SPECTRAL CLASSIFICATION OF EARLY TYPE STARS FROM THE LOW DISPERSION ULTRAVIOLET SPECTRA

K. Nandy
Royal Observatory, Edinburgh

SUMMARY

The methods of spectral classification from the low dispersion ultraviolet spectra obtained with the S2/68 experiment in the TD1 satellite have been described. The bright stars, the spectra of which are photometrically accurate, can be divided into natural groups according to the spectral appearance of the features. These features vary in strength with spectral type and luminosity, and enable separation between main sequence and luminous stars. The limits for these stars are V = $6^m.0$ at BO to $5^m.0$ at AO. For fainter stars the spectral data have been combined to obtain narrow band magnitudes at several wavelengths. These photometric bands have an effective width of 100 A. An ultraviolet photometric system which enables determinations of spectral type and luminosity of early type stars is described and the results for about 3000 stars is presented. The photometric system considered here consists of the ultraviolet colour indices (m_{2740}-V,) (m_{2190}-V) and (m_{1490}-V).

1. Introduction

The skysurvey telescope (S2/68) in the TD1 satellite (for details see Boksenberg et al 1973) provides stellar energy distributions on an absolute scale in the wavelength range from 1350A to 2350A with a resolution of 30A. In addition the experiment gives a broad band measurement at 2740A ($\Delta\lambda \sim$ 340A). The survey has provided a homogenous set of spectral data of a large number of stars distributed all over the sky. The limits are V = $9^m.0$. at BO to $8^m.0$ at AO. Each object has been observed at least three times, more if the objects are nearer to the

Edith A. Müller (ed.), Highlights of Astronomy, Vol. 4, Part II, 289-301.

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

ecliptic pole.

Existing methods of stellar classification are based on line intensities and the colours in the optical wavelength range. In the ultraviolet wavelength region closely spaced atomic transitions of ionized metals (line blocking) occur and also the energy distributions of early type stars reach their Planck maximum. Therefore, the stellar classifications based on the ultraviolet data and their comparison with the classifications from the visible spectra would provide additional information on stellar physical parameters e.g. effective temperature and surface gravity etc. Since the S2/68 spectra have been taken with the same instrument a quantitative classification method will provide a homogenous classification of a large number of stars complete up to the limiting magnitude $V = 9^m.0$. In this paper we shall discuss the classification criteria which can be derived from the spectral features observed in the low dispersion spectra as well as from the observed flux distributions.

2. Spectral features observed in the low dispersion spectra

The absolute stellar fluxes derived from measurements obtained with the S2/68 experiment are based on the results of independent laboratory calibrations performed in Edinburgh and Liege (Humphries et al 1976). For each star a mean spectrum has been constructed from the repeated observations, and the accuracy of the mean spectrum is better than 3% for the bright stars ($V < 6^m.0$, and $E_{B-V} < 0.2$). A number of distinct features appear in the spectra, the strength of which vary with the spectral type and luminosity. Due to the low resolution ($\Delta\lambda$ = 30A) the observed features correspond to the blends of a large number of appropriately situated atomic lines.

As a result of the chance accumulations of many faint lines the main contributors of the features depend on the temperature. The strong features which are important for spectral classifications and their main contributors are given in Table 1.

3. Classification criteria based on spectral features.

From a systematic examination of the spectra of about 400 stars brighter than $V = 6^m.0$ in the spectral type range from O to A2 the spectral appearances of the features, their approximate wavelength positions, and their

