7 The universe

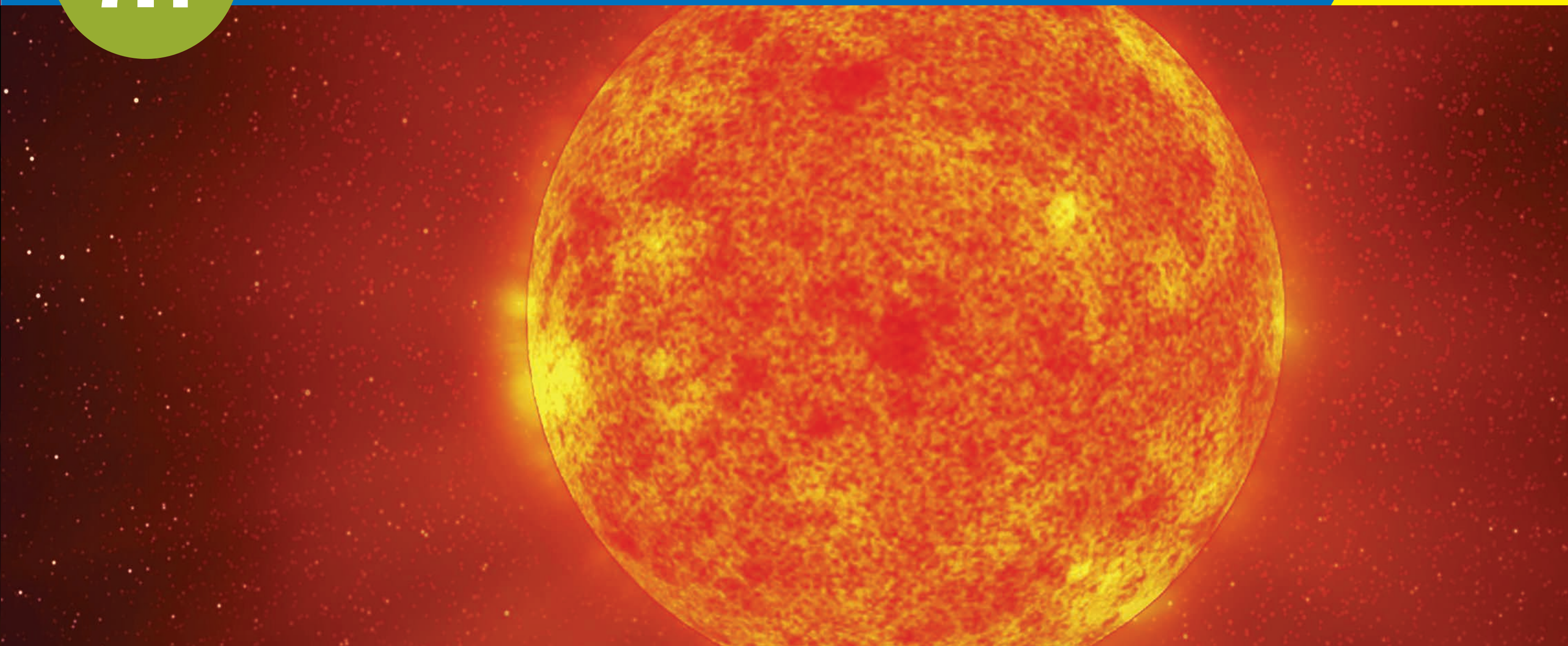
HAVE YOU EVER WONDERED…

- how far away the stars are?
- how the universe began?
- whether the universe will ever end?
- how old the solar system is?
- when the Earth was formed?

After completing this chapter students should be able to:

- identify the evidence supporting the Big Bang theory
- recall that the age of the universe can be derived using knowledge of the Big Bang theory
- describe how the evolution of the universe has continued since the Big Bang
- recall that the study of the universe involves teams of specialists from different branches of science, engineering and technology
- describe the formation of galaxies and stars.

7.1 Stars



Astronomy is the study of stars (*astra* means stars, *onomy* means study of). Not all stars are like our Sun. Like people, stars can vary in age, size and appearance. Stars can also change over time. Understanding the reasons for the differences between stars will help us understand our universe. It will also show how the beginnings of life were created in a star.

Brightness

Look up at the night sky and you will see that stars differ from one another in two very obvious ways—brightness and colour. Astronomers refer to the brightness of a star as its **magnitude**. The colour of a star is due to its temperature.

A star's **apparent magnitude** is a measure of how bright it will appear to an observer on Earth. Although confusing, the brightest stars are given the lowest magnitudes, while dimmer stars are given higher magnitudes. The very brightest stars are given negative magnitudes. For example, Alpha Centauri (the brighter of the two Pointers to the Southern Cross) has an apparent magnitude of –0.27. In most cities, the dimmest stars that can be observed with the naked eye have a magnitude of 3.5. Under ideal conditions, the human eye can see stars down to a magnitude of 6.5.

Apparent magnitude is measured on a logarithmic scale. On this scale, a change of one unit changes the brightness of the star by a factor of about 2.5. For example, two of the brightest stars in the constellation Orion are Betelgeuse and Bellatrix (Figure 7.1.1). Betelgeuse is the bright red star that makes the

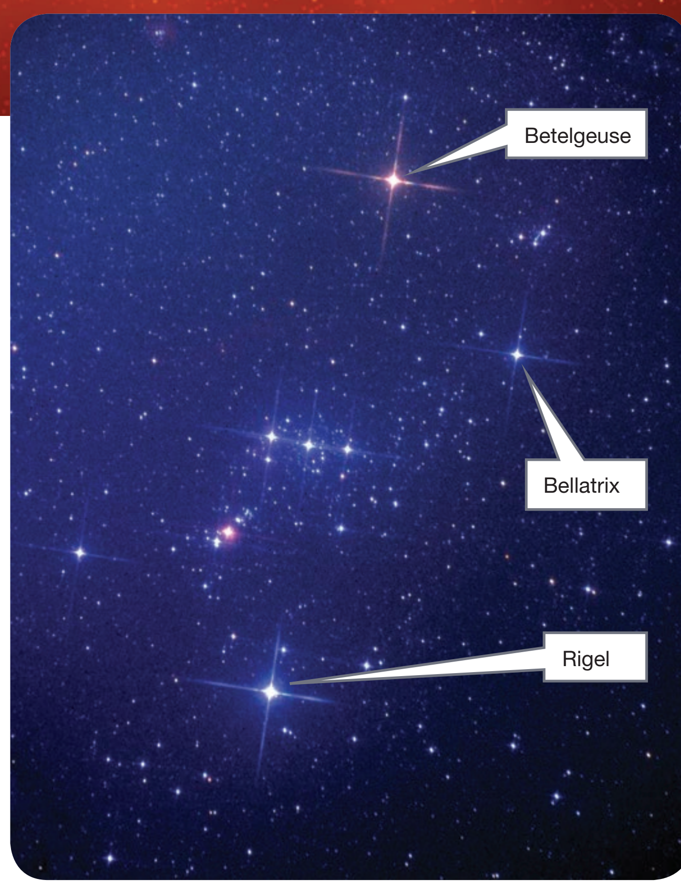


Figure 7.1.1 The constellation Orion (the hunter) contains stars of different brightness and colour.

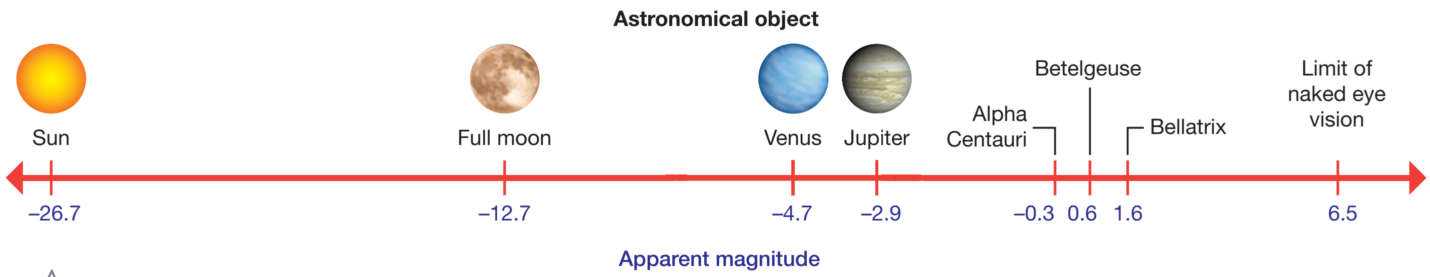


Figure 7.1.2 The apparent magnitudes of various astronomical objects. The magnitude of planets such as Venus changes over time and so the values given here are their maximum values.

right shoulder of the hunter in the constellation and Bellatrix is its left shoulder. Betelgeuse has an apparent magnitude of 0.6 and Bellatrix has an apparent magnitude of 1.6 (Figure 7.1.2). Since Betelgeuse's apparent magnitude is one unit lower than that of Bellatrix, it appears about two and a half times brighter than Bellatrix.

