ASTRONOMY, SPACE & RADIO BOARD

at Rutherford Appleton Laboratory

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Astrophysics

Solar Interplanetary Physics

Observation of the Sun gives a uniquely detailed look at a star and knowledge of the phenomena occurring there provides an understanding of other stars. RAL is involved in various aspects of solar physics to this end, particularly the study of ultra-violet and X-ray emission which can only be detected from spacecraft. RAL has had major involvements in the successful Solar Maximum Mission, repaired by Space Shuttle astronauts in 1984 and, more recently, in the CHASE instrument on Spacelab 2. The Sun has a dominating influence in interplanetary space; one example is the way in which solar radiation and the solar wind detach material from comet nuclei to form the coma and tail. RAL has been supporting a university team in preparing a dust-impact instrument on the European GIOTTO spacecraft, due to encounter Halley's Comet early in 1986.

SMM: Solar Maximum Mission

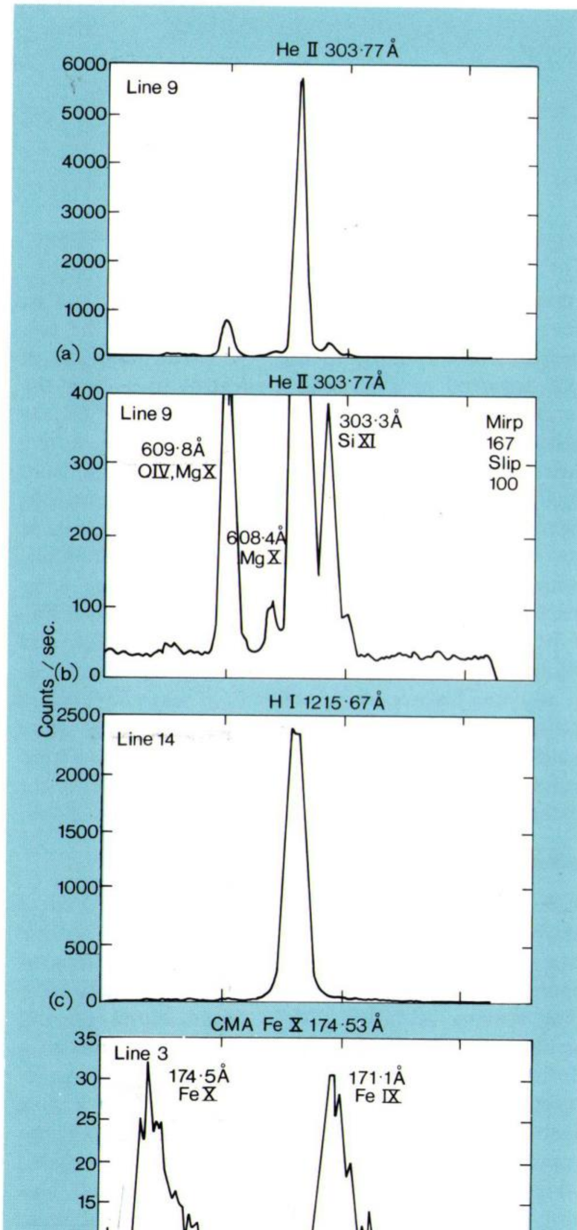
SMM is a NASA spacecraft observatory dedicated to studying solar activity, flares in particular, using radiation ranging from γ-rays to visible light. It was launched in 1980, worked for 9 months until a pointing control failure and was repaired in 1984 by Space Shuttle astronauts. Six of the original seven instruments are still in working order, including the X-ray Polychrometer (XRP) in which RAL has ⅓ share in the original design, building and operations. RAL staff continue to support operations at NASA's Goddard Space Flight Center, despite the decline in solar activity since the last sunspot maximum in October 1980. This vigilance was amply rewarded in the past year by observation of a surprising frequency of large flares and a greatly increased recording of spectroscopic data by the Flat Crystal Spectrometer (FCS), one of the two spectrometers making up the XRP. The highlight of data acquired in 1985 was a spectral scan over the complete FCS range during a major flare (X-ray classification M4-5) on 2 July. This was triggered by a flare flag from the other XRP instrument, the Bent Crystal Spectrometer (BCS) and, unlike the previous attempt at doing this (in 1980), the initial rising part of the flare was caught during the spectral scan. Consequently, lines due to much hotter ions were observed on this occasion, including the Lyman-α line of hydrogenic sulphur and lines of helium-like and lithium-like nickel, emitted at 30×10^6K. The latter are the only high-resolution spectra of these lines, from Space or in the laboratory. On other occasions, quite complex sequences involving spectral scans within spatial rasters were successfully run which will lead, for example, to maps of electron density in active regions.

Laboratory Astrophysics

To help interpret the wealth of data from the Sun, a number of lines of research into fundamental atomic data are being pursued, one this year consisting of seven studies; one reports new line identifications in solar spectra acquired with a rocket-borne grazing incidence spectrograph, one describes extensions to a Multi-Configuration Dirac-Fock (MCDF) atomic-structure computer program and its interface with a Hartree-Fock Relativistic (HFR) program, while the remainder provide computations of oscillator strengths, energy levels and wavelengths for over 60 ions. This atomic data is crucial to the interpretation of solar spectral line intensities in the spectral regions covered by CHASE and the SMM flat crystal spectrometer. Grazing incidence laser-produced spectra have also been recorded to aid the identification of spectral lines in astrophysical spectra.

During the year, two investigations concerning solar flares were completed. The first was an analysis of SMM data for a flare on 12 November 1980. The other was an examination of the effect of deviations of the electron distribution functions from Maxwellian and the response of transition region spectral intensities to the predicted hydrodynamic behaviour of the flare. Currently, this theoretical work is being extended by developing an 8-moment fluid computer code which allows for anistropic distribution functions and is therefore consistent with a time-dependent dissipation of heat fluxes. In this way, it is possible to escape from the usual simplifying and unjustified assumption that heat fluxes in the solar atmosphere can be described by the Spitzer-Harm formula.

Fig 1.1 Spectral scans taken when CHASE was pointed at the solar disc: a) He II 303.77 Å line, second order; b) ordinate change allows less intense lines to be identified, especially Si XI 303.31 Å line to be resolved from He II 303.77 Å; c) H I Lyman α at 1215 Å; d) spectral scan from Channel Multiplier Array.



In the course of the year, a major contribution was made to the Daresbury Atomic Data meeting with the presentation of an introductory paper on the application of atomic data to fusion research and assessments of the available lithium-like and beryllium-like excitation rate coefficient data. A collaborative project with the University of Strathclyde on the use of its theta-pinch plasma device to measure atomic rate coefficients is continuing to develop. The current objective is to uncover the reason for the disparities between measurements of ionization rate coefficients by crossed-beam and plasma spectroscopy methods.

CHASE: Coronal Helium Abundance Experiment

CHASE was one of 13 experiments aboard the Space Shuttle Challenger on the flight of Spacelab 2. Challenger's multidisciplinary payload included biology, astronomy and solar physics experiments. As one of four solar instruments, CHASE was mounted on the European Space Agency (ESA) Instrument Pointing System, IPS. Developed at a cost of some £45M, IPS is destined to become an essential part of the Spacelab system, and a major goal of Spacelab 2 was to test its performance.

The main objective of the CHASE experiment was to measure the intensities of selected emission lines emitted within the solar corona. The corona is the very tenuous outer layer of our Sun, and is visible from Earth only during total eclipses. Its lower boundary is well defined by a very steep rise in temperature (5×10^3 K to 10^6 K) and a correspondingly sharp drop in density. With such high temperatures, much of the radiation appears in the form of emission lines from ionised atoms. Most of the strong resonance lines from these ions occur in the extreme ultra-violet (EUV) and, for this reason, the instrument has a spectral range covering 150 Å to 1350 Å.

Ratios of particular emission line intensities can give valuable information about the temperature, density, and composition of the solar atmosphere. A particularly important measurement involves the He II 304 Å and H I 1216 Å lines, where the aim is to derive the abundance of helium relative to hydrogen in the Sun to a high order of accuracy. With helium contributing approximately 10% of the solar mass, this ratio is obviously a vital parameter in models of the solar interior. In addition, the helium abundance is thought to have changed little since the 'Big Bang' creation of the Universe and accurate measurement of its abundance will provide a constraint to cosmological models.

The instrument, built jointly by RAL and Mullard Space Science Laboratory (MSSL), is a combination of a grazing incidence telescope and a Rowland circle spectrometer. Scanning mechanisms associated with the telescope mirror and spectrometer entrance slit provide a means of spatial scanning and a further mechanism, which rotates the spectrometer grating, extends the wavelength coverage of the fixed detectors. Within the spectrometer, there are 12 open channel multipliers, each positioned to receive an emission line of particular interest, and a channel multiplier array (CMA) plate covering the wavelength region 150–220 Å.

On 29 July at 20.23 BST, Challenger blasted off from the Kennedy Space Center, Florida. An engine problem occurred late into the launch which resulted in an altitude lower than optimum for the orbit. This could have had serious consequences for CHASE since the EUV atmospheric absorption becomes significant below 350 km. Fortunately, this absorption is variable, depending strongly upon solar activity, and measurements indicated an adequately low absorption figure.

The turn-on of the instrument by the crew in conjunction with the two shifts of experiment teams at the Johnson Space Flight Center, Texas, was alarmingly fast for people more used to the leisurely pace of satellite missions. Nevertheless, all systems worked perfectly and, within only 17 hours mission elapsed time, a solar map and several fine spectral scans were produced. IPS was under CHASE experiment control at this stage. Because of a software problem in the IPS tracking system, the pointing was delegated to the Sun sensor and, throughout the mission, the Shuttle crew routinely used this device to acquire the Sun. At every opportunity, CHASE was able to gain valuable data and achieve a large proportion of its primary scientific objectives.

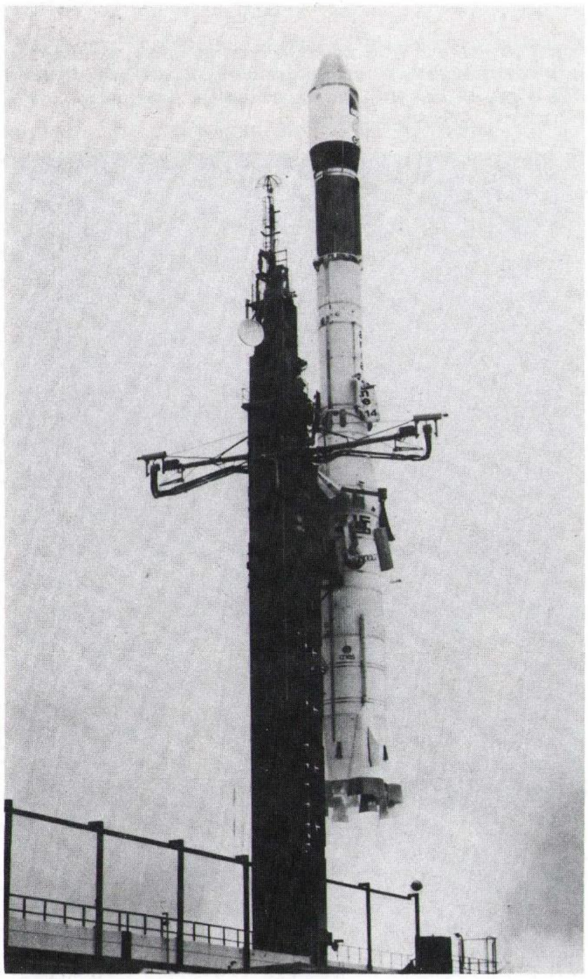
Data analysis is proceeding. Fig 1.1 shows the results of a spectral scan where the mirror and slit were held fixed with CHASE pointed at the solar disc while the grating was moved through its full range. The spectral resolution was as expected. The throughput of the instrument was within a factor two of what was expected, except for the H I channel where it is thought that the LiF filter used to suppress the fourth order of the strong He II 303.77 Å line was more opaque than estimated.

With the grating fixed at the 'home position', ie the peak of the lines, raster maps of the disc and corona were obtained by moving the mirror and the slit and Plate III shows such a map for the O VI $2s^2S - 2p^2P$ transition at 1031.9 Å. On the disc, an active region can be discerned. The limb brightening seen round the edge of the disc is absent at the coronal hole near the solar south pole. Such maps are invaluable in analysis of helium abundance measurements. The main observations were made by stepping a rectangular slit from the disc across the limb and into the corona, covering ~8 arc-minutes from the limb. At each spatial position the grating was rocked to allow measurement of the spectral lines. Since the disc is so bright compared with the corona for the lines of He II and H I, checks are being made to ensure that it is indeed the coronal lines that are observed off the disc and not scattered disc light. This and other checks are very necessary to ensure that the measurements of the elusive helium abundance are as accurate and precise as possible.

DIDSY: the GIOTTO Dust Impact Detection System

The Laboratory is involved in two of the experiments carried on the ESA spacecraft, GIOTTO, which was launched successfully by an Ariane rocket from Kourou in French Guiana on 2 July this year to begin its journey towards its 13 March 1986 encounter with Halley's Comet (Fig 1.2). A description of the Positive Ion Spectrometer experiment is given under Space Plasma Science.

Fig 1.2 Launch of GIOTTO to Halley's Comet by Ariane. (85FC5118)



Our present knowledge of the composition and the conditions which exist in comets is limited to measurements of the radiation emitted when the Sun interacts with their constituent parts. A significant advance is expected when GIOTTO passes within 500 km of the nucleus. The spacecraft carries 10 experiments designed to study various aspects of the Comet. It is thought that the nucleus consists of a large 'dirty snowball' with a diameter of about 5 km made from a mixture of dust particles and larger solids embedded in a matrix of ices containing both water-ice and other frozen volatile substances. As the Comet approaches the Sun and becomes heated, the ices evaporate to form a 'coma' of gas, releasing the solid material to create a cloud of solid dust particles around the nucleus. These dust particles are then 'blown away' by solar radiation pressure to form the well-known curved tail (Plate VIII).

When GIOTTO encounters the Comet, the relative velocity of the spacecraft and the cometary dust particles will be about 68 km/s. At this velocity, a particle with a mass of about 1 μg will be capable of penetrating the outer 1 mm 'bumper shield' which forms the first part of GIOTTO's two-stage dust impact protection system, the second part being a 14 mm Kevlar composite shield located 230 mm behind the bumper shield to exclude any impact debris. DIDSY consists of an array of sensors designed to record impacts of particles with a wide range of masses. It was developed by a consortium led by the University of Kent with a substantial RAL contribution. Several different detection techniques are used, including measurement of the plasma produced by impacts, recording the events when a thin plastic film is penetrated, and detection of the acoustic signals from an impact by using piezo-electric sensors on the GIOTTO spacecraft structure.

RAL work on DIDSY has included responsibility for the flight data processing system and for various aspects of the momentum sensor calibration work. Because of the technical problems involved in simulating hypervelocity particle impacts, this work has made use of high-power pulsed lasers as an alternative technique for the simulation of dust particle impacts. Laser measurements have been made to estimate the attenuation of the flexural waves from simulated impacts as they propagate through the bumper shield to the three crystal sensor locations. Related work has been carried out using the SPRITE ultra-violet KrF laser of the RAL Central Laser Facility to simulate marginally penetrating impacts on the 1 mm aluminium bumper shield in order to calibrate the sensor mounted on the rear shield.

Fig 1.3 HRH Prince Claus of the Netherlands (centre) operating the Millimetre Wave Telescope structure at its handing over to the Director RAL (right) on 19 April. Also shown is Mr H Bruggink of Genius Fabricage B V, the manufacturer.

Cosmic Research

Millimetre Wave Telescope

Although the heaviest snowfalls on Mauna Kea, Hawaii, for many years restricted access to the construction site early in the year, significant progress was made. The enclosure, installed in 1984, was fitted with lighting and power systems, a control/computer room, an instrument preparation room and crew room and the electrical system was connected to a 12.7 kV generator. Fabrication of the antenna structure was completed in Holland early in the year and test-assembled to check mechanical components. Azimuth and elevation drive systems were fitted and their servo control systems set up and tested in collaboration with Mullard Radio Astronomy Observatory (MRAO). Although the antenna was incomplete, being short of surface panels and secondary mirror system, it was demonstrated that the drive systems will meet their specifications. Some of the measured resonant frequencies, 4–5 Hz, were lower than expected but not all structural members were installed. A number of panels with their adjusters were fitted, as was the tetrapod which had been assembled in the laboratory from filamentary carbon fibre reinforced plastic tubes. At the end of these tests and on the occasion of the 40th anniversary of the founding of the manufacturer, Genius Fabricage B V, HRH Prince Claus of the Netherlands handed over the antenna structure to the RAL Director (Fig 1.3).

When the structure arrived in Hawaii in July, a team of ten RAL staff and three from the National Foundation for Radio Astronomy (NFRA), Dwingeloo, with the assistance of Hawaiian contractors and Genius Fabricage, reassembled the structure inside the enclosure in five weeks (Plate II). Since then, work has become more diverse and detailed. Wiring harnesses were attached to the antenna structure and all 828 panel adjusters fitted and checked. Also, some 50 platinum resistance thermometers were attached and preliminary tests carried out. Recognising that the Telescope was not completed, the measured high uniformity of temperature is very encouraging.

Manufacture of 276 surface panels, together with some spares, was completed in November and all panels necessary for the reflecting surface shipped to Hawaii. More than half of the panels have an rms error of less than 12μm and the weighted rms surface error for all 276 panels is less than 11μm, well within the 25μm called for by the specification. An important accessory of the antenna is the measuring machine which will be used to set the surface panels. This was built at RAL and shipped to Hawaii at the end of the year.

The initial package of control system software has been developed at MRAO and a VAX 11/730 transported to Hawaii. During the year, MRAO staff played an active part in the tests of the servo controls of the drive systems and completed the development of the major microprocessor systems, including extensive testing with both the antenna and enclosure control consoles before they, too, were shipped to Hawaii.

The design and construction of the secondary mirror system, including the controls, has reached an advanced stage at the University of Utrecht. The unit for producing movements of the secondary mirror in 3 mutually perpendicular directions, including the axis of symmetry of the antenna, has been assembled and tested over its full range.

Plans for the commissioning and 'day one' receivers have remained unchanged throughout the year, except for the omission of the 690GHz channel from the 345/690GHz receiver. The continuum bolometric receiver being built originally for use on the UK Infra-Red Telescope (UKIRT) has been completed and shipped to Hawaii and will be used on UKIRT before transfer to the Millimetre Wave Telescope for the commissioning programme. A full-sized Nasmyth platform has been constructed to allow this receiver to be used without any modification to its optical system. The second commissioning receiver, the wide band heterodyne 230/270GHz system being built by MRAO in collaboration with RAL, is well advanced although there has been some delay due to the failure of the commercial local oscillators during mixer tests. Although there have been technical difficulties in developing the 345/690GHz line receiver at NFRA, it is likely to be available for use on the Telescope somewhat earlier than expected because it will not now be used on UKIRT. Initially, it will be without the 690GHz channel because of vibration from the helium refrigerator. The final 'day one' system is the 470/490GHz narrow band indium antimonide receiver being developed by a collaboration between MRAO, RAL and Queen Mary College, London. This is still planned for delivery to Hawaii in the first half of 1987.

