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THE ROYAL GREENWICH OBSERVATORY

Director: Professor F.G.Smith FRS (until 1981 September 30)
Professor A.Boksenberg FRS (from 1981 October 1)

Report for the two-year period 1980 October 1 to 1982 September 30

(Received 1984 January 18)

1 INTRODUCTION

The report covers work done at the Royal Greenwich Observatory in the period 1980 October 1 to 1982 September 30. The main emphasis is on the astronomical research even though this represented only about 10 per cent of the direct manpower effort of the establishment. The main task of the RGO is now the construction and running of the British telescopes and equipment in the new Observatorio del Roque de los Muchachos on La Palma. However, most of the numerous other activities of the RGO such as the provision of a national time service and the preparation of almanacs have continued unabated. Some of these are mentioned in this report but in general only where there have been significant changes during the report period.

For each of the report years from 1974 to 1979/80 a comprehensive annual report for the Royal Greenwich Observatory was published as a separate booklet. This style of report is being discontinued.

Professor F.Graham Smith, who became Director on 1976 January 1, resigned on 1981 September 30 to take up an appointment as Professor of Radio Astronomy at Manchester University and Director of the Nuffield Radio Astronomy Laboratories at Jodrell Bank. Professor A. Boksenberg succeeded Professor Smith as Director of the Royal Greenwich Observatory.

Other notable staff changes were the retirements of Mr G.A.Harding, who was Officer-in-Charge at the Cape of Good Hope 1969–72 and then Assistant to the Director RGO, Mr W.A.Goodsell, who was in charge of the La Palma Division, and Mr R.H.Tucker, who was in charge of the Meridian Department. Mr M.C.Morris, formerly at the Daresbury Laboratory, became Head of the Facilities Division on 1982 August 2.

2 ASTRONOMICAL RESEARCH

In this section, no institutional affiliation is given to astronomers who were Royal Greenwich Observatory staff members or research fellows during the report period.

2·1 *Solar System*

L.V.Morrison has continued investigations into the rate of rotation of the Earth using lunar occultations and solar eclipses after AD 1600. Together with F.R.Stephenson (Liverpool), he is also determining the secular deceleration of the Earth's rotation from ancient Babylonian records of lunar eclipses.

G.E.Taylor continued his search for occultations of stars by planets, satellites and minor planets. He issued predictions for over 100 such events. An analysis of occultation observations has produced improved diameters for five minor planets.

A.T.Sinclair and G.M.Appleby have written computer programs to calculate the orbits of artificial satellites to high precision, and to analyse satellite laser ranging data for station coordinates, polar motion and other geophysical parameters.

D.B.Taylor has investigated several aspects of the three-body problem with reference to the orbits of minor planets. He has also obtained revised orbits for the principal satellites of Saturn using photographic observations from 1966 onwards to improve the orbital elements.

B.D.Yallop, C.Y.Hohenkerk, L.Murdin and D.H.Clark (RAL) examined seventeenth century records of sunspots. They found no detectable change in the Sun's equatorial rotation period but confirmed that the differential rotation varies with the sunspot cycle.

2.2 *Astrometry*

Regular observations of the Sun, Moon, planets and fundamental stars were made with the Cooke Transit Circle until this instrument was withdrawn from service on 1982 April 29. All measurements of star positions made with the transit circle at Herstmonceux are being prepared for publication. The observations of all FK4 stars made between 1957 and 1981 have been reduced and sent to Heidelberg for inclusion in the Fk5 catalogue.

Nearly 60 per cent of the plates of the Cape Photographic Overlap Survey have now been measured on GALAXY. In collaboration with C. de Vegt (Hamburg), W.Nicholson has nearly completed the astrometric reduction of the declination zone from $-40°$ to $-52°$. The corresponding photometric reductions are being undertaken by M.J.Penston.

E.D.Clements determined the optical positions of radio sources using photographic plates taken with the 26- and 13-inch refractors at RGO. Positions have been derived for 185 Seyfert galaxies, 65 quasars and 70 stars detected at radio wavelengths. The results for most of these objects have either been published or are in press.

C.A.Murray and C.G.Wynne have continued to serve on the ESA *Hipparcos* science team. For the input catalogue, RGO has undertaken to be responsible for determining the positions of programme stars in the Southern Hemisphere which are not in existing catalogues. Positions of many of these stars will become available from the Cape Photographic Overlap Survey mentioned above. RGO will be involved in the reduction of data from *Hipparcos* as part of a consortium which also includes MSSL and institutes in Sweden and Denmark.

2.3 *Galactic astronomy*

Two catalogues giving the measurements of radial velocities of stars were published. The first catalogue was prepared for publication by

M.J.Penston, G.A.Harding, W.L.Martin and J.E.Sinclair. It lists the radial velocities obtained from observations with the Isaac Newton (2·5-m), Yapp (36-inch) and Kottamia (1·9-m) telescopes in the period 1964–71 as part of astronomical programmes instituted and directed by the then Astronomer Royal and Director of the RGO, Sir Richard Woolley. Of the 1246 stars in the catalogue, 835 are ones of spectral type G or K which were observed in a programme to investigate galactic structure and dynamics. The analysis of these velocities was published earlier. This programme represents the result of several years' fruitful collaboration with Egyptian astronomers. Also included in the catalogue are radial velocities of nearby stars, spectroscopic binaries, RR Lyrae variables, Cepheids, semi-regular variables and miscellaneous other stars. The second catalogue by D.S.Evans (Texas), R.M.Catchpole (SAAO), D.H.P.Jones, D.L.King and R.E.Wallis contains radial velocity measurements of 340 nearby stars in the Southern Hemisphere.

