THE COMPLETE COSMOS
Chapter 17: Aurorae and Eclipses


The Sun continuously emits a stream of electrified particles known as the solar wind. Earth is normally protected from these particles by its magnetosphere, a great magnetic "bubble". Occasionally the solar wind increases to "storm-force" as a result of gigantic eruptions on the Sun. On Earth, such bursts cause geomagnetic storms, blacking out cities and knocking out satellites. Between these major storms, electrified particles often leak through Earth's magnetic defenses, around the poles, causing beautiful displays in the night sky known as aurorae - the aurora borealis in the northern hemisphere and the aurora australis in the southern.

Another form of celestial spectacular is an eclipse - either an eclipse of the Sun or an eclipse of the Moon. Eclipses are caused by special alignments of the Sun, Earth and Moon. The mechanisms of solar and lunar eclipses, always difficult to explain, are carefully and graphically illustrated. From the Caribbean island of Curacao, coverage of the 1998 total eclipse of the Sun. Observers travel thousand of kilometers to catch the show. Tension mounts during build-up phases when the Sun is only partially obscured. Then comes the splendor of totality - with dramatic footage of prominences and the solar corona - and, finally, the spectacular diamond ring when totality is over.

Solar Wind
* Introducing the Sun as the source of all our energy, emitting heat and many forms of radiation.
* The solar wind, the continuous stream of electrified particles emitted by the Sun.
* How great eruptions on the Sun can boost the solar wind to "storm-force".
* The effects on Earth of the resulting geomagnetic storm, disabling power lines, sending satellites into a spin and disrupting communications.
* Animation reveals how the Earth's magnetic field is squeezed as the material ejected from the Sun strikes, causing a geomagnetic storm.

Lights of the Aurora
* How the normal steady stream of solar wind particles is funneled down towards the Earth only around the poles.
* Formation of the auroral ovals - one around the north magnetic pole, another around the south pole.
* The mechanism of the aurora. How atmospheric atoms are excited to fluoresce by collisions with electrified particles spiraling down magnetic field lines.
* The majesty and beauty of an auroral display.

How Eclipses Happen
* Eclipses occur because sunlight is blocked.
* The mechanics of the Moon's orbit around the Earth, the inclination of its orbit and why we don't see an eclipse every lunar month - explained with computer graphics.
* The "nodes" of the Moon's orbit and their significance.
* Geometry of an eclipse - both lunar and solar. How the Earth's atmosphere causes the Moon to turn red during a lunar eclipse.

Eclipses of the Sun
* Mechanism of solar eclipses in detail. The ellipticity of the Moon's orbit, and how the Moon's
shadow cone sometimes doesn't reach Earth - resulting in an annular eclipse.
* How a total solar eclipse occurs when the shadow cone does reach Earth, and how that shadow sweeps across the Earth's surface. The speed of the shadow.

The Real Thing
* February, 1998. Enthusiasts from around the world gather on the island of Curacao, in the Caribbean, to witness a total eclipse of the Sun.
* First contact, as the Moon bites into the solar disk. The partial phases.
* Using special filters to view the eclipse in safety. Projecting crescents of the Sun.
* Clouds threaten the show, tension rises. But clear skies return as totality approaches.
* The full glory of totality, showing the corona and prominences, with the planets Mercury and Jupiter visible.
* The Moon exactly covers the solar disk - 400 times smaller, yet 400 times closer. An incredible coincidence of Nature!

Background
The Solar Wind and Earth's Magnetosphere
The continuous outwards motion of the gas in the Sun's corona gives rise to the solar wind. Even though the total outflow of material from the Sun is about one million tons per second, this mass-loss has a negligible influence on the Sun's evolution. The high temperatures of the corona (1-2 million degrees) ensure that the constituents of the solar wind (mainly electrons, protons and alpha-particles) are ionized, i.e. electrically charged.

This stream of electrified atomic particles normally flows outwards from the Sun at speeds of 300-400 kilometers per second. On occasions, however, solar flares or massive ejections of material from the Sun can boost the solar wind to "storm-force", reaching speeds up to 800-1,000 kilometers per second. At these velocities, a burst of electrified particles from the Sun may take only about 48 hours to travel the distance to Earth.

