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MAP-BASED TRIGONOMETRIC PARALLAXES OF OPEN CLUSTERS: COMA

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ABSTRACT

This is the fourth study in a series to determine the direct trigonometric parallaxes of four of the nearest open star clusters, the Hyades, the Pleiades, the Praesepe, and the nearby cluster in Coma (Gatewood et al. 1990; Gatewood et al. 1992; Gatewood & Kiewiet de Jonge 1994). The results for the open star cluster in Coma are compared with those of the other three clusters, and the members are found to be significantly subluminous. The trigonometric parallax of the cluster is estimated from that of three members studied with the Multichannel Astrometric Photometer (MAP) at the Thaw Refractor of the University of Pittsburgh's Allegheny Observatory. The weighted mean parallax of the cluster is $+13.53 \pm 0.54$ mas (0.″00054), corresponding to a distance modulus of 4.34 ± 0.09 mag. The $U-B$ excess of the Coma cluster members may be used to adjust the observed absolute magnitudes and the $B-V$ measurements as suggested by Sandage & Eggen (1959). The agreement obtained in this manner suggests that, like subdwarf stars, the stars of the Coma cluster appear subluminous because of line blanketing. One of the three members observed in this study was recognized as a member by its parallax and is the faintest known member of the cluster.

Subject headings: astrometry — open clusters and associations: individual (Coma) — stars: distances

1. INTRODUCTION

Near the end of what is generally considered the defining study of this cluster, Trumpler (1938) remarks, "If we were led to designate the Coma cluster as poor in comparison with the Pleiades, this, by no means, implies that it is an exceptional object. On the contrary, nearly one-half of the galactic star clusters which have been listed and classified were noted as poor (containing less than 50 stars), and the Coma group seems to be a typical representative of this most important class of clusters, which so far has been but little investigated."

We note that, while it might not be an exceptional object in this sense, it would seem to have a number of characteristics that set it apart from the other three clusters studied in our series. Having discovered that cluster members show a $U-B$ excess, Johnson & Knuckles (1955) comment: "While the deviation of the Coma cluster stars from those of the Hyades is in the same sense as those for the 'subdwarfs' in the Hyades, it is not reasonable to suppose that this comparison suggests that the Coma cluster main-sequence stars are subdwarfs, since the spectra of these stars indicate that they are normal main-sequence objects (Weaver 1952)." From a study of spectroscopic and photometric characteristics of cluster members, Mendoza (1963) states: "the A5–G0 stars of Coma radiate 0.05 mag more ultraviolet than do similar stars of the Hyades and the Pleiades." He adds: "that other stars (cluster members) than A5–G0 have, on the average, a little ultraviolet excess." Crawford & Barnes (1969) note "In terms of spectral energy distribution, the F stars in the Hyades have stronger 'Balmer discontinuities' than do stars of the same Hβ or $b-y$ in Coma or along the 'zero-age line.' This deviation does not appear to be an effect of the difference in blanketing between the stars. The blanketing affects $c1$ less than it does $m1$, yet the effect in $c1$, in the difference between the two clusters is larger in $m1$."

The most extensive proper motion study since Trumpler's is that of Artyukhina (1955). Argue & Kenworthy (1969) also list photographic photometry and proper motions for a 3.°3 field near the cluster's center. DeLuca & Weis (1981) measured photoelectric V, $B-V$, $V-R$, and $R-I$ for 88 stars in an attempt to identify red dwarf members of the Coma cluster. Of the 25 stars suggested as possible faint members by Artyukhina, only three were found to be possible members. The measured right ascension proper motion of one of these, Artyukhina's number 278, differed from that of the cluster by 3.3 standard deviations. Unaware of its significance, we did not identify this star on our finding charts.

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 fourth 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; Gatewood et al. 1992; Gatewood & Kieweiet de Jonge 1994).

2. DATA

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).

