Q. Jl R. astr. Soc. (1977) **18**, 60–102

Reports from Observatories, University Departments and Research Establishments

THE ROYAL GREENWICH OBSERVATORY

(Report for the period 1975 January 1 to September 30: Tercentenary Report)

(*Director: A.Hunter*)

1. INTRODUCTION – POLICY AND ORGANIZATION

This report covers the first nine months of 1975 only. Future annual reports of the work of the Royal Greenwich Observatory will be phased to coincide with the UK academic year (October–September), in order to tie in with the general programme of review by the Science Research Council of the work it supports in the universities and its own establishments.

The year 1975 marks the tercentenary of the foundation of the Royal Observatory at Greenwich. The year has therefore been the occasion of much contemplation and review of the history and achievements of the RGO. Perhaps the most important conclusion to be drawn is that a scientific institution such as the RGO could not be entering its fourth century in a vigorous state had it not proved itself capable not only of applying new technology to old problems, but of adapting itself to the surprises and challenges of the frontiers of scientific knowledge.

It is in response to the challenges now facing optical astronomy that the Science Research Council has approved in principle the construction of a major new Northern Hemisphere Observatory (NHO) at a superior site overseas. Since April 1975, the Director RGO has had executive authority for the procurement of the NHO; even though full approval has yet to be given to the project, this task has now become the RGO's first priority. Build-up of the NHO Project Team, under the leadership of the Director Designate, Professor F. G. Smith, has continued, and the senior members of the team are now all in post. Mr. W. A. Goodsell, formerly associated with the Anglo–Australian Telescope Project, has

been appointed Project Manager on secondment from the Property Services Agency of the Department of the Environment. He is supported by Mr. G. A. Harding as Project Scientist, Mr. J. D. Pope as Chief Telescope Engineer, and scientists and engineers drawn from the RGO and other SRC establishments or on contract from universities and industry. Details of the progress of the NHO Project are reported in Section 2.

On staffing and organizational matters connected with the changing role of the RGO, the Director has benefited from the advice of the RGO Restructuring Panel, which has completed the first phase of its work and presented an interim report to the Chairman, SRC. The NHO Project Team has now been constituted into a division of the RGO, headed by Mr. Goodsell. Because of its widening fields of activity and increasing work load, the Instrumentation and Engineering Division has been divided into an Instrumental Science Division, headed by Dr. D. McMullan, and an Engineering Division, with Mr. J. W. Gietzen acting part-time as its head until an engineer at Principal Professional and Technology Officer level can be obtained. The remaining divisions are unchanged: Astrophysics (Dr. R. J. Dickens—acting); Astrometry and Galactic Astronomy (Mr. C. A. Murray); Almanacs and Time (Dr. G. A. Wilkins); Administration (Mr. R. Gordon). Dr. D. V. Thomas has continued as Assistant to the Director. The appointments at Senior Principal Scientific Officer level of a permanent head of the Astrophysics Division and Assistant to the Director will require the approval of the Chairman SRC.

The RGO complement at the beginning of the year was 237, although only 228½ staff were in post pending agreement on the recruitment of staff for the NHO Project Team. By 1975 September 30 the number in post had fallen to 223, of whom 90½ were members of the Science Group and 30 members of the Professional and Technology Group; there were 39 non-industrial and 63½ industrial support staff and 11 vacancies in the official complement of 234.

As last year, this Report has been divided into sections corresponding to the three main components of the new role of the RGO: Section 2 deals with the provision and operation of national facilities for optical astronomy; the progress which has been made in research programmes is reported in Section 3; and the various national and international services and observing programmes are described in Section 4. Internal services, which are essential to the support of the Observatory's primary activities, are dealt with in Section 5. A report of some of the activities connected with the celebration of the RGO Tercentenary is contained in Section 6. A list of publications issued during the nine-month period is contained in Section 7.

2. NATIONAL FACILITIES

Northern Hemisphere Observatory

General Progress. Policy control of the NHO Project has remained the responsibility of the NHO Planning Committee (NHOPC), a subcommittee of the Astronomy II Committee of SRC; Professor F. G. Smith, Professor B. E. J. Pagel and Dr. M. V. Penston are members of the NHOPC. The NHOPC has recently set up three Working Groups to advise on the instrumentation needed for the proposed NHO telescopes. Dr. D. McMullan is a member of Working Group A (photometry and detectors), Professor Pagel of Working Group B (spectrographs and interferometers), and Dr. J. S. Beale of Working Group C (computers and control). The following members of RGO staff have been appointed project scientists: Dr. R. J. Dickens (large telescope); Dr. M. V. Penston (2·5 m); Dr. D. H. P. Jones (1 m). At the behest of the NHOPC, and with the assistance of the project scientists and working groups, the period under review has been devoted to the preparation of definitive proposals to be submitted to the Council for approval. By the end of the period, these proposals were substantially complete. The proposals, which are, of course, subject to financial approvals and international agreements, would allow the 1-m and 2·5-m telescopes to be commissioned early in 1979, and the large telescope not before July 1982.

Professor Smith has been involved with detailed discussions with Spanish authorities and representatives of other interested European countries in preparing draft agreements which would allow these countries and the UK to erect and operate telescopes at a selected site in the Canary Islands. Apart from the supervision of site-testing, the NHO Project Team has carried out preliminary design work, placed contracts with consulting engineers for detailed design studies, and formulated specifications. Further details are given below.

Site Testing. The tests carried out at the four sites under consideration have now established a clear superiority on scientific criteria for Fuente Nueva, at an altitude of 2366 m on the northern rim of the caldera of the island of La Palma (latitude 28°N) in the Canary Islands. The evidence suggests that this site should be usable for spectroscopic work on 75 per cent of nights, and give good photometric quality on more than 50 per cent of nights. The seeing, as determined by the Polaris-trail test telescope, is excellent, about one-third of nights having produced stellar images less than 1 arcsecond diameter. Two sets of recording microthermal sensors, carried on movable masts, have been installed at Fuente Nueva. The arrangement is an adaptation by Mr. R. J. Foord of a Meteorological Office design; the sensor heads, wound with 25-μm platinum wire, were made by Mr. C. W. Taylor in

the Engineering Workshop. The aim is to produce criteria to enable decisions to be taken on the precise location and height of telescope buildings. Operations at the remaining sites have now been terminated.

Throughout the period, the site-testing teams have been led by Mr. B. McInnes of the Royal Observatory Edinburgh (ROE). Since April, the direction of site-testing operations has been the responsibility of Mr. G. A. Harding. Operations at La Palma have been conducted on an international basis, personnel being provided by Spain, Sweden, Denmark and Holland, as well as the UK.

Site Development. A contract has been placed with Freeman Fox and Partners for an investigation, in collaboration with the local authorities, into the provision of roads, support buildings and general services at the Fuente Nueva site.

Design of the Large Telescope. A new investigation of the supply of glass blanks for primary mirrors has established that the economic size of the large telescope appears to be 4·2 m, not 4·5 m as originally proposed. Design studies have shown that the proposed alt-az mounting offers considerable economies and no serious disadvantages over a conventional equatorial mounting. Mr. C. A. Murray has studied the problems caused by field rotation at the prime focus of an alt-az telescope and has shown that the inaccessible area of sky will be acceptably small.

The configuration and size now proposed for this telescope will allow the dome design to follow closely that of the Anglo–Australian Telescope, with a significant reduction in design costs.

Remounting of the Isaac Newton Telescope. The change from latitude 51° to 28° has required detailed studies of the mounting and drive of the INT; these have been carried out by the telescope's manufacturers, Grubb Parsons Ltd. An alt-az configuration has been found to involve expensive changes; instead it is proposed that the equatorial mount be rebalanced and adapted for the lower latitude. A new configuration for the coudé spectrograph is now proposed, so that it can be mounted horizontally.

A new primary mirror has been acquired which will allow the effective aperture to be increased to 100 inches (2·54 metres). The Zero-dur blank is being rough-ground preliminary to accurate figuring at Grubb Parsons Ltd. Grubb Parsons are also investigating, under contract, the feasibility and economics of removing the existing INT dome to the new site.

Mr. J. R. Stokoe has recently been appointed Project Engineer for this telescope.

Specification of the 1-metre Telescope. This telescope is being designed primarily for field and on-axis photometry and for astrometry. The user specification, which has now been completed, calls for a field of at least 1°; it is hoped to extend this to about 1°·5 in the detailed design. The larger field is desirable for astrometry, if this can be achieved within the budgetary constraints and without reducing the effective aperture.

In connection with the specification of this telescope, Mr. C. A. Murray and Dr. D. H. P. Jones have concluded their study of the best astrometric model to use in measuring plates taken with telescopes of the Bowen–Ritchey–Chrétien type. The plates used were taken by Jones at the Wise Observatory in Israel in 1974.

Telescope Control. As a result of recent experience with the INT, and following a recommendation of the NHOPC, it is proposed that all three telescopes should be equipped with separate computers for control and for instrumentation. Integrating television systems are proposed both for acquisition and for manual guidance. The possible adaptation of these systems for automatic telescope guidance is being studied. Two members of Computer Applications Services, working under contract at RGO, are providing assistance with servo-control problems, including an investigation into the dynamic response of the INT as it now exists.

Instrumentation. The Working Groups have identified a range of new instruments which will be required for the NHO telescopes. Dr. R. G. Bingham and other members of the Optical Instrumentation Department have collaborated closely with Working Group B in the investigation of several new spectrograph designs. It is expected that some of the new instruments will be developed and built by other observatories and university departments, with coordination provided by the Instrumentation Engineer, Mr. J. W. Gietzen. The remaining instruments, including the new INT coudé spectrograph, will probably be constructed at RGO.

Anglo–Australian Telescope

Commissioning. Dr. R. J. Dickens and Dr. B. L. Webster each spent 1–2 months at the AAT, assisting the resident staff with the commissioning of the telescope.

Intermediate Dispersion Spectrograph. Modifications have been made to the case of the spectrograph which have resulted in a reduction in the flexure by a factor of 7. These modifications were designed by Mr. P. A. Ellis, with the advice of Dr. R. O. Stafford of the Department of Aeronautical Science, Imperial College of Science and Technology, who carried out a finite element analysis of the modified case. There

was quite good agreement between the theoretical and actual measurements of flexure. Some further modifications have also been made to the collimator and grating mounts, and the mechanical performance of the 82-cm camera is now within the acceptable limits of a maximum of 2 μm per hour image displacement along the dispersion and 10 μm per hour across it.

The manufacture of duplicate electronic equipment has been virtually completed. A three-stage cascade intensifier having satisfactory performance has been received from EMI Ltd., but Spectracons with S.20 photocathodes are still awaited because of manufacturing difficulties in meeting the low ion-noise specification.