There are two main factors that determine a star's apparent magnitude. One is how much light the star emits. The other is the distance between the star and Earth—the greater the distance, the dimmer the star will appear. In order to study stars, it is important to eliminate the effect of distance on our measurements.

7.1

The distances between stars

Given the enormous distances between stars, the kilometre is not a convenient unit of length in astronomy. Astronomers often measure interstellar distances (the distances between stars) in **light-years (l.y.)**. One light-year is the distance that light will travel in one year. This distance is a little under 9.5 trillion kilometres. The distance to Betelgeuse is 650 l.y. This means that the light you see when you look at Betelgeuse was emitted by the star nearly 650 years ago. Looking at stars is like looking backwards in time!

Another commonly used astronomical unit of length is the **parsec** (pc), which is equivalent to 3.26 light-years.

SKILL BUILDER

Converting between light-years and parsecs, l.y. → pc

To convert from light-years into parsecs, divide by 3.26:

$$\text{distance in parsecs} = \frac{\text{distance in light-years}}{3.26}$$

To convert from parsecs to light-years, multiply by 3.26:

$$\text{distance in light-years} = \text{distance in parsecs} \times 3.26$$

WORKED EXAMPLE

Converting light-years to parsecs

Problem

Betelgeuse is 650 light-years away. Calculate how many parsecs this represents.

Solution

$$\text{Distance in parsecs} = \frac{650}{3.26}$$

$$= 199 \text{ pc}$$

INQUIRY science 4 fun

Eye parallax

Yes

Do this …

1. Place an object on a table about arm's length in front of you.
2. While looking at the object, close or cover your left eye. Note the position of the object relative to its background.
3. As quickly as possible, close or cover your right eye while you open your left eye. Note how the position of the object changes.
4. Quickly swap back to looking with just your right eye. Swap from one eye to the other as quickly as possible. Note how the position of the object changes against its background as you change from one eye to the other. This apparent change in position is parallax.
5. Repeat this process with an object about 2 metres away.
6. Repeat the process with an object at the other side of the room and then with a distant object (for example, through a window).

Record this …

Describe what happened. Was the effect for more-distant objects greater or smaller than for closer objects?

Explain why you think this happened. Use a diagram to help you

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Definition of a parsec

A parsec is defined as the distance a star would need to be from our Sun if it was to have a stellar parallax of exactly 1 arcsecond (1 arcsecond = $\frac{1\text{ degree}}{3600}$). The closest star to our Sun is Proxima Centauri. Its parallax is 0.768 arcsecond, giving it a distance 1.3 parsecs or 4.2 light-years.

The parsec is based on a phenomenon known as **parallax**. Parallax causes you to see different views of the same object. Shut one eye, open it, then shut the other and you will see slightly different views of the same scene. This is parallax! Parallax can be used to measure the distance between the Sun and other stars. As the Earth moves around the Sun, our changing point of view means that the positions of stars in the sky change very slightly over the course of the year. This is shown in Figure 7.1.3.

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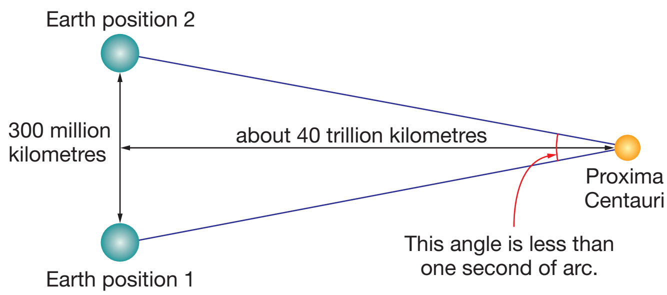

Figure 7.1.3 The position of Proxima Centauri in the sky changes slightly due to the Earth's movement around the Sun. This diagram is not to scale.

Even for the closest stars, this shift in position (known as **stellar parallax**) is tiny—less than one-thousandth of 1 degree. It is only since the 19th century that astronomers have had instruments sensitive enough to reliably measure stellar parallax and calculate the distance to the nearest stars. Many stars are so far away that their stellar parallax is too small to be measured. Astronomers need to use more indirect methods to measure the distances to these stars.

Absolute magnitude

As a way of measuring a star's actual brightness, scientists use a measurement called **absolute magnitude**. This measures how bright a star would appear to us if it was a distance of 10 parsecs from Earth. Using absolute magnitudes allows the brightness of stars from different parts of the galaxy to be meaningfully compared.

Betelgeuse is almost 200 pc from Earth whereas Bellatrix is only 75 pc away. Betelgeuse has an absolute magnitude of –5.14. This means that if it was only 10 pc from Earth, it would be almost 200 times brighter than it currently appears. In comparison, the absolute magnitude of Bellatrix is –2.72, meaning that even if Betelgeuse and Bellatrix were the same distance from Earth, Betelgeuse would still be the brighter of the two stars. (Remember that brighter stars have lower magnitudes.)

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Seeing the colour of stars

The colours you see in Figure 7.1.4 will probably seem much clearer than those you see when you look at stars in the night sky. One reason for this is that your eyes have two different types of light receptors called rods and cones. Cones are responsible for colour perception. They require a lot of light to be activated and do not work well at night. Also, our eyes suffer from an effect called small-field tritanopia. This means that we have difficulty detecting the colour of small points of light. The long exposure time used in taking the photo in Figure 7.1.4 makes many of the stars small disks rather than points. This allows our eyes to perceive their colour easier than with normal stars.

Figure 7.1.4 This is a photo taken by the Hubble Space Telescope of a section of sky in the constellation Sagittarius. It shows some of the variety in the colour of stars in our galaxy.

Colour

Each star emits light at a range of different wavelengths. Some of this light is in the visible part of the **electromagnetic spectrum** (Figure 7.1.5), while some of it will be in the invisible infrared or ultraviolet range. Your eyes collect the visible light from stars and your brain performs a complex averaging process that results in you perceiving the star as a particular colour.

Rather than rely on the human eye and the brain to interpret the colour, scientists analyse the light from a star by using filters. By comparing the magnitude of the star when viewed through coloured filters, its colour can be precisely measured.

A star's spectrum is mainly determined by its surface temperature. Cooler stars emit most of their energy in the infrared and red parts of the spectrum and therefore appear red to your eyes. Very hot stars emit a lot of energy in the violet and ultraviolet part of the spectrum and appear blue. Stars with temperatures in between these extremes emit light across a range of wavelengths and can appear orange, yellow or white.

Another device that is used to analyse starlight is a **spectrometer**. This is a device that splits light into a spectrum to reveal its component colours.

Scientists can determine what chemical elements are present in a star from distinctive lines that appear in its spectrum. Particular elements emit colours of particular wavelengths. These can be measured precisely to determine the elements in the star.

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When studying the spectra from stars, scientists also see dark lines showing missing colours. The Sun has dark lines called Fraunhofer lines in its spectrum. You can see them in Figure 7.1.6. The lines are due to light interacting with atoms in the outer layers of the star. The light energy is absorbed by electrons in atoms of all the elements in the outer gas layers. These electrons absorb light energy of particular wavelengths. The absorption occurs at exactly the same wavelength that the same element would emit when it is extremely hot.

