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A STUDY OF B6 STARS

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ABSTRACT

A study of the spectra of ζ Draconis, B6 III, β Sextantis, B6 V, and α Leonis, B7 V, has been made from high dispersion spectrograms which cover the spectral region 3100 Å to 6700 Å and from OAO-II spectral scans covering the spectral region 1100 Å to 3600 Å. Profiles, equivalent widths and central intensities of many lines in the spectrum of ζ Draconis are presented as well as profiles, equivalent widths and central intensities of the major lines of β Sextantis. The star α Leonis rotates too rapidly for these measurements to be made from high resolution spectrograms. The somewhat broadened profiles of ζ Draconis may be well represented by a macroturbulence of 41 km s^{-1} while those of β Sextantis appear to be broadened chiefly by a projected rotational velocity of about 58 km s^{-1}. The electron density in the atmosphere of ζ Draconis is less than that in the atmosphere of β Sextantis in accord with the assigned difference in luminosity class. The microturbulence velocity is 2.9 $\pm$ 1.5 km s^{-1} in the atmosphere of ζ Draconis.

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The visible spectrum of ζ Draconis corresponds to an excitation temperature of about 13000°K or an effective temperature of about 13500°K, but not all spectral details can be explained satisfactorily with the hypothesis of line formation in LTE. Less material is available for analysis for β Sextantis; it seems clear that the effective temperature and log g are larger than for ζ Draconis. The visible spectrum of ζ Draconis has weakly the characteristics of a Bp(Si) star.

Flux envelopes for ζ Draconis and α Leonis, from 1100 Å to 6050 Å are derived from published spectrum scans and from new spectrum scans obtained with OAO-II. Fitting these energy distributions to those from reference model atmospheres which predict well the visible continuous spectrum distribution leads to estimates of the radii and masses of these single stars. A set of results is obtained which is consistent with the condition that the stars lie in the main-sequence band of stellar structure theory or just above it. The star ζ Draconis seems to be less massive than α Leonis. This discrepancy may be typical of Si stars. The star β Sextantis is the most massive and the hottest of the three stars studied. There is a substantial line blanketing in the ultraviolet spectrum of B6 stars relative to the fluxes predicted from lightly line-blanketed models, about half the predicted flux being obtained at 1500 Å.

I. INTRODUCTION

Detailed information about the spectra of normal late B type stars is almost absent from the literature. A study of the spectrum of ζ Draconis (HD 155763), β Sextantis (HD 90994) and α Leonis (HD 87901) has been undertaken to fill this lack and to provide data for comparison with observations of Bp stars, many of which are of late B spectral type. The material used is high dispersion spectra obtained at the Dominion Astrophysical Observatory (DAO) and at the Kitt Peak National Observatory (KPNO) by the author and at the Palomar Observatory by J.R.W. Heintze as well as of rocket and satellite UV spectral scans of the selected stars. Estimates of the physical characteristics of B6 stars and of the total radiation field from B6 stars are obtained. Such information permits one to check the consistency or otherwise of current theories on the energy generation and evolution of late B type stars.

Information available in the literature about ζ Draconis, β Sextantis and α Leonis is given in Table 1. The star ζ Draconis was originally classified as B8 IV (Morgan and Keenan 1951) but its type is given as B6 III in the Bright Star Catalogue (Hoffleit 1963). The B-V color supports the classification as B6. The radial velocities are from the General Catalogue of Radial Velocities (Wilson 1963) and the projected rotational velocities are from the work of Slettebak and Howard (1955) and Slettebak (1963). The V magnitudes and B-V colors are taken from the Bright Star Catalogue. Slightly different values can be found in some photometric lists.

The star α Leonis rotates too rapidly to make it a useful object for high dispersion studies. Therefore β Sextantis has been selected as representative of the main sequence in the neighborhood of type B6. However, β Sextantis is too faint to be observed in the ultraviolet using presently available rocket or satellite-borne spectrometers. Thus, α Leonis is used as an example of main-sequence ultraviolet spectrum near types B6 or B7. The $M_V(H\gamma)$ is obtained from Petrie's (1964) relation and the equivalent widths measured here; the M_V(type) is from Blaauw (1963). The effective temperature and log g values are from Schild, Peterson and Oke (1971) and come from fitting spectral scans to predicted continuum fluxes from model atmospheres. The study of photographic spectra is concentrated chiefly on the spectrum of ζ Draconis because the lines of this star are reasonably sharp and well defined and a good selection of spectrograms is available. The material available for β Sextantis permits only to show some of the major differences between a B6 star somewhat above the main sequence (ζ Draconis) and one on the main sequence.

The spectrograms used are listed in Table 2 together with the spectral region studied on each and the purpose for which each was used. The emulsions are IIaO, 103aF and IIaF. Each spectrogram was calibrated by the intensity calibration system in use at the observatory where it was obtained, namely a rapidly rotating step sector at the DAO, a spot sensitometer with filters at KPNO and a linear wedge at Mount Palomar.

Spectrograms 3184, 3185, D246 and D265 were traced in density with the Nonius microphotometer of the Utrecht Observatory while plate 1257[2] was traced in intensity. The other spectrograms were traced in intensity with the microphotometer of the Amsterdam University.

II. EQUIVALENT WIDTHS AND CENTRAL INTENSITIES

Mean equivalent widths and central intensities for lines in the spectra of ζ Draconis and β Sextantis are given in Tables 3 and 4. These are unweighted means of the individual values which have been obtained. The listed log gf values are from Wiese, Smith and Glennon (1966), Wiese, Smith and Miles (1969), Groth (1960), Fischer (1968), Warner (1967, 1968) and Underhill (1963).

The uncertainties in the equivalent widths of the lines, including the hydrogen lines are no greater then 20 percent. Most of the uncertainty comes from the uncertainty in drawing the continuum in the case of the hydrogen lines and in the uncertainty of drawing consistent profiles for the weak lines. Lines of moderate strength, such as most of the He I lines, probably do not have significant errors greater than 10 percent. The central intensities obtained from the DAO plates of ζ Draconis are about 5 percent deeper than those obtained from the Palomar plates. This difference is illustrated in Figure 1a. The central intensities measured on the DAO plates and on the KPNO plates are systematically the same, see Figure 1b. It seems rather probable that the intensity calibration of the blue Palomar spectra of ζ Draconis used here is faulty. The results from the blue Palomar spectrograms are not contained in Tables 3 and 4 because there seems to be no way of clearing up this discrepancy at present. The red-yellow results are more consistent.

III. THE RADIAL VELOCITY OF ζ DRACONIS

To test the hypothesis that the difference in central intensities between the DAO and Palomar spectrograms might be due to ζ Draconis being a double-lined spectroscopic binary, the radial velocity of ζ Draconis was measured on all of the DAO spectrograms. The results are given in Table 5. The following lines were used: H15 to H8; He I 3819, 3867, 4026, 4387, 4471; Si II 3853, 3856, 3862, 4128, 4130; Mg II 4481, all with laboratory wavelengths. The average radial velocity is -15.5 ± 1.6 km s^{-1} which is in good agreement with the value from Wilson (1963). It is concluded that ζ Draconis is not a spectroscopic binary and that the discrepancy between the central intensities from the Palomar spectrograms and those from DAO and KPNO must be due to a poor photometric calibration of the Palomar spectrograms used here.

IV. LINE PROFILES OF ζ DRACONIS AND β SEXTANTIS

Profiles of lines of H, He I, C II, N II, Si II, Si III, Mg II, Ca II and Fe II in the spectra of ζ Draconis and of β Sextantis are presented in Figures 2 to 11. These profiles are given in detail because they are fundamental observational data which can be compared with computed profiles from any model atmosphere and a theory of line formation. In every case the instrumental profile of the spectrograph is sufficiently narrow that no correction need be made for instrumental distortion. The average profiles are presented as they appear on the tracings. In some cases an asymmetry may be caused by an unresolved blend (a forbidden line in the case of He I) or by difficulties with the photometric grain. The asymmetries in the nominally unblended lines indicate the degree of uncertainty in the final profiles. If the power of modern methods of analyzing stellar spectra is to be exploited fully, predicted line profiles should be compared with observed profiles like these.

V. INTERPRETATION OF THE SPECTRA OF ζ DRACONIS AND β SEXTANTIS

a) The rotational velocity. Both ζ Draconis and β Sextantis rotate moderately slowly (Slettebak and Howard 1955) whereas α Leonis rotates rapidly (Slettebak 1963). Consequently, since the expected natural half-width due to thermal motion is less than 0.2 to 0.1 of the roughly estimated rotation, it is adequate to use the formula presented by Unsöld (1955) to estimate $v_r \sin i$ from the shape of the line profile (cf. Underhill 1968). At a distance x from the line center the shape of the profile may be found from

$$A(x) = \left[\frac{2}{\pi}(1-x^2)^{1/2} + \frac{\beta}{2}(1-x^2)\right] / \left(1 + \frac{2}{3}\beta\right), \tag{1}$$

where

$$x = \Delta\lambda / v_r \sin i \,, \tag{2}$$

and β is the limb-darkening coefficient for the continuous spectrum. Equation (1) is not particularly sensitive to the adopted value of β; an appropriate value for B6 stars is 0.40 (Grygar 1965). The total width of essentially unblended profiles has been measured for all available lines of representative spectra at A(x)/A(0) = 0.00, 0.30, 0.50 and 0.75 and $v_r \sin i$ has been determined. The resulting average values are given in Table 6. The lines C II 4267 and Mg II 4481 were not used because each is a close double which could, in principle, be resolved on the present spectrograms were the stellar lines unbroadened.

The uncertainty in each average value listed in Table 6 is about $\pm$ 8 km s^{-1}. The rotational velocity estimated from the total extent of the wings is in each case significantly larger than that estimated by fitting the flanks of the profile to equation (1). This might be due to the natural profile of the line. Roundly speaking, the profiles of ζ Draconis correspond to a projected rotational velocity of 44 km s^{-1} but they seem to be too sharply pointed. The profiles of β Sextantis correspond rather well to a projected rotational velocity near 58 km s^{-1}.

The profiles of ζ Draconis are rather well fitted by an exponential function. A macroturbulence corresponding to a most probable velocity of 41 km s^{-1} gives an acceptable representation of the ζ Draconis profiles. This interpretation of the observed line shape is preferable to simple rotation in the case of ζ Draconis. It is somewhat disturbing that the rotational velocities estimated by Slettebak and Howard (1955) from spectra of low resolution are not consistent with the profiles measured on high resolution spectra.

b) <u>The hydrogen lines</u>. The Balmer lines are shallower and the wings are a little broader in β Sextantis than in ζ Draconis. The Balmer series breaks off at $n_m = 17$ in β Sextantis and at $n_m = 19$ in ζ Draconis, which corresponds to log $N_e = 13.74$ and 13.37 respectively if the Inglis-Teller formula is used with the number of Stark broadening perturbers put equal to $2N_e$. If the empirical formula of Kurochka (1967) which takes account of the overlapping of the wings of the higher Balmer members is used, one finds log $N_e = 13.39$ and log $N_e = 13.05$ for β Sextantis and ζ Draconis respectively. These electron densities are consistent with the assigned luminosity classes of these stars. The confluence of the Balmer series in ζ Draconis is shown in Figure 4. of Underhill (1970). The larger central intensities of the hydrogen lines in β Sextantis relative to those of ζ Draconis is probably due to the rotation of β Sextantis. Fischel and Klinglesmith (1971) using hydrogen-line blanketed model atmospheres in LTE have derived the dependence of n_m and W(Hγ) on T_{eff} and log g for models of normal composition, X = 2/3 and Y = 1/3. The following results are found from the present data:

Star	T_{eff}	log g
ζ Draconis	13,600°K	3.6
β Sextantis	15,400	4.3

The work of Auer and Mihalas (1970) has shown that the central parts of the Balmer lines must be computed using models and a theory of line formation that takes into account the departures from LTE in the outermost layers of stars like ζ Draconis and β Sextantis. The sharp core of Hα in β Sextantis is reminiscent of the sharp deep cores shown by the NLTE-L Balmer line profiles of Auer and Mihalas (1970) for T_{eff} = 12500°K and for 15000°K with log g = 4.0 but the actual fit between the observed Hα profile and the available predicted profiles is poor, the observed wings being significantly stronger than the predicted wings. More observational material will be required to resolve this question. The observed wings of Hβ are shallower than the predicted wings for the model with T_{eff} = 15000°K and log g = 4.0. The observed Hγ profile in β Sextantis falls between the predicted profiles for the Auer and Mihalas models with T_{eff} 15000°K, log g = 4.0 and T_{eff} = 12500°K, log g = 4.0. A comparison with LTE Balmer lines predicted by Underhill for an unblanketed LTE model with T_{eff} = 15326°K, log g = 4.0 gives a reasonable fit for the lines Hα to Hδ in β Sextantis. In summary, the hydrogen-line spectrum of β Sextantis indicates an effective temperature a little greater than 15000°K and log g greater than or equal to 4.0. A similar comparison for ζ Draconis indicates that a model with T_{eff} about 14000°K and log g about 3.7 would represent the observed Balmer line profiles quite well. Such values are not inconsistent with the effective temperature of 13400°K and log g = 4.0 deduced by Schild, Peterson and Oke (1971) from the shape of the continuous spectrum of ζ Draconis.

The shallowness of the Balmer lines of β Sextantis is probably chiefly due to the rotation of the star (cf. the numerical example computed by Underhill (1968)).

c) The He I lines. Observed profiles of the He I lines in ζ Draconis are shown in Figures 4 and 5; those of β Sextantis in Figure 6. Lines of the diffuse series (2P-nD), both for the singlets and the triplets, are wider and deeper than the lines of the sharp series (2P-nS). The HeI lines in β Sextantis are shallower and broader than in ζ Draconis and they tend to have larger equivalent widths. The increased Stark effect and rotational broadening of the He I lines in β Sextantis is evident.

