In the night sky: Orion

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Week 1: Beginning the journey

Introduction

Figure 1 The night sky

Travel back in time and space to just before the Sun was born then move forward into the future to watch a star die. Exciting enough? Stick with us, and explore places you could never imagine, as you travel to Orion, explore the night sky and study the birth, life and death of stars.

The course

In Week 1, you'll discover the constellation of Orion, find it in the sky and find out how the constellations can be used for navigation.

In Week 2, you will learn about the lifecycle of different types of star, their birth and what happens when they die. Find out about nuclear fusion that happens inside a star and how their mass, luminosity and temperature are related to their lifecycle.

In Week 3, you will investigate what the night sky can reveal about how it all began. You'll be able to join our team investigating the night sky via the Pirate telescope, The Open University's observatory in Mallorca – weather permitting!

In Week 4, you will consider how planets and planetary systems formed and find out about our place in the Universe. You'll also find out about exoplanets and consider whether other stars have planets like ours.

Glossary

A glossary has been provided for this course. We encourage you to look at it now and refer to it through the next four weeks.

We would love to know what you think of the course and how you plan to use it. We're really interested in hearing from you, whether you plan to study every week or dip in and out. Your feedback is anonymous but will have massive value to us in improving what we deliver. Take our Open University start-of-course survey.

1.1 Map of the night sky

Figure 2 Map of the night sky.

Before you get going, as on every well-prepared expedition, you need to take a map. In this case, though, the map is of the night sky. Two different versions of the map are available – either electronic or paper.

Stellarium

You can download the Stellarium software for Windows, Mac or Linux computers for free from the Stellarium website.

Click on the appropriate operating system and wait for an option to save the file – don't click on any buttons saying 'download'. If you need help, look at the Stellarium User Guide.

Alternatively, you could purchase the app for your tablet or smartphone:

- Stellarium for Apple
- Stellarium for Android

The app will show you what is (or will be) visible in the night sky on a particular date, at a particular time. You can overlay the image of the sky with the shapes of constellations and the names and pictures of the constellations also. You can use it throughout the course to find Orion and other constellations that are mentioned. It's no substitute for going outside and seeing with your own eyes, though!

Star wheel

You can download and print out a copy of a star wheel from the PDFs below. Cut out where indicated and attach the two pieces together using staples.

Star wheel holder pdf

Star wheel constellation pdf

Set the top disc to the date and time you want to view, and the window will display the stars that will be in the sky.

Use whichever version you prefer. But it has to be robust, as you will be using it to travel billions of kilometres for millions of years!

1.1.1 Meeting Orion

So, what is Orion? Very simply, it is a pattern of stars in the sky that, hundreds of years ago, was interpreted to look like a hunter. You'll most probably know what it looks like as it's a familiar feature of the night sky in both the northern and southern hemispheres. You'll find out more about the mythology behind Orion later in the course.

Figure 3 Orion.

Have a look at the picture of Orion in Figure 3. If you look closely at the pattern of stars, you can see that they are not all the same colour. Inside the circle you can see that there is a bright fuzzy pinkish patch in between two of the stars. The bright fuzzy patch is called a nebula, and is a place where new stars are created. The different colours of the stars indicate that they are of different temperatures. So, within Orion, you can see a whole variety of different star types, which you'll discover more about over the next four weeks.

Next, you'll find out where Orion is in the night sky.

1.1.2 Where is Orion?

Orion is clearly visible in the night sky from November to February. If you are in the Northern Hemisphere it is visible in the southwest sky, if you are in the Southern Hemisphere it is in the northwest sky but appears upside down.

In the following video, Monica Grady talks to Janet Sumner about finding Orion in the night sky.

Video content is not available in this format.

1.1.3 Finding Orion

Monica and Janet found Orion, now it’s your turn.

Figure 4 Orion seen in winter in the northern hemisphere.

In Figure 4, you'll see an image of the night sky in winter in the northern hemisphere. Orion is very easy to identify because of the distinctive line of three stars which form his belt.

Now it is your turn to find Orion. Go outside, and look upwards, you should be able to see Orion somewhere in the sky. Where Orion actually is will depend on the time of night and where you live.

You could use the star wheel you made or the Stellarium app you downloaded in Map of the night sky to help. If you can't see anything, maybe because it is raining, or cloudy, then try again another evening.

Make a note of where the lowermost star in the belt is, relative to a local marker. For example, is it just above a branch of a tree? Or just to the left of a chimney pot?

If you can, take a picture of what you can see. To get a good photo, use a good camera such as an SLR, on a tripod on long exposure setting. The camera on a smartphone may not be able to capture light from a star, but give it a go if you don't have a camera. You could watch Monica's advice about taking photos of stars.

Pick a time and a place to take your picture that you can go back to each week. You will repeat this activity each week. If you can take the picture at the same time, by the end of the course, you will have seen that Orion 'moves' in the sky.

Figure 5 Orion, seen from Weston Underwood at 9.45 pm on 13 December 2014.

Here is an example, taken from the village of Weston Underwood, just north of Milton Keynes, at 9.45 pm on 13 December 2014. You can see the tree and the telephone wires in the image which can be used as a marker.

You might like to share your images via social media. If using Twitter, try using the hashtag #OLOrion to share your images and compare them with other people studying this course.

1.1.4 Who was Orion?

Figure 6 An artist's impression of the hunter Orion.

In Greek mythology, Orion was a hunter, the son of Poseidon, god of the sea, and there are several variations of his story.

A common thread between the legends is that Orion made a rash boast that no creature could kill him and that his final adventure involved a giant scorpion.

In one version of this final adventure, Orion could not overcome the scorpion, so he jumped into the sea to escape. Following this he was shot through the head with an arrow fired by Artemis, goddess of the hunt. In sorrow at what she had done, Artemis placed Orion's image among the stars.

Figure 7 The constellation of Scorpio as seen in the night sky

The constellation of Scorpio

Zeus, the king of the gods, in admiration for the scorpion, placed its image among the stars, where it appears as the constellation Scorpio. This is mainly visible in the southern hemisphere and Orion is at the opposite side of the sky so they never appear in the night sky together!

Now you have seen what Orion looks like in the night sky, you'll be able to use him as a marker. Look at the night sky, find Orion, and then look at the patterns of other stars which also appear in the sky. You'll discover more about them next.

1.2 What are constellations?

In the following video, Phillipa Smith explains what a constellation is and points out the most obvious ones to look for in the night sky.

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1.2.1 Patterns in the sky

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A constellation is a group of stars that appears to form a picture or pattern. Orion is a constellation – the word constellation comes from the Latin, 'con' meaning 'with' and 'stella' meaning 'star'. There are 88 named constellations that can be seen in the night sky.

Some of them are only visible in the northern hemisphere, like the Plough (which is part of the Great Bear, or Ursa Major), while others are only visible in the southern hemisphere, for example, the Southern Cross. Although there are billions of stars in the sky, only a small number are used to make up the constellation shapes. They are the brightest ones that can be seen easily by the naked eye.

We perceive the stars in a constellation to be close to each other, and the same distance from the Earth. Remember, though, that we are seeing them as a two-dimensional pattern on the sky. In reality, the stars that make up a constellation are often at different distances from Earth. If we were sitting on a different planet orbiting around a different star from the Sun, the constellations are likely to look completely different!

In the next section, you'll discover what Orion looks like in 3D.

1.2.2 Orion in 3D

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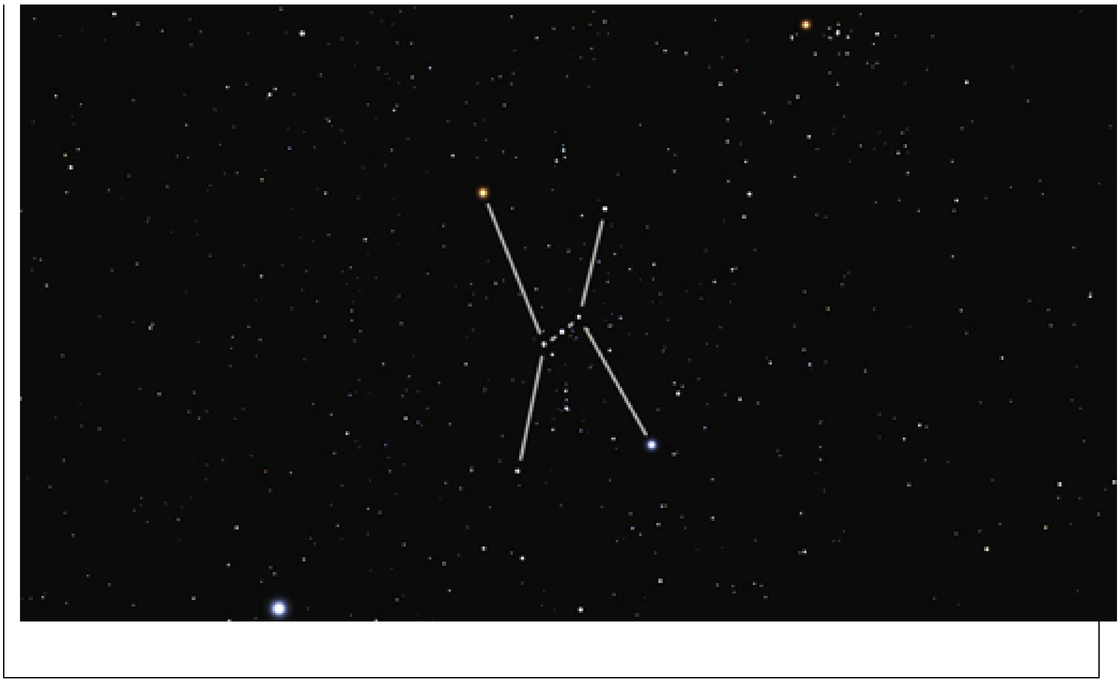

Orion looks completely different in three dimensions! This video was put together using images from the Hubble Space Telescope.

Note that this video has no sound.

Next, you'll find out how the constellations appear to move across the sky.

1.2.3 Moving constellations

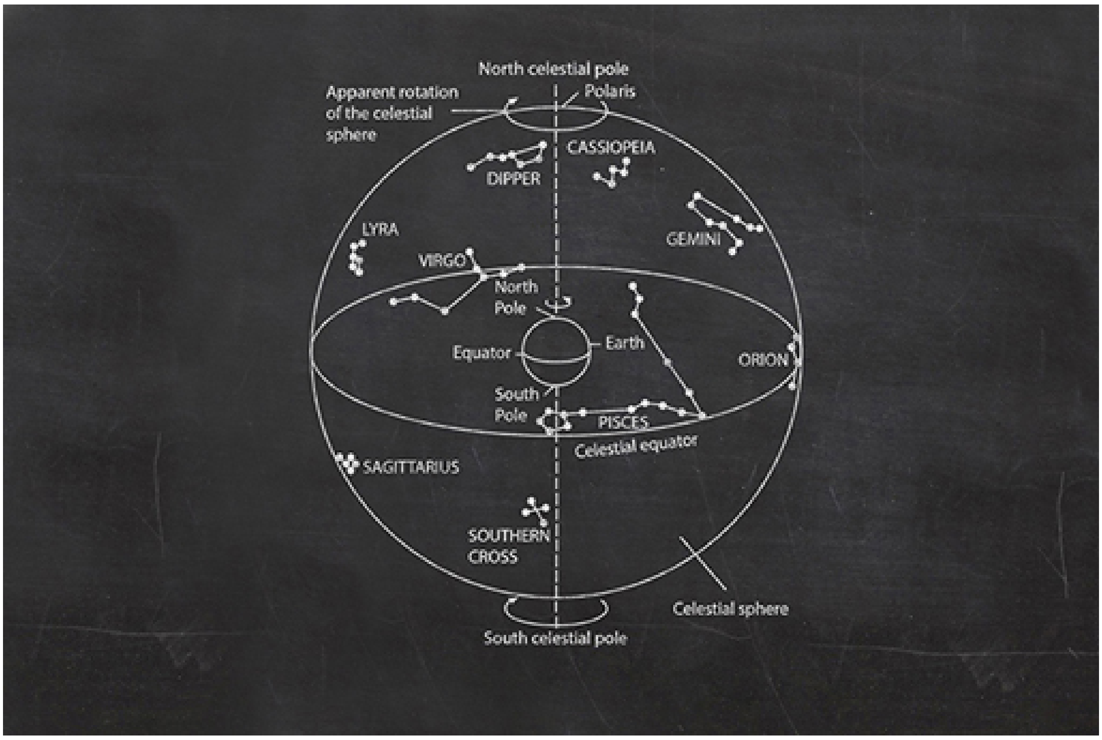

Figure 8

Most of the names that we know constellations by come from ancient Middle Eastern, Greek, and Roman mythologies. The movement of stars through the sky has been the topic of stories and superstitions throughout human history.

The constellations appear to move across the sky because of the rotation of the Earth and the orbit of the Earth around the Sun, so different constellations can be seen at different times of the year and at different times of the night.

Activity 1.1

Get out your star wheel or open the Stellarium app that you looked at in Map of the night sky, and use it to find out what stars you might be able to see in the sky this evening.

- Star wheel – turn the top circle around until it reveals the current date and time.
- Stellarium – the app will fast forward to what you'll see as soon as it's dark and track the movement of the stars as the timer moves forward. You can speed this up so that you can see the stars 'move' over the course of a night.

1.2.4 Signs of the Zodiac

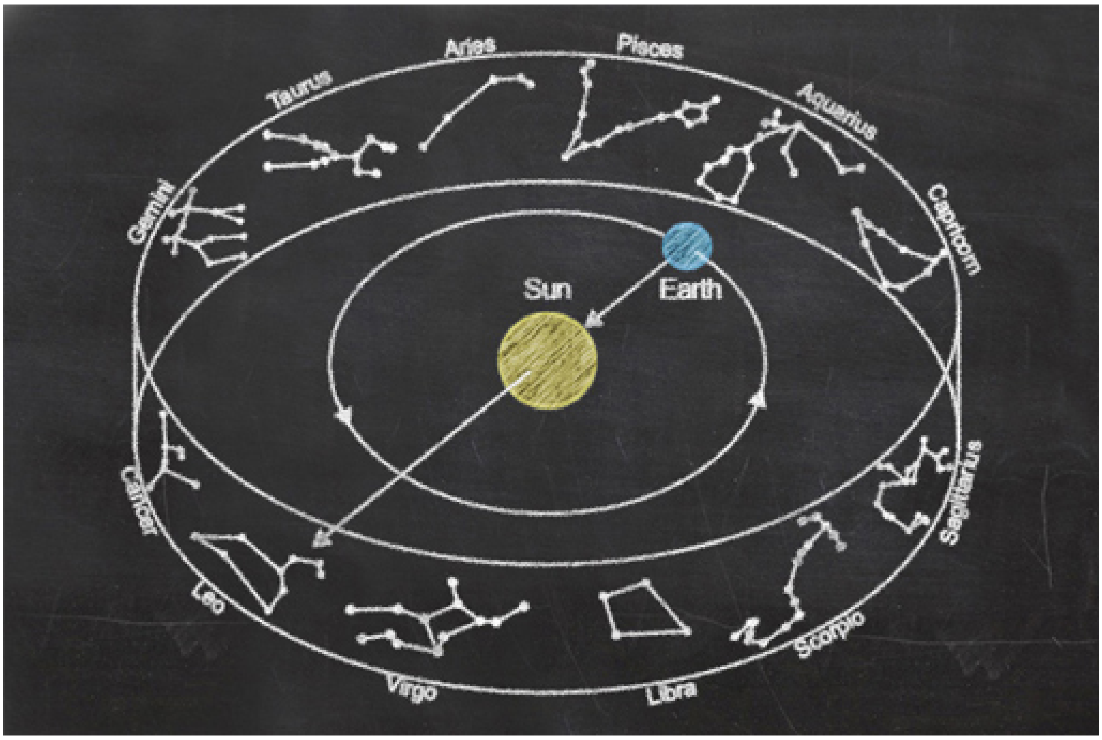

Figure 9 'The Sun is in Leo'.

The apparent movement of the Sun across the sky throughout the year tracks the circular path or 'belt' that is known as the zodiac, and the constellations that lie on this belt are the 'signs of the zodiac'. There are 13 of these constellations – the 12 that are also used in astrology as the 'star signs', plus the constellation of Ophiuchus.

Figure 9 shows how the phrase ‘the Sun is in Leo’ comes about. Imagine that you could see the constellations when the Sun was up (i.e., during the day). Then looking towards the Sun, it appears to be set against the background constellation of, in this case, Leo.

Because, of course, we cannot see the constellations during the day, the constellations we see in the night sky are the ones diametrically opposite to it, again, in this case, Leo, which is opposite Aquarius. If you know your star sign, you might have wondered why the constellation with which it is associated is not visible in the night sky during the month of your birthday. This illustration should have explained why that is the case.

The annual cycle of the zodiac was used by ancient cultures to determine the time of year and helped to mark the passage of time between planting and harvesting. From these beginnings, the idea eventually came that the passage of stars across the heavens could be linked to predictions of a good harvest or a cold winter, etc. This developed into modern day astrology, but there is no science to suggest that the position of the stars has any effect to what happens in our lives.

Astronomy is the scientific study of stars, planets and other celestial objects. For more on the differences between astronomy and astrology, watch Phillipa’s explanation video.

In the next section, you will create your own constellation!

1.2.5 Name a constellation

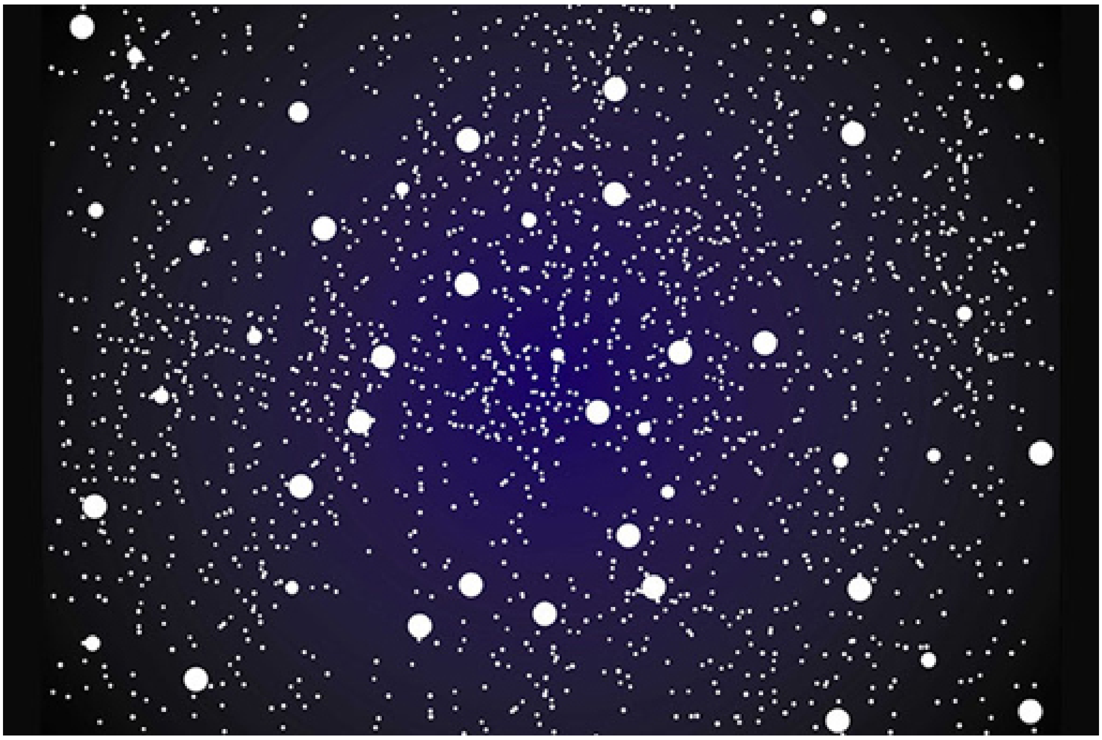

Figure 10

Now, give your imagination a workout by naming your own constellation.

Activity 1.2

Figure 10 shows a pattern of stars of that are not currently part of any known constellation. Can you invent a constellation to be associated with this pattern of stars?

You can download the constellation as a jpeg image or as a PDF. Edit it in a photo editing application such as MS Paint or an online application such as Pixlr on your desktop, or in a photo editing app on your smartphone or tablet. Or, if you'd prefer, download the black and white PDF, print it out and draw on it. Don't forget to give your constellation a name, then come up with a legend to go with it.

You might like to share your images on Twitter, using the hashtag #OLOrion.

To get you started, here are three examples.

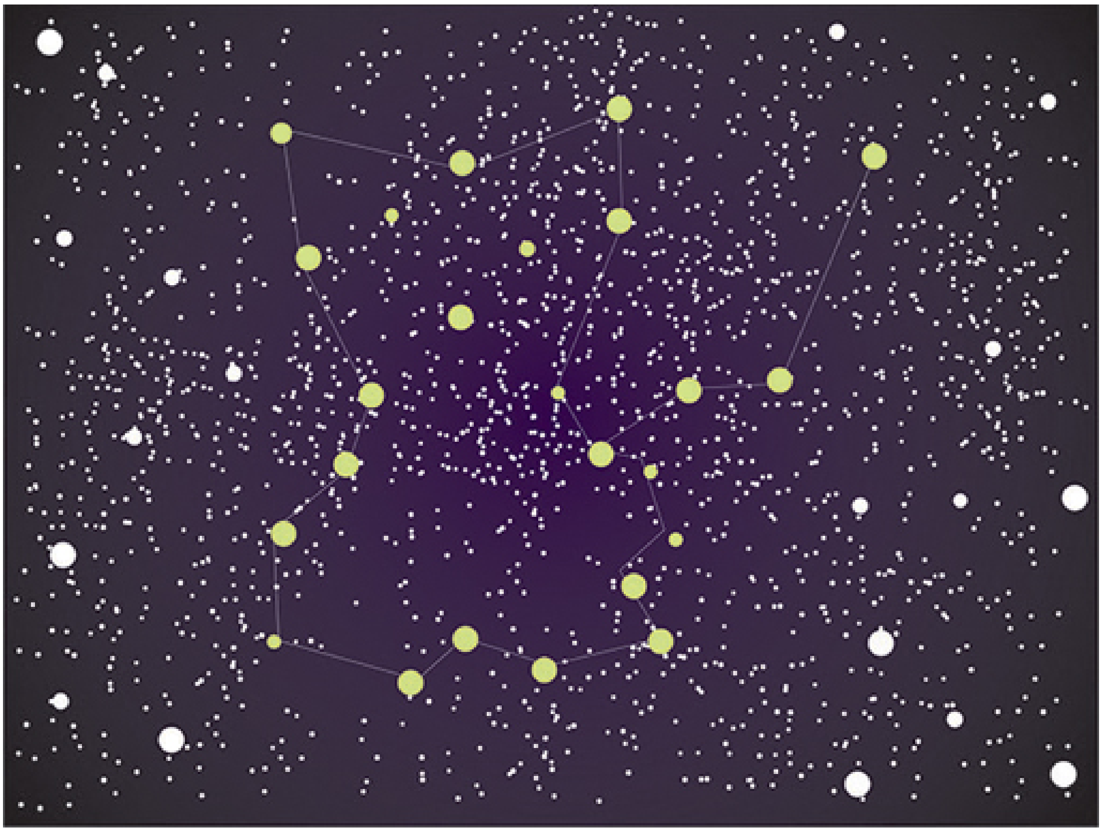

Figure 11 Felis

Monica's constellation: This is the cat, Felis. She was a kitten who followed Orion on his adventures, and tried to help him battle the scorpion. Although she managed to kill the scorpion, she got stung by its tail as it died. In gratitude for Felis' sacrifice, Artemis placed Felis among the stars where she could chase the scorpion and keep him away from Orion.

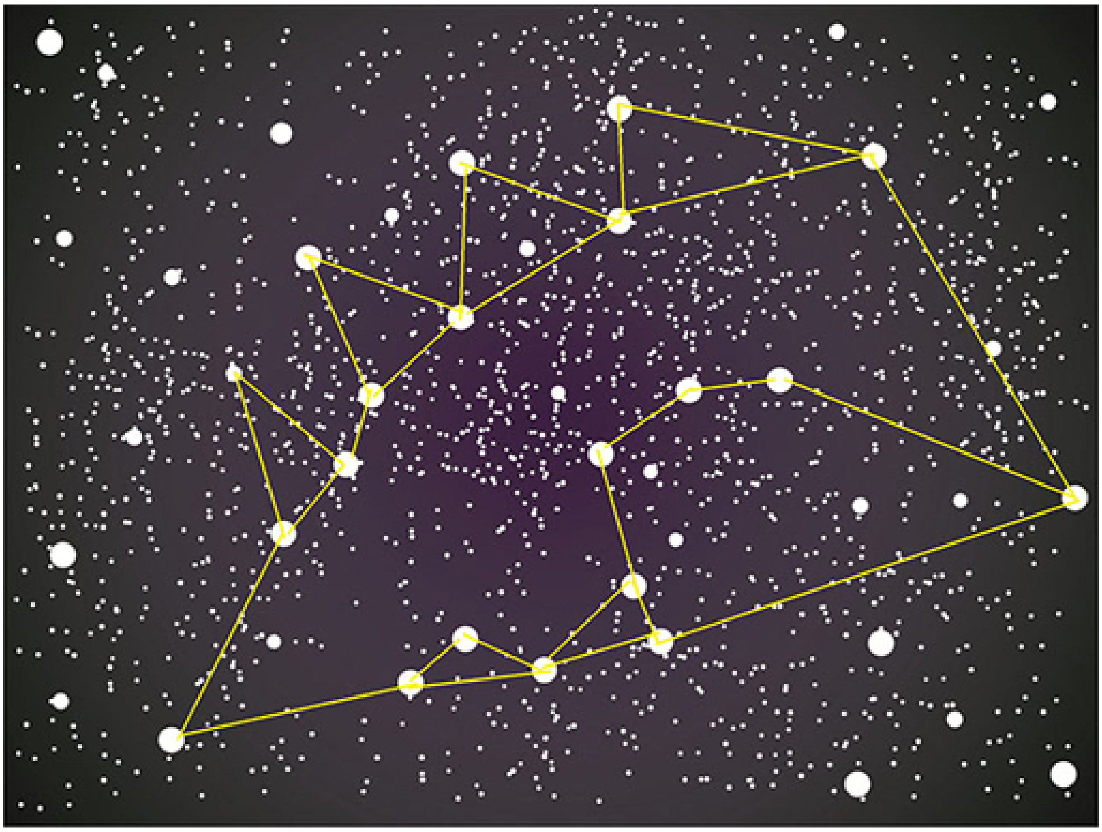

Figure 12 Snuffly the Hedgehog

Phillipa’s constellation: Snuffly the Hedgehog marks the beginning of autumn and guides animals through the passage of wintertime to the following spring.

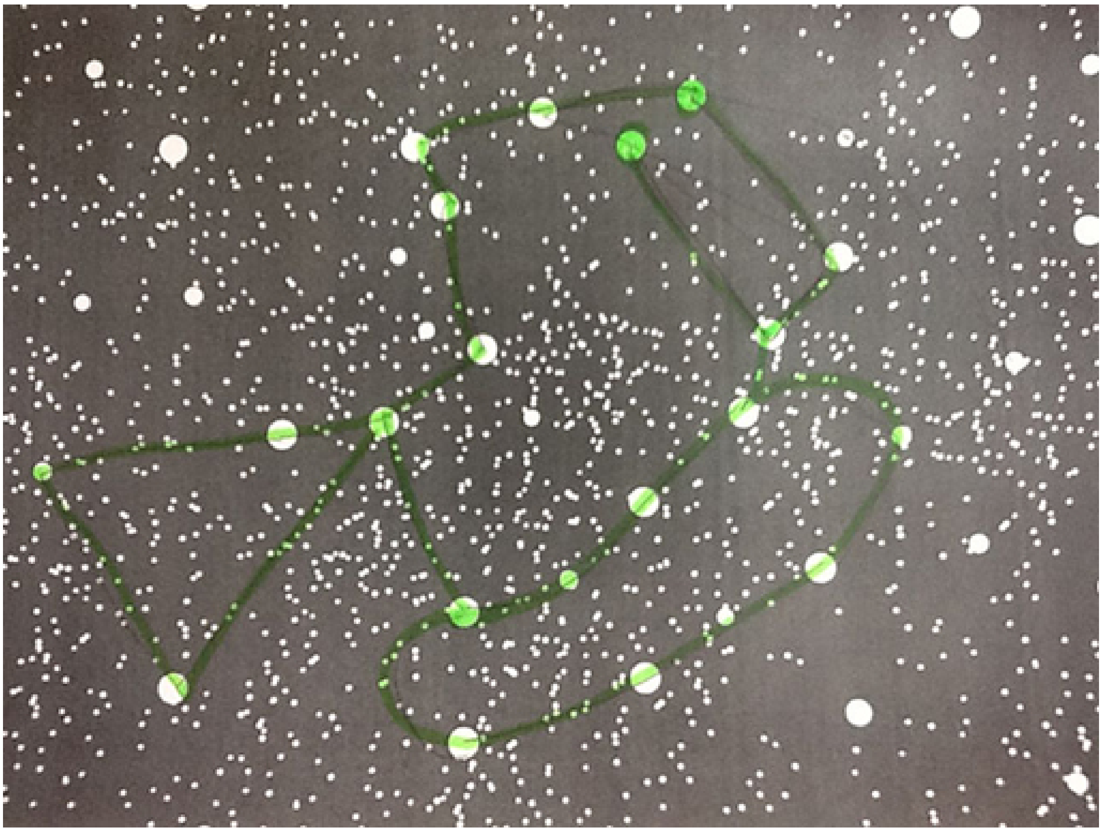

Figure 13 Legasus

Liz's constellation: The sad story of Pegasus's younger brother Legasus, who tried to follow his brother's exploits with Bellerophon. He snuck behind them to try and defeat the Chimera. Spotting him out of the corner of his eye, Pegasus allowed the Chimera to bathe Legasus in a breath of warm fire. He melted to glass, his wings and legs becoming a cradle to rock himself on. Shaking his head at the stupidity of winged horses, Zeus placed Legasus into the northern sky. There he broods and composes long poems about sibling rivalry, and the injustice of being the younger brother of Pegasus.

