SPACE SCIENCE RESEARCH

at Rutherford Appleton Laboratory

Reprinted from "Rutherford Appleton Laboratory 1987"

1. Astronomy and Planetary Science Board and BNSC

This year was notable for a number of successes and milestones. Perhaps the most significant was the completion of the James Clerk Maxwell Telescope on Mauna Kea in Hawaii to cost, schedule and specification. The telescope was officially inaugurated by HRH the Duke of Edinburgh in April and, in July, was formally handed over to the Royal Observatory Edinburgh for operations. Already the telescope is making important new observations with excellent data being recorded by, for example, the 230 GHz receiver developed by Mullard Radio Astronomy Observatory and RAL.

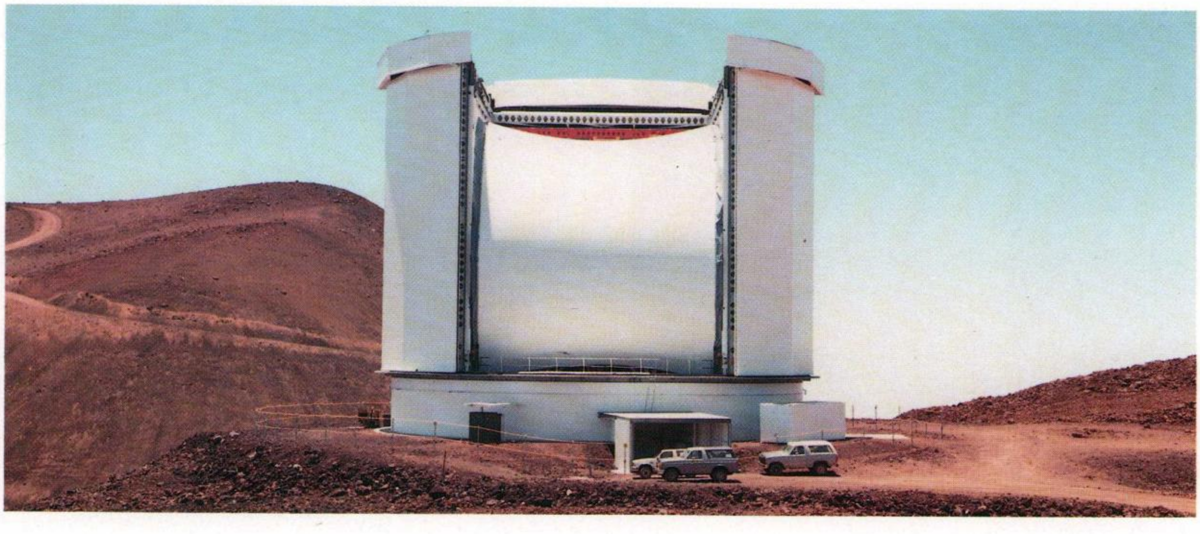
In space, the Japanese X-ray satellite GINGA (previously ASTRO-C) was launched in February carrying the Leicester-RAL-Japan Large Area Proportional Counter. This mission was fortuitously timed with respect to the 1987 supernova in the Large Magellanic Cloud and has obtained valuable observations of that object. Several projects, including the X-ray astronomy satellite ROSAT, the Earth observation projects ISAMS, MLS and ATSR, and the European infrared observatory, ISO, have all made progress. Special mention is deserved for MLS, the Microwave Limb Sounder, led by the Jet Propulsion Laboratory in the USA. Consistently, the UK Heriot-Watt - RAL team has achieved integration and test targets and specifications well ahead of US colleagues, despite the comparatively small size of the British team.

On the ground, STARLINK has continued to provide an excellent service to UK astronomers although the increase in the size of the system continues to outstrip the increase in resources. The analysis and interpretation of results from the AMPTE and VIKING missions in space plasma science have produced many new insights and advances. The Geophysical Data Facility has now been established and is beginning to provide a valuable service to UK geophysicists. The Aberystwyth VHF radar for atmospheric studies is partially completed. The UK has continued to obtain excellent results from the European Incoherent Scatter Radar supported by RAL. Another important advance is the breakthrough to sub-20 K temperatures using a Stirling cycle space cooler.

COSMIC RESEARCH

The last two decades have witnessed a dramatic opening of the window on the Universe as increasingly sophisticated experiments to observe celestial sources across much of the electromagnetic spectrum have been successfully launched into space. In some spectral regions only tantalising glimpses have been possible so far while, in others, data of a quality to rival ground-based observations has been returned. Developments in the technology of ground-based telescopes have not stood still, however, and the completion of the James Clerk Maxwell Telescope (Fig 1.1) should advance understanding of the atomic and molecular processes in space which are a prelude to star formation. The UK has played a major role in virtually all these areas and RAL is in the vanguard of this progress.

1.1 James Clerk Maxwell Telescope on Mauna Kea, Hawaii. (RAL neg 87FC3120)



James Clerk Maxwell Telescope

Following the first successful reception of radio signals from astronomical sources in December 1986, the performance of the telescope has been improved and the facility commissioned. It has been carrying out a programme of scheduled observing since early September 1987 (Fig 1.2).

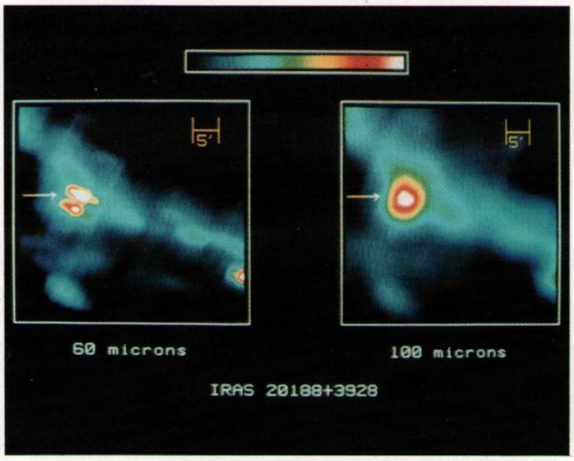
At the time of receiving the first radio signals, the surface accuracy of the 15 m diameter telescope was measured to be approximately 95 μm. Using a 94 GHz millimetre wave metrology system, the surface accuracy was improved to close to the specified value of 50 μm rms by the time scheduled observing began; thermal and gravitational effects will set a limit to the accuracy achievable. Another important element of the specification is pointing accuracy. By detailed changes in the drive systems and encoder mounts, the pointing accuracy about the elevation and azimuthal axes was improved to 3 arcsec compared to the specification of 5 arcsec. Similarly, the associated tracking accuracy has been measured, over short timescales, to be better than the specification of 2 arcsec.

After commissioning the telescope and its enclosure, a period of trial observing was carried out during August using the 230 GHz line receiver and the bolometric receiver UKT-14. During this period the latter received signals at 350 μm wavelength, demonstrating the good performance of the telescope and the transparency of the atmosphere above Mauna Kea. Both receivers performed very well and reliably, while new filters for UKT-14 gave much improved transmission.

