A PHYSICS LESSON

Stars and Galaxies

Our place in the Universe

The Sun is a star, like the thousands of dots that shine at night. So how can it look so big, and they so small?

1 The stars
2 The night sky
3 The galaxies



The “Cosmic Cliffs” of the Carina Nebula, where stars are being born, photographed by the James Webb Space Telescope. NASA, ESA, CSA, STScI

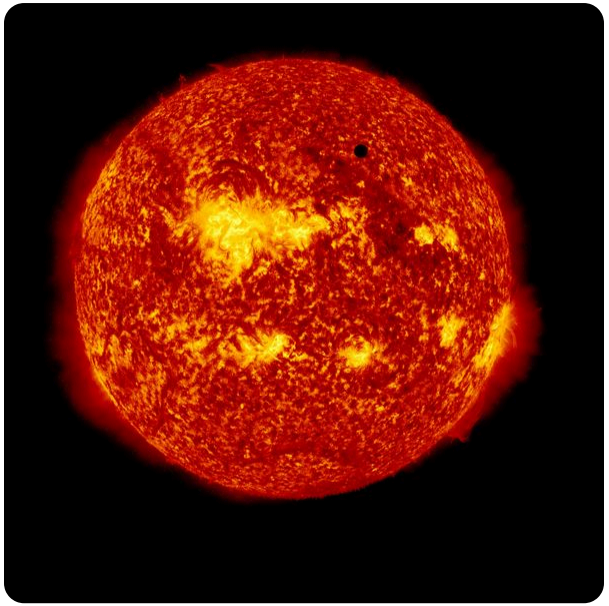
The Sun, one star among many

A **star** is a huge ball of very hot gas that makes its own light. The Sun is one: it is the star closest to us.

- **Energy at the core:** at the centre, at 15 million °C, hydrogen turns into helium. This is **nuclear fusion**: it releases the star's light and heat.
- **Size:** 1.4 million km across, 109 Earths side by side.
- **Temperature:** about 5,500 °C at the surface.
- **Age:** 4.6 billion years. It will keep shining for about 5 billion more.
- **Star or planet?** A planet makes no light: it only reflects the light of its star, like the Moon.

A DISC OR A DOT

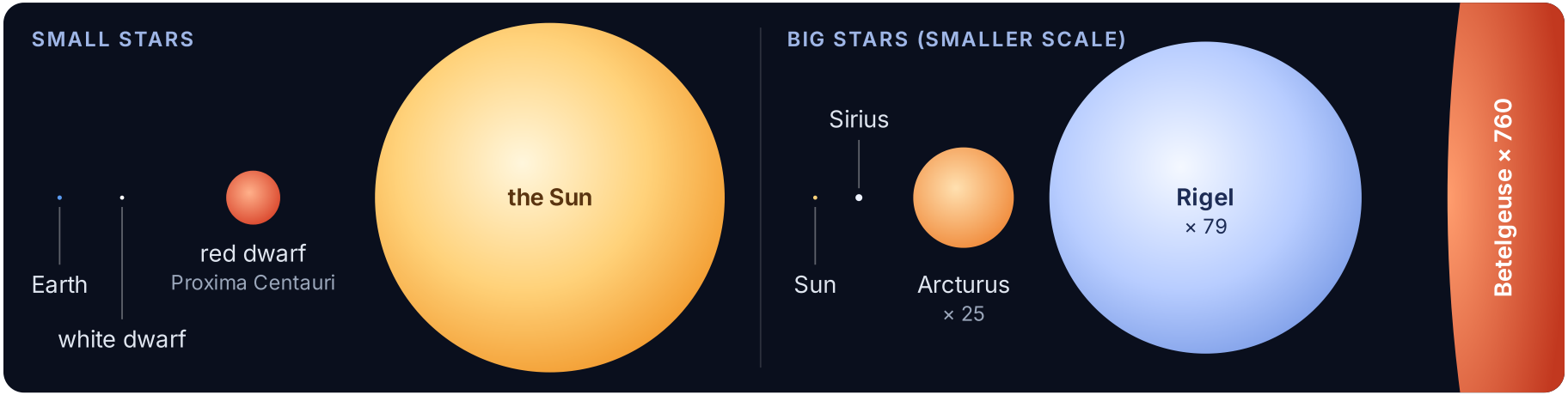
The Sun is not a giant star: it is simply very close. The other stars are so far away that they are only dots, even in the biggest telescopes. And they shine in daytime too, but the sunlit blue sky hides them.



