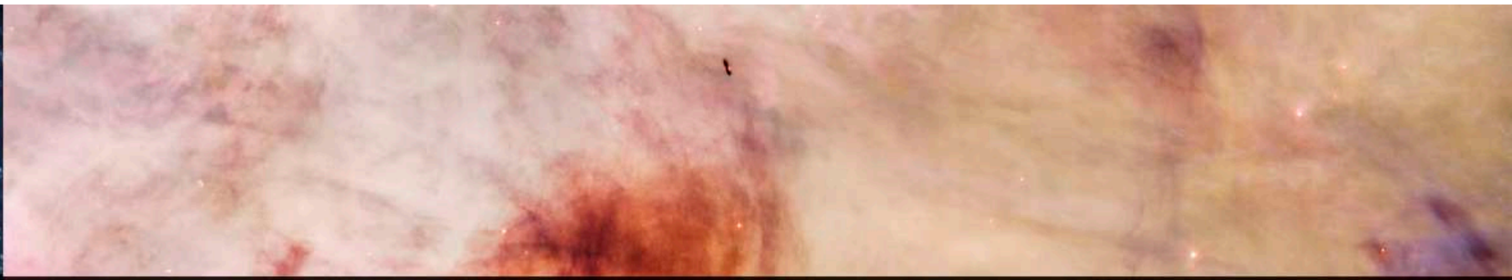
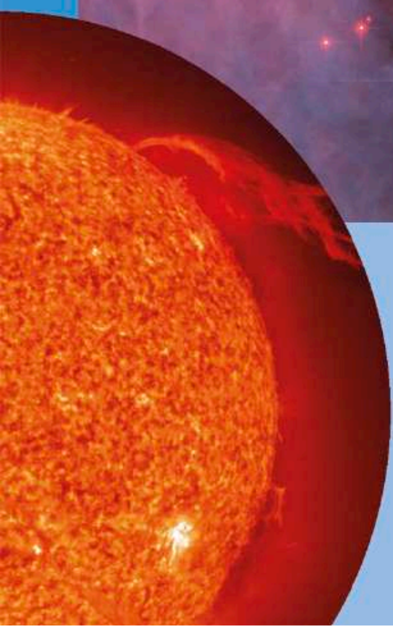


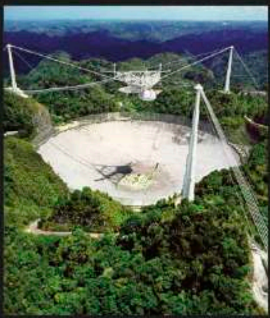
SPACE

- Many scientists think the universe began in a big bang about 13.7 billion years ago.
- Space begins where the atmosphere disappears 60 miles (100 km) above Earth.
- Our solar system has 8 planets, 5 dwarf planets, and more than 180 known moons.
- The sun is orbited by billions of space rocks, such as asteroids and comets.
- The first artificial satellite, Sputnik, was launched by the Soviet Union in 1957.



Which star is our nearest star? *Find out on pages 12-13*

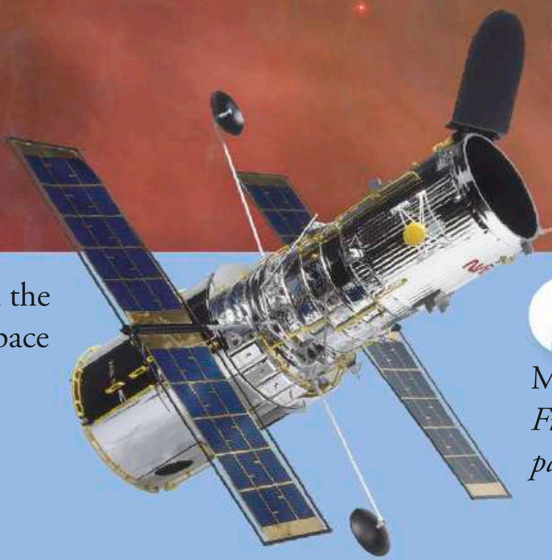
Which planet is the king of the planets? *Find out on pages 16-17*



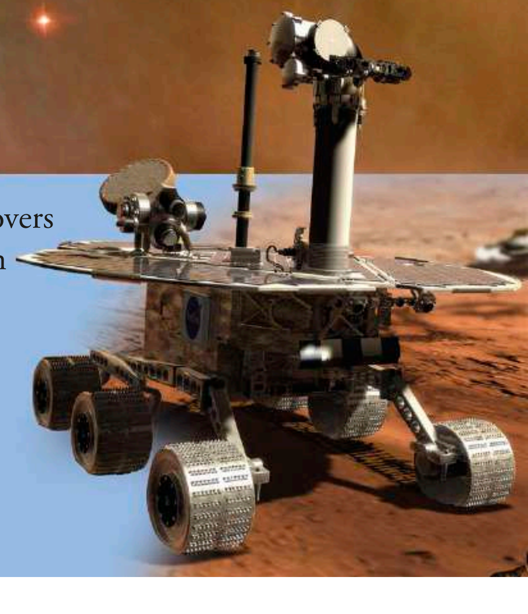
Definition: **Space** includes the universe beyond Earth's atmosphere—planets, moons, stars, and galaxies. Since its beginning in the big bang, space has been expanding outward continuously.

- More than 550 people have flown in space since the first person did it, in 1961.
- A teaspoonful of material from a neutron star would weigh 5.5 billion tons on Earth.
- A black hole is a region of space where gravity is so strong that nothing can escape.
- The temperature at the center of the sun is 27,000,000°F (15,000,000°C).
- When a dying star explodes, it releases about as much energy as it emits in its lifetime.

When did the Hubble Space Telescope go into orbit? *Find out on pages 20-21*



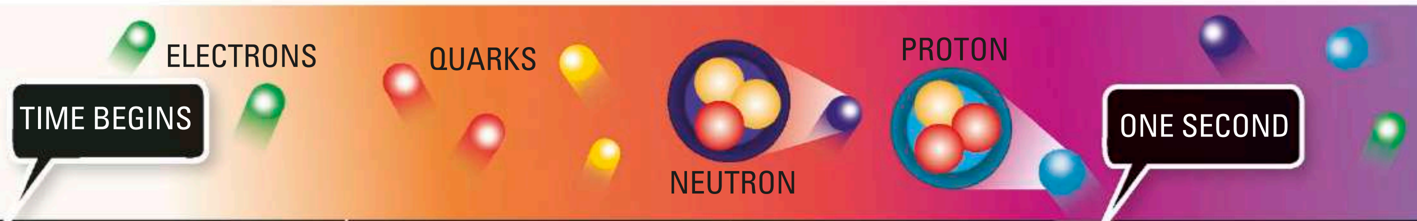
Which rovers landed on Mars in 2004? *Find out on pages 26-27*



The universe

The universe is unbelievably huge. It is everything we can touch, feel, sense, measure, or detect, and much that we cannot. It includes people, plants, stars, galaxies, dust clouds, light, and even time. Scientists believe our universe has existed for almost 14 billion years.

EXPANDING UNIVERSE
Across the visible universe, galaxies are found to be moving away from each other—rather like spots on an inflating balloon. However, it is actually space that is expanding. The farther away from us galaxies are, the faster they seem to be moving.



TIME	10^{-43} seconds	10^{-32} seconds	10^{-6} seconds	3 minutes
TEMPERATURE		10^{27}°C	10^{13}°C	10^{8}°C

1 Moments after the big bang, the cosmos goes through a superfast "inflation." It expands from smaller than an atom to the size of a grapefruit in a tiny fraction of a second.

2 Post-inflation, the universe is a seething, hot soup of particles, including electrons and quarks.

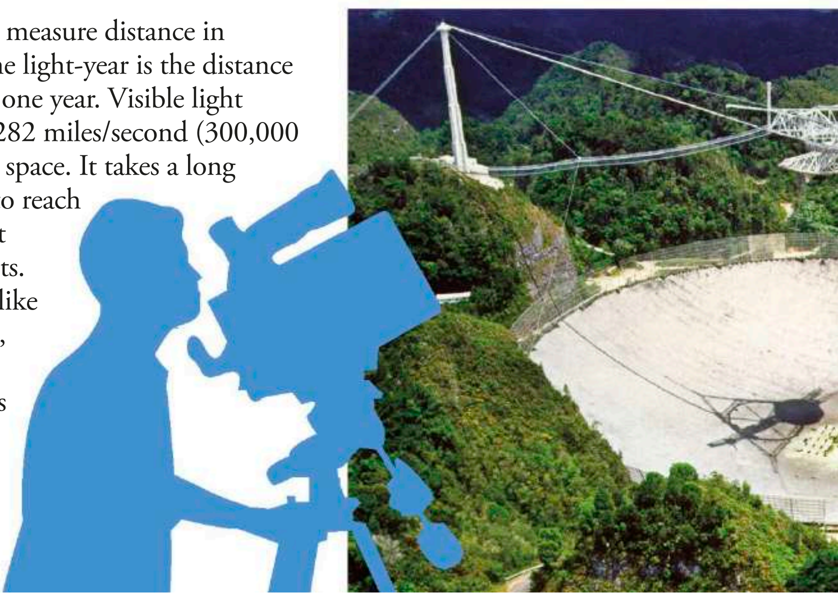
3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons.

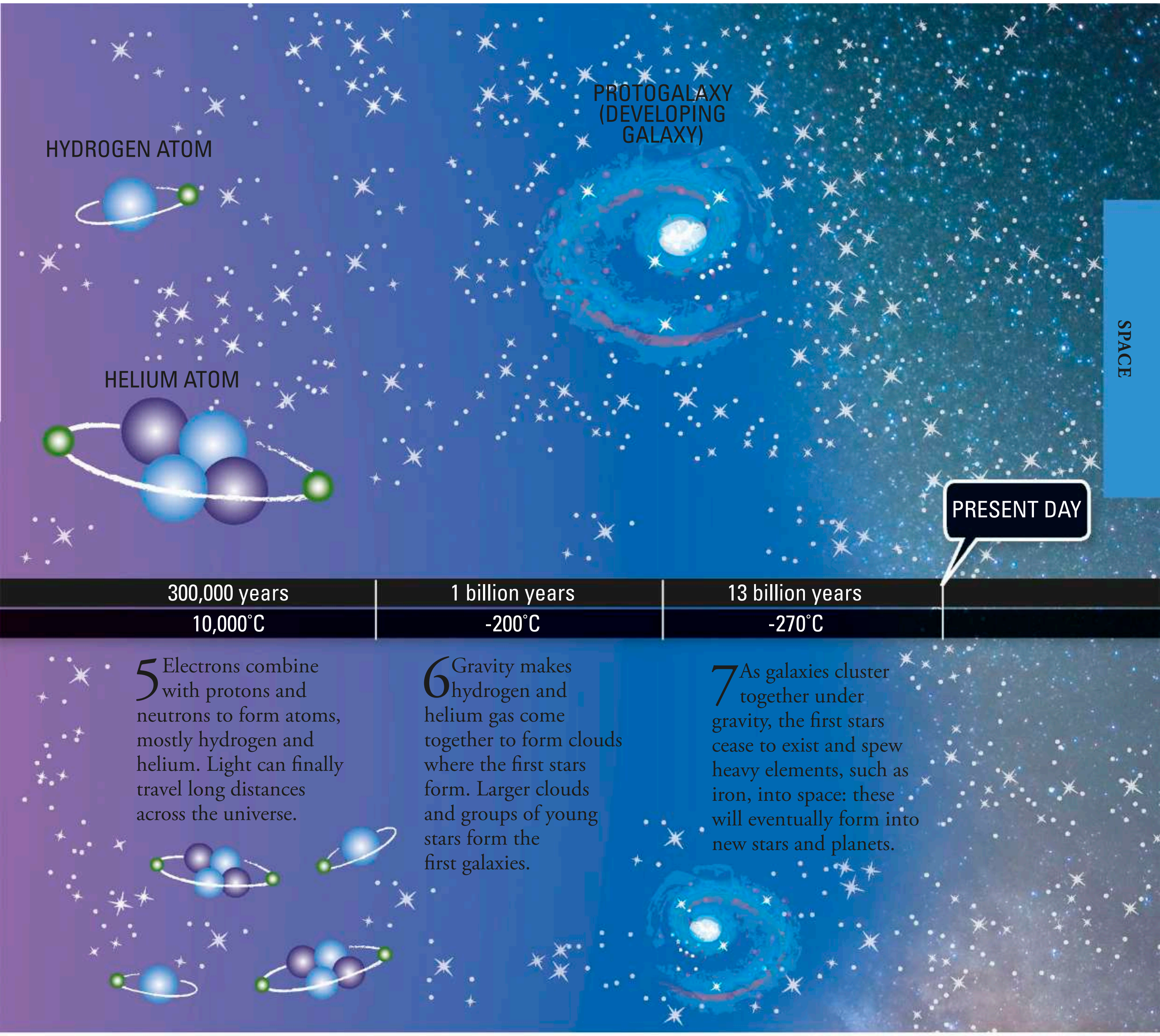
4 Still too hot to form into atoms, charged electrons and protons scatter light: the universe is a superhot fog.

SPACE FACTFILE

- Light from distant galaxies has taken more than 12 billion years to arrive—so we see them as they were before Earth formed.
- There are more stars in the universe than there are grains of sand on all of Earth's beaches.
- In its first second, the universe grew from smaller than an atom to about 1,000 times the size of our solar system today.

Astronomers measure distance in light-years. One light-year is the distance light travels in one year. Visible light travels at 186,282 miles/second (300,000 km/second) in space. It takes a long time for light to reach us from distant stars and planets. Telescopes are like time machines, allowing us to see what things looked like in the past.

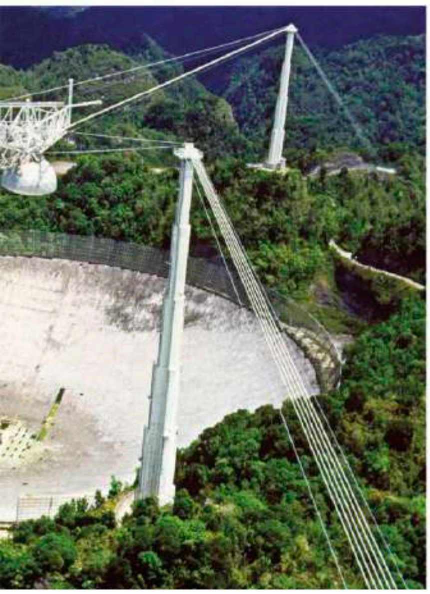




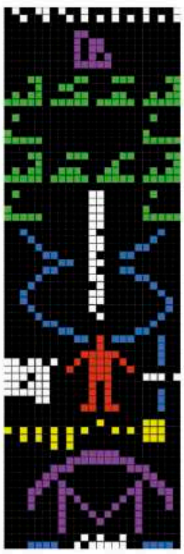
5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally travel long distances across the universe.

6 Gravity makes hydrogen and helium gas come together to form clouds where the first stars form. Larger clouds and groups of young stars form the first galaxies.

7 As galaxies cluster together under gravity, the first stars cease to exist and spew heavy elements, such as iron, into space: these will eventually form into new stars and planets.



◀ *In 1974, a coded radio message (right) was sent toward the M13 star cluster from the huge Arecibo radio telescope (left). The message will take about 25,000 years to get there, so we may get a reply 50,000 years from now!*



▶ *From the top, the symbols represent the numbers from one to ten, some atoms, molecules, DNA, a human, the basics of our solar system, and information about the sending telescope.*

WOW!

Does ET really exist? The only place known to support life is Earth. But scientists believe that life could exist on other worlds if they possess liquid water and the right temperature. As telescopes become more powerful, scientists expect to find huge numbers of Earth-like planets. Some may support life.

Galaxies

Scattered across the universe are billions of galaxies, each containing millions or even billions of stars. They come in many different shapes and sizes. Modern telescopes can now see very old galaxies that formed not long after the universe began.

SHAPES AND SIZES

Some galaxies are "elliptical" or almost round, like huge eggs. Some are spirals, with long, curved arms. Many small galaxies are "irregular," with no special shape. Small galaxies may contain a few million stars and measure less than 3,000 light-years across. The galactic supergiants contain billions of stars and are more than 150,000 light-years across.

GALAXY SHAPES

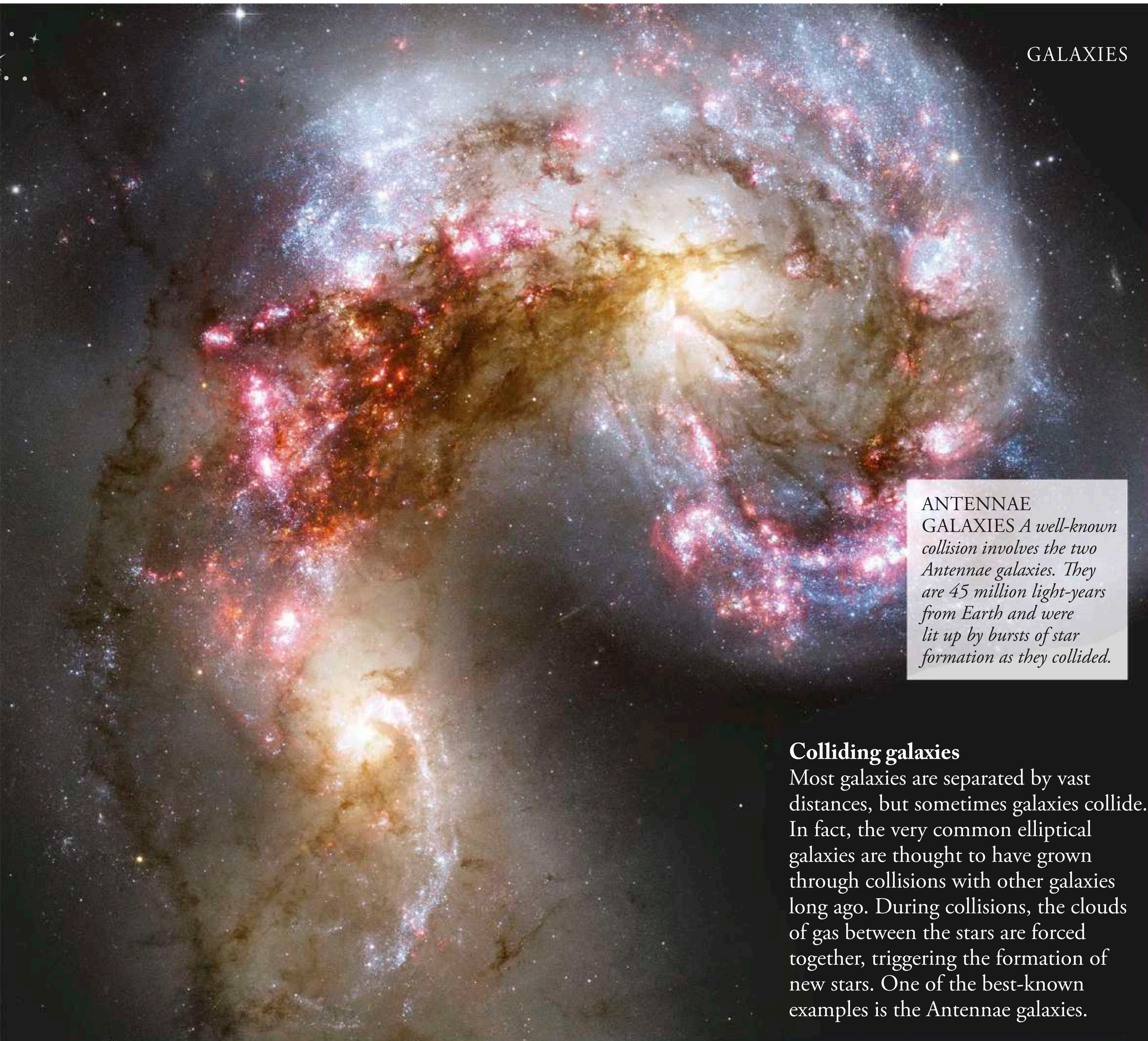
- **Spiral galaxy** Spinning spiral galaxies have long, curved arms. Young stars, pink nebulas, and dust are found in the arms.

- **Barred spiral** Barred spirals have long, trailing arms and a central bar. The most recent stars form at the ends of the bar.

- **Elliptical galaxy** These galaxies are oval and made up of older stars. Many are found in galaxy clusters. Most are thought to hold supermassive black holes.

- **Irregular galaxy** Galaxies with no recognizable shape are irregular. They are small with lots of young stars and bright nebulas.

◂ THE WHIRLPOOL GALAXY
This is a huge, well-defined spiral galaxy, 31 million light-years away. Its smaller satellite galaxy can be seen to the right. Scientists think there are supermassive black holes at the center of most spiral galaxies.

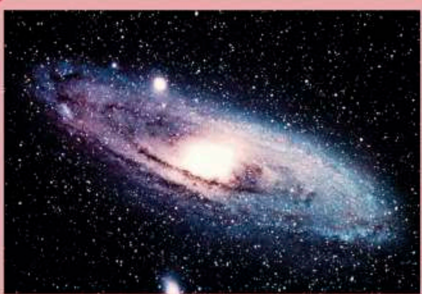


ANTENNAE GALAXIES *A well-known collision involves the two Antennae galaxies. They are 45 million light-years from Earth and were lit up by bursts of star formation as they collided.*

Colliding galaxies

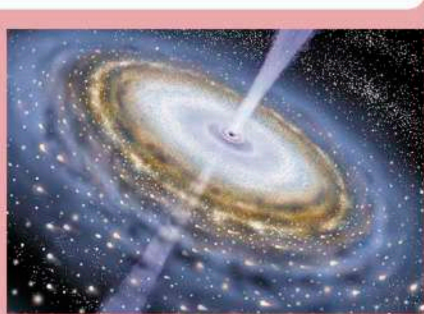
Most galaxies are separated by vast distances, but sometimes galaxies collide. In fact, the very common elliptical galaxies are thought to have grown through collisions with other galaxies long ago. During collisions, the clouds of gas between the stars are forced together, triggering the formation of new stars. One of the best-known examples is the Antennae galaxies.

GALAXY FACTFILE



▲ SATELLITE GALAXIES *Most large galaxies have smaller satellite galaxies orbiting them. The Andromeda galaxy has many satellite galaxies—two appear as bright spots in this photo. Our own galaxy, the Milky Way, has several dozen.*

▲ GALAXY CLUSTER *Galaxies form clusters because of their huge gravitational pull. They often pull each other out of shape and may collide.*



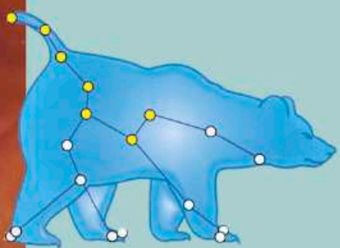
▲ BLACK HOLE *Most galaxies have supermassive black holes at their center. Their gravity is so strong that not even light can escape. We can see only the hot gas, dust, and stars being pulled in.*

Balls of gas

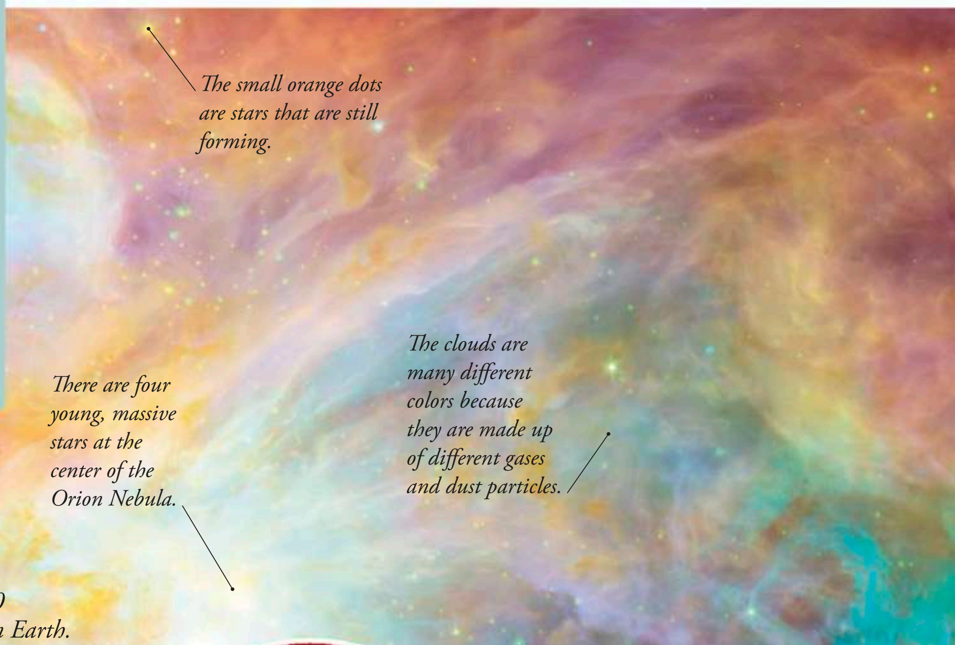
A star is a huge, glowing ball of hydrogen gas that shines because of nuclear reactions in its core that turn this fuel (hydrogen) into helium, releasing a lot of energy. The hottest stars last up to a few million years. Red dwarf stars are the coolest and last the longest.

