THE INTERNATIONAL ULTRAVIOLET EXPLORER

A. Heck

Villafranca Satellite Tracking Station, ESA

As the IUE satellite is the subject for a series of detailed papers to be published in a forthcoming issue of Nature, we will give only a brief description here. The interested reader should refer to Nature.

The telescope is a Ritchey-Chretien type with a clear aperture of 45 cm. The effective focal ratio is f/15. Two spectrographs can be operated, one, in the low dispersion mode (about 6 A) and another in the high dispersion mode (about 0.1 A). The detectors are SEC Vidicon television cameras. Each spectrograph has two apertures: a 3 arc sec circle and a 10 X 20 arc sec ellipse. The limiting magnitudes for objects observed are $V = 8$ for hot stars at high dispersion, $V = 14$ for galaxies at low dispersion. The output is available as plots, magnetic tapes and photowrites. The observatories are located at Goddard Space Flight Center, Greenbelt, Md. for U.S. observers and Villafranca Satellite Tracking Station, Madrid, Spain for U.K. and E.S.A. observers.

Continued from page 286

the digitized intensity curve. Furthermore, this interaction is the most subjective part of the measuring process.

Barry et al. obtained a measure ΣH of the Balmer line strength ΣH (= $W_\gamma + W_\delta + W_\xi$) linearly correlated to the β index corresponding to a mean error of $\pm 0^{m}.010$ in β for one plate. The ratios 3860/3872 and 4078/4064 were used for luminosity calibration with a m.e. of about $+0^{m}.8$ in M_V. The metallicity was inferred from the FeI lines 4046, 4072, 4326, 4384 with an accuracy [Fe/H] ≅ ±0.2 again comparable to the δm_1 index of the Strömgren photometry. Comparison shows, however, that the photoelectric uvbyβ photometry takes half the time at the telescope than to take the image tube spectra. Of course, quite a bit of information was not extracted from these spectra. The advantage lies in the direct physical meaning of the equivalent widths compared to the indices which are related to physical quantities by complicated relations needing difficult calibrations.

Thompson worked on photographic spectra of F and G type stars in the region 5400-6600 A at 15 A/mm with a digitized Joyce-Loebl microphotometer, measuring one plate with 4 spectra per day. By variance analysis about 600 lines down to very faint intensities $W\lambda$ = 10 mA can be treated. The r.m.s. error of the equivalent widths is of the order of 5 mA. A similar error is indicated by Cassatella et al. for 3.2 A/mm spectra of K giants. As in the case of Thompson the measured data are transferred to magnetic tape, and then processed by an IBM 370/125, taking about 15 min. for a 35 A wide window with about 200 lines.

3. SEMI-AUTOMATIC CLASSIFICATION AT LOW DISPERSIONS

3.1 Hardware and Software

The examples which I am going to describe are based on objective prism plate material. But one may reach even fainter limits and correspondingly larger numbers of spectra by using a transmission grating in the converging beam of a large telescope (Hoag and Schroeder 1970; Miller and Graham 1974) or by construction of what I called a field spectrograph such as the one to be described by Geyer (1978). In this way one may reach with modern photographic emulsions stars of 21^{m} over the whole optical field of about 0.8^{o} with a modern large telescope.

Before one can start the programming of the automation process one has to digitize the microdensitometer. Lynga and Arinder (1972) gave a very instructive description of how they computerized their

Chalonge-Laffineur microphotometer using the interpretative language BASIC. Lynga and Arinder's ASTOL BASIC incorporates a set of interconnected programmes which allow to measure transparencies on the plate, transform them to magnitudes m(λ) and store them on tape. We digitized the Brückner/Göttingen microphotometer in much the same way, and applied in addition two exact glass scales to digitize the X- and Y-coordinates (Schmidt-Kaler et al. 1976). The software system (which was designed by Dr. Schlosser) is called ASTRO BASIC and executes all the processes mentioned above in continuous interrelated succession.

Nowadays fast digital microphotometers with extensive software are commercially available. The best example is probably the PDS machine (Photometric Data Systems, Perkin Elmer Corp.) coupled to a PDP11 minicomputer. This machine can produce a detailed two-dimensional map of photographic density. It scans the plate automatically, linearizes and takes account of the variations in background density; it will be dealt with in detail in section 4.

The first step in handling the plates is to determine the dispersion curve D (λ, P), where P denotes the position on the plate. On a Schmidt plate this is very nearly given by the Hartmann formula, constant over the plate. On astrograph plates we could approximate the dependence from the southern edge of the plate (the prism edge) sufficiently well by a third degree polynomial.

