

Chapter 1

Introduction

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Space research is one of the most evocative and challenging fields of human endeavour. In the half-century that has elapsed since the beginning of the space age, we have been exposed to wonders beyond the imagination of even the most visionary of science fiction writers. We have peered deep into the Universe and studied physics that we can never duplicate on the Earth. We have begun to understand our own Sun, and the flow of energy outward through the Solar System that is fundamental to our existence. Robotic agents have explored the planets in the Solar System and the environment of our own planet, the Earth. Human beings have trodden on the surface of the Moon, and now have a constant presence in near-Earth orbit. We are also advancing on that most fundamental of questions: whether life has ever evolved elsewhere in the Solar System or elsewhere in the Universe.

Beyond the primeval urge to explore, this knowledge has a fundamental effect on the evolution of human society, its ethics and values (for example, how different would life be if we still believed the Earth to be flat?). Gaining that knowledge has also spawned more direct benefits. The challenge of successfully building machines to operate in the hostile environment of space has led to countless advances in technology and the way in which we organise and deliver complex systems. Earth-orbiting satellites, a novelty but a few short decades ago, are now taken for granted in areas such as communication, navigation and weather forecasting. Increasingly we have come to recognise the fragile nature of the Earth's ecosystem and how it can be influenced by external factors, from space weather, with its origins in the turbulent atmosphere of the Sun, to asteroid impact. By studying the Earth as a planet, we are also coming to appreciate the potential deleterious effects human society can have on its own environment. The tools that we have honed in the study of the distant Universe are now increasingly being deployed to monitor the health of our own backyard.

The purview of space science is nowadays very broad, covering a large number of subject areas that many would regard as distinct. Nevertheless there is a great

deal of commonality in the physics that underlies these areas, not to mention the technology, data analysis techniques and management challenges. This book has its origins in a series of lectures given to graduate students at University College London's Mullard Space Science Laboratory (MSSL). These lectures were designed to broaden the perspective of students beyond their immediate field of study and encourage cross-fertilisation between fields. The subjects dealt with cover the core research themes of MSSL, the UK's oldest university space research laboratory. While certainly not a complete survey of space science disciplines, the chapters herein sample a breadth of activity that we hope will give anyone interested in space research, and particularly those starting out in the field, a better perspective of the subject as a whole. The topics included cover disciplines from the Earth's environment, through the interplanetary medium, to the dynamic and sometimes violent Sun, to the outer Universe looking at exotic regions such as black holes. To complement these areas there are chapters that cover the basic physics necessary for understanding these subjects, such as quantum physics, magnetohydrodynamics and relativity. There are also chapters that describe basic techniques necessary to progress in space science research. These include engineering skills, space instrumentation and data analysis techniques.

1.1 A Brief History of Discovery

The first artificial Earth satellite, *Sputnik 1*, was launched by the Soviet Union on October 4, 1957. While this was a momentous event in human history, the beginnings of space science preceded the launch of *Sputnik 1* by about a decade, and employed sub-orbital 'sounding rockets'. The earliest of these were captured German V2 rockets developed during World War II, and the sounding rocket programme achieved numerous successes, including mapping the upper atmosphere and discovering X-ray emission from the Sun.

The first major scientific breakthrough to be made using artificial satellites was the discovery of the Earth's radiation belts. This was achieved using *Explorer 1*, the first successful satellite launched by the United States on January 31, 1958. *Explorer 1* contained scientific detectors designed and built by James Van Allen that were intended to measure the flux of cosmic rays. In fact *Explorer 1* measured an anomalously low count rate, and Van Allen suggested that this was because the detectors were being saturated by a large flux of energetic particles. This was confirmed two months later using *Explorer 3* (number two failed to achieve orbit!), and established the existence of the 'Van Allen' belts, which we now know to be an important feature of the Earth's magnetosphere (Chapter 4).

Since those early days, the capabilities of spacecraft for scientific discovery have mushroomed. In general terms, scientific data from spacecraft can be obtained in two ways. We can fly a craft to the region of interest and take *in situ* measurements of its immediate surroundings, or we can equip the spacecraft with telescopes for

remote sensing that allow it to examine distant objects, making use of the unique vantage point that space provides.