A curve of growth was made for the He I lines of ζ Draconis using the universal curve of growth of Unsöld as a reference curve. (See Hummer (1968), Table I for a useful numerical representation of this curve.) Because the lines of the sharp series are weak they fall on the knee of the curve of growth. Consequently, the value of the effective damping constant does not affect significantly the fit of the theoretical curve to the observed points. It was considered that both 4713, 2^3P-4^3S, and 4437, 2^1P-5^1S, should fit on the curve of growth since the equivalent widths of these lines are secure. The weaker lines of each series spread more or less uniformly around the theoretical curve. The points for the 2^1P-n^1D lines fit the adopted curve of growth very well. As may be expected owing to the relatively low electron density and the fact that the lines of He I are weak at spectral type B6, these lines fall on the transition part of the curve of growth.

Therefore, the Stark broadening of the 2^1P-n^1D lines does not affect the positioning of the theoretical curve of growth in a singificant manner. The lines from 2^3P-n^3D are stronger. They do not fall as close to the adopted theoretical curve.

The shift needed to unite the partial curves of growth from 2^1P and 2^3P corresponds to a nominal excitation temperature of $3300^oK \pm 1000^oK$. The excitation temperature is not well determined because the difference in excitation potential is only 0.254 volt. Nevertheless, it is certain that the resulting fit is better than that obtained with $T_{exc} = 13,000^oK$, a value of the excitation temperature which one might expect for a B6 star (Heintze 1969).

Formally the low excitation temperature derived by fitting the 2^1P-n^1S and 2^3P-n^3S lines to one curve of growth means that the ratio of the population of 2^1P to that of 2^3P is smaller than the ratio expected for LTE at an excitation temperature near $13,000^oK$. This fact and the position of the lines from the 2^3P-n^3D series on the curve of growth lends strength to the deduction, which can be made from the known behaviour of helium plasmas at electron densities near 10^{13} and temperatures near $13,000^oK$, that the populations of the excited levels of He I are not in their LTE ratios. To determine precisely what these ratios are in the atmosphere of ζ Draconis is beyond the scope of this study. The LTE calculations of Leckrone (1971) suggest that W(4438)/W(4713) should be about 0.40 at type B6 and that W(4388)/W(4026) should be about 0.43. The observed equivalent widths lead to singlet to triplet ratios of 0.55 and 0.68 respectively for ζ Draconis. The singlets are stronger with respect to the triplets than LTE theory predicts which is an opposite conclusion to that deduced from the curve of growth.

d) Lines of C II, N II, Mg II, Si II, Si III, Ca II and Fe II.

Profiles of the strongest C II lines in ζ Draconis are shown in Figure 7; those of β Sextantis in Figure 10. The increased rotational broadening of the C II lines in β Sextantis is evident. The C II lines at 6578 and 6582 Å could not be resolved from the wing of Hα in β Sextantis although they are readily measured in ζ Draconis. This is an indication that ζ Draconis is more luminous than β Sextantis. Simple curve-of-growth analysis indicates that the relative strengths of the C II lines in ζ Draconis are not seriously inconsistent with the hypothesis of LTE at 13,000°K.

Profiles of the strongest N II lines in ζ Draconis are shown in Figure 7. The N II lines are present in β Sextantis, but they are so weak and shallow that meaningful measurements could not be made on the present spectrograms. The profiles of the N II lines in ζ Draconis are too pointed to be due solely to rotation.

Profiles of the Mg II lines in ζ Draconis are shown in Figure 7; the 4481 Å line in β Sextantis is shown in Figure 10. The other lines could not be well resolved on the present spectrograms of β Sextantis. The relative strengths of the Mg II lines in ζ Draconis are consistent with the adopted simple curve of growth and the hypothesis of LTE at 13,000°K. The difference in profile of 4481 between ζ Draconis and β Sextantis is due chiefly to the rotation of β Sextantis.

The observed profiles of lines of Si II and Si III in ζ Draconis are shown in Figure 8; those in β Sextantis in Figure 10. The differences due to the difference in projected rotational velocity are evident. Furthermore it is clear that the Si III lines are greatly strengthened in the more luminous star. The Si II lines of ζ Draconis do not differ greatly in strength from those of β Sextantis although they do differ in shape. Curves of growth for the Si II and the Si III lines in ζ Draconis consistent with an excitation temperature of 13,000°K can be made. A value of log N_e can be estimated from the shift necessary to bring the partial curves of growth due to Si II and to Si III together and the hypothesis that the relative ionization between Si II and Si III follows the Saha law. If it is assumed that the ionization temperature is 13,000°K, log N_e = 17.3. If, in accordance with the hydrogen spectrum, log N_e is put equal to 13.0, then the ionization temperature is 7,400°K $\pm$ 1,000°K. Clearly the relative strengths of the Si II and the Si III lines are not consistent with the simple hypothesis of a single-layer atmosphere in LTE at a temperature near 13,000°K.

The profile of Ca II 3933 in ζ Draconis is given in Figure 9. This line has about the same shape as the Si II lines, quite different from the shape in β Sextantis, see Figure 10. The radial velocity from Ca II 3933 in ζ Draconis is -17.7 $\pm$ 1.8 km s^{-1} while the average radial velocity of ζ Draconis is -15.5 $\pm$ 1.6 km s^{-1}. Thus, Ca II 3933 at type B6 is probably a stellar line. This resonance line in the more luminous star is stronger than in the main-sequence star.

Profiles of the strongest Fe II lines in ζ Draconis are shown in Figure 11. A curve of growth was made using an excitation temperature of 13,000°K. The points scatter rather widely around the theoretical curve of growth but no factor can be isolated that points towards a distinctive departure from LTE relative level populations.

This check of the consistency between the observed equivalent widths of lines in the spectrum of ζ Draconis and an adopted simple theory of the curve of growth in a single-layer atmosphere at 13,000°K was concluded by estimating the microturbulence from the vertical shift necessary to fit the observed curves of growth to the adopted theoretical curve. The resulting average value is 2.9 $\pm$ 1.5 km s^{-1}. Thus although the line shapes suggest a macroturbulence of the order of 40 km s^{-1}, the microturbulence is small and close to the velocity of sound in the atmosphere of ζ Draconis.

VI. THE FLUX ENVELOPE AT TYPES B6 III AND B7 V

Absolute energy scans on a relative scale between about 3300 Å and 6050 Å using band passes approximately 50 Å wide are available for ζ Draconis (Schild, Peterson and Oke 1971), for β Sextantis (Wolff, Kuhi and Hayes 1968) and for α Leonis (Hayes 1970, Schild, Peterson and Oke 1971). These may be converted to absolute energies in ergs cm^{-2} s^{-1} Å^{-1} received at the earth by means of the V magnitude and the energy equivalent given by Schild and Oke (1970) of magnitude 0.00 at the reference wavelengths. To obtain all these energy distributions on a consistent scale, the observations for β Sextantis have been corrected from Hayes (1970) calibration of the spectrum of Vega to that of Oke and Schild (1970).

Scans made with the Wisconsin Experiment, Scanner 1 of OAO-II (Code, et al. 1970) used with a preliminary relative sensitivity curve communicated by B.D. Savage yield a relative energy distribution between 1800 Å and about 3800 Å. These relative values for ζ Draconis and for α Leonis have been put on an absolute scale by fitting the observed near UV flux envelope to the ground-based observations in their region of overlap. Scans made with the Wisconsin Experiment, Scanner 2 of OAO-II give the flux envelope between 1100 Å and 1800 Å. These have been put on an absolute energy scale using an energy calibration function derived by D.S. Leckrone (1971, private communication) from the absolute energy scans for two stars obtained by D.C. Evans (1971) with rocket-borne spectral scanners having known energy response functions. The entire flux envelope for ζ Draconis from 1100 Å to 6050 Å is shown in Figure 12; that for α Leonis in Figure 13. Different symbols are used to represent data from the various sources. These are explained in the captions to the Figures. The spectral resolution of the OAO-II Scanner 2 is about 10 Å while that of Scanner 1 is about 20 Å. The star β Sextantis is too faint to be observed with the OAO-II spectrum scanners. In the following discussion we assume that the flux envelope for α Leonis is typical of the main sequence near type B6.

The consistency of the adopted calibration function for Scanner 2, which was derived from observations of κ Orionis and α Leonis, is shown by the overlap of the rocket results for α Leonis with the plotted points from Scanner 2 shown in Figure 13. No significant discrepancy is apparent.

The predicted continuous energy flux envelope from a hydrogen-line blanketed, LTE model atmosphere with $T_{eff} = 14{,}000^{o}K$, log g = 4.0 and composition X = 2/3 Y = 1/3 has been plotted in Figure 12 to serve as a reference line; the flux envelope from a model with $T_{eff} = 13{,}000^{o}K$, log g = 4.0, X = 2/3, Y = 1/3 is used in Figure 13. The 13,000-degree model is similar to the models published by Klinglesmith (1971) and I am grateful to D.A. Klinglesmith for permission to use this unpublished material. The model flux has been adjusted to the scale of the observed stellar flux by fitting the model flux distributions to the observed flux distributions in the region 4600 to 5400 Å. The analysis of the absorption line spectrum of ζ Draconis given in Section 5 has shown that a $14{,}000^{o}K$, LTE model should be representative for ζ Draconis. Various estimates of T_{eff} and log g for α Leonis, see Heintze (1969) and Schild, Peterson and Oke (1971) indicate that a $13{,}000^{o}K$ model is representative for α Leonis. It should be noted that the shape of the predicted continuous spectrum for models with $T_{eff} \approx 13{,}000^{o}K$ is insensitive to the precise value of log g used (see Klinglesmith 1971). The ground-based spectral scan for β Sextantis (Wolff, Kuhi and Hayes 1968) fits best with an effective temperature of $15{,}000^{o}K$, log g = 4.0 which is consistent with the estimate of T_{eff} and log g made from the hydrogen-line spectrum in Section V.

The data presented in Figures 12 and 13 deserve several comments:

1. The absolute fluxes estimated from the OAO-II Scanner 1 observations using the preliminary sensitivity function communicated by B.D. Savage appear to be too large in the spectral region 1800 Å to at least 2400 Å. These fluxes do not match up with the Scanner 2 fluxes which are on an independent absolute basis and which near 1800 Å are not expected to be seriously in error (Evans 1971). An improved sensitivity function has been found by forcing the OAO-II Scanner 1 observations of α Leonis to fit the energy envelope derived from the rocket observations. When this modified relative sensitivity function is used for ζ Draconis, the observed points (which are plotted as open circles in Figure 12) join smoothly to the absolute energy distribution found from OAO-II Scanner 2. (The modified points are not shown in Figure 13 for α Leonis because this diagram is then too crowded.)

2. In each case the reference theoretical flux curve fits well the observed fluxes over the region 4200 Å to 6000 Å where line blanketing is expected to be negligible and where the hypothesis of LTE is expected to be adequate for predicting the shape of the continuous spectrum. However, it does not fit well at wavelengths shorter than about 3200 Å. A considerable line blocking appears to be present. This is discussed more fully below.

The scaling factor between the model fluxes and the observed fluxes incident on the earth's atmosphere gives a measure of d/R where d is the distance to the star and R is the radius of the star, for

$$\pi F_\lambda (\text{model}) / \mathcal{F}_\lambda (\text{observed}) = d^2 / R^2 \qquad (3)$$

The distance to the star may be estimated from the parallax or from the visual absolute magnitude of the star, thus an estimate of the radius may be obtained. The results are given in Table 7, column 4 for several plausible estimates of the distance of each star. Unfortunately none of these stars is close enough that the measured parallax determines accurately the distance of the star.

A check on the consistency of these estimates of radius may be obtained from the difference in bolometric absolute magnitude between the star and the sun, for

$$\Delta M_{Bol} = 10 \log \left(T_{eff} / T_{eff}(\odot) \right) + 5 \log R/R_\odot \ . \qquad (4)$$

Here

$$M_{Bol}(\text{star}) = M_v + B.C.$$

In applying equation (4) it is appropriate to use the bolometric correction (B.C.) which goes with the effective temperature of the adopted model used to predict the flux envelope (see discussion by Underhill 1964). The standard values T_{eff} ($\odot$) = 5785°, M_{Bol} ($\odot$) = + 4.62, and $R_{\odot}$ = 6.96 x 10^{10} cm are used. These estimates of radius are given in column 5 of Table 7. For this calculation it is assumed that log g = 3.8 for ζ Draconis and 4.0 for β Sextantis and α Leonis. If log g is larger than these values, the listed mass should be increased proportionately to the change in g.

It is clear that equations (3) and (4) give consistent estimates of the radius of each star. In the case of ζ Draconis, values midway between those listed for each M_V would be appropriate since the effective temperature seems to be near 13,500 degrees. The greatest uncertainty is attached to the estimate of distance. The absolute magnitude estimated from the equivalent width of $H\gamma$ seems a good compromise. If ζ Draconis were as bright as -1.9, W($H\gamma$) should be about 6.3 Å which it clearly is not (see Table 5). Although there has been some uncertainty whether the empirical relationship established by Petrie between M_V and W($H\gamma$) is valid for early B type stars, there has never been serious disagreement about the part relevant for the late B type stars. If M_V = -1.00 is about right for ζ Draconis, then this star is less massive than the main-sequence star α Leonis. In the case of β Sextantis, there is little reason to decrease W(H γ) and thus to make the star brighter than 0.00 mag. but see below. This star seems to be smaller than ζ Draconis, but there is no strong indication that it is significantly less massive. In the case of α Leonis the parallax is large enough to be fairly reliable. Whether the absolute magnitude appropriate statistically to the spectral type, or whether the absolute magnitude appropriate to the parallax is chosen, it turns out that this star is more massive than ζ Draconis but it is smaller than ζ Draconis. Hanbury Brown et al. (1967) have measured the angular diameter of α Leonis. Adopting the distance corresponding to the parallax they find that the radius is 3.8 $\pm$ 1 solar radii, a value consistent with the estimates given in Table 7 for this distance. Hanbury Brown et al. note that their result has not been corrected for the rapid rotation of the star.

