Science 9–10

Chapter 13 — Earth and space sciences B: the universe and space exploration

Aboriginal and Torres Strait Islander content has been excluded as accuracy cannot be guaranteed, and it is better to be respectful than cover the entire curriculum inaccurately.

Contents

Features of the universe: galaxies, stars, solar systems and black holes — and the scales used to describe them

Chapter 13 — Earth and space sciences B: the universe and space exploration (Science, Levels 9 and 10)

Subtopic 13A · VC2 Science Understanding — Earth and space sciences

CD code: `VC2S10U13` (delivered in split with 13B — 13A owns the features limb: galaxies, stars, solar systems and black holes, and the scales used to describe them; 13B owns the big bang limb) **Content description (word for word):** "the universe contains features including galaxies, stars, solar systems and black holes; the big bang theory models the origin and evolution of the universe and is supported by evidence" **Elaboration ids drawn on:** `VC2S10U13.E02` · `VC2S10U13.E03` (`VC2S10U13.E01` is withheld under the TOC's D10 ICIP decision and is not taught here; `VC2S10U13.E04`–`VC2S10U13.E06`, the big bang theory and its evidence, are delivered by subtopic 13B.) **Achievement standard (extract served):** "They distinguish between different features in the universe and sequence key events in the origin and evolution of the universe, including an outline of the supporting evidence for the big bang theory." (13A serves the first half — distinguishing the features of the universe; 13B serves the sequencing-and-evidence half — TOC D6.) **Maths interlock (D11):** `VC2M9M02` — scientific notation and orders of magnitude for very large measurements and timescales, used here for astronomical units, light-years and the distance ladder.

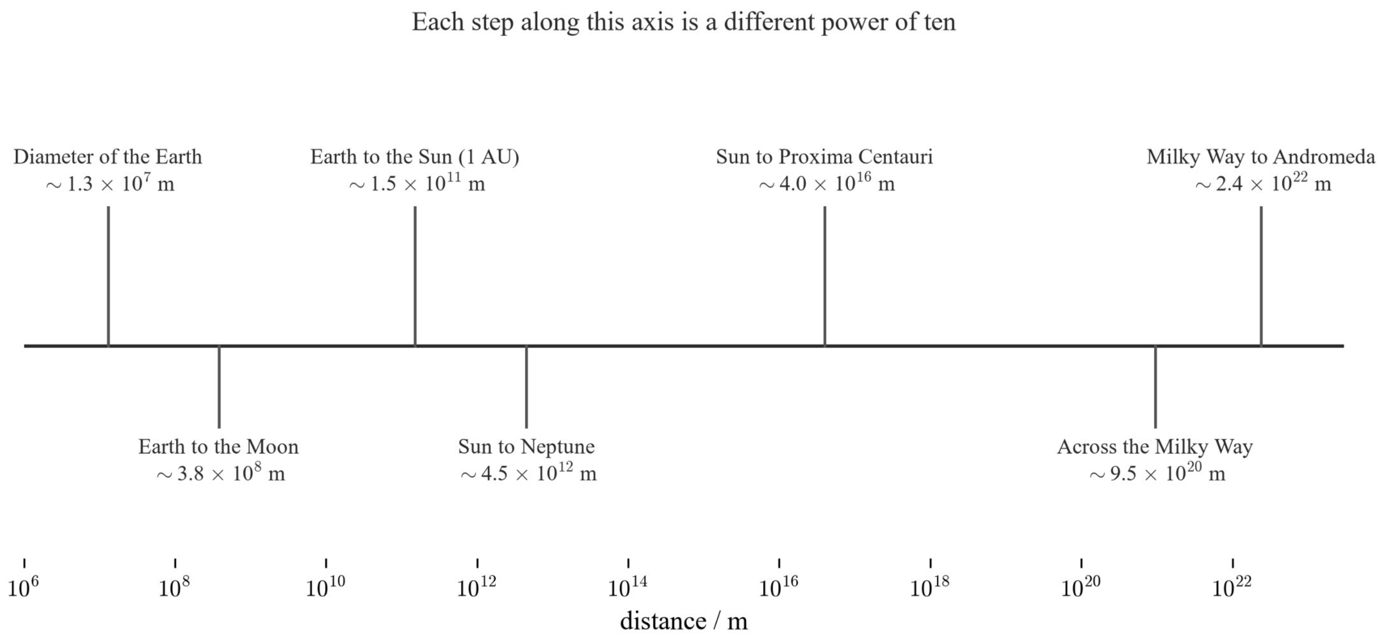
Theory

The universe and its features. The **universe** is everything there is: all matter, all space, and all the light and other radiation travelling through it. The universe is not a jumble — it has structure, and that structure comes in a nested hierarchy of **features**, four of which this subtopic names and describes.

- A **star** is a huge ball of hot gas that gives out its own light and energy. The Sun is a star — an ordinary one, but the only one close enough to study in detail.
- A **solar system** is a star together with everything held to it by gravity: planets, moons, asteroids and comets. Our solar system is the Sun and everything orbiting it.
- A **galaxy** is a huge collection of billions of stars, together with gas and dust, all held together by gravity. A galaxy is far bigger than a single solar system: our galaxy, the **Milky Way**, contains the Sun and its solar system along with billions of other stars.
- A **black hole** is a region of space where gravity is so strong that nothing — not even light — can escape from it once it has crossed the boundary of the region.

So the hierarchy runs: planets and smaller bodies orbit stars; stars are grouped into galaxies; and galaxies, in enormous numbers, fill the universe. Black holes sit inside galaxies, and most large galaxies — including the Milky Way — have a supermassive one at their centre.

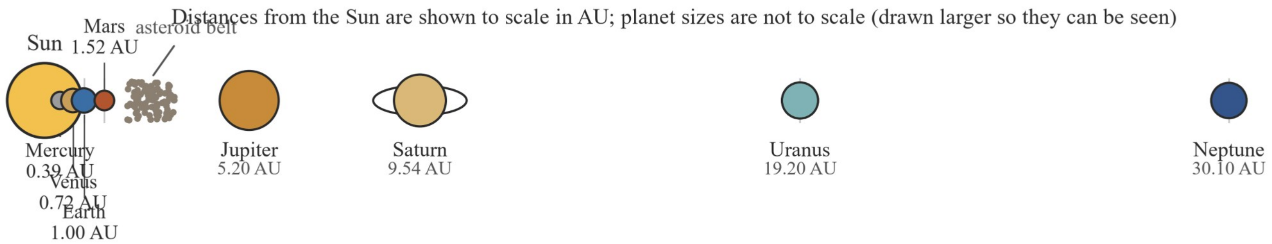
The scales used to describe the universe. The distances between these features are far bigger than any distance on Earth, so they are described with very large numbers written in **scientific notation** — a number between 1 and 10 multiplied by a power of ten (as in `VC2M9M02`). Each extra power of ten is a **step of ten times**, also called an **order of magnitude**: something at 10^9 m is three orders of magnitude (a thousand times) bigger than something at 10^6 m.



A log-scale number line of distances in metres with seven labelled steps, from the diameter of the Earth (about 1.3 × 10^7 m) up to the distance from the Milky Way to the Andromeda galaxy (about 2.4 × 10^22 m)

The ladder of distances in the figure runs from 10^7 m (the diameter of the Earth) to 10^22 m (the gap between our galaxy and its neighbour). Every step to the right is ten times the one before. The distance to the Moon is about 30 times the diameter of the Earth; the distance to the Sun is about 390 times the distance to the Moon. Holding this ladder in your head is the key skill of the subtopic: it lets you check whether an answer about space is even roughly sensible.

The solar system. The Sun holds 99.8% of the mass of the solar system, and its gravity keeps everything else in orbit. In order from the Sun, the eight planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. The four inner planets are small and rocky; the four outer planets are much larger and are made mostly of gas and ice. Between the orbits of Mars and Jupiter lies the **asteroid belt**, a ring of rocky fragments; most are far smaller than a planet, and the largest, Ceres, is a dwarf planet about 940 km across.



The solar system drawn with distances from the Sun to scale in astronomical units, from Mercury at 0.39 AU to Neptune at 30.10 AU, with the asteroid belt shown between Mars and Jupiter; planet sizes are not to scale

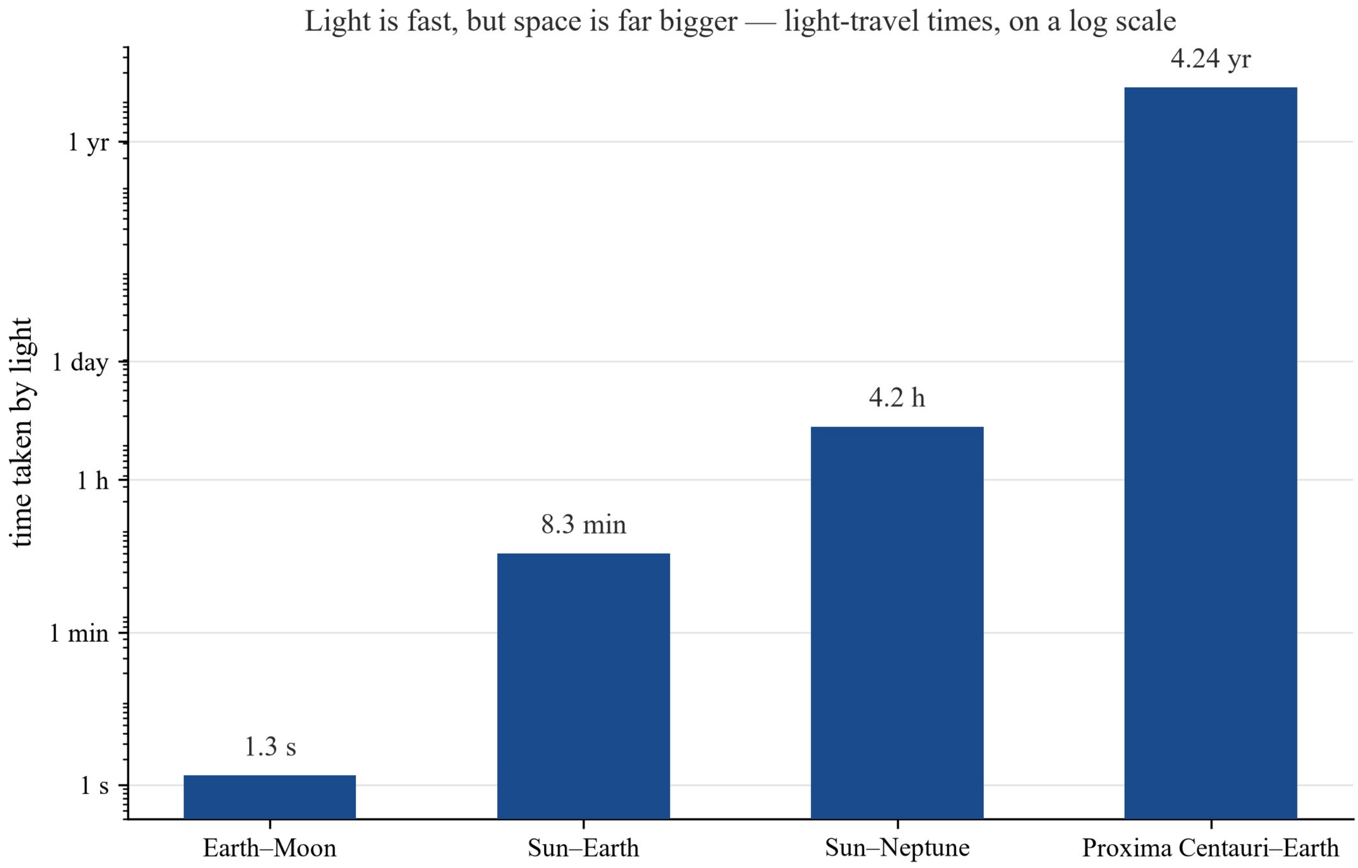
Within the solar system, distances are measured in **astronomical units** (AU). One astronomical unit is the average distance from the Earth to the Sun, about 149.6 million km (1.496 × 10^8 km). Mercury orbits at 0.39 AU and Neptune at 30.1 AU, so Neptune is about 30 times further from the Sun than the Earth is.

Source: NASA Jet Propulsion Laboratory, "Planetary Orbits & Ephemerides", n.d. https://ssd.jpl.nasa.gov/planets/orbits.html — retrieved 2026-08-21.

Two rulers for space: the astronomical unit and the light-year. Light is the fastest thing there is: in a vacuum it travels at exactly 299 792 458 m/s — for most work in this subtopic, 3.00 × 10^8 m/s or 300 000 km/s.

Source: BIPM, "SI Brochure: The International System of Units (SI)", 9th ed., 2019. https://www.bipm.org/en/publications/si-brochure — retrieved 2026-08-21.

Even at that speed, light takes time to cross space, and the times involved are a useful way to feel the scale:



Bar chart on a log scale of light-travel times: Earth to Moon about 1.3 s, Sun to Earth about 8.3 min, Sun to Neptune about 4.2 h, and Proxima Centauri to Earth about 4.24 years

Light from the Moon reaches us in about 1.3 s; light from the Sun takes about 8.3 min; light from Neptune takes about 4.2 h. When you look at Neptune through a telescope you see it as it was 4.2 hours ago. Looking out into space is looking back in time.

For distances beyond the solar system the astronomical unit becomes awkwardly large, so astronomers use the **light-year** (ly): the distance light travels in one year. One year (365.25 days) is about 3.156×10^7 s, so:

1 ly = 299 792 km/s × 3.156×10^7 s ≈ 9.46×10^{12} km (about 9.5 million million km).

A light-year is a distance, not a time — it is named after the time light takes to cross it. In astronomical units, 1 ly is about 63 200 AU.

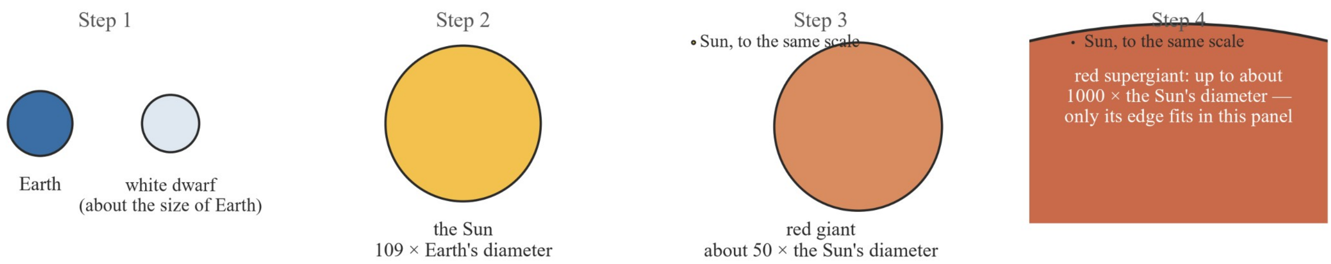
The star nearest to the Sun, **Proxima Centauri**, is 4.24 ly away. Its distance in kilometres is $4.24 \times 9.46 \times 10^{12} \approx 4.01 \times 10^{13}$ km — about 268 000 AU, or nearly 9 000 times the Sun–Neptune distance. The light arriving from Proxima Centauri tonight left the star more than four years ago.

Source: NASA Space Place, “What Is a Light-Year?”, n.d. https://spaceplace.nasa.gov/light-year/en/ — retrieved 2026-08-21.

Stars: colour, size and life. A star shines because deep in its core the pressure and temperature are so high that hydrogen nuclei join together to form helium nuclei — a process called **fusion** — and this releases energy that slowly works its way out and radiates into space. (The details of fusion and where the released energy comes from belong to later study; here the point is simply that a star is powered by fusion of hydrogen into helium in its core.) A star’s **surface temperature** decides its colour: the hottest stars look blue-white, mid-temperature stars like the Sun look yellow-white, and the coolest stars look red. The Sun’s surface is about 5 500 °C (about 5 800 K).

Source: NASA Science, “Sun”, n.d. https://science.nasa.gov/sun/ — retrieved 2026-08-21.

Stars also vary enormously in size:



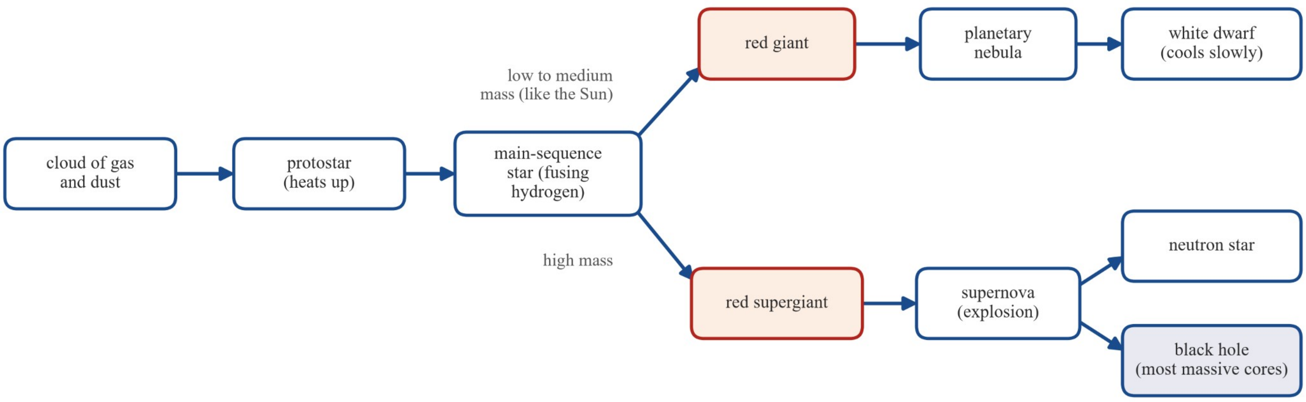
Sizes compared in steps — each panel uses one scale, and the Sun is redrawn at that scale where it no longer fits beside the star

Four panels comparing star sizes in steps: the Earth next to a white dwarf of about the Earth's size; the Sun at 109 times the Earth's diameter; a red giant about 50 times the Sun's diameter with the Sun redrawn as a dot at the same scale; and the edge of a red supergiant up to about 1000 times the Sun's diameter

A **white dwarf** is about the size of the Earth; the Sun is 109 times the Earth's diameter; a **red giant** is tens of times the Sun's diameter; and a **red supergiant** can be up to about a thousand times the Sun's diameter. If a red supergiant replaced the Sun, its surface would reach past the asteroid belt, almost as far as Jupiter's orbit.

A star's life is a balance: gravity pulls it inward, and the energy released by fusion pushes outward. A star begins as a contracting **protostar** (a hot, forming star), and once its core is hot enough for fusion it settles onto the **main sequence**, the long stable middle age that the Sun is in now. What happens next depends almost entirely on the star's mass:

The life of a star — what happens next depends on the star's mass

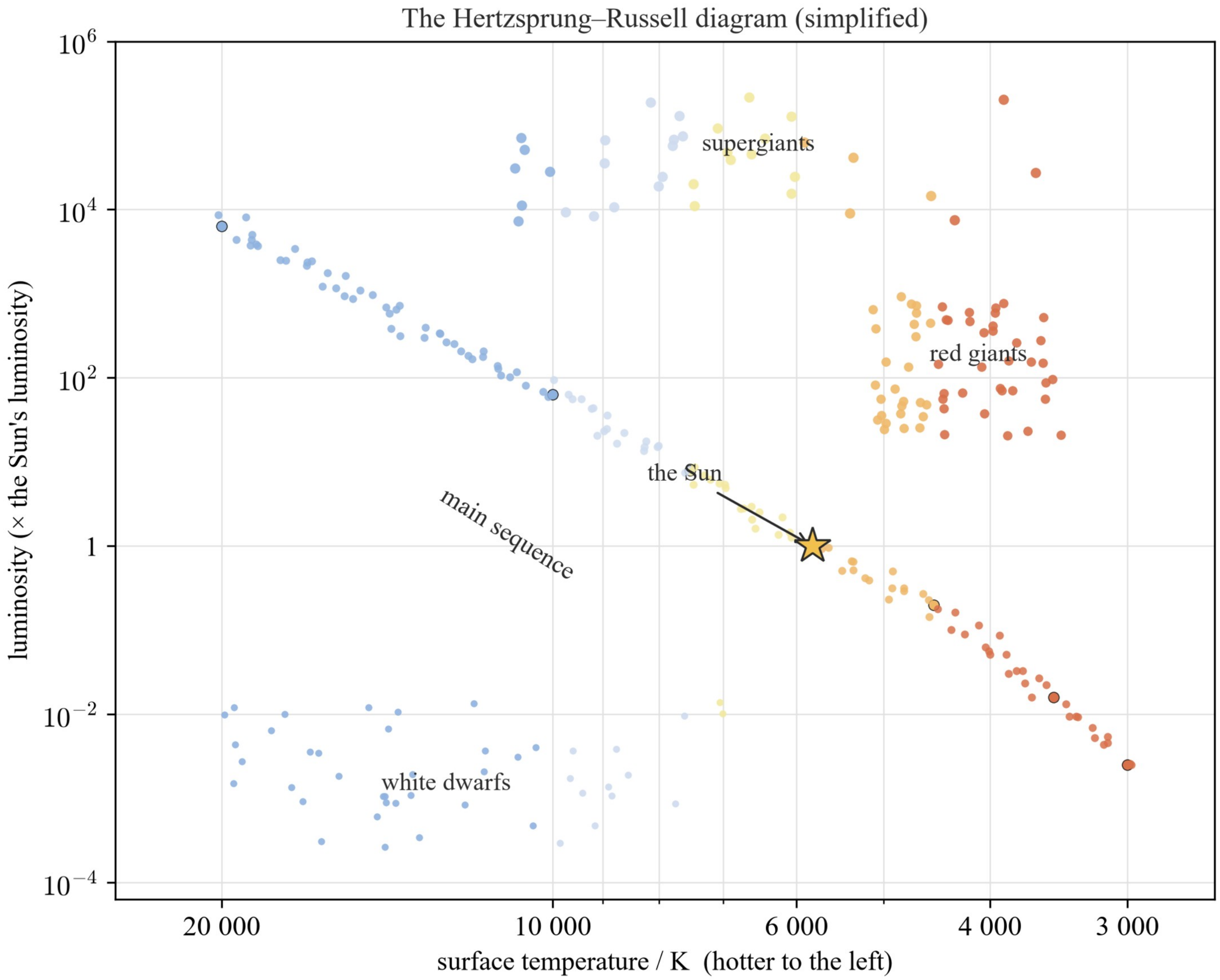


Times not to scale: main-sequence life lasts millions to billions of years

Flow chart of the life of a star: cloud of gas and dust, then protostar, then main-sequence star; the low-to-medium-mass branch runs red giant, planetary nebula, white dwarf; the high-mass branch runs red supergiant, supernova, then neutron star or black hole

- A **low- to medium-mass star (like the Sun)** swells into a red giant, sheds its outer layers as a glowing shell of gas (a **planetary nebula**), and leaves behind a slowly cooling white dwarf.
- A **high-mass star** swells into a red supergiant and then ends in a **supernova** — a catastrophic explosion. The crushed core left behind becomes either a **neutron star** (a city-sized ball of packed nuclear matter) or, if the core is massive enough, a **black hole**.

Astronomers organise all of this on one chart, the **Hertzsprung–Russell diagram**, which plots each star's **luminosity** (the total energy it radiates per second, here compared with the Sun's) against its surface temperature:



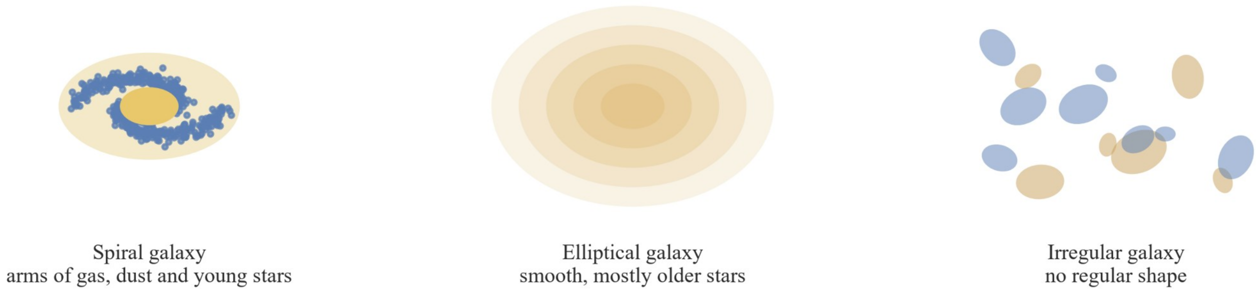
0 K is −273 °C; the Sun's surface is about 5500 °C, or about 5800 K

A simplified Hertzsprung–Russell diagram: luminosity on a log scale against surface temperature (hotter to the left), showing the main sequence running from hot and bright to cool and dim, with red giants, supergiants and white dwarfs as separate groups and the Sun marked on the main sequence

Most stars, the Sun included, lie on the diagonal band called the **main sequence**; red giants and supergiants sit above it (cool but bright because they are enormous), and white dwarfs sit below it (hot but dim because they are tiny). The diagram is a picture of the life cycle: as a star ages and changes size, it moves off the main sequence into the giant regions.

Galaxies. Galaxies are the largest single structures held together by gravity, and they come in three main shapes:

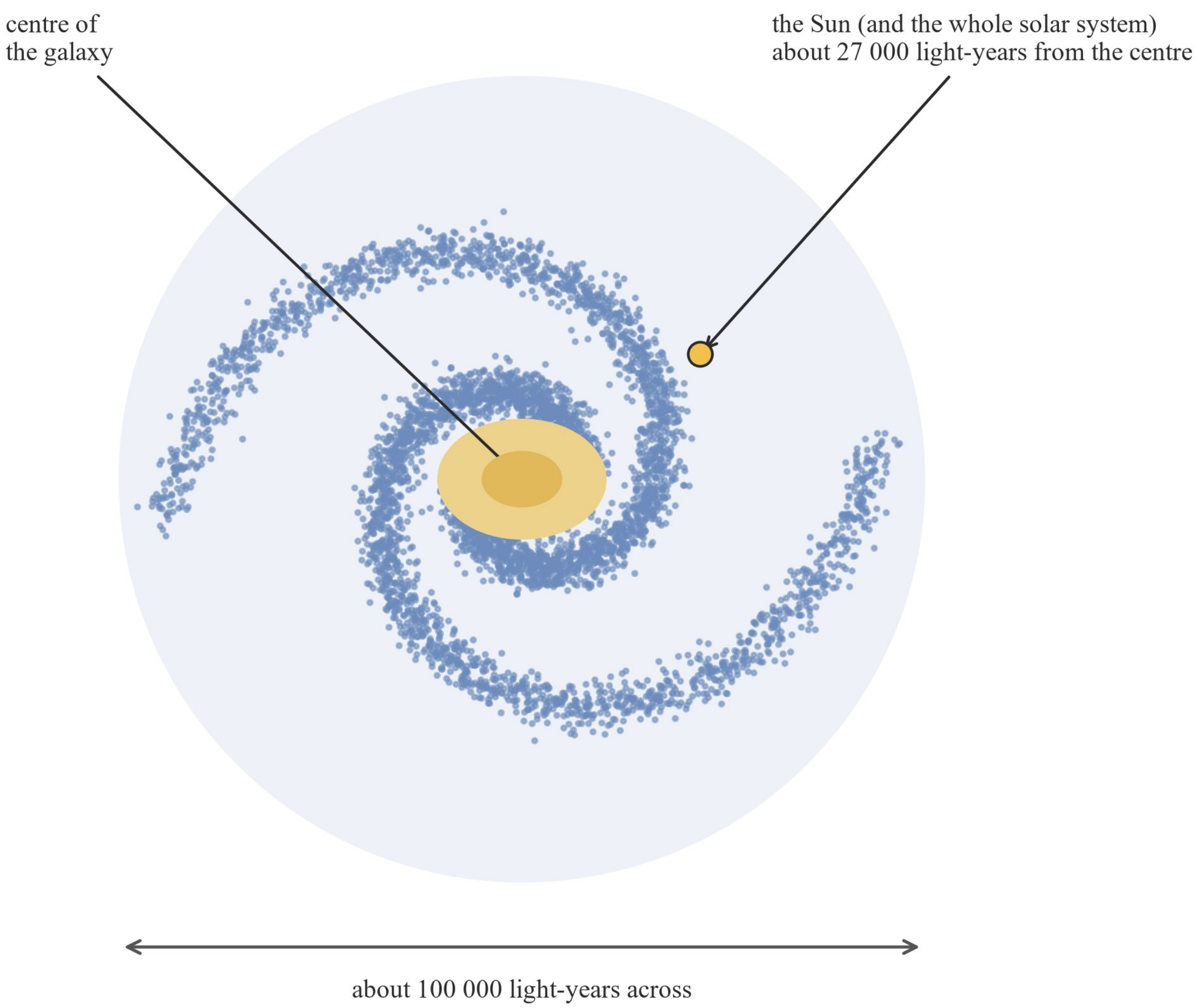
The three main types of galaxy



Three panels showing the main galaxy types: a spiral galaxy with arms of gas, dust and young stars; a smooth elliptical galaxy of mostly older stars; and an irregular galaxy with no regular shape

Spiral galaxies have a flat disc with arms of gas and dust in which new stars keep forming; **elliptical galaxies** are smooth balls of mostly older stars; **irregular galaxies** have no regular shape. The Milky Way is a spiral galaxy.

The Milky Way, face on (artist's sketch — not a photograph)

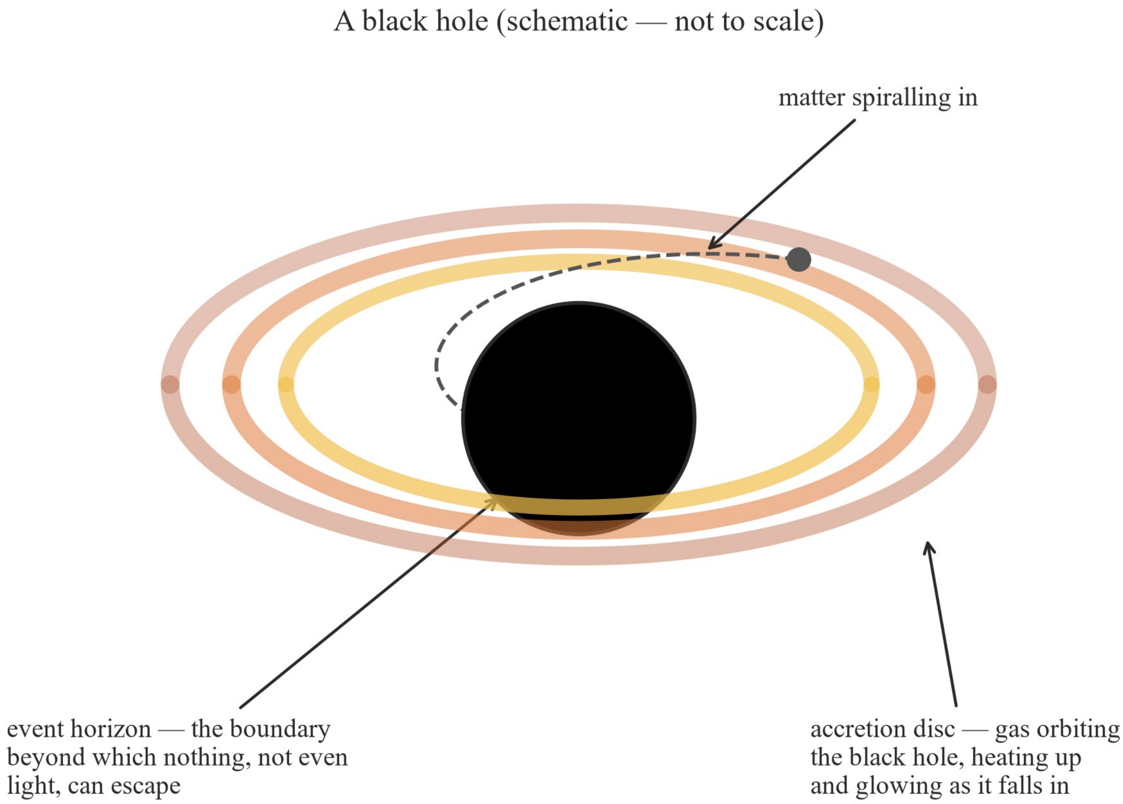


Face-on sketch of the Milky Way as a spiral galaxy about 100 000 light-years across, with the Sun marked about 27 000 light-years from the centre in one of the spiral arms

The Milky Way is about 100 000 light-years across and contains billions of stars. The Sun sits about 27 000 light-years from the centre, in one of the spiral arms, and the whole solar system orbits the galactic centre along with everything else. The nearest large galaxy to us, the **Andromeda galaxy**, is about 2.5 million light-years away — about 2.4 × 10^22 m, the far end of the distance ladder in the first figure.

