

## 45. STELLAR CLASSIFICATION (CLASSIFICATION STELLAIRE)

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### 1 INTRODUCTION (D.J. MacConnell)

This report covers research in the field of stellar taxonomy in the period July 1990 to June 1993. It is divided into several sections which were written by experts in each subfield. It is a pleasure to thank them for their efforts and cooperation.

Our field continues to thrive and flourish as evidenced by the activity reported here and by the number of active participants. Advances in instrumentation, data reduction tools, and data storage continue to make impressive strides and to have great impact on our speciality. With new opportunities come new challenges and responsibilities, however. High-quality data are gathering faster than ever before, and it behooves us to make certain that they are properly calibrated, used, and archived. We commend the establishment of the Spectroscopic Data Archives WG of Comm 29 chaired by Dr R.E. Griffin (see Inf Bull. Nos 67, 40 and 68, 14) in this respect.

In the last triennium, the spectrometers aboard the Hubble Space Telescope have started returning data of unprecedented quality which will have a large influence on UV spectroscopy for many years to come. On the other hand, during the next triennium, it is almost certain that IUE, the "workhorse" of UV spectroscopy for the past decade and a half, will cease to return data.

To conserve space, all references are given with only one name followed by a + sign if there are additional authors.

#### 1.1 Meetings

There was only one meeting covering the whole range of stellar types in the period between IAU GAS XXI and XXII - "The MK Process at 50 Years: A Powerful Tool for Astrophysical Insight" - and for which IAU support was not sought. It was sponsored by the Vatican Observatory under the chairmanship of Dr C. Corbally and was held in Tucson (USA) in Sept 1993 just before the due date for this report. The proceedings are to appear in the ASP Conference Series. It will be referred to as "MK50" here. IAU Symposia/Colloquia which Comm 45 sponsored or co-sponsored:

- Coll 138: "Peculiar vs. Normal Phenomena in A-Type & Related Stars"  
Trieste July 1992
- Symp 162: "Pulsation, Rotation, & Mass Loss in Early-Type Stars"  
Juan-les-Pins Oct. 1993
- Coll 148: "Future Utilisation of Schmidt Telescopes"  
Bandung Mar. 1994
- Symp 166: "Astronomical & Astrophysical Objectives of Sub-milliarcsecond  
Optical Astrometry" The Hague Aug. 1994
- Symp 167: "New Developments in Array Technology & Applications"  
The Hague Aug. 1994

### 2 CLASSIFICATION USING SLIT SPECTRA (R.O. Gray)

#### 2.1 Early-type Stars

##### 2.1.1 Wolf-Rayet stars

A catalogue of the 157 known galactic Wolf-Rayet stars was published by Conti+ (52.155.027). New galactic WR stars were discovered by Moffat+ (54.153.049) and by Cohen+ (54.112.064). Crawford+ (A&A 251, L39) suggested that the star We 21 is a massive Pop I WN8 star instead of a PN central star. Niemela+ AJ (101, 572) obtained spectra of many WR stars and reclassified them. Lewis+ (ApJ 405, 312) carried out a spectroscopic study of an eclipsing WR binary. The spectral-type changes of the star AG Car were reviewed by Viotti+ (53.114.015). The luminous blue star, He 3-519, was shown by Hajiant+ (ASP Conf Ser 35, 240) to have WN features in the optical and UV. Underhill (ApJ 398, 636) showed that a WC7 star (HD 192641) has ionized N. In a similar vein, Nugis+ (52.114.029) showed that the O VI feature, known to appear in WC stars, can also appear in WN stars. Moffat+ (53.112.003) discussed the spectral variability of WR stars and the peculiar WN8 subclass. Méndez+ (54.114.069) discussed the features of the two types of WR stars - massive Pop I stars and the central stars of PN. Smith+ (52.115.002) suggested a "quantification" of the WC classification system and have reclassified 10 stars to fit this new definition. Vreux+ (52.114.033) and Eenens+ (54.114.096) discussed classification of WR stars in the IR and Lortet (53.002.003) the nomenclature of spectral types of WR stars.

### 2.1.2 O- and B-type stars

Garmany+ (53.114.071) presented new spectral types for 32 OB stars including two new O3 stars. Herrero+ (A&A 261, 209) commented on the spectral types of 25 luminous galactic OB stars. HDE 269676 was revealed to be a massive star cluster (Heydari-Malayeri+ 53.156.134) with many of the brightest components being O-type stars. Bagnuolo+ (55.120.007) classified O-type binaries with the method of "tomographic separation." Spectra of the luminous stars in Tr 14 and Tr 16 were classified by Massey+ (AJ 105, 980). Underhill (54.112.085) discussed the spectral type of the star  $\lambda$  Per. Garrison+ (54.114.045) have reclassified 200 of the brighter late B- and Bp-type stars on their refined MK system, while Abt+ are classifying about 1000 B-type stars in the Bright Star Catalogue. Conti+ (ApJ 406, L21) have detected He II absorption lines in the K-band spectra of early O-type stars, and Morrell+ (53.114.070) discussed the unidentified stellar emission lines near 4500 Å in O-type main sequence spectra. Spectral types of a number of O9 - B9 supergiants were presented by Lennon+ (A&AS 94, 569, A&AS 97, 559) who discovered a new N-weak star, and Carpay+ (54.115.013) discussed the luminosity of a B2 hypergiant. Walborn+ (51.114.102) classified HD 93840 as a new extreme BN supergiant. Lopes+ (A&A 261, 482) have commented on the optical and IR spectra of 10 luminous peculiar B-type stars. The nature of a number of subluminous blue stars was discussed by Saffer+ (54.114.086), Schulz+ (53.114.083), Unglaub+ (52.117.002) and Theissen+ (A&A 273, 524). Slit classifications of stellar candidates/blue stellar objects from a number of surveys were reported by Heber+ (54.114.087), Berg+ (55.114.016), Stepanyan+ (53.002.137), Wegner+ (AJ 105, 660), Bixler+ (A&A 250, 370), Usher+ (52.002.078), Beers+ (55.114.011), Moehler+ (52.114.030), Kilkenny+ (53.155.043), Wegner+ (52.114.028) and Jordan+ (A&A 273, L27). A review by Shore (ASP Conf Ser 35, 186) discussed the nature of the massive stars of the upper main sequence (the LBV, Of/WN, and the B[e] stars). Hack (52.114.157) reviewed the characteristics of WR, and dwarf, giant and supergiant O, B, and A stars. HD 160529 was declared a new LBV by Sterkent+ (54.122.005) who tracked the spectral-type changes of this star during the last eight years. Similarly, the changes of HR Car, a LBV, were tracked by Hutsemékers and van Drom (54.112.024) and V439 Cyg by Polcaro+ (52.153.028). WRA 751 was discovered as a new LBV by de Winter+ (55.122.052). HR 446 was discovered to be a He-weak star (Hric, 52.114.043). Blue stars at high galactic latitudes were classified and analyzed by Dufton+ (A&A 269, 201), Kilkenny+ (MNRAS 258, 57), Arnold+ (MNRAS 257, 225), Holmgren+ (MNRAS 258, 521) and Conlon+ (A&A 269, L1).

