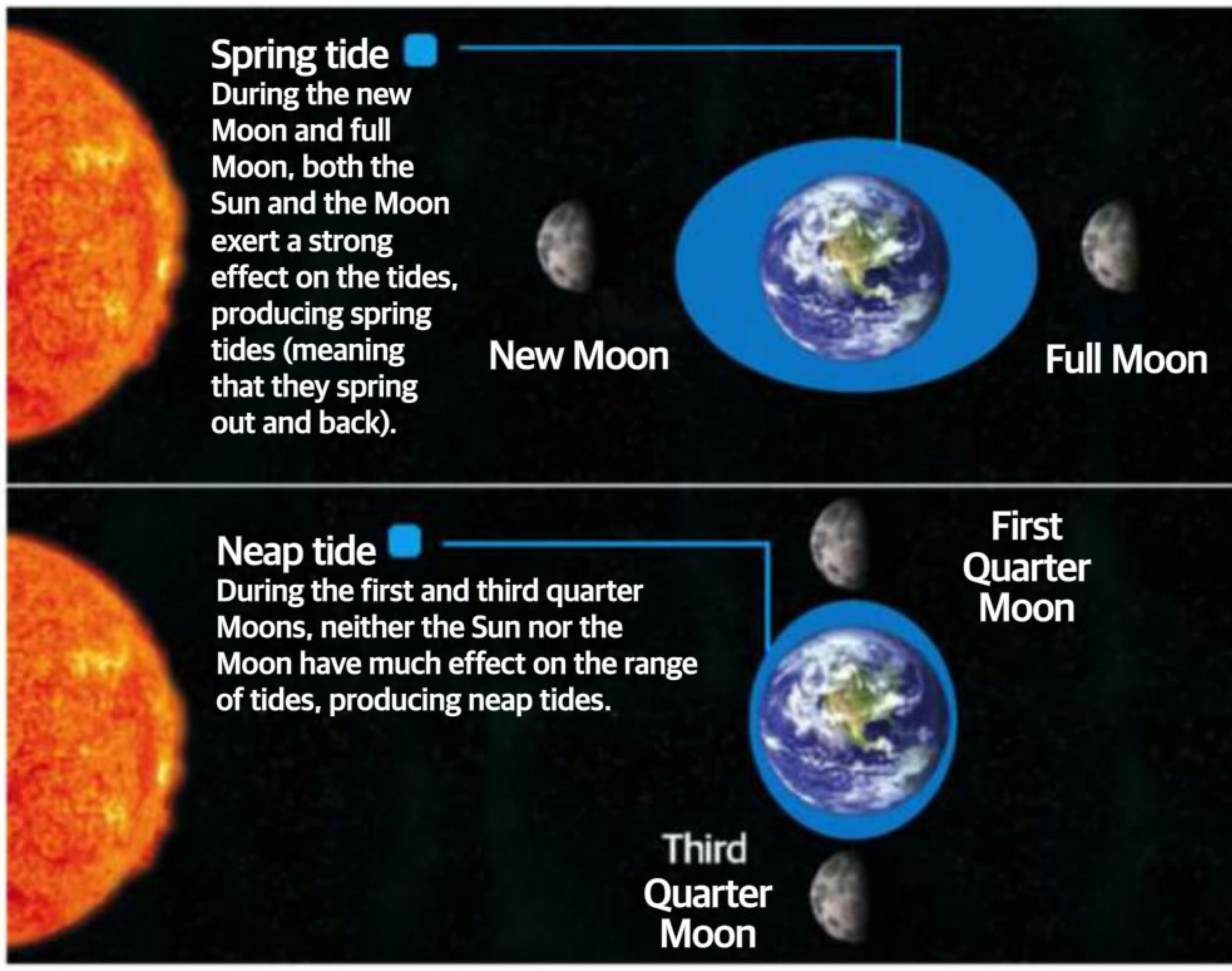
All About... THE MOON

Written by Shanna Freeman

The Moon is the Earth's only natural satellite, and the only celestial body that we've set foot on other than our own planet. But even though we know more about it than any other celestial body, the Moon continues to fascinate



The Moon and tides

Along with the Sun, the Moon exerts serious force on the Earth's tides. Whether the tides vary widely or not much at all has a lot to do with the interactions between the solar and lunar cycles. When they are together, their combined effects produce tidal variations called spring tides – high tides are very high and low tides are very low. If the Sun and Moon are on the opposite sides of the sky, they nullify each others' effects, producing neap tides – with little variation.

Because we can easily discern features on the Moon with the naked eye, it has been a sense of wonder to us since ancient times. The Moon is the brightest object in our sky after the Sun, and influences everything from our oceans to our calendars. It's always been 'the Moon' because we didn't know that there were any others. Once Galileo discovered in 1610 that Jupiter had satellites, we've used the word 'moon' to describe celestial bodies that orbit larger bodies, which orbit stars. Since the Moon has always been so present, it might not seem worth studying. Yet there's a reason why we continue to return to it – we still have plenty to learn from our satellite.

The Moon is the fifth-largest and second-densest satellite in the Solar System. Its diameter is 27 per cent of Earth's at 3,476 kilometres (2,160 miles), while its mean density is 60 per cent that of the Earth's. This makes the Moon the largest satellite in size relative to the planet that it orbits. The Moon is also unusual because its orbit is more closely aligned to the plane of the ecliptic – the plane in which the Earth orbits. Most planetary satellites orbit closer to their planet's equatorial plane, but the Moon is inclined from the plane of the ecliptic by approximately 5.1 degrees.

Its average distance from the Earth is 384,400 kilometres (239,000 miles), and it completes an orbit once every 27.3 days. The Moon is in synchronous rotation with the Earth – its rotation and orbital period are the same – so the same side is almost always facing our planet. This is called the 'near side' of the Moon, while the opposite side is the 'far' or 'dark' side (although it gets illuminated just as often as the near side). This hasn't always been the case; the Moon used to rotate faster, but the influence of the Earth caused it to slow and become locked.

Although we say that we can only see one side of the Moon at a time, that's not strictly true. The Moon's orbit isn't quite circular – it has an eccentricity of 0.0549. The Moon also wobbles a bit along its orbit. These two factors cause some variations in how much of the Moon that we see, called librations. When the Moon is closest to the Earth, called the perigee, it orbits slightly slower than it rotates. This means that we can actually get a glimpse of about eight degrees of longitude of its eastern far side. When the Moon is at its furthest point away in its orbit, the apogee, its orbit is slightly faster than its rotation. So we get a glimpse of eight degrees of longitude on its western far side. This is called longitudinal libration.

The Moon also appears to rotate towards and away from the Earth. This is due to the 5.1-degree inclination of its orbit, as well as the 1.5-degree tilt of the Moon's equator to the plane of the ecliptic. This results in us seeing about 6.5 degrees of latitude on the far side along both the sides of the poles. The Moon's orbit also means that it appears to move about 13 degrees across the sky each day, and this movement accounts for the lunar phases.

"The Moon is the fifth-largest and second-densest satellite in the Solar System. Its diameter is 27% of Earth's"

The Moon's gravitational pull has a strong effect on the Earth. The most obvious effect to us is the tides. High tide occurs when the level of water at the coastline rises, and low tide occurs when the water rushes further out. While some coastlines experience one high tide and one low tide per day, of equal strength, others have different strengths, timing and numbers of tides. Measuring and predicting these tides is incredibly important for everything from fishing to navigating intercoastal waterways. We use the term 'tides' to describe oceanic tides, but tides also occur on a smaller level in lakes as well as the Earth's atmosphere and crust.