The Sun seen by NASA's SDO probe on 5 June 2012, in ultraviolet light our eyes cannot see (the colours are added). The small black disc is Venus, almost as big as the Earth, passing in front of it.
NASA/SDO

Dwarfs and giants

Stars are not all alike. Astronomers sort them by their **mass** (how much matter they hold), their **size**, their **temperature** and their **luminosity** (how much light they give off).



Sizes to scale within each half. “× 25” means 25 times wider than the Sun.

Red dwarfs are small, cool and dim: the most common stars, but too faint for the naked eye.

The Sun is a yellow dwarf: a medium-sized star, bigger than most.

Supergiants like Betelgeuse, in the Sun’s place, would swallow Mercury, Venus, the Earth and Mars.

White dwarfs, the size of the Earth, are what is left of a star like the Sun when it dies.

The colour of a star

Look closely: some stars are reddish, others yellow, white or bluish. A star's colour tells us its **temperature**.

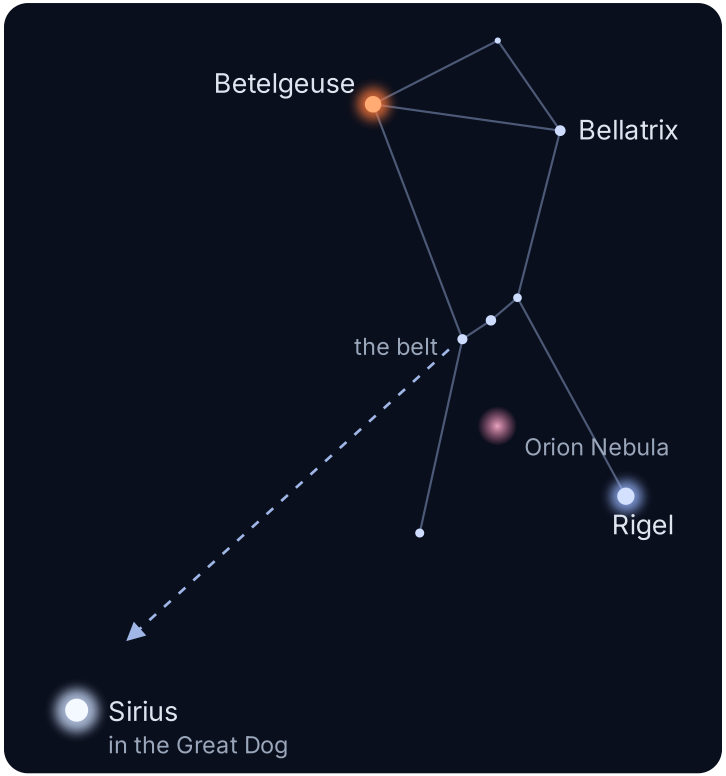


LIKE HEATED METAL

A piece of iron in a fire glows red, then orange, then yellow, then white as it gets hotter. Stars follow the same rule, all the way to blue: unlike on taps, blue is the hottest colour!

? In Orion, which star is hotter: Betelgeuse or Rigel?

Rigel, which is bluish white: about 12,000 °C at the surface. Red-orange Betelgeuse is only about 3,300 °C.



Orion, high in the southern sky on winter evenings. Follow its belt down to the left: you reach Sirius, the brightest star of the night.