Source: ESA, "Gaia", n.d. https://www.esa.int/Science_Exploration/Space_Science/Gaia — retrieved 2026-08-21.

Black holes. A black hole forms when the core of a very massive star collapses at the end of its life, and the biggest ones — **supermassive black holes**, millions to billions of times the mass of the Sun — sit at the centres of galaxies. Nothing that crosses the **event horizon**, the boundary of a black hole, can ever get out again; because no light escapes, the hole itself is invisible. What can be seen is the **accretion disc**: gas spiralling in, heating up and glowing brightly before it falls past the horizon.



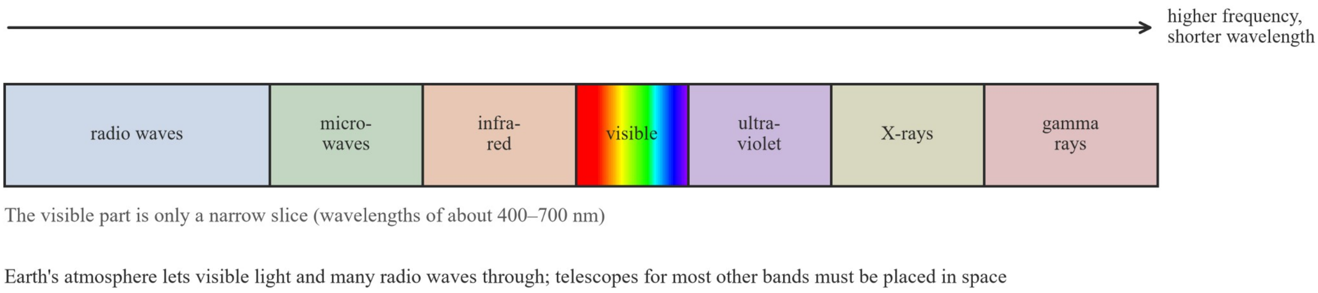
Schematic of a black hole: a black sphere bounded by the event horizon, surrounded by a glowing accretion disc of gas spiralling in; labelled, not to scale

In 2019 the **Event Horizon Telescope** — a world-wide network of radio telescopes working together as one — produced the first image of a black hole: the supermassive black hole at the centre of the galaxy M87. In 2022 the same network imaged **Sagittarius A***, the supermassive black hole at the centre of our own Milky Way. Both images show the glowing gas around a dark central shadow — direct evidence that black holes are real features of the universe, not just theory.

Source: Event Horizon Telescope Collaboration, "First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole", 2019. https://doi.org/10.3847/2041-8213/ab0ec7 — retrieved 2026-08-21.

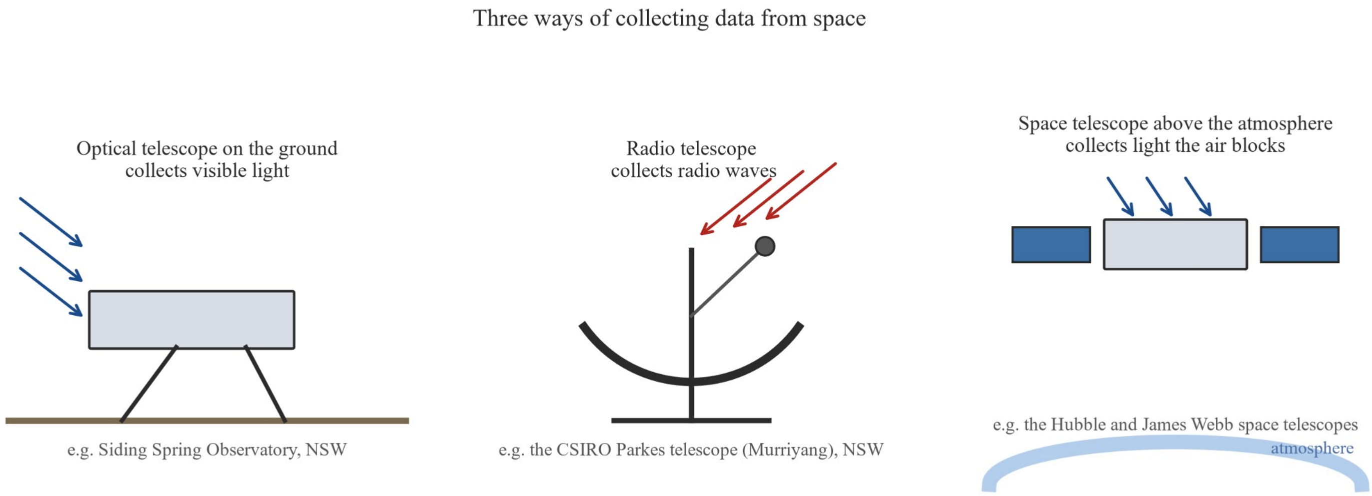
Source: Event Horizon Telescope Collaboration, "First Sagittarius A Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole at the Galactic Center", 2022. https://doi.org/10.3847/2041-8213/ac6674 — retrieved 2026-08-21.*

Collecting data from space. Everything known about the features of the universe has been learned from the radiation that reaches Earth, so the technology that collects that radiation matters. Radiation from space arrives across the whole **electromagnetic spectrum** — the family of waves that includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays, arranged by wavelength:



The electromagnetic spectrum from radio waves to gamma rays with an arrow towards higher frequency and shorter wavelength; the visible part is shown as a narrow slice of about 400–700 nm between infrared and ultraviolet

Human eyes detect only the narrow **visible** slice. The rest is invisible but carries just as much information. Earth's atmosphere lets visible light and many radio waves through but blocks most infrared, ultraviolet, X-rays and gamma rays, so different telescopes are needed for different waves:



Three panels showing three ways of collecting data from space: an optical telescope on the ground collecting visible light (e.g. Siding Spring Observatory, NSW); a radio telescope collecting radio waves (e.g. the CSIRO Parkes telescope, Murriyang, NSW); and a space telescope above the atmosphere collecting light the air blocks (e.g. the Hubble and James Webb space telescopes)

- **Optical telescopes on the ground** collect visible light — for example the telescopes at Siding Spring Observatory in NSW.
- **Radio telescopes on the ground** collect radio waves with large dish antennas — for example the CSIRO Parkes telescope (Murriyang) in NSW.
- **Space telescopes above the atmosphere** collect the light the air blocks — for example the Hubble Space Telescope (visible and ultraviolet) and the James Webb Space Telescope (infrared).

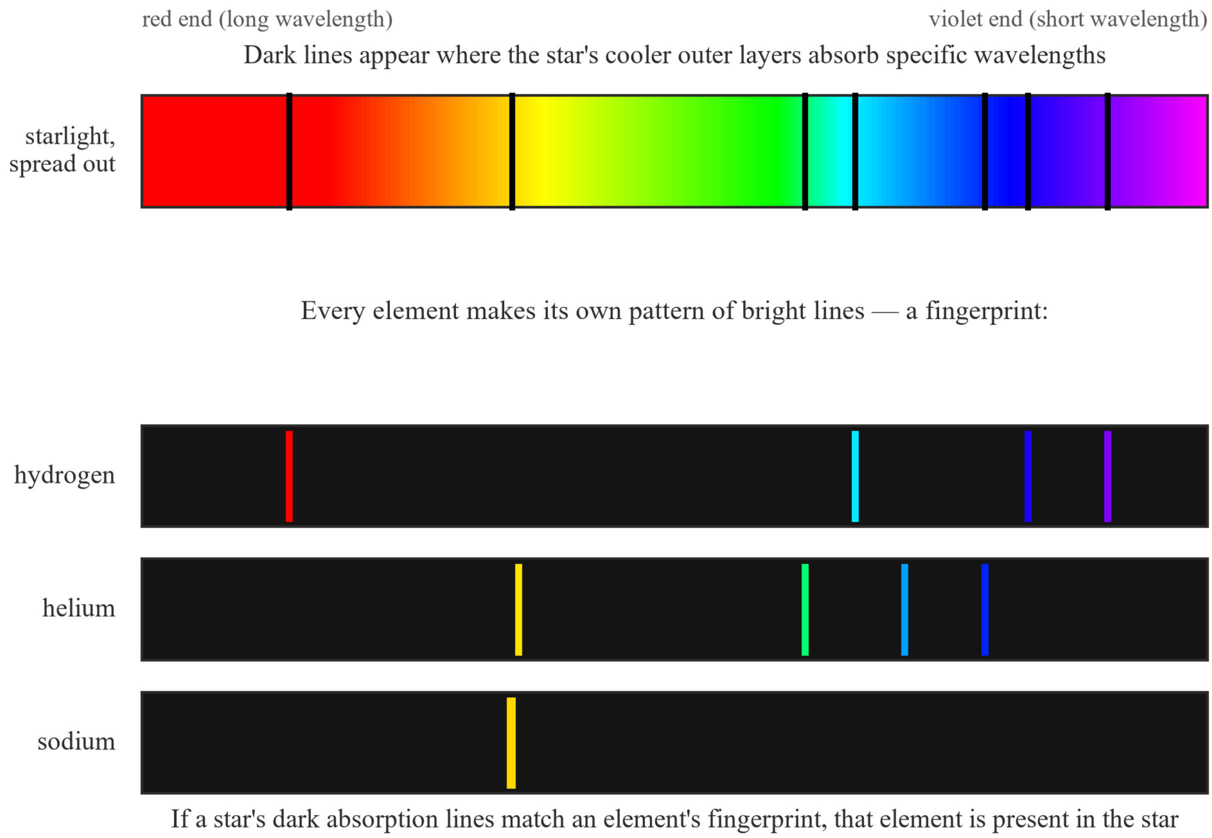
The data collected are not just photographs: telescopes record **images** in chosen bands, **spectra** (light spread out by wavelength), and **brightness over time**. Each type of data answers different questions.

Source: CSIRO ATNF, "Parkes Observatory", n.d. https://www.parkes.atnf.csiro.au/ — retrieved 2026-08-21.

Source: ANU Research School of Astronomy and Astrophysics, "Siding Spring Observatory", n.d. https://rsaa.anu.edu.au/observatories/siding-spring-observatory — retrieved 2026-08-21.

Source: NASA, "Hubble Space Telescope", n.d. https://science.nasa.gov/mission/hubble/ — retrieved 2026-08-21; NASA, "James Webb Space Telescope", n.d. https://science.nasa.gov/mission/webb/ — retrieved 2026-08-21.

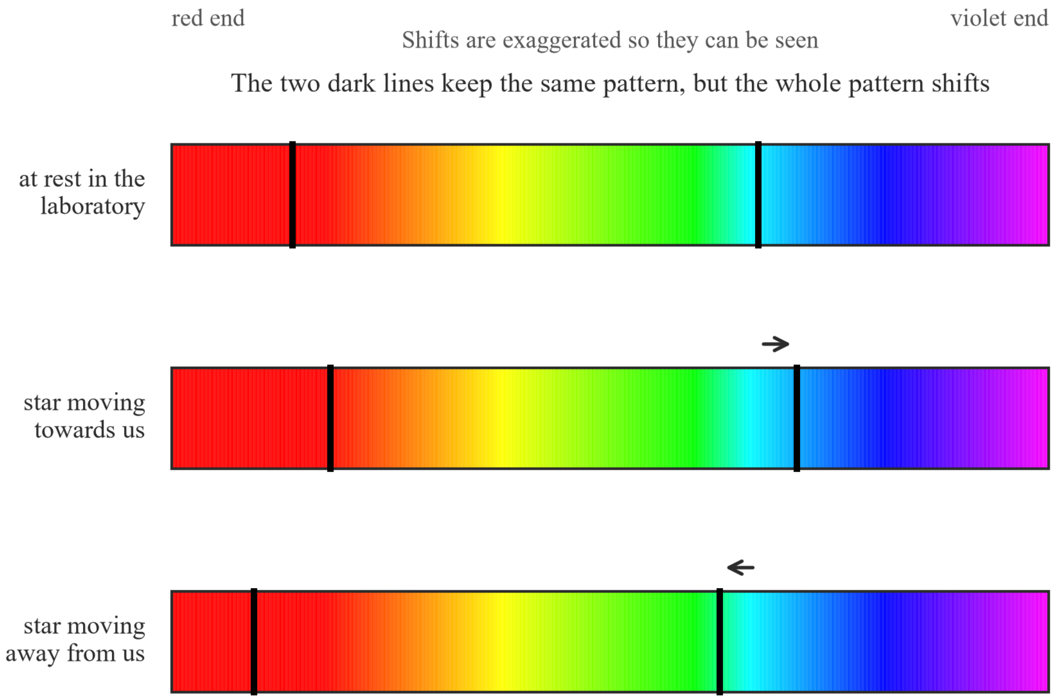
Reading the data: what starlight tells us. Spreading a star's light out into a spectrum is the most powerful single tool in astronomy. A star's spectrum is a rainbow-like band crossed by **dark absorption lines** at particular wavelengths, where the cooler outer layers of the star have absorbed light. Every chemical element makes its own pattern of lines — a fingerprint — so matching the dark lines in starlight against laboratory fingerprints shows which elements the star contains:



Top: starlight spread into a continuous spectrum crossed by dark absorption lines, labelled red end (long wavelength) at the left and violet end (short wavelength) at the right. Bottom: the emission-line fingerprints of hydrogen, helium and sodium on the same wavelength scale, so matching lines identify the elements present in the star

If the dark lines in a star's spectrum sit at exactly the wavelengths of hydrogen's fingerprint, hydrogen is present in the star. This is how helium was first found — in the Sun's spectrum, before it was found on Earth.

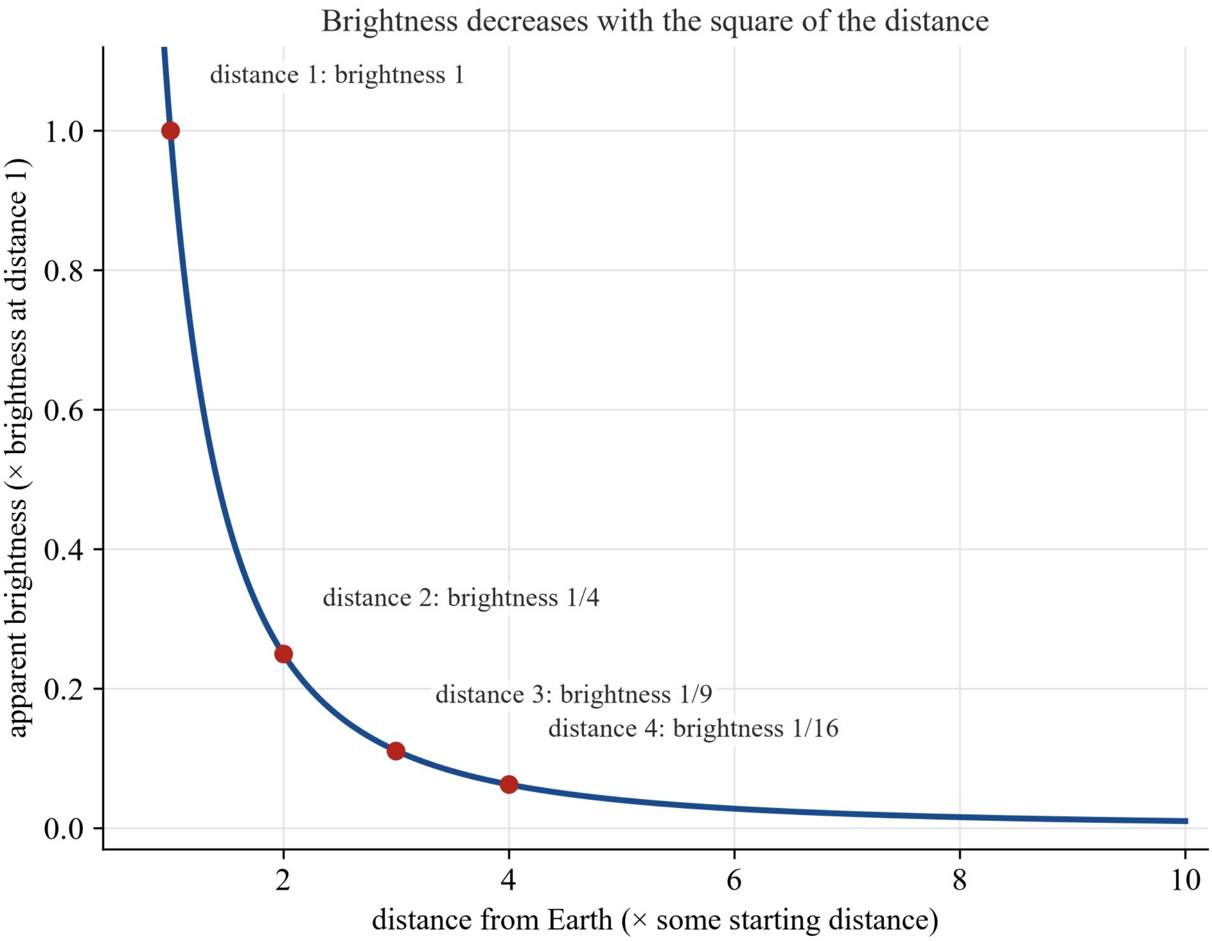
The same lines also reveal **motion along the line of sight**. If a star is moving towards us, all its lines shift a little towards the violet (short-wavelength) end; if it is moving away, they shift towards the red end. The pattern stays the same — only its position slides:



Three spectrum strips with two dark hydrogen lines: at rest in the laboratory; shifted towards the violet end for a star moving towards us; and shifted towards the red end for a star moving away from us; shifts are exaggerated so they can be seen

This **Doppler shift** of spectral lines measures how fast a star approaches or recedes. (When the same red-shifting is measured for whole galaxies, and what it says about the universe as a whole, that is the story of the big bang theory — subtopic 13B.)

Finally, spectra and brightness together give **distances**. A star's apparent brightness — how bright it looks from Earth — falls off with the square of its distance:



Graph of apparent brightness against distance showing an inverse-square curve: at distance 1 the brightness is 1, at 2 it is 1/4, at 3 it is 1/9 and at 4 it is 1/16

Double the distance and the star looks 1/4 as bright; triple the distance and it looks 1/9 as bright. So if two stars are known to be identical (same luminosity, from their spectra and position on the Hertzsprung–Russell diagram) and one looks 1/9 as bright as the other, it is 3 times further away. This **inverse-square law** of brightness is one of the main rungs of the distance ladder that reaches from nearby stars out to other galaxies.

Activities

Activity 1 — Ordering the distance ladder. Copy the seven steps of the distance ladder figure (diameter of the Earth through to Milky Way–Andromeda) onto cards, with each distance in metres in scientific notation. Shuffle the cards and deal them to a partner, then race to put them back in order from smallest to largest. Next, for each pair of neighbours on the ladder, divide the larger distance by the smaller and write the answer as a power of ten (for example, 10^8 m ÷ 10^7 m = 10^1, “one order of magnitude”). Which gap on the ladder is the biggest jump in orders of magnitude?

Activity 2 — A scale model of the solar system. On a long oval or corridor, let 1 AU = 2.0 m. Using the AU values in the solar system figure, calculate where each planet should stand: Mercury at 0.39 × 2.0 = 0.78 m from the Sun, and so on out to Neptune. Mark the positions and the asteroid belt. Then calculate where Proxima Centauri would be on the same scale (its distance is about 268 000 AU). Comment on what the model shows about the difference between the size of a solar system and the distance between stars.

Activity 3 — Spectrum detective. The spectrum figure shows the fingerprints of hydrogen, helium and sodium. Your teacher will give you three simulated star spectra drawn on the same wavelength scale (“simulated data for practice”). For each star, list which of the three elements are present and which are absent, and explain the rule you used to decide. One of the stars shows lines of hydrogen plus one extra dark line that matches no fingerprint shown — suggest what the extra line means.

Worked examples

Data in this section are quoted to the significant figures shown (two to four), and final answers match the precision of the given data unless the arithmetic is exact.

Example 1 — scaffolded

The speed of light is 3.00 × 10^5 km/s and one year is 3.156 × 10^7 s. (a) Show that one light-year is about 9.46 × 10^12 km. (b) Proxima Centauri is 4.24 ly from the Sun. Calculate this distance in kilometres.

Working	Comment
1 ly = speed × time = 3.00 × 10^5 km/s × 3.156 × 10^7 s = 9.47 × 10^12 km	A light-year is the distance light travels in one year: speed multiplied by time.
≈ 9.46 × 10^12 km	Multiplying with the rounded speed gives 9.47 × 10^12 km; using the exact speed, 299 792 km/s, gives the accepted value, 9.46 × 10^12 km. The difference is rounding only.
(b) distance = 4.24 × 9.46 × 10^12 km	The star is 4.24 light-years away, so multiply 4.24 by the length of one light-year.
distance = 4.01 × 10^13 km	About 40 million million kilometres.

Example 2 — scaffolded

Two stars are identical. Star B is 4 times further from Earth than star A, and star A has an apparent brightness of 8.0 units. (a) State the fraction of star A’s brightness at which star B appears. (b) Calculate star B’s apparent brightness.

Working	Comment
(a) brightness fraction = 1 ÷ 4^2 = 1/16	The inverse-square law: brightness falls off with the square of the distance.
(b) brightness of B = 8.0 ÷ 16	Multiply star A’s brightness by the fraction.
brightness of B = 0.50 units	Four times further away means 1/16 as bright, not 1/4 as bright.

Example 3 — unscaffolded

Jupiter’s average distance from the Sun is 5.20 AU. Calculate how long light takes to travel from the Sun to Jupiter, in minutes. (1 AU = 1.496 × 10^8 km; speed of light = 3.00 × 10^5 km/s.)

Distance in kilometres:

$$5.20 \times 1.496 \times 10^8 = 7.78 \times 10^8 \text{ km.}$$

Time = distance ÷ speed:

$$t = \frac{7.78 \times 10^8}{3.00 \times 10^5} = 2.59 \times 10^3 \text{ s} = 2590 \text{ s.}$$

In minutes: 2590 ÷ 60 = **43.2 min**. Sunlight reaching Jupiter is about 43 minutes old.

Example 4 — unscaffolded

How many times further away is Proxima Centauri (4.01 × 10^13 km) than Neptune (4.50 × 10^9 km from the Sun)?

Divide the larger distance by the smaller:

$$\frac{4.01 \times 10^{13}}{4.50 \times 10^9} = 0.891 \times 10^4 = 8.91 \times 10^3.$$

Proxima Centauri is about **8 910 times** further away than Neptune — nearly four orders of magnitude. Crossing the gap to the nearest star is a far bigger step than crossing the entire solar system.

Practice questions

Scaffolded questions

Question 1 Arrange these five items from largest to smallest: *star, universe, planet, galaxy, solar system*. (a) Write the list in order. (b) For each item, give one feature from this subtopic that distinguishes it from the item inside it (for example, a galaxy is distinguished from a solar system because it contains billions of stars, not one).

Question 2 Jupiter orbits at 5.20 AU and 1 AU = 1.496×10^8 km. (a) Write 1 AU in metres in scientific notation. (b) Calculate Jupiter's distance from the Sun in kilometres, in scientific notation. (c) How many times further from the Sun is Jupiter than Earth is?

Question 3 Light from the Sun takes 8.3 min to reach the Earth. (a) Convert 8.3 min to seconds. (b) Hence calculate the Sun–Earth distance in kilometres (speed of light = 3.00×10^5 km/s). (c) Compare your answer with the definition of the astronomical unit.

Question 4 A star has an apparent brightness of 1.0 unit at some distance. (a) State its brightness at 2 times that distance. (b) State its brightness at 5 times that distance. (c) At what multiple of the original distance would the star appear 1/100 as bright?

Question 5 A star's spectrum shows dark lines that match the hydrogen and sodium fingerprints of the spectrum figure, but none of helium's lines. (a) Which elements are present in the star's outer layers? (b) Which of the three elements is absent? (c) State the rule that allows these conclusions.

Question 6 Star X looks blue-white and star Y looks red. (a) Which star has the hotter surface? (b) On the Hertzsprung–Russell diagram, which end of the main sequence (left or right) is star X near? (c) A red giant is cool but very bright. Explain how the Hertzsprung–Russell diagram shows this.

Unscaffolded questions

Question 7 Define the term *galaxy*, and state the type of galaxy the Milky Way is.

Question 8 About the black hole figure: (a) State what the event horizon is. (b) Explain why a black hole itself cannot be seen. (c) Name the feature that makes a black hole detectable in the figure, and explain why it glows.

Question 9 Using the values on the distance ladder figure, write these four distances in metres in scientific notation and arrange them from smallest to largest: the distance across the Milky Way; the Earth–Moon distance; one light-year ($\approx 9.46 \times 10^{15}$ m); the Earth–Sun distance.

Question 10 Neptune orbits at 30.1 AU. Calculate how long light takes to travel from the Sun to Neptune, in hours. (1 AU = 1.496×10^8 km; speed of light = 3.00×10^5 km/s.)

Question 11 From the Milky Way figure, state (a) the approximate diameter of the Milky Way in light-years, and (b) the approximate distance of the Sun from the galactic centre. (c) Hence explain why "the solar system" and "the Milky Way" are different features of the universe.

Question 12 (a) Which part of the electromagnetic spectrum does the CSIRO Parkes telescope (Murriyang) collect? (b) Why must telescopes for X-rays and most infrared be placed in space? (c) Name one space telescope from this subtopic and the band it collects.

Question 13 (a) What are the dark lines in a star's spectrum? (b) How would an astronomer conclude that a star contains sodium? (c) Why is a spectrum described as a "fingerprint"?

Question 14 (a) Write one light-year, 9.46×10^{12} km, in metres in scientific notation. (b) Given 1 AU = 1.496×10^8 km, show that one light-year is about 63 200 AU. (c) What does this ratio tell you about when to use AU and when to use light-years?

Question 15 Two identical stars, P and Q. Star Q is twice as far from Earth as star P. Which star appears brighter, and how many times brighter?

Question 16 (a) What single property of a star decides whether it ends as a white dwarf or as a neutron star/black hole? (b) Name the explosion that ends the life of a high-mass star. (c) List, in order, the three stages a star like the Sun passes through after its main-sequence life.

Answers

Question 1 (a) universe, galaxy, solar system, star, planet; (b) see solution. **Question 2** (a) 1.496×10^{11} m; (b) 7.78×10^{8} km; (c) 5.20 times. **Question 3** (a) 498 s; (b) 1.49×10^{8} km; (c) it is 1 AU by definition. **Question 4** (a) 1/4 (0.25 unit); (b) 1/25 (0.040 unit); (c) 10 times. **Question 5** (a) hydrogen and sodium; (b) helium; (c) matching dark lines = element present. **Question 6** (a) star X; (b) the left (hot) end; (c) see solution. **Question 7** A huge collection of billions of stars with gas and dust, held by gravity; spiral. **Question 8** (a) see solution; (b) no light escapes it; (c) the accretion disc — gas heating and glowing as it spirals in. **Question 9** 3.8×10^{8} m (Moon) < 1.5×10^{11} m (Sun) < 9.46×10^{15} m (1 ly) < 9.5×10^{20} m (Milky Way). **Question 10** ≈ 4.2 h. **Question 11** (a) about 100 000 ly; (b) about 27 000 ly; (c) see solution. **Question 12** (a) radio waves; (b) the atmosphere blocks those bands; (c) e.g. James Webb — infrared (or Hubble — visible/ultraviolet). **Question 13** (a) wavelengths absorbed by the star's cooler outer layers; (b) dark lines at sodium's fingerprint wavelengths; (c) see solution. **Question 14** (a) 9.46×10^{15} m; (b) see solution; (c) AU inside solar systems, light-years between stars. **Question 15** P, 4 times brighter. **Question 16** (a) its mass; (b) supernova; (c) red giant, planetary nebula, white dwarf.

Fully-worked solutions

Question 1 (a) From largest to smallest: **universe, galaxy, solar system, star, planet**. (b) The universe contains many galaxies. A galaxy contains billions of stars, not one. A solar system is one star and its orbiting bodies, not billions of stars. A star gives out its own light; a planet does not — it orbits a star and reflects the star's light.

Question 2 (a) 1 AU = 1.496×10^{8} km = **1.496×10^{11} m** (1 km = 10^{3} m). (b) $5.20 \times 1.496 \times 10^{8}$ = **7.78×10^{8} km**. (c) Jupiter's distance is 5.20 AU and Earth's is 1.00 AU, so Jupiter is **5.20 times** further from the Sun than Earth is.

Question 3 (a) 8.3 min = 8.3 × 60 = **498 s**. (b) distance = speed × time = 3.00×10^{5} km/s × 498 s = 1.494×10^{8} km ≈ **1.49×10^{8} km**. (c) This is the astronomical unit: 1 AU is defined as the average Sun–Earth distance, about 1.496×10^{8} km — the calculated value matches it.

Question 4 (a) At 2 times the distance, brightness = $1 \div 2^2$ = **1/4** (0.25 unit). (b) At 5 times the distance, brightness = $1 \div 5^2$ = **1/25** (0.040 unit). (c) 1/100 = $1 \div 10^2$, so the distance is **10 times** the original distance.

Question 5 (a) **Hydrogen and sodium** — their fingerprint lines match dark lines in the star's spectrum. (b) **Helium** — none of its lines appear. (c) Every element absorbs light at its own pattern of wavelengths, so if a star's dark absorption lines match an element's fingerprint, that element is present in the star's outer layers.

Question 6 (a) **Star X** — blue-white stars have hotter surfaces than red stars. (b) The **left** end, the hot end of the main sequence (the Hertzsprung–Russell diagram runs hotter to the left). (c) On the Hertzsprung–Russell diagram the red giants sit at the right (cool side) but high up (bright). They are bright *because* they are enormous: a cool surface that is bright must be a very large star.

Question 7 A **galaxy** is a huge collection of billions of stars, together with gas and dust, all held together by gravity. The Milky Way is a **spiral** galaxy.

Question 8 (a) The **event horizon** is the boundary of a black hole — the surface beyond which nothing, not even light, can escape. (b) No light can escape from inside the event horizon, so no light from the hole itself ever reaches a telescope: it appears black. (c) The **accretion disc**. Gas spiralling towards the hole is squeezed and heated until it glows brightly, so the region around the black hole shines even though the hole itself does not.

Question 9 Earth–Moon 3.8×10^{8} m; Earth–Sun 1.5×10^{11} m; one light-year 9.46×10^{15} m; across the Milky Way 9.5×10^{20} m. Smallest to largest: **Earth–Moon < Earth–Sun < one light-year < across the Milky Way**.