Infrared Astronomical Satellite (IRAS)

The IRAS Post Mission Analysis Facility (IPMAF) is now in its fourth year of operation since the end of the IRAS data collection phase. In 1987, several catalogues (and a number of non-IRAS ones) were incorporated into the astronomical database maintained by IPMAF and distributed to the STARLINK nodes.

1.2 False colour picture of the compact H II region W3 from early James Clerk Maxwell Telescope observations at 350 μm showing two groups of newly formed stars. (88FC1123)



1.3 Bipolar IRAS source 20188+3928. (87RC5378)

The data analysis system for producing images of small regions of the sky has undergone a programme of continuous improvement (Fig 1.3) and several visitors from UK and overseas laboratories have used the system to produce images to complement data obtained in other parts of the electromagnetic spectrum. These research programmes include the comparison of molecular line and far infrared emission in star formation regions and the correlation of the infrared cirrus with the distribution of atomic hydrogen.

The influence IRAS has had on all branches of astronomy was evident at the 3rd International IRAS Conference 'Comets to Cosmology' held at Queen Mary College London in early July. There was a significant contribution from UK astronomers who had used IRAS data made available by IPMAF.

In collaboration with the University of Kent, research at RAL utilising the IRAS database has concentrated on studying the distribution of compact molecular clouds (sites of star formation) within the Galaxy following their identification in the IRAS Point Source Catalogue. Also, molecular line observations have been carried out on the strongest of these sources revealing that many of them exhibit interesting astrophysical phenomena such as bipolar outflow.

Infrared Space Observatory (ISO)

ISO is an ESA infrared astronomy satellite due to be launched in 1993. It consists of a 60 cm diameter telescope and four focal plane instruments, each cooled to cryogenic temperature with liquid helium. Cooling is needed to eliminate the thermal radiation of the telescope and instruments which would otherwise saturate the very sensitive infrared detectors. The UK is involved in three of the focal plane instruments in collaboration with European and American partners.

Technical innovation involved with the ISO instruments covers a wide range from fundamental aspects, such as the change in design properties of materials upon cooling down to cryogenic temperatures, to the design of special motors and mechanisms. In many cases, the properties of

1.4 Supernova 1987A in the Large Magellanic Cloud.

materials have had to be specially measured. The instrument design must also accommodate the substantial mechanical stresses which can occur when cooling is taking place. Very close limits are placed on the size and weight of the instruments and the power they dissipate when operated, since these bear directly on the lifetime of the mission.

In addition to providing the required electrical ground support equipment with computing and software systems, facilities are being built at RAL for testing and calibrating the complete Long Wavelength Spectrometer instrument models and sub-units. These involve providing the very low thermal background to match their operating environment in space without which the very high sensitivity cannot be obtained.

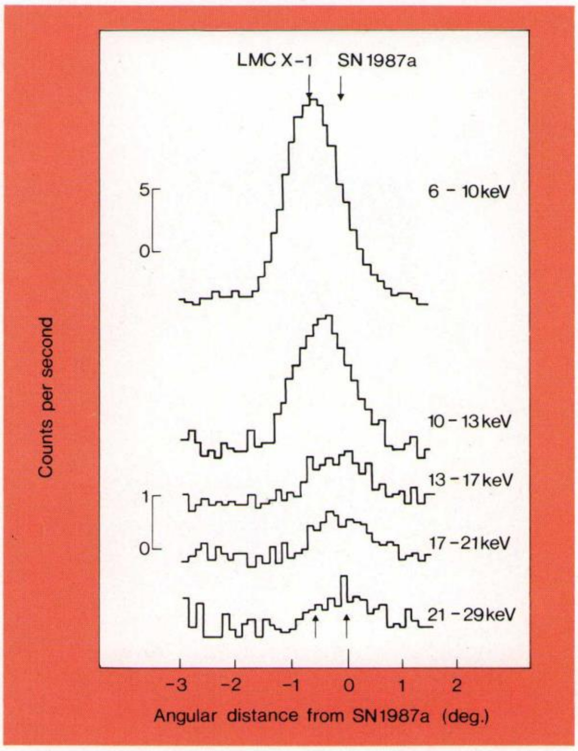
International Ultraviolet Explorer (IUE)

As IUE approaches the tenth anniversary of its 26 January 1978 launch, its prospects for several more years of valuable operation remain good with all systems functioning well, except for a slow but expected degradation of the solar arrays which provide power to the satellite.

That IUE is still a flexible and powerful tool was clearly demonstrated during 1987 by the response to the appearance of a supernova in the Large Magellanic Cloud, Earth's nearest extragalactic neighbour (Fig 1.4). This event, marking the death of a massive star, is probably one of the most important in astronomy this century. Its significance lies in its close proximity, permitting astronomers to study it in detail with all their modern instrumentation with the expectation that its decline can be followed for many years, and in that its distance - and thus its absolute brightness - are well known.

Within a few hours of its discovery on 24 February 1987, IUE was slewed to observe the supernova with both its spectrographs covering the range 1150-3200 Å and in both high and low resolution modes. As the supernova cooled, the amount of energy it emitted in the far ultraviolet declined until only a faint stellar spectrum was observed. Careful measurements on the spatial extent of this spectrum provided a key to the nature of the progenitor star: it was the early type supergiant Sk-69°202. Monitoring of spectral changes continues.

1.5 Detection of supernova 1987A by GINGA.



RAL personnel remain closely involved with the operation of IUE and the provision of facilities to UK university astronomers who travel to Madrid to carry out their observations. An equally important role is that of providing ready access to archival IUE data and a new facet of this activity will be the introduction of an on-line archive of low resolution spectra early in 1988; RAL personnel have been involved in its implementation.

GINGA

On 5 February 1987, 0630 UT, the Japanese rocket M3SII-3 launched the ASTRO-C satellite precisely on schedule. In orbit, it was renamed GINGA (Japanese for Galaxy). The principal instrument on board is the Large Area Counter, built by Leicester University and RAL. It consists of a set of eight multiwire proportional counters sensitive over the energy range 1.5-36 keV and capable of observing X-ray fluctuations on timescales down to milliseconds. From launch until mid-October, it was operated in a calibration mode. Efficiency, field of view, dead time corrections, energy resolution, etc were calculated from observations of well known objects such as the Crab Nebula. Since then, the wider astrophysics community has been able to make observations.

Several exciting objects were studied during the calibration period, including the supernova observed optically in the Large Magellanic Cloud on 24 February. Regular observations at first failed to find a candidate in the X-ray band but a new source was seen in August at the position of the supernova, close to the known LMC X-1 but exhibiting a more intense hard X-ray spectrum (Fig 1.5). Its evolution is now being carefully followed and the data will give a new insight into the explosion and its interaction with the nearby environment.

