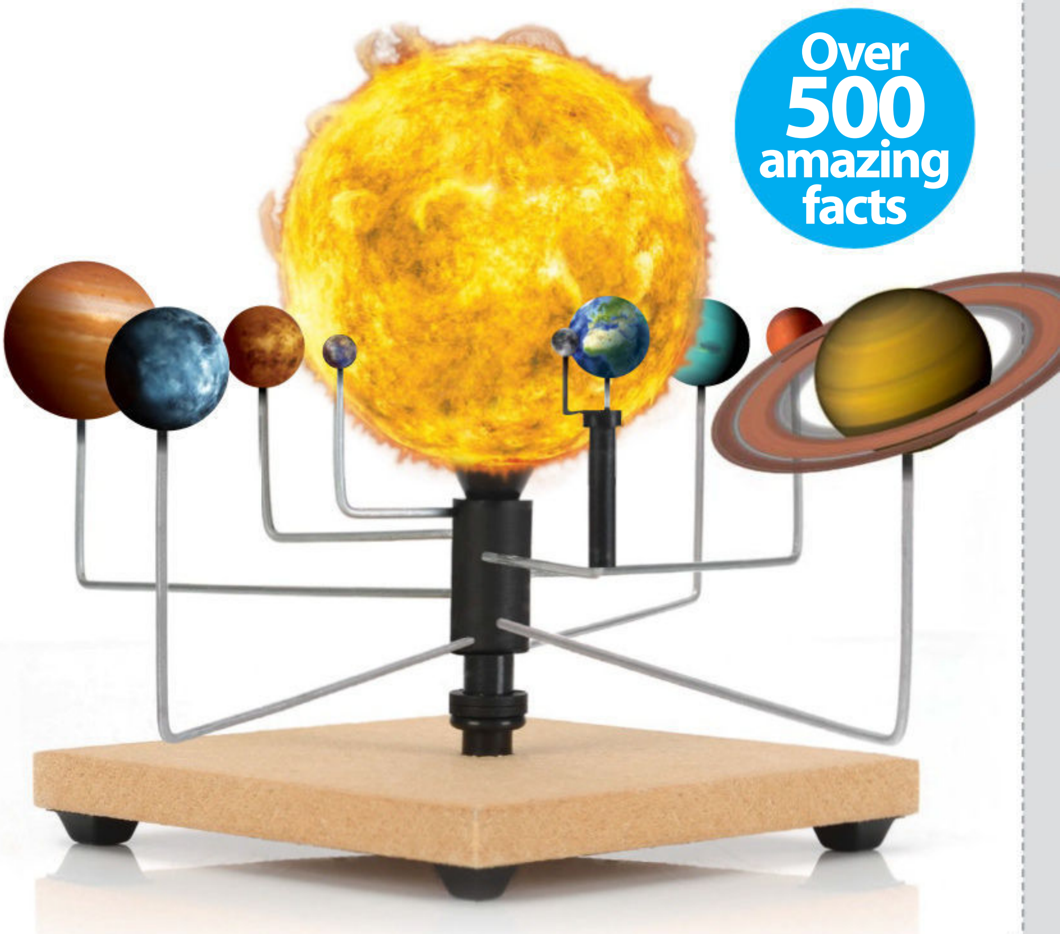
NEW

Planets & Solar System

The Complete Manual

An essential guide to our solar system

Over 500 amazing facts

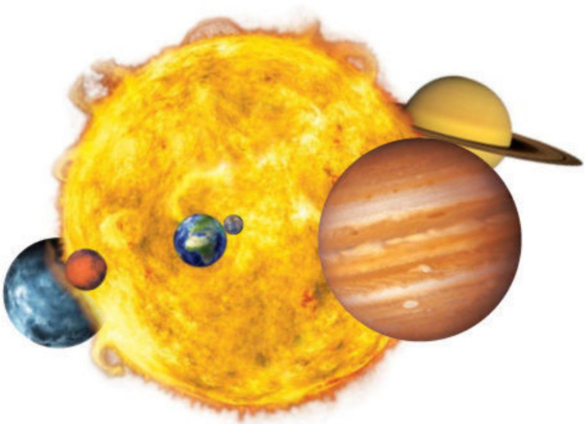


Welcome to

Planets & Solar System

The Complete Manual

Throughout history, humankind has looked up at the stars and wondered what they were. Playing a central role in mythology, philosophy and superstition, it wasn't until the rise of astronomy that we began to understand these celestial bodies. After Galileo Galilei's incredible discovery, we now know the role of the Sun as the centre of a system of planets, dubbed the Solar System. As new technology advances we discover more and more about our fellow planets, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune and the dwarf planet Pluto. Read on to discover just how much we've learned about our neighbours so far, and how much more knowledge is still to come.



Planets & Solar System

The Complete Manual

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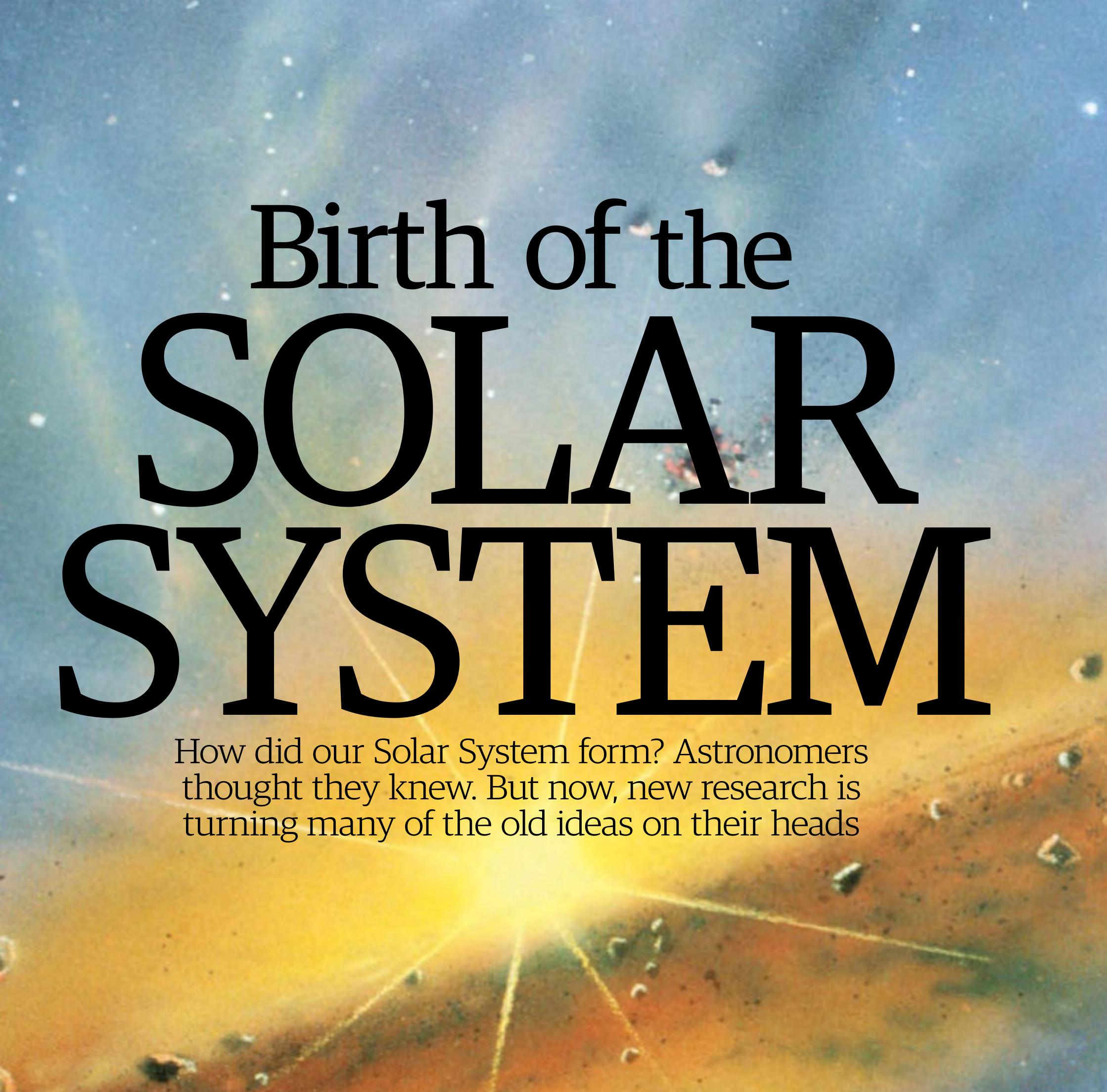


Birth of the SOLAR SYSTEM

How did our Solar System form? Astronomers thought they knew. But now, new research is turning many of the old ideas on their heads

Around 4.5 billion years ago, our Sun and all the other objects that orbit around it were born from an enormous cloud of interstellar gas and dust, similar to the glowing emission nebulae we see scattered across today's night sky. Astronomers have understood this basic picture of the birth of the Solar System for a long time, but the details of just how the process happened have only become clear much more recently – and now new theories, discoveries and computer models are showing that the story is still far from complete. Today, it seems that not only did the planets form in a far more sudden and dynamic way than previously suspected, but also that the young Solar System was rather different from that we know now.

The so-called 'nebular hypothesis' – the idea that our Solar System arose from a collapsing cloud of gas and dust – has a long history. As early as 1734, Swedish philosopher Emanuel Swedenborg suggested that the planets were born from clouds of material ejected by the Sun, while in 1755 the German thinker Immanuel Kant suggested that both the Sun and planets formed alongside each other from a more extensive cloud collapsing under its own gravity. In 1796, French mathematician Pierre-Simon Laplace produced a more detailed version of Kant's theory, explaining

how the Solar System formed from an initially shapeless cloud. Collisions within the cloud caused it to flatten out into a spinning disc, while the concentration of mass towards the centre caused it to spin faster (just as a pirouetting ice skater spins faster when they pull their arms inwards towards their bodies).

In the broad strokes described above, Laplace's model is now known to be more or less correct, but he certainly got some details wrong, and left some crucial questions unanswered – just how and why did the planets arise from the nebula? And why didn't the Sun, concentrating more than 99 per cent of the Solar System's mass at the very centre of the system, spin much faster than it does? Solutions to these problems would not come until the late 20th Century, and some of them are still causing doubts even today.

Much of what we know about the birth of our Solar System comes from observing other star systems going through the same process today. Stars are born in and around huge glowing clouds of gas and dust, tens of light years across, called emission nebulae (well known examples include the Orion Nebula, and the Lagoon Nebula in Sagittarius). The nebulae glow in a similar way to a neon lamp, energised by radiation from the hottest, brightest and most massive stars within them, and remain active for perhaps a few million years, during which time they may give rise to hundreds of stars forming a loose star cluster. Since the brilliant, massive stars age and die rapidly, it's only the more sedate, lower-mass stars like our own Sun that outlive both the nebula and the slow disintegration of the star cluster.

Star birth nebulae develop from the vast amounts of normally unseen, dark gas and dust that forms the skeleton of our Milky Way galaxy, and subside as the fierce radiation from their most massive stars literally blows them apart. The initial collapse that kick-starts formation can be triggered in several ways - for instance by a shockwave from a nearby exploding supernova, or by tides raised during close encounters with other stars. However, the biggest waves of star birth are triggered when material orbiting in our galaxy's flattened outer disc drift through a spiral-shaped region of compression that extends from the galactic hub and gives rise to our galaxy's characteristic shape.

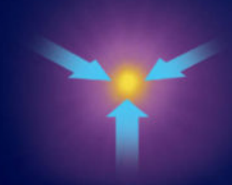
Inside the nebula, stars are incubated in huge opaque pillars of gas and dust. As these pillars are eroded by outside radiation from massive stars that have already formed, they break apart into isolated dark globules whose internal gravity is strong enough to hold them together - the seeds of individual solar systems. Gas falling towards the very centre of the globule becomes concentrated, growing hotter and denser until eventually conditions are right for nuclear fusion, the process that powers the stars, to begin. As the star begins to generate energy of its own, its collapse stabilises, leaving an unpredictable stellar newborn surrounded by a vast disc of gas and dust that will go on to form its solar system. But how?

The first person to put Laplace's hypothesis on a sound theoretical footing was Soviet astronomer Viktor Safronov, whose work was first translated from Russian in 1972. Safronov's modified 'solar nebular disk model' allowed the Solar System to form from much less material, helping to resolve the problem of the Sun's slow

"Star birth nebulae develop from the vast amounts of unseen, dark gas and dust that forms our Milky Way"

How stars are formed

Disturbed nebula
A star is born when a cloud of interstellar gas and dust passes through a galactic density wave, or is compressed by shock from a nearby supernova or tides from a passing star



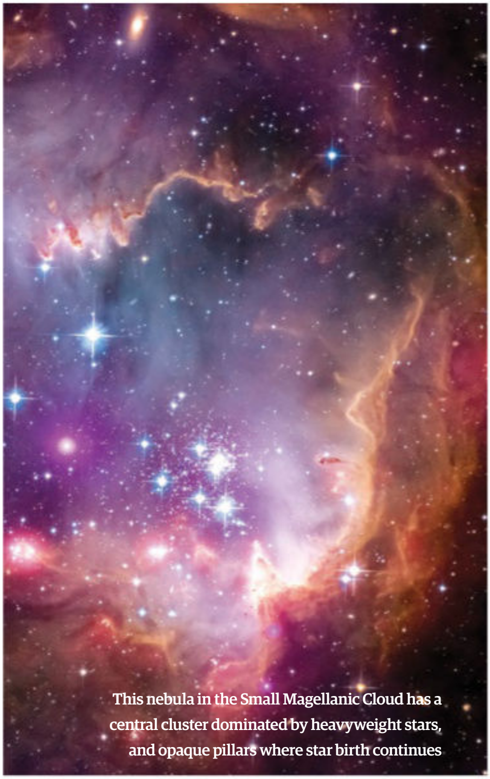
Slow collapse
Denser regions in the nebula collapse under their own gravity. As mass concentrates towards their centres, they begin to spin more rapidly, and their cores grow hotter

Flattening disc
Collisions between randomly moving gas clouds and dust particles tend to flatten out their motions into a narrow plane, creating a disc that spins ever more rapidly

spin. Also, Safronov provided a basic mechanism for building planets out of primordial dust grains, known as 'collisional accretion'.

This simple mechanism involves small particles colliding and sticking to each other one at a time, eventually growing into objects that were large enough to exert gravitational pull and drag in more material from their surroundings. This produced objects called planetesimals, the largest of which might have been about the size of the dwarf planet Pluto. A final series of collisions between these small worlds created the rocky planets close to the Sun, and the cores of the giant planets further from the Sun. The difference between the two main types of planet is then explained by the existence of a 'snow line' in the early Solar System, around the location of the present-day asteroid belt. Sunward of this, it was too warm for frozen water or other chemical ices to persist for long enough - only rocky material with high melting points survived. Beyond the snow line, however, huge amounts of ice and gas persisted for long enough to be swept up by the giant planets.

It all sounds simple enough, and has been widely accepted for the best part of four decades. But now that seems to be changing. "There's been the beginning of a paradigm shift away



This nebula in the Small Magellanic Cloud has a central cluster dominated by heavyweight stars, and opaque pillars where star birth continues

Birth of a protostar
As more material falls in the core of the nebula, it start radiates substantial infrared radiation that pushes back the tendency to collapse. The core of the nebula is now a protostar

Ignition!
The protostar is hot and dense enough for nuclear fusion to convert hydrogen into helium. The star starts to shine but goes through violent fluctuations before it stabilises

Bipolar outflow
Gas continues to fall onto the infant star, accumulating round its equator but flung off at its poles in jets: bipolar outflow. Radiation pressure drives gas out of the surviving nebula

from the two-body build-up that Safronov modelled," says Dr Hal Levison of the Southwest Research Institute (SwRI) in Boulder, Colorado. "The idea of things growing by collisions hasn't really changed but over the last five years, new theories invoking the idea of pebbles [are] coming to the fore. We've only now got to the stage where we can discuss these ideas in any great detail."

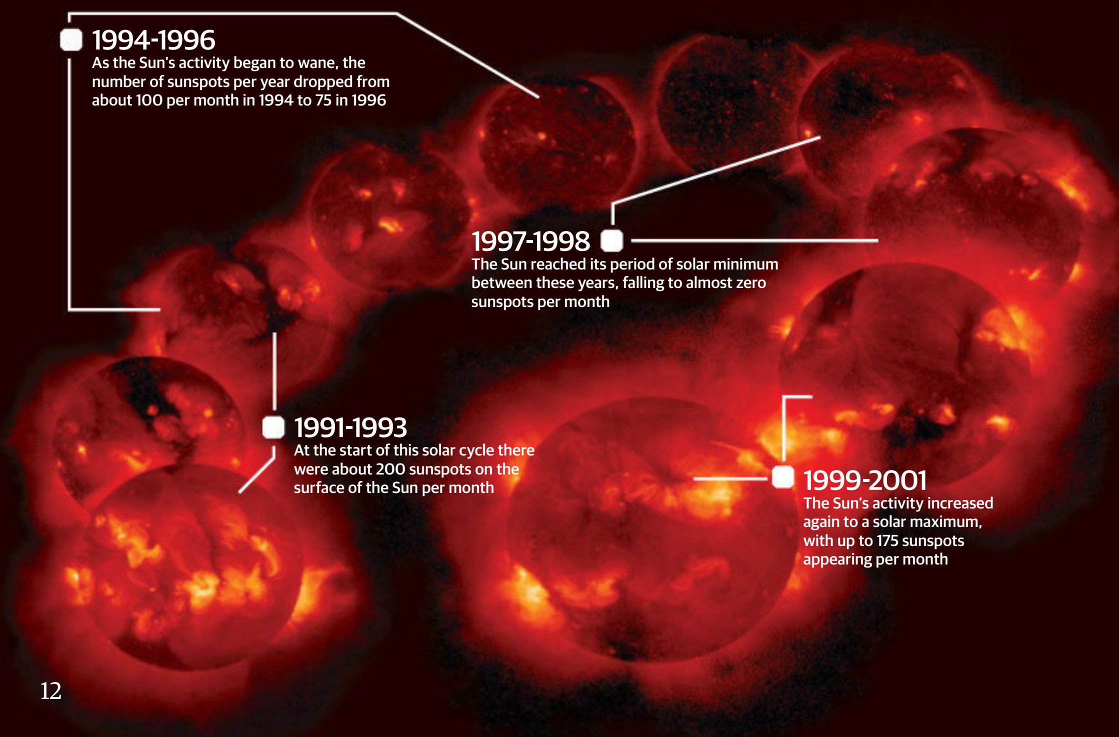
The new approach stems from a long-standing problem: "The big question is how you get the first macroscopic objects in the Solar System - things that are bigger than, say, your fist," explains Levison. "Safronov's idea was that you just did that through collisions, but people have always recognised there's a problem we call the metre barrier."

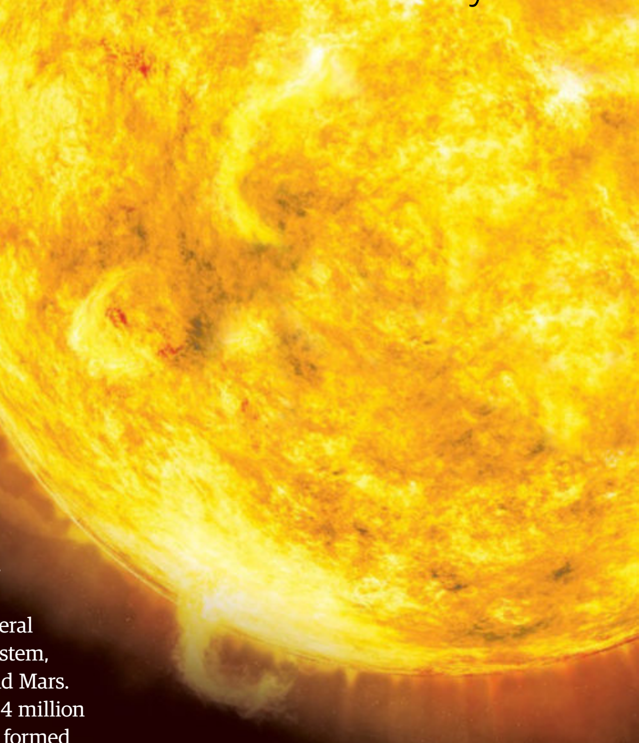
"You only have to look under your bed to see plenty of evidence that when small things hit one another, they can stick together, making these dust bunny clumps that are held together by electrostatic forces [weak attraction between innate static electric charges]. And if you look at objects bigger than, say a few kilometres across, gravity can hold things together. But if you're looking at something, say, the size of a boulder, it's hard to imagine what makes them stick."

Fortunately ten years ago, researchers including Andrew Youdin and Anders Johansen came with a way around the problem. "What they've shown is as dust grains settle into the central plane of the protoplanetary disc, that causes a kind of turbulence that concentrates the pebbles into large clumps. Eventually these can become gravitationally unstable and collapse to form big objects. This model predicts you go directly from things the size of a nail to hundred km [62mi]-sized objects, in one orbit"

Over the past few years, as various teams including Levison's group at SwRI have worked

The solar cycle





on the theory, they've found that the clumping process is even more effective than they first thought: "We're talking about objects up to the size of Pluto forming this way, out of pebbles." And that's just the first stage: "Once you get up to that size, you get a body that can grow very effectively by eating the surrounding pebbles, pulling stuff in with its gravity and maybe growing into something the size of Mars. So the old idea of getting to Mars-sized objects by banging of Moon-sized things together could be wrong."

This new theory could help solve several outstanding problems with the Solar System, such as the relative ages of the Earth and Mars. "Mars seems to have formed about 2 to 4 million years after the Sun formed, while Earth formed about 100 million years later," explains Levison. The theory, then, is that Mars was entirely formed by the two stages of the pebble accretion process, while Earth still had to go through a final phase of Safronov-style planet-scale collisions in order to reach its present size.

"Pebbles can also help to explain how the giant planets formed as quickly as they did. Most astronomers accept the 'core accretion' model for the giant planets, where you start out with four objects the size of Uranus and Neptune, and two of those then accumulate gas and grow to become Jupiter and Saturn. But the problem is that you need to build those cores before all the gas goes away. In the traditional Safronov model, that's hard to do, but again this new pebble accretion model can do it really quickly." The difference in scale between the Mars-sized rocky objects and the much larger giant-planet cores, meanwhile, is still to do with availability of raw material, with copious icy pebbles surviving only in the outer Solar System.

But there's one other big problem in matching the Solar System we know today with the original solar nebula – the positions of the planets, and in particular the cold worlds of the outer Solar System. Today, Uranus orbits at a distance of 2.9 billion kilometres (1.8 billion miles) from the Sun, and Neptune at 4.5 billion kilometres (2.8 billion miles). Beyond Neptune, the Kuiper belt of small, icy worlds (including Pluto and Eris) extends to more than twice that distance, and then there's the Oort cloud – a vast spherical halo of icy comets that extends to around 15 trillion kilometres (9.3 trillion miles). The solar nebula, meanwhile, would have been most concentrated around the present orbit of Jupiter, and trailed off from there – while computer models suggest Uranus and Neptune could not have grown to their present size unless they were closer to Jupiter and Saturn.

All of which brings us to the work for which Levison is best known – his contribution to the 'Nice model' of planetary migration. This explains the configuration of the Solar System as the result of the dramatic shifting of the planets that happened around 500 million years after its initial formation.

The birth of the planets

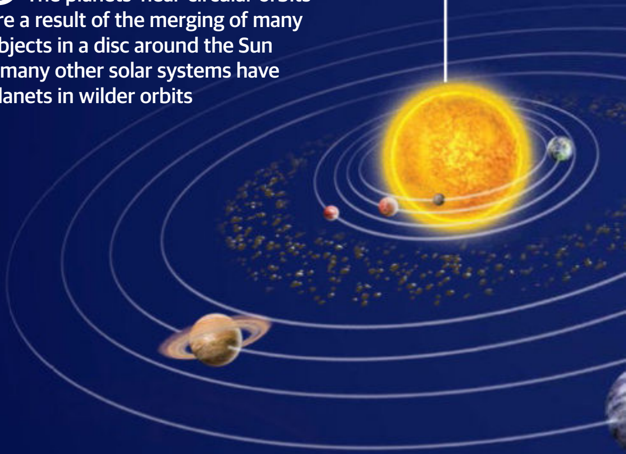
Our Solar System was cooked up in a swirling cloud of gas and dust

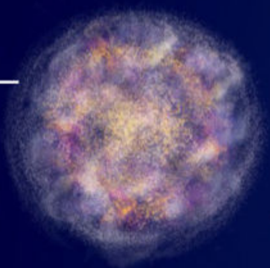
8 Planetary migrations

During planetary migration, giant planets of the outer Solar System change configurations and locations, moving through smaller bodies. Their havoc gives rise to the asteroid belt, Kuiper belt and Oort cloud

9 The Solar System today

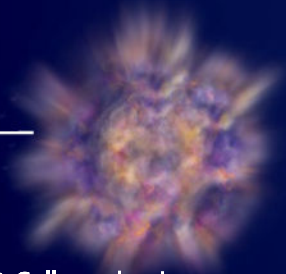
The planets' near-circular orbits are a result of the merging of many objects in a disc around the Sun – many other solar systems have planets in wilder orbits





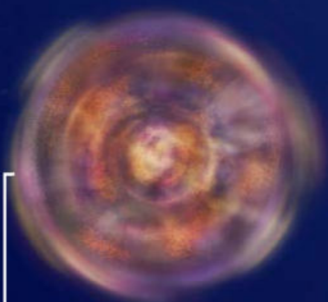
1 Shapeless cloud

4.5 billion years ago, the Solar System's raw materials lay in a cloud of gas and dust. Dominant components were hydrogen and helium, but also carbon, oxygen, nitrogen and dust grains



2 Collapse begins

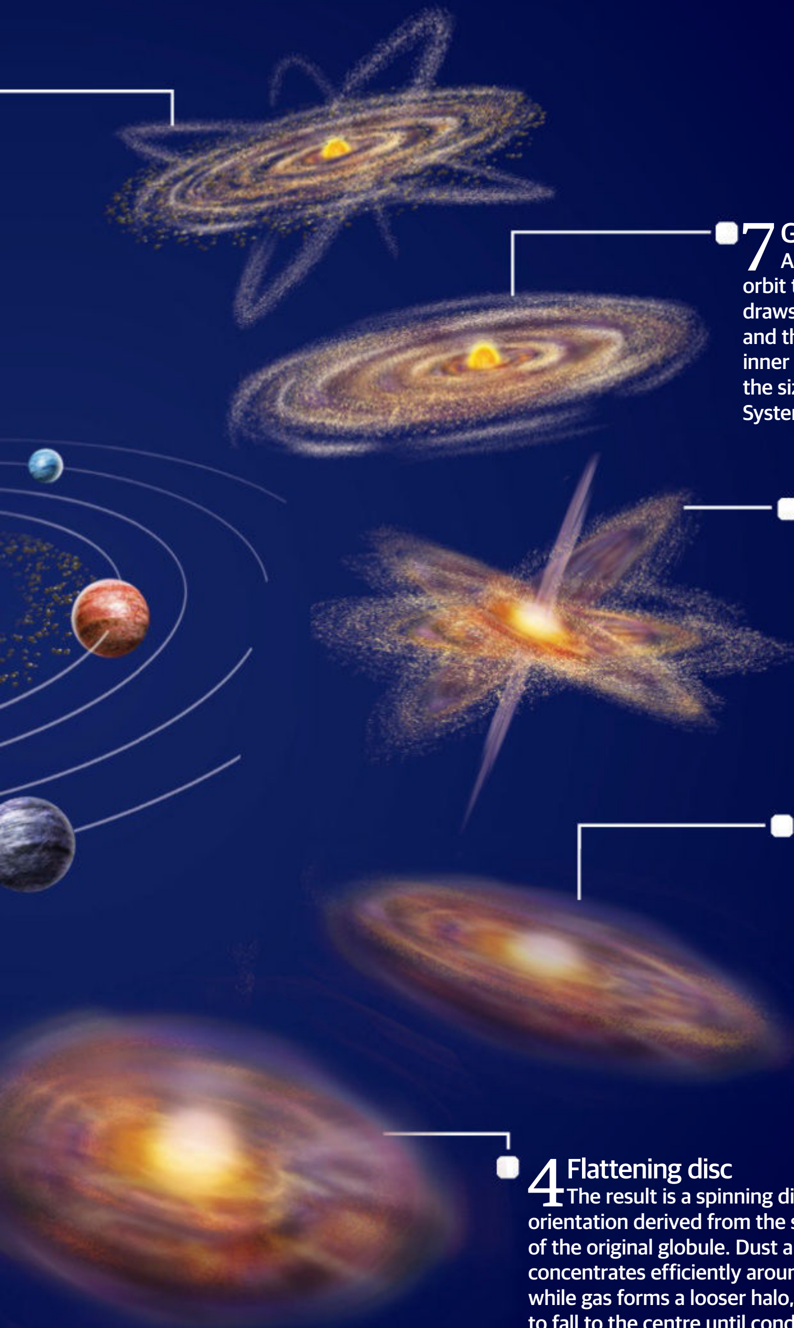
The trigger for an emission nebula produces condensation in regions of the cloud with high densities. Each gives rise to a group of stars – once the first begin to shine, their radiation helps energise the nebula, dictating where the younger generations of stars form



3 Individual systems

As material falls inward, collisions between gas clouds and particles cancel out movements in opposing directions, while the conservation of angular momentum causes the cloud's central regions to spin faster

Birth of the Solar System



7 Growing pains

As the new protoplanets orbit the Sun, their gravity draws in remaining pebbles and they grow rapidly. In the inner Solar System, they reach the size of Mars - in the outer System the size of Uranus

6 From pebbles

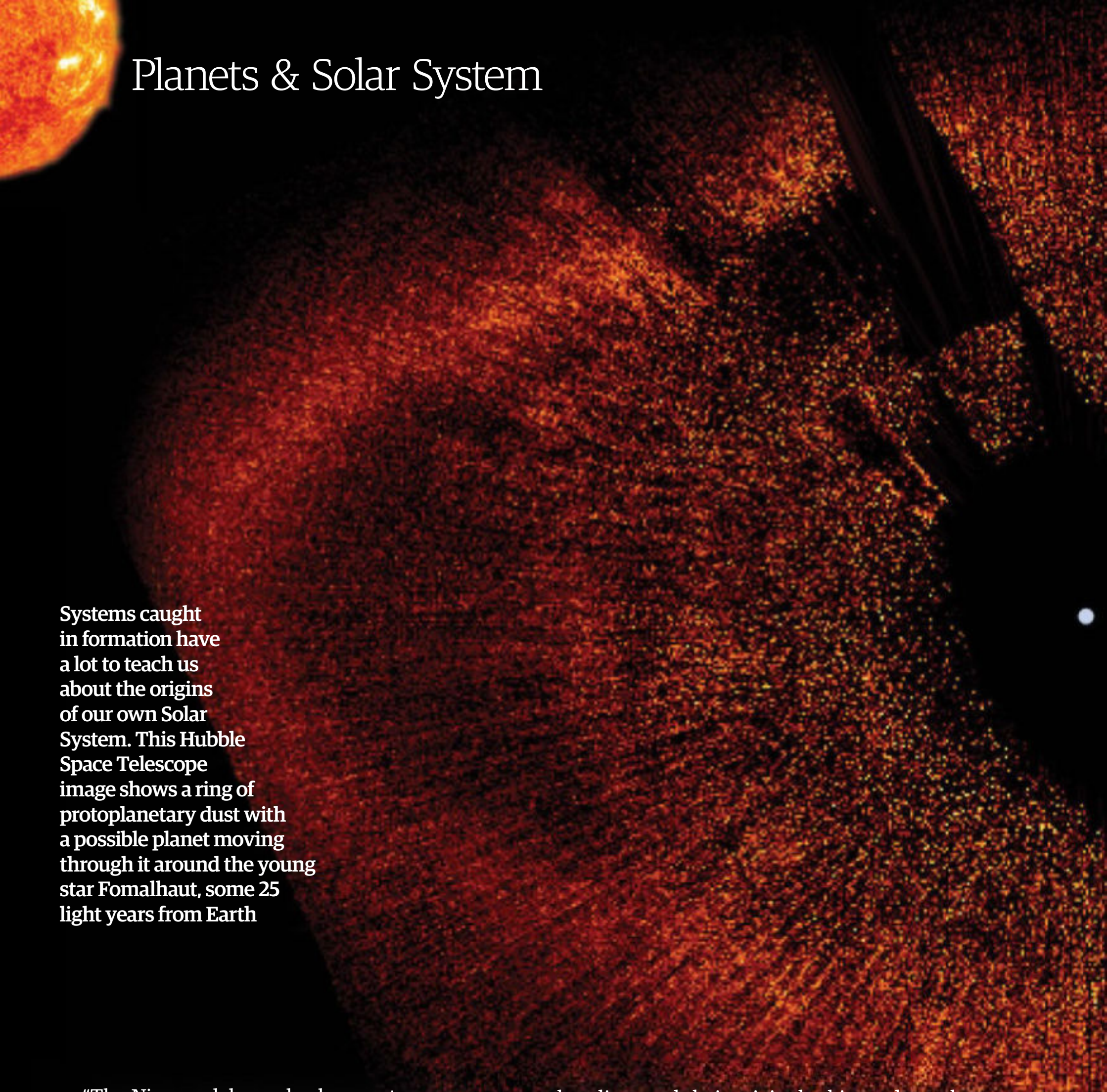
Seeds of planets form as huge drifts of pebble-like particles herded by turbulence in surrounding gas. They cluster to reduce headwinds and grow enough to collapse under their own gravity, forming protoplanets up to 2,000km across

5 Protoplanetary

Millions of years after the collapse, nuclear fusion has ignited in the central star, and most excess gas has disappeared by the Sun's gravity. What remains is closer to the Solar System, and is gradually being driven away by the Sun's radiation

4 Flattening disc

The result is a spinning disc, its orientation derived from the slow rotation of the original globule. Dust and ice concentrates efficiently around the centre, while gas forms a looser halo, and continues to fall to the centre until conditions there become extreme enough to create protostars



Systems caught in formation have a lot to teach us about the origins of our own Solar System. This Hubble Space Telescope image shows a ring of protoplanetary dust with a possible planet moving through it around the young star Fomalhaut, some 25 light years from Earth

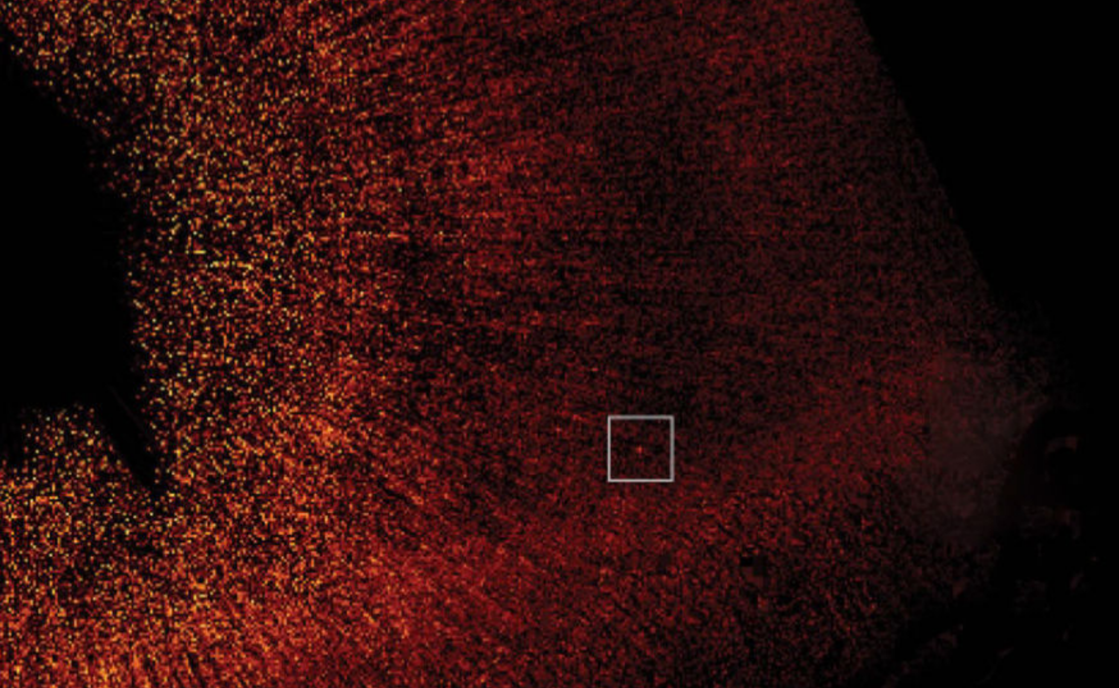
"The Nice model goes back some ten years now," recalls Levison. "It postulated a very compact configuration for the outer planets when they formed, with Jupiter and Saturn, probably Neptune next, and then Uranus all orbiting in the outer Solar System, and beyond that, a disc of material with the mass of about 20 Earths. The biggest objects inside that disc would have been about the size of Pluto."

In the Nice scenario, all four giant planets formed within the present-day orbit of Uranus, with the Kuiper belt extending to about twice that diameter, yet still inside the current orbit of Neptune. But around 4 billion years ago, Uranus and Neptune began a series of close encounters that disrupted their original orbits and put them onto new paths around the Sun, which they remain in today.

"Now, for various reasons, the orbits of Uranus and Neptune became unstable – they started having encounters with each other that threw them into orbits going all over the Solar System, then having encounters with Jupiter and Saturn.

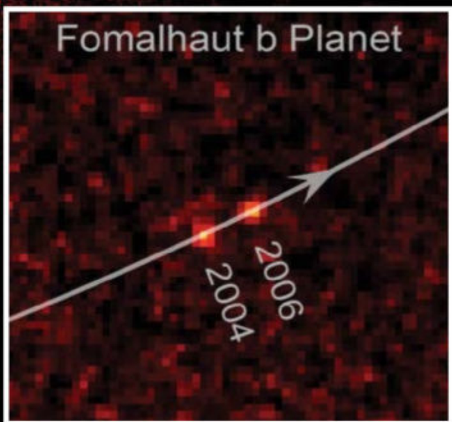
"Before long, they began having encounters with Jupiter and Saturn, and the gravity of these giant planets threw them into the disc of Kuiper belt objects. Gravitational interactions between Uranus, Neptune and these objects circularised the orbits of the giant planets, and ejected most of the smaller objects out into the present-day

"The new pebble accretion model can help to explain how the giant planets formed as quickly as they did"
Dr Hal Levison

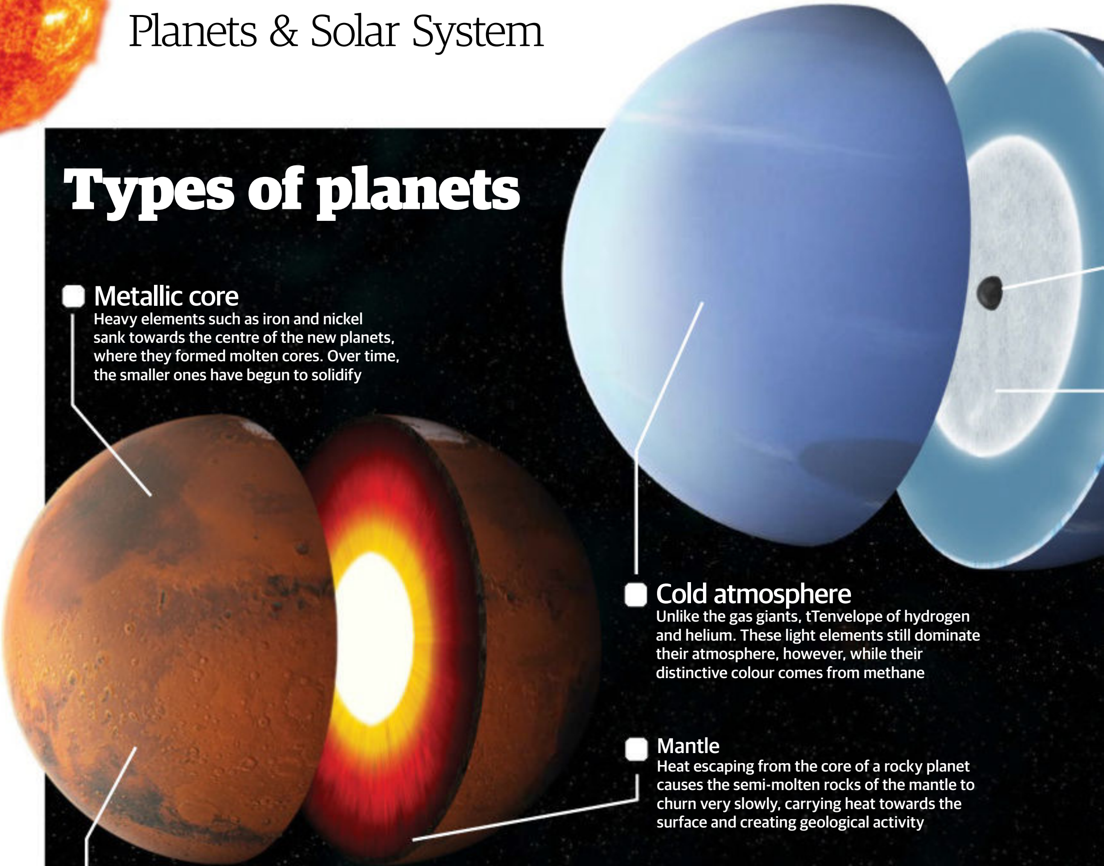


Kuiper belt, or in towards the Sun. It was a very violent, short-lived event lasting just a tens of million of years, and we think we see evidence for it on the Moon, where the impact rate went up around 4 billion years ago in an event called the Late Heavy Bombardment."

Unsurprisingly, the Nice model has been tweaked and updated to match new discoveries and research in the decade since its initial publication: "The exact mechanism that causes the instability has changed, and there's work by David Nesvorny, here at SwRI, arguing that you're more likely to end up producing the Solar System that we see if there were initially three ice giants, and we lost one in the process."



Types of planets



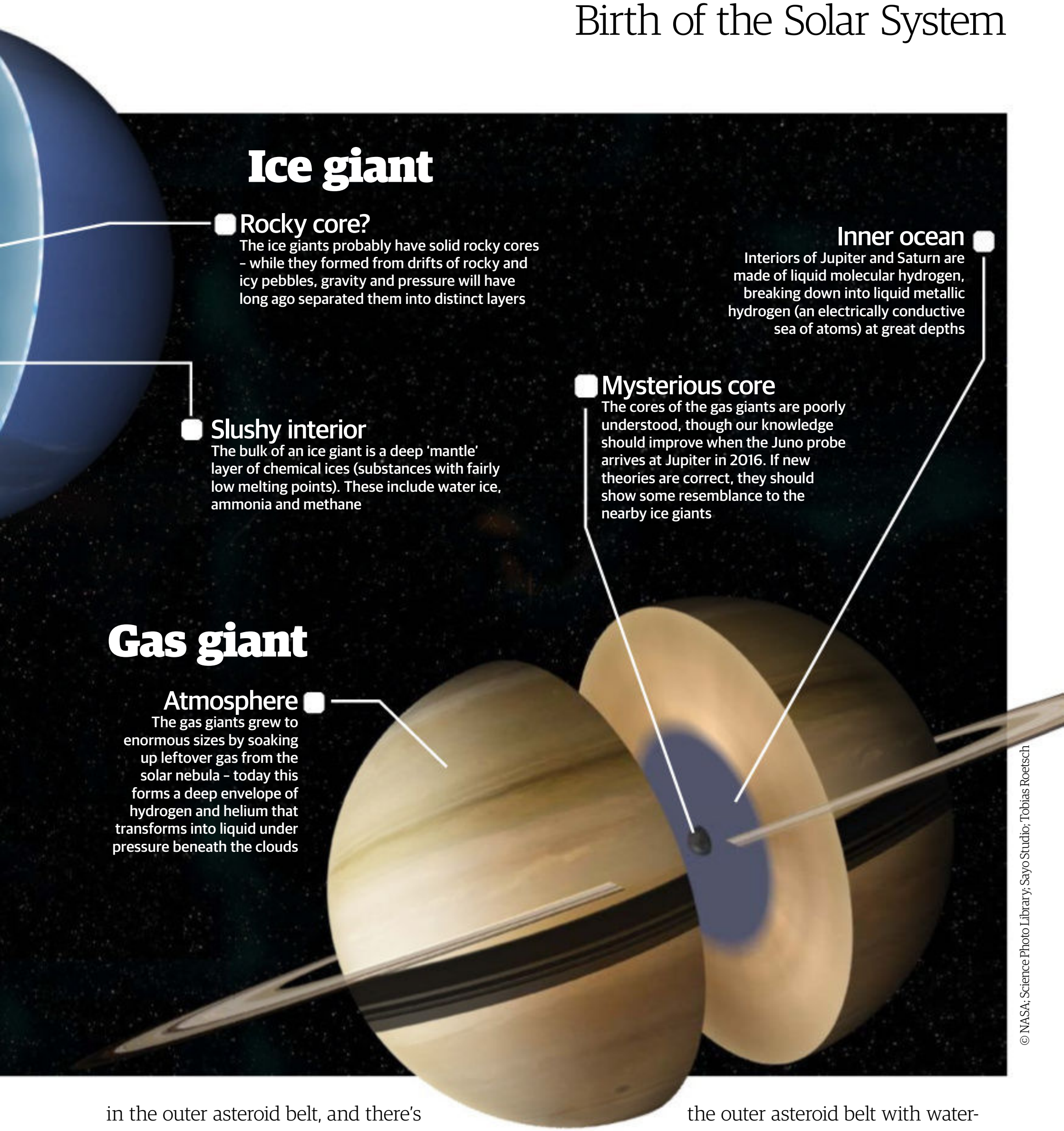
Rocky planet

Rocky crust
The rocky planets of the inner Solar System formed from high-melting point 'refractory' materials that could survive close to the young Sun. This is mirrored in their composition today

> "Jupiter wields too big of a baseball bat for comets to have made much of a contribution to water on Earth"
> **Dr Hal Levison**

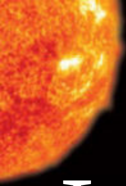
Mention of the Moon's late bombardment raises an interesting question – could some form of planetary migration also help resolve the long-standing question of where Earth's water came from? According to current theories, the environment in which the planets formed was a dry one, so the theory that our present-day water arrived later is very popular among astronomers. Yet measurements from comet probes like ESA's Rosetta shows subtle but important differences from the water on Earth.

"In fact, Jupiter wields too big of a baseball bat for comets to have made much of a contribution to water on Earth," Hal Levison points out to us. "Its gravity simply forms too big a barrier between the outer and inner Solar Systems, so, at the very most, ten per cent of water on Earth could have come from comets. We've known that for some time from dynamics – we don't really need the cosmochemical measurements taken by probes like Rosetta to prove that at all. Instead, Earth's water probably came from objects



in the outer asteroid belt, and there's a separate planetary migration model called the Grand Tack that offers one way to do that, though I think it has some problems."

The Grand Tack is part of the planet formation story itself – it involves the idea of Jupiter moving first towards, and then away from the Sun, due to interaction with gas in the solar nebula. During this process, its gravitational influence robbed Mars of the material it would have required to grow into an Earth-sized planet, but later enriched the outer asteroid belt with water-rich bodies that might later have found their way to our Earth. If that's the case, then Japan's recently launched Hayabusa 2 probe (launched on the 3rd of December 2014, expected to arrive July 2018), which aims to survey a nearby asteroid and return samples to Earth around 2020, could provide more information if it discovers Earth-like water in its target, a small body called 162173 Ryugu (formerly called 1999 JU3).



Inside the Sun

The giant star that keeps us all alive...

