45. STELLAR CLASSIFICATION (CLASSIFICATION STELLAIRE)

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I. Introduction

Stellar Classification is an important activity for astronomers, since it provides "systems" for comparison with new types of stars. A good classification scheme can be used cannily to segregate "peculiar" objects and to gain insight into the processes which generate "normal" objects. Eventually, when there are enough objects in a given "peculiar" class, the definition of "normal" can be extended to include them. Through the process of classification, prototypes can be isolated for detailed study, providing a short-cut to the lengthy process of studying all stars in detail. Thus, classification of stars and maintenance of the reference frames are important on-going processes in astronomy.

In recognition of increased activity in the subtopics of automatic classification and calibration, they have been assigned separate headings and reporters.

II. Classification Using Slit Spectra (C.J. Corbally)

A) O- AND B-TYPE STARS

Wolf-Rayet stars in the Galaxy were classified in several studies: Moffat and Seggewiss (38.114.029); Lundstrom and Stenholm (38.114.047); Downes (38.114.081), who included a star with strong Fe II emission; Lortet *et al.* (38.132.031), who found a WC star while observing O-stars; Torres *et al.* (41.114.003), who revised WC types using red region spectra; Aller and Keyes (41.134.010), who found W-R stars during a survey of the central stars of planetary nebula; Gomez and Niemela (MNRAS **224**, 641), who were using both blue and red region spectra to classify supergiant O-stars (as also in RevMex AA **14**, 293).

From normal O-stars with the same effective temperature but different spectral types, Underhill (38.114.138) has argued for their having similar photospheres but different mantles. Ruban (39.114.039) compared classifications from line information with those from the continuum distribution for O9-A0 stars.

The star exciting the RCW 34 nebula was classified from line ratios as O9.5 I by Vittone *et al.* (AA **179**, 157). Be stars were classified by Goraya and Padalia (37.112.114), Corbet and Mason (37.114.024), Wolf and Stahl (40.114.023), and Finkenzeller (40.121.023). The extensive survey of 1874 UV excess objects by Green *et al.* (41.002.074) contains mainly subdwarf sdB stars. A helium rich SdO star, CD -24° 9052, was classified by Kilkenny *et al.* (41.126.011), and Kilkenny (42.126.061) also studied WD 1225-079, a DZA_4 star.

B) A- AND F-STARS

The peculiar stars have dominated studies in these spectral classes. Hauck (41.002.012) has produced a 3rd catalogue of Am stars. Zverko (38.114.063) has reclassified HR 830 and 21 CVn as silicon stars. Gray (AJ, in press) has found that λ Bootis stars form a morphologically distinct set of stars that subdivide naturally into normal hydrogen-line or peculiar hydrogen-line types. High radial velocity stars, generally weak-lined, were studied by Stock *et al.* (38.111.021). White dwarfs, classified by Greenstein (41.126.060) at high signal-to-noise, proved to be mainly of DA type. The star exciting the HH57 object was classified by Cohen *et al.* (41.121.035) as F8 III, implying 5 magnitudes of extinction.

Abt (38.114.071) has made spectroscopic tests on photometric stellar classifications for 169 abnormal A5-G0 stars. Similar spectroscopic tests were made for the weak-line stars by Abt (42.114.079) and by Corbally (AJ **94**,161) who both used Houk's extension of the MK System. Corbally and Boyle (AA, in press), while testing classifications predicted from Vilnius photometry, found unacceptable disagreement in the A- to F-star region, though satisfactory agreement was shown among late-type stars.

C) LATE TYPE-STARS

Keenan and Yorka (40.114.147) have continued to revise and extend their list of classifications for stars later than G0, with an eventual goal of more than 800 stars. Yorka is observing M-stars in the yellow-red region to improve classifications, especially in the range M2 to M5. Other M-star classifications were made by Dahn *et al.* (41.115.023), Ianna and Bessell (42.111.002), and Sabbadin *et al.* (AA Suppl **67**, 541). The differentiation of J type carbon stars from N-type stars is discussed by Lloyd Evans (41.065.121), and carbon stars were also classified by Azzopardi *et al.* (40.114.073), Hartwick and Cowley (40.155.046), and Lloyd Evans (40.114.040).

Cool stars with excesses of heavy elements were treated by several speakers at the Strasbourg Observatory Colloquium (39.012.101). The classification of giant barium stars was discusssed by Yorka and Keenan (39.114.141). Keenan *et al.* (PASP **99**, 629) have commented on the recognition and classification of strong-CN giants.

Rose, using quantitative classifications, has found red horizontal branch stars (39.114.082) and strong-lined G-dwarfs (39.114.083) in the galactic disk. Friel (AJ **93**, 1388) has also applied quantitative methods to low resolution spectra of yellow giants in a galactic structure study. MacConnell (RevMexAA **14**,367) is using 4Å/pixel spectra of the Ca II triplet in the near infrared to classify possible cool supergiants along the southern galactic plane. The pre-main-sequence star HDE 283572 was classified as G5 IV by Walter *et al.* (ApJ **314**, 297), and the variable shell star HD 50845 was found to be KO by Sahade and Ringuelet (39.112.125). The puzzling solar-type twin system, ζ^1 and ζ^2 Ret, was studied by Da Silva and Foy (AA **177**, 204).

Solar analog stars were investigated by Neckel (42.114.011). Keenan is constructing a small, Garrison Type, slit spectrograph to allow monitoring of the spectral type of the sun.

Silva *et al.* (40.114.140) have classified three X-ray-selected stars. An optical candidate for the Geminga γ-ray source received a rough classification from Halpern *et al.* (40.143.007), and Bertre (AA **180**, 160) found that two type-II OH/IR sources have a Mira variable and a K-star optical counterpart, respectively.

D) BINARIES AND MULTIPLES

The comprehensive studies include the 1000 MK types of visual multiples by Abt (40.118.017), the companions to Am stars by Abt and Levy (40.120.019), the companions to Be and B stars by Abt and Cardona (38.112.059), the trapezium systems by Abt (41.118.027), the cool components of symbiotic stars by Kenyon and Fernandez-Castro (AJ **93**, 938), and the search for symbiotic stars among PN objects by Stenholm and Acker (AA Suppl **68**, 51). Composite spectra of rather subtle appearance were presented by Corbally (ApJ Suppl **63**, 365), who listed clues to help their discovery. Decompositions of composite spectra were made by Noordanus *et al.* (39.120.003), Fekel and Scarfe (42.118.040), and Stahl and Leitherer (AA **177**, 105). Torres *et al.* (140.117.087) propose dM03 and dM4e for the components of Gl 425, a BY Dra type star.

Eclipsing binaries were classified by Yamasaki *et al.* (37.117.145), Krzeminski (IAU circ 4014), Nakamura *et al.* (38.117.080), Milone *et al.* (39.119.009), Etzel and Olsen (39.119.016), Kartasheva and Snezhko for a Wolf Rayet system (40.117.103), St. Cyr and St. Cyr (41.119.053), Milone (41.119.071), and Davidge (42.119.069). Spectroscopic binary classifications by Harmer are cited in Griffin (39.120.002). The symbiotic star AG Dra was confirmed to have a G7 V component by Iijima *et al.* (AA **178**, 203), but Ipatov *et al.* (37.117.219) cannot reject the single star hypothesis for the symbiotic CH Cyg. Close binary systems were classified by Howell and Bopp (39.117.087), Lu (41.117.016), Mochnacki *et al.* (41.117.240), Martin *et al.* (MNRAS **224**, 1031), and Mukai and Charles (MNRAS **226**, 209).

