Rev. Mexicana Astron. Astrof., 5, 25-30 (1980).

THE ABSOLUTE CALIBRATION OF STELLAR SPECTROPHOTOMETRY

Harold L. Johnson

Instituto de Astronomía
Universidad Nacional Autónoma de México
Received 1979 June 16

RESUMEN

Se presentan nuevas calibraciones absolutas de 16 estrellas en el intervalo espectral de 4 000 a 10 300 Å, mediante la combinación de fotometría de 13 colores con espectrofotometría Michelson reciente. Las nuevas calibraciones son notablemente parecidas a la de Tüg, White y Lockwood. La calibración absoluta de la espectrofotometría estelar parece estar ahora firmemente establecida en el intervalo espectral de 4 000 a 10 300 Å.

ABSTRACT

The combination of 13-color photometry with recent Michelson spectrophotometry, covering the entire spectral range from 4 000 to 10 300 Å, has made possible new absolute calibrations for 16 stars. The new calibrations are remarkably similar to the recent one by Tüg, White and Lockwood. The absolute calibration of stellar spectrophotometry appears now to be quite firm over the spectral range from 4 000 to 10 300 Å.

Key words: **INTERFEROMETRY – PHOTOMETRY.**

The problem of the absolute calibration of the fluxes received from the stars has been very difficult to solve. This difficulty has been exacerbated by the fact that many of the stars which were chosen initially as standard stars have turned out to be variable and, therefore, not suitable as standards for precision photometry and spectrophotometry. Very recently, it was pointed out by Wisniewski and Johnson (1979) that Vega, the star almost universally used as the primary standard, is variable by several percent; the variability of two other standard stars, Gamma Gem and Theta Vir, was noted by Breger (1976). It had begun to appear that the calibration of absolute stellar spectrophotometry rests largely upon observations of slightly variable stars, and that this problem might be difficult to overcome without an extensive and intensive observational program. Such a program would require at least five years, and preferably more, before adequate data could be obtained and would be very difficult to carry out in the present research climate.

It is fortunate, therefore, that photoelectric photometry begun in 1950 can be used to select a number of stars which have been nearly constant in brightness over the past 30 years. These photometric observations were made on the *UBV* system (Johnson and Morgan 1953; Johnson and Harris 1954), the extended *UBVRI* system (Johnson *et al.* 1965, 1966), and the 13-color medium narrow-band system (Johnson, Mitchell and Latham 1967; Mitchell and Johnson 1969; Johnson and Mitchell 1975).

If we restrict our attention to stars near spectral type A0 V, there are eight stars for which it is possible to say with a considerable degree of confidence that their magnitudes have remained constant ± 0.01 mag. These stars are Alpha Del, Beta Lib, Gamma Crv, Gamma Oph, Xi–2 Cet, Zeta Aql, BS 875 and BS 3314. Three other stars, Eta Hya, Upsilon Ori and 10 Lac, with spectral types near B0, also appear to be nearly constant. One more star, Zeta Peg, (B8 V) appears to be nearly constant, but the number of observations is too small to make a strong case.

Other stars for which definite statements can be made are Alpha CMa, Alpha Lyr, Alpha Peg, Beta Leo and 109 Vir. Alpha CMa has become steadily fainter by 0.05 mag. since 1950, while 109 Vir brightened by 0.03 mag. during this time. Alpha Peg and Beta Leo may be variable by ± 0.02 mag. I have published mean values for Alpha Lyr ranging from $V = 0.00$ to $+0.04$; the individual data indicate that Alpha Lyr (Vega) is variable by ± 0.03 mag. (and possibly more), in agreement with

Guthnik's observations of 50 years ago (Wisniewski and Johnson 1979). The mean magnitude for Alpha Lyr is very near to $V = +0.03$.

Few of the nearly-constant stars have been observed for absolute calibrations. Most recently, Tüg, White and Lockwood (1977) made absolute measures of Alpha Lyr and 109 Vir. The absolute calibration of the 13-color photometry by Johnson and Mitchell (1975), based upon all of the absolute calibrations prior to that of Tüg, White and Lockwood, is available. The Johnson-Mitchell calibration is, as will become evident below, remarkably close to that of Tüg *et al.*

Recently, I published spectra (Johnson 1977*a*, 1978) covering the entire range from 4 000 to 10 300 Å, obtained with a Michelson spectrophotometer system (Johnson 1977*b*). These spectra are on a linear intensity scale and, since they are in digital form, can be used very effectively to interpolate the 13-color photometry.

The computation of the absolute calibration of the Michelson spectra from the 13-color photometry is straightforward but, since the spectra do not cover the entire range of the photometry, the computations can be made only for the *99, 86, 80, 72, 63, 58, 52, 45* and *40* filters. First, the filter sensitivity curves published by Johnson and Mitchell (1975) were converted, point by point, from (relative) flux-per-wavelength-interval to flux-per-frequency-interval. Second, these data were interpolated, using a parabolic interpolation subroutine, to produce one point for each of the points of the Michelson spectra. Third, these interpolated data for each filter were multiplied by the spectra, point by point, and summed; the sums for the nine filters, converted to magnitudes, comprise the synthetic photometry. Since the spectra do not extend beyond 4 000 Å or 10 300 Å, but the responses of filters *40* and *99* do, linear extrapolations of the spectra were made in order that synthetic *40* and *99* photometry could be computed.

The fourth step was to apply zero-point corrections (no color-term corrections) to put the synthetic photometry on the 13-color system; fifth, the corrections needed to convert to the absolute calibration of Johnson and Mitchell (1975) were applied. Sixth, the interpolation subroutine was used to interpolate corrections to the observed spectrum for each spectral element. Lastly, this derived absolute spectrum was used in a second iteration of the process. The corrections produced by the second iteration average less than one percent, with a maximum of about two percent.

