45. SPECTRAL CLASSIFICATIONS AND MULTI-BAND COLOUR INDICES (CLASSIFICATIONS SPECTRALES ET INDICES DE COULEUR À PLUSIEURS BANDES)

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INTRODUCTION

During the past three years there has been much activity in the field of spectral classification by photographic and photoelectric techniques. The general tendency of the spectral classification has been one of refinement of the criteria applied in visual classification, the more frequent appearance of criteria based on equivalent widths measured in higher-dispersion spectra and the use of narrow-band photometry on individual often rather weak spectral lines. In the area of objective prism classification important extensive programmes are under way at many observatories. Here, the increased interest in and importance of automation of data available on spectral plates is perhaps most obvious.

Classification studies using three parameters: spectral type, luminosity, and metal abundance, are appearing more and more frequently.

Here, the photometric systems, in particular the narrow band ones, appear to lead in refined classification over the systems based on photographic plates. However, it is still most efficient to do the first selection of objects by objective-prism surveys, using spectral ranges and dispersions adapted to the purpose.

Important symposia and colloquia of interest for the work of our Commission have been held. A 'pure', or almost pure, Commission 45 Symposium was held in Villa Carlos Paz, in October, 1971; references made to papers presented there are identified as (50: No. of session, No. of paper). This Symposium was co-sponsored by Commission 25. Review papers were presented by Keenan (Slit spectrograms), Stephenson (Objective-prism spectra), Strömgren (Photoelectric quantitative spectral classification) and C. Jaschek (Catalogues). These papers not only give important reviews but indicate also the trend of development in our field.

IAU Symposium No. 54, on Calibration Problems was held in Geneva in September, 1972. The initiative for holding this symposium was taken by Commission 45. Its value was significantly increased by the participation of astronomers of the many collaborating Commissions; co-sponsoring were Commissions 24, 25, 29, 33, 37 and 44. An impressive amount of valuable information for the work in our field was presented, as well as wishes and requirements for observational data to be derived. Of great importance were the discussions of the fundamental data on which all calibrations are based. Many of the introductory papers contain rich bibliographies.

Papers dealing with the topics of our Commission were also presented at the Colloquium on Supergiant Stars (Trieste, September, 1971, editor of the Proceedings, M. Hack).

At the Woolley Symposium (*Astron. Astrophys. Abstracts* 07.012.025) important questions of calibration were discussed.

In the Conference on the Role of Schmidt Telescopes in Astronomy in Hamburg, March 1972, objective-prism classification work was reviewed by Bidelman and a number of papers in this area were presented (ed. of Proceedings, U. Haug).

At a Conference on Late Type Stars in Tucson in October, 1970 (05.012.009), classification problems and multicolour photometry were discussed.

In the preparation of this report I have had the difficulties expressed by the previous Presidents

regarding the material to be included. The topics of our Commission form the foundation for or at least a supporting part of the topics of several other Commisions. In order to avoid overlaps I have omitted here most of the papers dealing with wide-band photometry in three and less passbands (Com. 25); variable stars (Com. 27), detailed studies, including classification, of individual stars (Com. 29); application of classification techniques for studies of galactic structure (Com. 33) and clusters and associations (Com. 37); and the rich and very important work on the Magellanic Clouds (Com. 28, Working Group; see also my review at the First European Astronomical Meeting under the auspices of the IAU).

As undoubtedly Presidents of other Commissions have to deal with their material in a similar way there is a certain risk that some important contribution may be omitted. It appears desirable for the IAU to define more in detail the working areas of the various Commissions in view of the developments during the last few years.

From the view of Commission 45 I am im particular thinking of two rapidly developing areas of investigation: the ultraviolet spectral range (presently under Commission 44) and the infrared spectral range (probably dealt with by many Commissions, including Commission 45). In the latter field I refer to the reviews by Neugebauer, Becklin and Hyland (06.113.010), by Hyland (06.114.062) and by Borgman (First European Astronomical Meeting under the Auspices of the IAU).

Investigations of the far ultraviolet spectral range are not considered in my report though a most interesting paper was presented at Symposium No. 50, dealing with the Celescope Catalogue and giving a multicolour ultraviolet system (50: 4.8).

In this introduction I wish to call attention to the question of establishing a number of 'HR standard' stars, introduced by Golay at Symposium No. 54 (54: VIII.1).

These stars should be observed by photometrists as well as spectroscopists and astrometrists. They must fulfil certain conditions:

(1) Not be binaries;
(2) Not be reddened by interstellar matter;
(3) Not be suspected to be variables; and
(4) Not have $v \sin i > 150$ km s^{-1}.

They should preferably belong to certain series of existing standard stars, be members of open clusters with known distances or have been studied in high-dispersion spectroscopy for abundances.

The object of this project is to gather a sufficient amount of observations of each selected HR standard to allow the precise fitting of stellar models liable to give us M_v, log g, T_{eff} and the chemical composition χ. Calibrations of any criteria – spectroscopic or photometric – in such terms is obviously extremely important.

I have received much information in responce to a circular memorandum sent to all members of Commission 45, and the following report is based on it and on my search of the literature published during the last three years. Due to the limited space available a selection of topics has had to be made. I have attempted to put the emphasis on criteria and the definition of systems.

A brief introduction is given to each section of the Report, but most of the space is used to demonstrate the diversity of approach in the field of our Commission.

The Report of the Group for collection of photometric and spectroscopic data has been written by Dr B. Hauck. It is a pleasure to thank him for his efficient work as the Chairman of the Group. We hope that its work will continue with an increased support from the Commission members and in closer cooperation with the IAU Working Group on Numerical Data.

I. CLASSIFICATION EMPLOYING INSPECTION OF OR MEASUREMENTS IN SPECTROGRAMS

1. *Slit spectra*

a. *Definitions of criteria*

Despite the rapidly increasing use of quantitative methods for stellar classification the *MK system* continues to be very useful and frequently used. Its usefulness would be increased if it were possible to improve the precision with which it is defined.

The early MK system has become progressively more blurred by the increasing appearance of special categories of stellar spectra such as those of metallic-line stars, helium-rich and helium-poor young stars and stars of various degrees of metal richness.

W. W. Morgan and associates have attacked this problem and have arrived at an explicit formulation for a phenomenology of spectral lines and bands, described in a language separate from that of stellar atmospheres and general spectroscopic astrophysics. As soon as an astrophysical model is superposed on a stellar spectrum a certain amount of information on the spectrum is lost for the sake of deriving the desired physical characteristics. Morgan and his associates aim at preserving certain peculiar spectral characteristics and to isolate and describe them in a manner suitable for future astrophysical investigations. Two papers have been completed in this series. Morgan and Abt (07.114.075) have described the two-dimensional field for the F II–IV stars in terms of five criteria. The new, MKA, system defines a structure of higher internal precision than the MK system.

Abt and Morgan (07.153.028) have also studied IC 2602 as a first in a series of open clusters: the purpose is to sharpen the spectroscopic morphology so that a variety of peculiar objects can be recognized. In order to achieve the desired systematic accuracy it is necessary to observe the B-type members of open clusters *with two different dispersions*. An interesting example is θ Car, brightest member of IC 2602, which proves to be a uniquely peculiar member for any known cluster in the enhancement of lines of N III and weakening of C III.

A reexamination of the MK system by Morgan and Keenan will appear in *Ann. Review Astron. Astrophys.* 1973. Revised standard stars are given. C. and M. Jaschek have undertaken a study of the *accuracy of spectral classification*, especially in view of a comparison with photometric classification (50: 1.11). The main result is that among A-type stars the accuracy of MK classification is equivalent to those of the photometric systems, whereas in B-type stars the latter are superior.

Gliese (05.115.015 and 50: 1.12) has also examined the accuracy of spectral classification of main-sequence stars for various classification systems. He finds for example for K dwarfs the following errors in units of tenths of a spectral class: $\pm 0{\cdot}6$ (MK); $\pm 1{\cdot}2$ (Mt. Wilson); $\pm 0{\cdot}7$ (Kuiper).

Dispersions higher than that used in the original MK system have been used frequently.

Walborn has carried out spectral classification of OB stars in both hemispheres (06.114.101; 07.114.071). He finds that a dispersion of 63 Å mm^{-1} is well suited for spectroscopic study and MK spectral classification of this group. The improved spectral resolution has led to: an increased classification resolution in the range O9–B1; an empirical luminosity classification for the early O stars; and the detection of anomalous behaviour of the nitrogen and carbon absorption spectra in some OB stars.

He finds that the spectral types and the absolute magnitudes of the Victoria system are later and fainter respectively than in his 'MK' system. He gives 19 new southern OB-classification standards and classification for a total of near 300 OB stars in both hemispheres. Among the bright O stars near η Car four stars were found of types earlier than the earliest MK classification standards (05.114.095). One of them, HD 93129, is an unusual higher-excitation analogue of the Of class.

Using the same dispersion Walborn (05.114.043) found absorption-line OB spectra with enhancement of nitrogen together with a weakening of carbon and/or oxygen relative to spectra of normal stars; they are classified ON or BN. Similarly, some spectra with nitrogen deficiency and with evidence for an enhancement of carbon are classified OC or BC. Stars having these anomalies are most likely not in excess of 5% of the OB stars.