E) VARIABLE STARS

Celis (37.122.093) has related classifications of late-M Mira variables with photometry. Margon and Anderson (40.122.151) claim M28 V7 is a Mira variable not a cataclysmic variable, and Gosset *et al.* (39.123.002) have classified the red variable CPD -59° 2857.

Lloyd Evans has classified RV Tauri variables (38.122.070, 40.112.067), giving new Preston spectral types for some of the stars. Timoshenko (39.122.096) has used quantitative classification techniques for irregular variables. HR 7671, a possible UU Her star, was studied by Fernie (41.122.021). Tsvetkov (41.122.164) has investigated luminosities of two δ Scuti stars. The spectral type of AH Her's secondary was determined by Bruch (AA **172**, 187), while UY Phe was confirmed as an RR Lyrae variable, not a dwarf nova, by Warner and Barrett (42.122.018) using spectra from Lloyd Evans.

F) CLUSTERS AND ASSOCIATIONS

Open cluster stars have received classifications from Loden for M7 (38.153.037), from Christian for King 8 and Be 19 (38.153.047), from Abt for Praesepe's bright stars (41.153.022), from Corbally and Garrison for Praesepe's faint stars (42.153.017), and from Sowell (ApJ Suppl **64**, 241). Specific investigations have been made into Be stars in 12 open clusters by Slettebak (40.115.034), into cocoon stars in M17 by Chini and Krugel (39.112.071), into OB stars in Puppis by Stetson and FitzGerald (39.114.119), into ZAMS stars in the Cha I association by Wesselius *et al.* (40.121.060), into blue stragglers by Abt (40.153.009), and into CP2 stars by Maitzen *et al.* (42.153.010). The new edition of Mermilliod's catalogue (Bull.Inf.CDS **31**, 175), giving UBV data and spectral types for stars in open clusters, has drawn together current information in this field.

Garrison and Albert (41.114.015) have found that good spectra of UV bright stars in globular clusters cannot be confused with normal Population I OB stars. An UV-bright star in M22 has been classified as SdO by Glaspey (39.114.040).

Stars near dark clouds were classified by Vrba and Rydgren (38.131.112 and 40.131.018) to determine total-to-selective extinction. Low-resolution spectra were similarly used by Whittet *et al.* (MNRAS **224**, 497). Two stars towards the Taurus dark cloud were investigated by Straižys *et al.* (39.113.052), and some towards the Bok globule B361 were classified by Hasegawa and Seki (42.131.312). The ionizing O-stars in IC 2944 were reconsidered by Walborn (AJ **93**, 868).

G) STARS IN GALAXIES

The increasing availability of digital detectors has fostered extra galactic stellar classification. Regrettably, some workers omit observing standard stars, thus making their results quite approximate.

Wolf-Rayet stars in the LMC were classified by Cowley *et al.* (38.111.026), Azzopardi and Breysacher (40.156.007), Moffat *et al.* (ApJ **312**, 612), and Morgan and Good (MNRAS **224**, 435). Other OB stars in the LMC were classified by Conti *et al.* (42.156.014) and Fitzpatrick (ApJ **312**, 596); in the SMC by Walborn and Blades (41.114.102), Garmany and Walborn (PASP **99**, 240), and Garmany *et al.* (AJ **93**, 1070); and in M31 and M33 by Massey *et al.* [no standards] (40.157.096) and Bianchi *et al.* (42.114.117). Melnick (AA **153**, 235) and Walborn (41.114.143) have found a spectacular clustering of very early O type stars surrounding R136 in 30 Doradus. The early O-type stars in 30 Doradus continue to be investigated by Walborn and Blades (ApJ Lett, in press) for their bearing on recent massive star formation. A massive double-lined O type binary in the LMC was found by Niemela and Morrell (42.120.030).

Supergiant candidates in the Clouds were investigated by Baird and Flower (41.111.017, AJ **93**, 851) and Sowell (AJ **91**, 79). Crampton (39.142.022) examined X-ray candidates in the LMC. By using MK catalogues, Morel (Bull Inf CDS **31**, 167) identified some HD "O, P, Pec" objects as stars in the LMC.

Late-type stars in the Clouds were classified by Elias *et al.* (39.115.004), and Reid and Mould (40.156.044). Lloyd Evans (39.156.004) has compared large amplitude red variable stars in the Clouds with those in the Galaxy, and Cepheids were studied by Wallerstein (38.122.121) and Welch [no standards] (ApJ **317**, 672). Aaronson et al (39.157.123) discovered the first S-type star in NGC 6822, while several M- and C-type stars were confirmed there.

A young open cluster in the LMC was studied by Niemela *et al.* (42.153.050), and stars in the LMC association LH39 were classified by Schild (AA **173**, 405).

H) GENERAL

MK dwarf-giant standards cooler than the sun are being re-examined by Morgan, Abt, and Garrison (Std Star Newsletter **9**, 15) to determine the "strong points" of the MK system between F8 and M2. These will be used to define (a) parallel sequences of strong-line and weak-line standards, and (b) two sets of faint secondary standards, at about 10th and 15th magnitudes, to be located near the equator (Std.Star Newsletter **6**, 5).

Kuiper's spectral classifications of over 3200 stars, mainly of large proper motion, are listed by Bidelman (40.114.119), who points out that, while these are not MK classes, they are valuable.

Jaschek has reviewed the classification of all groups in "The Classification of Stars", which book's strength lies in the many references included. Kaler, starting with the spectral morphology of each classification group in his book "Stars and their Spectra", has broadly introduced the different kinds of stars encountered in the Universe.

III. Objective-Prism and Slitless Spectral Classification (D.J. MacConnell)

A) WORK IN THE GALAXY

1) General and galactic latitude-independent.

Vol. 4 of the Michigan Spectral Catalogue appeared (Houk 1987) containing MK classifications for 33,124 HD stars between -26° and -12° Houk and Sowell (41.002.034) reported on some results from the first three volumes and part of the fourth, and Houk (42.114.136) and MacConnell (42.114.135) discussed the problems of recognition and classification of weak-lined stars on plates of moderate dispersion. Bidelman (39.114.027) published the second in a series listing 244 newly recognized peculiar/interesting stars from blue spectrum plates taken for the re-classification of the northern HD stars. Plate-taking continues on this project and Bidelman continues to search them for interesting objects; the plate collection remains in Cleveland.

Rajamohan (38.114.100) demonstrated the usefulness of very low dispersion spectra for studies of star clusters, and Kharadze, *et al.* (40.114.061) compared the classifications in the Abastumani catalogue with those of Morgan and colleagues and found a high degree of correlation. Savage *et al.* (39.002.109,.110,.111) discussed the properties of the UKST prisms and gave illustrations of various types of objects distinguishable on spectrum plates.

Kilkenny and Kelly (39.114.104,42.114,083,.084) present several hundred stars earlier than F0 found at very low dispersion on UKST plates in two high latitude and one low latitude fields. Savage, *et al.*(39.002.109,.110, .111) discussed the properties of the UKST prisms and gave illustrations of various types of objects distinguishable on the plates.

Microdensitometer scans and image-processing software were used by Fuenmayor and Bulka (41.114.136) to recognize M and C stars. Stephenson (39.114.081) presented a list of 105 new cool C stars to V=13.5 and indicated (41.114.122) that three stars in his S-star catalogue are in fact M dwarfs with exceptionally strong CaH bands. Robertson and Jordan (39.114.157 and BAAS **19**, 703) classified nearly 600 late K and M stars in the 24 equatorial Selected Areas in the range 10<V<16. Voroshilov *et al.* published B,V mags and spectral classes for 6000 stars (40.002.010).

2) In the Galactic plane.

All spectral types: Reed and FitzGerald (38.155.035) classified >3000 stars in a low-absorption field in Pup. Fehrenbach, *et al.* (AASuppl **68**, 515) listed types and radial velocities for 258 stars near α Per from plates taken with the OHP Schmidt.