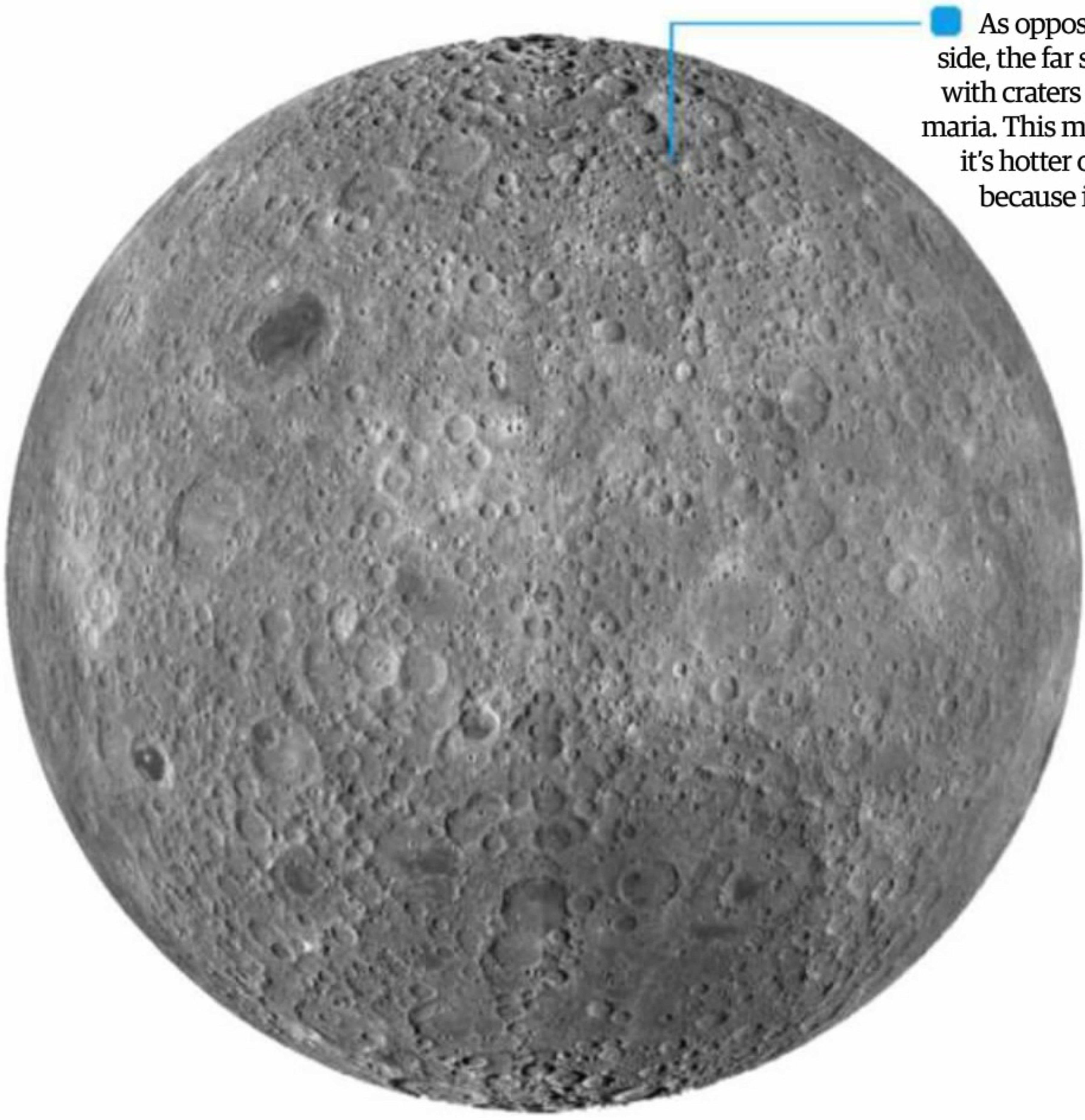
Scientists believe that the Moon formed when a huge celestial body about the size of Mars (which has been given the name Theia) impacted with a young Earth. This is known as the giant impact hypothesis. This force sent debris out into Earth's orbit, which fused to form the Moon. However, in 2012, an analysis of rock samples taken from the Moon during the Apollo missions showed that the Moon's composition is almost identical to Earth's. This calls the giant impact hypothesis into question, because previously we thought that at least some of the Moon's material had to have come from Theia.

How the Moon measures up

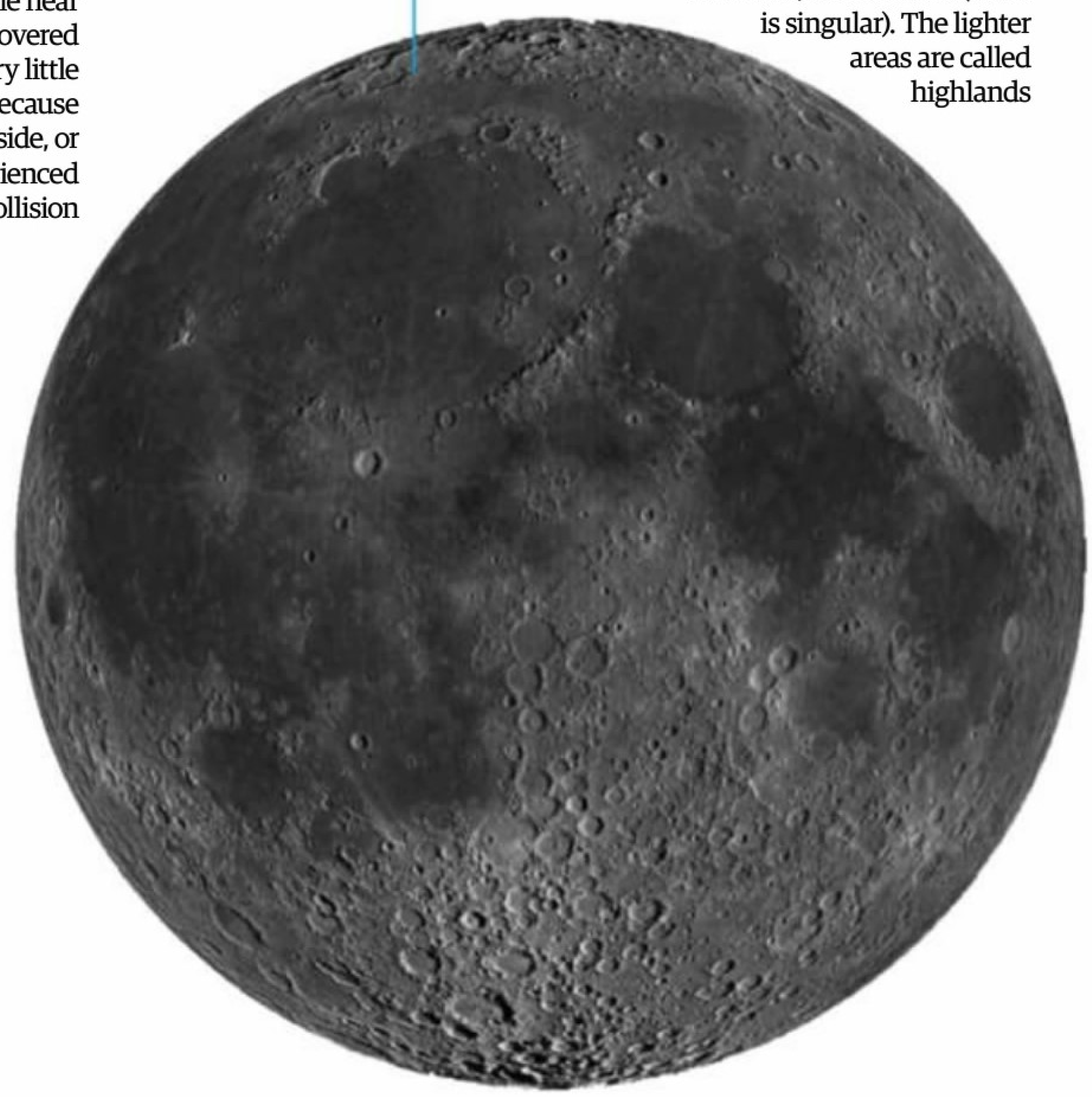
The Moon's orbit

Two sides of the Moon

As opposed to the near side, the far side is covered with craters and very little maria. This may be because it's hotter on that side, or because it experienced a collision



The near side of the Moon is mostly covered in dark areas that were originally thought to be seas, called maria (mare is singular). The lighter areas are called highlands



The Moon inside and out

The Earth's only known satellite shares some remarkable similarities with our home planet

Although the Moon may seem like a solid rock, it's actually differentiated like the Earth; it has a core, a mantle and a crust. The Moon's structure likely came from the fractional crystallisation of a magma ocean that once covered the Moon. This probably happened not long after the Moon was formed, about 4.5 billion years ago. This means that as the magma ocean cooled, its composition changed as the different minerals within the melt crystallised into solids. The denser materials sank, forming the mantle, while less dense materials floated on top and formed the crust.