The observations for the programme of determining trigonometric parallaxes with the 26-inch Thompson refractor ceased at the end of 1981. B.F.G.Scales and J.Zhao (Shanghai) have submitted a paper containing the results for 28 fields.

As a check on the frequency of physical double stars in the North Galactic Gap as predicted by Bachall and Soneira (both Princeton), R.W.Argyle has measured the proper motions of 19 bright pairs in this region. Common proper motion is observed in only five of these pairs, which is half the number predicted. R.W.Argyle has also observed 115 close physical pairs using the 26-inch refractor at Johannesburg.

J.B.Alexander investigated the kinematics of subdwarfs. Although all known subdwarfs are probably in bound orbits, he found evidence that the mode of origin of the peculiar velocities of subdwarfs with extremely high galactocentric velocities is different from that of other high-velocity stars. D.H.P.Jones collaborated with W.B.Wilson (Cambridge) on a new distribution-free method of discussing stellar motions perpendicular to the galactic plane.

E.A.Bingham and R.J.Dickens have completed a two-colour photographic study of the globular cluster M15. They find that the scatter in the period–colour relationship implies a dispersion in mass precisely as proposed by Rood to account for the observed spread in colour on the horizontal branch. J.B.Alexander has commenced a programme to look for possible secular changes in the periods of RR Lyrae variables in the globular cluster M2.

A.J.Penny has completed the reductions in a two-colour (B,V) electronographic study of the globular clusters NGC 288, NGC 4590 and NGC 6809. Preliminary results for NGC 4590 show a main sequence located as predicted with $M_v = +0{\cdot}5$ for the RR Lyraes and with an age of $1{\cdot}5 \times 10^{10}$ yr. Provisional results for NGC 288 do not support the extreme age obtained by other workers.

P.J.Andrews has made photoelectric observations of four multiperiodic RR Lyrae variables in the globular cluster NGC 4590. The value of P_1/P_2

for V3 is significantly lower than that found for the variables in the similar cluster M15. Further observations are needed to define the period ratios for the remaining multiperiodic variables in NGC 4590.

P.J.Andrews has made photoelectric observations of known binary stars in the young cluster NGC 6231. He has shown that three of the stars are eclipsing. In one of the stars, there is possible evidence for rotation of the line of the apsides.

I.G.van Breda in collaboration with D.C.B.Whittet (Preston) continued the observational programme at SAAO to obtain extinction curves of highly reddened stars in the Southern Milky Way.

2.4 *Stellar spectroscopy and abundances in the Galaxy*

B.E.J.Pagel and E.A.Mallia (Oxford) have completed an abundance analysis of eight red giants in the globular cluster ω Centauri. They confirm the existence of a wide range in metal abundance. Oxygen and calcium are somewhat enhanced relative to iron, particularly in the more metal-deficient stars. S.Caldwell (Sussex) has developed a completely automatic programme to derive from a stellar spectrum the abundances of iron, carbon and nitrogen together with the Doppler broadening velocity. He has used this method to re-analyse 21 stars in ω Centauri using spectra taken by R.J.Dickens. Stars on the red side of the giant branch in the (V, B–V) diagram are more metal-rich than those on the blue side. Both [C/Fe] and [N/Fe] have a range of about 1 and are anti-correlated. There is no trend of either carbon or nitrogen abundance with visual luminosity.

Spectral and photometric monitoring of supergiants has been continued by D.L.Harmer, D.J.Stickland, C.Lloyd, P.J.Andrews and E.N.Walker. The exceptional stars HR 8752 and HR 5171 have much redder values of B–V than for several years although there have been no observed changes in spectral type. The star ε Aurigae entered its year-long eclipse in 1982 July. This star is being observed on the 30-inch telescope as part of an international campaign. The composite star 58 Persei has been studied over a wide range of wavelengths to yield parameters important to our understanding of the evolutionary behaviour of supergiants.

D.J.Stickland has continued his studies of Wolf-Rayet and similar stars in collaboration with other astronomers. In collaboration with A.J.Willis (UCL), he has investigated IUE spectra of HD 45166 and HD 62910. Together with A.J.Willis (UCL), R.Wilson (UCL) and K.A.van der Hucht (Utrecht), D.J.Stickland has studied the variation of the profiles of emission lines in γ^2 Velorum using *Copernicus* data. There is evidence for a dense stream of gas flowing between the WR and the O star. The light curve of CQ Cephei has been constructed at 10 wavelengths from 1300 Å to 3·4 μm by a team involving D.J.Stickland, G.E.Bromage (RAL), W.M.Burton (RAL), E.Budding (Manchester), R.G.Jameson (Leicester) and A.J.Willis (UCL). Progress in modelling the system has been made. It now appears that the companion to the Wolf-Rayet star in this system may be a collapsed object. The system CV Serpentis is now being investigated by a team involving D.J.Stickland, C.Lloyd, E.N.Walker and A.J.Willis (UCL).

E.N.Walker, C.Lloyd, C.D.Pike, D.Stickland and M.M.Dworetsky (UCL) have concluded a study of the Ap star HR 3413 using optical spectra taken at SAAO and high-dispersion ultraviolet spectra from *IUE*. The photometric and spectroscopic variations have been explained using a model with two uniform circular spots on the stellar surface. D.J.Stickland has concluded a radial-velocity study of all known manganese stars and candidate Hg-Mn stars in the Northern Hemisphere.

