6 The mysterious universe

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 in our minds about the past and the future.

The Large Magellanic Cloud is 160 000 light-years from Earth. It is about one-third the size of our galaxy, the Milky Way.

OVERARCHING IDEAS

- Patterns, order and organisation
- Form and function
- Stability and change
- Scale and measurement
- Matter and energy
- Systems

SCIENCE UNDERSTANDING

The universe contains features including galaxies, stars and solar systems, and the Big Bang theory can be used to explain the origin of the universe.

Elaborations

Identifying the evidence supporting the Big Bang theory, such as Edwin Hubble's observations and the detection of microwave radiation

Recognising that the age of the universe can be derived using knowledge of the Big Bang theory

Describing how the evolution of the universe, including the formation of galaxies and stars, has continued since the Big Bang

THINK ABOUT THE UNIVERSE

- What is cool about sunspots?
- Where are stars formed?
- Why do stars appear to show different colours?
- How old is the universe?
- How does a red giant become a white dwarf?
- What can we actually see from space?
- Is there life elsewhere in space?
- The universe may have started with a 'big bang', but what is the 'big crunch'?

YOUR QUEST

Twinkle, twinkle

Twinkle, twinkle little star, how I wonder . . .

So the nursery rhyme goes. When you gaze at the night sky, it's difficult to avoid wondering about what stars really are. What are they made up of? From where do they get their energy? How are they created? Do they shine forever?

THINK

1 What is a star? Write your own description of what a star is.

2 What is the name of the nearest star to the planet Earth?

3 How are stars formed?

4 Does a star ever die?

5 List all of the objects other than stars that you can see in the night sky.

Looking back in time

The object in photograph (a), above right, is not a star. It is a quasar called PG 0052+251. It emits much more light than any star could. Quasars are found only at very large distances from the solar system. Observations of distant objects like quasars provide clues about how the universe began.

THINK

6 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?

7 The photograph of PG 0052+251 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?

Where Earth fits into the universe

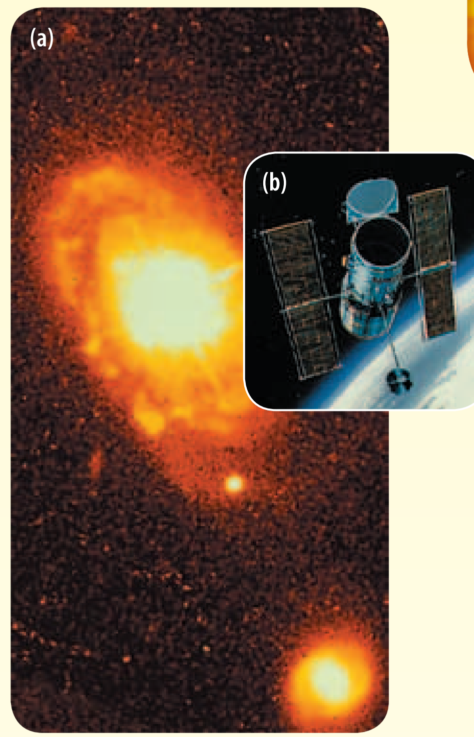
Until almost 400 years ago, most astronomers believed that the Earth was at the centre of the universe. It was surrounded by a 'celestial sphere' on which the stars were attached. The moon orbited the Earth. The sun and planets were also believed to orbit the Earth. Then, quite quickly, the idea that the sun was the centre of the universe became accepted. We now know that the Earth is just a tiny part of the solar system, which is a tiny speck in a galaxy known as the Milky Way. The sun is one of about 400 billion stars in the Milky Way, and the Milky Way galaxy is one of about 130 billion galaxies in the universe.

THINK

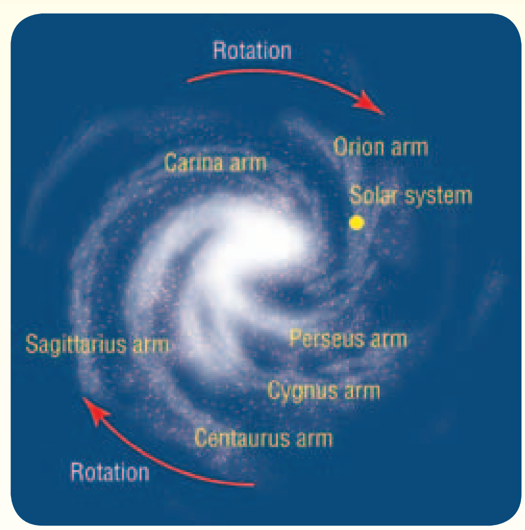
8 Which people and events caused the change in thinking about the place of the Earth in the universe about 400 years ago?

9 How do we know so much more about the distant parts of the universe now, in the twenty-first century, than we did 400 years ago when people were arguing about whether the Earth or the sun was the centre of the universe?

10 Given that the Earth is such a tiny speck, would you expect to find other, similar planets in the universe? If so, where would you expect to find them?



(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 because it is above the Earth's atmosphere.



The solar system is just a tiny part of the rotating Milky Way galaxy.

Observing the night sky

When you look up into the sky on a clear night, you will see countless specks of light stretching from horizon to horizon.

Seeing stars

Looking again later the same night, you should clearly see many of the same recognisable patterns as before, but they will have moved to a different position in the sky. From these simple observations, it is easy to conclude that the sky is a crystal-clear sphere dotted with the tiny lights we call stars. This 'celestial sphere' seems to rotate above our heads, carrying with it the fixed patterns or **constellations** of gleaming stars.

Wandering stars

Close observation shows stars that appear to wander about among the constellations. These include the **planets** (meaning 'wanderers'), the sun and the moon, and a few other heavenly bodies such as meteorites and comets. We now know that the celestial sphere model, first proposed by the Greek astronomer Ptolemy in 150 AD, was not correct. The apparent circular motion of the fixed pattern of stars at night is in fact due to the rotation of the Earth.

A closer view

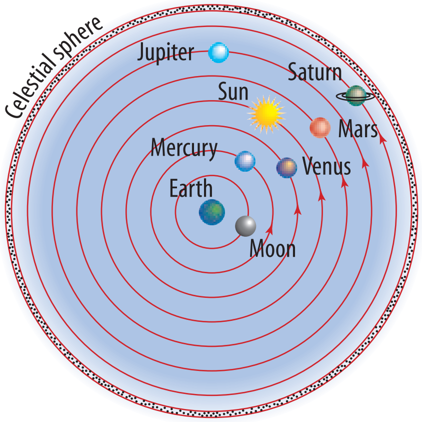
The development of the telescope in the sixteenth century allowed Earth-bound astronomers to see objects in the sky with much greater precision than ever before. Observations using telescopes showed that many different types of objects in the sky could be identified. These included single or double stars, groups of stars called **galaxies**, clusters of galaxies, and clouds of gas and dust called **nebulae**.

In 1718, English astronomer Edmond Halley, who is perhaps more well-known for his identification of the comet named after him, used his telescope to check three particularly bright stars: Sirius, Procyon and Arcturus. He found that the position of each one relative to surrounding stars was noticeably different from the positions recorded by ancient Greek astronomers centuries before. There were even slight differences between Halley's observations and those of Danish astronomer Tycho Brahe about 150 years earlier. Never again could the stars be described as 'fixed in the heavens'.

Questions about stars

Halley's observations raised some new questions about stars. Why should only a few stars move quickly enough for their motion to be noticed? Why do they happen to be among the very brightest stars? Perhaps some stars are closer to Earth than others. Being closer, they would appear brighter than other stars and their motion would be detectable against the backdrop of more distant, and therefore dimmer, stars.

A time-lapse photograph of the sky clearly shows the apparent movement of the stars.



In 150 AD, the Greek astronomer Ptolemy suggested that the stars were attached to a 'celestial sphere' that rotated above our heads. According to Ptolemy, the sun, the planets and the moon also orbited the Earth.

The Horsehead Nebula in the constellation of Orion. A nebula is a cloud of dust and gas, visible as a glowing or dark shape in the sky against a background of stars.

It's all relative

The apparent movement of objects at different distances is due to the actual movement of the observer. It is an effect called **parallax**. In 1837, German astronomer Friedrich Bessel became the first person to provide proof of a parallax effect when observing stars. As the Earth orbits the sun, the positions of stars change very slightly relative to each other. If all the stars were the same distance from the Earth, this would not happen.

Observations of a stellar parallax effect indicate that some stars are relatively close to us while others are much further away. The transparent celestial sphere of the past must be banished, to be replaced by an even more awe-inspiring image — that of star-studded space stretching before us with no known boundary or end.

HOW ABOUT THAT!

A light-year is not a measure of time! It is a measure of distance. In one year, light travels a distance of 9 500 000 000 000 or 9.5×10^{12} kilometres. This distance is called a light-year.

USING LARGE NUMBERS

Very large numbers are often written using **scientific notation**. This allows us to avoid writing lots of zeros and also makes the number easier to read, because the reader does not have to count the zeros. 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:

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

INQUIRY: INVESTIGATION 6.1

The effect of parallax

KEY INQUIRY SKILL:

- processing and analysing data and information

Equipment:

a number of traffic cones ('witches' hats')

pencil and paper

- Mark a circle on the school oval to represent Earth's orbit around the sun.
- Place a series of traffic cones at different distances from the circle to represent stars nearby and far away.
- Take a walk around Earth's 'orbit' and, at several different points, sketch the appearance of the 'stars' relative to one another and to even more distant objects such as trees and fence posts.

DISCUSS AND EXPLAIN

1 Looking at your sketches, did the positions of the stars relative to one another appear to change as you moved around the orbit?

2 Can you see any difference between the relative movements of the nearby stars compared with those of the more distant stars?

UNDERSTANDING AND INQUIRING

REMEMBER

1 How did the invention of the telescope change our view of the night sky from Earth?

2 Explain why the planets were given a name that means *wanderer*.

3 What do we mean by the term *parallax*?

4 How did observations of a stellar parallax effect change our ideas about the universe?

EVALUATE

5 The estimated distances from Earth to some stars and galaxies are listed below. How long would it 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

THINK

6 Explain why the planets that are visible to the naked eye appear to change position against the fixed patterns of other stars.

7 Radio waves travel through space at the same speed as light, which is about 300 000 km/s. How long would it take a radio message from Earth to reach the solar system's nearest neighbouring star?

IMAGINE

8 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.

work sheet 6.1 Observing stars

The sun

Possibly the most important single object we see in the sky is our nearest star, the sun. Without it, life would not exist on Earth. We depend directly on the sun for the light and heat it shines onto the surface of the Earth. Energy from the sun is stored in plants for food and heat, and the sun's energy controls the world's weather. The movement of the Earth on its axis and in its orbit around the sun gives us day, night and the seasons; these regular patterns determine our natural biological rhythms.

