

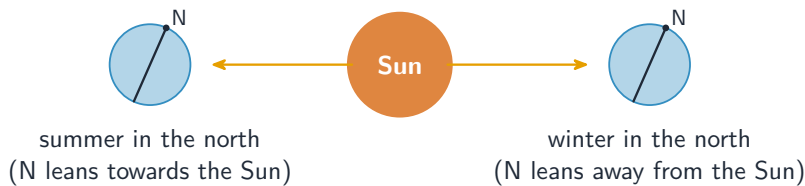
Space physics

IGCSE Physics

The Earth, the Sun and the Moon

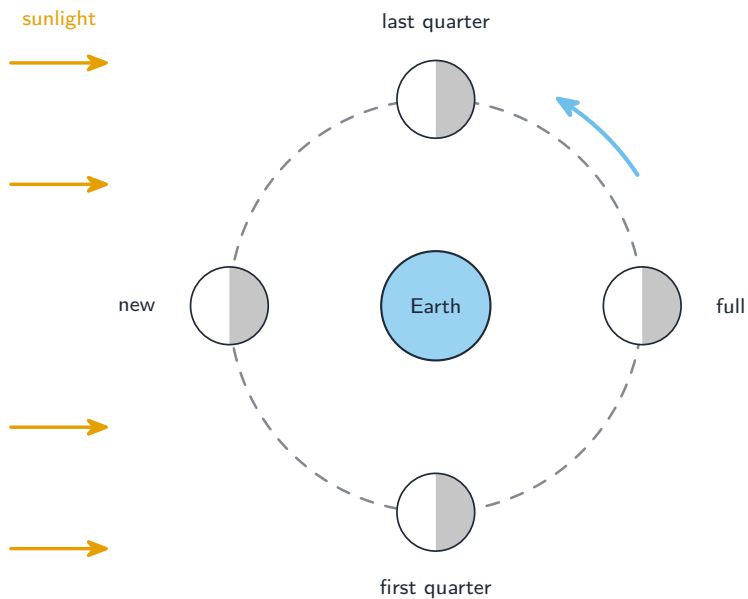
The Earth spins (**rotates**) on its **axis** once in about 24 hours. The axis is **tilted** (not straight up). This spin gives us day and night, and makes the **Sun** appear to move across the sky each day.

The Earth also moves around the Sun in an **orbit** , once in about 365 days (one year). Because the axis is tilted, different parts of the Earth lean towards the Sun at different times of the year. This gives the **seasons** : it is summer in the half of the Earth that leans towards the Sun.



The axis keeps the same tilt all year, so each hemisphere leans toward the Sun for one half of the orbit and away for the other

The **Moon** orbits the Earth once in about one month. As it goes round, we see different amounts of its lit side, which gives the **phases** of the Moon (new moon, half moon, full moon).



The Moon's lit half always faces the Sun, so as it orbits we see different amounts of it: a new moon between us and the Sun, a full moon opposite the Sun, and half moons in between

So, from shortest to longest: one day (Earth's spin) < one month (Moon's orbit) < one year (Earth's orbit).



The full Moon, Earth's natural satellite

Orbital speed

For an object going round a circle, the distance for one full orbit is the **circumference** $2\pi r$, where r is the radius of the orbit. The **orbital speed** is this distance divided by the **period** T (the time for one orbit):

$$v = \frac{2\pi r}{T}$$

The same equation works for planets, moons and satellites.

Worked example. A space station orbits the Earth at a radius of $r = 7000$ km and takes $T = 5800$ s for one orbit. Find its orbital speed.

