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Effective temperatures, angular diameters, distances and linear radii for 160 O and B stars

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Summary. The significance of the effective temperatures, angular diameters, distances and linear diameters which we have found from published ultraviolet spectrophotometry, visible and near infrared intermediate-band photometry and model-atmosphere fluxes for 160 O and B stars using a method which is fully explained and evaluated in the full paper which is reproduced on *Microfiche* MN 189/1 is discussed here. An appendix to our full paper presents BCD spectrophotometry for 77 of the program stars. Our angular diameters are systematically the same as those measured by Hanbury Brown *et al.* and the flux effective temperatures of the main-sequence and giant stars reproduce well the relationship established by Code *et al.* for main-sequence and giant O and B stars. The O8–B9 supergiants have systematically lower temperatures than do main-sequence stars of the same subtype. The Beta Cephei stars and most Be stars have the same effective temperature as normal stars of the same spectral type. The radii of O and B stars increase from main-sequence to supergiant. The late B supergiants are about twice as large as the O9 supergiants.

1 Introduction

Comparison of the effective temperatures found by Code *et al.* (1976) (henceforth CD+), Beeckmans (1977) and Brune, Mount & Feldman (1979) from OAO-2, S2/68 and sounding-rocket ultraviolet observations, respectively, combined with the same visible and near infrared absolute fluxes and the angular diameters by Hanbury Brown, Davis & Allen (1974) (henceforth HB+) for main-sequence, giant and supergiant stars shows that a fairly well defined relationship between effective temperature and spectral type has been established for main-sequence and giant O and B stars but that the effective temperatures of the supergiants of the same spectral classes seem to be some 2000–15 000 K lower. The effective temperatures found by the above authors for the main-sequence and giant O and B stars are about the same as those suggested by the shape of the visible spectrum of unreddened

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stars (*cf.* Schild, Peterson & Oke (1971) henceforth SPO) and by detailed analyses of the line spectrum of main-sequence O and B stars performed by several authors.

To investigate more fully what the flux effective temperatures are for the O and B supergiants, the Beta Cephei stars and some Be stars, we have applied to 160 O and B stars the methods used successfully by Blackwell & Shallis (1977) for finding angular diameters and effective temperatures of stars of type B8 and later from near infrared and visible absolute photometry. We made use of the 13-colour absolute photometry of Johnson & Mitchell (1975), the ultraviolet spectrophotometry of Jamar *et al.* (1976) and the model-atmosphere fluxes of Kurucz (1977, 1979). The method is fully explained and evaluated in our full paper where results are given for each star.

It is necessary to determine accurately the interstellar extinction for each star using information outside that used to find $T_{\rm eff}$ and angular diameter for confirming the final result. Reliable spectral types, all ostensibly on the MK system, are required. The BCD spectrophotometry available at the Institut d'Astrophysique for many of the stars proved to be invaluable for confirming the spectral classification and the interstellar extinction of many of the program stars; BCD spectrophotometric data on 77 stars is given in the appendix to our paper. We reviewed the evidence concerning the distance of each star *ab initio*, making use of calibrations in terms of M_V of measured spectroscopic parameters. A distance is determined for each star and linear radii are derived from the angular diameters which we have found. Tables 1 and 2 of our full paper give the adopted parameters for the 160 program stars, the resulting effective temperatures, angular diameters and radii as well as the observed part of the integrated flux.

2 Discussion

The first thing to demonstrate is that our angular diameters, θ, are systematically the same as those of HB+. We have 10 main-sequence and giant O and B stars in common with HB+ who measured angular diameters with the intensity interferometer. We also applied our method to α Lyr, A0 V, obtaining $T_{\rm eff} = 9470$ K and $\theta = 32.67 \times 10^{-4}$ arcsec. Fig. 1 shows our

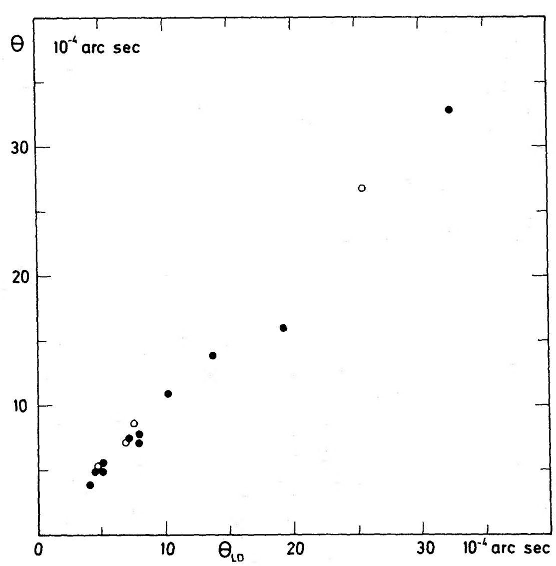

Figure 1. The relation between our angular diameters and those of Hanbury Brown *et al.* (1974). The supergiants are shown by open circles; they were not included in the least-squares solution. The second filled circle from the right is α Eri.

angular diameters plotted against the limb-darkened angular diameters, θ_{LD}, of HB+. Only one of the main-sequence and giant stars (filled circles), α Eri at $\theta = 15.91 \times 10^{-4}$ arcsec, $\theta_{LD} = 19.2 \times 10^{-4}$ arcsec, diverges significantly from a straight-line relation. Alpha Eri is a Be star and for the reasons given in our full paper we feel that its results are not typical. When this star is rejected, a least-squares fit gives

$$\theta = -(0.1214 \pm 0.2184) + (1.0116 \pm 0.0172)\,\theta_{LD}. \tag{1}$$

Here angular diameter is measured in units of 10^{-4} arcsec. Relation (1) shows that our angular diameters for main-sequence and giant stars are systematically the same as those of HB+. The errors in the HB+ results are typically ± 0.2–0.4 units. The uncertainty in our values is less than 2 per cent.

For the supergiants, the choice of reddening correction is interlocked with the choice of the model effective temperature. We have demonstrated that it is possible to reproduce the results of HB+ for supergiants only by selecting model atmospheres which have effective temperatures corresponding to the $(B-V)_0$ values for supergiants given by FitzGerald (1970) and by using an interstellar extinction corresponding to the value of $E(B-V)$ resulting from the observed $(B-V)$ and the $(B-V)_0$ of FitzGerald for the adopted spectral type. The open circles in Fig. 1 show the angular diameters resulting from such choices of model and $E(B-V)$ for the four supergiants in common between us and HB+, namely β Ori (B8 Ia), ϵ Ori (B0 Ia), ζ Ori A_1 (O9.5 I) and η CMa (B5 Ia). We examined the question of whether one should use predicted model continuous fluxes for supergiants and Of stars selected from the results published for a few spherical model atmospheres and concluded that use of the fluxes from the existing spherical models was not desirable.

The 160 stars were sorted into spectral-type and luminosity-class boxes and average effective temperatures and linear radii were derived for each box. These values (*cf.* Tables 8 and 9 of our full paper) are displayed in Figs 2 and 3. The dispersion about each mean value is given in Tables 8 and 9. It is of the order of the size of the symbols in most cases. The dispersions are as much due to the disparity between the various stars gathered in each

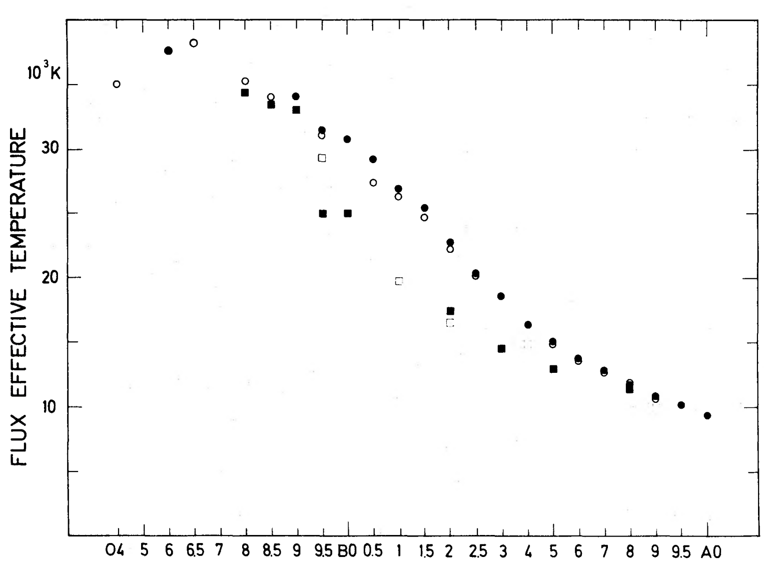

Figure 2. The relations between average effective temperature and MK spectral type for O and B stars. The results for main-sequence stars (luminosity classes IV and V) are shown by filled circles, those for giants (luminosity classes II and III) by open circles, those for the Ib or I supergiants by open squares and those for the Ia supergiants by filled squares.

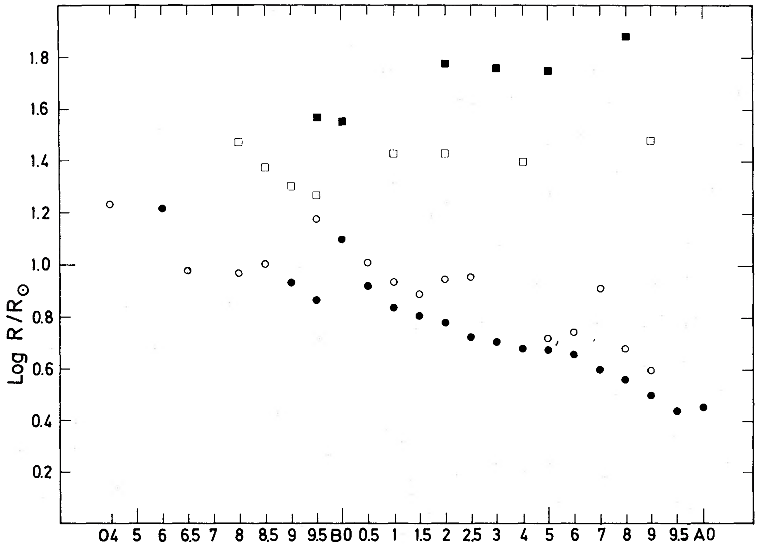

Figure 3. The relations between $\log R/R_\odot$ and MK spectral type for O and B stars. The meaning of the symbols is as in Fig. 3.

spectral-type-luminosity-class box as to the uncertainties in the individual results. Typically the error in effective temperature for one star due to uncertainties in the photometric data and to the choice of model atmosphere should not exceed 5 per cent; the error in the linear diameter depends upon the accuracy of the estimate of distance. The internal agreement of the several estimates of distance for each star suggests that typically the error in the distance should not exceed 15 per cent. We feel that the data given in Tables 1 and 2 for each star should be used in preference to the mean values for each spectral type and luminosity class.

A detailed comparison of our effective temperatures with those of SPO, Morrison (1975), Henry *et al.* (1975), Conti (1975), CD+, Barlow & Cohen (1977), Beeckmans (1977) and Brune *et al.* (1979) is given in our full paper. The temperature versus spectral type relations shown in Fig. 2 appear to be securely established as are the radius versus spectral type relations of Fig. 3. There is no doubt that the flux effective temperatures of the O and B supergiants are lower than those of main-sequence and giant stars of the same subtype. The discrepancy is −7000 K at type B1. We interpret this to mean that the lines which have been empirically selected to define spectral type for the supergiants reflect electron temperatures and densities in a hot transition layer between the cooler photosphere (which is in radiative equilibrium and whose spectrum over most spectral regions can be modelled by LTE procedures) and the hot corona which is known from ultraviolet observations to exist rather than temperatures and densities in a layer in radiative equilibrium with the flux of radiation emerging from the centre of the star. We infer that the corona and transition layer are heated by mechanical and/or magnetic energy, by a mechanism which is at present unknown, because the relative strengths of the lines/continua formed in these regions reflect higher electron temperatures than can be produced under the constraint of radiative equilibrium even when due attention is paid to the small outward rise in temperature resulting from NLTE effects.

We find that the effective temperatures and radii of the Beta Cephei stars are the same, so far as we can tell, as those of non-variable stars of the same spectral type. Also we find that Be stars which do not have two Balmer jumps (the second one, from the shell, being in emission or in absorption) have effective temperatures closely similar to those of normal B stars of the same spectral type. However, when the Be phenomenon is strong, as evidenced for instance, by the presence of two Balmer jumps, our method fails. The failure may be due to the star not having the same effective angular diameter at all wavelengths as well as to an abnormally shaped continuous spectrum resulting from emission and absorption in the envelope of gas surrounding the star. It is implicitly assumed in every determination of effective temperature from integrated fluxes and angular diameters that θ is independent of wavelength.

The O and B stars increase in size from main-sequence to supergiant stars; the late B supergiants are approximately twice as large as the O9 supergiants. The Beta Cephei stars are not significantly larger than non-variable stars of the same spectral type.

The full paper may be found in *Microfiche* MN 189/1.

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EFFECTIVE TEMPERATURES, ANGULAR DIAMETERS, DISTANCES AND LINEAR RADII FOR 160 O AND B STARS

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SUMMARY

In this paper we present angular diameters, linear radii and flux effective temperatures for 160 O and B stars derived from published absolute photometry and model atmosphere fluxes. We also give values of E(B–V) to represent the extinction due to the interstellar material between us and the 160 stars and the distances to these stars. An appendix is attached which gives BCD spectrophotometry for 77 of the stars.

We derive average effective temperature and linear radius as functions of spectral type for stars in luminosity classes IV and V, II and III, Ib, and Ia. The effective temperatures for luminosity classes II to V vary with spectral type as has been established by the work of others. Those for luminosity classes Ib and Ia are significantly lower than for other stars of the same subtype, the difference being about 7000 K at type B1. The absorption lines that have been selected to define spectral type for the B-type supergiants represent conditions in a superheated transition layer between the photosphere and a hot coronal layer rather than the total radiation field of the star.

The effective temperatures and radii of Beta Cephei stars and of many Be stars are like those of normal B stars of the same subtype, but in the case of Be stars with double Balmer discontinuities our method fails. There is a distinct increase in size of O and B stars from main-sequence to supergiant star.

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1. INTRODUCTION

By definition the flux effective temperature of a star is given by

$$T_{\rm eff}^4 = 4f/\theta^2\sigma_R , \qquad (1)$$

where θ is the angular diameter of the star, in radians, f is the flux received at the earth integrated over the full extent of the spectrum and σ_R is the Stefan–Boltzmann constant. Classical model–atmosphere analysis of the shape of the continuous spectrum and the strengths of the absorption lines in the visible spectrum of a star determines a model effective temperature which corresponds to the energy put into the model ab initio in order to establish the electron temperature at each level in the model under the constraint of radiative equilibrium. The classical model consists of plane parallel layers with the pressure at each level determined using the constraint of hydrostatic equilibrium. If the radiation field flowing from the interior is the sole source of energy in the outer layers of the star, the observed flux effective temperature of a star should be identical with that deduced from the analysis of the visible spectrum by means of model atmospheres.

The existence of absolute ultraviolet fluxes from the OAO–2 and TD1 satellites (see, for instance, Code and Meade, 1976 and Jamar, et al., 1976), as well as the angular diameters measured by Hanbury Brown, et al., (1974) (HB+) allows a test of the adequacy of the hypothesis of radiative equilibrium which underlies all classical model–atmosphere analysis. Beeckmans (1977) has shown that the absolute fluxes from the S2/68 experiment yield effective temperatures for the O and B stars like those found by Code, et al., (1976) (CD+) from OAO–2 fluxes, although the S2/68 fluxes tend to be slightly smaller than the OAO–2 fluxes at wavelengths shortward of 1800 Å. From Beeckmans' analysis it is not clear which set of absolute ultraviolet fluxes is the more realiable; Brune, et al., (1979) have shown that the S2/68 fluxes are in better agreement with their rocket results than are the OAO–2 fluxes.

For 12 stars of types O9.5 to B8 in luminosity classes V to II, the flux effective temperatures found by CD+ are about the same as those that have been deduced from the shape of the continuous spectrum by Schild, et al., (1971) (SPO); the average difference $T_{\rm eff}$(continuous spectrum) – $T_{\rm eff}$(flux) is –650 K, and the differences scatter about the value zero. In this comparison, the results for δ Sco, B0.5 IV, have been omitted because the difference for that star is –5660 K. Flux effective temperatures for four supergiants, β Ori, B8 Ia, η CMa, B5 Ia, ϵ Ori, B0 Ia, ζ Ori A_1, O9.5 I and for the luminous O star ζ Pup have been determined by CD+. Model atmosphere analyses of the spectra of these stars, see for instance, Underhill and Fahey (1972), Lamers (1974), Conti (1975), Snijders and Underhill (1975), and Stalio, et al., (1977), suggest significantly higher effective temperatures than CD+ find. The differences, T_{eff}(model) – T_{eff}(flux), vary from about +2000 to +15000K. If this trend towards large positive values is meaningful, it implies that the electron temperature in the layers where the visible spectrum of early-type supergiants is formed corresponds to a greater energy input than is afforded, under the constraint of radiative equilibrium, by the integrated flux. The additional energy resident in the electrons and made visible by the absorption-line spectrum must come from mechanical or magnetic sources of energy which are not considered in classical model atmospheres. Magnetic fields cannot be detected for stars of the types studied here owing to the width of the absorption lines, so nothing can be said about the presence of magnetic fields. Micro and macroturbulence are believed to occur in the atmospheres of the early-type stars. Practically all early-type stars are thought to rotate fairly rapidly. Thus the presence of mechanical sources of energy is not excluded a priori.

The ultraviolet spectra obtained with the OAO-3 satellite (Copernicus) show the presence of resonance lines from highly ionized atoms in the spectra of many O and B stars, see, for instance, Snow and Morton (1976) and Lamers and Snow (1978). This fact has been interpreted as evidence for a hot corona lying just outside the photospheric layers. The energy for this hot layer must come from somewhere. Possibly, superheating already occurs in the layers of the star which form the lines by which the spectrum of the star is classified.