TAKE A LOOK

Constellations Only a few thousand stars can be seen without a telescope. All of these are in our own galaxy. Ancient people saw patterns and shapes (constellations) in them and named them after mythological creatures or people. The most famous are the 12 zodiac constellations. They form a belt across the sky.



▼ URSA MAJOR
The seven brightest stars, located in the Bear's hindquarters and tail, form the well-known Big Dipper.



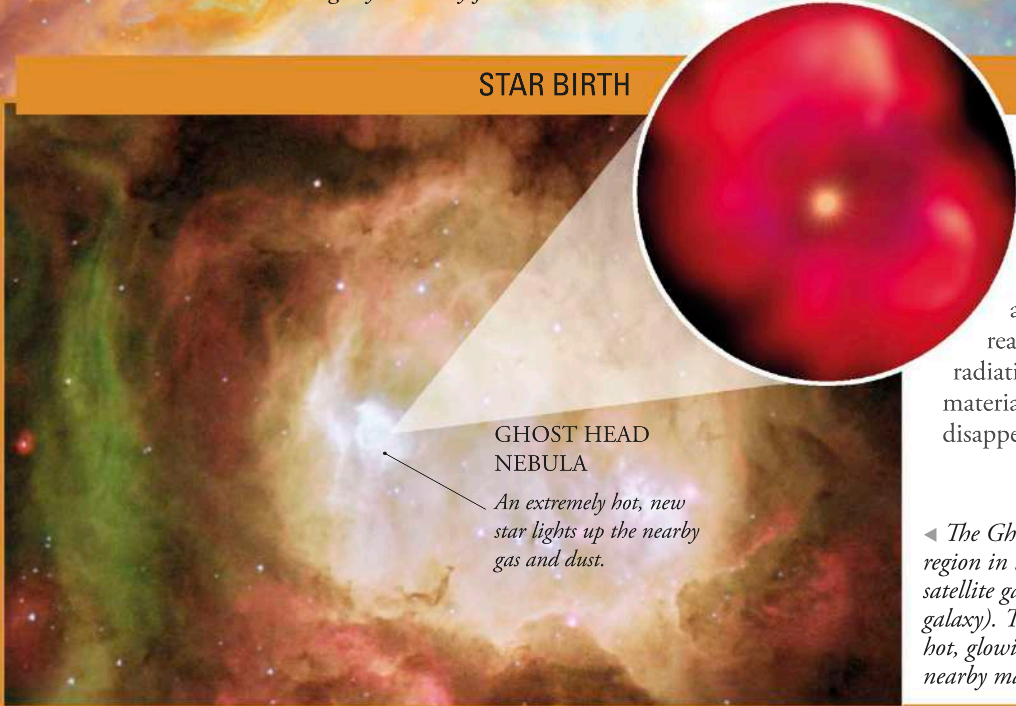
The small orange dots are stars that are still forming.

There are four young, massive stars at the center of the Orion Nebula.

The clouds are many different colors because they are made up of different gases and dust particles.

Orion Nebula
This galaxy is 15,000 light-years away from Earth.

STAR BIRTH



GHOST HEAD NEBULA
An extremely hot, new star lights up the nearby gas and dust.

■ **Most stars are born** inside giant dust clouds called nebulas. Parts of these clouds collapse and as they shrink, the gas and dust get hotter and form a star. When nuclear reactions begin in its core, radiation makes the surrounding material glow. Eventually this disappears and the star appears.

◀ *The Ghost Head Nebula is a star-forming region in the Large Magellanic Cloud, a satellite galaxy of the Milky Way (our own galaxy). The "eyes of the ghost" are two very hot, glowing blobs of gas that are heated by nearby massive stars.*

The sun

- **Diameter** 864,000 miles (1,390,000 km)
- **Mass (Earth=1)** 330,000
- **Core temperature** 27,000,000°F (15,000,000°C)
- **Average Distance from Earth** 93,000,000 miles (150,000,000 km)

The sun is our nearest star. Without the sun, Earth would be frozen and lifeless. The sun formed in a cloud of gas and dust about 4.6 billion years ago and has another 5 billion years to go.

WOW!

The color of a star is a guide to its surface temperature. The hottest stars are blue or white, stars like the sun are yellow, and cool stars are orange or red.

Huge plumes of hot gas sometimes stream away from the sun. They are called prominences.

FACTFILE

- Betelgeuse, a red supergiant, is about 700 times the size of the sun.
- Light from the next nearest star after the sun takes just over four years to reach us.
- Brown dwarfs are stars that weren't hot enough for nuclear reactions to begin.

Brown dwarf (right) with a nearby orbiting object (red).

THE SUN

The sun is a yellow dwarf, a fairly ordinary star made mainly of hydrogen. Hydrogen is changed to helium at its center (the core). When this happens, huge amounts of radiation are released.

STAR DEATH

- **Planetary nebulas** Small stars expand to become red giants. When they run out of fuel, they collapse. Their outer layers are puffed out in rings called planetary nebulas. Each star creates a different shape, such as a cat's eye (below), a butterfly, or a ring. The central star shrinks to a tiny, hot white dwarf.

▲ *The Cat's Eye Nebula is made up of many gas clouds ejected by a dying star.*

Before

After

- **Supernovas** Larger stars collapse in a different way when they run out of fuel. Their outer layers explode into space in a supernova (right). These can briefly outshine an entire galaxy, but are rare events. The photograph on the left shows the same star 10 days before a supernova. Medium-sized stars become neutron stars. Massive stars create black holes.

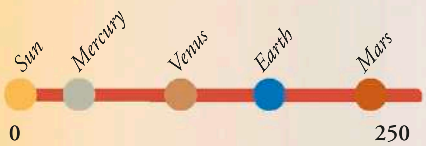
The solar system

The solar system is our local area of space. At its center is the sun, our nearest star, which accounts for almost all (99.9 percent) of the solar system's mass. The sun's gravity keeps the planets in their orbits.

DISTANCE FROM THE SUN

The red line to the right shows the distance of each planet from the sun in millions of miles. Mercury is closest and Neptune is farthest away. Earth is about 93 million miles from the sun.

All of the planets and asteroids go around the sun in near-circular orbits in the same direction (west to east).



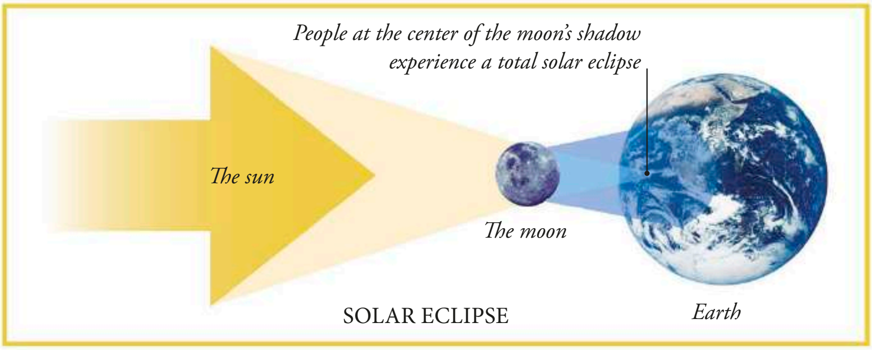
INNER PLANETS

The four planets nearest the sun are called the inner planets. They are also known as the rocky planets because they are balls of rock and metal. They are dense and have central cores made of iron.

LUNAR AND SOLAR ECLIPSES

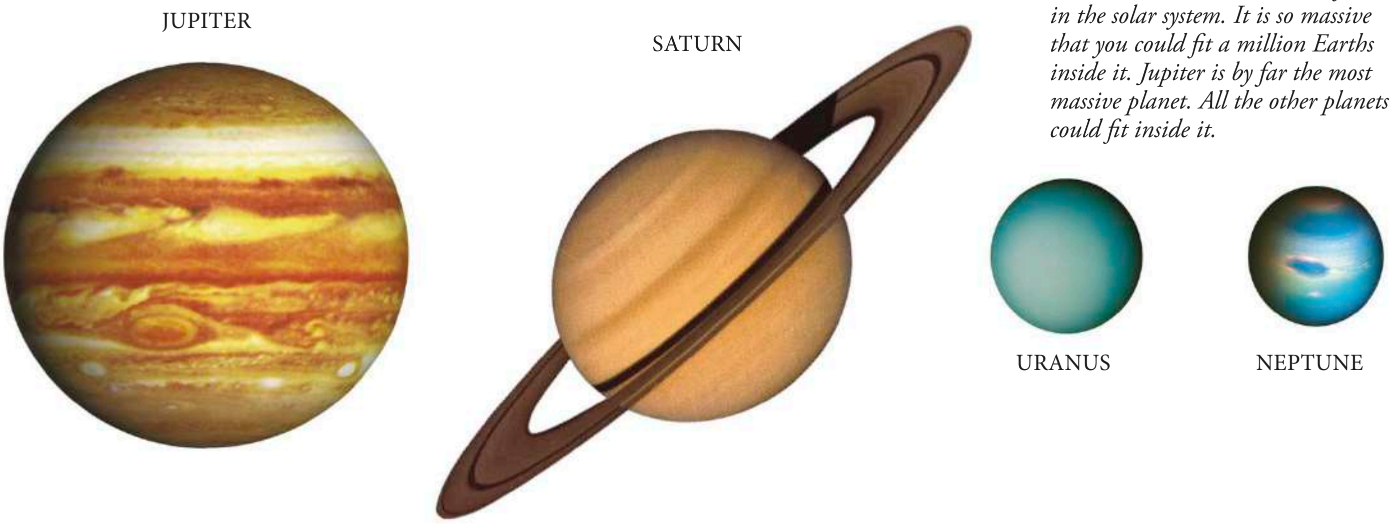
In any year there can be up to seven solar or lunar eclipses, when Earth, the moon, and the sun line up. Solar eclipses are more common, but are seen only in a narrow area. Lunar eclipses can be seen anywhere on Earth where the moon is shining in the sky.

A "diamond ring effect" appears just before or just after an eclipse of the sun. Then the sun's corona (atmosphere) can be seen around the moon.

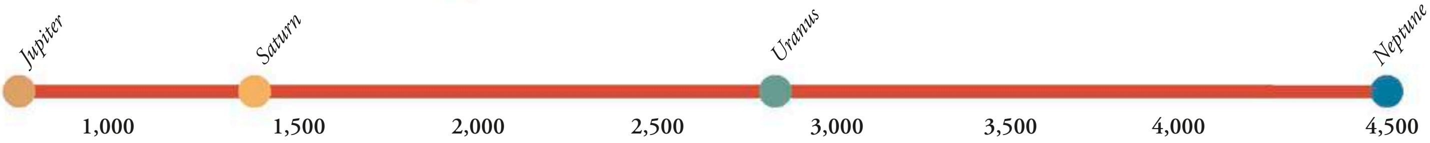


SOLAR ECLIPSE

- A lunar eclipse happens when Earth passes between the sun and the moon, so that Earth casts a shadow on the moon.
- A solar eclipse happens when the moon passes between Earth and the sun, casting a shadow on Earth. A total eclipse lasts for up to eight minutes.

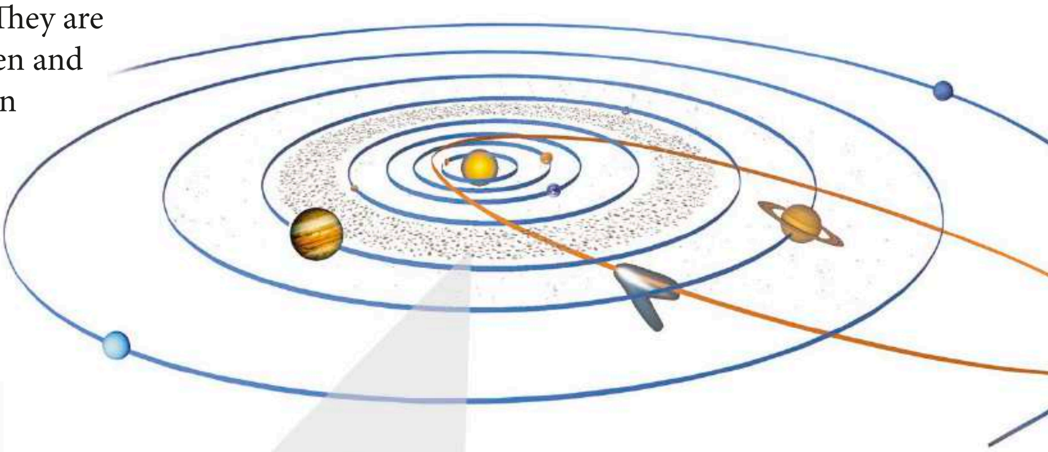


▼ SCALE OF THE PLANETS *The sun is the most massive object in the solar system. It is so massive that you could fit a million Earths inside it. Jupiter is by far the most massive planet. All the other planets could fit inside it.*



OUTER PLANETS

The four planets farthest away from the sun are called the outer planets. They are huge balls of gas (mainly hydrogen and helium) and liquid and are known as the gas giants. Uranus and Neptune are also known as the ice giants.



FAST FACTS

- Only six planets are visible to the naked eye. The first planet to be discovered using a telescope was Uranus, in 1781.
- The planets formed in a huge cloud of gas and dust about 4½ billion years ago.
- About 4 billion years ago the sun was 25 percent dimmer than it is today.
- Halley's comet doesn't orbit the sun in the normal clockwise direction. It travels from beyond Neptune to inside the orbit of Venus as it circles the sun.
- Excluding the sun, Jupiter and Saturn contain 90 percent of the solar system's mass.

▶ ASTEROID BELT *Between Mars and Jupiter is the asteroid belt. It separates the inner planets from the outer planets. About 15,000 asteroids have been found and named. They are thought to be rocks that never clumped together to form planets.*

ORBITING THE SUN

The solar system includes eight planets, at least five dwarf planets, more than 180 moons, and millions more comets and asteroids. These bodies are all orbiting the sun.

Mercury

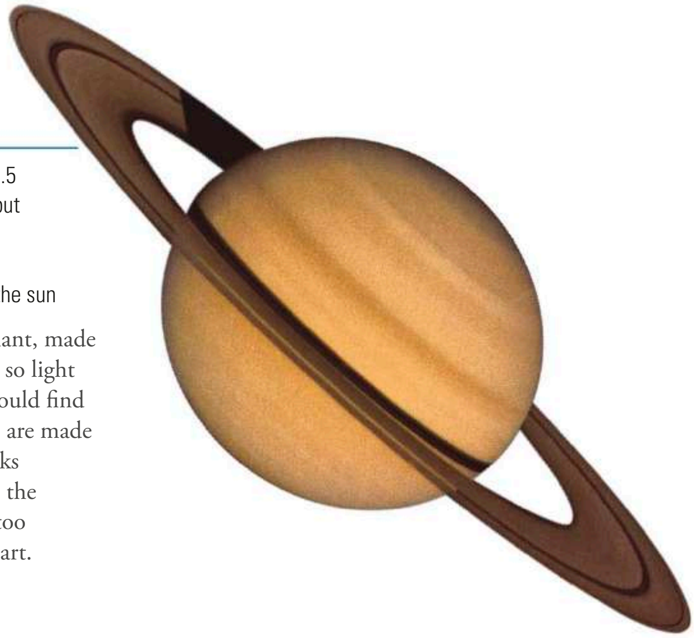
Messenger of the Roman gods

- **Earth days to orbit sun** 88
- **Discovery date** Unknown (but known since ancient times)
- **Number of moons** 0
- **Location** First planet from the sun

The solar system's smallest planet, and the densest, temperatures on Mercury range from a freezing 279°F (-173°C) to a blistering 801°F (427°C). Unlike Earth, Mercury has no atmosphere, so the planet cannot retain heat.

Saturn

Roman god of agriculture



- **Earth years to orbit sun** 29.5
- **Discovery date** Unknown (but known since ancient times)
- **Number of moons** 62
- **Location** Sixth planet from the sun

Saturn is an enormous gas giant, made mainly of hydrogen gas. It is so light that it would float—if you could find a big enough ocean! Its rings are made of billions of small, icy chunks orbiting the planet. They are the remains of a moon that got too close to Saturn and broke apart.

Venus

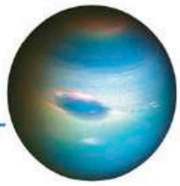
Roman goddess of love

- **Earth days to orbit sun** 224.7
- **Discovery date** Unknown (but known since ancient times)
- **Number of moons** 0
- **Location** Second planet from the sun

Venus is almost the same size as Earth, but you wouldn't want to visit Venus. Its atmosphere is incredibly dense and the temperature is so high you would be fried to a crisp. The planet is covered in acid clouds that trap heat.

Neptune

Roman god of the sea



- **Earth years to orbit sun** 165
- **Discovery date** 1846
- **Number of moons** 14
- **Location** Eighth planet from the sun

This is an icy planet. That's because it is 30 times farther away from the sun than Earth. A day on Neptune lasts 16 hours and 7 minutes. Neptune has huge storms and very strong winds. It also has five dark, thin rings.

Jupiter

King of the Roman gods

- **Earth years to orbit sun** 12
- **Discovery date** Unknown (but known since ancient times)
- **Number of moons** 69
- **Location** Fifth planet from the sun

The solar system's largest planet, Jupiter is a gas giant made mainly of hydrogen. It has many storms in its deep, cloudy atmosphere. The largest of these, which has been blowing for at least 300 years, is called the Great Red Spot. Jupiter has more moons than any other planet.

Uranus

Greek god of the sky

- **Earth years to orbit sun** just over 84
- **Discovery date** 1781
- **Number of moons** 27
- **Location** Seventh planet from the sun

Uranus was discovered in 1781 by astronomer William Herschel. Much of the planet is thought to be made of water and ice. It has 13 thin, dark rings. The planet spins on its side, like a top that has fallen over. This is probably the result of a huge impact long ago.

Mars

Roman god of war

- **Earth days to orbit sun** 687
- **Discovery date** Unknown (but known since ancient times)
- **Number of moons** 2
- **Location** Fourth planet from the sun

Mars is one of the closest planets to us in space. It is barren and mainly covered with dust and rocks. Two ice caps cover the poles. It is about half the size of Earth, but has no flowing water, and, so far, no signs of life.

Earth

Terra

- **Earth days to orbit sun** 365.2
- **Number of moons** 1
- **Location** Third planet from the sun

Earth is the only planet known to support life. It has the right temperature for life because it's neither too close to the sun, nor too far from it. Earth is the only planet with oceans on its surface. It is also the only planet with lots of oxygen—the gas that keeps us alive.

Moon

Luna

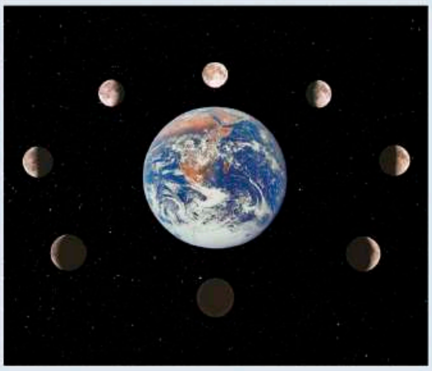
- **Days to orbit Earth** 27.3
- **Discovery date** Unknown (but known since ancient times)
- **Location** Only moon of Earth

The moon orbits Earth at an average distance of 238,855 miles (384,400 km)—a journey of three days by spacecraft. It formed when a huge Mars-sized object crashed into the young Earth. The dark patches on its surface that make up the face of "the man in the moon" are old seas of lava. The moon has no atmosphere.

◀ HIDDEN FAR SIDE *The moon always keeps the same side pointing toward Earth. We never see the "far side."*

TAKE A LOOK: PHASES OF THE MOON

As the moon orbits Earth, it seems to change shape night after night. We say it goes through phases. This is because we see different amounts of the moon's sunlit side. At new moon it is dark and cannot be seen (except during a solar eclipse). At full moon the entire Earth-facing side is lit up by the sun. (p31)



▶ MOONS *The period from full moon to full moon lasts 29½ days.*

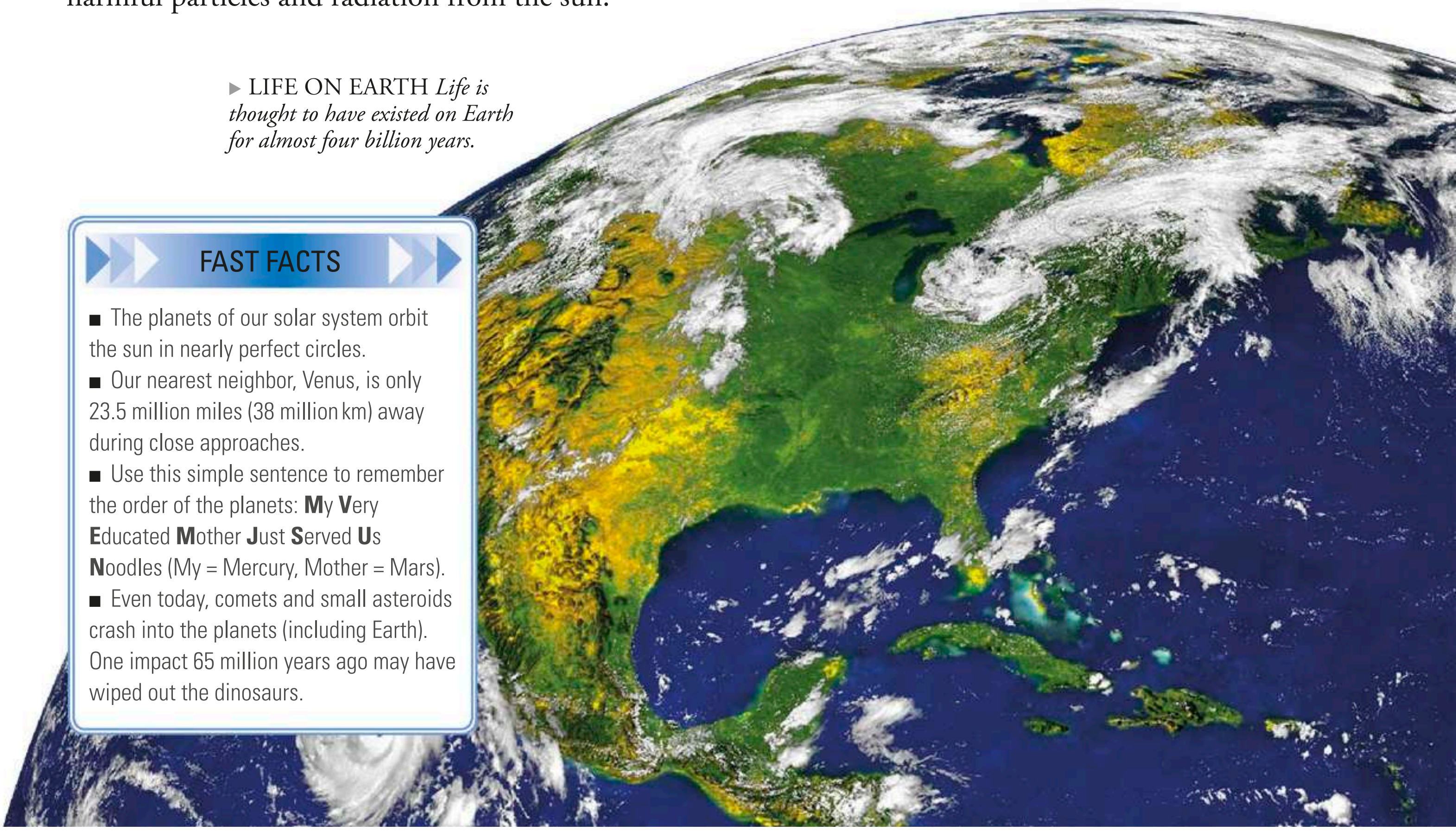
WOW!

