Rutherford and Appleton Laboratories

SPACE RESEARCH

Science Research Council

Rutherford and Appleton Laboratories, Chilton, Didcot, Oxfordshire **OX11 0QX**

The Science Research Council, through its Astronomy, Space and Radio Board, supports United Kingdom Universities in Space Research projects through direct grants to University groups, through support provided by the Rutherford and Appleton Laboratories and through its subscription to the European Space Agency.

The Stars from Space

Astronomy is the most ancient of the sciences. Until comparatively recently, however, man's view of the night sky was restricted to the narrow band of visible light (the "rainbow" of colours, red through to violet) to which the human eye is sensitive. But celestial objects produce other radiations beyond the visible — infrared and ultraviolet radiation, gamma and X-rays, and radio waves. Historically, these various types of radiation were discovered before the realisation that they were of a similar nature, all travelling through space at the incredible speed of 300,000 kilometres each second.

In present-day astronomy, the detection and analysis of all types of radiation are important. Each tells something different about the nature of the cosmos. Thus, for example, certain radio emissions originate from objects undergoing violent change, X-rays and ultraviolet radiation from particularly hot regions, infrared radiation from comparatively cool regions. Of the various types of radiation, only visible light, some infrared radiation and radio waves from outer space can penetrate the Earth's atmosphere to be detected at ground level. Astronomical observations in other radiations have been made possible over the past few decades by lifting equipment into the clarity of space above the atmosphere's obscuring blanket using balloons, rockets or satellites. (See Figure 1.).

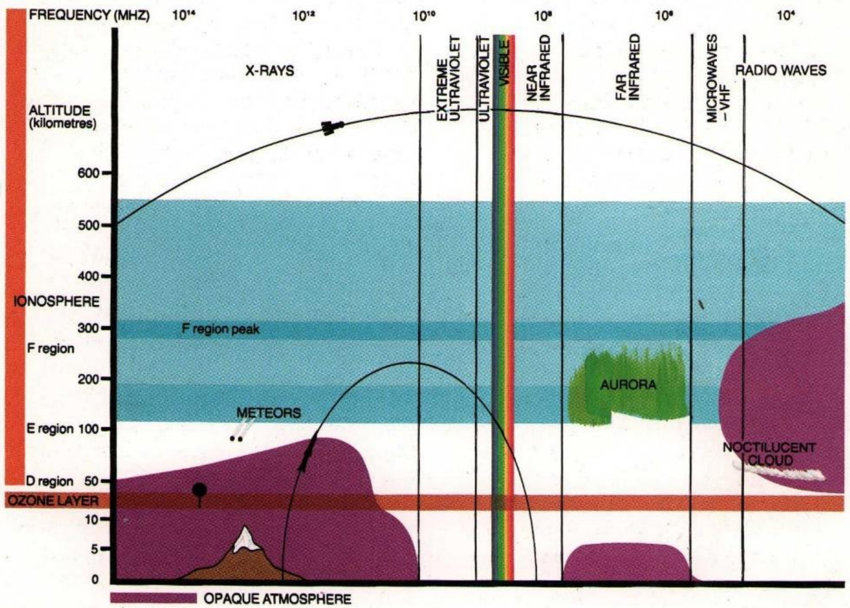


Figure 1 Visible light and infrared radiations can be observed from the Earth's surface. Other radiations are absorbed at various altitudes, shown in the figure, and can only be detected by instruments carried above the absorbing regions by satellites, balloons and rockets.

The scope of astronomical research from space extends from the Earth's nearest, and comparatively well understood, planetary and stellar neighbours to bizarre and enigmatic objects at the very limits of the Universe observable only with the most powerful instruments that technology has been able to devise to extend the limited scope of the human senses. It calls on the skills of a host of research disciplines: for example, those of the engineers who design and build the spacecraft and instruments, extending engineering techniques to new bounds of precision and reliability; those of the designers and operators of ground stations and highly sophisticated computers used to control the spacecraft and process the information they acquire; and those of the astronomers, physicists, chemists and mathematicians who interpret the astronomical data in terms of known natural processes.

The stars show new phenomena when studied from space, and the heavens are seen as a place of violent change and turmoil in startling contrast to the apparently quiet Universe man has observed since antiquity as he looked with unaided vision out into the night sky. The very rarified external atmospheres, or *coronae,* of stars have been found to glow in the ultraviolet and X-rays. Stars which have reached the end of their natural evolution sometimes blow themselves apart in events called *supernovae.* The energy released in these spectacular acts of stellar suicide is almost beyond comprehension — at least equivalent to the simultaneous explosion of 10,000 million, million, million, million 10 megatonne hydrogen bombs. The debris from the holocaust is blasted into space and may glow in X-rays and ultraviolet radiation for tens of thousands of years. The burnt-out core of the original star implodes to a state of high density — a so-called *neutron star,* which may be observed as a radio pulsar or an X-ray star. If a neutron star is in orbit about a normal companion star, material from the companion may swirl onto the neutron star, like water flowing down a plug hole. In the process it is heated to the extreme temperatures required to produce X-rays. The vast majority of bright X-ray stars in the sky are such objects.

The space between the stars is not merely a void, but is occupied by gas and dust. Within the interstellar matter astronomers find evidence for the birth of stars and planets. Cold dark cocoons of gas and dust shrink under the action of gravity, heating as they shrink to eventually 'switch-on' as newly radiating stars. These regions are opaque to optical light, but can be penetrated and seen in the infrared radiation detected by refrigerated telescopes on spacecraft. Between the cool regions lies tenuous hot material which is detected as a faint background glow of X-radiation.