Question 10 Distance = $30.1 \times 1.496 \times 10^{8}$ = 4.50×10^{9} km. Time = $4.50 \times 10^{9} \div 3.00 \times 10^{5}$ = 1.50×10^{4} s. In hours: 15 000 ÷ 3600 = **4.17 h ≈ 4.2 h** — matching the light-travel figure.

Question 11 (a) About **100 000 light-years**. (b) About **27 000 light-years**. (c) The solar system is one star and its orbiting bodies — a few light-*hours* across at most. The Milky Way is billions of stars spread over 100 000 light-years; the whole solar system is just one point inside it. They differ by many orders of magnitude.

Question 12 (a) **Radio waves** — Parkes (Murriyang) is a radio telescope with a large dish. (b) Earth's atmosphere **blocks** X-rays and most infrared, so those waves never reach the ground; a telescope above the atmosphere can collect them. (c) The **James Webb Space Telescope**, which collects infrared (or the Hubble Space Telescope, visible and ultraviolet).

Question 13 (a) The dark lines are wavelengths of light **absorbed by the cooler outer layers** of the star as its light passes out. (b) The astronomer spreads the star's light into a spectrum and checks whether dark lines appear at **sodium's fingerprint wavelengths** (the sodium double line in the yellow part of the spectrum). A match means sodium is present. (c) Each element produces its own pattern of lines, just as each person has their own fingerprint, so the pattern identifies the element.

Question 14 (a) 9.46×10^{12} km = **9.46×10^{15} m**. (b) 9.46×10^{12} km ÷ 1.496×10^{8} km = 6.32×10^{4} = **63 200 AU**. (c) The AU is a handy ruler *inside* a solar system (planet distances are small multiples of it); the light-year is the handy ruler *between* stars, where even thousands of AU are too small a unit to be convenient.

Question 15 Brightness falls with the square of the distance, so at twice the distance star Q looks 1/4 as bright. **Star P appears brighter — 4 times brighter.**

Question 16 (a) The star's **mass** (low- to medium-mass stars end as white dwarfs; high-mass stars end as neutron stars or black holes). (b) A **supernova**. (c) **Red giant → planetary nebula → white dwarf.**

Where this leads: within this book, the second half of `VC2S10U13` — the big bang theory and the evidence supporting it, including the redshift of galaxies — is delivered by subtopic 13B, which builds directly on the scales and the Doppler shift of spectral lines introduced here. Beyond school, be honest about the destination: cosmology is not a VCE science Area of Study, and no VCE unit teaches galaxy classification or black holes as content (TOC §5, reference-only, D12). What does carry forward is the numeracy and the reasoning: orders of magnitude and scientific notation for very large measurements (`VC2M9M02`), assumed by Chemistry and Physics alike, and reading a spectrum as a fingerprint rather than a trend — the only place before VCE Physics Units 3 and 4 where a graph is used as an identity check. No VCE content is pre-taught here (TOC D9).

The big bang theory and its evidence: cosmic microwave background, redshift, Hubble's observations

Chapter 13 — Earth and space sciences B: the universe and space exploration (Science, Levels 9 and 10)

Subtopic 13B · VC2 Science Understanding — Earth and space sciences

CD code: `VC2S10U13` (delivered in split with 13A — 13A owns the features limb; 13B owns the big bang limb: the big bang theory, the evidence supporting it, and recent advances) **Content description (word for word):** "the universe contains features including galaxies, stars, solar systems and black holes; the big bang theory models the origin and evolution of the universe and is supported by evidence" **Elaboration ids drawn on:** `VC2S10U13.E04` · `VC2S10U13.E05` · `VC2S10U13.E06` (`VC2S10U13.E01` is withheld under the TOC's D10 ICIP decision and is not taught here; `VC2S10U13.E02`–`VC2S10U13.E03` are delivered by subtopic 13A.) **Achievement standard (extract served):** "They distinguish between different features in the universe and sequence key events in the origin and evolution of the universe, including an outline of the supporting evidence for the big bang theory." (13B serves the second half — sequencing key events in the origin and evolution of the universe, and outlining the supporting evidence for the big bang theory — TOC D6.) **Maths interlock (D11):** `VC2M9M02` — scientific notation and orders of magnitude for very large measurements and timescales, reused here (not re-taught) for the age of the universe and the gaps between its key events; the gradient of a line of best fit, taught earlier in this series, is reused for Hubble's graph.

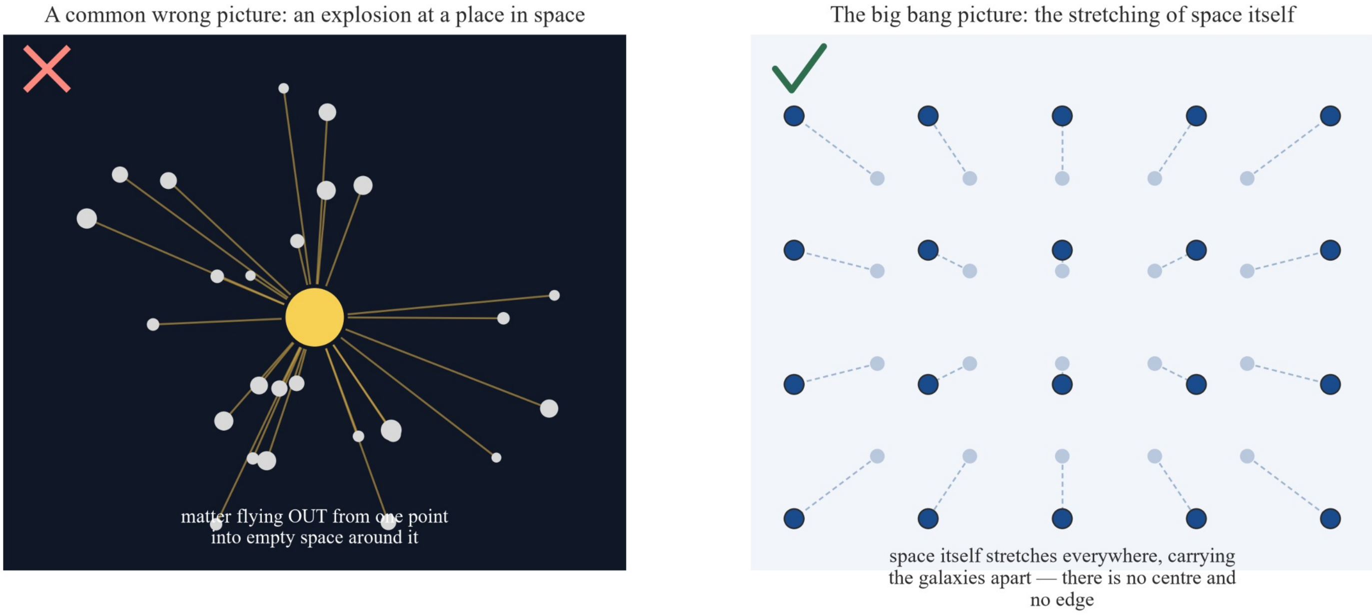
Theory

Two terms to get straight first.

The Victorian Curriculum uses the term *big bang theory* but does not define it. This subtopic therefore treats it as the scientific model in which the universe began about 13.8 billion years ago extremely hot and extremely dense, and has been expanding and cooling ever since; and every question is answerable on that definition alone.

The Victorian Curriculum uses the word *theory* in the scientific sense but does not define it. This subtopic therefore treats it as a model that ties together many independent lines of evidence and makes testable predictions — the opposite of a guess; and every question is answerable on that definition alone.

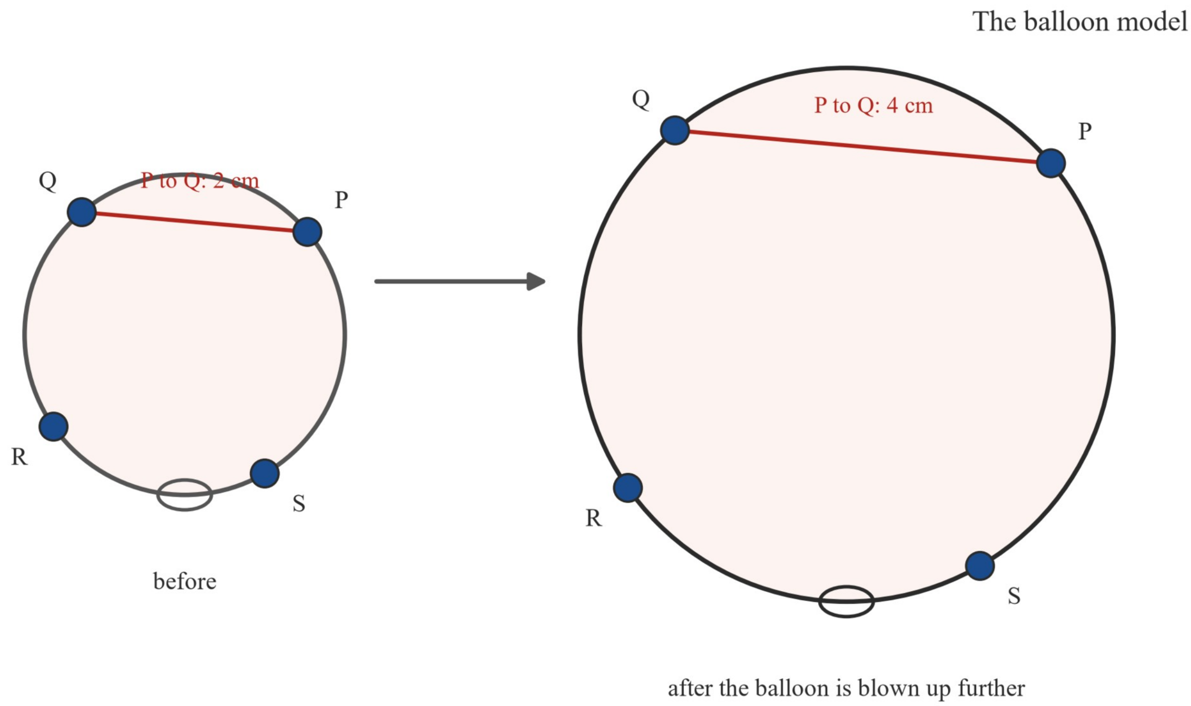
The big idea: space itself stretches. The most common wrong picture of the big bang is an explosion at one place in space, with matter flying out into empty space around it. That picture has a centre and an edge, and the real universe has neither. The big bang is better pictured as the stretching of space itself, everywhere at once, carrying the galaxies apart:



Faint dots: earlier positions; dark dots: later positions. Every dot sees every other dot moving away.

Left panel, crossed out: the wrong picture, matter flying out from one point into empty space around it. Right panel, ticked: the big bang picture, a grid of galaxies with space itself stretching everywhere and carrying every galaxy away from every other galaxy, so there is no centre and no edge

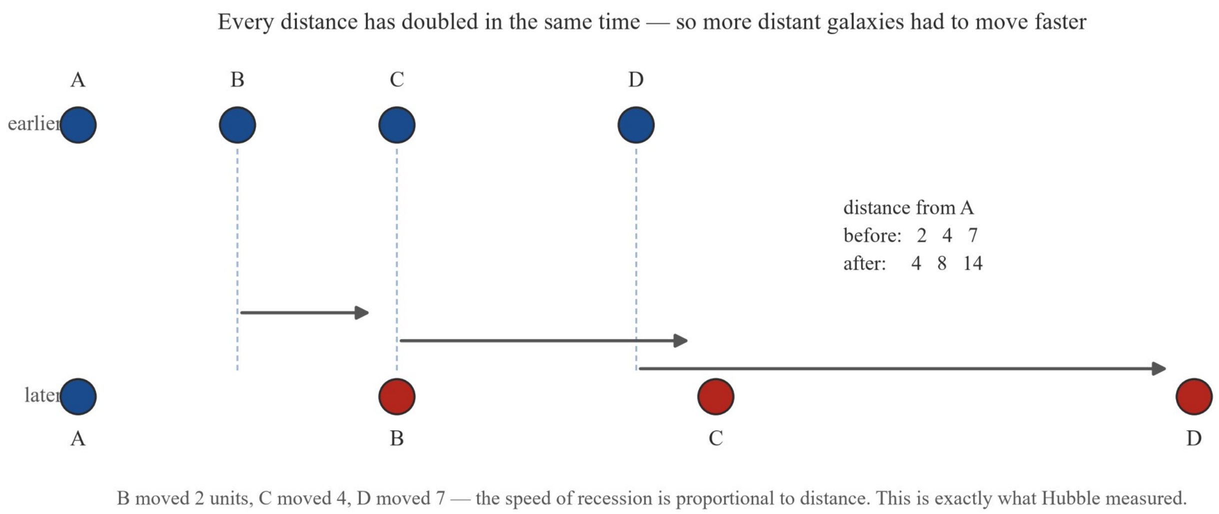
A good hands-on picture is the balloon model. The rubber stands for space and the dots stand for galaxies. As the balloon is blown up, every dot sees every other dot moving away, and dots that were further apart to start with separate faster — yet no dot on the surface is the centre:



The rubber is space and the dots are galaxies: every dot sees every other dot receding, and no dot on the surface is the centre.
(The real universe is not stretched INTO anything — only the surface matters.)

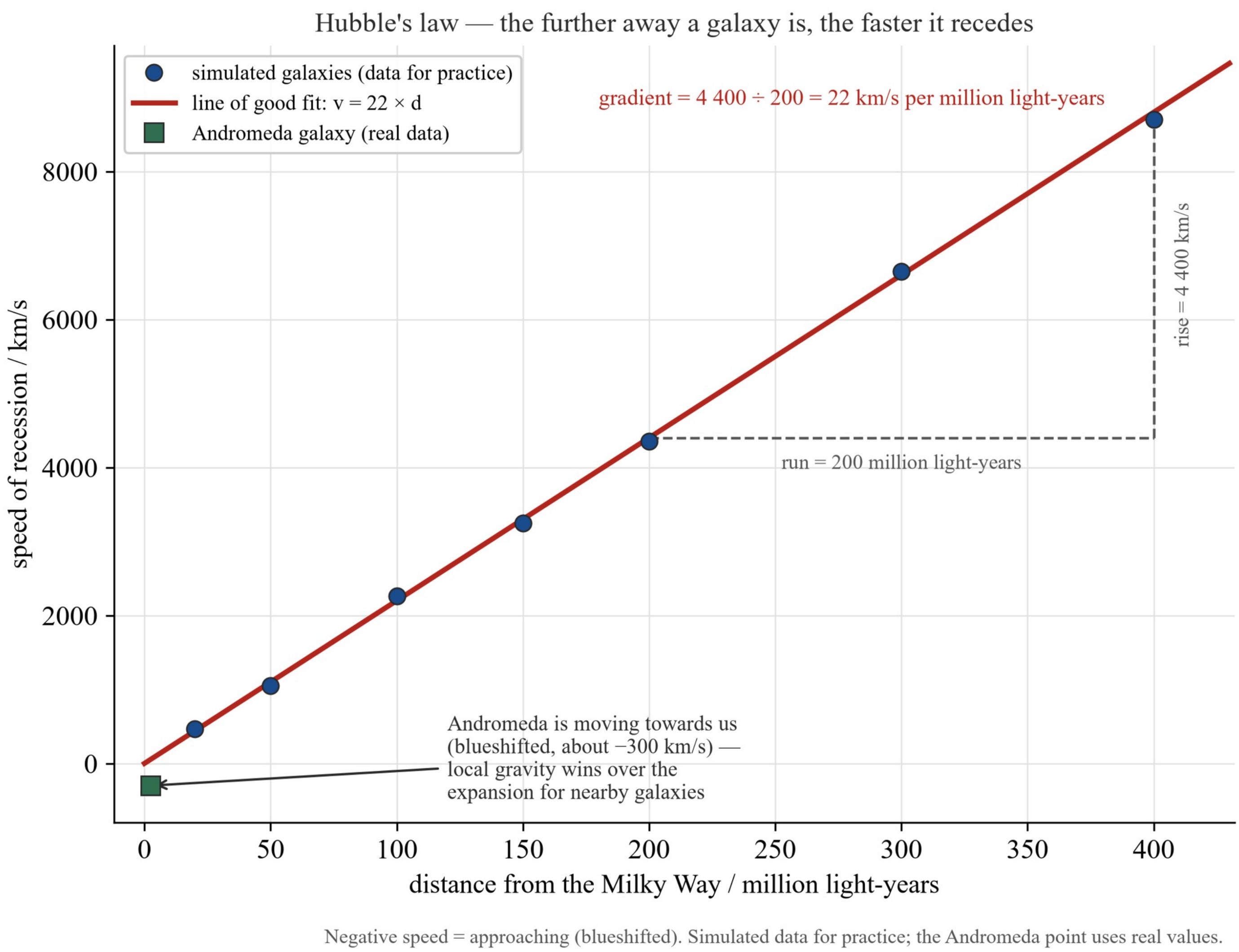
The balloon model: a partly blown balloon with four dots P, Q, R and S and the distance from P to Q marked as 2 cm, then the same balloon blown up further with P to Q now 4 cm; the rubber is space and the dots are galaxies, and no dot on the surface is the centre

The same idea on a flat strip of space: if every distance doubles in the same time, then the galaxy that was twice as far away had to cover twice the distance in the same time — so it moved twice as fast. Speed of moving away proportional to distance is exactly the pattern a stretching space must produce:



A strip of space with four galaxies A, B, C and D: when every distance doubles in the same time, B moves 2 units, C moves 4 units and D moves 7 units, so the more distant the galaxy the faster it moves — the pattern Hubble measured

Hubble's observations. In 1929 the American astronomer Edwin Hubble published a graph of galaxies' distances against their speeds of moving away, building on Vesto Slipher's earlier speed measurements and on Georges Lemaître's 1927 analysis. The points fell close to a straight line through the origin: the further the galaxy, the faster it moves away. That line is **Hubble's law**, and its gradient is called the **Hubble constant**, H_0:



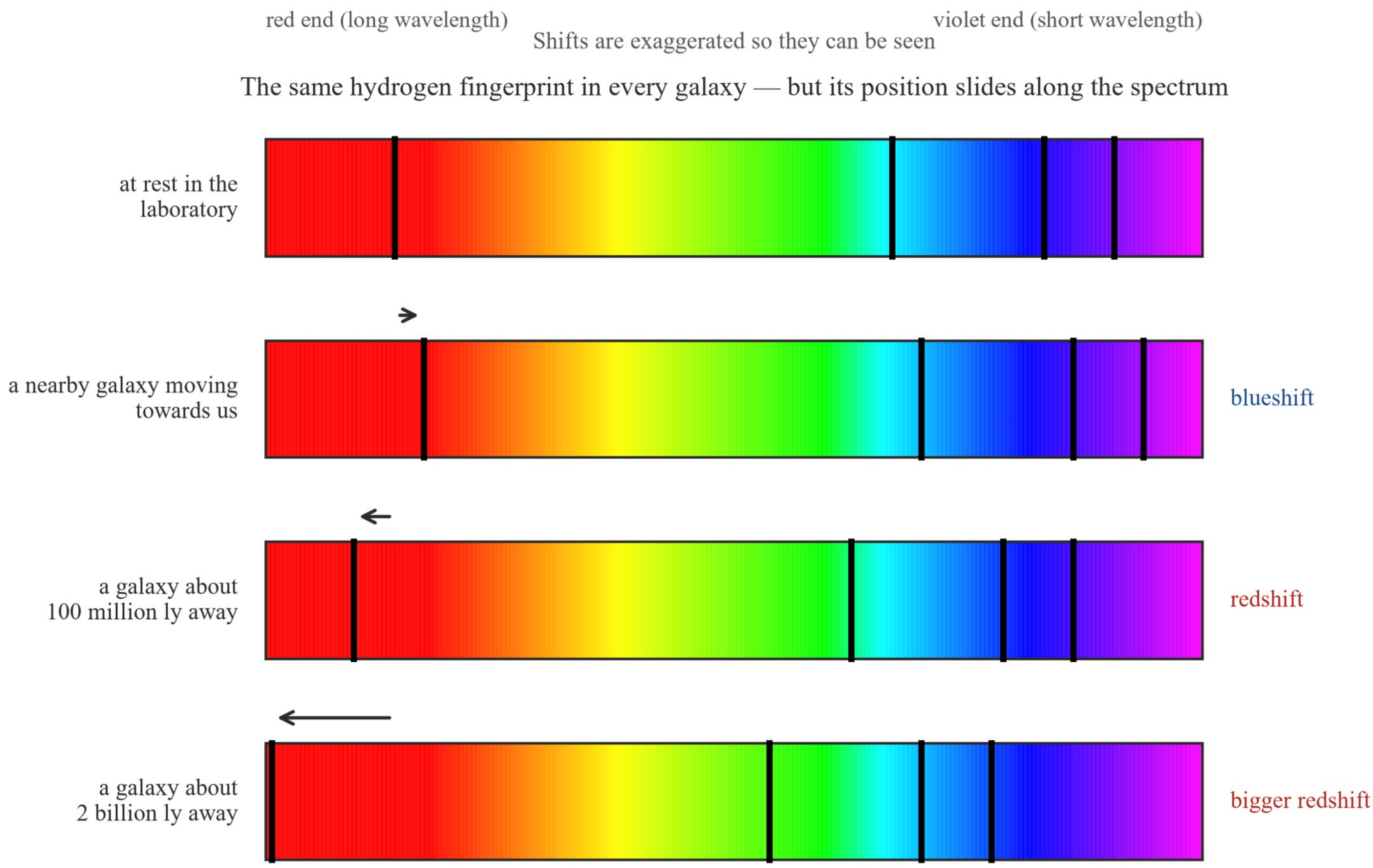
Graph of speed of moving away in km/s against distance in millions of light-years for galaxies, simulated data for practice in the shape of Hubble's real measurements: the points fall close to a straight line through the origin with *gradient about 22 km/s per million light-years; the Andromeda galaxy is plotted below the axis at about 2.5 million light-years, moving towards us at about 300 km/s*

In the units this book uses (13A's light-years, not the professional megaparsec), the gradient is about **22 km/s per million light-years**: a galaxy 100 million light-years away moves away at about 2200 km/s, and one 200 million light-years away at about 4400 km/s. The one nearby galaxy plotted below the axis, Andromeda, is moving *towards* us at about 300 km/s — its light is shifted to the violet end. That is no surprise to the model: Andromeda is close enough that the pull of gravity between it and the Milky Way wins over the stretching of space. Over larger distances the stretching always wins.

Source: Hubble, E., "A relation between distance and radial velocity among extra-galactic nebulae", Proceedings of the National Academy of Sciences, 1929. https://doi.org/10.1073/pnas.15.3.168 — retrieved 2026-08-21.

Source: NASA/IPAC Extragalactic Database (NED), "Andromeda galaxy", n.d. https://ned.ipac.caltech.edu/ — retrieved 2026-08-21.

Redshift — the evidence in the light. Subtopic 13A introduced the tool: spread a galaxy's light into a spectrum and the dark lines of each element's fingerprint appear. If the galaxy is moving away, every line is shifted towards the red end of the spectrum — a **redshift**; if it is moving towards us, towards the violet end — a **blueshift**. In an expanding universe there is a deeper way to say the same thing: while the light travels to us, space itself stretches, and the light's wavelengths are stretched with it. Longer wavelength means shifted towards the red:

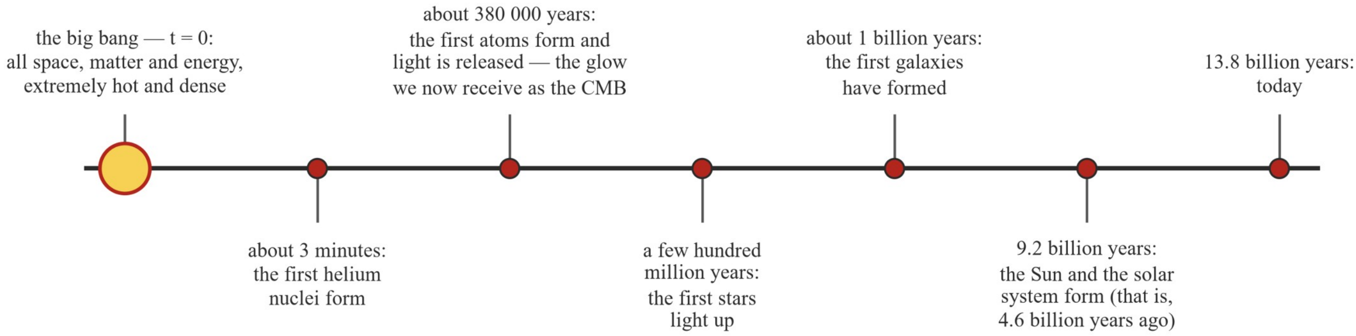


Four spectrum strips on the same wavelength scale with the red end at the left: the hydrogen fingerprint lines at rest in the laboratory; the same lines shifted towards the violet end for a galaxy moving towards us (blueshift); shifted towards the red end for a galaxy moving away (redshift); and shifted further towards the red end for a galaxy moving away faster (bigger redshift); the shifts are exaggerated so they can be seen

Hubble's great discovery was that almost every galaxy shows a redshift — almost every galaxy is moving away from us — and that the further away the galaxy, the bigger the redshift and the faster it moves away. We are not at the centre of anything: in a stretching space, every galaxy sees the same pattern. Run that film backwards and the universe was once smaller, hotter and denser. That backwards run is the big bang theory, and it makes predictions. The rest of this subtopic is the evidence that those predictions came true.

The history of the universe — the order of the key events. Sequencing these events is the key skill of this subtopic (as the achievement standard says). The timeline below shows the order; the true time gaps grow enormously, from minutes to billions of years:

The history of the universe — the order of the main events



Schematic — the equal spacings show the ORDER of events, not the true time gaps, which grow enormously (from minutes to billions of years: work them out in Activity 2 and Worked example 2).

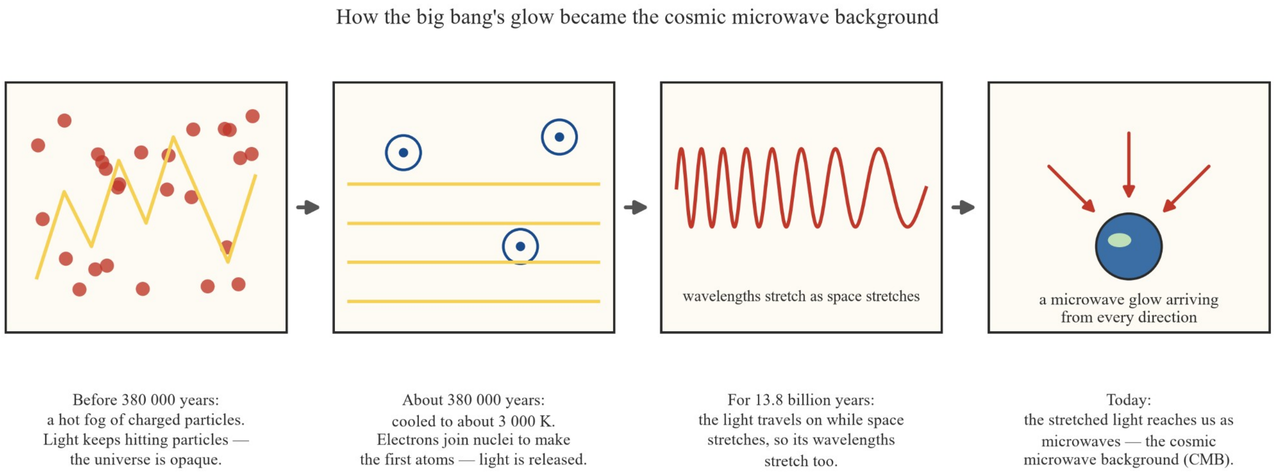
A timeline showing the order of the key events in the history of the universe: the big bang at t = 0; about 3 minutes, the first helium nuclei form; about 380 000 years, the first atoms form and light is released — the glow now received as the cosmic microwave background; a few hundred million years, the first stars light up; about 1 billion years, the first galaxies have formed; 9.2 billion years, the Sun and the solar system form; 13.8 billion years, today; the equal spacings show the order of events, not the true time gaps

Source: NASA, "The Big Bang", n.d. https://science.nasa.gov/universe/the-big-bang/ — retrieved 2026-08-21 (the order of the key events; the first helium nuclei in the first minutes; light released at about 380 000 years).

Source: NASA, "Solar System", n.d. https://science.nasa.gov/solar-system/ — retrieved 2026-08-21 (the age of the Sun and the solar system, 4.6 billion years).

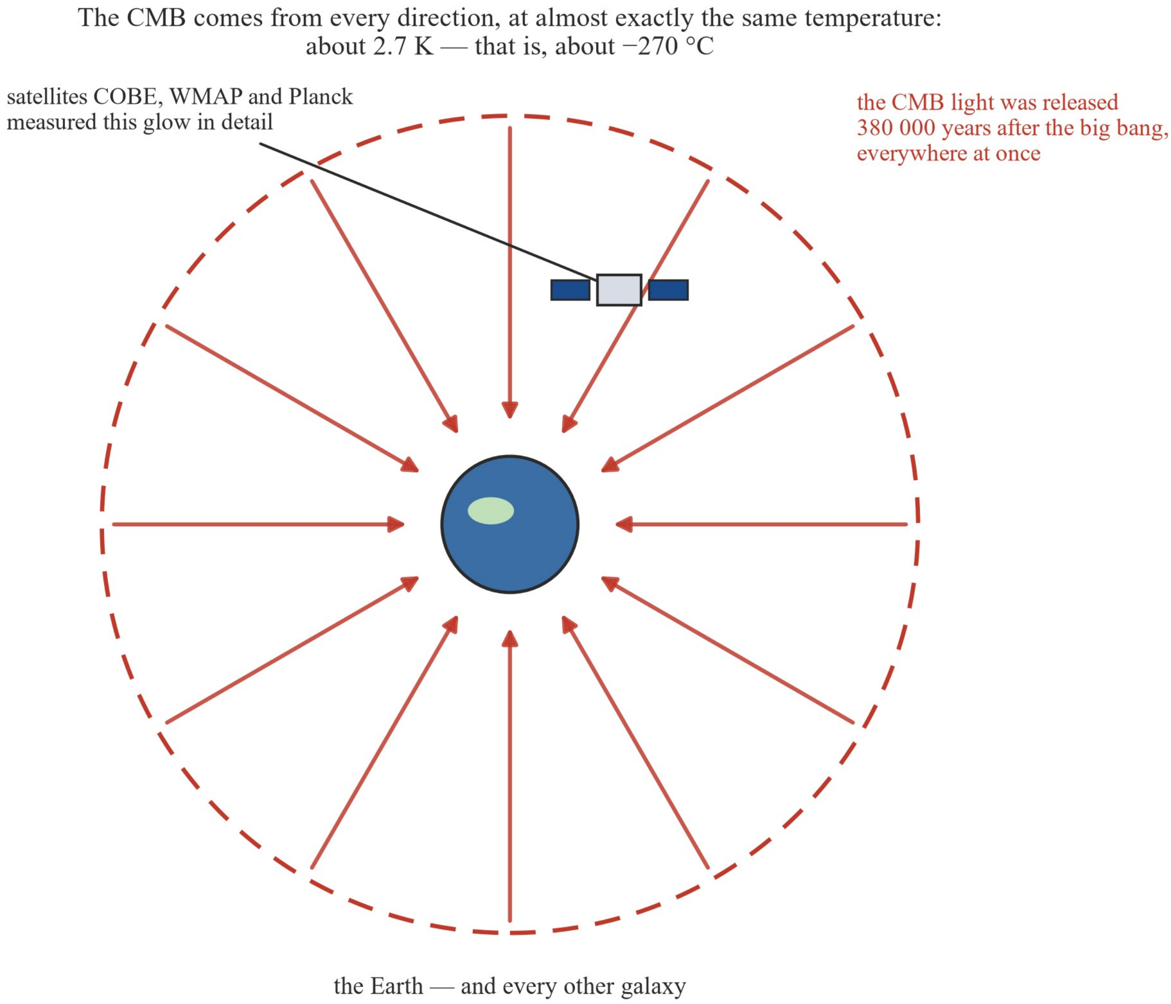
Source: NASA, "James Webb Space Telescope: First Galaxies", n.d. https://science.nasa.gov/mission/webb/science/first-galaxies/ — retrieved 2026-08-21 (the first stars a few hundred million years after the big bang; the first galaxies by about 1 billion years).