The membrane, which will span the aperture of the enclosure during normal operations to protect the antenna from wind forces and solar heating, has been fabricated and shipped to Hawaii. Its support structure, designed to tension the membrane and to roll it away, was installed in the enclosure during the year. It is planned to test the full membrane system early in 1986.

Towards the end of the year, a further three RAL staff members took up residence in Hawaii. They will be concerned with control system software and the surface measuring machine. Work at RAL will now be mainly of a supporting nature, all significant manufacturing commitments having been satisfied.

IRAS: the Infra-Red Astronomical Satellite

IRAS was launched in January 1983 and carried out its mission to survey the sky at infra-red wavelengths until November that year. The operation of the main instrument, a cryogenically-cooled telescope, ceased when the supply of liquid helium coolant was exhausted a month early but was sufficient to view the whole sky twice and 70% of a third survey was completed. The data were analysed at the Jet Propulsion Laboratory (JPL) in California and, in November 1984, the IRAS Point Source Catalogue was released. This increased the known number of infra-red objects in the sky from about 6,000 to over 250,000. As well as the catalogue, data from one of the three surveys had been analysed to produce a set of 212 pseudo-images covering the whole celestial sphere. Since then, other analyses of the survey data have produced a Small Structure Catalogue and another set of images of the whole sky.

Besides the survey, IRAS was operated for about 40% of its time mapping small regions of the sky in more detail and at higher sensitivity. These observations covered the interests of extra-galactic and galactic astronomy and solar system objects. About 10,000 additional observations were carried out. In November this year, the images derived from these observations were released to the astronomical community.

In order to make this wealth of data readily available to UK astronomers and preserve the experience gained at RAL during the IRAS mission phase, the IRAS Post Mission Analysis Facility (IPMAF) was set up in 1984. This facility makes use of the STARLINK system of computers which are distributed around the UK at a number of centres of astronomical research. IPMAF provides software to access and analyse IRAS data and maintains an archive of complete sets of IRAS data, including the raw data from which the catalogues and images were derived.

The software tasks are now well advanced and, in September this year, programs were released to STARLINK to analyse both the catalogue and image data. The catalogue software can handle any astronomical catalogues and provides comprehensive means for the statistical analysis of these data. Existing STARLINK programs may be used to display the image data so IPMAF has provided software to allow the quantitative analysis of these data. A major software effort is now under way to provide analysis tools for the raw data. Similar work at JPL has shown that it is possible to combine the multiple raw survey observations to see objects 3 times fainter than those in the IRAS Point Source Catalogue and show detail 3 to 5 times finer than evident in the all-sky images. The data archive now exists and, with the recent release of the additional observations, is being increasingly used by astronomers from all over the UK. In order to increase the awareness of UK astronomers to the IRAS data and software, a number of 'roadshows' have been held at various STARLINK sites. These have presented examples of the scientific work being carried out with the IRAS data and how they relate to the software which has been developed by IPMAF (Plate VI).

IPMAF has been involved in a number of astronomical studies using IRAS data. A statistical study of galaxies has also sought to determine the infra-red properties of the average galaxy. Among the sample of average galaxies, spirals and irregulars are found to be preferentially seen by IRAS whereas ellipticals and lenticulars are not. The spirals were expected to be detected because they contain the dust and star formation regions which particularly emit in the infra-red but IRAS data shows there is a strong correlation between infra-red luminosity and dust temperature and that some spiral types are up to twice as luminous as others. The few lenticulars and ellipticals which are detected are found to be more interesting, evidence at other wavelengths suggesting they have active nucleii. A search in the data for infra-red bright galaxies has found another seven which are super-luminous, ie two orders of magnitude brighter than average. Only three such galaxies were previously known.

Another area of research in which IPMAF is involved and to which IRAS data will make a major contribution is star formation. Sites of massive star formation have been identified by the detection of molecular line emission from water molecules in the clouds of gas and dust (molecular clouds) from which the stars have formed. This suggests that these objects are at a very early stage of formation. The large column densities of dust surrounding these stars frequently prevent them from being seen optically but they can be observed as compact far infra-red sources. By associating the IRAS Point Source Catalogue with known molecular clouds, the far infra-red properties of these sources have been identified. Using these properties, it has been possible to search the IRAS catalogue for similar objects throughout the whole galactic plane. The resulting sample contains sources which have not previously been identified as molecular clouds. To confirm that these IRAS sources are molecular clouds, a search for emission from the $J = 1-0$ transition in HCO^+ was made at the Metsahovi Observatory, Finland. These observations yielded detections in two thirds of the stronger sources. Further observations are planned in the infra-red to identify the exciting stars in these sources and to observe the dust at higher resolution. This work is being carried out in collaboration with the Universities of Kent and Helsinki.

IUE: International Ultra-Violet Explorer

Launched in January 1978, IUE was designed for a 3-year mission of astronomical spectroscopy in the 1150–3200Å region. Almost 8 years later, it is still working productively securing both high and low resolution spectra of all manner of celestial bodies from Halley's Comet to faint quasars. Although this year saw a potentially serious set-back, the failure of one of the three remaining gyros, spacecraft engineers at the Goddard Space Flight Center brought into play a new operational mode using two gyros and the fine Sun sensor which, after only a month of commissioning, is now permitting normal working again; should another gyro fail, a single gyro mode is being developed, making observing prospects brighter for the next few years.

IUE is a joint project involving NASA, ESA and SERC, with RAL providing logistical and technical help for British astronomers in their observations with the satellite from the ESA satellite tracking station near Madrid. The IUE Support Team also assists astronomers to access and use the rich store of data already gathered by IUE, now in excess of 50,000 images, copies of which are lodged with the World Data Centre at RAL. With image de-archiving requests already running ahead of the addition of new images to the data bank, this role will grow in importance.

Because of the nature and success of IUE as an observatory, a very wide range of topics in observational astrophysics is covered in these collaborations. Research areas involving RAL astronomers include cometary physics, nearby cool and flaring stars, interstellar gas and dust, emission nebulae, very luminous stars, interacting hot binary stars, cataclysmic variables, the galactic halo, globular clusters, the stellar content of galaxies, very young galaxies, clusters of galaxies, the intergalactic medium, active galactic nuclei including both nearby Seyfert galaxies and high red-shift quasars, and the age and mass of the Universe. Many of these projects are dominated by IUE data acquisition and analysis but complementary optical, ground-based infra-red and radio observations and IRAS and EXOSAT (X-ray) spacecraft observations are also important.

All the data are reduced on STARLINK. A further valuable interface between RAL and the UK community it supports is provided by RAL astronomers' contributions to the work of most of the STARLINK Special Interest Groups, including those for IUE and IRAS. Four areas of IUE-related research at RAL were highlighted by the Board's In-House Research Assessment Panel this year, and these are briefly summarised:

An IUE and optical study of the binary flare-star ATMic has produced the most detailed investigation yet of the characteristics of dMe stellar flares in the far ultra-violet. These are the very smallest, dimmest and coolest stars, but they occasionally erupt with hot energetic X-ray, ultra-violet and optical flares which are extremely spectacular for a few minutes. This work has provided new insights into the physical properties and mechanisms involved in such flare plasmas and, for the first time, a large stellar flare has been directly compared in the far ultra-violet with solar flare continua and detailed line spectra.

Several important new results have been obtained this year as part of the RAL programme of studies of interstellar gas in our Galaxy. Particularly significant results from work on interstellar gas element abundances based on IUE observations included: the discovery that the volatile element zinc does deplete on to interstellar grains but only in very dense interstellar regions; the lack of any simple relationship between the degree of element depletion and interstellar shock velocity in supernova remnants and interstellar bubbles, suggesting that destruction of dust grains by these shocks is less important than previously assumed; and some new evidence that highly ionised (C IV, Si IV) gas pervades the diffuse interstellar medium in the Galactic disc.

Ultra-violet, optical and infra-red observations of the so-called Blue Compact galaxies have continued to produce interesting results this year. Information on bursts of star formation and on the dust content of these galaxies indicates that they are comparatively young. The dust mass of these galaxies has been shown to be exceptionally low.

The European collaborative IUE programme monitoring the Seyfert galaxy NGC 4151 has produced two further important results from RAL data analysis. A detailed study of the absorption lines in this object revealed that they are likely to be formed in part of the Broad Emission Line region and that there must be a substantial optically thin component to the region. A second discovery was of rapidly variable components of the C IV 1549 Å emission line. These must arise in localised regions which have a special excitation mechanism, most likely from instabilities in a two-sided jet.

ROSAT: Roentgensatellit

In view of the complexity of the technologies involved, major space research projects invariably extend over a number of years between the early conceptual studies and the operational phase. The ROSAT project is a typical example and employs the resources of the UK, Germany and the USA in the cooperative astrophysics programme. It aims to place two telescopes in orbit to conduct the first X-ray imaging survey of the complete sky in a wavelength range from 6 Å to 300 Å.

The joint programme has been under way for about two years and it is planned to launch ROSAT from Space Shuttle into a 57° inclination near-Earth orbit within the next two years. The two co-aligned telescopes known as the X-ray Telescope (XRT) and Wide Field Camera (WFC) will first scan the sky in a systematic way with a spatial resolution of 2 arc-minute at a rate of 4°/minute for 6 months. During a second pointed phase of the mission, the instruments will be operated as a space observatory with finer resolution and longer observing time on specific objects, or regions of sky, for at least a further year.

WFC, which complements XRT, covers the virtually unexplored EUV wavelength range between 60 Å and 300 Å and beyond, and is shown in Fig 1.4. Its approximate dimensions are 700 mm diameter and 1300 mm long. The spacecraft and XRT are the responsibility of BMFT, Germany, while WFC is being developed with the aid of SERC funding by a UK consortium of astrophysics research groups from Leicester University, MSSL, Birmingham University, Imperial College and RAL.

RAL is responsible for ROSAT programme management in the UK, liaison with the German and US project offices and the prime contractor (Dornier System GmbH), development of a number of WFC sub-systems, procurement of major payload items, and coordination of the UK share of data processing and operations software.

During the last year, two development models of WFC have been built, tested and integrated in turn into the structural model of ROSAT. The electrical engineering model was first assembled and then tested for its electromagnetic characteristics and susceptibility to radiation before delivery to Germany. Preliminary integration with ROSAT power and data handling sub-system was completed in July. The structural and thermal model (STM) has been extensively tested to verify the mechanical design under vibration and acoustic environments representative of the launch phase. Already, STM has also been used with the structural model of ROSAT to conduct investigations of the structural response to vibration modes. As the telescope performance requires a stable and controlled thermal environment in orbit, the thermal design has received considerable attention at RAL supported by tests with STM in vacuum.

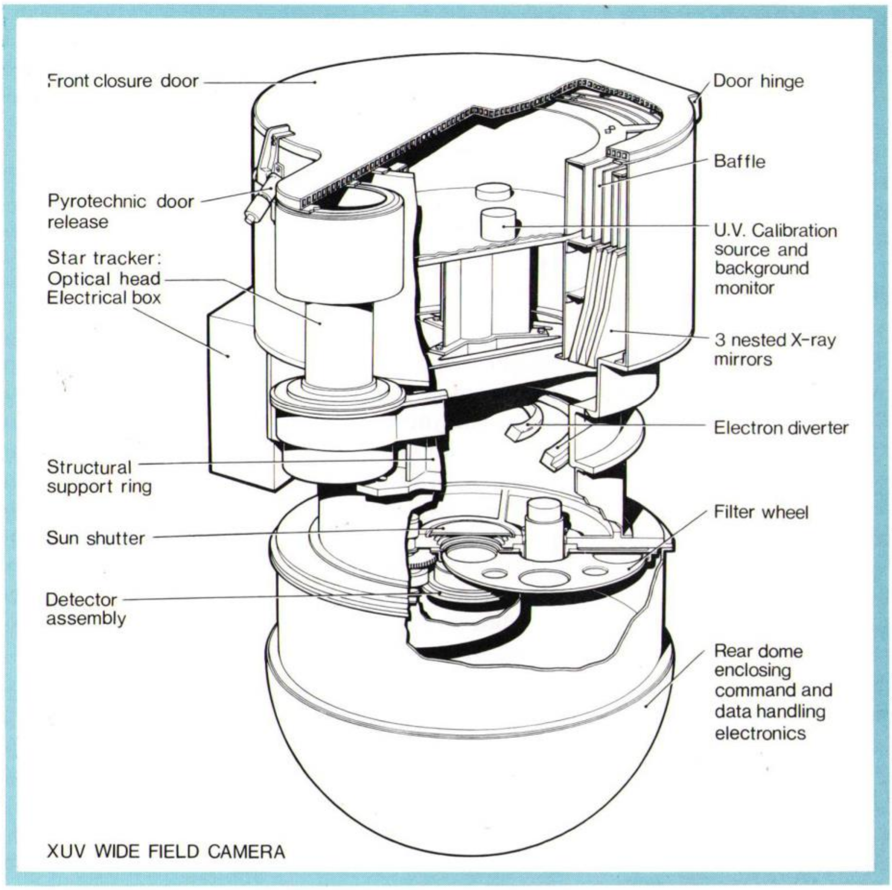


Fig 1.4 ROSAT Wide Field Camera.

At present, electrical compatibility tests using both telescopes are being conducted with the spacecraft engineering model and checkout equipment at the premises of the prime contractor. Overall performance of the telescopes depends on the capability of the various elements of the spacecraft which have to function effectively in a supporting role and on the performance of the X-ray sensors and mirrors. These central elements of the flight model of WFC are being brought together. At RAL, the filters which determine the wavelength ranges in which WFC can operate are being assembled in their final form for detailed calibration. A filter wheel assembly is nearing completion for use in the flight model of WFC. The detector assembly, based on a microchannel plate with resistive anode readout and built to the flight design is to be qualified shortly by the University of Leicester which is also testing the first flight mirror with an X-ray beam facility.

Other WFC sub-systems for the flight model are already under manufacture by various groups in the WFC consortium. The multilayer thermal insulation being constructed at RAL is expected to be ready for the full solar simulation tests with ROSAT early next year. Under a contract between RAL and SIRA, an independent star tracker for WFC has been developed and manufacture of this flight model has commenced. This will provide pointing measurements for the WFC to an accuracy of 15 arc-seconds irrespective of the spacecraft operating mode. Following delivery of the first flight mirror, procurement of the remainder by RAL is on schedule.

Preparation for the operational phase of the mission has been coordinated during the past year by RAL with the WFC consortium. Operations involve a single ground station in Germany which will receive all data from ROSAT during 5–6 passes per day. Essential scientific data will be routed to a ROSAT Science Data Centre at the Max Planck Institut which will be staffed by WFC personnel and will supervise transmission of commands to the WFC and master data records to the UK. Data processing and analysis in the UK will be centralised at RAL for initial data reduction and at Leicester University for final production of the results of the sky survey. All WFC consortium groups will participate in the survey analysis, and some of the pointed phase observations, which will be shared in an equitable way between the three collaborating nations, will be extended to guest observers.

ASTRO-C

ASTRO-C will be the third Japanese satellite dedicated to X-ray Astronomy. A UK consortium of RAL and Leicester University is responsible for providing the major instrument known as the Large Area Counter (LAC). This consists of eight multi-wire array proportional counters having a total area of 5000 cm^2. The scientific objectives will include the variability of active galactic nuclei and galactic sources within the spectral range 1 to 35 keV.

Delivery of the eight flight counters to Japan is being phased over the next eight months for final delivery in June 1986. Integration of the satellite has started in Japan and preliminary LAC interface tests will commence early in 1986. The integration phase will take about a year and the satellite will be launched in February 1987.

ISO: Infra-Red Space Observatory

A large fraction of the energy emitted or absorbed by astronomical objects, from small clouds of dust and gas to galaxies, occurs at infra-red wavelengths. Observation at these wavelengths enables the temperature and conditions of such emitting regions to be measured as well as the presence and concentration of its constituent ions, atoms or molecules. The range of infra-red wavelengths and the sensitivity available to astronomers using ground-based telescopes are severely limited by the Earth's atmosphere. This barrier will be overcome by ISO which will allow astronomers to observe the sky at these wavelengths for the first time with a comprehensive range of very sensitive instruments operating with a 60 cm telescope. The RAL involvement with ISO is a natural sequel of its work as operations centre for IRAS, which mapped the sky photometrically at four infra-red wavelengths. As with IRAS, the ISO telescope and instrument assembly need to be cooled to cryogenic temperatures in order to eliminate their thermal radiation, which would otherwise blind the sensitive infra-red detectors.

In common with many other scientific satellites, it was planned from the outset that the scientific instruments for ISO should be provided by research institutes funded nationally. Proposals from four consortia of research groups to build the focal plane instruments have been accepted by ESA. Contact between the consortia during the development of the proposals enabled the four instruments to be viewed as an observatory facility at an early stage. RAL, together with a number of university groups and the Royal Observatory, Edinburgh, is involved with three of the instruments in a variety of ways.

The focal plane instruments include an infra-red camera (ISOCAM), which is designed to operate from 3 to 17 μm wavelength using 2-dimensional arrays. Its primary function is detailed imaging of infra-red sources with the capability of searching for very distant objects within selected regions of the sky. Facilities are also included for polarimetric mapping and imaging in selected spectral bands. RAL is involved with the computer software for data analysis and operating the camera.

A photo-polarimeter (ISOPHOT) is included as an assembly of four sub-instruments within one housing with shared input optics. One unit provides multiband photometry and another is an infra-red photometric camera covering wavelengths from 30 to 200 μm. An Ebert-Fastie spectrometer is included to give mid-resolution spectra from 3.3 to 16 μm. Finally, two linear arrays of detectors provide a mapping capability when the ISO telescope is scanned in a raster fashion over a selected region of sky. Drawing on the experience gained with IRAS, RAL will provide software for instrument operation and for scientific data analysis and display.

To provide spectroscopic observations, a long wavelength spectrometer (LWS) is included covering wavelengths from 45 to 180 μm. Spectra at mid-resolving power (about 230) are obtained with a diffraction grating and high resolving power (about 10,000) is given by one of two Fabry-Perot interferometers. In the high resolution mode, a single order of interference is selected by the grating. The output spectrum is sampled with a line of 10 photoconductive detectors. RAL is providing the overall project management for this instrument, as well as the integration and testing facilities and the ground operations hardware and software. Fig 1.5 shows a model of the instrument. The outer shape is dictated by the requirement to fit within an 80° sector of a cylinder 600 mm in diameter and 250 mm high. This volume fits behind the 600 mm diameter primary mirror of the ISO telescope.

Spectroscopic performance for ISO is extended to wavelengths over the range 4 to 45 μm with the fourth instrument, a short wavelength spectrometer (SWS). The basis of the instrument is an echelle grating which provides a spectral resolving power of around 5,000. The spectral orders of the echelle are separated by means of a prism into four bands, each with detectors optimised for that wavelength range.