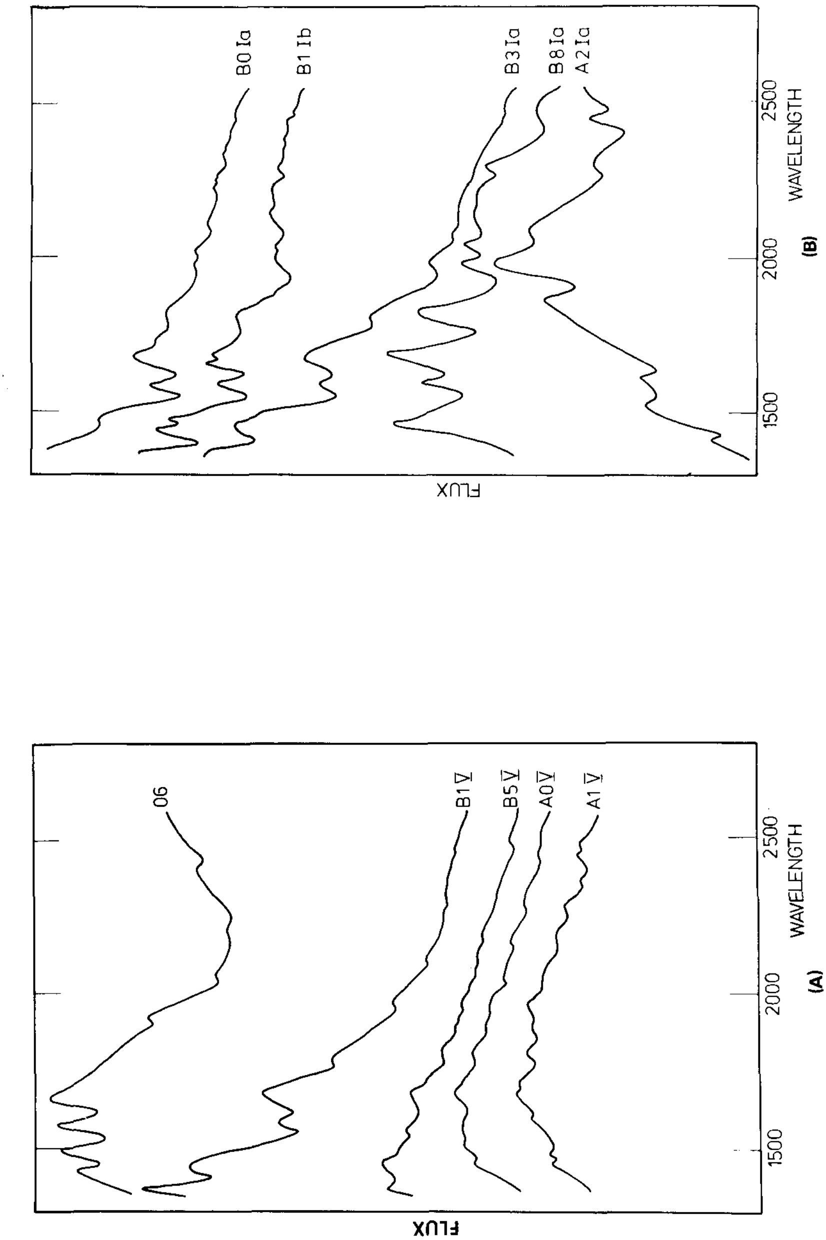

Fig. 1a-b. Typical S2/68 UV spectra of Class V and Class I stars.

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

dependance on the spectral types and luminosity classes have been studied and are summarised in column 3 of Table 1. For example, Fig 1 shows typical spectra of class V and class I stars. It is to be noted that some features are present only in luminous stars and are suitable for luminosity classification. According to the presence of the features the stars can be divided into natural groups. The range of MK spectral types of these groups and their characteristic features are given in Table 2. These observations yield an empirical two dimensional classification from a visual examination of the ultraviolet spectra; the classification scheme is described in Table 3. For an accurate classification, it is, however necessary to measure the relative strengths of the distinguishing features. For example, the strength of the 1450A feature, which is present only in O stars increases with earlier types.
Houziaux(1976) has found tentatively that the pseudo-equivalent width of this feature is 1A for O9.5V increasing to 5A for O4V. Cucchiaro et al (1976) have used the intensity ratio of the features occurring at 1410A and 1550A, and of the 1620A and 1550A features for a two dimensional classification of the stars in the spectral range from BO to B8. For later types the strengths of the 2250A and 2450A are useful classification parameters.

The accuracy which is required to measure the relative strengths of the features observed in the low dispersion spectra restricts the classification to relatively bright stars whose spectra are photometrically accurate. The limits for these stars are $V = 6^m.0$ at BO to $5^m.0$ at AO. For fainter stars the spectral data have to be combined into wider bands to give statistically useful results, and the classification parameters can be obtained from the study of the ultraviolet colours as described in the following section.