Evidence 1 — the cosmic microwave background. If the universe began hot and dense and has been cooling as it expands, then early on it was a hot fog of charged particles that light could not get through. About 380 000 years after the big bang the fog cooled to about 3 000 K, electrons joined nuclei to make the first atoms, and light was suddenly released. That light has been travelling ever since, and the stretching of space has stretched its wavelengths. Ralph Alpher, George Gamow and Robert Herman predicted in the 1940s that this leftover glow should still fill the sky; in 1965 Arno Penzias and Robert Wilson at Bell Labs in the United States found it by accident, as a steady radio noise coming from every direction. They shared the 1978 Nobel Prize in Physics for it.



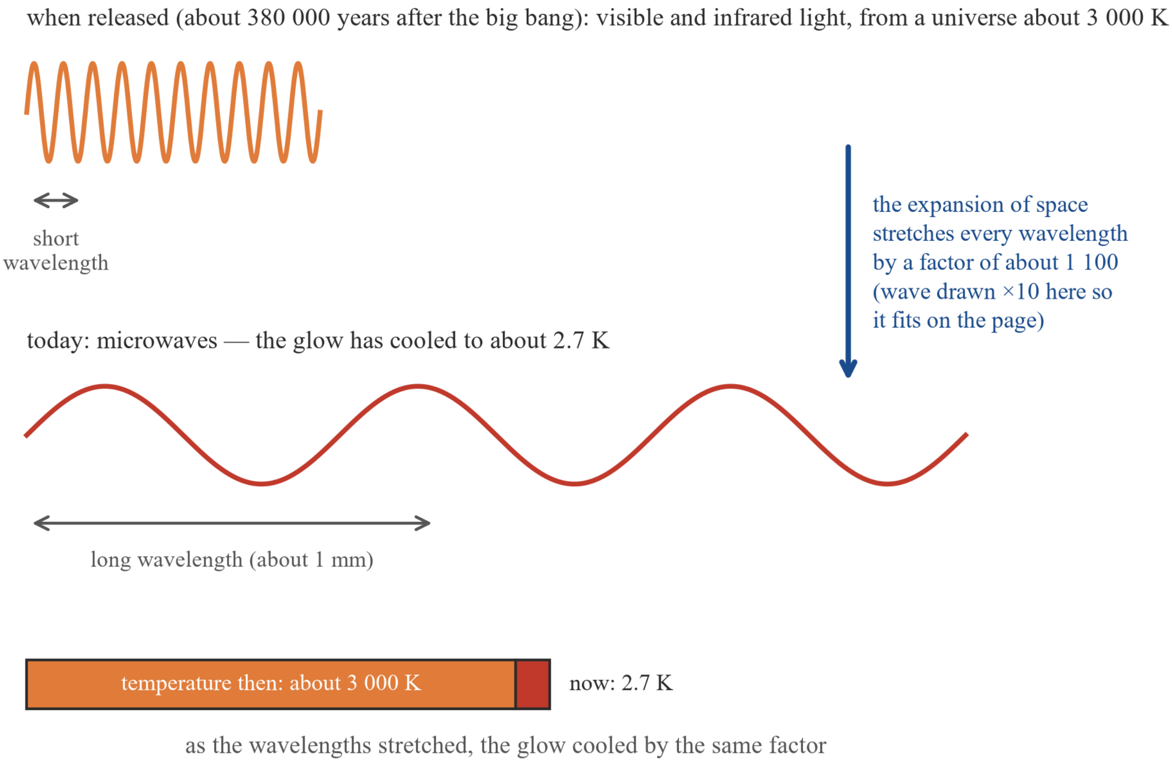
Four panels showing how the big bang's glow became the cosmic microwave background: before 380 000 years, a hot fog of charged particles that light keeps hitting, so the universe is not see-through; about 380 000 years, cooled to about 3 000 K, electrons join nuclei to make the first atoms and light is released; for 13.8 billion years the light travels on while space stretches, so its wavelengths stretch too; today, the stretched light reaches us from every direction as microwaves — the cosmic microwave background

The glow we receive today is the strongest single piece of evidence for the big bang theory. It arrives from every direction at almost exactly the same temperature, about 2.7 K — that is, about −270 °C — just as the model predicts for a glow released everywhere at once by a universe that was once hot:



The cosmic microwave background arriving at the Earth from every direction at almost exactly the same temperature, about 2.7 K; the satellites COBE, WMAP and Planck measured this glow in detail; the light was released 380 000 years after the big bang, everywhere at once

Why microwaves? When released, the glow was visible and infrared light from a universe at about 3 000 K. The expansion of space has stretched every wavelength by a factor of about 1 100 (the wave is drawn only about 10 times longer in the figure, or it would not fit on the page), and as the wavelengths stretched, the glow cooled by the same factor, from about 3 000 K to about 2.7 K. A wavelength of about 1 mm is in the microwave band — hence the name **cosmic microwave background (CMB)**:



Top: a short-wavelength wave, labelled "when released, about 380 000 years after the big bang: visible and infrared light, from a universe about 3 000 K". Bottom: the same wave stretched to a long wavelength of about 1 mm, labelled "today: microwaves — the glow has cooled to about 2.7 K"; a note states that the expansion of space stretches every wavelength by a factor of about 1 100, with the wave drawn 10 times longer here so it fits on the page

Source: Penzias, A. A. and Wilson, R. W., "A Measurement of Excess Antenna Temperature at 4080 Mc/s", The Astrophysical Journal, 1965. https://doi.org/10.1086/148307 — retrieved 2026-08-21.

Source: The Nobel Foundation, "The Nobel Prize in Physics 1978", 1978. https://www.nobelprize.org/prizes/physics/1978/summary/ — retrieved 2026-08-21.

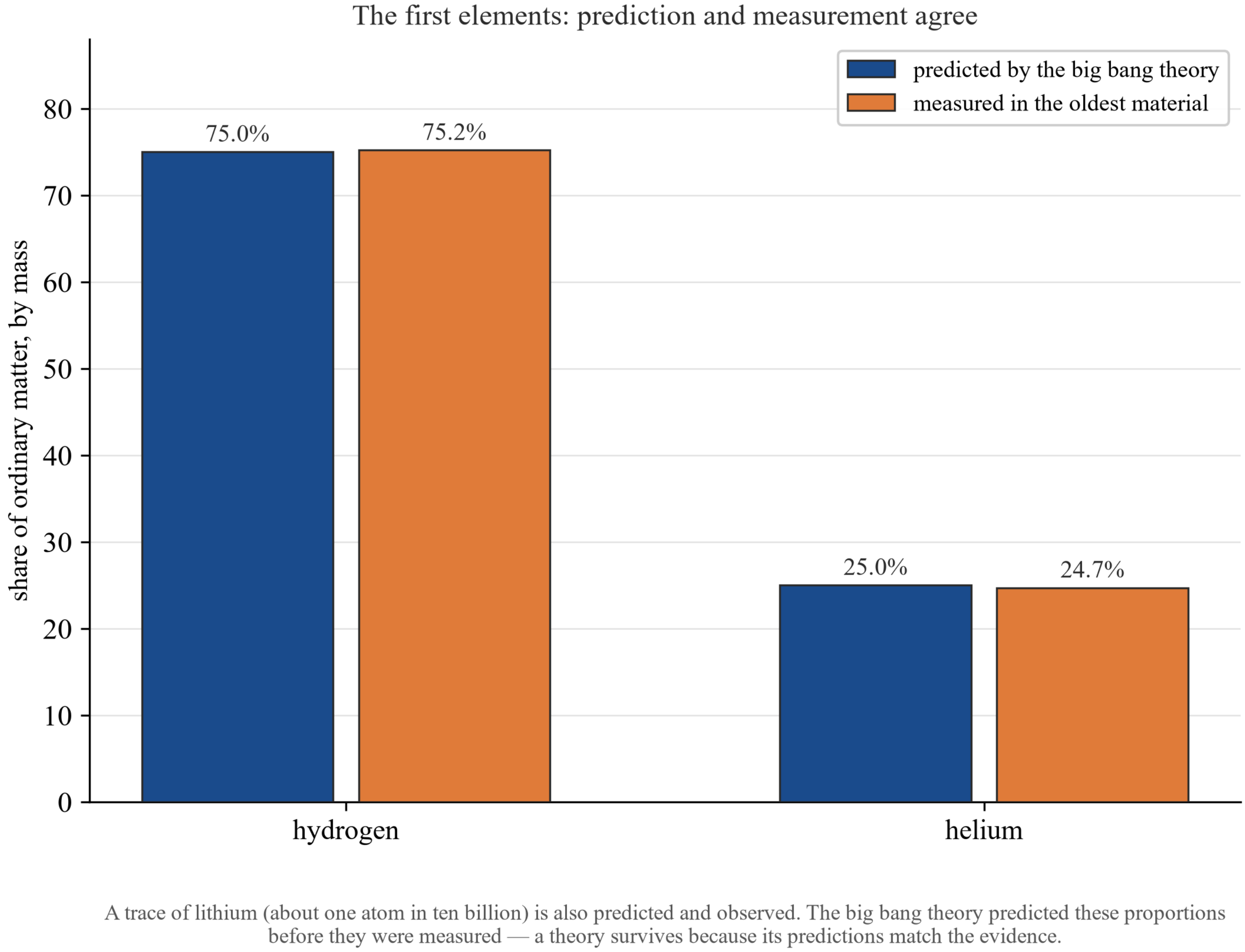
Source: Fixsen, D. J., "The Temperature of the Cosmic Microwave Background", The Astrophysical Journal, 2009. https://doi.org/10.1088/0004-637X/707/2/916 — retrieved 2026-08-21.

Source: NASA, "Cosmic Background Explorer (COBE)", n.d. https://science.nasa.gov/mission/cobe/ — retrieved 2026-08-21.

Source: NASA, "The Big Bang", n.d. https://science.nasa.gov/universe/the-big-bang/ — retrieved 2026-08-21 (the 1940s prediction of the leftover glow by Alpher, Gamow and Herman).

Evidence 2 — the redshift pattern and Hubble's law. The second line of evidence is the one Hubble measured: almost every galaxy is redshifted, and the speed of moving away is proportional to distance. That straight line is exactly what a stretching space must produce (the strip figure above), and running the expansion backwards gives a universe with a beginning. The gradient of the line, H_0, even lets us estimate the age of the universe: if the speed has been steady, the time since everything was together is $1 \div H_0$, which comes out close to 14 billion years — matching the measured age of 13.8 billion years (Worked example 3).

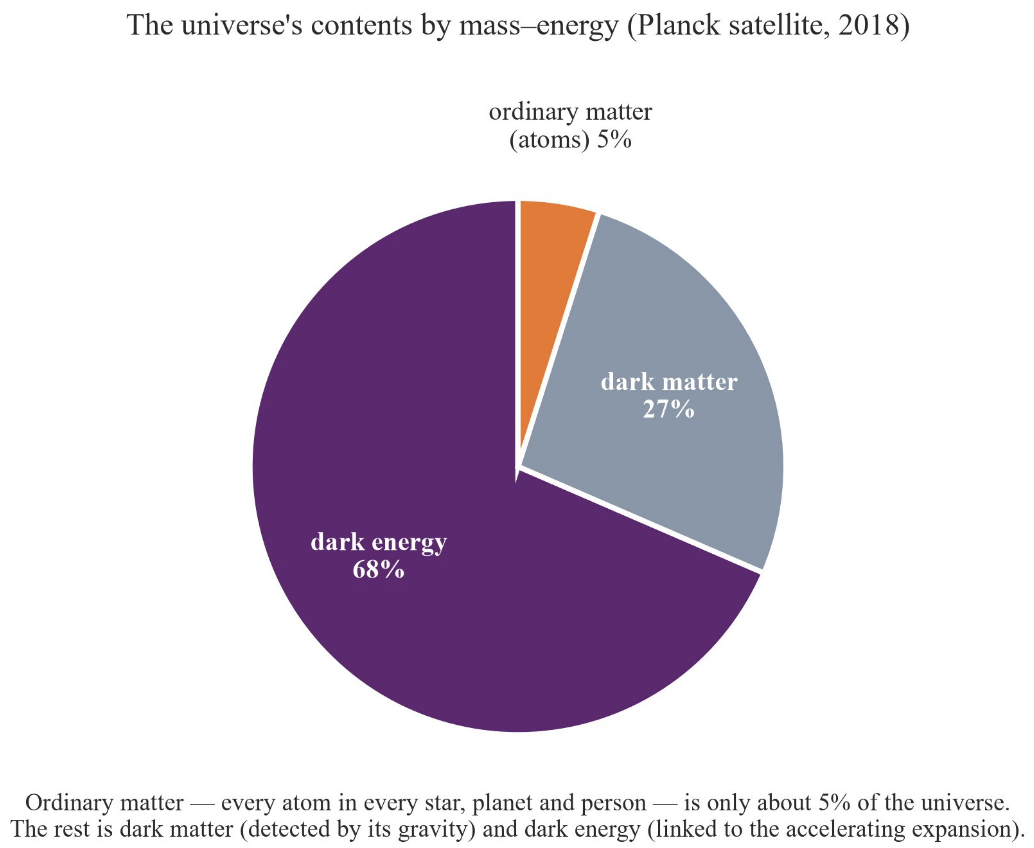
Evidence 3 — the mix of the elements. In its first few minutes the universe was hot enough and dense enough for hydrogen nuclei to join together and build helium nuclei. The big bang theory predicts how much: about one quarter of the mass of ordinary matter should be helium, with only traces of the next-lightest element, lithium. Astronomers measure the helium share in the oldest clouds of gas in the universe and find about 25% by mass — the prediction and the observation match. No other model explains why the oldest gas in the universe is one quarter helium:



Bar chart comparing prediction and observation for the share of the mass of ordinary matter: hydrogen about 75 parts in 100 and helium about 25 parts in 100, with the predicted bars and the observed bars almost identical; a note adds that only traces of lithium are predicted and observed

Source: Fields, B. D., Olive, K. A. and Yeh, T.-H., "Big-bang nucleosynthesis after Planck", Journal of Cosmology and Astroparticle Physics, 2020. https://doi.org/10.1088/1475-7516/2020/03/010 — retrieved 2026-08-21.

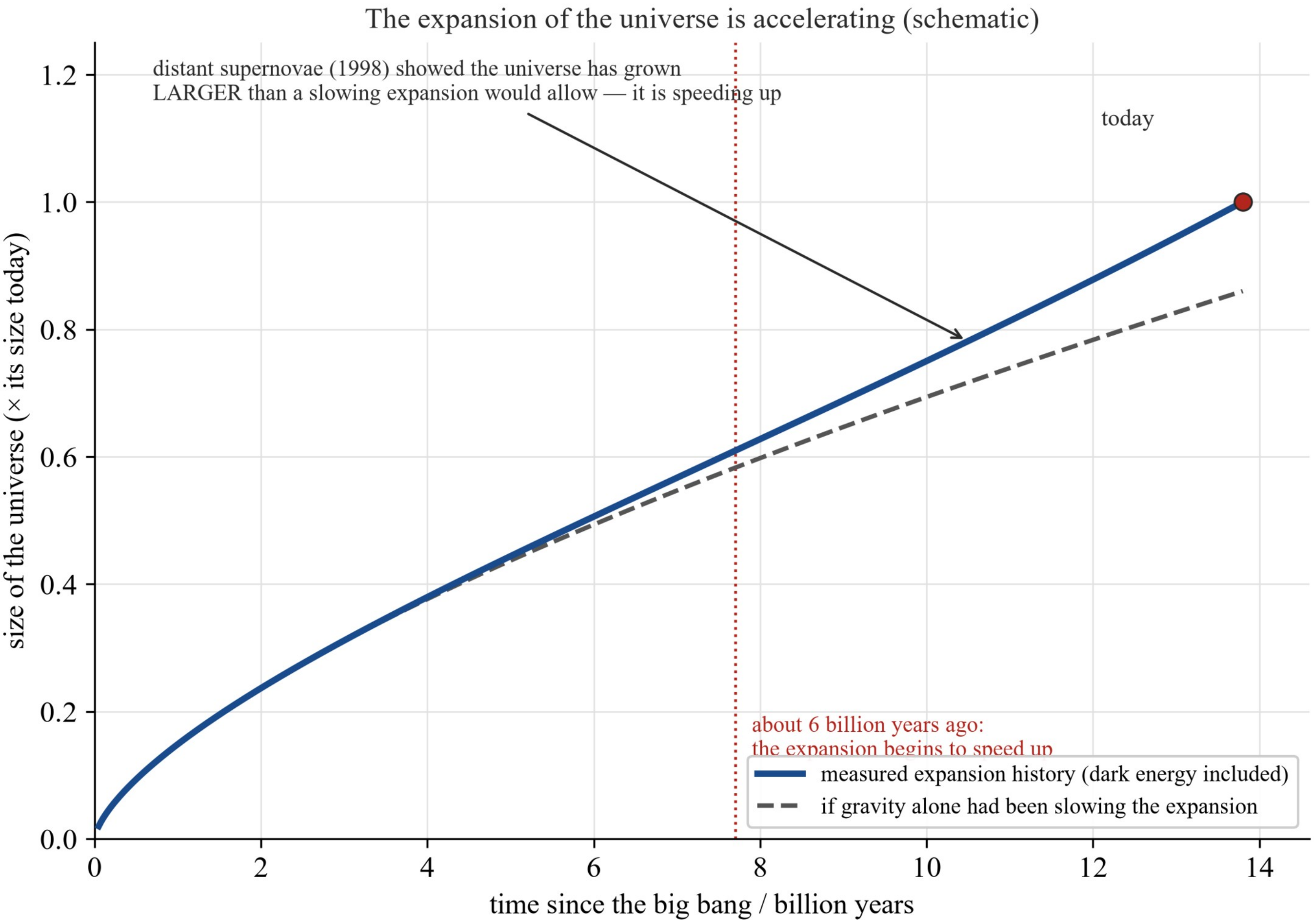
What the universe is made of. Adding up all the evidence, the Planck satellite's 2018 measurements give the recipe of the universe: ordinary atoms — everything in this book so far, every star and galaxy in 13A — are only about 5 parts in 100. About 27 parts in 100 are **dark matter**, matter that gives gravity but gives out no light; it is the extra gravity that holds galaxies together. About 68 parts in 100 are **dark energy**, the name given to whatever is making the expansion speed up. Honest note: dark matter and dark energy are names for things the evidence forces us to accept but does not yet fully explain — working them out is current research:



Pie chart of what the universe is made of, from the Planck satellite's 2018 measurements: dark energy about 68 parts in 100, dark matter about 27 parts in 100, and ordinary atoms about 5 parts in 100

Source: Planck Collaboration, "Planck 2018 results. VI. Cosmological parameters", Astronomy & Astrophysics, 2020. https://doi.org/10.1051/0004-6361/201833910 — retrieved 2026-08-21.

Evidence 4 — the expansion is accelerating. If gravity were the only actor, the pull of all that matter should be slowing the expansion down. In 1998 two teams measuring very distant supernovae — the explosions of dying stars, bright enough to see across billions of light-years — found the opposite: the universe has grown larger than a slowing expansion would allow, which means the expansion is speeding up. The 2011 Nobel Prize in Physics went to that discovery. The cause is what we call dark energy, the largest slice of the pie chart above:



Curves computed from the standard cosmological parameters (Planck 2018); drawn to show the shape of the expansion.

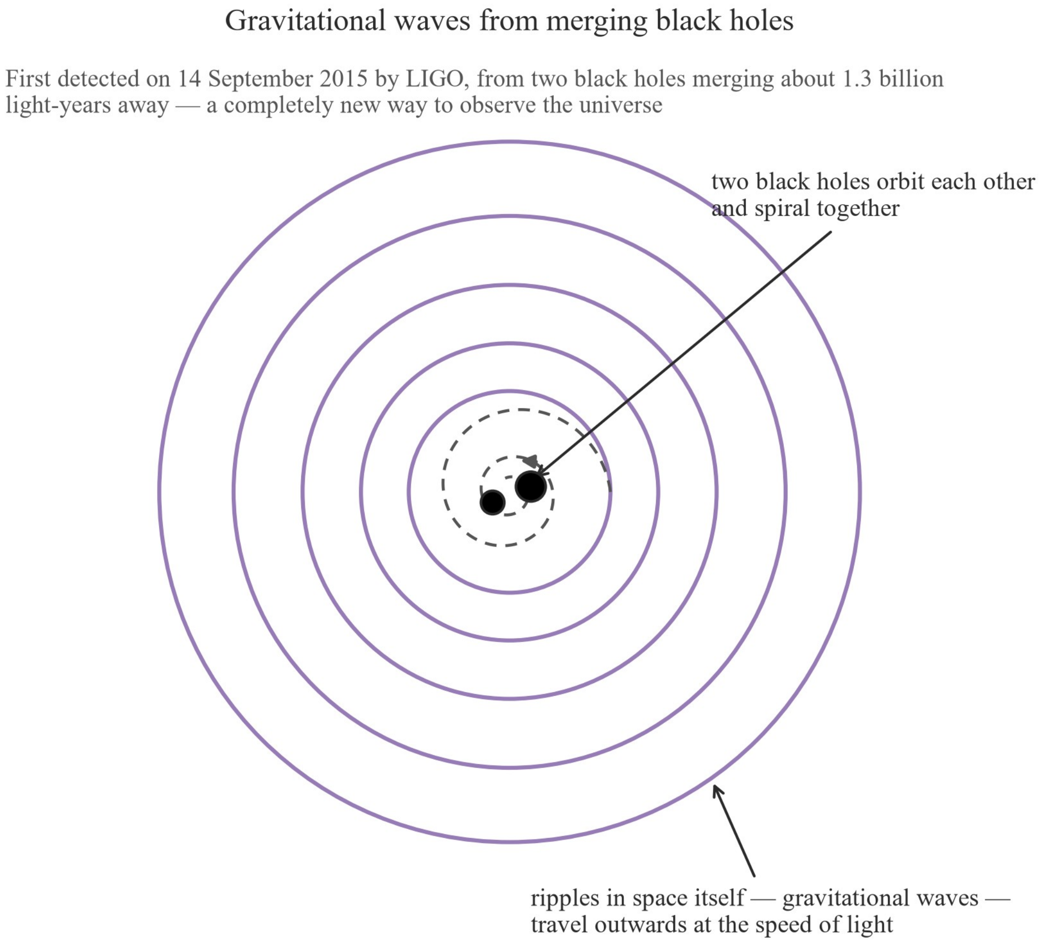
Graph of the size of the universe against time since the big bang, in billions of years: the measured expansion history, computed from the standard model parameters, rises above the dashed curve showing what gravity alone would have produced, so the expansion is speeding up; the speed-up begins about 6 billion years ago, and the distant supernovae of 1998 showed it

Source: Riess, A. G. et al., "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant", The Astronomical Journal, 1998. https://doi.org/10.1086/300499 — retrieved 2026-08-21.

Source: The Nobel Foundation, "The Nobel Prize in Physics 2011", 2011. https://www.nobelprize.org/prizes/physics/2011/summary/ — retrieved 2026-08-21.

Recent advances — new windows on the universe. The story does not stop in 1998. New instruments keep opening new windows, and each new window brings new data that the big bang theory has to face (E06):

- **Gravitational waves.** When two black holes spiral together and merge, they shake space itself, sending out ripples — **gravitational waves** — that travel outwards at the speed of light. On 14 September 2015 the LIGO detectors in the United States recorded such waves for the first time, from two black holes merging about 1.3 billion light-years away; the 2017 Nobel Prize in Physics followed. Until then, everything known about the universe had come from light and other radiation; gravitational waves are a completely new kind of signal:

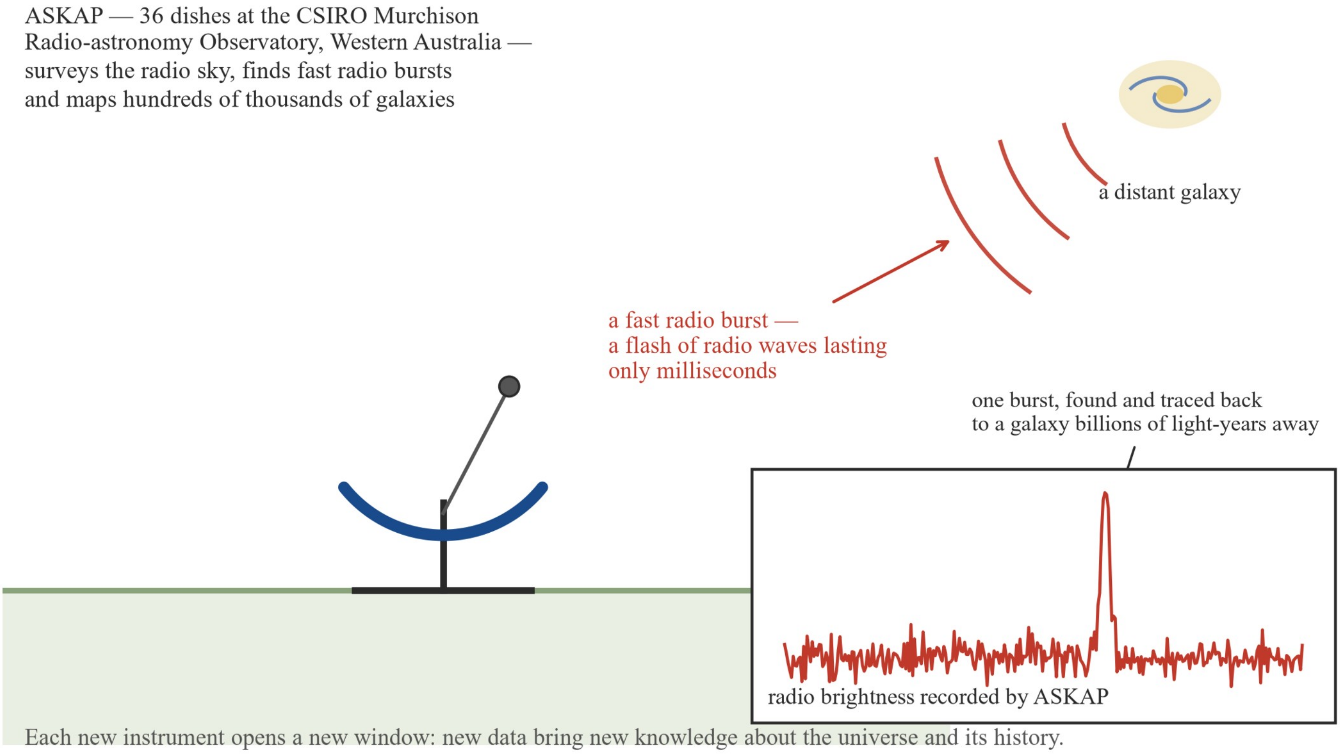


Two black holes orbiting each other and spiralling together at the centre, with rings of ripples in space itself — gravitational waves — travelling outwards at the speed of light; first detected on 14 September 2015 by LIGO, from two black holes merging about 1.3 billion light-years away

Source: Abbott, B. P. et al. (LIGO Scientific Collaboration and Virgo Collaboration), "Observation of Gravitational Waves from a Binary Black Hole Merger", Physical Review Letters, 2016. https://doi.org/10.1103/PhysRevLett.116.061102 — retrieved 2026-08-21.

Source: The Nobel Foundation, "The Nobel Prize in Physics 2017", 2017. https://www.nobelprize.org/prizes/physics/2017/summary/ — retrieved 2026-08-21.

- **ASKAP.** The Australian Square Kilometre Array Pathfinder is 36 radio dishes at the CSIRO Murchison Radio-astronomy Observatory in Western Australia, working together as one telescope. ASKAP surveys the radio sky, finds **fast radio bursts** — flashes of radio waves from distant galaxies that last only milliseconds — and maps hundreds of thousands of galaxies, tracing how the universe's structure grew:



One of ASKAP's 36 radio dishes at the CSIRO Murchison Radio-astronomy Observatory in Western Australia receiving wavefronts of a fast radio burst from a distant galaxy; an inset shows the radio brightness recorded by ASKAP, a single short spike above the background noise, for one burst traced back to a galaxy billions of light-years away

Source: CSIRO, "Australian Square Kilometre Array Pathfinder (ASKAP)", n.d. https://www.csiro.au/en/research/technology-space/askap — retrieved 2026-08-21.

- **Dark matter and dark energy surveys.** The same new instruments, with space telescopes, are measuring the 95 parts in 100 of the universe we cannot yet identify — the current frontier named in the pie chart above.

Why a theory, not a guess. Return to the definition box. The CMB, the redshift pattern, Hubble's law, the helium share and the expansion history are independent lines of evidence, and each one matches a prediction the model made before the measurement was done. A model that survives test after test like that is, in the scientific sense of the word, a **theory** — and when new data arrive, as with the accelerating expansion in 1998, the model is tested again and sharpened, not protected. That is the behaviour of science working as it should.

Activities

Activity 1 — The balloon universe, measured. Work in pairs with one balloon, a marker and a ruler. Partly blow up the balloon and mark four dots A, B, C, D on it. Measure the six distances between the dots along the rubber and record them in a table ("before"). Blow the balloon up further, measure the same six distances again ("after"), and add two columns: the increase (after − before) and the increase divided by the before-distance. Compare your pairs: which pair of dots separated fastest, and how does that relate to their before-distance? Does any dot sit at the "centre" of the rubber's surface? Connect your last two columns to Hubble's law. (A simulated example: before 2, 4, 7 cm and after 4, 8, 14 cm gives increases 2, 4, 7 cm — every increase equal to its before-distance, so the further apart the dots, the faster they separate. Simulated data for practice.)

Activity 2 — Sequencing the universe and its gaps. Using the timeline figure, copy the seven events onto cards and shuffle them; race a partner to put them back in order. Then do the arithmetic of the gaps (scientific notation, `VC2M9M02`, reused not re-taught): (a) write the age of the universe, 13.8 billion years, in years as 1.38×10^{10}; (b) write the release of the CMB, 380 000 years, as 3.8×10^5 years, and calculate how many years later the Sun formed (9.2 billion years after the big bang): $9.2 \times 10^9 - 3.8 \times 10^5$; (c) calculate the CMB time as a percentage of the age of the universe and comment; (d) the figure spaces the seven events equally — using your answers, explain in one sentence why the figure says the spacings show the order, not the true gaps.

Activity 3 — Hubble's graph from the data. The table below is simulated data for practice, in the shape of Hubble's real 1929 measurements.

distance / million light-years	20	50	100	150	200	300	400
speed of moving away / km per s	470	1050	2260	3250	4350	6650	8700

Plot speed (y-axis) against distance (x-axis), draw a line of best fit through the origin, and calculate its gradient using two points on the line (for example the gradient triangle on the Hubble figure: 4400 km/s ÷ 200 million light-years). State the gradient with its units and say what it is called. Use your line to estimate the distance of a galaxy moving away at 5500 km/s. Finally: if every galaxy has been moving at a steady speed, a galaxy 100 million light-years away has taken its-distance ÷ its-speed to get there — calculate that time in years (about 1.4×10^{10} years) and say what it suggests about the universe's past.

Worked examples

Data in this section are quoted to the significant figures shown, and final answers match the precision of the given data unless the arithmetic is exact.

