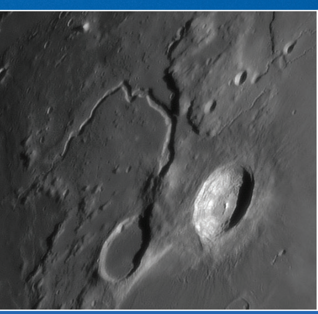
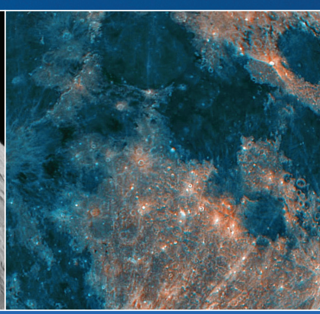
BBC Sky at Night MAGAZINE

GUIDE TO THE MOON

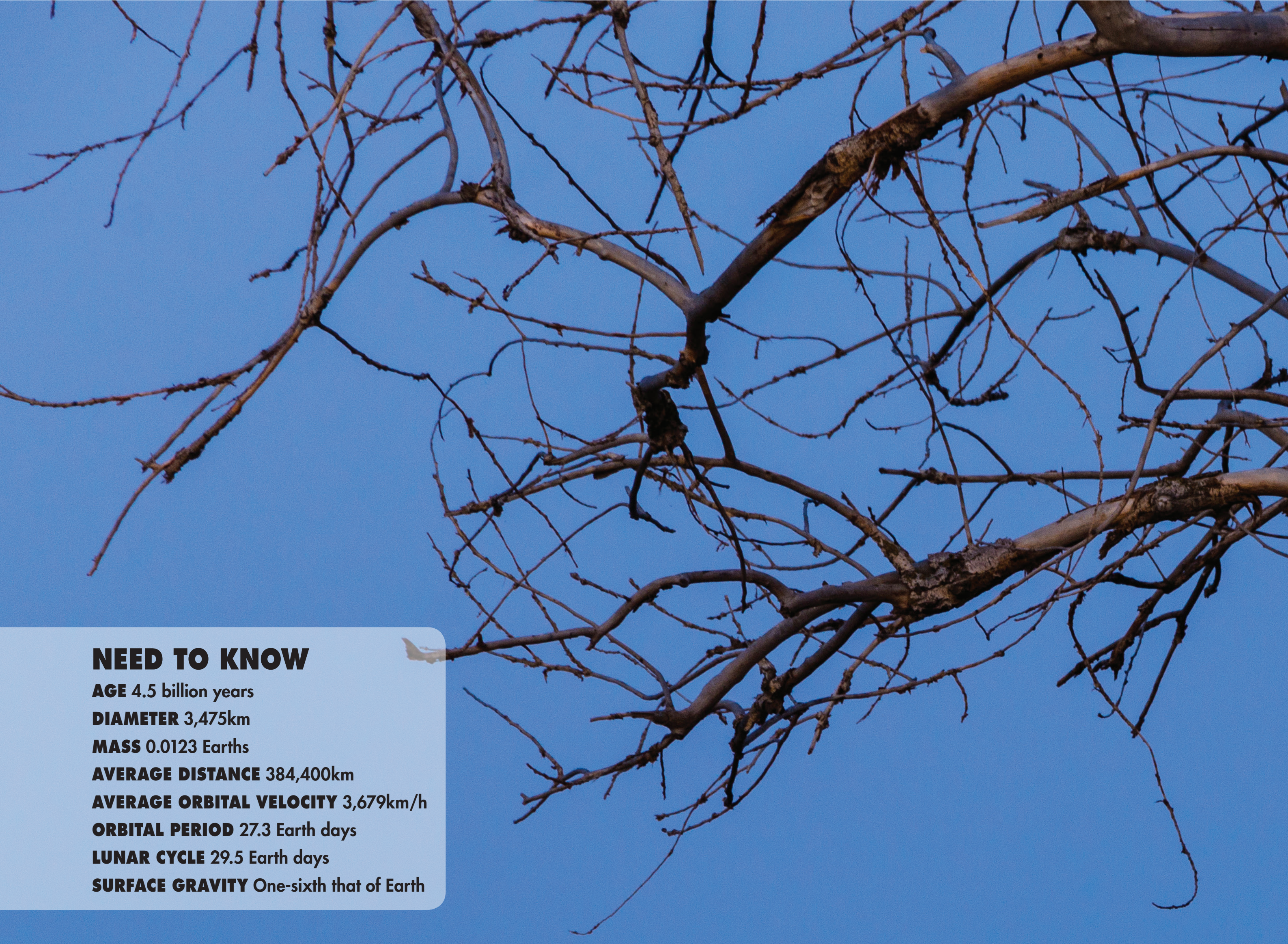
Discover our celestial neighbour and its most stunning features



FIND OUT ALL ABOUT THE MOON'S ORBIT, PHASES AND HOW IT FORMED

EXPERT ADVICE FOR VIEWING THE SEAS AND CRATERS ON THE LUNAR SURFACE

THE MOON ILLUSION AND OTHER LUNAR ODDITIES EXPLAINED



NEED TO KNOW

AGE 4.5 billion years
DIAMETER 3,475km
MASS 0.0123 Earths
AVERAGE DISTANCE 384,400km
AVERAGE ORBITAL VELOCITY 3,679km/h
ORBITAL PERIOD 27.3 Earth days
LUNAR CYCLE 29.5 Earth days
SURFACE GRAVITY One-sixth that of Earth

OUR CONSTANT COMPANION

A familiar sight in our skies from ancient times, the Moon is threaded through humanity's history

The source of our ocean tides, subtle chronobiological cycles and the only other world that humankind has so far set foot upon, the Moon seems a familiar and tangible place. A quarter of Earth's diameter and just a quarter of a million miles away, it's 100 times closer than Venus. Given its proximity, brightness and large apparent size, it's easy to see why the Moon has enchanted humankind for centuries.

Before the emergence of widespread street lighting, the Moon was the primary source of light for nocturnal activities. Its sheer size and regular cycle of phases made it an obvious timepiece to our ancient ancestors, forming the basis of some early calendars, and in various cultures the Moon either had deities associated with it or was considered to actually be one. In the following centuries, when astrology and astronomy were one and the same, it continued to bear a supernatural significance, marking when certain activities and plans would go well – and when they were doomed to fail.