As detailed in a previous publication in this series (Gatewood et al. 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. Differ-

TABLE 1

ADJUSTMENT TO WEIGHTED ABSOLUTE PARALLAX IN THE FIRST COMA 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)
1143.....	K0 III	3.00	1.38	2.75	0.64	0.25	0.43	2.33	0.67
1145.....	F7 V	5.00	2.30	4.58	1.03	0.42	0.16	4.16	0.84
1148.....	F7 V	3.00	1.38	3.18	0.84	−0.18	0.38	2.76	0.24
1149.....	F2 V	3.00	1.38	5.09	0.88	−2.09	0.37	4.67	−1.67
1150.....	F3 V	5.00	2.30	5.67	1.26	−0.67	0.15	5.25	−0.25
1153.....	G8 V	10.00	4.60	7.83	1.00	2.17	0.05	7.41	2.59
1154.....	F5 V	4.00	1.84	3.39	1.00	0.61	0.23	2.97	1.03
1156.....	K2 III	1.00	0.46	1.75	1.19	−0.75	0.61	1.33	−0.33

NOTES.—Weighted adjustment to mean = −0.42 mas; standard error of weighted adjustment to mean = 0.35 mas.

ences 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 1 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. The tabulated spectral classifications come from the multiband photometry of Castelaz et al. (1991). At a Galactic latitude of 83°, Coma is thought to lie in a region of little or no interstellar absorption (Crawford & Burns 1969). The photometry of Castelaz et al. indicates no visual absorption for cluster members but up to 0.25 mag for stars lying well behind the cluster. We have adopted the photometric parallaxes determined by Castelaz et al. for all stars in the calibration to absolute parallax. The spectral classification of the reference star is followed by the published 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 to a weighted mean and its standard error are listed at the bottom of the table. The adjustment is based upon the luminosity classifications adopted in Table 1, the absolute magnitudes given by Allen (1973), and the estimated individual interstellar absorption corrections. The adjustment is applied throughout Table 2 and elsewhere in this paper.

Table 2 presents astrometric parameters determined in the region of 12 Coma, the central star in this study of the Coma cluster. The positions and motions, at the epoch and equinox of J2000, of the stars under study are listed in the last four

TABLE 2

STAR PARAMETERS IN THE FIRST COMA PARALLAX REGION

AO Number	d	V (mag)	$B-V$	Parallax (mas)	R.A. (2000)	PM (r.a.) (s yr^{-1})	Decl. (2000)	PM (Decl.) (arcsec yr^{-1})
1143.....	2	8.60	1.06	2.3	12^h21^m $4^s.80645$	−0.001299	25°43′11″.5952	−0.03025
				0.6	0.00016	0.000023	0.0022	0.00030
1145.....	2	10.25	0.58	3.9	12 21 22.29020	−0.005129	25 55 49.7473	−0.03088
				1.0	0.00026	0.000036	0.0034	0.00047
1148.....	2	11.40	0.62	2.8	12 21 33.18697	0.001929	26 6 52.4461	0.00017
				0.9	0.00022	0.000031	0.0029	0.00041
1149.....	2	10.67	0.36	4.7	12 21 53.53590	−0.001979	25 37 11.9275	−0.00271
				0.9	0.00023	0.000032	0.0031	0.00042
1150.....	2	9.57	0.45	5.1	12 21 57.68043	−0.000692	25 41 9.1328	−0.00645
				1.3	0.00032	0.000044	0.0042	0.00057
*1270.....	2	4.83	0.50	13.2	12 22 30.31592	−0.000676	25 50 45.9412	−0.01053
				0.5	0.00014	0.000019	0.0019	0.00026
1153.....	2	10.48	0.71	7.6	12 22 40.58280	−0.003025	25 40 11.4403	−0.03950
				1.0	0.00025	0.000035	0.0033	0.00046
1154.....	2	10.02	0.44	3.2	12 22 41.96903	0.002806	25 48 22.3113	−0.01786
				1.0	0.00026	0.000036	0.0034	0.00047
*1155.....	2	9.10	0.54	14.5	12 23 8.38464	−0.001206	25 51 4.7144	−0.01228
				0.7	0.00019	0.000027	0.0025	0.00035
*1271.....	2	12.13	1.20	12.4	12 23 28.19324	−0.001203	25 53 39.7447	−0.01119
				1.9	0.00049	0.000068	0.0065	0.00090
1156.....	2	10.33	1.28	1.9	12 23 35.19653	0.000016	26 4 43.4849	−0.00235
				1.2	0.00030	0.000043	0.0040	0.00056

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). An * denotes a cluster member.