HST: Hubble Space Telescope

The NASA HST is scheduled for launch in August 1986 into a circular orbit of about 590 km altitude and 28.5° inclination. This telescope has an aperture of 2.4 m, weighs some 11000 kg and will occupy almost the entire cargo bay of the Space Shuttle. It will detect objects 50 times fainter with 10 times better resolution than the best ground-based observatories, thus starting a new era in astronomical observations in the ultra-violet, optical and infra-red regions of the spectrum (Plate V). HST will carry five scientific instruments, High Speed Photometer, Wide Field Camera (WFC), High Resolution Spectrograph, Faint Object Spectrograph (FOS) and Faint Object Camera (FOC). All five instruments have been integrated with the telescope

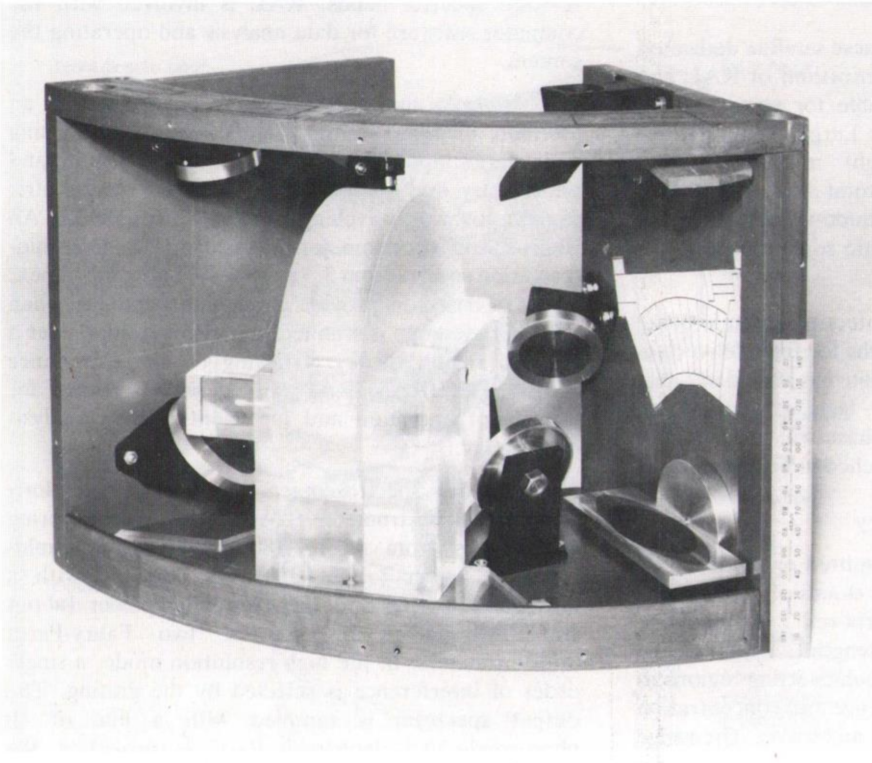


Fig 1.5 Model of the long wavelength spectrometer for ISO. The input-collimating optics are on the left, the unit housing the two Fabry-Perot interferometers is in the centre, and the refocusing optics, detectors and the diffraction grating are on the right. (85FC5756)

assembly and the support systems module but some detector changes are still planned for WFC, FOS and FOC. FOC is provided by ESA and RAL is involved with the development and provision of computer programs needed for image processing.

LYMAN

The very successful IUE observatory has been mentioned above. A new mission known as LYMAN is now being studied by ESA with RAL support in a collaboration with NASA and Australia. This mission will build on the areas opened by research with IUE and extend these to the rich and largely unexplored region of the spectrum between 90 and 120nm. This region embraces many of the most important spectroscopic transitions in astronomy such as the Lyman series of atomic hydrogen and deuterium and the Lyman bands of their molecules; it also covers the resonance lines of C III, N I, II, III, O VI, S III, IV, VI, A I, II and Fe III. It is unexplored because optical materials which are transparent and coatings which are highly reflective are not available over this wavelength range.

The nature of the 90–120nm range is such that its exploitation will extend to most areas of modern astronomy from detailed observations of solar system objects, the interstellar medium, stars and galaxies to studies of crucial cosmological significance. The mission will therefore be a very broad one but, in order to specify the scientific performance, one goal has been adopted, viz the determination of the primordial deuterium abundance from observations of a wide variety of objects. This is quite ambitious and results in a requirement for a system of high sensitivity and spectral resolution. To complement this prime mission, it is proposed to include two additional, subsidiary spectrographs to cover ultra-violet (120–200nm) and EUV (10–35nm) ranges.

The design concept envisages a grazing-incidence telescope of 80cm diameter feeding either the prime, ultra-violet or EUV spectrographs. A grazing-incidence telescope is selected because, with presently available coatings, it has a higher throughput than a normal-incidence telescope in the 90–120nm range. Further, it gives the added capability of extending the mission into the EUV range.

For the prime spectrograph, two concepts are being studied. The first is a Rowland circle design, adopted because it has only one optical component, a concave diffraction grating, thereby minimising the effect of low reflectivity (typically about 25% for developed coatings). The second is a classical, 3-component echelle spectrograph where adoption depends on the availability of a highly reflecting coating. With this in mind, the study is being supported at RAL by a development programme to use pure aluminium, the only material known to have a high reflectivity (80–90%) over the 90–120nm range. This is described below under the heading CAMEO. The ultra-violet spectrograph design is based on three reflecting components (echelle, concave collimator and concave grating) coated with $Al + MgF$. The EUV spectrograph has to be based entirely on grazing-incidence optics. Designs using cross grazing incidence diffraction gratings in an echelle-like configuration have been shown to be feasible.

CAMEO (Coating with Aluminium of Mirrors by Evaporation in Orbit)

Pure aluminium is an excellent normal-incidence reflector at wavelengths above 90nm but, in the terrestrial environment, a fresh surface undergoes rapid oxidation which leads to severe reflectivity losses at wavelengths below 180nm. In the Space environment, it is expected that a freshly deposited aluminium surface would remain unoxidised for a considerable time; for example in a 1000km orbit, the time needed to absorb a single monolayer of oxygen would be more than the lifetime of a 10-year satellite mission. In fact, spacecraft outgassing would be a more serious constraint.

The purpose of the CAMEO study is to investigate in detail the mechanism of oxidation and reflectivity loss and the constraints placed on the spacecraft environment, and hence to prepare a suitable design for the spectrograph and coater. A laboratory experiment has been set up to measure the ultra-violet reflectivity loss produced by controlled absorption of air and water vapour on to fresh aluminium films prepared and maintained in ultra high vacuum (UHV) ($\sim 10^{-10}$ torr) conditions. Surface analysis techniques (Auger electron spectroscopy and electron energy loss spectroscopy) have been used to monitor the evolution of the surface chemical environment of evaporated aluminium coatings, while the reflectivity at 120nm is simultaneously measured.

Work is continuing but results have already shown that in a spacecraft spectrometer constructed to conventional UHV standards, one would expect an exposure to oxidisers of 10 Langmuir (1 Langmuir is approximately 1 monolayer) in one year, which would reduce the 121.6nm reflectivity to 70%. This would be acceptable for spectrographic optics if arrangements were made to recoat every year by thermal evaporation of aluminium from in-situ tungsten filaments. A scheme for arranging this has been proposed. Recoating could be avoided if the overall vacuum environment could be improved by, for example, using large gettering areas on the walls of the spectrometer enclosure. Measurements of the effect of getters will be carried out in the next phase of this programme with University College London.

Optical, Ultra-Violet and Soft X-ray Instrumentation

Work on instrumentation development is an important part of the space astrophysics programme carried out at RAL. The ability to provide effective support for the wide range of space projects funded by the Board depends to a large extent on the underlying instrumentation research and the associated facilities developed at the Laboratory.

RAL support for the ROSAT project described above includes several instrumentation contributions which are based on these laboratory programmes. Optical alignment facilities have been developed for the RAL work on procurement, evaluation and environmental testing of the ROSAT WFC star-tracker. The structural-thermal model and the electrical engineering model were completed during the year and have operated satisfactorily. Work on the flight model is now in progress at SIRA and delivery to RAL for qualification testing is expected soon.

The EUV filters for the ROSAT WFC, which form an important part of the flight system, depend to a large extent on the RAL instrumentation development programme. Because the EUV absorption cross-sections of materials are high, filters must necessarily be thin and consequently fragile. The filters for WFC are based on lexan polycarbonate sandwiched with other materials. Lexan is characterised by its extreme toughness even in films as thin as 1000Å, and its opacity to far ultra-violet radiation but, in general, no single material can provide both high rejection of the geo-coronal flux and the required EUV transmission so a combination of materials is used. This year, engineering model filters consisting of lexan/carbon and lexan/aluminium and mounted in a flight-like filter wheel assembly have survived testing at the very high acoustic and vibration levels experienced during Shuttle launch. In addition, a prototype lexan/carbon filter was flown in a rocket experiment and survived undamaged. Work on the WFC flight filter designs is in progress and completion is expected in the early part of 1986.

In another research programme, carried out in association with the University of Reading, RAL has been investigating the production of multilayer, normal incidence X-ray mirrors. Such mirrors could provide significant advances in X-ray astronomy by removing the constraints of grazing incidence optics and allowing for the development of high efficiency, high angular resolution (sub arc-second) X-ray telescopes.

The multilayer mirror uses constructive interference from many layer-pairs of materials to produce a substantial reflectivity for a particular X-ray wavelength at near normal incidence. At any one interface, the X-ray reflectivity is low as the refractive index of all materials at X-ray wavelengths is very close to (and slightly less than) unity. By arranging the weak reflections from different layers to add in phase, however, a usable reflection can be obtained. The principle places very severe constraints on the coating technology required to deposit the layers, since each interface must appear sharp and smooth to the wavelength being reflected. In practice, this means that boundaries are required with a roughness of less than 10Å (ie very few atomic diameters).

Using an ion beam sputtering technique in a UHV system, layers of various materials at various thicknesses have been deposited on atomically-smooth silicon substrates. The reflectivity of these simple gold and platinum layers and gold/carbon and platinum/carbon etalons has been measured as a function of angle using RAL X-ray spectrometers. By observing the effects of interference from the top and bottom surfaces of such layers, an accurate measurement of the gold, platinum, and carbon thickness and, hence, deposition rate have been established. Such measurements have shown that, for our deposition system, the deposition rate is constant for a given material, and that layer thickness is simply proportional to deposition time down to thicknesses of a few Å. As a result of this information, it has been possible to construct multilayer stacks of platinum interleaved with carbon which have produced X-ray reflectivities of 30%. Mirrors of this type are being considered for use in several Space experiments currently under study by the Laboratory.

STARLINK

STARLINK is the UK coordinated facility for interactive computing in astronomy. It is the primary computing resource of the UK astronomical community and is used by most astronomers. STARLINK is funded entirely by SERC and is managed by and coordinated from RAL. The project currently manages the running of 10 VAX superminicomputers located at centres of astronomical research throughout Britain and serves a large and growing community of users which currently numbers about 700. STARLINK aims to provide the most cost-effective facility for the astronomical community, coordinating both the purchase and maintenance of hardware and the development and distribution of software. A primary objective is to avoid unnecessary duplication of software effort, the major expense in most computer applications. A range of data-processing activities is supported, with interactive analysis of spectra and images high on the list of priorities.

During the year a node began operating at Jodrell Bank bringing the total to 10. A major role of the new node is the reduction and analysis of data from the MERLIN radio interferometer. The other 9 are at RAL, ROE, RGO, the University of Cambridge and University College London (VAX 11/780), and at the Universities of Manchester, Durham, Birmingham and Leicester (VAX 11/750). Each machine is equipped with identical or compatible peripherals, including Sigmex 7000 image display systems and a wide variety of printers, plotters, graphics terminals, etc.

All the STARLINK nodes are interconnected. Running the computers as a network has proved immensely valuable and users freely exchange software, messages, and (in modest quantities) data. The data traffic is via the Joint Academic Network (JANET) using X-25 protocols. It is also possible to communicate with non-STARLINK computers via JANET within the UK and overseas. Within JANET itself, astronomers can transfer data between STARLINK machines and large mainframe computers and can run jobs on the latter. Access to computers outside JANET is possible via the gateway to, for example, PSS, the British Telecom public packet switching service, the European Coordinating Facility for the Hubble Space Telescope near Munich and the Anglo-Australian Observatory in Sydney and Coonabarabran NSW.

Not all users are located near a STARLINK machine, and there is a considerable number of astronomers in Remote User Groups whose access to STARLINK is via terminals attached to communication lines or to campus networks with JANET access. Other groups of remote users run STARLINK software on locally available VAX machines. In many instances, remote users work with the help of STARLINK-funded terminals and other equipment. This year, for example, communication lines and terminals have been provided to improve STARLINK access for the astronomers at Lancashire Polytechnic. Terminals and modems at three new remote locations and computing facilities on the RAL node have been provided for the International Halley Watch programme. There are nearly 20 Remote User Groups in total.

Much software has been written throughout the STARLINK community since the project's inception five years ago. The STARLINK Software Collection now exceeds 500,000 source code lines, and there have been many individual software releases during the year. STARLINK software is now running on a dozen non-STARLINK VAX computers in the UK and on over 50 overseas, including sites in Europe, Australia, the USA and China.

Overall software development coordination is the responsibility of the RAL STARLINK Project Team, advised by seven Special Interest Groups of astronomer-users (IUE, Spectral, Image, Database, Radio, X-ray and IRAS), who meet regularly to monitor progress in their respective areas.

As an example of work using STARLINK, Plate IV presents a false colour representation, produced on a graphics terminal, of the surface number-density distribution of galaxies with diameters $\geqslant 1$ arc-minute listed in the ESO/Uppsala Southern-Hemisphere Catalogue. The south celestial pole is marked as a cross in the centre of the image and the $\delta = -18°$ catalogue limit is the outer circular limit. Right ascensions are marked around this outer limit. The 'zone of avoidance' caused by the Milky Way runs vertically to the left of the image centre. The image illustrates the location of the Centaurus and Hydra clusters. There is no prominent feature connecting these two groupings. It is possible that a further major cluster of the supercluster lies hidden by the galactic absorption and/or the supercluster extends through the galactic plane to include the clusters in the Pavo region, which have red-shifts similar to Centaurus.

The Centaurus cluster itself contains further substructure which is being studied in great detail. There are two major components in the cluster which have been shown to be falling into each other and are now merging. This confirms the importance of gravity in the dynamical evolution of clusters and shows that Centaurus consists mostly of dark material which has not yet been seen.

Space Plasma Science

Virtually all matter in the Universe exists in the plasma state (electrically-neutral assemblies of positively-charged ions and negative electrons). Plasmas involved in astrophysical phenomena can only be observed indirectly but those in the solar system are accessible to spacecraft. Plasma from the solar corona continuously expands into interplanetary space and this 'solar wind' interacts with the magnetic fields of planetary bodies and with comets. By studying the tenuous plasma which surrounds the Earth, precision measurements can be made without perturbing the medium. The resulting improvements in the understanding of plasma behaviour are also of relevance to plasmas in the laboratory where size and lifetime present difficulties for direct measurements.

In the AMPTE and EISCAT programmes, RAL supports university research into the nature of the solar wind, its interaction with the Earth's magnetosphere and hence its effect on the Earth's ionosphere and the feedback of ions and electrons into the magnetosphere and solar wind. These programmes, within which RAL also has a research role, are described below. Notable features of the past year have been the progress made in the analysis of results from the AMPTE mission, the continued success of the EISCAT UHF radar, the solar wind/ionosphere interactions observed using these two facilities and the successful operation in orbit of a positive ion detector on the GIOTTO spaceprobe now on its way to Halley's Comet.

AMPTE: Active Magnetospheric Particle Tracer Explorer

Operations and Data Processing

RAL has continued to support the community of ten university and other research groups in the UK studying the solar wind and its interaction with the Earth's magnetosphere in the unique three-satellite AMPTE mission. Activities centred around AMPTE-UKS, the satellite constructed by RAL and MSSL and launched with its American and German counterparts in August 1984. The aim of the mission was to investigate the transfer of matter from the solar wind to the Earth's magnetosphere, to determine the composition of the radiation belts, to study the effects of artificially-injected plasmas and to explore the dynamics of the magnetosphere, especially its plasma boundaries.

AMPTE-UKS was operated from a control centre at RAL via the Chilton and Chilbolton antennas, with data also being received on occasion by NASA's Deep Space Network. On 16 January, a power system failure ended the data flow after 82 orbits. In 5 months, UKS had produced a wealth of high resolution data, in approximately the same quantity as originally planned for the longer mission. Processing of data is well advanced; a database containing results from UKS and its orbital companion, the German Ion Release Module (IRM), is being established at RAL together with the necessary catalogues to which the scientific community has access via computer networks. A library of summary data from all three AMPTE spacecraft has been established and maintained. Analysis of the data has revealed several areas of research which will enhance our knowledge of space plasmas; these include the unique creation of 'artificial comets' near the Earth by releases of barium plasmas in the solar wind, the unexpectedly intense disturbances caused by lithium plasma releases in the solar wind and other releases within the magnetosphere. The structure and dynamics of the Earth's bow shock, where the solar wind becomes heated to circumvent the obstacle presented by the magnetosphere, has been revealed with great clarity while new insight has been gained into the properties of the magnetopause, the surface where solar and terrestrial plasmas meet and interact.

Electron Experiment

Using the high-quality measurements from the AMPTE-UKS electron spectrometers, RAL is studying the ways in which electrons are energized at the Earth's bow shock, how small-scale regions of energized plasma are produced in the solar wind upstream of the bow shock, and how energy is transported into the Earth's magnetosphere as a result of the collision of the solar wind with the Earth's magnetic field. Measurements obtained during the production of an artificial comet are being used to determine how energy is transferred from ions slowed down by the comet to electrons in its vicinity.

