ROYAL GREENWICH OBSERVATORY

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ROYAL OBSERVATORY, CAPE OF GOOD HOPE

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(Report for the year ending 1964 March 31)

CLUSTERS

(i) *ω Centauri*

Work on this globular cluster is now nearing completion. The basic photometric and astrometric data have been extracted from extensive observational material obtained at the Cape, and a catalogue containing two-colour magnitudes and rectangular coordinates for over 6500 stars, and measured proper-motion displacements for two-thirds of these, will shortly appear as *Royal Observatory Annals* No. 2. All available evidence (including radial velocities for 42 of the brighter stars in the field determined with the 74-inch reflector at Pretoria) has been used to distinguish so far as is possible between field stars and members of the cluster. Work is proceeding on analysing the wealth of data in this catalogue. Discussions of

(a) the proper motions of the field stars and of the cluster;
(b) the radial velocities, including the velocity dispersion and evidence for the rotation of the cluster; and
(c) the variable stars

have been completed. The data have been reduced, and analysis is almost complete, in respect of

(d) the distribution of the stars with radius and position angle;
(e) the colour-magnitude diagram; and
(f) the galactic orbit of the cluster.

It is planned to publish papers on all these topics in one or more issues of the *Royal Observatory Bulletins*.

On account of the small proper motion of ω Centauri, the separation of field stars from cluster members must be made mainly on a statistical basis. The distribution in apparent magnitude of the 1100 field stars down to $B = 16^{m}\cdot8$ agrees well with van Rhijn's tables down to $B \sim 12^{m}$, but the observed numbers fall off considerably after that. This deficiency is however confirmed by star counts in fields at a distance from the cluster

and is believed to be real. The proper motion of the cluster relative to nearby stars, corrected for solar motion, has been determined using 14 different groups of field stars in various colour-magnitude ranges. The final result is

$$\mu_x = +0{\cdot}0005 \pm {}''{\cdot}0006 \qquad \mu_y = -0''{\cdot}0077 \pm {}''{\cdot}0005 \text{ (s.e.)}$$

These standard errors represent an uncertainty of ±15 km/sec at the distance of the cluster.

Radial velocities of a total of 31 members of ω Centauri with B magnitudes between $10^m{\cdot}7$ and $13^m{\cdot}5$ yield a mean radial velocity for the cluster of

$$238 \text{ km/sec} \pm 3 \text{ (s.e.)}$$

The cluster appears somewhat elliptical on direct photographs, and a systematic difference is evident between the radial velocities of member stars at oppposite ends of the apparent major axis. Analysis of the 13 best-observed velocities gives a rotation (about the minor axis indicated by star counts) amounting to 0·84 cosec i km/sec per parsec displacement from the centre, where i is the inclination of the rotation axis to the line of sight. Discussion of the observed velocity dispersion freed from instrumental dispersion suggests a space-velocity dispersion of 10 km/sec ±4 (s.e.).

Studies of the variables in ω Centauri have largely concerned those of the RR Lyrae type, though period-luminosity relations in two colours found for six classical cepheids in the cluster show significant differences from Population I cepheids. From light curves of over 40 RR Lyrae variables, magnitudes $\langle B \rangle$ and $\langle V \rangle$ at mean light have been derived and compared with the results of Roberts and Sandage on M3. The observed relations between period, amplitude, colour and luminosity closely resemble those in M3, and the observations satisfy the pulsation criterion $P\sqrt{\rho}$ = constant, within the limits of the data. However, significant correlations between P and $\langle B \rangle$ or $\langle V \rangle$ are found amongst the RR Lyrae stars in ω Centauri that are not evident in the M3 data.

(ii) *M67*

Work on this galactic cluster is based on two pairs of plates taken respectively on the 26-inch refractor at Greenwich/Herstmonceux and on the 60-inch reflector at Mount Wilson. Discussion of the proper motions in the central regions down to $B = 16^m{\cdot}5$ is complete and will appear shortly in *Royal Observatory Bulletins*. The blue stars in the upper part of the main sequence are certain members, as also are several bright stars of intermediate colour. The crude proper motion of the cluster relative to an

undifferentiated group of 14^m field stars turns out to be virtually identical with that obtained by van Maanen twenty years ago on a base line only half as long, and it has the same formal uncertainty. Thus it is the real velocity dispersion of the stars themselves that determines the observed dispersion in proper motion. A more sophisticated derivation of the true proper motion of the cluster, corrected for parallactic motion of the field stars but not for differential galactic rotation, is based on a group of dwarfs in a restricted colour range and gives

$$\gamma_\xi = -0''\cdot0104 \pm ''\cdot0015 \qquad \gamma_\eta = -0''\cdot0053 \pm ''\cdot0013 \text{ (s.e.)}$$

Its peculiar space motion, determined by combining this with Popper's radial velocity, turns out to be well within the dispersion expected for Population I objects. The observed velocity component normal to the galactic plane gives a period of oscillation through the plane of nearly 10^8 years.