### 2.1.3 Be and Shell stars

The spectroscopic evolution of the shell star Pleione was reviewed by Goray+ (52.112.089) and Guo Xiaozhen (Pub Beijing Astron Obs 16, 7). HD 17520, an O9 V star, has undergone a transition to a Be-type star (Walter PASP, 104, 508). The long-term variations of the Be star EW Lac were discussed by Guo Yulian (Pub Beijing Astron Obs 16, 2), the spectral evolution of 27 CMA was reviewed by Ghosh (52.112.044) and that of MWC 560 by Pier (54.114.009) and Bopp+ (BAAS 24, 801). HDE 245770, an X-ray/Be system, was classified as O9.7 IIIe by Giovannelli+ (Sp Sci Rev 59, 1) and X Per, another such system, was studied by Reynolds+ (MNRAS 258, 439). The spectra of a number of Be stars in the near-IR were described by Andriolat+ (52.112.003, 52.112.020), and the behavior of the OI line in Be stars was described by Jaschek+ (A&AS 97, 781). Waters+ (A&A 272, L9) suggested that  $\tau$  Sco is a pole-on Be star, and HD 50138 was identified as a mild B[e] star (Jaschek+ 53.112.209). Two B[e] stars were studied in the IR by Jaschek+ (55.114.029). Jaschek+ (A&AS 95, 535) defined 12 classes of Be stars according to the shape of the H-emission lines. Pollacco + (53.122.023) classified BG Cep as a Be star instead of a hot R CrB star.

### 2.2 A- and F-type Stars

Classifications were made for a wide variety of stars: Jaschek+ (54.112.035, 53.112.210) studied the Ae and A-type shell stars in the near IR, Corbally+ (IAU Circ 5452) noted the shell phase of HD 37258, Am stars were studied by Okyudo+ (51.114.086), Wegner+ (PASP 104, 322) and Rao+ (52.116.053, Bull Astr Soc India 18, 299, MNRAS 258, 819). A few Am and Ap stars were classified in OB associations by Gray+ (IAU Col 138). Lagrange-Henri+ (52.112.025) carried out a systematic search for  $\beta$  Pic-like stars, while Holweger+ (54.112.062) and Stürenburg (A&A in press) in high-resolution studies of the  $\lambda$  Boo stars identified a number of them as showing  $\beta$  Pic characteristics. Jaschek+ (54.112.061) did a spectroscopic survey of 26 A-type stars with IR excesses detected by IRAS. Philip+ (53.114.067) identified features in high-resolution spectra which can help to distinguish FHB A-stars. Lodén (55.114.055) reclassified two stars previously classified as evolved Ap stars, while Renson+ (54.002.026) published a catalogue of Am and Ap stars. Noskova (Sov Astron Lett 18, 283) classified a  $\delta$  Scu variable, while Krzesiński+ (54.117.066) has classified the primary of CK Boo. López+ (52.153.032, A&A 273, 482) identified the He I D<sub>3</sub> 5876 Å line as an activity indicator in F-type stars. Bartkevičius (Baltic

Astron 1, 194) published a catalogue of Pop II A-F supergiants, while Lu+ (ApJS 83, 203) have published 2D-Frutti MK types for some of the stars in their catalogue of faint A, F and G stars at the SGP. Sowell (52.114.022) classified a sample of yellow supergiants from their H $\alpha$  profiles. Abt+ are classifying all the northern A-type stars in the BSC and some southern A-stars as well.

The  $\lambda$  Boo stars received considerable attention during the past three years. Gray (54.036.126) discovered two new  $\lambda$  Boo stars in the field as well as two new shell stars, and Gray+ (IAU Col 138, AJ 106, 632) discovered a  $\lambda$  Boo star in Ori OB1 and a number of mildly metal-weak A stars in Ori OB1 and Lac OB1. Stürenburg (A&A in press) has identified HR 7960 as a  $\lambda$  Boo star. Iliev (IAU Col 138) and Stürenburg (A&A in press) confirmed, using high-dispersion spectra and theoretical Balmer-line profiles, the reality of Gray's classification (45.114.012) of the  $\lambda$  Boo stars into normal and peculiar H-line types. Corbally+ (IAU Col 138) classified about 60 A-type stars in the halo; 10 of them show characteristics of  $\lambda$  Boo stars. Gerbaldi+ (IAU Col 138) have published a review on the  $\lambda$  Boo stars.

### 2.3 Late-type Stars

Keenan (54.071.033) investigated the constancy of the solar spectral type during the solar maximum and finds no change at 68 Å/mm. Corbally+ (55.155.058) have classified 299 early G dwarfs in the NGP and SGP regions. Garrison+ (BAAS 24, 1207) classified a number of peculiar G stars. Bohlender+ (PASP 104, 1152) reclassified two K0 giant stars on the basis of near-IR spectra. MacConnell+ (AJ 104, 821) obtained confirming spectroscopy for distant, cool supergiants discovered in an objective-prism survey. This paper contains a description of luminosity criteria in the near IR, and a discussion of the classification of stars of unusual type. Garrison+ (53.122.073) presented spectra of Mira during recent maxima. Feng+ (53.114.075) classified 10 emission-line M stars, and Noguchi+ (PASJ 45, 85) classified the near-IR spectra of 26 S-type stars. Optical spectra of two OH/IR sources were classified by Le Bertre (54.112.040), and Berdyugina+ (Sov Astron 36, 425) used MgH as a luminosity criterion in the analysis of 12 red giants. Olivat+ (55.114.050) identify features in H-band spectra which can be used to classify K and M stars. Faraggiana+ (54.114.059) discussed the members of the class of super-Li-rich stars. Ruelas-Mayorga+ (55.155.076), Terndrup+ (52.155.013) and Sadler (55.155.039) discuss the classification of giants in the galactic bulge. Lu (53.114.060) classified 389 Ba stars some of which may be dwarfs. Briley+ (55.154.028), Smith+ (AJ 105, 173) and Vanture+ (PASP 104, 888) and Penny+ (MNRAS 257, 89) have classified CN and CH stars in globular clusters. Lazaro+ (53.114.061) found HR 8795 to be exceptionally C deficient. Beers+ (55.114.013) found 50 stars showing anomalously strong G-bands.

