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ROYAL GREENWICH OBSERVATORY

Director, E. Margaret Burbidge, FRS (from 1972 July 12)
Acting Director, A.Hunter (1972 January 1–July 11)

(Report for the year ending 1972 December 31)

X-RAY SOURCES

INT spectra of HD 226868, coincident with a radio source and the X-ray source Cygnus X–1, showed it to have the spectrum and interstellar features of a B supergiant at about 2 kpc. Analysis by P.Murdin and B.L.Webster shows it to be a single-line spectroscopic binary whose unseen companion has a mass of at least a quarter of the mass of the supergiant (**76**).

During 1972 March to June, E.N.Walker investigated the optical variability of HDE 226868, the optical counterpart of Cygnus X–1, using the Granada University telescope in the Spanish Sierra Nevada (**74**). The star was found to have variations of $0^{m}{\cdot}07$ with two maxima and minima per (spectroscopic) orbital period. Its light curve cannot be explained in terms of two 'normal' stars eclipsing each other: it has been speculated that the companion is a black hole surrounded by an opaque disk which occults the rotationally distorted supergiant.

The light curve of HZ Her (=Her X–1) was observed by P.G.Murdin with a photon-counting system built around a Nicholet 1024-channel analyser. Apart from the 1·7-day period of HZ Her, there is activity on short time scales (a flare seen on 1972 August 9·0 was reported in *IAU Circular* No. 2433) but no fluctuations at the 1·2 s period of the pulsar in this system, with an upper limit corresponding to a 20th magnitude star switching on and off.

Close co-operation with the group at the Mullard Space Science Laboratory has led to a programme aimed at reducing the positional uncertainty of selected X-ray sources using the UK experiment on the OAO–C satellite, and investigating optical objects within the smaller error boxes.

Following the suggestion that the eclipsing spectroscopic binary HD 152667 might be associated with an X-ray source, Sco X–2, E.N.Walker has carried out a detailed analysis of its light curve (**73**). No unique solution has been found; the photometric observations could be equally well explained either by eclipses or by the changing aspect of a gravity-darkened star filling its Roche lobe and accompanied by a massive object of low luminosity. The unusual redshift of the emission

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lines can be best explained as a result of the presence of a collapsed object in the system, and therefore supports the second of these alternatives.

The distribution of X-ray sources over the sky has been investigated by R.G.Bingham, who finds that a high proportion of known sources lie in a galactocentric slab roughly 6 kpc in diameter and 800 pc thick (6).

EXTRAGALACTIC STUDIES

A preliminary analysis by R.J.Dickens and N.Henbest of redshifts measured from Pretoria spectra of galaxies in the cluster Abell 1367 shows a small velocity dispersion, contrary to that predicted from the observed X-ray flux on the basis of a thermal Bremsstrahlung model. A more extensive programme on this cluster is being planned.

M.J.Penston and M.V.Penston (with A.Sandage of the Hale Observatories) have published photoelectric observations and finding charts for 59 stars near 18 quasars and 2 unidentified radio sources, and for 54 stars near 10 Seyfert galaxies and four N-type galaxies (**56**). Some of the stars are suitable for use as faint photoelectric standards, while others may be used for calibration in photographic monitoring programmes.

M.V.Penston and K.P.Tritton contributed to a world-wide programme of intensive observation of the rapidly varying sources OJ287, BL Lac and 3C120: the results were reported by Epstein *et al.* (**58**).

M.V.Penston has measured the *V–K* colours of six bright galaxies. These colours are not as homogenous as those given by Johnson (*Astrophys. J.*, **143,** 187, 1966). For M32, the *V–K* colour is bluer than that predicted by the population models of Spinrad and Taylor (*Astrophys. J. Suppl.*, **22,** No. 3).

M.V.Penston, together with Parkes of the University of Sussex, made a complete set of identifications of the 5C3 radio sources. The small number of identifications found (only 3) provides a constraint for quasar luminosity functions.

M.V.Penston and Margaret J.Penston have found a faint extended object about 1 arcmin. south of the compact object BL Lac. Scanner observations of the N-galaxy 3C390·3 and other galaxies close to it on the sky show that the light from an annulus centred on 3C390·3 is probably emitted by stars and that one of the other galaxies shares the redshift of 3C390·3. Thus any non-cosmological component in the redshift of the N-galaxy is small.

Twenty redshifts of radio galaxies mainly from the Parkes catalogue, obtained with the Radcliffe 74-in. and INT, were published by

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K.P.Tritton (71). Programmes to obtain redshifts of radio galaxies from the 4C catalogue and of radio galaxies that are double or have double nuclei are now in progress on the INT by K.P.Tritton. A spectrum by K.P.Tritton of Olsen's (*Astr. J.*, 75, 764) identification of 4C 31·63 proves it to be a quasar.

In collaboration with G.D.Nicolson, K.P.Tritton has shown that an early identification of the radio source 2204–54 with a galaxy is incorrect. An alternative identification is likely to be a quasar (72). The photographic optical monitoring of the variability of quasars and related objects continued on the 26-in.

R.G.Bingham has used a Kron camera for direct electronography of the nuclear region of M31 through a narrow-band filter centred on 4215 (CN) and has also observed λ8190 (Na) as part of a programme to determine the distribution of metal content and mass-to-light ratio. The semi-stellar nucleus shows apparently weaker CN bands than the surrounding background (5).

E.M.Burbidge has continued spectroscopic observations of suggested identifications of radio sources, mainly blue stellar objects, in collaboration with P.A.Strittmatter at Steward Observatory. A collaborative programme was undertaken with E.J.Wampler and L.Robinson at Lick Observatory and C.Hazard at the Institute of Astronomy, Cambridge, using the Wampler–Robinson image-dissector scanner at Lick.

SUPERNOVAE

D.R.Branch and B.E.Patchett (54) have completed their search for identifications of features in supernovae spectra. Examination of the time dependence of wavelengths of absorption features and comparison of published and synthetic spectra suggest that, near the time of maximum light, both Type I and Type II spectra, like the principal spectra of novae, contain relatively low-excitation features (Fe II, Ca II, Na I) superimposed on thermal continua. Hydrogen lines are conspicuous in Type II spectra, but are absent from Type I. A method analogous to the well-known Baade–Wesselink method has been applied to the rising part of a composite Type I light curve to obtain an estimate of the mean absolute magnitude of Type I supernovae ($M_v = -20{\cdot}8$). This absolute magnitude, combined with apparent magnitudes of supernovae in distant galaxies of known redshift, leads to an independent estimate of the Hubble constant (40 km s^{-1} Mpc^{-1}).

