THE HYADES: DISTANCE, STRUCTURE AND DYNAMICS

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ABSTRACT

A combination of absolute trigonometric parallaxes and proper motions from Hipparcos, and radial velocities from ground-based observations, are used to determine the position and velocity components of candidate members with respect to the Hyades cluster centre, providing new information on cluster membership. The 3-dimensional structure of the cluster is constructed and 13 new candidate members within 20 pc of the cluster centre have been identified. Further from the cluster centre there is a gradual merging between certain cluster members and field stars, both spatially and kinematically. Within the cluster, the kinematical structure is fully consistent with parallel space motion of the component stars with an internal velocity dispersion of about 0.3 km s^{-1}. The spatial structure and mass segregation are consistent with N-body simulation results, without the need to invoke expansion, contraction, rotation, or other significant perturbations of the cluster. The distance to the observed centre of mass for the objects within 10 pc of the cluster centre (corresponding to the tidal radius) is determined. This distance is close to, but significantly better determined than, that derived from recent high-precision radial velocity studies, somewhat larger than that indicated by recent ground-based trigonometric parallax determinations, and significantly smaller than recent studies of the cluster convergent point and dynamical parallaxes. These discrepancies are investigated and explained.

Key words: Space astrometry; Hipparcos; Open cluster and associations: Hyades; Distance scale.

1. INTRODUCTION

The considerable importance of the Hyades cluster in studies of Galactic structure, in the understanding of the chemical evolution of the Galaxy, and in the determination of the Population I distance scale, is well documented in the literature. The nearest moderately rich cluster, with some 300 possible members, a total mass of some 300–400 M$_\odot$, and an age of around 600–800 Myr, it has an extension in the sky of about 20°. Although uncertainty in the distances of individual members has limited the definition of the cluster's main sequence, and thereby its helium content and corresponding evolutionary sequence, it has nevertheless been used as the basic observational material for several fundamental relationships in astrophysics, including the location of the main sequence in the Hertzsprung-Russell diagram and the mass-luminosity relationship, as well as forming the basis for the determination of luminosities of supergiants, OB stars, and peculiar stars in clusters. Determinations of the distance to the cluster have provided the zero-point for distances within our Galaxy and, indirectly through the Cepheids, one of the foundations on which the extragalactic distance scale ultimately rests.

The aim of this work is to combine the Hipparcos parallaxes and proper motions with radial velocities in order to select Hyades members based on the three-dimensional space velocities of the stars, and to construct the 3-dimensional spatial and velocity structure of the cluster. It represents part of a larger study of the cluster using Hipparcos data reported by Perryman et al. (1997). We will show that this leads to a consistent picture of both the motion and the distance of the Hyades cluster.

2. OBSERVATIONAL MATERIAL

All 5499 objects in the Hipparcos Catalogue inside the field given by: $2^{\rm h}15^{\rm m} < \alpha < 6^{\rm h}5^{\rm m}, -2° < \delta < +35°$ are considered here. This sample includes some 240 objects that were specifically included in the Hipparcos observations as candidate Hyades members. Radial velocities for the stars in our sample are taken from the Hipparcos Input Catalogue and culled from various sources in the literature. These velocities are supplemented by Coravel radial velocity results specifically acquired in the context of this study. The radial velocity studies are also used to identify as much as possible the spectroscopic binaries in our sample. Note that the radial velocities

Table 1. Distance and velocity of the inferred centre of mass of the Hyades. As described in the text, the 134 stars located within r = 10 pc from the cluster centre, or the 180 stars in the inner 20 pc, are used to determine the centre of mass. The components of the centre of mass position $\mathbf{b}_{\rm C}$ *and velocity* $\mathbf{v}_{\rm C}$ *are given in Galactic coordinates.*

	$\mathbf{b}_{\rm C}$ (pc)			$\mathbf{v}_{\rm C}$ (km/s)			D	V
	x	y	z	x	y	z	(pc)	(km/s)
$r \leq 10$ pc	-43.08 ± 0.25	$+0.33 \pm 0.06$	-17.09 ± 0.11	-41.70 ± 0.16	-19.23 ± 0.11	-1.08 ± 0.11	46.34 ± 0.27	45.93 ± 0.23
$r \leq 20$ pc	-43.37 ± 0.26	$+0.40 \pm 0.09$	-17.46 ± 0.13	-41.73 ± 0.14	-19.29 ± 0.11	-1.06 ± 0.10	46.75 ± 0.31	45.98 ± 0.20

form a very inhomogeneous set of observations. The precision of the various sources varies considerably, as well as the velocity zero-point. This will be reflected as an additional spread in the space velocities of the cluster members (see Sections 3 and 5.2 below).