Using spectra of 16 Å mm^{-1} Conti and Alschuler (06.114.115) classified 130 O type stars in intermediate MK types (e.g. O 7·5) using equivalent widths of He I and He II for the spectral classification and of Si IV λ4089 and He I λ4143 for the luminosity classification of the later O type stars. Calibration was obtained from O stars in clusters and associations. The Of stars, defined by having the N III multiplet $\lambda\lambda$4634, 4640 and 4641 in emission, were all found to be in the hotter and most luminous part of the H–R diagram.

The introduction of ultraviolet features in the 3300–4000 Å region of 117 Å/mm grating spectra (03.114.069) has led to a revised MK system for A and F stars with a substantial gain in the accuracy of the spectral classification. Visual estimates of the blends at 3859 Å and 3871 Å gave absolute

magnitudes for late F and early G dwarf stars with an accuracy equal to or better than in previous spectroscopic or photometric work (05.115.010).

A good spectroscopic crtiterion for the detection of metallic-line stars appears to be the ratio Sc II λ4320/Y II λ4309 (04.114.053). This ratio is insensitive to differences in effective temperature and surface gravity. Comparisons with Strömgren's Δm_1 index shows, however, that the Am stars exhibit a range in Sc and Y abundances.

Leushin has developed two-dimensional quantitative spectral classification of peculiar stars. The equivalent widths of a number of element lines He I, Fe I, Fe II, Ti II have been used as the criteria of spectral classes and the equivalent widths of hydrogen lines Hγ, Hδ, Hε as criteria of absolute magnitude. These criteria are less affected by spectral anomalies than other ones.

Spectral classes and absolute magnitudes have been determined for 56 peculiar stars on the base of 14 Å mm^{-1} dispersion spectra.

The results are presented in (07.114.051; 114.055).

The spectral region $\lambda\lambda$5700–6800 Å has been investigated by Gahm and Hultquist for classification criteria for stars of types K2–M6 in spectrograms of the dispersion 185 Å mm^{-1} (03.114.061; 07.114.022). Criteria for luminosity classification were found from the following features: Ba II, λ 6497; Fe, V and YO, λ 6135; Hα; NaD and the TiO bands.

Near-infrared spectrograms of M, S, and Carbon stars have been studied in low-dispersion (204 Å mm^{-1} to 385 Å mm^{-1}) with particular emphasis on the Mira-type long-period variables near minimum light (04.114.075; see also *Publ. Astron. Soc. Pacific*, **84**, 424, 1972). Classification criteria were the TiO and VO bands. The Ca II triplet, $\lambda\lambda$ 8498, 8543, 8662 could not be used for the variables.

A near-infrared two-dimensional classification scheme for carbon stars has been established by Richer based on the CN-bands and the Ca II triplet (06.114.010) in a dispersion of 124 Å mm^{-1}.

Spectral classification of He-weak stars has been carried out by Bernacca and Ciatti (*Astron. Astrophys.*, **19**, 482, 1972) and by Molnar (*Astrophys. J.*, **175**, 453, 1972). The latter gives the following definition of a He-weak star:

(a) No enhanced or peculiar metal lines as in the Si or Mn-Hg stars

(b) The hydrogen line profiles and metal line strengths such as Ca II K, Si III, λ 4552 and C II λ 4267 are indicative of the intrinsic colours

(c) The spectral type according to the helium lines is later by at least two-tenths than the type inferred by the colour.

The ultraviolet-excess stars in the Orion nebula cluster and NGC 2264 have been classified by Walker (07.114.122). The spectra are described in terms of the various types of emission that are encountered as well as of the absorption lines.

D. Chalonge and L. Divan have summarized the characteristics and results of *the B, C, D system* (*Astron. Astrophys.*, in press). The new data have permitted a more accurate twin-diagram λ_1, D to be established for this classification of stars referred to as 'normal' with the following results:

(1) A spectral type can be represented by a parameter s (s may be the point where the curves S, dividing the λ_1, D plane into spectral sub-classes, intersect a particular straight line).

(2) For each value of s the gradient Φ_b remains practically constant, independent of luminosity class.

(3) For the late A and F dwarfs the values of Φ_b for a given s may show some scatter; this is most likely due to differences in chemical composition between the various 'normal stars'.

(4) The λ_1, D diagram is calibrated in absolute magnitudes for O, B and the first sub-classes of A from $M = 0$ to $M = -8$.

Applications of the BCD system have been reported in (50:1.5) and in (54:III. 5; IV.6; VIII.3).

The method has also been applied to non-stable stars (06.114.081).

b. *Applications of classification systems*

An extensive stellar classification programme has been set up by Garrison using classification spectrographs in Toronto and on Las Campanas in Chile.

Garrison, Hiltner and Schild are involved in a combined spectroscopic and photometric study of

galactic structure in the southern hemisphere. The *UBV* and MK classification dispersion observations have been completed for all OB stars south of $-30°$ and brighter than 10th mag. that are listed in the Heidelberg Objective Prism Catalogue. Preliminary results from the fainter portions (For the bright stars see *Astrophys. J.*, **157**, 313) indicate that there are many O-type stars in the south which have been misclassified as A or late B in the HD Catalogue. Most of them have strong interstellar K lines and/or are heavily reddened. Among the many interesting stars discovered is CPD $-31°$ 1701, which is a helium-rich, sub-luminous, O-type star located in the plane of the Milky Way (*Bull. Am. Astron. Soc.*, **4**, 312, 1972).

Garrison (04.152.006) has classified stars in the region of the association III Cephei; this association was considered one of the best examples for a high ratio of total to selective absorption. The new classification indicates that a background star and several foreground stars artificially increased the ratio. It appears now to be 3, as in most other regions.

Morgan, Hiltner and Garrison (05.153.006) have classified all stars in the nearby moving cluster α Persei from B3 to G2. A long and narrow main sequence was obtained. The Bp star, HD 21 699, falls significantly below the main sequence when plotted according to its colour. Garrison has used this main sequence, with those of the Hyades (*Astrophys. J.*, **141**, 177) and the inner region of Upper Scorpius (*Astrophys. J.*, **147**, 1003) in a cluster fitting procedure involving only MK types for stars in moving clusters (54: IV.5).

A spectral classification study of the moderately old galactic cluster NGC 752 has been carried out by Garrison. This cluster contains F stars with several luminosity classes. There are conflicting previous results regarding the metallicity of the cluster members. He finds no convincing evidence for weak metallic lines in the spectra of its stars (*Astrophys. J.*, in press).

Other classification studies being carried out by Garrison include the cluster Tr 37 and the Orion Belt region.

During a search of the spectrographic plate file of the David Dunlap Observatory, Gulliver found 18 new Ap stars, mostly of the 7th and 8th magnitudes. Included in these new discoveries is HD 51 418, a Chromium-Europium spectrum variable with a period of 6 days. This extreme example has the largest visual light amplitude ($\Delta V = 0{\cdot}19$) of any known Ap star (M. Sc. Thesis, University of Toronto, 1971).

Stars with unusual spectra have been classified by Cowley and Crawford (05.114.09). The MK classification of the stars in the stellar rings in Orion and Hydra by Schild and Cowley (06.152.001) supported the identity of the former but gave no evidence that the stars in the latter shared a common distance or age. A similar result was obtained for the two rings No. 373 and 519 (07.152.002). The low-dispersion study (380 Å mm^{-1}) indicated a chance configuration of field stars, no star was of class OB.

Pesch and McCuskey have classified 86 B8 to A3 stars in the surrounding of the cluster Stock 2 in the two-dimensional MK system using slitspectra at dispersions 127 and 103 Å mm^{-1}. Pesch has also completed *uvby* β photometry for these stars.

A. Cowley and M. and C. Jaschek have studied bright A-type stars (04.114.034). They derived relations between the *UBV* colours and spectral types, between $\langle V_{\sin i} \rangle$ and spectral types and mean colours for supergiants, Am, and Ap stars.

Spectra of 122 A and F stars have been classified by Bertaud (03.114.065) in 60 Å mm^{-1} dispersion. For 89 Am stars classes were derived following the strength of the K-line and selected metallic lines.

A search for Am stars in the extremely young Orion 1c association by means of 127 and 63 Å mm^{-1} spectrograms and *uvby* photometry resulted in the discovery of five stars (*Astrophys. J.*, **175**, 765, 1972). The Am stars in the pre-main sequence contraction phase occupy the same domain in the H-R diagram as do the evolving Am stars.

Graham and Slettebak have classified 40 spectroscopically peculiar stars near the South Galactic Pole using dispersions of 39 Å mm^{-1} for 14 of the brightest stars and 200 Å mm^{-1} for the fainter ones. In addition to normal MK spectral types, the categories sdO, sdB, Bw and Aw, as defined in *Astrophys. J.*, **152**, 443 were used. *uvby* photometry was carried out for a total of 93 stars.

A wide range in physical characteristics exists among the O- and B-stars observed. Some of the brighter stars are normal main-sequence objects, but most are sub-dwarfs. Among the sub-dwarf B stars the helium lines are almost invariably weak for their colours.

The A and F stars fall into two groups: one with unusually weak metallic lines (small m_1, large c_1 indices) consists probably of horizontal branch stars; the other consists of normal A and F stars plus a few metallic-line stars.

A large number are classified as late-type sub-dwarfs.

For an investigation of the relationship between the continuous spectrum and the line spectrum of early-type stars Sinnerstad has recently carried out photometric and spectrographic observations of 75 bright main-sequence B2–B5 stars at the European Southern Observatory in Chile. All stars with known or suspected duplicity were omitted.