1.2.6 Navigating by the stars

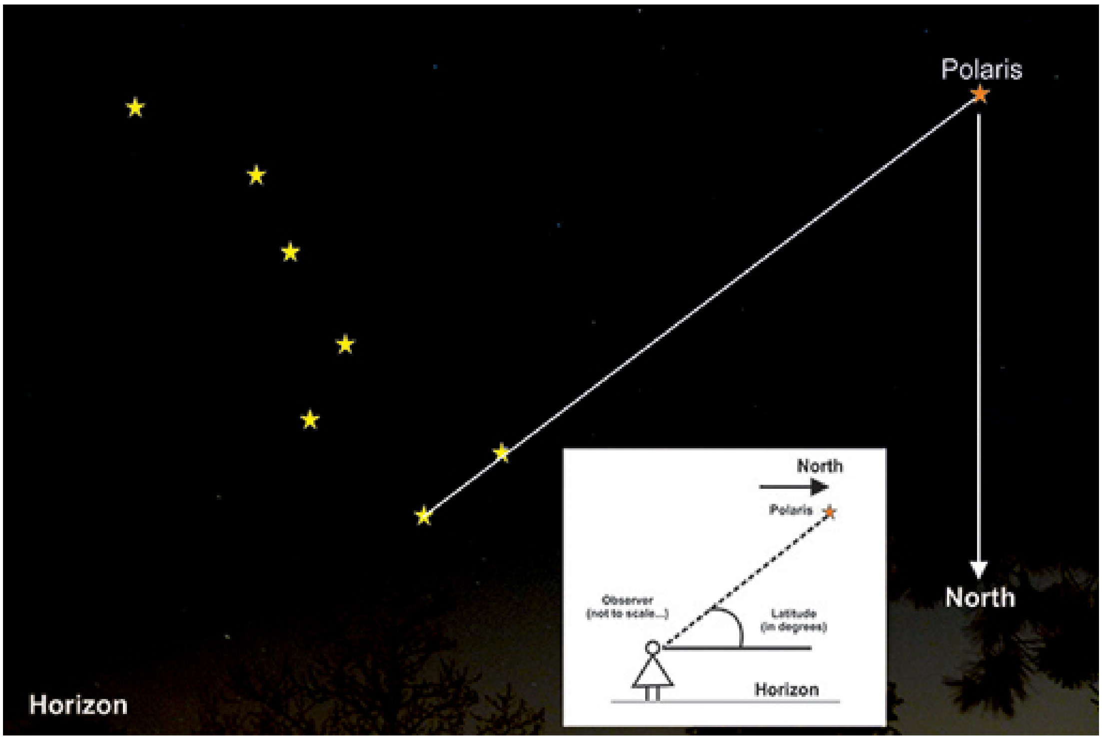

Figure 14 Finding your latitude using the Pole star

Constellations weren't just for telling stories in the ancient world. Because they are easily recognisable patterns, people have used the night sky for navigation when no landmarks were available. Celestial navigation has helped sea captains for centuries, and also aircraft pilots during the early days of aviation.

The Plough (or the Big Dipper) is part of Ursa Major, the Great Bear. It can be used to locate the 'Pole star' (or 'Polaris' or the 'North star') in the northern hemisphere. Use the two stars at the end of the Plough, known as the pointers, to indicate a direction. Follow this line for about five times the distance between the two stars, and the next bright star you reach will be the Pole star. Looking at the Pole Star, if you imagine a line vertically down from the Pole Star to the horizon, this is North. East is to the right, and west to the left. South is 'behind' you.

The Pole star currently sits in the sky directly over the Earth's North Pole. Because the Pole star is above the Earth's axis of rotation, it stays in practically the same place in the sky throughout the night and throughout the year, and as such can be used to help with navigation at night.

Finding your latitude using the Pole star

Once you have determined which direction is North, you can use the Pole Star to determine how far north you are – your latitude. As shown in the inset to the image above, when you face the Pole Star (i.e. are looking north), the angle between the horizon and the Pole Star is equivalent to your latitude. For example, from southern England the Pole star will be about 52 degrees above the horizon, indicating a latitude of 52 degrees north. Polaris will be directly overhead at the North Pole, and on the horizon at the equator.

Finding south using Orion

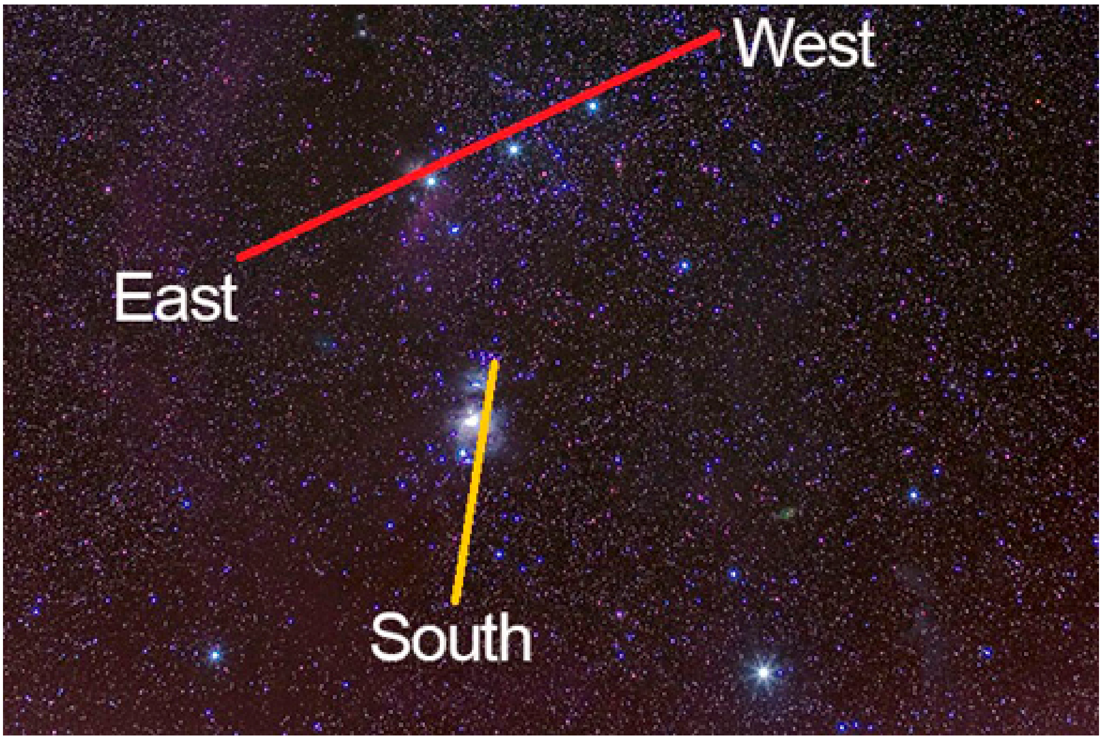

Figure 15 The sword hanging from Orion's belt points towards the south

In the northern hemisphere, we can also use the constellation of Orion to help us navigate. The three bright stars that make up the belt run in a line roughly from east to west. The sword that hangs from the belt points towards the south.

Finding south using the Southern Cross

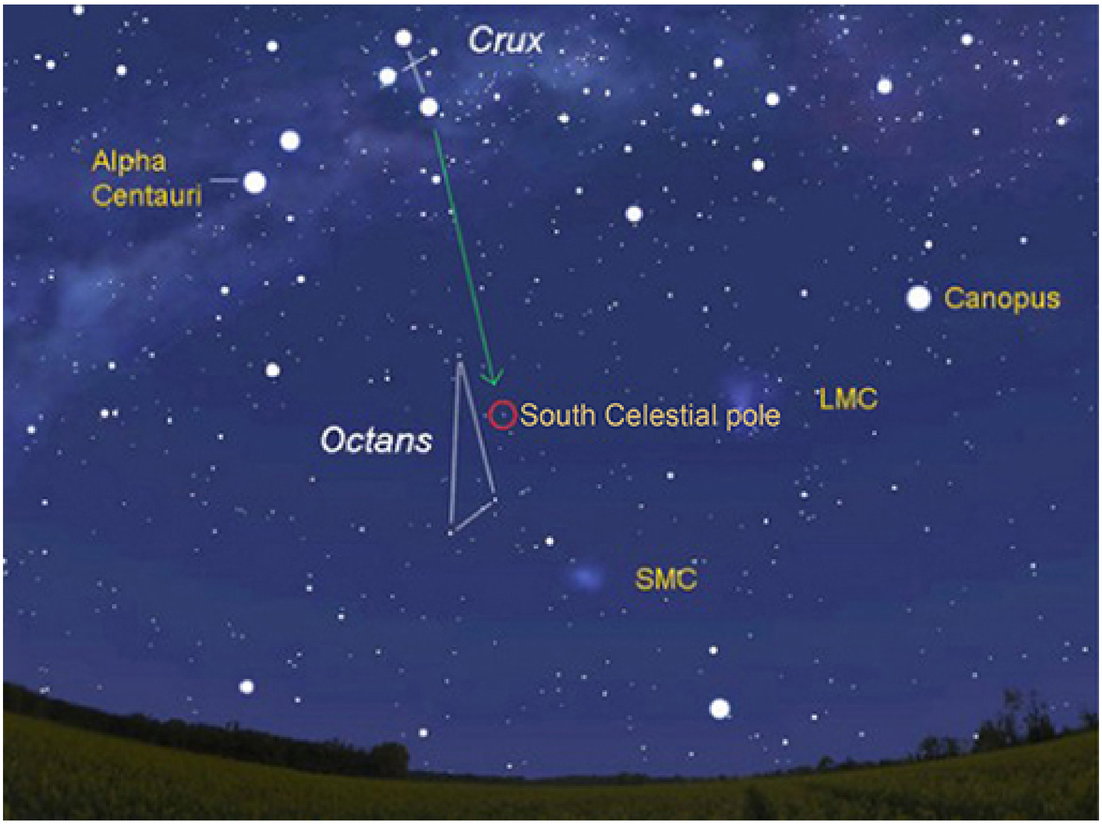

Figure 16 Finding south using the Southern Cross

In the southern hemisphere, one of the brightest constellations in the sky is the Southern Cross (or ‘Crux’). This constellation allows navigators to determine which direction is south.

Next, you will find out how to discover your longitude.

1.2.7 Finding your longitude

Figure 17 The Prime Meridian monument found in Greenwich, London. The line on the ground marks where the Prime Meridian runs.

Finding your latitude is only half of the information required to determine your location on the globe. The other piece of information required is your longitude.

Your longitude is your distance east or west in time from the prime Meridian, which runs through Greenwich, south London. The prime Meridian is defined as zero degrees longitude.

A method for finding longitude was eventually devised when clocks that could keep accurate time at sea were made.

Figure 18 A John Harrison marine chronometer used for establishing the longitude of a ship at sea

Remember, this was in the days long before digital watches, and the clocks of the period were based on the action of springs and pendulums, which did not behave regularly when tossed about on the ocean wave.

You can find out more about how the longitude problem was solved by reading the book *Longitude* by Dava Sobel, or visiting the Royal Observatory in Greenwich or the National Maritime Museum, also in Greenwich.

1.3 Mapping the stars

Figure 19 The constellation of Orion

Looking again at the constellation Orion, you can see that there are many stars in the constellation that are not labelled.

All the main stars in the constellation of Orion have names. They have ‘scientific’ names and ‘historical’ names. Here are two pictures of Orion; in one, the stars are labelled with their scientific name and in the other, they are labelled with their historical name.

Figure 20 The scientific names of the stars that make up the Orion constellation

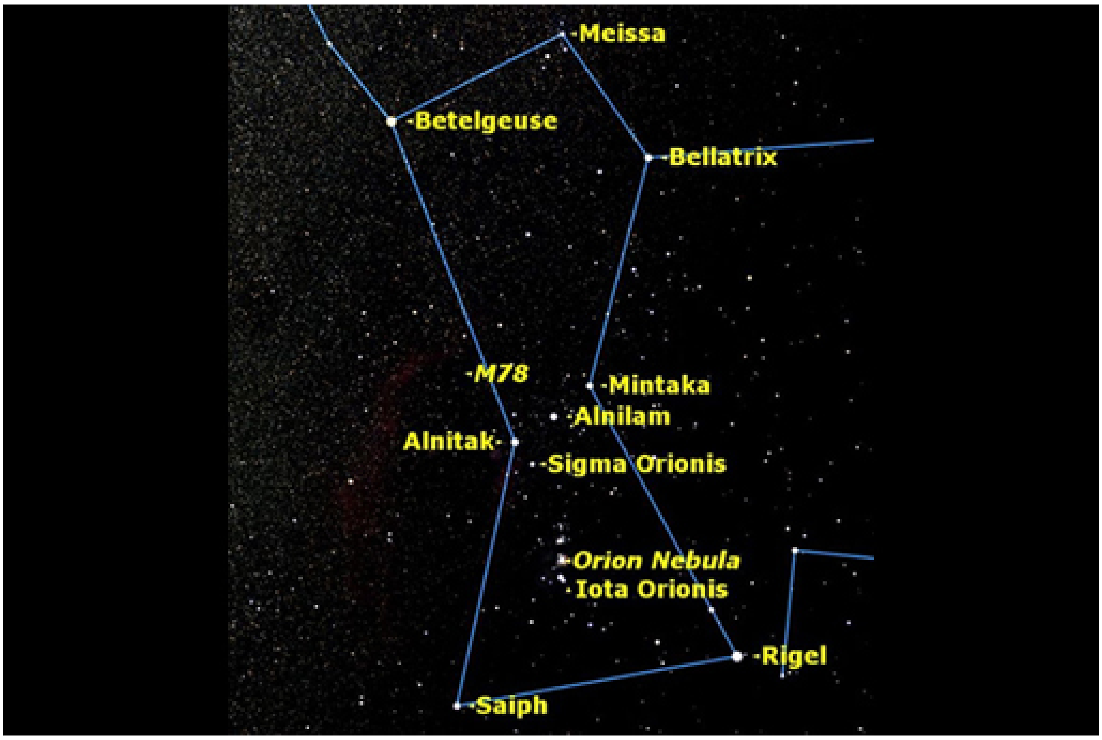

Figure 21 The historical names of the stars that make up the Orion constellation

Usually, the brightest star is given the designation ‘Alpha’. So the brightest star in the Orion constellation is known as ‘Alpha Orionis’ or ‘Alpha Ori’ for short. It is also called ‘Betelgeuse’.

Figure 22

How many stars are there? We don't know! We can't see them all. When we look at the night sky, all the stars we can see with the naked eye are in our own Galaxy, the Milky Way.

In the next section you'll find out about the European Space Agency mission to study the stars.

1.3.1 Gaia mission

The European Space Agency launched a mission in 2013 to study the stars. The mission is called Gaia.

Gaia's main objective is to measure the position of 1 billion (1,000,000,000) stars, and measure the speed that they move at, creating a 3D map of the Galaxy. This will be the largest dataset so far, and will provide astronomers with a wealth of information covering a wide range of research fields: from Solar System studies, galactic astronomy, and cosmology to general relativity.

Video content is not available in this format.

In the next section, you'll find out about The Open University's involvement with Gaia.

1.3.2 Behind the scenes with Gaia

The Open University's Department of Physical Sciences is involved in many different research projects, one of which is the Gaia satellite.

Ross Burgon is one of the scientists working with the Gaia project team. In the following video he talks to Phillipa about the research carried out in the Centre for Electronic Imaging (CEI).

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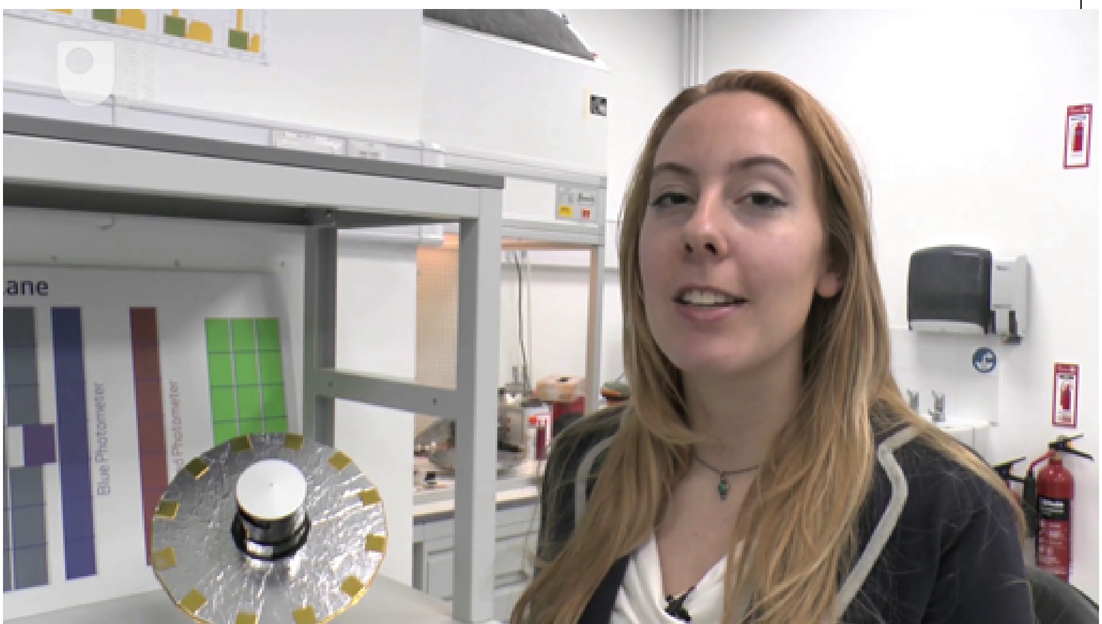

Next, you'll have an opportunity to test your knowledge in the end-of-week quiz.

1.4 Week 1 quiz

Check what you've learned this week by taking this Week 1 quiz.

Open the quiz in a new window or tab then come back here when you're done.

Summary of Week 1

Figure 23 Photograph of Orion taken by Monica Grady

You started your journey through the night sky taking Orion as a guide.

In this first week, you have learned to recognise Orion in the night sky, learned the names of the main stars in the constellation, how to recognise different constellations and how to use some of them to help you navigate.

You have heard about the Gaia mission which plans to produce a map of the billions of stars in our Galaxy.

The next part of the journey, in Week 2, is to look at the creation of new stars and follow the evolutionary history of different stars as they grow old and then die.

Week 2: Travelling from star birth to star death

Introduction

Last week, you looked at the constellation of Orion, and named its brightest stars. At the start of Week 2, you'll dive straight in and find out what a star actually is, how they form and their lifecycle, then travel more deeply into Orion and study those stars.

The following video, which has no sound, zooms into the Orion Nebula, moving from images of the whole Orion constellation in the night sky, to pictures taken by the Hubble Space Telescope of the Orion Nebula, showing its swirling clouds of gas and dust. Embedded within the clouds are newly forming stars and planets, as well as older stars and the remains of dead and dying stars.

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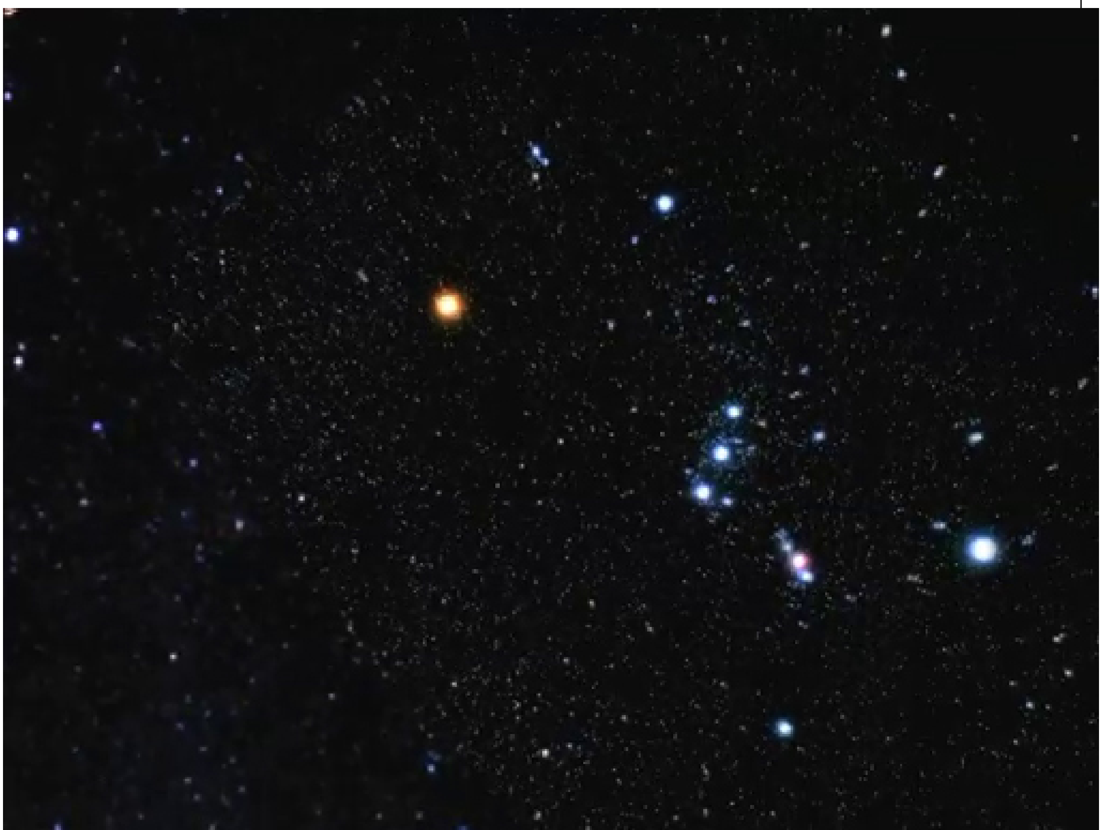

Before you learn about different types of stars, it is a good idea to learn a bit more about our own star – which is what you will do next.

2.1 What is a star?

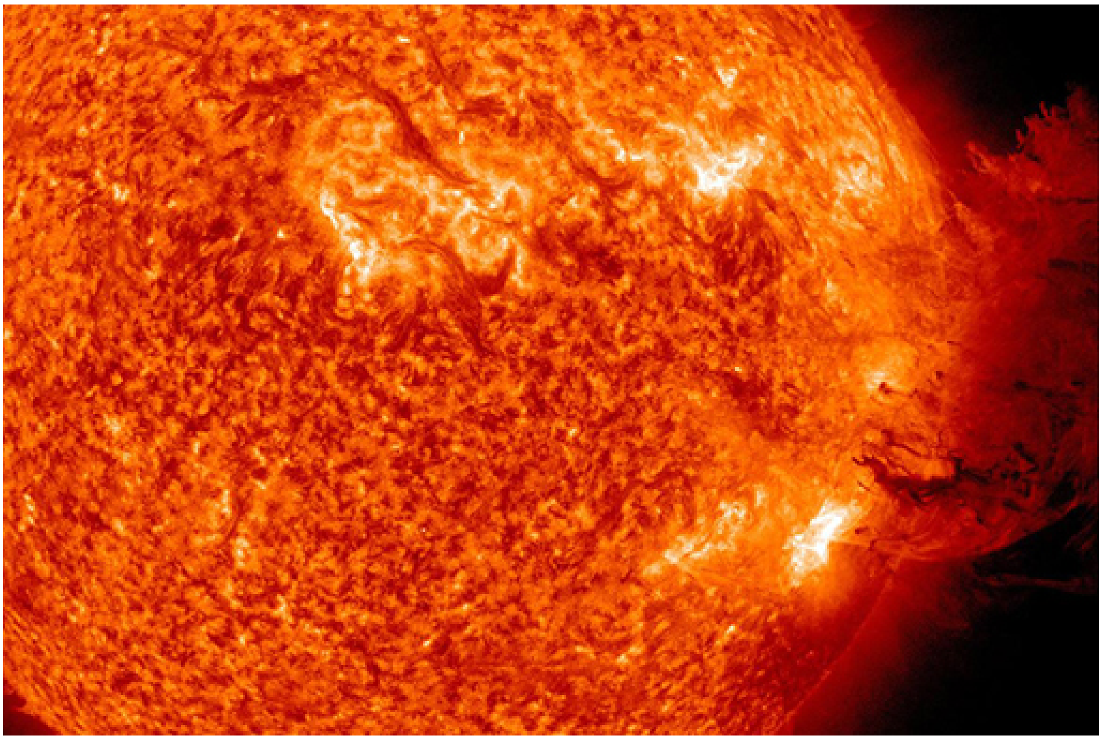

Figure 1 The sun releasing a gush of magnetised plasma following a solar flare.

The star closest to the Earth is, of course, the Sun, shown in Figure 1. Studying the composition of the Sun illustrates the composition of stars in general. The composition of the Sun is determined by the technique of spectroscopy – more about this later.

The Sun, as a typical star, is almost completely made from hydrogen and helium gas – about 98%. The remainder is decreasing amounts of every other known element, all the way up to the heaviest element, which is uranium.

The core of the Sun is undergoing a process called **nuclear fusion**, in this case, hydrogen burning. In the Sun, this process occurs in three stages. First, two hydrogen nuclei fuse together to make a single nucleus of deuterium (D). This then fuses with another hydrogen nucleus to form helium-3. Finally, two helium-3 nuclei fuse to form one helium-4 nucleus and two separate hydrogen nuclei. A huge amount of energy is also released in the process, which is what creates the heat and light that comes from the Sun.

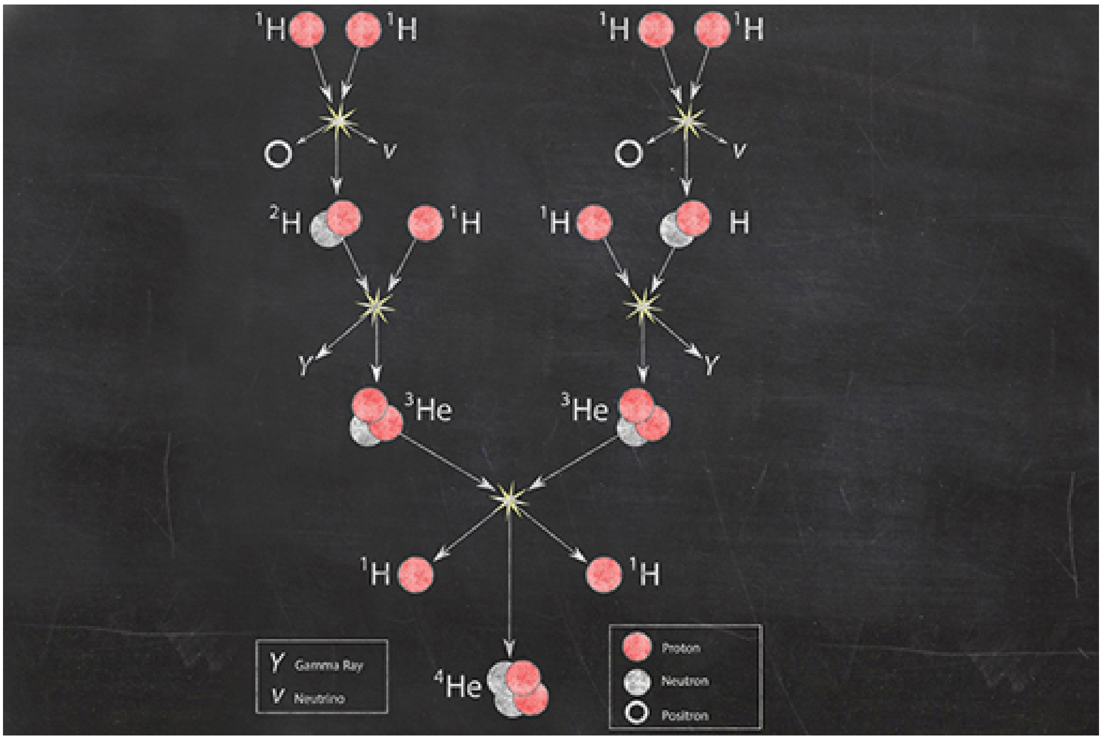

Figure 2

The Sun, then, is a gigantic sphere with a core of burning gas. The core is about 50 times as dense as rock, and has a temperature of 15 million K. The surface of the Sun is much cooler, only about 5800 K!

You may not be familiar with the abbreviation ‘K’ to signify temperature. This stands for ‘Kelvin’, and is the international unit of temperature (it is given as K and not °K). A difference of 1 K is the same as a difference of 1 °C but the Kelvin scale starts from a different zero point. 0 °C corresponds to the temperature at which water freezes (at the Earth’s atmospheric pressure). 0 K, which is equal to −273.15 °C, corresponds to absolute zero where all motion of atoms stops, so 10,000 K is 9726.85 °C! The Celsius scale, which is generally used in everyday life, is more commonly used for biological environments, whereas the Kelvin scale is used for the wider temperature ranges found in astronomy.

The Sun is not an unusual star: it is about halfway through its life, and will continue to burn hydrogen for about another 4.5 billion years. More massive stars than the Sun are hotter, and burn their hydrogen faster, so have shorter lifetimes. You will learn about how long a star lives later this week, but before that, you need to know about how the brightness of a star is related to how far away it is, which you will learn about next.

2.1.1 Luminosity of a star

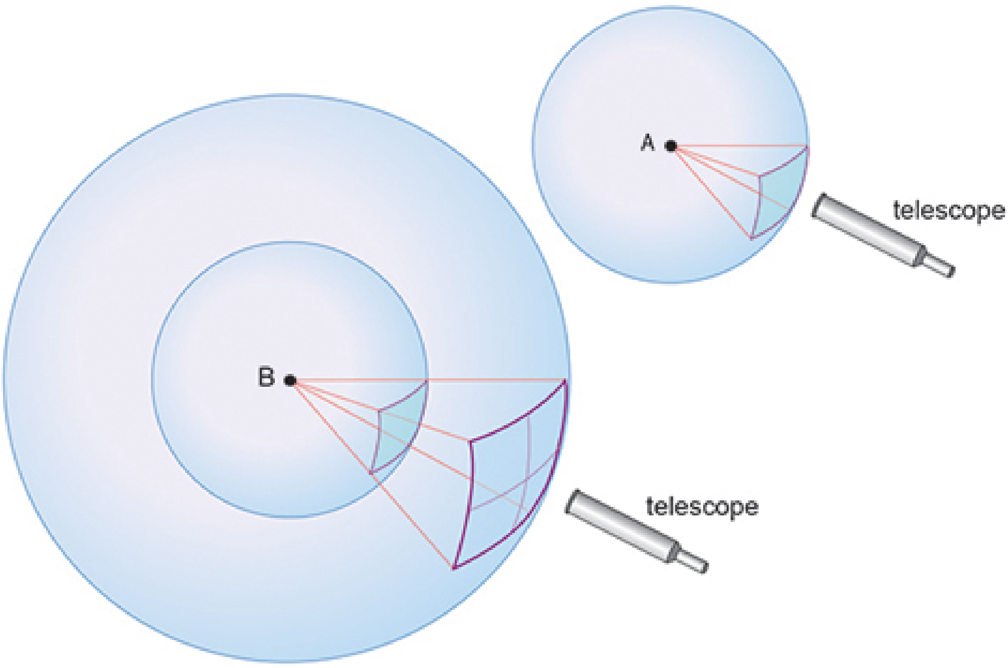

Figure 3 Light from a more distant star B is more spread out, so the star appears fainter than an identical star A nearby.

