THE ASTROPHYSICAL JOURNAL, 161:1015–1023, September 1970

THE ABSOLUTE SPECTRAL ENERGY DISTRIBUTION OF ALPHA LYRAE

J. B. OKE AND R. E. SCHILD*
Hale Observatories, California Institute of Technology, Carnegie Institution of Washington
Received 1970 January 26

ABSTRACT

The prime-focus photoelectric spectrum scanner and a small telescope 4 inches in diameter have been used to make spectrophotometric comparisons between the primary standard star, α Lyr, and several radiation sources to determine the absolute spectral energy distribution of α Lyr from 3300 to 10800 Å. The radiation sources were (1) a tungsten ribbon-filament lamp accurately calibrated at the U.S. National Bureau of Standards, (2) a blackbody cavity operated at the melting point of copper, and (3) a blackbody cavity operated at the melting point of platinum. The spectral energy distribution of α Lyr is shown in a figure and given in a table. The absolute flux from a star of apparent visual magnitude $V = 0.00$ at 5480 Å is found to be 3.65×10^{-20} erg sec^{-1} cm^{-2} Hz^{-1} or 3.64×10^{-9} erg sec^{-1} cm^{-2} Å^{-1}. The accuracy of this figure is estimated to be 2 percent.

I. INTRODUCTION

As computing technology and the theory of model stellar atmospheres advance, the comparison of computer-generated models with observations of stellar spectra becomes an increasingly important technique in modern astronomy. However, while stellar fluxes may be determined relative to a standard with an accuracy of 1 percent, the comparison with models has been hampered by the lack of an absolute calibration of this accuracy. Early calibration results, many of them based on photographic spectrophotometry, have been summarized by Code (1960). The most recent decade has seen advances in instrumentation and a number of new calibrations, especially those of Bahner (1963), Glushneva (1964), Kharitonov (1963), Willstrop (1965), and Hayes (1970). However, discrepancies among these modern calibrations are still as high as 10 percent at some wavelengths.

The present calibration project was undertaken in an attempt to reduce the uncertainty of the calibration, if possible, to 1 or 2 percent. To this end a stable photoelectric data system, scanner, and telescope were constructed, and the observations were made at Palomar Mountain which experience has shown to be an excellent photometric site. In addition, fundamental sources were observed directly, where possible, to eliminate the large errors intrinsic in the calibration of secondary sources (Bless, Code, and Schroeder 1968). In the present work, all equipment was designed to permit a determination of the absolute monochromatic flux of the standard star α Lyr at 5556 Å in units of ergs sec^{-1} cm^{-2} Hz^{-1}, since this fundamental parameter is also very uncertainly known.

The reduction of the new observations of fundamental sources uses the new Thermodynamic Kelvin Temperature Scale (Kostkowski 1967). This scale differs from the International Practical Temperature Scale of 1948 by 1° or more at the relevant temperatures. Thus we have used values of $T = 2044.6°$ K and $T = 1357.8°$ K for the melting points of platinum and copper, respectively, and 1.4388 cm deg for the radiation constant c_2.

II. RADIATION SOURCES

The spectrum of α Lyr was compared with three radiation sources: (1) a tungsten ribbon-filament lamp for 3300–8080 Å, (2) a copper-point blackbody for 6050–10800 Å,

* Now at Smithsonian Astrophysical Observatory, Cambridge, Massachusetts.

and (3) a platinum-point blackbody for 3300–10800 Å. The calibrations of the lamp and copper-point blackbodies can be traced directly to the gold-point blackbody maintained as a fundamental source by the U.S. National Bureau of Standards.

