

30. RADIAL VELOCITIES (VITESSES RADIALES)

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MARSEILLES AND HAUTE PROVENCE OBSERVATORIES

Les mesures de vitesse radiale (VR) ont été continuées par les trois techniques: prisme objectif, spectrographie à fente, interférométrie, avec des instruments en fonction à l'Observatoire de Haute Provence ainsi qu'à celui de l'ESO.

Mesures au prisme objectif

Grand Nuage de Magellan: Le travail de 13 champs est pratiquement achevé et sera publié dès que les mesures de spectres de fente pris au Chili seront complètement dépouillés.

Un catalogue comprenant 1765 étoiles galactiques et 469 étoiles du Grand Nuage de Magellan est achevé. Un supplément comprend environ 200 étoiles particulières de cette région.

Toutes ces étoiles ont été reportées sur des calques directement applicables sur les cartes P. N. Hodge et F. N. Wright (1). Ce catalogue sera imprimé dès cette année (1969). Une étude d'ensemble de ce matériel au point de vue cinématique et dynamique est en cours.

Des mesures *UBV* de plusieurs centaines d'étoiles du Nuage complètent ce matériel (J. P. Brunet, P. Mianes, Mlle M. N. Perrin).

Galaxie: Les mesures dans la Galaxie ont été un peu retardées par le travail sur le Grand Nuage. Néanmoins une liste de 309 VR d'étoiles situées dans Carina ont été publiées par Mlle N. Martin (2); de 97 étoiles dans la SA8 par Mme M. Barbier (3), et aussi une étude de la rotation galactique qui contient 52 VR des étoiles O, A, B (4); dans l'Amas NGC752 par Mme E. Rebeiro (5); et par Mme Georgelin dans Cassiopee (164 étoiles) (6).

Spectrographe à fente

Un spectrographe pour la mesure des VR a été installé sur le télescope de 152 cm de diamètre du Chili. Sa dispersion de 72 \AA mm^{-1} permet la mesure des étoiles brillantes des nuages de Magellan. Plusieurs centaines de spectres ont été obtenus par E. Maurice, L. Prevot, Ch. Fehrenbach et ont été mesurés. Des classifications spectrales très précises de ces étoiles ont été faites; résultats prêts à la publication en 1969.

A l'Observatoire de Haute Provence des mesures de VR seront continuées avec les télescopes de 193 cm et de 120 cm. Des cartes tests d'étoiles standard ont été publiées par Ch. Fehrenbach et Imbert (7), (8), mais de nombreuses autres mesures n'ont pas encore été publiées. Elles seront activement poussées dès la mise en service du nouveau télescope de 152 cm et de son spectrographe coudé.

Des mesures des raies de Ca II, interstellaires sont en cours à Haute Provence et au Chili (Chu-Kit).

Interférométrie

Le groupe de M. G. Courtès s'est beaucoup développé et de très nombreuses mesures tant galactiques qu'extragalactiques ont été publiées. Un catalogue de VR des régions d'émission a été publié (9).

Signalons particulièrement les mesures de P. Cruvellier sur les régions H II de la Galaxie, de G. Courtès, G. Monnet *et al.* sur les nébuleuses extragalactiques M33, NGC4449, Andromède etc.

RADCLIFFE OBSERVATORY, PRETORIA

(1) *B stars*. D. Hube (David Dunlap Observatory) used the Radcliffe 2-prism Cassegrain spectrograph to determine radial velocities of southern B8 stars in the Bright Star Catalogue (10).

E. N. Walker has measured velocities of 101 stars of type B5 or earlier with $m \leq 7.5$ and unknown or poorly determined velocities.

63 other such stars have been observed by Thackeray. Taken jointly this will complete the survey of bright early-type stars.

R. Wood has observed B8-B9 stars suspected to be members of the Sco-Cen association, the more northerly being selected from Garrison's list, the more southerly selected partly from proper motions. Wood has also observed B8-B9 stars at distances of order 500 ps in two longitude-groups for investigation of galactic rotation.