The next step usually is the construction of the photographic calibration curve. Sensitometer spots, half filters, multiple exposures, objective gratings, step wedges and other devices have been used. We obtained the best results by constructing the characteristic curve of the plate directly from measurements of the spectra on it near 3600 and 4400 A, which had been observed photoelectrically in the UBV system (Schmidt-Kaler 1966, Ardeberg and Virdefors 1972, Schmidt-Kaler et al. 1976). Corrections of the photoelectrically measured broad-band magnitude have been computed to obtain the monochromatic magnitude near 4400 and 3650 A, resp., for various spectral types and reddenings. If the calibrating sequence is restricted to O-F5 stars with $E_{B-V} < 1^m$ such corrections amount to $0^m.02$ at most. This procedure to obtain spectral intensities on a large-field plate is the analog of the usual photoelectric calibration of direct photographic plates. From the measurements the photographic calibration curve can be interpolated at any desired wavelength. The accuracy of an average curve, based on about 30 suitable stars, is better than $\pm 0^m.02$. Such accuracy is absolutely vital for quantitative spectrophotometric measurements which in turn are vital to obtain a two-dimensional quantitative classification from those low-dispersion spectra. For the approximation of the characteristic curve the Baker density or its generalization by Moffat (1969) has proved more practical than the transparency.

The next and most difficult step is the determination of the continuum. This was done after thorough inspection of the available high dispersion spectral atlases (e.g. Griffin 1968, Hiltner and Williams 1946, Moore et al. 1966, Seitter 1970) to take account of blends. For O-F5 stars at the spectral resolution of the Hamburg Schmidt objective prism survey (568 A/mm near H_γ dispersion and 14 A resolution, corresponding to 2" seeing) we found 9 useful windows in the blue-ultraviolet region. The continuum was then well fitted by tan hyp f(x), where f(x) represented a fourth-order polynomial; the fit was checked and corrected on the display. In the case of later-type stars we defined a pseudo-continuum and correspondingly an equivalent area (=line depth x half width) instead of equivalent width, when the wings of the line are heavily disturbed by blends. Equivalent widths (or similar quantities) must be used in the case of objective prism plates with varying resolution because of the variations of the seeing since only these are (as a measure of energy) in principle independent of the variable (or unknown) instrumental profile. Only strong straylight effects (at full moon) can vitiate the equivalent widths from plates obtained under very different seeing conditions.

3.2 Results

Using the methods described above we were able to classify in two dimensions with an accuracy comparable to the MK-system from the same plate material which had been used for very rough estimates of the spectral type in the Hamburg-Cleveland survey. Most of the plates were taken from the stock at Hamburg where they had been used just to pick out OB-stars - and we had to take them with all their scratches and other signs of perusal.

Color indices and Balmer jump were determined with errors of $\pm 0\overset{\mathrm{m}}{.}03$ (from one plate). The intensity distributions were rectified and equivalent widths of 16 lines were determined, using Gauss profiles. Internal errors from one plate are about ±15 %; the corresponding accuracy in the β-index is $\pm 0\overset{\mathrm{m}}{.}020$. For one line and one plate is

$$\varepsilon(W_\lambda) \cong 1 + 0.1\, W_\lambda \;[\mathrm{A}] \tag{1}$$

In the average we find $\varepsilon(W_\lambda) \cong \varepsilon(W_\delta) \cong 1.5$ A (or 1.27 A in the scale of Petrie) corresponding to ±23%.

The error estimates are confirmed by comparison with W_λ, from slit spectra and with photoelectric measurements of the $H\beta$-index. A similar error was found by Clausen (1973) from objective prism spectra of much higher dispersion (102 A/mm at H_γ) for A5-G1V stars with error equivalent $\pm 0^{m}020$. Azzopardi et al. (1978) determined W_γ from objective prism plates with 125 A/mm at $H\gamma$. The scatter against the measures of Balona, and those of Crampton et al. turns out to be ±0.45 A. Assuming equal contributions to the error one finds ±0.32 A or about ±9% (from 3.4 plates in the average), or $\Sigma(W_\gamma) \cong \pm 0.6$ A = ±17% (one plate). On the other hand, we determined Balmer line equivalent widths from Michigan Schmidt Thin Prism plates with 1400 A/mm dispersion and $R \cong 11$ A spectral resolution still with $\Sigma(W_\gamma) \cong 1.6$ A $\cong$ 25% (Schmidt-Kaler 1978). Apparently in a wide range of dispersion and spectral resolution the error of a Balmer line W_λ is about ±20%, or more exactly given by equ. (1).