Green+ (ApJ 400, 659) discuss the use of the C<sub>2</sub> 6191Å bandhead in C stars as a luminosity indicator. Green (PASP 104, 977) classified 19 C-star candidates from the Case survey. Green+ (52.114.134) presented low-resolution spectra of 11 faint, halo C stars. <sup>13</sup>C-rich C stars (J-type) were classified by Chan (PASP 105, 440), Evans (53.112.061) and Barnbaum+ (54.112.049). Abia+ (53.114.076) discovered a new super-Li-rich C star, IY Hya. Warren+ (MNRAS 261, 185) have discovered some new dwarf C stars. Other studies of C stars involving classification include Le Bertre+ (52.112.011), Noguchi+ (51.114.091) and Le Van+ (ApJ 392, 702). Heber+ (A&A 267, L31) have found what appears to be a Pop I dwarf C star.

Kirkpatrick+ (ApJ 402, 643) presented a sequence of spectra in the 0.6-1.5  $\mu$ m region of well-studied M2 - M9 dwarfs. They discussed a number of temperature-sensitive features which can be used in classification. Red/near-IR spectra of 39 K and M dwarf standards and 38 secondary standards were presented by Kirkpatrick+ (54.114.094) and classified on the Boeshaar system. The spectra of 14 giant and higher luminosity stars are also presented, and spectral features which may be used to distinguish giants from dwarfs are listed. Davidge+ (ApJ 403, L47) compared the properties in the 1.5 - 2.5  $\mu$ m interval of a number of extreme M dwarfs. Several unidentified features, perhaps due to polyatomic molecules, are present. Other studies of red dwarfs include Mathioudakis+ (53.112.062), Fulbright+ (BAAS 24, 799), Bessell (53.114.014), Schneider+ (54.114.073), Leggett+ (BAAS 23, 1416), and Doyle+ (52.122.070).

Brown dwarfs were the subject of many studies even though they remain elusive. Boeshaar+ (53.114.099) have examined the spectra of a sample of very cool M dwarfs and giants in the 1.4 - 2.5  $\mu$ m range. H<sub>2</sub>O bands are insensitive to metallicity but saturate at M7. First overtone bands of CO, however, appear to continue to strengthen with decreasing temperature. Tinney+ (AJ 105, 1045) also studied the H<sub>2</sub>O bands of low-luminosity stars. Davidge+ (54.118.019) compared the near IR spectrum of the suspected brown dwarf binary Gl 473 with those of Gl 65AB and Gl 866AB, while Kirkpatrick+ (ApJ 406, 701) compared the red/near-IR spectrum of the brown dwarf candidate GD 165B to the spectra of other low-luminosity objects. Magazzù+ (ApJ 404, L17) suggested that the Li abundance should be preserved in brown dwarfs, but a search in low-mass stars led to a null detection. Irwin+ (54.115.031) discovered a star of

exceedingly low luminosity. Kirkpatrick (BAAS **23**, 1396) has compiled a library of late dwarf spectra to provide a basis for the recognition of brown dwarfs. Other studies of brown dwarf candidates include: Stauffer+ (53.114.034), Ruiz+ (53.115.011), Rebolo+ (55.115.012), Zuckerman+ (BAAS **24**, 1158), and Graham+ (AJ **104**, 2016).

#### 2.4 Pre-Main Sequence Stars

The following authors used spectroscopic observations to identify new T Tau stars and to estimate their spectral types: Gomez+ (AJ **104**, 762), Kogure+ (54.121.087), Miranda+ (A&A **271**, 564) and Gyul'budagyan (53.121.061). Spectral types of T Tau stars have been published by Franchini+ (55.121.021), Martín+ (55.118.017), Alcalá+ (A&A **272**, 225), and Martín (PASP **105**, 277). Spectral types of other emission-line PMS stars have been given by Herbig (52.121.030), Kolotilov (53.121.057) and Walter+ (52.121.057). Carter+ (54.121.083) established a classification sequence of emission PMS flare stars. A number of X-ray sources have been studied and turned out to be PMS stars of some sort: Nations+ (53.121.041), Walter (AJ **104**, 758) and Bouvier+ (55.142.023). The classification of a sample of PMS binaries has led to the discovery of a new T Tau binary, GG Tau (Martín+ IAU Col 135, 63). Herbig-Haro objects have been identified spectroscopically by Ogura (53.121.009, Proc Astron Soc Aus **9**, 295), and Ogura+ (53.121.003). Herbig Ae/Be stars have been classified by Yoshida (55.121.055), Persi+ (54.121.071), Welty+ (55.112.028), Hughes+ (53.112.024) and Andrillat+ (52.112.004). FU Ori stars were studied by Stauder+ (53.121.014, ApJ **400**, 556), Kenyon+ (54.121.062, AJ **105**, 1505), Kolotilov (53.121.025) and Parsamyan+ (Sov Astron Lett **18**, 247).

#### 2.5 Highly Evolved Stars

"Proto-planetary nebula" stars or "HR 4049" stars were a "hot" topic during the past few years. Parthasarathy+ (A&A **267**, L19) has identified an interesting star, SAO 244567, which seems to have turned into a PN within the last 40 years. The central star of the "Red Rectangle" has been studied by Waelken+ (55.114.018), and Sloan+ (ApJ **409**, 412). Other papers dealing with the classification of PPN stars include Hrivnak+ (53.112.094), Geballe+ (52.112.012), Waelken+ (54.122.059), Arkhipov+ (55.122.081), Conlon+ (ApJ **408**, 593) and Hu+ (A&A **273**, 185). Other post-AGB stars have been studied by Gonzalez+ (54.114.015, 028), Johnson+ (BAAS **23**, 1410), and Conlon+ (53.114.057). Sion+ (54.002.105) discuss the classifications of a number of highly evolved stars.