At the Earth's bow shock, AMPTE-UKS has obtained electron measurements at energies which, on earlier space missions, were normally discarded because of fears of contamination from the spacecraft. Special care had been taken during construction of AMPTE-UKS to minimize the effects of photoemission and electrostatic charging. This was so successful that RAL has discovered a population of electrons which traverse the bow shock apparently unaffected by the intense turbulence (Fig 1.6). This significant discovery brings

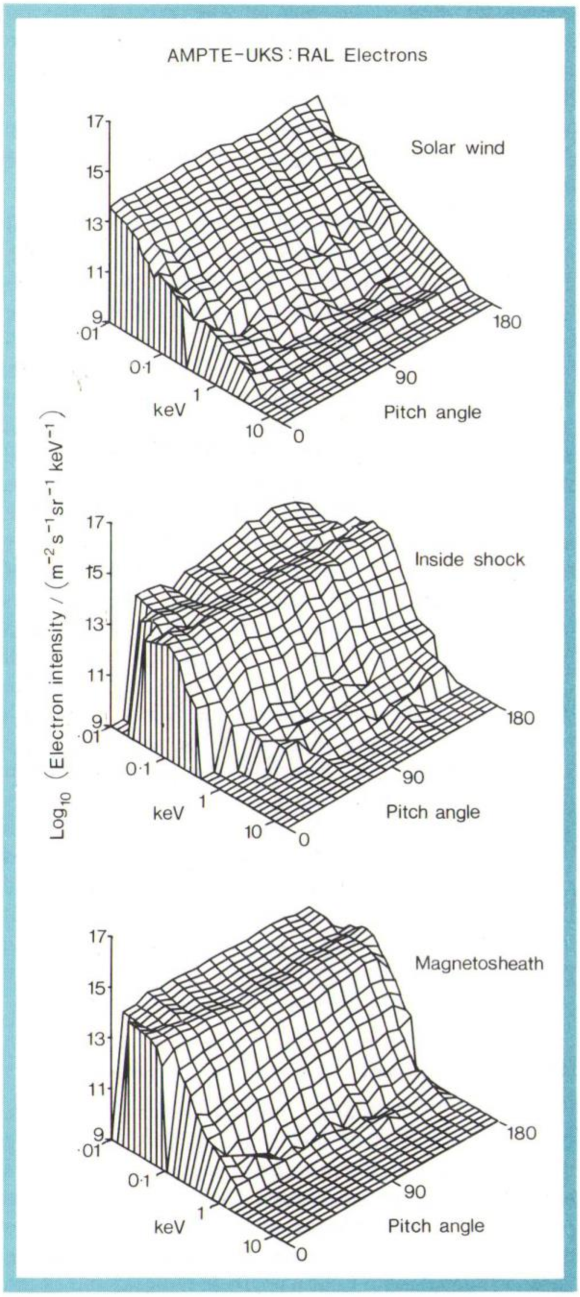


Fig 1.6 Electron distribution as a function of energy and angle to the magnetic field, measured by the RAL 3-D electron spectrometer on the AMPTE-UKS spacecraft during a crossing of the Earth's bow-shock. (86MB1023-5)

into question our present understanding of the physics of electron energization at bow shocks, suggesting that the acceleration process involves resonance between electrons and waves in the plasma.

The electron experiment is also helping to establish the nature of isolated regions of energized particles found in the solar wind. Routine high-detail summaries of the electron data enable the isolated regions to be immediately recognized, although they are traversed by the spacecraft in one or two minutes. It is apparent from the summaries that particle energization is the result of processes similar to those that take place at the bow shock, thus revealing that the phenomena are either magnetically conjugate with the shock or are shock 'precursors'.

Measurements at the magnetopause are being used to distinguish the various intermediate plasma states found in this region and, using the high-resolution measurements of the directions from which the electrons arrive, to determine the sources of the intermediary plasmas.

The artificial comet produced in the solar wind by the injection of barium ions slowed down and deflected the ions of the solar wind but the electrons were energized. The process mimics that which was proposed earlier to account for energization of auroral electrons and which is a strong contender to account for the newly-discovered form of energization which takes place at the bow shock.

GIOTTO – Mission to Halley's Comet

The GIOTTO spacecraft, ESA's spectacular mission to Halley's Comet, was launched successfully on 2 July. The spacecraft is now on course to encounter the Comet on 13 March 1986. All ten experiments on board are working well and, in particular, the Positive-Ion Spectrometer is being used routinely for solar wind studies. This instrument includes the Fast Ion Sensor, which comprises a hemispherical electrostatic analyser and a sectored channel-plate ion detector, providing 3-D ion distribution measurements as the spacecraft spins. In its high-resolution solar wind mode, fine structure in the highly variable plasma stream, travelling at average speeds of 450 km s^{-1}, is being revealed. The high resolution enables the character of the protons and the alpha particles to be determined independently. In collaboration with MSSL and an international consortium, RAL has provided the high-voltage generator. RAL is engaged in experiment operations at the ESA control centre in Germany and is collaborating with MSSL in the analysis and interpretation of results. Software is being prepared for the real time display of the ion data during the Comet encounter and for the systematic detailed analysis of these observations.

EISCAT: European Incoherent Scatter Radar Facility

Since its inauguration in 1981, EISCAT has been used to study a wide range of phenomena associated with the terrestrial magnetosphere and high-latitude ionosphere. In the past, UK scientists have concentrated on exploiting the unique features of the radar; this approach is now paying dividends with several exciting discoveries, particularly in the area of solar wind-magnetosphere coupling.

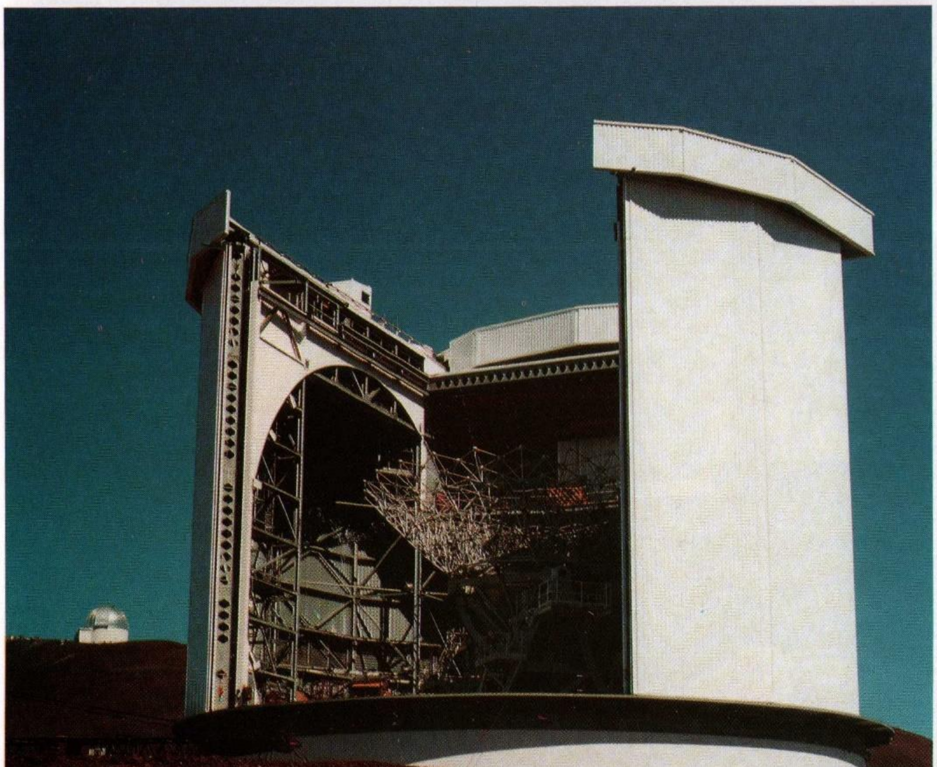
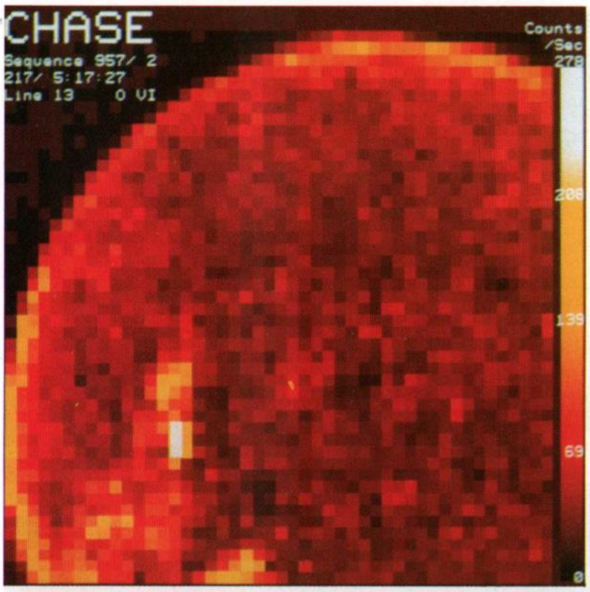


PLATE I
Millimetre Wave Telescope under construction on Mauna Kea, Hawaii at 4,300m altitude. (85 RC 4789)

PLATE II
The Telescope structure being installed in its rotatable housing. (85 RC 4916)



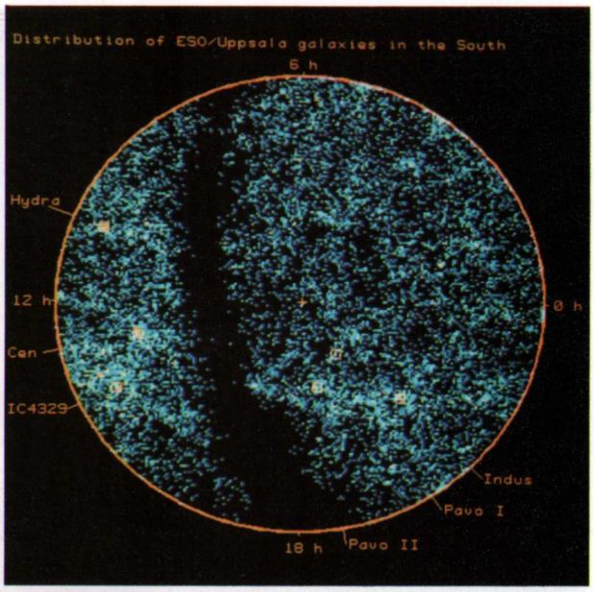


PLATE III
Raster map of part of the Sun's disc and corona. An active region on the disc is easily discernable. The limb brightening seen round the edge of the disc is absent at the coronal hole near the south solar pole.

PLATE IV
STARLINK reveals the clustering of galaxies. (86 RC 1095)

PLATE V
The Hubble Space Telescope, due for launch in 1986. (By Kerby Smith (c) 1981 National Geographic Society)

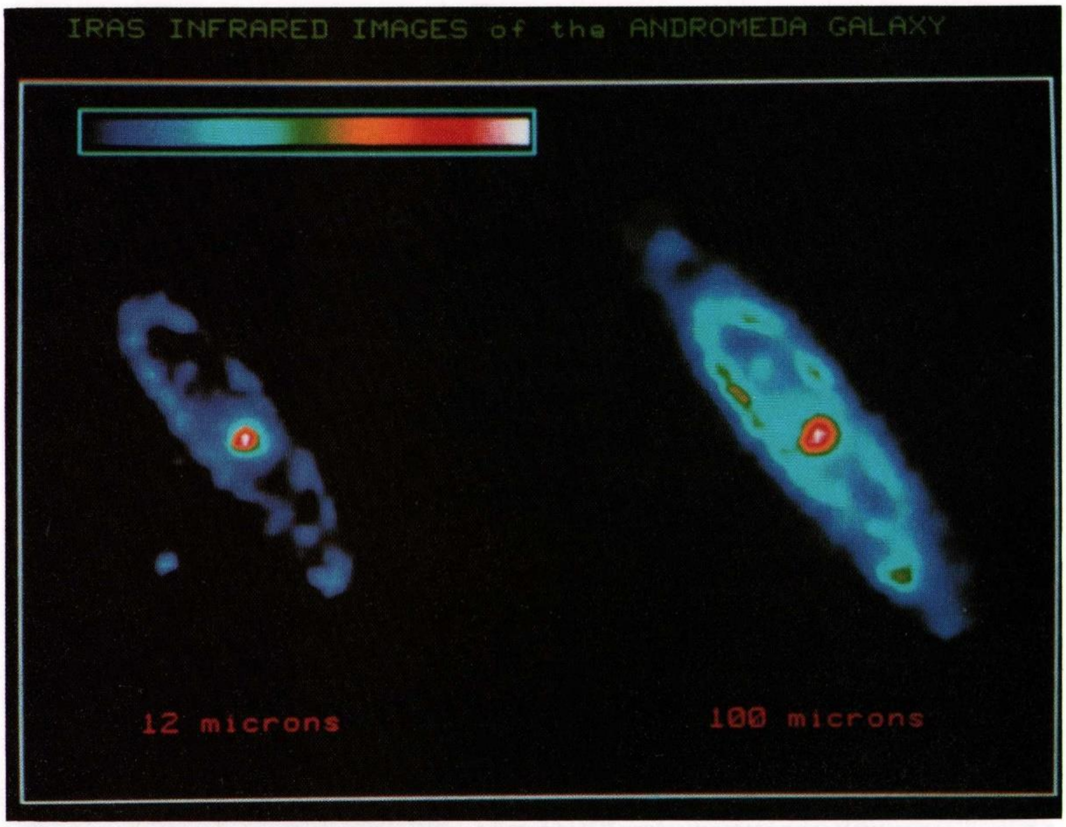


PLATE VI
The nearby spiral galaxy in Andromeda as seen through the infrared eyes of IRAS at two wavelengths. The intensity of radiation is colour-coded from blue (weak) to white (strong).
(86 RC 1034)

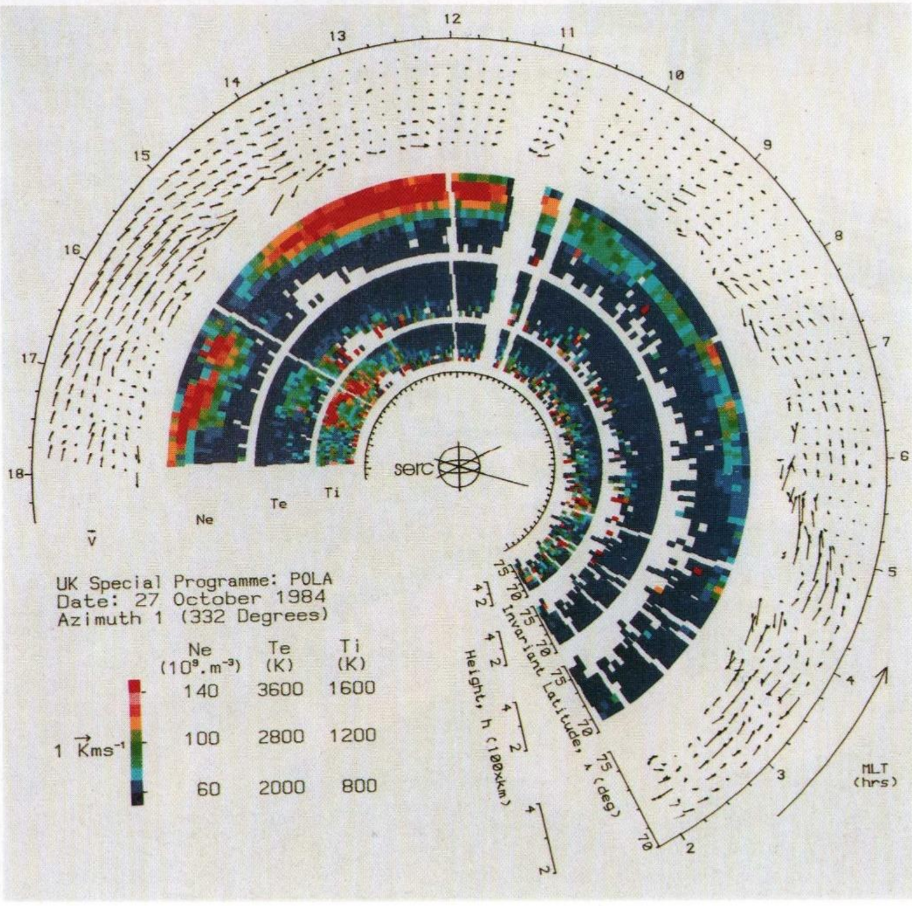
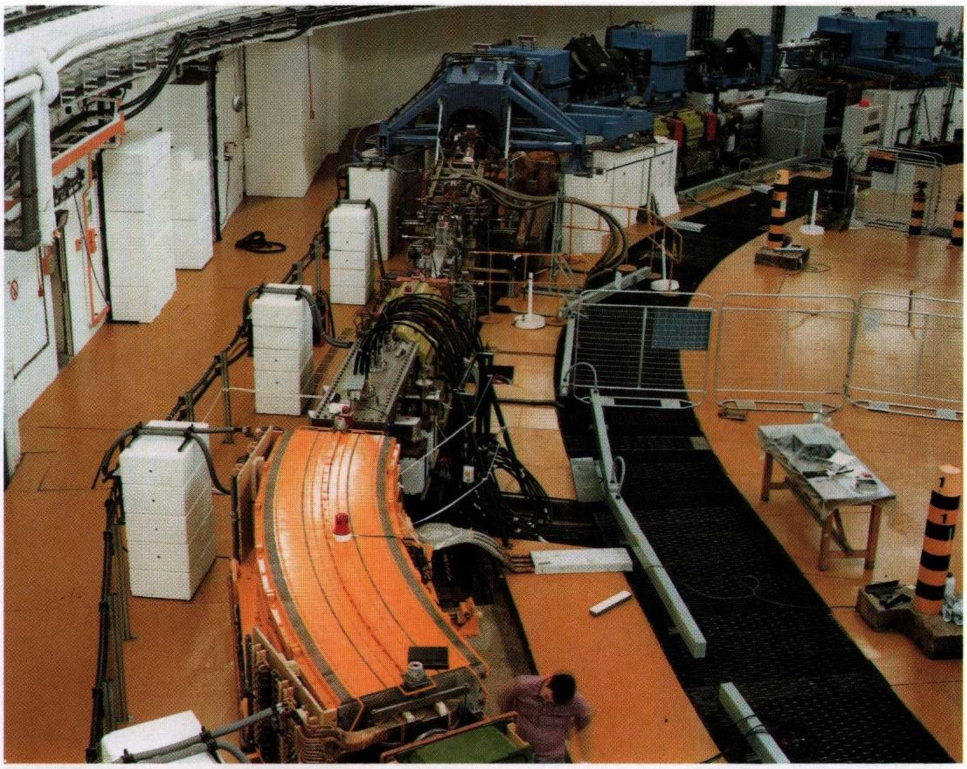


PLATE VII
EISCAT data showing the response of the high-latitude ionosphere to a southward turning of the interplanetary magnetic field' at 1400 hrs Magnetic Local Time.
(85 FC 5720)

PLATE VIII
Photograph of Halley's Comet taken on 12 January 1986 by A L Lintern and P D Wroath (retd.) of RAL.
An 8-inch Schmidt Cassegrain telescope, focal length 1000mm was used at f5 with a telecompressor and the exposure time was 10 minutes.
In this picture the Comet exhibits a curved tail, a feature noticed in November.
The orange-brown background is skyshine from the sodium street lighting of Swindon.

