29. COMMISSION DES SPECTRES STELLAIRES

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1. INTRODUCTION

Spectroscopy, like photography, is a widely used tool in stellar astronomy. A discussion of stellar spectroscopy, therefore, involves not only considerations of spectral energy distributions and of wavelengths, displacements, identifications, profiles, and total intensities of spectral lines in single, 'normal' stars but also in binaries, shell stars, and variable stars. Consequently, there is going to be a great deal of overlap between subject matter of Commission 29 and of other Commissions, e.g. 27. Indeed, so vast is the area covered by stellar spectroscopy that serious consideration must be given to limiting the mission of Commission 29 to a better-defined area. A step in the right direction was taken in setting up a separate commission on spectra and luminosity classification, an area of greater concern to students of galactic structure than to most spectroscopists. The efforts of Commission 29 will therefore be directed to studies of stellar spectra for their own sake, rather than to routine problems of spectra and luminosity classification which can be handled best by a combination of low dispersion spectroscopy and multi-color photometry.

2. INSTRUMENTATION AND MEASUREMENT OF SPECTRAL LINE INTENSITIES

As high dispersion spectrographs become available, more attention is being paid to measurements and reductions of line profiles and intensities by automatic techniques. At Merate Observatory, Fracassini, Hack, and Pasinetti (1962) developed a digitilized microphotometer. They apply a digitilizer at the screw commanding the movement of the plateholder and another at the pen of the recorder. Every five microns a number giving the position of the pen is punched on a tape which is used with an IBM 1620. Fracassini, Pasinetti, and Faraggiana have prepared programs for constructing calibration curves, for tracing the continuum, and for computing the equivalent widths and line profiles. A somewhat similar technique is being employed in Edinburgh. Many workers with high dispersion spectra, trace the plates with a microphotometer whose output is fed into an X-Y recorder which incorporates the calibration curve so that the final tracing is on an intensity scale. In the procedure employed at University of California, Los Angeles, the observer draws in smoothed profiles and the continuum. Next, the marked tracing is fed through an 'Oscar', a device which enters upon a punch-card for each

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

point chosen in the profile, its χ-co-ordinate (wavelength), line depth, and position of continuum. Then the cards are fed through an IBM 7094 which prints out equivalent widths and profiles if needed.

Other techniques are being developed for the direct measurement of profiles of standard lines directly at the telescopes. Some years ago, Oke and Wilson developed a scanner for use at the coudé focus of the 100-inch telescope at Mount Wilson. More recently, at Mt. Stromlo, Th. Dunham has developed a photo-electric scanning and Fabry-Pérot system to compare photographic and photo-electric measurements of line profiles at the coudé focus of the 74-inch reflector.

At the other extreme of dispersions, G. Worrall of Cambridge Observatory is developing a technique for measuring equivalent widths on unbroadened objective prism spectra. This method uses a one-dimensional 'Iris' diaphragm and promises to give useful equivalent widths down to $11^{m}\cdot5$. Of course, Strömgren's narrow band pass filter techniques are most useful for photo-electric observations of strategic intensity ratios, especially after calibration for true intensities by spectroscopic methods.

Measurements of standard stars are urgently needed in many phases of stellar spectroscopic work. At Mt. Stromlo, Dunham has prepared an atlas of high dispersion spectra from 3200 Å to 9000 Å for the following stars: Canopus, α Centauri *A* and *B*, Sirius, and Procyon (1·3 Å/mm in the region 3200 Å–5000 Å, 1·8 Å/mm in 5000 Å–7000 Å and 2·5 Å/mm for 7000 Å–9000 Å). The spectrum of the integrated disc of the Sun is also photographed with the same dispersions. The measured line intensities are to be used for differential curve of growth analyses.

Of great interest is the reliability of stellar equivalent widths measured by various observers using different equipment. K. O. Wright, E. K. Lee, T. V. Jacobsen, and J. L. Greenstein made a careful comparison of line intensities measured in the spectra of representative B to G-type stars measured in the wavelength region 3900 Å to 4520 Å at Dominion Astrophysical Observatory and at Mount Wilson and Palomar Observatories. Although, for each observatory, the average percentage differences of line intensities from the mean are five per cent or less when several series are compared, Victoria intensities tended to be higher than Mount Wilson values. Their work substantiated the oft-mentioned result that intensities derived from spectra with a dispersion of 30 Å/mm (or lower) are usually systematically too large by about 25% and even larger for weaker lines. Similar studies should be carried out for different spectrographs and observers to identify systematic discordances, which, entering through equivalent width measurements, cause differences in final abundance determinations.

3. EARLY-TYPE STARS (GENERAL SPECTROSCOPIC STUDIES)

a. 10 *Lacertae.* Detailed wavelength and spectrophotometric studies of the spectrum of this star have been carried out by A. B. Underhill and by Jugaku and Aller. Miss Underhill finds that the stronger lines of Si III and Si IV are broadened by macroscopic motions of about 25 km/sec. She also calls attention to the unexpected strength of Mg II 4481 Å, which may be formed in a shell of moderately high excitation temperature—since the star is so very hot we could expect it to be weakened.

b. Pleione. L. Houziaux, (1962) measured equivalent widths of infra-red lines in the spectrum of this star, but found that the great strength of O I 8446 Å does not require an anomalous oxygen abundance in the shell.

c. Other studies. At La Plata, C. and M. Jaschek have continued their survey of O and B stars south of declination $-30°$ and brighter than seventh magnitude. They are studying the O stars HD 151 806, HD 152 248, and HD 152 408 in detail.

At Radcliffe Observatory, P. W. Hill is making a general spectroscopic study of B stars (including the brightest Luyten objects) that fall out of the galactic plane. The Radcliffe

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

observers are also investigating spectral classes of stars that excite emission nebulae. Thackeray is observing members of the Scorpio-Centauris association, including faint common proper-motion companions not heretofore studied.

Spectra and colors of early type stars near the north galactic pole have been studied by Slettebak, Bahner, and Stock (1961). They observed 84 stars to a limiting magnitude of 12 and spectral class F2 and earlier. Most of these stars belong to 'older population I' which appear to have lower axial rotation speeds than do stars of a similar spectral class near the Sun. Ten of their stars showed pronounced population II characteristics; they included hot sub-dwarfs, F and G sub-dwarfs, and horizontal branch stars. Some had large radial velocities, but none showed axial line broadening.

Using the ratio of the intensity of the line 4471 Å of He I to the average intensity of the lines 4541 Å and 4200 Å of He II as a temperature criterion, and the total intensity of Hγ or the quantum number n of the last visible Balmer line as a luminosity criterion, Botto and Hack (1962) have separated super-giants ($M_v = -7$ to -8) from main sequence objects ($-3{\cdot}5 \leqslant M_v \leqslant -5{\cdot}5$) from spectral classes O6 to O9.

The Edinburgh program of equivalent widths in B stars has now been completed (Butler and Thompson, 1961). A spectrophotometric study of a number of sharp level B stars, including 22 Ori, 114 Tauri, HD 36 959, HD 36 960, ξ Can Maj, 15 Can Maj, λ Orionis, is now being prepared for publication (Jugaku and Aller).

At Radcliffe, P. J. Andrews has measured Hα intensities in B stars (Sco-Centaurus association mostly) by the Cambridge photo-electric technique [Andrews and Peat, 1963].

At the Crimean Observatory, Kumaigorodskya (1962) has studied the spectra of emission O-stars, 9 Sge. (1962), ξ Per, and λ Cep and has analyzed the dependence of N III and He II lines upon absolute magnitude. The absorption lines 4497·58 Å and 4487·46 Å attributed by Miss Underhill to B III are not confirmed.

T. M. Bartash (1964) finds that variables of the RW Aur, NU Ori type do not differ in their spectral characteristics from normal B stars.

4. SPECTRA OF GIANTS AND SUPER-GIANTS

At Victoria, Wright is carrying out a detailed study of G and K giant stars, while D. Koelbloed observed δ Draconis (G 9 III w), ϵ Draconis (G 8 III w), ζ Cephei (Ko-III- IV wk CN), ϵ Cygni, η Cephei and ι Cephei (K 1 IIIs) — w and s denoting weak and strong lines respectively. Other stars included in Wright's program are χ Andromedae, 31 Cygni, Arcturus, 37 Com Ber, χ Ursae Maj and φ Urs Maj. Koelbloed observed with a dispersion of 3 Å/mm in the yellow and red (5300–6600 Å) and 2 Å/mm in the region 4000–4800 Å.

Using data obtained at Mount Wilson Observatory, W. K. Bonsack has undertaken a detailed study of the spectra of 3 giant G and K stars from 4000 Å to 9000 Å with dispersions of 1 Å/mm in the blue, 2·8 Å/mm in the green-red, and 10 Å/mm in the infra-red. The aims of the program are to provide a catalog of wavelengths and line intensities for the apparently normal star of the three, Epsilon Virginis; to identify as many of these lines as possible; to study the structure of the atmosphere of the star by means of these data; to use the line intensities and the atmospheric parameters to obtain relative transition probabilities for the many lines for which quality data of this type are lacking; and finally to compare with respect to chemical composition and physical structure the atmospheres of a weak-lined and an exceptionally strong-lined star with the atmosphere of Epsilon Virginis.