We believe that the core is probably very small, with a radius about 20 per cent the total size of the Moon. By contrast, most differentiated celestial bodies have cores about 50 per cent of their total size. The core itself comprises a solid innermost core that is rich in iron as well as nickel and sulphur, with a radius of 240 kilometres (150 miles). This is surrounded by a fluid outer core, with about a 300-kilometre (186-mile) radius. Between the core and the mantle, there's a boundary layer of partially melted iron that has about a 500-kilometre (300-mile) radius. It is also known as the lower mantle. The upper mantle is mafic - rich in magnesium and iron, topped by a crust of igneous rock called anorthosite. It mainly includes the elements aluminium, calcium iron, magnesium and oxygen, with traces of other minerals. We estimate the crust to be around 50 kilometres (31 miles) thick.

The Moon has no plate tectonics, but it does have seismic activity. When astronauts with the Apollo programme visited the Moon, they discovered that there are moonquakes - the Moon's equivalent of earthquakes. Moonquakes aren't nearly as strong as earthquakes, but they can last longer because there's no water to lessen the effects of the vibrations. Seismometers placed by Apollo astronauts showed that the strongest moonquakes are about 5.5 on the Richter scale. There are four different types of moonquakes: shallow, deep, thermal and meteorite. Shallow ones occur just 20 kilometres (12 miles) below the surface, while deep moonquakes can be as deep as 700 kilometres (435 miles). These deep moonquakes are probably related to stresses on the Moon caused by its eccentric orbit and gravitational interactions between it and the Earth. Thermal earthquakes occur when the crust of the Moon heats and expands. This happens when the Moon is bathed in sunlight again after its two-week-long night. Finally, meteorites hitting the Moon can also cause a type of moonquake. However, shallow moonquakes are the strongest and most common. Nearly 30 of them were recorded between 1972 and 1977 by seismometers (turned off in 1977) that were left on the Moon's surface. This seismic data has helped us to determine the Moon's internal composition.

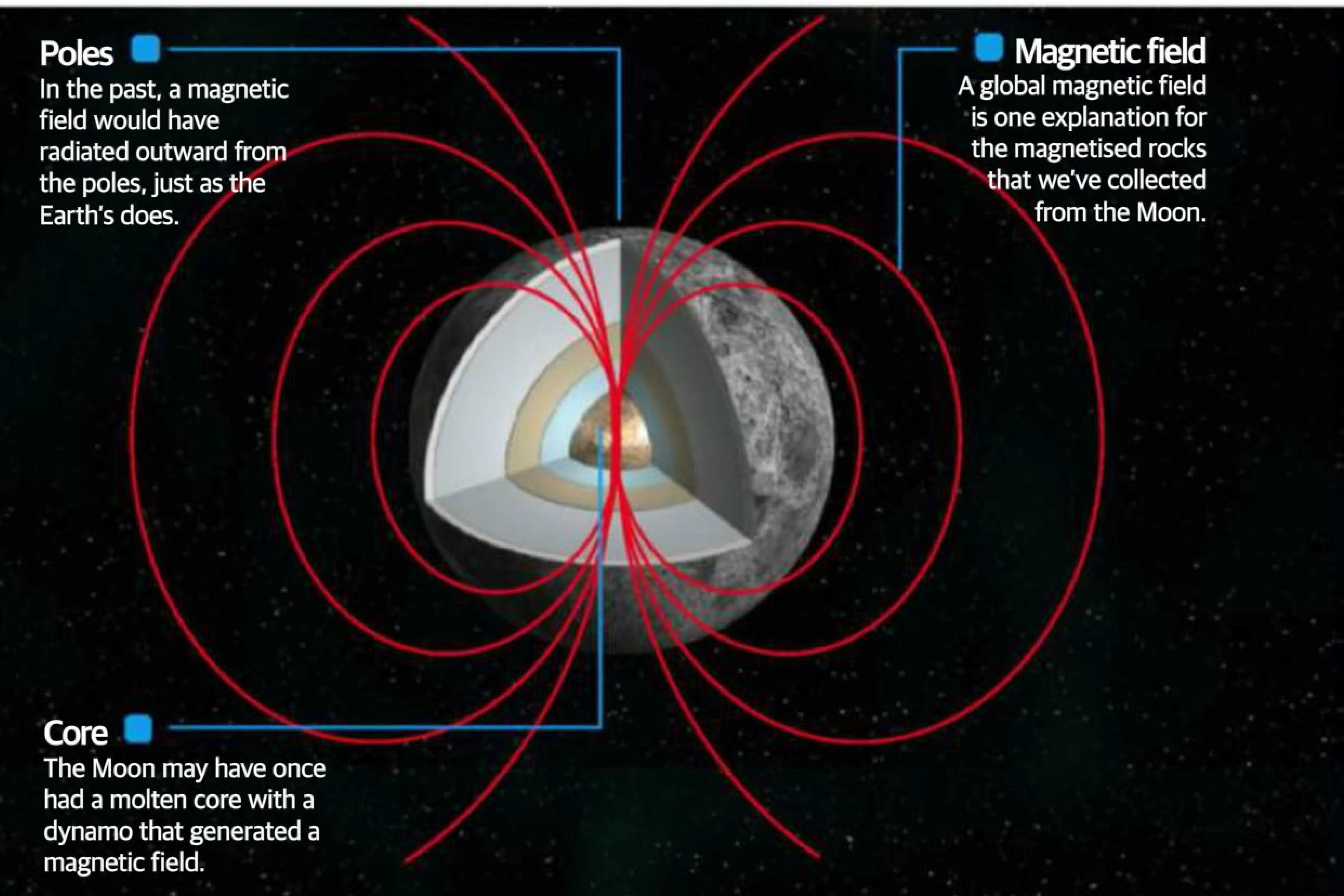
> "The Apollo astronauts discovered seismic activity on the Moon"

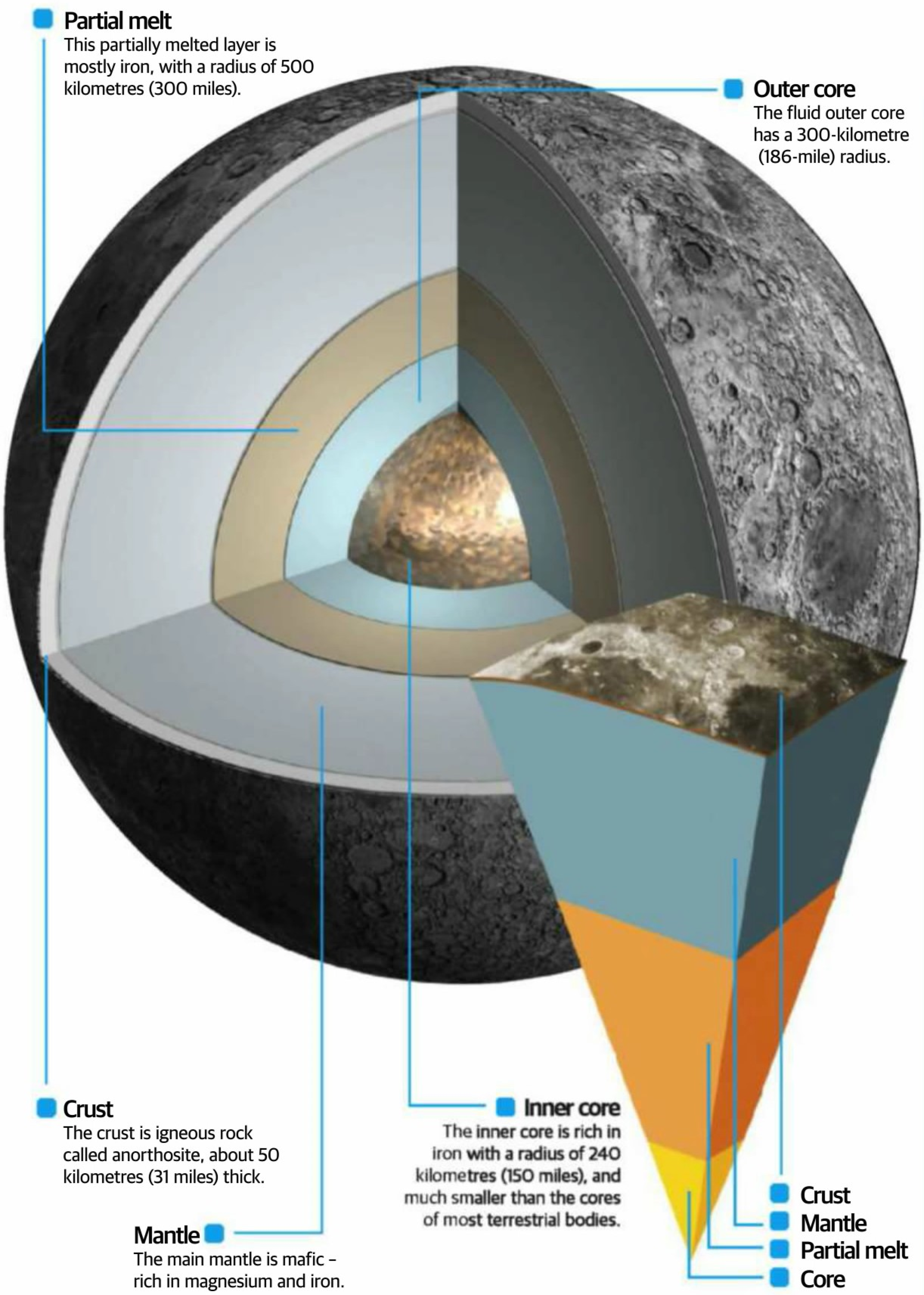
The dominating feature on the near side of the Moon's surface, called maria, are the result of ancient volcanic activity. These vast, dark plains are basalts - igneous rock that formed after lava erupted due to partial melting within the mantle. These basalts show that the Moon's mantle is much higher in iron than the Earth's, and has a varied composition. Some basalts are very high in titanium, while others are higher in minerals like olivine. For the most part, they flowed into impact basins.