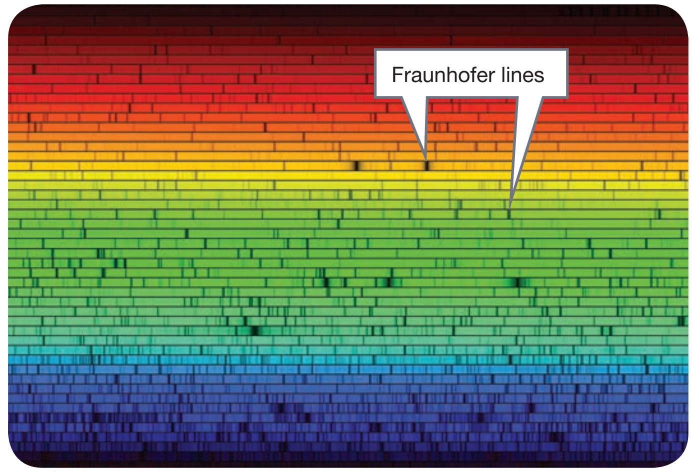

Figure 7.1.6 The spectrum of the Sun, showing dark vertical lines called Fraunhofer lines

From the spectra, scientists have created a classification system called **spectral class**. Spectral class indicates the elements present in the star, the temperature and colour of a star. This is shown in Table 7.1.1. Our Sun has a surface temperature of just under 6000°C so it is classified as a G-type star. It has a yellow-white colour.

The source of energy that keeps stars at these extraordinarily high temperatures is a process known as **nuclear fusion**.

Table 7.1.1 Spectral classes and their associated temperatures and colours

Spectral class	Temperature (°C)	Colour of star
O	50 000–28 000	Blue
B	28 000–10 000	Blue-white
A	10 000–7500	White
F	7500–6000	White-yellow
G	6000–4900	Yellow
K	4900–3500	Orange
M	3500–2000	Red

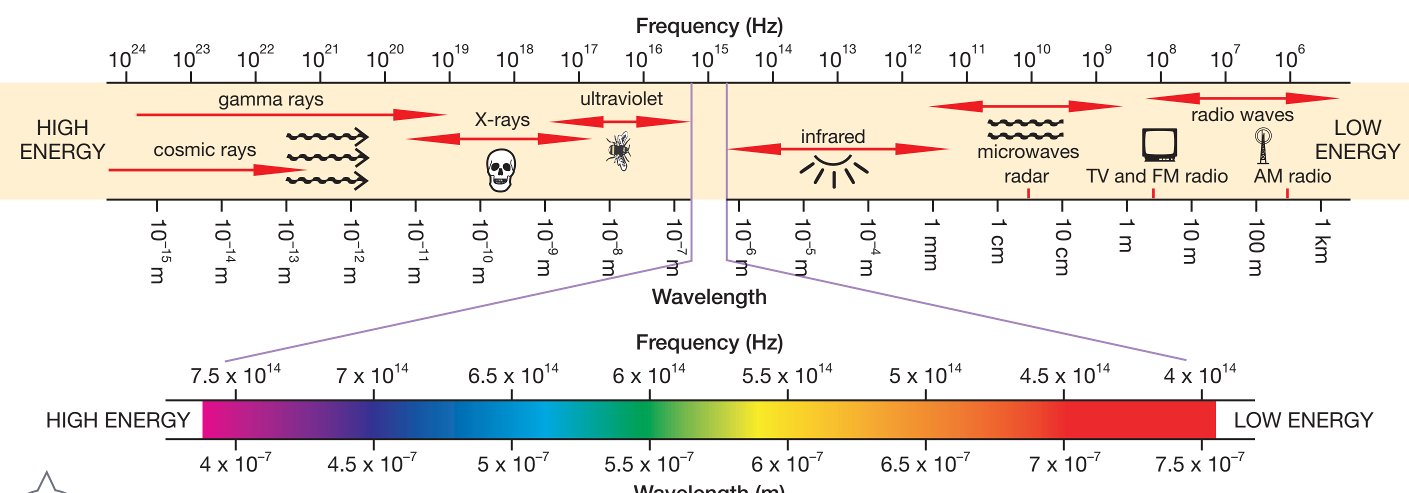

Figure 7.1.5 The visible part of light is just a small part of the electromagnetic spectrum.

Nuclear fusion

Data from spectral analysis has indicated that three-quarters of the material in a typical star is hydrogen. Most of the remaining quarter consists of helium and small amounts of iron and other heavy elements.

The enormous gravitational forces within a star can heat the material at its centre to a temperature of almost 15 million degrees Celsius. Hydrogen is the simplest element in the periodic table, consisting usually of a single proton and an electron. At the enormous temperatures inside a star, the electrons have too much energy to stay bound to the protons so the material takes the form of **plasma**. Plasma is a state of matter consisting of a 'soup' of positively charged ions and free electrons.

Protons are positively charged and so they strongly repel each other. However, in the centre of a star, the massive gravitational force is enough to bring individual protons close enough so that they will fuse together into a new nucleus. This is shown in Figure 7.1.7.

proton + proton → deuterium + positron + neutrino + energy

Figure 7.1.7 In the centre of a star, protons join to form a new nucleus called deuterium (a proton and neutron joined), a positron and a neutrino.

During the fusion process, one of the protons is converted into a neutron and two tiny particles are released—a small positively charged particle called a **positron** and a tiny, neutral particle called a **neutrino**. A positron is the antimatter particle for an electron. It is identical to an electron except that it has a positive charge. The positron does not stay in existence for long. As it is positively charged, it will be attracted to any electrons in the plasma. When a positron collides with an electron, the two particles annihilate (destroy) each other and become two high-energy **gamma rays**. As these gamma rays make their way out from the core of the star, their wavelengths increase and they are stretched into the heat, light and ultraviolet radiation that we can observe from Earth.

The new nucleus formed in this fusion reaction consists of a proton and a neutron. This is still the nucleus of a hydrogen atom, but it is an **isotope** of hydrogen known as deuterium.

Neutrinos

Neutrinos are extremely difficult to detect. They have almost no mass and, since they have no charge, they are not affected by electric or magnetic fields. It is suspected that trillions of neutrinos produced by the Sun pass through your body each second without having any effect on you at all!

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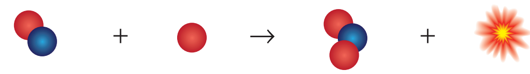
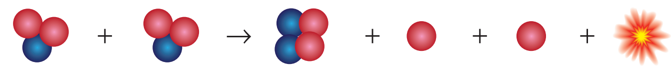
The deuterium can undergo further fusion reactions as shown in Figures 7.1.8 and 7.1.9.



deuterium + proton → helium-3 + energy

Figure 7.1.8 Hydrogen fusion reaction



helium-3 + helium-3 → helium-4 + proton + proton + energy

Figure 7.1.9 Helium–helium reaction (protons shown in red, neutrons in blue)

The overall result of all these reactions is that hydrogen is converted into helium and energy.

The life cycle of stars

Hertzsprung–Russell diagrams

In the early part of the 20th century, two astronomers, Ejnar Hertsprung of Denmark and Henry Norris Russell of the United States, independently came up with the idea of plotting stars on a diagram. Absolute magnitude (brightness) was placed on one axis and spectral class (colour) on the other. When they did this, they noticed that the stars fell into a number of clearly defined groups. This type of diagram became known as the Hertzsprung–Russell or H–R diagram. A typical H–R diagram is shown in Figure 7.1.10 on page 220.

The H–R diagram revolutionised astronomy because it showed that there was a relationship between the brightness and temperature of stars. H–R diagrams were also interpreted as showing that stars were changing from one 'type' to another. These changes became known as the 'life cycle' of a star. Using an H–R diagram is a bit like going into a forest and seeing all the trees at different stages of growth and concluding that the stages represent different life stages of the species. You can't actually see a tree at one stage grow into the other, but it is clear that they must. It became apparent that as stars develop and change, they move from one section of the H–R diagram to another. Thus the H–R diagram acts as a map of the life-cycle of a star.

