Key Stage 5 Worksheet

Earth LIVE Lessons: Earth's place in the Universe

What is it about?

In this video, Mark Thompson, Astronomer, Science Broadcaster and Author, uses a remote telescope to make live observations of a variety of astronomical objects. Mark discusses what these objects can tell us about the history and future of the Earth, and our place in the universe.

Watch video here:
youtu.be/RNiQbvF7p2w

Open file in your web browser to click on the links.

Note: There are some technical difficulties at the start of this video, skip to 8:45 for the start of the Live lesson.

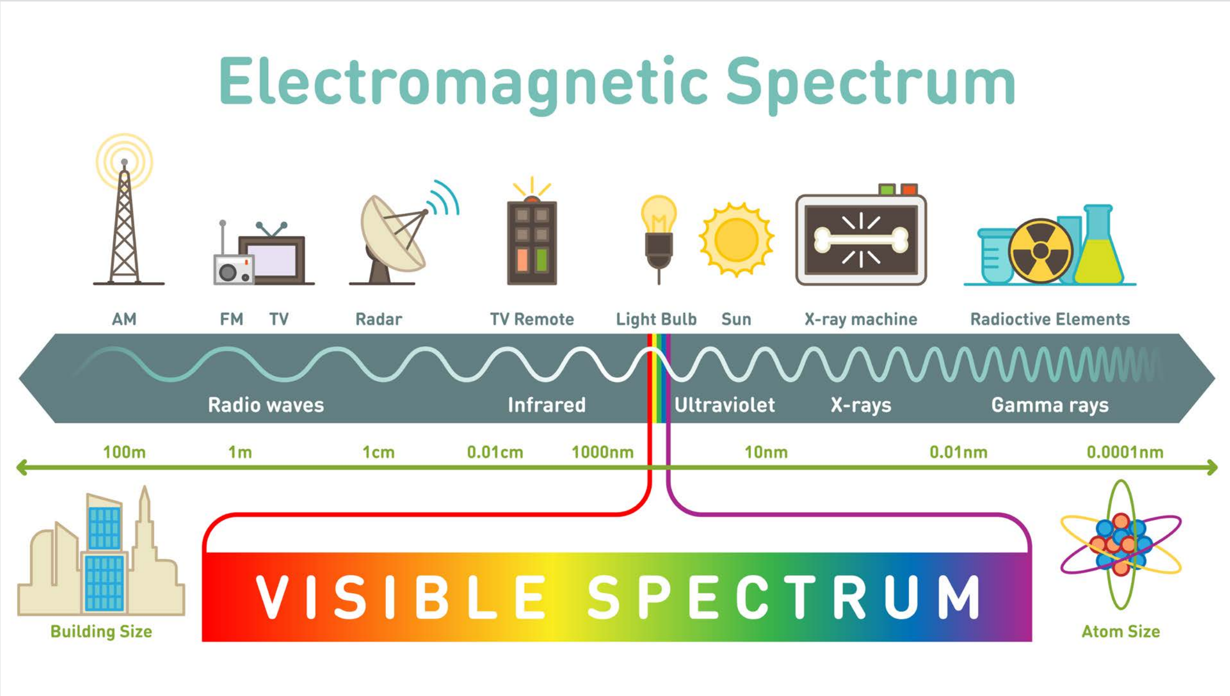
The Las Cumbres Network

The Las Cumbres Observatory is a global network of robotic telescopes that can be accessed and controlled remotely from anywhere in the world. In this network there are 27 telescopes at 7 different sites. In this video, Mark captures astronomical images live by remotely controlling a telescope in Hawaii from his home in the UK. The telescope he uses is one of the 0.4 m telescopes at the Haleakala Observatory in Maui, Hawaii.

Haleakala Observatory, Hawaii.

The Electromagnetic Spectrum

The electromagnetic spectrum is a group of seven types of radiation including radio waves, visible light, and x-rays. These can travel as waves, even in space. The seven types of radiation are grouped by the lengths of their waves, which give them different properties or behaviours.



Our eyes can detect visible light, which is a small part of the electromagnetic spectrum. However, to study the universe, we use telescopes that can detect all types of radiation within the electromagnetic spectrum. This helps us to understand and study distant objects in more detail than if we just look at the visible light they emit (give off). We can use these observations to learn a lot of information about stars and other objects in space, including what materials they are made from.

Our past – how did we get here?

Mark uses the remote telescope to take an image of the deep-space object, M16, which is more commonly named the Eagle Nebula.

