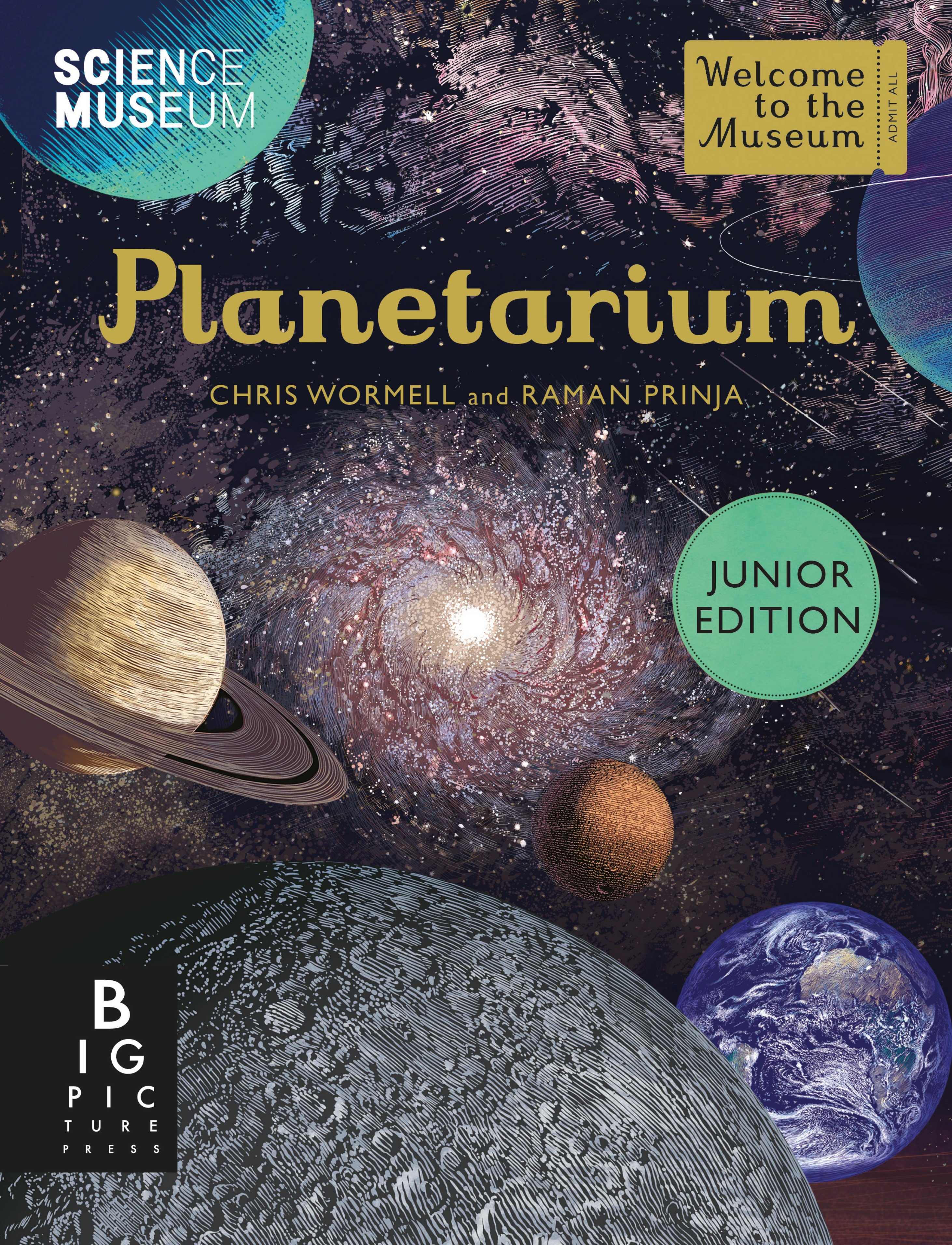

SCIENCE MUSEUM

Welcome to the Museum

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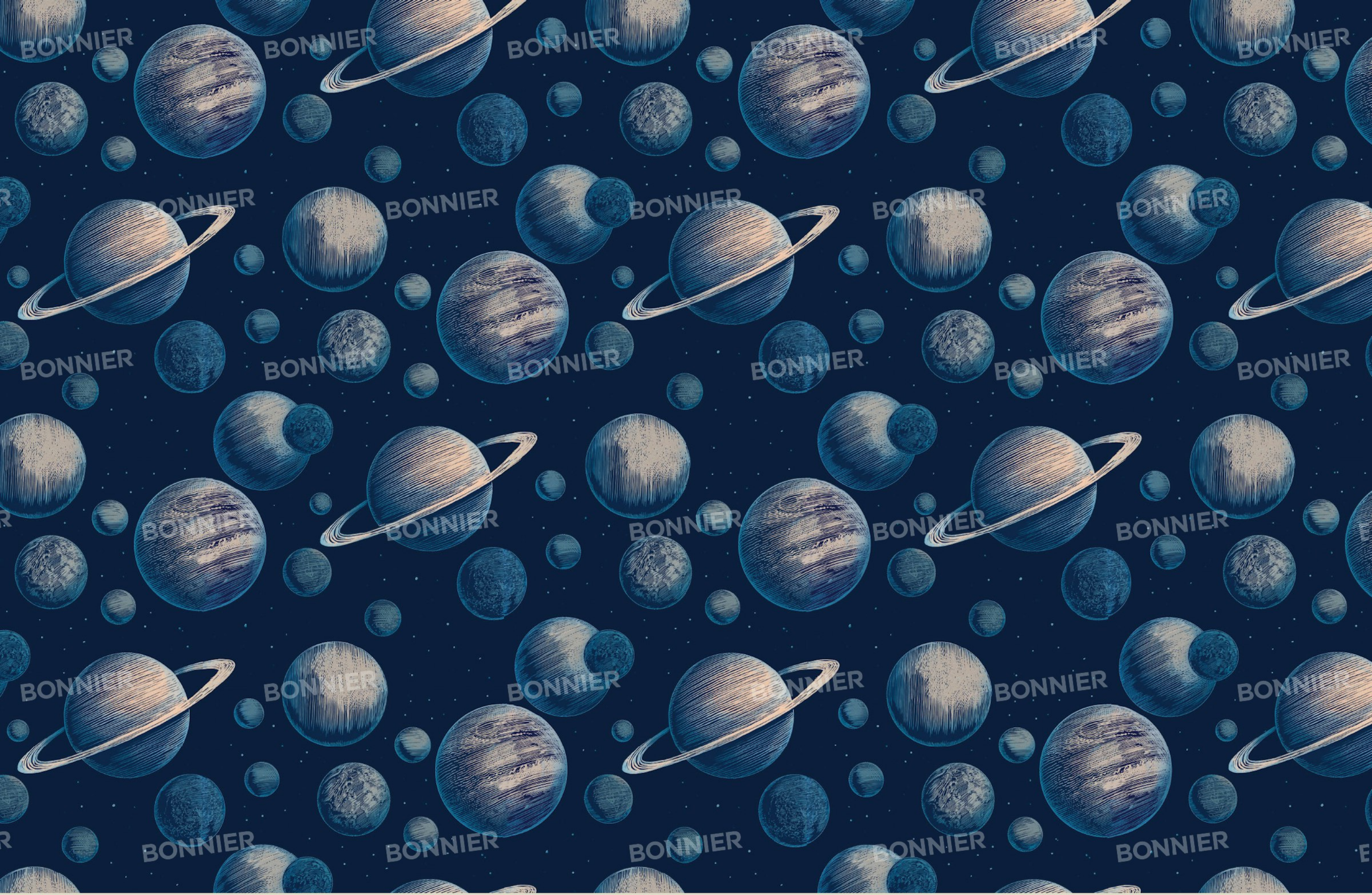
Planetarium

CHRIS WORMELL and RAMAN PRINJA

JUNIOR EDITION

BIG PICTURE PRESS



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Planetarium

Illustrated by CHRIS WORMELL
Written by RAMAN PRINJA

B P P

BIG PICTURE PRESS

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Entrance

Welcome to Planetarium

This book is laid out like a museum, with lots of rooms to explore. It will take you on an incredible journey into space, across the Solar System and on towards the most distant stars. You will visit places where no human has ever been, and view events from billions of years back in time.

Humans have looked at space for thousands of years and wondered what lies out there. In the last hundred years, we have made huge steps forward in space exploration. We have sent space probes to every planet in the Solar System, we have discovered how old the Universe is and we have even landed humans on the Moon. Who knows what steps we could take in the next hundred years . . .

Your tour will begin here on Earth with a look at some of the earliest telescopes. As you move on, you will encounter objects so huge and strange that they could never fit inside a normal museum. You will see a star being born, watch it die in a huge explosion and even get up close to a black hole. This is the only museum to hold whole stars and galaxies within its collections. So enter here to begin your voyage of discovery, and uncover the many wonders of the Universe.

Our Place in the Universe

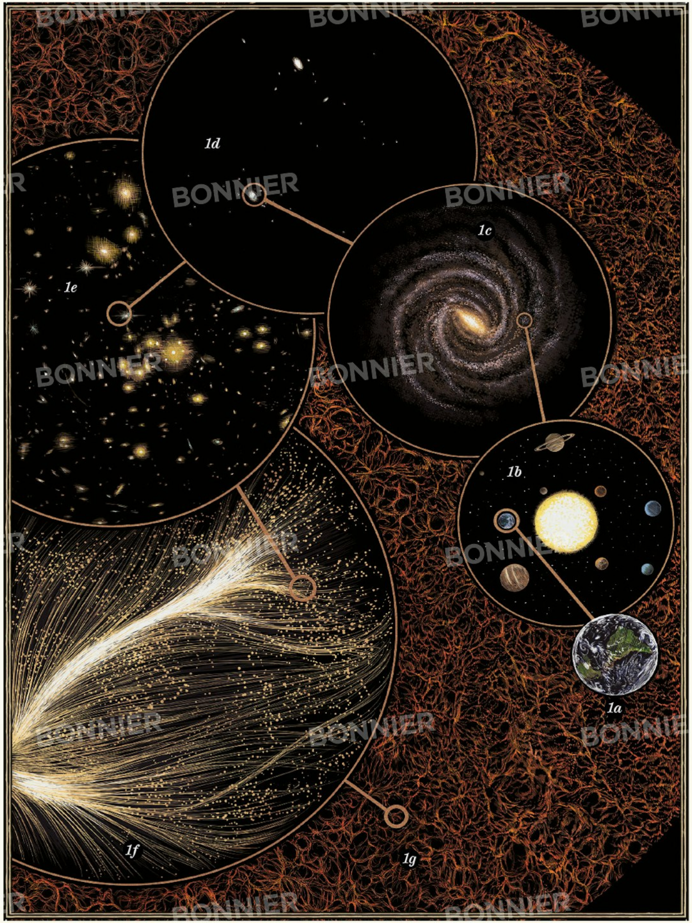
The Universe contains absolutely everything, from tiny atoms to giant galaxies. It is so big that it can be hard for us to imagine its size. But one way of doing this is imagining Earth's 'cosmic address'. So, instead of writing down a house number, street, town and country, we replace each line with larger and larger structures in space.

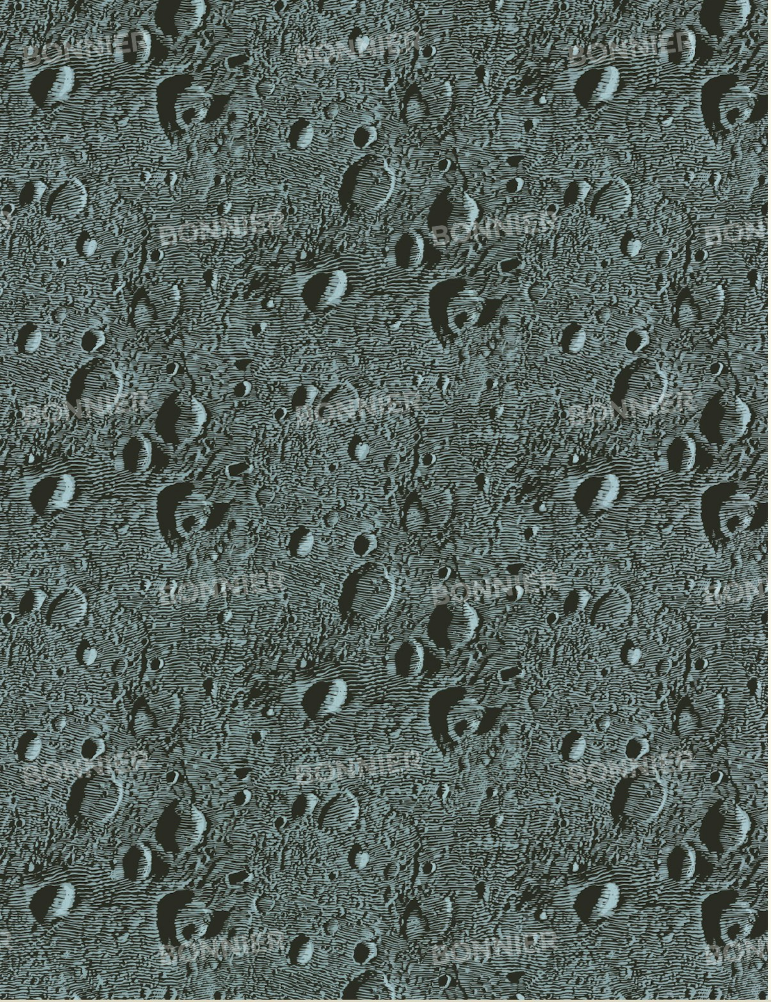
Our cosmic address starts with our planet, Earth. Earth is one of eight planets in the Solar System, so that is the next line. The Sun is at the centre of the Solar System and is one of 200 billion stars in the Milky Way Galaxy; the Milky Way is one of about 50 galaxies in a cluster called the Local Group; this is one of many galaxy clusters in the Virgo Supercluster; and finally the Virgo Supercluster is part of a region in space called Laniakea. This means that our cosmic address is: Earth, Solar System, Milky Way Galaxy, Local Group, Virgo Supercluster, Laniakea, Universe.