The central stars of PN were classified by Kaler+ (53.134.021), Tweedy+ (MNRAS **259**, 315), Bond+ (52.134.018), McCarthy+ (53.134.015), Werner+ (55.134.032), who report on the dramatic change in type of the central star of Longmore 4, Peña+ (A&A **265**, 757), Menzies+ (52.133.002), who discovered a probable new [WC11] star, Sun+ (Chin Astron Ap **16**, 322), and Napiwotzki+ (54.134.024, .056) who found a new class of hot central stars.

#### 2.6 Binaries and Multiples

During the past three years, significant advances have been made in the ability to separate the spectra of binary stars. The Griffin subtraction technique has led to the identification of the secondary star of  $\tau$  Per (Griffin+ A&A **254**, 289) as a rapidly rotating early A-type star which may be a  $\lambda$  Boo star. Griffin ("Binaries as Tracers of Stellar Formation", p 93) discussed the application of this technique to HR 6902 and  $\zeta$  Aur. Fekel (IAU Col 135, 89), Stockton+ (55.120.024), Cole+ (55.118.008) and Fekel+ (AJ **105**, 2265) used the method of "spectrum addition" to study a number of multiple stars and speckle binaries. Bagnuolo+ (BAAS **23**, 1378, 54.120.011, 55.120.007) have used "tomographic separation" to reconstruct the spectra of the components of SB2 systems. Perhaps even more exciting is the promise of being able to use dispersed speckle data to obtain the separated spectra of close binaries (see Kuwamura+ AJ **105**, 665). Other papers dealing with the classification of both members of a binary include Wegner+ (55.117.035), Bord+ (54.118.023) and Ginestet (54.120.005). Classification of binary systems containing a white dwarf can be found in: Fulbright+ (ApJ **406**, 240), Bergeron+ (ApJ **407**, 733), Jordan+ (54.126.046), Roberts+ (53.126.064), Beck+ (BAAS **23**, 1418), Oswalt+ (54.126.065) and Sion+ (54.126.066). Krzeminski+ (53.117.389) studied a low-mass X-ray binary. Classification of components in eclipsing systems is considered by Tomkin (55.119.011) and Grygar+ (54.119.032).

Numerous papers dealt with symbiotic systems and spectroscopic estimates of the spectral types of the component stars; see Munari (55.117.132), Barbá+ (55.124.045), Kaler+ (53.117.119), Bode+ (54.117.233), Schild+ (MNRAS **258**, 95), Kotnik-Karuza+ (A&AS **94**, 251), and Goehermann (54.117.076). IR spectroscopy of the symbiotic system V1016 Cyg was used (Rudy+ 52.117.133) to estimate the spectral type of the secondary star. Kaler+ (PASP **105**, 599) obtained spectra of a collection of PN nuclei and found that the nucleus of Ha 1-2 has the spectral characteristics of a symbiotic star. Gutiérrez-Moreno+ (PASP **104**, 1187) confirmed the symbiotic nature of 5 systems,

Calabró+ (Ap Sp Sci **197**, 251) did the same for QW Sge, and Munari (54.157.147) found that the C star C-1 in the Dra dwarf galaxy was a symbiotic binary. Remillard+ (ApJ **396**, 668) found that the optical spectrum of S-154 in the LMC evolved from an LBV to a symbiotic star over the course of four years.

### 2.7 Variable Stars

Wade+ (53.119.043) have undertaken a spectral classification survey of about 100 classical Algol variables, and Walker+ (54.155.063) studied RR Lyr variables in Baade's Window with the  $\Delta S$  method. Mantegazza (53.122.054) has found that consideration of the Ca II triplet and the Paschen lines allows the separation of RV Tau stars from Pop I supergiants. Much attention has been paid to R CrB stars: Kilkenny+ (51.122.182) classified UX Ant as an "F-type" R CrB star, Kilkenny+ (Obs **112**, 158) suggested V517 Oph is an R CrB star, and Evans+ (54.122.042) classified three stars as probable R CrB stars. On the contrary, Giridhar+ (52.114.014, J Ap Astr **13**, 307,) suggested that LR Sco was misclassified as an R CrB star. Pollacco+ (53.122.023) reviewed the criteria for R CrB stars and showed that DY Cen, possibly a unique transition object, displays marked differences from other members of the class. The spectroscopic evolution of R CrB itself was summarized in Cottrell+ (54.122.093), and the type of V482 Cygni was discussed by Rao+ (PASP **105**, 574). Bidelman (PASP **105**, 578) examined the 1893 spectrum of  $\eta$  Car and suggested a relationship to stars of the R CrB type.

The cataclysmic variable nature of a number of systems was confirmed spectroscopically by Szkody+ (55.117.038), Maza+ (PASP **104**, 1060), and Patterson+ (55.117.006). The nature of other CV's was examined by Abbot+ (ApJ **399**, 680), Dobrzycka+ (55.117.115), Mukai+ (52.117.091), and Kubiak (Acta Astr **42**, 177). Cutispoto+ (53.114.023) obtained spectral types of 8 southern stars found in EXOSAT X-ray images, while Mereghetti+ (A&A **263**, 172) determined the spectral types of 3 stars in the X-ray circle around an X-ray pulsar. Spectroscopic studies which led to the confirmation of a nova or dwarf nova nature and/or the determination of spectral types of components in a nova-like system include: Jablonski+ (55.117.186), Drew+ (MNRAS **260**, 803), Marsh (52.117.011), Szkody+ (55.117.046), Thorstensen+ (54.117.139), Shara+ (52.124.003), Anupama (55.124.002), Bruch+ (55.117.157), Bianchini (53.124.064), and Wenzel+ (Contr Astr Obs Skalnaté Pleso **22**, 69). The nova-like object PU Vul was studied by Kanamitsu+ (53.124.110, .111), Tomov+ (54.117.223) and Belyakina+ (Bull Crim Ap Obs **81**, 25). Spectral classification of flare stars was carried out by Mirzoyan+ (55.122.149), Carter+ (54.121.083) and Honeycutt+ (PASP **104**, 1039). Optical spectroscopic chromospheric diagnostics in RS CVn stars and related objects were reviewed by Bopp (52.117.296).