Earth and Mars have had many ice ages in the past. When they get colder, ice sheets spread out from the poles and cover large areas. Most of Earth may have been covered in ice 600 million years ago. Ice ages happen because of changes in the orbits and tilt of the planets.

THE OCEAN PLANET

Earth is the only planet with oceans of water on its surface. This water turns to gas, then forms clouds and rain (or snow). It is also the only planet we know with lots of oxygen—the gas that keeps us alive. Its powerful magnetic field shields Earth from harmful particles and radiation from the sun.

▶ LIFE ON EARTH *Life is thought to have existed on Earth for almost four billion years.*



FAST FACTS

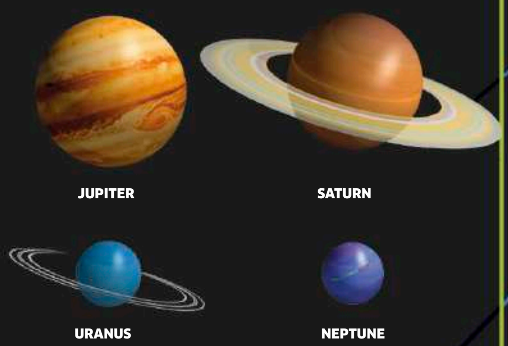
- The planets of our solar system orbit the sun in nearly perfect circles.
- Our nearest neighbor, Venus, is only 23.5 million miles (38 million km) away during close approaches.
- Use this simple sentence to remember the order of the planets: **M**y **V**ery **E**ducated **M**other **J**ust **S**erved **U**s **N**oodles (My = Mercury, Mother = Mars).
- Even today, comets and small asteroids crash into the planets (including Earth). One impact 65 million years ago may have wiped out the dinosaurs.

Size comparison

With a diameter of nearly 870,000 miles (1.4 million km), the sun is 10 times wider than Jupiter, the biggest of the planets, and over 1,000 times more massive.

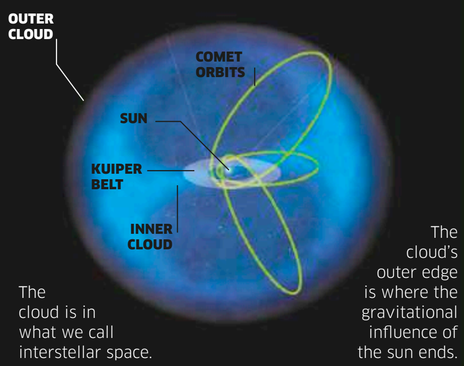
Inner planets
The inner four planets are smaller than the outer four. They are called terrestrial planets.

Outer planets
The outermost four planets are larger and made up of gas, so they are called the gas giants.

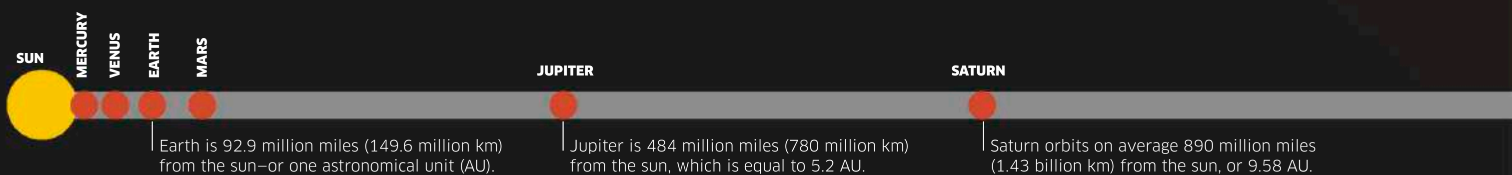


Oort Cloud

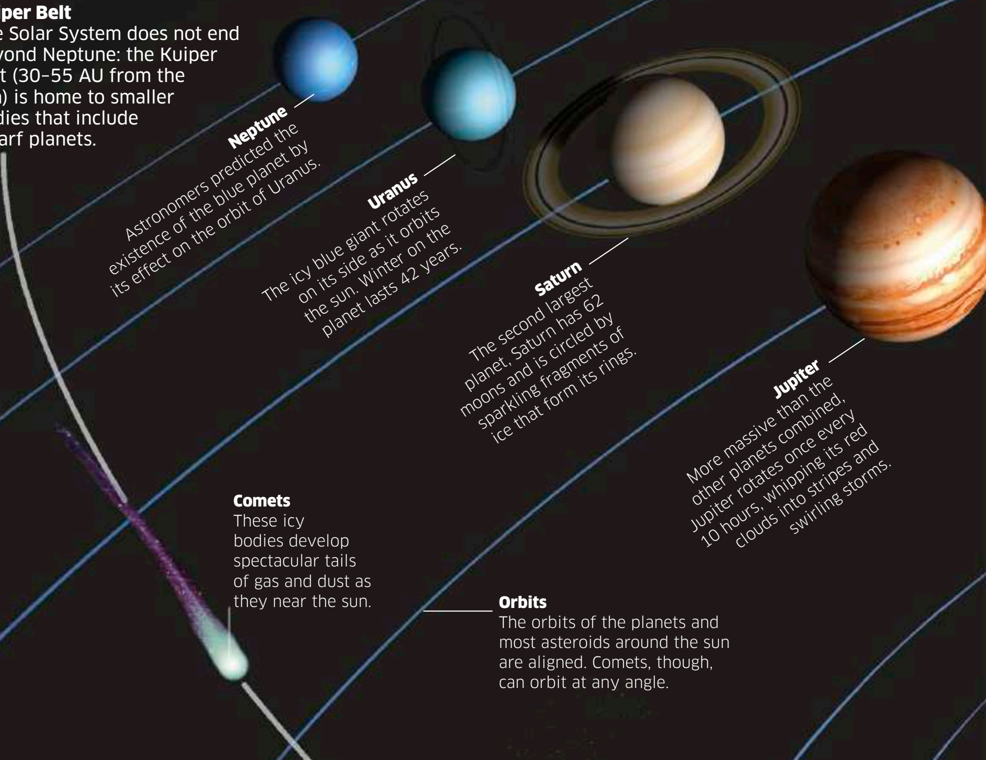
The Oort Cloud is a ring of tiny, icy bodies that is thought to extend between 50,000 and 100,000 times farther from the sun than the distance from the sun to Earth—but it's so far away that no one really knows.



Distance from the sun
It is hard to imagine how far Earth is from the sun, and how much bigger the sun is than Earth. If Earth were a peppercorn, the sun would be the size of a bowling ball—100 times bigger.



Kuiper Belt
The Solar System does not end beyond Neptune: the Kuiper Belt (30–55 AU from the sun) is home to smaller bodies that include dwarf planets.



Comets
These icy bodies develop spectacular tails of gas and dust as they near the sun.

Orbits
The orbits of the planets and most asteroids around the sun are aligned. Comets, though, can orbit at any angle.

Orbiting planets

There are eight planets in the solar system. They form two distinct groups. The inner planets—Mercury, Venus, Earth, and Mars—are solid balls of rock and metal. The outer planets—Jupiter, Saturn, Uranus, and Neptune— are gas giants: enormous, swirling globes made mostly of hydrogen and helium.

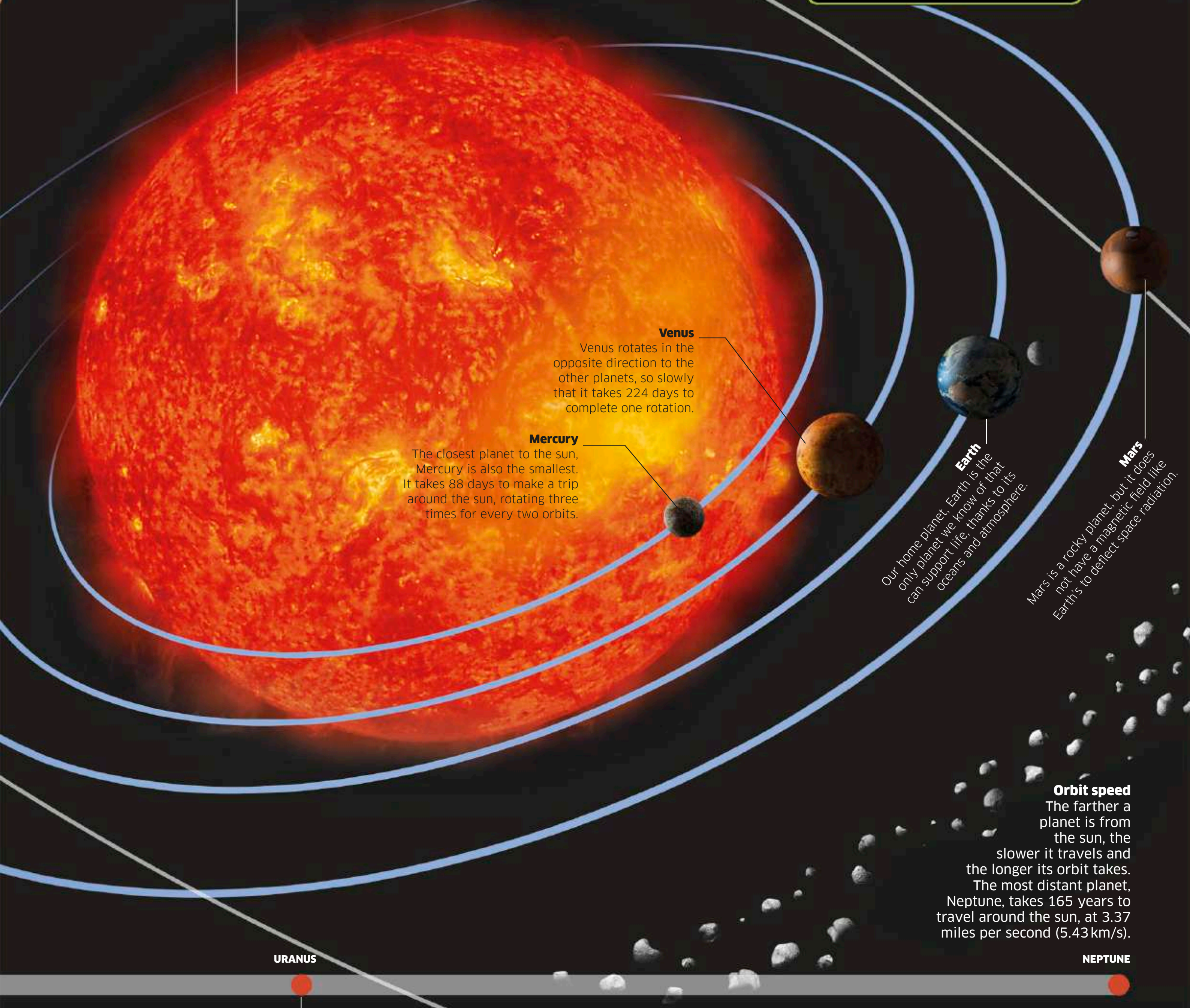
The Solar System

The solar system is a huge disk of material, with the sun at its center, that stretches out over 19 billion miles (30 billion km) to where interstellar space begins.

Most of the solar system is empty space, but scattered throughout are countless solid objects bound to the sun by gravity and orbiting around it. These include the eight planets, hundreds of moons and dwarf planets, millions of asteroids, and possibly billions of comets. The sun itself makes up 99.8 percent of the mass of the solar system.

There are five known dwarf planets:
Ceres, Pluto, Makemake, Eris, and Haumea.

Asteroid 234 Ida
In between the orbits of Mars and Jupiter lies the asteroid belt. Asteroids are made up of a mixture of rock and ice. This space rubble is the detritus of planet formation.



Sun
The sun lies in the center of the solar system. It spins on its axis, taking less than 25 days to rotate despite its massive size.

Venus
Venus rotates in the opposite direction to the other planets, so slowly that it takes 224 days to complete one rotation.

Mercury
The closest planet to the sun, Mercury is also the smallest. It takes 88 days to make a trip around the sun, rotating three times for every two orbits.

Earth
Our home planet, Earth is the only planet we know of that can support life, thanks to its oceans and atmosphere.

Mars
Mars is a rocky planet, but it does not have a magnetic field like Earth's to deflect space radiation.

Orbit speed
The farther a planet is from the sun, the slower it travels and the longer its orbit takes. The most distant planet, Neptune, takes 165 years to travel around the sun, at 3.37 miles per second (5.43 km/s).

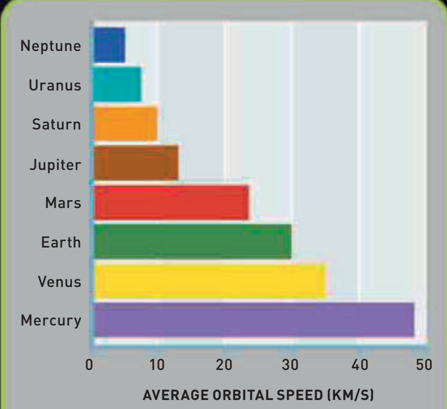
URANUS
Uranus is 1.78 billion miles (2.87 billion km) from the sun on average, or 19.14 AU.

NEPTUNE
Neptune orbits at 2.81 billion miles (4.53 billion km), an average of 30 times the distance between Earth and the sun, or 30 AU.

UNDERSTANDING PLANETARY ORBITS

THE MOVEMENTS OF THE PLANETS CAN BE DESCRIBED WITH THREE LAWS AND EXPLAINED BY GRAVITY

The eight planets of the Solar System, as well as millions of smaller bodies such as comets and asteroids, travel around the Sun in closed loops called orbits. What keeps these objects on their curved trajectories is the same force that makes things fall to the ground on Earth: gravity.



Orbital speeds
The closer a planet is to the Sun, the greater its average orbital speed. The closest, Mercury, moves almost nine times faster than Neptune, the farthest.

For centuries it was generally believed that the Earth was the center of the Universe, with the Sun, Moon, planets, and stars rotating around it. However, this geocentric model could not satisfactorily account for planetary orbits, and in 1543 Danish astronomer Nicolaus Copernicus (1473–1543) proposed his heliocentric (Sun-centered) model, with the planets moving around the Sun in circular orbits (see 1543).

KEPLER'S LAWS

In the early 1600s, German astronomer Johannes Kepler (1571–1630) used observations of planetary movements to try to prove Copernicus right. However, he could make the observations fit a heliocentric system only if the orbits were not circles but ellipses, with the Sun at one focus (see below left). This fact became the first of Kepler's three laws of planetary motion. His second law (see below right) relates to the way a planet's speed changes during its orbit, and his third law (see opposite) concerns the relationship between a planet's distance from the Sun and how long it takes to complete each orbit (its orbital period).

GRAVITATIONAL FORCE

Kepler had no idea why orbits should be elliptical. The answer came after his death from English scientist Isaac Newton (1642–1727), who

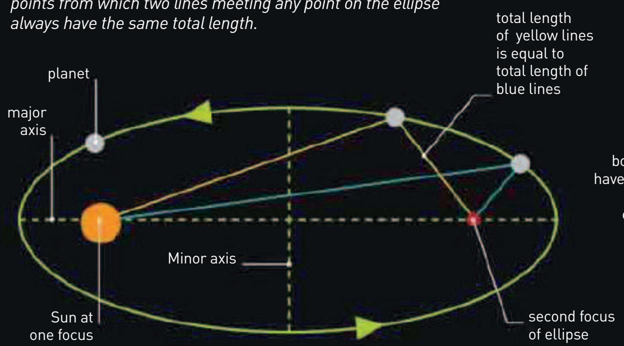
JOHANNES KEPLER
Kepler was an assistant to the great Danish astronomer Tycho Brahe. He used Brahe's observations of the planets when formulating his laws of motion.

suggested that the same force that makes objects fall to the ground on Earth—gravity—might also be keeping the Moon in orbit around our planet. Newton realized that the force of gravity is weaker the further you are from the center of the Earth, and he proposed that gravity weakened in direct proportion to the square of the distance. When he applied this to the Moon, he was able to work out the Moon's orbital period. This allowed him to formulate his universal law of gravitation (see 1687) and to realize that gravity must also be responsible for keeping the planets in orbit around the Sun.

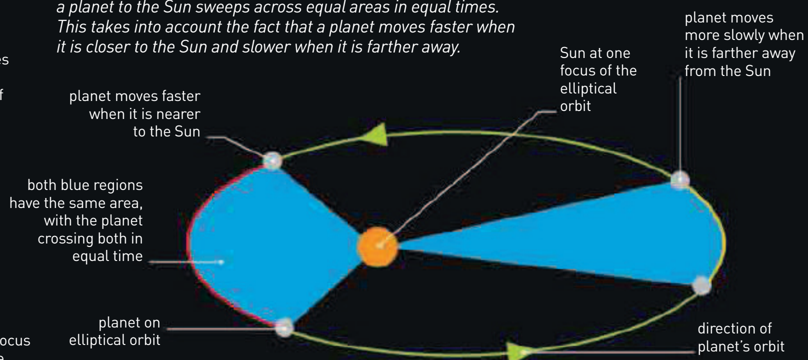
92,955,778

THE AVERAGE **DISTANCE** IN MILES **BETWEEN** THE **SUN** AND THE **EARTH**

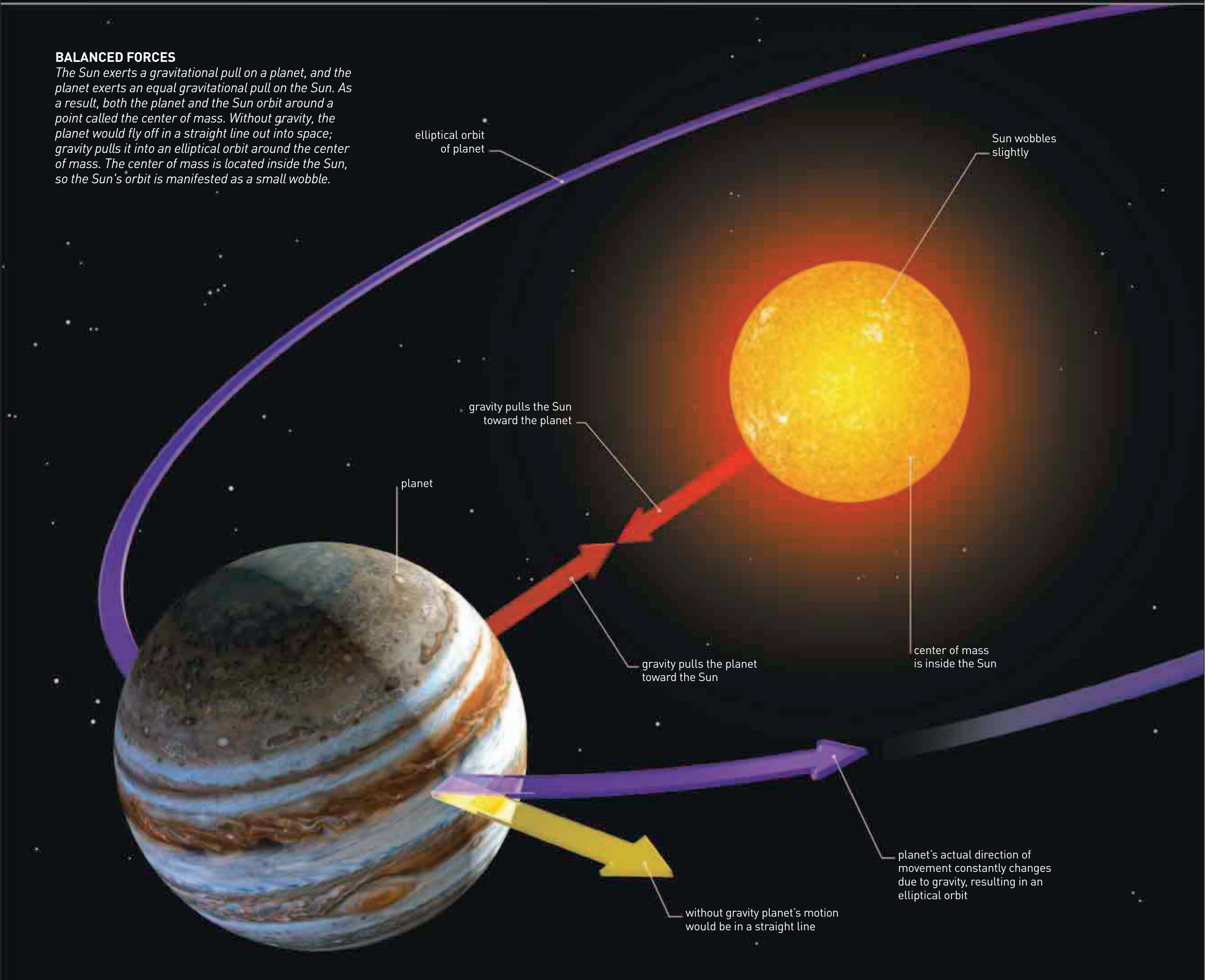
ELLIPTICAL ORBITS
Kepler's first law states that every planet's orbit is an ellipse with the Sun at one focus. An ellipse has two foci; they are the points from which two lines meeting any point on the ellipse always have the same total length.



SPEED AND DISTANCE
The second of Kepler's laws states that an imaginary line joining a planet to the Sun sweeps across equal areas in equal times. This takes into account the fact that a planet moves faster when it is closer to the Sun and slower when it is farther away.



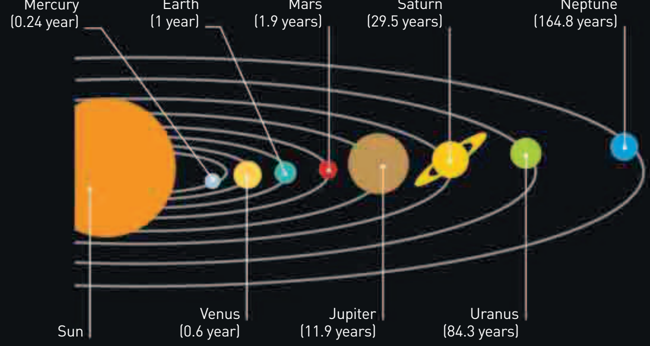
BALANCED FORCES
The Sun exerts a gravitational pull on a planet, and the planet exerts an equal gravitational pull on the Sun. As a result, both the planet and the Sun orbit around a point called the center of mass. Without gravity, the planet would fly off in a straight line out into space; gravity pulls it into an elliptical orbit around the center of mass. The center of mass is located inside the Sun, so the Sun's orbit is manifested as a small wobble.



ORBITAL PERIODS

Kepler's third law gives a mathematical relationship between a planet's average distance from the Sun and its orbital period (the time to complete each orbit). Specifically, it states that the square of the orbital period is proportional to the cube of the semimajor axis (half the diameter of an ellipse at its widest point). This makes it possible to quantify the increase in the orbital period with increasing distance from the Sun. Although Kepler's third law is not as simple as the second law, it enabled Newton to develop his universal law of gravitation.