A nebula is a vast cloud of gas and dust in space. Nebulae (plural of nebula) are mostly hydrogen and helium gas, with some other trace elements and materials, like oxygen, carbon and dust. The Eagle Nebula is a type of nebula which is often referred to as a *Stellar Nursery*, because they are where new stars form. Our Sun and everything in our solar system, including Earth, formed from a similar gas cloud.

Our past continued...

In Stellar Nurseries, the gases contract and condense in different regions to produce stars. The dust and gases in nebula are very diffuse (spread apart) but some small, charged particles will be pulled together by electrostatic forces. This is the same force that we experience when we rub a balloon against an object (e.g. a jumper) until a charge accumulates (builds up) on its surface and small objects (e.g. dust or our hair) become attracted to it.

The charged particles in a nebula will be attracted to each other and collect together to create small clumps. Gravity then pulls these clumps together. The clumps will continue to grow, so their gravitational force will get stronger and stronger, pulling in more and more material from the nebula. As they get larger, the pressures and temperatures inside the large clumps rises. When the temperature and pressure at the centre of a clump becomes high enough, hydrogen atoms will fuse together to form helium atoms, releasing heat and light energy. This is the birth of star.

The Eagle Nebula is 7,000 light years away from Earth. This means it takes 7,000 years for the light from this nebula to reach us here on Earth, so when we look at it, we are actually seeing what it looked like 7,000 years ago. This means that when we look at distant objects in space, we are looking back in time, so we can use deep-space objects to study history of our universe.

Our present – where are we now?

Our Sun is now in the *main sequence* stage of its life cycle. During the main sequence, stars will fuse hydrogen in their core (centre) to form helium and release energy. This is called nuclear fusion and it produces an outward pressure which pushes material out from the star's core. This outward force is counteracted by the inward force of gravity pulling material towards the centre of the star. These two forces are balanced, keeping the star stable. The colour and temperature of a main sequence star depend on its size. Small stars are red and orange in colour and cooler than large stars, which are blue and white in colour. Our Sun is a yellow, average-sized star. Stars are found within galaxies. A galaxy is a huge collection of dust, gas, billions of stars and their solar systems (including planets). They can be a few different shapes, including round, oval, spiral, and barred.

Our present continued...

Mark took an image of the NGC 6643 spiral galaxy, which is 65 million light years from Earth and can be found in the constellation Draco. We live in a similar spiral galaxy, the Milky Way galaxy, and we are thought to be about two thirds of the way out along one of the spiral arms.

Earth is 1 of 8 planets orbiting our Sun, which is one of over 400 billion stars in our galaxy. There are at least 100 billion galaxies in our Universe. However, Earth is the only place that we know with certainty that life exists and has evolved.

