LINE BLANKETING MEASUREMENTS

FOR THE STAR PROCYON

By

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CHAPTER I

INTRODUCTION

Originally, "line blanketing" (or "line blocking" as it is sometimes called) referred to the effect of absorption lines on the temperature distribution of a stellar atmosphere. If the radiation of a star in the photospheric layers is assumed to be a blackbody curve with the absorption lines in the observed radiation curve due to the cooler gases of the star's atmosphere, then these lines could be said to "block" the radiation. The level of radiation exclusive of the blocking effect is the continuum level. At a given wavelength blanketing reduces the observed emergent flux. It should be noted that this blocked radiation at the so-called "reversing layer" must eventually pass through at another wavelength if the assumption of equilibrium, which is essential to numerous calculations, is to hold. Therefore, the result is an increase in the continuum flux between the lines. The back-scattered radiation causes an increase in temperature in the photospheric layers. This is sometimes called the back-warming effect. If all lines were removed, the level of the continuum would drop from F_1 to F_2 where

$$\int_0^\infty F_2(\lambda)\, d\lambda = (1-\eta_T) \int_0^\infty F_1(\lambda)\, d\lambda\,. \qquad (1\text{-}1)$$

η_T is the blanketing factor for all wavelengths. These factors and the distortion of energy distribution produce a significant color change. Change in U, B, and V magnitudes due to the back-warming effect alone is

$$\Delta M = 2.5 \log \frac{\int F_1(\lambda) S(\lambda) d\lambda}{\int F_2(\lambda) S(\lambda) d\lambda}, \qquad (1\text{-}2)$$

where $S(\lambda)$ is a function dependent on the photometric system. Interdependency of blackbody curves and temperature and color brings about a relationship among all these values due to line absorption.

Most of the early work concentrated on the sun. Subsequently, calculations for an increasing number of stars over wider wavelength ranges have been made. Also, the term line blanketing has become somewhat more encompassing in that it includes the absorption line effect as applied to those previously mentioned and other determinations as discussed in part here and in Chapter II.

The importance of line blanketing with respect to composition is made apparent by the determination that the effects of composition on the ionization relation and the continuous absorption coefficient are small, while absorption lines are the most sensitive to composition of a star. Therefore, as would be expected, line-blanketing effects vary according to the spectral type of a star. A change in chemical composition will change the interior structure of the star and hence, the effective temperature. Lines in moderate temperature stars come mostly from the metals group due to elements such as potassium, calcium, and iron. Normal stars are composed mainly of hydrogen and helium, but they still have enough of the heavier elements to undergo a large blanketing effect. Absorption lines due to metals are stronger and more crowded in the blue spectral region than in the visual and still more crowded in the ultraviolet. Subdwarfs, however, have a distinct lack of metals which causes much less radiation distortion than in a normal star and makes them appear bluer for the same temperature. They have an ultraviolet "excess" expressed as a difference in (U-B) for a subdwarf and normal star of same (B-V).

This would account for some if not all of the shift of subdwarfs off the main sequence in the color-magnitude diagram. Sandage and Eggen (1959) give a procedure correcting U-B, B-V, and V by using the observed ultraviolet excess, δ(U-B). They made use of data similar to the type in this report for their evaluation.

How this effect is analyzed and applied to problems varies, but of basic interest is the loss of flux due to these lines over a given wavelength range. By using the intensitometer tracings of the radiation from a star, the continuum may be found directly on the tracings as explained in Chapter III. The ratio of the area under the intensitometer tracing to the area under the continuum for a given wavelength range is called the blanketing coefficient, γ, where this is equivalent to

$$\gamma_\lambda = \int_\lambda^{\lambda + \Delta\lambda} F_\lambda d\lambda \Big/ \int_\lambda^{\lambda + \Delta\lambda} F_c d\lambda , \qquad (1\text{-}3)$$

where F_λ is the observed flux and F_c is the continuum flux. The blanketing factor is

$$\eta_\lambda = 1 - \gamma_\lambda . \qquad (1\text{-}4)$$

These are the measurements which are determined in this investigation over the wavelengths of available data.

CHAPTER II

DISCUSSION ON USES OF LINE BLANKETING MEASUREMENTS

Numerous studies have been made incorporating line-blanketing measurements. Line blanketing is an essential part of model atmosphere calculations. The corrections for the measured flux are necessary for comparison of emergent fluxes, one flux being observationally determined and the other calculated by the selection of a model atmosphere. Edmonds (1964) calculated a set of non-gray model atmospheres for Procyon, the selection being best made with respect to effective temperature by comparing the variation with wavelength of the measured emergent flux with that predicted by the model atmosphere. The blanketing factor (η_T) for all wavelengths and effective temperature (T_e) corrected for line blanketing are used in calculating a star's radius (R) where

$$R^2 = \frac{L_o d^2}{\sigma T_e^4 (1-\eta_T)} . \qquad (2\text{-}1)$$

d is the star's distance, σ the Stefan-Boltzmann constant, and L_o the observed luminosity. Other values determined within Edmonds' analysis which used line blanketing include bolometric magnitudes, effective surface gravity, luminosity, and the temperature-optical depth relation.

Due to the back-warming effect, the background continuum flux corresponds to a model of higher effective temperature, T_e', than the true stellar effective temperature, T_e. The value, T_e, may be calculated by

$$\sigma T_e^{\,4} = \sigma T_e'^{\,4} - \Delta F(o), \tag{2-2}$$

where $\Delta F(o)$ is the flux absorbed by the lines.

Atmospheric effects on the color of subdwarfs are discussed in a note by Schwarzchild, Searle, and Howard (1955). They converted the mean blanketing fractions into magnitudes by using

$$\Delta B = 2.5 \log (1-\bar{\eta}_B), \tag{2-3}$$

where $\bar{\eta}_B$ is a weighted mean for a blue range from λλ3850-4900. Similar methods could be used for the yellow range, then

$$\Delta B - \Delta V = \Delta C, \tag{2-4}$$

which is the blanketing correction for color. For advancing spectral types, ΔC increases. They also noted that due to line weakness a subdwarf has too small a color correction for its spectral type. Parsons (1970) evaluates UBV color indices relationships using blanketing factors. He also makes calculations using a six-color (UVBGRI) system.

The effective temperature of a star may be calculated using color indices, but the blanketing factors must be taken into account. The change in temperature due to line blanketing has been calculated by Sandage and Eggen (1959) for subdwarfs in the Hyades.

Thomas (1965) studied the line-blanketing effect on effective temperature with respect to local thermodynamic equilibrium (LTE). He found that the effect is considerably less than when using a non-LTE approach.

Monochromatic magnitudes may be defined by

$$\Delta m = -2.5 \log \frac{F_\nu(\lambda)}{F_\nu(5560)} , \tag{2-5}$$

where $F_\nu(\lambda)$ is the monochromatic flux per frequency interval centered on λ. $F_\nu(5560)$ is chosen as a standard for comparison. The blanketing-free monochromatic flux (Δm^*) may then be obtained by

$$\Delta m^*(\lambda^{-1}) = \Delta m\ (\lambda^{-1}) + 2.5 \log (\gamma_\lambda/\gamma_o), \tag{2-6}$$

where γ_o is the mean blanketing coefficient at about 5560 Å. Data pertaining to this are calculated in the Appendix.

Myrick (1970) in his thesis covering material similar to that in this thesis summarized line blanketing as used by Milne (1922), Chandrasekhar (1935), Münch (1946), and Athay and Skumanich (1969) which can be referred to if additional information is desired.