7.2

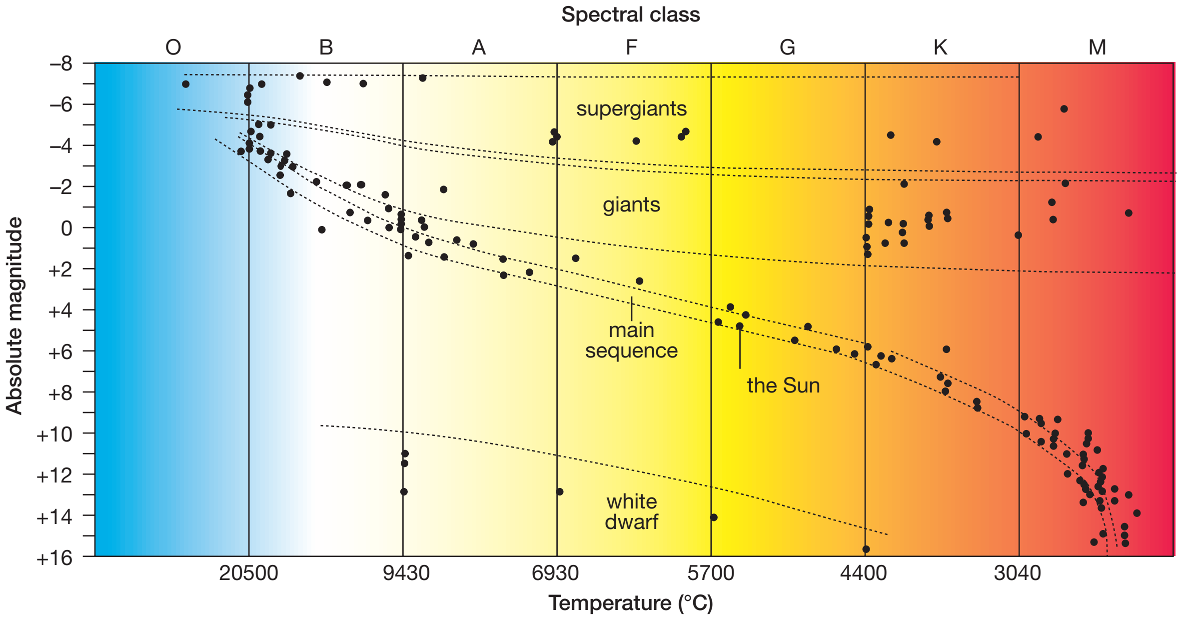


Figure 7.1.10 Hertzsprung–Russell diagram

Main sequence

On an H–R diagram, most stars fall on a broad line running from the top left-hand corner to the bottom right-hand corner. This line is known as the **main sequence**.

The structure of any star is determined by the balance of two opposing forces. One of these forces is **gravity**, which causes the material within the star to fall in towards the centre of the star. Opposing gravity is the **radiation pressure**, which is produced by the heat generated by nuclear fusion.

In a main sequence star, gravity and radiation pressure are in equilibrium—they balance each other out, giving the star a constant radius and brightness. This equilibrium can last for millions or even billions of years until the hydrogen in the core of the star starts to run out.

For main sequence stars, there is a simple relationship between the mass of the star and its temperature and brightness—the heavier the star, the hotter and brighter it will be. This is because more mass results in a greater gravitational force. The greater gravity from the large mass causes the core of the star to be more tightly compressed and therefore nuclear fusion occurs more rapidly. Hydrogen is converted into helium more quickly and produces more heat and light. This also means that more massive stars burn up their fuel more quickly.

Our Sun is a medium-sized star on the main sequence. At a temperature of around 6000°C. Our Sun's nuclear fuel will last for about 10 billion years. In comparison, a star ten times as massive as the Sun will be 10 000 times brighter, have a temperature of 22 000°C and burn out in 20 million years.

On an H–R diagram, the stars in the top left-hand corner are brighter, hotter and larger. Stars in the bottom right-hand corner are dim, cool and small.

Typical stars in the main sequence start their lives at the bottom right-hand corner of the main sequence and move towards the top left of the H–R diagram. When the hydrogen in the core of a main sequence star runs out, it undergoes a dramatic transformation and moves off the main sequence. Where it goes next on the diagram depends on its mass.

Red giants

When the hydrogen in the core of a medium-sized star runs out, fusion stops and the outward radiation pressure also stops. Gravity causes the star to collapse inwards and the outer layers of the star to start to fuse. Heat from this fusion produces radiation pressure, which causes these outer layers to expand and cool. The star becomes a **red giant** with a small dense core and a large, relatively cool outer atmosphere.

Fusion in the outer layers of a red giant occurs at a lower temperature than in a main sequence star. Therefore, a red giant produces more light in the red part of the spectrum, giving the star its distinctive colour. As the hydrogen in the outer layers of the red giant fuses, the helium produced sinks into the core of the star. As more and more matter is added to the core, its gravitational force and temperature increase until helium atoms start to fuse into heavier elements such as beryllium and carbon. This is shown in Figure 7.1.11.

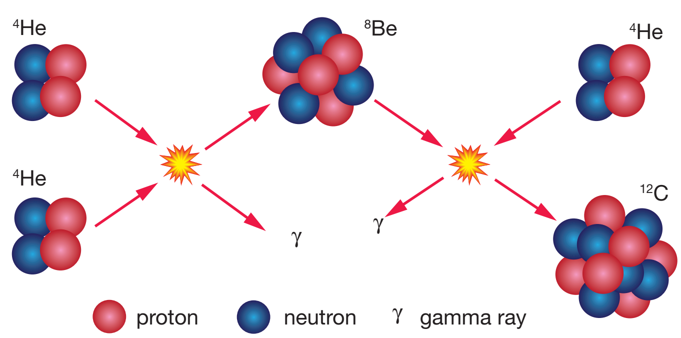


Figure 7.1.11 Fusion can create heavier elements from helium (He). This example shows how beryllium (Be) and carbon (C) form.

Typically, a red giant that has formed from a medium-sized star has enough helium fuel in its core to last for around 100 million years. When this runs out, the star collapses further

Figure 7.1.12 Planetary nebulae form spectacular shapes and patterns.

and the outer layers escape to become a cloud of gas known as a **planetary nebula.** Almost half of the mass of the original star is lost into this planetary nebula. The remaining core of the red giant is extremely hot and emits ultraviolet light. This causes the planetary nebula to glow in spectacular patterns. You can see some in Figure 7.1.12.

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'Planetary' nebula

The name *planetary nebula* was first used in the late 18th century by William Herschel, the discoverer of Uranus. Through the low-power telescopes available at the time, these clouds of gas looked like Uranus and other gaseous planets. The name is misleading since scientists now know that these phenomena have nothing to do with planets.

Over a 'short' period of 20 000 years, a planetary nebula will disperse to reveal the hot, dense sphere of carbon and hydrogen that is the remains of the red giant (its core). This fades to become a very dense star called a **white dwarf**. White dwarfs are so dense that if our Sun became a white dwarf, its mass could be packed into a sphere only slightly larger than the Earth. While a white dwarf is very hot, it is much dimmer than the red giant from which it forms. The lower brightness now places it off the main sequence and this means that the white dwarf drops to the bottom of the H–R diagram.

Nuclear fusion has ceased on a white dwarf, so the star will fade to become a cold, dark ball of inert matter known as a **black dwarf**.

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Do black dwarfs really exist?

Since white dwarfs are very small and have a relatively small surface area, they radiate heat very slowly. It would take hundreds of billions of years for a white dwarf to turn into a black dwarf. Scientists currently believe that the universe is less than 20 billion years old, so it is possible that black dwarfs exist only in the imaginations of astrophysicists!

Supergiants

Stars that are ten or more times as massive as our Sun follow quite a different life-cycle from the stars on the main sequence. These massive stars start at the top left-hand corner of the H–R diagram and are known as **blue supergiants**. Being much larger than main sequence stars, they have much higher gravitational forces and consume their hydrogen much more quickly—in millions rather than billions of years.

When the hydrogen runs out and helium fusion begins, the star's brightness stays approximately the same but it slowly cools down. On the H–R diagram, this is seen as movement from left to right. Once all the helium has been fused into carbon and oxygen, the temperature in these massive stars is hot enough to cause these atoms to fuse into even heavier and heavier elements. Eventually though, even this fuel will have to run out and then the results are nothing short of spectacular—a supernova occurs!

Supernovae

Once all the material in the core of a supergiant has been fused into iron, it cannot fuse any further. Creating heavier elements than iron absorbs more energy than it releases. If the core of the star stops producing energy, there is no force to act against gravity and all of the material in the outer layers collapses inwards at incredible speeds. When this material reaches the solid core, it rebounds in a massive explosion called a **supernova**. The star will become over 100 million times brighter than it was originally, outshining the rest of the stars in its galaxy combined! In 1987, astronomers were fortunate enough to capture this process occurring in a star in the Large Magellanic Cloud. The black and white images in Figure 7.1.13 on page 222 show how dramatically the brightness of the star increased.