Just one of many

Despite its importance to life on Earth, the sun is a very ordinary star in a relatively unremarkable part of the universe. It is only the sun's closeness to our planet that makes it so important to us. Most of the other stars in the universe have a mass somewhere between one-half and four times that of our sun. The most massive star known, in the constellation Cygnus (the Swan), has a mass 600 times that of the sun. Massive stars like this are very rare.

In the beginning . . .

Stars like the sun are thought to have formed from the material found in the space between the stars. The density of this interstellar matter is incredibly low; on average, there is one atom in every two cubic centimetres of space. Compare this with about 3×10^{19} atoms per cubic centimetre in the air we breathe! Although this interstellar matter has an extremely low density, it has been estimated that there is as much matter in the space between the stars as there is in the stars themselves. Most of this interstellar matter is hydrogen gas and small amounts of helium. Only one per cent is made up of heavier elements found in particles of dust.

Like other stars, our sun was formed from a collapsing cloud of gas and dust. Its core temperature and pressure eventually rose high enough for atomic nuclei to become joined together by a process called **nuclear fusion**. As a result of fusion, hydrogen is transformed into helium and vast amounts of energy are released. It has been estimated that the sun has been turning hydrogen into helium for about five billion years. It is very stable and will probably stay as we now see it for another five billion years.

HOW ABOUT THAT!

Extreme conditions are needed for fusion to take place. The temperature of the sun's core is thought to be about 15 000 000 °C, and the pressure there is equivalent to 2.2×10^{11} times the normal atmospheric pressure on the surface of the Earth.

Under these conditions, matter breaks down. Electrons are stripped from the atoms to form positive nuclei (the plural of *nucleus*). The very high concentration of nuclei and their energetic movements produce violent collisions, leading to fusion reactions and an outpouring of energy.

Holiday on the sun?

A visit to the surface of the sun would reveal violently churning gas and massive amounts of particles and energy spreading out into space. Billowing out from the surface are huge luminous arcs of gas that are usually seen only through a telescope on Earth during an eclipse or by sensors onboard interplanetary space probes. During an eclipse, the moon blocks out the main body of the sun as seen from Earth and leaves the **corona** visible.

The outer layers of the sun form the corona, which becomes visible only during an eclipse.

The sun is a very active place. It displays many different moods.

Seeing spots — they're cool!

The amount of activity on the sun's surface is not constant. It varies over a fairly regular cycle, which takes about 11 years to complete. Each stage of this cycle can be seen from Earth because the number of visible **sunspots** provides clues about the level of activity. Sunspots look dark because they are cooler than the surrounding areas. However, the temperature of sunspots is still extremely high.

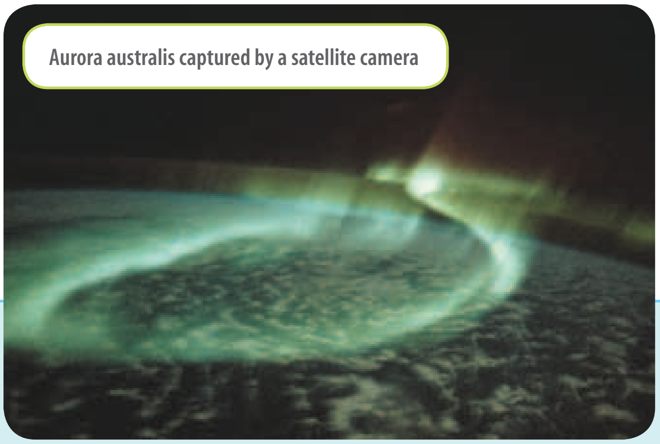
The presence of many sunspots corresponds with a time of high activity on the sun's surface. This activity produces a large number of particles that spread out from the sun. The Earth's magnetic field captures some of the particles, often producing patterns of light visible from the surface known as the **aurora borealis** and **aurora australis**. The captured particles in turn interfere with the Earth's own magnetic field. This has a severe effect on long-distance radio transmission.

Radio problems

Long-distance radio transmission relies on the reflection of high frequency radio waves from the **ionosphere**, high in the Earth's atmosphere. The particles captured by the Earth's magnetic field during high sunspot activity cause small changes in the Earth's own magnetic field. These changes interfere with the reflection of radio waves by the ionosphere, severely disrupting long-distance radio transmission.

Low sunspot activity also disrupts long-distance radio communication. It reduces the ability of the Earth's ionosphere to reflect high-frequency (short-wave) radio waves.

Aurora australis captured by a satellite camera



UNDERSTANDING AND INQUIRING

REMEMBER

1 Which element makes up most of the matter in space?

2 What are sunspots and when do they occur?

3 Explain why sunspots interfere with long-distance communication on Earth.

EVALUATE

4 In any fusion reaction, mass is converted directly into energy. Hydrogen nuclei can be fused to form helium nuclei. The helium nuclei have less mass than the original hydrogen nuclei. Some of the 'lost' mass is accounted for by the production of other tiny particles, but most of it is converted directly into energy. Albert Einstein wrote the equation describing this conversion as $E = mc^2$, where E is the energy (in joules), m is the mass (in kilograms) and c is the speed of light (which is about 3×10^8 m/s).

The sun releases 2.2×10^{25} J of energy in one minute as a result of fusion. Use Einstein's equation to determine how much mass is converted to energy in one minute.

THINK

5 Why is the sun sometimes called a 'middle-aged' star?

6 Explain why it is so difficult to develop a fusion reactor for power generation.

7 If the Earth's atmosphere absorbs two million times the energy requirements of humans from the sun, why is there an energy crisis?

INVESTIGATE

8 Find out about the element called helium. Why is its name linked to the Greek word for sun, *helios*?

9 Find out more about fusion science by using the **Princeton Plasma Physics Laboratory** weblink in your eBookPLUS.

eBook*plus*

work sheet 6.2 The sun and nuclear fusion

6.3 OVERARCHING IDEAS

Stability and change: Stars — a life story

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. However, their 'careers' are usually much longer than those of the movie variety.

A star is born

Dust and gas are not evenly distributed in interstellar space. There appear to be currents of denser material swirling throughout the universe. 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, forming a cloud. Such clouds of interstellar matter are called nebulae and are really like star nurseries. The Great Nebula in the constellation of Orion (see the next photograph in this section) is a nebula large enough to be seen with the naked eye. The collapse continues under the influence of gravity, forming visible globules in the nebula cloud. As the globules collapse further, any original gas cloud is accelerated. Before the temperature is high enough for nuclear fusion to occur, the now dense cloud is known as a **protostar**. At the same time, the increasing pressure causes the temperature to rise and the conditions are right for a star to be born.

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 6.3). 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 of development of typical and 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.

Ancient Babylonian astronomers divided the stars visible to the unaided eye into six classes. (The number 6 was clearly important — the Babylonians were also responsible for dividing an hour into 60 minutes!) The brightest stars were called class one; the dimmest, class six. This scale became the basis for the **magnitude** scale we use today. The scale has been extended to higher numbers to include very dim objects that are visible only through the most powerful telescopes. Also, some of the brightest objects turn out to be brighter than magnitude one, so zero magnitude and even negative magnitudes are included in today's scale.

INQUIRY: INVESTIGATION 6.2

Heat produced by compressing a gas

KEY INQUIRY SKILL:

- processing and analysing data and information

Equipment:

a bicycle pump

a tyre with inner tube

- 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.

DISCUSS AND EXPLAIN

1 What change has been observed?

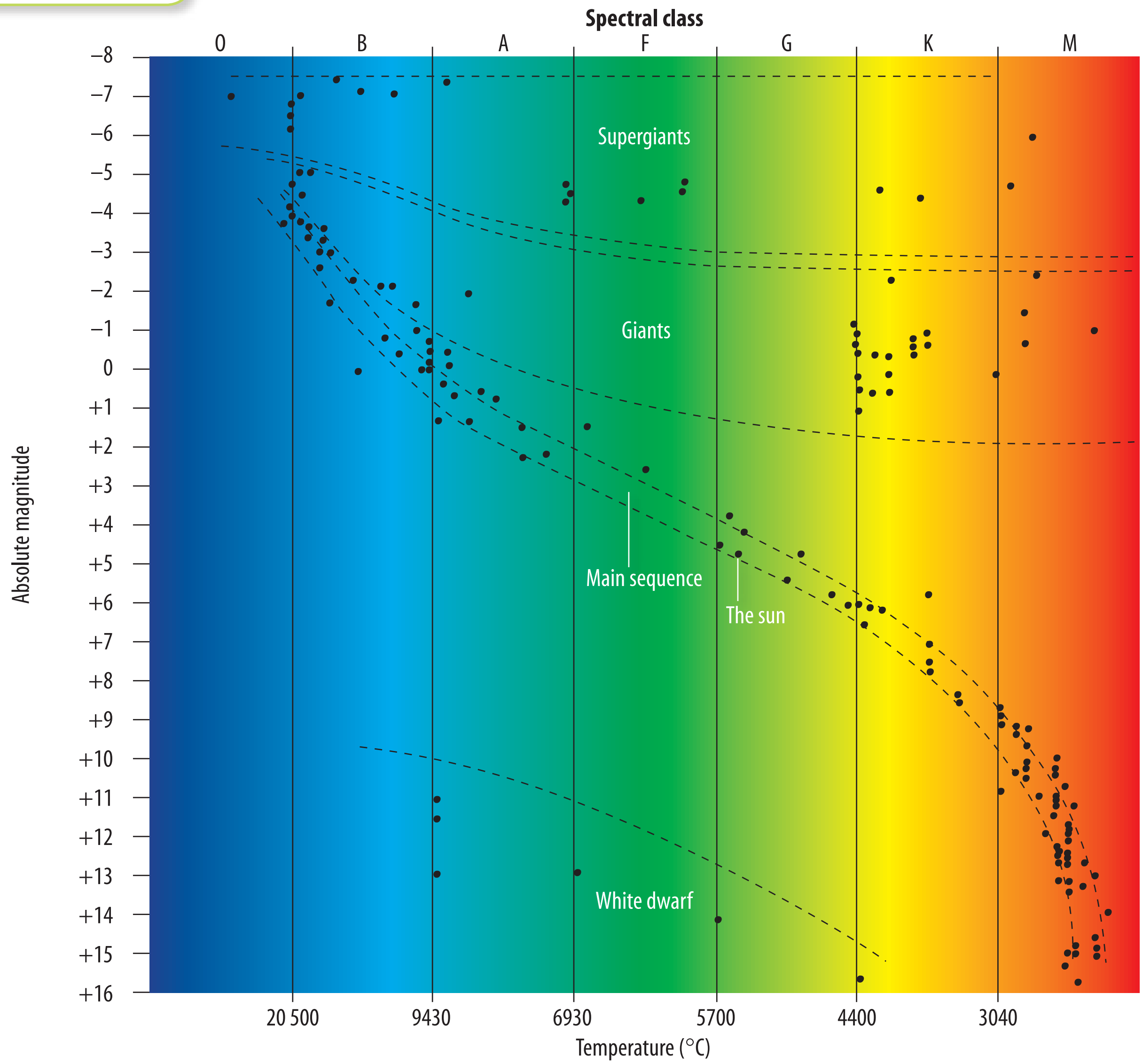
2 How does an increase in air pressure affect the temperature of the surroundings?

