10 The mysterious universe

Why learn this?

On any cloudless night, a pattern of stars, galaxies and clouds of gas appears to spin above our heads. Yet against this backdrop, changes are taking place — often hard to see and sometimes spectacular, but always raising questions about the past and the future.

In this chapter, students will:

10.1 outline some of the major features of stars and constellations

10.2 describe the life cycle of stars

account for the brightness and colour of stars

10.3 outline some of the major features contained in the universe, including galaxies, solar systems and nebulae

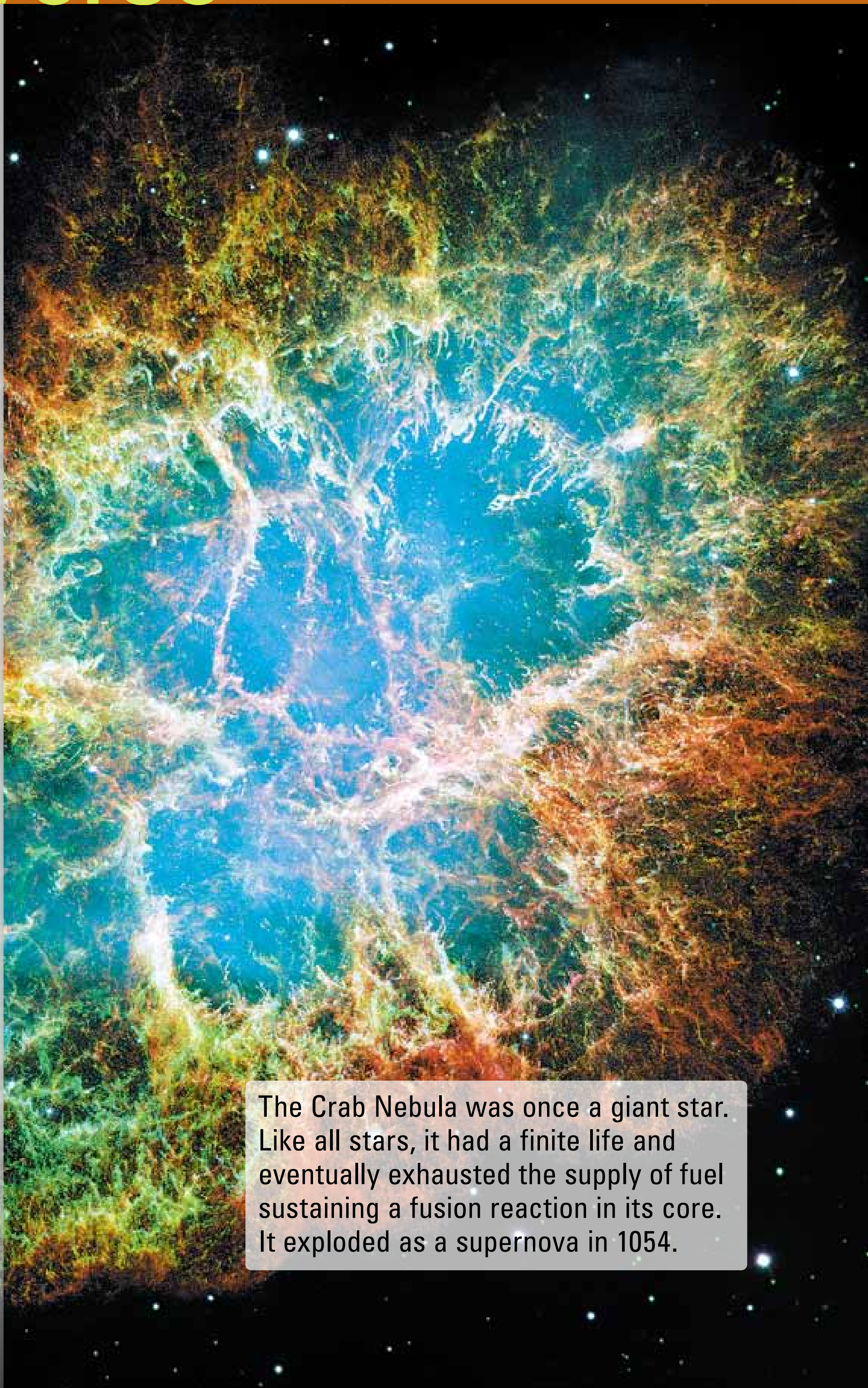
identify that all objects exert a force of gravity on all other objects in the universe

describe differences in sizes of and distances between structures making up the universe

10.4 describe, using examples some technological developments that have advanced scientific understanding about the universe

10.5 use scientific evidence to outline how the big bang theory can be used to explain the origin of the universe and its age

describe how scientific thinking about the origin of the universe is refined over time.

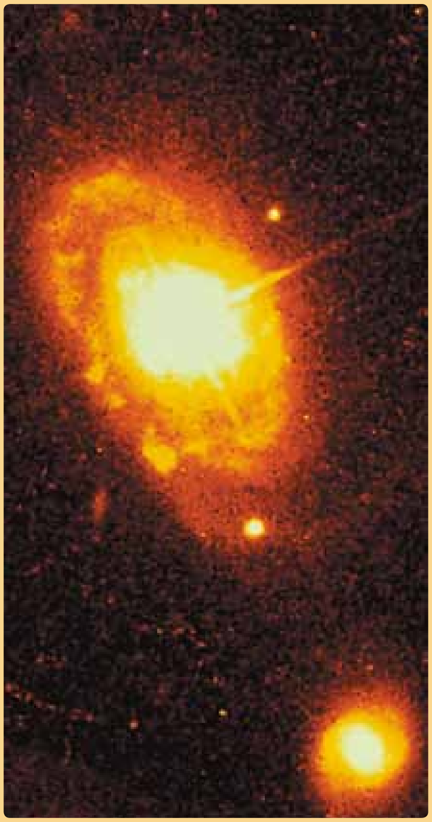


The Crab Nebula was once a giant star. Like all stars, it had a finite life and eventually exhausted the supply of fuel sustaining a fusion reaction in its core. It exploded as a supernova in 1054.

Thinking about the night sky

1. (a) What are stars and what are they made of?
   (b) What is the name of the nearest star to Earth?
2. Each of the following objects might be visible in the night sky:
   - galaxies
   - planets
   - stars
   - moons
   - constellations.

   Arrange these objects in a table from largest to smallest. Work in pairs and use your current knowledge to suggest a definition for each object.
3. Observe the stars on a dark night, preferably around the time of a new moon. Draw the positions of the ten brightest stars and label your diagram to indicate the colour of each.
4. While observing the night sky, you might notice stars of different brightness and slightly different colours. Can you explain why?
5. Explain why the positions of stars change over the weeks and months.
6. What is a light-year? Why is it a useful concept in astronomy?
7. Form a group with two or three other students that have a different star sign from your own. Ask each group member to collect their horoscope from a magazine or newspaper each week for two to three weeks. Paste yours into your workbook and record whether any of the predictions seem to match incidents in your week.
8. Astronomers believe that quasars are formed when black holes at the centre of galaxies begin to pull in gas and stars from the galaxy.
   (a) What is a black hole?
   (b) What is a galaxy?
   (c) To which galaxy does the solar system belong?
9. The photograph of the quasar on the right was taken by the Hubble Space Telescope.
   (a) Where is the Hubble Space Telescope?
   (b) Why are the photographs taken by the Hubble Space Telescope clearer than those taken by larger telescopes on the Earth's surface?
10. How do we know so much more about the distant parts of the universe now, in the twenty-first century, than what we knew about 400 years ago when people were arguing about whether the Earth or the sun was the centre of the universe?
11. Given that the Earth is such a tiny speck in the universe, would you expect to find other, similar planets in the universe? Explain.



(a) The quasar PG 0052+251 is 1.4 billion light-years away. That is, when you look at its image, you are seeing it as it was 1.4 billion years ago.

(b) The *Hubble Space Telescope*. Even though it is much smaller than many telescopes on the ground, it can 'see' much further into the universe.

INVESTIGATION 10.1

Light pollution

AIM To model the effect of light pollution on the visibility of stars

You will need:
2 sheets of A4 paper
pen
sticky tape
torch

- Prick holes in a sheet of A4 paper using the tip of a pen to model the five stars of the Southern Cross (see page 327).
- Stick this sheet of paper over another sheet and tape them both to a window so that daylight shines through them.
- Record your observations.
- Now shine a torch over the stars and record any changes that you observe.

DISCUSSION

1. **What effect did shining the torch have on the visibility of the stars?**
2. **Explain what this investigation demonstrates about when and where astronomers can observe celestial objects.**

Stars and constellations

The brightness of stars

Many stars in the night sky are visible to the naked eye. One of the brightest celestial (sky) objects is, in fact, not a star but the planet Venus. Unlike stars, planets do not produce their own light but reflect the sun's light. Stars are immense spherical masses of hydrogen gas undergoing a fusion reaction, producing helium and enormous amounts of light and heat energy.

The brightness of a star does not necessarily tell us how far away a star is. The closest star to our solar system, Proxima Centauri, was not discovered until modern telescopes were invented. It is so dim that it cannot be viewed with the naked eye. The brightest star in the sky is Sirius. It is almost twice the distance of Proxima Centauri, at 8.6 light-years from Earth, but Sirius is much larger.

Sirius, the brightest star in the night sky

The magnitude scale

Astronomers use the term 'apparent magnitude' when referring to the relative brightness of stars viewed from Earth. The magnitude scale was developed by the ancient Greeks around 150 BC. The Greeks put the stars they could see into six groups. The brightest stars were placed in group 1, and called them magnitude 1 stars. Stars that they could barely see were put into group 6. So, in the magnitude scale, bright stars have lower numbers.

Using this scale, a star that is one magnitude value lower than another star is about 2.5 times brighter. For example a magnitude 4 star is 2.5 times brighter than a magnitude 5 star and so a star that is five magnitude numbers lower than another star is 2.5^5 or 100 times brighter.

Astronomers have extended the magnitude scale at each end to include celestial objects brighter than magnitude 1 and dimmer than magnitude 6.

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eLessons

Twinkle, twinkle
Have you ever wondered why stars twinkle? Find out in this video lesson.
eles-0071

Hubble and the expansion of the universe
Watch a video from *The story of science* about Hubble's telescope and the universe.
eles-1766

Celestial object	Apparent magnitude
Sun	–26
Full moon	–12
Venus	–4.3
Sirius	–1.5
Alpha Centauri	–0.04
Delta Crucis (Southern Cross Constellation)	2.8
Proxima Centauri	11.1

Increasing brightness

Using scientific notation

Very large numbers are often written in a special way called scientific notation. This allows us to avoid writing lots of zeroes and also makes the number easier to read, because the reader does not have to count the zeroes. For example, the distance between the Earth and the sun averages 150 million kilometres. This could be written as 150 000 000 km or, in scientific notation, as 1.5×10^8 km.

Some other examples are:

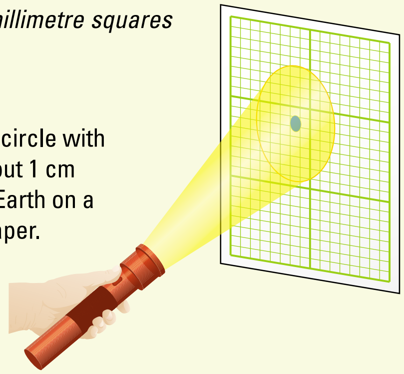
- $45\,000\,000\,000 = 4.5 \times 10^{10}$
- $700\,000\,000\,000\,000\,000 = 7.0 \times 10^{17}$.

INVESTIGATION 10.2

The brightness of stars

AIM **To investigate the relationship between a star's distance and the proportion of light reaching us**

You will need:
graph paper with millimetre squares
ruler
small torch



- Colour in a small circle with a diameter of about 1 cm to represent the Earth on a sheet of graph paper.
- Hold a torch, representing a star, 2 cm from the graph paper and record the diameter of the circle of light created.
- Move the torch back a further 2 cm at a time and repeat the process until the diameter of the light circle exceeds the size of the graph paper.
- Record the proportion of total light output of the star received by the 'Earth' (as a percentage) at each distance as follows:

$$\text{proportion of light received} = \frac{\text{diameter of Earth}}{\text{diameter of light circle}} \times 100$$

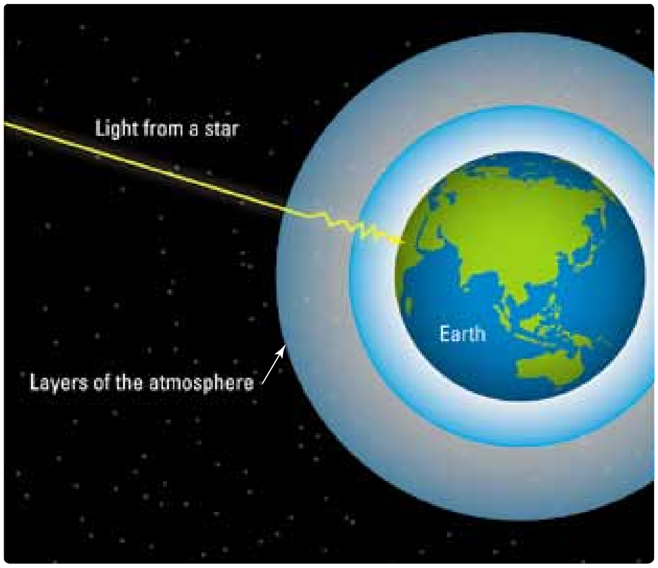
- Record all your data in a suitable table.
- Plot a line graph to demonstrate the relationship between the distance from a star (x-axis) versus the proportion of light received on Earth (y-axis). Draw a line of best fit.

DISCUSSION

1. **This investigation models the effect of distance on the brightness of stars viewed from Earth. Write a suitable conclusion for this investigation.**
2. **What benefits does modelling have in science?**

Twinkling stars

Stars appear to 'twinkle' in the night sky. This is because the light travelling from a star is distorted by the Earth's atmosphere. The light is bent in all directions as it passes through the moving air of the atmosphere. This causes the image to change slightly in brightness and position and hence twinkle. This is one of the reasons the Hubble telescope in orbit high above the Earth is so successful at capturing clear images of celestial objects. In space, there is no atmosphere to make the stars twinkle, allowing a much clearer image to be obtained.



Pockets of warm and cold air in the Earth's atmosphere bend light from a star, making the star appear to twinkle.