TABLE 3

AO, BD, TRUMPLER NUMBER CROSS INDEX

AO Number	BD Number	Trumpler Number
1143.....	+26°2332	80
1156.....	+26°2341	A11
1154.....	+26°2339	95
1150.....	+26°2336	87
1149.....	+26°2335	A8
1145.....	+26°2334	B6
1270 (12 Coma).....	+26°2337	91
1155.....	+26°2340	97

columns of Table 2 above their corresponding standard errors. The system of the positions and motions is that of the PPM Catalogue (Röser & Bastian 1991), ostensibly that of the FK5 Catalogue. 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.

Table 3 list the AO, BD, and Trumpler numbers for each of the stars in this study. AO 1271 (Artyukhina 278) was not listed by Trumpler and was not included in the photometry of Castelaz et al. because it was added to the MAP reference frame only when another reference star was dropped. Its cluster membership was not suspected until a preliminary pass indicated a parallax consistent with the distance of the cluster. To our knowledge, this is the first time that cluster membership has been determined via trigonometric parallax techniques. The photometry of this star is that of DeLuca and Weis. With a proper motion matching that of the other two cluster members in this region, we have assumed membership in all further discussions.

3. DISCUSSION

Despite its proximity there have only been five attempts to measure the trigonometric parallax of members of the Coma cluster, all of them photographic studies initiated by Trumpler while he was at the Allegheny Observatory. Since the number of plates in these studies varies by less than 10% we have entered their straight mean, as adjusted to absolute by the precepts of van Altena (1991), 14.5 ± 2.8 mas in Table 4. Also listed are the parallaxes found for the three cluster members included in the present study. We note that the range in these three parallaxes is in close agreement with the proper motion of each star in the direction of the cluster motion. Thus, as suggested by their trigonometric parallaxes, AO 1155 (T97) probably is in the front of the cluster while AO 1270 (T97) and AO 1271 lie farther back in it. Unfortunately the dynamics of the cluster are not as well known as they were in our study of the Hyades, and we have simply chosen to adopt the weighted mean of the three parallaxes as that of the Coma cluster.

TABLE 4

TRIGONOMETRIC PARALLAXES OF THE COMA CLUSTER

AO Number	Parallax (mas)	S.E. (mas)	Weight
1155	14.34	0.73	1.00
1270 (12 Coma)	13.15	0.54	1.83
1271	12.00	1.91	0.15
Mean of electronic	13.49	0.55[a]	1.76
Mean of five photographic[b].....	14.46	2.77	0.07
Mean of all trigonometric.....	13.53	0.54	1.83

[a] This value includes the error of the adjustment found in Table 1. Thus its weight in the mean of "all trigonometric parallaxes" is reduced.

[b] We have followed the example of Trumpler (who initiated these studies) of using the straight mean.

One of the mysteries of this cluster has been the lack of members later that KO. AO 1271 would seem to extend the main sequence of this cluster down to approximately K5, adding another magnitude to the main sequence. The study of DeLuca and Weiss suggests that AO 1271 may in fact represent the bottom of that sequence. The unusually low precision of its parallax, ±1.9 mas, is a direct result of the low photon counts of our current sensors for a star of this magnitude, a situation that is being corrected.

Figure 1 compares the $M_v/(B-V)$ sequences, adjusted to absolute by the distance modulus found in this trigonometric parallax series for the Hyades, the Pleiades, and the Praesepe clusters, with that of the stars of the Coma cluster. While the differences between the first three cluster sequences fall within the errors of the measured distance moduli (not shown to reduce confusion), the Coma cluster members fall well below them in a pattern reminiscent of subdwarfs.