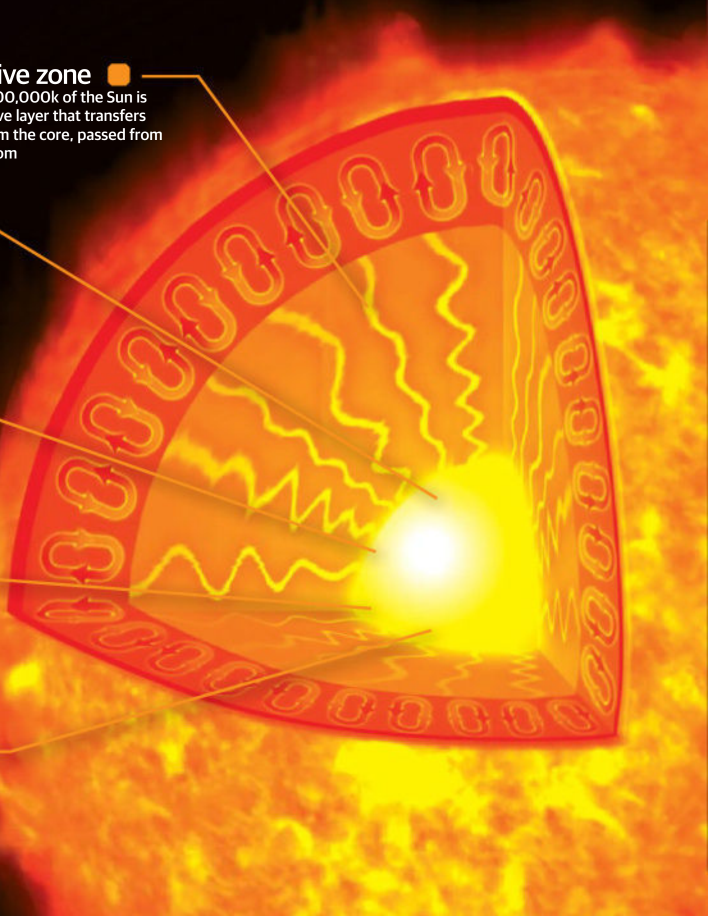
The Sun was formed from a massive gravitational collapse when space dust and gas from a nebula collided, and became an orb 100 times as big and over 300,000 times as heavy as Earth. Made up of 70 per cent hydrogen and about 28 per cent helium (plus other gases), the Sun is the centre of our solar system and the largest celestial body anywhere near us.

"The surface of the Sun is a dense layer of plasma at a temperature of 5,800 degrees kelvin, continually moving due to the action of convective motions driven by heating from below," David Alexander, professor of physics and astronomy at Rice University, says "These convective motions show up as a distribution of granulation cells about 1,000 kilometers across, which appear across the surface."

At its core, its temperature and pressure are so high and the hydrogen atoms move so fast it causes fusion, turning hydrogen atoms into helium. Electromagetic raditation travels out from the Sun's core to its surface, escaping into space as electromagnetic radiation, a blinding light, and incredible levels of solar heat. In fact, the core of the Sun is actually hotter than the surface, but when heat escapes from the surface, the temperature rises to over 1-2 million degrees.

Beneath the surface of the Sun

What is the Sun made of?



Radiative zone
The first 500,000k of the Sun is a radioactive layer that transfers energy from the core, passed from atom to atom

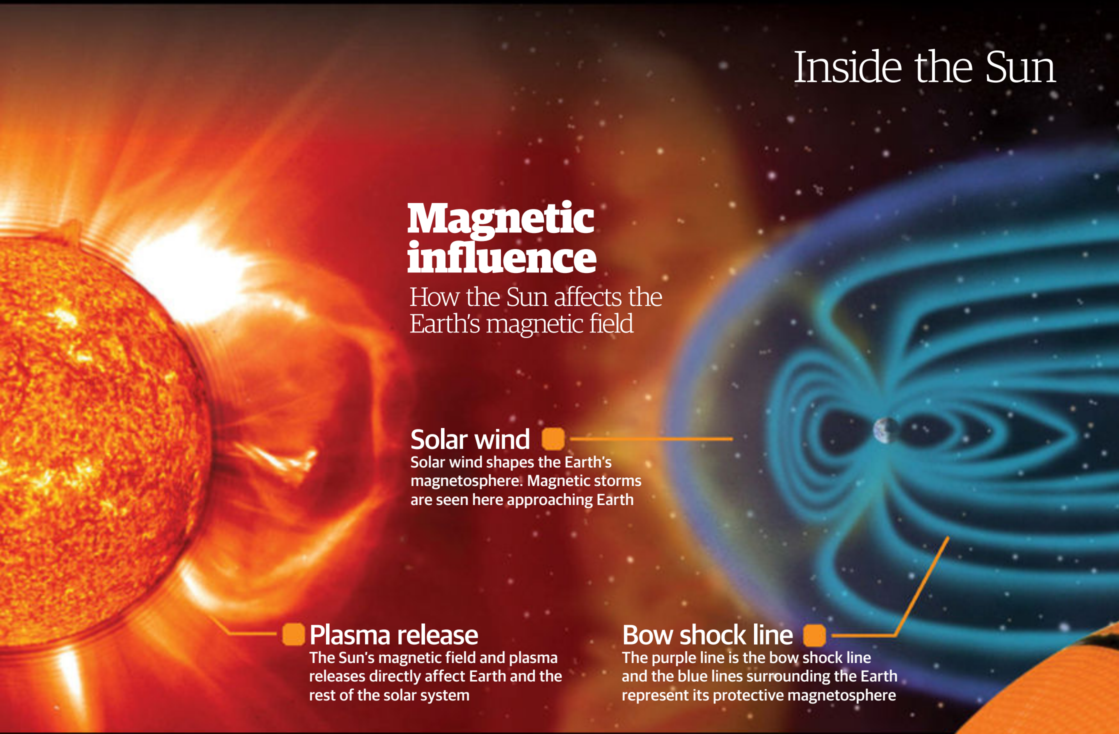
Convective zone
The top 30 per cent of the Sun is a layer of hot plasma that is constantly in motion, heated from below

Sun's core
The core of a Sun is a dense, extremely hot region – about 15 million degrees – that produces a nuclear fusion and emits heat through the layers of the Sun to the surface

Right conditions
The core of the Sun, which acts like a nuclear reactor, is just the right size and temperature to product light

Engine room
The centre of a star is like an engine room that produces the nuclear fusion required for radiation and light

All images courtesy of NASA



Magnetic influence

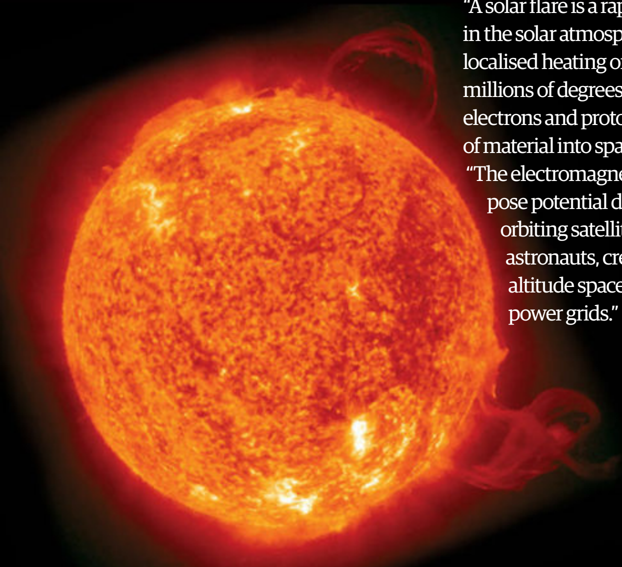
How the Sun affects the Earth's magnetic field

Solar wind
Solar wind shapes the Earth's magnetosphere. Magnetic storms are seen here approaching Earth

Plasma release
The Sun's magnetic field and plasma releases directly affect Earth and the rest of the solar system

Bow shock line
The purple line is the bow shock line and the blue lines surrounding the Earth represent its protective magnetosphere

What is a solar flare?



"A solar flare is a rapid release of energy in the solar atmosphere resulting in localised heating of plasma to tens of millions of degrees, acceleration of electrons and protons, and expulsion of material into space," says Alexander. "The electromagnetic disturbances pose potential dangers for Earth-orbiting satellites, space-walking astronauts, crews on high-altitude spacecraft, as well as power grids."

Solar flares can cause geomagnetic storms on the Sun, including shock waves and plasma expulsions

How big is the Sun?

Our Sun has a diameter of 1.4 million km and Earth a diameter of almost 13,000km

If the Sun were the size of a basketball, Earth would be a little dot no more than 2.2 mm

PLANETS

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The smallest planet in our solar system, this little guy still has a lot to explore

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Named after the goddess of love, the hottest planet in the System demands attention

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How well do you know our home? Discover the mind-blowing truths behind our planet

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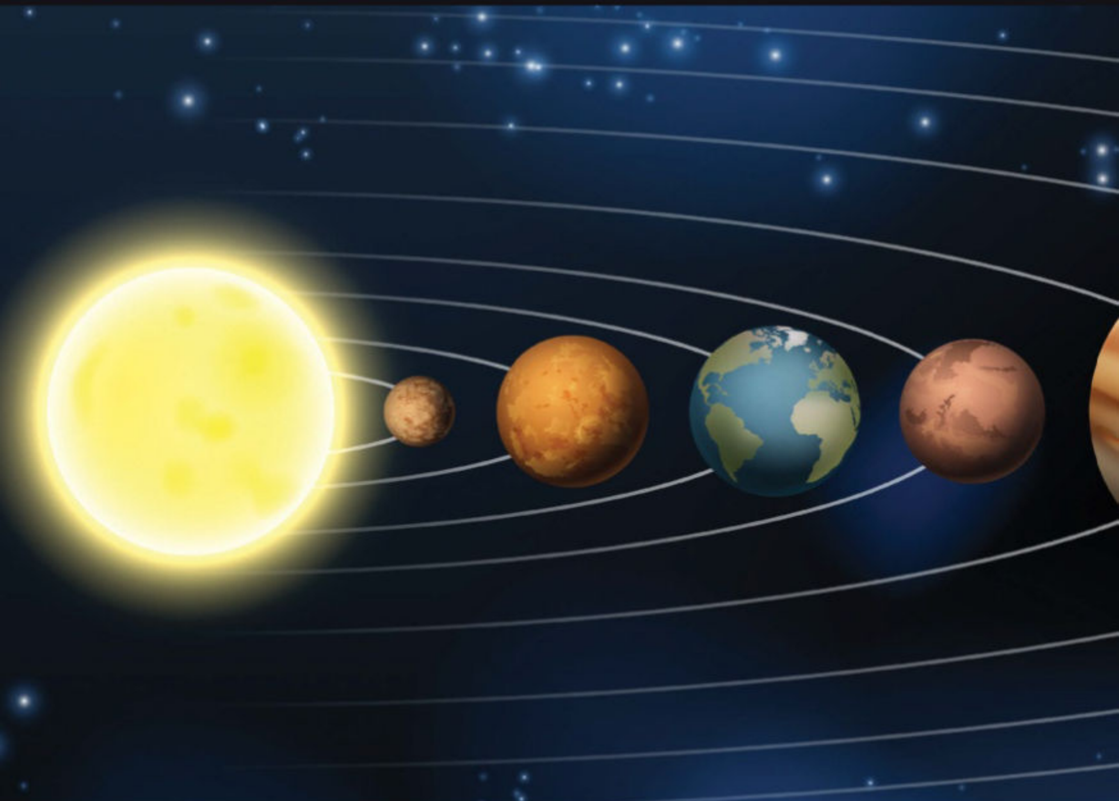
The "Red Planet" is one of the most explored and most researched planets

80 Jupiter
This gas giant is so large even astronomers of ancient times knew of its existence

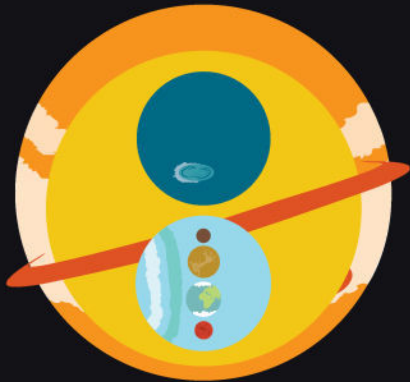
92 Saturn
What would you find in the rings of Saturn, and why do they exist? Find out here

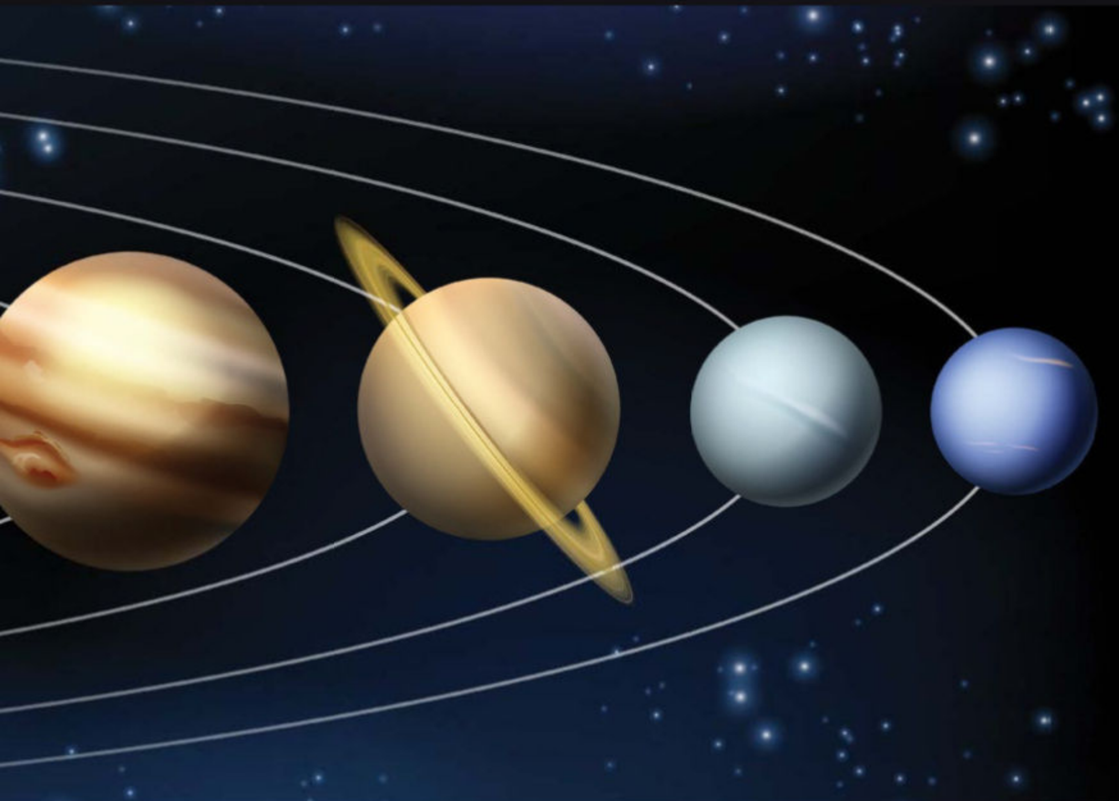


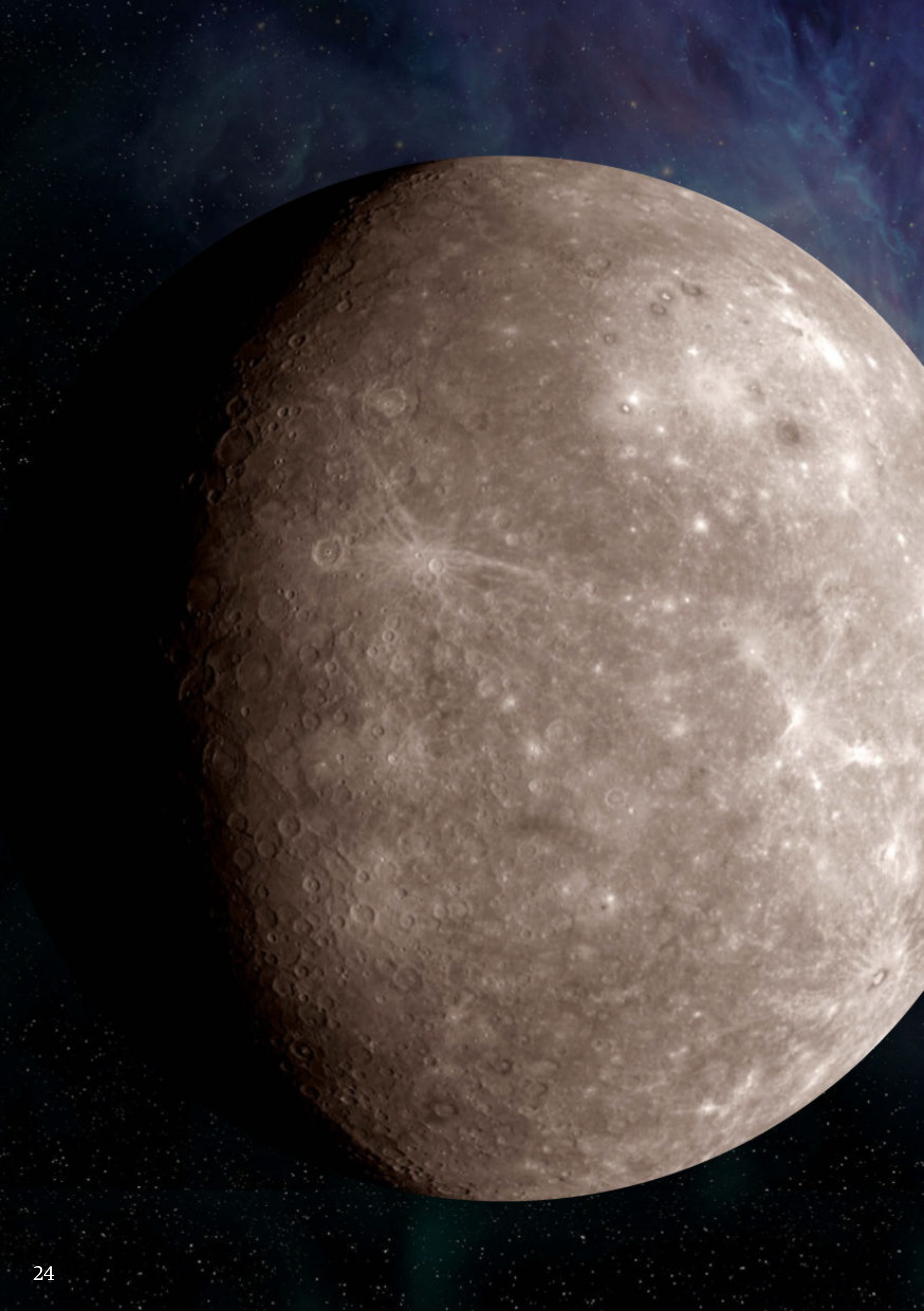
104 Uranus
Stop giggling - this ice cold planet is one of the most complex and interesting

112 Neptune
This planet may be far away, but it's close to our hearts. What makes it so special?

122 Pluto
It may be a dwarf planet, but recent exploration efforts uncovered its riches





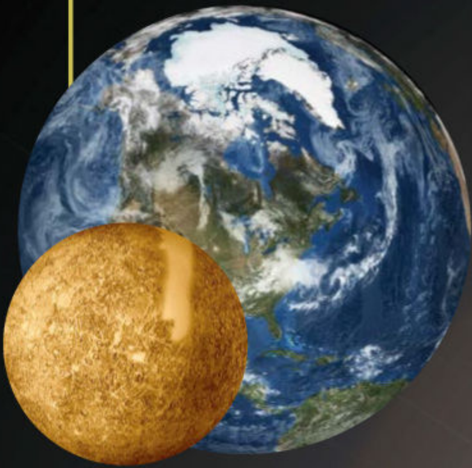


MERCURY

Small, dense, incredibly hot and the closest planet to the Sun. Until recently we've known very little about Mercury, so join us on a journey to discover the secrets of the smallest planet in the Solar System

> "Mercury has a diameter of 4,880km (3,032 mi); the Sun's is 1,392,000km (865,000 mi)"

Mercury size comparison
The Earth is about 2.54 times the size of Mercury



Every planet is unique, but Mercury is a planet of paradoxes and extremes, and that's just based on what we know so far. It's the innermost planet, the smallest planet and has the most eccentric orbit. We've known about its existence since the third millennium BC, when the Sumerians wrote about it. But they thought that it was two separate planets – a morning star and an evening star – because that's just about the only time you can see it due to its closeness to the Sun. The Greeks knew it was just one planet, and even that it orbited the Sun (long before acknowledging that the Earth did, too). Galileo could see Mercury with his telescope, but couldn't observe much.

This little planet has a diameter that's 38 per cent that of Earth's diameter – a little less than

three Mercurys could fit side by side Earth. It has a diameter of about 4,880 kms (3,032 mi). There are two moons in the Solar System that are bigger than Mercury, but the Earth's Moon is only about a 1,000 kms (621 mi) smaller. In surface area, it's about ten per cent that of Earth (75 million square kms or 29 million square mi), or about twice the size of Asia if you could flatten it out. Finally, in volume and mass Mercury is about five per cent that of Earth. Volume-wise that means that 18 Mercurys could fit inside one Earth. While it's small, it's incredibly dense; almost on par with Earth's density due to its heavy iron content.

Mercury is odd in other ways, too. It's tilted on its axis just like Earth (and all the planets in the Solar System), but its axial tilt is only 2.11 degrees away from the plane of the ecliptic. Contrast that with the Earth's tilt at 23.4 degrees. While that causes the Earth's seasons, Mercury has no seasons at all. It's simple – the side that faces the Sun is incredibly hot, and the side away from the Sun is incredibly cold. There's also no atmosphere to retain any heat.

Mercury rotates once every 58.6 days, and revolves around the Sun once every 88 days. For a very long time, we thought Mercury rotated synchronously, meaning that it kept the same side facing the Sun at all times (like the Earth's Moon does), and rotated once for each orbit. Instead, it rotates one and a half times for every trip around the Sun, with a 3:2 spin-orbit resonance (three rotations for every two revolutions). That means its day is twice as

When the sun rises over Mercury, it warms from -150°C (-238°F) to 370°C (698°F)

long as its year. Even stranger than this, when Mercury is at its perihelion (closest to the Sun), its revolution is faster than its rotation. If you were standing on the planet's surface, the Sun would appear to be moving west in the sky, but then stop and start moving very slowly eastward for a few days. Then as Mercury starts moving away from the Sun in its rotation (known as aphelion), its revolution slows down and the Sun starts moving westward in the sky again.

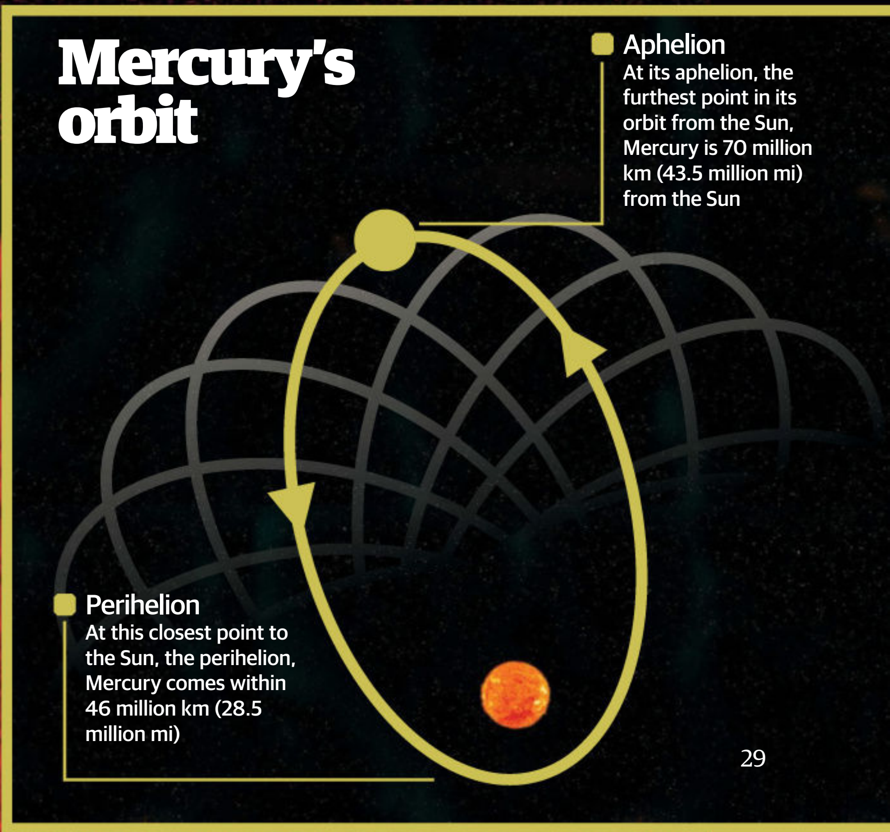
Exactly how this might appear to you would depend greatly on where you were located on the planet and where the Sun was in the sky overhead. In some places it might look like there were multiple stops, reverses and starts in the rising and setting of the Sun, all in one day. Meanwhile, the stars would be moving across the sky three times faster than the Sun.

Mercury has the most eccentric orbit of any planet, meaning it's nowhere near a perfect circle. Its eccentricity is 0.21 degrees, resulting in a very ovoid orbit. This is part of the reason for its extreme temperature fluctuations as well as the Sun's unusual behaviour in its sky. Not

A satellite grabbed this image of Mercury passing in front of the Sun in 2003

only is it eccentric, it's also chaotic. At times in Mercury's orbit, its eccentricity may be zero, or it may be 0.45 degrees. This is probably due to perturbations, or interactions with the gravitational pulls of other planets. These changes happened over millions of years, and currently Mercury's orbit is changing by 1.56 degrees every 100 years. That's much faster than Earth's advance of perihelion, which is 0.00106 degrees every century.

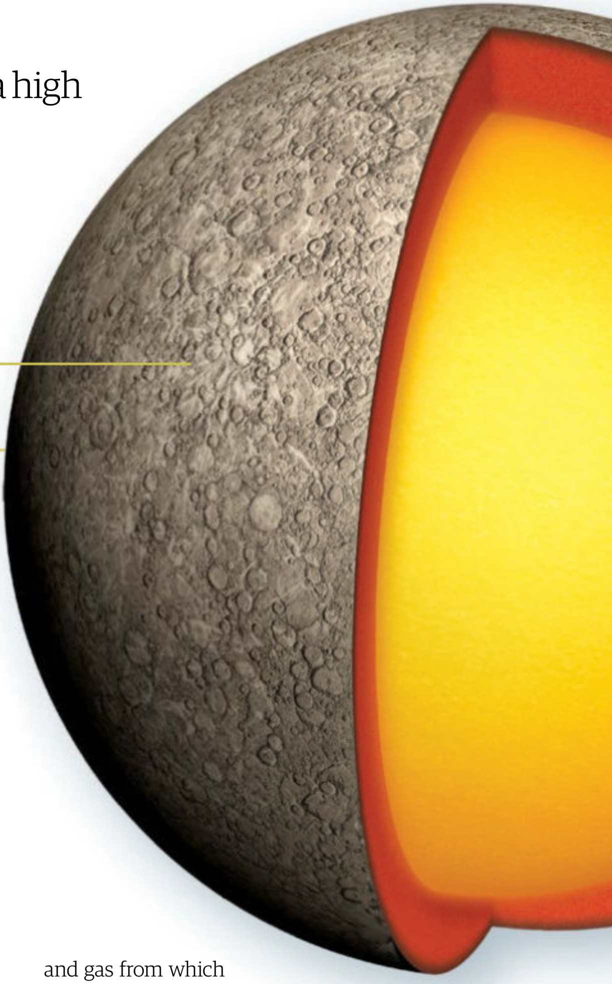
Mercury's chaotic, eccentric orbit is inclined from the Earth's ecliptic plane by seven degrees. Because of this, transits of Mercury - when the planet is between the Earth and the Sun in its rotation - only occur about once every seven years on average. But like so many things about Mercury, its averages don't tell the whole story. For example, there was a transit of Mercury (when it appears to us as a small black dot across the face of the Sun) back in 1999, in 2003, and in 2006...but we haven't had one in a while. Luckily, it is expected this year, 2016, is going to be the year! They usually happen in May (at aphelion) or November (at perihelion), and the latter come more frequently. Transits may also be partial and only seen in certain countries. They're occurring later as the orbit changes. In the early 1500s, they were observed in April and October.



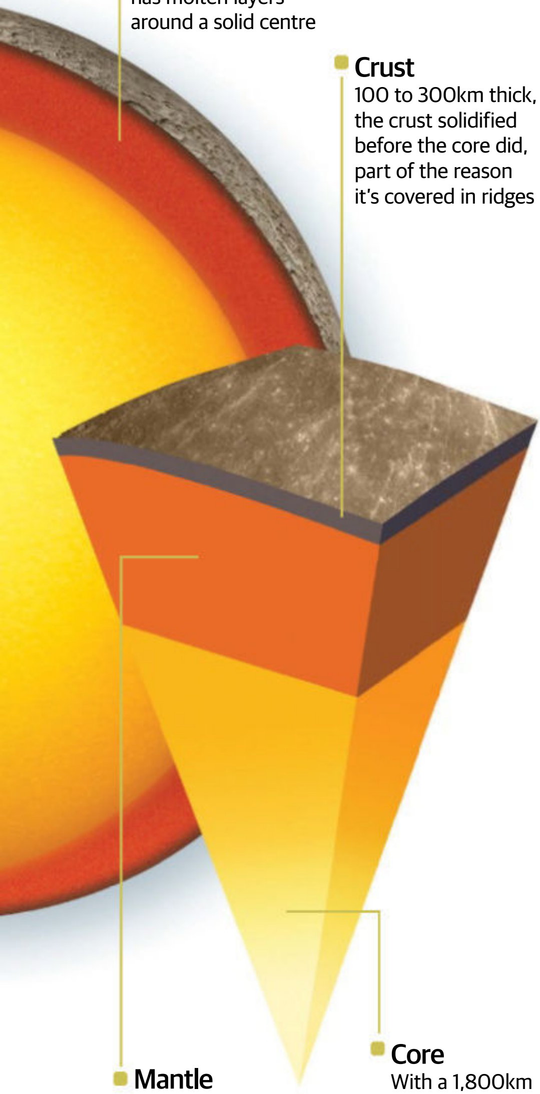
Mercury inside and out

Mercury has a huge core and a high concentration of core iron

The structure of Mercury



Mercury contains about 30 per cent silicate materials and 70 per cent metals. Although it's so small, this make-up also means that it's incredibly dense at 5.427 grams per cubic centimetre, only a little bit less than the Earth's mean density. The Earth's density is due to gravitational compression, but Mercury has such a weak gravitational field in comparison to the Earth's. That's why scientists have decided that its density must be due to a large, iron-rich core. Mercury has a higher concentration of iron in its core than any other major planet in the Solar System. Some believe that this huge core is due to what was going on with the Sun while Mercury was forming. If Mercury formed before the energy output from the Sun stabilised, it may have had twice the mass that it does now. Then when the Sun contracted and stabilised, massive temperature fluctuations vaporised some of the planet's crust and mantle rock. Or a thinner mantle and crust may have always existed due to drag on the solar nebula (the Sun's cloud of dust and gas from which the planets formed) from the close proximity to the Sun itself. Our latest information from the Messenger spacecraft supports the latter theory, because it has found high levels of materials like potassium on the surface, which would have been vaporised at the extremely high temperatures needed for the former theory.



Mercury in numbers

Fantastic figures and surprising statistics about Mercury

176 DAYS

Mercury revolves in 59 Earth days but it takes 176 days for the Sun to return to the same point in the sky

2nd

Densest planet in the Solar System after Earth

427°

Mercury's maximum surface temperature

2.5x bigger

The Sun appears two and a half times larger in Mercury's sky than it does in Earth's

45%

Until the Messenger spacecraft began imaging Mercury in 2008, we'd only ever seen this much of the planet

0 moons

Mercury is one of the few planets which has no moons or satellites captive within its gravity well

7x stronger

The Sun's rays are seven times stronger on Mercury than they are on Earth

Mercury mapped by Mariner

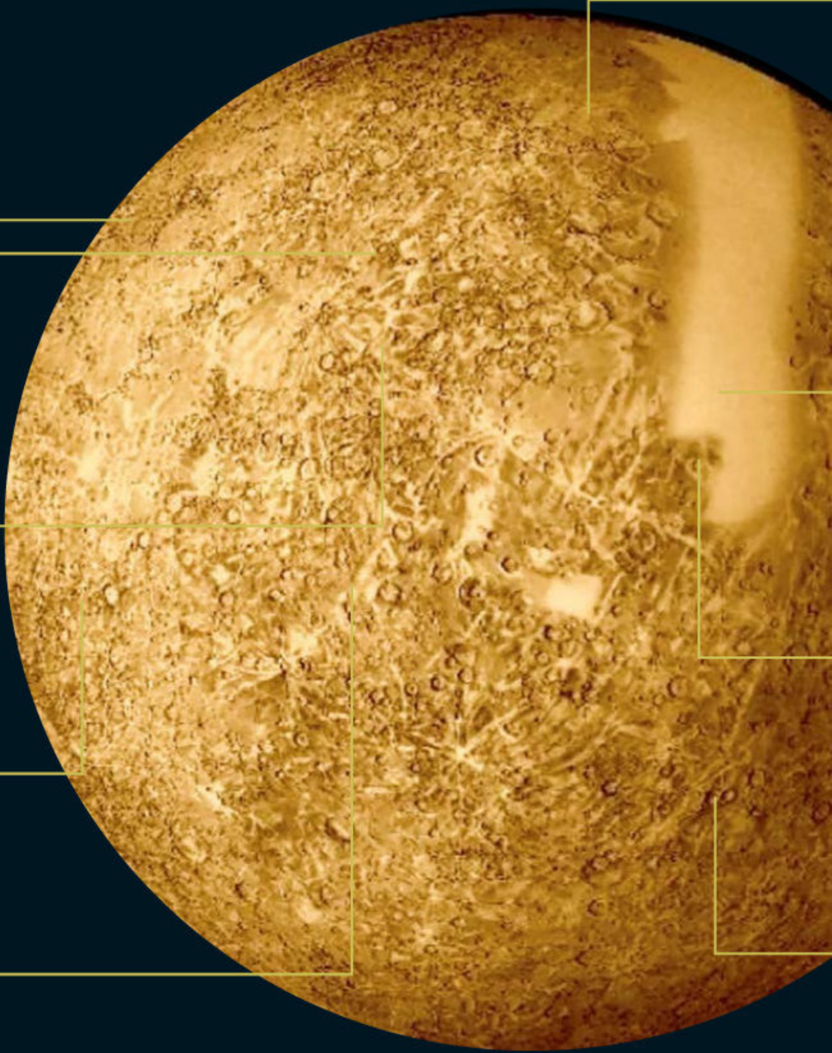
Caloris Basin
Caloris the largest impact crater on the planet, at 1,550 km (960 mi), it's one of the largest ones in the Solar System

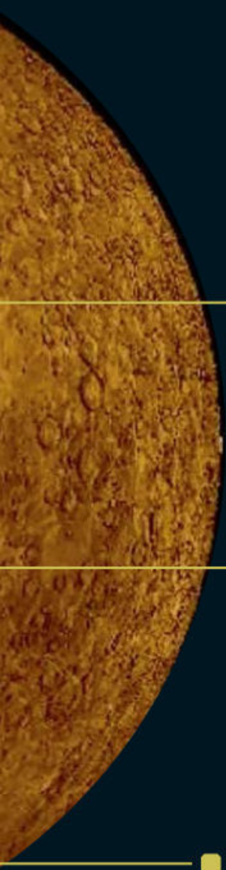
Sobkou Planitia
These plains contain several craters. Sobkou is the Egyptian messenger god

Budh Planitia
This was an alternative name for Mercury. Budh is its official Hindu name

Tolstoj Basin
The impact that caused this crater occurred early in Mercury's history

Bello
Bello, named after a South American writer, is about 129km in diameter





Borealis Planitia
This basin has a smooth floor and may be similar to the basaltic basins on Earth's Moon

Blank area
Mariner 10 was only able to map about 45% of Mercury's surface (the night-time side) and missed a few areas

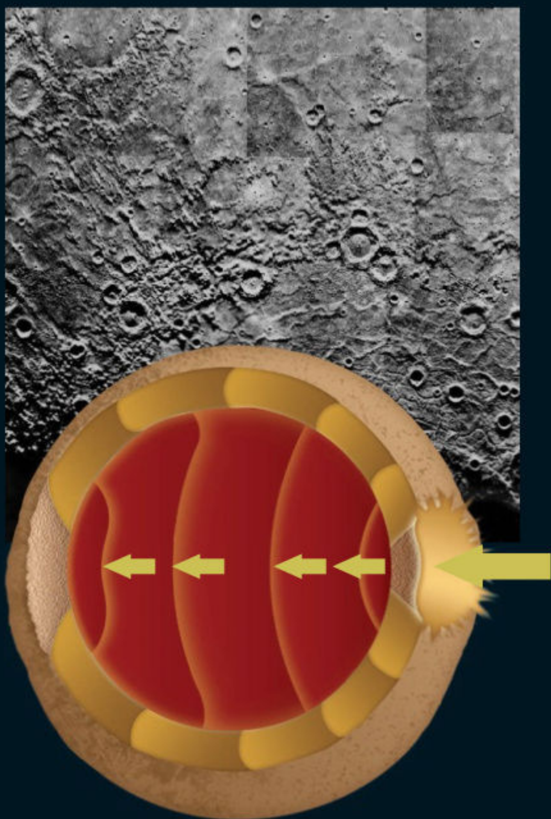
Vivaldi
A prominent crater at about 210km wide. Features a double ring

Fram Rupes
This cliff was formed when the core cooled and contracted. It's named after the first ship reaching Antarctica

The Caloris Basin

This diagram shows how the large impact craters on Mercury's surface - and particularly the Caloris Basin - have impacted the rest of the planet. At the antipode (a point on the other side of the planet exactly opposite of the basin), the ground is very uneven, grooved and hilly. It's called the Chaotic Terrain because it stands out so much among the otherwise smooth plains. The terrain may have formed due to seismic waves or material actually ejected from the antipode.

The image of Mercury's surface was taken at a distance of about 18,000km (11,100 mi)

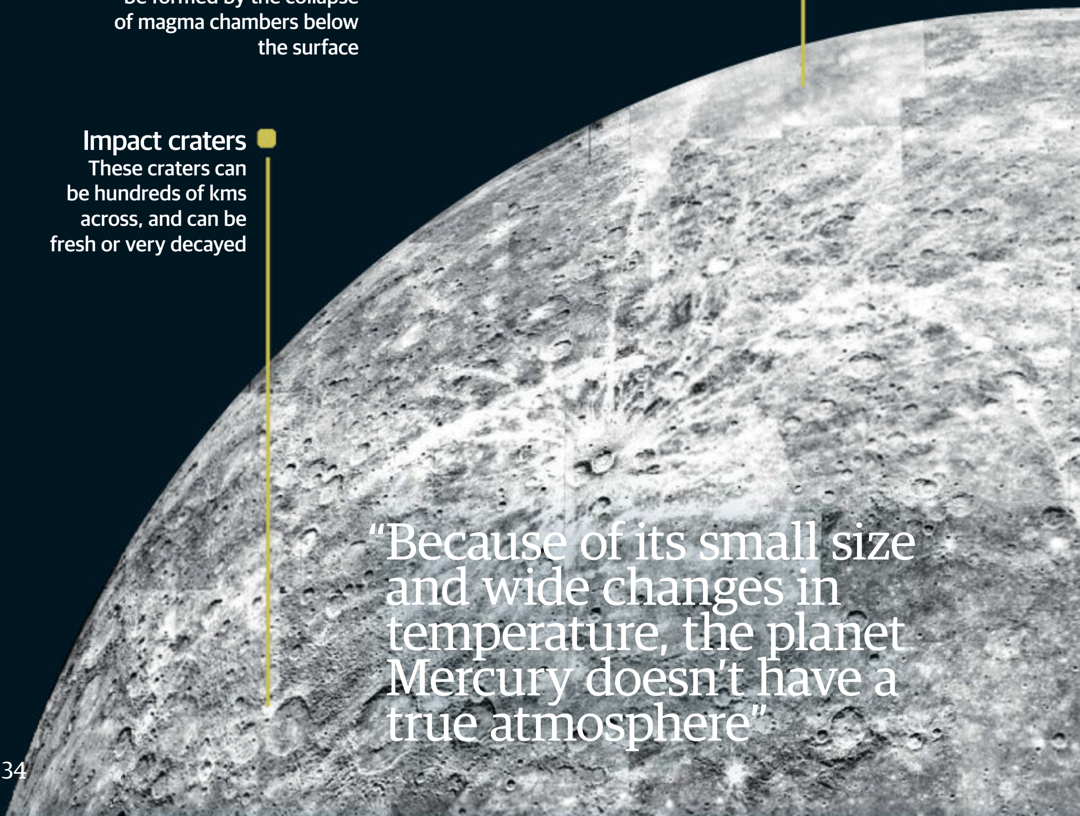


On the surface

Mercury is a planet of extreme variations in temperature, in its surface features and in its magnetic field

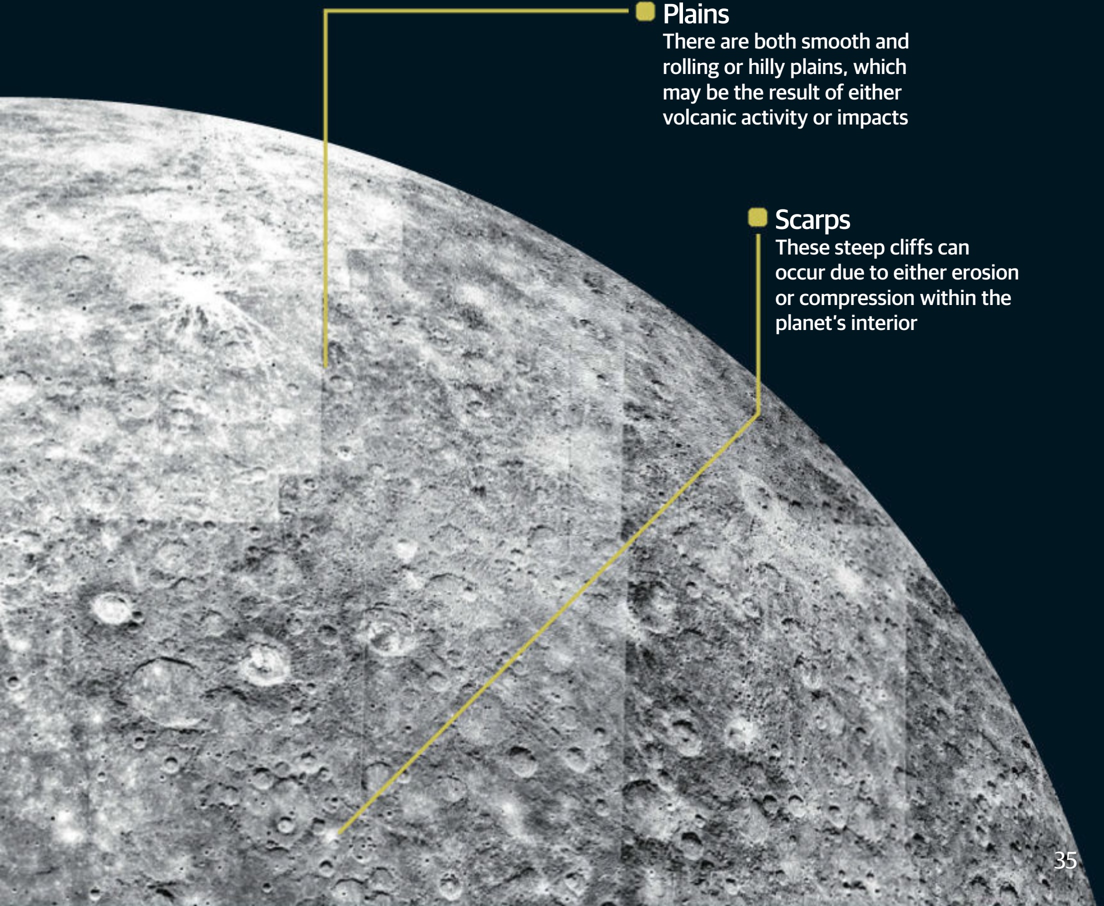
The surface of Mercury is not very well understood, but mapping by Mariner 10 and Messenger has revealed numerous craters and plains regions, crisscrossed with compression folds and escarpments. Not long after it formed, the planet was hit heavily and often in at least two waves by large asteroids and comets, which caused its extremely cratered surface. Couple this with periods of strong volcanic activity, which resulted in the smooth plains, and you have a very hilly surface.

Mercury can reach 427 °C (800 °F), and there's a big difference between the temperature at the equator and the temperature at its poles. It has the most temperature variations of any planet in the Solar System, getting as low as -183 °C (-297 °F). There may be deposits of minerals and ice within craters near the poles. The deepest



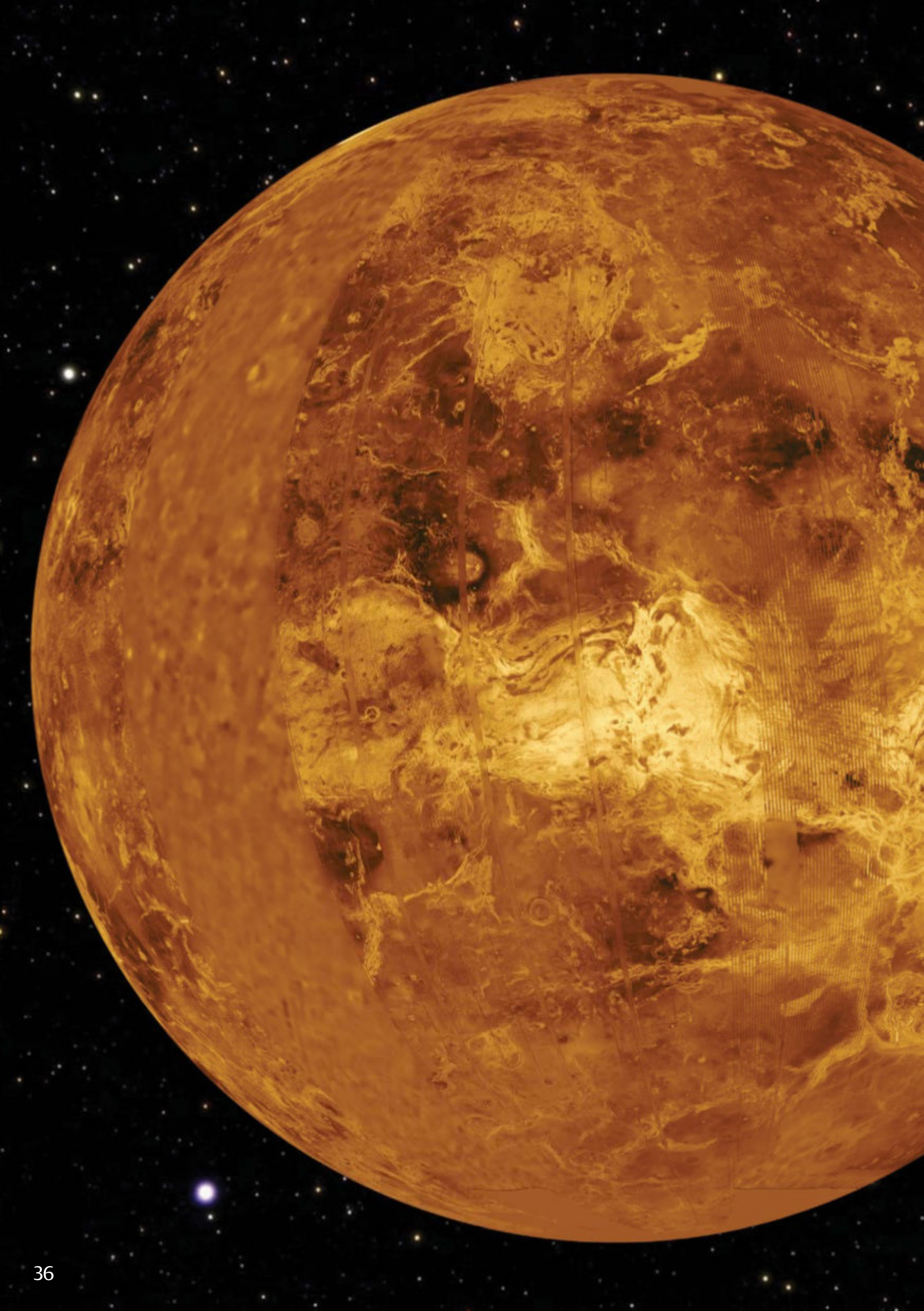
"Because of its small size and wide changes in temperature, the planet Mercury doesn't have a true atmosphere" craters are located there, and are the most likely candidates to hold ice because they always stay shadowed, never rising above -17°C.