PLATE IX
SUN 2, Whitechapel MG-1 and PERQ 2 single user systems showing the range of graphics these systems can provide. (85 FC 5609)



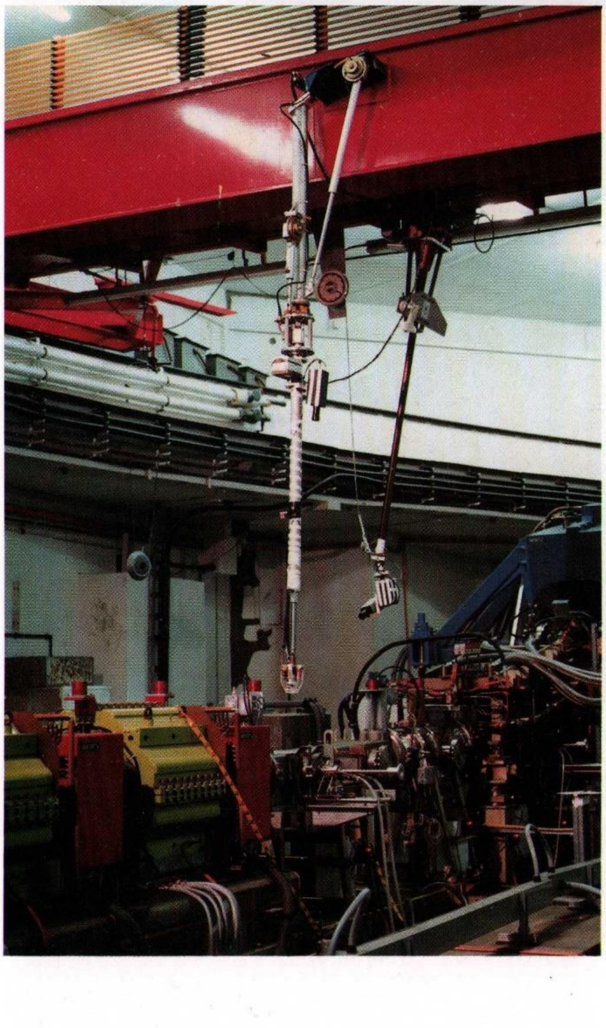


PLATE X
Part of the ISIS synchrotron showing one of the ten dipole magnets in the foreground, kicker magnets which deflect accelerated protons into the extraction beamline channel and the start of the extracted beam line, at rear centre.
(85 RC 2819)

PLATE XI
ISIS remotely controlled arms carrying radiation probe and closed circuit television camera, attached to radio controlled crane.
(85RC1590)

ISIS

Inauguration and Naming by The Prime Minister 1 October 1985

PLATE XII
ISIS Naming and Inauguration Ceremony.

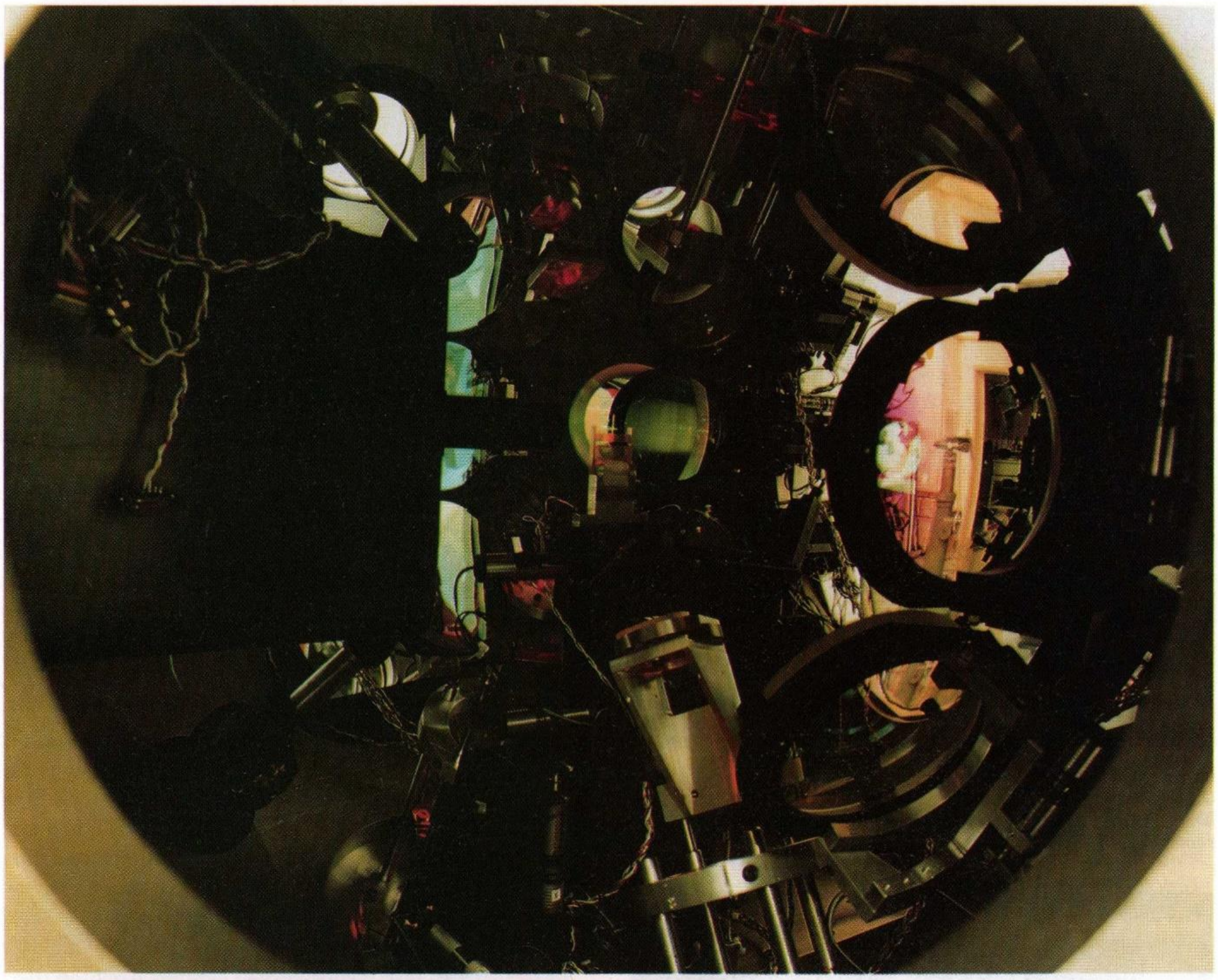
Centre (L–R): Dr G Manning (Director RAL). The Prime Minister, Prof E W J Mitchell (Chairman SERC), Sir John Kingman (former Chairman SERC).

Top left: Prof R Chabbal (France), Mr Alan Carne (RAL), Prof A J Leadbetter (RAL), The Prime Minister, Sr J M Rojo (Spain).

Top right: Dr Manning, Sig L Granelli (Italy). The Prime Minister, Prof Chabbal.

Bottom left: Mr D A Gray (RAL), Mr J L R Huydecoper (Netherlands), Mr Geoffrey Pattie MP (DTI), Mr T Abrahams (DTI), Hon Peter Brooke MP (DES), Dr P A J Tindemans (Netherlands).

Bottom right: Mr Robert Jacksòn MP, Mr H Wroe (RAL), Sir Trevor Skeet MP, Prof A Vaciage (Italy).



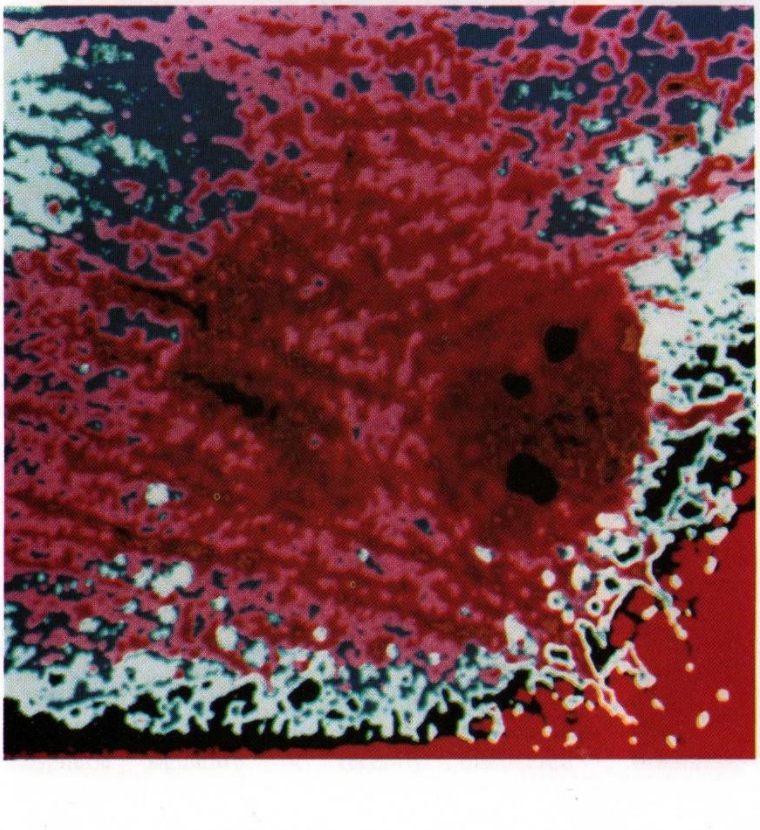


PLATE XIII
The new VULCAN laser target chamber, showing optics to produce line-focus illuminations for x-ray laser research.
(85 RC 5376)

PLATE XIV
False colour flash x-ray image of unprepared human fibroblasts. The photoresist used to record the image has been enlarged by a transmission electron microscope. (IBM)

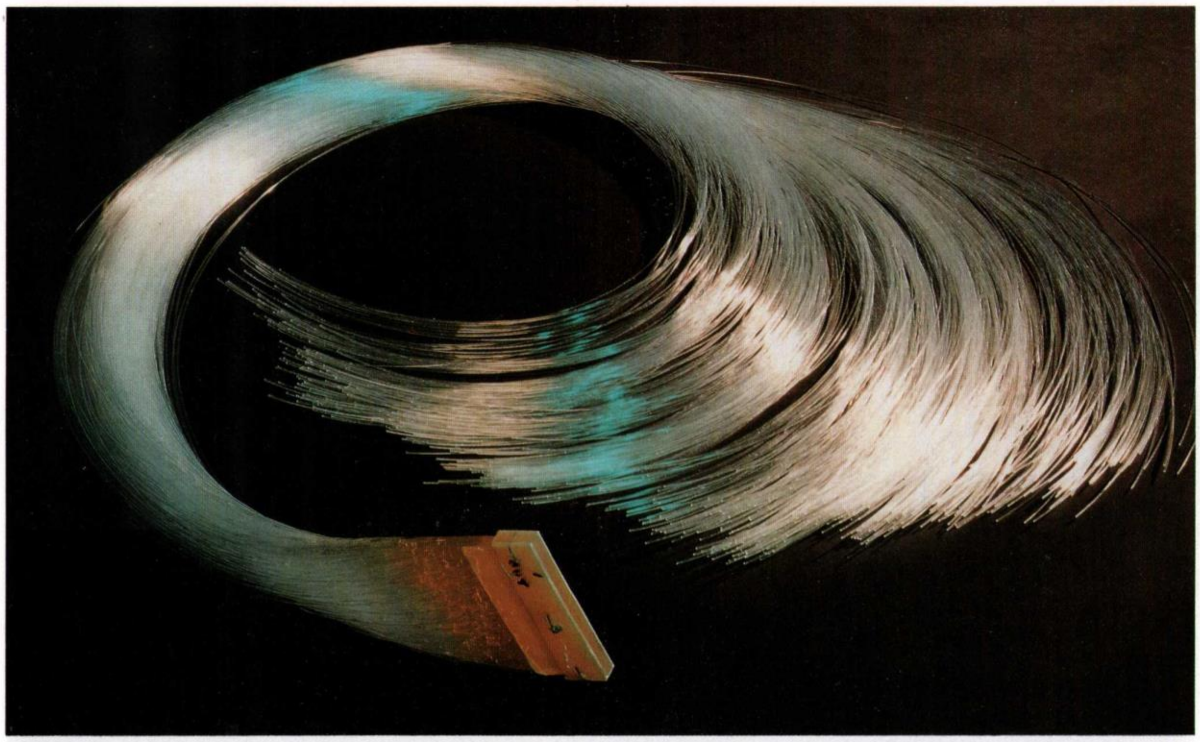


PLATE XV
One of the twenty four optical fibre light-guides for the HELIOS experiment (Expt 260) at CERN. Each guide comprises 700 x 1 mm fibres. The advantage of using fibres is their flexibility and the ease with which they can be bundled into a circular cross-section at the photomultiplier. (85 FC 2967)

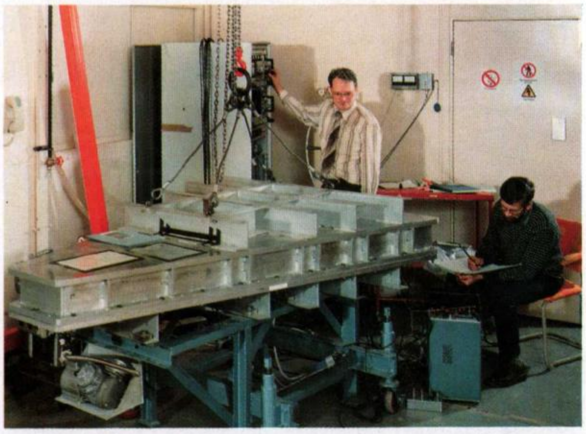


PLATE XVI
Checking the high voltage integrity of six of the proportional wire tube layers of the ALEPH End Cap Calorimeter using the vacuum tight test vessel. All 1080 layers must pass this test before being assembled into the calorimeter. (86 FC 1014)

PLATE XVII
Assembling the Proportional Wire Tube layers for the ALEPH End Cap Calorimeter. Each layer of 220 fine gold wires is accurately tensioned and laid into 22 lengths of aluminium extrusion. (85 FC 5430)

The facility consists of two radar systems located in Northern Scandinavia: the UHF (933 MHz) radar, which has been in operation since 1981, and the VHF (224 MHz) radar, which recorded its first test data in May this year and is expected to become fully operational in 1986. Half the available observing time is allocated to Common Programmes from which data are made available to the entire EISCAT community. The other half is used to run Special Programmes (SP) designed by individual experimenters.

Within the UK, RAL supports the eight universities and three government establishments associated with the project in a variety of ways, including the provision of advice, assistance and software for design and analysis and the maintenance of raw and processed databases. For this purpose, the EISCAT project computer, a NORSK ND560/CXA located at RAL, is available to all members of the UK EISCAT community. This machine provides several important facilities but its major role is in the analysis of the radar spectra to obtain the plasma parameters required for scientific research.

As in previous years, the UK SP observations of 1984 and 1985 were organised on a campaign basis, with RAL and university scientists manning the EISCAT sites. Five such campaigns were mounted in the period October 1984 to October this year and all were highly successful. The data gathered have contributed much to many areas, for example, studies of magnetospheric convection and sub-storms (in particular from observations in conjunction with the UK and German AMPTE satellites and with the Sondrestromfjord radar in Greenland), auroral arcs and sporadic E layers, and some were included in the World Atmospheric Gravity Wave Survey. In certain cases, data were transmitted in near real time to RAL and, in one instance, facilities were provided to enable an experiment to be conducted remotely from the Laboratory.

The large-scale circulation of ionospheric plasma at high latitudes (termed 'convection') has been studied in a collaboration between RAL and Imperial College. These motions are driven by the interaction of the solar wind with the magnetosphere and are strongest for a southward orientation of the interplanetary magnetic field (IMF) embedded within the solar wind. By comparison with data from the UK satellite of the AMPTE mission, the uniquely high time resolution of the EISCAT data has allowed the lag between a southward turning of the IMF and the associated convection response to be accurately quantified for the first time. This convection enhancement is shown by the averaged velocity vectors in Plate VII. In addition, the EISCAT data show that the pattern of enhanced convection expands, after the southward turning, at a speed set by the merging rate of the southward IMF with the geomagnetic field. Short-lived bursts of high-speed convection have also been observed. These are of limited spatial extent and may well be the ionospheric signature of recently discovered reconnection events on the magnetopause, the Flux Transfer Events.

These exciting new scientific results were all obtained using the UHF radar. The value of the EISCAT facility will increase still further when the VHF system comes into regular service. The Laboratory is currently preparing observational VHF programmes to study plasma physics, high-altitude regions and convection at even better time resolution.

Ionospheric Ions

Work with NASA's Marshall Space Flight Center on low-energy ions in the Earth's magnetosphere has revealed the day-side auroral ionosphere to be a major source of plasma. This effect, termed the 'cleft ion fountain', was discovered using the Retarding Ion Mass Spectrometer (RIMS) of the Dynamics Explorer mission. The warm (tens of eV) ions dominate the composition of the polar magnetosphere and are dispersed in both mass and energy by the combined action of the geomagnetic field and the convection electric field, an effect analogous to the operation of a spectrometer. The gravitational effect on cold (<10 eV) ions is large and downward fluxes are observed in the polar cap for O^+, He^+, N^+, O^{++}, and even molecular ions. This shows that the field-aligned ambipolar electric field is smaller than expected and is only large enough to eject H^+ ions. All these ions have been shown to originate from the dayside auroral ionosphere with a two-dimensional kinetic trajectory model. Current studies with conjugate observations by the low-altitude spacecraft and the EISCAT radar are aimed at defining the acceleration mechanisms responsible for the outflow.

Theoretical Studies

Particle Acceleration

The wave-particle acceleration model developed to explain the acceleration of the high-energy electrons which produce the aurora has been extended to explain the acceleration of solar wind electrons observed during the AMPTE ion release experiments and electron acceleration occurring at the bow shock. In both cases, plasma wave turbulence is generated by the streaming solar wind ions. The plasma turbulence, in the form of lower-hybrid waves, is capable of producing the degree of acceleration observed in the experiments. The model is based on a description of the spectral distribution of lower-hybrid waves and the velocity distributions of super-thermal electrons, within the framework of quasi-linear plasma theory.

Plasma Wave Turbulence

The effect of strong turbulence on the propagation of intense electron beams in space plasmas has been examined. It has been shown that the generation of plasma wave turbulence by electron beams and the subsequent interaction of the turbulent wave fields with the beams allows beams to propagate through plasmas with minimal attenuation. The theory is being applied to electron beams in auroras and in solar flares.

Nonlinear Wave-Plasma Interactions

The nonlinear electrodynamic theory of large-amplitude magnetosonic waves reveals the presence of a force which modifies the behaviour of the plasma parameters such as density, electric field etc. The field tends to expel plasma from regions of high field strength which has the effect of increasing the field even more. A nonlinear equation of the Kortweg de-Vries type has been derived to describe this process. The results are being applied to the AMPTE release experiments, where a large coherent magnetic field structure has been observed. The above three projects are in collaboration with Glasgow University, Oxford University and Culham Laboratory.

Quantitative Magnetospheric Models

Work has continued on the establishment of a library of computer programs for the calculation of the magnetic field within the terrestrial magnetosphere, both for the purposes of research and for the support of Laboratory projects such as the EISCAT radar and various spacecraft experiments. Some of these programs are based only on the internally generated magnetic field of the Earth, whereas others also take account of the electric currents which flow in various parts of the outer magnetosphere. Further studies have been made of the nature of magnetospheric physics during geomagnetic polarity reversals. Analytic expressions have been derived for the radius of curvature of planar particle trajectories in multipole magnetic fields; these results extend Stormer's classical work on particle trajectories in a dipole magnetic field.