The tungsten ribbon-filament lamp has been calibrated in a direct comparison with the gold-point blackbody at the National Bureau of Standards. A small rectangular area, 0.6 by 0.8 mm, in the center of the filament was observed through a diaphragm whose alignment was checked with an engineer's transit. Many of the errors intrinsic in the calibration of ribbon-filament lamps as secondary standards (Bless, Code, and Schroeder 1968) are presumed to have been avoided in the present work, since edges of the filament, where significant temperature gradients exist, were not observed. In addition, the orientation of the lamp was carefully maintained by the use of fiducial marks on the tungsten filament and the glass envelope. Lamp current was maintained constant to one part in 10^4 by a highly regulated power supply, and the value of the current was determined and monitored by means of a shunt and a Fluke transistorized differential voltmeter, Model 883A, whose calibrations were checked before and after the observing. The current was thus known to 0.05 percent, a value corresponding to an error in the lamp flux of 0.3 percent at 3300 Å and half as much at 5556 Å. The lamp calibration provided by the National Bureau of Standards was quoted to an accuracy ranging from ± 2 percent at 3000 Å to ± 1 percent at 8000 Å ,the longest wavelength for which calibration was available.

The second source observed was a blackbody cavity maintained at the melting point of copper. Two of the devices were built according to the plans of Lee (1969), who has shown that his design provides a source of radiation whose temperature is $1357.8 \pm 0.2°$ K. The first of these copper-point blackbodies was observed on two nights in 1969 May, and the second was observed on three nights in September. Agreement between the two was within 2 percent both in the shape of the energy distribution from 6000 to 10800 Å and in the absolute level of the monochromatic flux at 6370 Å. The copper blackbody could not be observed below 6000 Å because at shorter wavelengths its emission is too faint.

The third calibration source employed was a blackbody cavity maintained at the melting point of platinum. Because this source operates at a much higher temperature than the somwehat similar copper-point blackbody, it can be observed in the ultraviolet; it thus provides a measurement of the Balmer discontinuity which is independent of the calibrated lamp. Unlike the two sources mentioned previously, which were observed with no intermediate optics except for a diaphragm limiting the source aperture, the platinum blackbody optics include a quartz prism to direct the beam (which is necessarily vertical in the present design [Roeser, Caldwell, and Wensel 1931]) into a horizontal direction. Because the platinum sample and its containing crucible are relatively small, the aperture of the system must be small. Diffraction corrections are, nevertheless, negligible according to the calculations of Bender (1968). The blackbody cavity consists of a thoria tube with an inside diameter of 3 mm and a length of 22 mm. The tube has a hemispherical closure at its bottom end, and is fitted over a smaller, short tube of 1.1 mm inside diameter at its upper end. This short tube defines the aperture of the cavity. The pressed thoria tubing is diffusely reflecting, and calculations by DeVos (1954) show that for the geometry involved the emissivity is within 1 percent of unity. The sight tube is immersed in a small crucible containing 5 cm^3 of platinum and is supported at its upper end only. Thus platinum surrounds the sight tube at its lower end.

The platinum blackbody has been in operation for over 2 years and continues to display melts and freezes of constant level. However, evidence presented below suggests that the temperature of our furnace is 6° lower than the standard value of the platinum point. It is possible that some lowering of the freezing point has resulted from gradual contamination of the metal by contact with the crucible and with air which can diffusely circulate into the crucible. Although platinum is chemically inactive at ordinary temperatures, it becomes far more reactive at the elevated temperatures at which the furnace has been operated for several hundred hours. Since experiments with the apparatus are still in progress, no chemical analysis of the platinum sample has yet been made.

III. OBSERVING EQUIPMENT AND PROCEDURES

A special Newtonian telescope of 4-inch aperture was constructed to fill the f/3.3 collimator of the prime-focus scanner of the Palomar 200-inch telescope. This telescope has sufficient aperture to permit observations of bright stars and standard sources, but is not so large as to necessitate large coincidence corrections with pulse-counting electronics. In addition, its 13-inch focal length is sufficiently short to provide starlike images from the relatively nearby calibrated sources without focus change. The telescope features a sealed optical system with quartz entrance and exit windows, and it has been flushed and sealed with dry nitrogen; it thus provides a very stable optical system with very little scattered light. A slide permits filters to be located between the telescope and scanner to keep unwanted light out of the scanner; this is required to minimize scattered light and to separate orders in the spectrum scanner. Problems of order separation are especially severe in calibration, where the standard sources are very red.