Imagine a light some distance away from you (also imagine that it is dark, and all you can see is that light …).

The light is shining with a particular brightness. Can you tell how far away the light is? Is it a really, really bright light that is quite far away? Or a more dim light, that is much closer? Without some more information, you cannot distinguish between the two possibilities.

Figure 3 shows how this effect is important when it comes to stars. The two stars, labelled A and B, have the same luminosity but, as you can see, the light from the more distant star is more spread out by the time it reaches the observer (indicated as a telescope), and so appears to be less bright.

So when you look at two stars which seem to have the same brightness, you have to consider their distance. Do they actually have the same brightness or is one star much closer than the other?

Why is it important to know whether a star is luminous or not, close to us or far away? It is important because this is directly related to what type of star it is, and to its age. You'll explore this idea later on, when you consider different types of star.

It is important to know the distance to a star so we can start to put together a better understanding of our Galaxy. If we can understand our Galaxy, then we can understand all galaxies, and the Universe itself!

In the next section, you will learn about the Orion Nebula, where stars are born.

2.1.2 What is a nebula?

Figure 4 Close-up of the Orion Nebula

The word nebula (plural, nebulae) comes from the Latin word meaning unclear, or literally ‘mist’. When we look at Orion with binoculars, or even the naked eye, if it is sufficiently dark, we can see that just above the tip of Orion’s sword is a fuzzy patch. This is the Orion Nebula.

Early astronomers described features in the night sky they could not resolve (i.e. could not get clear images of) as **nebulae**. We now know that the Orion Nebula, also known as M42, is actually a massive cloud of gas and dust. The gas is mainly hydrogen and helium, although there are significant amounts of other gases, including oxygen. The dust is mainly made from silicon and oxygen, similar to the minerals which make up many of the rocks on Earth.

2.1.3 How far away is the Orion nebula?

How far away is the Orion Nebula? An ‘astronomical’ distance would be a good description!

It is estimated to be about 1600 light years away. It may sound a bit odd, to use time as a measurement of distance, but as Monica explains in the video, that is because the distances are so large. A light year is the distance light travels in one year. We can calculate what that is in kilometres or miles, as you can see in the following video.

Video content is not available in this format.

So light travels about 9.5 million million kilometres, or 6 million million miles in a year.

If the Orion Nebula is 1600 light years away, that is 1600 x 9.5 million million kilometres – the best part of 15.2 thousand million million kilometres or about 9.6 thousand million million miles – which is quite far away. And also explains why astronomers use light years as a unit of distance.

2.1.4 Size of a nebula

How big is the Orion Nebula? Or at least, how far across is it?

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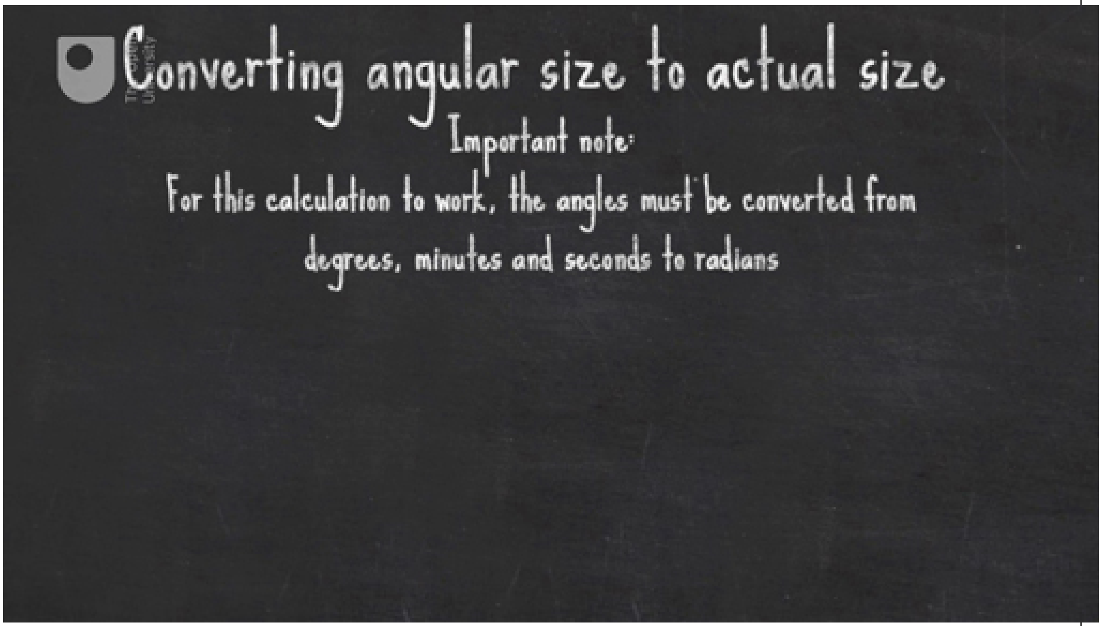

Astronomers have a different way of estimating the size of objects, using the angle that the top and bottom of an object appears to make with the eye. This is shown in Figure 5 where the plant, the bush and the tree, while all at different distances from the observer, make the same angle at the eye.

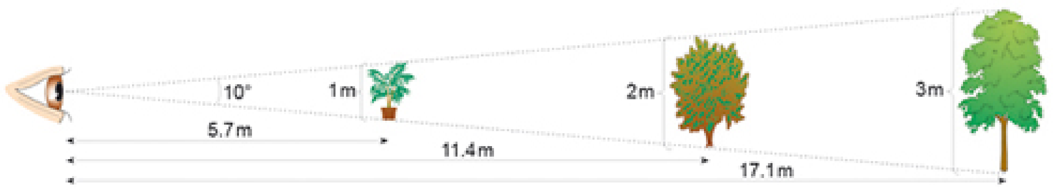

Figure 5

The observed angular size of an object depends on the size of the object and its distance from the observer.

The further away something is, the smaller it appears – and the smaller the angle it will make with the eye. Although the objects studied by astronomers are very large, they are at such vast distances away that their angular sizes are often very small. These small angles could be written as fractions of a degree, but, in practice, subdivisions of degrees are used, known as 'minutes of arc' (or **arcmin**) and 'seconds of arc' (or **arcsec**). A degree can be divided into 60 minutes of arc, and a minute of arc can be further divided into 60 seconds of arc. A single tick mark is used to represent arcmin, so 1/60 of a degree is written 1'. A double tick mark denotes arcsec, so 1/3600 of a degree (1/60 of an arcmin) is written 1".

The Orion Nebula is about 60 arcminutes (60') across. What does this mean? Again, we can convert this measurement to kilometres or miles, as shown in the video above.

So the Orion Nebula is about 267 million million kilometres, or 167 million million miles across – I don't know about you – but I have difficulty in getting my mind around these sorts of distances and sizes!

Next, you will find out about the Trapezium cluster which forms part of the Orion Nebula.

2.1.5 Trapezium cluster

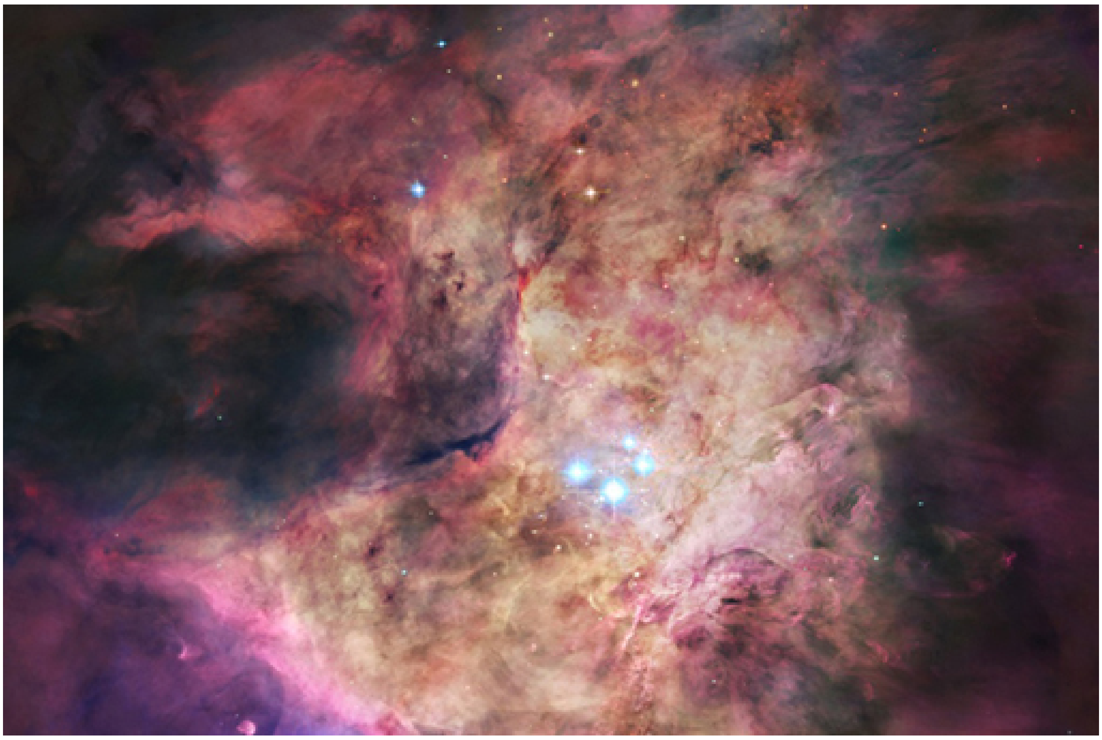

Figure 6 A cluster of bright stars, called the 'Trapezium'.

At the heart of the Orion Nebula is a cluster of bright stars, called the 'Trapezium', which can be seen with a telescope, but not the naked eye.

These stars are quite young – only about 300,000 years old – and very hot, and it is the energy they produce which causes the gas in the nebula to glow.

Much more numerous than the bright stars in the Trapezium cluster are fainter bodies called **brown dwarfs**. You will find out more about these failed stars later in the course.

Next, you'll find out about the birth of a star.

2.1.6 Birth of a star

How is a star formed?

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Stars form in clouds of dust and gas called giant molecular clouds, the debris of old stars. The constellation of Orion includes the molecular cloud complex we know as the Orion Nebula.

While the density of dust and gas in a giant molecular cloud is high compared with the rest of interstellar space, in comparison with the atmosphere of the Earth, they are a thousand million million times less dense.

The dust and gas cloud is highly structured, with lots of clumps where the dust and gas is slightly more dense. These relatively high density areas are where star formation will occur.

Initially, the clumps are quite stable, but once a clump is sufficiently dense, it will start to contract under its own gravity. As it contracts, the temperature rises. Eventually, after further collapse and fragmentation, a **protostar** develops. After only a few thousand years, the surface temperature of the protostar will have risen to 2000–3000 K!

In the next section, you will take a closer look at the Orion Nebula.

2.1.7 The Orion nebula

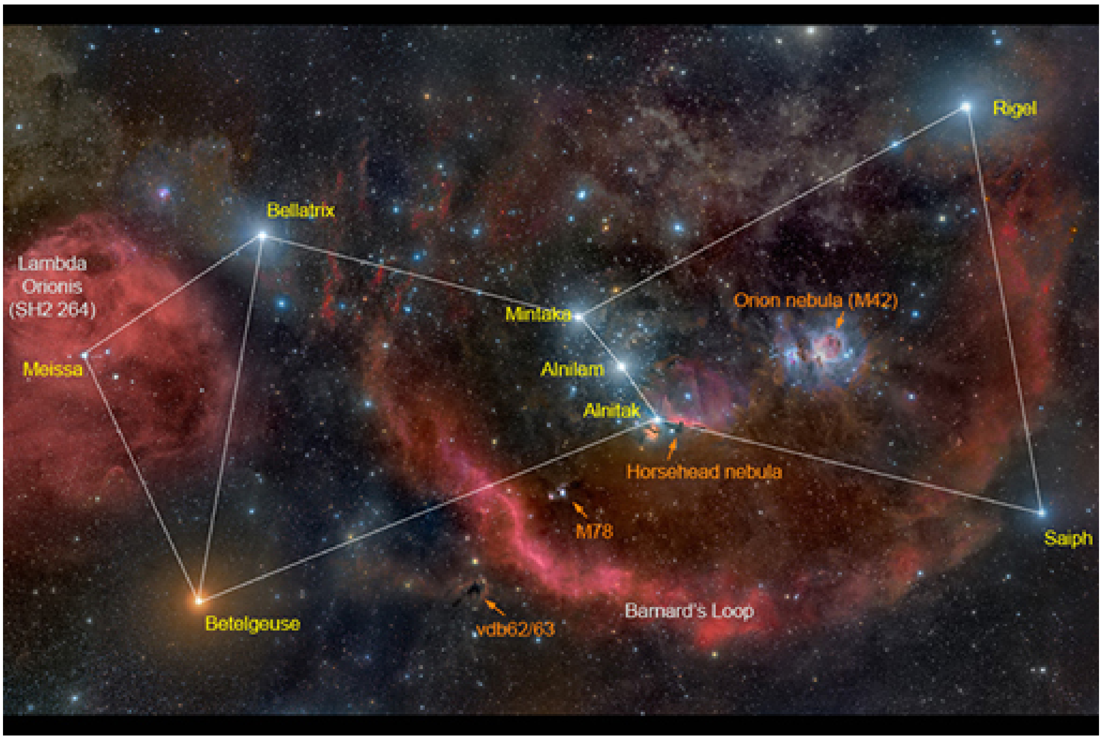

Figure 7 Features in the Orion constellation with dust and gas clouds.

The stellar nurseries in Orion are positioned at the edge of a giant molecular cloud.

Figure 7 shows the dust and gas clouds around the Orion Nebula. To its left are the Horsehead Nebula, M78 and the glowing Lambda Orionis (Meissa) Nebula at the far left, near Orion's head.

In the next section, you will find out more about protostars.

2.1.8 Protostar

Figure 8 The protostar V1647 Orionis

The cloud clumps heat up as they collapse and also begin to spin more rapidly.

As they spin more rapidly, they change their shape, becoming flatter and more disc-like. Material falling onto the central protostar now passes through a flattened region surrounding it called an **accretion disc**.

Figure 8 shows a small region of Orion, where a hot young protostar is picked out by the light it is radiating at infrared wavelengths.

At the same time, as material falls onto the equatorial regions of the protostar, powerful jets of material are ejected from its poles. Astronomers are currently unsure of the detailed processes that cause these jets, but their effect is to remove both material and energy from the protostar.

Eventually, the core of the protostar will become so hot that nuclear fusion reactions can begin and a new star is born.

This whole process is surprisingly rapid and is thought to be complete within about 100 million years for the lowest mass stars. More massive protostars have a greater gravitational attraction, so material is pulled onto them at a much higher rate, so more massive stars form more quickly. Stars with masses more than 15 times that of the Sun form in only about 100,000 years.

In the next section, you will be taking a photograph of Orion.

2.1.9 Photographing Orion

Figure 9

It's time to take your weekly photograph of Orion!

Activity 2.1

You could use the star wheel you made or the Stellarium app you downloaded in Map of the night sky to help.

Hear Monica's advice about taking photos in this video.

If possible, take a picture at the same time from the same spot each week. Remember to include your marker point (chimney pot, tree branch, etc.) in the image, so that they can be compared from week to week. Fingers crossed that it is clear and not cloudy wherever you are!

Once you have taken the picture, compare it to the one you took last week. Can you notice how Orion has moved?

2.2 The life of a star

Once a star has formed, it has a lifecycle which is fairly predictable, and which depends on how massive the star is at its birth.

It is possible to determine how a star will evolve by working out where it sits on a **Hertzsprung-Russell** (HR) diagram below. The diagram plots stellar luminosity against temperature, and was first constructed by the Danish astronomer Ejnar Hertzsprung in 1906 and then, independently, by the American Henry Norris Russell, using a more extensive set of data, in 1913. Note that temperature, which is plotted on the horizontal axis, decreases from left to right.

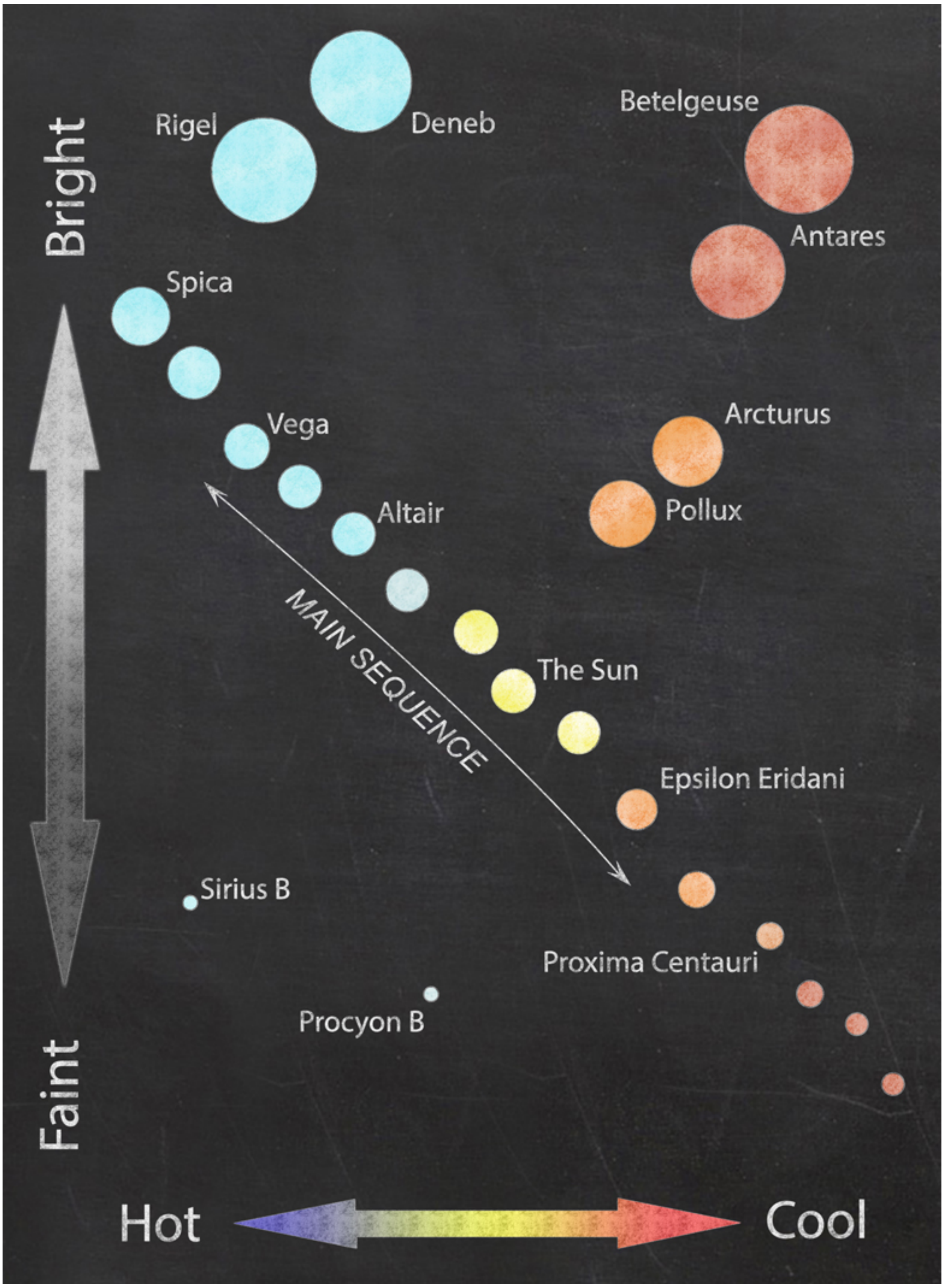

Figure 10 Hertzsprung-Russell diagram

The HR diagram shows that stars have only certain combinations of temperature and luminosity. The clearest feature to notice is that most stars occupy a thin strip in the diagram from top left (very luminous stars of high temperature) to bottom right (very faint, cool stars). In colour terms, the most luminous stars known are bright blue, becoming redder as they become fainter. The Sun is on this strip too, as are 90% of stars. Since this is where stars spend the vast majority of their lives, it is known as the **main sequence**.

The position of a star on the main sequence depends solely on its mass: the more massive a star is, the hotter and more luminous it is. The main sequence cannot be an evolutionary sequence because the stars along it have very different masses and will change in different ways as they age and move away from the main sequence.

Stars on the main sequence are sub-classified with letters, O-B-A-F-G-K-M. O-type stars are the hottest, largest and brightest stars, and M-type stars are the smallest, dimmest and coolest (**red dwarfs**). The Sun is a G-type star. Because the main sequence is not an evolutionary sequence O-type stars do not become B-type then A-type as they age.

In fact, when stars evolve, they move off the main sequence to different parts of the HR diagram. The blue giant stars (hot and bright), red giant stars (cool and bright) and white dwarf stars (hot and faint) shown on the diagram above represent some of these stages of evolution, which you'll read about in later sections.

You can see that high mass, hot stars on the main sequence have high luminosity, whilst low mass, cool stars on the main sequence have low luminosity. This indicates that high mass stars use up their fuel quickly and so have relatively short lives, while low mass stars use up their fuel slowly and so have longer lives.

Look at this image showing different endings for different types of star, depending on their original mass. In the image, mass is increasing from the bottom upwards. The biggest stars (those with masses at least eight times the mass of the Sun) become supernovae, while the smaller ones just gradually burn away.

In the next section, you will look at different types of star.

2.2.1 Types of star

Not all stars are the same and it is mainly their differences in mass that produce the wide variety of stars we see and many we can't.

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Red Dwarfs

Red Dwarfs are small stars with temperatures cooler than that of the Sun. They are the most common stars in our galaxy and are less than half of the mass of the Sun. They are positioned on the lower main sequence on the Hertsprung-Russell diagram.

Red Giants

Red Giants are cooler than the Sun, so they have a red–orange tinge to the visible light they emit. They may be over 100 times the size of the Sun and are stars near the end of their life. They come above the main sequence on the Hertsprung-Russell diagram.

Supergiants

Stretching across the upper regions of the Hertsprung-Russell diagram the Supergiants are truly enormous. Rigel is the brightest star in the Orion constellation and is a blue-white supergiant. Supergiants are high mass stars. Near the end of their life, when a supergiant dies, it explodes as a supernova, then shrinks to become a black hole.

White Dwarfs

White Dwarfs are faint but hot stars in the bottom left of the Hertsprung-Russell diagram. They are very small and dense, formed when a main sequence star reaches the end of its life. White dwarf stars gradually cool over time until they no longer emit light.

Brown Dwarfs

The smallest, dimmest and coolest stars are Brown Dwarfs. They appear at the lowest part of the main sequence on the Hertsprung-Russell diagram. They are also known as ‘failed stars’ and are very difficult to detect as they do not have sufficient mass for nuclear fusion to occur.

Explore star types for yourself.

Activity 2.2

Pick a star, this could be a star you’ve heard something about already or a group of stars such as brown dwarfs, and see what else you can find out about it.

For example, where is it on the Hertzsprung-Russell diagram that you looked at in The life of a star, approximately how old is it, roughly how far away is it, what constellation is it part of?

Write a short paragraph about what you found most interesting.

Provide your answer...

Next, you’ll look at the reactions going on inside a star, and see how they affect how the star evolves.

2.2.2 Mass, luminosity and temperature

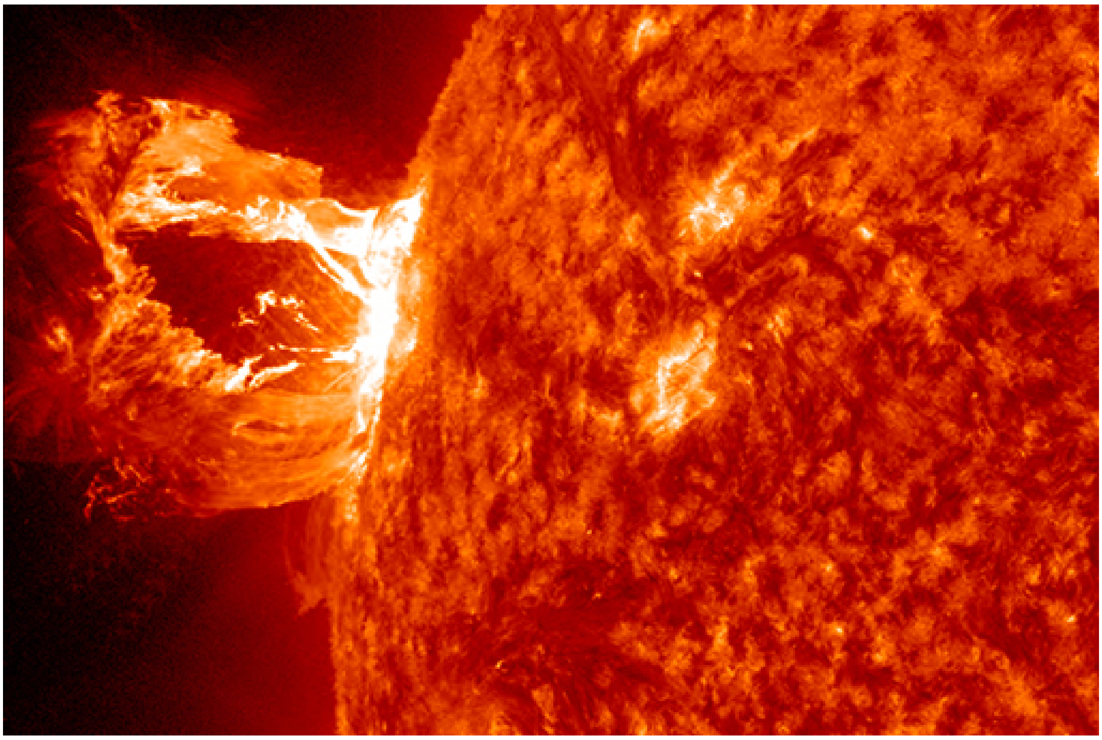

Figure 11 An eruption on April 16, 2012 captured by NASA's Solar Dynamics Observatory.

Stars need a power source, since they are constantly radiating away energy into space as light and heat – if they didn't have one, they would gradually fade away and cool.

Luminosity

The Hertzsprung-Russell diagram implies that on the main sequence the more massive a star is, the more luminous it is as well. So massive stars must produce more energy than less massive stars. This sounds sensible – surely massive stars have more fuel to burn, which is why they produce more energy. This is true – but the mass of a star is not directly proportional to the amount of energy it emits.

Imagine a star with ten times the mass of the Sun. This would have ten times as much fuel to burn as the Sun, so would have the same brightness as the Sun but live for ten times longer if it burned its fuel at the same rate. However, such stars are approximately ten thousand times brighter than the Sun rather than being the same brightness. It turns out that the luminosity of a star is proportional to its mass (M) to the power four (that is M × M × M × M). In other words, a star that is twice as heavy as the Sun, is not twice as luminous – it would be 2 × 2 × 2 × 2 = 16 times as luminous.

Knowing this relationship between mass and luminosity helps to understand how long a star will live. A star that is twice as massive as the Sun is 16 times as luminous, so it must be burning its fuel 16 times more quickly. But because it is only twice the mass of the Sun, it only has twice as much fuel – so it will run out of fuel much more quickly than the Sun. It will only live for 2/16 (= 1/8) of the lifetime of the Sun. Therefore, more massive stars have much shorter lifetimes than smaller stars.

Temperature

The internal temperature of a star is also proportional to its mass, so a star twice as massive as the Sun is twice as hot at its core.

This might seem obvious, as it is related to what is shown on the Hertzsprung-Russell diagram – but remember that the Hertzsprung-Russell diagram plots the surface temperature of a star, and not its core. This is the key to understanding the relationship between stellar luminosity and mass on the main sequence.

The rate at which energy is released in a star – and hence its luminosity – appears to be directly related to its core temperature, which in turn depends on the star's mass. But why does the energy release depend on core temperature? Considering at the reactions going on in the interior of stars can help explain.

In the next section, you'll think about the nuclear reactions that are going on inside of stars.

2.2.3 Nuclear fusion

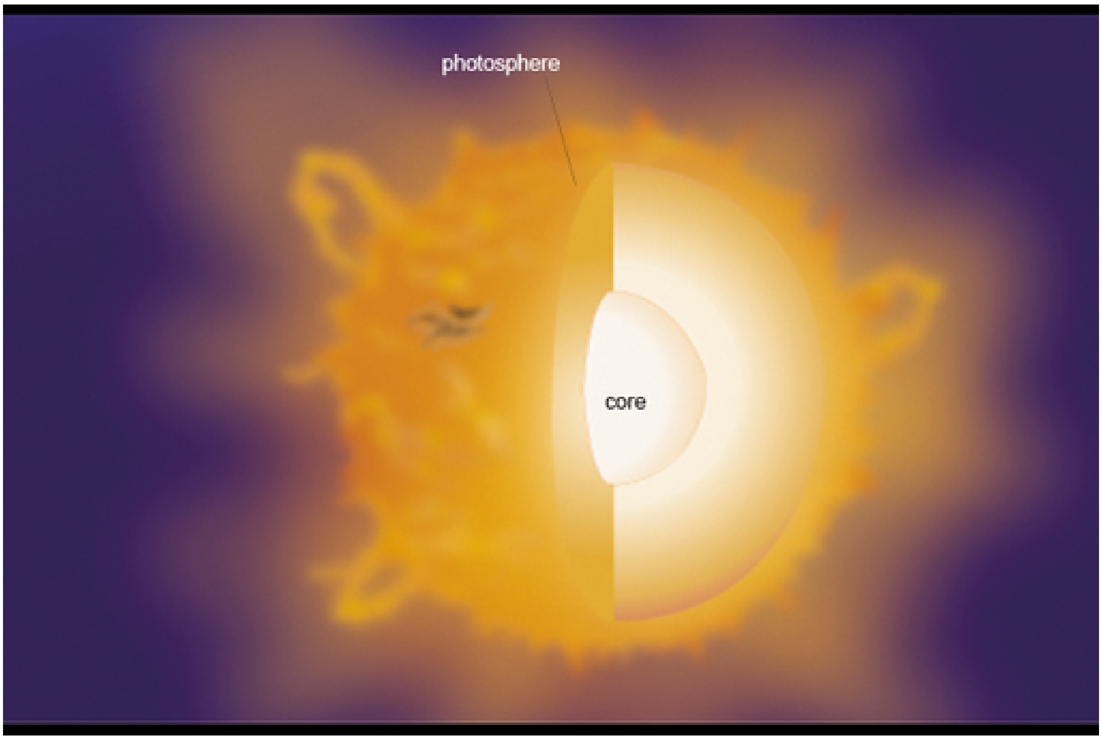

Figure 12 The solar interior. Temperature and density increase rapidly with depth inside the Sun, but only in the central core are conditions right for nuclear reactions to occur

The reactions that take place inside stars are the source of the light and heat (energy) that the stars give out.

