PUPIL
RESEARCHER
INITIATIVE

Star Trail

Setting the Scene

In this Brief you will work in small groups to produce materials for a talk and science trail exhibition on the topic of stars. The work you will do, taken all together, will cover the examination syllabus content to do with stars, galaxies and the Sun. You will also learn about new research on stars, especially the Sun, and find out why studying the solar wind and sunspot activity is important.

Pupil Research Brief

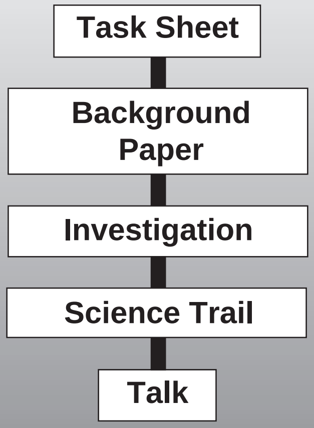
Study Guide

Syllabus Targets

Science you will learn about in this Brief

- ☐ the stars in the night sky stay in fixed patterns, called constellations
- ☐ our Sun is just one of many millions of stars in a group of stars called a galaxy
- ☐ the stars in a galaxy are often millions of times further away from each other than the planets in the solar system
- ☐ the universe as a whole is made up of at least a billion galaxies
- ☐ galaxies are often millions of times further apart than the stars within a galaxy
- ☐ stars, including the Sun, from when enough dust and gas from space is pulled together by gravitational attraction
- ☐ individual stars do not stay the same for ever
- ☐ stars are very massive so that the force of gravity, which tends to draw the matter from which they are made, is very strong
- ☐ the very high temperatures of stars create forces which tend to make them expand
- ☐ during the main, stable period of a star these forces are balanced
- ☐ the Sun is at this stage of its life
- ☐ the star then expands to become a red giant
- ☐ at a later stage it contracts under its own gravity to become a white dwarf
- ☐ the matter from which the star is made may then be millions of times denser than any matter on Earth
- ☐ if the star is massive enough, it may explode (become a supernova) throwing dust and gas into space
- ☐ a very dense neutron star often remains
- ☐ during a star's lifetime, nuclei of light elements (mainly hydrogen and helium) gradually fuse to produce nuclei of heavier elements
- ☐ these nuclear fusion reactions release energy which is radiated by stars

Route through the brief



Outcome Checklist

You are going to prepare materials for a science trail about stars and galaxies. You should make sure you produce the following items as you work through the Brief.

Background papers 1 - 10

- ☐ notes for use when planning talk to class
- ☐ display materials for science trail
- ☐ questions and answers for visitors to science trail

Investigation

- ☐ drawings of the Sun
- ☐ display or working model of a method of making observations of the Sun and sunspots

Star Trail

Task sheet

In this Brief you are going to help to create a science trail or exhibition on the subject of stars and galaxies. You will also plan a five minute presentation for your class, or for visitors to the science trail, or more precisely, the *Star Trail*, on the section of the exhibition which you have produced.

The work you will do will cover the science syllabus component concerned with stars, and you will also learn a little about the latest research work astronomers are doing in this area of science. Your section of the work is important, as are the different sections produced by other groups in your class. You will only concentrate on one section of the syllabus, and although you may become an expert on that, you will be depending on other groups to provide you with accurate information on their sections of the syllabus. You will then have to get that information from the group presentations and from the displays and questions in the Star Trail.

The Brief contains a number of Briefing Papers. Your teacher will supply you with one of the papers, sharing them out so that all the papers are covered by the whole class. Each Briefing Paper contains information about a topic related to stars and galaxies but you should also find out more by looking in books and magazines and at CD-Roms, videos and the relevant sites on the World Wide Web, if this is available to you. Each group could also carry out the investigation into methods of observing sunspots. Using all this information, you will need to:

- plan a five minute presentation for the rest of your class about your topic

- produce any visual aids, demonstrations or models to help you with your presentation

- help put together a public display of your work, including a working demonstration, with sample results, of a method for observing sunspots which could be used at a parents' evening or School Science Fair

- produce a few short questions, based on the section of the display you helped to produce, for other groups in your class and for visitors to the display.

As pupils and visitors go round your display, which is part of the Star Trail, they should be able to answer your questions by using the information you have provided.

Briefing paper 1

The night sky

The night sky

The number of stars you can see at night depends on where you live. If you live in a city you are likely to see very few stars. This is because the bright lights from houses, cars and above all street lamps 'drown out' most starlight. Even bright moonlight can stop you from seeing many stars. If you go far away from the light pollution of a city you will be able to see many more stars. In fact there are some 3000 stars visible above the horizon on any one night. All these stars are part of a collection of millions and millions of stars which make up a galaxy called the Milky Way.

Constellations

From the earliest times people around the world have tried to make sense of the jumble of stars they see, and they tended to group them into patterns called *constellations.* Different civilisations have grouped these stars into different patterns. The constellations we know today are mainly named after creatures or characters in Greek and Roman mythology. There are 12 constellations named after the signs of the Zodiac, and there are others named after such characters as *Perseus*, *Orion* (the hunter) or *Cassiopeia* (the reclining queen). Some of the brightest stars also have names. Many of these names are of Arab origin, such as *Aldebaran* ('the follower'), *Deneb* ('the tail') or *Betelgeuse* ('arm of the Central One').

People in the Northern hemisphere see different stars to those in the Southern hemisphere. Some star patterns are visible all the time. These are called 'circumpolar constellations'. The easiest ones to spot, if you live in a city or in the country, are *Ursa Major* (The Great Bear), *Ursa Minor* (The Little Bear) and *Cassiopeia.* These are shown in **Figure 1**.

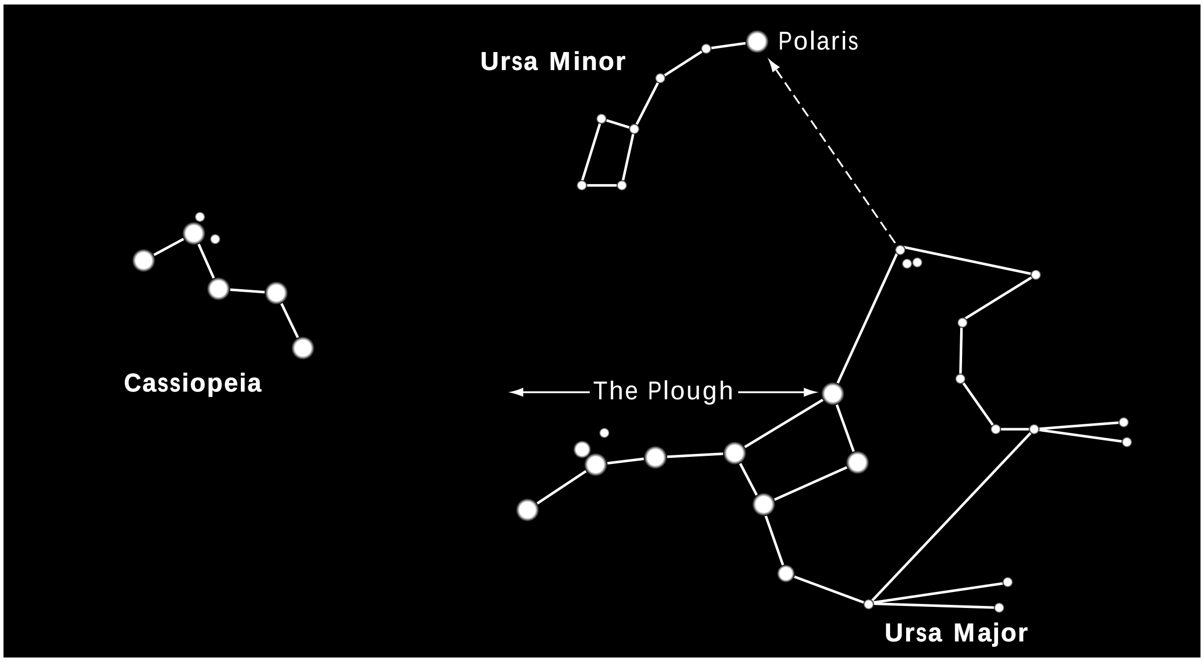


Figure 1. Ursa Major, Ursa Minor and Cassiopeia

Briefing paper 1 continued

The night sky

The full constellation of Ursa Major is shown in **Figure 1**, but for most people only the stars that make up the group known as the Plough will be clearly seen.

The 'tail' of Ursa Minor contains the star *Polaris,* the Pole Star. It is called this because it appears to be directly above the North Pole. During the course of the night the stars seem to revolve very slowly round Polaris, which does not move. This is because the Earth is spinning on its axis, which goes through the North Pole. **Figure 2** shows the positions of the Plough at dusk, at midnight and at dawn in Spring.

Seasonal changes

The Earth orbits the Sun, and so its position with regard to the stars changes throughout the year. This means that some constellations will only be seen at certain times of the year, when they are in the opposite side of the sky to the Sun. **Figure 4** on the next page shows the positions of the Plough at midnight in Spring, Summer, Autumn and Winter. Seasonal constellations that can be recognised easily are shown in **Figure 3**.

Figure 3 shows only the brightest stars in each constellation. Star atlases and *planispheres* give more details of the way the night sky looks from season to season. Some newspapers also publish guides to the night sky at regular intervals.