The 200-inch prime-focus scanner is of conventional design, and is equipped with a 15-Hz chopper for background subtraction. A filter slide in the scanner permits measurement of the red leaks of the main filters in front of the scanner. Two photomultiplier tubes were used in the calibration; an Ascop 541B (equivalent to a 641A) with an S17 cathode was used from 3300 to 6000 Å, and an RCA 7102 with S1 cathode was used from 5500 to 11000 Å. Pulse-counting electronics were used throughout, and coincidence connections for the blue and red tubes were, respectively, 3 and 2 percent at counting rates of 1 MHz. At no time did counting rates exceed 300 kHz, so that the coincidence corrections applied to the data were always much less than 1 percent. A slit width of 25 Å was used from 3300 to 4780 Å, 50 Å from 4780 to 6000 Å, and 100 Å for all observations with the RCA 7102 photomultiplier. Since all sources gave almost point images and could easily be kept aligned in the center of the entrance aperture, no further degradation of the resolution was present.

Direct measurement of filter red leaks showed them to be less than 0.5 percent for the calibrated lamp and the copper blackbody (which was not observed in the ultraviolet). Filter red leaks for the platinum blackbody were only 2, 6, and 4 percent, respectively, at 3500, 3600, and 3680 Å, and were negligible for all other wavelengths. Light-scattering effects in the 4-inch telescope were also found to be inconsequential.

Locations of telescope and standard sources on the Palomar mountaintop were dictated by the local topography and the availability of facilities. The 4-inch telescope and scanner were mounted on the side of the Palomar 18-inch Schmidt telescope which provided a very stable equatorial mount and one in which the telescope could be pointed to the northern horizon, where the standard sources located at the roof level in the power house came into view. The line of sight between the telescope and the sources passed over a shallow draw of 15 m maximum depth. Calculations show that the optical path of 380 m is equivalent to 5 percent of a vertical air mass, so that the horizontal extinction amounts to only a few hundredths of a magnitude for the shortest wavelengths observed. Attempts to measure this horizontal extinction by observing a stable quartz-iodine lamp at two carefully measured positions along the line of sight were inconclusive, and scaled-down standard Palomar extinction coefficients were used in the final reduction of the data. Only nights of exceptional transparency were used.

On a typical observing night, two standard sources as well as α Lyr were measured. On all but a few nights, α Lyr was observed many times while setting from an air mass of 1.0 to approximately 2.0. In addition, the horizontal extinction was measured at least once, and usually twice.

IV. RESULTS: THE COLOR OF α LYRAE

Independent calibrations of the flux of α Lyr, normalized to zero at 5556 Å and based upon the three sources discussed above, are summarized in Table 1 and Figure 1. As previously noted, two copper blackbodies were constructed and observed in the different seasons, and the agreement was excellent. The data listed in Table 1 for the copper blackbody are the simple average for the two. The data for the platinum blackbody obtained in the spring of 1969 agree to within 2 percent with the data obtained in the