Spiral galaxy

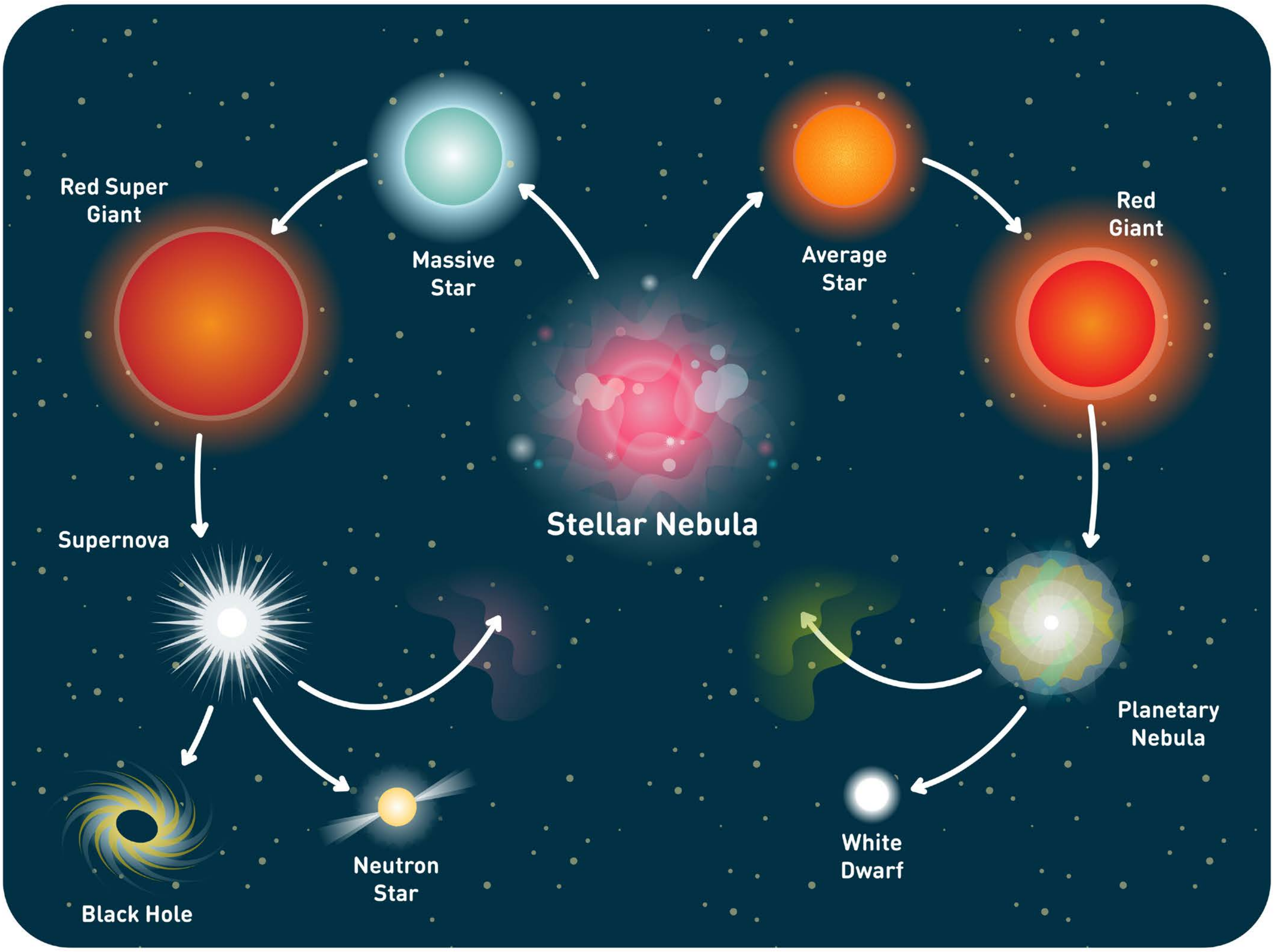
Our future – what will happen to us in the end?

Mark took an image of the object M27, which is a type of nebula called a Planetary Nebula.

When an average-sized star (like our Sun) uses up all its fuel for fusion, it expands (grows) and turns red as it cools down. We call it a Red Giant. The Red Giant will shed its outer layers, which become a glowing shell of hot gas and plasma called a planetary nebula. A small dense core, called a white dwarf is left behind. A *white dwarf* is so dense that a chunk of its surface, the size of a matchbox, would weigh the same as 15 elephants! The white dwarf will cool and dim to become a black dwarf. This is what will happen to our Sun in about 5 billion years.

When a larger star (more than 7 times bigger than our Sun) comes to the end of its life, it will expand and cool to become a Red Supergiant. The death of a Red Supergiant is much more spectacular. The core of the star will keep contracting and getting hotter. The star eventually collapses in on itself and then explodes as a fiery supernova, creating a type of nebula called a supernova remnant. This can shine as bright as an entire galaxy and can take a few days to fade completely. The core of the star is left behind as a neutron star. These are even denser than white dwarfs and spin around really fast, sometimes several hundred times a second. However, if the star was big enough (more than 20 times bigger than our sun), instead of a neutron star, the core will be left behind as a black hole. Black holes are so dense that their gravity is strong enough to stop anything escaping them, even light!

Star life cycle



Find out more

- Learn more about the **Las Cumbres Observatory**, a network of remote telescopes.
- Explore the night sky using this free **Stellarium software**.
- Get help identifying constellations and other night-sky objects with this free **Star Walk 2 Stargazing app**.
- Watch this **YouTube video by NASA** about how stars form.
- Watch S4's **'What's in the Night Sky? Science Club videos** to get astronomy tips and learn more about stars and deep-space objects.
- Learn this **BBC Bitesize** about the lifecycle of a star.

Questions

Q1. Nuclear fusion that occurs in the cores of main sequence stars can be represented by the equation.

$$4\,{}^{1}_{1}H + 2\,e^{-} \rightarrow {}^{4}_{2}He + 2\nu_e$$

Where:

${}^{1}_{1}H$ is a hydrogen atom with a mass of 1.00784 u

e^{-} is an electron with a mass of 0.00055 u

${}^{4}_{2}He$ is a helium atom with a mass of 4.00260 u

ν_e is an electron neutrino with a mass of 0.00000 u

1 u is one atomic mass unit = 1.66×10^{-27} kilograms (Kg)

Calculate the energy released in this reaction, in Joules (J). Use the equation $E=mc^2$, where c is the speed of light and has a value of $c = 3 \times 10^{8}$ metres per second (ms^{-1}).