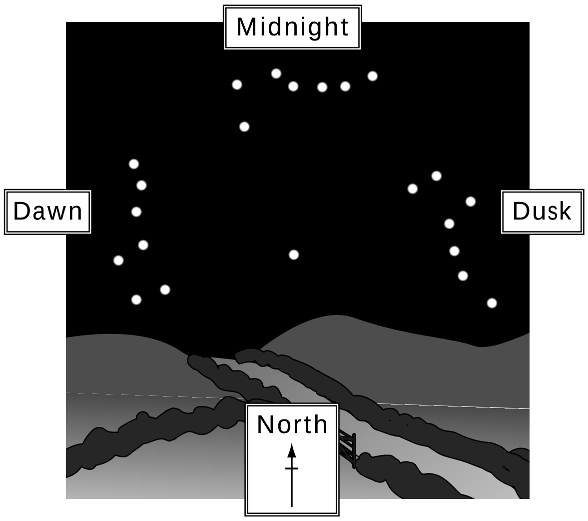


Figure 2. The Plough at different times of the night in Spring

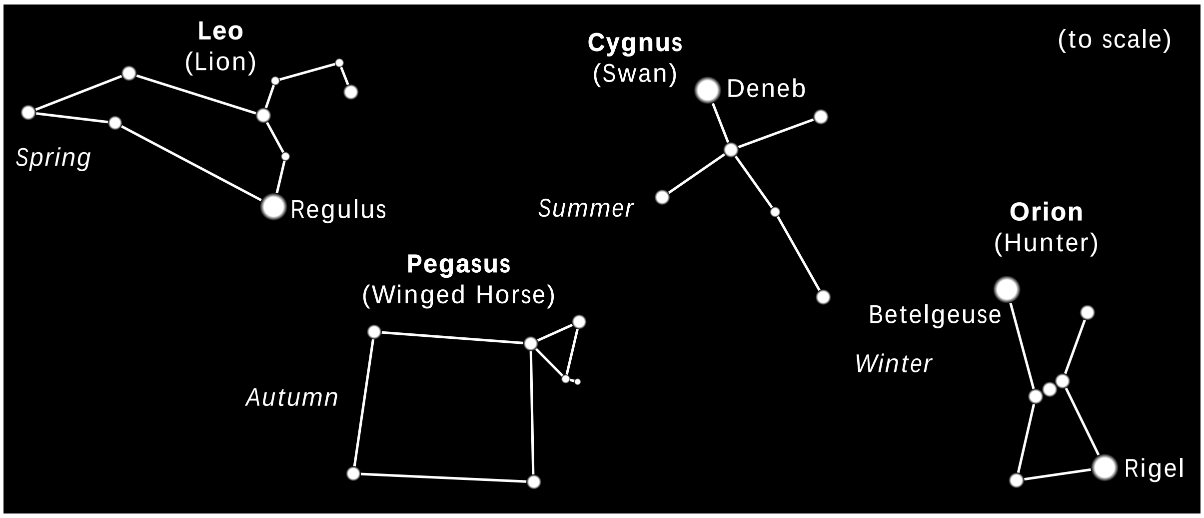
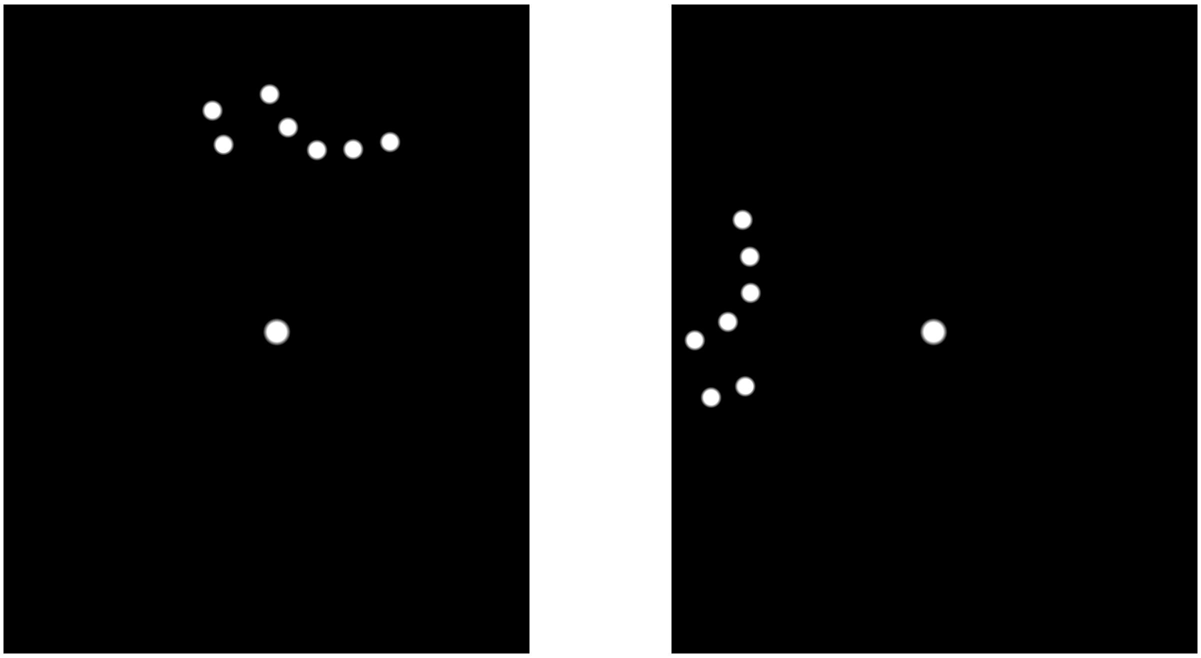


Figure 3. Seasonal constellations

Briefing paper 1 continued

The night sky



Spring

Summer

Autumn

Winter

Figure 4. The position of the Plough and the Pole Star through the seasons at night looking North

Briefing paper 1 continued

False patterns

The groups of stars that form a constellation all appear to be the same distance from Earth. In fact they are highly likely to be at vastly different distances from us. **Figure 5** shows this clearly. The seven brightest stars in the constellation of Orion are shown at the real distances they are from the Earth (Figure 5a), and as they appear in the night sky (Figure 5b)

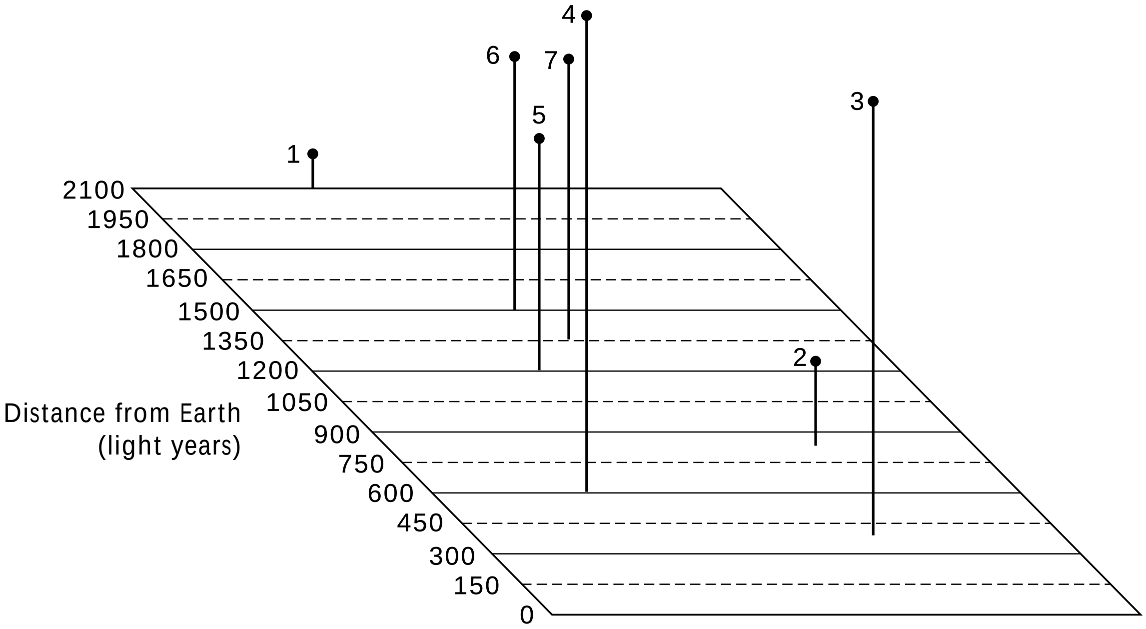


Figure 5a Real distances from Earth of Orion's seven brightest stars

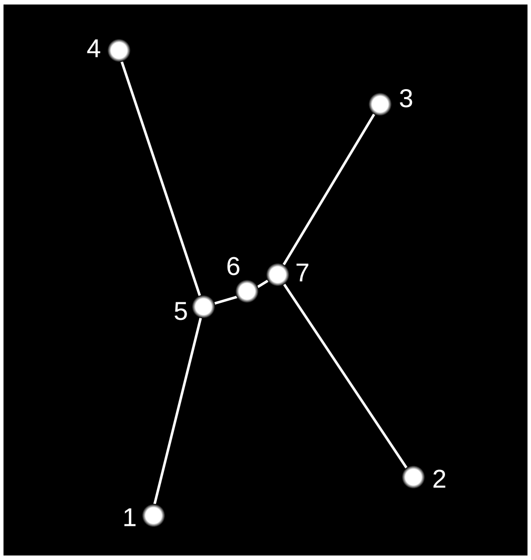


Figure 5b Orion's seven brightest stars as they appear in the night sky

Briefing paper 2

Photographing stars

You can photograph star trails if you have a camera that has a shutter that can be kept open. It is very important to have the camera kept completely still, and so it is very useful to have a tripod and a cable release attachment. The cable release allows you to open the shutter without jogging the camera.

Choose a clear, moonless night, preferably far away from city lights. Remember that you should always do this with a few friends along and, if possible, a responsible adult - but *never* alone!

You need a fast film - something like 400 ASA. This means that the film is very sensitive to light. Focus the camera on infinity. (The infinity symbol on the focus ring is like an 8 on its side). Adjust the aperture to its widest setting. This will be the lowest number on the aperture ring (usually 2.8 or 2). Point your camera at the night sky and press the cable release keeping the shutter open for 5 minutes. Close the shutter, wind the film on and try an exposure of 10 minutes. Repeat the procedure for increasing times of exposure up to, say, 40 minutes.