Geophysical Research

Ocean Surface Sensing

Sea Surface Temperature and ATSR

Satellite observations are revolutionising the study of oceans, their interaction with the atmosphere and the resultant effect upon the global climate. This is because of the near-global coverage afforded and because the accuracy achievable for sea surface temperature (SST) from space-borne platforms rivals that obtainable from surface measurements. The absolute accuracy of SST measurements made using satellite instruments depends upon how well the effects of the intervening atmosphere can be eliminated. SST is required to ± 0.3K for useful accuracy in computing the ocean-atmosphere heat fluxes which drive the global climate system. Numerical simulations of radiation transfer in the atmospheric 'windows' based on computer models developed at RAL include the effects of anomalous atmospheric conditions on SST measurements at wavelengths 11 and 12μm.

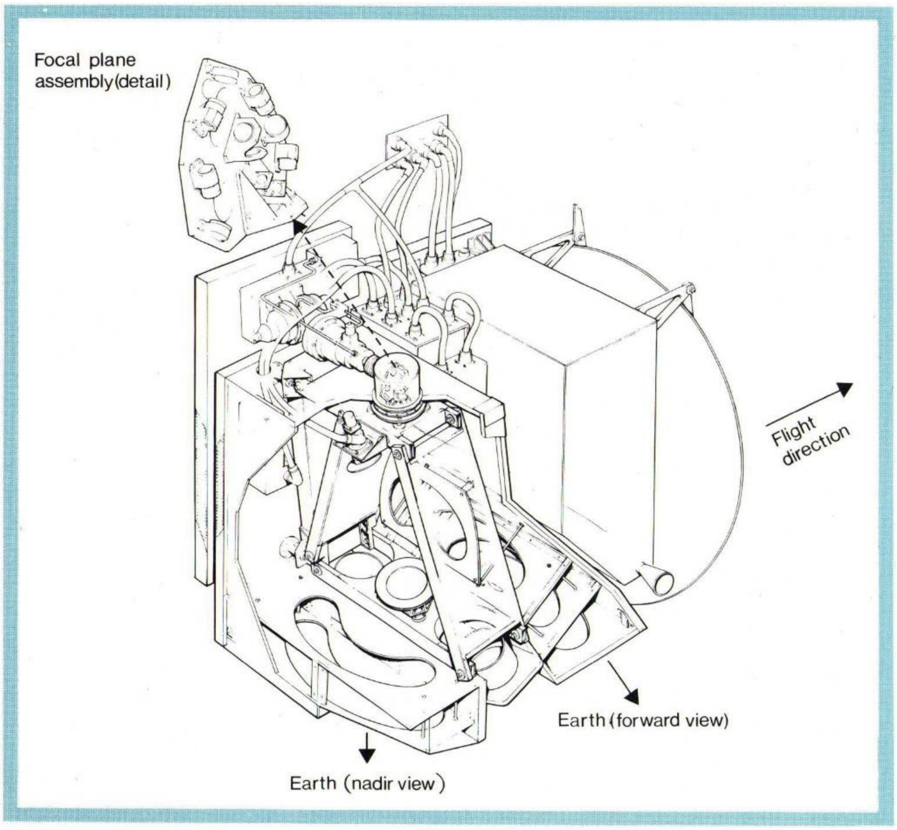
ATSR, the Along Track Scanning Radiometer to be flown on ESA's ERS-1 satellite at the end of the decade, is designed to provide SST measurements of this accuracy. The instrument is an advanced infra-red and microwave radiometer being developed by RAL in collaboration with Oxford University, MSSL, the Meteorological Office and collaborators in France and Australia. The infra-red radiometer views, in three narrow wavebands, two swaths across the sub-satellite track having different atmospheric lengths to the sea surface. The required detector sensitivity is obtained by cooling to 80K using a Stirling cycle refrigerator being developed at Oxford and RAL. The microwave radiometer, which is being developed and built in France, has two passive channels viewing at the sub-satellite point to provide water vapour and liquid water amounts. Detailed design of the ATSR instrument is now in progress. Development models of several subsystems have already been produced for performance evaluation. The instrument configuration is shown in Fig 1.7. Scientific support is aimed at the production of data reduction algorithms to derive accurate SST measurements (even in the presence of large fractional cloud cover), cloud temperature maps and atmospheric water content.

Radar Altimetry

The ESA Remote Sensing (ERS-1) satellite programme has progressed to the instrument construction phase. RAL now directs its support for the ERS-1 altimetry mission to ensuring that a well calibrated and validated data set is made available in convenient form to the UK oceanography, glaciology, geodesy and climatology communities. To this end, RAL has collaborated with universities and other research institutes in the definition of the data products which will be routinely derived from ERS-1 data, the algorithms and facilities required to produce them and the calibration and validation procedures which must be implemented.

During the Polar Regions Marginal Ice Zone Campaigns in 1983/4, RAL collected a large set of airborne altimeter/scatterometer data. The analysis of that data has progressed with support from ESA and in collaboration with the Scott Polar Research Institute and MSSL. A new altimetric technique for measuring relative vertical positions with a resolution of about 2cm has been demonstrated by operating the airborne altimeter over ground-based transponders. When implemented with the ERS-1 altimeter, this technique promises to be of great value in geodetic studies. It offers the possibility of relating conventional geodetic

Fig 1.7 ATSR configuration.



networks in the vertical direction over distances of 2000 or 3000 km and of providing low-cost accurate measurements of land deformation over the same distances. Significant wave height measurements made with the altimeter have been analysed and the value of that instrument for the calibration and validation of the ERS-1 altimeter has been demonstrated. The use of a look-ahead beam when tracking over land-ice surfaces has been tested and its value in an advanced altimeter design assessed. A degree of dependence between ice concentration in the marginal ice zone and the power of the signals returned to the airborne altimeter has been demonstrated. This suggests that the combined analysis of satellite altimetric and radiometric data collected in the marginal ice zone will be valuable.

An advanced Radar Altimeter, incorporating techniques derived from the RAL airborne studies, is being developed by RAL, MSSL and British Aerospace in the context of a joint study for ESA. This Altimeter could eventually be the first instrument capable of a complete global oceans, ice and land altimetric mission. In a joint study with British Aerospace and the Technical University of Denmark, the techniques developed for terrestrial altimetry have been applied in the design of an altimeter for a mission to Mars.

Atmospheric Research

UARS: Upper Atmosphere Research Satellite

NASA will launch UARS in 1989, the most ambitious study ever of the photochemistry, dynamics and energy balance of the region above the troposphere. Of the 11 instruments on board the satellite measuring solar and atmospheric variables, RAL has hardware involvement with two, ISAMS and MLS.

ISAMS, the Improved Stratospheric and Mesospheric Sounder, is being developed by Oxford University and RAL. The instrument will measure the global distribution of various atmospheric constituents, including water vapour, ozone and various nitrogen compounds. Measurements are made by high-resolution pressure-modulated radiometry, a development from successful earlier satellite missions. RAL is responsible for the ISAMS project management and for mechanical, optical and electronic design. Structure and thermal design and assembly are taking place at British Aerospace, with instrument testing at Oxford. The design phase of the instrument is now complete and manufacture of the structure and major optical components has begun. Development modules of most of the mechanisms being supplied by

RAL and Oxford have been completed, with engineering models of the scan mirror mechanism and Stirling cycle cooler having undergone vibration trials. In the first quarter of 1986, the Mechanical Test Model will be assembled for the first major tests of the instrument.

MLS, the Microwave Limb Sounder, is another of the major experiments forming part of the integrated payload for UARS. It will provide profiles of key constituents of the stratosphere and mesosphere by measurement of thermal emission from selected molecular lines at millimetre wavelengths. MLS, a Jet Propulsion Laboratory (JPL) experiment, will provide the first global measurement set of ozone, water vapour, chlorine monoxide and hydrogen peroxide. These measurements are essential for an understanding of the complex photochemistry governing changes in the Earth's protective ozone layer by chlorine from industrial byproducts. The UK is providing the 183 GHz radiometer for measurement of water vapour and ozone, its calibration and integration with the instrument. The 183 GHz system is a joint development by Heriot-Watt University and RAL. Heriot-Watt leads the UK scientific involvement and is responsible for the overall design and electronics for the UK contribution. The advanced millimetre components, build and qualification of the flight hardware and project management are RAL responsibilities. Algorithms for interpretation of the 183 GHz data will be developed with JPL. The development model of the 183 GHz system has now been completed and a preliminary integration into the MLS instrument has taken place. Work on electronics modules and the radiometer assembly has now started for delivery of the engineering model early in 1986.

Middle Atmosphere Data Analysis

Results from satellite-borne experiments, in particular from the Nimbus 7 Limb Infrared Monitor of the Stratosphere (LIMS), have been used to investigate the water vapour budget in the stratosphere which is influenced by the oxidation of methane. This is confirmed to be a dominant factor because the combined hydrogen from the two constituents is found to be conserved.

Differences between modelled and observed ozone and also nitric acid in the upper stratosphere may arise in the averaging process of a model if the true abundances are interdependent. Correlation studies of various constituents such as O_3, NO_2 and H_2O based on LIMS data have shown that such interdependences are too weak to explain the disagreement with models. Methane and N_2O data from the Nimbus 7 Stratospheric and Mesospheric Sounder (SAMS) showed unexpected latitudinal variations. This was originally modelled by forcing the observed semi-annual oscillation in equatorial winds in a 2-D photochemical and dynamical model of the stratosphere. This empirical approach has now been superseded by introducing the appropriate Kelvin wave equations into the model. The observed effects in CH_4 and N_2O can now be well reproduced and the agreement of the model with observed NO_2 and ozone distributions has also improved. This is a good illustration of the importance of dynamical effects in determining the stratospheric composition.

ATMOS: Atmospheric Molecular Spectroscopy

RAL has been closely involved in science planning and data analysis for the ATMOS experiment, built by JPL and flown on Space Shuttle in April. This experiment measured the infra-red spectrum of the Sun, and the atmospheric molecular absorption spectra imposed on it, when the Sun was seen to rise or set from the Shuttle orbit. The radiation detected was at wavelengths between 2 and 16 μm. Much of this wavelength range is inaccessible to ground-based measurements so the new high resolution (0.015 cm^{-1}) spectra are of great interest to solar and atmospheric scientists. Given the spectral signatures of atmospheric gases, measured in the laboratory, one can infer from ATMOS data the concentrations of many constituents of the stratosphere and mesosphere. This analysis is in progress at JPL, Oxford, RAL and other centres. Early results show that the molecules N_2O_5 and $ClONO_2$ have been observed for the first time in the atmosphere. RAL work has focused on CH_4, O_3, H_2O and N_2O retrievals and HNO_3 band identification (Fig 1.8).

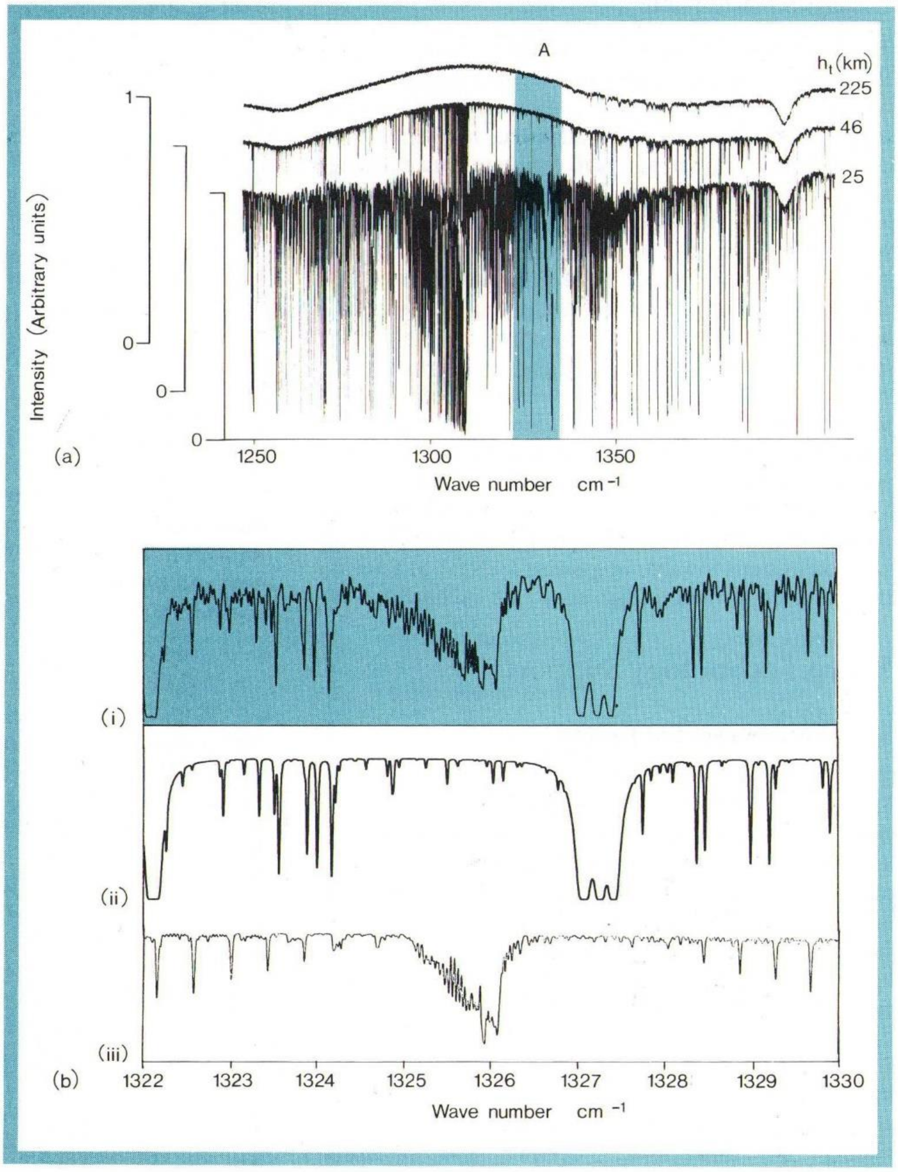
Laboratory Spectroscopy

Accurate laboratory measurements of the 'spectral signatures' of various molecular gases are essential if the chemical composition and temperature structure of Earth and planetary atmospheres are to be measured using remote-sensing techniques. The RAL programme of laboratory spectroscopy is providing these measurements, using a high resolution interferometric spectrophotometer and a number of absorption cells designed to give absorber pathlengths from 1 mm to 1 km at pressures up to 5 bar and temperatures down to 100 K. The experimental programme is heavily biassed towards the spectral data requirements of the space projects ISAMS and NIMS-Galileo (with Oxford University), ATSR and ATMOS. A laboratory programme to study atmospheric radical chemistry spectroscopically is also being pursued in collaboration with Oxford University.

Mid-infra-red spectra of pure CH_4, CH_4/N_2 mixtures, NO and NO/N_2 mixtures have been recorded at temperatures between 200 and 300 K. Line strengths, self-broadened line widths, N_2 broadened line widths and their temperature dependence, have all been extracted from these spectra. The near infra-red and visible spectra of CH_4 and NH_3 have been recorded to characterise absorption by these molecules in the atmosphere of Jupiter. Spectra of HNO_3 in the 1325 cm^{-1} region have been measured and assigned and used to interpret atmospheric spectra recorded by ATMOS (Fig 1.8). Infra-red signatures of all gases involved in NO_3 production and decay have been

Fig 1.8 a) ATMOS infra-red spectra of the Sun measured at sunset from the Space Shuttle at 3 different tangential heights, h_t, above the Earth's surface, ie with 3 different degrees of atmospheric absorption. Only a small part of the spectral range of the results is shown. (JPL)

b) Detail of above spectrum interpreted using absorption spectra of HNO_3 obtained in the laboratory: i) Expansion of Region A for h_t = 25 km. (JPL) ii) Synthetic spectrum derived using known spectra of many atmospheric constituents. (JPL) iii) HNO_3 spectrum derived from parameters measured using the RAL Laboratory Spectroscopy Facility. The feature at 1325–6 cm^{-1} in i) is attributable to HNO_3.



recorded, including the visible spectrum of the NO_3 radical.

Hardware additions made over the last year include a new stainless steel absorption cell for very short path-lengths (1–3 mm), a coolable glass 5 cm path cell and a flow system for the 20 m cell to allow continuous generation of radicals.

Data Support

World Data Centre

The World Data Centre at RAL is part of the worldwide WDC System, whose purpose is to provide secure archives of geophysical data available without restriction to scientists and engineers in all countries, the RAL Centre holding extensive solar data. WDC is giving increasing emphasis to the provision of computer-based services which can be accessed via data networks such as JANET and PSS. During the year, WDC has introduced several new services which are now being used extensively by university groups in the UK. These include:

on-line access to databases containing solar-geophysical indices (such as Sunspot Number, K_P, IF2) on daily and monthly time scales,

an on-line implementation of the MSIS83 model of upper atmosphere (85–700 km) temperature and composition, the values of indices required by this model being retrieved automatically from a database,

an on-line catalogue of all WDC ionosonde data, updated daily.

Geophysical Data Facility

The Geophysical Data Facility (GDF) is being set up at RAL to enable the geophysics research community to access data obtained from a wide range of middle atmosphere, climate, solar-terrestrial and planetary experiments. Its main aim is to facilitate data exchange and to ease the problem of magnetic tape handling which is rapidly becoming a severe burden. During the year, data from the Nimbus series of satellites and AMPTE (UKS and IRM) have been consolidated into databases on the IBM central computer. These include measured values of the temperature of the middle atmosphere, and of density, temperature, pressure and energy spectra of electrons and ions in the magnetosphere. A user at a remote site can access catalogues of the data holdings, select data of interest and transfer these to his own installation via JANET. High-speed data links have been installed between RAL and Oxford University and University College London as steps towards upgrading JANET to cater for the expected growth in high data rate exchanges.

Space Technology Support

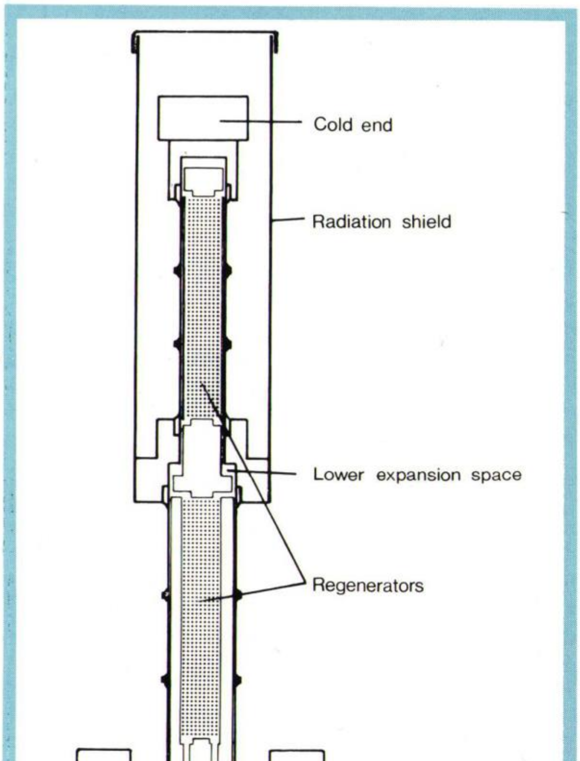
Space Environment Test Facility

This facility provides support to university and RAL Space projects by environmental testing for development and qualification of components and sub-systems, together with dynamic and thermal response analysis of structures. The two main environmental test systems are a vibrator with a computer control system, capable of testing sub-systems up to 6kg to typical spacecraft levels for random and sinusoidal vibration, and a thermal vacuum system for items up to 1m in diameter and 1.7m long operating between 100K and 350K. The thermal vacuum system has a clean turbo-molecular pumping system with cold finger and mass spectrometer contamination monitoring to allow testing of ultra-violet, optical and infra-red experiments. Modal analysis facilities are provided and their use has built up over the year. Vibration and thermal vacuum tests have been carried out on flight systems from DIDSY, GIOTTO and ISPM. Similar work has been carried out on prototype and engineering models on the ISAMS, ATSR, ROSAT, MLS, ASTRO-C, CAMEO and space cooler projects. Modal analysis tests have in particular proved of great value in the design and development of the ATSR optical bench and focal plane assembly.