4. Ultraviolet spectrophotometry of early type stars.

4.1 Classification from the spectral energy distribution

The basis of classification is that the stars can be grouped according to their intrinsic flux distributions which are determined primarily by their effective temperatures, since the spectral range considered here contains most of the energy of the early-type stars. We have shown earlier that the luminous stars have a flux deficiency increasing with $1/\lambda$ as compared to the main sequence stars of similar spectral types, this probably being due to the luminous stars having lower effective

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

temperatures than the corresponding main sequence stars (Humphries et al 1975, Nandy and Schmidt 1975). Therefore, by proper choice of colours the stars can be separated according to their temperature and surface gravity.

Photometric bands of effective widths of 100A have been constructed centred at 2500A, 2400A, 2300A, 2190A, 2100A, 2000A, 1900A, 1800A, 1700A, 1600A, and 1490A. The fluxes obtained at these wavelengths were converted to magnitudes m_λ, where $m_\lambda = -2.5 \log I_\lambda - 21.1$ (Oke and Schild, 1970) and I_λ is the mean flux at λ in erg s^{-1} A^{-1} cm^{-2}. The photometric error of the ultraviolet magnitude is $\pm 0^m.03$ for stars brighter than $V = 6^m.0$ rising to $\pm 0^m.12$ for fainter stars at wavelengths other than 2190A. Due to large interstellar extinction at 2190A, the uncertainty of m_{2190} can be as high as $\pm 0^m.3$ for moderately reddened stars ($E_{B-V} > 0.4$).

The problem of a two dimensional classification from the stellar flux distributions lies in choosing three colour-indices which fulfil the following requirements:-

(1) The interstellar reddening path and the thermal reddening path in the colour-colour diagram should be well separated,

(2) The separation between the main sequence stars and the supergiants of similar spectral types in the colour-colour diagram, and the change of the colour-indices per unit spectral class should be larger than the photometric errors.

Since the flux deficiency of the luminous stars increases with $1/\lambda$, the effect of luminosity on the ultraviolet colour ($m_{1490} - m_{2740}$) is very large as compared to the colours at longer wavelengths e.g. (m_{2740} - V) (see Humphries et al 1975). We have chosen to use the colour-indices (m_{2740} - V) and ($m_{1490} - m_{2740}$) as earlier results indicated that the first primarily determines the colour temperature (spectral type) while the second is sensitive to both temperature and luminosity. These colours have been corrected for interstellar extinction, using the colour-index (m_{2190} - V) as a reddening indicator. In the intrinsic colour-colour diagram $(m_{1490} - m_{2740})_o$ vs $(m_{2740} - V)_o$ the main sequence stars are well separated from the luminous stars. (Nandy et al 1976). The change of colour index $(m_{2740} - V)_o$ and $(m_{1490} - m_{2740})_o$ per unit spectral class is $0^m.2$ for B-stars.