If you point the camera anywhere you will get star trails that may show different colours but if you point the camera at Polaris (the Pole Star) your star trails will be circular, as shown in **Figure 1**.

You may also get the trails of satellites and shooting stars on your photographs. When you take the film to be processed make sure that you ask for **all** the exposures to be printed, since negatives that look blank will often not be printed.

Figure 1. Star trails produced by long exposure times

Briefing paper 3

Star life cycles

Space is not empty. In fact it is filled with gases (mainly hydrogen) and dust, spread out very thinly. This matter is not evenly distributed, however. Some of it gathers together in a large mass, and it will attract more and more gas and dust. Over billions of years this will become a vast, dense cloud, or *nebula,* and in its thickest parts it will begin to collapse under its own gravity. These collapsing clumps of matter begin to get hotter and hotter as the gas and dust compress. When the central temperature reaches about 10 million °C a *nuclear fusion* reaction begins and stars are born. Groups of stars formed like this are called an *open cluster*. The nuclear fusion reaction causes huge amounts of energy to be radiated out, much of it in the form of light. This period in a star's life is very stable and the outward pressure from the nuclear reaction at the core is balanced by the gravitational forces pulling inward. It will continue the nuclear fusion process until all the hydrogen is used up. What happens next depends on how massive the star is. **Figure 1** shows two alternative paths (1 and 2) that represent the life story of the two main types of star. In *path 1*, where a small, average star like the Sun is formed, the star will continue in its stable phase for about 10 billion years. When the hydrogen runs out the core collapses and heats up. The star expands and cools down to become a red giant. After this phase the star once again collapses, jettisoning its atmosphere, and leaving behind a small glowing ember, a white dwarf. The *white dwarf* slowly cools down, eventually becoming a cold globe, known as a *black dwarf*.

In the case of path 2, where a Rigel-type star that is more than 10 times the mass of the Sun is formed, there is a stable period of only a few million years, before the star becomes a *red giant*, or even a *red supergiant*. This phase ends when the star collapses. Under conditions of extreme pressure and temperature the star's core, its 'nuclear reactor', breaks down, and it implodes dramatically. Eventually it forms a solid mass of neutrons only a few kilometres in diameter. The upper layers of star are blown into space. This is a *supernova.* The explosion produces light equivalent to 10 billion Suns, and these conditions create an environment like a particle accelerator. Atoms smash into one another and fuse together to create heavier atoms, like iron or gold or copper.

The material left behind becomes a neutron star, almost the densest form of matter. One cubic centimetre of neutron star has a mass of 1000 000 000 tonnes !

If the mass of the neutron star is more than 3 times the Sun's mass it will collapse further, eventually becoming a *black hole*. The gravitational attraction of a black hole is so great that it can absorb everything coming its way - even light!

Star life cycles

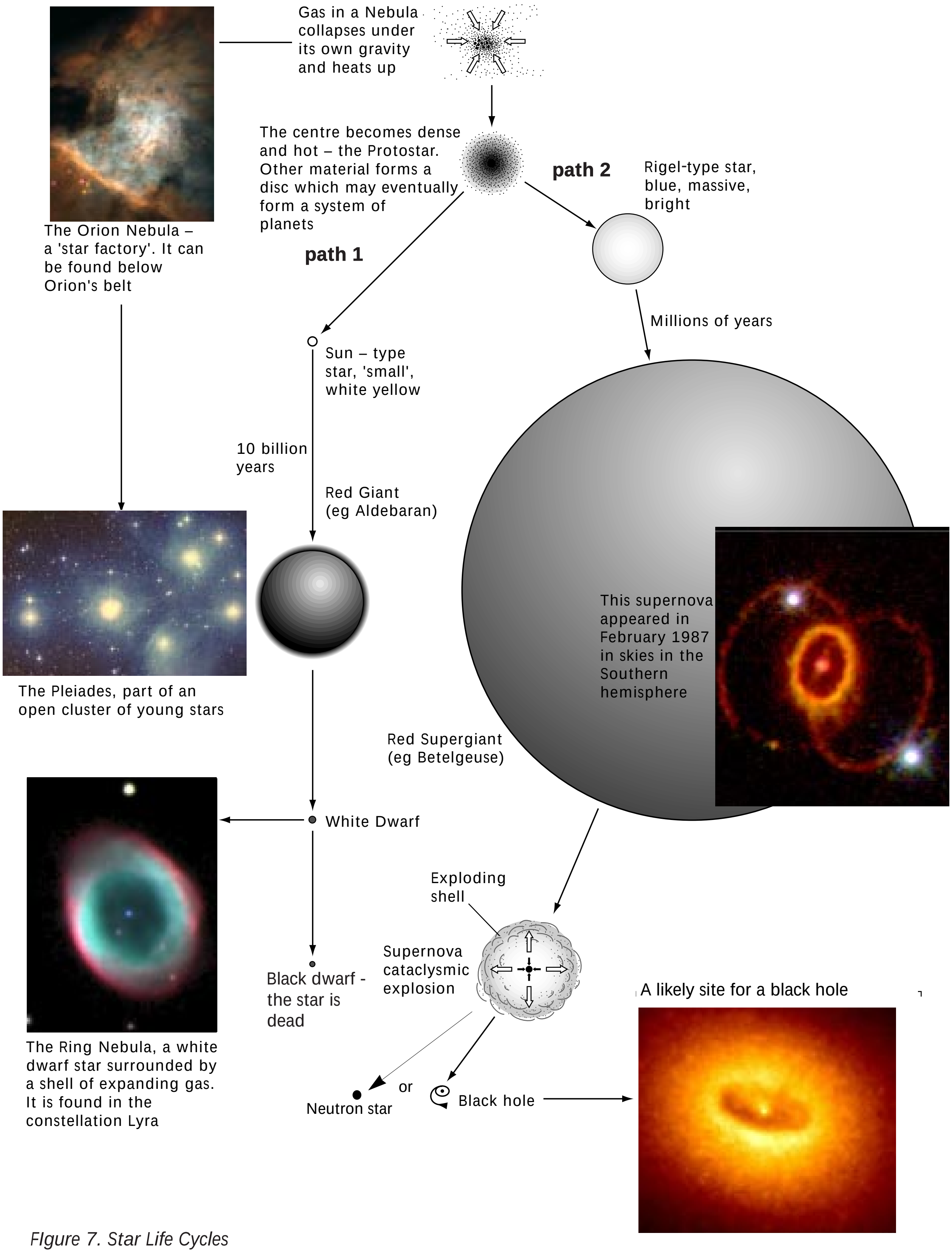


FIgure 7. Star Life Cycles

Briefing paper 4

Classifying stars

Stars are not all the same. Some appear to be brighter than others in the night sky, and stars are also different colours - although this is difficult to see with the naked eye. The colour of a star gives us a good idea of its surface temperature. The main colours are as follows:

Type	Colour	Surface temperature	Example
O	vivid blue-white	>30 000 °C	Naos
B	pale blue-white	11 - 30 000 °C	Rigel
A	white	7500 - 11 000 °C	Sirius
F	yellow	6 - 7500 °C	Polaris
G	orange	5- 6 000 °C	Capella, the Sun
K	orange-red	3 - 5000 °C	Arcturus
M	red	~ 3500 °C	Betelgeuse

The letters were assigned to these colours by two astronomers, Annie Cannon and Wilhelmina Fleming, and this system is known as the *Harvard Classification* because they worked at Harvard University.

In the early part of the 20th Century two astronomers called Henry Russell and Ejnar Hertzsprung drew up distribution graphs for stars, plotting their surface temperature against brightness. They found that stars were grouped in five different areas on the graph. These two astronomers worked out the way of classifying stars completely independently of each other. So, this graph has become known as the *Hertzsprung - Russell diagram* (see **Figure 1**).

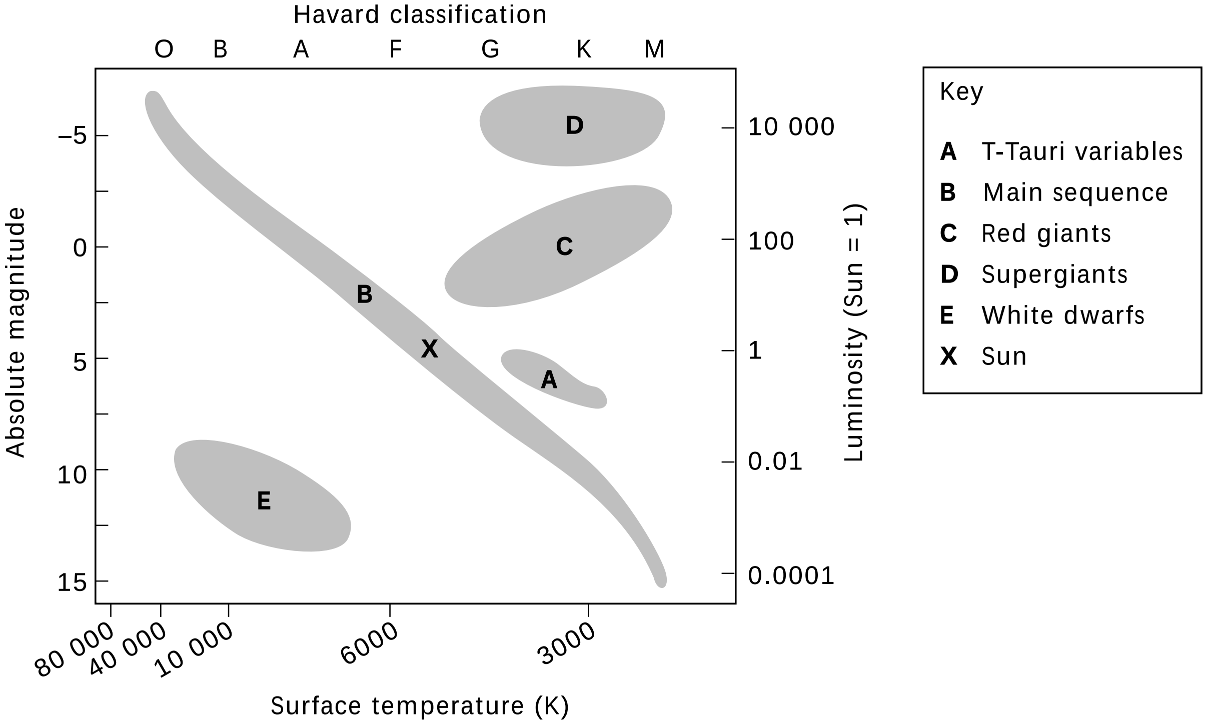


Figure 1. The Hertzsprung-Russell diagram

Briefing paper 4 continued

Classifying stars

The brightness of a star can be expressed in different ways. Luminosity compares the brightness of stars with that of the Sun if they were all the same distance away from us. The absolute magnitude uses a system where the brighter the star, the lower the number. The very brightest stars have negative numbers! **Figure 2** below shows you how to find some of the stars mentioned in the first section of this paper. The star *Sirius,* not illustrated, is in the constellation Canis Major. Many stars are found along a diagonal band on the Hertzsprung-Russell diagram. These are the main sequence stars, and our Sun is a typical main sequence star.