The reactions are the fusion of atoms together – **nuclear fusion** – where the nuclei of atoms are combined to form a new nucleus of different mass.

The Sun is mainly hydrogen and helium, and is gaseous throughout. The nuclear reactions occur only in the Sun's core, deep in its centre, because the hydrogen fuel has to be at very high temperature, over 15 million K, before nuclear reactions can begin.

Main sequence stars, like the Sun, convert hydrogen to helium as you learned in What is a star?.

The two hydrogen nuclei involved in the first step of the reaction have identical positive charges, so they repel each other with greater and greater force the closer they get to each other. In order for the hydrogen nuclei to combine, they have to be close enough to interact and undergo fusion. They have to be moving rapidly to overcome the repulsion. The higher the temperature of the gas, the faster the nuclei are moving.

The higher core temperatures of stars more massive than the Sun also allow other nuclear reactions to occur that involve nuclei of heavier and heavier elements.

2.3 The death of a star

What happens, though, when a star runs out of fuel?

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The Sun will gradually run out of fuel but we probably have about another 4.5 billion years' worth of hydrogen still to go, so there's no need to worry quite yet!

As the hydrogen gets used up, the rate of energy production will also decrease. This upsets the balance between the outward pressure of hot gas and the inward pressure of gravity that has kept the Sun stable. The core of the Sun will then begin to collapse under its own weight, and as it collapses, the core will begin to heat up.

As the core contracts, it heats up the layers above it, which eventually become hot enough for nuclear fusion to take place in the same way as it did in the core. At the same time, the core continues to contract and get hotter, eventually becoming hot enough for the fusion of helium nuclei into heavier elements.

Three helium nuclei fuse together to form a nucleus of carbon – this is called **helium burning**, and produces sufficient energy to stabilise the star against further collapse. Because the star has to consume its fuel much faster to prevent it collapsing, this part of its lifecycle is much shorter than the time spent on the main sequence.

How does the appearance of the star change as the different nuclear reactions take place? In a star burning helium in its core and hydrogen in a shell surrounding the core, the rate of energy production rises. At the same time, the radius of the star increases, so its surface area also increases. Although there is now a greater supply of energy, it isn't sufficient to keep the outer layers of the star at their previous temperature, so the temperature of the photosphere decreases to below 4000 K. The star is now orange-red in colour, and has become a **Red Giant**.

This isn't the end, though, for the star! The star loses hold of its outer layers and it becomes a planetary nebula. The remains are no longer burning helium but are still hot, this is known as a **white dwarf**. This is true for all stars that are born with less than about eight times the mass of the Sun.

You will find out more about planetary nebula in the next section.

2.3.1 Planetary nebula

Figure 13 Planetary nebula NGC 2440

The star keeps on burning until the core runs out of helium, then it collapses again.

The contraction heats up the core, and the temperature rises so much that helium burning starts in a shell around an inert core of carbon and oxygen. This leads to a further expansion and cooling of the star.

Helium shell burning is not a stable process, and leads to a series of pulses, where the shell alternately expands and contracts. Each pulse can last a few thousand years, and is marked by a variation in energy output of the star. The pulses can be so strong that they push off the outer layers of the star as a **planetary nebula** – beautiful shells of gas ejected from and heated by the dying star.

Planetary nebulae come in a wide variety of shapes and colours. The name planetary nebula is an unfortunate accident. When they were first discovered, they looked like giant gas planets, but since, it has been discovered that the only link they have to planet formation is that they produce elements that are needed for planet building.

Next, you'll hear about supernovae.

2.3.2 Supernovae

In contrast to a low mass main sequence star, the death of a massive star is much more rapid and violent.

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In the next section, you'll see how beautiful this process is.

2.3.3 Beautiful supernovae

What do the stars look like as they go through all these nuclear reactions?

Supernovae are so bright that they can outshine a galaxy! However they only shine this brightly for a few days or weeks, before fading away, leaving beautiful remants.

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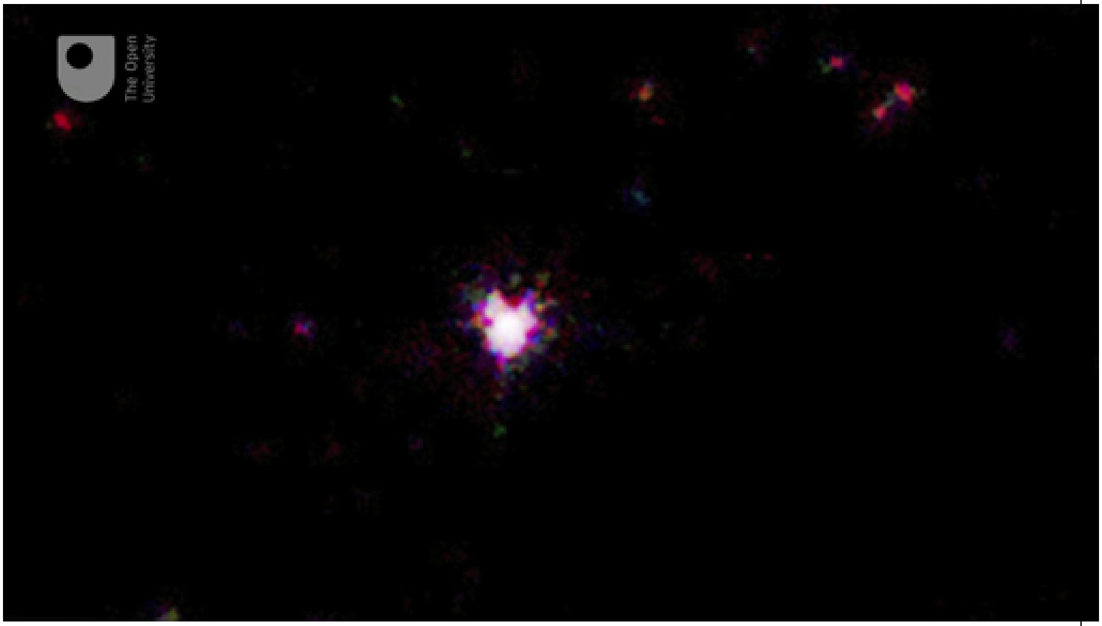

This video features GRB 111209A, a red supergiant that exploded on 9 December 2011, producing high-energy gamma ray emissions; V838 Monocerotis, which unlike a normal nova grew enormously in size instead of expelling its outer layers; N 63A, whose shockwaves are destroying the surrounding gas clouds; and SN 1006, possibly the brightest supernova in recorded human history.

2.3.4 Cosmic onion

Nuclear fusion can continue in a massive star, with succeeding generations of nuclei combining to produce heavier and heavier elements.

When a star's core reaches a temperature of about 500 million K, carbon fuses to neon plus helium. Once the carbon runs out, the core contracts, raising the temperature to about 1,500 million K, and neon combines with leftover helium to form magnesium.

This process continues, until the core temperature reaches 7,000 million K, by which time the star is like a 'cosmic onion', with an iron core, surrounded by concentric shells of silicon and sulphur, magnesium and neon, oxygen and carbon, helium and an outer shell of hydrogen. Each layer is cooler than the one below.

2.3.5 Supergiant stars

What happens to supergiant stars?

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As with low mass, Sun-type stars, the extra sources of energy cause the star to expand and then cool, although their higher temperatures mean that they usually turn into hot blue or blue-white supergiants.

A great example of a supergiant is Rigel from the Orion constellation.

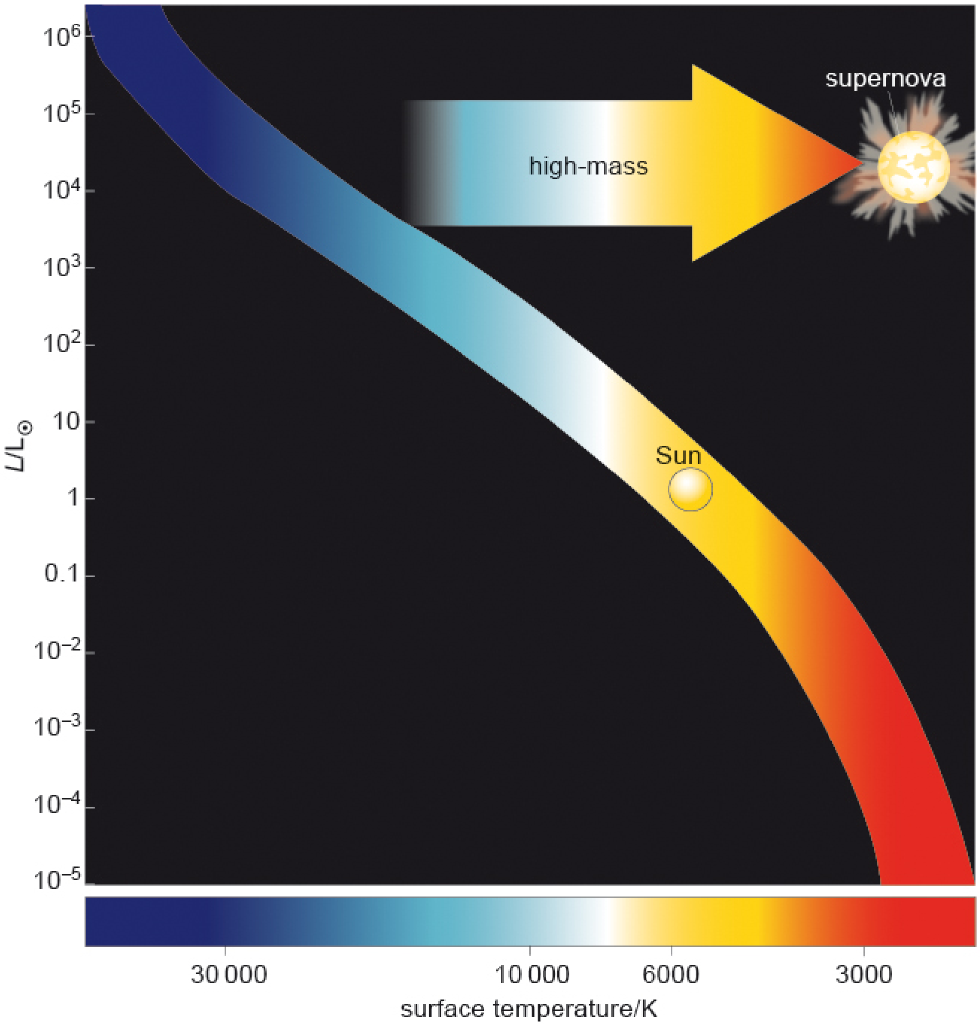

Figure 14 Evolutionary track of a high-mass star across the HR diagram

On the graph in Figure 14, the evolutionary path of a massive star is shown. The hot, blue supergiant evolves to even greater sizes and cooler temperatures, passing through both yellow and blue supergiant phases.

The largest of all known stars are the **red supergiants**, like Betelgeuse in the Orion constellation. If a red supergiant were placed in the centre of our Solar System, its radius would reach out past Jupiter!

The video explains what happens when the temperature rises further. You can read more about this process in the next section.

2.3.6 Exploding supernova

What happens to the supergiant next?

As before, the core collapses under gravity and the temperature rises until fusion between the iron nuclei could take place. But this is where things change: when elements lighter than iron fuse together, they give out energy. To get iron nuclei to fuse together, energy needs to be taken in. When this happens, there is no longer sufficient energy to support the star against gravity, and the core collapses even more rapidly.

The collapsing core continues to rise in temperature until it reaches the point at which the nuclei of iron atoms start to break up into protons and neutrons.

The core stops collapsing when it reaches a temperature of about 1 million million degrees and a density of about a million million million times that of rock – fairly unimaginable! Even though the core of the star has stopped contracting, its outer layers are still falling inwards. As this material hits the core, its energy is turned outwards, and the star explodes as a **supernova**.

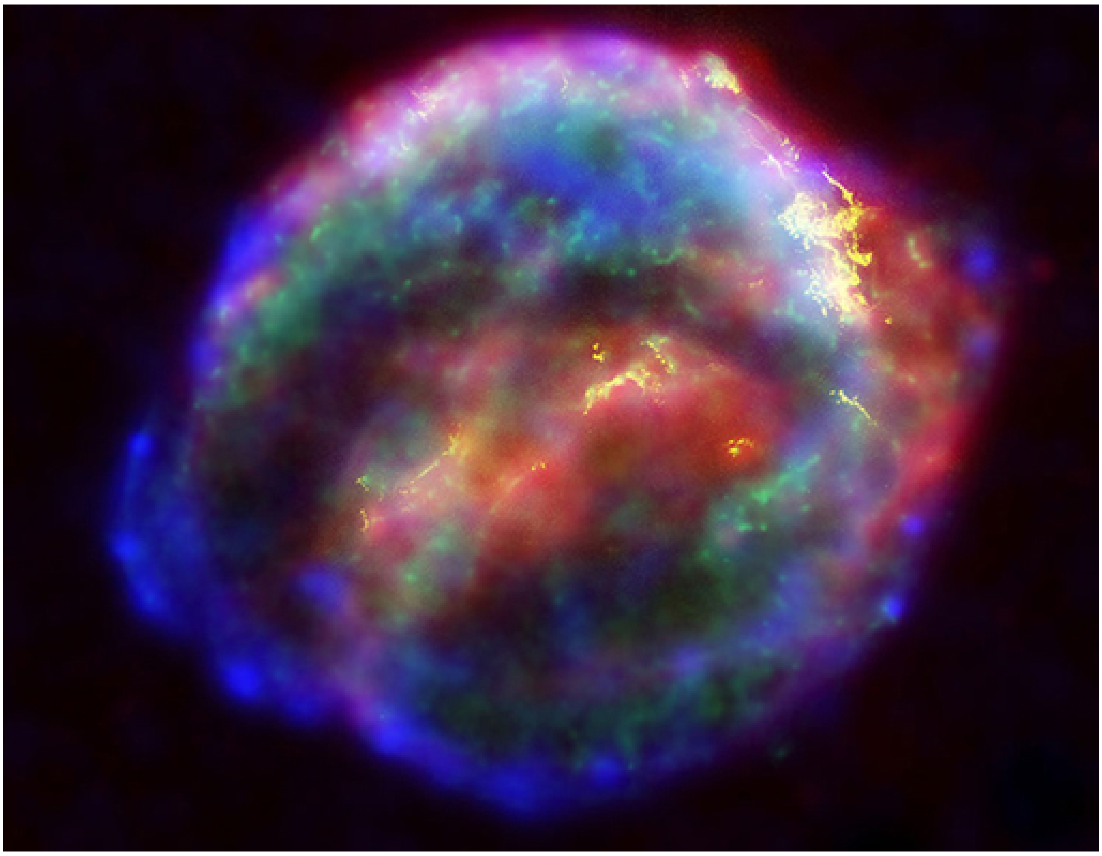

Figure 15 Remnants of Kepler's supernova that exploded over 400 years ago, the bubble-shaped shroud of gas and dust is 14 light-years wide and is expanding at 4 million miles per hour (2,000 kilometers per second).

Whatever the cause of the explosion, the high temperature allows the star to undergo one final round of nucleosynthesis, producing the heavy elements, which include gold and uranium. The explosion takes only a few seconds, and so much energy is released that the star brightens by about a hundred million times.

If a supernova occurred in our own galaxy, it would be visible during the day for a few weeks. During the explosion, all the elements produced by nucleosynthesis during the star's lifetime are thrown back into the galaxy, becoming part of the interstellar gas and dust which forms the next generation of stars. Without supernovae, planets would not exist – and neither would we!

At the end of the explosive supernova, a supernova remnant is left behind. Next, you'll look at what becomes of the final remnants of a dying star.

2.3.7 The final remnants

Figure 16 The Cat's Eye planetary nebula with its central white dwarf.

So far, you have seen that low mass stars (like the Sun) and high mass stars (like Rigel) have different evolutionary pathways, but both types end up ejecting large quantities of material back into space.

This process doesn't lead to the complete destruction of the star – a dead remnant is left behind, with the remnants from low and high mass stars having different properties.

White dwarfs are the remains of low mass stars such as the Sun. After the outer layers of the star are ejected as a planetary nebula, the hot stellar core is exposed. The core is made of carbon and oxygen from nuclear fusion, and is still very hot, because the nuclear reactions have only just finished. Surface temperatures are up to around 150,000 K – although some old white dwarfs may be as cool as 5000 K.

White dwarfs are very faint, much less luminous than the Sun. This combination of high temperature and low luminosity is because they are very small – typically only about the size of the Earth. Despite this, they still contain a large amount of the matter that made up the original star – the largest white dwarfs maybe up to 1.4 times the mass of the Sun, and so they are extremely dense objects, with densities around a thousand million times as dense as rock.

The final fate of a white dwarf is a slow dwindling into obscurity, as they gradually radiate away their heat, becoming cooler and progressively dimmer. Because white dwarfs have a smaller surface area than other stars, it takes a long time for all the energy to be radiated away – about 10 billion years, which is about the age of the universe. Low mass stars end up as cold dark spheres, rich in carbon and oxygen.

In the next section you'll discover what happens to the remnants of larger stars.

2.3.8 Neutron stars

In the description of a white dwarf, you heard that they had masses up to about 1.4 times that of the Sun.

In stellar remnants more massive than this, the force of gravity again comes into play, and the remnant collapses in on itself, forming a **neutron star**.

Note: this video has no sound.

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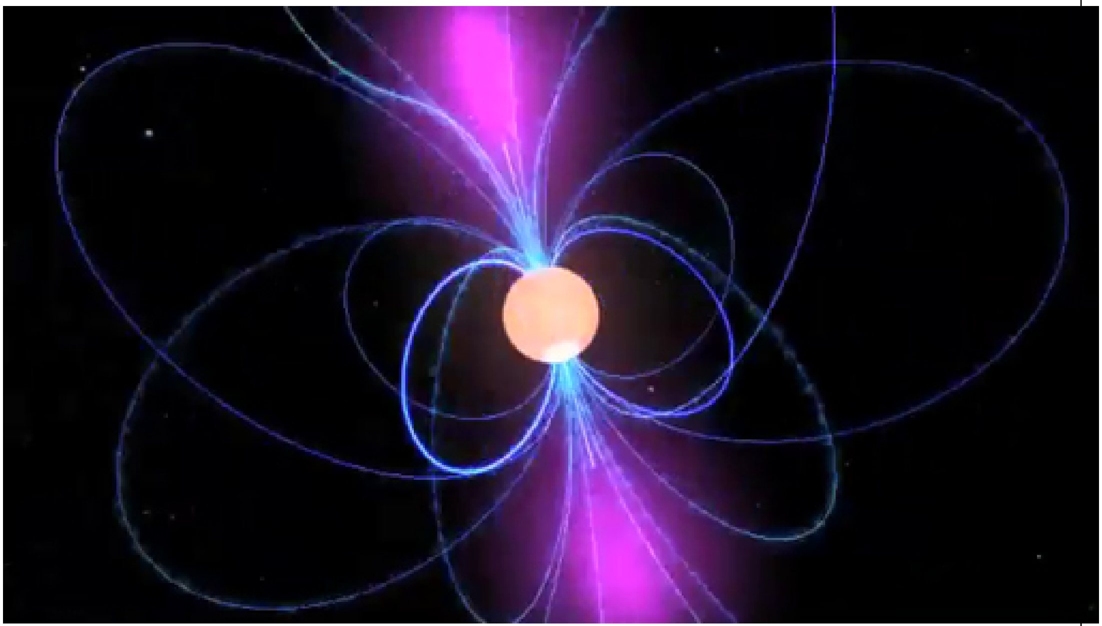

Neutron stars are very small, super-dense stars composed almost entirely of tightly-packed neutrons, only about 10–20 kilometers across. Neutron stars are around 100,000 million million times as dense as a rock. These huge densities mean that neutron stars also have powerful gravitational fields.

Another extreme property of neutron stars is the rate at which they rotate, up to several hundred rotations every second. Imagine watching a skater spinning. As they pull in their arms, the rate at which they spin increases. This is exactly the same phenomenon that takes place during the collapse of the remnant which leads to the formation of a neutron star. The comparatively slow rotation of the original star rapidly increases as the star contracts by a factor of almost a million.

It is possible to measure the rotation rate of a neutron star directly because it sends out beams of radiation (mainly radio waves). The result is a regular series of pulses that show how quickly the star is rotating. They also give neutron stars their alternative name: pulsars.

Next, you'll hear about black holes.

2.3.9 Black holes

A black hole may form when a massive star runs out of fuel causing it to collapse.

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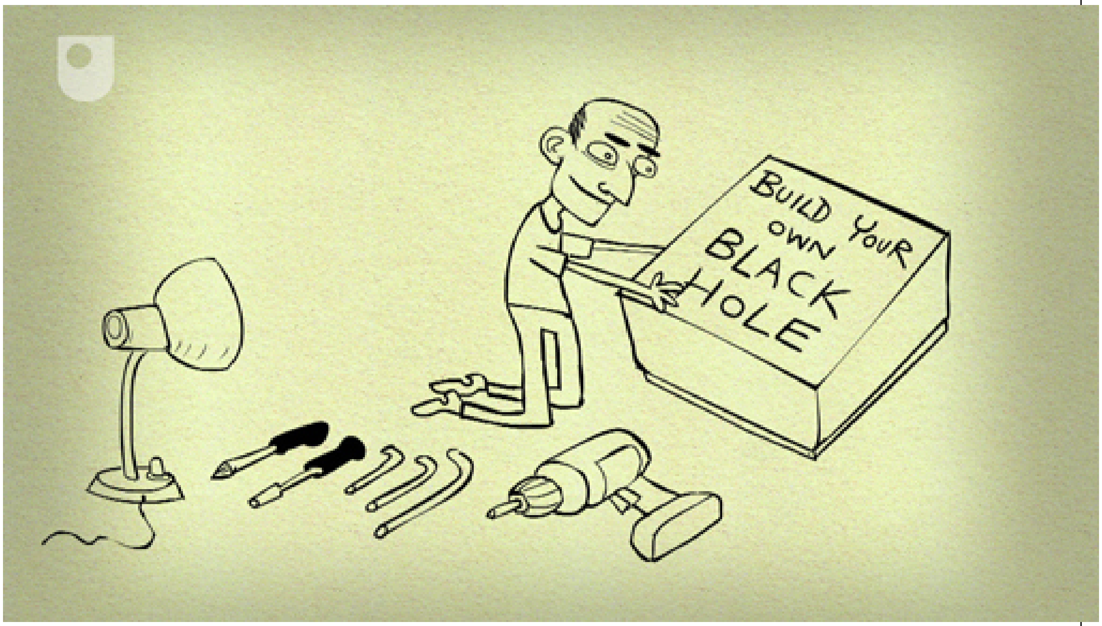

As the collapse continues, the core will become so dense that nothing, not even light, can escape the gravitational pull of the core. At this point, a **black hole** will have formed. Alternatively, if a single star is massive enough, the supernova explosion that forms the neutron star might not be able to release sufficient energy to eject all the outer layers of the star. That material will then fall back onto the newly-born neutron star, causing it to collapse to form a black hole.

Astronomers have found that black holes can have very strong magnetic fields which might be related to bright jets of radio signals from the black holes.

2.3.10 Black hole cannibal

How can anyone find black holes? No light can escape from one, so it might seem impossible to observe them, but they can have a detectable influence on nearby objects.

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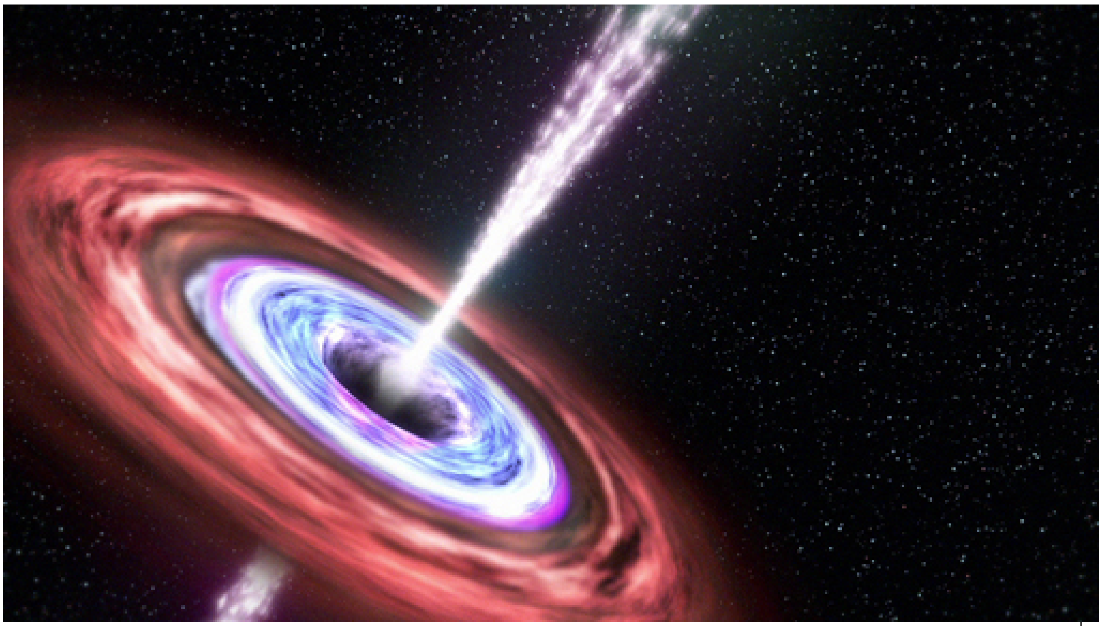

As you can see in the animation, if a star orbits too closely to a black hole, the intense gravitational field of the black hole tears material from the surface of the star, which then falls into the black hole. As the material falls in, it heats up to very high temperatures and the energy can be radiated away as X-rays.

2.4 Week 2 quiz

Check what you've learned this week by taking the Week 2 quiz.

Open the quiz in a new window or tab then come back here when you're done.

Summary of Week 2

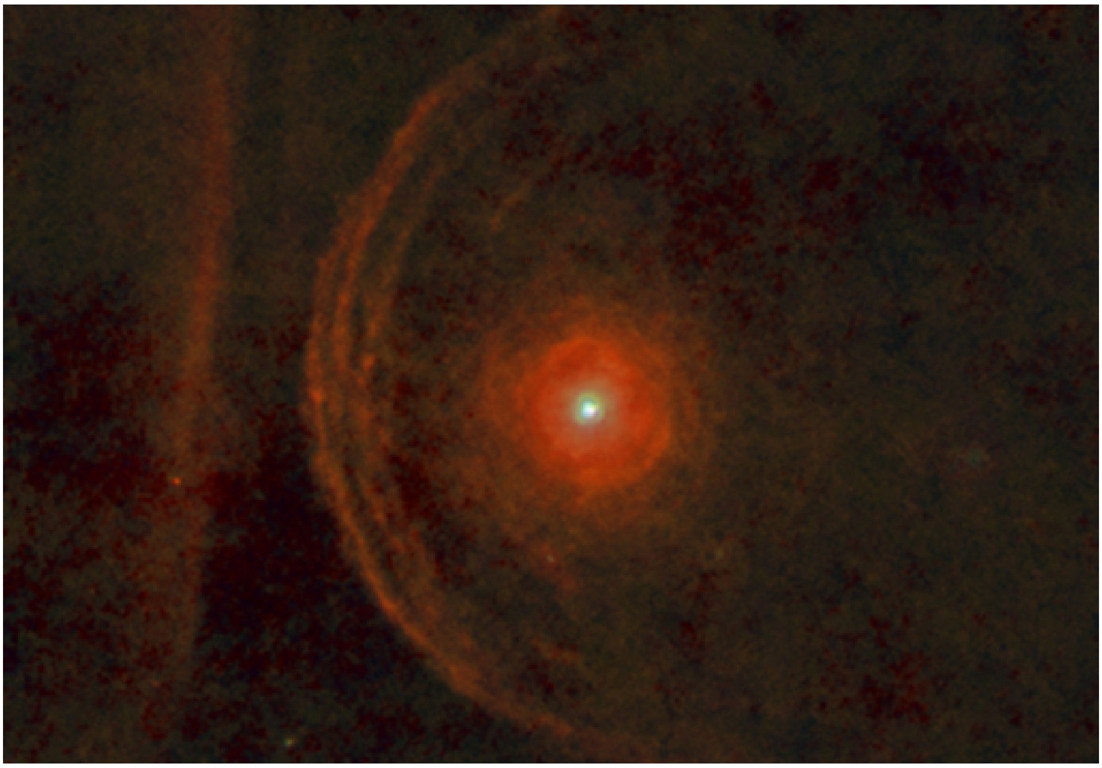

Figure 17 The red supergiant star Betelgeuse as seen from the Herschel Space Observatory.

This week, you have travelled a long way! By taking a journey through the lifecycle of a star, you found out about red giants and white dwarfs, and what would happen to the Sun in five billion years' time.

The tour ended with a bang, with stars exploding as supernova or collapsing into neutron stars, and material falling down a black hole.

In Week 3 you'll start with a bang – travelling back in time, to learn about the Big Bang, in which space and time and all matter was created. You will also learn about different types of galaxies.

Week 3: From the beginning

Introduction

Figure 1 The spiral galaxy Messier 81, or M81.

This week, you'll investigate what the night sky can reveal about how it all began. You'll also learn about different galaxies and find out about dark matter and dark energy.

3.1 The Big Bang

What is the Big Bang and just how big was it?