INVESTIGATION 10.3

Twinkling stars

AIM **To model the twinkling of stars**

You will need:
aluminium foil *glass dish* *torch*

- Fill a glass dish with water.
- Take a sheet of aluminium foil large enough to cover the base of your dish.
- Crinkle the foil into a loose ball then open it out again.
- Put the crinkled foil under the glass dish.
- Darken the room and then shine a light down at an angle into the dish while the water is still. Observe the reflected image.
- Stir the water and, while it is still moving, shine the torch into the dish and once again observe the reflected image.

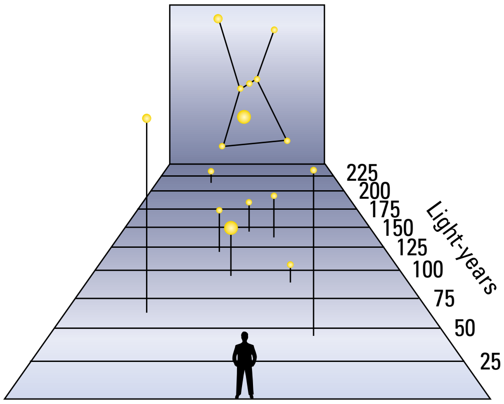
DISCUSSION

1. **What effect did the turbulence of the water have on the image of reflected light?**
2. **How do these results help explain why stars twinkle?**

Constellations

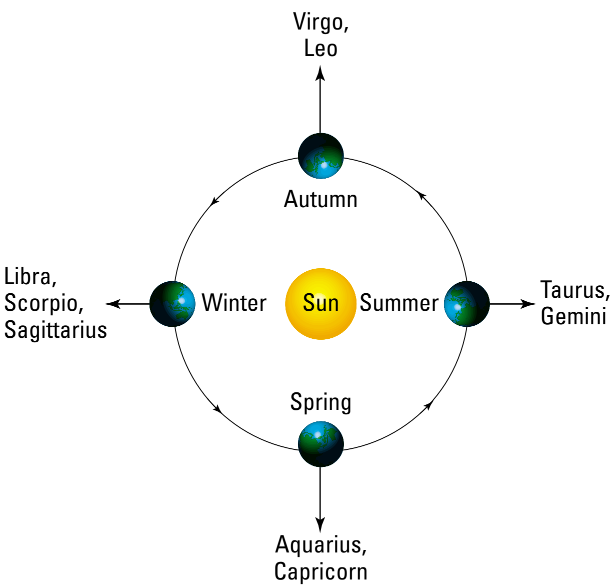
Astronomers of ancient civilisations grouped stars according to the patterns or shapes they seemed to form. These shapes were usually of gods, animals or familiar objects. Today, astronomers divide the sky into 88 regions of stars. The group of stars within each region is called a constellation.

When viewed from Earth, the individual stars in a constellation may appear to be very close to each other. However, they can be separated by huge distances in space and in fact have no real connection to each other at all. The stars that make up the constellation Orion, for example, are at very different distances from Earth.



The distances to stars in the constellation Orion from Earth

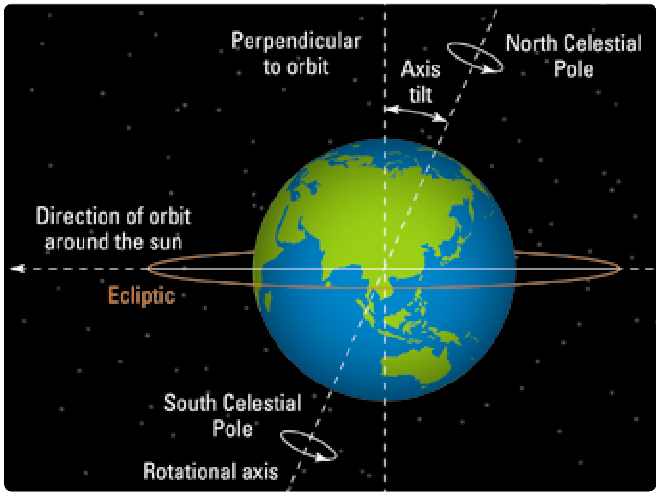
The constellations visible on any given night depend on the time of year. For example, Gemini and Leo are clearly visible in March but not in October.



The constellations that are visible depend on the position of the Earth in space.

In ancient times, it was thought the stars wandered through the night sky; today we explain the stars' apparent movement in terms of the motion of the Earth through space as it orbits the sun.

Over the course of an evening, the positions of constellations appear to move from east to west. This is due to the Earth's spin. Just like the sun and the moon, stars rise in the east and set in the west. A time-lapse photograph of the stars taken over several hours shows the changing positions of the stars due to the Earth's spin. The central point around which the star trails appear to rotate is called the South Celestial Pole and it indicates the Earth's axis of rotation.

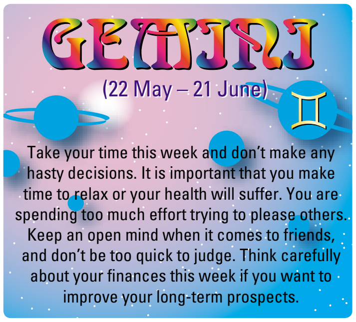


Stars appear to move around the celestial poles due to the spin of the Earth.

Star trails produced by time-lapse photography

The zodiac

Twelve constellations pass through what is known as the **ecliptic**, the path that the sun traces in the sky during the year. Ancient Greek astronomers believed that these twelve constellations had a special significance and are known today as the constellations of the **zodiac**.



A horoscope prediction for a 'Gemini' — someone born between 22 May and 21 June

INVESTIGATION 10.4

Star charts

AIM **To observe the relative motion of the moon and stars over a period of time**

- Observe one night when the moon is visible and try to find some stars that appear close to the moon.
- Sketch the positions of the moon and nearby stars.
- Observe again one or two nights later at the same time and compare your previous drawing with what you see.
- Observe again a few weeks later at the same time and compare your original drawing again with what you see.

DISCUSSION

1. **The stars you drew should be in about the same position a few nights later, but the moon will have moved. Explain why, in terms of the motion of the moon.**
2. **When viewed a few weeks later, the stars are in a slightly different part of the sky. Explain why, in terms of the motion of the Earth.**

INVESTIGATION 10.5

Using a sky map

AIM **To use a sky map to identify and locate celestial objects in the night sky**

A sky map, sometimes called a star chart or star map, shows the positions of planets, stars and constellations visible in the night sky from a given location at a certain time of the year. Use the **Star maps** weblink in your eBookPLUS to find and print a map of the stars for the current month of the year.

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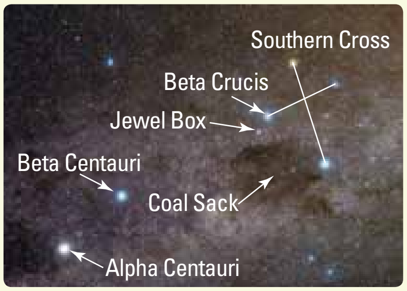
A key is provided with most star maps to indicate whether the celestial object viewed is a planet, star or other object. The brightness of stars is indicated by the diameter of the circle depicting them. A magnitude scale is used to compare the brightness of stars; brighter stars such as the Southern Pointers have a low magnitude value while fainter stars have a larger magnitude value.

You will need:

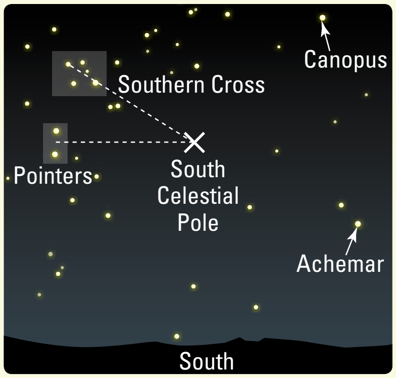
star map for the Southern Hemisphere for the current month
small torch (preferably with red cellophane taped over the end)
pair of large binoculars or a telescope (optional)
highlighter pen

- Select a clear night, preferably with little moonlight available.
- Once you have selected a viewing position, you might like to lie down and turn the chart so that the direction you are facing (north, south, east or west — use a compass if you are unsure) is shown at the bottom of the map. The centre of the chart represents the point directly above your head, called the zenith point, and the outer circular edge represents the horizon.
- Use the small torch to view your star map at night.
- Find the Southern Cross constellation and the two nearby Pointers, Alpha and Beta Centauri. There are many stars forming a cross pattern in the night sky; the key to finding the Southern Cross is locating the pointers alongside.
- If you have a pair of large binoculars or a telescope, locate and view some prominent celestial objects near the Southern Cross.
  – Alpha Centauri, at 4.3 light-years away, is the closest star visible to the naked eye in the night sky.
  – The Coal Sack is a dark patch in the Milky Way between the two brightest stars of the Southern Cross (Alpha and Beta Crucis). This is a dark cloud of gas about 60 light-years across and 500 light-years away that blocks our view of the stars in the Milky Way behind it.



Stars around the Southern Cross

  – The Jewel Box is a bright cluster of stars on the edge of the Coal Sack and near Beta Crucis. It gets its name from the various colours visible when the stars are viewed through a telescope. The Jewel Box contains about 50 bright stars, all of which are only a few million years old. It is about 25 light-years across and about 7700 light-years away.
- Locate the approximate position of the South Celestial Pole by following the line of the long arm of the Southern Cross and finding where it intersects with a line perpendicular to the line joining the two Pointers.



- Locate as many constellations and other prominent celestial objects as possible.
- Highlight each of the constellations on your sky map once you have viewed them.

ACTIVITIES

REMEMBER

1 What are stars? How are they different to planets?

2 Explain why stars appear to twinkle.

3 Define the term 'constellation'.

4 There are 88 named constellations. What is special about the 12 constellations of the zodiac?

5 Explain why different constellations are visible in different months of the year.

6 Explain why the positions of stars appear to change over the course of an evening.

7 Define the term 'South Celestial Pole' and describe how it can be found.

THINK

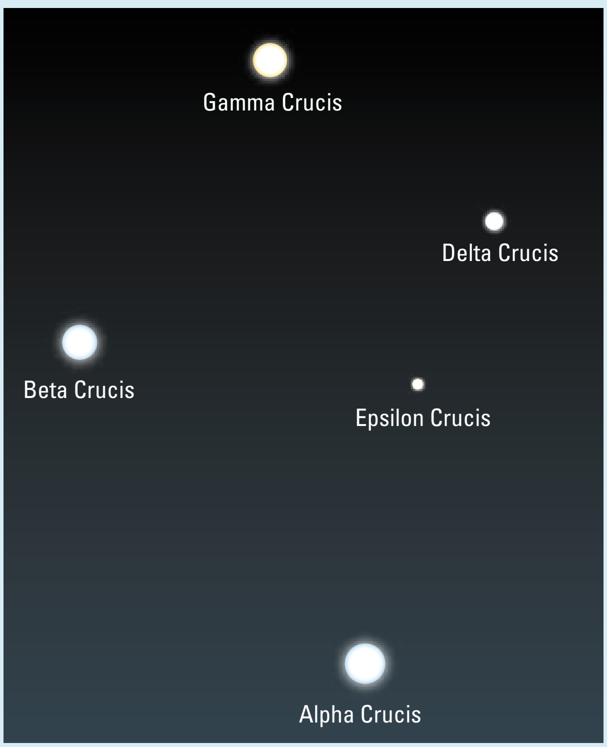
8 Explain why so many more stars are visible in the night sky in rural areas than in the city.

9 Explain why stars, apart from the sun, are not visible during the day.

10 In investigation 10.5 it was suggested that the torch should be covered in red cellophane. Explain why.

11 Refer to a star map to identify a:
(a) star of magnitude 0
(b) constellation along the ecliptic
(c) planet that should be visible.

12 The five main stars of the Southern Cross constellation are shown below. All five stars appear to be the same distance from the Earth but they are not.



The brightness of each star and its actual distance from Earth are listed in the table below.

Star	Distance from Earth (light-years)	Brightness (magnitude value)
Alpha Crucis	321	0.8
Beta Crucis	353	1.3
Gamma Crucis	88	1.6
Delta Crucis	364	2.8
Epsilon Crucis	228	3.6

(a) Identify the star closest to the Earth.
(b) Identify the brightest star.
(c) Beta Crucis and Gamma Crucis have a similar brightness when viewed from Earth. Identify which star emits more light and justify your response.

CALCULATE

13 It takes 8 minutes for light from the sun to reach the Earth. If light travels at 300 000 km/s, calculate the distance of the sun to the Earth in kilometres.

14 The distances to some prominent celestial objects are listed below. Copy the table and calculate the time it would take a space probe to travel from Earth to each destination if travelling at a speed of 6 km/s (using current technology) as follows:

$$\text{time taken by space probe} = \text{time taken by light} \times \frac{300\,000 \text{ km/s}}{6 \text{ km/s}}$$

Destination	Time taken by light	Time taken by a space probe
Moon	1.3 seconds	____ seconds
Mars (at its closest point in orbit)	3.1 minutes	____ minutes
Sun	8.3 minutes	____ minutes
Alpha Centauri (the closest star visible in the night sky)	4.3 years	____ years
Sirius (the brightest star in the night sky)	8.7 years	____ years
Large Magellanic Cloud (a galaxy close to the Milky Way)	179 000 years	____ years

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15 Match each constellation to the correct representation on the sky map by completing the **Star matching** interactivity in your eBookPLUS. **int-0232**

16 Use the **Star maps** weblink in your eBookPLUS to print a map of the stars for any month of the year.

work sheet — 10.1 Observing stars

The life cycle of stars

Movie stars come and go. Some have brief careers while others seem to go on forever. It's very much the same with the stars in the sky. Stars come and go — they don't last forever.

A star is born

Dust and gas are not evenly distributed in interstellar space. Some regions of the universe contain denser concentrations of swirling dust and gas. Within these currents, the density sometimes reaches the critical figure of 100 atoms per cubic centimetre. At this point, gravity takes hold and the gas and dust begin to collapse into the beginnings of a new star. The collapse continues under the influence of gravity, forming visible clumps in a nebula cloud. As the clumps collapse further, the original gas cloud begins spinning at ever increasing speed. At the same time, the increasing pressure causes the temperature to rise and the conditions are right for a star to be born.

These clouds of interstellar matter are called nebulae and could be considered star 'nurseries'.

INVESTIGATION 10.6

Heat produced by compressing a gas

AIM To model the heat generated when stars form

You will need:

a bicycle pump *a bicycle tyre*

- Using an energetic pumping action, inflate a tyre with the bicycle pump. Alternatively, just pump the bicycle pump with your finger partially covering the open end so the air does not escape.
- Now feel the body of the pump.