First convert the radius to metres: $7000 \text{ km} = 7.0 \times 10^6 \text{ m}$. Then

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 7.0 \times 10^6}{5800} \approx 7600 \text{ m/s}$$



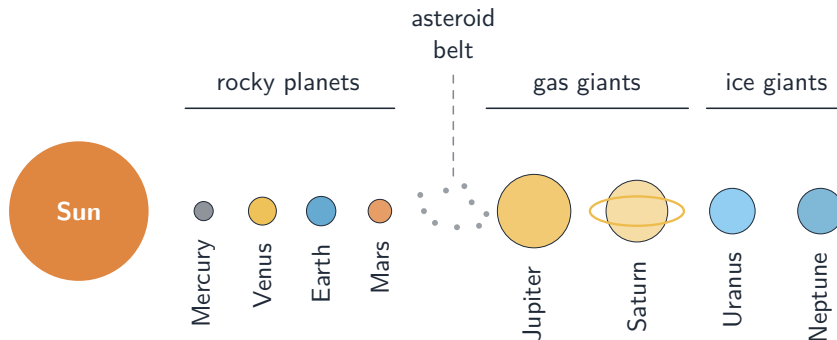
The ISS in orbit: orbital speed is the speed that keeps a satellite in free-fall circular motion

The Solar System

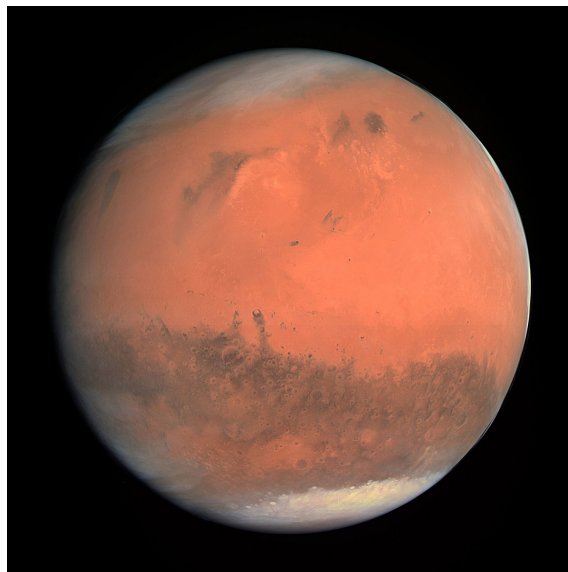
The **Solar System** has one star, the Sun, at its centre. Around it move the eight **planets**. In order from the Sun they are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

- The four planets nearest the Sun are small and **rocky**.

- The four planets furthest from the Sun are large and **gaseous** in the syllabus comparison: they have deep atmospheres of gas rather than an Earth-like solid surface.
- The two nearer giants, Jupiter and Saturn, are **gas giants**. The two outer giants, Uranus and Neptune, are **ice giants**: their composition differs from that of Jupiter and Saturn. The name does not mean that their interiors are solid frozen ice.



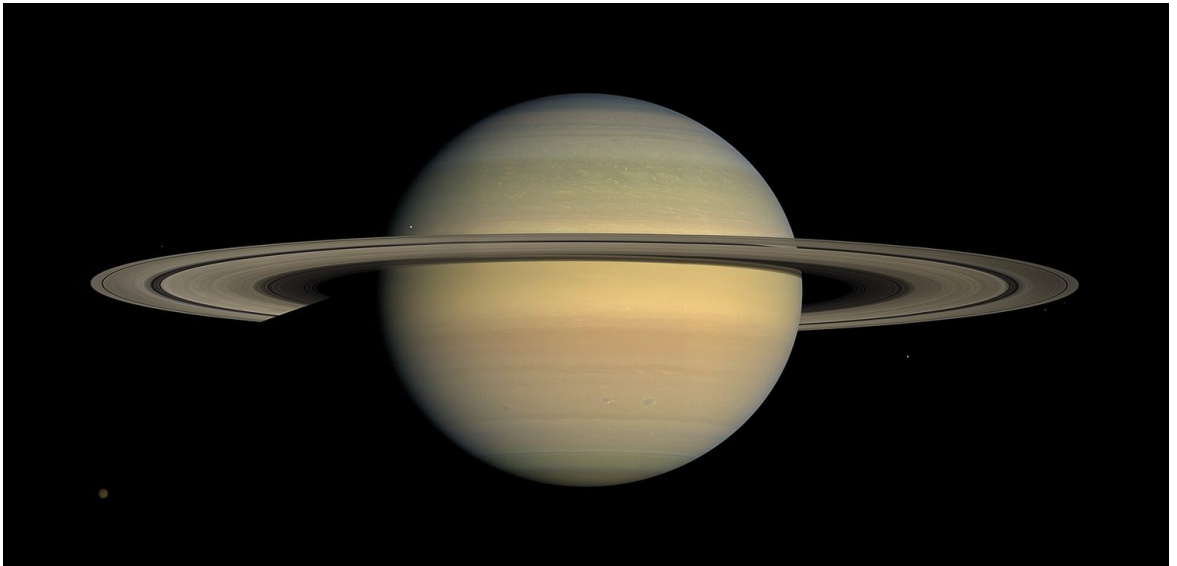
The Sun and its eight planets in order: four small rocky planets, then the asteroid belt, then four large gaseous planets – the gas giants Jupiter and Saturn and the ice giants Uranus and Neptune (not to scale)