We stress here that the Hipparcos observations in the Hyades are far from complete. Specifically, at the faint end of the Hyades luminosity function we are limited by the satellite observability limit of around $V \sim 12$ mag. In the area of the sky around the Hyades the Hipparcos observations are complete to $V \sim 8$ mag, which translates to about 1 $M_\odot$ at the distance of the cluster.

3. MEMBERSHIP AND DISTANCE

To select members from the sample described above we make use of the common space motion of the cluster members. From a preliminary list of members, we constructed a preliminary space velocity, $\mathbf{v}_{\rm C}$, for the cluster. For each star in our sample we can construct the velocity vector $(V_{\alpha*}, V_\delta, V_{\rm R})$, where $V_{\alpha*} = \mu_{\alpha*}A_v/\pi$, $V_\delta = \mu_\delta A_v/\pi$ ($A_v = 4.74047...$ km yr s^{-1}) and $V_{\rm R}$ is the radial velocity. From $\mathbf{v}_{\rm C}$ one can calculate the value the vector $(V_{\alpha*}, V_\delta, V_{\rm R})_0$, which is the predicted tangential and radial velocity for each cluster member. The difference $\mathbf{z}$ between the observed and predicted velocity vectors can be used to select cluster members. By considering the Jacobian of the transformation from the parallaxes, proper motions and radial velocity to the velocity vector one can calculate the covariance matrix of the errors on $(V_{\alpha*}, V_\delta, V_{\rm R})$. The cluster space velocity also has an associated covariance matrix, which reflects the observational errors in $\mathbf{v}_{\rm C}$, the inhomogeneity of the radial velocities, the presence of binaries and the intrinsic dispersion in the motions of the cluster members. Assuming that the observed and predicted velocity vectors are statistically independent, the combined confidence region is described by the sum of the two covariance matrices, $\mathbf{\Sigma}$, as:

$$c = \mathbf{z}'\mathbf{\Sigma}^{-1}\mathbf{z}\,, \tag{1}$$

where the prime denotes matrix transposition. The quantity c is distributed as a χ^2 with three degrees of freedom and the 99.73 per cent confidence region (corresponding to '$\pm3\sigma$' for a one-dimensional Gaussian) is given by $c = 14.16$. If no radial velocity is known for a particular star one can use the same procedure with $(V_{\alpha*}, V_\delta)$ only and then the limit on c is 11.83. For full details on the membership selection procedure we refer to Perryman et al. (1997).

This procedure results in the selection of 1027 candidate members. The parallax distribution of this sample shows that most of these stars are located beyond ~ 100 pc. Most of the distant objects have small parallaxes with relatively large σ_π/π, and small expected proper motions, due to a combination of their large distances and/or their location close to the cluster's convergent point. Radial velocity information is largely absent for these additional objects, which are generally likely to be unassociated with the Hyades cluster. The distribution of π offers no unambiguous criteria for further constraining possible membership. We therefore decided to retain only those stars with a parallax larger than 10 milliarcsec (mas). This leaves us with a list of 218 candidate Hyades members. Radial velocities are known for 197 of the stars on this list. We find 39 new Hyades members (new in the sense that they have not been considered as members before) of which 13 are located within 20 pc from the cluster centre.

After membership selection a redetermination of the centre of mass of the cluster is possible. We did this for the stars located in the inner 10 pc of the cluster, which corresponds roughly to its dynamical limit, as well as for stars in the inner 20 pc. Starting from the preliminary centre of mass only two iterations were needed to converge on a final value. The resulting position, and velocity vectors ($\mathbf{b}_{\rm C}$ and $\mathbf{v}_{\rm C}$) are listed in Table 1. The resulting value of the space velocity in equatorial coordinates (ICRS) is $(-6.28, +45.19, +5.31)$ km s^{-1}, with a corresponding convergent point of $(\alpha, \delta) = (97.^\circ91, 6.^\circ66)$ for the inner 10 pc (134 stars), and $(-6.32, +45.24, +5.30)$ km s^{-1} with a corresponding convergent point of $(\alpha, \delta) = (97.^\circ96, 6.^\circ61)$ for the inner 20 pc (180 stars). The resulting motion of the Hyades with respect to the LSR is derived from a solar motion of 16.5 km s^{-1} in the direction $(\ell, b) = (53^\circ, 25^\circ)$ (Binney & Tremaine 1987), and is approximately $(-32.7, -7.3, +5.9)$ km s^{-1} in Galactic coordinates.