Early-type stars: Balazs and Paparo (41.155.095) gave temperature types for nearly 1000 stars <F7 to mag 12.5 near the open cluster NGC 7686. Gieseking (40.153.002) estimated types for 76 stars in the M7 field on plates from the ESO/GPO astrograph, and Geyer and Nelles (40.153.019) gave types for 153 stars in 7 open clusters. Radoslavova (41.114.127) used plates at 166Å/mm taken with the Abastumani meniscus telescope to find 22 Am and Ap stars in Vul OB4. Wiramihardja, *et al.*(41.114.081, 115.002) surveyed the CMa complex using plates from the Kiso Schmidt; they report 1800 OBA stars and 128 emission stars.

Late-type stars: Blanco (41.155.014,.087, AJ **93**, 321) has surveyed cool giants in Baade's Window and other clear bulge regions near l=0°, b=−2.4° to b=18° using a grism and IV-N plates at the prime focus of the CTIO 4-m. Ichikawa and Sasaki (41.155.080) classified about 1500-late M giants near l=116 to study the warping of the old stellar disk. MacConnell (41.002.033) continues classifying southern stars in the IRAS Point-Source Catalogue and continues a search for K/M supergiant candidates (41.113.015, RevMex AA **14**, 367) on 3400Å/mm I-N plates. Stephenson has begun a similar survey at 1700Å/mm along the northern plane over the interval 0° <l<240°. Azzopardi, *et al.*(39.114.073,.107) report the discovery with a grens of 15 C stars toward the galactic center. Digitized spectra from Kiso Schmidt plates were used by Maehara (40.114.053) to classify 56 known and 3 new C stars in Cas on Yamashita's T,A system. Mechara and Soyano (AnnTokyo **21**, #3,4) reported finding 98 new C stars in Cas and 21 in the anticenter direction on Kiso 4°, I-N plates. Zlakomanova (42.114.147) found 7 new faint C stars toward l=178°, b=0° on near-ir plates. Alksnis *et al.* (Sun and Red Stars No. 25, p42, 1987; Sci Inf USSR Riga No.65) have found 55 new carbon stars in Cygnus.

H-α emission stars: Kun (42.113.006) reports 155 new stars of V>13 near the IC 1396 HII region on Konkoly plates. Tsvetkov and Semkov (39.114.086) list six new stars in the region of the Khavtassi 193 dark cloud. Ogura and Maehara (41.131.223) discuss several on-going surveys in the Bosscha-Kiso collaboration, and Wiramihardja, *et al.*(42.121.069) found 157 new objects in the Ori B and Belt regions. Parsamyan and Khodzhaev (40.114.064) identified 20 certain and 18 suspected stars in the Taurus region.

3) Out of the plane.

Markarian, *et al.* (41.002.014,42.002.075) list blue galactic stars found in a search for emission-line QSO's, and Pesch and Sanduleak (41.002.013, ApJ Suppl **163**, 809; IBVS No. 2989) in a similar survey gave blue stars of various types, suspected subdwarfs of intermediate type, and faint C and late M stars. Sion, *et al.*(40.126.052) present two peculiar, subluminous stars near B=18 found on grens plates. Morton, *et al.* (39.114.015, 41.155.083) studied spectra of 753 objects in a small field in Aqr to B~19; 3 new white dwarfs were found. Philip (39.114.161) reported finding many faint A stars at the SGP and at b=−60° which may be 10 to 20 kpc off the plane.

Beers, *et al.* (40.114.042) searched for extremely metal-poor stars to B~16 using short-band-pass filters around the Ca II doublet. Corbally and Garrison isolated the natural group of F8-G5 dwarfs on IIIa-J plates taken with the thin prisms on the Burrell and Curtis Schmidt telescopes and are publishing lists for 2 sq. deg. areas toward the NGP (192 stars) and the SGP (214 stars) to mag 16. McNeil (39.002.105) presents a list of >2200 G5-M stars to V~13.5 at the SGP for a study of their spatial distribution. Stephenson (41.114.085, 42.111.007) lists more than 3800 dwarf K and M stars and (41.002.011) 206 new H-α-emission stars over a large area of sky. His survey was done in the green-red region at 750Å/mm (D-lines). Stock's catalogue (40.002.083) of more than 10,000 stars giving types, positions, and indicative radial velocities appeared on microfiche. Bidelman (IBVS **2993**) gives types for 60 red, named variables which are in the IRAS Point Source Catalogue and classified a few thousand IRAS sources in 71 5x5 sq. deg. northern areas; these types as well as those by MacConnell mentioned above are in the database at the IRAS processing and analysis center at Cal Tech.

B) WORK IN OTHER GALAXIES

1. Magellanic clouds

Morgan and Good (40.114.039) presented 6 new W-R stars in the LMC found on IIIaJ plates taken with the UKST, while Kontizas, *et al.* (41.156.011,.037,.040, 42.156.007,.010, AASuppl **67**, 25; 68,357; 69,213) gave classifications of stars in SMC and LMC clusters over the range 14<B<18.5 from film copies of UKST plates. Westerlund, *et al.* (42.156.004) used the grism technique on IIIaJ plates at 2200Å/mm to find more than 450 C-type stars in two 3/4° areas of the SMC, and A. Cowley and Hartwick (BAAS **18**, 997) searched for C and CH stars to B~19 in a 400 sq. deg. area around both Magellanic Clouds. Azzopardi, *et al.* (AASuppl **69**, 421) discussed the classification of 195 luminous SMC stars using the H-γ equivalent width/luminosity relation found from galactic standards.

2. Other galaxies

Bohannan, *et al.* (39.157.078) used grism plates from the KPNO 4-m to find several W-Rs in M33, and Lequeux, *et al.* (AASuppl **67**, 169) searched the local-group galaxies M33 and IC1613 for emission-line objects on CFHT grens plates, finding W-Rs among them. Westerlund, *et al.*(AA **178**, 41) identified 47 C, 30 M, and one S star in the Fornax dwarf galaxy using the red grism at the ESO 3.6-m. Azzopardi, *et al.*(41.157.213) found new C stars in several spheroidal galaxies using an objective grating at the CFHT.

IV. Automatic Spectral Classification (M.J. Kurtz)

A) AUTOMATED MK CLASSIFICATION

No automated MK classification has yet been achieved. Kurtz (39.036.063) has suggested an algorithm consisting of the iterative application of multiple weighted linear discriminant functions, which he claims can be used to automate the MK Process and with spectra of the proper dispersion to automate the MK Classification. One feature of the algorithm is that it requires the entire (large) learning set to be considered as equal standards. This he calls the machine equivalent of experience. One advantage of this technique is that one may obtain additional local classification dimensions through normal statistical classification techniques, and one may obtain easy measures for the degree of peculiarity of any spectral feature in a classified object. Rybski (39.034.035) has suggested that any algorithm requiring the use of multiple standards is incapable of classifying spectra according to the MK-78 prescription, as set forth in the MAT atlas.

Zekl (30.036.064) discussed his program for quantitative spectral classification. His is by far the most fully realized program for classification at MK dispersion. Unfortunately work on it has ceased. LaSala, in *Astronomy from Large Data Bases*, reports on his preliminary work in establishing an automated MK classification. He is using the APM machine and its spectra extraction software, plates loaned from the Michigan survey by N. Houk, and the algorithm described by Kurtz.

B) CONTINUING WORK

Einasto, Malyuto, and Karchenko (41.155.064) report automatic classifications for 3000 spectra in their continuing galactic structure program and have developed new algorithms (Bull Abast Ap Obs). Fehrenbach and Burnage (37.036.190) report the routine use of Simien's classification program as a step in their radial velocity measurements. Ratnatanga (41.036.063) is continuing his study of K giant halo stars using low resolution objective prism spectra.