CHAPTER III

OBSERVATIONAL DATA

The star, Procyon (Alpha Canis Minoris), used in this study is a subgiant (luminosity class IV-V) with a visual magnitude of 0.5 (Keenan and Morgan 1951). Its spectral type is F5, and coordinates are: $\alpha(1900) = 7^h\ 34.1^m$; $\delta(1900) = +5^\circ 29'$. The Procyon spectograms were taken at the Cassegrain focus of the 72-inch telescope of the Dominion Astrophysical Observatory by Dr. K. O. Wright. The dispersion ranged from 4.6 Å/mm at 4050 Å to 7.0 Å/mm at 5500 Å (Schroeder 1958). Microphotometer and intensitometer tracings were made at Victoria by Dr. Marshal H. Wrubel. Tracing magnification used was 200. Listings of information pertaining to this data appear in Table I. The continuum was drawn directly on the intensitometer tracings as the average of the galvanometer deflections due to the plate grain in the regions between the lines by Dr. Leon W. Schroeder. In a few cases the continuum was first drawn on the microphotometer tracing and then transferred to the intensitometer tracing. The continuum in the vicinity of the Balmer lines was located in this manner since the more compact nature of the microphotometer tracing made drawing in the continuum over the large width of these lines easier.

Numerous lines were already identified on the intensitometer tracings by previous investigators. Some additional ones were identified by the author, and then the lines close to each 25-Å interval were used to calculate the dispersion of the intensitometer tracings in the region

TABLE I

PLATE, MICROPHOTOMETER, AND INTENSITOMETER DATA

Victoria Plate Number	Microphotometer and Intensitometer Tracing Number	Wavelength Range (Angstroms)
43168	636	3899 - 4086
43329	613	4028 - 4428
43331	612	4035 - 4428
43167	638	4224 - 4598
43169	639	4224 - 4405
43189	616	4394 - 4792
43191	617	4399 - 4795
43330	614	4547 - 4740
43332	615	4544 - 4740
43182	623	4773 - 5220
43185	624	4740 - 5220
43188	621	4919 - 5289
43190	622	4917 - 5295
43259	625	5135 - 5627
43262	626	5177 - 5626
43183	627	5388 - 5626
43186	628	5388 - 5658

near each interval which in turn was used to rule off the tracings exactly at these 25-Å intervals. Line identification was made by reference to the tables in Swensson's (1946) paper on "The Spectrum of Procyon" and A Multiplet Table of Astronomical Interest, Revised Edition, (RMT) by Moore (1945).

The blanketing coefficient is defined by Equation (1-3) where $\Delta\lambda$ is chosen as 25-Å. The blanketing coefficient is therefore a measure of the fraction of the continuum flux which is emitted in this 25-Å range. The number of tracings used to determine the coefficients for each range is given in Table II (Chapter IV).

The actual determination of the coefficient requires the measurement of the area enclosed by the continuum over the interval $\Delta\lambda$, and then the area below the line profiles on the intensitometer tracing. An OTT-Rolling Disk Planimeter was used in the measurement of the areas involved. A clockwise movement of the planimeter's tracing point over the curves was used with both continuum and tracing area measurements being made at the same time to limit variance. Due to a partial common boundary shared by the tracing and continuum areas, it was possible to overlap the two measurements associated with a single 25-Å range. This increased the speed of measurement and produced additional error limitation with the basis being if a line on the common boundary were not followed accurately, it would make both areas larger or smaller by the same amount. Since the two areas are nearly the same in most cases and never is the tracing area less than one-half the continuum area, this would make the ratio error less than if only one of the two areas were mismeasured by this same amount.

The planimeter readings were recorded with a setting of 44.40 on the planimeter arm. The ratios were calculated without the conversion of units, and ratio averages were calculated where more than one set of readings were taken due to duplication on different tracings. Large differences were rechecked to limit the chance of recording errors.

The blanketing factor, η_λ, is then calculated simply from Equation (1-4). These values are given in Table II for $\lambda\lambda$3900-5650.

Scale drawings of a microphotometer tracing and an intensitometer tracing are shown in Figures 1 and 2. Figure 3 shows the method of blanketing coefficient calculation by area measurement.

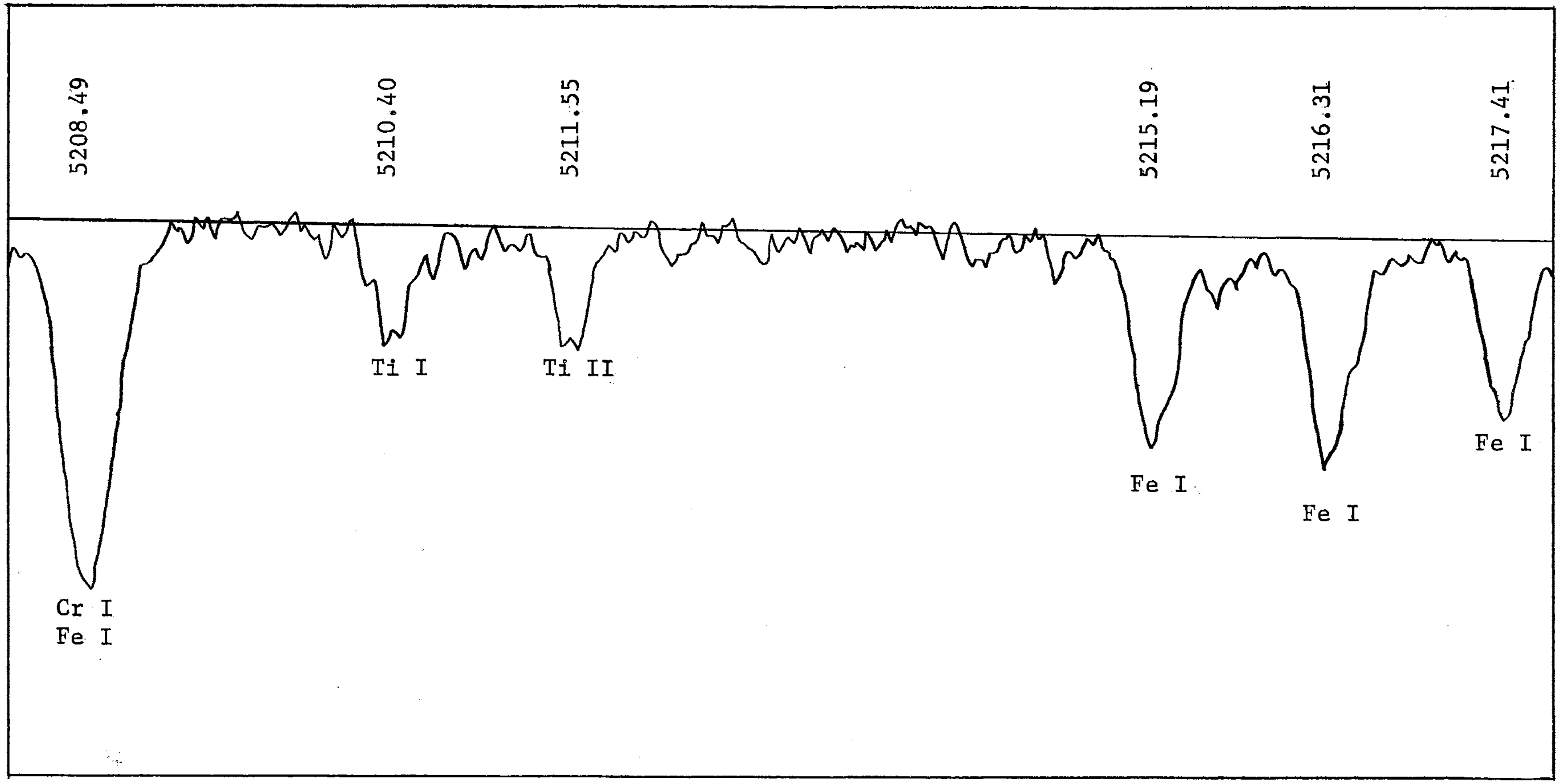

Figure 1. Scale Drawing of Microphotometer Tracing With Continuum Inserted and Lines Identified

