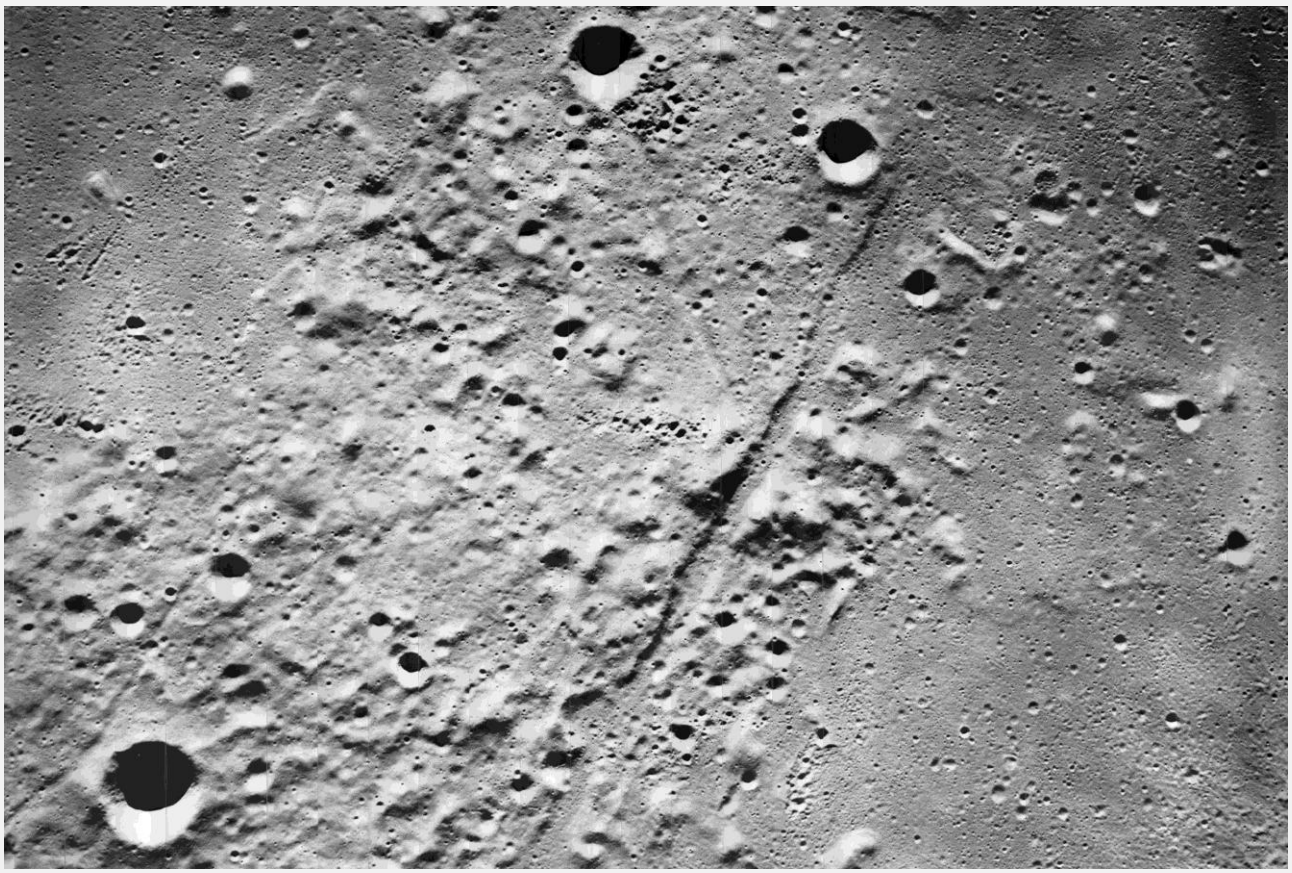
Below: A view of the partially filled Maskelyne D crater complex in Mare Tranquillitatis.





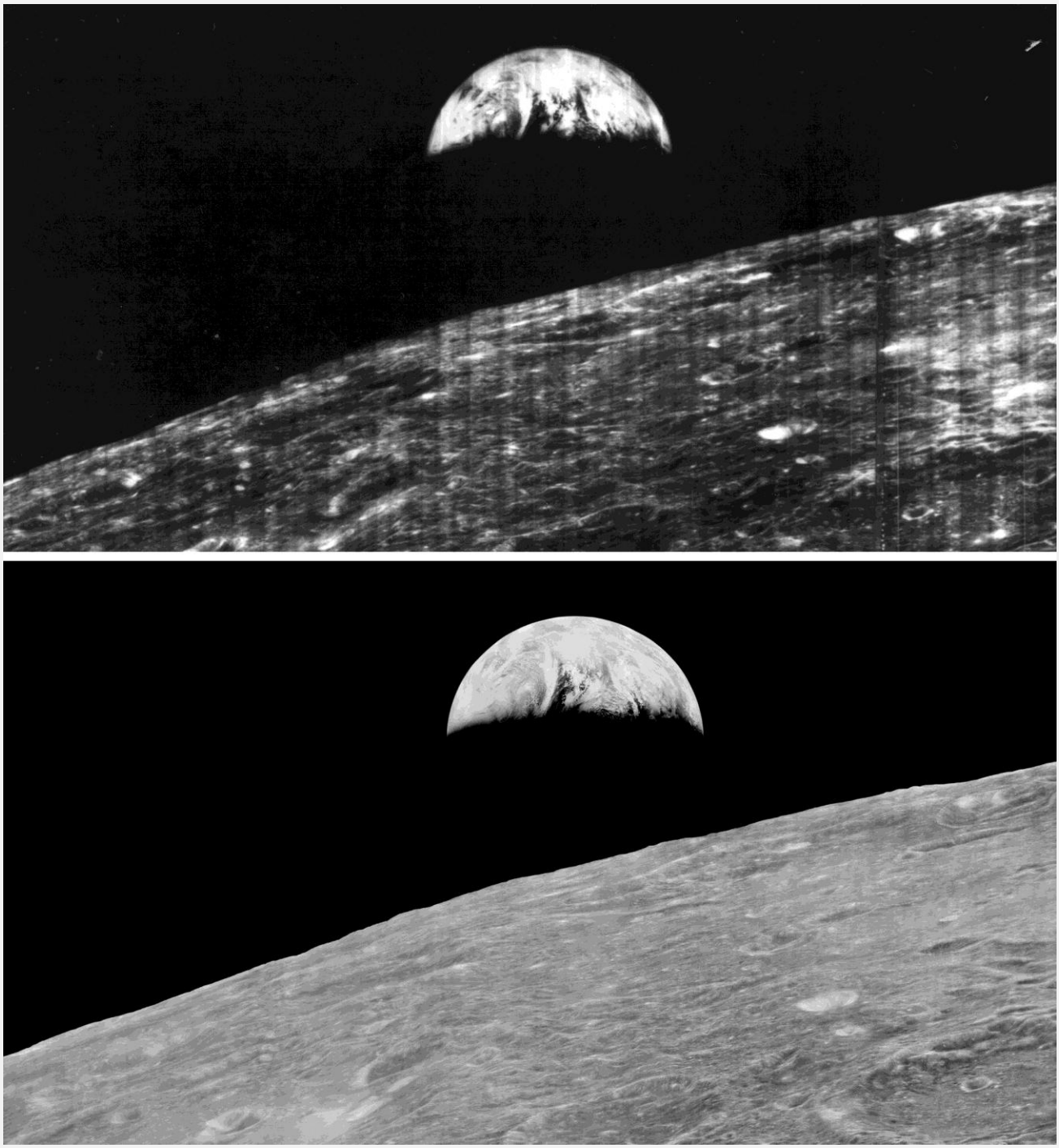
Above: Ridges and rilles criss-cross a heavily cratered Rimae Bode region near the lunar highlands. Images: NASA

Below: (bottom left) Craters Kunowsky G and (top centre) Kunowsky H, near Mare Insularum.



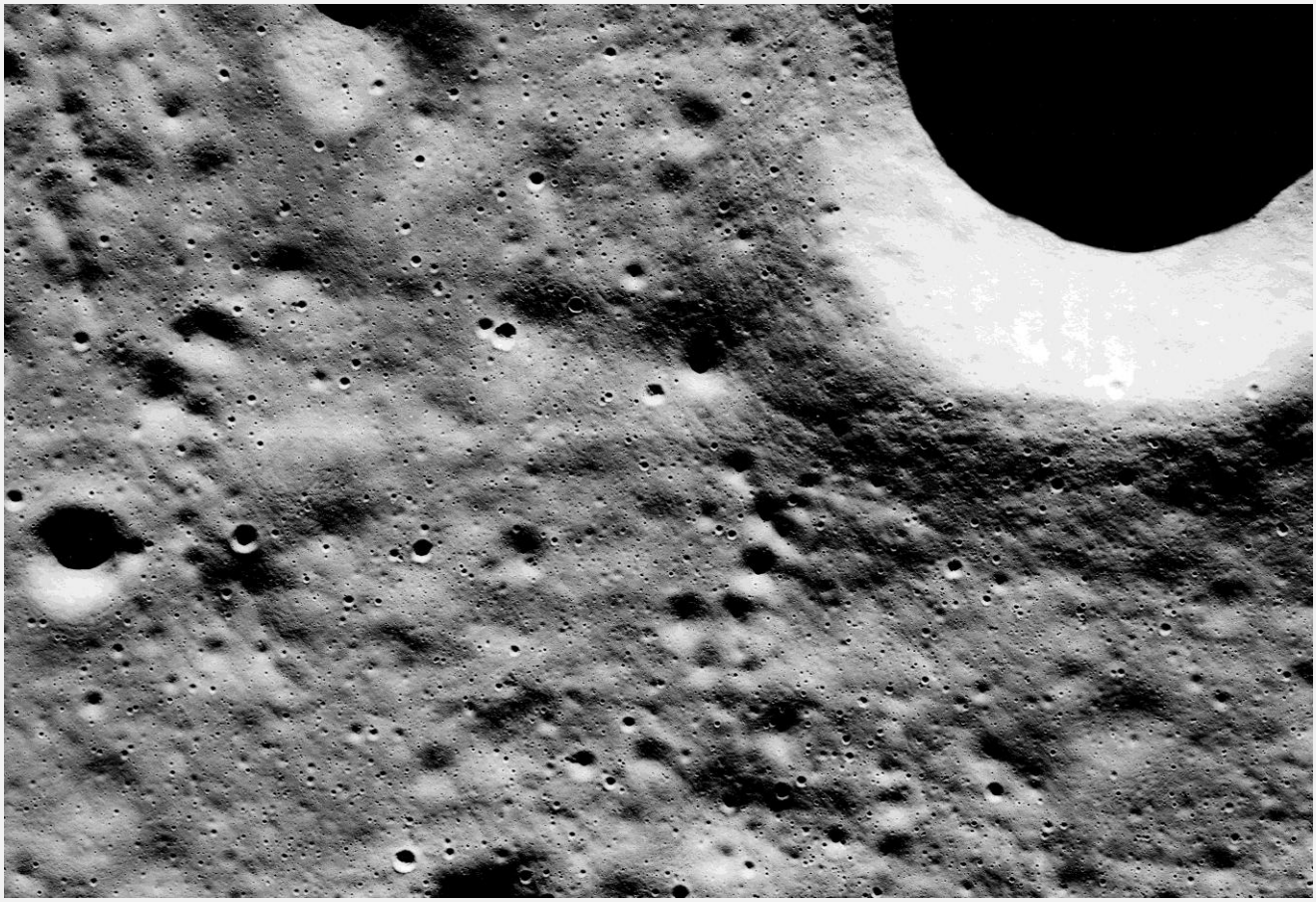
Lunar Orbiter I achieved its mission objectives, and, with the exception of the high-resolution camera, the performance of the photo subsystem and other spacecraft subsystems was outstanding. At the completion of the photo readouts, the spacecraft had responded to about 5,000 discrete commands from the Earth and had made about 700 manoeuvres.

There were some problems with the Bimat system. There was some image imperfections when a partial dry-out of the Bimat web was caused by a pressure variation of a roller resulted in a strip of incorrectly processea0re Id film, and some smearing of high-resolution images was caused by inadvertent triggering of the focal plane shutter of the telephoto lens.



Old and new views of the Earth above the Moon. Images: NASA/LOIRP

The Lunar Orbiter Image Recovery Project (LOIRP) took the original analogue data tapes from the Lunar Orbiter missions, and using a working magnetic tape drive system and demodulator, converted it into a digital format, running it through modern image processing software to produce cleaner and clearer images. LOIRP was funded by NASA, SkyCorp, SpaceRef Interactive, and private individuals.