Example 1 — scaffolded

Hubble's law with $H_0 \approx 22$ km/s per million light-years: speed of moving away = H_0 × distance. (a) Calculate the speed of a galaxy 150 million light-years away. (b) A galaxy moves away at 5500 km/s. Calculate its distance.

Working	Comment
(a) speed = 22 km/s per million light-years × 150 million light-years	Hubble's law: multiply the distance by the gradient H_0.
speed = 3300 km/s	Three significant figures, matching the data.
(b) distance = speed ÷ H_0 = 5500 km/s ÷ 22 km/s per million light-years	Rearranging the same law: distance is speed divided by the gradient.
distance = 250 million light-years	The same line read backwards.

Example 2 — scaffolded

The age of the universe is 13.8 billion years; the Sun and solar system formed 4.6 billion years ago; the CMB light was released 380 000 years after the big bang. (a) Calculate how long after the big bang the Sun formed. (b) Calculate the release of the CMB as a percentage of the age of the universe.

Working	Comment
(a) 13.8 − 4.6 = 9.2 billion years	"4.6 billion years ago" means 4.6 billion years before today, so subtract from the age.
(b) age = 1.38×10^{10} years; CMB time = 3.8×10^5 years	Scientific notation (`VC2M9M02`): billion = 10^9.
percentage = ($3.8 \times 10^5 \div 1.38 \times 10^{10}$) × 100 = 0.0028%	The CMB light went out before 0.003% of the universe's history had passed.

Example 3 — unscaffolded

Professionals quote $H_0 \approx 70$ km/s per megaparsec, where one megaparsec (Mpc) is about 3.26 million light-years, or 3.09 × 10^19 km. (The Planck satellite's precise value is 67.4 km/s per megaparsec — source above; 70 is the rounded value used for this estimate.) Estimate the age of the universe by running the expansion backwards at steady speed.

Time = distance ÷ speed for a galaxy at 1 Mpc moving at 70 km/s:

$$t = \frac{3.09 \times 10^{19}\,\text{km}}{70\,\text{km/s}} = 4.4 \times 10^{17}\,\text{s}.$$

Convert seconds to years (1 year = 3.156 × 10^7 s):

$$t = \frac{4.4 \times 10^{17}}{3.156 \times 10^{7}} = 1.4 \times 10^{10}\,\text{years} = 14\,\text{billion years}.$$

That estimate — called the Hubble time — is close to the measured age of 13.8 billion years. It is not exact because the expansion speed has not been steady (the expansion is accelerating), but the match is a striking piece of the evidence.

Example 4 — unscaffolded

The CMB glow was released at about 3 000 K and is received today at about 2.7 K. The expansion stretched every wavelength by the same factor the glow cooled. Show that a wave released at 1000 nm (infrared) arrives today at about 1 mm, in the microwave band.

Stretch factor:

$$\frac{3000\,\text{K}}{2.7\,\text{K}} \approx 1100.$$

Stretched wavelength:

$$1000\,\text{nm} \times 1100 = 1.1 \times 10^{6}\,\text{nm} = 1.1\,\text{mm},$$

since 1 mm = 10^6 nm. A wavelength of about 1 mm is a microwave — which is why the big bang's glow is called the cosmic microwave **background**: it fills the sky from every direction.

Practice questions

Scaffolded questions

Question 1 The big bang theory models the origin and evolution of the universe. (a) State the age of the universe in this model. (b) State two words describing the universe at the beginning. (c) State what has been happening to the universe ever since.

Question 2 About the cosmic microwave background. (a) State the band of the electromagnetic spectrum it is in today. (b) State its temperature today, in kelvin and in degrees Celsius. (c) Explain in one sentence why its arriving from every direction supports the big bang theory.

Question 3 A galaxy's spectrum shows the hydrogen fingerprint lines shifted towards the red end, compared with the laboratory. (a) Is the galaxy moving towards us or away from us? (b) State what has happened to the wavelengths of its light. (c) Give the one-word name of this shift.

Question 4 Use Hubble's law with $H_0 \approx 22$ km/s per million light-years. (a) Calculate the speed of moving away of a galaxy 50 million light-years away. (b) Calculate the speed of a galaxy 200 million light-years away. (c) Compare (a) and (b): what pattern do they show?

Question 5 Put these six events in order from earliest to latest: today; the first atoms form and light is released; the Sun and the solar system form; the big bang; the first galaxies have formed; the first helium nuclei form.

Question 6 About the balloon model. (a) State what the rubber stands for. (b) State what the dots stand for. (c) Explain why it is a mistake to ask which dot is at the centre of the universe.

Unscaffolded questions

Question 7 (a) Explain in two sentences why the big bang was not an explosion at one place in space. (b) State what is actually expanding.

Question 8 About Hubble's 1929 graph. (a) Describe the pattern the points showed. (b) State what the gradient of the line is called and what its value is in this book's units. (c) The Andromeda galaxy moves towards us at about 300 km/s. Explain why this does not break the model.

Question 9 A galaxy moves away from us at 6600 km/s. Use $H_0 \approx 22$ km/s per million light-years to estimate its distance in millions of light-years.

Question 10 The CMB was released at about 3 000 K and is received at about 2.7 K. (a) Calculate the factor by which the expansion has stretched the wavelengths. (b) A wave released at 1000 nm is received at what wavelength, in millimetres? (c) Name the band it is in today.

Question 11 (a) State the big bang prediction for the share of helium in the mass of ordinary matter. (b) Explain in one sentence why the match between that prediction and the observation counts as evidence for the theory.

Question 12 (a) Write the age of the universe, 13.8 billion years, in years in scientific notation. (b) The solar system is 4.6 × 10^9 years old. Calculate how many times older the universe is than the solar system, to 3 significant figures. (c) The CMB was released 3.8 × 10^5 years after the big bang. Calculate that time as a percentage of the age of the universe.

Question 13 About the pie chart of what the universe is made of. (a) List the three shares, largest first. (b) State which share is the name given to the cause of the accelerating expansion. (c) State honestly what the theory says about our current knowledge of the two "dark" shares.

Question 14 In 1998 two teams measuring very distant supernovae made a discovery that won the 2011 Nobel Prize in Physics. (a) State what they found out about the expansion of the universe. (b) Give the name assigned to the cause. (c) Which feature of a scientific theory (as defined in this subtopic's definition box) does this episode show?

Question 15 (a) State what produced the gravitational waves first detected on 14 September 2015, and how far away the source was. (b) Name the instrument that detected them. (c) Explain in one sentence why gravitational waves are called "a completely new way to observe the universe".

Question 16 (a) State where ASKAP is and what kind of waves it collects. (b) Define a fast radio burst. (c) Explain in one sentence how new instruments such as ASKAP and LIGO keep the big bang theory a testable model rather than a settled story.

Answers

Question 1 (a) about 13.8 billion years; (b) extremely hot and extremely dense; (c) expanding and cooling. **Question 2** (a) microwaves; (b) about 2.7 K, about −270 °C; (c) see solution. **Question 3** (a) away from us; (b) they have been stretched (made longer); (c) redshift. **Question 4** (a) 1100 km/s; (b) 4400 km/s; (c) four times the distance, four times the speed — proportional. **Question 5** Big bang; first helium nuclei form; first atoms form and light is released; first galaxies have formed; Sun and solar system form; today. **Question 6** (a) space; (b) galaxies; (c) see solution. **Question 7** (a) see solution; (b) space itself. **Question 8** (a) a straight line through the origin: speed proportional to distance; (b) the Hubble constant, about 22 km/s per million light-years; (c) see solution. **Question 9** 300 million light-years. **Question 10** (a) about 1100; (b) about 1.1 mm; (c) microwaves. **Question 11** (a) about one quarter (25%) by mass; (b) see solution. **Question 12** (a) 1.38 × 10^10 years; (b) 3.00 times; (c) about 0.0028%. **Question 13** (a) dark energy about 68%, dark matter about 27%, ordinary atoms about 5%; (b) dark energy; (c) see solution. **Question 14** (a) the expansion is speeding up, not slowing down; (b) dark energy; (c) see solution. **Question 15** (a) two black holes merging, about 1.3 billion light-years away; (b) LIGO; (c) see solution. **Question 16** (a) the CSIRO Murchison Radio-astronomy Observatory, Western Australia; radio waves; (b) see solution; (c) see solution.

Fully-worked solutions

Question 1 (a) About **13.8 billion years**. (b) **Extremely hot and extremely dense.** (c) The universe has been **expanding and cooling** ever since.

Question 2 (a) **Microwaves** — hence "microwave background". (b) About **2.7 K**, which is about **−270 °C**. (c) The big bang happened everywhere at once, not at one place, so its leftover glow must arrive from every direction — and it does, at almost exactly the same temperature everywhere.

Question 3 (a) **Away from us —** lines shifted to the red end mean the wavelengths have stretched. (b) The wavelengths have been **stretched** (made longer). (c) A **redshift**.

Question 4 (a) 22 × 50 = **1100 km/s**. (b) 22 × 200 = **4400 km/s**. (c) 4 times the distance gives 4 times the speed: the speed of moving away is **proportional to the distance** — Hubble's law.

Question 5 Big bang → first helium nuclei form (about 3 minutes) → first atoms form and light is released (about 380 000 years) → first galaxies have formed (about 1 billion years) → Sun and solar system form (9.2 billion years) → today (13.8 billion years). The first stars light up a few hundred million years after the big bang, between the release of the light and the first galaxies.

Question 6 (a) The rubber stands for **space**. (b) The dots stand for **galaxies**. (c) The stretching happens everywhere on the surface at once, so every dot sees every other dot moving away; no dot on the surface is the centre, and the question assumes the wrong picture (an explosion from a centre).

Question 7 (a) An explosion at one place would have a centre and an edge, and matter flying out into empty space around it; the universe shows neither a centre nor an edge, and the galaxies are not moving *through* space away from a point. (b) **Space itself** is expanding — stretching everywhere at once, carrying the galaxies apart.

Question 8 (a) The points fell close to a **straight line through the origin**: the further the galaxy, the faster it moves away. (b) The **Hubble constant**, H_0, about **22 km/s per million light-years**. (c) Andromeda is close enough that the pull of **gravity** between it and the Milky Way wins over the stretching of space; the law describes the stretching, which always wins over larger distances.

Question 9 Distance = speed ÷ H_0 = 6600 ÷ 22 = **300 million light-years**.

Question 10 (a) 3000 ÷ 2.7 ≈ **1100**. (b) 1000 nm × 1100 = 1.1 × 10^6 nm = **1.1 mm** (1 mm = 10^6 nm). (c) **Microwaves** — a wavelength of about 1 mm is in the microwave band.

Question 11 (a) About **one quarter of the mass (25%)** of ordinary matter should be helium, with only traces of lithium. (b) The theory **predicted the share before it was measured**, and the observation of the oldest gas clouds matches it; a model whose predictions come true is supported by that match, and no other model explains the quarter-helium oldest gas.

Question 12 (a) 13.8 billion years = 13.8×10^9 years = $\mathbf{1.38 \times 10^{10}}$ **years**. (b) $1.38 \times 10^{10} \div 4.6 \times 10^9 =$ **3.00** (3 s.f.) — the universe is about three times older than the solar system. (c) $(3.8 \times 10^5 \div 1.38 \times 10^{10}) \times 100 = 2.75 \times 10^{-3}$ % ≈ **0.0028%** — the CMB light was released before 0.003% of the universe's history had passed, which is why the timeline figure's equal spacings cannot be to scale.

Question 13 (a) **Dark energy about 68 parts in 100; dark matter about 27 parts in 100; ordinary atoms about 5 parts in 100** (Planck 2018). (b) **Dark energy.** (c) They are names for things the evidence forces us to accept but does not yet fully explain — current research, not settled knowledge.

Question 14 (a) The expansion of the universe is **speeding up (accelerating)**, not slowing down as gravity alone would make it. (b) **Dark energy.** (c) A scientific theory makes **testable predictions**, and when new data arrive the model is tested and sharpened: the 1998 supernova data tested the prediction of a slowing expansion and changed the model.

Question 15 (a) **Two black holes spiralling together and merging**, about **1.3 billion light-years away**. (b) The **LIGO** detectors (United States). (c) Everything before 2015 came from light and other radiation; gravitational waves are ripples in space itself — a **new kind of signal**, so a new window on the universe.

Question 16 (a) At the **CSIRO Murchison Radio-astronomy Observatory in Western Australia**; it collects **radio waves** with 36 dishes working together. (b) A **fast radio burst** is a flash of radio waves from a distant galaxy that lasts only milliseconds. (c) Each new instrument brings **new data the model must face** — new bursts, new maps of galaxies, new events in gravitational waves — so the theory keeps being tested rather than taken for granted.

Where this leads: within this book, 13B completes `VC2S10U13` together with 13A: the features limb delivered there is the cast of this subtopic's story, and 13A's Doppler shift of spectral lines is the tool its redshift evidence is read with. `VC2S10U13.E01` remains withheld under the TOC's D10 ICIP decision and is not restored anywhere in this series. Beyond school, be honest about the destination: cosmology is not a VCE science Area of Study, and no VCE unit teaches the big bang as content (TOC §5, reference-only, D12). What does carry forward is the reasoning and the numeracy: sequencing events and reading a model against several independent lines of evidence, the scientific meaning of *theory* (CONTESTED_TERMS Rule 1), and scientific notation and orders of magnitude for very large timescales (`VC2M9M02`), assumed again by Chemistry and Physics. No VCE content is pre-taught here (TOC D9).

Space exploration: what it seeks to learn, and the problems of humans travelling and living away from Earth

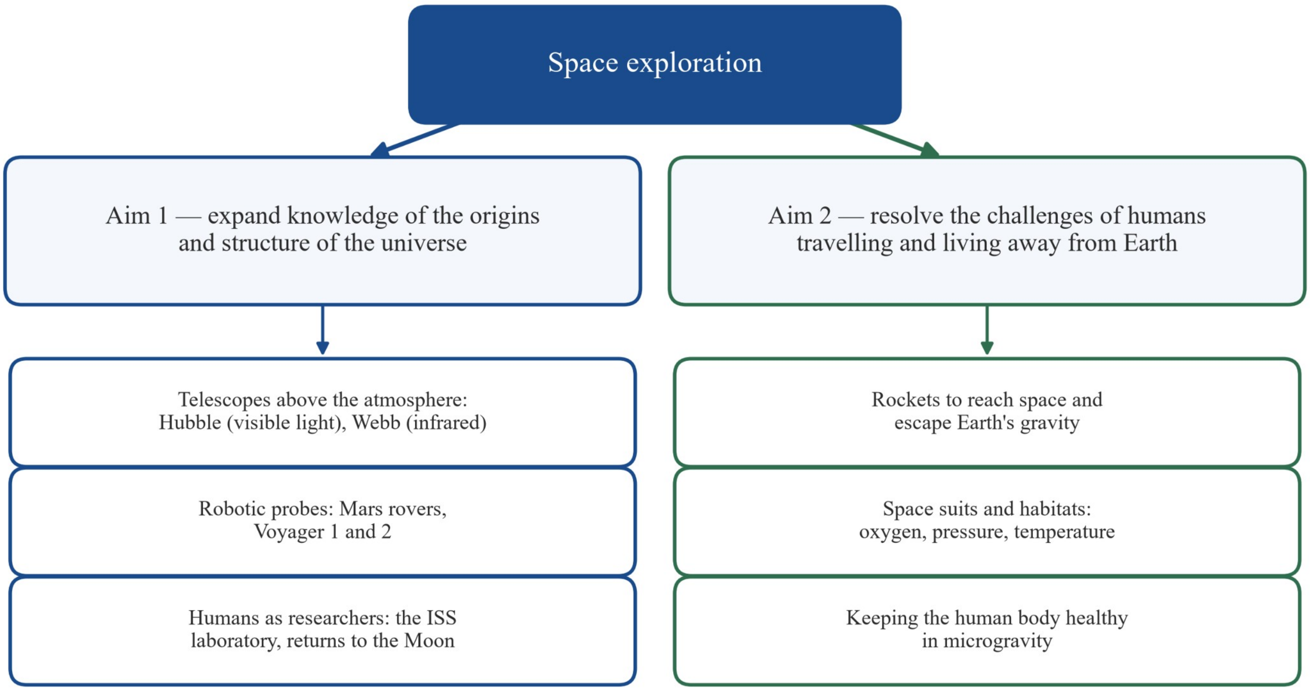
Chapter 13 — Earth and space sciences B: the universe and space exploration (Science, Levels 9 and 10)

Subtopic 13C · VC2 Science Understanding — Earth and space sciences

CD code: `VC2S10U12` (13C owns this content description whole — it is not split) **Content description (word for word):** "space exploration seeks to expand knowledge of the origins and structure of the universe and to resolve the challenges of humans travelling and living away from Earth's surface" **Elaboration ids drawn on:** `VC2S10U12.E01` · `VC2S10U12.E02` · `VC2S10U12.E03` · `VC2S10U12.E04` · `VC2S10U12.E05` · `VC2S10U12.E06` **Achievement standard (extract served):** "They discuss the advantages and disadvantages of space exploration." **Maths interlock (D11):** `VC2M9M02` — scientific notation for the Earth–Mars distances; the rest is prior maths (speed = distance ÷ time, circumference of a circle, converting units).

Theory

What space exploration is for. The content description gives space exploration two aims, and everything in this subtopic belongs to one of them.

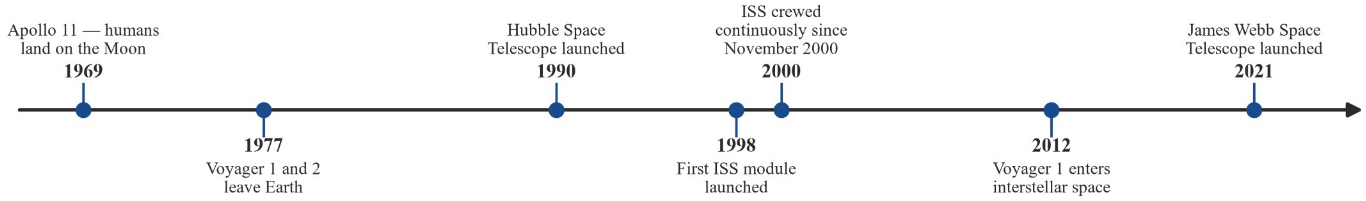


Both aims belong to the one content description (VC2S10U12): knowing and surviving are worked on together.

A chart with "Space exploration" at the top branching into two aims. Aim 1 — expand knowledge of the origins and structure of the universe, with three boxes: telescopes above the atmosphere (Hubble, Webb), robotic probes (Mars rovers, Voyager 1 and 2), and humans as researchers (the ISS). Aim 2 — resolve the challenges of humans travelling and living away from Earth, with three boxes: rockets to reach space and escape Earth's gravity; space suits and habitats supplying oxygen, pressure and temperature; and keeping the human body healthy in microgravity

Aim 1 — *knowing* — leans on the rest of Chapter 13: the features of the universe (subtopic 13A) and its origins (subtopic 13B). Telescopes above the atmosphere, robotic probes, and humans working as researchers all gather the evidence those subtopics describe. Aim 2 — *surviving and working* — is the new material of this subtopic: a human body was not designed to leave the Earth, so every trip and every stay has to solve a list of problems. The two aims are worked on together: the same rocket that carries a telescope up also has to keep its builders and operators alive.

The record so far. Space exploration is young — the whole record fits on one timeline.



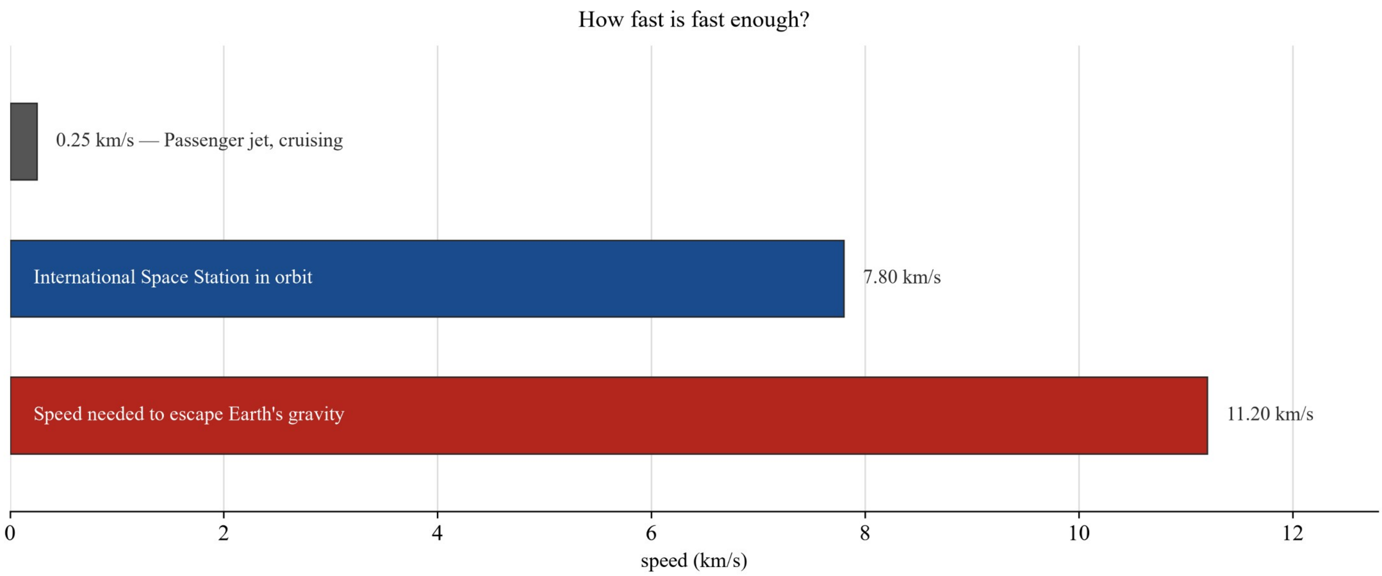
Milestones of space exploration — the record this subtopic draws on. Each date is a mission this section names.

A timeline of space-exploration milestones from 1969 to 2021: 1969 Apollo 11 — humans land on the Moon; 1977 Voyager 1 and 2 leave Earth; 1990 Hubble Space Telescope launched; 1998 first ISS module launched; 2000 ISS crewed continuously since November 2000; 2012 Voyager 1 enters interstellar space; 2021 James Webb Space Telescope launched

In 1969, Apollo 11 put the first humans on the Moon — and Australia is part of that story: the CSIRO Parkes telescope (Murriyang) in NSW helped carry the first television pictures of humans walking on the Moon to the world. The robotic probes Voyager 1 and 2 left Earth in 1977; in 2012, Voyager 1 became the first human-made object to reach **interstellar space** — the space between the stars. The Hubble Space Telescope (1990) and the James Webb Space Telescope (2021) observe from above the atmosphere, and the International Space Station (ISS) has been a home and laboratory in orbit: its first module launched in 1998 and crews have lived aboard continuously since November 2000.

Source: NASA, "Apollo 11 Lunar Surface Journal", n.d. https://www.nasa.gov/history/alsj/a11/a11.html — retrieved 2026-08-21; CSIRO ATNF, "Parkes Observatory" (Apollo 11 history material), n.d. https://www.parkes.atnf.csiro.au/ — retrieved 2026-08-21; NASA, "Voyager", n.d. https://science.nasa.gov/mission/voyager/ — retrieved 2026-08-21; NASA, "Hubble Space Telescope", n.d. https://science.nasa.gov/mission/hubble/ — retrieved 2026-08-21; NASA, "James Webb Space Telescope", n.d. https://science.nasa.gov/mission/webb/ — retrieved 2026-08-21; NASA, "International Space Station", n.d. https://www.nasa.gov/international-space-station/ — retrieved 2026-08-21.

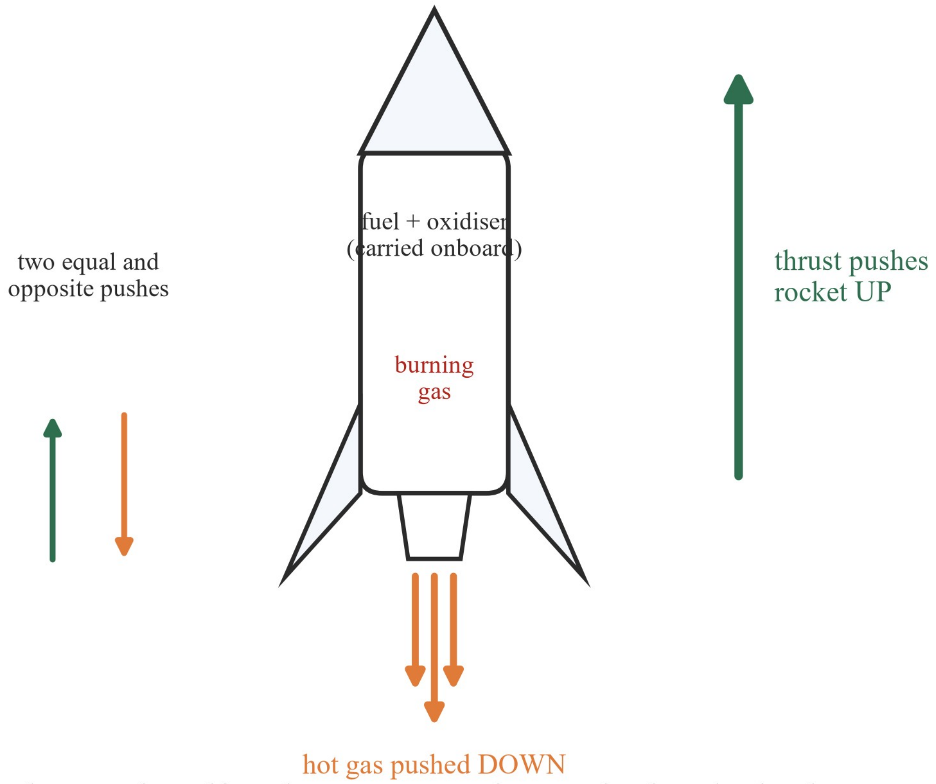
Getting off the Earth. The first problem is gravity: it holds everything to the surface, and leaving means climbing *and* going sideways extremely fast. A passenger jet cruises at about 0.25 km/s; to stay in a low orbit a craft must travel at about 7.8 km/s; and to escape Earth's gravity altogether a craft needs about 11.2 km/s.



The ISS travels about 30 times faster than a jet. Reaching orbit is not about going up — it is about going sideways so fast that the craft keeps missing the Earth as it falls.

Bar chart of speeds in kilometres per second: passenger jet cruising, 0.25 km/s; International Space Station in orbit, 7.80 km/s; speed needed to escape Earth's gravity, 11.20 km/s. The caption notes the ISS travels about 30 times faster than a jet, and that reaching orbit is about going sideways so fast the craft keeps missing the Earth as it falls

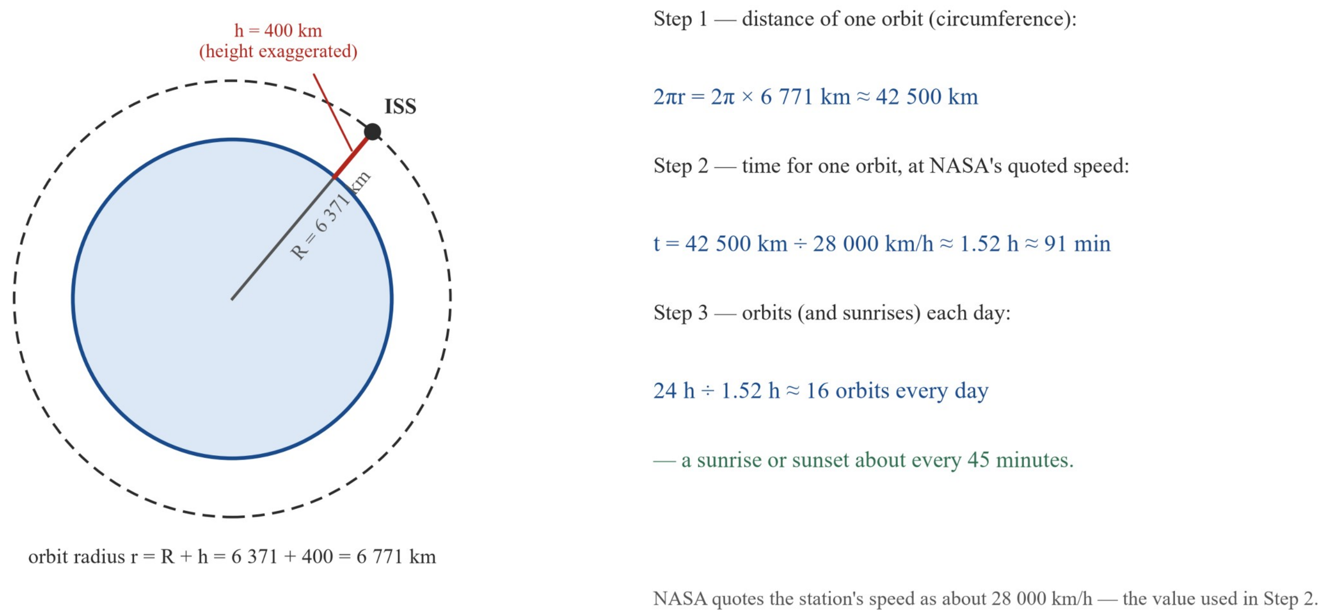
No aircraft engine can do this, because no aircraft engine carries its own air. A rocket burns **propellant** — fuel together with an **oxidiser**, the oxygen supply a rocket must carry because there is no air in space — and throws the hot gas out of the back at high speed. Pushing the gas backwards pushes the rocket forwards; this forward push is called **thrust**. (The rule that the two pushes are equal and opposite is stated formally as Newton's third law in subtopic 15B; here the idea is simply that the exhaust pushes the rocket as the rocket pushes the exhaust.)



A rocket moves by pushing exhaust gas one way; the gas pushes the rocket the other way. Rockets carry their own fuel and oxygen supply, so they work where there is no air. (The rule is stated formally as Newton's third law in subtopic 15B.)

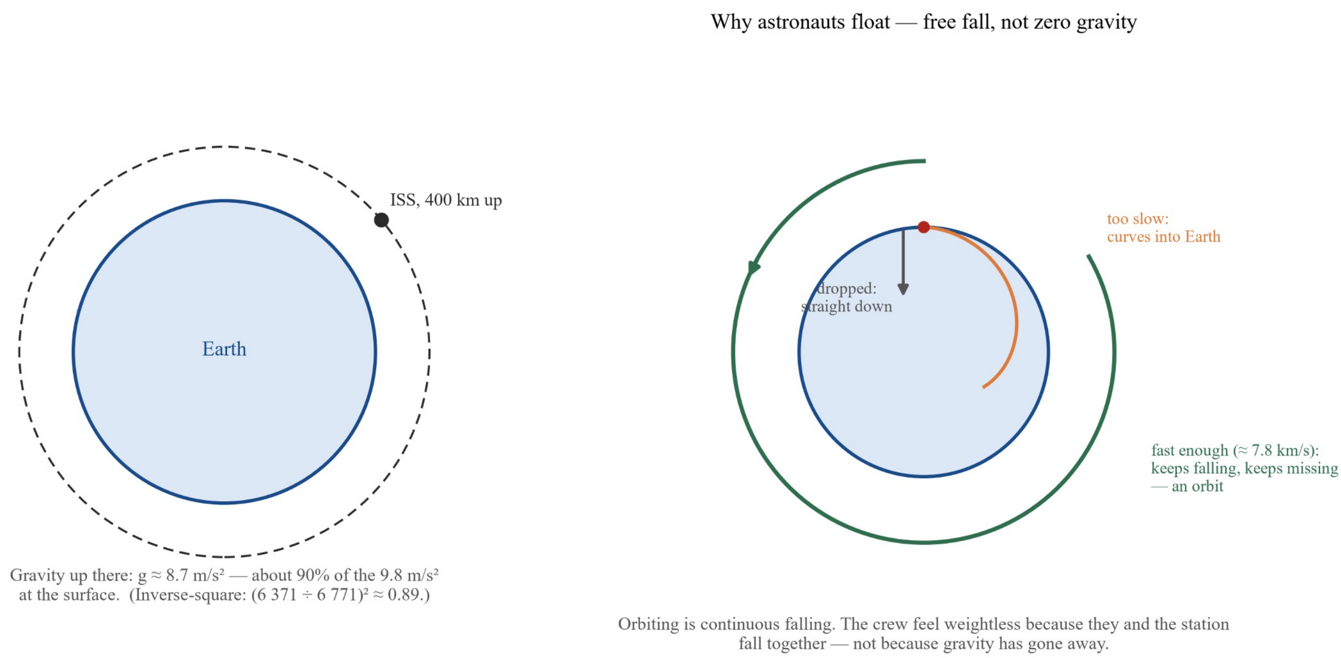
A labelled drawing of a rocket carrying its fuel and oxidiser on board, pushing burning gas out of the bottom (hot gas pushed down) while a green arrow shows thrust pushing the rocket up; a side note shows the two pushes as equal and opposite

Orbit: falling and missing. Reaching orbit is not about going up — it is about going sideways so fast that the craft keeps missing the Earth as it falls. The ISS orbits at about 400 km up, where the orbit radius is $r = R + h = 6\,371 + 400 = 6\,771$ km, and NASA quotes its speed as about 28 000 km/h.