R.Wood has worked on the reduction of data obtained at Pretoria on the supernova in M83, and has published photometric observations of various other supernovae (*IAU Circulars* 2434, 2452).

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GLOBULAR CLUSTERS

High-dispersion spectra of the F-type giant member of Omega Centauri, HD 116745, have been obtained at Pretoria by R.J.Dickens with a spectracon image tube. Together with A.L.T.Powell, curve-of-growth analyses have been made, resulting in a value of [Fe/H] = $-1{\cdot}2 \pm 0{\cdot}3$, as compared to a value of $-1{\cdot}7$ expected for the cluster giants. This result, taken together with the small derived mass of $\sim 0{\cdot}4\, M_{\odot}$, suggests that mass loss may have occurred, with the possibility of partial mixing from the interior into the observable atmosphere. This work was presented at IAU Colloquium No. 21 in Toronto.

A second CH star in Omega Centauri was discovered by R.J.Dickens in the course of an extensive spectroscopic programme on red giants in many globular clusters carried out at Pretoria (**15**). Both CH stars (Nos. 55 and 70 in *R.O. Annals No.* **2**) show absorption features due to the main and isotopic bands of C_2, those due to $C^{12}\,C^{13}$ being of nearly equal strength to those of $C^{12}\,C^{12}$ in the $\lambda 4737$ group. In collaboration with R.A.Bell, synthetic spectra have been constructed for these stars, and show conclusively that the observed absorptions at $\lambda 4723$ and $\lambda 4744$Å are indeed due to $C^{12}\,C^{13}$ (and not caused by red CN bands as suggested for $\lambda 4744$ by Utsumi). An abundance isotope ratio of $C^{12}/C^{13} \approx 10/1$ is derived which, by comparison with some field CH stars also studied, suggests that values of C^{12}/C^{13} significantly smaller than the terrestrial value of 90/1 also occur in these stars.

An investigation of RR Lyrae properties in all galactic globular clusters is under way by R.J.Dickens and E.A.Epps in order to evaluate the precision and completeness of the data, to perform analyses where possible, and to select clusters most suitable for further photometric investigations.

Pseudo colour–magnitude diagrams have been obtained by E.A.Epps for NGC 5286 and NGC 5986 from plates taken with the Pretoria 74-in. telescope. Both clusters show blue-populated horizontal branches.

Models of the integrated light from globular clusters have been used by R.G.Bingham, W.L.Martin and a vacation student, B.D.Turland, to extend previous work on the use of *UBV* colours to deduce metal abundance. Deutsch–Kinman classification of individual giants in globular clusters often seems to indicate a higher metal abundance than is found for the cluster as a whole, casting doubt on the use of evolved stars for characterising the cluster. Computations of the strengths of spectral lines in integrated light are being made from the same models with a view to studying extragalactic clusters.

A programme has been started by E.G.Schmidt to determine the distribution of light intensity and colour within globular clusters, using the Kron camera.

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VARIABLE STARS

D.H.P.Jones has observed one hundred RR Lyrae stars and ultra-short-period variables on his intermediate-band photometric system. The different colours correlate strongly with temperature, metal abundance, gravity and interstellar reddening. When grouped by metal abundance the RR Lyrae stars fall into remarkably small regions in the (θ_e, log g) plot. An account of this research will appear in the *Astrophys. J. Supplement.*

The same observations have been extended to ω Cen which is metal deficient by a factor of thirty. Apparently only one RR Lyrae in 47 Tuc is a member. It has a solar metal abundance, but is $0^m{\cdot}7$ brighter than the horizontal branch. These observations were reported at *IAU Colloquium No.* **21**.

D.H.P.Jones, in collaboration with R.R.Shobbrook, has studied the luminosities of the β Cephei variables. The basic datum is Jones's revised distance to Sco–Cen. This is shown to accord much better than previous distance scales with the interferometric distance of Spica and with the spectrophotometric observations of Watson.

M.J.Penston has published light curves in the *UBV* system for the short-period RR Lyrae variables AE Boo, TV Lyn and RW Ari. A new period was derived for AE Boo.

P.G.Murdin has used a high-speed photometer to time and measure eclipses of the white dwarf BD 16°516B, and to observe its limb darkening in two colours.

An analysis by E.G.Schmidt of the atmospheres of non-variable stars within the Cepheid instability strip is under way. The method employed uses effective temperatures previously obtained (*Astrophys. J.*, **174**, 605) for these stars together with model atmospheres. A comparison will be made between non-variable stars and Cepheids of similar temperatures and luminosities to see if any differences can be found which might explain the presence of non-variable stars in the instability strip.

STELLAR ATMOSPHERES AND ABUNDANCE STUDIES

Stellar CN bands

The photographic survey of stellar CN-band strengths by D.L.Harmer and B.E.J.Pagel has been completed by a study of published photoelectric CN indices for stars of Population I, interpreted in the light of model-atmosphere computations by D.R.Fawell. The Population I stars differ from those of Population II, described in a previous report and in (27), in that normal dwarfs and giants show little change in the abundance ratio N/Fe, even though Fe/H varies by about an order of magnitude in the extreme range. Hence CN strength

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indices can be treated as a sensitive and fairly accurate criterion of metal abundance in Population I, provided that the surface temperature and gravity are known. This method has been used to check metal abundances in several controversial cases. The 'super-metal-rich' stars μ Leo and ϕ Aur are judged by this criterion to have at least the metal abundance of the Hyades, but HD 6497 is metal-deficient as found by G.Cayrel and L.E.Pasinetti. Giants observed by H.Spinrad and B.J.Taylor in the old galactic clusters M67 and NGC 188 appear to be intermediate in composition between the Sun and the Hyades; stars occupying the horizontal-branch-like 'clump' at $(B-V)_0 \approx 1{\cdot}05$, $M_v \approx 1{\cdot}0$ seem to have slightly strengthened CN bands, perhaps owing to mixing after the helium flash.

The suggestion made by R.F.Griffin and R.O.Redman in 1960 that the λ 4215 CN band is detectable in stars of high luminosity having spectral types as early as F5 is not confirmed by a study of the λ 3883 region on a 10 Å mm^{-1} coudé spectrogram of α Persei, since the CN band head at this wavelength is not clearly visible and must therefore be greatly weakened relative to the Sun. This result is in accordance with theoretical expectation if α Persei has normal chemical composition, and it suggests that the nitrogen abundance may not be as great as was suggested by S.B.Parsons in 1967.