At Edinburgh, Butler and Thompson have started a spectro-photometric study of late-type F5 - G8 III - V stars (both giants and dwarfs) in the red. At Radcliffe, D. W. Peat (Andrews and Peat, 1963) has measured Hα intensities in late-type stars.

Miss Underhill (1960) made radial velocity and line profile observations of the super-giant

B stars 67 Oph, 55 Cyg, and χ^2 Orionis. She found irregular motions with a range of 30 km/sec while Hα suggested motions as large as 200 km/sec. Super-giants belonging to the clusters h and χ Persei, I Ceph, II Ceph, I Gem. and I Cam have been studied by L. Divan.

Attention may be drawn to the remarkable number of K super-giants discovered at the Radcliffe Observatory in the rich cluster NGC 6067, as well as the sprinkling of intermediate super-giants which straddle the Hertzsprung gap.

5. SHELL AND EMISSION-LINE STARS

A survey of all B0-B5 stars south of the equator and brighter than 6·5 magnitude was carried out at La Plata with a prism spectrograph that gives a dispersion of about 180Å/mm at Hα. This survey has produced 13 new Be objects which have been reported by Kucewicz (1963) and a preliminary discussion by the Jascheks and Kucewicz (1962 *d*) concerning statistics of Be stars. A more detailed discussion is ready to go to print. HD 133 738 was found by the Jascheks to be a shell star.

Adela Ringuelet-Kaswalder has found that the stellar lines of the V/R variables 27 Canis Majoris (which suggest a B0 spectral type) and 48 Librae (B3) display short-period velocity variations, the periods being 0·262 day and 0·115 day, respectively. It is interesting to note that the spectrum of 48 Lib shows an unidentified absorption line at about 4619Å, the relative intensity of which is only comparable to that of the same line in the He-rich star of spectral type around B3, BD + 10°2179. Mrs Ringuelet-Kaswalder considers that the identification of this line with C II should be revised.

The analysis of Hα and Hβ emissions in shell V/R and rotationally unstable Be stars, brighter than seventh magnitude, by Mrs Ringuelet-Kaswalder, has indicated that the two groups of stars differ in the emission width-rate Hα and Hβ, in the relation between the rotational velocity and the emission width at Hα, and, very probably, in the Balmer decrement. These results will be checked on a larger sample of objects.

Mrs Ringuelet-Kaswalder has found that the spectrum of 48 Librae displays a Si II absorption component at 4128Å and 4130Å, that apparently shares the behavior of the so-called 'stationary' components at Ca II and Na I reported previously by other workers, thus raising doubts as to the circumstellar origin of the 'stationary' lines as it had been suggested.

At Haute-Provence Observatory, C. Bertaud (1961) has observed the P-Cygni-type star 377·1943 Sagittae in which the Balmer lines can be followed to H_{20}. At the Uccle Observatory the spectrophotometric gradients of γ Cas and of AC And have been measured by E. Vanderkerkhove.

At Michigan, McLaughlin (1962, 1963) has studied a number of typical V/R variables, in which the maximum of V/R nearly coincides in time with the maximum positive radial velocity of the absorption and of the emission structures the way he measures them. Opinion as to the meaning of the displacements is divided (see McLaughlin, (1961); Underhill, (1961.*b*)). The star Zeta Tauri has shown a most remarkable behavior which has been studied by a number of investigators. In 1958 the shell was expanding at a velocity of −50 km/sec and in 1959 at −80 km/sec. Studies at Merate Observatory (Hack, 1963, Hack and Gökgöz, 1962, 63) showed that the Balmer lines had a velocity of about 20 km/sec less than those given by the metallic lines; if they are formed in higher layers than the metallic lines, expansion velocities slow down in the higher layers. (See also Pringle and McNamara 1962). They derived a mass for the shell of 2×10^{-8} solar masses in 1958–59 and 2×10^{-9} solar masses in 1960.

In 1961–62 the shell of Zeta Tauri contracted at a velocity of +85 km/sec (Fe II, Ca II) and +75 km/sec (H I). In the winter 1962–63 the contraction slowed down (+60 km/sec for H I, Fe II, Ca II) and in the winter 1963–64 it became equal to +35 km/sec (Hack, Aydin, Islik, 1964).

At the Crimean Observatory, Boyarchuk and Pronik (1963–64) found the turbulent velocity in the shell to vary with time (5 – 50 km/sec) and that the wings of Hα in the spectra of Be stars (shell and pole-on) are determined by radiation damping [as indeed one could expect].

A comprehensive list of lines in the spectrum of Zeta Tauri from 3650 Å to 8800 Å has been given by L. Houziaux (1963).

At Paris-Meudon Observatory and Haute-Provence Observatory, Mme Herman and her associates (1961, 1962, 1963), have studied Zeta Tauri very intensively. They have found radial velocity variations amounting to as much as 100 km/sec. The line profiles show variations that follow the velocity variations. At certain times the envelope is quasi-stationary. At other times it exhibits movements indicating involvement of deep layers. Probably the envelope variations are due to pulsations of the star itself.

The Be stars are being studied by Mme Herman and her associates in a number of intensive programs: viz (1) a systematic study of all Be stars brighter than 7th magnitude and north of $-20°$ to get statistics on the intensity of emission; (2) low dispersion (100 Å/mm) studies of certain selected stars; (3) high dispersion (10 Å/mm) studies of particularly interesting stars; (4) *UBV* photometry by M. Rojas in Mexico; (5) use of the image-converter to follow development of certain selected lines, e.g., Hβ; (6) theoretical studies. The following results are reported: (*a*) M. Lacoarret (1962) investigated periodicities by study of the equivalent widths of Balmer lines in absorption on the one hand and by the V/R ratio on the other. She finds periods ranging from three years for HD 174 237, which shows line profile variations similar to those in ζ Tauri but more rapid, to 17 years for HD 175 869. The Hα line profile in HD 174 237 shows important variations. HD 4180 (o Cas) showed no emission from 1953 to about 1962 when the Hα line profile showed pronounced fluctuations. It evidently has a period of about 20 years. (*b*) V. Doazan (1962) selected a number of stars presenting an envelope sufficiently extended to show the α Cygni lines in absorption. Three of them showing the most rapid variations: HD 45 910 (which seems to be double), HD 50 138, and HD 218 393 were studied by high dispersion. These studies showed the existence of (*a*) secondary red or violet absorptions presenting differences of radial velocity that may attain 100 km/sec or more. The velocity of the variations often changed rapidly indicating momentary instabilities of the envelope; (*b*) a stratification of the envelope indicated by differences in radial velocity of lines of Ca II, Fe II, and Ti II; (*c*) an important variation of the Balmer series which can be positive or negative, indicating accelerations or de-celerations in the envelope; (*d*) variations of intensity of metallic lines.

K. Özemre made a spectrophotometric study of HD 217 050.

Using spectra of high dispersion of HD 23 552, 45 910, 50 138, 37 202, 174 237, 217 050, J. M. Le Contel (1963) found the method of Huang and Struve to be most rapid for the determination of $v \sin i$. He has also worked on the image tube.

Doazan and Duval have worked out computer programs to apply the theory of Sobolev to a study of these stars.

At Merate, M. Hack has derived a mass of 10^{-9} solar masses for the shell surrounding W Serpentis; Pasinetti is studying the shell star Omicron Andromedae.

6. STELLAR ROTATION AND ATMOSPHERIC TURBULENCE

At Edinburgh, B. N. G. Guthrie (1963) has investigated the effect of stellar rotation on Balmer line intensities. He investigated the tendency for B stars with high rotational velocities to have weaker Balmer lines for the same $(U\text{-}B)_0$ and confirmed Abt's explanation of the effect in terms of a reduction in effective surface gravity due to rotation. He also showed how Crawford's method for determining ages of stars from Balmer line intensities and *UBV* photometry can be corrected for effects of rotation; in particular it is better to use the wavelength λ of the Balmer discontinuity rather than Balmer line intensities. Guthrie suggested methods of getting $v \sin i$ and the inclinations of axes of rotation of cluster members from Balmer line intensities and *UBV* photometry. The 'cosmic dispersion' in the relation between Balmer line intensities and absolute magnitude is largely caused by rotation. Methods of estimating stellar rotational velocities from very low dispersion material is also being studied at Edinburgh.

A summarizing report on turbulence in stellar atmospheres has been given by Underhill (1961). At Crimean Observatory, M. E. Boyarchuk (1962, 1963, 1964) has studied turbulent velocities in stellar atmospheres. He finds that in the atmospheres of super-giants, turbulent velocities increase as optical depth decreases while in the atmospheres of dwarfs, the turbulent velocities do not change. Furthermore, the excitation temperature increases with optical depth at a greater rate in super-giants than in dwarfs. In a study of 25 super-giants (O9·5 – F2 spectral classes) A. A. Boyarchuk, I. M. Kopylov, etc., found that turbulent velocities increase with height. They also studied how turbulent velocity depended on spectral class.

At University of W. Ontario, W. Wehlau compared the spectrum of Chi Serpentis with the standard star, gamma Geminorum. By curve of growth methods, he finds that Chi Serpentis shows an increase in turbulent velocity with excitation potential. The line profiles show a broadening that is consistent with a period of rotation of 1·6 days which is the period of spectrum and light variability.

Numerous writers have commented on how difficult it is to separate turbulence broadening from rotational broadening. At the present time this problem remains difficult particularly when relatively small rotational velocities are involved as in super-giant stars.