Pre-telescopic observers noticed an unchanging pattern of darker patches that would later become known as maria, or 'seas', because they were assumed to be vast bodies of water. They act as a Rorschach test for ►

WHAT'S OUR MOON MADE OF?

Our natural satellite has a small core composed predominantly of iron, a distinct mantle, and a crust of varying thickness comprised of anorthosites and basalt

ISTOCK X 2

▸ different cultures – the face of the 'Man in the Moon' observed in Western tradition, the 'Rabbit' pounding rice of East Asian folklore, or the 'Lady Reading a Book' from the southern hemisphere, to give just three examples.

Until the middle ages, the Moon was believed to be a smooth sphere, neatly slotting into the Aristotelian view of the 'perfect heavens'. It wasn't until after 1609, when Galileo turned his telescope to the Moon, that this perception was undone.

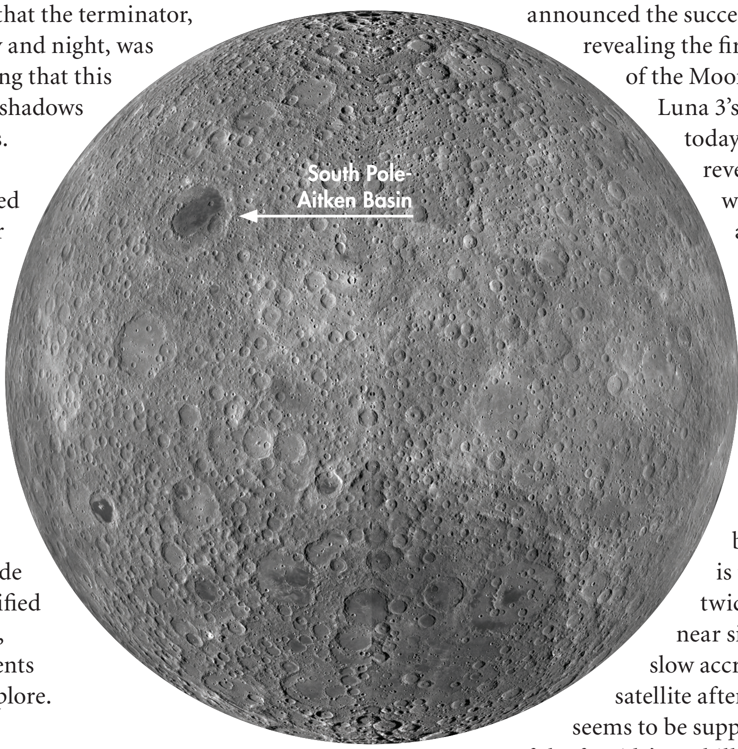
Galileo was not the first to examine the Moon through a telescope – that accolade falls to Englishman Thomas Harriot, whose sketches predate Galileo's by several months – but he was the first to publish. In his *Sidereus Nuncius*, Galileo revealed a world pockmarked with craters and mountains. He had seen that the terminator, the line that divides lunar day and night, was often jagged, correctly inferring that this irregularity must result from shadows cast by topographical features.

About a dozen lunar landforms can be distinguished with a keen eye. A typical pair of binoculars, if suitably steadied, will transform your view of the Moon into a scarred, airless world, and most likely will give you a better view than Galileo had in the 1600s. Through even the smallest modern scope innumerable impact craters appear, often fringed by long rays of ejecta. Alongside them sit grand basins of solidified lava, soaring mountain peaks, curious fissures and escarpments – it's a whole new world to explore.

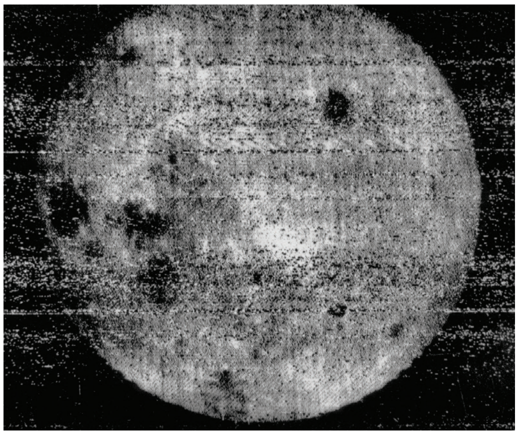
Locked on Earth

You don't need a telescope to reveal that night after night we always see the same lunar features staring back at us. This is because the Moon has a

▲ This is one of many lunar sketches Galileo made through his telescope in 1609, sketches that challenged prevailing views of what the Moon was like



▲ The far side as we know it today, forever turned away due to tidal locking



▲ Our first view of the far side came from Luna 3 in 1959 – and revealed a startling lack of maria

synchronous rotation with respect to Earth, meaning that spins once on its axis in the same 27.3 days (the sidereal month) it takes to complete an orbit of our planet.

This is no coincidence. Earth's gravitational pull on the Moon has caused a bulge in the body of the Moon itself, similar to the tides in Earth's oceans. This bulge unbalanced the Moon's gravitational force, slowing its rotation until the bulge aligned with the Earth. Despite its appearance in the sky, our Moon is nowhere near round; it is closer to a lemon shape.

A consequence of this 'tidal locking' is that for much of human history the Moon held a closely guarded secret: no one knew what the far side was like. This didn't change until 1959, when the Soviet Luna 3 probe became the first to pass image the hitherto unseen side.

In a memorable episode of *The Sky at Night* broadcast on 26 October 1959, Patrick Moore announced the success of the Soviet mission, revealing the first shadowy photographs of the Moon's far side live on air. Luna 3's imagery was crude by today's standards, but it revealed that the 'dark side' was strikingly different in a number of ways.