Differential curve-of-growth analyses

D.L.Harmer and J.A.Motylinski are investigating the effect of the use of the revised solar curve of growth obtained by R.Foy on the results of differential curve-of-growth analyses. For stars having similar line strengths to the Sun there is no significant effect, but the metal abundances of weak-lined and strong-lined stars appear to be appreciably lower and higher, respectively, e.g. [Fe/H] may have to be revised from $-1{\cdot}2$ to $-1{\cdot}4$ for υ Indi, and from $+0{\cdot}3$ to $+0{\cdot}4$ for δ Pav. J.Tomkin has incorporated this and other corrections into a revised abundance analysis of the subdwarf Groombridge 1830, carrying out a spectrum synthesis investigation in collaboration with R.A.Bell. This leads to a metal-abundance parameter [Fe/H]$=1{\cdot}3$ with an overdeficiency of nitrogen by a factor 5 in agreement with previous results (**27**), (**70**).

Studies of weak-lined stars

Weak-lined stars discovered in the objective-prism survey by H.E.Bond are being studied by D.L.Harmer using spectra with a resolution of 0·35 Å taken with the INT Unit Spectrograph with a spectracon image tube. The sample includes a number of possible extreme subdwarfs and two stars having 4-colour photometric parameters resembling HD 122563. A search of the Stromgren–Perry catalogue for early F stars that might be used as standards for early F stars in

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Bond's list showed that the bright star HR 8799 seems to be metal-deficient, and this star is now being studied on the basis of coudé spectra.

Metallic-line stars

Work on model stellar envelopes for Am stars carried out by D.J.Stickland in collaboration with J.Whelan gave much support to the hypothesis of element diffusion by predicting the rough form of the abundance anomaly curve and the location of these stars in the H–R diagram (**68**). The study also led to the expectation of evolved early F type stars with Am characteristics, and an abundance analysis of a candidate Fm star, HD 103877, was undertaken (**65**). An investigation of seven double-lined Am binaries was concluded (**66**) with the result that an evolutionary scheme for the generation of the Am phenomenon was suggested. In this, as a star evolves away from the ZAMS, it passes through regions where it pulsates (δ Scuti type) and the metallicity is destroyed, and through stable regions where the diffusion process can operate effectively. Some complementary data on δ Scuti stars support this scheme.

Colour indices and the distribution of metal abundances

Data in the Herstmonceux *Catalogue of Stars within twenty-five parsecs of the Sun* have been used by D.Lynden-Bell, B.E.J.Pagel and a vacation student, T.Ponman, to extend the statistical study of metal abundances in late G stars originally carried out on a small sample of stars by M.Schmidt in 1962. The cumulative distribution $N(\leq Z)$ of the number of stars having a given heavy-element abundance Z or less, as a function of Z, is somewhat less curved than Schmidt found, and can probably be reconciled with models of galactic enrichment of the type proposed by J.W.Truran and A.G.W.Cameron (uniform enrichment after an initial minimum metal abundance) provided that (a) the scatter due to observational error and spatial variations at a given epoch is taken into account, and (b) it is assumed that something like 10 per cent of the initial interstellar gas is still left over. The data are definitely inconsistent with a model proposed by R.B.Larson in which the mass of gas in the region of star formation is maintained constant by the introduction of unprocessed gas from outside; but it is possible that the Larson mechanism (as opposed to a birth-rate function biased towards greater masses) could account for the initial degree of enrichment that seems to be required. This latter possibility has been suggested by L.Searle.

J.B.Alexander and D.R.Branch have considered further the unusual colours of certain strong-lined dwarf stars like δ Pav, and conclude that these can be explained by an anomalously high damping constant, possibly associated with an abnormally high proportion of helium.

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The relationship between *UBV* and *uvby* photometry of unreddened F and G stars in the main-sequence band has been investigated by J.B.Alexander and a vacation student, D.G.Lawrie; for most of these stars, *U–B* and *B–V* can be predicted quite accurately from *uvby*.

STELLAR CHROMOSPHERES

R.A.E.Fosbury has completed a survey of Hα profiles in 33 late-type stars and begun a study of H and K reversals using the 30-in. coudé spectrograph with a spectracon image tube (**20**). A Fourier transform technique has been developed to give accurate line profiles which can then be used to revise the Wilson–Bappu K–line luminosity calibration, and to help in building up a composite picture of the relationship between luminosity and the widths of Hα, Ca^+ and Mg II chromospheric features. After reanalysing the Mg II resonance line profiles obtained by Y.Kondo *et al.* in 1972 in α CMi and α Ori, and attempting to remove the photospheric contribution to the width of the Hα core in the dwarfs, it seems that the five lines form parallel sequences in the (M_v, log W_o) plane, although there is scatter in the case of Hα as was previously noted by R.P.Kraft *et al.* in 1964. An attempt is being made to interpret this effect in terms of an increase in microturbulence with height associated with the propagation of mechnical energy in a stratified chromosphere. This type of study is being extended to dM and dMe stars by measuring Balmer and Ca^+ line intensities on 30 Å mm^{-1} spectrograms taken with the INT Unit Spectrograph with a spectracon image tube. Preliminary reductions show that, at least in some cases, the K/H intensity ratio is very close to unity, and the hydrogen emission lines are significantly broader than those of Ca^+. This implies that turbulence is not a major contributor to the hydrogen line widths.

STAR FORMATION AND INTERSTELLAR MATTER

Photoelectric measurements of an index of the diffuse interstellar line at λ 6284 were made in 48 stars by P.G.Murdin. After allowing for experimental uncertainty, the λ 6284 feature appears to correlate perfectly with the similar diffuse line at λ 4430 (**48**).

A map in Hα of Barnard's Loop is under construction by P.G.Murdin, using a montage of four monochromatic 2-hr exposures taken with an *f*/1·2 wide-angle (60°) camera of 1-cm aperture, mounted on the 13-in. astrographic telescope. An isodensity map of a region 40° × 30° centred on Orion's Belt and Sword has been constructed around a net of 105 density measurements made with the Joyce Loebl Autodensidator. Photoelectric calibration of Hα intensity is under way.