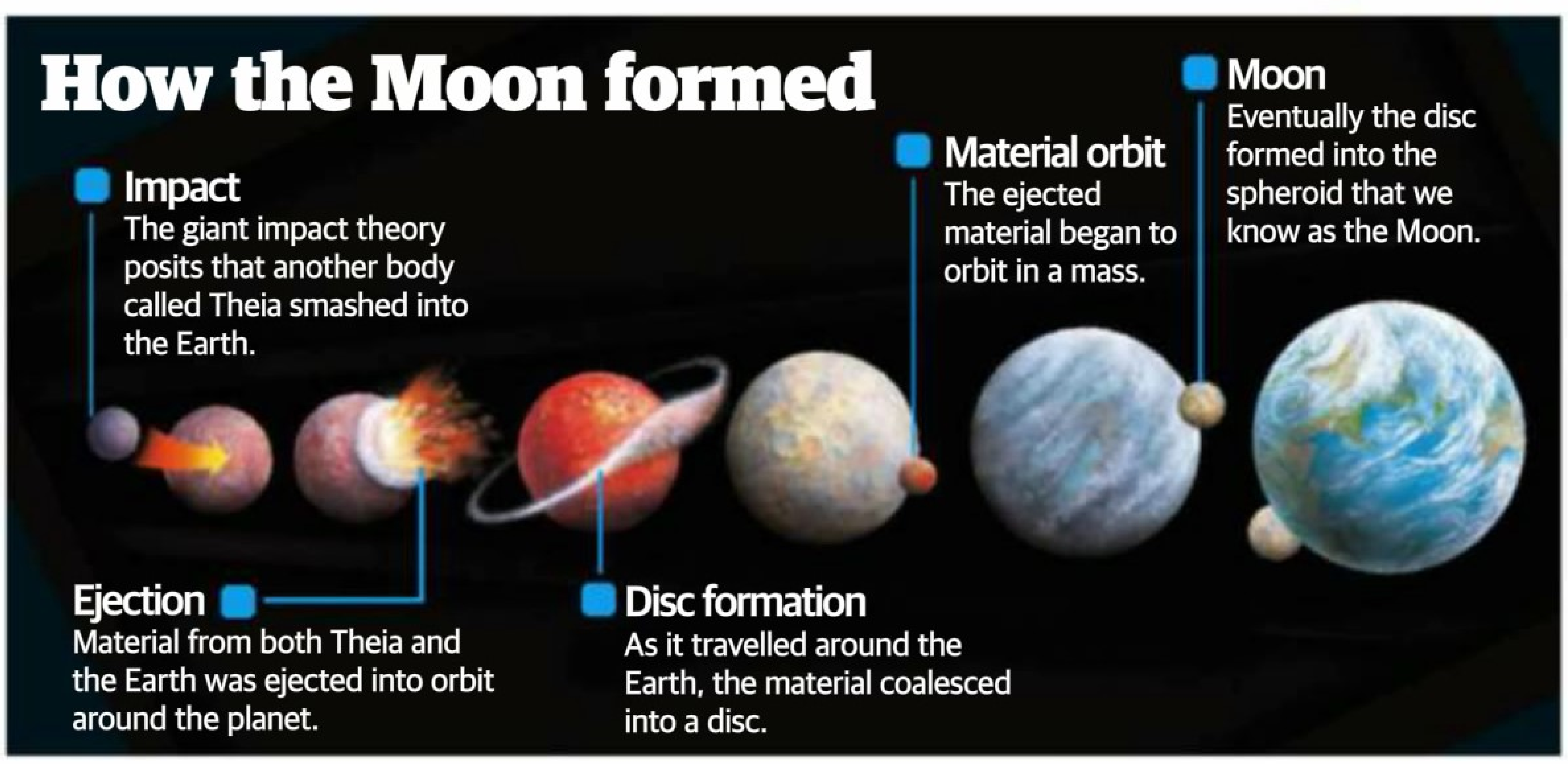
These basalt maria have influenced the Moon's gravitational field because they're so rich in iron. The gravitational field contains mascons, big positive gravitational anomalies that influence how spacecraft orbit the Moon. They're also a bit of a mystery, however; the maria can't explain all of the mascons that have been tracked by the Doppler effect on the radio signals emitted by spacecraft that orbit the Moon. And there are also some large maria without associated mascons.

The magnetic field mystery

The Moon does have an external magnetic field - it's weak, less than one-hundredth that of the Earth's magnetic field. It's not a dipolar magnetic field like the Earth, which has a field that radiates outward from the north and south poles. So where did this magnetism come from? Researchers believe that the Moon once did have a dipole magnetic field, created by a dynamo - a convecting liquid core of molten metal. But we aren't sure what powered that dynamo. It could have worked like the Earth's dynamo. The Earth's dynamo powers itself, as elemental radioactive decay maintains convection in the core of our planet. The Moon could also have had a dynamo powered by the cooling of elements at the core. Yet if this were true, the magnetic field would have been completely gone about 4 billion years ago because the core is so small. Yet we have discovered magnetised lunar rocks that are younger than this. Another theory is that the Moon's dynamo was powered by the pull of the Earth's gravity when they were much closer together, or that impacts from large asteroids generated the magnetic field.







The Moon in numbers

Fascinating facts and figures about Earth's only satellite

400

How many times bigger the Sun is than the Moon. But it's also about 400 times further away from the Earth, which is why they look the same size in the sky

29.5 days

The length of a lunar month. It's longer than the amount of time it takes the Moon to orbit the Earth because the Earth is moving, too

12

The number of people who have actually set foot on the Moon

3.8cm (1.5in)

The distance the Moon is moving away from the Earth each year

13 hours

The amount of time it takes to reach the Moon by rocket

16.6kg (36.5lb)

The amount you would weigh on the Moon if you weighed 100kg (220lb) on the Earth

On the surface

The surface of the Moon is about contrasts: light and dark, hot and cold

The landscape of the Moon is dominated by three main features: maria, terrae and craters. The basalt maria appear dark due to their high iron content and are much more prevalent on the near side of the Moon. Other volcanic features located on the surface of the Moon include domes and rilles. Domes are shield volcanoes that are round and wide with gentle slopes, while rilles are twisting sinuous formations caused by channels of flowing lava.

