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MAP–BASED TRIGONOMETRIC PARALLAXES OF OPEN CLUSTERS: THE PRAESEPE

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ABSTRACT

Trigonometric parallaxes for stars in the Praesepe open star cluster are deduced from data collected with the Multichannel Astrometric Photometer (MAP) at the Thaw Refractor of the University of Pittsburgh's Allegheny Observatory. The weighted mean parallax of five cluster members is $+5.21 \pm 0.79$ mas ($0\overset{''}{.}00079$), corresponding to a distance modulus of 6.42 ± 0.33 mag. We briefly compare this result with that derived earlier for the Hyades and note agreement with the distance found by main-sequence fitting. We also discuss briefly an improvement in the weighting scheme of the centroiding algorithm used in this series.

Subject headings: astrometry — open clusters and associations: individual (Praesepe)

1. INTRODUCTION

The recently developed Multichannel Astrometric Photometer (MAP) and new optical system of the Thaw Refractor (Gatewood 1987) of the University of Pittsburgh's Allegheny Observatory combine to give that instrument a precision sufficient to determine significant trigonometric parallaxes of objects within several hundred parsecs (Gatewood 1989). Thus we have instituted an observing effort to measure the trigonometric parallaxes of luminosity standards too distant for accurate study by photographic techniques. This study is the third in a series of measurements of the parallaxes of stars in the Hyades, the Pleiades, the Praesepe, and the Coma open star clusters (Gatewood et al. 1990, 1992).

The instrumentation and reduction procedures utilized here 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. Much of the information for the latter is obtained from a parallel series of reports detailing intermediate-band photometry results (e.g., Castelaz et al. 1991).

Table 1 presents astrometric parameters determined in the Praesepe region. 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.

As detailed in a previous publication in this series (Gatewood, Kiewiet de Jonge, & Stephenson 1993), parallaxes were reduced directly into an absolute frame using our best estimate of the spectroscopic parallax of each reference star. These estimates are included in the formation of the first approximation to a MAP–based catalog, and parallax terms remain, in all following iterations, among the unknowns that model each star's position and motion. Like the catalog positions, the estimates of the parallax are subject to verification and possible adjustment. Differences between the predicted and observed parallax are handled like any other residual. If the parallax derived from the astrometric data is significantly different from that initially derived from the spectroscopic and photometric data, and the latter include indications that an alternate luminosity classification is possible, a reevaluation of the spectroscopic parallax may be in order. Otherwise, one may decide to leave this reference star out of the initial parallax pass, letting later iterations converge on the parallax dictated solely by the astrometric constraints.

An unweighted estimate of the adjustment to absolute is used during the computation of the individual sets of field variates. Thus the adjustment of the parallaxes to absolute can still be improved (e.g., Stein 1991). Listed in Table 2 are the Allegheny Observatory (AO) catalog number and the adopted spectral classification-luminosity type of the noncluster members for which trigonometric and spectrophotometric studies were meaningful. With the exception of star AO 931, the tabulated spectral classifications come from the multiband photometry of Persinger & Castelaz (1990) and Castelaz et al. (1991) 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 Table 2, the absolute magnitudes given by Allen (1973) and the estimated individual interstellar absorption corrections. The adjustment to a weighted mean and its standard error are listed at the bottom of the table. The adjustments found for the region are applied throughout Table 1 and elsewhere in this paper.

At a galactic latitude of 32°, Praesepe lies in a region of little or no interstellar absorption and no corrections for visual absorption were applied. Multiband photometry of star AO 931 has been published by both Persinger & Castelaz and by Castelaz et al. The latter study also measured AP 931 independently as Russell 124 (Russell 1976). Comparison of the mean DDO band photometry of these measurements suggest a spectral classification of G9 IV is possible and that value is adopted in Table 2. The Persinger & Castelaz DDO photometry for star AO 928 does not match any known stellar type and the