While this helps us imagine the Universe, scientists still need ways of measuring its sheer size. Miles and kilometres are no help at this scale. Instead, astronomers use light years – the distance light travels in one year. Since light has a speed of 300,000km per second, the distance it travels in a year is 9.5 trillion km. The distance between our Sun and the planet Neptune is 0.0005 light years. The Milky Way is 100,000 light years across. But largest of all, the Universe is 93 billion light years wide.

Key to plate

1: Our place in the Universe
a) Earth
b) Solar System
c) Milky Way Galaxy
d) Local Group
e) Virgo Supercluster
f) Laniakea
g) Universe





PLANETARIUM

Gallery 1

Looking at Space

Telescopes;
Observatories;
Space Telescopes

Telescopes

Objects in space, such as stars and galaxies, are very far away, and only a tiny amount of their light reaches Earth. This is because light spreads out as it moves further from its starting point. To look at space in any detail, we rely on telescopes – special instruments which make distant objects appear much larger.

Telescopes act like 'buckets' for collecting faint light. Just as a bigger bucket catches more rainwater, a bigger telescope gathers more light. The pupils of our eyes are barely 5mm across, but modern telescopes can be more than 10m wide – a telescope that size can see objects four million times fainter than those we can see just with our eyes.

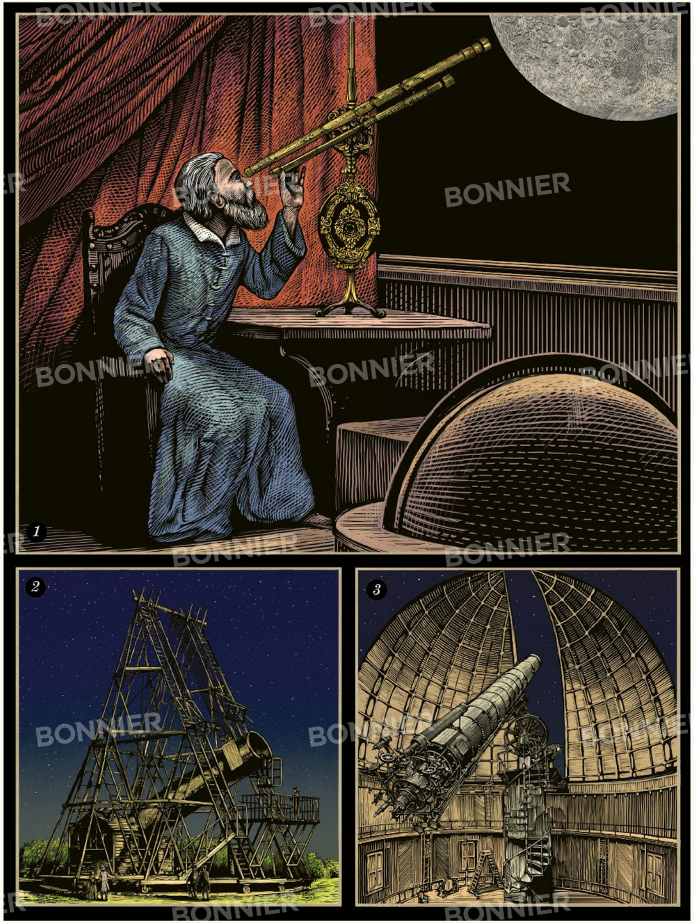
Telescopes work by collecting light using a lens or mirror. The light is focused into a small sharp image and the image is magnified (made bigger). The two main types of telescope are refractors and reflectors. Refracting telescopes use lenses to bend, or refract, light. The light enters through the front lens and travels through the telescope to the eyepiece, where it is magnified. Reflecting telescopes use mirrors to reflect light. Light enters the telescope, bounces off a curved primary (first) mirror, then is reflected off a smaller secondary mirror, which magnifies the image.

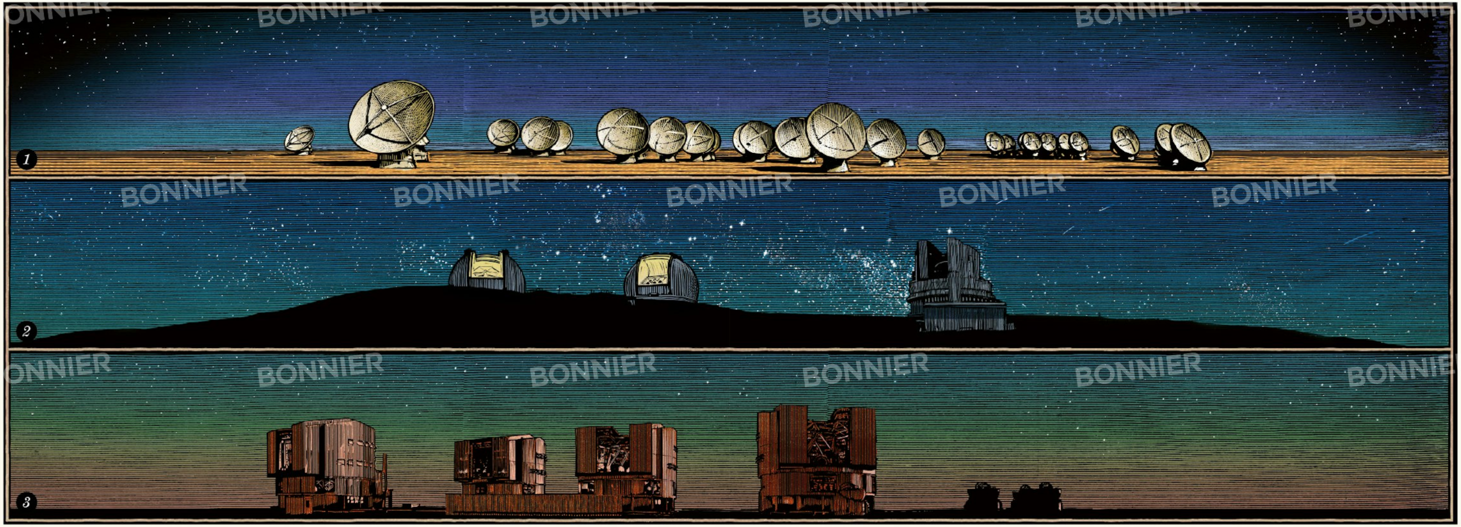
Key to plate

1: Galileo's x20 telescope
Lens width: 37mm
This imagined view shows famous astronomer Galileo Galilei using a refracting telescope in 1609. It was one of the first telescopes ever made.

2: Herschel's 40-foot reflecting telescope
Mirror width: 120cm
William Herschel started constructing the telescope in 1785. At the time, it was the largest telescope in the world.

3: James Lick telescope
Lens width: 91cm
At the time of its construction in 1888 this was the largest refracting telescope in the world – it is the third largest today.





Observatories

The power of a telescope mainly depends on its size. The mirrors in some modern telescopes can be up to 10m wide! (Refracting lenses become too heavy at large sizes so are not used in modern telescopes.)

Huge telescopes are housed in multi-storey buildings called observatories, usually high on mountaintops, where the air is clear, calm and dry, and the skies are very dark.

The telescopes being built today are larger than anything that has come before them, and will allow us to glimpse objects in space we have never seen before. One example is the European-Extremely Large Telescope (E-ELT). Once assembled it will have a diameter of 39m and be able to detect eight million times more light than the telescope used by Galileo in 1609. This light will have taken millions or even billions of years to reach Earth.

Key to plate

1: Atacama Large Millimeter Array (ALMA)
Located in the Atacama Desert in Chile, each of ALMA's 66 antennae detect radio waves. The detectors are kept at a chilly -296°C to avoid heat confusing their signals.

2: Keck Observatory
The twin telescopes of the Keck perch 4200m high on Mauna Kea, Hawaii. Each main mirror is 10m wide and made of 36 hexagonal pieces. Computer controls move the segments so they act as a single reflecting glass.

3: Very Large Telescope (VLT)
Placed high on a mountain in the Atacama Desert, Chile, the VLT enjoys some of the clearest night skies on Earth. Each of its four telescopes has a primary mirror 8.2m wide.

Space Telescopes

Stars and galaxies are so far away that we could never visit them. Everything we know about them comes from studying the energy, or radiation, they give off. Light is the only type of energy we can see with our eyes, but there are other types we cannot see. These include gamma rays, X-rays, ultraviolet radiation, infrared radiation, microwaves and radio waves. Fortunately we can use technology to detect these energies and learn much more about the stars and galaxies.

Unfortunately, our atmosphere – the blanket of gases surrounding the planet – can block out some types of energy. In order to detect them, astronomers have to position telescopes high above the atmosphere. To begin with, in the 1950s, they did this by attaching telescopes to helium balloons. Then, in the 1960s, several telescopes were launched into space attached to satellites. Most of these orbit (circle) Earth, hundreds or even thousands of kilometres above the planet's surface. Here you can see four of NASA's biggest ever satellites. This image also shows NASA's newest telescope, the James Webb Space Telescope. This will see further from Earth than ever before!

Key to plate

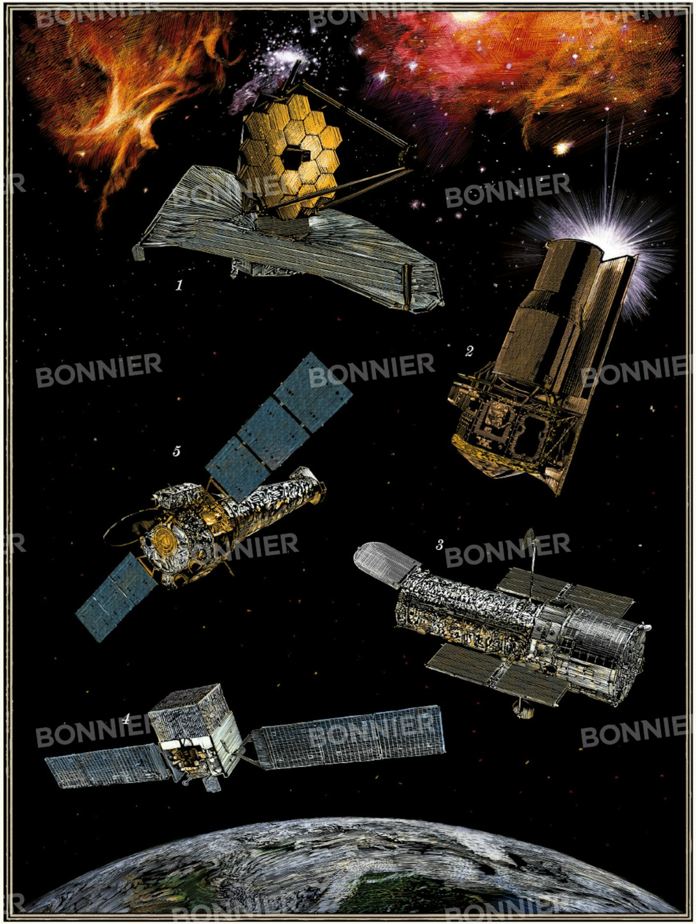
1: James Webb Space Telescope
Location: 1.5 million km above Earth
Launch: Due 2020
This telescope will use infrared light to see more than 13.5 billion light years away!

2: Spitzer Space Telescope
Location: 230 million km above Earth
Launched: 25 August 2003
This telescope looks for infrared light.

3: Hubble Space Telescope
Location: 550km above Earth
Launched: 24 April 1990
Hubble detects ultraviolet, visible and infrared light.

4: Fermi Gamma-ray Space Telescope
Location: 550km above Earth
Launched: 11 June 2008
This telescope detects gamma rays.

5: Chandra X-ray Observatory
Location: max. 139,00km above Earth
Launched: 23 July 1999
Chandra detects X-rays emitted by very hot objects.



PLANETARIUM

Gallery 2

The Solar System

The Solar System; The Sun; Mercury; Venus; Earth; The Moon; Mars; Jupiter; Saturn; Uranus; Neptune; Dwarf Planets; Comets & Asteroids; Exoplanets

The Solar System

The Solar System is a collection of eight planets, more than 180 moons and millions of rocky comets and asteroids, all circling a star called the Sun. The Sun is so enormous that its gravity pulls smaller objects towards it – just like gravity on Earth keeps us pulled to the ground and makes objects fall. The Sun's gravity stops planets drifting off into space. Instead, the planets move around the Sun in roughly circular paths known as 'orbits'.

The four planets nearest to the Sun are Mercury, Venus, Earth and Mars. They are called rocky planets because they are made of rock and metal. A wide asteroid belt separates the rocky planets from the planets beyond them. These are the gas giants Jupiter, Saturn, Uranus and Neptune. These enormous planets are called gas giants because they have no solid surface, as they are surrounded by layer after layer of clouds.

The Solar System is about 4.6 billion years old. It started as a cloud of gas which collapsed and started to spin. The gas and dust spread out, like pizza dough being spun in the air, and the Sun formed in the centre. The rest of the gas and dust made the planets and moons around it.