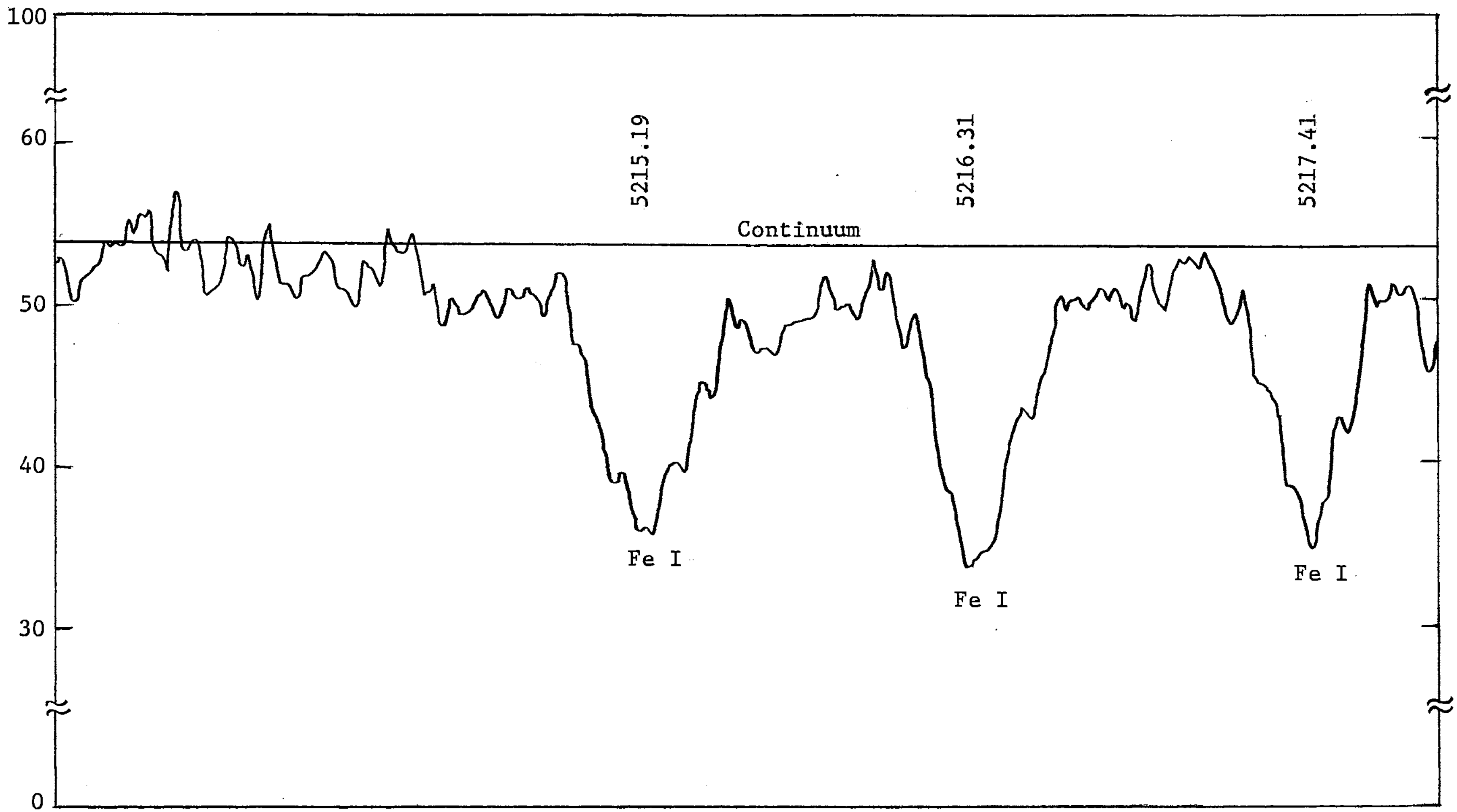

Figure 2. Scale Drawing of Intensitometer Tracing With Continuum Inserted and Lines Identified

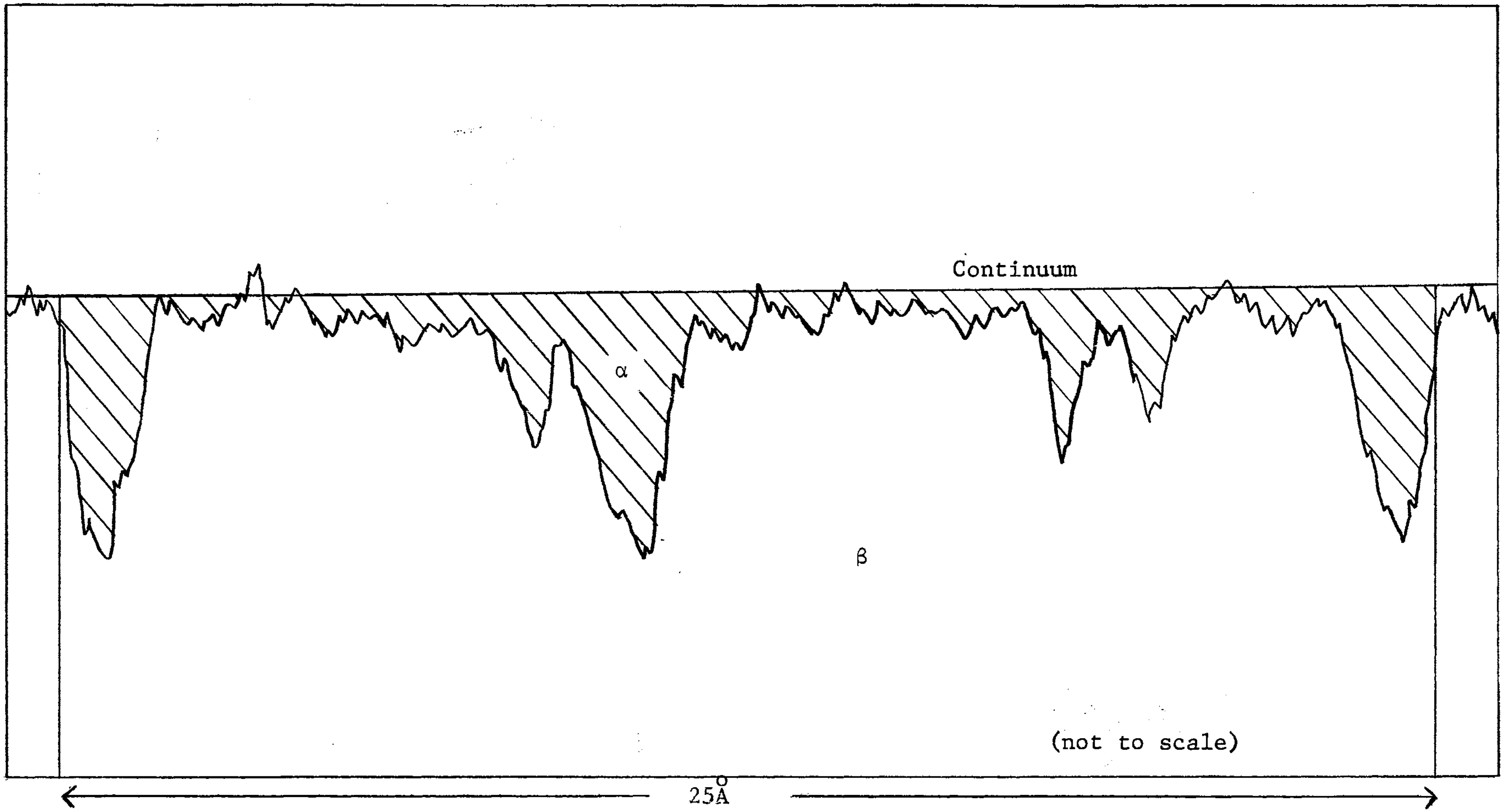

Figure 3. Sample Intensitometer Tracing Showing the Method of Determining the Blanketing Coefficient for a 25-Å Interval by Area β/Area (α + β)

CHAPTER IV

RESULTS

The object of this study was to obtain the line-blanketing coefficients for the stellar spectrum under consideration. The values are listed in Table II along with other pertinent information.

Column 1 lists the wavelength (RMT) in Å of the lower limit of the 25-Å interval being measured.

Column 2 shows the reciprocal wavelength in microns.

The number of different tracings employed to obtain the corresponding blanketing coefficient is listed in Column 3.

The blanketing coefficient, γ, is written in Column 4, and Column 5 has the blanketing factor, η.

The blanketing factors are displayed in Figures 4 through 8 with 350 Å covered on each graph. Figure 9 shows the entire range of $\lambda\lambda$3900-5650.