Because of its small size and wide changes in temperature, Mercury doesn't have a true atmosphere. It has an unstable exosphere, a very loose, light layer of gases and other materials. Gases within it include helium, oxygen and hydrogen, some of which come from solar wind. Minerals such as calcium and potassium enter the exosphere when tiny meteors strike the surface and break up bits of rock. Mercury also has a magnetosphere, formed when the solar wind interacts with its magnetic field. Although that magnetic field is only about one per cent as strong as Earth's, it traps in some plasma from the solar wind, which adds to its surface weathering. The Messenger spacecraft discovered that Mercury's magnetosphere is somewhat unstable, causing bundles of magnetic fields to be pulled out into space and wrapped into tornado-like structures by the passing solar wind. Some of these tornadoes are as long as 800km (497mi), about a third of the planet's size. Before Mariner 10 flew by Mercury, it was thought not to have a magnetic field at all. The current theory is that it is caused by a dynamo, much like Earth's magnetic field, which means that the planet has an outer core of electrically conducive, rotating molten iron. Not all scientists agree that Mercury is capable of generating a dynamo, however.



Plains
There are both smooth and rolling or hilly plains, which may be the result of either volcanic activity or impacts

Scarps
These steep cliffs can occur due to either erosion or compression within the planet's interior

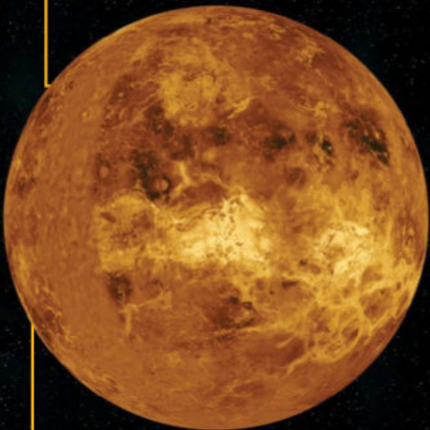


VENUS

Venus is the most Earth-like planet in the Solar System, but there are a few key differences between the two planets, such as clouds of acid and temperatures hot enough to melt lead. Read on to discover more about Earth's 'evil twin'

Earth's twin planet

Mass
Venus has a mass that is about 81.5 per cent of Earth's, at approximately 4.868 x 10^{24} kilograms



Diameter
Earth's diameter is just 650 km greater than that of Venus – Earth's is 12,742 km (7,918 mi). Venus's is 12,092 km (7,514 mi)

Surface
Both planets have relatively young surfaces, without many craters

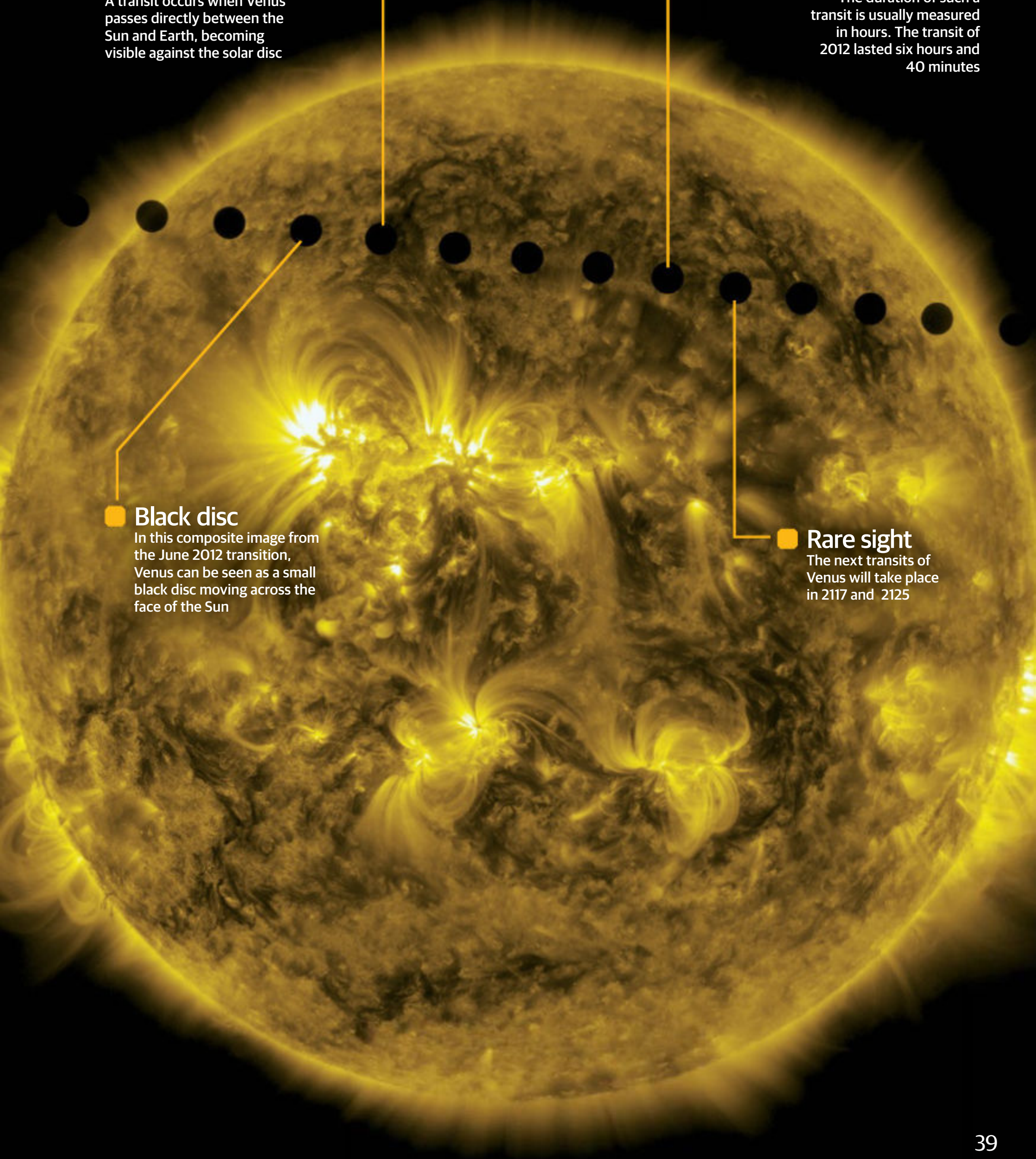
Venus, named after the Roman goddess of love and beauty, is a study in contradictions. It was likely first observed by the Mayans around 650 AD, helping them to create a very accurate calendar. It's well-known to us because of its apparent magnitude, or brightness, in our sky – the second-brightest after our own Moon. It's most visible at sunrise and sunset, and like Mercury was thought of as two different planets by the Ancient Egyptians – Morning Star and Evening Star. It's the second-closest planet to the Sun, the closest to Earth, and the sixth-biggest planet in the Solar System.

Venus is often described as the Earth's 'twin' or 'sister planet'. Like Earth, Venus is a rocky planet, with a mass that's 81.5 per cent of the Earth's mass. It's 12,092 km (7,514 mi) in diameter, which is just 650 km (404 mi) shy of Earth's diameter. Both planets have relatively young surfaces, with few craters. But that's where the similarities end. Venus has been called possibly one of the most inhospitable planets in the Solar System, because lurking beneath its dense cloud cover is an atmosphere that's anything but Earth-like, which is why some astronomers have taken to calling it Earth's 'evil twin' instead.

Of all the planets, Venus has the most circular orbit, with an eccentricity (deviation from a perfect circle) of 0.68 per cent. By comparison, the Earth has an eccentricity of 1.67 per cent. Venus comes within 108 million km (67 million mi) of the Sun on average. When it happens to lie between the Sun and the Earth – which occurs every 584 days – it comes closer to the Earth than any other planet. Around 38 million km (24 million mi) close, that is. Because Venus's orbit around the Sun passes inside the Earth's orbit, it also goes through phases that go from new to full and back to new again. These phases are the different variations of light emanating from it as seen from the Earth, much like the Moon's phases. When Venus is new (not visible) it is directly between the Earth and the Sun. At full, it is on the opposite side of the Earth from the Sun. These phases were first recorded by Galileo in 1610.

The rarest of predictable events in our Solar System involve Venus. Known as transits of

The transit of Venus



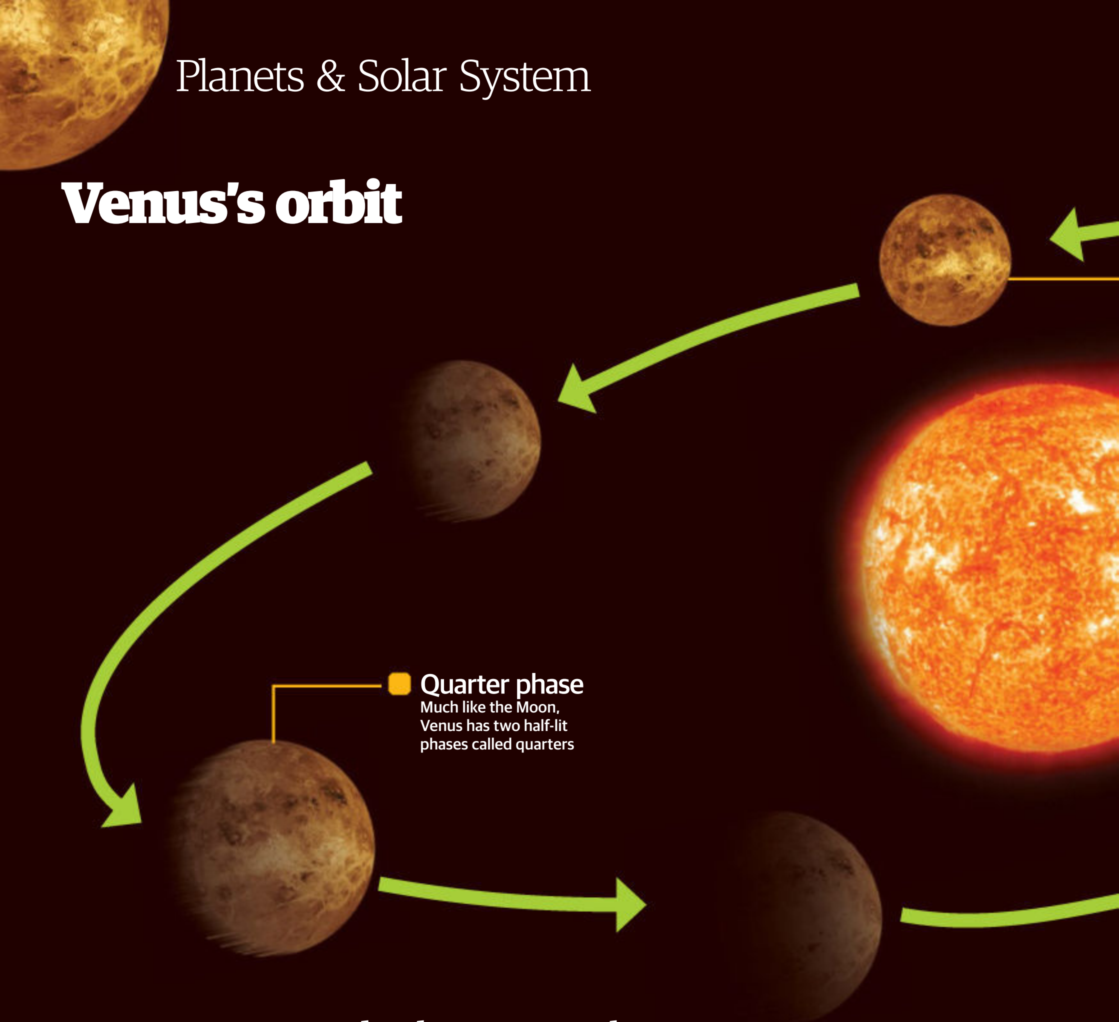
In-between
A transit occurs when Venus passes directly between the Sun and Earth, becoming visible against the solar disc

Time taken
The duration of such a transit is usually measured in hours. The transit of 2012 lasted six hours and 40 minutes

Black disc
In this composite image from the June 2012 transition, Venus can be seen as a small black disc moving across the face of the Sun

Rare sight
The next transits of Venus will take place in 2117 and 2125

Venus's orbit

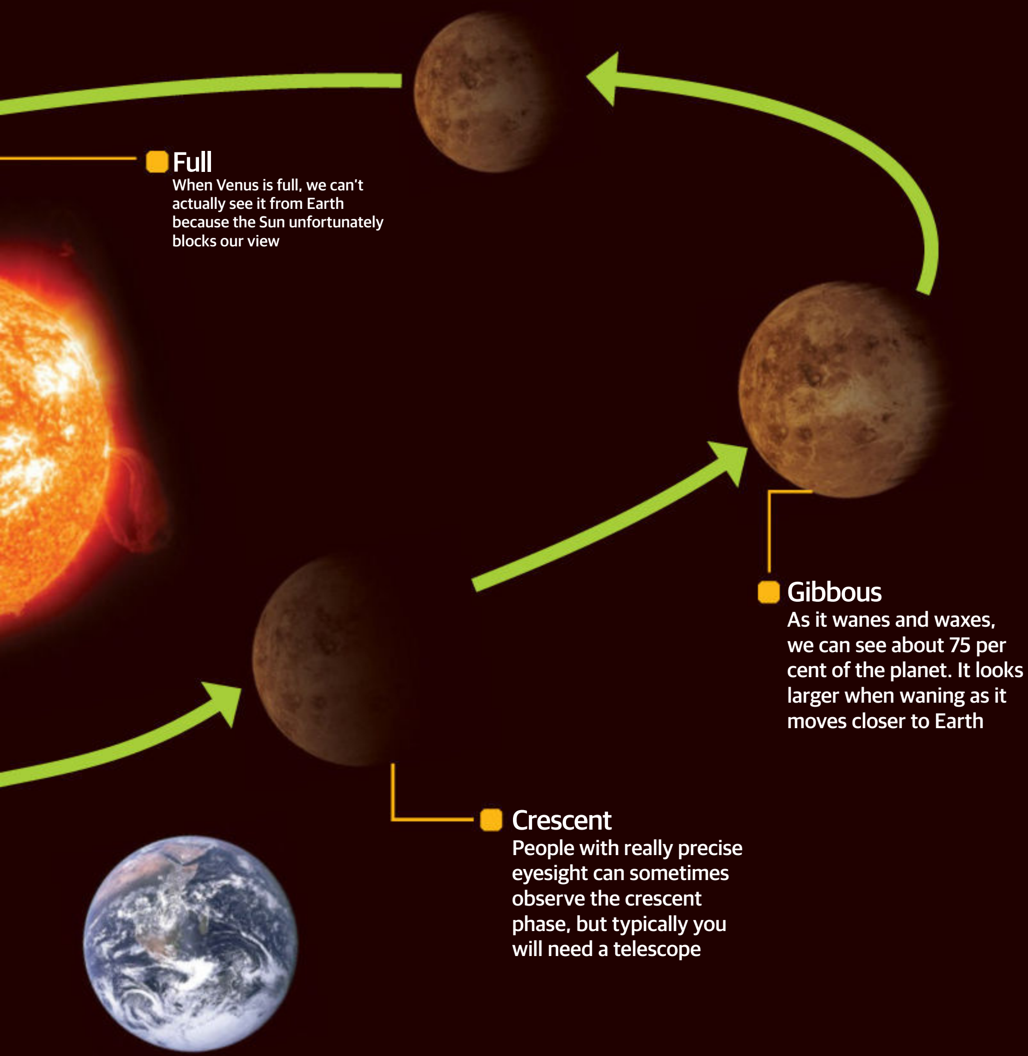


"Venus rotates clockwise, making a Venusian sidereal day last the equivalent of 243 days on Earth"

Venus, this only happens once every 243 years in a pattern. A transit is somewhat like a solar eclipse, occurring when the planet is between the Earth and the Sun. Transits of Venus happen eight years apart, then with gaps of 105.5 years and 121.5 years between them.

The odd pattern has to do with the relationship between the orbital periods of the two planets. Usually they happen in pairs, but not always. During a transit, Venus looks like a tiny black disc passing across the Sun's surface. The first modern observation of a transit of Venus occurred in 1639, while the most recent was on 5 and 6 June 2012. The transits have always provided astronomers with lots of information about not only Venus, but our Solar System. The earliest helped gauge the size of the Solar System itself, while the one in 2012 is hoped to help us find planets outside our Solar System, or exoplanets.

What else sets Venus apart from the other planets in the Solar System? Its retrograde rotation. Every planet orbits the Sun anti-



lockwise, and most of them rotate anti-clockwise, too. But Venus rotates clockwise, making a Venusian sidereal day last about 243 Earth days - incidentally one of the slowest rotations of any planet that we know of. But its orbit around the Sun lasts 224.7 days, making Venus's days longer than its years. All of this means that if you were standing on the surface of the planet, you'd see the Sun rise in the west and set in the east, but only every 116.75 Earth days or so.

Many astronomers have wondered why Venus has such a circular orbit and unusual rotation. All planets came from the solar nebula - matter left over from the formation of the Sun - but maybe Venus had a more violent beginning. One theory is that it formed from the collision of two smaller planets, which impacted at such high speeds that they simply fused together, leaving little debris. Another is that the planet experienced other multiple impact events - and even had one or more moons - that caused its spin to reverse.

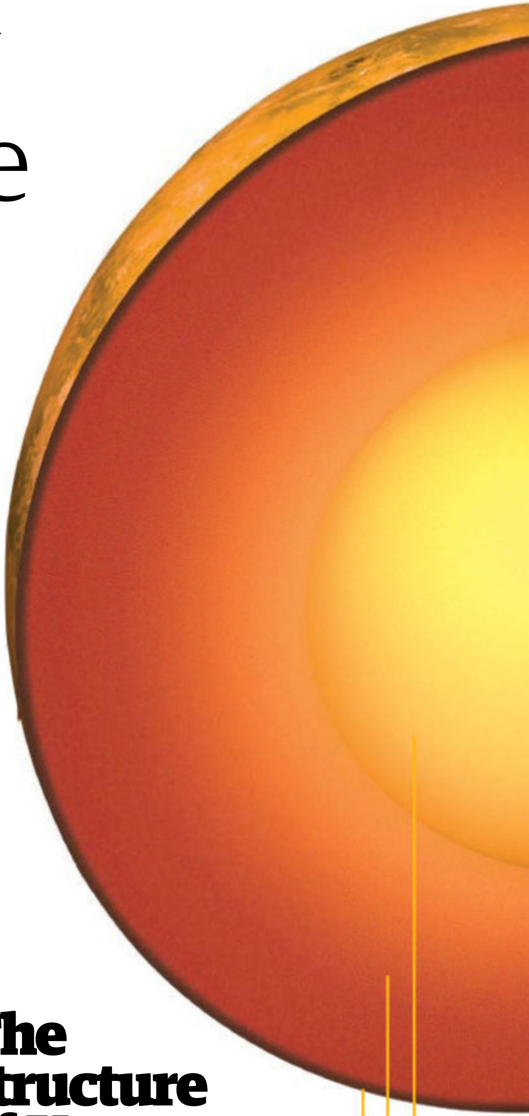
Venus inside and out

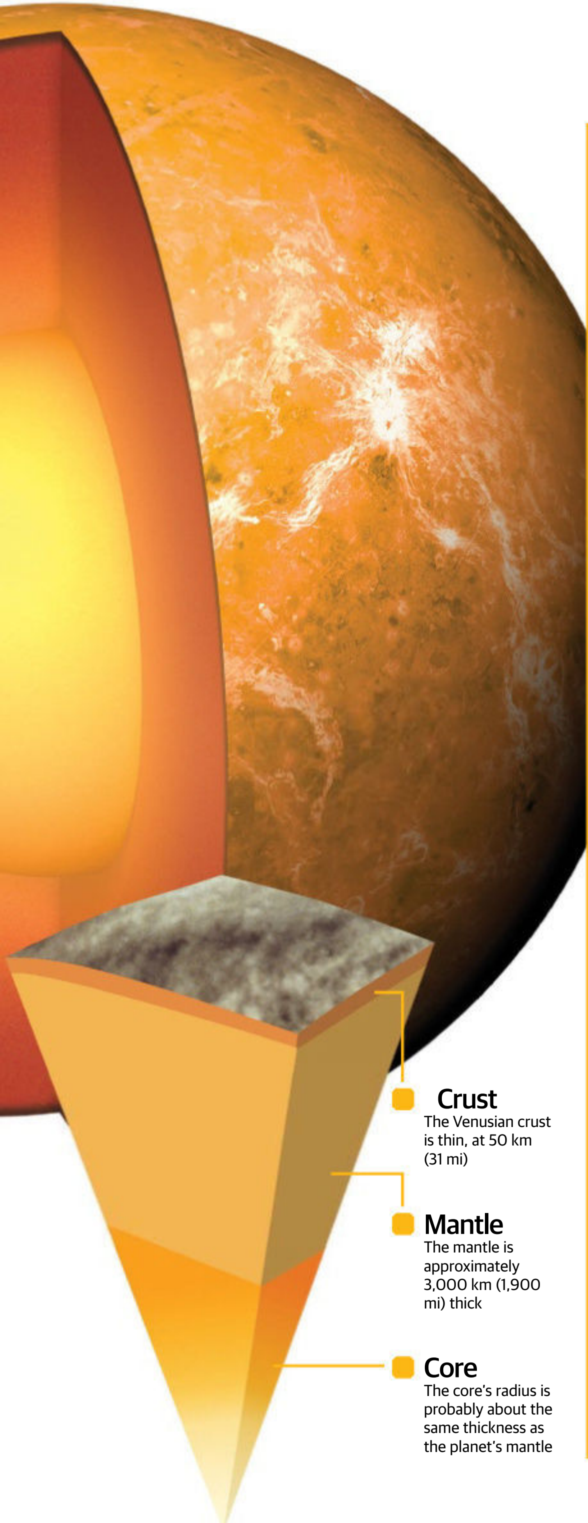
We don't know much of Venus's interior, and what we know of its atmosphere isn't pretty

While our knowledge of Venus's internal make-up is mostly based on speculation, we do know that it does not include a dynamo, like Earth's. A dynamo is a convecting, rotating fluid that conducts electricity and is responsible for a planet's magnetic field. Venus may have a liquid outer core and that conducts electricity, but does not convect and rotates too slowly to produce a dynamo. The Earth has a dynamo in part because its liquid core is hotter on the bottom than on the top, creating convection. Venus's core may be all one temperature. But why? Some believe Venus was subject to an unknown event on its surface, which caused an end to plate tectonics on the surface and led to a cooling of the core. Venus's core could be completely solid or liquid. What we do know is its magnetic field, which is very weak, is caused by interactions between the ionosphere (ionised upper atmosphere) and solar wind.

Venus has the densest atmosphere in the Solar System, with a mass about 90 times that of Earth's atmosphere. There's a heavy, sulphuric layer of clouds that scatter about 90 per cent of the sunlight, which prevents viewing of the planet's surface and keeps it dim. Below the cloud layer is a layer of carbon dioxide, mixed with a bit of nitrogen. Pressure on the surface is 92 times that of Earth's surface. Although Venus is far away from the Sun, its atmosphere creates a greenhouse effect that results in an incredibly hot temperature of 460°C (860°F). The temperature stays the same most of the time, with winds of up to 300 km/h (186 mph). Some scientists believe Venus once had an atmosphere like Earth's, and even had oceans, but the greenhouse effect eventually evaporated all of the water.

The structure of Venus



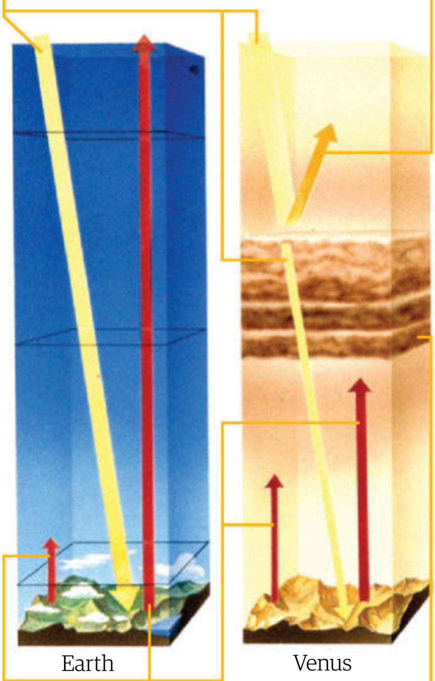


The greenhouse effect on Venus

How Venus's extreme and inhospitable temperatures are created

Incoming sunlight
Most of the sunlight passing through Earth's atmosphere makes it through. However, only a very little amount of sunlight gets through Venus's thick atmosphere

Reflected sunlight
Most of the sunlight that reaches Venus is reflected away from the planet before reaching the surface



Infrared radiation
Both Venus and Earth emit infrared radiation but most of Venus's does not make it off the planet

Reflective clouds
The heavy cloud cover on Venus means that the planet stays incredibly hot, as most of its heat cannot escape from the planet's atmosphere

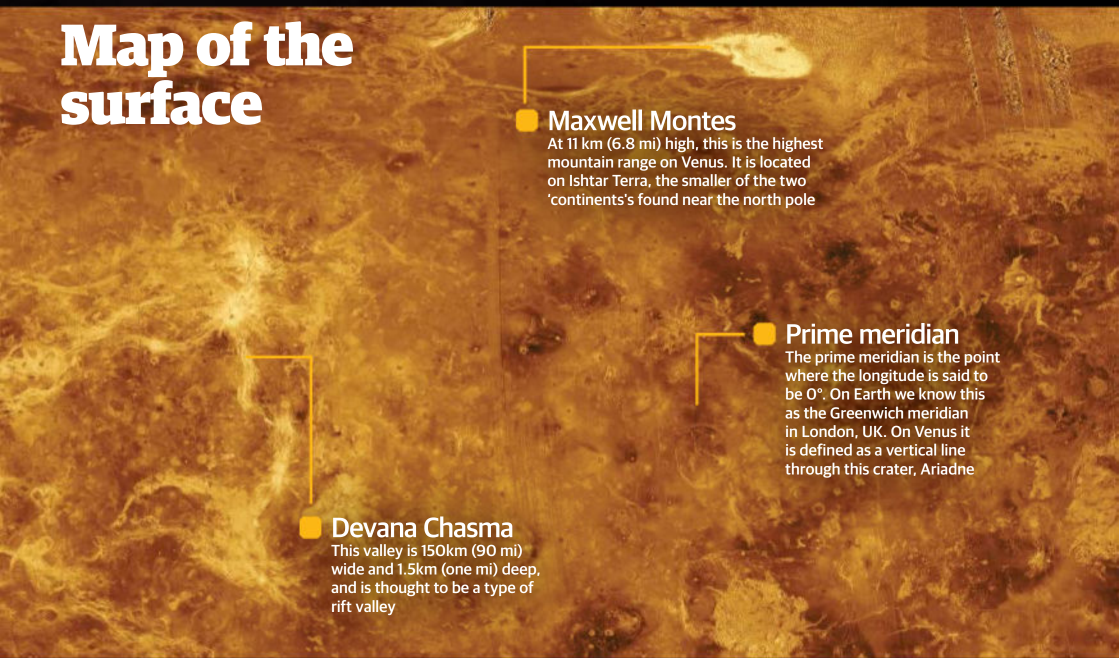
On the surface

Venus is smooth, with a young surface – but it is also covered in volcanoes and lava flows that may have lasted for millions of years

Everything we've learned about Venus's surface is from radar, because the atmospheric pressure is too great for a probe to survive longer than an hour. But Magellan has mapped most of the surface, and showed Venus has a lot of interesting surface features. It has a relatively flat surface, with about 13 km (eight mi) between the lowest point and the highest. It is divided into three categories: highlands, deposition plains and lowlands, plus some mountain ranges, with the highest one, Maxwell Montes at 11 km (6.8 mi). The highlands comprise about ten per cent of the surface, and there are two main 'continents's – Ishtar Terra and Aphrodite Terra. The deposition plains (formed from lava flows) cover over half the surface; the rest of the planet is lowlands.

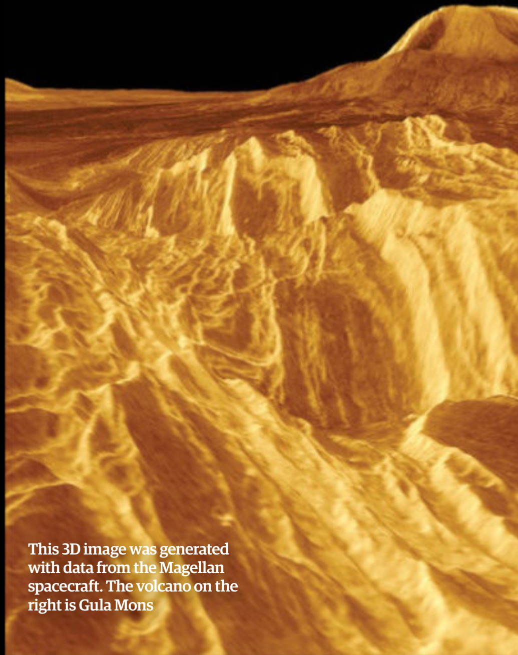
Venus has a relatively smooth surface compared to other terrestrial planets, but this is probably because the atmosphere burns up smaller meteors before they can reach the surface. There are still about 900 impact craters, and few are smaller than 30 km (19 mi). The lower number of craters shows that Venus's surface is young. Of course the planet itself isn't young, so this points to major events that have remapped the surface entirely. Scientists theorise these events happened about 300 million years ago, and probably were due to low-viscosity lava

Map of the surface



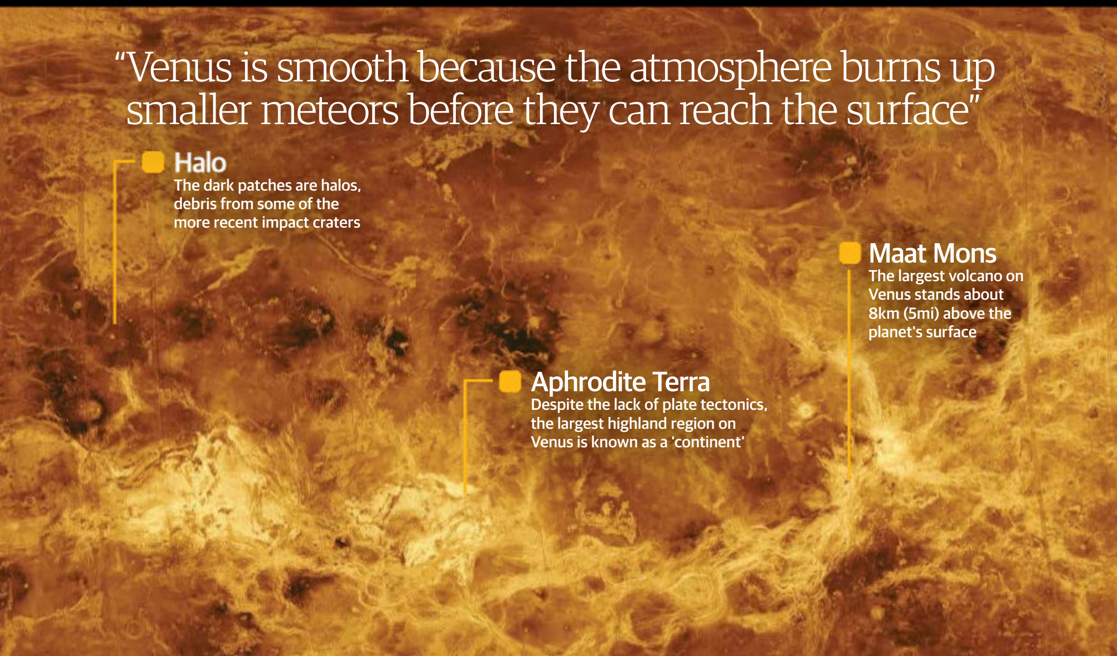
flows that lasted for millions of years. One theory is that decaying radioactive elements heated up in the mantle, forcing their way to the surface. The lava flows covered most of the planet, and then the mantle cooled down periodically.

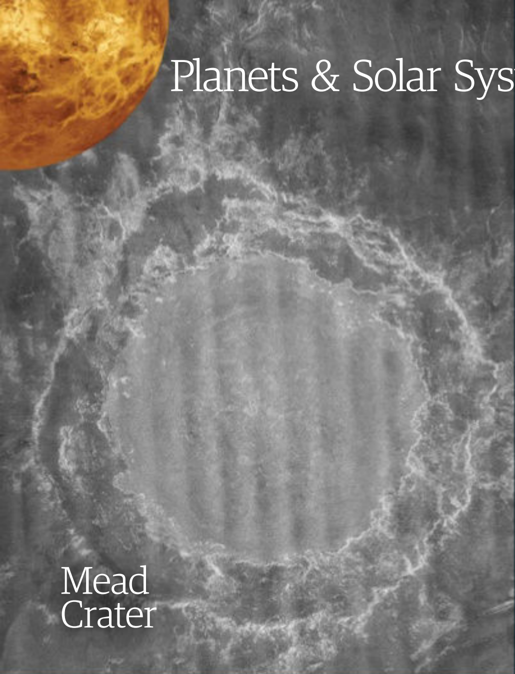
The most prominent features on Venus are due to volcanism, such as 150 large shield volcanoes, many of which are called pancake domes as they're very wide and flat. They are usually less than one km (0.6mi) tall and up to 65km (40mi) in diameter, and they're often found in clusters called shield fields. The shape is due the high pressure atmosphere and thick, silica-rich lava. There are also up to hundreds of thousands of smaller volcanoes, and coronae: ring-shaped structures about 300km (180mi) across and hundreds of metres tall, formed when magma pushed up parts of the crust into a dome, but cooled and leaked out as lava. The centre collapsed, resulting in a ring. Venus also has arachnoids, networks of radiating fractures in the crust that resemble a web. They may also form by magma pushing through the surface.



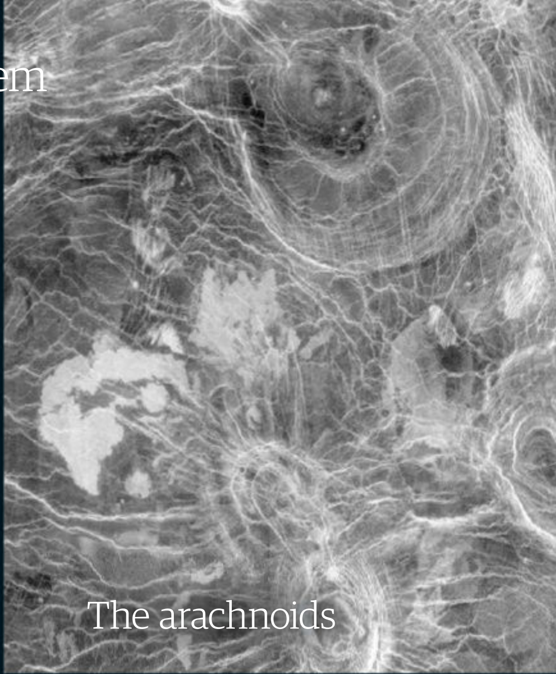
This 3D image was generated with data from the Magellan spacecraft. The volcano on the right is Gula Mons

"Venus is smooth because the atmosphere burns up smaller meteors before they can reach the surface"





Mead Crater



The arachnoids

Mountains, volcanoes and craters

The extraordinary features that dominate the surface of Venus

Maxwell Montes

Maxwell Montes is the tallest mountain range on Venus, reaching 11 km (6.8 mi) above the mean planetary radius. By comparison, the tallest mountain on Earth, Mount Everest, is 8.8 km (5.5 mi) tall. Although this is a computer-generated image, it was formed using data from the Magellan spacecraft.

The arachnoids

Spider-web like formations crawl across the surface of Venus. Arachnoids are formations of unknown origin that look like concentric circles of cracked crust. They can cover as much as 200 km (124 mi).

Mead Crater

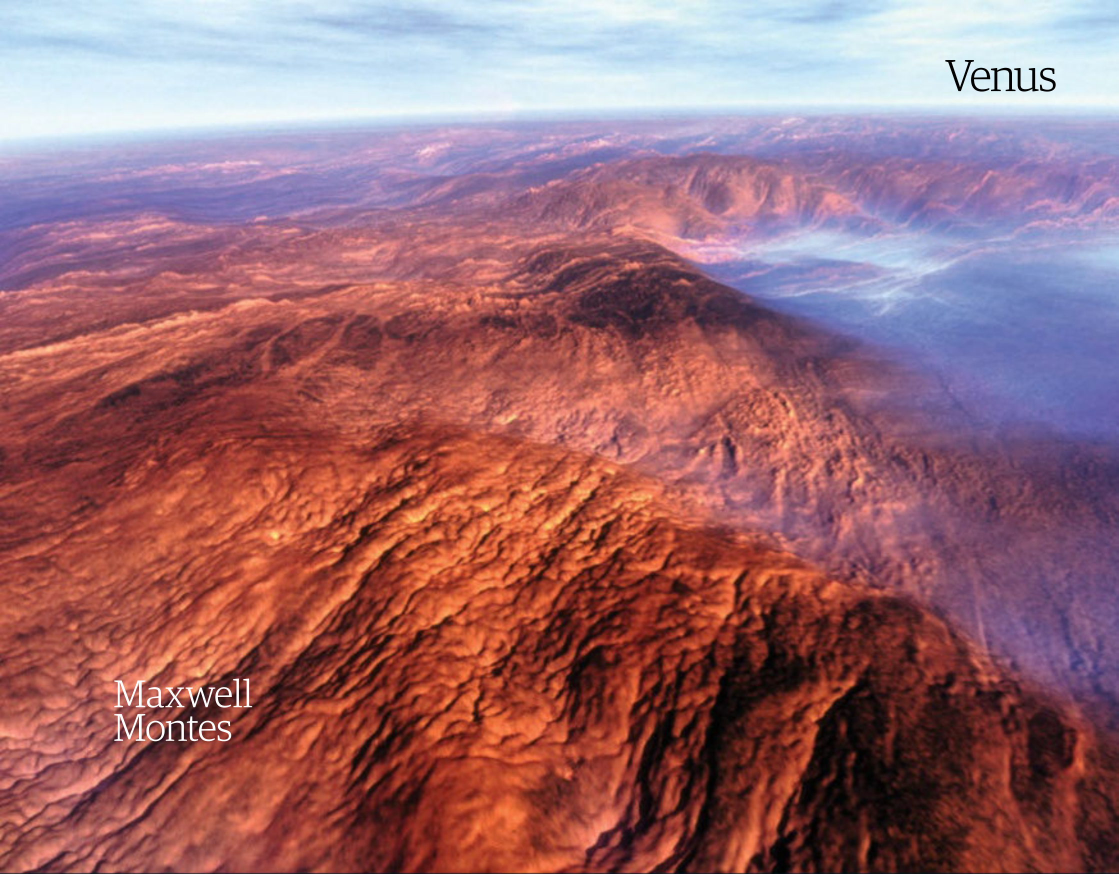
A crater almost as big as the largest crater on Earth. Mead Crater, named after anthropologist Margaret Mead, is the largest impact crater on Venus's surface. It's 280 km (170 mi) wide, just 20 km shy of Earth's widest crater Vredfort. It has an inner and outer ring and is located north of Aphrodite Terra.

Maat Mons

Maat Mons is approximately eight km (five mi) above the surface of Venus, and is its highest volcano. It has a huge caldera, or cauldron-shaped collapse, about 28 km (17 mi) by 31 km (19 mi). The caldera contains five smaller craters as a result of the volcano's collapse. Magellan also revealed some relatively recent volcanic activity in the area.

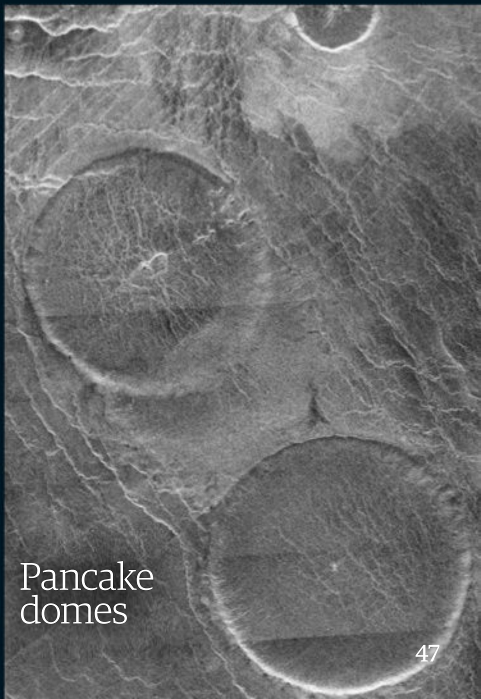
Pancake domes

Venus is known for unique volcanic formations called pancake domes. These pancake dome volcanoes are located in the Eistla region of Venus. They're about 65 km (40 mi) in diameter with tops that are less than one km (0.6 mile) in height. These volcanoes are formed when viscous lava is extruded under Venus's high-pressure atmosphere.

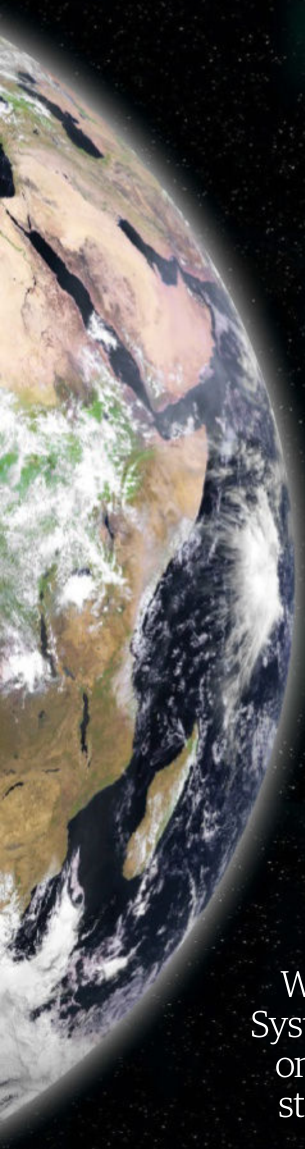


Maxwell Montes

Maat Mons



Pancake domes



EARTH

When it comes to studying the planets of the Solar System we often overlook the Earth. However, as the only planet known to be able to support life, there's still lots to learn about our fascinating home planet

Like the TV show says, the Earth is indeed the third 'rock' from the Sun – it's also the largest of our Solar System's four terrestrial planets, the fifth-largest planet and the densest planet overall. It's called an oblate spheroid – it's flattened at the poles, but bulgy at the equator, thanks to forces from the Earth's rotation. The bulge means that the furthest point from the centre of the Earth to the surface is located in Ecuador. The Earth has a density of 5.52 grams per cubic centimetre, a mass of 5.98 x 10^{24} kilograms and a circumference of 40,075 kilometres (25,000 miles).

Earth rotates on its axis once approximately every 24 hours, although the length of a true solar day (measured from noon to noon) always varies slightly due to small changes and eccentricities in the planet's rotation and orbit. Speaking of orbit, Earth has an eccentric, elliptical one. It completes an orbit around the Sun once every 365.26 days, at a mean distance of 150 million kilometres (93 million miles). The axial tilt of 23.4 degrees means that the northern and southern hemispheres are exposed to the Sun at different times, resulting in our seasons.

The Earth is not the only planet to have a moon, but the relationship that we have with ours has had a measurable effect on everything from our climate to the length of our year. The Moon is tidally locked to the Earth – it has a rotational period that's the same length as it takes to orbit our planet. This means that the same side is always facing us. Tidal interaction means that the Moon is moving away from us at a rate of about 38 millimetres (1.5 inches) per year. The tides aren't just caused by the gravitational pull of the Moon, though; it's a complex relationship between the Moon, the Sun's gravity, and Earth's rotation. Not only do the tides cause sea levels to rise and fall, but they may also be what's keeping the Earth's tilt stable. Without it, some scientists believe, the tilt may be unstable and result in chaotic changes over millions of years.

Just as the Sun and Moon affect the Earth, our planet also has a noticeable effect on objects around it. Since the Moon's formation, the Earth has acted like a bit of a cosmic bully, pushing and pulling it until it fell into line. There are other objects that Earth has an effect on as well. Asteroids, comets and spacecraft have all been hindered or helped by the Earth's gravity in their motion, unable to avoid the inevitable influence when they come into its vicinity.

An object falling freely near Earth's surface will experience an acceleration of about 9.81 metres (32.2 feet) per second every second, regardless of its size. Owing to the bulge mentioned earlier, this gravitational force is slightly different across the Earth. At the equator a falling object accelerates at about 9.78 metres

Orbits and seasons

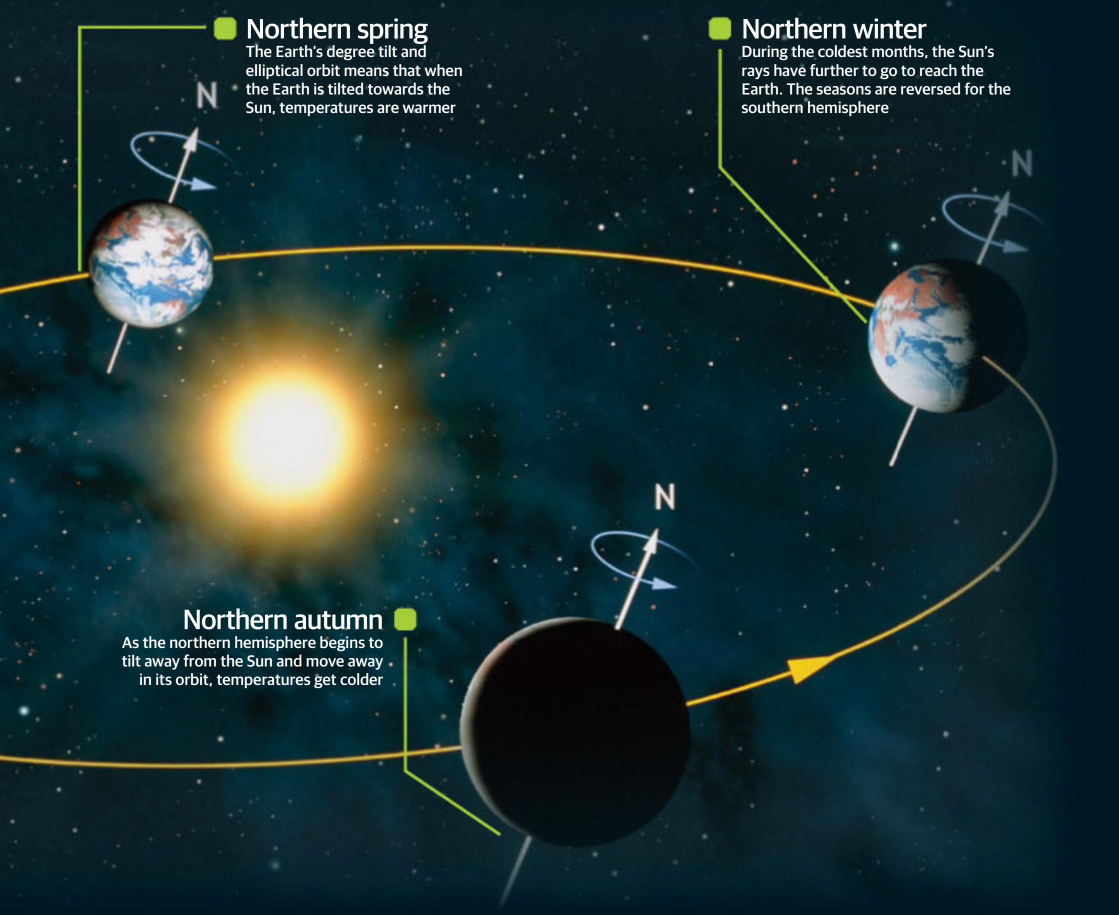
Northern summer
The northern hemisphere receives the most direct sunlight during the summer months, resulting in the hottest temperatures on the planet

(32.09 feet) per second every second, while at the poles it is closer to 9.83 metres (32.35 feet).