C.D.Pike, E.N.Walker and C.Lloyd have produced a suite of STARLINK programs to derive periodicities from unevenly-spaced data on multiperiodic variable stars. Observationally, spectra of the β Cephei star V986 Oph are being taken with the 30-inch telescope at RGO and will be analysed using these programs.

D.J.Stickland found some correlation between chromospheric activity and stellar rotation. With F.Sanner (Texas), he wrote a paper on the far-ultraviolet continua of K and M stars in relation to chromospheric behaviour.

M.Pettini in collaboration with A.P.Phillips (UCL) and P.M. Gondhalekar (RAL) has studied element depletion in the interstellar gas using high-resolution *IUE* spectra of seven highly reddened stars at intermediate galactic latitude. The degree of correlation between depletion and density is found to vary from element to element; for example, the depletion in iron is strongly density dependent whereas that in silicon is not. M.Pettini, C.Laurent (Saclay) and J.Paul (Saclay) have studied the interstellar medium associated with the Carina Nebula by examination of the absorption lines seen on high-dispersion *IUE* spectra of HD 93205. Four high-velocity and two low-velocity systems were observed. The two main high-velocity systems show different abundances. M.Pettini in collaboration with A.Vidal-Madjar, C.Laurent and J.Paul (all Saclay) and M.Oliver (RAL) has investigated the Monoceros loop by examination of spectra of the more distant star HD 47240.

J.B.Alexander has found that at least four independent parameters are needed to predict accurately the Stromgren *uvby* colours of unreddened G stars. He concluded that the photometry does not provide good evidence at present that the helium abundance of the Hyades is less than that of the Coma cluster or Ursa Major nucleus.

2.5 *Rapid stages of stellar evolution*

D.H.P.Jones, F.G.Smith and P.T.Wallace (RAL) have shown that the quiescent light of the Crab pulsar is highly polarized and much fainter than previously supposed. A search by J.S.B.Dick (Sussex) in collaboration with R.N.Manchester (CSIRO), B.A.Peterson (Stromlo) and P.T.Wallace (RAL) failed to find optical pulses from PSR 1913 + 16. A study of optical extinction in the field of this pulsar indicates that this is about 2·3 mag in the first kiloparsec. P.G.Murdin has found some optical candidates for the X-ray pulsar in the supernova remnant MSH15-52.

P.G.Murdin, R.Wood and R.Gilmozzi (RGO/ESA) studied the three-dimensional structure of the Crab Nebula using radial velocity

measurements. The Nebula is a hollow, thick shell with inner and outer components surrounded by a more extensive halo. P.G.Murdin and D.H.Clark (RAL) have found evidence from deep red UK Schmidt plates of a very faint halo. If this is Hα emission, then the supernova may have been a massive one of type II. P.G.Murdin, D.H.Clark (RAL), R.Gilmozzi (RGO/ESA) and collaborators have studied also the 30 Doradus B supernova remnant, which from its size and velocity is probably a result of a type II outburst, and the remarkable oxygen-rich MSH 11-54 which they conclude is less than 1000 yr old. Infrared spectroscopy by P.G.Murdin and D.A.Allen (AAO) shows the [Fe II] lines at 1·6 μm in the supernova remnant MSH 15-52, the first detection of these lines in an astronomical object in the Galaxy.

The type II supernova in NGC 6946 (1980k) was monitored photographically at Herstmonceux for about 100 day using the 26-inch Thompson refractor. Spectra were also taken during the first half of this period using the image-tube spectrograph on the 36-inch Yapp reflector.

P.G.Murdin, S.M.Scarrott (Durham) and R.F.Warren-Smith (Durham) have analysed spectra of the Red Rectangle. A molecular feature in emission has been identified tentatively as carbyne.

D.H.P.Jones, J.Echevarría (Sussex) and R.E.Wallis have continued their *UBVRI* and spectroscopic observations of cataclysmic variables. In collaboration with J.E.Pringle, J.A.J.Whelan and B.J.M.Hassall (all IOA, Cambridge), simultaneous *IUE* and optical observations were made. For the outbursts observed, the increase in brightness in the ultraviolet occurred after that in the visual. At 2500 Å the lag was about 0·5 day and at 1400 Å about 1·0 day. This can be understood if the outer, cooler parts of the accretion disc are filled by material from the secondary overflowing through the inner Lagrangian point. The material then settles towards the hotter, inner parts of the accretion disc under the influence of viscosity. As an important by-product of the optical photometry, a set of equatorial secondary standards for *UBVRI* photometry has been set up using Cousins's E-region stars as the primary standards. This work was done by D.H.P.Jones and R.W.Argyle with the 0·5-m reflector at SAAO.

Observations were also made of stars of the AM Her class. J.Echevarría (Sussex) found evidence of the red star in the optical spectrum of PG 1550 + 191. P.G.Murdin, K.O.Mason (Berkeley) and collaborators identified 2A 1405-45 as being of the AM Her class.