The spectrograph is currently undergoing temperature testing and calibration in the Environmental Chamber.

South African Astronomical Observatory

Mark I Unit Spectrograph. During trials of the universal solenoid developed for this and other spectrographs, it was found that the anti-freeze agent used in the coolant was attacking the epoxy adhesive employed in the manufacture of the water jacket. The construction has now been modified and a graded soldering technique used for the joints. This has proved to be completely satisfactory. The completed camera unit and optics were tested and dispatched to the SAAO during the year.

Radcliffe Telescope. Mr. M. Dermody, Workshop Foreman, returned to Sutherland to assist the contractors in the re-erection of the Radcliffe telescope after its transportation from Pretoria. At the time of his return to RGO in March, all major items had been erected.

Infrared Photometer. Dr. I. S. Glass spent one month at Sutherland, commissioning the new infrared photometer for use in the *JHKL* wavebands (1–3 μm).

Isaac Newton Telescope

Developments related to the proposed removal of the INT to become one of the instruments of the NHO are reported above.

Mark II Unit Spectrograph. The problem associated with the solenoid for the Mark I spectrograph (mentioned above) has also delayed the final fitting of a similar coil to the Mark II spectrograph.

A Westinghouse SEC vidicon television camera, storage unit and TV monitor have been purchased for remote viewing of the spectrograph slit. The system has been given preliminary trials by mounting the camera in place of the $X-Y$ slides and using the existing transfer optics.

Although this is far from being an ideal arrangement the system has already proved to be invaluable during observational use. Together with remote operation of some of the spectrograph controls, the system enables remote operation and guiding to be carried out from the new control room.

Radial-Velocity Speedometer. Mr. R. E. Wallis has built a "speedometer" for the direct measurement of stellar radial velocities, following the principle of the radial-velocity spectrometer initiated and exploited by Griffin. In Wallis's version, which comprises an additional unit to the Mark II Unit Spectrograph, seeing and transmission variations are compensated by a 5-Hz chop of the mask along the dispersion. The instrument has been undergoing operational trials.

Michelson Interferometer. Development and testing is being continued by an Imperial College team at the coudé focus.

Echelle Spectrograph. Some of the optical component cells have been modified to ensure stability and full control of adjustment. The system has been realigned and is ready for astronomical tests at the specially-reduced focus of the 30-inch coudé telescope.

People's Photometer. A visual image intensifier (Varo 3-stage) has been fitted to the People's Photometer as an aid for finding faint stars. The optical system has been redesigned so that the same eyepiece can be used with or without the intensifier.

Control System. The new control room to house the control and instrumentation computers and detector electronics was completed in March.

The NOVA 1200 control computer has been installed and the interface to the telescope, developed by Mr. P. D. Read, has been tested. This interface is used to transfer encoder readings from the telescope and dome, time from local clocks, and demands to the telescope and dome drives. The software has been developed on the ICL 1903T by Dr. J. S. Beale using a cross-assembler written at RGO. The telescope can now be slewed to coordinates given in equatorial, galactic, ecliptic or altazimuth form, and a display is continuously updated to give the observer information on the motion and position of the telescope. Experiments are now being made to calibrate systematic errors of the telescope including, in particular, flexure and gear errors. This information will also be useful in the design of modifications to the telescope before its removal to the NHO site.

Instrumentation Computer. The enhanced computer system is now fully operational and has been used successfully with the Imperial College Michelson and Fabry–Perot interferometers. Preliminary

studies have been made by Mr. G. B. Wellgate and Dr. K. F. Hartley on interfacing the People's Photometer to the computer, both for general photometry and for high-speed photometry of pulsars.

The computer has been found to be extremely useful for the off-line analysis of digitized spectra. Data obtained with the University College, London (UCL), Image Photon Counting System (IPCS) and with the Image Dissector Scanner (IDS) on the AAT are being analysed.

"*Seeing*" *Investigation.* Observations have been made by Dr. R. G. Bingham and Dr. P. G. Murdin to find out the effect on "seeing" of heat released in the domes of the INT and the 36-inch telescope. The seeing with the INT was found to be degraded by 0·05 arcsec per kilowatt; the coefficient appears to be inversely proportional to the radius of the dome.

INT Operation. Operation of the INT continues under the management of Mr. P. J. Willmoth. During the nine-month period, observing was carried out on 170 nights, and 414 spectra, 181 direct photographs, and over 150 other observations were obtained. In addition, spectra of 133 objects were recorded in digital form using the IPCS. There was a total of 866 hours of clear sky. Of the 170 nights when observing was carried out 59 were clear throughout, 57 were 50 per cent to 99 per cent clear and 54 were less than 50 per cent clear; no observing was possible on 98 nights. The number of instrument changes was 35 and there were 24 end changes. The stand-down period, April 21–24, was kept to a minimum and used only for essential maintenance of the main telescope and dome contactors. The primary mirror was aluminized twice during the period of the Report.

The Isaac Newton Telescope was used by 13 groups of visiting observers. The Large Telescope Users' Panel and its successor the Panel for the Allocation of Telescope Time allocated 157 nights for these programmes. Collaborative programmes between visitors and RGO staff were allocated 21 nights; 95 nights were allocated to RGO observers.

Equatorial Group

36-inch Yapp Reflector. Responsibility for the renovation of this telescope has been assumed by Mr. P. M. Corben. The telescope will be taken out of service early in 1976 in order to fit the redesigned secondary mirror mounting, new right ascension and declination drives and encoders for both axes. The telescope has been scheduled for use on approximately 75 per cent of nights during the period. On many of the remaining dark nights the telescope was not used because of the higher priority accorded to the INT both in regard to auxiliary instrumentation (which is shared between the two telescopes) and personnel.

The 36-inch reflector was used by a group from the Appleton Laboratory (Culham), led by Dr. W. M. Burton (1 week), by Dr. A. D. Andrews, Armagh Observatory (2 weeks) and by a group from the University of Durham, led by Dr. S. M. Scarrott (in progress at the end of the period). Dr. R. G. Bingham collaborated with each of these groups.

30-inch Coudé. In January 1975 the entire mirror system (4 telescope mirrors, spectrograph collimator and 3 camera mirrors) was shipped to Balzers (Germany) to be treated with broad-band reflection-enhanced coatings. As a result, the telescope was out of service for a total of 5 months, but has otherwise been used on most fine nights. Over the wide range of wavelengths required ($\lambda\lambda$ 3300–9000) the new coatings have proved their worth in keeping the instrument operational at speeds which, 9 months after coating, compare favourably with freshly aluminized surfaces.

The 30-inch coudé reflector was used by Dr. J. van Paradijs, University of Amsterdam (1 week), with the assistance of RGO staff.

26-inch Thompson Refractor. There have been no major changes to the telescope. A redesigned breech end for the Merz guider telescope is being constructed. This is to provide both a stronger mount for the autoguider and to make manual guiding more convenient when the autoguider is not in use. The telescope has been scheduled for use virtually every night during the period.

13-inch Refractor. There have been no major changes to this telescope, which has been in regular use during the dark of the Moon.

1-metre Hargreaves Reflector. Mr. C. M. Lowne and Mr. P. M. Corben have carried out laboratory tests on the Schmidt corrector plate and primary mirror. Bad radial asymmetry has been found in both components, thus explaining the poor plates obtained in earlier stellar exposures. All work on this telescope has been stopped.

30-inch Steavenson Reflector. All mechanical parts have been manufactured and erection in Dome C is almost complete. Design and construction of the electronics for the right ascension and declination drives are also finished, and the installation of this and other wiring is in progress. Negotiations aimed at the eventual installation of the telescope at the Sierra Nevada outstation of the Cartuja Observatory (University of Granada) have continued.

Coating Plant. The installation of a Varian electron-beam evaporation source in the 40-inch coating plant has been completed. Mr. D. M. Jackson has used the system to deposit protected silver and protected aluminium reflective coatings. Quartz crystal and optical thin-film

monitors are being purchased and it is intended that procedures should be developed for depositing multilayer reflective and anti-reflective dielectric coatings on large optical components.

Measuring Machines

A motor alternator set has been installed to provide an independent supply to the measuring machines in the West Building basement. This will generate an interference-free supply isolated from mains interruptions of less than one second duration.

GALAXY. From January to April the machine was in regular operation for about 250 hours per month.

Installation of the NOVA 2/10 control computer system to replace the paper tape input/output medium was started at the beginning of May, and has continued throughout the report period. The CAMAC interface was designed by Mr. G. S. Walker (Computer Advisory Services) and constructed at RGO. The software interface was developed by Mr. J. J. Redfearn (sandwich student) under the supervision of Dr. J. S. Beale. Mr. W. Nicholson, assisted by Mrs. D. E. Hobden, has developed the main computer programs needed for the operation of GALAXY. The system was working satisfactorily by mid-July, but the time since then has been spent on further development of the software interface to include control of the Zeiss Ascorecord and the recently-acquired Coradograph.

Dr F.V.Prochazka, Vienna Observatory, spent one week measuring plates on GALAXY, with the assistance of RGO staff.

Zeiss Ascorecord. Comprehensive documentation for the modifications completed last year has now been produced. Initial design of circuits and equipment to interface the machine to the NOVA computer is now complete.

Coradograph. A Coradograph measuring machine has been purchased and installed. Its 800-mm square table allows two-coordinate measurements of the largest plates and charts held at RGO (including Palomar charts) to be made to an accuracy of a few microns.

PDS Microdensitometer. About two-thirds of the time on this machine has been devoted to the development of the system and of associated procedures. The remaining time has been used by RGO staff and visitors for a wide range of astronomical programmes, and also for some non-astronomical work such as the examination of electron micrographs.

Members of nine astronomical groups from UK universities, and four from abroad, as well as three non-astronomical groups (all assisted

by RGO staff) made use of the PDS Microdensitometer for a total of seven weeks during the period.

Dr. J. D. H. Pilkington has commissioned the additional peripheral equipment (extended core store, disk store, and visual display unit) that was purchased earlier in the year. This has greatly increased the potential of the system for data analysis, although an incompatibility between the original magnetic-tape hardware and the new system software is not yet fully resolved. The control programs provided by the microdensitometer manufacturer are in routine use after substantial modifications. A new control program providing similar facilities but incorporating checks to prevent acceptance of invalid commands from the user is almost operational. This program will run under the new system software and will be capable of further development.

Mr. A. J. Penny, who is investigating the use of electronography in stellar photometry, is developing techniques for the on-line analysis on the microdensitometer of electronographs of star fields.