As you move away from Earth's surface the gravitational force decreases but at a barely noticeable rate. If you stood atop Mount Everest, at 8,848 metres (29,029 feet) tall, you'd weigh about 0.28 per cent less. Even at an altitude of 400 kilometres (250 miles), the gravitational force you'd feel is still 90 per cent as strong as it is on Earth's surface; the feeling of weightlessness in orbit is instead due to your horizontal velocity, which is so fast that you continually fall towards Earth.

Beyond Earth, our planet's gravitational pull continues to decrease, but in smaller increments. Even at a height of 2,000 kilometres (1,240 miles) you'd still experience a pull of just under six metres (20 feet) per second every second.

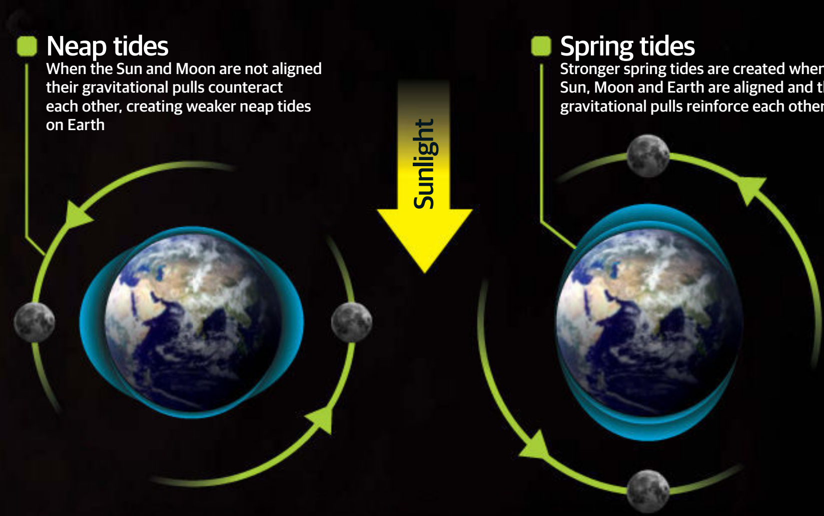
"Just as the Sun and Moon affect the Earth, our planet also has a noticeable effect on objects around it."



Earth's tides

The alignments of the Sun and Moon affect the tides. The Sun's large mass means that the tidal forces it exerts on the Earth are half those of the Moon despite its distance from the Earth. At the first and third quarter Moons (above left), the Sun and Moon are in opposition and produce neap tides, which are lower amplitude. Higher-amplitude spring tides are produced during times of new Moon and full Moon.

> "Tidal interaction means that the Moon is moving away from Earth at a rate of about 38 millimetres per year"



The planets in relation to the Sun

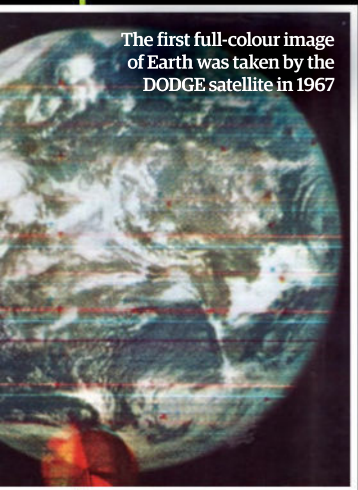
Earth is 150 million km (93 million mi) from the Sun on average: 1 astronomical unit

The Earth in numbers

Fantastic figures and surprising statistics about Earth

2 As well as the Moon, the Earth has two co-orbital satellites. They're the asteroids 2002 AA29 and 3753 Cruithne

360° It looks like a perfect sphere, but the Earth bulges at the equator and is flattened at the poles



The first full-colour image of Earth was taken by the DODGE satellite in 1967

3,000 *There are around 3,000 operational satellites and 8,000 man-made objects (including decommissioned satellites) in Earth orbit*

17 days *It would take about 17 days at 100km/h (62mph) to drive around the Earth*

10cm The islands of Hawaii move about 10cm towards Japan each year

5 billion *The Sun will expand and become a red giant in about five billion years – likely engulfing all of the inner planets, including Earth*

All figures = million miles from Sun

Earth inside and out

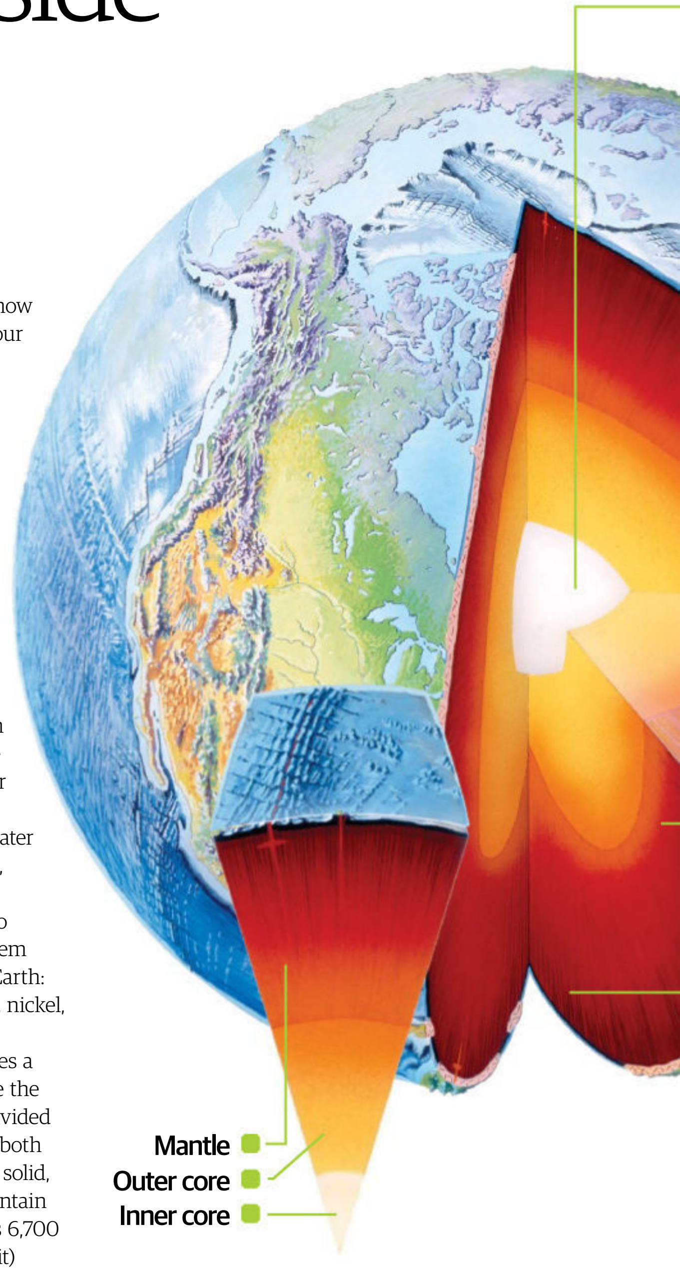
How Earth formed into the habitable world we know today

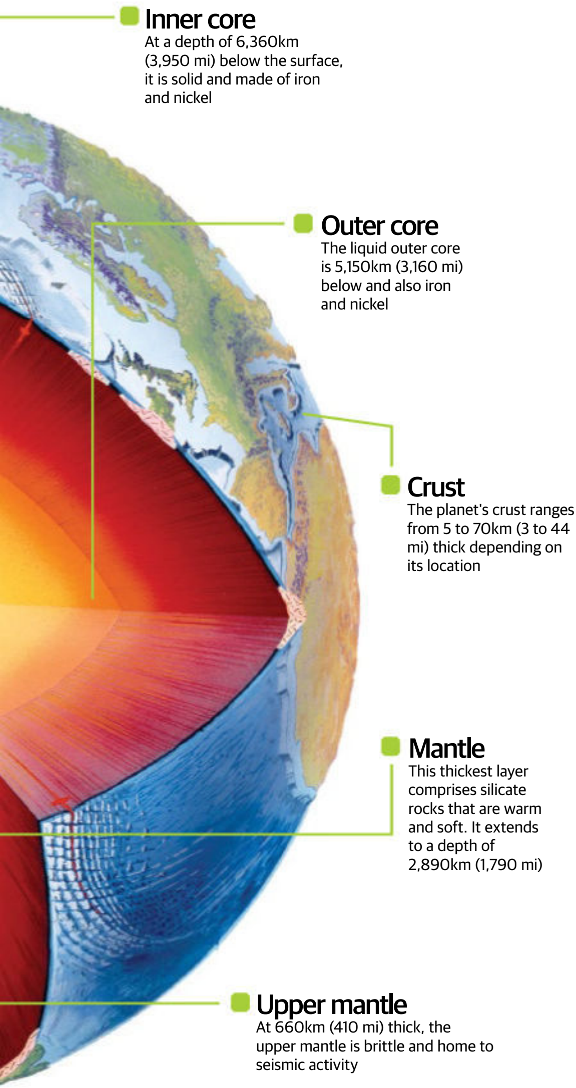
You may think you know all there is to know about Earth, but we take the wonders of our home planet for granted sometimes. It's unique because it's the only planet that has all of the elements needed to support life. It's also incredibly diverse, from the vast array of geographic features to the millions of plant and animal species. If you want to explore the unknown, there's no need to look to the stars; we're always discovering something new about our own planet.

But let's start with the basics. Along with the other planets, the Earth formed from the solar nebula – a cloud of dust and gas left over from the Sun's formation – about 4.54 billion years ago. It may have taken between 10 and 20 million years for the Earth to fully form. It initially started out as a molten planet, but a buildup of water in the atmosphere cooled the outer layers, eventually forming a solid crust.

The minerals found in the Earth are too numerous to mention, but just eight of them make up about 99 per cent of the entire Earth: iron, oxygen, silicon, magnesium, sulphur, nickel, calcium and aluminium.

From the inside out, the Earth comprises a core, mantle, crust and atmosphere. While the other terrestrial planets are also mostly divided this way, Earth is different because it has both an inner and outer core. The inner core is solid, while the outer core is liquid, and both contain mostly iron and nickel. The Earth's core is 6,700 degrees Celsius (12,100 degrees Fahrenheit)





"The Earth formed from the solar nebula – a cloud of dust and gas left over from the Sun's formation"

at the centre. This heat has two sources. The major source is radioactive decay, while about 20 per cent comes from energy generated by the gravitational binding of the planet. At formation, the Earth's core was even hotter – it has cooled as some of the radioactive isotopes have depleted.

Enclosing the core is the mantle, which is divided into two layers – a highly viscous liquid, topped by a rigid rocky layer. Finally, there's the crust – a thin rocky layer separate from the mantle because the mineral make-up is different.

Of course, these are the layers of the Earth as we know them today – numerous processes over our planet's life span have influenced and changed its make-up. The Moon is one example. It formed not long after the Earth. There have been several theories as to how this happened, but the prevailing belief is that a large object about the size of Mars collided with the Earth. Some of the object's mass merged with the Earth, some shot out into space and some formed into the Moon.

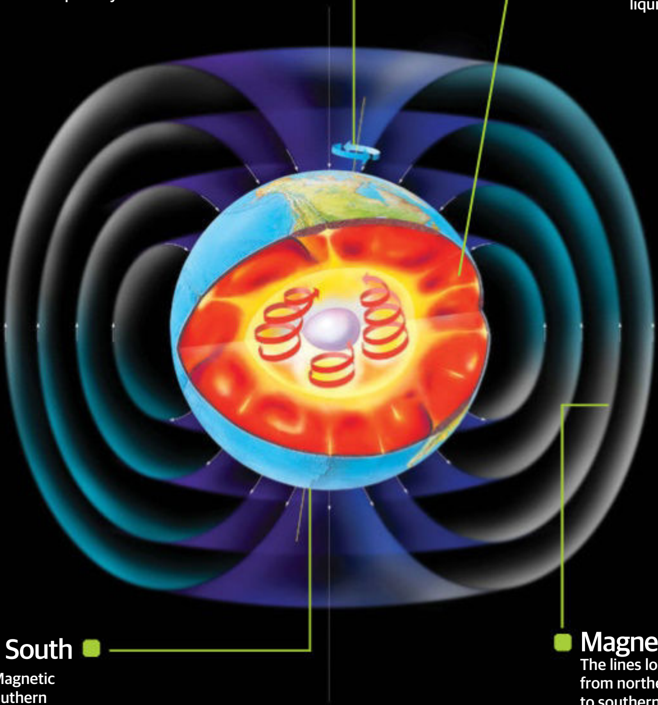
Asteroids, comets and other objects passing by deposited water and ice, ultimately leading to the formation of the oceans. The Sun was still forming at this time, too, and as its activity increased, so did the Earth's temperature. Volcanic activity and outgassing are responsible for the Earth's initial atmosphere. This multilayered atmosphere includes 78 per cent nitrogen, 21 per cent oxygen, and trace amounts of other elements. The layer of ozone blocks ultraviolet radiation from the Sun, protecting life below. Ozone is also part of the greenhouse effect, which helps sustain life on Earth. Gases trap heat rising from the surface, which keeps the average temperature at 15 degrees Celsius (59 degrees Fahrenheit).

Beyond the thinnest, uppermost layer of the atmosphere, the troposphere, lies the magnetic field. It protected the gases in the atmosphere from being sheared away and carried off into space by the solar wind. The field surrounds the Earth and has poles that roughly correspond to the Earth's magnetic poles.

Earth's magnetic field

"The Earth formed from the solar nebula – a cloud of dust and gas left over from the Sun's formation"

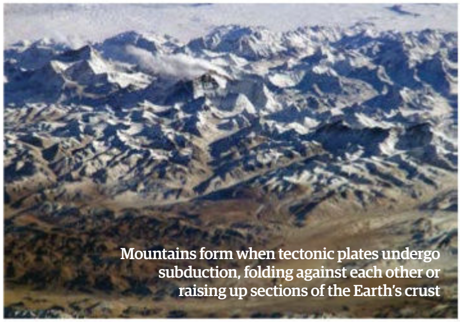
The Earth's magnetic field is generated from its molten outer core, known as a dynamo. It's created when the liquid iron within rotates, convects and generates electricity. The field extends about 63,700km (39,500 mi) from Earth on its Sun side and 384,000km (238,600 mi) on the Moon side. To make it easier, you can imagine it as if there's a bar magnet at the centre, with northern polarity corresponding with the South Geographic Pole and vice versa, but the 'magnet' is tilted at about 11 degrees. Every several hundred thousand years, the magnetic poles swap. Magnetic lines extend from each pole and loop around to each other, with the lines spreading further apart as they move out from the centre.



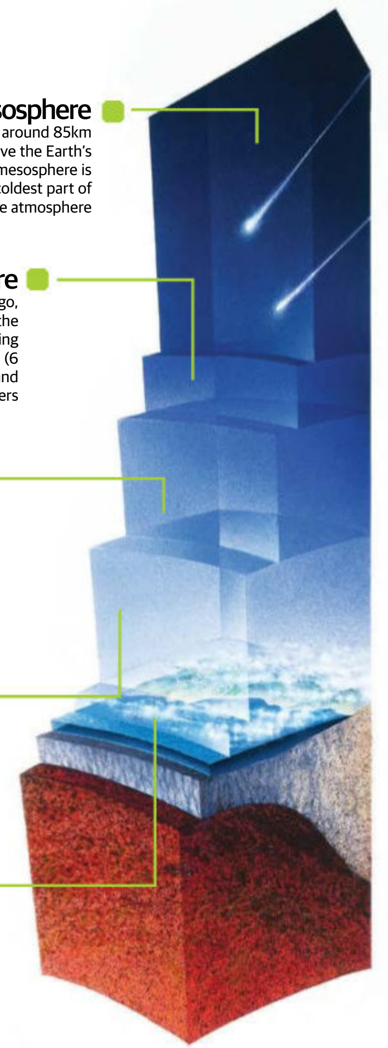
Earth's atmosphere

Earth is the only planet in the Solar System with an atmosphere that supports life. It was oxygen-rich thanks to the prevalence of water in the form of gas, ice and liquid, which came from its formation and other astral bodies. Some gases were released by activity on Earth while it formed, and others came from organisms. Carbon dioxide, for example, is necessary for plant growth. The plants in turn release oxygen. Carbon dioxide also helps to keep the planet warm to sustain life. The ozone layer traps in heat, too. But without the pull of gravity and the magnetic field, Earth would've lost its atmosphere a long time ago.

> "The Earth formed from the solar nebula – a cloud of dust and gas left over from the Sun's formation"



Mountains form when tectonic plates undergo subduction, folding against each other or raising up sections of the Earth's crust

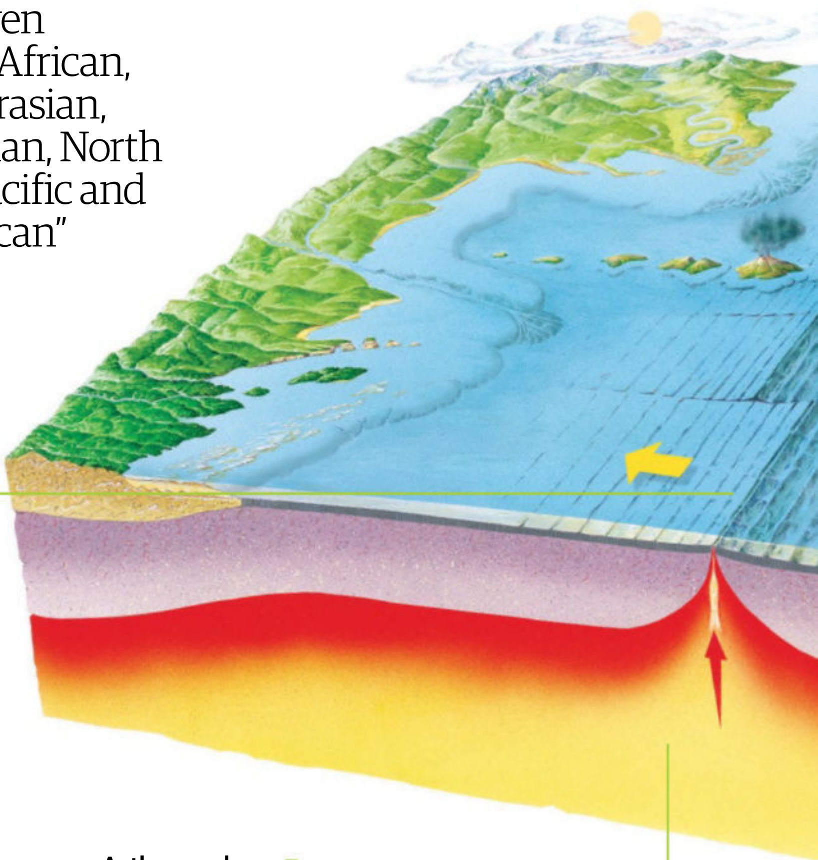


On the surface

Our planet is changing all the time, all the way down to its mantle

We typically divide the Earth into crust, mantle and core, but we can differentiate the outer layers differently. The lithosphere comprises both the crust and part of the upper mantle - specifically, the part that is rigid but has elasticity and becomes brittle. Next, the asthenosphere, a part of the mantle that's like a viscous fluid. The lithosphere is made of tectonic plates that are about 100km (62mi) thick and move on top of the flowing asthenosphere. There are seven major plates: African, Antarctic, Eurasian, Indo-Australian, North American, Pacific and South

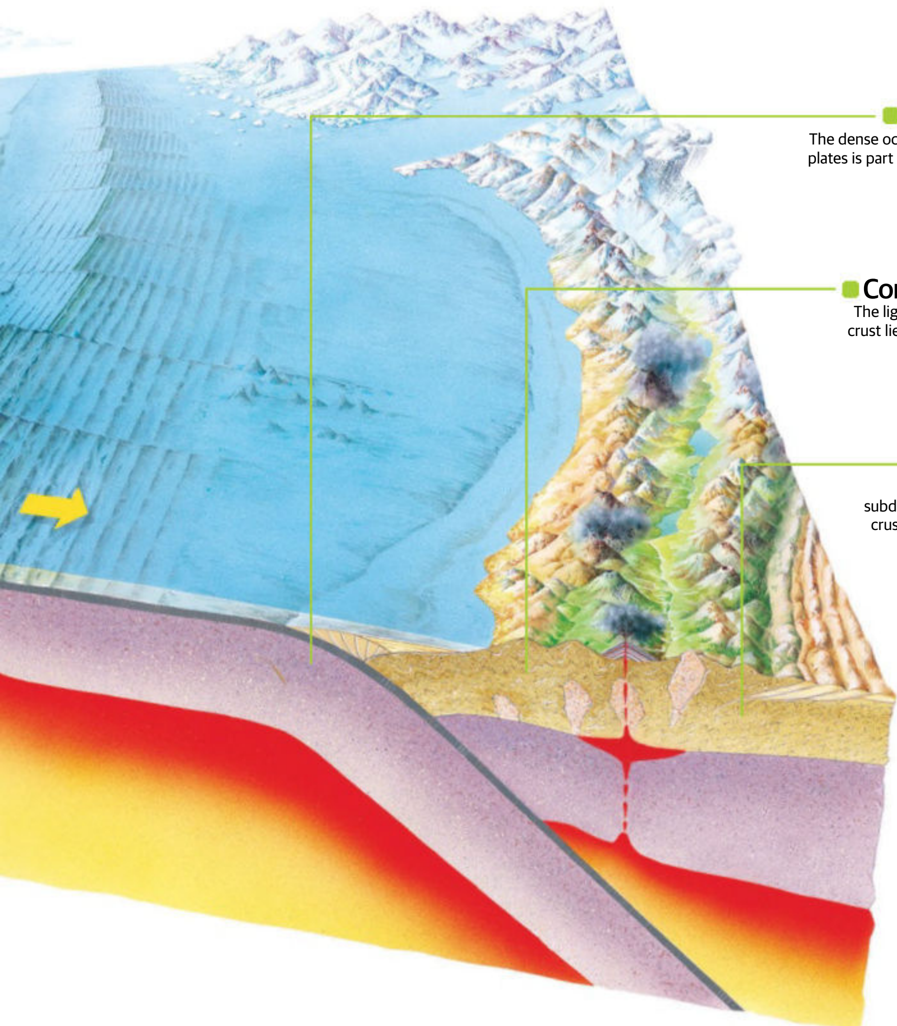
> "There are seven major plates: African, Antarctic, Eurasian, Indo-Australian, North American, Pacific and South American"



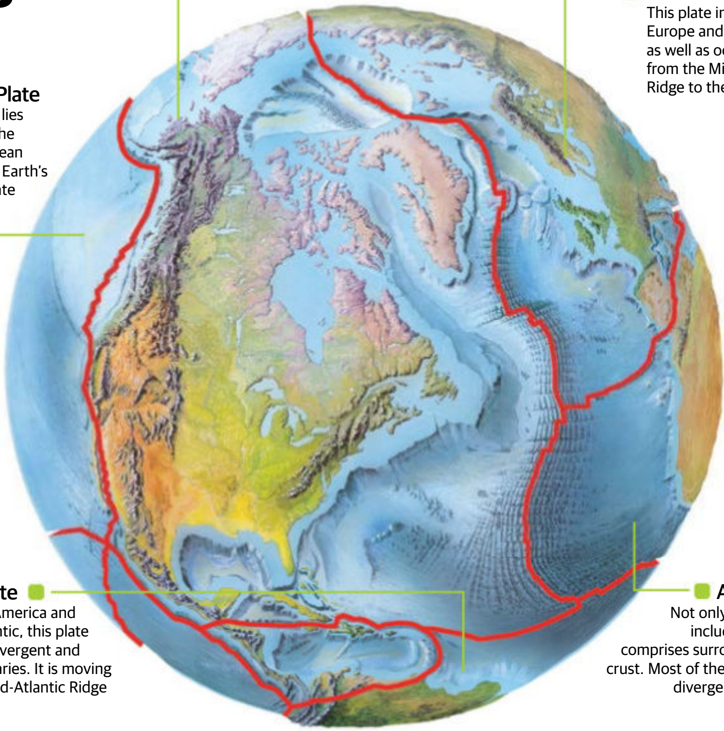
American, with extra smaller plates. They can comprise continental crust (mostly granitic rock), oceanic crust (mostly mafic rock), or both.

Plate movements occur at the boundaries. At convergent boundaries, plates can move under each other (subduct) or collide in the case of continental crust. At divergent boundaries, the plates slide away from each other. Plates grind along each other at transform boundaries. Volcanoes and earthquakes occur along plate boundaries. Plate boundary movement is also responsible for oceanic trenches and mountains. Some have hot spots of volcanic activity under the mantle within the plate, where volcanoes can form. While material can be lost through subduction, more is formed along divergent boundaries through sea floor spreading, so the total surface area remains the same.

Why do the plates move? The lithosphere is much denser than the asthenosphere, so we understand why it can slide, but where does it get the energy? It could be dissipating heat in the mantle, or gravitational pull through the Earth's rotation and the pull from the Moon or Sun.



Earth's fault lines



North American Plate
This plate extends from the Mid-Atlantic Ridge along the floor of the Atlantic Ocean to the Chersky Range. It has divergent, convergent and complex boundaries

Eurasian Plate
This plate includes all of Europe and much of Asia as well as oceanic crust from the Mid-Atlantic Ridge to the Gakkel Ridge

Pacific Plate
This plate lies beneath the Pacific Ocean and is the Earth's largest plate

South American Plate
Including South America and much of the Atlantic, this plate has complex, convergent and divergent boundaries. It is moving away from the Mid-Atlantic Ridge

African Plate
Not only does this plate include Africa, it also comprises surrounding oceanic crust. Most of the boundaries are divergent, or spreading

Surface features

Desert
Deserts get little precipitation, so they can't support much life, but there are desert-dwelling plants and animals. A true desert gets less than 400mm (16in) of rainfall per year. They make up about one-third of the Earth's land surface.

Rainforest
Rainforests have very high levels of rainfall, usually a minimum of 1,750mm (68in) each year. They cover 5% of the Earth and are the source of about 25% of our natural medicines, and home to millions of species of plants and animals.

Oceans
Saline or saltwater makes up about 71% of the Earth's surface. No other observable planet has as much water on its surface. The total volume of saltwater on Earth is approximately 1.3 billion cubic kilometres (311 million cubic miles).

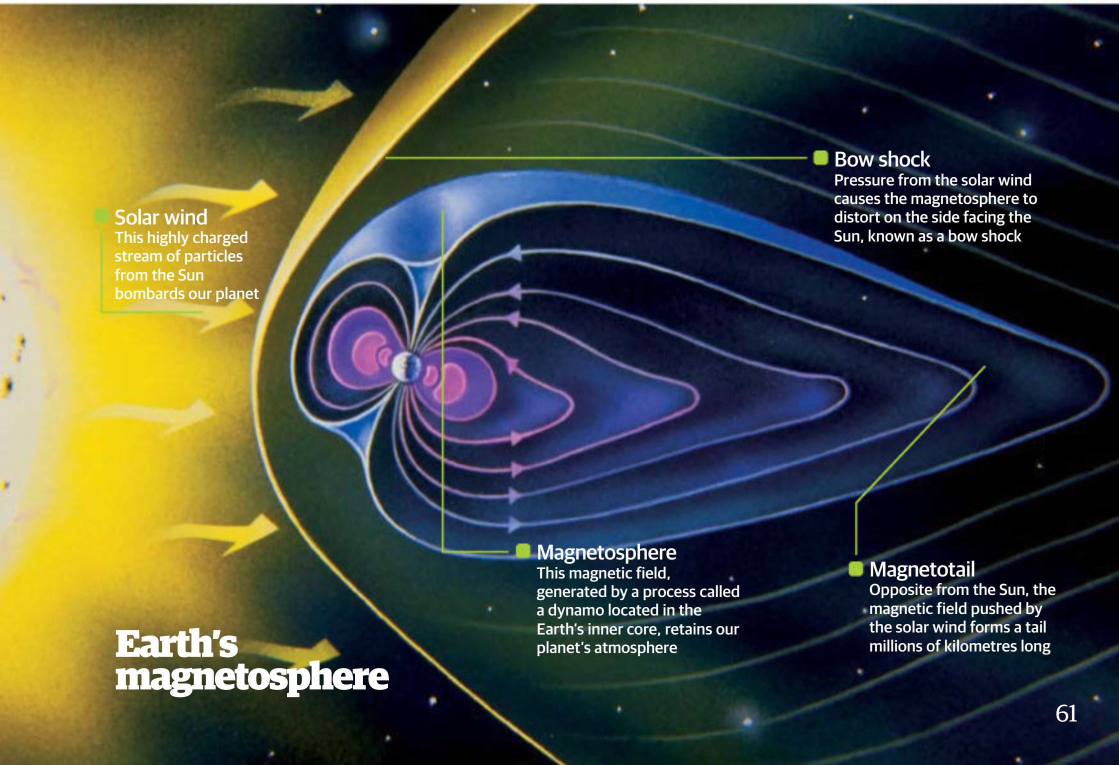
Ice caps
Ice caps and glaciers cover about 10% of the surface, and hold about 70% of our freshwater. Glacier movement helped shape the topography of the land in many areas. If they all melted, our ocean levels would rise by 70m (230ft).

Why is there life on Earth?

The Earth has the perfect recipe to support life. But why?

Astronomers have coined the term 'Goldilocks Zone' to describe star systems that theoretically have planets with atmospheres capable of retaining water. All known forms of life require liquid water, so this has become the gold standard for finding life on other planets. They may also be called circumstellar habitable zones (CHZ). But a planet needs more than just water – other bodies within our Solar System are believed to have it but we still haven't found life there. Earth is 'just right' for a number of reasons. The atmosphere is one. All known forms of life require oxygen-rich air, and our atmosphere is full of it. It's being continually replenished by plant respiration and by the water cycle. Thanks to the Earth's gravity and its magnetic field, the atmosphere stays put and hasn't been swept out to space. Our Sun is also an important factor, because the Earth is the perfect distance from it, with temperatures and heat levels that, while varied, allow life to grow and thrive. Sunlight is also very necessary, because without enough sunlight, the plants on the Earth would not be able to photosynthesise.

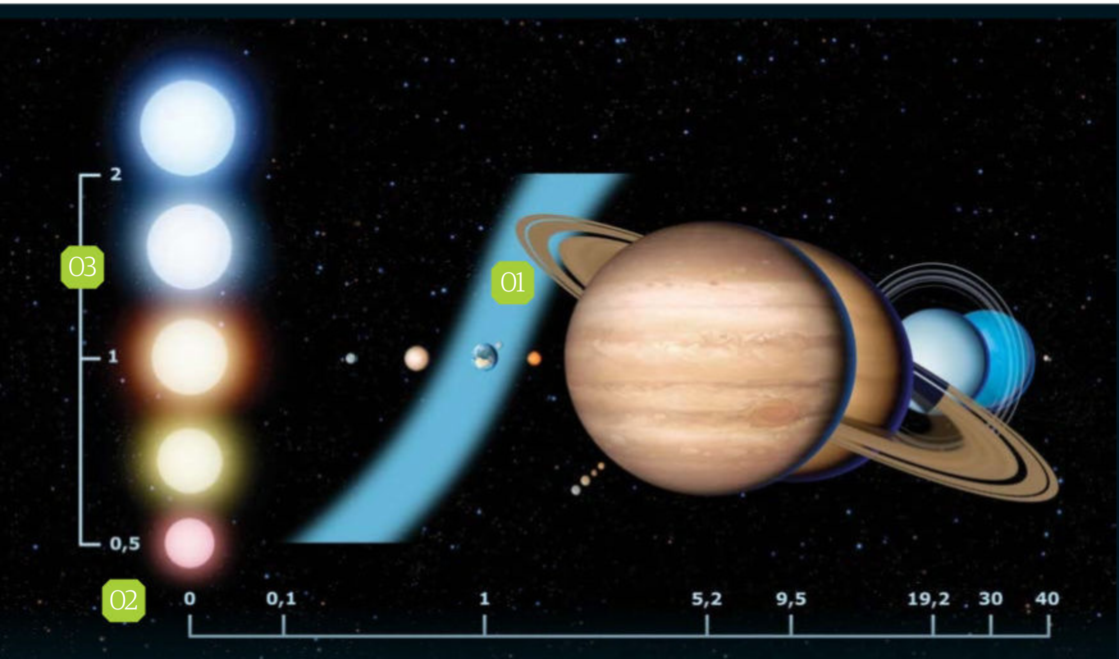
The water cycle, proximity to the Sun, sunlight and atmosphere all contribute to a suitable climate for life. While temperatures vary across the globe, Earth doesn't experience the extreme swings of other planets. On Mars, it can be as warm as 25 degrees Celsius (77 degrees Fahrenheit) but as cold as minus 140 degrees Celsius (minus 220 degrees Fahrenheit).



Earth's magnetosphere

Water

Although other planets have been found to have water, none have as much as Earth. Sometimes our water mass, including the oceans and freshwater sources, is known as the hydrosphere. Without such plentiful sources, the water cycle could not function and there wouldn't be enough oxygen to support life. Human bodies comprise about 70 per cent water, and life on Earth needs it to survive.



The Goldilocks Zone

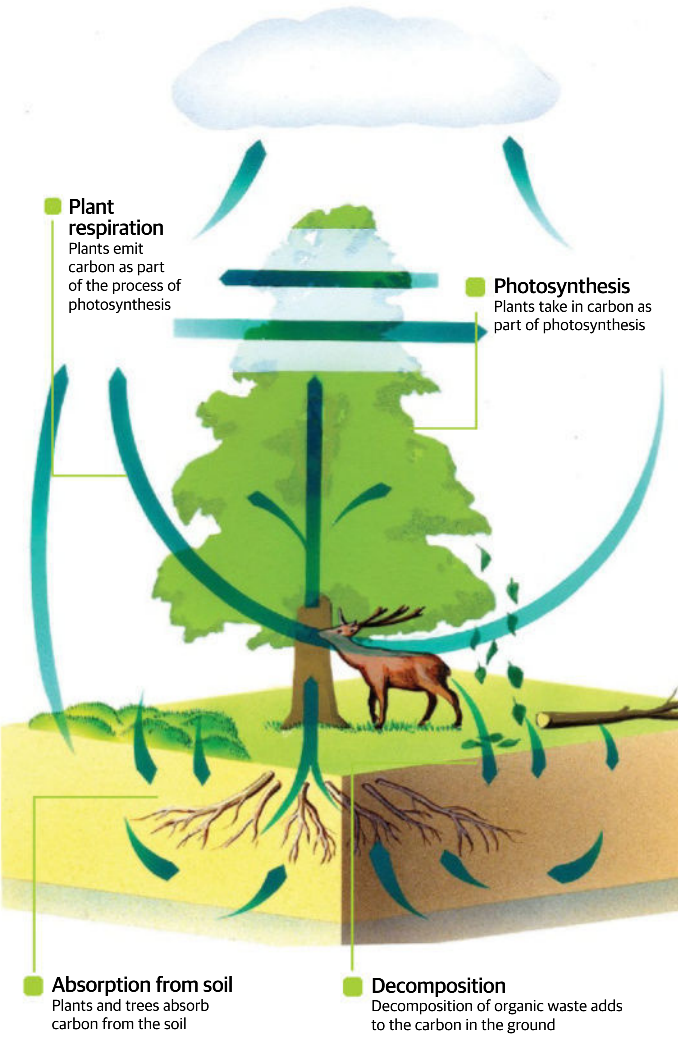
1. Habitable Zone
This narrow band shows Earth is the only planet in our system known to be capable of sustaining life.

2. Radius of planet's orbit relative to Earth
Earth is at '1'. The other planets are too big or too small to support life.

3. Mass relative to the Sun
The Sun has the perfect stellar mass to provide the right amount of light and energy to the Earth.

Carbon

The carbon cycle is just as important to our climate and survival on this planet as the water cycle is. Carbon dioxide is an element of the greenhouse effect, which traps heat in and keeps our planet at a regular temperature, maintaining our regular climate. Most of the life on our planet is carbon-based, with this abundant element bonded to other elements to create the building blocks of life. It is replenished in the atmosphere by plant and microbial respiration, as well as decomposition of various organic materials.

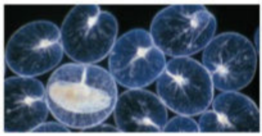


5 kingdoms of life

Animalia
The animal, or Animalia, kingdom (also called Metazoa), includes about 1,000,000 multicellular, heterotrophic species.

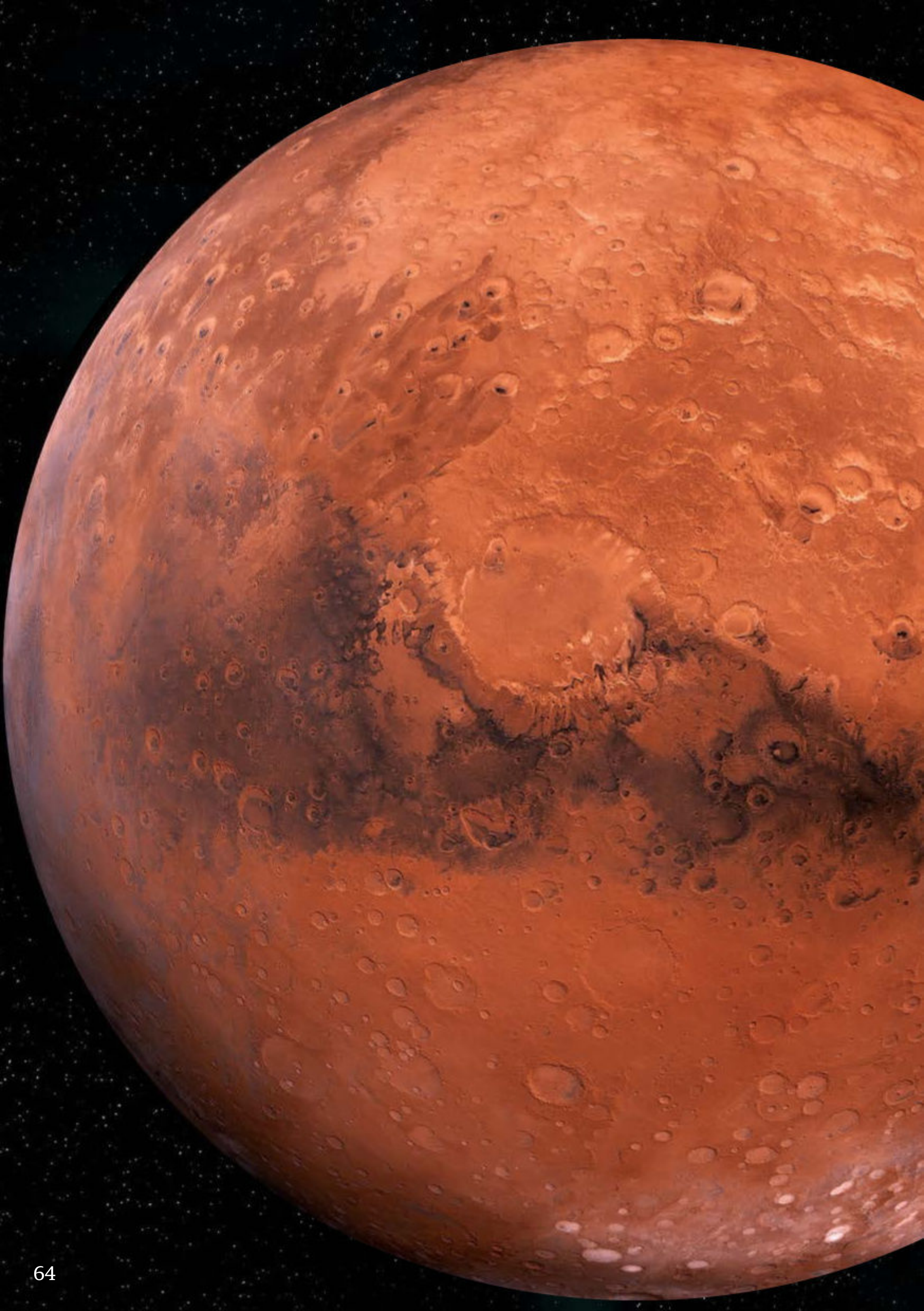
Plantae
Kingdom plant, or Plantae, includes everything from multicellular flowers to mosses. There are about 250,000 plant species.

Fungi
Fungi include around 100,000 identified species. The Fungi kingdom includes mushrooms, yeasts and moulds.



Protista
The Protista kingdom has 250,000 species which don't have much in common with each other, apart from not belonging elsewhere.

Monera
The Monera kingdom is made up of species such as algae and bacteria. There are approximately 10,000 species in this kingdom.



MARS

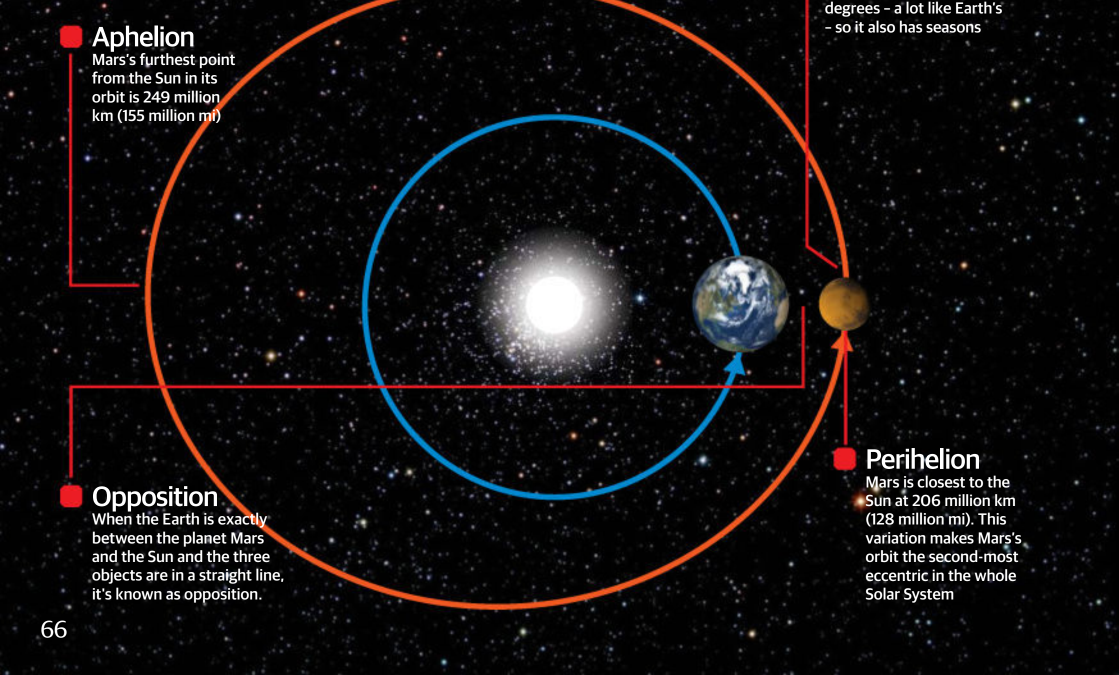
The fourth planet from the Sun and the seventh largest, the red and varied landscape of this once Earth-like planet has fascinated humanity since we first viewed it in the night sky. We explore just why this planet holds such allure

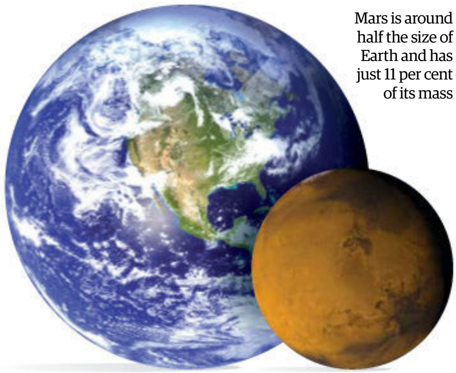
Because it appears red due to the rust in its atmosphere, Mars has long been called The Red Planet. Its 'bloody' appearance is also why it was named after the Roman god of war. But that potentially scary appearance hasn't kept us from wanting to learn more about it. Mars formed about 4.6 billion years ago, along with the other planets in the Solar System. After the initial formation, Mars was bombarded at length by meteors, which caused its heavily cratered appearance. As the planet separated into layers, molten rock in the mantle pushed through the crust, resulting in volcanic activity. The activity released a lot of heat from the core, which led it to cool down very quickly. Atmospheric water likely froze, causing flooding, but the lack of atmospheric pressure meant that water was swirled away by solar winds. Eventually Mars settled down into the dry, dusty planet we've been watching since ancient times.

We can easily see Mars from Earth without a telescope, and it's actually easier to see when it's further away from the Earth in its orbit because our atmosphere gets in the way. We've sent lots of probes to the planet, including the recent addition of NASA's Curiosity rover. So far we've discovered that Mars is so much like the Earth, but also so very different. It is a terrestrial planet and has almost identical geographical features and a similar axial tilt (which results in seasons). It also has basically no atmosphere, no liquid water and wildly fluctuating temperatures on

"Because there are no oceans on Mars, it has the same amount of dry land as the Earth does"

An eccentric orbit





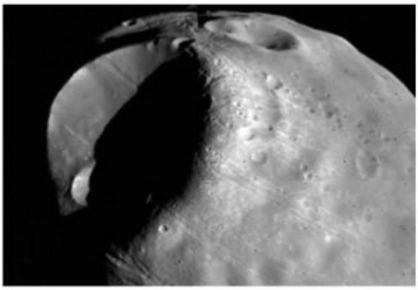
Mars is around half the size of Earth and has just 11 per cent of its mass

the surface. If there are any Martians lurking around, they have to be a hardy group - and so far they've eluded detection. Mars is red, but not all red. Although we can see the planet, we can't actually see any of its features. We do, however, see albedo features, areas of light and dark. While most of the planet is red there are also bright white areas at the poles, some upland areas, and also in the form of ice clouds. The darker spots are places where the intense wind has removed the dust to expose basaltic volcanic rock.

Mars is the fourth planet from the Sun in the Solar System, right between the Earth and Jupiter. Size-wise it is the second-smallest planet behind Mercury. Despite all of the Earth comparisons, it's about half the diameter of Earth, and much less dense. In fact, its mass is about 11 per cent that of Earth's and its volume is about 15 per cent. But because there are no oceans on Mars, it has the same amount of dry land as the Earth does.