C) NEW LOW-RESOLUTION WORK

Schucker (41.036.232, 42.036.211) has developed a system to classify low-resolution objective-prism spectra. Especially noteworthy is his use of a fuzzy-rule-based, continuum-finding algorithm. Adorf (42.036.206) has developed a cross-correlation classifier for low resolution spectra, primarily as a tool to search for QSOs. Ichikawa (42.036.203) and Timoshenko (41.034.104) have developed new quantitative classification software at low dispersion. Ruban (38.114.133) discusses the limits of low resolution classification.

D) OTHER OBJECTIVE-PRISM WORK

Much work involving objective-prism spectra involves the use of techniques which are very similar to the techniques used in automated spectral classification, indeed a rough classification is often a step in the reductions. Cooke *et al.* (41.036.017) gives a general description of the use of objective prism data by the COSMOS group. Objective prism redshift surveys are discussed by Beard *et al.* (41.160.019) (Edinburgh), Seitter (42.161.352) and Schucker and Horstmann (42.036.123) (Munster), and by Borra *et al.* (preprint Laval University). QSO surveys are discussed by Hewett *et al.* (39.036.068) and by Clowes (42.036.120), who gives a general review.

E) CLASSIFICATION USING THEORETICAL SPECTRA

Comparing model-atmosphere calculations with data can often be very similar to spectral classification. Cairney, Laird and their collaborators (preprint) have obtained metallicities for late type stars by global comparison of echelle spectra with a grid of model atmospheres. This procedure is essentially identical to the unweighted euclidean-distance metric used by Kurtz in his thesis (32.031.649) to classify spectra by comparison with standard stars. McMahan (42.126.043) has actually used portions of Kurtz' software to classify white-dwarf spectra to a two-dimensional grid of his model atmospheres. Malagini and Morossi (37.036.006) also discuss fitting observations to theoretical spectra.

F) MISCELLANEOUS METHODS

Ramella *et al.* (38.036.032) have discussed new algorithms for automated line identification. LaSala and Kurtz (40.036.083) have discussed their Fourier technique for rectification of spectra.

G) MATHEMATICS AND THE THEORY OF CLASSIFICATION

Kurtz (37.021.004) has discussed the epistemology of the classification process, and has given an overview of some of the major mathematical classification techniques, along with an extensive bibliography. Murtagh and Heck in ***Multivariate Data Analysis*** have considerably expanded on Kurtz' introductory survey paper and the earlier monograph of Bijaoui (27.021.032) with a detailed survey of current methods and a very extensive bibliography of astronomical applications. Kurtz in ***Astronomy from Large Databases*** discusses the current state of classification in large datasets.

H) IN A CLASS BY ITSELF

Heck *et al.* (41.114.026) have independently established a classification scheme for low-dispersion IUE spectra based on a multivariate statistical analysis of measured features in the spectra themselves. They have shown that the classification scheme developed corresponds very closely with that obtained by using the classical morphological approach, thus confirming both methodologies. This work has the potential to lead to the first real working automated classification for stellar spectra, as opposed to the programs which have actually been predictions of spectral class on the basis of similar measurements.

V. Classification from Extra-Atmospheric Spectra (A. Heck)

All the work in this field during the period covered by this report has been based on spectra collected by the International Ultraviolet Explorer (IUE).

A synthesis of the IUE stellar spectral classification work has been published by Heck in the IUE memorial book (*Exploring the Universe with the IUE Satellite*, eds. Kondo *et al.*, Reidel, 1987, pp. 121-137). A statistical classification of IUE low-dispersion spectra for normal stars has been carried out by Heck *et al.* (40.114.071 + 41.114.026) confirming the classification system introduced in the IUE Low-Dispersion Spectra Reference Atlas (Heck *et al.*, 38.002.015 + 38.114.002). Walborn and Panek (38.114.134 + 39.114.088) and Walborn and Nichols-Bohlin (42.114.081 + PASP **99**, 1987, pp. 40-53) have studied IUE short-wavelength high-resolution spectra of O-type stars (main sequence, ON and OC stars), and OB supergiant stars respectively. They illustrate standard sequences and introduce classification criteria. Rountree *et al.* (40.114.073 + IAU Comm 45 Meeting, New Delhi, Nov 1985) announced a programme of spectral classification of B stars, using high-resolution IUE spectra. Nandy (IAU Comm 45 Meeting, New Delhi, Nov 1985) investigated the measurements of major stellar features in the UV over a range of luminosity and spectral types for a large number of B stars in our Galaxy and the Magellanic Clouds.

Heck *et al.* (38.002.015 + 39.002.101 + 42.002.091) have continued their classification work of peculiar IUE low-dispersion stellar spectra slowed down by the lack of correspondence between peculiarities in the visible and UV ranges. Jaschek *et al.* (40.114.107) have investigated the peculiarities in UV IUE range of λ Bootis and HB stars. Cacciari (40.114.026) studied the UV fluxes of Population II stars from IUE low resolution spectra.

Parsons and Ake (AAS Bull. **19**, 1987, 708) have used IUE low-resolution spectra of binaries to derive estimates of luminosities and spectral classes of the components. Gurzadian has used ORION-2 spectra (3800-2000 Å) for a catalogue (41.002.027,.047).

VI. Classification Using Multicolor Photometry (E.H. Olsen)

A) WIDE-BAND SYSTEMS

1) The UBVRI System

a) Relationships: The calibration of UBV photometry, utilizing theoretical and observed spectra, has been discussed by Buser *et al.* (40.113.037,038). The influence of metallicity and interstellar reddening on the position of stars in the two-color diagram was studied by Cameron (39.115.010). Saxner & Hammarback (40.113.047) have published an empirical T_e calibration of B-V for F- and early G-type dwarfs. A period-color relation for dwarf novae has been found by Echevarria & Jones (37.117.024). Gliese & Jahreiss discuss the use of nearby stars in calibrating UBV photometry (40.115.012).

b) Field Stars and General Surveys: UBV catalogues of faint field stars were published by Oja (38.113.011; 39.113.007; 40.113.003; 42.113.014; AA Suppl. **68**, 211).

The "Hyades supercluster" stars were studied by Eggen (39.153.008,009); common proper motion pairs by Caldwell *et al.* (38.113.001); proper motion stars by Carney & Latham (AJ **93**, 116) and by Eggen (AJ **93**, 379); FK4 stars by Moreno & Carrasco (42.113.013); stars in HII regions by Lahulla (40.113.012); population II stars by Norris *et al.* (40.155.017) and by Sandage & Kowal (41.113.053); and nearby stars by Torra *et al.* (40.113.018 and AA Suppl. **67**, 157).

The UBVRI system has been used to investigate helium stars and hydrogen-deficient stars by Drilling *et al.* (37.113.046), and early-type stars for galactic structure by Forbes (37.155.051).

A list of possible solar analogs was given by Neckel (42.113.020). Other late-type dwarfs have been studied by Hartwick *et al.* (38.114.121, 42.113.031), by Eggen (42.113.032), by Stauffer & Hartmann (42.116.002), and by Robertson & Hamilton (AJ **93**, 959). Photometry of late-type giants has been carried out by Celis (41.113.016) and of supergiants by Arellano (40.122.035). Fekel *et al.* (41.116.009) studied chromospherically active stars.

A search for white dwarfs in the Praesepe cluster has been continued by Anthony-Twarog (37.153.011). Shaw & Kaler (40.134.010) studied the nuclei of planetary nebulae Kilkenny *et al.* (40.113.065) looked at early-type shell and pre-main-sequence stars. A UBV catalogue of cataclysmic variables was compiled by Bruch (37.117.183).