The light-year

The stars are so far away that we measure their distance in **light-years**: the distance light travels in one year, at 300,000 km per second. Looking at a star means seeing into the past: the light of Sirius, the brightest star of the night, left it 8.6 years ago.

1 light-year ≈ 9.46 trillion km

Object	Distance	Light takes
the Moon	384,400 km	1.3 seconds
the Sun	150 million km	8 min 20 s
Proxima Centauri	4.2 light-years	4.2 years
Sirius	8.6 light-years	8.6 years
the Orion Nebula	1,350 light-years	1,350 years
the Andromeda Galaxy	2.5 million light-years	2.5 million years

1 **To Proxima Centauri, the nearest star after the Sun, by car at 100 km/h?**

4.2 light-years is about 40 trillion km. At 100 km/h, that takes 400 billion hours: about 46 million years.

2 **And at the speed of the Voyager 1 probe?**

At 61,000 km/h, about 75,000 years. Voyager 1, launched in 1977 and now the farthest probe, is about one light-day from us: its messages take almost a day to reach the Earth.

3 **Can we see Proxima Centauri from Canada?**

No. It is a red dwarf, too faint for the naked eye, and it is so far south in the sky that it never rises above the horizon in Canada.

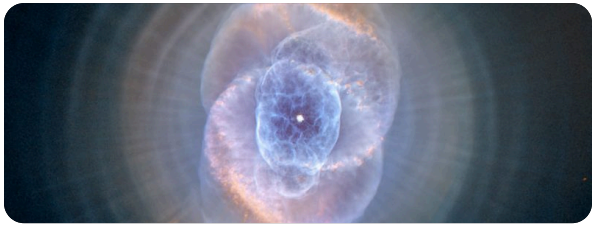
The life of a star

Stars are born, shine for millions or billions of years, then die. The heaviest live the shortest lives.



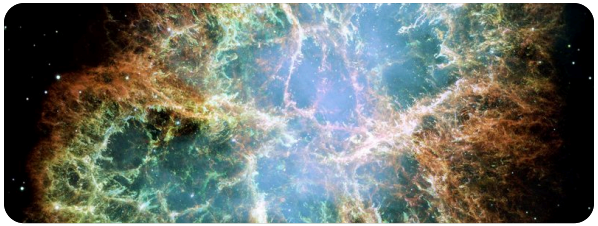
The “Pillars of Creation”, in the Eagle Nebula, 6,500 light-years away. NASA, ESA, CSA, STScI (Webb)

Birth. A star is born in a cloud of gas and dust, a **nebula**. Gravity pulls the matter into a ball, which heats up until fusion switches on.



The Cat’s Eye Nebula, 3,300 light-years away: a dying star throws off its gas.
ESA, NASA, HEIC, Hubble Heritage Team (STScI/AURA)

The end of a star like the Sun. In about 5 billion years, the Sun will swell into a **red giant**, then puff off its outer layers. Its core will be left: a **white dwarf** that slowly cools.



The Crab Nebula, left by a supernova that Chinese astronomers saw in 1054, even in daylight.
NASA, ESA, J. Hester, A. Loll (ASU)

The end of a very heavy star. More than 8 times heavier than the Sun, it explodes as a **supernova**. What is left is a **neutron star**, no wider than a city, or a **black hole**.

STARDUST

The carbon in your cells, the calcium in your bones and the iron in your blood were made inside stars that died long before the Sun was born. We are made of stardust.