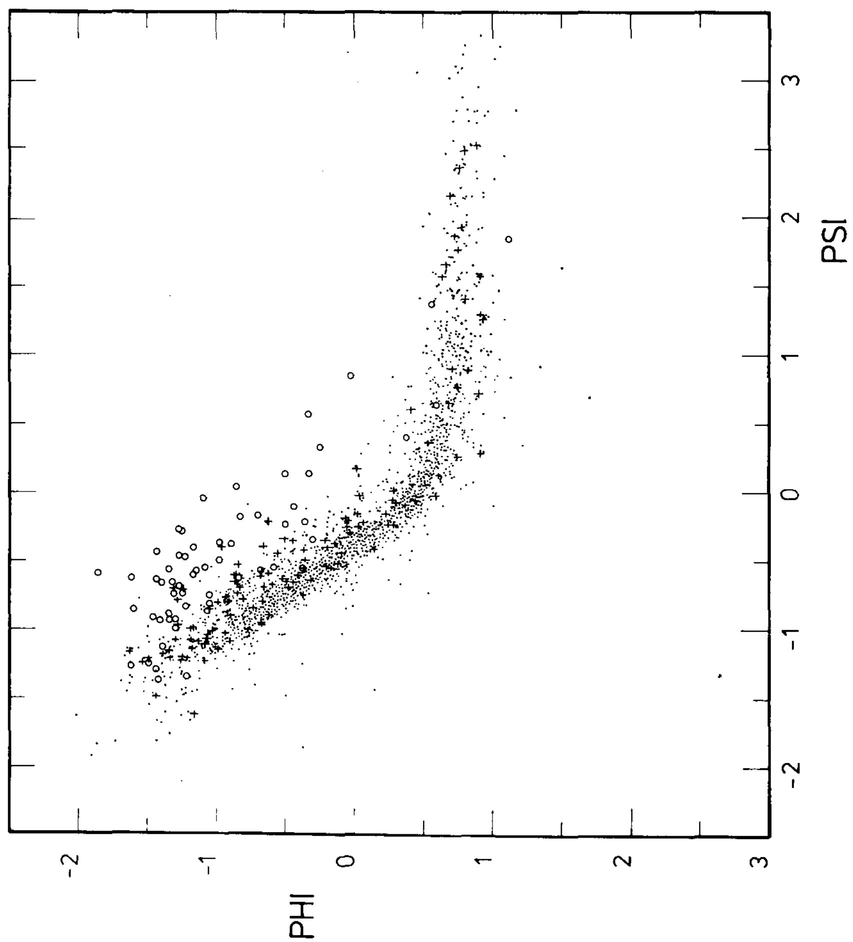

Fig. 2. The plot of PHI vs PSI. Luminosity Class I, III and V are denoted by circles, crosses and dots, respectively.

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

4.2 Classification parameters

For a two-dimensional classification, two extinction free parameters are defined as follows:-

$$PHI = (m_{2740} - V) - \frac{E_{2740 - V}}{E_{2190 - 2740}} (m_{2190} - m_{2740})$$

$$PSI = (m_{1490} - V) - \frac{E_{1490 - V}}{E_{2190 - V}} (m_{2190} - V)$$

The colour-excess ratios have been determined from the mean extinction law derived from the sample of several hundred reddened stars distributed in different galactic regions; for these samples no significant variation from the mean extinction law in the ultraviolet range concerned has been detected (Nandy et al 1976). The mean values of the colour excess ratios are:-

$$\frac{E_{2740 - V}}{E_{2190 - 2740}} \sim 1.1$$

$$\frac{E_{1490 - V}}{E_{2190 - V}} \sim 0.8$$

It is to be noted that the parameter PHI is nearly the colour difference, $(m_{2740} - V) - (m_{2190} - m_{2740})$. The relation between PSI and PHI for about 3000 stars is shown in Fig 2. The sample includes a large number of stars which show considerable amounts of reddening as indicated by the colour index $(m_{2190} - m_{2740})$. The points plotted fall naturally into two groups: most of the points lie in a fairly narrow region on the lower part of the diagram (as denoted by dots) and all of these are class V; also many points lie significantly above (open circles) and all of these belong to luminosity class I and II. Class III stars (denoted by crosses) tend to lie between the two sequences. A change of slope for the lower sequence occurs near (PSI $\sim$ -1, PHI $\sim$ 0.5); this is caused by the Planck maximum moving longward of 1500A for cooler stars.

The mean values of PHI and PSI as a function of spectral type and luminosity classes have been determined from those stars for which MK spectral types are known; these are taken from Blanco et al (1968). There are very few class I and II stars which are later than B8. The mean PHI-PSI relation for the class V stars is shown in Fig 3; the error box indicates the r.m.s. scatter of the mean