1.1.1 *Exploration of the Solar System*

The discovery of the Earth's radiation belts is a classic example of an *in situ* measurement, where detectors on the *Explorer 1* satellite were measuring the immediate environment through which the spacecraft was flying. This is the main way in which we have gathered information on the Earth's magnetosphere, the cocoon carved out of the solar wind by the Earth's magnetic field. An up-to-date example is the European Space Agency's *Cluster* mission (launched in 2000), in which four identical spacecraft equipped with an array of sensitive instruments fly in formation through the magnetosphere. Having measurements from more than one adjacent spacecraft means that we can determine how plasma and magnetic fields are moving in space, as well as their properties at any given point.

As the techniques of space flight were mastered, the range of *in situ* measurements was rapidly extended, first to the Moon, and then to other bodies in the Solar System. In September 1959, the Soviet *Lunik 2* spacecraft measured solar wind particles for the first time, confirming the existence of the solar wind, which until that time had been inferred only indirectly. A further advance in our knowledge of the solar wind came from the flight of the US *Mariner 2* spacecraft to Venus. *Mariner 2*, launched in August 1962, measured the velocity of the solar wind and identified both slow and fast components. In common with many planetary probes, it contained both *in situ* and remote sensing devices. The latter were in the form of microwave and infrared radiometers, which allowed us to measure the temperature and composition of Venus and its atmosphere as the spacecraft flew by the planet.

A common remote sensing device is some sort of camera, an early example of which was an instrument on *Lunik 3* that photographed the far side of the Moon for the first time in 1959. Close-up photographs of the Moon were obtained with the *Ranger* spacecraft in the last minutes before they crashed onto the surface, and the whole Moon was surveyed from the *Lunar Orbiter* spacecraft in 1966 and 1967. Several *Surveyor* spacecraft landed on the Moon between 1966 and 1968 and obtained photographs from its surface, as well as probing the terrain with mechanical scoops (Figure 1.1). The exploration of the Moon in the 1960's culminated in the landing of astronauts, who conducted a range of investigations including the deployment of seismic detectors and laser ranging targets, and collecting rock and dust samples that were returned to the Earth for analysis. The results of this exploration, the *Apollo* programme, have, over the years, contributed greatly to our understanding of the Moon's origin, and of the formation of the Solar System.

Turning further afield, spacecraft have now been sent to every planet in the Solar System bar Pluto/Charon. The *Mariner 4* spacecraft discovered craters on Mars during a flyby in July 1965, while a large part of Mars was mapped using

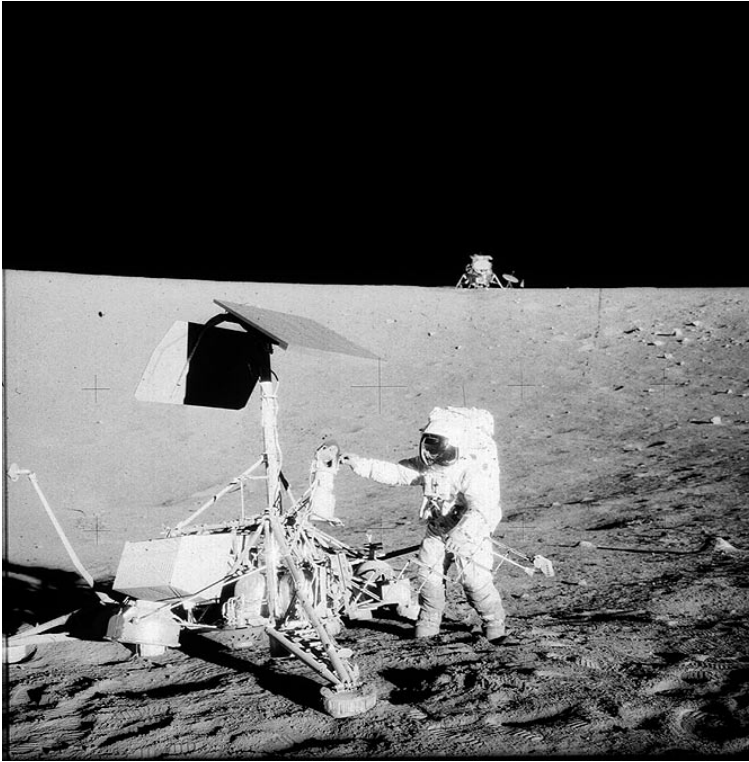


Figure 1.1 The *Surveyor 3* spacecraft landed on the Moon in April 1967. Astronauts Conrad and Bean later visited *Surveyor 3* in November 1969 during the *Apollo 12* mission. Here Conrad is pictured examining the camera on *Surveyor 3*. The *Apollo 12* lunar excursion module 'Intrepid' is visible in the background. (NASA)