Key to plate

1: The Sun

2: Mercury
Distance from the Sun: 0.4AU
(An Astronomical Unit (AU) is the distance from Earth to the Sun).
Orbital period (time it takes to orbit the Sun): 88 Earth days

3: Venus
Distance from the Sun: 0.7AU
Orbital period: 224.7 Earth days

4: Earth
Distance from the Sun: 1.0AU
Orbital period: 365 Earth days

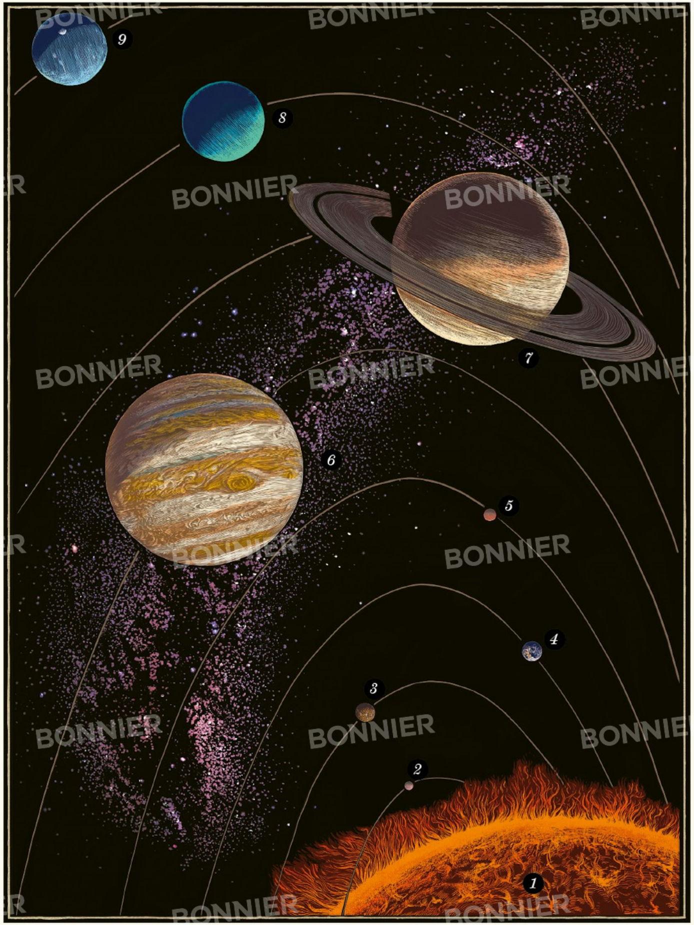
5: Mars
Distance from the Sun: 1.5AU
Orbital period: 1.8 Earth years

6: Jupiter
Distance from the Sun: 5.2AU
Orbital period: 11.9 Earth years

7: Saturn
Distance from the Sun: 9.6AU
Orbital period: 29.4 Earth years

8: Uranus
Distance from the Sun: 19.2AU
Orbital period: 84.1 Earth years

9: Neptune
Distance from the Sun: 30.1AU
Orbital period: 164.8 Earth years



The Sun

At the centre of our Solar System is the Sun, a star which has been shining for 4.6 billion years. It is constantly emitting heat and light, burning with as much energy as 100 billion tons of dynamite exploding every second. It is also the largest object in the Solar System, so big that Earth would fit inside it 1,000,000 times.

Because it is so far away and so hot, nobody has ever been able to visit the Sun. Everything we know about it comes from carefully watching its surface. For instance, sound waves bouncing inside the Sun make the Sun's surface vibrate very slightly, and the rising and falling of this layer can be measured. From this, we know that the Sun must have lots of different layers beneath its surface.

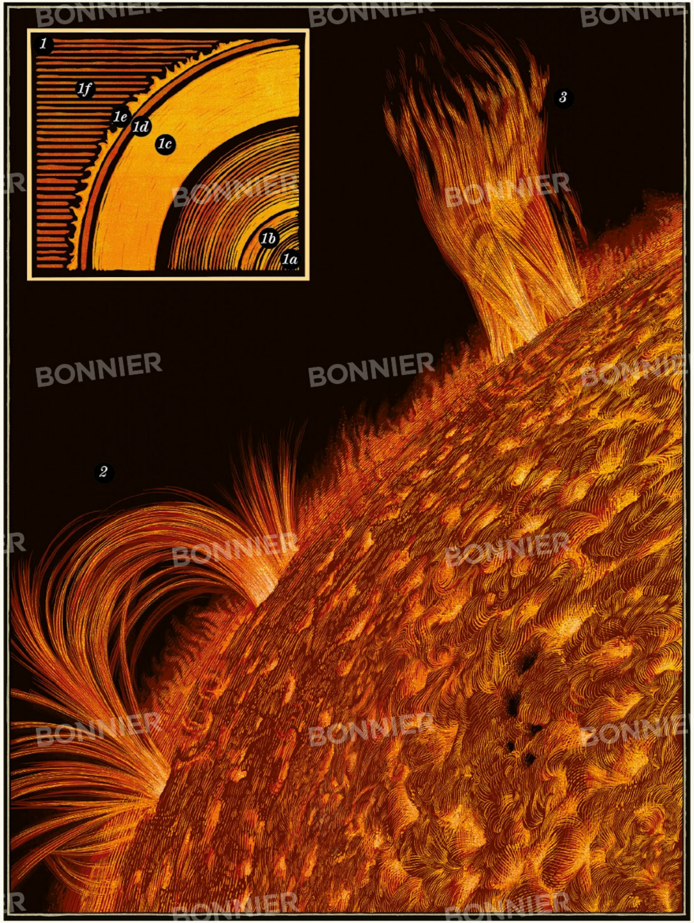
The layer of the Sun that we see, the photosphere, is an incredible 6000°C. But the deeper you go into the Sun, the hotter it gets. Its innermost region (the core) is an incredible 15 million°C. Here, it is so hot and the pressure is so great, that hydrogen atoms fuse together to make helium. This process, called nuclear fusion, releases lots of energy – and it is this that makes the Sun shine.

Key to plate

1: **Layers of the Sun**
a) The core: the innermost part of the Sun
b) The radiative zone
c) The convective zone
d) The photosphere: the visible surface of the Sun
e) The chromosphere: this cannot easily be seen due to the brilliant light from the photosphere
f) The corona: a thin atmosphere of very hot gas

2: **Coronal loops**
Coronal loops are loops of hot gas that arc from the Sun's photosphere.

3: **Solar flares**
Eruptions on the Sun's surface are called solar flares.



Mercury

Mercury is a hot, rocky planet just a third the size of Earth. It is the smallest and fastest planet in the Solar System – zooming through space at 170,500km/h. It is also the closest planet to the Sun.

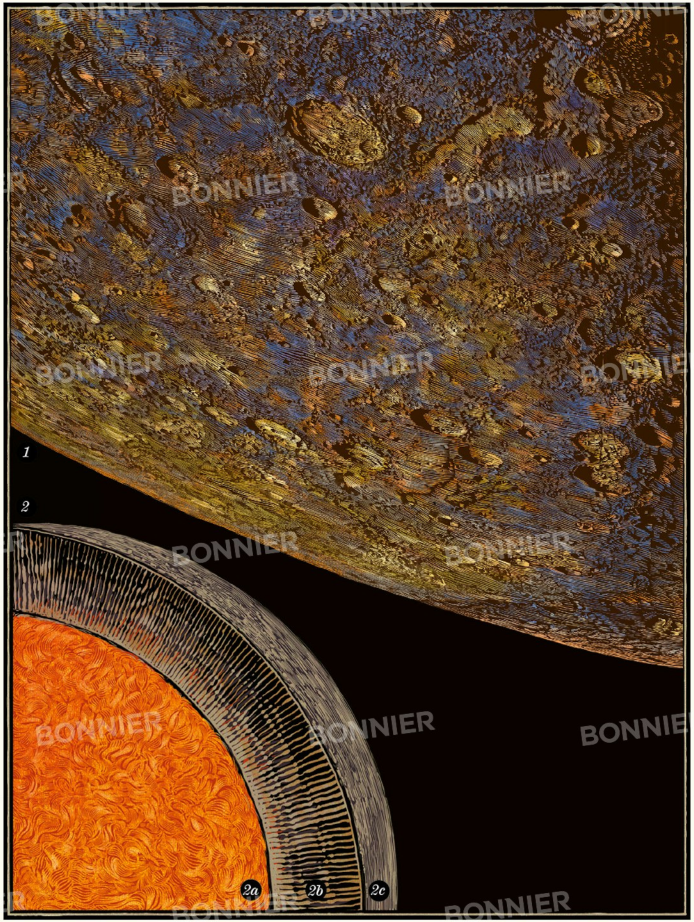
Mercury's surface is surprisingly similar to that of our Moon. Its smooth flat plains were probably made when ancient volcanoes erupted and their lava spread out and hardened, while its craters were most likely made by comet impacts. Above its surface is a very thin atmosphere of gases. Without enough atmosphere to trap the planet's heat, and with the Sun's hot surface so near, Mercury experiences extreme heat and cold as it spins. Temperatures soar to 340°C in the day then plummet to a freezing -180°C at night – that's the most extreme range of temperatures anywhere in the Solar System.

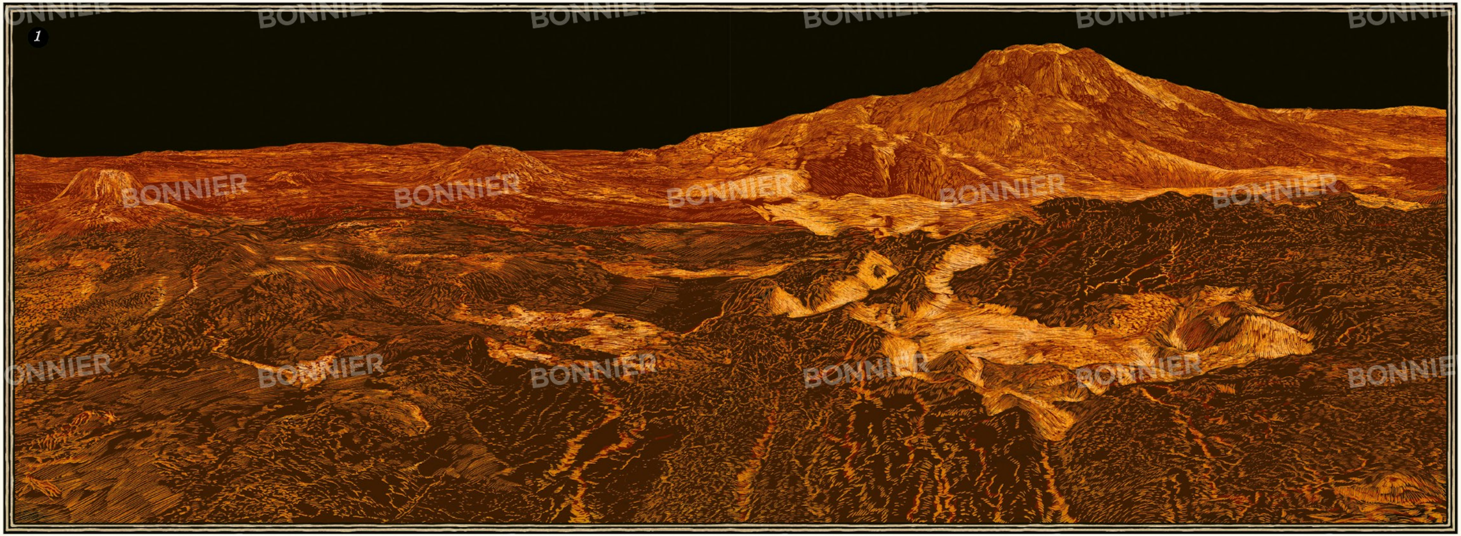
Between 2011 and 2015, a space probe called MESSENGER flew past Mercury several times and discovered there are regions of ice at its north pole. These can only exist because deep craters there hide the ice from the Sun's heat. Scientists think the water probably landed in the form of an icy comet.

Key to plate

1: Mercury
Diameter: 4879km
Orbital period (year): 88 Earth days
Rotation period (day): 1407.6 hours
Known moons: None
Because it orbits the Sun so fast, Mercury was named after the speedy Roman messenger god.

2: Cross-section of the interior
a) Core: the enormous core is made of iron and nickel. It is probably partly molten
b) Mantle: this is around 500km thick
c) Crust: Mercury's surface crust is very thin





Venus

Venus is the second planet from the Sun, and the hottest planet in the Solar System. It is surrounded by a layer of thick, poisonous clouds. These act like a greenhouse, trapping heat from the Sun so that it builds up, making temperatures of up to 462°C – hot enough to melt metal.

It would be impossible for humans to survive on Venus. The planet's terrific surface pressure would crush anyone who landed on it, the carbon dioxide atmosphere would be deadly to breathe, and the intense heat would boil you alive!

Venus is the second brightest object in our skies, but looking at it through a telescope we can only see its cloud cover, and none of its actual surface. In order to see beneath the clouds, we rely on spacecraft called probes, which can fly close to planets. The Magellan and Venus Express spacecraft have both been around Venus. They used radar (bounced radio waves) to reveal its features, including old volcanoes, giant sand dunes, wide plains and high mountains.

Key to plate

1: Venus
Diameter: 12,104km
Orbital period (year): 224.7 Earth days
Rotation period (day): 5832.5 hours
Known moons: None
Venus was named after the Roman goddess of love.

This image shows large volcanoes on Venus's surface.

Earth

Our home planet is the only place in the Solar System where life is known to exist. When it formed 4.6 billion years ago, it was just a boiling hot ball of rock, but today it contains rich habitats from jungles to deserts, and supports around two billion different species.

Earth is unique in the Solar System for its oxygen-rich atmosphere, and for all the water covering its surface. Without Earth's atmosphere we could not survive. It contains the oxygen we breathe, but also acts as a shield against harmful rays from the Sun, and burns up meteors as they approach. Earth's liquid water is also crucial for life on our planet. Scientists think it was brought here billions of years ago by icy comets from the edge of the Solar System.

Beneath Earth's surface, its interior is split into several layers. In the very middle is its core, a solid ball of iron as hot as the Sun's surface. Above this is the outer core, where whirlpools of molten iron make Earth's magnetic field (an invisible force field stretching around the planet). Above the core is Earth's thickest layer, the mantle, formed of rock so hot that it starts to flow like a liquid. And last of all is the fine outer layer of the crust.