The purposes of this paper are (1) to estimate T_{eff}(flux) for all O and B stars for which ultraviolet and visible absolute fluxes exist and for which an estimate of the angular diameter can be made using the method applied by Blackwell and Shallis (1977) and (2) to compare the resulting values with those deduced from normal model-atmosphere analyses of the continuous spectrum in order to clarify whether or not heating by mechanical/ magnetic energy is important in the atmospheres of some O and B stars. Finally, linear radii are found for the program stars using distances determined from visual absolute magnitudes estimated from measured properties of the stellar spectra. A by-product of this work is a value of E(B–V) for each star.

2. METHOD

The angular diameter of a star is given by

$$\theta_\lambda = 2(f_\lambda/\mathscr{F}_{s,\lambda})^{1/2}, \qquad (2)$$

where f_λ is the absolute monochromatic flux, corrected for interstellar extinction, received at the earth from the star at wavelength λ and $\mathcal{F}_{s,\lambda}$ is the absolute monochromatic flux emitted at the star. Blackwell and Shallis (1977) showed for 6 stars of spectral types B8 to F8 that this expression reproduces the angular diameters measured by HB+ when $\mathcal{F}_{s,\lambda}$ is approximated by the predicted flux from a model atmosphere. Many numerical results have demonstrated that if the wavelength is sufficiently long, lying well into the Rayleigh–Jeans tail for a blackbody at the model effective temperature, the predicted monochromatic flux is rather insensitive to the details of the model and to the precise value adopted for the representative effective temperature. In principle, one can estimate an angular diameter using observed fluxes in the infrared, then use observed fluxes over the whole wavelength range and this angular diameter to find the integrated flux and T_{eff}. One or two iterations should produce consistent values of θ. One must be careful to use observed absolute monochromatic fluxes that are not affected by an infrared excess.

For the O and B stars it is sufficient to use absolute fluxes in the range 6000 to 12000 Å. We use the medium-band, 13-colour, absolute photometry of Johnson and Mitchell (1975) to obtain f_λ. The data for filters [63], [72], [80], [86], [99] and [110] are used. These filters have effective wavelengths at 6356, 7241, 8000, 8584, 9831 and 11084 Å; the FWHM of the rectangular pass bands are 324, 587, 432, 481, 580 and 820 Å respectively. We find that this photometry gives observed absolute fluxes for stars in good agreement with that of Davis and Webb (1974), when the Davis and Webb relative photometry has been placed on an absolute scale by reference to the absolute energy distribution for Vega by Hayes and Latham (1975). Independent absolute photometry of Vega and of 109 Vir over the range 3295 to 9040 Å (Tüg, et al., 1977) also agrees with the absolute 13-colour photometry of Johnson and Mitchell.

In the case of Vega, the Johnson and Mitchell fluxes are systematically smaller than those of Tüg, et al., by a few percent. For filters [63] through [86] the average deviation is −2.6 percent. In the case of 109 Vir, there is no systematic trend. (For 109 Vir, the units of Tüg, et al., for F_λ are 10^{-10} ergs cm^{-2} s^{-1} Å^{-1} rather than as listed.) For the four filters [63] to [86], the Johnson and Mitchell fluxes are 0.5 percent smaller than those of Tüg, et al., on the average. We conclude that the absolute fluxes given by Johnson and Mitchell contain no systematic error and that their claim that their large body of data is homogeneous and free from systematic error is valid. The relative narrowness of the pass bands of Johnson and Mitchell ensures that there is no shift of the effective wavelength of any filter with spectral type.

The observed fluxes for our program stars were corrected for interstellar extinction using linear interpolation against λ^{-1} in the reddening law of Nandy, et al., (1975) for wavelengths longward of 3000 Å and in the reddening law of Nandy, et al., (1976) for wavelengths shortward of this to find $A_\lambda/E(B-V)$ at the wavelength for each of our flux values. The adopted extinction law corresponds to $A_\lambda/E(B-V) = 3.02$ for the wavelength of the V band. The adopted values of E(B–V) are given in Table 1. They were found usually from the UBV photometry of Johnson, et al., (1966) and the intrinsic colours suggested by FitzGerald (1970) for the spectral type which we adopt for each star. These colour excesses were checked by reference to BCD spectrophotometry which one of us (LD) has for many of the program stars, see the appendix. In the case of the O stars, the Ib and Ia supergiants and the Be stars, we measured the depth of the interstellar absorption feature at 2200 Å on the S2/68 spectrum tracings (Jamar, et al., 1976) and used this datum with the relation of Beeckmans (1978) to find additional estimates of E(B–V).

In the case of some of the O stars and for a few B stars, a correction was made for the light of companion(s), see the notes to Table 1. Usually those B stars for which the photometry refers to two stars were omitted because a sufficiently large number of B stars could be found without attempting a somewhat uncertain correction.

Selection of which predicted model-atmosphere monochromatic fluxes to use is discussed in Section 4. We find that the monochromatic fluxes from a grid of models (Kurucz 1977, 1979) similar to those of Kurucz, Peytremann and Avrett (1974) are satisfactory for our purposes.

To determine the integrated flux for each star, we used the published absolute ultraviolet fluxes measured by the S2/68 experiment on the TD1 satellite (Jamar, et al., 1976) and the absolute fluxes of Johnson and Mitchell (1975) in all 13 bands. These data together when corrected for interstellar extinction give absolute fluxes from 1380 to 11084 Å.

The observed integrated flux received at the earth is found by the trapezoidal law; it is

$$f_{obs} = \int_{1380}^{11084} f_\lambda \, d\lambda . \qquad (3)$$

In the case of a few stars, the S2/68 photometry was corrected for the presence of companions, see the notes to Table 1.

The program stars, their E(B–V), spectral type, θ, σ/θ and f_{obs} are given in Table 1. Here σ is the root-mean-square deviation of θ_λ about the mean value. Values of θ_λ at 11084Å and occasionally at 9831Å were omitted from the mean value, θ, when an infrared excess seemed to be present resulting in a θ_λ greater than θ by more than 1.5σ.

The integrated flux in the unobserved regions shortward of 1380Å and longward of 11084Å, f_{est}, was estimated using the adopted angular diameter for each star and the flux distribution from the adopted representative model fluxes. From Equation (2) one sees that

$$\int_{\lambda_1}^{\lambda_2} f_\lambda \, d\lambda = \frac{\theta^2}{4} \int_{\lambda_1}^{\lambda_2} \mathscr{F}_{s,\lambda} \, d\lambda. \qquad (4)$$

At long wavelengths, the flux integral is small and the value is insensitive to the choice of model, but at wavelengths shortward of 1380Å, the value is slightly model dependent. Some examples of typical model results are discussed in Section 4. For $T_{eff} > 30000$K, the estimated part of the flux integral is usually larger than the part of the flux integral in the observed spectral range.

Finally the flux effective temperature of the star was determined from Equation (1) using the derived θ, f_{obs} and f_{est}. The resulting flux effective temperatures, the adopted model log g, the difference $\Delta T_{eff} = (T_{eff}(\text{model}) - T_{eff}(\text{flux}))$, the ratio f_{est}/f_{obs}, a distance and the resulting linear radius are given in Table 2. The choice of distance for each star is discussed in Section 5.

3. SELECTION OF STARS

A list was compiled of all O and B type stars having 13-colour and S2/68 photometry. This list was then reduced by removing all stars known to show two spectra (see notes to the major radial-velocity catalogues and to the Sixth Catalogue of Spectroscopic Binaries (Batten 1967)), and all stars for which double-star information (Innes 1927, Aitken 1932, Rossiter 1955) indicates that two or more stars differing in visual apparent magnitude by less than 4 mag were present in the 11 x 17 arc min^2 field of view of the S2/68 experiment. We also searched the HD Catalogue for stars within 20 arc min of each possible program star and rejected those stars which had companion(s) which might contribute a significant ultraviolet flux.

The correction for companion(s) made for some stars makes use of the photometry of single stars of the same spectral type as the companions, the ultraviolet and the visible photometry being scaled to take account of the difference in V magnitude between the companion and the representative star, that difference being corrected for the difference in interstellar extinction. If a star is known to have a variable radial velocity but two spectra are not known explicitly to be visible, the star has been retained in the program.

The notes to Table 1 give information on which stars are known to be Beta Cephei stars (Lesh and Aizenman 1978), which are known to have shown shell characteristics at some time (Bidelman 1976), and which seem to have an infrared excess in that θ_λ found from the photometry in the [110] filter is significantly larger than the values found from the filters at shorter wavelengths. In only two cases was there a significant dependence of θ_λ on wavelength, which means that the shape of the adopted model continuous spectrum is the same as that measured for each of the stars in the range 6356 to 11084 Å. For practically all of the O stars we have used the spectral types by Conti and Leep (1974) and Conti and Frost (1977) because we have used the effective-temperature scale for O stars of Conti (1975) as a basis for our selection of model effective temperatures for the O stars. For the B stars we have adopted spectral types which are consistent with the (λ_1 D) data which we have on many of the stars (see the appendix) and with other spectral information in our files. We weigh heavily MK types determined by W. W. Morgan and by Hiltner, Garrison and Schild (1969). The spectral types given for the Be stars reflect, so far as possible, the spectrum of the star when the emission lines are weak or absent. In many cases, see Lesh (1968, 1972) for instance, the MK types for these stars correspond to a mixture of true photospheric lines and the absorption lines of the overlying shell spectrum.

4. SELECTION OF MODEL ATMOSPHERES

4.1 General Considerations

We need monochromatic fluxes from model atmospheres in order (1) to evaluate $\mathscr{F}_{s,\lambda}$ at wavelengths between 6356 and 11084 Å, and (2) to evaluate the estimated flux in the unobserved spectral regions shortward of 1380 and longward of 11084 Å. One wishes to use a grid of models which is internally consistent, which covers the range 10000 K to 50000 K in effective temperature and which has a wide enough range in log g to permit study of stars in luminosity classes Ia to V.

The most comprehensive body of data available is that obtained by methods parallel to the procedures of Kurucz, et al., (1974) (KPA). We have used the monochromatic fluxes from a tape provided by Kurucz in January 1977. We use the case of normal solar composition and microturbulence equal to 2 km s^{-1}. The KPA models are composed of plane parallel layers in radiative, hydrostatic and local thermodynamic equilibrium. The sources of opacity are continuous opacity due to H I and H II, He I–He III, C I–C IV, N II–N V, O II–O VI, Ne I–Ne VI, Mg I, Al I, Si I, H_2^+, H^-, hydrogen Rayleigh scattering and electron scattering, absorption in the hydrogen lines and absorption in up to 30000 lines, this opacity being evaluated by means of line–absorption distribution functions.

We evaluated the integrated flux for each model in the region shortward of 1380 Å and in that longward of 1108 Å. We interpolate linearly against T_{eff} to obtain a value for the total estimated flux at effective temperatures not present in the grid of models. For each tabulated model, we interpolated $\mathscr{F}_{s,\lambda}$ linearly at precisely the filter wavelengths for [63] to [110]. Kurucz (1977) gives H_ν at approximately 25 Å intervals. To obtain $\mathscr{F}_{s,\lambda}$ at effective temperatures intermediate between those for the tabulated models, we interpolate linearly against T_{eff} in the tables of $\mathscr{F}_{s,\lambda}$. We do not attempt to interpolate fluxes for values of log g different from the tabulated values. The predicted long wavelength monochromatic fluxes are rather insensitive to the adopted value of log g. The adopted values of log g for the representative model atmospheres are given in Table 2. They reflect knowledge obtained from model–atmosphere analyses to be found in the literature of the last 20 years. The values of T_{eff} for the models are equal to T_{eff}(flux) + ΔT_{eff}. The selection of T_{eff}(model) for each spectral type is discussed below.

Auer and Mihalas (1972) have constructed a set of model atmospheres for O and early B stars which takes account of non–LTE effects in the spectra of H, He I and He II and which takes account of the continuous absorption from a representative light element which approximates the properties of the ions of C, N and O; their models do not take line blanketing into account. The models and their emergent monochromatic spectra have been published by Mihalas (1972a) (M72). The range in effective temperature is from 15000 to 55000 K; log g ranges from 2.5 to 5.0, the range being selected so that hydrostatic equilibrium is always maintained. The geometry is plane parallel layers and radiative equilibrium is assumed. The relative abundance of helium to hydrogen by number is 0.1. The composition of the models of Mihalas and Auer does not differ by a significant amount from that of Kurucz.

We do not choose to use Mihalas' model data because the range in effective temperature is inadequate for our purposes and because interpolation for emergent fluxes at the effective wavelengths of the 13–colour filters which we use to find the angular diameters would be imprecise, since Mihalas gives monochromatic fluxes at only 6 wavelengths in the range 5695 to 14579 Å. Furthermore, the published monochromatic fluxes for these models, both in LTE and NLTE, have the disturbing property that their integral, evaluated by means of the trapezoidal law, does not reproduce exactly the nominal effective temperature. In the cases which we checked (15000 and 30000K with log g = 4.0, and 45000K with log g = 4.5), the integrated flux is about 2.4 percent larger than its nominal value. The numerical procedures followed by Auer and Mihalas are described by Mihalas, Heasley and Auer (1975).

An important point in our procedures is to select the representative model effective temperature for each spectral type in such a way that the predicted monochromatic fluxes in the range 6356 to 11084Å are accurate for each spectral type and such that the integrated flux from the unobserved spectral regions is accurately estimated for each star. As noted above, the results are relatively insensitive to the choice of log g.

A problem arises in assigning equivalent spectral types to LTE model atmospheres representing O and B stars because O and B spectral types are normally assigned by visual evaluation of the relative strengths of dominant lines in the blue-violet spectral region, whereas LTE model-atmosphere computations provide numerical data on the shape of the unreddened continuous spectrum and sometimes on the profiles and equivalent widths of a few absorption lines. When the models and the theoretical spectra have been found using LTE physics, the observed shapes and the strengths of the prominent lines in O and B types spectra are usually not accurately reproduced. The difficulties this result raises for assigning equivalent spectral types to models have been discussed, for instance, by Underhill (1966, 1972). She concluded that the best criterion to use for assigning equivalent spectral types to LTE models was the size of the Balmer jump.

Auer and Mihalas (1972) and Mihalas (1972b) have shown that taking into account non-LTE effects in the spectra of H, He I and He II markedly improves the agreement with the observed values of the predicted shape of the continuous spectrum and the predicted shapes and strengths of the strong lines of H I, He I and He II in models for O and early B-type stars. Non-LTE studies of the Mg II spectrum (Mihalas 1972c, Snijders and Lamers 1975) and of the spectra of the silicon ions (Kamp 1973, 1978) have shown the same thing: the profiles and equivalent widths of the strong lines in O and B-type spectra, which include the lines used as criteria for spectral classification, are most accurately reproduced by modelling processes which take into account simultaneously the constraints of radiative, hydrostatic and statistical equilibrium.

For main-sequence stars of spectral type B0 and later, non-LTE effects on the continuous spectrum in the blue-violet region are small (Mihalas 1972b). Consequently, the shape of the continuous spectrum as observed from ground and the size of the Balmer jump may be compared to predictions based on LTE physics in order to relate LTE model atmospheres to the standard MK spectral types. We adopt the size of the Balmer jump as the primary criterion by which to select the Kurucz model data when the effective temperature is in the range 10000 to 30000 K. Another consideration, described below, is used to select Kurucz model data for the O stars.

Numerical results assembled by Guillaume (1966), demonstrate that LTE model atmospheres constructed with differing assumptions about the sources of continuous opacity and the amount of line blocking may produce closely the same Balmer jump, but that their effective temperatures and the absolute values of the monochromatic fluxes in the 6000 to 10000 Å region may differ. One has to assume that models which take account of all conceivable sources of opacity, as do the Kurucz models, produce realistic monochromatic flux distributions. In the case of the Kurucz models, the listed monochromatic fluxes, when integrated, reproduce accurately the nominal effective temperature.

We evaluated the fractions f_{obs}/f_{total} and f_{est}/f_{obs} for typical Kurucz and Mihalas models with the results shown in Table 3. These fractions vary a little with the methods used to construct the model; their most significant dependence is on T_{eff}. We conclude that using monochromatic fluxes from the Kurucz models to find f_{est} by means of Equation (4) rather than monochromatic fluxes from models which take into account the non-LTE behaviour of H, He I and He II will not invalidate our estimates of flux effective temperature for the B and O stars. If the evaluation of the total flux from stars earlier in type than B0 is to be made more secure than the results obtained here, it is important to measure accurately in absolute units, the flux between 912 and 1380 Å, for when $T_{eff} > 30000$ K, the flux shortward of 1380 Å constitutes more than half of the total integrated flux, see Table 3. At 10000 K f_{est}/f_{total} is about 0.086.

Measurements of the radio flux from galactic H II regions surrounding O stars permit an estimate of the ratio of the flux emitted by O stars shortward of the Lyman limit to that emitted in the V band, $N_L/\pi F_V$. Churchwell and Walmsley (1973) and Georgelin, et al., (1975) have used the Zanstra method to show that the ratios $N_L/\pi F_V$ found from radio observations agree reasonably well with the predictions from LTE and from non-LTE models. This confirms that the available model atmospheres do represent well the flux from O stars in the frequency range important for the ionization of hydrogen.

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4.2 Choice of Model Effective Temperatures for B Stars

We use two observed photometric indices by means of which to select an appropriate value of effective temperature for a Kurucz (1977) model that will give representative values of the needed parts of the continuous flux: (1) the observed value of D and (2) the intrinsic $(B-V)_0$ recommended by FitzGerald (1970) for the spectral type which we have assigned to the star. Method (1) is preferred and it is used when the necessary data exist. If we find the results from our first choice of model are unsatisfactory, we iterate using our first results to guide our next choice of model. We are also free to vary our choice of E(B–V) as seems desirable.

The choice of log g for the representative models is not a sensitive action. We adopt log g = 4.0 for B stars of luminosity classes IV, IV–V and V and log g = 3.5 for stars of luminosity classes II and III. The appropriate value of log g for the Ib and Ia supergiants is more difficult to ascertain. We considered results drawn from analyses of the line spectrum, when such information was available, and the electron density indicated by the break off of the Balmer series at about n = 23, see Underhill (1970). A final factor which influenced the choice of log g for the supergiants was the necessity to select one of the log g values for which Kurucz models exist.