PLANETARY YEARS
The length of a planet's "year," or orbital period, depends on its average distance from the Sun. The innermost planet, Mercury, has the shortest year at just 88 Earth days. Neptune's is the longest: 60,190 Earth days (164.8 Earth years). The diagram on the right (which is not to scale), shows the planets' orbital periods in Earth years.

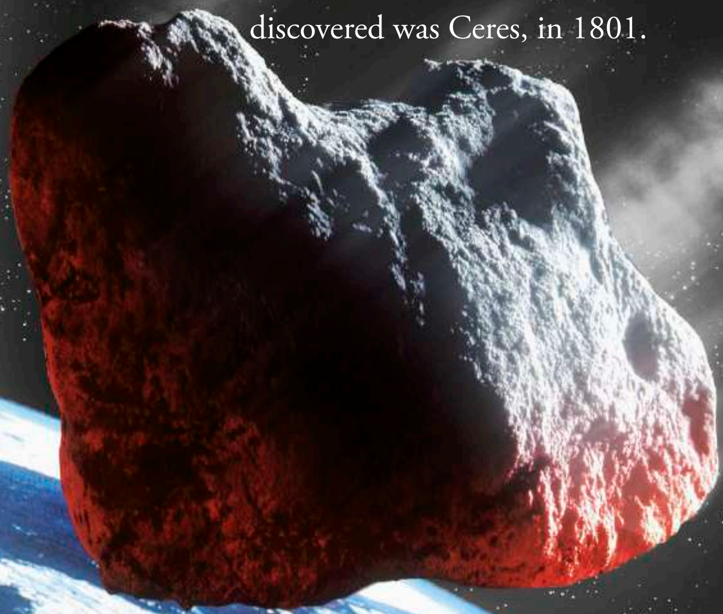


Flying rocks

There are billions of rocks in the Milky Way that never became big enough to be planets. They orbit the sun and sometimes crash into each other and the planets. They create spectacular light shows in the sky and could devastate whole planets.

ASTEROIDS

Asteroids are small, rocky bodies that orbit the sun. Most of them are found between the orbits of Mars and Jupiter. They are leftovers from the formation of the planets 4.6 billion years ago. The main asteroid belt contains tens of thousands of asteroids. The first asteroid to be discovered was Ceres, in 1801.



PLUTO

The Roman god of the underworld

- **Diameter** 1,441 miles (2,320 km)
- **Mass (Earth=1)** 0.002
- **Earth years to orbit sun** 248
- **Number of moons** 5

Pluto was discovered in 1930. In 2006, astronomers decided it should be classed as a dwarf planet. It is smaller and lighter than the moon and its egg-shaped orbit means that it sometimes comes closer to the sun than Neptune. Pluto is very cold because it is so far away from the sun.

DWARF PLANETS

Pluto, Haumea, Eris, Makemake, and Ceres are the only confirmed dwarf planets. Ceres is the only asteroid big enough to be classed as a dwarf planet. The other dwarf planets are much like Pluto and are found in the outer solar system beyond the orbit of Neptune.

WOW!

Most meteorites are too small to cause much damage. However, 65 million years ago, a 6-mile (10-km) wide asteroid hit Earth, causing massive earthquakes and tidal waves. A cloud of dust from the impact entered the atmosphere and blocked sunlight, causing plants and animals to die. This impact may have ended the age of the dinosaurs.

▸ COMETS *orbit the sun in the outer solar system and sometimes appear in our skies. They have two tails—of gas and dust—and a solid nucleus made of ice. The Hale-Bopp comet passed near our Earth in 1997. It was one of the brightest comets of the 20th century.*

Meteor showers occur at the same time each year, when Earth passes through trails of dust left by passing comets. Very rarely, a shower may produce thousands of shooting stars that light up the sky.

TAKE A LOOK: METEORS

Look up at the sky on a cloudless night and you will eventually see a meteor, or "shooting star." Meteors are particles of dust and rock that burn up as they enter Earth's atmosphere.

It's strange to think that the Willamette meteorite (above), now found in a museum, was once a brilliant fireball shooting toward Earth. It's made of iron and nickel.

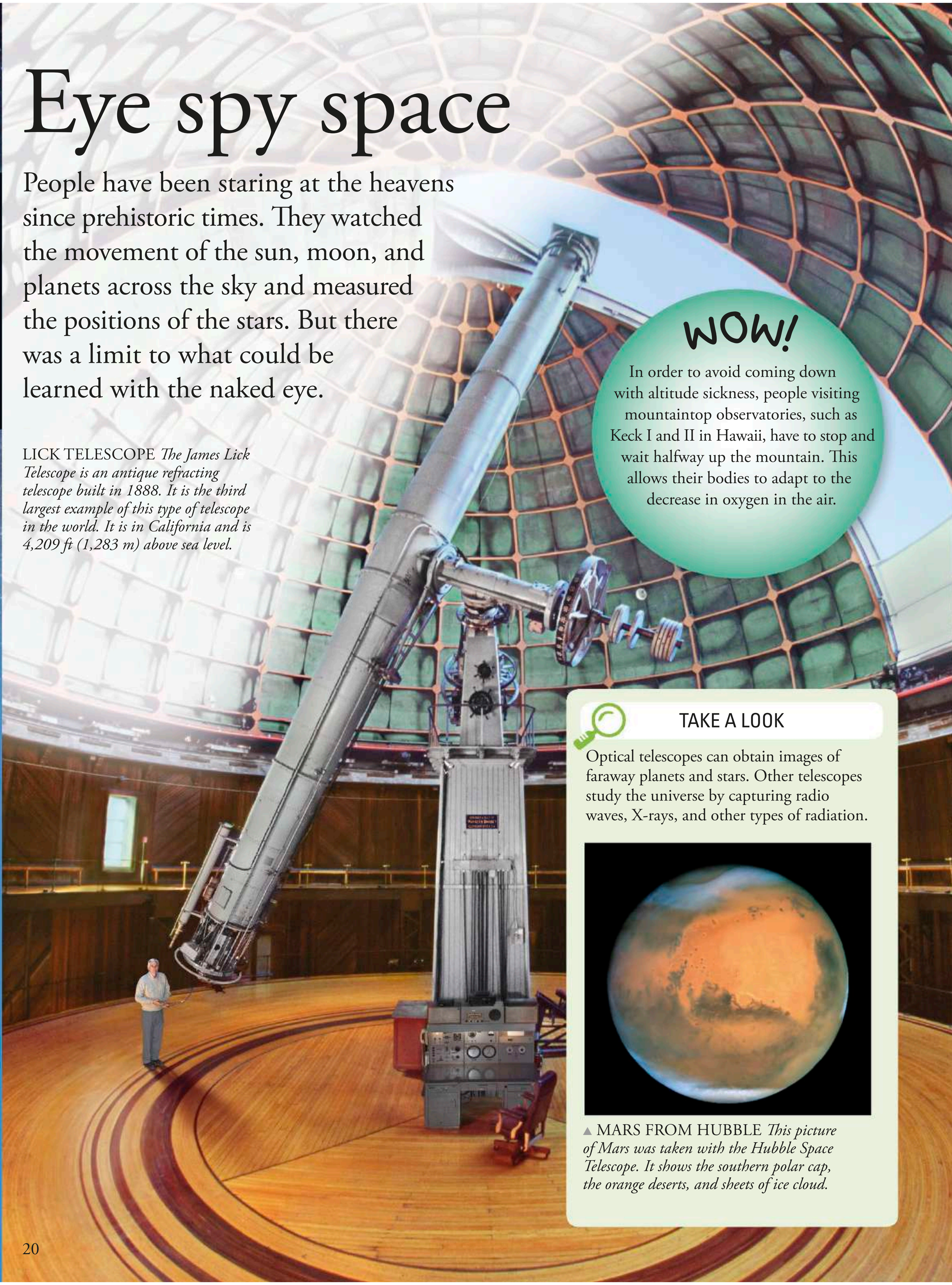
METEORITES

Meteorites are small chunks of rock that have come from space and landed on Earth's surface. Most of them are pieces that have broken off asteroids. A few have come from the moon and Mars.

▸ METEOR CRATER
One of the youngest and best-preserved craters on Earth is in Arizona. It is 50,000 years old and 600 ft (180 m) deep.

Eye spy space

People have been staring at the heavens since prehistoric times. They watched the movement of the sun, moon, and planets across the sky and measured the positions of the stars. But there was a limit to what could be learned with the naked eye.



LICK TELESCOPE *The James Lick Telescope is an antique refracting telescope built in 1888. It is the third largest example of this type of telescope in the world. It is in California and is 4,209 ft (1,283 m) above sea level.*

WOW!

In order to avoid coming down with altitude sickness, people visiting mountaintop observatories, such as Keck I and II in Hawaii, have to stop and wait halfway up the mountain. This allows their bodies to adapt to the decrease in oxygen in the air.

TAKE A LOOK

Optical telescopes can obtain images of faraway planets and stars. Other telescopes study the universe by capturing radio waves, X-rays, and other types of radiation.

▲ MARS FROM HUBBLE *This picture of Mars was taken with the Hubble Space Telescope. It shows the southern polar cap, the orange deserts, and sheets of ice cloud.*

Gran Telescopio Canarias
Largest optical telescope

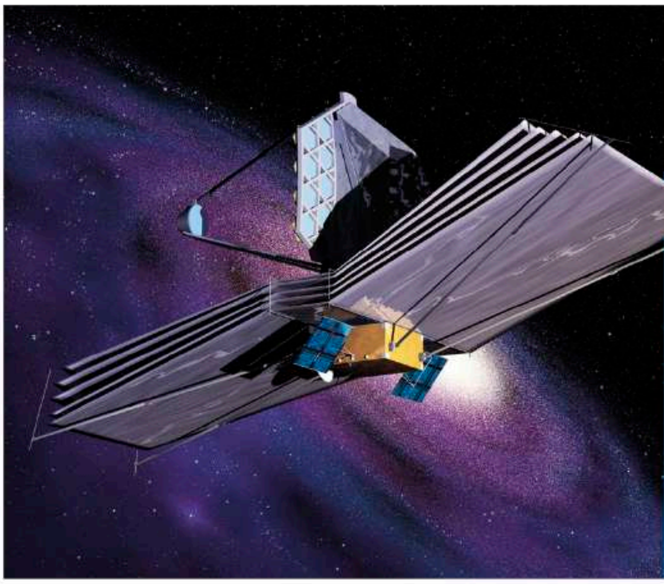
- **Diameter of main mirror** 34 ft (10.4 m)
- **Weight of main mirror** 19 tons (17 metric tons)
- **Altitude** 7,440 ft (2,270 m) above sea level
- **Location** La Palma, Canary Islands, Spain

The world's largest single-mirror reflecting telescope is the Gran Telescopio Canarias, built on the peak of an extinct volcano on La Palma. The main mirror is made up of 36 hexagonal segments each 6¼ ft (1.9 m) across. The metal segments are coated with aluminum, which is a very good reflector of light. Observations began in 2009.

James Webb
Largest space telescope

- **Length** 72 ft (22 m)
- **Weight** 14,300 lb (6,500 kg)
- **Mission length** 5–10 years
- **Location** 1 million miles (1.5 million km) from Earth

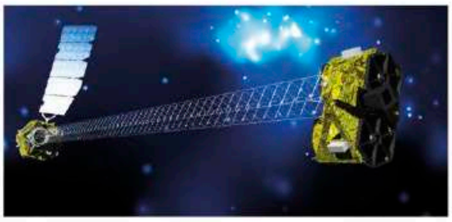
In 2021 or later, the James Webb Space Telescope will be launched into space. It will have a 21-ft (6.5-m) mirror (nearly three times bigger than Hubble's).



NuStar
Most powerful X-ray observatory

- **Length** 36 ft (10.9 m)
- **Weight** 377 lb (171 kg)
- **Launched** 2012
- **Location** Earth orbit

From its observation point above our atmosphere, NuSTAR (Nuclear Spectroscopic Telescope Array) gathers X-rays produced by high-energy objects such as collapsing stars and massive black holes.



Hubble Space Telescope
Famous NASA-ESA observatory

- **Height** 43½ ft (13.3 m)
- **Weight** 23,855 lb (10,843 kg)
- **Mission length** 31 years
- **Location** Earth orbit

Launched in 1990, the world's most famous space observatory has a 7½ ft (2.4 m) mirror. It is named after American astronomer Edwin Hubble, who showed that the universe is expanding.

ALMA
66-dish radio telescope

- **Size** 66 dishes; 54 with a 39-ft (12-m) diameter, 12 with a 30-ft (9-m) diameter
- **Altitude** 3 miles (5 km) above sea level
- **Location** Atacama Desert, northern Chile

The Atacama Large Millimeter/submillimeter Array (ALMA) is the world's largest radio telescope array. Its 66 dishes work together to gather information about newly forming stars and planets.

Allen Telescope Array
42-dish radio telescope

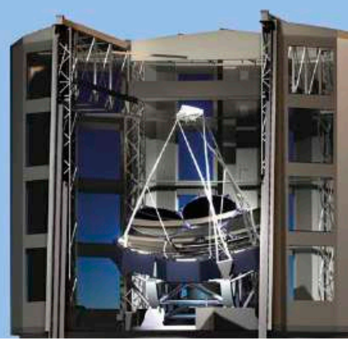
- **Size** 42 dishes, each 20 ft (6.1 m) across
- **Location** Hat Creek, California

Under construction, this array is planned to contain 350 dishes inside a ½ mile- (1 km-) wide circle. They will be linked and act as a single dish to study the distant universe and search for alien life.

Giant Magellan Telescope
7-mirror optical giant

- **Height** Seven 28-ft (8.4-m) mirrors
- **Total moving weight** more than 1,000 tons (more than 1,000 metric tons)
- **Location** Cerro Las Campanas, Chile

Due to be operational in 2023, the Giant Magellan Telescope will produce images ten times sharper than the Hubble Space Telescope.



The Apollo program

In the early 1960s, Russia was ahead in the space race, so President John F. Kennedy announced that American astronauts would land on the moon before 1970. In July 1969, after spending 25 billion dollars on the *Apollo* program, they did.

GETTING THERE

■ The astronauts' journey to the moon would not have been possible without the *Saturn V*, the most powerful rocket ever built. The huge, three-stage rocket towered 361 ft (110 m) above the Florida launch pad. After the first two stages ran out of fuel, they were released and the third stage was used to boost the *Apollo* spacecraft and its crew toward the moon.

First man on the moon *Apollo 11* was the first manned mission to land on the moon. On July 20, 1969, Neil Armstrong made the first lunar footprint. He was joined on the Moon's surface by Buzz Aldrin.

APOLLO TIMELINE

1966

February 26
First unmanned test flight of *Saturn* 1B rocket. It eventually carried the first manned *Apollo* test flight to orbit Earth.

1967

January 27
Gus Grissom, Edward White, and Roger Chaffee were killed on the launch pad by a fire in their *Apollo* spacecraft during a launch test.

1968

October 11
First manned *Apollo* flight tests the Command Module in Earth's orbit.

December 21
Apollo 8 is the first manned spacecraft to leave Earth orbit and orbit the Moon.

1969

July 20
Apollo 11 makes the first manned landing on the moon.

APOLLO SPACECRAFT

For the three-day trip between Earth and the moon, the *Apollo* crew spent most of its time in the cone-shaped Command Module (CM). The crew also returned to Earth in the Command Module and landed by parachuting into the ocean.

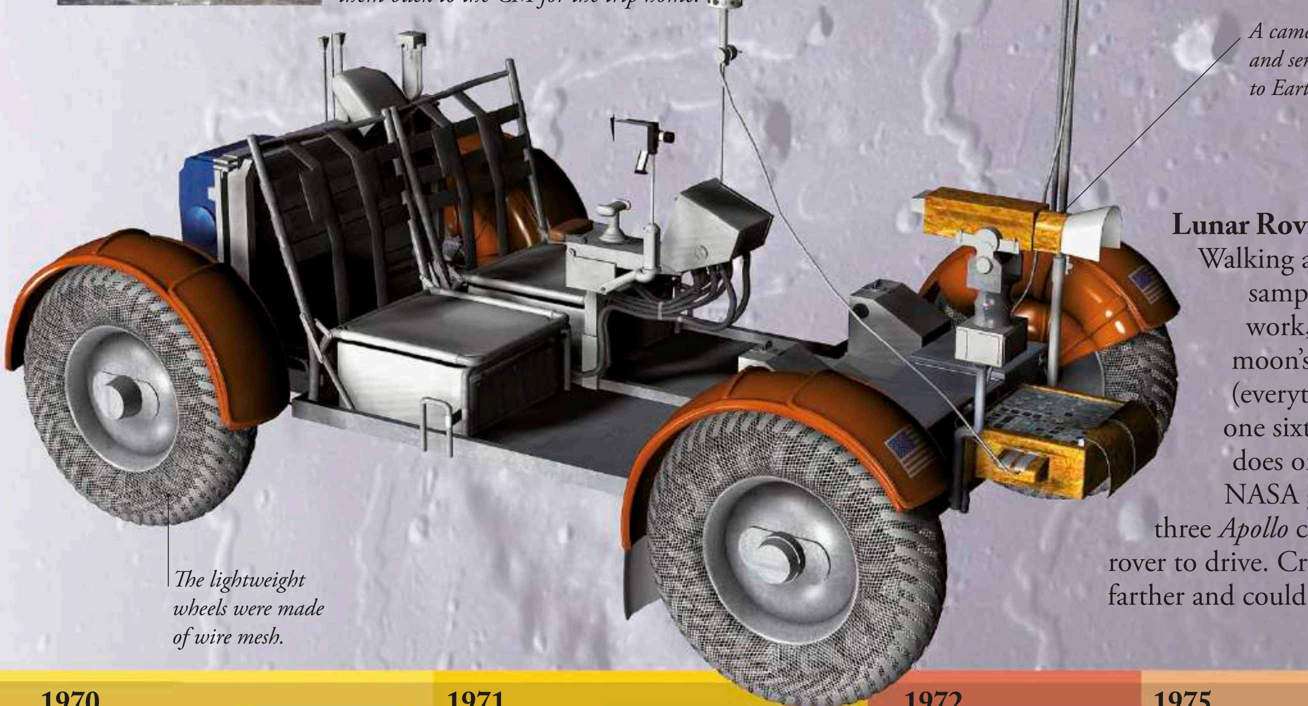
▼ COMMAND MODULE *One astronaut stayed in the CM in orbit around the moon. The others went down to the moon's surface.*

◀ LUNAR MODULE *The moon lander was officially called the lunar module. The crew lived in the upper of the two sections. It was this section that blasted off from the moon and carried them back to the CM for the trip home.*

TAKE A LOOK

Scientists wanted to learn more about the moon, so astronauts collected lots of soil and rock samples.

▶ *Bending in spacesuits wasn't easy, so tools were designed to pick things up. Altogether, 838 lb (380 kg) of rocks were brought to Earth and stored in a special laboratory.*



Dish antenna for communications with Earth.

A camera took pictures and sent them back to Earth.

The lightweight wheels were made of wire mesh.

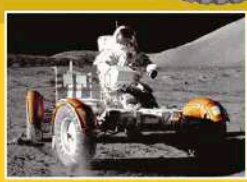
Lunar Roving Vehicle Walking and carrying samples was hard work, even in the moon's low gravity (everything weighs one sixth of what it does on Earth). So NASA gave the last three *Apollo* crews a lunar rover to drive. Crews traveled farther and could carry more.

1970

April 13 An oxygen tank exploded on *Apollo 13,* canceling its moon landing.

1971

July 26 Launch of *Apollo 15*, the first mission with a rover.



1972

December 19 Splashdown of Apollo 17, the last manned mission to the moon.

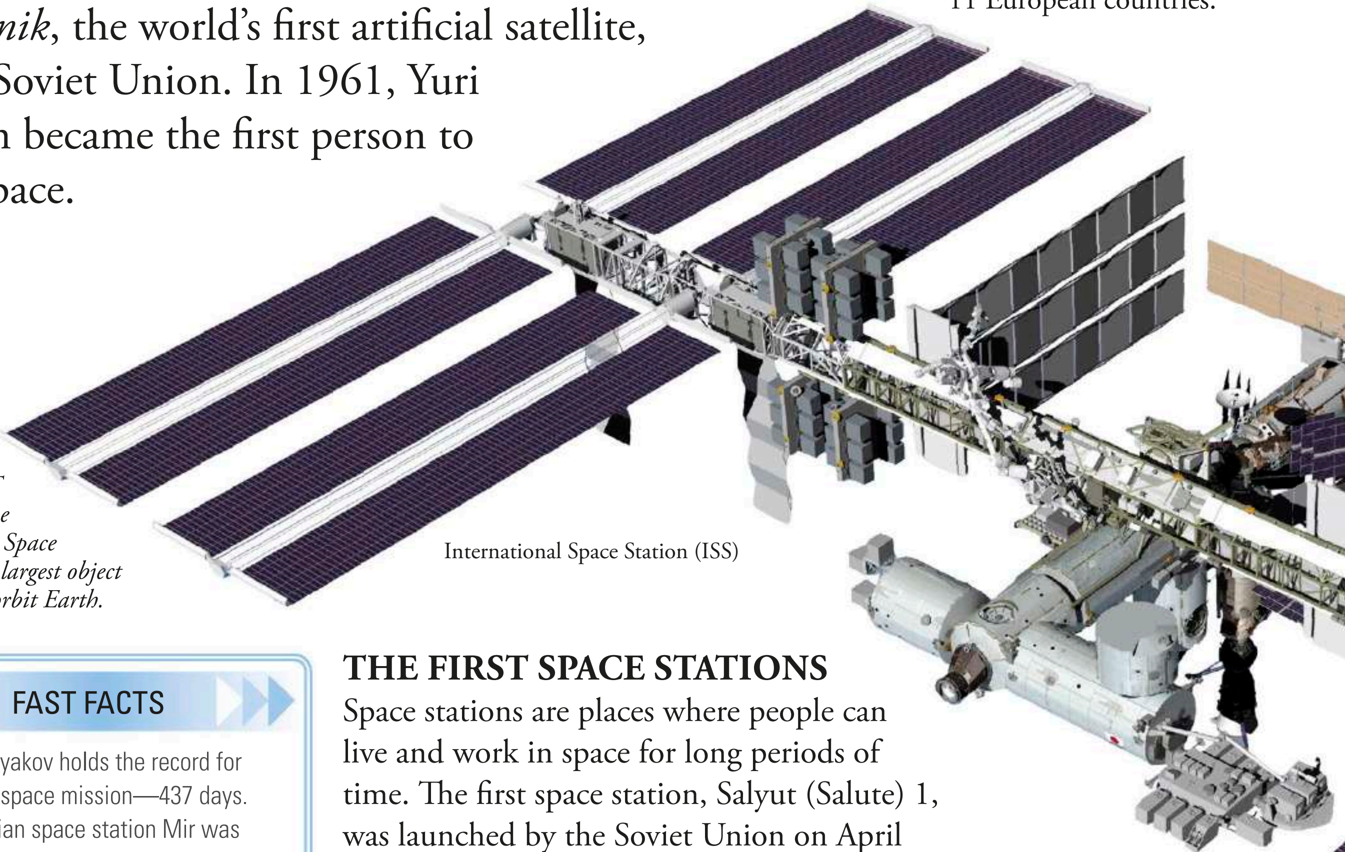
1975

July 17 *Apollo-Soyuz* docking: first joint US-Russian manned mission.

Exploring space

The Space Age began in 1957, with the launch of *Sputnik*, the world's first artificial satellite, by the Soviet Union. In 1961, Yuri Gagarin became the first person to fly in space.

The International Space Station is the most expensive and ambitious object ever flown. The 496-ton (450-metric-ton) station was built in Earth's orbit by the US, Russia, Japan, Canada, and 11 European countries.