The comparison of the derived absolute Vega spectrum with the results of Tüg, White and Lockwood is illustrated in Figure 1. Spectral bands averaged over 11 spectral elements (square filter width = 42.4 cm^{-1}) were used, providing spectral resolution similar to that of Tüg *et al.*

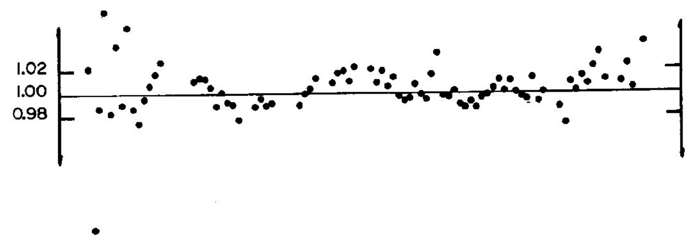

Fig. 1. The comparison of the absolute fluxes for Vega by Tüg, White and Lockwood, and those of this paper. F(TWL)/F(J). The wavelength is 9 000 Å at the left edge of the figure; 4 000 Å at the right edge.

The agreement is remarkably good, particularly since the two absolute calibrations are completely independent.

I have no spectrum of 109 Vir. However, when the Vega spectrum is used to interpolate the 109 Vir 13-color data (both stars have spectral type A0 V), the comparison illustrated in Figure 2 is the result. Again, the comparison is remarkably good. The two comparisons of Figures 1 and 2 are not identical, although the same interpolation spectrum (Vega) was used.

The large scatter at the left (red) ends of the two figures is due primarily to the unfortunate choice of wavelengths by Tüg *et al.*; their bands do not avoid very well the broad lines of the Paschen series of hydrogen. At the shorter wavelengths, it is clear that there are small systematic differences between our two sets of data due, perhaps, to systematic errors in the two photometries and/or to variations of the two stars. However, the scatter (except for the Paschen-line vicinity) is within plus or minus two percent, and I see no reason to adjust either calibration. For the remainder of this paper, I shall use the Johnson-Mitchell calibration and shall rely upon the comparison shown in Figures 1 and 2 for support of the new calibration.

Since I do not have observed spectra of all of the stars discussed here as standards, it was necessary to produce a mean A0 V spectrum for use as an interpolation spectrum for the stars which have been shown to be essentially constant in brightness since 1950. For this purpose, I used a weighted mean of the spectra of Alpha Lyr,

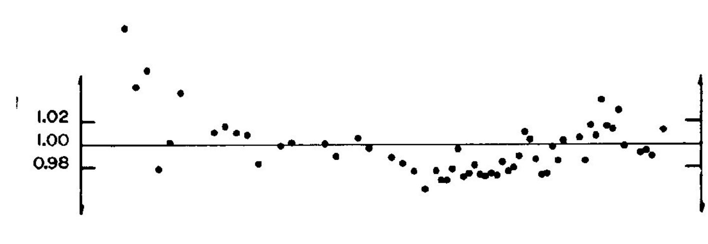

Fig. 2. The comparison of the absolute fluxes for 109 Vir by Tüg, White and Lockwood, and those of this paper, F(TWL)/F(J). The wavelength is 9 000 Å at the left edge of the figure; 4 000 Å at the right edge.