### 2.8 Clusters and Associations

Spectral types of 105 members of Car OB2 were published by Garcia (ApJS, **87**, 197). Perry provided spectral types for stars in Sco OB1 and the nuclear cluster NGC 6231 (52.152.004), Massey and Thompson (53.152.001) classified the massive stars in Cyg OB2, red spectra have been used by Torres-Dodgen (52.114.136) to classify the brightest stars in Cyg OB2 and de Lara+ (53.131.082) classified stars in the Ser cloud. Levato and Malaroda have just completed the classification of 500 stars in the Ori OB1 association.

In his continuing study of clusters containing Cepheid variables, Turner obtained spectral types in NGC 1647 (AJ **104**, 1865), NGC 129 (Turner+ AJ **104**, 1132) and undertook a search for OB associations near certain long-period Cepheids (Turner+ ApJS **85**, 119). In addition, Turner (A&AS **97**, 755) has studied the open cluster Roslund 3. Faint stars in NGC 3114 were classified by Sagat+ (53.153.039), FitzGerald+ (52.153.047) obtained MK types in NGC 2353, Battinelli+ (55.153.014) in NGC 433, Landolt+ (52.153.010) in the van den Bergh and Hagen Cluster No. 99, and Lattanzi+ (54.153.036) in NGC 225. Lodén (Ap Sp Sci **199**, 165) has shown that HD 108353 is actually a multiple system or small cluster of stars of late-B spectral type. A "stellar diamond" in Virgo was studied by Brosch (54.152.011). Munari (55.153.053) discussed the involvement of the Torino and Asiago Observatories in a program of classification of stars in young open clusters. Types of stars in Berkeley 86 were obtained by Forbes+ (55.153.012) and by Polcaro+ (Mem Soc Astron Ital **62**, 933) in Berkeley 87.

Spectral types and emission-line strengths of young stars in the molecular cloud L1641 were obtained by Wouterloot+ (A&A **265**, 144). Block+ (A&A **273**, L41) obtained K-band spectra of two stars in a new cluster at the Rosette GMC CO peak. In a search for faint members of the Pleiades, Prosser+ (53.153.011) has classified 77 K and M candidate members, Hamilton+ (AJ **105**, 1855) classified four red stars in the Pleiades, and Mirzoyan+ (53.122.178) have classified 17 flare stars in the Pleiades. Kogure (55.121.056) classified 34 emission-line stars in Ori OB1b, and Prosser (AJ **105**, 1441) classified a number of faint stars in the fields of IC 4665 (55.153.010) and the  $\alpha$  Per cluster. Hughes+ (AJ **104**, 680) classified stars in the region of the

Cha II dark cloud, Meyer+ (AJ **105**, 619) studied low-mass stars in the vicinity of  $\sigma$  Sco, and a study of PMS stars towards the Sco OB1 association was carried out by Piers+ (55.153.023).

## 2.9 Stars in Galaxies

The discovery and classification of WR stars in external galaxies has been particularly fruitful this triennium. WR stars were discovered and/or classified in the LMC by Testor+ (52.114.036) and Heydari-Malayeri+ (53.156.038) and in the SMC by Pakull+ (IAU Symp 143, 260). Heydari-Malayeri+ (A&A **258**, L13) discovered a peculiar Of?-like star in the LMC which they believe may be a transition object between Of supergiants and WR stars. The LMC star R127, originally classed as a WN star, is now an A-type star (Nota+ IAU Symp 143, 561). Morgan+ (54.156.035) have discovered a new WR star in the SMC. Spectroscopy of 4 WR candidates in IC 10 was obtained by Massey+ (55.157.076). A large number of WR stars in M31, M33, NGC 6822 and IC 1613 were classified by Armandroff+ (54.157.199). WR stars in M33 and M31 were classified by Schild+ (52.157.070, A&A **261**, 419) and an Ofp/WN9 star in M33 detected. Types for a number of WR stars in NGC 300 were presented by Schild+ (A&A **266**, 145).

Walborn and colleagues have classified a number early-type objects in the 30 Dor region including OB supergiants in compact groups associated with R127 and S Dor (53.112.019), Sk-69\*203, a B0.7 Ia star, an O3 If/WN6-A object and two companions of SN 1987A (PASP in press). Walborn+ (ApJ **399**, L87) have classified a number of young O-stars in the LMC H II region N11. Parker (IAU Sym 149, 467, PASP **104**, 1107) has undertaken an extensive photometric and spectroscopic survey of the stars in the 30 Dor region and has classified most of the early-type stars. Parker (53.152.010) has also classified a number of stars in LH 58. Schild+ (A&AS **92**, 729) have also classified stars in 30 Dor. Parker+ (AJ **103**, 1205) classified stars in the LH 9 and 10 regions, and Conti+ (53.114.101) studied individual stars in the LMC. Wolf (53.156.068) has studied LBV stars in the MCs, and Parker+ (BAAS **24**, 1236) has found a new LBV in 30 Dor. Fitzpatrick (54.156.030) has set up recommended classification standards for B supergiants in the LMC and has classified about 100 stars on his system, and Humphreys+ (53.156.139) have studied a group of anomalous A-type supergiants in the MCs. Welch+ (AJ **105**, 146) studied the variable stars of NGC 1866, Sekiguchi+ (52.124.024) a recurrent nova in the LMC and Lawson+ (53.156.086) the R CrB stars in the LMC. Lortet+ (53.156.037) have obtained the spectra of 95 stars in the stellar association LH99; 40 are newly discovered O stars, including 3 O3-4 stars.

Li-rich red giants in the MCs have been classified by Lubowich+ (BAAS **24**, 1158). C stars between the MCs have been discovered by Demers+ (MNRAS **260**, 103), and four new proto-stars near 30 Dor were found by Hyland+ (MNRAS **257**, 391). Spectral types in the young SMC cluster N90 were obtained by Hutchings+ (53.156.031). SMC supergiants were studied by Nandy+ (52.156.014), SMC AGB stars by Reid and Mould (52.156.013), B[e] supergiants were discovered in the SMC by Heydari-Malayeri (52.112.007) and Zickgraf+ (A&A **260**, 205). Faint C stars in the SMC were studied by Westerlund+ (A&A **260**, L4).