Research and Development of Electronic Imaging Devices

Electronographic Tube Development. Reprocessing of electronographic tubes has continued with considerable success in spite of an interruption of several weeks during the summer due to the failure of the 6-inch bakeable valve on the processing rig. Six tubes with 4-cm diameter photocathodes and mica windows are now completed. All have good S.20 photocathodes and four are known to have low dark currents; the remaining two await evaluation. Photocathode stability appears to be good, the two oldest tubes having lasted 12 and 9 months respectively without any significant loss of sensitivity.

A second tube with a 10-cm photocathode and 8-cm mica window has been constructed. The first tube has been reprocessed after modifications to the electrode structure. The main background problem has been solved, the remaining non-thermal background becoming evident only on long exposures. The source of this has been deduced and can easily be corrected. Both tubes are shortly to be reprocessed. Construction is well advanced of two small tubes having 5 mm × 30 mm slot-shaped mica windows exposed to atmospheric pressure. These tubes are intended as alternatives to the Spectracon; they will have the advantage of superior input transmission through the single silica window and they may be reprocessed in the event of mica window breakage.

Electronographic Cameras. Two electronographic cameras, designed by Dr. D. McMullan and incorporating 4-cm tubes, have been constructed. The first was taken to the Wise Observatory, Israel, by Dr. McMullan and Dr. R. A. E. Fosbury and installed at the Cassegrain focus of the 1-metre telescope. Good results were obtained on a variety

of objects including Seyfert galaxies and the Crab Nebula. The camera has since been used by Dr. J. R. Powell and Mr. H. Netzer (research student), by Dr. R. G. Bingham with Mr. D. J. Bonnick and a team from Durham University (with a nebular polarimeter), and on a number of occasions by Wehinger and Wyckoff (Tel-Aviv University). It has proved to be very reliable.

A second camera has been built for use at Herstmonceux. It was first operated in September at the Cassegrain focus of the INT as the detector for Meaburn's (Manchester University) insect-eye Fabry–Perot spectrograph. A third camera is under construction.

Application of Silicon Diodes. A 4-cm electronographic tube incorporating a quadrant silicon diode as an autoguider sensor has been successfully processed. A full assessment of its performance has not been completed but it is clear that the silicon diode was not affected by the processing procedure.

No further work has been done on the silicon diode array detector pending the receipt of better samples of silicon chips from The Plessey Co. Ltd. These are expected in October.

Major modifications to the processing equipment, carried out by Dr. J. R. Powell, have made it possible to process tubes with the photocathode substrate at the top of the system. This has greatly reduced the number of image blemishes previously caused by debris falling on to the photocathode during processing.

The testing of Spectracon image tubes manufactured by Instrument Technology Ltd. was continued during the period.

General Optics

An optical design team has been formed under Professor C. G. Wynne who has been seconded to RGO from Imperial College. Mr. C. F. W. Harmer is working with him. Copies of the Imperial College optimization program are now available for RGO use in a full-size version (50 surfaces) on the Atlas Computer Laboratory ICL 1906A (via the remote job-entry work-station link) and a smaller version (25 surfaces) on the RGO ICL 1903T computer. The ordinary ray-tracing program has been updated to compute the geometrical optical transfer function, and the general ray-tracing program is being modified to cope with systems containing up to five diffraction gratings. Programs to compute the effect of ghost images and to plot spot diagrams are currently being modified at Imperial College for use at RGO.

Harmer has demonstrated the use of the general ray-tracing programs in predicting the performance of a spectrograph used under conditions departing from its design parameters (13).

A study of the use of image tubes in spectrograph cameras, particularly those of longer focal length, has been carried out by Dr. R. G. Bingham.

3. ASTRONOMICAL RESEARCH

X-ray Sources

A computer program for power-spectrum analysis of data sampled at unequal time intervals and subject to periodic constraints has been written by Dr. P. G. Murdin and Mr. C. S. Buck (sandwich student), and has been used extensively on X-ray, radio and infrared observations of X-ray sources made by other observers. The program takes account of the periodicities in the "window" through which the star is seen by computing the window-spectrum and analysing how a frequency in the star appears in its power spectrum when seen through the window. The program has revealed a 22-hour and a 14-minute period in the X-ray intensity of 3U 0352+30, associated with X Per, observed with the *Copernicus* satellite. A 5·6-day periodicity in the X-ray flux from Cyg X-1, observed with *UK5*, has been confirmed, thus making secure the identification of the X-ray source with the 5·6-day spectroscopic binary HDE 226868. Upper limits have been established to the periodic radio variability of Cyg X-3.

In collaboration with the Mullard Space Science Laboratory (MSSL) Group, Murdin (25) has shown that the change of state of Cyg X-1 in May 1975 could be correlated with the behaviour of the mass transfer in the binary star system as revealed by the gas which absorbs low-energy X-rays near the superior conjunction of the B star with its secondary.

Mr. E. N. Walker has re-analysed his photometric observations of HDE 226868 obtained during 1972, 1973 and 1974 at the Sierra Nevada observing station of the University of Granada, using the program described above. The analysis confirms that the light curve of this star has evolved significantly since 1972. The first observations obtained since the May 1975 eruption at X-ray and radio wavelengths indicate that a substantial change has also occurred in the optical emission from the star.

The optical counterpart of 3U 0352+30, X Per, has been studied by Dr. R. G. Bingham, Dr. P. G. Murdin, Mr. A. J. Penny, Dr. M. J. Penston, Dr. M. V. Penston and Mrs. J. E. Sinclair. X Per B is shown to have colours, spectrum and radial velocity of an M1 III star, possibly a physical companion to the spectroscopic binary X Per A. During simultaneous monitoring of the Hα intensity and continuum of X Per A,

a drop in the Hα intensity was seen, coinciding with a flare in the continuum. This is interpreted as an obscuration passing over the unseen secondary of X Per A and crashing into its accretion disk.

Photometric observations of the optical counterpart of Cen X-3, made by M. V. Penston, M. J. Penston and Murdin, have established upper limits to its optical activity, and a distance to it of 5 to 10 kpc on the basis of its reddening.

The image of the optical counterpart of the transient X-ray source A 0620 – 00 was located on the Palomar Observatory Sky Survey charts by M. V. Penston, Mr. M. J. Ward (research student), Mr. C. A. Murray and Mr. E. D. Clements. It has $B \sim 20^{m}{\cdot}5$, $B-R \sim 3^{m}{\cdot}6$, and is probably a red dwarf star at about 500 pc, as predicted by models of transient X-ray sources resembling current explanations of novae, with a neutron star or black hole replacing the white dwarf as the body accreting material.

The error box of the X-ray source 3U 1410 – 03 contains the galaxy NGC 5506. The nucleus of this galaxy possesses a high-excitation spectrum, observed by M. V. Penston, including the species He II, [Ne V] and [Fe VII]. The high ionization could indicate that the galaxy is the X-ray source. The Balmer lines are no broader than the forbidden lines, so the galaxy can be classified as a Seyfert type 2, and is the first such to be proposed as an X-ray identification.

M. V. Penston and Miss L. Sparke (vacation student) have suggested that the X-ray source 3U 0400 – 59 may be identified with the NGC 1566 cluster of galaxies. If confirmed, this identification would extend the Solinger–Tucker $L_X \propto V^4$ relationship to sources of lower energy (38).

Continuing their examination of photometric and spectroscopic observations of stars in the fields of 20 southern X-ray sources, M. V. Penston, M. J. Penston and Murdin (37) have found few good candidates for identification, but some stars can certainly be eliminated.

Extragalactic Studies

Quasars and Seyfert Galaxies. A study of the quasar 3C 273 by Dr. M. V. Penston, Dr. R. A. E. Fosbury and Mrs. A. Savage, in collaboration with Boksenberg and Shortridge (UCL), has yielded improved spectra showing previously-undetected features in the blue region (9). Emission-line equivalent widths were compared with photoionization models. The forbidden lines are well fitted by a model with an ion number-density of $2 \times 10^{8}\,\mathrm{cm}^{-3}$, and an upper limit on the [Ne V] λ 3426 to [Ne III] λ 3868 ratio gives indirect evidence that the helium to hydrogen ratio is greater than 0·01 by number. The Balmer decrement is steeper than the case B value and may be explained by Balmer line

self-absorption with $\tau_H \sim 200$. The emission previously identified as the D lines should now be attributed to He I $\lambda 5876$.

Spectra and scans of the Seyfert galaxy NGC 4151, obtained by the above group and Dr. D. A. Allen, have shown broad lines of He I and Fe II. The helium lines are double the width of the Balmer-line wings (which may be explained by "quasar-wind" models) and the broad-line spectrum closely resembles that of 3C 273. The density of the broad-line emitting region is $> 10^7$ cm^{-3}: the narrow lines indicate a density $\sim 10^4$ cm^{-3} and a temperature of 12000 K. The permitted line $\lambda 8446$ of O I has also been found in this galaxy with an intensity 5 per cent of the broad component of Hα. Its strength may be explained as the result of resonant absorption of Ly β and subsequent cascade if the broad-line region is optically thick in Hα. The observation of low-energy X-ray absorption in NGC 4151 by *Ariel V* is of interest, since optical absorption lines are also seen. The column densities deduced from X-ray and optical absorptions can be explained if the absorption arises in the broad-line emission region.

Fosbury and Dr. D. McMullan have used the RGO 4-cm electronographic camera at the Cassegrain focus of the Wise Observatory 1-m telescope to obtain broad-band electronographs of galaxies with active nuclei, as part of a study of the colour of their faint outer regions. One of the objects studied was Markarian 231, an exceedingly luminous Seyfert galaxy, whose optical spectrum and infrared colours are the subject of an intensive study by a team consisting of Allen, Fosbury, Penston, Boksenberg (UCL), Carswell (UCL), and Sargent (Hale Observatories). This galaxy, though of moderate redshift, has a strong absorption-line spectrum which is more reminiscent of some high-redshift QSOs than a normal Seyfert galaxy. High-resolution spectra taken with the IPCS on the INT have shown these absorption lines to be multiple with some components narrower than 100 km s^{-1}. The permitted spectrum of Fe II is strong in emission and the forbidden lines are very weak, indicating a high ($\gtrsim 10^8$ cm^{-3}) electron density in the line-emitting region. Both this high density and the observed very large infrared excess seem to be characteristics which are found predominantly in the most luminous of the Seyfert galaxies. Markarian 231 must assume an important place in our attempts to understand the relationships between galaxies and QSOs since it shows so many QSO-like characteristics and yet has the dimensions of a large galaxy.

The studies of the crucial objects 3C 273, NGC 4151 and Markarian 231 have led to a picture of the quasar/Seyfert-nucleus phenomenon in which the broad emission lines of H, He I and Fe II are made in a number of fast-moving (radially outflowing?) dense clouds near the source of the non-thermal continuum. If this dense region has "holes"

in it, the narrow-line Seyfert spectrum is made by excited gas in the galaxy at much greater distances from the nucleus. The dense clouds are optically thick in the Balmer lines, and in cases where the nucleus is viewed through a cloud optical and X-ray absorptions are seen.