TABLE 1

ABSOLUTE FLUXES

Wavelength (A)	Alf Del	Bet Lib	Gam Crv	Gam Orh	Xi 2 Cet	Zet Aql	BS 875	BS 3314
	Flux (Ergs/cm x cm x Hz)							
4045	1.624E-21	5.016E-21	5.092E-21	1.449E-21	9.800E-22	3.048E-21	3.637E-22	1.324E-21
4145	1.553E-21	4.739E-21	4.817E-21	1.414E-21	9.406E-22	2.954E-21	3.568E-22	1.282E-21
4195	1.574E-21	4.772E-21	4.853E-21	1.448E-21	9.548E-22	3.014E-21	3.662E-22	1.308E-21
4245	1.526E-21	4.599E-21	4.681E-21	1.418E-21	9.275E-22	2.941E-21	3.595E-22	1.277E-21
4395	1.423E-21	4.219E-21	4.302E-21	1.358E-21	8.690E-22	2.792E-21	3.469E-22	1.211E-21
4445	1.404E-21	4.143E-21	4.226E-21	1.350E-21	8.584E-22	2.768E-21	3.456E-22	1.200E-21
4495	1.391E-21	4.089E-21	4.172E-21	1.347E-21	8.516E-22	2.756E-21	3.457E-22	1.194E-21
4545	1.396E-21	4.089E-21	4.173E-21	1.360E-21	8.553E-22	2.777E-21	3.497E-22	1.202E-21
4595	1.389E-21	4.060E-21	4.144E-21	1.361E-21	8.523E-22	2.775E-21	3.508E-22	1.200E-21
4645	1.414E-21	4.126E-21	4.212E-21	1.392E-21	8.686E-22	2.836E-21	3.595E-22	1.224E-21
4695	1.406E-21	4.098E-21	4.183E-21	1.390E-21	8.645E-22	2.830E-21	3.597E-22	1.220E-21
4745	1.405E-21	4.093E-21	4.176E-21	1.394E-21	8.648E-22	2.837E-21	3.614E-22	1.221E-21
4795	1.392E-21	4.052E-21	4.133E-21	1.385E-21	8.571E-22	2.818E-21	3.596E-22	1.210E-21
4945	1.328E-21	3.866E-21	3.940E-21	1.331E-21	8.197E-22	2.710E-21	3.477E-22	1.157E-21
4990	1.297E-21	3.777E-21	3.850E-21	1.303E-21	8.014E-22	2.653E-21	3.410E-22	1.131E-21
5040	1.265E-21	3.683E-21	3.753E-21	1.273E-21	7.820E-22	2.592E-21	3.339E-22	1.103E-21
5090	1.266E-21	3.686E-21	3.756E-21	1.277E-21	7.833E-22	2.599E-21	3.358E-22	1.105E-21
5140	1.241E-21	3.610E-21	3.679E-21	1.254E-21	7.681E-22	2.550E-21	3.305E-22	1.084E-21
5190	1.201E-21	3.494E-21	3.562E-21	1.217E-21	7.443E-22	2.473E-21	3.216E-22	1.051E-21
5240	1.182E-21	3.436E-21	3.504E-21	1.200E-21	7.331E-22	2.436E-21	3.181E-22	1.036E-21
5290	1.179E-21	3.424E-21	3.494E-21	1.199E-21	7.318E-22	2.431E-21	3.189E-22	1.035E-21
5340	1.166E-21	3.383E-21	3.453E-21	1.187E-21	7.242E-22	2.405E-21	3.169E-22	1.025E-21
5390	1.168E-21	3.384E-21	3.457E-21	1.190E-21	7.259E-22	2.408E-21	3.190E-22	1.028E-21
5440	1.160E-21	3.360E-21	3.434E-21	1.185E-21	7.220E-22	2.392E-21	3.186E-22	1.023E-21
5490	1.156E-21	3.345E-21	3.421E-21	1.182E-21	7.200E-22	2.384E-21	3.190E-22	1.022E-21
5540	1.141E-21	3.299E-21	3.377E-21	1.168E-21	7.115E-22	2.353E-21	3.166E-22	1.010E-21
5556	1.147E-21	3.313E-21	3.391E-21	1.174E-21	7.148E-22	2.364E-21	3.185E-22	1.015E-21
5590	1.137E-21	3.284E-21	3.363E-21	1.166E-21	7.092E-22	2.344E-21	3.169E-22	1.008E-21
5640	1.125E-21	3.246E-21	3.326E-21	1.155E-21	7.021E-22	2.320E-21	3.150E-22	9.987E-22
5690	1.111E-21	3.205E-21	3.285E-21	1.143E-21	6.940E-22	2.294E-21	3.126E-22	9.881E-22
5740	1.101E-21	3.173E-21	3.254E-21	1.134E-21	6.879E-22	2.275E-21	3.112E-22	9.803E-22
5790	1.097E-21	3.159E-21	3.241E-21	1.131E-21	6.853E-22	2.269E-21	3.113E-22	9.776E-22
5840	1.098E-21	3.160E-21	3.244E-21	1.135E-21	6.861E-22	2.276E-21	3.129E-22	9.796E-22
5890	1.060E-21	3.049E-21	3.130E-21	1.098E-21	6.622E-22	2.202E-21	3.033E-22	9.465E-22
5940	1.063E-21	3.057E-21	3.139E-21	1.103E-21	6.640E-22	2.214E-21	3.054E-22	9.500E-22
5990	1.049E-21	3.017E-21	3.098E-21	1.091E-21	6.552E-22	2.192E-21	3.027E-22	9.384E-22
6040	1.041E-21	2.994E-21	3.074E-21	1.086E-21	6.501E-22	2.182E-21	3.016E-22	9.320E-22
6090	1.031E-21	2.963E-21	3.043E-21	1.077E-21	6.431E-22	2.166E-21	2.996E-22	9.231E-22
6140	1.017E-21	2.923E-21	3.001E-21	1.065E-21	6.343E-22	2.144E-21	2.967E-22	9.113E-22
6190	1.005E-21	2.888E-21	2.966E-21	1.055E-21	6.266E-22	2.125E-21	2.943E-22	9.011E-22
6240	9.891E-22	2.840E-21	2.918E-21	1.040E-21	6.163E-22	2.097E-21	2.905E-22	8.870E-22
6290	9.667E-22	2.774E-21	2.850E-21	1.018E-21	6.020E-22	2.054E-21	2.848E-22	8.671E-22
6340	9.686E-22	2.777E-21	2.854E-21	1.022E-21	6.028E-22	2.062E-21	2.862E-22	8.689E-22
6390	9.664E-22	2.768E-21	2.846E-21	1.021E-21	6.011E-22	2.061E-21	2.863E-22	8.669E-22
6440	9.527E-22	2.726E-21	2.804E-21	1.008E-21	5.923E-22	2.034E-21	2.829E-22	8.544E-22
6490	9.367E-22	2.676E-21	2.754E-21	9.914E-22	5.818E-22	2.002E-21	2.787E-22	8.395E-22