4.2.1 Calibration of the KPA and the Kurucz (1977) Models in Terms of D

This calibration was done using the published fluxes of the KPA models. We have checked that it is also valid when the more detailed fluxes of the Kurucz (1977) models are used. By a method entirely parallel to that used by Chalonge and Divan (1952) to find observed values of D for stars, we derived a value of D for each KPA model with $T_{eff} \geqslant$ 10000K. The results are shown in Figure 1 which presents the calculated values of D in terms of model T_{eff} and log g. The effective temperature of a representative model for a star is found by entering Figure 1 with an observed value of D and an assigned log g and reading the appropriate value of T_{eff}(model).

4.2.2 Estimation of T_{eff}(model) from an Observed $(B-V)_0$

This method was developed using the published B–V values for the KPA models. Later Relyea and Kurucz (1978) published B–V colours for the Kurucz (1977) models. For the same values of effective temperature and log g, their values of B–V differ systematically from those of KPA, the differences being almost constant for a given value of log g over the range $10000\,K \leqslant T_{eff}(\text{model}) \leqslant 30000\,K$. The differences are almost identical with the zero-point corrections to the KPA B–V colours which we derive below. Relyea and Kurucz

(1978) have demonstrated that their calculated B–V colours correlate linearly with their calculated b–y colours and that their set of calculated b–y, c_1, m_1 and u–b colours vary as the observed uvby colours do for unreddened stars. We restrict our attention to the B–V intrinsic colour. It may readily be shown that the calculated U–B colours do not change with model effective temperature in a way which closely parallels the observed change of $(U-B)_0$ with effective temperature along the main sequence.

As KPA have pointed out, one zero–point correction to the computed B–V colours should be valid for all the B spectral types if the shapes of the model flux distributions and the shapes of the adopted sensitivity functions for B and V filters are correct over the range of models representing B stars. We derive zero–point corrections for the $(B-V)_{KPA}$ for models with effective temperatures in the range 10000 to 30000 K and with log g = 3.5 and 4.0.

By comparing spectrophotometric scans to continuous spectra predicted from blanketed LTE model atmospheres, SPO have derived effective temperatures for 10 unreddened main-sequence B stars, while CD+ from integrated fluxes and measured angular diameters have determined effective temperatures for 9 unreddened B stars in lumniosity classes III to V. The observed B–V colours of these stars (Johnson, et al., 1966) when plotted against the derived effective temperatures produce a well defined relation between effective temperature and the intrinsic broad–band colour. This relation has the same shape as the relation found by plotting the $(B-V)_{KPA}$ against model effective temperature in the range 10000 to 30000 K. We determine the zero–point shift for the models with log g = 3.5 and those with log g = 4.0 by finding that shift which produces the best overall agreement between the theoretical and the observed relations. For models with log g = 4.0, $(B-V)_{KPA} = (B-V)_0 - 0.063$, while for models with log g = 3.5, the zero–point correction is –0.059. The shape of the observed and the calculated relations diverges a little at both ends of the range, but we consider that the above zero–point corrections are adequate for using the adopted $(B-V)_0$ values for each spectral type together with an assigned value of log g to obtain a first estimate of the effective temperature of a representative model. The present zero–points are superior to the rather arbitrary choice made by Peytremann and Davis (1974) for models with log g = 4.0.

The basis for a choice of model effective temperature for the B–type supergiants is quite uncertain. In each case we use two values: a low value somewhat as indicated by the $(B-V)_0$ of FitzGerald (1970) and the zero–point correction of model colours valid for log g = 3.5, and a high value approximately as suggested by the existing analyses of the absorption-line spectrum by LTE methods. Measured values of D exist for a few B-type supergiants, see the appendix. They tend to be small and to indicate unbelievably high temperatures, so we have not used them to guide our choice of model. The meaning of the results from the possible choices of model parameters for the supergiants is discussed in Section 6. For stars of luminosity classess II to V the values of D and of $(B-V)_0$ result in consistent choices for T_{eff}(model).

4.3 Choice of Model Effective Temperatures for O Stars

The spectral types of O stars are assigned primarily according to the strength of He I 4471 relative to He II 4541. Therefore, the representative-model effective temperatures for O stars should be assigned on the basis of models which reproduce the behavior of this observed line ratio. The size of the Balmer jump is an unsatisfactory criterion of spectral type for the O stars because it is small in the spectra of O stars and it is not very sensitive to the various subtypes which are recognized.

The choice of log g for the O stars is not a sensitive action. We use log g = 4.5 for stars of luminosity class V and log g = 4.0 or 3.5 for stars of luminosity classes III and I.

Conti (1973a) has measured the strengths of He I and He II lines on O-type spectra and has shown that they behave as the spectral type becomes earlier very much as the predicted equivalent widths of Auer and Mihalas (1972) from NLTE/L model atmospheres do when the effective temperature increases. From this information Conti (1973b) derived a temperature scale for the O stars; he gives a definitive temperature scale in Conti (1975). We adopt these latest results. Since we will use the monochromatic continuum fluxes from Kurucz model atmospheres calculated in LTE to find the angular diameter, we must demonstrate that these fluxes are closely similar to those which would result from NLTE/L models of the same nominal effective temperature. It is clear that NLTE/L models are required to interpret the strengths of the lines in O-type spectra. Fortunately, the predicted continuum fluxes which we require are not sensitive to NLTE physics.

We have interpolated linearly against wavelength in the listing of monochromatic fluxes, F_λ, which we derived from the published monochromatic magnitudes (M72) for two of the Auer and Mihalas NLTE/L models to find fluxes at the effective wavelengths of the six filters which we use to find angular diameters and we have compared these fluxes with those from Kurucz (1977) for models having the same T_{eff} and log g. The results are shown in Table 4. The irregular trend with wavelength of the ratio F_λ(NLTE/L)/F_λ (Kurucz) may be in part due to inaccuracies resulting from our use of linear interpolation over the rather wide wavelength ranges used by Mihalas and Auer. It seems that, on the average, using monochromatic fluxes from the Kurucz models in place of fluxes from NLTE/L models will lead to no significant systematic error in the derived angular diameters for O stars. The resulting θ_λ for different wavelengths will be more consistent if Kurucz fluxes are used than if monochromatic fluxes from the NLTE/L models are used.

In Table 3 we have shown that for the O stars use of the Kurucz models in place of the NLTE/L models of the same T_{eff} and log g will lead to an underestimate of f_{est} by about 8 percent, providing that the angular diameter is the same in the two cases. Since the value of f_{est} dominates the value for the total integrated flux when T_{eff}(model) exceeds 35000 K, use of data from the Kurucz models in place of that from the NLTE/L models will lead to an underestimate of the total flux by 4 to 6 percent for the early O-type stars. This means that our choice of model will produce flux effective temperatures that are systematically about 1 to 1.5 percent smaller than those which would have resulted if we had used the NLTE/L models. We emphasise that our choice of model data has probably not affected our derived angular diameters in any systematic manner. The uncertainty in flux effective temperatures for the early O-type stars is concentrated in the estimate for the unobserved flux shortward of 1380 Å.

5. DISTANCES

Distance moduli for the program stars have been found using measured properties of the spectra to determine M_V. To find V_0, we used the V magnitudes of Johnson, et al., (1966) corrected for interstellar extinction by means of the E(B−V) given in Table 1. For the stars not in Johnson, et al., (1966), we used the UBV photometry of the Bright Star Catalogue (Hoffleit 1964). The resulting distances are listed in Table 2 together with the number of estimates which have been averaged in each case. For the few visual binaries included in the program for which the photometry refers to two or more stars, the apparent magnitudes were corrected for the presence of the companions, see the notes to Table 1.

The sources of distance modulus were (1) BCD spectrophotometry which is used with the extinction, A_V, and the M_V found by the methods of Chalonge and Divan (1952), (2) uvby, β photometry, which is available for most of the stars (Lindemann and Hauck 1973, Hauck 1978), used with the calibrations of Eggen (1974) and of Crawford (1978) to find M_V, (3) equivalent widths of Hγ on the Victoria scale (Petrie and Moyls 1956, Balona 1975) which were used with the calibration in terms of M_V by Balona and Crampton (1974), and

(4) the assigned spectral types which were used with the calibration of MK types in terms of M_V given by Balona and Crampton (1974). In a few cases we also used cluster or association distance moduli determined by others, see Table 5, and for six stars (25 Ori, δ Ori A, υ Ori, ϵ Ori, σ Ori AB and ζ Ori A_1) we also used the distances determined by Warren and Hesser (1978) from a detailed study of the Orion OB1 association.

Distances for 66 stars were found from the available BCD spectrophotometry. The uvby, β photometry was not used for stars known to show Hβ in emission nor could it be utilized for all the supergiants and all the O stars. A total of 116 stars have M_V from the Eggen calibration, 113 from the Crawford calibration. The two calibrations are in essential agreement although there are small systematic differences for some of the evolved stars owing to the different methods used by Eggen and by Crawford to deal with these stars. We were able to find Hγ equivalent widths for 40 stars and 152 had spectral types which could reasonably be used with the calibration in terms of M_V of the MK types by Balona and Crampton. The values of M_V found by the various methods agree well, in general, the results from the two calibrations of the uvby, β photometry giving the tightest correlation.

Typically, 3 or 4 estimates of modulus are available for each star. The internal agreement between the different values corresponds to a dispersion about the mean value of about ±0.15 mag. This small dispersion occurs largely because the various absolute magnitude calibrations have been established using the same standard stars.

Lesh (1968, 1972) has given distances for many bright O and B stars. We have 126 stars in common with her. Savage, et al., (1977) and Bohlin, et al., (1978) (together designated as (SBD)) have given E(B–V) and distances for 45 stars in common with our list. Their distances and colour excesses are derived from the calibrations of the spectral types which they adopt in terms of M_V provided by Walborn (1971, 1972, 1973) for the O stars and by Lesh (1968, 1972) for the B stars and from their adopted UBV photometry. The differences of their E(B–V) from our values are too small to affect the distances by a significant amount.

The agreement of our distances with these other values is generally good. The percentage difference without regard for sign of the other distances from ours is 18.7% in the case of Lesh and 19.6% in the case of SBD. When account is taken of sign, the distances of Lesh are 0.1% larger than ours, on the average, while those of SBD are 1.5% larger. The small size of these latter differences indicates that the three sets of distance are internally consistent, as they should be, for they are all based on the same set of standard distances.

For a few stars our distances differ from those of Lesh or of SBD by more than 30 percent. Notes in Table 2 identify these stars. Usually the star has a poorly determined distance because it is very luminous (supergiant or O star), or because it is a Be star for which we give a significantly different spectral type than do Lesh or SBD.

We conclude that our distances generally have an error of less than 15 percent. In many cases the consistency of the data suggests that the probable error is of the order of 10 percent. The distances derived for the Be stars which have two Balmer jumps (stars designated by Note 3 in Table 2) are quite uncertain because the estimate of interstellar extinction is uncertain and most of these stars are known to be light variables of small amplitude. We do not know whether the adopted values of V and M_V refer to the same phase of activity.

6. DISCUSSION

6.1 Selection of the Best Solution

Two parameters must be accurately determined if our angular diameters and flux effective temperatures are to be accurate, namely E(B–V) and T_{eff}(model). Experience with the results for the main-sequence, normal (not Be or β Cephei) B stars having BCD spectrophotometry quickly showed that the ratio σ/θ is sensitive to the choice of E(B–V) and rather insensitive to the choice of T_{eff}(model), while T_{eff}(flux) is predominantly influenced by the choice of T_{eff}(model). Overcorrection for interstellar extinction drives ΔT_{eff} to negative values as does omission of the correction for the light of a companion.

There are 39 normal B stars with E(B–V) $\leqslant$ 0.02 and for these, the average value of σ/θ is 0.9 percent. The small size of the average value of σ/θ for the unreddened stars indicates that the shape of the Kurucz predicted monochromatic fluxes for the range 6356 to 11084 Å is closely the same as that observed by Johnson and Mitchell and that the 13-colour photometry is very consistent.

In Table 1 we have noted 94 stars for which the θ_λ from [110] is more than 1.5σ larger than the mean θ from the other 5 filters. This increase may be due to a temperature effect at the extreme longward tail of the red-sensitive photomultiplier response curve (Johnson 1978). The error in the photometry, percentage wise, is small, rarely exceeding 2.5σ/θ. For only 2 stars, HR 811 and HR 1617, is the [110] residual, $\theta_\lambda - \theta$, negative. For some stars the residual for [63] is negative and close to 1.5σ. We suspect that here also a small temperature effect on the longward end of the blue-sensitive photomultiplier may occur (Johnson 1978). None of the [63] values for θ_λ were omitted from the mean. We do not think the relatively large positive residuals found in some cases for the [110] filter are due to an infrared excess because many normal stars show this irregularity and it is not evident for all supergiants nor for all Be/shell stars. We emphasise that the irregularities in the 13–colour photometry that we are discussing here have a small amplitude even for the stars having the largest values of σ/θ. Eleven stars have σ/θ greater than 2 percent; six of these are Be/shell stars. As a result of this analysis, we have developed the rule of thumb that when σ/θ is of the order of or less than 1.5 percent, we have the correct E(B–V). Typically if T_{eff}(model) is held constant, a change in E(B–V) of +0.02 mag will decrease σ/θ by 0.3%.

The work of Guillaume (1966) illustrated the fact that for early–type stars when one considers a limited range of wavelength, it is possible to fit the shape of an observed spectrum reasonably well using models of rather different opacity properties but that the absolute energy emitted at these wavelengths may differ significantly from model to model. Thus we must be aware that use of model–atmosphere fluxes may introduce a systematic error in the derived angular diameters. This possibility can be checked by comparing the angular diameters derived for main–sequence and giant O and B stars with those measured by HB+. We have 11 such stars in common (α Eri, γ Ori, β CMa, ϵ CMa, ζ Pup, α Leo, δ Sco A, ζ Oph, α Lyr, α Pav and α Gru). The results for HR 7001 = α Lyr were obtained with E(B–V) = 0.00, log g = 4.0 and T_{eff}(model) = 9500 K. They are $\theta = 32.67 \times 10^{-4}$ arcsec, σ/θ = 0.83%, T_{eff}(flux) = 9469 K, ΔT_{eff} = +31 K and $R/R_\odot$ = 2.79.

We have made a least–squares fit between our angular diameters and those of HB+ using a relation of the form

$$\theta = a + b\theta_{LD} . \tag{5}$$

The solution using all 11 stars gives a = –0.0016 ± 0.5484 and b = +0.9716 ± 0.0409. However, our angular diameter for α Eri differs by more than 20 percent from the value of HB+. Because α Eri is a Be star, we do not trust our result. If we reject α Eri from the solution, we find a = –0.1214 ± 0.2184 and b = +1.0116 ± 0.0172. Both solutions show that our angular diameters agree excellently with those of HB+ and that there is neither a significant zero–point nor a scale error in our angular diameters.

After a preliminary trial of our method on a few main–sequence stars and after considering the likely errors in the integrated fluxes, we decided to stop all iterations for T_{eff}(flux) when ΔT_{eff} lay within the range ±500 K. We consider any solution with $|\Delta T_{eff}| <$ 500 K to be "acceptable" in the sense that in such cases the constraint of radiative equilibrium seems to be valid. Theory and observation agree. We attained ΔT_{eff} within our chosen limit with one trial for 78 stars. For the 39 essentially unreddened normal B stars, the average ΔT_{eff}, without regard for sign, is +171 K; with regard for sign, it is +75 K. Thus it appears that for normal stars we can expect the absolute photometry and the adopted model atmospheres to yield effective temperatures which agree to within ±200 K with the effective temperatures of the representative models selected for predicting the continuous spectrum. This agreement indicates that the modelling methods of Kurucz are reliable so far as representing the long-wavelength part of the continuous spectrum of O and B stars is concerned and that for this purpose the underlying assumptions of plane parallel layers, hydrostatic equilibrium, radiative equilibrium and LTE are adequate. If, for a given star, $|\Delta T_{eff}|$ is larger than 500 K, then it is likely that one or more of the assumptions underlying our method, including the assumption that the angular diameter is the same at all wavelengths, are violated.

We have four O and B supergiants in common with HB+: β Ori, ϵ Ori, ζ Ori A_1 and η CMa. For B-type supergiants, the $(B-V)_0$ colour suggests a significantly lower model effective temperature than has been suggested by analyses of the line spectrum, see the references given in Section 1. Since the interstellar extinction for supergiants is not well known, we tried several cases for each star. Typical individual results are listed in Table 6 together with the angular diameters of HB+. Our criterion for selecting E(B–V) leads us to the choice designated by #. These values for E(B–V) are supported by comments to be found in the literature and they are reasonable considering the distances of these supergiants. Our angular diameter for η CMa, whatever the choice for E(B–V), is a little large but it is not inconsistent considering the standard errors of the HB+ result and our result.

The choice of model effective temperature for the supergiants is readily resolved by noting that only a low effective temperature, like that suggested by the $(B-V)_0$ colours when they are used with our zero-point established for the KPA models with log g = 3.5, gives an angular diameter in accord with the measurements of HB+. Choice of a high effective temperature for the model like that suggested by analyses of the line spectrum gives neither an acceptable angular diameter nor an acceptable ΔT_{eff}. We conclude that to obtain correct angular diameters for supergiants, one should use a model which will predict $(B-V)_0$ like the value assigned by FitzGerald (1970) to the spectral type. It should be noted that Shobbrook (1976) has shown from uvby photometry that for the same c_0 (spectral type), B-type supergiants have a more positive value of $(b-y)_0$ than do main-sequence B stars, a result entirely parallel to FitzGerald's results.

The significance of our flux effective temperatures for supergiants is discussed in Section 6.3. We have found no reason to doubt that for supergiants the angular diameter is constant and independent of wavelength.