The crust and part of the mantle form huge slabs called tectonic plates. These shift over the molten part of the mantle, moving just a few centimetres a year. This slow movement is responsible for volcanic eruptions, earthquakes and for the slow growth of new mountains.

Key to plate

1: Earth
Diameter: 12,756km
Orbital period (year): 365 Earth days
Rotation period (day): 23.9 hours
Known moons: One

In images taken from space, Earth is sometimes called a 'blue marble'. It appears this way because blue light from the sky is reflected off its watery surface. Almost three-quarters of Earth's surface is covered with water, most of it in the planet's oceans.

The *Moon*

Our planet has just one natural satellite – a rocky object we call the Moon. It is covered in powdery soil, craters, dead volcanoes and wide flat plains. From Earth, the plains appear as shadowy areas, whereas the mountains appear much brighter. The lunar plains are known as *maria*, which is the Latin word for 'seas'.

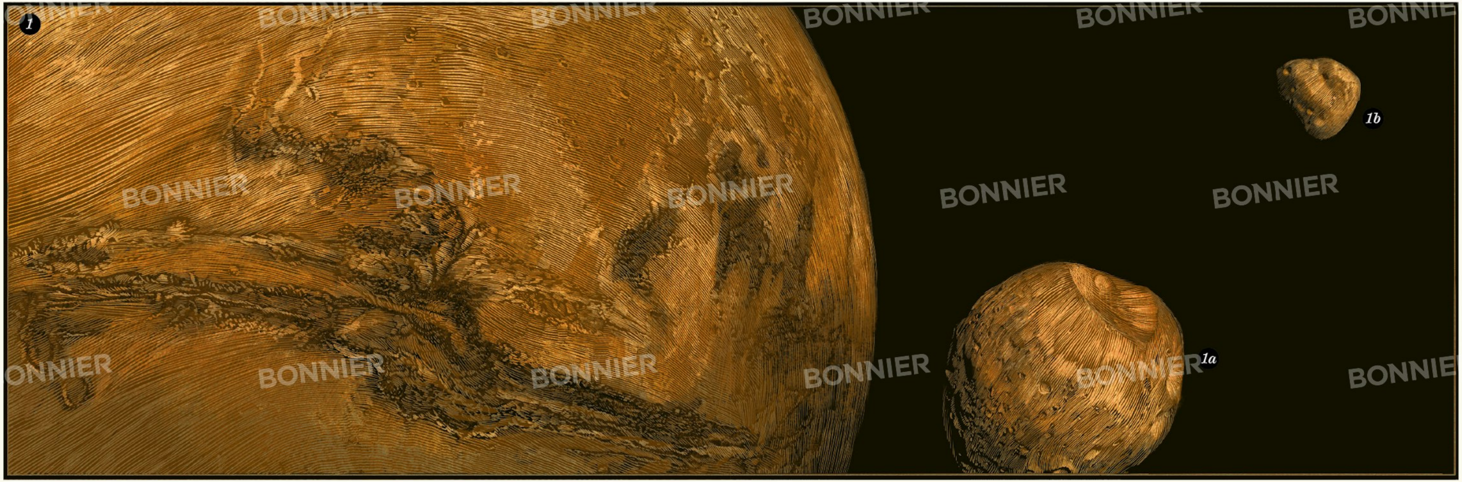
When the Moon appears to shine, it is in fact reflecting the Sun's light back at us. Viewed from Earth, different amounts of its surface are lit up as the Moon orbits, creating the phases of the Moon. Although this makes our view of the Moon appear to change through the month, we only ever see one side of it. This is because the Moon takes exactly the same time to spin on its axis (middle) as it takes to complete a single orbit of the Earth (around 27 days).

Beyond Earth, the Moon is the only object in space where humans have set foot. Only six manned Moon landings have taken place, starting with Neil Armstrong and Buzz Aldrin in July 1969 and ending with Eugene Cernan and Harrison Schmitt in December 1972. The rest of us can only imagine what it would be like to stand on the Moon and watch our planet from a distance.

Key to plate

1: The far side of the Moon
This image shows the far side of the Moon, which is never seen from Earth. It is covered in many more craters than the side that we can see from Earth.

2: Lunar phases
The Moon's appearance from Earth constantly changes as it orbits our planet. These changes are known as lunar phases. During the first phase, the new moon, the Moon reflects no light so is invisible to us. After this we see:
a) Waxing crescent
b) First quarter
c) Waxing gibbous
d) Full moon
e) Waning gibbous
f) Last quarter
g) Waning crescent
This cycle ends with a return to a new moon, and takes an average of 29.5 days to complete.



Mars

Sometimes called the 'red planet', Mars is the last of the rocky inner planets. Its red colour comes from the iron oxide in its surface – the same combination of iron and oxygen that gives blood and rust their red colour. This forms a red dust which covers the planet's craters, valleys and mountains.

The planet's highest point, Olympus Mons, is the tallest mountain in the Solar System. It is an extinct volcano stretching 21km high – around three times the size of Earth's tallest peak, Mount Everest. Mars also has the largest storms in the Solar System – raging dust storms which stretch for thousands of kilometres. During some seasons they are so severe that they can cover the entire planet.

Today Mars is a dry, dusty planet, but water once flowed over it. We know this because there are channels and valleys all over its surface, which must have been made by flowing water. This water dried up long ago, but it's possible that life may have lived there in the past. Even today, Mars is thought to have water beneath its surface, and has thick ice at its north and south poles. Spacecraft are exploring the planet to find out if life could ever have existed there.

Key to plate

1: Mars
Diameter: 6792km
Orbital period (year): 1.8 Earth years
Rotation period (day): 24.6 hours
Known moons: Two

Mars is named after the Roman god of war.

a) Phobos
This moon orbits 5800km above Mars's surface.

b) Deimos
Mars's smaller moon has a lumpy shape like an asteroid. It is gradually getting further away from Mars, so it will eventually drift off into space.

Jupiter

Jupiter is the largest planet in the Solar System, so big that Earth could fit inside it 1300 times. It is known as a gas giant: a planet with a thick, swirling atmosphere but without any solid surface you could stand on.

At its centre is a solid core of ice, rock and metal, surrounded by a layer of liquid. Above this are several layers of thick gases. The top layer appears as a swirling pattern of red, yellow and white: a mix of different gases at varying temperatures. This atmosphere has a stripy appearance because the gases are pushed into dark 'belts' and bright 'zones' by the planet's fast rotation – it spins on its axis once every 10 hours. Inside the atmosphere huge storms often occur. The largest of these is called the Great Red Spot. It has been raging non-stop for more than 300 years and is wider than Earth.

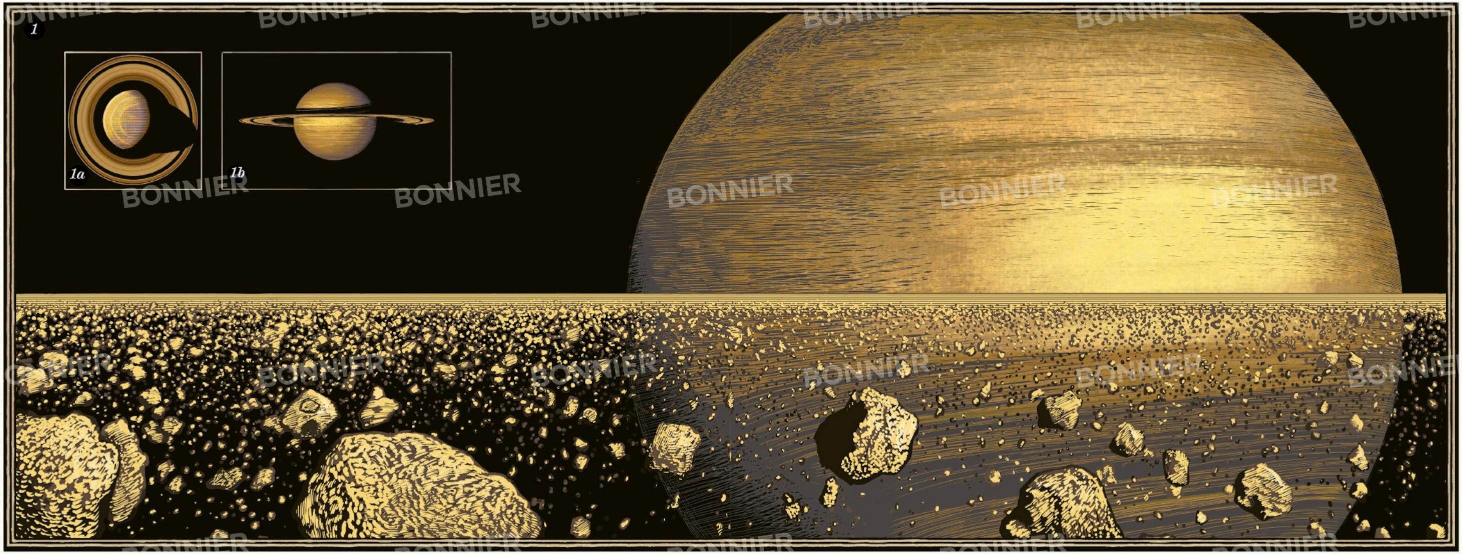
Jupiter has at least 67 moons circling it. The four largest are Ganymede, Callisto, Io and Europa. They are known as the 'Galilean satellites' after their discovery by the scientist Galileo Galilei in 1610.

Key to plate

1: Jupiter
Diameter: 142,984km
Orbital period (year): 11.9 Earth years
Rotation period (day): 9.9 hours
Known moons: 67
The Romans named Jupiter after the king of their gods, who was also the god of the sky and thunder.

a) Great Red Spot
This powerful storm spins around once every six Earth days. At 16,000km long, it is so large it can be seen using telescopes on Earth.

b) Ganymede
This huge moon is larger than the planet Mercury.



Saturn

Saturn is the sixth planet from the Sun. It is a huge gas giant surrounded by beautiful, bright rings. Although the rings look solid from a distance, up close they are made of billions of ice particles, along with fine dust and house-sized boulders. Scientists think the rings formed when a moon drifted too close to Saturn and was broken up by the planet's gravity.

Like the other gas giants, Saturn is a huge ball of gases and liquids. It is mostly made up of hydrogen and helium, which are some of the lightest gases in the Universe. In fact, Saturn would float in water if you could find a bathtub big enough to hold it!

Saturn is surrounded by more than 60 moons. Its moon Titan is the second largest in the Solar System. Scientists are very interested in this moon because it looks a lot like Earth did at the time when life first appeared on our planet – it might even be home to extraterrestrial life.

Key to plate

***1:* Saturn**
Diameter: 120,536km
Orbital period (year): 29.4 Earth years
Rotation period (day): 10.7 hours
Known moons: 62

The Romans named Saturn after the father of Jupiter in mythology.
a) The planet viewed top-down
b) The planet viewed edge-on

Uranus

This blue gas giant is the coldest planet in the Solar System. Its icy clouds can have temperatures as low as an astonishing -220°C and are the site of huge ice storms.

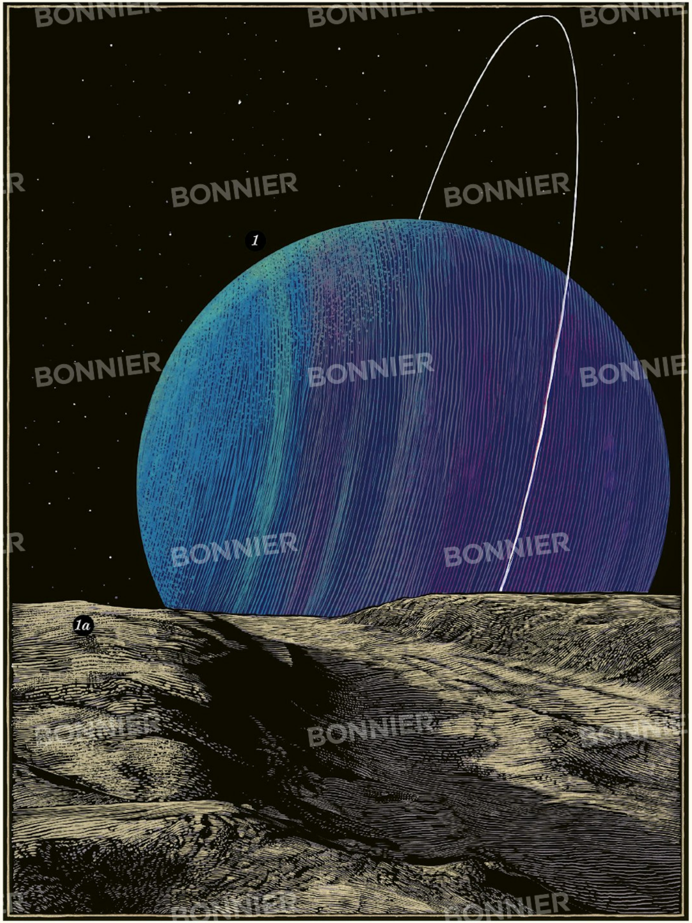
Unlike other planets, Uranus is tipped on its side as it orbits the Sun. This means its north pole points at the Sun for half of its year and its south pole points at the Sun for the rest of the year. If you could stand on its north pole, you would see the Sun stay in the sky for 42 Earth years without ever setting. After this incredibly long 'summer', the Sun would finally drop below the horizon and you would enter 42 Earth years of 'winter' darkness.

Scientists guess the planet's surprising tilt may have resulted from a collision with a large object which tipped the planet onto its side. The force of this impact could also have created the thin rings surrounding Uranus.