The Earth's magnetic field causes a bubble in the solar wind. This cavity, called the magnetosphere, partially shields Earth from the high-speed electrically-charged particles of the solar wind. Such particles are often energetic enough to damage living cells and are, therefore, potentially harmful to us.

The magnetic field protects us because when charged particles encounter it, they are deflected by its magnetic force into a spiraling motion around the field lines. This slows the particles of the solar wind, causing them to flow around the Earth in much the same way as water in a stream is diverted around a partially-submerged rock. Thus we are spared the full impact of the Sun's charged particles.

The Aurora and Earth's Radiation Belts
As the solar wind particles stream past the Earth, they generate electric currents in our upper atmosphere. These currents cause electrified particles - electrons and protons - to spiral down the Earth's magnetic field lines. The particles rain on the upper atmosphere in two oval-shaped regions around the Earth's north and south magnetic poles. When the particles collide with gases in the upper atmosphere, atoms of oxygen and nitrogen light up like the gases in a fluorescent tube. The result is the beautiful shimmering display called the aurora borealis (Northern Lights) or aurora australis (Southern Lights), depending upon the hemisphere from which the phenomenon is being observed. The exact process by which the aurora forms is still controversial. The beautiful streamers of an auroral display are shaped by the Earth's magnetic field, much
as sprinkled iron filings outline the field of an ordinary bar magnet.

Deep inside Earth's magnetosphere, our planet's magnetic field is strong enough to trap charged particles which have managed to leak through the magnetopause, the outer boundary of the Earth's magnetic domain. These particles are held captive in two huge, doughnut shaped rings called the Van Allen radiation belts. These belts were discovered in 1958 during the flight of the first successful US artificial satellite, Explorer 1. The inner Van Allen belt contains mainly protons and extends from 2,000-5,000 kilometers above the Earth. The outer Van Allen belt contains mainly electrons. It is about 6,000 kilometers thick and centered at an altitude of 16,000 kilometers. The particles trapped in the Van Allen belts are energetic enough to penetrate spacecraft and to be a hazard to astronauts, damaging tissue. Astronauts, therefore, try to avoid passing through the belts or to get through them as quickly as possible.


Eclipses of the Moon
Like all non-luminous bodies, the Earth casts a shadow in space, and if the Moon passes into this cone of shadow - which can only occur at Full Moon - its supply of direct sunlight is cut off, producing a lunar eclipse. The Full Moon turns a dim, often coppery-red color, before passing out of the shadow again. In general it does not vanish completely, because some of the Sun's rays are bent or refracted on to the Moon by way of the layer of atmosphere surrounding the Earth, but there are times when the eclipsed Moon is hard to trace with the naked eye. Everything depends upon conditions in the Earth's upper air through which the refracted sunlight has to pass.

Lunar eclipses may be either total or partial, and as seen from any particular location on Earth are more common than eclipses of the Sun - because when a lunar eclipse happens it can be seen from any place from which the Moon is above the horizon at the time. This is not true of solar eclipses, as we shall see below.

Eclipses of the Sun
Eclipses of the Sun are of three types: total, annular and partial. All are interesting, but for sheer grandeur total eclipses are unrivalled. Only then can the deep red chromosphere, the "flame-like" prominences and the pearly corona be seen with the naked eye.

Total eclipses occur when the Sun, the Moon and the Earth are exactly lined up, so that the Moon's shadow reaches the surface of the Earth. But the shadow is only just long enough to do this, and totality can be seen from only a very restricted area of the Earth's surface which explains why from any particular location, eclipses of the Sun are much less common than those of the Moon. The width of the track of totality can never be more than 272 kilometers, and is usually less. For example, the path of totality during the 11 August 1999 total eclipse is only just over 100 kilometers wide as it crosses Cornwall and Devon. To either side of the main cone of the shadow, the Sun is only partly hidden. Moreover, totality is brief. From any one site it can never last for longer than seven minutes 31 seconds, and so far as I know there has never been an observation of an eclipse as protracted as this. The record appears to be held by the 1955 totality as seen from the Philippine Islands, which lasted for seven minutes eight seconds. The last English total eclipse, that of 29 June, 1927, lasted for a mere 24 seconds, and the width of the track of totality was only 52 kilometers.