The nature of the Fe II emission in Seyfert galaxies is being studied by Allen and Fosbury who have obtained spectrum scans with the IDS on the AAT of IZw-1, a compact Seyfert galaxy with strong well-resolved Fe II lines. Scans of two stars showing narrow Fe II emission lines have also been used to compile a list of accurate relative line intensities which can be used in a computer program to synthesize the spectra of galaxies where the lines are broad and too blended to measure.

Fosbury has used the IDS on the AAT to obtain high signal-to-noise spectral scans of some relatively bright QSOs with $0{\cdot}3 \lesssim Z \lesssim 1$ in order to study the region of the Fe II resonance lines near 2500 Å, this to decide the relative importance of resonance fluorescence and electron collisions as excitation mechanisms for the visible lines.

Using the AAT, Savage and Fosbury have spectroscopically confirmed several new Parkes radio-source identifications with QSOs and galaxies. One of the radio galaxies (PKS 1718 −649) is now the subject of a detailed spectrophotometric study.

Using spectrum scans made with the IDS on the AAT, Fosbury has made a study of the emission-line intensities in the nucleus of the peculiar radio galaxy PKS 1650+024 (= NGC 6240 = 4C+02.44). This has a highly disturbed appearance and is distinguished spectroscopically by extremely strong forbidden lines from the lower ionization species, namely [O I], [N I], [O II], [N II], and [S II]. This is possibly the best candidate found so far for collisionally-ionized gas in a galactic nucleus, and the spectrum is well matched by models of a shock-heated, low-density gas. NGC 6240 appears to be a close relative of the well-known exploding galaxy M82 while offering us the important advantage of being able to see its nucleus relatively unobscured by dust.

AAT spectrum-scans of the rapid radio-variable compact galaxy IIZw-2 have been obtained by Fosbury and Allen as part of a long-term collaborative monitoring programme involving RGO, the Anglo–Australian Observatory (AAO) and NRAO (Parkes). The scans show extremely broad permitted emission lines of H, He I and Fe II but nothing which is obviously related to its peculiar radio behaviour.

Spectra of a number of QSO candidates from the Jodrell Bank 966-MHz survey have been obtained by Dr. R. J. Dickens, in collaboration with Walsh and Browne (Jodrell Bank) and Boksenberg (UCL), using the IPCS on the INT. Successful spectra of 18th magnitude objects invisible against the sky background have been obtained using blind-offset techniques, resulting in the identification of 4 new QSOs and 4 possibly continuous-spectrum objects.

In collaboration with a NRAO (Parkes) group, Savage has begun work on a project to determine the ratio of radio to radio-quiet QSOs in five regions near the South Galactic Pole.

Optical Identification of Radio Sources. Over 1500 radio-source positions have been examined by Mrs. A. Savage, in collaboration with Bolton (NRAO, Parkes), on 76 rejected UK Schmidt survey plates and 100 European Southern Observatory "quick blue survey" plates. Of the 80 new identifications, relatively few have been made on the 25 plates in the region south of $-45°$ for which no previous survey plates exist. It seems that either there is a marked anisotropy in the distribution of bright galaxies, or that there is substantial obscuration over a large part of the sky south of $-45°$. The positive identifications have been used to calibrate the Parkes radio position system south of $-45°$.

Optical positions to an accuracy of $\pm 0{\cdot}3$ arcsecond of all possible candidates from the 5C surveys visible on Palomar Schmidt plates, without regard to colour or fuzziness, are being measured by Dr. M. V. Penston and Mr. C. Lloyd. As a result of systematic errors in the 5C2 positions of up to 10 arcseconds (confirmed by a Westerbork survey of the same region) the initial proportion of positional coincidences was unexpectedly low. Mapping the 5C2 positions into the Westerbork positional system has dramatically increased the number of optical identifications. Work has commenced on the 5C1 and 5C5 surveys, which suffer from similar systematic errors.

Optical Positions of Extragalactic Radio Sources. Observations at the prime focus of the INT, and with the 26-inch and 13-inch refractors, have continued under the direction of Mr. C. A. Murray. A total of 120 fields is being observed. The priority programme of 52 fields, in collaboration with Ryle (Mullard Radio Astronomy Observatory (MRAO)) and Argue (Institute of Astronomy, Cambridge) is nearly complete; 12 of these fields require further plates on the INT. Measurement and reduction by Mr. E. D. Clements of all 44 fields requiring only plates taken on the two refractors, are virtually complete. Measurement of the INT fields has been delayed while GALAXY has been out of commission.

As a subsidiary part of this programme, an examination of field errors of the 13-inch (Astrographic) refractor, using plates taken of the Pleiades, is being carried out by Mr. P. M. Corben.

At the request of Dr. M. S. Longair (MRAO), accurate positions of reference stars near extremely faint radio sources are being obtained from plates taken on the 26-inch telescope. So far, positions in 12 fields have been measured.

Optical Monitoring of Radio Sources. Under the direction of Mr. C. Lloyd, optical monitoring of extragalactic radio sources has continued, 114 plates having been taken with the 26-inch refractor during the period under review.

Clusters of Galaxies. Reduction of data on the redshifts of galaxies in Abell 262 and Abell 1367 has now been completed by Dr. R. J. Dickens and Mr. C. Moss (research student). The surface density distributions of galaxies in both clusters show evidence of segregation by morphological type, with the ratio of E and SO to S and I galaxies decreasing with increasing distance from the cluster centre. For the cluster Abell 262 the velocity dispersion for E and SO galaxies is significantly lower than the corresponding value for S and I galaxies. There is some evidence for a similar effect in Abell 1367 and in Virgo, both also spiral-rich clusters. A simple, but not a unique, explanation is that a higher velocity dispersion for S and I galaxies in the inner cluster region is a result of dynamical equilibrium, since the E and SO galaxies are expected to be the most massive in the cluster.

Dickens and Moss have also determined redshifts for two galaxies in the X-ray cluster Abell 2256, and thus estimated the total X-ray luminosity of the cluster and the size of the X-ray emitting region.

The IPCS was successfully used on the INT for the first time in full two-dimensional mode by Dickens and Moss, in collaboration with Boksenberg (UCL), to obtain 18 spectra simultaneously along the major axis of an edge-on spiral galaxy in the cluster Abell 1367. The relative strengths of the emission lines of [O II] and [O III] can be seen to vary substantially across the galaxy, over a distance of at least 50 kpc.

Spectrum scans of nearly 100 galaxies in two southern clusters have been obtained by Dickens, in collaboration with Dawe (ROE) and Peterson (AAO). The data are currently being analysed to determine the redshifts of the galaxies. Morphological types for the galaxies are being obtained from plates taken on the UK Schmidt and on the AAT in collaboration with Cannon (ROE).

Mr. C. J. Corbally (volunteer vacation student) has discussed Sandage and Peterson's colours of the brightest galaxies in clusters. He finds a strong correlation with the columnar total of hydrogen in our own Galaxy—stronger than the dependence on $|\mathrm{cosec}\, b|$. This indicates a small dispersion in the intrinsic colours of the galaxies and a high correlation between gas and dust in our own Galaxy.

Double Galaxies. Dr. R. J. Dickens, in collaboration with van Albada and Schwarz (Kapteyn Laboratory, Groningen), has started a survey of double galaxies, with separations greater than 10 arcmin, in the 21-cm line with the Westerbork synthesis radio telescope. As part of this survey, a detailed study has been made of the spiral pair NGC 672/

IC 1727. For both galaxies, the neutral hydrogen extends far beyond the optical image and there may be a bridge of H I between the two galaxies. There are anomalies in the velocity fields which are consistent with a warp of the H I layer.

Galaxies. The collaboration on nebular polarimetry with the University of Durham has continued. Observations of a number of galaxies and other nebulae were made by Dr. R. G. Bingham with White and Pallister (Durham) in March using the Durham University/RGO polarimeter and electronographic camera on the 1-m telescope at the Wise Observatory, Israel. The observations of M82 have been reduced and prepared for publication. The results are being interpreted in terms of a model of the galaxy and yield a new position for the central object. Comparison with other types of observation suggests that the active central feature is extended over perhaps 150 pc. Observations of NGC 1275 have been reduced by Pickles (Durham): they show a structure which suggests that the polarizing mechanism differs from that in M82.

Deep photographs taken with the UK Schmidt by Cannon (ROE) of the remarkable radio galaxy Cen A have revealed optical filaments extending 5 to 10 arcmin from the central dust lane of the peculiar elliptical galaxy NGC 5128, which lies between the two strong innermost components of the radio source. The alignment of the radio source and the filaments suggests a related origin. Spectroscopic observations of some of these filaments, made by Dr. R. J. Dickens and Peterson (AAO) using the IDS on the AAT, have revealed features typical of H II region spectra. A preliminary analysis indicates a normal temperature of about 10^4 K for a region of low gas density. The radial velocity of the filaments is about 200 km s^{-1} less than that of emission regions on the rotation axis of the galaxy, indicating that the material in the filaments may be falling in, rather than undergoing ejection.

Dr R. A. E. Fosbury and Hawarden (ROE) have used the IDS on the AAT to study the nature of a peculiar double-ring galaxy found by Cannon (ROE) on the SRC southern sky survey. Scans have been obtained of the nucleus, the inner ring, various condensations in the outer ring and two nearby galaxies which turn out to be associated. With a major axis of 60 kpc, this is the largest of the known ring galaxies. The knots in the outer ring are giant H II regions excited by hot stars, but no evidence for ionized gas has been found inside the ring; the nucleus and the inner ring have pure late-type stellar spectra.

Dr. D. A. Allen has secured 1–20 μm photometry of some bright emission galaxies from Markarian's and Zwicky's lists, using the telescopes at Tenerife, Mount Lemmon and Mauna Kea. The following are shown by the data: (i) Many emission-line galaxies have continua

bluer than normal galaxies, implying an earlier spectral type; (ii) An infrared excess is generally present in radio galaxies and is most pronounced in Seyferts; (iii) This excess cannot be fitted by a power-law synchrotron model superimposed on the stellar component: thermal emission from dust is a better explanation; (iv) In the double galaxy NGC 3690/IC 694 the dust is not, as normally, constrained to the nucleus but is distributed throughout the entire galaxy: at least two discrete dust temperatures are needed to explain the photometric data; (v) The very luminous galaxy Markarian 231 has an absorption feature at 11 μm probably identified with silicate dust.