Cepheids in the Magellanic Clouds have been studied by Wayman *et al.* (37.122.084), and Freedman *et al.* (40.122.111). In our galaxy Cepheids have been studied by Barnes & Moffett (39.122.045,046, 40.122.051), by Gieren (40.122.030, 42.122.014,045), by Madore (40.122.098), by Petersen & Diethelm, (41.122.016) and by Coulson *et al.* (41.122.103).

T Tauri stars were the subject of work by Vrba *et al.* (39.121.010, 040). RR Lyrae stars have been studied by Cacciari & Clementini (42.122.173), and RV Tauri stars by Goldsmith *et al.* (MNRAS **227**, 143).

c) Open clusters and associations: Many investigations of stars in open clusters have been made (del Rio, (37.153.020); Janes & Smith, (37.153.022; 38.153.001,049,050); Fenkart & Schroder, (39.153.004); Clariá, (39.153.005,021); Richtler, (39.153.007); Stauffer *et al.*, (39.153.015); Turner & Pedreros, (40.153.006); Upgren *et al.*, (40.153.015); Tokhtas'ev, (41.002.039); Forbes, (41.153.021); Sagar *et al.*, (40.153.026; 41.153.025; 42.153.008); Clariá & Lapasset, (41.153.027); Reimann & Pfau, AN **308**, 111). The detection of a possible new cluster was made by Turner (37.153.071), while a search for clusters around five Cepheids was unsuccessful (van den Bergh *et al.*, 39.152.004).

Associations have been studied by Gasparyan (39.113.030) by Nurmanova (39.152.002) by Heske & Wendker (40.152.008) and by Whittet *et al.* (MNRAS **224**, 497).

d) Globular clusters: Broad-band photometry in globular clusters has been carried out by A. Wehlau & Hogg, (40.154.027).

e) Magellanic Clouds and other galaxies: Stars in the Magellanic Clouds were studied by Ardeberg *et al.* (40.156.004), by Bernazzam *et al.* (40.156.010) and by Grieve & Madore (42.156.027,028). Studies in the direction of the Clouds were carried out by Robin *et al.* (AA Suppl. **68**, 63).

2) The RIJHKLMNQ system.

The calibrations of the system were discussed and improved by Rieke *et al.* (38.113.057,058; 39.113.027,028), Tapia *et al.* (Rev. Mexicana **13**, 115), and Glass (39.113.022). A classification system for late-type giants has been developed by Tignanelli & Feinstein (40.113.015). The temperature calibrations for cool stars were reviewed by Bessell *et al.* (40.113.041). Color-metallicity relations for population II red giants were derived by Martinez Roger (AA **171**, 77). A discussion of intrinsic colors of hot stars was given by Moreno & Chavarria (41.131.206).

The system was used to detect and investigate winds from and shells around early-type stars (Abbott *et al.*, 37.112.077; v.d. Hucht *et al.*, 37.112.108; Stahl *et al.*, 37.122.012; Chini & Krugel, 39.112.071), and to study the properties of Ap stars (Groote & Kaufmann, 37.113.005; Kroll *et al.*, AA Suppl. **67**, 195), Be stars (Goraya, 39.113.051), helium stars and hydrogen-deficient stars (Drilling *et al.*, 37.113.046), and other early-type stars (Kilkenny et al., 40.113.065; The *et al.*, 42.002.040).

The system was used to study late-type giants in the nuclear bulge of our galaxy (Frogel *et al.*, 37.155.105; 38.113.027; Jones *et al.*, 37.155.105; 38.122.015; Whitelock *et al.*, 42.133.006), and the population structure of low-mass dwarfs (Reid & Gilmore, 37.115.004; Hartwick *et al.*, 38.114.121). Other studies included carbon stars (Gao *et al.*, 39.133.053), late-type giants (Noguchi & Akiba, 42.113.043), and late-type dwarfs (Stauffer & Hartmann, 42.116.002).

The system was used to detect and investigate winds from and shells around RV Tauri stars (Lloyd Evans, 40.112.067; Goldsmith *et al.*, MNRAS **227**, 143), and to study the properties of Cepheids (Welch *et al.*, 37.122.131; 39.122.133; ApJ **317**, 672; Fernley *et al.*, MNRAS **225**, 451).

The system and similar systems were used extensively to identify, classify and study infrared sources (Ghosh, 37.133.005; Persi *et al.*, 37.133.007; Danks *et al.*, 37.155.023; Gao, 38.112.094; 40.112.081,105; Herman, 38.122.081; Gehrz *et al.*, 39.112.065; Band *et al.*, 39.112.092; Whitelock, 39.133.002; Vrba et al., 40.121.010; Hrivnak *et al.*, 40.133.002; Elias *et al.*, 41.112.059; Kwok et al., 41.112.145; Churchwell & Koornneef, 41.121.005; Th *et al.*, 41.121.011; Melnick *et al.*, 41.131.246; Jones & Hyland, 42.112.101; Kawara, 42.131.062; Le Bertre & Epchtein, AA **171**, 116; Braz & Epchtein, AA **176**, 245).

Open clusters and associations were studied by Tapia *et al.* (37.153.065; 38.153.008), Whittet *et al.* (MNRAS **224**, 497) and Wilking *et al.* (42.153.002), while Caputo *et al.* (40.154.036) studied the CNO abundances in both globular and open clusters.

A review of the properties of red giants in the Magellanic Clouds was given by Aaronson (37.156.039). Other stars in the Magellanic Clouds were also studied: (Frogel, 38.156.017; Welch & Madore, 37.156.044; Feast & Whitelock, 38.156.001; Wood *et al.*, 39.156.014; Laney & Stobie, 42.156.009). A comparison between cluster supergiants in the galaxy and in the Magellanic Clouds was made by McGregor & Hyland (37.156.081).

3) The RGU System.

The calibration of RGU colors in terms of MK classes has been investigated by Labhardt & Buser (40.113.038). The investigations of galactic structure by classification of faint stars in galactic fields have continued (Fenkart *et al.*, 38.113.004,005,012; 39.113.004; 40.155.024; 41.155.011; AA Suppl. **67**, 245; 68,397; 69,33,281; Alfaro & Garcia-Pelayo, 38.113.019; Topaktas, 38.113.051; Becker *et al.*, 39.002.010; 39.155.073; Spaenhauer *et al.*, 39.113.012).

4) The Washington system.

By adding the DDO 51 filter to the Washington filter system, Geisler (38.113.026) has improved its luminosity classification. A comparison between the classification properties of the Washington system and the medium-band DDO system was made by Smith (41.113.030). The abundance indices have been recalibrated (Canterna *et al.*, 42.153.016; Geisler, 42.113.027) and applied to LMC cluster giants (Geisler, AJ **93**, 1081).

The system has been used to investigate open cluster giants (Geisler & Smith, 38.153.045; Clariá & Lapasset, 39.153.021; 41.153.017,027; Canterna et al., 42.153.016) and six metal-rich globular clusters (Geisler, 42.154.024).

5) Far-infrared systems.

For stars of all types, the relations between Johnson's BVRIN colors and IRAS colors were studied by Waters *et al.* (AA **172**, 225), and the relations between MK classifications and IRAS colors by Cohen *et al.* (AJ **93**, 1199).

In the range 53-200 microns, shells around carbon stars have been studied by Goebel & Moseley (39.112.068), who propose solid MgS to be present. Circumstellar disks around exciting stars of Herbig-Haro objects were studied at six wavelengths between 40 and 160 microns (Cohen *et al.*, 40.121.012). Mass-loss rates have been estimated for evolved stars by observations of thermal emission at 400 microns (Sopka *et al.*, 40.112.004; Werner, 40.112.038).