E.J.Zuiderwijk completed an extensive spectroscopic study of the X-ray binary Vela X-1. By fitting model-computed line profiles to the optical spectra, it is estimated that the primary supergiant rotates with 0·63 ± 0·04 times the orbital angular velocity. The mass of the neutron star may be as low as 1·45 $M_\odot$. P.G.Murdin in collaboration with X-ray astronomers from MSSL and Berkeley has studied the faint blue optical object identified with the X-ray source 2S 0921-63. Photometry has revealed a period of about 18 day which has been interpreted as the precession of an accretion disc around a black hole. P.G.Murdin and R.Gilmozzi (RGO/ESA) have taken spectra of the X-ray binary V471 Tau using the Reticon system on the 1·9-m

telescope at SAAO. They found periodic variations in Hα and in H and K emission. The spectrum of the white dwarf was recovered by the subtraction of an appropriate standard K star spectrum. D.J.Stickland analysed *IUE* observations of RZ Gru. A model has been constructed fitting the observations to an accretion disc energy distribution.

A.Lawrence has submitted for publication his analysis of X-ray bursters originating from the wide-ranging collaborative observations which he organized while he was at MIT. He and his collaborators were the first to detect a simultaneous X-ray and optical burst from MXB 1636-53. The integrated energy in a burst is proportional to the waiting time which has elapsed since the previous burst. This is consistent with a model in which the bursts are caused by an accumulated layer of helium on the surface of a neutron star where there is a catastrophic thermal-nuclear runaway.

M.V.Penston, M.T.V.T.Lago (Porto) and R.McD.Johnstone (Sussex) have examined optical and *IUE* spectra of T Tauri stars. This work has put constraints on wind models linking the flow velocity with the temperature and density in the outer layers of these stars. The observations of RU Lupi are consistent with a model which is wind driven by Alfvén waves; after reaching a maximum velocity of about 250 km s^{-1}, the wind velocity decreases and the gas temperature increases as one goes away from the star. From the weakness of the [Fe x] line at 6374Å, M.V.Penston, M.T.V.T.Lago (Porto) and G.F.Gahm (Stockholm) conclude that there is no appreciable corona around this star. There is an extremely large flux of mechanical energy which may be as much as one-tenth of the radiative flux.

Together with colleagues in other European observatories, M.V. Penston has worked on the problem of the identification of lines in the ultraviolet spectrum of the symbiotic star RR Tel.

S.P.Worswick and N.K.Reay (Imperial College) have used electronography to map the electron temperature derived from [O II] emission across the planetary nebulae NGC 3242, 6543, 6826, 7662 and IC 3568. S.P.Worswick has also studied the irregular planetary nebula NGC 5189 in which excess reddening is associated with the filamentary structure embedded in the nebular envelope.

F.van Leeuwen in collaboration with P.Alphenaar and J.J.M.Meys (both Leiden) has studied periodic variations in the brightness of the K-type stars in the Pleiades. The observations which were made with the Dutch 0·9-m telescope on La Silla during 1980 and 1981 have all been published. Spectroscopic observations of some of these stars by M.F. Walker (Lick) yield rotational velocities which imply that the periodic photometric variations are probably a result of rotational modulation. The lack of rotational symmetry may be caused either by the equivalent of very large sunspots on the surface of the star or by a gross deformation of the stellar structure arising from the high angular velocity.

2.6 *Extragalactic astronomy*

B.E.J.Pagel together with collaborators has studied the chemical composition of several galaxies. Together with M.G.Edmunds (Cardiff),

D.Alloin (Meudon) and P.O.Lindblad (ESO), he found that the abundances in the bar of the spiral galaxy NGC 1365 are more uniform than in the corresponding regions of spirals without bars. B.E.J.Pagel, M.G. Edmunds (Cardiff) and M.M.Phillips (AAO and CTIO) have observed H II regions in the S0 galaxy NGC 7793 and the nuclei of several galaxies both with and without emission-lines in their spectra. The spectra of the nucleus of NGC 7793 indicate that the weak metallic lines arise from young metal-rich stars near the main sequence and not from old stars of extreme metal deficiency as suggested by a group from DAO. B.E.J.Pagel, D.H.Clark (RAL) and B.J.Kent (RAL) are using observations of M83 made with TAURUS to check that the line ratios of all H II regions confirm the abundance gradients derived from slit spectroscopy of a sample of such regions. Together with M.G.Edmunds (Cardiff), B.E.J.Pagel has reviewed the abundance determinations made of extragalactic H II regions both by themselves and by other investigators. They have compared these results with galactic structural parameters assembled by McCall (Texas). It appears that the oxygen abundance (assumed to be typical of that of heavy elements in general) is an increasing function of the local inverse gas fraction. The rate of increase steepens towards the denser parts of galaxies either because of inflow or because the nucleosynthetic yield increases with the local surface density in the disc.

The primordial helium abundance provides a severe upper limit to the cosmological baryon density that is available from Big Bang nucleosynthesis models. B.E.J.Pagel and K.Wood (Sussex) have examined the differences in the values of helium abundance derived by different authors for various extragalactic H II regions. Because of observational uncertainties, particularly in the ionization corrections, it is unlikely that the helium abundance of the regions will be determined to better than 10 per cent in the foreseeable future. For this reason, there is little likelihood of a contradiction arising between the upper limit on the baryon density derived from the primordial helium abundance and the lower limit derived from deuterium or ^{3}He.

In addition to the abundance studies in NGC 1365, investigations have been made of the velocity fields. B.E.J.Pagel, M.M.Phillips (AAO and CTIO), M.G.Edmunds (Cardiff) and A.J.Turtle (Sydney) have discussed two possible models for this galaxy in which the highly-ionized material is distributed either in a disc inclined to the main disc or in a biconical ejection pattern similar to that proposed by Axon and Taylor for M82.

