CHAPTER 06

Astrophysics

From the very earliest days, humans have looked into the sky and wondered what it's all about. Thousands of years ago priests in Babylon (now present-day Iraq) stood gazing into the night sky, not realising just how big it was. All sorts of theories, all sorts of myths and legends have grown out of attempts to understand how the universe works.

The big questions on everyone's mind concerned the solar system (Sun and planets) and the universe in general. The old **geocentric** view of our solar system said that the Sun went around the Earth (Greek *geo* from *gaia* = 'Earth' and *centro* = 'centre'). The modern view belongs to the Polish astronomer and priest Nicolas Koppernigk (**Copernicus**, as he was better known in Latin), who published his **heliocentric** or Sun-centred theory in 1540. Not that it was a new concept, for the Greek philosophers Heraclides and Aristarchus put forward a similar view in 300 BC, but after they were threatened with death they kept quiet.

The modern view of the entire universe came much later. The general opinion up until the 1920s suggested that the universe was infinite in size and in a steady unchanging 'static' state, made up of fixed stars that had always shone and would continue to shine forever. This view was well entrenched — even Einstein believed it! But in 1929 an astronomer made a finding that was to shake the foundations of this steady state model forever. His name was Edwin Hubble and his story follows later. The **steady-state** theory clung on until the 1970s when it died and was buried.

Like those before us, do you ever wonder about these:

- What makes the Universe tick? How do the four forces work together?
- What is the Universe made of? We don't know what's out there.
- Was Einstein's anti-gravity theory really a great mistake or ahead of its time?
- Why do we live in a three-dimensional world; is it just a fluke?
- Can we travel in time and could we come back?
- Can black holes collapse to infinite density? How would you know?
- Where does consciousness come from; where does life come from?
- Are we alone?

6.1 THE NATURE OF THE UNIVERSE

Here's what *The Hitch Hiker's Guide to the Galaxy* has to say about the size of the universe:

> Space is big. Really big. You just won't believe how vastly hugely mindbogglingly big it is. I mean you may think it's a long way down the road to the chemist, but that's peanuts to space ... It's just so big that by comparison, bigness itself looks small.

Photo 6.1
The sky at night is almost black — but so what?

Astrophysicists agree. They can also answer some of the other questions above.

- The universe is between 10 and 15 billion years old, with most scientists agreeing on 13.4 billion years (a billion is 10^9).
- The remotest object from us is the quasar PC 1247+3406 at 13 200 million light years (1.25×10^{23} km). One light year is the distance light travels in one year or 9.46×10^{12} km. Hence, the edge of the universe is believed to be 15 000 million light years from us.

Some of the other questions will be answered later in this chapter. Some may never be answered but physicists will keep on trying. Many laws have been developed in this quest.

To appreciate the size of the universe, imagine the Earth is the size of a pinhead. The Sun would be the size of a grape about $1\frac{1}{2}$ metres away. Jupiter would be a pea 8 metres away, and Pluto a grain of dust 70 m in the distance. That's our solar system. Whew!

Now imagine the whole solar system shrunk down so that the Sun is now a pinhead. The Earth would orbit a few centimetres away, and Pluto about 60 cm away. On this scale our nearest star system — containing Proxima Centauri — is 3 km away and the size of a tiny sand grain. Other stars are also like sand grains and they reach out a distance equal to the distance from us to the moon. That's our galaxy. Big in anyone's language!

Lastly, imagine our galaxy shrunk down to the size of a dinner plate. Our nearest neighbouring galaxy is Andromeda — another dinner plate just a few metres away. The edge of the visible universe is many kilometres in every direction. But extending past that are more galaxies that we can't see because light has yet to reach us. Scientists believe that there are approximately 100 billion galaxies, with each galaxy containing between 100 and 200 billion star systems. That's our universe. To better understand the universe as it is today, you have to appreciate three fundamental observations: Olbers's paradox, Hubble's law, and the Cosmic Microwave Background Radiation, of which more later.