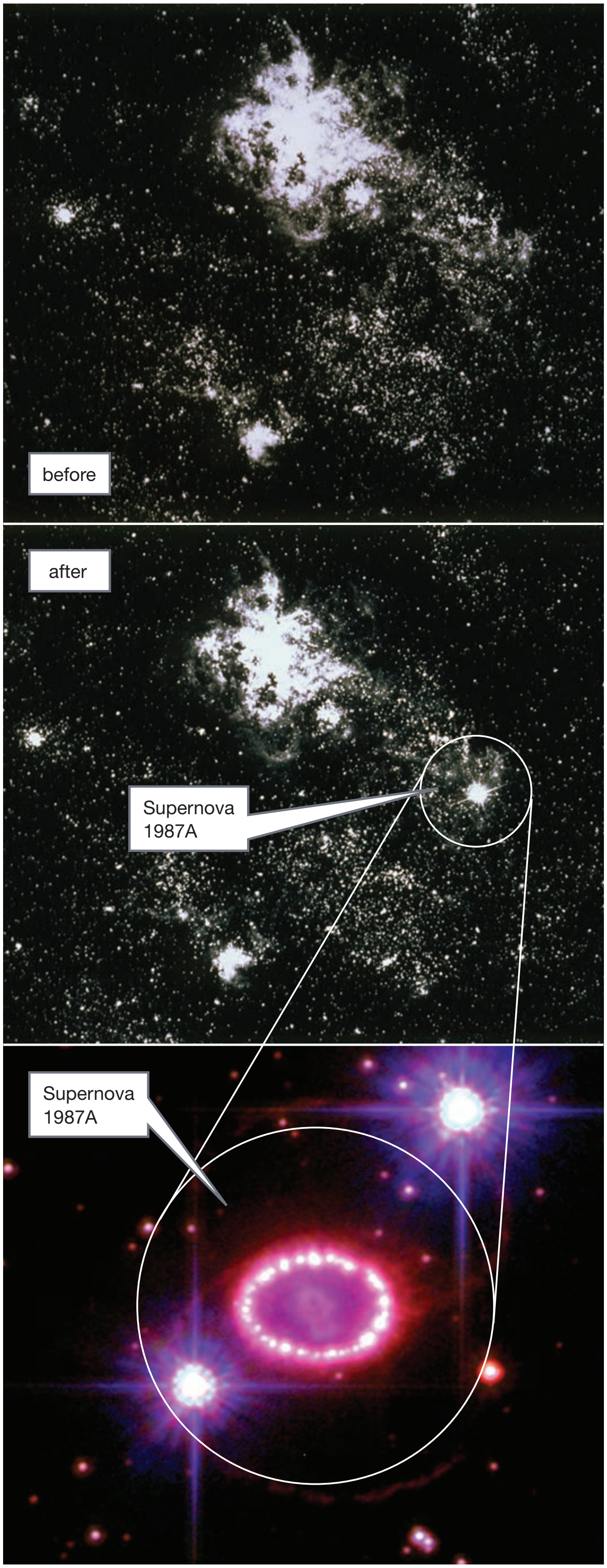

Figure 7.1.13 Before and after photos of Supernova 1987A.

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Supernova—'big, new star'

In Latin, the word *nova* means 'new'. This term was originally used by the earliest astronomers because it seemed that a 'new' star was being born. A nova would appear, burn brightly for a few weeks or months and then fade dramatically. If a nova was particularly spectacular, it came to be known as 'supernova'. Scientists now understand that a nova or supernova is not a new star at all. The star that exploded into the supernova was always there, it may just have been too dim for astronomers to notice it.

When a star explodes this violently, much of its mass is blown in to space. You can see this in the bottom photo of Figure 7.1.13 and in Figure 7.1.14. This material is mostly in the form of neutrons, which collide with other atomic nuclei as they are flung outwards. Many of the neutrons are captured by these nuclei to form heavy elements such as gold and silver.

What happens to the material left behind by this explosion depends on the size of the star.

Figure 7.1.14 This image shows a section of the Cygnus loop, a cloud of gas produced in a supernova explosion. The bright colours indicate the presence of elements such as oxygen.

SKILL BUILDER

Calculating density

Density is defined as mass per unit volume.

Density = $\frac{\text{mass}}{\text{volume}}$

Density is commonly measured in units of either grams per cubic centimetre (g/cm^3) or kilograms per cubic metre (kg/m^3).

WORKED EXAMPLE

Calculating Earth's density

Problem

The planet Earth has a mass of 6.0×10^{24} kg and a volume of 1.1×10^{21} m^3. Calculate its average density.

Solution

$$\begin{aligned}\text{density} &= \frac{\text{mass}}{\text{volume}}\\ &= \frac{6.0 \times 10^{24}}{1.1 \times 10^{21}} = \frac{6.0}{1.1} \times \frac{10^{24}}{10^{21}}\\ &= 5.5 \times 10^{3} = 5.5 \times 1000\\ &= 5500\,\text{kg/m}^3\end{aligned}$$

Neutron stars

If the amount of material left behind by a supernova is 1.4–3 times the mass of our Sun, then gravitational forces are strong enough to cause the structure of the atoms within it to break down. Electrons and protons combine to form neutrons. The resulting **neutron star** has an enormous **density** since its entire mass can be compressed into a sphere about 10–15 km across.

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Black holes

For supernova remnants that are more than three times the mass of our Sun, the process of collapse after a supernova does not end with the formation of a neutron star. The immense gravitational forces cause the star to shrink even further into what scientists refer to as a **singularity** or **black hole.**

The gravitational field of a black hole is so strong that not even light is fast enough to escape from it. This makes black holes very hard to detect as they do not emit any visible light. However, it is possible to find black holes indirectly by the effect they have on other stars. One method of detection occurs when a black hole is part of a **binary star system** (Figure 7.1.15). This occurs when two stars form close to one another and orbit a common centre of mass between them. If one of these stars becomes a black hole, its enormous