(iii) *NGC 6522*

This globular cluster appears in a "window" in the Milky Way not far from the direction of the galactic centre and its study is likely to throw light on the distance to the centre. Photometry of the region round the cluster has been completed and the results will shortly appear in the *Royal Observatory Bulletins*. The work is based on a series of plates taken in *B* and *V* light on the Radcliffe 74-inch reflector (stopped down to 44 inches) and calibrated by a photoelectric sequence recently set up by Arp in both colours. It has been necessary to adopt some provisional magnitudes for the fainter stars. The colour-magnitude diagram for the cluster has been deduced by a process of subtracting the contribution due to field stars. Six short-period variables are identified as cluster members: their mean colour excess gives a visual absorption of $1^m\cdot56 \pm 0^m\cdot54$ (s.e.) in front of the cluster. Correcting for this, the distance of the cluster from the Sun turns out to be $8\cdot5 \pm 1\cdot2$ kpc. and its distance from the galactic plane 540 pc. Analysis of the radial distribution of stars in the cluster suggests that it is somewhat smaller than average, but in total luminosity, HR diagram and population of short-period variables it does not differ significantly from other globulars.

GALACTIC RR LYRAE VARIABLES

The great importance of RR Lyrae stars as indicators of distance in the globular clusters justifies paying the closest attention to the study of nearby variables of this type by all available means. In 1953 Pavlovskaya

estimated the photographic absolute magnitude of these stars, from observations of radial velocity and of proper motion, at $+0^{m}\cdot8$, a value substantially fainter than had been supposed. More recently, however, Missana and Plaut using further proper-motion data obtain $+0^{m}\cdot0$, a figure that represents a return to earlier values. The observational data have now been re-examined at Herstmonceux, paying particular attention to the velocity dispersion in the radial-velocity measures as well as to the mean velocity.

It appears that there is a very wide range in the luminosities of short-period RR Lyrae stars ($P < 0^{d}\cdot44$) and they can probably be divided into (at least) two groups: one with little or no difference Δs between hydrogen spectral type and metals spectral type, and mostly of Bailey type a and amplitude averaging over a magnitude; the other with large differences Δs, with c characteristics and with low amplitudes. The former group probably has a negative mean absolute magnitude, whereas that of the latter group is about $+2$.

The stars of periods greater than $0^{d}\cdot44$ appear to be a more homogeneous group. Their mean absolute magnitude (as before on the V photoelectric system) becomes $+0^{m}\cdot48 \pm 0\cdot23$ (s.e.) when the dispersion is used in the analysis as well as the mean velocity.

The many questions raised by these stars cannot be settled without more data, and further astrometric and photometric programmes have been started at Herstmonceux and at the Cape. Second-epoch Carte du Ciel plates are being secured on fields containing over 40 RR Lyrae stars that appear on early plates taken in the Greenwich, Oxford and Vatican zones. Measurement of the plate pairs has already started, and reductions are being carried out in two independent ways:

(a) relative to faint stars, with reduction to absolute motions by means of secular parallaxes; and
(b) relative to astrographic reference stars for which proper motions can be derived by comparing early meridian places with AGK2.

The astrographic telescope at Herstmonceux is also being used to obtain plates in B light of northern RR Lyrae variables so as to establish periods and light curves.

An attempt to use the 28-inch visual refractor at Herstmonceux photoelectrically for the same purpose has met with some success. For ten nights around New Moon in the last three lunations of the report year a conventional photomultiplier has been used to obtain light curves in B and V for several RR Lyrae stars. The Herstmonceux sky is too variable to allow comparison between stars over long arcs, but enough reference stars are available on the (B,V) system to keep the typical transfer down

to 7°. Thus only a very approximate value of the extinction is needed. A standard error of $\pm 0^{m}\cdot02$ in V and $\pm 0^{m}\cdot03$ in B-V is attained.

Astrometric observations of southern RR Lyrae stars are being pursued at the Cape, where proper motions are being secured for those appearing on the Cape astrographic plates and for about two dozen of the brighter ones in the South Galactic Cap. The same stars are being simultaneously observed with the photoelectric photometer attached to the 24-inch refractor. Spectroscopic observations of the brighter objects in the list have been made with the $f/1$ camera of the Radcliffe Cassegrain spectrograph, and radial velocities have been found for ten of them. The brighter RR Lyrae stars in ω Centauri are just within reach of the fast low-dispersion Newtonian spectrograph at Pretoria and observation of these has started.