7. SPECTROSCOPIC STUDIES OF BINARY STARS

a. Visual Binaries

For earlier spectral classes (O → F8), we may refer to an important study by J. Berger (1962). Slettebak (1963) has estimated spectral types, luminosity classes and axial rotational velocities for the components of 116 physical visual binary systems. He found no significant differences between the mean rotational velocities for double star components and single stars, neither for giant nor for main sequence stars. Furthermore, systems with normal components appear to fit the conventional color luminosity diagram.

Detailed studies have been made of components of particular binaries. High dispersion coudé spectra of Procyon have been secured both at Lick and at Mt. Stromlo. Mugglestone and Hyland are using the Mt. Stromlo data in connection with a model atmosphere to make an analysis of the star. Wallerstein proposes to use the Lick data to establish Procyon as a standard star for abundance analyses. At the Crimean Observatory, A. A. Boyarchuk (1963) investigated the atmosphere of Sirius by model atmosphere methods—using spectrograms with a dispersion of 0·7Å obtained at the solar tower telescope. He concluded that Sirius had seven times as much metals and twice as much helium as the Sun; its effective temperature was established as 9900° ± 400° K. We have already mentioned Dunham's study of the components of Alpha Centauri.

b. Spectroscopic Binaries

J. Sahade (1964) (La Plata) has undertaken the study of the spectroscopic binary HD 698 on the basis of plates generously taken by J. L. Greenstein at Mt. Wilson and Palomer Observatories. These do not show any double lines and strengthen the doubts raised by Struve and Rudkjöbing in 1948. The masses that are assigned to the components of HD 698, should be, therefore, discarded. The investigation will be extended with plates also generously taken by Dr J. Jugaku and with other material.

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

A period and orbital elements have been derived for Zeta Horologii by Sahade and Hernandez (1964). They have also made a study of γ_1 Velorum, the velocity curve of which resembles those of systems with gaseous streams.

In a discussion of the problem of the evolution of close binaries, Sahade (1962) considered the problem of the maximum stellar masses, reaching the conclusion that the observational evidence does not suggest the existence of masses larger than about $65M_\odot$, the limit for stable stars according to Schwarzschild and Härm.

An interpretation for the peculiar behavior of the velocities of the secondary components of HD 47 129, AO Cassiopeiae, V 448 Cygni and β Scorpii was suggested by Sahade; such interpretation implied values for the masses of the components and a description of HD 47 129 as a system formed by a O8 V primary and a later type, larger, secondary which is underluminous for its mass. The latter star must be in a more advanced stage of evolution than the primary. In the same paper Sahade discussed several other early type systems, including β Lyrae.

The groups of the so-called R Canis Majoris systems was discussed also by Sahade in regard to their masses. He concluded that these stars do not necessarily have characteristics such as to justify setting up a separate group for them. He also concluded that mass-ratios should not be derived by imposing conditions that are related to the relative sizes of the star and the corresponding lobe of the first critical equipotential surface.

c. Eclipsing Binaries

Beta Lyrae remains one of the most puzzling objects in the sky. Huang (1962) has reinterpreted the spectroscopic and photometric peculiarities of this system on the assumption that, contrary to previously held beliefs, its primary is less massive than its secondary. This assumption follows from the determinations of the absolute magnitude of the system by Abt *et al.* (1962). Huang proposes that β Lyrae is similar to Algol-type binaries. The B8 primary, like the secondary in the Algol-type variables, has completely filled its equi-potential lobe, while the more massive secondary, like the primary in the Algol-type variables, is comparatively smaller in size and is surrounded by a rotating disk, which is presumed to be dense and opaque. This model explains a number of the obscure characteristics of the system; e.g., why the radial velocities of the emission lines are in phase with the secondary and why their 'γ' velocity is shifted about 100 km/sec upward from the γ velocity of the primary's absorption lines.

A quantitative analysis of Beta Lyrae has been undertaken by M. Hack. She finds that the deficiency of hydrogen in this system is not as marked as in Upsilon Sagittarii, which Boyarchuk (1959) and also Struve (1961) regarded as a somewhat similar system.

The massive binary system, VV Cephei, which consists of an M super-giant and B companion, has been investigated very carefully by B. Peery. The system is also being studied by Wright at Victoria, who has been unable to detect any lines of the B-type star other than hydrogen emission features.

The Zeta Aurigae program is described elsewhere in this volume. An intensive series of spectroscopic observations was planned by Odgers and his associates at the Dominion Astrophysical Observatory.

The typical Algol system of δ Librae is being investigated by J. Sahade and C. Hernandez. The system of V 453 Scorpii, studied by Sahade and H. Frieboes-Conde involves a secondary component which displays only emission lines but may be the more massive star of the system.

AX Monocerotis has been studied intensively by A. Cowley (see report Commission 27). ζ Phoenicis is being studied by the Jascheks in Argentina.

A spectroscopic orbit for BD + 20°785 was derived by Wellman.

d. Epsilon Aurigae

On the basis of spectrograms secured during the 1955–57 eclipse, Hack (1962) has proposed a new interpretation of ϵ Aurigae. She suggests that the invisible companion is a hot star which excites a surrounding gaseous shell. This shell, which has a high electron density, about 10^{11} electrons/cm^3, is the body responsible for the eclipse of the principal star.

On the basis of plates secured by K. O. Wright at Victoria, S. C. Morris has derived the dilution factor (0·1), density ($N_e = 8 \times 10^{10}$), and excitation temperature (4000–4700° K) for the shell. He suggests that the super-giant F star ($M = -7{\cdot}3$) and the secondary ($M = -3$), both originated on the main sequence as O stars, and the fainter star has not yet moved far from the main sequence. In Morris's model part of the mass ejected by the F star remains around it, while part passes through the inner Lagrangian point and forms a disk around the less massive star. The central star totally ionizes the inner region of the disk, the intermediate region becomes sufficiently hot to be opaque near the central plane. The outermost zone remains transparent and produces the shell spectrum observed during eclipse.

At the Crimean Observatory, Kopylov and Kumaigorodskaya (1963) determined temperatures and electron pressures in the F component's atmosphere. The spectrum and properties of the atmosphere vary both during the eclipse and outside it.

e. 31 *Cygni*

Studies by Hack (1962) and by R. Faraggiana and M. Hack (1963) suggest that the B star has a strong Balmer discontinuity and a spectral class of B 5 V. K. O. Wright and G. J. Odgers (1962) studied the K line during the 1962 eclipse, and found it to be stronger than during corresponding ingress phases in 1951 with satellites appearing as early as five months before totality. Relatively large masses of material move with velocities as high as 50 km/sec between us and the B star. The mass ratio of the system is about 1·5, but the orbit is being revised (Wright, 1962). Chromospheric intensities of the K line have also been measured by Groth and Wellmann.

f. 32 *Cygni.*

This star has been studied by M. Hack at Merate Observatory and by Wright at Victoria.

M. Hack has discussed the possible evolutionary paths of stars in close binary systems.

8. WOLF-RAYET STARS

Studies of both the carbon and nitrogen sequences have been carried out by Miss Underhill (1962) who finds that HD 192 641, (WC 7) is a binary (WC 7 + Be), HD 193 793 (WC 6 + O6) is surrounded by a shell expanding at a velocity of 2700 km/sec. She gives a list of lines in HD 184 738, WC 8 and points out that N III 4634Å appears as a moderately strong line. Also excitation temperatures in WC atmospheres are lower than in WN atmospheres.

At Haute-Provence, Mme Y. Andrillat (1962) has studied a number of Wolf-Rayet stars including Campbell's hydrogen envelope star, a WC 8 star discovered by Blanco, and has undertaken a search for possible helium discontinuities in the continuous spectrum.

Measurements of radial velocity and emission line intensity measurements have been completed by M. K. Vainu Bappu for the Wolf-Rayet binaries HD 214 419, HD 193 576, HD 186 943, HD 211 853 and HD 193 928.

By means of his theory, S. V. Rublev (1961) has attempted quantitative interpretations of some emission lines in WR spectra and has derived conclusions concerning the motion of material in the envelopes from the line profiles (Rublev, 1962).

γ_2 *Velorum.* At Kodaikanal, Vainu Bappu has undertaken a study of the changes in emission line profiles and intensities. Aller and Faulkner (1963) obtained a color temperature of this star near 31 000° K and measured intensities of the stronger lines with a spectrum scanner.

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

9. SPECTROSCOPIC STUDIES OF VARIABLE STARS

The following notes are intended as a supplement to the report prepared by George Herbig for Commission 27, which the reader is referred to.

a. Cepheids and RR Lyrae Stars

Important studies on abundances and atmospheric parameters in Southern Cepheids and comparison stars have been undertaken by Rodgers and Bell at Mt. Stromlo. At Radcliffe, B. Warner undertook a study of the spectrum of *l* Carinae.

At Cordoba, L. Milone studied β Crucis and found indications of a fluctuation of 1000° during a pulsation. Either the phenomenon is not strictly periodic or more than two waves are involved.

J. Sahade and H. Friesboes-Conde find evidence that γ Ursae Minoris is at the boundary of an unstability region in the HR diagram. Thus, it may be a transition object.