## 2.10 General

Keenan (PASP **105**, 905) has developed a new spectral classification system for the C stars to bring them into the Revised MK system. The notation separates the four population groups: R, N, CH, and Hd (H-deficient) C stars. New criteria have been identified which allow more realistic temperature sequences and, for the first time, a rough luminosity classification. Keenan is also working on a second edition of the Perkins Catalog of Revised MK types for the Cooler Stars and gave a review on classification standards (54.114.099). Hoffleit (54.114.097) spoke about "Pre-MK classifications."

Walborn's continuing spectral classification studies of OB stars are based on both optical and space-ultraviolet spectra, and concentrate on the MCs. He is preparing an optical digital atlas of peculiar OB spectra to complement the earlier atlas of normal OB stars (51.002.144).

Drilling and Vijapurkar have nearly completed a project of MK classification of all non-emission OB+ stars in the Case-Hamburg-LSU OB-star surveys. Vijapurkar+ (ApJS in press) has classified 253 stars at 70 A/mm, and spectral types for 500 more stars are in process. This project has led to the discovery of more than 400 new O stars and early B supergiants and other stars of astrophysical interest.

Abt is classifying the 750 stars lacking MK classifications in the BSC, 1000 members of visual multiples brighter than  $B = 8$ . Abt+ are classifying at least one star in each of 264 known Trapezium systems. Levato+ are classifying a sample of Ap stars and are continuing their classification program of members of southern clusters and associations. Torres-Dodgen+ (PASP **105**, 693) investigated classification in the near-IR. Sato+ (52.114.018) classified 591 stars on the MK system. Lançon+ (A&AS **96**, 593) published a library of near-IR spectra sampling the HR diagram. A new Atlas of Stellar Spectra (Obs **113**, 100) has been prepared by a French team containing 470

spectra of specific types and MK standards.

Corbally+ have completed classifying slit spectra of NGP and SGP G-dwarf stars, and Garrison+ are publishing a classification study of the late B-type stars. Garrison+ will be publishing spectral types in the cluster NGC 3532. Garrison+ are reviewing the MK standards over the entire HR diagram; Garrison will present the results at MK50. He is also classifying the nearest 800 G dwarfs and the 1500 brightest stars in the sky. Corbally (Trans IAU **21B**, 328) discussed problems of accurate classification using digital spectra. Gray+ are continuing to investigate the astrophysical context of the  $\lambda$  Boo phenomenon. They also (BAAS **24**, 1279) are using MK classification of synthetic stellar spectra to calibrate MK types in terms of effective temperature, gravity, microturbulence and metallicity.

### 3 OBJECTIVE-PRISM AND SLITLESS CLASSIFICATION (C.B. Stephenson)

This report can be kept rather brief by making reference to the book "Objective-Prism and Other Surveys" (55.011.021; OPOS). While the purpose of that book was not precisely that of the present review, the fact is that it does summarize a very large amount of recent results in the field of objective-prism astronomy.

The review will be further shortened by my making no mention of several pilot programs carried out in recent years without any real surveys resulting; in any case, much of this is discussed in the following section on automated methods.

In my opinion, one of the most salutary things bearing upon objective-prism work that has happened in recent years is the rather large amount of follow-up work done on objective-prism surveys at higher spectroscopic resolution than that of the surveys. For example, see the report by Sion+ in OPOS; also Green+ (52.114.134). The quantity of the follow-up has been made possible entirely by the sensitivity of current spectrographs and detectors.

During the report period, the most significant astrophysical result to emerge is arguably the discovery of the second, third, and fourth dwarf C stars (54.114.090). Papers XII-XIV of the Case Low-Dispersion Northern Sky Survey (Pesch and others; ApJS) appeared listing blue stars and galaxies, A-F stars, and various emission objects.

At Abastumani Observatory, Kharadze+ have done MK classifications (166 Å/mm near H $\gamma$ ) for several thousand stars in special regions (Bull Abast Obs No 72, 3-294). Kharadze+ published several hundred generally faint, early-type peculiar stars in the galactic anticenter (AJ **99**, 379). From Byurakan, several astronomers have published numerous lists of mainly blue objects plus follow-up spectroscopy, e.g. 52.002.045, .116; 53.002.149, .150; 54.002.088, .106, .107, .131, .133. This material has been appearing in *Astrofysica*.

At Warner and Swasey, Stephenson published two more lists resulting from his recently-completed photographic near-IR survey of the northern Milky Way: some 75 new, relatively faint S stars (AJ **100**, 569) and highly reddened stars likely to be distant and luminous (AJ **103**, 263).

V. Blanco and colleagues continued very productive in identifying new C stars, both in the Milky Way (52.155.043) and in the LMC (52.156.008).

Houk is nearing completion of classification for Vol. 5 of the *Michigan Spectral Catalogue* which will cover  $-12^\circ < \delta < +5^\circ$  and will appear in 1994.

A considerable number of small sky-area H $\alpha$ -emission surveys were published; any attempt for me to summarize them would neither be complete nor very useful. We sorely need a new edition of something like Wackerling's catalogue of emission-line stars (3.041.018).

### 4 AUTOMATIC SPECTRAL CLASSIFICATION (M.J. Kurtz)

A Special Session on automated spectral classification was held as part of the Comm 45 meetings during the General Assembly in Buenos Aires. Kurtz, Garrison, Kurucz, Golay, and Jaschek spoke; abstracts of the talks are in Trans. IAU XXIB.

The group from Tartu and Abastumani of Malyuto, Pelt, Shvelidze and collaborators continues to improve their methodology for the study of galactic structure. Recent work appears in *Baltic Astron* **1**, 526, as well as in the conference proceedings "Data Analysis in Astron IV", IAU Symp 161, and MK50.

Kurtz+ (in OPOS) have demonstrated their variance-weighted metric technique on a sample of B stars from the Michigan Survey plates. They show that the variance weighting substantially improves the classification over direct comparison methods. They introduce the technique of reflattening to eliminate residual errors in the continuum removal. LaSala has continued this work with a collection of slit spectra of G dwarfs and has automated classification accuracies similar to the B star sample of about one subtype. He presents his work in MK50.

Penprase (ApJS **83**, 273) has classified about 100 spectra using the unweighted distance technique, with photometry providing the first approximation. A group from Athens and Trieste (Hantzios+, in IAU Symp 161) have extended their criteria

evaluation methods from low- to moderate-resolution (830 Å/mm) spectra to study some of the less crowded regions of the LMC.