Complex chemical compounds have been identified in the interstellar material. These include some of the same organic molecules that on Earth play a role in living organisms. Space observations in the ultraviolet and infrared, as well as ground-based observations of extemely short wavelength radio emissions, may eventually link the complex chemical reactions of interstellar space to the processes which led to the evolution of life on Earth.

Stars are found to be grouped together in massive conglomerates called *galaxies*. The Earth's parent star, our *Sun*, lies in the Milky Way galaxy containing some 100,000 million stars. The nearest star beyond the Sun is at a distance of 40 million, million kilometres. The remote stars in our galaxy are 20 thousand times more distant. The observable Universe contains in the order of 10,000 million galaxies. Galaxies are detected from space in a variety of radiations. Many are found to be sites of violent upheaval.

It is important to stress that in looking out into the cosmos one is looking not only deep into space but also back in time. Thus the history of the Universe is laid out, like a cosmic kaleidoscope, for astronomers to view. Spacecraft give us a "magic carpet" from which we can study in radiations not detectable from the Earth's surface stars and galaxies at various stages of their evolution — nascent stars procreated from giant clouds of interstellar gas and dust, young stars and old stars, dying stars and dead stars — young galaxies, interacting galaxies, galaxies in formation and galaxies being torn apart. The Universe reveals itself as a site of unfolding drama, as stars and star-systems are born and die, often violently.

UK involvement in space astronomy began in earnest in the early nineteen-sixties, with ultraviolet and X-ray experiments launched in Skylark rockets, more than 250 of which were launched before the programme was terminated in 1978. The first UK scientific satellite missions concentrated on studies of the near-Earth space environment (more later), and it was not until 1974 that a UK national satellite (Ariel V) was launched dedicated to space astronomy. Described below are the scientific objectives of some recent and current space astronomy programmes in which the Appleton Laboratory has played a principal role.

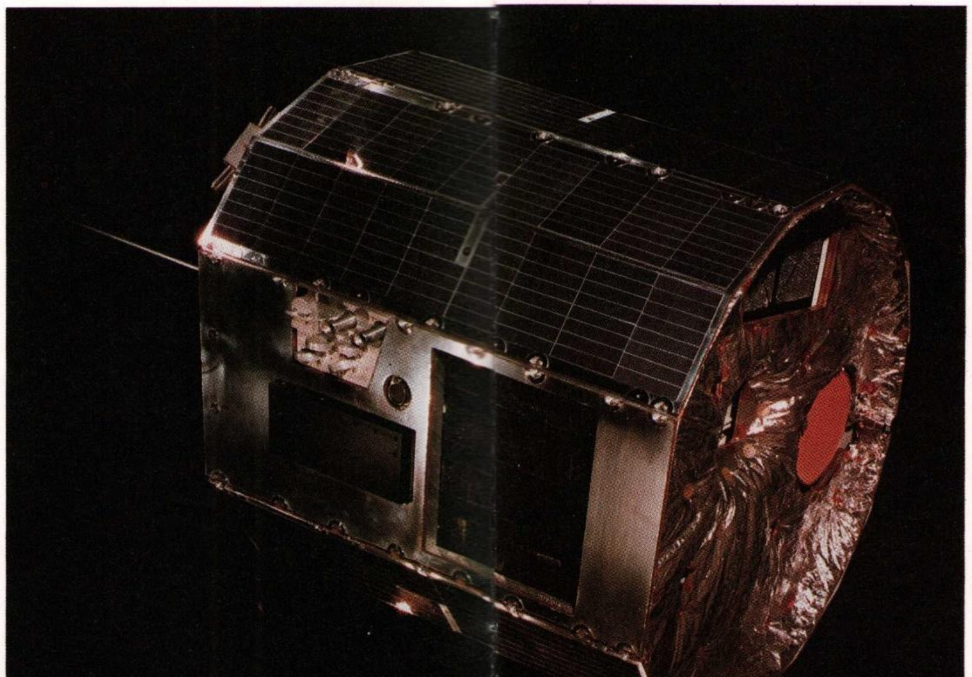


Figure 2 Ariel V satellite. The list of university groups involved is shown in table one.

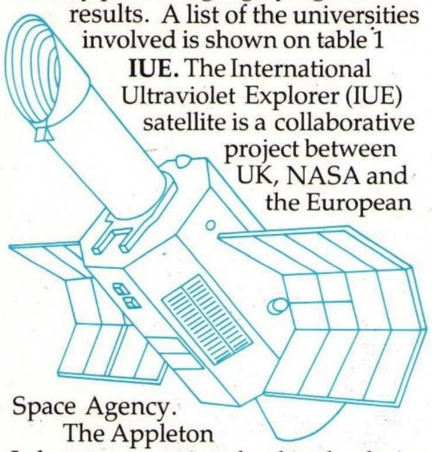
Ariel V. The launch in October 1974 of a satellite dedicated to X-ray astronomy helped establish the UK university groups who had supplied experiments for the mission at the forefront of the field. The Appleton Laboratory provided overall management and ground support for the project during the 5 year mission. (The spacecraft was actually designed for a lifetime of two years!). The technical expertise and knowhow in the Ariel V Control Centre at Appleton Laboratory will be invaluable for subsequent space projects, and could be an important factor in UK involvement in future international space programmes.

The scientific returns from Ariel V far exceeded even the most optimistic predictions. While planned objectives were fulfilled, the mission was highlighted by the number of unexpected discoveries. A USA satellite called UHURU had prepared the first catalogue of X-ray sources. But Ariel V made a host of new detections, particularly of objects outside our own galaxy — the Ariel V (2A) catalogue of X-ray sources remains the most sensitive, uniform and reliable list available for the region of sky away from the central plane of the Milky Way. Accurate positions enabled identifications of many of the Ariel V sources with active galaxies studied with optical telescopes — enigmatic objects, called Seyfert galaxies, BL Lac objects, and quasars. The X-rays were found to be concentrated to the centres of these systems, requiring central sources of energy hitherto uncontemplated.