Spectrophotometric studies of Cepheids have been carried out by M. Schneider in France who compared several of these variables with super-giants whose spectra resemble those of Cepheids. L. Divan and M. Schneider investigated stars physically associated with Cepheids.

At Abastumani, I. F. Alania (1962) has investigated the continuous spectra of short-period Cepheids in relation to phase of variability. The stars included in these Abastumani studies are RZ Cep, SW And, X Ari, DH Peg, TV Boo, RR Leo, ST and W Com, S CVn, and AC Her.

The 3.7 day Cepheid RT Aurigae has been analyzed by Bappu who finds a change in excitation temperature from 5400° to 4580° over the cycle.

The continuous spectra of RR Lyrae stars has been studied throughout the primary cycle (and also a secondary cycle) by A. M. Fringant (1961). At Mount Wilson and Palomar, J. B. Oke has carried out very extensive spectroscopic and photo-electric spectrophotometric observations of RR Lyrae stars. New observations for the prototype have been obtained and he has also completed observations for X Arietis, a very metal-deficient star, and SW And, a metal-rich star. The scanner observations yield effective temperatures and gravities, a check on the temperature being provided by the Hγ profiles which also permits one to estimate interstellar reddening by comparing the two sets of data. Detailed analyses will provide mean ratio and absolute magnitudes for these stars. The metal/hydrogen ratios in RR Lyrae stars has been investigated by G. Preston (see Commission 27 report).

b. Me-type and Long Period Variables

At Radcliffe Observatory, Feast finds that Me variables cover the whole range of population types. He also found an anomalously small motion and velocity dispersion for the group with periods less than 150 days which suggests that these stars pulsate in the first overtone (cf Bailey '*C*' types among RR Lyrae variables).

Theoretical studies of long period variable stars with implications of interest to spectroscopists have been carried out by F. Kamijo (1962, 63).

At Mount Wilson and Palomar, Keenan studied interstellar lines in Mira variables to get information on the behavior of interstellar sodium, since the absolute magnitudes of these stars at different phases are well-known.

Working at Toruń Observatory with coudé spectra from Haute-Provence Observatory, S. Grudsineka is studying emission lines in the visible and infra-red spectrum of o Ceti.

ι_2 Puppis is being studied by J. Landi Dessy and Adele Abraham.

c. T Tauri Stars (see Commission 27 report).

At Abastumani Observatory, E. K. Kharadze and R. A. Bartaya (1963) have carried out a

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

spectrophotometric investigation of RW Aurigae as part of a co-operative investigation by a number of Soviet astronomical observatories.

d. Novae

The Haute-Provence Symposium on novae and related stars in 1963 gave many astronomers an opportunity to review progress in this field. The reader is referred to symposium volume for details; we summarize here some of the results presented there as well as other data.

Nova Aquilae 1918. Working with the Shain reflector at the Crimean Observatory, Baztash *et al* (1963) find the energy distribution in the continuous spectrum to correspond closely to that of a black body at 30 000° K.

Nova Cygni 1948. M. Bloch finds that the Balmer decrement agrees with Menzel and Baker's case '*B*'; the color temperature is 6800° K.

Nova Lacertae 1950. V. G. Gorbatsky (1961, 1962) has considered the secondary maximum of this star and also has derived the abundances of oxygen and nitrogen relative to hydrogen. He finds no substantial differences in the relative abundances of these elements between this nova and other objects.

RS Ophiuchi. Using data obtained at Haute-Provence Observatory during the 1958 outburst J. Dufay and M. Bloch found a large space reddening and a color temperature of 6800°K. J. Dufay, M. Bloch, C. H. Bertaud, and M. Dufay found coronal lines [Fe x] 6374Å, [Fe xi] 3987Å and 7892Å, [Fe xiv] 5303Å, [Ni xii] 4231Å, [A x] 5535Å, [Ne xv] 6701Å and [A xi] 6919Å, [Ca xiii] and probably [Sc vi]. At a certain phase, previously sharp [O iii] lines became broad and diffuse as though the region where they originated were suddenly 'blasted'. The outbursts of 1933 and 1958 were completely parallel, including low color temperatures, Balmer decrements, line profiles, etc., even permitted and forbidden lines appeared at the same dates after the outbursts.

Nova Herculis 1960 *and Nova Herculis* 1963 have been followed by many observers including Asaad at Helwan, D. Chalonge, M. Bloch, M. Fringant, and also Y. Andrillat at Haute-Provence, and McLaughlin and Maran at Michigan.

Nova Her 1963 was a 'classical' slow nova with broad undisplaced emission lines with absorption lines on their violet edges. The excitation increased in the usual way with time. Chalonge, Bloch and Fringant measured the continuous spectrum and found that between the maximum and the first of April it appeared possible to observe the continuum of the star itself. Their results suggested a contraction of the star accompanied by an increase in its surface brightness, but a decrease occurred in the total brightness. After the first of April, the totally ionized envelope became more luminous than the central star. Y. Andrillat described significant spectral changes in mid May, 1963, notably the development of spectra of He ii and forbidden lines of [Fe vii], [Fe x], [A xi], and [Ni xv], while the spectra of W i and O i weakened. The radial velocity varied from −1620 to −1830 km/sec between March 6 and April 7. In comparing the spectra of Nova Her 1960 and Nova Her 1963, Mme Andrillat noted the tardier appearance of He i, He ii, C iv, [Fe vii], and [Fe x] in Nova Her 1963. On the other hand, no absorption appeared in Nova Her 1960, and [Fe xi] developed very rapidly; it was totally absent in Nova Her 1963. She has also compared the spectra of these novae with those of Wolf-Rayet stars.

Orlov (1964) has described the spectrum of Nova Her 1963 as observed in February 1963 from a station near Kiev. He measured the expansion velocities of the envelope and also did photometry on the hydrogen lines. Maran followed the development of this object with a spectrum scanner.

A. Underhill (1964) suggests that the chief features of nova spectra can be explained by a sudden expulsion of a dense shell containing particles moving with different velocities. Also a wave of increasing excitation energy moves outward through the gas. It is not necessary to postulate a continuous ejection from the underlying star.

e. Combination Variables

Z Andromedae. Mlle M. Bloch has given a description of detailed changes from 1959 to 1962. In late 1959, the Ti O spectrum virtually disappeared, [Fe VII] was feeble and [Ca VII] had disappeared. The Balmer discontinuity was strong in emission. In 1961, the Hydrogen lines showed a P-Cygni structure, the emission lines were weaker, and numerous metallic absorption lines appeared, and the Balmer emission had weakened. By October 1962, the spectrum again resembled that of 1959.

A. A. Boyarchuk (1964) using spectrograms obtained at Lick found an electron temperature of 24 000°K for the shell, and a Zanstra temperature of 24 000°K for the hot source.

From a study of continuous energy distributions (3000 Å–5000 Å) in Z Andromedae, BF Cygni, and AG Draconis, Belyakina *et al.* (1963), at the Crimean Observatory, concluded that the ultra-violet spectra of these stars is due primarily to recombination of hydrogen at a temperature of 40 000°K, while the long-wave spectral region is dominated largely by the cool star (T_{eff} = 3000°K). Photometry of the continuous spectra of AG Drac, AG Peg, and Z And has also been carried out at Abastumani Observatory by Dolidze and Pugach (1962). RS Oph and XX Oph have been observed by Dolidze and Alania (1962).

At Haute-Provence Observatory, M. Bloch has observed Z And, BF Cygni, CI Cygni, TY Canum Venaticorum, FR Scuti, RY Scuti, AG Pegasi, AX Persei, and MWC 603.

At Lick Observatory, L. H. Aller has observed BF Cygni, RW Hydrae, and XX Ophiuchi.

An observational program of southern combination variables is being pursued by the Jascheks who also find that the VV Cephii type binary, HR 2902 = Boss 1985 did not display Fe II emission while [Fe II] remained visible (Jaschek, 1963*d*).

At Abastumani Observatory, R. A. Bartaya (1962) found an ultra-violet excess in the spectrum of FU Orionis.

Eta Carinae. The possibility that this exotic variable was a very massive star undergoing rapid evolution was suggested by G. Burbidge (1962). At Radcliffe Observatory, the infra-red spectrum has been studied in detail. Thackeray finds that the visually estimated intensities of [Fe II] agree well with Garstang's calculations. O. Melnikov arrived at a somewhat similar conclusion.

Observations secured at Mt. Stromlo with a spectrum scanner have been combined with coudé spectra to obtain a definitive set of relative intensities for the principal lines in the emission spectrum of this star (Dunham, Aller and Faulkner). The high resolution of the coudé permits separation of nearby lines, but the principal source of difficulty in obtaining accurate intensities is the uncertainty in the position of the underlying continuum.

Spectra of RR Telescopii have been obtained at Radcliffe by Thackeray and Feast and by J. Landi Dessy at Córdoba. [Fe VII] and [Fe VI] continue strong, but in recent years [Fe II] emissions appear to have gained in strength relative to the intermediate levels of ionization (II, IV and V). Observations by Aller and Faulkner at Mt. Stromlo with a spectrum scanner in 1961 are being analyzed to obtain the relative intensities of the principal lines. Further spectrophotometric observations of these stars are much to be desired.

f. Supernovae

Spectrophotometric observations of the supernova 1960 in NGC 4496 have been made by Dolidze and Pugach (1962) at Abastumani and by M. Bloch and D. Chalonge. It showed a similarity to the supernova 1937 in IC 4192.