The terrain near Ariandaeus B crater (upper right), taken on 19 November 1966. Image: NASA

Mission Fact Box

Launch
Launch Complex - 13 Cape Kennedy/Canaveral
Sunday, 6 November 1966
1821:00 US EST / 2321:00 UTC
[Monday, 7 November 1966, 0921:00 AEST]

Spacecraft
Rocket: Atlas SLV-3 Agena-D
Probe: *Lunar Orbiter 2*

Primary mission
Apollo landing site survey

Images returned
211 – between 18-25 November 1966

Lunar orbital data
Closest approach: 50 kilometres
Periselene: 1,790 kilometres
Aposelene: 3,598 kilometres
Inclination: 11.9°
Period: 3 hours 28 minutes 4.2 seconds
Orbits: 2,346 over 11 months 5 days

Lunar Impact
11 October 1967, 0712:54 UTC
Near King Crater, 3.0°N 119.1°E

Lunar Orbiter II

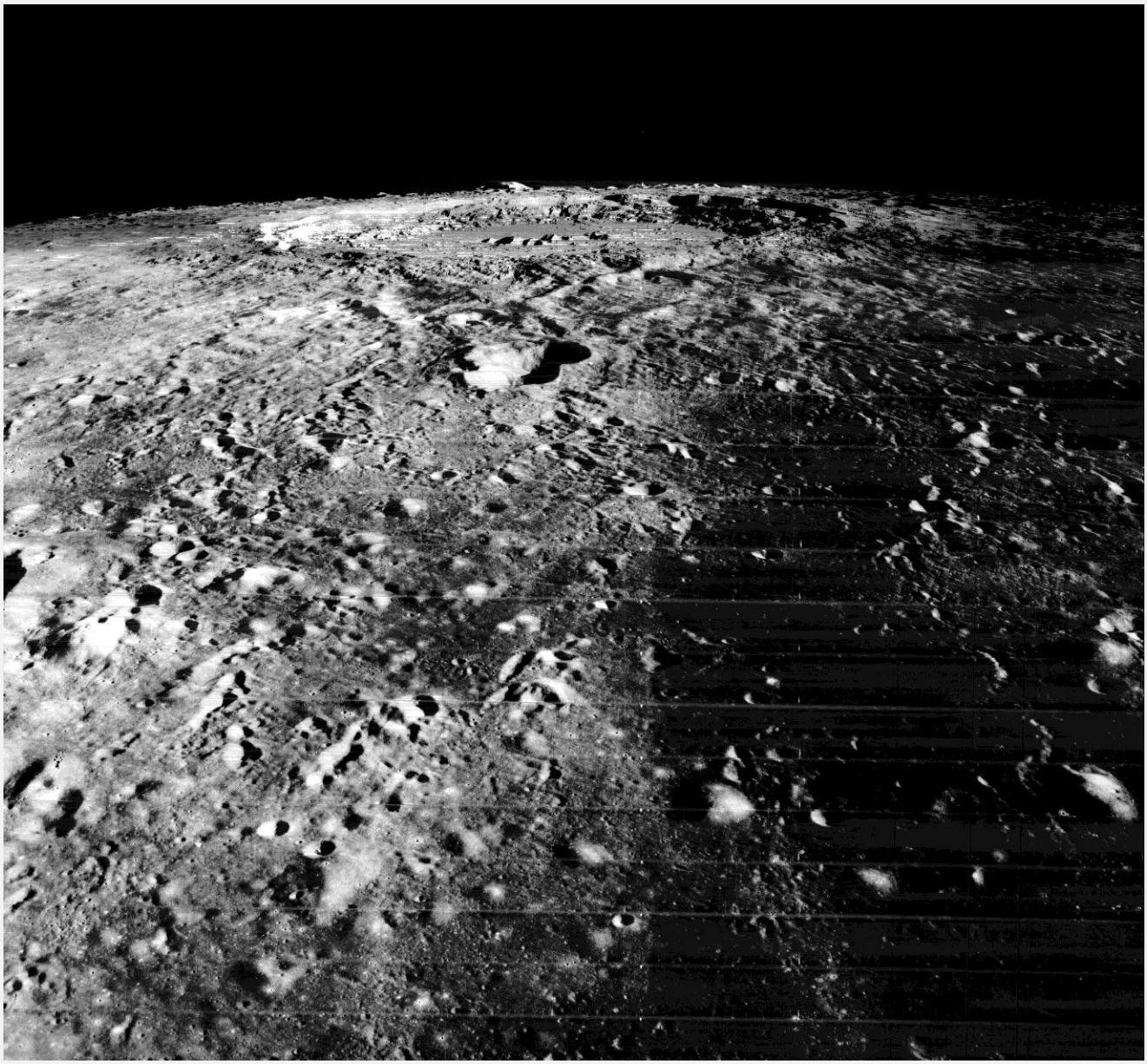
Less than three months elapsed between the launch of the first Orbiter and that of Lunar Orbiter II. On 6 November 1966 the second mission began, with the launch of the spacecraft at 1821 USEST. Lunar Orbiter II commenced its photographic work on 18 November and two days later it photographed the impact point of Ranger VIII.

On 23 November it recorded one of the most spectacular pictures of the lunar surface ever seen, billed as the 'Picture of the Century.'

The picture of the Crater Copernicus was taken as a result of the threat of the Bimat film sticking and the need to move new film onto the processor drum at regular intervals

A certain amount of the film would be wasted if no exposure were made and a choice arose as to the use of this "film-set" frame.

One mission ground rule called for the frames to be used to take pictures of any areas in the Apollo zone of interest, should the spacecraft be over one at the time.



Taken from an altitude of 45.91 kilometres, Lunar Orbiter 2 captured this image on approach to the 100 kilometre wide, Copernicus Crater. In the distance, the Carpathian Mountains are 1,000 metres high. Image: NASA

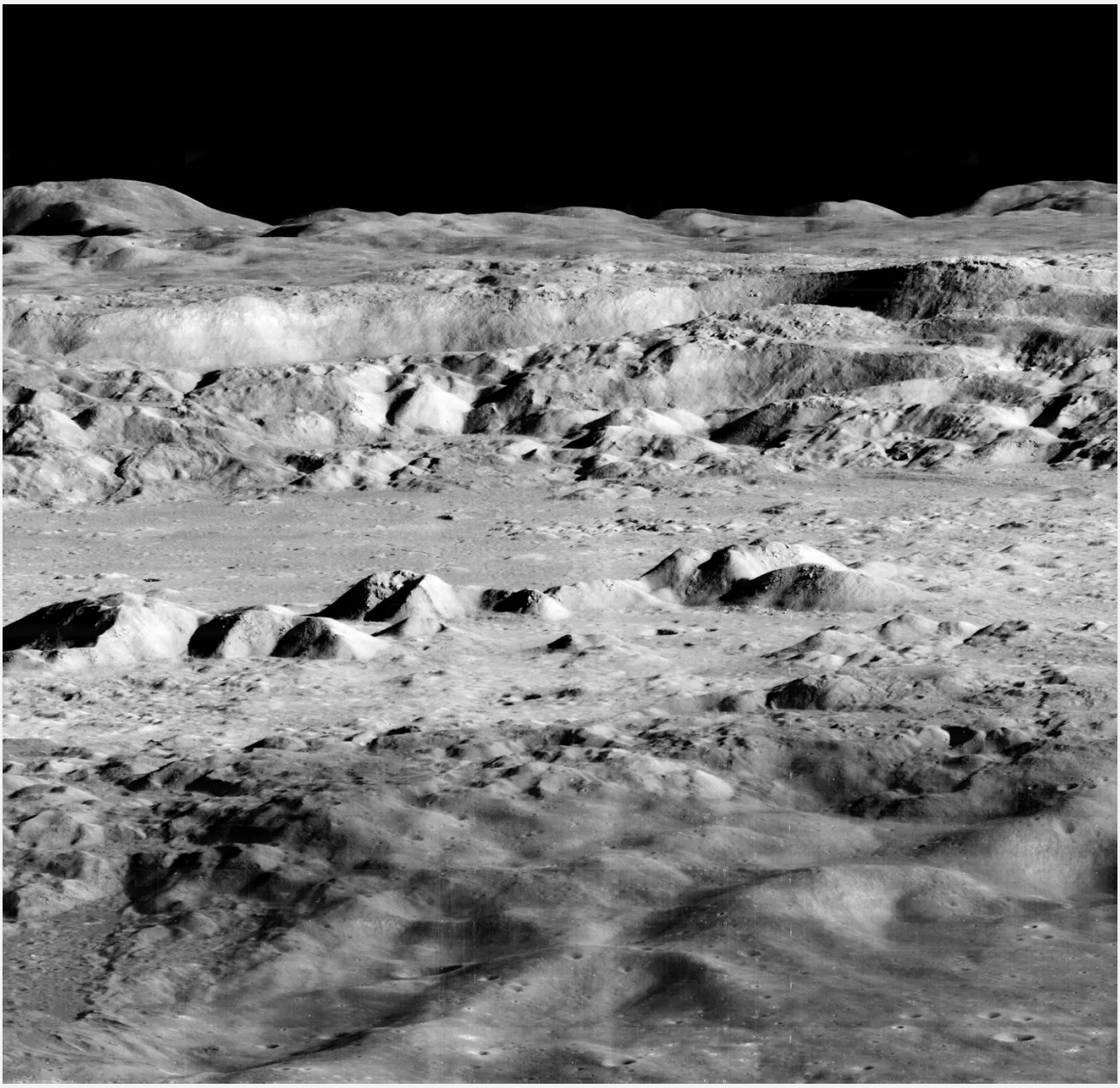
On the other hand, Douglas Lloyd of Bellcomm, Inc., had suggested during mission planning that this particular "film-set" frame be used to take a photograph of the crater Copernicus when the spacecraft passed due south of it at a distance of 240 kilometres and a vertical altitude of 45 kilometres above the lunar surface.

Twice his suggestion was turned down by NASA officials because of the Apollo ground rule. However, upon Lloyd's third suggestion program officials consented, and the decision to make the picture came during actual mission operations.

The Orbiter's camera made a dual wide-angle/telephoto exposure, and the 610 mm telephoto image of the crater from a long, low, oblique angle to the lunar surface when lighting conditions were optimum for best contrast, was chosen. The resulting picture revealed geographic and topographic features of the central portion of this 100 kilometre-wide crater which had never been seen before.

On the horizon, behind the ledges and crater rim, the Gay-Lussac Promontory in the Carpathian Mountains could be seen towering 1,000 meters above the lunar surface.

It was taken with the wide-angle lens at 1905 USEST on 23 November 1966 when the spacecraft was 45.91 kilometres above the lunar surface and 240 kilometres south of the crater.



"Picture of the Century" – The inner walls and central peaks of Copernicus Crater. Image: NASA/LOIRP

Copernicus Crater was formed by a giant meteorite, and is 96 kilometres in diameter and 3.2 kilometres deep.

The rim of the crater is surrounded by angular blocks up to 46 metres across, while strings of small craters seen in the foreground were formed by the impact. Fifty-three kilometres south of Copernicus is Fauth, the double crater in the middle foreground. It is about 21 kilometres long by 1.4 kilometres deep.

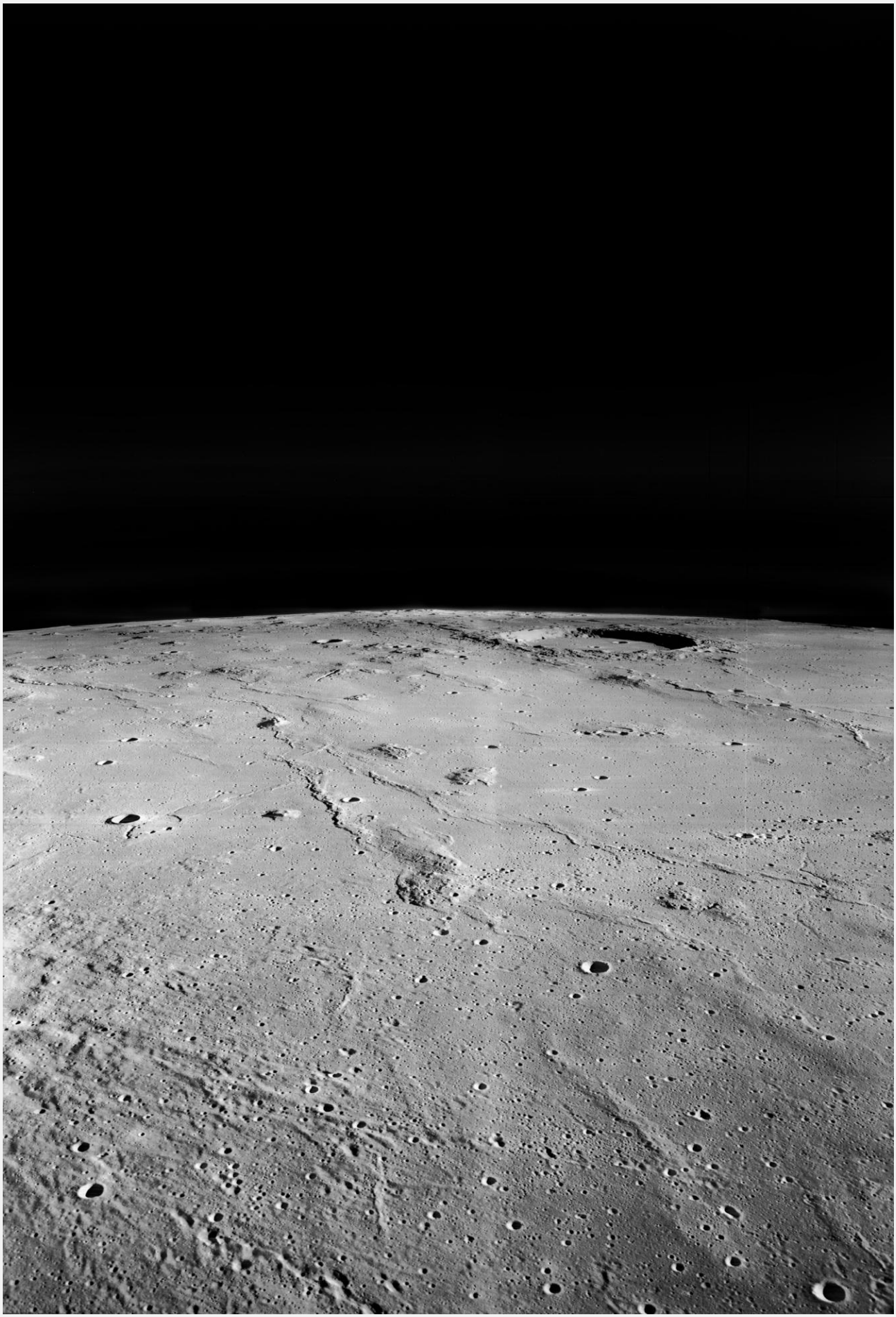
A close-up of Copernicus Crater taken at the same time as the previous photo, on 23 November 1966 by Lunar Orbiter II.