6640	9.162E-22	2.603E-21	2.684E-21	9.716E-22	5.677E-22	1.960E-21	2.738E-22	8.191E-22
6690	9.166E-22	2.599E-21	2.682E-21	9.725E-22	5.674E-22	1.961E-21	2.743E-22	8.187E-22
6740	9.110E-22	2.578E-21	2.662E-21	9.669E-22	5.634E-22	1.949E-21	2.730E-22	8.128E-22
6790	9.051E-22	2.556E-21	2.642E-21	9.610E-22	5.593E-22	1.937E-21	2.715E-22	8.067E-22
6840	8.968E-22	2.528E-21	2.614E-21	9.526E-22	5.537E-22	1.919E-21	2.693E-22	7.986E-22
6890	9.008E-22	2.534E-21	2.623E-21	9.572E-22	5.557E-22	1.927E-21	2.709E-22	8.014E-22
6940	8.957E-22	2.515E-21	2.605E-21	9.523E-22	5.522E-22	1.917E-21	2.697E-22	7.963E-22
6990	8.759E-22	2.455E-21	2.544E-21	9.316E-22	5.396E-22	1.874E-21	2.641E-22	7.780E-22
7040	8.721E-22	2.441E-21	2.531E-21	9.281E-22	5.370E-22	1.867E-21	2.634E-22	7.743E-22
7090	8.702E-22	2.432E-21	2.523E-21	9.266E-22	5.355E-22	1.863E-21	2.633E-22	7.723E-22
7140	8.626E-22	2.408E-21	2.499E-21	9.192E-22	5.307E-22	1.848E-21	2.615E-22	7.654E-22
7190	8.578E-22	2.392E-21	2.482E-21	9.148E-22	5.275E-22	1.839E-21	2.606E-22	7.610E-22
7240	8.428E-22	2.348E-21	2.437E-21	8.997E-22	5.183E-22	1.808E-21	2.566E-22	7.478E-22
7290	8.481E-22	2.361E-21	2.451E-21	9.062E-22	5.215E-22	1.821E-21	2.589E-22	7.527E-22
7340	8.394E-22	2.335E-21	2.425E-21	8.980E-22	5.162E-22	1.804E-21	2.570E-22	7.452E-22
7390	8.366E-22	2.326E-21	2.416E-21	8.962E-22	5.147E-22	1.800E-21	2.569E-22	7.430E-22
7440	8.339E-22	2.318E-21	2.407E-21	8.946E-22	5.133E-22	1.797E-21	2.570E-22	7.409E-22
7490	8.263E-22	2.296E-21	2.384E-21	8.878E-22	5.089E-22	1.784E-21	2.555E-22	7.346E-22
7540	8.223E-22	2.284E-21	2.372E-21	8.848E-22	5.068E-22	1.778E-21	2.552E-22	7.314E-22
7690	8.026E-22	2.227E-21	2.313E-21	8.673E-22	4.954E-22	1.742E-21	2.516E-22	7.154E-22
7740	7.919E-22	2.197E-21	2.281E-21	8.567E-22	4.889E-22	1.721E-21	2.490E-22	7.064E-22
7790	7.764E-22	2.154E-21	2.236E-21	8.409E-22	4.795E-22	1.689E-21	2.448E-22	6.932E-22
7840	7.736E-22	2.146E-21	2.227E-21	8.387E-22	4.778E-22	1.685E-21	2.445E-22	6.914E-22
7890	7.554E-22	2.095E-21	2.173E-21	8.196E-22	4.665E-22	1.646E-21	2.393E-22	6.758E-22
7940	7.523E-22	2.087E-21	2.163E-21	8.168E-22	4.645E-22	1.641E-21	2.388E-22	6.738E-22
7990	7.481E-22	2.075E-21	2.150E-21	8.127E-22	4.616E-22	1.632E-21	2.378E-22	6.709E-22
8040	7.357E-22	2.041E-21	2.113E-21	7.994E-22	4.536E-22	1.605E-21	2.341E-22	6.606E-22
8090	7.348E-22	2.039E-21	2.109E-21	7.984E-22	4.526E-22	1.603E-21	2.340E-22	6.608E-22
8140	7.260E-22	2.015E-21	2.082E-21	7.886E-22	4.466E-22	1.583E-21	2.313E-22	6.539E-22
8190	7.241E-22	2.011E-21	2.075E-21	7.862E-22	4.448E-22	1.578E-21	2.307E-22	6.533E-22
8240	7.249E-22	2.014E-21	2.075E-21	7.867E-22	4.446E-22	1.579E-21	2.310E-22	6.552E-22
8290	7.199E-22	2.001E-21	2.060E-21	7.809E-22	4.409E-22	1.567E-21	2.294E-22	6.518E-22
8340	7.138E-22	1.985E-21	2.040E-21	7.739E-22	4.365E-22	1.552E-21	2.274E-22	6.474E-22
8390	7.012E-22	1.951E-21	2.002E-21	7.600E-22	4.282E-22	1.524E-21	2.234E-22	6.370E-22
8570	7.201E-22	2.003E-21	2.048E-21	7.805E-22	4.381E-22	1.564E-21	2.296E-22	6.574E-22
8630	7.446E-22	2.068E-21	2.113E-21	8.082E-22	4.531E-22	1.620E-21	2.377E-22	6.801E-22
8707	7.681E-22	2.128E-21	2.174E-21	8.357E-22	4.677E-22	1.675E-21	2.458E-22	7.019E-22
8807	7.853E-22	2.169E-21	2.214E-21	8.567E-22	4.785E-22	1.717E-21	2.519E-22	7.180E-22
8940	7.813E-22	2.150E-21	2.193E-21	8.551E-22	4.763E-22	1.713E-21	2.514E-22	7.151E-22
9090	7.675E-22	2.104E-21	2.144E-21	8.430E-22	4.681E-22	1.689E-21	2.477E-22	7.033E-22
9140	7.678E-22	2.102E-21	2.141E-21	8.444E-22	4.684E-22	1.691E-21	2.481E-22	7.038E-22
9300	7.506E-22	2.046E-21	2.082E-21	8.289E-22	4.584E-22	1.660E-21	2.435E-22	6.887E-22
9650	7.174E-22	1.933E-21	1.965E-21	8.008E-22	4.400E-22	1.604E-21	2.348E-22	6.583E-22
9750	7.084E-22	1.901E-21	1.932E-21	7.938E-22	4.353E-22	1.590E-21	2.326E-22	6.497E-22
9850	7.024E-22	1.876E-21	1.908E-21	7.902E-22	4.326E-22	1.583E-21	2.313E-22	6.438E-22
9950	6.757E-22	1.800E-21	1.830E-21	7.622E-22	4.165E-22	1.526E-21	2.231E-22	6.195E-22
10150	6.454E-22	1.710E-21	1.737E-21	7.315E-22	3.985E-22	1.465E-21	2.140E-22	5.920E-22
10220	6.384E-22	1.688E-21	1.715E-21	7.248E-22	3.943E-22	1.451E-21	2.119E-22	5.856E-22