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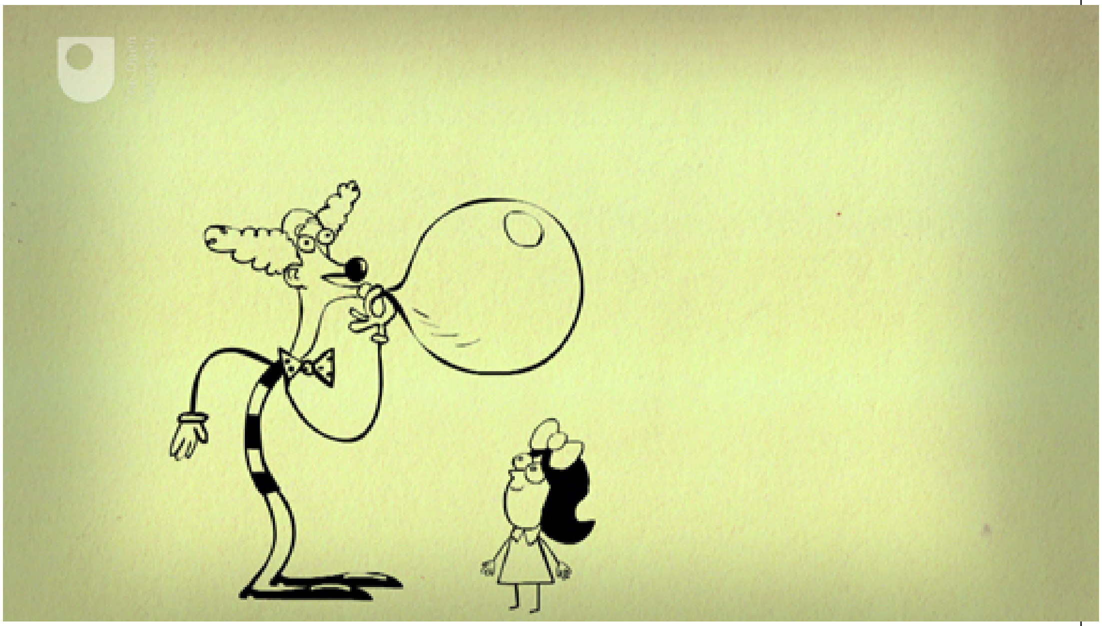

Scientists have observed that the galaxies in the Universe appear to be moving away from each other. If it were possible to wind time backwards, 13.7 billion years ago, all the galaxies would seem to have come from a single, compacted, super dense region – or singularity.

The singularity expanded and cooled to become every thing in the Universe. It is also important to realise that all the matter in the Universe was created in this instant. Since then, matter has changed form, but no extra matter has been formed. This is the **Big Bang** theory.

One way of envisaging the expansion of space is to think about the surface of a balloon, with galaxies drawn on its surface. As the balloon is blown up, the galaxies appear to move away from each other. What is happening is that the space between the galaxies is expanding. The distance from the surface of the balloon to its centre is a measure of time. When the Universe starts, the balloon has zero size, and as time goes on, the balloon gets bigger. Because all of space was 'contained' in the singularity, the Big Bang happened everywhere in space simultaneously.

The Big Bang theory is illustrated on the History of the Universe Timeline.

Next, you'll consider whether the Universe will keep on expanding forever.

3.1.1 Open or closed universe

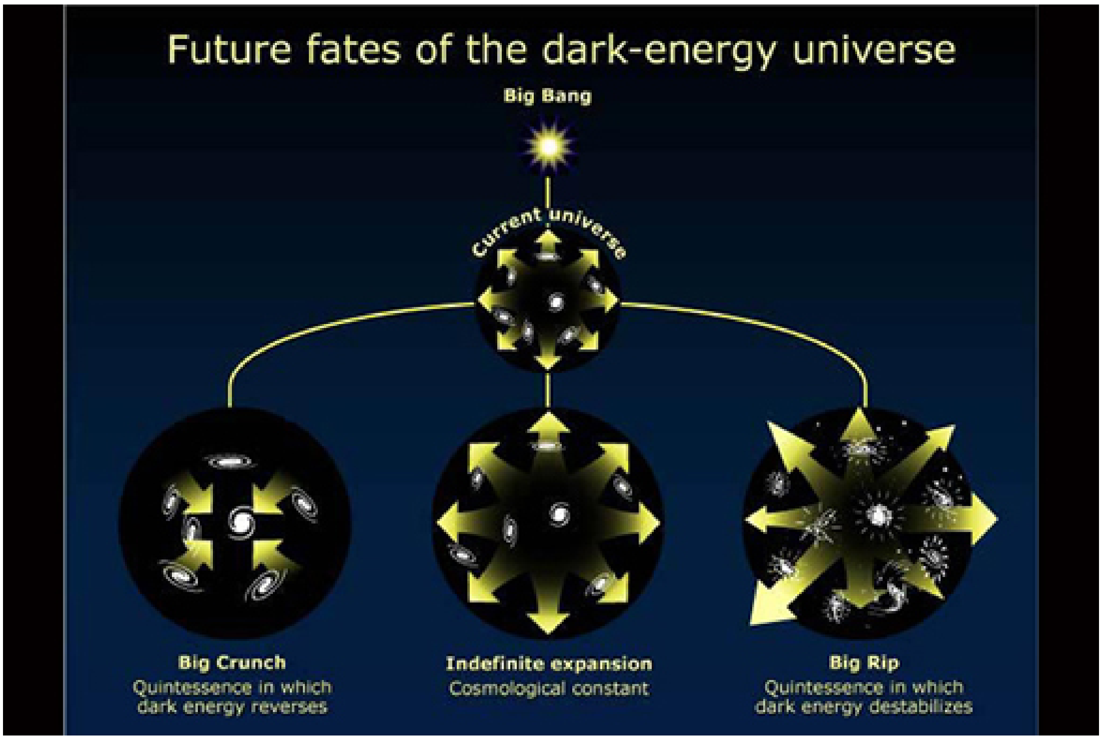

Figure 2 An illustration of the theorised possible fates of the universe

You've already heard that the Universe is expanding, but consider what will happen in the future. Is the expansion going to go on for ever?

Astronomers used to think that there might be a point at which the Universe stopped expanding and started to contract. They described this as a **closed universe**, suggesting that the Universe might reach a point where the expansion would slow down as objects reached a maximum separation. Then it would recoil, collapsing back on itself.

During the collapse, the Universe would become denser and hotter until it ended in an infinitely hot, infinitely dense, singularity. A closed universe would lead to a big crunch – the opposite of the Big Bang.

However, more recent observations from space telescopes have concluded that this scenario is very unlikely. In fact the expansion of the Universe is accelerating. Astronomers describe this as an **open universe**.

If the expansion continues forever the matter in the Universe will be spread more and more thinly. Eventually, galaxies will run out of the materials they need to make new stars. Stars that already exist will slowly extinguish. At that point, the Universe will become dark, cold and lifeless.

Activity 3.1

Considering what you have learned so far this week, how does this picture of the end of the Universe sound to you?

Write a paragraph explaining your thoughts.

Provide your answer...

3.1.2 Particle formation

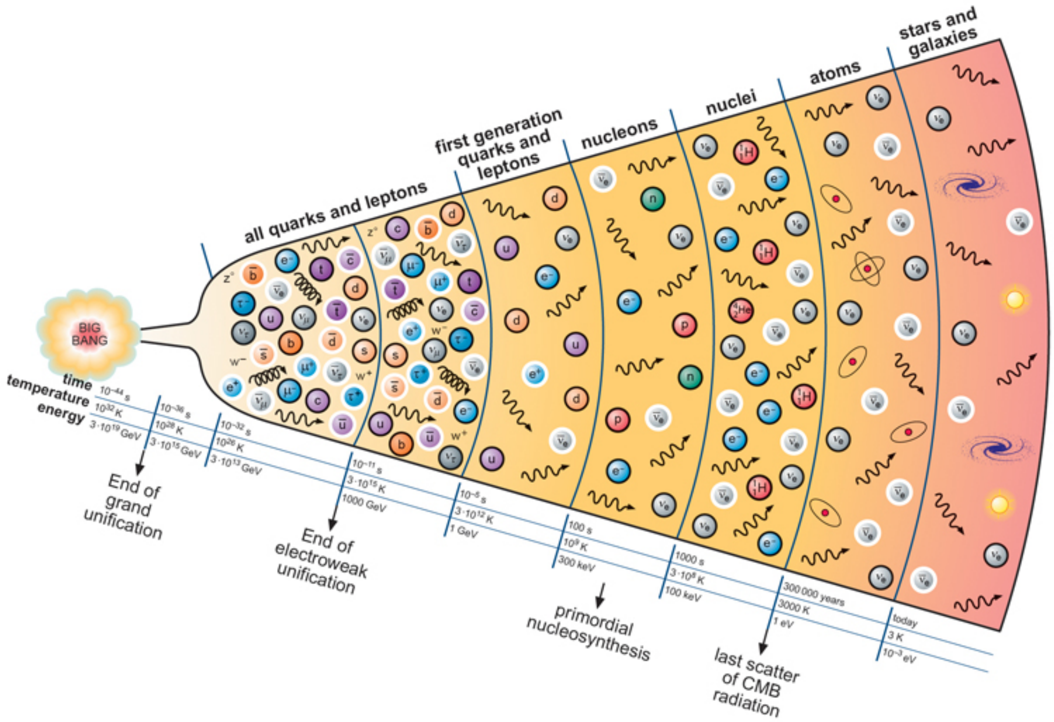

Figure 3

At the instant of the Big Bang, all the matter in the universe formed – but because the temperature was so hot, only subatomic particles could exist.

These subatomic particles are called ‘quarks’, ‘leptons’ and ‘bosons’. In the currently accepted theory of the origin of these particles (the ‘standard model’), there are 36 of these particles including the recently discovered ‘Higgs boson’.

There was a very rapid period of expansion and cooling – known as **inflation**. The period of time for which **inflation** lasted was unimaginably small: about 0.00000000000000000000000000000001 of a second.

It was not until about 0.00001 of a second after the Big Bang that protons, neutrons and electrons – the building blocks of atoms – could form. These particles are made up of different combinations of the subatomic particles.

If you look at the History of the Universe Timeline. you can see that over several hundred million years the tiny particles eventually became enormous galaxies. These galaxies appear to be moving away from each other like the expanding balloon you saw in the video.

In the next section, you’ll discover how astronomers have found out about the expanding Universe.

3.1.3 Evidence of expansion

Astronomers deduced that the Universe was expanding because light from distant galaxies is redshifted. What does this mean?

In order to explain what ‘redshift’ means it is useful to consider an example from everyday life. The phenomenon is known as the Doppler effect and it is probably familiar to you in the context of sound waves, although it applies equally to any wave motion, including electromagnetic radiation such as light. The Doppler effect with sound is perhaps most noticeable when an approaching ambulance sounds its siren or as a speeding car races past.

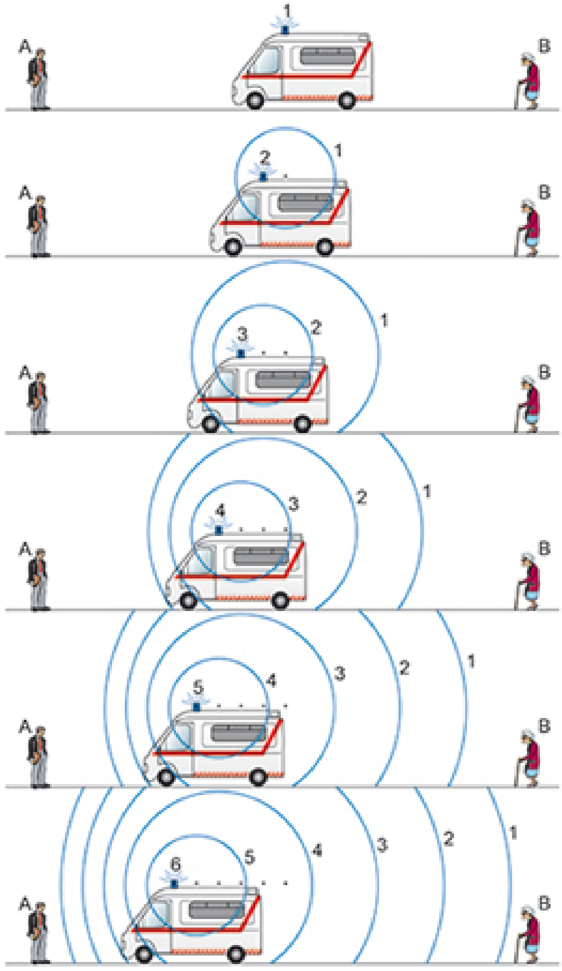

Figure 4 A demonstration of the Doppler effect with sound

Figure 4 shows how wavelength appears to change with distance between object and receiver. The ambulance sounds its siren as it moves towards observer A. Six successive time intervals are shown in the six sketches, with the curved lines representing successive crests of the sound wave emitted by the siren. You may like to think of the curved lines as being similar to the ripples produced when a stone is dropped into a pond – the wave crests spread out from the centre just as shown here. The wavelength is then just the distance between any two successive crests at any point.

By the time the second wave crest is emitted, the ambulance has caught up slightly with the first wave crest. By the time the third wave crest is emitted, the ambulance has caught up with the second wave crest, and so on. The consequence is that a person at A will perceive a sound wave with a shorter wavelength than that emitted by the siren when at rest, while a person at B will perceive a longer wavelength.

The wavelength of sound waves may be appreciated by the pitch of the sound perceived by the human ear. The wavelength of a light wave is perceived by the human eye as the colour of the light. A shift in the colour to longer wavelengths (towards the red end of the spectrum) is an indication of motion away from the observer, a shift in the colour to shorter wavelengths (towards the blue end of the spectrum) is an indication of motion towards the observer.

The wavelengths of light from distant galaxies, when observed from Earth, are shifted towards the red. This is interpreted as meaning that the galaxies are moving away from us, i.e. the spectrum of light is redshifted.

It is important to realise that although we are using the Doppler effect to explain how a redshift comes about, the Doppler effect results from motion of objects through space (the ambulance is moving towards or away from an observer). Redshift arises from the expansion of space i.e. causing galaxies to be moving further away.

Next, you will view an image of distant galaxies taken by the Hubble Space Telescope.

3.1.4 Hubble Ultra Deep Field

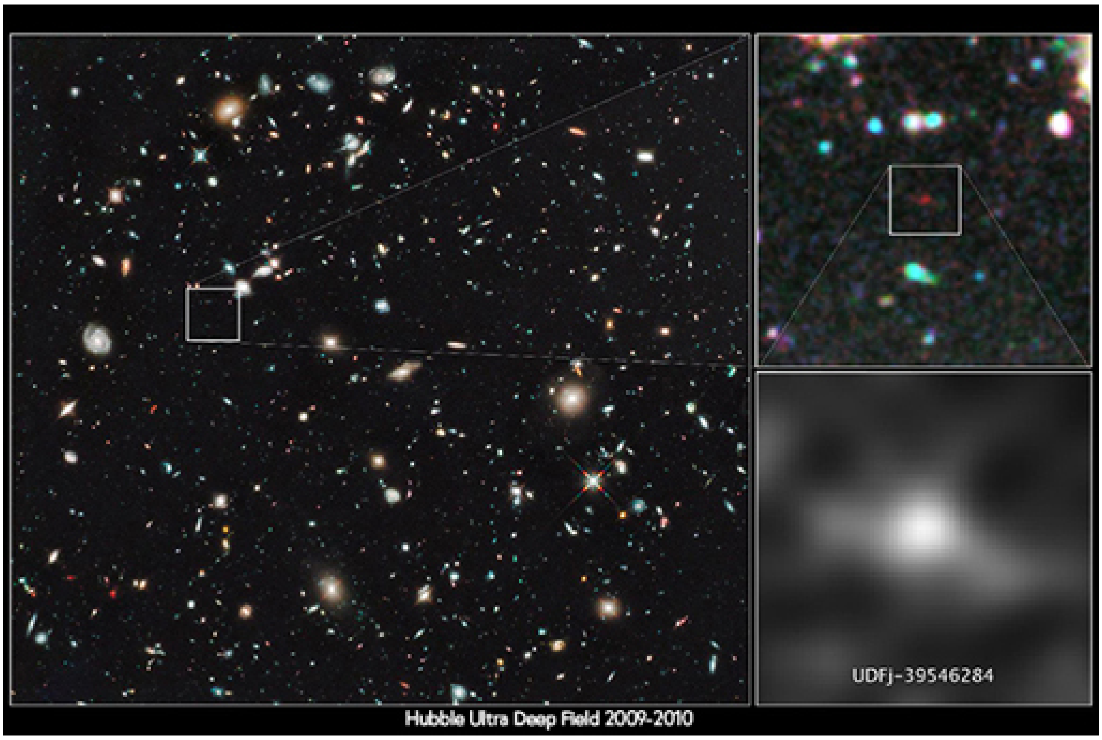

Figure 5 UDFJ-39546284, one of the most distant galaxies seen. Astronomers believe it is 13.2 billion light-years away

The Hubble Space Telescope observed a single area for about 100 hours in order to collect sufficient light from distant galaxies.

The image, known as the Hubble Ultra Deep Field (UDF) is of a patch of sky only about one tenth of the size of the full moon in the night sky. The image shows thousands of galaxies with different redshifts.

In the next part of the course, you will look at the variety of shapes and sizes that galaxies come in. Before that you'll take your photo of Orion for this week.

3.1.5 Photographing Orion

Figure 6 Orion in the night sky.

It's time to take your weekly photograph of Orion!

Activity 3.2

If possible take a picture at the same time from the same spot each week. Remember to include your marker point (chimney pot, tree branch, etc.) in the image, so that they can be compared from week to week. Fingers crossed that it is clear and not cloudy wherever you are!

You might find it useful to look at Monica's advice on taking photos of Orion.

Once you have taken the picture, compare it to the others you have taken during the course. Did you notice that Orion had moved from your image last week?

3.2 What is a galaxy?

Figure 7 The Andromeda galaxy seen through a telescope.

A galaxy is a huge assemblage of stars, planets, nebulae, gas and dust. Objects within a galaxy are bound by gravity and orbit around a common centre of mass. It is estimated that there are probably more than 170 billion galaxies in the observable universe.

Most galaxies are believed to have supermassive black holes at their centre around which everything rotates. Our Galaxy, the Milky Way, is thought to have a supermassive black hole at the centre with a mass of four million times the Sun – you will come back to this a bit later.

The space between galaxies is known as ‘intergalactic space’ and is very sparse, with less than one atom per cubic metre.

You’ll learn about different types of galaxy in the next section.

3.2.1 Different types of galaxy

Galaxies are categorised according to their apparent shape.

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Galaxy shapes are typically divided into elliptical, spiral or irregular. The shape of a galaxy gives a clue to the age and types of star within the galaxy.

Spiral galaxies have a central bulge of stars surrounded by a disk that contains 'arms' which form a spiral structure. Stars in the bulge of a spiral galaxy tend to be older and redder than the rest.

There's also a much fainter, roughly spherical stellar halo encompassing the disc. An example of a spiral galaxy is one of our nearest neighbours, the Andromeda Galaxy.

Barred spiral galaxies are spiral galaxies with a bar of stars across the middle of the galaxy. The Milky Way is thought to be a barred spiral galaxy.

Elliptical galaxies don't show any structure, but have a smooth ellipsoidal shape, appearing as large spherical or elliptical balls of stars.

Irregular galaxies are those with no defined shape. Many irregular galaxies probably used to be spiral or elliptical until they were disrupted by the gravitational pull of neighbouring galaxies.

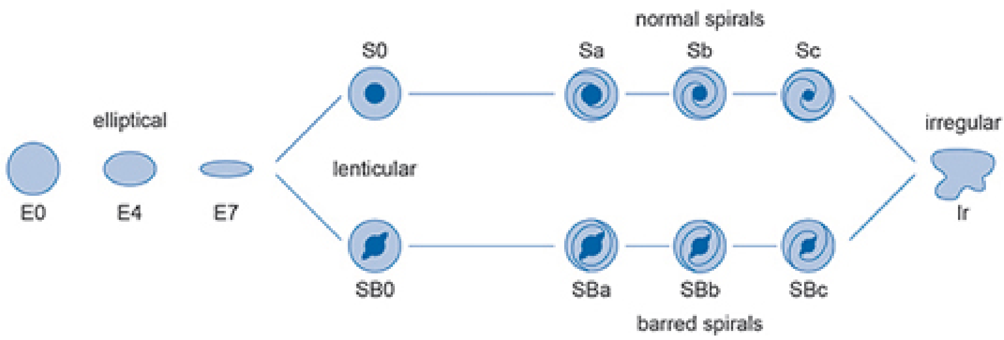

Figure 8 The Hubble tuning fork classification scheme for galaxies

Edwin Hubble proposed a 'tuning fork' classification of galaxies that is still in use today, shown in Figure 8. The Milky Way Galaxy is somewhere on the barred spirals fork.

3.2.2 Merging galaxies

Figure 9 The Large and Small Magellanic Clouds, as seen from New South Wales, Australia.

The shapes of galaxies are influenced by their neighbours: larger galaxies can merge with smaller ones and smaller ones can merge with each other.

The Milky Way is in the process of engulfing the Large and Small Magellanic Clouds, two irregular galaxies that can be seen in the night sky in the southern hemisphere, although the merger won't be complete for another three billion years.

Because everything in space is moving, occasionally galaxies collide. Find out more in the next section.

3.2.3 Colliding and merging galaxies

Collisions between galaxies take hundreds of millions of years to complete, and are driven by the effect of gravity. Actual collisions between stars are rare, as so much of a galaxy is empty space.

Note that this video has no sound.

Video content is not available in this format.

The Milky Way is itself falling towards the Andromeda galaxy, and in about five billion years, these galaxies will merge. What will this be like? For one thing, the stars themselves won't collide – they are too sparsely distributed. The galaxies will splash together, flinging some stars out in the process. Eventually the combined system will settle down, perhaps resembling an elliptical galaxy.

The merger won't affect life on Earth, as our planet will have long since become uninhabitable! As we considered when we were discussing different types of star, in about four billion years from now, the Sun's luminosity will be too high for liquid water to exist on Earth. At that time, the Andromeda galaxy will appear as large in the sky as either of the Magellanic Clouds do today.

See some images of galaxies colliding that have been taken by the Hubble telescope in the next section.

3.2.4 Galaxies gone wild!

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Interacting galaxies are found throughout the Universe, sometimes as dramatic collisions that trigger bursts of star formation, on other occasions as gradual mergers that result in new galaxies.

These images were collected by the Hubble telescope.

3.2.5 The Milky Way

Figure 10

Our Galaxy, the Milky Way, is considered a typical galaxy. It has hundreds of billions of stars, gas and dust to make billions more stars, and dark matter (you'll learn about this later this week).

The Milky Way is shaped like a huge spiral that rotates once every 200 million years. It is so big that light takes 100,000 years to cross from one side to the other. Our Solar System is on one of the arms of the spiral, about half way out from the centre of the Galaxy.

In the next section, you'll learn about galaxies close to ours.

3.2.6 The Local group

Figure 11 The Local Group, includes over 30 galaxies such as our Milky Way, Andromeda, and the Magellanic Clouds

There are billions of galaxies in our Universe. Most of these are clumped together in groups.

Our Galaxy, The Milky Way, lies within a group of galaxies that are called 'The Local Group'. The Local Group consists of about 30 galaxies. The three largest are the Andromeda galaxy, the Milky Way galaxy, and Triangulum. The Local Group is part of the much larger Virgo Supercluster of galaxies.

The Milky Way contains the debris of the many smaller galaxies it has encountered and devoured in the past, and it is currently absorbing the Sagittarius dwarf elliptical galaxy.

Help to discover more about galaxies with the Galaxy Zoo project you'll hear about in the next section.

3.2.7 Galaxy Zoo

Galaxies are categorised according to shape; our Galaxy, the Milky Way, is thought to be a barred spiral galaxy. Get involved with classifying galaxies for yourself.

Galaxy Zoo provides photos of other galaxies and categories to help scientists to classify the galaxies they discover.

Activity 3.3

Visit Galaxy Zoo and classify three or more galaxies.

Did the galaxies you classified fit the suggested categories? Did they pose any specific challenges?

Provide your answer...

In the next section you'll hear about what scientists think holds galaxies together.

3.2.8 Dark matter

What do scientists think holds galaxies together?

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Many spiral galaxies have had their masses estimated from how fast their stars are orbiting. The more mass that a galaxy contains, the faster its stars go in their orbits. This is because the more powerful the tug of gravity, the faster the stars have to move to avoid falling towards the centre.

The trouble is, if you add up all the masses of the stars in a galaxy, plus the mass of gas, it doesn't come close to the mass estimated from the stars' orbits. If stars and gas were all there was in a galaxy, the stars would be flung out of the galaxy, because they are moving so quickly. So what's keeping galaxies together? It must be something non-luminous because it cannot be seen. Astronomers have called this **dark matter**.

Dark matter is needed to explain the motion of galaxies in general and in galaxy clusters in particular. Dark matter is found wherever 'normal' matter, such as the stuff that makes up galaxies (of all shapes), is found. For example, a large galaxy cluster will contain a very great amount of dark matter, which exists within and around the galaxies that make up that cluster.

Dark matter is so named because astronomers don't know what it actually is – we can't see it directly and can only infer its existence by the effect it has on the regular matter that we can see.

We are not able to observe dark matter directly, however the strong gravity can distort the light from galaxies behind the dark matter on its way to us. This distortion is known as 'gravitational lensing' and is a useful way of observing black holes and dark matter. Read more about gravitational lensing from the link below.

Next, we'll look at dark energy.

3.2.9 Dark energy

Dark energy causes the expansion of the Universe to accelerate, but what is dark energy?

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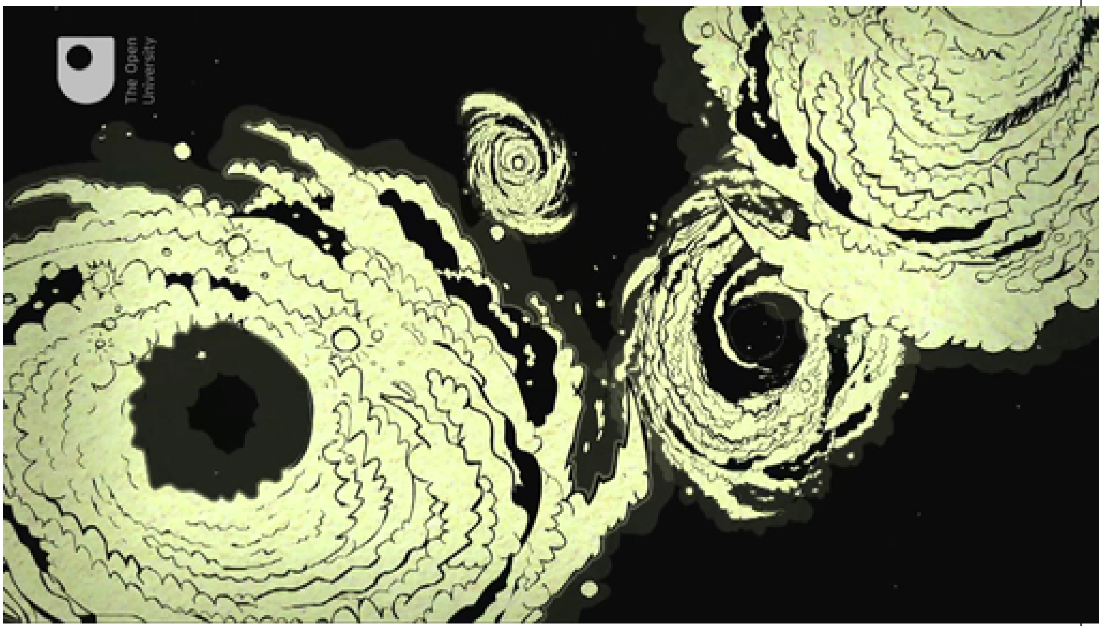

Scientists are looking for dark energy! The Euclid mission aims to observe both dark matter and dark energy in the Universe.

For more information on the Euclid mission and The Open University's involvement with this and other astronomy missions see e2v centre for electronic imaging.

3.3 The electromagnetic spectrum

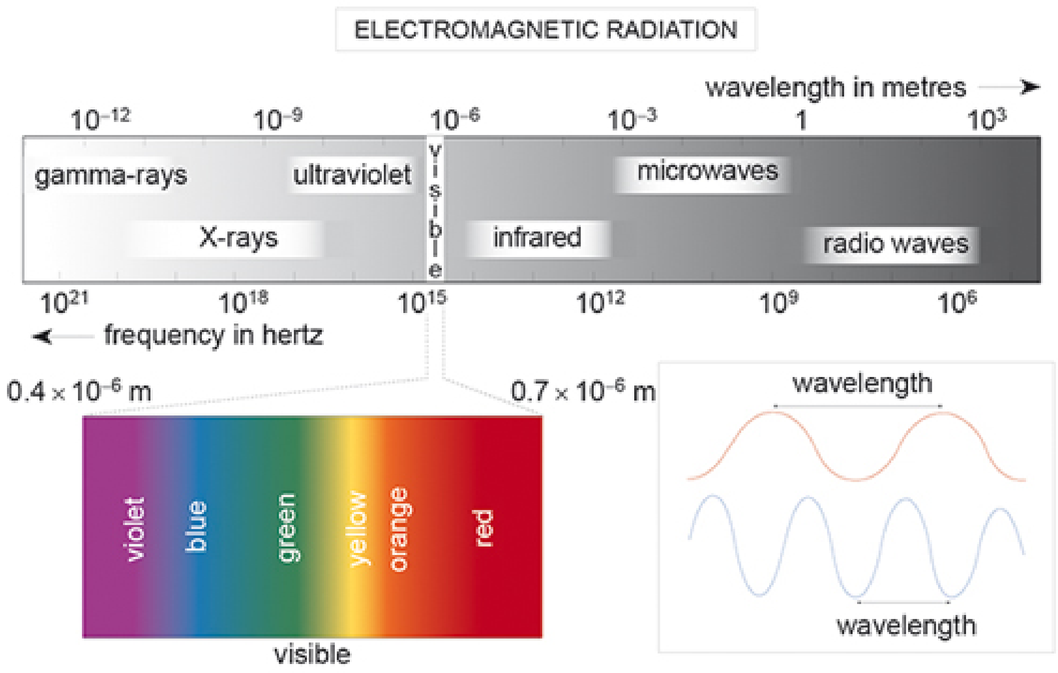

Figure 12 Various kinds of electromagnetic radiation can be distinguished by their wavelength or frequency. In case of visible light, different wavelengths are perceived as different colours but there is no fundamental distinction between the parts of the spectrum

In this section, you will consider different kinds of electromagnetic radiation, and what information comes from the different parts of the spectrum.

Most astronomical observations are made by the detection of **radiation** (often used as an abbreviation for **electromagnetic radiation**). The light we receive from the Sun is actually all the visible colours summed together.

Think of a rainbow. A rainbow is formed when light passing through drops of rain is refracted (or bent) in such a way that the rays of light are spread out according to their **wavelength**. This is called a **spectrum**. The colours of the rainbow are the visible parts of the electromagnetic spectrum – the part of the spectrum to which human eyes are sensitive. These colours are just a tiny part of the electromagnetic spectrum, which includes X-rays, microwaves and radio waves.

One way to describe the different components of the electromagnetic spectrum is in terms of waves. A wave may be defined as a regularly repeating disturbance that transports energy from one place to another. For instance, the regular crashing of an ocean wave on a beach.

The distance between one part of the wave profile and the next identical part of the wave profile is known as the **wavelength** of the wave. Two adjacent crests of the wave are a convenient pair of locations to use for this definition, although any pair of similar points will do. This is shown in the lower right-part of the figure at the start of the section.