DISCUSSION

1. What change has been observed?
2. How does an increase in air pressure affect the temperature of the surroundings?
   (The opposite effect can be observed when carbon dioxide gas is released from a soda bulb.)
3. How does this activity model star formation?

A star-forming region in the Carina nebula captured by the orbiting Chandra telescope. In this image, the blue hues indicate regions emitting high energy X-rays and the red regions are associated with lower energy X-rays.

The young, the old and the dead

A quick glance around the night sky shows us that stars differ quite noticeably from one another, both in how bright they appear to us and in their colour (see Investigation 10.8). Some of them are relatively close to the Earth, while others are much further away. There are young stars, middle-aged stars like the sun, old and dying stars and exploded stars. By collecting details of a wide range of stars, we can trace the various stages in the development of typical as well as unusual stars. This is like looking at the characteristics of hundreds of people and using patterns in the data to draw conclusions about the life of one individual.

Star light, star bright

The apparent magnitude of a star is a measure of how bright it appears from Earth and is the result of the star's distance from the Earth and how much light it emits. The amount of light a star emits is referred to as its 'absolute magnitude' and determined by the star's:

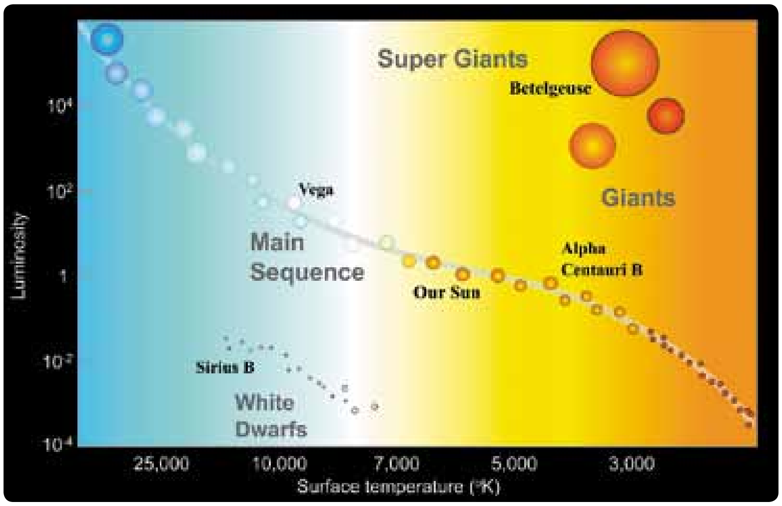
- size: larger stars tend to be brighter
- surface temperature: brighter stars tend to have a high surface temperature and are white in colour, while cooler stars are red and less bright.

The interplay between these two features determines the rate of light output of a star and hence the actual brightness of a star. For example, Betelgeuse is a bright star due to its large size even though it is a relatively cooler red star.

A dim star close to us may appear brighter than a really bright star a long way away. To calculate the absolute magnitude of a star, astronomers must know how far away it is.

An interesting way of displaying the data collected about stars was developed independently by two astronomers, Ejnar Hertzsprung from Denmark and Henry Norris Russell from America. This diagram has now been named after both of them. In the Hertzsprung–Russell diagram, the absolute brightness of a star is plotted against its surface temperature, which is deduced from its colour. When data for many stars is plotted, most of them, including our sun, fall into a group known as the **main sequence**. Exactly where a star is found along the main sequence is determined by its mass. Low-mass stars tend to be cooler and less bright than high-mass stars.

Other types of star show up very clearly on the Hertzsprung–Russell diagram but in much smaller numbers than in the main sequence. The names of these stars — white dwarfs, red giants, blue giants and super giants — clearly describe their characteristics. Astronomers suggest that all stars begin their existence in the main sequence and spend the largest part of their life there. This explains why most of the stars observed at a particular time are in the main sequence phase. The rarer types are stars that pass relatively quickly through later stages of development on the way to extinction as their nuclear fuel runs out.



The Hertzsprung–Russell diagram sorts stars according to their absolute magnitude (or luminosity) and surface temperature.

INVESTIGATION 10.7

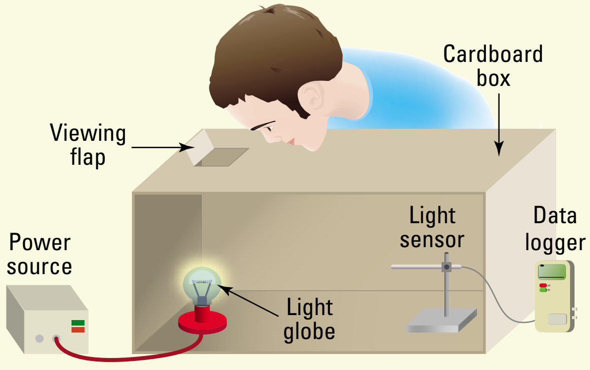
Colour and brightness

AIM To investigate the relationship between the colour and brightness of a light-emitting object

You will need:

12V incandescent light globe
2 wire leads
DC power source
data logger and light sensor
scissors
cardboard box e.g. photocopy paper box

- Cut a viewing flap and a slot for the light sensor to be placed in position.



- Connect the light globe to a power source.
- Place the box over the globe and position the light sensor in the slot of the box and a fixed distance from the globe.
- Turn the power source to 2 volts and turn it on.
- Pull back the viewing flap and through the hole observe the colour emitted by the filament and record.
- Close the viewing flap and record the light intensity indicated by the light sensor.
- Increase the voltage by 2 volt increments and repeat the experiment.
- Record all your data in a suitable table.

INVESTIGATION 10.8

Seeing the colours of stars

AIM To observe stars within the constellation Orion

You will need:
sky map (optional)
pair of binoculars (optional)

- Use the information below, a sky map or an astronomy computer program to help you to find the constellation Orion (the Hunter). Alternatively, find a colour photograph of the constellation Orion.
  - The star α-Orionis (also known as Betelgeuse) is a red giant which has a diameter bigger than Earth's orbit. It appears red to the naked eye and this distinctive colour shows up even more clearly through binoculars. The star β-Orionis (also known as Rigel) is 60 000 times as bright as the sun.
- Compare the colours of Betelgeuse and Rigel.
- Try to locate the Great Nebula using the following information.
  - The constellation Orion (the Hunter) is visible from every inhabited place on Earth. It is most easily recognised from the line of three stars that represent the hunter's belt. Remember, the constellations were named by observers in the Northern Hemisphere so, to southern observers, the constellations appear upside down. This is why Orion's sword points upwards from the belt. This group of stars, making up the sword and the belt, is often known as the Saucepan.
  - Orion's sword, pointing upwards from the belt, contains a misty patch visible to the naked eye. This is the Great Nebula, labelled M42 by the astronomer Messier, who prepared a catalogue of such objects. Through binoculars, stars can be seen embedded in the gas and dust of the Great Nebula and new stars have been seen as they begin to emit light. The Great Nebula and other similar formations are the birthplace of the stars.

From cradle to grave

Stars are 'born' within nebulae from gas and dust coming together through the force of gravity. During this process, the centre of the nebula may heat up and glow. Eventually sufficient hydrogen gas may accumulate to form young stars. Stars then spend most of their life cycle as stable 'main sequence' stars, and are powered by a fusion reaction within their core which converts hydrogen to helium. The size of a star determines how quickly the hydrogen in the core is used up. Small to medium sized stars like the sun have a life span of 10 billion years. The sun is currently 4.6 billion years old and in the main sequence phase, slowly consuming hydrogen gas. Beta Centauri is a larger, hotter star and, because it consumes its hydrogen at a faster rate, will reach the end of its life within a relatively short 10 million years.

Main sequence to red giants

In a stable main sequence star, hydrogen is steadily turned into helium by the process of fusion. As helium builds up in the core of the star, the remaining hydrogen forms a shell around the core. The shell gradually expands and the star swells to 200 or 300 times its original size, cooling as it does so, to become a **red giant**. This will eventually happen to our sun, which will grow large enough to swallow up the inner planets, including Earth.

In the core of a red giant, new fusion processes take place, turning helium into heavier elements such as beryllium, neon and oxygen. This increases the rate of energy production and raises the star's temperature. A sun-like star which has become a red giant might shine 100 times more brightly than it did in its stable period.

Eventually red giants collapse inwards leading to the destruction of the star. The nature of its death depends on the size of the original star.

White dwarfs

For stars less than about eight times the mass of our sun, the destruction of a red giant begins when the outer layers are thrown off into space and the core flares brightly, forming a ring of expanding gas called a **planetary nebula**. The name 'planetary nebula' is misleading because it is not related to planets. But it does have the cloud-like nature of a nebula.

The remaining star fades to become a **white dwarf**, typically about the size of a planet like the Earth but with a very high density and a surface temperature of about 12 000 °C. It then slowly cools, becomes a cold black dwarf and disappears from view.

Coming to a violent end

Stars that are more than about eight times the mass of our sun come to a much more violent end. They swell into much larger red giants called **supergiants**, then blow up in a huge explosion called a supernova. The matter making up the star is hurled into space along with huge amounts of energy. A supernova can emit as much energy in a month as the sun radiates in a million years. Supernova events are very rare, being seen only every 200 to 300 years on average and fading within a few years. They are extremely important in the universe because it is within these violent explosions that the heavy elements such as iron and lead are produced.

What remains of a supernova is extremely dense; the pull of gravity becomes so great that even the protons and electrons in atoms are forced together. They combine to form neutrons and the resulting solid core is known as a **neutron star**. If the remaining core has a mass more than about three times that of our sun, the force of gravity is great enough to 'suck in' everything — even light. Such a core becomes a **black hole**. To find out more about the life cycle of a star use the **Stellar evolution** weblink in your eBookPLUS.

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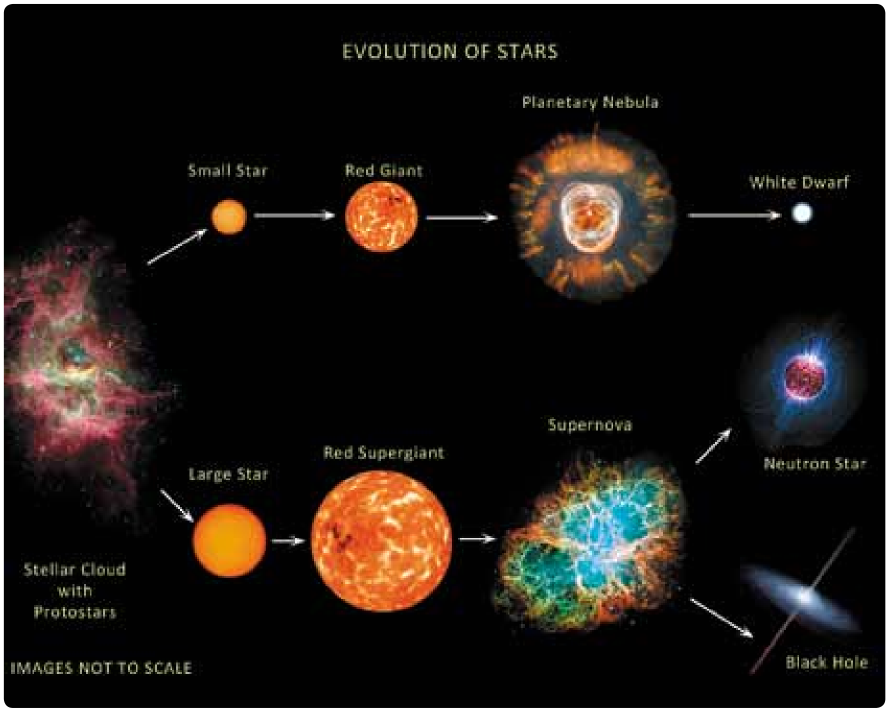


Large stars follow a different evolutionary sequence to smaller stars like the sun.

ACTIVITIES

REMEMBER

1 (a) What are nebulae?
(b) Why are nebulae often called 'star nurseries'?

2 **Explain** why most stars are found in the main sequence of the Hertzsprung–Russell diagram.

3 Which group of stars shown on the Hertzsprung–Russell diagram does the sun belong to?

4 **Describe** how a red giant becomes a white dwarf.

5 **Explain** why the term 'planetary nebula' is a misleading way to describe the ring of expanding gas thrown out by a red giant during its transformation into a white dwarf.

USING DATA

6 The table below lists information about three bright stars.

Star	Apparent magnitude	Absolute magnitude
Rigel (Orion)	+0.11	–7.5
Aldebaran (Taurus)	+0.86	–0.3
Canopus (Carina)	–0.73	–4.6

Use this information to **identify**:
(a) which star emits the most light
(b) which star is the faintest as seen from Earth.

THINK

7 Is it likely that our own star, the sun, will become a supernova? **Explain** your answer.

8 **Describe** what the night sky would look like if you had eyes that could 'see' like the *Hubble Space Telescope*.

INVESTIGATE

9 **Research** the formation and destruction of a supernova. For example, when was the last supernova seen? Can we predict when the next one will be seen?

eBook*plus*

10 Test your knowledge on the life of a star by completing the **Star cycle** interactivity in your eBookPLUS. **int-0679**

work sheets
10.2 Star life cycles
10.3 The brightness of stars
10.4 The sun and nuclear fusion

The Milky Way and beyond

The Milky Way Galaxy

The sun is the closest star to the Earth. It formed about 4.5 billion years ago from a cloud of dust and gas making up a nebula. The Earth and our neighbouring planets formed from leftover nebula materials soon after the sun gases started to clump together. This marked the birth of our solar system.