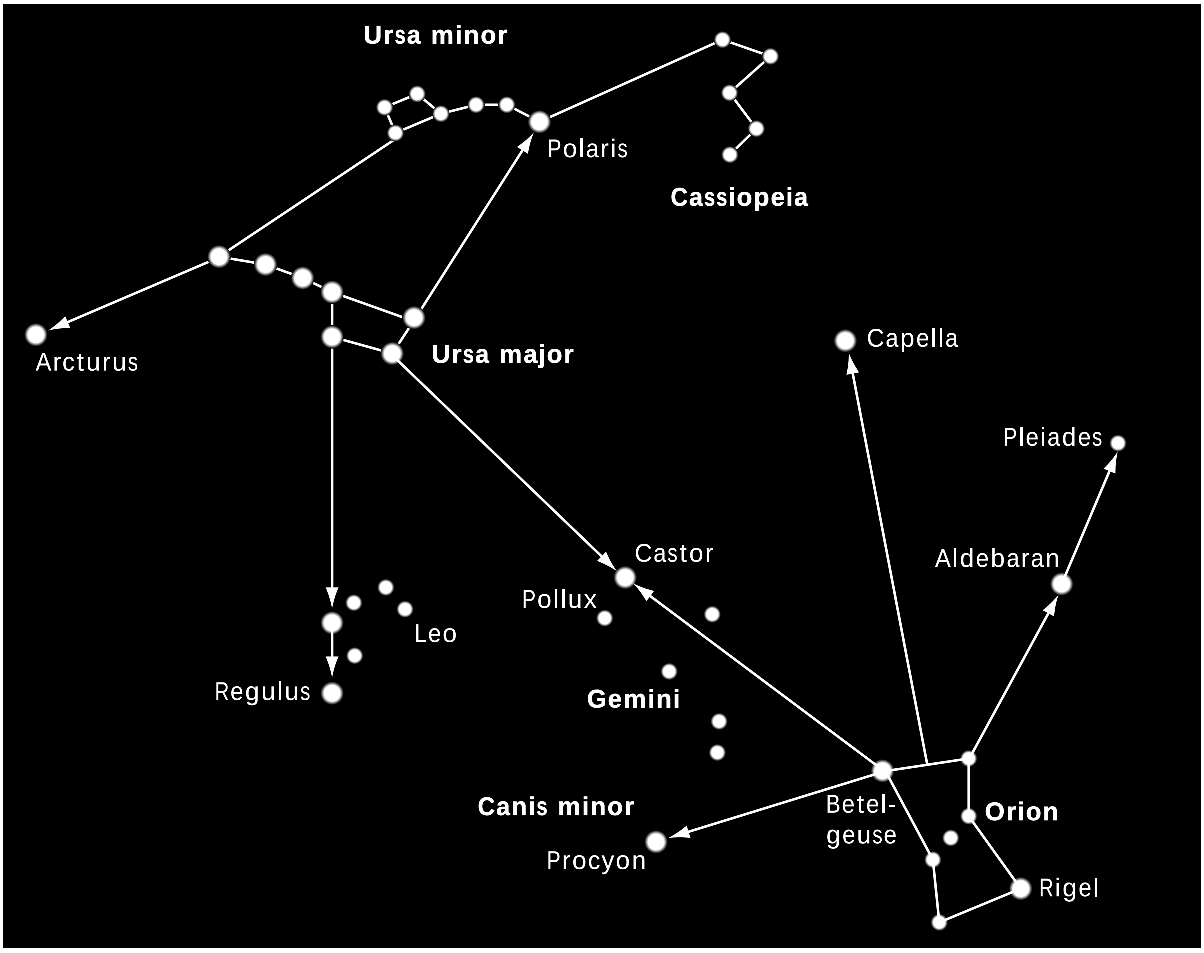


Figure 2. Were to find stars named in this section

The luminosity of a star depends on its surface temperature and upon its surface area, and so you can find cool stars that are luminous because of their large size and very hot stars which are faint because they are so small (white dwarfs).

Briefing paper 5

Star distances and sizes

Distances in space are so enormous it is nearly impossible to visualise them. Special units of distance are used in astronomy. These include: the *astronomical unit* (au), which is used for 'local objects' such as distances within the Solar System. This is the mean distance between the Sun and the Earth and is about 150 million kilometres. So, the distance between the Sun and Jupiter (778 million km) is 5.19 au.

The *light-year* (ly) is the distance travelled by light in one year. Light travels at 300 000 km/s. There are 60 x 60 x 24 x 365 seconds in a year. So, in one light-year light travels 300 000 x 60 x 60 x 24 x 365 km, which works out at about 9.46 million million kilometres (9.46 x 10^{12} km).

The *parsec* (pc) is equal to 3.26 ly. It is a specialised unit used only by astronomers.

One way of visualising distances and sizes is to use scales. If we scale down Earth to 1mm in diameter (real diameter 12 719 km), Jupiter would be 11.2 mm in diameter and the Sun would have a diameter of 109 mm (see **Figure 1**). On this same scale the largest known star, Antares, would be over 30 metres in diameter! **Figure 2** shows the variation in the sizes of different types of stars. If we want to visualise the distances between stars we need to use an even more extreme scale. If we use a scale of 1mm for 1000 million kilometres (1x10^9km) the distance between the Sun and the planet Pluto would be nearly 6mm. Pluto is so far away that light from the Sun takes nearly 5.5 hours to reach it. The nearest star to the Sun is Proxima Centauri, 4.3 ly away. On our scale this distance becomes 40.7 metres.

The closest large galaxy to us is Andromeda. On the same scale Andromeda would be 20 812 km away! (Compare this distance with the actual distance between London and Wellington in New Zealand - 18 800 km).

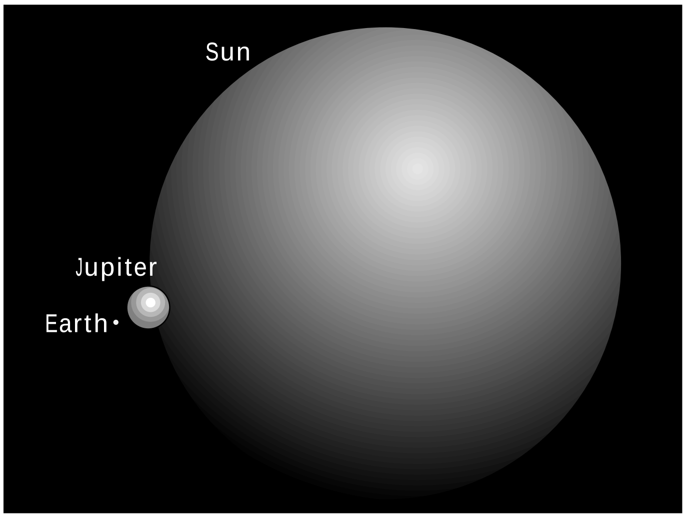


Figure 1. Scale in the Solar System

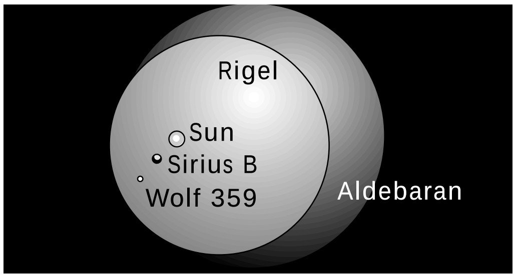


Figure 2. Comparing different star sizes

Briefing paper 6

Nuclear fusion

At the core of a star a process called nuclear fusion occurs, and vast amounts of energy are released as a result.
It works by bonding together (fusing) the nuclei of hydrogen to form helium nuclei. The sequence is shown in **Figure 4,** but it is perhaps best to show the process in stages.

Stage 1: two hydrogen nuclei (also known as protons) collide and bond together to produce another form of hydrogen (or isotope) called *deuterium.* Deuterium has a nucleus of 1 proton and 1 neutron. When a deuterium nucleus is formed a positron and a neutrino are ejected. A positron is a particle that is the size of an electron but it has a positive charge, and a neutrino is an uncharged particle so small that it could pass straight through the Earth without colliding with anything!

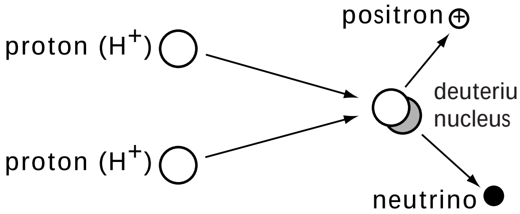


Figure 1. Stage 1

Stage 2: a deuterium nucleus collides with a proton (hydrogen nucleus). These fuse to produce a nucleus of helium-3 (2 protons and 1 neutron).