Considerable attention has been paid to the origin of the absorption-line systems in the spectra of QSOs. Statistical studies by A.Boksenberg and collaborators from Caltech find that the behaviour of systems with lines of heavy elements is different from those with Lyman α only. The properties of the former are consistent with an origin in the haloes of galaxies if large galaxies have haloes of diameter $40(H/100)$ kpc. These absorption-line systems appear to be randomly distributed in redshift and show a peak in their two-point correlation functions. On the contrary, the systems with Lyman α only show no evidence for clustering. The number density of these systems varies with redshift as $N(z) = N_o(1 + z)^{1.8\pm0.5}$. Analysis of high-

dispersion *IUE* spectra of 3C 273 is in progress to set limits to the number density of Lyman α lines at recent epochs.

In addition to the statistical studies already described, the absorption systems in a number of quasars and BL Lac objects have been studied in detail. Of particular interest are the absorption systems in the BL Lac object 0215 + 015 studied by M.Pettini, J.C.Blades (VILSPA), H.S. Murdoch (Sydney) and R.W.Hunstead (Sydney). While the properties of most absorption systems are compatible with the intervening galaxy hypothesis, the system with the largest redshift appears to be intrinsic because of the large line-widths and the presence of excited fine-structure lines. This interpretation is further supported by the discovery that the absorption line profiles in this system change with time.

M.Pettini, M.V.Penston, A.Boksenberg and D.L.King were part of an international team which studied *IUE* and ground-based optical spectra of the supernova 1980k in NGC 6946. The velocity range of the ultraviolet interstellar lines implies a dimension of 40–50 kpc for our Galaxy in this direction ($l = 296°$, $b = +11°$). However, in directions at higher galactic latitude, a study of interstellar absorption in 24 halo stars by M.Pettini and K.West (UCL) suggests that a concentrated transition layer about 2–3 kpc above the galactic phase produces the Si IV and C IV absorption lines.

M.V.Penston and M.Pettini have detected 12 optical and ultraviolet interstellar lines in the spectrum of ESO 113-IG45, a Seyfert galaxy behind the Magellanic Stream. The abundances, being solar or somewhat lower, are consistent with those in the Magellanic Clouds. A.S.Pocock, M.V.Penston, M.Pettini and J.C.Blades (VILSPA) have found four quasars near the spiral galaxy NGC 253 from an inspection of UKSTU prism plates and these identifications were confirmed by slit spectroscopy at SAAO. It is planned to take high-dispersion spectra of these quasars to search for possible interstellar absorption lines in the halo of NGC 253.

An entirely different piece of evidence for large gaseous haloes around galaxies comes from the discovery of A.Boksenberg, J.Bergeron (Paris), M.Tarenghi (ESO) and M.Dennefeld (ESO) of diffuse [O II] emission from a region about 115 by 30 (H/100) kpc around the quasar MR2251-178.

Nuclear activity in galaxies has been studied using data obtained at wavelengths ranging from X-rays to radio. M.V.Penston, M.Pettini, A.Boksenberg and collaborators have studied temporal variations in the IUE spectra of the Seyfert galaxy NGC 4151. These observations seem to indicate a chain of cause and effect in which events are first seen in the thermal continuum component, then in the non-thermal power law continuum and finally in the emission lines. There is evidence for the existence of a $5\times10^8 M_\odot$ black hole in the nucleus and the fit to the Lynden-Bell accretion disc model is satisfactory.

Published data at all wavelengths on active galaxies are being collected, correlated and interpreted by A.Lawrence and M.Elvis (CFA). This study is centred around a complete X-ray selected sample. The present data indicate a flattened structure for the emission-line regions and that the covering factor is a function of X-ray luminosity.

Very-long-baseline interferometry by R.A.E.Fosbury and E.Preuss (MPIFR) at 6 cm has probed the radio structure of Seyfert galaxies at parsec resolution. Radio emission on this scale is detected for the first time from NGC 4151 and Mk 231.

Work by R.A.E.Fosbury, A.Boksenberg, M.V.Penston with several outside collaborators has shown that the elliptical radio galaxy PKS 2158-380 is surrounded by a high-excitation nebula of more than $10^8 M_\odot$ which extends to 15 kpc radius. By considering the photoionization by the ultraviolet flux from the nucleus, it can be shown that the nebula covers a large fraction of the sky as seen from the centre of the galaxy. This sky coverage is achieved by a warped disc which may have originated during the capture of a small gas-rich galaxy. Capture of gas in this way may fuel nuclear activity in elliptical radio galaxies generally.

The exciting possibility that our own Galaxy has an active nucleus is hinted at by CCD images of the Galactic Centre obtained by J.V.Wall, P.R.Jorden, D.J.Thorne, J.W.V.Storey (AAO) and J.O.Straede (AAO) during the commissioning of the RGO CCD system on the AAT. Two stellar images of apparent magnitude about 19 at 9000 Å separated by 3 arcsec along the galactic plane lie astride the non-thermal radio source at the Galactic Centre.

Observations of quasars and active galaxies have been made with the 26-inch refractor since 1965 in order to monitor photometric variations. The main part of this programme has concluded and C.Lloyd is preparing the results for publication. Observations of a few particularly interesting objects such as NGC 4151 and the double quasar 0957 + 56AB are being continued.