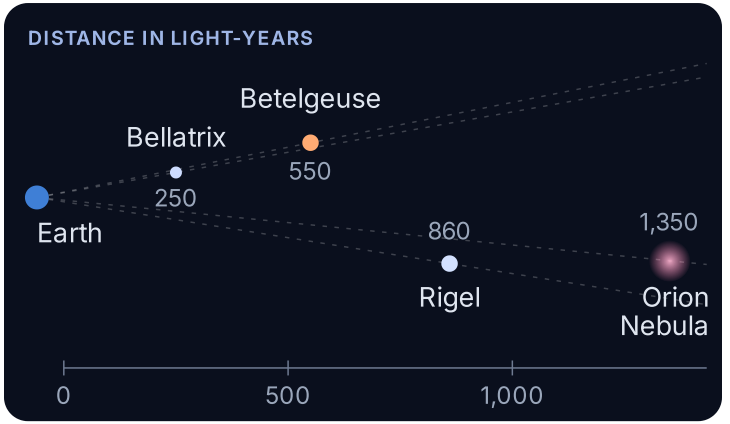
Pictures in the sky

To find their way around the sky and to tell its stories, peoples of every age have grouped the stars into figures: the **constellations**.

- In 1922, astronomers from around the world agreed on **88 official constellations**. Since 1930, every corner of the sky belongs to one of them, as every town belongs to a country.
- Many are named after animals (the Lion, the Swan, the Great Bear) or come from the legends of ancient Greece (Orion the hunter, Perseus, Andromeda).
- Each people saw its own pictures. The seven bright stars of the Great Bear form the Big Dipper in North America and a plough in Britain. For the Mi'kmaq, the four stars of its bowl are a bear chased by bird hunters.

THE PLANISPHERE

A **planisphere** is a sky map with a disc that turns: set the date and the time, hold it above your head with north towards the north, and it shows the constellations of that evening. On a screen, Stellarium Web does the same.



Seen from the Earth, the stars of Orion seem side by side. Seen from the side, they are at very different distances, in light-years: Rigel is more than three times farther than Bellatrix.

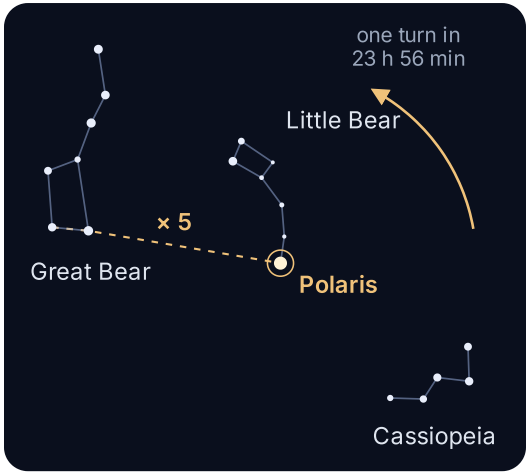
? **Name four constellations with an animal's name.**

For example: the Great Bear, the Little Bear, the Lion, the Bull, the Swan, the Eagle, the Dragon, the Scorpion, the Whale, the Great Dog, the Little Dog, the Hare, the Ram, the Dolphin, the Giraffe…

The North Star

All night long, the stars turn slowly around one point of the sky that hardly moves: the **North Star**, or Polaris. It shows the way north.

- It is the Earth that turns: its axis points almost exactly at Polaris, so the whole sky seems to go round it.
- To find it, extend the line of the two stars at the end of the Big Dipper's bowl about five times.
- Polaris is the tip of the Little Bear's tail. It is not very bright: about fifty stars outshine it.



Looking north. The whole picture turns around Polaris; in Canada, the Big Dipper never sets.



A long exposure at Kitt Peak, in Arizona: each star draws an arc around Polaris, at the centre. KPNO/NOIRLab/NSF/AURA

1 How high above the horizon is Polaris?

Its height equals your latitude: about 45° in Montreal, halfway up to the point straight overhead. At the North Pole, it is overhead; at the equator, on the horizon.