Beauchemin, Borra, and collaborators at Laval University have improved their low-resolution classification based on synthetic photometry (AJ 103, 405) and have applied a statistical cluster analysis to the data and have recovered the known types (AJ 105, 1587).

Three groups are investigating the use of back-propagating, artificial neural networks for automated classification. Von Hippel will review this research in MK50 as well as talk about his own work in this area (also in a preprint to appear in MNRAS). He is using Michigan Survey plates, digitized at the APM, in collaboration with researchers at Cambridge; their mean error, using only the line information, is currently about 2 subtypes.

Weaver has applied the neural network technique to moderate-resolution, near-IR spectra of W-R stars (BAAS 22, 848), O-M dwarfs, to get a mean classification accuracy of about 2 subtypes (BAAS 22, 859), and to A stars, where he shows very good temperature and luminosity errors (in MK50). Smareglia+ will show results from their neural network experiments, with mean classification accuracies of about 2 subtypes, at Astronomical Data Analysis Software and Systems III.

## 5 CLASSIFICATION FROM EXTRA-ATMOSPHERIC SPECTRA (J. Rountree)

This reporting period has seen a considerable increase in efforts at classification in the far UV largely due to the continuing success of the IUE satellite. It is to be expected that this activity will grow in the future as more recently launched instruments, such as HST/GHRS, build up a substantial archive of standard stars. Classification in the far IR is currently limited to the IRAS archive but may also be expanded with the launch of ISO. Much attention is being paid to the methodology of classification in non-traditional wavelength regions as well as to the classification of individual objects. Recently published spectral atlases of UV spectra illustrate the morphology of stellar classes in this region.

### 5.1 Methodology

Prinja (52.114.050) measured the EWS of photospheric absorption lines in 300 O and B stars and verified the temperature dependence of Si III  $\lambda$  1299 in O stars and of Si II  $\lambda$  1265 in B stars; he found that C III/O IV varies with luminosity class in O stars. Fanelli+ (52.114.063) examined the spectral morphology of 218 O-K stars in the 1900-3200 Å region; they concluded that there is excellent temperature discrimination in the mid-UV but only moderate luminosity discrimination for classes III-V. Slettebak (priv. comm.) recently measured the EWS of 17 spectral lines in Be and B-type standard stars and concluded that, while there is no significant difference between the photospheric line spectra of Be and B normal stars of the same type, the wind lines are generally stronger in the Be stars. He found the ratios Si II/III, C II/III, Al II/III, and Fe II/III are sensitive to spectral type.

Faragianni+ (52.114.016, .101) demonstrated the importance of using IUE short-wavelength spectra in classifying  $\lambda$  Boo stars. Walborn (MK50) found that the O V  $\lambda$  1371 wind profile is a signature of spectral type O3 in the UV.

Rountree+ (52.114.096, 53.114.079) defined a set of photospheric-line criteria for two-dimensional classification of B stars in the UV using high-resolution IUE spectra and MK standards. Imadache+ (52.036.258) devised an automated classification of low-dispersion IUE spectra based on multi-variate data analysis to detect abnormal objects.

### 5.2 Individual Objects

Hack+ (52.112.112) classified Herbig Be-Ae stars by comparing low-resolution IUE spectra with standards. Monterinos et al (52.115.019) used UV data to show that the spectral type of FG Sge is F6-7 I. Prinjat (54.122.036) observed the LMC supergiant HDE 269216 and classified it as B8 Ia from the IUE line spectrum. However, the shallow continuum led them to conjecture that the star is an S Dor-type variable. Tovmasyan+ presented observations with the Glazur telescope in the associations Per OBI, Sco OBI, and Cyg OBI (52.152.006); in Ori (52.114.046, .147); in Cas, Gem, and Mon (54.114.042, .088) and in Pup (55.152.006). These observations at 1640 Å reveal the presence of a number of previously unclassified hot companions some of them subdwarfs (52.117.165, 53.117.020).

Bopp+ (53.117.107) classified three composite systems as F II + B interacting binaries by observing the UV spectrum of the hotter component. Parsons+ (ApJ 412, 814) continued this work by classifying 22 late B and early A companions of late-type giants and supergiants. Evans pursued a similar program of determining the luminosities of Cepheids (53.122.070, 55.122.059) and yellow supergiants (AJ 105, 1956) by classifying their hot companions. Akalin+ (55.117.095) used high-resolution IUE spectra to determine the spectral type of the hot component of  $\delta$  Sge.

Walborn+ (ApJ **393**, L13) compared GHRS spectra of Mk 42 and R 136a with each other and with IUE standards to show that Mk 42 is of intermediate O3/WN type while R136a is a stronger WN. Landsman+ (ApJ **395**, L21) observed three UV-bright stars in  $\omega$  Cen with UIT and found that the corresponding low-resolution IUE spectra were similar to those of normal B2-B6 stars but with weaker lines.

### 5.3 Atlases

Wu+ produced an enlarged and updated version of *The IUE Ultraviolet Spectral Atlas* (IUE Newsletter 43), a widely used compendium of low-resolution standard spectra. Rountree+ prepared an atlas of B-type standard spectra (NASA Reference Pub 1312) for use in classifying high-resolution IUE spectra on their two-dimensional UV system. Walborn+ (MK50) worked on an atlas of high-resolution B-type spectra to illustrate the gradual disappearance of stellar wind features as a function of temperature and luminosity.

Doazan+ (52.002.091, 54.114.097) published an atlas showing the spectral characteristics of Be stars at far UV and at optical wavelengths. Ewald+ (52.114.104) described an atlas of high-dispersion Mg II profiles of standard stars of spectral types B0-G9.

### 5.4 Infrared Classification

Volk+ (54.133.006), using data from the slitless, low-resolution spectrometer on IRAS, classified 486 point sources into nine groups, based on their spectral morphology.

## 6 CLASSIFICATION USING MULTI-COLOUR PHOTOMETRY (M. Grenon)

In the following, references are restricted to papers presenting new calibrations or substantial sets of new data.

### 6.1 Wide-band systems

A catalogue of homogenized UBV data covering 40 years of UBV photoelectric photometry has been produced by J.C.Mermilliod. It contains cross-identifications, spectral classifications and references for 102000 stars. Cousins BVRI photometry is used by Dawson+ (AJ **103**, 2063) to classify high-proper motion stars. Infrared IJHK photometry is used by Leggett to rank 322 red dwarf stars in metallicity (ApJS **82**, 351). The solar (R-I) index and the relation  $T_{\text{eff}}/(R-I)$  for F-K dwarfs are revisited by Taylor (PASP **104**, 500).