A further consistency test to select plausible dimensions from the sets of values given in Table 7 may be obtained by looking at where each star falls in the theoretical HR diagram for various masses, see Iben (1967), Figure 3 and in Iben's Figure 4 shich shows the main-sequence band as a function of log $(M/M_{\odot})$ and log $(L/L_{\odot})$. From spectra obtained with ground-based telescopes it is clear that ζ Draconis has moved off the main-sequence while β Sextantis and α Leonis lie within the main-sequence band. The most consistent results are obtained if a visual absolute magnitude of -1.00 is adopted for ζ Draconis, -0.7 mag for β Sextantis and -0.4 mag for α Leonis. These values are marked with an asterisk in Table 7.

3. There is a large amount of line blanketing in B6 stars at wavelengths shortwards of 2900 Å. The line blanketing in B and A type main-sequence stars between 2000 Å and 3000 Å has been commented upon by Underhill (1971). That discussion was based on use of the relative sensitivity curve due to Savage for OAO-II

Scanner 1 and fitting the observed flux at 3000 to 3800 Å to the predicted continuum from a representative model atmosphere. The revised sensitivity curve derived here shows that the line blanketing with respect to the continuum predicted from a hydrogen-line blanketed model atmosphere becomes large as the wavelength decreases. At 1500 Å about 50 percent of the predicted light is received, thus the blanketing is about 0.75 mag. Davis and Webb (1969) have compared published broad-band ultraviolet photometry of B5 and later stars with the fluxes predicted from hydrogen-line blanketed models and they have also found a line blanketing which increases greatly with decreasing wavelength, particularly for later type stars.

The flux deficit of ζ Draconis relative to the flux from the reference model with T_{eff} = 14,000°K corresponds to reducing the effective temperature to 13,100°K. The flux deficit for α Leonis relative to a model with T_{eff} = 13,000°K suggests an effective temperature of 12,400°K.

Although the flux envelope of the part of the spectrum accessible from the ground is not very sensitive to the precise effective temperature, gravity and composition of the models suitable to represent B6 stars, at short wavelengths the predicted flux varies quite sensitively as a function of effective temperature. This may be seen from the theoretical flux distributions shown in Figure 12. The hydrogen-line blanketed model with T_{eff} = 13,500°K gives practically the same flux envelope as that for the model with T_{eff} = 14,000°K over the wavelength range 3400 Å to 6000 Å. The line-blanketed model of Van Citters and Morton (1970) with T_{eff} = 14,400°K, log g = 4.0, He/H - 0.15 by number (shown by plus signs in Figure 12) gives a continuum energy distribution very similar in shape and intensity to that of a Klinglesmith hydrogen-line blanketed model of the same effective temperature. The LTE calculations of Van Citters and Morton which take account of the additional opacity of 98 lines between 911 Å and 1600 Å appear to produce a model not significantly different from those of Klinglesmith. The present observations show that neither type of model predicts a UV spectrum like what is observed for B6 stars because many of the lines which are present in the ultraviolet spectra of B6 stars are neglected. In Underhill (1971) it was noted that the spectra of the first and second ions of the metals contain such a large number of lines at wavelengths shorward of 3000 Å, that considerable line blanketing can be expected. In addition many lines from lighter elements may be expected to be strong.

4. The present observations do not have sufficient spectral resolution for detailed line identification studies to be made. In particular the Scanner 1 points are obtained at about 21 Å steps with 20 Å resolution. The zero point of the wavelength scale has to be established by assigning the nominal wavelength 2800 Å to grating step 50. The actual wavelength to which each observed point corresponds could differ from the nominal value by 20 or even 40 Å. The spectral resolution with OAO-II Scanner 2 is about 10 Å and the points are taken at intervals of approximately 10.5 Å. The zero point of the wavelength scale is established by the center of Lyman α . The scale is that found by Underhill, Leckrone and West (1972). In the spectral region of OAO-II

Scanner 2, several prominent absorption "lines" can be seen. Each feature is a blend of several lines. The positions of a few intrinsically strong multiplets have been marked in Figures 12 and 13. The Si IV and C IV resonance lines which are prominent in early B type stars cannot be resolved. Lines of C II, Si II and Si III are conspicuous and it seems probable that lines of C I and of Fe II will be strong. The feature at 1720 Å discussed by Underhill, Leckrone and West (1972) is identified by a question mark. In the case of these B6 stars Fe II probably contributes strongly. The contribution from Ni III will be small, for the strong multiplet near 1765 Å is not conspicuous. On the present plots the feature at 1720 Å in the spectra of ζ Draconis and α Leonis seems quite distinct. This feature, however, is weak in comparison to the feature which occurs in the spectra of the Ia supergiants and in the spectrum of the shell star ζ Tauri. The spectrum of α Leonis is shown in Figure 2 of Underhill, Leckrone and West and there the 1720 Å feature appears as only a weak dip.

VII. DISCUSSION

A quantitative study of the profiles of essentially unblended lines in the part of the spectrum accessible from the ground of the presumably normal stars ζ Draconis, B6 III and β Sextantis, B6 V has shown that ζ Draconis is definitely more luminous than β Sextantis. The profiles of lines of ζ Draconis are broader than thermal motions in the atmosphere would suggest. The lines of β Sextantis are even broader. The hypothesis of macroturbulence with a most probable velocity of 41 km s^{-1} gives a better representation of the observed profiles of ζ Draconis than does the hypothesis of rotation with $v_r \sin i$ = 44 km s^{-1}. The lines of β Sextantis are not so broad as the measurements of Slettebak (1963) would suggest, a projected rotational velocity of 58 km s^{-1} giving a fairly good representation of the observed profiles.

The Balmer lines in ζ Draconis are deeper (central intensities near 24 percent) than in β Sextantis (central intensities near 36 percent) and their Stark broadening is not so severe. The break off of the Balmer series and the profiles of $H\gamma$ and $H\delta$ indicate that the electron density lies in the range $13.0 < \log N_e < 13.4$ for ζ Draconis and in the range $13.4 < \log N_e < 13.7$ for β Sextantis.

The relative strengths of lines from various multiplets of He I, C II, N II, Mg II, Si II and Si III in ζ Draconis have been compared using the simple hypothesis of a curve of growth in a stationary layer of gas at 13,000°K. The population of level 2^1P of He I appears to be larger relative to that of 2^3P than predicted for LTE at 13,000°K. The strength of the C II lines at 6578 and 6582 Å, and of the strong N II and Si III lines relative to the other lines is not consistent with the hypothesis of LTE at 13,000°K in a single layer. Very probably these lines must be treated by a theory of spectrum formation which takes account of the actual relationships between radiation and matter in an atmosphere with a particle density of the order of 2×10^{13} rather than by assuming line formation in LTE. The average nominal microturbulence resulting from the curve of growth studies is 2.9 ± 1.5 km s^{-1} in the atmosphere of ζ Draconis. It appears that the gross characteristics of the spectrum of ζ Draconis can be represented by a LTE model atmosphere with an effective temperature near 13,000°K and log g near 3.8 but that such treatment will not reproduce all the spectral details. Such a model would not take account of the motions, whether macroturbulence or rotation, required to represent the line profiles.

There is insufficient material to make a similarly detailed study of the spectrum of β Sextantis. The hydrogen-line spectrum of β Sextantis is consistent with a LTE model atmosphere having $T_{eff} \leq 15400$°K and log g ≤ 4.3. The rather sharp core of Hα is suggestive of non-LTE line formation, but the observed profile is somewhat uncertain.

The equivalent widths of lines in the spectrum of ζ Draconis have been compared with the equivalent widths measured by Butler and Thompson (1961) in the spectra of ten B5 stars. The He I lines of ζ Draconis are about 1.5 to 2 times weaker than the He I lines of the stars studied by Butler and Thompson. The Si II lines at 6347 and 6371 Å are roughly twice as strong as in the ten B5 stars while the C II, Mg II, Si III and Fe II line of ζ Draconis are on the whole of the same strength as in the B5 stars studied by Butler and Thompson. The best match between ζ Draconis and these ten stars is with δ Persei (HD 22928, B5 III) which has a projected rotational velocity of 255 km s^{-1} and a B-V color of -0.16. A reasonable match may also be obtained with

ϵ Delphini (HD 195810, B6 III) which has a projected rotational velocity of 40 km s^{-1} and a B-V color of -0.16, and with λ Cygni (HD 198183, B5 V) which has a projected rotational velocity of 148 km s^{-1} and a B-V color of -0.15.

Flux envelopes from 1100 to 6050 Å have been prepared for ζ Draconis and for α Leonis from spectrum scans obtained with ground-based telescopes and from spectrum scans obtained with the OAO-II. These flux envelopes, shown in Figures 12 and 13, are particularly interesting because they enable one to obtain an estimate of the radius and mass of single stars, using the techniques explained in Section 6. The flux envelopes show a considerable ultraviolet line blanketing relative to the flux from a hydrogen-line blanketed model atmosphere or from a line-blanketed model atmosphere such as given by Van Citters and Morton (1970).

If one insists that the luminosities, radii, effective temperatures and masses of ζ Draconis, β Sextantis and α Leonis be consistent with the predictions of stellar structure theory for stars near and just off the main sequence, one obtains the following results:

Star	Sp. Type	log g	$M/M_\odot$	$R/R_\odot$	T_{eff}
β Sex	B6 V	≥ 4.0	≥ 4.1	3.3	$15000^\circ K$
α Leo	B7 V	≥ 4.0	≥ 3.8	3.2	13000
ζ Dra	B6 III	≈ 3.8	≈ 3.5	4.1	13500

All of the data considered here indicate that ζ Draconis is less massive than the main-sequence star α Leonis, yet its spectral type is earlier and its effective temperature is higher. Clearly the relationship between empirically assigned spectral types near type B6 and the physical variable effective temperature is not the same for main-sequence stars as for stars above the main sequence. The effective temperature is assigned chiefly by comparing the shape of the hydrogen spectrum observed for the Paschen and Balmer continua and the Balmer lines with hydrogen spectra predicted by means of models which are calculated using the hypothesis of LTE. Use of more elegant spectral theory would not change the results appreciably. The visible flux envelope and the hydrogen lines do correspond to an effective temperature near 13500°K even though the mass and radius of the star, according to stellar structure theory, would be more appropriate for an effective temperature less than 13,000°K. This mild discrepancy may be an indication of chromospheric heating in the outer atmosphere of ζ Draconis. The fact that ζ Draconis has somewhat weak He I lines relative to other B5 III or B6 III stars studied by Butler and Thompson (1961) is another indication that the present LTE model atmosphere and spectrum synthesis theories are too simple to describe accurately the existing situation. In fact, ζ Draconis appears to have the characteristics of a Si star.

The extensive ultraviolet line blanketing at type B6 relative to the predicted flux envelopes from lightly line-blanketed model atmospheres, see Figures 12 and 13, is a significant new fact which should be taken into account when considering the meaning of spectral type. Although the precise amount of the blanketing is uncertain by approximately $\pm$ 10 percent owing to the preliminary nature of the absolute energy calibration of the OAO-II spectrum scanners, it is certain that a considerable blanketing exists relative to the chosen reference flux distributions. The reference flux distributions have been fitted to the observed flux distributions over the range 4000 Å to 6000 Å where no serious blanketing is known to occur. Therefore there is no doubt what the predicted ultraviolet flux of each star should be if the star behaved like the model. Some confusion about the amount of blanketing has occurred when predicted and observed fluxes have been "normalized" at ultraviolet wavelengths, cf. Opal et al. (1968). It is admissable to fit the predicted fluxes to the observed fluxes only in spectral regions where line blanketing is known to be small or non-existent, i.e. at wavelengths greater than 4000 Å. Although about one-half the light is missing at 1500 Å for a B6 star relative to the reference models, this is not unexpected because there are very many strong absorption lines from the second and third spectra of the metals and light elements which could cause the observed line blanketing. Guillaume, van Rensebergen and Underhill (1965), Guillaume (1966), and Elst (1967) have demonstrated the expected strengths of a few lines at type B1.5; Smith (1969) from high resolution spectra has noted that in the atmosphere of α Virginis the line blanketing due to weak but numerous lines is significant at wavelengths shortward of 1350 Å and may be comparable in strength to the opacity of continuous absorption sources.

The question of line identification and line blanketing in the ultraviolet at type B6 cannot be pursued with the low resolution spectra at present available. High resolution spectra will be required to show what lines are present. There is little reason to expect that the ultraviolet line blanketing will become less severe at earlier spectral types than shown here. The presence of severe ultraviolet line blanketing, not obviously indicated by ground-based spectra, raises the spectre of stars having the same ground-based spectral type but significantly different ultraviolet spectra. Such differences must be established and allowed for before deductions are made about the amount of ultraviolet interstellar extinction. No set of model atmospheres and predicted spectra for B stars available at this time takes into account a line blanketing of the magnitude of that found here. It is conceivable that differences in ultraviolet line blanketing between normal B stars and peculiar B stars (Bp stars) may exist and that these differences will be significant for understanding the peculiarities of the Bp spectra.