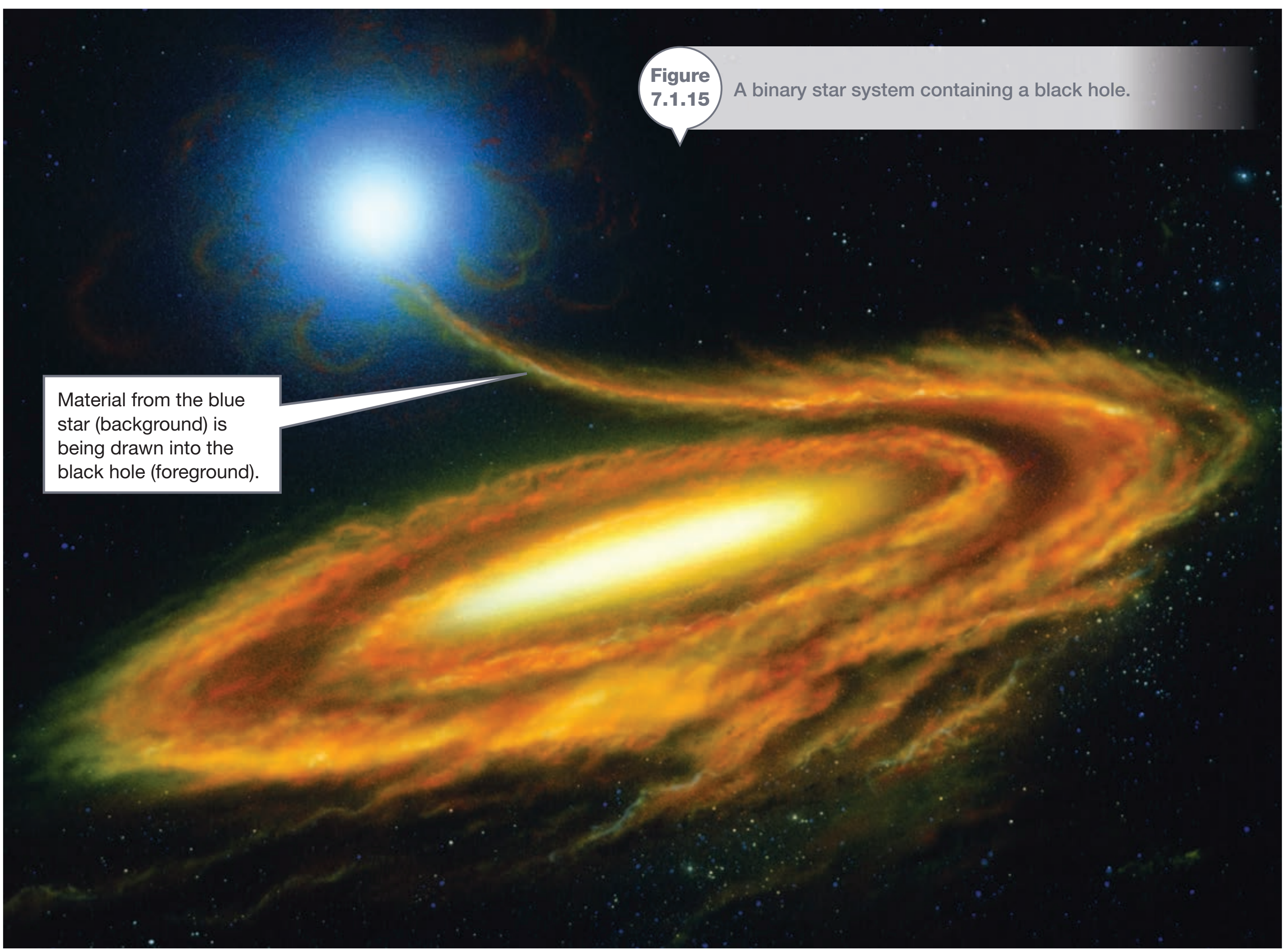

Figure 7.1.15 A binary star system containing a black hole.

gravitational field will start to strip material from the other star. As this material spirals into the black hole, it emits a distinctive high-energy X-ray signal, which indicates the presence of the black hole.

Another way to detect a black hole is by a process called **gravitational lensing**. According to Einstein's theory of relativity, the gravitational field around a black hole is so strong that it can actually distort the shape of space itself. This means that light from a distant star passing either side of the black hole can be bent back towards an observer on Earth. Due to this lensing effect, the observer sees identical stars on either side of the black hole (Figure 7.1.16).

Scientists now believe that most galaxies have an enormous black hole at their centre. These **supermassive black holes** may have masses equivalent to millions or billions of stars the size of our Sun. Evidence suggests that the black hole at the centre of the Milky Way galaxy lies in the constellation Sagittarius.

The initial size of a star is critical in determining its life cycle and the type of star it will eventually become. The various possibilities are summarised in Figure 7.1.17.

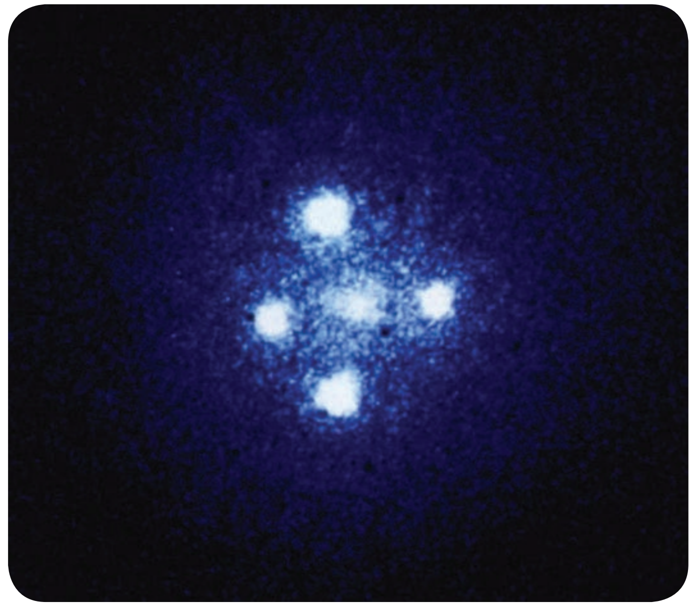

Figure 7.1.16 This image taken by the Hubble Space Telescope shows five different images of the same star. These images are caused by gravitational lensing.

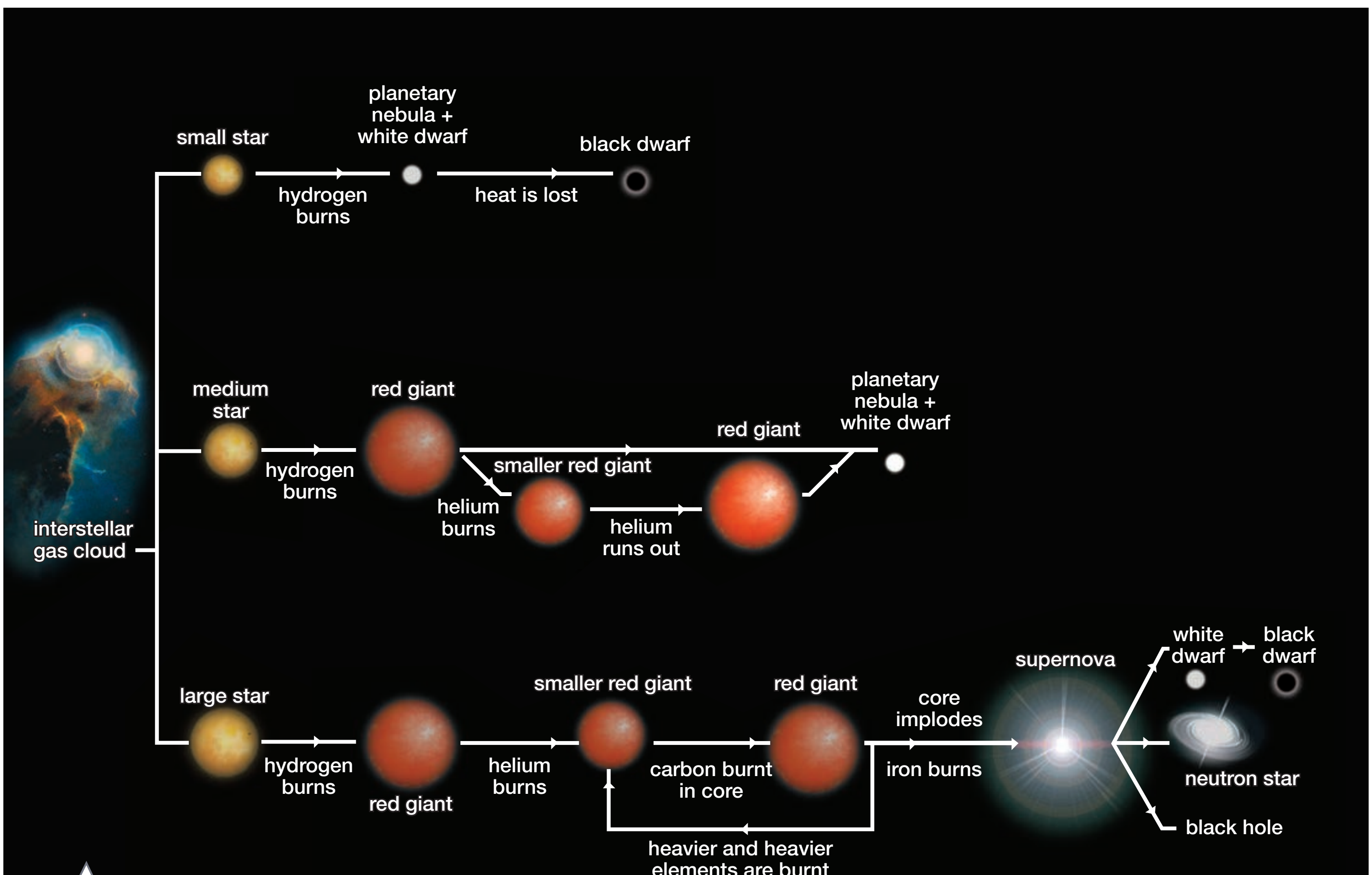

Figure 7.1.17 Possible life cycles of a star

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Magellanic Clouds

Figure 7.1.18 Ferdinand Magellan, the Portuguese explorer after whom the Magellanic Clouds are named

In 1519, Ferdinand Magellan was sent by the king of Spain to make the first circumnavigation (trip around the circumference) of the world. He set out with 237 men and five ships. Three years later, just 18 men and one ship returned. While on his travels through the Philippines, Magellan had been killed in a battle with native tribes.

Fortunately for science, one of the survivors was Antonio Pigafetta, a scholar from Venice, who took detailed notes on the flora, fauna, geography and languages encountered on the trip. He also recorded the first Western observations of the astronomical objects now known as the Magellanic Clouds. These are two of the closest galaxies to the Milky Way (Figure 7.1.19).