TABLE II

BLANKETING COEFFICIENTS (25-Å INTERVALS) FOR λλ3900-5650

λ	λ^{-1}	Number of Tracings	γ	η
3900	2.564	1	0.7818	0.2182
3925	2.548	1	0.5481	0.4519
3950	2.532	1	0.5647	0.4353
3975	2.516	1	0.7917	0.2083
4000	2.500	1	0.8445	0.1555
4025	2.484	1	0.8560	0.1440
4050	2.469	3	0.8320	0.1680
4075	2.454	2	0.7608	0.2392
4100	2.439	2	0.7372	0.2628
4125	2.424	2	0.8430	0.1570
4150	2.410	2	0.8297	0.1703
4175	2.395	2	0.8384	0.1616
4200	2.381	2	0.8658	0.1342
4225	2.367	3	0.8334	0.1666
4250	2.353	3	0.8432	0.1568
4275	2.339	4	0.8304	0.1696
4300	2.326	4	0.7987	0.2013
4325	2.312	4	0.7068	0.2932
4350	2.299	4	0.8714	0.1286
4375	2.286	4	0.8593	0.1407
4400	2.273	6	0.8689	0.1311
4425	2.260	2	0.8810	0.1190
4450	2.247	2	0.8627	0.1373

TABLE II (Continued)

λ	λ^{-1}	Number of Tracings	γ	η
4475	2.235	3	0.8914	0.1086
4500	2.222	3	0.9180	0.0820
4525	2.210	3	0.8668	0.1332
4550	2.198	5	0.9131	0.0869
4575	2.186	3	0.8991	0.1009
4600	2.174	3	0.9166	0.0834
4625	2.162	3	0.9294	0.0706
4650	2.150	4	0.9250	0.0750
4675	2.139	4	0.9454	0.0546
4700	2.128	4	0.9314	0.0686
4725	2.116	2	0.9402	0.0598
4750	2.105	3	0.9269	0.0731
4775	2.094	2	0.9260	0.0740
4800	2.083	2	0.9286	0.0714
4825	2.073	2	0.9095	0.0905
4850	2.062	2	0.7300	0.2700
4875	2.051	2	0.8858	0.1142
4900	2.041	2	0.9022	0.0978
4925	2.030	3	0.9268	0.0732
4950	2.020	4	0.9340	0.0660
4975	2.010	3	0.9188	0.0812
5000	2.000	3	0.8959	0.1041
5025	1.990	4	0.9151	0.0849
5050	1.980	4	0.9378	0.0622

TABLE II (Concluded)

λ	λ^{-1}	Number of Tracings	γ	η
5075	1.970	4	0.9214	0.0786
5100	1.961	3	0.9495	0.0505
5125	1.951	4	0.9150	0.0850
5150	1.942	5	0.8896	0.1104
5175	1.932	5	0.9102	0.0898
5200	1.923	4	0.9298	0.0702
5225	1.914	4	0.9238	0.0762
5250	1.905	4	0.9009	0.0991
5275	1.896	2	0.9284	0.0716
5300	1.887	2	0.9455	0.0545
5325	1.878	2	0.9275	0.0725
5350	1.869	2	0.9505	0.0495
5375	1.860	2	0.9525	0.0475
5400	1.852	2	0.9370	0.0630
5425	1.843	4	0.9542	0.0458
5450	1.835	4	0.9562	0.0438
5475	1.826	4	0.9498	0.0502
5500	1.818	4	0.9609	0.0391
5525	1.810	4	0.9592	0.0408
5550	1.802	4	0.9632	0.0368
5575	1.794	4	0.9504	0.0496
5600	1.786	3	0.9592	0.0408
5625	1.778	1	0.9680	0.0320