This study of presumably normal B6 stars was begun in 1966. The results presented here have been obtained with the kind assistance and active collaboration of several colleagues. I am most grateful to the Directors of the Dominion Astrophysical Observatory and of the Kitt Peak National Observatory for the opportunity to obtain high resolution spectra of the program stars, and to Professor A.D. Code of the University of Wisconsin for permission to use spectrum scans of ζ Draconis and α Leonis made with OAO-II. Most of the work on the spectrograms of · Draconis was done by Mr. H. Visser at the Astronomical Institute of the University of Utrecht assisted by Mrs. G. den Boggende-Dorresteijn and by Mr. H.J. Repelaer. Dr. J. Grygar of Ondreyov Observatory, Czechoslovakia did the preliminary work on β Sextantis while he was a visitor at the Astronomical Institute in Utrecht. have used his results and have measured a few more lines on tracings prepared by him. I am indebted to Dr. D.S. Leckrone, Dr. D.A. Klinglesmith and Mr. D.C. Evans of the Goddard Space Flight Center respectively for the preliminary energy and wavelength calibration of OAO-II Scanner 2, for voluminous material on B type model atmospheres and their predicted flux envelopes, and for spectral scans of α Leonis obtained from a rocket flight. My thanks go to Dr. B.D. Savage of the University of Wisconsin for a preliminary energy and wavelength calibration of OAO-II Scanner 1.

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CAPTIONS FOR THE FIGURES

Fig. 1.- An intercomparison of the central intensities of lines in the spectrum of ζ Draconis measured on spectrograms from three observatories.

Fig. 2.- Hydrogen lines in ζ Draconis.

Fig. 3.- Hydrogen lines in β Sextantis.

Fig. 4.- Singlet He I lines in ζ Draconis.

Fig.5.- Triplet He I lines in ζ Draconis.

Fig.6.- He I lines in β Sextantis.

Fig.7.- Lines of C II, N II and Mg II in ζ Draconis.

Fig.8.- Lines of Si II and Si III in ζ Draconis.

Fig.9.- The Ca II K line in ζ Draconis.

Fig.10- Lines of C II, Mg II, Si II, Si III and Ca II in β Sextantis.

Fig.11- Lines of Fe II in ζ Draconis.

Fig.12- The flux envelope for ζ Draconis: OAO-II Scanner 2 data - solid points connected with a line; OAO-II Scanner 1 data using Savage relative calibration - solid points, using new relative calibration - open circles; scanner observations of Schild, Peterson and Oke - crosses; Klinglesmith hydrogen line blanketed model with $T_{eff} = 14000^{\circ}K$ - thin line; interpolated Klinglesmith model with $T_{eff} = 13500^{\circ}K$ - broken line; predicted F_{λ} from van Citters and Morton model with $T_{eff} = 14400^{\circ}K$ - plus signs. The unit of $\mathfrak{F}_{\lambda}$ is 10^{-10} erg cm^{-2}s^{-1} Å^{-1}.

Fig.13- The flux envelope for α Leonis: OAO-II Scanner 2 data - solid points connected with a line; OAO-II Scanner 1 data using Savage relative calibration - solid points; Evans' absolute flux measures from Aerobee 4.251 - plus signs; Evans' absolute flux measures from Aerobee 13.041 - crosses; scanner observations of Schild, Peterson and Oke - filled triangles; scanner observations of Hayes - open circles; Klinglesmith hydrogen line blanketed model with $T_{eff} = 13{,}000^{\circ}K$ - thin line. The unit of $\mathcal{F}_{\lambda}$ is 10^{-10} erg $cm^{-2}s^{-1}\text{Å}^{-1}$.

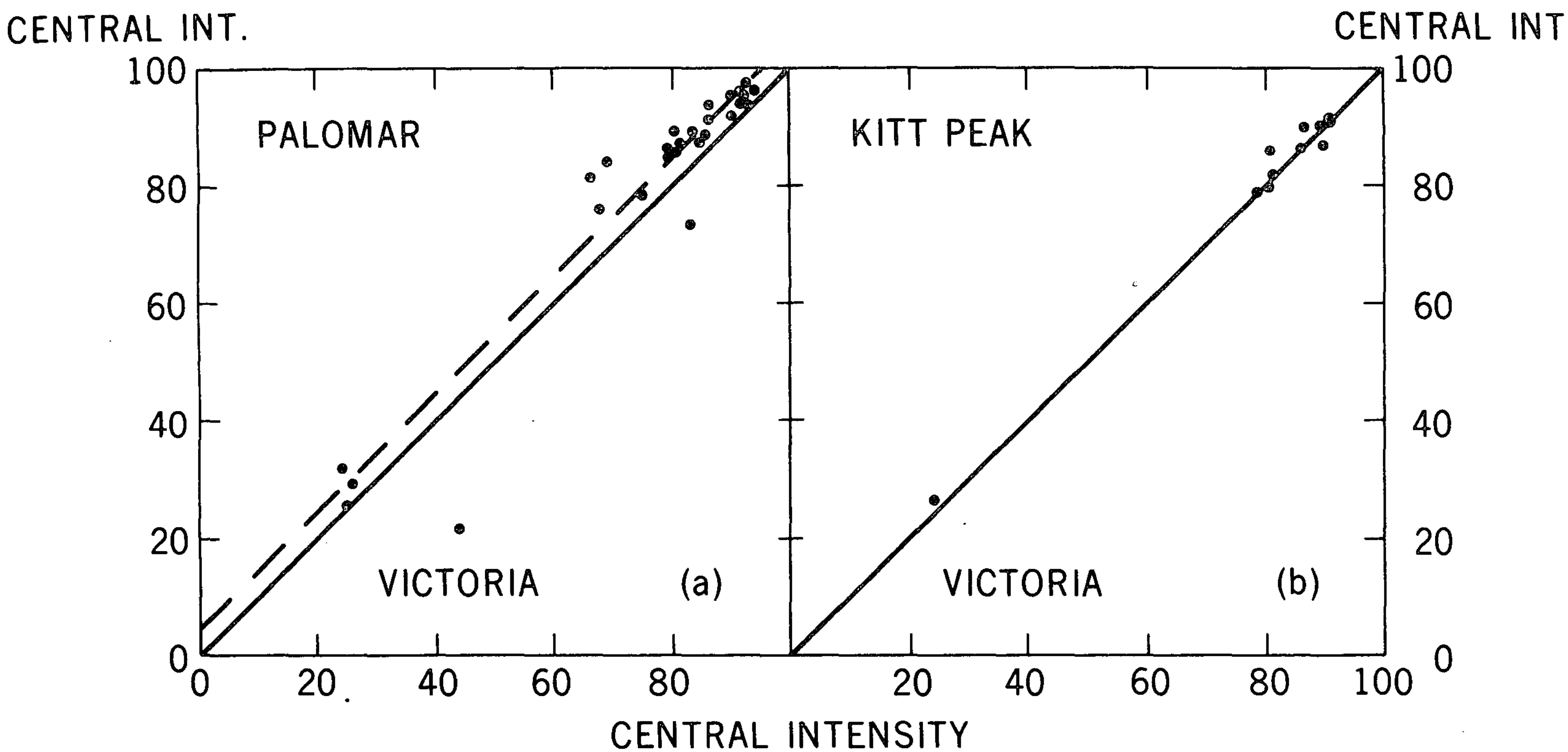

CENTRAL INT.
CENTRAL INT.
100
80
60
40
20
0
PALOMAR
VICTORIA
(a)
KITT PEAK
VICTORIA
(b)
0
20
40
60
80
100
CENTRAL INTENSITY

FIGURE 1

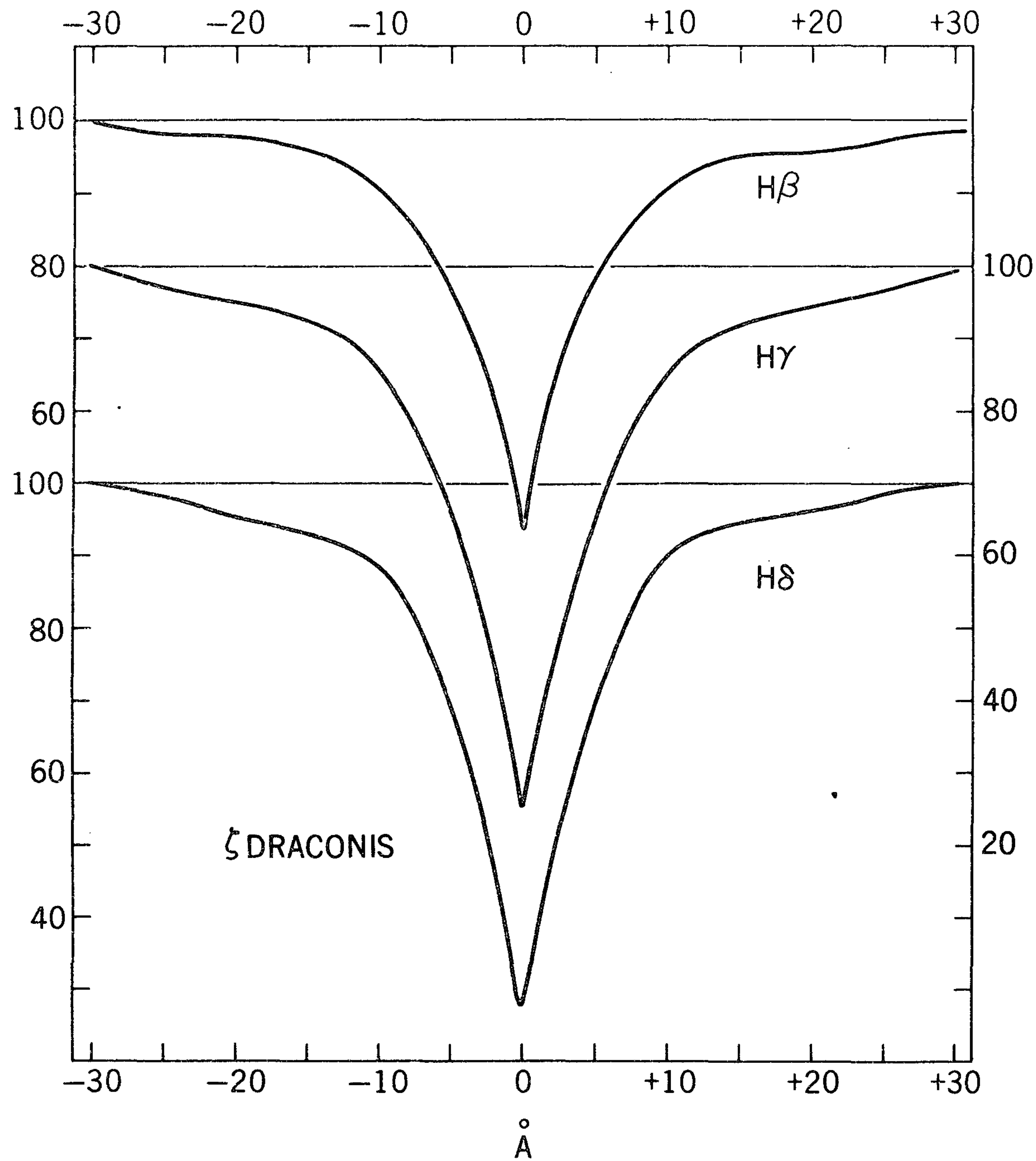
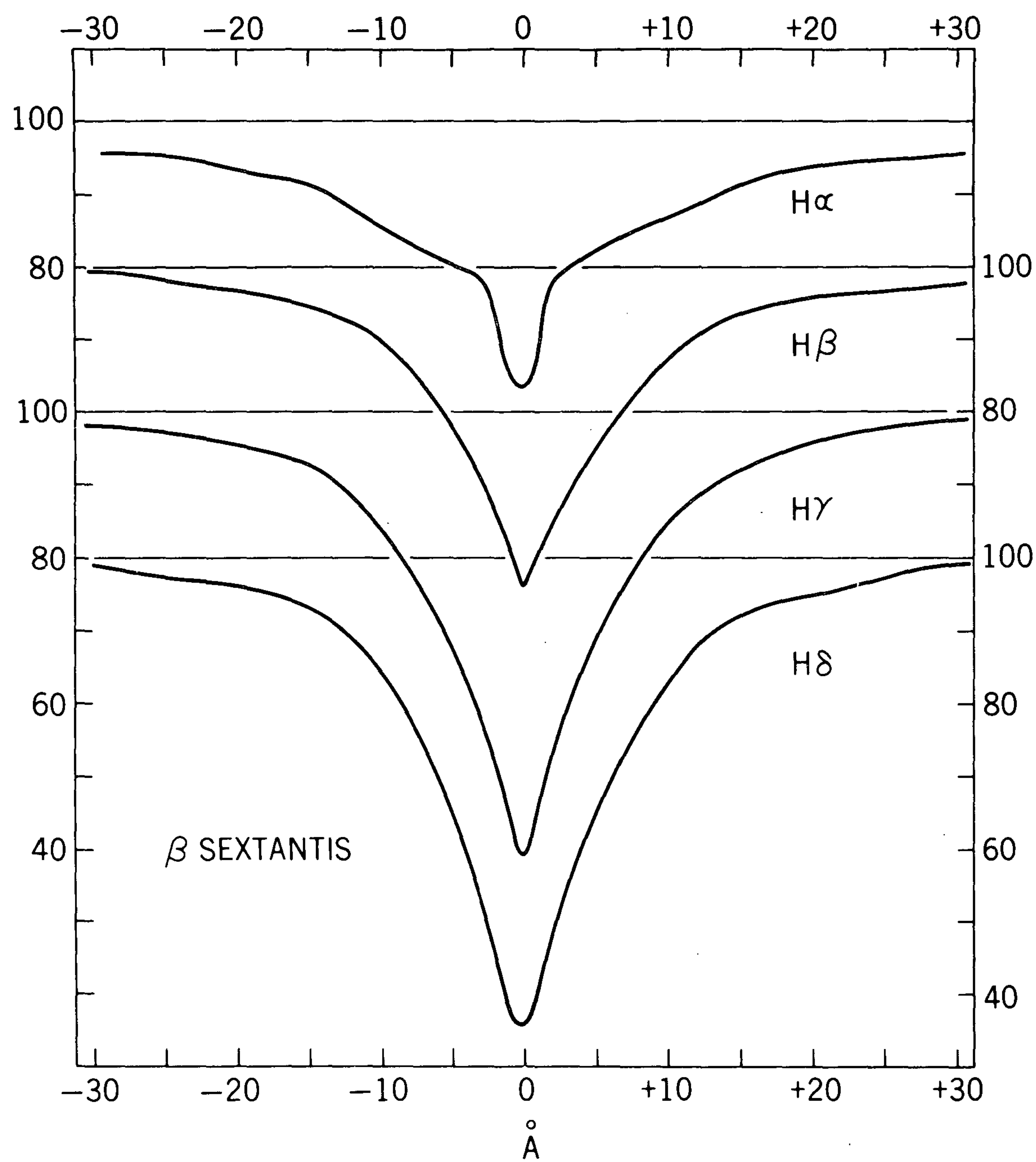