From time to time it is suggested that the atmospheres of supergiants and Of stars should be represented by spherical model atmospheres rather than by models consisting of plane parallel layers. We require models which predict the shape and absolute value of the continuous spectrum accurately in the range 6356 to 11084 Å and which predict an accurate value of f_{est}/f_{obs}. The continuous spectrum has been predicted in detail for a few static, spherical model atmospheres by Mihalas and Hummer (1974) (MH) and by Kunasz, et al., (1975) (KHM). In these models the continuous opacity is from electron scattering, H, He I, He II and absorption in the primary ionization continua of the first three ions of a fictitious, representative light element which has properties similar to those of the first three ions of C, N and O and which has an abundance commensurate with that of C, N and O combined, see M72. In constructing the models, the term in the equation for hydrostatic equilibrium which takes account of the effects of the gradient in the radiation pressure is represented schematically as $\gamma = \gamma_1 + \gamma_2 \exp(-\tau_R)$, where γ_1 and γ_2 are arbitrary constants specified for each model and τ_R is the Rosseland mean optical depth. The parameter γ_2 is called α by MH; their models have either $\gamma_1 = \gamma, \alpha = 0$ or $\gamma_1 = 1.0$ and $\gamma_2 = \alpha$, where γ and α are specified. According to MH and KHM, the cases with $\gamma_1 = 1.0$ and $\gamma_2 \neq 0$ are the most realistic choice. Other defining parameters for the models are L and M, the luminosity and mass of the star, and $R_{2/3}$, $T_{2/3}$ which are the radius in solar units and the temperature at the level in the atmosphere where $\tau_R = 2/3$. The quantity $g_{2/3}$ is also listed.

The models of MH have $T_{eff} \approx 39500$ K and $\log g_{2/3} = 3.45$; the adopted values of L, M and $R_{2/3}$ loosely represent ζ Pup. These models may be compared with the M72 NLTE/L model having $T_{eff} = 40000$ K and $\log g = 3.5$. To find the equivalent planar models for models 1, 3, 14 and 16 of KHM, we have integrated the predicted fluxes using the trapezoidal rule to find the equivalent effective temperature. The value of $\log g_{2/3}$ is given by KHM. Review of the values for L, M and $R_{2/3}$ adopted by KHM indicates that models 1 and 14 may represent α Cam while models 3 and 16 resemble ζ Pup loosely. The defining properties for KHM models 1, 3, 14 and 16 and our calculated T_{eff} and f_{est}/f_{obs} are given in Table 7. In model 14 the abundance by number of the representative light element relative to hydrogen is 10^{-10}; in the other models it is 0.00115. The abundance of helium, by number, relative to hydrogen is 0.1 in all the spherical models.

Comparison of the m_ν values for the selected KHM models and for the MH models with the m_ν values of the corresponding M72 NLTE/L models shows that over the range 5000 Å to 14000 Å the energy distributions have essentially the same shape. Thus planar geometry is adequate for predicting the shape of the observed continuous spectrum of OB supergiants in the range needed to find angular diameters.

The absolute flux at observed wavelengths from the spherical models is, however, considerably less than that from a planar model of similar T_{eff} and log g, see Table 7 where the ratio of the flux at 5695 Å in the spherical atmosphere to that from the equivalent NLTE/L planar model is given. In the far ultraviolet, $\lambda < 911.2$ Å, the spherical atmospheres have significantly greater flux than do the planar models, a point commented upon by KHM. Consequently f_{est}/f_{obs} is significantly larger for the spherical models than it is for the planar models, as can be seen by comparing the data in Table 7 with that in Table 3.

However, we are distrustful of the far ultraviolet fluxes for the hot spherical models and for the M72 planar models with $T_{eff} > 32500$K because of the peculiarly large jumps that occur at $\lambda^{-1} = 38.6934 \mu m^{-1}$ (258.4 Å, the primary ionization limit of the second ion (M^{++}) of the representative light element) and at $\lambda^{-1} = 43.8970 \mu m^{-1}$ (227.8 Å, the primary ionization limit of He^+) when $T_{eff} > 32500$K. Perusal of the tables of m_ν given by M72, MH and KHM shows that jumps greater than 8 mag occur. Much model calculation has shown that such large jumps are usually found only when a very abundant element is concentrated in one stage of ionization, for instance, neutral hydrogen in models with $T_{eff} \approx$ 10000K at 912 Å. The jump at 504 Å, the primary ionization limit of neutral He, never becomes this large because in hot models the helium atoms become ionized and thus contribute no longer to this edge. The occurrence of jumps of 8 or more mag at the ionization edge of the second ion of the representative light element seems improbable because this element is present with only 0.0115 the abundance of helium and it can be distributed over several higher stages of ionization. To produce an edge as strong as that of He^+, M^{++} would have to have an absorption coefficient more than 100 X stronger than that of He^+.

If the source function may be approximated by $B_\nu(T)$, a jump of about 4 mag might occur at these short wavelengths because of the rapid change of $B_\nu(T)$ with depth in the atmosphere. Mihalas (1978) says that this effect is enhanced because the source function at the M^{++} ionization edge is better approximated by B_ν/b_1, where b_1 is the usual NLTE coefficient describing the change of the population of the ground level of the second ion from LTE values, and that in the cases in question $b_1 \ll 1$. Unfortunately, the published data on the spherical and the planar models give no information on b_1 for the representative light element and on its apparent sudden change in size in certain effective temperature ranges.

To obtain by our method an angular diameter for ζ Pup which is reasonably close to the value measured by HB+, we must use a model which gives H_ν at $\lambda^{-1} = 1.756$ (5695 Å) in the range 3.09 to 4.63 x 10^{-4} ergs cm^{-2} s^{-1} Hz^{-1}. To obtain exact agreement we require a model giving $H_\nu = 3.86 \times 10^{-4}$. Perusal of the data on NLTE/L models of M72, MH and KHM shows that the planar models with T_{eff} in the range 32500 K to 40000 K and with log g = 3.3 to 4.5 provide monochromatic fluxes of the appropriate size, as do the MH models with γ = 1.0 and 1.4, and the models with $\alpha = 0.4$ and 0.6. Neither model 3 nor model 16 of KHM has a value of $H_\nu(1.756)$ that will reproduce the measured angular diameter of ζ Pup. In the case of the four satisfactory models of MH, the shape of the emergent spectrum over the range which we use for determining the angular diameter of ζ Pup does not depart by a significant amount from that of the comparable planar model. Thus we conclude that our use of predicted fluxes from a planar model to find the angular diameter of ζ Pup has introduced no significant systematic error into our angular diameter for this star.

In the case of α Cam, O9.5 Ia, we do not have a measured angular diameter. Our deduced angular diameter can be reproduced by the fluxes from KHM model 14. The H_ν (1.756) from KHM model 1 is too low to reproduce our result. We believe the angular diameter in Table 1 is acceptable because it leads to a linear radius, see Table 9, which is in line with those for other stars of comparable spectral type. There seems to be no pressing need to use the predicted energy distributions from the few available spherical atmospheres to interpret the observed parts of the continuous spectra of luminous O and B stars. We know that the outer atmospheres of OB supergiants are expanding rapidly, so the use of numerical data from static models is philosophically unsatisfactory. However, in the range 6000 to 11000 Å the opacity is chiefly due to electron scattering and allowing for the outflow motion will not change the shape of the continuous spectrum. When hydrodynamical model atmospheres become available, it will be desirable to reassess the question of whether the absolute flux estimated from planar models has the correct magnitude or not.

The data in Table 7 show that f_{est}/f_{obs} is significantly larger for a static spherical model of a given effective temperature than it is for a planar model. If f_{est}/f_{obs} in OB supergiants were as large as the results of KHM suggest, then the H II regions around OB supergiants should be more highly ionized than those around OB main-sequence stars of similar spectral type. Morton (1969) has used the H II region around ζ Ori, O9.5 I, to estimate T_{eff} and he finds a low value, like we do. Similarly, Georgelin, et al., (1975) find a low value of $N_L/\pi F_V$, thus of T_{eff}, for the O9.5 Iab star they study. For the O7 I star discussed by them, $N_L/\pi F_V$ has a value which is about the same as for the O7 V stars. Thus the observational evidence, although weak, indicates that f_{est}/f_{obs} is not significantly larger in supergiant O stars than it is in main-sequence O stars. This makes it undesirable to use spherical atmospheres like those now available. Our use of f_{est}/f_{obs} from the Kurucz (1977) model atmospheres should not seriously invalidate our estimates of T_{eff} for the O stars and the supergiants. Nevertheless, the reliability of the effective temperatures for the O stars would be greatly increased if observed absolute energies to 911 Å were available for those stars, because the contribution of f_{est} to the flux integral is large when T_{eff} is greater than 30000 K and the uncertainty in f_{est} would be greatly reduced if absolute spectrophotometry shortward of 1380 Å were available for more stars.

6.2 Results for Normal O and B Stars of Luminosity Classes II–V

In general the flux effective temperatures and radii deduced for the O and B stars of luminosity classes II to V agree well with the data for these stars to be found in the literature, mostly derived from analyses of the line spectrum. For orientation, we have compiled Tables 8 and 9 which give the average effective temperatures and radii for the MK spectral-type boxes represented in our list. The given standard deviation of the mean, $\sigma/\sqrt{n}$, represents as much the disparity among the stars collected in each box as the uncertainties of the results. We emphasise that for individual stars, the results in Tables 1 and 2 are preferable to those of Tables 8 and 9. Typically, for a normal star, the uncertainty in T_{eff}(flux) is about 2 percent; that in linear radius may be between 10 and 15 percent, the error being chiefly due to the uncertainty in distance.

The Be stars having Note 4 in Table 1 and Note 3 in Table 2 have not been included when finding the mean values of Tables 8 and 9. We first separated all the other Be stars and the Beta Cephei stars from the normal stars, but we found that their effective temperatures and radii did not differ significantly from the mean values for the normal stars, thus all but the exceptional Be stars are included in the results of Tables 8 and 9. The box B1 II and III contains only Beta Cephei stars.

There is a slight tendency for the flux effective temperatures of stars in luminosity classes II and III to be lower than those of stars in luminosity classes IV and V for a given subtype, but the differences are barely significant. The radii of the giant stars (II, III) are somewhat larger than those of main-sequence (IV, V) stars. We have placed HR 3165 = ζ Pup and HR 8469 = λ Cep, O stars which have no luminosity class, in the boxes for luminosity classes II and III at types O4 and O6 respectively.

6.3 Results for the O and B Supergiants

The flux effective temperatures for the O and B supergiants are distinctly lower than those of main-sequence and giant stars of the same subtype. Our data for 20 supergiants clearly demonstrate this trend which was suspected from the work of CD+ and of Beeckmans (1977) and which was suggested by Humphries, et al. (1975) from a comparison of the shapes of the ultraviolet energy distributions of main-sequence and supergiant stars of the same subtype. The differences suggested by Humphries, et al., were used by Barlow and Cohen (1977) to develop a temperature scale for O, B and A supergiants that gives lower effective temperatures than are usually accepted for main-sequence O, B and A stars.

Our results, Table 8, indicate that the Ib and the Ia supergiants have about the same flux effective temperature. At type B1 the flux effective temperature of a supergiant is nearly 7000K lower than that of a B1 main-sequence or giant star. This fact is due entirely to the "ultraviolet flux deficiency" of B-type supergiants (documented fully by Humphries, et al.) with respect to B-type main-sequence stars of the same subtype. We conclude that the relative line strengths used to classify O and B-type supergiants are not predominantly determined by the total radiation field of the star, but instead reflect the electron temperatures in a transition layer between the photosphere of the supergiant and the hot coronal layer which is known from ultraviolet spectra to exist. This transition layer is hotter than can be obtained from the hypothesis of radiative equilibrium and this result means that mechanical/magnetic energy must be being deposited in the transition layers and coronas of B-type supergiants.

The assumption that supergiant spectral types, assigned from a careful evaluation of the relative strengths of absorption lines in the blue-violet spectral region, can be related by the relation valid for main-sequence stars to the total radiation field (flux effective temperature) of a star is not valid. It also may not be valid for some of the O stars. For instance, the relative strengths of the He I and He II lines in the spectrum of ζ Pup, O4ef, demand electron temperatures which, when radiative equilibrium is the only source of heating, require flux effective temperatures in the range 45000 to 50000K, see Snijders and Underhill (1975) for a recent review of this subject. The flux effective temperature of ζ Pup, as the present results and those of CD+, Beeckmans (1977) and Brune, et al., (1978) show, falls in the range 31500 to 35010 K. It is thus significantly lower than the value suggested by the relative strengths of the He I and He II lines interpreted under the constraint of radiative equilibrium. The only way to drive the flux effective temperature to a value as high as 45000 or 50000 K is to adopt an angular diameter which is near 3.2×10^{-4} arc sec, a value which is significantly smaller than the results of HB+ indicate. We have demonstrated above that going to models with spherical geometry will not resolve the problem of the "ultraviolet flux deficiency." We conclude that the blue–violet line spectrum of ζ Pup is revealing a heated transition layer between the photosphere and the hot coronal region which is known from ultraviolet spectra.

An interesting attempt has been made by Holm and Cassinelli (1977) to resolve the inconsistencies of the observations of ζ Pup. We doubt that their explanation is the full one, but we note that their point that the ionization of the Gum Nebula gives a constraint on the far ultraviolet flux from ζ Pup is a good one, provided that this ionization is dominated by radiation from ζ Pup. The hot coronal region of ζ Pup is surely heated by mechanical/ magnetic energy deposited by some presently unknown mechanism.

Measured Balmer Jumps, D, exist for 14 of our supergiants, see the appendix. For 12 of these stars (ζ Per, α Cam, β Ori, ϵ Ori, ζ Ori A_1, χ^2 Ori, ι CMa, o^2 CMa, η CMa, 55 Cyg, 9 Cep and 4 Lac) the measured D is about 40 percent of what the predicted fluxes from the adopted representative model suggest. This systematic difference is not due to the uncertainties in the measured values of D nor in the calculations of D values for the models.

It is difficult to understand how this mismatch in D could be due to deficiencies of the model calculations when we find that the selected models represent well the shape and absolute fluxes for B–type supergiants in the range 5000 to 11000 Å. Several of the above supergiants have been shown by Barlow and Cohen (1977) to possess an infrared excess due to free–free emission. However, neither the 13–colour photometry, specially the results from filter [80], nor the relative energy distributions on high–dispersion spectra covering the range 3400 to 4000 Å, as studied, for instance, by Underhill (1970), give support to the idea that the Balmer continuum is strongly in emission in B–type supergiants. If that were so, the BCD spectrophotometry would have revealed a rise starting near 3650 Å; it does not do so. We suspect that this difference from the model values for D may occur because the continuous radiation observed immediately shortward of 3650 Å in B–type supergiants comes from the heated transition layers which determine the relative strengths of the absorption lines used to classify the O and B–type supergiants. Comparison of the relative energy distributions derived from the 13-colour and S2/68 photometry with the relative energy distributions of KPA models with log g = 3.0 and T_{eff} = 20000 K (see Underhill 1979) shows that for B1 supergiants there is a weak emission Balmer continuum.

The linear radii of the Ib supergiants are significantly smaller than those of the Ia supergiants, see Table 9. However, all supergiants are considerably larger than giant or main-sequence stars of the same subtype.

6.4 Results for the Be Stars

The interpretation of the results for the Be stars presents difficulties because the spectra of these stars sometimes differ from normal B-type spectra owing to the presence of additional relatively sharp absorption lines and emission lines, and to changes which occur in the spectra. In addition, the shape of the spectrum in the visible range, as measured by ϕ_{rb} and the B–V colour, often differs from that of a normal star with the same subtype. A search of the literature shows that the spectral types for some of the Be stars on our program differ considerably depending on the source consulted and on the date of the observations. This is true also for the BCD spectrophotometric quantities and for the UBV photometry. Many of these stars are known to be light variables. We do not know the dates of the photometric measurements which we use; they were certainly all made at different epochs.

Since we believe that it is interesting and useful to investigate how well the Be stars agree in effective temperature and radius with normal B stars of the same nominal spectral type, we have carried through the calculations for 31 Be stars for which we have 13-colour and S2/68 spectrophotometry. We have used the parameter D, when possible, for selecting the representative model atmosphere because D does not seem to change when the emission lines change (Divan 1978). It is important that the nominal E(B–V) obtained from the published UBV photometry and our best estimate of the spectral type, thus intrinsic colour, should measure accurately the interstellar extinction. To check that this is so, we have also found E(B–V) from the BCD spectrophotometry given in the appendix and from the depth of the interstellar absorption feature at 2200 Å, see Beeckmans (1978). Usually all results are consistent.

If the energy distribution of the Be star has an abnormal shape, the ratio σ/θ may become large and the residuals $\theta_\lambda - \theta$ may have a systematic trend with wavelength. If the absolute flux in the wavelength range from 6356 to 11084 Å is significantly modified from that of a normal B star of the nominal type assigned to the Be star and at the same distance, the deduced value for the angular diameter will be in error. The most probable type of error is that the measured flux is too large owing to the presence of an infrared excess.

A final difficulty in interpreting our results is that Equation (1) is based on the assumptions that the star is spherical and that the radius of the photosphere is the same at all wavelengths. If the star rotates rapidly, as it is thought to do for Be stars in general, the disc of the star will be distorted. Some models of Be stars suggest the presence of an equatorial disc, or layer. Our method finds the equivalent angular diameter of a sphere having an area equivalent to the deformed shape of the Be star. This remark holds true also for non-spherical rapidly rotating B stars.

So far as E(B–V) is concerned, in only 3 stars (HR 496 = ϕ Per, HR 8047 = 59 Cyg and HR 8539 = π Aqr) was the spread in estimated values greater than 0.09 mag. For the other 28 stars it is less than 0.06 mag. Thus we believe that the values of E(B–V) given in Table 1 measure reliably the interstellar extinction suffered by the 31 Be stars which we study, with the possible exception of the above 3 stars.

Review of the results in Tables 1 and 2 shows that 19 of the stars (the 16 without Note 4 in Table 1 and Note 3 in Table 2 plus HR 472 = α Eri, HR 6712 = 66 Oph and HR 8402 = o Aqr) have $\sigma/\theta < 1.70\%$ and $|\Delta T_{eff}| < 500$ K. For these stars the flux effective temperatures and linear diameters are within the normal range for stars of their subtypes. The presence of emission lines, which lead to the designation Be, has not distorted the radiation field of these stars by a significant amount from that of normal B stars without emission lines.

Twelve stars have $\sigma/\theta > 1.70\%$. In 7 cases, ΔT_{eff} is greater than +500 K. In 5 cases ΔT_{eff} falls in the normal range. Among the 12 Be stars which have $\sigma/\theta > 1.70\%$ and ΔT_{eff} large, 8 have a second Balmer discontinuity in emission and 2 have a second discontinuity in absorption, see the appendix. We have no BCD spectrophotometry for HR 2538 and HR 7565. We have BCD spectrophotometry for 10 of the 19 stars with effective temperatures and radii like those of normal B stars and only 2 have a second Balmer discontinuity, each time in emission. The presence of second Balmer discontinuities in emission or in absorption is closely correlated with the occurrence of large values of σ/θ and of ΔT_{eff}.