TABLE 1

PALOMAR CALIBRATION RESULTS

λ(Å) (1)	1/λ(μ⁻¹) (2)	Lamp (3)	Copper Blackbody (4)	Platinum Blackbody (5)	Weighted Mean (6)	Smoothed Calibration* (7)
3300	3.030	1.086	...	...	1.073	+1.11
3400	2.941	1.079	...	...	1.066	+1.08
3500	2.857	1.059	...	+1.02	1.046	+1.06
3600	2.778	1.042	...	+0.99	1.025	+1.04
3680	2.717	1.014	...	+0.99	1.006	+1.02
4036	2.478	−0.306	...	−0.28	−0.297	−0.283
4167	2.400	−0.288	...	−0.29	−0.289	−0.263
4255	2.350	−0.259	...	−0.28	−0.266	−0.250
4460	2.242	−0.252	...	−0.23	−0.245	−0.206
4566	2.190	−0.194	...	−0.21	−0.199	−0.185
4780	2.092	−0.154	...	−0.16	−0.156	−0.141
5000	2.000	−0.098	...	−0.11	−0.102	−0.096
5263	1.900	−0.057	...	−0.06	−0.058	−0.039
5556	1.800	0.000	...	0.00	0.000	+0.025
5840	1.712	+0.063	...	+0.07	+0.065	+0.086
6050	1.653	+0.115	...	+0.12	+0.117	+0.127
5556	1.800	+0.011	...	0.00	+0.007	...
5840	1.712	+0.057	...	+0.05	+0.055	...
6050	1.653	+0.119	0.120	+0.14	+0.124	...
6370	1.570	+0.170	0.175	+0.19	+0.176	+0.19
6800	1.471	+0.223	0.215	+0.24	+0.223	+0.27
7100	1.408	+0.277	0.270	+0.29	+0.277	+0.31
7550	1.325	+0.397	0.375	+0.42	+0.393	+0.38
8080	1.238	+0.472	0.415	+0.46	+0.447	+0.46
8400	1.190	...	0.460	+0.50	+0.47	+0.49
8804	1.136	...	0.435	+0.48	+0.45	+0.47
9700	1.031	...	0.475	...	+0.49	+0.51
9950	1.005	...	0.480	+0.54	+0.50	+0.53
10250	0.976	...	0.530	+0.57	+0.54	+0.56
10400	0.962	...	0.540	+0.59	+0.55	+0.57
10800	0.900	...	0.595	+0.65	+0.61	+0.64

* Adjusted to 0.00 at 5480 Å.

fall of 1969 over the wavelength interval 4000–6000 Å. Beyond this range, in the infrared and ultraviolet, scatter is as high as 6 percent, but no systematic differences between spring and fall are evident. The data have again been simply averaged. Results tabulated for the calibrated lamp are based on six nights of observations in 1969 September, three with the red-sensitive and three with the blue-sensitive photomultipliers. In reducing the data for the lamp and the platinum blackbody, where observations from 3300 to 6050 Å were made with one photomultiplier tube and observations from 5556 to 10800 Å were made with the other, it was unnecessary to shift curves relative to one another to obtain a fit in the overlapping wavelengths; rather, it was found that, for the two sources, observations reduced in an absolute way agree to within 1 percent at the three overlapping wavelengths.

As noted in a previous section, data for our platinum blackbody cavity consistently indicate a melting temperature lower than the standard value. We adopt the standard platinum melting temperature $T_{\rm Pt} = 2044.6°$ K. If we treat the temperature of our melting point as an unknown, we may determine it from four criteria: (i) temperature indicated by the 4000–8000 Å spectral range = $T_{\rm Pt} - 6°$; (ii) temperature indicated by absolute calibration at 5556 Å = $T_{\rm Pt} - 6°$; (iii) temperature indicated by infrared data = $T_{\rm Pt} - 16°$; (iv) temperature indicated by ultraviolet data = $T_{\rm Pt} - 16°$. These criteria have been listed in decreasing order of their trustworthiness, and we have adopted $T_{\rm Pt} - 6°$. The data in Table 1 for all wavelengths are based on this temperature, and we adopt an approximate 5 percent uncertainty in our platinum blackbody results