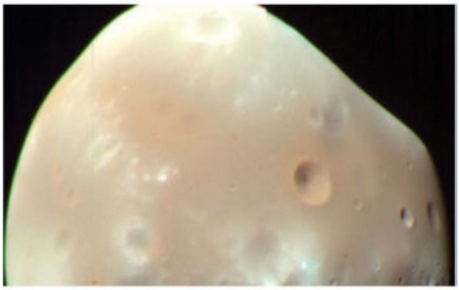
The planet's average distance from the Sun is about 228 million kilometres (142 million miles). It takes 687 Earth days to orbit the Sun, but Mars has a very eccentric elliptical orbit. Its eccentricity is 0.09, which is the second-most eccentric in the Solar System behind Mercury (the Earth has an orbital eccentricity of 0.0167, which is almost a circle). But we believe that Mars once had a much rounder orbit - it has changed due to gravitational influences from the Sun and other planets. Rotation-wise, a Martian day is just a bit

The moons of Mars



Phobos

Phobos is the bigger of Mars's two satellites, and orbits the closest. It orbits closer to its planet than any other in the Solar System. The distance from the moon to the planet is about 6,000km (3,700 mi) from the surface. It has a radius of about 11km (seven mi), is irregularly shaped and is non-spherical. Its biggest feature is an impact crater named Stickney, which has a diameter of about 9km (5.6 mi).



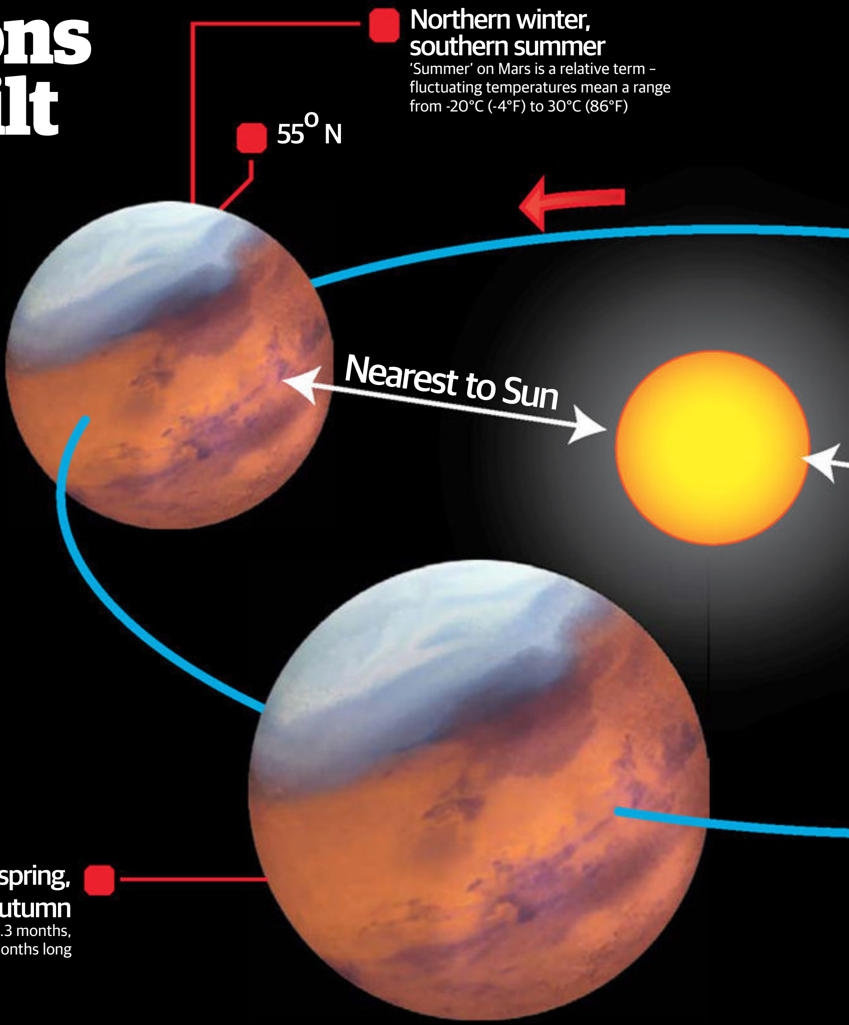
Deimos

Deimos is farther from Mars at around 23,400km (14,600 mi) away, and significantly smaller, with a radius of around 6km (four mi), and takes much longer to orbit Mars at 30.4 hours. Deimos, like Phobos, is not at all spherical. It has a very porous surface, and also features large craters relative to its size, with the two largest being Swift and Voltaire. Both craters are believed to be between 1 and 3km (0.6 and 1.9 mi) in diameter.

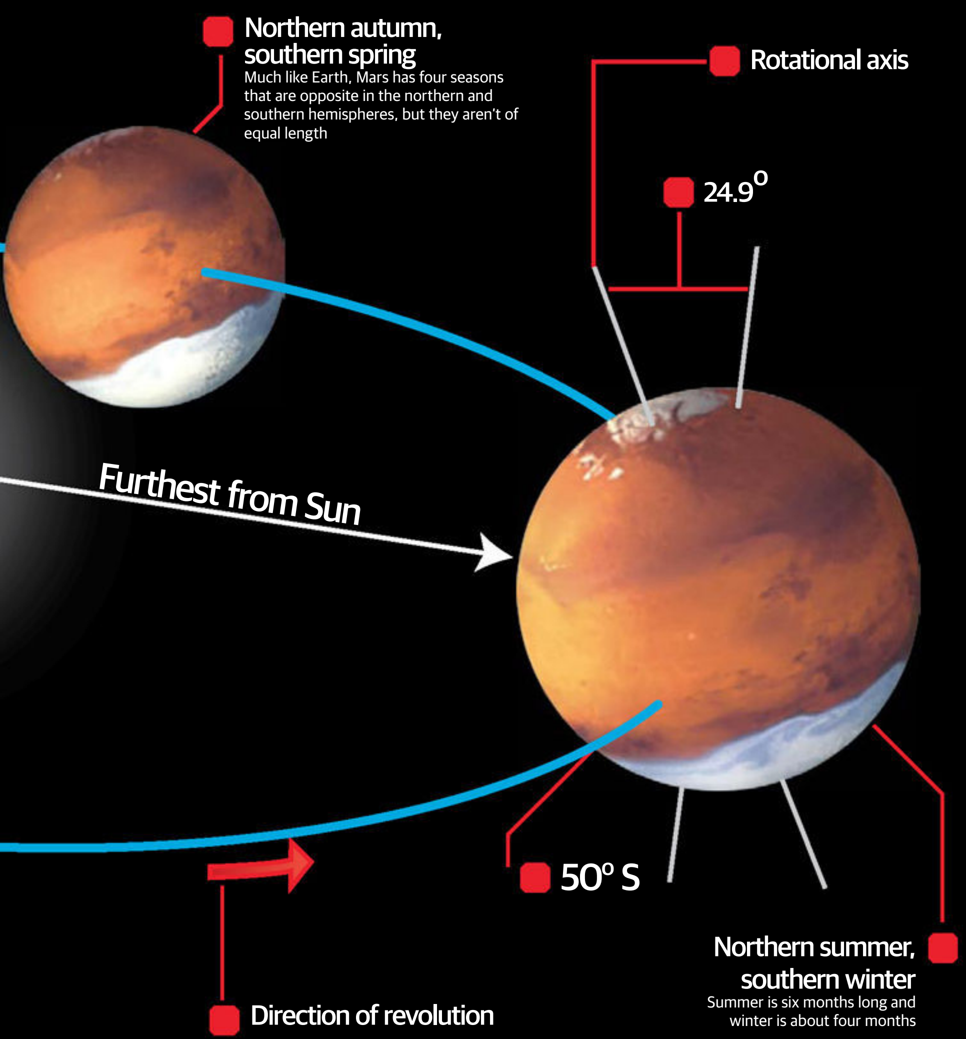
longer than an Earth day at 24 hours, 39 minutes and 35 seconds. Mars is also tilted 25.19 degrees, close to the Earth's axial tilt of 23.44 degrees. That means depending on where the planet is in its orbit around the Sun, different hemispheres will be exposed to more light - better known as seasons. They aren't seasons like we know them, which are fairly equal in length on Earth. On Mars, spring is seven months long, for example, while winter is only four. The seasons are longer because the year is longer - Mars is further away from the Sun than the Earth - but they vary because of the eccentricity of Mars's orbit.

Mars also has two natural satellites, or moons - Phobos and Deimos. Both are potato-shaped and may have been asteroids that got trapped by Mars's gravitational pull or they could have formed from material ejected from Mars during impact. The planet might also have other tiny satellites that have yet to be discovered.

Seasons and tilt



Science fiction often portrays Mars as a sister planet to Earth and despite key differences - the small matter of life, for example - comparisons can be made. NASA has referred to Earth as 'one of the best comparative laboratories' and the study of Mars can provide scientists with a control set for studying the potential for life. As mentioned, the chief of these differences is the size of the planet: Mars is a smaller world with 53 per cent the diameter and just 11 per cent the mass of Earth. The surface gravity on the Red Planet is 38 per cent that of Earth's, meaning that a human who can jump one metre (3.3 feet) on Earth could jump 2.6 metres (about nine feet) on Mars. The atmospheric chemistry is relatively similar too, especially when compared to other planets in the Solar System. Both planets have large polar ice caps made primarily of water ice. Other similarities include a similar tilt in their rotational axis, causing seasonal variability.



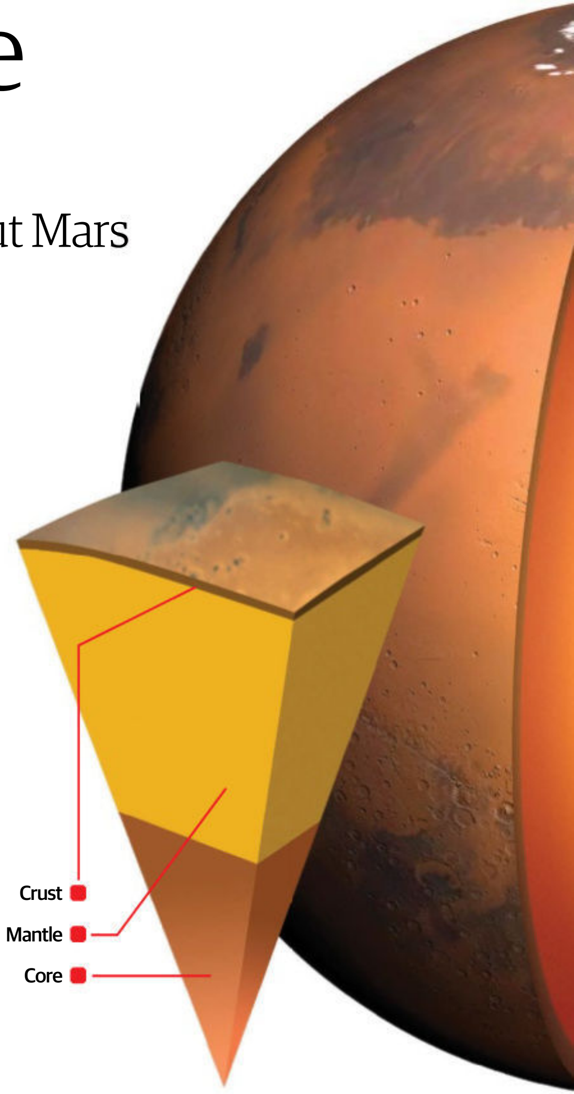
Mars inside and out

It may resemble Earth, but Mars is a very different planet

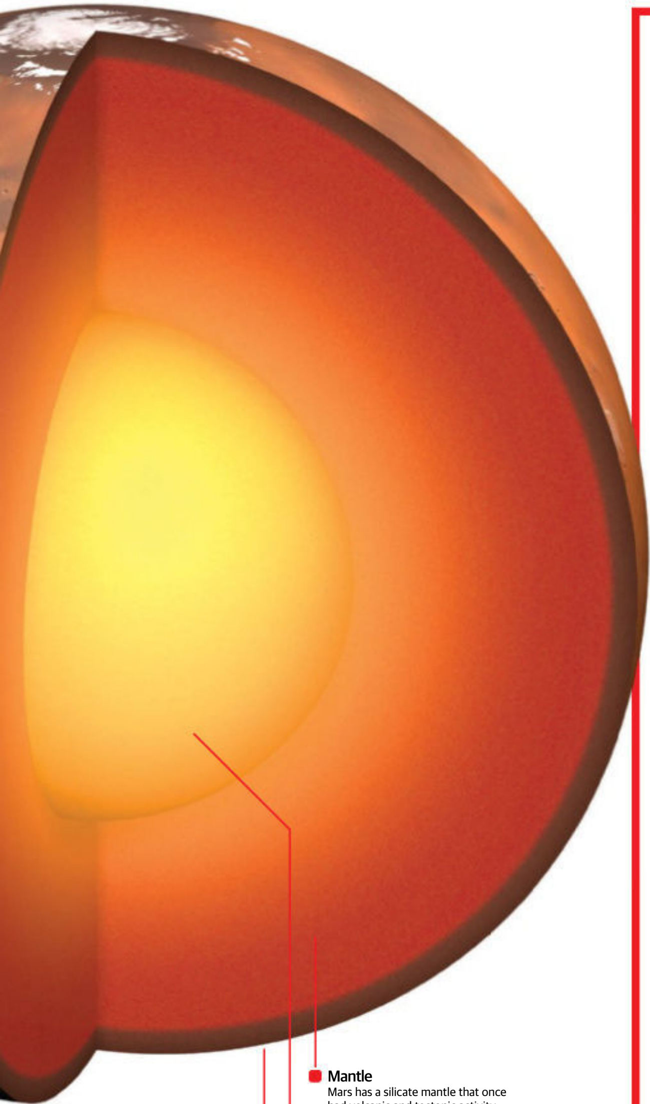
Mars is a terrestrial, or rocky, planet - like Earth. It also has a differentiated internal structure, with an outer crust, a mantle and a core. Mars's core is between around 3,000 and 4,000 km (1,850 and 2,500 mi) in diameter. It's mostly made up of iron, with nickel and traces of other elements, such as sulphur. Scientists believe that the core is mostly solid but may also contain a fluid layer. There is no magnetic field generated at the core, but Mars may have had a magnetic field in the past. There are currently areas of magnetisation at different places on the planet's surface. The differentiation process, in which heavier metals such as iron sunk through to the core while Mars was forming, may be responsible for the end of the Red Planet's magnetic field.

Atop the core lies Mars's silicate mantle, which is between 1,300 and 1,800 km (800 and 1,100 mi) thick. Volcanic activity on the planet's surface originated here, resulting in the huge volcanoes, lava flows and other features that can be found on Mars's surface - however, the most recent volcanic activity likely took place about 2 million years ago. That may not be particularly recent by our standards, but it's fairly recent when it comes to Mars's history. These were lava flows, however; the volcanoes appear to be extinct.

Finally, the crust is about 25 to 80 km (16 to 50 mi) thick. It contains oxygen, silicon, iron, calcium and other metals. The high concentrations of iron and oxygen result in rust - iron oxide - which is responsible in part for the red appearance of Mars. At its thickest the crust is more than twice as thick as the Earth's crust. The surface is covered with regolith in many places - a loose conglomerate of broken rocks, dirt and dust.



"The crust is more than twice as thick as the Earth's crust"

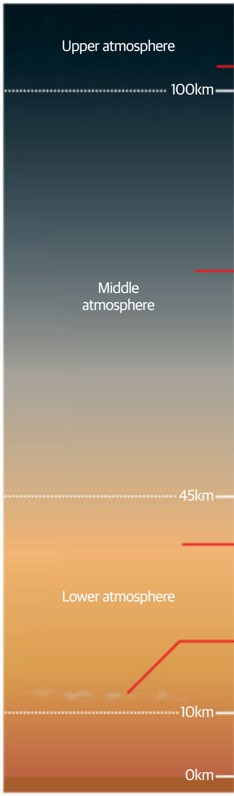


Mantle
Mars has a silicate mantle that once had volcanic and tectonic activity, which helped shape the planet

Core
The core is mostly solid, containing iron and nickel as well as sulphur. It does not generate a magnetic field

Crust
Mars's crust appears to be thicker than that of Earth's, especially in areas of prior volcanic activity

A thin atmosphere

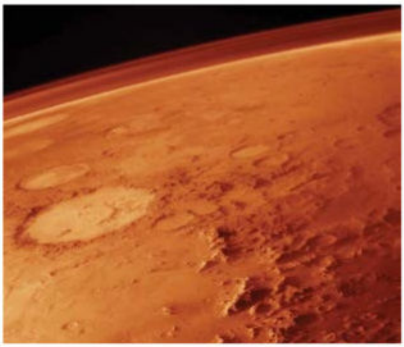


Upper atmosphere
Also known as the thermosphere, this layer is heated by the Sun. The lack of a magnetic field means that the gases separate out into space

Middle atmosphere
In the middle atmosphere, the Martian jet stream swirls the surface dust and gives the sky its orange colour

Lower atmosphere
The atmosphere contains 95 per cent carbon dioxide, three per cent nitrogen, two per cent argon and traces of elements such as methane

Thin ice clouds
Strong winds eroding Mars's ice caps, along with atmospheric sublimation of carbon dioxide, help create these thin ice clouds



This image, taken by the Viking Orbiter from low orbit, shows the thin layer of Mars's atmosphere – less than one per cent the thickness of Earth's atmosphere

On the surface

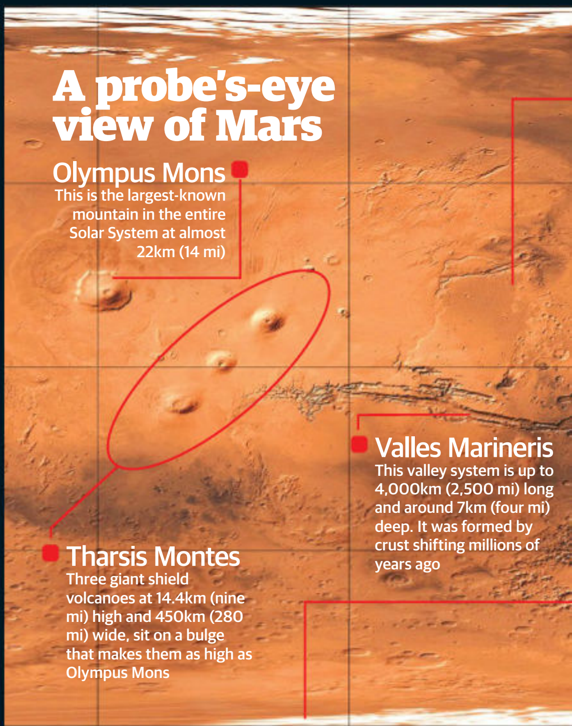
Mars has geographical similarities with Earth, but there's a reason why we haven't found life yet

Thanks to the images from various probes, we know that Mars has a lot of interesting geographical features. The biggest one is that Mars has incredibly different northern and southern hemispheres. Most of the northern hemisphere is lower in elevation (up to six kilometres or four miles lower). It also has far fewer impact craters, and is much smoother and uniform. Finally, the crust on the northern hemisphere appears to be much thinner. While astronomers aren't sure of the reasons behind this dichotomy, it involves the three main forces that have influenced the planet's surface: volcanic activity, tectonics and impacts.

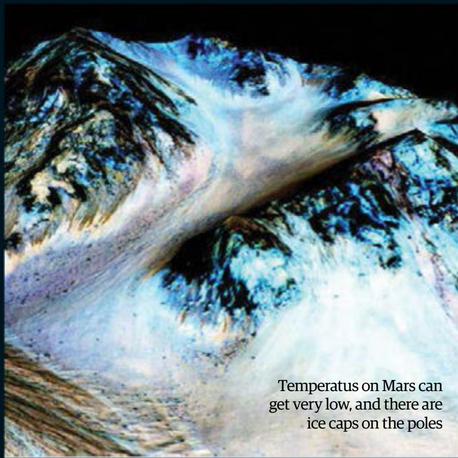
Some of the most striking features on Mars's surface are its mountains - which are all inactive volcanoes. The western edge of the southern hemisphere contains two different areas - the Tharsis bulge and the Elysium volcanic complex - each of which contain several volcanoes. The Tharsis bulge covers about 25 per cent of the planet's surface and lies seven to ten kilometres (four to six miles) above it. This includes Mons Olympus, a shield volcano that is the largest mountain in the Solar System.

Scientists were sure that Mars didn't have plate tectonics like Earth - until last year. That's when we discovered that there are in fact tectonics at work. Not only do features like steep cliffs and the flat walls of canyons show faults at work, but so do the fact that Mars's volcanoes are concentrated in two different areas. The huge valley system known as the Valles Marineris is the deepest in the Solar System and takes up a quarter of the planet's circumference. It's also a plate boundary, with horizontal movement along the plates. With just one known fault as opposed to many on Earth, some believe that Mars's tectonic system is much younger.

Impact craters and basins are prevalent in the southern hemisphere. The Hellas basin is the largest at 1,800 km (1,100 mi) across. The largest basins most likely date back to a period of heavy bombardment 3.8 billion years ago. They show signs of erosion and contain a lot of regolith (soil deposits). The smaller craters are younger, and look like the Moon's craters. Mars has many different types of craters due to erosion, deposits and volcanic activity. They also contain ejecta blankets - flows formed in the soil after an impact melts ice under the planet's surface.

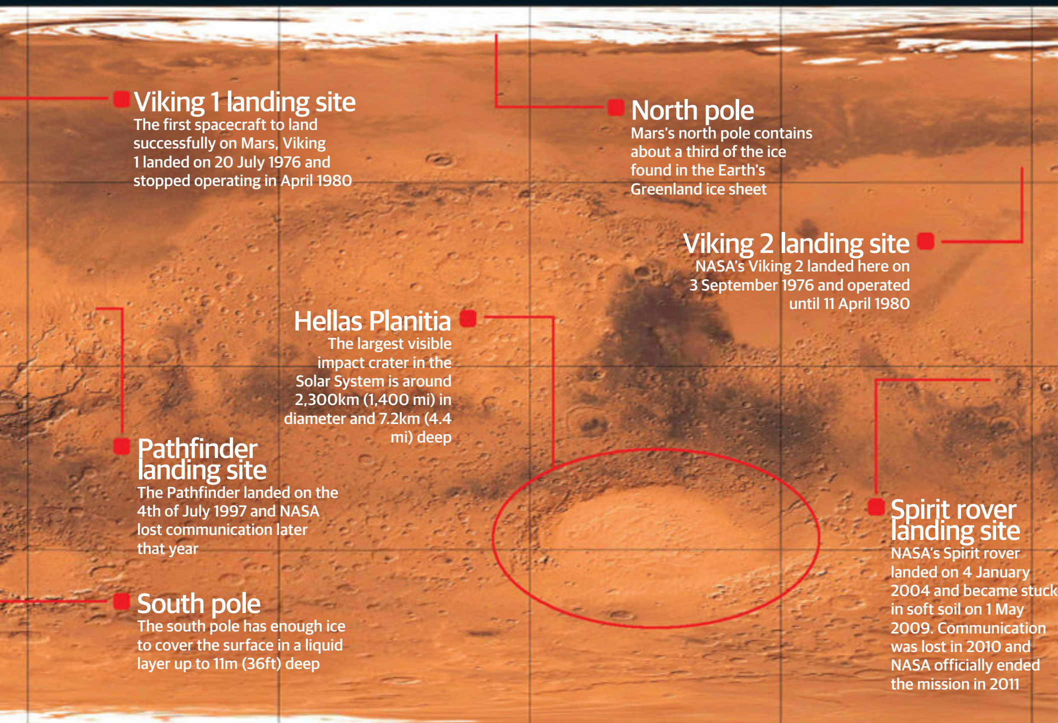


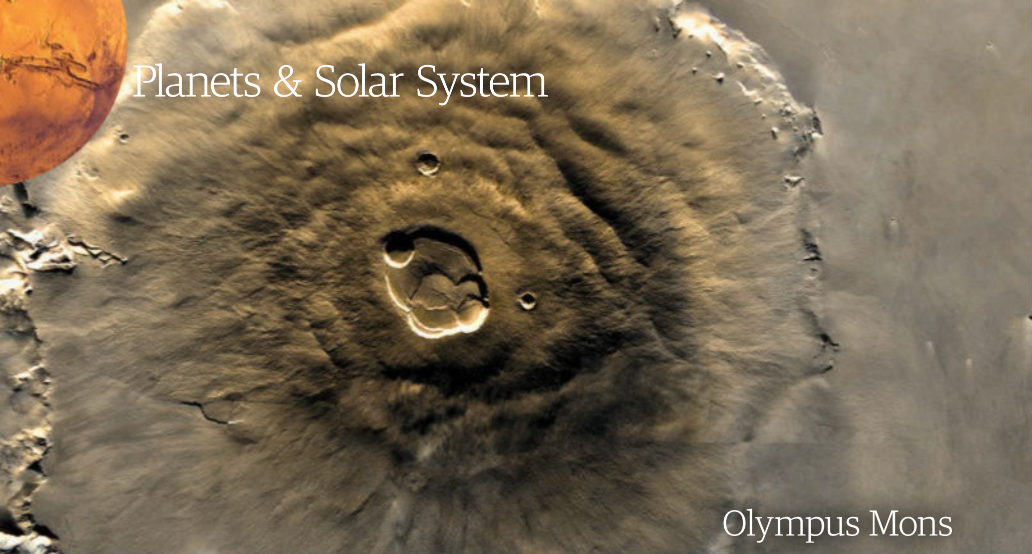
Mars is believed to have ice underneath its surface - and there are also ice caps at the poles, their size depending on the seasons. Because Mars has a similar tilt to the Earth, it does have four seasons - they're just longer and of varied lengths. Temperatures can get as low as minus 143°C (minus 225°F) at the ice caps in the winter. The ice beneath the surface freezes and melts depending on the temperature. The atmospheric pressure on Mars is much lower than the Earth's, and it's so thin that there is very little to block the surface from the Sun's heat. There are ice clouds, probably caused when the wind kicks up dust, while one of the Red Planet's biggest weather features is dust storms, which can last up to a month.



Temperatus on Mars can get very low, and there are ice caps on the poles

"Mars has four seasons - they're just longer and of varied lengths."





Olympus Mons

Polar ice caps

Canyons, craters and deserts

Mars is home to some of the largest planetary features in the Solar System

Olympus Mons
Olympus Mons is the tallest known mountain in the Solar System at 22km (14 mi) high. It's more than twice the size of Mount Everest and is an extinct volcano.

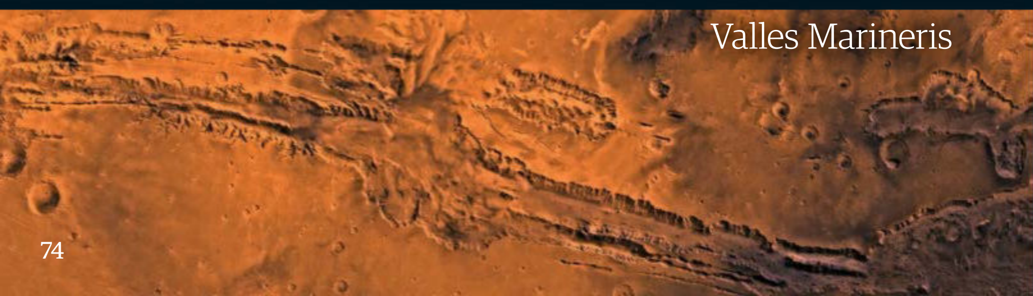
Polar ice caps
This polar ice cap on the southern end of Mars grows and wanes each year depending on the season. It is made up of both water ice and dry ice (frozen carbon dioxide).

Valles Marineris
Valles Marineris is a system of canyons located along the equator of Mars and covers almost 25 per cent of the planet's circumference. It is around 7km (four mi) deep, 200km (124 mi) wide and 4,000km (2,500 mi) long. On Earth, that would be the approximate distance between New York and LA.

Water erosion
Reull Vallis is one of the valleys on Mars that look as if they may have been carved out by water movement. Many of these valleys contain grooves on their floors that may be rich in ice.

Sand dunes
Regolith - a mix of soil, sand, dust and broken rocks - has drifted into dunes on Mars's surface. We once thought they were stationary, but observations have shown that the dunes actually constantly move due to the prevailing winds.

Hellas Basin
The Hellas Basin is one of the biggest impact craters in the Solar System. At 2,300km (1,400 mi) in diameter, it is wider than Texas.



Valles Marineris


Water erosion


Sand dunes


Hellas Basin

Mars in numbers

Fantastic figures and surprising statistics about the Red Planet

2,300km

The diameter of Mars's Hellas Basin is the same as the diameter of Pluto

2

Mars has two known satellites: the moons of Phobos and Deimos

271 years and 221 days

How long it would take you to get to Mars from Earth if you could drive there in an average car at 97km/h (60mph)

14.5

Travelling at a speed of 14.5 miles per second compared to the Earth's 18.5 miles per second, Mars is slower to orbit the Sun

687 Earth days

A year on Mars is 687 Earth days, while a day on Mars is equivalent to 1.026 Earth days

37.5%

Gravity on Mars as a percentage of Earth's. If you could visit, you could jump three times as high as you can on our planet

Exploring Mars

The failure rate for exploring Mars has been high

MSL launches atop a Atlas V rocket on 26 November 2011

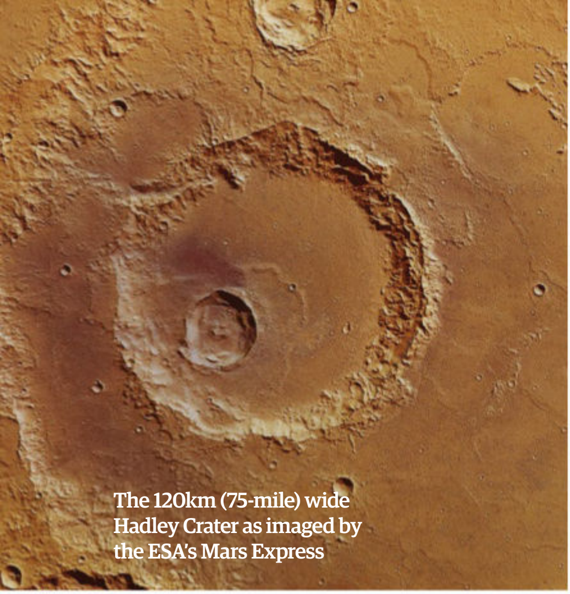
The Soviet Union, not the United States, was the first country to attempt a Mars exploration - but it was unsuccessful. The Mars 1M was just the first of many failed attempts to visit Mars. Since that first attempt in 1960, 43 different spacecraft have tried and only 14 of them completed their missions. Mars 1M had a launch failure, but other probes have been the victims of communication problems, computer malfunctions and even the planet itself. It's been so difficult to get to Mars that some have dubbed the challenge the "Martian curse", and one journalist in the United States jokingly said that there's a "Galactic Ghoul". So why has it proved so difficult to get there?

It takes a spacecraft about seven months on average to travel the 225 million kilometres (140 million miles) to Mars. Once it reaches the planet, if the orbiter has a lander then it must successfully separate and have the lander touch

Major missions

Mars 1M
Oct 1960
These Soviet missions were the first in the quest to explore Mars. Mars 1M No 1 experienced a launch failure on 10 October 1960. Mars 1M No 2 met the same fate.

Mariner 4
28 Nov 1964-21 Dec 1967
Mariner 4 performed the first flyby and returned the very first colour images of Mars. These were also the first images taken of another planet from deep space.



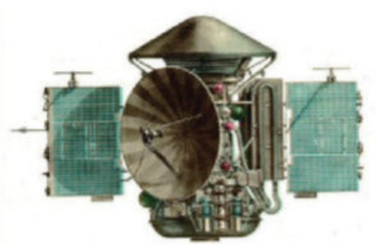
The 120km (75-mile) wide Hadley Crater as imaged by the ESA's Mars Express

The Opportunity rover has been on Mars's surface since 2004

down gracefully. And Mars can be unpredictable. Things like dust storms and soft soil have impeded landers, for example. But we do have to remember that most of total failures were early in our space exploration. While there have been some memorable failures, e.g. the 1999 Mars Climate Orbiter, which was pure human error. In that case, a contractor used imperial units instead of metric, which caused the probe's rocket to shut down early and crash into the planet.

Currently there are three orbiters around Mars: the Mars Odyssey and Mars Reconnaissance Orbiter, both from NASA, and the European Space Agency's Mars Express. The Opportunity rover has been on the surface since 25 January 2004 and Curiosity recently joined it. Despite the high failure rate, we'll continue to explore the Red Planet. It's just too fascinating to keep away.

"It takes a spacecraft about seven months to travel the whole 225 million km to Mars"

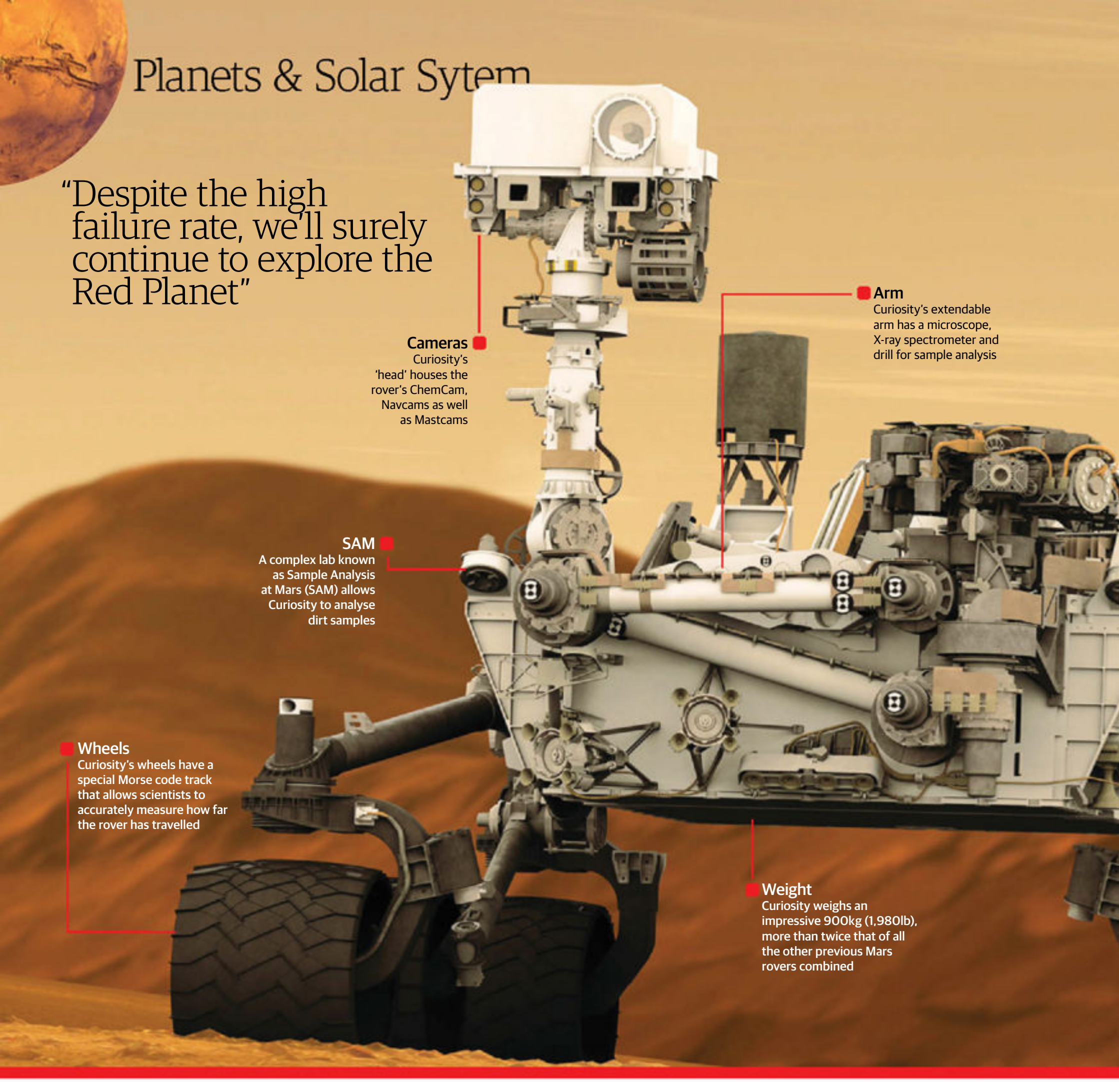


Mars 2 & 3
19 May 1971-22 Aug 1972

The Soviet-built Mars 2 became the very first spacecraft to land – or rather crash – into the surface of the planet. Mars 3 had a soft landing on 2 December 1971.

Viking 1 & 2
20 Aug 1975-13 Nov 1982

The Viking 1 landed softly and safely, and sucessfully completed its mission. It also held the record for longest Mars mission until the Opportunity rover.

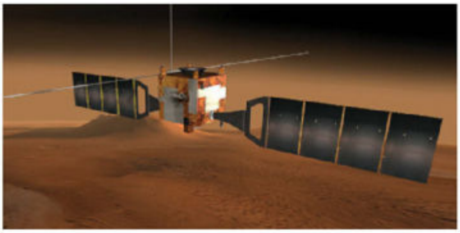


"Despite the high failure rate, we'll surely continue to explore the Red Planet"

Mars Polar Lander

3 Jan 1999-3 Dec 1999

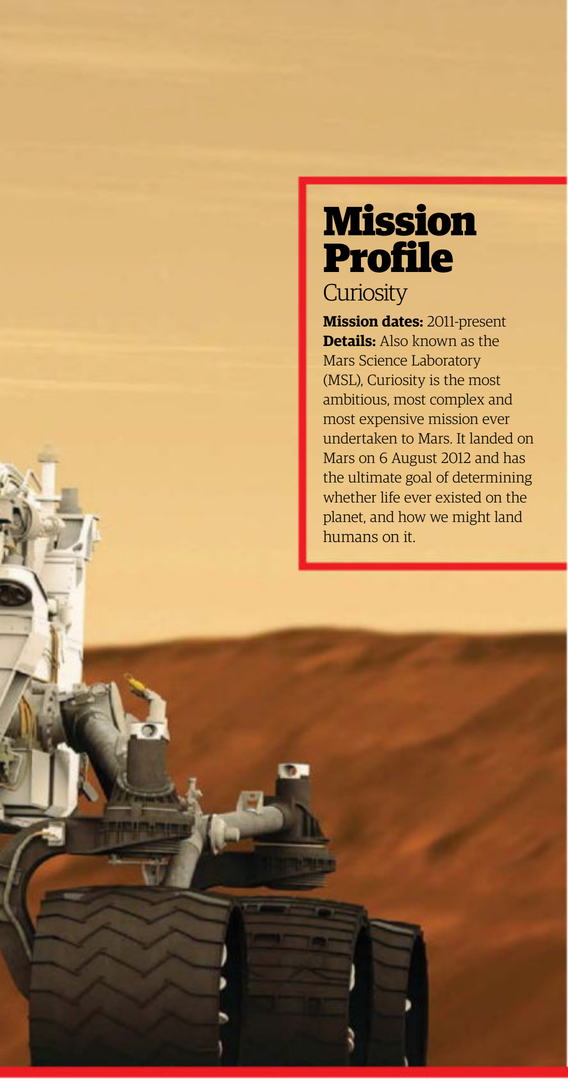
The Mars Polar Lander was meant to perform soil and climatology studies on Mars, but NASA lost communication with it and it's believed it crashed.



Mars Express Orbiter

2 Jun 2003-present

The ESA's first planetary mission consisted of the Beagle 2 lander and the Mars Express Orbiter, with the latter still operational today.



Mission Profile

Curiosity

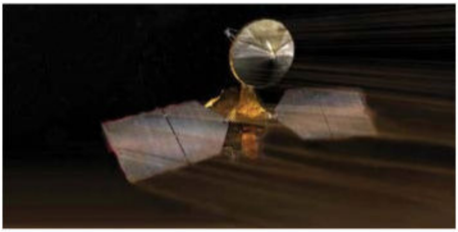
Mission dates: 2011-present
Details: Also known as the Mars Science Laboratory (MSL), Curiosity is the most ambitious, most complex and most expensive mission ever undertaken to Mars. It landed on Mars on 6 August 2012 and has the ultimate goal of determining whether life ever existed on the planet, and how we might land humans on it.

The Curiosity rover is equipped with an arsenal of technology, but its remote use is limited. The next major step in the exploration of Mars is returning samples: the aim of NASA's proposed Mars sample-return programme.

Several attempts to plan such a mission have failed, like the proposed ExoMars mission for 2018, with cost and technological barriers preventing progress. However, with the continuing success of Curiosity, and the planned Mars 2020 rover mission, new plans for Mars sample-return are underway. The current model involves three separate launches, allowing smaller rockets to be used, and enabling NASA to carefully time each stage of the mission.

The Mars 2020 rover could mark the first stage of the project. It will study the history and potential habitability of Mars by analysis of collected rock samples. It's based on Curiosity, so much of the technology has been developed and tested. The difference is it will carry equipment to retrieve and analyse geological samples.

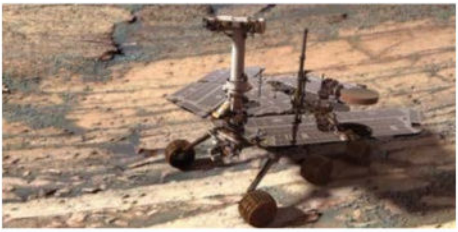
The rover will contain the equipment required to identify samples, including digital imaging software, and using a combination of infrared, ultraviolet and visible light, samples will be selected based on colour and texture. The surfaces of Martian rocks have been chemically altered by weathering and radiation, so drilling equipment will access the core where traces of biological material could have survived.



Beagle 2

2 Jun 2003-19 Dec 2003

The Beagle 2 lander was lost six days before it was due to enter the Martian atmosphere. Attempts were made to contact it, but these ended in failure.



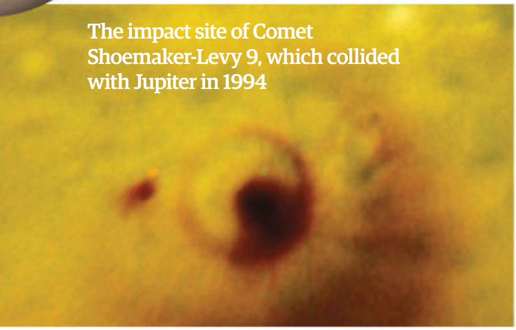
Opportunity

7 Jul 2003-present

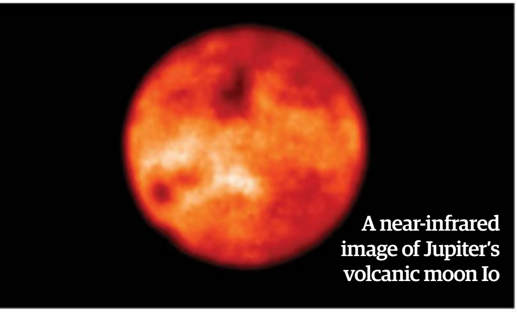
Opportunity was a rover launched shortly after its twin, Spirit. While Spirit ceased communications back in 2010, Opportunity is still going strong.

JUPITER

Volatile and violent in nature and named after the Roman king of gods, the largest world in our Solar System has twice the mass of all other planets combined. Discover more about the gas giant that is king of the planets



The impact site of Comet Shoemaker-Levy 9, which collided with Jupiter in 1994

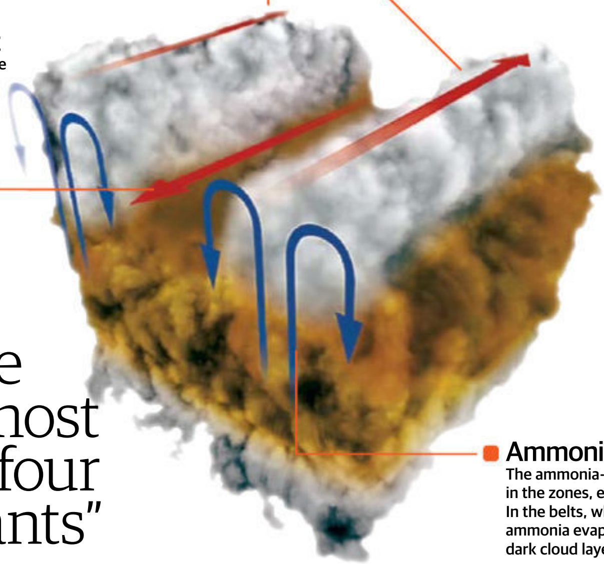


A near-infrared image of Jupiter's volcanic moon Io

If you had to choose one word to describe Jupiter, it would have to be 'big'. It has a diameter of 142,984 km (88,800 mi) at its equator, about 11 times that of Earth's diameter. With a huge magnetic field and 64 moons and natural satellites, Jupiter could almost be a miniature solar system. Sometimes it's even been referred to as a 'failed star' because it's made of the same gases as the Sun - though it would need a mass about 80 times that of its current one to qualify. But 'star' is how the ancients thought of it, at least until Galileo noticed that the planet had four prominent moons - Callisto, Europa, Ganymede and Io. It was the first time movement in the Solar System not centred on Earth was discovered, which helped cement Copernicus's theory of a heliocentric - or sun-centred - astronomical model.

Jupiter is the innermost of the four gas giants, along with Saturn, Uranus and Neptune - planets that mainly comprise gas and are more than ten times that of Earth's mass. The gases get denser as you get closer to the planet's core.