The variability of X-ray sources and their distribution of X-ray energies was investigated in detail for the first time with Ariel V, and a distinct new class of transient X-ray source, which flared brilliantly, was discovered. A particular new X-ray source identified by Ariel V (SS433) has proved to be one of the most unusual astronomical objects ever studied — a star system spraying out material at a quarter the speed of light in two finely collimated "jets", like a rotating garden sprinkler.

Ariel V was returning scientific data almost up until final re-entry to the Earth's atmosphere in March 1980. It had served UK X-ray astronomy well.

Ariel VI. The second UK space astronomy satellite was successfully launched in June 1979, with the mission management and data acquisition again under the control of the Appleton Laboratory. Its scientific objectives were two-fold — to follow-up Ariel V's survey of the X-ray sky with more detailed investigations and to study cosmic rays. Cosmic rays are energetic atomic particles continually bombarding the Earth from outer space. Some originate from the Sun, and some from the Galaxy and beyond. The origin of Galactic cosmic rays remains uncertain, although one possibility is that they include part of the debris from supernova explosions accelerated to extreme speeds. Cosmic rays remain the only sample of matter we have from beyond the solar system and are therefore of importance in helping to understand the origin of the elements and the chemical evolution of our Galaxy. This aspect of the Ariel VI mission is already producing highly significant results. A list of the universities involved is shown on table 1

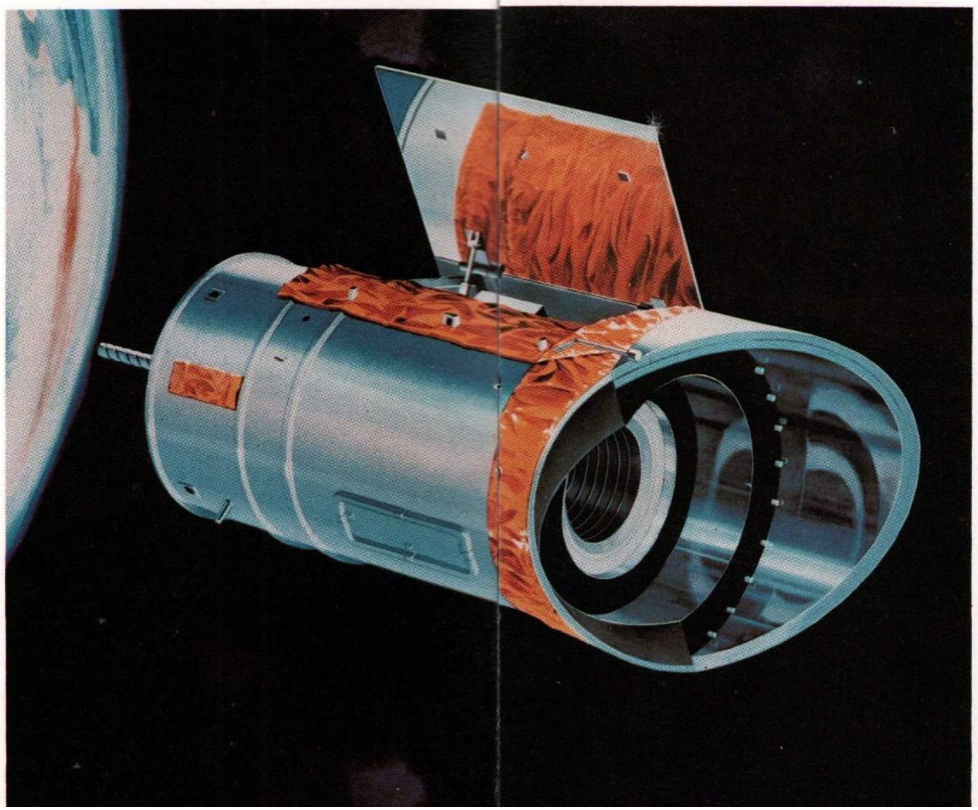


IUE. The International Ultraviolet Explorer (IUE) satellite is a collaborative project between UK, NASA and the European Space Agency.

The Appleton Laboratory was involved in the design and development of certain parts of the instrumentation, and continues to provide data reduction facilities and management of UK participation. IUE, launched in February 1978, is operated like a ground-based observatory. The satellite is located high above the South Atlantic Ocean in a geosynchronous orbit, and is under the control of the European ground station near Madrid in Spain for one 8 hour shift each day. Half of these shifts are assigned to UK astronomers, who visit the ground station to supervise their observations and process data transmitted to the ground at the end of an exposure.

IUE breaks down the ultraviolet light from a star or some other astronomical object into its component "colours". The fact that a beam of white light passing through a prism produces the colours of the rainbow has been demonstrated since ancient times. The prism bends the different components of white light (red being bent least, violet most) into a merging row of colours called a *spectrum*. Since white light produces a continuous range of colours, it is said to have a *continuous spectrum*. By contrast, the spectrum of some particular light source may show just selected features of different colours against a dark background. Such a spectrum is called a *line spectrum*, each spectral line being an image of the slit-shaped instrument aperture in a single colour. The spectrum of a light source provides important information on its nature and composition — as a consequence spectroscopy has proved to be an extremely powerful observational technique in astronomy.

IUE produces spectra of stars and stellar systems. The astrophysical gains have been impressive. Ultraviolet spectra of stars have enabled the composition, temperature and density of their outer atmospheres to be studied. Observations of the debris from ancient supernovae have suggested how the medium surrounding the site of a supernova explosion is heated, and contributed to studies of the composition of this interstellar medium. The steady flow of hot gas from certain hot stars is revealed, as are halos of hot gas surrounding active galaxies. Indeed, our own Galaxy is found to be imbedded in a halo of hot gas.