### 6.2 Medium-band systems

#### Geneva system:

Hauck+ (A&A **269**, 403) produced  $T_{\text{eff}}$  calibrations valid for the various types of chemically peculiar stars, e.g. magnetic Ap, He-weak, Hg-Mn, and Am using Geneva colours. The resolving power for stellar classification of the multidimensional space of Geneva colour-indices was investigated by Guarinos+ (1992, ESO Conf Proc **43**, 307). A catalogue of 400 photometric and spectroscopic standards, covering the whole HR-diagram, was produced by these authors. Intrinsic colours for O to early A-type stars are defined by Cramer (A&A **269**, 457).

#### Strömberg system:

Lodén is submitting a catalogue of uvby and  $H\beta$  data for 620 B-A3 stars observed in selected directions in the galactic plane. Gray+ (A&AS **87**, 541) published a catalogue of over 600 A-G supergiants. Gray extended the empirical calibrations of the Strömberg photometry to F and G supergiants (A&A **252**, 237); temperature, gravity and colour excess are precisely determined for Ia-II supergiants Cepheids of solar composition. The calibration was extended to population I A0-F5 supergiants by Gray (A&A **265**, 704); the accuracies are  $150^\circ$  in  $T_{\text{eff}}$  and 0.02 in  $E(b-y)$ . A combination of Strömberg and Cousins BVRI data will allow the determination of the  $[M/H]$  ratio for luminous A-G stars. The uvby system is being increasingly used for objects outside the original A-G5 range, namely for late-type giants and dwarf novae, cf. Echevarría+ (A&A **275**, 201).

#### Washington system:

Geisler+ (ApJ **102**, 1836) have significantly improved the metal abundance calibration. It is now valid for the whole range of  $[Fe/H]$  -4.0 to +0.5 and is applied to field and cluster giants of Population I and II.

#### DDO system:

The properties of the DDO system with respect to CNO abundance anomalies were tested by Tripioco+ (AJ **102**, 744) with synthetic spectra. Metal-weak giants towards the galactic center were classified by Morrison (AJ **105**, 539).

**Vilnius system:**

The system was redefined for CCD detectors and used for faint object classification (A&AS 88, 87, A&AS 95, 51). Bartkevičius+ used it for the classification of Population II supergiants (Baltic Astr 1, 216). An automatic method of absolute magnitude determination was proposed by Smriglio+ (A&A 266, 634).

**Near-infrared eight-color system:**

Wing has used his narrow-band system, which measures continuum points and bands of TiO, CN, and VO to study the red supergiants of the LMC. More than 100 M stars in the central 25 square degrees have been observed, and Wing+ (BAAS 24, 773) have used the rich LMC cluster NGC 2100 to calibrate the CN-based luminosities. An important result is the discovery of a large number of K supergiants (BAAS 24, 785).

**6.3 Other systems**

The theoretical colours and isochrones for the Hubble Space Telescope FOC colour system are predicted by Paltoglou+ (MN 253, 449). Empirical relations with other systems, namely the UBVRI, are investigated by Harris+ (AJ 101, 677). The Hipparcos broad-band Hp and Tycho BT,VT system provide a new tool for the classification of the 96000 stars measured in the three bands. For O to K stars of known MK type, accurate E(B-V) are deduced. For M stars, an equivalent spectral type and a colour excess are precisely determined.

**7 CATALOGUES AND ATLASES (D. Egret)**

An increasing number of tools are now provided to astronomers world wide in order to gain access to catalogues and atlases in computer-readable form, either on magnetic media, or directly through the electronic networks (with the help of new data retrieval tools such as WAIS, gophers, WorldWideWeb, etc. see Heck+, "Adding Intelligence to Information Retrieval", Kluwer Acad Publ, 1993). The major data centers (CDS, Strasbourg, NSSDC, NASA-Greenbelt and a number of other regional data centers) are currently offering direct on-line access to the data as well as to complementary data analysis tools. This tends to replace the traditional means of data distribution (magnetic tapes, diskettes, CD-ROMs, or paper versions). Simultaneously, the editors of the major astronomical journals are moving to make tabular data more quickly available in digital form (CD-ROMs and "ftp" services being the adopted solutions). These efforts are complemented by ambitious projects of general information systems for astronomy such as ADS (Astrophysics Data System in the U.S.) and ESIS (European Space Information System) for which public releases have been made available in 1993. In the following we mention some of the most significant recent catalogues related to stellar classification.

**7.1 Spectroscopic catalogues**

Renson+ have now released their General Catalogue of Ap and Am stars (A&AS 89, 429). And at the same time, Renson (Liège), Kobi and North (Lausanne) have proposed a database of Ap stars developed on a personal computer using the previous catalogue as a starting point (A&AS 89, 61).

A new catalogue by Cayrel+ (A&AS 95, 273) of [Fe/H] determinations appeared.

**7.2 Photometric catalogues**

The leading group in the field is located at Institut d'Astronomie de l'Université de Lausanne and Observatoire de Genève. They are maintaining an impressive collection of photometric data, known as the General Catalogue of Photometric Data (A&AS 85, 989). Mermilliod is keeping the Catalogue of Observations in the UBV System (about 100000 stars) up-to-date. A new edition of the Catalogue of Am Stars with known Spectral Types has been issued by Hauck (Bull Inform CDS 40, 19).

**7.3 Compilation catalogues and atlases**

The publication of the HIPPARCOS Input Catalogue, with a printed version (ESA SP-1136, 7 volumes), and a computer version (with some revisions, available from the data centers) provides a wonderful compilation of the astrophysical data (including spectral classification and multicolor photometry) available for some 120,000 stars of the HIPPARCOS observing program. It is to be noted that a large fraction of the multicolor photometry represents new observations.

A CD-ROM version is announced for the beginning of 1994. Significant progress has been made toward filling in MK types for the 5th edition of the Bright Star Catalogue. In addition to a variety of MK classifications from various sources, the revised Perkins types for cooler stars (Keenan, 50.002.011) have been included. While the 4th edition of the BSC contained MK types for 87% of the catalogue stars, the latest version of the 5th edition (1993) includes such classifications for 93%.