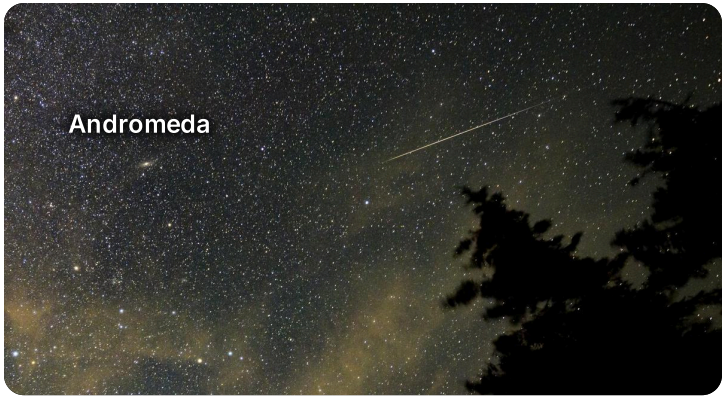
2 Will Polaris always be the North Star?

No. Like a spinning top, the Earth's axis slowly traces a circle, in 26,000 years. In about 12,000 years, it will point near Vega.

Not always a star

In the night sky, not every point of light is a star. Here is how to tell the others apart.

- **Planets:** Venus, Jupiter, Mars and Saturn look like bright stars that twinkle less. From week to week, they move slowly among the constellations; *planet* comes from a Greek word meaning “wanderer”. Venus, the “evening star”, is the brightest point in the sky after the Moon.
- **Satellites:** a dot that crosses the sky in a few minutes, without blinking. The brightest is the International Space Station, 400 km up.
- **Planes:** lights that blink, often red and green.
- **Shooting stars:** they are not stars at all, but grains of dust from space, often smaller than a grain of sand. They hit the air at tens of kilometres per second, about 100 km up, and burn up in a streak of light.



A Perseid over Spruce Knob, West Virginia, on 11 August 2021 (30-second exposure). The small fuzzy patch on the left is the Andromeda Galaxy. NASA/Bill Ingalls

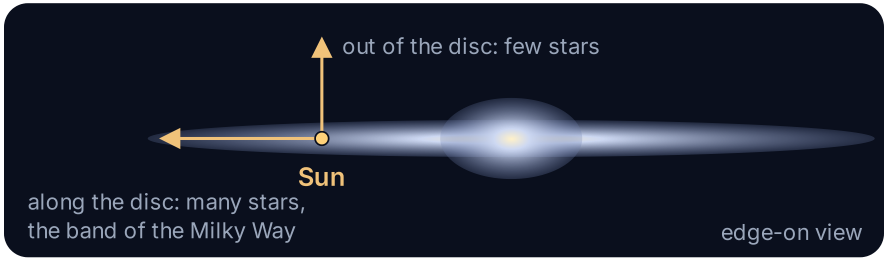
METEOR SHOWERS

When the Earth crosses the dust left by a comet or an asteroid, dozens of shooting stars fall each hour. The **Perseids**, around 12 August, come from comet Swift–Tuttle; the **Geminids**, around 14 December, from the asteroid Phaethon.

The Milky Way, our galaxy

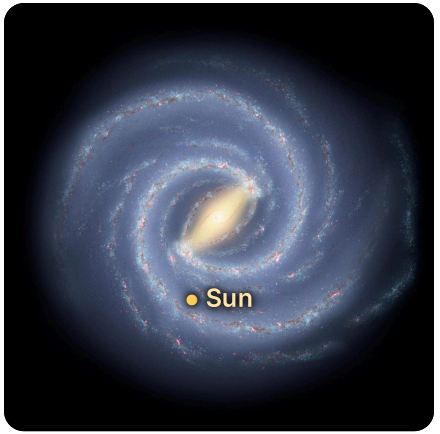
On a moonless night, far from city lights, a pale band crosses the sky: the **Milky Way**. It is our galaxy, seen from the inside.

- A **galaxy** is a huge collection of stars, gas and dust, held together by gravity. Ours has 100 to 400 billion stars.
- It is a flat disc about 100,000 light-years across, with a bar of stars in the middle, spiral arms, and a giant black hole at the centre.
- The Sun lies in a small arm, 26,000 light-years from the centre. It goes around it once every 230 million years, at more than 800,000 km/h.