IRAS. Astronomical sources of infrared radiation are generally cool objects with temperatures less than just a few hundred degrees, and range from planets and cool stars to galaxies. But valuable information can also be obtained in the infrared of much hotter sources where the radiated energy is degraded by obscuring dust clouds. And, as noted earlier, infrared and radio line spectra reveal the composition of molecular clouds in the interstellar medium.

The Infra-Red Astronomical Satellite (IRAS) is a collaborative project involving the United States, the Netherlands, and the UK. The prime objective of the project is to carry out the first complete survey of the infrared sky; in addition some time will be made available for selected scientists to carry out detailed investigations of particular infrared objects of special scientific interest.

Infrared radiation is "heat" radiation, and while the heat radiated by a celestial object is enormous, the amount reaching the Earth over the vast distances of space is extremely small. At room temperature an infrared telescope itself produces approximately 10 million times more heat radiation than could be detected from the brightest infrared source in space. This problem is overcome by cooling the instrument to an extremely low temperature. When so cooled, IRAS is sensitive enough to pick up the heat radiation from the rear light of a bicycle at a distance of 3000 kilometres.

Figure 3 The Iras satellite

The IRAS operations control centre is sited at the Rutherford-Appleton Laboratories, and a large 12 metre diameter antenna has been erected for satellite communications. Much of the expertise gained during the Ariel V and VI operations has been brought to bear on the IRAS project. The scientific advances are expected to be great — astronomers will get their first complete view of the infrared sky. If pioneering space surveys in other radiations are anything to go by, there will be many surprises.

Balloon Projects. While experiments on satellites provide observational data for periods of up to several years, the complexity of design and construction with the need for extreme reliability means that any satellite project is very expensive and takes up to a decade from inception to launch. In the past there has been no facility for recovering spacecraft. By contrast, the development time for balloon-borne instrumentation is relatively short and experiments can be recovered for reflight. One needs to relate these advantages to the disadvantages of a balloon flight lasting at most a few tens of hours and the fact that certain radiations still do not penetrate to balloon altitudes (of order 40 kilometres).

The Rutherford and Appleton Laboratories manage the UK national balloon programme and provides supporting facilities. A stabilized balloon-borne pointing platform has been developed to accept a wide variety of experiments to study astrophysical phenomena. More than 100 successful flights have been completed, providing valuable contributions to the study of cosmic rays, gamma rays, X-rays, and infrared radiation from space. See table 1 for the list of university experiments in recent years.

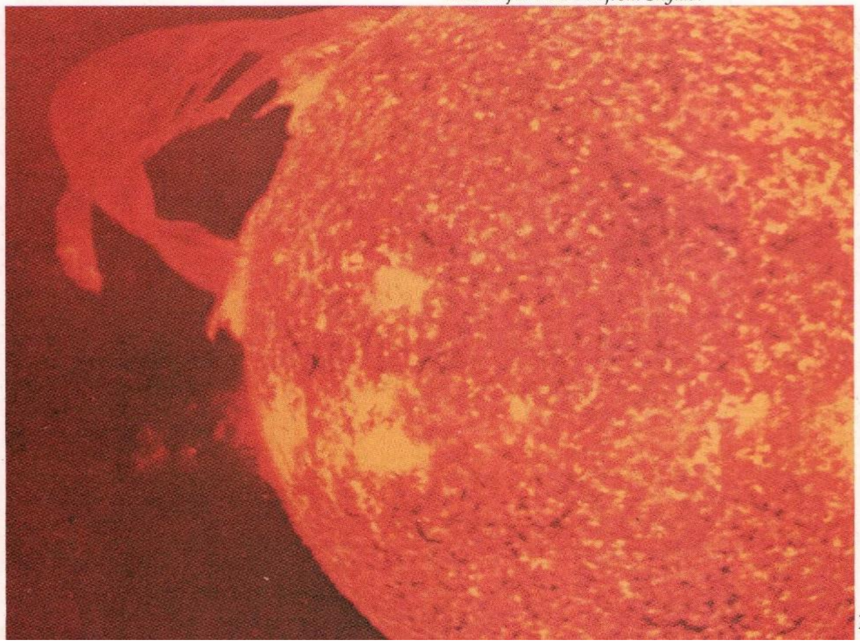
Figure 4 The launch of a balloon payload.

The Sun from Space

The Sun is the Earth's ultimate power-house. Nearly all energy available to us, in coal, oil, gas, wood, etc. is "stored" solar energy. In addition solar radiation is the dominant input to the Earth's climate system. Scientists study the Sun, therefore, because it is the principal source of present and potential energy, and to learn more about the Earth's weather and climate. The Sun is also the astronomer's bridge to the study of other stars. It is the only star close enough to study in fine detail, and solar astronomy is the basis for our understanding of what happens on other stars. Finally, the Sun represents a "laboratory" where properties of matter can be investigated at temperatures, pressures and magnetic field intensities not reproducible in laboratories on Earth.

The Sun has no permanent features, and is entirely gaseous — a glowing ball, chiefly of hydrogen and helium with a "pinch" of heavy elements (mainly oxygen, carbon, nitrogen, magnesium and iron). Exceedingly high temperatures and densities of the solar interior trigger nuclear *fusion* reactions that produce the energy that fuels the solar furnace. The nuclear process involved is believed to be one by which hydrogen is converted to helium, with the release of energy. Although we speak of the "surface" of the Sun, it is really all atmosphere. The surface visible in optical light, the *photosphere*, is at a temperature of about 6000 degrees centigrade. The tenuous outer reaches of the Sun, by contrast, are at a million degrees — this is the

A solar flare viewed from Skylab.



corona. The region of rapidly increasing temperature and decreasing density between these extremes is called the *chromosphere*.