Figure 2 illustrates the ultraviolet excess of each star, first noticed by Johnson & Kunckles against the "fiducial main sequence" of Sandage & Eggen (1959) and Sandage & Kowal (1986). It is not our purpose to study this phenomenon or to find its exact effect in Figure 1. Thus for illustrative purposes only, we note that the approximate excess illustrated in Figure 2 is 0.04 mag. Applying the correction suggested by Sandage & Eggen to all of the stars in the cluster results in Figure 3. A more precise application of this correction would be accomplished star by star as outlined by Sandage & Kowal and may not include all of the Coma cluster members. The illustration does, however, suggest that the stars of the Coma cluster show the effects of line blanketing common to subdwarfs. They differ from the latter in that the effect is less than in most stars classified as subdwarfs and in that their motion is very similar to that of the Sun. These facts suggest that they could be representative of a class of stars with mild ultraviolet excess and space motions similar to that of the Sun.

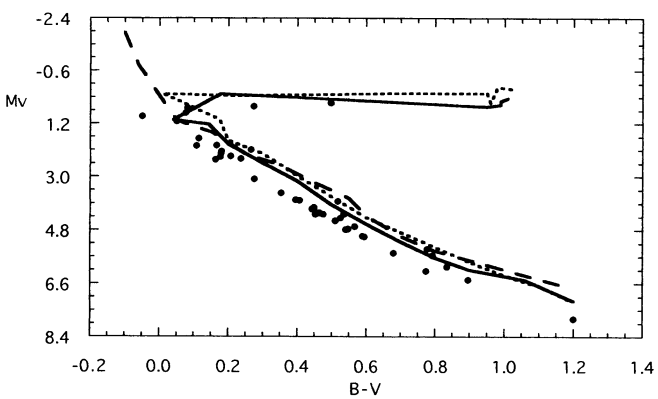

FIG. 1.—H-R diagrams of the four clusters studied in this series. The main sequence of the Hyades, Pleiades, and Praesepe clusters coincide to within the mean errors of those three studies. To reduce confusion those errors are not plotted. The stars of the Coma cluster lay several standard errors below the mean of the other three clusters.

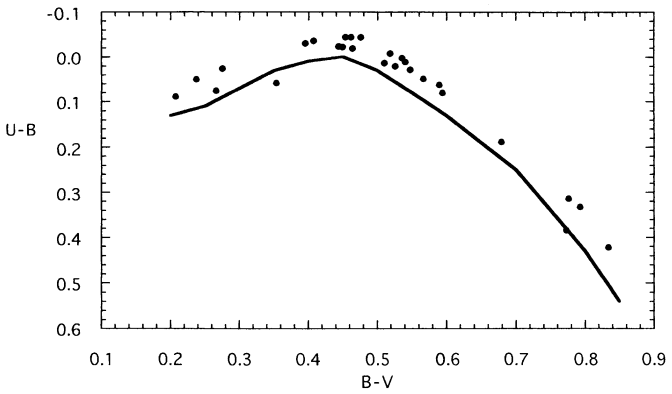

FIG. 2.—The $(U-B)/(B-V)$ sequences of the Hyades and Coma clusters indicated a $U-B$ excess of approximately 0.04 mag. While this effect is common in subdwarf stars, the amount of excess is usually larger.

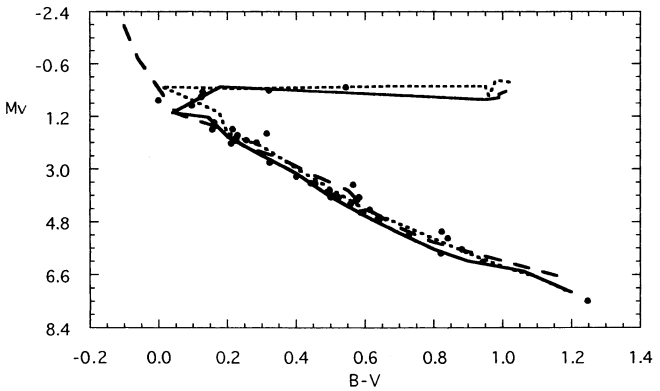

FIG. 3.—H-R diagram of the four clusters after the Coma cluster stars are all corrected for a color excess of 0.04 mag in the manner suggested by Sandage & Eggen (1959) for subdwarf stars.

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