(The opposite effect can be observed when carbon dioxide gas is released from a soda bulb.)

The Great Nebula of Orion

Star light, star bright

How bright a star appears to us (its **apparent magnitude**) depends on its actual brightness (its **absolute magnitude**) and its distance from Earth. 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. The colour of a star depends on its surface temperature: red stars are cool, and white and blue stars are hot.



The Hertzsprung–Russell diagram sorts stars by their absolute magnitude and surface temperature or colour.

A QUESTION OF MAGNITUDE

How bright a star or planet appears as viewed from Earth is measured on a scale of apparent magnitude. On this scale, the brighter objects have the lowest apparent magnitudes. For example, the sun has an apparent magnitude of –27. A full moon has an apparent magnitude of approximately –13. The brightest stars have an apparent magnitude between –1 and 1. The weakest objects visible with the naked eye have an apparent magnitude of approximately 6.

The absolute magnitude is a measure of how much light an object emits. The sun is much smaller than Rigel in Orion and it emits a lot less light. However, it appears brighter to us because it is much closer than Rigel. The moon emits no light of its own.

The table on the right shows some typical values of apparent and absolute magnitudes.

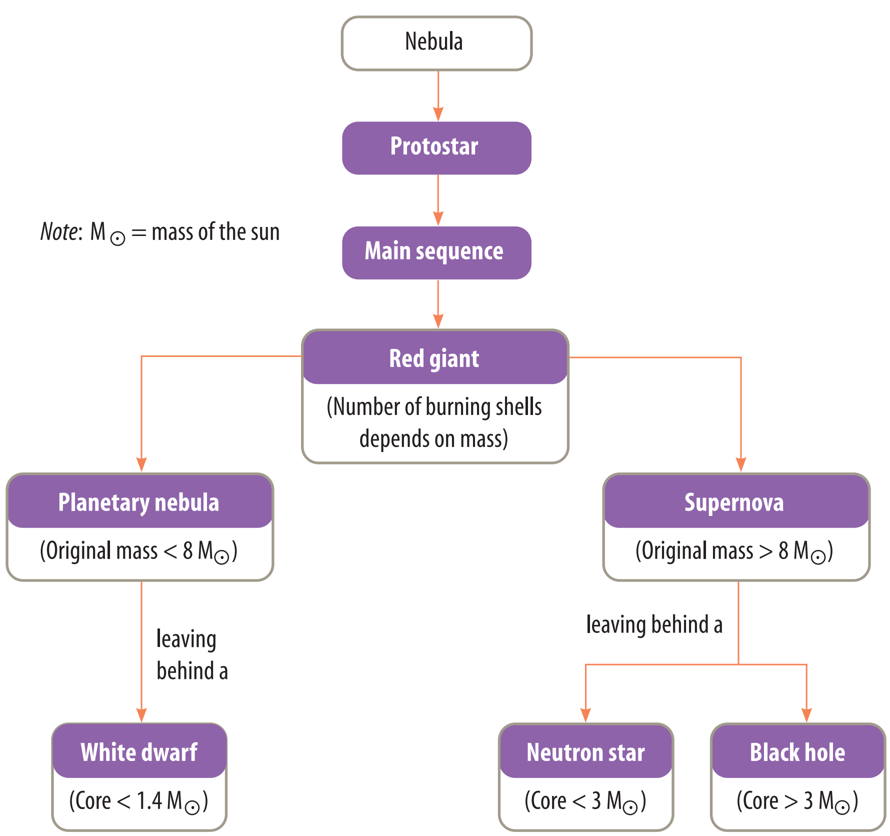
Star and constellation	Apparent magnitude	Absolute magnitude
Sun	–27	+4.7
Sirius (Canis Major)	–1.5	+8.7
Canopus (Carina)	–0.73	–4.6
Alpha Centauri (Centaurus)	–0.33	+4.7
Rigel (Orion)	+0.11	–7.5
Beta Centauri (Centaurus)	+0.60	–5.0
Betelgeuse (Orion)	+0.80	–5.0
Aldebaran (Taurus)	+0.85	–0.3
Alpha Crucis (Southern Cross)	+0.90	–3.9

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 method 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 are plotted, most of them, including our sun, fall into what is 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 stars 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 found in the main sequence. The rarer types are stars passing relatively quickly through later stages of development on the way to extinction as their nuclear fuel runs out.

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 region where energy is produced by the fusion of hydrogen



INQUIRY: INVESTIGATION 6.3

Seeing the colours of stars

KEY INQUIRY SKILL:

- processing and analysing data and information

Equipment:

star atlas (optional)

pair of binoculars (optional)

- Use the information below, a star atlas 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 that has a diameter bigger than Earth's orbit. It appears quite visibly 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 brightness and 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 in an attempt to prevent observers being distracted by them. 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 birthplaces of the stars.

DISCUSS AND EXPLAIN

1 How do the colours of Betelgeuse and Rigel compare?

2 Which of Betelgeuse and Rigel appears to be brighter? Relate your observation to the table in this section under the heading *A question of magnitude*.

3 Which of the two stars is cooler?

becomes 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.

The brightness of many red giants varies greatly because they have become unstable after many millions of years of stability. The red giant Mira in the constellation Cetus (the Whale) was the first variable red giant to be discovered. The brightness of Mira increases and decreases over a huge range in a cycle that averages 320 days. Not surprisingly, it is known as a **pulsating star**. The shorter cycles of some pulsating stars are so predictable that they can be used as markers to measure vast interstellar distances in the universe.

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 might shine 100 times more brightly than it did in its stable period as part of the main sequence.

The Crab Nebula, the remains of a supernova observed almost a thousand years ago. At the centre is a rapidly spinning neutron star called a pulsar.

eBook*plus* **eLesson**

Biggest bang
Watch a video from the ABC's *Catalyst* program about gamma rays.
eles-1074

The death of a star

Eventually, the rapid pulsations lead to the destruction of the star. The nature of its death depends on the size of the star.

WHITE DWARFS

For stars less than about eight times the mass of our sun, the destruction 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 other nebulae. The name came about because astronomers using very early telescopes thought that the clouds resembled the planets Uranus and Neptune.

The remaining star fades to become a **white dwarf**, typically about the size of 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**. They 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**.

eBook*plus* **Weblink**

Stellar evolution
Use the **Stellar evolution** weblink in your eBookPLUS to find out more about the life cycle of stars.

UNDERSTANDING AND INQUIRING

REMEMBER

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

2 To which group of stars shown on the Hertzsprung–Russell diagram does the sun belong?

3 How does a red giant become a white dwarf?

4 Why is the term *planetary nebula* a misleading way to describe the ring of expanding gas thrown out by a red giant during its transformation into a white dwarf?

EVALUATE

5 The table below lists information about three bright stars.

Star	Apparent magnitude	Absolute magnitude
Rigel	0.11	–7.5
Aldebaran	0.86	–0.3
Canopus	–0.73	–4.6

(a) Which star has the greatest actual brightness?
(b) Which star is the faintest as seen from Earth?

THINK

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

7 What would the night sky look like if you had eyes that could see like the Hubble Space Telescope?

INVESTIGATE

8 Find out more about 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*

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

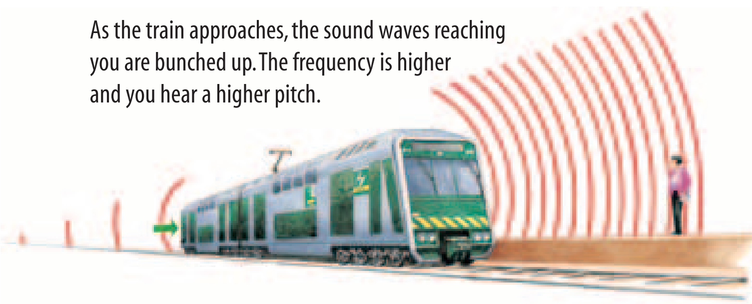
work sheets
6.3 The brightness of stars
6.4 Star life cycles

Stability and change: The changing universe

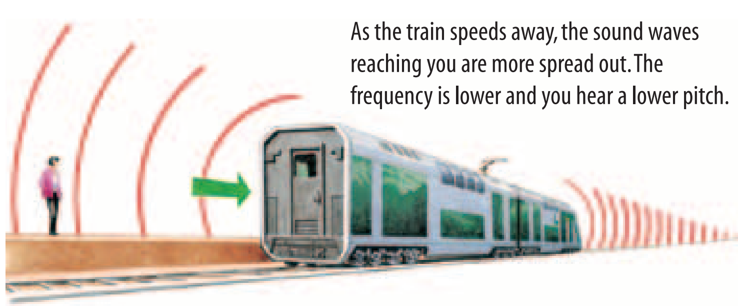
Will the sky you see tonight ever be the same again? Within a person's lifetime, the patterns of stars and galaxies in the night sky do not seem to change. The constellations move across the sky as the Earth spins on its axis and moves in its orbit around the sun, but any changes in their relative positions can not be seen with the unaided eye. Photographic techniques show us the movements of the stars and tell us that what we see as permanent is actually a universe in a state of continuous and often violent movement and change.

Stars on the move

The movement of stars towards or away from the Earth can be measured 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 drop as the fire-engine goes by.



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.

Doppler suggested that the same effect we notice in sound waves might be seen in light as well. 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.

INQUIRY: INVESTIGATION 6.4

Doppler effect using rotating sound source

KEY INQUIRY SKILL:

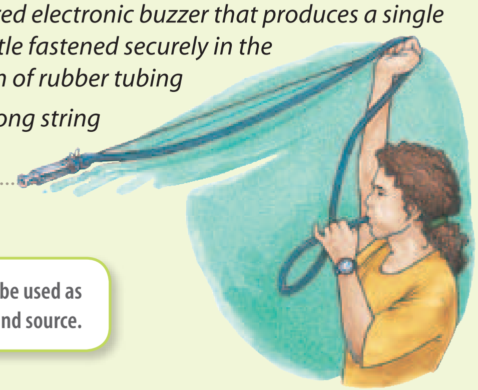
- processing and analysing data and information

Equipment:

a source of sound that can easily be spun in a circle, e.g. a battery-powered electronic buzzer that 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.