International Space Station (ISS)

▸ LARGEST OBJECT *The International Space Station is the largest object ever built to orbit Earth.*

FOOTBALL FIELD ▴ *The ISS is about the size of a US football field.*

FAST FACTS

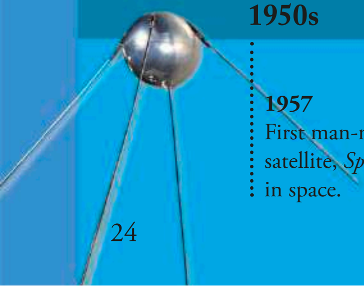
- Valeri Polyakov holds the record for the longest space mission—437 days.
- The Russian space station Mir was home to 111 people, from 1986–2001.
- Mir flew more than 2 billion miles (3 billion km) in its lifetime.
- In 1986, the shuttle *Challenger* and its crew perished during ascent, just 71 seconds after launch.
- The shuttle *Columbia* broke apart during its return to Earth in 2003.
- More than 90 percent of the world's population can see the International Space Station when it flies overhead.
- The International Space Station orbits Earth every 90 minutes.

THE FIRST SPACE STATIONS

Space stations are places where people can live and work in space for long periods of time. The first space station, Salyut (Salute) 1, was launched by the Soviet Union on April 19, 1971. Six more *Salyuts* were launched by 1986. *Skylab*, the first US space station, launched in 1973.

▸ SALYUT 7 SPACE STATION *The 22-ton (20-metric-ton)* Salyut 7 *space station was launched in 1982 and burned up during reentry in 1991.*

TIMELINE OF SPACE EXPLORATION



1950s

1957 First man-made satellite, *Sputnik*, in space.

1959 First pictures of the far side of the moon *(Luna 3)*.

1960s

1961 First human in space, Yuri Gagarin.

1963 First woman in space, Valentina Tereshkova.

1965 Alexei Leonov makes first spacewalk.

1969 First man to walk on the moon, Neil Armstrong.

Space shuttle In 1981, a new space age began when the first reusable spacecraft lifted off from Cape Canaveral, Florida. Five US space shuttle orbiters were built and flew a total of 135 missions. The final flight was in 2011.

▼ SPACE SHUTTLE LANDING
The shuttle came back to Earth like a giant glider. It landed on a runway at a speed of 215 mph (345 km/h). A tail parachute helped it to slow down.

REUSABLE LAUNCHERS

Only part of the Space Shuttle was reusable—and other rockets are simply lost forever once they launch a payload into space. But the Falcon Heavy, built by SpaceX, is a system that can launch satellites and other objects into space, then land its rockets back on Earth to be reused.

▲ THE FALCON HEAVY *has three "cores" that return to the launchpad after launching the payload.*

Dennis Tito

Space tourism Almost all of the astronaut and cosmonaut flights have been funded by governments. However, space tourism is becoming increasingly popular. The first real space tourist was millionaire businessman Dennis Tito, who paid $20 million for a week on board the ISS.

WOW!

Just 12 astronauts have walked on the moon. They are the only people ever to have set foot on another world. More than 550 people have flown in space since Gagarin's historic flight. Most have come from the Soviet Union/Russia or the United States.

▼ SPACESHIPTWO
Virgin Galactic's suborbital spacecraft SpaceShipTwo is carried into space by the WhiteKnightTwo, a four-engine jet aircraft. This spacecraft can carry eight people on a suborbital flight.

1970s

1973
Skylab launch—the first US space station.

1977 *Voyager* 2, then 1 are launched to Jupiter, Saturn, and beyond.

1980s

1986
First section of *Mir* space station launched.

1990s

1998
First part of the ISS launched.

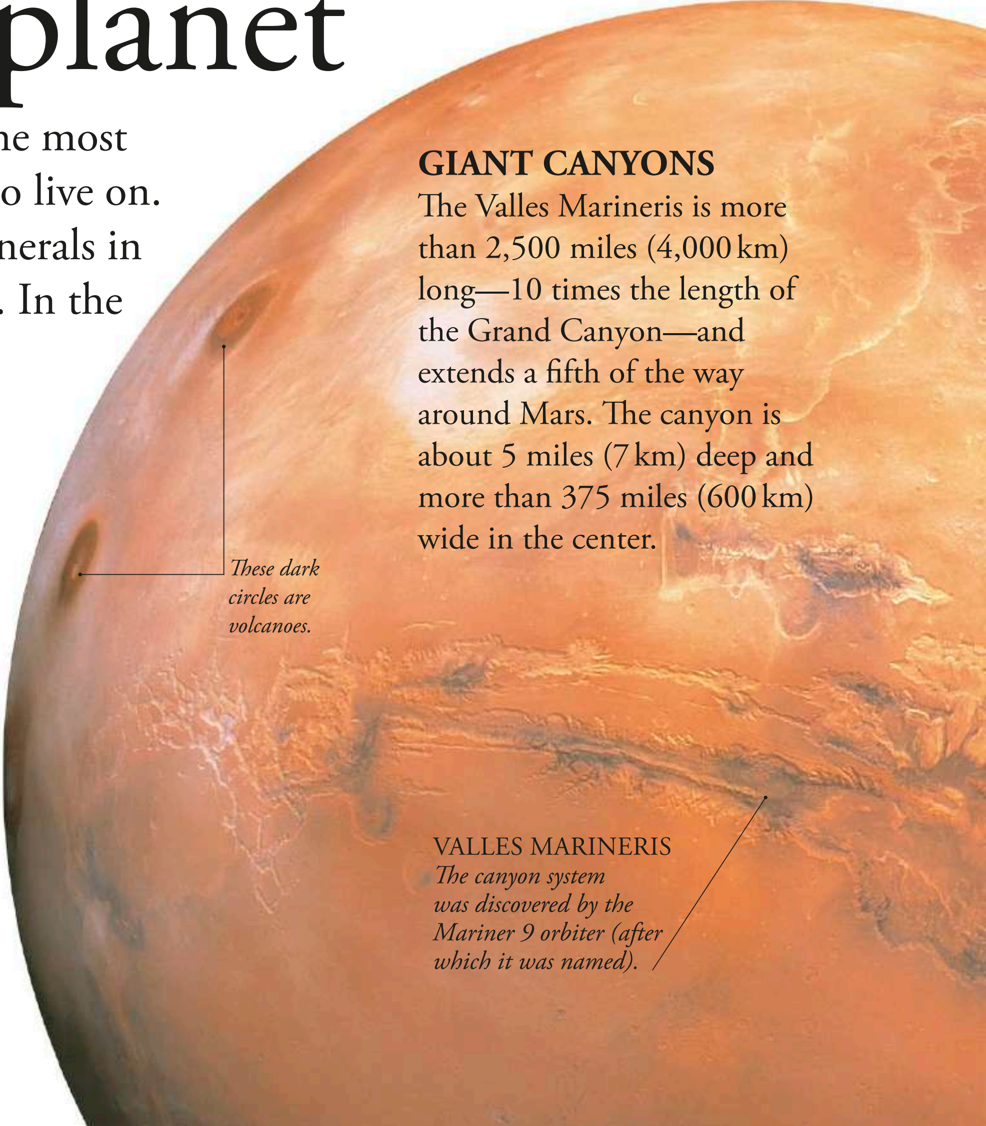
2000s

2004
Cassini-Huygens arrives at Saturn.

2015
New Horizons reaches Pluto and sends back images of its surface.

The red planet

Apart from Earth, Mars is the most suitable planet for humans to live on. It looks red because iron minerals in its surface rocks have rusted. In the past, it was much more like Earth than it is today.

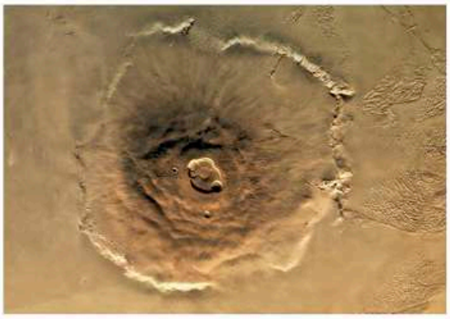


GIANT CANYONS

The Valles Marineris is more than 2,500 miles (4,000 km) long—10 times the length of the Grand Canyon—and extends a fifth of the way around Mars. The canyon is about 5 miles (7 km) deep and more than 375 miles (600 km) wide in the center.

These dark circles are volcanoes.

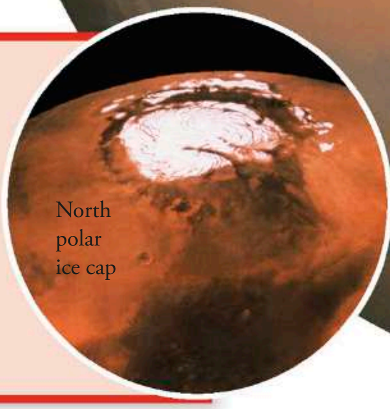
VALLES MARINERIS
The canyon system was discovered by the Mariner 9 orbiter (after which it was named).



Volcanoes Mars has the largest volcanoes in the solar system. The most impressive is Olympus Mons, which is 375 miles (600 km) across and more than 16 miles (26 km) high. The volcano hasn't erupted for millions of years.

POLAR ICE CAPS

■ There are ice caps at both Martian poles, but they are much smaller than Earth's. Each pole is different. The northern sheet is about 2 miles (3 km) thick and mainly water ice. The southern polar cap is colder but thicker, and made of water ice with a coating of carbon dioxide ice. The polar caps melt and shrink in summer, then grow in winter when the temperature drops.



TIMELINE OF MARS EXPLORATION

1960s

1960 *Korabl 4* (USSR) did not reach Earth's orbit.

1962 *Mars 1* (USSR) lost contact on way to Mars.

1964 *Mariner 4* (US) the first success returned 21 images.

1969 *Mariner 7* (US) was a success and returned 126 images.

1970s

1971 *Mariner 9* (US) the first successful Mars orbiter.

1973 *Mars 5* (USSR) orbiter got 22 days of data.

1976 *Viking 1* (US) made the first successful landing on Mars.

WHERE IS THE WATER?

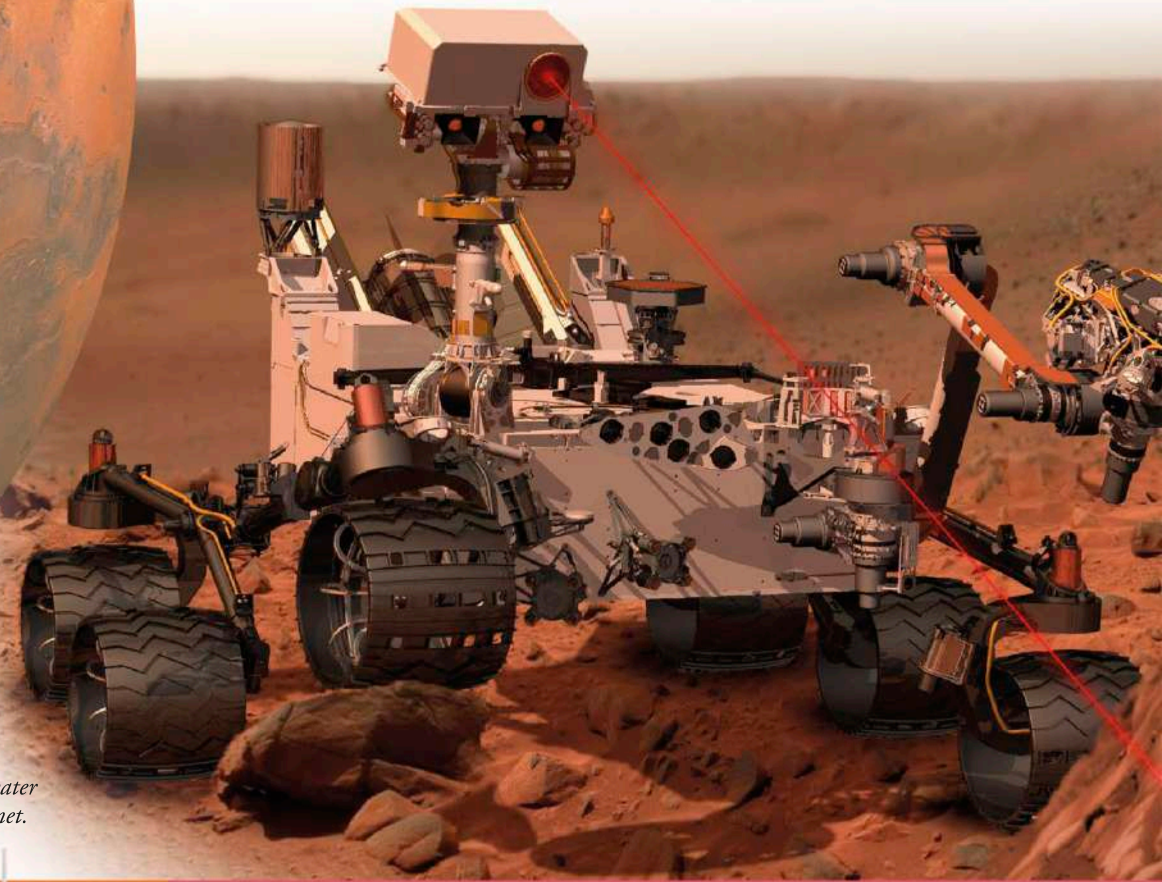
Today, Mars is very cold and the air is too thin for liquid water to exist on the surface. However, huge, winding channels suggest that large rivers flowed over the surface long ago. The water was probably released in sudden floods, possibly when underground ice melted. These river channels have been dry for billions of years.

WOW!

Mars has two small moons, Phobos and Deimos. They are thought to be asteroids that were captured by Mars long ago. Phobos is no more than 17 miles (27 km) across with large craters on its surface. Deimos is just 7 miles (12 km) across and has a smoother surface.

Phobos

Mars Explorers During a long-running study of Mars, the US have sent robotic spacecraft to explore the planet. The successful *Viking* missions in the 1970s included two orbiters and two landers. The first rover was part of the *Mars Pathfinder* mission of 1997. Today there are two large rovers on Mars (*Opportunity* and *Curiosity*) that are still returning images and data to Earth. Missions carrying humans to Mars are planned for the 2020s.



▶ CURIOSITY ROVER *In 2012,* Curiosity *detected water vapor on the red planet.*

1990s

1997
Mars Pathfinder (US) delivers first successful rover to Mars.

2000s

2003
Europe's *Mars Express* orbiter began taking detailed pictures of Mars.

2008
Phoenix (US) landed in Martian Arctic and operated for over 5 months (before its batteries went flat).

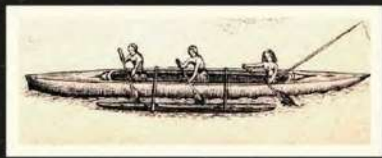
2012
Mars Science Laboratory landed on Mars in 2012, with the *Curiosity* rover (p266).

2016
ExoMars Trace Gas Orbiter (Europe and Russia) launched to examine gases in the Martian atmosphere.

First stargazers
A cave painting at Lascaux in France depicts the bright stars of the constellation Taurus overlaid on the image of a bull—the earliest evidence for prehistoric astronomy.

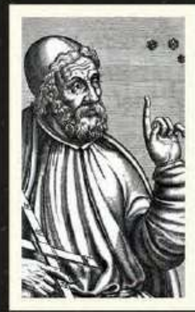
c. 15,000 BCE

Sailing by stars
Explorers from East Asia colonize the islands of Polynesia in the Pacific Ocean, using the stars to help them navigate.



c. 3000 BCE

Naming constellations
Greek mathematician Ptolemy writes an astronomical manual called the *Almagest*. As well as attempting to explain the workings of the heavens, it lists 48 bright constellations and gives them names that are still used today.



c. 150 CE

The night sky

Since prehistoric times, people have gazed at the night sky and tried to make sense of what they could see. Early astronomers used the regular cycles of the moon and stars to keep track of time. Later, the changing patterns of constellations were used to guide sailors across the oceans. It wasn't until the 1600s that a more scientific approach to astronomy transformed our understanding of Earth's place in space and the way forces like gravity govern the universe.

1781

New planets
German-British astronomer William Herschel discovers the planet Uranus, the first planet to be found since ancient times. In 1846, irregularities in Uranus's orbit lead to the discovery of a further planet: Neptune.

1838

Far, far away
German astronomer Friedrich Wilhelm Bessel measures slight changes in the apparent direction of a star when seen from different points in Earth's annual orbit around the sun. He uses these changes to calculate the star's distance from the sun, which proves far greater than anyone had imagined possible.

1859

Studying starlight
German scientists Gustav Kirchhoff and Robert Bunsen discover that chemical elements absorb and emit characteristic wavelengths of light. They invent the spectroscope, a machine that can identify the elements in stars, allowing study of their temperature, age, and other properties.

Catalogue of stars
Scottish astronomer Williamina Fleming and a team of female scientists at Harvard Observatory in Massachusetts compile a detailed catalog of the spectra (color patterns) of stars, helping to reveal how stars evolve as they age. Over nine years, Fleming catalogs more than 10,000 stars.

Williamina Fleming discovered the Horsehead Nebula in

El Caracol, the observatory tower near Chichen Itza, gives 360-degree views of the skies.

Maya observatory

Maya astronomers in ancient Mexico build an observatory tower near the city of Chichen Itza. They use it to track the risings and settings of Venus throughout an eight-year cycle.

c. 906 CE

Copernican revolution

Polish mathematician and astronomer Nicolaus Copernicus proposes that Earth orbits the sun—a controversial idea that becomes more widely accepted in the 1600s after the invention of the telescope.

1543 CE

"The Earth is a very small stage in a vast cosmic arena."
Carl Sagan

Southern stars

Dutch mapmaker Petrus Plancius produces a map of constellations that includes stars observed by Dutch sailors exploring Earth's southern hemisphere. He introduces 12 new constellations, mostly named after birds and other animals.

1597

Through the telescope

Italian astronomer Galileo builds his own telescope. He discovers that the moon's surface is covered in craters, and that there are many more stars than previously thought. Galileo also discovers and names the moons of Jupiter.

1609

Seeing double

Italian mathematician Benedetto Castelli uses an early telescope to observe that the bright star Mizar in the constellation Ursa Major is actually a tight pair of near-identical stars—the first hint that many stars in the sky are binary pairs or multiple groups.

1617

The Pleiades *is a cluster of stars born around the same time. They are also known as the Seven Sisters, Messier 45, and other names.*

Blurry objects

French comet-hunter Charles Messier publishes a list of objects that appear blurry through telescopes. Messier's catalog includes nebulae (interstellar gas clouds), star clusters, and mysterious objects that are now known to be distant galaxies.

1774

Distant galaxies

Building on the work of US astronomer Henrietta Leavitt, astronomer Edwin Hubble calculates the distance to faint patches of light in the night sky. This confirms that they are entire galaxies far beyond our own, and that the scale of the universe is unimaginably vast.

Space telescope

NASA launches the Hubble Space Telescope, the first large telescope to be placed in orbit around Earth. It has unrivaled views of the sky and takes pictures of the most distant objects ever seen.

Defining constellations

The 88 modern constellations combine the 48 listed by Ptolemy in his *Almagest* with 40 additions from the 16th to 18th centuries (largely in southern-hemisphere skies unknown to Ptolemy). At first, constellations were simply patterns made by joining up stars. As telescopes improved and astronomers discovered ever-fainter stars between the shapes, the definition of constellations changed to include areas of sky separated by internationally agreed borders.

URSA MAJOR
THE GREAT BEAR

Around the sun

For centuries, most people believed that the daily movements of the sun, moon, and stars across the sky meant that these heavenly bodies traveled around a stationary Earth, which was the center of creation. The alternative explanation—that Earth rotates while it flies through space around the sun—seemed absurd. The Earth-centered (geocentric) view of the universe held sway until the 1500s, when a Polish astronomer and mathematician called Nicolaus Copernicus published a revolutionary book that suggested it was wrong.

Ptolemy's model had Earth in the centre, but Copernicus's model (right page) puts the Sun in the centre.

4th century BCE

Heavenly spheres

Inspired by his teacher Plato, Greek philosopher Eudoxus proposes that the stars, sun, moon, and planets are all fixed to dozens of gigantic, concentric spheres revolving around a central, stationary Earth.

c. 250 BCE

Sun-centered universe

Greek philosopher Aristarchus of Samos calculates that the sun is much larger than Earth and proposes a model of the universe with the sun in the middle. However, his idea doesn't catch on.

c. 150 CE

Ptolemy's model

Ptolemy, a Greek mathematician, devises a mathematical model of the solar system with Earth in the middle. Although wrong, it proves to be good at predicting the movement of planets.

c. 510

Spinning Earth

Indian astronomer and mathematician Aryabhata writes that the apparent motion of stars in the night sky is caused by Earth rotating. Later astronomers say this can't be true as a spinning Earth would create ferocious wi

1377

Heavens and Earth

French philosopher Nicolas d'Oresme writes a book rejecting the idea that Earth's rotation would cause winds. In his view, the air would rotate along with the

1514

Copernicus's theory

Copernicus develops a mathematical model of the solar system with Earth in the middle. It's simpler than Ptolemy's model but it isn't
—Copernicus doesn't
planets follow
rather than

Copernicus's book

1543

Copernicus writes a book about his model. Worried it will offend the Catholic Church, he waits many years before publishing it. Even then, he says it is just a calculating aid. The Church bans the book for more than 200 years.

Great comet

1577

Danish astronomer Tycho Brahe observes a comet on a path that crosses the orbit of Mars, proving the planets cannot be orbiting on gigantic spheres.

Tycho's model

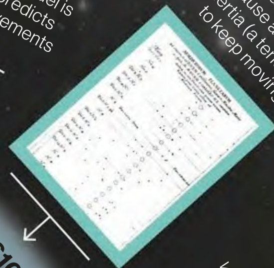
1588

To address problems in both Copernicus's model and Ptolemy's, Brahe puts forward an alternative model in which the sun orbits Earth but all other planets orbit the sun.

Kepler's ellipses

1609

While studying records of planetary movements made by Tycho Brahe, German mathematician Johannes Kepler discovers that the orbits of planets are not circular but elliptical. When Copernicus's model is adjusted, it predicts planetary movements perfectly.



Galileo's discoveries

1610

Italian astronomer and mathematician Galileo discovers moons orbiting Jupiter, proving not all heavenly bodies orbit Earth. It convinces him Copernicus was right. Galileo also proposes that Earth can rotate without causing winds because air, like Earth, has inertia (a tendency to keep moving).

Heresy

1633

After publishing a book that supports Copernicus, Galileo is charged with heresy by the Catholic Church and forced to publicly renounce his views. He is sentenced to house arrest for the remainder of his life.