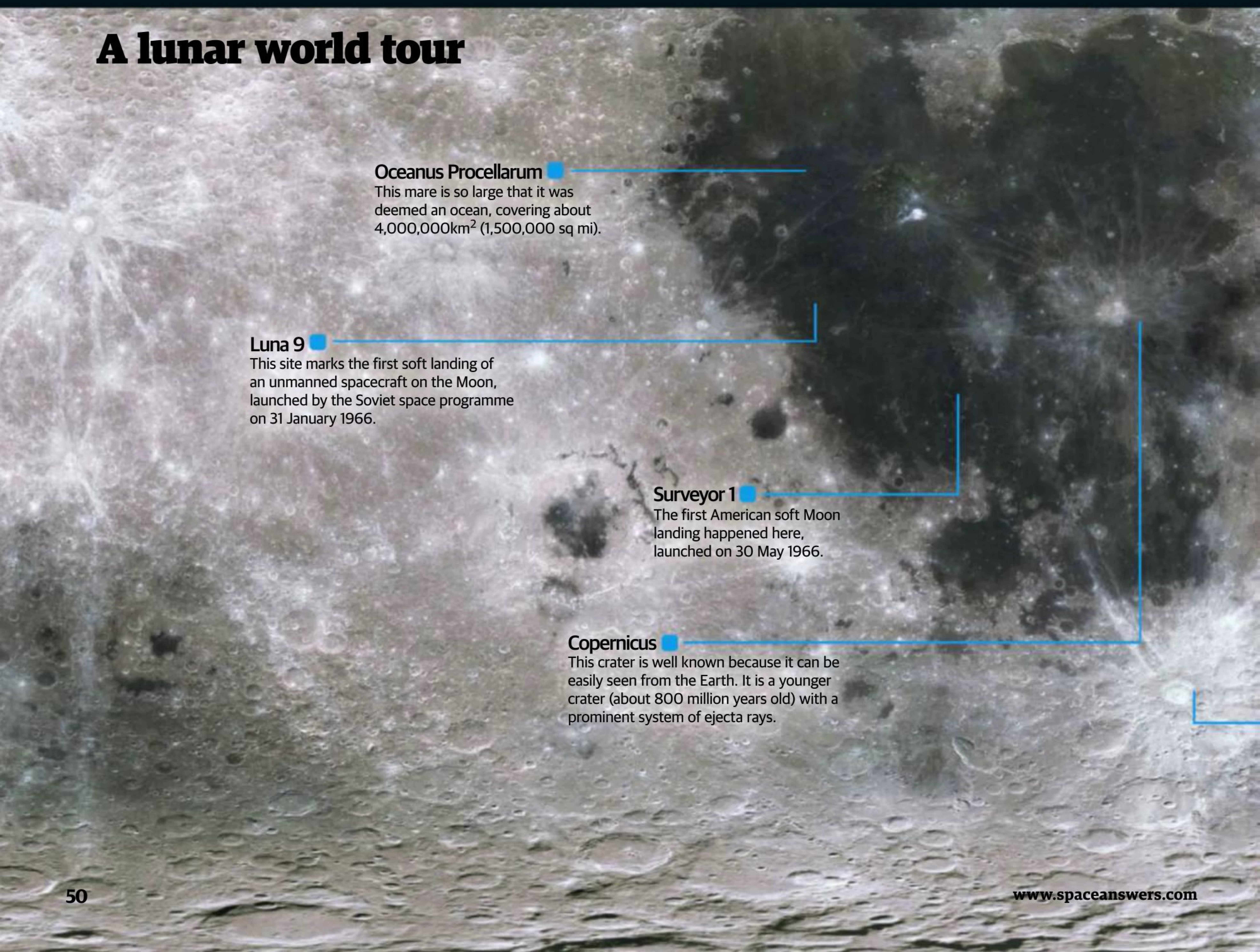
The lighter areas on the Moon are called terrae (terra is singular), or lunar highlands. They are made up of anorthosite, the type of igneous rock that dominates the overall crust of the Moon. While this type of rock can be located in some places on Earth, it's not generally found on the surface due to plate tectonics and deposits. These highlands reflect light from the Sun and make it appear that the Moon is glowing at night.

Both the maria and terrae have impact craters which were formed when asteroids and comets struck the surface of the Moon. These craters range in size from very tiny to massive. It is estimated that there are around 300,000 craters on the near side of the Moon that are wider than one kilometre (0.62 miles). The largest impact crater, called the South Pole-Aitken Basin, is about 2,500 kilometres (1,550 miles) in diameter and 13 kilometres (eight miles) deep. The biggest craters also tend to be the oldest, and many are covered in smaller craters. Younger craters have more sharply defined edges, while older ones are often softer and rounder. If the impact was especially large, material may be ejected from the surface to form secondary craters.

In some cases, the basalt eruptions flowed into or over large impact craters called basins. In general, the terrae have far more craters, because the maria are younger in age than the terrae. While the Moon isn't much younger than the Earth, the Earth has processes that continue to change its surface over time, like erosion and plate tectonics. The Moon doesn't experience these, which is why some impact craters are up to 500 million years older than the basalt filling them.

The loose soil on the Moon is called regolith. It's powdery and filled with small rocks. Over time,

A lunar world tour

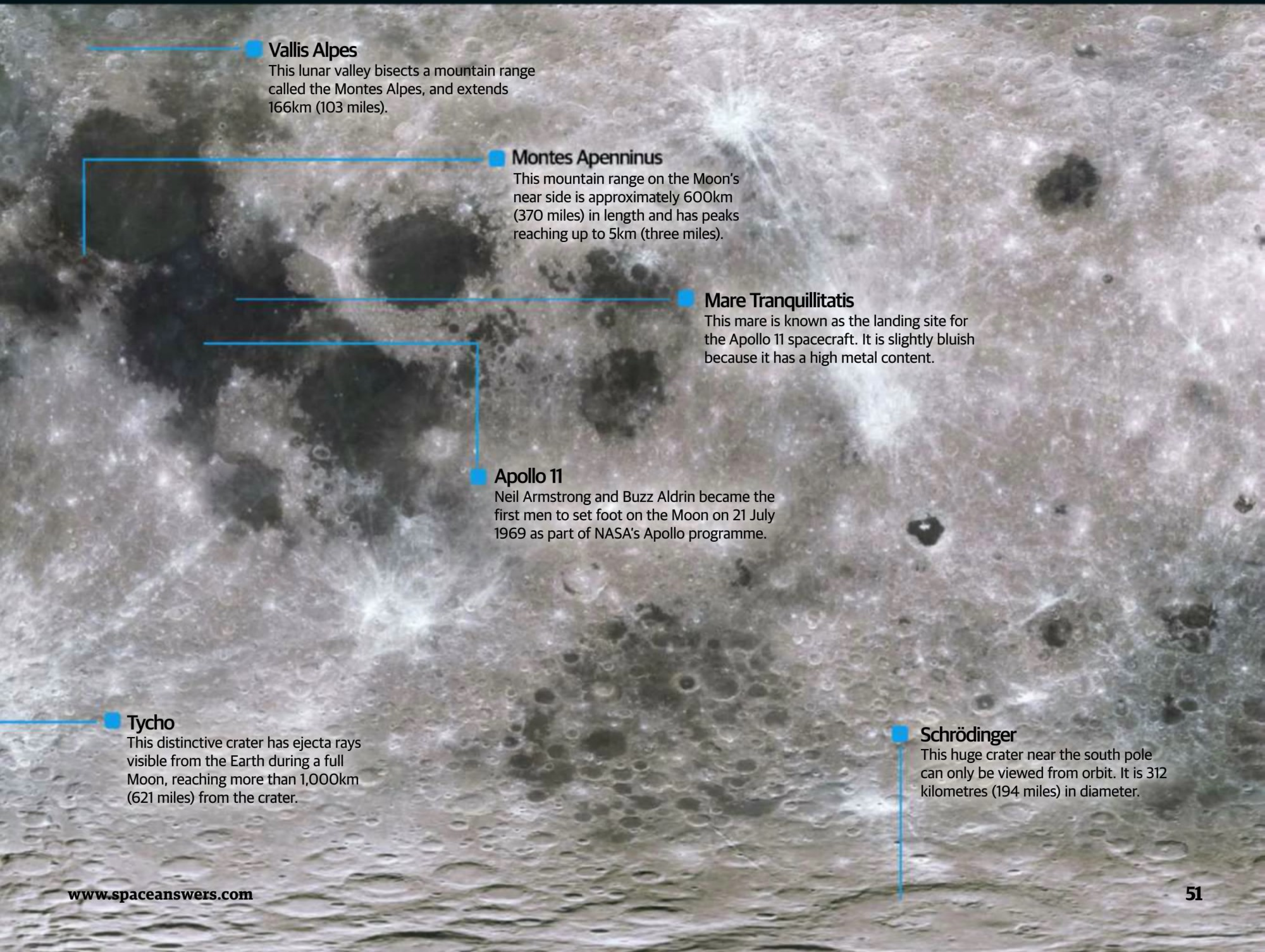


impacts from meteors, as well as space weathering (solar wind, cosmic rays, meteorite bombardment and other processes), break down the rocks and grind them into dust. Aside from the basalt and anorthosite rocks, there are also impact breccias – rock fragments that were welded together by meteor impacts – and glass globules from volcanic activity.