Thackeray and Emerson (11) have published orbits of two O-type spectroscopic binaries. HD 93403 is a massive system ($m_1 \sin^3 i = 5.2 \odot$) with eccentric orbit ($e = 0.524$). Thackeray is completing a discussion of the orbits of the O sub-dwarf binary HD49798 and the double-lined B3 binary ϵ Lup (known as such for 60 years but hitherto without orbit). Other early-type binaries being studied include HD72754, 101131, 101205, 104631, 161756 (Thackeray), HD152667 (E. N. Walker), 151976 (T. Lloyd Evans), 204370 and 209278 (R. Wood). A few spectra have been obtained of GLCar and HD86118.

(2) *Cepheid variables*. Lloyd Evans (12) has reobserved velocity curves of many of Stibbs' southern Cepheids and is continuing this work; he finds that Abt's estimate of the frequency of cepheid binaries must be increased from 2% to about 15%.

M. Breger has reobserved ν Sgr (13) and SNor (14), for velocity and light variations.

(3) *SR variables*. Feast has completed observations of some 70 SR variables for velocity and hopes to commence reduction shortly.

(4) *Solar and late-type stars*. Feast and Catchpole are carrying out an extensive spectroscopic programme on southern C and S type stars for radial velocity and astrophysical purposes, in part with the new 8-inch camera in the Radcliffe coude spectrograph.

As a by-product of work on lithium isotope ratios, velocities of about 25 bright southern solar-type stars have been observed with the Radcliffe coude spectrograph at 13.6 \AA mm^{-1} .

Further plates of the eclipsing variable SEqu have been taken for M. Plavec.

D. Jones and Catchpole continued (until April 1969) the Cape F. D. S. programme. In May 1969 R. Wallis (Herstmonceux) began an extension of this programme on Gliese stars distant between 20 and 25 parsecs.

(5) *Instrumental*. The velocity system of the two new 8-inch Grubb Parsons cameras in the coude spectrograph (with field flatteners to cover visual and ultra-violet wavelengths) is being examined. R. Wood has observed the 9th magnitude stars HD205650, 220647 as potential faint standard velocity stars, and is conducting tests on the velocity system of the Cassegrain d-camera.

Plans are going ahead with the Royal Greenwich Observatory for the installation of an image-tube spectrograph at the Cassegrain focus.

(6) Other references to Radcliffe work on radial velocities will be found under the Reports of Commissions 28 (Magellanic Clouds group), 29, 33, and 34.

DOMINION ASTROPHYSICAL OBSERVATORY

Since the last report of this Commission, the Cassegrain spectrograph of the 72-inch telescope has been completely redesigned. We now have all-reflection grating spectrographs of dispersions ranging from 120 to 15 \AA mm^{-1} . Dispersions of 10 , 6 , and 2.4 \AA mm^{-1} are available at the coude focus of the 48-inch telescope. Much of our effort during the past three years has been directed towards establishing new wavelength systems for these spectrographs. Several changes are clearly necessary from the systems set up by Petrie and his associates for prism spectrographs of similar dispersions. Only for the 10 \AA mm^{-1} spectrograph have we yet completed wavelength selection

over the whole range of spectral types. The accompanying table shows the accuracy that we can achieve at the various dispersions as measured both by internal and external agreement. In due course, the wavelengths chosen will be published. In the meantime, we are ready to provide this information on request.

The speed of the coude spectrograph has been greatly increased by the use of Richardson image slicers (15), new, high-reflectance coated secondary mirrors and the Mount Wilson and Palomar developer formula. In addition a mosaic of four gratings has been constructed for use at the highest dispersion of 2.4 \AA mm^{-1} . These improvements together allow us to obtain spectrograms of this dispersion of stars as faint as 6th, or even 7th magnitude. Fletcher has investigated the stability of this mosaic for radial-velocity work. It is necessary to readjust the mosaic for each night's work. Careful attention is being given to all possible causes of instability, and it is hoped to reduce the external mean error quoted in Table 1.