Key to plate

1: Uranus
Diameter: 51,118km
Orbital period (year): 84.1 Earth years
Rotation period (day): 17.2 hours
Known moons: 27
Uranus was discovered by accident in 1781 by the astronomer William Herschel. Although Herschel wanted the planet to be named Georgium Sidus, after King George III, it was instead named after the Roman god Uranus, who was the father of Saturn.

a) Miranda
Miranda is Uranus's smallest moon. It has a jumbled, broken appearance. This is thought to be because an asteroid impact broke the moon apart, before it joined up again thanks to its own gravitational pull.



Neptune

Neptune is the most distant planet in the Solar System and the second coldest planet after Uranus. The methane gas in its atmosphere gives it a deep blue appearance. This atmosphere is the location of the fastest storms in the Solar System. Winds race at speeds of up to 2400km/h – nearly 10 times faster than a Category Five hurricane on Earth (the most intense winds known on our planet). Neptune also has smaller storms which appear as dark spots on its surface. Amazingly, scientists think Neptune's lower atmosphere experiences 'diamond rain' where the temperature and pressure make diamonds form and rain down on the planet's centre!

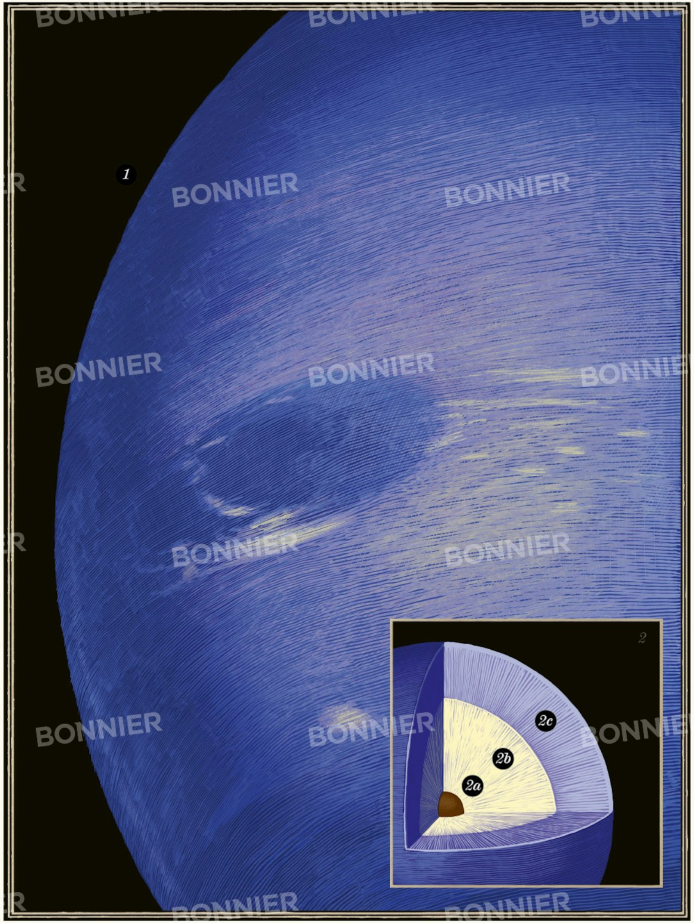
Neptune was first observed in 1846 by the astronomer Johann Gottfried Galle. The planet is so far away, and has such a long orbit, that by July 2011 it had only just completed its first full orbit of the Sun since its discovery.

Key to plate

1: Neptune
Diameter: 49,528km
Orbital period (year): 164.8 Earth years
Rotation period (day): 16.1 hours
Known moons: 14

Neptune is named after the Roman god of the sea.

2: Cross-section
a) Core: this is made of rock and ice and is a little larger than the whole of Earth
b) Mantle: this is probably a slush of water, ammonia and methane ices
c) Atmosphere: made up of hydrogen, helium and methane gases



Dwarf Planets

As well as the eight planets, the Solar System is full of other objects, from tiny chips of rock to objects as big as the planets themselves. So what makes a planet a planet? In 2006, astronomers answered that question and came up with three rules all planets have to meet. Firstly, a planet has to orbit (circle) the Sun. Secondly, it should have enough mass (size) and gravity to pull itself into a perfectly round shape. Thirdly, it cannot share its path around the Sun with any other objects.

For years, astronomers thought Pluto was a planet. But while it orbits the Sun and is perfectly spherical, it also shares its neighbourhood with other icy objects. So in 2006, 76 years after it was discovered, Pluto was re-labelled as a dwarf planet.

Astronomers think there could be dozens of dwarf planets beyond Pluto, but so far we have found just five in the Solar System. Most of these are in the Kuiper Belt, a region of space stretching far beyond Neptune. But much closer to us is Ceres, the largest object in the Asteroid Belt between Jupiter and Mars.

Key to plate

1: Dwarf planets
Here the five dwarf planets are shown to scale next to Earth. They are in fact far apart, mainly in the outer Solar System.

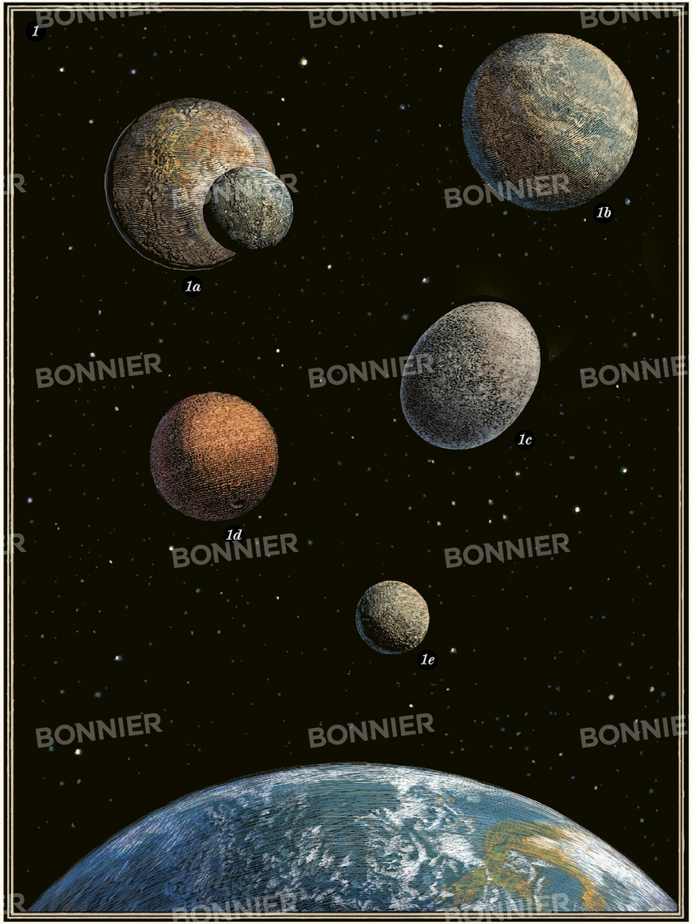
a) Pluto
Diameter: 2374km
Orbital period (year): 248 years
Rotation period (day): 6.4 days
Distance from the Sun: 29.6–49.3AU
Here Pluto is shown with Charon, its largest moon.

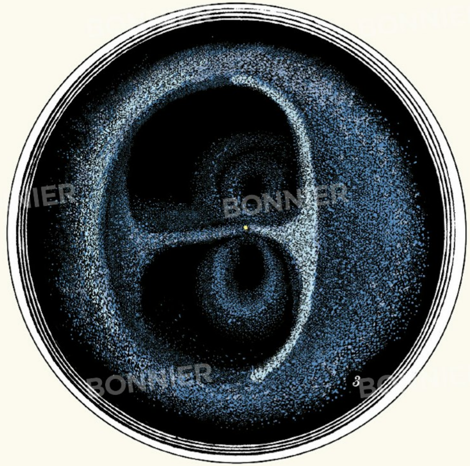
b) Eris
Diameter: 2400km
Orbital period (year): 560.9 years
Rotation period (day): 1.1 days
Distance from the Sun: 38.3–97.5AU
Eris is the largest dwarf planet.

c) Haumea
Diameter: 1960km (long side)
Orbital period (year): 283.3 years
Rotation period (day): 0.2 days
Distance from the Sun: 34.7–51.5AU

d) Makemake
Diameter: 1430km
Orbital period (year): 306 years
Rotation period (day): 0.3 days
Distance from the Sun: 38.1–52.8AU

e) Ceres
Diameter: 946km
Orbital period (year): 4.6 years
Rotation period (day): 0.4 days
Distance from the Sun: 2.6–3.0AU





Comets & Asteroids

Comets are balls of ice and dust like huge dirty snowballs barrelling through space. They begin their journey far out in the Solar System, either in the Kuiper Belt (which is 4.5 to 15 billion km from the Sun) or in the Oort Cloud (even further away, at 7500 billion km from the Sun). Sometimes a passing star will 'knock' a comet out of its position and send it hurtling towards the inner Solar System. As it gets closer to the Sun, the comet will warm up, and some of its ice will turn into vapour (gas). This makes a thick cloud around the comet's middle, which 'blows' backwards into a brilliant trail behind it. The largest comets have tails millions of kilometres long and bright enough to be seen from Earth.

Asteroids are made of metals and rocks, and have lumpy shapes, often a bit like potatoes. The largest asteroids orbit the Sun in the asteroid belt between Mars and Jupiter. If asteroids crash into each other, the collision can knock one of them off its path and push it out into the wider Solar System.

Many smaller pieces of ice, rock and dust also drift through the Solar System. Sometimes pea-sized lumps enter Earth's atmosphere and burn up. We see these as meteors or shooting stars – bright trails streaking across the sky. Anything that enters our atmosphere is known as a meteoroid. If it survives its fall through the atmosphere, it is known as a meteorite.

Key to plate

1: Comet core
The core (middle) of a comet is a ball of ice and dust, loosely held together by gravity. It is surrounded by a fuzzy cloud of dust and gas known as a coma.

2: Comet tails
As a comet nears the Sun, two tails stretch away from it. A white tail forms from dust and a blue tail, or 'ion tail', forms from gas.

3: Oort cloud
The Oort cloud is a ring of icy objects surrounding the Solar System and is home to many comets. Seen here, the Sun and its planets lie within the yellow dot at the centre of the cloud.

Exoplanets

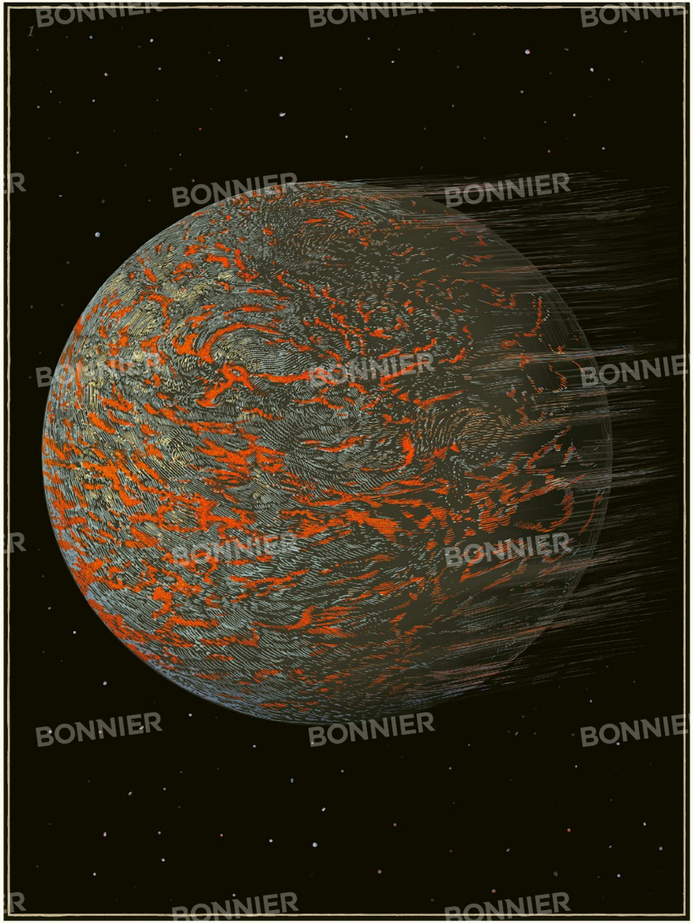
Using modern telescopes and technology, astronomers have discovered there are thousands of planets outside our Solar System. These far-away planets, called exoplanets, are orbiting distant stars, just like our planet orbits the Sun.

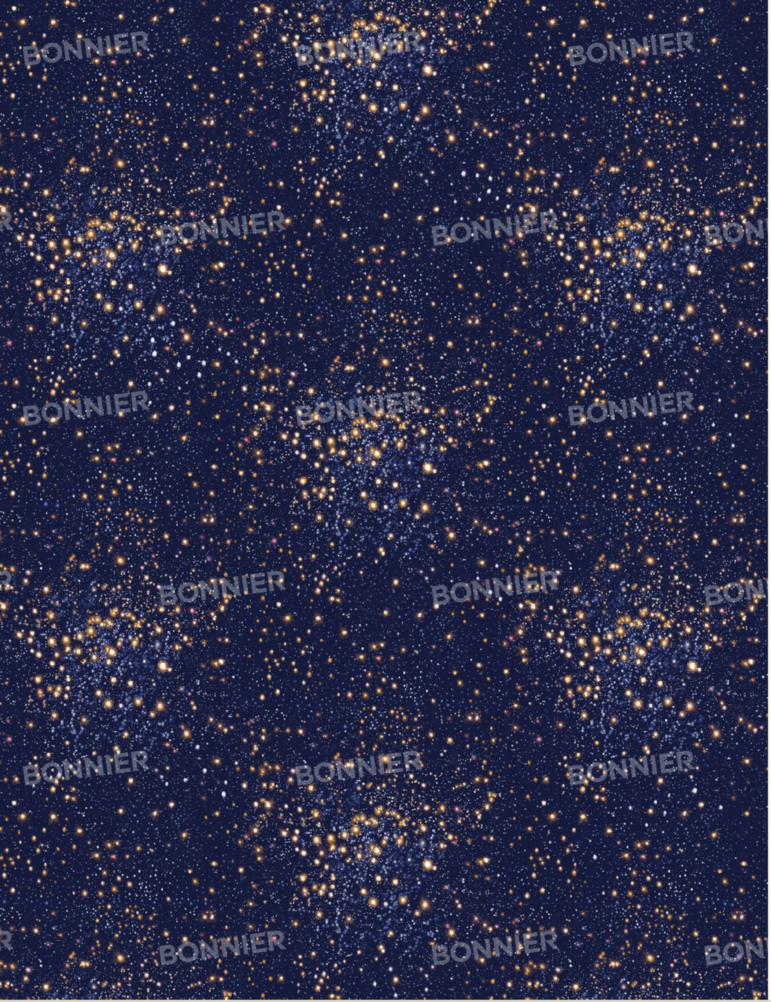
Some exoplanets are completely different to anything seen in our Solar System. They include enormous planets surprisingly close to their stars, and rocky planets as large as our gas giants! But most interesting to scientists are the exoplanets that resemble our own planet, Earth. Some of these may even have the conditions needed for life to exist.