TABLE 2

ABSOLUTE FLUXES

Wavelength (A)	Flux (Ergs/cm x cm x Hz)							
	Alf CMa	Alf Lyr	Alf Peg	Bet Leo	Ups Ori	10 Lac	109 Vir	Zet Peg
4045	1.810E-19	4.595E-20	5.002E-21	5.942E-21	8.869E-22	6.589E-22	1.562E-21	2.374E-21
4145	1.756E-19	4.467E-20	4.794E-21	5.858E-21	8.163E-22	6.084E-22	1.509E-21	2.250E-21
4195	1.792E-19	4.563E-20	4.863E-21	6.028E-21	7.640E-22	5.702E-22	1.536E-21	2.270E-21
4245	1.751E-19	4.461E-20	4.720E-21	5.933E-21	7.791E-22	5.823E-22	1.497E-21	2.192E-21
4395	1.663E-19	4.251E-20	4.415E-21	5.763E-21	7.005E-22	5.259E-22	1.414E-21	2.019E-21
4445	1.649E-19	4.219E-20	4.360E-21	5.753E-21	6.976E-22	5.245E-22	1.400E-21	1.985E-21
4495	1.641E-19	4.203E-20	4.326E-21	5.764E-21	6.927E-22	5.217E-22	1.393E-21	1.961E-21
4545	1.652E-19	4.236E-20	4.346E-21	5.842E-21	6.749E-22	5.092E-22	1.402E-21	1.962E-21
4595	1.649E-19	4.234E-20	4.333E-21	5.869E-21	6.934E-22	5.243E-22	1.400E-21	1.948E-21
4645	1.681E-19	4.326E-20	4.420E-21	6.024E-21	6.758E-22	5.120E-22	1.430E-21	1.980E-21
4695	1.674E-19	4.314E-20	4.405E-21	6.037E-21	7.187E-22	5.458E-22	1.426E-21	1.965E-21
4745	1.673E-19	4.322E-20	4.412E-21	6.075E-21	7.018E-22	5.342E-22	1.430E-21	1.961E-21
4795	1.657E-19	4.289E-20	4.380E-21	6.055E-21	6.896E-22	5.262E-22	1.420E-21	1.939E-21
4945	1.579E-19	4.111E-20	4.208E-21	5.876E-21	6.458E-22	4.963E-22	1.365E-21	1.845E-21
4990	1.542E-19	4.022E-20	4.120E-21	5.767E-21	6.330E-22	4.875E-22	1.337E-21	1.801E-21
5040	1.503E-19	3.927E-20	4.025E-21	5.651E-21	6.119E-22	4.723E-22	1.306E-21	1.755E-21
5090	1.505E-19	3.936E-20	4.037E-21	5.684E-21	6.034E-22	4.668E-22	1.310E-21	1.756E-21
5140	1.474E-19	3.862E-20	3.963E-21	5.596E-21	5.914E-22	4.585E-22	1.287E-21	1.719E-21
5190	1.428E-19	3.745E-20	3.843E-21	5.444E-21	5.755E-22	4.470E-22	1.249E-21	1.664E-21
5240	1.406E-19	3.691E-20	3.788E-21	5.382E-21	5.656E-22	4.402E-22	1.231E-21	1.637E-21
5290	1.404E-19	3.687E-20	3.784E-21	5.389E-21	5.514E-22	4.298E-22	1.230E-21	1.632E-21
5340	1.389E-19	3.651E-20	3.748E-21	5.349E-21	5.462E-22	4.264E-22	1.218E-21	1.613E-21
5390	1.392E-19	3.661E-20	3.759E-21	5.375E-21	5.448E-22	4.260E-22	1.222E-21	1.615E-21
5440	1.385E-19	3.643E-20	3.740E-21	5.359E-21	5.378E-22	4.211E-22	1.216E-21	1.605E-21
5490	1.381E-19	3.635E-20	3.732E-21	5.358E-21	5.290E-22	4.148E-22	1.213E-21	1.599E-21
5540	1.365E-19	3.594E-20	3.689E-21	5.307E-21	5.238E-22	4.114E-22	1.199E-21	1.578E-21
5556	1.371E-19	3.611E-20	3.707E-21	5.336E-21	5.248E-22	4.124E-22	1.205E-21	1.585E-21
5590	1.361E-19	3.584E-20	3.679E-21	5.305E-21	5.124E-22	4.031E-22	1.197E-21	1.572E-21
5640	1.347E-19	3.549E-20	3.643E-21	5.266E-21	5.117E-22	4.032E-22	1.186E-21	1.555E-21
5690	1.332E-19	3.510E-20	3.602E-21	5.222E-21	5.122E-22	4.043E-22	1.173E-21	1.537E-21
5740	1.320E-19	3.480E-20	3.571E-21	5.194E-21	4.941E-22	3.908E-22	1.165E-21	1.523E-21
5790	1.315E-19	3.469E-20	3.558E-21	5.195E-21	4.877E-22	3.865E-22	1.163E-21	1.517E-21
5840	1.317E-19	3.474E-20	3.562E-21	5.223E-21	4.904E-22	3.894E-22	1.166E-21	1.519E-21
5890	1.271E-19	3.355E-20	3.437E-21	5.067E-21	4.682E-22	3.727E-22	1.129E-21	1.466E-21
5940	1.275E-19	3.365E-20	3.445E-21	5.109E-21	4.690E-22	3.743E-22	1.136E-21	1.471E-21
5990	1.258E-19	3.321E-20	3.398E-21	5.071E-21	4.591E-22	3.675E-22	1.124E-21	1.453E-21
6040	1.248E-19	3.295E-20	3.369E-21	5.062E-21	4.533E-22	3.639E-22	1.119E-21	1.443E-21
6090	1.235E-19	3.261E-20	3.331E-21	5.039E-21	4.423E-22	3.561E-22	1.112E-21	1.429E-21
6140	1.218E-19	3.217E-20	3.284E-21	4.998E-21	4.377E-22	3.533E-22	1.100E-21	1.410E-21
6190	1.203E-19	3.179E-20	3.243E-21	4.964E-21	4.292E-22	3.473E-22	1.090E-21	1.394E-21
6240	1.184E-19	3.128E-20	3.189E-21	4.906E-21	4.178E-22	3.389E-22	1.075E-21	1.372E-21
6290	1.157E-19	3.058E-20	3.116E-21	4.813E-21	4.071E-22	3.308E-22	1.052E-21	1.341E-21
6340	1.159E-19	3.064E-20	3.122E-21	4.835E-21	4.080E-22	3.321E-22	1.056E-21	1.343E-21
6390	1.156E-19	3.059E-20	3.116E-21	4.834E-21	4.031E-22	3.286E-22	1.054E-21	1.338E-21
6440	1.140E-19	3.017E-20	3.074E-21	4.769E-21	3.997E-22	3.260E-22	1.039E-21	1.317E-21
6490	1.121E-19	2.968E-20	3.026E-21	4.688E-21	3.927E-22	3.205E-22	1.020E-21	1.293E-21