In none of the 31 Be stars is there a systematic trend of the residuals, $\theta_\lambda - \theta$, with wavelength, as might arise from an infrared excess systematically perturbing the 13–colour photometry, nor do the results from the [80] filter suggest the presence of a significant Paschen emission continuum for any star. We find no systematic difference between those stars known to have the Paschen lines in emission (Andrillat and Houziaux 1967) and the others.

If the equivalent angular diameter of a Be star is the same at all wavelengths and the error in θ is less than 2%, as our results for the normal B stars indicate, then $\Delta T_{eff} > +500$K implies a significant depletion of the total radiation field of the Be star from what would be expected according to its spectral type. The "missing" radiation might have been transferred to the unobserved part of the spectrum longward of 11084Å or it might have been used in supplying the internal energy of the atoms and ions of the shell. On the other hand, if the angular diameter of a Be star is dependent on wavelength, then our method of analysis fails and our results are meaningless. This may be the case for the 12 stars with large σ/θ and ΔT_{eff}.

Comments on two Be stars follow:

HR 472 = α Eri: The angular diameter of this star was measured by HB+, but their angular diameter is more than 20 percent larger than the value we give in Table 1, which was found by taking the spectral type to be B3 Vpe (Hiltner, et al., 1969) and using the UBV photometry of the Bright Star Catalogue (Hoffleit 1964). These data result in E(B−V) = 0.05 mag, which is rather large considering that α Eri is at a distance of about 29 pc at most. The B−V colour may be suspect, since α Eri is a Be star. Taking E(B−V) = 0.00 and T_{eff}(model) = 18000K gives an angular diameter of 15.26×10^{-4} arc sec, T_{eff}(flux) = 17003 and ΔT_{eff} = +997K. This large positive value of ΔT_{eff} indicates that the data do not fit the normal pattern for main-sequence B stars.

On the other hand, the spectral type is listed as B5 IV by Hoffleit (1964). This agrees with the observed B−V colour and the condition that E(B−V) = 0.00. If this spectral type is correct, then the appropriate T_{eff}(model) is 15000K, which gives $\theta = 17.33 \times 10^{-4}$ arc sec, T_{eff}(flux) = 14974K, ΔT_{eff} = +26K. This solution seems very reasonable; it gives σ/θ = 1.41%. However, the HB+ value for θ_{LD} is then 1.11 times our value, a discrepancy which is still far larger than what we expect from the good agreement between our results and those of HB+ for other stars.

There is no possibility that the 13-colour fluxes are too small by about 23 percent, for they agree within 10 percent with the relative fluxes of Davis and Webb (1974) when those fluxes are placed on an absolute scale using the absolute photometry of Vega by

Hayes and Latham (1975). Furthermore, the 13-colour photometry in filters [52] and [58] of α Eri and of Vega indicate that $\Delta V = 0.44$ mag between these stars, a value in agreement with the adopted UBV photometry.

Clearly spectroscopic observations at high dispersion and BCD spectrophotometry of α Eri are required to define accurately its spectral type and the shape of its continuous spectrum. The most consistent solution at present is to assume that the spectral type is B5 IV, but that still leaves a problem with the results of HB+.

HR 8047 = 59 Cyg: For this star we have BCD observations obtained in 1948 and in 1965 when a second Balmer discontinuity in emission was visible, as well as in 1977 when the Balmer discontinuity was that of a normal B1.5 star and we have high-dispersion spectra obtained in 1965 and 1977. The Balmer emission lines were not present in 1977 although they were strong in 1965. The star was about 0.4 mag brighter in the visible in 1965 than in 1977 and the blue and the ultraviolet gradients were redder in 1965 than in 1977. By using the BCD spectrophotometry from 1977 we may obtain a reliable estimate of the interstellar extinction for this star. However, since we do not know exactly the epochs of the 13-colour and the S2/68 photometry, our values for the angular diameter and the integrated flux are most probably not typical of those for normal B stars of the assigned spectral type. Clearly the interpretation of our results for stars known to show two Balmer discontinuities may be fraught with danger.

6.5 Comparison with the Estimated Effective Temperatures of Others

We have 17 main-sequence and giant B stars in common with SPO who determined effective temperatures from the shape of the visible continuous spectrum. For 10 stars the differences in effective temperature between our and their values lie in the range ±500 K; for 3 (HR 779 = δ Cet, HR 1910 = ζ Tau and HR 8238 = β Cep) the differences exceed 1000 K, in each case our temperature being the higher value. Generally our temperature scale is like that of SPO but the effective temperatures of SPO appear to be low in the range B0 to B2.

An attempt was made by Morrison (1975) to estimate the effective temperatures of O stars using a calibration of the uvby photometric indices in terms of model effective temperature which resulted from the calculations of Mihalas (1972b). We have 9 O stars in common with Morrison. The agreement in effective temperature is generally poor and our results bear out her conclusion that the use of uvby photometry to find the effective temperatures of O stars does not lead to precise results.

The O–star effective temperatures of Conti (1975) are based on an analysis of the relative strengths of certain He I and He II lines. For luminosity–class V stars of types O6.5, O9 and O9.5, our flux effective temperatures are a little lower than the T_{eff} of Conti. We agree well in the case of the supergiants of types O8, O8.5 and O9. For supergiants of type O9.5, whether Ia or Ib, we find significantly lower effective temperatures than Conti suggests. For stars of types O6 and earlier, we find that the flux effective temperature is at least 2000 K lower than the values suggested by Conti for stars of all luminosity classes. We strongly suspect that the effective temperatures for early O–type stars determined from analyses of the line spectrum reflect the presence of a heated transition layer between the hot corona of these stars and a relatively cool photosphere, see our discussion of ζ Pup, rather than the integral of the radiative flux flowing from the star. Thus we urge caution in interpreting Conti's temperature scale for the early O stars as a true measure of the radiative flux from these stars.

Our scale of effective temperatures for the B–type supergiants agrees well with that of Barlow and Cohen (1977). The only large differences are that we find T_{eff} = 25000 K for O9.5 Ia and 29910 K for O9.5 Ib while Barlow and Cohen suggest 30000 K for O9.5, no subdivision according to Ia or Ib being given, and at type B2 we find 17460 K for Ia and 16480 for Ib whereas Barlow and Cohen suggest 18000 K for both the Ia and the Ib supergiants.

Flux effective temperatures have been determined for a number of O and B stars using observations of the ultraviolet spectrum as well as absolute photometry obtained from the surface of the earth and we give in the following a comparison of the various results, noting only those cases where significant differences occur between the various sources.

Code, et al., (1976) used OAO–2 ultraviolet data, Beeckmans (1977) used S2/68 ultraviolet data, and Brune, et al., (1979) used ultraviolet data from a sounding rocket; all used the same absolute fluxes longward of 3300 Å and the angular diameters of HB+. In addition Brune, et al., estimated effective temperatures for their stars by comparing the shape of their ultraviolet spectra with the shape of the Kurucz (1977) spectra when these had been reddened appropriately. Henry, et al., (1975) also have estimated effective temperatures for a few stars from the shape of the ultraviolet spectra which they obtained from Apollo 17.

HR 472 = α Eri: This star has been discussed above. CD+, Beeckmans, and Brune, et al., adopt without comment the inconsistent values of spectral type B3 Vp and E(B–V) = 0.00.

Because they all use the large angular diameter of HB+, their effective temperatures, which are near 14200K, are low, particularly for what is characteristic of type B3 V, see Table 8. Use of an angular diameter near 16×10^{-4} arc sec with their integrated fluxes would yield an effective temperature near 15500K, a value which is appropriate for type B5 V. Henry, et al., find T_{eff} = 15800K; they adopted spectral type B5 IV and E(B–V) = 0.00.

HR 1910 = ζ Tau: Our effective temperature is 2700K higher than that estimated by Henry, et al.; it is in good agreement with what we find for other B2 III stars. This is a shell star with two Balmer discontinuities.

HR 1948 = ζ Ori A_1 : The results of CD+ and Beeckmans suggest an effective temperature near 30000K; our results suggest 27600K, a value close to that found by Morton (1969). This star is a poor candidate for study because the photometry must be corrected for the light from two companions each about 2 mag fainter than A_1.

HR 2618 = ϵ CMa: Our flux effective temperature is 1700K higher than that of CD+ and 2700 higher than that of Beeckmans. Our value is in line with the value expected for the B2 giants, according to our results from many stars.

HR 3165 = ζ Pup: We have discussed this star above. According to all studies its flux effective temperature is too low to generate the electron temperatures needed to account for the observed strengths of the He I and He II lines.

HR 5953 = δ Sco A: Our effective temperature is 1500K lower than that of CD+ and 800 lower than that of Beeckmans. The effective temperature of CD+ is high for spectral type B0.5 IV; it is typical for type O9.5 V. Our result is in good agreement with that for the other B0.5 IV star on our list, HR 1756 = λ Lep.

HR 6175 = ζ Oph: Our flux effective temperature is 2200K higher than that of CD+ and 4200K higher than that of Beeckmans. Our value is in good accord with that for the other O9 V star on our list, HR 1855 = υ Ori; Henry, et al., suggest 35000K, in agreement with our result.

HR 7790 = α Pav: Our effective temperature is 1700K higher than that of CD+ and 2300K higher than that of Beeckmans. Our value is in good agreement with that for the other B2.5 main-sequence stars in our list. The effective temperatures of CD+ and of Beeckmans are typical for B3 or later. Our angular diameter is 10 percent smaller than that of HB+.

HR 8425 = α Gru: The effective temperature of CD+ is nearly 800K higher than that found by us. Our result is in good accord with the results of Beeckmans and of Henry, et al. The results of CD+ is typical of type B6 rather than of type B7.

Using a preliminary calibration of the OAO–2 spectrum scanners in terms of absolute energy, some published spectrophotometry longward of 3300 Å, and model–atmosphere energy distributions from lightly line–blanketed model atmospheres, Underhill (1973a, b) estimated effective temperatures from the shape of the spectrum and also found radii for five of our program stars. Her results for T_{eff} and $R/R_{\odot}$ are 30900K, 9.4 for HR 1756 = λ Lep; 13000K, 3.4 for HR 3982 = α Leo; 18000K, 4.5 for 5191 = η UMa; 14000, 4.2 for HR 6396 = ζ Dra and 9750K, 2.7 for HR 7001 = α Lyr. These values are in surprisingly good accord with the more precise results that can now be found. The most significant change is that the present results give $R/R_{\odot}$ = 6.2 for ζ Dra, B6 III. This change resolves the problem noted by Underhill (1973a) that the mass of the B6 III star deduced from the spectroscopically estimated log g seemed to be less than that of α Leo, B7 IV. With the larger radius now found, the difficulty disappears.

Strongylis and Bohlin (1977a) have studied all the available absolute spectrophotometry for HR 5191 = η UMa. They have noted that the Kurucz (1977) model with log g = 4.0 and T_{eff} = 17000K represents well the shape of the spectrum of this star, as we find. In a later paper (Strongylis and Bohlin 1977b), they have critically compared the absolute calibration of observations in the range 1750 to 3350 Å of several stars, and they have demonstrated the typical differences that occur between the several sources of absolute photometry shortward of 3300 Å.

7. CONCLUSIONS

This study, based on homogeneous sets of published absolute photometry over the range 1380 to 11084 Å for 160 O and B stars, has shown that accurate angular diameters and flux effective temperatures can be found for single stars when the observed data are combined with the monochromatic fluxes from the fully line–blanketed, LTE, plane–parallel–layer model atmospheres of Kurucz (1977, 1979). The model fluxes represent well the shape and absolute value of the continuous flux from stars of types O and B in luminosity classes II to V over at least the range of wavelengths from 3371 to 11084 Å, a conclusion reached independently by Buser and Kurucz (1978). The fluxes from models with low log g seem to represent well the part of the continuous spectrum of O and B supergiants longward of 5000 Å. There is no need to consider spherical geometry when interpreting the continuous spectrum of O and B supergiants.

We have found effective temperatures for the O and B stars of luminosity classes II to V in accord with what was previously known. Because we have results for many stars over the range A0 to O4, we are able to establish a secure temperature scale for the O and B main-sequence and giant stars, see Table 8. However, we emphasise that the properties of the stars collected in any one spectral-type-luminosity-class box are diverse and that it is preferable to use the effective temperatures and radii for individual stars given in Tables 1 and 2 rather than mean values. The highest effective temperature which we find for an O star is 37700 K. Most of our O stars have effective temperatures at or below 35000 K.

We have results for 20 supergiants of types O and B and from this material we are able to derive a temperature scale for the O and B supergiants. It is clear that the flux effective temperatures of O and B supergiants are significantly lower than the flux effective temperatures of main-sequence or giant stars of the same subtype. The difference is a maximum near type B1 where it is 7000 K. The O and B supergiants are "ultraviolet-flux-deficient" in comparison to main-sequence and giant stars of the same subtype, as others have previously noted. This fact underlines the need for caution in selecting pairs of stars, one reddened, the other unreddened, for determining the shape of the interstellar extinction law.

We conclude that the absorption lines selected to define spectral types in all luminosity classes of the O and B range do not always represent a level of excitation and ionization that can be attributed solely to the radiation field from the star. Therefore, spectral type in the O and B range is not necessarily a single-valued function of flux effective temperature. In the case of the O and B supergiants, we suspect that the relative strengths of the classification lines reflect electron temperatures in a heated transition layer between the photosphere and the hot coronal region known from ultraviolet spectra to exist for all O and B supergiants. Some early-type luminous O stars, for instance ζ Pup, O4ef, also show this effect. Caution should be used in interpreting spectral types O5, O4 and O3 in terms of flux effective temperatures greater than 40000 K. These types may reflect instead the visibility of the hot transition layer between the photosphere and a very hot corona.

Clearly, some layers of the atmospheres of O and B supergiants and the early O stars, layers visible in spectra obtained from the sufrace of the earth, are heated by mechanical and/or magnetic energy. It has been obvious ever since the resonance lines of high ions of C, N and O were discovered in the ultraviolet spectra of these stars that these stars possess a hot corona of considerable extent. This fact added to our confirmation that the effective temperatures of B–type supergiants are low makes it imperative to find the mechanism(s) that cause the heating and probably the strong, rapidly moving stellar wind.

The continuous spectrum of the O and B supergiants longward of about 4500 Å seems to come from a photosphere that can be modelled using classical, LTE procedures. However, we have noted that the observed flux just shortward of the Balmer jump is larger than classical models predict. The increase is considerably greater than is predicted by NLTE/L models of the same T_{eff} and log g. The extra flux may come from the heated transition layer which is revealed by the classification absorption lines.

In the case of the normal O and B stars of luminosity classes II to V, the heated transition layer, which must also be present between their normal photospheres and the hot coronas known from ultraviolet spectra to exist for some of them, is not conspicuous. Their flux effective temperatures are consistent with the effective temperatures which may be deduced by means of classical modelling of the continuous spectrum and of weak absorption lines.

Many of the Be stars which we have studied behave in our analysis like normal main–sequence or giant B stars. For 2/3 of the Be stars in our sample, the occurrence of hydrogen emission lines apparently does not distort the total flux from the star by a significant amount and it appears that the angular diameter is independent of wavelength, an assumption that is necessary for all determinations of flux effective temperature. Our solutions for these stars are in reasonable accord with what we have shown is usual for normal B stars of the same subtype. However, for 1/3 of the Be stars in our sample, the dispersion in θ is greater than for normal stars. The majority of these stars are known to show a double Balmer discontinuity and gradients in the blue and in the ultraviolet which differ from those of normal stars. We cannot interpret the discordant results for these stars. We doubt that the basic assumption that the angular diameter is independent of wavelength is valid for them.

The ten Beta Cephei stars and the four Bp stars (HR 1638, HR 5982, HR 6023 and HR 6567) studied by us have effective temperatures and radii in accord with the average values for stars of their spectral types.

We have derived an E(B–V) colour excess and a distance for each star. The linear diameters which result are given in Table 2; they are summarized in Table 9. There is a distinct progression in size from main–sequence to supergiant stars. The agreement with radii determined from the study of eclipsing variables is good. For B–type stars of luminosity classes IV and V Popper (1974) has shown that the radii range from 2.6 to 8.1 $R_\odot$, while for O stars the few available eclipsing binaries suggest values between 6 $R_\odot$ (at type O9.5 V) and 19 $R_\odot$ (at type O8.5 If) (Underhill, et al., 1979). The radii derived by Conti (1975) for O stars from his adopted effective temperatures, M_V and bolometric corrections are also in reasonable accord with our results.

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Much of the precision of our results is due to our access to the vast body of accurate spectrophotometric measurements compiled at the Institut d'Astrophysique during the last 30 years for the purpose of finding the physical characteristics of stars. We should like this paper to be a memorial to one of astronomy's pioneers in the accurate measurement of the wavelength dependence of the light from stars and its interpretation, D. Chalonge.

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FIGURE CAPTIONS

Figure 1. The calculated values of D as functions of model log g and T_{eff} for KPA and Kurucz (1977, 1979) model atmospheres. The observed position of the main-sequence band, according to Chalonge and Divan, is indicated.