However, this was not the first human observation of these cloud-like objects. In 964 CE, a Persian astronomer known as Al-Sufi observed the Large Magellanic Cloud and named it the White Ox.

Perhaps the earliest references to the Magellanic Clouds come from the myths (stories) of Australian Aborigines, who refer to the clouds as an old man and woman and as two 'lawmen' whose fire sent sparks into the sky to form the clouds.

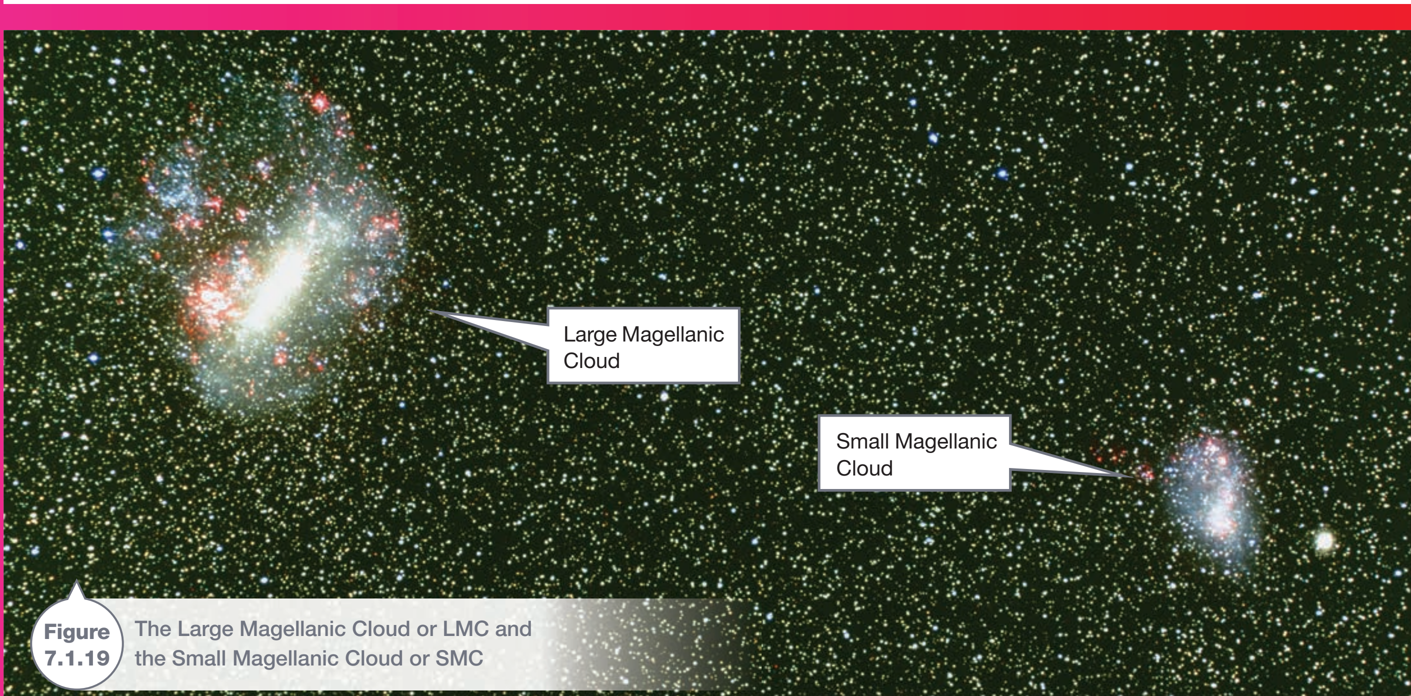

Figure 7.1.19 The Large Magellanic Cloud or LMC and the Small Magellanic Cloud or SMC

7.1 Unit review

Remembering

1 **Name** the type of nuclear reaction that produces energy stars.

2 **Recall** the type of star produced by the collapse of a star that is the same size as our Sun.

Understanding

3 a **Define** the term *spectral class*.

b **Name** the device used to measure it.

4 The 'twins' of the constellation Gemini are the stars Castor and Pollux. **Explain** how these two stars can have almost identical apparent magnitudes when Castor (50 l.y.) is almost 1.5 times further away than Pollux (33 l.y.).

5 **Explain** why stars on the main sequence get brighter as they get bigger.

6 **Predict** what will happen to a star 15 times the size of our Sun when the hydrogen fuel in its core runs out.

Applying

7 a Betelgeuse is a star that is 640 light-years away. **Calculate** this distance in parsecs.

b Bellatrix is 75 pc from Earth. **Calculate** this distance in light-years.

8 Rigel and Betelgeuse are the two brightest stars in the constellation Orion. Rigel has an apparent magnitude of 0.18 and an absolute magnitude of –6.8. Betelgeuse has an apparent magnitude of 0.6 and an absolute magnitude of –5.1.

a **Identify** which of the two stars appears brighter.

b **Identify** which of the two stars produces more light.

9 **Calculate** the density of:

a the planet Jupiter, mass = 1.9×10^{27} kg, volume = 1.4×10^{24} m^3

b the Sun, mass = 2.0×10^{30} kg, volume = 1.4×10^{27} m^3

c a red giant, mass = 3.6×10^{31} kg, volume = 1.2×10^{36} m^3.

Analysing

10 **Contrast** the terms *absolute magnitude* and *apparent magnitude*.

11 Just as a year can be broken up into 365 days, a light-year can be broken up into 365 'light-days'. A light-year is 9.5×10^{12} km (9.5 million million kilometres).

a **Calculate** the length of 1 light-day.

b **Calculate** the length of:

i 1 light-hour

ii 1 light-minute.

c Given that the Earth is, on average, 150 000 000 km from the Sun, **calculate** this distance as a value in light-minutes.

d **Interpret** the answer to part c to give the time it takes for light from the Sun to reach Earth.

Evaluating

12 The term *supernova* literally means 'big, new star'. Modern astronomers now understand that supernovae are not 'new' stars but stars that have suddenly become much brighter, so this term is misleading. **Propose** a more scientifically accurate name for this type of star.

13 a **Critically analyse** the accuracy of the term *planetary nebula*.

b **Propose** a more appropriate term.

Creating

14 **Construct** a physical model that shows how two stars that are a long way apart might appear close together when viewed from Earth.

15 **Construct** an instrument that uses parallax to accurately measure the distance to objects up to 100 metres away.

Inquiring

1 Design an investigation to test the instrument you constructed in Question 15.

2 Research methods other than stellar parallax that can be used to measure the distances to astronomical objects.

3 Research pulsars, stating how these are related to the types of stars discussed in this unit and why Australia is a leader into research on pulsars.

4 Use the internet to research and design your own spectrometer using an old CD.

7.1 Practical activities

1 Distances and parallax

Purpose

To measure the distance to an object by parallax.

Materials

- wooden metre ruler
- 10 m of string
- drawing pins
- protractor
- scissors
- tape measure

Procedure

1. Copy the table from the results section into your workbook.
2. Cut the piece of string into two equal lengths.
3. Pin one end of one piece of string to the 20 cm mark of the metre ruler. Pin the end of the other piece of string to the 80 cm mark of the metre ruler. This gives a measurement baseline of 60 cm (i.e. 80 cm – 20 cm).
4. Identify a distant object. A tree or wooden post would be ideal. Pin the free ends of both pieces of string to the object.
5. Face the object that the string is pinned to and walk backwards away from it, holding the ruler horizontally in front of you. Continue walking away until both strings are tight and form an isosceles triangle with the ruler (Figure 7.1.20).
6. Use the protractor to measure the angle formed between each string and the ruler. Ideally, the angle should be the same for each string. If the two angles are slightly different, take the average of the two. If there is a big difference, reposition yourself to make them closer. Record the values in your results table.
7. Calculate the distance to the object, d, using the formula:
   $d = \frac{1}{2}b\tan\theta$
   where b is the length of the baseline (i.e. 60 cm or 0.6 m) and θ is the parallax angle measured between the string and the ruler.
8. Change the length of the baseline by changing the positions of the pinned ends of the string on the ruler.
9. Repeat the measurement using this new baseline.
10. Repeat the measurements using a number of different baselines.
11. Measure the distance to the object directly using a tape measure.