Table 1. Accuracy of new Victoria spectrographs

Spectral type Dispersion	B0-B9		A0-F2		F5-K4	
	int.	ext.	int.	ext.	int.	ext.
2.4	-	-	-	-	0.05	(0.10)
6	-	-	-	-	0.12	0.25
10	-	4.4	0.75	0.92	0.23	0.49
15	-	-	-	-	(0.7)	(1.6)
60	-	-	-	-		

Figures given are the mean errors per plate derived from internal and external agreement and expressed in km s^{-1} . Bracketed figures are preliminary only. Too few lines were measurable in the B-type spectra for a meaningful internal mean error to be derived.

One of the difficulties is the absence of good wavelengths for the iron-argon discharge tube now used as a comparison source. At first, the image slicers introduced a small systematic error into the velocities (about -0.3 km s^{-1} at 10 \AA mm^{-1}). Improved adjustment of them, however, has eliminated this.

Radial velocities have been determined in the course of several investigations of spectroscopic and visual binaries, variable stars, novae, and galactic structure and the results will be communicated to the appropriate Commissions.

Finally we should report the publication and distribution of the *Sixth Catalogue of the Orbital Elements of Spectroscopic Binary Systems* (16) since it was undertaken at the request of this Commission.

DAVID DUNLAP OBSERVATORY, TORONTO

The grating spectrograph has been modified to include a 12 \AA mm^{-1} system which is more efficient than the previous 10 \AA mm^{-1} system. With the 12 \AA mm^{-1} system a good spectrogram of a late-type star of magnitude 9.0 ptg can be obtained in two hours. Radial velocities with external mean errors of 1.0 km s^{-1} for a single plate have been obtained on tests with standard-velocity stars. The average systematic deviation of our velocities from the IAU standard velocities is 0.3 km s^{-1} .

Heard and Petrie (17), have published the radial velocities and luminosity data for 77 stars in the field of the α Per cluster.

From an analysis of radial velocities of early-type Be stars within 1.5 kpc of the Sun, including new velocities obtained here as well as previously published data, Crampton (18), has obtained values of the solar-motion and galactic-rotation parameters, and has shown that they support the hypothesis that the commonly adopted local standard of rest has an outward motion from the galactic centre.

Hube (10) has published the radial velocities of 335 late B-type stars obtained here and at the Radcliffe Observatories. Combining these data with other published data, and using the age calibration of Kelsall and Strömgren, he has found that these stars were formed intensively about 190 and 150 million years ago and then more continuously during the past 120 million years. His results do not support the suggestion that stars tend to be formed in the extreme portions of their orbits about the galactic centre.

Gorza and Heard have measured the radial velocities from a number of spectrograms of Nova Del and Nova Vul obtained in 1968.

Heard has re-observed the stars listed by him (19) as candidates for a proposed list of 9th magnitude standard-velocity stars. At the time of writing, 14 of the 24 stars have been adequately observed; of these, eight are confirmed as having constant velocity, the remaining six have exhibited variations suggesting that they are long-period small-range spectroscopic binaries.

Heard and collaborators have continued radial-velocity observations of spectroscopic binary stars, particularly eclipsing systems. These latter have been reported to Commission 42. Hickok has completed a new radial-velocity study of the Be spectroscopic binary, ϕ Per.

ROYAL OBSERVATORY, CAPE OF GOOD HOPE

1. Data for a further 220 stars in the Fundamental Data for Southern Stars series is now available and is being prepared for publication.

2. Clube, Evans, and Jones (20), have obtained radial velocity and photometric curves for 50 southern RR Lyr stars.

3. Orbital elements for 8 single-lined (HD 2070, 15064, 123 515, 155 099, 159 656, 183 007, 194 184 and 200 334) and the double-lined (HD 188 164) spectroscopic binaries have been published by Barker, Evans and Laing (21). The orbital elements were determined using a computer program developed by Barker.