Astronomical distances

It takes light about 10 billion years to get from the edge of the observable universe to us. That's a huge distance and the units metre and kilometre seem inadequate. Astronomers use the unit megaparsec (Mpc) for distance. A parsec (pc) is a distance based on how far away a star would be if it appeared to change position by an angle of one second when viewed from the Earth at 6-month intervals. It sounds complex but astronomers assure us it is eminently suitable for their work. They also use light-years (ly) for distance: the distance light travels in a year. They use km s^{-1} for velocity or express it as a fraction of the speed of light (c).

1 light-year (ly)	9.47×10^{15} m
1 parsec (pc)	3.262 ly
	3.09×10^{16} m
1 megaparsec (Mpc)	1 million parsec
	3.262×10^{6} ly = 3.262 Mly
	3.09×10^{19} km
Speed of light (c)	3×10^{8} m s^{-1}
Temperature (T)	K = °C + 273

Example

The Hydra galaxy is 1960 million light-years (Mly) away and has a radial velocity of 60 500 km s^{-1}. Convert the distance to Mpc and the speed to units of c.

Solution

Mpc = Mly/3.262, hence Mpc = 1960/3.262 = 600 Mpc

$$\boldsymbol{v} \text{ in units of } c = \frac{\text{m s}^{-1}}{3 \times 10^{8}} = \frac{60\,500 \times 1000}{3 \times 10^{8}} = 0.20\text{ c}$$

Olbers's paradox

In 1823, a German astronomer Heinrich Olbers stumbled on a contradiction that could not be easily explained. The following activity poses this contradiction.

Activity 6.1 THE NIGHT SKY

You don't really need to carry out this experiment — a *gedanken* (thinking) experiment will do!

Have a look at the sky at night. Is it black or white? Of course it is mostly black (see Photo 6.1), with about 4000 tiny stars twinkling away; but why doesn't the night sky look uniformly bright? If there were an infinite number of stars which had been glowing for an infinite time, no matter where you looked you'd see a star and so the night sky should be ablaze with light. But it's not!

We now know that the old-fashioned idea of an infinite, static universe is simply wrong. The universe has a finite age, and is not just three-dimensional as we perceive things on Earth. Because only 10 billion years have elapsed thus far, we can only observe stars out to a large, but strictly finite, distance of 10 billion light-years or so. This 'observable universe' contains a large but finite number of stars, about 1000 billion (10^{12}). These stars contribute to the observed brightness of the night sky, which glows very faintly.

Activity 6.2 LIGHT AT A DISTANCE

Here's a good experiment you could try using a computer-based laboratory such as the TI graphing calculator and the CBL. There are plenty of other ways to do it as well.

Set up equipment as shown in the Figure 6.1.

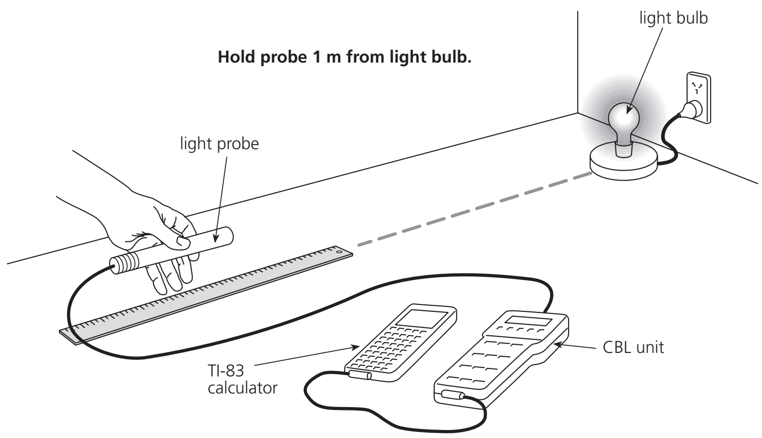

Figure 6.1
Apparatus to measure how light intensity varies with distance.