6640	1.098E-19	2.910E-20	2.973E-21	4.567E-21	3.803E-22	3.101E-22	9.931E-22	1.255E-21
6690	1.099E-19	2.913E-20	2.980E-21	4.560E-21	3.696E-22	3.012E-22	9.913E-22	1.252E-21
6740	1.092E-19	2.898E-20	2.967E-21	4.522E-21	3.714E-22	3.025E-22	9.829E-22	1.241E-21
6790	1.086E-19	2.882E-20	2.953E-21	4.482E-21	3.695E-22	3.007E-22	9.743E-22	1.229E-21
6840	1.076E-19	2.858E-20	2.931E-21	4.431E-21	3.632E-22	2.954E-22	9.631E-22	1.215E-21
6890	1.082E-19	2.873E-20	2.949E-21	4.441E-21	3.613E-22	2.937E-22	9.651E-22	1.217E-21
6940	1.076E-19	2.860E-20	2.937E-21	4.408E-21	3.595E-22	2.922E-22	9.577E-22	1.207E-21
6990	1.053E-19	2.799E-20	2.876E-21	4.303E-21	3.505E-22	2.849E-22	9.346E-22	1.178E-21
7040	1.049E-19	2.790E-20	2.867E-21	4.279E-21	3.504E-22	2.848E-22	9.291E-22	1.170E-21
7090	1.047E-19	2.786E-20	2.863E-21	4.267E-21	3.509E-22	2.853E-22	9.257E-22	1.166E-21
7140	1.038E-19	2.764E-20	2.840E-21	4.228E-21	3.427E-22	2.788E-22	9.167E-22	1.154E-21
7190	1.033E-19	2.751E-20	2.826E-21	4.206E-21	3.397E-22	2.767E-22	9.109E-22	1.147E-21
7240	1.015E-19	2.706E-20	2.777E-21	4.136E-21	3.371E-22	2.749E-22	8.947E-22	1.126E-21
7290	1.022E-19	2.725E-20	2.794E-21	4.168E-21	3.291E-22	2.689E-22	9.003E-22	1.133E-21
7340	1.012E-19	2.700E-20	2.765E-21	4.134E-21	3.279E-22	2.685E-22	8.913E-22	1.121E-21
7390	1.009E-19	2.694E-20	2.754E-21	4.131E-21	3.245E-22	2.664E-22	8.888E-22	1.118E-21
7440	1.007E-19	2.688E-20	2.744E-21	4.129E-21	3.204E-22	2.638E-22	8.866E-22	1.115E-21
7490	9.984E-20	2.667E-20	2.717E-21	4.104E-21	3.163E-22	2.612E-22	8.793E-22	1.106E-21
7540	9.942E-20	2.658E-20	2.702E-21	4.097E-21	3.108E-22	2.574E-22	8.758E-22	1.101E-21
7690	9.721E-20	2.603E-20	2.630E-21	4.037E-21	3.051E-22	2.550E-22	8.574E-22	1.078E-21
7740	9.595E-20	2.570E-20	2.593E-21	3.995E-21	3.000E-22	2.514E-22	8.467E-22	1.064E-21
7790	9.410E-20	2.521E-20	2.540E-21	3.927E-21	2.952E-22	2.480E-22	8.308E-22	1.044E-21
7840	9.378E-20	2.514E-20	2.529E-21	3.923E-21	2.884E-22	2.428E-22	8.285E-22	1.041E-21
7890	9.158E-20	2.456E-20	2.468E-21	3.839E-21	2.847E-22	2.401E-22	8.096E-22	1.017E-21
7940	9.120E-20	2.446E-20	2.457E-21	3.830E-21	2.834E-22	2.393E-22	8.068E-22	1.014E-21
7990	9.067E-20	2.432E-20	2.443E-21	3.814E-21	2.782E-22	2.352E-22	8.027E-22	1.009E-21
8040	8.912E-20	2.391E-20	2.402E-21	3.754E-21	2.741E-22	2.318E-22	7.896E-22	9.921E-22
8090	8.896E-20	2.386E-20	2.398E-21	3.752E-21	2.711E-22	2.293E-22	7.888E-22	9.912E-22
8140	8.781E-20	2.355E-20	2.369E-21	3.707E-21	2.673E-22	2.261E-22	7.795E-22	9.796E-22
8190	8.750E-20	2.346E-20	2.362E-21	3.698E-21	2.671E-22	2.257E-22	7.776E-22	9.773E-22
8240	8.751E-20	2.346E-20	2.365E-21	3.702E-21	2.621E-22	2.214E-22	7.785E-22	9.787E-22
8290	8.682E-20	2.327E-20	2.348E-21	3.676E-21	2.604E-22	2.198E-22	7.733E-22	9.722E-22
8340	8.599E-20	2.304E-20	2.328E-21	3.644E-21	2.578E-22	2.174E-22	7.667E-22	9.641E-22
8390	8.439E-20	2.261E-20	2.287E-21	3.579E-21	2.525E-22	2.128E-22	7.532E-22	9.472E-22
8570	8.643E-20	2.317E-20	2.350E-21	3.679E-21	2.511E-22	2.115E-22	7 734E-22	9.724E-22
8630	8.936E-20	2.399E-20	2.432E-21	3.810E-21	2.515E-22	2.120E-22	7.993E-22	1.004E-21
8707	9.220E-20	2.480E-20	2.512E-21	3.939E-21	2.514E-22	2.124E-22	8.241E-22	1.035E-21
8807	9.426E-20	2.542E-20	2.572E-21	4.038E-21	2.468E-22	2.091E-22	8.418E-22	1.056E-21
8940	9.377E-20	2.536E-20	2.563E-21	4.030E-21	2.416E-22	2.053E-22	8.368E-22	1.048E-21
9090	9.211E-20	2.498E-20	2.522E-21	3.973E-21	2.374E-22	2.024E-22	8.212E-22	1.027E-21
9140	9.214E-20	2.502E-20	2.525E-21	3.980E-21	2.346E-22	2.003E-22	8.212E-22	1.027E-21
9300	9.009E-20	2.455E-20	2.473E-21	3.906E-21	2.241E-22	1.920E-22	8.020E-22	1.001E-21
9650	8.623E-20	2.371E-20	2.376E-21	3.772E-21	2.138E-22	1.852E-22	7.641E-22	9.497E-22
9750	8.522E-20	2.351E-20	2.351E-21	3.737E-21	2.118E-22	1.841E-22	7.537E-22	9.355E-22
9850	8.459E-20	2.341E-20	2.335E-21	3.719E-21	2.085E-22	1.820E-22	7.466E-22	9.252E-22
9950	8.139E-20	2.258E-20	2.250E-21	3.586E-21	2.015E-22	1.763E-22	7.177E-22	8.885E-22
10150	7.778E-20	2.167E-20	2.154E-21	3.441E-21	1.845E-22	1.622E-22	6.845E-22	8.458E-22
10220	7.694E-20	2.147E-20	2.132E-21	3.409E-21	1.757E-22	1.547E-22	6.767E-22	8.356E-22