M.V.Penston has completed an analysis of 9-colour photometry of 53 stars in the Orion I association. Stars with infrared excesses and

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high absorptions were found. No stars earlier than B9 have infrared excesses at 2 μ. The 2μ excess correlates with range of variation and possibly with foreground absorption. For nearly all stars more energy is absorbed in the visual than is radiated in the infrared.

M.V.Penston, with Chaldu and Honeycutt of the Goethe Link Observatory, has derived an extinction curve for the highly reddened star Cyg OB2 No. 12 from scanner observations.

Programmes have been started by E.G.Schmidt on the following topics:

(a) The physical conditions in, and evolution of, H II regions.

(b) The distribution of material in Bok globules and comparison with theoretical models for collapsing gas clouds.

PHOTOELECTRIC PHOTOMETRY

R.G.Bingham and A.W.J.Cousins have shown that a photometric system which transforms well to *V*,*R* and *I* can be obtained with extended S20 cathodes, and they have observed variable stars in this system. The two-star photometer is being used for observation of BL Lac and similar objects. Small-amplitude variability of early-type stars was investigated by E.N.Walker in Spain, and, at Herstmonceux, Walker and P.G.Murdin are using pulse-counting equipment and a multi-channel analyser attached to the 36-in. Yapp reflector to search for ultra-rapid light fluctuations in X-ray sources and eclipsing white dwarfs. R.A.E.Fosbury and Walker are investigating the application of a fast Fourier transform technique to the analysis of quasi-periodic and non-periodic light variations.

D.H.P.Jones has developed an interference filter technique which separates M giants from M dwarfs by the relative strengths of their CaH and TiO bands. About six hundred faint M stars have been observed on this system. Of the hundred discovered in the South Galactic Cap by McCarthy, twenty-two were found to be dwarfs. Their density appears too low to explain the 'missing matter' required by the distribution of the velocity vectors of the M dwarfs, and is indistinguishable from earlier determinations where a large bias was believed to exist.

Reduction and analysis of the *UBV* photoelectric observations made at the Cartuja Observatory between 1969 and 1971 has been completed by E.A.Epps (**19**). The results included *UBV* photometry for 115 nearby stars (within 25 pc of the Sun), for bright secondary standards in ten quasar fields and ten galaxy fields, and for stars in eleven Kapteyn Selected Areas.

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INFRARED PHOTOMETRY

D.A.Allen is investigating the relationships between spectral features and infrared excesses in early-type emission-line stars. A good correlation of infrared flux with the intensities of certain forbidden lines is emerging.

A photometer constructed during 1971 at the Royal Greenwich Observatory was placed in service on the 18-in. reflector at Cape Town in January 1972. It has been used by I.S.Glass for observations between 1·25 and 20 μ at the Cape, Radcliffe and Sutherland observatories. A programme in collaboration with M.W.Feast on R CrB stars has been completed. Work has also been done on OH sources, symbiotic stars, RW Aur stars and other interesting objects.

THEORETICAL STUDIES

J.C.Jackson has studied the dynamical stability of general-relativistic equilibrium systems. Several new hydrodynamical equations, which should simplify the solution of problems of this nature, have been derived.

Studies of statistical techniques for analysing complete quasar samples have been pursued by J.C.Jackson. An optimum method for combining samples characterised by different optical and radio limits has been devised, and the uncertainty in the answers so obtained has been derived.

J.C.Jackson has devised a model of a highly anisotropic radiation source. This uses the properties of the gravitational field of a relativistic disk of material, which concentrates any radiation generated in the disk into its plane. The work was motivated by Weber's claim to have detected a large flux of gravitational radiation from the Galactic nucleus, the idea being that the nucleus contains such a disk, whose plane coincides with that of the Galaxy.

STELLAR KINEMATICS

Radial velocities

The measurement of spectra of suspected spectroscopic binaries taken on the Herstmonceux 36-in. and Kottamia 74-in. reflectors has been completed by A.Savage, J.E.Sinclair and M.J.Penston. These were mostly early-type stars listed in the *General catalogue of stellar radial velocities* as having velocity variations of large amplitude, or of having double lines seen in their spectra. On the Yapp, 1000 spectra of 60 stars were obtained, mostly at 80 Å mm^{-1}. Seventy-five per cent of these stars had more than four spectra, and a statistical test on the results showed that approximately 50 per cent of them were probably true spectroscopic binaries. On the Kottamia programme, 200 spectra at 25 Å mm^{-1} or 66 Å mm^{-1} on 27 stars were measured.

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In most cases it was not possible to detect the double lines previously reported, even when higher dispersion spectra were taken on the INT. From the two programmes, periods and elements have been obtained for the six stars HD 51565, 86590, 88512, 144359, 160613 and 175742. Provisional periods have also been obtained for five: HD 13018, 41547, 84184, 87504 and 119537. In addition, the previously published periods for HD 24733 and 134646 are confirmed. Included in the programme was HD 154431 which lay in the original error box for the X-ray source 2U 1702+35. From 30 plates A.Savage and P.G.Murdin were unable to confirm the suspected variation of the radial velocity. Most of the results from this work will be published in *R. Obs. Annals*, together with the results from galactic kinematic studies mentioned in last year's report.

Measurement of radial velocities of B8 and B9 stars observed in Pretoria by R.Wood is continuing.

The proper motion of the star HD 27947, whose position, radial velocity and spectroscopic parallax suggested it may be a previously undetected member of the Hyades cluster, was measured by J.E.Sinclair and shown to be inconsistent with cluster membership.

D.H.P.Jones has measured the radial velocities of HD M stars in the South Galactic Cap with a photoelectric stellar speedometer. His results indicate a density of gravitating matter in the solar vicinity of $0{\cdot}21\ M_{\odot}\ pc^{-3}$. He is preparing a list of radial velocities of ninety southern red variables for publication.

Proper motions and photographic photometry in selected areas

Observations with the 26-in. refractor for the repetition of the old Radcliffe proper-motion plates are more than 95 per cent complete, and measurement on GALAXY has started.

Photometric plates for determining B and V magnitudes are also being obtained on the 26-in. Plates on SA 51, 94 and a field in Aquila have been taken through a 4-in. Racine objective prism, to test the efficacy of the prism for providing faint standards by comparison with Purgathofer's sequences: these plates are being measured on GALAXY.

A series of computer programs for the reduction and analysis of the GALAXY measurements on the photometric and astrometric plates is being developed by C.A.Murray, B.F.Jones and S.B.Tritton. The measurements made on the ROE GALAXY on the plates of SA 54 are being reduced. Average standard errors of relative positions over six magnitudes on a plate of unit weight, derived from residuals from a plate overlap solution programme developed by B.F.Jones, are smaller than $0''{\cdot}2$ and correspond to standard errors of relative annual proper motions of about $0''.002$.