1. Mark off distances of 1 m and 2 m from the light socket. Then divide the distance into 10-centimetre intervals between the one-metre and two-metre marks.
2. While you are taking intensity readings during the activity, the light sensor should be pointed directly at the illuminated bulb with the end of the sensor held a certain distance from the bulb, as specified in the calculator program.
3. Darken the room, with the exception of the light source.
4. Collect light intensity data for different distances.
5. The data you collected will be modelled with a power relation of the form $y = ax^b$. First, you will need to find the values of A and B. The rest is up to you and your graphing calculator. Good luck.
6. According to scientific theory, the correct model for light intensity against distance is an inverse square relationship. This relation is expressed mathematically as: $y = a/x^2$ (inverse square law).

   If this equation is expressed in the form $y = ax^b$, what would be the value of b? Is this consistent with the models you found earlier?

NOVEL CHALLENGE

Try these Fermi questions:

A How long would a beanstalk (elevated to geosynchronous orbit) have to be? What tensile strength would it require? How does this compare to steel, kelvar, spider silk, the maximum theoretical material strength?

B According to one hypothesis, 20% of the mass of the asteroid that killed the dinosaurs was uniformly deposited over the surface of the Earth at a density of 0.02 g/cm^{-3}. What was the mass of this asteroid?

Falling into a black hole

If a black hole were to exist near some other stellar object such as a **quasar** (quasi-stellar radio source) the gravitational attraction would drag matter from the quasar into the black hole. Atomic particles would accelerate to near the speed of light as they approached. Rather than falling straight in, they would swirl in like a whirlpool, becoming compressed and heated and giving off enormous amounts of energy. It is this radiant energy that astrophysicists detect as they try to identify the location of black holes.

If you tried to travel into a black hole would you survive? It's hardly likely! You'd be stretched, compressed and heated. Hardly the romantic stuff of science fiction novels. If you could avoid getting too close then you wouldn't get sucked in. The minimum distance from which it is still just possible to escape (Schwartzchild radius) marks the boundary called the **event horizon**.

The dilation of time caused by gravity

One of the consequences of Einstein's general theory of relativity is that the passage of time is affected by gravity. To an astronaut falling into a black hole time would pass normally. But to outside observers, for example us on Earth, time would appear to slow down because of the immense gravity near a black hole. It would seem to take ages for the astronaut to disappear into the hole. This is called the **dilation** of time (Latin *dilato* = 'expand').

What's it like inside a black hole?

You can't escape from a black hole — it's sort of like our universe. You can't travel off into space and leave our universe so some scientists have said that our universe is like a black hole in someone else's universe. And their universe is a black hole in some higher universe. Perhaps within black holes in our universe are smaller universes. Who knows? It's all speculation but makes an intriguing thought. Books by Steven Hawking, Carl Sagan, Paul Davies and Kip Thorne examine the possibilities and consequences of such theories. Magazines such as *Scientific American* and *New Scientist* tell of the latest research. There's no room for it here.

What is the fate of a black hole?

Stephen Hawking was the theoretical physicist who showed that black holes eventually evaporate. That's right — evaporate. His technical paper had the unusual title of 'Black holes ain't so black!!' Hawking's calculations confirmed that a spinning black hole loses energy by emitting radiation (the so-called 'Hawking radiation') and as it does it becomes smaller and hotter, eventually becoming so small and hot that it simply evaporates. In fact, today, physicists applying the laws of thermodynamics and quantum gravity require black holes to eventually evaporate in about 10^{67} years. The smaller the black hole, the faster it will evaporate. An interesting theory but who'll be around to see if it's true?

ASTRONOMY VERSUS ASTROLOGY 6.10

Astronomy is the scientific study of heavenly bodies — stars, planets, comets, quasars etc. **Astrology** is a pseudo-science (i.e. non-scientific) that claims to foretell the future by studying the supposed influence of the relative positions of the Moon, Sun and stars on human affairs. Up to the time of Kepler (1600) only astrology existed. Observations and experiments by Galileo, Kepler and Newton produced universal laws and the new science of astronomy began. Astrology slowly became the mumbo-jumbo side of sky watching and was relegated to the irrational, non-scientific and hoaxers club together with pyramid power, clairvoyance, ESP, water divining, flat earth theory, numerology, faxes from the dead, Feng Shui, Tarot Cards, Bermuda Triangle, runes, UFOs, levitation, Philadelphia experiment, faces on the Moon and Elvis sightings, to name just a few.