The photometric part of the investigation consists of *uvby* photometry and narrow-band photometry for the line indices of Hβ, Hγ and He I 4471.

Keenan has discussed (50: 1.1) the HR diagram region of the giant branches near types G8 and K0; this is important as a locus where evolutionary tracks for stars of different ages, populations, etc., either cross or come close together. He emphasized the need of reviewing the general appearance of a spectrum after it has been classified by the usual criteria. Then, if CN or other features look abnormal, the classification should be revised by means of those criteria which are least affected by the abnormality. This will prevent too high luminosities to be derived for strong-CN stars as well as too low for the weak-CN stars.

Keenan discussed also the classification of the carbon stars and the various proposals that have been made for new sequences or groupings (06.114.110, *Astrophys. J.*, **167**, 521; *Astron. Zhir.* No. 601, 6). Due to the many composition parameters that vary within the group of carbon stars the general picture still remains one of confusion. The problem may be solved by combining information from several spectral regions; in particular adding information from the far red and infrared regions for comparison with the blue and yellow lines and bands would be very valuable.

The carbon stars are also being studied by Tamashita at Tokyo Astronomical Observatory. He has obtained spectra of about 180 carbon stars brighter than about 10th magnitude and classified them on Keenan and Morgan's C-System. Three new members (HD 189711, BD $+8°$ 2654, BD $+17°$ 4421) have been added to the CH-star group. Several CH-like stars were also found; they show some of the characteristic spectral features of CH-stars, however, their proper motions and radial velocities are quite small. There is a possibility that the effective temperature of Mendoza and Johnson (*Astrophys. J.*, **141**, 161) is an indicator not only of a temperature but also of a CN-intensity (*Annals Tokyo Astron. Obs.*, in press).

Six new SC stars have been identified (06.114.044).

Other data from spectral classifications, mainly in the MK-system, are available for:

138 early-type stars away from the galactic plane (04.113.001)

Stars in IC 417 and IC 1318a (05.114.033)

Exciting stars in southern H II regions (05.114.048)

60 stars in the bright H II region surrounding HD 101205 (Ardeberg, Maurice, Rickard).

166 stars of HD types F2–G5, brighter than $m_v = 7{\cdot}5$ (03.114.012).

In a classification of 27 K-type stars near the South Galactic Pole (04.114.002) 23 were found to be normal giants, 4 supergiants, 1 a giant with weak CN and 1 an extremely metal-poor halo giant.

Southern visual, spectroscopic and photometric binaries are observed for spectral classification and determination of $V \sin i$ values of both components (H. Lovato, La Plata).

All southern HR stars are being classified at 100 Å mm^{-1}. A number of new peculiar objects (Fp, Fm, δ Scuti, etc.) have been detected (S. Malaroda, La Plata).

c. *Calibration of absolute magnitudes*

Symposium No. 54 dealt with calibration problems and extensive reviews and bibliographies will be found in the Proceedings.

The Third Colloquium on Astrophysics, Trieste 1971, dealt with supergiant stars. An Introductory

Lecture by Fehrenbach discusses classification criteria and wide-band and narrow-band photometry of this class. In the same volume Bouw and Parsons give a recalibration of the absolute magnitudes of A and F supergiants and discuss the use of various spectroscopic and photometric criteria. They conclude that much progress has been made in our ability to determine absolute magnitudes for the difficult case of intermediate-type supergiants.

Classification of supergiants may be found in (04.114.139, 05.114.081, 03.114.120). Good sequences of supergiants of luminosity classes Ib and Ia exist now.

A recalibration of the absolute magnitudes of supergiants has been made by Stothers (*Publ. Astron. Soc. Pacific*, **84**, 373, 1972; see also 05.115.001) by the method of group membership. The main sources for uncertainties in the derived values of M_v are:

(1) the assumed difference of extinction ratio between the supergiants and the B-type main-sequence stars; for the latter $R = 3{\cdot}0$; for M supergiants $R = 3{\cdot}6$ (04.113.038) and for intermediate types $R = 3{\cdot}3$; and

(2) the adopted M_v of the B-type main-sequence stars.

A redetermination of the Zero Age Main Sequence has been presented by Lloyd Evans (07.115.018) who notes some discrepancies between distance moduli derived from different procedures. The zero point has usually been established by the moving cluster parallax of the Hyades. (The distance modulus of the Hyades was extensively discussed at the Symposium No. 54 and values up to $m - M = 3{\cdot}25 \pm 0{\cdot}3$ were mentioned.)

At the Woolley Symposium on the Galaxy and the Distance scale (07.102.025) a number of calibration problems were considered.

Of particular interest here is the discussion of the Wilson-Bappu method to determine K-line absolute magnitudes M_v (K). Kjaergaard had previously found that M_v (K) depended upon the metal content [Fe/H] (03.115.003). No strong dependence was noted by Wilson, Olsen and Kjaergaard at the Symposium (p. 161) for the abundance range covered by their observations, whereas Pagel (p. 164) confirmed that a dependence exists by finding that the K-line luminosities are about 0^m5 too faint in the range G7 III to K5 III.

The problem of K-line absolute magnitudes has also been studied by Lutz (04.115.013) and by Jennings and Dyck (05.114.031). The latter conclude that the method may be used in moderate-dispersion spectra, to 63 Å mm^{-1} but not further.

A study of stars with strong CN absorption has been made by Schmitt (05.114.004). Mean absolute magnitudes were determined from the mean parallaxes of various groups of the G8–K4 stars. A comparison with absolute magnitudes derived by other means was made. The strong CN-stars have mean absolute magnitudes which are about 0^m5 to 1^m0 too faint for their mean spectral type. However, this result may be affected by the methods of calibration as well as by the low dispersion used (50: 1.1).

2. *Objective prism spectra*

In this area a great deal of work has been done, mostly by the application of already existing criteria.

Recently completed surveys are those of the southern Milky Way for luminous stars of early type (06.041.023) and for carbon stars (06.114.013) and of the region of the South Galactic Pole for early-type stars (06.114.072). A series of surveys have also been made of the Magellanic Clouds (see Commission 28). Three major surveys are under way: one by Stock and Wroblewski (50: 4.5; *Publ. Obs. Astron. Nac., Cerro Calan*, **2**, 59, 1972); one by Bidelman and associates for southern peculiar stars (50: 2.3; also 04.114.035; 05.114.053 and *Publ. Astron. Soc. Pacific*, **84**, 388, 1972) and the extremely welcome reclassification of the stars of the HD catalogue on the MK system by N. Houck and A. Cowley (50: 2.2). The last programme will originally deal with HD stars south of Dec. $+20°$ but it is hoped that it will eventually be extended to the North Celestial Pole. It is expected that good spectral and luminosity types will be obtained for 80 to 90 % of the HD stars. The first volume will contain all stars south of $-59°$ and will give two-dimensional spectral types on the MK system for about 24000 stars.

It is desirable that good northern surveys be carried out that would correspond to those referred to above for carbon stars and peculiar stars in the south. Other extensive surveys of special objects in the southern hemisphere are those of early-type stars with emission lines (04.114.004) and of M supergiants (*Astrophys. J.*, **176**, 623, 1972).

The collection of objective-prism plates for the Michigan Curtis Schmidt telescope has been searched by Bond for metal deficient stars (04.114.044). The relatively high dispersion, 108 Å mm^{-1}, at Hγ made it easy to detect effects of low metal content under good seeing conditions. *uvby* photometry was obtained for over 250 suspected weak-lined stars of 7th to 9th magnitude. The effects of differing stellar metal contents, temperatures and luminosities are somewhat better separated photometrically than by visual classification of low-dispersion slit spectrograms.

Among the newly discovered metal-deficient stars are several extremely low-metal red giants similar to HD 122563; giants showing large but less extreme heavy-element deficiencies, sub-dwarfs, stars possibly showing evidence of nucleosynthesis in their interiors; a possibly very metal-poor supergiant; and a group of early F-type metal-poor dwarfs. Most of the metal-deficient stars brighter than a given apparent magnitude are evolved giants.

During the search for metal-deficient stars other peculiar objects (Ap, Am, Bp, Ba II stars etc.) have been found and lists have been published (03.114.072; *Publ. Astron. Soc. Pacific*, **84**, 446, 1972).

In the course of the Michigan Spectral Survey of the Southern Sky 205 new Barium stars have been discovered (07.114.118). These stars along with the 35 previously known objects of this kind have been divided into two groups on the basis of the presence and strength of the λ 4554 line of Ba II. 150 stars show the λ 4554 feature whereas in the remaining 90 stars the existence of the line is less certain. Mean absolute visual magnitudes have been derived; they are $-0{\cdot}4$ and $+1{\cdot}0$ for the 'certain' and 'marginal' groups, respectively. This is equivalent to normal giants; thus they are considerably fainter than normal stars with comparable Sr II-line intensities.

Also in the course of this survey, 624 dwarf stars of type K2V and later have been identified (*Astron. J.*, **77**, 486, 1972). Many previously unrecognized stars within 20 pc from the Sun are listed. The programme when complete will extend the region covered by the McCormick lists of dwarf M stars to the entire sky (about 10 % remains to be surveyd). Spectral types are assigned based on the MK system. No systematic error in these classifications exists but the McCormick classifications are found to be systematically too late.

Nine new faint Wolf-Rayet stars have been found in Carina (03.114.019). The Curtis Schmidt telescope is also being used for an extensive survey for stars earlier than A7 at high galactic latitudes (04.114.127; 04.114.128; 06.114.023).