Although you may see the term 'lunar atmosphere' used in some places, the Moon is actually considered to exist in a vacuum. There are particles suspended above the surface, but the density of the Moon's atmosphere is less than one hundred trillionth that of the Earth's atmosphere. What little atmosphere there is gets quickly lost to outer space, and is constantly replenished. Two processes help to replenish the Moon's atmosphere: sputtering and outgassing. Sputtering occurs when sunlight, solar wind and meteors bombard the surface and eject particles. Outgassing comes from the radioactive decay of minerals in the crust and mantles, which can release gases like radon.

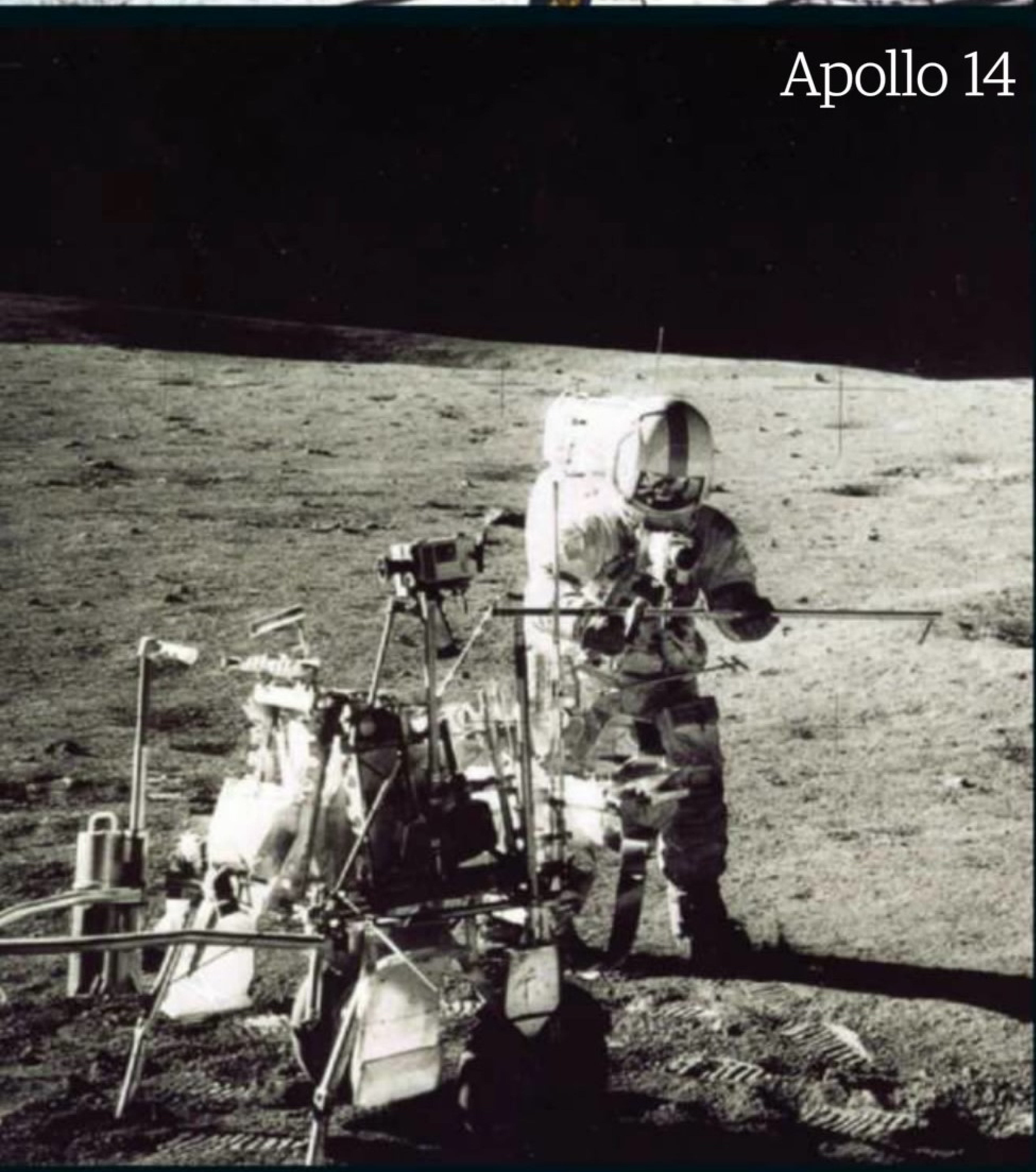
The Moon has a very minor axial tilt, so there aren't seasons in the same way that we have them here on Earth. However, temperatures on the Moon can change dramatically because there's no atmosphere to trap heat, and portions of the Moon may be either in full sunlight or total darkness depending on where it is in its rotation. Full sunlight can mean temperatures of greater than 100 degrees Celsius (212 degrees Fahrenheit). But at the end of the lunar day, the temperature can drop by hundreds of degrees. There are also big differences in temperatures depending on the surface features. For example, the Moon is coldest in its deepest craters, which always remain in darkness. The coldest temperature ever recorded in the Solar System by a spacecraft was measured by the Lunar Reconnaissance Orbiter in the Hermite Crater near the Moon's north pole at -248 degrees Celsius (-414 degrees Fahrenheit).

This rover travelled across the Moon's surface as part of the Apollo 17 mission in 1972




Apollo 11


Apollo 12


Apollo 14

Exploring the Moon – The Past

Apollo 11 21 July 1969
NASA astronauts Buzz Aldrin and Neil Armstrong became the first humans to set foot on another body in space when they landed on the Moon in 1969. This mission ended the race to the Moon between the United States and the USSR.

Apollo 12 19 November 1969
The second spacecraft to land on the Moon, Apollo 12 used a Doppler effect radar technique to precisely land the spacecraft within walking distance of the Surveyor 3 probe, which had landed on the lunar surface about two years prior.

Apollo 145 February 1971
The commander on board the third spacecraft to land on the Moon was Alan Shepard, who, a decade earlier on 5 May 1961, had become the second person in space after Yuri Gagarin and the first American as part of the Mercury programme.

Apollo 15 30 July 1971
NASA deemed this Moon landing the most successful so far out of its manned missions. It is also known as the first of the longer missions to the Moon, called 'J missions', staying for three days.

Apollo 16 21 April 1972
Apollo 16 became the first spacecraft to land in the highlands on the Moon, which let them gather older lunar rocks. The astronauts also spent about three days on the surface.