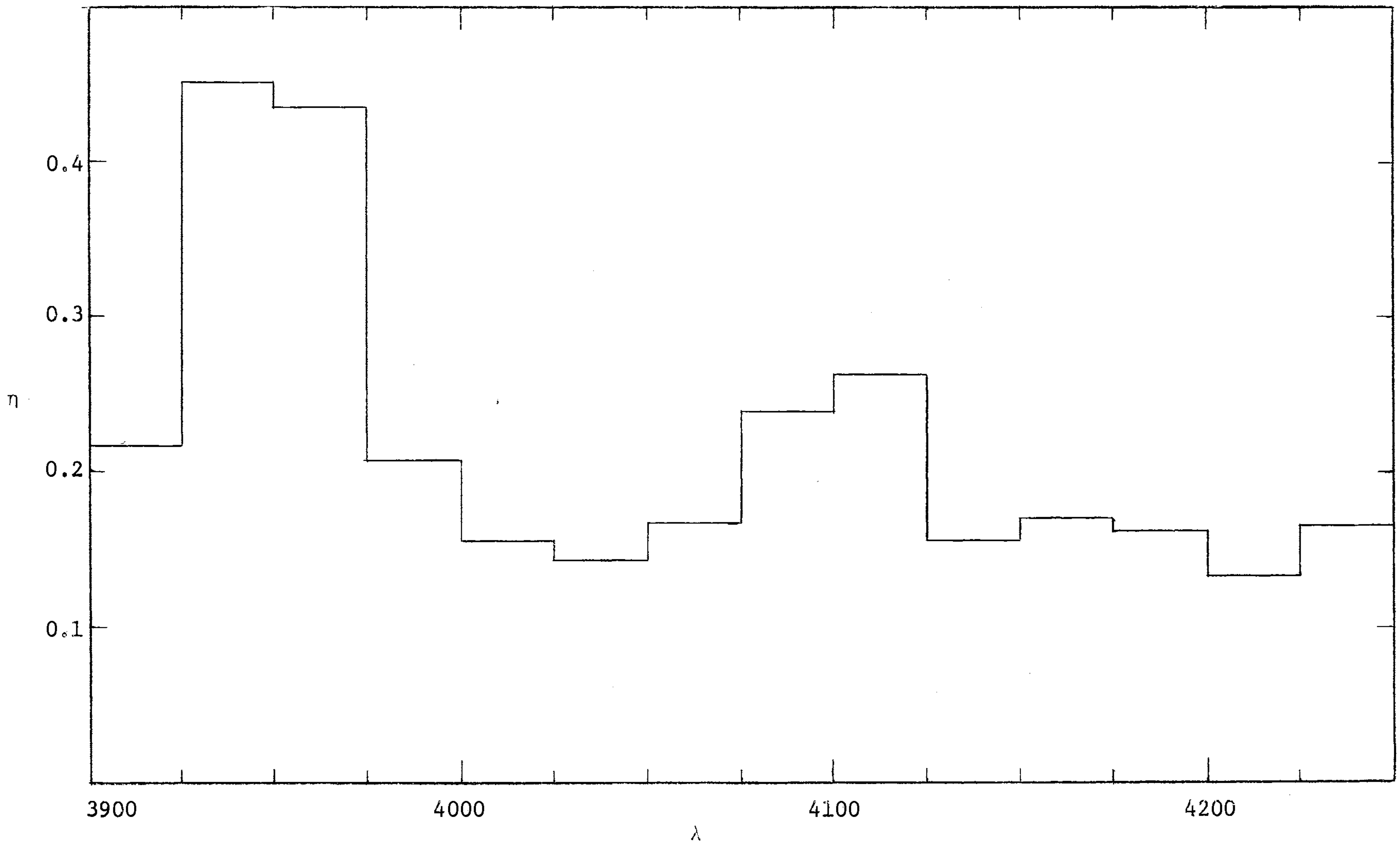

Figure 4. Blanketing Factors for λλ3900-4250

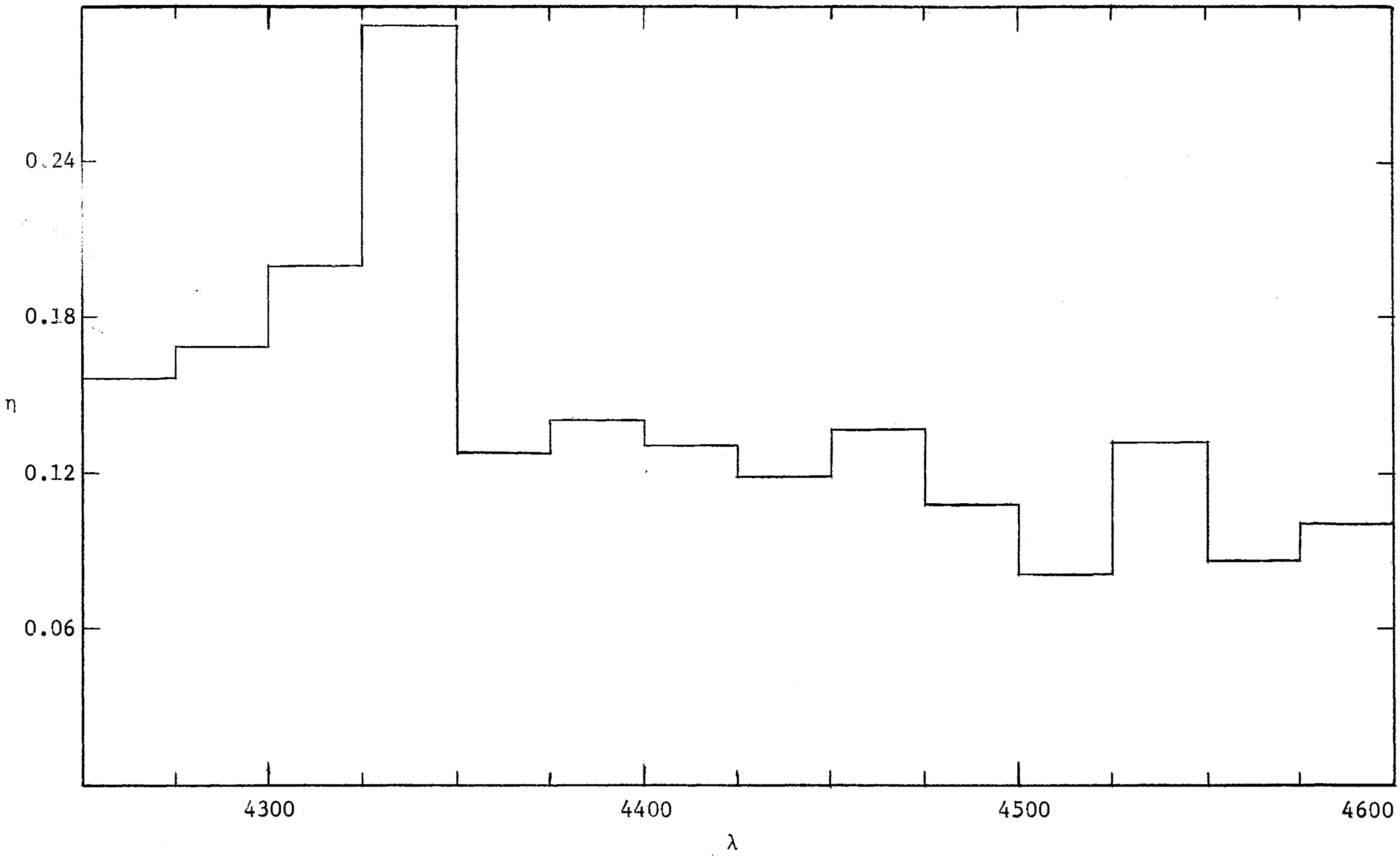

Figure 5. Blanketing Factors for λλ4250-4600

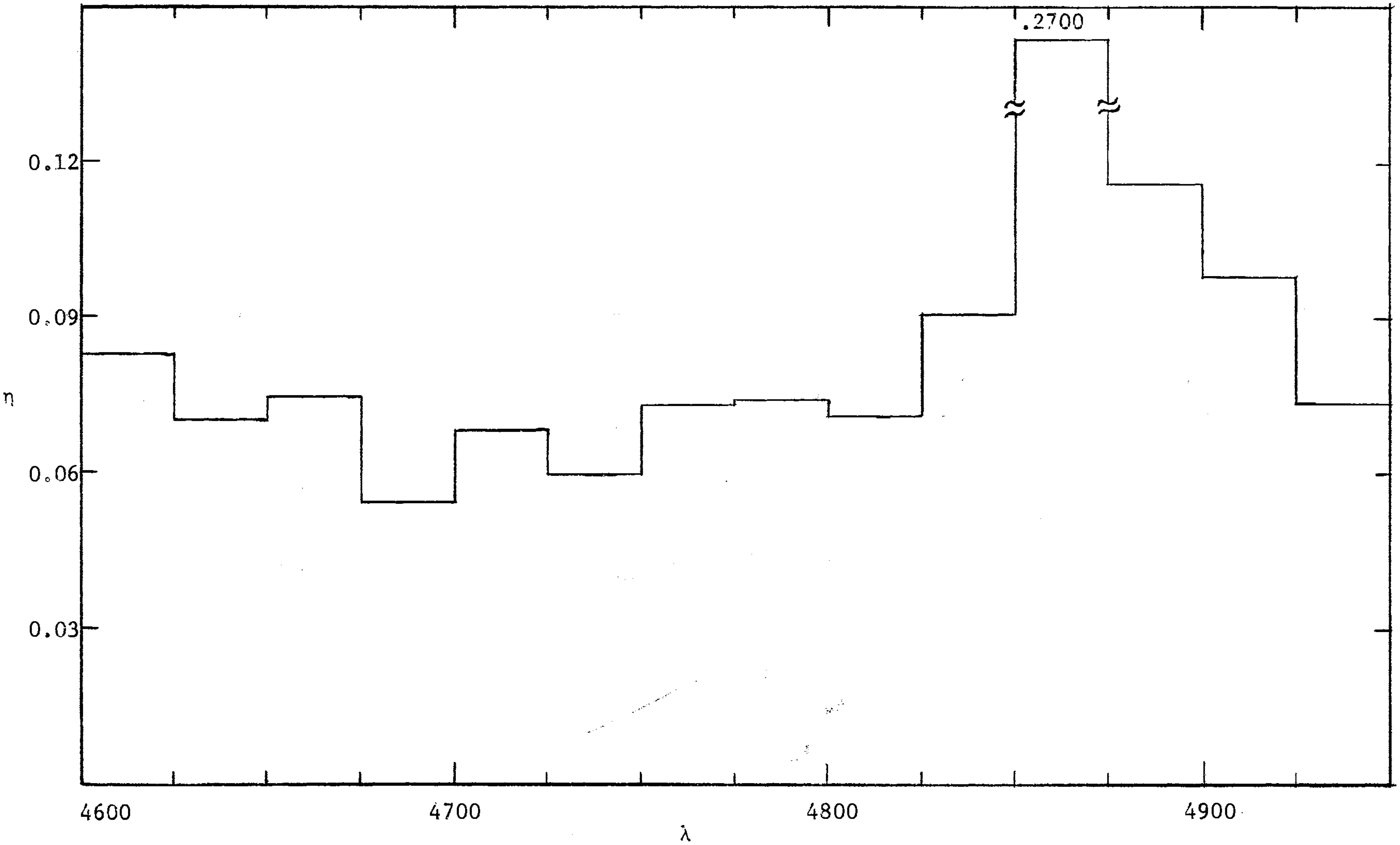

Figure 6. Blanketing Factors for λλ4600-4950

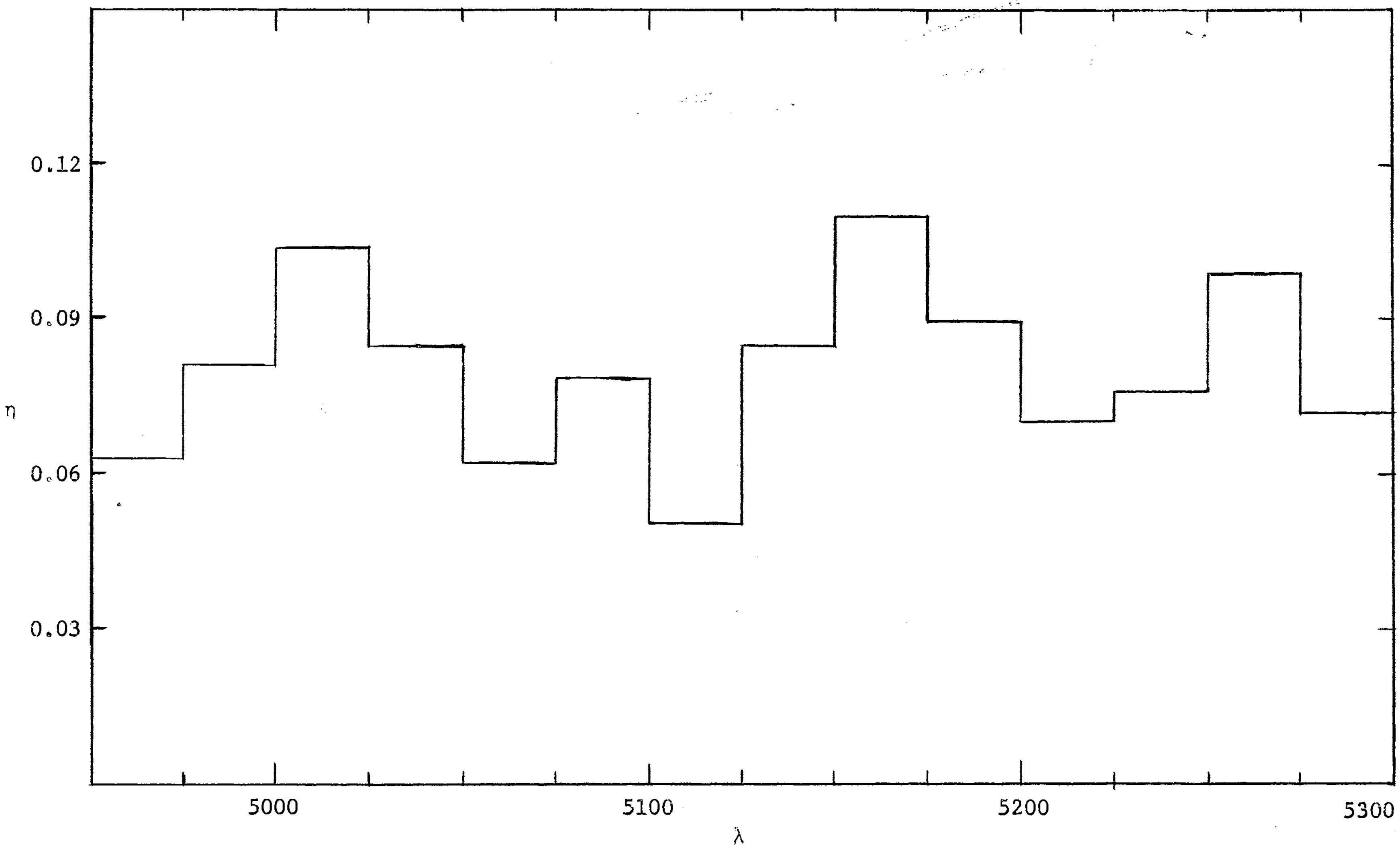

Figure 7. Blanketing Factors for λλ4950-5300

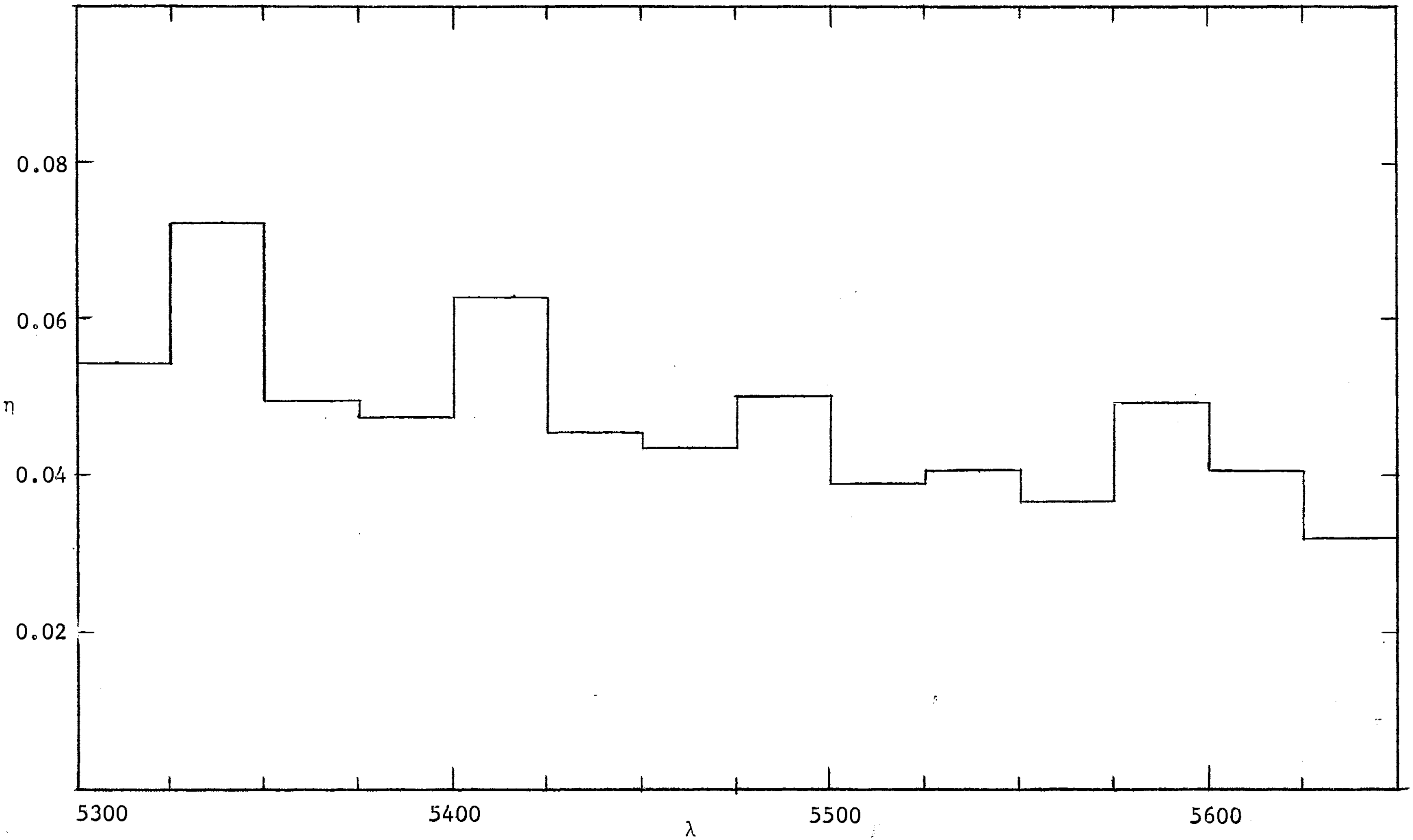

Figure 8. Blanketing Factors for λλ5300-5650

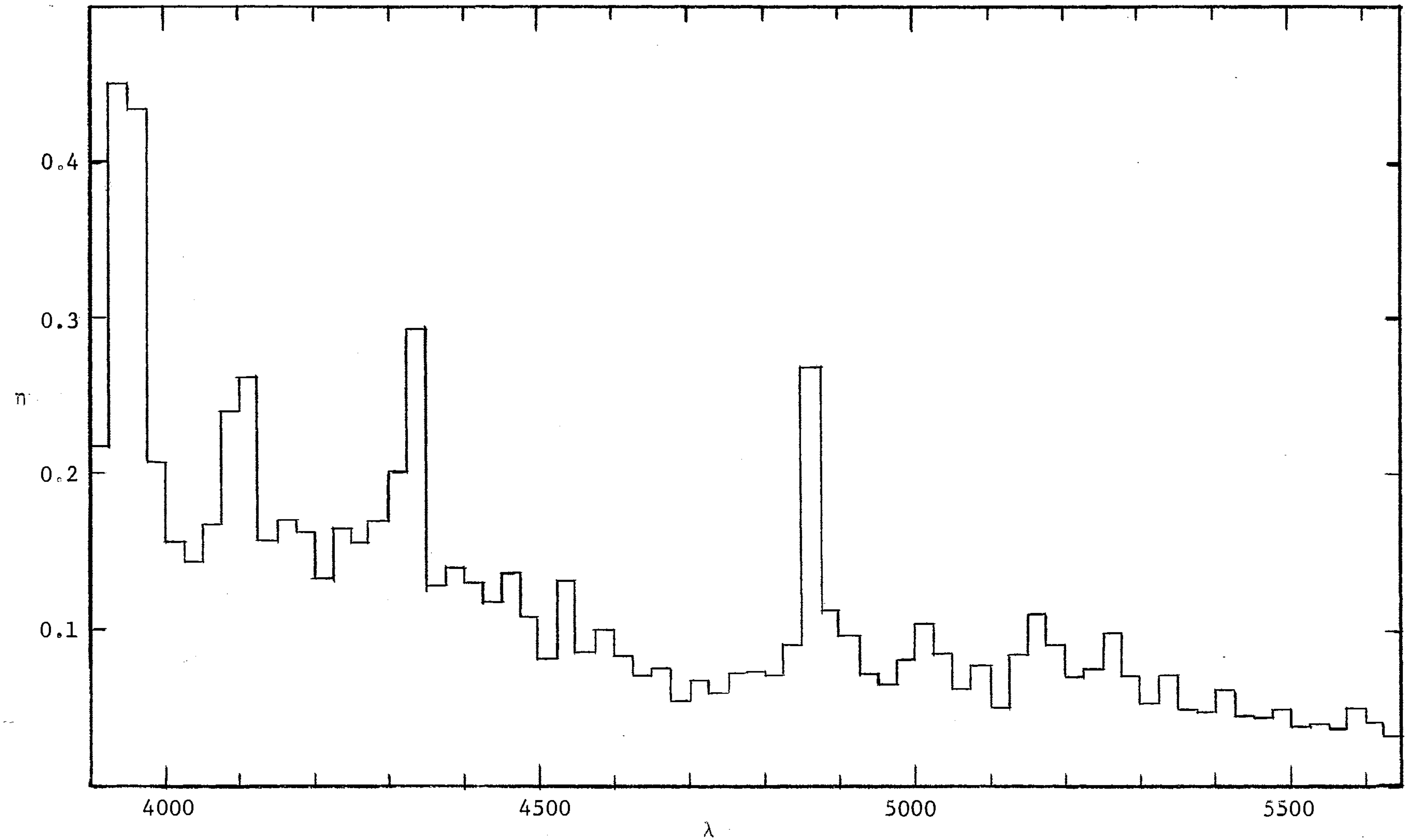

Figure 9. Entire Range of Blanketing Factors for λλ3900-5650

CHAPTER V

SUMMARY

The object of this study as expressed in Chapter IV was to calculate the blanketing coefficients over the range of available tracings which was accomplished with the results being listed in Table II. In order to best analyze the results and the relative quality of the tracings, the available investigations on line blanketing of Procyon are compared.

Shajn (1934) made calculations for line blanketing in the range λλ3775-6450. His spectrograph dispersion was 19 Å/mm near 3750 Å to 140 Å/mm near 6500 Å. The spectograms were taken using a 40-inch reflecting telescope. He used either one or two spectograms for his calculations.

Milford (1950) made calculations in the range λλ4000-6100. He used the 21.6 magnification intensity tracings from the Hiltner and Williams Photometric Atlas which were made using the 82-inch McDonald reflector with a spectograph dispersion of 3 Å/mm at H_γ (compared to 36 Å/mm for Shajn at H_γ).

The most recent previously published work was by Talbert and Edmonds (1966) over the range λλ3025-4075. They used an 82-inch reflector and a spectograph dispersion of 4.8 Å/mm at the higher wavelengths and 3.2 Å/mm at the lower. In most cases they used one spectogram plate with a maximum of four for a few ranges.