Cloud formation



Prograde jet
The lighter-coloured zones are bordered by eastward, or prograde jets, and comprise denser clouds with high concentrations of ammonia

Retrograde jet
Dark-coloured bands are bordered by westward, or retrograde jets, comprising low clouds which are very high in sulphuric compounds

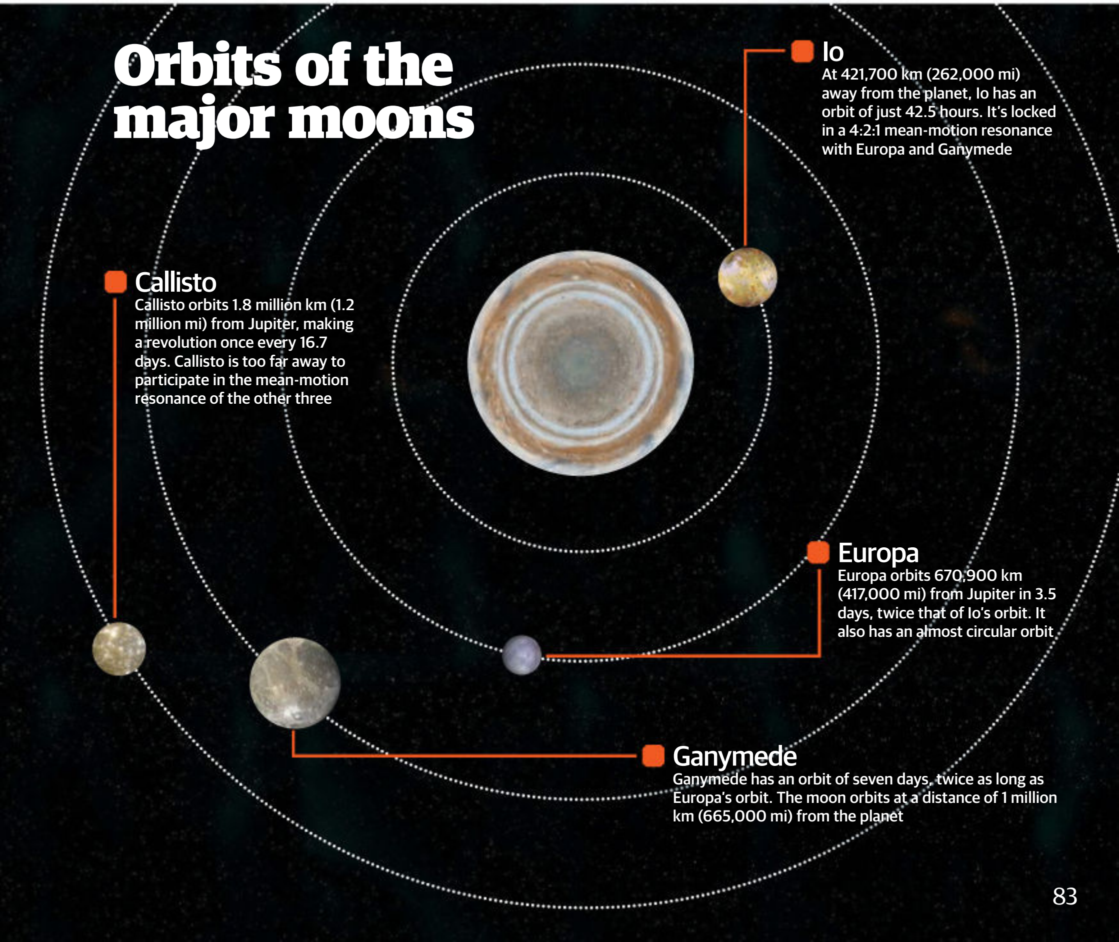
Ammonia-rich air
The ammonia-rich air on Jupiter rises in the zones, expanding and cooling. In the belts, which are warmer, the ammonia evaporates and reveals the dark cloud layer below

"It is the innermost of the four gas giants"

Jupiter's surface area is over 120 times greater than Earth's

Since Jupiter is the largest – the next-largest is Saturn with a diameter of 120,536 km (75,000 mi) – it's not surprising that these gas giants are also called the Jovian planets. Jupiter's mass is 317.8 times that of Earth's and 0.001 times that of the Sun's; sometimes planets outside the Solar System are defined in terms of Jupiter's mass. What's amazing is that Jupiter was actually larger when it was first formed – it's been shrinking about two centimetres (0.8 inches) per year due to its heating and cooling process. Jupiter's so massive that its barycentre – or centre of mass with the Sun – lies outside the Sun at 1.068 solar radii above its surface. Although Jupiter is large in diameter and mass, it's not very dense thanks to its gaseousness. Jupiter has a density of 1.33

"With a huge magnetic field and 64 moons it could almost be a miniature solar system"

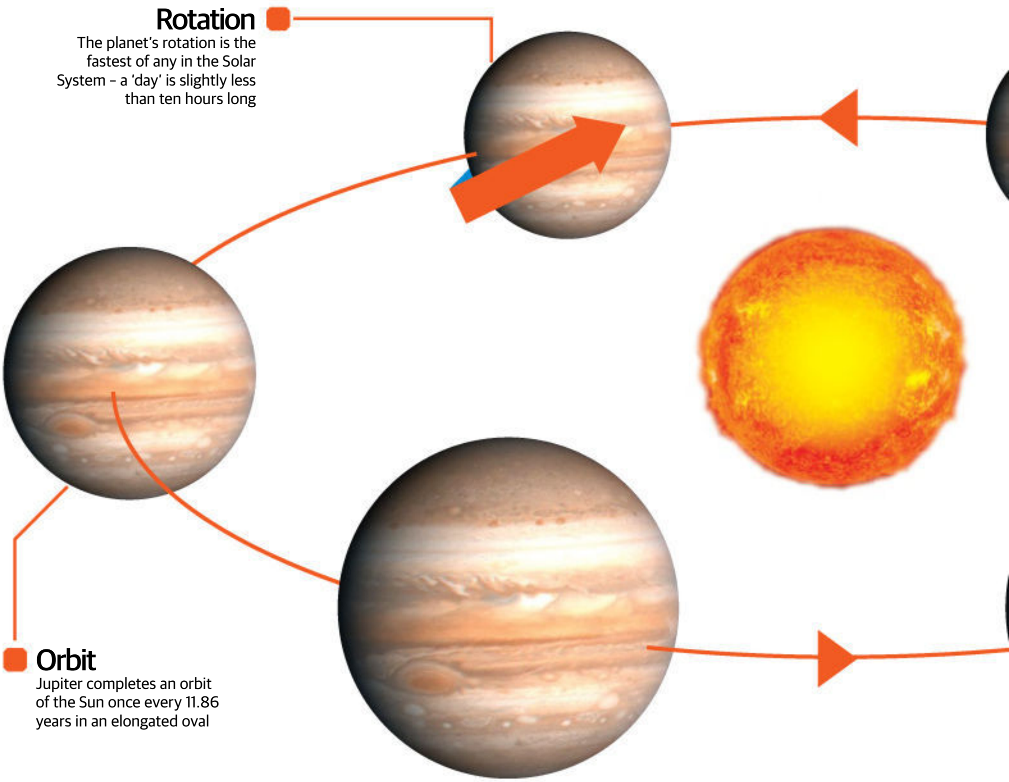


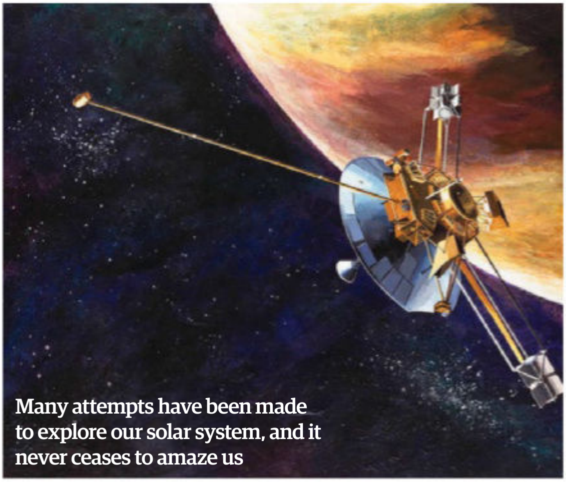
grams per cubic centimetre, which is about 25 per cent that of Earth's density.

Jupiter is 779 million km (484 million mi) from the Sun on average, completing an orbit once every 11.86 years. This is two-fifths the orbit of Saturn, putting the planets in an orbital resonance of 5:2. It has a very small axial tilt of just 3.13 degrees, so there are no seasons on the planet. It has the fastest rotation of all the planets, taking a quick spin on its axis once every ten hours or so. This gives the planet a bulge around its equator and the shape of an oblate spheroid - it has a larger diameter around its centre than its poles. Because Jupiter is a gas planet, not all of the planet orbits at the same speed. It basically has three different systems - the atmosphere at the poles rotates about five minutes faster than the equatorial atmosphere, which is a little bit slower than the rotation of the magnetosphere (just under ten hours, the official rotation period).

Jupiter is about more than just its size, of course. It has a very striking and unusual appearance, with moving bands of red, orange, white and brown. The planet is the fourth-brightest object in our night sky. If you do some long-term observation of Jupiter, you might notice that at some point it appears to move backwards, or in retrograde, with r espect to the stars. That's because the Earth overtakes Jupiter during its orbit once every 398.9 days. You'll also see that Jupiter never appears completely illuminated - its phase angle, the angle of the light reflected from the Sun, is never greater than 11.5 degrees. To see the entire planet, we had to visit it. ●

The gas giant in orbit

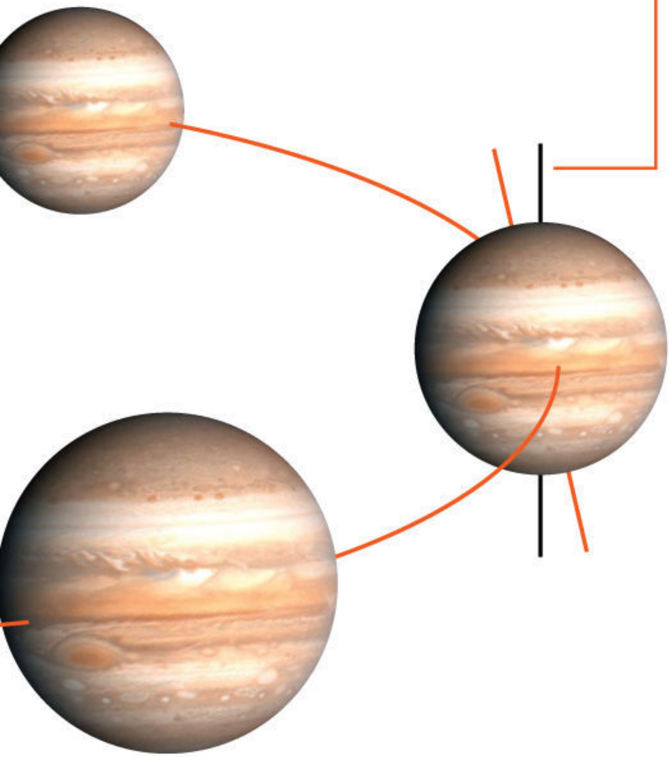




Many attempts have been made to explore our solar system, and it never ceases to amaze us

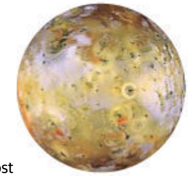
Axial tilt

A tilt of 3.13 degrees means that the northern and southern hemispheres get equal exposure to the Sun – therefore there are no seasons on Jupiter



The Galilean moons

Io



Io is the innermost of the Galilean moons, and also the fourth-largest moon in the Solar System at 3,642 km (2,200 mi) in diameter. Unlike most moons, Io is mainly silicate rock and has a molten core. That's probably why it has more than 400 active volcanoes, making it the most volcanically active body – moon or planet.

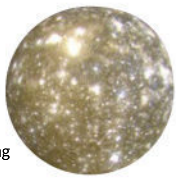
Europa

The second-closest Galilean moon to Jupiter, Europa is also the smallest of the four moons. It's slightly smaller than our own Moon with a diameter of around 3,100 km (1,940 mi). It has a smooth surface of ice and probably has a layer of liquid water underneath, leading to theories that life may be able to exist on this moon.

Ganymede

Ganymede is the largest moon in the Solar System – at 5,268 km (3,300 mi), it's actually larger than the planet Mercury, although it has half the mass. This moon is also the only known moon with a magnetosphere, probably due to a liquid iron core. This moon also comprises both ice and silicate rock, and it's believed that there may be a saltwater ocean below the surface.

Callisto



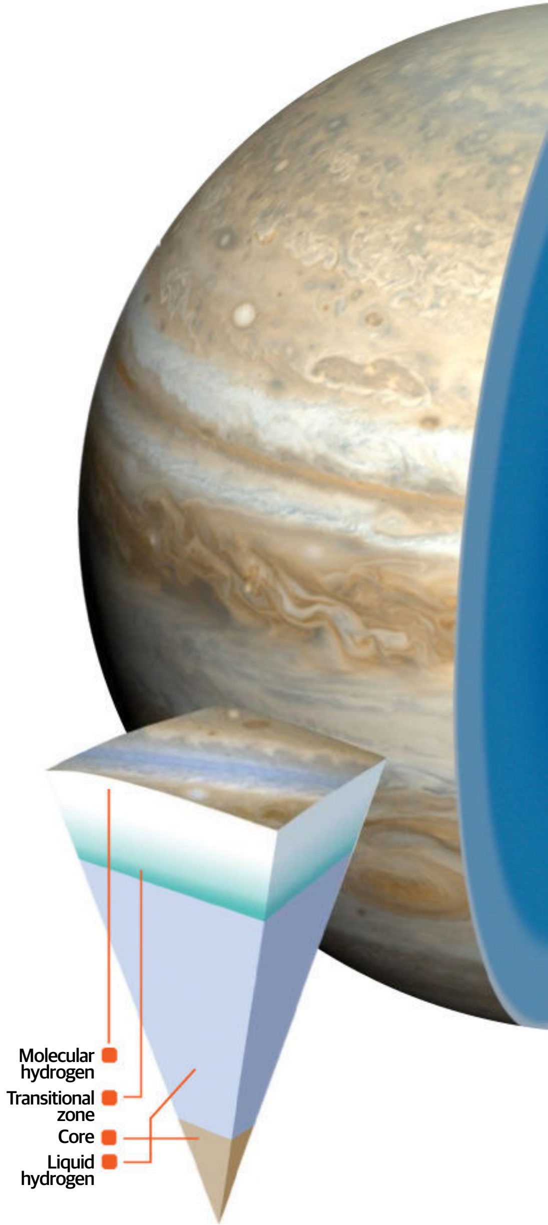
Being the outermost Galilean moon, Callisto is furthest from Jupiter and its strong radiation and therefore might be a good base for exploring the planet. The moon is composed equally of water-ice and rock, and there's also the possibility that it may be able to support life. It has a heavily cratered surface as well as a thin atmosphere, which is most likely composed of oxygen and carbon dioxide.

Jupiter inside and out

Jupiter gets more interesting the closer you get to its centre

Since Jupiter is a gaseous planet, it's mostly about atmosphere. The gases just get denser, hotter and under greater pressures as you go further towards the centre. Jupiter is about 90 per cent hydrogen and ten per cent helium - volume-wise. But if you measure the composition of the planet by mass, there's 75 per cent hydrogen and 24 per cent helium. There are also traces of ammonia, methane, carbon, hydrogen sulphide and other elements and compounds. No probe has penetrated the cloud cover below 150 km (93 mi), but we believe Jupiter isn't entirely gaseous and has a rocky core containing silicates and other elements, with a mass that is 10 to 15 times that of Earth. The idea of a rocky core is based on gravitational measurements taken by probes, but this model is uncertain until we get more data from NASA's Juno mission (set to enter Jupiter's orbit in July 2016). Current projections for the interior show a layer of liquid metallic hydrogen along with helium surrounding the core, with a layer of molecular hydrogen outside.

Temperatures on Jupiter vary widely. In the cloud layer, they're as cold as -145°C (-234°F), but further towards the core, as the hydrogen becomes liquid, it reaches 9,700°C (17,500°F), and the core may be as hot as 30,000°C (54,000°F). Jupiter generates almost as much heat it receives from the Sun, via the Kelvin-Helmholtz mechanism. The surface cools, which also results in a loss of pressure. The whole planet shrinks, compressing the core, causing it to heat up. The core's pressure is up to 4,000 GPa (gigapascals) compared to Earth's core's 360 GPa.



Magnetic axis
Jupiter's magnetic field is a dipole, radiating from each end of its magnetic axis (poles)

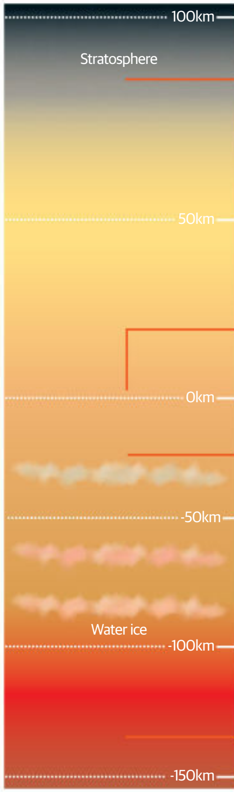
Core
This rocky core is believed to be 10 to 15 Earth masses, super-hot and highly pressurised

Liquid hydrogen
Temperatures are hot enough to turn the hydrogen here into a metallic liquid, also the source of Jupiter's magnetic field

Transitional zone
The liquid metallic hydrogen transitions as temperatures and pressures drop closer to the surface

Molecular hydrogen
Plain hydrogen with a little helium changes from liquid in the under layer to gas at the surface

The structure of the atmosphere

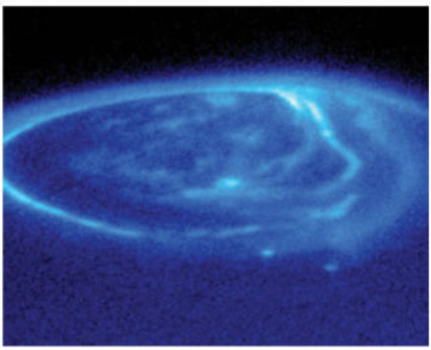


Stratosphere
The stratosphere is still mostly hydrogen, with methane, ethane, acetylene and other light hydrocarbons

Haze layer
Above the cloud layer there's a layer of hydrazine haze, made by interactions between ultraviolet radiation from the Sun and methane in the stratosphere

Troposphere
The upper clouds are the lightest, of ammonia, and get denser as they change to ammonium hydrosulphide, then to water

Gas layer
The 'surface' of the planet is defined by pressure and temperature – both begin to drop as the gases dissipate



Jupiter has auroras just like Earth – charged particles from the solar wind interact with the planet's magnetic field, resulting in a glowing display

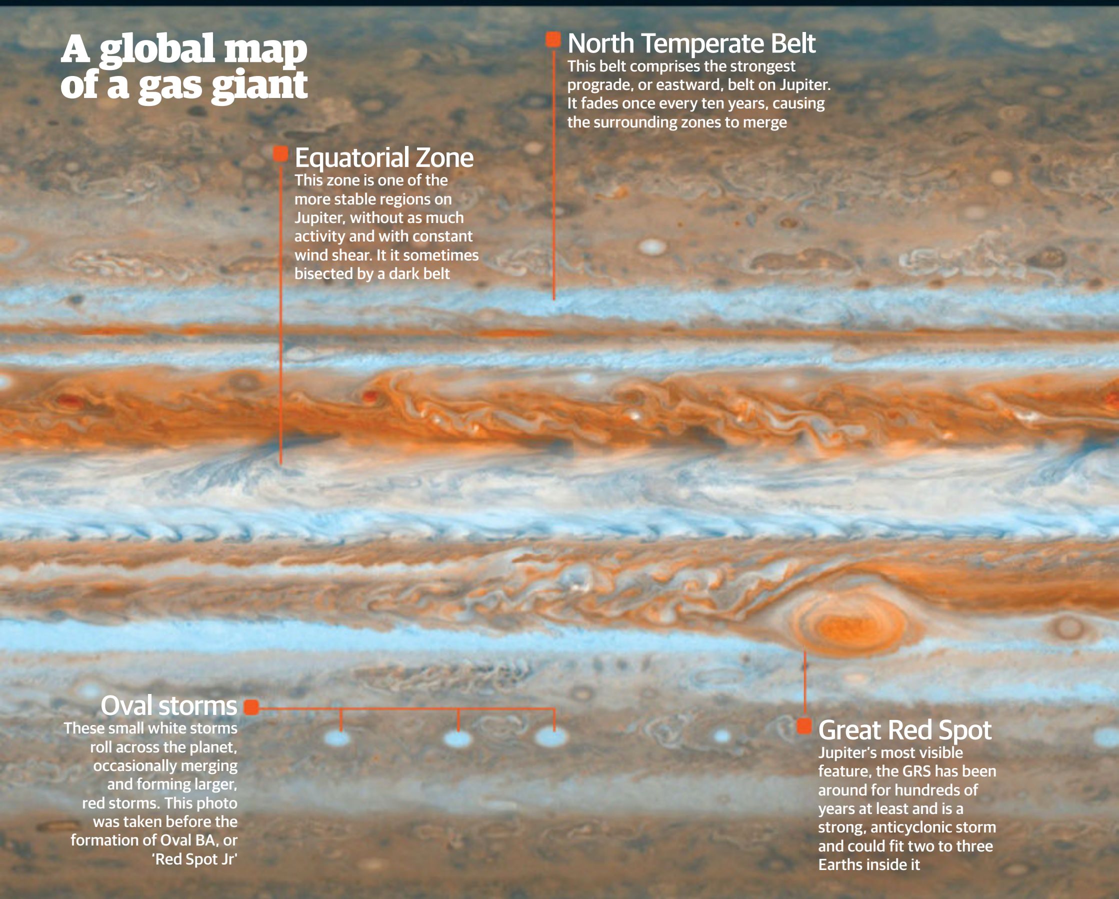
In the clouds

It might not have a surface like a rocky planet would, but the clouds of Jupiter are a fascinating phenomena worth exploring

The colours visible in photos of Jupiter are a result of the different layers of clouds in the atmosphere which move and flow in complex patterns. They're called bands, and there are two different kinds: lighter-coloured areas, known as zones, and dark-coloured ones called belts.

Zones are dense ammonia ice clouds in higher areas, while the dark belts contain thinner, lower, warmer clouds. Their red/orange colours come from sulphur and phosphorous, while carbon creates some of the lighter grey colours.

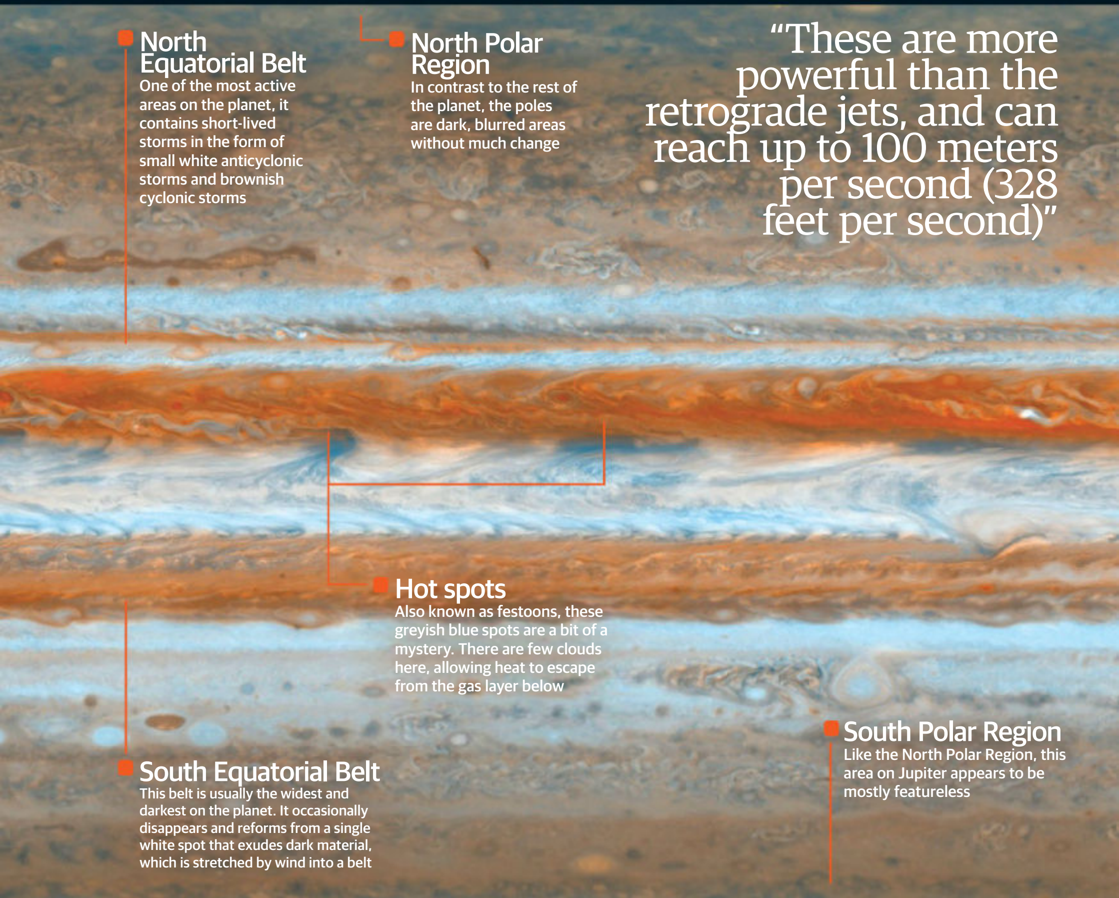
The equator is circled by a zone, known as the Equatorial Zone (EZ), that stretches from seven degrees north and seven degrees south of the equatorial line. There are dark Equatorial Belts (EB) extending from the EZ at 18 degrees north



and south on either side. Tropical zones are on either side of each EB. The zones and belts then alternate until reaching each of the poles, where they become more difficult to distinguish. Many of the belts and zones have names, each with distinctive features and movements.

Each belt is surrounded by wind jets, called zonal atmospheric flows. The transitional areas from the belts to the zones (headed towards the equator) are marked by westward, or retrograde jets. Eastward, or prograde jets, mark transitions from zones to belts heading away from the equator. These are more powerful than retrograde jets, and reach speeds of up to 100 metres (328 feet) per second. In the belts, the wind shear is cyclonic - the air flows in the same direction as Jupiter's rotation. Zone wind shear, however, is anticyclonic. An exception is the Equatorial Zone - it has a prograde jet with little movement along the equator.

While Jupiter doesn't have seasons because of its small axial tilt, it does have weather patterns. The evaporation and condensation process of water creates dense clouds. These are strong storms, including powerful lightning strikes, mainly in the belts. Storms on Jupiter tend to be very short, but a few major storms have been raging for a long time. The biggest and most well-known of these is the Great Red Spot, which has been around for 180 to 300 years.



The changing Great Red Spot

A storm with the circumference of Earth that's raged for centuries

Sometimes our storms seem like they're never going to end, but imagine a storm that's been going for hundreds of years. The Great Red Spot is a dark red, anticyclonic storm with an extremely high pressure.

It is currently between 12,000 and 14,000 km (7,500 to 8,700 mi) wide north to south and 24,000 to 40,000 km (15,000 to 25,000 mi) east to west. Some data suggests that it was originally much bigger, but its shrinkage doesn't mean that it's disappearing.

The clouds that make up the GRS are higher - at least eight km (five mi) - and therefore colder than the surrounding clouds. Its darkest, reddest area in the centre is significantly warmer than the rest, and actually has a mild clockwise rotation. The colours of the GRS vary wildly - sometimes they're strong, dark reds and oranges, other times, it gets so pale that it disappears, leaving a sort of niche behind in the South Equatorial Belt until it reappears. The colour is linked to that of the SEB - when the GRS is darker, the SEB tends to be lighter, and vice versa.

Why has the Great Red Spot lasted so long? We can't be sure, but one theory is that it's continually powered by the intense heat from the planet, there's no landmasses or other formations to disrupt it. It has also absorbed smaller storms in the past.

As you can see in the images taken between 1979 and 2008, the Great Red Spot has changed in appearance over time. In 1979, an image taken by Voyager 1, a white spot is visible which has a diameter roughly the same size as that of Earth. In 1999 the Great Red Spot seems to be getting darker, a change that keeps increasing between 2000 and 2006, and the Oval BA also forms.

Jupiter in numbers

Fantastic figures and surprising statistics about the gas giant

1,321

This is how many Earths could fit inside Jupiter

2.4 times

How much more you would weigh on Jupiter if you could stand on it, due to its stronger gravity

64

Of Jupiter's 64 natural satellites, most of them measure less than five km (3.1 mi)

1st

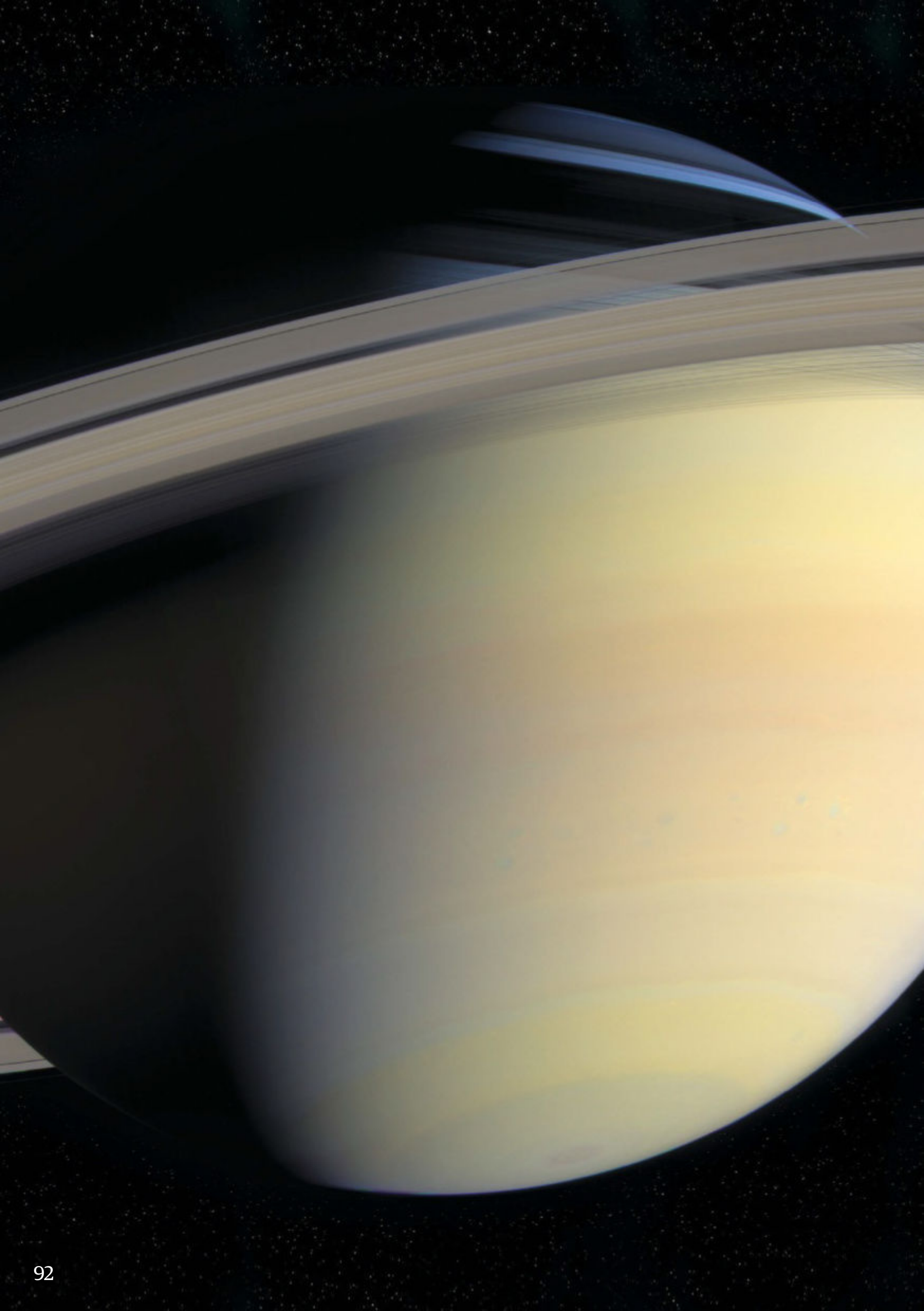
The Galilean moons of Jupiter were the first objects in the Solar System discovered by telescope

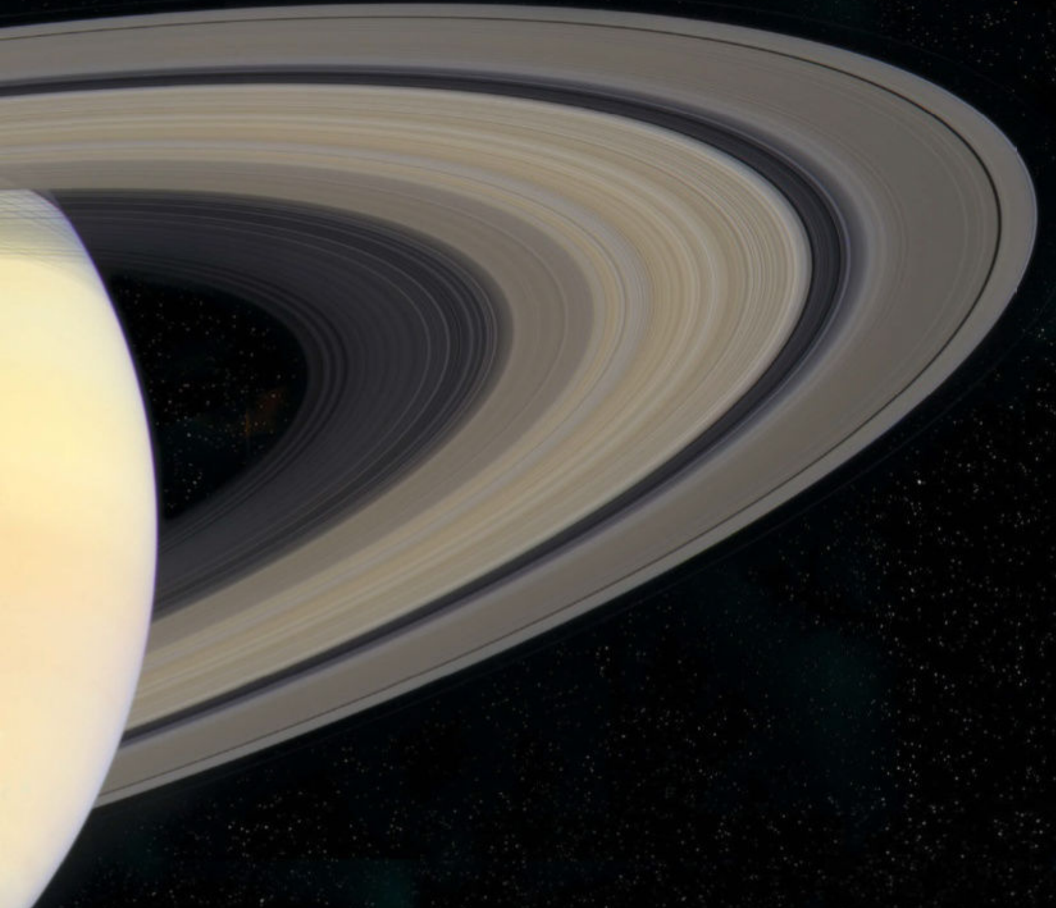
318 times

The mass of Jupiter is 318 times greater than the mass of Earth and 2.5 times that of all the other planets in our Solar System combined

50km

The thickness of the clouds and storms on the planet





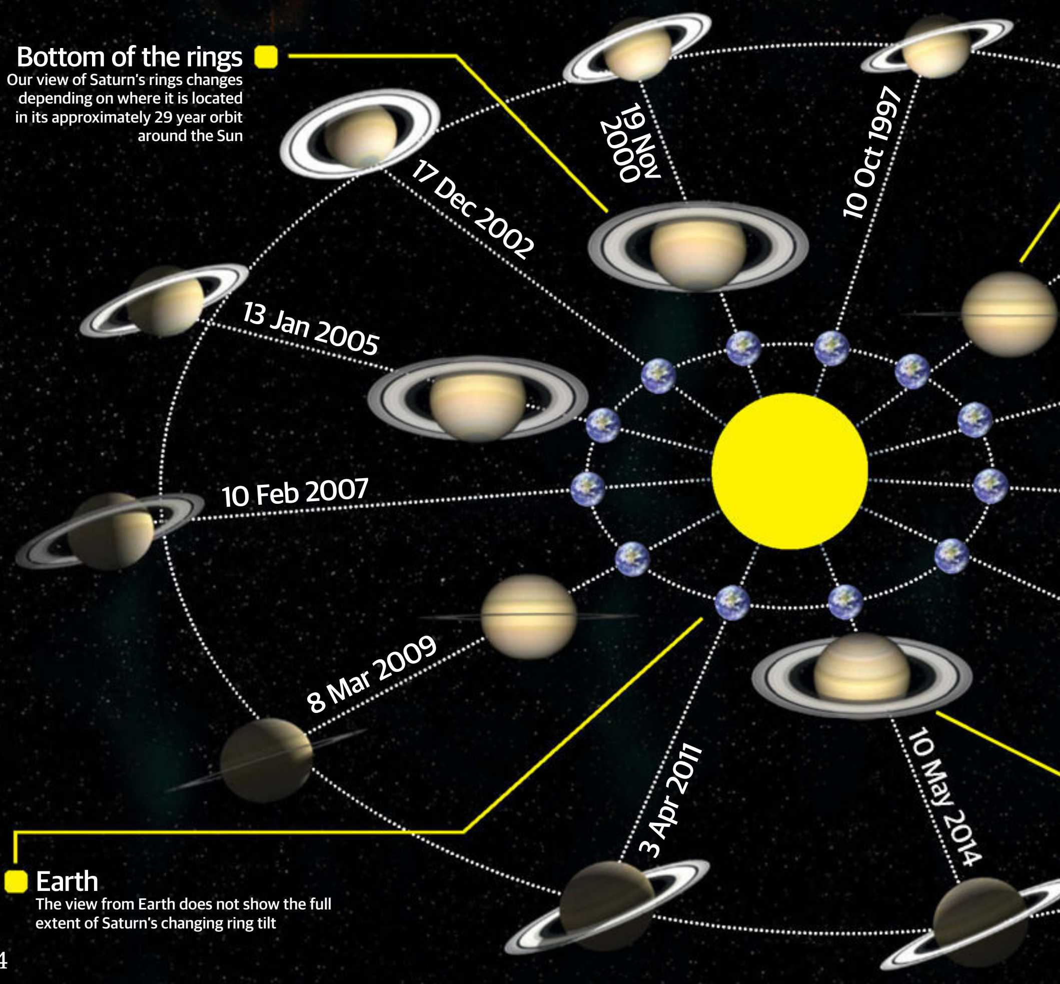
SATURN

A breathtaking and complex ring system, moons that might have the capacity to support life and awesome storms that rage at over 1,000mph. There's good reason why this beautiful planet is called the 'jewel' of the Solar System

Gas giant Saturn is the second-largest planet in the Solar System behind Jupiter and the sixth planet from the Sun. As such, it is the most distant planet that is easily visible with the naked eye from Earth. From here, it looks like a bright yellowish point. You need at least some strong binoculars if you hope to see the rings, though.

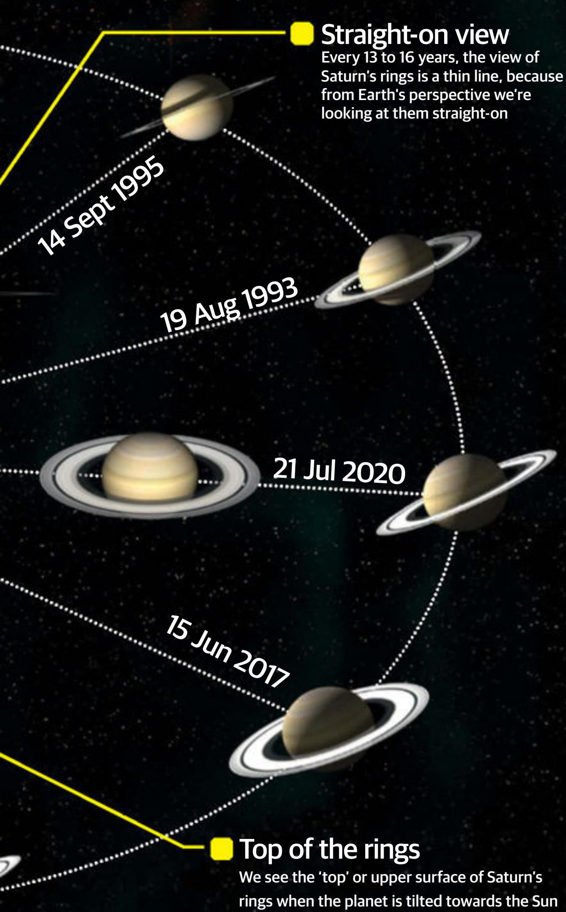
Saturn is more than 95 times more massive than the Earth, although it has just one-eighth the density. In fact, with a density of just 0.687 grams per cubic centimetre (0.397 ounces per cubic inch), it is less dense than water, meaning that it would float in an ocean if there were one big enough to hold it. Saturn is often compared to Jupiter; the two planets have similar compositions, and both have systems of cloud bands with storms that take place on the surface - although Jupiter's dark areas are much darker and its storms are much more frequent and severe than Saturn's.

Saturn's orbit



Saturn has become known as the 'jewel' of the Solar System for its appearance. But it didn't gain that moniker until we began to learn about the rings. Italian astronomer Galileo Galilei used a telescope in 1610 and spotted what we now know as Saturn's ring system (although Christian Huygens was the first to identify them as actual rings). The planet has nine rings and three arcs, with two different divisions. They might have originated with some of the nebulous material

"Saturn has more than 95 times the mass of Earth, while its radius is about nine times that of Earth's"



left from Saturn's formation, or the rings could have come from a moon that got too close to the planet and disintegrated. Most researchers believe that the rings can't be as old as Saturn itself.

Some of the planet's 62 moons have serious impacts on the rings, either contributing to the matter within them or helping to shape them with their own gravitational pulls. Most of Saturn's moons are so tiny that they're less than ten km (6.2 mi) in diameter, but some of them are unique in the Solar System. Titan, for example, is the biggest, comprising approximately 90 per cent of the mass around the planet and is larger than Mercury. It's also the only known moon to sport an atmosphere, while Saturn's moon Rhea might even have rings of its own.

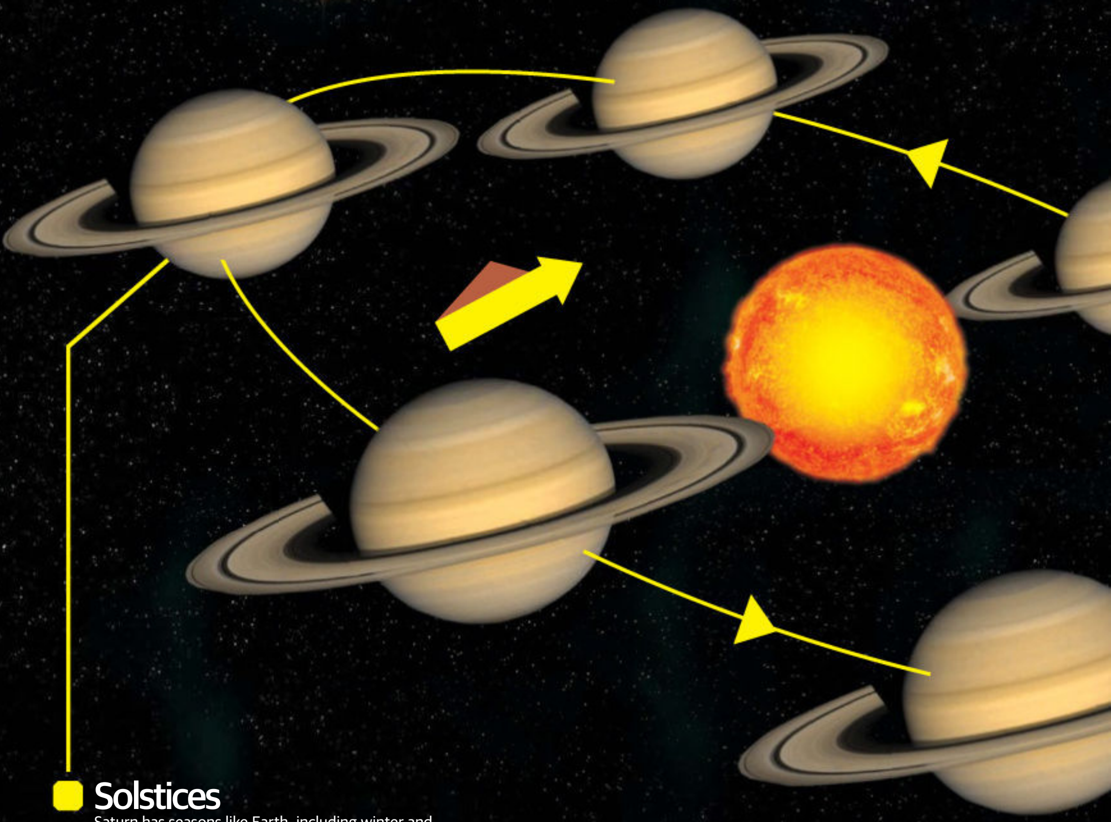
On average, Saturn is 1.4 billion km (890 million mi) away from the Sun. It receives approximately one per cent of the sunlight that we get here on Earth. Saturn has an extremely slow orbit, taking around 29.5 years to complete one. This means that although the planet's tilt gives it seasons during the rotation, each of these seasons are a little more than seven years long. Because of the rings, the seasons give us very different views of the planet from Earth - they might tilt 'up', 'down', or on the same plane as Earth depending on where Saturn is located in its orbit (meaning that they can seem to disappear unless you're using a very powerful telescope).

But how long is a day on Saturn? We aren't entirely sure. The haze and clouds prevent us from directly viewing the surface of the planet using telescopes or probes, and we know the clouds generally orbit at a constant speed so we can't use variations to make that determination. In 1980, the Voyager 1 space probe took readings of radio emissions from the planet to measure the rotation of the planet's magnetic field, and gave an estimate of ten hours, 39 minutes, and 22 seconds. In 2004, the Cassini spacecraft estimated ten hours, 45 minutes, and 45 seconds.

While six minutes may not sound like a particularly big difference, it has left scientists puzzled as to whether Saturn is slowing down in its orbit, or whether something else, such as solar wind, is interfering with the emissions. It's most likely to be the latter, however, and the current estimate (ten hours, 32 minutes and 35 seconds) is a composite made up of various readings.

Regardless, it's a speedy rotation - so fast that Saturn looks like a squashed ball as it spins on its axis - and the planet is also approximately ten per cent wider along its equator because of it.

Seasons and tilt



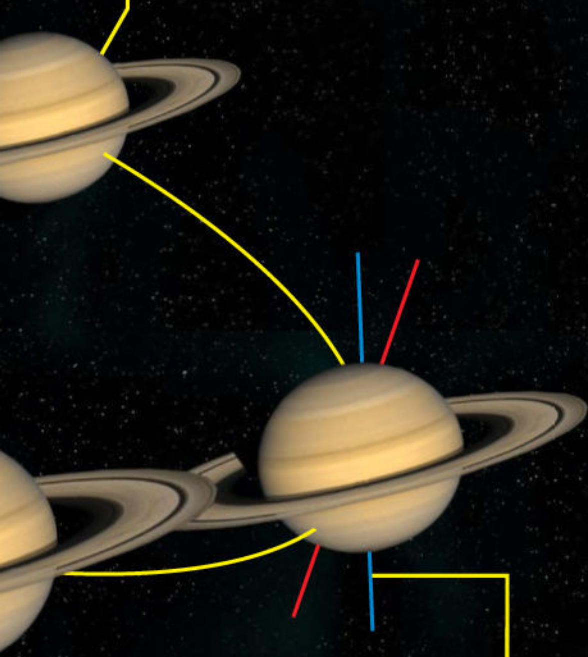
Solstices

Saturn has seasons like Earth, including winter and summer solstices (depending on which hemisphere is facing the Sun). But they last more than seven years. We see the underside of the rings during the winter and the topside during the summer


The surface of Titan holds giant lakes of liquid methane

Equinoxes

Equinoxes signal the beginning of autumn or spring depending on the hemisphere. The seasons and tilt mean that during equinoxes the rings seem to almost disappear from Earth because they're edge-on



Axial tilt

Saturn's tilt on its axis is about 26.7 degrees, very close to Earth's 23.5-degree tilt and rendered easy to see because of its rings

The major moons

Mimas

"That's no moon!" But in this case it is. Mimas is known for its appearance, which is similar to the *Star Wars* Death Star because of an extremely large impact crater (140km or 87 mi in diameter) in its northern hemisphere known as Herschel. It is a heavily cratered planet with a surface area that's about the same as Spain's.

Enceladus

Enceladus is the sixth-largest moon of Saturn and is believed to have ice water under its frozen surface. The moon is unique because it's one of just three in the Solar System that has active eruptions – in this case, gigantic ice geysers that shoot out into space. This water ice contributes to the matter in Saturn's rings as well as falling as snow on the moon itself.

