SPECTROSCOPIC ANALYSES OF HOT MAIN SEQUENCE STARS

Kozo Sadakane
Astronomical Institute
Osaka kyoiku University
Tennoji-ku, Osaka, Japan 543

ABSTRACT: Spectroscopic studies of normal O and early B type stars in the visual region are discussed. Present status of UV spectroscopic analyses of hot normal stars is reviewed. Discussions on a few practical problems in analyses of UV spectra are presented.

1. Introduction

Spectroscopic studies of photospheres of non-magnetic, normal and chemically peculiar (CP) O and B type stars have been relatively inactive in recent years. Attention has been mainly focused on outer atmospheres and active phenomena such as mass loss of these hot stars. This is in contrast with the recent activity in studies of late B type (mainly Hg-Mn type) CP stars in both visual and UV regions. Instead of summarizing a few results on hot CP stars, I will concentrate here on spectroscopic analyses of hot normal stars. Abundances of only a dozen or so elements have been well determined observationally for O and early B type normal stars. Elements heavier than Ca (except for Fe) have not been studied in them. Data of chemical composition of hot stars yield information on the state of recent nuclear processing in the Galaxy because the ages of these objects are only a fraction of the solar lifetime. Studies of normal stars are also necessary because they can be used as reference standards in analyses of CP stars. Detailed studies of normal stars are indispensable especially in the UV region where many spectral lines of heavy elements not observable in the visual region can be found. In view of the present day incompleteness of atomic data such as laboratory lists of atomic and ionic lines or transition probabilities, we have to carry out comparative studies of CP stars using normal stars of correponding temperatures as standards. Spectroscopic study of hot stars in the UV region is now in its early stage and much more efforts should be devoted to normal stars.

I will first summarize some recent analyses of O and early B type stars made in the visual region. Next, I will review recent spectroscopic works in the UV region. Several practical problems such as the damping constants and the microturbulence for UV metallic lines will be discussed. Finally, I will compare the results obtained in the UV and the visual regions and discuss the consistency of the current scheme of spectroscopic analyses.

C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 369–380.

2. SPECTROSCOPIC ANALYSES IN THE VISUAL REGION

Present status of both theoretical and observational studies of atmospheres of B type stars is summarized in Underhill (1982a). Discussions on the calibrations of basic physical quantities such as mass, radius, colors, effective temperature, and bolomecric correction are given in this article. Spectroscopic studies of O type stars have been extensively carried out by Conti and his associates (e.g., Garmany, Conti, and Massey 1980). A review article on O type stars will be given in a forthcoming book by Underhill and Divan (to be published).

Detailed spectroscopic analyses of 15 O and early B type stars in the visual region published before 1971 are reviewed in Scholz (1972). We can see on his Table 1 that abundances of elements heavier than Si are not known observationally in O type stars. In addition, abundances of P, S, Ar, Ca, and Fe are obtained in B type stars. Effective temperatures and surface gravities are determined mainly from ratios of line strengths (ionization equilibria) such as O II/O III or Si III/Si IV in these early studies. It has been known that ratios of line strengths in three different stages of ionization for the same element or in two stages of ionizaton for several different elements do not necessarily lead to the same temperature. The effective temperatures deduced from ionization equilibria are generally higher than the values obtained from the size of the Balmer jump or from the slope of the Paschen continuum. Sometimes we find discrepancies in the adopted effective temperatures by a few thousand degree in different analyses of the same star.

Table 1 lists the results of more recent analyses of O and B type normal stars. The B2 IV star γ Peg was studied by Peters (1976) and the B5 IV star τ Her was studied by Adelman (1977). Determinations of T_{eff} and log g in these studies are mainly based on the flux distributions and the profiles of the Balmer lines. They found that abundances are normal in these two stars except for slight overabundances of Ne, Cl, and Ar in γ Peg. Five O type stars are analyzed by Kudritzki and his associates and they determined effective temperatures, surface gravities and He abundances. Abundances of He in these hot stars are normal except for ζ Pup in which He is slightly overabundant. It is to be noted here that abundances of such elements as Cr or Mn which are important in physics of CP stars are not known observationally in hot O and B stars. This is because of the intrinsic weakness of absorption lines of singly or doubly ionized ions of these elements in the visual spectra of hot stars.