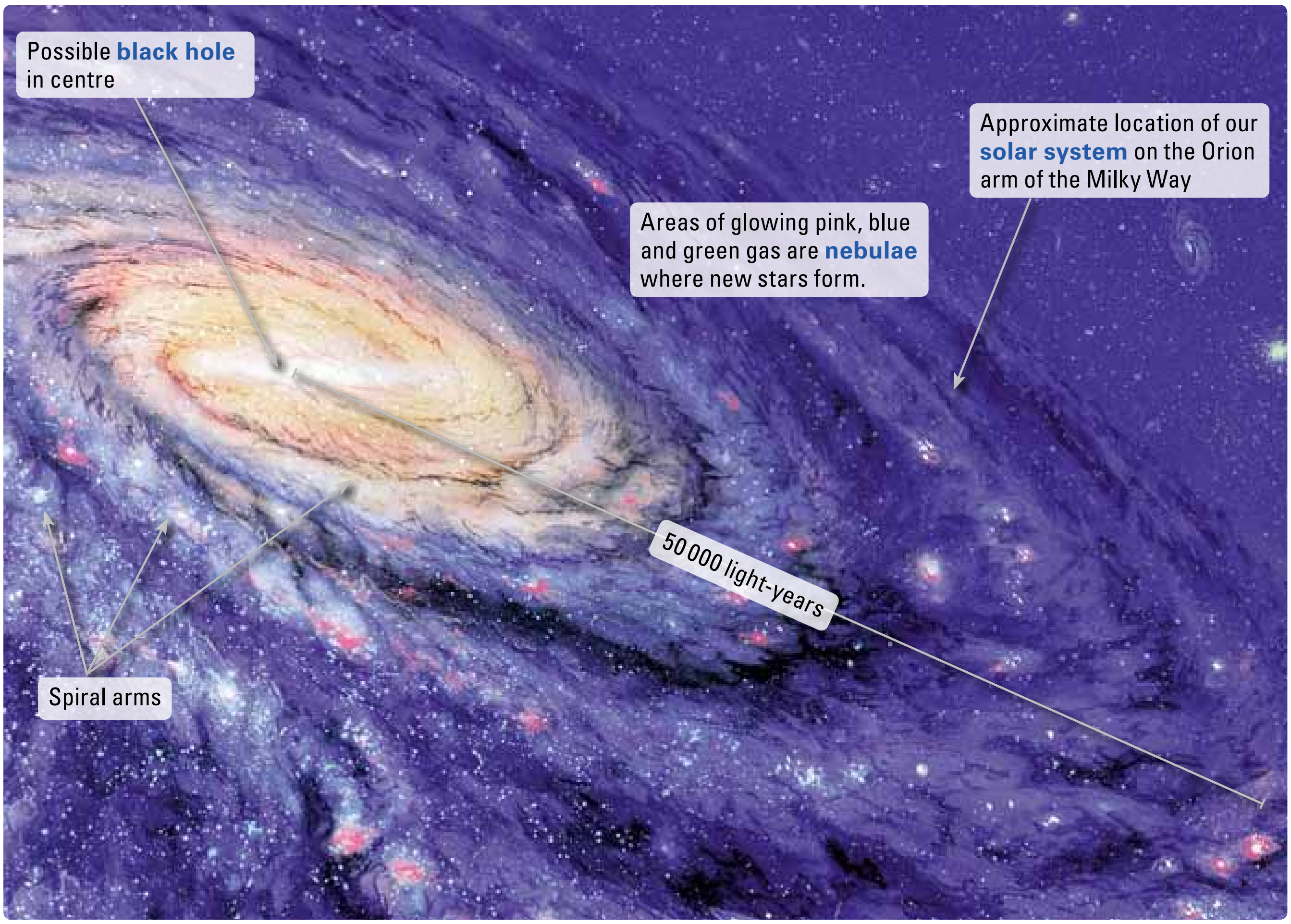
Stars group together to form galaxies, which are bound by gravitational forces. Our sun is one of the 200–400 billions of stars within the Milky Way Galaxy. We know of about 100 billion more galaxies of different shapes and sizes throughout the universe. Each of these galaxies is home to stars at all stages of their life cycles, including those undergoing violent explosions, known as supernovas.

The Milky Way Galaxy (shown below) is a spiral galaxy with a radius of 50 000 light-years. Our solar system is found on the Orion arm of the spiral. Due to the rotation of the galaxy, our solar system orbits the centre of the galaxy at a speed of about 200 kilometres per second! Scientists believe that, since its birth, our solar system has travelled around the centre of the galaxy up to 20 times.

Light-years away

The universe is so big it is difficult to comprehend its size. It would take light almost 14 billion years to reach the most distant objects in the universe.

The closest star to our solar system that is visible to the naked eye, Alpha Centauri, is about 41 000 billion kilometres away. The distances between objects in the



An artist's impression of the Milky Way. The Milky Way, along with our neighbouring galaxy, the Large Magellanic Cloud, forms part of the Local Group of galaxies.

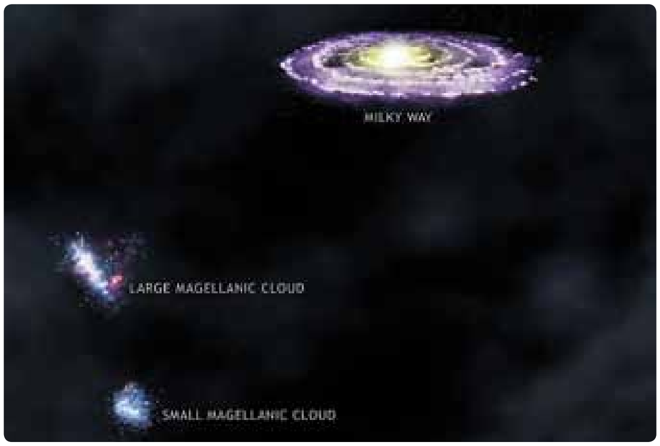
universe are so vast that expressing them in kilometres would involve immense numbers. Instead, astronomers use a much larger unit of distance, the **light-year**. A light-year is the distance that light travels in one year. If light travels 300 000 km per second, then in one year it travels 300 000 × 60 s/min × 60 min/h × 24 h/day × 365.25 day/yr = about 9500 billion kilometres. This means that Alpha Centauri is 4.3 light-years away.

When we look at the stars, we see the light produced by them. However, because of the vastness of space, that light takes a long time to reach us here on Earth. So, in fact, viewing stars is like looking back in history; the light we see today from Alpha Centauri was emitted 4.3 light-years ago. The Andromeda Galaxy is the most distant object visible to the human eye; at 2.2 million light-years away we are looking at the light it released 2.2 million years ago, before the appearance of modern humans, *Homo sapiens*.

Galactic shapes

American astronomer Edwin Hubble recognised that galaxies could be grouped according to their shapes.

Spiral galaxies, like the Milky Way and Andromeda galaxies, rotate. They have a bright bulging middle with two or more curved arms of stars spiralling out from the centre. The middle parts of spiral galaxies spin faster than the edges. The older red stars are found closer to the centre and the younger blue stars are located on the outer arms of the spiral.

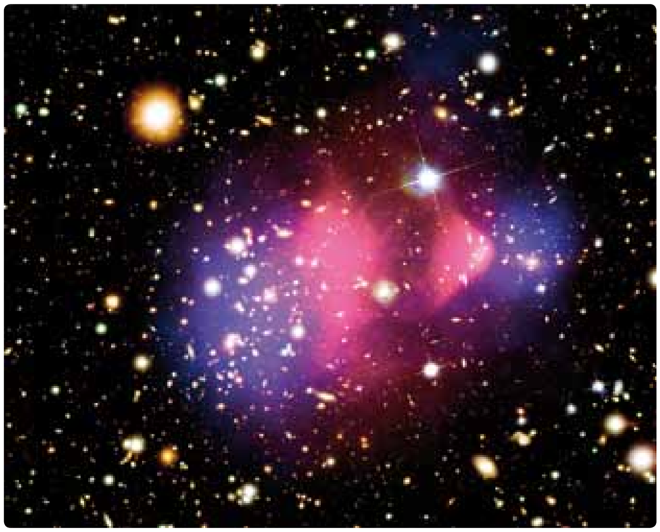


An illustration showing the relative sizes and location of the Large and Small Magellanic clouds, the two closest galaxies to the Milky Way

Irregular galaxies have no definite shape and tend to have very hot, new stars mixed in with lots of dust and gas. The Magellanic clouds are two small, irregular galaxies that look like two fuzzy clouds visible near the Southern Cross constellation. The Large Magellanic Cloud, at a distance of 160 000 light-years, is the closest galaxy to our own Milky Way Galaxy.

M87 is an elliptical galaxy. Unlike spiral galaxies, the stars in elliptical galaxies move in different directions. M87 has grown to an enormous size by pulling in other galaxies.

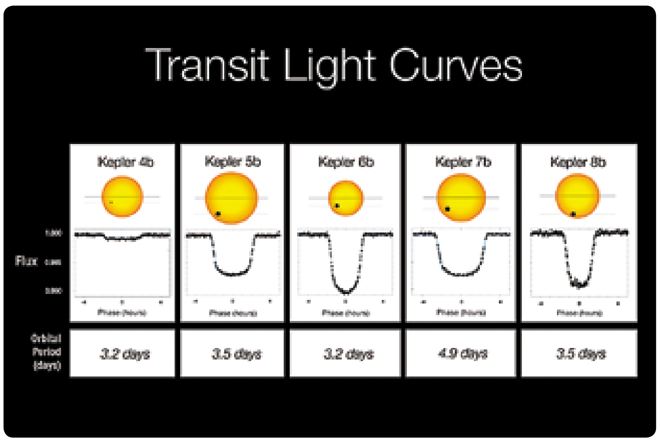
A computer-simulated view of a cluster of galaxies far from our own Milky Way Galaxy



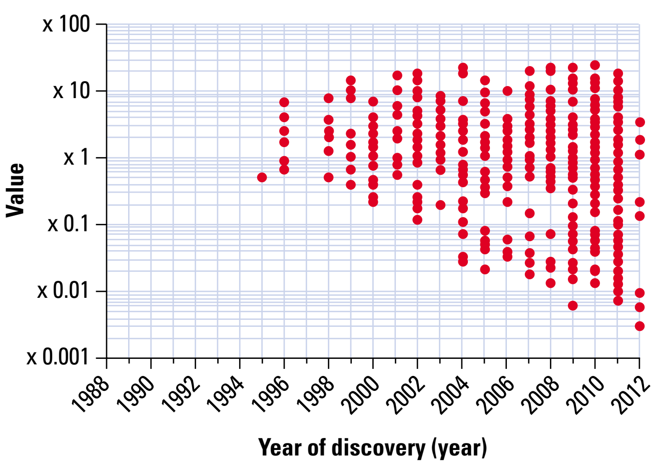
The two Antennae galaxies colliding. During this collision, billions of stars will be formed. They give us a preview of what may happen when our Milky Way Galaxy collides with the neighbouring Andromeda Galaxy in several billion years.

Searching for other planets

As the sun is just one of over 200 billion stars in the Milky Way Galaxy alone, and with billions of galaxies beyond our own in the universe, one would think the likelihood of there being other planets like our own would be high. In fact astronomers have so far discovered over 840 exoplanets, or planets beyond our solar system in a total of around 660 star systems. This may not be as many as one would expect given the tremendous size of the universe. One reason for this is that distant planets are difficult to detect as they are tiny compared to stars and are dim as they do not produce their own light. In 1995 astronomers discovered the first planet beyond our solar system by detecting the wobble back and forth on its parent star due to the gravitational pull from the orbiting planet. Other planets have been discovered by detecting a regular dip in the light intensity observed from stars as the orbiting planet passes in front of it.



Many exoplanets are detected by monitoring the drop in brightness of the stars around which the planet orbits.



The exoplanets discovered so far plotted against their size relative to the mass of Jupiter, the largest planet in our solar system. Most of the planets discovered so far are of a size similar to Jupiter.

Nebulae — stellar nurseries

In the photograph of the constellation Orion below, there is a cloudy-looking, pink region. This is the Orion Nebula, known as M42. It looks small, but it is about 30 light-years across.

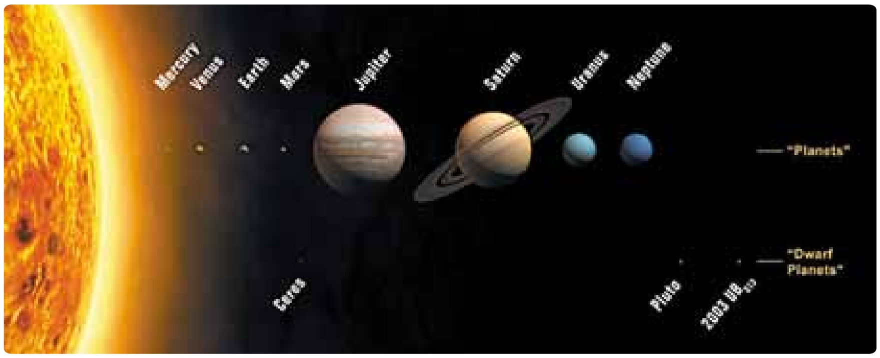
A nebula is an interstellar cloud of dust and gas. They are considerably smaller than a galaxy and in some nebulae, such as the Orion nebula, they are regions of star formation. Planetary systems may form from the remaining dust.

The constellation Orion. Part of this constellation is also commonly known as the Saucepan.

Not all nebulae glow. Some of them absorb light from nearby stars and appear as dark spots in the sky. One of these dark nebulae can be seen in the Southern Cross constellation as a dark patch to its lower left. It is known as the Coal Sack.

The Southern Cross and the Pointers. The Coal Sack Nebula is the dark patch to the lower left of the Southern Cross.

The Eagle nebula, often called the 'pillars of creation'. Within this region of dust and gas, new stars are forming.



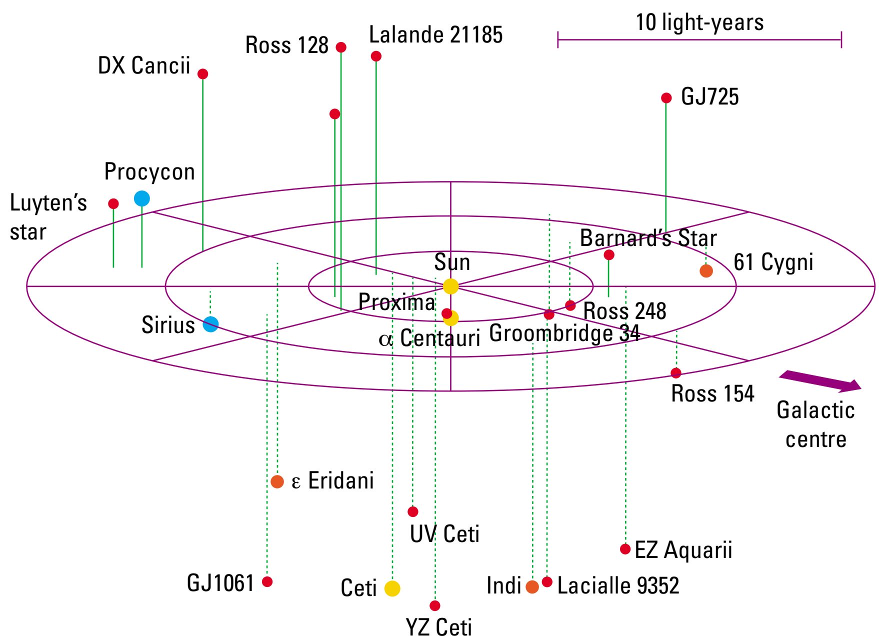
The solar system, including the major planets and dwarf planets. The size of the sun and planets are to scale but not the distances between them.