As we know it, life depends on liquid water, and temperatures neither too hot nor too cold. This means astronomers are looking for planets that are just the right distance from their star – if they are too close to the star they will be too hot; if they are too far away they will be too cold. These planets are known as 'Goldilocks planets' after the fairytale character and her porridge. Every Goldilocks planet that is discovered will be carefully studied. If all the conditions are right, it might just be that one of these planets is home to extraterrestrial life, and that we are not alone in the Universe . . .

Key to plate

1: Exoplanet
The planet known as 55 Cancri e (or Janssen) is classified as a 'super Earth'. This means that it is bigger than Earth but not as big as the gas giants within the Solar System. It is orbiting so close to its Sunlike star that its dayside temperatures can reach between 1000 and 2700°C. Besides its incredibly hot temperatures, it is thought to have a hostile surface, covered in lava flows, and with hot gas and dust sometimes smothering the whole planet.





PLANETARIUM

Gallery 3

The Night Sky

The Night Sky;
Northern Hemisphere Constellations;
Southern Hemisphere Constellations

The Night Sky

On a clear night away from city lights, we can see about 2000 stars. Even without a telescope, you should be able to notice three main things about them.

Firstly, stars are not all the same brightness. Some are larger and more powerful than others, meaning they appear brighter from a distance. Some also appear brighter to us because they are nearer to our planet.

Secondly, stars aren't all the same colour. Most appear white, but some have a red, blue or yellow tint. These colours reveal the stars' different surface temperatures: hotter stars look blue, while cooler ones look red. Be careful not to confuse these subtle colours with the more colourful planets (Mercury looks yellowish; Venus looks silvery and Mars is famously the 'red planet'). The planets usually appear brighter than stars, but they do not 'twinkle'.

Thirdly, the stars are not evenly spread across the sky. Some of them – although vast distances apart in space – seem to cluster in groups as we view them from Earth, making patterns which we call constellations.

Key to plate

1: **View of the night sky**
As well as the stars, we can also see other astronomical objects in the night sky. At certain times of year we can see the Milky Way Galaxy as an arc of stars. During the year you can also look out for firework-like displays of meteor showers. These include the Orionids (late October), Leonids (November), Geminids (mid December) and Lyrids (mid-April).

Northern Hemisphere Constellations

Since ancient times, humans have seen patterns in the stars, and imagined them to be the shapes of gods, heroes, wild creatures and mythical beasts. Occasionally civilisations 'shared' the same figures. For example, the constellation the Greeks named Orion the hunter was seen by the ancient Chinese as a hunter or warrior named Shen. In other cases, different cultures saw completely different shapes in the same pattern. For instance, the seven brightest stars within Ursa Major are called the Plough in the UK; the Big Dipper in the US; known as the saucepan in France; considered a mythological parrot to the ancient Maya; called the Seven Rishis (or Wise Men) in Hindu folklore; and thought of as a special chariot for the Emperor of Heaven by the Chinese.

By the early twentieth century, there were so many constellations in use that the International Astronomical Union (IAU) officially chose 88 constellations across the northern and southern skies. These official constellations fit exactly together like jigsaw pieces, so that every place in the sky belongs to one. They are used by astronomers like areas on a map to help them locate objects.

Key to plate

1: Northern Hemisphere Constellations

a) Leo
One of the oldest constellations known, Leo is Latin for 'lion'.

b) Cancer
Commonly shown as a crab, this constellation contains two stars which we know have planets.

c) Cygnus
This swan-shaped constellation contains the five stars of the Northern cross – a pattern of stars easily sighted in summer.

d) Monoceros
Monoceros takes its name from the Greek word for 'unicorn'.

e) Pisces
This constellation is named after the Latin for 'fish'.

Southern Hemisphere Constellations

The southern hemisphere is one of the best places in the world to go stargazing. It offers incredible views of the Milky Way and is the only place where we can see two of our neighbouring galaxies, the Large and Small Magellanic Clouds. The southern hemisphere also contains the three brightest stars in the night sky: Sirius, Canopus and Alpha Centauri (the nearest star to our own).

The indigenous peoples of Australasia were among the first humans to name objects in the night sky, but the majority of constellations adopted by the IAU were mapped out by European explorers in the sixteenth century. During this time, charting the stars was especially important as star charts were the only way to navigate (find your way) at sea. One of the most important constellations for navigation was Crux, or the Southern Cross, as its four main stars are unusually bright, and it can be seen all year long. Crux can be seen on several national flags, including those of Australia, New Zealand, Papua New Guinea, Samoa and Brazil.

Key to plate

1: Southern Hemisphere Constellations

a) Aquarius
One of the oldest documented constellations, Aquarius is also the 10th largest.

b) Hydra
Imagined in the form of a twisting snake, Hydra is the largest constellation in the whole sky.

c) Libra
Libra's name is Latin for 'scales'. The constellation is depicted as a pair of balanced scales.

d) Centaurus
This constellation is shown as a centaur: a mythical creature which is a horse from the waist down and a man above the waist.

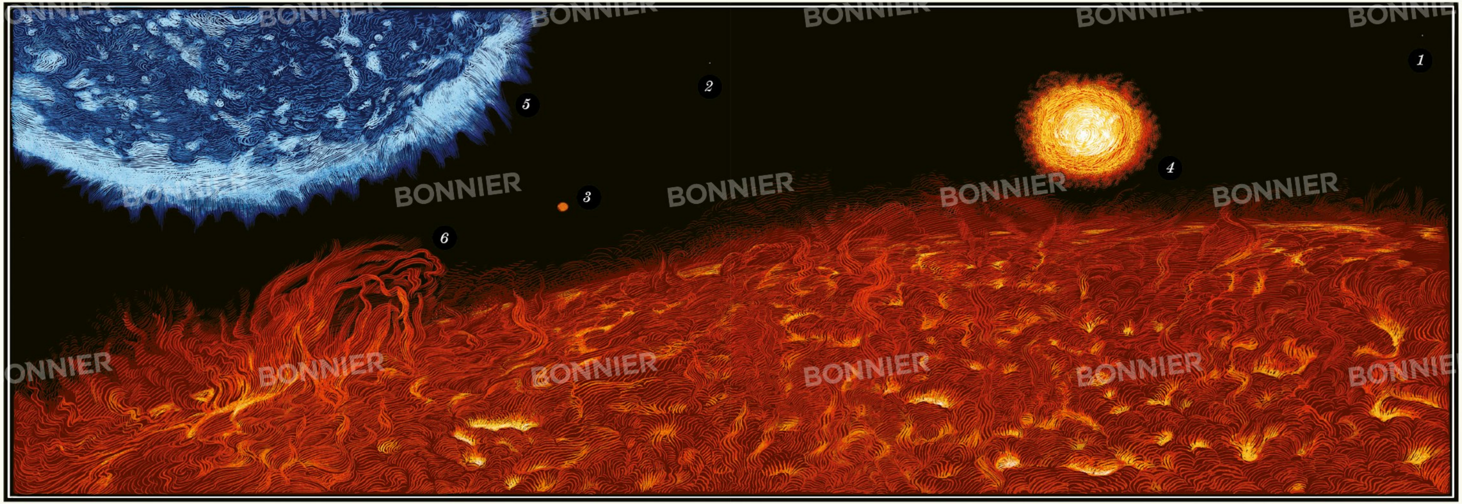
e) Carina
This cluster of around 300 stars includes the enormous star Eta Carina, and the Carina Nebula, a bright area of space where stars are constantly being born.

PLANETARIUM

Gallery 4

The Stars

Star Types;
Where Stars are Born;
Star Life Cycles;
Black Holes



Star Types

Stars are giant balls of gas that create enormous amounts of heat and light. They come in many shapes and sizes, as well as varying temperatures, colours and brightnesses. Stars shine with different colours depending on their temperatures, so this is an easy way for astronomers to group them. The hottest stars appear blue, while the coolest appear red. Stars are also grouped by size, as dwarfs, giants or supergiants. Our star, the Sun, is a dwarf star. We can group stars by age, too – from newly born stars to ancient and dying stars. How long a star will live depends on how heavy it was when it was born. The heaviest stars always lead the shortest lives.

Key to plate

1: Brown dwarf
Surface temperature: 1000–2000°C
Radius: 0.05–0.12 solar radii
(1 solar radius – singular of radii – is the radius of the Sun, or 695,700km)
Energy emitted: 0.00001 times the Sun's output

2: White dwarf
Surface temperature: 4000–150,000°C
Radius: 0.008–0.2 solar radii
Energy emitted: 0.0001–100 times the Sun's output

3: Yellow dwarf
Surface temperature: 5000–7000°C
Radius: 0.96–1.4 solar radii
Energy emitted: 0.6–5.0 times the Sun's output

4: Red giant
Surface temperature: 7000–9000°C
Radius: 20–100 solar radii
Energy emitted: 100–1000 times the Sun's output

5: Blue supergiant
Surface temperature: 10,000–20,000°C
Radius: 100–2000 solar radii
Energy emitted: 1000–800,000 times the Sun's output

6: Red supergiant
Surface temperature: 3000–5000°C
Radius: 100–2000 solar radii
(but mostly larger than blue supergiants)
Energy emitted: 1000–800,000 times the Sun's output

Where Stars are Born

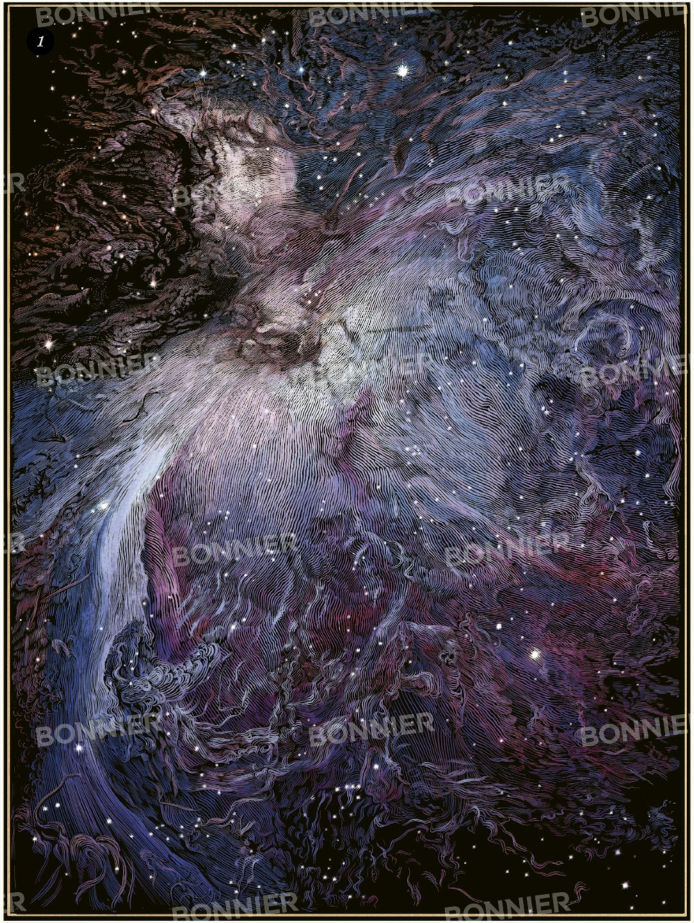
No stars live forever – they are all born, and at the end of their lives they will all die. Every single star you see in the sky was born inside a cloud of gas and dust, called a nebula. These beautiful clouds are like nurseries for all the new stars in the Universe. On average, somewhere in our Milky Way Galaxy, about three new stars are born every year. But in some galaxies, hundreds or even thousands of stars are born each year.

Nebulae (plural for nebula) are made of hydrogen and helium gas, along with lots of tiny particles of dust. The clouds may stay motionless for millions of years until they are disturbed, for example by a nearby star exploding. If this happens, the cloud will suddenly collapse, shrinking in on itself and spinning faster and faster. The outer part of it will spread into a flat Frisbee shape, while the middle part will gradually form a ball-shape. Growing hotter and hotter, the ball will eventually form a very young star – known as a protostar.

Over time, the protostar will keep getting hotter. Eventually it will become hot enough to change hydrogen atoms in its core into helium atoms. This process is called nuclear fusion, and is how stars make their heat and light. Finally, the star will start to shine!

Key to plate

1: **The Orion Nebula**
The Orion Nebula is a cloud of dust and gas over a thousand light years away from Earth. The light made by new stars being formed lights up the nebula. It is so bright that it can even be seen from Earth – though only on very clear, dark nights.