COUDÉ SPECTROGRAPH

The coudé spectrograph designed and built in the Herstmonceux Engineering Department, with optics by Grubb Parsons, has been installed on the 30 inch reflector in Dome A and aligned and tested. It is intended to use the telescope permanently at the north coudé focus with this spectrograph, thus avoiding the frequent removal, replacement and re-alignment of mirrors necessary with most other coudé telescopes.

The coudé secondary mirror narrows the $f/4\cdot5$ primary beam to $f/47$. The returning beam is reflected from the rotating flat at the intersection of the polar and declination axes through an aperture in the side of the telescope tube, travelling northwards and upwards to a fixed flat at the top of a 12-foot tower. From this mirror the converging beam passes vertically downwards to the slit, which is mounted horizontally at a convenient height above the observing floor. The collimator mirror is on the ground floor, 19 feet below the slit, and returns a parallel beam, inclined slightly to the west of the down-coming light, to the plane grating and camera on the mezzanine floor. The camera is an off-axis Schmidt with a double-pass corrector plate attached to the grating. The spectrum is focused on a 7 inch × 1 inch plate curved to a radius of 32 inches and the dispersion is 10 A/mm in the second-order blue. Widening is achieved by rocking a glass plate just underneath the slit.

Economy in the number of reflections by using a north coudé focus cannot be purchased without cost. In this case the mechanical construction renders certain areas of the sky inaccessible: observations are restricted to objects between declinations $-20°$ and $+50°$. A few test plates of I.A.U. radial-velocity standards have been measured: the results are encouraging

and indicate that satisfactory spectra at this dispersion can be obtained at $m_{pg} = 5^{m}\cdot5$ in about one hour.

ASTROPHYSICAL SPECTROSCOPY

(i) *Peculiar A stars*

Using the 40 A/mm camera in the wavelength range 3500–4500A, spectra have been obtained of 97 of the 120 Ap stars in Bertaud's catalogue north of the equator and brighter than $7^{m}\cdot0$, and of 13 A- and B-type sharp-lined MK standards. Intensity tracings have been made of 50 plates and work on line identification begun in the hope of devising a new classification scheme for the Ap stars and estimating crude abundances of certain elements. The results will be used to test the conclusion reached by Sargent from a study of the literature that only three of the recognized groups of Ap stars (namely the manganese, silicon and europium-strontium groups) represent distinct chemical compositions, other spectroscopic differences being at least partly excitation effects.

One Ap star, HD 4778, has been studied intensively using several successive exposures and has shown rapid spectral variations, particularly of Ca II *K* and of Eu II λ 4130, occurring on a time scale of a few hours; this effect demands detailed study at higher dispersions.

(ii) *Nova Herculis 1963*

Observations began on 1963 February 14 (six days after discovery) and continued for eight months until 1963 October 11, when the star had fallen below $V = 10^{m}\cdot5$. Using the two cameras (40 A/mm and 80 A/mm in third order blue) according to the magnitude reached by the star, 75 good spectra were obtained covering the blue and red regions, and these are being measured for velocity and relative line intensities.

(iii) *Metal Abundances in Cool Stars*

Tracings of several spectra of G dwarfs taken with the 40 A/mm camera indicate a good correlation between the strength of the λ 3883 CN band and metal abundances deduced from curve of growth analysis. Naturally CN strength is also very sensitive to luminosity, and this programme is now being extended to cover other spectral features and a wider range of spectral types in the hope of developing an accurate system of 3-dimensional classification of faint stars (the limit of the 80 A/mm camera is about $10^{m}\cdot5$ photographic). In conjunction with this programme, colour indices on the 6-colour system have been calculated on the ICT 1201 computer from published flux distributions corresponding to theoretical model atmospheres; these tend to confirm previous

estimates of the "line-free effective temperature" based on [*R-I*] and [*G-I*] for models corresponding to a wide range of metal abundance.

The programme on abundance determination in late-type stars has been supplemented by numerous coudé plates obtained at Mount Wilson Observatory by the Astronomer Royal and B. E. J. Pagel and by coudé plates and photoelectric observations on Kron's (*R,I*) system secured by Pagel while visiting Mount Stromlo Observatory. The photoelectric programme, carried out with the active assistance of Dr B. Westerlund and Mr J. Sommerville, was designed with special reference to K dwarfs previously found by O. C. Wilson to be exceptionally "blue" or "red" in (*P-V*) for their spectral types as estimated at high dispersion. By combining eight new (*R-I*) colours for outstanding cases with colours previously published by Kron, Gascoigne and White, it was possible to confirm the interpretation of Wilson's results as being largely due to a differential blanketing effect, the corresponding range in metal abundance being the same (between about twice and one third of the solar value) as had been previously found by G. Wallerstein to be characteristic of G dwarfs of Population I. The combined (*R, I*) data show that the correlations between metal abundance and the components of space motion in and at right angles to the galactic plane for K dwarfs are identical with those previously found by Wallerstein for the G dwarfs and by O. J. Eggen, D. Lynden-Bell and A. R. Sandage for nearby stars having known ultra-violet excess on the (*U, B, V*) system.