One of the principal activities of stellar spectroscopists has been the study of chemical compositions of atmospheres of different kinds of stars.

We shall discuss the problem of abundance determinations in separate sections depending on the type of stars involved.

10. COLD STARS

a. Carbon Stars

We mention first Wyller's (1960) comprehensive report on the carbon stars based on observations obtained at Mount Wilson and Palomar Observatories. He compared the C-classification scheme which depends largely on the strength of the sodium D-lines and the older (R, N) classification. Since the (7,2) red CN band has a rotational structure which extends completely through the D-line region, the usefulness of the D-line as a classification criterion is largely impaired.

Wyller also constructed pyrometer curves of the theoretical intensity ratios of (2,0), (3,1) red CN band pair as a function of vibrational temperature. He found very little spread in vibrational temperatures from early to late carbon stars; possibly the bands are formed in strata outside the main atmospheric regions responsible for the atomic lines. The fact that CN temperatures are consistently higher than C_2 temperatures also suggests a stratification effect, although influences of uncertain *f*–values cannot be excluded.

He also considered anew the C^{13} abundance problem and decided that a rotational line profile analysis should be carried out on selected regions of the (3, 0) C_2 Phillips band at 7714Å and the (2, 0) red CN band at 7850Å.

Using high dispersion spectra from Haute-Provence, R. Bouigue has investigated the C^{12}/C^{13} ratio and the rotation temperatures of a number of carbon stars. Infra-red spectral features of some carbon stars have been investigated by Fujita (1963) and by Fujita and Utsumi (1963) using high dispersion [8 Å/mm] spectrograms obtained with the coudé spectrograph of the new 74-inch telescope at the Okayama Astrophysical Observatory.

Y Canum Venaticorum. Using high dispersion (4Å/mm–7Å/mm) plates obtained at Dominion Astrophysical Observatory, Fujita (1962) and Fujita and Yamashita (1963) have identified spectral lines in the visual region of this star and estimated their intensities. They have also measured equivalent widths of the D lines and the lithium line.

Measurements of wavelengths, eye intensity estimates, and identifications for about 2300 lines from 6678Å to 8906Å on spectrograms with a dispersion of 8Å/mm have been carried out by Utsumi. Most of the lines in this spectral region are due to CN. Utsumi derived a rotation temperature of 2700 °K from carbon bands and a C^{12}/C^{13} ratio of about 7.

A study of spectral features of Y Can Ven and also 19 Piscium by Wyller for the region 9600Å–10 800Å on plates obtained at Mount Wilson shows numerous lines of unknown origin which may be related to the fact that elements from the 5th and 6th period are very abundant in atmospheres of carbon stars.

R Coronae Borealis. Wavelengths of 1200 lines between 3700Å and 8600Å in the spectrum of R Cr B have been measured by Greenstein and Keenan (1963) who found 243 lines of neutral carbon. They confirmed a great abundance of helium in this star and a considerable excess of lithium.

RY Sgr appears to be a carbon star which is hydrogen deficient. See the discussion under hydrogen deficient stars.

b. Comparison of M, S, and C Stars

Sixty spectrograms of twenty-five M, S, and C stars obtained at Dominion Astrophysical Observatory have been analyzed by Y. Fujita, Y. Yamashita, F. Kamijo, T. Tsuji, and K.

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

Utsumi. They identified atomic and molecular bands, measured equivalent widths of seclected atomic lines and molecular bands. They investigated the relation of the C_2 swan band and the Si C_2 Merrill-Sanford band intensities with the C classification and of Ti O, Sc O, VO and YO band intensities with the M and S classification and tried to correlate C sub-type and M sub-types with respect to excitation temperature.

These studies are part of a program carried out by the 'late-type star' group at the University of Tokyo astronomical department in which a systematic study of spectral line identifications, branching of spectral types and relative intensities of atomic and molecular lines among M, S, and C types, is undertaken. Yamashita and Kamijo have carried out theoretical studies of cool type stellar atmospheres.

c. Rotational Temperature Determinations of Cool Stars

Using a suggestion by Herzberg that the separation of the intensity maxima of R and P branches be used as a measure of rotational temperature, Wyller (1961) found a mean rotational temperature of 3362°K in satisfactory agreement with the effective temperature 3140°K derived by Pettit and Nicholson.

Theoretical aspects (models) for cool stars are very complex and hence quantitative supporting observational studies required good data with highest dispersions practicable.

d. M and S Stars

At Toulouse Observatory, A. Pédoussaut has undertaken a systematic study of relative abundances of metals and Ti O molecules as a function of temperature in atmospheres of M-type stars.

Using infra-red region spectrograms of the M2 giant Beta Pegasi obtained at Okayama Observatory, Yamashita and Utsumi (1962) constructed a curve of growth. They found an excitation temperature of 3010°K and a Doppler velocity $\xi = 3{\cdot}5$ km/sec, and concluded that the negative hydrogen ion was the principal contributor to the opacity both in the normal and infra-red spectral regions.

As the source of continuous extinction in M-type stellar atmospheres, Y. Yamashita (1962) considered bound-free and free-free absorption by the negative hydrogen ion, Rayleigh scattering by hydrogen atoms and molecules, absorption lines of metallic atoms, electronic bands of Ti O, rotational lines of CO and OH, vibration-rotation and rotation absorption coefficient as a function of λ, T, and P_g and calculated the opacity as a function of T and P_g.

At Radcliffe Observatory, D. W. Peat has measured the intensities of Hα in late type stars by the Cambridge photo-electric technique.

At Haute-Provence Observatory, M. Bretz obtained photometrically calibrated plates of MS stars (Keenan's notation) in the red and infra-red spectral regions to make a comparative study of M, MS, and S stars with regard to gradual changes in atmospheric parameters and abundance ratios.

Spectrophotometric studies of the S-type stars, HD 216 672 and HD 22 649 in the infra-red region have been carried out by T. Tsuji (1962) who used curve of growth methods, and considered the dissociative equilibrium of compounds to get the O/C ratio and the chemical composition. He found the Zr/Ti ratio to be three times larger in HD 216 672 and six times larger in HD 22 649 in comparison with the Sun. As one proceeds from M or MS stars towards stars of stengthened S-characteristics, you find not only a steady increase of the Zr abundance but also a continuous decrease of the O/C ratio—as had been suggested by Fujita on theoretical grounds.

Equivalent width measurements (5880Å–6867Å) in late type stars have been published by Warner and Garstand (1963).

II. ABUNDANCE DETERMINATIONS

a. Barium Stars

Closely related to the cool, heavy metal stars are the Ba II stars (proto-type Zeta Capricorni). A search of stars of this type carried out by the Cowleys with the Michigan Schmidt in Cygnus where large numbers of earlier stars were found turned up only small numbers (Cowley and Cowley (1962)). At Radcliffe, B. Warner (1962) observed a number of southern barium stars for abundance determinations.

At Mt. Stromlo, J. Danziger's study of the abundances in the barium stars HD 116 713 and y Velorum substantiate previous work on these objects, but gadolinium and tungsten remain problems in S-process formation. Abundances from molecules show carbon and nitrogen to be overabundant by a factor of five in both stars. Technetium has not been found in Ba II stars.

b. The Holmium Star, HD 101 065

Probably a record of fantastic chemical compositions is set by HD 101 065, which A. Przybylski at Mt. Stromlo found to be iron deficient. Some of the strongest lines in the spectrum are due to Holmium.

c. Hydrogen Deficient Stars

High dispersion spectrograms of the peculiar star HD 30 353 obtained at Okayama Observatory have been studied by K. Nariai using the curve of growth method. From *B-V* and *U-B* colors corrected for line blanketing, and for space absorption, he concludes that this object is a normal giant [M $= -1{\cdot}6$]. Helium is the most abundant element in the star; the abundance of hydrogen is 10^{-5} in number and the metal content is 0·03 of the normal cosmical abundance. Nariai finds the relative abundances among the metals to be about the same as in Deneb.

Spectral scans of the hydrogen deficient star HD 96 446 were secured by Aller and Faulkner in 1960, 1961 and by Faulkner in 1962 and observed with the Mt. Stromlo coudé by Dunham and Aller. Photometry of the stronger lines (Dunham, Aller, and Cowley, 1963) suggests $T = 18\,000°$ K, and a H/He ratio by numbers of 0·38. This star is not an extreme example of this class. Numerous narrow absorption lines in the spectrum are being identified.

Abundance analyses of the helium stars HD 168 476 and HD 124 448 based on Radcliffe spectra have been carried out by P. W. Hill. The energy distributions in the spectra of these stars have been measured by Faulkner and Aller at Mt. Stromlo.

At Mt. Stromlo, J. Danziger has found RY Sag is probably a helium star since hydrogen is negligible. This star shows an excess of carbon by a factor 25/1 and a sodium excess of 5/1.