Called by the media the "Picture of the Century," it is looking in the same direction, to the north, but the telephoto lens has changed the whole atmosphere of the crater.

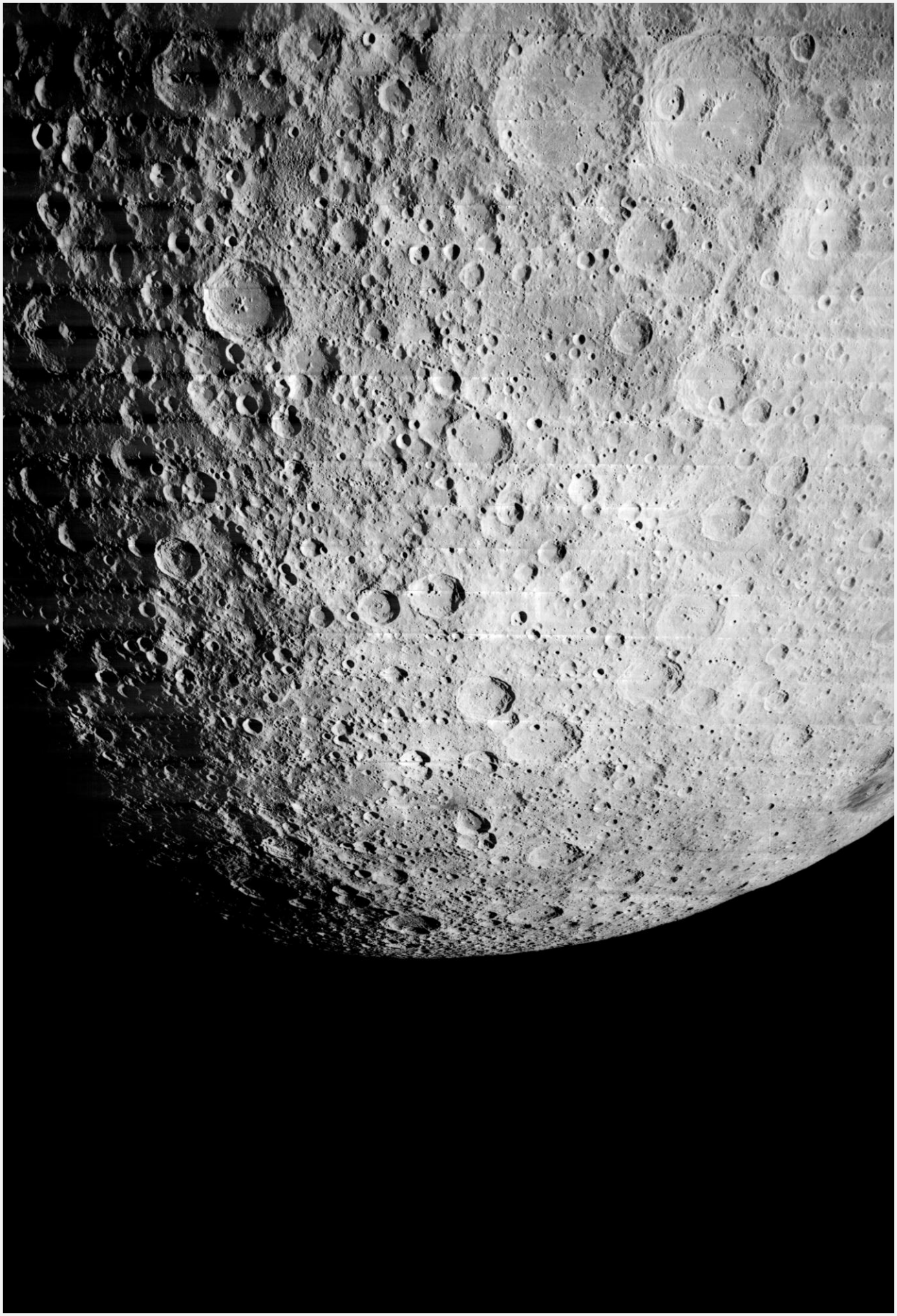
Now the frame is filled with a forbidding landscape of plunging cliffs, sweeping escarpments, and tumbling landslides backed by desolate mountain ranges rolling away into the distance. Ringed by rugged 600 metre high cliffs, a jagged mountain ridge thrusts up from the crater floor to a height of 305 metres.

This view must have awed the Apollo astronauts, about to embark on their voyages to the Moon.

In fact, this is the crater that was supposed to be the destination of Apollo 20, the last Apollo mission, as a spectacular finale of the Moon landing program.



View approaching the 41 kilometre wide crater called Marius, located in Oceanus Procellarum.
Image: NASA (Note: Sky darkened/extended from original)



(Upper right) the craters Heaviside and Keeler. (Upper left) the triangle formed by (top) Krasovskiy, (bottom) Daedalus, and (left) Icarus craters. Image: NASA (Note: Sky darkened/extended from original)

One suggestion was for the astronauts to fly a small spacecraft to the ledges of the surrounding cliffs. It's a pity it was cancelled – it would have been an exciting mission.

The status report of the Lunar Orbiter II mission as of 28 November 1966 indicated that the first phase of the photographic mission was completed when the final photo was taken on the afternoon of 25 November. On 26 November, the Bimat developing web was cut with a hot wire in response to a command from the Earth. Failure to achieve the cut would have prevented the final readout of all 211 photos. Readout began immediately after the cut was made.

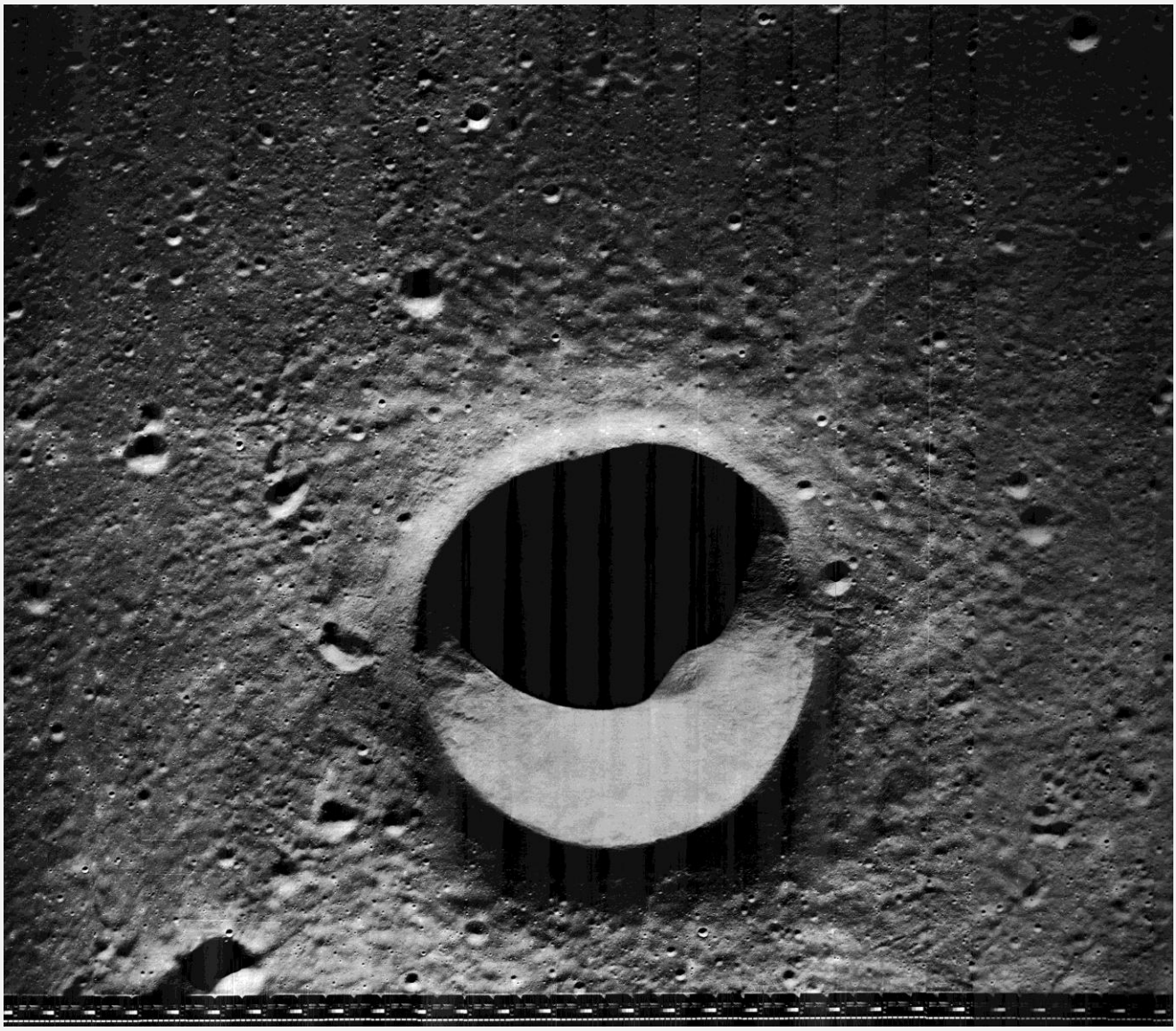
One day early, on 6 December, the readout terminated when a transmitter failed, and three medium-resolution and two high-resolution photos of primary site 1 were lost.

Full low-resolution coverage of the site had been provided, however, and other data continued to be transmitted.

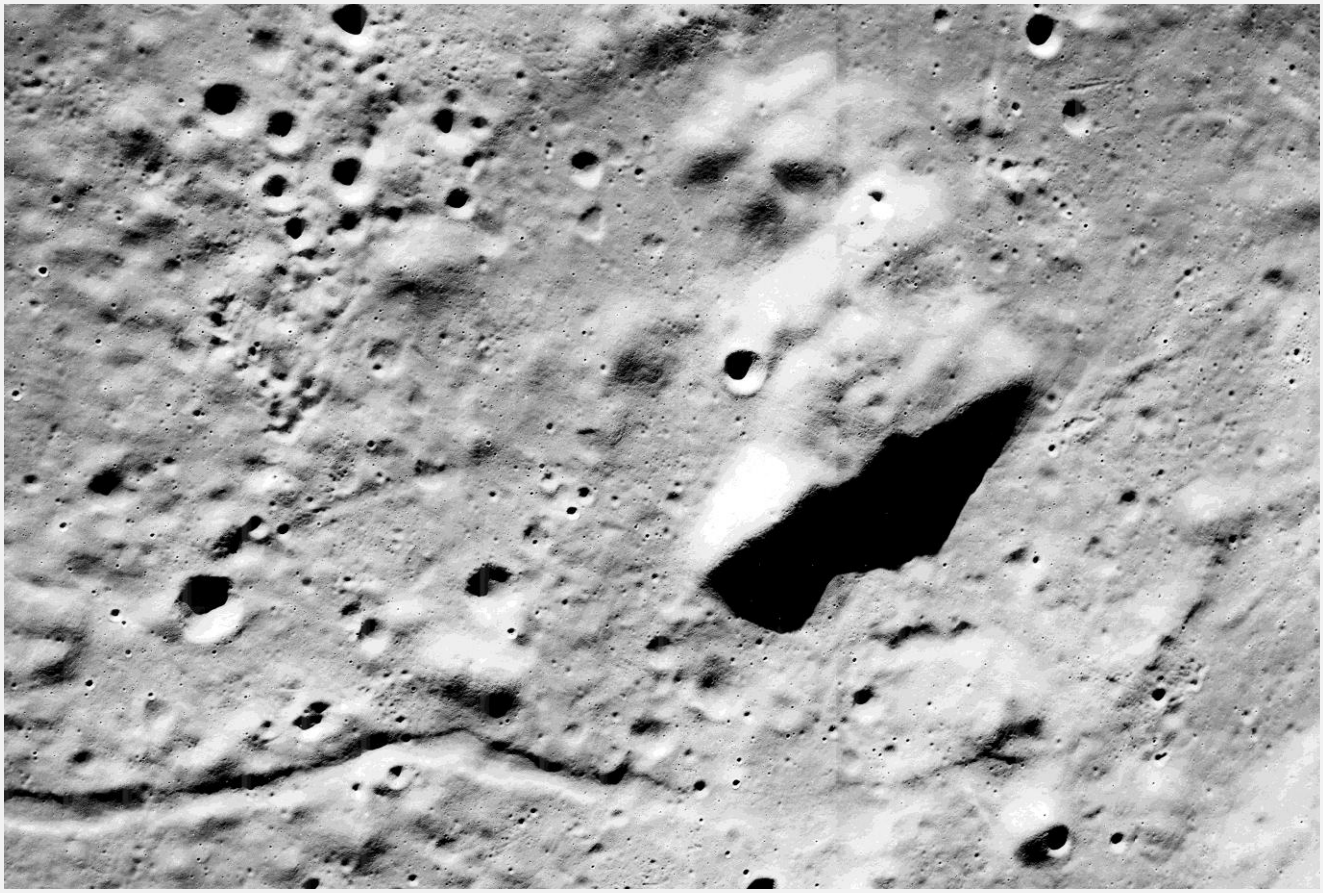
Lunar Orbiter II had sufficient attitude control gas to survive until early November 1967. Ground control operators planned to impact it into the Apollo zone on the Moon's surface, even though analysis of tracking data indicated that it could probably remain in orbit one or two years longer.