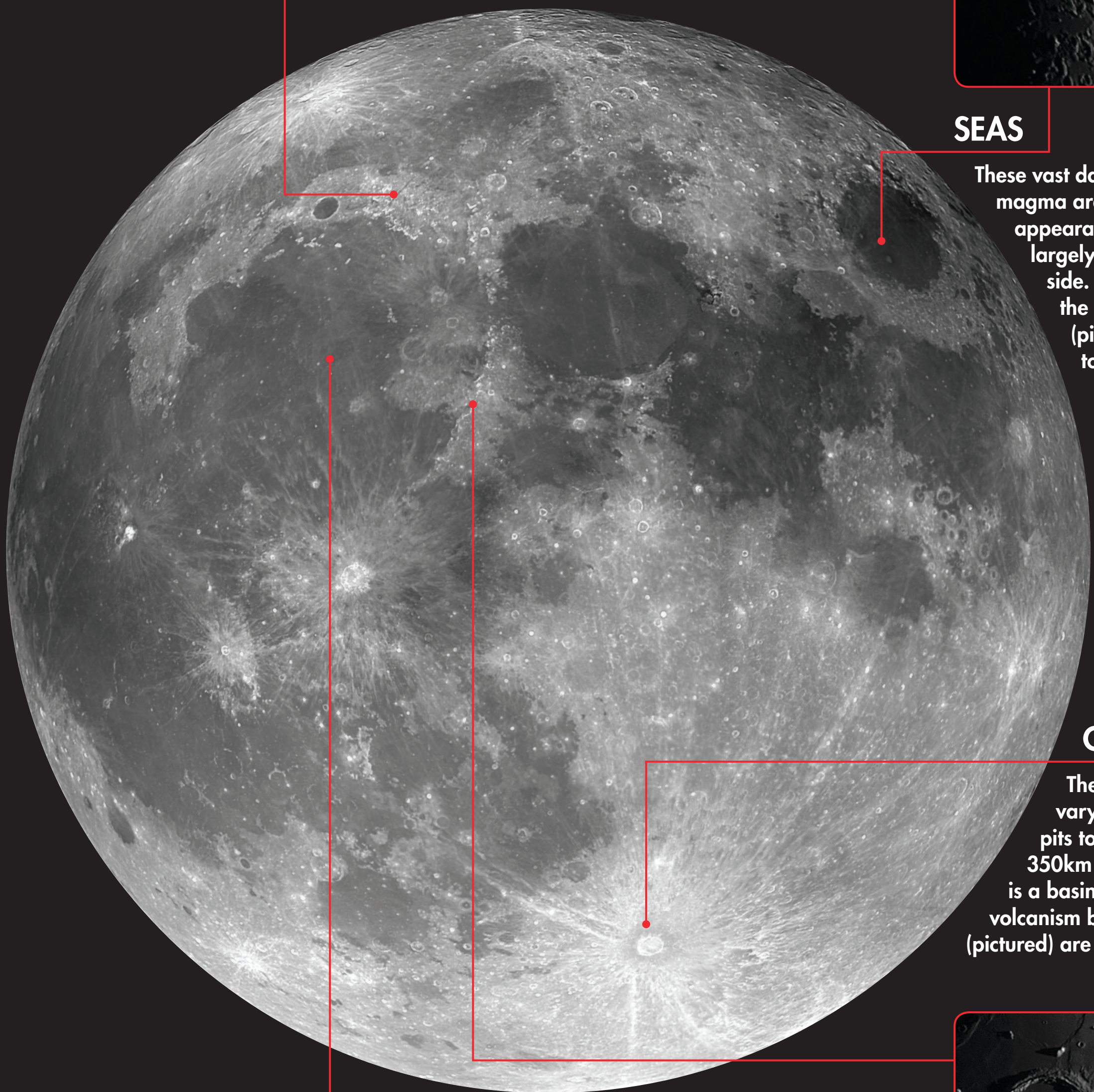
While 35 per cent of the Moon's Earth-facing hemisphere is covered with mare lava, very little molten material made it to the surface on the far side, so maria account for just one per cent. It's thought this is because the far side's crust is thicker – it may be up to twice as thick as that of the near side – possibly due to the slow accretion of a companion satellite after an impact. This theory seems to be supported by the discovery of the far side's 3.9 billion-year-old South Pole-Aitken Basin, over 2,400km wide and around 13km deep. To date, our best views of the Moon come from NASA's Lunar ▸

MIDDLE TEMPLE LIBRARY/SCIENCE PHOTO LIBRARY, NASA/GODDARD/ARIZONA STATE UNIVERSITY, NASA/JPL, STEVE MARSH X 5

THE MAJOR CLASSES OF LUNAR FEATURES

VALLEYS

There are 14 official valleys on the Moon, the longest around 600km. Most are named after nearby craters. One of the most familiar is the 180km-long Vallis Alpes (pictured), which cuts across the northern Montes Alpes and almost connects the Mare Imbrium and the Mare Frigoris.



SEAS

These vast dark plains of solidified magma are notable for both their dark appearance and the fact that they are largely absent from the Moon's far side. One of the most distinct is the 560km-wide Mare Crisium (pictured) which is just visible to the naked eye.