Although these results are reasonably consistent, it should be evident that we are not in a position to provide an unambiguous value for the 'mean distance' of the Hyades, since the centre of mass is sensitive to the subset of stars used to calculate it, which also in turn depends on the selection of stars actually contained within the Hipparcos observing programme, as well as on the contribution of faint stars, white dwarfs, and secondary components of unresolved double systems.

Note that the membership selection process is not sensitive to the precise value of the preliminary space velocity of the cluster. The consistency of the results can in principle be improved by using the newly determined centre of mass to redo the membership selection. However this leads to convergence after 1 further iteration, and only 10 objects located beyond the inner 10 pc region drop out as non-members. We therefore decided to retain the 218 members found after the first iteration.

We have not attempted to correct the derived distances and velocities of the Hyades members for the bias due to the Lutz-Kelker effect (see Brown et al. 1997). It is shown by Perryman et al. (1997) that the resulting bias is small and of the same size as the errors quoted in Table 1 and the uncertainties in the definition of the mean distance referred to above. Basically, this is because for $\sim$ 80 per cent of the Hyades members the relative error on the parallax is less than 0.1.

4. COMPARISON WITH PREVIOUS DISTANCE DETERMINATIONS

The most recent determination of the distance modulus of the Hyades from the moving cluster method is that by Schwan (1991), who finds $m - M = 3.40$. This value is arrived at by determining the convergent point of the cluster from the proper motions (taken from the FK5/FK4Sup, N30 and PPM catalogues), calculating the space velocity by using the radial velocity of the Hyades measured by Detweiler et al. (1984), and finally using the formula:

$$\pi = \frac{\mu}{|\mathbf{v}| \sin \lambda} \tag{2}$$

to derive the distances to the cluster members. We explain the discrepancy between Schwan's distance and ours (3.4 per cent) as follows. His value for the magnitude of the space velocity is larger by about 2 per cent. This is due to a larger cluster radial velocity and a larger angle between the cluster centre and the convergent point (as compared to our values). The $\sin \lambda$ term in Equation 2 is larger for all stars when using Schwan's convergent point instead of ours; on average the difference is 0.3 per cent. The magnitudes of the proper motions used by Schwan are on average 0.7 per cent smaller. Together all these effects lead to smaller parallaxes and hence a larger distance modulus.

The distance to the Hyades has also been determined via the orbital parallaxes of 51 Tau, 70 Tau and 78 Tau by Torres et al. (1997a,b,c). The orbital parallaxes are 17.9 ± 0.6, 21.44 ± 0.67 and 21.22 ± 0.76 mas, respectively. The Hipparcos values of the parallaxes are in excellent agreement; 18.25 ± 0.82, 21.47 ± 0.97 and 21.89 ± 0.83 mas. However the cluster distance derived by Torres et al. (1997a,b,c), based on these three specific objects, is sensitive to the proper motions adopted for the individual cluster members. While they derive a resulting distance modulus of 3.40 ± 0.07 based on 51 Tau, of 3.38 ± 0.11 based on 70 Tau, and of 3.39 ± 0.08 based on 78 Tau, we can infer that any revised estimate of the mean cluster distance based on the use of the Hipparcos proper motions would yield essentially the same distance modulus as that presented here. For example, using the Hipparcos parallax for 51 Tau, our convergent point for the inner 20 pc region, and the Hipparcos proper motions, we find a mean cluster distance of 46.14 pc for the 53 stars used by Torres et al. (1997a), a value very close to our centre of mass value. The formula used by Torres et al. to derive distances ($d_i = d_0(\mu_0/\mu_i)(\sin(\lambda_i)/\sin(\lambda_0))$, where the subscript zero refers to the reference object), utilises the PPM proper motion for 51 Tau (about 5 per cent larger than the Hipparcos value), and the PPM proper motions of the additional cluster stars, which are almost all smaller than those of Hipparcos. These effects together cause the systematically larger distances derived by Torres et al. for the cluster.