Strobel, Torun Observatory, has established spectrophotometric criteria for three-parameter classification, *Sp*, *L*, [Fe/H], of objective prism spectra of F, G, and K stars. Photographic density of spectra is recorded on tape, transformation into intensity scale and evaluation of parameters is being made with the aid of a computer (*Bull. Astron. Obs. Torun*, in press).

At Abastumani Observatory classification of objective-prism spectra with the dispersion 166 Å mm^{-1} is being carried out in collaboration with some other observatories. Successful classification in the MK system has been achieved for stars brighter than 11th mag with simultaneous identification of peculiars, particularly of the types Ap, Am and Ba II stars (50: 2.7).

R. A. Bartaya has classified in the MK system about 15000 stars down to 11th magnitude in Kapteyn Selected Areas No. 2–43, $4^{\circ}5 \times 4^{\circ}5$ each. More than 150 peculiar stars have been detected, mainly Ap and Am stars. 7 Ba II stars have been found and 5 stars with composed spectra.

Extensive catalogues of spectral classes and luminosities of stars brighter than 12^{m} are being published (*Bull. Abastumani Obs.*, No. 44, 1972):

1. In the area of the North Galactic Pole – 6500 stars (D. G. Chipashvili, Abastumani Observatory);
2. In the same area – 4300 stars (E. I. Zaitseva);
3. In the area of Orion ($\alpha = 5^{h}\ 10^{m}$, $\delta = 0^{\circ}$) – 4200 stars (M. S. Kazanasmas; Odessa Observatory);
4. In the same area ($\alpha = 1^{h}\ 30^{m}$, $\delta = +4^{\circ}$) – about 3000 stars (N. A. Miskin, Odessa Observatory);
5. In the area of stellar clusters NGC 6834 and 7654 – 920 stars (V. I. Kuznetsov, Golossevo);

6. In the area of Local Galactic System – 5000 stars (A. D. Chuadze, Abastumani Observatory).

At Sonneberg the work of classifying variable stars on objective-prism plates has been continued by Götz and Wenzel. The following lists have appeared since 1967 in the MVS Sonneberg: XI (**4**, 121, 1967); XII (**4**, 180, 1967); XIII (**5**, 5, 1968); XIV (01.123.011); XV (01.123.035); XVI (03.123.029) and XVII (**6**, 35, 1972).

A discussion of the Sonneberg programme for the determination of spectral types of variable stars will be given in NVS Sonneberg, **6**, No. 3.

E. Želwanowa and W. Schöneich have classified 150 stars in the region of NGC 7039 in the MK system (07.153.005). No Ap stars were found in the cluster, whereas in the open cluster Tr2 E. Želwanowa has found 6 Ap stars (07.153.006).

Diaz-Santanilla and Th. Schmidt-Kaler have carried out a quantitative three-parameter classification of stellar spectra of stars of types F5–K5 in southern Kapteyn selected areas. The material consists of objective-prism plates (dispersion 88 Å mm^{-1} between Hγ and Hε) of 115 Areas. Spectrophotometry has been done for about 340 F5 to K5 stars between 4th and 9th magnitude. The three parameters used are spectral type, S, luminosity, L, and metal abundance, M_E. Equivalent widths, F, are determined for 16 absorption lines and relations of the type $F = C_1 + C_2 \cdot S + C_3 \cdot L + C_4 \cdot M_E$ studied.

A large number of equations of this type are obtained and computer treated.

The results for 191 stars are: In all stars is the spectral type obtained with an error of $\pm 0{\cdot}5$ sub-classes. For 89 percent is a MK luminosity class determined with a mean error of $\pm 0{\cdot}7$ luminosity classes. For 116 of the 191 stars could the Fe abundance and for 175 stars the Sr abundance be determined; the mean errors in the logarithmic abundance are $\pm 0{\cdot}3$ and $\pm 0{\cdot}5$, respectively.

In the Stockholm Observatory spectral survey of the Southern Milky Way, 13200 stars in the Carina-Centaurus region have now been classified by L. O. Lodén and A. Sundman (see *Astron. Astrophys.*, **20**, 49, 1972) and 3430 stars in a part of the Norma region by H. Rickman. The stars in question are exclusively of types O–B9 and MRNS. The classification has been made by visual inspection of objective-prism plates. There have been strong efforts to get as close as possible to the MK spectral classification, but generally it has not been realistic to obtain any luminosity classification. A special investigation by B. Nordström shows that there is no obvious systematic deviation between the Stockholm and the MK systems.

The principles of the spectral classification have been given by B. Nordström and A. Sundman (50: 2.6; see also 02.114.089).

About 730 early A stars in the direction towards the galactic centre have been classified by K. Lodén.

At Lund Observatory, Karlsson (*Astron. Astrophys. Suppl.*, **7**, 35, 1972) has determined a number of spectrophotometric quantities from measurements in the micrometer tracings of objective-prism spectra of 825 O–F7 stars in a field in Monoceros. A one-dimensional classification is based on the strengths of the Hγ, Hδ and K lines. The absolute magnitudes and intrinsic colours for the O–A1 stars are obtained from their H$\gamma\delta$ strengths.

At Warner and Swasey Observatory objective-prism spectral classification data and related *UBV* data have been obtained for stars in several fields:

5400 stars of all spectral types to $V = 11{\cdot}5$ in $70° \leqslant l \leqslant 100°$, $-2° \leqslant b \leqslant +2°$ (Chartrand, Ph. D. Thesis, Case Western Reserve Univ., 1970);

6195 stars in an area of 17·1 sq. deg. at $l = 281°$, $b = 3{\cdot}°9$ (Wooden II, *Publ. Warner and Swasey Obs.*, **1**, No. 2, 1971);

159 OB stars in LF5 at $l = 129°$, $b = -2°$ (Snyder, Ph. D. Thesis, Case Western Reserve Univ., 1970). These data have been re-examined by McCuskey from classifications of slit spectra of 103 Å mm^{-1} dispersion, taken by Pesch.

A large scale survey for the detection of early A star concentration is also underway. Spectra for this survey have a dispersion of 1100 Å mm^{-1} at Hγ. The first results have appeared (06.155.040).

Geyer has completed his survey of the Southern Milky Way for stars earlier than A5 in the longitude interval $230° \leqslant l \leqslant 320°$ for latitudes $-10{\cdot}°5 \leqslant b \leqslant +10{\cdot}°5$. The limiting magnitude is about

10·5. Some 35000 stars are filed on punchcards. The classification system is close to the Henry Draper system.

Barbier, Bernard, Bigay and Garnier have classified about 300 stars in a region of $2° \times 2°$ in Cepheus (22^h; $+54°$) and determined the corresponding *UBV* data.

Bigay, Y. P. Garnier and Y. M. Georgelin have classified 29 exciting or early-type stars in the Carina nebula (07.155.033).

The criteria introduced by Nassau and collaborators for the identification and classification of M, C and S stars from very low dispersion objective-prism spectra in the near infrared have been measured quantitatively by Nandy and Smriglio and used for classification (03.113.058; 04.114.003; 06.114.073 and 50: 2.8). The accuracy achieved for the M stars is apparently about the same as for visual classification whereas the spectrophotometric technique permits R and N stars to be separated; the former are frequently not identified in the visual survey. In neither case can giants and dwarfs be separated.

A higher dispersion 300 Å mm^{-1} has been used by Rybski (50: 2.9) to study southern carbon stars in the spectral region 5100–6600 Å. He finds it possible to divide the objects into five groups: one with weak C_2 and CN features and Hα in absorption; a second with features attributable to a low C^{12}/C^{13} ratio; a third with strong C_2 and CN features and only moderately strong Na I in absorption; a fourth with very strong Na I in absorption and a fifth with Hα in emission. There remains a group of peculiar stars, all with weak CN (4.0) sequence and most with the low-temperature λ 6259 line present, and the group of stars with features similar to carbon as well as S stars.

A list of M, C and emission line stars has been presented by M. Barbier (04.114.027) and another containing about 100 stars is under preparation. Her search has also led to the detection of new VV Cep stars (06.122.040).

An Atlas of low-dispersion spectra of S stars in the blue spectral region has been published (03.114.104).

A number of papers list newly identified objects in various parts of the sky, e.g. (04.114.72; 06. 113.023, 114.021, 114.022, 114.027, 114.034–037).

3. *Automatic spectral classification*

Already the classification of objective-prism spectra by means of measurements of well-defined quantities in microphotometer tracings of the spectra pointed towards the advantage of a partial automation in the field of classification.

The arrivals of digitized microphotometers and the availability of computers for the processing of the data have contributed to a rapid development in the direction of complete automation. The advantages are obvious; for a number of galactic structure problems it is highly desirable to have two or three dimensional classification of a large number of stars together with their magnitudes and colour indices or gradients.

Whereas visual classification of low-dispersion spectra leads to a division of the objects into a number of natural groups the microphotometer-computer classification would in addition give the photometric data and possibly a refinement of the classification.

Papers dealing with these problems were presented at Symposium No. 50 (2.10; 11; 12; 13).

Automated spectrophotometry of high-dispersion spectrograms has also been undertaken (05.114.062).

The method of quantitative classification of late-type stars has been discussed by Spite (50: 1.14) and checked by measuring more stars with known parallaxes. The method was adapted to automatic measurements by L. da Silva and M. Spite, and is now used by S. Grenier. The precision of the method appears to depend critically on the focussing stability of the spectrograph.