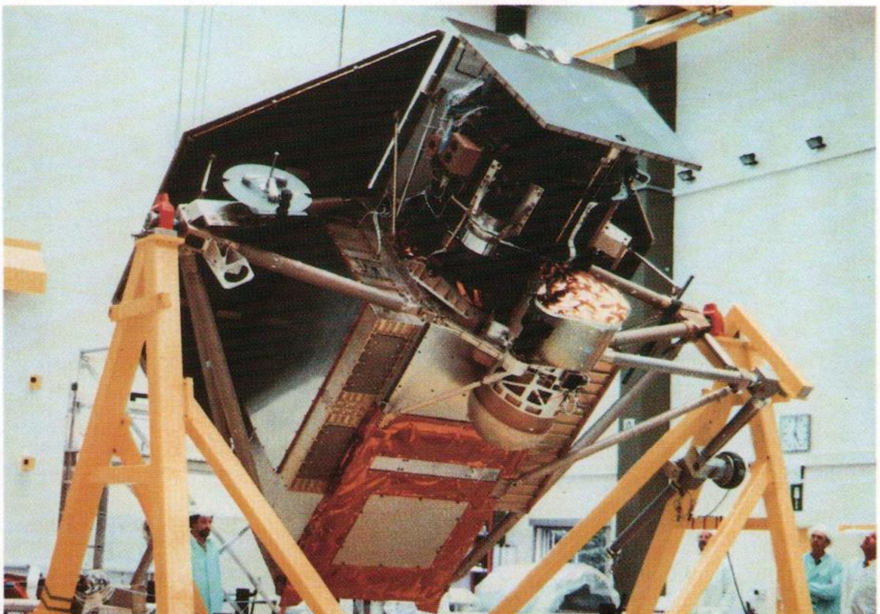
Roentgensatellit (ROSAT)

For this joint German/UK/US space project, five astrophysics groups in the UK are combining their expertise to construct an imaging XUV telescope. Known as the Wide Field Camera (WFC), the instrument forms part of the German ROSAT due to be launched in 1990. WFC will conduct the first survey of the complete sky at extreme ultraviolet wavelengths between 60 and 300 Å. The large sky coverage of ROSAT and its high sensitivity promise unexpected astronomical discoveries for the 1990s.

Four major activities were completed during the year using various versions of the WFC hardware. A fully functional WFC electrical model was used with the ROSAT spacecraft to conduct a series of simulated in-orbit operational sequences. A full scale structural model of WFC was instrumented and integrated with the ROSAT structural model for acoustic noise tests (Fig 1.6). The WFC telescope assembly with flight mirrors was tested in a full aperture X-ray facility which verified the mirror performance. An electrically representative version of the WFC flight model was integrated and tested for interface and functional compatibility with ROSAT. This model is now being refurbished in readiness for environmental tests with the complete spacecraft in Germany next year.

ZEBRA

ZEBRA, a balloon borne γ-ray imaging telescope, is expected to break new ground in providing high resolution images of γ-ray sources at high sensitivity over a broad energy range. It has been developed by Southampton University in collaboration with RAL and three Italian laboratories. The RAL contribution covers design and development of the 3-axis platform



1.6 Structural model of the UK Wide Field Camera mounted on the ROSAT spacecraft. (86FC2233) and control system, provision of a control ground station and a test facility and full participation in integration, test and flight operations. Preparation of the platform and control system for the first flight of ZEBRA, due in spring 1988, has reached an advanced stage and work at RAL now centres on integrating the experiment hardware and evaluation of the platform control and experiment electronics prior to shipment to Texas.

SOLAR PHYSICS

Understanding solar phenomena gives unique insight into other stars. RAL scientists are particularly interested in the energetic occurrences on the Sun such as solar flares and active regions, the output of which is mostly in the ultraviolet and X-ray regions. Detecting this emission means placing detectors and other instrumentation in space. RAL has been involved in experiments on the highly successful Solar Maximum Mission and the CHASE instrument on Spacelab-2, launched on the Shuttle in 1985.

Solar Maximum Mission (SMM)

SMM is a NASA spacecraft observing solar activity phenomena over a wide range of wavelengths from γ-rays to visible light and is the only spacecraft able to take space borne observations of the Sun at present. The X-ray Polychromator (XRP), in which RAL was closely involved, continued to work well and return data, especially over the past year when solar activity had increased, approaching its 1991 maximum which experience suggests may be high.

RAL attention is focused on wavelength scans performed by the part of the XRP instrument known as the Flat Crystal Spectrometer. The main aim of this spectrometer was to take high-resolution spectra during flares and active regions. Several new spectral lines have been seen and, though their identifications remained puzzling for a time, it soon became clear that they were due to highly ionised iron and had useful capabilities as diagnostics of the flaring region itself.

Coronal Helium Abundance Spacelab Experiment (CHASE)

CHASE was developed by RAL and the Mullard Space Science Laboratory (MSSL) and flew aboard the Space Shuttle 'Challenger' in July 1985. The complete catalogue of flight data is now available and is proving to be an essential aid to the scientific analysis.

Emission line measurements of several EUV spectral lines measured by CHASE have been analysed in terms of the differential emission measured as a function of temperature. Such data is particularly useful for studying the differences between various feature such as coronal holes, active regions and the quiet Sun regions. To improve the accuracy of this analysis, an intensity calibration was derived for the instrument by comparing the CHASE results with those of previous measurements. Data analysis on this project is almost complete.

The determination of the helium abundance data is clearly of prime importance in data analysis. The major difficulty associated with placing a definitive value to this has been the inability to determine the in-flight mirror scatter with sufficient precision. As a consequence, a programme of laboratory work has been initiated with the goal of measuring the scatter at a number of EUV wavelengths. This work is progressing well but it is too early to establish a value for the scatter.

SPACE PLASMA SCIENCE

Research into the wide and still expanding field of interaction between the Sun, the Earth and other bodies is being pursued within a number of different programmes at RAL. In-situ measurements from space and radio sounding from the ground are carried out with related theoretical studies in support of and in collaboration with university groups. Current projects range from those where results already in hand are in course of interpretation to those where instrumentation is being designed and produced and where new proposals are being advanced. Considerable progress has been made in understanding the chain of events linking the Earth to the Sun through the solar wind and in advancing the knowledge of fundamental plasma physics essential to applications ranging from the terrestrial laboratory to distant stars.

SOLAR SYSTEM PLASMAS

Research into space plasmas has been based on in-situ measurements from spacecraft at four locations: in the solar wind, where the flow of the solar wind is first disrupted by the Earth, at the magnetospheric boundary layers, and just above the atmospheric polar regions where the aurora borealis is produced when electrons enter the atmosphere.

Solar Wind

On 1 November 1984, the NASA spacecraft of the AMPTE mission found itself in the solar wind for a brief period owing to a sudden compression of the Earth's magnetic field. This prompted a study of the state of the solar wind on that day using measurements from the UK spacecraft of the AMPTE mission (AMPTE-UKS) which revealed that the cause of the compression was the exceptionally high density of the solar wind. It has also been possible to establish the influence of the Earth's bow shock on the solar wind, even upstream from the shock. In particular, bursts of wave activity in the solar wind have been identified and the causes of waves observed upstream have been found.