He2–10 is classified as a planetary nebula. An AAT spectrum by Allen shows it to be an emission-line galaxy with a recession velocity of nearly 1000 km s^{-1}. If Hubble's law can be invoked for so local an object, it is at the lower end of the luminosity function for galaxies. Nonetheless, it contains a non-thermal radio source, and has a sizeable infrared excess.

Further work by Dr. I. S. Glass on the *JHKL* colours of galaxies, including some recent observations made using the 60-inch flux collector on Tenerife, shows most galaxies to have similar *JHK* colours. Some have "infrared excesses" at *L* which imply radiation from dust. The *JHK* colours, combined with previous work with the same photometric system on the colours of giant and dwarf stars, enable an upper limit to be set on the dwarf content of galaxies.

Magellanic Clouds. Further measures have been made by Dr. P. J. Andrews of three small clusters in the NGC 371 field of the LMC. Two of the clusters are typical young clusters, one with a red supergiant member; the third is like NGC 458 in the SMC and has two Cepheid members. Photographic plates of the region have been measured to give improved coverage and allow a check on the periods, etc., of the known Cepheids. Several new variable stars have been discovered in the field by Andrews and Lloyd-Evans (SAAO). Some are Cepheids, but others are red variables of as yet unknown type.

Mr. A. J. Penny has completed the measurement and analysis of electronographic films taken of the cluster NGC 1466 in the LMC, using the 40-inch telescope at SAAO (32). The resulting two-colour diagram ($U-B$,$B-V$)—the first for any extragalactic cluster—and the colour-magnitude diagram show that the cluster stars are old and metal poor. A new estimate of the distance of the LMC has been obtained; this is significantly less than the generally-accepted figure, but in agreement with two other recent studies.

Supernovae. Photoelectric *B* and *V* measures of brightness of almost all southern supernova-parent galaxies brighter than about $m_{pg} = 16$ have been made by Mr. R. Wood using SAAO telescopes. In order to

be able to extrapolate to integrated magnitudes and colour, the measures were made through a number of different apertures. Preliminary reductions show fair agreement with previous work for some of the brighter galaxies.

Clusters and Variable Stars

Globular Clusters. Several red giant stars in the metal-rich globular cluster 47 Tuc have been found by Dr. R. J. Dickens to show varying degrees of CN enhancement in their spectra. Preliminary spectral synthesis, in collaboration with Bell (University of Maryland), indicates smaller enhancements of nitrogen than those found in the ω Cen stars. The low luminosity of W 167, which occurs at a magnitude level near that of the horizontal branch, suggests that the nitrogen enhancement has occurred during the first ascent of the giant branch, by convective mixing from the hydrogen-burning region.

The study of the RR Lyrae variables in ω Cen by Dickens and Miss E. A. Epps, using *B* and *V* plates taken with the SAAO Victoria and Radcliffe telescopes, has continued. Measurement of the plates using GALAXY is nearly complete and computer reduction of GALAXY photometry is proceeding.

Dickens has directed a search for faint blue horizontal-branch stars, analogous to those known to exist in the similar globular cluster NGC 6752, in the globular cluster NGC 288 using plates taken with the Radcliffe telescope and the AAT. Measurement of 1000 stars in the region of the turn-off point in the HR diagram has failed to reveal any such blue stars in NGC 288.

Further work on the RR Lyrae variables in the distant globular cluster IC 4499 has been carried out by Dickens and Epps, in collaboration with Coutts (David Dunlap Observatory). Plate material in *B* and *V* has been obtained with the Las Campanas 1-m telescope, from which periods for a further 24 a-types and 15 c-types have been derived. The mean periods are intermediate between those expected for Oosterhoff class I and II clusters. Work is in progress to determine the mean colours of the variables.

Dr. P. J. Andrews has shown Pal 12 to be a dwarf globular cluster with a colour-magnitude array similar to that of 47 Tuc, including a well-defined red horizontal branch. A distance of 20 kpc has been estimated.

Study of the RR Lyrae variables in NGC 4590 has been continued by Andrews. Periods have now been obtained for all the variables with reliable photometry, except for three variables which have variable amplitudes.

Galactic Open Clusters. Mr. C. A. Murray has developed a new formulation of the convergent point method, in which kinematic parameters of a moving cluster and the parallaxes of individual members are derived in a simultaneous solution. This has been applied to Hyades stars; the mean distance modulus of main-sequence stars appears to be about 3·2 which is significantly larger than that derived by the same method for the bright A and K stars.

The measurement of photographic plates of NGC 6231 obtained by Dr. P. J. Andrews is in progress. Agreement of photoelectric measures by Andrews with published work is excellent. Both this cluster and NGC 3293, also studied by Andrews, seem to have a deficiency of faint members. Variable reddening has been found across NGC 3293.

Radial velocities have been measured by Andrews on 33 Radcliffe spectra of a double-lined binary in κ Cru (NGC 4755), and a period has been derived. *UBV* photometry by Andrews shows elliptical variation with this period.

Variable Stars. Analysis of *ubv* photometry by Dr. P. J. Andrews and infrared photometry by Dr. I. S. Glass of southern R CrB stars has shown that all have extended shells around them which are seen both near maximum light and during faint periods. The suggestion by Alexander *et al.* that the bolometric magnitude of R CrB stars remains constant during a decline has been shown to be incorrect. A model for the R CrB phenomenon has been developed by Andrews. This involves the ejection from the photosphere of a cloud in which there is rapid formation of graphite particles when the cloud reaches a radius for the star where the black-sphere temperature is less than the critical temperature for graphite formation. If the cloud is in the line of sight there is a sudden drop in light together with the observed spectral changes. The recovery takes place when the cloud recedes from the star and expands, giving the observed slow increase in brightness associated with a decrease in reddening. The model also explains some of the complex behaviour associated with the pulsating star RY Sgr in which the pulsation cycle has a marked effect on the shape of the light curve during some declines.

Analysis of *ubv* photometry and spectra by Andrews (6) has shown HD 268892 to be a c-type RR Lyrae variable in front of the LMC. The object has a high radial velocity and is metal-poor.

A period, light and colour curves have been determined by Andrews for the only known high-velocity S-type Mira variable. Comparison with the photometric properties of the other S-type Miras fails to show any distinct differences.

Photometry by Andrews of two S-type stars in the η Car nebula has been analysed to give an improved estimate for the absolute magnitude

of the stars of $M_v = -1$, assuming them to be members of the Carina complex and to have similar reddening to nearby early-type stars. One of the two stars has been shown to be variable.

Andrews has compared his *ubv* photometry of the two super-supergiants HR 6392 and HD 268757 (in the LMC) with published values for HR 5171. All three stars are variable, but only HR 5171 shows complex behaviour. Further observations are required to distinguish between different possible explanations. Determination of the distance of HR 6392 from its blue companion is complicated by the companion being a WN6 star.

Radial velocities and equivalent widths have been measured by Mr. E. N. Walker on 21 spectra of the Ap variable star HD 73340 in order to test the "oblique rotator" theory for the origin of the variations. The results have been reduced and subjected to a detailed analysis, which indicates that the variations seem not to have been caused by this mechanism. There is some evidence for multiperiodic variations which, if confirmed, will require a reappraisal of the nature of at least some of the Ap stars.

Mr. B. Emerson has continued to collaborate with Griffin (Institute of Astronomy, Cambridge) on the determination of the orbital elements of spectroscopic binaries (8).

Star Formation and Interstellar Matter

Spectral types for 16 stars, *UBVRI* photometry for 13 stars and *UBVRIHKL* photometry for 35 stars in the Orion Nebula cluster have been determined under the direction of Dr. M. V. Penston (36). Analysis of this and earlier data shows the reddening law in the cluster to be normal. Previous claims for high ratios of total to selective absorption are caused by mistaking infrared emission for a hole in the absorption at that wavelength. The distance modulus of M42 is $8^{m}{\cdot}0 \pm 0^{m}{\cdot}1$. Star formation has been in progress over the last 10^7 years. The infrared colours are correlated with the range of variation in the optical for stars in this cluster.

Photographic photometry of 477 stars in the Orion Nebula cluster has also been performed in wavebands relatively free from nebular emission lines. The distribution of faint stars in the colour-magnitude diagram and the presence of stars with $V \sim 14$ near the zero-age main sequence suggest that current models of low-mass contracting stars are wrong. The reddest stars show a concentration centred near the position of the molecular and infrared complex OMCZ.

GALAXY measures of 355 stars on 41 plates are being analysed to find variables in the Orion Nebula cluster. Because of the mass of data, careful statistical treatment is necessary.

Other star-formation regions have also been examined. *JHKL* photometry by Dr. I. S. Glass and Penston of 44 stars in the R CrA association has revealed no new cases of dust emission, but several highly-reddened stars have been discovered (12). These show the dark cloud to have $A_v \sim 8$ magnitudes. The ratio E_{J-H}/E_{H-K} may be higher in the cloud than predicted by traditional reddening laws.

New highly-reddened stars in Taurus and Cygnus have been found and examined by Dr. D. A. Allen and Penston observing from Tenerife (4). In the λ Ori association *HK* photometry of 27 stars has revealed only one with dust emission. The λ Ori association is thus probably older than the M42 region.

Stellar Atmospheres, Structure and Evolution

Miss G. Ockleston (research student), working under Professor B. E. J. Pagel's supervision, has investigated the time-dependence of the abundances of the light elements D, Li, Be, B with special reference to the effects of continuous inflow of intergalactic material as suggested by Audouze and Tinsley. Neither the light elements nor any other elements provide evidence that abundances in the interstellar medium have been affected by inflow during the bulk of the history of the Galaxy.

Pagel and Miss J. Drew (vacation student) have investigated a recent report of helium-isotope shift in the spectroscopic binary 68 Her (B2V; $v \sin i = 120$ km s^{-1}). They find that blending effects, which would not have been troublesome in a sharp-lined spectrum, leave very little evidence for an isotope effect.

Progress has been made by Pagel and Mrs. D. L. Harmer in the identification of weak lines in the Mount Wilson spectra taken in 1973 for an abundance analysis of μ Leo relative to the Sun and α Ser, and further interesting stars have been identified in the programme of detailed spectroscopy of metal-weak stars discovered by Bond's objective-prism survey.

Harmer has obtained spectra at DAO (Victoria) and at RGO of the extremely luminous supergiant HD 217476 which show significant spectral changes over a year in the blue and some metallic emission lines in the infrared.

Mr. T. G. R. Beynon (research student) is investigating abundances in solar-type stars of elements exhibiting large hyperfine structure. He has developed a simple approach to permit estimates of hyperfine-splitting constants in iron-group elements, which satisfactorily reproduces experimental data for Mn and is being extended to astrophysically interesting levels in Mn and other elements for which experimental data are not available. Some relevant observations have been secured using a Spectracon on the 30-inch coudé reflector.