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In order to investigate further the possible presence of large numbers of intrinsically faint M dwarfs in the solar neighbourhood, old deep photometric plates on some Kapteyn areas taken on the Mount Wilson 60-in. telescope and repeat plates taken by S.V.M.Clube in the summer of 1972, have been borrowed from the Hale Observatories.

TRIGONOMETRIC PARALLAXES

26-in. refractor

Observations of more than 50 of the 150 fields in the programme have now been completed: 32 fields have been measured, and a discussion by D.V.Thomas of the results for 22 fields is in course of publication.

The residuals of individual plates from the adopted parallax solutions are being investigated, to improve the plate weighting system and to study systematic errors affecting declination measurements. For the latter purpose, information on diurnal and seasonal temperature variations on clear nights for the past 12 years is being obtained from temperatures recorded at the transit circle pavilion.

At the request of Cambridge Observatories the computer reduction programs were adapted in order to reduce measurements, made on the ROE GALAXY, of parallax plates taken with the Cambridge Schmidt telescope.

Isaac Newton Telescope

Observations for the parallax programme of faint stars have continued. It is hoped that sufficient plates will have been obtained on two fields for measurement and reduction during 1973.

POSITIONAL ASTRONOMY

Meridian observations

On the Cooke Transit Circle at Herstmonceux, observations of the zodiacal stars in the lunar occultation range have continued, and the programme is now 57 per cent complete. Observations of the Yasuda list of northern PZT stars were started, and this programme is now 37 per cent complete.

Observations of the Sun and planets have continued. The observations for the period 1957–71 have been reduced on a provisional system, and the results will be published shortly.

Progress continues in the investigation of the FK4 star observations of this period, prior to establishing the fundamental Herstmonceux system of positions.

A total of 17 meridian observations of Algol made at Herstmonceux between 1957 and mid-1972 have been combined to give a modern

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position on the FK4 system at mean epoch 1964·6. This has been used for calibrating the position system of the Cambridge 5-km radio interferometer. Observations made since 1972 October will be used to derive an even more up-to-date position at the end of the current season; so far a further 15 observations have been secured.

The Gill Transit Circle at the Cape Town station of the South African Astronomical Observatory continues to participate in the international Southern Reference Star programme, and the current zone ($-52°$ to $-64°$) is about 70 per cent complete. The associated observations of the Bright Star list are also continuing, and some observations of major and minor planets have been made.

Radio sources

Observations on both the INT and the 26-in. refractor for optical positions of 60 radio sources have continued. Twenty-seven fields have now been completed.

The position system defined by the 26-in. refractor may be affected by atmospheric dispersion effects. In order to investigate these, a series of some 80 plates on h and χ Persei in the blue and in a narrow waveband (IIaD+RG1) have been taken during 1971–2 at widely varying hour angles, including sub-pole. These have all been measured on GALAXY.

The position of the infrared star MWC 349 has been measured on IIaD plates using an RG1 filter. The optical position of this source agrees very closely with the radio position recently obtained with the Cambridge 5-km telescope.

Planetary occultation predictions

Astrometric plates on Pluto have been taken with the 26-in. refractor in order to find faint stars which may possibly be occulted by the planet.

Plates on Jupiter's satellites taken at the Cape and in Perth were measured and reduced at RGO. As a result, an occultation by Ganymede was predicted and observed successfully by a US expedition to Java, and also in India.

Cape astrolabe reductions

The 1965–69 astrolabe campaign at the RO Cape was designed to provide accurate positions of 1200 southern reference stars. Provisional corrections to the adopted co-ordinates of the standard stars have now been obtained. In an attempt to account for the significant closing error ($0^s·024 \pm 0^s·007$ se) in the time results, the time and latitude group-differences have been re-examined. It was found that these could be represented by a rather large and seasonally-variable sinusoidal diurnal variation in each co-ordinate. However, the application of

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such seasonal diurnal variations and their associated group corrections does not significantly reduce the day-to-day scatter in the time and latitude results. There appear to be no significant correlations with meteorological conditions, so the origin of the day-to-day variations, and of the time closing-error, remains obscure. A preliminary analysis of the prism angle results is now nearly completed.

TIME AND LATITUDE SERVICE

Photographic Zenith Tube

The PZT was maintained in service without major interruption, and observations of 2298 star transits were obtained on 137 plates. Co-operation with the BIH and the IPMS has continued and the results are regularly reported to these agencies. Research in methods of improving the instrument performance has made some progress: new equipment for effecting rotary reversals has been developed, and a Moiré fringe linear displacement transducer for monitoring the motion of the photographic plate is now being assembled.

Analysis of the time and latitude observations made between 1958·0 and 1970·0 has revealed effects of systematic deflexions of the vertical that depend on the hour angle and declination of the Moon. Preliminary results of this study are in press, and further work is in progress. Analyses have also shown the existence of fortnightly terms, with amplitudes of the order of 0″·01, in both the time and latitude observations. From a review of the results over the years 1958·0 to 1971·2 corrections have been derived, in both co-ordinates, to the adopted proper motions of the catalogue stars. These corrections are now being utilized to compute corrections for the adopted mean positions of the stars. This work is being carried out in collaboration with the Calgary PZT Observatory, which continues to work in close co-operation with the RGO.

Danjon astrolabe

Tests on the Danjon astrolabe showed that its optical quality had greatly deteriorated since it was previously used at Herstmonceux (1964). The transmission optics were returned to the manufacturers (SOPELEM, Paris) for investigation, and defects discovered in these components were rectified. Re-assembly has just been completed and the instrument is now ready for further tests.

Gravimetric recording

A recording gravimeter (North American Type) employed in a programme of determination of gravity profiles across Europe was installed in the sub-basement of the West Building at Herstmonceux in October. Collaboration of the RGO in this work was organized by P.Melchior, and the results obtained to date are very encouraging.

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Rotation of the Earth

Until the end of September, the average rate of rotation of the Earth was 3·2 ms per day losing, relative to the atomic time scale; since then there appears to have been a change of rate in the sense that there was a small reduction in the losing rate.