Now, I will briefly discuss the importance of re-analyses of sharp lined normal stars with modern techniques. These sharp lined stars can be used as reference standards in studies of CP stars of corresponding temperatures. A new systematic survey seems necessary because of the following reasons.

Table 1. Recent Analyses of O and B Type Stars

Star	HD/HDE	Author	T_{eff}	log g	Abundance
γ Peg	886	Peters 1976	21,500	3.7	14 elements
τ Her	147394	Adelman 1977	14,500	3.5	8 elements
	93250	Kudritzki 1980	52,500	3.95	He
ζ Pup	66811	Kudritzki et al. 1983	42,000	3.5	He
	93128	Simon et al.	48,000	3.85	
	93129A	1983	45,000	3.60	He
	303308		45,500	3.90	

(1) Very high signal to noise ratio (S/N) spectroscopic observations are now possible with modern electronic devices such as Reticon or CCD. A combination of these devices with a high resolution spectrogragh enables us to analyse profiles of even faint lines with high accuracy. For example, Smith (1981) detected extremely faint (equivalent width: $\lesssim 1 \sim 3$ mÅ) lines due to P II, Ar II, or Cl II near 4130 Å in the spectrum of ι Her using a Reticon detector system. Quantitative analyses of He I lines by Heasley and Wolff (1981) and Heasley, Wolff, and Timothy (1982) and of the H_α line by Heasley and Wolff (1983) in B type stars well illustrate the advantages of these new tools.

(2) Reliable data of transition probabilities are now available for many atomic and ionic lines. Although astrophysicists even today suffer from the lack of atomic data as discussed in the previous session of this colloquium, the situation has significantly improved in these ten years. Data used in older analyses should be replaced with the more reliable ones. It is important to incorporate the latest atomic data into analyses of both normal and CP stars.

(3) The effective temperature scale has been revised. Various methods of determining the effective temperatures of hot stars are discussed in Böhm-Vitense (1981) and in Underhill (1982a). Underhill (1982b) determined effective temperatures of 24 O3 to O5 stars and found no correlation between the effective temperature and spectral type or luminosity class for these hot stars. Recent revisions of the temperature scale depend on extensive high quality photometric observations from UV to IR regions. As discused by Code (1984), the calibration of UV flux measurements is critically important for O and B stars because these stars radiate most energy in this region. An uncertainty of at least ± 1000 K is expected even in the latest determinations of effective temperatures for early B type stars.

Table 2. Non-LTE Calculations

Ion	Ref.	T_{eff} (10^3 K)	log g	ξ_t (km s^{-1})
He I, II	1	30 - 50	3.3, 4.0, 4.5	
He I	2	15 - 27.5	2.5, 3.0, 4.0	
	3	15 - 27.5	2.5, 3.0, 4.0	
	4	15 - 27.5	2.5, 3.0, 4.0	
	5	15 - 27.5	3.0, 4.0	
Be II	6	10 - 15	4.0	0
B II	7	10 - 15	4.0	0
C II, III	8	25 - 35	3.5, 4.0, 4.5	
C III	9	30 - 55	3.3, 3.5, 4.0	10
N II	10	20 - 32.5	4.0	0, 5
N III	11	32.5 - 50	3.3, 4.0	5, 10
O I	12	7.5 - 17.5	1.0, 2.5, 4.0	0, 5
Ne I	13	15 - 22.5	3.0, 4.0	0, 4
Mg I, II	14	10 - 15	4.0	0
Mg II	15	15 - 40	4.0	0, 4
	16	15 - 35	2.5, 3.0, 4.0	0 - 15
Si II, III, IV	17	15 - 35	2.5, 3.0, 4.0	0 - 15
	18	15 - 35	3.0 - 4.5	0
Ca II	19	15 - 27.5	2.5, 3.0, 4.0	0, 4
	20	10 - 15	4.0	0
Sr II	20	10 - 15	4.0	0
Ba II	14	10 - 15	4.0	0