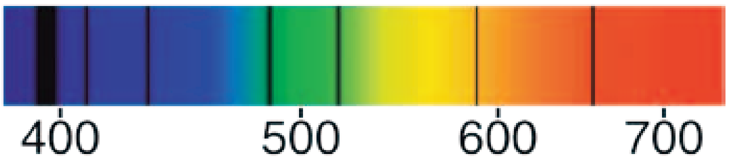
CAUTION: Take care while spinning the source. Ensure that the string is strong enough and that no-one is in the path of the rotating source of sound.

DISCUSS AND EXPLAIN

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

THE SPECTRA OF STARS

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.

Nearby objects show a range of Doppler shifts. Some stars, like Sirius (the Dog star), are moving away from us and others are moving slowly towards us. Some even show alternate red and blue shifts in step with changes in brightness, suggesting that these stars have an invisible dark companion orbiting them. The brightness is reduced as the circling star passes between us and the main star, while the Doppler shift is caused by the main star moving in response to the gravitational pull of its dark companion.

RETREATING GALAXIES

On a much larger scale, the study of the Doppler shifts of galaxies provides us with an amazing picture of the universe. A relatively small number of galaxies, including the nearby Andromeda galaxy, are moving towards the Earth, but the majority of 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.

ESTIMATING THE SIZE OF THE KNOWN UNIVERSE

We can only say that the universe is as big as we can see, so the size of the known universe has steadily increased over the centuries as observation techniques have improved. The Hubble Space Telescope is finding more and more distant objects and so the known universe is still getting bigger. Objects have been seen at distances estimated to be about 15 billion light-years from Earth.

UNDERSTANDING AND INQUIRING

REMEMBER

1 Why are there black lines in the spectra of the light emitted by stars?

2 Which colour of light has the higher frequency — red or blue?

3 What is a red shift? What does it tell us about how a star is moving relative to the Earth?

4 What is Hubble's law?

THINK

5 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?

IMAGINE

6 Imagine living on a planet circling a star in the Andromeda galaxy, a distance of 1.5×10^6 light-years from Earth. How would your view of the universe compare with the view we have from Earth?

7 Collect and summarise a media report about a new discovery about space outside the solar system.

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

eBook*plus*

work sheet 6.5 The expanding universe

How it all began

eBookplus **eLesson**

The expanding universe
Learn about the big bang theory and why the universe continues to expand today.
eles-0038

When and how did the universe begin? Was there a beginning? Perhaps it was always there. If there was a beginning, will there be an end? The study of the answers to these questions is called **cosmology**.

Following the discoveries about the expanding universe by Edwin Hubble, two major theories about the beginning of the universe became popular — the **big bang theory** and the **steady state theory**.

1. The big bang (t = 0)
It's hard to imagine, but at this moment there was no space and no time. All that existed was energy. All of the energy was concentrated into a single point called **singularity**.

2. One ten million trillion trillion trillionths of a second later ($t = +\frac{1}{10^{43}}$ s)
Time and space had begun. Space was expanding quickly and the temperature was about 100 million trillion trillion degrees Celsius. (The current core temperature of the sun is 15 million degrees Celsius.)

3. One ten billion trillion trillionths of a second after the big bang ($t = +\frac{1}{10^{34}}$ s)
The universe had expanded to about the size of a pea. Matter in the form of tiny particles such as electrons and **positrons** *(positively charged electrons) had formed. Particles collided with each other, releasing huge amounts of energy in the form of light. Until this moment there was no light.*

4. One ten thousandth of a second after the big bang ($t = +\frac{1}{10^4}$ s)
Protons and neutrons had formed as a result of collisions between smaller particles. The universe was very bright because light was trapped as it was continually being reflected by particles.

5. One hundredth of a second after the big bang ($t = +\frac{1}{100}$ s)
The universe was still expanding and cooling rapidly. It had grown to the same size as our solar system, but there was still no such thing as an atom.

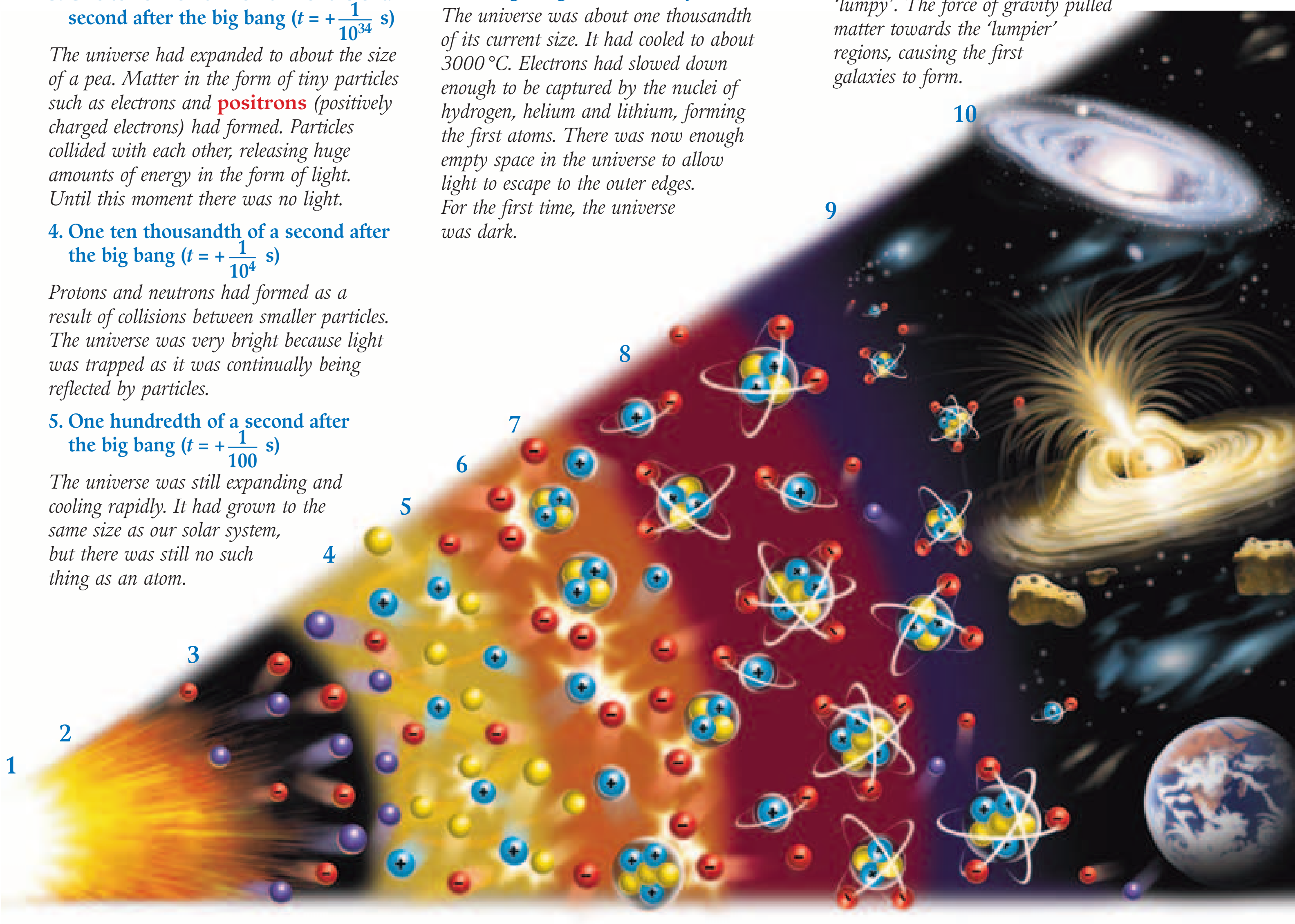
6. One second after the big bang (t = +1 s)
The universe was probably more than a trillion trillion kilometres across. It had cooled to about ten billion degrees Celsius.

7. Five minutes after the big bang (t = +5 min)
The nuclei of hydrogen, helium and lithium had formed among a sea of electrons.

8. Three hundred thousand years after the big bang (t = +300 000 years)
The universe was about one thousandth of its current size. It had cooled to about 3000 °C. Electrons had slowed down enough to be captured by the nuclei of hydrogen, helium and lithium, forming the first atoms. There was now enough empty space in the universe to allow light to escape to the outer edges. For the first time, the universe was dark.

9. Two hundred million years after the big bang (t = +200 000 000 years)
The first stars had appeared as gravity pulled atoms of hydrogen, helium and lithium together. **Nuclear reactions** *took place inside the stars, causing the nuclei of the atoms to fuse together to form heavier nuclei. Around some of the newly forming stars, some of the swirling clouds of matter cooled and formed clumps. This is how planets began to form.*

10. One billion years after the big bang (t = +1 000 000 000 years)
The universe was beginning to become a little 'lumpy'. The force of gravity pulled matter towards the 'lumpier' regions, causing the first galaxies to form.



The big bang

According to the most commonly accepted theory among cosmologists, the universe began about 15 billion years ago with a 'big bang'.

THE EINSTEIN CONNECTION

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.

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, nuclear weapons and stars.

WORKING WITH BILLIONS AND TRILLIONS

One billion is equal to one thousand million; that is, 1 000 000 000, or 10^9.

One trillion is equal to one thousand billion; that is, 1 000 000 000 000, or 10^{12}.

So one billion trillion is 1 000 000 000 000 000 000 000, or 10^{21}.

When numbers get that large, there are too many zeros to count. It is much easier to use powers of ten notation, or scientific notation.

The steady state theory

According to the steady state theory, proposed in 1948, there was no beginning of the universe. It was always there. The galaxies are continually moving away from each other. In the extra space left between the galaxies, new stars and galaxies are created. These new stars and galaxies replace those that move away, so that the universe always looks the same.

The great debate

A huge debate between those who supported the steady state theory and those who supported the big bang theory raged from 1948 until 1965. During that period, the evidence supporting the big bang theory grew.

THE RED SHIFT

The red shift provides evidence for an expanding universe. This evidence supports the big bang theory and causes problems for those supporting the steady state theory. A steady state universe could expand only if new stars and galaxies replaced those that moved away. There is no way to explain how these new stars and galaxies could be created from nothing. Apart from that, these young stars and galaxies have not been found by astronomers.

THE ELEMENTS

The amounts of hydrogen and helium in the universe support the big bang theory. According to the steady state theory, the only way that helium can be produced is by the nuclear reactions taking place in stars. About 8.7 per cent of the atoms in the universe are helium. This is far more than could be produced by the stars alone. The percentage of helium atoms can, however, be explained by their creation as a result of the big bang.

HOW ABOUT THAT!

The big bang theory was first proposed in 1927 by Georges Lemaitre, a Catholic priest from Belgium. But it wasn't called the 'big bang theory' then. Ironically, the name 'big bang' was invented by Fred Hoyle, one of the developers of the steady state theory. He used the name to try to ridicule the cosmologists who proposed the big bang theory.