Recent distance determinations based on ground-based trigonometric parallaxes are by Upgren et al. (1990) and Patterson & Ianna (1991). They find distances that are smaller than the Hipparcos distance. A comparison of the ground-based and Hipparcos parallaxes shows that the ground-based values are systematically larger than the Hipparcos values. As discussed in the Introduction to the Fourth Edition of the General Catalogue of Trigonometric Stellar Parallaxes (van Altena et al. 1995) the heterogeneous nature of ground-based parallaxes makes any comparisons between them and the corresponding Hipparcos parallaxes difficult to interpret in any unified manner. Thus, in establishing the system of the Fourth Edition of the GCTSP (van Altena et al. 1995) three distinctly different problems were addressed: (1) the correction from relative parallax to absolute parallax; (2) the relative accuracy of parallaxes determined at different observatories; and (3) systematic differences, or zero-point differences between observatories. A recent determination of the Hyades distance modulus based on 104 Hyades members from the GCTSP yielded $m-M = 3.32 \pm 0.06$ mag (van Altena et al. 1997), in good agreement with our present determination, suggesting that the GCTSP and Hipparcos systems are indistinguishable to within the limits set by the accuracy of the ground-based parallaxes, at least for the Hyades region.

5. STRUCTURE AND KINEMATICS

5.1. Spatial Distribution

Figure 1a shows the positions of the 218 candidate Hyades members in Galactic coordinates. The figure shows clear evidence for a centrally concentrated group possibly extended in b_x (in the direction of the Galactic centre). Note that the lack of objects around $b_x = -20$ and $b_z = -60$ in the middle panel of Figure 1a is caused by the limited field of view on the sky towards the Hyades.

A striking feature of Figure 1a is the large number of stars that are found outside the central concentration. The dynamical limit of the cluster is roughly indicated by the so-called tidal radius. This is the