Size and scale of the universe

The universe is so large, it is difficult to comprehend the size and scale of the varied structures making up the universe. To begin with, the solar system consists of 8 planets and several dwarf planets, including Pluto. The distance to the outermost planet, Neptune, is 4.2 light hours while the distance to the nearest star, Proxima Centauri, is 4.2 light-years or almost 9000 times farther away.

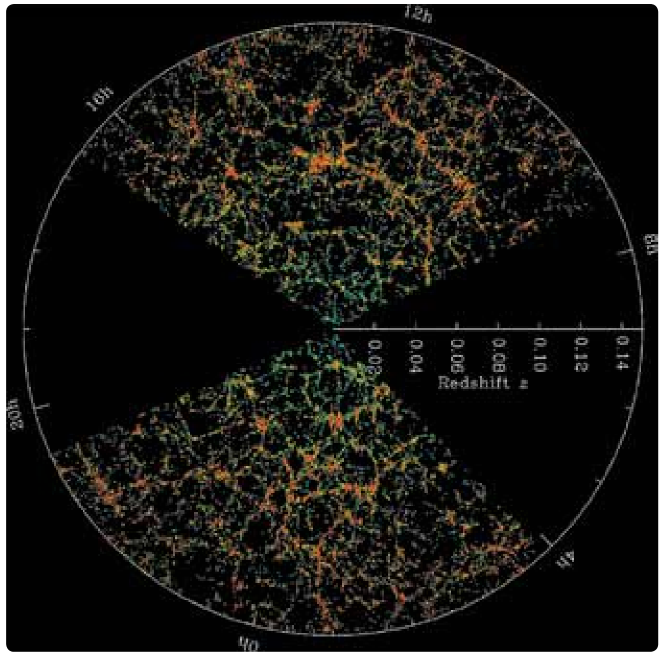
There are numerous stars within 10 light-years of the sun including Proxima Centauri, Alpha Centauri and Sirius. Their close proximity generally means that they are the brighter stars in the night sky. These neighbouring stars generally move with the sun in its orbit around the centre of the Milky Way Galaxy.

As illustrated earlier, the sun and neighbouring stars are located on the Orion arm of the Milky Way, a spiral galaxy with a diameter of 100 000 light-years. The illustration opposite shows our local galactic

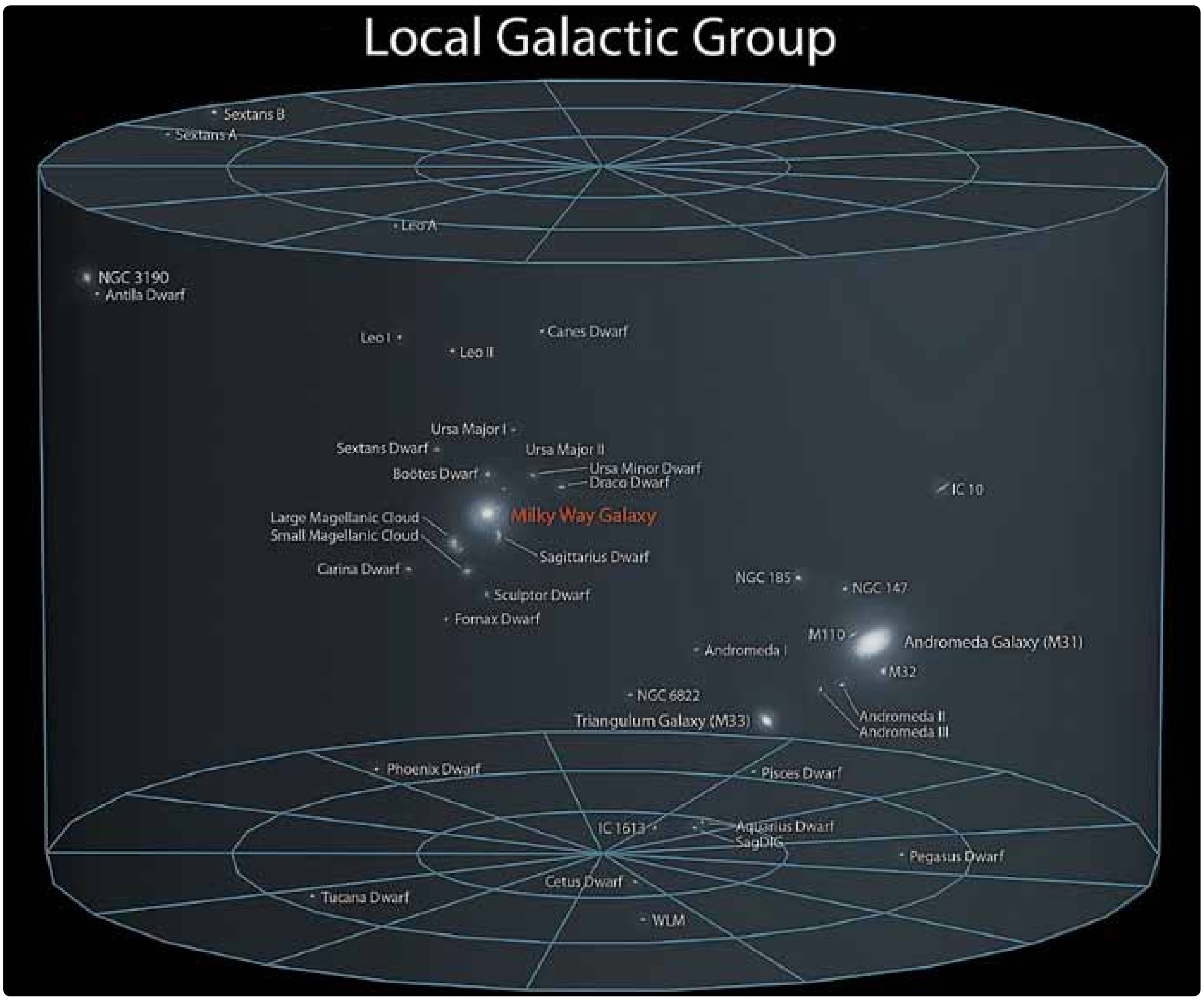


Our neighbouring stars, located within 10 light-years of the sun neighbourhood, called the Local Group, a collection of more than 30 galaxies within approximately 4 million light years of the Milky Way and gravitationally bound together. Two spiral galaxies, the Milky Way and Andromeda, are the two largest members of the Local Group which also includes many dwarf galaxies such as the Magellanic clouds.

Telescopes that are able to peer into the farthest reaches of the universe reveal a web-like structure to the universe with clusters of galaxies surrounded by voids of low density matter, mainly of hydrogen containing no galaxies. The observable universe is 27 billion light-years in size and contains over 100 billion galaxies!



The plane of the Milky Way Galaxy obscures our view of what lies beyond. This creates the wedge-shaped gaps in all-sky galaxy surveys such as those shown here. These surveys indicate a clumped distribution of galaxies.



The solar system and Milky Way Galaxy in relation to our Local Group of galaxies

INVESTIGATION 10.9

The scale of the universe

AIM To develop a scale that models the distances in the universe

You will need:
trundle wheel (if available)
Blutak

- Make 9 large cardboard labels, one for the Earth and one for each celestial object listed below.
- Copy the table below and calculate the relative distance from the Earth to each celestial object assuming a scale:

1.0 m = 1000 light-years
So that 1 cm = 10 light-years

The first distance has been calculated for you.

Celestial object	Distance from Earth	Relative distance from Earth
Neptune (the outermost major planet of the solar system)	4.0 light hours	<1 mm
Proxima Centauri (nearest star to Earth)	4.2 light-years	
Sirius (brightest star in the night sky)	8.7 light-years	
Rigel (brightest star of the constellation Orion)	780 light-years	
Orion nebula (closest star forming nebula to Earth)	1340 light-years	
Centre of the Milky Way	38 000 light-years	
Large Magellanic Cloud (closest galaxy to the Milky Way)	160 000 light-years	
Andromeda Galaxy (closest spiral galaxy to the Milky Way)	2 200 000 light-years	

- Blutak the label of the Earth at the starting point and walk the correct scale distance to each celestial object using the trundle wheel. Blutak each label at the appropriate point. If a trundle wheel is not available, assume each pace is 1 m in length. You may run out of space for the last couple of celestial objects!

DISCUSSION

1. **Were you surprised at the relative distances to any of the celestial objects?**
2. **Explain how this modelling exercise assists with understanding the scale of the universe.**

ACTIVITIES

REMEMBER

1 **Define** the term 'light-year' and identify the number of kilometres in a light-year.

2 **Identify** how big the universe is thought to be.

3 (a) **Identify** three types of galaxies.
(b) Name an example of each type of galaxy.

4 **Identify** the diameter of the Milky Way Galaxy.

5 **Outline** where we are located within the Milky Way Galaxy.

6 **Identify** the force that holds the stars together within a galaxy or nebula.

7 Name the galaxy closest to our own.

THINK

8 **Explain** why looking at stars is like looking back in time.

9 Arrange these astronomical objects from largest to smallest: galaxy, moon, universe, planet, star, nebula.

10 **Explain** why we can see the Milky Way in the night sky even though we are within this galaxy.

11 Write your address in the universe by stating your:
- suburb
- state
- country
- planet
- planetary system
- region within the galaxy
- galaxy
- galaxy cluster.

USING DATA

12 The estimated distances from Earth to some stars and galaxies are listed below. **Calculate** how long it would take to reach each of them, travelling at the speed of light (about 300 000 km/s).

Sun	Our own star	1.5×10^{8} km
Proxima Centauri	The closest star after the sun	4.0×10^{13} km
Centre of Milky Way	Our own galaxy	2.5×10^{17} km
Magellanic Clouds	One of the closest galaxies	1.5×10^{18} km
Andromeda Galaxy	One of the closest galaxies	1.4×10^{19} km
Quasars	Very distant objects	1.4×10^{23} km

IMAGINE

13 **Describe** the difficulties we would have if we tried to communicate by radio with civilisations on planets orbiting even the stars closest to Earth.

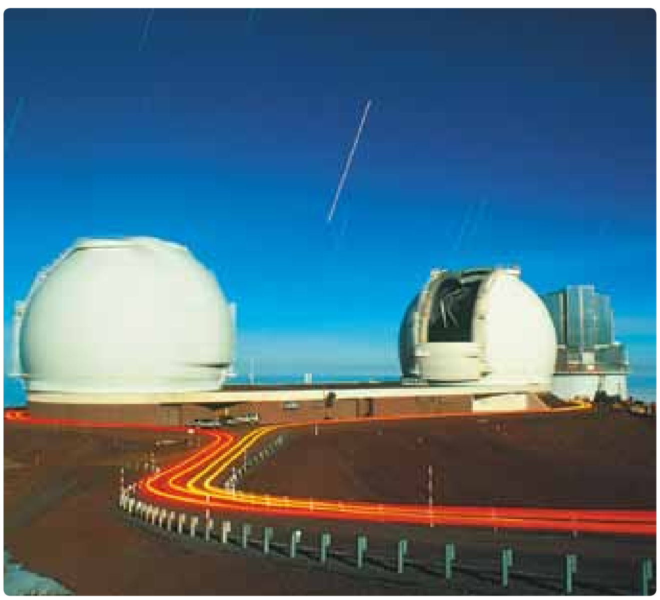
14 Is it likely that a spacecraft from Earth will ever venture out to planets orbiting the closest stars? Present some calculations to support your answer.

Eyes on the skies

Smarter optical telescopes

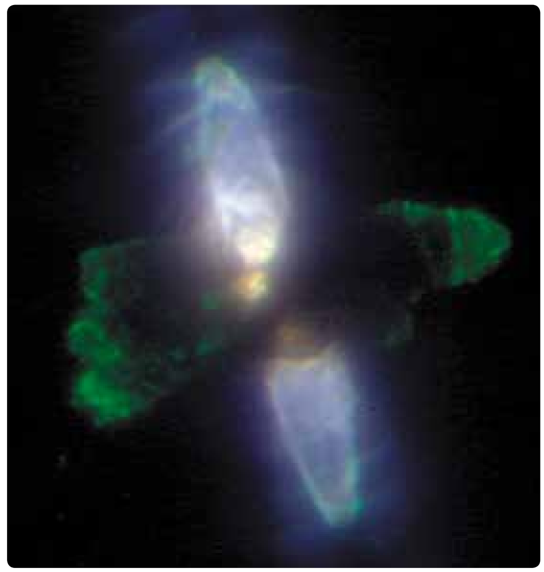
Our understanding of the variety of celestial objects in the universe relies on astronomers' ability to make observations and to collect data from them. Galileo constructed and used one of the first telescopes in the early 1600s and with it described the crater surfaced moon. He also discovered the moons of Jupiter which compelled him to reject the well accepted geocentric (Earth-centred) model of the universe.

Today optical telescopes are much more sophisticated; they utilise mirrors rather than glass lenses and so are able to exceed 10 m in diameter. Large diameter telescopes have the potential to see more distant objects as they have greater sensitivity, or light collecting capacity. Observatories are generally located at high altitude on mountain ranges to minimise the distortion of images resulting from light passing through the atmosphere, and generally far from urban centres to escape light pollution.



The Keck I and II optical telescopes in Hawaii are amongst the largest in the world.

The Keck observatory for example is located at an altitude of 4100 m in Hawaii and consists of two 10 m optical telescopes. Even at this altitude, images of distant objects are blurred somewhat by the atmosphere. Engineers have developed a technology called adaptive optics which eliminates the image distortions by measuring and then correcting for the atmospheric effects using a deformable mirror that changes shape 2000 times per second. As a result the Keck telescopes are able to produce sharp images of celestial objects.



The formation of a planetary nebula captured by the Keck observatory. A dying star is shedding its outer layers in the final stages of its life.

INVESTIGATION 10.10

Looking for detail

AIM To compare the resolution of optical instruments and the naked eye

Background

Wider diameter telescopes not only collect more light and so can see deeper into the universe but they also provide better resolution, or ability to see finer detail. Telescopes with good resolution are able to distinguish close objects in the night sky as separate and distinct.