Spectroscopic abundance determinations normally involve the assumption of local thermodynamic equilibrium (LTE) in stellar photospheres. This assumption has been challenged, particularly in the course of investigations of solar line profiles by J.-C. Pecker and his collaborators. However, the absolute *f*-values published by C. H. Corliss and W. R. Bozman have made it possible to re-investigate the excitation temperature of weak solar lines of neutral metals such as Ti I, which turned out to be entirely consistent with LTE and inconsistent with the corrections proposed by Pecker; together with similar data obtained for V I, Cr I, Fe I and Co I by Mr B. Warner of University of London Observatory, these results strongly suggest that the use of the assumption of LTE together with models derived from limb-darkening observations leads to valid abundances for the Sun and similar stars.

MERIDIAN OBSERVATIONS

The work involved in fulfilling Herstmonceux's international commitments in respect of the AGK3R programme is nearing completion. It will be recalled that contemporary meridian positions of about 13,000

reference stars are required to reduce the photographic plates taken for second-epoch positions of the 200,000 stars in the AGK2 catalogue. One-sixth of the transit observations necessary were assigned to Herstmonceux, and between 1957 and 1961 some 75,000 observations were made on the Reversible Transit Circle for this purpose. The transit times were recorded directly on to punched cards using the electronic chronograph EPIC, and processing has been carried out on the ICT 1201 computer. The reductions are now complete to observed place 1950·0 and a duplicate pack of punched cards containing the results awaits dispatch to the U.S. Naval Observatory at Washington for incorporation into the AGK3R as soon as the final checks have been completed.

The probable errors of a single observation of a zenith star with the Cooke T.C. turn out to be ± 0″·18 in right ascension and ± 0″·28 in declination. The right ascensions can be regarded as very satisfactory in this respect, and the somewhat larger probable error in declination can probably be ascribed to the difficulty of maintaining an entirely stable nadir circle reading and to difficulties associated with the circle microscope films.

An analogous international scheme aimed at providing a grid of well-observed reference stars in the southern sky is being contributed to by the Cape Observatory, where observations for the *Third Cape Catalogue for 1950·0* and for the middle zones of the *Faint Star Catalogue* have been continued. The meridian places of the zone stars are being strengthened by photographic measures, and all the necessary astrometric plates for the − 40° to − 52° zone have been taken.

TIME SERVICE

Since the spring of 1957 the Earth has had a fairly constant losing rate of about 1·3 milliseconds a day relative to an atomic time scale based on the adopted frequency of the caesium resonance of 9 192 631 770 cycles a second (of Ephemeris Time). During April there appears to have been a change in the rate of rotation, and since then the losing rate has increased to 1·7 ms/day.

In 1963 the carrier frequencies of the coordinated emissions were offset from values based on the nominal caesium frequency by − 130 parts in 10^{10}, which is equivalent to a losing rate of 1·1 ms/day of the time signals relative to the atomic time scale. The offset agreed internationally for the calendar year 1964 (determined over the previous year by comparing observed U.T.2 with the atomic scale) is − 150 parts in 10^{10}, equivalent to a losing rate of 1·3 ms/day. Because of the Earth's change of rate in April, the time signals have been emitted in advance of U.T.2 throughout the

report year by amounts varying from 25ms. to 150ms.; this in spite of retardations, agreed internationally, of 100ms. on November 1 and again on 1964 April 1. If the co-ordinated time signals are to remain within 100ms. of U.T.2, as was originally intended for the benefit of navigators and surveyors using uncorrected signals, then frequent adjustments of this kind may be necessary.

Nevertheless, the present system of forecast "offsets" from the atomic rate combined with *ad hoc* step adjustments appears to offer the best practical compromise between the requirements of the navigators and those of the physicists who are primarily interested in accurate frequencies.

There has been a significant improvement in the accuracy of the results obtained with the Photographic Zenith Tube since its complete overhaul last year. Analysis of the results obtained during the current programme yields residuals of individual plates from the adopted smoothed mean latitude and U.T.2 that support Popov's recent discovery of a nearly diurnal term in the rotation of the Earth's axis with an amplitude of about 0″·02. Redetermination of the coordinates of the programme stars indicates that an apparent diurnal variation in the latitude of Herstmonceux may result from poorly-determined group corrections.

The Danjon astrolabe has been withdrawn from service and overhauled prior to its removal to the Cape for use there. The closing error of 1″·5 in the observed zenith distances has been satisfactorily accounted for in terms of a temperature effect on the apparent prism angle, and empirical corrections have been applied to the observations to allow for this.