The total radiative output from the Sun is constant, at least on short time scales. There are, however, features which vary. The longest observed and best documented variable is the appearance of *sunspots*, dark areas on the photosphere. The frequency of occurrence of sunspots waxes and wanes over an interval of approximately 11 years, the so-called *sunspot cycle*. Localised areas of surface activity occur, most frequently at times of maxima in the sunspot cycle, and occasionally great eruptions called *flares* hurl vast clouds of matter into space. There is evidence that solar activity is linked to global climate, although the mode of this interaction remains uncertain. Certainly solar flares effect the upper atmosphere, and will disrupt radio communications.

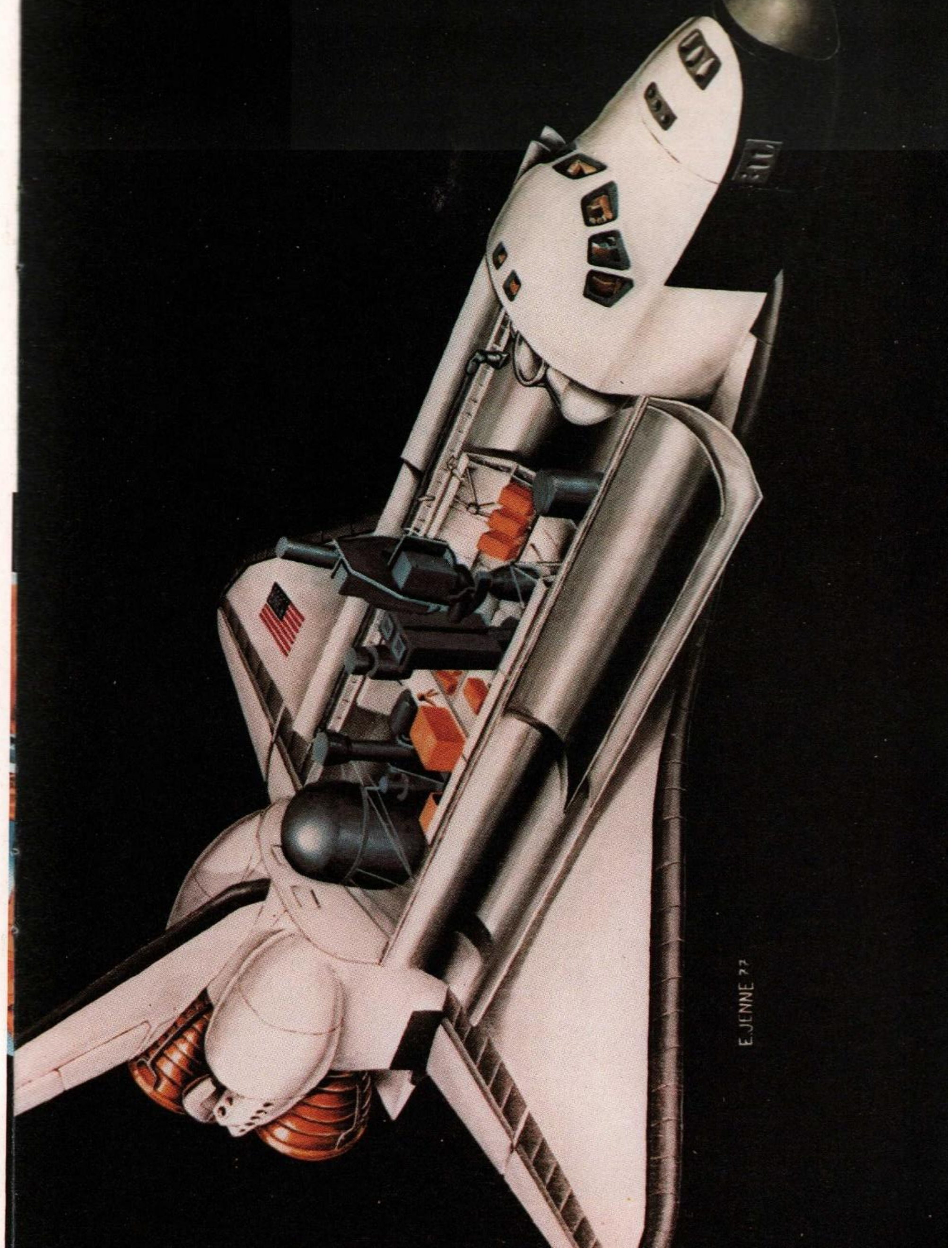
The Appleton Laboratory has a long history of involvement with U.K. university and overseas collaborators, in solar astronomy from space and supporting laboratory investigations. The Sun's X-ray and ultraviolet radiations, originating in the chromosphere and corona, have been studied in considerable detail, and the nature of active regions and flares investigated. The Laboratory, in collaboration with University College, London, has a major experiment on the Solar Maximum Mission spacecraft, launched in February 1980 to coincide with the maximum of the solar cycle. The experiment records the X-ray spectrum of active regions and flares, to determine the composition, temperature, density and velocity of the radiating material and learn how these vary in time and over the solar surface.

Two solar experiments are now being prepared in the Laboratory, again in association with University groups, for inclusion on early Shuttle-launched Spacelab Missions — see Figure 6. The first experiment (called CHASE) is to measure the relative abundance of helium to hydrogen in the Sun, still only poorly determined. This result is an important clue to the exact nature of the Sun's energy-generating nuclear reactions and the formation of helium, the bulk of which is believed to have been produced in the 'Big Bang' creation of the Universe.