FIGURE 2



−30 −20 −10 0 +10 +20 +30
100
80
100
80
60
40
Hα
Hβ
Hγ
Hδ
100
80
100
80
60
40
β SEXTANTIS
Å

FIGURE 3

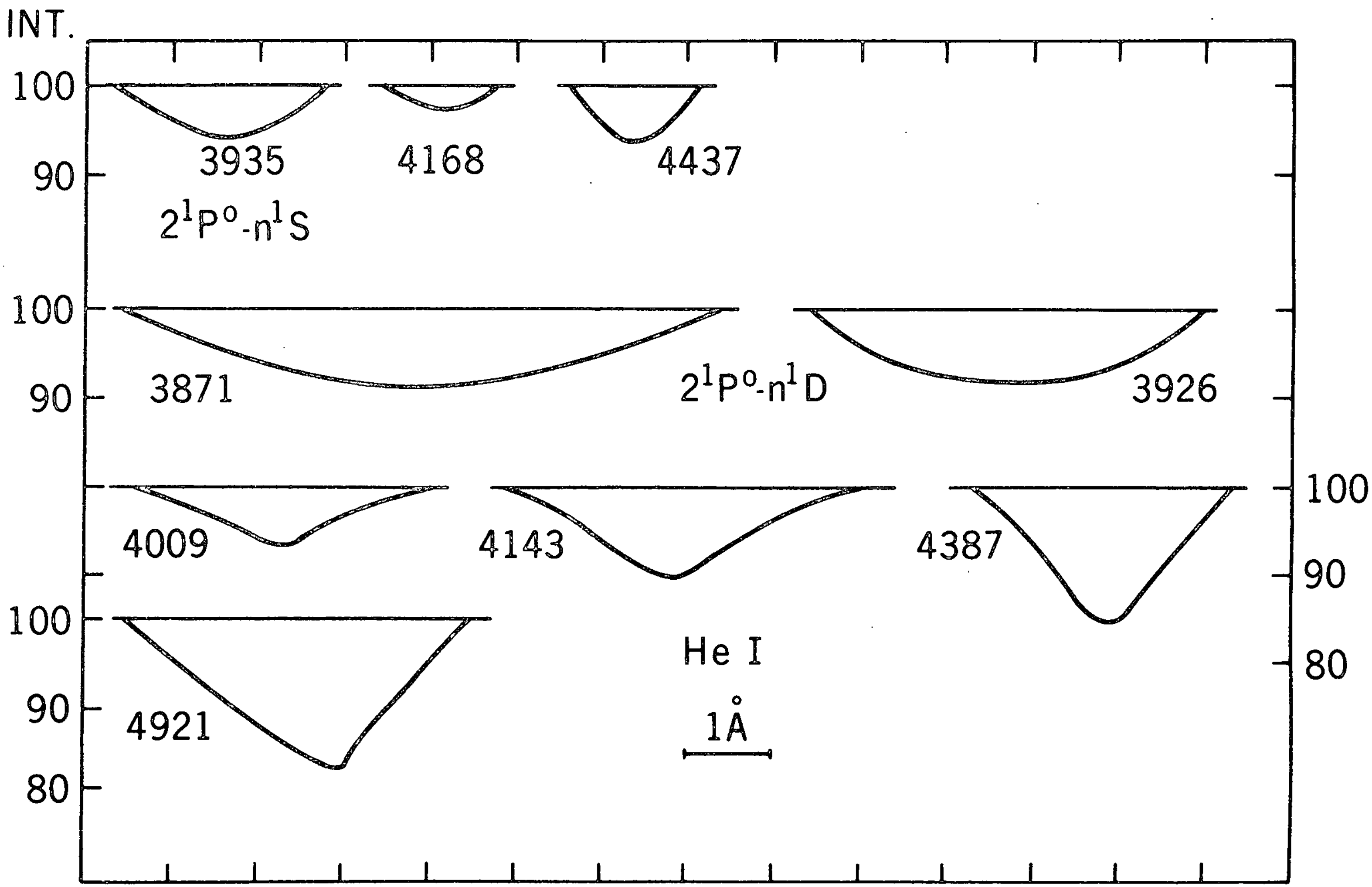
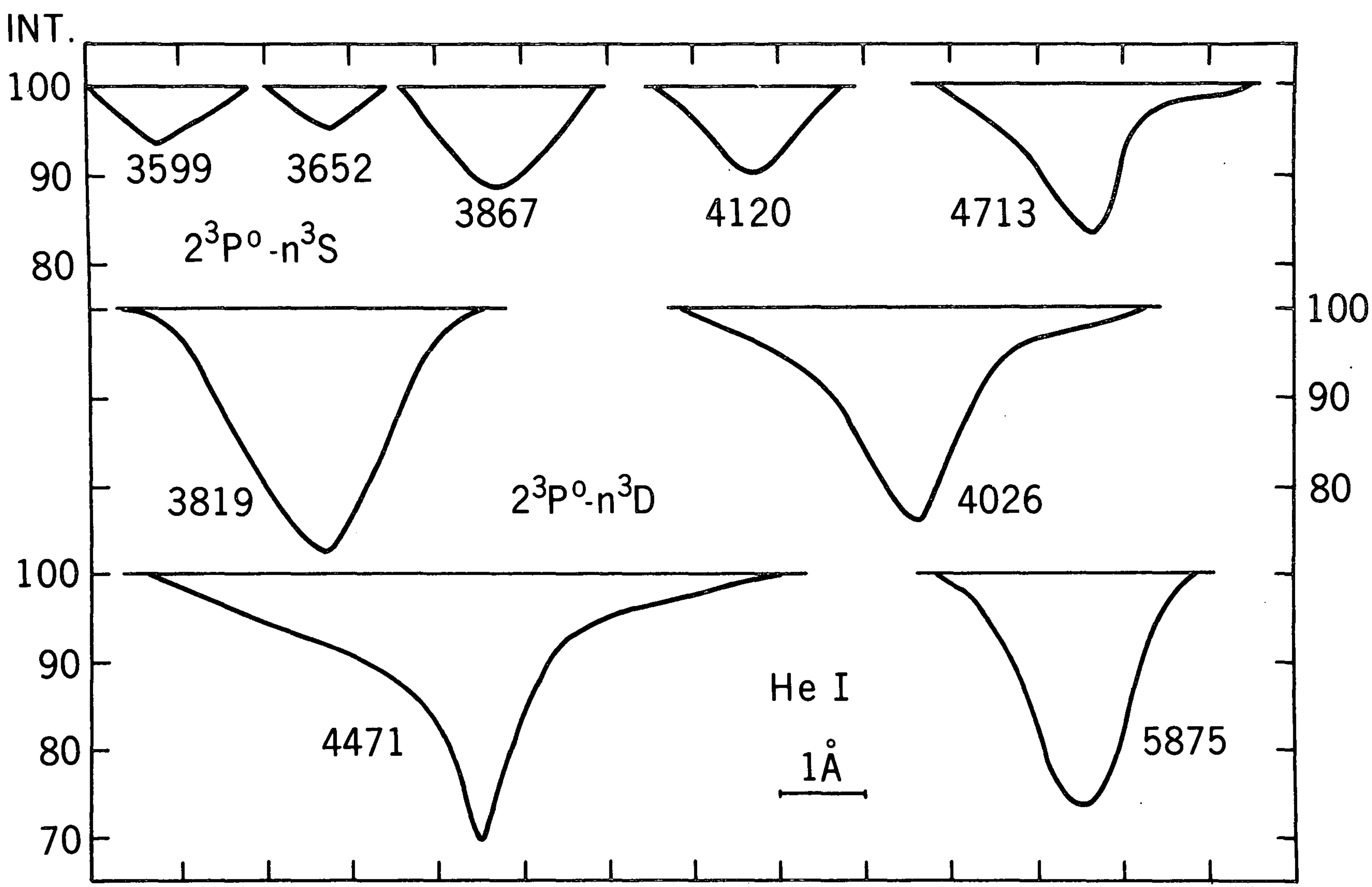
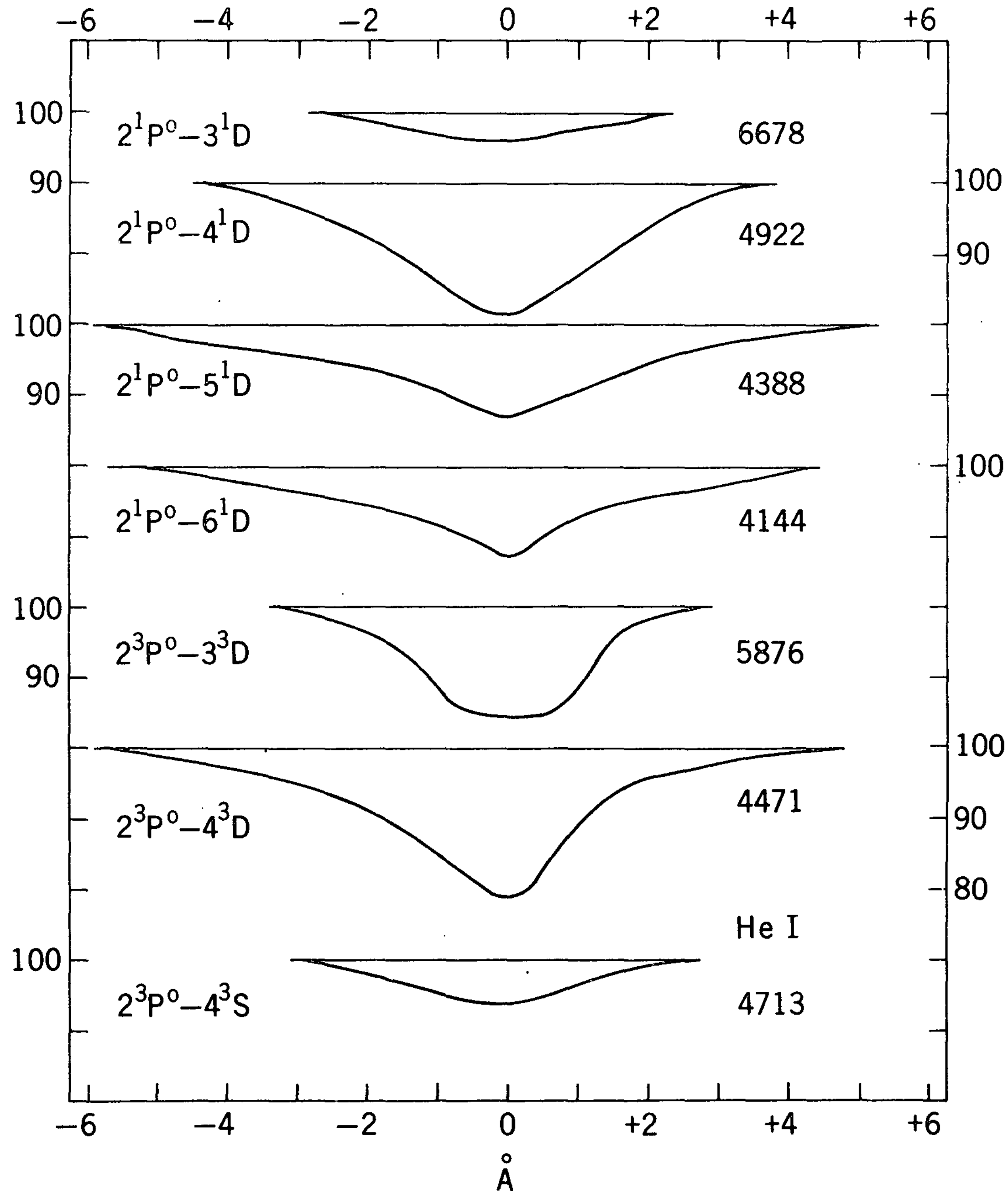

INT.
100
90
100
90
100
90
80
100
90
80
3935
4168
4437
2¹P°-n¹S
3871
2¹P°-n¹D
3926
4009
4143
4387
4921
He I
1Å

FIGURE 4



INT.
100
90
80
100
90
80
70
100
90
80
3599
3652
3867
4120
4713
2³P°-n³S
3819
2³P°-n³D
4026
4471
He I
1Å
5875

FIGURE 5



-6
-4
-2
0
+2
+4
+6
100
90
100
90
100
90
100
100
100
90
100
90
80
100
$2^1P^o-3^1D$
6678
$2^1P^o-4^1D$
4922
$2^1P^o-5^1D$
4388
$2^1P^o-6^1D$
4144
$2^3P^o-3^3D$
5876
$2^3P^o-4^3D$
4471
He I
$2^3P^o-4^3S$
4713
Å