The Milky Way above Spruce Knob, West Virginia. NASA/Bill Ingalls



Our galaxy seen from above, as drawn from the measurements of NASA's Spitzer telescope. NASA/JPL-Caltech/R. Hurt

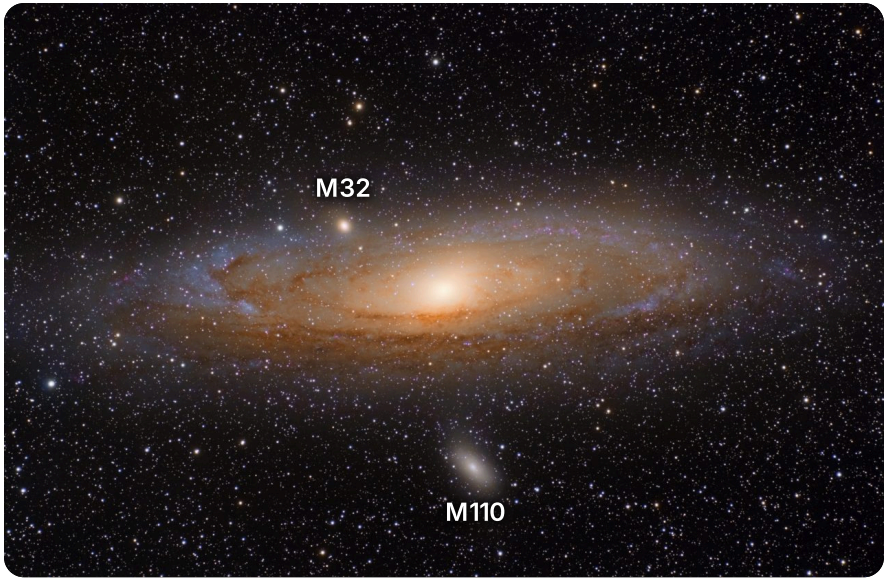
WHERE IS THE CENTRE?

In 1785, William Herschel and his sister Caroline counted stars in every direction and drew the first map of our galaxy: a flattened disc, with the Sun near the middle. Dust hid the distant stars from them. In 1918, Harlow Shapley showed that the Sun is far from the centre.

Andromeda, our big neighbour

The Milky Way's big neighbour, the **Andromeda Galaxy**, is 2.5 million light-years away: the light you see from it left when our distant ancestors were making their first stone tools.

- It is a spiral, like ours, but bigger: about a trillion stars.
- On autumn evenings, far from the city, you can see it with the naked eye: a small fuzzy patch between the Great Square of Pegasus and the W of Cassiopeia. Nothing farther is as easy to see without a telescope.
- In 1923, Edwin Hubble measured its distance: far too great for it to be part of the Milky Way. It was another galaxy, and the Universe suddenly became much bigger.
- It is coming towards us at about 110 km/s. One day the two galaxies may merge, but it is not certain: about one chance in two within 10 billion years.



The Andromeda Galaxy, with two small galaxies that go around it, M32 and M110.
Brody Wesner (CC0)

The shapes of galaxies

In 1926, Edwin Hubble sorted the galaxies by their shape. Astronomers still use his four big families.



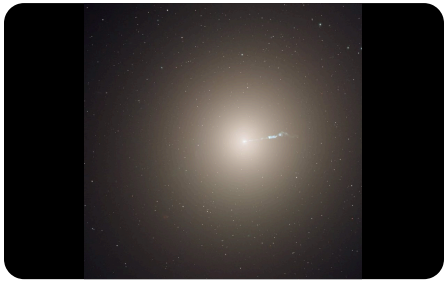
Spiral. A disc with arms where young, bluish stars are born. M51, the Whirlpool Galaxy, near the tail of the Great Bear, is pulling on a small galaxy.