CRATERS

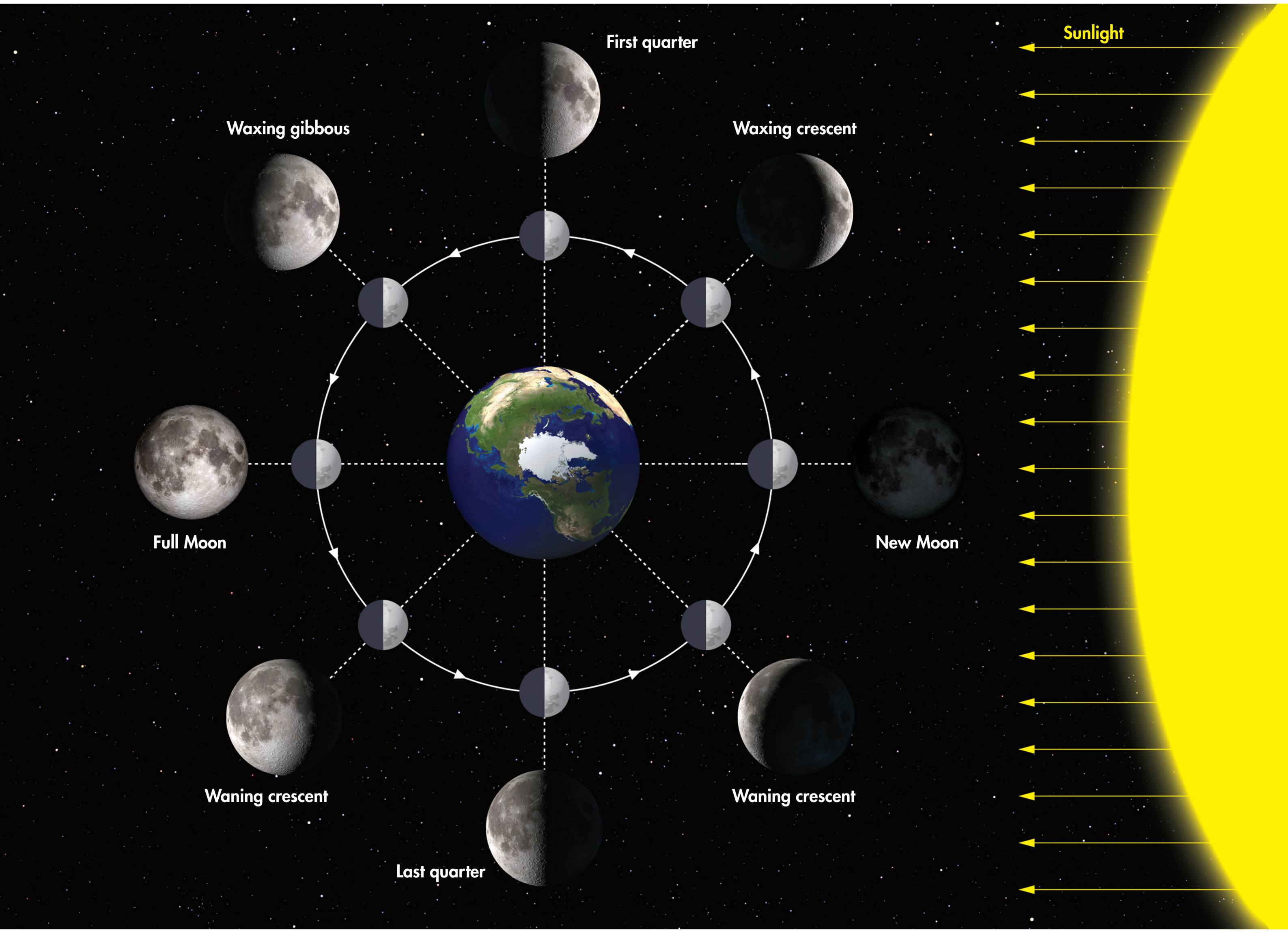
The ubiquitous lunar feature, varying in size from microscopic pits to sprawling depressions up to 350km in diameter — anything larger is a basin. Some were formed through volcanism but the majority, like Tycho (pictured) are the result of ancient impacts.

BASINS

The oldest and largest impact craters on the Moon, exceeding 350km in diameter. All lunar maria are found within them. The South Pole-Aitken Basin on the Moon's far side holds the record for being the largest, at around 2,400km; the biggest on the near side is the Imbrium Basin, shown here, which stretches across 1,160km of the lunar surface.

MOUNTAINS

The Moon's peaks are named in two ways: 'Montes' for mountain ranges and 'Mons' for singular peaks and massifs. The most spectacular of the 18 named lunar ranges is the gently curved, 600km-long Montes Apenninus (pictured), which form the southeastern edge of the Imbrium Basin. Mons Huygens, the Moon's tallest mountain at 5.4km, soars skyward here.



▸ Reconnaissance Orbiter, now in its sixth year of operations and, at the time of its launch, the first US mission to the Moon in 10 years.

▲ **The Moon's cycle of phases is the result of its position relative to us and the Sun in it orbit**

The Sun always shines

It's equally obvious that the illumination of the Moon's Earth-facing hemisphere changes over the course of the month – a word, incidentally, that we get from 'Moon'. Although the Sun is always shining on a full half of the Moon, the proportion of the lit side we are able to see depends on where the Moon is in its orbit around Earth, giving rise to the phases we see.

Imagine you are looking down on the Earth, Moon and Sun from above. When the three line up with the Moon in the middle, the Moon's lit half points away from us on Earth, producing a new Moon. Slowly emerging from its new phase into the evening sky, the lunar crescent thickens from one day to the next. The term 'waxing' is used to indicate this thickening phase. The waxing crescent leads to the Moon appearing as an illuminated semicircle roughly a week after new.

This is somewhat confusingly called 'first quarter', referring to the Moon's position in its 29.5-day orbit rather than proportion of its disc is illuminated from our vantage point on Earth. The bulging phases after first quarter are known as waxing gibbous. These increase in size until roughly two weeks after new, the Moon is on the opposite side of its orbit from the Sun and appears fully lit as a full Moon. The point of new and full Moon, when our planet, satellite and star are aligned, is technically known as a 'syzygy'.

After full Moon the phases reverse, and the illuminated part of the Moon begins to shrink or wane. After passing through the waning gibbous phases, the Moon reaches the three-quarter point of its orbit, giving rise to the 'last quarter' phase. The Moon takes the appearance of a semicircle once again, although it's the opposite half that is illuminated than that at first quarter. After this, it takes approximately a week for the Moon to go through its waning crescent phases, visible in the early morning sky, before it once again becomes new again. It takes 29.5 days for the Moon to return to complete this cycle of phases or 'lunation', slightly longer than it does to complete an Earth orbit. This is known as a synodic month.

Ellipse and eclipse

The Moon's elliptical orbit is inclined to Earth's by an average of 5°. This means that on most of the occasions that a full Moon occurs, it actually

ILLUSTRATIONS BY STEVE MARSH, NASA/JPL/NORTHWESTERN UNIVERSITY, ISTOCK

passes above or below the shadow Earth casts into space. But in the instances that the full Moon passes into Earth's shadow we see a different phenomena: a lunar eclipse.

Because the Sun is much bigger than Earth, it splits our planet's shadow into two parts: the darkest, called the umbra, and a lighter outer ring, called the penumbra. The intensity of a lunar eclipse depends on how much of the Moon passes into Earth's shadow, and which part of the shadow it passes through.