References: (1) Auer and Mihalas 1972, (2) Auer and Mihalas 1973a, (3) Mihalas et al. 1974, (4) Mihalas et al. 1975, (5) Dufton and McKeith 1980, (6) Boesgaard et al. 1982, (7) Borsenberger et al. 1979, (8) York 1980, (9) Sakhibullin and Solov'eva 1983, (10) Dufton and Hibbert 1981, (11) Mihalas and Hummer 1973, (12) Baschek et al. 1977, (13) Auer and Mihalas 1973b, (14) Borsenberger et al. 1984, (15) Mihalas 1972, (16) Snijders and Lamers 1975, (17) Kamp 1976, (18) Kamp 1978, (19) Mihalas 1973, (20) Borsenberger et al. 1981.

(4) Non-LTE computations of line profiles and strengths for many ions are now available. Published non-LTE predictions and thier range of applicability in T_{eff} and log g are summarized in Table 2. We can see on this table that detailed non-LTE computations are mainly carried out for light ions in the high temperature range. Kamp (1982) compared observed and predicted strengths of C II, and III and also Si II, III and IV lines in the UV region using high dispersion data obtained with the IUE satellite. He found reasonably good agreements but noted that theoretical predictions not always give satisfactory explanations of very strong and very weak lines. Quantitative comparisons of predictions with high S/N observations of normal stars are necessary before we apply them in studies of CP stars.

An important feature found in hot stars is the mass loss phenomenon. Mass loss effects are detected from asymmetric profiles of strong resonance lines such as C IV, N V, and Si IV in the UV region. Snow and Morton (1976) found that stars brighter than M_{bol} = -6.0 mag generally show mass loss effects. According to Gathier, Lamers, and Snow (1981), six stars among the 15 O and B stars listed in Table 1 of Scholz (1972) are losing mass. Lamers and Rogerson (1978) and Hamann (1981) analyzed the profiles of UV resonance lines in the B0 V star τ Sco and determined a mass loss rate of log $\dot{M}$ = -8.9 ± 0.5 $M_{\odot}$/yr in this star. Smith and Karp (1978) found slight asymmetries in the photospheric lines of τ Sco and suggested that a subphotospheric, convective velocity field is responsible for these asymmetries.

3. ANALYSIS OF HIGH RESOLUTION UV SPECTRA

Now, we shall turn our attention to the observations made in the ultraviolet region below 3000 Å. Studies of high resolution UV spectra of various stars began in 1972 with the OAO-3 (Copernicus) satellite. The IUE satellite continues its activity since 1978 and a large amount of spectroscopic data are now available. The Soviet astrophysical space station Astron began its observation in 1983 (Boyarchuk et al. 1984). The importance of the UV region lies in the anticipation that we may find new infomation not yet discovered in the visual region. Because spectroscopic analyses in the UV region began recently, we do not have sufficient practical experience in the region yet.

The initial works to be carried out in a new wavelength region is to register the observed spectral features and to try thier identifications using available line lists. Table 3 summarizes these pioneering works on hot normal stars from high resolution spectroscopic data obtained with the Copernicus and the IUE satellites. B type supergiants are not included in this table. We can see on this table that no line identification list in the region between 1430 Å and 2000 Å has been published for B type main sequence stars so far. This is because of the restriction of the spctrogragh of the Copernicus satellite. Line lists in this spectral region for B type stars are urgently needed.

Table 3. Analysis of High Dispersion UV Spectra

Star	HD	Sp. T.	Range (Å)	Ref.
			Line List	
ζ Pup....	66811	O4f	923 - 3205	1
	49798	O6p	1175 - 2935	2
3 O-type Stars			1150 - 2000	3
42 Ori....	37018	B1 V	1040 - 1424, 2061 - 2903	4
γ Peg....	886	B2 IV	1000 - 1436, 2000 - 2990	5
ι Her....	160762	B3 IV	999 - 1467	6
τ Her....	147394	B5 IV	1025 - 1425, 2023 - 2959	7
ζ Dra....	155763	B6 III	1035 - 1425, 2000 - 3000	7
α Lyr....	172167	A0 V	1100 - 1460, 2000 - 3000	8
			2746 - 2881	9
			Atlas	
τ Sco....	149438	B0 V	949 - 1420, 1418 - 1560	10
ι Her....	160762	B3 IV	999 - 1422, 1418 - 1467	6
60 O and B Stars			1000 - 1450	11