Mars, the red planet, one of the rocky inner planets



Jupiter, the largest planet, with its swirling bands of gas



Saturn and its rings, photographed by the Cassini spacecraft

The Solar System also contains:

- minor planets, such as **dwarf planets** like Pluto, and **asteroids** (most lie in the asteroid belt between Mars and Jupiter);
- moons (natural **satellites**) that orbit the planets;
- **comets** and other small bodies.

Worked classification. The Sun is a star. Mars and Jupiter are planets. Pluto is a dwarf planet, so it is not one of the eight named planets. An asteroid or a comet orbits the Sun; the Moon is Earth's natural satellite and orbits Earth while Earth orbits the Sun.

■ Orbits and gravity

The Sun holds most of the mass of the Solar System. Its **gravity** (gravitational pull) reaches out and keeps the planets in their orbits. This force is the gravitational attraction of the Sun.

The **gravitational field strength** tells you how strong gravity is:

- at the surface of a planet it depends on both the mass and the radius of the planet;
- around a planet it gets weaker as you move further away.

In the same way, the Sun's gravity gets weaker further out, so the outer planets move more slowly (smaller orbital speed) than the inner ones.

■ Planetary data

Exam questions often give a table like this one and ask you to read a pattern from it.

Planet	Distance from Sun / million km	Orbital period	Density / g/cm^3	Temperature / $^{\circ}\text{C}$	Surface g / N/kg
Mercury	58	88 days	5.4	170	3.7
Venus	108	225 days	5.2	460	8.9
Earth	150	365 days	5.5	15	9.8
Mars	228	687 days	3.9	-60	3.7
Jupiter	779	11.9 years	1.3	-110	23
Saturn	1430	29.5 years	0.7	-140	9.0
Uranus	2870	84 years	1.3	-195	8.7
Neptune	4500	165 years	1.6	-200	11

For the giant planets, temperature values refer to atmospheric levels, not a solid surface.

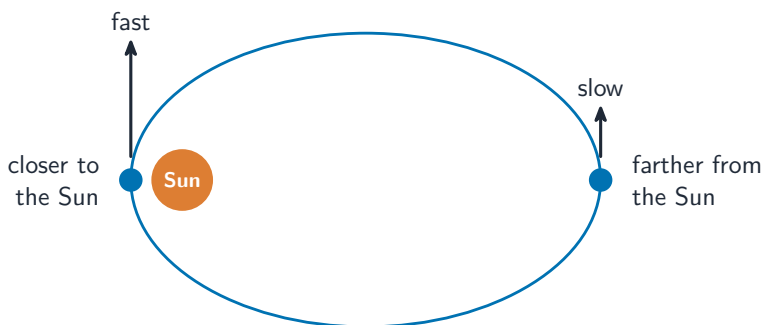
Patterns to notice: the further a planet is from the Sun, the longer its orbital period. The outer planets are colder, but temperature does not fall for every successive planet: Venus is hotter than Mercury. The four inner planets are dense (rock and metal), while the four outer planets have low densities (gas and ice). The gravitational field strength at the surface depends on the planet's mass and size, not on its distance from the Sun.