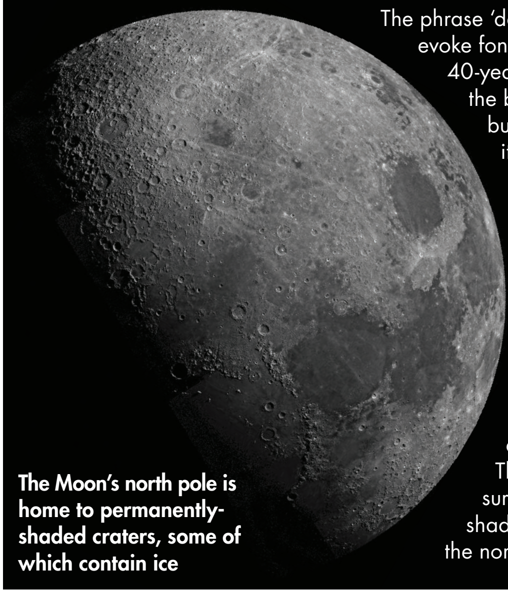
In a total lunar eclipse, the entire Moon passes through the penumbra and into the umbra, gradually darkening until it is completely covered, a point known as totality. During totality no sunlight shines directly on the Moon, but some is refracted onto it via Earth's atmosphere. As our atmosphere filters out blue light, the Moon often gains a strange orange-brown colour.

As the Moon goes into eclipse and dims, the sky gets darker too. You may not have realised how bright a full Moon can be. It lights up the sky around it with a blue haze, out of which only the brighter stars are visible. During a total lunar eclipse, the darker Moon means that the fainter stars can come out and we end up with the eerie sight of a deep-red Moon surrounded by twinkling stars.

There are two other types of lunar eclipse: partial, where only a portion of the Moon passes through Earth's dark umbral shadow, and penumbral, where part of the Moon only passes through the lighter, outer shadow. Partial eclipses can be quite noticeable, but penumbral eclipses often only cause a slight dimming.

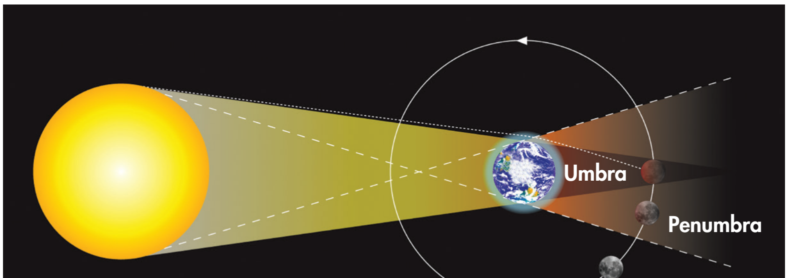
When the same thing happens at new Moon the opposite occurs, and we may see a partial or total solar eclipse. By staggering coincidence, right now the Moon is both 400 times smaller than the Sun ▸

THE BIG MYTH
The dark side of the Moon



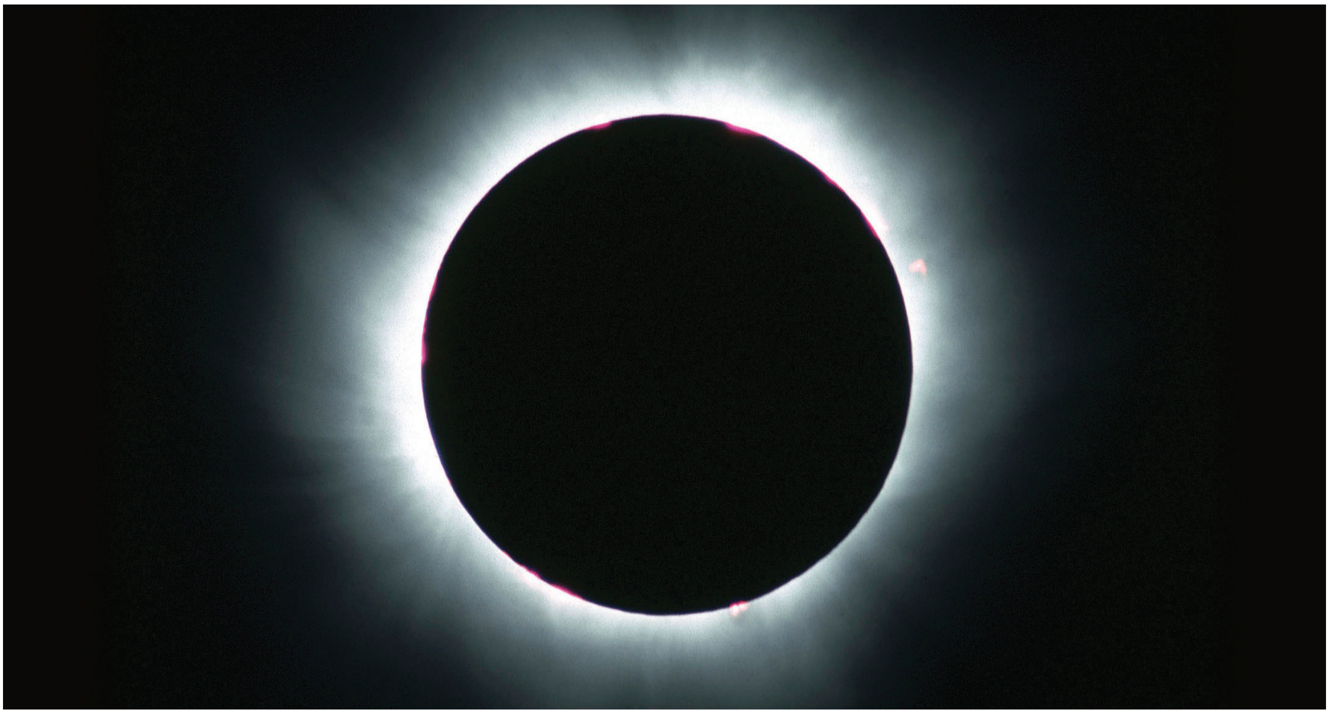
The Moon's north pole is home to permanently-shaded craters, some of which contain ice

The phrase 'dark side of the Moon' may evoke fond memories of Pink Floyd's 40-year-old prog-rock album to the baby boomer generation, but in an astronomical context it's often used to refer (erroneously) to the Moon's far side. The phrase is something of a misnomer, since the lunar far side goes through the same cycle of illumination as the phases of the Moon seen on the Earth-facing hemisphere. Technically, the far side is the 'dark side' at the instant of full Moon. The only places on the Moon's surface permanently bathed in shadow are a few deep craters at the north and south poles.