Titan

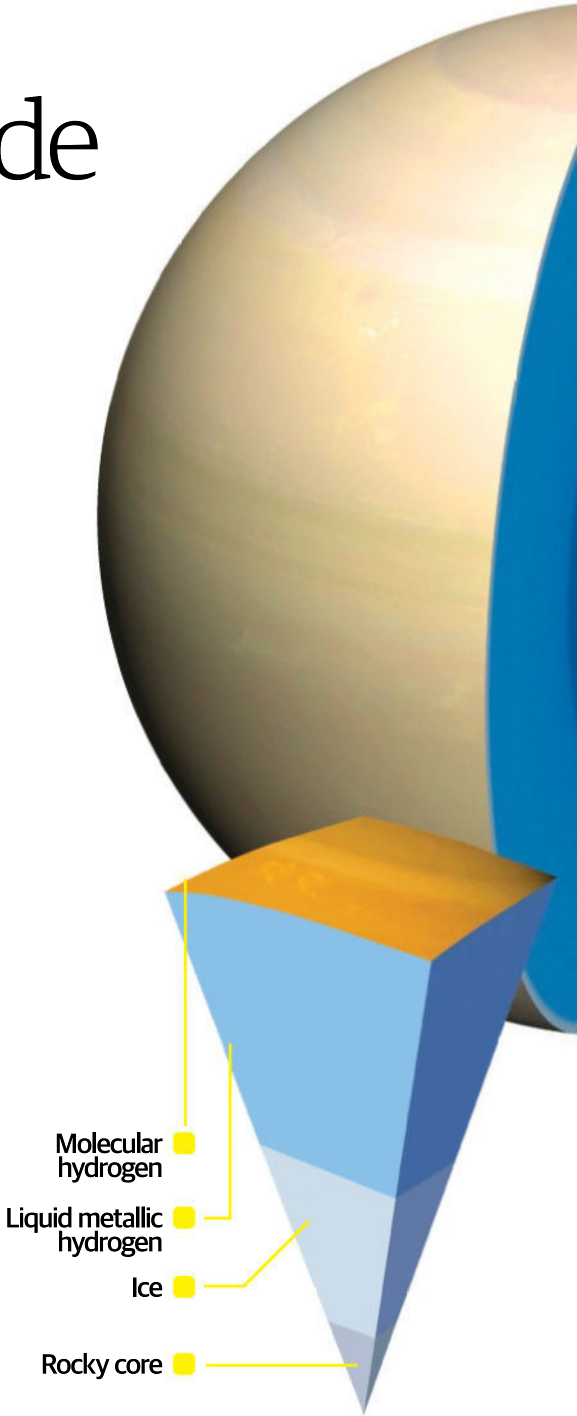
The largest moon of Saturn is particularly interesting as it's the only moon in our Solar System known to have an actual atmosphere around it. This is highly unusual and very interesting to astronomers. While we could obviously never live on Saturn, some think that Titan is a viable option for colonisation in the future or even for extraterrestrial life. The moon also has liquids on its surface, a feature so far found only on Earth.

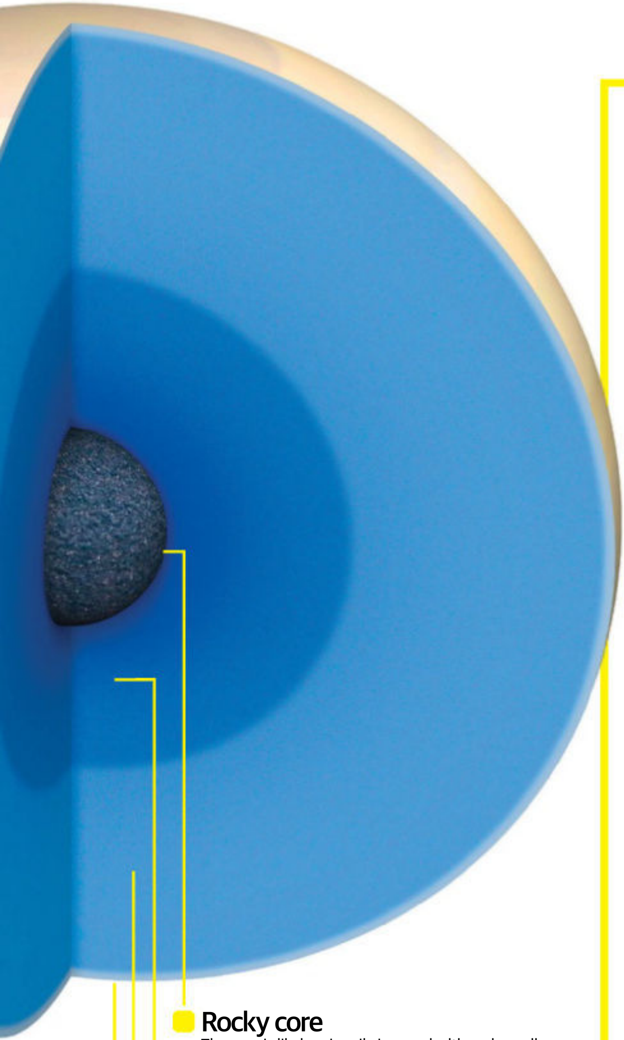
Saturn inside and out

Saturn is often compared with Jupiter, but it can hold its own

Saturn is a gas giant as it has no solid surface and is mostly composed of gas. But it does have a rocky core, which is similar in composition to the Earth's. Comprising iron, nickel and silicate rock, it is estimated to be between 10 and 20 times the size of the Earth's core. Surrounding the core, there's a layer of ice made of ammonia and other elements, then a layer of highly pressurised metallic hydrogen, and finally molecular hydrogen that changes from a liquid to a gas. The outer layers of the planet are different types of ice, including ammonia, ammonium hydrosulphide and water. The cloud cover is coloured yellow by ammonia. Density, pressure and temperature all increase as you pass through the atmosphere and into the core, resulting in a very hot interior at about 11,700°C (21,000°F). Saturn sends out more than twice the energy it receives from the Sun. Some of this is due to gravitational compression, but we aren't sure if that can account for such a huge energy output. One possibility is an interaction between helium and hydrogen in the atmosphere, which may put out heat in the form of friction.

Saturn has a magnetic field 578 times stronger than Earth's. Scientists believe that the metallic hydrogen layer generates an electric current that is responsible for the magnetic field, called a metallic-hydrogen dynamo. The magnetic field is a dipole, with north and south poles. Aside from the rings, one of the most interesting features of Saturn is its auroras. These beautiful light displays have been captured at both the north and south pole regions by the Hubble Space Telescope and the Cassini probe, and appear as circles of light around each pole.





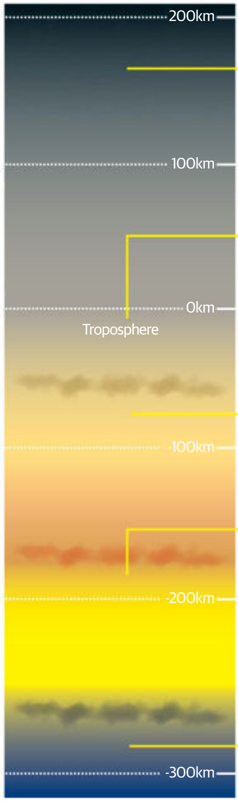
Rocky core
The core is likely primarily iron and, although small, very dense

Ice
This isn't water ice as we know it, but a mixture of ammonia, methane, hydrogen and water

Liquid metallic hydrogen
The hydrogen at this depth is under such high pressure that it transforms to a metallic state

Molecular hydrogen
This layer of hydrogen is liquid that transitions to a gas as you get closer to the atmosphere

The atmosphere of a gas giant



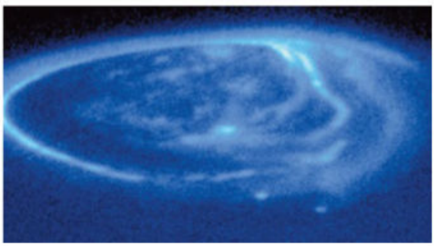
Stratosphere
This upper level is warmed by the Sun. The temperature here varies depending on the weather below

Troposphere
The outer atmosphere comprises about 96.3% hydrogen and 3.25% helium, with additional traces of other elements

Ammonia ice
Pure ammonia ice clouds sit under the troposphere, which is at 0.5 to 2 bars of pressure and -173°C to -113°C (-280°F to -171°F)

Ammonium hydrosulphide
With a pressure of 3 to 6 bars and temperatures of 17°C to -38°C (62°F to -37°F), the ice clouds are ammonium hydrosulphide

Water ice
Temperatures in this level drop all the way to -88°C to -3°C (-124°F to 26°F) and the pressure is greatest at 10 to 20 bars



This image shows one of Saturn's auroras – loops of light that occur when gases in the upper atmosphere are excited by electrons in the planet's magnetic field

In the clouds

Saturn's atmosphere has some similarities to Jupiter's

The pressure in Saturn's layered clouds increases and temperatures drop as you travel further down towards the planet's core. At the upper layer, the clouds are made up of ammonia ice, followed by water ice clouds with a layer of ammonium hydrosulphide ice, and the bottom layer is ammonia mixed in water droplets.

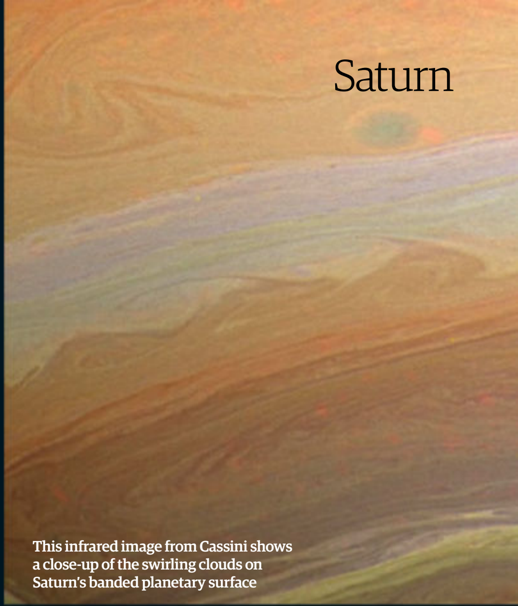
Saturn has bands of clouds that are divided into zones and belts. The zones are the lighter-coloured areas and the bands are darker, with the orange and reddish hues coming from sulphuric compounds. The bands of clouds are named in the same way that Jupiter's are labelled, according to their locations in the northern or southern hemisphere of the planet. Saturn's cloud bands are very faint and more difficult to distinguish from each other than Jupiter's. We weren't able to clearly see the

Global picture of a gas giant

distinctions between the fainter bands until the Voyager probes flew by Saturn in the Eighties.

Like Jupiter, Saturn has wind jets that alternate westwards and eastwards out from the equator. But Saturnian winds are fast, reaching maximum speeds of around 1,800 km/h (1,120 mph), they are the second fastest winds among the Solar System's planets after Neptune's.

Saturn's north polar vortex has a unique hexagon-shaped cloud pattern, with straight sides estimated to be about 13,800 km (8,600 mi) long, which appears to rotate at the same speed as the interior of the planet. The south pole is much warmer than the rest of the planet; it's believed to be the warmest spot on Saturn.


This infrared image from Cassini shows a close-up of the swirling clouds on Saturn's banded planetary surface

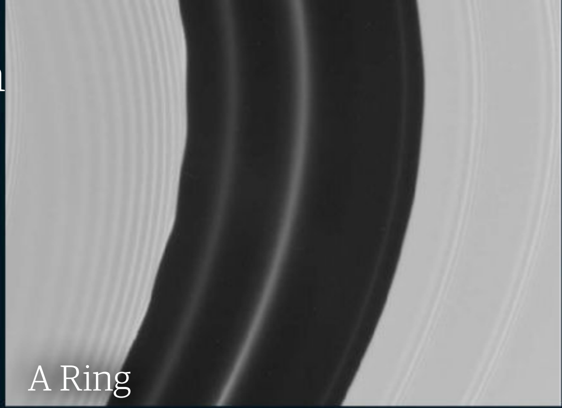
"The north polar vortex has a unique hexagon-shaped cloud pattern, with straight sides estimated to be about 13,800km long"

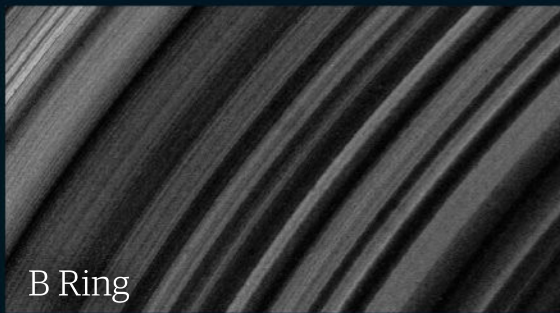
The ring system

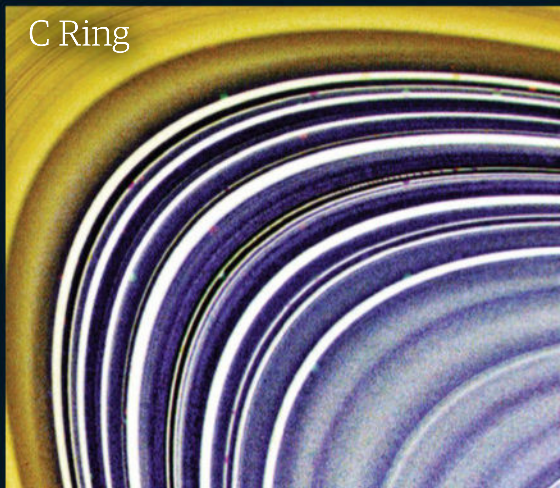
Saturn's crown jewel

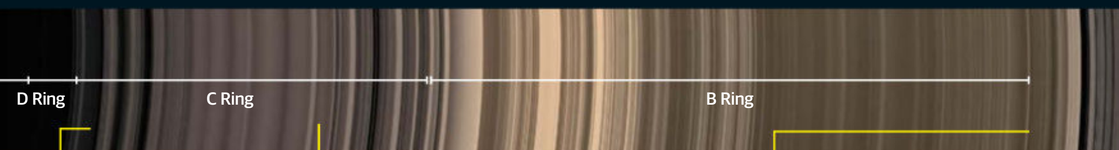
Although Saturn isn't the only planet in our Solar System with rings, it's the only one with a system this big. There are billions of tiny particles, mostly ice but with some rocky material, too. Despite the fact that they increase Saturn's brightness, we weren't even aware of its rings until Galileo observed them via telescope. He was confused a few years later when the rings seemed to disappear, not knowing that they just weren't visible with his telescope when Earth is on the same plane as Saturn. By the 1800s we knew that the rings were just that - not moons, not a single disc, but many rings comprising tiny particles.

Saturn's ring system is divided into rings, arcs, divisions and gaps. The first seven rings to be discovered were designated with letters of the alphabet A through G, but they were named in order of discovery so from innermost to outermost ring they are D, C, B, A, F, G and E. Three other named rings have been discovered since Ring G, but these are named after the moons that orbit with them: Janus, Epimetheus, Pallene and Phoebe. In addition to the rings, there are two ring arcs, incomplete trails of dust ejected by the moons Methone and Anthe kept in arc formation via resonance with two other gaps. There are also two divisions - the Cassini Division, between Rings A and B, and the Roche Division, a space between Rings A and F.







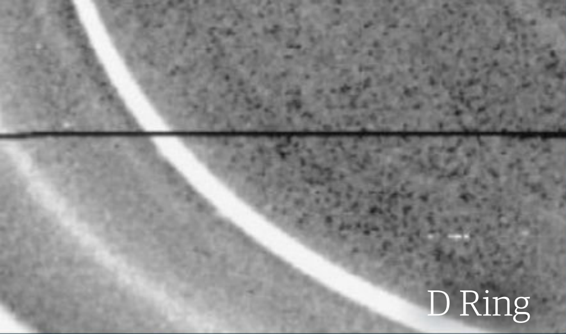


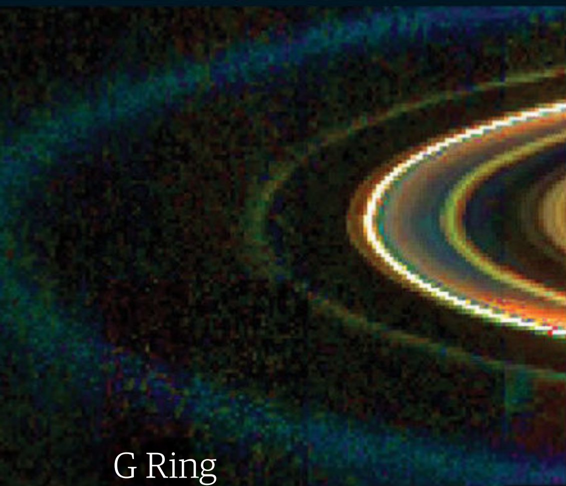
Colombo Gap
This gap, in the inner C Ring, contains a ringlet of its own called the Titan Ringlet (named because it is in orbital resonance with the moon Titan)

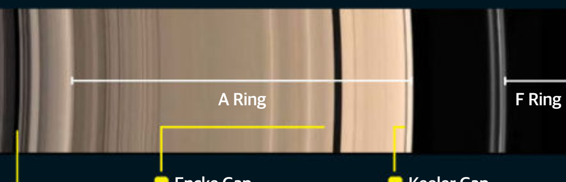
Maxwell Gap
Situated within the outer C Ring, the Maxwell Gap also has a ringlet, but it's not circular and contains wavy structures

Huygens Gap
Found at the inner edge of the Cassini Division, this gap contains a dense ringlet with an unusual structure caused by resonance with the moon Mimas

Cassini Division
Located between the A and B rings, this apparent gap in reality actually contains darker-coloured ring material







Encke Gap
This gap is located within the A Ring, and its existence is due to the moon Pan orbiting inside. Encke also contains small ringlets and has spiral density waves

Keeler Gap
The moon Daphnis is responsible for this gap located in the A Ring. Daphnis also creates waves around the gap's edges

Saturn in numbers

Fantastic figures and surprising statistics about the ringed planet

578 times

Saturn's magnetic field is 578 times more powerful than Earth's

92%

Saturn and Jupiter together comprise about 92 per cent of the planetary mass of the Solar System

14 years

Saturn's rings seem to disappear about every 14 years or so due to the fact they're so thin and we see them edge-on

80.00kg

A person weighing 80.00kg (176.37lb) on Earth would weigh 85.10kg (187.61lb) on Saturn

75%

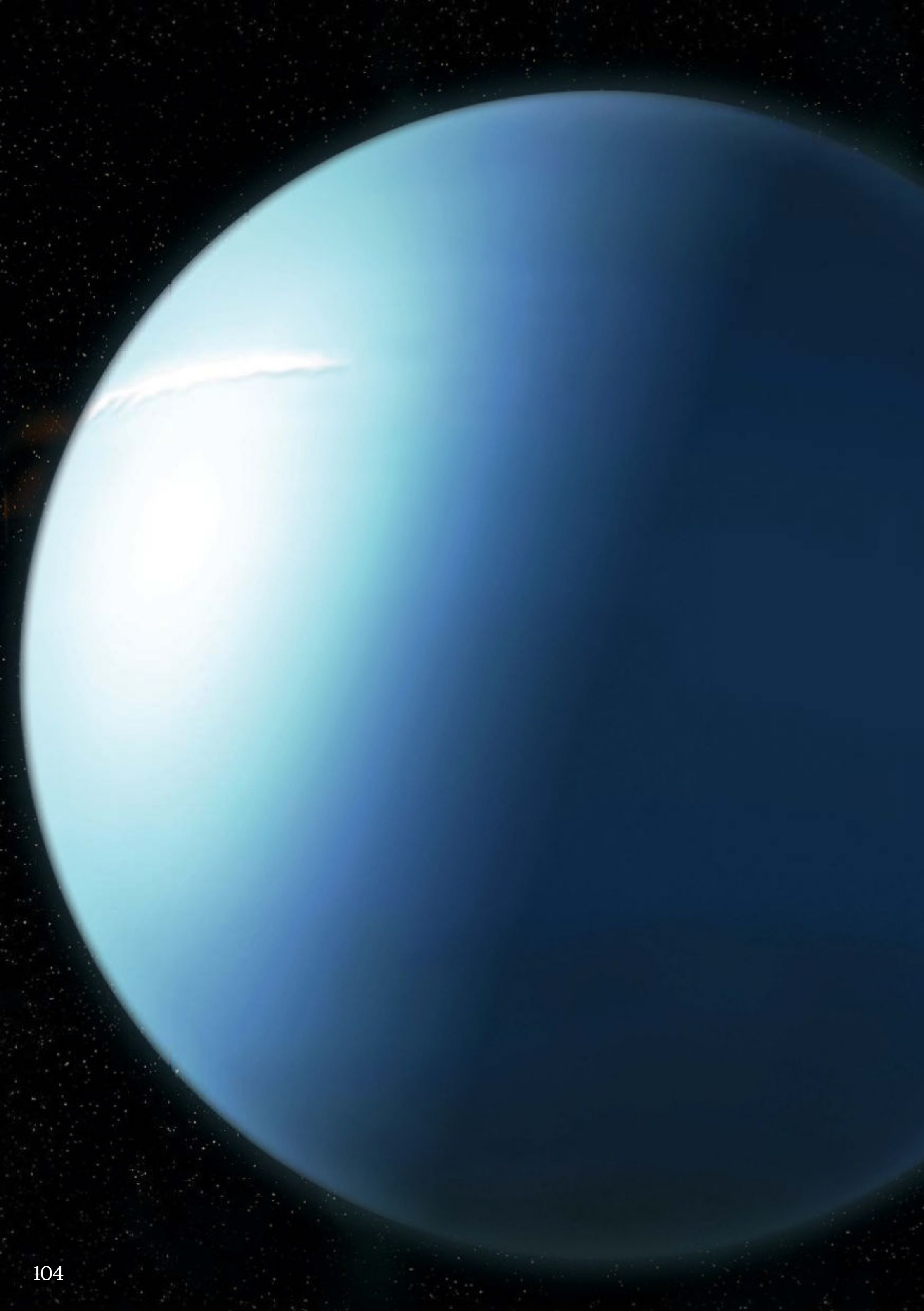
If the Earth had rings that spanned as wide as Saturn's, the rings would be 75 per cent of the way to the Moon

1/8th

Saturn is 1/8th as dense as Earth, so light that if there were an ocean big enough to hold it, it would float

x2

Saturn is twice as far away from the Sun as Jupiter is



URANUS

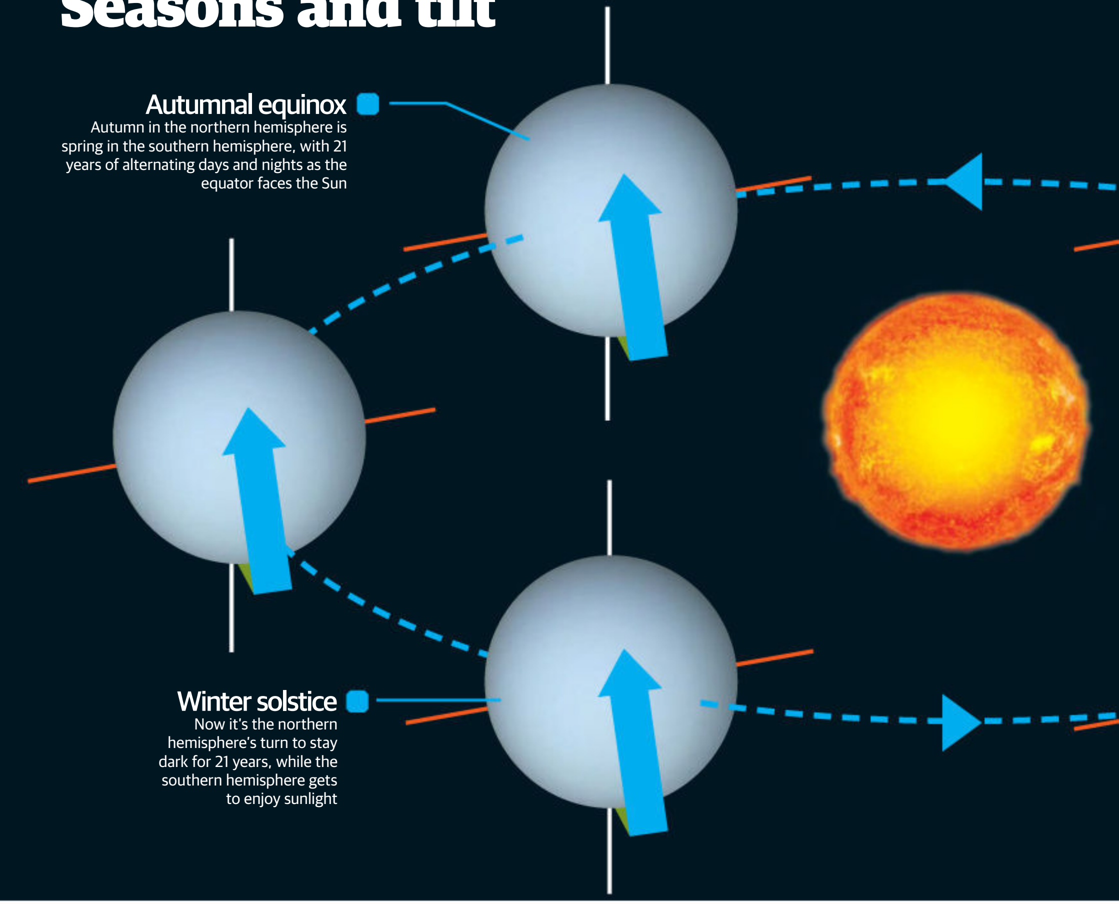
The Solar System's forgotten planet has long been thought of as a dark, cold, characterless world, but the seventh planet from the Sun has its own unique twist and some fascinating features

While William Herschel officially discovered Uranus in 1781, he wasn't the first to observe it. Others thought it was a star and Herschel himself called it a 'comet' before deciding that it was, in fact, a planet – and the first one discovered by telescope. Although Uranus can be seen from Earth with the naked eye, it's so dim and has such a slow orbit compared to the other known planets that it didn't register as one. It just looks like a faint pinpoint of greenish or bluish light.

Uranus's acceptance as a new planet overturned beliefs that had been held for millennia about the size of our Solar System, and kicked off a flurry of planetary discovery. But despite Uranus's significance, we haven't spent much time visiting the planet. A flyby by Voyager 2 in 1986 marks the only time we've explored it. Because of this, we simply don't know a great deal about Uranus. Until telescope observations in the past few decades, we thought of it as a rather bland planet: dark, cold, slow and with few interesting features.

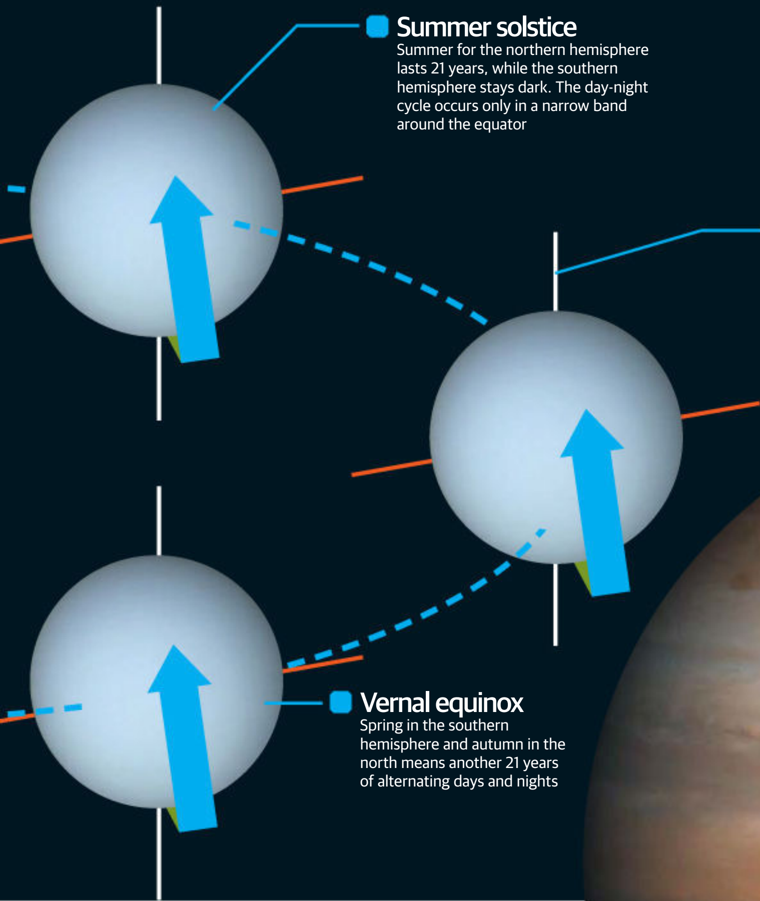
Uranus is the third-largest planet by radius and the fourth-largest by mass. It's about 3 billion kilometres (1.86 billion miles) from the Sun, which means that it receives 0.0025 per cent of the sunlight that the Earth gets.

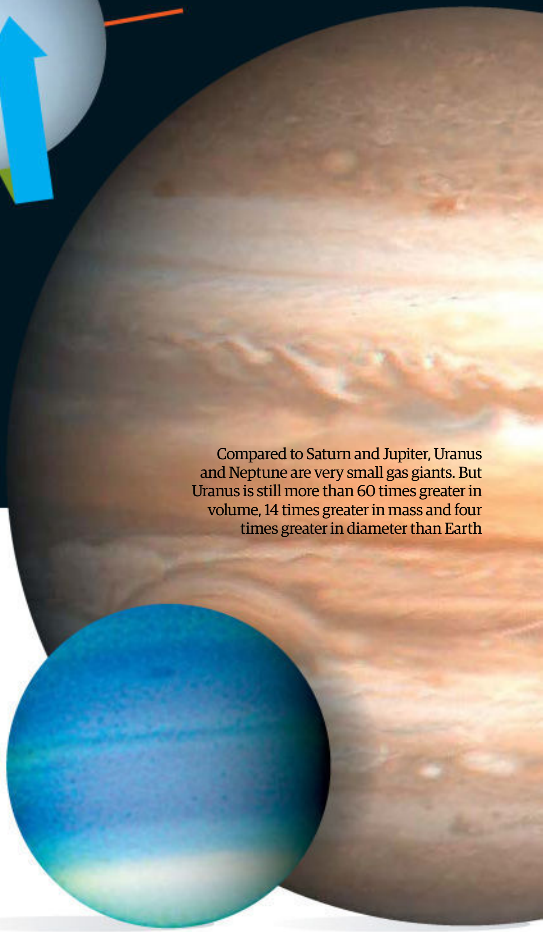
Seasons and tilt



Uranus is a gas giant, along with Jupiter, Saturn and Neptune, with the latter planet sometimes being referred to as its twin. It is the least massive of the four, but still more than 14 times more massive than Earth. Uranus has a diameter four times that of Earth's. It also has the coldest atmosphere of any other planet in the Solar System, with a mean temperature of approximately -197 °C (-322 °F). Uranus also has a multilayered cloud system, although without the flashy variations of colour seen on planets such as Jupiter and Saturn. However, it does have a lot in common with the other gas giants. It has a magnetosphere that is very similar to Jupiter's. It has 27 moons, and a system of 13 rings that was discovered not long after Saturn's ring system. It's most like Neptune in terms of composition, mostly hydrogen and helium with icy volatiles. Uranus and Neptune are often referred to as the 'ice giants'.

But Uranus can't just be lumped in with the other gas giants because the planet has its own unique twist. Literally, as Uranus's 97.77-degree axial tilt means that it is parallel with the plane of the Solar System – its poles are on either side. While other planets have extreme tilts, none are so perfectly perpendicular to the plane of its orbit. Studies show that Uranus is probably tilted due to





Compared to Saturn and Jupiter, Uranus and Neptune are very small gas giants. But Uranus is still more than 60 times greater in volume, 14 times greater in mass and four times greater in diameter than Earth

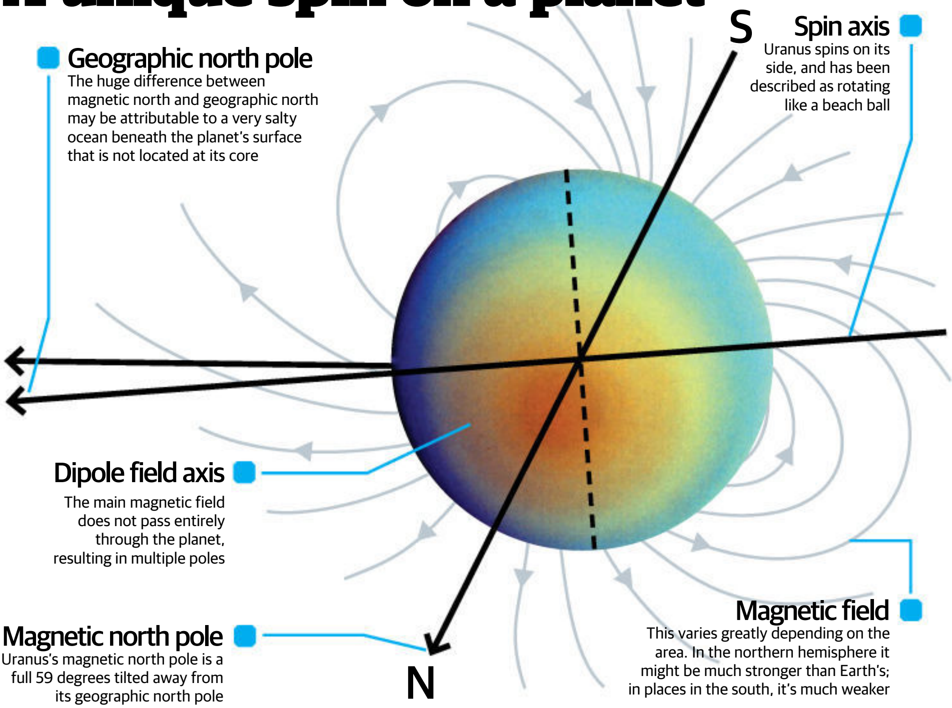
at least two violent, massive collisions one after another, with objects larger than Earth. These impacts likely occurred early in the planet's life, before its moons formed, and made astronomers rethink how other gas giants formed.

The tilt has impacted just about everything about Uranus. It has extreme seasons and weather fluctuations since each hemisphere experiences either full Sun or deep space. Its magnetosphere is tilted and asymmetric. The ring system is also on its 'side', and comes close to rivalling Saturn's in complexity. The moon system is less massive than any other gas giant's system. So, in many ways, Uranus is unique. ●

“Uranus can’t just be lumped in with the other gas giants as it has its own unique twist”

Uranus, as viewed from Miranda in this artist's impression, has a unique 97.77-degree axial tilt

A unique spin on a planet



Uranus inside and out

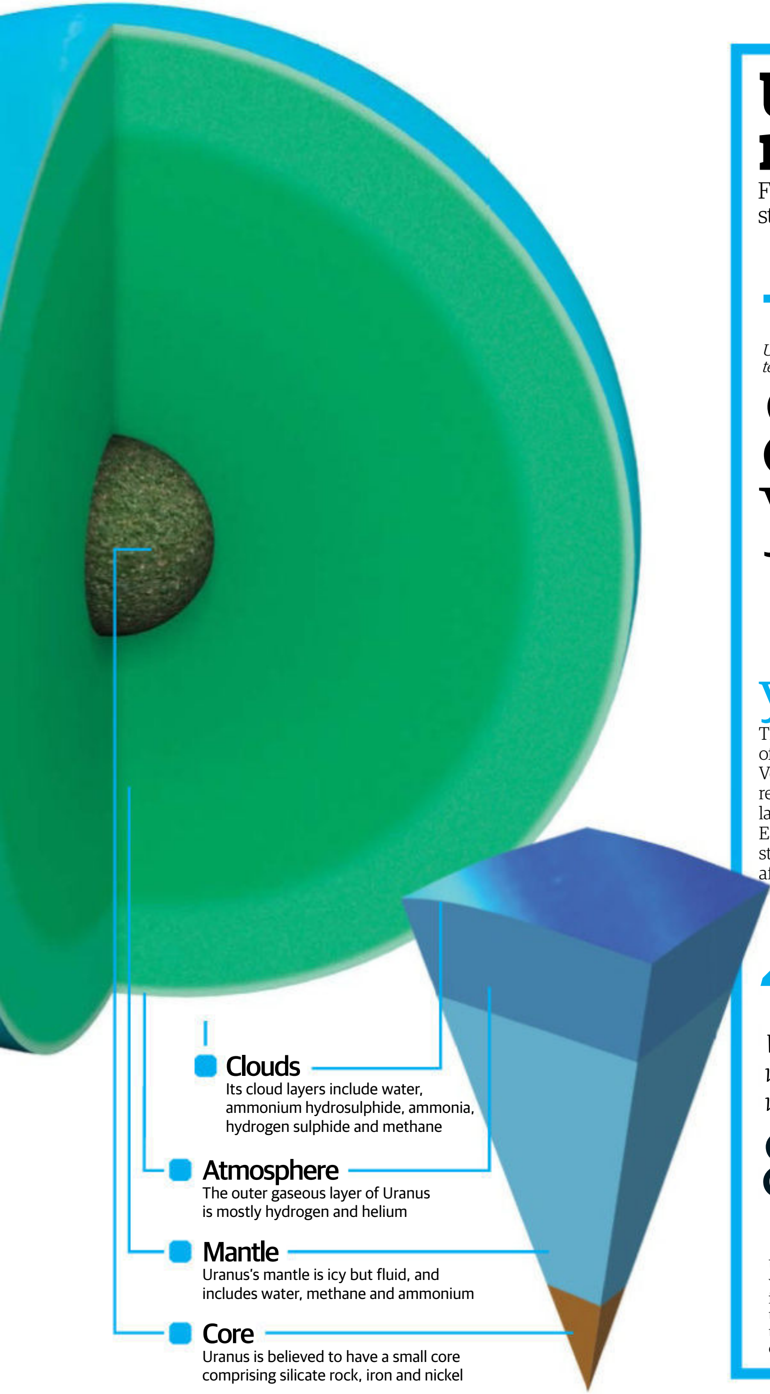
It has a very similar structure to Neptune but this ice giant still retains its mysteries

The term 'gas giant' implies that Uranus is solely composed of gases, but studies indicate that it actually has a core of silicate rock, encased in ices and topped with a gaseous layer. The core must be very small, since Uranus is the second-least dense planet. It likely takes up only 20 per cent of the planet's radius. The ice mantle surrounding the core is fluid, with volatiles like methane, ammonia and water. In fact, this electrically conducive fluid is often called an ammonia-water ocean by experts. The outer layer is mostly helium and hydrogen.

Uranus is also much cooler inside than the other gas giants – it's actually the coldest planet in the Solar System. Neptune radiates 2.61 times the heat that Uranus does. We aren't sure why Uranus is so cold in comparison, but it may have been struck by a large body that forced it to expel most of the heat it had when formed, or there could be a complex system at work in the atmosphere that keeps core heat from getting out.

The atmosphere contains three layers: the thermosphere, the stratosphere and the troposphere. The lowest layer, the troposphere, is the most interesting and is rich in volatile ices like methane and ammonia. It has four cloud layers: methane, hydrogen sulphide and ammonia, ammonium hydrosulphide, and water clouds at the upper limit. We've only observed the top two layers, along with a hazy layer above them. The stratosphere sits between the troposphere and the outermost layer, the thermosphere. Uranus tends to look light bluish or greenish in colour, and it has faint darker bands. The overall colour is due to the way that methane absorbs visible and near-infrared light.

Until Voyager 2 explored Uranus's atmosphere, we didn't know much about its features. The probe found a bright polar cap at the south pole, as well as a lighter band called a collar. There were darker bands in the southern hemisphere and about ten lighter clouds around the middle latitudes. The timing of Voyager 2's arrival meant that it could not fully observe the northern hemisphere. In the Nineties, Hubble and ground-based telescopes like the Keck Observatory began to see more atmospheric features on Uranus. They spotted many more clouds in the northern hemisphere, which are brighter and at a higher elevation than the ones in the southern hemisphere. They also observed in 2007 that the southern collar had nearly disappeared, while one in the north had grown.



Uranus in numbers

Fantastic figures and surprising statistics about the distant planet

-197°C

Uranus is the coldest planet: its average temperature is around -197°C (-322°F)

84 years

It takes Uranus 84 years to complete its orbit around the Sun

9 years

The number of years it took Voyager 2 to reach Uranus after launching from Earth. Voyager 2 is still going strong after 35 years

900km/h

Wind speeds on Uranus can reach 250 metres per second (900km/h, 560mph)

40kg

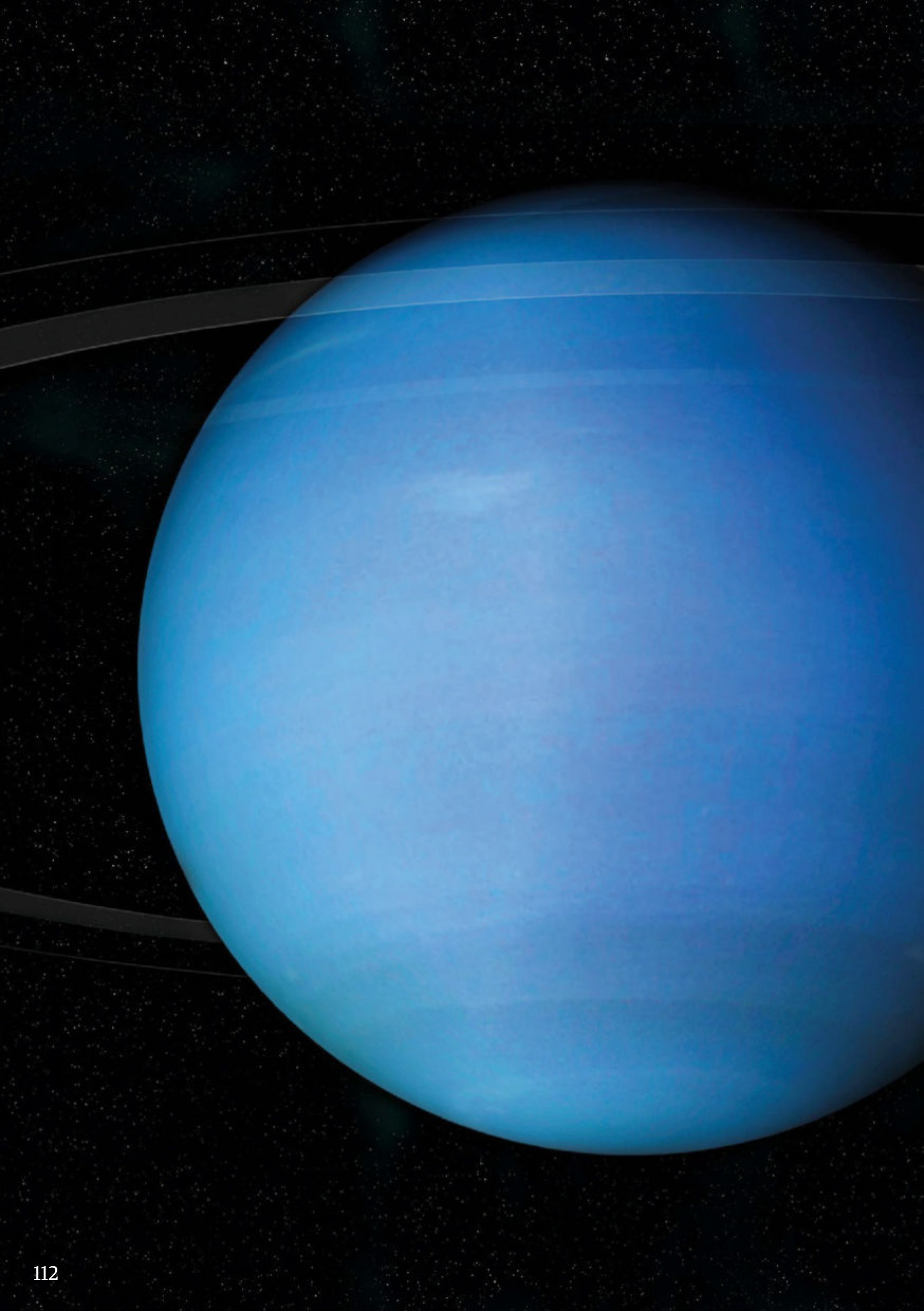
What you would weigh on Uranus if you weigh 45kg (100lb) on Earth

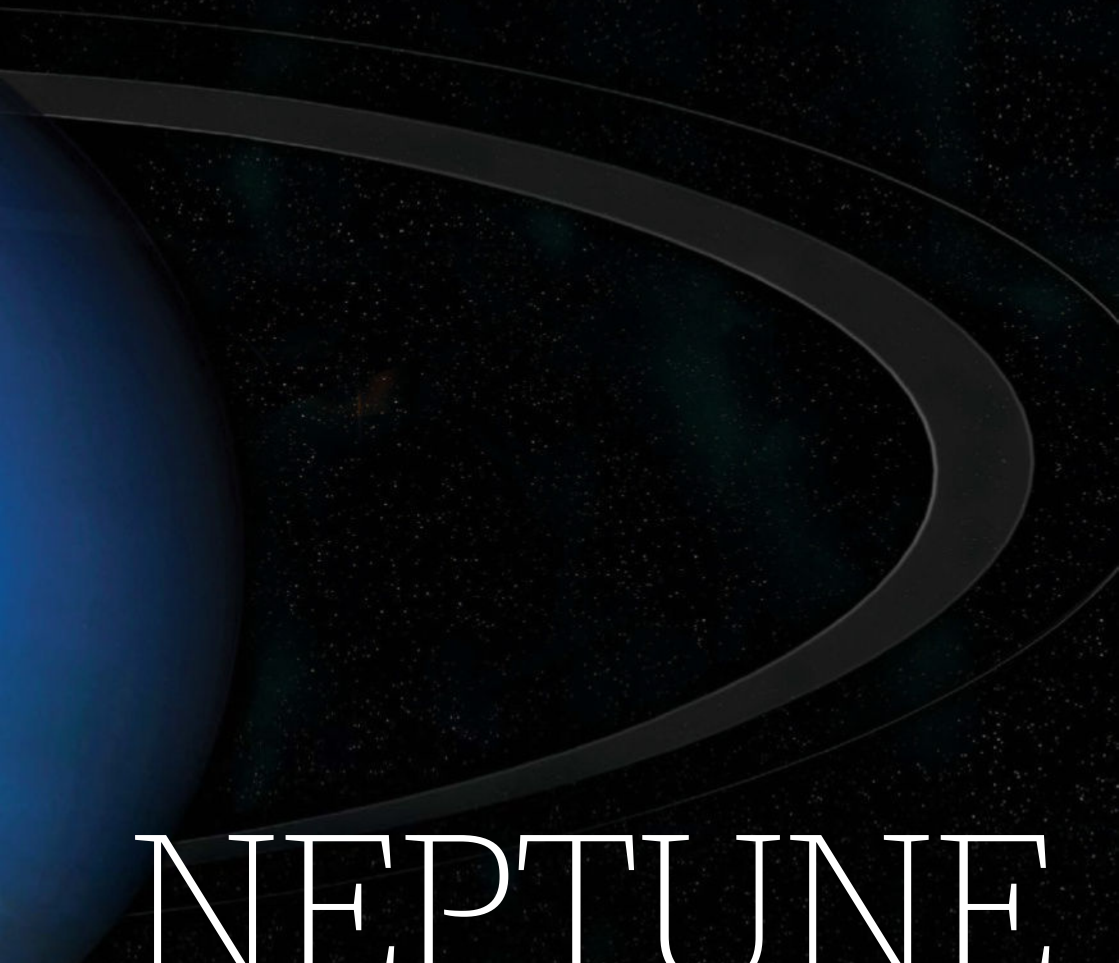
8.69m/s²

The acceleration due to gravity on Uranus, compared to 9.8m/s² on Earth

60x

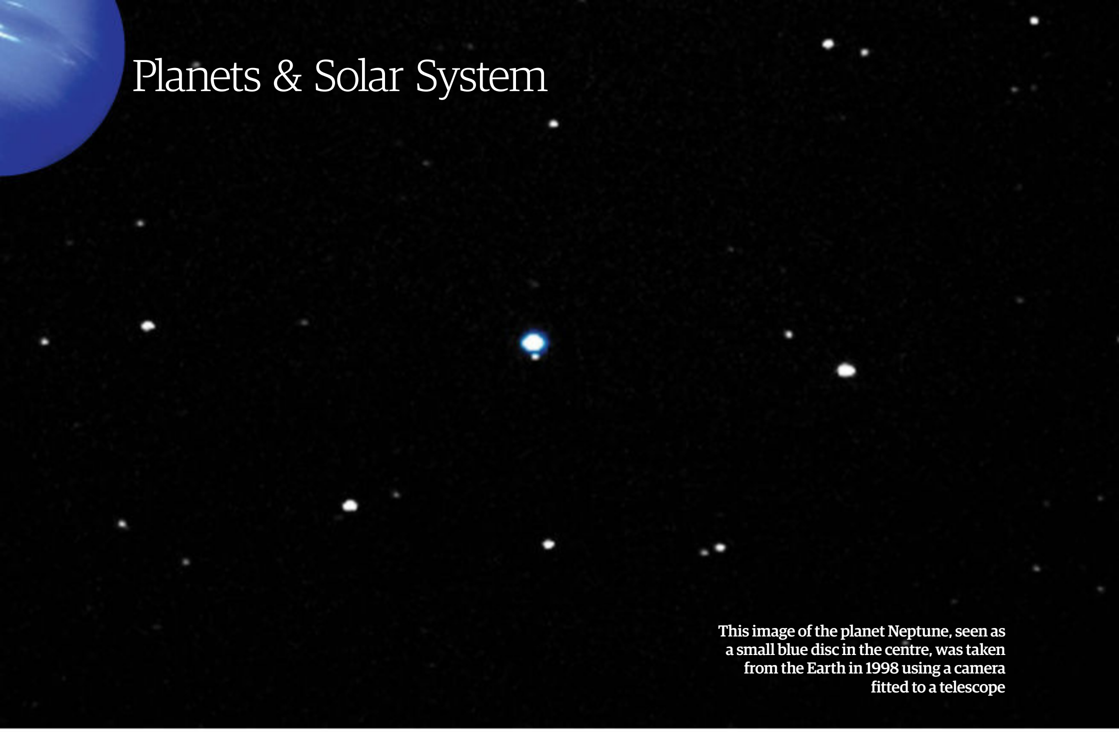
Uranus's volume is more than 60 times that of Earth





NEPTUNE

A frozen world on the outermost limits of our Solar System, Neptune is a mysterious planet with its own unique characteristics



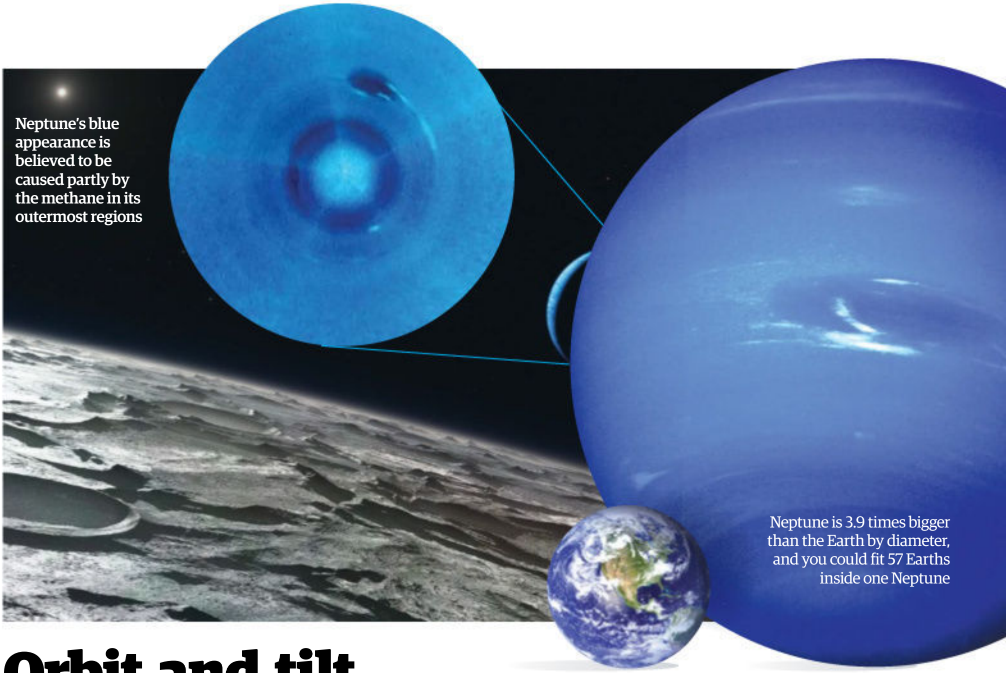
This image of the planet Neptune, seen as a small blue disc in the centre, was taken from the Earth in 1998 using a camera fitted to a telescope

Neptune's claim to fame is being the first planet discovered not by observation, but by prediction. French astronomer Alexis Bouvard closely observed the orbit of Uranus, and detected a gravitational perturbation that he deduced could only be explained by another planet. From his observations, other astronomers calculated the location of Neptune. Galileo actually spotted Neptune 200 years before, but thought it was a star.