Atomic time scale

The Greenwich atomic time scale, GA2, has been determined from the mean of selected caesium standards at Herstmonceux, and is one of seven atomic time scales from which the International Atomic Time Scale is determined. Atomic clocks are compared internationally by measurements of Loran–C pulses and by travelling clocks. Measurements commenced of the Loran–C pulses from Estartit, in the Mediterranean chain, in June, and from Ejdes, the master in the Norwegian Sea chain, in August. These results, together with those from Sylt, which have been measured for several years, have been published each month in the *Time Service Circulars, Series B.* Staff from the USNO have made two visits with caesium clocks on regular flights.

At the end of July, the Time Department took part in an experiment to compare atomic clocks at the US Naval Research Laboratory, Washington, and the RGO, using a clock carried by a satellite. The satellite, known as Timation II, is in a circular orbit 500 nautical miles above the surface of the Earth and at an inclination of 70° to the equator. Members of the staff of the US Naval Research Laboratory brought the satellite receiving equipment to the RGO, and signals received from the satellite were measured at RGO and NRL, Washington.

Radio time signals

In accordance with international agreements, the new UTC system was brought into operation on 1972 January 1 at 0000 UT. Under this system the emitted pips differ from the International Atomic Time Scale, determined by the Bureau International de l'Heure, by an integral number of seconds, and the intervals between seconds pips corresponds to SI second. In order that the time signals shall not depart from UT1 by more than about 0·7 s, leap seconds are applied when necessary. A positive leap second was applied as the last second of June 30 and again as the last second of December 31.

THE SUN

The Sun was photographed at Herstmonceux in white light on 269 days, and in Hα light on 197 days.

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Overall, activity remained remarkably similar to that recorded during 1971, except that an unusually active period occurred in early August, resulting in a wide range of solar-terrestrial effects.

Current information was widely distributed by monthly *RGO Solar Activity Circulars.*

INSTRUMENTATION

Isaac Newton Telescope

The telescope drive has been satisfactorily converted to use stepping motors with digital rate insertion and offset provision. The system has been constructed to be compatible with the existing manual arrangements for telescope control, and uses digital electronic techniques which ensure it is fully accessible to future computer control. Work is now in hand on the design of the interface necessary for control using a NOVA 1200 computer, and suitable encoders for the telescope axes are being procured. The programming of the computer will be a major task for 1973-74.

The coudé spectrograph has been brought into operation. A first investigation of the performance of the 340-cm camera showed image displacements, and the resolution was below that expected. The displacements were found to be caused by temperature gradients within the room, and improvements so far effected have partially overcome this problem. The resolution was improved by modifications to the mounting of the grating, so that the expected 0·01 nm resolution has been achieved. A stepping motor drive has been added to the grating position, and a post-dispersion flat mirror provided to enable the Imperial College Michelson interferometer to be used with this system. Finally, 'through the system' stepped-aperture calibration and an exposure meter have been provided.

The Mk II Unit Spectrograph (**53**) has been fitted with an image tube rear slit viewer for faint acquisition and with an instantaneous exposure meter. A 3-stage EMI cascade image intensifier has been tested in a shielded solenoid of RGO design for use on the spectrograph. Results to date show low background, good resolution and geometry, and freedom from image drift.

A single-stage fibre-optic image intensifier of 4 cm cathode diameter has been introduced experimentally at the prime focus: this tube has an extended red response photocathode.

The redesign of the prime focus breech-end has been started. This will permit the use of 16 cm square plates, offset autoguiding, and the accommodation of an electronographic image tube with an 8-cm diameter photocathode.

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The application of autoguiders has been considered. At the coudé, 'off-the-slit' should present no problems, but for the prime and Cassegrain foci a fibre-optic coupling system is to be investigated.

The experimental sky-photometer has been successfully used to prevent over-exposure of prime-focus plates in bright sky conditions. Its performance during long exposures in dark-sky conditions has still to be tested.

A new and improved crane has been installed on the ground floor to allow mirrors up to 2 tons to be loaded into the aluminising plant without the need for the dome-mounted 5 ton crane.

Two full-time night assistants have been appointed; it is hoped that a third will be recruited during 1973 so that the winter nights can be fully covered.

Other telescopes

The 30-in. reflector has had modifications inserted in the optical path that enable the beam to be re-imaged at 1 m above ground floor level to facilitate tests of the Imperial College echelle spectrograph. An ROE autoguider has been used experimentally with success at the entrance slit of the main spectrograph of this telescope. An autoguider of this type has also been fitted to the Merz guiding telescope of the 26-in. refractor. Both have been modified to reduce the tendency to guide erratically when the field is uniformly bright (e.g. moonlit cloud).

The internal layout of Dome E has been changed by erection of a fixed access gallery and provision of a new observing desk and dark cupboard, in order to remove restrictions on the use of the 26-in. refractor. A series of Hartmann test plates has been obtained to study the optical performance and alignment of this telescope. Preliminary results indicate that on-axis images are slightly flared, and that figuring of successive annular zones of the objective is uneven.

The erection of the Hargreaves (Congo) telescope in Dome F continues. The observing floor has been completed, and the assembly of the declination axis and tube will take place soon.

The Steavenson telescope has been received from South Africa, and its completion and erection is under consideration. Much work needs to be done to make this a usable instrument.

Work is proceeding on the modernization of the control and recording circuits of the Photographic Zenith Tube. Prototype models are being assembled and tested prior to the final specification of the system, which will ultimately provide automatic operation.

An integrated circuit control and timing system for the Danjon astrolabe has been completed and tested.

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Meridian instruments

At Herstmonceux, preparations are being made to digitize the Z.D. micrometer and the measurements of air temperature, pressure and humidity. The R.A. drive is being re-designed to include a stepping motor mounted on the telescope. Some progress has been made in the development of a Moiré-fringe arrangement for reading the circle.

At the Cape, the printing chronograph has been replaced by a solid-state punching and indicating chronograph.

Miscellaneous instruments

The design work has been completed for the Intermediate Dispersion Spectrograph, which is being built for the Anglo-Australian Telescope (**52**). Manufacture is on schedule, and the major parts of the instrument will be complete for first assembly by February 1973. First tests of the 82-cm camera system show a spectral resolution of about 0·03 nm at 400 nm.

The Mk I Unit Spectrograph at the Radcliffe Observatory has been fitted with improved *x-y* slides for offset guiding, a rear-slit image tube viewer for faint acquisition and a new photographic plateholder.

The two-camera photographic spectrograph of the 36-in. reflector has been sent on loan to the new SAAO station at Sutherland for use at the Cassegrain focus of the 40-in. reflector.