In 1933, Lemaitre presented the details of his theory to an audience of scientists in California. Albert Einstein, by then recognised as one of the greatest scientists of all time, was in the audience. At the end of Lemaitre's presentation Einstein stood, applauded and announced, 'That was the most beautiful and satisfactory explanation of creation that I have ever heard'.

THE AFTERGLOW

When George Gamow and Ralph Alpher proposed their version of the big bang theory in 1948, they calculated that the universe would now, about 15 billion years after creation, 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.

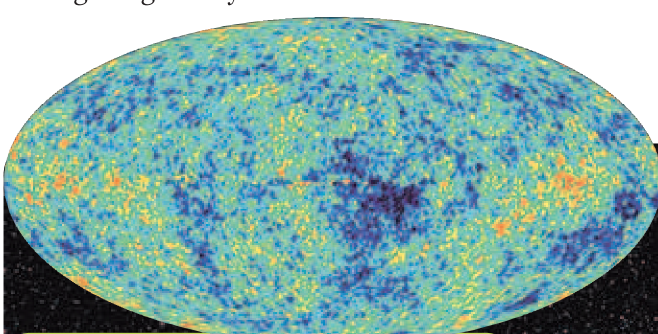
This radiation was discovered by accident in 1965. Engineers trying to track communications satellites picked up a consistent radio noise that they couldn't get rid of. The noise wasn't coming from anywhere on Earth, because it was coming from all directions. It was the cosmic microwave background radiation 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

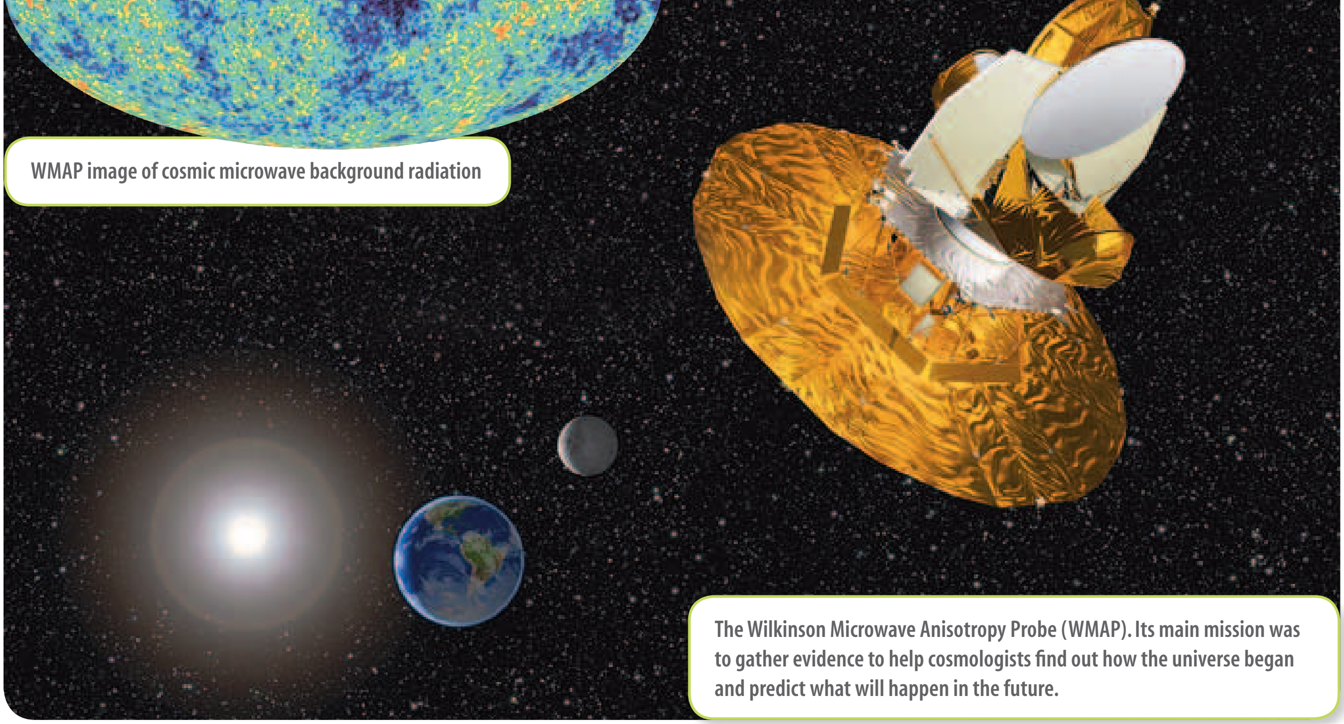
In 1989, a satellite named COBE (COsmic Background Explorer) was put into orbit around Earth to accurately measure the background radiation and temperature of the universe. COBE could detect variations as small as 0.000 03 °C. As predicted by Gamow, it detected an average temperature of –270 °C.

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 below 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 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.



WMAP image of cosmic microwave background radiation



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.

Will it ever end?

Will the expansion of the universe continue forever? If the universe does stop expanding, what will happen to it? There are several competing theories about the answers to these questions. One theory suggests that there is not enough mass in the universe for gravity to be able to pull it all back and that it will continue to expand forever. Other theories suggest that the universe will eventually end. According to these theories, the end will come when:

- the universe snaps back onto itself in a 'big crunch' (the **big crunch theory**). If this happens, the end result will be a single point — singularity. Some cosmologists believe that the big crunch will be followed by another big bang.
- the expansion of the universe continues and stars use up their fuel and burn out, causing planets to freeze (the **big chill theory**). The universe would then consist of scattered particles that never meet again.
- the universe rips itself apart violently as a result of expanding at an increasing speed (the **big rip theory**). According to this theory, the end of the universe will also be the end of time itself.

eBook*plus* **eLesson**

Entropy: Is the end of the universe nearer than we thought?
Watch a video from the ABC's *Catalyst* program about the end of the universe.

eles-1073

UNDERSTANDING AND INQUIRING

REMEMBER

1 What is the science of cosmology?

2 How old is the universe believed to be?

3 According to the big bang theory, what was there at the time of the big bang?

4 Why could there not have been anything before the big bang?

5 Approximately how long after the big bang did:
(a) time and space begin to exist
(b) matter appear
(c) protons and neutrons form
(d) neutral atoms first exist
(e) galaxies begin to form?

6 How did galaxies begin to form?

7 What does Einstein's famous equation have to do with the big bang theory?

8 Which of the two theories about the 'beginning' of the universe proposed that there was no beginning?

9 How did the steady state theory explain that the universe was expanding, yet remained the same?

10 What evidence put an end to the steady state theory?

11 List three major pieces of evidence that supported the big bang theory.

12 Name and describe three theories about how the universe might end.

THINK

13 What would have happened to the universe if, one million years after the big bang, the matter in it was perfectly evenly distributed and not moving?

14 Explain why neutral atoms were not likely to form during the first five minutes after the big bang.

15 WMAP is able to provide a picture of the universe as it was 380 000 years after the big bang. Why is it unable to provide a map of the universe as it was before that time?

16 Why go to the expense of measuring background radiation with a satellite or space probe when it could be done from Earth?

CREATE

17 Draw flowcharts to describe:
(a) the big bang theory
(b) how the big bang and big crunch cycle might work together.

18 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. Use the information obtained from the website to answer the following questions. eBook*plus*
(a) What is the average temperature of the universe as measured by WMAP?
(b) When were the first stars formed?
(c) According to WMAP, how old is the universe and how accurately is its age known?

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

work sheet 6.6 The big bang

6.6 SCIENCE AS A HUMAN ENDEAVOUR

Eyes on the universe

For hundreds of years, light telescopes have been used to observe what lies beyond the solar system. To find out what's in deep space, in the most distant parts of the universe, observing visible light is not enough. We rely on other parts of the electromagnetic spectrum.

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

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 light telescopes. Like light and other forms of **electromagnetic radiation**, radio waves travel through space at a speed of 300 000 kilometres 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 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. They can detect signals from much further away than light telescopes can.

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

SHARPEN UP!

Images produced by single 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.

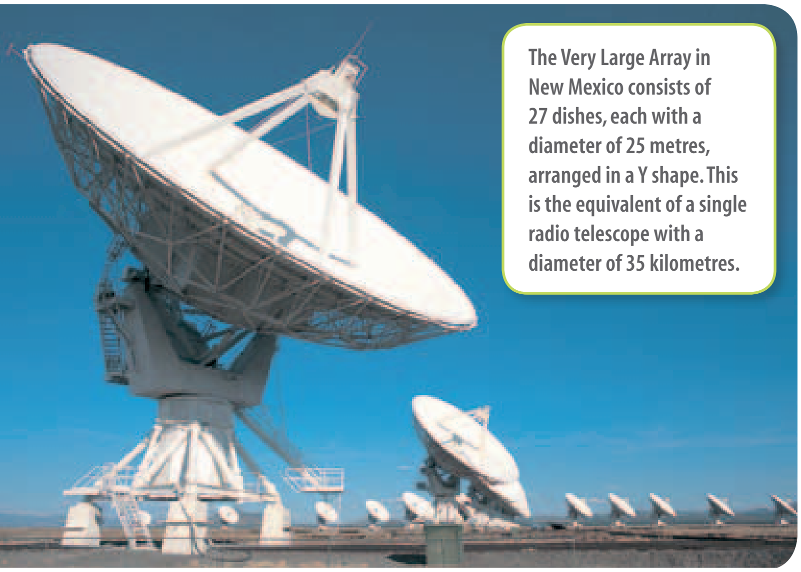
Learning from radio waves

As well as telling us about the size, shape and movement of every type of star (from our own sun to stars at the outer edges of the universe), radio telescopes reveal information about a star's temperature and the substances from which it is made. Radio telescopes can work out what a star is made up of by using the fact that different elements emit different frequencies of radio waves.

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

- they 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 Very Large Array in New Mexico consists of 27 dishes, each with a diameter of 25 metres, arranged in a Y shape. This is the equivalent of a single radio telescope with a diameter of 35 kilometres.

Eyes in orbit

There are more than 2500 satellites currently orbiting the Earth, many of them constantly watching the Earth's surface and atmosphere. Others provide views of the universe that could never be seen from the Earth's surface through the atmosphere.

Trash 'n' treasure in orbit

Some of the satellites orbiting the Earth are active and use radio signals to send streams of data down to the surface. Others have stopped working but continue to circle the globe. Some satellites in lower orbits will gradually slow down as a result of the thin atmosphere. They will spiral in towards the Earth in a fiery finish as they burn up on re-entry. The fate of others far beyond the atmosphere is an eternity of circling the Earth. They have joined the pile of 'space junk' gradually accumulating in near-Earth orbit.

