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THE DISTANCE TO THE HYADES CLUSTER BASED ON *HUBBLE SPACE TELESCOPE* FINE GUIDANCE SENSOR PARALLAXES

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ABSTRACT

Trigonometric parallax observations made with the *Hubble Space Telescope* (*HST*) Fine Guidance Sensor (FGS) 3 of seven Hyades members in six fields of view have been analyzed along with their proper motions to determine the distance to the cluster. Knowledge of the convergent point and mean proper motion of the Hyades is critical to the derivation of the distance to the center of the cluster. Depending on the choice of the proper-motion system, the derived cluster center distance varies by 9%. Adopting a reference distance of 46.1 *pc* or $m - M = 3.32$, which is derived from the ground-based parallaxes in the General Catalogue of Trigonometric Stellar Parallaxes (1995 edition), the FK5/PPM proper-motion system yields a distance 4% larger, while the Hanson system yields a distance 2% smaller. The *HST* FGS parallaxes reported here yield either a 14% or 5% larger distance, depending on the choice of the proper-motion system. Orbital parallaxes (Torres et al.) yield an average distance 4% larger than the reference distance. The variation in the distance derived from the *HST* data illustrates the importance of the proper-motion system and the individual proper motions to the derivation of the distance to the Hyades center; therefore, a full utilization of the *HST* FGS parallaxes awaits the establishment of an accurate and consistent proper-motion system.

Subject headings: astrometry — stars: distances — stars: fundamental parameters

1. INTRODUCTION

The Hyades is the nearest rich star cluster to the Sun, and it provides us with, among other things, a benchmark for the determination of the distances to other star clusters through the technique of main-sequence fitting. While the Pleiades is sometimes used as a standard for this process because of its more "normal" metallicity, its 3 times greater distance leads to a more uncertain zero point in the derived distance scale. Through the determination of the absolute magnitudes of nearby classical Cepheids in clusters with respect to the Hyades and/or the Pleiades, the Population I extragalactic distance scale is derived.

Through the early 1960s the accepted distance to the Hyades was determined by deriving the convergent point from the cluster members' proper motions, as was done, for example, by van Bueren (1952). This distance was questioned by Hodge & Wallerstein (1966), who found it to be in conflict with a number of secondary distance estimators. Redeterminations of the convergent point by Hanson (1975) using absolute proper motions, Gunn et al. (1988) and Griffin et al. (1988) using radial velocities and the proper motions from Hanson (1975), and, most recently, Schwan (1990, 1991) using FK5 and PPM proper motions have led to a distance that is

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TABLE 1

HST FGS OBSERVATIONS

vA[a]	Ha[b]	GH7[c]	BD or Os[d]	N_{obs}	N_{ref}	$\sigma_1(x)$ (mas)	$\sigma_1(y)$ (mas)
310	312	196	+17°715	7	6	1.6	4.0
383	378	212	Os 373	7	6	2.1	3.4
472[e]	420	228	+13°685	6	4	1.2	3.3
548	472	241	+15°634	7	5	1.2	2.6
622	505	249	...	7	7	2.2	2.6
627	509	250	+17°744	7	7	2.2	2.6
645	517	253	Os 749	6	5	1.7	3.6

[a] van Altena 1969.
[b] Hanson 1975.
[c] Giclas, Burnham, & Thomas 1962.
[d] Osvalds 1954.
[e] vB100 in van Bueren 1952.

approximately 17% larger than the earlier accepted value of 40 pc. Using accurate masses for the double-lined eclipsing binary vB22 and an adopted mass-luminosity relation for field stars, McClure (1982), followed by Peterson & Solensky (1987, 1988) who used the slope of the Hyades mass-luminosity relation, obtained a distance to the cluster center of 47 pc. Torres, Stefanik, & Latham (1997a, 1997b, 1997c) have derived orbital parallaxes from a combination of radial velocity and astrometric observations that lead to a distance to the cluster center of about 48 pc using the Schwan (1991) convergent point solution. The ground-based trigonometric parallaxes listed in the new edition of the Yale Parallax Catalogue (YPC; van Altena, Lee, & Hoffleit 1995) were recently analyzed by van Altena, Lee, & Hoffleit (1997), who found a distance of 46 pc. The YPC investigation included 100 stars and used a weighted mean of the parallaxes without use of the proper motions. This result should not be too much in error, because of the large number of stars and full spatial coverage of the cluster. A more detailed analysis of the YPC data is in preparation.