Mariner 9, which was placed in orbit about the planet in 1971, and two *Viking* spacecraft, which arrived at Mars in 1976. The *Viking*'s also carried landers, which obtained the first pictures from the Martian surface. The *in situ* exploration of the planet was continued in 1997 from the *Mars Pathfinder* lander, which included a rover vehicle. Meanwhile surveys of the planet from orbit have continued using the *Mars Global Surveyor* (arr. 1997) and *Mars Odyssey* (arr. 2001) spacecraft.

Mariner 10 visited both Venus and Mercury, obtaining the first detailed view of the latter and revealing Moon-like craters in three encounters with the planet between 1974 and 1975. As noted above, the first spacecraft to visit Venus was *Mariner 2* in 1962. It was followed by many others (more than 20 in all so far), including *Pioneer Venus*, which made the first detailed map of its surface, and the Soviet *Venera 7*, the first spacecraft to land on another planet. Another Soviet lander, *Venera 9*, returned the first photographs of the surface of Venus, while the lander *Venera 13* survived for over two hours in the hostile Venusian environment,

returning colour pictures. In the early 1990's, the orbiting US spacecraft *Magellan* produced detailed maps of Venus' surface using radar.

Exploration of the outer Solar System began with NASA's *Pioneer 10* and *11* spacecraft, launched in 1972, followed by the pair of *Voyager* spacecraft, which took the first close-up photographs of the outer planets. *Galileo*, launched by NASA to Jupiter in 1989, included an atmospheric probe as well as an orbiter, while the NASA *Cassini* spacecraft, currently on its way to Saturn, also contains an atmospheric probe, known as *Huygens*, which was built by ESA. Spacecraft have explored minor Solar System bodies as well as the main planets. *Galileo* was the first mission to make a close flyby of an asteroid (Gaspera), and also the first mission to discover a satellite of an asteroid (Ida's satellite Dactyl; Figure 3.20). Another example is the ESA *Giotto* mission, which made a close approach to Comet Halley in 1986, and subsequently also encountered Comet Grigg-Skjellerup, in 1992.

There are future aspirations to return samples from a comet, which are expected to be representative of the primitive state of the Solar System, and to determine the composition of the Martian surface, first by *in situ* robotic methods (as planned for example with the UK *Beagle 2* lander which will shortly be launched on ESA's *Mars Express*) and later by returning samples to the Earth. A major goal is to identify how and where life originated in the Solar System by searching for evidence that primitive life once evolved on Mars. The ultimate aim is manned exploration of the planet.

1.1.2 *The Sun and beyond*

There are some regions of the Solar System where conditions are too hostile to send spacecraft, the Sun itself being a prime example. To study these regions, and anything beyond the Solar System, we must use telescopes of one form or another. The advantage of placing these telescopes in space is that we take advantage of the clarity afforded by the vacuum of space, and avoid the absorption effects of the Earth's atmosphere. The latter consideration means that we can access a much larger range of the electromagnetic spectrum.

Soon after the inception of NASA in the USA in 1958, programmes were started in three scientific areas that made use of specially designed spacecraft. These were the *Orbiting Geophysical Observatory (OGO)*, *Orbiting Solar Observatory (OSO)* and *Orbiting Astronomical Observatory (OAO)* series. The *OGO* spacecraft provided *in situ* measurements of the Earth's environment. The *OSO* series was dedicated to studying the Sun, and designed to provide a continuous watch of its activity, concentrating on high-energy radiation from the Sun's outer atmosphere. The *OAO* programme was primarily aimed at ultraviolet observations of stars, but the last in the series, *OAO-3* or *Copernicus* (see Figure 1.2), also included an array of X-ray-sensitive telescopes. *Copernicus* was launched in 1972, and was operated