How does this change our view of Orion, most particularly the Orion Nebula? In the next section, you will see what the Orion Nebula looks like when radiation from other parts of the electromagnetic spectrum is examined.

3.3.1 Objects at different wavelengths

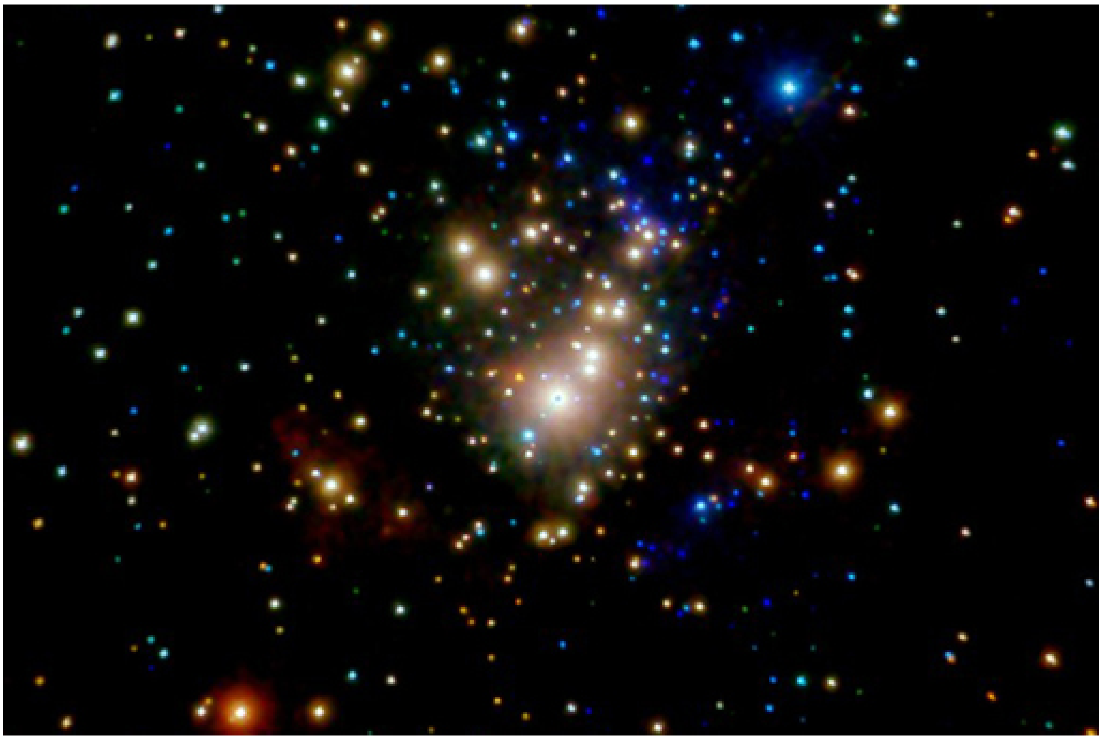

Figure 13 X-Ray sources within the Orion Nebula, as recorded by the Chandra X-Ray Observatory.

The Orion nebula is full of stars – but many of them are hidden from us. This is because their light is prevented from reaching us by dust, which absorbs the light. However, we can see the stars if we look at them at a different wavelength.

What extra information can scientists get by looking at the radiation of different wavelengths that comes from astronomical objects? The answer is simple: objects like planets, stars and galaxies can look very different when observed in different parts of the electromagnetic spectrum.

Figure 13 shows the Orion Nebula – an object that you have seen several times already! But this picture is very different from the one you saw last week. This image, taken by the Chandra Orbiting Observatory, shows radiation from the X-ray part of the spectrum, not the visible part. The very bright stars in the centre of the image are those of the Trapezium Cluster.

Figure 14 and 15 show more images of the Orion Nebula, again with the bright Trapezium cluster in the centre. The first image is taken by NASA's WISE observatory, of the infrared radiation emitted.

Figure 14 Orion Nebula in the infrared wavelength.

Figure 15 Orion Nebula in the visible wavelength.

In all the images, the bright stars of the Trapezium cluster can be located, but each image picks up something different. The X-ray image no longer shows the ‘whispy’ part of the nebula – as there are only isolated sources of X-rays. Clearly, whatever is emitting this high-energy radiation is not directly related to the dust that is visible at other wavelengths.

In the next section, you’ll find out more about where telescopes might be located for their most effective use.

3.3.2 Observing the stars

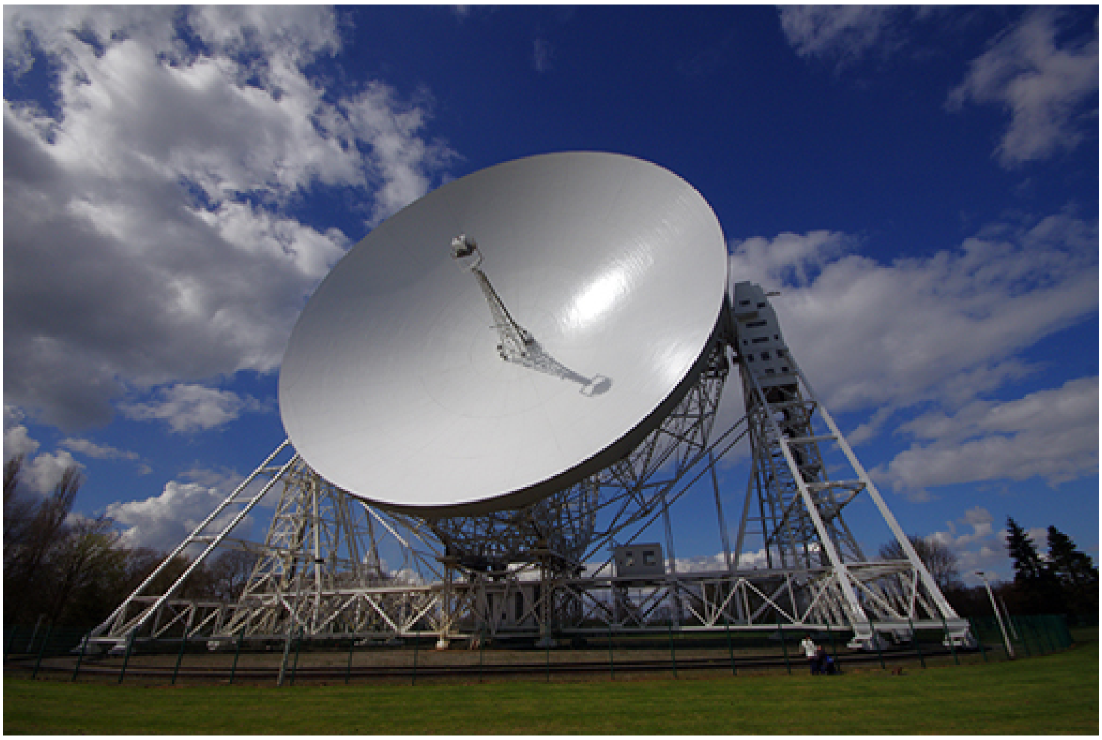

Figure 16 The Lovell Telescope, a radio telescope at Jodrell Bank Observatory in Cheshire, England.

The most common tool used for astronomical observations is a telescope, which is simply a piece of equipment that collects radiation and focuses it on to a detector.

The most well-known telescope in the UK is the Lovell Telescope at Jodrell Bank (shown in Figure 16), with its 76.2 m dish. The dish collects radio waves.

Radiation from stars and galaxies hit the Earth's surface after travelling through the Earth's atmosphere. At some wavelengths (e.g. radio), the Earth's atmosphere is not a problem: the radiation travels through without modification.

At other wavelengths, however, the atmosphere interferes. Just think what it's like when you are outside on a sunny day and a cloud passes across the surface of the sun. It grows a bit darker and the temperature drops. When the sun 'comes out' from behind the cloud, it immediately feels warmer and lighter. This is an example of optical and infrared radiation from the sun being absorbed by the Earth's atmosphere.

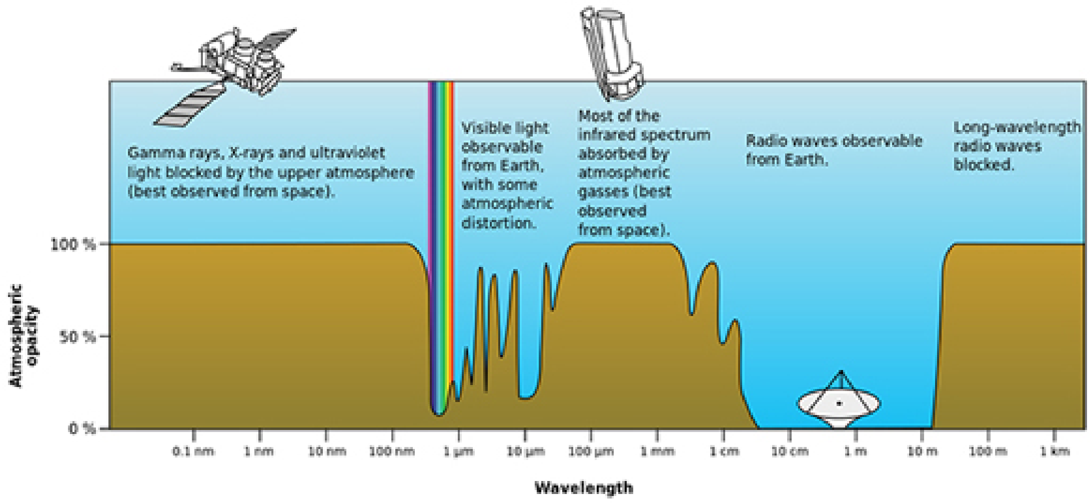

Figure 17 Absorption by the Earth's atmosphere at sea-level of light at different wavelengths.

The diagram in Figure 17 is a schematic illustration of how much radiation at different wavelengths is absorbed by the Earth's atmosphere at sea-level. Very little visible radiation is absorbed, although there may be atmospheric distortion – the effect that causes stars to appear to 'twinkle'. Almost all radiation with shorter wavelengths is blocked by the atmosphere. This is a good thing for us – otherwise we would be fried by the X-rays coming from the Sun!

There is also almost no interference from the atmosphere for radiation with wavelengths of around 1 m – the radio part of the spectrum. This is why radio telescopes can be located almost anywhere on the Earth's surface. The Lovell Telescope is at Jodrell Bank, just outside Manchester, UK, and the Arrow Telescope is at the Open University in Milton Keynes, UK. Neither location is particularly noted for its atmosphere!

Between the visible and the radio, there is a very variable absorption pattern, with some narrow 'windows' where radiation can get through, although most infrared, sub-millimetre and millimetre radiation is blocked.

The thinner and drier the atmosphere, the better the 'seeing' is for a telescope that is collecting optical and infrared radiation. Therefore, many telescopes that operate at these wavelengths are positioned on mountain tops.

Figure 18 The four units of the VLT at Paranal in Chile.

The Very Large Telescope (VLT) of the European Southern Observatory (pictured) is sited at Paranal in Chile, at an altitude of over 2600m, one of the world's driest environments.

3.3.3 Telescopes in space

Figure 19 The Hubble Space Telescope being released from the bay of the Space Shuttle

in 1990.

One option, which circumvents any issues from atmospheric distortion, cloud cover or humidity and interference from city lights, is to position your telescope in space.

The disadvantages of space telescopes are their cost – which means that only relatively small instruments can be launched.

The short wavelength Gamma and X-ray radiations are blocked by the upper atmosphere, therefore objects emitting this radiation are best observed from space. Very highly-energetic objects, such as black holes, gamma ray bursts and supernovae have been recorded by ESA's Integral Gamma Ray observatory and NASA's Chandra X-Ray observatory.

Ultraviolet radiation (UV) is measured from the interstellar medium and from molecular clouds, as a record of the chemical composition of the gas, dust and ice which reside there. Instruments on the Hubble Space Telescope and the GALEX observatory have made notable contributions to UV astronomy.

Because most of the infrared radiation (IR) and sub-millimetre radiation coming from space is absorbed by the atmosphere, it is more effective to observe objects emitting this wavelength radiation in space. The Spitzer space telescope and Herschel space telescope have been recent successes for NASA and ESA in this field.

Some of the most significant observations made by instruments on these telescopes are of the distribution of dust in molecular clouds, and of dust around newly-forming stars.

3.3.4 Behind the scenes with Monica Grady

In the following video, Monica Grady explains some of her research with meteorites and comets, and why they are significant in finding out how the universe came into being.

She explains how the remote telescope PIRATE, The Open University's robotic telescope in Majorca, Spain, works and demonstrates how to use it.

Video content is not available in this format.

In the next section, you'll have the opportunity to check your learning in the Week 3 quiz.

3.4 Week 3 quiz

Check what you've learned this week by taking the Week 3 quiz.

Open the quiz in a new window or tab then come back here when you're done.

Summary of Week 3

Figure 20 VLBI (Very-long-baseline interferometry) telescopes against the night sky at the European Southern Observatory.

This week started with a bang – a big one!

Studying the Universe has revealed so much about how it formed and about our Solar System, but there is still a lot we don't know! Dark matter is a good example – scientists still don't know what it is, as only the effects it has on other objects can be observed.

This week you have made your own contribution to the scientific knowledge of the Universe, through classifying galaxies in the Galaxy Zoo project. The many images of galaxies included in the study have been identified by a variety of telescopes, both on the ground and in space, and the results of the study have been used to investigate these galaxies further.

Knowing about other galaxies leads to curiosity about whether any of them might host planetary systems. In Week 4, you'll find out what it is that makes the Solar System special, how planets and comets form around stars and about the search for a planet like ours. The big question, then, will be, could life exist on another planet…?

Week 4: Our place in the Universe

Introduction

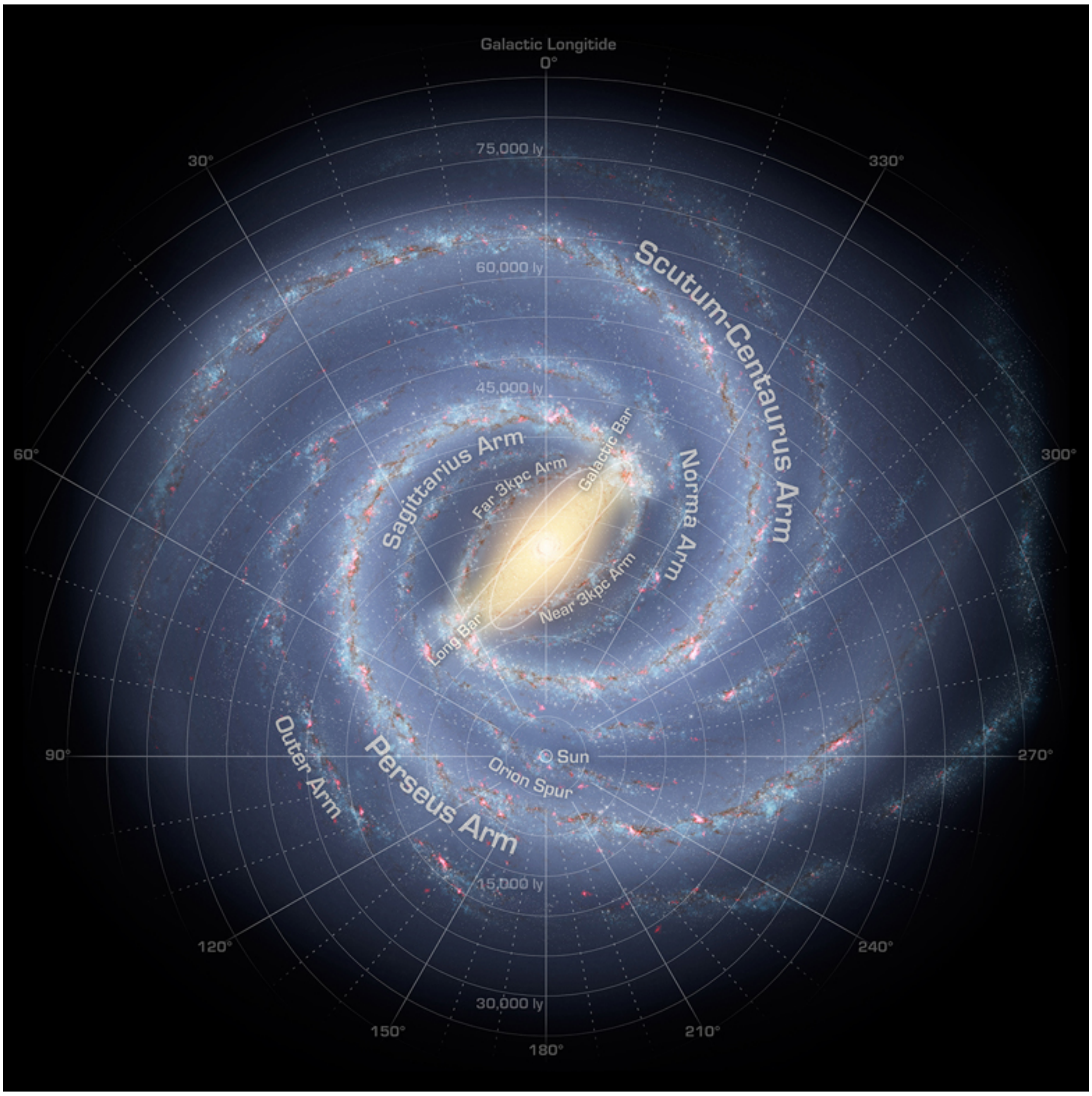

Figure 1 The Milky Way with the position of the Sun marked on it

So far in the course, you have learned about Orion and the different types of stars and galaxies that make up our Universe.

In the final week, you will consider how planets and planetary systems formed and find out about our place in the Universe.

First up, you'll find out what is meant by the 'habitable zone'.

4.1 Habitable zone

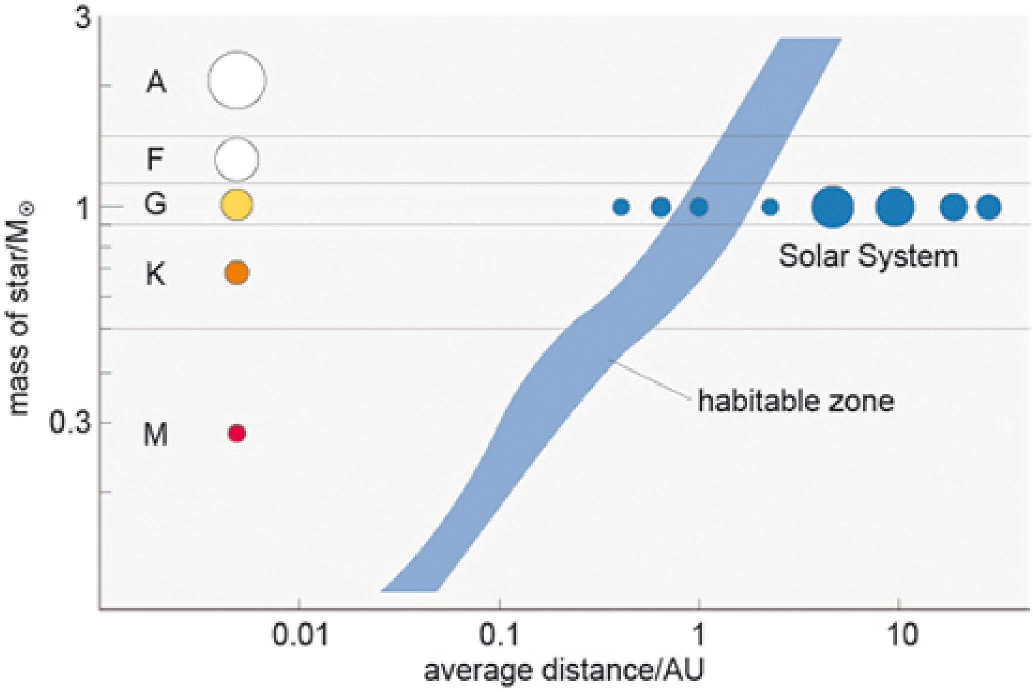

Figure 2 The location of habitable zones around different stars.

Is where we are (half way along a spiral arm in an undistinguished galaxy) particularly special? Has the origin of life on Earth been enabled because of the type of star our planet orbits, and where that star sits within the Galaxy?

This brings us to the concept of a **habitable zone**. This is a region within a planetary, stellar or galactic system where conditions are sufficiently suitable and stable to allow life to arise. A habitable zone is often taken to mean a place where liquid water can exist.

The blue band in the image above is the region within a planetary system where water would be liquid on the planet's surface. The position of this region is a trade-off between the size (or temperature) of the star and the distance a planet is away from the star.

So a planet orbiting a star hotter than the Sun would have to be further away from its star than the Earth is from the Sun in order for water to be liquid. As you can see from the diagram above, Jupiter would be just outside the habitable zone of an A-type star (such as Sirius), while Mars would be well inside the habitable zone. Similarly, a planet orbiting a star cooler than the Sun would have to be closer in than the Earth is to the Sun.

In the next section, you will find out what makes the Sun the 'right type of star' to allow life to have arisen on at least one of the planets in orbit around it.

4.1.1 The right type of star

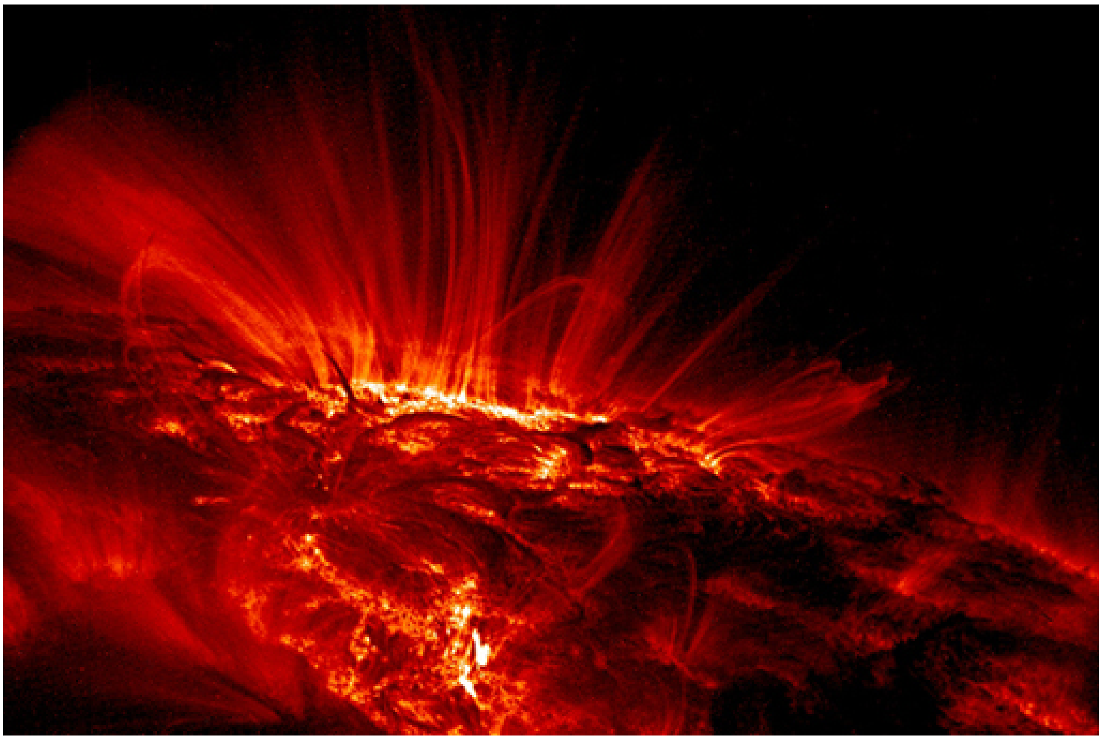

Figure 3 The Sun from the TRACE spacecraft

Is the Sun the right sort of star for life? Is there anything that sets our star apart from other stars?

You have already considered the type of star our Sun is: a hydrogen-burning main sequence star of spectral class G2, around 4.56 billion years old. The Sun is not particularly special – but it does have a system of planets orbiting it.

Possession of a planetary system implies the presence of dust, which comes from recycling of stellar nucleosynthetic products. Remember back in Week 2, you learned that some stars go through a progression through the elements, burning hydrogen to helium and eventually to carbon, oxygen, silicon, magnesium and iron. Without at least one generation of stellar cycling to produce these elements, no planets could form. The lifecycle of a star, and the production of different elements was considered in The life of a star.

Figure 4 Image of globular star clusters; on the right lies the globular star cluster UKS 1 and on the left lies a much less conspicuous new discovery, VVV CL001 — a previously unknown globular, which appears as a faint grouping of stars about 25% of the width of the image from the left edge.

Do other types of star have the potential to host a planetary system containing a planet on which liquid water is stable, upon which life might arise?

Not all stellar types are likely to evolve to allow development of planetary systems. Star systems made up of the very oldest stars, such as **globular clusters**, as shown above, have very low abundances of elements other than hydrogen (H) and helium (He), and so are unlikely to produce rocky planets.

So, for a star to have a planetary system, the star must be sufficiently old for the dust and gas from which it formed to contain material from earlier generations of stars that have produced the different elements. But is this sufficient?

In the next section, you will see what other types of star have histories which would not allow planets with life to form.

4.1.2 Lifetime of a star

Figure 5 Composite image of supernova remnant W49B.

It is not sufficient that a planet is in the habitable zone of a star. As you've just heard, the star must be the right type of star!

For planets to form (and life to arise), a star must have a reasonably long lifetime during which stable conditions exist. Highly energetic stars that have sudden outbursts of radiation, or extremely rapid spin are not stable. For any of these types of star, the environment (temperature, radiation, etc.) changes too rapidly to allow life to develop.

Stars liable to become supernovae, such as giant stars reaching the end of their lifetimes or rapidly rotating stars like pulsars are also unsuitable – as the environment disappears altogether in the explosive outburst in the case of a supernova.

Figure 6 Blue-white giant, Rigel, and the Witch Head Nebula.

Massive stars like Rigel, above, have a shorter lifetime than the Sun (10 million years rather than 10 billion years). They are also hotter and emit much more ultraviolet (UV) radiation. A higher UV flux can lead to the destruction of an atmosphere. This means that the UV radiation can reach the planet's surface. The effect of this radiation would be to destroy any organic molecules (i.e. including anything that might be living). Massive stars are therefore unlikely to be hosts for life-bearing planetary systems.

Figure 7 Artist's concept of a record-setting flare from a small star known as EV Lacertae.

Stars less massive than the Sun are cooler, emitting less heat. So for a planet to be warm enough for life, it would have to orbit close in to the star, resulting in problems from higher radiation.

Next, find out what makes our Galaxy the right type of galaxy.

4.1.3 The right type of galaxy

Figure 8 The Antennae Galaxies (also known as NGC 4038 and 4039). This is a composite view, combining ALMA observations, made in two different wavelength ranges, with visible-light observations from the NASA/ESA Hubble Space Telescope.

So, if our star is the right sort of star, what makes the Milky Way the right sort of galaxy for life to get going?

As we saw earlier, galaxies are vast accumulations of stars which evolve and change with time: they collide and merge with each other, cannibalising dust and gas from their companions in the process. The same sort of arguments that applied to stars also applies to galaxies: they must be old enough (but not too old), stable and dusty.

Figure 9 The spiral galaxy Messier 81. Located in the northern constellation of Ursa Major, this galaxy is easily visible through binoculars or a small telescope.

The necessity for elements heavier than hydrogen (H) and helium (He) for dust formation, leads to the conclusion that the dust-poor elliptical galaxies will be poor in the rock-forming elements necessary for planet building, and so are less likely to provide an environment in which life might develop. Spiral galaxies (like the Milky Way) have abundant dust mixed in with the gas, and so have the potential for planet formation.

Location

The location of a star within a galaxy is also important, because stars are not distributed evenly within a galaxy. The density of stars increases towards the centre of a spiral galaxy, leading to decreased distances between stars, and an increasing number of neighbours per star.

Shorter distances between stars implies that mutual stellar attractions will be increased, resulting in higher gravitational instabilities for interacting stars. The higher stellar density implies that there will be a higher rate of stars becoming supernovae, with accompanying explosions of energy.

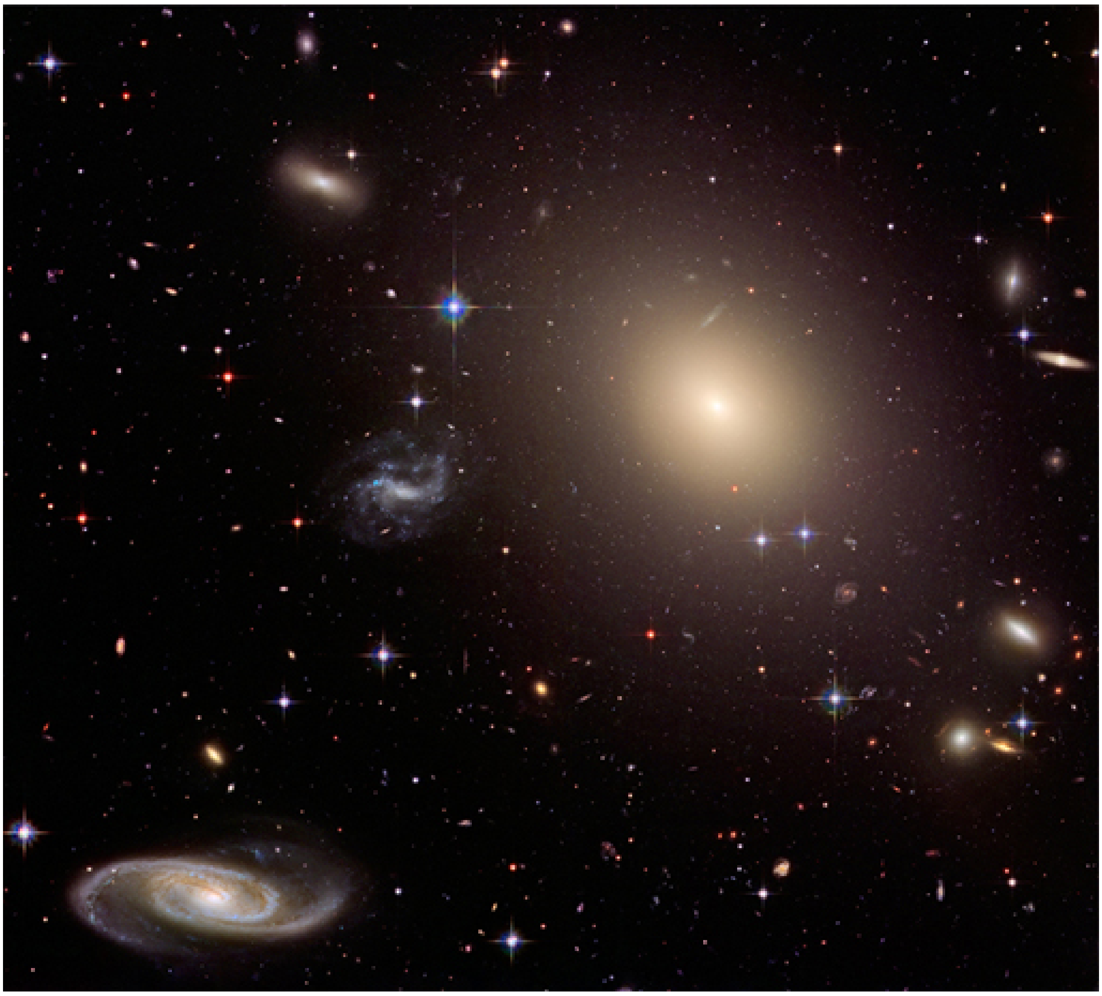

Figure 10 Galaxy cluster Abell S0740, a group of galaxies that is about 450 million light-years from planet Earth.