4. The triple system p Vel has been rediscussed by Evans (22).

5. Nine spectra of the 1966 outburst of Nova TPyx were discussed by Catchpole (23).

6. D. H. P. Jones obtained 18 spectra at 86 \AA mm^{-1} of the brightest variable in the globular cluster ω Cen. A discussion of the radial velocity and light curves has been published (24).

7. Harding obtained radial velocities for the 126 stars in the south galactic cap which are classified as A0 in the Henry Draper Catalogue but for which velocities were not available. An analysis of the velocities (25), confirms the increase in velocity dispersion with height above the galactic plane found by Woolley *et al.* (26) in the northern cap.

8. Using observations of standard radial velocity stars Clube and Wallis have carried out an investigation of the instrumental errors of the Radcliffe Cassegrain spectrograph (27).

9. The Cape-Radcliffe agreement, under which the Cape Observatory was allocated one-third of the time on the Radcliffe 74-inch was terminated on 1969 March 31. In future all 74-inch time for visitors will be allocated by the Large Telescope Users Panel.

Any time which is allocated to the Royal Greenwich Observatory will be used by Wallis to observe those southern stars within a distance of 25 pc (Gliese Catalogue and extension) with no known radial velocity.

10. Jones, in conjunction with the photometric workers at the Cape has observed radial velocity curves for eight δ Sct stars.

11. Radial velocities and line identifications for 17 planetary nebulae were obtained with the Newtonian spectrograph of the Radcliffe 74-inch by Jones, Evans and Catchpole (28).

12. Radial velocities of 8 southern galaxies obtained with the Radcliffe Newtonian spectrograph were published by Catchpole, Evans and Jones (29).

13. Evans and Wild (30), have conducted a photometric area search for subdwarfs and have new velocities for subdwarfs in the area RA $10^{\text{h}}-12^{\text{h}}$, Dec. -20° to -50° .

14. Evans (31) has discussed the possibility that the radial velocity of the central star of the planetary nebula, NGC 3132 may be variable.

15. Bopp, Evans, and Laing (32) have determined orbital elements for the spectroscopic binaries, HD 1273, 148704, 167954, 194215, 202940, and 217792.

The paper includes an appendix on period finding by T. J. Deeming.

16. Evans (33) has discussed coude plates of the multiple system HD 118261 in an effort to develop methods of analysis suitable for stars of higher multiplicity.

The preparation of a supplement to the General Catalogue of Radial Velocities commenced by Evans with assistance from Cape Staff approaches completion at Texas.

ROYAL GREENWICH OBSERVATORY, HERSTMONCEUX

The closer relationship between the Cape and Herstmonceux Observatories and interchange of staff makes it difficult to separate the reports for the two institutions.

Work carried out wholly at Herstmonceux includes Palmer *et al.* (34), on the radial velocities, spectral types and projected rotational velocities of 633 bright northern A-stars: radial velocity observations of standard stars with the 30-inch coude spectrograph (35); and the determination of orbital elements of the sharp-lined, metallic-lined A-type spectroscopic binary, HD 184552 by Walker and Jones (36).

MOUNT STROMLO OBSERVATORY

Work on the radial velocities of OB stars in Puppis and Norma described in preliminary form in the 1967 Draft report has been published (37).

Publications by Buscombe and Kennedy include studies of M 7 (38); coude spectrograph measures of 40 early and 30 late-type stars (39), and a further list of 124 southern OB stars and supergiants with apparent magnitudes between 4 and 9 (40).

C. R. Chambliss has published a radial velocity curve for the eclipsing binary 9 Cha (BV 430) based on spectra obtained at Mount Stromlo (41).

