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MAP-BASED TRIGONOMETRIC PARALLAXES OF ALTAIR AND VEGA

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ABSTRACT

Trigonometric parallaxes for stars in the regions of the nearby main-sequence A stars Altair and Vega are derived from data collected with the Multichannel Astrometric Photometer (MAP) and associated Thaw refractor of the University of Pittsburgh's Allegheny Observatory. The weighted mean parallax of all trigonometric studies of Altair is now $+0\farcs1963 \pm 0\farcs00077$, corresponding to a distance modulus of 1.465 ± 0.009 mag and an absolute visual magnitude of 2.22 ± 0.012. Altair's diameter is 1.63 ± 0.08 solar diameters. The weighted mean trigonometric parallax of all trigonometric studies of Vega is now $0\farcs1300 \pm 0\farcs00077$, yielding a distance modulus of 0.570 ± 0.013 and an absolute visual magnitude of 0.60 ± 0.013. Vega's diameter is 2.68 ± 0.06 solar diameters. The apparent motion of both stars is linear over the period of observation, strongly suggesting the absence of short-period (1–6 yr) stellar or brown dwarf companions to either star. We also find a parallax of $0\farcs0155 \pm 0\farcs0006$ for the high proper motion F8 reference star BD +38°3231. The derived luminosity, UV excess, and high space motion of this star all indicate that it is a subdwarf.

Subject headings: stars: distances — stars: fundamental parameters — stars: individual (Altair, Vega) — stars: low-mass, brown dwarfs

1. INTRODUCTION

Altair and Vega are the nearest northern hemisphere, ostensibly single, main-sequence type A stars. Both stars have been studied extensively with Vega serving as a standard in many spectrophotometric systems. Infrared measurements indicate that Vega has a circumstellar shell (Aumann et al. 1984), and it has been suggested that the star's larger than expected angular diameter (Hanbury-Brown, Davis, & Allen 1974), unusual line profiles, and higher than expected luminosity might be explained by a "pole-on" orientation (Gulliver, Hill, & Adejman 1994). Although nearer, Altair is slightly fainter, cooler, smaller, and the least studied of the two. As nearby main-sequence type A stars, these two stars provide an unusual opportunity to accurately calibrate the absolute magnitude of stars on the upper portion of the local main sequence and to establish that at least some stars in this temperature class are in fact single.

Altair has now been on the Multichannel Astrometric Photometry (MAP) program at the Allegheny Observatory for six seasons yielding 78 observations. Vega has been observed 53 times in 7.5 yr. The instrumentation and reduction procedures utilized in this continuing astrometric series of MAP and photographically determined astrometric stellar parameters have been described extensively (Gatewood 1987). The algorithm by which the absolute parallaxes are determined includes the estimation of the intrinsic luminosities of the reference stars. This need is the basis for a parallel series of reports detailing intermediate-band photometry results (e.g., Castelaz et al. 1991) and a further program by Stephenson based on the 10° objective prism of the Warner and Swasey Observatory 24 inch (61 cm) Schmidt telescope.

Table 1 presents astrometric parameters determined in the regions of Altair and Vega with the 0.76 m red-light Thaw refractor and associated MAP detector (Thaw/MAP). The Cartesian coordinates derived from the Thaw/MAP system are reduced by the iterative algorithm known as the central overlap technique (Eichhorn 1988) and are presented in a consistent format. The positions and motions, at the epoch and equinox of J2000, of the stars under study are listed in the last four columns of Table 1 above their corresponding standard errors. The system of the positions and motions is that of the PPM Catalog (Röser & Bastian 1991), ostensibly that of the FK5 Catalog. The standard errors are given in units of the last shown digit of the parameter to which they pertain and are strictly internal at J2000. We note that they do not include an allowance for the zero-point, scale, orientation, or proper motion uncertainties of the reference system.