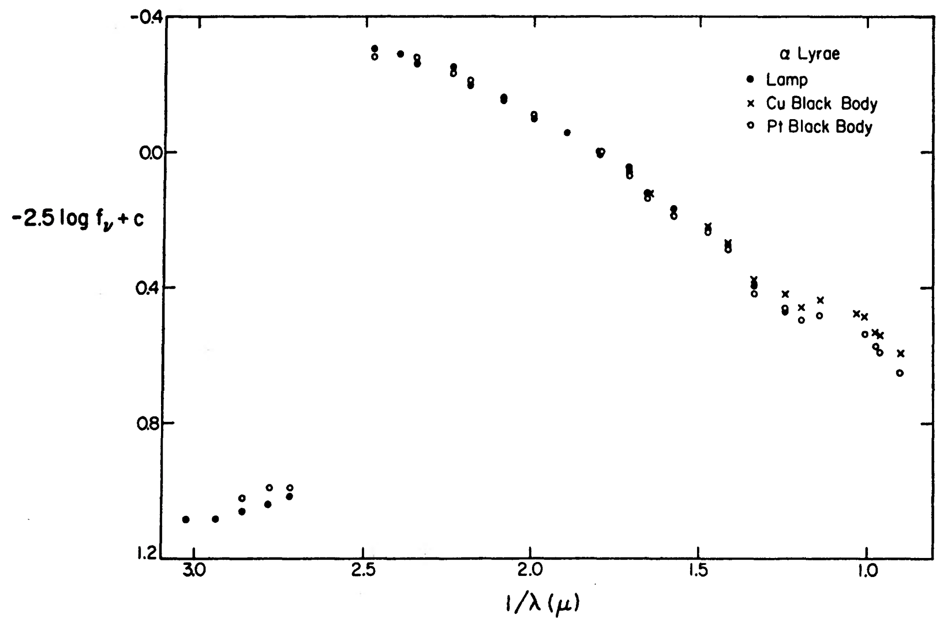

FIG. 1.—Spectral energy distribution of α Lyr as determined by comparison with a lamp, copper-point blackbody, and platinum-point blackbody. Vertical scale is in magnitudes; horizontal scale is 1/λ, where λ is the wavelength in microns.

due to this problem. We have given the adjusted platinum blackbody results half-weight in deriving our overall average for the calibration, listed in column (6) of Table 1. Thus our final average is based primarily upon results from the calibrated lamp in the ultraviolet, and upon the results from the two copper blackbodies in the infrared.

Our final results, in the form of a smoothed curve which will ordinarily be used in stellar investigations, are listed in column (7) of Table 1. This tabulation has been renormalized to a magnitude of 0.00 at 5480 Å.

V. ERRORS

It is clear that substantial errors in the operation of the standard sources exist and are in large part responsible for systematic differences in our results for the different sources. This must be so because calibrations made on the same night with the same detector and presumably the same extinction give different results for the different sources. Evaluations of errors peculiar to the operation of the several sources are summarized in Table 2. The error in column (6) for the platinum blackbody assumes that an adjustment downward of 6° K of the temperature in the cavity is justified.

Alignment of each source was adjusted on each night of observation, and slight fluctuations in source brightness from night to night have been attributed in Table 2 to alignment errors. Without doubt, slight variations in detector sensitivity and horizontal extinction are in part responsible for the observed fluctuations, but since the effects are small and difficult to separate, they are included in only a single category. The data in column (4) thus reflect the overall night-to-night variation of the observed brightness of the source. Since some contributions to the fluctuations are likely to be not very wavelength-dependent, the data of column (4) provide generous estimates of these effects upon the shape of the spectral energy distribution of α Lyr. Other effects causing systematic wavelength-dependent errors, such as coincidence corrections, corrections for red leaks, and lamp-current determination errors, are quite small by comparison.

In addition to the errors discussed above, which are seen in the intercomparison of the sources, there may be other systematic errors which affect the comparisons of all the sources with α Lyr. The largest of these are likely to be errors in the determination of

TABLE 2

ESTIMATED MAXIMUM ERRORS IN MAGNITUDES

Source	Coincidence Corrections	Red Leak	Alignment	Lamp Current	Lamp Calibration or Temperature	Background	Σ
I. Calibrated lamp:							
a) Ultraviolet	0.000	0.001	0.020	0.002	0.020	0.000	0.028
b) Paschen continuum	0.001	0.000	0.014	0.001	0.010	0.000	0.017
II. Cu Blackbody:							
a) Paschen continuum	0.000	0.000	0.012	...	...	0.005	0.013
b) Infrared	0.000	0.000	0.012	...	...	0.000	0.012
III. Pt Blackbody:							
a) Ultraviolet	0.000	0.006	0.030	...	0.03	0.004	0.043
b) Paschen continuum	0.000	0.000	0.020	...	0.02	0.000	0.028
c) Infrared	0.000	0.000	0.020	...	0.02	0.000	0.028

the horizontal and vertical extinction. Observations of α Lyr made through air masses ranging from 1.0 to 2.0 indicate that the use of standard Palomar extinction coefficients introduces uncertainty in the vertical extinction of not more than 1 percent, primarily because only the clearest nights were used for calibration. This uncertainty was not found to be worse in the ultraviolet down to 3300 Å. When observations for several nights are averaged, the errors introduced by the vertical extinction are expected to be negligible.