Star Life Cycles

Stars shine by converting hydrogen atoms into helium atoms inside their core. But at some point, every star will run out of helium 'fuel'. What happens next depends on how big the star is.

The smallest stars (or lightweight stars) range from lighter than our Sun to eight times its mass (the amount of matter it has). They spend several years making energy before running out of fuel. Then they swell out into red giants, and turn into white dwarf stars.

Middleweight stars start off 8 to 20 times the mass of the Sun. They burn much faster than Sunlike stars, using up their fuel supply in less than a billion years. At this point they swell into supergiants, then die in a huge explosion called a supernova. The only thing left behind will be a very dense, city-sized core called a neutron star.

The most massive (heavyweight) stars are more than 20 times the mass of the Sun. In just a few million years they use up all their fuel. They quickly grow into enormous blue supergiants, then just as quickly collapse in the lead up to a supernova explosion. The life cycle of heavyweight stars ends with the creation of a black hole (see p.62).

Key to plate

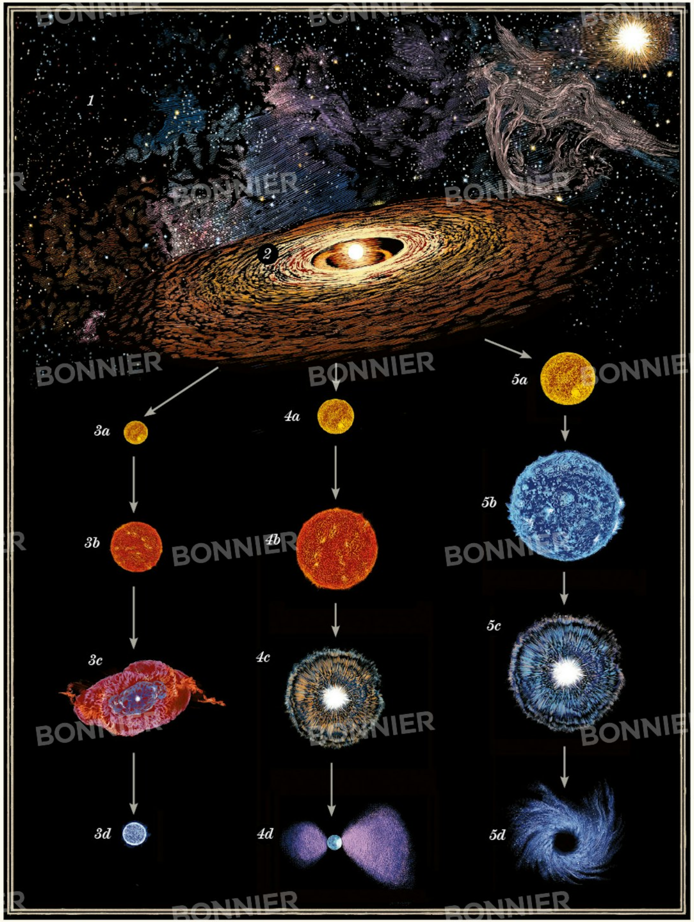
1: **Interstellar nebula**
This is a cloud of dust and gas where stars are born.

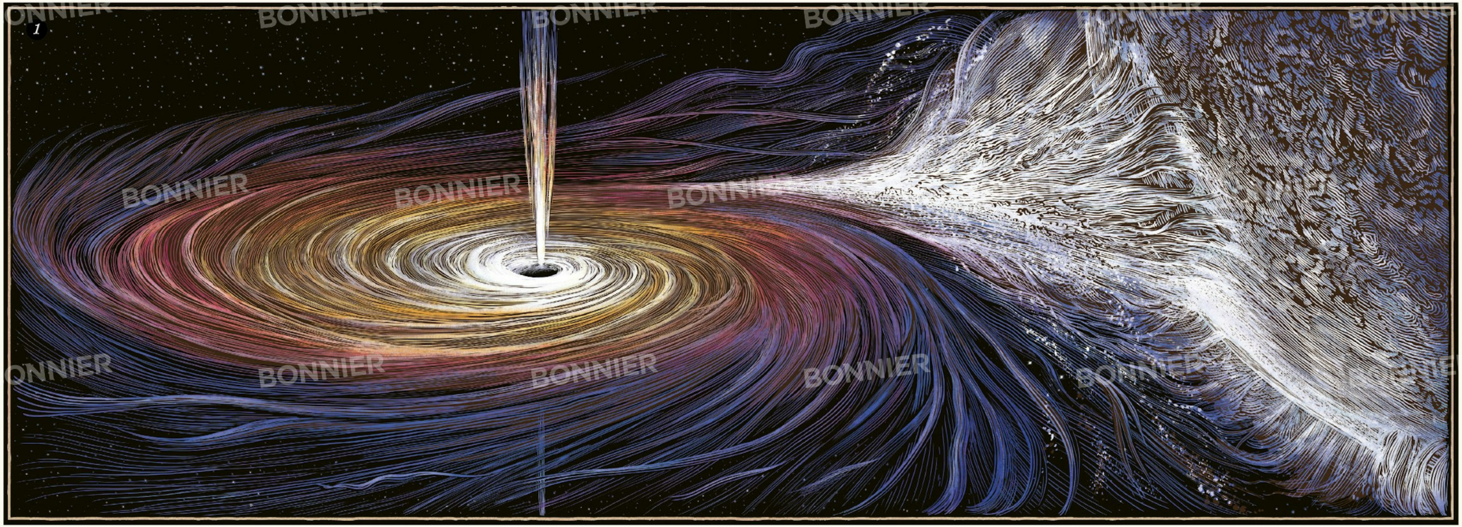
2: **Protostar**
Gas spins round the star as it forms, making a wide disc.

3: **Lightweight star life cycle**
a) The star shines for a few billion years.
b) The star becomes a red giant when it runs out of hydrogen. Its core collapses and its outer layers swell.
c) Its outer layers are shed – this is called a planetary nebula.
d) All that remains is the shrunken core, called a white dwarf.

4: **Middleweight star life cycle**
a) The star burns its fuel very quickly.
b) When the star runs out of fuel, it expands into a red supergiant.
c) The star explodes – this is called a supernova.
d) All that remains is a dense core called a neutron star.

5: **Heavyweight star life cycle**
a) The star shines.
b) When the star runs out of fuel, it expands into a huge blue supergiant.
c) The star explodes as a supernova.
d) If the core is more than three times the mass of the Sun, it becomes a black hole.





Black Holes

A black hole forms when a massive star (more than 20 times the size of the Sun) uses up the last of its fuel, collapses and blows up in a huge explosion called a supernova. All that is left of the star after this is the core, which is so enormous that it collapses under its own weight and makes a black hole.

Because it is so massive, and spinning so fast, the black hole bends the space around it. It has an incredibly strong gravitational pull – nothing, not even light can escape from it. However, it is not like a giant vacuum cleaner sucking up the Universe. Objects only fall into a black hole if they stray too close to it.

If a human got too close to a black hole, they would be sucked in by its gravitational pull, stretched out like spaghetti and burned up in a wall of fire. Some scientists call this 'spaghettification'. The same thing would happen to anything that approached a black hole, from a planet to a star.

Key to plate

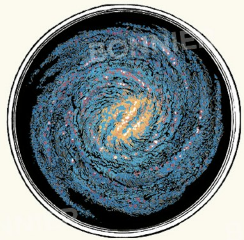
1: **Black hole**
When a black hole and an ordinary star orbit each other as a pair, gas can be pulled off the ordinary star by the gravity of the black hole.

The matter spirals towards the black hole and gets heated up. Before falling into the black hole, this matter lets off X-rays, which we can detect using special telescopes. By measuring the X-rays, astronomers can work out that the object pulling the matter must be a black hole. Since nobody has ever seen a black hole, we can only imagine what they look like by studying the effects they have on the stars around them.

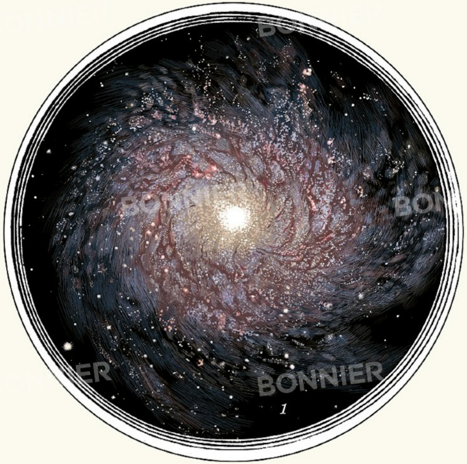
PLANETARIUM

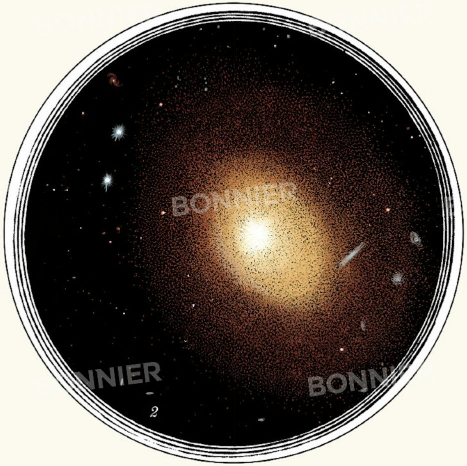
Gallery 5

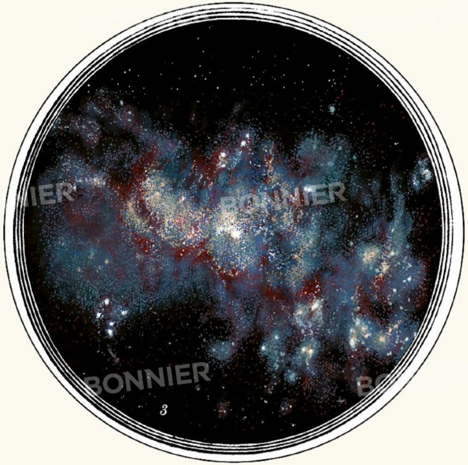
Galaxies



Galaxy Types;
The Milky Way;
Galaxy Clusters







Galaxy Types

Galaxies are huge collections of stars, gas and dust, held together by gravity. There are thought to be 2000 billion galaxies across the Universe and they are found in many shapes and sizes. However, most can be grouped into three main types: spirals, ellipticals and irregulars.

Around three-quarters of all galaxies are spiral galaxies, including our own Milky Way. They have a round bulge at their centre, which is full of red and yellow stars (and sometimes a black hole). Around the bulge is a flat circle of gas, dust and stars. This is sometimes split into 'arms' like the arms of an octopus, making the galaxy look like a pinwheel. Finally, around the galaxy is an almost invisible halo.

The second most common type of galaxy are ellipticals, which have an egglike shape. They mostly contain old stars and don't have enough gas and dust to make new stars.

Lastly, irregular galaxies have no regular shape or structure. They contain lots of gas and dust, which makes them the perfect place for new stars to form, so they are full of bright, newly born stars.

Key to plate

1: **Spiral galaxy**
The Messier 83 (M83) is a spiral galaxy almost three times smaller than our galaxy.

2: **Elliptical galaxy**
This giant elliptical galaxy, called ESO 325-G004, is around 100 billion times the mass of our Sun.

3: **Irregular galaxy**
NGC4449 is an irregular galaxy nearly 12.5 million light years away from us. Like most irregular galaxies, it is a busy star nursery!

The Milky Way

Our galaxy, the Milky Way, is a beautiful spiral galaxy. At certain times of the year we can see it as a magnificent arc of stars stretching across the sky. The faint band of light seen from Earth gives the galaxy a 'milky' appearance, after which it is named.

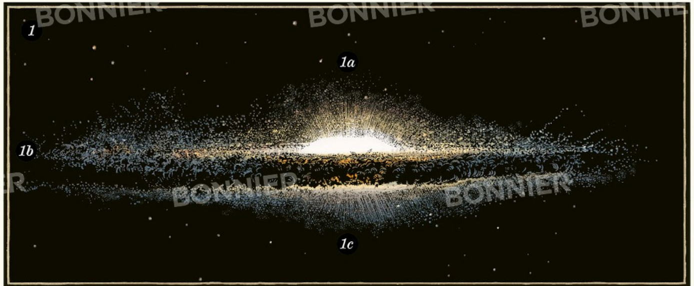
Like other spiral galaxies, the Milky Way looks a bit like two fried eggs stuck back-to-back: the yolks are the galaxy's bulge and the egg whites are its disc. The flattened disc is around 100,000 light years across and contains at least 200 billion stars, all gradually orbiting the middle of the galaxy. This means that the Milky Way spins like a whirlpool, completing a full rotation once every 220 million years.

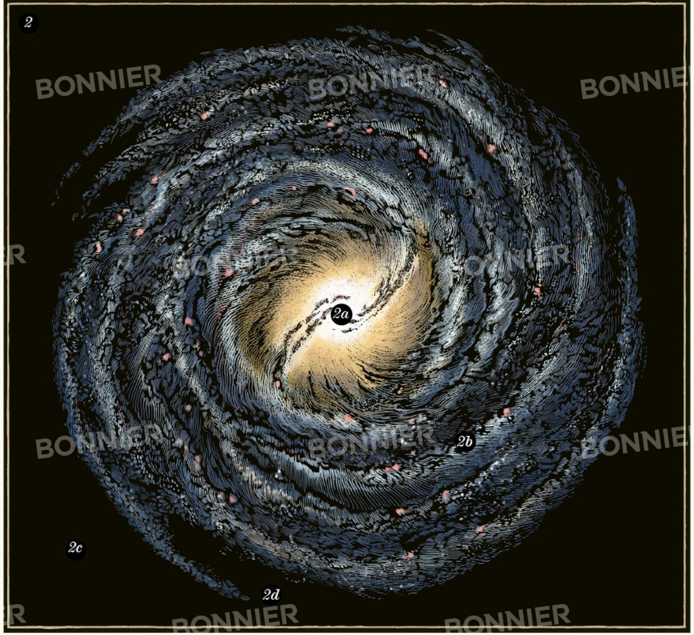
Spiral galaxies spin so fast that we would expect their outer stars to get 'flung' into space. However, this never happens. Scientists have used this surprising fact as the basis for an incredible theory. They think an invisible glue-like substance holds every galaxy together. Not much is known about this substance – only that it has a very strong gravitational pull. Scientists have named it 'dark matter.'