Once the spacecraft lost its attitude control gas, however, it would become a derelict in orbit, beyond the control of ground operations. Program officials decided to crash the spacecraft while they could, to avoid any potential communications interference in future manned missions.

On 11 October 1967 the flight controllers sent commands to destroy Lunar Orbiter II by crash landing on the lunar surface.



Crater Gambart C taken from an altitude of 41.69 kilometres. Image: NASA



A hill at the southern end of Rima Schröter, a rille on the southeastern edge of Mare Insularum. Image: NASA

Mission Fact Box

Launch
Launch Complex - 13 Cape Kennedy/Canaveral
Sunday, 5 February 1967
2117:01 US EDT / 5/0117:01 UTC
[Sunday, 5 February 1967, 1117:01 AEST]

Spacecraft
Rocket: Atlas SLV-3 Agena-D
Probe: *Lunar Orbiter 3*

Primary mission
Apollo landing site survey

Images returned
211 – between 15-23 February 1967

Lunar orbital data
Closest approach: 55 kilometres
Periselene: 1,791 kilometres
Aposelene: 3,598 kilometres
Inclination: 20.9°
Period: 3 hours 28 minutes 6 seconds
Orbits: 1,702 over 8 months 4 days

Lunar Impact
9 October 1967, 1027:11 UTC
Near Mees Crater, 14.3°N 97.7°W

Lunar Orbiter III

Lunar Orbiter III showed us the battered side of the Moon we can't see.

Taken on 19 February 1967 from an altitude of 1,448 kilometres, the large, black-floored crater is the 180 kilometre wide Tsiolkovsky Crater.

Named after the deaf Russian school teacher Konstantin Tsiolkovsky (1857-1935) whose vision of travelling in space, liquid fuel rockets, multi stage rockets, closed life-cycle systems, space suits, inspired the early Russian cosmonauts.

One of his famous quotations is,
"Earth is the cradle of the mind,
but one cannot live in the cradle forever."

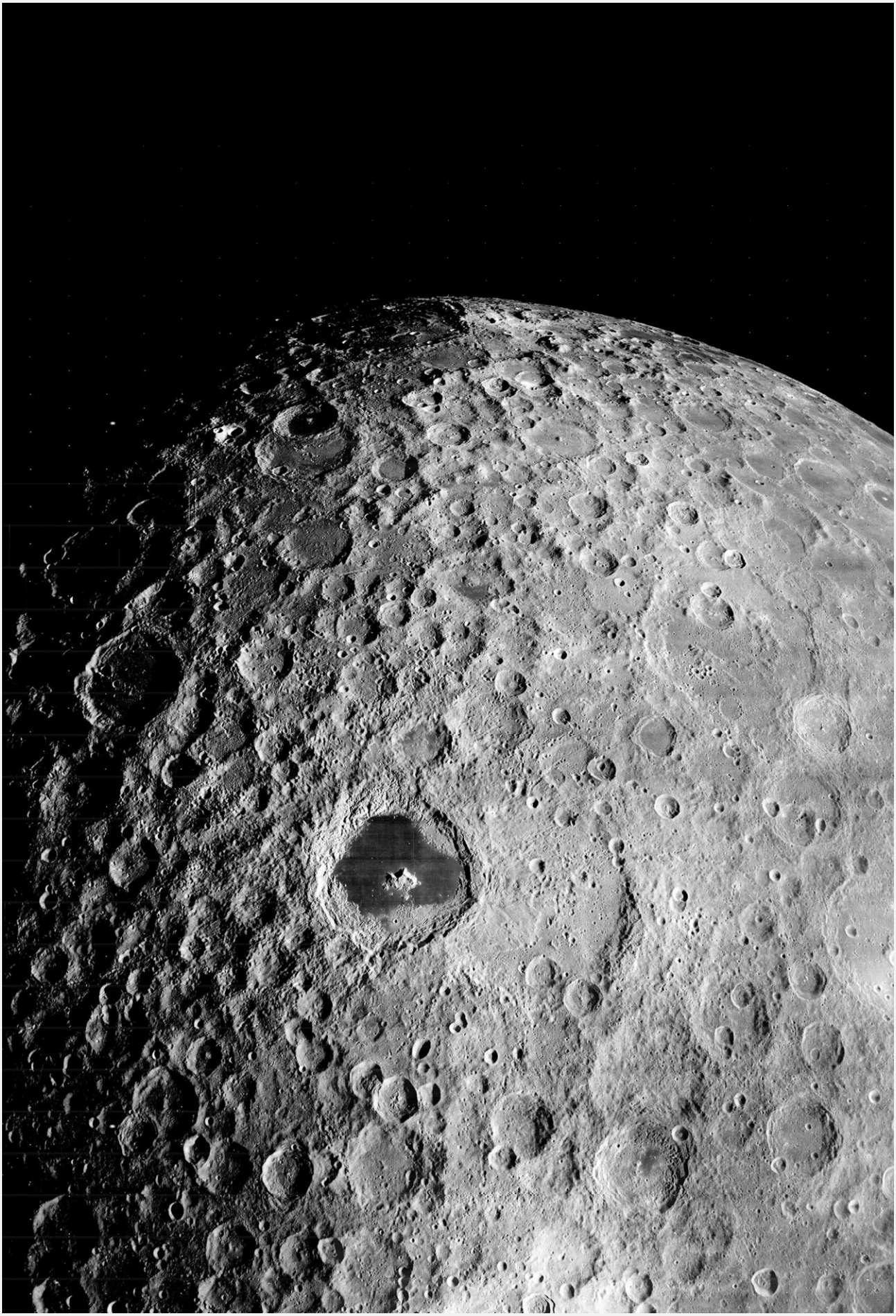
In the shadows to the lower right is a crater named after Jules Verne.

The flight controllers planned to lower Lunar Orbiter III's apolune to make its orbit as circular as possible for further training for Apollo tracking. However, expiration of its gas meant it would have to be crashed, so on 9 October 1967, the final commands were transmitted to destroy Lunar Orbiter III by lunar impact.

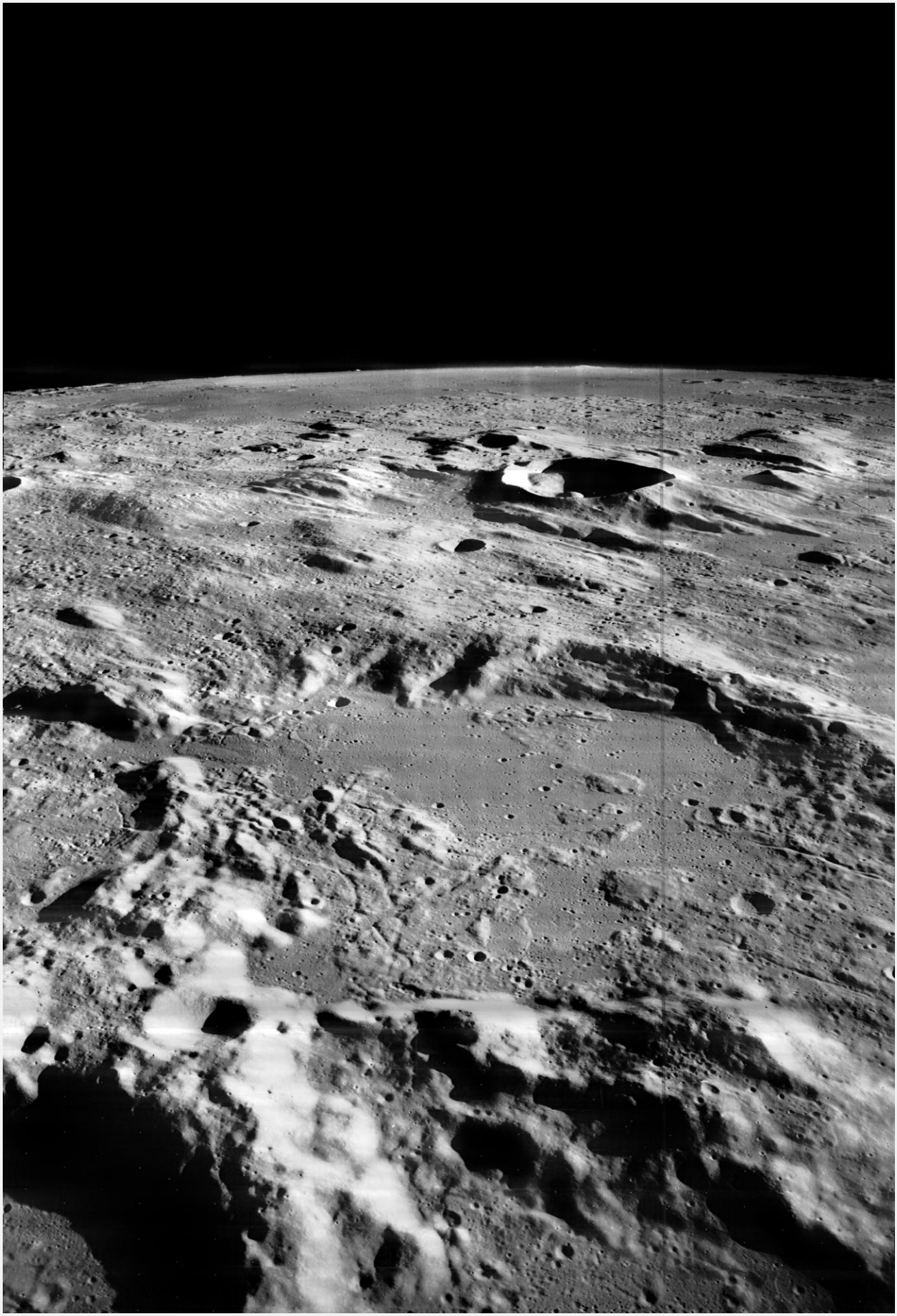
The Atlas-Agena D vehicle for the Lunar Orbiter 3 mission, being prepared for launch. Image: NASA

Launch Complex 13 featured a 'mobile service tower' where vertical integration of the rocket and its payload could be conducted. It served as the launch pad for all of the Lunar Orbiter missions.

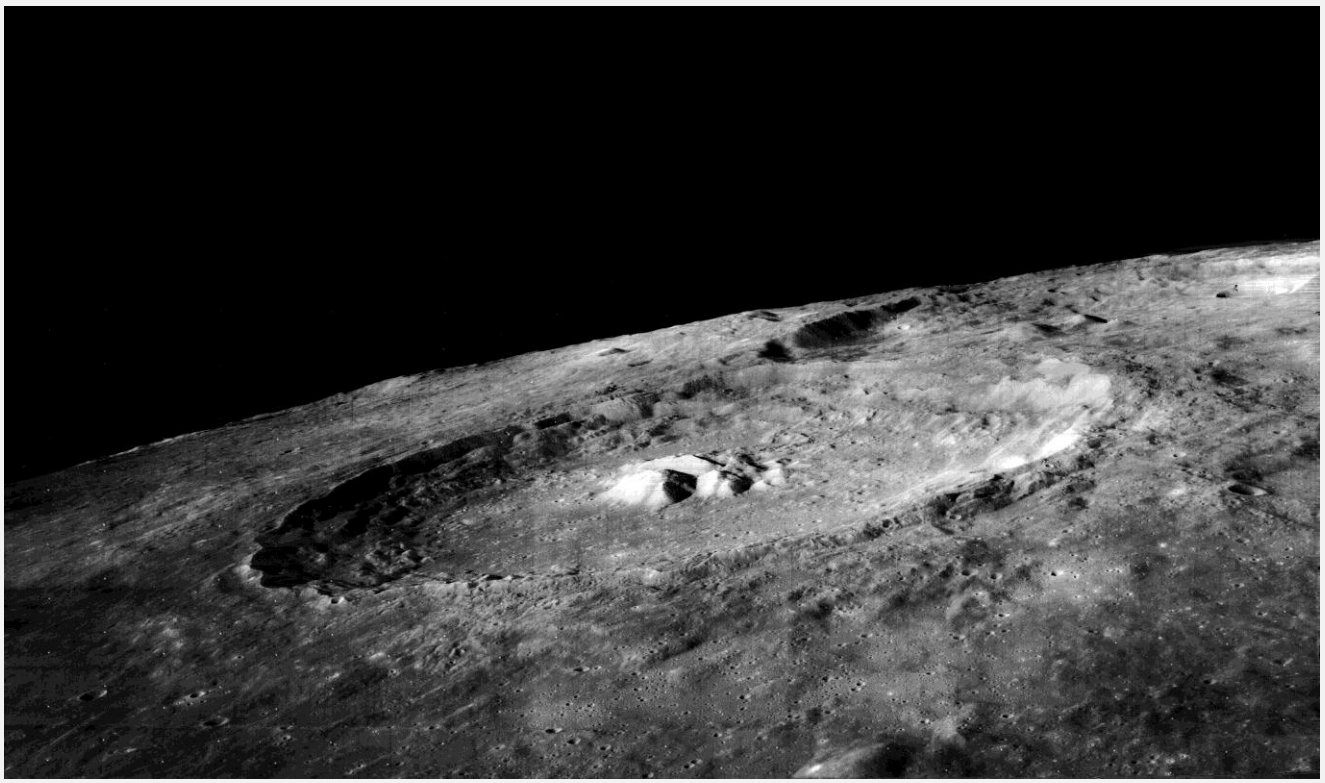
Starting its life at the Cape in 1958, Launch Complex 13 has been modified many times to serve various missile tests and Atlas rockets. The mobile tower was demolished in 2005, and in 2015 became the large circular 'Landing Zones 1 and 2' for SpaceX's Falcon 9 and Falcon Heavy rockets.