Worked interpretation. Mercury has density 5.4 g/cm^3 and Jupiter has density 1.3 g/cm^3 . These values support the inner/outer density comparison. But a claim that every more distant planet is colder fails: Venus is farther from the Sun than

Mercury (108 versus 58 million km) yet has a higher listed temperature (460°C versus 170°C). Venus's thick atmosphere traps heat. Use the data to support a pattern, then state exceptions; distance alone does not determine temperature.

■ Elliptical orbits

Most orbits are not perfect circles but **ellipses** (a stretched circle), and the Sun is not at the centre of the ellipse. A comet has a very stretched orbit. An object in an elliptical orbit moves **faster** when it is closer to the Sun. We explain this with the **conservation of energy** – the total **energy** stays the same, so as the object's **gravitational potential energy** falls (coming closer), its **kinetic energy** rises (it speeds up).



The Sun sits at one focus of the ellipse; the planet speeds up as it comes closer and slows down as it moves away

■ Light travel time

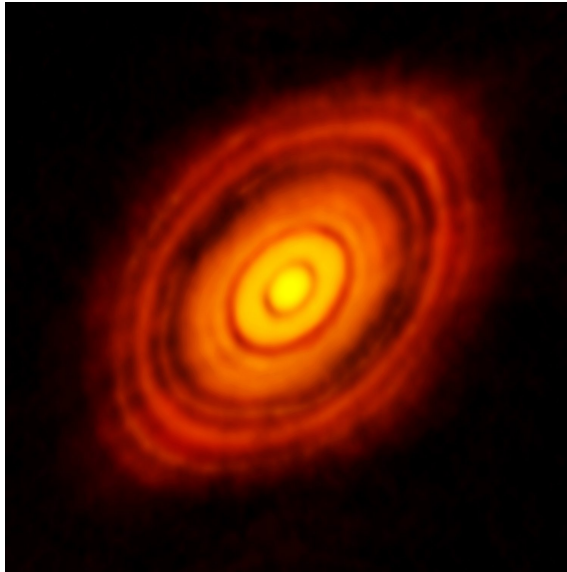
Distances in space are huge, so we often work out how long light takes to cross them. Light travels at 3.0×10^8 m/s. Using $\text{time} = \frac{\text{distance}}{\text{speed}}$, light from the Sun (about 1.5×10^{11} m away) takes about 500 s, which is roughly 8 minutes, to reach the Earth.

How the Solar System formed

The planets formed from a giant cloud of **gas** and **dust** in space, which contained many chemical **elements**. This is the **accretion** model:

- gravity pulled the cloud together;
- the cloud was spinning, so it flattened into a spinning **accretion disc** ;
- most of the matter fell to the centre and became the Sun, while the planets grew from the leftover material in the disc.

Near the hot young Sun, only rock and metal could stay solid, so the inner planets are rocky. Far out, where it was cold, gases could also collect, so the outer planets grew large and gaseous.