Left: the Earth (radius R = 6 371 km) with the ISS on a dashed orbit 400 km higher (height exaggerated), giving an orbit radius r = 6 771 km. Right: the working — one orbit is the circumference, 2πr ≈ 42 500 km; at 28 000 km/h one orbit takes 42 500 ÷ 28 000 ≈ 1.52 h ≈ 91 min; 24 h ÷ 1.52 h ≈ 16 orbits a day, so a crew member sees a sunrise or sunset about every 45 minutes

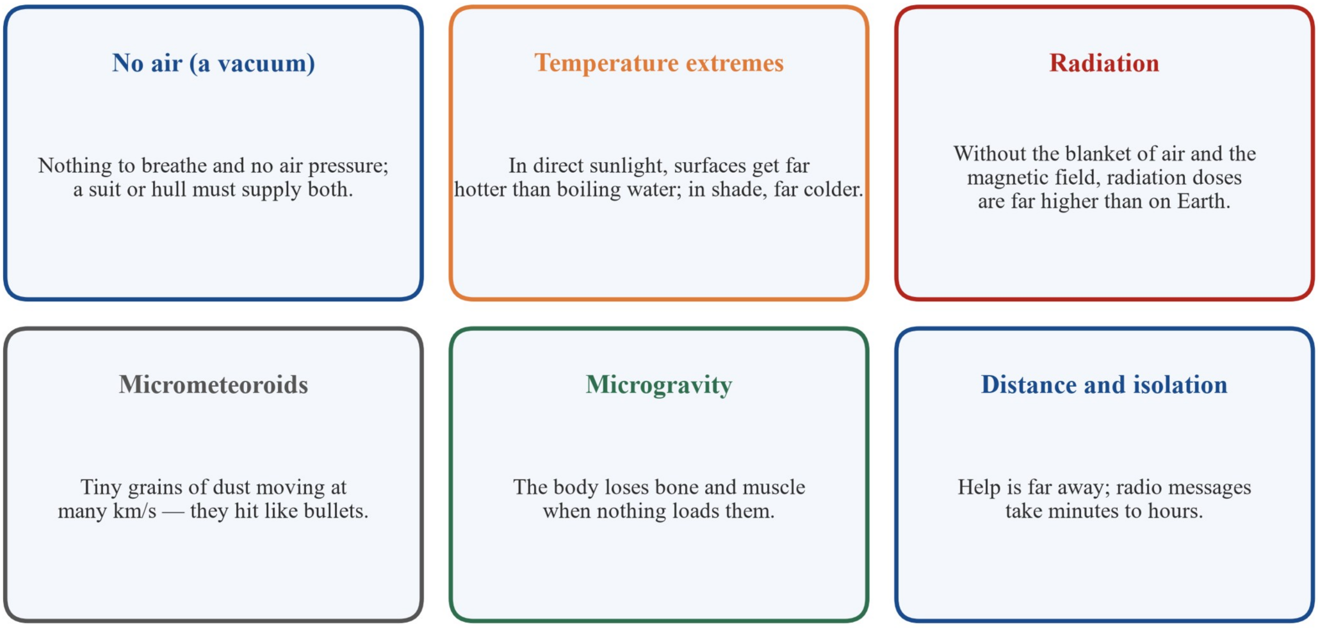
A common mistake is to think astronauts float because there is no gravity up there. There is: at 400 km, gravity is still about 90% as strong as at the surface (Worked example 3 shows the calculation). The crew float because they and the station are **falling together** — the condition called **microgravity**, the state of feeling almost weightless inside a freely falling craft.



Left: the Earth with the ISS on a dashed orbit 400 km up, where gravity is still about 8.7 m/s^2 — about 90% of the 9.8 m/s^2 at the surface. Right: three paths from the same point — dropped straight down; too slow, curving into Earth; and fast enough (about 7.8 km/s) to keep falling and keep missing, an orbit

Six hazards. Beyond the atmosphere, every design — rocket, suit, station — is an answer to a short list of hazards.

Six hazards of space — every design in this subtopic answers one or more of them



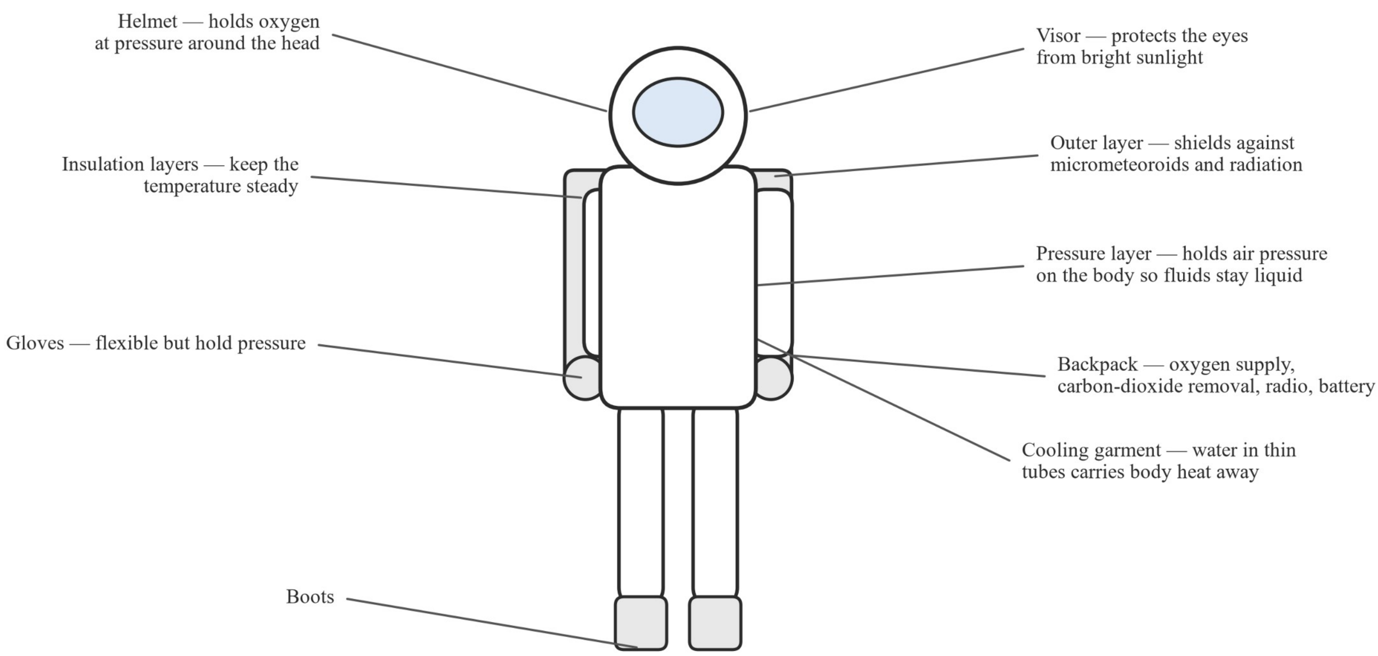
These are the conditions behind every feature of a space suit, a spacecraft and a habitat.

Six cards naming the hazards of space: no air (a vacuum) — nothing to breathe and no air pressure; temperature extremes — far hotter than boiling water in direct sunlight, far colder in shade; radiation — far higher doses without the blanket of air and the magnetic field; micrometeoroids — tiny grains moving at many km/s that hit like bullets; microgravity — the body loses bone and muscle when nothing loads them; distance and isolation — help is far away and radio messages take minutes to hours

Space is a **vacuum** — a space with no air at all — so there is nothing to breathe and no air pressure holding body fluids where they belong. With no air to carry heat in or out, an object in direct sunlight gets far hotter than boiling water while its shaded side gets far colder. Without the blanket of air and the magnetic field, radiation doses are far higher than on the surface. **Micrometeoroids** — tiny grains of rock and metal, often smaller than a grain of sand, moving at many km/s — strike like bullets. Microgravity slowly unwinds the body. And distance isolates: help is far away, and even radio messages take minutes to hours (more below).

The space suit: a personal spacecraft. A space suit answers the hazard list one item at a time, which is why it looks the way it does.

What a space suit must do



A space suit is a small personal spacecraft: oxygen, pressure, temperature control, radiation protection and a radio — all worn on the body.

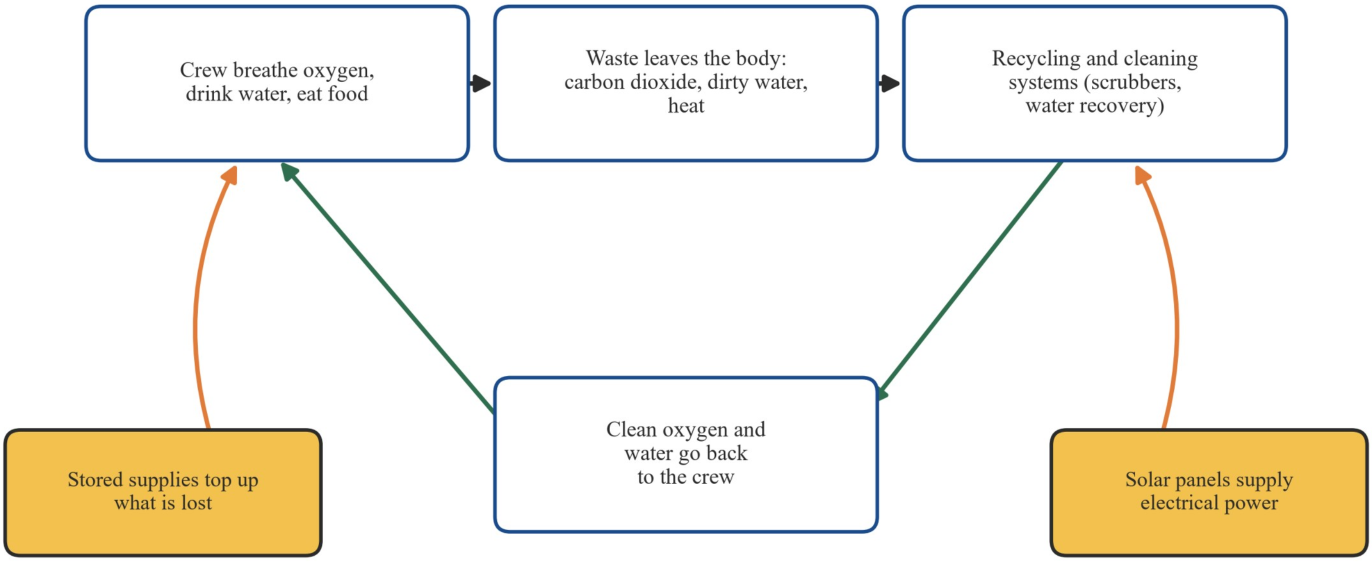
A labelled drawing of an astronaut in a space suit: a visor protecting the eyes from bright sunlight; a helmet holding oxygen at pressure around the head; an outer layer shielding against micrometeoroids and radiation; insulation layers keeping the temperature steady; a pressure layer holding air pressure on the body; flexible gloves that still hold pressure; a cooling garment with water in thin tubes carrying body heat away; boots; and a backpack holding the oxygen supply, carbon-dioxide removal, radio and battery

The suit gives the astronaut oxygen to breathe and removes the carbon dioxide they breathe out; it holds air pressure on the body; it protects against getting too hot or too cold, against radiation, and against space dust; and circulating cooling water carries body heat away, because in a vacuum there is no air to carry it. A suit is, in short, the smallest spacecraft there is.

Source: NASA, "What Is a Spacesuit?", n.d. https://www.nasa.gov/humans-in-space/what-is-a-spacesuit/ — retrieved 2026-08-21.

Living in space: a closed world. A spacecraft is the same idea at room scale: almost nothing can leave except waste heat, so almost everything must be cleaned and used again.

A spacecraft is a small, closed world

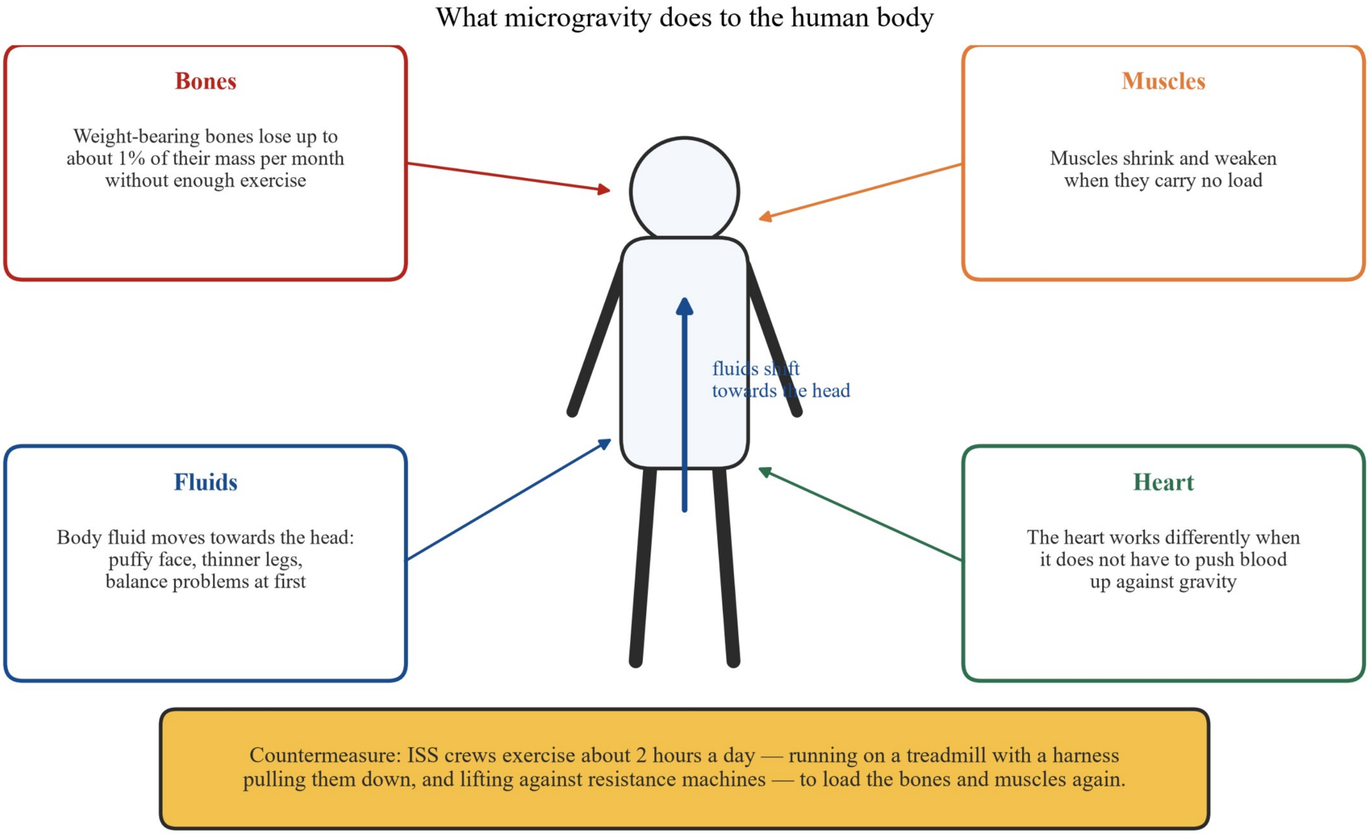


Waste heat is radiated into space; nothing else can leave — so almost everything on board is cleaned and used again.

A flow chart of a spacecraft as a closed world: the crew breathe oxygen, drink water and eat food; waste leaves the body as carbon dioxide, dirty water and heat; recycling and cleaning systems (scrubbers and water recovery) clean it; clean oxygen and water go back to the crew; two yellow input boxes show solar panels supplying electrical power and stored supplies topping up what is lost

The ISS is this closed world in real life, and it is also the laboratory of Aim 1: crews run experiments on flames, fluids, plants, materials and their own bodies — research that can only be done in microgravity.

What microgravity does to the body. A body that no longer has to carry its own weight starts to wind down.

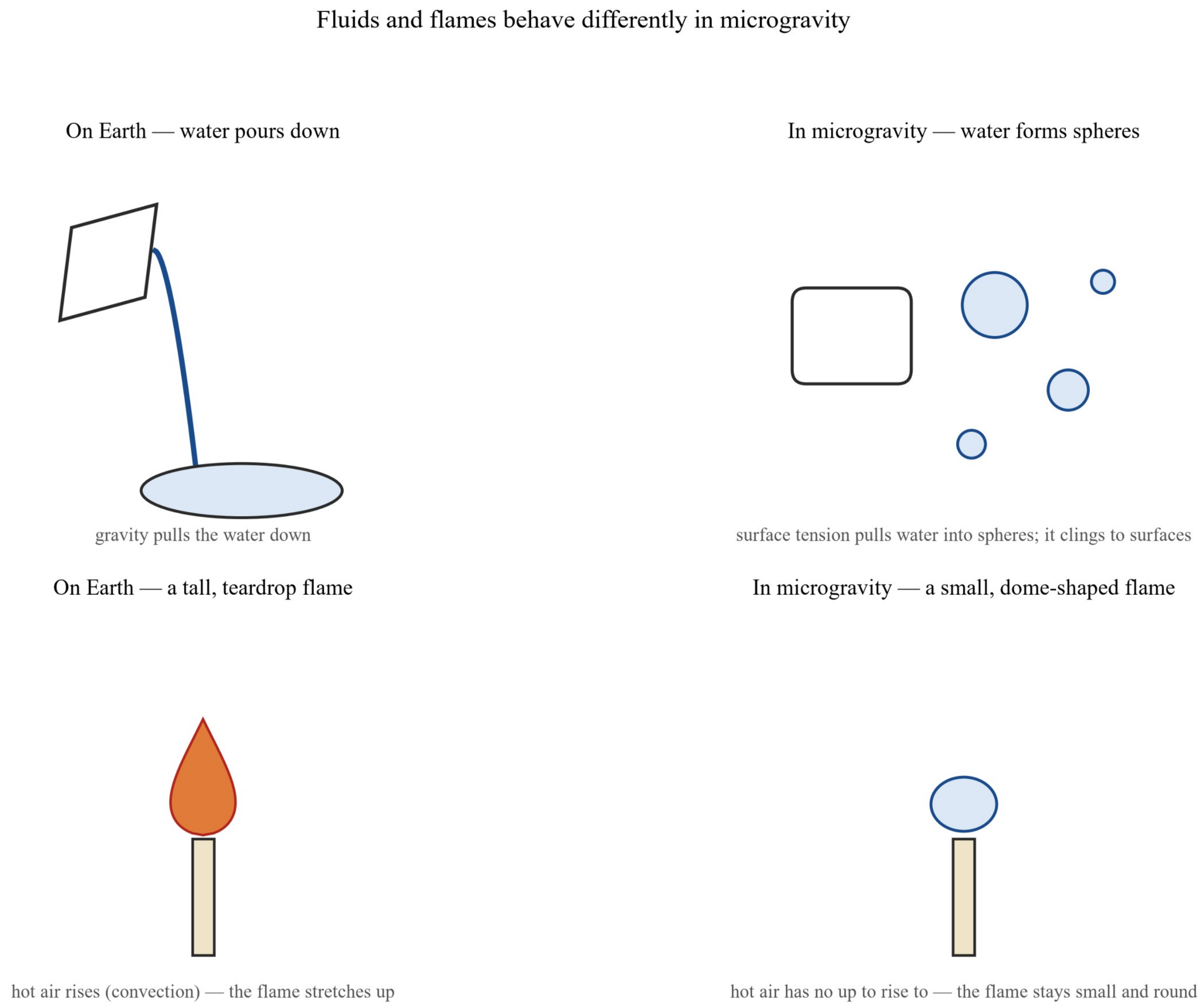


A drawing of a human body with an upward arrow showing fluids shifting towards the head, surrounded by four cards: bones — weight-bearing bones lose up to about 1% of their mass per month without enough exercise; muscles — they shrink and weaken when they carry no load; fluids — body fluid moves towards the head, giving a puffy face, thinner legs and balance problems at first; heart — it works differently when it does not have to push blood up against gravity. A banner gives the answer: ISS crews exercise about 2 hours a day, on a treadmill with a harness pulling them down and against resistance machines, to load the bones and muscles again

Weight-bearing bones lose up to about 1% of their mass per month without enough exercise, muscles shrink and weaken, body fluid shifts towards the head (puffy face, thinner legs, balance problems on return), and the heart changes too when it no longer has to push blood uphill. The answer is work: ISS crews exercise about two hours every day — running on a treadmill with a harness pulling them down, and lifting against resistance machines — to load the bones and muscles again.

Source: NASA, "NASA Twins Study", n.d. https://www.nasa.gov/twins-study/ — retrieved 2026-08-21; A. LeBlanc et al., "Bone mineral and lean tissue loss after long duration space flight", 2000.

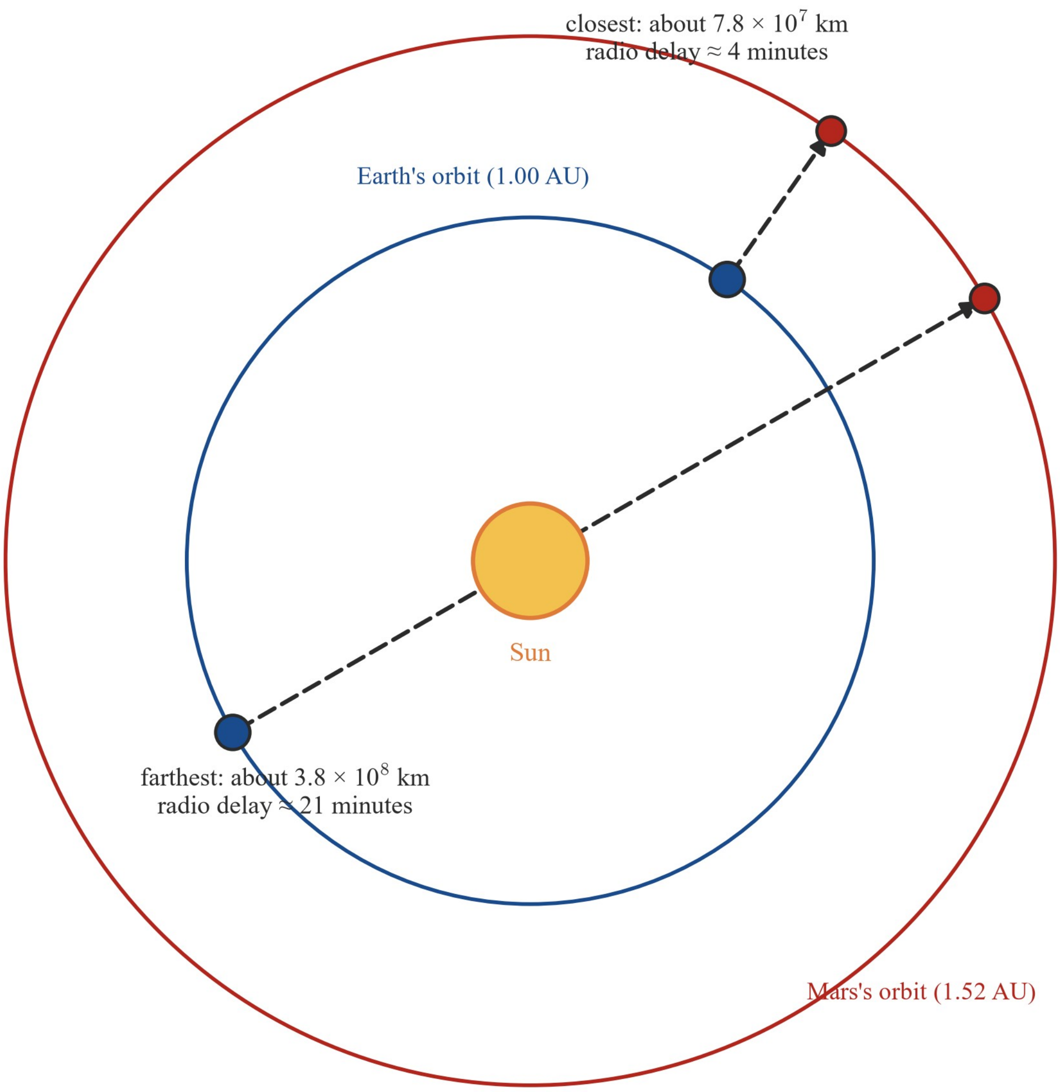
Even simple fluids behave differently, which is both a hazard and a research tool. On Earth, gravity pulls poured water down and **convection** — the carrying of heat by a moving fluid, as when hot air rises — stretches a candle flame into a tall teardrop. In microgravity there is no down and no up: **surface tension** — the skin-like pull that holds a liquid's surface together — pulls water into floating spheres, and a flame stays small and dome-shaped because hot air has no up to rise to.



Four panels comparing Earth and microgravity: on Earth, water pours down into a basin and a candle flame is a tall teardrop because hot air rises (convection); in microgravity, water forms floating spheres held by surface tension and a candle flame is small and dome-shaped because hot air has no up to rise to

The distance problem: talking to Mars. The last hazard is distance itself. Radio waves travel at the speed of light — exactly 299 792 458 m/s — and Mars is a very long way away. Earth orbits at 1.00 AU and Mars at 1.52 AU (1 AU = 1.496×10^8 km), so the gap between the two orbits ranges from 0.52 AU to 2.52 AU.

Talking to Mars — the distance problem



Radio waves travel at the speed of light, so every message to Mars — and every answer — costs minutes.
Orbit sizes are drawn in the true 1.00 : 1.52 ratio; crews must act for themselves,
because nothing can be controlled live from Earth.

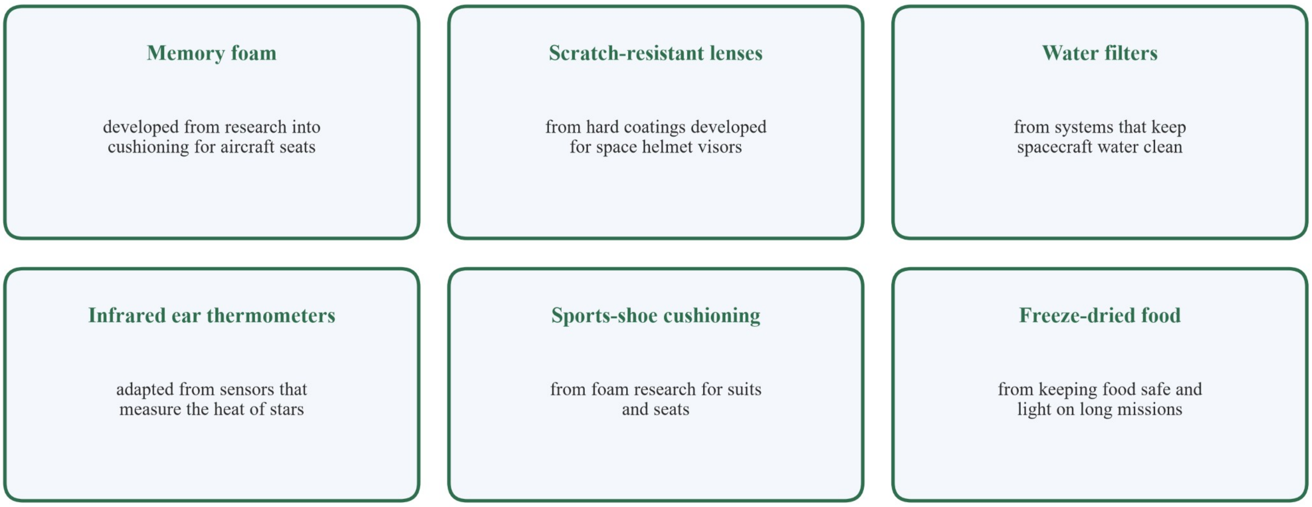
A diagram with the Sun at the centre and the orbits of Earth (1.00 AU) and Mars (1.52 AU) drawn in the true ratio: at closest, the planets are about 7.8 × 10^7 km apart and the radio delay is about 4 minutes; at farthest, on opposite sides of the Sun, they are about 3.8 × 10^8 km apart and the delay is about 21 minutes

At closest approach a radio message to Mars takes about 4 minutes; at farthest, about 21 minutes — and the reply takes just as long back. Nothing can be controlled live from Earth: crews and rovers on Mars must act for themselves. A day on Mars (a **sol**) is about 24.6 hours — a little longer than an Earth day — the atmosphere is thin and made mostly of carbon dioxide, and temperatures can fall to about −153 °C. Living away from Earth's surface means living on Mars time, in Mars conditions, a long radio delay from help.

Source: BIPM, "SI Brochure: The International System of Units (SI)", 9th ed., 2019, https://www.bipm.org/en/publications/si-brochure — retrieved 2026-08-21; NASA Jet Propulsion Laboratory, "Planetary Orbits & Ephemerides", n.d. https://ssd.jpl.nasa.gov/planets/orbits.html — retrieved 2026-08-21; NASA Science, "Mars Facts", n.d. https://science.nasa.gov/mars/facts/ — retrieved 2026-08-21.

Spinoffs: space research on Earth. Solving the hazard list keeps producing everyday gifts. Technologies first developed for space missions regularly find uses at home — a **spinoff** is exactly that, a space-born technology in everyday use.