Tsiolkovsky crater on the far side of the Moon.
Image: NASA (Note: Sky darkened/extended from original)

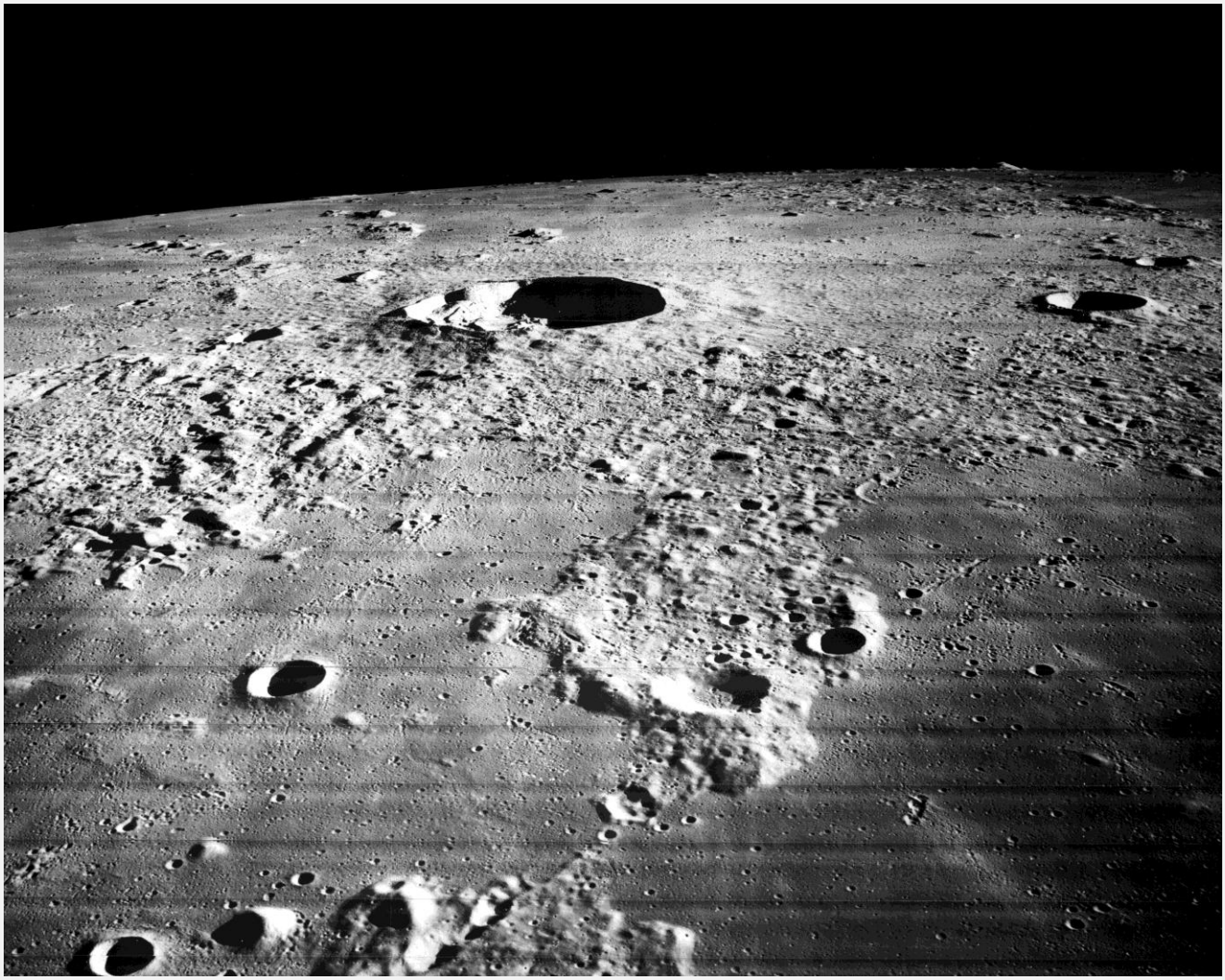


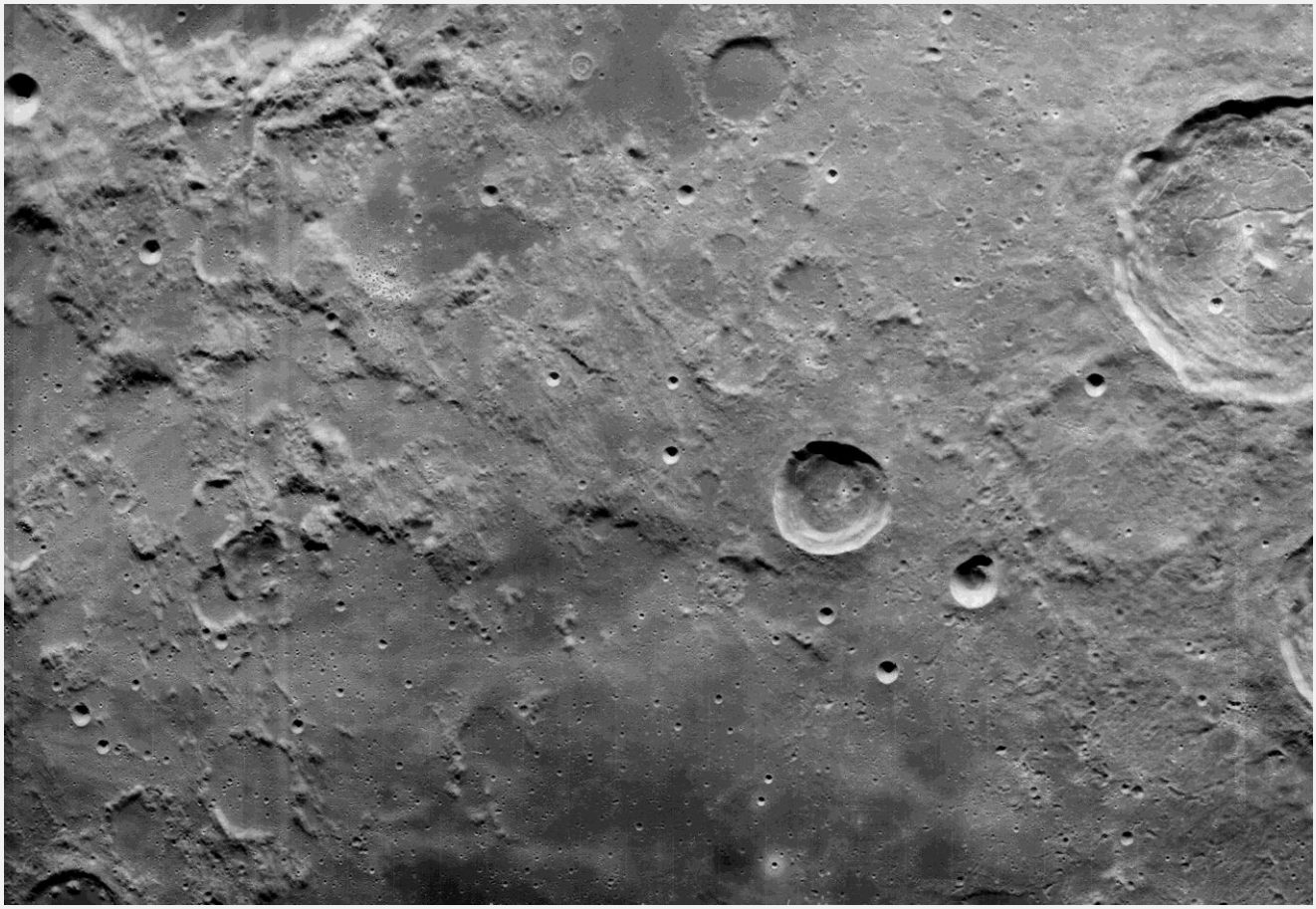
The intricate young ejecta blanket on ancient Murchison crater.
Image: NASA (Note: Sky darkened/extended from original)



Above: The 100 kilometre wide crater Theophilus (centre) and 98 kilometre wide Cyrillus (upper right). Images: NASA (Note: Sky darkened/cropped from original)

Below: Kepler crater borders the terrain between the 'mares' Procellarum and Insularum.





Craters Keldysh (right of centre) and nearby Hercules, and Atlas (top right) in Mare Frigoris. Image: NASA

Mission Fact Box

Launch
Launch Complex - 13 Cape Kennedy/Canaveral
Thursday, 4 May 1967
1825:00 US EDT / 2225:00 UTC
[Friday, 5 May 1967, 0825:00 AEST]

Spacecraft
Rocket: Atlas SLV-3 Agena-D
Probe: *Lunar Orbiter 4*

Primary mission
Lunar mapping

Images returned
199 – between 11-26 May 1967

Lunar orbital data
Closest approach: 2,706 kilometres
Periselene: 4,449 kilometres
Aposelene: 7,856 kilometres
Inclination: 85.5°
Period: 3 hours 28 minutes 6 seconds
Orbits: 360 over 180 days

Lunar Impact
6 October 1967 – last contact 17 July 1967
time and location unknown

Lunar Orbiter IV

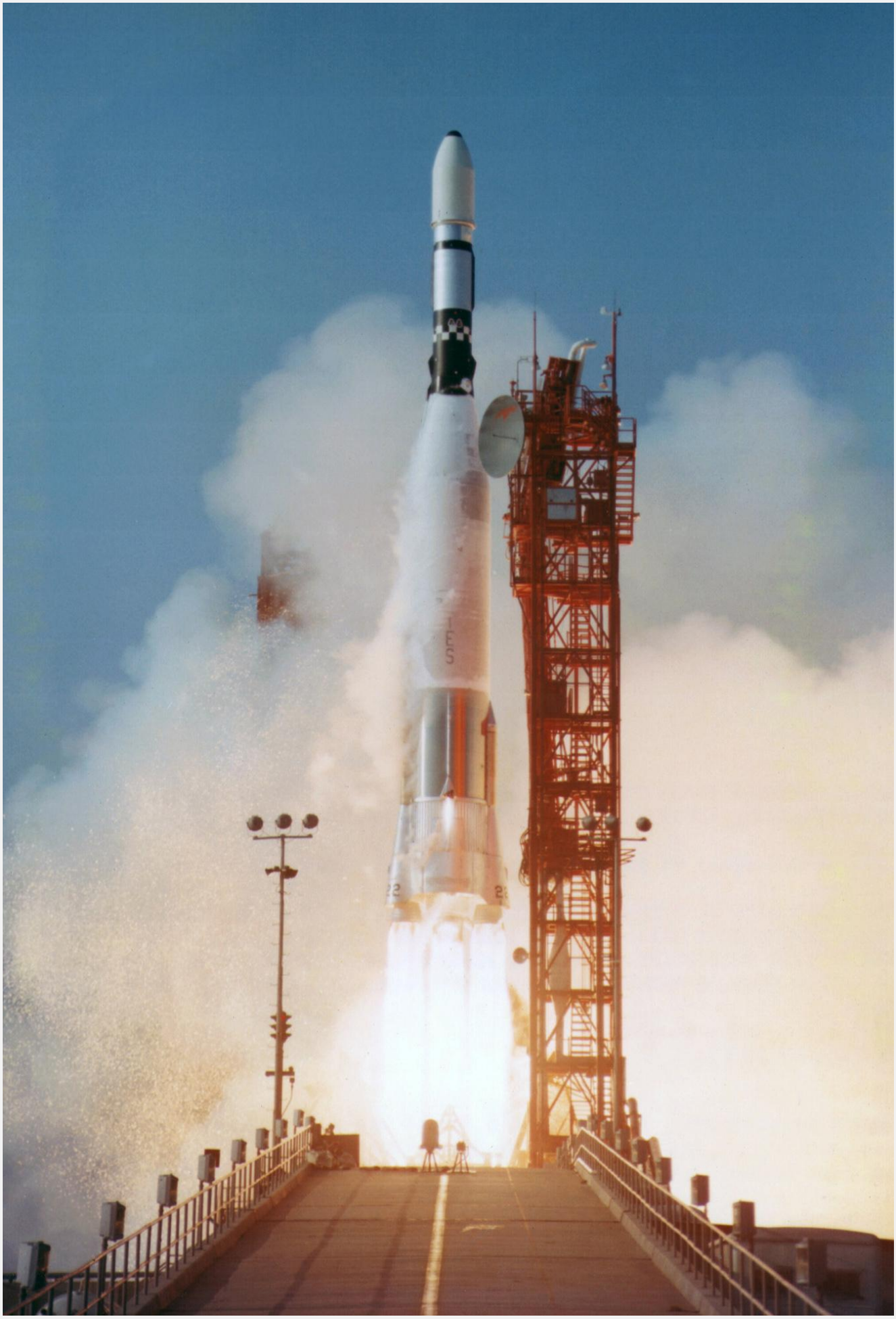
Last minute tests did not reveal any problems of a magnitude serious enough to delay a launch, and at 1825 USEDT on 4 May Lunar Orbiter IV rode into space from Launch Complex 13 at Cape Canaveral, Florida.

In its sixth orbit around the Moon the spacecraft began its first photographic pass at 1146 USEDT on 11 May.