Earth has two shadows, the umbra and penumbra; only sunlight that is refracted by Earth's atmosphere reaches the Moon when it is in the umbral shadow

Light scattered by Earth's atmosphere can cause the Moon to redden during lunar eclipses



▸ and 400 times closer, meaning that they appear to be the same size in the sky. The fact the Moon only just covers the Sun during a total solar eclipse allows us to glimpse our star's ghostly outer atmosphere, the corona.

▲ Total solar eclipses can only happen because of a staggering cosmic coincidence

A changing relationship

Life on Earth owes a lot to our rocky companion. Without it, our planet's axis would tilt wildly between 0° and 85°, albeit over a period of a million years, sending our hemispheres veering between chaotic ice ages and searing hellscapes. It would have been a death sentence for evolving life.

But our relationship with the Moon is becoming increasingly distant. When it formed, the Moon was only 22,500km from our planet. Today, it's nearly 10 times farther away and getting more distant by 3.8cm a year – around the same rate as your fingernails grow. As a result, Earth's spin speed is slowing down and our days are getting longer.

Eventually, there will come a point when the length of the day and the month will be the same, and the Moon will cease to cross our skies. There will be no new or full Moon, only a small static disc in the night sky visible from one side of the planet, a situation we see today in the Pluto-Charon system. By the time that happens, humans will hopefully be looking out at other moons from distant planets.

NASA/JPL-CALETCH X 24, ISTOCK X 2, ISTOCK, WILL GATER

WHERE DID THE MOON COME FROM?

Most scientists now believe that the Moon was formed around 4.5 billion years ago when an object the size of Mars (and since named Theia) collided with the early Earth, giving it a glancing blow. The impact spewed debris into Earth's orbit, which coalesced to form the Moon at just the right distance to be an independent body; any closer and Earth's gravity would have pulled the material back.

This theory was born from the chemical analysis of lunar samples returned by the Apollo missions, which showed a remarkable similarity between Earth's composition – hinting at a common heritage. But there is a problem: the compositions look too similar. If this collision occurred, the Moon should have more of Theia's material and should therefore be more different from Earth.

The Apollo samples were obtained from a very small area – could this explain the similarities? It would seem not, because we do have other lunar material. The Russian Luna programme returned 0.33kg of Moon samples and we also have a number of lunar meteorites. Analysis of this material brings up a similar problem, it is just too similar to the composition of Earth.

So where does this leave the collision theory? It still has a lot of support, but what would be a great help is having more lunar samples from known but more varied locations.

THE BASICS OF LUNAR OBSERVING

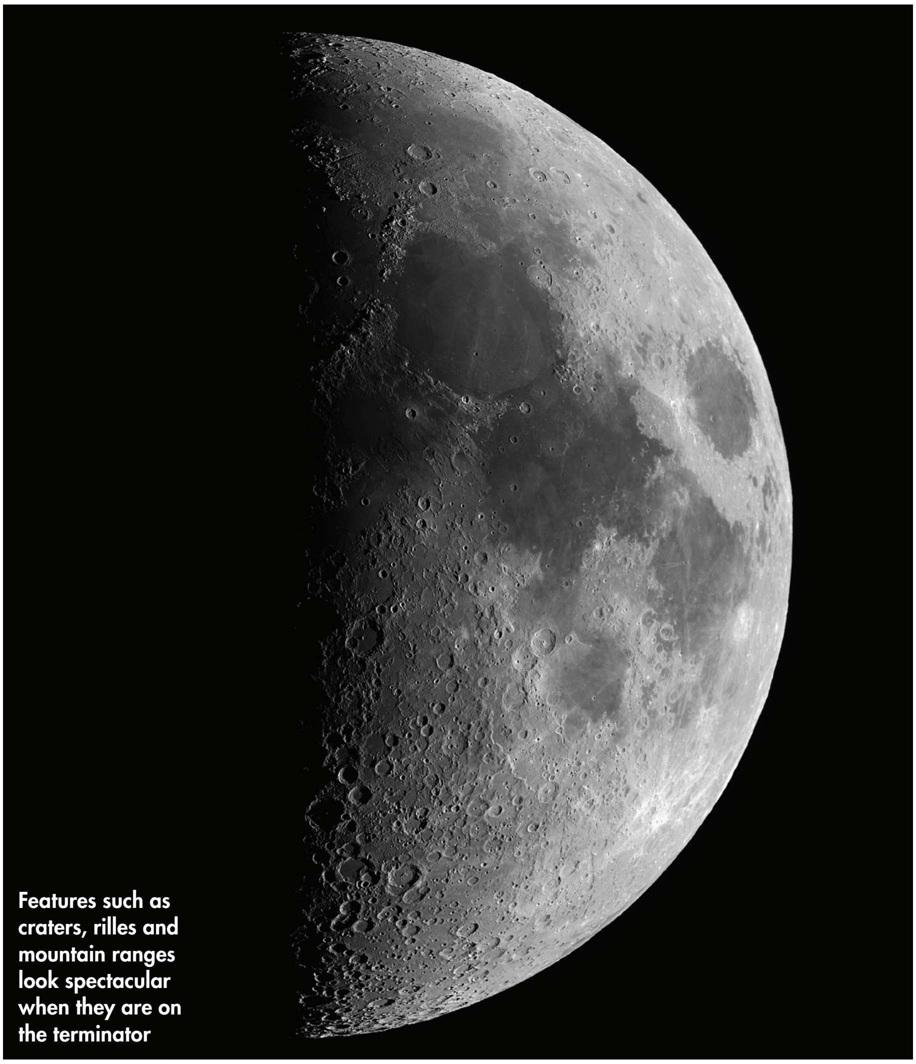
Explore the seas and craters that texture the lunar surface with our beginners' observing guide ▸

The Moon is an ideal object to begin your observing odyssey because it is big, bright and covered with amazing detail. But the thing that surprises most novice observers is the variation it holds. Though the same hemisphere faces Earth at all times, what you can see on the Moon changes from one night to the next.