Computation of synthetic ultraviolet spectra has been continued by Dr. D. J. Stickland using the ICL 1906A at UCL in an attempt to reproduce the results of the S59 spectrometer aboard the *TD-1A* satellite for the binary star β Aur. The spectra were found to depend strongly on the adopted microturbulence, but with the new *f*-values of Kurucz and Peytremann, fairly good agreement was possible even at the shortest wavelengths.

The double-lined binary system λ Vir has been subjected to close spectroscopic examination by Stickland, and found to consist of two very similar Am stars with different values of the projected rotational velocity. The orbital elements have been redetermined, and the earlier value of the period (207 days) restored.

Stickland has commenced an observing programme on the INT to discover sharp-lined mercury stars using Cassegrain spectra at 8·5 Å mm^{-1}. The results will be communicated to Tomkin and Lambert at the University of Texas, where interesting stars can be examined with the high-resolution coudé scanner.

Mr. J. B. Alexander has continued his stellar observations of the Swan band of C_2 using the INT and the 36-inch telescope at Herstmonceux and the 40-inch SAAO telescope at Sutherland. Although it appears that the dispersion in [C/Fe] for dwarf F and G stars is less than about 0·1, differential abundance effects are probably important in explaining the *UBV* colours of stars somewhat cooler than the Sun where competitive effects are significant.

Dr. I. S. Glass has made observations of more M-dwarfs in the infrared. They are clearly separated from giants in the $(J-H, H-K)$ diagram, and their positions in this and the $(H-K, K-L)$ diagrams are reasonably predicted by recent model atmospheres dominated by water vapour. Those dwarfs with emission-line spectra are more scattered, but are still separated from the giants.

Emission-Line Objects and Planetary Nebulae. The spectroscopic survey of emission-line stars selected by infrared photometry (3) has led to some unexpected findings. Dr. D. A. Allen and Dr. R. A. E. Fosbury have discovered that some of Kohoutek's planetary nebulae are merely late M stars and one, K3–47, is an Me star with unusual emission lines (2). The strength of the [O III] lines in the symbiotic stars with circumstellar dust, previously identified by Dr. B. L. Webster and Allen (48), correlates with the presence or absence of dust; this is interpreted as evidence that the dust lies in neutral condensations. Most of the stars with dust emission have low-excitation spectra; a catalogue of their spectra is being prepared by Allen and Swings (Université de Liège).

The same selection of stars is being examined at other wavelengths. A surprisingly large number of them have been detected in the radio by Wright (NRAO, Parkes), Purton (York University, Toronto) and Allen. The radio spectra are interpreted as arising in circumstellar ionized gas which has a roughly inverse-square variation of density with distance from the star, implying mass loss. For many of these stars the optical spectra also indicate mass loss.

Cohen (University of California, Berkeley) and Allen observing from Mount Lemmon, Arizona, have secured 2–4 μm scanner spectra of MWC 819 and M2–9. MWC 819 has an emission feature at 3·3 μm previously reported only in NGC 7027. No satisfactory identification of this feature has been proposed.

Sanduleak has drawn attention to an emission-line star recorded on his objective-prism survey, which showed only a single feature near 4650 Å. Allen and Fosbury, using the IDS on the AAT, have found it to be a conventional WC6·5 star.

Webster has completed her observational comparison of the properties of planetary nebulae in the galactic bulge and the Large and Small Magellanic Clouds. A spectroscopic survey of over 50 suspected planetaries towards the galactic centre was carried out, followed by a detailed study of 13 planetaries in the galactic bulge and 7 objects in each of the Magellanic Clouds. The galactic bulge objects have been used to investigate the validity of various methods for determining the distances of planetary nebulae. To assist in the analysis, theoretical models of the ionization structure of nebulae have been constructed for a range of star temperature, gas density, abundance, etc. The energy-balance method for calculating oxygen abundances has been formalized and the relation between the excitation class and the nebular parameters has been defined. The only plausible explanation for the difference between the planetaries in the two Clouds is that the LMC objects have hotter central stars than those in the SMC. From the new observational data it appears that the helium abundance of all the nebulae studied is normal to within the errors.

Rocket Infrared Sources. Dr. D. A. Allen has begun a programme to examine the optical counterparts of infrared sources discovered by the Air Force Cambridge Research Laboratories rocket sky survey. To date, most of the sources for which spectra have been obtained are late M stars, but one is of spectral type WC8, being the first such star found to have an infrared excess. Further identifications are being sought by Allen and Longmore (ROE) by comparing red (1N) and blue (III aJ) UK Schmidt plates of the fields.

Nova Cygni 1975. Dr. D. J. Stickland and Mrs. D. L. Harmer have obtained spectra on the 30-inch coudé reflector, the most interesting

being those taken prior to maximum. Velocities have been obtained by Dr. P. J. Andrews for the emission peaks which were seen in the hydrogen lines, and other strong features. These give constant velocities for what are taken to be condensations in the nebular envelope. The development of the nova spectrum has been extremely rapid, and some of the early stages in the development of a typical nova have not been seen.

Galactic Astronomy

Kinematics and Photometry in Selected Areas. Mr. K. Muanwong (research student) has continued his study of kinematics and photometry in SA 51, 54, 57, 71, 82, 94, 107. Reductions of measurements in all seven areas, yielding B,V and preliminary proper motions for over 3000 stars, have been carried out. Final results in SA 57, giving annual proper motions with standard errors of $\pm 0''{\cdot}001$ in each coordinate, have been obtained after an extensive investigation of the plate-overlap technique as applied to the problem of simultaneous adjustment of data for many plates on a single field.

Solar Neighbourhood. Dr. D. H. P. Jones and Mr. J. B. Alexander have continued the search for new M dwarfs using a narrow-band technique. It now appears that the currently known number of M dwarfs cannot be less than about 60 per cent of the total, and that there is still probably a significant difference in mass-density between identifiable stars, gas and dust and the dynamical mass-density. If more M dwarfs are to be found in substantial numbers they are probably very faint. Fifty faint red stars in the South Galactic Cap (from an unpublished objective prism survey kindly communicated by Pik Sin Thé) observed with the IDS on the AAT have a median spectral type about dM2; a concentration at dM6 would be required to provide the necessary mass.

Work continues on the trigonometric parallax programme on the 26-inch telescope, under the direction of Mr. B. G. F. Scales, and on the INT. During the period covered by this report, trigonometric parallaxes were determined for 12 stars. Measurements for an additional eight fields have been completed and are in the process of being reduced. A series of plates of the South Galactic Cap is being taken on the UK Schmidt telescope for parallax measurement at RGO. A search will be made for all stars with trigonometric parallaxes greater than about 0·05 arcsecond down to $m_{pg} = 18$.

Alexander has made some four-colour observations (on a system similar to Strömgren's) at Sutherland (SAAO) with a view to investigating possible systematic effects between Cape and Allegheny trigonometric parallaxes.

Photometric Systems

A comparison between values of $(R-I)_{KC}$ published by Cousins (SAAO) and values of $(b-y)$ obtained by Mr. J. B. Alexander for stars in the Harvard E regions indicates that there is a tight correlation between the two colours for normal F and G stars. The apparent lack of such a good correlation for northern stars is almost entirely caused by large random errors in the $R-I$ photometry rather than by real effects in stellar atmospheres.

Dr. D. H. P. Jones has cooperated with Cousins in making simulated numerical models of the Cape natural photometric systems.

Solar System

Planetary Satellites. Photometry by Dr. P. G. Murdin and Dr. M. J. Penston of the occultation of Jupiter's satellite Europa by its larger satellite Io showed the change of colour across Europa's disk, and enabled maps of the disk in the V and B photometric bands to be made (24).

Mr. G. E. Taylor and Mr. E. N. Walker have analysed the timings of an occultation of a star by Saturn's satellite Rhea, which were secured by observers at the Sierra Nevada Observatory of the University of Granada. The observations provide a lower limit to the diameter of Rhea consistent with earlier determinations.

4. NATIONAL AND INTERNATIONAL SERVICES

Time and Latitude Service

Photographic Zenith Tube (PZT). The programme for the determination of universal time (UT) and the variation of latitude by astronomical observations with the PZT was continued under the supervision of Mr. N. P. J. O'Hora. 2022 star transits were observed on 101 nights and the results were sent weekly to the Bureau International de l'Heure (BIH) and the International Polar Motion Service. The use, from January 1, of an improved catalogue of stellar positions and proper motions and better reduction techniques has led to reductions of about 10 per cent in the external standard error of the results from a single plate and about 15 per cent in the internal standard errors for each star.

A new rotary drive, powered by a stepping motor, has been constructed in the Observatory workshop, and tests on the PZT indicate that it will prove much more efficient than the present drive. Design studies of the necessary alterations for fully-automatic operation are nearly complete and some of the new equipment has already been

ordered. The time distribution equipment at the Spencer Jones Group terminal is also being redesigned.

Danjon Astrolabe. It has not been possible, because of a shortage of staff, to make the observations required to evaluate the performance of the new reflecting prism in the Danjon astrolabe. The roof of the observing hut was replaced in August by a new roof assembled in the Observatory workshops.

Atomic Time. Under the supervision of Miss C. J. A. Penny, the Greenwich Atomic time-scale (GA2) was formed throughout the period by combining the scales of the individual caesium-beam time standards (atomic clocks) at RGO. The GA2 scale was based on four clocks for most of the period.

The results of the comparisons of the clocks with the time pulses of the radio signals of the Loran-C navigational system were sent to the BIH for use in the formation of the international atomic time-scale (TAI).

A sixth caesium standard was brought into operational use; it has a high-performance beam-tube, but it is too early yet to assess its long-term stability. Prototype equipment for making clock comparisons with an accuracy of better than one nanosecond (10^{-9} s) has been designed and tested by Mr. H. G. Gill; he was assisted in the production and initial evaluation of the equipment by Mr. R. Zerrander of the Swedish Research Institute for National Defence.

Radio Time Signals. The national time signals (GBR) emitted by the Post Office from Rugby, and some international time signals, have been monitored regularly at Herstmonceux. A special series of clock comparisons with Loran-C emissions has been made at the request of the US Naval Observatory in order to measure directly the difference between the Norwegian Sea Chain and the North Atlantic Chain, and so to increase the accuracy of the transfer of time across the Atlantic.

Travelling-Clock Comparisons. Travelling clock comparisons were made with an RGO caesium standard as follows: in January, at the request of Government Communications Headquarters, Cheltenham, to synchronize their timing system; in March, at the request of the Nuffield Radio Astronomy Laboratories, to synchronize their clock with the US Naval Observatory time scale in connection with a joint Jodrell Bank–USA programme of very long baseline interferometric observations.