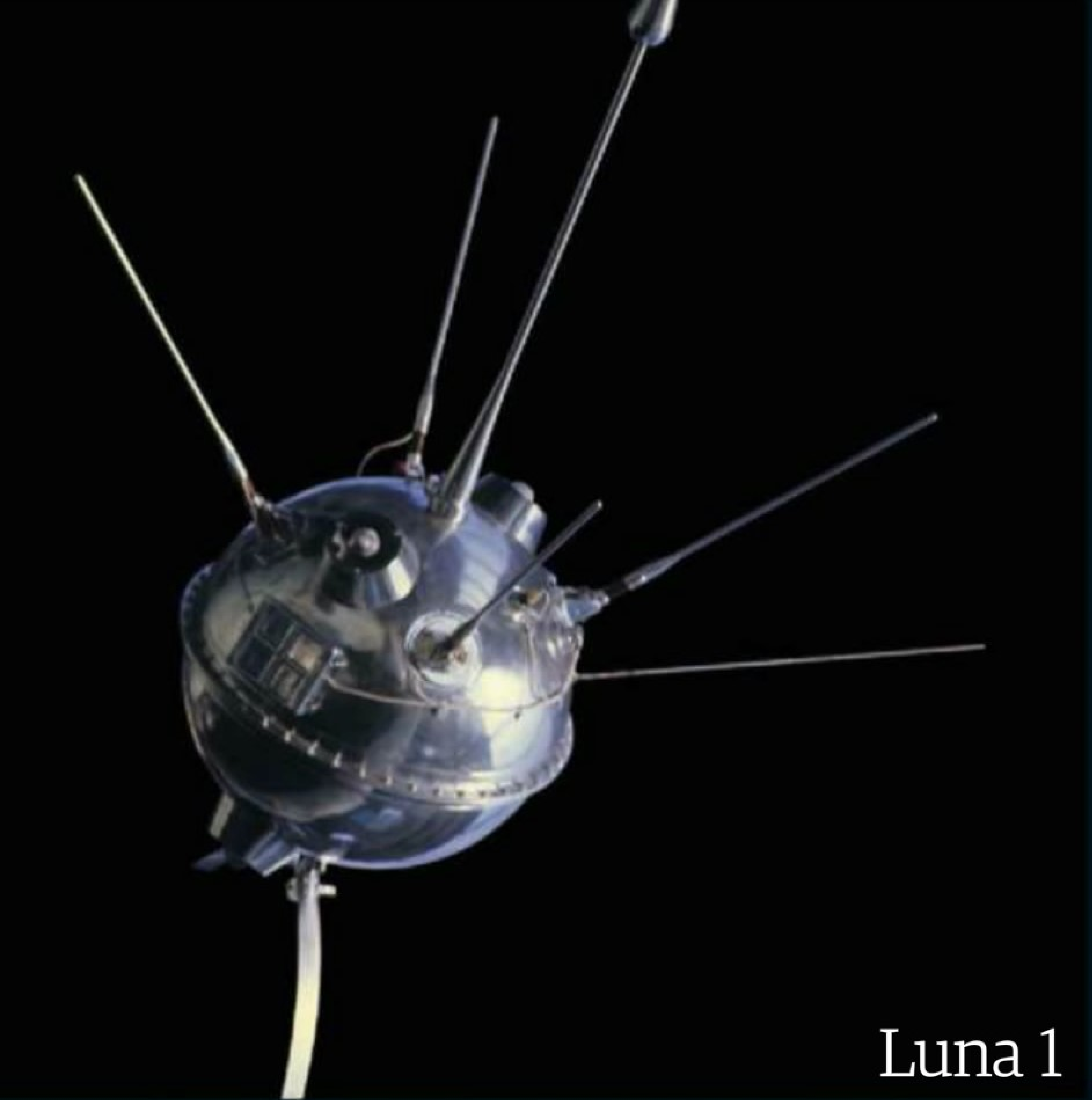
Apollo 17 11 December 1972
This last manned mission to the Moon was the only one to carry the Traverse Gravimeter Experiment (TGE) that measured relative gravity at different sites on the Moon.

Luna 1 4 January 1959
This Soviet probe was the first to reach the vicinity of the Moon and the first to break out of geocentric orbit, however, it did not actually impact the Moon as had originally been planned.

Luna 21 15 January 1973
This Soviet spacecraft landed on the Moon and carried a lunar rover, Lunokhod 2. It performed numerous experiments and sent back more than 80,000 images before failing.

Luna 24 22 August 1976
This was the last of the Luna missions, successfully landing near Mare Crisium to recover samples. It remains the last spacecraft to have a soft landing on the Moon's surface.

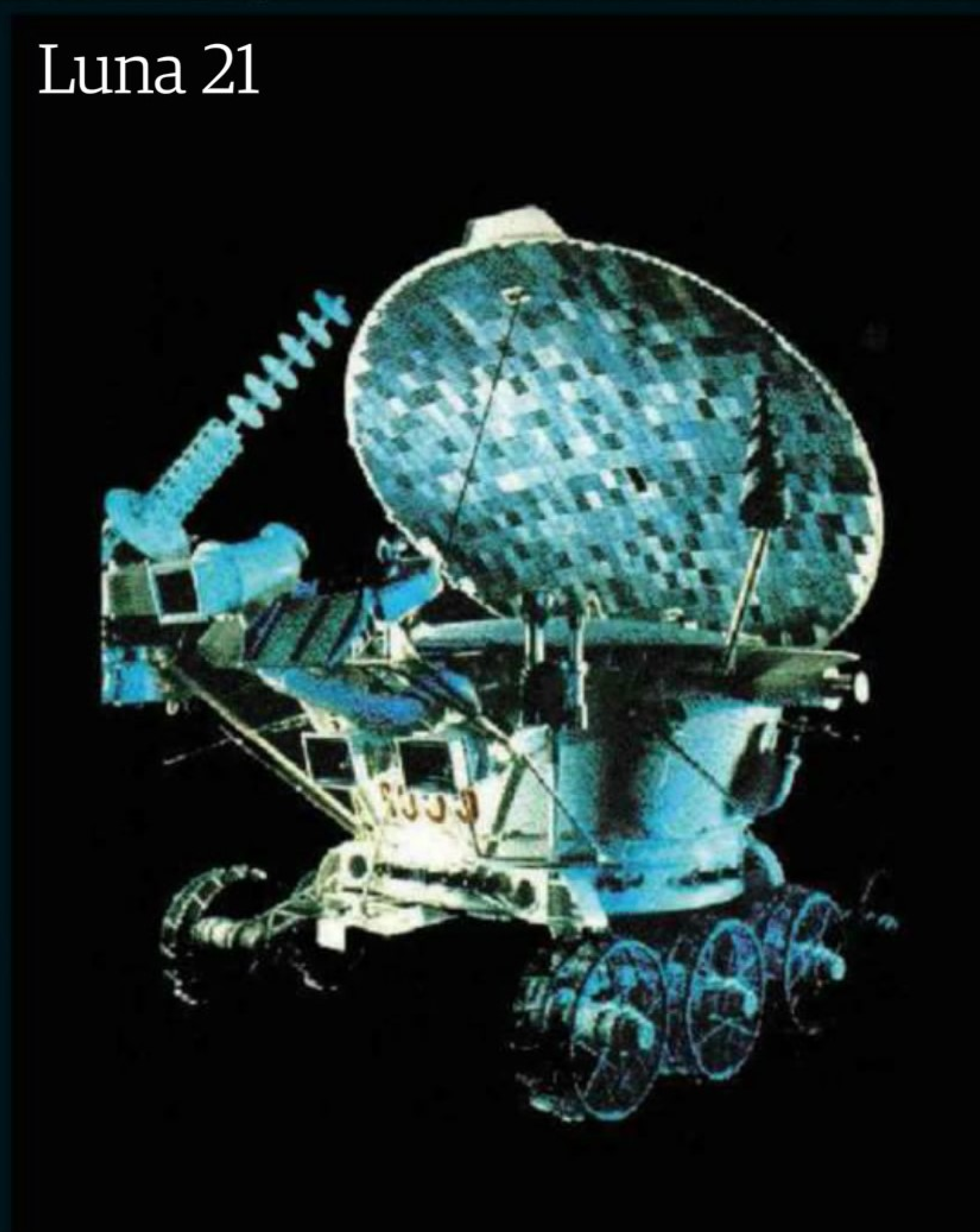
Apollo 15



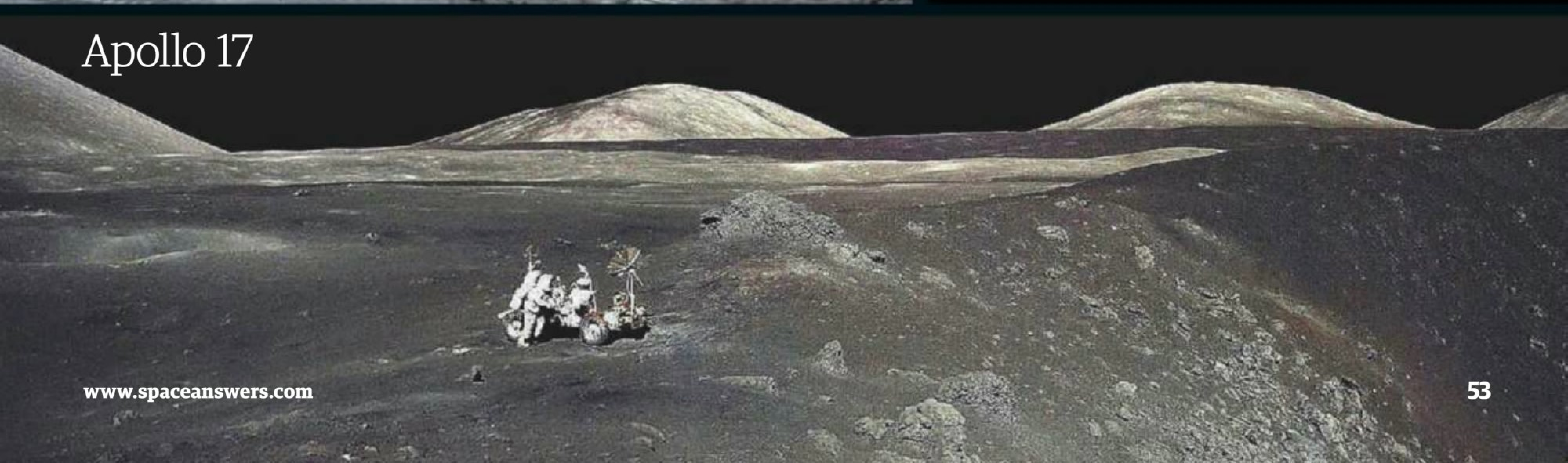
Luna 1

Luna 24

Apollo 16



Luna 21



Apollo 17

Exploring the Moon – Present and future

We've been studying the Moon for over 50 years, and thanks to a host of pioneering missions we now know more about our satellite than ever before