Using spectrograms obtained by Henize, Carlson has obtained radial velocity data for 24 southern peculiar emission line stars. He has also investigated 23 visual binary stars using plates obtained at David Dunlap Observatory (42).

ALLEGHENY OBSERVATORY

Beardsley (43), has published 2935 individual radial velocities of 129 stars based on plates obtained at the Allegheny Observatory between 1906 and 1917. The results are compared statistically with the Mount Wilson General Catalogue. The contribution includes preliminary orbital elements for ϕ Dra and 6 Lac. Some 1400 plates still remain to be analysed.

With the general introduction of image tubes in spectrographic cameras the question of the accuracy of determination of radial velocities has become of general concern. Beardsley *et al.* (44), report favourably on the performance of a fiber optics electrostatic image tube by Westinghouse. Workers elsewhere, using varied equipment, seem less optimistic.

INDIVIDUAL WORKERS

Radial velocity programmes used to be undertaken on an institutional basis and could thus readily be reported observatory by observatory. The work is now devolving more on individuals, with interests in special problems, or in the development of special techniques. The remainder of the report is presented in a form suited to this development. The opinion should, however, be stated that systematic programmes ought to be continued, both because they often produce more accurate results than isolated projects, and because the coverage of even bright stars, especially in the south, is so far inadequate.

Griffin reports that his photoelectric radial-velocity spectrometer has been used from time to time in essentially its original form (45). The method requires reference stars of known velocity,

and four selected stars have been intercompared using the instrument. The standard deviation of a single comparison is 0.6 km s^{-1} , and the closing error round the sky, 0.58 km s^{-1} (46). Velocities have been measured for some 700 stars, mostly unobserved, and mostly in the range from 7^m to 10^m in the $+15^\circ$ selected areas. Late-type HR stars north of declination -9° , of unknown velocity are also being observed.

Lutz and Yoss (47), have investigated the possibility of determining stellar radial velocities from microphotometer measurements, with promising results.

O. C. Wilson (48), has published an important list of more than 300 radial velocities of dwarf K and M stars.

Sandage (49), reports radial velocities obtained at Mount Wilson and Mount Palomar for 112 stars of large proper motion as part of a general study of new subdwarfs.

Oetken reports that the Cassegrain spectrograph of the Tautenburg two-meter telescope is being used to obtain radial velocity data for magnetic stars such as $\alpha^2 \text{ CVn}$, $\gamma \text{ Equ}$, $\beta \text{ CrB}$.

Jaschek, in collaboration with Miss A. Gómez has studied the proportion of spectroscopic binaries in different parts of the H-R diagram, and confirms Petrie's conclusion of a constant percentage among dwarf stars, but only 30% (in place of Petrie's 50%), among the giants.

Anne B. Underhill (Utrecht), reports (50) observations made at Victoria of ten OB stars in the vicinity of the open cluster NGC 7380 of which six are definitely double-lined binaries, five being new discoveries, and the remainder may also be binaries. De Groot is engaged in a similar study for the neighbourhood of IC 1805 and has published detailed measures of P Cyg (51).

Bertiau and Grobben (Vatican Observatory) have a computer program for reduction of spectroscopic binaries which distinguishes between single and double-lined binaries, and in the latter case treats the data differently according to whether the lines are of comparable strength or not (52). The capacity of the programme is 220 observations. Bertiau also has some radial velocity measures of 26 late B-type stars in the Scorpio region using Pretoria plates.

Kharadze reports that E. A. Vitrichenko, in collaboration with astronomers of the Tartu Observatory (Eelsalu, Kivila and Joëveer), is using the 122 cm reflector of the Crimean Astrophysical Observatory for radial velocity work. A programme on K0 stars is being started and on the velocity curves of the double stars, $\gamma \text{ Cyg}$, HD 175 514, $\delta \text{ Cep C}$, HD 188 439 and HD 193 793.