Because the weighting system in effect during the computation of the field variates reflects the effects of field position and photon count, instead of the errors of the estimated spectroscopic parallaxes, the frame of the absolute parallaxes can still be improved. Thus a final weighted adjustment to absolute parallax is justified. Listed in Table 2 are the Allegheny Observatory catalog number (AO no.) and the adopted spectral class-luminosity type of the reference stars for which trigonometric and spectrophotometric studies were meaningful. With the exceptions noted in the individual descriptions below, the tabulated spectral classifications result from an evaluation of catalog listed spectral types or are derived from the multiband photometry of these regions given by Castelaz et al. (1991). Unless otherwise noted, the Castelaz et al. spectral classifications have been adopted and the ratio $A_v/E(B-V)$ was assumed to be 3.1. In Table 2 the spectral classification of the reference star is followed by the implied spectroscopic parallax, an estimate of its standard error, the provisional absolute parallax, its calculated standard error, the adjustment found by subtracting the observed parallax from the spectroscopic parallax, and an estimate of the statistical weight of that individual estimate of the mean adjustment. The weighted residuals to this adjustment are listed in the last column. The adjustment found for each region is based upon the luminosity classifications adopted in the section of Table 2 addressed to that region, the absolute magnitudes given by Allen (1973, p. 200) and the estimated individual interstellar absorption

TABLE 1A

STAR PARAMETERS IN THE REGION OF ALTAIR

AO (1)	*d* (2)	*V* (mag) (3)	$B-V$ (4)	Parallax (mas) (5)	R.A. (2000) (6)	PM (r.a.) (s yr^{-1}) (7)	Decl. (2000) (8)	PM (Decl.) (″ yr^{-1}) (9)
1272......	2	10.23	1.02	1.9	$19^h49^m53^s.56908$	−0.000319	8°53′43″.0279	0.00215
				0.8	0.00025	0.000040	0.0037	0.00058
1273......	2	9.49	0.79	0.4	19 50 2.67137	0.000409	8 35 57.7465	−0.00370
				0.6	0.00018	0.000030	0.0027	0.00045
1274......	2	10.31	0.69	6.0	19 50 31.19880	0.002214	9 3 5.9246	0.07312
				1.2	0.00038	0.000062	0.0057	0.00091
1275......	2	9.24	1.20	0.1	19 50 34.73062	0.000461	8 53 2.0217	0.00040
				0.8	0.00024	0.000039	0.0036	0.00058
1276......	2	9.12	0.75	1.8	19 50 37.13358	−0.000069	8 38 39.7679	−0.00130
				0.8	0.00025	0.000040	0.0036	0.00059
1277......	2	0.77	0.22	196.0	19 50 47.00158	0.036248	8 52 5.9151	0.38647
				0.8	0.00023	0.000036	0.0034	0.00054
1278......	2	8.92	0.96	2.4	19 50 50.50777	−0.000054	8 45 5.7669	−0.00822
				0.9	0.00028	0.000046	0.0042	0.00068
1279......	2	9.59	−0.04	5.1	19 51 1.97863	−0.000413	8 55 32.9019	−0.00863
				1.2	0.00035	0.000056	0.0052	0.00083
1280......	2	9.16	1.12	2.5	19 51 6.10003	0.000353	9 10 20.7377	0.01208
				0.7	0.00020	0.000033	0.0030	0.00048
1281......	2	9.77	0.76	11.5	19 51 13.35766	0.000515	8 42 19.4634	−0.02191
				1.5	0.00048	0.000079	0.0071	0.00118
1282......	2	8.96	0.31	9.7	19 52 4.01760	0.000878	9 4 27.1214	−0.02826
				0.5	0.00016	0.000025	0.0023	0.00038
1283......	2	9.90	1.24	0.5	19 52 7.76496	−0.000001	8 54 50.4740	−0.01286
				1.0	0.00029	0.000046	0.0043	0.00068