Helpful hint: 1 J = 1 kg m^2 s^{-2}.

Interactive: Click on box to start typing

Mass input:
4x mass of hydrogen atom + 2x mass of electron
= (4 x 1.00784) u + (2 x 0.00055) u = (4.03136 + 0.00110) u = 4.03246 u

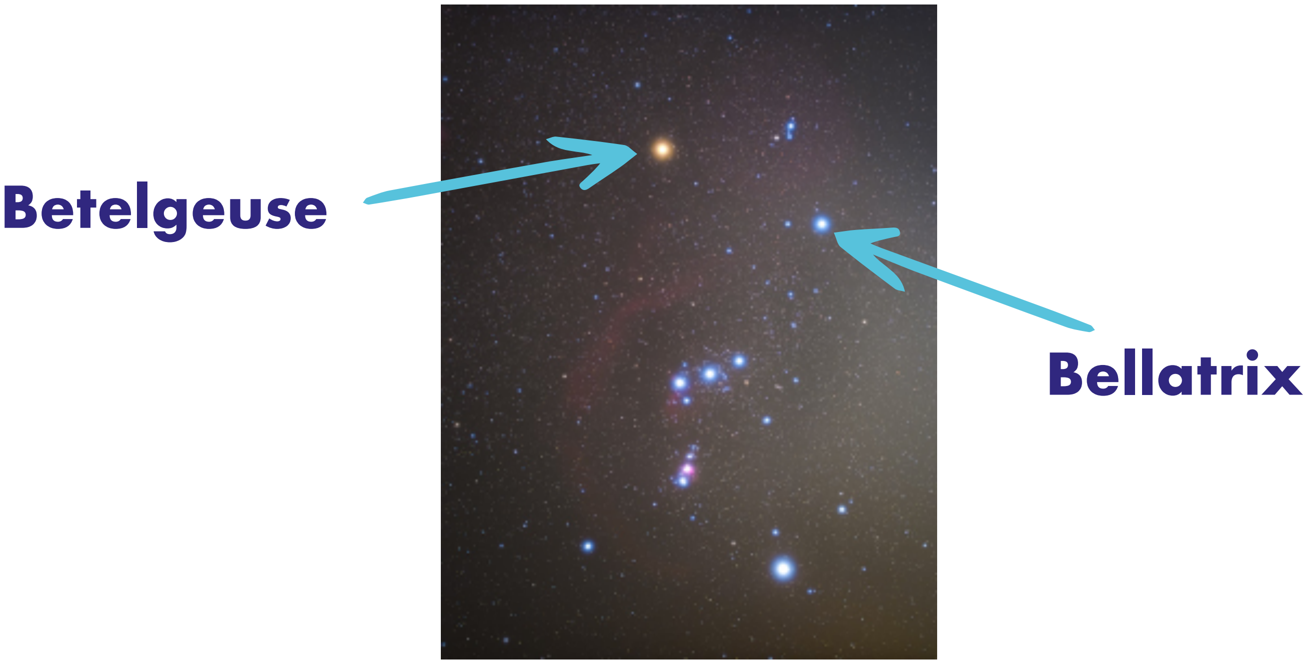
Mass output:
Mass of helium atom + 2x mass of electron neutrino
= 4.00260 u + (2 x 0.00000) u = 4.00260 u

Mass defect = mass input - mass output = (4.03246 - 4.00260) u = 0.02986 u
Mass defect in kg = 0.02986 x 1.66x10^-27 kg = 4.957x10^-29 kg

E= mc^2: Energy released = mass defect x (speed of light)^2
4.957x10^-29 kg x (3x10^8 ms^-1)^2 = 4.461x10^-12 kg m^2 s^-2 = 4.461x10^-12 J (Joules)

Q2. An astronomer measures the radiation emitted by two stars in the Orion constellation, Bellatrix and Betelgeuse. They find that the intensity of the radiation peaks at a wavelength of 1.32×10^{-7} m for one of the stars and at a wavelength of 8.53×10^{-7} m for the other star.

a. These two stars are shown in the picture below.



Which star has a peak wavelength of 1.32×10^{-7} m and which has a wavelength of 8.53×10^{-7} m? How can you tell from the picture?