References: (1) Morton and Underhill 1977, (2) Bruhweiler et al. 1981, (3) Dean and Bruhweiler 1985, (4) Johnson et al. 1977, (5) Hill and Adelman 1978, (6) Upson and Rogerson 1980, (7) Underhill and Adelman 1977, (8) Faraggiana et al. 1976, (9) Michelson 1981, (10) Rogerson and Upson 1977, and (11) Snow and Jenkins 1977.

Note: Data used in (9) are obtained with a balloon-borne spectrograph.

Discussions on difficulties in the analyses of UV spectra of hot stars have been given in the previous session and they are not repeated here. I think it is important to check, at the beginning, whether we can have consistent results with those obtained in the visual region for some well studied stars. This process has to be done quantitatively before we carry out analyses of some lines of unexplored elements in the UV region. I will discuss a few practical problems in the following.

(1) Damping Constants

It has been customary to assume ten times the classical damping constant in analyses of metallic lines of B and A type stars in the visual region when no experimental data are available. The choice of a damping constant raises no serious problem in the visual region because metallic lines are generally weak in this region. In contrast, many strong metallic lines are overlapping in the UV region even in the spectrum of an early B type star.

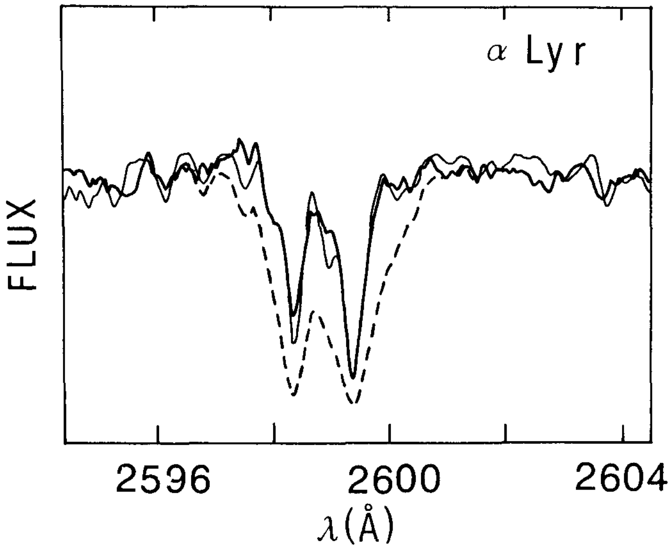

Fig. 1. Spectrum of α Lyr around 2600 Å. Bold line: Observed spectrum, thin line: computed spectrum with classical damping, and dashed line: computed spectrum with ten times the classical damping.

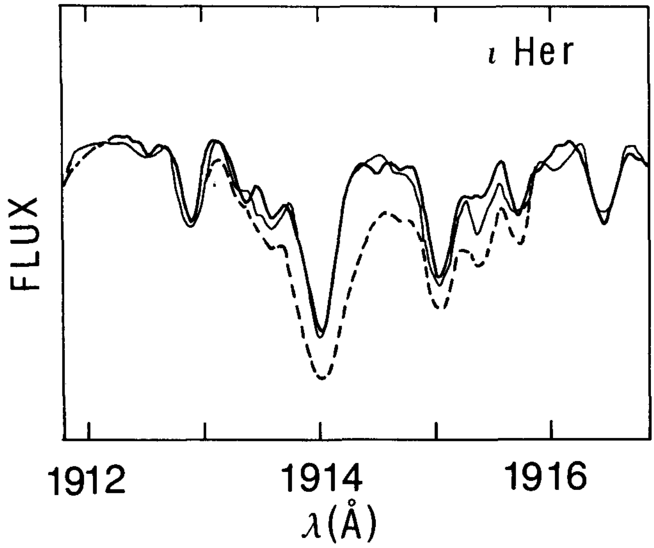

Fig. 2. Spectrum of ι Her around 1910 Å. Symbols are the same as in Fig. 1.