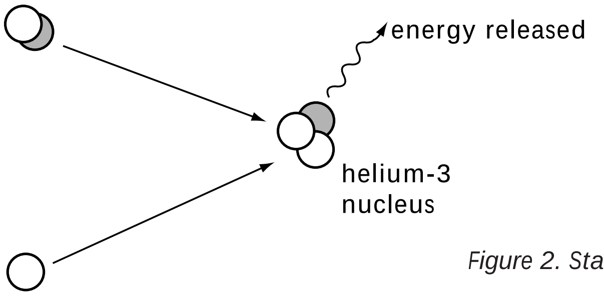


Figure 2. Stage 2

Stage 3: two helium-3 nuclei collide, bonding together to form a helium-4 nucleus and ejecting 2 hydrogen nuclei. These can take part in other fusion reactions. Helium-4 has a nucleus of 2 protons and 2 neutrons. A helium-4 nucleus is only 99.3% of the mass of the 4 hydrogen nuclei from which it was formed. The other 0.7% of its mass is converted into energy. Einstein's famous equation $E=mc^2$ shows the relationship between energy and mass when matter is converted to energy.

E = energy released
m = mass converted to energy
c = speed of light (300 000 000 m/s)

This equation shows that a vast amount of energy is released when a nuclear fusion reaction takes place. Inside the Sun 600 million tonnes of hydrogen are converted in nuclear fusion reactions energy second, and 4 million tonnes of this is converted into energy.

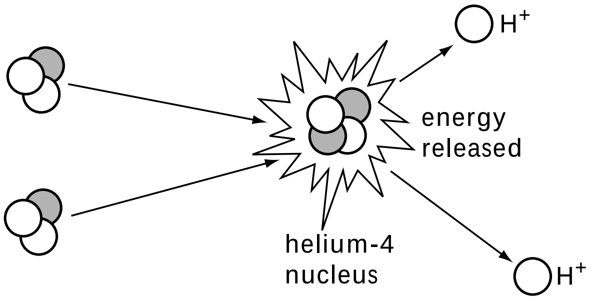


Figure 3. Stage 3

Briefing paper 6 continued

Nuclear fusion

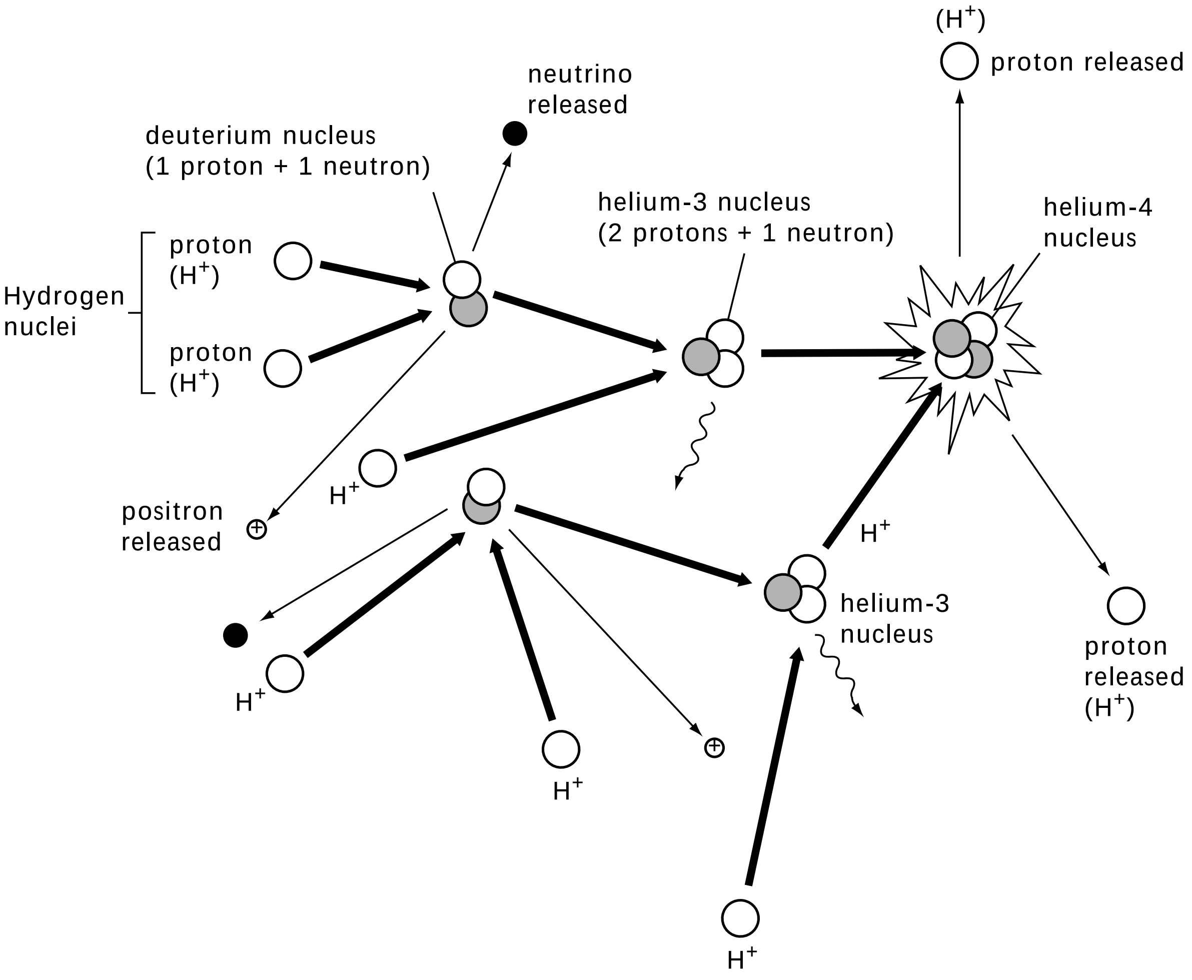


Figure 4. The complete process

Nuclear fusion is not the same as the process that goes on in a nuclear power station. That reaction is called *nuclear fission* and involves the radioactive decay of uranium- 235. Nuclear fusion produces unimaginably greater amounts of energy than nuclear fission. Scientists have been trying to produce sustained, controlled nuclear fusion on Earth for decades, but so far they have only managed it for a tiny fraction of a second. Creating conditions similar to those at the core of the Sun is not easy! However, *uncontrolled* nuclear fusion occurs when a hydrogen bomb explodes.

Briefing paper 7

The Sun

The Sun is an ordinary main sequence, G-type star. It is about 4600 million years old, and is expected to remain in this stable phase of its life-cycle for another 5000 million years. It has a diameter of 1392 000km, 109 times that of Earth. It's volume is more than 1 million times that of Earth, but its mass is only 333 000 times greater. It spins round once every 25.4 days at the equator. This rotation period is longer at the solar poles, because the Sun is not a solid body. In fact it is made up mostly of hydrogen, with some helium and a few other elements. At the centre of the Sun - the core - the temperature is about 14 000 000 °C. At this temperature, and under immense pressure, the nuclei of hydrogen atoms join together to produce nuclei of helium. This nuclear fusion reaction produces vast amounts of energy. The energy starts off as x-rays and gamma-rays, but it spends millions of years passing through the layers of the Sun, and eventually it emerges as heat and light.

There are five layers, as shown in **Figure 1**. Surrounding the core is the *radiative zone* where the core loses some of its energy. Above this is the *convective zone* where vast convection currents are set up, like swirling water in a heated pan. Energy passes into the *photosphere*, which is the Sun's visible surfaces where the temperature is about 6000 °C. Surrounding this is the lower atmosphere, known as *chromosphere* ('colour sphere', because of its reddish appearance). The temperature of the chromosphere rises from 6000°C to 50 000°C. Above this is the thin outer atmosphere called the *corona.*

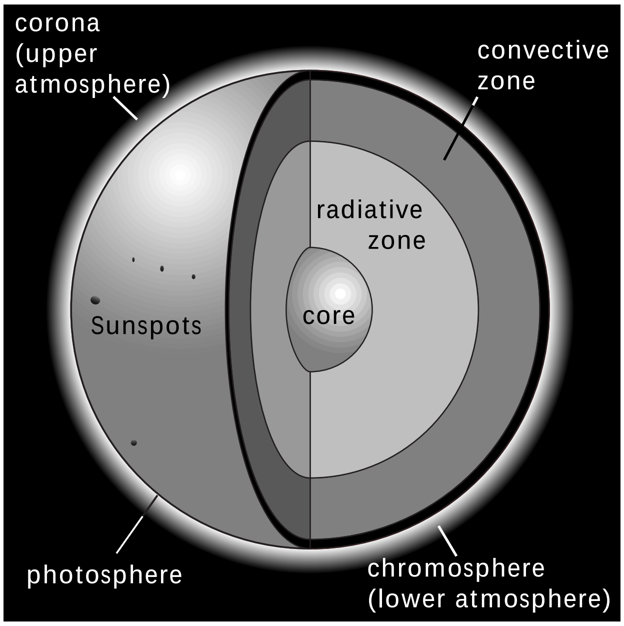


Figure 1. The Sun's layers

The surface of the Sun is turbulent. There are nearly always *sunspots* (see next section) and enormous arcs of material are thrown up from the surface. These are called prominences and are often associated with sunspots, as are *solar flares*.

Solar flares are huge outbursts of electromagnetic radiation from the Sun (see **Figure 2** on the next page). Solar flares can be detected with a radio telescope. (Pupils at Taunton School in Somerset have their own VHF Solar flare Detector Radio Telescope ! See the PRI pupil magazine - *PRISM* Issue 2 for further information). Apart from the bursts of particles in solar flares, the Sun sends out a constant stream of charged particles which is called the *solar wind*. The Earth's magnetism shields us from most of the solar wind particles, keeping them out of a volume surrounding our planet called the *magnetosphere.*

Some particles from the solar wind do get through, however, especially at the magnetic North and South poles where the Earth's magnetic field lines dip in towards the planet.