Upsilon Sagitarii. Abundance analyses of this helium star have been undertaken by Sargent and by Hack and Pasinetti (1963). Line identification in the visual region of the spectrum by Sargent and Mrs. D. Locanthi indicate the presence of As II, Ge II, Se II, Kr I and F I. Hack and Pasinetti proposed that the atmosphere of this star could be represented by a model in which lines of the ionized metals are formed in an upper layer with an excitation temperature of 6500°K and an electron pressure of 0·8 dyne/cm², and a deeper layer with ionization temperature 12 000°K, $P_e = 60$ dynes/cm² where lines of H I, He I, C II, N II, Ne I, Mg II, and S II are formed. These deeper layers are visible because the deficiency of hydrogen makes the atmospheres transparent. If one assumes the abundance of iron to be normal, H is deficient by a factor of 200, C, N, Ne, Mg, Si, S are overabundant by factors of 4, 60, 5, 25, 5 and 25 respectively. Metals and He are normal or slightly overabundant (Cr by a factor of 4 and Ni of 3) with the exception of Al and Mn which are deficient by factors of 25. Ca and Ba are deficient by factors of 10.

Analyses of stars such as υ Sag are difficult because model atmospheres cannot be constructed and the range in temperature and pressure is such that conventional curve of growth procedures are not likely to be valid either.

The hydrogen-deficient star HD 160 641 is being investigated by Jugaku and Aller with new observational material obtained at Mount Wilson and at Lick Observatories.

d. Abundances in O and B0 – B5 Stars

References to recent work are given in the bibliography.

At the Crimean Observatory, A. A. Boyarchuk, I. M. Kopylov *et al.* 1963, have studied physical conditions in 25 super-giants ranging from O9·5 to F_2 by the curve-of-growth method. They found no obvious anomalies in chemical abundances (except for the A0Ib star, Eta Leonis) and concluded that a single value of the temperature cannot be used in the analysis of a stellar atmosphere. Further, the turbulent velocity appears to increase with height in the atmosphere. In this context we may refer to theoretical calculations by A. K. Kolesov (1962) who computed the continuous spectra of pure hydrogen stars and surface temperatures between 10 000°–20 000°K.

A systematic study of stars of spectral classes O and B is being prepared for publication by Jugaku and Aller. The stars included λ Orionis (O7 I), 10 Lacertae, φ Orionis, HD 36 959, HD 36 960, ξ Canis Majoris, 15 Canis Majoris, 22 Orionis, and 114 Tauri. The abundances appear to be similar to those found for γ Pegasi, τ Scorpii, etc.

The composition of the peculiar sharp-lined B5 star, 3 Centauri A has been studied by Sargent and Jugaku (1961); Jugaku, Sargent and Greenstein (1961) and by Jugaku and Sargent (1963). The star has a He^3/He^4 ratio of about 5:1, P is overabundant by a factor of 100, Ga by 8000 and Kr by 1300. He and O are underabundant by factors of about 6 and Cr by a factor of more than about 40. The spectral range studied ranges from 3100Å to 8600Å. Spectral scans by Aller and Faulkner show that the star has a normal continuous energy distribution for B5 V.

Alpha Sculptoris (B5 V) was found to have a peculiar spectrum by Jugaku and Sargent (1961). The ratio Si III: Si II is normal for B5 V but He and O are weak and the metallic lines are too strong. A rough analysis shows He and O to be deficient by factors of 5 while Si and C have normal abundances.

e. 'Peculiar' A Stars: Manganese and Silicon Stars

Ch. Bertaud is preparing a second supplement to his valuable *Catalogue et Bibliographie des Etoiles A à Spectre Particulier*.

The Jascheks (1962) have undertaken an intensive study of the peculiar A-stars of the so-called 'λ4200 group'. The heretofore unidentified line at 4200Å was independently simultaneously found to be due to high excitation lines of Si II by Bidelman and by the Jascheks. In some stars of the Si II – 4200Å group, lines of Fe III have been identified by the Jascheks, (1962*a*). They have also reported the presence of Ga II in π Bootis and μ Leporis, it may be present in HR 4817 and β Sculptoris, which is also a spectrum variable.

The Jascheks have identified lines on high dispersion coudé material loaned by H. W. Babcock (3700Å–4900Å). Results have been obtained for π Bootis and μ Leporis; seven more 'silicon – 4200' and 'silicon' stars are under study.

Sargent and Searle (1962.*a*) have made a study of the abundances of O and Mg in 20 Ap stars. They find the oxygen abundance is normal in the Mn stars, while in the Eu-Cr and Sr stars O is deficient by factors ranging from 8 to more than 100. A study of four Am stars by Sargent and Searle (1962.*b*) showed that these stars have a normal abundance ratio O:Mg.

Jugaku and Sargent are completing abundance analysis of the B8p star κ Cancri. Mn, P and Be are all overabundant by a factor of 100 while He is deficient by a factor of about 10. The abundances of Si, Mg, O, C, Ti, Cr and Fe are all normal.

Searle, Lungershausen and Sargent are studying the relative abundances of the Fe peak elements (Sc, V, Ti, Cr, Mn, Fe, Co and Ni) in about 20 Ap stars.

Preliminary results on the abundances of nitrogen and beryllium in Ap stars were reported by Sargent, Searle and Jugaku (1962). The infra-red N I lines were absent in all four stars bright enough to be studied, indicating abundance deficiencies greater than a factor of 10 for nitrogen. Four out of ten Mn stars have very strong lines of the Be II doublet λ 3130-3131—indicating an overabundance of beryllium by a factor of about 100. The remaining six Mn stars and all five Si stars which were studied had no detectable Be II lines.

Searle and Sargent (1963) have studied the abundances of silicon and magnesium in 31 Ap stars. The Mn stars have normal abundances of both Si and Mg, while the stars in which 4200 Å of Si II is strong are overabundant in Si by factors ranging from 10 to about 60; in the 4200 Å–Si stars the abundance ratio Si/Mg has an approximately constant value of about 60 times normal. All these stars have $B-V = 0{\cdot}0$ but otherwise show no dependence of Si abundance on colour. The redder Ap stars, having strong lines of Eu, Cr and Sr are slightly overabundant in Mg and have Si abundances varying from 10 times normal to 10 times less than normal. Weaknesses of the He I and C II lines in the 4200 Å–Si stars are tentatively interpreted as indications of very large abundance deficiencies of He and C.

A co-operative program on manganese and related stars has been undertaken by Bidelman at Michigan and Aller at University of California, Los Angeles. The B8 manganese star 53 Tauri, $T_{\text{ion}} = 11\,000°$K, log $P_e = 2{\cdot}7$ exhibits several striking abundance anomalies. Manganese seems to be the most abundant metal in this star, but gallium appears to show the greatest enhancement of abundance over the 'normal' value. Strontium, yttrium, and zirconium are also enhanced in abundance, calcium may be depleted, silicon is probably normal, and magnesium is only slightly depleted (if at all). An excess of gallium seems to be associated with an excess of manganese, a correlation noted independently by Bidelman and by the Jascheks.

Preliminary results for HR 8348 suggest $T = 11\,400°$K, $P_e = 400$ dynes/cm². Iron, carbon and magnesium show normal abundances. Sulfur and strontium may be slightly more abundant; calcium, titanium, miobium and chromium may be depleted by an order of magnitude.

HD 168 733 shows a remarkable range of excitation and reliable abundance estimates (Aller and Bidelman, 1963) must await some kind of a model atmosphere analysis. Ions identified in the spectrum include H I, He I, C II, N II. Na I, Mg II, Si II, Si III(?), S II, Cl II, Ca II, Ti I, Ti II, Cr II, Fe I, Fe II, Fe II, and Sr II. The iron/hydrogen ratio appears to be about 100 times larger than the solar value.

Other stars under intense study include 112 Herculis, HD 144 206, HD 145 389, HD 172 044, HR 8349, ι Cor Bor and π′ Herculis (especially for comparison with other observers.)

f. Peculiar A Stars: Magnetic A-Stars, Spectrum Variables

Polarizing equipment for measurement of stellar magnetic fields has been put into service by Preston at Lick Observatory and by Gollnov at Mt. Stromlo. The Lick program is primarily concerned with variable stars, while the Australian program will be concerned with all types of magnetic stars within reach of the equipment.

The Jascheks have prepared a third list of southern peculiar and metallic line stars.

The magnetic star, HD 187 474, has been analyzed by S. Leeman, who employed coudé spectra taken at Radcliffe Observatory.

A general investigation of Spectrum Variables of Type A by W. K. Bonsack has been begun, based on spectrograms secured with the Perkins 69-inch reflector. Points to be emphasized will be intensity, wavelength, and line profile variations; possible discontinuities in the variations; and exploration of possible relationships to the metallic-line stars through the study of binary systems.

High dispersion spectra of 73 Draconis, a magnetic and spectrum variable, are being studied by W. H. Wehlau. The spectrum of this star has been analyzed also by R. Faraggiana and M. Hack (1962) at Merate, who are determining also the chemical composition for 78 Virginis, 10 Aquilae, and θ Aurigae. They have also studied the spectrum of Gamma Equulei to determine if it is variable and have established that if it is, the period is very long. Gamma Equulei is also being studied at the University of Michigan.

With the completion of the Victoria 48-inch telescope and its coudé spectrograph, K. O. Wright and his associates are obtaining spectra of selected peculiar and metallic line A-stars brighter than magnitude 6·0 (dispersion 5·5 Å/mm) to study radial velocity variations and abundance differences.

g. Metallic-Line Stars

At the Crimean Observatory, I. M. Kopylov, T. S. Belyakina, and A. Vitrichenko studied 26 'metallic line' and 23 standard stars in the interval A2 – F5. They measured the K line, equivalent widths of hydrogen lines and took broad band pass measurements to assess the role of metallic lines. They find no sharp division between 'normal' and metallic line stars. The index of metallicity, spect. class (H) – Spect. class (metals) depends neither on temperature nor absolute magnitude.