The two-channel 'People's Photometer' was transported to Tenerife, and successfully installed and used for ten nights on the 60-in. flux collector. Additional facilities being fitted to the photometer include a rotary star-sky chopper and an image-intensifier viewer. A two-channel integrator is also being built.

A reflectometer for testing surfaces of mirrors *in situ* has been constructed and calibrated.

A fixed-focus enlarging camera has been built to facilitate the production of finding charts (on Polaroid film) from prints or transparencies for use at the telescope.

An environmental test chamber has been constructed, which will initially be used for controlled temperature testing of observational instruments.

The testing of spectracon image tubes manufactured by Instrument Technology Ltd has continued throughout the year in a room specially instrumented for the purpose.

Measuring machines

Installation of GALAXY was carried out during the summer, and the machine was accepted from the makers during the latter half of

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August. The Electronics Department is responsible for the day-to-day serviceability of the machine. Development of the associated software has been continued under W.Nicholson's direction. Various programmes of measurement are referred to elsewhere in this report.

The design of an integrated-circuit data-processing system to replace the original electronics of the Zeiss Ascorerecord has now been completed, and the prototype circuits are being made and tested prior to specification of the final equipment. The machine has been taken out of regular service until the new circuitry is installed.

Preliminary work has been done on fitting new digitizers to the Meridian Department's single-screw measuring machines and the Mann x-y co-ordinate machine.

Work for Time Department

Work has continued throughout the year to maintain the Greenwich Time Service, in particular:

New linear phase comparators have been designed, constructed and installed.

Equipment for evaluating the time stability of the national TV signals has been designed and constructed.

The West Building aerial system has been completely overhauled and renovated.

The frequency distribution system has been extended to cover four additional primary standards.

The battery supply system has been overhauled and improved.

PHYSICS DEPARTMENT

Tube processing

The special processing rig (**42**) for preparing alkali-metal photocathodes in the new RGO electronographic image tube was completed early in the year. There was considerable delay in commissioning it, largely because of unsatisfactory performance of a 6-in. bakeable gate valve which is an indispensible and costly part of the rig. This difficulty has been overcome, at least temporarily, and two tubes were processed at the end of the year. All stages in the processing procedure were carried out successfully, although the final photocathode sensitivities were poor because of small vacuum leaks which have since been identified. There now seems little doubt that this new method of processing photocathodes *in situ* will be very satisfactory.

Magnetically focused tubes

A magnetically focused tube (**42**) was processed in November and, except for low photocathode efficiency (about 20 A/lm), performed

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satisfactorily on test. Tube dark current was low, being of the same order as the estimated thermal emission from the S.11 photocathode. Limiting resolution was about 70 lp/mm and the image geometry was good.

The design has been started of a tube (41) with 8 cm diameter photocathode and mica window. It will include a 4-quadrant silicon diode as a sensor for autoguiding and remote focusing.

Electrostatically focused tubes

One of the Kron electronic cameras (modified to incorporate a mica window) has been used for several periods on the 36-in. reflector. Although the tube dark current is relatively high, some useful work was done by taking advantage of the linearity of the electronographic process.

In December, the second Kron tube was reprocessed on the new processing rig in the hope that tube background would be lower if the caesium vapour generated during photocathode processing were prevented from reaching the walls and electrodes. Unfortunately, a small leak in the tube base caused a drastic fall in photocathode sensitivity. On test, the tube background was found to be very low, and although this is not conclusive because of the poor photocathode, it is very probable that future tubes will be satisfactory in this respect.

Electron optics

K.F.Hartley has continued his theoretical investigations on electron focusing systems using approximately uniform electric and magnetic fields (59).

An electron-optical bench has been built which is being used to test solenoids and electrode structures, and also to study the problem of securing good contact between mica window and electronographic emulsion.

Silicon diodes

Further work has been done on the use of back-biased silicon diodes as electron detectors. Two uses are envisaged. First, the use of a quadrant diode in an image tube as an autoguider sensor (41). Second, the incorporation in an image tube of an array of several hundred diodes, associated amplifiers, and a shift register for serial read-out on a single line, all integrated on a single monolithic silicon chip (43). Such an image tube could be used on a spectrograph for on-line read-out, and would have many more channels than tubes that are at present available.

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HM NAUTICAL ALMANAC OFFICE

Publications and data services

The following almanacs were published during the year: *The Astronomical Ephemeris* for 1973; *The Nautical Almanac* for 1973, and for 1974; *The Air Almanac* for 1972 May–1973 April (3 parts); *The Star Almanac for Land Surveyors* for 1972 (reprint), and for 1973. The late date of publication of AE 1973 was due to unexpected delays at the printers. The automatic photosetting on a Linotron 505 by HMSO Press at Gateshead is now proving to be very reliable: this process was used for the composition of the first part of AE 1976, and a limited number of lightly-bound copies was distributed on a world-wide basis for use in the preparation of other almanacs.

The Explanatory Supplement to the Astronomical Ephemeris is now almost out of print. It has not been possible to prepare material for a completely revised edition, although there have been many changes in the AE since the Supplement was first prepared. Copy for a partially-revised edition was, however, prepared in order to give the publication a new lease of life. The seventh impression of *Interpolation and Allied Tables* was issued during the year, but little progress was made with the preparation of material for a revised edition, although here again the changes in computing practice make this very desirable.

Five of the six volumes of the new *Sight Reduction Tables for Marine Navigation* (NP 401) were published by the Hydrographer of the Navy during the year; the sixth is in press. The preparatory work for the new edition (for epoch 1975·0) of Volume 1 of *Sight Reduction Tables for Air Navigation* (AP 3270) was completed, and the volume is now in press.

The users of the experimental editions of the *Astrophysical Observers' Almanac* for 1972 had found the topocentric data to be of particular value, but it was decided that the usefulness of the special star lists was not sufficient to justify the effort required to duplicate and distribute these annually. For 1973, topocentric data only were prepared for 21 observatories. Special predictions and ephemerides, as listed in the report for 1970, were also issued, and the Office dealt with an increasing number of requests for astronomical information for civil purposes.

The use of Chebyshev series for the economical representation of the astronomical data in the *Nautical Almanac* has been extended, and such series are now used in programs for the computation of rising and setting times.