In 1968, van Altena (1973) prepared a list of very probable Hyades members suitable for parallax determination and distributed it to numerous observatories involved in the determination of trigonometric parallaxes. Those stars were selected to have high-accuracy proper motions indicative of membership in the Hyades, to have *UBV* photometry that placed the stars close to the main sequence or white dwarf ridge lines in the color-magnitude diagram and selected against double stars,[6] and to be in the magnitude range 9–14, i.e., accurately observable with the parallax telescopes and detectors then in use. Many of the high-weight parallaxes analyzed in the YPC study were the result of intensive observational efforts on the stars in that list. In addition, they formed the basis of our 1972 Phase B proposal to determine the distance to the Hyades using what was then called the Large Space Telescope and the 1977 Phase CD proposal for the *Hubble Space Telescope* (*HST*). Because of the reallocation of overhead in the observing procedures and ground control experienced by all Guaranteed Time Observers, and especially by those using the Fine Guidance Sensors (FGSs), the original list of 20 Hyades members was reduced to seven main-sequence members in six fields, each observed 6 to 7 times (N_{obs} in Table 1) instead of the originally planned 24 times. As a consequence, what was to be a definitive determination of the Hyades distance is now only a "teaser." Finally, by the time this Letter is in print, we will have the first results from the *HIPPARCOS* Astrometric Satellite on their determination of the distance to the Hyades.

[6] Griffin et al. (1985) list vA627 = J285 as a single-lined spectroscopic binary with a period of 850 days, indicating that our screening against binary stars was not entirely successful. That should not be an important factor in this Letter, since we are limited here by the lack of a consistent proper-motion system.

2. OBSERVATIONS AND REDUCTIONS

The observations of the seven stars in six fields (Table 1) were made over a period of three years from 1993 October through 1996 September, each field being observed during one orbit with FGS 3 at times of maximum parallax factor (average absolute value = 0.97). Also listed in Table 1 for each field, is the name of the Hyades member from van Altena (1966, 1969) that is the principal target (627 is in the same field as 622), additional cross-identifications, the number of reference stars used, N_{ref}, and the unit weight error of the parallax and proper-motion solution in x and y corrected for degrees of freedom. The observing procedures and corrections for coordinate drift and optical field angle distortion (OFAD) were similar to those outlined in Benedict et al. (1994). Coordinate drift in FGS 3 during an orbit can amount to several thousandths of an arcsecond (mas), and for that reason, the target star and at times a second star were observed at the beginning of the orbit, halfway through measurement of the six (on average) reference stars and again at the end. Changes in the position of the target star and/or the second star were interpreted as a drift in the coordinate system and interpolated corrections were made to the positions of all measured stars. The drift was modeled as being linear in time, although a quadratic drift yielded similar results. The OFAD for FGS 3 was developed by Jefferys et al. (1992), and the OFAD appropriate to each observation date was computed by McArthur. Local deviations of the actual focal plane from that predicted by the OFAD exist at the milliarcsecond level, but these introduce noise into the solutions and not systematic errors. A minor systematic deviation of the OFAD from the focal plane was detected in the y-coordinate, but since the observations were made at maximum parallax factor, the y-solutions are used only for the proper-motion determination and not for the parallax. Since the target stars were about 4 mag brighter than the reference stars, we have searched for a possible systematic error as a function of star brightness, the magnitude equation. No magnitude equation has been found in either the OFAD or long-term stability tests, which both have magnitude ranges similar to the Hyades observations, so we do not believe that a magnitude equation exists in the Hyades data. Since we have on average only six reference stars in each field (N_{ref} in Table 1), and they are all rather faint (14th–16th magnitude), we are unable to test conclusively for the existence of a magnitude equation in the Hyades data.