Peak wavelength for Betelgeuse = 8.53 x10-7 m, because it is a redder star, so must have peak at a longer wavelength than the bluer star Bellatrix.
Peak wavelength for Bellatrix = 1.32×10-7 m

Helpful hint: Take a look at the picture of the electromagnetic spectrum above. 100 nanometres (nm) = 1×10^{-7} metres (m)

b. Calculate the temperature of the 2 stars using Wien's displacement law, assuming that the stars can be modelled as black bodies.

Wien's displacement law: $$\lambda_{max} = \frac{W}{T}$$

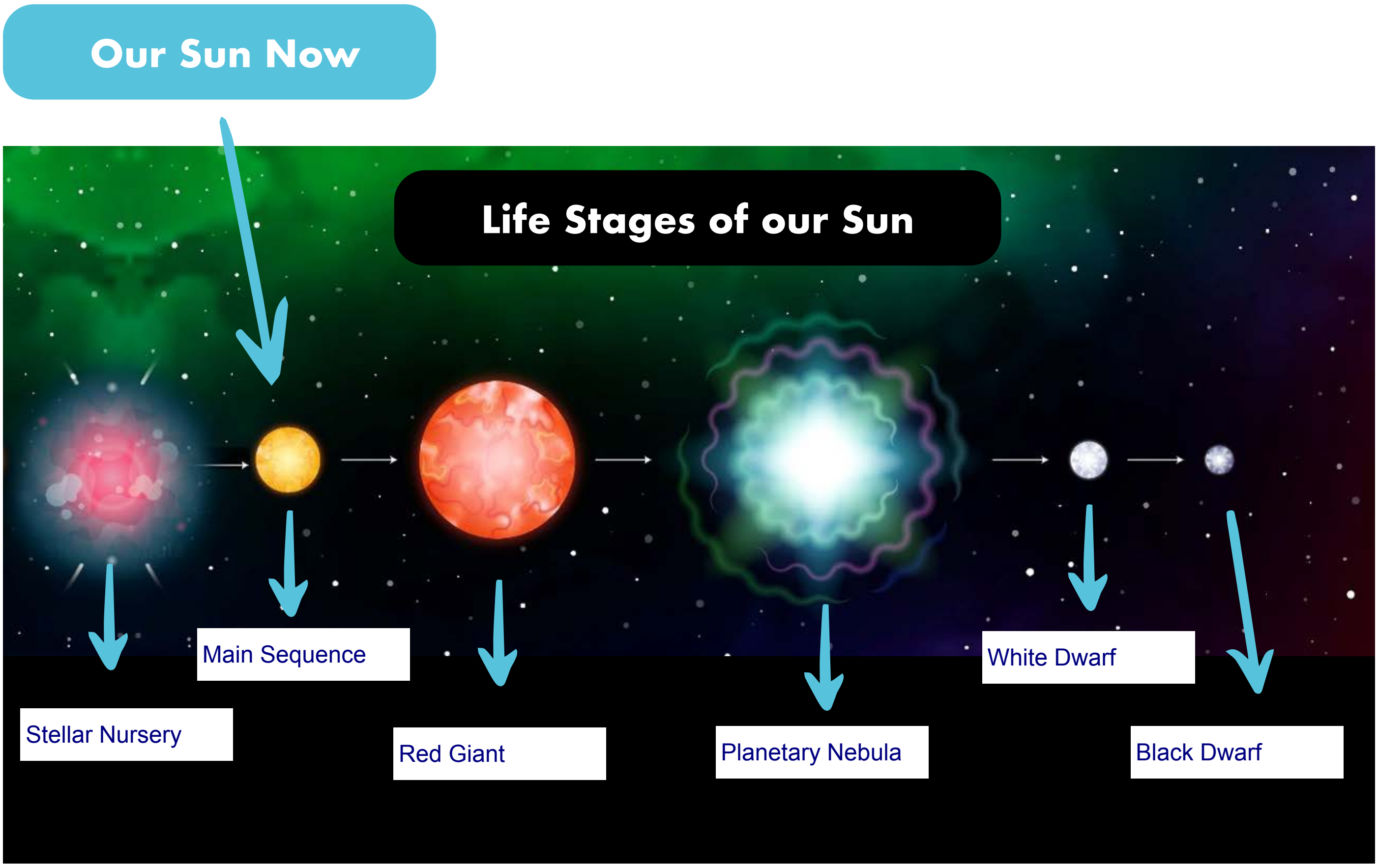
λ_{max} max is the peak wavelength of emission, measured in metres (m)

W = the Wien constant = 2.90×10^{-3} m K

T is the temperature, measured in Kelvin (K)

Temperature of Betelgeuse = Wien constant / peak wavelength = (2.90 x 10-3 m K)/(8.53 x10-7 m) = 3,400 K
Temperature of Bellatrix = (2.90 x 10-3 m K)/(1.32×10-7 m) = 21,970 K

Q3. Fill in the life stages for our Sun in the picture below.