Attempts to measure the horizontal extinction for the 380-m path between the standard sources and the telescope were generally inconclusive, primarily because the amount of the extinction is extremely small. A coiled-filament quartz-iodine lamp was connected to a highly regulated power supply and observed at the location of the standard sources. The lamp and power supply were then moved to a new location halfway between the original position and the telescope. This was usually repeated at another time during the night. The distances involved were carefully measured, and from the ratio of the measured fluxes the extinction was calculated. Because of small fluctuations apparently associated with the possible small errors in lamp alignment, or with effects of switching the lamp on and off, the results were not consistent. We have therefore corrected for horizontal extinction in our standard sources by using 0.05 a_λ, where a_λ are the Palomar standard extinction coefficients (Oke 1965) and where 0.05 is the ratio of the horizontal to the vertical air mass for a standard atmosphere at Palomar. This procedure is justified since (*a*) measurements of the horizontal extinction which we did make did not reveal any consistent abnormal extinction and (*b*) measurements of the horizontal extinction over a somewhat longer light path on Mount Hamilton (Stebbins and Kron 1957, 1964) show that a fraction of the vertical extinction is appropriate. The horizontal extinction, even at 3500 Å, is only 0.03 mag.

We conclude that the principal sources of error are in the operation of the calibrated sources, and these are evident in the comparison of results for different sources. The systematic errors, apart from those of the calibrated sources, appear to be small, in comparison.

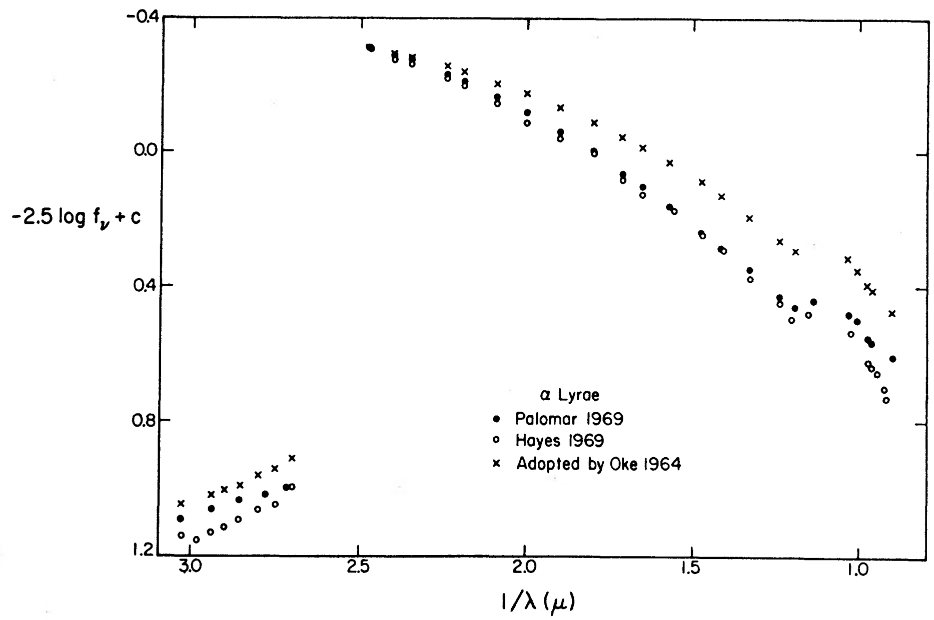

FIG. 2.—Comparison of the spectral energy distribution of α Lyr as adopted (*a*) in this paper, (*b*) by Hayes (1970), and (*c*) by Oke (1964). Units are the same as in Fig. 1.