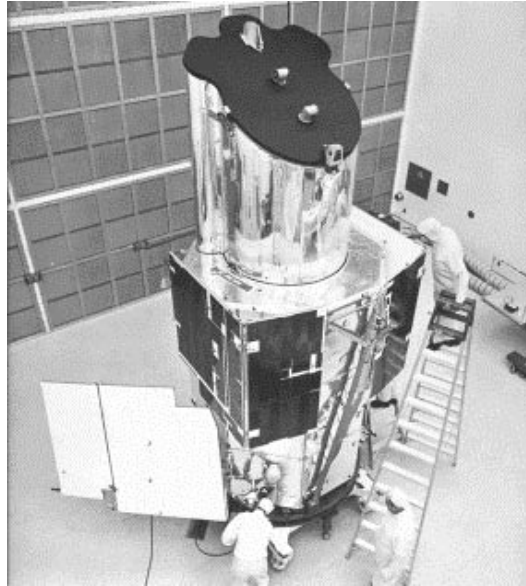


Figure 1.2 The *Copernicus* spacecraft (*OAO-3*), shown being prepared for launch. *Copernicus* carried an 80-cm UV telescope built by Princeton University, and a set of small X-ray telescopes built by MSSL/UCL. Launched in 1972, the last of the *OAO* series, it operated until it was switched off in 1981.

continuously until 1981, when it was switched off for financial reasons. The orbiting observatories were very sophisticated for their era, and provided a benchmark for work that was to follow.

An important milestone in studying the Sun from space was the programme conducted from the *Skylab* space station, launched in 1973. This was the first manned observatory in space, and the mission lasted for nine months. *Skylab* was placed in orbit 435 km above the Earth. It carried an array of instruments (the Apollo Telescope Mount — ATM), which included a white light coronagraph, a soft X-ray telescope, a soft X-ray spectroheliograph and an extreme ultraviolet spectroheliograph. The astronauts responded to events occurring on the Sun seen by means of $H\alpha$ telescopes. Their response to flares was fast — within a few minutes or so. *Skylab* results changed our vision of the Sun forever. The data showed that the corona was far from uniform — and summarised the coronal structure as consisting of coronal holes, coronal loops and X-ray bright points. This was the last mission to use photographic plates.

The next major solar observatory was the NASA *Solar Maximum Mission* (*SMM*), which was launched in 1980 and designed to study flares and solar activity. There were seven instruments on board, covering a wide wavelength range, from white light to gamma rays. The spacecraft was unmanned and hence the data were recorded electronically and telemetered to ground stations. There was

unfortunately an early failure in the attitude control system. Astronauts on the space shuttle repaired this in 1984, and observations continued successfully until 1989. Re-entry occurred in 1989 (at solar maximum) and was ironically triggered by a storm from the Sun!

There were two other major missions launched around the same time as *SMM*. The first was a Japanese mission named *Hinotori* (meaning ‘firebird’). *Hinotori* had a soft X-ray spectrometer and an imaging hard X-ray instrument on board with the purpose of studying solar flares. The second was a US satellite, *P78-1*, which was launched in 1979 and had soft X-ray spectrometers, and a white light coronagraph on board. These missions discovered and verified large shifts occurring in the early stages of a flare, which provided vital clues to understanding the flaring process.

In 1991, the highly successful Japanese spacecraft *Yohkoh* (meaning ‘sunbeam’) was launched. It had four instruments on board, including a soft X-ray imager and spectrometer, and a hard X-ray telescope. The data obtained with *Yohkoh* had the best resolution of X-ray images to date, and brought about huge leaps in understanding not only flares, as was its original goal, but also coronal mass ejections and coronal heating. The mission operated successfully for 10 years, finally ceasing in December 2001. *Yohkoh* provided the first-ever space dataset to cover a solar cycle, and will be studied for many years to come.

Another exciting mission launched in the 1990s was the joint ESA/NASA *Ulysses*. This mission has an extremely complex orbit that uses gravity assists from Jupiter in order to orbit over the solar poles. The first orbit over the poles took place in 1994/1995 during the solar minimum, and the second took place in 2000/2001 coinciding with the solar maximum. The results from this mission have allowed an accurate *in situ* measurement of the slow and fast solar wind.

The joint ESA/NASA *SoHO* spacecraft was launched in 1995 and contained 12 instruments. As discussed later, it is located at a Lagrangian point, and hence full 24-hour coverage of the Sun is achieved. The payload, consisting of a collection of imagers, spectrometers and particle instruments, continues to provide a wealth of information on the interior of the Sun, right out to 30 solar radii.