All satellites orbiting the Earth are held there by the Earth's gravitational pull directed to the planet's centre. This means that the centre of every orbit coincides with the centre of the Earth. Some orbits skim as close as a few hundred kilometres above the surface. Others take a more distant view. The time taken for one complete revolution (the period of orbit) of a satellite depends on its height above the Earth. Greater heights result in greater periods.

LOOKING IN, LOOKING OUT

Artificial satellites can be used to look at the Earth or to look into space. An inward-looking satellite can sweep the surface of the Earth every day, using cameras and remote sensors to observe and measure events on the surface hundreds or thousands of kilometres below. An outward-looking satellite can see directly into space, its view unobstructed by the atmosphere, pollution and dust. Light pollution, an increasing problem for Earth-bound observers as our cities grow, is not an issue for an observer in space.

Inward-looking satellites are used for:

- collecting weather and climate data, providing early warning of events (such as volcanic activity and changing ocean currents) and showing long-term trends
- collecting data used for mineral exploration, crop analysis, mapping, and identifying long-term erosion or degradation
- strategic defence ('spy-in-the-sky') systems
- communications for telephones, television, radio and computer data.

Outward-looking satellites are used for:

- observing the other planets and bodies circling the sun
- observing stars, galaxies and other remote objects in space
- watching for comets and asteroids that may hit the Earth
- listening for signs of extraterrestrial life.

The Hubble Space Telescope is an example of an outward-looking satellite. It was carried into orbit about 600 kilometres above the Earth's surface by the space shuttle *Discovery* in 1990. The Hubble Space Telescope, until it stops working, collects images by collecting and analysing data in the form of visible light, **ultraviolet radiation** and **infra-red radiation** from deep space. It produces spectacularly clear images that are relayed back to Earth by radio waves.

The Hubble Space Telescope was the first space telescope that could be serviced while in orbit, and its useful life has been dependent on transporting astronauts to and from Earth aboard space shuttles. Now that NASA's space shuttle program has ceased, servicing is no longer possible. When the orbiting telescope stops functioning it will be 'deorbited' by an unmanned space mission so that it plunges harmlessly into the ocean.

The Hubble Space Telescope will eventually be replaced by the James Webb Space Telescope, which will collect infra-red radiation from the most distant parts of the universe. At the time of publication of this book, the launch is scheduled for no sooner than 2014. The uncertainty of the launch date is not surprising, because the James Webb project is a collaboration between three space agencies: NASA, the European Space Agency (ESA) and the Canadian Space Agency (CSA). Each of these agencies is dependent on government funding, which is often uncertain.

The Hubble Space Telescope

There are several other space telescopes in orbit around the Earth. They all collect radiation from parts of the electromagnetic spectrum and send images and other data back to Earth using radio waves. They include the Chandra X-ray Observatory, carried into orbit by the space shuttle *Columbia* in 1999. Most **X-rays** from space approaching the Earth are absorbed by the atmosphere. By collecting high-energy X-rays coming from neutron stars and black holes, Chandra is able to gather data about them that could never be collected by X-ray telescopes on the surface.

DATA OVERLOAD?

The unprecedented amount of data coming from telescopes of all types on the ground and in orbit requires processing by **supercomputers** with capabilities well beyond those of personal computers and even large computers used in most industries. IT specialists play a crucial role in developing new and faster computer systems to ensure that exploration of the universe is not limited by data overload.

UNDERSTANDING AND INQUIRING

REMEMBER

1 Describe at least two advantages of Earth-based radio telescopes over light telescopes.

2 Images produced by single radio telescopes are not very sharp. Explain how this problem is solved.

3 List the information that can be revealed by images from radio telescopes.

4 Outline the advantages of telescopes in orbit over telescopes on the surface of the Earth.

5 Which part or parts of the electromagnetic spectrum have been collected by the Hubble Space Telescope?

6 Explain why fast computers are important to exploration of the universe.

THINK

7 Explain why orbiting space telescopes have a limited lifetime.

8 Outline at least four reasons why there can be no certainty about the launch dates of future space missions.

INVESTIGATE

eBook*plus*

9 Use the **Astronomy** weblink in your eBookPLUS to find out about the research conducted by the Centre for Astrophysics and Supercomputing in Melbourne. Report on:
(a) the areas of research being conducted
(b) the range of courses available for students with an interest in the universe
(c) career opportunities in astrophysics and supercomputing.

10 Australia has always played a crucial role in space missions and space exploration. Use the internet to research and report on the role of each the following Australian facilities in space exploration and the way in which they are funded.
(a) The Australia Telescope Compact Array
(b) The Canberra Deep Space Communication Complex
(c) The Parkes Radio Telescope

11 Identify one scientist, engineer or IT specialist who works at one of the facilities listed in question 10 and write a brief report about his or her role in investigating the universe.

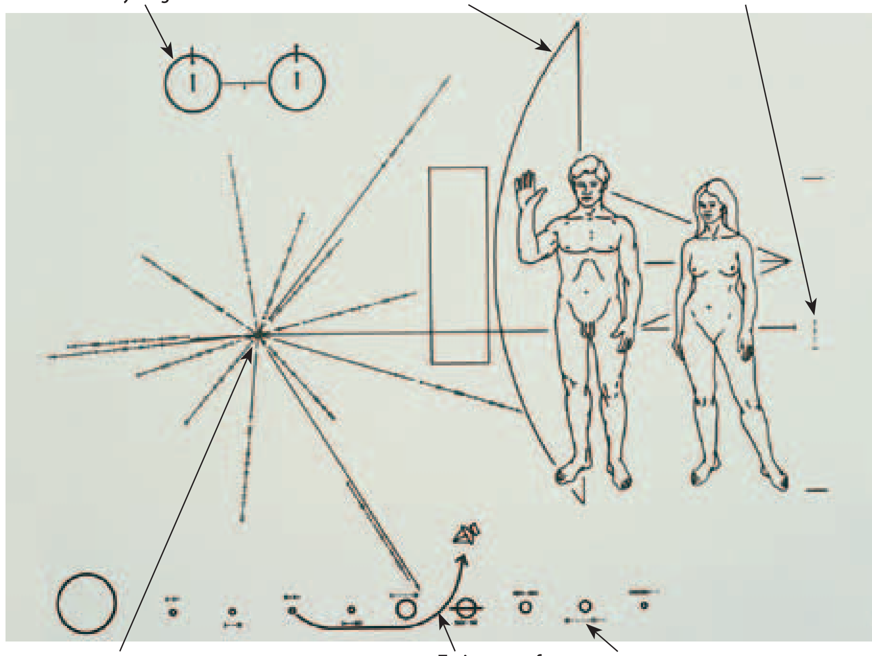
6.7 SCIENCE UNDERSTANDING

Anybody out there?

There are billions of stars in the known universe, many of them similar to our own sun. It is very probable that planets orbit many of these stars. Perhaps the right conditions for life to develop can be found on some of them. How would we know about the presence of other life forms on these distant planets? And how might *they* know about us?

Prove it!

Ideas and theories in science must be supported by evidence. Direct evidence in this case could take the form of actual sightings or communication with other beings but, as we will see, this evidence might be very hard to find. There is a greater chance of collecting indirect evidence, but the interpretation of this kind of information is often open to argument.



This is the plaque designed to be read by alien civilisations that has been carried by *Pioneer 10* and *Pioneer 11* since they were launched more than 25 years ago.

Getting in touch

How would extraterrestrial beings on planets orbiting distant stars know of our existence? Some of the features of the Earth's surface would provide clues to observers who are close enough to see. For example, the lights of our cities or the largest of our structures, such as the Great Wall of China, are visible from orbiting satellites.

There is a slight chance that our long-distance space probes might be observed from afar. Because of this, scientists have sent along with several probes some vital clues about us and the nature of our civilisation. The *Pioneer 10* and *Pioneer 11* spacecraft, launched in 1972 and 1973, carry a gold-plated plaque that depicts a man and a woman, a simplified map of the solar system and other important scientific clues that show humans have reached a particular level of technological development. Some of the information is coded in a way that would be easy for another civilisation that has reached a similar level of development to interpret.

Pioneer 10 skimmed past Jupiter in December 1972, then accelerated to a speed great enough for it to escape from the gravitational pull of the sun. It is now heading off in a direction that will take it between the constellations of Taurus and Orion, a reasonably clear tract of space in which it might easily be noticed. *Pioneer 11* is following a similar path to the stars after its close encounter with Saturn. The two *Voyager* probes are carrying information in a quite different form — a gramophone disc containing speech and music, with instructions on how to play it!

The problem with relying on space probes as messengers is that they travel so slowly, only about 11 kilometres per second. The *Pioneer* and *Voyager* space probes are likely to travel for thousands, possibly millions of years through the vacuum of space, but the

Two of the large dish-shaped radio antennas at the Tidbinbilla Canberra Deep Space Communication Complex, which is operated jointly by NASA and the Australian Space Office.

distance they will cover in that time will be tiny on an astronomical scale. A much speedier way of sending a message is to load it onto a radio wave, which travels through space at 300 000 kilometres per second, which is the speed of light.

Calling ET

Space is already full of radio waves coming from violently erupting stars and swirling clouds of gas. Scientists and engineers discovered this background 'noise' very early in the history of radio and this discovery led to the science of **radio astronomy**. Radio messages carrying information are different, however, from the squeaks and whistles of the background radiation, because such messages usually contain regular patterns. Digital signals, made up of a series of ones and zeros, are particularly distinctive and can be used to carry a large amount of easily decoded information.