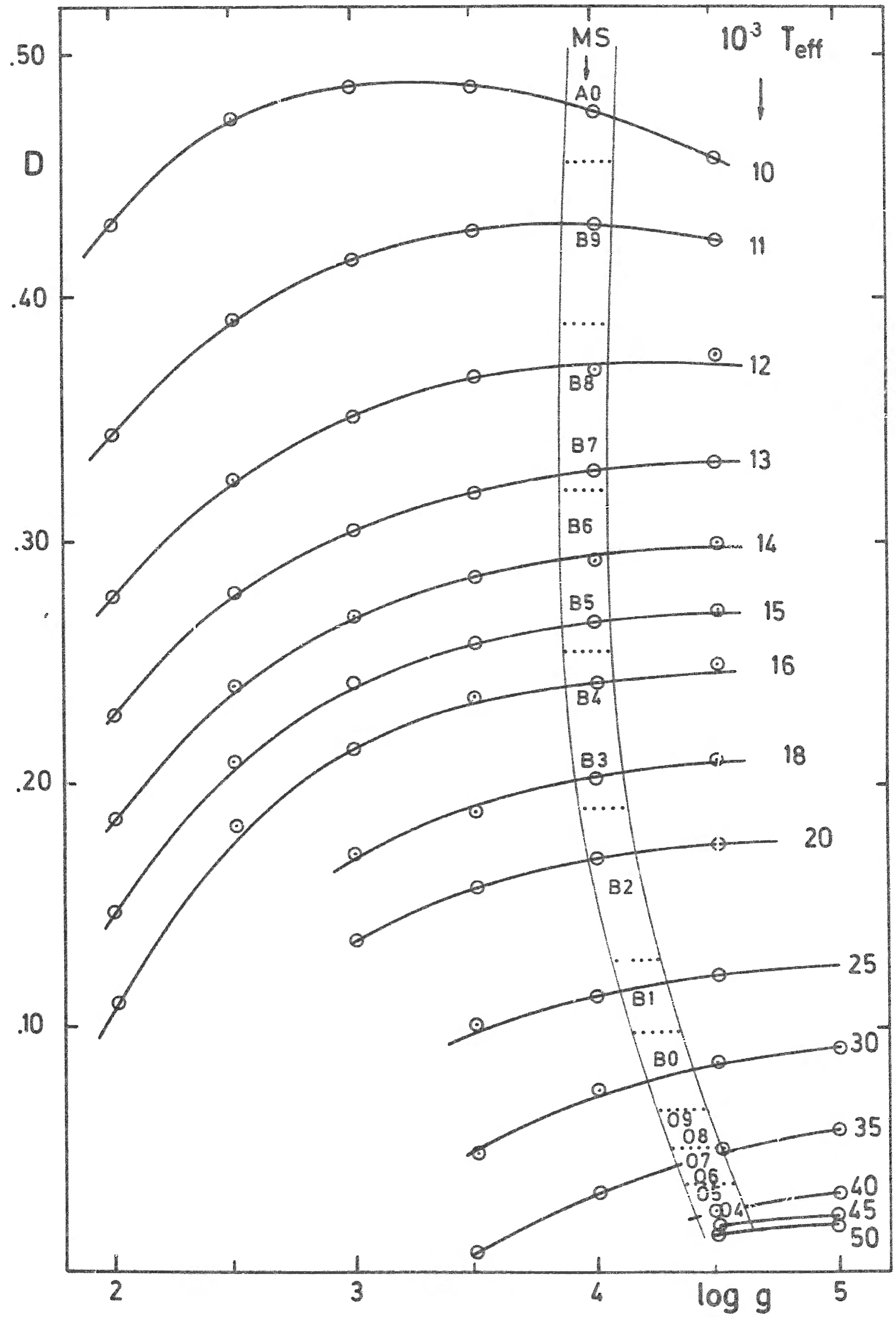

Table 1. The program stars, their angular diameters and observed integrated fluxes.

HR	Name	Spectral Type	E(B-V) mag	θ^*	σ/θ %	f_{obs} †	Notes
39	γ Peg	B2 IV	0.01	4.32	0.60	7.825	1,2
153	ζ Cas	B2 IV	0.05	3.03	0.73	4.135	
472	α Eri	B3 Vpe	0.05	15.91	1.49	52.18	2,3,4
496	ϕ Per	B0 IVe	0.26	2.64	1.74	10.13	2,3,4
542	ε Cas	B4 IV	0.03	4.68	0.53	3.067	2,3
779	δ Cet	B2 IV	0.04	2.37	1.56	3.062	1
811	π Cet	B7 IV	0.00	3.34	2.22	0.9266	5
985	1H Cam	B2.5 Ve	0.07	2.00	1.45	1.297	2,3
1034	21278	B4 V	0.08	2.28	0.75	0.8436	2
1044	34 Per	B4 V	0.09	2.63	0.49	1.249	
1087	ψ Per	B4 IVe	0.12	3.49	1.26	1.868	2,3
1122	δ Per	B5 III	0.04	5.95	0.59	3.725	2
1156	23 Tau	B6 IVe	0.08	3.92	1.02	1.298	2
1165	η Tau	B7 IIIe	0.07	7.19	1.06	3.811	2,3
1203	ζ Per	B1 Ib	0.31	7.02	0.80	16.16	2
1204	24479	B9 Ve	0.00	3.04	0.66	0.3593	2
1273	48 Per	B4 IVe	0.15	3.87	1.27	2.467	2
1350	53 Per	B4 IV	0.16	2.59	0.39	1.242	2
1463	ν Eri	B2 III	0.03	2.45	0.98	3.082	1,2
1520	μ Eri	B5 IV	0.02	3.52	1.02	1.594	2
1542	α Cam	O9.5 Ia	0.30	2.92	0.96	6.124	2
1552	π^4 Ori	B2 III	0.08	3.15	0.57	4.115	
1567	π^5 Ori	B2 III	0.05	3.04	0.59	3.492	2
1617	ψ Eri	B3 V	0.01	1.95	0.97	1.029	2,5
1621	32309	B9.5 V	0.00	3.26	0.74	0.3532	
1638	11 Ori	B9 V(Si)	0.02	3.60	0.81	0.4131	2
1679	λ Eri	B2 IVe	0.04	2.24	0.67	2.376	2,3
1696	ι Lep	B9 V	0.00	3.56	1.18	0.7503	
1713	β Ori	B8 Ia	0.04	26.67	1.32	39.95	
1735	τ Ori	B5 III	0.04	4.50	0.82	2.173	2
1756	λ Lep	B0.5 IV	0.03	1.69	0.83	3.289	2
1789	25 Ori	B1.5 IVe	0.05	1.55	1.68	1.510	3
1790	γ Ori	B2 III	0.02	7.43	0.67	23.48	2

Table 1. (cont.)

HR	Name	Spectral Type	E(B-V) mag	θ*	σ/θ %	f_{obs} †	Notes
1791	β Tau	B6 IV	0.01	10.65	0.93	10.60	2
1852	δ Ori	O9.5 I	0.05	4.26	0.73	21.71	2,6
1855	υ Ori	O9 V	0.05	1.32	0.68	3.134	2
1879	λ Ori	O8 III ((f))	0.12	2.35	1.40	9.346	2,7
1903	ε Ori	B0 Ia	0.09	7.08	0.65	37.11	2
1910	ζ Tau	B2 IIIe	0.05	4.30	2.86	6.106	2,3,4
1931	σ Ori	O9.5 V	0.06	2.22	1.85	6.058	2,8
1948	ζ Ori	O9.5 I	0.06	5.27	1.96	24.07	2,9
1956	α Col	B8 Ve	0.00	7.82	1.15	3.942	2
2010	134 Tau	B9 IV	0.00	3.10	0.65	0.3773	2
2128	3 Mon	B5 III	0.04	2.15	2.00	0.8516	2
2135	χ^2 Ori	B2 Ia	0.45	4.25	0.78	3.905	2
2159	ν Ori	B3 IV	0.03	2.59	1.16	1.474	
2198	69 Ori	B5 Ve	0.04	2.26	1.02	0.7768	
2199	ξ Ori	B3 IV	0.03	2.49	0.76	1.371	2
2244	43445	B9 V	0.00	2.97	0.74	0.3470	2
2282	ζ CMa	B2.5 IV	0.06	4.13	1.50	6.966	2
2294	β CMa	B1 II -III	0.04	5.55	0.56	22.82	1,2
2343	ν Gem	B6 IIIe	0.00	3.38	1.15	1.056	2,3
2344	10 Mon	B2 V	0.06	1.64	0.67	1.152	2
2451	ν Pup	B8 III	0.00	6.28	0.89	2.078	2
2456	S Mon	O8 III ((f))	0.07	1.25	1.60	2.994	10
2467	48099	O6.5 V	0.27	0.76	1.18	1.107	2
2538	κ CMa	B1.5 IVe	0.02	2.68	3.13	3.473	2,3,4
2571	15 CMa	B1 III	0.05	1.56	0.90	1.782	1
2596	ι CMa	B4 Ib	0.10	3.38	1.66	1.442	
2618	ε CMa	B2 II	0.03	7.75	0.71	27.29	2
2648	19 Mon	B1 V(e)	0.08	1.52	1.12	1.612	2
2653	o^2 CMa	B3 Ia	0.05	5.87	0.46	4.210	11

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Table 1. (cont.)

HR	Name	Spectral Type	E(B-V) mag	θ*	σ/θ %	f_{obs}†	Notes
2657	γ CMa	B6 III	0.03	3.63	0.85	1.197	
2749	ω CMa	B2 IV -Ve	0.06	3.00	1.97	2.617	2,4
2781	UW CMa	O8.5 If	0.16	1.44	1.81	3.251	
2782	τ CMa	O9 I	0.13	1.71	1.23	4.590	2,12
2812	57821	B7 IV	0.08	2.79	1.08	0.6032	2
2827	η CMa	B5 Ia	0.04	8.62	1.10	5.938	2
2845	β CMi	B8 IVe	0.01	7.33	0.97	2.772	2,3
3117	χ Car	B3 IV	0.02	3.69	1.44	3.425	2
3165	ζ Pup	O4 ef	0.05	3.85	0.22	27.33	11
3192	16 Pup	B5 IV	0.01	2.82	1.06	1.140	
3454	η Hya	B3 V	0.00	2.46	0.93	1.531	2
3468	α Pyx	B1.5 III	0.07	2.86	0.91	4.509	2
3571	76728	B8 III	0.00	4.54	0.62	1.209	2
3659	a Car	B2 IV-V	0.05	3.40	0.74	4.452	2
3849	κ Hya	B5 V	0.01	2.07	1.01	0.5959	
3982	α Leo	B7 V	0.02	13.65	0.87	12.41	2
4140	PP Car	B4 Ve	0.08	5.03	2.94	4.859	2,3,4
4467	λ Cen	B9 III	0.04	7.22	1.36	1.842	
4656	δ Cru	B2 IV	0.00	4.21	2.68	8.442	
4773	γ Mus	B5 V	0.01	3.59	1.31	1.879	
4787	κ Dra	B5 IVe	0.02	4.05	0.86	1.591	3
4798	α Mus	B2 IV-V	0.04	4.42	1.92	10.98	
5190	ν Cen	B2 IV	0.02	3.12	0.74	5.292	2
5191	η UMa	B4 V	0.00	8.26	0.77	12.75	
5571	β Lup	B2 III	0.02	4.18	0.91	9.813	2
5576	κ Cen	B2 IV	0.04	3.64	0.74	6.272	2
5695	δ Lup	B1.5 IV	0.03	3.07	1.34	6.564	2
5778	θ CrB	B6 Ve	0.01	3.38	0.68	1.193	2
5812	τ Lib	B2.5 V	0.06	3.27	1.13	3.838	
5902	λ Lib	B2.5 V	0.21	2.08	1.39	1.775	2
5928	ρ Sco	B2 IV-V	0.04	2.70	0.78	3.355	

Table 1. (cont.)

HR	Name	Spectral Type	E(B-V) mag	θ^{*}	σ/θ %	f_{obs} †	Notes
5941	48 Lib	B3 Ve	0.10	2.11	1.90	1.056	3,4,11
5948	η Lup	B2.5 IV	0.00	3.17	0.38	4.421	2
5953	δ Sco	B0.5 IV	0.16	4.84	1.18	25.31	2,13
5982	υ Her	B9 III (Hg-Mn)	0.00	3.23	0.59	0.4840	
5993	ω^1 Sco	B1 V	0.21	2.61	1.26	6.582	2
6023	φ Her	B9 III (Mn)	0.01	4.16	0.62	0.7226	
6084	σ Sco	B1 III	0.39	5.68	2.45	36.99	1,2,14
6092	τ Her	B5 IV	0.01	3.58	0.34	1.661	2
6161	15 Dra	B9 IV	0.01	3.03	0.89	0.3349	
6175	ζ Oph	O9 V(e)	0.33	4.94	0.55	40.47	2,3
6245	151804	O8 If	0.38	1.57	1.53	4.068	2
6252	μ^2 Sco	B2 IV	0.03	3.02	0.60	4.635	
6396	ζ Dra	B6 III	0.03	5.86	0.48	2.709	
6453	θ Oph	B2 IV	0.03	3.50	1.57	5.746	1,2
6462	γ Ara	B1 Ib	0.06	4.10	0.80	5.581	
6500	δ Ara	B8 V	0.01	4.99	0.70	1.491	2
6508	υ Sco	B2 IV	0.01	4.38	0.73	8.920	
6510	α Ara	B2 Ve	0.07	4.93	2.58	7.848	2,3,4
6527	λ Sco	B1.5 IV	0.03	6.38	0.88	29.01	1,2
6567	μ Oph	B8 III (Mn)	0.21	4.35	1.10	1.011	2
6580	κ Sco	B1.5 III	0.04	4.48	0.42	14.66	1,11
6588	ι Her	B3 IV	0.02	3.32	0.90	2.468	
6712	66 Oph	B2 Ve	0.22	2.60	1.50	3.478	2,3,4
6743	θ Ara	B2 Ib	0.08	4.05	1.14	3.531	2
6787	102 Her	B2.5 III	0.07	2.46	1.06	2.237	2
6812	μ Sgr	B8 Iap	0.25	7.17	1.46	2.380	2,3,14
6897	α Tel	B3 IV	0.03	3.62	0.64	3.522	
7121	σ Sgr	B3 IV	0.00	6.80	0.99	12.31	
7236	λ Aql	B9 V	0.00	5.63	0.39	1.586	

Table 1. (cont.)

HR	Name	Spectral Type	E(B-V) mag	θ*	σ/θ %	f_{obs}†	Notes
7298	η Lyr	B2.5 IV	0.08	2.70	0.44	1.716	
7306	1 Vul	B4 IV	0.14	2.61	0.84	1.288	
7372	2 Cyg	B3 IV	0.11	2.06	1.07	1.302	2
7426	8 Cyg	B3 IV	0.07	2.15	0.42	1.176	2
7437	9 Vul	B8 III	0.03	2.59	1.31	0.4988	
7446	κ Aql	B0 IVn	0.30	1.76	1.08	3.866	
7447	ι Aql	B5 III	0.07	3.22	0.78	1.166	2
7565	12 Vul	B2.5 Ve	0.10	1.86	2.26	1.275	4
7574	9 Sge	08 If	0.32	0.91	1.32	1.465	
7589	188209	09.5 Ib	0.20	1.09	0.92	1.413	
7613	22 Cyg	B5 IV	0.12	2.50	0.52	0.9218	
7708	28 Cyg	B2.5 Ve	0.06	1.93	1.87	1.047	4
7750	κ Cep	B9 III	0.03	3.98	0.25	0.6029	2
7767	193322	08.5 III	0.41	1.13	0.80	2.078	2,15
7790	α Pav	B2.5 V	0.02	7.11	0.15	14.83	11
7844	ω^1 Cyg	B2.5 IV	0.13	2.24	0.94	1.124	
7852	ε Del	B6 III	0.02	3.76	0.74	1.330	
7906	α Del	B9 IV	0.01	5.31	1.09	1.105	
7977	55 Cyg	B3 Ia	0.55	5.31	0.51	3.259	2
8047	59 Cyg	B1 IVe	0.07	2.21	5.57	1.849	4
8146	υ Cyg	B2 Ve	0.14	2.66	2.11	2.932	3,4
8238	β Cep	B1 III	0.04	3.09	1.29	7.586	1,2
8279	9 Cep	B2 Ib	0.46	4.35	1.20	2.887	
8301	π^1 Cyg	B3 IV	0.08	2.34	0.60	1.214	
8353	γ Gru	B8 III	0.00	6.66	0.63	2.519	2
8402	ο Aqr	B7 IVe	0.08	3.01	0.56	0.8312	2,3,4
8418	ι Aqr	B9 IV	0.00	3.96	1.14	0.7662	
8425	α Gru	B7 IV	0.00	10.74	0.83	9.842	2
8469	λ Cep	06 ef	0.56	2.01	0.90	8.058	2
8539	π Aqr	B1 Ve	0.22	2.33	3.91	4.698	3,4
8541	4 Lac	B9 Ib	0.11	4.59	1.53	0.6198	
8579	6 Lac	B2 III	0.15	2.51	1.35	2.258	

Table 1.(cont.)

HR	Name	Spectral Type	E(B-V) mag	θ*	σ/θ %	f_{obs}†	Notes
8597	η Aqr	B9 V	0.00	4.37	1.12	0.8889	
8622	10 Lac	O8 III	0.11	1.23	1.30	2.866	
8762	o And	B6 IIIe	0.09	4.80	1.25	2.647	3
8797	1 Cas	B0.5 III	0.25	1.90	0.63	3.323	2
8858	ψ^2 Aqr	B5 V	0.02	2.86	1.15	1.076	
8965	ι And	B8 IV	0.03	3.83	1.12	0.8476	

*Units are 10^{-4} arc sec.
†Units are 10^{-6} ergs $cm^{-2} s^{-1}$.

Notes to Table 1.