TABLE 1B

STAR PARAMETERS IN THE REGION OF VEGA

AO (1)	*d* (2)	*V* (mag) (3)	$B-V$ (4)	Parallax (mas) (5)	R.A. (2000) (6)	PM (r.a.) (s yr^{-1}) (7)	Decl. (2000) (8)	PM (Decl.) (″ yr^{-1}) (9)
1284......	2	6.70	0.03	6.7	$18^h35^m21^s.51313$	−0.001246	38°53′41″.9404	0.00655
				0.6	0.00019	0.000028	0.0022	0.00032
1159......	2	9.25	0.58	15.5	18 35 36.74840	0.013490	39 3 42.4221	0.25132
				0.6	0.00017	0.000025	0.0020	0.00029
1160......	2	9.84	1.09	9.1	18 36 29.35486	0.000127	39 4 12.2373	0.03286
				2.1	0.00143	0.000233	0.0167	0.00271
1161......	2	9.92	1.58	−0.1	18 36 31.91541	−0.000748	38 30 15.4651	0.02003
				0.7	0.00021	0.000031	0.0025	0.00036
1162......	2	10.72	0.62	6.2	18 36 38.12766	−0.004919	38 53 29.6328	−0.01237
				1.4	0.00058	0.000090	0.0068	0.00105
1163......	2	10.00	1.12	2.0	18 36 40.56433	0.000671	38 41 29.2805	0.02427
				0.8	0.00024	0.000036	0.0029	0.00042
1164......	2	8.01	0.39	10.5	18 36 48.70559	−0.000407	38 31 15.4669	0.01561
				0.7	0.00021	0.000031	0.0025	0.00036
1285......	2	0.03	0.00	130.1	18 36 56.35956	0.017436	38 47 1.7446	0.29617
				0.9	0.00027	0.000040	0.0031	0.00046
1165......	2	9.62	1.12	2.6	18 37 0.52142	−0.000302	38 52 17.7729	0.00563
				0.8	0.00024	0.000037	0.0029	0.00042
1166......	2	10.14	0.78	4.0	18 37 26.31599	0.000349	38 52 10.2867	0.01204
				1.1	0.00032	0.000049	0.0039	0.00057
1167......	2	10.25	1.33	0.9	18 38 21.61041	0.001435	38 49 33.2933	−0.00187
				0.4	0.00013	0.000020	0.0016	0.00023

NOTES.—All standard errors, for example, those of the positions, are strictly internal and do not allow for the zero point errors of the reference system. A "2" in column "*d*" indicates that the data were obtained with the Multichannel Astrometric Photometer (MAP).

corrections. The adjustment to a weighted mean and its standard error are listed at the bottom of the table. The adjustments found for each of the two regions under discussion is applied throughout Table 1 and elsewhere in this paper. Table 3 is a cross index of AO, BD, and HR number of stars found in Table 1.

2. THE REGION CENTERED ON ALTAIR

The Allegheny Observatory photographic plate collection of the region has been analyzed by Russell, Gatewood, & Wagman (1978). The perturbation noted in that study was explained in a later study as an artifact of a neutral density

TABLE 2A

ADJUSTMENT TO WEIGHTED ABSOLUTE PARALLAX IN THE REGION OF ALTAIR

AO Number	Spectral Class	Spectral Parallax (mas)	S.E. (mas) (estimated)	Provisional Parallax (mas)	S.E. (mas) (calculated)	Adjustment (mas)	Weight	Observed Parallax (mas)	Spectral-Observed (mas)
1272.........	K0 III	1.10	0.51	2.32	0.81	−1.22	1.10	1.94	−0.84
1273.........	G5 III	1.80	0.83	0.76	0.58	1.04	0.98	0.38	1.42
1274.........	G6 V	9.50	4.37	6.36	1.23	3.14	0.05	5.98	3.52
1275.........	K2 III	1.60	0.74	0.44	0.79	1.16	0.86	0.06	1.54
1276.........	G5 III	1.60	0.74	2.18	0.83	−0.58	0.81	1.80	−0.20
1278.........	K2 III	1.80	0.83	2.74	0.93	−0.94	0.64	2.36	−0.56
1279.........	A2 V	2.20	1.01	5.55	1.15	−3.35	0.43	5.17	−2.97
1280.........	K2 III	1.60	0.74	2.84	0.65	−1.24	1.04	2.46	−0.86
1281.........	G8 V	14.00	6.44	11.83	1.53	2.17	0.02	11.45	2.55
1282.........	F8 V	10.20	4.69	10.12	0.52	0.08	0.04	9.74	0.46
1283.........	K2 III	1.20	0.55	0.83	0.96	0.37	0.82	0.45	0.75

NOTES.—Weighted adjustment to mean = −0.38 mas. Standard error of weighted adjustment to mean = 0.38 mas.