You may be forgiven for thinking that full Moon is the best time to examine our close companion – not so. While this is a good time to see the long, bright rays of ejecta surrounding prominent craters such as Tycho, the high altitude of the Sun in the lunar sky means no shadows are cast, resulting in a washed-out view of the Moon.

In general, the best time to view a given lunar feature is when the terminator, the demarcating line that separates lunar day and night, is nearby. This is the region where the Sun is either rising or setting, where crater rims and mountain peaks stand out in stark relief, casting inky black shadows across the lunar surface that exaggerate their presence. Those further from the terminator show hardly any shadows and are harder to make out.

At day zero of the lunar cycle – new Moon – the whole of the dark lunar hemisphere points towards Earth. Over the next 15 days the terminator slowly



Features such as craters, rilles and mountain ranges look spectacular when they are on the terminator

THE MANY GUISES OF THE MOON

Even to the naked eye, our satellite is a beguiling subject

EARTHSHINE

The Moon is not solely lit by sunlight. When it is in a slender crescent phase in the evening or dawn twilight, it's sometimes possible to see its dark portion gently glowing due to sunlight reflected off the oceans and clouds of planet Earth. This effect is known as earthshine. Our planet actually reflects more light onto the lunar surface than the Moon gives us when it is full.

LUNAR HALOES

On frosty nights, often when the Moon is or near full, you may be able to spot a faint ring of light caused by ice crystals refracting the moonlight in the upper atmosphere. Since the ice crystals are normally all hexagonal, the ring is almost always the same size; it has a diameter of 22°. Sometimes it is also possible to detect a second ring, 44° in diameter.

RED MOON

There are two reasons the lunar disc may take on a ruddy hue. The first is if it is low in the sky, so light reflected from it passes through more of our atmosphere. Blue and violet light is scattered more easily, so we see a redder Moon. The other is during a total lunar eclipse: longer sunlight wavelengths are refracted by the Earth's atmosphere onto the eclipsed Moon.

SUPERMOON

A supermoon is a full Moon that coincides with the closest point to Earth in its orbit, causing the lunar disc to appear larger by as much as 14 per cent. The word is rooted in astrology but, given the correct astronomical term is a 'perigee-syzygy Moon', you can see how it caught on.

A supermoon also occurs with a new Moon at perigee – but you aren't able to see this one.

▲ Though the Moon completes an orbit of Earth in 27.3 days, it takes 29.5 to complete a cycle of phases due to our planet's motion around the Sun

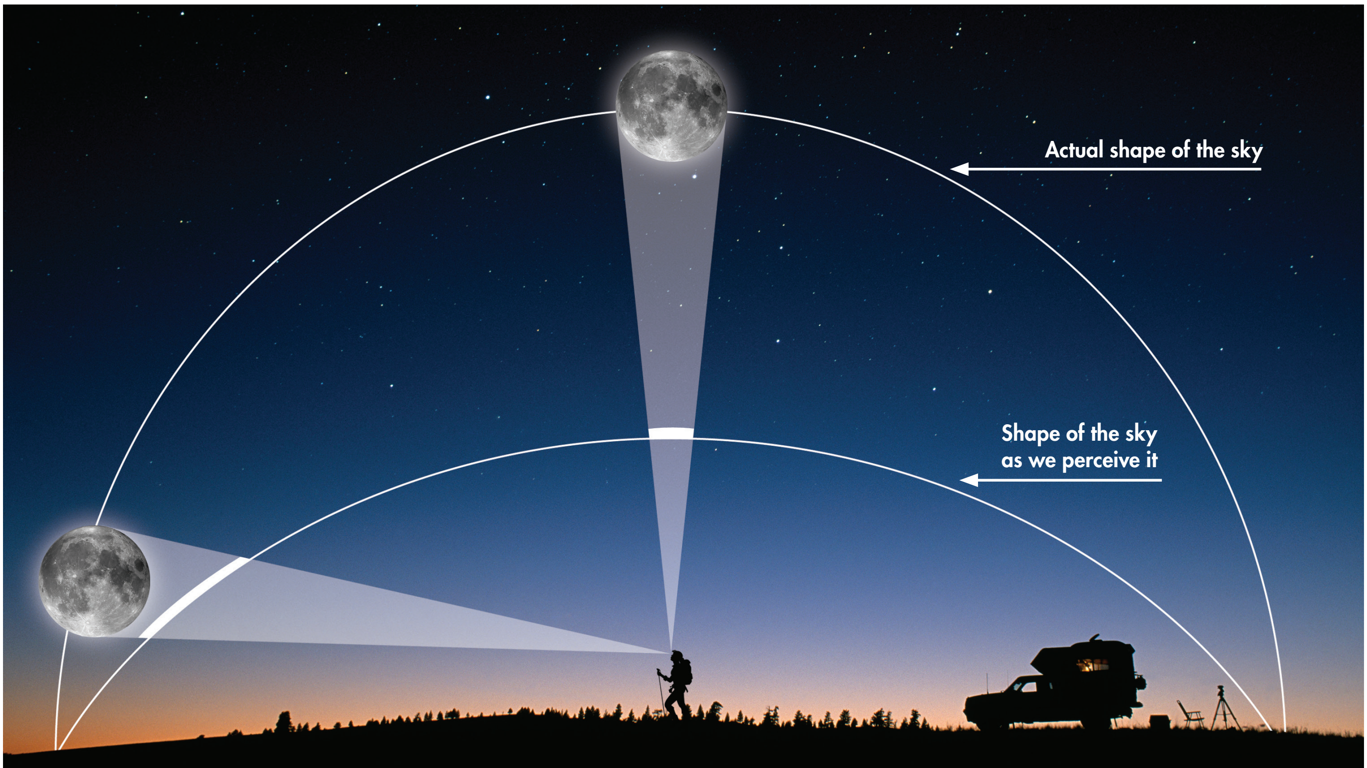
creeps across the lunar surface from east to west until the disc is fully illuminated at full Moon. Then the tables are reversed as the encroaching darkened hemisphere heads west with each passing day, until the diminishing crescent becomes lost in the pre-dawn twilight.