Newtonian laws

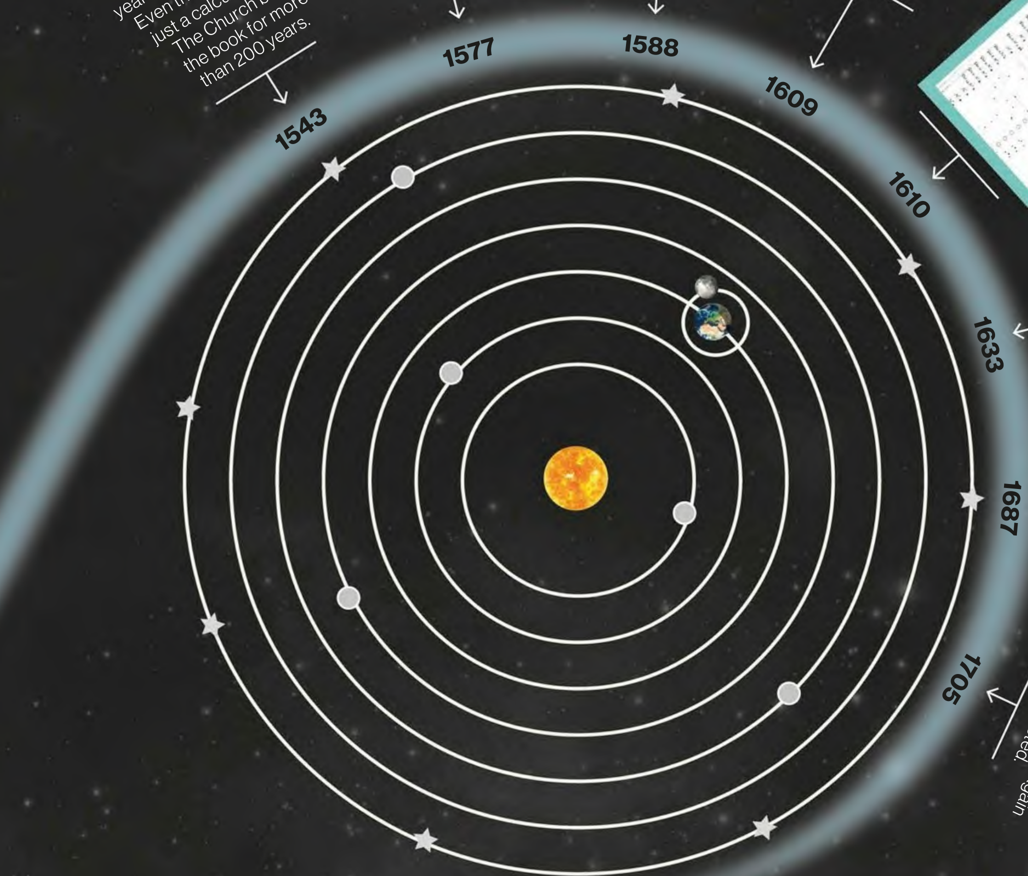
1687

Inspired by Kepler's discoveries that planets move in ellipses (and that they speed up when closer to the sun), English mathematician Isaac Newton derives his famous laws of motion and gravity. This is the birth of the modern science of physics.

Halley's comet

1705

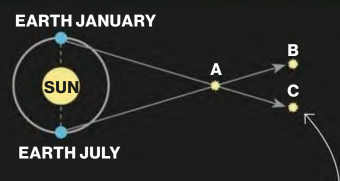
English astronomer Edmond Halley uses the work of Newton to predict the return in 1758 of the comet that now bears his name. He is proved right when the comet appears again as predicted.



"Since the sun remains stationary, whatever appears as a motion of the sun is really due rather to the

Parallax

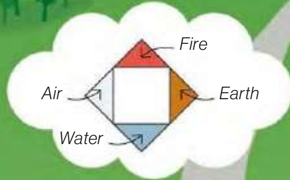
One objection to Copernicus's model was that the stars do not shift in their apparent position from month to month as might be expected if Earth is moving around the sun. The fact that this shift, known as parallax, could not be detected meant either that Copernicus was wrong or the stars were unimaginably far away. In 1838, German astronomer Wilhelm Friedrich Bessel finally detected parallax in a star, proving



When seen at different times of year, star

Gravity

We take it for granted that an object falls to the ground when dropped, but the force that pulls it down—gravity—was misunderstood for centuries. The mystery of gravity wasn't solved until the 17th century, when English mathematician Isaac Newton showed that this invisible force is the same one that governs the motion of the planets. Yet the story didn't end there, and in the 20th century the work of Albert Einstein once again changed our understanding of how gravity works.



The natural place

Greek philosopher Aristotle thinks that everything is made up of four elements (earth, water, air, and fire). Objects are drawn to their "natural place," so a rock (made of earth) will fall downward and fire moves upward. He also thinks that heavier objects fall faster than lighter ones. His ideas are later proved wrong.

c. 350 BCE

Halley's Comet

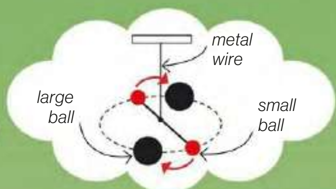
Edmond Halley, an English astronomer, studies the orbital path around the sun of the comet now named after him, and using Newton's law of gravity predicts that it will return in 1758. Though he does not live to see its reappearance, he is proved right.

1705

Measuring Earth's mass

English astronomer Nevil Maskelyne calculates the gravitational force of a mountain by measuring the tiny deflection it produces in a pendulum. The result, which confirms Newton's law of gravity, allows him to roughly estimate Earth's density and mass.

1774



1798

Cavendish experiment

English experimenter Henry Cavendish estimates Earth's mass far more accurately than Maskelyne. He does it by suspending lead balls of different masses, and measuring the tiny gravitational pull between them.

1846

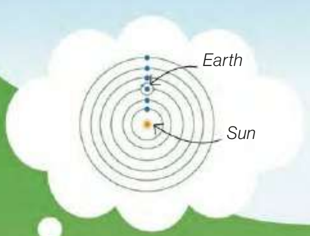
Finding Neptune

Astronomers notice that the recently discovered planet Uranus doesn't follow the orbital path predicted using Newton's law and they wonder if this is due to the gravitational pull of an undiscovered planet. They train their telescopes on the area beyond Uranus and discover Neptune.

1915

Curved space

German physicist Albert Einstein presents his theory of general relativity. It redefines gravity as a warping of space and time due to the presence of massive objects. This curved space–time



Copernican Revolution

Polish astronomer Nicolaus Copernicus proposes a revolutionary theory—that the sun is the center of the solar system, not Earth, and the planets move around it on circular paths. This idea will later prove very important in the story of gravity.

1543 CE

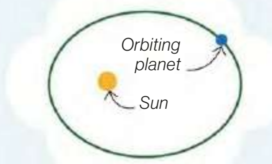
Testing gravity

By rolling balls down slopes and timing them, Italian experimenter Galileo demonstrates that heavy and light objects fall at the same rate, proving Aristotle wrong. It is air resistance that slows objects down. He concludes that an object will remain in motion unless a force causes it to stop, a realization that later influences Newton.

1589

Elliptical orbits

Johannes Kepler, a German mathematician, discovers that planets travel around the sun in oval shapes called ellipses (not circles as Copernicus had thought) and speed up as they approach the sun. He doesn't know why, though, and wrongly suspects magnetism might be the reason.



1609

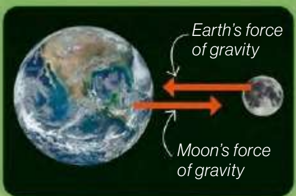
Falling apple

Supposedly inspired by a falling apple, Isaac Newton wonders if the force that makes objects fall could be responsible for the way planets move. He calculates the shape of orbits assuming the sun's gravity controls the planets and finds they match Kepler's ellipses perfectly.

c. 1666

Law of gravity

Newton ties together Galileo's and Kepler's discoveries in his theory of gravity. In his masterpiece, the book *Principia*, he explains that every object in the universe exerts a force of gravity on every other object. This force varies with the mass of objects and how far apart they are.



1687

Dark matter

US astronomer Vera Rubin observes that spiral galaxies rotate so fast that they should fly apart, according to Newton's law. The logical explanation is that they have far more mass, and therefore more gravity, than astronomers can observe. The missing mass—dark matter—is now thought to make up 85 percent of the mass of the universe.

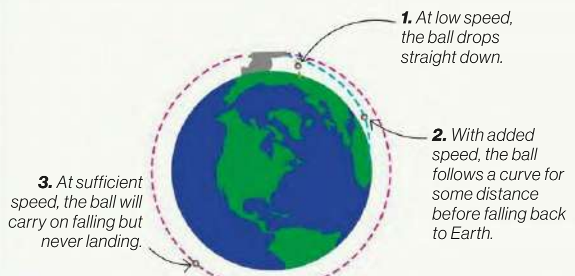
1970s

Space-time ripples

Using a giant observatory, scientists in the US detect for the first time the existence of gravitational waves—ripples in the fabric of space-time caused by the violent collision of massive objects far away in space. This confirms a prediction made by Einstein almost a century earlier.

Newton's mountain

Isaac Newton's book *Principia* explained how orbits work with an imaginary experiment involving a cannon on a mountain. The faster and higher the cannonball is fired, the gentler the curve of its trajectory. If fired fast enough, the ball's trajectory would match the curvature of Earth. It would then be orbiting Earth.



Galileo

The Italian experimenter Galileo Galilei (known usually as just Galileo) used math to describe the natural world and helped prove that Earth orbits the sun rather than vice versa—an idea that got him into trouble with the Catholic Church. His method of testing ideas by experiment, and measuring everything meticulously, had a great influence on later experimenters, including Isaac Newton.

A scientific family

Galileo is born in the Italian city of Pisa, the son of a musician. His father carries out experiments in musical theory and the vibration of strings, which may have inspired Galileo's interest in experimentation.

1564

Pendulum motion

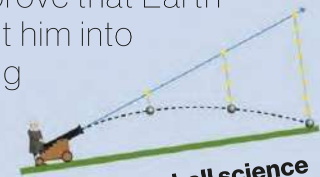
While watching a chandelier swing in Pisa Cathedral (it is said), Galileo realizes that a pendulum keeps regular time. He goes on to discover that the swing time is determined only by the pendulum's length, not by how widely it swings. His discovery leads eventually to the creation of the pendulum clock.

1582

Rate of fall

Galileo investigates how gravity makes falling objects speed up. By rolling balls down ramps to "dilute" gravity, he discovers that objects of different weights fall at the same rate—contrary to the widely accepted idea that heavier objects fall faster.

1589



Cannonball science

Galileo calculates the path of a ball in flight by separating its motion into two parts: a constant horizontal speed and, due to gravity, an accelerating downward speed. The result is a mathematical curve called a parabola.

1608

Inertia

Galileo's experiments on motion lead him to conclude that, contrary to ancient Greek ideas, a moving object has "inertia"—a tendency to remain in motion unless a force acts on it. This helps explain how Earth can rotate on its axis while orbiting the sun without causing violent winds.

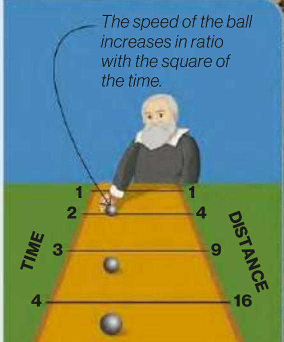
1608

Using math

Galileo searched for mathematical patterns in his experiments. For example, he found that to double the time of a pendulum's swing, he had to make the string four times longer. To triple it, the string had to be nine times longer. It was a pattern of square numbers. He found the same sequence of square numbers in the curving paths of cannonballs, and in an experiment in which he rolled balls down a ramp to test the speed of falling objects.

Testing speed

In his experiment, Galileo placed lute strings across the ramp so he'd hear the balls make a sound as they rolled. Then he adjusted the strings so the intervals between sounds were equal, and measured the distances between each string.



The speed of the ball increases in ratio with the square of the time.

Galileo's telescope

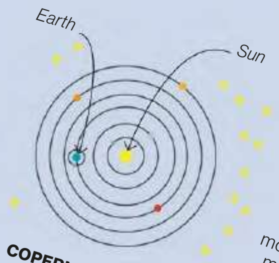
Hearing reports of the newly invented telescope, Galileo builds his own. He rapidly improves on the basic design through experiment, and then uses it to observe the night sky.

1609

Jupiter's moons

Using his telescope, Galileo discovers mountains on the moon, four moons orbiting Jupiter (now known as the Galilean moons), and later, sunspots. These observations provide hard evidence that the traditional idea of an Earth-centered universe, with all heavenly bodies circling Earth, is wrong.

1610



COPERNICAN MODEL

Under investigation

Galileo's support for the sun-centered model of the universe, proposed by Polish astronomer Nicolaus Copernicus, upsets the Catholic Church. They warn him not to "hold or defend" Copernican theory as they regard it as heresy (against the Bible's teachings).

1615–1616

Relativity principle

Using an example of a ship traveling smoothly at sea, Galileo writes that a traveler below deck would not know if they were moving or stationary, as the motion of objects around them would be identical in either case. Einstein later refines this idea in his theory of relativity.

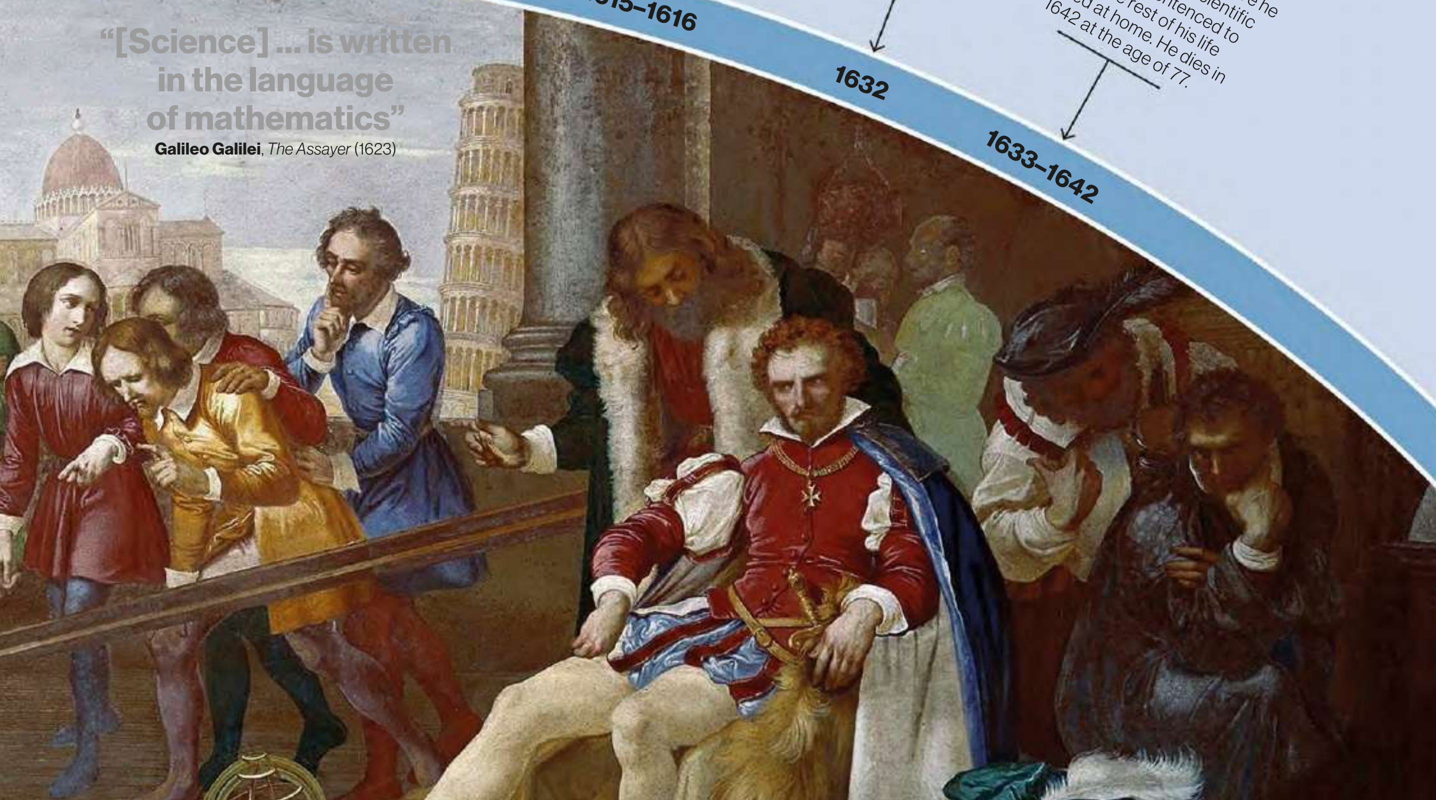
1632

Trial and death

After provocatively publishing a book supporting Copernican theory, Galileo is charged with heresy and forced to declare he has renounced his scientific beliefs. He is sentenced to spend the rest of his life confined at home. He dies in 1642 at the age of 77.

1633–1642

> "[Science] … is written in the language of mathematics"
>
> **Galileo Galilei**, *The Assayer* (1623)



Comets

Comets are giant lumps of ice and dust that swoop through the solar system, developing spectacular glowing tails as they approach the sun. In the past, people were alarmed by the way comets appeared without warning and thought they were bad omens. We now know that comets follow predictable orbits and come from distant clouds of icy rubble in the

c. 350 BCE

Comets as weather

Greek philosopher Aristotle writes about comets in his influential book *Meteorology*. He thinks they occur between Earth and the moon and are caused by volcanic gases rising to the top of the atmosphere and catching fire.

1066 CE

Halley's Comet

The first picture of Halley's Comet—one of the most famous comets—appears in the 230-ft- (70-m-) long Bayeux Tapestry, which depicts a battle in England. The comet continues to be observed at roughly 76-year intervals but is not named until the 1700s.

1577

Tycho's comet

Danish astronomer Tycho Brahe proves that comets are further away than the moon by comparing his observations of one with those of an astronomer in a different city. The absence of parallax (the apparent shift caused by a change in viewing angle) shows the comet is very distant.

1680

Newton's Comet

A bright comet with a spectacularly long tail approaches the sun and disappears, only to reappear a few days later. English mathematician Isaac Newton works out its orbit and finds that it follows a curved path called an ellipse.

1705

Halley's prediction

Newton's friend Edmond Halley uses Newton's law of gravity to plot the orbits of comets observed in the past. He discovers that comets seen in 1456, 1531, 1607, and 1682 have suspiciously similar orbits. He suggests they are a single comet and correctly predicts its return in 1758.

1811

A comet's tail

German astronomer Heinrich Olbers notices that the tails of comets always point away from the sun and don't necessarily trail behind the comet. He forms a theory that comet tails are shaped by "repulsive forces" from the sun and the comet.

1864

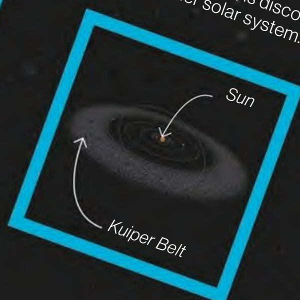
Comet elements

Italian astronomer Giovanni Donati analyzes the spectrum of light from a comet to work out which elements are present. His work leads to the discovery that comets contain the element carbon.

1943

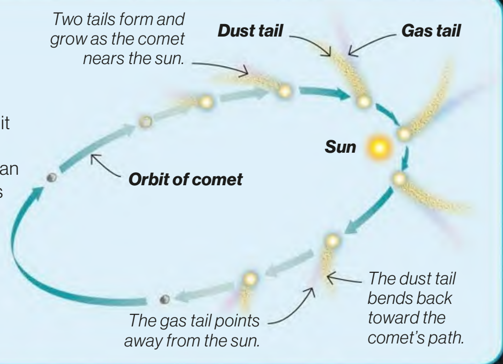
Belt of comets

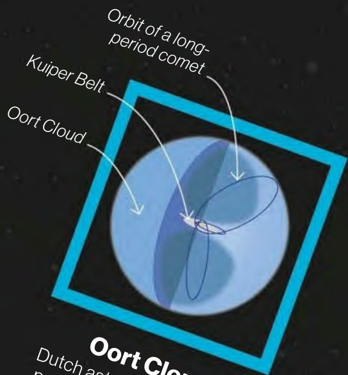
Irish astronomer Kenneth Edgeworth suggests that short-period comets come from a ring of icy debris beyond Neptune's orbit. His idea is confirmed 50 years later when the Kuiper Belt, containing hundreds of objects, is discovered in the outer solar system.



How comets work

Comets travel around the sun in long, thin, elliptical orbits that take longer to complete than most planetary orbits. Short-period comets complete an orbit around the sun in less than 200 years, but the orbits of long-period comets can take thousands or millions of years. As a comet approaches the sun, its icy surface starts to evaporate, releasing a bright cloud of gas and dust called a coma. This jets out from the comet's nucleus (center), along with two tails.





1950

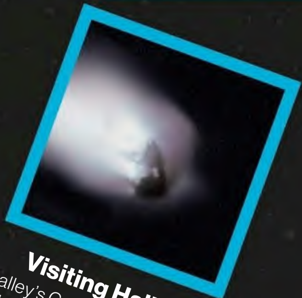
Oort Cloud

Dutch astronomer Jan Oort proposes that comets with the longest orbits, which last thousands or even millions of years, come from a vast, spherical cloud in the outermost reaches of the solar system.

1950

Dirty snowball

US astronomer Fred Whipple proposes the "dirty snowball" model of comets. According to this theory, comets contain ice that melts as they near the sun, releasing dust and gas that form a bright cloud and tail.



1986

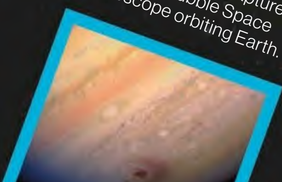
Visiting Halley

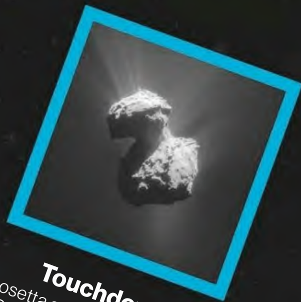
Halley's Comet is visited by a fleet of five spacecraft during its passage around the sun, helping confirm the dirty snowball model. The Giotto space probe flies within 373 miles (600 km) of the nucleus and takes pictures of jets of gas erupting from it.

1994

Comet crash

Comet Shoemaker-Levy 9 smashes into Jupiter after being torn into a string of fragments by the giant planet's gravity. Scars of the collision are captured by the Hubble Space Telescope orbiting Earth.





2014

Touchdown

The Rosetta spacecraft flies to comet 67P/Churyumov-Gerasimenko and releases a lander that touches down on the comet's surface. The lander attempts to drill into the ice to take a sample, but the comet's surface is too hard. Rosetta's sensors detect carbon compounds in the dust.

2017

Interstellar visitor

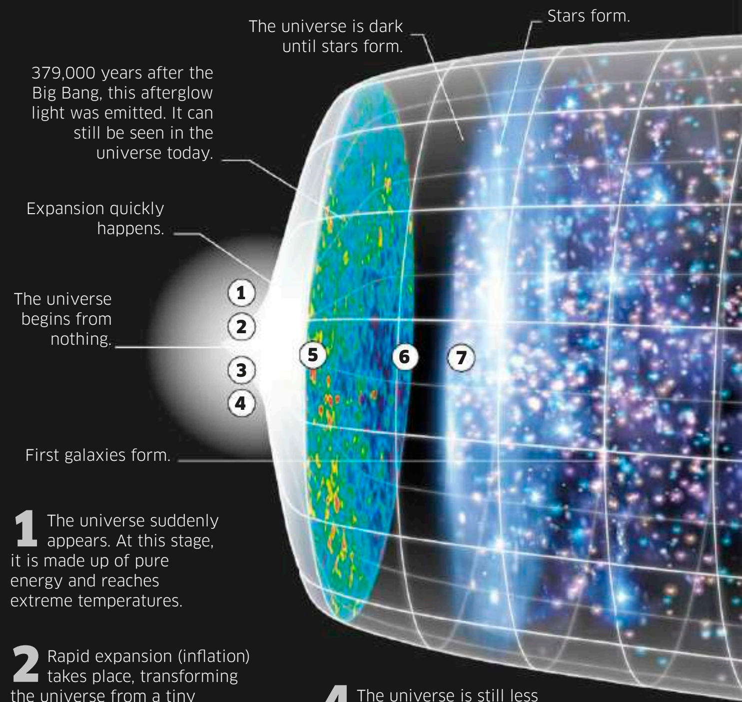
Astronomers discover 'Oumuamua, the first known object to visit our solar system from interstellar space. The cigar-shape body is probably from a

SPACE AND EARTH

All of space, matter, energy, and time make up the universe—a vast, ever-expanding creation that is so big it would take billions of years to cross it, even when traveling at the speed of light. Within the universe are clumps of matter called galaxies, and within those are planets like our own—Earth.

THE BIG BANG

The universe came into existence around 13.8 billion years ago in a cataclysmic explosion known as the Big Bang. Starting out as tinier than an atom, it rapidly expanded—forming stars, and clusters of stars called galaxies. A large part of this expansion happened incredibly quickly—it grew by a trillion kilometers in under a second.



1 The universe suddenly appears. At this stage, it is made up of pure energy and reaches extreme temperatures.

2 Rapid expansion (inflation) takes place, transforming the universe from a tiny mass smaller than a fraction of an atom into a gigantic space the size of a city.