The solutions for relative parallax and proper motion were made with the Yale parallax program developed by Auer & van Altena (1978) modified for use with *HST* FGS observations. Parallel solutions were made by McArthur with the completely different University of Texas Gaussfit program by McArthur, Jefferys, & McCartney (1994), and negligible differences in the derived relative parallaxes attributable to weighting and modeling schemes were obtained. The results presented here are from the Yale program.

Since the parallaxes and proper motions determined with the *HST* FGS are relative to the means of those quantities for

TABLE 2

DERIVED DATA FOR THE HYADES MEMBERS[a]

Name	π Type	α(1950)	δ(1950)	V (mag)	$B - V$ (mag)	π (mas)	σ (mas)	μ_α (mas yr^{-1})	σ (mas yr^{-1})	μ_δ (mas yr^{-1})	σ (mas yr^{-1})	SCHWAN D_c (pc)	SCHWAN σ (pc)	GUNN D_c (pc)	GUNN σ (pc)
vA310	H	4 21 22.9	17 53 21	9.99	1.05	15.4	0.9	105.0	0.9	−14.1	0.8	59.0	3.5	54.3	3.2
vA383	H	4 23 14.1	14 55 46	12.14	1.45	16.0	0.9	91.7	0.8	−15.8	1.0	52.1	3.2	47.9	3.0
vA472	H	4 25 15.1	13 45 29	9.03	0.84	16.6	1.6	78.9	1.3	−16.7	1.5	44.5	4.6	40.8	4.3
vA548	H	4 26 38.9	16 8 12	10.32	1.17	16.8	0.3	98.7	0.4	−15.5	0.3	53.9	1.5	49.5	1.4
vA622	H	4 28 35.2	17 36 46	11.85	1.44	21.6	1.1	99.6	1.0	−26.1	1.3	43.4	2.4	39.9	2.2
vA627	H	4 28 43.2	17 36 15	9.55	0.98	16.5	0.9	106.6	1.1	−16.2	3.0	58.9	3.5	54.2	3.2
vA645	H	4 29 1.2	15 23 38	11.05	1.28	15.7	1.2	102.5	1.4	−14.0	1.4	60.8	4.8	55.9	4.4
Weighted mean												52.5	1.0	48.3	0.9
vB24	O	4 15 25.4	21 27 31	5.87	0.24	17.9	0.6	101.4	0.9	−36.6	1.0	49.1	1.6	…	…
vB57	O	4 22 45.8	15 45 42	7.05	0.49	21.4	0.7	105.0	3.1	−25.3	3.5	44.8	1.9	…	…
vB72	O	4 25 48.2	15 49 42	3.74	0.18	21.2	0.8	111.7	1.6	−25.5	1.8	49.0	1.9	…	…
Weighted mean												47.8	0.9	…	…
vB24	G	4 15 25.4	21 27 31	5.87	0.24	19.4	1.1	96.8	0.7	−36.0	0.4	43.5	2.5	…	…

NOTE.—Units of right ascension (α) are hours, minutes, and seconds, and units of declination (δ) are degrees, arcminutes, and arcseconds.

[a] For cross-identifications see Table 1.

[b] The π-type definitions are as follows: H is the *HST* trigonometric parallax from this study; O is the orbital parallax from Torres et al. 1997a, 1997b, 1997c; and G is the ground-based parallax from Gatewood 1992.

TABLE 3

HYADES CENTER DISTANCES[a]

PARAMETER	AVERAGE AND "INTERNAL" ERROR *HST*	AVERAGE AND "INTERNAL" ERROR Orbital	WEIGHTED MEAN AND "EXTERNAL" ERRORS *HST*	WEIGHTED MEAN AND "EXTERNAL" ERRORS Orbital
Schwan	53.2 ± 1.0	47.6 ± 0.9	52.5 ± 2.7	47.8 ± 1.4
Gunn	48.9 ± 0.9	...	48.3 ± 2.0	...