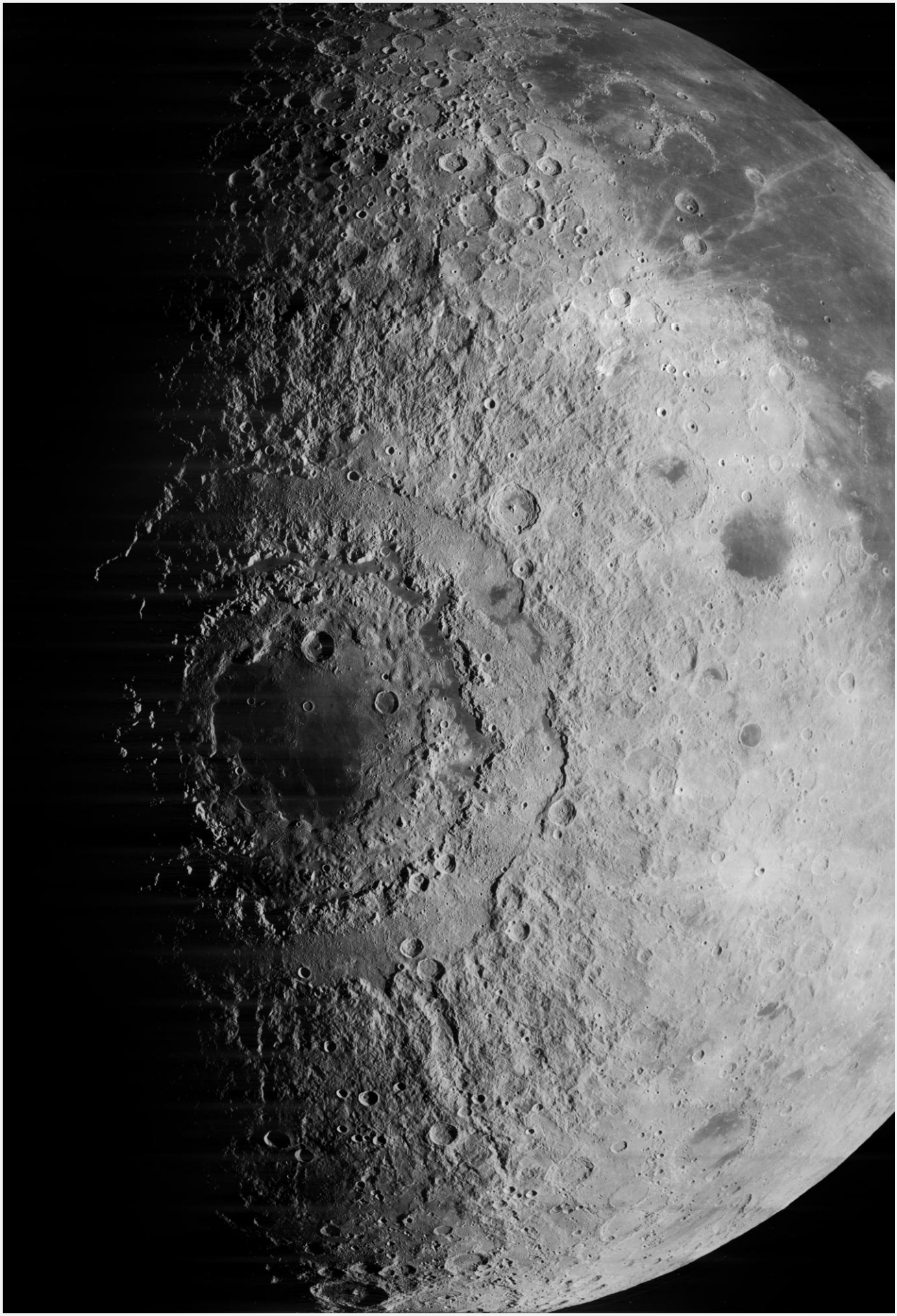
Despite this apparent success, the spacecraft had already developed a serious problem which threatened to jeopardize the whole mission. Telemetry data indicated that after the second set of four frames had been exposed, the camera thermal door failed to close until ground control had sent additional commands to close it.

After the third set of four frames had been made, spacecraft telemetry did not confirm if the door had opened sufficiently.

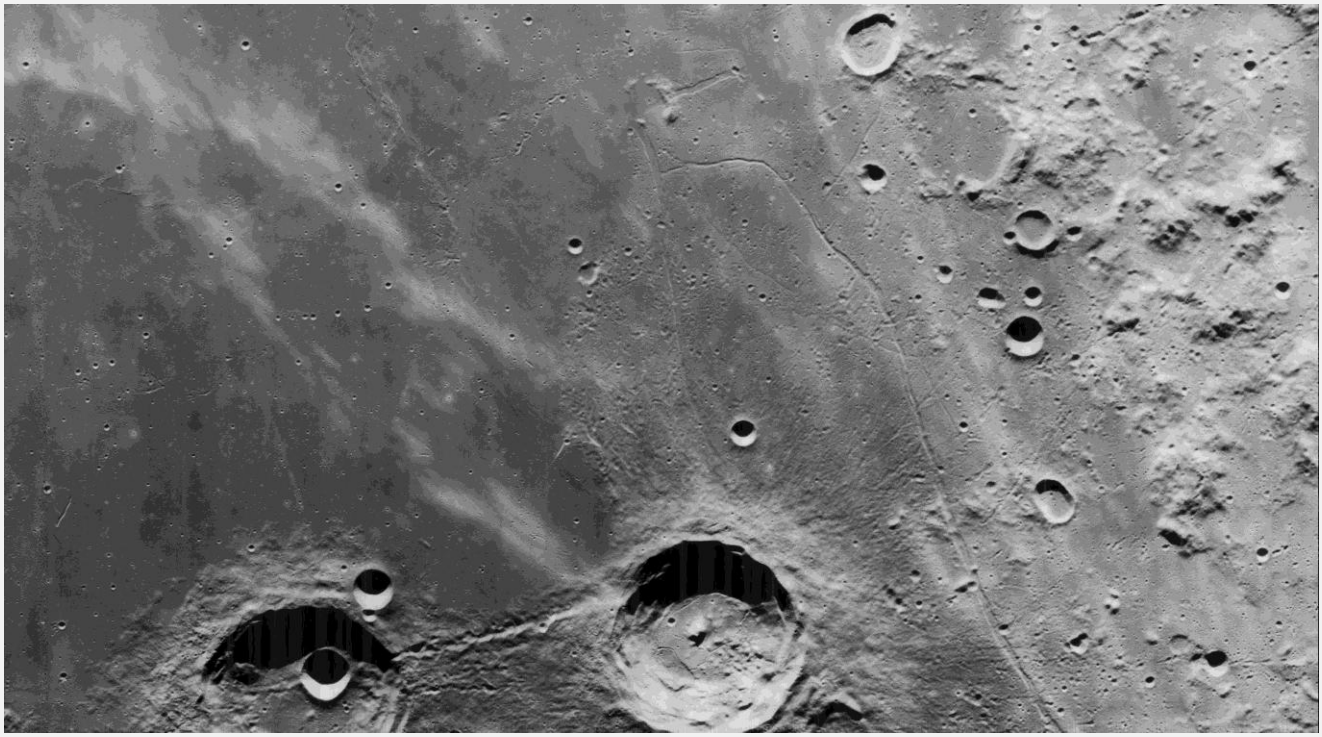
Flight controllers initiated a preliminary corrective action by commanding the door to open far enough in advance of the fourth set's exposure time to allow for additional commands if required.



Moonbound! Lunar Orbiter 4 roars away from Launch Complex 13. Image: NASA

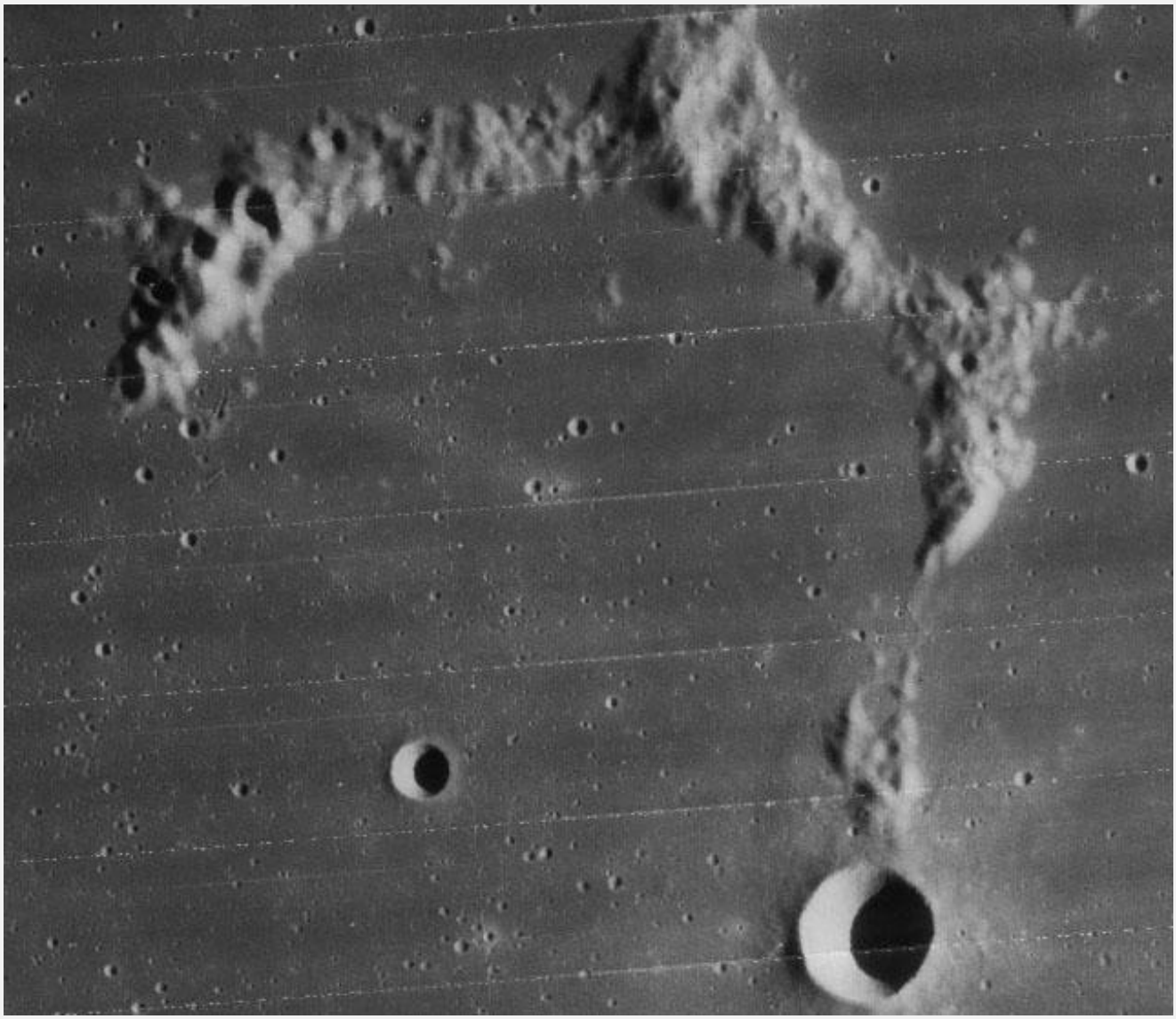


Mare Orientale and surrounding basin on the lunar far side is 900 kilometres in diameter.
Image: NASA (Note: Shadows and sky darkened/cropped from original)



Above: A chain of craters connects craters Krafft (left) and Cardanus, with lunar wisps across the plains. Images: NASA

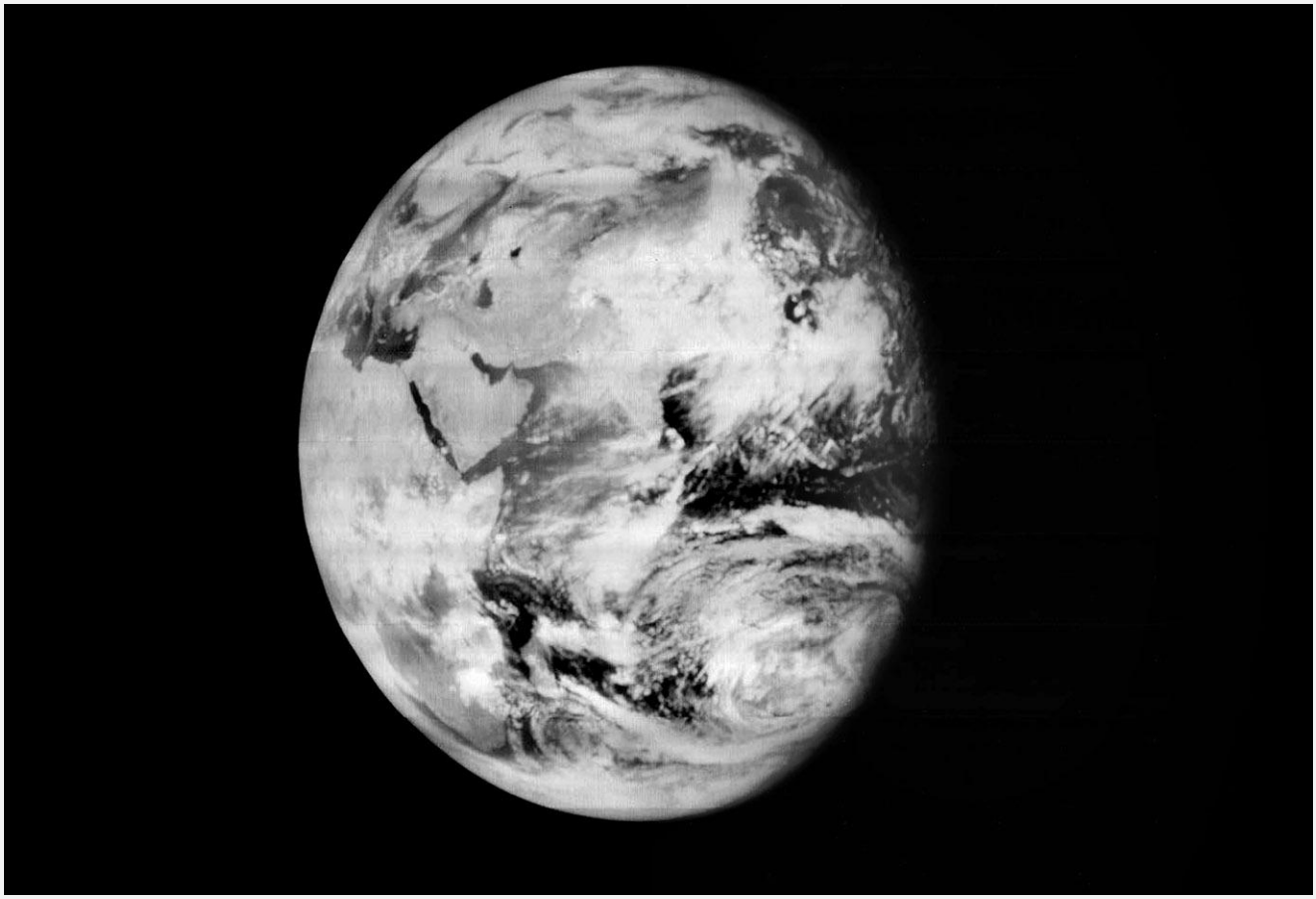
Below: Lunar questions!? The arc of Wichmann R crater, punctuated by smaller Wichmann crater.