Results

1. Copy and complete the following table.
2. Calculate the distance to the object for each baseline.

Baseline, b (m)	Parallax angle, θ (°)			Distance to object, d (m)
	1	2	Average	
0.6				
Distance using tape measure				

Discussion

1. **Compare** distances measured by parallax with the distance measured with the tape measure.
2. **List** the advantages of using a longer baseline for parallax measurements.
3. **Identify** situations where parallax measurements could be used where direct measurements (such as with a tape measure) could not.
4. **Explain** why the formula $d = \frac{1}{2}b\tan\theta$ gives the distance of the object.

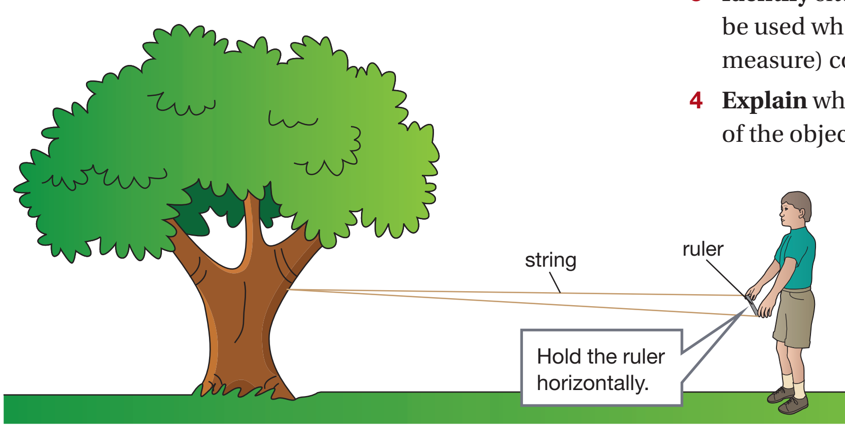

Figure 7.1.20

7.1 Practical activities

2 Using a spectrometer

Purpose

To compare the spectrum of light produced by different sources.

Materials

- spectrometer (spectroscope)
- light globe and coloured filters (a Hodgson's light box or similar would be suitable)
- fluorescent light tube
- coloured pencils

SAFETY

Never look directly at the Sun, whether using a spectroscope or not.

Procedure

1 Use a spectrometer to study the spectrum of light from a light globe. Sketch this spectrum.

2 Use a red filter to change the colour of the light. Observe and sketch this spectrum.

3 Use a blue filter to change the colour of the light. Observe and sketch this spectrum.

4 Use the spectrometer to study the spectrum of light from a fluorescent tube. Sketch the spectrum from the fluorescent tube, clearly showing the differences between it and the one produced by the light globe.

5 Looking through a window, observe and sketch the spectrum of light reflected off the ground or a building. (Do *not* point the spectrometer directly at the Sun!)

Discussion

1 **Identify** the differences in the spectrum observed for:
  - a light seen through the red filter and light seen through the blue filter
  - b sunlight and light from a fluorescent tube
  - c light from a fluorescent tube and from an incandescent light globe.

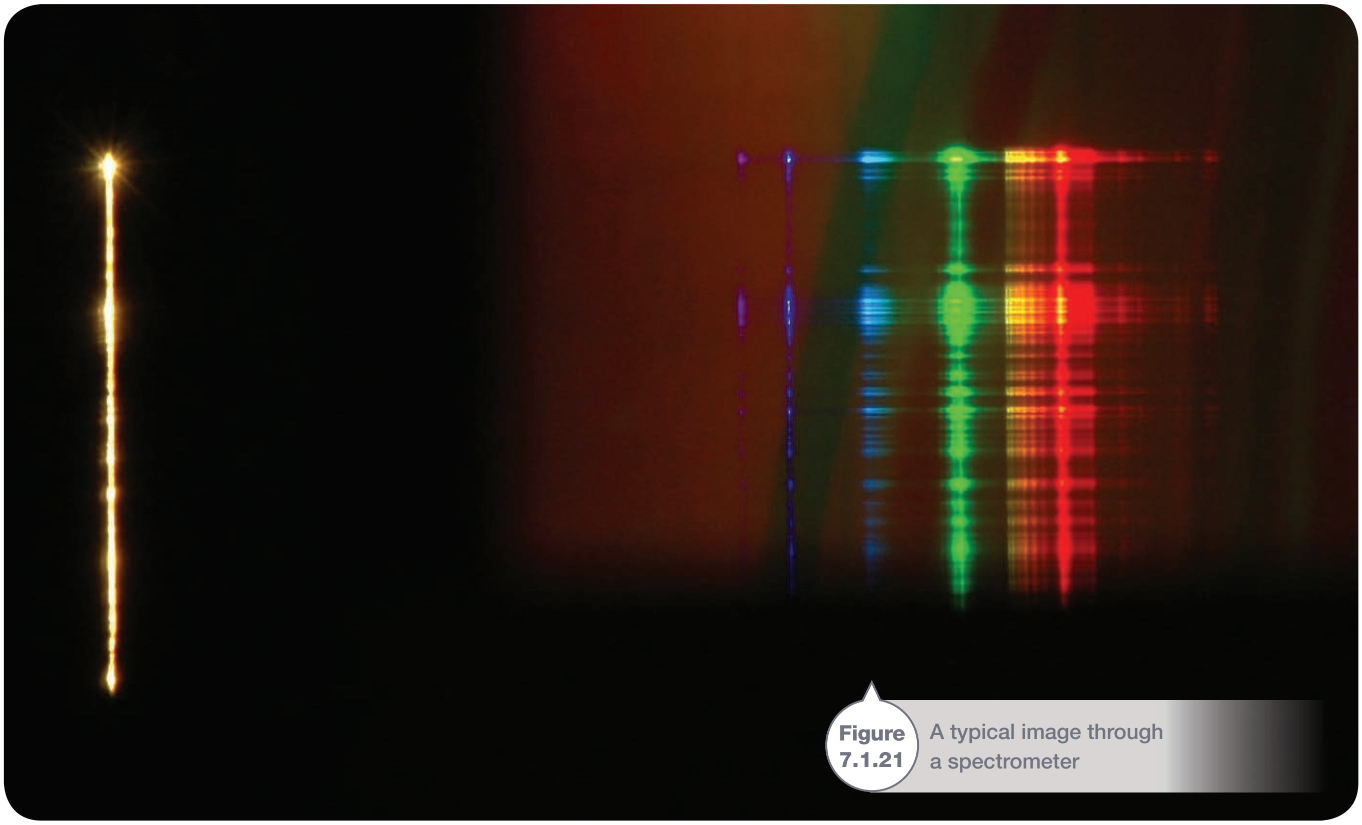

Figure 7.1.21 A typical image through a spectrometer

3 Modelling the collapse of a neutron star

Purpose

To model the change in density that occurs when a star collapses to form a neutron star.

Materials

- round balloon
- tape
- 2–3 metres of aluminium foil
- electronic balance
- metre rule
- pin

Procedure

1. Copy the table from the results section into your workbook.
2. Inflate the balloon to a diameter of about 15 cm. Tie the balloon so it remains inflated.
3. Cover the outside of the balloon with aluminium foil. Leave no gaps. Use tape to fix the foil to the balloon if necessary. This model represents the original star.
4. Measure the diameter of the model with the ruler. Halve this measurement to get the radius. Record this measurement in your table.
5. Measure the mass of the foil covered balloon with the electronic balance. Record this in your table.
6. Prick the balloon with a pin so that it bursts. Crumple the foil into a very loose ball. This model represents the star as it starts to collapse. Repeat steps 4 and 5 for this model.
7. Crush the foil into the smallest ball possible. This model represents the neutron star. Repeat the measurements for this model.
8. Calculate the volume and density of each model. For a sphere, $V = \frac{4}{3}\pi r^3$ and density $= \frac{\text{mass}}{\text{volume}}$

Results

Copy and complete the following table.

Model	Mass (g)	Radius (cm)	Volume (cm^3)	Density (g/cm^3)
Original star				
Collapsing star				
Neutron star				

Discussion

1. **Discuss** the changes (if any) in the following quantities as the ‘star’ collapses:
   - mass
   - volume
   - density.
2. **Assess** the ways in which this model is like a collapsing star.
3. Scientists estimate that a neutron star is 100 000 000 000 000 (i.e. 10^{14}) times more dense than the star that formed it. If you wanted to crush your model enough to make it 100 000 000 000 000 times more dense than the original model, **calculate** the volume and radius it would need to be.