Placing particular emphasis on $U-B$, $B-V$ diagrams, the Jascheks have discussed metallic line and peculiar stars. They found that the metallicity of the metallic line stars is strongly correlated with the $U-B$ deficiency. They also found that the number of metallic line in open clusters increases sharply with the cluster's age.

The Jascheks are going to undertake the study of the atmospheres of β Cr B and γ Cap through curve-of-growth analysis. Sahade and Frieboes-Conde will do line identifications of β Cr B on coudé plates.

At Merate, Faraggiana has also studied the spectrum of γ Capricorni. The rare-Earth lines are not strong so this object resembles the metallic line stars more closely than the magnetic stars. The spectrum shows some peculiar blends, however, which are not observed at the same wavelengths in comparison stars, i.e. ι Pegasi (normal F5 V star) and the magnetic stars γ Equ, β Cor Bor, and 73 Draconis.

At the Institut d'Astrophysique in Paris, C. Van't Veer-Menneret (1963) has studied systematically the classification of metallic line stars in the 3-dimensional Chalonge system. She has studied one of these objects, 63 Tauri, in some detail. For a number of years much effort has been expended in trying to explain the metallic A-stars by unusual atmospheric models, by deviations from local thermodynamic equilibrium, etc. None of these attempts have been successful. It now appears from the work of C. Van't Veer-Menneret and Peter Conti (University of California, Berkeley) that these stars actually have the abnormal compositions one would infer from their spectra. That is, there are real abundance anomalies which cannot be mimicked by abnormalities in atmospheric physical conditions.

h. Strong and Weak Lined Stars and Sub-dwarfs

A careful study of the relations between age or membership in clusters, and chemical compositions of stars has been made by Wallerstein and his collaborators and by Greenstein and his group. A number of sub-giants of presumably very great age and metal deficiency have been investigated.

At Merate, Passinetti (1961) has compared strong (st) and weak line (w) stars, e.g., 16 Cep (F5 V st) and 36 Dra (F5V w), Iota Peg (F5 V st) and Omega Dra (F5 V w); Theta Dra (F8 IV st) and HD 198 084 (F8 I w). It turns out that valid comparisons can be made only by quantitative studies of the spectrograms.

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

The high velocity A star, 7 Sextantis, has a normal composition (Sargent, Searle, and Wallerstein, 1963).

Baschek has investigated the abundance of carbon in sub-dwarfs.

Blocking of radiation by Fraunhofer lines and distortion of the temperature gradient by back scattered radiation affects the *UBV* colors of stars. Wildey, Sandage, and the Burbidges (1962) constructed a family of curves which allow corrections $\Delta(B - V)$, $\Delta(U - B)$, and ΔV to be applied to any weak-lined star to reduce the *U*, *B*, *V* measurements to what they would have been for stars with as strong metal lines as the Hyades stars.

In this connection we mention the work of Oke who is making photo-electric scanner observations of a selection of Hyades stars and sub-dwarfs in order to determine accurate effective temperatures for both kinds of stars. The blanketing theory recently developed to correct *UBV* colors for the effects of variable metal line strengths is designed, in effect, to do this. For the cooler stars, however, it is necessary to assume in the blanketing theory, that the real continuum is in fact observed in the blue and ultra-violet. This is almost certainly not the case. The scans are being made in the wavelength region from 3400 to 10 800 Angstroms. The absolute energy distribution in the red and infra-red, where lines are very weak, is compared with fluxes computed from model atmospheres to determine the effective temperature. The model atmosphere for the appropriate effective temperature can now be used to determine where the true blue and ultra-violet continuum lies relative to the observed one. In the extreme sub-dwarfs it is found that the model atmosphere flux is in excellent agreement with the observed continuum, and an effective temperature is easily obtained. In the cool Hyades stars only the red and infrared measures can be used. A selection of hotter Hyades stars, and the giant stars, has also been observed and used to obtain effective temperatures over the whole range of spectral types observed in the Hyades, with the exception of the very faint dwarfs.

At the Cape Observatory, Evans and Stoy (1962) undertook a special search for sub-dwarf stars in the southern skies.

The term: sub-dwarf is really a misnomer. As has been emphasized by many writers, these stars really do not lie below the main sequence. They are actually stars with very low metal/hydrogen ratios.

A star with one of the smallest metal/hydrogen ratios known is BD + 39°4926 which has been studied by L. Divan. This object has the largest Balmer discontinuity known. It resembles the stars found on the horizontal branch of the globular clusters.

An O-type sub-dwarf, HD 49 798, ($m = 8{\cdot}3$) appears to be the brightest hot star of this type known. The Jascheks (1963*b*) found nitrogen to be enhanced, N IV being very strong—but C and O are absent. Feast, Thackeray and Wesselink had reported its radial velocity as variable in 1957; the Jascheks conclude that it is a spectroscopic binary.

12. MISCELLANEOUS STUDIES OF STELLAR SPECTRA

At Mt. Stromlo Observatory, A. Przybylski and Mrs. Kennedy are making good progress with coudé spectra in the analyses of HD 211 998 (ν Indi) and HD 214 539.

Supergiants and Circumstellar Envelopes

(*a*) Sargent (1961) has estimated the rate of mass loss from the F8 Ia star, ρ Cas. Work is now in progress on the circumstellar envelope of 89 Herculis (F2 Ia) using Mt. Wilson coudé spectra.

(*b*) Searle, Sargent and Jugaku (1963) have reconsidered the work by Abt (1960) on the compositions and luminosities of the high-galactic-latitude supergiants 89 Herculis and HD 161 796. Contrary to Abt, they find that the stars have a normal composition and that they are probably evolved examples of the 'runaway' B-stars.

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press

Groth (1962) has investigated the composition of α Cygni.

Ultra-violet Stellar Spectra

Perhaps the most exciting development in the field of stellar spectroscopy is provided by measurements made by instruments flown above the Earth's atmosphere. So far, results have been obtained only for the continuous spectrum (Stecher and Milligan, 1962). Eventually it will be possible to make measurements from an orbiting astronomical observatory both for the continuous spectrum (Code) and for the line spectrum (Spitzer).

The observations by Stecher and Milligan indicated pronounced discrepancies in the ultra-violet energy distributions from those predicted by theory. Although some of the discordance can be removed by improvements in the theory (Underhill, 1963), many astrophysicists are not convinced that line absorption and small changes in the temperature gradient can remove it entirely. If the ultra-violet deficiency arises from quasi-molecules as Milligan and Stecher (1962) have suggested, we still have to identify these sources and account for the effect quantitatively. Huang, Milligan, and Stecher (1962) have pointed out that such opacity sources could also have a pronounced effect on the structure of the outer atmosphere and might tend to produce convection in surface layers of B-stars. Further speculation seems unwarranted until accurate measurements of the continuum energy distribution and the line spectrum have been made.

Lithium Abundance in Stellar Atmospheres

Since lithium is invariably destroyed in thermo-nuclear reactions that occur in stellar interiors and can only be produced by surface reactions presumably occurring in early stages of star formation, its presence or absence in stellar atmospheres is of great cosmogonic interest.

Herbig reasoned that if the low Li content of the Sun was the result of a large Li depletion over 5×10^9 years, then there should be some younger G dwarfs in the solar neighborhood that still retained a major fraction of their original Li. Using the 120-inch coudé, he discovered (in 1960 and 1961) that there were indeed many G dwarfs that showed Li I 6707 very strongly; in a few it approached the strengths observed in the T Tauri stars. A preliminary report has appeared on this program and its results for G0-G8 dwarfs within 20 parsecs (Herbig, 1963). Herbig, Wallerstein and Conti (1963) investigated the Li abundance in F dwarfs, mostly in the Hyades.

The main arguments supporting the idea that the lithium abundance is really an age index in G dwarfs are as follows:

(*a*) The F and G dwarfs in the relatively young clusters observed thus far (Pleiades and Hyades) show high Li abundances; extension of these observations to the Coma and α Persei clusters is planned.

(*b*) A clear preference of the Li-rich stars for low space velocities, and the absence of Li in high-velocity stars.

(*c*) A tendency for Li-richness in early G dwarfs to correlate with the presence of strong H, K emission cores, a phenomenon reminiscent of T Tauri spectra.

(*d*) The fact that the relative proportions of G0-G8 dwarfs with strong, medium, and weak Li lines among nearby stars conforms approximately to expectation if the depletion of Li is an age effect, and if the rate of production of G dwarfs has been roughly constant over the past 15×10^9 years.

The hypothesis cannot as yet be regarded as proven without question, however, and Herbig is attempting to apply other observational tests. One of these is a determination of the Li^7/Li^6 ratio in some of the brighter Li-rich stars at 4 Å/mm. The isotopic splitting of the line at 6707 Å corresponds to a velocity shift of 7 km/sec, which is a conspicuous displacement at this dispersion. Preliminary results for about 10 stars indicate a real variation in this ratio from star to star. An effort to determine the 'primeval' ratio in T Tauri at 16Å/mm was not conclusive.