TABLE 1

Star Parameters in the First Praesepe Parallax Region

AO Number	d	V (mag)	$B-V$	Parallax (mas)	R.A. (2000)	PM (r.a.) (s yr^{-1})	Decl. (2000)	PM (Decl.) (arc sec yr^{-1})
924.........	*2	8.70	0.33	5.7	$8^{\mathrm{h}}37^{\mathrm{m}}33\overset{\mathrm{s}}{.}81504$	−0.002804	$20^\circ0'49\overset{''}{.}0056$	−0.00998
				0.8	0.00019	0.000021	0.0026	0.00028
925.........	*2	7.80	0.22	4.4	8 37 36.99996	−0.002719	19 43 58.1343	−0.01895
				0.4	0.00009	0.000010	0.0013	0.00014
926.........	2	10.90	0.46	−0.2	8 37 51.34298	−0.000590	20 18 24.7793	0.01522
				2.0	0.00046	0.000050	0.0062	0.00068
927.........	2	7.80	0.48	9.1	8 38 2311193	0.000881	20 12 26.1799	−0.00460
				0.9	0.00021	0.000023	0.0029	0.00032
928.........	1	11.20	1.12	−2.6	8 38 23.66578	−0.001240	20 3 37.7029	−0.00287
				2.8	0.00071	0.000084	0.0098	0.00116
929.........	2	9.00	1.39	3.1	8 38 34.24356	−0.001659	19 51 36.6693	−0.02401
				1.2	0.00026	0.000028	0.0035	0.00039
930.........	*2	8.10	0.21	5.6	8 38 37.85555	−0.002636	19 59 22.8461	−0.01533
				1.0	0.00023	0.000025	0.0031	0.00035
931.........	2	9.20	1.08	3.2	8 39 19.72172	0.001148	20 3 10.5056	−0.01662
				1.0	0.00023	0.000025	0.0031	0.00035
932.........	2	9.10	1.27	0.5	8 39 33.40192	−0.001630	20 10 10.0362	0.00489
				1.2	0.00026	0.000029	0.0036	0.00040
933.........	*2	6.70	0.25	4.7	8 39 42.64229	−0.002963	19 46 42.1662	−0.01235
				0.4	0.00008	0.000009	0.0011	0.00012
934.........	*2	7.70	0.22	5.8	8 39 42.76856	−0.03097	20 5 10.1271	−0.01442
				1.0	0.00022	0.000024	0.0031	0.00034

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 was obtained with the Multichannel Astrometric Photometer (MAP). An asterisk denotes a cluster member.

star was observed only during about two-thirds of the 47 MAP observations. Thus the star was not used in the calibration to absolute parallax in Table 2. The *UBVRI* photometry is consistent with a temperature class of KO and the very small parallax suggests that the star is a giant.

Table 3 list the AO, BD, and Klein Wassink (1927) numbers of each of the stars in this study.

2. DETERMINATION OF THE CENTROID IN THE PRESENCE OF BACKGROUND

Virtually all signals are contaminated by some form of background "noise." Background noise has a random component but is usually approximately constant while the signal usually approximates a known profile with random variations about that profile. Frequently, the composite signal is integrated into bins or pixels that are delineated in image space. Drawn from a single population, the signal counts are assumed to have unit weight. Thus, in the analysis of the centroid of the signal, each bin is treated as if it were an independent estimate of the mean with a weight equal to the count in that bin. The centroid is then the count weighted mean of the bins.

The background counts, however, both bias the result toward the center of the range of the observations and degrade the information content of the signal by increasing its random noise. To remove the bias an estimate of the constant background may be subtracted from the observed composite count (e.g., Stone 1989). Unfortunately this removes only the bias. Without detailed knowledge of the random variations of the background, the effect of this noise cannot be removed from the estimated signal. Thus, the variance of the estimated signal is that of the composite count, not that of the signal alone, and the weight of each signal count is diminished by the random noise generated by the background.

Where the observed composite count within a bin or pixel is K, the estimate of the background count is β, the estimated signal is

$$\chi = K - \beta \,, \tag{1}$$

where, since the effect of the random variations of the background count is not removed by equation (1), the variance of χ, $V\chi = V_k$.[1] Assuming a Poisson distribution, we may estimate

TABLE 2

Adjustment to Weighted Absolute Parallax in the First Praesepe Region

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)
927.........	F3 V	11.40	2.62	10.14	0.91	1.26	0.13	9.10	2.30
926.........	F5 V	2.80	1.29	0.82	2.08	1.98	0.17	−0.22	3.02
932.........	K3 III	1.50	0.35	1.51	1.16	−0.01	0.68	0.47	1.03
931.........	G9 III	1.90	0.87	4.15	1.00	−2.25	0.57	3.11	−1.21
929.........	G8 III	1.80	0.41	4.08	1.15	−2.28	0.67	3.04	−1.24

Note.—Weighted adjustment to mean = −1.04 mas. Standard error of weighted ajustment to mean = 0.74 mas.

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[1] Here we ignore the uncertainty of the estimate of β (e.g., Parratt 1961) and treat β as an adopted constant.