IRAS observations have been utilized to study a wide variety of stellar objects and their environments: Supergiants later than type F0 (Stickland, 40.112.069; 41.112.124), stars with disks of possibly protoplanetary material (Aumann, 40.112.107; Gillett, 41.112.134; Sadakane & Nishida, 42.118.004), symbiotic objects (Whitelock, 41.117.329; Kenyon *et al.*, 42.117.257) and binary systems containing compact objects (Schaefer, 41.117.297).

IRAS has also been used to study hydrogen-deficient stars (Walker, 40.112.072; 42.114.171); Wolf-Rayet stars (v.d. Hucht *et al.*, 40.112.099, 40.112.137, 41.113.045); O, B and A stars (Waters *et al.*, 41.113.064; 41.116.011); Be stars (Waters *et al.*, 41.112.136; AA **176**, 93); and planetary nebulae (Pottasch, 41.134.065; 42.134.054; Iyengar, AA Suppl. **68**, 103),

IRAS observations of variable and other late-type stars include RV Tauri stars (Jura, 42.122.163), T Tauri stars (Beichman *et al.*, 42.133.004), other cool stars (Rowan-Robinson *et al.*, 41.112.140; Odenwald, 41.113.063; 42.112.042; Perrin & Karoji, AA **172**, 235; Herman *et al.*, 42.112.049; Glass, 42.133.005), and carbon stars (Willems, 41.113.065),

B) MEDIUM-BAND SYSTEMS

1) The Strömgren uvbyβ system.

Strömgren has reviewed the properties of population-II stars of types F and G. He summarizes the most recent calibrations and surveys in the context of galactic structure and evolution (39.155.020; 40.113.026).

Cousins has published secondary standards in the E regions (41.113.061; 42.113.019). Bell & Oke (42.114.039) discuss scans and colors of four F subdwarfs defined as spectrophotometric standards. General problems of observation and reduction were discussed by Manfroid (40.113.032,035) and Kilkenny & Menzies (42.113.015). The intrinsic colors of early-type supergiants were determined by Kilkenny & Whittet (40.113.010).

Several authors have re-discussed the uvbyβ calibrations (Moon & Dworetsky, 38.113.024; 40.114.098; Balona & Shobbrook, 38.115.011,016; Shulov, 40.113.067; 42.115.004; Alexander, 41.113.036; McNamara & Powell, 41.114.008; Olsen, Observatory **105**, 99; Lester, MNRAS **227**, 135).

An improved theoretical calibration based on unpublished models by Kurucz and the secondary spectrophotometric standards was given by Lester *et al.* (42.113.002). Saxner & Hammerback have published an empirical T_e calibration of b-y and *gb* for F- and early G-type dwarfs (40.113.047), which has been extended to population II by Magain (AA **181**, 323). Luminosity calibrations have been published for white dwarfs (Greenstein, 37.126.042) and for F-type supergiants (Antonello, 40.115.020). Tables and diagrams giving luminosities, radii, and MK types over a large area of the HR diagram were published by Moon (40.115.031; 41.114.067).

Gray and Garrison (Ap.J.Suppl. 1988) have published detailed comparisons between the MK system and the uvbyβ system and have discussed the effects of rotation on the two systems. The photometric effects of rotation in A-type stars were computed from model atmospheres by Collins & Smith (39.116.016), and also studied by Schmidt & Forbes (37.153.023). Empirical calibrations for late-type stars, also in terms of MK classes, were presented by Olsen (38.113.014), Nelles *et al.* (40.113.033) and Ardeberg & Lindgren (40.113.036). Abt (42.114.079) finds that 97% of stars photometrically predicted to be weak-lined F- and G-type dwarfs, are indeed so.

For horizontal-branch stars masses and other properties have been determined (Philip *et al.*, 37.115.023; 40.115.027). The zero point of the PLC relation for classical Cepheids was discussed by Schmidt (38.122.199) and Balona & Shobbrook (39.122.070). The distance to the LMC was determined by observations of non-supergiant B stars (Shobbrook & Visvanathan, MNRAS **225**, 947).

Studies and classifications have been published for the galactic poles (Hilditch *et al.*, 40.155.022; Philip, 41.155.021), for four fields at b = −60° degrees (Andersen & Jensen, 39.113.005), for SA 132 (Knude, 41.113.003), and for stars on the Hipparcos observing program (Manfroid *et al.*, AA Suppl. **69**, 505),

The system was also used to study early-type stars (Wade & Smith, 39.113.001; Kilkenny *et al.*, 40.113.065; Eggen, 42.153.035; vander Linden & Sterken, AA Suppl. **69**, 157), β Cephei stars (Shobbrook, 39.122.106), B-type supergiants in the Magellanic Clouds (Shobbrook, 41.156.008), white dwarfs (Howell, 41.113.039; Fontaine *et al.*, 39.126.089), hot subdwarfs (Wade, 38.117.083), and faint or high-latitude blue stars (Kilkenny *et al.*, 38.113.048; 41.114.006; Tobin, 39.113.037; 40.113.034),

RR Lyrae stars (Alania, Ap Sp Sci. **132**, 313), horizontal-branch stars (Philip, 42.113.047,048), A-type stars (Eggen, 38.114.020), 38.114.020), Ap stars (Schneider, 41.113.037), Am stars (Dworetsky & Moon, 41.114.129), and Cepheids (Eggen, 40.122.004,005,006; 40.122.004,005,006; Kim, Ap Sp Sci **133**, 1) have been studied. Late-type dwarfs have been observed by Eggen, (42.113.032),

Visual binaries have been classified by Duncan (37.113.039), while Lindroos has continued his investigation of young binary systems with O-or B-type primaries and pre-main-sequence secondaries (39.118.013; 41.118.013).

Blue stragglers in open clusters have been studied by Twarog & Tyson, 40.153.007). Other observations in open clusters include: (Lynga and Wramdemark, 37.153.008; Schmidt & Forbes, 37.153.023; Jakobsen, 37.153.064; Schmidt, 38.122.199; 38.153.-001,049; Shobbrook, 38.153.034, 39.153.002; 41.153.038; MNRAS **225**,999; Delgado *et al.*, 38.153.036; 39.153.006; Richtler, 39.153.007; Schneider, 40.153.001; AA Suppl. **67**, 545; Eggen, 39.153.009,039; 40.111.024; Reimann & Pfau, AN **308**, 111) and in associations include: (de Zeeuw & Brand, 40.152.013; Perry & Landolt, 42.152.005).

A very detailed study of M67, including a rediscussion of the calibrations for F-and early G-type stars, was made by Nissen *et al.* (AJ **93**, 634). CCD photometry in M67 and the globular cluster NGC 6397 was published by Anthony-Twarog (AJ **93**, 647,1454).

2) The Geneva System.

A discussion of the intrinsic colors of A- and F-type supergiants were given by Meynet & Hauck (40.113.-013). Metallicism among A and F giants was studied by Hauck (41.113.007), who also gives a list of λ-Bootis-type candidates (41.114.005) and discusses Be and shell stars (AA **177**, 193) and population II stars (42.113.046). The discovery of a new class of variable stars with mid-B-type classifications was announced by Waelkens & Rufener (40.122.074). They identified them with the so-called 53 Persei variables, which show line-profile variations. Accurate physical parameters were derived for pulsating stars, by combining the photometry with precise radial velocity curves (Meylan *et al.*, 41.122.010,014,027,028; Grenon & Waelkens, 41.122.012). The main-sequence gap around F0 and its possible relation to onset of convection has been discussed by Jasniewicz (38.113.035). Cramer continued his study of B-type stars (38.113.036). Bp stars were studied by Lanz (39.114.031) and Ap stars by North *et al.* (38.116.027; 40.116.002; 42.116.026; AA Suppl. **69**, 371) and Waelkens (40.113.001). The relation between mean surface magnetic field and D(V1 - G) for Ap stars was questioned by Oetken (40.116.061).