Peering beyond the limb

The nature of the Moon's orbit generates another effect that is a boon to lunar observers, a rocking and rolling motion that we call libration. The Moon's orbit is elliptical, and as a result its distance from Earth does not remain constant. When closest it speeds up slightly; when more distant it slows down. This small variation is enough to cause the Moon to 'nod' back and forth on its axis, giving us an occasional chance to see a little more around its eastern and western edges.

The orbit is also slightly inclined, and this causes it to sometimes appear above the Earth's orbital plane and sometimes below. This gives us an opportunity to peek over the top, and under the bottom, of the Moon over time. Taken together, this libration allows us to see a total of 59 per cent of the Moon's globe, revealing tantalising features normally hidden from view – some of which we'll cover later on in this special edition.

With the naked eye it's easy to see the progression of lunar phases, full disc effects such as earthshine and the ▸



THE BIG MYTH The Moon illusion

Look for the Moon when it is low to the horizon and you may get the impression that it is unnaturally large – this is the phenomenon known as the Moon illusion, and it appears to be more pronounced around full Moon when the maximum area of its disc is illuminated. In reality, the Moon has more or less the same apparent diameter of around 0.5°, whether it is looming over the horizon or riding high in the sky.

One explanation for the illusion arises from our perception of the shape of the celestial sphere above us; instead of a hemisphere, we perceive the sky to be a flattened dome. Consequently the lower the Moon is in the sky, the farther away and larger it is perceived to be. When the Moon is high in the sky we conversely perceive it to be closer to us and therefore smaller in apparent size.

Few people seem to be immune to the Moon illusion, even though the viewer may be fully aware that for any given evening there is actually no appreciable difference in the Moon's apparent diameter, regardless of its height above the horizon.

THE RAREST MOON

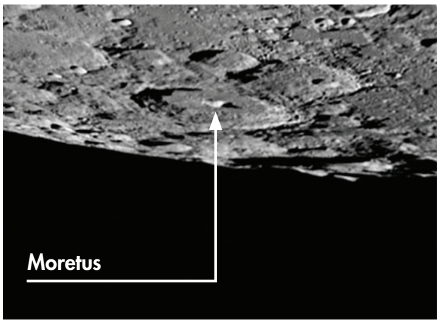
No doubt you've heard the expression 'once in a blue Moon' – meaning something that is exceptionally rare. But what exactly is a blue Moon, and does our neighbour ever adopt an azure appearance?

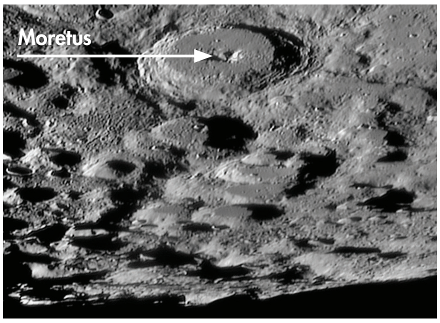
When astronomers use the term, they are most likely referring to one of two lunar events – neither of which cause the Moon to turn blue.

Traditionally, a blue Moon is considered to be the third full Moon in a season that has four. Normally, there are only three. The second and more modern interpretation is that it is the second full Moon that occurs in a calendar month, which can happen as a lunar cycle only takes 29.5 days to complete.

Why the discrepancy in definitions? It appears to be the result of a publication mistake that appeared in 1946 that confused the traditional meaning, which dates back to 19th-century editions of the *Maine Farmers' Almanac*.

And yet there is circumstance that can cause the Moon to truly appear bluish, as it did in the wake of the Krakatoa eruption in 1883, and it is exceptionally rare. The secret is that the atmosphere needs to flooded with dust particles of a specific size – slightly smaller than the wavelength of red light – and that size alone. These particles scatter red light, causing the Moon to take on a slight cerulean cast.





▲ Libration brings features on the lunar limb into better view, as seen here. Crater Moretus appears squashed and foreshortened (top) but this changes under favourable libration (above)

► major lunar seas. Binoculars increase the detail you'll see: as well as dark seas, you'll now be able to spot individual craters and large mountain ranges, especially when they are close to the terminator. The smallest craters you'll be able to pick out will depend on how still you can hold your binoculars, but a pair of 7x50s should comfortably reveal features down to about 50km across.

A telescopic view of the Moon is amazing and one that never gets old. At low magnifications, the amount of detail visible is breath-taking, especially close to the terminator where relief shadows really help to emphasise the detail. Upping magnification by using shorter focal length eyepieces will get you in closer and give you opportunity to 'roam' around the lunar landscape.

Trifles and troubles

The view you have of the Moon through a telescope will differ from what you see with the naked eye or binoculars depending on its optical arrangement. Through a refractor or compound instrument, the Moon will appear flipped west to east, while through a reflector the image will be inverted.

If you look at the Moon with a telescope you may also notice the surface appears to gently wobble or sometimes even shimmer. This effect is caused by air moving through the atmosphere of our planet, and the greater the turbulence the worse the views.

Such 'seeing' conditions can vary from minute to minute and night to night. The best views will always be had when the seeing is steady and these undulations are less intense; poor seeing, on the other hand, results in loss of detail and fuzzy lunar features.

For centuries, telescopic observers have also reported seeing short-lived changes in brightness on the surface of Moon, events that are collectively referred to as transient lunar phenomena, or TLPs. They have been described as luminous spots that suddenly appear and vanish, localised patches of colour and temporary blurring or misting of the Moon's fine surface detail. However, despite several high-profile reports – including those from Sir William Herschel in 1787 and French astronomer Audoiun Dollfus in 1992 – their existence remains debated to this day.

The problem is that TLPs, being transient by nature, are hard to independently verify and impossible to reproduce. Most are spotted by lone observers, or are only witnessed from a single location on Earth, casting doubt on whether they truly occurred at all. Some believe that TLPs are little more than the result of poor observing conditions or equipment issues. Assuming they do occur, the most popular theory to explain them is residual outgassing from below the lunar crust.

What does seem clear is that TLPs, whether real or imagined, are more prone to occur on some areas of the lunar surface than others, with more than one-third of official reports coming from the region around the Aristarchus plateau.