Clusters of galaxies will also be regions of high activity: interaction between stars, turbulence, high radiation flux, frequent supernovae, etc., just as for regions of high stellar density within the Milky Way. Galaxies were clustered more closely together at an earlier epoch within the history of the Universe, and consisted of less-evolved stars. Galactic evolution, as well as stellar evolution, must also have played an important role leading up to the formation of life.

In the next section, you will explore what makes the Sun's position in the Milky Way just right.

4.1.4 Where we are

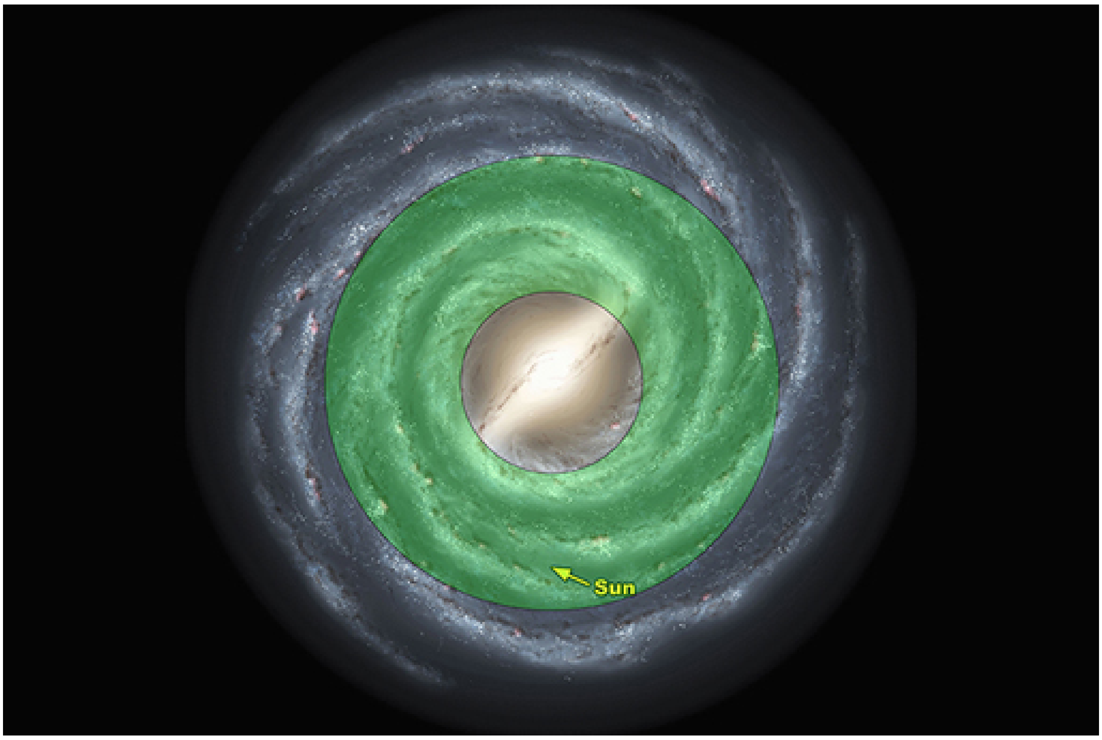

Figure 11 The galactic habitable zone of the Milky Way

Look at Figure 11. It shows that the Sun is in the habitable zone of the Milky Way.

It is far out enough to be relatively isolated from its nearest neighbours and in less danger from the effects of potential supernovae, but sufficiently close in from the outer fringes, where unknown quantities of dark matter lurk.

The search for habitable planetary systems around stars, then, should be directed towards looking for Earth-like planets (ELP) orbiting Sun-type stars at distances considered to be within the habitable zone of the observed star located within the habitable zone of its galaxy.

Next, you will take your photo of Orion for this week.

4.1.5 Photographing Orion

Figure 12 Orion in the night sky

Before we go on to consider the Solar System in greater detail, have you taken your weekly photograph of Orion yet?

Activity 4.1

If possible take a picture at the same time from the same spot each week. Remember to include your marker point (chimney pot, tree branch, etc.) in the image, so that they can be compared from week to week. Fingers crossed that it is clear and not cloudy wherever you are!

Don't forget that you can consult Monica's advice on taking photos of Orion Monica's advice on taking photos of Orion.

Once you have taken the picture, compare it to the others you have taken during the course. Did you notice that Orion had moved from your image last week? Compare it to the first image you took. Has Orion moved since then?

If you've enjoyed photographing Orion, you could continue, maybe monthly, to see how Orion moves in the sky over the course of the year.

4.2 Protoplanetary discs

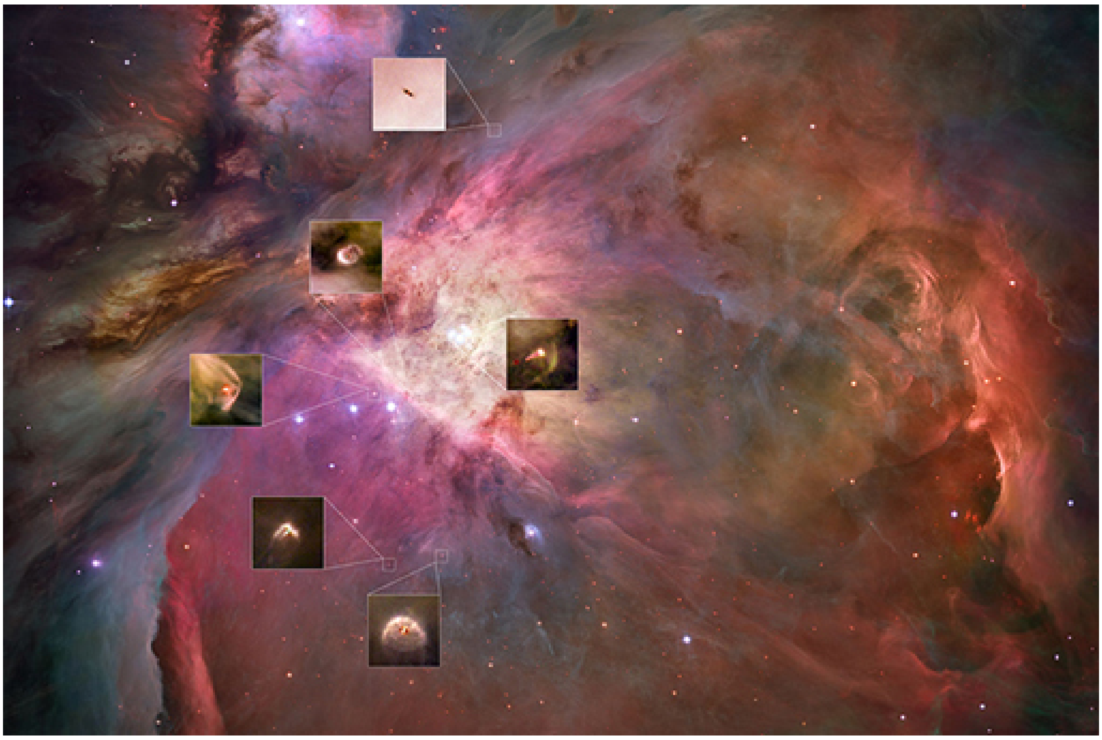

Figure 13 A small selection of the many protoplanetary discs in the Orion Nebula.

In your journey through the course, you have seen many images of the Orion constellation, and of the Orion Nebula, which occurs towards the tip of Orion's sword.

Images of the Orion Nebula, taken by the Hubble Space Telescope, show that it is a region where new stars are forming. Many hundreds of stars are being created; many of them seem to be surrounded by discs of dust which might become planetary systems.

Figure 13 is a small selection of the protoplanetary discs in the Orion Nebula. The images were taken by the Hubble Space Telescope.

Next, you'll find out how protoplanetary disc form.

4.2.1 Protoplanetary disc formation

The following animation shows the process of proplyds forming within a nebula.

Note: this video has no sound.

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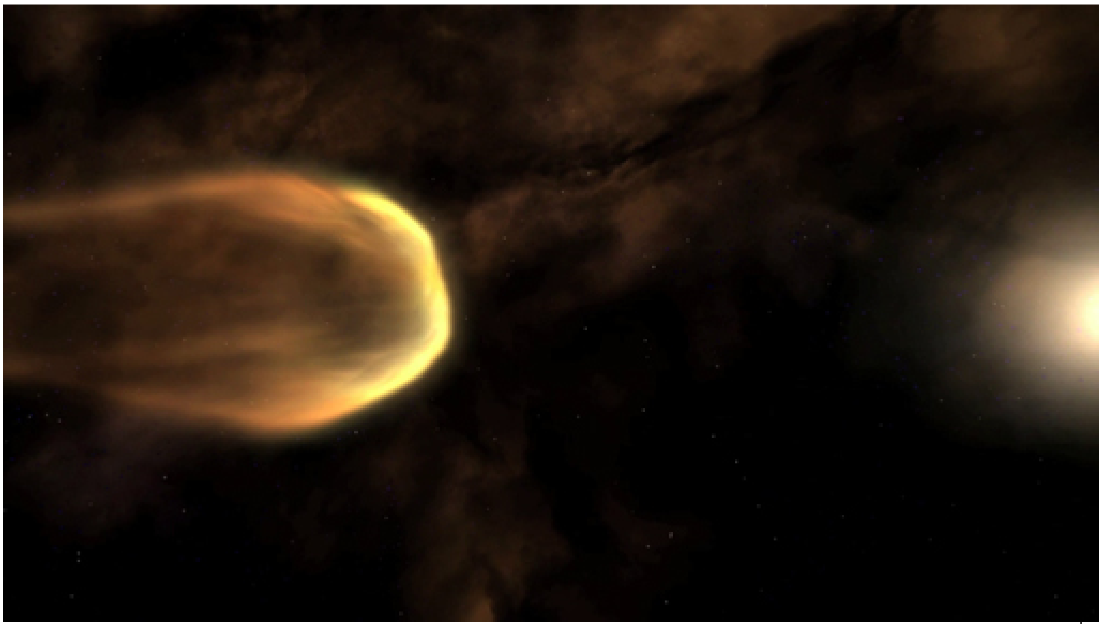

The proplyds, visible as small bright points, are illuminated by the star Theta 1 Orionis C, which is the most massive of the four stars in the Trapezium cluster in the Orion Nebula. The illumination, which heats up the disc material as well as lighting the proplyds, is also a threat, as the hot disc material will dissipate before planets can form.

The hypothesis that stars and planets form in a nebula suggests that our Sun and Solar System formed from a rotating, flattened disc. This idea was first proposed by the Prussian philosopher and astronomer Immanuel Kant in 1755, and further developed by Pierre Simon Laplace in 1796. It remains the most widely accepted theory of planet formation to this day.

In the next section, you will see what happens when part of a nebula collapses.

4.2.2 Collapse of a nebula

In the video, a fraction of the nebula collapses under gravity to produce a rotating disc of gas and dust.

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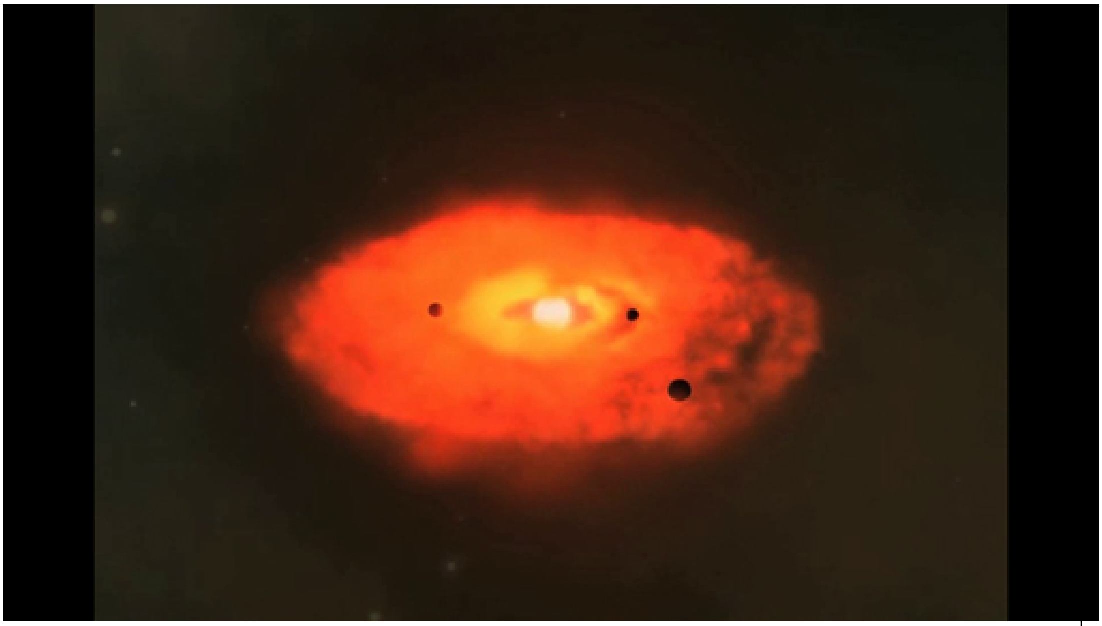

Parts of the disc clump together to form bodies which eventually become planets. The central region of the disc is the hottest area, and eventually emerges as a star.

Most very young stars – less than about 10 million years old – have these discs of dust and gas around them. The discs are seen less and less around older stars, suggesting that, over time, they dissipate or form planets. Around 15% of nearby stars have discs around them. These discs have proportionally high amounts of dust, and low amounts of gas. The dust is a mix of ice, silicates and carbonaceous (containing carbon) material and the gas is mostly hydrogen and helium.

The dust grains are initially less than a thousandth of a millimetre across. Aided by heating events that allow the dust to melt and stick together, the dust coagulates. Eventually, metre to kilometre-sized boulders, called **planetesimals**, form.

Next, you will find out more about planetesimals.

4.2.3 Planetesimals

Once the planetesimals reach a certain size – greater than a kilometre or so – they begin to have a significant gravitational field.

This makes their growth much easier and quicker, as other planetesimals are attracted to them and their growth progresses by impacts of these relatively large bodies.

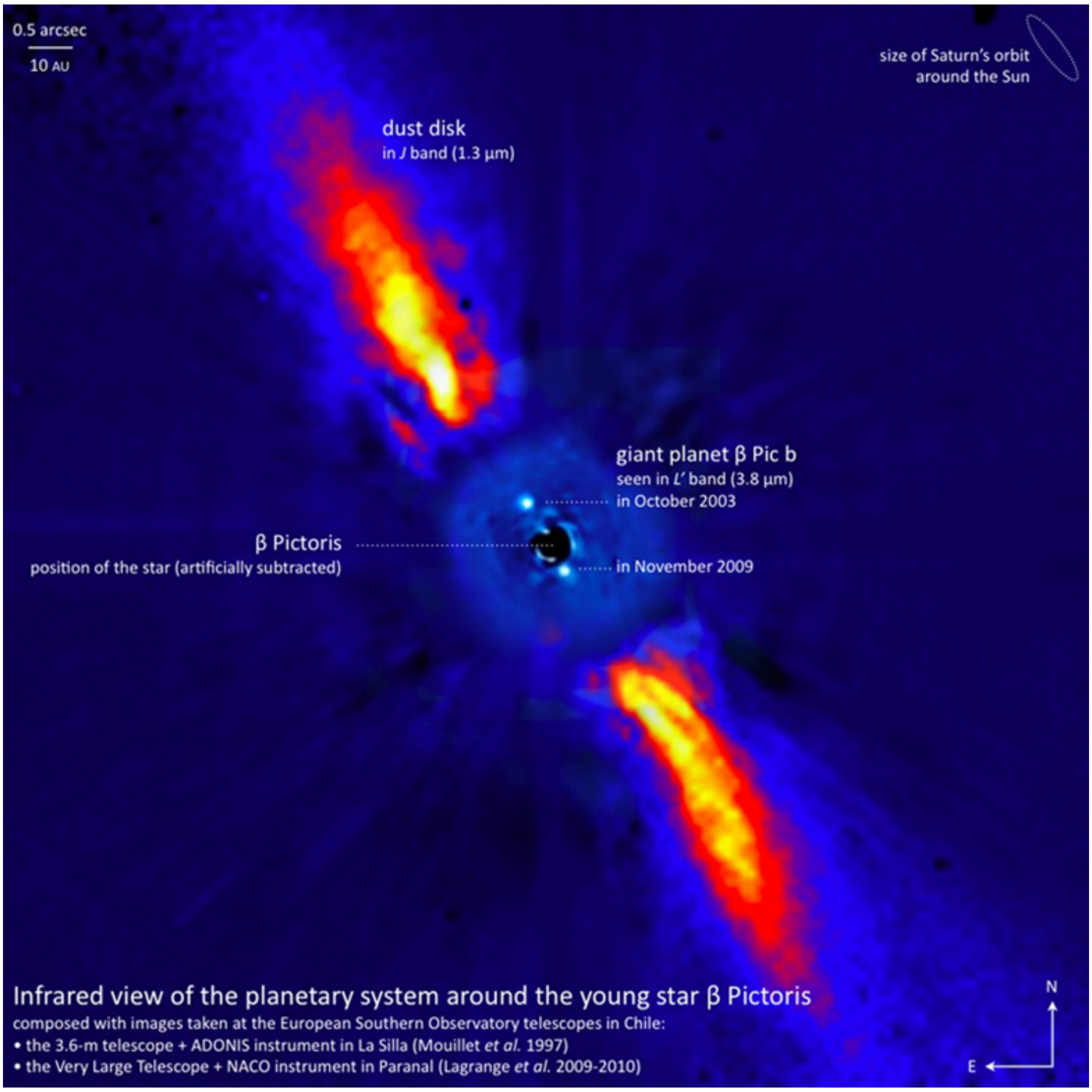

Figure 14 The star Beta Pictoris

One of the best known examples of a star surrounded by a disc is Beta Pictoris, as shown in Figure 14. The bright colours represent the disc, which you are viewing as if it was edge-on. In the centre, the star has been blanked out, so that additional detail can be seen. The central part of the disc appears to be empty, apart from a two bright spots. These are two separate observations of a single giant planet around Beta Pictoris, taken at different times. The rest of the central part of the disc appears to be empty. In the top right hand corner of the image, you can see an ellipse which is the size of the orbit of Saturn drawn on the same scale.

If you looked at the Solar System from a neighbouring star, it would appear to be a star surrounded by empty space – the planets would not be distinguishable. What would be seen, though, is a ring of dust out beyond Neptune. This is the **Kuiper Belt**, and you will learn more about it, and the other small bodies in the Solar System in the following sections.

4.2.4 The Solar System

The next animation simulates a flight through the Solar System.

Note: this video has no sound.

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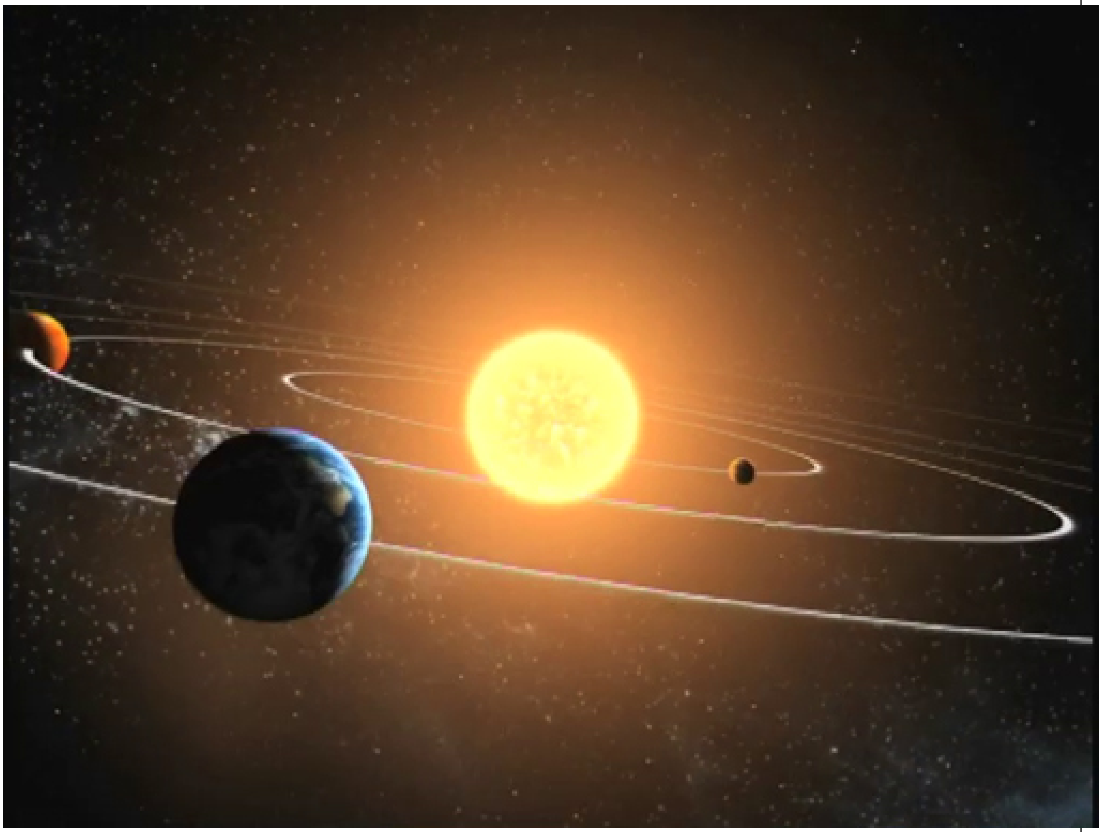

In Week 2, you heard about stars, and learned that the Sun is a main sequence star, undergoing hydrogen burning. It most probably formed in a nebula very similar to that of the Orion Nebula, first with a protoplanetary disc which eventually developed into the Solar System.

The outermost planets of the Solar System, labelled in the image below, are Neptune and Uranus, formed of ice and gas. Coming inwards towards the Sun are the gas giants, Saturn and Jupiter, and then the four rocky planets, Mars, Earth, Venus and, closest of all to the Sun, Mercury.

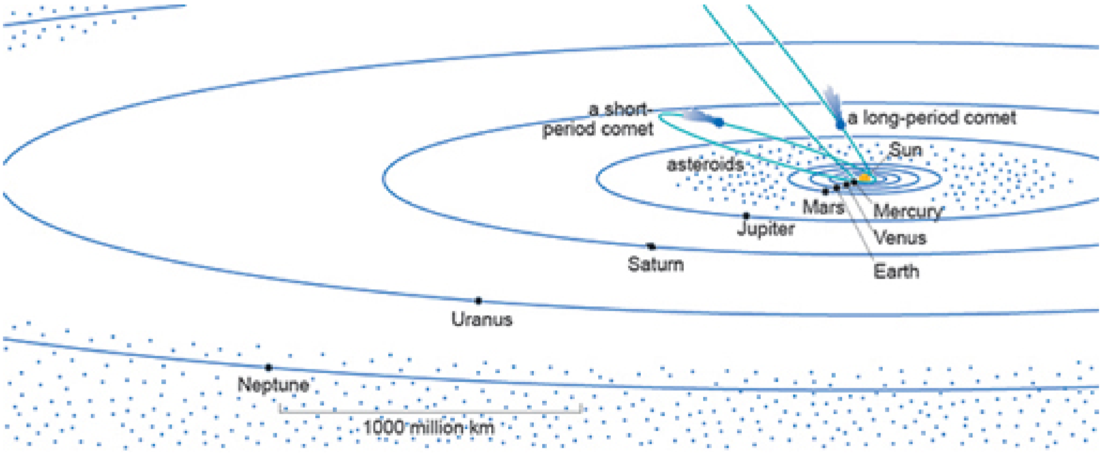

Figure 15 The Solar System

You may be familiar with pictures of Saturn, with its beautiful system of rings, and the stripy appearance of Jupiter. Recent missions to Mars have returned very detailed images of its rocky surface, while pictures of the Earth's surface are regularly featured by the media. The planets are the most significant of the objects that orbit the Sun, but are by no means the only occupants of the Solar System.

There are many hundreds of thousands of asteroids and comets which orbit the Sun. Comets are bodies of ice, silicates and organics which develop a long dust tail as they approach the Sun – you will hear more about them shortly, but first you will learn about their less flamboyant cousins, asteroids.

4.2.5 The asteroid belt

Figure 16 Artist's concept of a view from the asteroid belt looking towards the Sun.

Marking the boundary between the innermost rocky planets (Mercury, Venus, Earth and Mars) and the outer planets is a belt of rocky and metallic bodies, known as the asteroid belt.

The asteroids, also called minor planets, are not a planet that has been broken up; rather, they are the building blocks of a planet that was never assembled. The reason that the building blocks never clumped together was that Jupiter's gravitational attraction kept pulling them apart.

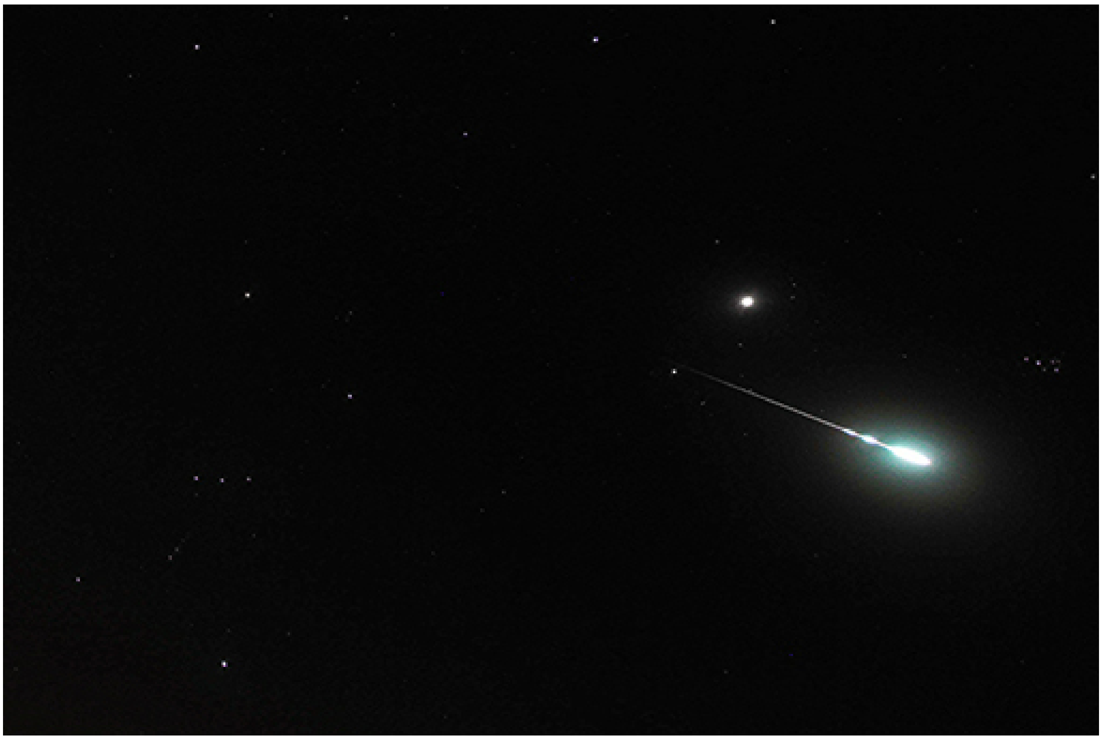

Figure 17 A meteor from the Geminid shower passing by the Taurus constellation with Orion also visible to left of the photo

The asteroids are in stable orbits around the Sun, but they do occasionally collide with each other. Fragments of broken asteroids can leave the asteroid belt, and fall towards the Sun. Asteroid fragments which land on Earth are meteorites. More often than not, a meteorite falls unnoticed – but sometimes they make a dramatic entry through the Earth's atmosphere, as was seen with the Chelyabinsk meteorite that landed in Russia in February 2013. You can read how the BBC reported the event in the article 'Meteor strike injures hundreds in central Russia'.

The final objects in the Solar System that you will encounter are comets – read on to find out about these spectacular visitors.

4.2.6 Comets

Figure 18 Halley's comet. Image taken at the Kitt Peak National Observatory near Tucson, Ariz. on 7 May 2004.

Comets are clumps of dust and organic material bound together by ice, with an irregular shape and up to a few kilometres across.

Figure 19 The irregular shape of Halley's comet. The 'potato shaped' nucleus of the comet measures roughly 15 kilometers across.

When the European Space Agency's Giotto mission photographed Halley's comet in 1985, it was the first time that the irregular shape of a cometary nucleus had been observed.