The diameter of the lens of our eye is approximately 10 mm. In this experiment you will be comparing the resolution of the eye with optical instruments such as binoculars and the telescope.

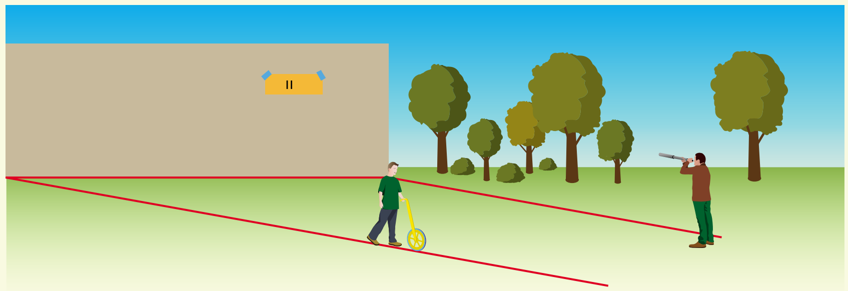
You will need:

A4 sheet of cardboard
ruler
trundle wheel
optical telescope
thick black marker
sticky tape
pair of binoculars

- Measure and record the diameter of a lens or a mirror of the binoculars and the telescope. Record this data along with the diameter of the human eye.
- On a sheet of cardboard draw two thick black lines approximately 2 cm long and with a gap of exactly 2 mm between them. These lines represent two stars that appear close to one another in the night sky.
- Tape the sheet of cardboard to a wall or bench in open space in the playground.
- Position a member of your group as an observer, some distance from the 'stars' so that when viewed with the naked eye they appear as one single star.
- Ask the observer to slowly walk towards the stars until they appear as two separate and distinct objects. At this point, use a trundle wheel to measure the distance between the observer and the stars.
- Repeat this experiment with the assistance of binoculars and the telescope.
- Record all your data in a suitable table and present it in an appropriate graph.

DISCUSSION

1. **Which instrument provided the greatest resolution? Support your response with suitable data.**
2. **What advantages does a large diameter telescope provide when viewing the night sky?**
3. **Explain why the diameter of a telescope is not the only factor to consider when building a telescope and locating an observatory.**



Making use of the spectrum

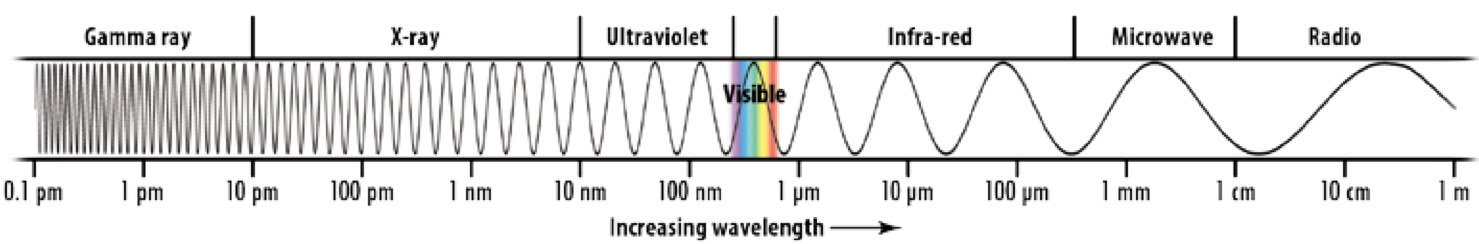
Relying on optical telescopes that detect only visible light would not provide astronomers with a complete picture of the universe. Many celestial objects do not emit radiation in the visible range and so would be invisible if it were not for the development of telescopes that detect other frequencies of electromagnetic radiation. For example, black holes, the remnants of large stars, do not emit visible light. However, astronomers can locate them by detecting X-rays emitted by material in the immediate environment of the black hole.

Ultraviolet light reveals hot stars and quasars while visible light allows us to image hot stars, planets, nebulae and galaxies. In the infra-red we see cool stars, regions of star birth and cool dusty regions of space. Radio waves are unimpeded by the dust in our galaxy so they can be used to detect other galaxies unable to be seen by optical telescopes behind the centre of our galaxy.

Detecting radio waves

Until the accidental discovery in 1931 that stars emitted radio waves as well as light, the only way to observe distant stars and galaxies was with optical telescopes. Like light and other forms of **electromagnetic radiation**, radio waves travel through space at a speed of 300 000 km per second. Radio waves from deep in space are collected by huge dishes and reflected towards a central antenna. The waves are then analysed by a computer, which produces an image that we can see. **Radio telescopes** can also detect tiny amounts of energy. In fact, the total amount of energy detected in ten years by even the largest radio telescopes would light a torch globe for only a fraction of a second. Radio telescopes can also detect signals from much further away than light telescopes can.

Unlike visible light, radio waves can travel through clouds in the Earth's atmosphere, and can be viewed in daylight as well as night. Radio waves also pass through clouds of dust and gas in deep space.



The electromagnetic spectrum

The Arecibo dish in Puerto Rico is the largest single radio telescope in the world. It is 305 m across.

Sharpen up!

Images produced by individual radio telescopes are not very sharp. To solve this problem, signals from groups of telescopes pointed at the same object are combined to produce sharper images.

Learning from radio waves

Many celestial objects emit radio waves but this wasn't discovered until 1932. Today, radio telescopes are used to study giant clouds of dust and gas as well as stars and galaxies. By studying the radio waves originating from these sources, astronomers can learn about their composition, structure and motion. Radio telescopes have the advantage that sunlight, clouds and rain do not affect observations.

Radio waves have, among other things, allowed us to:

- analyse the distribution of stars in the sky
- discover **quasars**, which, before 1960, were believed to be normal stars. They are like stars, but emit a lot more radiation and are travelling away from us at huge speeds. Quasars are believed to be the most distant objects in the universe.
- discover **pulsars**, which are huge stars that have collapsed, emitting radio waves. Because pulsars spin rapidly — a bit like a lighthouse — the radio waves reach the Earth as radio pulses.

The Australia Telescope Compact Array in Narrabri, rural New South Wales, consists of six 22 m dishes used for radio astronomy. The dishes work together which allows them to capture images with much finer detail, equivalent to that possible with a single radio telescope of much larger diameter.

Space telescopes

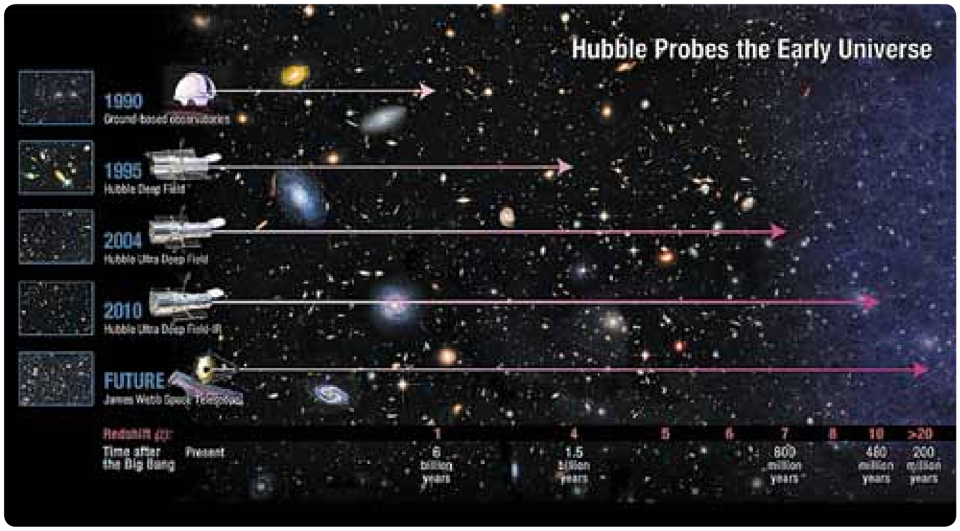
Visible light and radio waves are the only two frequencies within the electromagnetic spectrum that penetrate the Earth's atmosphere to any large extent, allowing us to place optical and radio telescopes on the ground. The remaining types of radiation are filtered out by the atmosphere. Ultraviolet light for example is absorbed by ozone in the atmosphere. So, to place X-ray or infra-red telescopes on the ground would be fruitless. Rather, astronomers have teamed up with space agencies like NASA and the European Space Agency (ESA) to launch telescopes in orbit around the Earth (beyond the atmosphere) and within space probes travelling throughout the solar system and beyond.

Space telescopes utilising the electromagnetic spectrum

EM radiation detected	Celestial objects studied	Space telescopes (and launch date)
Gamma rays	Supernovae, neutron stars, pulsars and black holes	• Compton Gamma-Ray Observatory (1991) • Swift Gamma Ray Burst Explorer (2004)
X-rays	Galaxy clusters, black holes and neutron stars	• Chandra X-ray Observatory (1999) • Nuclear Spectroscopic Telescope Array (2012)
Ultraviolet light	Galaxies, the sun and other stars	• International Ultraviolet Explorer (1978) • Hubble Space Telescope (1990)
Visible light	Stars, galaxies, planetary nebulae etc.	• Hubble Space Telescope (1990) • Kepler Space Probe (2009)
Infra-red light	Cooler stars (including brown dwarves), active regions of star formation and nebulae	• Spitzer Space Telescope (2003) • Hubble Space Telescope (1990) • James Webb Space Telescope (JWST) (2015)
Radio waves	Clouds of gas in interstellar space, supernova remnants such as pulsars (rapidly spinning neutron stars)	• Cosmic Background Explorer (1989) • RadioAstron (2011)

The Hubble Space Telescope is the only telescope designed to be serviced in space by astronauts. Between 1993 and 2009, five missions repaired, upgraded and replaced systems on the telescope.

The Cat's Eye nebula, a composite image utilising optical data from the Hubble Space Telescope and X-ray emissions captured by the Chandra X-ray telescope. The blue-purple hues near the nebula's centre indicate intense X-rays expelled from the dying star as it approaches the planetary nebula phase of its evolution. It is located 3000 light-years from Earth.



Modern space telescopes can see deeper into the early universe.

ACTIVITIES

REMEMBER

1 **Outline** some of the astronomical discoveries made by Galileo through the use of his early telescope.

2 **Describe** two key developments in optical telescopes that have allowed astronomers to view more distant objects more clearly from ground-based telescopes.

3 **Explain** why orbiting telescopes such as the Hubble Space Telescope provide a significant advantage when viewing distant stars and galaxies.

4 **Identify** the components of the electromagnetic spectrum from highest frequency to lowest frequency.

5 **Explain** why is it important for telescopes other than optical telescopes to be built and used by astronomers.

6 **Identify** an example of:
(a) an X-ray telescope
(b) a UV telescope
(c) a radio telescope based in Australia.

THINK

7 (a) **Explain** why the location of the Sydney observatory, near the centre of the city, is not optimal for astronomical viewing.
(b) With this in mind, why would it have been built there?

8 On the weekend Sally sampled two telescopes that she was thinking of purchasing. With telescope A she could distinguish the two stars in a binary system 25 light-years away, while looking through telescope B, they seemed to be a single star. However, with telescope B she could see a nebula 50 light-years away while through telescope A the same area looked pitch black. **Compare** these two telescopes using the terms resolution and sensitivity.

9 **Explain** why X-ray telescopes and UV telescopes are placed in orbit rather than based on the ground.

10 What type of telescope would astronomers use if searching for a:
(a) black hole
(b) region of star formation within a nebula
(c) cool star.

USING DATA

11 How long would it take visible light to travel from our nearest neighbouring star, Proxima Centauri, 4.2 light-years away to an optical telescope on Earth?

INVESTIGATE

12 Create a poster or multimedia presentation to showcase the Hubble Space Telescope. The purpose of your presentation is to **describe** the history of the program, the key astronomical findings and to **justify** the billions of dollars involved in building, launching and supporting the orbiting space telescope.

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work sheet 10.5 Telescopes

The evolving universe

Has the universe always existed, or does it have a beginning and an end? If there was a beginning to the universe, how did it come into being? The study of the origins and evolution of the universe is called cosmology.

The big bang

The 'big bang' is the most widely accepted theory for the origin and evolution of the universe. In the big bang theory, the universe is thought to have come into existence about 13.7 billion years ago, creating time and space.

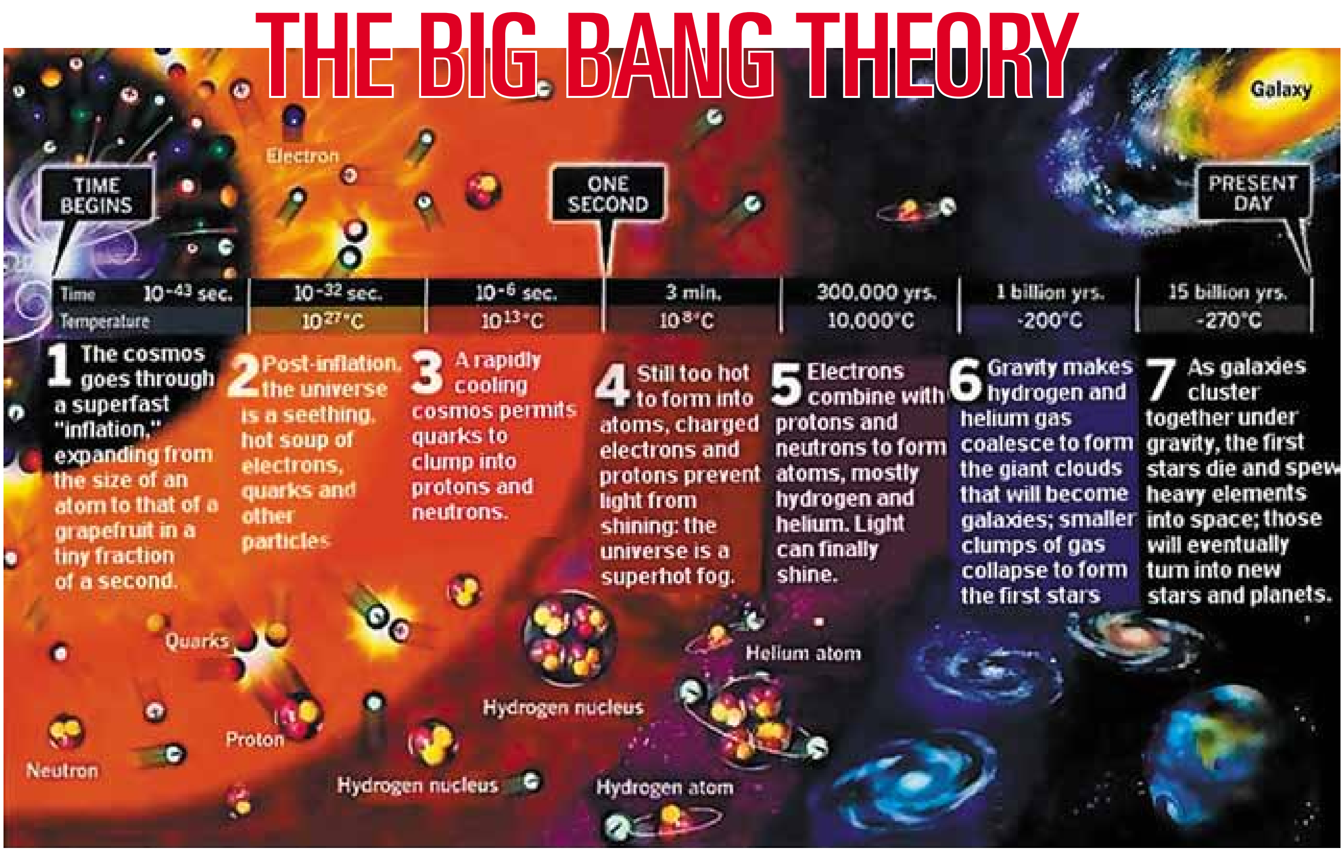
According to the big bang theory, in the beginning the universe was thought to have been concentrated into a single point of immense energy. An explosion within the first split second converted some of this energy to the simplest form of matter, particles such as quarks which are the building blocks of protons and neutrons. Over time, the universe expanded and cooled and more complex matter such as hydrogen atoms was formed. Stars formed from the gravitational attraction of hydrogen leading to the development of the complex universe we observe today.