Alpha Peg and Zeta Aql. The resultant interpolated fluxes are listed in Table 1. The wavelengths of Tüg *et al.* were adopted except in the region of the Paschen lines, where more appropriate positions between the lines were used. The spectral resolution is 11 spectral elements, or 42.4 cm^{-1}. The adopted mean A0 V spectrum was used only for interpolation purposes and the points listed in the table were chosen to lie in spectral regions where there are no significant lines in A0 V stars. The usefulness of an interpolation spectrum having a similar spectral type is demonstrated by the comparison of Figure 2.

Since my spectra and photometry extend beyond 9 000 Å (the long-wavelength limit of the data of Tüg *et al.*), it was possible to add several longer-wavelength points. Some of these infrared points are within the strong 9 500 Å water-vapor bands, where the extinction corrections of the spectra made possible data not previously available. These eight stars and their absolute data in Table 1 represent the best absolute stellar fluxes available today. It seems very likely, considering the comparisons of Figures 1 and 2, that the data will stand and may very well have a precision of one percent. The photometric system upon which they are based (the 13-color photometry) is well established and, by now, around 2 000 stars have been observed on the system.

In Table 2 are listed data of lesser reliability for eight more stars. The data for Vega (Alpha Lyr) should be reliable as mean values for this star (single observations of Vega should not be used for calibrations), as should the data for Alpha CMa and 109 Vir (for which recent *V*-magnitudes were used); the latter have exhibited only slow changes since 1950, without the rapid variations of Vega. Alpha Peg, Beta Leo and Zeta Peg probably are reliable to the same degree as is Vega.

The interpolated data for Upsilon Ori and 10 Lac were derived using a mean spectrum from Zeta Ori,