A method for absolute calibration of objective-prism plates suitable for computer reduction has been presented by Ardeberg and Virdefors (*Astron. Astrophys.*, **20**, 177, 1972). Monochromatic magnitudes and absolute gradients in international systems are derived. No calibration devices are

needed provided each plate has about ten stars with known B and V magnitudes and MK classes. Possibilities exist to do also two- or three-dimensional spectral classification 'on line'.

II. CLASSIFICATION EMPLOYING MULTICOLOUR WORK

The development in this field is very fast. A large number of photometric systems exists. The indices defining the systems are as a rule chosen on the basis of experience gained from methods for spectral classification of slitspectra by visual inspection (narrow-band systems) or through measurements in microphotometer tracings of objective prism spectra (medium-band). The choice of indices is influenced by the aim: Should the system be applicable to all or nearly all types of stars, or only to stars occupying a well-defined limited area of the H-R diagram. Most of the medium and narrow band systems refer to the latter case.

A summary of photometric systems is given be Golay in *Introduction à la photométrie astronomique* (in press). A comparison of the systems is given as well as various applications. Stressed is also the care that has to be taken in interpreting the photometric information.

A review of the application of multicolour photometry has also been presented by Golay (05.113.038) with a view in particular to its use for spectral classification.

Comparisons of photometric systems have been discussed by Hauck (05.113.062), by Kuznetsova (05.113.028), and by Todoran (05.113.026). Moreno (05.113.037) has looked into the transfer between photometric systems in the two hemispheres.

1. *Wide-band systems*

The UBVRI system has been used extensively, in particular by Eggen for a number of stellar population studies of red stars (05.113.003, 113.011, 113.019, 115.004; 06.113.032; 07.122.088; *Monthly Notices Roy. Astron. Soc.*, **159**, 403, 1972; *Astrophys. J.*, **177**, 489, 1972; *Publ. Astron. Soc. Pacific*, **84**, 406, 1972). It has also been combined with his narrow-band system (102, 65, 62) for a large number of bright southern K- and M-stars (04.113.002). A study of the variability of M stars in a medium-band system, transformed to the *VRI* system is found in (05.113.017).

Blanketing corrections for Am stars have been deduced from *UBVRI* photometry alone (03.113.029).

Infrared stars have been observed in this system (04.113.021) and it has been used to derive [Fe/H] values for K giants (04.113.049) and G giants (05.113.036) near the North Galactic Pole.

At Edinburgh photographic *UBVRI* photometry has been made of stars in NGC 2264 (05.113.056) and for the identification of T-Tauri-like stars (50: 3.12).

Mendoza has used the *UBVRIJKL-system* or variations of it for a number of investigations. He has discussed flare stars (03.113.049), T-Tauri-like stars and peculiar objects (05.122.048, 06.122.100, 06.122.137, and *Bull. Tonantzintla Tabacuya Obs.*, **6**, in press).

A young stellar group has been studied in the *UBVJHKLN system* (07.152.003). Most of the stars were found to have infrared excesses.

Some observations in the *UBVRIJHKLMNQ system* (from 0·36 to 22 μ) or in a number of its passbands have been published:

The photometry of 6 infrared stars in K–Q is described in (03.113.027) together with spectroscopic observations from 2500–7000 cm^{-1}. Infrared spectra are also described in (03.114.011). Observations in the U–L bands have been made of high-luminosity M stars (04.113.038) and of Haro-Chavira infrared stars (*Astron. J.*, **77**, 374, 1972). Northern Wolf-Rayet stars have been observed in the H and K bands (*Astron. Astrophys.*, **20**, 333, 1972) and combined with b and v.

Other multiband infrared systems have been used:

The Minnesota system: B, V, R, I, 2·3 μ, 3·6 μ, 4·75 μ, 8·6 μ, 10·75 μ, 12·2 μ and 17·5 μ; has been used for observations of high-luminosity G supergiants (05.115.011) and for photometry of M, S and C stars (*Astron. Astrophys.*, **21**, 239, 1972). 11 of the latter were also observed spectroscopically between 7·5 and 14·5 μ. The spectral shapes obtained from the photometry and the spectrometry are in general agreement.

On a related 4 band system (3·5 μ, 4·9 μ, 8·4 μ, 11·0 μ) more than 100 C, S and M stars have been observed (05.113.010; 05.113.016) and several hot stars associated with nebulosity (05.114.039).

It is of interest to note in this connection that 93 % of the infrared sources in the Two-Micron Sky Survey have been identified with faint red stars in the Dearborn Catalogue (05.113.012) for the declination zone where the two surveys overlap. It is expected that only a few of the non-identified objects are peculiar.

Kron, Guetter and Riepe have prepared a catalogue containing all published *six-colour photometry* of stars *on the Lick system* plus a considerable amount of new photometry done at the U.S. Naval Observatory, Flagstaff. (Vol. XX, part 5 of the Publ. of the U.S. Naval Observatory, in press). A catalogue has also been prepared by Nicollier (Centre de Donneés Stellaires, RISP 2/1971). Practically ready is also a paper on six-colour photometry of 88 globular clusters (Kron and Guetter). 66 are in the Galaxy, 15 in the Magellanic Clouds and 7 in M 31.

J. Rousseau has revised the *B–G* index for G and K dwarfs in the six-colour system (06.113.034). Previous measurements were too small by a mean value of 0·08 mag.

M.-N. Perrin (50: 3.16) has carried out six-colour photometry of 9 foreground stars found in the Fehrenbach-Duflot survey of the Magellanic Clouds. They were all found to be metal-deficient. She has discussed the blanketing line and the *G–I* index of the six-colour system. The effects of blanketing on this index are small. Another advantage of this index is that it is little affected by stratification effects.

J. D. Fernie (07.113.011) has transformed the Lick six-colour data for 139 supergiants to the Johnson *UBVRI* system. The gain in this is that the latter system has been more widely used for galactic structure studies whereas the former has proved extremely useful for such purposes as fitting of model atmospheres (cf. 05.115.005–006).

The problem of the influence of spectral lines on the *GRI* magnitudes has been considered (05.113.004) and the correction for blanketing effects on these measurements have been computed for some stars.

Much photometry has been done in the *Geneva 7 colour-system*. The characteristics of the system have been summarized by Golay (50: 3.2) together with various applications and the main bibliographical references. A review has just appeared in *Vistas in Astronomy*, vol. **14**.

The pass-bands have been analyzed (06.113.006) by means of observations of stars with particularly well-known energy distribution as a function wavelength.

A catalogue of about 1500 stars has been compiled (05.113.009). It is expected that next edition will contain more than 2500 objects with about 250 stars of the southern sky.

In the applications five parameters are used to determine effective temperature, luminosity and metal abundance effects.

Stellar atmosphere models, calculated by Peytremann at Geneva Observatory (Thesis 1970) are used to analyze the various diagrams of the $UBVB_1B_2V_1G$ photometry. Energy distributions of uniformly rotating stars have also been calculated and compared with the seven-colour photometric observations (03.116.012 and Maeder and Peytremann, 1972, *Astron. Astrophys.*, in press). There is a complete agreement for main-sequence stars earlier than A7; for later types observed effects are larger by a factor of 2.

Golay has presented a paper on a new method to determine distances by using the seven-colour Geneva system (54: II.2). The method can be applied only if a very large number of stars with well-known parallaxes are observed in the system and if the assumption "Two stars (unreddened and not spectroscopic binaries) with the same seven colours have the same absolute magnitude". This appears to be correct for stars near the main sequence, and the method may be useful for the determination of the distances of galactic clusters. At the same time it will give spectral classification and the chemical composition of the star photometrically.

The photometric classification has been applied to the following samples of stars (Grenon, Thesis, Geneva Observatory): Gliese's catalogue; Red giants in the local system; Stars in the regions of the North and South Galactic Poles; and Eggen's high velocity star catalogue.

Among special groups of stars observed in the Geneva system are Am stars (03.113.045;04.113.007),

δ Scuti stars (05.122.010) and A, F supergiants (B. Hauck, C. Nicollier 1972, Third Coll. on Astrophys., Trieste (ed. M. Hack), p. 153). For all groups temperature, luminosity and metallicity are derived.

Hauck has also revised the calibrations of the three-dimensional classification of stars of types A0 to G5. A comparison between spectroscopic measures of strong-line and weak-line stars with the parameters of the Geneva system (04.114.134) indicates that the metallicity parameter of the latter is to be preferred.

Colour excesses have been simulated by exact integration with the aid of electronic computer and the results have been compared with the *UBV* and Geneva systems (06.113.057). Also the question of the classification parameters was studied. Certain properties were found allowing the discrimination of individual peculiarities in the different extinction laws.

The available material has been used by Maeder and Rufener to study 660 stars for variations of small amplitude (*Astron. Astrophys.*, **20**, 437, 1972). They find that all Ia supergiants are variable in light with an amplitude in colour index of about 0^m02–0^m04; for the Ib supergiants a large fraction show variability.

Also a large fraction of the OB stars show photometric variations.

2. *Medium-band systems*

H. L. Johnson and collaborators have been working on two projects. One, *the 13-colour medium-narrow band photometry* of bright stars, has been completed. All stars brighter than $V = 4$ have been observed in the 13 colours over the entire sky, plus many fainter stars. The total is about 2000 stars. Using these data, plus *UBVRIJKL* photometry, smoothed flux density distributions have been computed from 3000 to 13000 Å for every star on the list. At the present time the only publication is a computer-printed book.