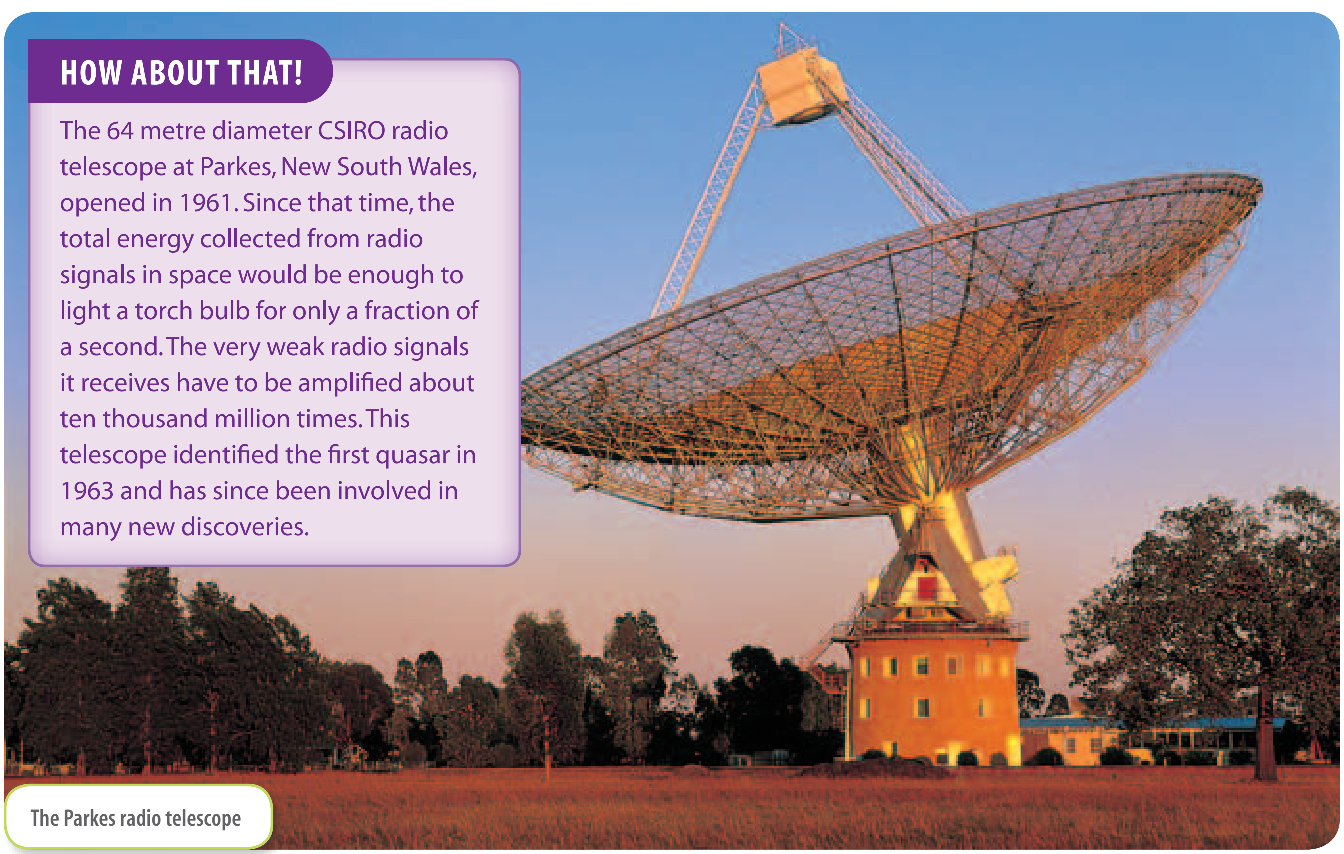
Guglielmo Marconi first experimented with radio transmissions around the beginning of last century. This means that weak radio signals have been travelling outwards from Earth for just over 100 years. It is possible that signals like these could be intercepted by beings on other worlds up to 100 light-years away, as long as these beings had reached a level of technology sophisticated enough to receive the incredibly weak signals.

Searching for signals

Could we receive signals from space that carry information? This is the focus of SETI, an international group of scientists who are conducting

HOW ABOUT THAT!

The 64 metre diameter CSIRO radio telescope at Parkes, New South Wales, opened in 1961. Since that time, the total energy collected from radio signals in space would be enough to light a torch bulb for only a fraction of a second. The very weak radio signals it receives have to be amplified about ten thousand million times. This telescope identified the first quasar in 1963 and has since been involved in many new discoveries.



The Parkes radio telescope

a Search for ExtraTerrestrial Intelligence. As part of SETI's Project Phoenix, for example, the CSIRO in Australia agreed to the use of the Parkes radio telescope for a period of time in 1995 for SETI observations.

A total of 172 stars were observed, each for between 2.5 and 5 minutes, over a range of radio frequencies from 1200 MHz to 3000 MHz. In all, more than 20 000 observations were made in 2400 hours of telescope time. Particular stars were chosen for observation because of the high likelihood that they have planets. Any signals that showed signs of regularity were investigated more closely to eliminate the effects of interference from radio transmitters on Earth or carried on orbiting satellites.

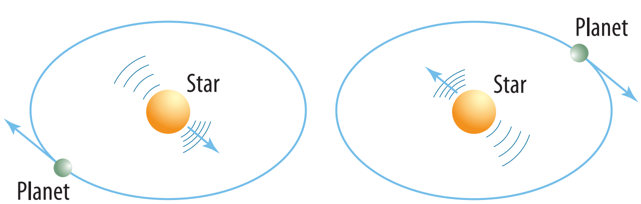
The summary of Project Phoenix in Australia is very brief: 'No signs of extraterrestrial intelligence were found'.

Looking for clues

If they cannot communicate directly with extraterrestrials, scientists must collect other forms of evidence to support the case for the existence of life elsewhere in the universe. They might, for example, look at the conditions organisms need to develop and survive and then at how likely it is that planets that provide these conditions exist. If scientists could discover which molecules are typical of life, they would be able to strengthen their case by searching for planets where the conditions that produce these molecules are found.

Planets outside the solar system

At the time of publication of this book, more than 150 planets outside the solar system have been discovered. Planets orbiting stars other than our sun are called **exoplanets**. Although the existence of exoplanets was suspected for many years, the first discovery of an exoplanet was not confirmed until 1994. Since that time, improvements in telescope technology have made it easier for astronomers to identify these planets. Most exoplanets have been discovered using observations of stars that appear to wobble.



How planets are found using the Doppler effect

STARS WITH THE WOBBLES

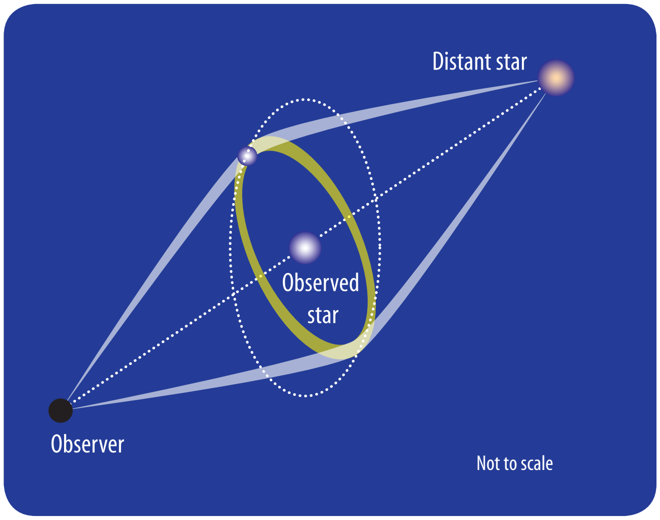
When a small mass orbits a larger one, it causes the central mass to wobble slightly (see Investigation 6.5). The larger mass may be a visible glowing star and the smaller mass a dark planet. If the planet is massive, the star's wobble may be directly seen by a nearby observer. In some cases, the wobble is too slight to be seen and the movement of the star can be deduced only from frequency changes in the light it emits caused by the Doppler effect (see section 6.4).

A large planet orbiting a star can cause the star to move towards and away (wobbling) from the observer. As it does so, the frequency of lines in the spectrum of light from the star will be shifted higher or lower than normal by the Doppler effect.

By measuring the amount of wobble it is possible to estimate the number and mass of planets orbiting a star. Each of these stars could be orbited by one or more planets. However, the planets discovered by observing wobbling stars are very large and similar to the gas giants of the solar system.

Rocky planets

In recent years, a new technique called **micro-lensing** has enabled astronomers to discover smaller, rocky planets. These are the planets most likely to support life. Micro-lensing involves observing a star when it passes directly in front of a more distant star. The gravity of the star in front acts like a lens as it pulls the light inwards. As a result, the light from the distant star converges. To the observer, it appears much brighter. If the star in front has one or more exoplanets, there are variations in the brightness of the observed light.



Based on the evidence collected so far, it is not possible to say whether any of these exoplanets could support life of any type. Scientists believe that life is most likely to exist only within a narrow range of conditions. These conditions are found in our solar system in a belt extending from just inside the orbit of Venus to just outside the orbit of Mars. Within this belt, the temperature range can be tolerated by living organisms, although Venus is much hotter than might be expected because of the greenhouse effect caused by its complete cloud cover.

INQUIRY: INVESTIGATION 6.5

Modelling a wobbling star

KEY INQUIRY SKILL:

- questioning and predicting

Equipment:

two different round masses firmly fastened to a wooden rod

a nail

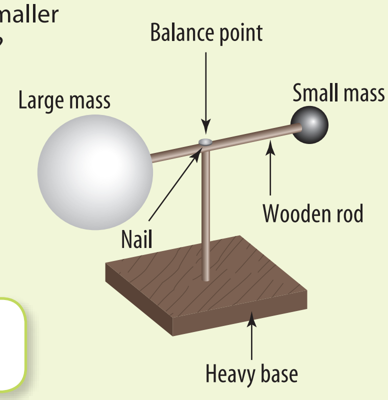
a stand on which to balance the rod and masses

- Find the point along the rod at which the two different masses balance. This will be closer to the larger mass. Drive the nail carefully into the rod at this point and fasten it to the stand so that the rod is horizontal and pivots on the nail.
- Start the rod spinning slowly and watch the larger mass closely, looking from a position level with the rod. (It helps if the larger mass is white and the smaller mass is black.)
- You should see the larger mass wobbling from side to side as the rod rotates. A similar wobble is seen when a star is orbited by a smaller companion star or a large planet.

DISCUSS AND EXPLAIN

1 What would you expect to see if the masses were equal?

2 What would happen to the apparent brightness of the larger 'star' as the smaller passes in front of it?



The two masses represent stars of very different size.

UNDERSTANDING AND INQUIRING

REMEMBER

1 What is an exoplanet?

2 Explain how the wobbling of a star can be used to demonstrate the existence of an exoplanet.

3 How is the wobbling of distant stars detected?

4 What is micro-lensing and how is it used to detect exoplanets?

THINK

5 Explain why it is unlikely that our radio transmissions have been picked up by extraterrestrial beings.

6 Why is Mars the most likely place, other than Earth, to find evidence of life in the solar system?

7 What is the greatest distance (measured in light-years) that radio waves have travelled from Earth since Marconi first used them to send a Morse code message in 1898? How far is this in kilometres?

8 How could a space probe carrying humans make its way to investigate planets orbiting other stars? Consider, for example, the distance involved, the speed of such a spacecraft, the time the journey might take and the needs of the crew onboard.

9 Should we be trying to contact 'ET'? Give reasons for your response.

CREATE

10 Design a plaque or a package to be carried on board a deep-space probe to give extraterrestrial beings important information about the Earth and the living things on it.