There is, of course, one way to overcome this problem. To prolong totality as long as possible, the eclipse should take place near the equator where the Earth's rotational velocity reaches a
maximum value of nearly 1,700 km per hour from west to east. This cancels out some of the motion of the Moon's shadow which travels at about 3,400 km per hour from east to west. Some eclipses are not total from anywhere on Earth. Such, for instance, was the eclipse of 12 October, 1996; as seen from London just over 60 per cent of the solar disk was hidden.

The third type of eclipse - the annular - occurs because the Moon's distance from the Earth varies appreciably; its orbit, like those of virtually all Solar System bodies, is appreciably eccentric. The distance ranges from 356,400 km at its closest (perigee) out to 406,700 km at its furthest (apogee), giving a mean center to center distance of 384,400 km. This means that the apparent diameter changes, from 29 arcminutes 22 seconds at apogee to as much as 33 arcminutes 31 seconds at perigee. The mean apparent diameter of the Sun as seen from Earth is 32 arcminutes. It follows that when the Moon is at or near apogee, its disk is too small to cover that of the Sun, and if the alignment is perfect we see a ring of sunlight left showing around the dark disk of the Moon. This explains the name; annulus is Latin for 'ring'.

The maximum possible duration of the annular phase of an eclipse is 12 minutes and 24 seconds, but most are much shorter. So far as we are concerned, the next British annular eclipse will fall on 31 May 2003, as seen from the very north of Scotland; from Aberdeen and Perth the eclipse will be only partial. Occasionally there are eclipses which are annular along most of the central track, but total at the mid-point. This happened on 3 October 1986, which was mainly annular but was total for about a tenth of a second as seen from the middle of the Atlantic Ocean. Note, incidentally, that since the average length of the Moon's cone of shadow is less that the mean distance between the Moon and the Earth, annular eclipses are more frequent than total eclipses in the ratio of 5 to 4.

**The Glory of a Total Solar Eclipse**
First Contact: The moment when the Moon's disk begins to move across the brilliant face of the Sun, and a tiny notch appears at the Sun's limb. Of course, the exact moment can be predicted with great accuracy, but it takes a few seconds for the notch to become noticeable.

To view the partial phases of the eclipse you MUST have proper eye protection. Viewing the Sun through ordinary sun-glasses, even dark ones, is certainly asking for trouble; these give no protection whatsoever, and neither do exposed photographic film, photographic filters, crossed polarisers, gelatin filters, compact disks, or smoked glass. Please DO NOT be tempted to use any of these.

The partial phases of the eclipse may be observed safely through a welder's glass rated at number 14 or higher, or a pair of aluminized mylar 'spectacles'. Mylar is a very tough plastic film, and solar filters are made by coating it with a thin layer of aluminium. DO make sure that any filters you use carry the "CE" mark, and check them very carefully for any damage. DO NOT use filters if they are scuffed, scratched or have holes in them, and DO NOT use any filter if you are not certain that it is approved and safe, or if you have any other doubts about it. Always hold the filter firmly over both your eyes BEFORE looking up at the Sun, and do not remove it until AFTER looking away. DO NOT look at the Sun through any optical instrument, e.g. telescope, binoculars or camera, even if you are wearing special filters.

Gradually the Moon passes on to the face of the Sun. For a surprisingly long time there is no perceptible diminution in light or fall in temperature, but when the Sun is more than half covered these effects start to become evident. If there are any sunspots (as there probably will be in August 1999) compare them with the darkness of the Moon; the lunar disk will be seen to be much the blacker. By the time that the Sun is nearly half covered, anyone standing near a tree or
bush will be able to see tiny crescent-shaped images on the ground around them. Gaps in the foliage act as 'pinhole cameras' and focus the images of the crescent Sun.

Shadow Bands: These curious, narrow wavy bands of light and dark are purely atmospheric phenomena. They are sometimes seen moving across the ground just before totality (and just after), but not always; conditions have to be exactly right.

Lunar Shadow: As totality approaches, the whole scene changes with amazing rapidity. The temperature falls, the sky darkens, and the shadow of the Moon can be seen rushing across the landscape - or, better, seascape.

Diamond Ring: Just before the last sliver of the Sun's brilliant disk disappears, we see the effect termed the Diamond Ring - a brilliant point which lasts for an all-too-brief period. It is usually better seen at the end of totality.