Our equivalent widths tend to be larger than those determined from slit spectra with, of course, much higher dispersion. This is the well-known dispersion effect (see, e.g., Unsold 1968). However, this effect is irrelevant for the purpose of spectral classification provided the standards are observed on the same plates (as in our case). If the relations defining the spectral classification are transferred from higher dispersion standards, only the constancy of the relation W_λ/W'_λ is supposed.[+]

In the domain O-F5 the Balmer line intensity $W_H = \frac{1}{2}(W_\gamma + W_\delta)$ and the Balmer jump were finally selected as best suited reddening-free[++] classification parameters; CaII K was used to discriminate spectral types earlier or later than A1. This yielded a quantitative two-dimensional classification of the measured stars in the domain B0-F2 within about ±0.5 spectral subtypes and ±0.5 to ±1.5 luminosity classes. Our accuracy is not much worse than what is obtained by photoelectric $ubvy\beta$ photometry for OB and AF stars (Faber 1977).

Remembering that the human observer from the same plates just could tell $OB^{+}/OB/OB^{-}$ and sometimes a little more about the supergiants we see that quantitative automatic classification not only adds speed but also accuracy and reliability.

[+] A method to calibrate the various stellar photographic equivalent widths from slit spectra against solar photoelectric equivalent widths was successfully tested by Edmonds (1978).

[++] A small reddening correction to the Balmer jump D has been pointed out by Ardeberg and Virdefors (1978).

The accuracy was checked by 194 stars with well-determined MK classification in the fields of three OB-associations. All O-stars are lumped together in one group. This would barely be changed by using the measured HeII-lines. The one-dimensional classification can easily be extended from F5 to late K with high accuracy by using CaII K, H; 4227 CaI, the G band and various FeI-lines. Luminosity determination, however, from SrII 4077 and CN 4173 or 3885 was so far not really successful at such low dispersion.

That quantitative two-dimensional classification of late-type stars from objective prism plates is possible at higher resolution (166 A/mm near H_γ) has been shown by West (1972, 1976). The error of the spectral type is about ±0.1, that of M_V is about $\pm 1^m$, furthermore the metallicity can be rather well measured with an error of about ±0.2 in [Fe/H] (see also Malyuto 1974, 1977 and McCarthy 1973). These results may be compared in accuracy to the photoelectric DDO photometry (Yoss 1973, 1977), which is about ±0.2 in spectral type and ±1/2 in luminosity class.

The time needed for the various steps can be broken down in the following way:

preparation of finding charts	10 Min. per plate (or 1 sec. per star)
construction of calibration curves	20 Min.
identifying	40 sec per star
registering I(λ), calculations (HP 2114B)	60 sec
readout and check on display by human eye	30 sec
storage on tape and/or print-out	20 sec
	2.5 Min. per star (1 plate)

If there is no control by the observer the whole machine time can be reduced to 30 sec.

This time should be compared with the time needed for the usual procedures

visual inspection for MK classification (preparatory work included)	10-20 Min. per star

quantitative classification from registering spectra with interactive methods	2.5-10 Min.
same without human interaction	0.5 Min.
fast digital scanning microdensitometer without human interaction	0.01-0.1 Min.

From this comparison it is evident that for really automatic classification the troublesome identification business and the setting by hand must be avoided. This narrows the possibilities down to fast digital scanning microphotometers. Secondly it is evident that the simplest way is to measure all stars down to a given limit with identifications prepared by the machine itself from a direct B-plate of the field. In this way also any bias in the reduction and classification should be done without interaction of the observer, otherwise the high speed of the fast microphotometer system would be completely lost.

4. FUTURE DEVELOPMENTS

What has been done and even what ought to be done in automizing stellar spectral classification has been very well and extensively described by West (1973, 1975, 1976, see also Lynga 1975). In agreement with West and the above considerations we conclude that complete automation is expected to lead to progress in the following respects:

(1) speed
(2) objectivity and homogeneity
(3) accuracy
(4) reliability

where the order reflects the certainty of these expectations or, conversely, the difficulty of the requirements (which seem partly contradictory). If, starting from the measurement on the plate until the final classification, nothing is touched by human hand, results will be obtained very fast and they will be very objective, but perhaps not reliable in cases especially of peculiar spectra. We therefore propose completely non-interactive procedures, with human interaction reserved for peculiar spectra and for cases with funny results.

5. AUTOMATIC CLASSIFICATION FROM LOW DISPERSION OBJECTIVE PRISM (OR TRANSMISSION GRATING) PLATES

5.1 Hardware

Typical plate material now becoming available in the photographic blue region is given by the following examples:

telescope	focal lengths	dispersing element	linear dispersion (at H_γ) Δ	typical seeing β	typical spectral resolution $R\lambda$	measurable limiting magnitude M_{lim}
80 cm-Hamburg Schmidt	2.4m	Objective Prism UBK 7	570 A/mm	2" Hamburg	14 A	13^{m}
61 cm-Michigan Schmidt	2.1m	Objective Prism	108 A/mm	$0.''7$ Cerro Tololo	2 A	12^{m}
		Thin Prism	1400 A/mm		11 A	15^{m}
1 m-ESO Schmidt	3.0m	same	450 A/mm	$0.''7$ La Silla	5 A	$15.^{m}5$
3.6 m-Telescope		Field Spectrograph	2000 A/mm		10 A	21^{m}
1.2 m-UK-Schmidt	3.0m	Thin prism BK7	2480 A/mm	1" Siding Spring	40 A	18^{m}

Modern fast plate material and small widening (down to 0.1mm) gives maximal limiting magnitudes and minimizes crowding. Background and overlap problems can further be minimized by use of various prism orientations. The grain of the plates selected should be matched to the seeing so that the additional spectral smearing does not substantially decrease the spectral resolution $R\lambda$.