INVESTIGATE

11 Find out about the search for extraterrestrial intelligence. Which organisations are involved? Why is this important? What do they hope to find? What kinds of evidence are they searching for? How would proof of the existence of beings on other planets change the way people think?

work sheet 6.7 Telescopes

Priority grids and matrixes

1. Draw two continuums that cross through each other at right angles.
2. Divide each line into six equal parts.
3. Put a label such as Difficult on the left end of the horizontal line and Easy on the right.
4. Put a label such as High reward at the top of the vertical lines and Low reward at the bottom.
5. Think of an activity and assess it using these two lines, placing a mark where you think it fits best. Repeat this for other activities or ideas.
6. Compare and discuss your marked positions with those of others in your class. Share your ideas, values, views and judgements, and listen to those of others.
7. After your discussions and reflections, write your final positions directly onto the grid.

how to ...?

why use?

Helps you make decisions and see how your views and judgements compare with others

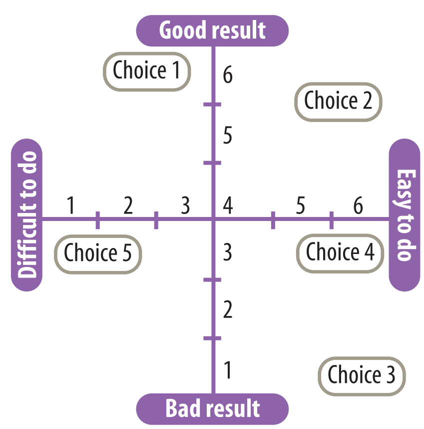
question

Which is the best option to follow and why?

also called

Priorities grid; decision grid

Priority grid



comparison

Similarity

Both help you to think about patterns or key points in the information.

Difference

Matrixes classify information based on the presence or absence of key features; priority grids help you to 'scale' various perspectives.

Matrix

example

Topic	Feature A	Feature B	Feature C	Feature D	Feature E
1	✓		✓	✓	✓
2		✓			✓
3		✓		✓	✓

UNDERSTANDING AND INQUIRING

THINK AND CREATE

1 Use a priority grid to evaluate each of the following current and future challenges in space exploration.
  (a) Completing and maintaining a permanent Earth-orbiting space station
  (b) Building and operating a permanent base on Mars
  (c) Sending a space probe to Proxima Centauri
  (d) Searching for extraterrestrial life forms

A permanent base on Mars is a real possibility. But how important is it? Are the benefits worthwhile? A priority grid can be helpful in answering questions like this.

2 A matrix can be used to compare the twentieth century's two competing theories about the universe. Copy and complete the matrix below, using ticks to show which statements apply to one, both or neither of the theories.

Statement	Big bang theory	Steady state theory
The universe has no beginning.		
The universe began with a single point called singularity.		
The universe is expanding.		
The universe always looks the same.		
The red shift in the spectrum of visible light coming from stars and galaxies provides evidence for the theory.		
New stars and galaxies are created to replace those that move away due to expansion of the universe.		
This theory explains the amount of helium in the universe.		
This theory is supported by the measurement of the current temperature of the universe (about –270 °C).		
This theory was first supported by a Catholic priest.		
The theory will never be proven incorrect.		
An end was put to this theory in 1965.		

3 Use matrixes to compare:
  (a) red giants and white dwarfs
  (b) three theories about how the universe might end
  (c) living in space and living on Earth.

New stars are forming right now in nebulae like this throughout the universe. According to one theory, this has been happening forever; according to another theory it has been happening only for about 14 billion years.

STUDY CHECKLIST

STARS

- describe and distinguish between planets, stars, constellations, galaxies and nebulae
- describe and explain the motion of stars and planets of the solar system as seen from Earth
- identify the sun as a star
- explain how stars are able to emit energy
- describe the lifetime of stars of different sizes and appreciate the timescale over which changes in stars take place
- interpret the Hertzsprung–Russell diagram in terms of the absolute magnitude, temperature and classification of stars
- distinguish between absolute and apparent magnitude

THE CHANGING UNIVERSE

- identify evidence supporting the big bang theory, such as Edwin Hubble's observations and the detection of background microwave radiation
- compare the big bang theory with the steady state theory
- describe how the universe has changed since the big bang and how it might continue to change in the future

SCIENCE AS A HUMAN ENDEAVOUR

- describe how radio telescopes and arrays of radio telescopes are used by astronomers and astrophysicists to observe distant parts of the universe
- explain how orbiting space telescopes are used to gather data from deep space and how they compare with Earth-based telescopes
- recognise the role of Australian astronomers and astrophysicists and facilities such as telescopes, arrays and observatories in the exploration and study of the universe
- recognise the importance of IT specialists and the development of fast computers in processing the data obtained by Earth-based and orbiting telescopes
- appreciate that the study of the universe and the exploration of space involves teams of specialists from different branches of science, engineering and technology
- recognise that financial backing from governments or other organisations is required for major scientific investigations and that this can determine if and when research takes place
- critically evaluate media reports about the existence of extraterrestrial life

ICT

eBook*plus* Summary

eLESSONS

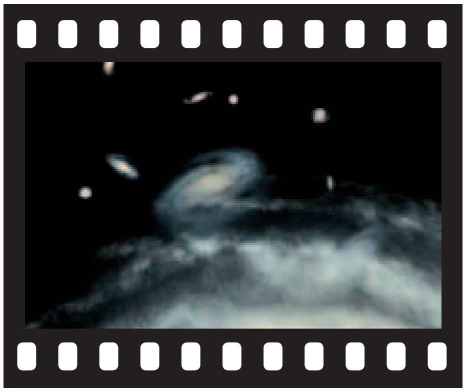
Biggest bang

Watch a video from the ABC's *Catalyst* program about gamma rays.

Searchlight ID: eles-1074

The expanding universe

In this eLesson you will learn about the big bang theory and why the universe continues to expand today.



Searchlight ID: eles-0038

Entropy: Is the end of the universe nearer than we thought?

Watch a video from the ABC's *Catalyst* program about the end of the universe.

Searchlight ID: eles-1073

INTERACTIVITIES

Star cycle

This interactivity tests your understanding of the life cycle of a star by challenging you to drag and drop labels onto their correct places in the cycle.

Searchlight ID: int-0679

Shifting spectral lines

This interactivity tests your understanding of red shift and blue shift by challenging you to choose the correct spectrum in a series of questions.

Searchlight ID: int-0678

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

INDIVIDUAL PATHWAYS

eBook*plus*

Activity 6.1	Activity 6.2	Activity 6.3
The mysterious universe	Investigating the universe	Investigating the universe further

LOOKING BACK

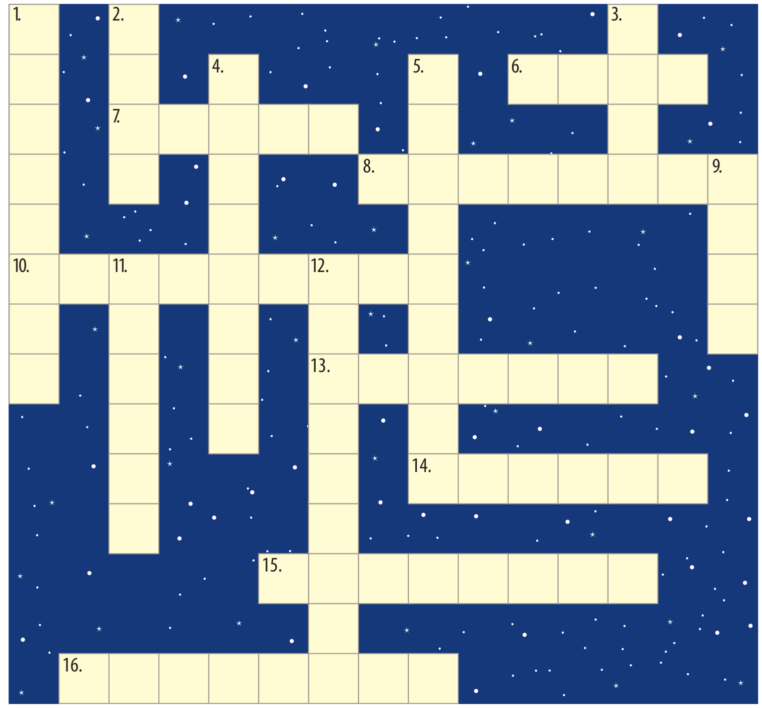
1 Solve the crossword puzzle at right.

Across

6. Search for ExtraTerrestrial Intelligence (abbreviation)
7. The constellation of which the Saucepan is a part (also known as the Hunter)
8. The name given to the range of colours of visible light
10. The distance travelled by light in a year (two words)
13. The name of two space probes that are carrying messages into space in the form of gold plaques
14. A natural display of lights on Earth that occurs during periods of high activity on the sun's surface
15. The galaxy of which the solar system is a part (two words)
16. Most of the interstellar matter between the stars consists of this element.

Down

1. An effect that shows that some stars are closer to us than others
2. The Earth's only natural satellite
3. The sun is one of these.
4. The famous equation $E = mc^2$ is attributed to this man.
5. The violent fate of some very massive stars
9. The 'red' planet of the solar system
11. A group of stars. The solar system is a tiny speck in one such group.
12. The universe seems to be doing this.



2 Why are the constellations we see now so different from the way they were many centuries ago?

3 During which process is the energy emitted by stars released? Describe the process.

4 Explain the difference between the apparent magnitude of a star and its absolute magnitude.

5 Use the data in the table in section 6.3 to answer the following questions.

Which of the stars Alpha Centauri, Betelguese and Rigel:

(a) is brightest when viewed from Earth on a clear night

(b) has the greatest actual brightness

(c) is faintest when viewed from the Earth on a clear night?

6 How have scientists gained their knowledge of the life and death of stars if the processes involved take millions of years to occur?

7 What is the difference between a neutron star and a black hole?

8 The Doppler effect is most commonly associated with the changing pitch of a sound as its source moves past you. For example, the pitch of the noise made by a speeding train increases as it approaches you and decreases as it moves away from you. Explain how the Doppler effect is relevant to the study of the universe.

9 Two different theories about the beginning of the universe emerged during the twentieth century.

(a) Name the two theories.

(b) Which of the two theories proposed that there was no beginning?

(c) Which of the two theories lost favour in 1965? Why did it lose favour?

10 In your own words, write an account (about 200 words) of the first second after the big bang.

11 Which of the three theories about the end of the universe described in section 6.5 do you think is the most likely to be correct? Give reasons for your answer.

12 For what do each of the following abbreviations stand?

(a) COBE

(b) WMAP

13 What is cosmic microwave background radiation and why does it exist?

14 At what speed do radio waves travel through space?

15 Outline two major advantages of using radio telescopes instead of light telescopes to view events in deep space from the Earth's surface.

16 Many of the billions of stars in the universe are similar to our sun. We already know that planets orbit many of these stars. These planets are called exoplanets.

(a) Exoplanets are too small to be seen with any telescopes. Explain how we know that they exist.

(b) Why is it unlikely that a spacecraft carrying humans will ever reach planets outside the solar system?

work sheet 6.8 The mysterious universe: Summary