Although there hasn't been a manned mission to the Moon since 1972 and there were no soft landings at all until 1966, we're still exploring our satellite. Currently the Lunar Reconnaissance Orbiter (LRO) is still circling the Moon. It launched on 18 June 2009, and became the first NASA mission to the Moon in more than a decade. The LRO is meant to be a precursor to future manned missions, and was originally designed to spend just a year in orbit. However, the mission was extended several times. It was designed to extensively map the Moon in high resolution, explore the potential of ice in the polar regions, study the deep space radiation, and continue to map the surface of the Moon. The other current NASA mission is ARTEMIS, an extension of an earlier satellite mission. Two small probes have been orbiting the Moon together since summer 2011, having previously performed lunar and Earth flybys.

The Lunar Crater Observation and Sensing Satellite (LCROSS) was launched along with the LRO and considered an inexpensive way to look for water ice, and it was successful. The LCROSS discovered ice in the Cabeus crater near the Moon's south pole after its upper stage impacted as planned on 9 October 2009. Two small spacecraft under the name GRAIL A and GRAIL B were launched on 10 September 2011 and impacted on 17 December 2012, having collected data to help understand how terrestrial planets have evolved. Japan, India and China have all had lunar probes in the last six years as well. Currently there are several proposed lunar missions on the table for launch within the next few years, coming from the United States, China, Russia and India.

The image taken by the Lunar Reconnaissance Orbiter shows the Apollo 11 landing site, including the astronauts' footsteps, landing module and discarded tools

"It was designed to extensively map the Moon in high resolution"

This Lunar Reconnaissance Orbiter image shows the landing site of the Apollo 17 spacecraft, including the lunar rover

Buzz Aldrin and Neil Armstrong became the first humans to walk on the Moon in 1969

The Lunar Reconnaissance Orbiter captured this image of a recent impact in the Oceanus Procellarum, which deposited a huge ejecta blanket

Current and future missions

Luna-Glob
Russia

ROSCOSMOS

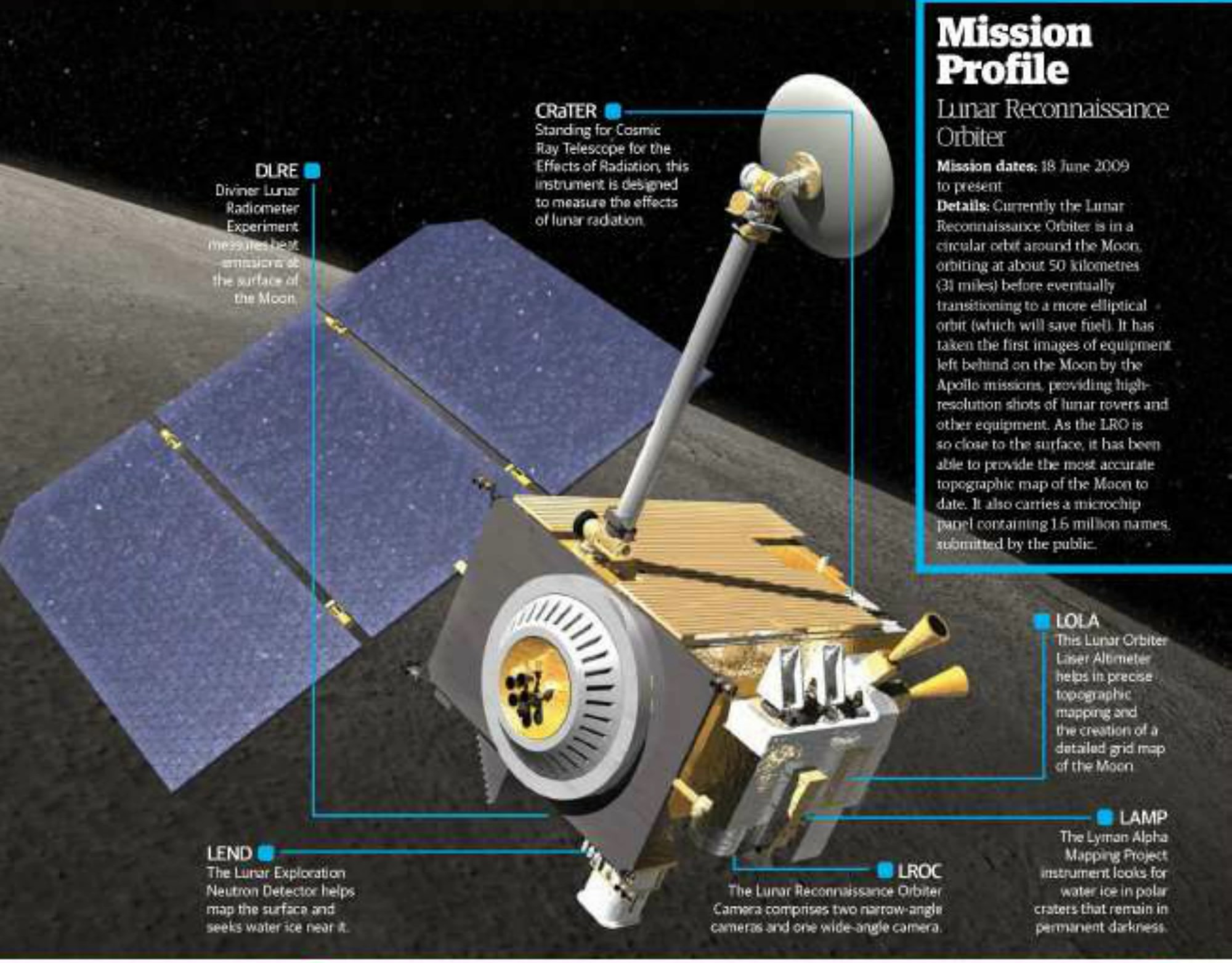
This Russian Federal Space Agency programme is scheduled to be the first of a series of missions, with the ultimate goal of creating a robotic base on the Moon. Its goals include gathering seismic activity, studying cosmic rays, and studying the origin of the Moon.

Chang'e 2
China

This Chinese probe was launched on 1 October 2010 and left lunar orbit in November to go on an extended mission. Chang'e 2 was designed to study future landing sites.

Kaguya
Japan

Also known as SELENE, this Japanese orbiter was launched on 14 September 2007 and circled the Moon before impacting on 10 June 2009. Kaguya measured the Moon's gravity, studied the surface and sought information on the Moon's history.



Mission Profile

Lunar Reconnaissance Orbiter

Mission dates: 18 June 2009 to present

Details: Currently the Lunar Reconnaissance Orbiter is in a circular orbit around the Moon, orbiting at about 50 kilometres (31 miles) before eventually transitioning to a more elliptical orbit (which will save fuel). It has taken the first images of equipment left behind on the Moon by the Apollo missions, providing high-resolution shots of lunar rovers and other equipment. As the LRO is so close to the surface, it has been able to provide the most accurate topographic map of the Moon to date. It also carries a microchip panel containing 1.6 million names, submitted by the public.

LADEE
USA

NASA plans to launch the Lunar Atmosphere and Dust Environment Explorer (LADEE) in August 2013. It hopes to learn more about the lunar atmosphere before there are more manned missions, including the dust on the Moon's surface.

Aurora
Europe

Aurora is the European Space Agency's programme to reach the Moon, Mars and the rest of the Solar System. It is currently in the assessment phase, expected to last until 2015. A manned mission to the Moon would not occur until 2020, after robotic missions to Mars.

Chandrayaan-1
India

This was India's very first unmanned space probe. It launched on 22 October 2008 and the mission ended on 29 August 2009. It launched an impact probe that planted an Indian flag on the south pole, making it the fourth country to place a flag on the Moon.