Stirling Cycle Coolers

Miniature coolers are being developed for space use by RAL in conjunction with Oxford University and will be used on two instruments, ISAMS on UARS and ATSR on ERS-1. Both instruments use infra-red detectors, whose performance is enhanced by cooling to low temperatures. The development programme has resulted in a cooler which exceeds the performance specifications of 0.5W of cooling at 80K for 30W electrical input power. Components for the ISAMS flight units based on the development models are being manufactured. The cooler development programme now has two goals, a cooler for ATSR and a two-stage displacer. The ATSR development model compressor is now undergoing assembly. The design of this compressor was particularly challenging because it must have intrinsically low vibration levels. It consists of two balanced pistons, moving in opposition, which have to be controlled electronically to give the necessary level of momentum compensation. Development of a two-stage displacer to reach even lower temperatures is being undertaken, aided by a design study contract from ESA. The cooler has a stepped displacer (Fig 1.9). Cooling produced in the lower expansion space interrupts most of the parasitic heat loads and allows the upper stage to cool to very low temperatures. These coolers have excited great interest in the Space community and a number of new Space-borne experiments have been proposed to utilise their outstanding qualities. Some ground-based applications are also being considered.

Fig 1.9 Displacer unit of 2-stage Stirling cycle cooler showing the lower expansion space (linear drive omitted). (85MB4656)



Balloon Platform for ZEBRA

ZEBRA is a balloon-borne γ-ray imaging telescope which will combine arc-minute angular resolution with high sensitivity over a broad energy range, enabling detailed and precise mapping of γ-ray sources to be carried out. RAL is collaborating with Southampton University and Consiglio Nazionale Delle Richerche in the development and operation of the instrument. The RAL contribution includes provision of the complete stabilised platform and associated control electronics, structural proof-load testing and participation in the integration, testing and operations programme. Construction of the instrument is nearing completion and the first flight is scheduled for Autumn 1986 at Palestine, Texas.

Millimetre Wave Technology

Specialised components which are not yet available commercially are being developed at RAL to exploit further the millimetre wave spectral region from ground and Space.

Cooled Schottky systems at UKIRT, Hawaii, have been used for astronomical studies at 230 GHz and 270 GHz in collaborative programmes with the University of Kent and MRAO. These systems have recently been enhanced by a dual polarization technique requiring a pair of closely matched mixers whose outputs are combined to double the sensitivity, thus facilitating the mapping of weakly excited molecules such as HCO^+ and HCN. The joint RAL-MRAO construction programme for the 230 GHz commissioning receiver for the Millimetre Wave Telescope is well advanced, with receiver trials under way prior to shipment to Hawaii in March 1986. Component development aimed at producing local oscillator power for a 460/490 GHz indium antimonide receiver by means of a solid state sextupler is progressing well. This receiver forms the basis for utilizing the expected high performance of the Telescope at the shorter wavelengths.

Detectors using newly-developed SIS (Superconductor-Insulator-Superconductor) mixing elements are theoretically capable of operation at the quantum noise limit and already surpass conventional Schottky mixer performance. They will enable full advantage to be taken of the challenging opportunities offered by the next generation of ground-based and Space-borne instruments. With the University of Kent, RAL has already constructed a 230 GHz receiver using a lead alloy SIS junction, achieving high performance.

RAL is providing the 183 GHz triplers and mixers for the MLS experiment on the UARS satellite (Fig 1.10). With support from the Meteorological Office, these components are being adapted for broad band use on the Advanced Microwave Sounder Unit, part of the next generation of satellite-borne meteorological sensors.

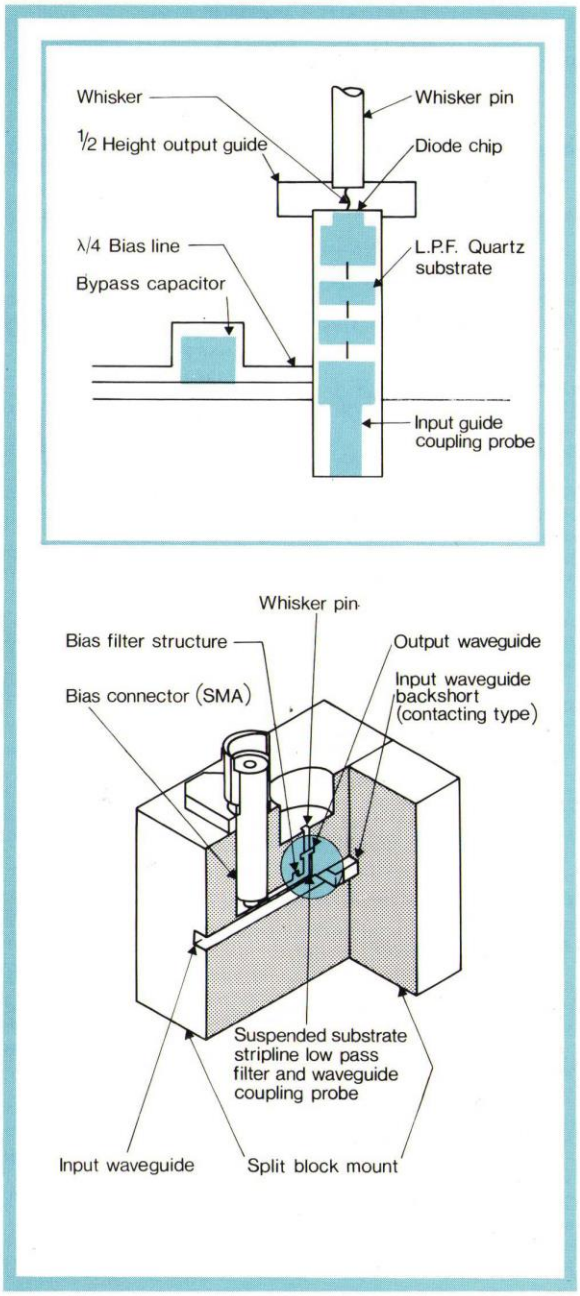


Fig 1.10 183 GHz microwave multiplier to be used on the Microwave Limb Sounder of UARS.

Mesosphere, Stratosphere and Troposphere Radar

A site near Aberystwyth is now being considered for the installation of a 100 kW atmospheric Doppler radar following the decision of the Ministry of Defence to retain its site at Angle. Assembly will begin, using temporary accommodation, in early 1986. The site choice is made possible by the recent closure of VHF television service in Band 1 and advantages include reduced risk of wind damage, no sea clutter and proximity to a major user group.

Publications and Reports

The following papers, reports and conference presentations on work involving RAL staff were published or submitted for publication during the year:

Astronomy, Space and Radio

Astrophysics

P A Aanestad, R J Emery
O III and N III far-infrared line emission in dusty H II blisters
Astron Astrophys **145** 347 (1985)

G E Bromage et al
Detailed observations of NGC 4151 with IUE; IV: absorption line spectrum and variability
Mon Not R Astr Soc **215** 1 (1985)

G E Bromage et al
Flares on dMe stars: IUE and optical observations of AT Mic and comparison of far-ultraviolet stellar and solar flares
Mon Not R Astr Soc (to be published)

A C Cassatella et al
IUE high-resolution observations of Mira B
Mon Not R Astr Soc **217** 589 (1985)

R J Dickens, M J Currie, J R Lucey
The Centaurus cluster of galaxies; I: the data
Mon Not R Astr Soc (to be published)

J H Fairclough
New ultra-luminous galaxies
Mon Not R Astr Soc (to be published)

P M Gondalekar
Depletion of elements in the interstellar medium
Astrophys J **293** 230 (1985)

P M Gondalekar
Depletion of elements in shock-driven gas
Mon Not R Astr Soc **216** 57P (1985)

P M Gondalekar
Depletion of sulphur in the interstellar medium
Mon Not R Astr Soc **217** 585 (1985)

P M Gondalekar et al
The extremely low dust content of blue compact galaxies. Results of IRAS observations
Mon Not R Astr Soc (to be published)

P M Gondalekar, P O'Brien, R Wilson
Ultraviolet spectra of quasars in the redshift interval 0.3 to 2.0
Mon Not R Astr Soc (to be published)

A W Harris, J M Mas Hesse
Interstellar zinc revisited: evidence for depletion?
Mon Not R Astr Soc (to be published)

R Holdaway
Orbit prediction for IRAS using vector and analytic techniques
Acta Astronautica **12** no 3 (1985)

R Holdaway
Controlling the software for a large multinational satellite
Acta Astronautica **12** no 10 (1985)

J R Lucey, M J Currie, R J Dickens
The Centaurus cluster of galaxies; II: the bimodal velocity structure
Mon Not R Astr Soc (to be published)

M Morini et al
Simultaneous EXOSAT and IUE observations of Fairall-9: short and long term variability
Astrophys J (to be published)

D A Naylor et al
Observations of 63 micron oxygen exmission in the Earth's atmosphere from balloon altitudes: astronomical implications
Infrared Physics **25** 485 (1985)

B E Patchett et al
A revised light curve for the 1985 supernova in M31
Observatory **105** 232 (1985)

A J Penny, R J Dickens
C C D photometry of the globular cluster NGC 6752
Mon Not R Astr Soc (to be published)

G C Perola et al
New results on the X-ray emission and on its correlation with the ultraviolet emission in NGC 4151
Astrophys J (to be published)

M Rowan-Robinson et al
Studies of IRAS sources at high galactic latitudes; I: source-counts at $b > 60$ deg and evidence for a north-south anisotropy of cosmological significance
Mon Not R Astr Soc (to be published)

S Sembay et al
IRAS observations of Mkn 501 with quasi-simultaneous observations at radio, near-infrared and ultraviolet wavelengths
Mon Not R Astr Soc **216** 121 (1985)

M A J Snijders et al
Nova Cygni 1975 Paper II
Mon Not R Astr Soc (to be published)

D J Stickland
IRAS observations of epsilon Aurigae during the 1983 eclipse
Observatory **105** 90 (1985)

D J Stickland, C Lloyd, A J Willis
IRAS observations of AS431: a superluminous WR star?
Astron Astrophys **150** L9 (1985)

D J Stickland
IRAS Observations of the cool galactic hypergiants
Observatory **105** 229 (1985)

M H Ulrich et al
Narrow and variable lines in the ultraviolet spectrum of the Seyfert galaxy NGC 4151
Nature **313** 745 (1985)

A Wilkinson et al
Stellar dynamics of Cen A
Mon Not R Astr Soc (to be published)

Conference Presentations

S P Caldwell, R J Dickens
Abundance determinations in Omega Centauri giants
Proc ESO Workshop "Production and distribution of CNO elements"

A Cassatella et al
Ultraviolet observations of the recurrent nova RS Oph in outburst
Proc ESA Workshop "Recent results on cataclysmic variables"
ESA SP-236 **281** (1985)

A H Gabriel et al
Interpretation of the oxygen VII soft X-ray spectrum from the Puppis A supernova remnant
Proc ESA Workshop "XMM"
ESA SP-000

P M Gondalekar
Ultraviolet and infrared properties of blue compact galaxies
Proc Workshop "Star-forming dwarf galaxies and related objects", Paris

M Grande, W M Burton
Aluminium mirror coatings in space
Proc ECASIA (to be published in Surface and Interface Analysis)

T G Hawarden et al
Starbursts in non-interacting galaxies
Proc IRAS Symp "New Light on Dark Matter" (Noordwijk)

R Holdaway
Quasi-inertial tracking for finding satellites
AAS meeting paper 85-267

R Holdaway
Spacecraft tracking from the UK IRAS/AMPTE control centre
Proc Int Astron Fed Meeting 85-385

J R Macdougall
Attitude calibration planning and implementation for IRAS
Proc AAS/AIAA Conf (Vail, Colorado)

G C Perola et al
Simultaneous EXOSAT and IUE observations of NGC 4151
Proc 18th ESLAB Symp "X-ray astronomy"

P T Wallace
ASPECT: area spectroscopy using IPCS with AAT scanning
Report – Anglo-Australian Observatory (1985)

P T Wallace
SLALIB: a library of subprograms (including fundamental subprograms concerned with astronomical position and time)
Report – Starlink SUN **67** 124 (1985)

Proc RAL Workshop "Astronomy and Astrophysics", No 4:

J Abolins
IRAS observations of the M81 group of galaxies

J H Fairclough
The infrared photometric properties of the average galaxy

P M Gondalekar
Infrared observations of blue compact galaxies

Proc IAU Symp 116:

D J Stickland et al
IRAS observations of AS 431

D J Stickland et al
IRAS observations of the Galactic hypergiants

RAL *Report*

RAL–85–041

Geophysics

J Ballard et al
Experimental determination of the temperature dependence of nitrogen-broadened line widths in the 1←0 band of HCl
J Quant Spectrosc Rad Transf **33** 365 (1985)

J Ballard, W B Johnston
Experimental determination of self-broadened widths and absolute strengths of $^{12}CH_4$ lines in the 1310–1370 cm^{-1} spectra region
J Quant Spectrosc Rad Transf (to be published)

A Brekke et al
Development of D-region electron and ion densities under various auroral conditions during the EBC
J Atmos Terr Phys **47** 101 (1985)

P H G Dickinson et al
Lower thermosphere densities of N_2, O and Ar under high latitude winter conditions
J Atmos Terr Phys **47** 283 (1985)

P H G Dickinson et al
Simultaneous observations of E-region irregularities by ground-based and rocket-borne techniques
J Atmos Terr Phys **47** 265 (1985)

M Friedrich et al
Synopsis of the D- and E- regions during the EBC
J Atmos Terr Phys **47** 89 (1985)

J E Harries, R Holdaway
Space research in SERC and links with NASA
Europe/United States Space Activities **61** 277

D B Jenkins et al
Resolved line profiles of atomic oxygen resonance lamps used in the upper atmosphere
J Quant Spectrosc Rad Transf **34** 123 (1985)

R J Knight, D T Llewellyn-Jones
Measurement of the complex refractive index of first-year sea ice and snow using a microwave untuned cavity
MIZEX Bulletin **6** 97 (1985)

R J Powell
Relative vertical positioning using ground-level transponders with the ERS-1 altimeter
IEEE Trans Geos Rem Sens (to be published)

J A Pyle, A M Zavody
The derivation of hydrogen-containing radical concentrations from satellite data sets
Q J Roy Met Soc **111** 993 (1985)

C R Webster, R D May, M R Gunson
Tunable diode laser Stark modulation spectroscopy for rotational assignment of the HNO_3 7.5 μm band
Chem Phys Lett **121** 429 (1985)

Conference Presentations

J Ballard, W B Johnston
Some recent results from the RAL spectroscopy programme related to middle atmosphere remote sensing
5th General Assembly IAGA/IAMP, Prague, August 1985

9th Colloquium on High Resolution Molecular Spectroscopy
Riccione September 1985:

J Ballard, W B Johnston
The RAL spectroscopy programme related to middle atmosphere remote sensing

J Ballard, W B Johnston, B J Kerridge
Experimental determination of line parameters and their temperature dependence in the 1–0 band of nitric oxide

M Gunson
High resolution spectra of the 7.5 μm band of nitric acid

D T Llewellyn-Jones
Precise SST Data from Satellites
Proc Conf 'Use of Satellite Data in Climate Models', Alpbach, June 1985

M B Oliver
Calibration strategy for the IRAS detectors; Calibration of detectors for the Along Track Scanning Radiometer
Inst Phys Spec Group, NPL, March 1985

R J Powell
The use of microwave airborne instruments to gather data for the validation of ERS-1 wind and wave products
Proc Conf 'The use of satellite data in climate models', Alpbach, Austria, June 1985

R J Powell, N MacIntyre, V Squire
A radar altimeter and the validation of its data products over ice surfaces
Proc Symp 'European Remote Sensing Opportunities', Strasbourg, April 1985

D Vizard
An SIS-based 230 GHz receiver for astronomy 'Millimetre and submillimetre receivers for UKIRT'
SPIE symposium, Cannes, Dec 1985

Solar Interplanetary Physics

L W Acton et al
Rocket spectrogram of a solar flare in the 10-100 Å region
Astrophys J **291** 865 (1985)

E Antonucci, A H Gabriel, B R Dennis
The energetics of chromospheric evaporation in solar flares
Astrophys J (to be published)

E Antonucci et al
Initial phase of chromospheric evaporation in a solar flare
Solar Phys **96** 129 (1985)

R D Bentley et al
Soft X-ray observations of high-velocity features in the 29 June 1980 flares
Astron Astrophys (to be published)

A G Emslie, K J H Phillips, B R Dennis
The excitation of the iron K-alpha feature in solar flares
Solar Phys (to be published)

B C Fawcett
Calculated wavelengths and oscillator strengths of $n = 2 - 2$ and 2–3 transitions for ions in the O I-like isoelectronic sequence between Mg V and Ni XXI
At Data Nucl Data Tables **34** (to be published)

B C Fawcett
Hypersensitive mixings between 2s3p $1p_1$ and $^3p_1$ levels which affect oscillator strengths of Be I-like transitions
At Data Nucl Data Tables **34** (to be published)

B C Fawcett
Calculated wavelengths oscillator strengths and energy levels for allowed 3–3 and 3–4 transitions for ions in the S-like isoelectronic sequence between S I and Ni XIII
At Data Nucl Data Tables (to be published)

B C Fawcett
Calculated wavelengths oscillator strengths and energy levels for allowed 3–3 and 3–4 transitions for ions in the P-like isoelectronic sequence between P I and Ni XIV
At Data Nucl Data Tables (to be published)

R A Harrison et al
The X-ray signature of solar coronal mass ejections
Solar Phys **97** 387 (1985)

A E Kingston et al
Theoretical line ratios for high temperature and high density Ne VII plasmas
J Phys B: At Mol Phys **18** 2561 (1985)

J Lang et al
A Thomson scattering experiment with a maximum likelihood data analysis
J Phys E: Sci Inst (to be published)

N N Ljepojevic, R W P McWhirter, S Volonte
Spectral intensities from hydrogen-like ions II
J Phys B **18** 3285 (1985)