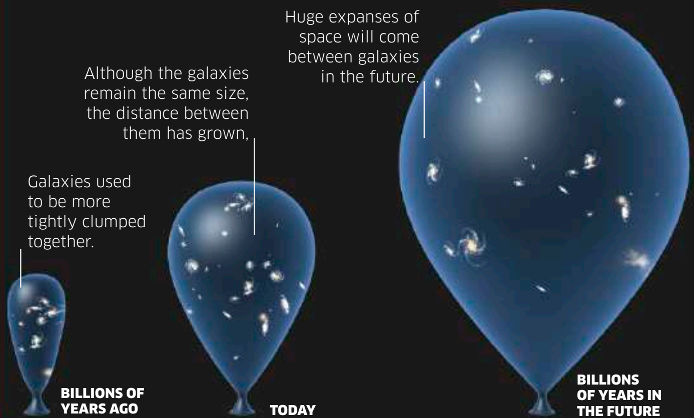
3 Matter is created from the universe's energy. This starts out as minuscule particles and antiparticles (the same mass as particles but with an opposite electric charge). Many of these converge and cancel each other out, but some matter remains.

4 The universe is still less than a second old when the first recognizable subatomic particles start to form. These are protons and neutrons—the particles that make up the nucleus of an atom.

5 Over the next 379,000 years, the universe slowly cools, until eventually atoms are able to form. This development changes the universe from a dense fog into an empty space punctuated by clouds of hydrogen and helium gas. Light can now pass through it.

THE EXPANSION OF SPACE

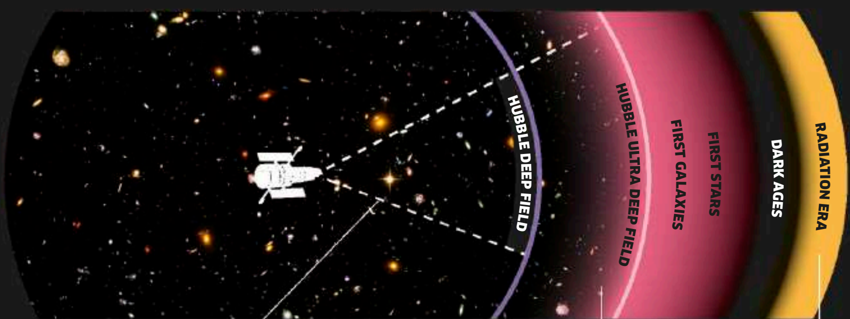
Astronomers on Earth can observe galaxies moving away from us, but in reality they are moving away from every other point in the universe as well. These galaxies are not moving into new space—all of space is expanding and pulling them away from each other. This effect can be imagined by thinking of the universe as a balloon. As the balloon inflates, the rubber stretches and individual points on it all move further away from each other.



THE OBSERVABLE UNIVERSE

When we look at distant objects in the night sky, we are actually seeing what they looked like millions, or even billions, of years ago, because that is how long the light from them has taken to reach us. All of the space we can see from Earth is known as the observable universe. Other parts lie beyond that, but are too far away for the light from them to have reached us yet. However, using a space-based observatory such as the Hubble Space Telescope, we can capture images of deep space and use them to decipher the universe's past.

Hubble imaging
The Hubble Space Telescope has been operating since 1990 and has captured thousands of images of the universe. Many of these have been compiled to create amazing views of the furthest (and therefore oldest) parts of the universe we can see. These are known as Deep Field images.



The first Hubble Deep Field observed one part of the night sky over 10 days. It revealed galaxies formed less than a billion years after the Big Bang.

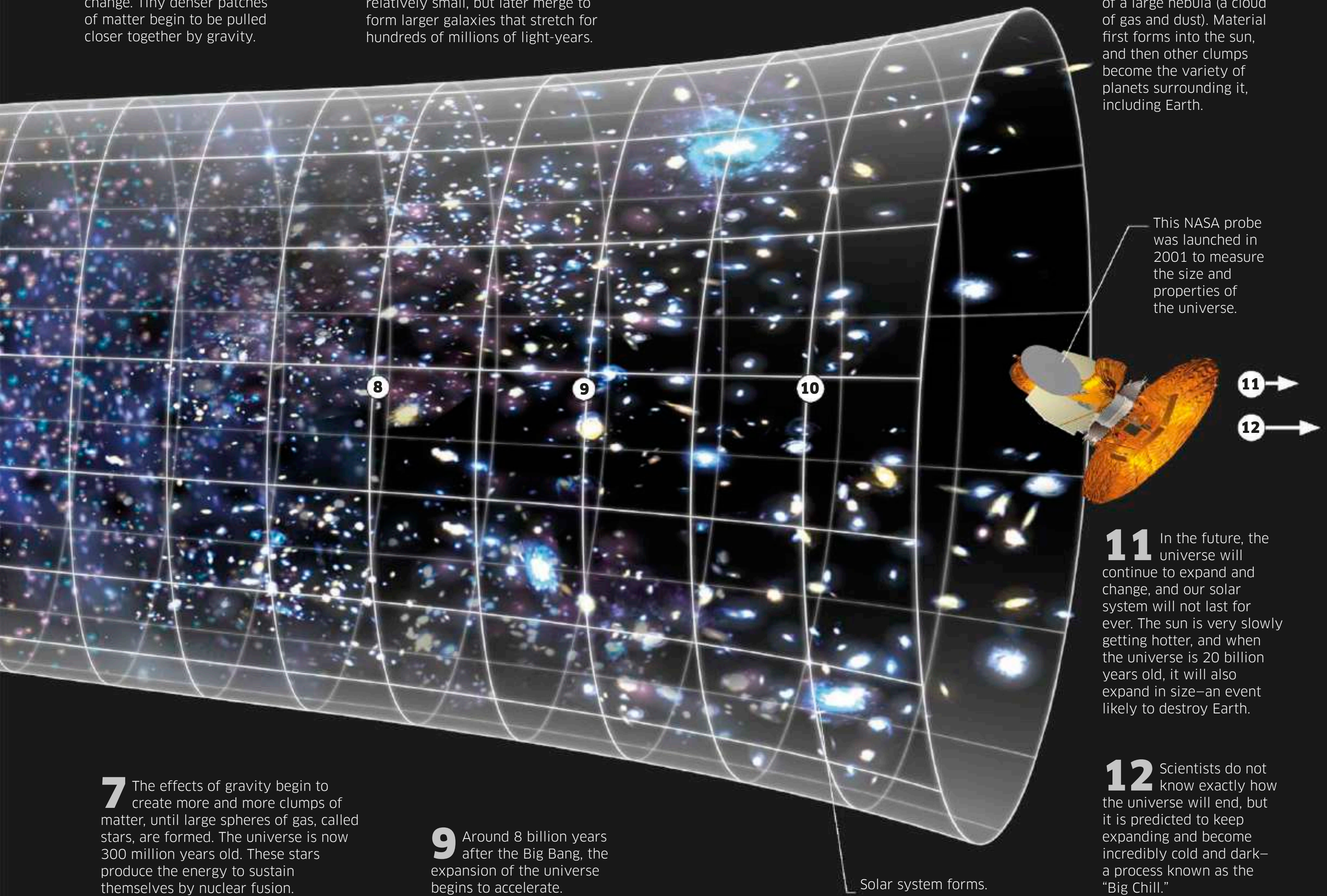
The later Hubble Ultra Deep Field image (above) shows even further into the past, picturing galaxies formed 13 million years ago, when the Universe was between 400 and 700 million years old.

There are regions of space further back in time that Hubble and other powerful space telescopes cannot see.

6 Just over half a million years after the Big Bang, the distribution of matter in the universe begins to change. Tiny denser patches of matter begin to be pulled closer together by gravity.

8 Stars form in groups within the universe's vast clouds of gas. The first groups become the first galaxies. Most of these are relatively small, but later merge to form larger galaxies that stretch for hundreds of millions of light-years.

10 Our solar system comes into being after 9 billion years, formed from the collapse of a large nebula (a cloud of gas and dust). Material first forms into the sun, and then other clumps become the variety of planets surrounding it, including Earth.



11 In the future, the universe will continue to expand and change, and our solar system will not last for ever. The sun is very slowly getting hotter, and when the universe is 20 billion years old, it will also expand in size—an event likely to destroy Earth.

7 The effects of gravity begin to create more and more clumps of matter, until large spheres of gas, called stars, are formed. The universe is now 300 million years old. These stars produce the energy to sustain themselves by nuclear fusion.

9 Around 8 billion years after the Big Bang, the expansion of the universe begins to accelerate.

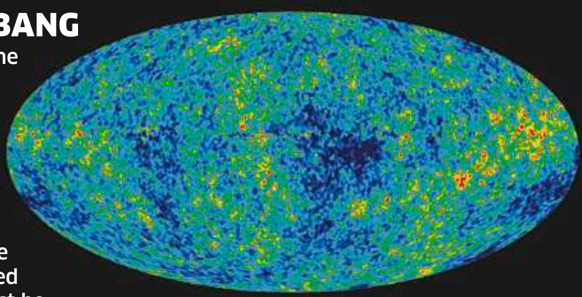
12 Scientists do not know exactly how the universe will end, but it is predicted to keep expanding and become incredibly cold and dark—a process known as the "Big Chill."

DISCOVERING THE BIG BANG

Scientists did not always believe in the theory of an expanding universe and the Big Bang. However, during the 20th century, several discoveries were made which supported this idea. In 1929, American astronomer Edwin Hubble observed that the light coming from distant galaxies appeared redder than it should be. He attributed this to a phenomenon called redshift, suggesting that galaxies must be moving away from us. Another piece of evidence was the discovery of cosmic background radiation—microwaves coming from all directions in space that could only be explained as an after effect of the Big Bang.

Redshift
When an object (a distant galaxy) is moving away from the observer (us), its wavelengths get longer. The light it produces therefore shifts into the red end of the light spectrum. More distant galaxies have greater redshift—supporting the theory that the universe is expanding.

Blueshift
A few nearby galaxies are actually moving toward us. Their wavelengths will be shorter, shifting the light they produce to the blue end of the spectrum.



Cosmic background radiation
This image, captured by NASA's Wilkinson Microwave Anisotropy Probe, shows a false color depiction of the background radiation that fills the entire universe. This is the remains of the intense burst of energy that was released by the Big Bang.

Most of a **galaxy's mass** is made up of **dark matter**.

It is estimated that there are **2 trillion galaxies** in the parts of **the universe** we can see.

Galaxies

Unimaginably huge collections of gas, dust, stars, and even planets, galaxies come in many shapes and sizes. Some are spirals, such as our own galaxy, others are like squashed balls, and some have no shape at all.

When you look up at the sky at night, every star you see is part of our galaxy, the Milky Way. This is part of what we call the Local Group, which contains about 50 galaxies. Beyond it are countless more galaxies that stretch out as far as telescopes can see. The smallest galaxies in the universe have a few million stars in them, while the largest have trillions. The Milky Way lies somewhere in the middle, with between 100 billion and 1 trillion stars in it. The force of gravity holds the stars in a galaxy together, and they travel slowly around the center. A supermassive black hole hides at the heart of most galaxies.

Astronomers have identified four types of galaxies: spiral, barred spiral, elliptical, and irregular. Spiral galaxies are flat spinning disks with a bulge in the center, while barred spiral galaxies have a longer, thinner line of stars at their center, which looks like a bar. Elliptical galaxies are an ellipsoid, or the shape of a squashed sphere—these are the largest galaxies. Then there are irregular galaxies, which have no regular shape.

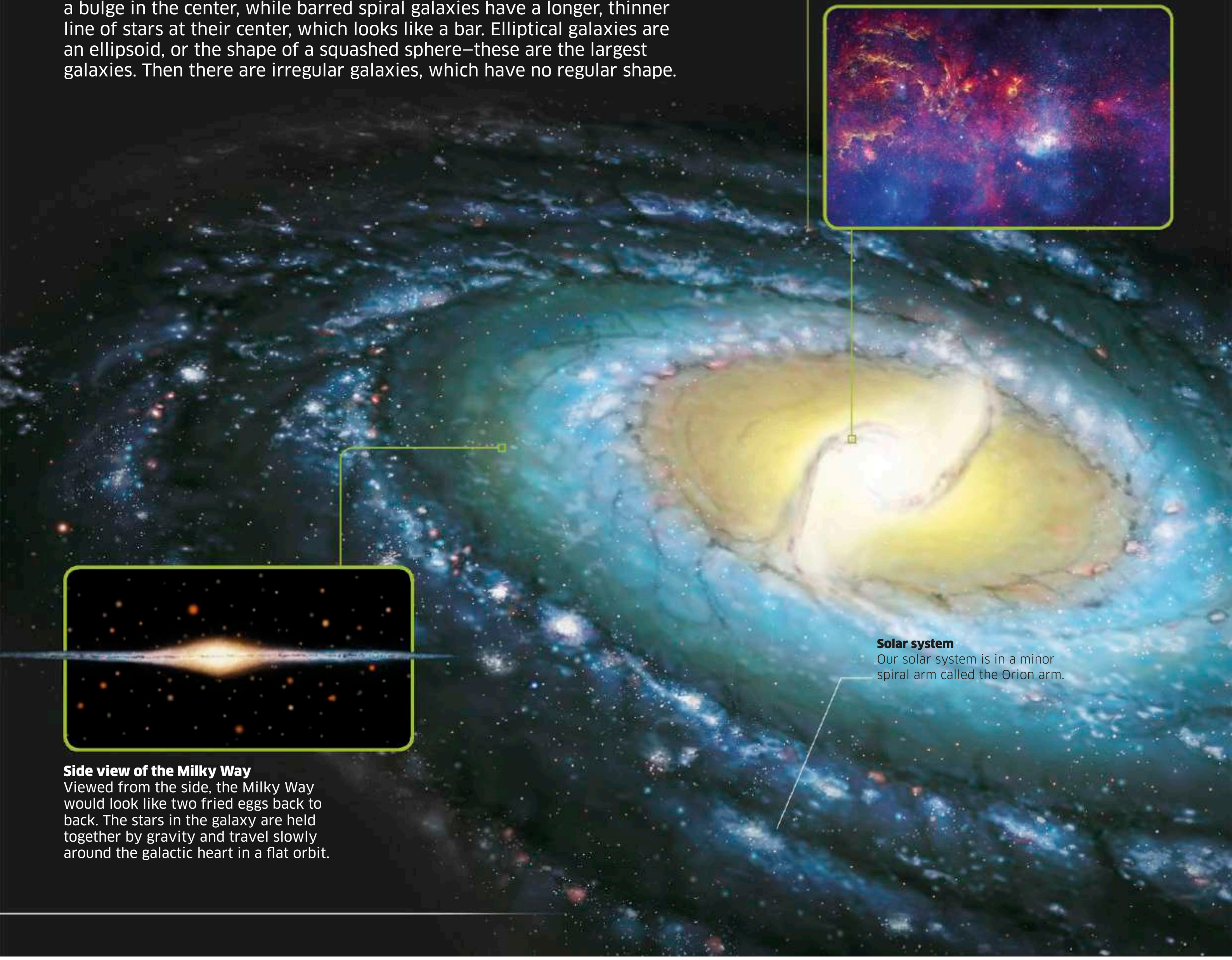
MILKY WAY

Type: *Barred spiral*

Diameter: *100,000 light years*

Our own galaxy, the Milky Way, is thought to be a barred spiral shape, but we cannot see its shape clearly from Earth because we are part of it. From our solar system, it appears as a pale streak in the sky with a central bulge of stars. From above, it would look like a giant whirlpool that takes 200 million years to rotate.

Galactic core
Infrared and X-ray images reveal intense activity near the galactic core. The galaxy's center is located within the bright white region. Hundreds of thousands of stars that cannot be seen in visible light swirl around it, heating dramatic clouds of gas and dust.



Side view of the Milky Way
Viewed from the side, the Milky Way would look like two fried eggs back to back. The stars in the galaxy are held together by gravity and travel slowly around the galactic heart in a flat orbit.

Solar system
Our solar system is in a minor spiral arm called the Orion arm.

ANDROMEDA
Type: *Spiral*
Distance: *2,450,000 light years*

Our closest large galaxy, Andromeda—a central hub surrounded by a flat, rotating disc of stars, gas, and dust—can sometimes be seen from Earth with the naked eye. In 4.5 billion years, Andromeda is expected to collide with the Milky Way, forming one huge elliptical galaxy.

MESSIER 87
Type: *Elliptical*
Distance: *53 million light years*

M87, also known as Virgo A, is one of the largest galaxies in our part of the universe. The galaxy is giving out a powerful jet of material from the supermassive black hole at its center, energetic enough to accelerate particles to nearly the speed of light.

SMALL MAGELLANIC CLOUD
Type: *Dwarf (irregular)*
Distance: *197,000 light years*

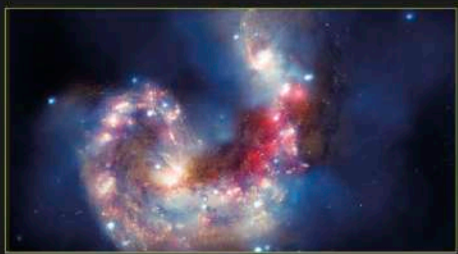
The dwarf galaxy SMC stretches 7,000 light years across. Like its neighbor the Large Magellanic Cloud (LMC), its shape has been distorted by the gravity of our own galaxy. Third closest to the Milky Way, it is known as a satellite galaxy because it orbits our own.

CARTWHEEL GALAXY
Type: *Ring (irregular)*
Distance: *500 million light years*

The Cartwheel Galaxy started out as a spiral. However, 200 million years ago it collided with a smaller galaxy, causing a powerful shock throughout the galaxy, which tossed lots of the gas and dust to the outside, creating its unusual shape.

ANTENNAE GALAXIES
Type: *Merging spirals*
Distance: *45 million–65 million light years*

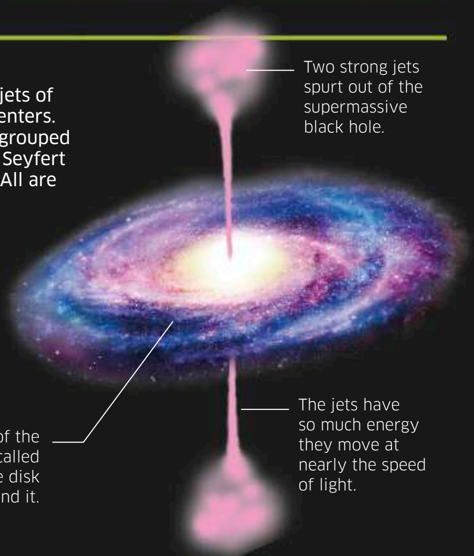
Around 1.2 billion years ago, the Antennae Galaxies were two separate galaxies: one barred spiral and one spiral. They started to merge a few hundred million years ago, when the antennae formed and are expected to become one galaxy in about 400 million years.



WHIRLPOOL GALAXY
Type: *Colliding spiral and dwarf*
Distance: *23 million light years*

About 300 million years ago, the spiral Whirlpool Galaxy was struck by a dwarf galaxy, which now appears to dangle from one of its spiral arms. The collision stirred up gas clouds, triggering a burst of star formation, which can be seen from Earth with a small telescope.

Active galaxies
Some galaxies send out bright jets of light and particles from their centers. These "active" galaxies can be grouped into four types: radio galaxies, Seyfert galaxies, quasars, and blazars. All are thought to have supermassive black holes at their core, known as the active galactic nuclei, which churn out the jets of material.



Two strong jets spurt out of the supermassive black hole.

The jets have so much energy they move at nearly the speed of light.

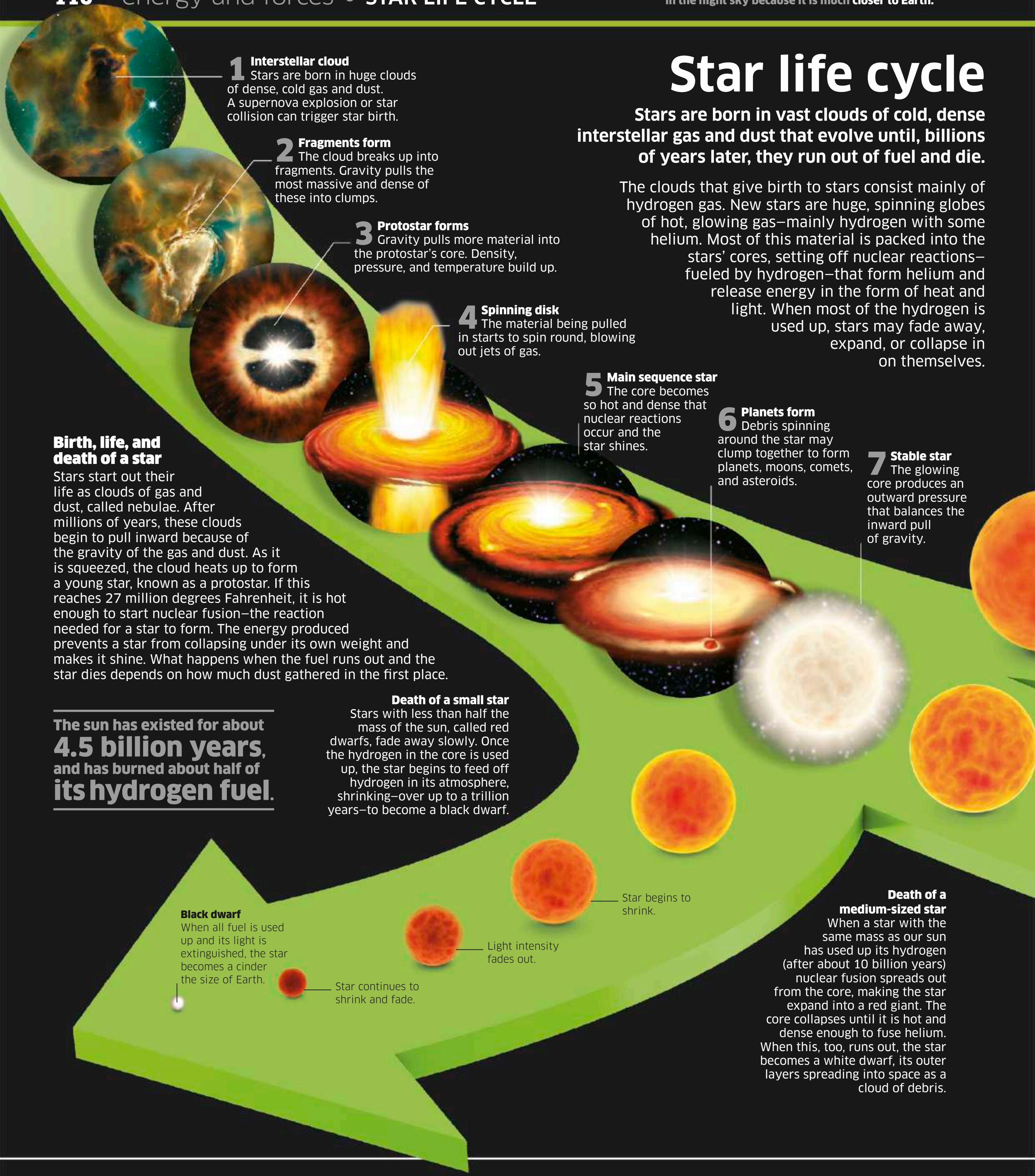
The material near the center of the supermassive black hole is called the accretion disk. An opaque disk of dust and gas gathers around it.

Our sun is a star—it only seems bigger than other stars in the night sky because it is much closer to Earth.

Star life cycle

Stars are born in vast clouds of cold, dense interstellar gas and dust that evolve until, billions of years later, they run out of fuel and die.

The clouds that give birth to stars consist mainly of hydrogen gas. New stars are huge, spinning globes of hot, glowing gas—mainly hydrogen with some helium. Most of this material is packed into the stars' cores, setting off nuclear reactions—fueled by hydrogen—that form helium and release energy in the form of heat and light. When most of the hydrogen is used up, stars may fade away, expand, or collapse in on themselves.