Lunar Orbiter IV photography had covered 99% of the Moon's near side at a resolution exceeding by ten times the best Earth-based telescopic photography.

The flight controllers had lost communications with Lunar Orbiter IV on 17 July 1967, and assumed that its orbit had decayed sufficiently to permit it to crash onto the Moon on 6 October 1967.

Above: Aristarchus crater (top) and Vallis Schröteri. The partially filled and eroded rim of Prinz crater (left). Images: NASA (Note: White 'blobs' in the image above are from processing errors)
Below: Planitia Descensus and craters (from lower left) Cavalerius, Hevelius and Lohrmann.



Lunar Orbiter V's image of Earth. Image: NASA/LOIRP

Mission Fact Box

Launch
Launch Complex - 13 Cape Kennedy/Canaveral
Tuesday, 1 August 1967
1833:00 US EDT / 2233:00 UTC
[Wednesday, 2 August 1967, 0833:00 AEST]

Spacecraft
Rocket: Atlas SLV-3 Agena-D
Probe: *Lunar Orbiter 5*

Primary mission
Lunar mapping and high-resolution survey

Images returned
174 – between 6-18 August 1967

Lunar orbital data
Closest approach: 97 kilometres
Periselene: 194.5 kilometres
Aposelene: 6,023 kilometres
Inclination: 85°
Period: 8 hours 30 minutes 5 seconds
Orbits: 1,380 over 5 months 30 days

Lunar Impact
31 January 1968 – last contact 17 July 1967
Near Schluter Crater, 02.79°S 83.01°W

Lunar Orbiter V

Scheduled for 1609 USEDT 1 August 1967, the launch of Lunar Orbiter V was the cause of high anxiety for a while when a heavy rain storm held up the proceedings for two and a half hours.

The launch window for 1 August only lasted from 1600 to 2000. A postponement until the following day was serious because it would mean the loss of some far-side photography.

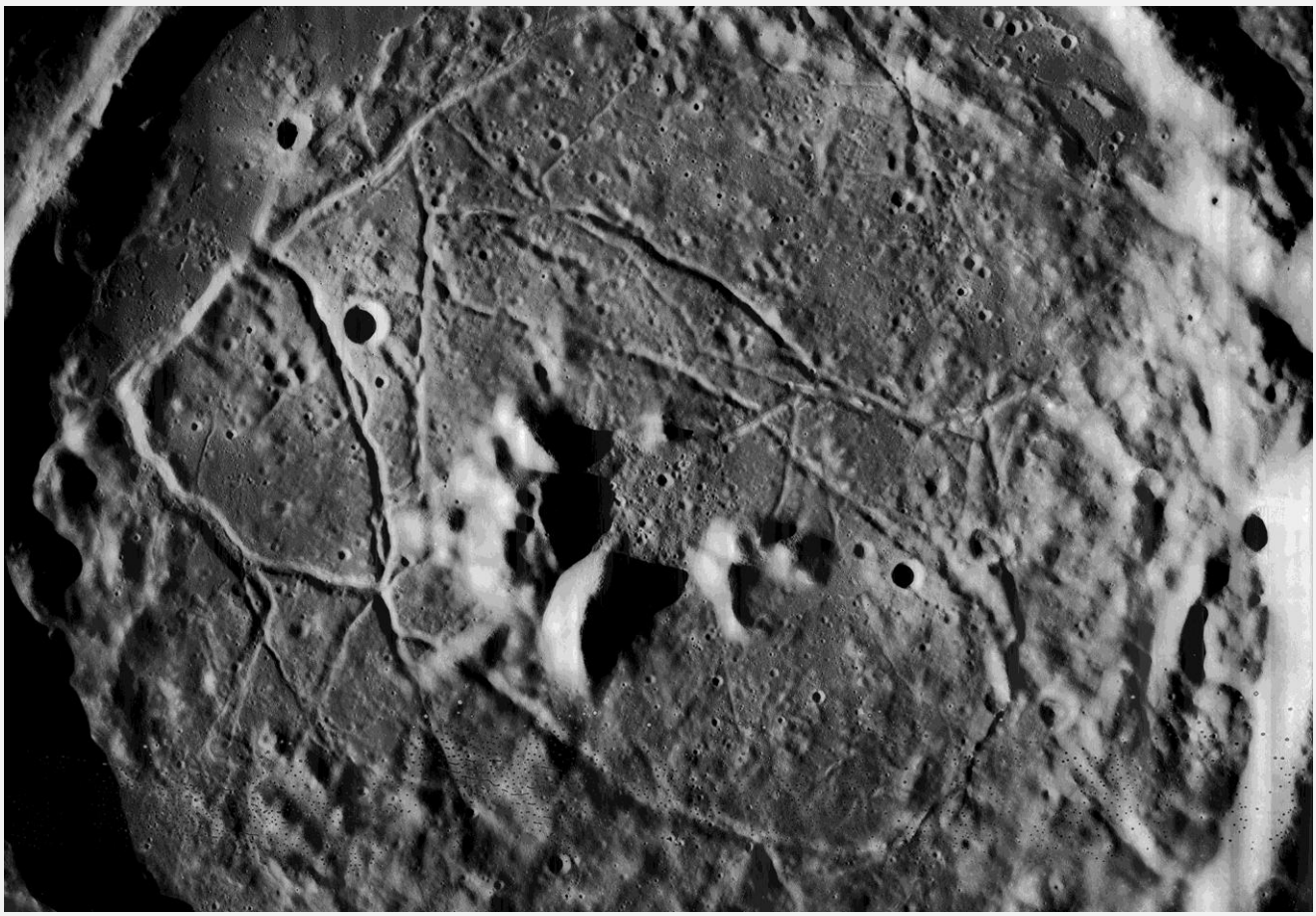
The Moon rotates 13° of arc on its axis per Earth-day, so a delay of one day would mean the loss of a 13° portion of the lunar far-side to darkness.

Fortunately, the weather improved, and the countdown resumed to send Lunar Orbiter V on its way at 1833 USEDT. Photography commenced at 1922 on 6 August.

At one stage Lunar Orbiter V was manoeuvred to reflect sunlight from its solar panels and underside mirrors with the reflected rays to be photographed by telescopes on Earth.

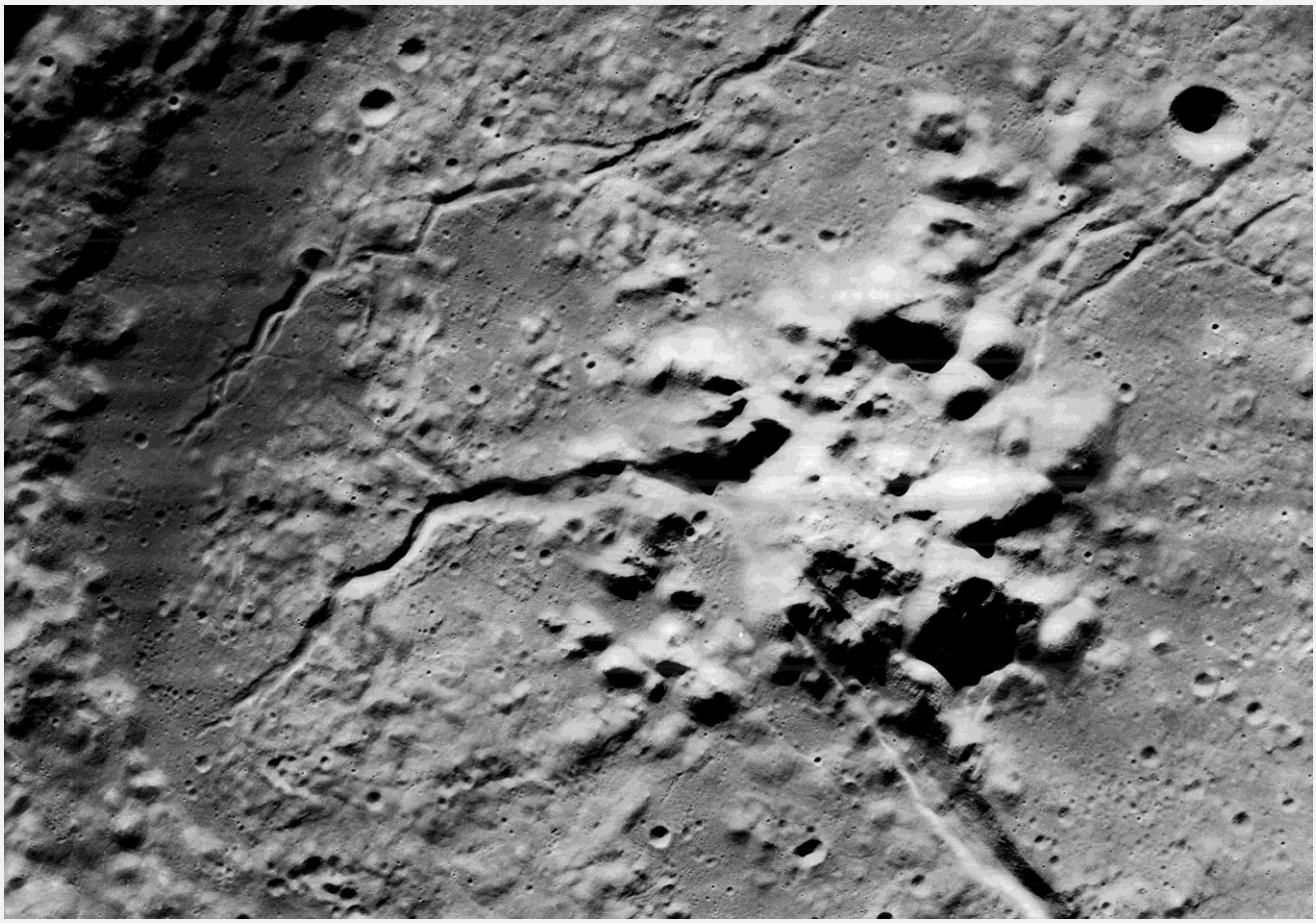
The photographic mission ended on 18 August when the spacecraft took its last photograph and ran out of Bimat film at 2320 USEDT.

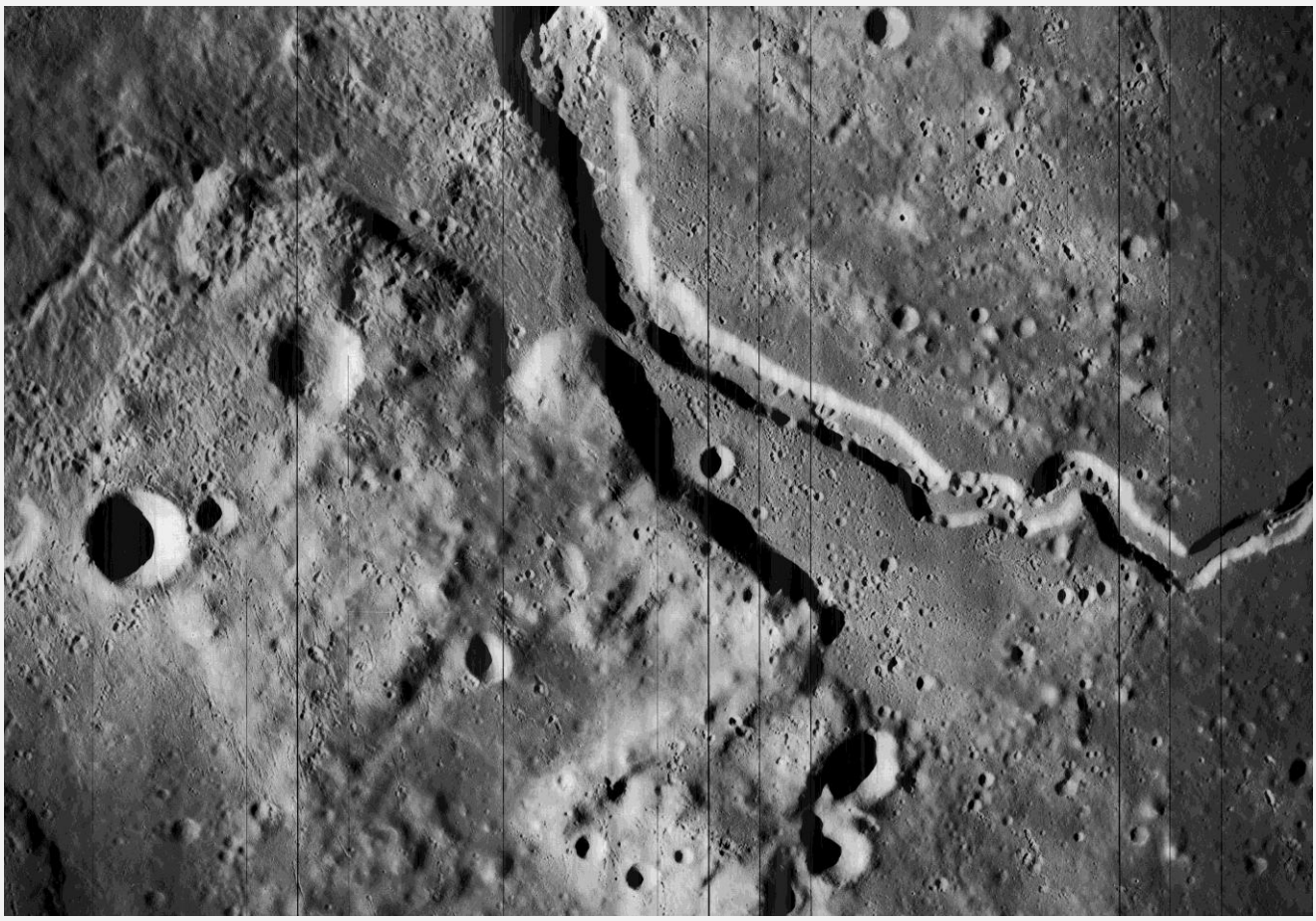
Lift-off of the final mission in the Lunar Orbiter series – 1 August 1967. Image: NASA