As noted above, instead of the one-dimensional slit microphotometer a measuring machine like the PDS (plus minicomputer) is necessary. Descriptions of such machines can be found, for instance, in the Proceedings of the Utrecht Conference on Image Processing Techniques in Astronomy (Eds. de Jager and Nieuwenhuyzen 1975), for the COSMOS machine by Pratt (1977) and for automatic measurements of spectrograms with the Grant machine by Palmer et al. (1978). The positional accuracy of the PDS machine attains ±0.5μ or less over large areas. It sets on a point given by its coordinates, switches from one spectrum to a neighboring spectrum in 0.1 sec, and focuses automatically. It scans a typical low dispersion spectrum of 5 mm length in 0.1 sec. Its two-dimensional scanning mode is important for recognizing plate errors of any kind and overlapping of adjacent spectra. Similar repeatibility and speed has been reported for other machines (Heintze et al. 1975, Pratt 1977, West 1975).

With an absolute accuracy of about ±1μ over the whole plate (Fresneau 1978, King 1978) and ±0.3μ resp. if the position error catalogue of the employed PDS is taken into account by an additional glass scale near the spectrum (Albrecht et al. 1978, Weiss et al. 1978) one may even expect to obtain as a by-product radial velocities from the same plates with an error of the order of $\pm 0.07\,\Delta \cong \pm$ km/s (and third of that) resp. Δ[A/mm] being the reciprocal linear dispersion. This error does not include the random error from the individual line widths which is of the order $\pm 0.1 c R_\lambda/_\lambda\ n \cong \pm 5$ km/s (the number of measurable lines is n). In fact, Fehrenbach and Burnage (1978) arrived at an error of ±5 km/s using normal field objective prism spectra 200 A/mm dispersion. Similar accuracies were reported by Gieseking (1976) and Weiss et al. (1978). The use of the reversion method with normal field prism is not essential since the coordinates of the stars - and therefore the location of the centre of, say, the H_γ line as well - can be measured and transferred from a direct to a spectral plate with the astrometric accuracy investigated by Fresneau (1978) in the case of Palomar Schmidt plates.

Such a determination of the full set of astrometric plate constants, the stellar coordinates and the transfer from a direct plate to the spectral plate is also necessary if only spectral classifications are aimed at. Of course the claim to accuracy can then be relaxed since only the location of H_γ or CaI 4227 etc. within its width is necessary, i.e. within wider limits than the spectral resolution. This location is necessary to allow the treatment of stellar spectra with very faint or no recognizable lines, to simplify the spectral pattern recognition in general, and to allow determination of equivalent widths near the noise limit of the plate.

Instead of the astrometric procedure (which provides not only exact identifications of stars and spectral features but also radial velocities) a simplified procedure could start from the properties of the emulsion or emulsion/filter/telescope material.

For instance the green plate cut-off of the IIIaJ emulsion is for galaxies and stars well defined at 5360±30 A (Cooke et al. 1977, Nandy et al. 1977). Since ±30 A correspond to ±1700 km/s this accuracy is in all practical cases sufficient to set on the most prominent features like H_γ, CaI 4227, TiO 4800/5000. Further supporting measurements include - just as discussed in section 1 - the dispersion curve fit, the photographic calibration on the plate by means of photoelectric UBV sequences, and the direct B plate for identification purposes. The spectral classification system (to which the classification is to be referred) may best be realized by a sufficient number of standard stars in and outside the MK domain. These should be measured in the same way as the program stars, or at least the standard star photographic measures should be simulated on the basis of well-calibrated higher resolution spectra, e.g. photoelectric spectrum scans. Multi-variate analysis of all measurable features will then yield final correlations to physical characteristics and the final selection of the criteria incl. the definition of the continua and the integration limits of lines.

Preprocessing is completed with the scanning of the direct plate and the construction of the calibration curve. Measurements with PDS or a similar device take full advantage of the facility only if setting is automatic and if there is no preselection of stars. The two-dimensional scanning may consist of two scans on the background above and below the spectrum, and two (or more) scans of the widened spectrum (including the background before and behind the spectrum), taking altogether 0.5 - 2 sec. This measuring mode permits automatic recognition of overlap since the physical restriction of the spectrum is known: spectra which overlap partially are either too wide or too long.