Spinoffs — space research on Earth



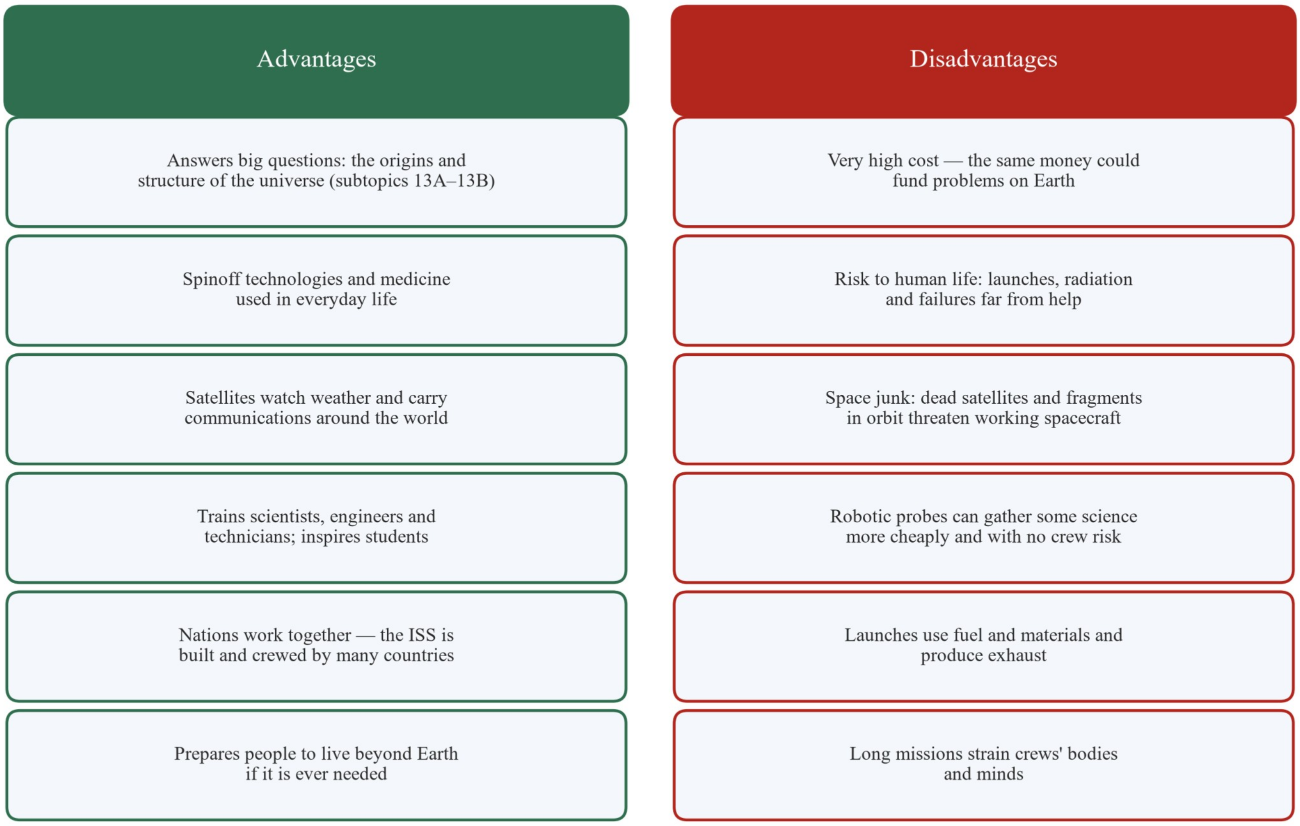
Everyday items with their roots in space research. NASA's Spinoff programme has recorded more than 2 000 such technologies since 1976.

Six cards of everyday spinoffs: memory foam, from research into cushioning for aircraft seats; scratch-resistant lenses, from hard coatings developed for space helmet visors; water filters, from systems that keep spacecraft water clean; infrared ear thermometers, adapted from sensors that measure the heat of stars; sports-shoe cushioning, from foam research for suits and seats; freeze-dried food, from keeping food safe and light on long missions

NASA’s Spinoff programme has recorded more than 2 000 such technologies since 1976, from memory foam and scratch-resistant lenses to water filters and infrared ear thermometers.

Source: NASA, “Spinoff”, n.d. https://spinoff.nasa.gov/ — retrieved 2026-08-21.

Weighing it up. The achievement standard asks you to discuss the advantages and disadvantages of space exploration — not to list them, but to argue with them.



The achievement standard asks you to discuss BOTH sides with reasons — a position is only as strong as the evidence and reasoning behind it.

Two columns of six cards each. Advantages: answers big questions about the origins and structure of the universe; spinoff technologies and medicine used in everyday life; satellites watch weather and carry communications around the world; trains scientists, engineers and technicians and inspires students; nations work together on the ISS; prepares people to live beyond Earth if ever needed. Disadvantages: very high cost that could fund problems on Earth; risk to human life from launches, radiation and failures far from help; space junk from dead satellites and fragments threatens working spacecraft; robotic probes can gather some science more cheaply with no crew risk; launches use fuel and materials and produce exhaust; long missions strain crews' bodies and minds

A useful way to argue is to pair each disadvantage with the advantage it buys, and ask whether the price is fair: robotic probes can gather some science more cheaply and safely than crews — yet humans on the ISS fix broken instruments and respond to surprises in ways probes cannot. The skill the standard is testing is exactly this: holding both columns in your head at once, and giving reasons.

Activities

Activity 1 — Water rockets and the speed gap (E02). In a safe open area, launch a water rocket (or watch a teacher launch) and measure its greatest height — for example with a home-made altimeter, or by timing the flight and using the fact that the climb and the fall take about the same time. Estimate the rocket's greatest speed. Then compare it with the speeds figure: 7.8 km/s for orbit and 11.2 km/s to escape. How many times faster is orbit speed than your rocket? Write two or three sentences explaining why reaching orbit is a speed problem, not a height problem.

Activity 2 — Design a suit against the hazards (E03). Copy the six hazard cards from the hazards figure down the left of a page. Beside each hazard, design one feature of a suit that answers it (use the suit figure for ideas, but add at least one feature of your own). Then answer: which two hazards does your design struggle with most on a long spacewalk, and why?

Activity 3 — A day in the life on Mars (E01). Write or storyboard "one sol in the life" of a crew member at a Mars base, using these facts: a sol is about 24.6 hours; the atmosphere is thin and mostly carbon dioxide (no oxygen to breathe, and no air pressure to rely on); temperatures can fall to about −153 °C; a radio message to Earth takes between about 4 and about 21 minutes each way. Your story must show what the crew member wears outside, what the base must supply, and one moment where the radio delay forces the crew to solve a problem without help from Earth.

Activity 4 — Research report from the ISS (E04). Choose one kind of research done on the ISS (for example flames, fluids, plants, materials, or the human body — your teacher may give you a list or the NASA ISS website). Write a one-page report with three parts: what the research studies; why it can only be done in microgravity; and one finding or use on Earth.

Activity 5 — Fluids without a down (E05). Using the fluids figure (or NASA videos of water and flames on the ISS), complete a two-column table, "On Earth" and "In microgravity", for: poured water; a floating water blob; a candle flame; and body fluid. For each row, name the thing that changes (gravity's pull, convection, surface tension) and explain the difference in one sentence.

Activity 6 — Spinoff hunt (E06). Using NASA's Spinoff website or the spinoffs figure, find three spinoffs not shown in the figure. For each, record: the everyday item; the space problem it was first solving; and one sentence on why the space version had to be better than what existed on Earth.

Worked examples

Data in this section are quoted to the significant figures shown (two to four), and final answers match the precision of the given data unless the arithmetic is exact.

Example 1 — scaffolded

The ISS orbits at about 400 km up (orbit radius r = 6 771 km) and NASA quotes its speed as about 28 000 km/h. (a) Show that one orbit is about 42 500 km long. (b) Calculate the time for one orbit, in hours and minutes. (c) Hence estimate how many sunrises a crew member sees in one Earth day.

Working	Comment
(a) circumference = $2\pi r = 2\pi \times 6\,771$ km ≈ 42 500 km	One orbit is a circle of radius 6 771 km; the distance around a circle is $2\pi r$.
(b) time = distance ÷ speed = 42 500 km ÷ 28 000 km/h ≈ 1.52 h	Speed = distance ÷ time, rearranged.
1.52 h ≈ 91 min	0.52 of an hour is 0.52 × 60 ≈ 31 min.
(c) orbits per day = 24 h ÷ 1.52 h ≈ 16	Each orbit brings one sunrise and one sunset.
≈ 16 sunrises a day — a sunrise or sunset about every 45 min	91 min per orbit, half of that between a sunrise and the next sunset.

Example 2 — scaffolded

Earth orbits at 1.00 AU and Mars at 1.52 AU, and 1 AU = 1.496 × 10^8 km. Radio waves travel at 3.00 × 10^5 km/s. (a) Show that the closest Earth–Mars gap is about 7.8 × 10^7 km, and find the radio delay at closest, in minutes. (b) Do the same for the farthest gap, about 3.8 × 10^8 km.

Working	Comment
(a) closest gap = 1.52 − 1.00 = 0.52 AU	Same side of the Sun: subtract the orbit sizes.
0.52 × 1.496 × 10^8 km ≈ 7.8 × 10^7 km	Converting AU to km.
time = 7.8 × 10^7 km ÷ 3.00 × 10^5 km/s = 260 s	Time = distance ÷ speed.
260 s ≈ 4.3 min	260 ÷ 60 ≈ 4.3.
(b) farthest gap = 1.52 + 1.00 = 2.52 AU ≈ 3.8 × 10^8 km	Opposite sides of the Sun: add the orbit sizes.
time = 3.8 × 10^8 ÷ 3.00 × 10^5 ≈ 1 270 s ≈ 21 min	The reply takes the same again — a conversation, not a chat.

Example 3 — unscaffolded

Gravity at the surface is 9.8 m/s². Gravity weakens with the square of the distance from the Earth's centre (the inverse-square idea used in subtopic 13A). Show that at the ISS's height (400 km up, distance 6 771 km from the centre, Earth's radius 6 371 km), gravity is still about 8.7 m/s² — and explain why the crew nonetheless float.

The strength of gravity at the ISS's height, compared with the surface, is the square of the distance ratio, turned upside down:

$$\left(\frac{6\,371}{6\,771}\right)^2 = (0.941)^2 \approx 0.885 .$$

So gravity up there is about 0.885 × 9.8 m/s² ≈ **8.7 m/s²** — about 90% of the surface value, not zero. The crew float because the station and everything in it are falling together: the ISS travels sideways so fast that it keeps missing the Earth, and a freely falling craft feels weightless inside. Microgravity is free fall, not the absence of gravity.

Example 4 — unscaffolded

Without enough exercise, weight-bearing bones in space lose up to about 1% of their mass each month. Treating each month's loss as 1% of the mass at the start of that month, calculate the fraction of bone mass remaining after a 6-month trip, and the percentage lost. Comment on the size of the answer.

Each month multiplies the remaining mass by 0.99, so after 6 months:

$$0.99^6 \approx 0.941 .$$

About 94.1% remains, so about **5.9% is lost** in half a year — close to the simple estimate of 6 × 1% = 6%, and a serious loss for a body that may land and walk about on arrival. This is why ISS crews exercise about two hours every day: loading the bones and muscles slows the loss dramatically.

Practice questions

Scaffolded questions

Question 1 The content description gives space exploration two aims. (a) State the two aims in your own words. (b) Which aim is served by the Hubble and Webb space telescopes, and by the Voyager probes? (c) Which aim is served by space suits and by the ISS's recycling systems?

Question 2 Use the timeline figure. (a) Put in order: first ISS module launched; Voyager 1 and 2 leave Earth; James Webb Space Telescope launched; Apollo 11 lands humans on the Moon. (b) How many years passed between Apollo 11 and the launch of Voyager 1 and 2? (c) Crews have lived on the ISS continuously since November 2000. How many full years was that by November 2025?

Question 3 Use the speeds figure. (a) How many times faster is the ISS (7.8 km/s) than a cruising jet (0.25 km/s)? (b) State the speed needed to escape Earth's gravity altogether. (c) In one sentence, explain why reaching orbit is a speed problem rather than a height problem.

Question 4 One ISS orbit takes about 1.52 h. (a) Convert 1.52 h to minutes. (b) Calculate how many orbits the ISS completes in one Earth day (24 h). (c) Hence explain why a crew member sees a sunrise *or* a sunset about every 45 minutes.

Question 5 Match the suit to the hazards. (a) Which hazard does the pressure layer answer? (b) Which hazard does the cooling garment answer, and why is it needed in a vacuum? (c) Which two hazards does the outer layer shield against?

Question 6 Radio waves travel at 3.00 × 10^5 km/s. (a) Calculate the radio delay, in minutes, when Earth and Mars are 7.8 × 10^7 km apart. (b) Calculate the delay when they are 3.8 × 10^8 km apart. (c) State what your answers mean for flying a rover on Mars "live" from Earth.

Unscaffolded questions

Question 7 Define *microgravity*, and explain why astronauts in orbit float even though gravity at 400 km is still about 90% as strong as at the surface.

Question 8 State what a rocket must carry that a jet engine does not, and why.

Question 9 Explain why a spacecraft needs both solar panels and stored supplies, even though almost everything on board is recycled.

Question 10 List three changes microgravity causes in the human body, and state the daily work ISS crews do to slow them.

Question 11 Explain why poured water falls on Earth but forms floating spheres in microgravity.

Question 12 A candle flame is a tall teardrop on Earth but a small dome in microgravity. Name the heat-carrying process that is missing in microgravity, and explain.

Question 13 Name two spinoffs from the spinoffs figure and the space problem each was first solving.

Question 14 What is the Australian connection to the Apollo 11 story named in this subtopic?

Question 15 The achievement standard asks you to discuss. Give three advantages and three disadvantages of space exploration, each with a one-line reason, and pair each disadvantage with the advantage it buys.

Question 16 A sol (a Mars day) is about 24.6 hours. (a) About how much longer is a sol than an Earth day, in minutes? (b) A Mars base keeps Mars time. Explain in one sentence what this does to the crew's routine as seen from Earth.

Answers

Question 1 (a) expanding knowledge of the origins and structure of the universe; solving the problems of humans travelling and living away from Earth; (b) the first aim; (c) the second aim. **Question 2** (a) Apollo 11 (1969), Voyager (1977), first ISS module (1998), Webb (2021); (b) 8 years; (c) 25 years. **Question 3** (a) about 31 times; (b) about 11.2 km/s; (c) see solution. **Question 4** (a) about 91 min; (b) about 16; (c) see solution. **Question 5** (a) no air / no air pressure (the vacuum); (b) temperature extremes — in a vacuum there is no air to carry body heat away; (c) micrometeoroids and radiation. **Question 6** (a) about 4.3 min; (b) about 21 min; (c) see solution. **Question 7** see solution. **Question 8** an oxidiser (its own oxygen supply) — there is no air in space to burn fuel with. **Question 9** see solution. **Question 10** any three of: bone loss, muscle loss, fluid shift to the head (or heart changes); about two hours of exercise a day. **Question 11** see solution. **Question 12** convection; see solution. **Question 13** any two, e.g. water filters — keeping spacecraft water clean; memory foam — cushioning for aircraft seats. **Question 14** the CSIRO Parkes telescope (Murriyang) helped carry the first TV pictures of the Moon walk to the world. **Question 15** see solution. **Question 16** (a) about 36 min; (b) see solution.

Fully-worked solutions

Question 1 (a) Aim 1: to expand knowledge of the origins and structure of the universe. Aim 2: to resolve the challenges of humans travelling and living away from Earth's surface. (b) The first aim — they gather evidence about the universe and the solar system. (c) The second aim — they keep humans alive away from Earth.

Question 2 (a) Apollo 11 (1969) → Voyager 1 and 2 (1977) → first ISS module (1998) → James Webb Space Telescope (2021). (b) 1977 − 1969 = **8 years**. (c) November 2000 to November 2025 is **25 years** of continuous crewing.

Question 3 (a) 7.8 ÷ 0.25 ≈ **31 times** faster. (b) About **11.2 km/s**. (c) A craft at any height falls back unless it is moving sideways fast enough to keep missing the Earth — the ISS's 400 km of height is easy compared with its 7.8 km/s of sideways speed.

Question 4 (a) 1.52 × 60 ≈ **91 min**. (b) 24 ÷ 1.52 ≈ **16 orbits** per day. (c) Each orbit carries the crew once around the Earth, through one sunrise and one sunset: 16 of each per day, spaced about half an orbit apart — 91 ÷ 2 ≈ **45 min** between a sunrise and the next sunset.

Question 5 (a) The vacuum — with no air pressure outside, the suit must hold pressure on the body so fluids stay liquid and the body keeps its shape. (b) Temperature extremes (and body heat). In a vacuum there is no air to carry heat away, so the suit's cooling water must carry body heat to a place where it can be radiated out. (c) Micrometeoroids and radiation.

Question 6 (a) $t = 7.8 \times 10^7 \div 3.00 \times 10^5 = 260$ s; 260 ÷ 60 ≈ **4.3 min**. (b) $t = 3.8 \times 10^8 \div 3.00 \times 10^5 \approx 1\,270$ s; 1 270 ÷ 60 ≈ **21 min**. (c) "Live" control is impossible: an order and its confirmation take at least about 9 minutes at closest and about 42 minutes at farthest, so a Mars rover must drive itself and its crew must act for themselves.

Question 7 **Microgravity** is the condition of feeling almost weightless inside a freely falling craft. Gravity at 400 km is still about 8.7 m/s^2 (about 90% of 9.8 m/s^2) — it is what bends the ISS's path into an orbit. The crew float because they and the station fall together at the same rate: there is nothing for the crew to press against, so they feel weightless.

Question 8 A rocket carries an **oxidiser** — its own oxygen supply. A jet engine takes oxygen from the air; in space there is no air, so a rocket must bring the oxygen its fuel burns with.

Question 9 Recycling is never perfect: a little oxygen, water and food is lost or used up each day, and waste heat is the one thing that must leave. Solar panels supply the electrical power the recycling systems run on, and stored supplies top up the small losses, so the closed world stays liveable.

Question 10 Any three of: weight-bearing bones lose mass (up to about 1% a month without enough exercise); muscles shrink and weaken; body fluid shifts towards the head (puffy face, thinner legs, balance problems on return); the heart changes when it no longer pushes blood against gravity. The daily work: about two hours of exercise — a treadmill with a harness pulling the crew down, and lifting against resistance machines — to load the bones and muscles again.

Question 11 On Earth, gravity pulls the falling water down into a stream and then a puddle. In microgravity there is no down to fall towards, so the water's own **surface tension** — the skin-like pull that holds a liquid's surface together — draws it into the shape with the smallest surface, a sphere.

Question 12 The missing process is **convection** — the carrying of heat by a moving fluid. On Earth the flame heats the air above it, hot air rises, and fresh air is drawn in from below, stretching the flame into a teardrop. In microgravity hot air has no up to rise to, so the flame feeds only by slow spreading, stays small, and sits in a dome.

Question 13 For example: water filters — first developed as systems that keep spacecraft water clean; infrared ear thermometers — adapted from sensors that measure the heat of stars. (Any two cards from the figure, correctly paired, are correct.)

Question 14 The CSIRO Parkes telescope (Murriyang) in NSW helped carry the first television pictures of humans walking on the Moon (Apollo 11, 1969) to the world — the observatory's own Apollo 11 history material tells the story.

Question 15 A model answer (any well-reasoned set scores): advantages — (1) it answers the big questions about the origins and structure of the universe, because telescopes and probes gather evidence no ground instrument can; (2) spinoffs such as water filters and ear thermometers improve everyday life; (3) satellites watch weather and carry communications, protecting lives and linking the world. Disadvantages — (1) the very high cost could fund problems on Earth, and the price is paid now for knowledge that arrives slowly; (2) crews risk their lives to launches, radiation and failures far from help, and the knowledge bought is not worth a life unless the risk is chosen openly; (3) space junk from dead satellites threatens working spacecraft, so each launch adds to a problem later crews must clear. Each disadvantage names the price of the advantage paired with it — which is what "discuss" means.

Question 16 (a) $24.6 - 24 = 0.6$ h; $0.6 \times 60 =$ **36 min** longer than an Earth day. (b) Each sol the base's daytime slips about 36 minutes later against Earth clocks, so the crew lives on a slowly drifting schedule and cannot match Earth's daily routine.

Where this leads: 13C closes Chapter 13 — it owns `VC2S10U12` whole, and no later subtopic splits or repeats it. It does not map onto a single VCE topic: the physics it leans on (why the exhaust pushes the rocket, forces and energy) is developed formally in subtopic 15B, and the habit it builds — arguing both sides of a question with evidence — is used in every senior science subject.

Test A

Topic test 5 — Carbon and climate, and the universe and space exploration

Earth and space sciences · Chapters 12–13 · Subtopics 12A, 12B, 12C, 12D, 13A, 13B and 13C · Codes VC2S10U10, VC2S10U11, VC2S10U12 and VC2S10U13

Total: 40 marks · Section A (multiple choice): 10 marks · Section B (short/structured response): 30 marks

8 of the 40 marks are science inquiry marks (codes `VC2S10I01` and `VC2S10I02`). They attach to the practical work of Chapters 12–13 — the pondweed-and-lamp investigation and the two-jar greenhouse model.

Planned for about 50 minutes. This paper is untimed — there is no time to beat.

This is a school-designed paper. It is not a VCAA instrument. Achievement at Levels 9 and 10 is reported against the Victorian Curriculum achievement standard on teacher judgement; the marks here are one source of evidence towards that judgement.

Conditions

- Completion is **untimed**. The 50 minutes is planning guidance only; take as long as you need.
- **Reading support** is permitted. Your teacher may read any question out to you if you need it. Reading is not what is being looked at, and your teacher will not help with the answer.
- **A scientific calculator is permitted.** Several questions involve calculation; nothing on this paper needs more than the four operations and a ratio. No formula sheet. No reading time.
- Answer every question. For multiple-choice questions, circle the letter of the best answer. There is only one best answer for each question.

In this test you will:

- trace carbon between Earth's interrelated systems and its stores — through photosynthesis, respiration and the combustion of fossil fuels (Q1, Q2, Q3, Q11)
- explain the greenhouse effect, and read the carbon dioxide record as a rising trend with a yearly cycle (Q4, Q5, Q13)
- estimate a carbon footprint from practice emission factors (Q6)
- identify the challenges of living on Mars and the designs that meet them (Q7, Q15)
- apply Newton's third law to rocket propulsion (Q8)
- use redshift and the cosmic microwave background as evidence for the big bang theory (Q9, Q10, Q16)
- identify variables, write a hypothesis, and evaluate models and claims using the chapter's practical work (Q12, Q14)

Section A — Multiple choice (10 marks)

Each question is worth 1 mark. Circle the letter of the best answer. Terms such as ppm (parts per million) and CO_2-e (carbon dioxide equivalent) are used as they are defined in Chapter 12.

Q1 *(1 mark · VC2S10U10)* When tree roots grow into a rock crack and widen it, which two Earth systems are interacting most directly?

A. Atmosphere and hydrosphere B. Biosphere and geosphere C. Hydrosphere and geosphere D. Atmosphere and biosphere

Q2 *(1 mark · VC2S10U10)* You see a campfire turn dry wood into carbon dioxide. What earlier process put atmospheric carbon into the wood?

A. Animal respiration B. Burning C. Weathering D. Photosynthesis

Q3 *(1 mark · VC2S10U10)* You measure a single leaf for one hour. Its photosynthesis removes 14 carbon dioxide units from the air, while its respiration adds 5 carbon dioxide units to the air. What is the overall change in the surrounding air?

A. Carbon dioxide decreases by 9 units B. Carbon dioxide increases by 19 units C. Carbon dioxide increases by 9 units D. Carbon dioxide does not change

Q4 *(1 mark · VC2S10U11)* Imagine you compare Earth with an identical planet that has no greenhouse gases. If both absorb the same amount of sunlight, what is most likely?

A. The planet without greenhouse gases is cooler because more infrared radiation can escape to space B. The planet without greenhouse gases is warmer because no gases block sunlight C. Both planets have the same surface temperature because gases affect only weather D. The planet without greenhouse gases is cooler only during the day

Q5 *(1 mark · VC2S10U11)* You graph global average temperature from 1980 to 2020 and find an overall rise of 0.18 degrees Celsius per decade, although 1992 is cooler than 1991. How should you interpret the cooler year?

A. It proves the long-term trend stopped in 1992 B. It shows that short-term variation can occur within a long-term warming trend C. It means annual temperatures must rise every year for climate change to occur D. It proves that the oceans were not warming

Q6 *(1 mark · VC2S10U11)* A student logs one weekend: 25 kWh of electricity, 30 km by train, and 0.5 kg of cheese. Using the practice factors — electricity 0.90 kg CO_2-e per kWh, train 0.03 kg CO_2-e per km, cheese 23.8 kg CO_2-e per kg — what is the weekend footprint from these three bars?

A. 55.50 kg CO_2-e B. 40.10 kg CO_2-e C. 73.15 kg CO_2-e D. 35.30 kg CO_2-e

Q7 *(1 mark · VC2S10U12)* You need water for drinking, washing and growing plants during a long stay on Mars. Which design would reduce the need for replacement water most?

A. Collect water from humidity and wastewater, then clean and reuse it B. Discard used water after each use C. Use one-use water supplies and depend on frequent deliveries from Earth D. Store used water in an open container outside the habitat

Q8 *(1 mark · VC2S10U12)* You use sensors during a rocket test. The rocket exerts an 8 newton downward force on its escaping water. What force does the water exert on the rocket at that instant?

A. A 4 newton upward force B. An 8 newton downward force C. An 8 newton upward force D. A 16 newton upward force

Q9 *(1 mark · VC2S10U13)* You observe a distant galaxy and record its spectrum. A hydrogen spectral line appears at a longer wavelength than the same line measured in a laboratory. Which data feature supports the conclusion that the galaxy is moving away?

A. An increase in the galaxy's apparent size B. A stronger magnetic field around the galaxy C. A lower number of X-ray photons D. The redshift of the spectral line to a longer wavelength

Q10 *(1 mark · VC2S10U13)* The timeline of the universe's history shows the key events in order. About 380 000 years after the big bang, what happened?

A. The Sun and the solar system formed B. The first galaxies formed C. The first atoms formed and light was released D. The first stars lit up

Section B — Short/structured response (30 marks)

Q11 *(5 marks · VC2S10U10)* Carbon is held in stores of very different sizes. Three of them are shown below.

Store	Carbon held
Atmosphere (as CO_2)	about 881 GtC
Permafrost (frozen dead matter)	about 1 672 GtC
Rock	about 65 500 GtC

(1 GtC = 10^9 tonnes of carbon.)

Source: atmosphere store computed from Friedlingstein et al. 2022, Global Carbon Budget 2022, ESSD 14, 4811–4900 (414.71 ppm × 2.124 GtC per ppm); permafrost and rock stores: NASA Earth Observatory, "The Carbon Cycle" (updated 23 Feb 2026).

(a) State the meaning of *store* as used for the carbon cycle. *(1 mark)*
(b) Use the table to compare the rock store with the atmosphere store: about how many times larger is the rock store? Show your working. *(2 marks)*
(c) Name the process that moves carbon from Earth's interior into the atmosphere. *(1 mark)*
(d) When fossil fuels burn, carbon moves between two of Earth's stores. Name the store the carbon leaves and the store it enters. *(1 mark)*

All readings below are simulated data for practice.

Q12 *(4 marks · VC2S10I01)* A group investigates how light affects photosynthesis in pondweed. They place a lamp at different distances from a beaker of pondweed and count the bubbles the pondweed gives off each minute.

Lamp distance (cm)	Bubbles per minute
10	42
20	28
30	17
40	9

(a) Name the independent variable and the dependent variable in this investigation. *(2 marks)*
(b) Write a hypothesis for this investigation. Your hypothesis must name a relationship between the two variables and give a reason. *(1 mark)*
(c) State the pattern shown by the results, and say whether the results support the hypothesis you wrote in (b). *(1 mark)*

Q13 *(6 marks · VC2S10U11)* The concentration of carbon dioxide in the air is measured directly at Mauna Loa in Hawai'i, and read further back from air bubbles trapped in polar ice cores. Concentrations this small are quoted in parts per million (ppm) — one molecule in every million molecules of air. Selected annual means are shown below.

Year	CO_2 concentration (ppm)
about 1750	about 280 (from ice cores)
1960	316.9
1980	338.8
2000	369.7
2024	421.1

Source: NOAA Global Monitoring Laboratory, "Trends in Atmospheric Carbon Dioxide", n.d. https://gml.noaa.gov/ccgg/trends/ — retrieved 2026-08-21. Ice-core value: NASA Earth Observatory, "The Carbon Cycle" (updated 23 Feb 2026).

(a) Calculate the total rise in CO_2 concentration from about 1750 to 2024. *(1 mark)*
(b) Calculate the average yearly rate of increase for 1960–1980 and for 2000–2024, and say how the two rates compare. *(2 marks)*
(c) Name the human process adding most of this CO_2, and state which store the carbon was in before it was released. *(1 mark)*
(d) On top of the long-term trend, the record shows a small yearly cycle of a few ppm. Name the two processes that make the cycle, and state why it is the trend, not the cycle, that changes the energy budget. *(2 marks)*

Q14 *(4 marks · VC2S10I02)* A class models the greenhouse effect with two jars standing under a lamp. Extra carbon dioxide is made inside one jar (from sodium hydrogen carbonate and vinegar); the other jar is left with ordinary air.

Temperatures in both jars are recorded every minute for 10 minutes, and the jar with extra carbon dioxide ends up warmer.

Safety: the lamp and its stand get hot — keep hands clear and let the lamp cool before packing away.

(a) State the purpose of the jar with ordinary air. *(1 mark)*
(b) Give two limits of this model compared with Earth's real climate system. *(2 marks)*
(c) A student writes: "The jar with extra carbon dioxide got warmer, so this investigation proves that carbon dioxide causes climate change." Evaluate this claim. *(1 mark)*

Q15 *(4 marks · VC2S10U12)* A crewed mission to Mars must keep people alive for years, far from Earth.

(a) Name two challenges of living on Mars, and give one design feature of a habitat or suit that meets each. *(2 marks)*
(b) Commands from Earth take between about 4 and 21 minutes to reach Mars. State what this means for a rover driving across rocky ground. *(1 mark)*
(c) State one advantage of space exploration that comes from work like this, and one cost or risk that has to be weighed against it. *(1 mark)*

Q16 *(7 marks · VC2S10U13)* The big bang theory models the origin and evolution of the universe, and is supported by several lines of evidence.

(a) State what the big bang theory says about the early universe. *(1 mark)*
(b) Give two observations that support the big bang theory. *(2 marks)*
(c) Explain how the redshift of galaxies supports the idea that the universe is expanding. *(2 marks)*
(d) The cosmic microwave background is a faint glow that arrives from every direction at almost exactly the same temperature. State what this glow is left over from. *(1 mark)*
(e) State which element's atoms released that light. *(1 mark)*

Test B

Topic test 5 — Carbon and climate, and the universe and space exploration

Earth and space sciences · Chapters 12–13 · Subtopics 12A, 12B, 12C, 12D, 13A, 13B and 13C · Codes VC2S10U10, VC2S10U11, VC2S10U12 and VC2S10U13

Total: 40 marks · Section A (multiple choice): 10 marks · Section B (short/structured response): 30 marks

9 of the 40 marks are science inquiry marks (codes `VC2S10I01` and `VC2S10I03`). They attach to the practical work of Chapters 12–13 — the insulated-cup heat-loss test and Hubble's graph.

Planned for about 50 minutes. This paper is untimed — there is no time to beat.

This is a school-designed paper. It is not a VCAA instrument. Achievement at Levels 9 and 10 is reported against the Victorian Curriculum achievement standard on teacher judgement; the marks here are one source of evidence towards that judgement.

Conditions

- Completion is **untimed**. The 50 minutes is planning guidance only; take as long as you need.
- **Reading support** is permitted. Your teacher may read any question out to you if you need it. Reading is not what is being looked at, and your teacher will not help with the answer.
- **A scientific calculator is permitted.** Several questions involve calculation; nothing on this paper needs more than the four operations and a ratio. No formula sheet. No reading time.
- Answer every question. For multiple-choice questions, circle the letter of the best answer. There is only one best answer for each question.