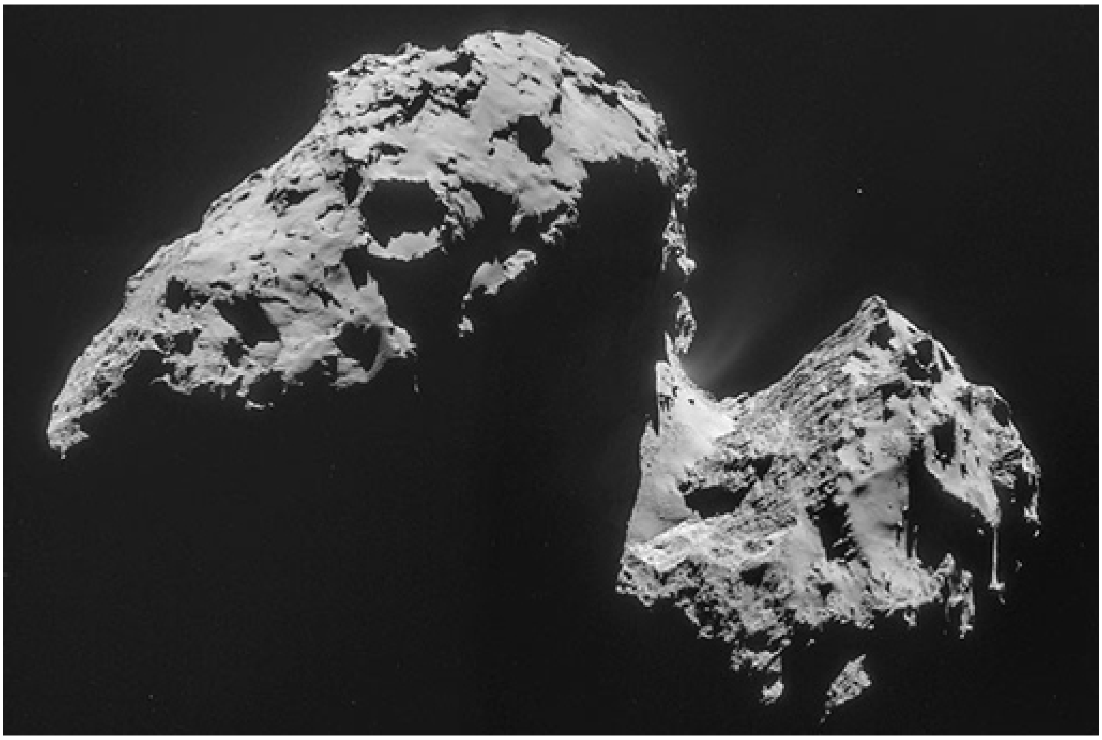

Figure 20 Comet 67P/Churyumov-Gerasimenko.

In March 2004, the European Space Agency (ESA) launched the Rosetta spacecraft, with the goal of meeting up with comet Churyumov-Gerasimenko (named after its discoverers) in July 2014, flying alongside it for 18 months. This included dropping a lander (Philae) onto the comet's surface which happened in November 2014.

Find out more about the Philae lander in the next section.

4.2.7 Philae lander

Figure 21 Artist's concept of Rosetta and the Philae lander on comet Churyumov-Gerasimenko.

A team from The Open University was involved in building instruments for the Philae lander and were very excited when it landed in November 2014.

Unfortunately, however, Philae didn't land smoothly, and came to rest below an overhanging cliff, preventing sunlight from reaching its solar panels. Nevertheless, the instruments on board managed to achieve many of their goals and collected a huge quantity of data before the main battery died. In the first few months of 2015, the mission engineers had hoped that the strengthening sunlight as the comet moved closer to the Sun would provide enough power to the solar panels to recharge the batteries and wake Philae up.

In June 2015, a brief contact was re-established with Philae, but since July 2015, no new communications have been possible. Mission controllers are still trying to communicate with the lander, but even if that proves not to be possible, the mission was still a great success so watch out for plenty of science results being announced over the coming months and years.

If you want to find out more about the OU's involvement with the Rosetta mission, then check out Rosetta in the UK.

Activity 4.2

Exactly how hard do you think it is to land on a comet? Play the BBC's Rosetta mission: Can you land on a comet? game.

If you want to find out more about the OU's involvement with the Rosetta mission, then check out Rosetta in the UK.

4.2.8 A comet's tail

Figure 22 Comet Hale-Bopp seen over Joshua Tree National Park in California.

A comet actually has two tails, one of dust and the other of plasma (charged particles). The tails point away from the Sun, as the particles are pushed away by the solar wind.

The dust tail can extend for millions of kilometres away from the nucleus; the accompanying plasma tail is usually more than ten times longer. The curved dust tail is made of particles shed from the cometary nucleus. Sunlight reflected off the dust gives the tail a yellowish colour. The grains are less than one micron across, and are mainly made from carbon-rich compounds layered on top of silicates.

In contrast, the bluer plasma tail is made up of ions and electrons. It is a long, straight tail, the structure of which is controlled by magnetic fields within the tail and the interaction of these fields with the solar wind magnetic field.

A comet can lose up to 1% of its mass each time it passes close to the Sun – in the case of Halley's comet, that was around 100 tonnes per second.

4.2.9 Where do comets come from?

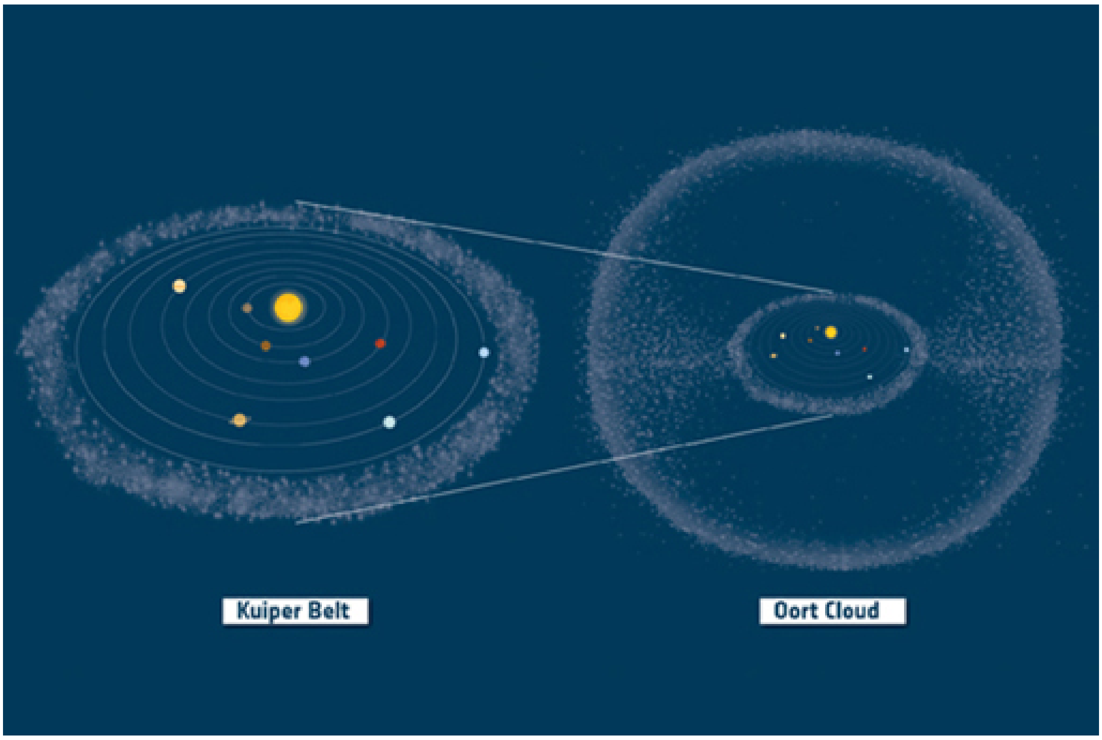

Figure 23 The Kuiper Belt, and the Oort Cloud.

There are two types of comet: long-period and short-period. Long-period comets approach the Sun from random directions.

Their elliptical orbits around the Sun can be very steeply inclined to the ecliptic plane, and take more than 200 years to complete. For example, the comet Hale-Bopp, which last appeared in 1997, has an orbital period of about 3000 years. Long-period comets seem to come from the outermost fringes of the Solar System, at least around 50,000 astronomical units away. This region is known as the **Oort Cloud**.

Short-period comets approach the Sun at fairly shallow angles and have much shorter orbits. For example, Halley's comet, which was closest to the Sun in 1985, orbits once every 76 years, so will return to the inner Solar System in 2061. Churyumov-Gerasimenko, the comet studied by the Rosetta mission, has an orbital period of about 6.5 years. Short-period comets were once thought to be long-period comets that had been affected by Jupiter's gravitational pull and moved into different orbits. Now, however, it is recognised that short-period comets come from the Kuiper Belt, the region of the Solar System out beyond Neptune.

Another noted Kuiper Belt object is Pluto. For many years regarded as a planet but now regarded simply as one of the hundreds of thousands of rocky and icy bodies which form the Kuiper Belt.

In the next section you'll leave the Solar System, to discover exoplanets – planetary systems around stars beyond our own.

4.3 What is an exoplanet?

An **exoplanet** is a planet that orbits a star other than the Sun. These planets could be similar to any of those in our Solar System including Earth.

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Find out more about exoplanets in the next section.

4.3.1 Exoplanet encyclopedia

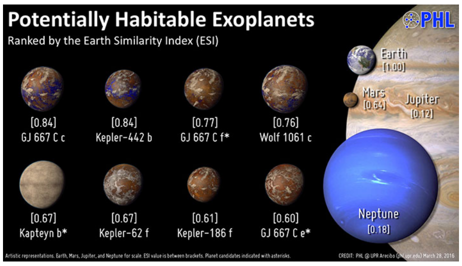

Figure 24 This chart shows artistic representations of all the known potentially habitable exoplanets ranked from best to worst by the Earth Similarity Index.

The Exoplanets Encyclopedia, run by the European exoplanet team, keeps an up-to-date list of how many exoplanets have been discovered – it now stands at more than 2000, including several systems where more than one exoplanet orbits its star.

Exoplanets are difficult to observe, partly because planets are very small compared with stars and partly because they don't give out light of their own – planets 'shine' by reflecting light from the star they orbit. And this is the main reason why it is difficult to detect exoplanets – they are incredibly faint compared to a star. So how do you detect a faint planet-sized object orbiting a star many light years away?

The first exoplanet orbiting a main sequence star was observed in 1995. It has a mass much greater than that of the Earth – it is about half the mass of Jupiter – but orbits its star, 51 Pegasi, at a closer distance than Mercury orbits the Sun. For many years, the only exoplanets to be discovered were similar to this.

These **hot Jupiters** are gas giants that orbit very close to their stars and thus have a very high surface temperature. Hot Jupiters were, until the advent of spaceborne telescopes, the most common form of extrasolar planet known, because of the relative ease of detecting them from ground-based instruments.

In the next section, you will learn about the methods used to detect exoplanets.

4.3.2 Planet hunting – identification and observing techniques

As exoplanets are generally too small to be observed directly, the star they are orbiting is observed instead. Very small changes to the star can be seen as an effect of the orbiting planet.

There are two main methods that can detect small changes to a star which are caused by an orbiting planet. These are the **radial velocity** and **transit** methods.

Radial velocity method

The radial velocity method measures the very slight wobble of a star which results from the gravitational pull of the orbiting planet. These wobbles cause a slight change in the observed light which can be measured. This was the first method that successfully identified an exoplanet.

Transit method

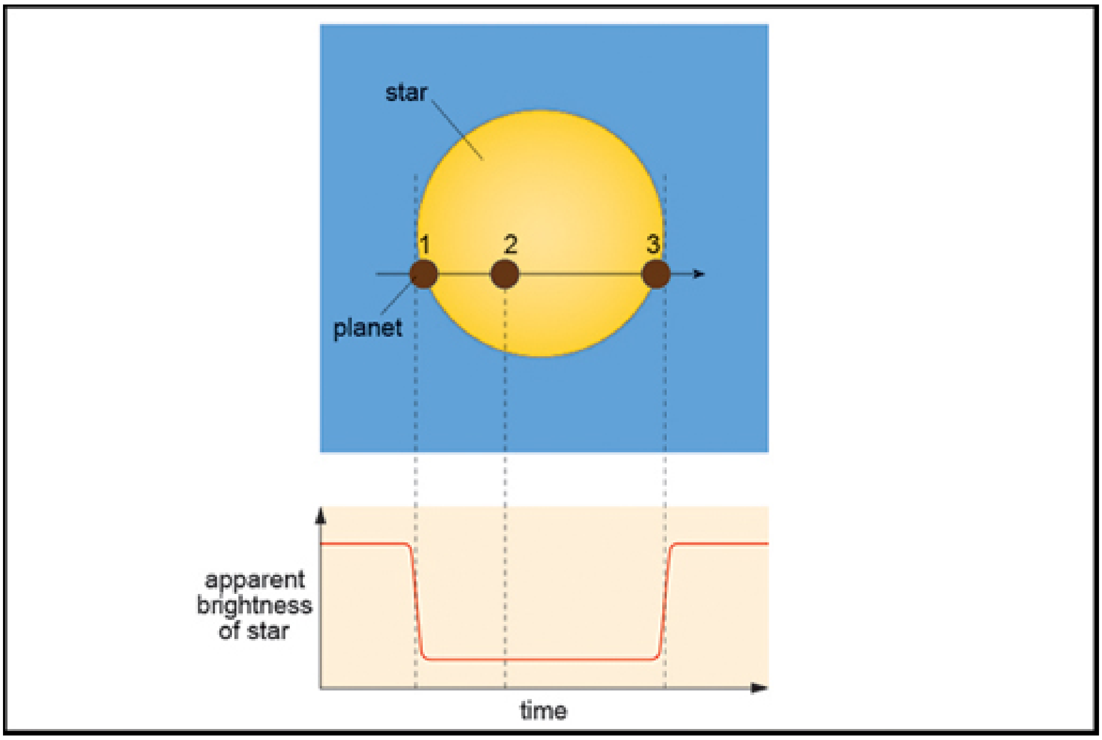

Figure 25 A planetary transit.

The transit method measures very small changes in brightness of the star as a result of the planet passing in front of the star (known as a **transit**) and blocking out a small amount of light when viewed from Earth. If this slight dimming in brightness is detected at regular intervals, it is likely that a planet is orbiting around the star.

The dimming of a star during transit directly reflects the size ratio between the star and the planet. A small planet transiting a large star will create only a slight dimming, while a large planet transiting a small star will have a more noticeable effect. For example, a Jupiter-sized planet passing in front of a Sun-sized star would cause a 1% dip in light from the star. The transit method only works when the planet passes directly in front of the star.

In the next section, you will hear about the red dwarf star Gliese 581 and find out for yourself about the planets orbiting it.

4.3.3 Gliese 581

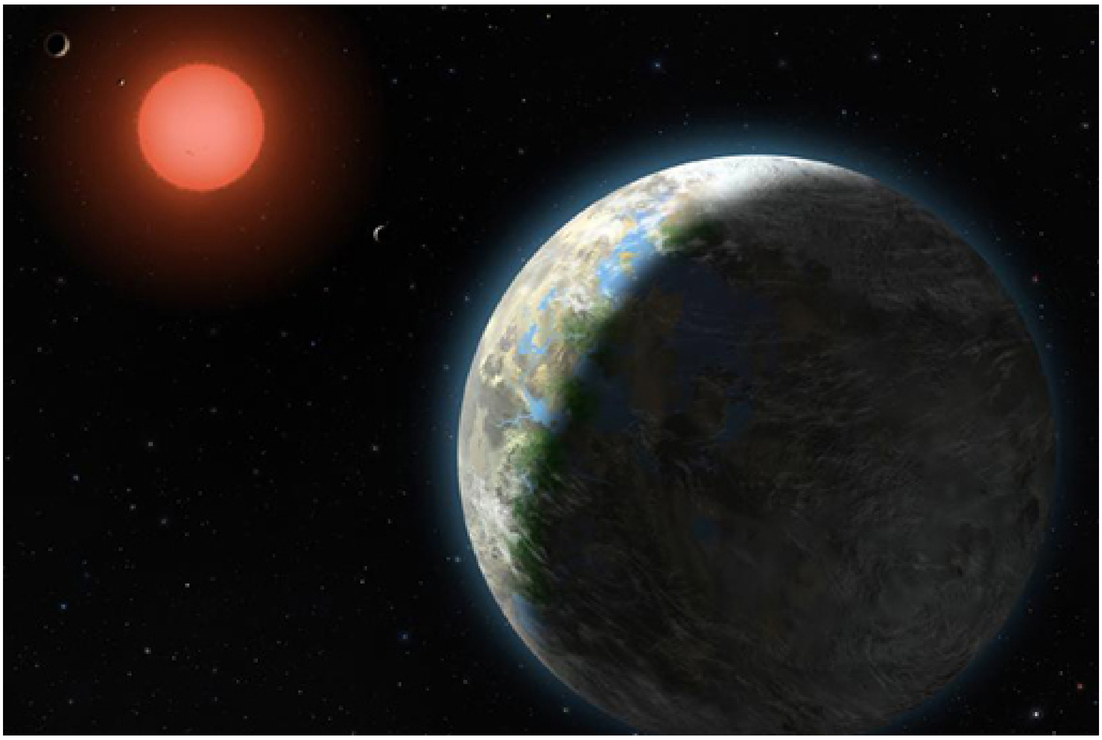

Figure 26 An artist's conception of the inner planets of the Gliese 581 system and their host star, a red dwarf star.

Three planets have been found orbiting the red dwarf star Gliese 581, which is about 20 light years from the Sun.

They are named Gliese 581 b, c and e. The smallest, Gliese 581 e, has a mass just under twice that of the Earth, but orbits more closely to the star.

You may find references to Gliese 581 d, f and g. These were planet candidates, but it was later confirmed that the variations in stellar activity were giving rise to 'astrophysical mimics' in the radial velocity measurements, leading to spurious results.

Activity 4.3

Spend 10 minutes doing some research into the planets Gliese 581 b or Gliese 581 c.

- How big is it?
- Is it more like Earth or Jupiter?
- How far from the central star does it orbit?
- Do you think any of the planets around Gliese 581 could be habitable?

Write a paragraph about your findings.

Provide your answer...

4.3.4 Transit experiment

Try for yourself to see how a transit works.

Activity 4.4

You will need a light source, for example in a table lamp with no lampshade, and a set of spoons of different sizes (e.g. teaspoon, dessert spoon, tablespoon). The lamp represents the star, and the spoons are planets.

Point the lamp at a flat surface, so that it illuminates part of the surface. Take the largest spoon and slowly move it in front of the lamp, watching the pool of light on the surface. You should see that it darkens where the spoon is in front of the lamp, i.e. less light is falling on the surface when the spoon is in position. This is an analogy for a planet passing between an observer and a star as it orbits the star – i.e. as it transits in front of the star.

If you repeat the experiment with a smaller spoon, you should see that the shadow again darkens, but not by quite as much. So you can also say something about the relative sizes of transiting planets.

Did the smaller spoons have a noticeable effect? Note down your findings.

Provide your answer...

Next, you will find out about planets found using the radial velocity method.

4.3.5 Other information from transits

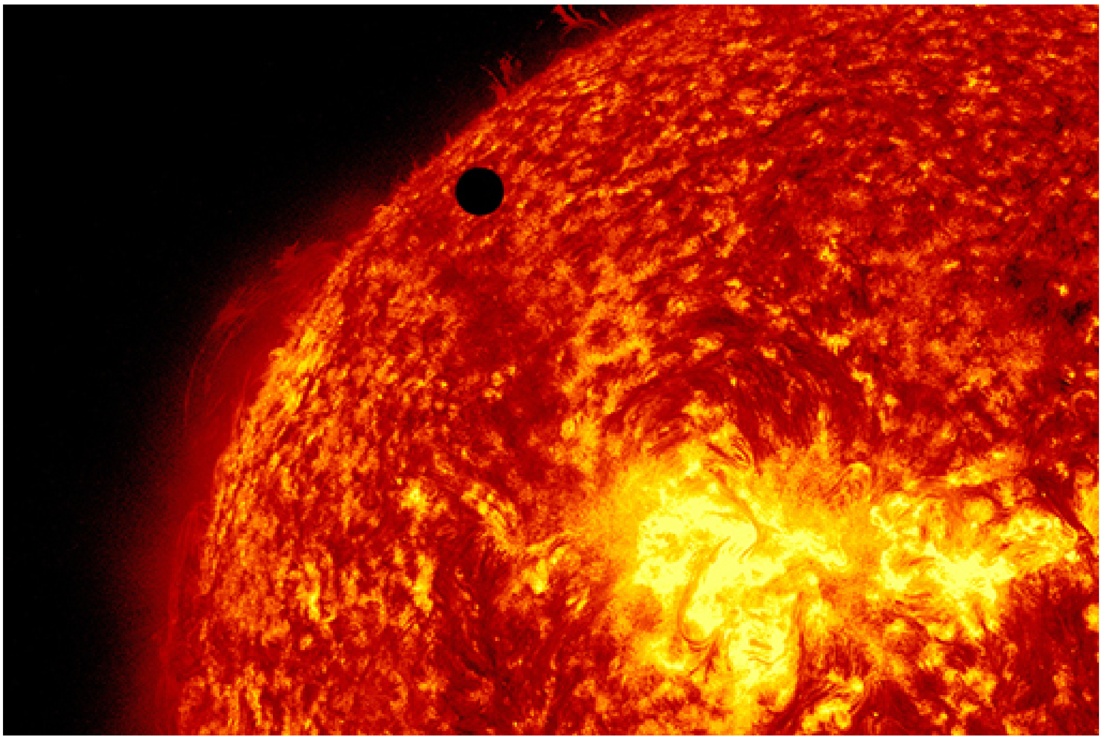

Figure 27 The transit of Venus across the face of the sun.

Transits can also provide additional information about the planet. The ‘dip’ in a star’s brightness during transit is proportional to the size of the planet.

Since the star’s size is known, the planet’s radius (but not its mass) can be deduced from the degree to which it dims during transit. If an exoplanet has an atmosphere, light from the star passing through the atmosphere will be absorbed at different wavelengths, depending on the composition of the atmosphere.

One problem with trying to observe a planetary transit is that it lasts only a short time compared with the length of time taken for the planet to orbit the star. A planet might take months or years to complete its orbit, but the transit would probably last only hours or days. Because of this, even when astronomers observe a star with a transiting planet, they are unlikely to see a transit in progress.

To get around this, observers have to scan the sky continuously for long periods of time. It then becomes more probable that at least some of the stars that are observed have planets, and some will pass between their star and the Earth.

Observing the same region of the sky for long stretches of time also makes it more likely that if a planet does transit its star, the event will be observed and recorded. To make sure that the transit is by a planet, and not a different object that just happens to be between observer and star, astronomers have to observe several transits occurring at regular intervals.

Only an automated telescope that records its observations over long stretches of time can effectively detect planets using this method. Several such projects are underway, using both ground- and space-based telescopes.

Another method of discovering planets is to search for protoplanetary discs, which you will find out more about in the next section.

4.3.6 Protoplanetary disc example

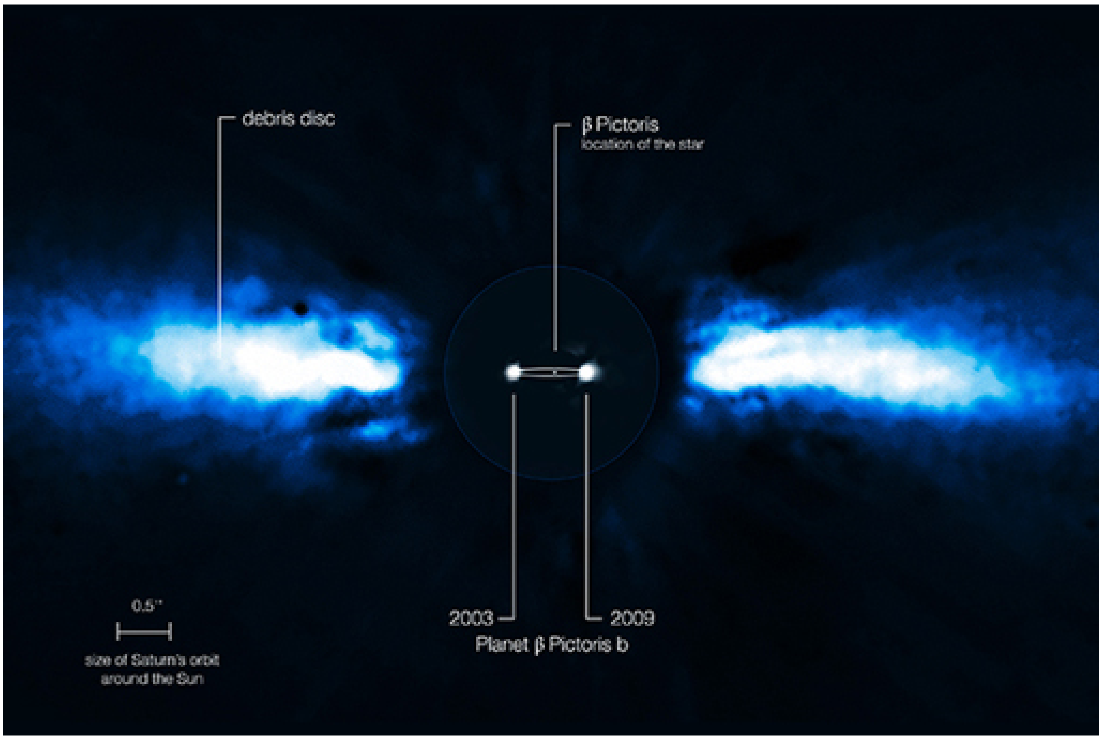

Figure 28 The protoplanetary disc of the planet Beta Pictoris

A complementary method to searching for planets around stars is to search for protoplanetary discs, the dusty discs you learned about earlier, that exist prior to aggregation into discrete planets.

The advantage of this technique over planet observation is that discs can readily be imaged by detection of emission of infrared radiation over and above that expected from a star. The excess radiation results from the presence of dust grains in the disc.

The Infrared Astronomical Satellite (IRAS) made the first observation of an infrared excess around the star Beta Pictoris. Subsequent optical imaging detected a flat disc of dust extending away from the central star – as you can see in the image above.

The disc is ~900 AU across (for comparison, the distance from the Sun to Pluto is ~39.5 AU) but the dust does not extend all the way inwards to the star itself. Images obtained by the Hubble Space Telescope have shown that the central inner zone (a region ~50 AU across) is relatively free from dust, implying that the dust has perhaps been swept up into a planetary system.

In the next section, you'll be invited to consider whether you think there could be life on an exoplanet.

4.3.7 Life beyond the Solar System

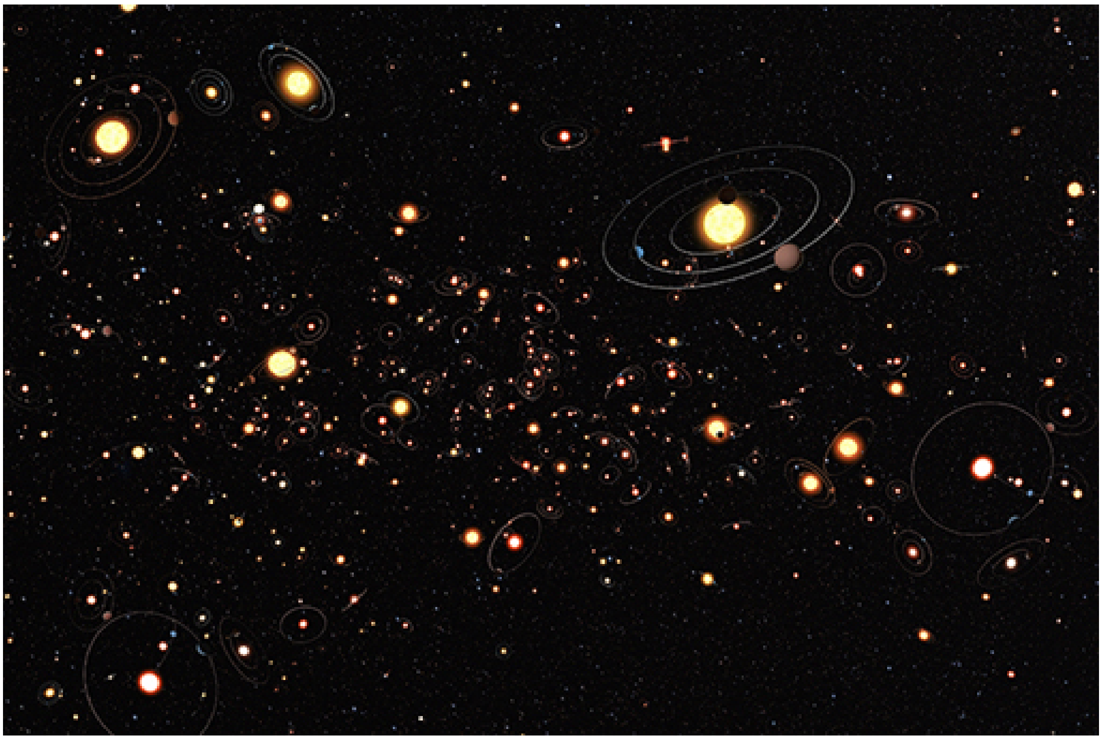

Figure 29 An artists' impression illustrates how common planets are around stars in the Milky Way.

The discovery of exoplanets has intensified interest in the search for extraterrestrial life, particularly for those that orbit in the host star's habitable zone where it is possible for liquid water (and therefore life) to exist on the surface.

The study of planetary habitability also considers a wide range of other factors in determining the suitability of a planet for hosting life.

Activity 4.5

What do you think? Do you think that there are planets beyond the Solar System where life might have got going? Do you think there might be life on any of the other planets in the Solar System? What about some of the moons of Jupiter and Saturn – could they host life?

Note down your ideas.

Provide your answer...

Next, you have the chance to review your learning on this course in the Week 4 quiz which will include questions from the whole course.

4.4 Week 4 quiz

Check what you've learned throughout the course by taking this Week 4 quiz.

Open the quiz in a new window or tab then come back here when you're done.

End-of-course summary

Figure 30 The Orion constellation with the Great Orion Nebula, Horsehead Nebula, dust clouds and interstellar gas visible behind.

Over the past four weeks, you've learned about the constellation of Orion and some of the different stars that make up the constellation.

You have seen that the Orion Nebula is a vast cloud of gas and dust in which new stars are being born and have discovered how stars form, and what happens to them as they age and die. You've also looked back in time to see how the Universe came into being, and what happens when a star gets close to a black hole.

We hope that you have enjoyed learning about the night sky, and will always be able to look up and recognise Orion as a friend.

We would love to know what you thought of the course and what you plan to do next. Whether you studied each week or dipped in and out, please take our Open University end-of-course survey. Your feedback is anonymous but will have massive value to us in improving what we deliver.

Tell us what you think

Now you've completed the course we would again appreciate a few minutes of your time to tell us a bit about your experience of studying it and what you plan to do next. We will use this information to provide better online experiences for all our learners and to share our findings with others. If you'd like to help, please fill in this optional survey.

Where next?

If you've enjoyed this course you can find more free resources and courses on OpenLearn.

Making the decision to study can be a big step and The Open University has over 40 years of experience supporting its students through their chosen learning paths. You can find out more about studying with us by visiting our online prospectus.

You may be particularly interested in our courses and qualifications in Science.

Further reading

Longitude by Dava Sobel

National Maritime Museum

Royal Observatory

BBC: Hubble Space Telescope achieves deepest cosmic view yet: A report from the BBC about the Hubble Space Telescope.

What is gravitational lensing?: Find out more about gravitational lensing from the Canada France Hawaii Lensing Survey.

Acknowledgements

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Week 1

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Week 2

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Week 3

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