5.2 Software

Overlap recognition is a task for a microcomputer. The problem is not trivial since the length of a spectrum depends on the spectral type which is determined only later on. Most of the reductions must be done on-line to avoid high demands on the storage capacity of the computer. Most reductions are, however, rather simple procedures so that a CPU cycle-time of 0.1-1μs appears to be sufficient for real-time reductions.

There are several alternatives to realize the spectral classification:

(I) Measurement of spectral criteria (including color indices). This method leads directly to quantitative spectral classifications (cf. section 1.2). In this case a continuum or a pseudo-continuum must be defined which will be very different for different spectral types. Even a raw spectral type, however, will be known only at a later step. Thus a time-consuming iterative process cannot be avoided. For this method the selection of the relevant spectral criteria is of vital importance.

(II) Pattern Recognition. In this case no continuum definition is needed; however, some complications will be introduced by strong interstellar reddening and very strong interstellar lines. This method leads to spectral classification in boxes. The number and kind of pattern (boxes) is decisive for the accuracy and homogeneity. The MK-domain in its classical definition comprises alone about 250 boxes. If, in addition, various reddenings, metallicities and further parameters have to be accounted for, the number of boxes becomes prohibitively large, even if interpolation is accepted. Direct recognition of so many patterns appears too lengthy a process again or presupposes a very great number of parallel microprocessors. However, the patterns can be split up into a hierarchy of raw patterns with only very few of the strongest lines and bands etc. (e.g. Balmer lines, CaII HK, G band, TiO bands) thus yielding very few raw types to begin with. In the second step these raw spectral types can be refined using the restricted number of additional pattern characteristics existing in each raw type group. The technique of pattern recognition has been greatly developed in the last years thanks to intensive mathematical work (e.g. Fu 1976, Grasselli 1969, Grenander 1978, Meyer-Brotz and Schurmann 1970, Watanabe 1969). For this method the selection of few, but reliable features is vital.

(III) Two-dimensional Fast Fourier Transformation (incl. noise filtering). This method also leads directly to quantitative spectral classifications. It necessitates rather extensive calculations and may therefore be too time-consuming to be applied online with the measurements, although attempts have been made to circumvent this difficulty by special software techniques (Schlosser et al. 1976). Cross-correlation methods can improve the recognition of faint lines remendously.

(IV) Search for special objects. If the task is restricted to pick out especially interesting objects like OB-stars, emission objects, WR-stars, QSO etc. some of the time-consuming procedures can be abridged considerably. It appears even possible to do the search work by very fast analog methods (Fourier inversion of standard spectrum by laser light, laser scanning of the plate and matching). Searching with a full set of standard spectra could be done either in a very slow, consecutive mode or in a fast quasi-simultaneous, very expensive mode. We do not further consider this very interesting possibility because we aim at spectral classifications of all stars of whole fields.

Weighing the pro's and con's of the various methods a mixed procedure seems to be most promising with present-day techniques. The first step is the determination of the raw spectral type by pattern recognition (o=no lines, b (Balmer lines) = O-F5, g (G band) = F5-G9, k (CaI 4227), m (TiO), p = pec + whole rest). This could be done by specially designed microprocessors (or microprograms) so that the computer itself is clear for its proper tasks. To take care of strong emission lines the recognition procedure is repeated without these lines and the results are compared. Very strong interstellar H and K lines may vitiate the b/g division, they will be recognized in the second step. The coordinates of stars with "peculiar" spectra are stored by the computer. These spectra will be dealt with separately; they will be inspected by the observer on the display or CRT before proceeding further.

In the second step four parallel microprocessors define the relevant continuum to the raw type from step 1, and calculate the appropriate spectral criteria (equivalent widths, discontinuities, colors). In the third step these criteria are used to obtain the spectral classification and an error estimate. Again this is done by a microprocessor. In the last step these data are taken over by another microprocessor (or microprogram unit) which calculates the physical quantities (based on correlations as a result of preceding multivariate analysis of given calibration data) like absolute magnitudes, intrinsic colors, reddening and extinctions, distances, metallicities etc. Only these final data (together with the coordinates and the spectral classification) are stored and printed out as basis for the follow-up by stellar-statistical, dynamical etc. discussion. It should be noted that the main computer can proceed with measuring the plate unimpeded by extensive calculations or great storage requirements since the microprocessors take over the measurements immediately and work parallel to the main computer.

The time needed for the completion of the above classification programs is estimated at 0.5 - 2 sec per spectrum or typically one working day per plate. The rather large share of time devoted to the peculiar stars is illustrated by the following example: if one fully automatic classification takes 0.8 sec, one classification with intervening human interaction 30 sec, and only 3% of the stars belong to raw class p, then more time is spent on the latter stars than on the normal classifications.