In this test you will:

- trace carbon between Earth's stores as fossil fuels burn, and estimate the carbon held in field samples (Q1, Q2, Q12)
- distinguish weather from climate, and read indicators, model runs and the sea level record of a warming climate (Q3, Q4, Q5, Q6, Q11)
- compare force, mass and acceleration in rocket propulsion (Q7)
- explain what microgravity changes about flames, and why research is done in orbit (Q8, Q14)
- observe black holes by what surrounds them, and put the universe's key events in order (Q9, Q10, Q16)
- process practical data — anomalies, repeat readings and fair comparisons (Q13) — and test the distance–speed relationship in Hubble's graph (Q15)

Section A — Multiple choice (10 marks)

Each question is worth 1 mark. Circle the letter of the best answer.

Q1 *(1 mark · VC2S10U10)* You trace carbon in petrol that was stored underground before people extracted it. When the petrol is burned, which Earth-system movement occurs?

A. From biosphere to hydrosphere B. From atmosphere to biosphere C. From geosphere to atmosphere D. From hydrosphere to geosphere

Q2 *(1 mark · VC2S10U10)* Inside a square frame that marks off a fixed area, a group collects dead wood and leaf litter. After drying, the dead wood has a mass of 48 kg and the leaf litter 22 kg. Using the rule that the carbon stored is about half of the dry mass, about how much carbon do the two samples hold together?

A. 70 kg B. 17.5 kg C. 140 kg D. 35 kg

Q3 *(1 mark · VC2S10U10)* The natural greenhouse effect keeps Earth's surface warmer than it would otherwise be. About what is Earth's average surface temperature with no greenhouse gases at all, compared with the natural mix of greenhouse gases?

A. About 0 degrees Celsius with none; about +15 degrees Celsius with the natural mix B. About −18 degrees Celsius with none; about +15 degrees Celsius with the natural mix C. About +15 degrees Celsius with none; about −18 degrees Celsius with the natural mix D. About −18 degrees Celsius with none; about +50 degrees Celsius with the natural mix

Q4 *(1 mark · VC2S10U11)* Which statement correctly distinguishes weather from climate?

A. Weather is the state of the atmosphere over hours to days, while climate is the pattern of weather averaged over about 30 years B. Weather is the pattern averaged over about 30 years, while climate is the state of the atmosphere over hours to days C. Weather describes only temperature, while climate describes only wind and rain D. Weather is the term used for the past, while climate is the term used for the future

Q5 *(1 mark · VC2S10U11)* You photograph the same mountain slope each year. Which pattern is a climate indicator consistent with warming?

A. Snow disappears early in one year after a dry winter B. Your camera is moved to a sunnier side of the mountain C. Snow-covered days decline from 130 to 82 over 25 years while winter average temperatures rise D. Fresh snow melts during one sunny afternoon

Q6 *(1 mark · VC2S10U11)* A scientist runs the same tested climate model forward to the year 2100 twice: once driven by a high-emissions scenario and once by a low-emissions scenario. Both runs project warming for the next few decades, but after mid-century the projected temperatures differ strongly. What mainly explains the difference after mid-century?

A. One run includes the Sun’s energy and the other leaves it out B. The two runs use grid cells of very different sizes C. Only one run is based on the physics of radiation and winds D. The two scenarios put different amounts of greenhouse gas into the modelled atmosphere

Q7 *(1 mark · VC2S10U12)* You test two rocket carts where friction and gravity are negligible. Both experience 10 newtons of thrust. Cart X has a total mass of 1 kilogram, and Cart Y has a total mass of 2 kilograms. How do their accelerations compare?

A. Cart Y has twice the acceleration of Cart X B. Cart X has twice the acceleration of Cart Y C. They have the same acceleration because the thrust is the same D. Neither cart accelerates because the force pairs cancel

Q8 *(1 mark · VC2S10U12)* On Earth, a candle flame is a tall teardrop because hot air rises. In microgravity the same flame stays small and dome-shaped. Which heat process is missing in microgravity?

A. Conduction — the carrying of heat by contact between objects B. Radiation — the carrying of heat by waves of light C. Convection — the carrying of heat by a moving fluid D. Evaporation — a liquid changing into a gas

Q9 *(1 mark · VC2S10U13)* You point an X-ray observatory at hot gas near a suspected black hole. What does its detector record?

A. The number and energy of arriving X-ray photons B. The visible colours of nearby stars C. The direction of a planet’s magnetic field D. Changes in the length of laser-detector arms

Q10 *(1 mark · VC2S10U13)* The universe is 13.8 billion years old. The Sun and the solar system formed 4.6 billion years ago. How long after the big bang did the Sun and the solar system form?

A. 4.6 billion years B. 13.8 billion years C. 18.4 billion years D. 9.2 billion years

Section B — Short/structured response (30 marks)

Q11 *(6 marks · VC2S10U11)* Global mean sea level is one of the standard indicators of climate change. The table shows the average rate of rise measured for three periods, and the total rise.

Period	Average rate of sea level rise
1901–1971	1.3 mm per year
1971–2006	1.9 mm per year

Period	Average rate of sea level rise
2006–2018	3.7 mm per year
Total rise, 1901–2018	0.20 m

Source: IPCC, "Climate Change 2021: The Physical Science Basis (Sixth Assessment Report)", 2021. https://www.ipcc.ch/report/ar6/wg1/ — retrieved 2026-08-21.

- (a) At the 1901–1971 rate, estimate how much sea level rose during that period. Show your working. *(1 mark)*
- (b) About how many times faster was the 2006–2018 rate than the 1901–1971 rate? *(1 mark)*
- (c) Name the two processes that make global mean sea level rise as the climate warms. *(2 marks)*
- (d) More than 90 % of the extra heat trapped by the enhanced greenhouse effect is stored in the ocean. State what this means for sea level even if greenhouse gas concentrations stop rising. *(1 mark)*
- (e) State what a rising rate — as opposed to a steady rate — says about the climate system. *(1 mark)*

Q12 *(4 marks · VC2S10U10)* A teacher demonstration tests what is made when a candle burns. A cold, dry beaker is held above the flame, and the gases are also bubbled through limewater.

Safety: tie hair back near the flame; the beaker gets hot — handle it with tongs and let it cool.

- (a) Water droplets form on the cold beaker. State what this shows about burning. *(1 mark)*
- (b) The limewater turns cloudy. State what this shows. *(1 mark)*
- (c) Candle wax is made from petroleum — a fossil fuel. When a fossil fuel burns, carbon moves between two of Earth's stores. Name the store the carbon leaves and the store it enters. *(1 mark)*
- (d) State how the result in (b) connects to the enhanced greenhouse effect. *(1 mark)*

All readings below are simulated data for practice.

Q13 *(4 marks · VC2S10I03)* A group tests how well a wrapping slows heat loss. They fill two identical cups with the same volume of warm water at the same starting temperature. One cup is wrapped; the other is left bare. They record both temperatures every 2 minutes with the same thermometer.

Time (min)	Wrapped cup (°C)	Bare cup (°C)
0	60.0	60.0
2	57.5	55.2
4	55.2	50.5
6	53.1	46.2
8	51.2	48.9
10	49.4	38.5
12	47.8	35.0

- (a) One reading for the bare cup does not fit the pattern. Identify it and give one possible cause. *(1 mark)*
- (b) Using the table, state what the wrapping did. *(1 mark)*
- (c) The group repeats the whole investigation three times and calculates a mean at each time. State what repeating adds to the data. *(1 mark)*
- (d) State why the group should use the same thermometer for both cups. *(1 mark)*

Q14 *(4 marks · VC2S10U12)* Space is hostile to the human body. A space suit is a small spacecraft worn on the body.

- (a) Give two hazards of working in space, and the part of the suit that meets each. *(2 marks)*
- (b) Crews on the International Space Station run experiments on flames, fluids and materials that cannot be run the same way on Earth. State why. *(1 mark)*
- (c) State the meaning of *spinoff*, and give one example. *(1 mark)*

All readings below are simulated data for practice.

Q15 *(5 marks · VC2S10I01)* A group plots the recession speed of seven galaxies — the speed at which each galaxy moves away from Earth — against its distance from Earth, and draws a line of best fit through the points.

Distance (million light-years)	Recession speed (km/s)
20	470
50	1 050
100	2 260
150	3 250
200	4 350
300	6 650
400	8 700

(a) State the relationship the graph shows between distance and recession speed. *(1 mark)*

(b) The line of best fit passes close to the origin and through the point (200, 4 350). Calculate its gradient. Show your working. *(2 marks)*

(c) Use your gradient to estimate the distance of a galaxy receding at 5 500 km/s. *(1 mark)*

(d) Explain why the pattern across seven galaxies is better evidence for the relationship than any single galaxy. *(1 mark)*

Q16 *(7 marks · VC2S10U13)* The universe contains features including galaxies, stars, solar systems and black holes, and a history that can be put in order.

(a) Put these four features in order from largest to smallest: solar system, universe, galaxy, star. *(1 mark)*

(b) The universe is about 13.8 billion years old and the Sun formed about 4.6 billion years ago. Calculate how long after the big bang the Sun formed. Show your working. *(2 marks)*

(c) A black hole itself is invisible. State one way astronomers can tell that a black hole is there. *(1 mark)*

(d) State what happens at the end of a very massive star's life that forms a black hole. *(1 mark)*

(e) A balloon with dots drawn on it is inflated as a model of the expanding universe. State what the spreading apart of the dots shows. *(1 mark)*

(f) State one limit of the balloon model. *(1 mark)*

Marking guide

This guide is written for a teacher marker — no specialist science background beyond Chapters 12–13 of this book is needed. Award a mark when the student's answer matches an acceptable response below or says the same idea in other words. Do not award half marks. The marks are a record that evidence was seen; they are not used to rank students.

Test A — Section A — Multiple choice

Q	Answer	Code	Source
Q1	**B**	`VC2S10U10`	bank item `VC2S10U10.E01.S01.D1.V10`
Q2	**D**	`VC2S10U10`	bank item `VC2S10U10.E02.S01.D1.V09`
Q3	**A**	`VC2S10U10`	bank item `VC2S10U10.E02.S01.D2.V02`
Q4	**A**	`VC2S10U11`	bank item `VC2S10U11.E01.S01.D1.V06`
Q5	**B**	`VC2S10U11`	bank item `VC2S10U11.E02.S01.D2.V05`
Q6	**D**	`VC2S10U11`	bank item `VC2S10U11.E06.S01.D2.V01`
Q7	**A**	`VC2S10U12`	bank item `VC2S10U12.E01.S01.D1.V05`
Q8	**C**	`VC2S10U12`	bank item `VC2S10U12.E02.S01.D1.V08`
Q9	**D**	`VC2S10U13`	bank item `VC2S10U13.E02.S01.D2.V02`
Q10	**C**	`VC2S10U13`	bank item `VC2S10U13.E04.S01.D1.V01`

All ten items are drawn from the MCQ bank under the codes assessed on this paper; none is drawn from a neighbouring code. Items mix easy (D1) and medium (D2) bank difficulties — six easy and four medium on this paper. Items are printed with their stem and options word for word; only the positions of the options have changed for this paper, so that the correct answers are spread across A, B, C and D (the printed positions are A × 3, B × 2, C × 2, D × 3). Where the bank text used plain characters, subscripts and minus signs are set in house style (CO_2, −). No item draws on the withheld elaborations (`VC2S10U10.E04`, `VC2S10U10.E05`, `VC2S10U13.E01`).

Why each answer is correct, in brief:

- **Q1 B** — the roots belong to the biosphere and the rock to the geosphere; roots growing into and widening a rock crack is a direct biosphere–geosphere interaction. Air and water are not the pair at work here.
- **Q2 D** — the carbon in wood entered from the air when the tree photosynthesised as it grew; the fire releases it again. Respiration and burning release carbon — they do not put it into wood.
- **Q3 A** — photosynthesis removes 14 units while respiration returns 5, so the air around the leaf loses $14 - 5 = 9$ units of carbon dioxide.
- **Q4 A** — with no greenhouse gases, more of the outgoing infrared escapes straight to space, so the surface sits cooler. Greenhouse gases do not block incoming sunlight.
- **Q5 B** — individual years wobble with natural variability; one cooler year inside a decades-long rise is short-term variation within the trend, not the end of it.

- **Q6 D** — 25 × 0.90 = 22.5; 30 × 0.03 = 0.9; 0.5 × 23.8 = 11.9; total 35.3 kg CO_2-e. The footprint is each activity multiplied by its emission factor, then added — the method of Subtopic 12D's footprint week.
- **Q7 A** — collecting water from humidity and wastewater, then cleaning and reusing it, cuts the need for replacement water; discarding, one-use supplies and open storage all lose it.
- **Q8 C** — Newton's third law: the rocket pushes the water down with 8 newtons, and the water pushes the rocket up with an equal 8 newtons.
- **Q9 D** — a known spectral line appearing at a longer wavelength is a redshift, and redshift means the source is moving away. Apparent size, magnetic fields and X-ray counts do not show motion.
- **Q10 C** — about 380 000 years after the big bang the first atoms formed and light was released; the first stars lit later, and the Sun later still.

Test A — Section B — Short/structured response

Q11 *(5 marks · VC2S10U10)* (a) a place where carbon sits for a while — such as the air, the ocean or rock. *1 mark* Accept any response that captures carbon held in one place before it moves on. (b) 65 500 ÷ 881 ≈ 74 — the rock store is about 74 times the atmosphere's store. *2 marks* — 1 mark for the division and answer, 1 mark for stating the comparison. Accept "between one and two orders of magnitude bigger" with the arithmetic shown. (c) vulcanism. *1 mark* Accept "volcanic eruptions". (d) it leaves the rock store (the geosphere/lithosphere — fossil fuels underground) and enters the atmosphere. *1 mark* Both ends must be there. Marker note: the store values are the book's figures from Subtopic 12A; the source line above the question carries them.

Q12 *(4 marks · VC2S10I01)* (a) independent variable: the distance of the lamp from the pondweed; dependent variable: the number of bubbles given off each minute. *2 marks* (1 mark each; the name and the role must match). (b) for example: "The closer the lamp, the more bubbles the pondweed gives off each minute, because the pondweed receives more light and photosynthesises faster." *1 mark* Accept any statement that names both variables, says how they change together, and gives a reason. A bare guess does not earn the mark — a hypothesis carries a reason. (c) the pattern: as the lamp distance increases, the bubble rate falls; yes, the results support the hypothesis (the closest lamp gave the most bubbles). *1 mark* Accept "support" with the pattern stated. Marker note: this is the Subtopic 12A practical in fresh simulated numbers.

Q13 *(6 marks · VC2S10U11)* (a) 421.1 − 280 = 141.1 ≈ 141 ppm. *1 mark* (b) 1960–1980: (338.8 − 316.9) ÷ 20 = 21.9 ÷ 20 ≈ 1.1 ppm per year; 2000–2024: (421.1 − 369.7) ÷ 24 = 51.4 ÷ 24 ≈ 2.1 ppm per year. The later rate is about twice the earlier rate. *2 marks* — 1 mark for the two rates, 1 mark for the comparison. Accept ppm per decade if the working is consistent (about 11 and about 21 ppm per decade). (c) the combustion of fossil fuels; the carbon was stored in the geosphere/lithosphere (underground, in coal, oil and gas). *1 mark* The process and the store must both be there. (d) *2 marks* — 1 mark for the cycle: photosynthesis draws CO_2 out of the air in the growing season, and respiration and decay give some back in winter; 1 mark for the trend: a trend is a steady addition of greenhouse gas that accumulates and traps more outgoing infrared, while a cycle of a few ppm that repeats each year does not accumulate. Marker note: the values are the real annual means of the Mauna Loa record as used in Subtopic 12C; the source line above the question carries them. This is the paper's sourced climate data interpretation.

Q14 *(4 marks · VC2S10I02)* (a) the control — it shows what happens without the extra carbon dioxide, so the two jars can be compared fairly. *1 mark* (b) any two, for example: the jars are small and warm for minutes, while Earth's climate involves the ocean, the land and the ice exchanging energy over decades and centuries; the extra carbon dioxide concentration in the jar is far higher than the real atmosphere's; the jars have no water cycle, no clouds and no changing albedo; the lamp is not the Sun — the real energy budget balances incoming visible light against outgoing infrared over the whole planet. *2 marks* (1 mark each; the limit must say how the model differs from Earth). (c) the claim is too strong: the model supports the mechanism — extra carbon dioxide traps more infrared and warms — but one small, short model of one part of the system does not prove the whole climate; the conclusion needs repeated trials and the real-world indicators of Subtopic 12C. *1 mark* Accept "supports, does not prove" with a reason. Marker note: the two-jar model is the Subtopic 12B practical; the evaluation skill sits with `VC2S10I02`'s valid-investigations clause.

Q15 *(4 marks · VC2S10U12)* (a) any two challenge–feature pairs, for example: the thin atmosphere holds almost no oxygen to breathe — a sealed habitat and suits with their own oxygen supply; nights down to about −153 °C — well-insulated walls, doors and pipes; fine dust gets into everything — seals and covers on moving parts; food cannot be grown outside — a sealed greenhouse; carbon dioxide builds up inside — a scrubber to remove it. *2 marks* (1 mark per pair; the challenge and a matching feature must both be there). (b) a command sent from Earth takes minutes to arrive, so the rover cannot be driven in real time; it must stop or steer itself using its own cameras and software. *1 mark* (c) any reasonable pair, for example: advantage — knowledge of how planets form and change, and technologies developed for the mission that later help on Earth (spinoffs); cost or risk — the money and energy spent, the risk to crews, or the debris and waste missions leave behind. *1 mark* Both sides must be there. Marker note: the challenges and features are the Subtopic 13C content; part (c) serves the advantages-and-disadvantages clause of the achievement standard.

Q16 *(7 marks · VC2S10U13)* (a) the universe began in a hot, dense early state and has expanded and evolved since; the theory models the origin and evolution of the universe. *1 mark* (b) any two of: the light from galaxies is redshifted — the galaxies are moving away; the cosmic microwave background — a faint glow arriving from every direction; the oldest clouds of gas hold about one quarter of their ordinary matter as helium, as the theory predicted. *2 marks* (1 mark each). (c) *2 marks* — 1 mark for the observation: spectral lines of distant galaxies appear at longer wavelengths than the same lines measured in a laboratory; 1 mark for the reasoning: the shift to longer wavelengths (redshift) means the galaxies are moving away, and galaxies moving away in every direction is an expanding universe. (d) the glow left over from when the first atoms formed, about 380 000 years after the big bang, and light was released. *1 mark* Accept "the afterglow of the early hot universe". (e) hydrogen. *1 mark* Marker note: the evidence is taught in Subtopic 13B; no knowledge beyond the book is asked of any student.

Test B — Section A — Multiple choice

Q	Answer	Code	Source
Q1	**C**	VC2S10U10	bank item VC2S10U10.E01 .S01.D2.V05
Q2	**D**	VC2S10U10	bank item VC2S10U10.E06 .S01.D2.V01
Q3	**B**	VC2S10U10	bank item VC2S10U10.E03 .S01.D1.V01
Q4	**A**	VC2S10U11	bank item VC2S10U11.S01 .D1.V01
Q5	**C**	VC2S10U11	bank item VC2S10U11.E02 .S01.D1.V07
Q6	**D**	VC2S10U11	bank item VC2S10U11.E03 .S01.D2.V01
Q7	**B**	VC2S10U12	bank item VC2S10U12.E02 .S01.D2.V03
Q8	**C**	VC2S10U12	bank item VC2S10U12.E05 .S01.D2.V01
Q9	**A**	VC2S10U13	bank item VC2S10U13.E02 .S01.D1.V06
Q10	**D**	VC2S10U13	bank item VC2S10U13.E04 .S01.D2.V01

All ten items are drawn from the MCQ bank under the codes assessed on this paper; none is drawn from a neighbouring code. Items mix easy (D1) and medium (D2) bank difficulties — four easy and six medium on this paper. Items are printed with their stem and options word for word; only the positions of the options have changed for this paper, so that the correct answers are spread across A, B, C and D (the printed positions are A × 2, B × 2, C × 3, D × 3). Where the bank text used plain characters, subscripts and minus signs are set in house style (CO_2, −). Q4 is a core-CD item (no elaboration id) assessing the weather–climate distinction taught at the start of Subtopic 12C. No item draws on the withheld elaborations (`VC2S10U10.E04`, `VC2S10U10.E05`, `VC2S10U13.E01`).

Why each answer is correct, in brief:

- **Q1 C** — petrol is fossil carbon stored underground in the geosphere; burning it releases the carbon to the atmosphere as carbon dioxide.
- **Q2 D** — the dry mass is 48 + 22 = 70 kg; carbon is about half of dry mass, so the samples hold about 35 kg of carbon — the field-survey rule of Subtopic 12B.
- **Q3 B** — with no greenhouse gases at all the surface would sit at about −18 °C; the natural mix holds enough outgoing infrared to keep it at about +15 °C — a difference of about 33 °C.
- **Q4 A** — weather is what the atmosphere does over hours to days; climate is the pattern of weather averaged over about 30 years.
- **Q5 C** — a decline in snow-covered days over 25 years alongside rising winter temperatures is a long-term pattern; single-year or one-afternoon events, and a moved camera, are not climate indicators.

- **Q6 D** — the two runs differ in their scenarios: the amounts of greenhouse gas put into the modelled atmosphere. The physics and the grid are the same tested model in both runs.
- **Q7 B** — with the same force, the smaller mass accelerates more: 10 ÷ 1 = 10 against 10 ÷ 2 = 5, so cart X has twice the acceleration of cart Y.
- **Q8 C** — the teardrop flame needs convection — the carrying of heat by a moving fluid. In microgravity the hot air does not rise, so the flame stays small and dome-shaped.
- **Q9 A** — an X-ray detector records the number and energy of arriving X-ray photons; the gas spiralling towards a black hole heats up and shines brightly in X-rays.
- **Q10 D** — 13.8 − 4.6 = 9.2 billion years after the big bang — the sequencing arithmetic of Subtopic 13B.

Test B — Section B — Short/structured response

Q11 *(6 marks · VC2S10U11)* (a) 1.3 mm per year × 70 years = 91 mm (about 9 cm). *1 mark* (b) 3.7 ÷ 1.3 ≈ 2.8 times faster. *1 mark* Accept about 3 times with the division shown. (c) warm water takes up more space (thermal expansion), and land ice melts and the meltwater enters the ocean. *2 marks* (1 mark each). (d) the ocean holds the stored heat and gives it back slowly; warmed, expanded water keeps sea level rising for centuries even if concentrations stop rising. *1 mark* (e) a rising rate means the system is accelerating, not coasting — the change itself is getting faster. *1 mark* Marker note: the rates and the 0.20 m total are the IPCC AR6 figures as used in Subtopic 12C; the source line above the question carries them. This is the paper's sourced climate data interpretation.

Q12 *(4 marks · VC2S10U10)* (a) water is made when the fuel burns — the droplets are condensed water vapour. *1 mark* (b) carbon dioxide is made — cloudiness is the limewater test for carbon dioxide. *1 mark* (c) it leaves the rock store (the geosphere/lithosphere — the fossil fuel underground) and enters the atmosphere. *1 mark* Both ends must be there. (d) carbon dioxide is a greenhouse gas; adding it to the air traps more of the outgoing infrared and re-emits some of it back towards the surface — the enhanced greenhouse effect. *1 mark* Marker note: the demonstration is the Subtopic 12B combustion-products practical; the safety line sits at the point of use.

Q13 *(4 marks · VC2S10I03)* (a) the bare-cup reading of 48.9 °C at 8 minutes — it sits above the 6-minute reading, and a cooling cup must fall. Any one cause: the thermometer was misread; the reading was taken at the wrong time; the wrong cup was recorded. *1 mark* The reading and a cause must both be there. (b) the wrapped cup cooled more slowly — at every time after the start it stayed warmer than the bare cup. *1 mark* (c) repeats let the mean settle, reduce the effect of a single bad reading, and expose anomalies; a pattern that repeats across runs is more trustworthy. *1 mark* (d) the same thermometer means any offset in the instrument sits in every reading equally, so the two cups are compared on the same scale — a difference between the cups cannot be a difference between thermometers. *1 mark* Marker note: the practical is the Subtopic 12D insulation test in fresh simulated numbers; the item serves `VC2S10I03`'s precision-and-sample-size clause.

Q14 *(4 marks · VC2S10U12)* (a) any two hazard–feature pairs, for example: space is a vacuum with almost no air pressure — the pressure layer holds air pressure on the body; body heat has no air to carry it away — a cooling garment with water moving through thin tubes; micrometeoroids — a tough outer layer; bright sunlight — a visor; temperatures swinging between sun and shade — insulation. *2 marks* (1 mark per pair; the hazard and a matching feature must both be there). (b) the microgravity aboard the station changes how flames and fluids behave, and that condition cannot be maintained for long in a laboratory on Earth. *1 mark* (c) a spinoff is a technology first developed for space missions that is now used in everyday life; any correct example, for example scratch-resistant lenses developed for space helmet visors. *1 mark* The definition and an example must both be there. Marker note: the hazards and features are the Subtopic 13C suit-design content.

Q15 *(5 marks · VC2S10I01)* (a) the greater the distance of a galaxy, the greater its recession speed — the two are directly proportional. *1 mark* (b) gradient = change in speed ÷ change in distance = 4 350 ÷ 200 = 21.75 ≈ 22 km/s per million light-years. *2 marks* — 1 mark for the method, 1 mark for the answer. Accept any two points on the line giving about 21–23 km/s per million light-years. (c) distance ≈ speed ÷ gradient = 5 500 ÷ 21.75 ≈ 253 — about 250 million light-years. *1 mark* Accept 240–260 million light-years with the division shown. (d) one galaxy is one point, and any two points sit on some line; a pattern across seven well-spaced points shows whether the relationship really holds, and exposes any galaxy that does not fit. *1 mark* Marker note: the activity is the Subtopic 13B Hubble graph in fresh simulated numbers shaped like the real measurements; the gradient idea is the `VC2M9M02` interlock taught in Subtopic 13B.

Q16 *(7 marks · VC2S10U13)* (a) universe, galaxy, solar system, star. *1 mark* (b) 13.8 − 4.6 = 9.2 billion years after the big bang. *2 marks* — 1 mark for the method, 1 mark for the answer. (c) any one of: the glow of the accretion disc — gas spiralling in, heating up and shining before it crosses the event horizon; the motion of stars or gas pulled by an unseen, very massive object; an image of a dark shadow surrounded by glowing gas, as the Event Horizon Telescope made for M87 and Sagittarius A. 1 mark *(d) the core of a very massive star collapses at the end of its life.* 1 mark *(e) the dots spread apart because the rubber between them stretches — as space expands, the distances between galaxies increase.* 1 mark *(f) any one of: the universe is not expanding into anything the way a balloon expands into air; the dots stand for galaxies, and the galaxies themselves do not expand; the balloon's surface is two-dimensional, while space is three-dimensional.* 1 mark* Marker note: the features and the star lifecycle are Subtopic 13A content; the balloon model and the sequencing are Subtopic 13B's.

Tracing the items to the achievement standard

Every item traces to the achievement-standard extract of the subtopic that owns its code (§4 of the plan of record). The extracts are quoted as the authority file gives them. `VC2S10U10` is split-delivered: 12A owns the four-systems and photosynthesis–respiration limb and 12B the fire, weathering, vulcanism and fossil-fuel-combustion limb. `VC2S10U11` is split-delivered: 12C owns the climate-dynamics limb and 12D the mitigation limb. `VC2S10U12` is delivered whole by 13C. `VC2S10U13` is split-delivered: 13A owns the features limb and 13B the big bang limb. The inquiry codes sit with their Chapters 1–3 owners; on this paper their items attach to the practical work of Chapters 12–13, per the D7 rule that the inquiry marks of T3–T6 attach to that chapter's own practical work.

Code	Subtopic	Achievement-standard extract	Test A items	Test B items
`VC2S10U10`	12A and 12B	"They explain how interactions within and between Earth's interrelated systems affect the carbon cycle."	Q1, Q2, Q3, Q11	Q1, Q2, Q3, Q12
`VC2S10U11`	12C and 12D	"They describe trends in patterns of global climate change and propose strategies to mitigate contributing factors."	Q4, Q5, Q6, Q13	Q4, Q5, Q6, Q11
`VC2S10U12`	13C	"They discuss the advantages and disadvantages of space exploration."	Q7, Q8, Q15	Q7, Q8, Q14
`VC2S10U13`	13A and 13B	"They distinguish between different features in the universe and sequence key events in the origin and evolution of the universe, including an outline of the supporting evidence for the big bang theory."	Q9, Q10, Q16	Q9, Q10, Q16
`VC2S10I01`	2A and 2B	"Students formulate and refine questions and hypotheses to make reasoned predictions, test relationships and develop explanatory models when investigating scientific questions, problems and claims."	Q12	Q15
`VC2S10I02`	3A and 3B	"They plan a range	Q14	—

Code	Subtopic	Achievement-standard extract	Test A items	Test B items
		of valid, reproducible and safe scientific investigations and explain how they have addressed any ethical and cultural considerations when generating or using primary and secondary data.”		
`VC2S10I03`	3C	“They select and use equipment to generate and record data, ensuring the use of suitable sample sizes and assessing the precision of multiple measurement readings.”	—	Q13

Inquiry weighting: 8 of the 40 marks on Test A sit on the inquiry codes `VC2S10I01` and `VC2S10I02` (Section B Q12 and Q14), and 9 of the 40 marks on Test B sit on `VC2S10I01` and `VC2S10I03` (Section B Q13 and Q15) — both above the required minimum of 6 inquiry-strand marks per topic test (D7). The inquiry items attach to the chapter practicals: the pondweed-and-lamp investigation and the two-jar greenhouse model on Test A; the insulated-cup heat-loss test and Hubble’s graph on Test B.

Mark record — Test A

Question	Code	Worth	Given
Q1 — roots and rock: two systems meet	VC2S10U10	1	
Q2 — campfire carbon	VC2S10U10	1	
Q3 — one leaf, two processes	VC2S10U10	1	
Q4 — a planet without greenhouse gases	VC2S10U11	1	
Q5 — one cool year in a warming trend	VC2S10U11	1	
Q6 — a weekend footprint	VC2S10U11	1	
Q7 — water on Mars	VC2S10U12	1	
Q8 — the rocket and its water	VC2S10U12	1	
Q9 — a galaxy moving away	VC2S10U13	1	
Q10 — 380 000 years after the big bang	VC2S10U13	1	
Q11 — carbon stores and their sizes	VC2S10U10	5	
Q12 — pondweed, light and bubbles	VC2S10I01	4	
Q13 — reading the CO_2 record	VC2S10U11	6	
Q14 — evaluating the two-jar greenhouse model	VC2S10I02	4	
Q15 — living on Mars	VC2S10U12	4	
Q16 — evidence for the big bang	VC2S10U13	7	
Total		**40**	

Mark record — Test B

Question	Code	Worth	Given
Q1 — petrol burning	VC2S10U10	1	
Q2 — carbon in dead wood and leaf litter	VC2S10U10	1	
Q3 — the natural greenhouse effect	VC2S10U10	1	
Q4 — weather or climate	VC2S10U11	1	
Q5 — snow days as an indicator	VC2S10U11	1	
Q6 — two model runs, two futures	VC2S10U11	1	
Q7 — same thrust, different masses	VC2S10U12	1	
Q8 — a flame without convection	VC2S10U12	1	
Q9 — seeing a black hole's neighbourhood	VC2S10U13	1	
Q10 — when did the Sun form	VC2S10U13	1	
Q11 — reading the sea level record	VC2S10U11	6	
Q12 — what a candle makes	VC2S10U10	4	
Q13 — insulated cups and repeat readings	VC2S10I03	4	
Q14 — the suit and the station	VC2S10U12	4	
Q15 — Hubble's graph	VC2S10I01	5	
Q16 — features of the universe, in order	VC2S10U13	7	
Total		**40**	