Looking beyond the Sun, early efforts naturally concentrated on those parts of the electromagnetic spectrum that were not visible from the Earth. The *Orbiting Astronomical Observatory* series, mentioned above, was the first venture into ultraviolet astronomy. Many important discoveries were made with the *OAO* spacecraft, including the first measurement of the cosmologically important abundance of deuterium, made using *Copernicus* (*OAO-3*). This was followed by the hugely successful NASA/ESA/UK *International Ultraviolet Explorer* (*IUE*) satellite, which operated between 1978 and 1996. *IUE* was the first general user space observatory, and was run much like a telescope on the Earth’s surface. Because *IUE* was in geosynchronous orbit above the Atlantic Ocean, it could be operated continuously, via a real-time link from ground stations in the eastern USA and Spain. During its lifetime, *IUE* conducted many thousands of scientific programmes, ranging from

observations of comets in the Solar System to quasars in the distant reaches of the Universe. *IUE*'s current successor is NASA's *Far-Ultraviolet Spectroscopic Explorer (FUSE)*, launched in 1999.

Orbiting observatories have also opened up many other wavebands. X-ray astronomy is a prime example (see Chapter 7), and very many satellites devoted to X-ray observations have been built over the past three decades by many different countries. Observations in the X-ray band have revealed hitherto unsuspected phenomena, including exotic objects such as massive black holes in the centres of galaxies, accretion onto neutron stars, hot gas in galaxy clusters, and activity in nearby stars. The German/USA/UK *Röntgen Satellite (ROSAT)*; 1990–1999) and the NASA *Extreme Ultraviolet Explorer (EUVE)*; 1992–2001) have probed the region between X-rays and the ultraviolet, known as the extreme ultraviolet band, while missions such as ESA's *COS-B* (1975–1982) and NASA's *Compton Gamma-Ray Observatory (CGRO)*; 1991–2000) have explored the gamma ray region of the spectrum, at wavelengths shorter than X-rays.

We have also probed the electromagnetic spectrum at wavelengths longward of the visible band. The *Infrared Astronomy Satellite (IRAS)*, a joint venture between the USA, the UK and the Netherlands, surveyed the sky during 1983 and made a major impact on astronomy. Long-wavelength infrared radiation is able to penetrate dusty regions much more effectively than short wavelength light, and one of *IRAS*'s many achievements was to identify large numbers of powerful starburst galaxies, which are a key element in understanding how all galaxies formed. Many of these discoveries were followed up with ESA's *Infrared Space Observatory (ISO)*, which operated between 1995 and 1998.

Another major advantage of flying a telescope in space is freedom from the distorting effects of the Earth's atmosphere. The *Hubble Space Telescope (HST)*, a NASA/ESA spacecraft that was launched in 1990, has amply demonstrated this. Because it is in space, *HST* can operate over a wide wavelength range, from the ultraviolet through the visible band to the infrared. Telescopes on the Earth's surface can also measure visible light of course, but *HST* is able to resolve much finer detail in astronomical objects because it does not have to peer through the turbulent atmosphere. It can also achieve much higher sensitivity because the sky background in space is much darker. *HST* has produced spectacular images of a huge range of astronomical targets — from planets in our own Solar System to galaxies at the edge of the known Universe.

The lack of atmospheric twinkling is also a major advantage when it comes to measuring the position of stars. This was used to good effect by the ESA mission *Hipparchos*, which measured the distance to large numbers of nearby stars. This was done by accurately measuring the slight shift in the position of the stars that occurs when they are viewed from opposite sides of the Earth's orbit about the Sun, known as the parallax. There are plans for a future mission, *GAIA*, which will be capable of measuring the slight shift of stars due to the rotation of our Milky Way

Galaxy. It will also measure their line of sight velocity and distance, building up a 3-D picture of how every star that is visible in the Galaxy is moving. This will be used to reconstruct the history of the Galaxy, and the way it has grown by mergers with other galaxies.

HST continues to operate today, and because it was designed to be serviced by space shuttle crews, its instrumentation has been regularly maintained and updated. The ‘Great Observatories’ *Chandra* (NASA) and *XMM-Newton* (ESA), both of which operate in the X-ray band, have now joined it in orbit. Soon, the NASA *Space Infrared Telescope Facility (SIRTF)* will be launched, to be followed by the Japanese/USA *Astro E* X-ray observatory. Plans are being laid for a follow-up to *HST*, the *James Webb Space Telescope* (named for the former NASA administrator), which will concentrate on the infrared regime, and for larger X-ray telescopes capable of probing the early Universe.