NASA, ESA, S. Beckwith (STScI), Hubble Heritage Team (STScI/AURA)



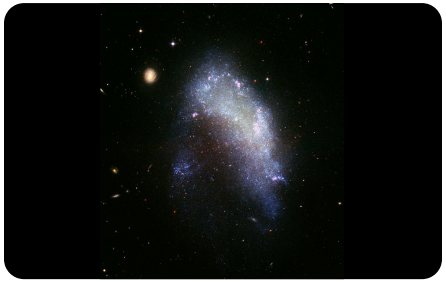
Barred spiral. The arms start at both ends of a bar of stars. NGC 1300 is one; so is the Milky Way.

NASA, ESA, Hubble Heritage Team (STScI/AURA)



Elliptical. A ball or an egg of old, yellowish stars, with almost no gas. M87 holds trillions of them; its central black hole was the first ever photographed, in 2019. The blue streak is a jet of matter it shoots out.

NASA, ESA, Hubble Heritage Team (STScI/AURA)



Irregular. No set shape, lots of young stars. NGC 1427A is falling into a cluster of galaxies, which stretches it and tears it apart.

NASA, ESA, Hubble Heritage Team (STScI/AURA)

WHEN GALAXIES MEET

The stars of two colliding galaxies almost never hit each other: they are too far apart. But gravity twists both galaxies out of shape, and they often end up as a single galaxy.

Hundreds of billions of galaxies

In 2022, the James Webb Space Telescope photographed a patch of sky no bigger than a grain of sand held at arm's length. It holds thousands of galaxies.

- Each little smudge is a galaxy, with its billions of stars. The dots with spikes are stars of our own galaxy, in front.
- The stretched arcs are faraway galaxies whose light is bent by the gravity of the cluster of galaxies in the middle, as if by a magnifying glass.
- Light from the farthest ones has travelled for more than 13 billion years: we see them as they were soon after the birth of the Universe, 13.8 billion years ago.
- In the whole observable Universe, there are hundreds of billions of galaxies.

YOUR ADDRESS IN THE UNIVERSE

Your house, your town, your country, the Earth, the solar system, the Milky Way, the Local Group (the Milky Way, Andromeda and dozens of small galaxies), the Universe.



Webb's First Deep Field, around the galaxy cluster SMACS 0723: 12.5 hours of exposure. The Canadian Space Agency supplied two of Webb's instruments. NASA, ESA, CSA, STScI

REVIEW

Test yourself

1 **Is the Sun a star? Then why does it look so different from the dots in the night sky?**

Yes. It looks big and dazzling because it is very close: its light takes 8 minutes to reach us, against 4.2 years for the next star.

2 **A bluish star and a red star: which is hotter?**

The bluish one. Red stars are the coolest (about 3,000 °C), blue ones the hottest (20,000 °C and more).

3 **Is a light-year a length of time or a distance?**

A distance: how far light travels in one year, about 9.46 trillion km.

4 **How do you find the North Star?**

Extend the line of the two stars at the end of the Big Dipper’s bowl about five times. It is the tip of the Little Bear’s tail.

5 **Is a shooting star a star?**

No. It is a grain of dust from space that burns up in the air, about 100 km up.

6 **Name the four families of galaxies. Which one does the Milky Way belong to?**

Spiral, barred spiral, elliptical and irregular. The Milky Way is a barred spiral.

TO SUM UP

The big ideas

1. A **star** is a ball of very hot gas that makes its light by nuclear fusion. Stars differ in size, mass, colour and temperature; the Sun is an average star, very close to us.

2. The **constellations** are imaginary pictures: 88 official ones. The Earth spins on an axis that points at the **North Star**, so the sky seems to turn around it.

3. A **galaxy** gathers billions of stars. Ours, the Milky Way, is a barred spiral; Andromeda, its big neighbour, is 2.5 million light-years away. The Universe holds hundreds of billions of galaxies.

Go further

▶ Tonight's sky in Stellarium Web

The Solar System in Motion

The Moon lesson

The gravity lesson

Practise in the Practice Room

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