Thus, it is critically important to use correct damping constants to reproduce the observed spectrum in the UV region. Peytremann (1972) found that the damping by electron collisions for UV lines is always much smaller than either the radiative or the classical damping except for lines arising from high-excitation levels. According to him, a damping constant equal to 10 times the classical value is always much too large for the UV lines. Since then, however, no quantitative evaluation of the empirical damping constant in the UV region has been published.

Preliminary analyses of some strong lines of Fe II and Fe III in α Lyr (A0 V) and ι Her (B3 IV), respectively, are carried out using a spectrum systhesis technique. Six LWR (α Lyr) and three SWP (ι Her) images obtained with the IUE high dispersion spectrographs are co-added to make up the observational data. Figure 1 shows the region around 2600 Å in α Lyr where two strong resonance lines of Fe II are contained. I tried to reproduce the observed spectrum with a line blanketed model atmosphere (T_{eff} = 9650 K and log g = 3.95) and with the same abundances obtained in the visual region. Abundances of α Lyr obtained by Sadakane and Nishimura (1981) are used. 114 lines which are taken from the lists of Kurucz and Peytremann (1975) and Kurucz (1981) are included in the computation between 2595 Å and 2605 Å. Transition probabilities of the Fe II resonance lines are taken from the new compilation by Martin et al. (1986). Also assumed are a microturbulence velocity of 2 km/s (discussed below) and a rotational velocity, v sin i, of 23 km/s. Then, the damping constant is changed as a free parameter until a good fit is obtained. I obtained a satisfactory agreement with the observed profile using the classical damping constant as shown in Figure 1. If we assume a damping constant equal to 10 times the classical value, we are forced to assume a much smaller (more than 1.0 dex) abundance of Fe to account for the resonance lines.

Figure 2 shows the region around 1910 A in ι Her where many lines of doubly ionized Fe are crowded. I tried to reproduce the observed spectrum with a model atmosphere (T_{eff} = 17,800 K and log g = 3.8) and assuming the solar abundances of metals. A microturbulence velocity of 2 km/s and a v sin i value of 10 km/s are assumed. 80 absorption lines (mostly of Fe III) are included in the region between 1910 Å and 1918 Å. Transition probabilities are taken from Kurucz and Peytremann (1975) except for the Fe III multiplet 51 lines. Data for the multiplet are taken from Fuhr et al. (1981). Again, a good fit is obtained when the classcal damping constant is used. We cannot account for the profiles of the strong line (Fe III multiplet 34 at 1914.06 Å) and other weak Fe III lines simultaneously with a single value of the Fe abundance if we assume 10 times the classical value. Thus, I conclude that the actual damping constant for Fe II and Fe III lines originating from low excited levels is very close to the classical value.