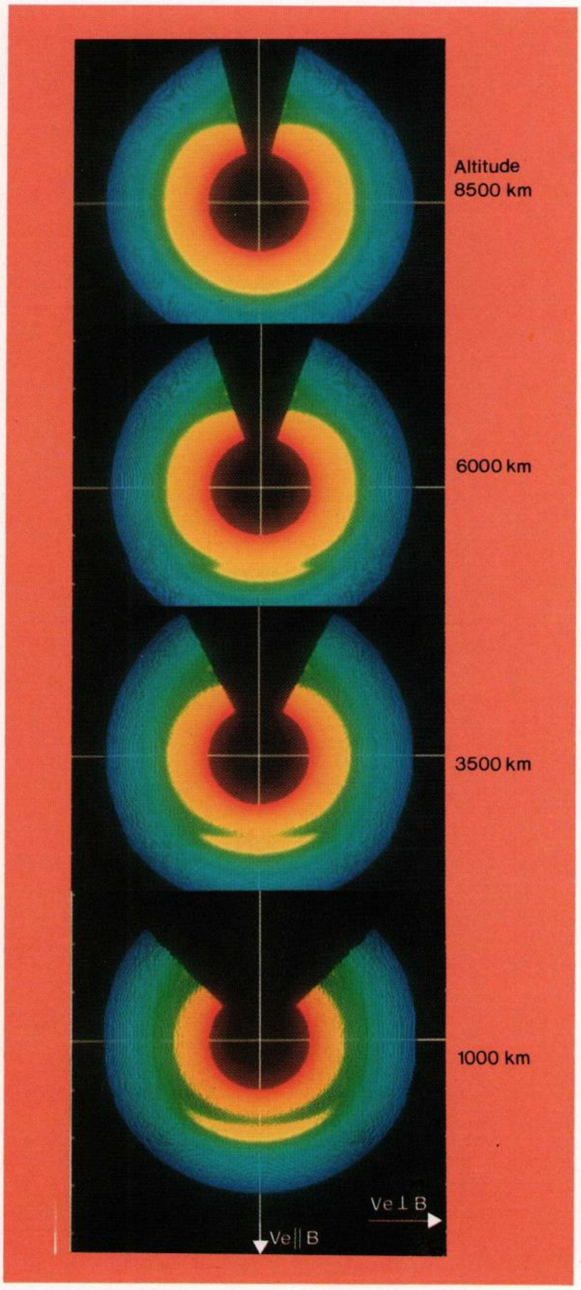
Bow Shock

The processes which generate the turbulence have been studied theoretically and the exact nature of the process which dissipates the solar wind energy has been uncovered. The calculations have been extended to predict the distance over which the main slowing and deflection of the wind should extend. The results agree well with distances measured directly from the spacecraft. AMPTE measurements have revealed the extent to which the shock surface is distorted in localised regions, some of which can protrude deep into the solar wind.

Magnetospheric Boundary Layers

The problem of where and how the solar wind breaks through the 'barrier' of the Earth's magnetic field at the magnetopause has been tackled in two ways: using measurements of electrons from AMPTE-UKS and of energetic helium ions from the Swedish spacecraft VIKING.

1.7 Cray supercomputer simulation of auroral electron acceleration.



The AMPTE-UKS electron measurements show that on most occasions solar wind electrons form a layer inside the Earth's magnetosphere on the sunward side of the Earth. The electron intensities do not fall monotonically as the Earth is approached, however; a layer of solar wind electrons with intensities even higher than those outside the magnetosphere is found. The intensities are high because the electrons appear to accelerate as they interact with the plasma from the inner magnetosphere.

In the solar wind, helium tends to be doubly ionised whilst in the Earth's magnetosphere singly ionised helium predominates. The VIKING measurements have shown that there is a layer of doubly charged 'solar wind' helium just inside the magnetosphere but, as the ions become transported closer to the Earth, collisions with hydrogen atoms of the geocorona allow the ions to gain one electron by charge exchange with hydrogen atoms. Consequently, deep within the magnetosphere, the helium ions are singly charged and no longer recognisable as of solar wind origin.

Auroral Electron Acceleration

A theory has been developed at RAL to explain the very marked and characteristic speeding up of electrons just before they reach the atmosphere in the polar regions. It predicts that ion streams observed 60,000 km above the atmosphere moving towards the Earth would induce electrostatic plasma waves as they traverse the ambient magnetosphere plasma. Accompanying electron streams, however, would absorb wave energy and accelerate, rather than inducing waves, especially if the electrons were moving at velocities just below those of the waves. It has now been possible to confirm the details of the theory by using the Cray supercomputer at RAL to simulate the behaviour of the plasma (Fig 1.7).

Theoretical studies reveal that entirely new mathematical treatments are required if turbulent plasma behaviour is to be understood. These new treatments are being developed at RAL. New ways have been found of describing how energy is transported through plasmas, either by waves or particle populations. One practical consequence of this is the finding that there is a need to take turbulence effects into account when interpreting remote radar-scattering measurements of plasma characteristics.

SOLAR-TERRESTRIAL PHYSICS

At the core of the RAL programme to investigate the solar-terrestrial interaction chain are the EISCAT radars. These are situated at three sites in northern Scandinavia within the auroral oval where energy from the solar wind is coupled into the Earth's ionosphere and upper atmosphere. Following the discoveries resulting from individual events observed simultaneously by the AMPTE satellites and EISCAT, a statistical survey has been made of the control of high-latitude ion flows ('convection') by the north-south component of the interplanetary magnetic field (IMF) which is embedded within the solar wind flow. This has confirmed the importance of magnetic reconnection between IMF and the geomagnetic field, given the first measurement of the ionospheric response time and yielded a model of convective flows as a function of IMF with unprecedented temporal resolution.

Variations in the global pattern of convection have also been studied using EISCAT in coordination with many other radars around the world and satellites such as VIKING, IMP8 and Dynamics Explorer 1. The effects of variations in reconnection rates have been observed as expansions and contractions of the polar cap (Fig 1.8). In addition, the effects of short-lived bursts of reconnection (flux transfer events) have been considered and observations of twin vortex flow signatures, impulsive damped wave trains and upward flows of ionospheric ions near the equatorial magnetopause have all been explained in terms of these events.

The major recent discovery made at the Laboratory using EISCAT has been that of non-thermal plasma in the ionosphere. This is caused by the driving of the convecting ion gas through the rather more sluggish neutral atmosphere (or 'thermosphere'). Predictions of when and where non-thermal plasmas should occur have been made and their effects on EISCAT data studied so that the RAL analysis algorithms can be used to investigate the 3-D distribution function of the ion velocity. Theoretical work with Imperial College has demonstrated that non-thermal plasma may well offer an explanation of RAL observations (using various EISCAT common programmes and data from Dynamics Explorer 1) of ion flows increased in response to enhanced ion-neutral frictional heating. Initial observations by EISCAT in conjunction with field-aligned thermosphere measurements using a Fabry-Perot interferometer were very successful and will give much information on momentum exchange and distribution function deformation by ion-neutral collisions.