Time Comparisons by Satellite. A joint US–Australian–British experiment to evaluate the use of the Navigational Technology Satellite (*NTS-1*, previously known as *Timation-3*) for global clock synchronization at the sub-microsecond level is now in progress. The satellite

carries two rubidium oscillators and one specially-developed quartz-crystal oscillator, and emits time signals which are compared with the clocks at the ground stations. The observations are analysed to improve the knowledge of the satellite's orbit and clock performance and hence to improve the precision of the comparisons between the time-scales of the ground stations. (If the observations are made simultaneously from two stations the comparison between their time-scales is independent of the performance of the satellite clock, but depends on the accuracy with which the travel times can be calculated.) Aerials and the associated timing and recording equipment, lent by the US Naval Research Laboratory, were installed at RGO under the direction of Mr. H. G. Gill. Satellite passes occur at intervals of about eight hours, and measurements are made at Herstmonceux for about two hours during each pass; 50 passes were observed between July 2 and August 28, but observations were then suspended while the receiving equipment was being modified.

Publications. The results of the time and latitude service have been published as follows during the period of this report:

Time Service Circulars A (weekly)
Time Service Circulars B (monthly)
Time Service Notices (irregularly)
Greenwich Time Reports 1974 January–September

HM Nautical Almanac Office Publications and Data Services

Almanacs and Ephemerides. The work of preparation and publication of almanacs and ephemerides has continued under the supervision of Dr. B. D. Yallop. The following almanacs have been published during the period of this report:

The Nautical Almanac 1976
The Astronomical Ephemeris 1976
The Air Almanac 1975 May to December (2 parts)
The Star Almanac for Land Surveyors 1976

The reprinting of the *Explanatory Supplement to the Astronomical Ephemeris* has not yet been completed, but it is hoped that publication will take place before the end of 1975. The printing of the *Advanced Data for the Astronomical Ephemeris for 1980* has been delayed by another industrial dispute at Her Majesty's Stationery Office, but it is hoped that it will be distributed early in 1976.

The preparatory work for the revised form of *The Astronomical Ephemeris* for 1981 onwards has continued in cooperation with the US Naval Observatory. Preliminary specimens for a new edition of *Planetary Coordinates* have also been prepared; it is intended that it

will cover a much wider range of ephemerides than previous volumes and will largely obviate the need for a special distribution of advanced data. *The Star Almanac* for 1977 will include new tabulations of polynomial coefficients for each month, as an alternative to the ordinary tabulations, for surveyors having small programmable electronic calculators; two pages of charts showing the distribution of the tabulated stars will also be included for the first time.

Astronomical Data Services. The preparation and distribution of astronomical data to meet the special requirements of individual observatories, navigators and astronomers, as well as the supply of astronomical and calendarial data for civil purposes, has continued as described in the Report for 1974. Sky-brightness data have been provided for use in the allocation of observing time on the large telescopes at Herstmonceux, Sutherland and Coonabarabran.

Occultations. The regular programme for the prediction and reduction of occultations of stars by the Moon has continued under the direction of Mr. L. V. Morrison. Worldwide predictions were distributed to observatories and individual observers and for publication in local journals. During the period of this report about 7000 timings were received, coded and reduced. The preparation of a reproducible listing of all occultation observations since 1943 is near completion. The computer programs, designed by Dr. P. G. Murdin and Mr. C. S. Buck (sandwich student) for the spectral analysis of data sampled at unequal time-intervals, have been used to analyse the reduced occultation data for unknown periodicities. The collection, coding and reduction of observations made before 1943 continued.

Morrison has continued to supply various X-ray groups in the UK and abroad with detailed predictions of lunar occultations of X-ray sources. General predictions for forthcoming occultations of the strongest sources lying near the ecliptic have been issued (20).

Lunar Laser Ranging. Dr. A. T. Sinclair has been seconded to work at Canberra for one year, as part of a collaborative project for lunar laser ranging between SRC and the Australian Division of National Mapping. He will assist with the development of computer programs for the predictions, the real-time processing of the signals, and the subsequent reductions. The data will be available to UK scientists through HM Nautical Almanac Office in due course.

Stellar Reference Frame and Related Observations

Proposed Anglo–Danish Collaboration. Detailed discussions have been held with astronomers of the Copenhagen University Observatory, Brorfelde, with a view to establishing collaboration in meridian

astronomy. The present proposal is that the existing Brorfelde transit circle should be transferred to the NHO site, assuming this to be in the Eastern Atlantic, and operated as a joint RGO–Copenhagen University venture. Automation of the instrument is scheduled to be completed at the end of 1975, but further enhancement would be needed to ensure reliability of operation at a distant site and to minimize the number of maintenance staff required. Once the instrument was fully operational at the NHO and the expected quality of its performance verified, the Cooke TC could be withdrawn from service at Herstmonceux; it would in any case be approaching the end of its useful life. No additional staff are expected to be needed to implement these proposals.

It is estimated that the automated Brorfelde TC operated at a good site could achieve an annual output of 100 000 observations (an order of magnitude greater than is possible at either Brorfelde or Herstmonceux), could reach magnitude $m_v = 13$ regularly (*i.e.* 3 or 4 magnitudes fainter than the Cooke TC at Herstmonceux) and would be comparable in accuracy with the advanced instruments which are now being developed elsewhere. It is proposed that RGO should be primarily responsible for fundamental observations of fundamental stars and solar system members and for the establishment of the fundamental stellar reference frame of the instrument, while the Copenhagen astronomers would be primarily responsible for the differential observations of reference stars.

Discussions are continuing, with the aim of producing definitive proposals as soon as possible.

Cooke Transit Circle. Observations of the Sun, Moon (limbs and Mösting A), planets and fundamental stars have continued with the Cooke Transit Circle at Herstmonceux, under the direction of Mr. R. H. Tucker.

The setting up of a fundamental right ascension and declination system from the observations made in the years 1957–1973 is now approaching completion.

The programme of observations of zodiacal stars is now 95 per cent complete, and the Herstmonceux programme of observations of the international list of northern PZT stars is 89 per cent complete.

Work on the automatic digital circle-reading system being constructed at the National Engineering Laboratory, Kilbride, is at an advanced stage. A fringe grating is being mounted in place of the second (movable) glass circle of the Cooke TC. It is expected that trials, involving comparison between the new digital read-out and simultaneous photographic readings with the existing cameras, will commence early in 1976. Work is proceeding on the renovation of the existing data-handling equipment, and the reserve Mk II EPIC (chronograph) installation is now complete.

Mr. M. E. Buontempo has general charge of the telescope.

Catalogues. The occasional observations of the Moon made with the Cook TC between 1958 and 1971 are about to be published. Observations of the Sun, Moon and Planets, 1972–1973 are also in press. The Third Greenwich Catalogue for 1950 (Airy Transit Circle, 1942–1954) is well advanced. Catalogue preparation continues under the direction of Mr. K. C. Blackwell.

Southern Hemisphere Reference Frame. All star observations made with the Gill Transit Circle at the Cape from 1961 March to 1974 April are now in computer-readable form at Herstmonceux. Preliminary O–C values are being analysed by Mr. A. Shortland.

Cape Photographic Survey. Measurement of the 6000 plates taken with the wide-angle astrometric camera at SAAO has been deferred until GALAXY becomes fully operational after the installation of the NOVA computer.

Solar Activity Service

Observations of Solar Activity. Under the supervision of Dr. A. L. T. Powell (until September 15), the Sun was photographed at Herstmonceux in white light on 186 days, and in the light of Hα using the Lyot filter on 131 days during the nine-month period. White-light photoheliograms were also obtained at Cape Town on 214 days for transmission to Herstmonceux through a cooperative programme with the SAAO.

Continuous monitoring of radio reception at 28·5 kHz for detection of sudden enhancements of atmospherics and at 6·090 MHz for detection of sudden ionospheric disturbances was maintained throughout the period of the report.

Current information on solar activity has continued to be distributed widely by monthly Solar Activity Circulars, while immediate notification of significant events has been made to interested organizations.

Solar activity continued to decline generally, although five flare events were observed during August and two new high-latitude sunspots were noted, heralding the start of a new cycle.

Photoheliographic Results. The preparation of a detailed daily record of the positions and areas of sunspots and faculae and of individual sunspot groups has been continued. Photoheliographic results for 1966 are in press and those for 1967 are in an advanced state of preparation. Considerable effort has gone into the computerization of the reductions and the production of the tabular results, so it should be possible to reduce the backlog substantially in the coming year.

RGO Archives

Due to the Tercentenary there was an expected increase in public enquiries (approximately 140 letters) received by the Archivist, Mr. P. S. Laurie, and some dozen historical researchers were given facilities and assistance on visits to examine the archives.

Close collaboration continues with the National Maritime Museum (NMM) on the subject of further microfilming of RGO archives. With Public Record Office (PRO) agreement, a section on chronometers (46 volumes) has been temporarily transferred for this to be carried out.

Late 19th century and early 20th century papers are being rearranged and additional material incorporated in the archives.

At the suggestion of the PRO, a complete set of Royal Observatory publications (from late 18th century to date) is in process of being transferred from store to the archives.

Laurie and Mr. D. A. Calvert (Senior Photographer), in consultation with Lt.-Cdr. H. D. Howse (NMM) have arranged the RGO Photographic Archives under broad headings; they will be catalogued under the system used at NMM.

5. INTERNAL SERVICES

Central Computer Services

Mr. A. E. Carter continues to be responsible for the central computer service, which is based on an ICL 1903T computer system, using the GEORGE 3 operating system. The system continued to be operated for two shifts on normal working days, under the general management of Mr. J. V. Carey who continues to develop the operating system. Four more exchangeable disk drives (2M words each) and a fourth teletypewriter have been added. A small graphics display unit has also been obtained but is not yet in use.

The average amount of useful time (*i.e.* excluding time lost for faults and hardware maintenance) was 259 hours a month. Of this useful time: 4 per cent was devoted to the provision of national facilities (mainly accounted for by GALAXY system development and initial data processing); 23 per cent was devoted to the provision of national and international services; 47 per cent was accounted for by astronomical research (the major part being analysis of plate material obtained using GALAXY); 14 per cent was used (and paid for) by the Geomagnetism Unit of the Natural Environment Research Council based at Herstmonceux; and 12 per cent was used for systems and software maintenance and development. The average serviceability ratio was 0·95.

The remote job-entry work-station link to the ICL 1906A computer at the Atlas Computer Laboratory has been used only to a limited extent during the period.

A programming advisory and punching service has continued to be provided for all users of the central computer.