At low dispersion (88Å/mm), Herbig made a survey of some 100 Mo-M5 giants for the presence of Li I 6707Å. About five per cent of these stars show the Li line strongly; the best examples are 45 Ari, δ Sge, and 29 Cap. A few of these stars have subsequently been observed at high dispersion, but this material has not been assessed yet. One result seems clear, however; careful measures of the position of the line 6707Å show that the *Li in these M giants is predominantly* Li^7.

At the David Dunlap Observatory, S. van den Bergh has undertaken photo-electric spectrophotometric measurements of stars in which Herbig has observed the strength of the lithium lines.

Faraggiana and Hack (1963) measured the Li I doublet at λ 6708 in the spectra of the magnetic stars β Coronae Borealis and γ Equulei. The abundance of lithium in the atmosphere of β Coronae Borealis is 3000 times larger than in the solar atmosphere. This result confirms the hypothesis by Fowler and the Burbidges that light elements might be produced by spallation process in the atmosphere of the magnetic stars.

Spectrophotometry and Stellar Energy Distributions

Spectrophotometric measurements play such an important role in modern quantitative stellar spectroscopy that much effort is being devoted to this problem at many observatories. At the Berkeley IAU meeting, a joint session of the photometry and stellar spectroscopic commissions was held to discuss setting up a set of fundamental photometric and spectrophotometric standards in the zone $\delta = -15^\circ$ to $+15^\circ$. J. B. Oke of Mount Wilson and Palomar Observatories was appointed chairman of this special spectrophotometry committee. His report is appended herewith. It includes a list of suggested spectrophotometric standards, which is somewhat shorter than the suggested list of photometric standards proposed by Kron and given here as Table 2. Successive columns give the designation of the star (HD number when available), name or BD number and colors and magnitudes compiled from different sources. Additional observations will have to be obtained for many of these stars. Kron's list naturally contains many stars of late spectral class which are not suitable as spectrophotometric standards but which are required for photometry.

We describe herewith a number of spectrophotometric programs devoted to individual stars or types of stars—and not covered in Oke's report which is devoted to fundamental spectrophotometry.

At the Vilnius Observatory, A. Azusienis and G. Kakaras (1963) investigated the continuous spectrum of semi-regular variable RU Cep in the yellow-red region. In a similar way, A. Azusienis, A. Bartkyavicius and A. Pucinskas investigated Z, RS, TZ, WY And and AR Cep stars. In the photographic region of the spectrum, A. Pucinskas and V. Zitkyavciaus investigated AE Aur, V568 Cyg, BN Gem, Her, and AG Peg stars. G. Kakaras, using the slitless spectrograph of the 48 cm reflector, carried out spectrophotometry of a number of red semi-regular and irregular variable stars in the spectral interval of 3500Å–6500Å.

V. Zitkyavicius (1963) investigated the contuous spectrum of Nova V_{446} Her in the photographic region. G. Kakaras, V. Straizis, V. Zitkyavicius using the series of photographs investigated the distribution of energy in the region of 3500Å–6500Å of the spectrum of N Her 1963.

At Abastumani Observatory, in addition to spectral classification work, spectrophotometry was done with the 70 cm meniscus telescope and 8° and 4° prisms which give dispersions of 166 and 668Å/mm near 4340Å.

Observations of FU Orionis show that this star has an ultra-violet excess. B. A. Bartaya (1962) assigns this star to the RW Aur class. Bartaya and Kharadze (1964) have undertaken a spectrophotometric study of RW Aur itself.

Spectrophotometric studies of RR Lyrae stars as a function of phase have been carried out by I. F. Alaniya.

At the Burakan Observatory, N. L. Ivanova, M. A. Kasaryan, and V. Kh. Oganesyan (1962) carried out spectrophotometric investigations of N Her 1960, while Oganesyan (1963) has studied a number of Be stars (30). Preliminarily, Ivanova, Kasaryan, and Oganesyan (1964) have also carried out preliminary studies of N Her-Lyr 1963 and AG Peg spectra.

The spectra of the supergiants in the systems of the eclipsing binaries were investigated at the Shemakin Observatory by S. M. Azimov (1962) using data obtained with the 700 mm prismatic camera in Abastumani. He measured spectrophotometric gradients and temperatures, equivalent line widths, electron density, pressure, etc.

S. V. Rublev (1963) determined the spectrophotometric gradients of nine WR stars taking into account the interstellar absorption, while V. P. Arkhipova (1962) made similar measurements for twenty stars of P Cyg type. The latter determined that the excess of color with respect to normal stars (i.e., those without emission lines) mainly is due to the irregular distribution of interstellar reddening. But seven stars have small stellar reddening which is due to the radiation of the shell.

V. P. Arkhipova and O. D. Dokuchaeva (1962) carried out photometry of slitless spectra of AG Peg. They obtained a spectrophotometric temperature of about 5000° K and measured the equivalent widths of a number of the emission lines. A definite decrement of the Balmer series at $T = 2000$ and 50 000° K is compared to the observed one and the dimensions of the shell were obtained.

The Toruń Observatory has installed a new Schmidt Cassegrain telescope of 60/90 cm with two objective prisms giving dispersions of 250 to 570 Å/mm. W. I. Iwanowska reports the following spectrophotometric research programs:

'Spectrophotometry of the continuum of stars in relation to their population type in the range 3500 Å–10 000 Å: These investigations are accompanied by an evaluation of the statistical probability of a star's belonging to one of the two main population types on the base of its position and motion, see e.g. Iwanowska and Burnicki (1962) and Iwanowska and A. Opaska-Burnicka (1962). Under current investigation are: F, G, K high velocity stars, RR Lyrae variables, RV Tauri variables, long period variables and carbon stars.

'Spectrophotometry of occasional objects, e.g. novae, comets: Nova Herculis is currently being investigated by A. Woszczyk, R. Glebocki and J. Smolinski for the intensity distribution in the continuum and the intensity of emission lines at different phases.

'For these topics and any possible future interests an observing program called "Spectral Sky Atlas" has been undertaken. Objective prism plates covering at first the Milky Way belt and then the whole accessible sky, calibrated photometrically, are taken to form a store of material for research.

'Our objective prism spectrophotometric work is supplemented with a study of high dispersion slit spectrograms of some representative objects observed with big instruments abroad.'

At David Dunlap Observatory, S. van den Bergh and his associates have made spectral scans of northern G-dwarfs for which photometric data are available. They have also measured metal abundance parameters defined as Δ and Λ.

R. V. Willstrop of Cambridge Observatories made spectra scans of 215 stars at 50 Å resolution at the Radcliffe Observatory in 1962 (July–September). The scans have been normalized, using observations made at the Cape of Good Hope (Willstrop, 1960) to determine the flux received outside the Earth's atmosphere from stars of apparent magnitude $V = 0.0$ at 24 Å intervals from 4000 Å to 6500 Å (Willstrop, *Memoirs RAS*, in press).

Observations secured by Aller and Faulkner at Mt. Stromlo Observatory (1960–61) for southern standard stars have now been reduced and a summary of their results is appended as Table 3.

At Abastumani, M. V. Dolidze, M. F. Mazni, and L. M. Fishkova (1961) have carried out a determination of the zero point of spectrophotometric temperatures.

Attempts have been made to combine stellar spectrophotometric data with predictions based on model atmospheres to deceive bolometric corrections and effective temperatures. Thus, Aller (1963) used model atmosphere to derive bolometric corrections for the range 12 000° K–45 000° K and spectral scan data plus model atmosphere data to get bolometric corrections for spectral classes A0 to M8. A number of discordances with the careful work of Popper appear, possibly due to difficulties in correcting spectral energy distributions with stellar colors and magnitudes.

At Crimean Observatory, Kopylov (1963) used atmospheric models to construct a scale of bolometric corrections and effective temperatures for main sequence O5 – G5 stars. He also constructed scales of ionization temperature and excitation temperature for the same spectral interval. Although the excitation temperature is always smaller than the ionization temperature which is usually smaller than the effective temperature, the ratios $T_{\mathrm{exc}}/T_{\mathrm{ion}}$ and $T_{\mathrm{ion}}/T_{\mathrm{eff}}$ vary as a function of spectral class.

In spite of progress in the theory of stellar atmospheres and in spectrophotometry, there still remain distressingly large uncertainties in the effective temperature scale. For example, D. L. Harris (1963) assigned an effective temperature of 10 800°K for A0 stars, while Popper (1959) and Aller (1963) assigned them a temperature near 9400°K. These discordances point out the necessity for securing accurate spectrophotometric observations from above the Earth's atmosphere—at least for the hotter stars whose principal radiation lies in inaccessible spectral regions.

As appendices to this report are printed the reports of the Committee on Spectrophotometry, prepared by Dr J. B. Oke, and of the Committee on Stellar Classification, prepared by Dr W. P. Bidelman.

L. H. ALLER
President of the Commission

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APPENDIX I: REPORT OF THE COMMITTEE ON SPECTROPHOTOMETRY

(Prepared by J. B. Oke, Chairman of the Committee)

There are two basic problems in spectrophotometry. One is the absolute calibration of the energy distribution in the spectrum of some standard star. The second is the setting up of secondary standards around the sky which can be used in practical spectrophotometry. Recent work on these two problems will be discussed.

https://doi.org/10.1017/S0251107X00014929 Published online by Cambridge University Press