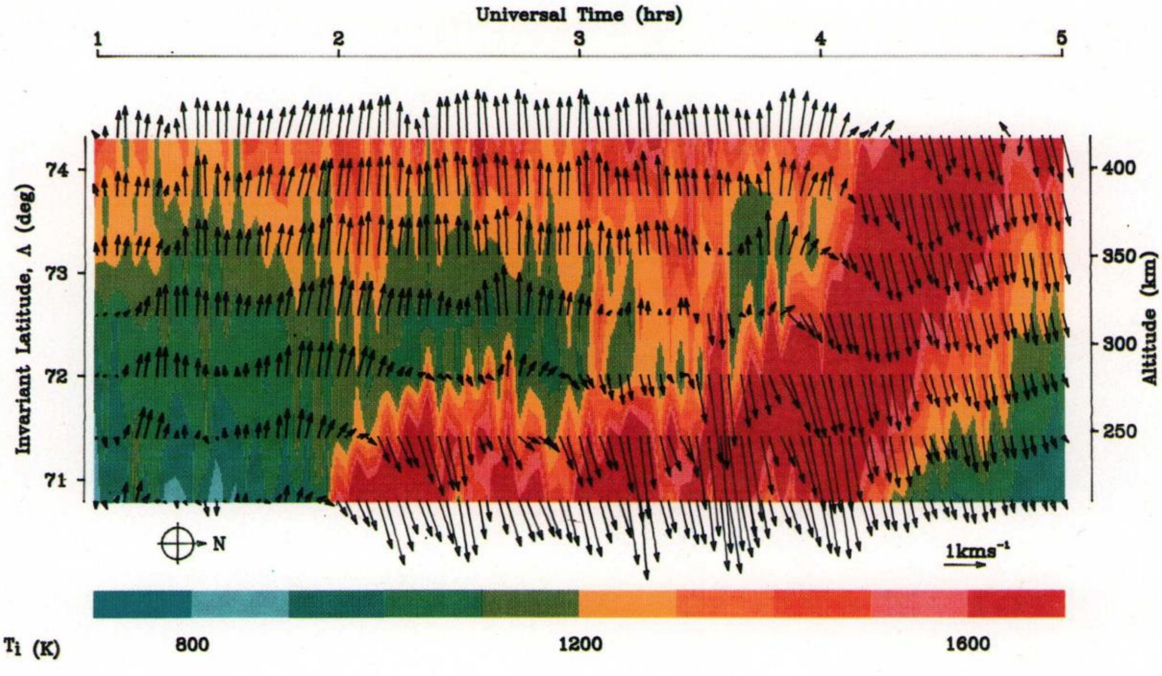
GEOPHYSICAL RESEARCH

Whilst exploration of the cosmos from space has an excitement all its own, the study of the Earth's atmosphere and surface from above is no less fascinating and offers immediate practical benefit to many areas of everyday life - climate, communications, meteorology, land management, etc. RAL is fully involved in the UK effort in this sphere.

ATSR and Lower Atmosphere Research

The accurate measurement of sea surface temperature (SST) is an important factor in climatology and measurements of the global energy balance. The Along-Track Scanning Radiometer (ATSR) is an infrared imaging radiometer designed to measure sea surface temperature from space with the very high levels of accuracy (about 0.3 K) required for modelling the behaviour of the global climate. It is due to fly on ERS-1, the European Space Agency's first Remote Sensing Satellite, in spring 1990.

1.8 Ion flow patterns over the polar cap at dawn. (87FC5348)



1987 has been a year of intense activity for RAL and its collaborators (Oxford University, MSSL, the Meteorological Office, Centre Recherche sur Physique d'Environment, France, and laboratories in Australia). Important achievements include completion of vibration tests of the structural model of the satellite which have verified the mechanical interfaces between the ATSR and the ERS-1 spacecraft. During the year, considerable progress has been made in the manufacture of the ATSR engineering model. Work has also started on the flight model which is due for delivery towards the end of 1988. Much progress has been made in defining the ground segment data processing requirements, and also in defining and formulating plans for the scientific investigation phase of the project.

Surface Temperature Radiometer

Future satellite missions, including ATSR, will have the ability to measure SST to an accuracy of about 0.3 K. SST measured by a satellite differs from the bulk temperature measured by a thermometer. To corroborate satellite measurements, a ground-based radiometer of similar characteristics and comparable accuracy has been developed by RAL in collaboration with MSSL, Oxford and Southampton Universities. It is intended for shipboard operation as an instrument capable of providing ground validation for ATSR. The instrument operates at two wavelengths, 11 m and 12 m, with a spectral response matched to that of ATSR and AVHRR, a current operational satellite-borne sensor. The measurement accuracy is of the order of 0.1 K with noise levels of about 0.04 K rms.

Space Radar Altimetry

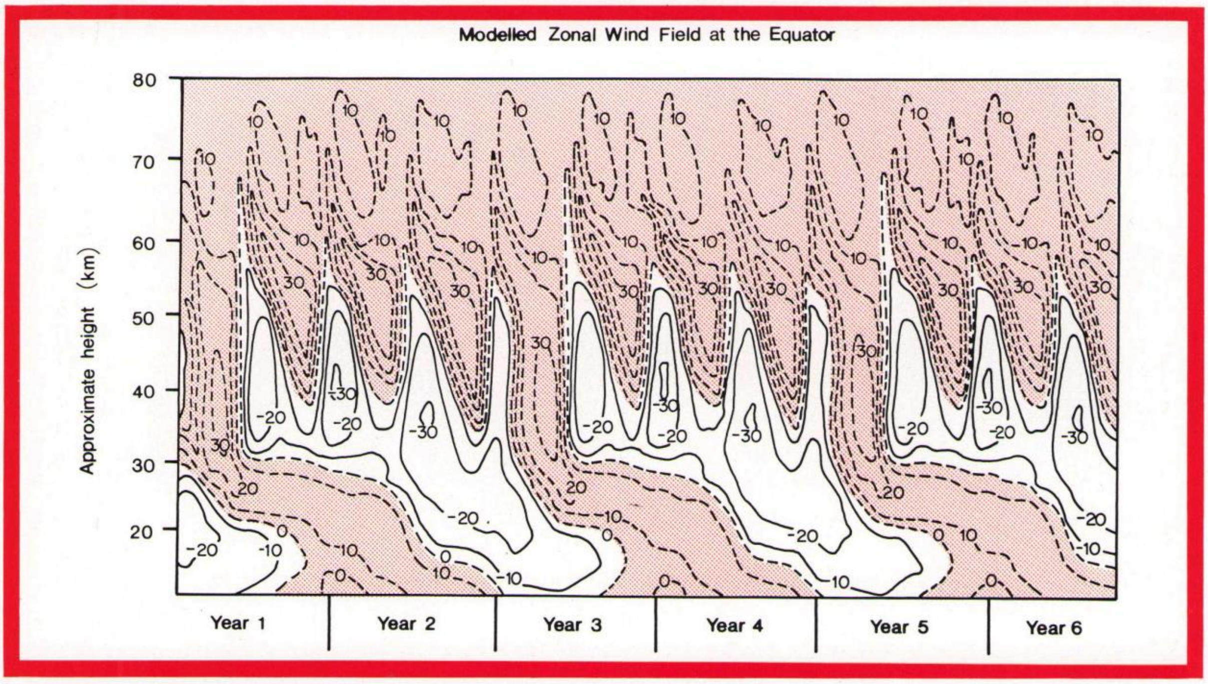
An accurate knowledge of the shape of the Earth's surface is a basic requirement for many geophysical studies. In the case of the oceans, the shape of the mean sea surface is determined by the gravitational field, the tides and currents, and the pressure of the atmosphere on the surface. This topography can be used to study the structure of the Earth's crust below the oceans and as a means of monitoring ocean currents to determine their role in global and local climates. Detailed knowledge of the topography of Greenland and the Antarctic will contribute to mass-balance analyses of those ice caps, which will also help to determine their role in climate change. The measurements required can be made from space using radar altimeters and RAL has for several years been supporting the development of a European programme of satellite altimetric measurement.