P MacNeice
A numerical hydrodynamic model of a heated coronal loop
Solar Phys (to be published)

P MacNeice et al
Multi-wavelength analysis of a well observed flare from SMM
Solar Phys (to be published)

B Sylwester et al
Investigation of the Mg XII 8 42A doublet in solar flare spectra
Solar Phys (to be published)

Conference Presentations

A H Gabriel et al
Interpretation of the O VII soft X-ray spectrum from the Puppis-A supernova remnant
ESA Scientific and Technical Publications

Proc US-SMM Workshop
Eds M Kundu, B E Woodgate (1985)

S K Antiochos et al
Chromospheric explosions

A H Gabriel et al
Impulsive phase observations

R A Kopp et al
Intercomparison of numerical model of flaring coronal loops

RAL *Report*

RAL–85–098

Space Plasma Physics

D A Bryant, S M Krimigis, G Haerendel
Outline of active magnetospheric particle tracer explorers(AMPTE) mission
IEEE Trans Geosci Rem Sens **GE-23** 177 (1985)

C P Chaloner et al
Electrons at the dayside magnetopause: recent observations by AMPTE-UKS
'Solar Wind/Magnetosphere Coupling'
Ed Y Kamide, Terra Sci Pub, Tokyo (to be published)

A Egeland et al
Fine structure and dynamics of the Harang discontunity
J Atmos Terr Phys **47** 693 (1985)

J L Horwitz, M Lockwood
The cleft ion fountain: a two-dimensional kinetic model
J Geophys Res **90** 9749 (1985)

D R Lepine et al
Data handling for the UKS spacecraft
IEEE Trans Geosci Rem Sens **GE-23** 221 (1985)

M Lockwood et al
A new sourceof suprathermal O^+ ions near the dayside polar-cap boundary
J Geophys Res **90** 4099 (1985)

M Lockwood et al
The geomagnetic mass spectrometer — mass and energy dispersions of ionospheric ion flows into the magnetosphere
Nature **316** 612 (1985)

M Lockwood et al
The cleft ion fountain
J Geophys Res **90** 9736 (1985)

T E Moore et al
Upwelling O^+ ion source characteristics
J Geophys Res (to be published)

T E Moore et al
Superthermal ion signatures of auroral acceleration processes
J Geophys Res **90** 1611 (1985)

H Rishbeth
Coherence from incoherence
Nature **313** 431 (1985)

H Rishbeth, P J S Williams
The EISCAT ionospheric radar: the system and its early results
Q J Roy Astr Soc (to be published)

H Rishbeth et al
Ionospheric response to changes in the interplanetary magnetic field observed by EISCAT and AMPTE-UKS
Nature (to be published)

S J Schwarts et al
An active current sheet in the solar wind
Nature (to be published)

H M Shah, D S Hall, C P Challoner
The electron experiment on AMPTE UKS
IEEE Trans Geosci Rem Sens **GE-23** 293 (1985)

R W Smith et al
Observation and theoretical modelling of a region of downward field-aligned flow of O^+ in the winter dayside polar cap
J Atmos Terr Phys **47** 489 (1985)

A K Ward
The AMPTE UKS spacecraft
IEEE Trans Geosci Rem Sens **GE-23** 202 (1985)

Conference Presentations

Proc 7th ESA Symposium 'European rocket and balloon programmes and related research' ESA report **SP-229** (1985)

D A Bryant, R Bingham, D S Hall
Acceleration of electrons by lower-hybrid waves

D A Bryant, D S Hall, C P Chaloner
Energization of electrons following ion releases in the solar wind

D S Hall, D A Bryant, C P Chaloner
Plasma variations at the dayside magnetopause

D S Hall, D A Bryant, T Edwards
Are parallel electric fields really the cause of auroral particle acceleration?

Chapman Conference
Terra Scientifica (to be published)

J L Horwitz et al
Transport of low energy ions in the polar magnetosphere

T E Moore et al
Observations of transverse ion acceleration

J H Waite et al
Solar wind control of the geomagnetic mass spectrometer

J H Waite et al
Ion energisation in upwelling ion events

World Data Centre

R Conkright et al (eds)
Combined Catalog of Ionosphere Vertical Soundings Data
(December 1984)

M A Hapgood, C M Doidge, J R Smith (eds)
WDC-Cl Catalogue of Vertical Soundings Data
(March 1985)

M A Hapgood
WDC-Cl Database Users Guide
(September 1985)

Monthly Bulletins of UK Ionospheric Data:

Slough	Mar 1984 – May 1985
Port Stanley	Nov 1983 – Apr 1985
South Uist	Jan 1985 – Mar 1985
Halley Bay	Dec 1979 – Nov 1980

RAL Reports

Internal reports in the RAL series produced during the year are listed below. Copies are available from the RAL Library.

RL–85–001
G Stuart, comp
Particle physics experiments 1984

RAL–85–002
H M Shah, D S Hall, C P Chaloner
The electron experiment on AMPTE-UKS

RAL–85–003
C F Rogers
Quasi-geostrophic ocean models employing spectral methods; part 1: theoretical background

RAL–85–004
T Barnes, G J Daniell, D Storey
An improved guided random walk algorithm for quantum field theory

RAL–85–005
T Barnes
Exotica for ELSA: baryonia, dibaryons, glueballs and hybrids

RAL–85–006
C W Trowbridge
Low frequency electromagnetic field computation in three dimensions

RAL–85–007
R W Witty
Sixth Annual Lecture of the C and CD of IEE Software Engineering

RAL–85–008
R J N Phillips
Fourth generation massive neutrinos

RAL–85–009
G Hallewell
The OMEGA ring imaging Cerenkov detector readout system user's guide; version 2, November 1984

RAL–85–010
J B Dainton, ed
Proceedings of the school for young high energy physicists, Rutherford Appleton Laboratory, September 16–29, 1984

RAL–85–011
C Greenough
The NAG/SERC Finite Element Library: from design to realisation

RAL–85–012
M Warner, R M Hornreich
The stability of quasi-two-dimensional lattices of magnetic holes

RAL–85–013
J D Lawson
Beat-wave accelerator studies at RAL

RAL–85–014
R J Apsimon et al
The design of the optical components and gas control systems of the CERN OMEGA ring imaging Cerenkov detector

RAL–85–015
R Bingham, W B Mori
Some nonlinear processes relevant to the beat wave accelerator

RAL–85–016
P J Lichfield
Baryon spectroscopy

RAL–85–017
J Mayers, R Cywinski
A Monte Carlo evaluation of analytical multiple scattering corrections for unpolarised neutron scattering and polarisation analysis data

RAL–85–018
S W Lovesey, K N Trohidou
F-sum rule for magnetic neutron-electron scattering (2); electrons in a magnetic field

RAL–85–019
S Evans, A Ridgeley
An analysis of the structure calibration and system test data obtained from the GIOTTO structural model spacecraft at ESTEC, Noordwijk, 22 October to 5 November 1983

RAL–85–020
D K Bradley et al
The analysis of colliding-shock experiments

RAL–85–021
P F Smith et al
A search for fractional electric charge on levitated niobium spheres

RAL–85–022
S J Rose
The calculation of the opacity of hot dense plasmas

RAL–85–023
R D Mount, C J Pavelin
Surveys of Engineering Board computing

RAL–85–024
C R I Emson, J Simkin
An optimal method for 3-D eddy currents

RAL–85–025
J B Dainton
Hadron photoproduction at medium energy

RAL–85–026
B Franek
A production model independent calculation of charmed particle lifetime using unconstrained decays

RAL–85–027
J E Bateman, J F Connolly, R Stephenson
High speed quantitative digital beta autoradiography using a multistep avalanche detector and an Apple-II microcomputer

RAL–85–028
R D Williams
Nematic liquid crystal droplets

RAL–85–029
T G Perring, A D Taylor, D R Perry
Absolute neutronic performance of SNS from gold foil activation

RAL–85–030
A J Leadbetter et al
First neutron results from SNS

RAL–85–031
G D Coughlan et al
Baryogenesis in supergravity inflationary models

RAL–85–032
P L Davidson
Thermal neutron beam line monitor

RAL–85–033
J Adam, D Adamova
The effect of the long wave length approximation on the one-photon transition rates for heavy quarkonia

RAL–85–034
M MacDermott
A review of charm hadroproduction

RAL–85–035
J W F Valle
Fitting Simpson's neutrino into the standard model

RAL–85–036
B Colyer, C W Trowbridge
Finite element analysis using a single-user computer

RAL–85–037
G E Forden, D H Saxon
Improving vertex position determination by using a kinematic fit

RAL–85–038
J Hoek, J Smit
On the 1/g(2) corrections to hadron masses

RAL–85–039
S Chadha, M Daniel
Comments on discrete symmetries in higher dimensions

RAL–85–040
S Chadha, M Daniel
Spinors and discrete symmetries in higher dimensions

RAL–85–041
W M Burton et al
CAMEO: coating aluminium mirrors by evaporation in orbit

RAL–85–042
J Hoek
Cooling of SU(3) lattice gauge field configurations

RAL–85–043
H-M Chan, P Scharbach, S T Tsou
On loop space formulation of gauge theories

RAL–85–044
H-M Chan, P Scharbach, S T Tsou
Action principle and equations of motion for non-Abelian monopoles

RAL–85–045
J Penfold, W G Williams
A pulsed source neutron reflectometer for surface studies

RAL–85–046
G Gerbia et al
Dilepton and trilepton production by antineutrinos and neutrinos in neon

RAL–85–047
RAL Laser Division
SERC Central Laser Facility. Annual Report to the Laser Facility Committee 1985

RAL–85–048
S F Biagi et al
A measurement of the branching ratio $\Sigma^+ \rightarrow \varrho\gamma/\Sigma^+ \rightarrow \varrho\pi^0$

RAL-85-049
S F J Cox, M C R Symons
Aspects of mechanism and structure in the formation of muonated radicals

RAL-85-050
R D Williams, S W Lovesey
Neutron scattering from a substitutional mass defect

RAL-85-051
D A Duce, E V Fielding
Formal specification – a comparison of two techniques

RAL-85-052
C J Carlile, A D Taylor, W G Williams
MARS – a Multi-Angle Rotor Spectrometer for the SNS

RAL-85-053
D E Baynham, R C Coombs, C N Uden
Magnet system studies for the ZEUS experiment

RAL-85-054
P R Norton
The experimental status of the EMC effect

RAL-85-055
K Abe et al
Lifetimes, cross sections and production mechanisms of charmed particles produced by 20 GeV photons

RAL-85-056
H-M Chan, S T Tsou
Gauge theories in loop space

RAL-85-057
H-M Chan, S T Tsou
Constrained Lagrangian theory for monopoles

RAL-85-058
P W Jeffreys et al
A phototriode instrumented lead glass calorimeter for use in a strong magnetic field in OPAL

RAL-85-059
S W Lovesey
Theoretical challenges in neutron scattering

RAL-85-060
R G Evans
The basic physics of laser fusion

RAL-85-061
X J Wang, M Warner
The Maier-Saupe theory of nematic polymers

RAL-85-062
R D Williams
Two phase transitions in nematic droplets

RAL-85-063
D R Perry
The induced radioactivity danger parameter for gamma radiation

RAL-85-064
G H Spalding
Orbit determination and control for the AMPTE-UKS satellite

RAL-85-065
R J Dickens, M J Currie, J R Lucey
The Centaurus cluster of galaxies; I: The data

RAL-85-066
J H Coupland
Solenoids with periodic windings

RAL-85-067
D H Saxon
Lepton-hadron scattering: past, present and future

RAL-85-068
J Kwiecinski
The Regge limit, Pomeron and Regge poles in QCD

RAL-85-069
R Marshall
Jets: the materialisation of quarks and gluons

RAL-85-070
T W Bradshaw et al
Performance of the Oxford miniature Stirling Cycle refrigerator

RAL-85-071
J M F Gunn, M Ortuno
Percolation and motion in a simple random environment

RAL-85-072
R J N Phillips
Top and bottom expectations at the CERN $p\bar{p}$ collider

RAL-85-073
S K Chanda
Nastran user guide for SERC system. Finite element stress analysis package, version MSC64A

RAL-85-074
S W Lovesey, C G Windsor
Studies of the dynamic properties of materials using neutron scattering

RAL-85-075
K L Au, D Morgan, M R Pennington
Discovery of the lowest mass scalar glueball?

RAL-85-076
G E Forden
Lifetime measurements of hadrons containing heavy quarks at PETRA and PEP

RAL-85-077
D H Saxon
Jet fragmentation

RAL-85-078
R Marshall
Electroweak effects in e^+e^- annihilation

RAL-85-079
S Quinton et al
The SNS data acquisition electronics

RAL-85-080
S W Lovesey
Collective motions in dense fluids observed in neutron scattering

RAL-85-081
C W Trowbridge
Status of electromagnetic field computation

RAL-85-082
J R Lucey, M J Currie, R J Dickens
The Centaurus cluster of galaxies; II: The bimodal-velocity structure

RAL-85-083
A G Emslie, K J H Phillips, B R Dennis
The excitation of the iron K_α feature in solar flares

RAL-85-084
R A Harrison et al
The X-ray signature of solar coronal mass ejections

RAL-85-085
R D Bentley et al
Soft X-ray observations of high-velocity features in the 29 June 1980 flares

RAL-85-086
P M Gondhalekar, ed
Extragalactic infrared astronomy; RAL Workshop on Astronomy and Astrophysics

RAL-85-087
S T Werret et al
Development of a small Stirling cycle cooler for spaceflight applications

RAL-85-088
M Teper
Axial anomaly suppression (and axial U(1) symmetry restoration) at high temperatures; a lattice Monte Carlo study

RAL-85-089
M Teper
The topological susceptibility in SU(2) lattice gauge theory: an exploratory study

RAL-85-090
J Hoek
Cooling of SU(3) lattice gauge field configurations and the η^1 mass

RAL-85-091
J Conboy
Constant scattering length fits to low energy K^-p interactions

RAL-85-092
J Hunt, K Jeffrey
SERC Administrative Computing Project – final report

RAL-85-093
S J Martin
An interactive graphical editor for UK5000

RAL-85-094
D A Bryant
Ion release experiments in the solar wind

RAL-85-095
G Smith, M Waters
MicroVAX 1: An evaluation

RAL-85-096
C R Walters, I M Davidson, G E Tuck
Long sample high sensitivity critical current measurements under strain

RAL-85-097
K S Narain
New heterotic string theories in uncompactified dimensions < 10

RAL-85-098
R D Cowan, et al
Classic Multi-Configuration-Direct-Fock and Hartree-Fock-Relativistic methods integrated into a program package for the RAL-IBM mainframe with automatic comparative output

RAL–85–099
K L Au, D Morgan, M R Pennington
Discovery of the lowest mass scalar glueball?

RAL–85–101
F E Close, R G Roberts, G G Ross
Nuclear properties from perturbative QCD

RAL–85–102
J A Blissett et al
Development of a tapered cell drift chamber II: operation in high magnetic fields and different gas pressures

RAL–85–103
W Renz, M Warner
Layer hopping by chains in polymeric smectics

RAL–85–104
C R I Emson, J Simkin, C W Trowbridge
Further developments in three dimensional eddy current analysis

RAL–85–105
C Greenough, ed
Finite element library user's meeting; papers from the first meeting held at RAL, 3 October 1984

RAL–85–107
T W Bradshaw
Miniature stirling cycle refrigerators for space use

RAL–85–108
A Ridgeley
A report on the mapping of the DIDSY sensor responses as a function of micro-meteorite impact position on the GIOTTO bumper shield

RAL–85–109
D R Vizard, D L John
Millimetre wave telescope project: receiver working group package WP7– Schotty diode multipliers, Final Report

RAL–85–111
J S Hutton
Resumé: Networking in high energy physics

Lectures and Meetings

Seminars, lectures and similar RAL activities and visits to RAL are listed below:

Astrophysics Seminars

J Abolins, RAL (9 January)
IRAS observations of interacting galaxies

H Schwarz, MSSL (16 January)
The Penning Gas Imager

J Pringle, IoA, Cambridge (23 January)
Accretion disks

C Mackay, Cambridge (6 February)
CCD detectors for astronomy — new techniques and results

R Willingale, Leicester (20 February)
Cygnus X-3

J Parkinson, MSSL (6 March)
Chasing shadows and clutching at straws: measuring the Sun

C Coleman, Oxford (20 March)
Active galactic nuclei

G Bromage, RAL (3 April)
Ultraviolet observations of the Seyfert Galaxy NGC 4151

M Sandford, R Turner, RAL (1 May)
The Space Station

D Gough, Cambridge (15 May)
Helioseismology

D Martin, QMC (29 May)
Observational aspects of the 3K cosmic background radiation

J-P Connerade, Imperial College (3 July)
Vacuum ultraviolet and soft X-ray spectroscopy

G Fisher, Lawrence Livermore Laboratory (8 July)
Radiative hydrodynamics in solar flares

T Hearn, Utrecht (11 July)
Models of small coronae in hot stars

B Anderson, Jodrell Bank (18 September)
QUASAT: a high-resolution, high-quality radio imager

P Gondhalekar, RAL (9 October)
Quasars — a visit to a zoo

L Acton, Lockheed (14 October)
An astronomer in orbit

R Bleaney, Oxford (15 October)
Edmund Halley

A Gabriel et al, RAL (23 October)
Preliminary results from CHASE

S Kerridge, JPL (25 October)
The Galileo Mission

A Penny, RAL (13 November)
The age of the Universe

B Dickens, RAL (27 November)
Dark matter in clusters of galaxies

R Speer, Imperial College (11 December)
Gratings, holograms and zone plates

Geophysics Seminars

D Southwood, Imperial (22 January)
Recent studies in space plasma

A Gill, D Anderson, Oxford (5 February)
Remote sensing needs for the world climate research programme

D Barraclough, British Geological Survey (19 February)
The earth's magnetic field in time and space

S Solomon, Colorado (5 March)
Stratospheric modelling

J Pyle, RAL (19 March)
Studies of middle atmosphere chemistry and dynamics using satellite data

J Ballard, RAL (30 April)
Laboratory spectroscopy at RAL

C F Rogers, IOS (7 May)
Models of the ocean circulation mixing

R W P McWhirter, RAL (21 May)
Physics of the solar corona and the solar wind

R G Derwent, AERE (11 June)
Acidification in the environment

A F Tuck, Met Office (18 June)
Aircraft studies of tropospheric ozone

D R Lepine, RAL (2 July)
Electron observations from AMPTE UKS

G Lister, Max Planck Inst (21 November)
Numerical Computational requirements for AMPTE

G Peckham, Edinburgh (26 November)
The microwave limb sounder for UARS

A O'Neill, Met Office (3 December)
Dynamics of the middle atmosphere: some recent developments

D Eccles, RAL (10 December)
The performance of the RAL OSCR

D Hartmann, Seattle (17 December)
The earth's radiation budget experiment — Purpose and method

M Wengler, CalTech (19 December)
Millimeter and sub-millimeter wave mixers based on superconducting tunnel junctions