J.V.Wall, C.R.Benn (Leiden), G.Grueff (Bologna) and M.Vigotti (Bologna) continued radio and optical observations of 5C12 at the North Galactic Pole. Of 299 steep-spectrum radio sources originally observed at 408 MHz with the Cambridge One-Mile Telescope, 250 were observed with the VLA. An examination of the optical colours of the galaxies which have been identified so far indicates that they are bluer by about 0·7 mag in B–R at $z = 0{\cdot}4$ compared with nearby ones. This is significantly less than the difference of 2·0 mag obtained by other investigators. A survey of the 5C12 region at 5GHz was completed using the Effelsberg 100-m telescope. Flat-spectrum sources are rare at flux levels less than 100 mJy suggesting a redshift cut-off at a z of about 3.

J.V.Wall and J.A.Peacock (ROE) have compiled an all-sky catalogue comprising the 236 brightest flat-spectrum sources at 2·7 GHz. A new class of compact ($\leqslant$2 arcsec) steep-spectrum sources has been discovered. Some of these sources have since been studied with the VLA and by VLBI techniques. Optical identification of the full all-sky sample is about 89 per cent complete and is being pursued using Schmidt plates and the CCD camera on the AAT.

A 40-hr survey with the VLA by J.V.Wall, K.I.Kellerman (NRAO) and E.B.Fomalont (NRAO) discovered 39 sources to a completeness limit of 50 Jy at 5GHz. This extends discrete source counts by some two orders of magnitude, the survey reaching a surface density of 600 000 sources per

steradian. Calculations using extrapolations of current radio luminosity functions suggest the existence of a new source population at these faint levels. This has stimulated further programmes to obtain spectra with the VLA and optical identification with a CCD camera on the KPNO 4-m telescope.

VLA observations of PKS 0521-36 by J.V.Wall, R.A.E.Fosbury and collaborators at Groningen, ESO and VLA show a radio jet diametrically opposite the optical jet. Long-slit optical spectroscopy reveals emission alongside the radio jet.

E.J.Zuiderwijk and H.de Ruiter (Bologna) have constructed models to examine the effect of quasar clustering on the probability of finding apparent associations between quasars and foreground galaxies. They have also observed at ESO to search for quasar pairs in the Savage–Bolton survey. A statistical analysis of two quasar triplets discovered by Arp and Hazard indicates that neither of these alignments is significant.

P.G.Murdin, J.V.Wall and R.Gilmozzi (RGO/ESA) observed X-ray-identified quasars using the RGO CCD on the AAT. Photometry of the QSOs confirmed their separation from stars in a photographic colour–magnitude diagram obtained previously. The CCD images showed one QSO embedded in a galaxy.

Work continued on clusters of galaxies. M.J.Currie (RGO/Sussex) completed his G and F photographic photometry of 319 galaxies in the Centaurus I cluster. An analysis of the two components of the cluster by various means, including colour–magnitude relationships and luminosity functions, indicates that these are at a similar distance despite a difference in radial velocity of 1550 km s^{-1}. This is the first evidence that major subcondensations can survive within a rich cluster of galaxies over the present lifetime. Intensity maps in G and F at a resolution of about 1 arcsec were also made for the Horologium-Reticulum supercluster. The two clusters 0342-538 and 0326-537 are connected by a bridge of galaxies whose position angles are aligned preferentially along the bridge. J.R.Lucey (RGO/Sussex), J.A.Dawe (UKSTU) and R.J.Dickens have completed a survey of redshifts in the region. R.J.Dickens, W.L.Martin and J.R.Lucey (RGO/Sussex) have also obtained redshifts for 74 galaxies in Abell 119 whereas M.J.Currie (RGO/Sussex) has obtained photometry for a much larger sample. The velocity dispersion of the spirals appears to be higher than that of the ellipticals. A mass to light ratio of about 400 h has been obtained for the cluster.

W.L.Martin has continued his study of Cepheids in the Magellanic Clouds. He has shown that the distance to these two galaxies may be obtained either by adopting a period–luminosity relationship and allowing for the reddening or by adopting a period–luminosity–colour relationship and allowing for abundance effects.

3 EL OBSERVATORIO DEL ROQUE DE LOS MUCHACHOS

3.1 *General*

Although the site was established, the access road, telephone links and mains electricity supply were not quite complete at the end of the report

period. At this time, 11 of the staff who will operate and support the UK–Dutch telescopes on La Palma were in residence on the island. This figure was comprised of two staff recruited locally, two Dutch technicians and seven staff transferred from the RGO at Herstmonceux.

3.2 *The Isaac Newton 2·5-m telescope and building*

The building was substantially complete. The dome was completed except for some minor modifications. The main mechanical parts of the telescope were installed in 1981.

3.3 *The 1·0-m telescope and building*

After delivery to the RGO from Grubb Parsons, the telescope was placed in the old INT building at Herstmonceux for extensive tests on its control system. Some modifications to the servo-system were made to improve the response. On the island, the building was well advanced at the end of the report period and the dome has been installed but not finally commissioned.

3.4 *The William Herschel 4·2-m telescope and building*

A contract was placed with Grubb Parsons in 1981 November for the manufacture of the telescope mounting. This includes the supply of the drive and control system by Marconi Radar Systems Ltd acting as sub-contractor. Work under this and other contracts placed with Grubb Parsons has progressed well.

Although invitations to tender for the construction of the main building itself were not made during this report period, a separate contract for the piled foundations has been let and work has already advanced well on this part of the project. A contract for the design and manufacture of the dome has been let with Brittain Steel of Vancouver. The design stage has been completed and manufacture has commenced. A contract for the manufacture of the aluminizing plant has been awarded to Balzers Vacuum of Liechtenstein. The control computer, a Perkin Elmer 3210, has been delivered to the RGO where it is being commissioned.