Q4. Describe what will happen to our Sun when it runs out of fuel for nuclear fusion in about 5 billion years.

When our Sun runs out of fuel, it will expands and turns red as it cools down, becoming a Red Giant. The Red Giant will shed its outer layers, creating a planetary nebula. A small dense core, called a white dwarf is left behind. The white dwarf will cool and dim to become a black dwarf.

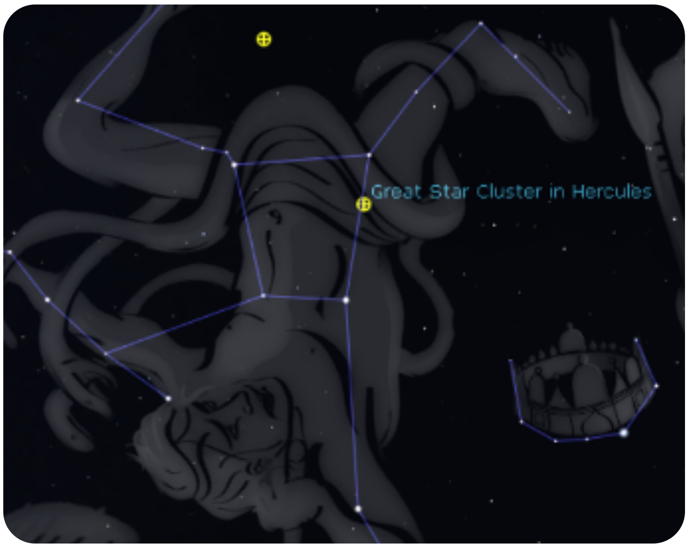
Try an exercise!

Looking for objects in the night sky.

There are some deep-space objects that you can see with the naked eye. Find a safe, dark place to view the stars, like your garden or a window with no streetlights outside. You should turn off any artificial lights (including your phone) and let your eyes adjust to the dark for at least 20 minutes before you start. To examine these objects more closely, you can use a telescope or a pair of binoculars. If you are using a telescope for the first time, you might find this **beginner's guide** helpful.

Globular cluster – Globular Clusters are spherical (round) systems of ancient stars held together by gravity. They are dense systems, which contain thousands or millions of stars. The globular cluster, M13, can be found in the Hercules constellation.

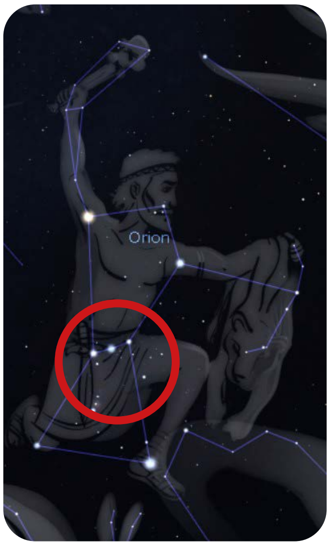
Find the constellation Hercules by locating the centre of the constellation, which is called the 'Keystone of Hercules'. This is four stars in a trapezium (a four-sided shape) which is wider at the top than the bottom. This is Hercules' body. His arms and legs stick out from the four corners of the trapezium. M13, which is commonly named the Great Cluster, can be seen as a blurry blob on the right side of Hercules' torso.



Hercules is a Summer constellation in the Northern hemisphere, so this object is best viewed in May – August in the UK.