For an external check of the accuracy results for stars on the plate field with MK or other sufficiently precise spectral classifications should be compared. Here it is noted that such classifications for fainter stars ($m \geq 9$) are in general badly lacking. The MK system is at this time the best available reference system for spectral classifications in 1, 2 or more dimensions. It would be a great help if in a few field stars (preferably with $m > 8$) covering the whole MK-domain would be accurately MK-classified to represent a general framework for any further classification procedures. The region around the double cluster in Perseus may serve as an example; there a large part of the MK-domain is already covered by the MK-classified stars. Other regions suitable for standard fields include areas in Cygnus, Carina and in the upper Sco-Cen region.

6. AUTOMATIC SPECTRAL CLASSIFICATION BY PHOTOELECTRIC SPECTROPHOTOMETRY

Modern multi-element detector systems are revolutionizing astronomical techniques (for reviews of presently or in the near future available multi-element detectors see Duchesne, Lelievre (1976) and Rudolph et al. (1978)). A whole series of classical instruments like multi-color photometer, spectrum scanner, radial velocity spectrograph and polarimeter can now be integrated into one instrument by means of such detector systems. Measuring processes and data handling (incl. raw reductions, convolutions to any desired multi-color system etc.) will be done by microprocessors and flexible software of the computer at the telescope. We intend to realize such an instrument at the Astronomische Institut der Ruhr-Universität Bochum using a Digicon as detector system. Control of measurement and data management will be provided by a special microelectronics/microcomputer system, being developed by the Institut fur elektronische Schaltungen der Ruhr-Universität Bochum. The Digicon Spectrum Scanner will have 212/512 channels with resolutions to be chosen between 0.5 A and 8 A. The photometric accuracy is better than 0.5%. Frequent measurements of black-body calibrated standard stars (Tug 1978) will guarantee a similar system accuracy. We expect to observe an A0 star of 12^m with 3 A resolution in the blue region and 3% photometric accuracy at the 61 cm-telescope in 15 min.

6.1 Application to multi-dimensional spectral classification

Such a multi-element spectrum scanner can be used for direct spectral classification at the telescope.

(1) The spectral classification system is set up by measurements of a sufficient number of MK-standards and

additional stars (p) in the spectral domain 3200 - 8000 A at R_λ = 1 - 2 A. This work is under way.

(2) By multivariate analysis all spectral features measurable at a given resolution R_λ (and step by step decreased by mathematical filtering from R_λ = 1 A to 8 A) the optimal features for 1-, 2- or more-dimensional classifications, and the minimum resolution for that are found. Then raw type domains are defined and correlations calibrated for M_V, $(B-V)_o$, [C/H], [Fe/H] etc. as outlined above in Section 5.

(3) The desired quantities UBV, uvbyβ, etc. and those of the optimally achievable color system are obtained by convolution.

Again, Fourier transform is an alternative to (2), see e.g. Johnson (1977).

Attached to a 3.6 m-telescope such a spectrum scanner should be able to give two - or three - dimensional quantitative spectral classifications immediately at the telescope for stars down to 16^m in less than 20 minutes.

6.2 Space UV/IR-observations for spectral classification

Low dispersion objective prism spectrograms in space have first been obtained by Henize et al. (1975) and by Gurzadian (1976) and coworkers. Recent progress has been reported by Houziaux (1977) and Cucchiaro et al. (1977). ESA plans to incorporate a low-dispersion facility in the Faint Object Camera of the Space Telescope. The various techniques discussed above can be applied to these data to obtain spectral classifications in the new spectral domains.

REFERENCES

Albrecht, R., Jenkner, H., Weiss, W.W. and Wood, H.J. (1977). Astron. Astrophys. **58**, 93.
Ardeberg, A. and Virdefors, B. (1972). Astron. Astrophys. **20**, 177.
Ardeberg, A. and Virdefors, B. (1978). Astron. Astrophys. **69**, 1.
Azzopardi, M. et al. (1978). Astron. Astrophys. **65**, 251.
Barry, D.C., Cromwell, R.H. and Schoolman, S.A. (1977). Astrophys. J. **212**, 462.
Cassatella, A., Gratton, L. and Nesci, R. (1975). In de Jager, Nieuwenhuyzen l.c., p. 353.
Clausen, J.V. (1973). In IAU Symposium No. 50, Spectral Classification and Multicolor Photometry, C. Fehrenbach and B.E.

Westerlund, eds., D. Reidel, Dordrecht, p. 134.

Cooke, J.A., Emerson, D., Nandy, K., Reddish, V.C. and Smith, M.G. (1977). Mon. Not. Roy. Astron. Soc. 178, 687.

Cucchiaro, A., Macau-Hercot, D., Jaschek, M. and Jaschek, C. (1977). Astron. Astrophys. Suppl. 30, 71.