FIGURE 6

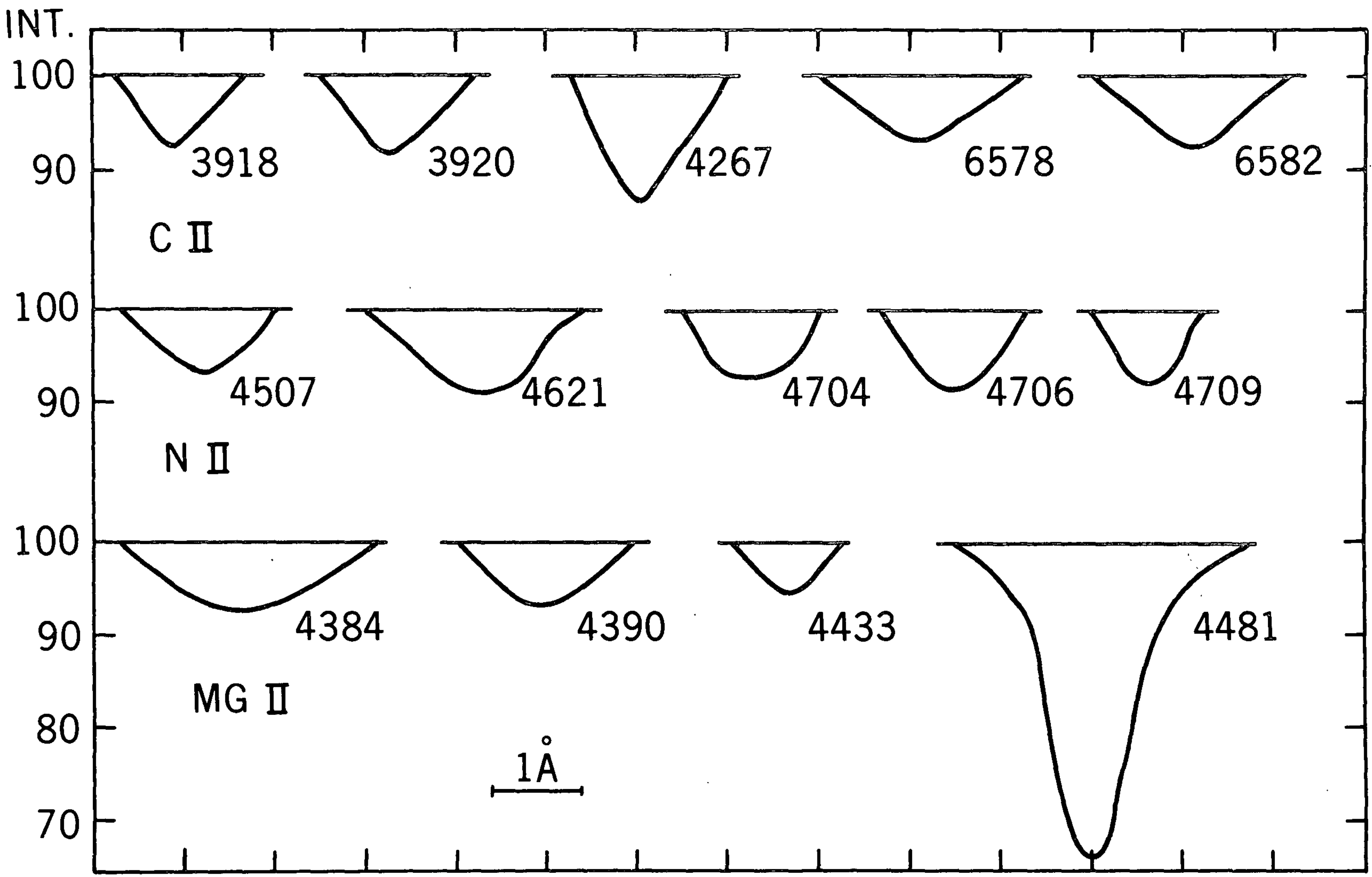

INT.
100
90
100
90
100
90
80
70
3918
3920
4267
6578
6582
C II
4507
4621
4704
4706
4709
N II
4384
4390
4433
4481
MG II
1Å

FIGURE 7

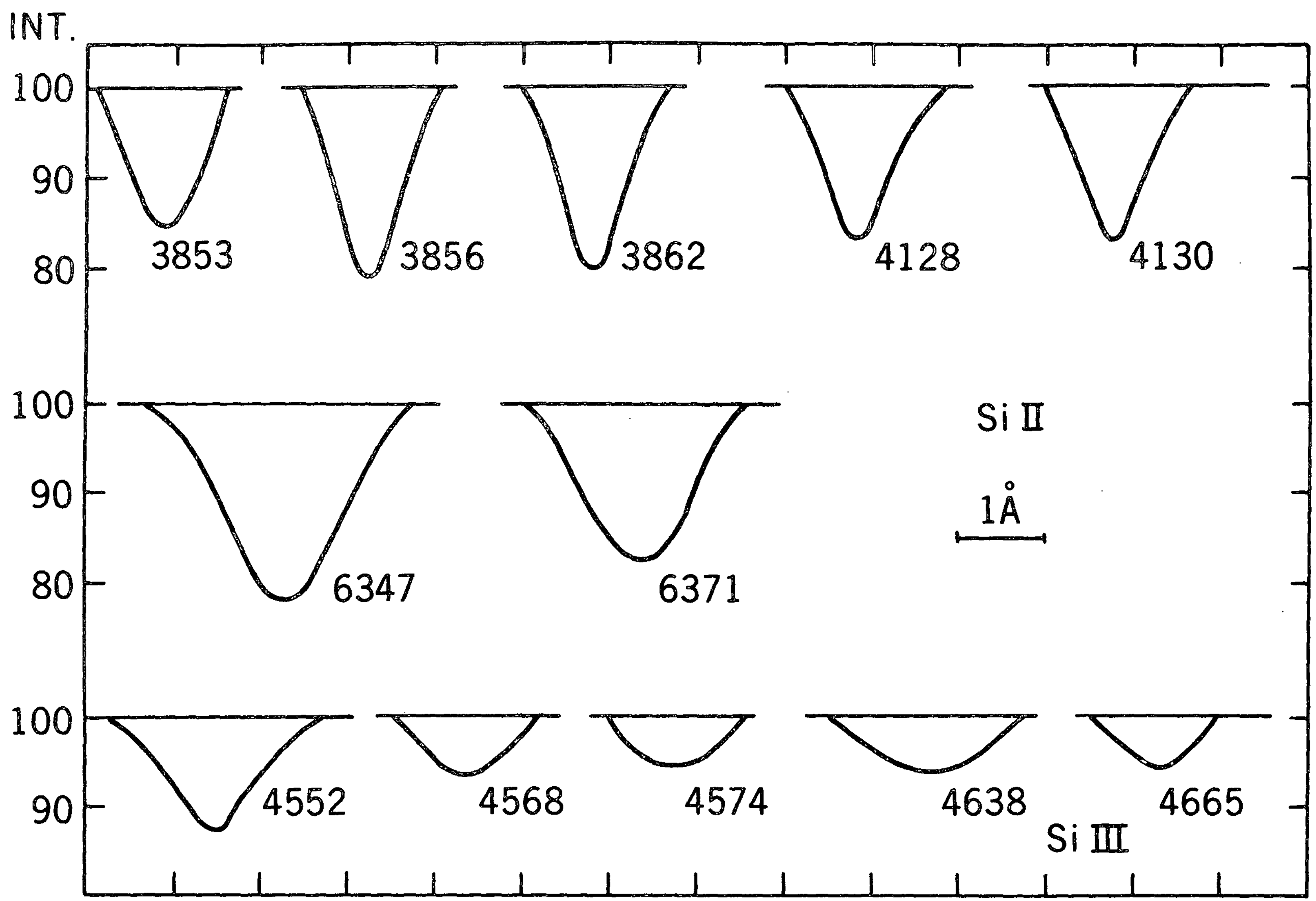

INT.
100
90
80
100
90
80
100
90
3853
3856
3862
4128
4130
6347
6371
Si II
1Å
4552
4568
4574
4638
4665
Si III

FIGURE 8

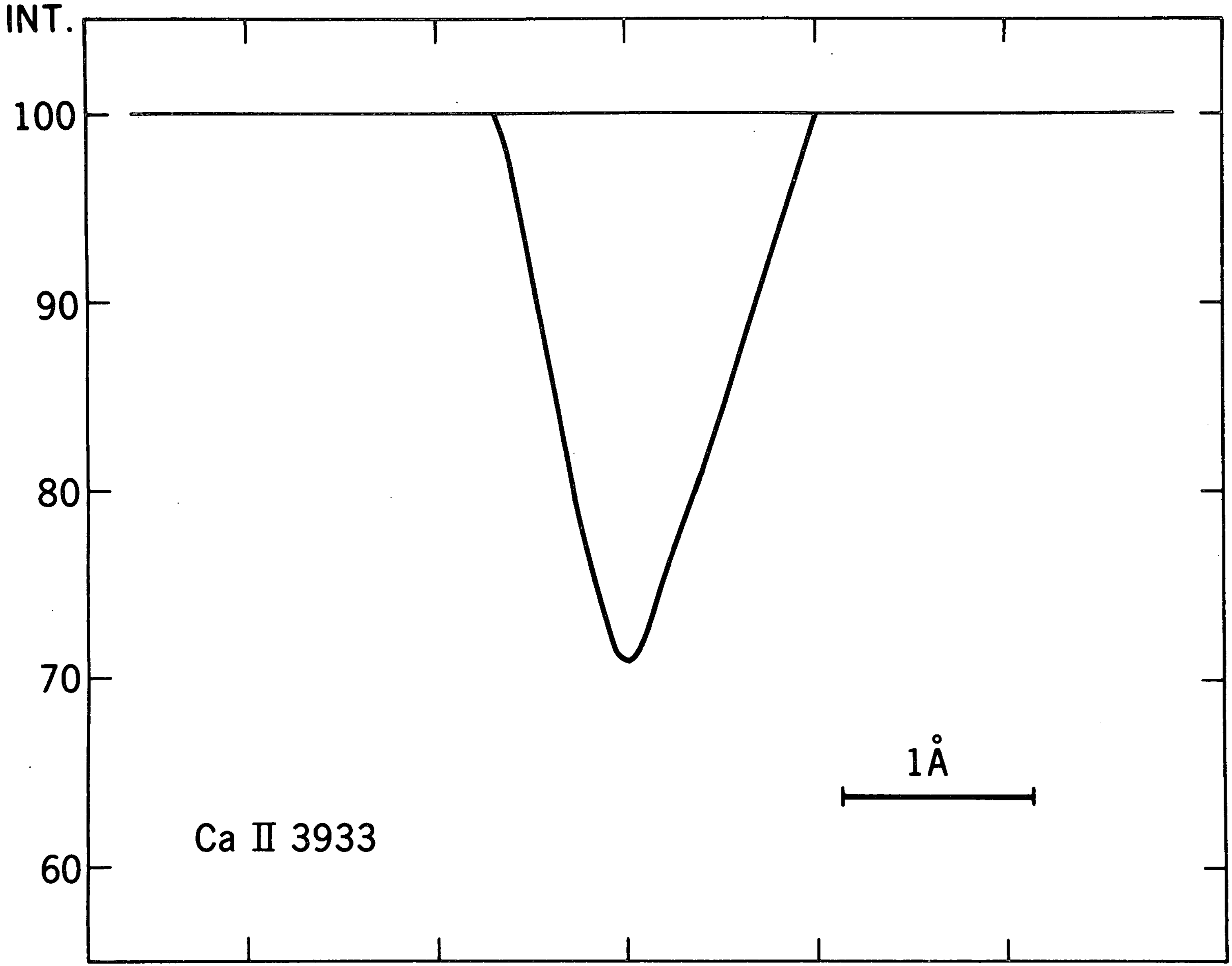


FIGURE 9

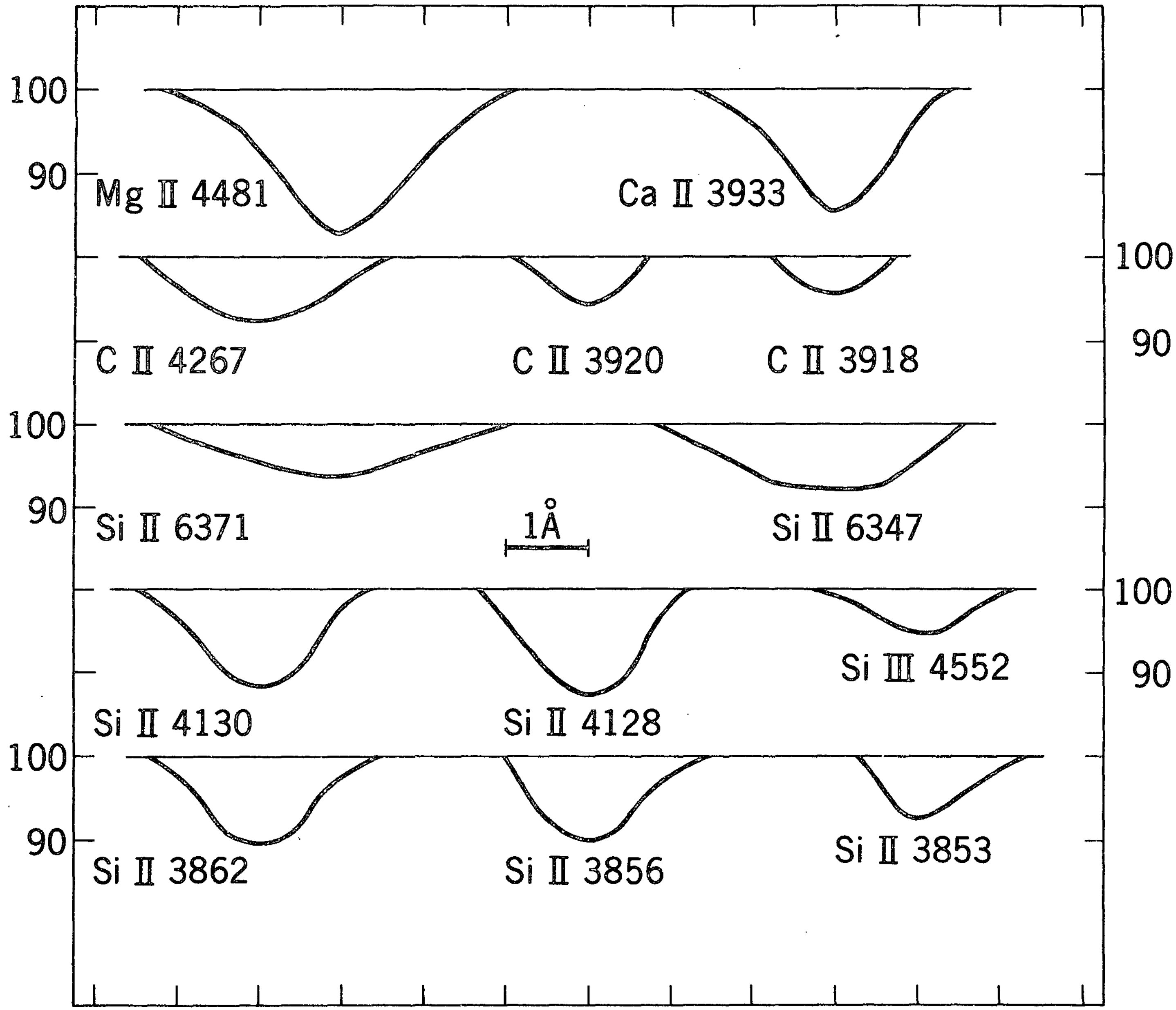

100
90
Mg II 4481
Ca II 3933
100
90
C II 4267
C II 3920
C II 3918
100
90
Si II 6371
1Å
Si II 6347
100
90
Si III 4552
Si II 4130
Si II 4128
100
90
Si II 3862
Si II 3856
Si II 3853