TABLE 2B

ADJUSTMENT TO WEIGHTED ABSOLUTE PARALLAX IN THE REGION OF VEGA

AO Number	Spectral Class	Spectral Parallax (mas)	S.E. (mas) (estimated)	Provisional Parallax (mas)	S.E. (mas) (calculated)	Adjustment (mas)	Weight	Observed Parallax (mas)	Spectral-Observed (mas)
1159.........	F8 V	17.00	7.82	15.70	0.57	1.30	0.02	15.52	1.48
1161.........	M2 III	0.80	0.37	0.12	0.71	0.68	1.56	−0.06	0.86
1162.........	G0 V	5.70	2.62	6.34	1.43	−0.64	0.11	6.16	−0.46
1163.........	K0 III	1.40	0.64	2.19	0.81	−0.79	0.93	2.01	−0.61
1164.........	F2 V	9.80	4.51	10.68	0.70	−0.88	0.05	10.50	−0.70
1165.........	K0 III	1.70	0.78	2.76	0.81	−1.06	0.79	2.58	−0.88
1166.........	G8 V	4.10	1.89	4.19	1.12	−0.09	0.21	4.01	0.09
1167.........	K3 III	0.90	0.41	1.06	0.44	−0.16	2.74	0.88	0.02
1284.........	A0 V	5.80	2.67	6.87	0.61	−1.07	0.13	6.69	−0.89

NOTES.—Weighted adjustment to mean = −0.18 mas. Standard error of weighted adjustment to mean = 0.22 mas.

filter used on some of the plates (Russel, Gatewood, & Worek 1982). This region has not been studied by either the photometric program of Castelaz and Persinger or the spectroscopic program of Stephenson. Thus the listed magnitudes are photographic and were derived from plates acquired with the red and blue corrected objectives of the Thaw refractor. The magnitude scale is tied to images of Altair obtained through neutral density filters and the image intensities of the brighter reference stars. The resulting magnitudes were compared with magnitudes given by the SIMBAD database, the PPM Catalog, the Toulouse zone of the Astrographic Catalog, and the Guide Star Catalog. The standard error of the estimated visual magnitude and color index of each star is approximately 0.15 mag. Spectral types were listed in the SIMBAD database for four of the reference stars in this region. The temperature classes listed in Table 2A are either those listed in the SIMBAD database or are based upon stellar color. Fortunately an unusual dichotomy exists, in this region, between blue main-sequence stars and red giant stars with all stars with temperature class earlier than G lying on the main sequence while all with a temperature class later than G are giant stars. Thus all of the estimated spectroscopic parallaxes were small and consequently even large uncertainties in the estimated temperature result in small errors in the estimated distance of the reference frame. Four of the stars listed in Table 2A were included in the study by Russell et al. The reference star parallaxes estimated in this way are in general agreement with those measured in the earlier photographic study.

The MAP based Allegheny parallax of Altair determined in this study is 196.0 ± 0.83 mas. The Preliminary Yale Parallax Catalog (van Altena, Lee, & Hoffleit 1991) gives the mean of seven previous parallaxes of Altair and 198.3 ± 2.1 mas. We conclude that the weighted mean of all trigonometric parallaxes of Altair is now 196.3 ± 0.77 mas equivalent to a distance

TABLE 3

NUMBER CROSS INDEX

BD Number	AO Number	HR Number
+8°4232.......	1275	
+8°4233.......	1276	
+8°4236.......	1277[a]	7557
+8°4237a......	1278	
+8°4239.......	1279	
+8°4240.......	1280	
+8°4245.......	1282	
+38°3229......	1284	
+38°3231......	1159	
+38°3233......	1161	
+38°3234......	1160	
+38°3235......	1163	
+38°3236......	1162	
+38°3237......	1164	
+38°3238......	1285[b]	7001
+38°3239......	1165	
+38°3240......	1166	
+38°3242......	1167	

[a] Altair.
[b] Vega.