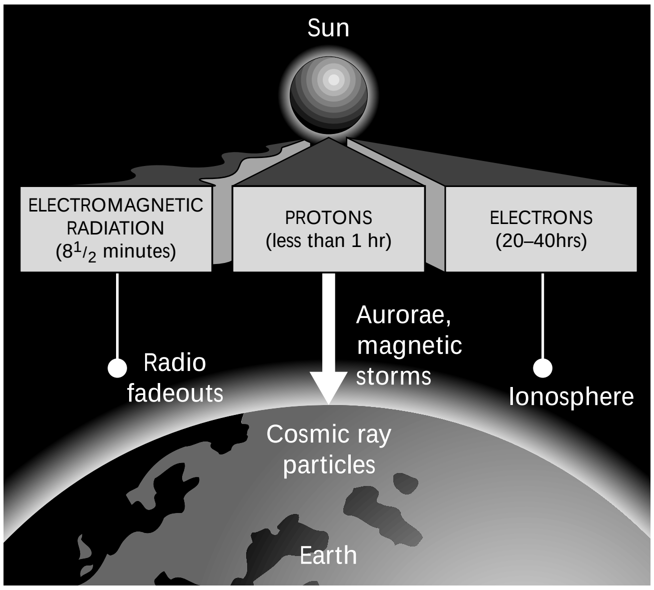


Figure 2. Solar emissions (times in brackets are how long it takes the radiation or particles to reach the Earth)

These charged particles can collide with air molecules in the upper atmosphere, causing coloured light to be given out. A beautiful display of moving curtains of light can be seen in the sky. This is the *aurora.* Occasionally a burst of particles from the Sun can allow the aurora to be seen in the British Isles.

Solar flares can disrupt long-distance radio and television signals. Normal rays from the Sun knock electrons out of atoms in the upper atmosphere in a region called the *ionosphere*. This layer acts as a sort of ‘electric mirror’ which we can use to reflect radio signals around the Earth. Explosions on the Sun produce flashes of ultraviolet and x-rays, and these liberate too many electrons in the ionosphere, so that they smother radio signals. Solar flares can produce electric currents in the ionosphere. They create strong magnetic fields that disrupt the Earth’s magnetic field. This is called a *magnetic storm*. During such a storm compass needles tend to wander from their normal directions, and surges of current can be sent along electricity power lines, sometimes causing blackouts. Surges can also occur in oil pipelines, and there could be a risk of an explosion. Satellites in Earth orbit can be severely damaged, and astronauts could also be at risk.

Sunspots

Sunspots are dark patches which can sometimes be seen on the face of the Sun. They were first recorded over 2000 years ago by Chinese astronomers who argued about what they might foretell. In the West, Galileo recorded sunspots in about 1610. This was one of the things which got him into trouble with the Church - he was suggesting that the Sun was blemished, and this was unthinkable, since this would have meant that God’s work was imperfect!

Nowadays, sunspots are relatively easy to observe and record. They give a good indication of how the activity of the Sun is changing, and this may be linked to changes in the weather here on Earth.

A sunspot is a region of the Sun’s surface which is cooler than its surroundings - 4000°C instead of 6000°C. They may be as big as 150 000 km across, ten times the diameter of the Earth.

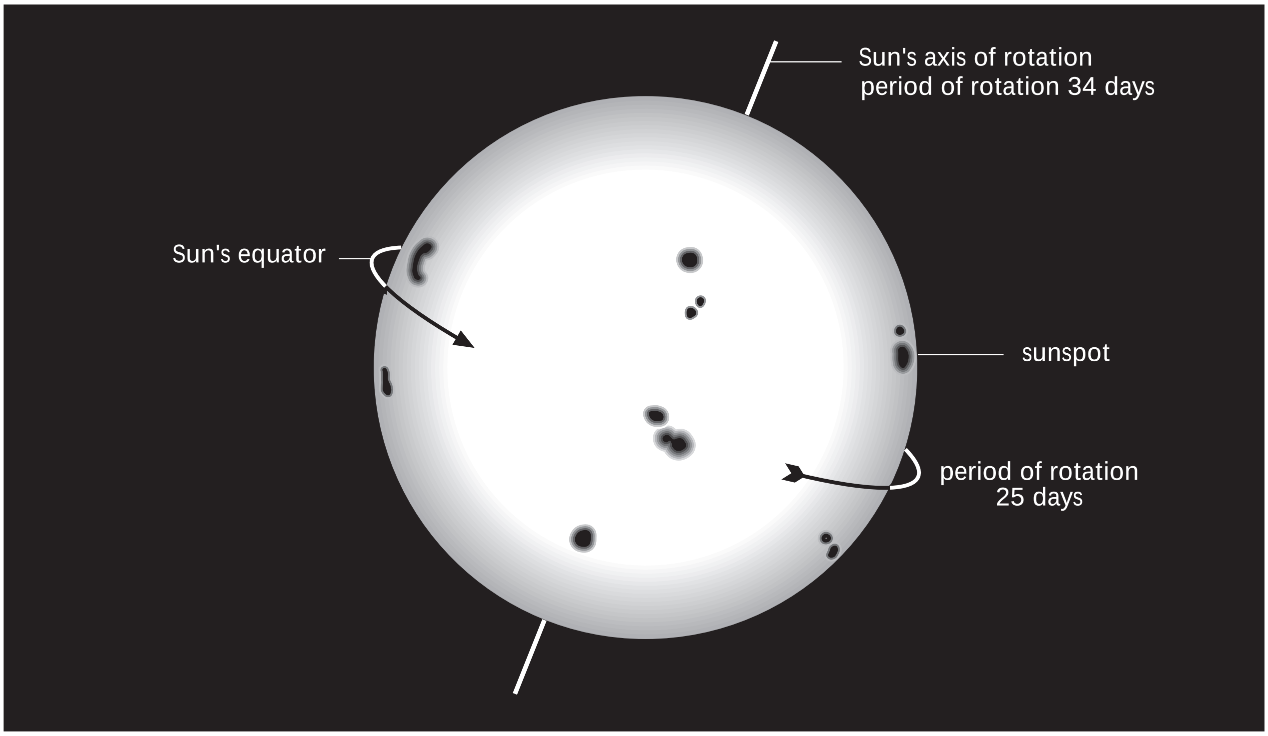


Figure 3. The Sun rotating on its axis

The Sun is made of hot gas. It spins round, just as the Earth spins on its axis. The region around its equator spins fastest, and poles spin slowest. This happens because the Sun is not solid.

How do sunspots vary?

The number of sunspots changes. It reaches a peak every 11 years or so. From the graph (**Figure 4**), you can see how the numbers have changed over the last 350 years.
You can also see that there have been times when the peaks have been high, and times when the peaks have been low. This is a cycle with a very long time between peaks.

The period between 1630 and 1700 was one of exceptionally low sunspot activity, and of very unusual weather with extremely cold winters.

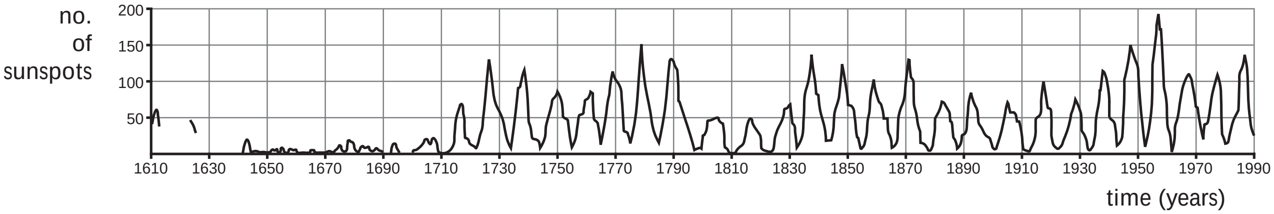


Figure 4. Variations in observed sunspot activity over the past 350 years

Briefing paper 7 continued

The Sun

Scientists are looking into the possibility that, over long periods, there have been changes in the energy output from the Sun. The amount of visible light seems to have varied, as has the ultraviolet (UV) radiation. UV is particularly important because it affects the ozone layer, high up in the Earth's atmosphere. The ozone layer protects living things from the harmful effects of UV radiation.

A number of pollutants, such as CFCs (chemicals that were used in some aerosol sprays and refrigerator cooling systems) damage the ozone layer. Scientists measure the amount of UV coming from the Sun so that they can work out whether the damage being done to the ozone layer is caused by human activity, or increased UV solar radiation. Sunspot activity, which rises and falls on an 11 year cycle, affects the amount of energy, including UV radiation which reaches us from the Sun. Scientists monitor sunspot activity to see if changes in global climate are linked to rises and falls in sunspot occurrence. The Pupil Research Brief *Ozone Conference* provides more information on this topic.

Briefing paper 8

Eclipses

Solar eclipses

The Sun is 400 times larger in diameter than the Moon. The Moon is 400 times closer to Earth than the Sun. This extraordinary coincidence means that the Moon and the Sun appear to be the same size in the sky. Occasionally, the Moon moves in front of the Sun, completely covering it. People in the Moon's shadow see a total eclipse of the Sun (or solar eclipse). Elsewhere a partial eclipse can be see, where only part of the Sun is covered by the Moon. **Figure 1** explains how eclipses occur.