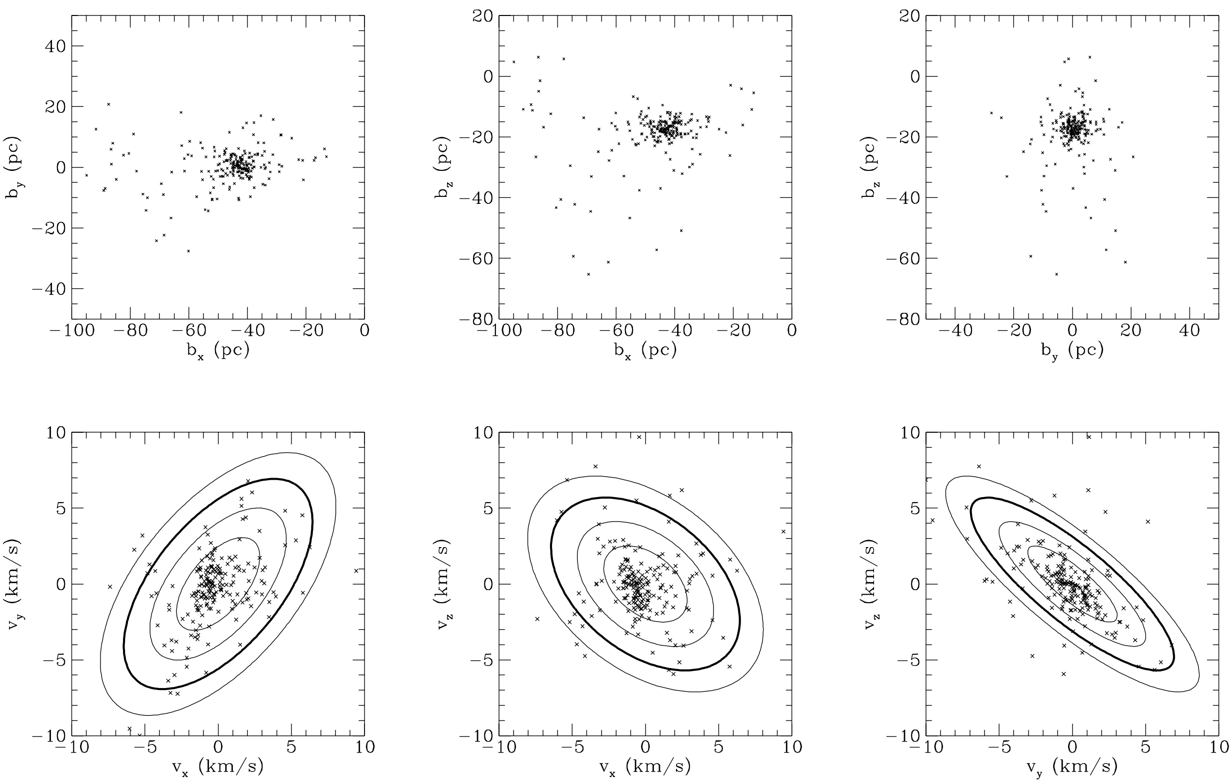

Figure 1. (a) Projected positions for the 218 candidate members, in Galactic coordinates (top); (b) Projected velocity distributions, in Galactic coordinates, for the candidate members with known radial velocities (bottom). The contours delineate the (projected) confidence region corresponding to the mean covariance matrix for all candidate members with known radial velocities. The confidence regions indicate the expected distributions of residual velocities in the absence of intrinsic dispersion. The contours correspond to the 68.3, 95.4, 99.73, and 99.99 per cent confidence levels. The thick line is the '3σ' contour (c = 14.16 in Equation 1).

distance at which the equipotential cluster surface becomes open, due to the effects of the Galactic tidal potential. This radius depends on the mass of the cluster which has been estimated at between 300 $M_\odot$ (Pels et al. 1975, Oort 1979), 400 $M_\odot$ (Gunn et al. 1988), and 460 $M_\odot$ (Reid 1992), according to the corrections made for duplicity, faint stars, and white dwarfs. These numbers lead to a tidal radius of $\sim$ 10 pc. About 45 stars are located between 10–20 pc in Figure 1a. This number is consistent with the simulations of Terlevich (1987), who consistently finds a halo formed by 50–80 stars in the region between 1–2 tidal radii – some of these stars, despite having energies larger than that corresponding to the Jacobi limit, are still linked to the cluster after 300–400 Myr. This can be explained by the location of the openings of the equipotential surface on the x-axis; stars can spend some considerable time within the cluster before they find the windows on the surface to escape through. Alternatively, stars beyond the tidal limit can remain bound to the cluster by an angular momentum-like non-classical integral of motion (e.g., Hénon 1970, Innanen et al. 1983).

A principal components analysis of the distribution of space positions for our Hyades members within 20 pc from the cluster centre shows that the cluster has a prolate shape. The major axis lies almost along b_x in Galactic coordinates, making an angle of $\sim 16^\circ$ with the positive x-axis. The intermediate axis lies almost along b_y, making an angle of $\sim 16^\circ$ with the positive y-axis. The short axis lies along b_z. The axis ratios are 1.6 : 1.2 : 1 (The inner 10 pc region of the Hyades is more nearly spherical.) The fact that the shape of the cluster is prolate suggests that it is primarily extended in b_x, although it is possibly also slightly compressed in b_z. This is consistent with the extension being caused by stars slowly escaping through the Lagrangian points on the x-axis. Flattening of the equipotential surfaces, perpendicular to and directed toward the Galactic plane, was predicted by Wielen (1967) and in the N-body models of Aarseth (1973). The effect is clearly evident in the N-body simulations by Terlevich (1987, Figure 8).

Figure 2 shows the cumulative distributions versus distance from the adopted cluster centre for three mass groups. In the central 2 pc region, only stars more massive than about 1 $M_\odot$ are found and most of these are binaries. This general effect was already noted by van Bueren (1952) and Pels et al. (1975), and is precisely as found in the simulations by Terlevich (1987). Less massive stars are more spatially extended than the more massive ones, with a lower density than for the high mass stars in the central regions. Binaries follow the radial distribution according to their mass, implying that mass is the predominant segregation factor, rather than whether the