(2) Microturbulence

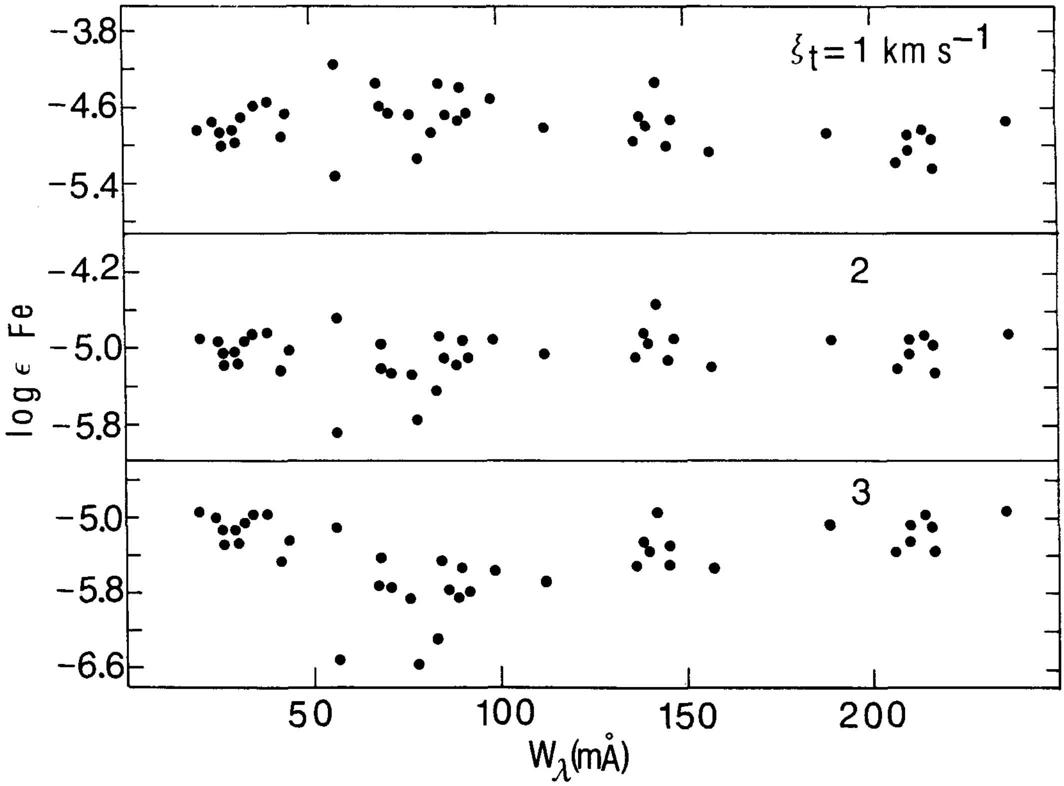

Fig. 3. Determination of the microturbulence ξ_t in the UV region (from 2300 to 3000 Å) from Fe II lines in α Lyr.

Castelli and Faraggiana (1979) noted that a depth-dependent microturbulence which decreases toward the surface has to be introduced in order to account for UV Fe II lines of α Lyr. I re-examined Fe II lines in α Lyr between 2300 Å and 3000 Å using high dispersion IUE data. Unblended lines are carefully selected using the two line lists (Kurucz and Peytremann 1975 and Kurucz 1981). Equivalent widths of 46 selected Fe II lines are measured. Transition probabilities (log gf values) for these lines are taken from the new compilation of Martin et al. (1986). Abundance of Fe is computed for each of the Fe II line using the same model atmosphere of α Lyr noted above. The microturbulence is changed as a free parameter in the range of 0 to 4 km/s. Figure 3 shows the dependence of the obtained abundance of Fe on measured equivalent widths for three microturbulences. The abundance is nearly independent on the equivalent width when a microturbulence of 2 ± 0.5 km/s is used. This value is the same as that obtained by Sadakane and Nishimura (1981) from the visual and the near UV (3250 Å to 3600 Å) spectrum of α Lyr. Thus it is apparent that we do not need to introduce a depth dependency in the microturbulence of α Lyr.

Table 4. Abundances of Iron Peak Elements in Vega

Ion	UV1[a]	N	UV2[b]	N	Visual	N
Cr I					-6.65	3
Cr II....	-6.99	7	-7.00	14	-6.81	15
Mn I					-6.87	3
Mn II....	-6.77	9	-6.81	4		
Fe I					-5.09	28
Fe II....	-5.06	46	-5.02	4	-5.10	19
Co II....	-7.45	7	-7.20	2		
Ni I			-5.94	11		
Ni II....	-6.04	8	-6.19	1	-6.43	1

a: 2100 Å to 3000 Å, b: 3250 Å to 3600 Å.

(3) Abundances

The abundance of Fe from the UV lines (log Fe/H = -5.0 ± 0.25) agrees with the result of Sadakane and Nishimura (1981). Iron is definitely underabundant in α Lyr when compared with the solar abundance of log Fe/H = -4.37 (Simmons and Blackwell 1982). Of course, it is to be noted that the above results depend on the adopted set of transition probabilities and the errors in the measurements. The gf values used here are revisions of the data of Fuhr et al. (1981) which for the most part resolve difficulties in the values of Fe II in the visual region.