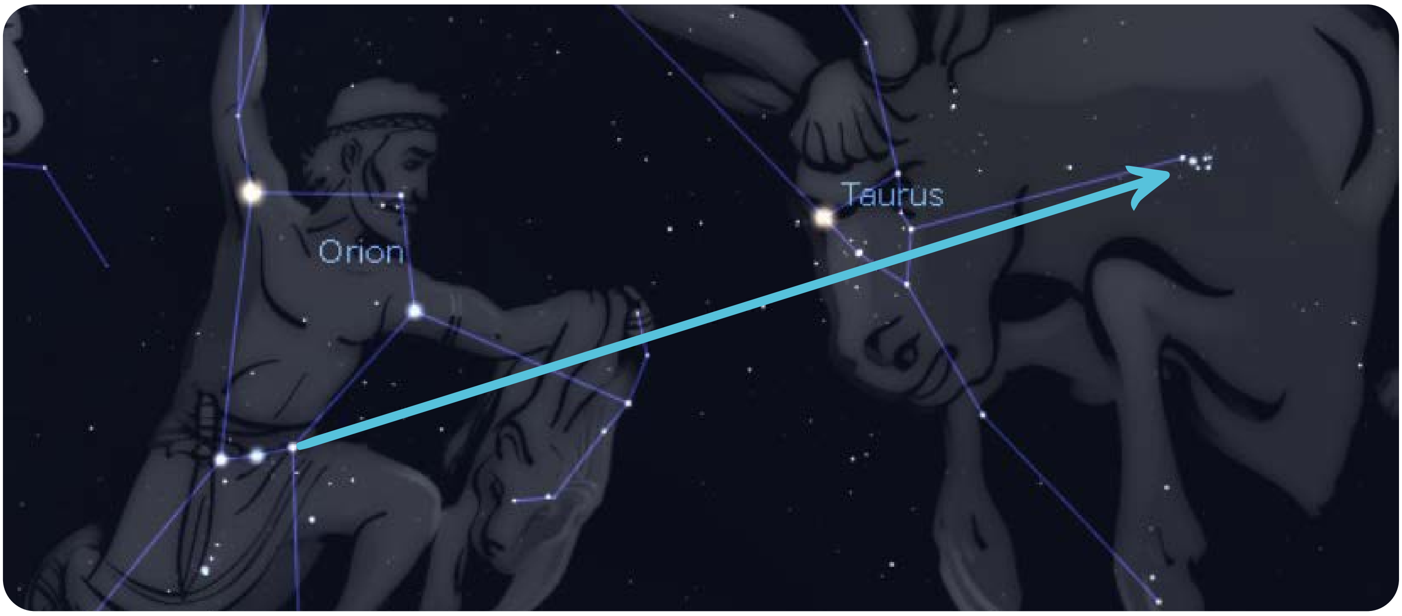
Stellar Nursery – A stellar nursery is a type of nebula (cloud of dust and gas) where new stars are forming. The stellar nursery M42 is also known as the Orion Nebula because it can be found in the Orion constellation.

The Orion constellation is one of the most recognisable and easiest to spot in the night sky. To find Orion, look for his belt, which is made from 3 bright stars in a short, straight, diagonal row. If you look closely, you'll notice a curved line of stars "hanging" from the three belt stars. These stars represent Orion's Sword. Look for the Orion Nebula about midway down in the Sword of Orion.



Orion is a Winter and Spring constellation in the Northern hemisphere, so this object is best viewed in November - March in the UK.

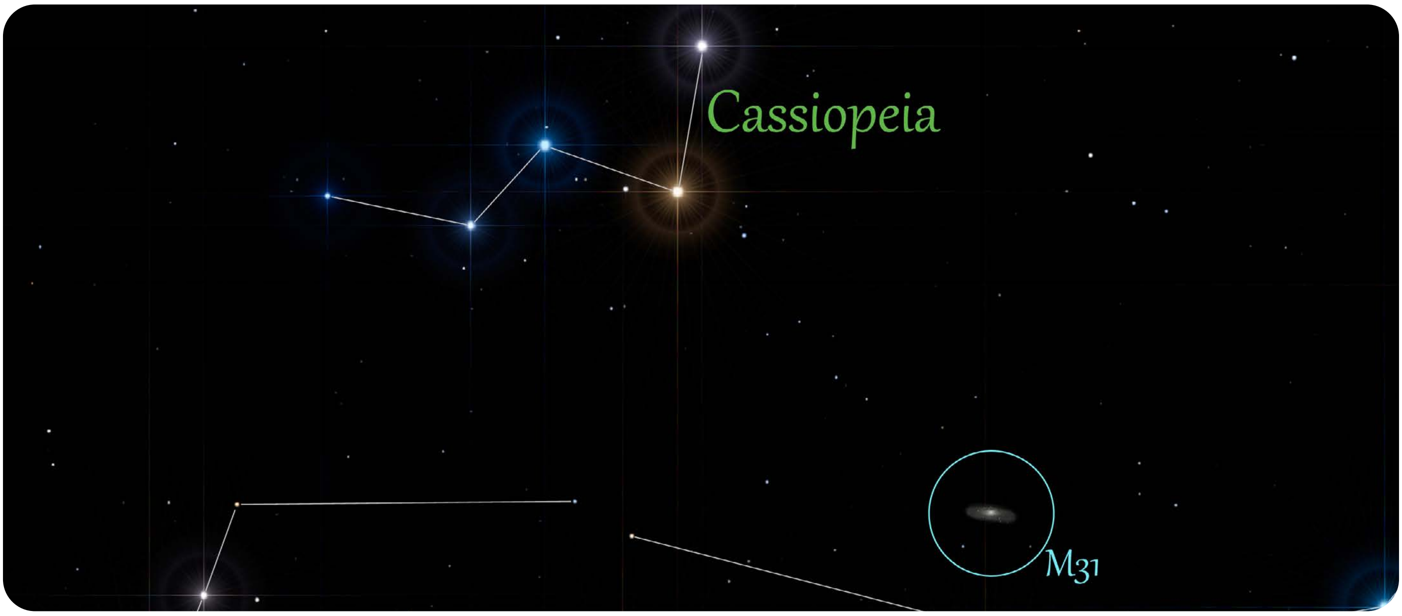
Open cluster – An open cluster is a loose group of hundreds or thousands of stars. The stars in an open cluster were all formed in the same nebula and so are roughly the same age. The open cluster in the picture is M45, which is more commonly called the Pleiades, or Seven Sisters. It can be found in the Taurus constellation.