FIGURE 10

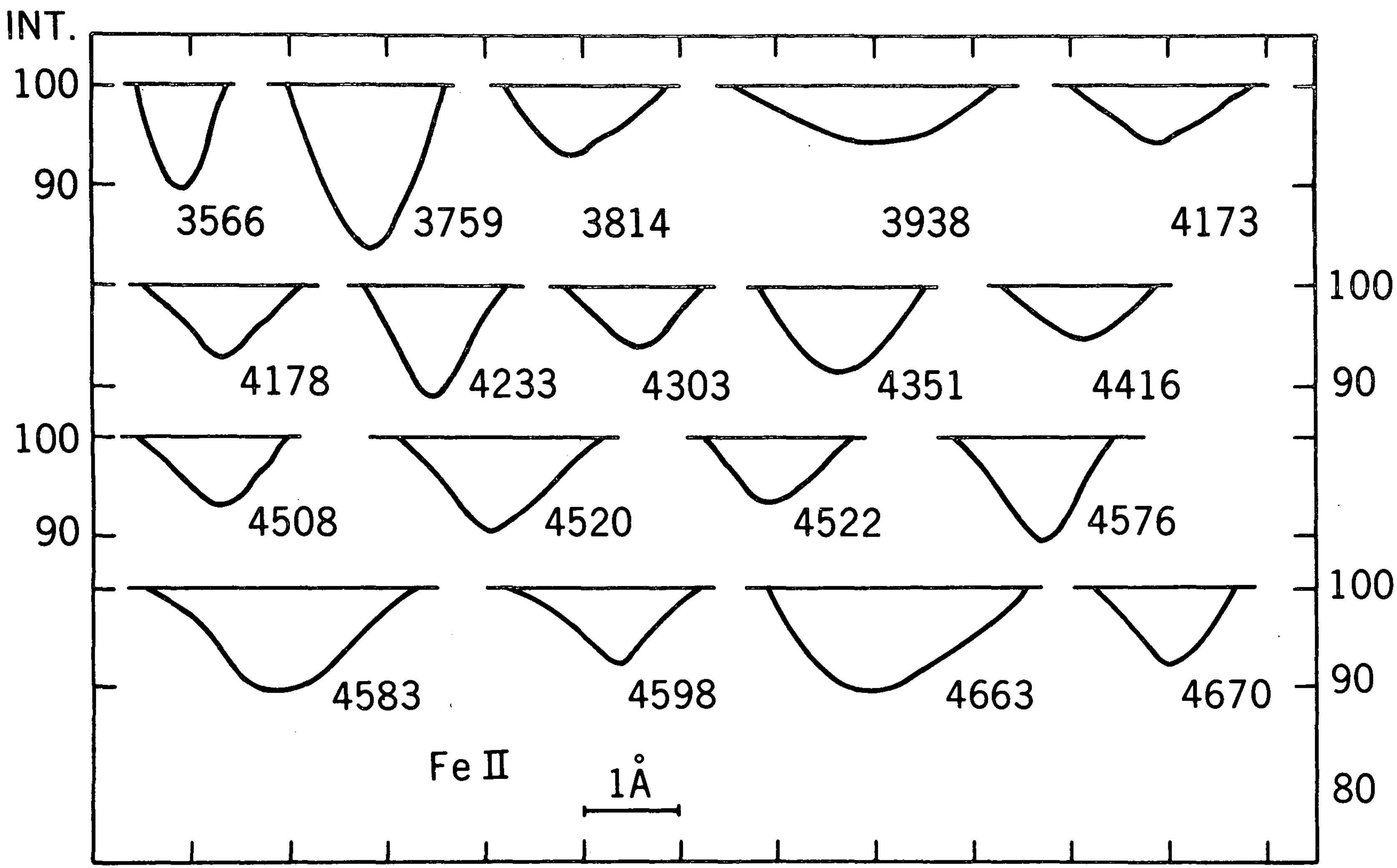

INT.
100
90
100
90
100
90
100
90
80
3566
3759
3814
3938
4173
4178
4233
4303
4351
4416
4508
4520
4522
4576
4583
4598
4663
4670
Fe II
1Å

FIGURE 11

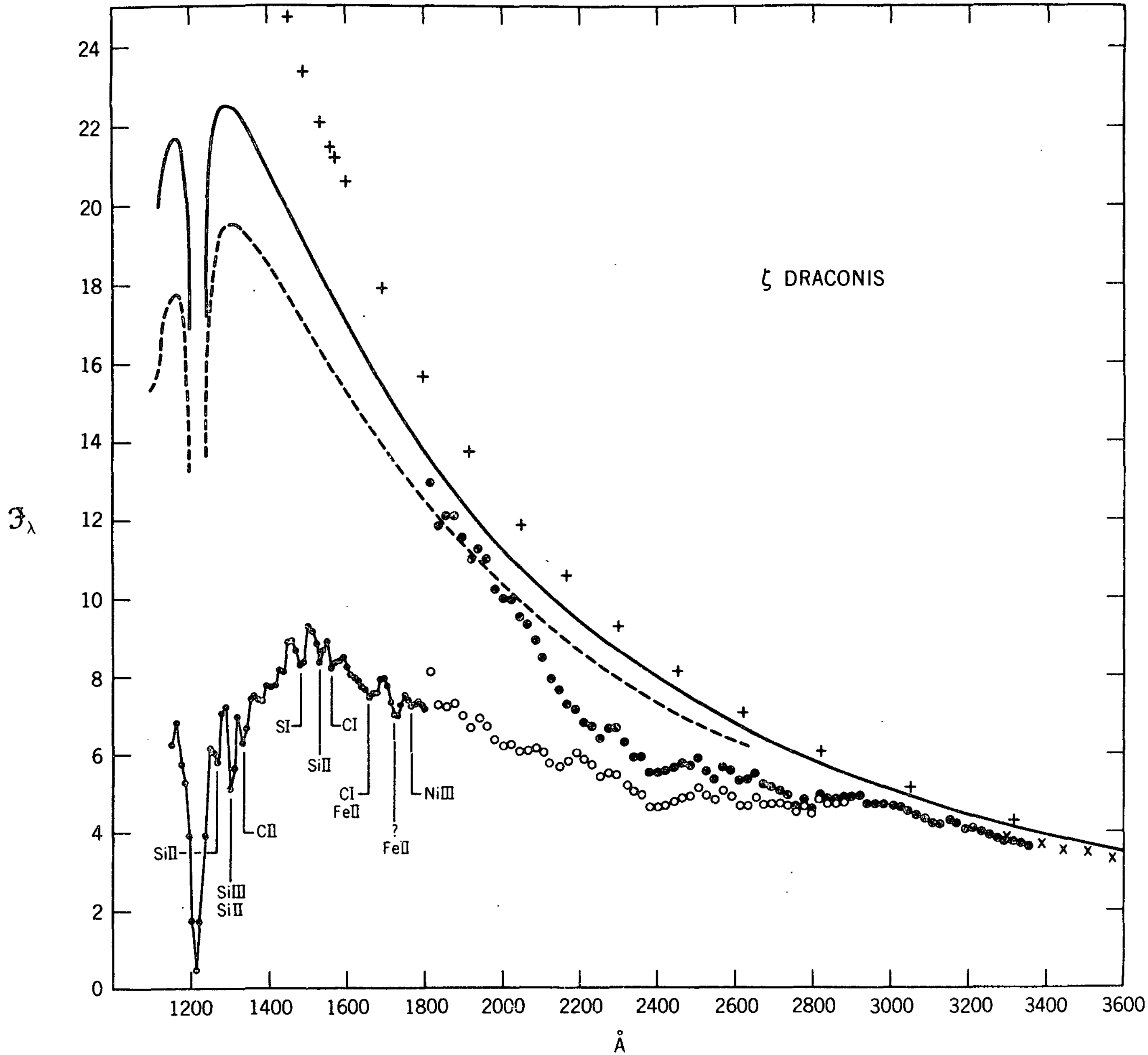
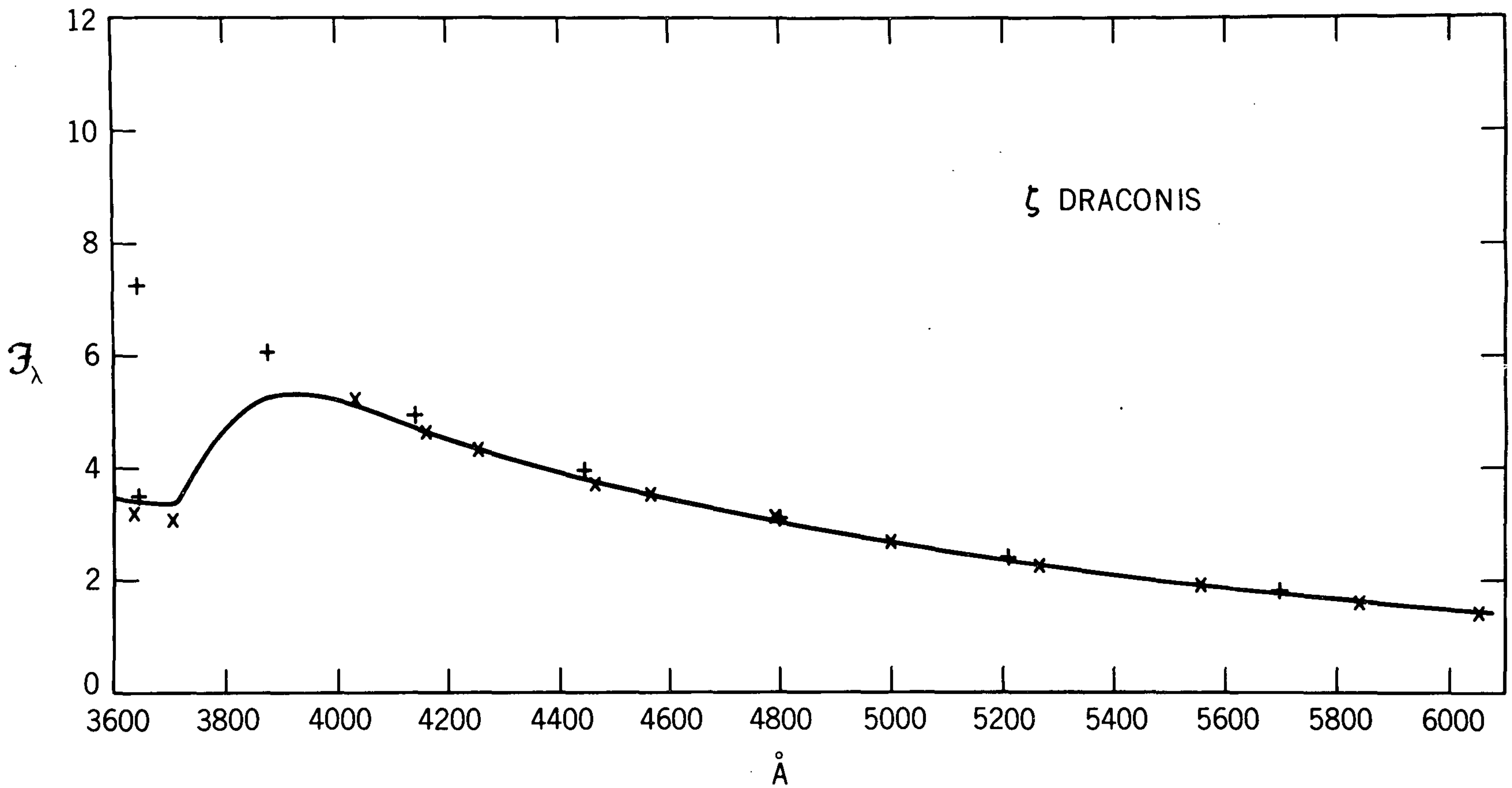
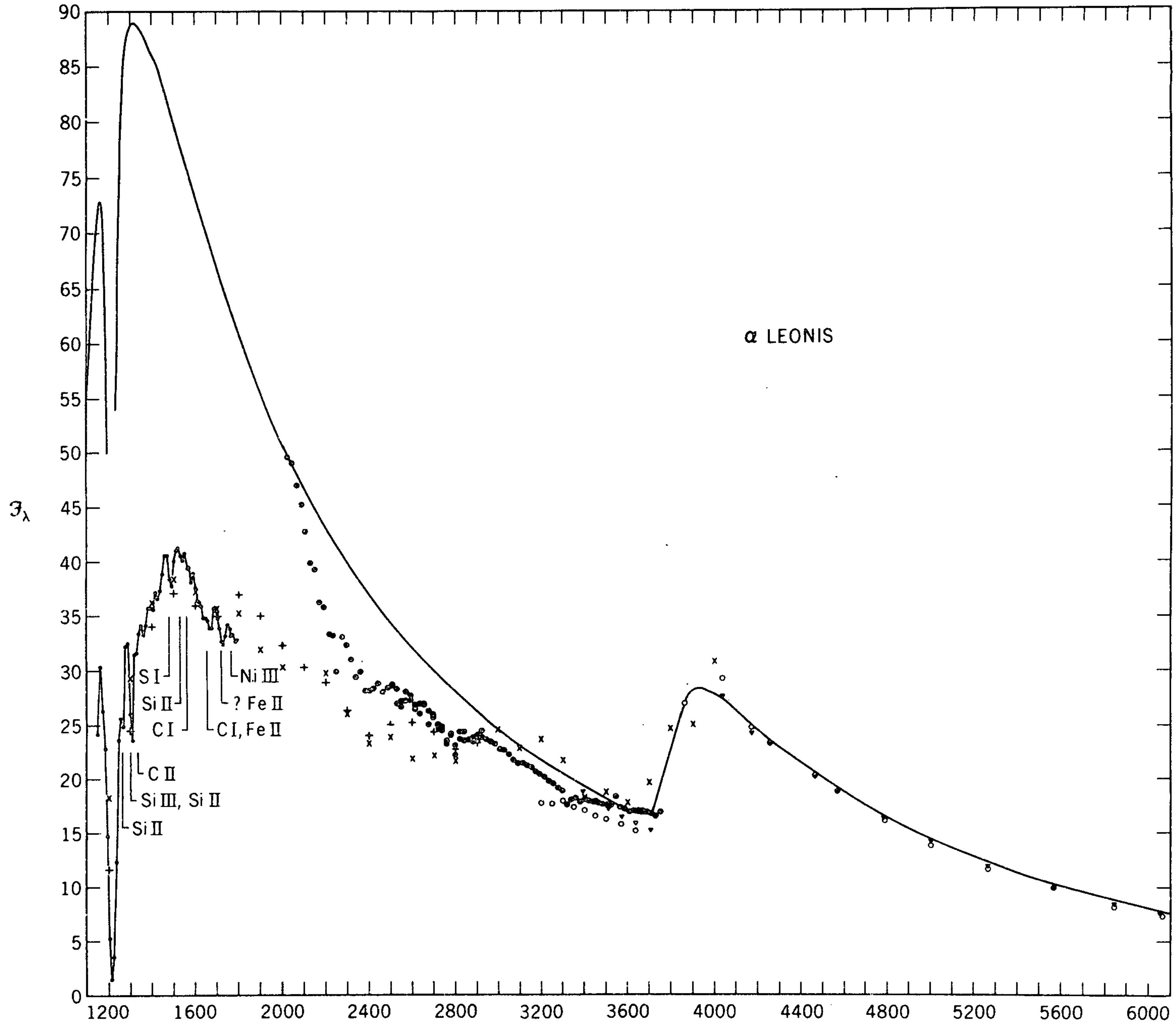