Evidence supporting the big bang theory

Supporters of the big bang theory point to three main pieces of scientific evidence to support their model:

1. There is evidence that the universe is expanding: galaxies are moving further apart, leading scientists to conclude that the galaxies were once closer together before some kind of explosion.
2. It explains the abundance of hydrogen, helium and other elements in the universe.
3. Astronomers have observed the cosmic background radiation throughout the universe, the afterglow of the big bang explosion.

Let us examine this evidence in more detail.



The expanding universe

The Doppler effect

Evidence that the universe is expanding is based on measuring the movement of stars and galaxies away from the Earth using the Doppler effect. Christian Johann Doppler was an Austrian physicist who noted the change in pitch that results from a source of sound approaching or moving away. We often hear the same effect when a high-speed train or aeroplane passes us or when we hear the pitch of a fire-engine's siren change as the fire-engine goes by.

Doppler suggested that this changing pitch in sound waves might be seen in light as well. He predicted that the Doppler effect would produce a change in the frequency of light waves emitted from a moving source. The French physicist Armand Fizeau suggested that this change in frequency might be seen by comparing the spectrum of light from a moving source with that from a stationary one.

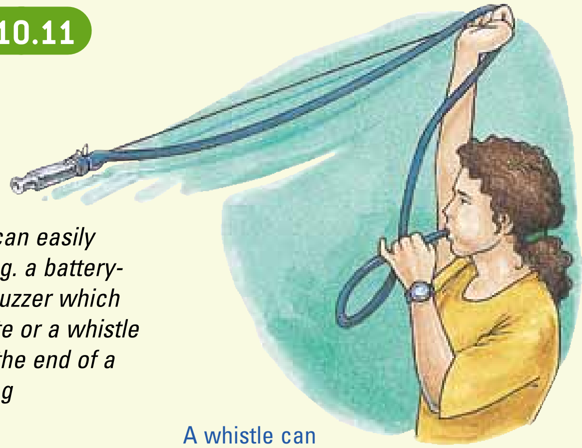
INVESTIGATION 10.11

The Doppler effect

AIM To observe the Doppler effect

You will need:

a source of sound that can easily be spun in a circle, e.g. a battery-powered electronic buzzer which produces a single note or a whistle fastened securely in the end of a length of rubber tubing
a length of strong string
a partner



A whistle can be used as a rotating sound source.

- Ask your partner to spin the sound source around in a circle on the end of the piece of string. If you are using a whistle, your partner should blow through the attached rubber tubing to produce a sound. Listen carefully to the note produced.

CAUTION *Take care while spinning the source. Ensure that the string is strong enough and that no-one is in the path of the rotating source of sound.*

DISCUSSION

1. **What can you hear happening to the pitch of the buzzer?**
2. **When is the pitch highest? When is it lowest?**

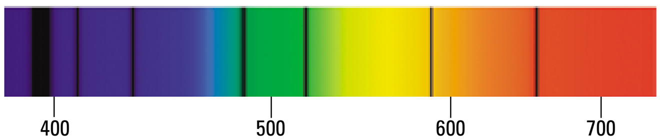
As the train approaches, the sound waves reaching you are bunched up. The frequency is higher and you hear a higher pitch.

As the train speeds away, the sound waves reaching you are more spread out. The frequency is lower and you hear a lower pitch.

The spectra of stars

Stars on the move

When the **spectrum** of the light from a star is analysed, some dark lines are observed. These dark lines correspond to colours of light that have been absorbed by substances in the star. Different substances absorb different colours of light. By identifying the wavelengths of the colours missing from the spectrum, astronomers can find out which elements are present in the star.



The spectrum of white light from a nearby star. The black lines show which colours have been absorbed by elements in the star. The numbers on the scale indicate the wavelength of the light in nanometres. A nanometre is 10^{-9} metre.

In many cases, the black lines, or missing colours, in the spectra of stars are shifted from their expected positions. A shift to lower or 'redder' frequencies is called a **red shift** and results from a star's movement away from the Earth. A shift to higher or 'bluer' frequencies is called a **blue shift** and is caused by a star's movement towards the Earth.

INVESTIGATION 10.12

Observing spectra

AIM To observe the spectrum produced by a fluorescent light

You will need:

hand-held spectroscope *fluorescent light*

- Aim the spectroscope at a fluorescent light in the room.
- Observe the bright spectral lines visible in the spectroscope; at least three should be visible.
- Record the wavelength of each of these lines by reading their position on the scale provided in the spectroscope. Units may not be provided with your scale so for values between 4.0 and 8.0, the wavelength will range from 4.0×10^{-7} to 8.0×10^{-7} metres.

DISCUSSION

1. **The spectral lines observed were bright emission lines rather than black absorption lines produced by stars but they still act as a 'fingerprint'. What might this fingerprint indicate about the fluorescent light?**
2. **If the fluorescent light were moving away from you at fast speed, how would the spectral lines differ to those observed from a stationary fluorescent light?**

Retreating galaxies

On a much larger scale, the study of the Doppler shift of galaxies provides us with an amazing picture of the universe. Galaxies within our local group, including the nearby Andromeda Galaxy, are moving slowly towards our own due to gravity. The other, more distant galaxies are moving away from us at a considerable speed. Even more extraordinary is the relationship between the size of the red shift and the distance from Earth. This was first investigated by the astronomer Edwin Hubble and is now referred to as Hubble's law. This law states that the further away a galaxy is, the greater is its red shift and so the faster it is moving away from us.

While this finding appears to put the Earth in a very special position at the centre of a rapidly expanding universe, it is in fact an illusion. Observers anywhere in the universe will see the surrounding galaxies moving away from them at a speed that is consistent with Hubble's law.

Elements in the universe

The amounts of hydrogen and helium in the universe support the big bang theory. According to earlier theories, the only way that helium can be produced is by the nuclear fusion reaction taking place in stars. Almost 10% of the atoms in the universe are helium and the remainder mainly hydrogen. This is far more than could be produced by the stars alone. The percentage of helium atoms can, however, be explained by their synthesis as a result of the big bang.

The afterglow

When George Gamow and Ralph Alpher proposed their version of the 'big bang' theory in 1948, they calculated that the universe now, about 13.7 billion years after creation, would have a temperature of 2.7 °C above **absolute zero**. That's −270 °C. Anything with a temperature above absolute zero emits radiation. The nature of the radiation depends on the temperature. Gamow predicted that, because of its temperature, the universe would be emitting an 'afterglow' of radiation. This afterglow became known as 'cosmic microwave background radiation'.

This radiation was discovered by accident in 1965. Engineers trying to track communications satellites picked up a consistent radio noise that they couldn't get rid of. The noise wasn't coming from anywhere on Earth, because it was coming from all directions out in space. In fact, it was the cosmic microwave background radiation predicted by Gamow. Its discovery put an end to the steady state theory, leaving the big bang theory as the only theory supported by evidence currently available. Even Fred Hoyle, who had ridiculed the idea of a 'big bang', admitted that the evidence seemed to favour the big bang theory.

'Mapping' the universe

In 1989, a satellite named COBE (COsmic Background Explorer) was put into orbit around Earth to accurately measure the background radiation and temperature of the universe. COBE could detect variations as small as 0.000 03 °C. As predicted by Gamow, it detected an average temperature of −270 °C.

In 2001, a probe called WMAP (Wilkinson Microwave Anisotropy Probe) was sent into orbit around Earth at a much greater distance to gather even more accurate data, detecting temperatures within a millionth of a degree. WMAP's first images were released by NASA in February 2003.

The computer-enhanced image of cosmic microwave background radiation shown at left was produced by the WMAP mission. The background radiation detected was released only 380 000 years after the big bang — the first radiation to escape. The image shows how the temperature varied across the universe as it was 380 000 years after the big bang. The blue parts of the map are the

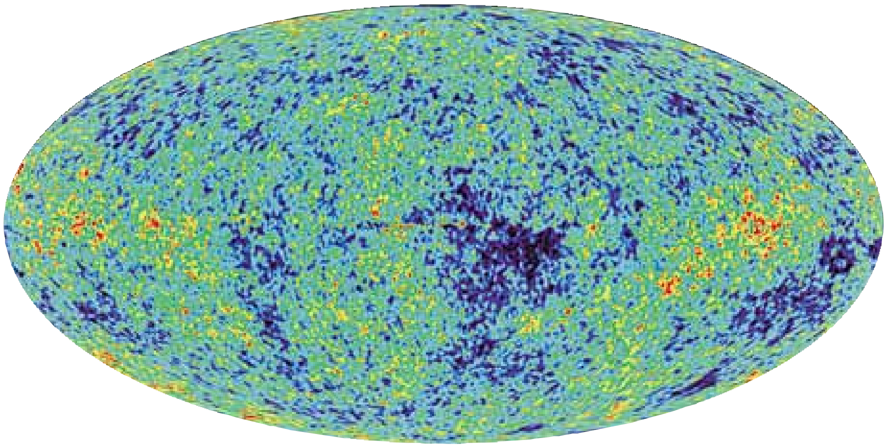
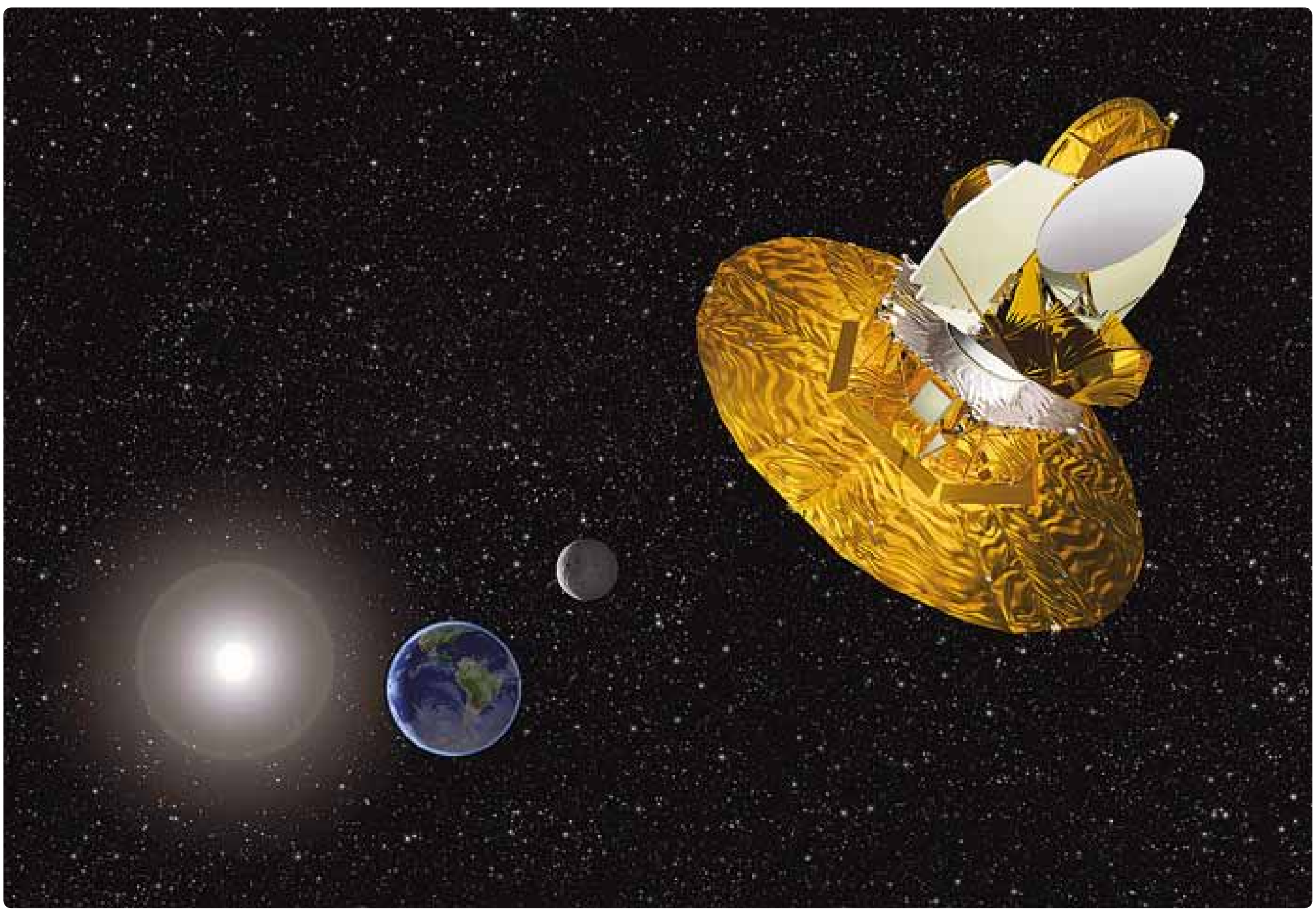


Image of cosmic microwave background radiation taken by the space probe below



The Wilkinson Microwave Anisotropy Probe (WMAP). Its main mission was to gather evidence to help cosmologists find out how the universe began and predict what will happen in the future.

cooler regions. These regions were cool enough for atoms, and eventually galaxies to form. The red parts are warmer regions. The map shows that galaxies are not evenly spread throughout the universe. They support the theory of an expanding universe that began with a big bang.