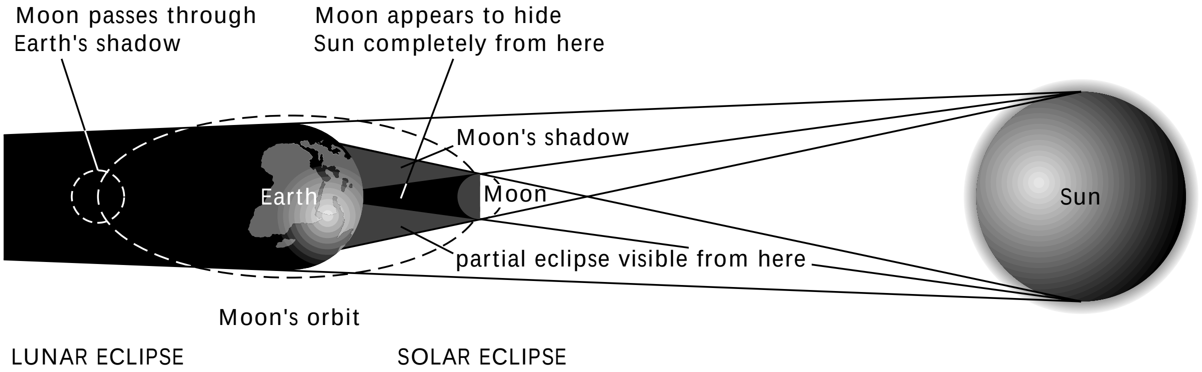


Figure 1. Lunar and solar eclipses. Note: the Sun, Moon and Earth, and all distances shown, are not to scale

Lunar eclipses

The Moon reflects the light from the Sun, which is why we see it at night. If the Moon passes into the Earth's shadow this light cannot reach the Moon. The Moon turns different colours and goes dark for a while - but it is usually still visible very dimly. Lunar eclipses can be seen whenever the Moon is above the horizon during the day and occur about every 25 weeks.

Briefing paper 9

Solar-terrestrial research

SOHO

The Solar and Heliospheric Observatory is a joint ESA/NASA (European Space Agency, and the National Aeronautical and Space Administration) space mission launched in 1995. SOHO is being sent into orbit around the Lagrangian Point L1. This is the point where the Sun's and the Earth's gravitational forces are in balance. From this position SOHO will be able to observe the Sun continuously. The instruments on SOHO will study the internal structure of the Sun, the Sun's outer atmosphere and the solar wind, which consists of charged particles that flow out from the Sun.

British scientists have built up a unique expertise in solar research, by building high quality instruments for previous space missions and by doing top quality observational and theoretical work. This has resulted in Britain taking the lead or playing an important part in building five of the instruments on SOHO. The main instruments carried by SOHO are set out below.

1. CDS

The Coronal Diagnostic Spectrometer will determine the gas flow patterns, temperature and density of the Sun's outer atmosphere (the corona) by measuring the ultraviolet radiation coming from the Sun. This will help to solve some of the major scientific questions concerning the Sun - `why is the corona hotter than the Sun's surface by over one million degrees?' - `how does the corona expel material into space?'

2. LASCO

The Large Angle Spectrometric Coronograph, by producing an artificial eclipse, will be able to look at the structure in the outermost layer of the Sun's atmosphere. The information gained will help with studies on coronal mass ejections where huge clouds of gas are ejected into space. The instrument will also help with research into how the Sun's magnetic field can extend into space.

3. GOLF

Seismic sound waves in the Sun's interior produce visible effects on the surface. The GOLF (Global Oscillations at Low Frequency) instrument will look at the way the Sun's entire visible surface oscillates, which will provide information on the internal structure of the very heart of the Sun where the nuclear reactions are taking place.

4. SOI

The Solar Oscillations Investigation study will observe the seismic oscillations of the solar surface, allowing the structure and motions within the convection zone to be studied. It will solve many of the most important problems concerning the dynamics of the Sun, from how energy is produced and transported, to how the surface erupts into solar flares.

5. VIRGO

This instrument will monitor the Variability of Irradiance and Gravity Oscillations, providing information on how energy is stored and transported through the convection zone. This will complement the measurements form GOLF and SOI helping us to understand the deep interior of the Sun.

POLAR

This is a NASA spacecraft which launched into a highly eliptical polar orbit at the end of 1995. The spacecraft will find out how much of the plasma in the Earth’s magnetosphere comes from the solar wind and how much is drawn up from the Earth’s atmosphere. It will also take pictures of aurorae over the entire polar cap and will measure the particles that are being accelerated down into the atmosphere to make the aurorae.

There are nine instruments on the spacecraft to make in-site measurements of the particles, magnetic and electric fields, and three instruments to take pictures in the visible, ultraviolet and x-ray spectral regions. British scientists are involved with two of these instruments.

1. TIMAS

The Torodial Imaging Mass Angle Spectrometer will measure the mass, energy and direction of positively charged particles. The electronics will work so fast that rare particles will be distinguishable from the common dominant particles. This instrument will be able to study the movement of charged particles into the magnetosphere from the solar wind and from the Earth’s atmosphere over the polar caps.

2. CEPPAD

British scientists have built one of the sensors on the Comprehensive Energetic Particle and Pitch Angle Distribution instrument. This will measure the distribution of electrons and protons and will provide information on particle acceleration and dynamics.

ULYSSES

This joint ESA and NASA mission to study the Sun and the region of space surrounding the Sun was launched in 1990. Ulysses is the first spacecraft to travel over the regions of the Sun, well outside the plane in which the planets orbit the Sun. After becoming the fastest spacecraft ever, it used Jupiter’s gravitational pull to swing into an orbit over the poles of the Sun. In 1994 it made many fascinating discoveries as it travelled under the Sun’s South Pole. After travelling over the Sun’s North Pole in 1995, it will make its long journey back to Jupiter’s orbit, returning to the Sun’s polar regions in 2000. By that time, the Sun will be at the maximum of its sunspot activity and Ulysses will observe conditions in space that are more disturbed.

British scientists were involved in the construction of several of the instruments on board, taking the leading role in one of them. Britain has also provided scientific help on one other instrument.

1. HI-SCALE

This instrument is measuring charged particles. It is looking at how particles from solar flares travel into space as a result of high speed solar wind streams. A major surprise is that high speed electrons have been detected in the Sun’s polar regions. These were thought only to be present at low latitudes. This proves that as the shocks from the solar flares move outwards to beyond the orbit of Saturn they also expand towards the Sun’s poles.

2. COSPIN

This Cosmic Ray and Solar Particles experiment is studying high energy particles as well as the composition of cosmic rays, which are highly energetic particles from the galaxy and beyond. Scientists have been surprised by how difficult it is for cosmic rays to penetrate the Sun’s polar regions. This appears to be due to turbulent magnetic fields that scatter the cosmic rays.

3. DUST

DUST is measuring the properties of dust particles in space. This instrument has made the first direct detection of interstellar dust particles. These extremely small particles travel at speeds over 90 000 km/h on orbits not bound by the Sun’s gravity. This shows they originate from outside our Solar System.

Briefing paper 10

Galaxies

The stars we can see in the night sky are just a tiny fraction of the 100-200 billion that are in our galaxy, known as the *Milky Way*. The galaxy is a spiral approximately 100 000 light years (ly) across, and the Sun lies about 25 000 ly from the central hub which is a mass of older stars. Some astronomers believe that there may be a huge black hole at the centre of the galaxy. The arms of the spiral contain younger stars and nebulae, where new stars are formed. The galaxy is surrounded by a vast region called a halo, which contains the oldest stars and possibly material we cannot see, called *dark matter*.

The Milky Way is just one of an estimated 100 billion galaxies in the Universe. They are not all the same. In the 1920's astronomer Edwin Hubble classified galaxies into spiral, barred spiral, elliptical and irregular. **Figure 1** is a diagram of the cluster to which the Milky Way belongs. There are also clusters of clusters, known as superclusters.

Some galaxies have violent activity going on inside them. Radio galaxies were discovered in the 1950's - so called because they emit vast quantities of radio waves - and in 1983 starburst galaxies were detected. Here sudden outbursts of star formation produce enormous amounts of infrared radiation. The advent of astronomical observations using satellites and space probes has vastly increased our knowledge of galaxies, and it is likely that there will be many exciting new discoveries from data collected by instruments in space in the years to come.

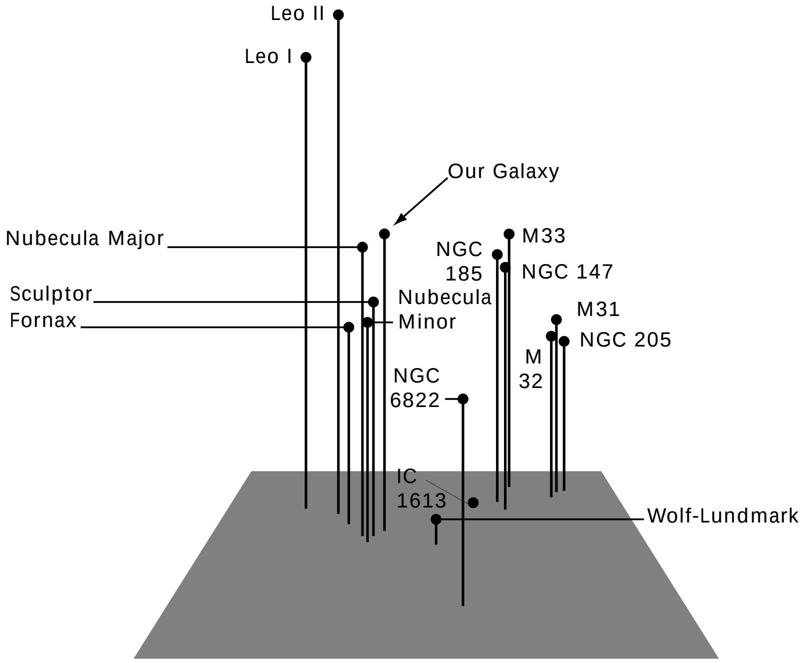


Figure 1. Our local cluster of galaxies

Investigation

Observing sunspots

You can find out about the Sun's activity and its rotation by observing sunspots. As the Sun spins, the sunspots move across its face. You have to carry out a pilot study. You should devise a reliable method of recording the positions and shapes of sunspots, and then carry it out in a consistent way over a period of days or weeks. When you have made a series of observations, you should evaluate your results.