3.5 *The Carlsberg Automatic Transit Circle*

In this tripartite collaboration with Denmark and Spain, the British are responsible for the building and the data-handling computer. A previous design for the building was cancelled in 1981 November because of budgetary considerations. Detailed drawings for a simpler structure were completed in 1982 August and contracts for the foundation and super-structure were placed in 1982 September.

3.6 *Instrumentation*

The intermediate-dispersion Cassegrain spectrograph for the INT has been completed and preliminary testing has been carried out. The IPCS has been modified after its return from temporary use at SAAO. The manufacture of a faint-object Cassegrain spectrograph for the INT has

started. This spectrograph is being made to a novel collimator-less design by C.G.Wynne. The INT prime-focus cone unit and camera have been completed except for the automatic plate-changer. The 1·0-m telescope Cassegrain camera unit is being modified after tests on the 36-inch telescope at RGO. Tests on the 1·0-m Cassegrain spectrograph have also revealed some problems and the instrument has been returned to St Andrews for minor modifications.

Much effort has been spent on developing software for controlling the telescopes, driving the CAMAC systems and handling data from various detectors such as a photometer, the IPCS and a CCD.

The initial instrumentation for the William Herschel telescope has been defined and the work contracted to various institutions including some in the Netherlands. These instruments include a collimator-less faint-object spectrograph, an intermediate-dispersion spectrograph, a high-resolution spectrograph, an imaging Fabry-Pérot system (TAURUS Mark II) and a prime-focus camera. A new version of the IPCS is being developed for use with the two spectrographs of higher dispersion and with TAURUS.

The main computer for data-handling on the Carlsberg Automatic Transit Circle was tested at RGO and then successfully linked to the control computer at Brorfelde.

4 INSTRUMENTATION RESEARCH AND DEVELOPMENT

4.1 *Detectors*

An intensified Reticon photon-counting system for use on the 1·9-m telescope at SAAO was completed and commissioned in 1981 July and August. This detector uses a 3-stage EMI intensifier in series with three Varo intensifiers. A similar Reticon system but with a microchannel plate as the intensifier has been made and tested. The existing CID system was modified to improve its noise level to 250 electron pixel^{-1} when averaged over 120 non-destructive read-outs. The system was used on the coudé spectrograph of the 30-inch telescope at RGO and by astronomers from the University of Durham at the Wise Observatory.

A CCD system for the AAO was completed and commissioned in 1981 September. Construction of further CCD systems is under way.

Existing electronographic cameras have been supported and maintained. However, because of recent developments with other area detectors, there is no longer any emphasis on electronography. The contract with Instrument Technology Ltd to reprocess tubes has not been renewed.

A low-light-level laboratory photometer designed by J.V.Jelley has been constructed. This instrument enables the light from a standard lamp to be attenuated sufficiently for the determination of the sensitivity of modern detectors such as CCDs.

4.2 *Optical design*

Work proceeded on a variety of design work for La Palma and elsewhere. C.G.Wynne has designed a new collimator-less form of spectrograph suitable for use on faint objects with a CCD as detector. A design

has been commissioned for the AAT in addition to the two proposals for similar spectrographs on the INT and WHT on La Palma which were mentioned previously. Aberrations introduced by the elimination of the collimator can be corrected to a high level using appropriate departures from axial symmetry in a wide aperture camera (up to $f/1{\cdot}4$) of novel design. The dispersing element is a transmission grating which is cemented to an order-sorting prism system and the camera aspheric plate.

Other projects included optical design for the *Hipparcos* satellite, optics for TAURUS Mark II and designs for possible beam-combiners in multi-mirror telescopes.

4.3 *Microprocessors*

Much emphasis was placed on the development and refinement of FORTH system software for image handling and processing for use with CCD, Reticon and other systems.

5 NATIONAL FACILITIES

5.1 *Steavenson telescope*

This is a joint venture with the Instituto de Astrofisica de Andalucia, Granada. The telescope was installed in the dome in 1980 November. Tests revealed a cyclic error in the drive. An outline design has been made for a new worm and bearing assembly. The Spanish Peoples Photometer is now working. The four-star photometer was tested. Although it was possible to observe through several magnitudes of cloud with a moderate degree of accuracy, the precision obtained so far on the best nights was disappointing.

5.2 *Equatorial telescopes at RGO*

The 36- and 30-inch reflectors were used both for astronomical programmes and for testing instruments. The 26- and 13-inch refractors were also in regular use, the latter telescope being used for student training some of the time. Modifications are being made to Dome C to accommodate a Hewitt camera which will be used by a team from Aston University to track artificial satellites.

5.3 *Computers*

A VAX 11/750 has been purchased and installed as a replacement for the ageing ICL 1903T. The RGO node of the national STARLINK network has had increasing use, not only by RGO staff but also by visiting astronomers from Britain and overseas.

5.4 *Measuring machines*

The rebuilding of the electronic hardware controlling GALAXY is now in an advanced state. This rebuild has not interrupted the running of the existing machine so far. Over 2000 plates were measured in the report period.

Several modifications have been made to the PDS. The addition of a cut-out, which operates in the event of a failure of the cooling fan, has enabled the machine to be left permanently switched on. This has increased the stability.

6 NATIONAL AND INTERNATIONAL SERVICES

6.1 *Time and latitude services*

The telescope for the satellite laser ranging facility has been installed in its dome and now tracks and points well under computer control. In 1982 August, the equipment was first used in eye-safe mode to range a retroreflector on a terrestrial target.