Birth, life, and death of a star

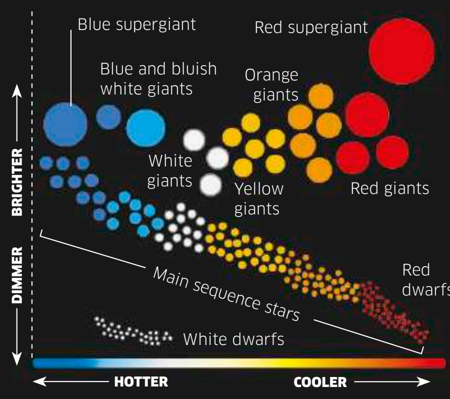
Stars start out their life as clouds of gas and dust, called nebulae. After millions of years, these clouds begin to pull inward because of the gravity of the gas and dust. As it is squeezed, the cloud heats up to form a young star, known as a protostar. If this reaches 27 million degrees Fahrenheit, it is hot enough to start nuclear fusion—the reaction needed for a star to form. The energy produced prevents a star from collapsing under its own weight and makes it shine. What happens when the fuel runs out and the star dies depends on how much dust gathered in the first place.

The sun has existed for about 4.5 billion years, and has burned about half of its hydrogen fuel.

If you sorted all the stars into piles, the biggest pile, by far, would be red dwarfs—stars with less than half of the sun's mass.

Star types

The Hertzsprung–Russell diagram is a graph that astronomers use to classify stars. It plots the brightness of stars against their temperature to reveal distinct groups of stars, such as red giants (dying stars) and main sequence stars (ordinary stars). Astronomers also classify stars by color, which relates to temperature. Red is the coolest color, seen in stars cooler than 6,000°F (3,500°C). Stars such as our sun are yellowish white and average around 10,000°F (6,000°C). The hottest stars are blue, with surface temperatures above 21,000°F (12,000°C).



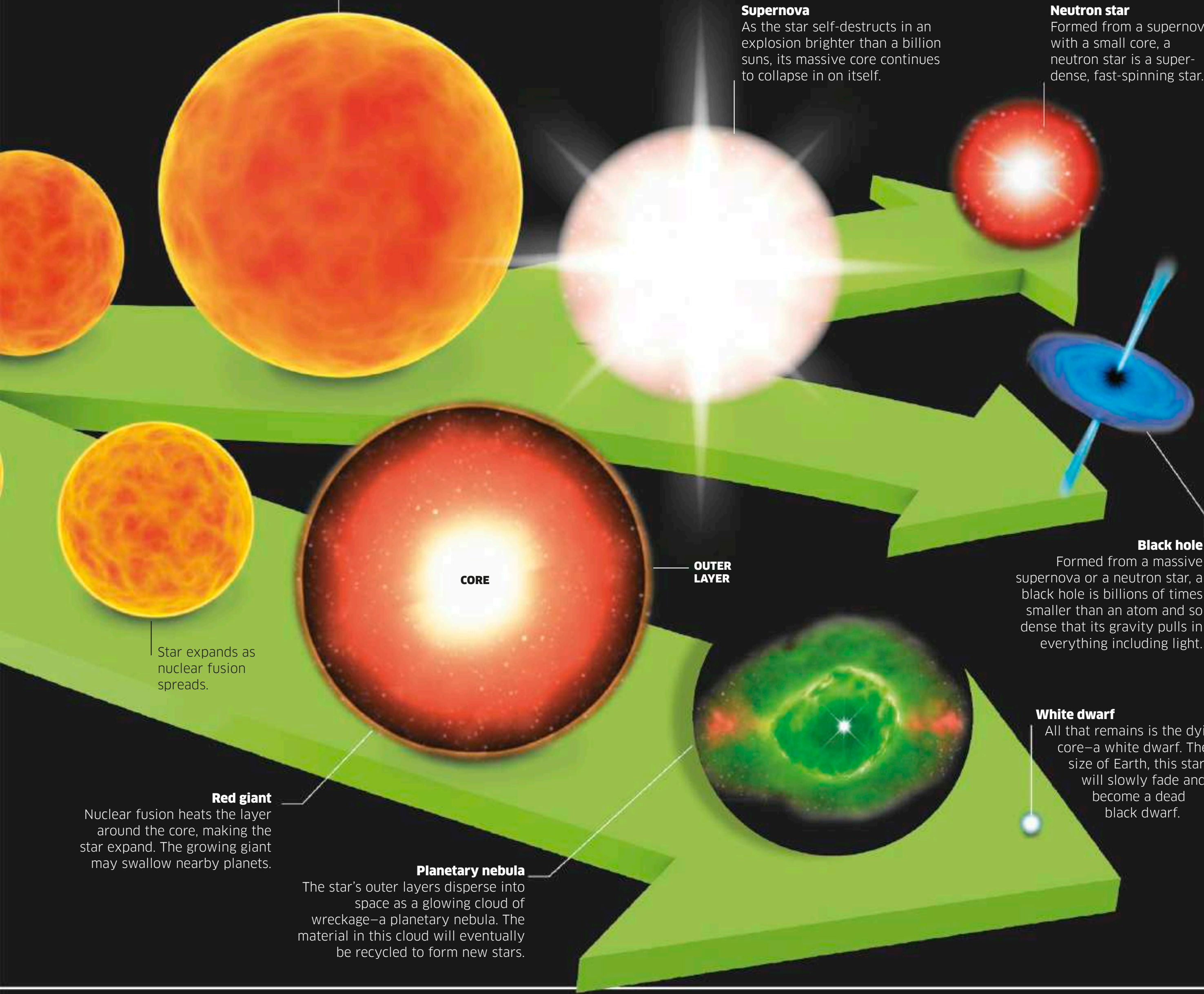
Death of a massive star

Stars more than eight times the mass of our sun will be hot enough to become supergiants. The heat and pressure in the core become so intense that nuclear fusion can fuse helium and larger atoms to create elements such as carbon or oxygen. As this happens, the stars swell into supergiants, which end their lives in dramatic explosions called supernovae. Smaller supergiants become neutron stars, but larger ones become black holes.

Red supergiant
Nuclear fusion carries on inside the core of the supergiant, forming heavy elements until the core turns into iron and the star collapses.

Supernova
As the star self-destructs in an explosion brighter than a billion suns, its massive core continues to collapse in on itself.

Neutron star
Formed from a supernova with a small core, a neutron star is a super-dense, fast-spinning star.



Black hole
Formed from a massive supernova or a neutron star, a black hole is billions of times smaller than an atom and so dense that its gravity pulls in everything including light.

Star expands as nuclear fusion spreads.

Red giant
Nuclear fusion heats the layer around the core, making the star expand. The growing giant may swallow nearby planets.

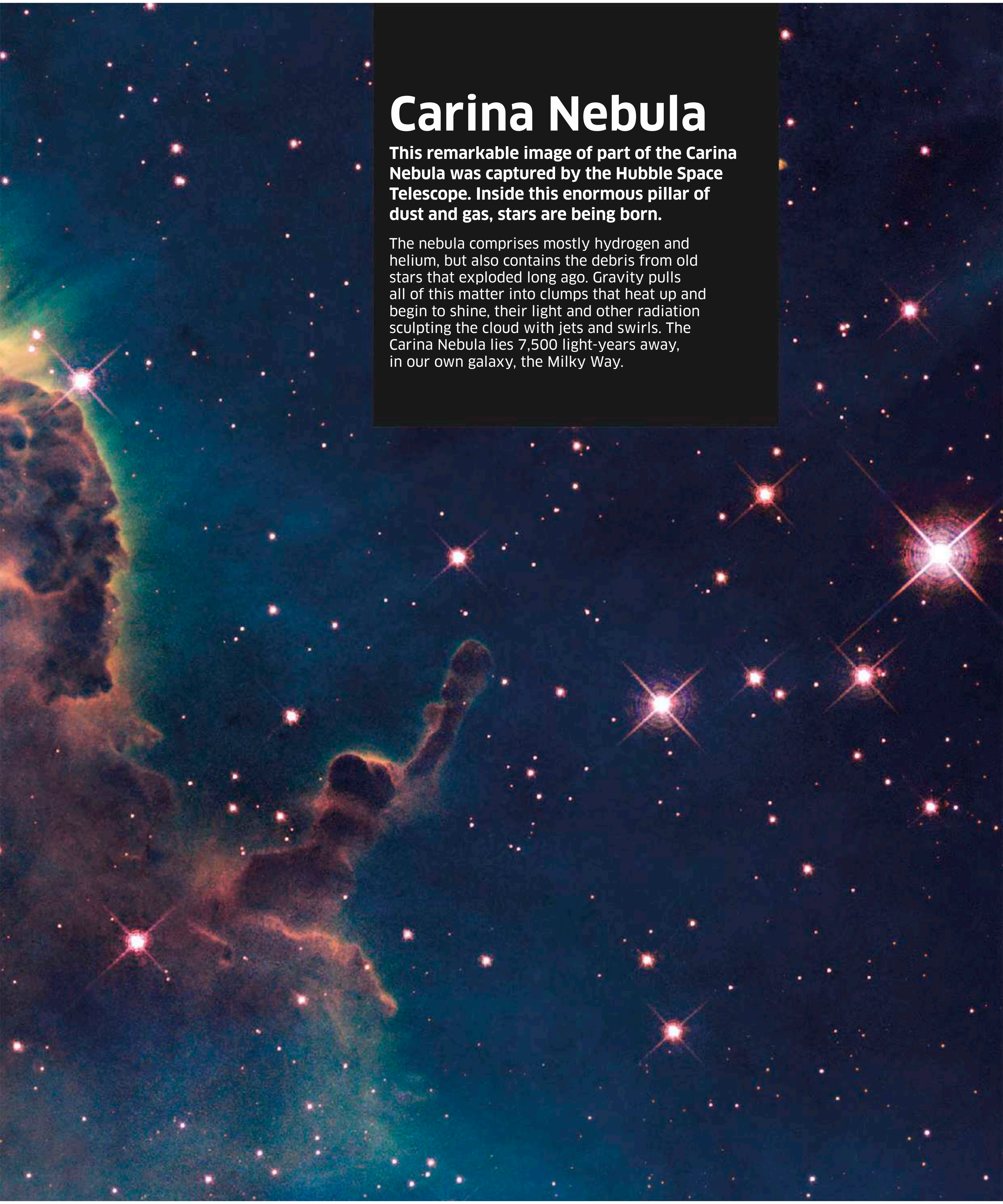
Planetary nebula
The star's outer layers disperse into space as a glowing cloud of wreckage—a planetary nebula. The material in this cloud will eventually be recycled to form new stars.

White dwarf
All that remains is the dying core—a white dwarf. The size of Earth, this star will slowly fade and become a dead black dwarf.

Carina Nebula

This remarkable image of part of the Carina Nebula was captured by the Hubble Space Telescope. Inside this enormous pillar of dust and gas, stars are being born.

The nebula comprises mostly hydrogen and helium, but also contains the debris from old stars that exploded long ago. Gravity pulls all of this matter into clumps that heat up and begin to shine, their light and other radiation sculpting the cloud with jets and swirls. The Carina Nebula lies 7,500 light-years away, in our own galaxy, the Milky Way.



Earth's rotation is getting slower by 17 milliseconds every 100 years.

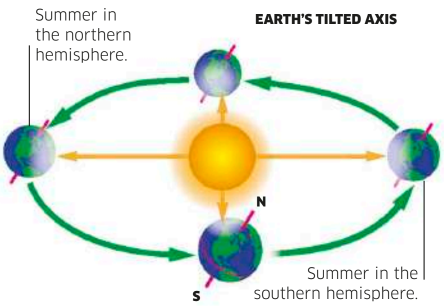
Earth and Moon

Our home, Earth, is about 4.5 billion years old. With a diameter of just over 7,500 miles (12,000 km), it orbits the sun every 365.3 days and spins on its axis once every 23.9 hours.

Of all the planets in the universe, ours is the only place life is known to exist. Earth is one of the solar system's four rocky planets, and the third from the sun. Its atmosphere, surface water, and magnetic field—which protects us from solar radiation—make Earth the perfect place to live.

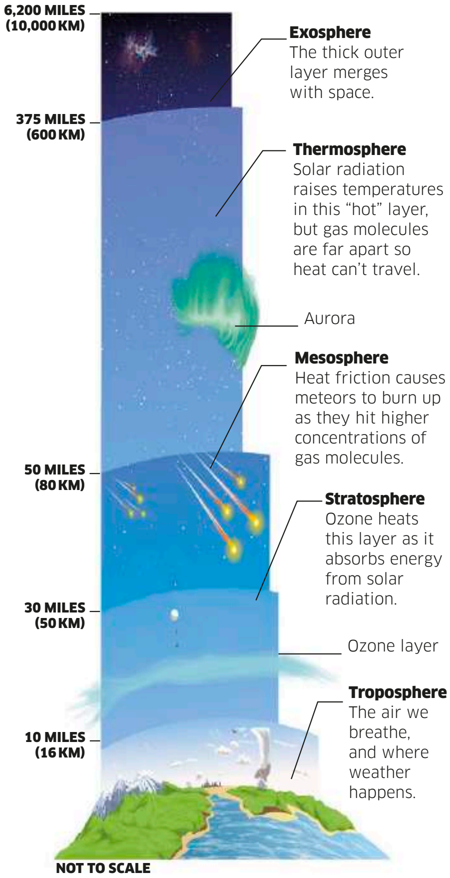
The seasons

As Earth orbits around the sun, it also rotates around its axis—an imaginary north–south line. This axis is tilted by 23.4º compared to Earth's orbit, so that one part of the planet is always closer to or farther away from the sun, resulting in the seasons.



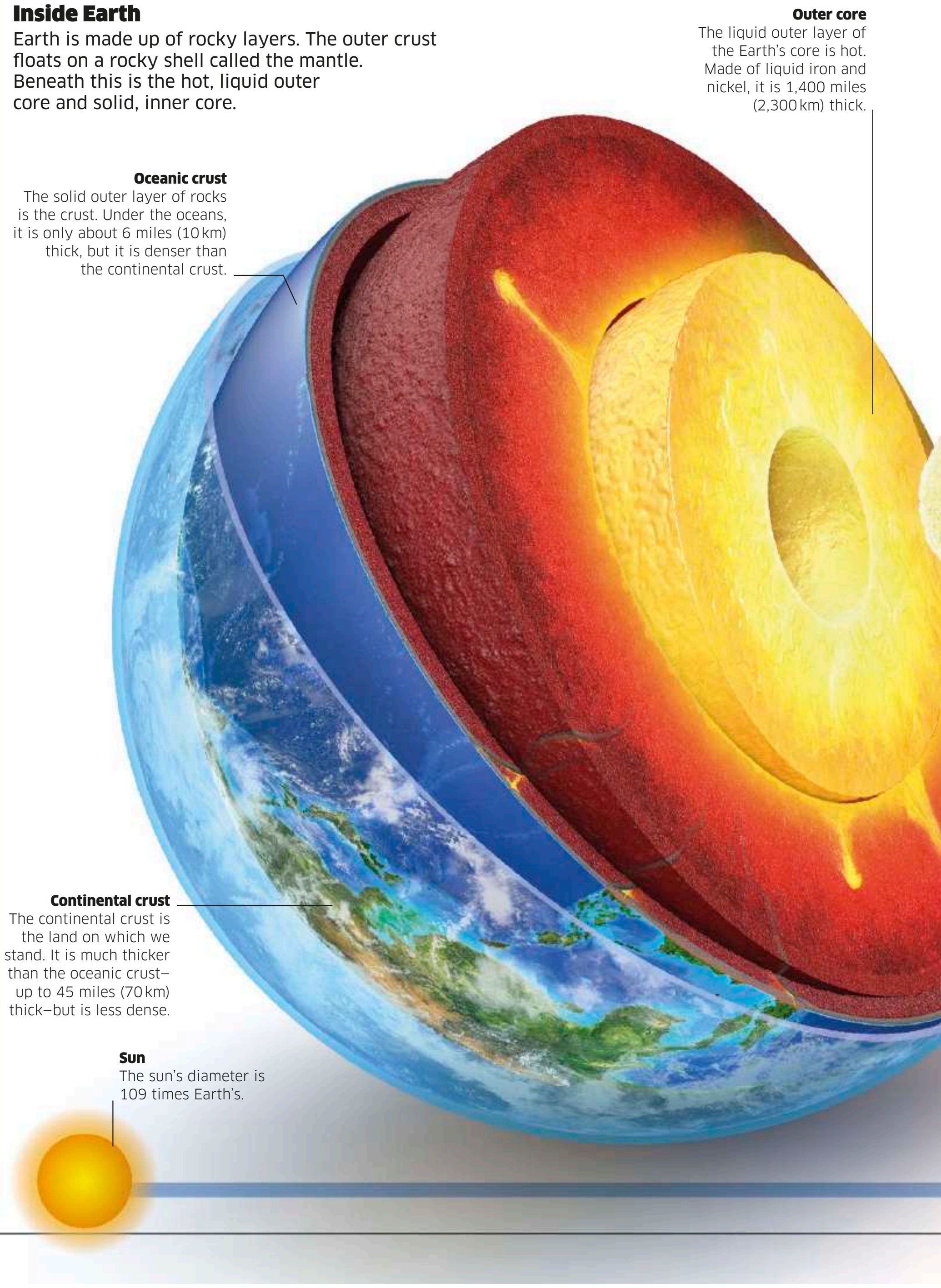
Atmosphere

Earth's atmosphere is made up of a mix of gases—78 percent nitrogen, 21 percent oxygen, and a small amount of others, such as carbon dioxide and argon. These gases trap heat on the planet and let us breathe. The atmosphere has five distinct layers.



Inside Earth

Earth is made up of rocky layers. The outer crust floats on a rocky shell called the mantle. Beneath this is the hot, liquid outer core and solid, inner core.

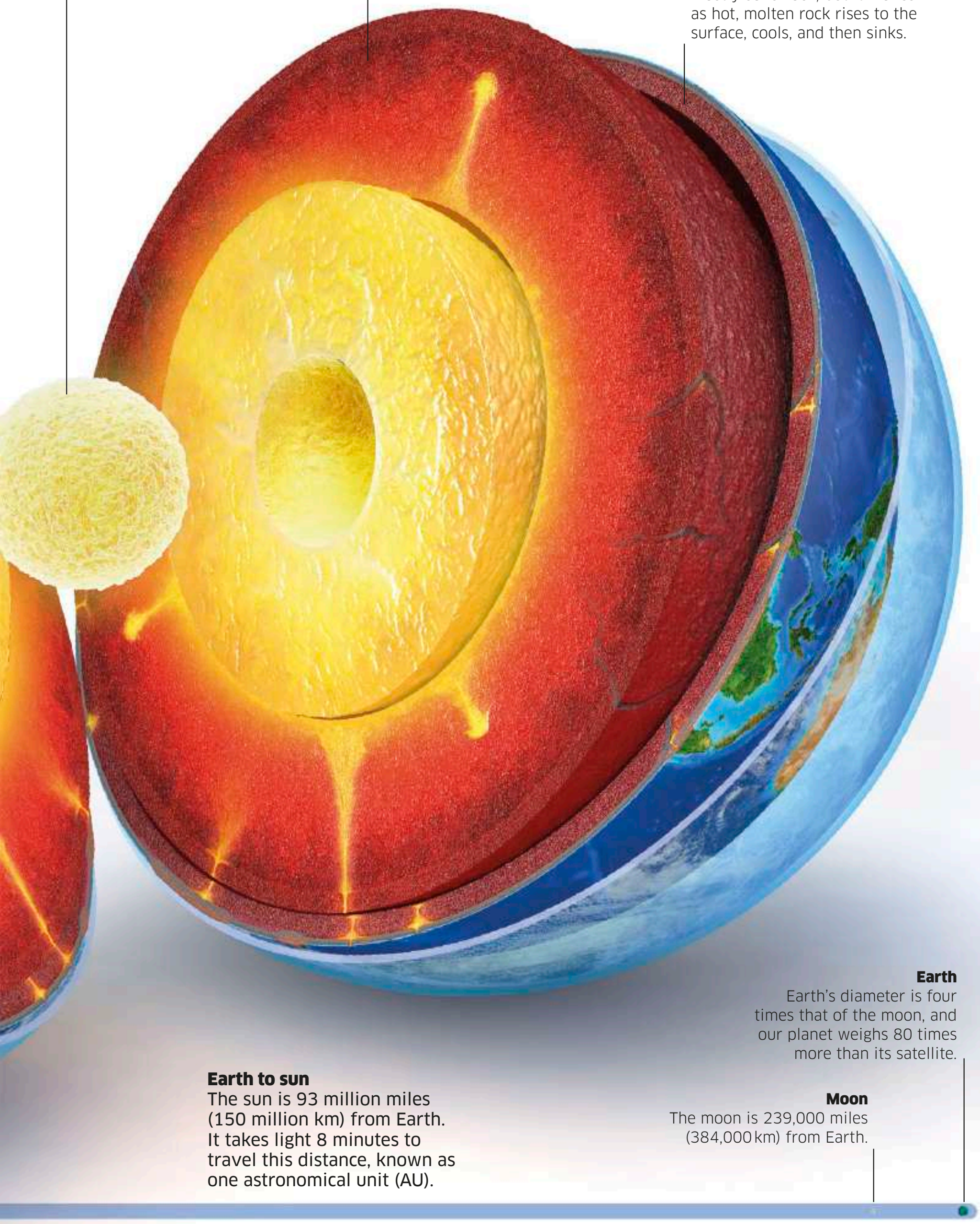


The moon
Orbiting Earth every 27 days, the moon is a familiar sight in the night sky. The same side of the moon always faces Earth. The dark side of the moon can only be seen from spacecraft.

Inner core
The iron inner core is just over two-thirds of the size of the moon and as hot as the surface of the sun. It is solid because of the immense pressure on it.

Lower mantle
The lower layer of the mantle contains more than half the planet's volume and extends 1,800 miles (2,900 km) below the surface. It is hot and dense.

Upper mantle
The layer extending 255 miles (410 km) below the crust is mostly solid rock, but it moves as hot, molten rock rises to the surface, cools, and then sinks.



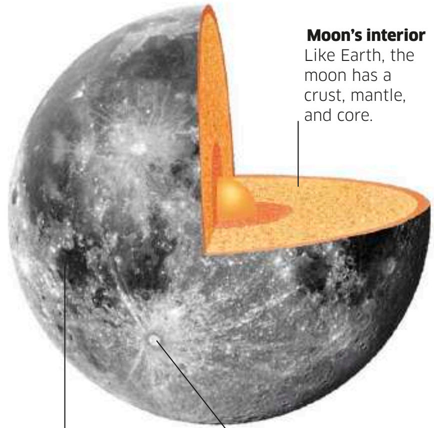
Earth
Earth's diameter is four times that of the moon, and our planet weighs 80 times more than its satellite.

Moon
The moon is 239,000 miles (384,000 km) from Earth.

Earth to sun
The sun is 93 million miles (150 million km) from Earth. It takes light 8 minutes to travel this distance, known as one astronomical unit (AU).

Moon

Our only natural satellite, the moon is almost as old as Earth. It is thought it was made when a flying object the size of Mars crashed into our planet, knocking lots of rock into Earth's orbit. This rock eventually clumped together to form our moon. It is the moon's gravitational pull that is responsible for tides.



Moon's interior
Like Earth, the moon has a crust, mantle, and core.

Lunar maria
Dark, flat areas known as maria, or seas, are in fact huge plains of solidified lava.

Lunar craters
Craters, formed by asteroid impacts 3.5 billion years ago, pockmark the moon.

Lunar cycle
The moon doesn't produce its own light. The sun illuminates exactly half of the moon, and the amount of the illuminated side we see depends upon where the moon is in its orbit around Earth. This gives rise to the phenomenon known as the phases of the moon.