Engineering Services

Engineering services, under the general direction of Mr. J. W. Gietzen, have been provided by the Drawing Office (managed by Mr. A. E. Morris), the Engineering Workshop (managed by Mr. P. F. Cottrell) and the Electronics Department (managed by Mr. H. G. Gill). The main effort has been devoted to the engineering design, development and construction of astronomical instrumentation. The effort was divided approximately: AAT and SAAO, 17 per cent; INT and other telescopes, 30 per cent; other projects, 53 per cent. Approximately 20 per cent and 35 per cent, respectively, of the time of the Engineering Workshop and the Electronics Department was devoted to the maintenance of all the telescopes, measuring machines and electronic equipment of the Observatory.

Libraries

The work on rearranging and recording the RGO Library's holdings of publications received from other institutions and of periodicals, has continued under the supervision of the Librarian, Miss J. E. Perry.

Including the Library of HM Nautical Almanac Office, a total of 30000 volumes is now held, in addition to reprints and unbound parts of current journals. Nearly 150 journals are obtained regularly, and 150 books were acquired during the nine months under review. The publications of observatories and ephemeris offices throughout the world continue to be obtained in exchange for RGO publications and those of HM Nautical Almanac Office.

6. RGO TERCENTENARY

The tercentenary of the Royal Greenwich Observatory was celebrated during 1975, marking the 300th anniversary of the appointment of the first Astronomer Royal and the establishment of the Royal Observatory at Greenwich. King Charles II's Warrant dated 4 March 1675 appointed the Reverend John Flamsteed "our astronomical observator", and a second Warrant dated 22 June 1675 founded the Royal Observatory.

The historical aspects of the tercentenary were featured in a number of events organized by the National Maritime Museum, which now has responsibility for the former Observatory buildings at Greenwich. At

Herstmonceux, the opportunity was taken of demonstrating the current work of the Royal Greenwich Observatory to interested scientific societies and to the general public. A Tercentenary Committee, under the chairmanship of Mr. H. M. Smith, was responsible for programme planning and made detailed arrangements for the various events.

In order to give visitors a comprehensive view of the range of RGO activities, arrangements were made for five telescopes (including the INT) to be demonstrated, and 12 displays incorporating specially-prepared exhibition panels were located at appropriate points throughout the establishment. Recorded commentaries were played at some of the display points. Mr. R. H. Tucker had overall responsibility for the preparation of the exhibitions; these included displays prepared by the Chronometer Section of the Hydrographic Department and by the Geomagnetism Unit of the Natural Environment Research Council, both of which were formerly departments of the RGO and are still housed at the Observatory. A new booklet, *Royal Greenwich Observatory Illustrated*, was prepared by Dr. D. H. P. Jones to give a general picture of the RGO, and 15 pamphlets were produced explaining different aspects of the work and instruments in more detail.

A Press Preview, attended by 35 representatives of the local, national and foreign Press, was held at RGO on 19 June. During the week 23 to 27 June, more than a thousand members of the following scientific societies and establishments with interests allied to astronomy accepted invitations to the Observatory:

The Royal Society
The Royal Astronomical Society
Establishments of the Science Research Council
The National Physical Laboratory
The Institute of Navigation
The Worshipful Company of Clockmakers
The British Horological Institute
The Institute of Physics
The British Astronomical Association

together with representatives from establishments with whom RGO has special connections. Nearly 22000 visitors were admitted to the Observatory during the Open Days, 31 July to 17 August.

At Greenwich, the National Maritime Museum has mounted a special exhibition "300 Years of Astronomy" in the Queen's House. The Times Publications has produced a commemorative catalogue for the exhibition, including articles written by members of RGO staff. Mr. P. S. Laurie, RGO Archivist, acted as liaison between RGO and the Museum on content and design of the exhibition; the modern section was largely the responsibility of RGO staff, Dr. D. V. Thomas acting as editor.

Two international symposia were held in celebration of the tercentenary. The first, on "The Origins, Achievements and Influence of the Royal Observatory, Greenwich, 1675–1975", was held at the National Maritime Museum from 14 to 18 July under the auspices of the International Astronomical Union and the International Union for the History and Philosophy of Science. Papers were presented by the following RGO staff: Dr. A. Hunter, Mr. P. S. Laurie, Mr. C. A. Murray, Mr. H. M. Smith, Dr. G. A. Wilkins; and by former members of staff: Professor R. d'E. Atkinson, Mr. B. R. Leaton, Dr. D. H. Sadler and Sir Richard Woolley.

The second symposium, held at Herstmonceux Castle on 22–25 July, was on the subject of "The Galaxy and the Local Group". A representative gathering of nearly 80 full participants, many from overseas, included 15 members of RGO staff. There were 11 invited review papers and 30 other paper contributions. Topics included the molecular content and chemical evolution of the Galaxy, the Galactic centre, classification, chemical composition and motions of the nearby galaxies, the extragalactic distance scale, and the gas content of the Local Group. Particularly stimulating discussions took place on models for the chemical evolution of the Galaxy and on the nature of the Magellanic Stream. The symposium concluded with a lively summary by Professor I. King (University of California, Berkeley) who contrasted the rapid progress that can now be expected on an annual time-scale employing current technology with the slow evolution of astronomy during the 300 years of existence of the RGO.

Guest of honour at the RGO symposium was Professor J. H. Oort, former President of the IAU, who gave an evening lecture to a wider audience on "The Nucleus of Our Galaxy". In this he emphasized the relevance of the study of the centre of our own Galaxy to the problems currently posed by the many peculiar phenomena observed to be associated with the nuclei of other galaxies. The text of Professor Oort's lecture will be included with the proceedings of the symposium, which will be published as a Royal Greenwich Observatory Bulletin. Dr. G. A. Wilkins was responsible for the general arrangements for the symposium; the scientific programme was organized by Dr. R. J. Dickens, assisted by Professor B. E. J. Pagel and Dr. B. L. Webster.

Nearly 900 guests attended the Tercentenary Garden Party at Herstmonceux Castle on 18 July, to which all present staff and long-serving former members of RGO staff and participants in the Tercentenary Symposia were invited. The guest of honour was Her Royal Highness The Princess Anne, Mrs. Mark Phillips, who unveiled a stone bust of John Flamsteed, the first Astronomer Royal, as the inauguration ceremony for a commemorative sundial erected behind it. Designed by Mr. G. E. Taylor, the reclining equi-angular sundial is made of

stainless steel and has a vertical gnomon. The 3-m diameter dial is adjusted to show Greenwich Mean Time to a nominal accuracy of one minute. The sundial was manufactured and constructed by Morfax Ltd. to an engineering design produced by the SRC Works Unit.

The Flamsteed bust was sculpted by Mr. G. Elliott, a member of the staff of Ancient Monuments Division of the Department of the Environment stationed at Herstmonceux, and grateful acknowledgment is made for permission to carry out the work. After the inauguration the Director presented Princess Anne with a commemorative Royal Observatory Plate by Wedgwood, which incorporates in its black and gold design medallion portraits of the 11 Greenwich Astronomers Royal.

Both European Architectural Heritage Year and the Tercentenary of the Royal Observatory were given royal recognition by the visit to Greenwich on 20 May of Her Majesty The Queen and His Royal Highness The Duke of Edinburgh. Her Majesty reinaugurated the 28-inch refractor, now back at its original site in a reconstructed "Onion Dome" at the Old Royal Observatory. The Engineering Department of the RGO gave advice and assistance in the re-erection of the telescope. The Royal visitors also toured the "300 Years of Astronomy" exhibition.

A reception was held jointly by the Royal Society and the Royal Astronomical Society in the rooms of the Royal Society on 17 July, when historical exhibits concerning the Observatory were displayed and a commemorative address was delivered by Professor W. H. McCrea, a former Chairman of the RGO Committee. After the address the Director of RGO presented the President of the Royal Society with a bronze copy by Mr. G. Elliott of his stone bust of Flamsteed, in commemoration of three centuries of association between the Society and the Observatory.

A service of Evensong held in Westminster Abbey on 20 July was devoted to celebrating the tercentenary of the Observatory, with lessons and hymns reflecting a triple theme of Time, Navigation and Astronomy. The lessons were read by Dr. A. Hunter and Mr. B. J. Greenhill, Director of the National Maritime Museum. Sir Bernard Lovell delivered the Address. At a private ceremony before Evensong, Sir Richard Woolley laid a wreath on the grave of Charles II.

The parish of Burstow in Surrey, where the Reverend John Flamsteed was rector from 1684 until his death in 1719, held a Flamsteed Festival during the summer. Dr. Hunter spoke on the astronomical significance of Flamsteed's work at a memorial lecture on 6 July, and read one of the lessons in Burstow Church at a Service of Thanksgiving on 13 July, when the Bishop of Kingston conducted Evensong and dedicated a new memorial tablet to Flamsteed.

In June a BBC film unit spent three days at RGO gathering material for a 50-minute documentary to be broadcast on television in the autumn. A film unit from the Central Office of Information also visited the RGO for two days to film for overseas television.

The Royal Mint collaborated with the National Maritime Museum in the production of a set of three commemorative medals struck in gold, silver, and gilt-bronze. Each medal has a common obverse showing Flamsteed House, while the reverse designs depict Astronomy, Time and Navigation.

In collaboration with the Post Office, specially-produced commemorative covers were posted at RGO on 22 June, the 300th anniversary of the foundation of the Observatory. The covers bore the 8p postage stamp featuring Flamsteed House.

Several special publications have appeared in association with the tercentenary:

The Royal Greenwich Observatory An Historical Review by Professor W. H. McCrea, FRS, commissioned by the Science Research Council.

Greenwich Observatory A history in three volumes, published by Taylor & Francis Ltd.

Vol. 1, *Origins and Early History* (*1675–1835*) by Eric G. Forbes.

Vol. 2, *Recent History* (*1836–1975*) by A. J. Meadows.

Vol. 3, *The Buildings and Instruments* by Derek Howse.

The Times (26 March)—Special Report: *Space, Place and Time.*

Nature (19 June)—Special Issue containing a 26-page section on the history of British astronomy entitled *300 Years of Greenwich.*

Herstmonceux Conference

The 19th annual Herstmonceux Conference on the subject of "Photometry", held from 8 to 11 April, was dedicated to Professor R.H.Stoy, former HM Astronomer at the Cape, on the occasion of his retirement. The Conference was organized by Professor D.S.Evans (University of Texas), Dr S.V.M.Clube (Royal Observatory, Edinburgh) and Mr C.A.Murray. It was attended by 44 visitors, of whom 17 gave invited papers. Four members of the staff also presented papers.

7. PUBLICATIONS

The following publications have been issued during the nine months under review, in addition to those mentioned in Section 4. The papers are listed under the names of the staff involved; those whose appointments terminated before 30 September are prefixed by an asterisk; staff on leave of absence and staff seconded to work for other establishments are prefixed by a dagger. Authors who are not members of staff or students working at RGO are shown in italics.

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