VI. COMPARISON WITH OTHER OBSERVERS

The new calibration given in column (6) of Table 1 is compared with the recent calibration of Hayes (1970) in Figure 2. Both sets of data, in magnitudes, are normalized to 0.00 at 5556 Å, and it may be seen that agreement in the Paschen continuum is excellent between 4000 and 8000 Å. Our results are brighter than those of Hayes by approximately 0.05 mag at the longest wavelength and in the ultraviolet below the Balmer jump. Comparison of the new calibration with the widely used calibration abopted by Oke (1964) is also made in Figure 2; for clarity the curves are normalized at 4036 Å. From 4000 to 7000 Å this 1964 calibration fits that found by Bahner (1963) and Willstrop (1965). The Balmer jump found by Bahner agrees with our new calibration.

Results of workers in earlier decades have been summarized by Code (1960). A detailed comparison of our new calibration with that of Code (1960), Glushneva (1964), Kharitonov (1963), and Willstrop (1965) is shown in Figure 3. In the Paschen continuum our results, which agree with those of Hayes, show a steeper and bluer slope than all previous work. In the near-infrared our results are in good agreement with those obtained by Whitford and Code (Code 1960).

VII. RESULTS: THE ABSOLUTE FLUX AT 5556 Å

The monochromatic flux received from α Lyr in physical units has been determined by direct comparison of α Lyr with our standard sources. Since data for the platinum blackbody have been used to determine the melting temperature, we cannot reuse them in the absolute flux determinations. The three sources available, a copper blackbody observed in May, a completely new copper blackbody observed in 1969 September, and the calibrated lamp, yield a mean value of $F_\nu = 3.46 \times 10^{-20}$ erg sec^{-1} cm^{-2} Hz^{-1} or $F_\lambda = 3.36 \times 10^{-9}$ erg sec^{-1} cm^{-2} Å^{-1} for α Lyr at 5556 Å. Agreement for the three different sources is within 1 percent and may be fortuitous. There may be some contribution to the error from systematic effects such as allowance for vertical and horizontal extinction, which equally affect all three determinations. Uncertainties in the extinction correction have been estimated in the previous section and found to be of the order of 1 percent. We feel that a realistic estimate of the overall uncertainty in the absolute flux at 5556 Å is ± 2 percent.

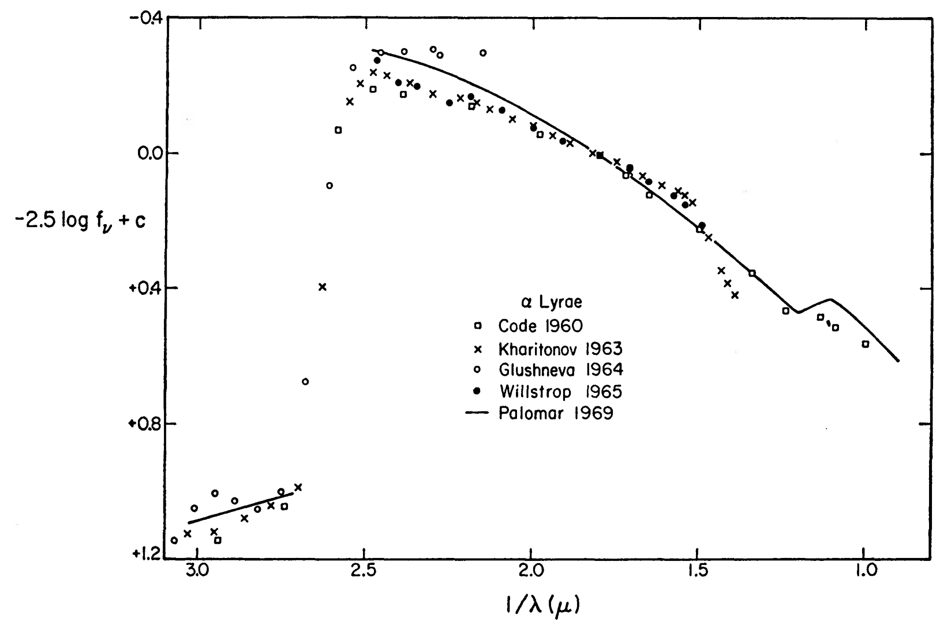

FIG. 3.—Comparison of the spectral energy distribution of α Lyr as determined by this study and by other studies.