The first results from the second project, *Fourier-transform infrared spectroscopy* have been published (04.114.033). Since then a new 0·5 cm^{-1} instrument has been put into operation. Two papers in press deal with the 0·5 cm^{-1} resolution infrared spectrum of α Herculis. Further papers are being prepared on the spectra of α Sco, R Leo, χ Cyg, VY C Ma, the Sun (observed from an altitude of 14 km), and other stars.

Intermediate-band photometry in the ultraviolet-visual portion (bands 33, 35, 37, 40, 45, 52, 58, 63) of the Johnson, Mitchell thirteen-colour system has been carried out by Mendoza for stars in the Scorpius-Centaurus association and bright southern stars (06.152.003). A reddening-free index, *b*, measuring the depression at passband 37 was found to give a satisfactory calibration with absolute magnitude. Application of the system has also been made to stars in the Magellanic Clouds (06.159.021). It is somewhat surprising that the calibrated absolute magnitude diagram leads to a distance modulus for the Small Cloud about 0·5 mag smaller than for the Large Cloud.

Walraven's five-colour system continues to be used by the Leiden astronomers at their Southern Station and magnetic variable stars (06.113.004), the eclipsing binary HO Tel (*Astron. Astrophys. Suppl.*, **7**, 83, 1972) and the supernova in M 83 (07.125.105) have been investigated.

Most of the B stars brighter than $m_v = 6{\cdot}5$ and with spectral types B5 and earlier have been observed with *the uvby and Hβ systems* (50: 3.7). D. L. Crawford and J. V. Barnes have published a list of 304 stars as standard-stars for the *uvby* system (04.113.050) together with a list of an additional 50 stars of special interest. Crawford (54: IV.1) has summarized the available data in the *uvby β* system giving a detailed bibliography, to which I refer. The application of this system is likewise discussed and in particular the absolute magnitude calibration. The latter is based on

(1) determination of the shape of the ZAMS relation between M_v and β for the A and F stars, by observations in clusters;

(2) determination of the zero-point of this relation from a fit to trigonometric parallax stars;

(3) determination of the V_0 versus β relation for individual clusters containing *B*-type stars;

(4) determination of the best fitting mean relation for *all* clusters;

(5) determination of the zero-point for the derived mean relation in (4). This was obtained by

forcing the distance moduli of the three clusters of step (2), the Pleiades, α Per and IC 4665, to agree with the calibration.

(6) Checking the preliminary calibration for systematic errors due to age differences, rotational velocity effects, frequency-of-binary differences from cluster to cluster, spectral type effects, emission line stars, etc. In general few significant effects of these types have been found. A preliminary M_v/β calibration curve is given, valid for stars on or near the ZAMS, for $-7 \leqslant M_v \leqslant +1$; the curve should also be useful for evolved stars. The final calibration will allow for evolutionary effects via a δM_v correction, in terms of a $\delta\beta$ above the ZAMS in the β versus c_0 diagram (c_0 is unreddened c_1 index).

Graham (04.113.057) has proposed a method for the photometric classification of high latitude blue stars using the Strömgren *uvby* system. The characteristics of the *uvby* system in this context were discussed and an application was made to 94 stars from the Feige list of high latitude blue stars. He has made additional remarks about the method (50: 3.15) and described its further application to stars from the Slettebak and Brundage list (06.114.072).

Graham (07.126.011) has also applied the *uvby* system to a study of white dwarfs. He notes that although the *uvby* photometry provides near line-free colours of the white dwarfs the proper interpretation depends upon the knowledge of the precise transmission characteristics of the filters as well as upon the calibration of those filters. Therefore, photoelectric scanning is probably to be preferred for studying the energy distribution of white dwarfs.

Eighty field horizontal-branch stars have been found by means of Strömgren four-colour photometry of faint A stars (60 by Philip and 20 by Drilling). Over 50 blue horizontal-branch stars have been measured in 10 globular clusters. The field stars have the same indices as do the blue horizontal-branch stars. In intermediate metal abundance clusters, such as M 3 and M 13, the blue horizontal-branch stars have lower surface gravities as measured by the δc_1 index (*Astrophys. J.*, **171**, L51, see also 50: 3.14).

Log g, θ_e diagrams are being constructed for field A stars and blue horizontal-branch stars in globular clusters. The observational data can be checked directly with the predictions of evolutionary theories.

uvby photometry has been used to study Ap stars for light variations (05.113.047) and for the determination of the surface gravities of the field blue-straggler stars (05.113.015).

Luminosity and metal abundance parameters for Hyades group stars and other young disk stars as well as for old disk stars have been examined (06.115.017) and a procedure for computing their luminosity from the intermediate-band indices (*uvbyβ*) has been developed.

A catalogue of 370 bright southern A, F and B stars in the *uvbyβ* system has been presented (*Monthly Notices Roy. Astron. Soc.*, **159**, 165, 1972).

437 field stars (mostly of type A) and A stars in the clusters Coma Berenices, Praesepe, NGC 6633 and NGC 1662 have been observed in a system similar to the Strömgren *uvby* and in Hβ (03.113.024).

By means of a four-colour spectrometer attached to the Copenhagen 50-cm telescope on La Silla, Strömgren, Olsen and Jörgensen, have completed observations in the *uvby* system of all stars in the Bright Star Catalogue, fainter than 4^m5, south of $+10°$, and of spectral type G0 and earlier (2700 stars). The reductions will probably be finished in the middle of 1973.

By means of the same equipment, Olsen has observed about 100 objects in a *uvby* programme of components of visual double stars consisting of a late-type giant primary and an AF type main-sequence secondary. The purpose is a calibration of absolute visual magnitudes of late-type giants.

An intermediate-band photometric system for the classification of the metal abundance of the RR Lyrae variables has been set up (06.122.038) by replacing the b band in the Strömgren system with a K-band of 60 Å half-intensity width, centered on λ 3933. The system has thus, u k, b, y and β filters and $k - b$ may serve as a metal index.

The general scheme of the three-dimensional photometric classification of stars *in the Vilnius system* has been described by V. Straižys and Z. Sviderskienė (07.115.007) with references to previous works Other references are found in (04.113.009–011; 058–065; 06.113.054–056).

The eight-colour intermediate band photometric system is developed for purely photometric determination of spectral classes, absolute magnitudes, [Fe/H] ratios and interstellar reddening of the stars. The glass filters defining the system have been replaced by high transparency interference filters. The classification will reach stars of magnitudes 15–15·5 with a 160-cm reflector.

Among the photometric programme being realized in the Vilnius system are:

(1) A two-dimensional classification of BS stars having no MK classification. About 700 stars are already observed and classified (*Bull. Vilnius Obs.*, No. 34, 1972).

(2) The investigation of interstellar absorption in the direction of a number of important galactic and extragalactic objects.

(3) The investigation of the stellar population in different galactic directions.

(4) The investigation of certain pulsating variable stars. Some programmes are being realized in collaboration with other Soviet observatories.

The theoretical investigation of photometric systems by integration of stellar energy curves continues also at the Vilnius Observatory. For this aim a catalogue of detailed energy distribution curves of 50 representative stars of different spectral types and luminosities in the interval 3000–10000 A is prepared summarising all the available data (*Bull. Vilnius Obs.*, No. 35, 1972). These energy curves can be used to compute the parameters of photometric systems and the relations bstween their magnitudes and colour-indices.

Notni, Babelsberg Observatory, reports that the Vilnius system extended to a 10-colour system has been used for observations of magnetic stars during 1970–1972.

The *Dominion Astrophysical Observatory photometric system* for early-type stars contains two reddening-independent parameters, $Q(35)$ and $Q(38)$: The former measures the Balmer discontinuity and the latter the strength of the upper members of the Balmer series (50: 3.3). The instrument and the colour system are described in (05.034.081). Preliminary calibrations of the parameters exist and applications to the Pleiades, NGC 7243, NGC 2169, h and χ Per and Cep. IV have been made. Standard stars defining the system have been given (05.113.013).

The *David Dunlap Observatory (DDO) photometric system* for classification of late-type stars measures by means of intermediate bandpass filters the strength of the cyanogen band shortward of λ4216, the break in the continuum at the G band, and a colour index in the λ4500–λ4900 region of the spectrum (50: 3.4). It permits classification of G and K stars in terms of effective temperature (spectral type), surface gravity (luminosity class) and heavy element abundance and the determination of the interstellar reddening.

The system has been used to isolate stellar population among field stars without any prior knowledge of their distances (05.155.013). It has also been used on a sample of bright field stars near the sun (05.113.025) to see whether strong CN stars have different kinematics than normal solar neighbourhood giants.

The giant stars in a number of old and intermediate clusters have likewise been investigated and the mean CN residuals determined (50: 3.4; 07.153.027).

The DDO photometric system has also been applied in a three-dimensional spectral classification of Population II stars (50: 3.5). Mean [Fe/H] values derived for the studies globular clusters are: M 3, −1·01; M 5, −0·68; M 10, −1·44; M 13, −1·69 and M 92, −1·96 with an uncertainty of about ±0·3. A second interesting result derived from the photometry and the subsequent analysis was that the masses for the stars in the post-helium flash stages of evolution (horizontal-branch and asymptotic-branch stars) were found to be systematically smaller than the masses for the pre-helium flash red giants.