Abt and Gregory Smith (53) have investigated the accuracy of determination of radial velocities and its dependence on dispersion, spectrum-width and line-width. Accuracy has generally improved over the years, but guiding error remains significant. Broadening the spectra produces little improvement to compensate for the extension of exposure time. Accuracy is almost independent of line-width for rotational velocities above about 100 km s^{-1} . Increasing dispersion is the best way to improve accuracy. Measuring engines of greater precision than the conventional long-screw machine are desirable if full advantage of potential accuracy is to be secured.

In a recent paper Abt and Levy (54) have investigated 68 high velocity dwarfs and find that short period binaries are rare.

Abt reports good progress on his general bibliography of radial velocities, in excess of 30000 references. His catalogue of individual plate radial velocities measured by Mount Wilson astronomers is complete to 12^h R.A. and has been submitted for publication (55).

G. and A. de Vaucouleurs report that the interference filter scanner (56), has been further developed for automatic scanning at pre-programmed wavelengths to record with a 400-channel multiscaler with teletype punched paper tape output. The theory of the system and properties of interference filters used for scanning in convergent light at nonnormal incidence have been studied in detail by W. Tolar (57).

About 600 scans were secured between 1966 and 1969 with the IFS scanner on the 36-inch and 82-inch reflectors at McDonald Observatory; 118 objects (73 galaxies, 12 clusters, 28 stars, 5 planetaries) were observed with the $\lambda 4006$ filter used for the H and K lines; 37 objects (15 galaxies, 5 clusters, 13 stars, 4 planetaries) with the $\lambda 4408$ filter used for G and H γ ; 60 objects (18 galaxies, 7 planetaries and 35 H II regions in M 33 and M 101) with the $\lambda 5055$ filter used for N $_1$, N $_2$. The radial velocities derived by computer fitting of Gauss curves to the line profiles (filter half-width $\sim 15 \text{ \AA}$)

have an indicated mean error of $\sim 0.5 \text{ \AA}$ (emission lines) to $\sim 0.1 \text{ \AA}$ (absorption lines). A detailed rotation study of M33 and M101 from H Π regions is in progress. Red shifts of about 70 galaxies have been obtained and will be prepared for publication in 1970.

Davis Philip, as part of a continuing program of study of horizontal-branch stars (58), has determined radial velocities of 12 of these stars in the general field using Mount Wilson and Kitt Peak plates. A z-velocity dispersion of 113 km s^{-1} is found for seven of them, confirming membership in Population II (59).

Perry has measured radial velocities of 109 early A-dwarf stars in the north galactic cap to determine the galactic force law, K_z . The results support the existence of two groups of A-stars in the z-direction (60). Velocities for 77 A-type stars in a north galactic pole region have also been determined by Slettebak, Wright and Graham (60a).

The following contributions, usually dealing with a single star may be noted: 17 Lep (Cowley) (63); RVUMa (Preston and Spinrad) (64); HD2665, 6755 (Koelbloed) (65); HD118216 (Conti) (66); RUCam (Wallerstein and Crampton) (67); 73 Dra (Preston) (68); FG Sag (Herbig and Boyarchuk) (69); SS Cyg (Walker and Chincarini) (70); HD10783 (Preston and Stepién) (71); CMLac, V477 Cyg, TV Cet (Popper) (72); HD215441 (Preston) (73); 17 Com, κ Cnc (Preston, Stepién and Wolff) (74); HR7484 (Snowden and Koch) (75); 12 Cam (Abt, Dukes and Weaver) (76); 78 Vir (Preston) (77); 21 Per (Preston) (78); HD222317 (Imbert) (79); ER Vul (Northcott and Bakos) (80); HD23631 (Conti) (81); HD107904 (4 CVn), (Crampton and Fernie) (82); 14 stars (Roman) (83); HD211853 (Bracher) (84); HD35921 (Mayer) (85); TXUMa (Swensen and McNamara) (86); HR3817 (M. Jaschek and M. L. Aguilar) (87).

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