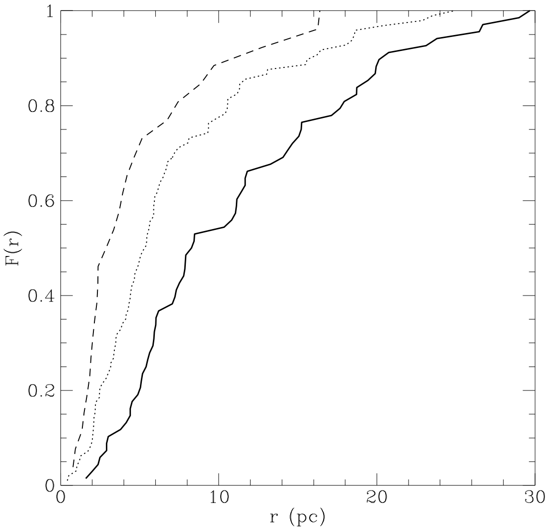

Figure 2. Cumulative distributions versus distance from the centre are shown for $M \leq 1\mathrm{M}_\odot$ (solid line 68 objects); $1 \leq M \leq 2\mathrm{M}_\odot$ (dotted line, 97 objects); and $M > 2\mathrm{M}_\odot$ (dashed line, 26 objects).

system is binary or not. In the numerical models, massive stars sink to the central region, forming binaries, which become harder through the interaction with lighter stars, which in turn acquire enough energy to reach the outer parts of the cluster. There is a strong preference for energetic binaries to be formed among the heaviest members, which tend to segregate towards the dense central part of the cluster. Binaries themselves may not play a significant role in the evolution of the cluster, unless there is a significant population of primordial binaries (e.g. as concluded by Kroupa 1995). We find in our sample of members a binary fraction of 40 per cent. This fraction increases to 61 per cent for the stars located within 2 pc from the cluster centre, with almost all binaries in the central region being spectroscopic.

The mean density distribution was compared to both a Plummer model and a King model. For the Plummer model the best fitting values of the core radius and central density are 2.9 pc and 1.8 $\mathrm{M}_\odot$ pc^{-3}, corresponding to a central velocity dispersion of 0.21 km s^{-1}. In the case of the King model the best fitting model has a core radius of 2.6 pc, a central density of 1.8 $\mathrm{M}_\odot$ pc^{-3} and a value of the ratio of the central potential ($\Psi(0)$) to the parameter σ^2 of 2.6 (see Binney & Tremaine 1987, Chapter 4, p. 232–236 for details). This corresponds to a true central velocity dispersion of 0.24 km s^{-1}.

For both models the central velocity dispersion is in very good agreement with the value derived in Section 5.2 below. However, results inferred from these particular models should be viewed with some caution. The masses in both models fall short of the total mass observed in the Hyades. This is in part due to the fact that we are missing the faint end of the luminosity function in the sample under study. Adding fainter members of the Hyades may change the overall density distribution and the conclusions above. On the other hand significant amounts of mass may be present in the outer regions of the Hyades. This is supported by the fact that the observed half-mass radius ($\sim$ 6 pc) is larger than the half mass radius for the models above (3.7 and 3.0 pc, respectively).

5.2. Velocity Distribution

The residual velocities of the candidate members are shown in Figure 1b. The deviations from the cluster mean motion are, by definition, within '3σ' of our mean cluster motion. Nevertheless Figure 1b suggest a very large spread as well as an evident correlation between the components in the Galactic y and z directions. The intrinsic dispersion expected for a cluster like the Hyades, in dynamical equilibrium, is $\sim$ 0.2 km s^{-1} (van Bueren 1952, Gunn et al. 1988), well below the observed spread.

In deriving space velocities for the cluster stars we make use of the observed vector $(\pi, \mu_{\alpha*}, \mu_\delta, V_\mathrm{R})$. This vector is transformed to a space velocity, implicitly invoking a transformation to $(V_{\alpha*}, V_\delta, V_\mathrm{R})$. Perryman et al. (1997) show that even in the absence of correlations between astrometric errors, the velocity components $V_{\alpha*}$ and V_δ will in general be correlated (this is obviously due to the parallax entering in the calculation of the two; see also Brown et al. 1997). Moreover, because of the position of the convergent point of the system with respect to the cluster centre, the uncertainties in $V_{\alpha*}$ and V_δ are anti-correlated for most stars. This will lead to systematic behaviour of the uncertainties in the sample as a whole.