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

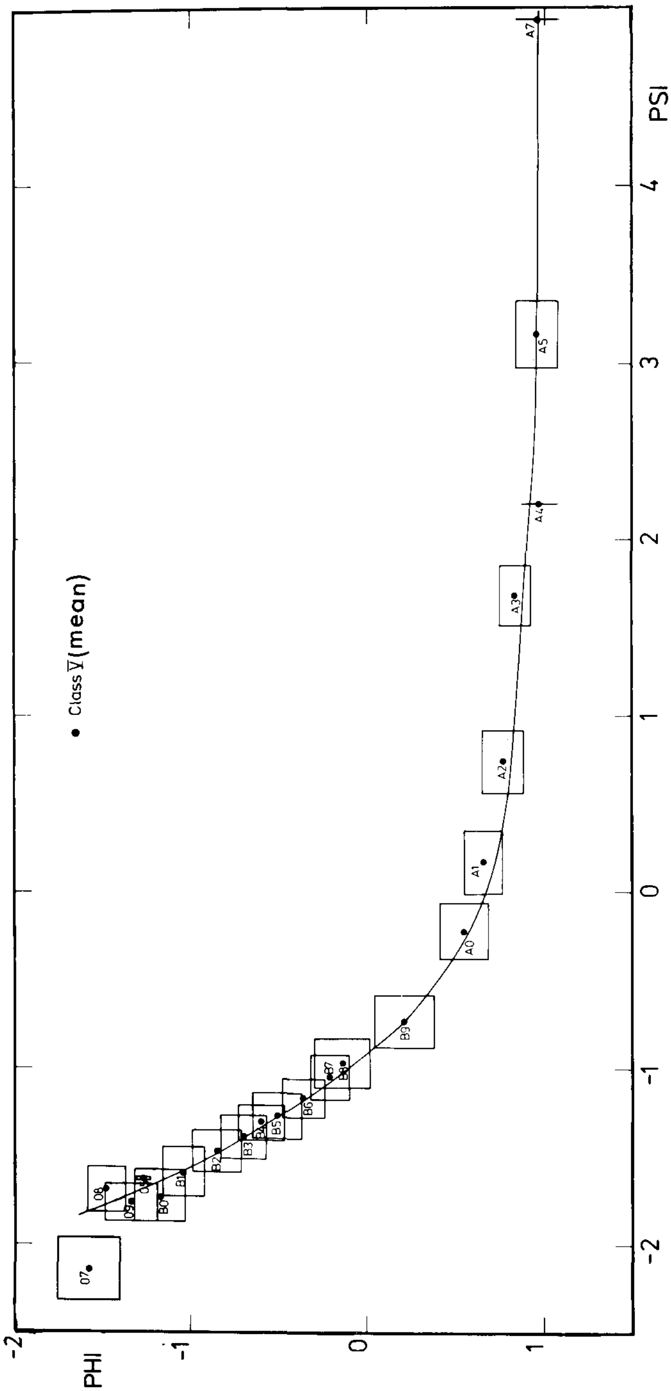

Fig. 3. The relation between PHI and PSI for Class V stars.

values of PHI and PSI for a given spectral class. The sample contains a few class II stars; the sequence for these stars is not well established, but in general they lie close to the supergiant sequence.

In establishing the correspondence between the classification parameters and the MK spectral types, we have excluded the known emission line and peculiar A stars. The Be stars are being studied by Houziaux (Private communication), while Jamar et al (1976) are investigating a large sample of peculiar A stars from the S2/68 data. The latter authors have found that the silicon stars are strongly deficient at 1400A as compared to the normal A stars, while the Hg,Mn stars are only weakly or not at all deficient.

Table 1

Spectral features in S2/68 UV spectra.

λ(A)	Main contributor	Appearance in sp. type
1400	Si IV Si II in late B's	O - B7 wavelength position of the minimum is ~ 1380A for O-stars, ~ 1410A for B-stars.
1450	FeV,CIII,CvIII,TiIII	O- stars
1550	CIV, SiII in late B's	Class V: O - B8 strong spectral type effect decreasing with later type. Wavelength (minimum) position appears to shift towards shorter wavelength for later types. Class I & II: seen till A2. Sharp and strong in comparison with class V stars.
1620	Fe II	Similar to 1550A feature.
1640	He II (emission)	WC
1720	Fe II, Fe III	BO - AO Present only in class I & II.
1909	He II (emission)	WC, WN

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

1920	Fe III	B0 - A2 Present only in class I & II stars. For later than B8 this feature seems to have double structure.
2050	Fe III, Cv II	Same as 1920A feature.
2250	Cv II, FeII, FeIII	Class V: Appears at A0 and increases with later type. Class I & II: Appears in B8 and strength does not appear to vary.
2340	Fe II, Cv II	Strong in late B and A class I & II stars; weak or absent in class V stars.
2420	Fe II and lines from singly ionized metals	Appears at B5 and increases with later type in Class V stars.

Table 2

Grouping of stars according to the spectral appearances of the features.

Spectral type range		Characteristic features
O-stars	class V:	1450A feature; wavelength position (minimum) of 1400A feature is 1380A$\pm$10. 1550A and 1620A features are sharp. No features in the spectral region between 1700A and 2550A. The strength of 1450A feature increases in the earlier type.
	Of:	1450A feature present but weak; 1720A feature strong. Other features same as in class V.