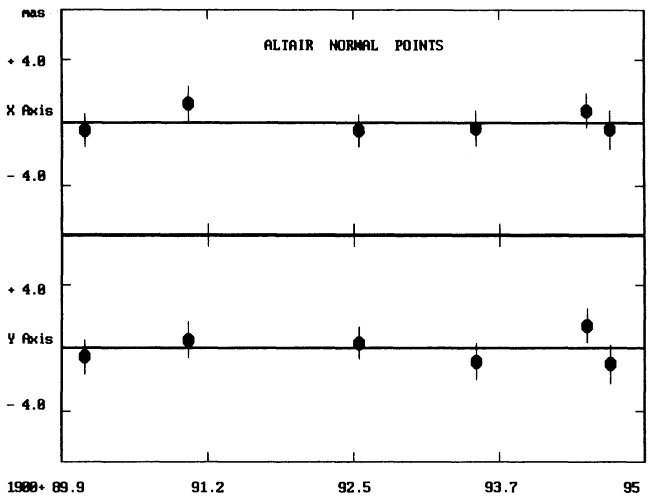

FIG. 1.—The residuals of the parallax solution for Altair are gathered successively into normal points of 13 observations each. The standard deviation of the normal points about each axis averages 0.85 mas.

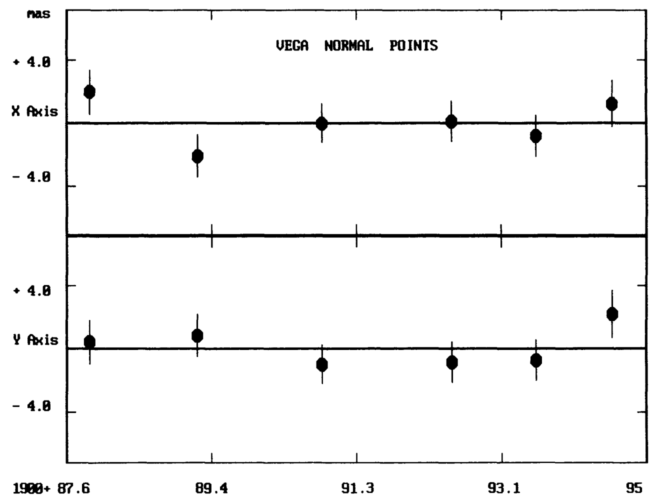

FIG. 2.—The residuals of the parallax solution for Vega are gathered successively into normal points of nine observation each, with the last point having the weight of eight observations. The standard error per point is 1.30 mas.

modulus of 1.465 ± 0.009 mag. The mean apparent magnitude of Altair from 15 visual bandpass estimates listed by SIMBAD is 0.759 ± 0.009 mag from which we find the absolute visual magnitude of 2.22 ± 0.012. From the interferometrically determined angular diameter of Hanbury-Brown et al. 1974), namely a limb darkened disk diameter of 2.98 ± 0.14 mas, we find a diameter of 1.63 ± 0.08 solar diameters.

Figure 1 illustrates the residuals to the parallax solution. The data are gathered successively into normal points of 13 observations each. The standard deviation of the normal points about each axis averages 0.85 mas. Experience with MAP results suggests that normal points of 13 observations of usual weight will have a standard error of approximately 0.94 mas (e.g., Gatewood 1989). No significant trend is obvious in Figure 1 and a standard period finding program failed to detect any significant periods within the time span of the individual data points. A dark mass equivalent to four Jupiters in a circular orbit with a period of 5 yr would cause a perturbation of approximately 1 mas (semiamplitude), and thus would significantly increase the noise level above that indicated in Figure 1. Possible elliptical orbits are also hard to hide from the astrometric technique (Gatewood et al. 1986). A body with a mass 8 times that of Jupiter, in an orbit with a similar period but an eccentricity of 0.87 (or less) would have been detected even if its orbit were presented in the worst possible orientation. The seasonal nature of the observations make it difficult to study periods near 1.0 yr, but the ability to search for such periods, as well as long orbital periods, improves with the time span of the observations. Because it is the nearest apparently single-type A star, Altair will remain on the MAP program for the foreseeable future. For now, we can conclude that Altair probably does not have a faint companion with a mass greater than 10 times that of Jupiter and an orbital period between 1.2 and 5 yr.