The NASA *Microwave Anisotropy Probe (MAP)* satellite was launched in 2001 and is currently surveying the microwave background radiation, which is left over from the Big Bang which created the Universe. The microwave background was previously studied from space using the *Cosmic Background Explorer (COBE)*; 1989–1993), but *MAP* has much better angular resolution and will search for fluctuations in the background that can be used to determine the fundamental parameters of the Universe. A further increase in sensitivity is planned with the ESA survey mission *Planck*. This is scheduled for launch in 2007, along with a large ESA space telescope for pointed observations in the microwave spectral region, *Herschel*. Further in the future, there are plans to build an array of telescopes that can search for Earth-like planets around other stars (for example the ESA mission *Darwin*), and to build a fleet of three spacecraft capable of detecting gravitational waves (*LISA*). To have the required sensitivity, the three *LISA* spacecraft will be separated by 5 million kilometres, but yet will need to determine their relative location to an accuracy comparable to the wavelength of light if they are to detect the tiny distortions in space caused by the orbits of binary stars scattered through our Galaxy and beyond.

1.2 Observing from Space

A great deal of experience has now been accumulated in the use of spacecraft for scientific investigations. Building a scientific spacecraft remains a challenging task, and many of the technical and design issues are discussed in Chapter 14. It is worth reflecting briefly here on how we go about using a space observatory, and how the technical issues affect what we can and cannot do.

A major consideration is the choice of orbit. This is important partly because of the concentrations of charged particles trapped in the radiation belts within the Earth’s magnetosphere (see Figure 4.5). These high-energy particles interact with many types of astronomical detectors and greatly increase the background signal,

rendering them insensitive. X-ray detectors are especially prone to these effects, for example, so it is wise to avoid these regions of charged particle concentration when making astronomical observations. To minimise the problem, one can choose to fly the observatory in a low Earth orbit (LEO), below the worst of the radiation belts, or in a high Earth orbit (HEO), above the radiation belts.

A disadvantage of a low Earth orbit, which will typically be at an altitude of 400–600 km, is that the Earth itself will block a substantial part of the sky. Moreover, the orbital period is only about 90–100 minutes, so the region of sky that is visible changes rapidly, making it difficult to observe a single target for an extended period. Another disadvantage for some applications is that the sunlit portion of the Earth is very bright. This can obviously lead to problems with stray light background for instruments that are sensitive to optical/infrared radiation, or problems with thermal control for instruments that need to be operated cold. A further disadvantage is that low Earth orbits decay relatively rapidly due to the drag caused by the tenuous outer atmosphere, limiting the lifetime of the satellite unless corrective action is taken. Nevertheless, many astronomical observatories have operated very successfully in a low Earth orbit, including *HST*. Satellites in a low Earth orbit can also in principle be serviced by the space shuttle, and repaired if they develop a fault. This was famously demonstrated in the recovery of the *Solar Maximum Mission (SMM)*, while *HST* was designed from the outset with shuttle servicing in mind.

The detrimental effects of the Earth on observing conditions are much reduced in a high Earth orbit, which is ideal for applications where long observations of a target are required under stable conditions. However, a penalty for choosing a high Earth orbit is that more energy is required to reach it. Put another way, for a given launch vehicle (which equates to cost) you can place a heavier and more capable observatory into a low Earth orbit than a high Earth orbit. Similarly, it takes more energy to achieve a circular orbit at a particular altitude, than an eccentric orbit with an apogee (furthest distance from the Earth) at the same altitude. Thus a compromise that is often adopted is to launch into an eccentric orbit with a high apogee. This takes advantage of Kepler's third law, which states that an orbiting body moves more slowly at the apogee, and therefore spends most of its time at the furthest points in its orbit. ESA's *EXOSAT* X-ray observatory (launched in 1983) was the first to use an eccentric high Earth orbit of this kind, and similar orbits are employed by the latest generation of X-ray observatories, *XMM-Newton* (Figure 1.3) and *Chandra*. These satellites spend most of their time outside the Earth's radiation belts, but one of the penalties paid for straying outside the Earth's protective shield is that they are vulnerable to the occasional burst of energetic particles originating from the Sun (Chapter 5).