3. *Narrow-band systems*

Wing has established an *eight-colour narrow-band system* for the spectral classification of late-type stars (05.113.042). The eight passbands follow from the reduction of an initial system with 27 bands. Compromises were necessary and the new system does not measure bands of ZrO and H_2O. Thus, S stars cannot be classified. The eight passbands are centered at $\lambda\lambda$7117 (for TiO), 7545 (cont. M stars) 7806 (cont. GKC), 8122 (CN), 10392 (cont.), 10544 (VO), 10800 (cont.) and 10968 (CN).

https://doi.org/10.1017/S0251107X0002513X Published online by Cambridge University Press

The system has been applied to the classification of M dwarfs (50: 3.11), carbon stars (05.113.043) and M-type supergiants (05.113.044; also in Coll. on Supergiant Stars, p. 160, (ed. M. Hack), Trieste 1972).

Somewhat related to the above system is a *five-colour near-infrared system* (05.113.045). The medium pass-band filters are centered at 7817 Å (TiO), 8778 Å (cont.), 8885 Å (TiO), 10351 Å (cont.) and 10506 Å (VO). The system has been designed in particular for the determination of the near-infrared properties of the intrinsically cool stars found in the Two-Micron Sky Survey (NASA SP-3047, 1969). TiO and VO indices are calculated together with a composite index D. The latter is dominated by TiO for stars earlier than M7 and then by VO. Most of the previously identified infrared objects have late M-type photometric indices. They may be long-period variables. The system has also been applied to a study of Mira variables (*Astrophys. J. Suppl. Ser.*, **34**, 375, 1972).

Narrow-band photometry has been used for problems of stellar metal abundance determinations: The techniques with the *Cambridge* grating spectrometer have been discussed by R. F. Griffin recently in an attempt to measure the Sc I 6305 Å line in late-type stars (03.114.043).

Williams has applied the method to the study of the iron abundance in G and K giants (06.114.004; *Monthly Notices Roy. Astron. Soc.*, **158**, 361, 1972) and sodium and manganese abundances in the Hyades and field giant stars (06.114.088).

In all cases the observed indices are compared with computed theoretical indices using stellar models of known composition to derive the abundances and other parameters. The temperatures of the stars are obtained from colour indices, and their gravities from independent luminosity estimates.

A similar technique has been applied by Nissen, who reports that photoelectric indices of the strength of groups of weak metal lines have been measured for a large number of F-type stars. The metal-to-hydrogen ratio of the stars has been derived by model-atmosphere calculations and Strömgren's m_1 index has been calibrated in terms of this ratio (03.114.082; 04.153.007; 07.064.043).

For G and K giants Andersen, Kjaergaard and Gustasson (*IAU Coll.* No. 17) compared observations of two photoelectric narrow-band indices, carried out with Nissen's echelle-spectrometer, with indices for the same regions computed as functions of the fundamental stellar atmospheric parameters on the basis of model atmospheres. The indices measure the strengths of two groups of faint and stronger metal lines, respectively. A new theoretical calibration of $R-I$ as a measure of effective temperature was used. The primary aim of the investigation was to provide accurate relative metal-to-hydrogen ratios for the calibration of photometric classification systems. It was found that [Fe/H] could be determined with an accuracy of about $\pm 0{\cdot}10$ (m.e.). Furthermore, the so-called micro-turbulence velocity was found to be practicly constant within the $T_{\rm eff} - g -$ [Fe/H] ranges considered (mean value $1{\cdot}1 \pm 0{\cdot}2$ km s^{-1}). Similar work is being done for dwarfs and supergiants of type G by Kjaergaard and collaborators.

This investigation is related to the calibration of atmospheric parameters for G and K stars (06.064.021) by means of photoelectric indices measured in the Copenhagen system (Gyldenkerne and collaborators). Another type of calibration work is being made by observations of components of visual binaries (06.113.029; 07.117.040). The Copenhagen photoelectric classification, with the *gnkmf* indices, is now being extended to the southern hemisphere.

Oja has continued his investigation of the calibration of the Uppsala narrow-band system for late-type stars (pass-bands of about 45 Å at $\lambda\lambda$ 4508, 4269 and 4176) in terms of intrinsic colours and absolute magnitudes. A first investigation (03.113.025) showed that colour excesses in $B-V$ can be obtained with a mean error of about $0^{\rm m}03$–$0^{\rm m}05$ and absolute magnitudes M_V with a mean error of about $0^{\rm m}6$. This investigation is now being extended to the magnitude limit $V=6$ all over the sky; the observations of all southern stars have been completed at the European Southern Observatory on La Silla and it is expected that the remaining northern stars are observed in 1972–1973. The resulting improved calibration will be applied to the study of the stellar distribution in the North Galactic Pole region according to the plan outlined in (03.113.025).

Narrow-band photometry of individual hydrogen lines have been carried out by many astronomers. Most frequently Hβ is measured (e.g. 04.115.012), often together with *UBV* (e.g. 06.113.049) or *uvby* (e.g. 06.113.007, 06.113.043).

Häggquist has observed the Hγ line for 365 northern stars and derived from his narrow-band system also a monochromatic magnitude, m_{4508}, and a colour equivalent (05.113.014).

Furenlid has attempted photographic narrow-band photometry of Hγ and Hδ in the spectra of a number of B-stars (05.113.001). He has also studied the possibility to extract main-sequence B stars of small and moderate rotational velocity by narrow-band photometry giving the hydrogen-line shape, and the magnitude of the Balmer jump (04.113.048). He proposes that filters with half-widths of 10, 30 and 130 Å would give useful parameters for the Hβ or Hγ line.

J. L. Lutz and Th. E. Lutz have made Hγ observations of early-type field stars (07.113.037).

Feinstein has measured the Hα, Hβ and Hγ lines of 350 stars with narrow-band interference filters. His list includes stars of spectral types: B, Be, metallic-line, helium-weak, etc. 90 of these stars, taken mostly from the list of Crawford and Mander for Hβ, were employed as standards and define the Hα and Hγ values. The programme was designed for detection and study of the variation with time of the emission in the Balmer lines in early-type stars. A preliminary report has been given (50: 3.9).

Photoelectric photometry of the Ca II K-line is now available for 369 field stars (06.113.052). A number of stars exhibiting spectral peculiarities are identified by means of the K-line and intermediate-band photometry.

K-line photometry has also been carried out for stars in Population I clusters (06.113.053).

The possibility to determine luminosities for O stars by narrow-band observations of the N III triplet $\lambda\lambda$ 4634, 4640, 4641 and the He II λ 4686 has been investigated (03.113.039). The technique applied is similar to the Hβ method with a narrow and a wide passband centered on each line.

In the near infrared the O I λ 7774 line has attracted much interest.

A narrow-band system of three passbands centered at λ 7755, 7772 and 7792 (half-widths 20, 25, 25 Å) has been set up by Mendoza (06.113.060) for measurements of the total absorption of neutral oxygen at λ 7774. The neutral oxygen index reaches a maximum of about $+0^{m}045$; it is measured with a probable error of $\pm 0^{m}004$. Comparison with equivalent widths is satisfactory.

Osmer (07.114.052) has observed the O I line with a similar system in 59 stars of types A0–G3 and luminosity classes Ia–V. He finds it possible to determine the absolute magnitude of the F supergiants with an accuracy of $\pm 0^{m}5$.

Sorvari, University of Rochester, is setting up a photometric system to measure the strength of the oxygen triplet $\lambda\lambda$ 7771, 7774, 7775. He expects that it will provide a photometric luminosity for A and F supergiants, more accurate than present spectroscopic luminosities. It should facilitate rapid coarse classification of fainter stars.

A spectral type indicator for M giants and supergiants in the near infrared is proposed (05.114.052). It measures the spectral region at λ 7125 which is part of the λ 7050 band system of TiO. Again the technique is similar to the normal Hβ method.

Model stellar atmospheres and laboratory data for atomic and molecular lines may be used to compute narrow-band indices for G and K giant stars.

Reasonable agreement has been obtained by Bell between computed indices and indices observed on the Cambridge system (03.113.016). The dependence of the indices on the model parameters has been examined.

Bell and Gottlieb (05.113.008) have also computed synthetic spectra and analyzed the dependence of Spinrad and Taylor's spectral indices on stellar atmosphere parameters.

A similar method has been applied to F and G dwarf stars (06.113.027). Comparisons between computed and observed data have been made for investigation of metallicity, luminosity and effects of interstellar reddening.

A similar investigation for selected regions in spectra of A and F stars has been undertaken (06.115.001) with the aim to derive luminosity criteria. The ratio λ 4178: λ 4172 is found to be well correlated with surface gravity for stars with solar abundances.

The consequences for spectral classification of possible variations of abundances and microturbulence at a given T_{eff} and log g are discussed.

4. *Spectrum scans*

A large number of investigations involving photoelectric scans have occurred. However, in most cases the aim of the scans is establishing support for the analysis of high-dispersion Coudé spectra, and the report of these continuum studies falls under another Commission.

An analysis of photoelectric spectrum scans from 3100 to 6000 Å of early type stars has been carried out by A. Gutiérrez-Moreno and H. Moreno (50: 3.17). It was found that the best correlative with MK classification is given by the equivalent width of Hβ and the Balmer discontinuity. The scheme works well for B0–A1 stars of luminosity classes V to III. Class I is clearly separated from the less luminous stars.