I compared the equivalent widths of 22 apparently unblended Fe II lines given in Castelli and Faraggiana (1979) with my measurements and found that their values are systematically (by about 25 %) smaller than my results. This difference is most probably due to their underestimations of the height of the continuum level. I searched on the spectrum of α Lyr for line free windows by comparing with the synthesized spectrum. Usually, a few such windows can be found in each 10 Å interval between 2000 Å and 3000 Å. The highest points in these windows are connected by segments of straight lines and they are used as the continuum level. In addition, I measured equivalent widths of selected lines of Cr II, Mn II, Co II and Ni II in the UV spectrum of α Lyr. Abundances of these elements derived from UV lines are also in satisfactory agreements with those obtained in the visual region (Table 4). The RMS errors in the obtained abundances are ± 0.25 dex for Fe II and around ± 0.3 dex for other ions. A full description of the analysis of the UV spectrum of α Lyr will be published in a separate paper (Sadakane, Nishimura, and Hirata 1985). The importance of careful selections of lines and also a careful determination of the continuum level can not be overemphasized in analyses of stellar UV spectra.

4. CONCLUDING REMARKS

(1) The importance of normal stars in studies of CP stars is reemphasized. Detailed analyses of normal stars in the visual region are still necessary. These analyses should be based on recent developements of both observational techniques and theoretical studies.

(2) Quantitative analyses of high resolution UV spectra of hot stars are now in the early stage of developement. Information on abundances of many unexplored elements will be obtained from UV data. Careful analyses of UV spectra of normal stars as reference standards are critically important in this region.

I would like to thank Dr. J. R. Fuhr for providing unpublished data of log gf values (Martin et al. 1986) and WDC-A at NASA/GSFC for providing released IUE data. Helpfull comments from Drs. J. Jugaku and M. Takada-Hidai are gratefully acknowledged.

REFERENCES

Adelman, S. J. 1977, M. N. R. A. S. 181, 667.
Auer, L.H., and Mihalas, D. 1972, Ap. J. Suppl., 24, 193.
——. 1973a, Ap. J. Suppl., 25, 433.
——. 1973b, Ap. J., 184, 151.
Baschek, B., Scholz, M., and Sedlmayr, E. 1977, Astr. Ap., 55, 375.
Boesgaard, A. M., Heacox, W. D., Wolff, S. C., Borsenberger, J., and Praderie, F. 1982, Ap. J., 259, 723.
Böhm-Vitense, E. 1981, Ann. Rev. Astr. Ap., 19, 295.
Borsenberger, J., Michaud, G., and Praderie, F. 1979, Astr. Ap., 76, 287.
——. 1981, Ap. J., 243, 533.
——. 1984, Astr. Ap., 139, 147.
Boyarchuk, A. A., et al. 1984, Pis'ma Astron. Zh., 10, 163, (Sov. Astr. Lett., 10, 67).
Bruhweiler, F. C., Kondo, Y., and McCluskey, G. E. 1981, Ap. J. Suppl., 46, 255.
Castelli, F., and Faraggiana, R. 1979, Astr. Ap., 79, 174.
Code, A. D. 1985, in IAU Symposium 111, Calibration of Fundamental Stellar Quantities, ed. D. S. Hayes, L. E. Pasinetti and A. G. D. Philip (Dordrecht: Reidel)
Dean, C. A., and Bruhweiler, F. C. 1985, Ap. J. Suppl., 57, 133.
Dufton, P. L., and Hibbert, A. 1981, Astr. Ap., 95, 24.
Dufton, P. L., and McKeith, C. D. 1980, Astr. Ap., 81, 8.
Faraggiana, R., Hack, M., and Leckrone, D. S. 1976, Ap. J. Suppl., 32, 501.
Fuhr, J. R., Martin, G. A., Wiese, W. L., and Younger, S.M. 1981, J. Phys. Chem. Ref. Data, 10, 305.
Garmany, C. D., Conti, P. S., and Massey, P. 1980, Ap. J., 242, 1063.
Gathier, R., Lamers, H. J. G. L. M., and Snow, T. P. 1981, Ap. J., 247, 173.
Hamann, W. -R. 1981, Astr. Ap., 100, 169.