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

BO - B4	class V:	1450A feature absent. 1400A, 1550A and 1620A features strong. No 1720A feature. 1920A and 2050A features absent or very weak. The spectral region between 2050A and 2550A relatively clear.
	class I & II:	All the features which are seen in class V are relatively strong. In addition 1720A, 1920A and 2050A features are strong.
B5 - B7	class V:	No 1450A feature. 1400A, 1550A and 1620A features weakly present. No 1720A, 1920A and 2050A features -2420A features appears at B5 and increases with later types No 2250A and 2340A features.
	class I & II:	No 1450A feature as in class V. 1400A, 1550A, 1620A features are stronger than in class V. 1720A, 1920A and 2050A features are strong. 2340A feature present, but no 2250A and 2420A features.
B8 - B9	class V:	No 1450A feature. 1400A, 1550A, 1620A features absent or very weak, 2420A feature is moderate and other features are absent.
	class I & II:	No 1450A feature. 1400A, 1550A and 1620A, 1720A, 1920A and 2050A features are present. 2340A feature is strong and 2250A feature is present. 2420A feature is absent or weak. 1920A feature has double structure.
AO - A2	class V:	No 1450A feature. 1400A, 1550A and 1620A are absent

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

or very weak. No 1720A, 1920A and 2050A features. 2250A feature appears at A0 and increases with later type. No 2340A feature. 2420A feature moderately strong.

class I & II: No 1450A feature. 1400A, 1550A and 1620A features present. 1920A, 2050A, and 2250A and 2340A features strong. 2420A feature weakly present. 1720A feature present in A0, becoming weak in A2.

Table 3

Spectral classification from S2/68 UV spectra

λ(A)	O	Of	B0-B4		B5-B7		B8-B9		A0-A2	
		class	V	I	V	I	V	I	V	I
1400	(1380A)	(1380)	S	S	P	S	W/A	S	A/W	P
1450	S	P(weak)	A	A	A	A	A	A	A	A
1550	S	S	S	S	P	S	W/A	S	A/W	P
1620	S	S	S	S	P	S	W/A	P	A/W	P
1720	A	S	A	S	A	S	A	P	A	P
1920	A	A	A	S	A	S	A	S	A	S
2050	A	A	A	S	A	S	A	S	A	S
2250	A	A	A	A	A	-	A	P	P	S
2340	A	A	A	A	A	-	W/A	S	W/A	S
2420	A	A	A	A	P	W	P	W	S	W

S = strong, P = present, W/A = weak in most cases and absent in some cases, A/W = absent in most cases and weakly present in some cases, A = absent.

https://doi.org/10.1017/S1539299600003452 Published online by Cambridge University Press

References

Blanco V.M., Demers, S., Douglass, G.G., Fitzgerald, M.P. 1968, Pub. U.S. Naval Obs. Vol. 21.

Boksenberg, A., Evans, R.G., Fowler, R.G., Gardner, I.S.K., Houziaux, L., Humphries, C.M., Jamar, C., Macau, D., Macau, J.P., Malaise, D., Monfils, A., Nandy, K., Thompson, G.I., Wilson, R., Wroe, H. 1973, Mon. Not. R. astr. Soc. 163, 291.

Cucchiaro, A., Jaschek, M., and Jaschek, C. 1976, Astron. and Astrophys. (in press).

Houziaux, L. 1976, (in preparation)

Humphries, C.M., Nandy, K., Kontizas, E. 1975. Astrophys, J., 195, 111.

Humphries, C.M. Jamar, C., Malaise, D., and Wroe, H. 1976, Astron. and Astrophys, 49, 389.

Jamar, C., Praderie, F and Macau-Hercot, D. 1976, (in preparation)

Nandy, K., Humphries, C.M. and Thompson, G.I. 1975, I.A.U. Symposium No. 72 (Lausanne).

Nandy, K., and Schmidt, E.G. 1975, Astrophys. J., 198, 119.

Nandy, K., Jamar, C., Monfils, A., Thompson, G.I., Wilson, R. 1976, Astron and Astrophys., 51, 63.

Oke, J.B., and Schild, R.E. 1970, Astrophys. J., 161, 1015.