H. Moreno (50: 3.18) has studied the intensity distribution of late-type stars using photoelectric spectrum scans of the same spectral range. In a preliminary classification scheme of the M stars the TiO band at 4955 Å and the 4226 Å line of Ca I are used.

Photoelectric scans of an M supergiant and of 3 carbon stars have been obtained with 20 Å resolution from 3400 to 6000 Å and with 40 Å resolution from 6000 Å to 11000 Å. (07.114.044). The variations of the dominant spectral features (C_2, CN, TiO) with spectral class are described.

III. CATALOGUES AND ATLAS

An important aid for keeping track of new data has been established in the Centre de Données Stellaires and its Information Bulletins (ed. J. Jung). Three issues have appeared: No. 1, (05.002.043); No. 2, (05.002.026), and No. 3, July 1972.

Of particular interest for Commission 45 are the "Lists of spectroscopic and photometric Catalogues recently published or to be published" prepared by B. Hauck, in No. 1 and No. 2.

Jaschek (50: 4.1) has considered the problem of keeping an astronomer well informed about new data, considering the steadily increased flow of information.

The annual growth of spectral types on the MK system is about 3000, on the HD system and related (with occasional indication of luminosity group) about 11000. Similarly photoelectric colour indices increase annually with about 4000, photographic indices with about 10000.

Obviously, updating catalogues have to be published rather frequently and probably continuously. The use of Data Centers should be considered. They may be of two types: passive centers store information and release it on request, active centers publish all information and distribute it.

Hauck (50: 4.2) has discussed the homogenization of data in photoelectric photometry. The principal sources of inhomogeneity are the photomultiplier, the filters, the reduction to outside the atmosphere and the lack or the bad use of standard stars. Reduction to a file of homogeneous data for each system is necessary. Another file should show in which systems a star has been measured so that comparisons between systems may be made.

A number of catalogues have been referred to in the various preceding sections. Below follow some additional complications of data.

C. Jaschek, L. Ferrer and M. Jaschek have published a "Catalogue and bibliography of B-type emission line stars" (06.114.129). Listed are stars of types B0 to B9 with accurate position known. Tabulated is also the number of Be stars in clusters, associations and special regions. An extensive bibliography is given.

Bidelman's Data Bank at Warner and Swasey Observatory is continually being updated (50: 4.3). Several of the new data catalogues are entered into the file in IBM-card-form. Eventually the entire file will be on punch cards.

A bibliographical card file of MK classifications is being maintained by Garrison at the David Dunlap Observatory.

P. Kennedy, Mt. Stromlo Observatory, has compiled a catalogue of MK spectral classification published since Jaschek's La Plata Catalogue. She is also distributing supplements to it (on cards).

G. Goy reports that "a new general O type stars catalogue" is in preparation at the Geneva Observatory. It is an "up-to-date" edition of the Hiltner Catalogue (*Astrophys. J. Suppl. Ser.*, **2**, 389).

This catalogue will contain: spectral types, polarisation data, H II region membership, complete monographies (binarity, multiplicity, peculiarities, etc).

A second catalogue of emission-line stars of the Orion population has been published by Herbig and Kameswara Rao (*Astrophys. J.*, **174**, 401, 1972). It contains spectral classification, emission-line intensity class, type of star, light range and classification of the light range and classification of this light curve, nebula with which the star is associated, remark when the star is nebulous or double and bibliography.

The "Catalogue of stars observed photo-electrically" by C. Jaschek, E. Hernandez, A. Sierra and A. Gerhardt is in press and will be distributed in the end of 1972. It contains the references to all photoelectric work done before 1969 taken from about 2000 bibliographic entries.

The "Atlas of spectral classification at 42 Å/mm" by J. Landi Dessy, M. Jaschek and C. Jaschek is in the final stages for publication.

The first Bonn Atlas for Objective Prism Spectra (03.003.033) gave spectra of standard stars in dispersions 240 Å mm^{-1} at Hγ. The work in the second part which will show spectra of standard stars in the dispersions 645 and 1280 Å mm^{-1} at Hγ has progressed far enough for samples to be available (Symp. 50: 2.4). Miss Seitter expects to follow this with a third part which will give spectra of about 70 peculiar stars in all three dispersions.

IV. CONCLUSIONS

A principal aim of the spectral classification is the division of the stars into subgroups which are homogeneous within specified linits. Presently the definition of these subgroups is becoming sharper. In the two-dimensional system there is in all classes a need of segregation of certain types: in the early classes there are peculiar stars of a variety of types as well as rapid rotators; in the later ones a division accordingly to metal content is necessary. This aim is achieved in the classification of slit spectra by the use of high dispersion for the study of weaker lines; attempts are made in the field of low-dispersion objective-prism work to achieve it by the use of quantitative criteria, and it is certainly achieved in the quantitative spectral analysis by photoelectric measures of the intensities in pass-bands selected to isolate the most sensitive criteria.

It is necessary that the refinement of these criteria continues. Additional criteria are certainly to come from the research in the ultraviolet and infrared spectral ranges. The combination of model-atmosphere and stellar-interior calculations will yield synthetic spectra and computed narrow-band indices for stars in various stages of evolution; thus, a calibration may be made of the observed criteria in terms of the basic parameter mass, age and chemical composition. The priorities in this area will most likely be set by the requests for data for model-atmosphere analysis.

An important step in the field of objective prism classification is the reclassification of the southern HD stars into a homogeneous MK system. It is hoped that every effort will be made to include also the northern stars in this project. Naturally, it is desirable that accurate two-dimensional classification surveys are extended to fainter stars at least in certain key areas (such as the galactic poles where surveys for certain types of stars have been successfully carried out). The search for special classes of objects needs to be continued and intensified, particularly in the north. As automation of the classification process appears to develop rapidly, complete surveys of rather faint stars may soon be undertaken with an accuracy sufficient not only for statistics of rather wide classes but for the identification of astrophysically important sub-groups.

The wide-band multicolour photometry suffers to a certain extent from the large number of systems in existence. As two photometric systems do not correlate unless they have closely identical response functions, comparison of systems may be confusing, unless, of course, it is limited to stars having smooth flux distributions and no interstellar reddening. However, it is difficult to see that a diminution of the number of systems will be made; it has been proposed before with no result, and undoubtedly all systems have their merits.

It appears fundamental to establish the HR standard stars so that the various parameters of the existing classification systems may be interpreted in terms of the fundamental astrophysical parameters.

Finally, there is the problem of information. The data flow will continue to increase and the various data centers will become more important. The question of having active or passive centers must be given serious thoughts; there were divided views on this at Symposium No. 50. Many astronomers may feel that printed catalogues available in the observatory library are more useful – just because they are on the spot when needed – than data on magnetic tape at a remote data center. However, the evolution in computer technology is fast and a situation in favour of the passive centers may soon exist. In the meantime it appears important that catalogues and supplements to existing catalogues be printed and distributed as widely as possible. Among the larger data banks not yet generally available is Bibelman's bibliography of spectroscopic data; it would be welcome to see it at least in a punch card format.

B. E. WESTERLUND

President of the Commission

WORKING GROUP FOR COLLECTION OF PHOTOMETRIC AND SPECTROSCOPIC DATA

This Group was formed during the meeting of the General Assembly in Brighton on August 22, 1970 with the following members: B. E. Westerlund, W. P. Bidelman, M. Barbier and B. Hauck. In the beginning of 1972 C. O. Jaschek was asked to join this group as he is also a member of the IAU Working Group on Numerical Data.

The first work of our Group was to establish a list of catalogues recently published or in preparation. For this purpose a circular letter was sent to all members of our Commission. Dr Crawford, President of Commission 25, kindly sent our letter to the members of his Commission. The first list was published in the "Bulletin d'Information no. 1 du Centre de Données Stellaires de Strasbourg". A complement has been published in the second issue of this bulletin. We thank all colleagues who have contributed, and we hope that many colleagues will contribute to the success of a second list sending us their information and data.

At the IAU Symposium no. 50 we decided to send a questionnaire to all members in order to help us with the selection of spectroscopic and photometric catalogues, which should be punched or registered on magnetic tape. 10 answers were received. Then the "Centre de Données Stellaires" was asked to punch those lists that were not yet on machine readable form.

All information concerning the material collected by our Group and available has been published in the "Bulletin d'Information du Centre de Données Stellaires".

The list of photometric catalogues compiled by B. Hauck and available at Strasbourg is given below.

In the future our Group should devote more effort to the collection of spectroscopic data. It would be most helpful, if contributors send information and data to Dr C. O. Jaschek and Dr W. P. Bidelman.

B. HAUCK

Chairman of the Working Group

List of photometric catalogues available at Strasbourg

(1) *uvby* system.

(2) two-micron sky survey (Cal Tech).

(3) six-color system; (a) Nicollier catalogue, (b) Kron catalogue.

(4) Catalogue of Blanco et al. (*UBV*).

(5) A new catalogue of Stellar *UBV* photoelectric photometry (see the description of Mermilliod in the "Bulletin no. 3 du Centre de Données Stellaires de Strasbourg").

(6) Tape with measurements in the following systems: Borgman, Argue, Kruszewski, Vilnius, (*P*, *V*), $(UBVr)_{20}$, Walraven, DDC, DAC, Bahng, Wood, Willstrop.

(7) Geneva system.

In order to obtain a tape write to Dr J. Jung, Director, Centre de Données Stellaires, Observatoire de Strasbourg, 11, rue de l'Université, F–67 Strasbourg.