Errors encountered in making line-blanketing measurements have been discussed by several investigators. Shajn felt his major error source was due to the uncertainty in the continuum placement, especially in areas of numerous lines (which is generally concurred with by subsequent researchers). Milford estimated his error as ± 0.005 where $\eta < 0.20$ and somewhat larger for greater η. Talbert and Edmonds made probable error estimates where multiple data were available. Their value differences ranged from 0.009 to 0.031 near λ4000 which lead them to set ± 0.03 as a maximum error estimate. Myrick (1970) obtained a value of ± 0.05 for his error estimate on his data pertaining to Theta Ursae Majoris by using comparisons of multiple spectra.

In each previous case the author believes that there are one or more factors which are not as conducive to obtaining accurate values as those measured in this study. Dispersion, tracing magnification, telescope size, and number of plates are all factors which affect the accuracy of data. From comparisons of values read from different plates used in this study, an error of ± 0.02 seemed to be the most reasonable. Keeping in mind that these various authors used different equipment, etc., with somewhat unresolved accuracy, the values obtained for η are presented in Table III. Figure 10 shows the comparison of this author's work with those of other investigators.

The accuracy of the data in each case is apparently limited due to factors which were not dealt with in the actual blanketing measurements. That is the major error occurs in the intensitometer tracings and the drawing of the continuum and not in the use of the planimeter. Variance in data among values obtained over the same wavelength range from different plates was roughly about six times the variance among a number of