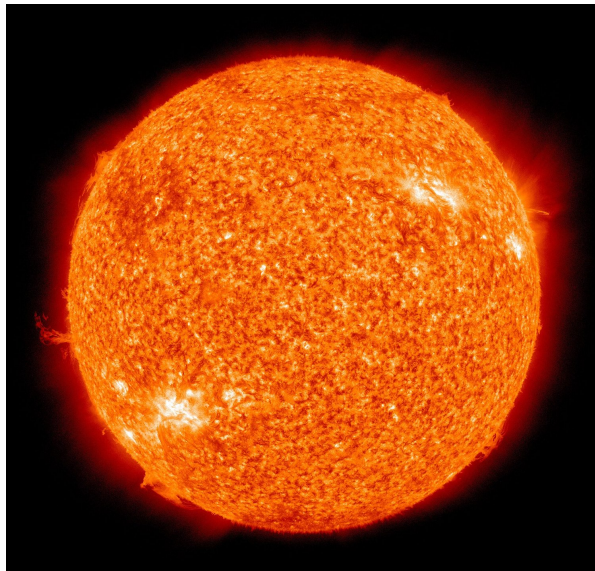


A real accretion disc around the young star HL Tauri: the dark gaps are where new planets are gathering up the dust – our Solar System began the same way

The Sun as a star

The Sun is a **star** of medium size, made mostly of **hydrogen** and **helium**. It radiates most of its **energy** in the infrared, visible light and **ultraviolet** parts of the **electromagnetic spectrum**.

A star is powered by **nuclear reactions** in its core. In a stable star, the reaction is **nuclear fusion**: hydrogen nuclei join to make helium, releasing huge amounts of energy.



The Sun, our nearest star, seen in ultraviolet light

Stars, galaxies and the Universe

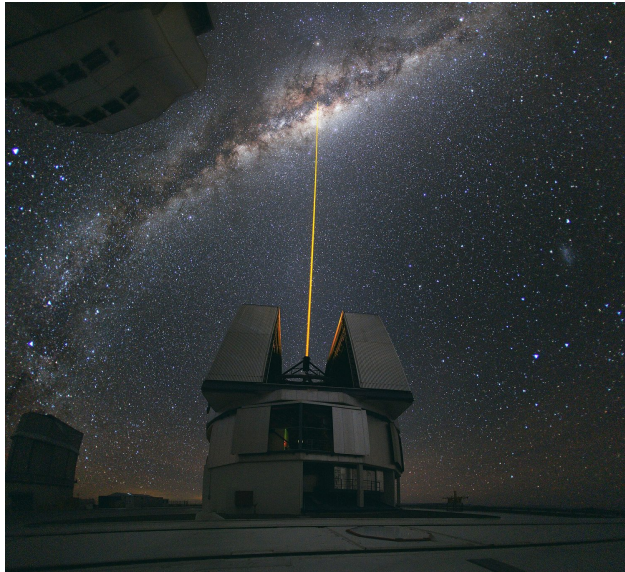
A **galaxy** is a group of many billions of stars held together by gravity. Our Sun is one star in the galaxy called the **Milky Way**. All the other stars in the Milky Way are very much further from the Earth than the Sun is.



A spiral galaxy: billions of stars held together by gravity

Distances between stars are so big that we measure them in **light-years**. One light-year is the distance light travels in one year (in the vacuum of space), which is about 9.5×10^{15} m.

The Milky Way is about 100 000 light-years across (its **diameter**). It is just one of many billions of galaxies. All of these galaxies together make up the **Universe**.



A giant telescope studies the night sky; the laser helps it make sharp images of distant stars

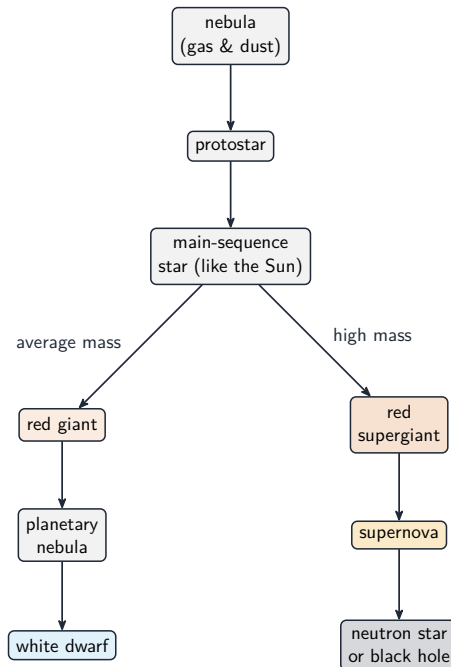
The life cycle of a star

A star is born, lives and dies over a very long time:

1. A star forms from an **interstellar cloud** of gas and dust that contains hydrogen.
2. Gravity pulls the cloud inwards, and it heats up. This collapsing, heating cloud is a **protostar**.
3. The protostar becomes a **stable** star when the inward pull of gravity is balanced by an outward push caused by the very high temperature in its centre.
4. In time, every star runs out of hydrogen **fuel** for fusion.

What happens next depends on the mass of the star:

- A medium star (like the Sun) swells into a **red giant**. It then throws off its outer layers as a glowing cloud called a planetary **nebula**, leaving a small, hot **white dwarf** at the centre.
- A much heavier star swells into a **red supergiant** and then explodes as a **supernova**. This blast spreads out a nebula containing hydrogen and new, heavier elements, and leaves behind a **neutron star** or a **black hole**.

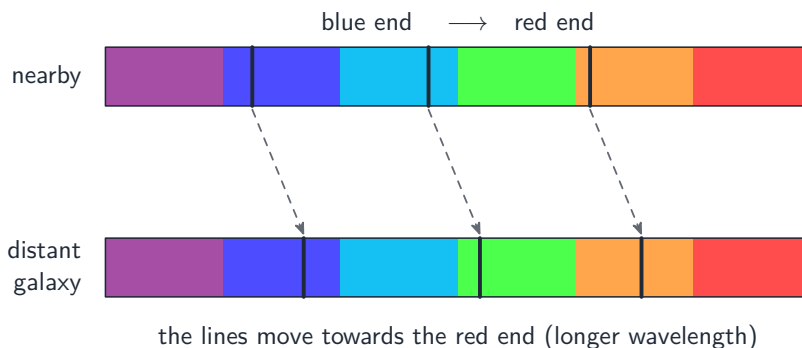


Every star begins in a nebula; how it ends depends on its mass

The nebula from a supernova can later form new stars, with planets orbiting them – so our own Solar System came from earlier stars.

The expanding Universe

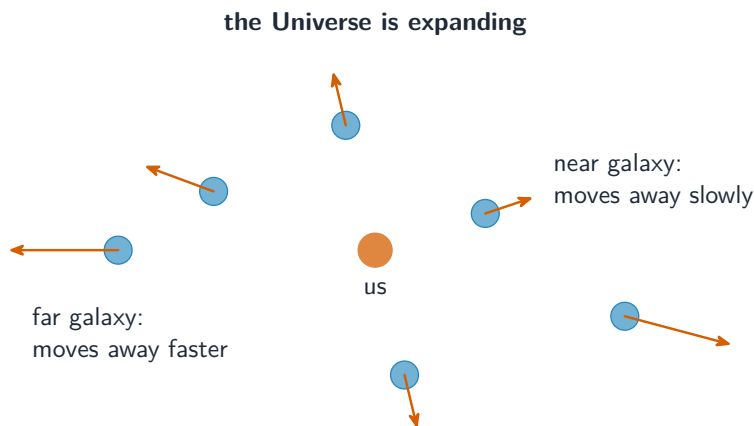
When a star or galaxy moves away from us (it is **receding**), the light we receive from it has a longer **wavelength** than normal – it is shifted towards the red end of the spectrum. This is **redshift**.