The second Spacelab experiment (called SAROS) will be to study the formation of active regions of the Sun.

The amount of new scientific data about our Sun obtained from space is impressive by any scale. Urgent and important questions have been answered about how stars evolve, how matter behaves under extreme conditions, and how our Sun influences the terrestrial environment.

Figure 6 An artist's impression of the shuttle in orbit.



The Earth from Space

A new era in space research was heralded with the launch of Sputnik I on 4 October 1957. The political and social consequences of this historic first satellite launch were profound — the impact on our understanding of the Earth's environment in space was truly revolutionary. Subsequent satellite missions by the USSR and US soon revealed that the near-Earth space environment is dominated by the continuous supersonic flow of hot gas from the Sun, the so-called *solar wind*. The Earth is shielded from the direct impact of this by its magnetic field, which carves a gigantic cavity in the wind. The region contained within the magnetic barrier is called the *magnetosphere* — see Figure 7. The magnetosphere is flattened on the side facing the Sun by the pressure of the solar wind, and is drawn out into a long tail on the night-side of the Earth as the wind streams past.

Energetic particles may be trapped within the Earth's magnetic field and zones of trapped particles, the *van Allen belts*, were discovered from an early US satellite. But there are two openings through which energetic particles can penetrate the Earth's atmosphere — these are "funnels" formed where the Earth's magnetic field terminates near the north and south poles. Energetic particles from the solar wind flood through these funnels to cause the spectacular atmospheric pyrotechnics we call the *aurorae*, or "northern (/southern) lights". How some of the solar wind penetrates the magnetosphere, and how particles are then accelerated down the funnels to produce the aurorae, are important unanswered question of space research.

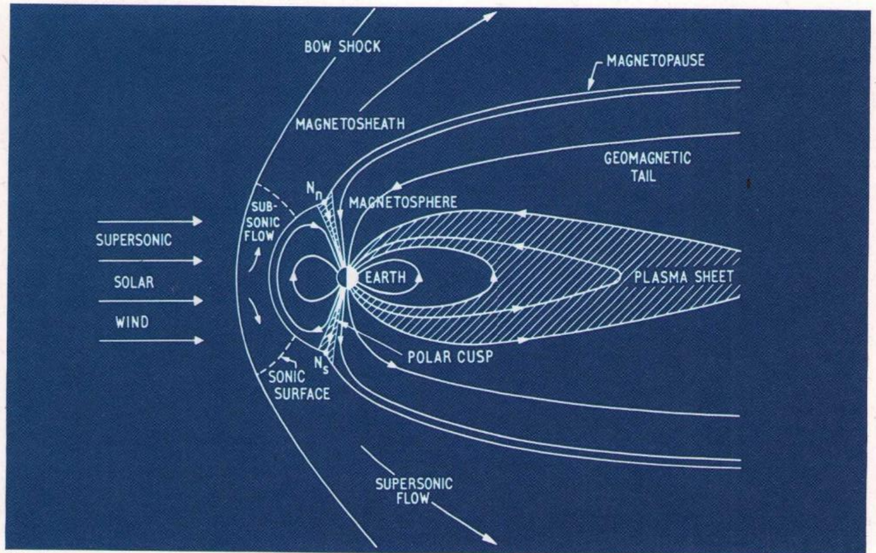


Fig 7

Whilst the magnetosphere shields the Earth from the solar wind, radiations from the Sun are able to reach the top of the atmosphere. Here most are filtered out (see Figure 1). Ultraviolet and X-ray radiations "ionise" the upper atmosphere (that is, cause individual atoms in the atmosphere to lose electrons). This ionised region, called the *ionosphere*, extends from a few tens of kilometres above the Earth's surface out beyond 1000 km. The ionosphere reflects certain radio waves, and has consequently played an important role historically in radio communications. Indeed, radio signals from the ground have been used to probe the lower ionosphere, although to fully study the higher reaches spacecraft-borne instruments are required.

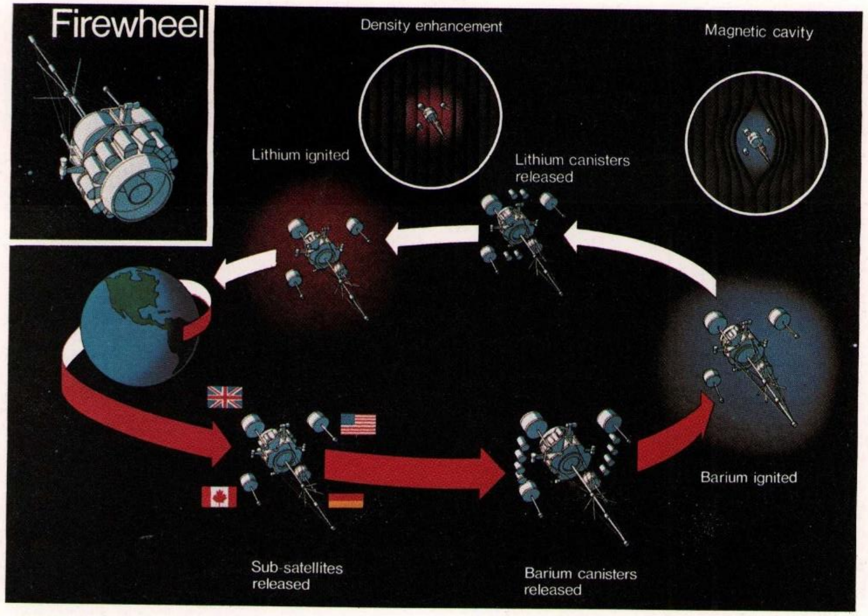
That portion of the upper atmosphere which is not ionised, the *neutral atmosphere*, is also studied from spacecraft. Monitoring of the temperature, composition and structure of the atmosphere is important to the world's weather services, as well as enabling chemical and physical processes in the atmosphere to be determined. Observations from space greatly extend the global coverage of such studies compared with ground-based or rocket/balloon experiments, although non-space techniques still have an important role to play.