Taurus is a Winter and Spring constellation in the Northern hemisphere, so this object is best viewed in October – April in the UK.

The easiest way to find the M45 open cluster is to look for the stars in Orion's belt. These 3 stars form a straight, diagonal line in the night sky. If you extend this line through the triangular head of Taurus, you will find a cluster of stars that seem to be grouped very close together. This is M45, the Pleiades or Seven Sisters.

Spiral Galaxy – The spiral galaxy M31, known as the Andromeda galaxy, is 2.5 million light years away from Earth, making it the most distant object that we can see with the naked eye. It can be difficult to spot this faint object, but for your best chance, you will need a very dark sky, away from the light pollution created by towns and cities. It is best to avoid times when the moon is bright and full as the moonlight may make faint objects difficult to see. The Andromeda galaxy can be found in the Andromeda constellation. between the constellations Cassiopeia and Pegasus.



The Andromeda galaxy is visible in the night sky throughout the year, but is best viewed on very dark nights in Autumn and winter in the Northern hemisphere.

To spot the Andromeda galaxy, look for the constellation Cassiopeia. This constellation is easily recognisable as a 'W' or 'M' shape made from 5 bright stars. It is made of 2 'V' shapes and one 'V' is deeper than the other. The deep V points at the Andromeda galaxy. The Andromeda galaxy can be seen as a hazy smudge, slightly bigger than a full moon.

For help finding these constellations and objects in the sky, you can:

- Download the free **Stellarium software** to map-out the night sky.
- Use the free **Star Walk 2 Stargazing app** which uses AR to help you identify objects in the sky if you point your smartphone towards them.
- Watch **S4's 'What's in the Night Sky?** Science videos to get astronomy tips and learn more.

Just remember to let your eyes readjust to the darkness after using a smartphone or other light source.

Swansea University Science for Schools Scheme

Swansea University Prifysgol Abertawe

Undeb Ewropeaidd European Union · Llywodraeth Cymru Welsh Government · Cronfa Gymdeithasol Ewrop European Social Fund

(S4) Funded by the European Social Fund and the Welsh Government.

For teachers and home schoolers

Links to Science in the National curriculum for Wales (KS5)

AS/A Level Physics

- AS UNIT 1: Motion, energy and matter: Using radiation to investigate stars: (a) the idea that the stellar spectrum consists of a continuous emission spectrum, from the dense gas of the surface of the star, and a line absorption spectrum arising from the passage of the emitted electromagnetic radiation through the tenuous atmosphere of the star
- AS UNIT 2: Electricity and light: Photons: (d) Wien's displacement law, Stefan's law and the inverse square law to investigate the properties of stars – luminosity, size, temperature and distance [N.B. stellar brightness in magnitudes will not be required]
- AS UNIT 2: Electricity and light: Photons: (f) the fact that the visible spectrum runs approximately from 700 nm (red end) to 400 nm (violet end) and the orders of magnitude of the wavelengths of the other named regions of the electromagnetic spectrum
- A2 UNIT 3: Oscillations and nuclei: Nuclear energy: (a) the association between mass and energy and that $E = mc^2$