INVESTIGATION 10.13

The expanding universe

AIM **To model the expanding universe**

You will need:
a round party balloon
a felt tip marker

- Draw evenly spaced dots all over the outside surface of the uninflated balloon. The dots should be about 1 cm apart from each other.
- Inflate the balloon by blowing three breaths into it. Hold the opening so air doesn't escape and observe the spacing between the dots.
- Keep inflating the balloon and observe how the spacing between the dots is affected.

CAUTION ***Do not over inflate the balloon!***

DISCUSSION

1. **Describe what happened to the distances between the dots as the balloon got bigger.**
2. **This can be used to model the expansion of the universe. In what ways is this is an accurate model? What aspects of the expansion of the universe are not represented very well?**

HOW ABOUT THAT!

The 'big bang' theory would not make any sense at all if it were not for Albert Einstein's famous equation. How could matter be created from 'nothing'? Well, the singularity before the big bang was not 'nothing'. It was a huge amount of energy (with no mass) concentrated into a tiny, tiny point.

Einstein proposed that energy could be changed into matter. His equation $E = mc^2$ describes the change, where:

E represents the amount of energy in joules

m represents the mass in kilograms

c is the speed of light in metres per second (300 000 000 m/s).

Einstein's equation also describes how matter can be changed into energy. That is what happens in nuclear power stations and nuclear weapons.

Steady state or big bang?

Until the early 1900s, astronomers had assumed that the universe was fixed in size. The work of a number of physicists in the early 1900s opened up the possibility of an expanding universe.

In 1915 Einstein formulated his famous general relativity theory that describes the nature of space, time, and gravity. This theory allows for expansion or contraction of the fabric of space. In the 1920s Willem de Sitter and Aleksandr Friedmann independently applied this theory to the entire universe and hypothesised that the universe could be expanding. To account for this expanding universe, Georges Lemaître, a Belgian astrophysicist and Catholic priest imagined all matter initially contained in a tiny universe and then exploding.

Around the same time that the idea of an expanding universe was seriously being considered by the astronomical community, Vesto Slipher collected the first piece of evidence supporting it. He observed the red shift of many spiral galaxies, indicating that they were moving away from us. Further, in 1929 Hubble discovered that galaxies further away were moving away from us at higher speeds. This suggested that the further back in time we go, the smaller the universe was.

In the late 1940s, George Gamow, an American physicist, conceived of the big bang theory as we know it today but it was certainly not universally accepted by physicists. In 1948 Sir Fred Hoyle and others developed an alternative model of the universe that did not start in a massive expansion. Their 'steady state' theory accepted that the universe is expanding but it proposed that matter is continuously created, as it is in stars today, at a rate that keeps the average density of the universe the same as it expands. Interestingly, it was Hoyle who coined the term 'big bang' in an attempt to ridicule the idea that the universe had a beginning. Supporters of steady state theory pointed to the rate of expansion of the universe that had been measured by 1948 which, when calculated backward to an initial big bang, gave an age for the universe of only a few billion years, well below the known age of the solar system. Assuming these calculations were correct, this posed a problem for the proponents of the big bang theory.

In steady state theory the expansion of the universe comes from the continuous creation of the element hydrogen throughout the universe. This hydrogen eventually gathers and condenses into stars. Through nuclear fusion of hydrogen in their cores, stars create all the heavier elements. As stars age, die and explode, they scatter the heavier elements around the galaxies. Consequently, a steady state universe does not change over time even though stars and galaxies are continuously forming within it.

In contrast, the evolutionary model envisaged by Gamow in his big bang theory proposed that the explosion at the birth of the universe created all hydrogen and some helium. These elements formed as the blast expanded and cooled and the first stars were made from this original hydrogen and helium. Those stars fused those original elements into new, heavier elements. These heavier elements were then scattered through the galaxies as the first stars died and led to the more complex mixtures of elements seen in stars now.

Problems with steady state theory began to emerge in the late 1960s, as observations surfaced supporting the idea that the universe was in fact evolving. Quasars were found only at large distances, therefore existing only in the distant past and not in closer galaxies. While the big bang theory predicted as much, steady state theory predicted that such objects would be found everywhere, including close to our own galaxy.

For most cosmologists, rejection of steady state theory came with the discovery in 1965 of the cosmic microwave background radiation, the afterglow of the big bang. Although steady state theory is largely discredited today, proponents of this theory in the 1950s and 1960s did push supporters of the big bang theory to support their theory with scientific evidence.

ACTIVITIES

REMEMBER

1 **Define** the science of 'cosmology'.

2 How old is the universe believed to be?

3 According to the big bang theory, **describe** what was there at the time of the big bang.

4 **Recall** approximately how long after the big bang:
(a) matter appeared
(b) protons and neutrons formed
(c) atoms first existed
(d) galaxies began to form.

5 **Identify** three major pieces of evidence that supported the big bang theory.

6 **Explain** why there are black lines in the spectra of the light emitted by stars.

7 **Recall** which colour of light has the higher frequency — red or blue.

8 **Define** the term 'red shift'. What does it tell us about how a star is moving relative to the Earth?

9 **Explain** what Einstein's famous equation has to do with the big bang theory.

10 **Explain** how steady state theory could accept that the universe was expanding, yet remained the same.

11 **Describe** the evidence that put an end to steady state theory.

THINK

12 The light from a star is often analysed by its wavelength instead of its frequency. Long wavelengths correspond to low frequencies and short wavelengths correspond to high frequencies. The spectrum of colours emitted by excited atoms of hydrogen on Earth contains the wavelength 6562.85 angstroms ($1\ \text{Å} = 1 \times 10^{-10}$ m). This same wavelength is observed in the spectrum of light from the bright star Vega at 6562.55 Å. Is Vega moving towards or away from Earth? **Explain** your answer.

13 WMAP is able to provide a picture of the universe as it was 380 000 years after the big bang. **Explain** why it is unable to provide a map of the universe as it was before that time.

14 **Justify** why scientists go to the expense of measuring background radiation with a satellite or space probe when it could be done from Earth.

15 Scientific theories are contested and refined over time by the scientific community. **Explain** why steady state theory was once well accepted by many physicists but it became discredited over time in preference to the big bang theory.

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16 Test your understanding of red shift and blue shift by completing the **Shifting spectral lines** interactivity in your eBookPLUS. **int-0678**

To find out more about the WMAP mission, including data and images obtained since the publication of this book, use the **WMAP** weblink in your eBookPLUS. Using the information obtained from the website answer the following questions.

17 What is the average temperature of the universe as measured by WMAP?

18 When were the first stars formed?

19 According to WMAP, how old is the universe, and how accurately is its age known?

20 Enhance your understanding of the model of the universe expanding like a balloon by using the **Expansion of the universe** interactivity in your eBookPLUS. **int-0057**

work sheets
10.6 The big bang theory
10.7 The expanding universe

LOOKING BACK

assess on

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FOCUS activity

Option 1

Governments are often looking for opportunities to cut funding to scientific institutions involved in pure research such as astronomical observatories. Create a display for an astronomical exhibit that helps to justify the use of public funding to support astronomy. Your exhibit should showcase the use of technology to advance our understanding of the universe. Illustrate the variety of advanced telescopes used to collect information about the diverse celestial objects in the universe.

Option 2

Create an historical exhibit or multimedia presentation to demonstrate how scientific thinking about the origin of the universe is refined over time. Describe the contribution of key physicists in developing our understanding of the origins and evolution of the universe and the evidence used to influence thinking. Research some of the more credible theories on how the universe may end. For example, examine whether physicists think that the universe will continue expanding.

Access more details about focus activities for this chapter in your eBookPLUS.

doc-10666

1 Give two reasons why a particular star would appear brighter than others in the night sky.

2 **Explain** why stars appear to twinkle.

3 Why do the positions of stars change over the course of a night's viewing?

4 The stars in a constellation are located close to each other. Do you agree? **Explain**.

5 (a) How old is the sun?
(b) How long before it reaches the end of its life?
(c) What will the sun become after it leaves the main sequence?

6 Draw a flow chart to outline the life cycle of a large star.

7 **Outline** how the colour of a star depends on its temperature.

8 **Distinguish** between the apparent magnitude of a star and its absolute magnitude.

9 **Contrast** a nebula and a planetary nebula.

10 (a) How are galaxies classified?
(b) In what category does the Milky Way Galaxy belong?

11 Where is the solar system located in the Milky Way?

12 Exoplanets, or planets beyond the solar system, are generally too small to be seen by direct observation. **Describe** how these planets are discovered.

13 Why do galaxies throughout the universe appear to be clumped, rather than evenly distributed?

14 **Outline** how optical telescopes can be designed and located to maximise the clarity of the images seen.

15 **Explain** why it is important for astronomy to utilise telescopes that detect a range of frequencies across the electromagnetic spectrum, not just visible light.

16 **Explain** why only optical telescopes and radio telescopes can be located on the ground.

17 New generations of space telescopes can see further and further into the universe. **Explain** why this allows astronomers to view the universe early in its evolution.

18 **Describe** the big bang theory.

19 The visible light spectrum emitted by stars can be analysed with an instrument called a spectroscope.
(a) **Explain** why the visible light spectrum from stars has some black lines in it.
(b) When the visible spectrum of a glowing fluorescent light tube is viewed on Earth, **describe** what information about the tube can be obtained from the positions of the bright lines.
(c) What happens to the black lines in the spectrum of a star if there is a red shift?
(d) What does a red shift in the spectrum of a star tell us about the star?

20 (a) What is the cosmic background radiation?
(b) How does it provide evidence of the big bang?

21 Steady state theory was accepted by many physicists prior to 1965.
(a) **Contrast** the steady state and big bang theories.
(b) **Explain** why steady state theory lost favour with many physicists after 1965.

TEST YOURSELF

1 A galaxy is defined as:
A a glowing cloud of gas and dust.
B a region of star formation.
C a concentration of stars, gravitationally linked.
D a ring of expanding gas. (1 mark)

2 **Identify** which of the following sequences best describes the life cycle of a medium sized star.
A Red giant, main sequence star, protostar, supernova
B Main sequence star, red giant, supernova, protostar
C Protostar, red giant, main sequence star, black hole
D Protostar, main sequence star, red giant, supernova
(1 mark)

3 Which of the following theories accounts for how the universe began?
A The big bang theory
B The Doppler effect
C General relativity
D Hubble's law (1 mark)

4 Stars that are red shifted:
A are becoming redder.
B are moving away from the solar system.
C have more spectral lines in the red region of the visible spectrum.
D have depleted the hydrogen in their core. (1 mark)

5 Use the big bang theory to account for how the universe originated and has evolved over time. **Describe** the evidence used to support this theory. (6 marks)

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work sheets

10.8 The mysterious universe puzzles
10.9 The mysterious universe summary

STUDY CHECKLIST

STARS AND CONSTELLATIONS

- [ ] **describe** the magnitude scale for comparing the brightness of stars 10.1
- [ ] **define** the apparent magnitude of celestial objects and identify the factors influencing it 10.1
- [ ] **account for** the apparent motion of stars in the night sky 10.1
- [ ] **interpret** a star chart and use it to celestial objects 10.1
- [ ] relate constellations to the arrangement of stars in the night sky 10.1

THE LIFE CYCLES OF STARS

- [ ] **describe** the formation of stars 10.2
- [ ] **interpret** a Hertzsprung–Russell diagram and relate it to the evolution of stars 10.2
- [ ] **outline** the nuclear fusion reaction taking place in main sequence stars 10.2
- [ ] relate the colour of stars to their size, surface temperature and age 10.2
- [ ] **summarise** the stages of stellar evolution for an average sized star and a large star 10.2
- [ ] **distinguish** between the terms 'absolute magnitude' and 'apparent magnitude' 10.2

THE STRUCTURE OF THE UNIVERSE

- [ ] **describe** the Milky Way Galaxy and relate it to the solar system, galaxies in the Local Group and beyond 10.3
- [ ] **compare** galaxies and nebulae 10.3
- [ ] **describe** efforts to discover exoplanets 10.3
- [ ] **identify** that all objects exert a force of gravity on all other objects in the universe
- [ ] **describe** differences in sizes of and distances between structures making up the universe 10.3

ASTRONOMICAL TECHNOLOGIES

- [ ] **describe** improvements in optical telescopes 10.4
- [ ] **account for** the location of ground-based telescopes 10.4
- [ ] **account for** the use of telescopes across the entire electromagnetic spectrum and for the need to locate some in space 10.4

THEORIES ON THE ORIGINS AND EVOLUTION OF THE UNIVERSE

- [ ] **define** the term 'spectrum', and explain how it can be used to determine the elements that make up a star 10.5
- [ ] **explain** the Doppler effect and describe how it can be used to observe the motion of stars 10.5
- [ ] **outline** how the cosmic background radiation and the synthesis of elements in the universe supports the big bang theory of the origin of the universe 10.5
- [ ] **contrast** the big bang theory and steady state theory of the origin and evolution of the universe 10.5
- [ ] **account for** the eventual rejection of steady state theory 10.5

SUMMARY

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Digital documents

Individual pathways

Activity 10.1	Activity 10.2	Activity 10.3
Revising the universe	Investigating the universe	Investigating the universe further
doc-10667	doc-10668	doc-10669

eLesson

Expansion of the universe
In this eLesson you will learn about the big bang theory and why the universe continues to expand today.
Searchlight ID: eles-0038

Interactivities

Expansion of the universe
Use this interactivity to help enhance your understanding of the model of the universe expanding like a balloon.
Searchlight ID: int-0057

Shifting spectral lines
This interactivity tests your understanding of red shift and blue shift by challenging you to choose the correct spectrum from a series of questions.
Searchlight ID: int-0678

Star cycle
This interactivity tests your understanding of the cycle of a star by challenging you to drag and drop labels onto their correct places in the cycle.
Searchlight ID: int-0679