Ariel I, the first UK satellite, was launched in 1962 with a range of experiments directed to the study of X-ray and ultraviolet emissions from the Sun and their effect on the ionosphere. The next three UK national satellites were also directed principally to the study of the near-Earth space environment. These emissions were complemented with a series of rocket campaigns, continuing ground-based programmes, and experimental opportunities on European and US spacecraft studying the neutral atmosphere, ionosphere, magnetosphere, and solar wind. The Appleton Laboratory has had an involvement in many of these, performing a project management role, providing spacecraft instrumentation, and carrying out long-term ground-based observations related to UK space programmes. A major ground-based facility, a very sensitive radar for probing the upper atmosphere, is being constructed in collaboration with five other European countries.

Described below are the scientific objectives of some recent and current projects to study the near-Earth space environment in which the Appleton Laboratory has played a principal role.

Firewheel

The international magnetospheric mission "firewheel" is scheduled to be the first scientific satellite launched by Ariane, the independent European launch vehicle. Firewheel is a complex system, consisting of a main vehicle and four autonomous sub-satellites to be released in orbit. One of these sub-satellites has been built in the UK with Appleton Laboratory and University College London involvement. It includes equipment to study particles with various energies, and to measure the strength of the magnetic field. A spectacular feature of Firewheel will be the release of clouds of ionised barium and lithium the growth and decay of which, to be studied by the five spacecraft and from the ground, will provide important information on the magnetic field in the tail of the



magnetosphere and particle acceleration processes. The barium cloud is expected to be visible to the naked eye and to appear somewhat like a comet.

High Altitude Rockets

A variety of experiments from the Appleton Laboratory and various UK university groups have been flown on high-altitude Skylark rockets launched from Northern Norway (Andoya) and Sweden (Kiruna). Smaller Petrel rockets, which attain only about one fifth the altitude of Skylarks but which are still of use in surveying the lower regions of the ionosphere and the atmosphere, are launched from South Uist in the outer Hebrides.

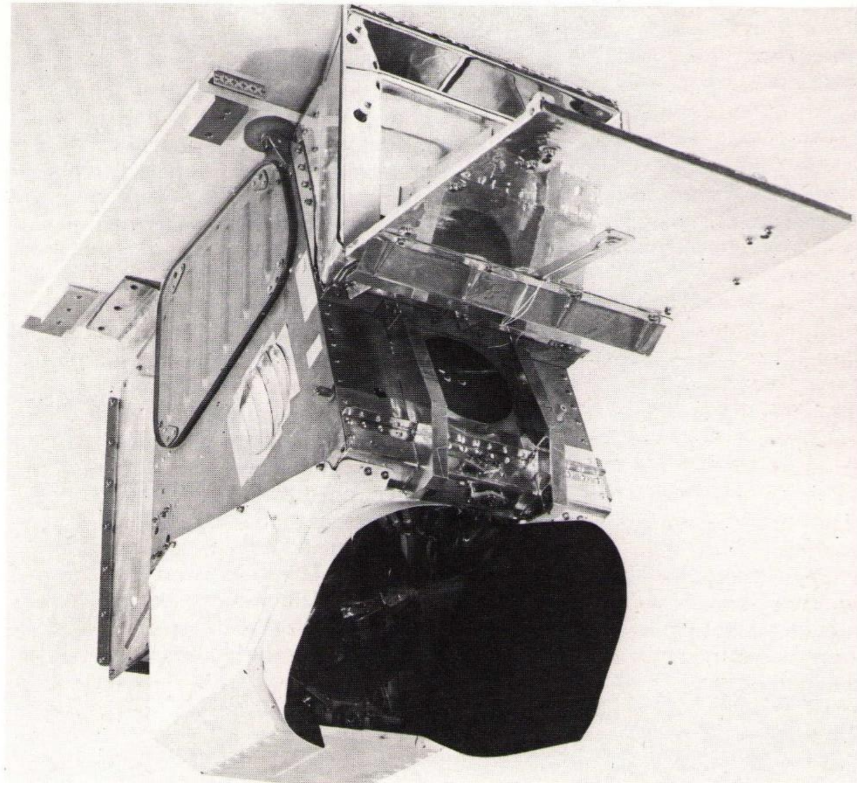
The Rutherford and Appleton Laboratories manage the UK rocket programme on behalf of university groups experiments and have explored the development of aurorae and related phenomena, and the origin and acceleration of the particles which produce the aurorae. Several of these experiments have been correlated with observations from ESA satellites called GEOS 1 and GEOS 2, both of which include experiments from UK groups and both of which study magnetospheric phenomena related to the production of aurorae.

Remote sounding of the atmosphere and earth's surface

The development of orbiting spacecraft has had a very large impact on man's ability to study and to monitor the atmosphere and surface of the Earth. For the first time it has been possible to take a truly global view in attempts to understand problems of atmospheric physics, atmospheric chemistry, meteorology, oceanography, geology, economic geography and climate. Proven space instruments have now been used to measure radiation emitted from the Earth/atmosphere itself (infrared, microwave) as well as reflected radiation from the sun (ultra-violet, visible, and infrared). Orbiting spacecraft in low near-circular orbits (about 1000 km altitude) permit detailed study of processes all over the globe, while geostationary satellites (about 36,000 km) provide hemispheric visible and infrared pictures with frequent time resolution permitting, for example, transient weather features such as storms to be studied. Moreover, pictures of the Earth and its atmosphere taken from space in visible and infrared light have given mankind a new philosophical view of his mother planet, which emphasises the unity of all who live on her surface, and the fragility of this beautiful planet in the large volume of space.