Baily's Beads: The Moon's limb is not smooth; there are high mountains and deep valleys. Moments before totality, the sunlight comes to us through the lunar valleys on the limb, and the result is a series of bright points of light. They were described in detail during the 1836 eclipse by the English astronomer, Francis Baily, and are named after him. In fact the 1836 eclipse was not total, but annular, so that during a 'short annular', when the Moon's disk is almost large enough to cover the Sun, Baily's Beads are quite conspicuous. They are not likely to be seen during the next British annular, that of 31 May 2003, because the Moon will be near apogee, and will cover no more than 94 per cent of the Sun.

The Sun is wholly hidden, and totality has begun. The pearly corona and 'flame-like' prominences flash into view; the sky is dark, and almost at once bright stars and planets can be seen. There is an abrupt fall in temperature; birds, understandably confused, start to roost, and some types of flowers to close. There is often a strange, somewhat eerie calm. The corona is not always of the same shape. Near sunspot minimum it sends out wings' and streamers, while near maximum it is more symmetrical - though of course no hard and fast rules can he laid down.

Mid-totality: Again no two eclipses are alike, but all in all it is fair to say that the corona gives out about as much light as the full moon. This means that direct viewing, even with a telescope, is safe. Pause to look round the sky; any bright planets will shine forth, together with bright stars, though if there is any trace of haze or thin cloud it is likely that only Venus and Jupiter, if favorably placed, will be obvious. Third contact: Totality ends as suddenly as it had begun.

The Diamond Ring: This is one of the most glorious moments of the entire eclipse, but it lasts for so short a time. In a few seconds the Sun's brilliant disk starts to reappear; the corona fades from view, and the Diamond Ring is lost. This is certainly the most dangerous moment for the careless observer. The slightest sliver of the Sun's brilliant disk is as dangerous as the uneclipsed Sun itself - and so if you have been viewing directly, make sure you take your eye away from the 'danger-zone' in time. Remember, too, that an SLR camera acts in the same way as a telescope or binocular lens. Partial phase: Gradually the Moon moves off the face of the Sun. The sky quickly brightens: birds leave their roosts and flowers open; the Earth seems to 'wake up'. With luck you may see the effects of the receding shadow of the Moon in the form of a curved dark, sometimes purplish patch covering part of the sky.

Fourth contact: The Moon finally moves off the Sun, and everything is hack to normal; the eclipse is well and truly over. In fact, it usually happens that few people wait to see fourth contact; they are too busy packing up their equipment and comparing notes.
Such is the sequence of events for a total eclipse seen under ideal conditions. Sadly, this does not often happen. If there is any cloud around, the outer corona will be lost and no stars or planets will be seen. It may happen that the sky is partly cloudy, in which case all that can be done is to hope for the best.

(End of extracts from Patrick Moore's book "THE WESTCOUNTRY ECLIPSE: 11 AUGUST 1999").

Links for Further Information
A page with information about Sun-Earth interactions, and auroral observations.
http://snowcat.polar.rm.cnr.it/artico/sun.html

Data and other links relating to solar-terrestrial environmental research.
http://shnet1.stelab.nagoya-u.ac.jp/omosaic/goin95/subg96/subg4.html
and
http://shnet1.stelab.nagoya-u.ac.jp/omosaic/goin95/goin95.html

Details of lunar eclipses, with geometry, applications, astronomy, mathematics, text and graphics.
http://www.ntplx.net/~mawdsley/m4apluna.htm

NASA's and Goddard Space Flight Center's very comprehensive eclipse home page, including images, eclipse alerts, data, photography, and links to many other sites relating to solar and lunar eclipses. A must for would-be eclipse-watchers!
http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Questions and Activities for the Curious
1. If the Earth rotated more slowly would you expect it to have a stronger or weaker magnetic field? Give your reasons.
2. What is the solar wind, and why does its speed vary?
3. Describe some of the effects that solar flares and massive solar ejections can have on the Earth.
4. How is the aurora related to the Earth's magnetic field?
5. Why aren't there eclipses every month?
6. Describe an annular eclipse of the Sun and explain how it occurs.
7. With diagrams, show the relative positions of the Sun, Earth and Moon at the time of a total solar eclipse and a total lunar eclipse.
8. Briefly describe some of the phenomena you would expect to see during a total eclipse of the Sun.