TABLE III

BLANKETING MEASUREMENTS OF OTHER INVESTIGATORS

λ (in Å)	η Talbert and Edmonds	Milford	Shajn
3025	0.357		
50	0.327		
75	0.290		
3100	0.279		
25	0.289		
50	0.277		
75	0.311		
3200	0.267		
25	0.326		
50	0.208		
75	0.201		
3300	0.201		
25	0.173		
50	0.225		
75	0.195		
3400	0.192		
25	0.203		
50	0.224		
75	0.262		
3500	0.225		
25	0.204		
50	0.239		
75	0.278		
3600	0.282		
25	0.263		
50	0.195		
75	0.275		
3700	0.325		
25	0.380		
50	0.368		
75	0.324		0.30
3800	0.252		0.24
25	0.422		0.35
50	0.215		0.20
75	0.349		0.31
3900	0.220		0.19
25	0.448		0.44
50	0.385		0.43
75	0.181		0.20
4000	0.238	0.21	0.16
25	0.174	0.18	0.15
50	0.159	0.215	0.13
75	0.168	0.28	0.22
4100		0.33	0.19

TABLE III (Continued)

λ (in Å)	η Talbert and Edmonds	η Milford	η Shajn
4100		0.33	0.19
25		0.185	0.10
50		0.19	0.10
75		0.21	0.15
4200		0.185	0.12
25		0.175	0.14
50		0.155	0.19
75		0.22	0.12
4300		0.27	0.12
25		0.37	0.16
50		0.185	0.25
75		0.185	0.13
4400		0.20	0.12
25		0.19	0.08
50		0.185	0.12
75		0.12	0.10
4500		0.09	0.08
25		0.17	0.09
50		0.105	0.09
75		0.13	0.08
4600		0.085	0.06
50		0.08	0.07
4700		0.065	0.08
50		0.07	0.07
4800		0.075	0.04
50		0.21	0.14
4900		0.10	0.10
50		0.095	0.08
5000		0.11	0.08
50		0.085	0.07
5100		0.09	0.05
50		0.135	0.07
5200		0.095	0.05
50		0.095	0.06
5300		0.085	0.06
50		0.07	0.05
5400		0.07	0.04
50		0.04	0.05
5500		0.055	0.03
50		0.05	0.04
5600		0.04	0.05
50		0.045	0.05
5700		0.025	0.05
50		0.025	0.03
5800		0.005	0.03
50		0.02	0.05

TABLE III (Concluded)

λ (in Å)	η Talbert and Edmonds	Milford	Shajn
5900		0.01	0.04
50		0.015	0.04
6000		0.025	0.04
50		0.015	0.05
6100		0.035	0.06
50			0.05
6200			0.03
50			0.04
6300			0.01
50			0.03
6400			0.01
50			0.04