[a] Units are parsecs.

the reference stars, it was necessary to determine the respective corrections to absolute parallax and proper motion. The corrections to absolute parallax were computed from a Galactic model used to compute those corrections for the YPC as well as from spectrophotometric parallaxes for the individual reference stars. The spectrophotometric parallaxes used spectra obtained by Deliyannis and King with the Wisconsin, Indiana, Yale, and the National Optical Astronomy Observatory (WIYN) multiobject spectrograph MOS/Hydra spectrograph and CCD photometry obtained by I. Platais with the Cerro Tololo Inter-American Observatory 0.9 m telescope. The data were reduced by Lu, Lee, and Kozhurina-Platais and are being prepared for publication. The two approaches yielded average corrections to absolute parallax of +1.3 to +1.4 mas; we have used the individual corrections derived from the spectrophotometric parallaxes. The corrections to absolute proper motion were derived from a new galactic structure and kinematic model developed by Méndez & van Altena (1997) and measurements made for this purpose of the reference stars by Hanson, Klemola, and Jones of the Lick Observatory Northern Proper Motion (NPM) plates. The Lick NPM corrections in mas yr^{-1} for the individual reference stars in right ascension and declination were respectively +6.9 ± 2, −1.2 ± 2, while for 400 faint anonymous stars of the same magnitude range they obtained +4.2 ± 2, −3.0 ± 2. Méndez calculated from his galactic structure and kinematic model +3.7 ± 0.4, −5.6 ± 0.4. We have adopted the Lick NPM corrections for the individual reference stars, although the final results are not significantly changed if we use the Méndez corrections. The error estimates for the Lick NPM proper motions are dominated by the zero-point error of the galaxy proper motions.

3. DISTANCE TO THE CLUSTER CENTER

The convergent point for the cluster was calculated by Schwan (1991) from 145 high-accuracy FK5 and PPM proper motions. Using a subset of 62 stars found to lie within 4 pc of the cluster center, he found a convergent point for the cluster ($\alpha = 97\overset{\circ}{.}68 \pm 0\overset{\circ}{.}42$, $\delta = 5\overset{\circ}{.}98 \pm 0\overset{\circ}{.}18$), a cluster center ($\alpha = 65\overset{\circ}{.}59$, $\delta = 16\overset{\circ}{.}27$), and a distance of 47.9 pc. Torres et al. (1997c) calculated the mean proper motion at the cluster center from 53 of the 62 stars as $\mu_c = 113.1 \pm 0.7$ mas yr^{-1}. Gunn et al. (1988) derived a slightly different convergent point ($\alpha = 98\overset{\circ}{.}2 \pm 1\overset{\circ}{.}1$, $\delta = 6\overset{\circ}{.}1 \pm 1\overset{\circ}{.}0$) based on the radial velocities determined by Griffin et al. (1988) and the bulk proper motion of the Hyades derived from the absolute proper motions of 59 stars from Hanson (1975). Combined with their cluster center ($\alpha = 66\overset{\circ}{.}15$, $\delta = 16\overset{\circ}{.}65$), they obtained a distance to the cluster center of 45.4 ± 1.2 pc. We can calculate the distance of the Hyades center, D_c, for each star observed with the *HST* FGS from

$$D_c = \pi^{-1} \left(\frac{\sin \lambda_c}{\sin \lambda} \right) \left(\frac{\mu}{\mu_c} \right), \quad (1)$$

where the subscript c refers to the cluster center, π is the absolute parallax derived here for each star, λ is the angular distance of the star from the convergent point on a great circle, and μ is the absolute proper motion determined here along that great circle. The errors of the individual estimates of the cluster center distance were derived from a propagation of the errors of the proper motions and parallaxes, as the errors of λ, λ_c, and μ_c do not contribute significantly to the total error. Systematic errors in λ_c and μ_c do, however, have a *very* important effect.