1. Beta Cephei star.
2. θ_λ from [110] rejected.
3. Shell star according to Bidelman (1976).
4. The E(B-V) and θ for this star are what result from the available photometry. In view of the known spectroscopic peculiarities and/or light variations of this star and the various, unknown, dates of the observations, the meaning of E(B-V) and θ is dubious, see text.
5. θ_λ from [63] is significantly low, but it is included in the mean.
6. The star HR 1851 = δ Ori C, B3 V (Berger 1962), is 53 arc sec from δ Ori A and it contributes light to the S2/68 photometry. According to Wallenquist (1954), Δm is 4.54 mag; this leads to V = 6.78 for δ Ori C. We adopt E(B-V) = 0.05 mag, as for δ Ori A. The equivalent S2/68 photometry for δ Ori C is found by scaling from the data for HR 5191 = η UMa. The 13-colour photometry is not corrected for the presence of δ Ori C. We ignore the indications that δ Ori A shows lines from two stars.
7. The star HR 1880 = λ Ori B, B0.5 V (Divan 1977), is at 4.5 arc sec from λ Ori A; it contributes light to the S2/68 and the 13-colour photometry. From the BSC III photometry (Hoffleit 1964), we adopt V = 5.56 for λ Ori B. We assume E(B-V) = 0.12 for both stars and approximate the photometry for λ Ori B by scaling from the results for HR 1756 = λ Lep.
8. The stars σ Ori D, B2 V, and HR 1932 = σ Ori E, B2 Vp, contribute light to the S2/68 photometry of HR 1931 = σ Ori AB; the 13-colour photometry is not affected by the presence of

Notes to Table 1 (cont.).

these stars. We have adopted the UBV photometry and spectral types of Greenstein and Wallerstein (1958) for σ Ori D and E which lead to V = 5.82 for D and E combined and to E(B-V) = 0.04. We find the equivalent S2/68 photometry for these stars combined by scaling from the data for HR 2344 = 10 Mon, B2 V. According to Bolton (1974, 1978), σ Ori AB is composed of three stars, all of which may be visible at some phases on blue-violet spectrograms. Bolton considers B to be somewhat fainter than A_1 or A_2, all three stars being within about 0.5 mag of each other at 4000 Å. Our angular diameter for σ Ori AB, calculated using no correction for multiplicity of AB, is an upper limit for the size of the O9.5 V star. The effective temperature may not be seriously affected, see eqt. (1). The estimate of distance (Table 2) is sensitive to the assumed value of V for the O9.5 V star. The distance given in Table 2 is for the case that A_2 and B contribute negligibly to the measured V magnitude. We assume that the measured photometric criteria give correctly M_V for the O star alone. If A_2 and B are 0.5 mag fainter than A_1, then the distance is 406 pc.

9. The star HR 1949 = ζ Ori B, B0 III (Murphy 1969), is 2.6 arc sec from ζ Ori A and it contributes light to the 13-colour and to the S2/68 photometry for ζ Ori. From Wallenquist (1954) we adopt Δm = 2.14 which gives V = 1.91 for ζ Ori A and 4.05 for ζ Ori B. We adopt E(B-V) = 0.06 for both stars and we find the equivalent 13-colour and S2/68 photometry for ζ Ori B by scaling from the data for HR 7446 = κ Aql. According to

Notes to Table 1 (cont.)

Hanbury Brown et al. (1974), ζ Ori A is double with Δm about 2 mag. To correct for component A_2 as well as for B we subtract twice the correction for ζ Ori B. The V magnitude of A_1 is then 2.07.

10. The star ADS 5322B contributes light to the 13-colour and the S2/68 photometry for S Mon. According to Burnichon (1975) ADS 5322B has V = 7.69 and spectral type B1.5-2 V. We adopt E(B-V) = 0.07 for both stars and we scale from the photometry for HR 5695 = δ Lup to correct for the light from ADS 5322B. Several stars from the cluster NGC 2264 fall within the field of S2/68 but only Walker 212, V = 7.47, B2.5 V at 7.8 arc min distance may contribute to the light measured by the S2/68 photometers. We have applied a small correction provided by Macau-Hercot (1977) to remove the light of this star. We adopt V = 4.72 for S Mon A.

11. θ_λ from [98] and [110] have both been rejected.

12. The star HD 57192, B3 III-IV, V = 6.81, E(B-V) = 0.02 is 6.8 arc min from τ CMa. We applied a small correction provided by Macau-Hercot (1977) to remove the light of this star from the S2/68 photometry. The B, C and D components of ADS 5977 are too faint to contribute a significant amount to the measured light of τ CMA at any wavelength.

13. The star HR 5953 = δ Sco is double, see Hanbury Brown et al. (1974) and Labeyrie et al. (1974); Δm is 1.9 or about 2 mag, respectively. We adopt Δm = 1.9, E(B-V) = 0.16 and assume that the secondary star is on the main sequence. Consequently its

Notes to Table 1 (cont.)

spectral type should be about B3 V. We correct for the contribution of δ Sco B to the 13-colour and the S2/68 photometry by scaling from the photometry for HR 5191 = η UMa.

14. The residuals $\theta_\lambda - \theta$ have a systematic trend with λ, being negative for short λ and positive for large λ.

15. The star ADS 13672B is 2.7 arc sec from HR 7767 = HD 193322; its spectral type is B1.5 V and V = 8.0 (Burnichon 1975). We estimate the contribution of ADS 13672B to the 13-colour and the S2/68 photometry by scaling from the photometry for HR 5695 = δ Lup. We adopt V = 5.97 for HD 193322.

Table 2. The flux effective temperatures, distances and radii of the program stars.

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	$\frac{f_{est}}{f_{obs}}$	d pc	No.	$R/R_{\odot}$	Notes
39	4.0	21987	+ 13	0.859	134	4	6.2	
153	4.0	22205	- 205	0.799	179	5	5.8	
472	4.0	17565	+ 435	0.539	29	1	5.0	3
496	4.0	31681	- 181	1.307	328	1	9.3	1,2,3
542	4.0	15353	+ 47	0.321	114	4	5.7	
779	4.0	23571	- 71	0.881	250	4	6.4	
811	4.0	13256	+ 244	0.235	99	3	3.5	
985	4.0	20260	+ 240	0.735	185	1	4.0	3
1034	4.0	15858	- 258	0.300	143	5	3.5	
1044	4.0	16534	- 34	0.375	136	5	3.8	
1087	4.0	16053	+ 447	0.443	164	3	6.2	
1122	3.5	14041	- 41	0.229	100	4	6.4	
1156	4.0	13360	+ 340	0.253	120	3	5.1	1
1165	3.5	12753	+ 147	0.194	106	3	8.2	1
1203	3.5	19867	+ 133	0.581	363	5	27.4	
1204	4.0	10668	- 68	0.108	96	3	3.1	
1273	4.0	16297	+ 303	0.427	134	2	5.6	
1350	4.0	16797	+ 203	0.431	161	4	4.5	
1463	3.5	23503	+ 497	0.978	298	3	7.8	
1520	4.0	14951	+ 49	0.292	155	4	5.9	
1542	3.5	24999	+ 1	0.806	1175	2	36.9	
1552	3.5	21874	+ 126	0.834	269	4	9.1	

Table 2. (cont.)

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	$\frac{f_{est}}{f_{obs}}$	d pc	No.	$R/R_\odot$	Notes
1567	3.5	21302	+ 198	0.814	303	4	9.9	
1617	4.0	19033	+ 267	0.618	225	3	4.7	
1621	4.0	10203	- 203	0.086	78	2	2.7	
1638	4.0	10198	+ 402	0.132	93	2	3.6	
1679	4.0	22895	+ 105	0.929	282	1	6.8	
1696	4.0	11864	- 364	0.118	72	3	2.8	
1713	2.0	11778	+ 222	0.141	228	3	65.3	
1735	3.5	14264	+ 236	0.286	111	3	5.4	
1756	4.0	29609	+ 391	1.232	404	3	7.3	
1789	4.0	24661	+ 339	0.960	382	3	6.4	
1790	3.5	21944	+ 56	0.814	99	4	7.9	
1791	4.0	13824	+ 475	0.302	37	4	4.2	
1852	3.5	31082	+ 418	1.602	345	6	15.8	2
1855	4.5	34347	+ 153	1.593	511	5	7.2	
1879	4.0	35046	+ 454	1.982	398	1	10.0	1,2
1903	3.5	25091	- 91	0.785	470	3	35.8	
1910	3.5	21237	+ 763	1.048	211	2	9.8	1,2,3
1931	4.5	31556	+ 444	1.678	292	5	7.0	2
1948	3.5	27583	+ 417	1.223	350	3	19.8	2
1956	4.0	12207	- 107	0.147	35	1	3.0	
2010	4.0	10693	- 93	0.107	81	3	2.7	
2128	3.5	16558	- 58	0.364	195	3	4.5	
2135	3.5	17463	+ 37	0.432	1300	3	59.4	
2159	4.0	17407	- 207	0.392	196	4	5.5	

Table 2. (cont.)

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	$\frac{f_{est}}{f_{obs}}$	d pc	No.	$R/R_{\odot}$	Notes
2198	4.0	15627	- 127	0.308	166	1	4.0	
2199	4.0	17781	+ 219	0.509	189	3	5.1	
2244	4.0	10689	- 89	0.107	126	3	4.0	
2282	4.0	21968	+ 132	0.901	88	3	3.9	
2294	3.5	25825	+ 175	1.000	149	4	8.9	1,2
2343	3.5	13757	+ 443	0.289	120	2	4.4	
2344	4.0	22064	- 64	0.859	261	3	4.6	
2451	3.5	11609	+ 91	0.148	70	3	4.7	
2456	4.0	35427	+ 73	1.751	695	2	9.3	2
2467	4.5	37207	+ 293	2.328	1159	3	9.5	2
2538	4.0	25294	+1406	1.813	287	1	8.3	3
2571	3.5	25493	+ 107	0.927	578	3	9.7	
2596	3.0	14861	+ 139	0.285	685	4	24.9	
2618	3.5	22668	+ 332	0.956	153	5	12.7	
2648	4.0	25725	+ 275	1.104	492	1	8.0	
2653	3.0	14764	+ 236	0.295	843	4	53.2	
2657	3.5	13596	+ 304	0.256	144	4	5.6	
2749	4.0	21019	+ 980	1.238	194	1	6.2	3
2781	3.5	33511	- 11	1.667	1535	2	23.8	
2782	3.5	33145	- 145	1.557	1076	4	19.8	
2812	4.0	13011	+ 289	0.228	157	3	4.7	
2827	3.0	12981	+ 19	0.183	608	3	56.3	
2845	4.0	11511	- 11	0.135	49	2	3.9	
3117	4.0	18823	+ 477	0.664	139	3	5.5	

Table 2. (cont.)

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	$\frac{f_{est}}{f_{obs}}$	d pc	No.	$R/R_{\odot}$	Notes
3165	3.5	35010	- 10	1.713	411	2	17.0	1
3192	4.0	15460	+ 40	0.326	151	3	4.6	
3454	4.0	18792	+ 408	0.643	181	4	4.8	2
3468	3.5	23723	+ 277	0.910	273	3	8.4	
3571	3.5	11880	- 180	0.133	103	3	5.0	
3659	4.0	21744	+ 256	0.934	138	4	5.0	
3849	4.0	15398	+ 202	0.350	153	5	3.4	
3982	4.0	12389	+ 111	0.179	26	5	3.9	
4140	4.0	17048	+ 252	0.464	97	1	5.3	2,3
4467	3.5	10471	+ 329	0.135	71	2	5.5	
4656	4.0	22906	+ 94	0.926	178	4	8.0	
4773	4.0	15506	- 6	0.321	119	2	4.6	
4787	4.0	13811	+ 189	0.250	129	2	5.6	
4798	4.0	23883	+ 117	0.930	102	4	4.8	
5190	4.0	23785	+ 215	0.960	191	4	6.4	
5191	4.0	16823	+ 177	0.428	39	4	3.4	
5571	3.5	23782	+ 218	0.961	147	4	6.6	
5576	4.0	22893	+ 107	0.930	136	4	5.3	
5695	4.0	26216	+ 484	1.265	186	4	6.1	
5778	4.0	14023	- 23	0.232	116	2	4.2	
5812	4.0	20911	+ 89	0.776	92	4	3.2	2
5902	4.0	21990	+ 110	0.894	144	4	3.2	
5928	4.0	22798	+ 202	0.961	174	4	5.0	
5941	4.0	18665	+ 635	0.703	291	2	6.6	3

Table 2. (cont.)

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	$\frac{f_{est}}{f_{obs}}$	d pc	No.	$R/R_{\odot}$	Notes
5948	4.0	22189	− 89	0.836	198	4	6.7	2
5953	4.0	28929	+ 71	1.157	173	4	9.0	
5982	3.5	11124	− 324	0.103	114	3	4.0	
5993	4.0	28064	+ 336	1.265	195	4	5.6	
6023	3.5	10864	− 64	0.114	49	3	2.2	
6084	3.5	29035	− 35	1.065	131	4	8.0	
6092	4.0	15012	+ 88	0.304	102	4	3.9	
6161	4.0	10509	+ 91	0.115	105	3	3.4	
6175	4.5	34100	+ 400	1.719	188	5	10.0	
6245	3.5	34326	+ 174	1.815	1995	1	33.7	2
6252	4.0	23113	− 113	0.865	214	4	7.0	
6396	3.5	12957	+ 43	0.189	98	2	6.2	
6453	4.0	22857	+ 143	0.942	168	4	6.3	
6462	3.5	19706	− 206	0.512	583	4	25.7	
6500	4.0	12007	+ 93	0.158	55	3	3.0	
6508	4.0	22831	+ 169	0.950	129	3	6.1	
6510	4.0	21885	+1115	1.364	126	2	6.7	3
6527	4.0	26292	+ 408	1.232	94	3	6.5	
6567	3.5	11645	+ 55	0.146	105	3	4.9	
6580	3.5	25780	+ 220	1.021	145	3	7.0	
6588	4.0	17814	+ 186	0.495	145	4	5.2	
6712	4.0	23149	− 149	0.855	194	1	5.4	3
6743	3.5	17231	− 231	0.365	461	3	20.1	1,2
6787	3.5	20320	− 220	0.537	339	4	9.0	

Table 2. (cont.)

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	f_{est}/f_{obs}	d pc	No.	$R/R_{\odot}$	Notes
6812	2.5	11142	- 142	0.109	1081	2	83.3	
6897	4.0	19025	+ 275	0.619	109	3	4.2	
7121	4.0	18987	+ 313	0.627	62	3	4.5	
7236	4.0	11414	- 14	0.132	42	4	2.6	
7298	4.0	17954	+ 46	0.722	252	4	7.3	
7306	4.0	16996	+ 304	0.473	167	3	4.7	
7372	4.0	19416	- 116	0.545	205	3	4.5	
7426	4.0	18855	+ 445	0.657	234	3	5.4	
7437	3.5	12738	- 38	0.176	160	3	4.4	
7446	4.0	30784	+ 216	1.387	661	4	12.5	
7447	3.5	14552	+ 448	0.332	123	4	4.3	
7565	4.0	21696	+ 404	0.993	255	2	5.1	3
7574	3.5	34527	- 27	1.701	2716	1	26.6	
7589	3.5	31078	+ 422	1.604	1652	3	19.4	
7613	4.0	15542	- 42	0.317	209	3	5.6	2
7708	4.0	19478	+ 522	0.698	244	1	5.1	3
7750	3.5	10653	+ 147	0.125	93	3	4.0	
7767	4.0	34075	+ 425	1.783	828	4	10.1	
7790	4.0	19592	+ 408	0.671	59	3	4.5	
7844	4.0	18143	+ 457	0.610	345	3	8.3	2
7852	3.5	13614	- 15	0.217	115	5	4.6	
7906	4.0	10681	- 81	0.107	62	5	3.6	
7977	3.0	14266	- 366	0.196	1072	3	61.2	
8047	4.0	23302	+1698	1.594	292	1	6.9	3

Table 2. (cont.)

HR	Model log g	$T_{eff}(F)$ K	ΔT_{eff} K	$\frac{f_{est}}{f_{obs}}$	d pc	No.	$R/R_{\odot}$	Notes
8146	4.0	21960	+ 40	0.867	200	1	5.7	3
8238	3.5	25775	- 175	0.853	231	5	7.7	
8279	3.5	15729	+ 71	0.338	708	6	33.1	
8301	4.0	17893	+ 307	0.539	252	4	6.3	2
8353	3.5	11800	- 100	0.137	63	3	4.5	
8402	4.0	13464	- 164	0.193	134	2	4.3	2,3
8418	4.0	11284	- 284	0.104	64	3	2.7	
8425	4.0	13263	+ 37	0.208	32	3	3.6	
8469	4.5	37721	+ 279	2.396	766	1	16.5	
8539	4.0	27094	- 94	1.069	249	2	6.2	3
8541	3.5	9932	+ 68	0.101	608	4	30.0	
8579	3.5	20836	+ 164	0.748	291	5	7.8	2
8597	4.0	11218	+ 82	0.134	61	4	2.9	
8622	4.0	35401	+ 99	1.766	631	4	8.3	
8762	3.5	14362	- 162	0.232	128	2	6.6	1
8797	3.5	27474	+ 26	1.069	497	4	10.2	
8858	4.0	15212	+ 288	0.355	148	3	4.6	
8965	4.0	11865	- 65	0.140	112	4	4.6	

Notes to Table 2.

*The listed T_{eff}(flux) are what are produced by the computer. Realistically, the T_{eff}(flux) values should be rounded to the nearest 100 K.

1. The distance differs by more than 30 % from that of SBD.
2. The distance differs by more than 30 % from that of Lesh.
3. The T_{eff}(flux) and $R/R_{\odot}$ for this star are what result from the available photometry. In view of the known spectroscopic peculiarities and/or light variations of this star and the various, unknown, dates of the observations, the meaning of T_{eff}(flux) and $R/R_{\odot}$ is dubious, see text.