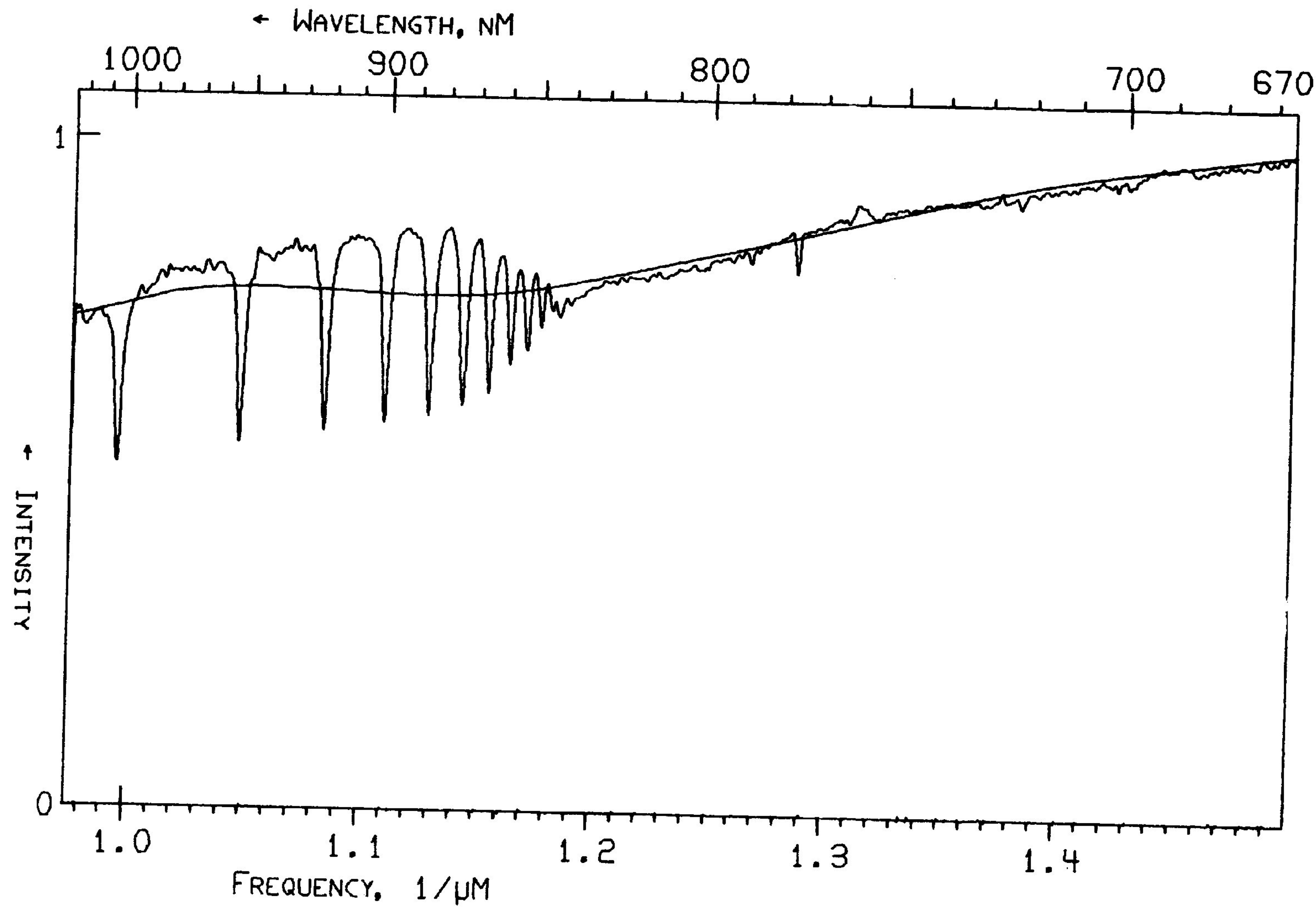

Fig. 3. The comparison of the spectrally interpolated flux for Vega with that interpolated smoothly from the 13-color photometry alone.

Epsilon Ori and Eta UMa. There are two uncertainties about the data for these two stars: First, the spectrum used for the interpolation probably represents a star of too high a luminosity and, second, the spectral bands (which were chosen to avoid spectral features in A0 V stars) may contain spectral features of significant intensity.

For the individual stars for which I have both Michelson spectra and 13-color photometry, it is, of course, possible to compute absolute spectra with a resolution of 3.858 cm^{-1}. It is prohibitive to publish such data here (4 000 points per star) but magnetic-tape data will be available in the future.

In addition to the data of Tables 1 and 2, interpolated using observed spectra, it is also possible to compute interpolated flux curves from the 13-color photometry alone. Since the filter photometry represents data integrated over rather large bands compared with the resolution of the spectra, these 13-color interpolations are smoothed energy curves. Especially in the regions of the higher members of the Paschen and Balmer series, there are significant differences between the two types of data; this is illustrated in Figure 3, which shows absolute spectra of Vega from the interpolated Michelson spectrum and from the smooth interpolation of the 13-color photometry alone. The smooth interpolation may be satisfactory for many purposes.

Between the absolutely-calibrated 13-color photometry and the Michelson spectra on the one hand, and the entirely independent absolute calibration of Tüg, White and Lockwood, on the other, it appears that the problem of the absolute calibration of stellar standards is well in hand for the spectral range from 4 000 to 10 300 Å. The new calibration, represented by the stars and data of Table 1 (and, with less reliability, Table 2) has considerably more weight than previous calibrations because of the extensive photometric history for these stars, which made possible the identification of stars which have proven to be variable.

REFERENCES

Breger, M. 1976, *Ap. J. Suppl.*, **32**, 1.

Johnson, H.L. 1977*a*, *Rev. Mexicana Astron. Astrof.*, **2**, 71.

Johnson, H.L. 1977*b*, *Rev. Mexicana Astron. Astrof.*, **2**, 219.

Johnson, H.L. 1978, *Rev. Mexicana Astron. Astrof.*, **4**, 3.

Johnson, H.L., and Harris, D.L. 1954, *Ap. J.*, **120**, 196.

Johnson, H.L., Mitchell, R.I., Iriarte, B., and Wisniewski, W.Z. 1965, *Sky Telesc.*, **30**, 21.

Johnson, H.L., Mitchell, R.I., Iriarte, B., and Wisniewski, W.Z. 1966, *Comm. Lunar and Planet. Lab.*, **4**, 99.

Johnson, H.L., Mitchell, R.I., and Latham, A.S. 1967, *Comm. Lunar and Planet. Lab.*, **6**, 85.

Johnson, H.L., and Mitchell, R.I. 1975, *Rev. Mexicana Astron. Astrof.*, **3**, 299.

Johnson, H.L., and Morgan, W.W. 1953, *Ap. J.*, **117**, 313.

Mitchell, R.I., and Johnson, H.L. 1969, *Comm. Lunar and Planet. Lab.*, **8**, 1.

Tüg, H., White, N.M., and Lockwood, G.W. 1977, *Astr. and Ap.*, **61**, 679.

Wisniewski, W.Z., and Johnson, H.L. 1979, *Sky Telesc*, **57**, 4.

Request reprints to E. Themsel, Instituto de Astronomía, UNAM, Apdo. Postal 70-264, México 20, D.F., México.