ζ DRACONIS
SiII
SiIII
SiII
CII
SI
SiII
CI
CI
FeII
?
FeII
NiIII
24
22
20
18
16
14
12
10
8
6
4
2
0
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
Å

FIGURE 12a



ζ DRACONIS
$\mathfrak{F}_\lambda$
0
2
4
6
8
10
12
3600
3800
4000
4200
4400
4600
4800
5000
5200
5400
5600
5800
6000
Å

FIGURE 12b



α LEONIS
$\mathcal{F}_\lambda$
S I
Si II
C I
Ni III
? Fe II
C I, Fe II
C II
Si III, Si II
Si II
Å

FIGURE 13

TABLE 1

Published Characteristics of the Stars Studied

Property	ζ Dra	β Sex	α Leo
Spectral Type	B6 III	B6 V	B7 V
V	3.20	5.04	1.36
B-V	-0.15	-0.14	-0.11
$v_r \sin i$	*20 km s^{-1}	*115 km s^{-1}	350 km s^{-1}
rad. velocity	-14.1 km s^{-1}	+11.6 km s^{-1}	+3.5 km s^{-1}
parallax	0".017	-----	0".039
M_v (π)	-0.65	-----	-0.68
M_v ($H\gamma$)	-1.00	-0.00	-----
M_v (type)	-1.9	-0.7	-0.4
T_{eff}	13400°K	-----	12900°K
log g	4.0	-----	4.0

*changed significantly as a result of this study

TABLE 2

THE SPECTROGRAMS STUDIED

Spectrogram	Observatory	Purpose	Wavelength Range (Å)	Dispersion (Å/mm)	Date (U.T.)
			ζ Draconis		
3184	DAO	r,l *	3600-4900	6.4	1967 June 20.366
3185	DAO	r,l	3600-4900	6.4	1967 June 20.373
3877^{1}	DAO	r,l	4000-4500	2.4	1968 July 6.376
3877^{2}	DAO	r,l	3300-4000	2.4	1968 July 6.376
3878^{1}	DAO	r,l	4000-4500	2.4	1968 July 6.402
3878^{2}	DAO	r,l	3300-4000	2.4	1968 July 6.402
3887^{1}	DAO	r	4000-4500	2.4	1968 July 17.311
3887^{2}	DAO	r	3600-4100	2.4	1968 July 17.311
3888	DAO	r	4600-6700	10.0	1968 July 18.212
3889	DAO	r	4600-6700	10.0	1968 July 18.222
$D1257^{1}$	KPNO	r	4200-4800	2.2	1968 June 4.442
$D1257^{2}$	KPNO	r,l	3600-4200	2.2	1968 June 4.442
10146^{1}	Pal.	l	6000-6800	4.5	1967 July 18.212
10151^{1}	Pal.	l	3100-4100	4.5	1967 July 19.195
10151^{2}	Pal.	l	4100-5000	4.5	1967 July 19.195
10154^{1}	Pal.	l	3100-4100	4.5	1967 July 19.348
10154^{2}	Pal.	l	4100-5000	4.5	1967 July 19.348
			β Sextantis		
D246	KPNO	l	3900-4950	8.9	1966 Jan. 3.455
D252	KPNO	l	4250-6700	17.8	1966 Jan. 5.463
D265	KPNO	l	3850-4950	8.9	1966 Jan. 10.512

* r means used for radial velocity; l means used for line profiles

TABLE 3

Equivalent Widths and Central Intensities of Lines in ζ Dra and β Sex

Line	log gf	ζ Draconis W (mÅ)	No.	Rc (%)	No.	β Sextantis W (mÅ)	No.	Rc (%)	No.
HI									
6562.817	+0.710	8362	1	-		7991	1	63.4	1
4861.332	-0.020	8087	2	32.5	2	7907	3	56.0	3
4340.468	-0.447	7859	7	26.8	7	9403	3	38.8	3
4101.737	-0.753	8147	7	26.5	7	9910	2	35.3	2
He I									
6678.149	+2.176	-		-		113	1	96.0	1
5875.618	+0.739	350	1	75.5	1	429	1	84.5	1
4921.929	-0.435	361	1	77.8	1	731	3	81.5	3
4713.143	-0.973	221	1	83.2	1	169	1	93.8	1
4471.477	+0.052	609	5	71.4	5	754	3	79.0	3
4437.549	-2.034	121	1	94.2	1				
4387.928	-0.883	233	7	85.7	7	595	3	87.2	3
4168.971	-2.338	23	2	97.4	2				
4143.759	-1.195	206	5	87.4	4	484	1	87.3	1
4120.812	-1.483	97	3	90.4	3				
4026.189	-0.370	341	3	76.0	3				
4009.270	-1.473	98	3	93.2	3				
3935.914	-2.778	111	3	94.4	3				
3926.530	-1.648	310	2	90.3	2				
3871.819	-1.850	378	1	89.0	1				
3867.477	-1.800	186	2	88.7	3				
3819.606	-0.714	507	3	73.9	3				
3651.971	-2.188	35	1	95.5	1				
3599.304	-2.365	62	1	93.7	1				
CII									
6582.85	-0.206	89	1	92.2	1				

Table 3
cont.

Equivalent Widths and Central Intensities of Lines in ζ Dra and β Sex

Line	log gf	ζ Draconis W (mÅ)	No.	Rc (%)	No.	β Sextantis W (mÅ)	No.	Rc (%)	No.
6578.03	+0.096	90	1	93.8	1				
4267.27	+0.860	132	5	86.5	5	145	3	92.4	3
3920.68	-0.242	76	6	90.7	5	59	2	91.8	2
3918.98	-0.54	63	6	92.2	5	40	2	95.6	1
Mg II									
4481.327	+0.98	395	5	68.2	2	343	3	83.0	3
4436.48	-0.73	16	1	96.2	1				
4433.991	-0.93	50	2	94.9	1				
4427.995	-1.23	21	1	-					
4390.585	-0.56	115	3	93.4	3				
4384.643	-0.81	119	3	92.7	3				
Si II									
6371.359	-0.024	246	1	87.2	1	245	1	93.5	1
6347.091	+0.279	344	1	78.0	1	195	1	92.5	1
4130.884	+0.747	160	6	82.4	5	178	1	88.3	1
4128.053	+0.571	156	7	82.1	6	188	1	87.5	1
3862.592	-0.870	153	5	82.2	6	166	1	89.5	1
3856.021	-0.613	159	5	81.3	4	144	1	89.8	1
3853.657	-1.569	124	5	82.8	4	91	1	92.5	1
Si III									
4665.87	-0.52	53	1	94.0	1				
4638.12	-0.38	86	1	93.8	1				
4574.777	-0.406	64	1	93.8	1				
4567.872	+0.070	52	1	94.8	1				
4552.654	+0.290	155	1	85.9	3	74	2	94.8	2
CaII									
3933.664	+0.140	281	1	71.0	1	222	1	85.5	1

TABLE 4

Equivalent Widths and Central Intensities of Lines in ζ Draconis

Line	log gf	W (mÅ)	Rc (%)	No.	Line	log gf	W (mÅ)	Rc (%)	No.
NII					Fe II				
4507.56	-1.237	68	93.0	1	4515.34	-1.91	18	97.2	1
4621.39	-0.54	120	91.3	1	4508.28	-1.76	55	93.5	1
4704.33		75	92.7	1	4472.29	-2.80	17	96.5	1
4706.41		85	91.5	1	4416.82	-2.09	47	94.8	1
4709.45		67	92.5	1	4351.76	-1.76	106	91.3	1
OII					4303.17	-2.00	43	94.7	2
4676.23	-0.296	71	91.7	1	4296.57	-2.36	38	95.2	1
SII					4278.13	-3.15	23	96.6	1
4924.08	-0.32	41	96.0	1	4273.32	-2.27:	22	95.8	1
4213.5	-1.30	46	96.3	1	4233.17	-1.43	120	87.1	2
3923.48	+0.44	196	92.1	1	4178.85	-2.00	72	92.3	2
Fe II					4177.70	-2.94	16	92.4	1
4670.17	-2.87:	62	92.6	1	4173.45	-2.01	60	94.3	2
*4663.70	-2.57:	160	89.7	1	4128.74	-2.76	20	97.0	1
4598.53	-0.72	71	92.4	1	3938.97	-1.39	96	94.4	1
4591.26		85	91.5	1	3814.12	-1.82	68	93.0	1
*4583.83	-1.25	155	89.5	1	3759.46	-1.39	157	83.5	2
4576.33	-2.22	92	89.5	1	3566.05	-1.81:	57	89.5	1
4522.63	-1.51	51	94.0	1					
4520.24	-1.87:	114	90.5	1					

* blended with other lines

Table 5. Measured Radial Velocities of ζ Draconis

Plate No.	Rad. Velocity ($km\ s^{-1}$)	No. Lines
3184	− 13.8	21
3185	− 16.3	7
3877[1]	− 17.5	4
3877[2]	− 14.6	14
3878[1]	− 13.6	4
3878[2]	− 16.9	7
3887[1]	− 16.8	3
3887[2]	− 15.1	15
3888	− 13.5	2
3889	− 13.5	2

TABLE 6

Estimated Rotational Velocities, $v_R \sin i$, in km s^{-1}

	ζ Draconis				β Sextantis			
A(x)/A(o)	0.00	0.30	0.50	0.75	0.00	0.30	0.50	0.75
CII	56	41	36	19	68	51	47	40
NII	53	42	43	25				
MgII	66	44	49	23				
SiII	65	42	34	21	103	78	67	63
Si III	61	45	37	22	95	63	54	51
Fe II	53	41	43	20				
Av Value	59	44	40	22	89	64	56	51

TABLE 7

Star Type	M_v	Distance (pc)	Model T_{eff} (°K)	log g	R/R⊙ eqt.(3)	R/R⊙ eqt.(4)	M/M⊙	source for Mv
ζ Dra	-0.65	58.8	13000	4.0	3.60	3.42	2.71	parallax
B6III			14000	4.0	3.39	3.28	2.41	
	-1.00*	69.2	13000	4.0	4.24	4.08	3.75	W(Hγ)
			14000	4.0	4.00	3.86	3.34	
	-1.9	105	13000	4.0	6.43	6.17	8.64	spectral type
			14000	4.0	6.06	5.83	7.68	
β Sex	0.00	102	14000	4.0	2.58	2.43	2.41	W(Hγ)
B6V			15000	4.0	2.42	2.28	2.12	
	-0.70*	141	14000	4.0	3.56	3.36	4.60	spectral type
			15000	4.0	3.34	3.14	4.06	
α Leo	-0.40*	22.5	12000	4.0	3.44	3.31	4.31	spectral type
B7V			13000	4.0	3.23	3.09	3.79	
	-0.68	25.6	12000	4.0	3.93	3.77	5.59	parallax
			13000	4.0	3.68	3.52	4.92	

* preferred value, see text