6.2 *Almanacs*

On 1981 January 1, responsibility for the prediction, reduction and publication of observations of occultations of stars by the Moon was transferred from HM Nautical Almanac Office to the Astronomical Division of the Hydrographic Department, Tokyo.

6.3 *Services to universities*

Ten PhD and five MSc students from the University of Sussex worked under supervision at RGO. Seven members of RGO staff held visiting appointments at the University at some time during the report period. The summer vacation courses in astronomy for undergraduates at British universities continued to be held.

6.4 *Archives and conservation*

Use of the Observatory Archives as a primary source for scientific history continued to increase. Some progress was made on the listing and indexing of the collections. The Conservation Laboratory was moved to a new premises and became fully operational towards the end of the report period with the purchase of two fume cupboards for use when working with chemicals. Conservation work on pieces from the Flamsteed and Airy papers has begun.

6.5 *Exhibition and grounds*

A complete revision of the astronomical displays in the West Room of the exhibition in the Castle has been made. A nature trail has been introduced in the grounds. The number of public visitors to the exhibition and grounds was 44 300 in the 1981 season and a record 57 900 in the 1982 season.

7 CONFERENCES AND WORKSHOPS

The 25th annual Herstmonceux Conference on 'Galactic Nuclei' was held in 1981 April. It was attended by 60 visiting astronomers.

The 26th annual Herstmonceux Conference on 'The Outer Regions of Galaxies' was held in 1982 April. It was attended by 55 visiting astronomers.

As part of a plan to extend the use of Herstmonceux Castle as a visitor and conference centre for astronomy, it was decided to hold workshops at frequent intervals. The intention of these workshops is for a small number of astronomers to discuss one particular topic in an informal atmosphere. The first two workshops were on 'The Remote Operation of Telescopes' and 'The Intimate Environment of Seyfert Galaxies'.

8 PUBLICATIONS

8.1 *Gemini*

The Royal Greenwich Observatory now produces a newsletter called *Gemini*. About 250 copies are circulated to astronomers and astronomical institutions throughout the world. The first issue was published in 1982 May.

8.2 *NAO publications*

The following annual volumes were published: *The Astronomical Almanac, The Nautical Almanac, The Air Almanac, The Star Almanac for Land Surveyors* and *Astronomical Phenomena.* In addition the following *NAO Technical Notes* were issued:

No. 54 Yallop, B.D., Geocentric and heliocentric phenomena.
No. 55 Yallop, B.D. & Emerson, B., The phase correction for Venus.
No. 56 Emerson, B., Approximate coordinates of Jupiter and Saturn.
No. 58 Yallop, B.D., Formulae for determining Carrington's elements and differential solar rotation.
No. 59 Sinclair, A.T., The effect of atmospheric refraction on laser ranging data.
No. 60 Yallop, B.D., A simple method of plotting position lines.
No. 61 Yallop, B.D., Methods for calculating the time of meridian passage from polynomial data.

8.3 *Time and SLR Publications*

The results of the time and latitude service continued to be published in *Greenwich Time Reports* (quarterly), in *Time Service Circulars A* (weekly) and *B* (monthly), and in *Time Service Notices* (irregularly).

In addition, the following *SLR Technical Note* was issued:
No. 1 Sharman, P., The UK Satellite Laser Ranging Facility.

8.4 *Theses*

(1) Carter, A.M., 1982. Flamsteed and Halley. A descriptive bibliography of the published work of the first two Astronomers Royal based on a collection of the Royal Greenwich Observatory, *BA Hons thesis,* City of Birmingham Polytechnic.
(2) Croft, D., 1981. Linear detectors in astronomy: Trials of an intensified Reticon on the RGO 30-inch Coudé telescope, *MSc dissertation,* University of Sussex.
(3) Ellis, S., 1981. Descriptive bibliography of the works of Leonhard Euler and Tobias Mayer based on the Airy Collection of the Royal Greenwich Observatory, *BA Hons thesis,* City of Birmingham Polytechnic.
(4) King, D.L., 1980. The maximum likelihood distribution of nearby dwarf K stars in velocity space, *MSc dissertation,* University of Sussex.

(5) Scanlon, M.J., 1982. A descriptive bibliography of nineteenth century voyages of discovery based on a collection of the Royal Greenwich Observatory, *BA Hons thesis*, City of Birmingham Polytechnic.

8.5 *Published papers*

The following is a list of papers etc. issued during the report period. In many cases, reports of conference proceedings have been omitted when the relevant research is described in detail elsewhere in the literature.

Co-authors who were not members of staff or students working at RGO are shown in italics. The papers are listed in the alphabetical order of the first mentioned RGO author.

During the whole of the report period, Dr K.Taylor was on special leave of absence at the AAO. Dr M.V.Penston and Dr A.J.Penny were on special leave of absence for some of the period at VILSPA (until 1980 December) and at SAAO (until 1981 November) respectively. Details of publications issued during the times of absence of these astronomers from the RGO will be found in the relevant annual reports of the observatories mentioned.

(1) *Clark, D.H.*, Andrews, P.J. & *Smith, R.C.*, 1981. Are we overdue for a galactic supernova?, *Observatory*, **101**, 203–205.

(2) Bingham, R.G., 1981. The advantages of a single large telescope, *Observatory*, **101**, 167–169.

(3) *Gething, M.R., Warren-Smith, R.F., Scarrott, S.M.* & Bingham, R.G., 1982. Optical polarization of the cometary nebula NGC 2261, *Mon. Not. R. astr. Soc.*, **198**, 881–888.

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