During the last two years, RAL working with scientists and engineers from MSSL and British Aerospace under ESA sponsorship, have made major progress in developing advanced concepts for future space altimetry systems. Key sub-systems have been designed and built and a conceptual study of the instrument is in progress.

Upper Atmosphere Research Satellite (UARS)

UARS will be launched by NASA in the early 1990s from the Space Shuttle. The photochemistry, dynamics and energy balance of the Earth's atmosphere above the tropopause will be investigated from data recorded by the 11 scientific instruments on board UARS. This data set will be the most comprehensive and coordinated yet obtained on the

1.9 Quasi – biennial oscillations in the equatorial wind field.



middle atmosphere and will be crucial to a proper understanding of many atmospheric phenomena, especially the recently discovered drastic reduction of the protective ozone layer over Antarctica.

ISAMS, the Improved Stratospheric and Mesospheric Sounder, is a joint development between Oxford University and RAL, with British Aerospace as the industrial prime contractor. It is a complex multichannel instrument based on the pressure modulation radiometry technique in which high radiometric sensitivity is achieved through the use of photoconductive detectors cooled to 80 K by miniature Stirling cycle coolers.

MLS, the Microwave Limb Sounder, is being developed by the US Jet Propulsion Laboratory (JPL). Atmospheric radiation from selected emission lines in the millimetre wavelength spectral region will be analysed using high-resolution heterodyne spectrometers to yield measurements of ClO, H_2O, O_3, H_2O_2 and pressure throughout the Earth's middle atmosphere. RAL and Heriot-Watt University are providing spectrometers at 183 GHz for the measurement of O_3 and H_2O with RAL producing the sensitive mixers at the heart of the instrument.

Atmospheric Trace Molecule Spectrometer (ATMOS)

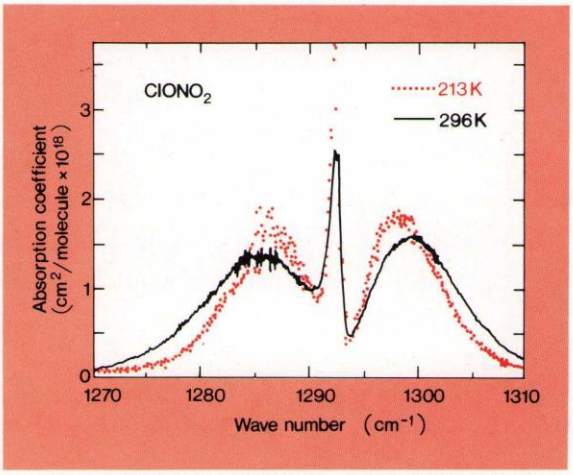
The ATMOS instrument, a high-resolution interferometric spectrometer developed at JPL, was flown on the Space Shuttle in 1985 to record atmospheric absorption spectra of the atmosphere using the Sun as the radiation source. RAL has been collaborating with JPL, Oxford University and other centres in the derivation of atmospheric temperature and gaseous chemical composition data from the spectra.

Work done at RAL this year includes determination of upper limits of stratospheric ClO, H_2O_2 and HOCl concentrations as well as the retrieval of nitric acid profiles from ATMOS data. $ClONO_2$ retrievals have been re-assessed using new measurements of absorption cross sections obtained in the laboratory spectroscopy facility at RAL.

Middle Atmosphere Data Analysis

Data from satellites and balloons is being used with theoretical models of the atmosphere to gain an increased understanding of the photochemical and dynamical behaviour of the middle atmosphere. Much of this work is directed towards preparation for the exploitation of UARS data.

A two-dimensional numerical model of the atmosphere is being improved to include the effects of the Quasi-Biennial Oscillation (QBO) which occurs in equatorial latitudes at relatively low altitudes (Fig 1.9). Results have been compared with observations of QBO in zonally averaged winds and temperatures and a comparison with the observed QBO in ozone distributions is in its early stages. A collaboration with several university groups, the Meteorological Office and the European Centre for



1.10 Experimental absorption coefficients for the ν2 band of $ClONO_2$.

Medium Range Weather Forecasting has been started to establish a 3-D modelling capability using the Cray supercomputer at RAL in preparation for scientific exploitation of the UARS data set.

Laboratory Spectroscopy

The programme of laboratory spectroscopy to quantify the high resolution infrared and visible molecular spectra of atmospheric species has continued. Such data is essential for the quantitative measurement of atmospheric parameters by remote sensing techniques as employed on UARS and ATMOS. Facilities at RAL include a high-resolution Fourier transform spectrometer and a number of coolable absorption cells with absorber pathlengths up to 500 m.

Work on unstable/reactive radicals and gases has been completed this year. In collaboration with Oxford University, long-path spectra of the ClO and NO_3 radicals have been recorded through an absorption cell in which gases are reacted and flowed. The temperature dependence of absorption cross-sections in infrared bands of $ClONO_2$ has been measured between 20°C and -60°C (Fig 1.10) and the results used to obtain new atmospheric $ClONO_2$ profiles from ATMOS data.

Self-broadening coefficients for spectral lines are the least understood and most poorly measured spectroscopic parameters which impact on the quality of atmospheric data from ISAMS. Preliminary measurements of self-broadening effects in the infrared spectra of H_2O have been completed.

MST Atmospheric Radar

RAL in collaboration with University College of Wales, Aberystwyth, is developing a new mesosphere-stratosphere-troposphere (MST) radar facility for atmospheric studies near Aberystwyth. The new site has been covered with the first 64 of an eventual 400 aerials (Fig 1.11). These are interconnected by a network of cables and power dividers to create the effect of a single aerial with a

1.11 MST radar array at Aberystwyth.

narrow vertical pencil beam. Another network of relays and cables allows this pencil beam to be deflected in various directions and detect movements in the atmosphere from Doppler shifts in frequency of the reflected signal.

The first two transmitter amplifiers and the radar receiver are being installed in temporary accommodation for the first phase of operations. The computer which will control the radar programme and reduce and present the incoming data has been delivered and is undergoing acceptance tests. First results from the radar are expected to produce wind profiles up to about 17 km with 150 m height resolution.