Duchesne, M. and Lelievre, G. (1978). In IAU Colloqu. No. 40, M. Duchesne and Lelievre, eds., Obs. Meudon.

Edmonds, F.N. (1978). Publ. Astron. Soc. Pacific 90, 322.

Faber, S.M. (1977). Publ. Astron. Soc. Pacific 89, 23.

Fehrenbach, C. and Burnage, R. (1978). C. R. Acad. Sc. Paris 286, B 289.

Fresneau, A. (1978). Astron. J. 83, 406.

Fu, K.S. (1976). In Digital Pattern Recognition, K.S. Fu, ed., Springer, Berlin.

Geyer. E.H. (1978). In IAU Colloquium No. 47, Spectral Classification of the Future, M. F. McCarthy, A. G. D. Philip, and G. V. Coyne, eds., Vatican Observatory, p. 271.

the same proposal was made by Bruckner and Schmidt-Kaler (1966).

see also Opt. Obs. Programs Gal. Struct. Dyn., Th. Schmidt-Kaler, ed. Bochum 1975, p. 92.

Gieseking, F. (1976). Astron. Astrophys. 47, 43.

see also (1977). ibidem 60, 9.

and (1978). Sky and Tel., in press.

Grasselli, A. (1969). In Automatic Interpretation and Classification of Images, A. Grasselli, ed., Academic Press, London.

Grenander, U. (1978). In Pattern Analysis, Vol. I, II, Springer, Berlin.

Griffin, E.E. (1968). In A photometric Atlas of the Spectrum of Arcturus, Cambridge.

Gurzadian, G.A. (1976). In Proceed. Third Europ. Astron. Meeting, E.K. Kharadse, ed., Tbilissi, p. 33.

Heintze, J.R.W., Porteous, R.L. and Brandie, W. (1975). In de Jager, Nieuwenhuyzen l.c., p. 185.

Henize, K.G. et al. (1975). Astrophys. J. 199, L119.

Hiltner, W.A. and Williams, R.C. (1946). In Photometric Atlas of Stellar Spectra, Ann Arbor.

Hoag, A.A. and Schroeder, D.J. (1970). Publ. Astron. Soc. Pacific 82, 1141.

Houziaux, L. (1977). In Highlights of Astronomy Vol 4, Pt. II E.A. Muller, ed., Reidel, Dordrecht, p. 277 ff.

de Jager, C. and Nieuwenhuyzen, H. (1975). In Image Processing Techniques in Astronomy, C. de Jager and H. Nieuwenhuyzen, eds., Reidel, Dordrecht.

Johnson, H.L. (1977). Revista Mex. Astron. Astrofis. 2, 71.

King, I. (1978). Colloquium on European Satellite Astronomy.

Lynga, G. and Arinder, G. (1972). Reports Obs. Lund No. 4.

Lynga, G. (1975). Reports Obs. Lund No. 5.

Malyuto, V. (1974, 1977). *Pub. Tartu* 43; 43, 150.

Meyer-Brotz, G. and Schurmann, J. (1970). In *Methoden der automatischen Zeichenerkennung*, Munchen.

Miller, E.W. and Graham, J.A. (1974). *Publ. Astron. Soc. Pacific* 86, 829.

Moffat, A. (1969). *Astron. Astrophys.* 3, 4, 458.

Moore, Ch.E., Minnaert, M.B.J. and Houtgast, J. (1966). *The Solar Spectrum*, NBS Monograph 61, Washington.

Nandy, K., Reddish, V.C., Tritton, K.P., Cooke, J.A. and Emerson, D. (1977). *Mon. Not. Roy. Astron. Soc.* 178, 63 P.

Palmer, B.A., Sansonetti, C.A. and Andrew, K.A. (1978). *Applied Optics* 17, 2280.

Pratt, N.M. (1977). *Vistas in Astronomy* 21, 1.

Rudolph, R., Schlosser, W., Schmidt-Kaler, Th. and Tug, H. (1978). *Ann. Astrophys.* 65, L5.

Schlosser, W., Buchholz, M. and Maitzen, H.-M. (1976). *Astron. Astrophys.* 50, 91.

Schmidt-Kaler, Th. (1966). In *IAU Symposium No. 24, Spectral Classification and Multicolor Photometry*, K. Lodén, L.O. Lodén and U. Sinnerstad, eds. Academic Press, New York. p. 118.

Schmidt-Kaler, Th., Diaz-Santanilla, G., Rudolph, R. and Unger, H. (1976). In *Quantitative Klassifikation von Sternspektren mittels Objektivprismenaufnahmen*, Forschungsberichte Nordrhein-Westfalen Nr. 2595, Westdeutscher Verlag, Opladen.