Consideration has been given to the form of the systems of astronomical units and time-scales that will be appropriate for use in almanacs and theoretical studies, now that SI units and atomic time

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are being used more widely. The preliminary conclusions are that the astronomical unit of length should continue to be defined in terms of the Gaussian gravitational constant, but that ephemeris time as currently defined should be superseded by a new system that would be compatible with international atomic time from 1955 onwards.

Research activities

The programme for the prediction, reduction and analysis of occultations of stars by the Moon (**45, 46**) was continued under the supervision of F.M.Sadler. About 10 000 observations were received, coded and reduced during the year, and the preliminary residuals of the observations sent to the observers. The analysis of some 50 000 observations for the period 1943–1972 was largely completed; corrections to the arbitrary constants of the lunar theory were derived, and the relationships between the ephemeris, atomic and universal time scales over this period were determined. The results were then used by L.V.Morrison to revise previous estimates of the variations in the rate of the rotation of the Earth over the period 1663–1972, and to derive an upper limit to the variation in the constant of gravitation.

Regional maps and local predictions of grazing occultations were prepared and distributed (e.g. (**47**)). A team of observers from the RGO successfully observed the grazing occultation of 139 Tauri on 1972 March 21 near Southampton.

Occultation predictions for 1973–74 for 38 radio observatories were computed using revised positions in the NAO catalogue of 582 discrete radio sources. Predictions for the next few years of lunar occultations of X-ray sources were published in *IAU Circular* No. 2415. More detailed predictions were prepared for the X-ray groups at Leicester University and the Mullard Space Science Laboratory.

Occultations of faint stars by Pluto, by satellites and by minor planets can now be observed successfully by photoelectric techniques, and have been shown to lead to interesting and useful results (**69**), and so intensified efforts to predict such events were made. The occultation of a star by Ganymede (Jupiter III) on 1972 June 7 was observed from Java and India, and the timings are being analysed by Mr G.E.Taylor. Accurate predictions are necessary to increase the chances of successful observations; special ephemerides of some minor planets have been supplied by the Institute of Theoretical Astronomy, Leningrad, and some astrometric plates have been taken on request by staff at Herstmonceux and at the Cape.

A.T.Sinclair (**63**) has continued his studies of the orbits of the satellites of Saturn with particular reference to the evolutionary effects of tidal forces and to inclination-type resonances. He is also studying the 3-body resonances in the satellite systems of Jupiter and Uranus.

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A programme of astrometric observations of the satellites of Saturn has been started so that improved orbits can be derived for theoretical studies, for occultation predictions and for use in connection with space-probe missions later in the decade.

B.Emerson has continued his co-operative work with other astronomers on the determination of the orbits of spectroscopic binary stars.

Computer services

Additional operating staff were recruited and trained during the first half of the year, and double-shift working on the ICL 1909 computer system was introduced in August. The amount of useful time (i.e. excluding time lost for faults and all hardware maintenance) increased to 52 hr a week, averaged over the year as a whole. Of this useful time, 23 per cent was for NAO work, 48 per cent for the rest of the Observatory, 20 per cent for the Geomagnetism Unit of the Natural Environment Research Council (based at Herstmonceux) and 9 per cent for software maintenance and development. The average serviceability ratio for the year was 0·95.

The Computer Section continued to provide a programming advisory service for all users, in addition to operating the computer. Some job programming for other departments, and studies of the future use of mini-computers for on-line control of telescopes and instrumentation, were carried out.

The library of astronomical data on magnetic tape was extended and its documentation was improved. G.A.Wilkins, as Chairman of the newly-formed IAU Working Group on Numerical Data, had much correspondence and discussions with other astronomers on the value and means of increasing international co-operation in the preparation and exchange of astronomical data in forms that are suitable for use with computers.

GENERAL

The previous Astronomer Royal, Sir Richard Woolley, retired from the directorship on 1971 December 31. In the interval before the new Director took up office on 1972 July 12, Dr A.Hunter was in charge of the Observatory as Acting Director.

The control and administration of works staff and services at Herstmonceux was transferred from the Department of the Environment to the Science Research Council on 1972 April 1. Major works services are now supervised by senior engineering staff from the Rutherford High Energy Laboratory instead of by DoE. The structure of the Castle exterior will, however, continue to be maintained by the Ancient Monuments Division of DoE.

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Mr C.A.Murray has been appointed to the council of the Centre de Données Stellaires (CDS) at Strasbourg, as one of the six foreign members; he is Chairman for the year 1972–73.

Professor D.Lynden-Bell resigned on 1972 September 18 to take up the post of Professor of Astrophysics in the University of Cambridge. Dr S.V.M.Clube transferred to the Royal Observatory, Edinburgh, as SPSO in charge of the Astrophysics Division there.

Dr D.H.Sadler retired in 1972 February after serving over 41 years in the Nautical Almanac Office, including over 33 as Superintendent. He has been awarded the Janssen Medal of the Astronomical Society of France in recognition of his services to astronomy through his work for the IAU and in the NAO.

The annual Herstmonceux Conference, held at the Castle on April 5–6, attracted a gathering of 55 visitors to discuss Cosmic X-ray Sources. Invited talks were given by Dr F.Pacini, Dr K.A.Pounds and Dr D.W.Sciama. Six of the sixteen papers delivered were by RGO staff.

Close co-operation continues between the Observatory and the University of Sussex. Increasing numbers of RGO staff now hold Sussex degrees of MSc or DPhil in Astronomy; the Observatory acts as host to a number of Sussex students whose studies can better be carried out at Herstmonceux than on the campus; members of the RGO staff regularly deliver courses of lectures at Falmer; and there is a steady interchange of audiences between the two sites for a wide-ranging series of seminars on Friday afternoons in term.

The Isaac Newton Telescope was used during the year by visiting observers, mostly from the universities, engaged on programmes for which the Large Telescope Users' Panel allotted them 126 nights. In the same period, the telescope was allocated to RGO observers for 150 nights. It is estimated that operating, maintaining and up-dating the telescope and its ancillary equipment absorbs the equivalent of 16 members of the RGO staff full time.

PUBLICATIONS

The following publications have appeared during the period under review in addition to the routine publications of the Nautical Almanac Office, which are referred to in the corresponding section of this Report. The *Greenwich Time Reports* for 1971 January to December and *Time and Solar Circulars* have been published by the appropriate departments.

Royal Observatory Annals No. 6 (Photoheliographic Results for 1962, 1963 and 1964) was published anonymously. *Royal Observatory Annals* No. 7 and *Royal Observatory Bulletins* Nos 171–176 are listed below under the names of their authors.

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