3) The Vilnius System.

Belyaeva has published a theoretical calibration of this system (42.113.012). An automated two-dimensional classification method based on photographic Vilnius photometry was developed by Smriglio *et al.* (42.113.018). B-type stars were studied by Straižys *et al.* (39.113.052). Bright stars in open clusters containing red giants were measured by Dzervitis & Paupers (41.113.019,020,023; 42.113.051) and by Kazlauskas (Vilnius No.75,p18). Stars in the Cygnus standard region were reobserved by Zdanavicius & Cerniene (41.113.024) and in SA 92,108, and 112 by Cernie (Vilnius No 75, p31). Large-proper-motion stars at the SGP and NGP were observed by Bartasiute (41.113.025) (Vilnius No 74, p15). The determination of metallicity and O/C ratio for late-type giants was discussed by Straižys & Sleivyte (41.113.054), while solar analogs were studied by Glushneva *et al.* (42.113.005). Ap stars were investigated by Nikolov & Iliev (42.113.017). Metal weak giants were studied by Straižys *et al.* (Vilnius No 75, p3); CH, barium stars by Sleivyte (41.114.063); carbon stars by Sleivyte (Vilnius No 74, p24, No 75, p36 and No 77); Ap stars by Zitkevicius (Vilnius No 76, p8); and subdwarfs by Straižys *et al.* (Vilnius No 77).

4) The DDO system.

The red giants in several open clusters have been investigated (Janes & Smith, 37.153.022; 38.153.050; Clariá *et al.*, 39.153.005,021; 41.153.017,027) as also yellow giants and supergiants (Schmidt, 38.153.001,049). A large sample of barium stars was studied by Lu & Upgren (39.114.143). Population II stars were investigated by Norris *et al.* (40.155.017), who also studied red giants of the old disk (AJ **93**, 616). Observations of red giants in two globular clusters were discussed by Smith & Hesser (42.154.023). Data on very strong-lined K giants were given by Johnson *et al.* (ApJ Suppl. **63**, 983).

5) The Walraven system.

Pel discussed the fundamental parameters of classical Cepheids (39.122.036; 41.122.107). The system was used to investigate associations (v. Genderen, 38.152.007; de Geus *et al.*, 41.152.002), open clusters (Th *et al.*, 40.153.028; Steemers & v. Genderen, 41.113.001; van Leeuwen *et al.*, 42.153.009), globular clusters (Nelles & Seggewiss, 38.154.024), stars in the Magellanic Clouds (v. Genderen *et al.*, 40.156.006; 41.156.006), fields around planetary nebulae (Gathier, 39.113.036; 41.134.006), supergiants (Steemers & v. Genderen, 41.113.001), F- and G-type stars at the SGP (Trefzger *et al.*, 37.155.026; 39.113.060; 39.155.019), Cepheids (Diethelm, 41.122.062), solar-type stars (Greve & v. Genderen, 41.113.017), G- and K-type dwarfs in the Pleiades (v. Leeuwen *et al.*, AA suppl. **67**, 483) and OB-type stars (v. Genderen *et al.*, 40.113.002,046; 40.122.099; 41.113.009; v. Paradijs *et al.*, 41.113.002; The *et al.*, 42.002.040).

6) The Arizona 13-Color System.

Mitchell & Schuster have investigated the solar colors on this system. They present photometry of 63 solar-like stars, and an improved absolute calibration of relative colors (40.113.016). A calibration of the system in terms of T_e and M_v, and applicable to B-type stars, was derived by Conconi & Mantegazza (40.113.043). A discussion of intrinsic colors of hot stars was given by Moreno & Chavarria (41.131.206). Stars associated with HII regions were studied by Chavarria (AA **171**, 216).

7) The Thuan-Gunn uvgr system.

This four-color system has effective wavelengths similar to the wide-band UBVR system, but half-widths between 400Åand 900Å, and thus essentially non-overlapping bands. Thuan & Gunn (18.113.025) published the list of standard stars that define the system, but so far it has had its main application in CCD photometry of galaxies. However, Kent (39.113.013) has published a revised set of standard stars, and he discusses uvgr photometry of more than 400 field and cluster stars covering a wide range of stellar properties. A mean main-sequence and reddening curves are derived. Bell & Oke (42.114.039) discuss four F subdwarfs defined as spectrophotometric standards.

C) NARROW-BAND SYSTEMS

Narrow-band H-β photometry was used together with medium-band uvby photometry (see section b1 of this report). H-α photometry for 150 dM and dK stars was reported by Layden & Herbst (42.113.054). Mendoza (41.153.043) has used the α λ system to measure intensities of H-α and OI in Hyades and Coma cluster stars, as well as Ap stars (42.113.009).

The Lockwood five-color narrow-band system and its application to M-type giants was discussed by Mennessier (40.113.024; 40.114.090). Maitzen *et al.* searched for Ap stars in open clusters by measuring the l5200 depression (38.153.015; 40.153.016; 41.153.047;

42.153.010,013; AA **178**, 313). This depression was also measured in field Ap stars (Schneider, 41.113.037).

CaH and TiO indices have been determined for late-type dwarfs (Hartwick et al., 38.114.121). A CO index (2.3 μ) was measured for 200 bright M giants in an unsuccessful attempt to discover extremely low carbon abundances (McWilliam & Lambert, 38.114.127). The same index was utilized in a comparison between late-type supergiants belonging to clusters in the galaxy and in the Magellanic Clouds (McGregor & Hyland, 37.156.081). Frogel, Cohen *et al.* continued to measure the infrared bands of CO and H2O in globular cluster giants (39.154.023; 41.154.065), M giants in the galactic nuclear bulge (41.155.049,124) and red giants in Local Group galaxies (39.115.004; 39.157.073).

Model atmospheres have been used to calibrate the Wing system (Steiman-Cameron & Johnson, 41.064.022). Frisk & Bell (40.114.088) determined Te for G and K subgiants by models and photometry in three filters at ll5900,7800 and 10600Å. Narrow-band 1-5 micron magnitudes have been measured for dwarf stars (B8-A3), relative to Vega, by Leggett *et al.* (42.113.029).

D) GENERAL

Buser (39.113.059) and Straižys (40.113.030) have reviewed photometric methods for determining stellar metallicity and stressed their importance in the context of galactic structure and evolution. The photometric properties of peculiar red giants were reviewed by Wing (39.113.062). Rufener has examined the experimental conditions which must be satisfied by photometric systems, if the observational parameters are to be correlated unequivocally with physical quantities of a star (40.113.028).

The significance of the closed loops described by classical Cepheids in color-color diagrams, was emphasized by Onnembo *et al.* (40.122.077). A new optimal four-filter medium-band system for F-and G-type dwarfs was suggested by Park & Lee. A combination of DDO and Strömgren filters is close to the optimal system (41.113.059). Photometric systems for classification of stars of population II were reviewed by Ardeberg & Lindgren (42.113.049).

VII. Astrophysical Calibration of Classifications (V. Straižys)

The UBV system has been calibrated in terms of temperatures, gravities, and magnitudes by Buser and Kurucz (40.113.037) and Straižys (Bull Vilnius Obs No 76,**17**,1987), in terms of temperatures and metallicities by Cameron (39.115.010) and in temperatures by Saxner and Hammarback (40.113.047). The M_V, B-V diagram has been calibrated in age by van den Berg and Bell (40.65.053, 40.154.014), the zero-age main sequence has been revised by Shulov (37.113.028, 40.113.067) and Kopylov (39.113.025). The solar UBV values have been discussed by Hayes (40.115.011), Makarova and Kharitonov (41.071.022), and Neckel (42.113.020, 42.114.011, 42.115.010).