- Did your chosen approach work well? Could it be improved? It may help if you compare your approach with someone else's.

- Can you use your observations to work out how fast the Sun rotates? How accurate do you think your answer is?

- If your pilot study is to be extended to make measurements over a longer period of time, how could your procedure be improved? Could you make use of IT to improve it?

Three ways to observe sunspots

SAFETY. Under no circumstances should you look directly at the Sun either with the naked eye or through binoculars or a telescope. The image of the Sun will be much bigger if you use binoculars or a telescope (method 3). If you use either method 1 or 2 (see below), the image of the Sun will be about 8mm across when the screen is 1m from the pinhole.

1 Camera obscura

Make a hole 2mm in diameter in a piece of black card. Fix it in the gap between a pair of curtains. An image of the Sun will be projected onto the screen.

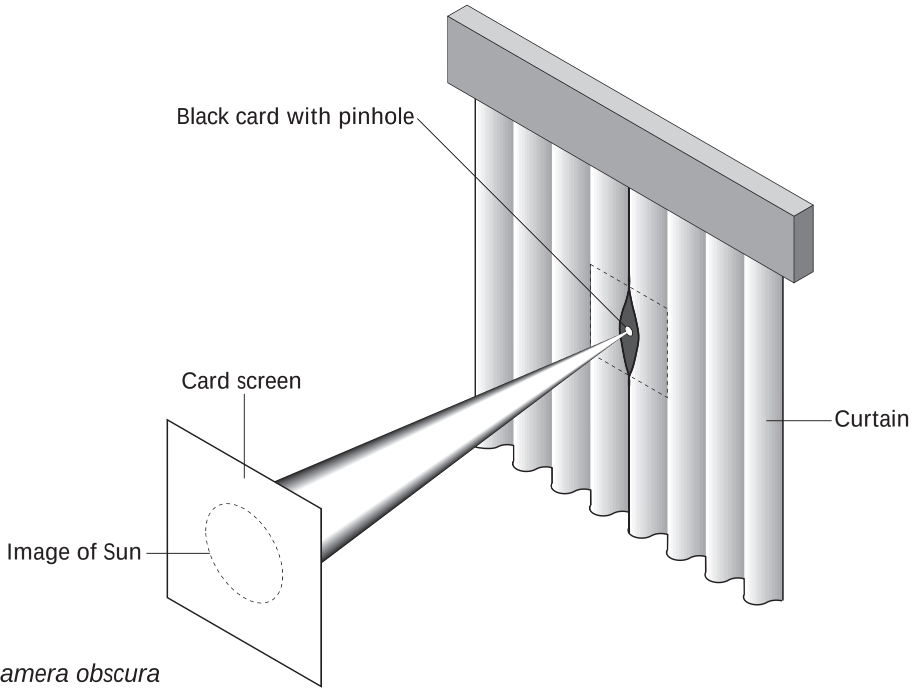


Fig 1. Camera obscura

Investigation continued

2 Pinhole camera

Make a long pinhole camera, perhaps using a cardboard tube. Direct the tube towards the Sun. You will see an image of the Sun on the greaseproof paper screen.

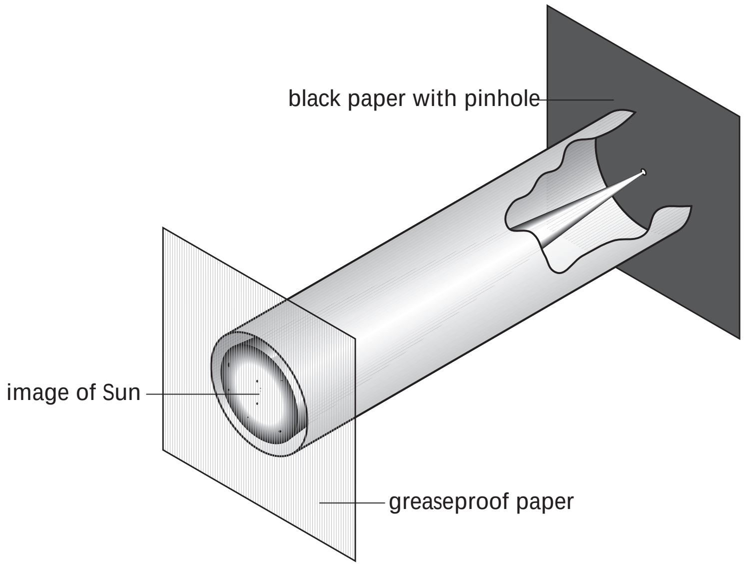


Fig 2. Pinhole camera

3 A projector

Mount a pair of binoculars or a telescope so that they are directed towards the Sun. An image of the Sun will appear on the screen. Focus this to get a clear image.

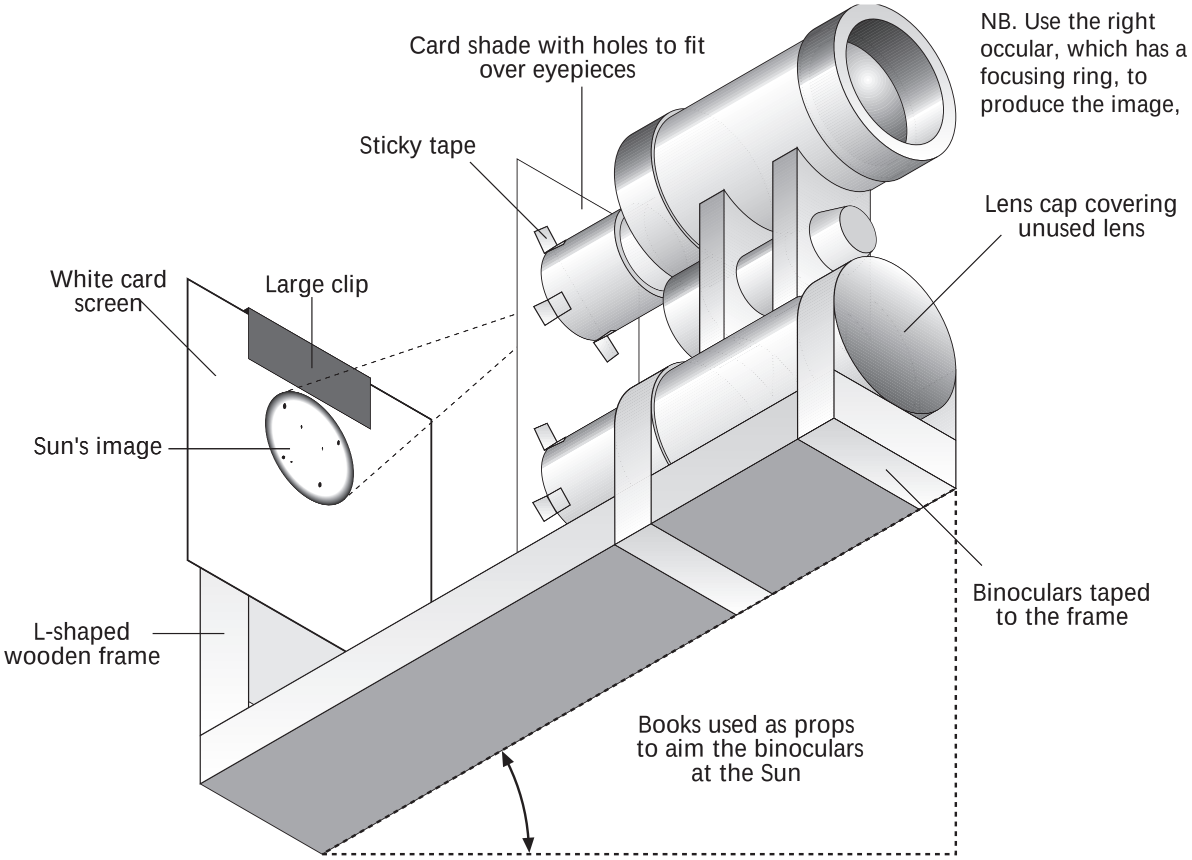


Fig 3. Projector method using binoculars

Investigation continued

Observing sunspots

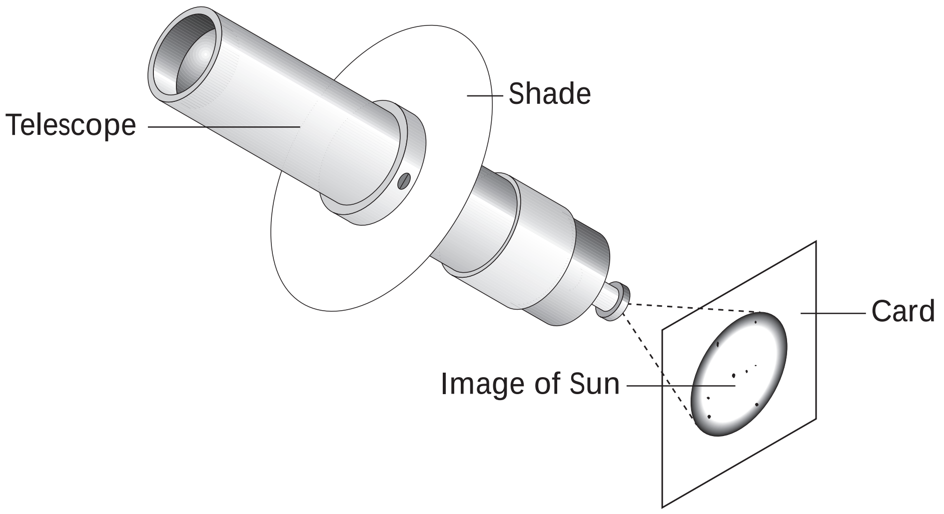


Figure 4. Alternative projector method using a telescope

Three ways to record sunspots

1 Drawing
Using a pencil, draw around the spots on the screen.

2 Using a grid
Place a piece of squared paper where the image of the Sun is formed. Note the squares in which you can see sunspots.

3 Photography
Make a photograph of the image of the Sun.