Key to plate

1: The Milky Way Galaxy
(viewed as from the side)
a) Bulge: this is thought to have a supermassive black hole four million times the size of the Sun at its centre
b) Disc: the flattened part of a galaxy that extends beyond its central bulge
c) Halo: an invisible area of dark matter surrounding the disc

2: The Milky Way Galaxy
(viewed as from above)
a) Bulge
b) Disc
c) Halo
d) Spiral arm: the Milky Way has four main spiral arms, which contain lots of gas, dust and star nurseries. Our Solar System is found inside one of its smaller arms called the Orion Arm.





Galaxy Clusters

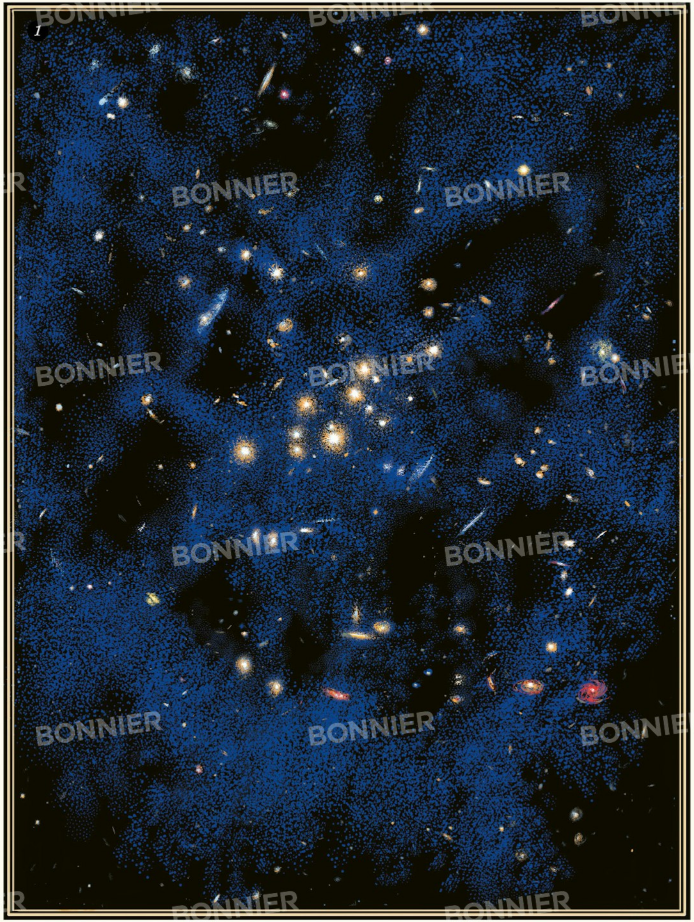
Most galaxies are not alone in the Universe but are relatively close to their neighbours – drawn together by their strong gravitational force. In fact, galaxies are usually found in groups known as clusters. These can be small groups of just a dozen or so galaxies, or can be collections of thousands of galaxies and trillions of stars, millions of light years across. Incredibly, astronomers think over three-quarters of every galaxy cluster is actually dark matter – the mysterious glue-like substance holding all galaxies together.

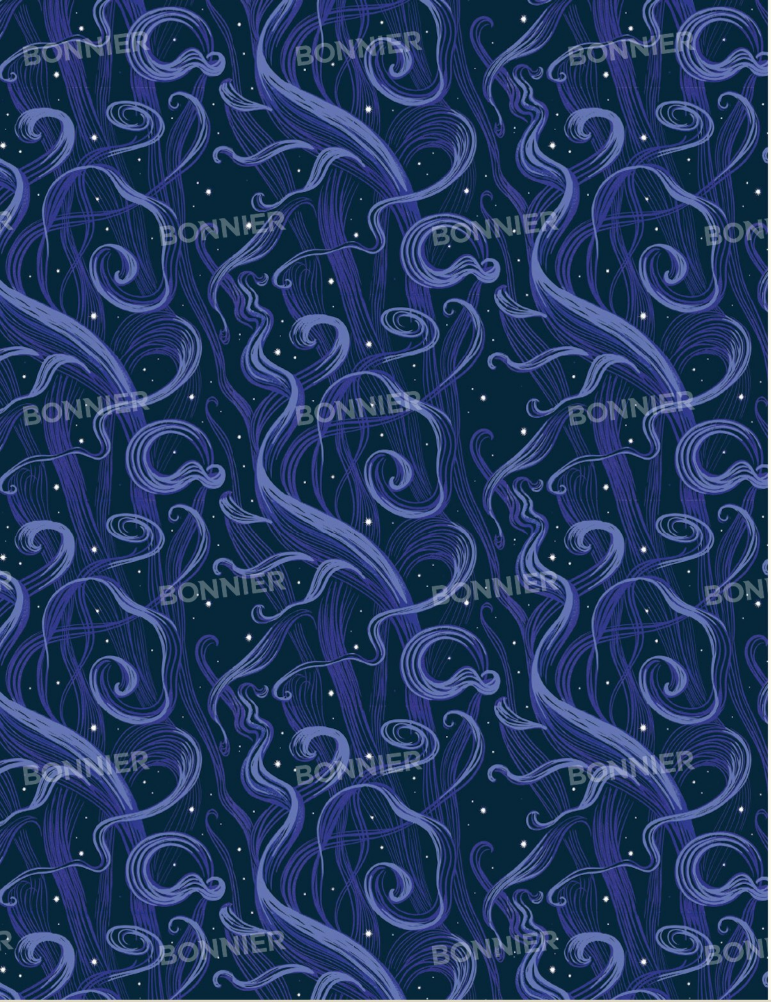
Although galaxy clusters are unbelievably big, they are still not the largest structures in space. That prize goes to groups of clusters known as superclusters. Together these stretch right across space like a giant spider's web, linking the most distant corners of the Universe together. The first superclusters may have been in place soon after the Universe started. That means we can study them to understand how the Universe has changed over time.

Key to plate

1: Galaxy cluster
CL 0024+17 is a cluster of galaxies about five billion light years away. Astronomers have used photographs taken with the Hubble Space Telescope to study this galaxy cluster. They look both at the galaxies and at the spaces between them.

From all this information it has been possible to work out a map showing how dark matter is probably spread around the cluster. Here, the predicted dark matter is shown as the ghostly blue area around the outside of the galaxies.





Gallery 6

The Universe

The Universe;
The Big Bang;
The End of the Universe

The Universe

The Universe is everything there is. It includes every single object you can think of, as well as energy and even time. It even includes things we haven't discovered yet! The study of the Universe is called cosmology. Scientists who study cosmology aim to answer some of our most important questions, including how the Universe began, how it will end and whether there are more universes than our own.

Our understanding of space has changed enormously in the last 2000 years. Back in the time of the ancient Greeks, most scientists believed that Earth was at the centre of the Universe, with the planets, Sun and stars circling around it. This was widely accepted until the 1500s, when a wave of new discoveries in mathematics and science prompted some scientists to rethink this theory. Instead they proposed that the Sun was the centre of the Universe. This was named the 'heliocentric model' after the Ancient Greek word *helios*, meaning Sun.

Today we know that the Sun is the centre of our Solar System – but not of the entire Universe. In fact, scientists today think the Universe doesn't even have a centre. Their theory also goes that the Universe is slowly spreading out and that it began 14 billion years ago in an event called the Big Bang.

Key to plate

1: **The Observable Universe**
The Universe is so huge that parts of it may not even be visible to us, as the light from those regions hasn't had time to reach us yet.

We call the part we can see the 'Observable Universe'. Because light always travels at the same speed, we can think of the Observable Universe as a 'bubble' around our own planet, growing bigger every year as more distant light starts to reach us.

Here, the Observable Universe is shown with Earth at its centre, surrounded by galaxies and stars. However, we know that the whole Universe doesn't have a single centre.

The Big Bang

Our Universe began around 13.8 billion years ago with an event we call the Big Bang. At that point, the whole Universe was contained in an incredibly small bubble, thousands of times smaller than the full stop at the end of this sentence. In an instant, the Big Bang made this bubble blow up, flinging energy and matter out in all directions.

In the first fraction of a second after the Big Bang, the Universe doubled in size at least 90 times, going from smaller than an atom to the size of a golf ball, with temperatures of more than 10 trillion°C. Around this time, the first elements formed, such as hydrogen and helium gas.

During the next 380,000 years, the Universe was too hot for light to shine from it – this is sometimes known as the 'dark ages' in the history of the Universe. Finally, when the Universe was about 380,000 years old, its temperature dropped enough that light started to shine.

Another 300 million to 500 million years later, clumps of gas collapsed and squeezed together, and the very first stars and galaxies were born. Ever since, space has kept stretching outwards, getting further and further away from its starting point.

Key to plate

1: **The Big Bang**
The Universe began in a sudden moment of expansion around 13.8 billion years ago. It was 380,000 years before the first atoms appeared. Next the first stars formed, followed by the first galaxies. Our Solar System only formed about nine billion years after the Big Bang.

The End of the Universe

Nobody knows how or even if the Universe will ever end. Whatever happens will depend on how much matter the Universe contains, and on a mysterious force known as dark energy, which works in the opposite direction to gravity. We only know about dark energy because we can see the Universe is expanding outwards at a faster and faster rate. This is surprising because we would expect the Universe's gravitational pull to have slowed its expansion after the Big Bang. The fact it hasn't slowed down means there must be a lot of dark energy fighting against that gravitational pull!

One possibility for the end of the Universe is that dark energy might one day stop pushing against gravity. If this happens, the Universe could stop expanding and even start contracting in a reverse of the Big Bang. This theory is called the 'Big Crunch'. Another possibility is that dark energy will become so strong that the Universe will expand even faster, eventually tearing itself apart in a 'Big Rip'. Alternatively, the Universe might continue to expand at a constant rate. The distances between galaxies will stretch wider and wider and the Universe will become too cold for any life to survive. This idea is called the 'Big Chill'. The good news is that none of these possible fates would happen for at least another 100 billion years – and there is always the possibility that the Universe will stay exactly as it is!

Key to plate

1: **The Big Rip**
The scenario called the Big Rip shows how the Universe could expand so fast that it would actually rip itself apart. Whole galaxies, stars and planets would be torn into pieces, then the very smallest objects in space, including molecules and atoms, would be destroyed.

Glossary

Asteroid A small rocky body that circles the Sun.

Astronomer A scientist who studies objects in space, including planets and stars.

Atmosphere A blanket of gases surrounding a planet.

Atom A basic building block of the Universe. Atoms are made up of particles called protons, electrons and neutrons.

AU (astronomical unit) The average distance between Earth and the Sun – around 150 million km.

Black hole A point in space which has an incredibly strong gravitational pull – so strong that even light cannot escape from it. A black hole is formed when a huge star dies and explodes.

Comet A ball of ice and dust circling the Sun, usually at the edge of the Solar System. As it nears the Sun, it warms up and develops a gas 'tail'. This can sometimes be seen from Earth.

Constellation A group of stars which appear to form a pattern when viewed from Earth.

Core The very centre of a planet or star.

Dark energy A mysterious force which works in the opposite direction to gravity. Dark energy is making the Universe expand at a quicker and quicker rate.

Dark matter An invisible glue-like substance that holds galaxies together.

Dwarf planet A large roundish object which circles the Sun or another star, but does not have enough mass (size) to pull itself into a perfectly round shape or to clear its neighbourhood of other objects.

Element A substance made up of atoms which all have the same arrangement. Scientists know of 118 elements in the Universe, including hydrogen, helium, gold and silver.

Galaxy A collection of stars, gas and dust, held together by gravity.

Gas A substance, like air, which has no solid shape, but can expand to fill whatever container it is inside.

Gas planet A planet with no solid surface, instead formed mostly of layer after layer of clouds.

Gravity A force which pulls objects towards one another – for instance, gravity on Earth makes objects fall to the ground. Objects with a larger mass (size) will pull on objects that are smaller than them.

Light year The time light can travel in one year – 9500,000,000,000 km.

Mass A measure of how much stuff an object contains. Mass is not the same as weight.

Matter Any substance that takes up space in the Universe.

Meteorite A meteorite that survives its fall through a planet's atmosphere and lands on the ground.

Meteoroid A rocky or metallic object from space that enters a planet's atmosphere.

Molecule Two or more atoms that are held together.

Moon A rocky object orbiting a planet. Some planets have several moons.

Nebula A cloud of gas and dust where stars are born.

Observatory A building where a telescope or other scientific equipment is housed.

Orbit The circling of an object in space, such as a star or planet, by another object.

Plain A wide, flat area of land.

Planet A perfectly round object orbiting a star.

Radar A method of detecting an object by sending out radio waves and recording the way they bounce off it.

Rocky planet A planet made mostly of rocks and metals. Rocky, or terrestrial, planets have solid surfaces, like our planet Earth.

Satellite An object that circles a planet – this can be a moon or a man-made satellite. Man-made satellites can have purposes such as satellite navigation, or else hold telescopes for observing space.

Star A giant glowing ball of gas that makes heat, light and other types of radiation. Our nearest star is the Sun.

Supernova A huge explosion that takes place at the end of some stars' life cycles.

Telescope An instrument made of lenses or mirrors, which collects and focuses light to make far away objects appear much larger.

Universe All time, energy and matter through the whole of space.