A new calibration of infrared magnitudes in absolute fluxes has been given by Campins *et al.* (39.113.027), Rieke *et al.* (39.113.028), and Beichman *et al.* (IRAS Cats&Atlases, Explanatory Suppl, JPL, 1985). Infrared color indices have been used for T_e determination by McGregor and Hyland (37.156.081), Aaronson and Mould (39.154.012, 39.157.089), Frogel (39.154.023), Steiman-Cameron and Johnson (41.064.022), and Wing *et al.* (40.114.092).

The Washington system has been calibrated in terms of luminosities and abundances for late-type giants by Geisler (38.113.026, 38.154.082, 42.113.027, 42.154.024), Geisler and Smith (38.153.045), and Canterna *et al.* (42.153.016).

The uvbyβ system has been calibrated in effective temperatures, luminosities, gravities, and metallicities for B-F stars by Moon and Dworetsky (40.114.097), for B-type stars by Balona and Shobbrook (38.115.011, 38.115.016), Lester *et al.* (42.113.002), and

Shulov (42.115.004), for A-type stars by Schmidt and Forbes (37.153.023), Anthony-Twarog (37.153.035), and Olsen (Obs105,**99**, 1985), for F-type stars by Laird (39.114.032), Saxner and Hammarback (40.113.047), Shulov (40.113.067), Antonello (40.115.020), McNamara and Powell (41.114.008), Lester *et al.* (42.113.002), for G and K type stars by Olsen (38.113.014), Nelles *et al.* (40.113.033), Laird (39.114.032), Ardeberg and Lindgren (40.113.035), Moon (40.115.031), Eggen (42.113.032), and for metallic-line stars by Dworetsky and Moon (41.114.129).

In the Geneva system the B_2-V_1 color index has been calibrated in temperatures by Hauck (40.113.029). Instrinsic color indices of supergiants have been determined by Meynet and Hauck (40.113.013). Effective temperatures and bolometric corrections of Bp stars have been studied by Lanz (38.114.050, 39.114.031).

The DDO system has been calibrated in element abundances by Norris et al.(40.115.017), Smith and Hesser (42.154.023), and Rego *et al.*(41.113.044).

The Walraven system has been calibrated in temperatures, gravities, and metallicities by Nelles *et al.* (38.113.021), Greve and van Genderen (41.113.017), and Gathier *et al.* (Astron Astrophys **157**,171,1986).

The MK spectral types have been calibrated in temperatures and/or absolute magnitudes by Grenier *et al.* (39.115.009), Keenan and Pitts (39.115.022), Keenan (40.114.066), Gliese and Jahreiss (40.115.012), Couteau (40.115.015), Rakos (40.115.016), Mikami (41.115.003), and de Jager and Neiuwenhuijzen (Astron Astrophys **177**, 217,1987). The Hγ absorptions have been related to absolute magnitudes by Millward and Walker (39.115.003, 39.115.006, 40.115.013) and Hill *et al.* (42.114.160). The luminosity dependence of the Mg II K-line emission widths has been studied by Parthasarathy (40.115.014).

VIII. Catalogues and Atlases (D. Egret)

A) SPECTROSCOPIC CATALOGUES

Lists of new machine-readable catalogues and atlases are regularly published in the "CDS Information Bulletin", Strasbourg, and by the NSSDC, NASA, Greenbelt. We give here a short list of catalogues made available on tape during the period, together with their reference number in the lists of the data centres:

Henry Draper Catalogue and Extension I (HD, HDE)(3099): revised version with a number of errors corrected. McCook and Sion (3100): A Catalogue of Spectroscopically Identified White Dwarfs, 2nd edition (37.002.084). Page (3110): Catalogue, Spectrum and Magnitude Data Bank of Be, Bp and Bpe Stars (Mt Tamborine Obs., 1984). Rousseau *et al.* (3111): Studies of the Large Magellanic Cloud Stellar Content III. Spectral Types and V Magnitudes of 1822 Members (21.159.002). Bartaya (3112): Catalogue of Spectral and Luminosity Classes of 10396 Stars in Kapteyn Areas NN 2-43 (BAAO 51, 1979). Sanduleak (3113): A Deep Objective-Prism Survey for Large Magellanic Cloud Members (1969; ADC Version 1987).

The 6th edition of "MK Spectral Classifications- General Catalogue" was published by Buscombe in 1984: the 7th edition is in preparation. Neither contain references and are thus less useful.

Stock published a Catalogue of Radial Velocity and Position from Objective-Prism Plates (1984, RevMex AA **9**, 77) (available on tape: 3101). Osborn and MacConnell have submitted to publication a list of metal-poor stars from the above catalogue.

Work with the Kiso 105-cm Schmidt telescope is reported by Maeara and collaborators: this includes catalogues of Cool Carbon Stars (40.114.053, and Annals Tokyo Astron Obs 2nd Ser **21**, 293 and 423, 1987), 598 Ultraviolet-Excess Objects (38.113.055), and a Catalogue of M-Type Stars (37.002.075).

The following catalogues are available on tape from the Soviet Data Center of the Astronomical Council, Academy of Sciences: Bartaya, Karadze (Catalogue of Spectral and Luminosity Classes for 5900 stars in Kapteyn areas 44-67). Chargeishvili (Catalogue of Spectral and Luminosity Classes for 5500 stars in the direction of the anticenter).

B) PHOTOMETRIC CATALOGUES

A large number of photometric catalogues has been published in machine-readable form, and an exhaustive list appears in the report by Warren to Commission 25. We will mention especially the compilations made in Lausanne by Mermilliod (UBV data), North (Vilnius photometry), Hauck and Mermilliod (uvby) and Lanz (UBVRI).

Hauck and collaborators have discussed the photometry of nearby stars (37.002.027), Be stars (38.113.053) and bright stars (CDS Inf Bull **31**, 131). Hauck has published a Third catalogue of Am stars with known spectral types (41.002.012), and Hauck *et al.* presented a review of photometric data files (42.002.029).

A new edition of the photometric catalogue in the Geneva system is announced by Rufener: the catalogue now contains 190,000 measurements for 28,200 stars, and is certainly the largest set of homogeneous photometric observations presently available. A new absolute calibration of the passbands is available.

A catalogue giving uvbyβ photometry for 650 stars of spectral types B0-A0 in magnitude range V=6.5 to 10 is in final preparation at Stockholm Observatory by Loden.

C) ATLASES

The following atlases have been published or are in preparation:

Walborn *et al.*: IUE Atlas of O-type Spectra from 1200 to 1900Å. (NASA, 1985; on tape: 3115). Oliversen *et al.*: An Atlas of IUE Spectra of Planetary Nebulae and Related Objects (announced in AAS Bull **19**, 1987). Corbally: An atlas of 12 rather subtle composite spectra (ApJ Suppl **63**, 365). The second volume of the IUE Reference Atlas devoted to peculiar stars is in preparation by Heck *et al.*. Ferland *et al.* have published the Spectrophotometry of Nova Cygni 1975 (41.124.101): the tape version is available under reference number 3109.

D) MISCELLANEOUS

A Critical Catalogue of Stellar Abundance Analyses including more than 400 analyses for 700 stars was presented by Koeppen at the Paris Symposium in June 1987.

A list of IUE meeting bibliographies for peculiar stars has been established by Heck (38.002.055).