SUPPORT ACTIVITIES

Whilst individual experiments involved in the advancement of research tend to be specifically designed to carry out particular tasks, their development and exploitation can most effectively take place in an environment containing the right support facilities and a continuity and depth of expertise. Such an environment is to be found at RAL and the support given to the numerous projects takes several forms.

STARLINK

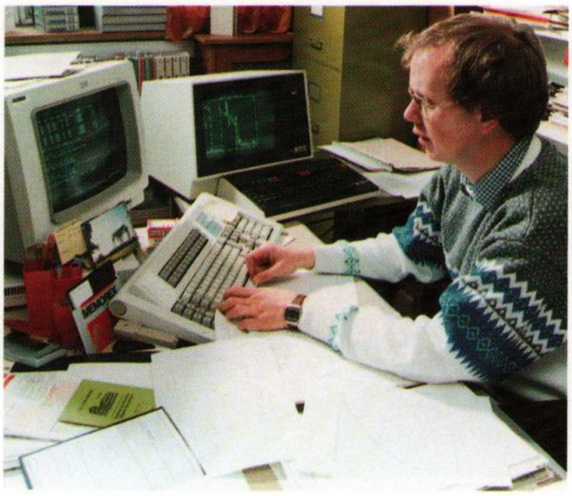
STARLINK is the UK national coordinated facility for interactive computing in astronomy and astrophysics. It is a computing system and a computing service with over 800 users throughout the UK. The use of STARLINK hardware and software for radio astronomy and space astronomy has increased considerably in recent years and is now split equally between space- and ground-based data analysis.

A new major node has been funded this year in Northern Ireland with computers at Belfast and Armagh bringing the total to 11 main centres. In addition, seven smaller Micro VAX-based sites are associated with STARLINK, including new sites this year at QMC and Oxford, and there are another dozen remote user group locations. All STARLINK nodes and associated sites are interconnected. Running the computers as a network has proved immensely valuable and users freely exchange software, messages, drafts of scientific papers and, in modest quantities, data.

STARLINK exists to provide the most cost-effective facility for astronomers. It achieves this by coordinated purchase and common maintenance of hardware and systems software, providing a service which is essentially identical to the user whether at Edinburgh, Birmingham or London, for example. STARLINK funds and supports eight national Special Interest Groups and funds contract programmers to act as coordinators and implementers of common software. The STARLINK Software Collection now has well over half a million lines of source code. There have been many further releases during the year. This collection is running on many non-STARLINK computers including over 80 sites throughout Europe and in the USA, Australia, China, India and elsewhere.

Geophysical Data Facility

The Geophysical Data Facility (GDF) has been established to enable the geophysics research



1.12 Using the Geophysical Data Facility. (87RC5395)

community to gain access to data from a wide range of middle atmosphere, climate, and solar-terrestrial experiments from ground based and space borne instruments (Fig 1.12).

An optical disk system has been acquired for data storage and exchange. This will allow GDF staff to gain experience in this new area of technology and will lead to a considerable reduction in the physical volume occupied by data. Another major step has been the establishment of a database containing middle atmosphere temperatures and composition measured by the LIMS experiment on the Nimbus 7 spacecraft.

The general user interface to the facility has been improved considerably, primarily to help and encourage users. By providing cross-links to other geophysical databases at RAL, data sets from different sources can readily be combined. High level command instructions and graph plotting routines are now also available to aid data manipulation.

World Data Centre

The World Data Centre (WDC) at RAL collects and makes data available to the scientific community on solar-terrestrial physics. About 140 requests for traditional data services (ie data on paper or microfiche) have been processed during the year. Many of these requests entail periodic despatch of data on daily, weekly or monthly time scales. Annual use of the digital database services has risen to about 1500 queries.

The major advance during the year has been the establishment of an on-line database containing scaled parameters (eg critical frequencies) from UK ionosondes. Users in UK universities can now display this data on their terminals and transfer it to their computers for specialised processing. The database is integrated with the ionosonde data processing software to facilitate updating and is also used by WDC staff to produce standard products such as the monthly data bulletins for each observatory. WDC staff prepared a major display to mark the 30th anniversary of the 1957/8 International Geophysical Year (IGY). The system of World Data Centres was first set up as part of IGY activities and the display also marked the WDC anniversary. The display was the centrepiece at a commemorative meeting at RAL on 3 July.

ERS-1 - Data Centre Support

The large volumes of data which will be produced by the experiments on ERS-1 will be processed in several European countries. RAL is playing a strong supporting role in developing the procedures to be used at the UK-ERS Data Centre to process the sea surface temperature data; it is also responsible for assessing the quality of all of the data products. The latter task involves the collection and rapid processing and evaluation of some engineering data and comparative geophysical data sets.

Atomic Structure Research

An essential ingredient of the analysis of the spectra of stars and nebulae is the fundamental atomic data relating to the observed absorption and emission lines. Such data includes wavelengths, levels of excitation, oscillator strengths and other parameters which determine the populations of levels giving rise to astrophysically important features. Whilst careful experimental work has given good results for a few atomic species in low levels of ionisation, computation of this basic data on fast modern computers can yield much larger quantities for a wider range of elements and ions. This was the motivation for the installation of two powerful codes (Hartree-Fock Relativistic and Multi-Configuration Dirac-Fock) to calculate extensive networks of interactions on the Cray supercomputer at RAL, taking advantage of its speed and vector processing capability. An important first task for the HFR program was computation of 2200 oscillator strengths for lines of the astrophysically important species Fe II; this involved eight complex interacting configurations. The results have been immediately applied to lines in the ultraviolet and optical regions of spectra of the Sun and the slow nova RR Telescopii.

Orbit Dynamics Research

RAL has been involved for several years in providing accurate predictions and determinations of satellite orbits operated from the Chilton tracking station, particularly for the IRAS and AMPTE missions. More recently, Department of Trade and Industry funding has been provided to study the mathematical and data requirements for the ultra-high accuracy orbit determination of the next generation of remote sensing spacecraft such as ERS-1. In order to make accurate measurements of sea surface height from ERS-1, it is necessary to calculate the absolute position of the satellite to an accuracy approaching 10 cm. One of the main tools used for this research is the NASA programme GEODYN II which has been purpose built by NASA for orbit calculations on the TOPEX and Shuttle programmes. This program has been installed on the Atlas 10 computer at RAL for initial tests.

Space Environment Test Facility

The Facility provided thermal vacuum and vibration testing services to many university and RAL scientists and engineers during the year, eg on components and subsystems from space projects such as ATSR, CRRES, ISAMS, MLS, ROSAT, SSU (for the Meteorological Office) and UARS. Most of the work was done during the development phase of these projects.

A large proportion of the vibration work involved measuring the dynamic response and modal characteristics of aerospace structures, of which the successful characterisation of the ATSR Optical Bench (a carbon fibre laminate frame) is typical. This technique is becoming an important tool for space mechanical engineering designers who use it to validate the dynamic response characteristics of structures predicted by finite element methods.