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Table 3. Relative values of the observed and estimated parts of the integrated flux of some models

log g	T_{eff}(K)	Model	f_{obs}/f_{total}	f_{est}/f_{obs}
4.0	15000	Mihalas LTE	0.6682	0.4965
		Mihalas NLTE/L	0.6674	0.4983
		Kurucz LTE	0.7770	0.2870
4.0	30000	Mihalas LTE	0.4607	1.1707
		Mihalas NLTE/L	0.4568	1.1893
		Kurucz LTE	0.4762	1.0998
4.5	45000	Mihalas LTE	0.2338	3.2770
		Mihalas NLTE/L	0.2240	3.4643
		Kurucz LTE	0.2281	3.3831

Table 4. Relative monochromatic fluxes from Mihalas NLTE/L and Kurucz models: F_λ (NLTE/L)/F_λ (Kurucz)

Filter	30000 K	45000 K	Filter	30000 K	45000 K
Wavelength	4.0	4.5	Wavelength	4.0	4.5
6356 Å	0.91	0.96	8584 Å	0.99	1.00
7241	0.98	1.03	9831	1.02	1.06
8000	0.94	0.98	11084	1.00	1.04

Table 5. Adopted group distance moduli

Cluster or Association	Modulus mag	Used for Stars
Per OB3	6.1	HD 21278, 34 Per, ψ Per
Pleiades	5.55	23 Tau, η Tau
Per OB2	7.7	ζ Per
λ Ori Association	8.0	λ Ori A
NGC 2264	9.5	S Mon A
NGC 2362	10.65	UW CMa, τ CMa
NGC 6231	11.5	HD 151804
Cep OB2	9.3	9 Cep

Table 6. Angular diameters and effective temperatures for supergiants in common with Hanbury Brown *et al.* (1974)

Star*	E(B-V)	Model Parameters		$\Theta^{\dagger}$	σ/Θ	T_{eff}(flux)	ΔT_{eff}
	mag	log g	T_{eff}		%	K	K
HR 1713	0.00	2.0	12000	25.86	2.13	11451	+ 549
β Ori	0.00	2.0	14700	22.22	3.78	12973	+1727
B8 Ia	0.04#	2.0	12000	26.67	1.32	11778	+ 222
25.5 ± 0.5	0.04	2.0	14700	22.91	2.94	13280	+1420
HR 1903	0.06	3.5	25000	6.91	1.09	24607	+ 393
ε Ori	0.06	3.5	30000	5.85	1.78	28749	+1251
B0 Ia	0.09#	3.5	25000	7.08	0.65	25091	− 91
6.9 ± 0.4	0.09	3.5	30000	5.99	1.27	29177	+ 823
HR 1948	0.04	3.5	28000	5.20	2.27	27195	+ 805
ζ Ori A_1	0.04	3.5	30000	4.90	2.50	28635	+1365
09.5 I	0.06#	3.5	28000	5.27	1.96	27583	+ 417
4.8 ± 0.4	0.06	3.5	30000	4.96	2.18	29010	+ 990
HR 2827	0.00	3.0	13000	8.33	1.58	12606	+ 394
η CMa	0.00	3.0	15000	7.51	2.29	13824	+1176
B5 Ia	0.02	3.0	13000	8.47	1.31	12788	+ 212
7.5 ± 0.6	0.02	3.0	15000	7.64	1.89	13994	+1006
	0.04#	3.0	13000	8.62	1.10	12981	+ 19
	0.04	3.0	15000	7.76	1.61	14177	+ 823

*The fourth line gives $_{LD}$ from HB+ in units of 10^{-4} arc sec.

†The units are 10^{-4} arc sec.

#This solution is given in Tables 1 and 2.

Table 7. Properties of some NLTE/L spherical model atmospheres by KHM (1975)

Model No.	$L/L_\odot$	$R_{2/3}/R_\odot$	$M/M_\odot$	$\log g_{2/3}$
1	3.38 +5	22.55	30	3.21
3	2.90 +5	11.50	30	3.79
14	1.25 +6	24.44	60	3.44
16	6.17 +5	10.94	60	4.14

T_{eff}(flux) K	f_{est}/f_{obs}	Mihalas NLTE/L Model		Flux Ratio 5695 Å
26240	1.188	27500	3.0	0.70
33510	3.147	32500	3.3	0.62
34930	1.646	35000	3.3	0.59
38720	5.886	40000	4.0	0.46

Table 8. Average effective temperature as a function of spectral type

Sp. Type	IV, V T_{eff} K	s.d. K	No.	II, III T_{eff} K	s.d. K	No.	Ib or I T_{eff} K	s.d. K	No.	Ia T_{eff} K	s.d. K	No.
O4				35010	-	1						
O6				37720	-	1						
O6.5	37210	-	1									
O8				35290	120	3	34420	70	2			
O8.5				34075	-	1	33510	-	1			
O9	34220	130	2				33140	-	1			
O9.5	31560	-	1				29910	950	3	25000	-	1
B0	30780	-	1							25090	-	1
B0.5	29270	240	2	27470	-	1						
B1	26900	830	2	26320	730	4	19790	60	2			
B1.5	25720	440	3	24750	730	2						

Table 8. (cont.)

Sp. Type	IV, V			II, III			Ib or I			Ia		
	T_{eff} K	s.d. K	No.	T_{eff} K	s.d. K	No.	T_{eff} K	s.d. K	No.	T_{eff} K	s.d. K	No.
B2	22820	170	14	22270	380	7	16480	530	2	17460	-	1
B2.5	20380	560	8	20320	-	1						
B3	18530	190	11							14520	180	2
B4	16340	190	8				14860	-	1			
B5	15170	180	9	14850	500	4				12980	-	1
B6	13740	160	3	13660	200	5						
B7	12980	180	4	12750	-	1						
B8	11900	130	4	11930	180	5				11460	220	2
B9	10920	480	10	10780	120	4	9930	-	1			
B9.5	10200	-	1									
A0	9470	-	1									

Table 9. Average radii as a function of spectral type

Sp.	IV, V			II, III			Ib or I			Ia		
Type	R/R	s.d.	No.	R/R	s.d.	No.	R/R	s.d.	No.	R/R	s.d.	No.
O4				17.0	-	1						
O6				16.5	-	1						
O6.5	9.5	-	1									
O8				9.2	0.4	3	30.2	2.5	2			
O8.5				10.1	-	1	23.8	-	1			
O9	8.6	1.0	2				19.8	-	1			
O9.5	7.4	-	1				18.3	1.0	3	36.9	-	1
B0	12.5	-	1							35.8	-	1
B0.5	8.2	0.6	2	10.2	-	1						
B1	6.8	0.8	2	8.6	0.4	4	26.6	0.6	2			
B1.5	6.3	0.1	3	7.7	0.5	2						

Table 9. (cont.)

Sp.	IV, V			II, III			Ib or I			Ia		
Type	R/R	s.d.	No.	R/R	s.d.	No.	R/R	s.d.	No.	R/R	s.d.	No.
B2	6.0	0.2	14	8.8	0.7	7	26.6	4.6	2	59.4	-	1
B2.5	5.2	0.7	8	9.0	-	1						
B3	5.1	0.1	11							57.2	2.8	2
B4	4.7	0.4	8				24.9	-	1			
B5	4.7	0.3	9	5.2	0.4	4				56.3	-	1
B6	4.5	0.2	3	5.5	0.4	5						
B7	3.9	0.2	4	8.2	-	1						
B8	3.6	0.3	4	4.7	0.1	5				74.3	6.4	2
B9	3.1	0.1	10	3.9	0.6	4	30.0	-	1			
B9.5	2.7	-	1									
A0	2.8	-	1									

Appendix: BCD spectrophotometry for 77 stars.

Seventy-seven of the stars considered in this paper have been observed in the BCD system. The three measured parameters D, λ_1 and ϕ_{rb} are given in Table A. The quantity λ_1-3700 in Å units is listed in column 3 and the number of spectra is given in column 4; st means that the star is a standard and that many observations exist.

Since the λ_1D plane has been calibrated in absolute magnitude and in intrinsic colour (Chalonge and Divan 1973), the following quantities can be found: (1) the visual absolute magnitude M_V; (2) the intrinsic colour ϕ_{orb}; (3) the interstellar extinction at a wavelength of 5490 Å, which is $A_V = 1.7e_{rb}$, where the colour excess $e_{rb} = \phi_{rb} - \phi_{orb}$; (4) the distance modulus of the star, $V-A_V-M_V$, and (5) the distance in parsecs which is given in column 8. The small negative values of A_V appearing in column 7 result from the uncertainties in ϕ_{rb} and ϕ_{orb}. They mean only that the corresponding star is very little reddened, if at all.

The λ_1D plane has been calibrated in terms of the spectral types and luminosity classes of the MK system (Chalonge and Divan 1973). The equivalent MK spectral type of each star according to its values of λ_1 and D is given in column 9.

In general, the BCD values of A_V agree well with the A_V deduced from MK types, UBV photometry and the $(B-V)_o$ of FitzGerald (1970). The reason is that Chalonge and Divan as well as FitzGerald derive the intrinsic colours from the bluest stars of each spectral type. However, for O stars and B supergiants, even the bluest stars are probably reddened and determining intrinsic colours for them is precarious.

O stars: In the UBV system it is inferred, on the basis of the increase in colour temperature deduced from the changes in $(B-V)_o$ from late to early-type B stars, that the colour temperature continues to increase through the O spectral types. In the BCD system, however, the adopted intrinsic colour, ϕ_{orb}, changes very little from about B1 to the early O types. Consequently, the values of A_V obtained for the O stars using the BCD system are systematically smaller than the A_V found by means of the UBV system. The use of the small BCD extinctions for the O stars would lead to lower flux effective temperatures than those given in Table 2 and thus to even larger discrepancies with the effective temperatures inferred from analyses of the line spectrum. The adopted trend of the intrinsic colours for O stars in the BCD system is supported by (1) the constancy of the bluest colour observed in each spectral type from B1 to O, and (2) the suprisingly blue colour of the early B-type companions of O stars in multiple systems (see, for instance, Burnichon 1975). In almost all cases the B-type companion is measureably bluer than the O star.

B supergiants: The $(B-V)_o$ intrinsic colours for supergiants have been deduced from stars belonging to open clusters or associations; they are redder than for the dwarfs of the same spectral type. This result can be only a statistical one because of the interstellar matter inside the cluster and the irregular absorption in front of the cluster. Chalonge and Divan, when determining the intrinsic colours for the supergiants in the BCD system considered that the problem of the true interstellar reddening of supergiants was not solved, and they arbitrarily attributed to the B supergiants the same intrinsic colour as for dwarf stars of the same spectral type, but with a large uncertainty, ± 0.10. As a consequence, the A_V of B-type supergiants in the BCD system are larger than in the UBV system and dereddening the supergiants with the BCD extinctions will lead to higher flux effective temperatures than are given in Table 2. We note that the depth of the 2200 Å interstellar band favours the lower extinctions found from the UBV photometry while the study of supergiants in multiple systems, see, for instance, Burnichon (1975), suggests that the UBV extinctions for the B-type supergiants may be somewhat underestimated.

<u>Be stars</u>: In the case of these stars, the measured parameters λ_1 and D are typical for normal B stars, but a second Balmer discontinuity is sometimes seen and in these cases the gradients may be abnormal. In the case of Be stars with two Balmer discontinuities, the first one (given in Table A) is situated as in ordinary main-sequence stars while the second one is situated at shorter wavelengths as in supergiants. This observation was first made for ζ Tau (Barbier and Chalonge 1939); the second discontinuity may be in absorption (for example, ζ Tau) or in emission (for example ϕ Per, ν Cyg). The second discontinuity and the gradients vary over long time intervals (for example, π Aqr, 1H Cam, 59 Cyg, X Per). The variations are accompanied by changes in the magnitude of the star (Divan 1978). Since for a Be star with two discontinuities, photometric or spectrophotometric magnitudes and colours cannot be used to determine the interstellar extinction or distance modulus, no value of A_V or of d is given for such stars in Table A. For ordinary Be

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stars (ones with only one Balmer discontinuity), the colours seem quite normal and these stars can be treated exactly as normal B stars. If the Be stars which sometimes show two Balmer discontinuities are observed in a state when only one Balmer jump is present, then they can be treated like normal stars. Among the stars considered in this paper such is the case for 1H Cam since 1965 and for 59 Cyg since 1977.

Table A. BCD spectrophotometry for 77 stars

HR	D	λ_1	Wt	M_V	ϕ_{rb}	A_V	d	λ_1 D	Notes
	dex			mag		mag	pc	Type	
39	0.146	54	st	−2.5	0.70	−0.02	118	B2 IV	
153	0.146	53	st	−2.5	0.75	0.07	165	B2 IV	
496	0.09	56	8	−3.5	1.10			B1 IV	1
542	0.259	44	44	−2.0	0.83	0.10	114	B5 III – IV	
779	0.136	49	14	−3.1	0.75	0.07	262	B2 III	
811	0.311	43	2	−1.8				B6 III – IV	
985	0.164	59	12	−1.7	0.84	0.20	186	B2.5 V	3,4
1034	0.249	56	8	−0.8	0.98	0.37	121	B4-5 V	
1044	0.235	54	8	−1.1	0.94	0.32	123	B4 V	
1087	0.217	45	12	−2.3	1.02	0.46	164	B4 III – IV	
1122	0.286	42	12	−2.1	0.86	0.14	99	B5-6 III	
1156	0.303	45	10	−1.6	1.06	0.46	116	B6 IV	
1165	0.344	32	14	−3.1	0.95	0.19	143	B8 III	
1203	0.068	35	st	−6.5	1.30	1.02	463	B1 Iab	
1273	0.229	47	8	−1.9	1.02	0.44	125	B4 IV	1:
1350	0.239	51	4	−1.4	0.97	0.37	151	B4 IV-V	
1520	0.251	47	6	−1.7	0.80	0.07	135	B5 IV	
1542	0.029	40	8	−7.0	1.19	0.87	1213	O9.5 Ia	
1552	0.138	43	14	−3.7	0.85	0.24	268	B2 III	
1567	0.143	42	12	−3.7	0.81	0.17	283	B2 III	

HR	D	λ_1	Wt	M_V	ϕ_{rb}	A_V	d	λ_1 D	Notes
	dex			mag		mag	pc	Type	
1713	0.162	12	15	−7.5	1.05	0.37	283	B8 Ia	
1789	0.114	53	8	−3.2	0.79	0.15	400	B1.5 IV	
1790	0.133	49	st	−3.1	0.70	−0.02	90	B2 III	
1791	0.287	44	16	−1.8	0.90	0.20	45	B5-6 IV	
1852	0.041	57	10	−4.6	0.75	0.12	221	O9 III	
1855	0.052	67	st	−3.6	0.65	−0.05	451	O9 V	
1903	0.030	38	st	−7.1	0.82	0.22	518	B0 Ia	
1910	0.132	43	8	−3.8	0.81	0.17	215	B2 III	2
1931	0.057	70	16	−3.5	0.71	0.05	282	O9 V	
1948	0.026	52	9	−5.6	0.76	0.14	298	O7 Ib	
2135	0.031	24	st	−8.1	1.61	1.53	1740	B2 Ia	
2159	0.217	54	13	−1.4	0.79	0.09	140	B3-4 V	
2294	0.089	45	10	−4.6	0.76	0.10	197	B1 II	
2343	0.301	50	2	−1.0	0.90	0.19	98	B6 IV	
2456	0.042	60	st	−4.3	0.73	0.10	608	O8 IV	
2467	0.028	67	st	−4.1	1.10	0.75	879	O6 V	
2596	0.156	26	10	−5.7	1.01	0.43	847	B4-5 Ib	
2618	0.101	45	10	−4.3	0.76	0.10	138	B1.5 II – III	
2653	0.105	22	10	−7.2	0.98	0.41	912	B3-4 Ia	
2657	0.289	43	8	−2.0	0.86	0.14	157	B5-6 III-IV	
2827	0.138	19	16	−7.0	1.05	0.46	625	B5 Ia	
2845	0.399	51	16	−0.6	0.87	0.02	49	B8 IV	
3165	0.016		6		0.77	0.19			

HR	D	λ_1	Wt	M_V	ϕ_{rb}	A_V	d	$\lambda_1 D$	Notes
	dex			mag		mag	pc	Type	
3454	0.181	55	12	−1.8	0.73	0.02	164	B2.5 V	
3849	0.250	59	10	−0.6	0.87	0.19	124	B5 V	
3982	0.348	51	14	−0.7	0.84	0.02	25	B7 IV	
4787	0.288	45	5	−1.7	0.84	0.10	125	B5-6 IV	
5191	0.222	61	st	−0.8	0.75	0.00	34	B3-4 V	
6092	0.265	51	9	−1.1	0.84	0.12	95	B5 IV-V	
6175	0.050	65	4	−3.8	1.25	0.97	120	O9 V	
6396	0.319	45	3	−1.5				B6 IV	
6588	0.204	51	14	−1.8	0.72	−0.03	134	B3 IV	
6787	0.156	43	8	−3.4	0.86	0.24	318	B2.5 III	
7236	0.405	60	1	+0.4				B9 V	
7446	0.064	57	6	−4.0	1.16	0.82	425	B0 III – IV	
7574	0.022	43	9	−6.9	1.23	0.95	2720	O8 Ia	
7589	0.038	45	st	−6.1	1.04	0.61	1670	O9.5 Ib	
7767	0.056	63	12	−3.9	1.32	1.09	573	O9.5 V	
7844	0.191	33	2	−4.1				B4 II	
7852	0.299	48	st	−1.2				B6 IV	
7906	0.447	54	4	−0.3	0.90	0.00	65	B9 IV	
7977	0.083	20	6	−7.7	1.85	1.89	1360	B3 Ia	
8047	0.116	63	4	−2.5	0.81	0.19	292	B1.5 V	1,3,5
8146	0.18	60	8	−1.6	0.97			B2.5 V	1
8238	0.095	54	st	−3.5	0.71	0.03	219	B1 III – IV	
8279	0.108	30	6	−6.1	1.62	1.53	725	B2.5 Ib	

HR	D	λ_1	Wt	M_V	ϕ_{rb}	A_V	d	λ_1 D	Notes
	dex			mag		mag	pc	Type	
8303	0.197	43	5	-2.7				B3 III	
8402	0.311	47	4	-1.4	0.95	0.26	147	B6 IV	
8469	0.019	52	10	-6.0	1.63	1.63	766	O6 Ib	
8539	0.095	65	2	-2.8				B1 V	1,3
8541	0.270	18	8	-5.5	1.24	0.63	776	B9 Ib	
8579	0.155	-	15	-3.2	0.99	0.46	282	B2 III	
8597	0.409	56	2	0.0				B9 V	
8622	0.048	69	st	-3.7	0.79	0.19	476	O8 V	
8762	0.281	38	4	-2.6	0.91	0.22	158	B6 III	
8797	0.074	46	18	-4.9	1.05	0.61	676	B0.5 II	
8965	0.380	43	12	-1.6	0.97	0.22	136	B8 IV	

Notes to Table A.

1. Second Balmer jump is in emission; a semicolon indicates that the second Balmer jump is small and that the colours are probably not much changed from those for normal stars.

2. Second Balmer jump is in absorption.

3. Variations have been observed in the second Balmer jump.

4. The photometric and spectrophotometric measurements refer to a period with no or very little emission; magnitudes and colours are probably not abnormal.

5. The photometric data refer to a state of strong emission; the magnitudes and colours are abnormal and cannot be used to determine interstellar absorption and distance modulus. The spectrophotometric measurements given in Table A refer to a period (1977) with no emission; the distance has been calculated using a V magnitude deduced from our spectra of 1977.