Communications are also an issue. A satellite in a low Earth orbit is typically visible to a given ground station for only a few minutes for each orbit, which means that some degree of autonomous operation is essential. NASA's *Tracking and Data*

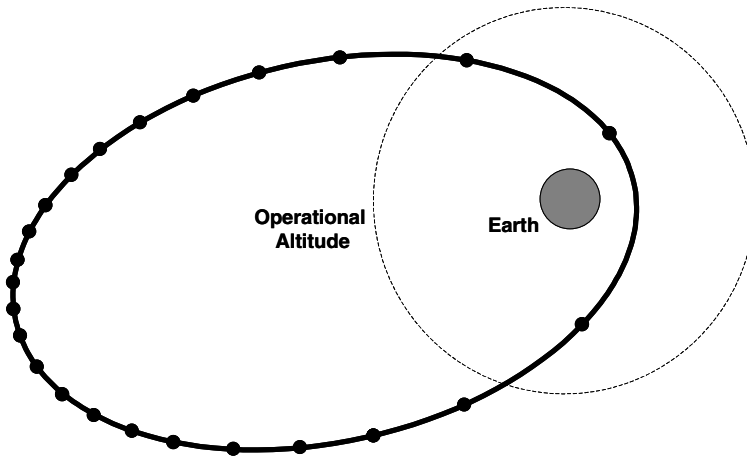


Figure 1.3 The orbit of *XMM-Newton* about the Earth, shown to scale. The solid circles mark the position of the spacecraft at two-hour intervals in its two-day orbit. The observatory collects scientific data only when it is above about 40,000 km altitude (shown as the dashed circle), but this amounts to about 90% of the time because of the fact that the spacecraft moves more slowly near the apogee than the perigee. The apogee is about 114,000 km above the Earth.

Relay Satellite System (TDRSS) provides an orbital relay through which continuous contact can be achieved, particularly for monitoring the state of the satellite, but this is expensive. The *IUE* satellite was placed into a geosynchronous orbit, which meant that it could be operated as a real-time observatory from a single ground station. (In fact the orbit was slightly eccentric, which meant that its apparent position in the sky oscillated every day to allow it to be operated from two ground stations, one in Europe and one in the USA). Geosynchronous orbits (altitude 40,000 km) are not completely free of the radiation belts, however, and the *IUE* detectors suffered from enhanced radiation background for part of each day. Instead of a fully geosynchronous orbit, X-ray observatories such as *EXOSAT*, *Chandra* and *XMM-Newton* were/are in eccentric orbits with periods that are an exact multiple of a day. These take them well above the radiation zones; in the case of *XMM-Newton*, which is in a two-day orbit, to an altitude of about 114,000 km at the apogee (Figure 1.3). Because the orbital period is a multiple of a day, continuous coverage can be achieved from a limited set of ground stations during the part of the orbit when the spacecraft are making observations, above the radiation belts. Set against the value of continuous coverage, the problem of transmitting the data collected to the ground becomes more acute the further the spacecraft is from the Earth.

Similar considerations apply in observing the Earth from space (Chapter 2). A low Earth orbit gives you the best spatial resolution, since the spacecraft is only a few hundred kilometres above the Earth's surface. However, the region being studied is moving quickly in the field of view, because of the satellite's orbital

motion, and any given point on the Earth's surface is visible for only a short time. A polar orbit is frequently used, so that every point on the Earth's surface is accessible. From a high Earth orbit, one can monitor a complete hemisphere of the Earth at one time but at the expense of spatial resolution. Geosynchronous orbits are useful if you want to keep a particular region of the Earth in continuous view.

Another alternative is to leave Earth orbit altogether. The ESA/NASA *Solar Heliospheric Observatory (SoHO)* flies at the Lagrangian point of the Earth's orbit about the Sun, in the same orbit as the Earth and kept in place by the shepherding effect of the Earth's gravity. From this vantage point, *SoHO* can monitor the Sun's activity continuously (Chapter 6). A similar location is being considered for many future observatories, particularly those that use cryogenic detectors (Chapter 13), where the cold and stable thermal environment is a major advantage. If high spatial resolution of a Solar System body is the ultimate target, however, there is no substitute for getting as close as possible. This is why we send space probes to other planets. For the Sun also, we would like to get much closer in order to resolve the detail that we need to understand how it works. For this reason ESA are currently planning their *Solar Orbiter* spacecraft, which is intended to fly to within 40 solar radii of the Sun (for comparison, the Earth's orbit is at a radius of about 200 solar radii). Withstanding the thermal and radiation stresses of flying that close to our parent star will be a major challenge, but will provide a powerful addition to our investigative arsenal.