The dark lines in a distant galaxy's spectrum are shifted toward the red end – this is redshift

The light from distant galaxies is redshifted, and the further away a galaxy is, the bigger its redshift. This tells us that the galaxies are moving apart: the Universe is

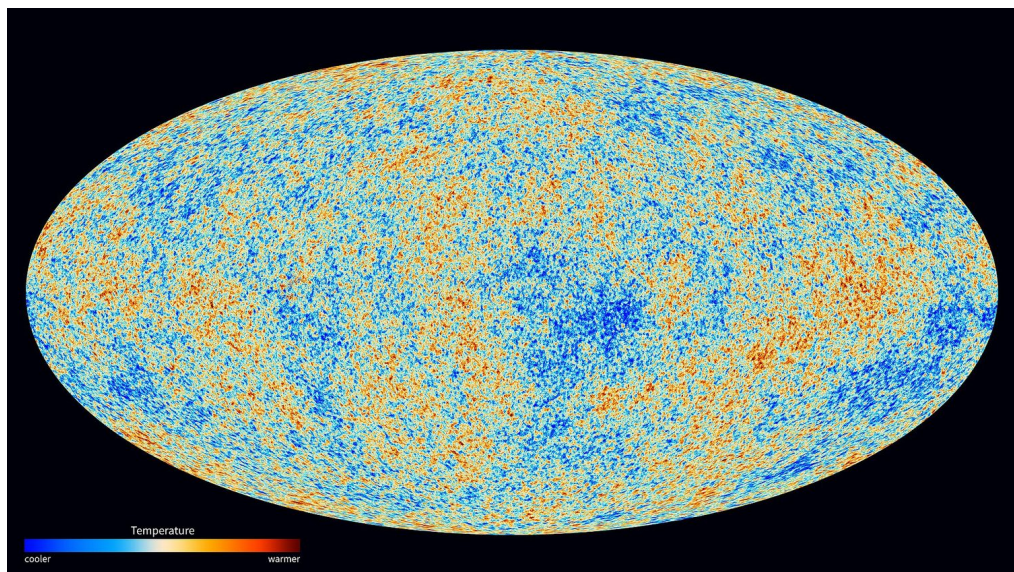
expanding . Running this backwards, everything was once together at a single point – this is the evidence for the **Big Bang** theory.



Every galaxy is moving away from us, and the farther ones move away faster – the Universe is expanding

■ More evidence and the age of the Universe

Faint **microwave radiation** is found coming from every direction in space. This is the **cosmic microwave background radiation** (CMBR). It was made as high-energy radiation soon after the Big Bang, and has been stretched out into the microwave part of the spectrum as the Universe expanded.



The whole sky mapped in microwaves: this faint glow reaches us from every direction as the leftover heat of the young Universe – strong evidence for the Big Bang

For a distant galaxy:

- its speed v of moving away can be found from the redshift of its starlight;
- its distance d can be found from the brightness of a **supernova** seen in it.

The **Hubble constant**

H_0 links these two:

$$H_0 = \frac{v}{d}$$

Its value today is about 2.2×10^{-18} per second. Turning this around gives an estimate for the age of the Universe:

$$\frac{d}{v} = \frac{1}{H_0}$$

Worked example. The Hubble constant is about $H_0 = 2.2 \times 10^{-18}$ per second. Estimate the age of the Universe.

$$\frac{1}{H_0} = \frac{1}{2.2 \times 10^{-18}} \approx 4.5 \times 10^{17} \text{ s}$$

That is roughly 14 billion years.

This works because every galaxy seems to have started from the same single point at the same time – more support for the Big Bang.

Exam tips

- In $v = \frac{2\pi r}{T}$, r is the orbit radius and T is the time for one full orbit in seconds – convert km to m and hours to seconds first.
- Planets closer to the Sun feel stronger gravity, so they orbit faster and take less time. In an elliptical orbit a body speeds up as it nears the Sun (gravitational potential energy turns into kinetic energy).
- A **light-year** is a *distance*, not a time – how far light travels in one year.
- A star is **stable** when the inward pull of gravity is balanced by the outward push from the energy released by **fusion** in its core. What it becomes when its fuel runs out depends on its **mass**.
- **Redshift** – light from distant galaxies shifted to longer (redder) wavelengths, with a bigger shift the further away – is the evidence that the Universe is **expanding**, which supports the Big Bang.