The visual magnitude V of α Lyr in the UBV system is $+0.03$ (Johnson and Morgan 1953) or $+0.04$ (Johnson and Harris 1956). Adopting an effective wavelength of 5480 Å (Allen 1963) for the V-filter, we find for α Lyr at this wavelength $F_\nu = 3.53 \times 10^{-20}$ erg sec^{-1} cm^{-2} Hz^{-1} or $F_\lambda = 3.52 \times 10^{-9}$ erg sec^{-1} cm^{-2} Å^{-1}. Thus for a star of visual magnitude $V = 0.00$ the flux at 5480 Å is given by $F_\nu = 3.65 \times 10^{-20}$ erg sec^{-1} cm^{-2} Hz^{-1} or $F_\lambda = 3.64 \times 10^{-9}$ erg sec^{-1} cm^{-2} Å^{-1}. These last two numbers can be used as an absolute calibration of the V-magnitude of the UBV system, although it must be emphasized that the precise color-dependent relationship between the narrow-band absolute flux system and the V-magnitude has never actually been determined observationally.

The above results can be compared with previous determinations. For this purpose the fluxes are quoted for an A0 star of visual magnitude $V = 0.00$ at 5556 Å. Code (1960) adopted $F_\lambda = 3.8 \times 10^{-9}$ erg sec^{-1} cm^{-2} Å^{-1}. Willstrop (1965) obtained 3.7×10^{-9} erg sec^{-1} cm^{-2} Å^{-1}, while Kharitonov (1963) found 3.49×10^{-9} erg sec^{-1} cm^{-2} Å^{-1}.

Our result, 3.48×10^{-9} erg sec^{-1} cm^{-2} Å^{-1}, is 6 percent lower than that of Willstrop and 9 percent less than that adopted by Code.

This work was supported by the Office of Naval Research through grant N00014-67A-0094-0005 and by the California Institute of Technology which furnished a grant from funds given by the Sloan Foundation. The authors wish to thank Dr. H. Kostkowski of the U.S. National Bureau of Standards and Dr. P. L. Bender for providing invaluable technical advice and the observatory staff on Palomar Mountain for their generous assistance.

REFERENCES

Allen, C. W. 1963, *Astrophysical Quantities* (2d ed.; London: Athlone Press), p. 195.
Bahner, K. 1963, *Ap. J.*, **138**, 1314.
Bender, P. L. 1968, private communication.
Bless, R. C., Code, A. D., and Schroeder, D. J. 1968, *Ap. J.*, **153**, 545.
Code, A. D. 1960, in *Stellar Atmospheres*, ed. J. L. Greenstein (Chicago: University of Chicago Press), p. 50.
DeVos, J. C. 1954, *Physica*, **20**, 669.
Glushneva, I. 1964, *Soviet Astr.—AJ*, **8**, 163.
Hayes, D. S. 1970, *Ap. J.*, **159**, 165.
Johnson, H. L., and Harris D. L., III. 1956, *Ap. J.*, **120**, 196.
Johnson, H. L., and Morgan, W. W. 1953, *Ap. J.*, **117**, 313.
Kharitonov, A. 1963, *Soviet Astr.—AJ*, **7**, 258.
Kostkowski, H. 1967, *Metrologia*, **3**, 28.
Lee, R. D. 1969, *N.B.S. Tech. Note*, No. 483, p. 1.
Oke, J. B. 1964, *Ap. J.*, **140**, 689.
———. 1965, *Ann. Rev. Astr. and Ap.*, **3**, 23.
Roeser, W. F., Caldwell, F. R., and Wensel, H. T. 1931, *J. Res. N.B.S.*, **6**, 1119.
Stebbins, J., and Kron, G. E. 1957, *Ap. J.*, **126**, 266.
———. 1964, *Ap. J.*, **139**, 424.
Willstrop, R. V. 1965, *Mem. R.A.S.*, **69**, 83.