3. THE REGION OF VEGA

The Allegheny Observatory photographic plate collection of the region has been analyzed by Russell et al. (1982). At a galactic latitude of 19°, interstellar absorption is generally light and only slightly variable (Castelaz et al. 1991). Two stars in this region were classified on the basis of objective prism spectra: star AO 1159 was classified F8 V and AO 1164 was classified F0 V. All but the two brightest stars were observed and classified photometrically by Castelaz et al. With one exception these classifications were adopted and are listed in Table 2B. Based upon a reevaluation of the DDO photometry and the preliminary parallax, we have adopted a luminosity class IV for AO 1166. Star AO 1284 was not observed by Castelaz et al. or Stephenson, but the SIMBAD database indicates an A0 temperature class and a $B-V$ value of 0.03. We have adopted a luminosity class of V for this star.

The MAP-based Allegheny parallax of Vega (see Table 1B) is 130.1 ± 0.9. The Preliminary Yale Parallax Catalog (van Altena et al. 1991) lists a mean of the five previously obtained parallaxes for this star as 129.8 ± 1.5 mas. We conclude that the weighted mean of all trigonometric parallaxes of Vega is now 130.0 ± 0.77 mas, equivalent to a distance modulus of 0.570 ± 0.013 mag. The mean apparent magnitude of Vega derived from 11 visual bandpass estimates listed by SIMBAD is 0.03 ± 0.004 mag which yields an absolute visual magnitude of 0.60 ± 0.017. Hanbury-Brown finds a limb-darkened disk diameter of 3.24 ± 0.07 mas for Vega, from which we find the linear diameter to be 2.68 ± 0.06 solar diameters.

Figure 2 illustrates the residuals of the 53 observations to the parallax solution. The data are gathered successively into normal points of nine observations each, with the last point having the weight of eight observations. The standard error per point is 1.30 mas, about 15% greater than expected. This may be explained by the fact that the second platen[1] for this region was less than perfect causing one reference star to be dropped for about half of the observations in this set, or it may be indicative of a small secondary body. No significant trend is obvious and a standard period finding program failed to detect any significant periods within the time span of the data. A dark body, in a 7 yr circular orbit, with a mass equal to 3 times that

[1] As explained by Gatewood (1987) the fiber optic probes, which transfer the light from each star to their respective photon counters, are held in place by metal plates called platens. In regions with stars of large proper motion these platens must be periodically replaced. If a probe is positioned with an error greater than a few tenths of a millimeter some of the modulated MAP signal will be lost.

of Jupiter could have caused a perturbation of approximately 0.6 mas, adding the 15% greater than that expected noise level noted above. But such a small increase is not significant in a data set of this size. On the other hand, a mass equal to 12 times that of Jupiter, in all but a small percentage of all possible elliptical orbits, would have increased the measured standard error by 50% or more. It is thus unlikely that Vega has a faint companion with a mass greater than 12 times that of Jupiter in an orbit with a period between 1.2 and 7 yr. Like Altair, Vega will remain on the MAP program.

A reference star in the Vega region, AO 1159, classified as an F8 V by both Castelaz et al. and Stephenson, has a proper motion in the same direction and 80% as large as that of Vega. This star was included in all of the Thaw/MAP observations of this region. The derived parallax, 15.5 ± 0.6 mas, and photometric data of Castelaz et al. indicate an absolute visual magnitude of 5.20 ± 0.09 in excellent accord with the accepted subdwarf sequence (Allen 1973). We note that the photometric data also show the UV excess typical of a subdwarf star (Sandage & Eggen 1959) and that as in MAP-based study of the Coma cluster, application of the Sandage & Eggen corrections brings the star to within our errors of the main sequence.

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