Above: The basin of Gassendi crater is dominated by criss-crossing rilles and a complex central peak. Images: NASA

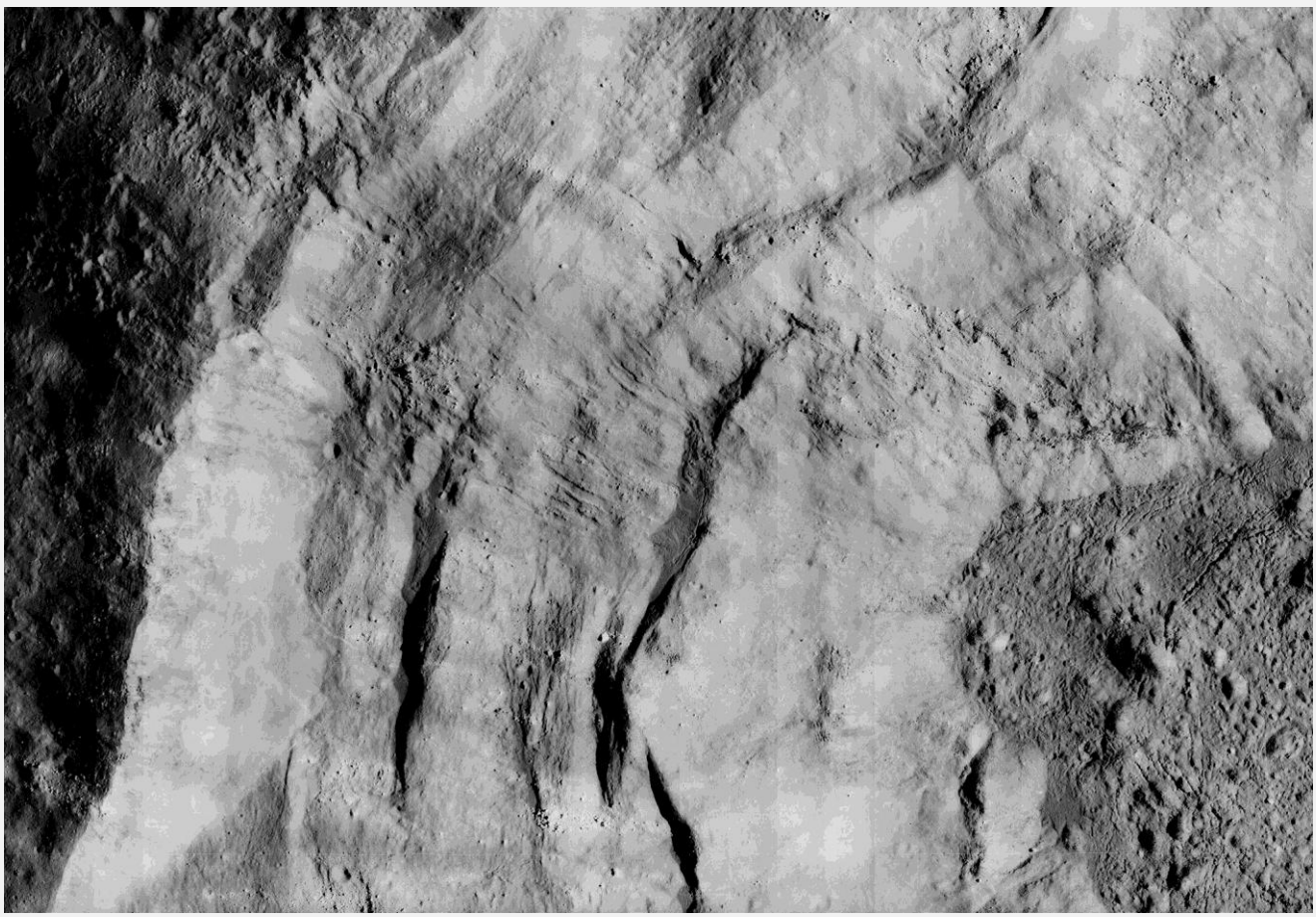
Below: Petavius crater features deep rilles, and central peaks up to 1.7 kilometres high.

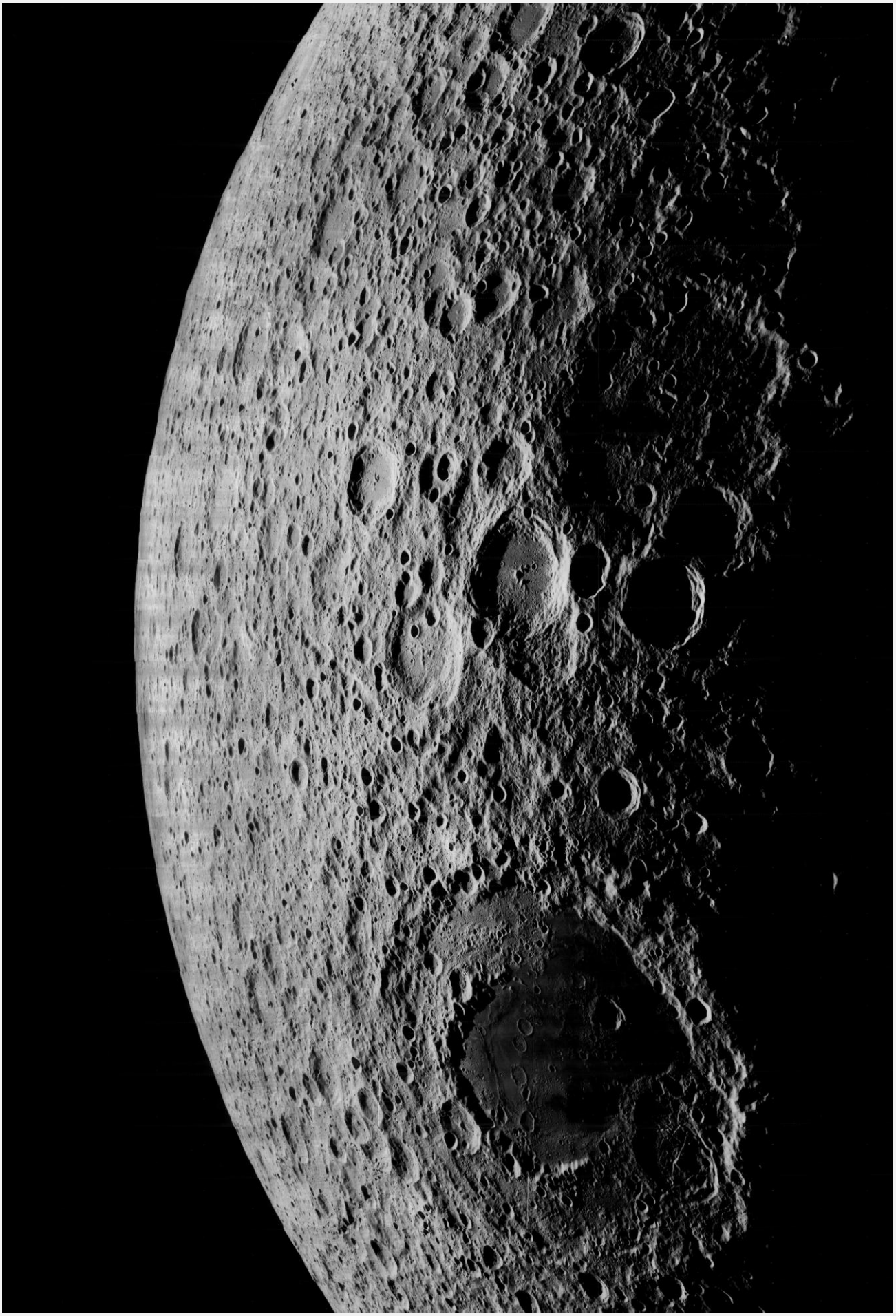




Above: A part of Vallis Schröteri which totals 160 kilometres in length and up to 10 kilometres wide. Images: NASA

Below: A close-up of the rim of the 40 kilometre wide, 2.7 kilometre deep, Aristarchus crater.





At 1,239.43 kilometres above the surface, Lunar Orbiter 5 captured this image of the Moon's far side and Mare Mascoviense. Image: NASA/LOIRP

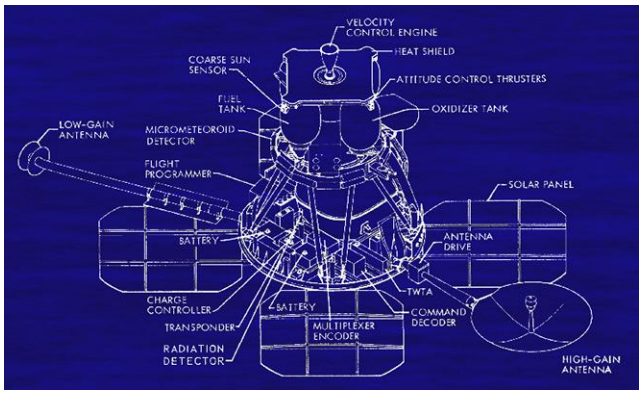
In all it had successfully covered 5 Apollo sites, 36 science sites, 23 previously un-photographed areas on the lunar far side, and a view of the nearly fully illuminated Earth.

Lunar Orbiter V began its extended mission late in August. Its orbit would be changed on 10 October so that it might better survive the umbral eclipse of 18 October so the spacecraft would pass through the eclipse and solar occultation by the Moon at the same time.

Apollo tracking stations continued to track the spacecraft as long as possible to increase their experience in preparation for future manned lunar missions.

Lunar Orbiter V continued to fly an extended mission until it experienced an unexpected anomaly, which threatened its safety. A sudden loss of pressure in the nitrogen tank forced flight controllers to destroy the spacecraft prematurely on the Moon to avoid losing it in orbit. They conducted this final manoeuvre on 31 January 1968, bringing it down near the equator on the Moon's western limb.

The destruction of Lunar Orbiter V brought the operational phase of the Lunar Orbiter Program to a close, and ended one of the most successful projects ever run by NASA.



Program Summary

To summarise the achievements of NASA's Lunar Orbiter Program;

- Lunar Orbiter II photography led to the identification of the Ranger VIII impact point on the Moon.
- The locations of all the Surveyor spacecraft were determined by Orbiter photography.
- The fifth Orbiter had photographed major lunar features of scientific interest at a resolution 100 times better than Earth-based telescopes could achieve under ideal observation conditions.
- The Orbiters photographed the entire lunar surface at a better resolution by at least an order of magnitude than Earth-based telescopes could attain, and surveyed the heavily cratered far side of the Moon.
- Tracking the spacecraft's orbits yielded improved data on the Moon's overall shape and gravitational field. Maps were produced of the lunar surface from the Orbiter photography.
- Altogether the Orbiters returned 2180 high resolution images of the surface of the Moon (near and far side) with resolution down to 1 metre, and 882 medium resolution frames.
- The micrometeoroid experiments recorded 22 impacts showing the average micrometeoroid flux near the Moon was about two orders of magnitude greater than in interplanetary space, but slightly less than the near Earth environment.
- The radiation experiments confirmed that the design of Apollo mission hardware would protect the astronauts from average and greater-than-average short-term exposure to solar particle events.

The use of Lunar Orbiters for engineering evaluation and training station personnel of the Manned Space Flight Network as well as the Apollo Orbit Determination Program, was very successful, preparing the stations for the manned lunar missions beginning with Apollo 8 in December 1968.

Three Lunar Orbiters (2, 3, and 5) were tracked simultaneously from August to October 1967.

The tracking stations could not have obtained the tracking experience in the lunar environment at a timely date if NASA had not flown the five Lunar Orbiter spacecraft.

Essay by Hamish Lindsay, 2012-2014.
Unless specified images are from NASA.
Enhanced images courtesy of the Lunar Orbiter Image Restoration Project.
Unless specified, illustrations and captions by Hamish Lindsay, Colin Mackellar, and Glen Nagle.
PDF formatted by Glen Nagle.

ABOUT THE AUTHOR

Hamish Lindsay (1937-2022) worked at the Muchea, Carnarvon and Honeysuckle Creek space tracking stations between 1963 and 1981.

He wrote many essays on the history of human spaceflight, and was the author of the book, Tracking Apollo to the Moon.