Schmidt-Kaler, Th. (1978). In *IAU Symposium No. 80, The HR Diagram*, A.G.D. Philip and D.S. Hayes, eds., Reidel, Dordrecht, p. 29.

Seitter, W.C. (1970). *Atlas for Objective Prism Spectra*, I, Bonn.

Thompson, G.I. (1967, 1971). *Roy. Obs. Edinburgh Publ.* Vol. 5, No. 12, Vol. 7, No. 2.

Tug, H. (1978). *Astron. Astrophys.* submitted.

Unsold, A. (1968). In *Physik der Sternatmospharen*, Springer, Berlin, p. 244, 267.

Watanabe, S. (1969). In *Grasselli* l.c., p. 131.

Watanabe, S. (1969). In *Methodologies of Pattern Recognition*, S. Watanabe, ed., Acad. Press, New York

Weiss, W.W., Jenkner, H. and Wood, H.J. (1978). *Astron. Astrophys.* in print.

West, R. (1972). *Abastumani Bull.* 43, 109.

West, R. (1973). In *IAU Symposium No. 50, Spectral Classification and Multicolor Photometry*, C. Fehrenbach and B.E. Westerlund, eds., Reidel, Dordrecht, p. 109.

West, R. (1975). In *Image Processing Techniques in Astronomy*, C. de Jager and H. Nieuwenhuyzen, eds., Reidel, Dordrecht, p. 223.

West, R. (1976). In *Proceed. Third Europ. Astron. Meeting*, E.K. Kharadze, ed. Tbilissi, p. 23.

Yoss, K.M. (1973). In IAU Symposium No. 50, Spectral Classification and Multicolor Photometry, C. Fehrenbach and B.E. Westerlund, eds., Reidel, Dordrecht, p. 125.
Yoss, K.M. (1977). Astron. J. 82, 832.

DISCUSSION

Lynga: Our 1972 system which you referred to has been updated considerably by the acquisition of a PDS machine. We have not changed our program philosophy in that we are still using BASIC language, considerably updated. This may make measuring times ten times larger, but it allows a flexible use of interactive methods in our measurement of spectrophotometric quantities. We have not entered into spectral classification.

Schmidt-Kaler: BASIC is an interpretative language and well suited for the purpose. However, this is a question of philosophy. If one wants really to do large numbers of spectra, one will finally be forced to do it without interactive methods.

Kinman: I have used the PDS microphotometer for the automatic measurement of stellar magnitudes. I prefer to make a selection of the star (and sky) positions to be measured (the values are punched on IBM cards) and give these to the PDS machine for automatic measurement. I feel that this is more efficient and satisfactory than having to investigate at a later stage the results of automatic measurements which are anomalous because of crowding, image defects etc., all of which I feel will be quite serious.

Schmidt-Kaler: Pre-selection of stars makes the procedures slower by a factor of 10 and is likely to introduce statistical bias.

Krawczyk: You have mentioned a density calibration of objective prism plates using stars on the same plate with UBV magnitudes. It is my experience that on an arbitrary photo with a field of 5° diameter there are only a few stars with published UBV magnitudes, and, as you know, the UBV system is the system with the most measures. It seems to me that the more recent Geneva system, Vilnius system, Strömgren, etc. may replace the UBV system. Do you have the same problems?

Schmidt-Kaler: If there are not enough dependable UBV measures we simply measure photoelectrically for our purpose 20-30 suitable stars in the field. The choice of the color system is unimportant;

for narrower pass bands the corrections to monochromatic magnitudes will become smaller.

Zekl: In the semi-automatic version you check your continuum by looking on a screen. In a completely automatic version you have to be very careful in defining your continuum. Did you compare the results from the semi-automatic version and the completely automatic one?

Schmidt-Kaler: For a physical significance of equivalent widths the definition of the continuum is of vital importance. For classification purposes you only need a reproducible recipe (which we call the pseudo-continuum). We compared the semi-automatic and preliminary automatic results and found, except for a few cases, quite a good agreement.

Fehrenbach: Our main research is the measurement of radial velocities with an objective prism with a normal field. The measurements are automatic. The transmittance is measured at 1375 points 4 micrometers apart from each other. These transmittances are then transformed into Baker densities: $I = -\log(1/T_A - 1)$ which allows one to disregard partially the differences in exposure time. Radial velocities are found by calculating the correlation coefficient between the intensity measurements and those of a standard star. The maximum of this coefficient corresponds to the superposition of the spectrum. The difference between this coefficient and that for the reversed spectrum gives the radial velocity. The correlation with the intensity values for the standard spectrum, stored in the computer, passes through a maximum when the spectral type and the luminosity are the same. In order to decrease the calculation time one correlates the modulus of the Fourier transform of the spectrum with that of the standard spectrum. The significant details are limited to the low frequencies. The correlation is fast and allows a choice between many boxes.