To confirm the prediction of correlations in the velocity residuals we proceed as follows. If we assume that the motions of the cluster members are only due to the mean motion of the cluster, then the observations of the velocities of the cluster members will all have the same expectation value. We can then average all measured velocities to obtain a mean motion, with the uncertainty in the mean given by the mean of the covariance matrices of the individual members. This mean covariance matrix can then be used to construct the confidence region within which all residual velocities should lie. This is illustrated in Figure 1b. The contours delineate the confidence region at confidence levels 68.3, 95.4, 99.73, and 99.99 per cent. From an eigenvector analysis of the mean covariance matrix, the minor axis of the distribution of velocity residuals is found to point in the direction $\ell = 105°, b = 46°$, which explains the flattened appearance of the distribution of residuals in Figure 1b.

We now restrict our attention to a 'high-precision' subset of cluster members: stars without any indications of multiplicity, with a radial velocity determined by Griffin et al. (1988), and with standard errors on the Hipparcos parallax and proper motions of less than 2 mas and 2 mas yr^{-1} respectively. A detailed analysis of the velocity residuals for these stars shows that there is an extra dispersion in the velocities that is unaccounted for by the simple model above. This extra dispersion can be explained by postulating an intrinsic dispersion in the velocity components of 0.3 km s^{-1}, which is in good agreement with the expected intrinsic dispersion and with the value derived by Dravins et al. (1997).

If the cause of the extra dispersion is attributed solely to the quoted standard errors being underestimates of the true external errors, then the standard errors in the astrometry would have to be increased by 50 per cent (factor 1.5), the errors on the radial velocities would have to be increased by a factor of 3, or both would have to be increased by 40 per cent. We consider such explanations to be unlikely. Furthermore, examination of the velocity residuals also excludes systematic errors in the data, or external perturbations of the velocity field (such as rotation, expansion, or shear due to encounters with molecular clouds) as possible causes for the observed deviations from the mean cluster motion.

6. CONCLUSIONS

The Hipparcos parallaxes and proper motions together provide a consistent picture of the Hyades distance, structure and dynamics. They yield a cluster convergent point motion consistent with the individual trigonometric parallaxes, and together explain the large distance modulus derived from the most recent ground-based proper motion investigations as originating from differences in the space velocity and small systematic effects in the ground-based proper motions. Conversely, the smaller distance modulus generally derived from a variety of ground-based trigonometric parallax programmes originates from systematically larger values of the ground-based parallaxes. Although recent distance determinations to individual objects in the cluster, most notably the results of Torres et al. (1997a,b,c), are in excellent agreement with the Hipparcos trigonometric parallaxes, extrapolation to a mean cluster distance is again affected by systematic effects in the ground-based proper motion studies.

The combination of the Hipparcos astrometry with radial velocity measurements from ground-based programmes provides three-dimensional velocities allowing candidate membership selection to be based on 3-dimensional positional and kinematical criteria. A number of new cluster members have been found within 20 pc of the cluster centre. No evidence for systematic internal velocity structure is found; rather, the results are fully consistent with a uniform cluster space motion with an internal velocity dispersion of about 0.3 km s^{-1}. Spatial distribution, mass segregation, and binary distributions are consistent with N-body simulations.

The cluster has a tidal radius of ~ 10 pc. Outside this region, the stellar distribution is elongated along the direction of the Galactic centre and anti-centre, and is slightly flattened in the direction perpendicular to the Galactic plane. Inside this sphere, the cluster has spherical symmetry with a core radius of $r_c \simeq 2.7$ pc, and a half-mass radius of ~ 6 pc. The presence of objects closely linked kinematically with the cluster core, but well beyond the tidal radius, probably originates from dynamical interactions in the centre combined with diffusion beyond the Lagrangian points.

With the caveat that the importance of the Hipparcos results is to provide individual distances to cluster members, rather than a mean cluster centre of mass (a concept meaningful only in the restricted context of the cluster members contained in the Hipparcos Catalogue), our estimated distance to the observed centre of mass for the objects within 10 pc of the cluster centre is 46.34 ± 0.27 pc, corresponding to a distance modulus $m - M = 3.33 \pm 0.01$ mag. This mean distance is only marginally modified (by about 0.4 pc) for the derived centre of mass for Hipparcos objects within $r < 20$ pc of the cluster centre. A possible bias in the cluster distance due to the Lutz-Kelker effect is small and of the same size as the error in the mean distance.

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