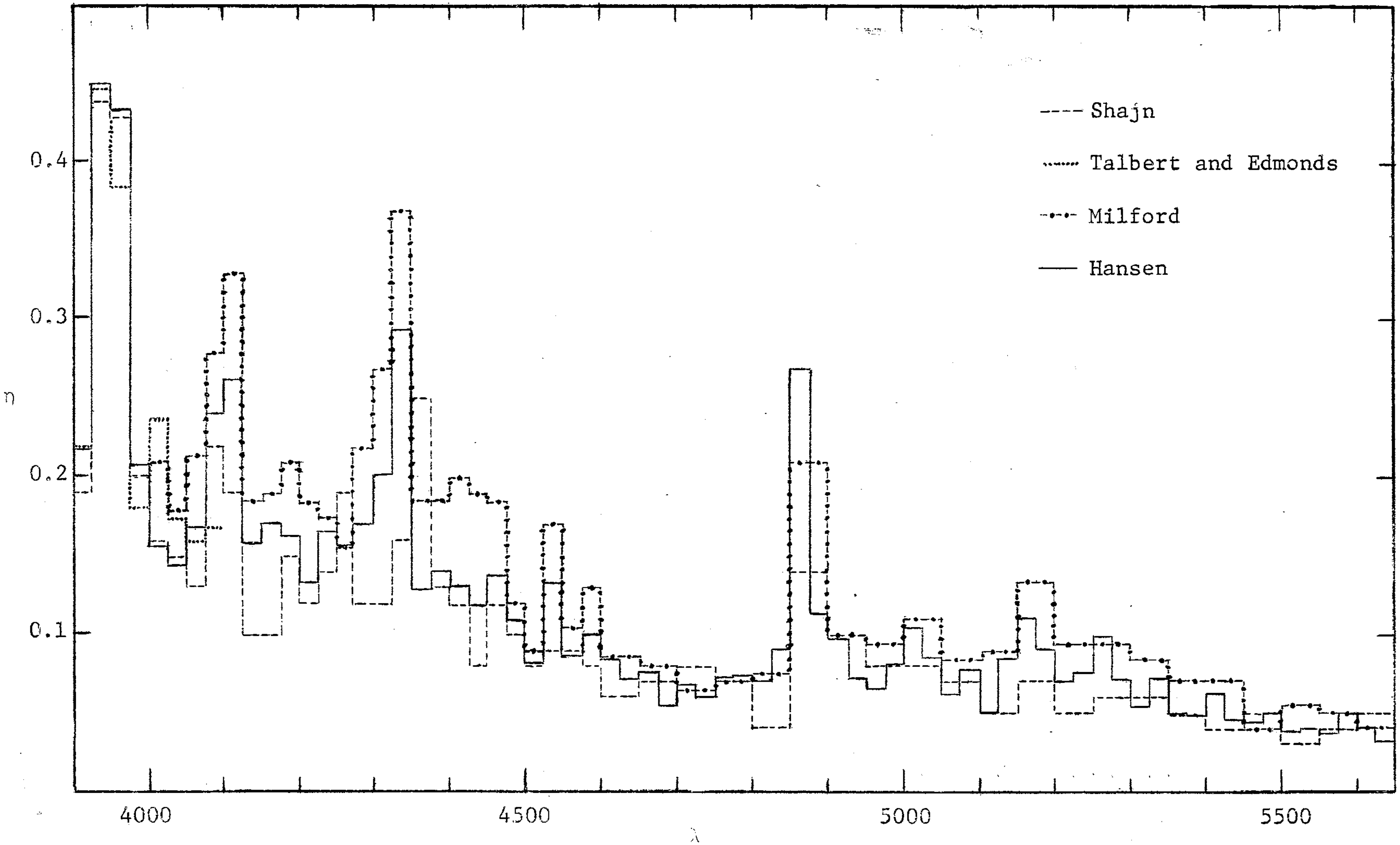

Figure 10. Comparison of Blanketing Factors for λλ3900-5650 by Shajn, Milford, Talbert and Edmonds, and Hansen

values measured on the same tracing which would correspond to planimeter-use error. The estimate of continuum error alone by Wildey, Burbidge, Sandage, and Burbidge (1962) is up to ten percent in some regions of heavy blanketing. Although this estimate is believed to be somewhat large for the data used in this report, a much smaller value would easily account for the ± 0.02 factor. Edmonds (1965) discusses the various effects which could introduce uncertainties in observations including developing and exposure procedures, grating ghosts, and scattered light in the spectograph.

Although the data from the various authors are by no means identical, the correlation is sufficient so that no single work can be discounted, however, certain measurements might be questioned. With this reinforcement the author is sufficiently assured of the acceptability of his results for future use.

For assistance in future blanketing investigations the author suggests that intensitometer tracings could be directly analyzed as they are recorded. Automatic recording of the area under the tracing seems well within the range of present technology. The extent of equipment sophistication might be determined by some desirability-cost relation. The availability of such equipment, in the author's opinion, would greatly enhance the volume of line-blanketing measurements and their future use in astrophysics.

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APPENDIX

BLANKETING DATA IN CONVENIENT TABULAR FORM

By using Equation (2-6), the blanketing-free monochromatic flux may be calculated. Some of the essential calculations are made and presented in Table IV for use in further work along this line.

The initial wavelength for each 25-Å interval is listed in Column 1. Column 2 gives the γ/γ_o ratio where γ_o is calculated for $\lambda\lambda$5550-5575. The values for $-2.5 \log (\gamma/\gamma_o)$ are given in Column 3.

TABLE IV

BLANKETING COEFFICIENT RATIOS, γ/γ_o

λ	γ/γ_o	$-2.5 \log \gamma/\gamma_o$
3900	0.8117	0.2265
25	0.5690	0.6122
50	0.5863	0.5797
75	0.8219	0.2130
4000	0.8768	0.1427
25	0.8887	0.1281
50	0.8638	0.1590
75	0.7899	0.2561
4100	0.7654	0.2903
25	0.8752	0.1447
50	0.8614	0.1620
75	0.8704	0.1507
4200	0.8989	0.1157
25	0.8652	0.1572
50	0.8754	0.1445
75	0.8621	0.1611
4300	0.8292	0.2034
25	0.7338	0.3361
50	0.9047	0.1087
75	0.8921	0.1240
4400	0.9021	0.1119
25	0.9146	0.0969
50	0.8957	0.1196
75	0.9255	0.0841
4500	0.9531	0.0522
25	0.8999	0.1145
50	0.9480	0.0580
75	0.9335	0.0747
4600	0.9516	0.0539
25	0.9649	0.0388
50	0.9603	0.0440
75	0.9815	0.0203
4700	0.9670	0.0364
25	0.9761	0.0263
50	0.9623	0.0417
75	0.9614	0.0427
4800	0.9641	0.0397
25	0.9442	0.0623
50	0.7579	0.3010
75	0.9196	0.0910
4900	0.9367	0.0710
25	0.9622	0.0418
50	0.9697	0.0334
75	0.9539	0.0512
5000	0.9301	0.0787
25	0.9501	0.0556

TABLE IV (Concluded)

λ	γ/γ_o	$-2.5 \log \gamma/\gamma_o$
5050	0.9736	0.0290
75	0.9566	0.0482
5100	0.9858	0.0155
25	0.9500	0.0557
50	0.9236	0.0863
75	0.9450	0.0614
5200	0.9653	0.0383
25	0.9591	0.0453
50	0.9353	0.0726
75	0.9639	0.0399
5300	0.9816	0.0202
25	0.9629	0.0410
50	0.9868	0.0144
75	0.9889	0.0121
5400	0.9728	0.0299
25	0.9907	0.0101
50	0.9927	0.0080
75	0.9861	0.0152
5500	0.9976	0.0026
25	0.9958	0.0046
50	1.0000	0.0000
75	0.9867	0.0145
5600	0.9958	0.0046
25	1.0050	-0.0054

VITA

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