TABLE 3

AO, BD, KW NUMBER CROSS INDEX

AO Number	BD Number	KW Number
924.........	+20°2131	38
925.........	+20 2132	40
926.........	...	54
927.........	+20 2136	94
928.........	...	99
929.........	+20 2137	109
930.........	+20 2138	114
931.........	+20 2145	167
932.........	+20 2147	190
933.........	+20 2149	204
934.........	+20 2148	203

the factor by which the weight of each signal photon has been diminished by the effects of the background noise,

$$W_\chi = (K - \beta)/K\,. \tag{2}$$

Instead of χ, the total weight of the bin is then

$$\chi W_\chi = (K - \beta)^2/K\,. \tag{3}$$

The effect of background is to significantly reduce the weight of signal counts in the wings of the image while having less relative effect on those hitting pixels near the center. For example, the weight of each count from a pixel with a total count of 100, four of which are from background sources, would be 0.96 instead of 1. But near the image's edge where the total count might be only five, four of which are assumed to be background counts, the weight is 0.2 per signal photon count, instead of 1. Thus the total weight of these two bins would be 92.16 and 0.2, respectively.[2] Where the subscript i denotes the ith bin the image centroid is

$$c = \sum \chi_i W_{\chi i} X_i / \sum \chi_i W_{\chi i}\,. \tag{4}$$

Simulations utilizing 30,000 random Gaussian distributions of 1000 counts each, set against six different background count levels, indicate that a significant increase in precision (and accuracy) is obtained utilizing equation (2). The improvement is greatest for stars producing the weakest signals, those having the strongest relative backgrounds. This expectation is borne out in the reduction of actual MAP data. Thus this refinement was added to the MAP reduction procedures beginning with this region. Since the effect is strictly random, there are no plans to rereduce previous regions.

We note with interest that the factor expressed in equation (2) explains the conventional wisdom that images of stars with apparent magnitudes near that of the frame limit are of reduced astrometric value (e.g., van de Kemp 1967; Chiu 1977). The various profile reduction techniques used broadly in astronomy should also be improved by the weights given in equation (2), allowing them to work nearer the magnitude limit of the frame or to better utilize images acquired in the presence of significant background noise.

3. DISCUSSION

Until now trigonometric parallax techniques did not have the precision required for meaningful estimates of the distances to the Praesepe cluster. Estimates generally relied upon a comparison of the main sequence of the Praesepe and Hyades clusters (e.g., Upgren, Weis, & Deluca 1979). Upgren et al. used $B-V$ and $R-I$ photometry of the lower main sequence to estimate a difference in the distance modulus of the two clusters to be 3.00 ± 0.04 mag. As noted in the first paper in this star cluster series, one of our goals is to test the validity of the main-sequence fitting used in studies exemplified by Upgren et al.

Falling within the range of several techniques, the distance to the Hyades cluster has been estimated many times (e.g., Upgren et al. 1990). Gatewood et al. (1992) combined a MAP-based parallax with the results of previous trigonometric studies of the Hyades to find a weighted mean parallax of 22.9 ± 0.6, a distance modulus of 3.20 ± 0.06 mag. This value is in excellent agreement with previous results. Combining the aforementioned Upgren et al. distance modulus difference to this Hyades trigonometric parallax yields a distance modulus of 6.20 ± 0.072 mag for the Praesepe cluster. The mean of the parallaxes for the five Praesepe cluster member stars[3] in the present study is 5.21 ± 0.79 mas (192 ± 29 parsecs) yielding a distance modulus of 6.42 ± 0.33 mag, well within its error of the value derived above. While a more significant test will require the completion of several parallax studies in each cluster we note that, for the Hyades and Praesepe clusters, the initial trigonometric results agree well with that obtained using main-sequence fitting.

Three steps may be taken to increase the precision of the trigonometric estimation of the distances of nearby star clusters. First we intend to observe additional regions within the Praesepe, Hyades, Pleiades, and Coma clusters. Next, estimates of the spectral and luminosity classifications of the reference stars used in these studies could be strengthened through independent photometric and spectroscopic studies. These first two steps, conducted in three additional regions, could yield a parallax estimate for the Praesepe cluster with half the formal error of the present study. The highest precision, however, can be obtained through the judicious use of large-aperture telescopes at sites where superior seeing conditions prevail. Gatewood (1991) and Shao and Colavita (1992) have shown that, because of the high correlation between the motions of nearby stellar images, the field centers of such instruments offer a potential for astrometric precision 10 times that currently being achieved. Indeed, since each cluster member is a target star and there is generally at least one near almost any bright background star, clusters are unusually good targets for such ground-based study. Thus the potential exists to calibrate the main sequences of the nearby stellar clusters to a precision of approximately one-hundredth of a magnitude.

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[2] The effect is rather like that of the arbitrary weighting function employed by van Altena & Auer (1975).

[3] Assuming a spherical distribution of stars, the line-of-sight depth of the cluster is less than 0.2 mas.

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