Millimetre Wave Technology

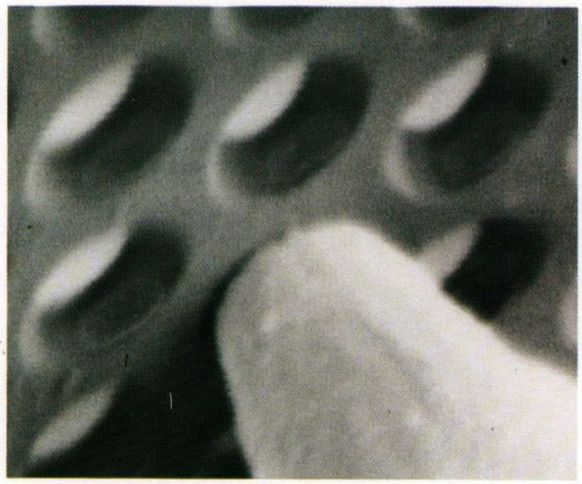
Specialised components are being developed for use in heterodyne radiometers to exploit further the millimetre wave spectral region from ground and space. Support and facilities have been provided for several university groups, the Meteorological Office and UK industry.

Two notable events occurred during the year: one was the first operational use on the James Clerk Maxwell Telescope of the two channel 230 GHz receiver developed by RAL and Cambridge University. Work is continuing at RAL on the development of mixers which will extend the frequency coverage of this receiver. Secondly, flight hardware which included whisker-contacted diode mixers (Fig 1.13) and multipliers was delivered to JPL for inclusion in the Microwave Limb Sounder experiment on the UARS satellite. RAL remains at the forefront in the development of space-qualified millimetre components.

Stirling Cycle Coolers

The joint development with Oxford University of small closed cycle coolers for space has advanced to commercial exploitation of single stage units. ATSR mechanical procurement and construction of the first flight standard hardware are complete. The electronics system has been designed and reviewed. A complete cooler system is required for ATSR instrument integration early next year.

RAL is carrying out a project supported by the European Space Agency to develop a long life 4 K mechanical refrigerator. This contract has three phases: a conceptual study leading to detailed drawings, production of a 20 K pre-cooler, a 4 K stage. Long life valves, heat switches and transducers are being evaluated. Work on the development multistage pre-cooler has continued and 25 mW of useful cooling power at 20 K or 100 mW at 25 K has been obtained for approximately 60 W input power. This will be optimised further for pre-cooling the 4 K stage to below 40 K using high pressure helium cooled by expansion.



1.13 A space qualified whisker diode contact. (87FB2673)

EUV Multilayer Reflectors

In the X-ray and extreme ultraviolet (EUV) wavelength regions, the use of grazing incidence optical systems had become accepted as the only feasible imaging technique but the recent development of EUV multilayer reflectors has made it possible to consider the use of normal incidence optical systems in this spectral region. A collaborative programme between Reading University and RAL aims to manufacture concave normal incidence reflectors for the wavelength region between 4 and 40 nm. These reflectors are produced by vacuum sputter-coating of alternate layers of a high Z material (eg platinum) and a low Z material (eg carbon or silicon), with layer thicknesses typically of 2 nm, to build a structure containing 20-40 individual layers resembling a synthetic crystal. Reflectance measurements on experimental multilayer samples indicate that it may be possible to obtain up to 30% reflectivity at selected wavelengths. Instrumentation using this technique has been proposed for the payload of the USSR X-Ray astronomy satellite Spectrum-X in the form of an Extreme Ultraviolet Imaging Telescope Array.

Ionosondes

The three ionosonde installations at Slough, South Uist and the Falkland Islands have been operated by RAL successfully throughout the year meeting the requirements for routine soundings, World Days and special events for the World Data Centre. The ageing valve-type ionosonde at South Uist was replaced in June with a new solid-state digital sonde in an air-conditioned container. A second transportable digital sonde was assembled for shipment to Port Stanley and will be established with a new antenna at a new site near the harbour.

Appendix 1 – Publications

APS Board & BNSC

Space Astrophysics

M A Barstow et al
Carbon and beryllium extreme ultraviolet filters: far ultraviolet performance
J Mod Optics (to be published)

A K Bhatia
A comparison of theoretical and solar flare intensity ratios for the Fe XIX X – ray lines
Mon Not R Astr Soc (to be published)

E R Breeveld et al
CHASE observations of the solar corona
J Astrophys Lett Comm (to be published)

M E Bruner, R W P McWhirter
Radiating properties of solar plasmas
Astrophys J (to be published)

S P Caldwell, R J Dickens
A spectroscopic study of chemical abundances in the globular cluster Omega Centauri
Mon Not R Astr Soc (to be published)

J Clavel et al
A detailed study of the C IV 1550 line profile and adjacent spectral features in NGC 4151 from 1978 to 1983
Astrophys J **321** 251 (1987)

R Cutler et al
CHASE observations from Spacelab 2
Adv Space Res (to be published)

T Dotani et al
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Nature **330** 230 (1987)

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Soft X – ray platinum – carbon multilayer mirrors
Appl Opt **26** 4491 (1987)

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At Data Nucl Data Tables **36** 129 (1987)

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Calculated wavelengths, oscillator strengths and energy levels for allowed 3 – 3 transitions for ions in the Cl – like isoelectronic sequence between Ar II and Ni XII
At Data Nucl Data Tables **36** 151 (1987)

B C Fawcett
Calculated wavelengths, oscillator strengths and energy levels for allowed 2 – 2 and 2 – 3 transitions for ions in the C – like isoelectronic sequence between F IV and Ni XXIII
At Data Nucl Data Tables **37** (to be published)

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Oscillator strengths of allowed transitions for C I, N II and O III
At Data Nucl Data Tables **37** (to be published)

B C Fawcett
Computed oscillator strengths and energy levels for Fe II, with calculated wavelengths and wavelengths derived from established data
At Data Nucl Data Tables **37** 333 (1987)

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Fe II oscillator strengths for identified lines in spectra of the Sun and of the slow nova RR Telescopii
At Data Nucl Data Tables **37** (to be published)

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Physica Scripta **36** 80 (1987)

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New spectral line identifications in high temperature flares
Mon Not R Astr Soc **225** 1013 (1987)

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Ultraviolet spectra of a large sample of quasars: I Data and data reduction
Mon Not R Astr Soc (to be published)

B M Haisch et al
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Astrophys J **322** 368 (1987)

R A Harrison
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Astron Astrophys **182** 337 (1987)

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The solar – stellar connection: the relationship between flaring rates, flaring power and quiescent X – ray background
Astrophys J (to be published)

A S Harvey et al
Spectroscopic binary orbits from ultraviolet radial velocities. Paper 3: delta Orionis
Observatory **107** 205 (1987)

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J Phys B: At Mol Phys **20** 43 (1987)

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J Phys D: Appl Phys **20** 1109 (1987)

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Observatory **107** 74 (1987)

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Proc Comets to Cosmology, QMC (1987)

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