UK scientists have realised the potential of remote sounding from space for scientific research. University scientists, working in collaboration with the Rutherford Laboratory, have developed a number of infrared atmospheric sounding radiometers for the NASA Nimbus series of satellites. An instrument called a Selective Chopper Radiometer was flown on Nimbus 4 in 1970, and again on Nimbus 5 in 1972. The basic principle of these devices, again pioneered in UK universities, is to isolate radiation emitted by a particular gas in the atmosphere (e.g. CO_2) by passing the incoming

Nimbus 7. Stratospheric and Mesospheric Sounder.



radiation through a small cell containing a sample of the same gas, within the instrument. This principle was further developed into the Pressure Modulator Radiometer for the Nimbus 6 and 7 satellites flown in 1975 and 1978 respectively. The latter experiment included channels to sound atmospheric composition as well as temperature, and viewed the horizon rather than the nadir. This series of experiments has yielded important information on atmospheric temperature structure, and more recently on composition: notable observations have included the detection of dynamical wave effects in the stratosphere and ionosphere; the breakdown of winter circulation during several of the fascinating "stratospheric warming" events; and global measurements of the important ozone layer in the stratosphere, and related constituents.

UK universities have also taken advantage of measurements made by operational meteorological satellites such as the European Space Agency METEOSAT which provides visible and infrared images from geostationary orbit, and the US TIROS-N weather satellites.

Rutherford and Appleton Laboratories have also been involved with the European Space Agency in studies of, and proposals for, remote sounding experiments. The Appleton Laboratory co-ordinated a study for ESA on the use of passive remote sounding of the atmosphere from Spacelab. Rutherford Laboratory staff have participated with universities and other laboratories in a design study of a liquid helium cooled infrared radiometer for atmospheric measurements also from Spacelab.

Current and future work at the Rutherford and Appleton Laboratories will in general be in collaboration with universities and other laboratories and includes participation in the NASA Upper Atmosphere Research Satellite programme (for atmospheric studies); participation in a proposed European climate, oceanography, ice studies and ocean applications satellite programme; and possible collaboration with other US and other national satellite programmes. In the Rutherford and Appleton Laboratories programme of remote sounding from space emphasis will be given to the study of the Earth's climate from space, a topic of great scientific interest and complexity, as well as one of economic importance.

British space research continues apace, despite economic stringencies. Spacecraft flying UK experiments now probe the depth of space in radiations that could never be observed from the Earth's surface, giving a new view of an ever changing Universe. The Earth's surface and atmosphere are probed from above, leading to more effective utilisation of the Earth's limited resources and a better understanding of its complex climatic system. Practical applications and social benefits of scientific achievements in space are numerous and varied, and are complemented by the continuing technical advances that sophisticated space instrumentation of exceptional precision and reliability demand of industry. The Rutherford and Appleton Laboratories look forward to playing an ever increasing role as Britain meets the challenges of the Space Age.

Scientific Satellites

Science	Experimenters	Launch Date
Radio Noise	Ariel I — Imperial College Birmingham University University College London	Dec 1962
Radio Noise	Ariel II — Cambridge and Manchester University	27 April 1964
Radio Noise	Ariel III — Birmingham, Manchester (Jodrell Bank), Sheffield and the Appleton Laboratory.	5 May 1967
Ionosphere Noise V4 Impulse Counts	Ariel IV — Birmingham, Manchester and Sheffield together with Appleton Laboratory	11 Dec 1971
	Ariel V — University College London (MSSL), Leicester University and Imperial College London	
	Ariel VI — Bristol University, Leicester and University College London (MSSL).	
Electron/Proton-Energy	ESRO 1A — University College London (MSSL)	30 Oct 1968
Electron/Proton-Energy	ESRO 1B — Appleton Laboratory	1 Oct 1969
IUE Cameras	IUE — University College London	Jan 1978
Particle plasma and fields (with MSL)	Firewheel — University College London (MSSL), Appleton Lab.	
X-ray Polychromator	Solar Max Mission — UCL	Feb 1980

1979/80 Rocket Programmes

Science	Experimenters	Launch Date
Pulsating aurorae	Appleton Laboratory	January 1979
VLF	Sheffield University	March 1979
Temperature	University College of Wales (UCW)	April 1979
'D' region studies	UCW/AL/MPI Heidelberg	July 1979
Double shaped charges	Sussex University	October 1979
VLF	Sheffield University	July 1980
Atomic oxygen	AL	Oct/Nov/Dec 1980

1980/81 Balloon Payloads

Science	Experimenters	Launch Date
Far IR astronomy using 41" ICST telescope	Imperial College	Spring/Summer 81
IR astronomy using 60cm Mk 2 IR telescope	University College London	November 80
Far IR Spectroscopy in galactic plane	Leeds University	June 80
Investigation of Gamma ray lines from galactic and extra-galactic sources	Durham University	April 81
Measurement of middle atmosphere winds by remote sensing	UCL	April 1980
High Energy X-rays	Soton/Milan/Ramsden	August 80
Isotope distribution of cosmic rays Fe Group	Bristol	September 80
Construction & flight of a large area detector for cosmic rays	Bristol	Spring 81
Far IR Spectroscopy	ICL/Queen Mary College Preston Poly.	Autumn 81
UV studies of interstellar medium	UCL	Spring 80
Hard X-ray detectors 20 to 200 KeV	ICST/Tasmania Univ.	November 80
Cosmic background measurement using sub-millimetre spectro- metric radiometry	QMC	Autumn 80