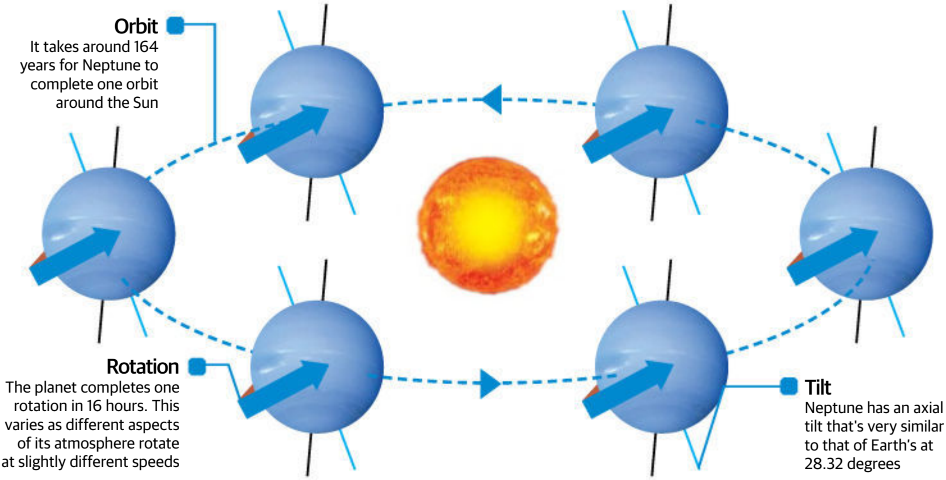
There's still some debate over who did deserve the credit – French astronomer Urbain Le Verrier or British astronomer John Couch Adams, or a third astronomer, Johann Galle. Galle was the first to look at Neptune and understand what it was, using calculations from Le Verrier, on 23 September 1846. He discovered Neptune's largest moon, Triton, shortly after. Given the distance – 4.3 billion km (2.7 billion mi) – Neptune is not visible to the naked eye. Until powerful modern telescopes and the invention of the Hubble Space Telescope, it was difficult to study Neptune.

Neptune is the third-largest planet by mass, and 17 times the mass of Earth. It's also the fourth-largest planet by diameter. As the eighth planet from the Sun, Neptune was the furthest known planet until Pluto was discovered in 1930. Although it's back to being the outermost planet since Pluto's demotion, Neptune was still occasionally the outermost planet before, as Pluto's eccentric orbit caused it to cross inside Neptune's orbit. It's one of the four gas giants, and is also called Uranus's 'twin'. Because they're very similar in composition, both planets are often known as ice giants to distinguish them from Jupiter and Saturn. They're mostly made up of hydrogen and helium, with ices of water, methane, and ammonia, surrounding an icy rock core. While the methane content results in Uranus having a blue-green colour, Neptune is a brighter blue. Neptune also has an extremely cold atmosphere like Uranus, topping out at about -218°C (-360°F) in the upper levels.

Although Neptune doesn't have the extreme horizontal tilt of Uranus, its magnetosphere is strongly tilted away from its rotational axis, at 47 degrees. Neptune also has a ring system and more than a dozen known moons. But whereas Uranus has a relatively dull atmosphere, a lot happens weather-wise on Neptune. When Voyager 2 flew by in 1989 (the only spacecraft to do so), it observed lots of interesting weather. This includes some of the fastest winds in the Solar System, at around 2,000 km/h (1,240 mph).



Orbit and tilt

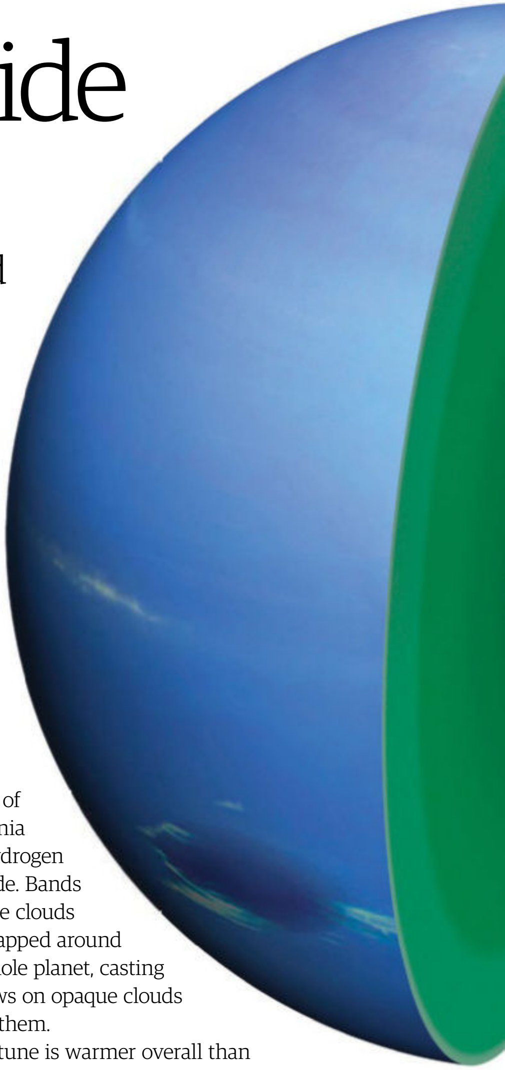


Neptune's tilt is much like Earth's at 28.32 degrees, so it has regular seasons, which happen to last about 40 years, because at 4.50 billion kilometres (2.8 billion miles) from the Sun, it has an orbit of 164.79 years. That means that in 2011, it completed its first orbit since it was discovered.

Neptune's gravitational pull also has an impact on the Kuiper belt, a large ring of tiny, icy objects - including the dwarf planet, Pluto. Neptune's gravity has destabilised areas of the belt, and it has also created a resonance between the planet and at least 200 of the objects.

Neptune inside and out

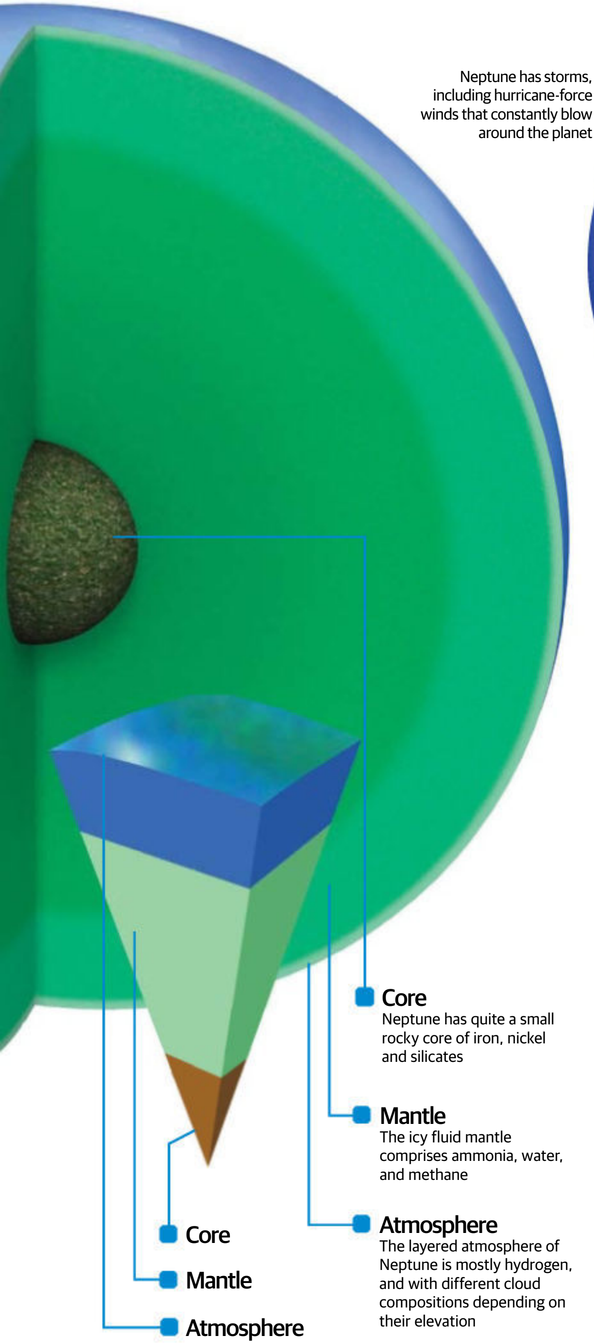
Neptune is a bright blue, warm and experiences active weather

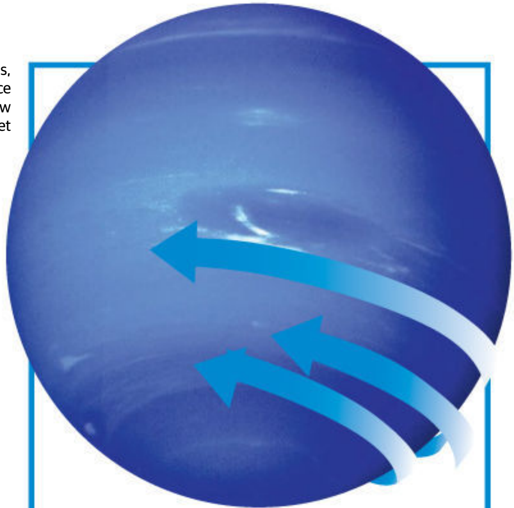


Like Uranus, Neptune is a gas giant but not solely comprising gases. Its core contains silicate rock, iron and nickel and is a little larger than planet Earth. Neptune's core is also under great pressure (twice as much pressure as the Earth's core) and about 5,100 °C (9,200 °F). The mantle surrounding the core is icy, but that's a relative term when it comes to planet temperatures because it's actually a hot, dense liquid. Made of methane, ammonia, and water, the mantle is electrically conductive and its temperature ranges between 1,700 °C (3,100 °F) and 4,700 °C (8,500 °F). The mantle may also consist of additional layers, including a layer of ionised water (with electrically charged hydrogen and oxygen) and a deeper layer of superionised water.

Neptune's atmosphere surrounding the mantle is about 80 per cent hydrogen, 19 per cent helium, and the rest traces of ammonia, water and methane. The methane, which absorbs red light in the spectrum, gives Neptune its colour. Since the atmospheric composition is supposed to be very similar to that of Uranus's, there must be something else in the atmosphere that makes Neptune a bright blue versus Uranus's bluish-green. It has two main divisions – the troposphere and the stratosphere. The troposphere probably has several different types of cloud bands, depending on where they're located. The lowest levels are clouds of hydrogen sulphide and ammonia. Then there are water ice clouds as the temperature drops, at a pressure of 50 bars. A cloud layer of water, hydrogen sulphide, ammonia and ammonium sulphide floats above five bars of pressure. Between one and five bars, in the uppermost layer of the troposphere, the clouds are made up out of ammonia and hydrogen sulphide. Bands of these clouds are wrapped around the whole planet, casting shadows on opaque clouds below them.

Neptune is warmer overall than Uranus. Its stratosphere has traces of carbon monoxide, and the thermosphere is unusually very warm at a high 480°C (900°F) given Neptune's distance from the Sun. The planet radiates more than twice the energy of Uranus and receives only 40 per cent of the sunlight of its twin, yet has about the same surface temperature. We aren't sure why, but these differences in heat may be why Neptune has weather like storms and high winds, while Uranus does not.

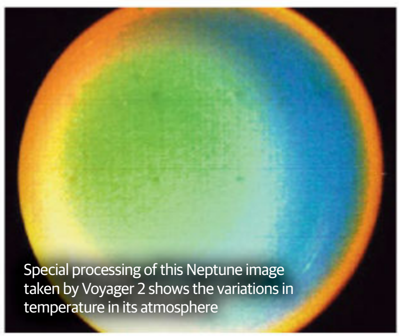




Supersonic winds and storms

Neptune's massive winds and storms set it apart from Uranus. Most of the winds blow in retrograde rotation (opposite the planet's rotation), but the general pattern is prograde rotation (in the direction of the planet) in the higher latitudes and retrograde rotation in the lower latitudes. The winds reach almost 2,000 kilometres per hour (1,240 miles per hour) – nearly supersonic speeds.

On Voyager 2's flyby in 1989, it observed a massive anti-cyclonic storm that was 13,000 by 6,600 kilometres (8,700 by 4,100 miles) in size. The storm was dubbed the Great Dark Spot. It wasn't present when the Hubble Space Telescope viewed the planet five years later, but another storm was found and given the name. Neptune also has other large storms named the Scooter and the Small Dark Spot.


Special processing of this Neptune image taken by Voyager 2 shows the variations in temperature in its atmosphere

Moons and rings

Neptune has two groups of moons – inner moons with regular, circular orbits, and outer moons with irregular orbits

Neptune has 13 known moons. Triton is by far the largest, holding more than 99 per cent of the total mass in the planet's orbit, with a diameter of 2,705 km (1,700 mi). It's the only spheroid moon. It was probably a dwarf planet in the Kuiper belt before being captured by Neptune's orbit. Astronomers believe it was captured instead of forming as a satellite because it has a retrograde orbit – it circles Neptune opposite of the planet's rotation. Triton is the second known moon (along with Saturn's Titan) to have an atmosphere. The atmosphere mostly comprises nitrogen, with traces of carbon monoxide and methane. It is also one of the coldest objects in the Solar System. The moon is very dense, and is probably two-thirds rock and one-third ice.

> "Triton holds more than 99 per cent of the total mass in orbit around the planet"

The rings of Neptune

1. Galle
Galle is 2,000km (1,240 mi) wide and orbits Neptune at a distance of 41,000 to 43,000km (25,500 to 26,700 mi).

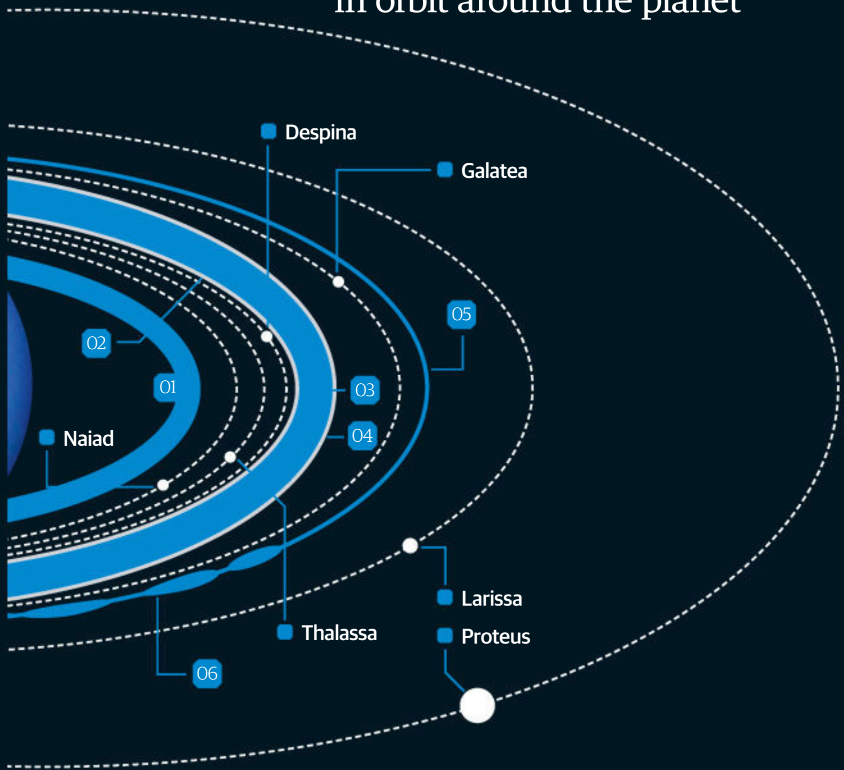
2. Le Verrier
Le Verrier is 113km (70 mi) wide and orbits 53,200km (33,000 mi) away from the planet.

3. Lassell
Lassell is like a broad dust sheet, with its orbit around Neptune between 53,200 and 57,200km (33,000 and 35,500 mi).

4. Arago
Arago orbits 57,200km (35,500 mi) away and is 100km (62 mi) wide.

5. Adams
At 35km (22 mi) wide, it orbits at 62,900km (39,000 mi).

6. Arcs
Arcs are particles of dust clustered in the Adams ring, named Fraternité, Égalité 1, Égalité 2, Liberté and, finally, Courage.



Triton is one of the seven outermost moons, all of which have irregular orbits like Triton does. The next moon to be discovered, Nereid, was found in 1949. It is the third-largest moon, and has a prograde orbit. Nereid's orbit is also extremely eccentric – it gets as close as 1.4 million km (850,000 mi) to Neptune, but is 9.6 million km (5.9 million mi) at its furthest point. The cause of its eccentricity is unknown, but it may have been perturbed by Triton, or have been a Kuiper belt object like Triton that was captured. We don't know exactly what Nereid looks like or what shape it takes. Two of the other irregular moons, Sao and Laomedeia, have prograde orbits. Both were discovered in 2002. Halimede, Psamathe and Neso all have retrograde orbits. Halimede and Neso were discovered in 2002, and Psamathe a year later. Neso and Psamathe both orbit very far away from Neptune; Psamathe orbits at 48 million km (30 million mi) away. Both of these moons may have come from a larger moon.

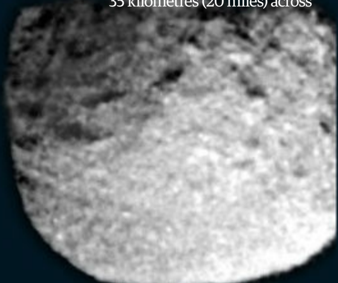
The six inner moons have regular, prograde orbits: Naiad, Thalassa, Despina, Galatea, Larissa and Proteus. Little is known about the four innermost moons, except that they are small and irregularly shaped. All of these likely formed from debris leftover when Triton was pulled into orbit. Naiad is the innermost moon and was discovered in 1989 by Voyager 2. It orbits just 23,500 km (14,600 mi) above Neptune. Thalassa was also discovered around the same time. These two innermost moons orbit between two rings, Galle and Le Verrier. Despina, the third-closest moon, lies inside the Le Verrier ring, and the next moon, Galatea, could serve as a shepherd moon according to some astronomers, holding the Adams ring in place.

Larissa, the fourth-largest moon, was discovered in 1981. It is known to be about 200 km (124 mi) in diameter and with an elongated shape. It's also heavily cratered. Proteus, the outermost of these moons, is also the second-largest moon in orbit around Neptune. Voyager 2 also discovered it, and we learned then that it is at least 400 km (248.5 mi) in diameter. Proteus is also heavily cratered.

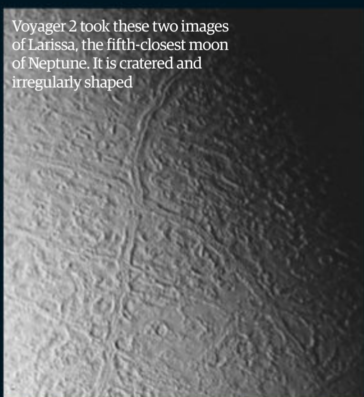
Neptune's ring system was first spotted in 1984 in Chile, by a group of international astronomers. Astronomers prior to this had suspected rings when observing dips in the brightness of stars viewed between the observer and the planet. The existence of the rings was proven by images taken by Voyager 2, and we have since viewed the brightest rings using the Hubble Space Telescope as well as Earth-based telescopes. There are five distinct rings, named in order of their distance from Neptune: Galle, Le Verrier, Lassell, Arago and Adams. Galle is a very faint ring, named after the first astronomer to view the planet. The next ring, Le Verrier, is extremely narrow at just 113 km (70 mi) wide. Le Verrier may be confined by the moon Despina, which orbits just inside it.

Neptune's widest ring, Lassell, is also called the plateau. It's a thin sheet of dust stretching from Le Verrier to the next ring, Arago. Some don't consider Arago to be a ring at all; it looks like a bright rim around the edge of Lassell, but is less than 100 km (62 mi) wide.

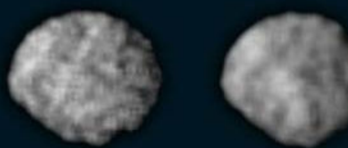
This image of Triton taken in 1989 shows its icy surface, including a graben (dropped fault block) about 35 kilometres (20 miles) across



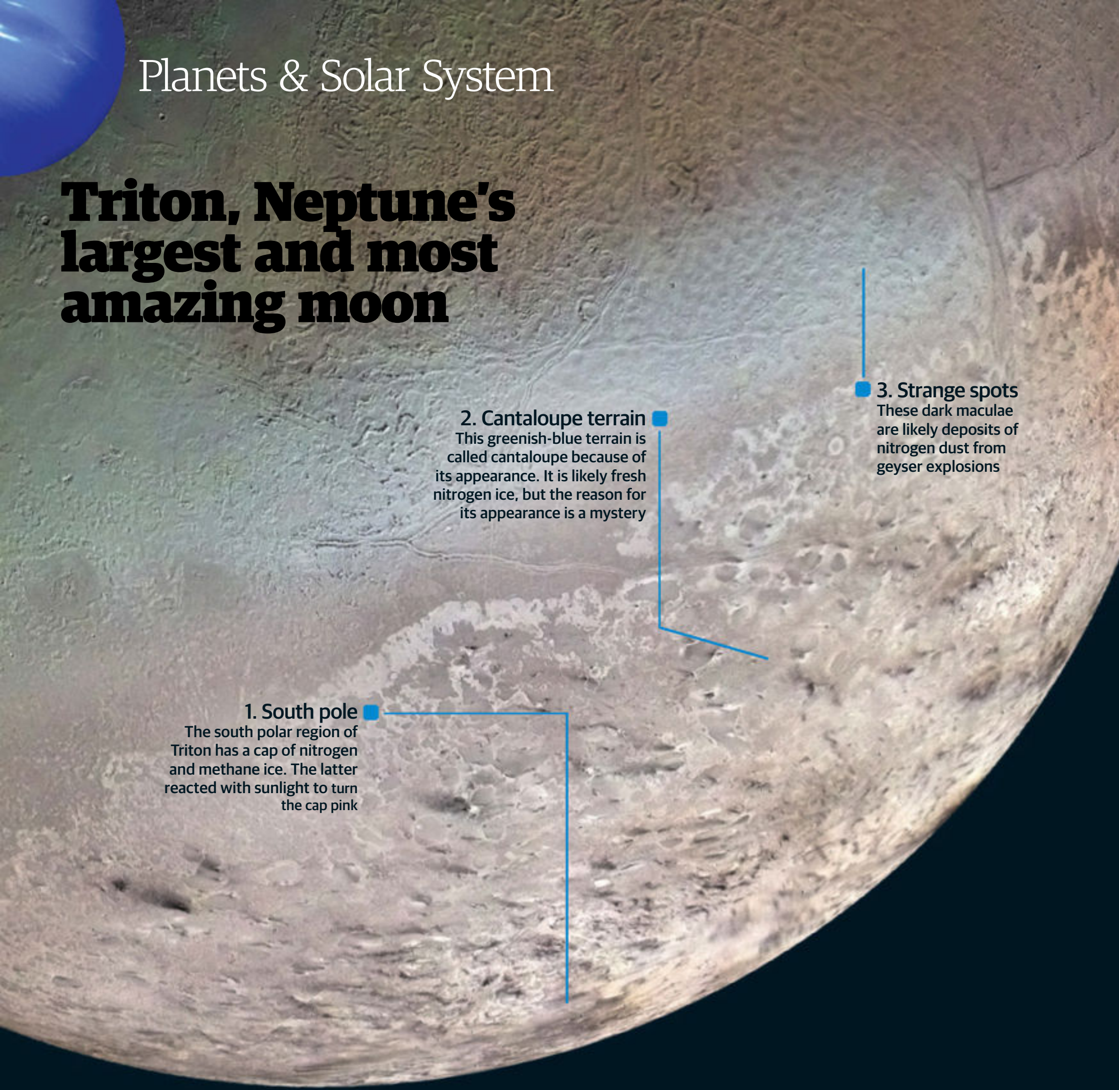
Voyager 2 took these two images of Larissa, the fifth-closest moon of Neptune. It is cratered and irregularly shaped



Although Proteus is the second-largest moon, it wasn't discovered until 1989 because of its dark surface and close proximity to the planet



Triton, Neptune's largest and most amazing moon



We know the most about the outermost ring, Adams. It is a narrow ring slightly slanted. The moon Galatea shepherds the Adams ring and creates 'wiggles', or perturbations, at 42 different places in the ring. Adams has an unusual feature: five bright spots called arcs located along the ring, where the particles of dust are clustered together. They're named Fraternité, Égalité 1, Égalité 2, Liberté and Courage. Courage is the faintest, while Fraternité is the brightest. Ground-based telescopes first detected them, and Voyager 2 confirmed their existence. They have dimmed slightly since their discovery and some of the arcs seem to have moved a little bit, but overall they seem to be stable. We just aren't sure why the dust particles have clustered together in those areas. There could be as-yet-undetected moons or moonlets, or the arcs could be caused by an unusual resonance with the moon Galatea. Hopefully further research and future exploration efforts will reveal more.

> "Neptune has some of the fastest winds in the Solar System, at around 2,000km/h"

Neptune in numbers

Fascinating figures about the eighth planet from the Sun

500,000

A 1999 study at the University of California simulated the atmospheric pressure of Neptune and estimated it to be 100,000 to 500,000 times that of the Earth's

100yrs

Neptune's moons are named after Greek and Roman water deities, since the planet is named after the god of the sea. None of the moons were named immediately after discovery – in Triton's case, it took over 100 years

2

Triton is locked in synchronous rotation with Neptune, so one side always faces it. But because of its unusual orbit, both poles still get time in the Sun

1/900

Neptune receives 1/900th of the energy from the Sun that the Earth receives

17%

Neptune's gravity is only 17% stronger than Earth's gravity – the closest of any planet in the Solar System

248 years

Neptune will be closer in its orbit to Pluto than to the Sun for 248 years, as Pluto's eccentric orbit takes it inside Neptune's orbit

PLUTO

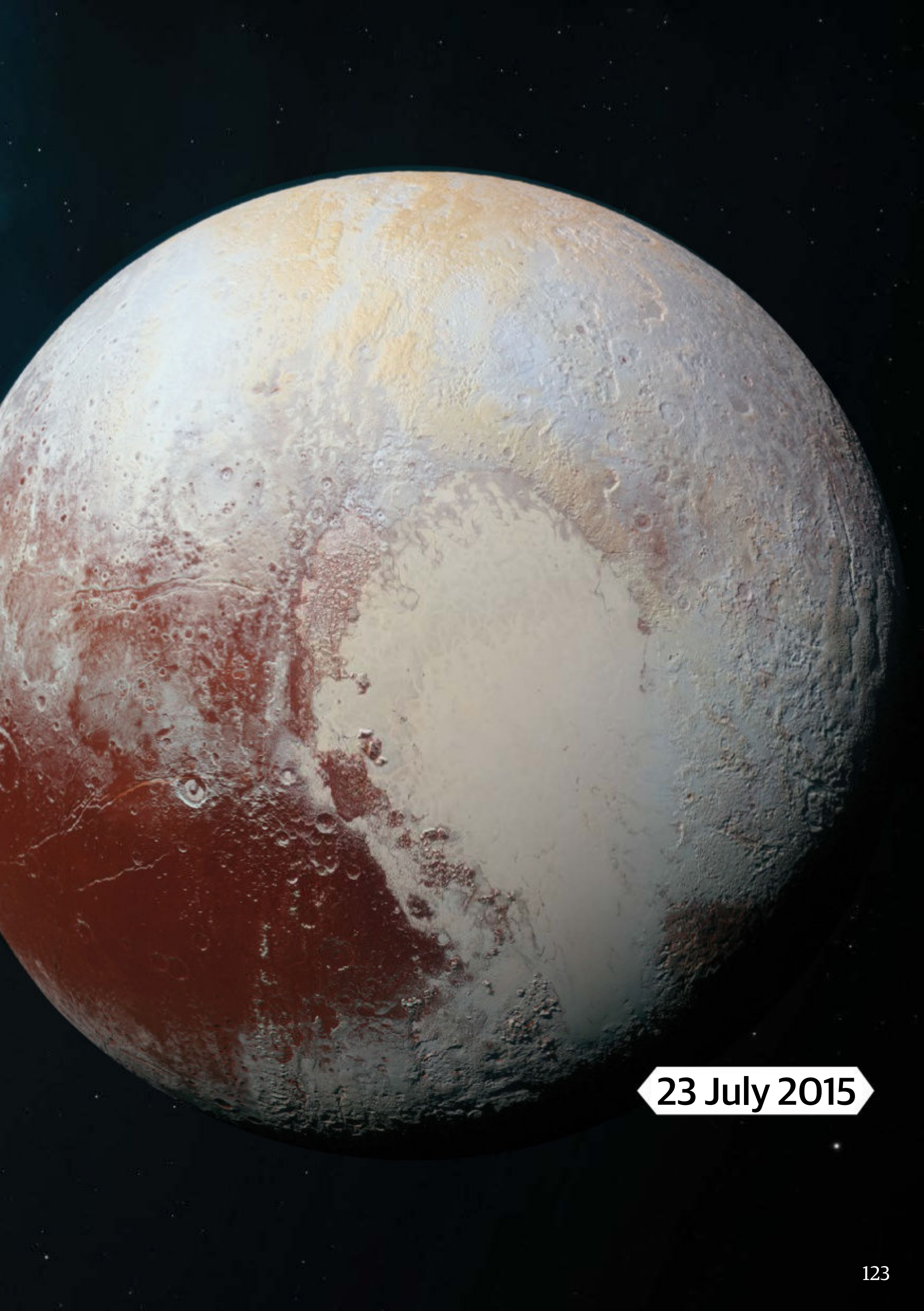
Welcome to the dwarf planet with a huge heart, the biggest discovery of the 21st century

1930

1994

2005

April 2015



23 July 2015

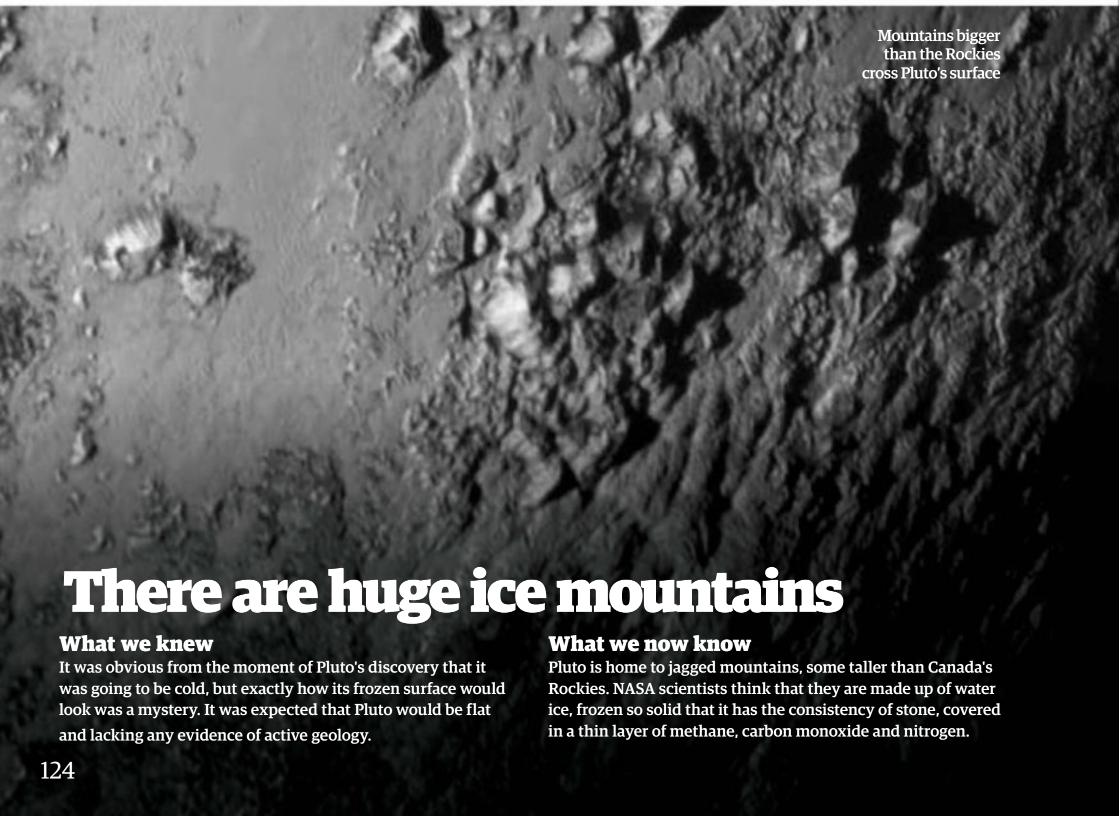
What has New Horizons taught us?

NASA's nine-year mission to study Pluto moved up a gear in July 2015 when New Horizons began its approach, carrying a battery of spectrometers, visual and infrared cameras to within 12,500 km (7,800 miles) of the mysterious dwarf planet.

On 4 June, with just ten days to go, New Horizons' systems overloaded and it went silent. A built-in recovery protocol directed the craft to engage its backup computer and call for help but communications take nine hours to travel back and forth, so fixing the problem was a tense process. A day later, New Horizons was once again in good shape for the approach to Pluto.

The two-hour-and-15-minute flyby was a triumphant success and with more than 50 gigabits of data gathered over nine days, the team must wait for it all to be transmitted back. For now, New Horizons is sending compressed versions of its observations, and the download won't be complete until late 2016.

The craft has enough fuel to remain active until 2020, and the team is already lining up a Kuiper Belt flyby for 2019. This extended mission is still pending approval from NASA but could provide an incredible insight into the mysterious objects found in the far reaches of our Solar System.



Mountains bigger than the Rockies cross Pluto's surface

There are huge ice mountains

What we knew

It was obvious from the moment of Pluto's discovery that it was going to be cold, but exactly how its frozen surface would look was a mystery. It was expected that Pluto would be flat and lacking any evidence of active geology.

What we now know

Pluto is home to jagged mountains, some taller than Canada's Rockies. NASA scientists think that they are made up of water ice, frozen so solid that it has the consistency of stone, covered in a thin layer of methane, carbon monoxide and nitrogen.

Pluto has a heart

The 'heart', or Tombaugh region, named after Pluto's discoverer

What we knew

Before New Horizons, our best images of Pluto were still a fuzzy blur, not even the Hubble Space Telescope could improve them much. All we knew was that it was reddish in colour, and that the blotchy patterns on its surface changed over time.

What we now know

The dwarf planet is much loved, and when New Horizons sped towards its closest approach, many people were delighted when it snapped images revealing that Pluto has a heart. The bright feature, found just above the equator, measures around 1,600km (1,000mi) across.

The bright part of Pluto's heart could be filled with snow, contrasting with Charon (right)

Frozen nitrogen snows on Pluto

What we knew

Snow is unusual in the Solar System. On Earth, it seems very familiar, but there are only a few other places where any frozen flakes fall - Mars, Jupiter's moon Io, and Saturn's moon Titan.

What we now know

Pluto has an atmosphere of nitrogen, and there is evidence of geological activity beneath its surface - making snow on its surface a possibility. When asked about whether surface features could be snow, New Horizons principal investigator Alan Stern told the media, "it sure looks like it".

The young, relatively smooth plains surprised scientists

The surface is changing

What we knew

Pluto is 4.5 billion years old and 5.9 billion km from the Sun, so we thought it'd be cold and dead. Without geological activity to reshape the surface, it should be covered in craters.

What we now know

We spotted unusual frozen plains. Uncratered, they were likely formed in the last 100 million years: one of the youngest features in the Solar System. Thus, something is keeping the inside of the dwarf planet warm.

It's bigger than we thought

What we knew

Pluto was demoted to dwarf planet in 2006, and was estimated to span around 2,306km (1,432mi).

What we now know

Pluto actually spans 2,370km (1,472mi). An extra 64km (40mi) might not seem much, but it makes Pluto slightly larger than dwarf planet Eris.

Earth, compared to Pluto (above centre) and Charon

Charon's cracked

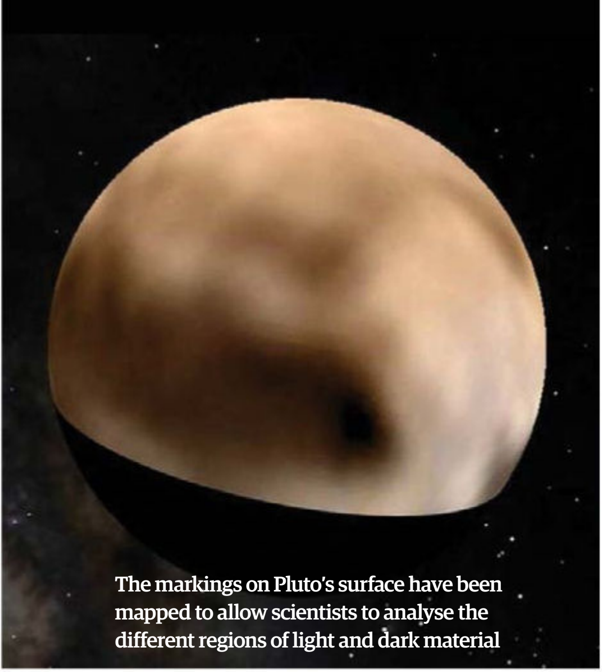
Charon's deep canyon can be seen in shadow on the right of the moon

What we knew

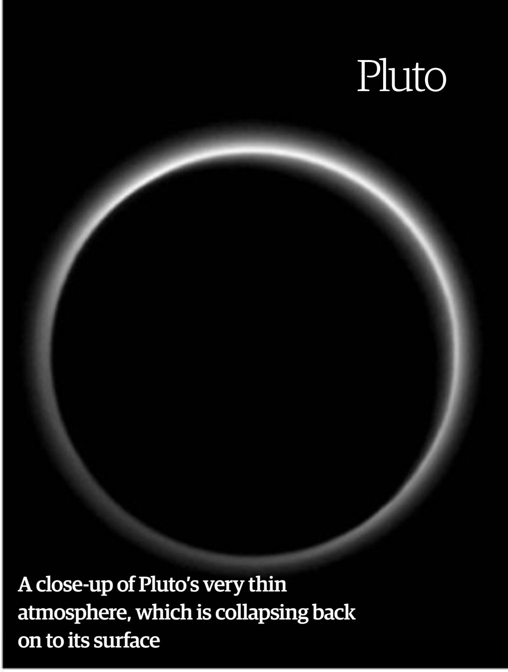
At half the size of Pluto, moon Charon sometimes is argued to be a dwarf planet in its own right.

What we now know

Charon shows a system of deep cracks, but surprisingly few impact craters, indicating there is some geological activity below the surface.



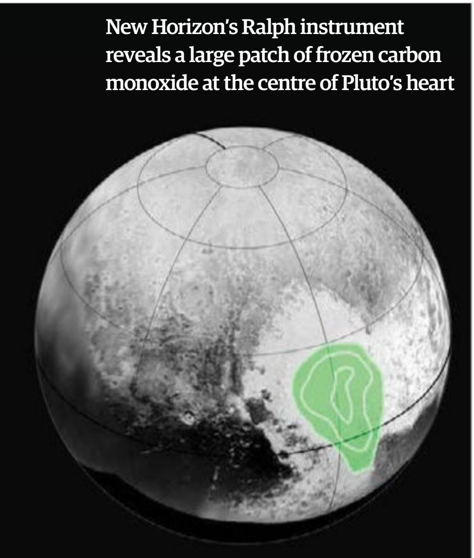
The markings on Pluto's surface have been mapped to allow scientists to analyse the different regions of light and dark material



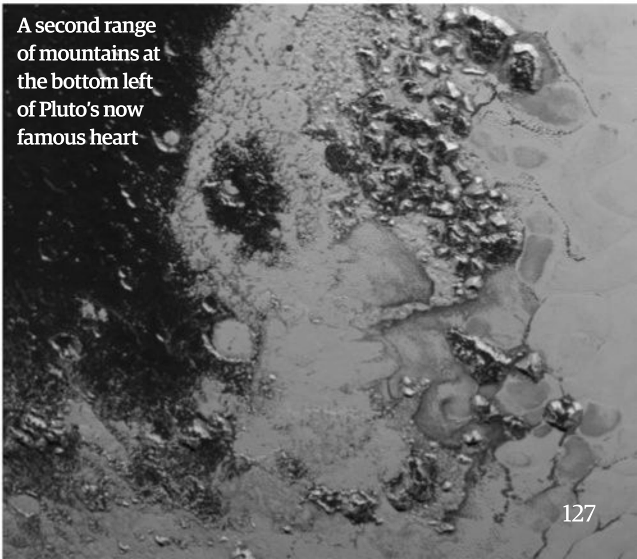
A close-up of Pluto's very thin atmosphere, which is collapsing back on to its surface

Pluto and its moon, Charon. You can see the geology coming into focus

These images show the irregular outlines of Hydra and Nix, two smaller moons



New Horizon's Ralph instrument reveals a large patch of frozen carbon monoxide at the centre of Pluto's heart



A second range of mountains at the bottom left of Pluto's now famous heart

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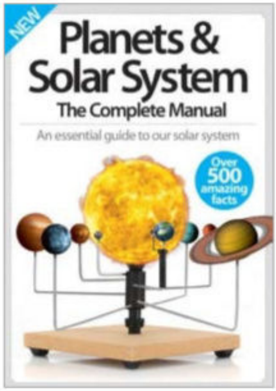

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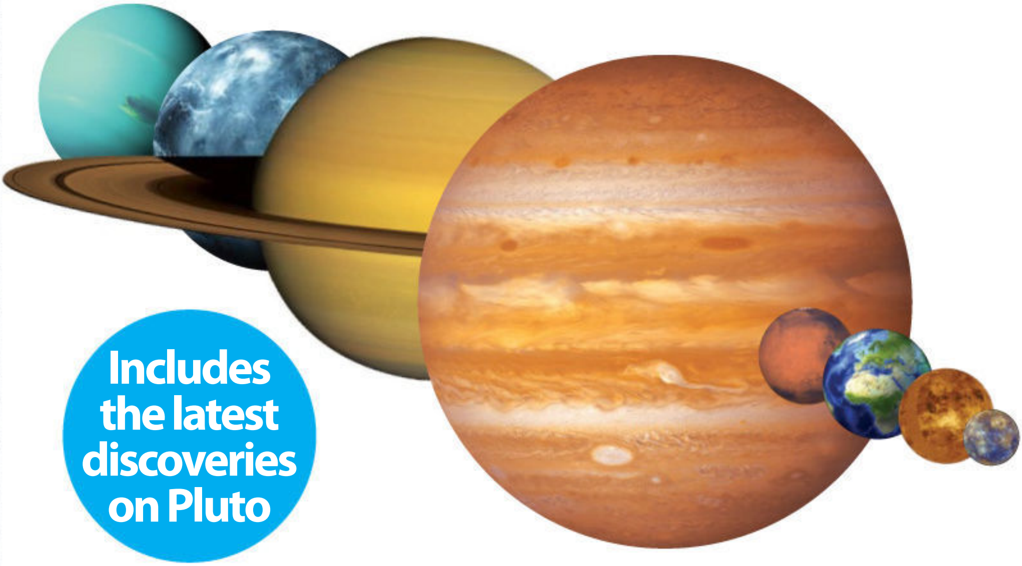

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