Heasley, J. N., and Wolff, S. C. 1981, Ap. J., 245, 977.
———. 1983, Ap. J., 269, 634.
Heasley, J. N., Wolff, S. C., and Timothy, J. G. 1982, Ap. J., 262, 663.
Hill, I., and Adelman, S. J. 1978, Ap. J. Suppl., 37, 265.
Johnson, H. M., Snow, T. P., Gehrz, R. D., and, Hackwell, J. A. 1977, P. A. S. Pacific, 89, 165.
Kamp, L. W. 1976, Statistical Equilibrium Calculations for Silicon in Early Type Model Stellar Atmospheres, NASA TR-R455.
———. 1978, Ap. J. Suppl., 36, 143.
———. 1982, Ap. J. Suppl., 48, 415.
Kudritzki, R. -P. 1980, Astr. Ap., 85, 174.
Kudritzki, R. P., Simon, K. P., and Hamann, W. -R. 1983, Astr. Ap., 118, 245.
Kurucz, R. L. 1981, Smithsonian Ap. Obs. Spec. Rept., No. 390.
Kurucz, R. L., and Peytremann, E. 1975, Smithsonian Ap. Obs. Spec. Rept., No. 362.
Lamers, H. J. G. L. M., and Rogerson, J. B. 1978, Astr. Ap., 66, 417.
Martin, G. A., Fuhr, J. R., and Wiese, W. L. 1986, Atomic Transition Probabilities - Scandium through Nickel (A Critical Data Compilation), to be published.
Michelson, E. 1981, M. N. R. A. S. 197, 57.
Mihalas, D. 1972, Ap. J., 177, 115.
———. 1973, Ap. J., 179, 209.
Mihalas, D., Barnard, A. J., Cooper, J., and Smith, E. W. 1974, Ap. J., 190, 315.
———. 1975, Ap. J., 197, 139.
Mihalas, D., and Hummer, D. G. 1973, Ap. J., 179, 827.
Morton, D. C., and Underhill, A. B. 1977, Ap. J. Suppl., 33, 83.
Peters, G. J. 1976, Ap. J. Suppl., 30, 551.
Peytremann, E. 1972, Astr. Ap., 17, 76.
Rogerson, J. B., and Upson, W. L. 1977, Ap. J. Suppl., 35, 37.
Sadakane, K., and Nishimura, M. 1981, P. A. S. Japan, 33, 189.
Sadakane, K., Nishimura, M., and Hirata, R. 1985, submitted to P. A. S. Japan.
Sakhibullin, N. A. and Solov'eva, L. I. 1983, Tr. Kazan Gorod. Astro. Obs. Vyp., 48, 27.
Scholz, M. 1972, Vistas in Astron., 14, 53.
Simmons, G. J., and Blackwell, D. E. 1982. Astr. Ap., 112, 209.
Simon, K. P., Jonas, G., Kudritzki, R. P., and Rahe, J. 1983, Astr. Ap., 125, 34.
Smith, M. A. 1981, Ap. J., 246, 905.
Smith, M. A., and Karp, A. H. 1978, Ap. J., 219, 522.
Snijders, M. A. J., and Lamers, H. J. G. L. M. 1975, Astr. Ap., 41, 245.
Snow, T. P., and Jenkins, E. B. 1977, Ap. J. Suppl., 33, 269.
Snow, T. P., and Morton, D. C. 1976, Ap. J. Suppl., 32, 429.
Underhill, A. B. 1982a, in B Stars With and Without Emission Lines, ed. A. B. Underhill and V. Doazan (NASA SP-456), p. 3.
———. 1982b, Ap. J., 263, 741.
Underhill, A. B., and Adelman, S. J. 1977, Ap. J. Suppl., 34, 309.
Upson, W. L., and Rogerson, J. B. 1980, Ap. J. Suppl., 42, 175.
York, L. A. 1980, Ph. D. thesis, Boston University.

Discussion appears after the following paper.