In Table 2 we list the equatorial coordinates for the equinox 1950 from Hanson (1975) for the first seven stars and from the PPM Catalog for the remainder. Also given are the magnitudes and colors, absolute parallaxes, proper motions and their standard errors, and the derived distance to the cluster center and its standard error. The latter two quantities are listed for both the Schwan (1991) and Gunn et al. (1988) cluster parameters. The first part of the table lists the seven stars measured in the *HST* FGS parallax program, while the second part lists the stars (vB24, vB57, and vB72) for which orbital parallaxes have been derived by Torres et al. (1997a, 1997b, 1997c), and the third part lists a trigonometric parallax and proper motion derived by Gatewood (1992) for vB24 that was inadvertently omitted from the YPC. The weighted mean distances of the cluster center are listed after each of the first two sections along with their formal errors.

The various Hyades distances are summarized in Table 3 along with their respective errors. Internal errors are defined as the formal propagation of the parallax and proper-motion errors into the error of the mean, while external errors are based on the dispersion of the individually derived cluster center distances. As can be seen from a comparison of the *HST* distances based on the Schwan (1991) and Gunn et al. (1988) solutions, the results depend critically on the proper-motion system and the individual proper motions. According to equation (1), after scaling due to differing angular distances from the convergent point, the distance of a star relative to the cluster center is given by the ratio of the star's proper motion to that of the cluster center. The cluster center distance is then derived from the scaled proper-motion distance and the parallax of the star. The *HST* parallaxes yield a cluster center distance (4.83 ± 2.0 pc) in agreement with the orbital parallaxes and the YPC for the Gunn et al. (1988) solution, since the *HST* proper motions are small relative to the bulk proper motion of the Hyades center as derived by Gunn et al. (1988) from Hanson (1975), and the parallaxes are small. In contrast, the smaller Schwan (1991) cluster center proper motion places the *HST* stars closer to the center, and therefore the small *HST* parallaxes move the center farther (5.25 ± 2.7 pc) from the Sun. The orbital parallaxes are essentially independent of the convergent point solution, since for consistency both must use the FK5/PPM proper motions and the cluster center proper motion derived from Schwan (1991), as the three stars were either too bright for accurate measurement in the study of Hanson (1975) or were outside his field of view.

Based on the agreement of the *HST* parallaxes and proper motions presented here with the Orbital parallaxes and the YPC parallaxes, we are inclined to prefer the Gunn et al. (1988) solution and therefore adopt 48.3 ± 2.0 pc or $m -$

$M = 3.42 \pm 0.09$ for the Hyades distance as derived from our *HST* results.

It would be unwise to advocate any increase in the distance scale based on the *HST* FGS parallax results, but it should be noted that Feast & Catchpole (1997) recommend an increase of 10% ± 14% based on *HIPPARCOS* parallax observations of the classical Cepheids and Reid (1997) suggests an increase of 5% to 15% based on *HIPPARCOS* parallaxes of subdwarfs. Once the *HIPPARCOS* parallaxes of Hyades members are released and carefully analyzed, we should have a clearer picture of the state of the distance scale and can then discuss the astronomical consequences of any revision.[7]

The fourth edition of the General Catalogue of Trigonometric Stellar Parallaxes in two volumes is available in printed form from the Yale Astronomy Department and in an abbreviated electronic form from the Astronomical Data Centers.

[7] At the *HIPPARCOS* Venice 1997 meeting, Brown et al. (1997) reported a distance to the Hyades center of 46.34 ± 0.27 pc, or $m - M = 3.33 \pm 0.01$, based on 134 stars. The weighted average distance derived from the four *HIPPARCOS* stars in common with our seven *HST* stars is 46.46 ± 2.24 *pc*, or 3.34 ± 0.10 *mag*. It appears that there are systematic differences between these *HST* and the *HIPPARCOS* parallaxes and proper motions, and we are continuing to investigate those differences. The *HIPPARCOS* distance is in excellent agreement with the YPC ground-based parallaxes reported by van Altena et al. (1997) and indicates that no change in the distance scale is required. Perhaps the Gunn et al. (1988) solution that uses the absolute proper motions of Hanson (1975) may be preferred to the Schwan (1991) FK5 system solution.

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