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Revisiting Hipparcos data for pre-main sequence stars*

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Abstract. We cross-correlate the Herbig & Bell and Hipparcos Catalogues in order to extract the results for young stellar objects (YSOs). We compare the distances of individual young stars and the distance of their presumably associated molecular clouds, taking into account post-Hipparcos distances to the relevant associations and using Hipparcos intermediate astrometric data to derive new parallaxes of the pre-main sequence stars based on their grouping. We confirm that YSOs are located in their associated clouds, as anticipated by a large body of work, and discuss reasons which make the individual parallaxes of some YSOs doubtful. We find in particular that the distance of Taurus YSOs *as a group* is entirely consistent with the molecular cloud distance, although Hipparcos distances of some faint Taurus-Auriga stars must be viewed with caution. We then improve some of the solutions for the binary and multiple pre-main sequence stars. In particular, we confirm three new astrometric young binaries discovered by Hipparcos: RY Tau, UX Ori, and IX Oph.

Key words: stars: distances – stars: formation – stars: pre-main sequence – stars: variables: general

1. Introduction

Star formation is widely thought to occur in molecular clouds, which then provide the raw material from which stars can accumulate during the course of the gravitational collapse. While many details of the star formation process remain topics of controversy, the idea that most young stellar objects (YSOs) should be physically associated with molecular clouds remained unchallenged until recently.

Two observational findings in the last few years did, however, cast some doubt on this widely held belief. First came the discovery by the ROSAT satellite of a population of X-ray active pre-main sequence stars – many identified as weak-emission line T Tauri stars (WTTSs) – extending far beyond the boundaries of known star-forming regions (e.g., Neuhäuser et al. 1995a, Neuhäuser et al. 1995b). This result was at first taken as an indication that YSOs could migrate far away from the region of their formation on short time-scales. Propositions to explain this fact included the formation of stars in fast-moving molecular cloudlets (Feigelson 1996) or tidally-induced escapes within multiple systems (Armitage & Clarke 1997). However, the recent finding that many of these pre-main sequence objects are most likely the low-mass counterpart of the Gould Belt OB associations (Guillout et al. 1998) reconciles the ROSAT results with the conventional idea that these stars formed in (now dispersed) molecular clouds.

Another observation which may contradict the hypothesis that YSOs and molecular clouds are associated was recently reported by Favata et al. (1998). On the basis of the Hipparcos satellite astrometric measurements, these authors assert that some classical T Tauri stars (CTTSs) of the Taurus-Auriga star-forming region are apparently much closer than previously thought and may not belong to the Taurus clouds. If this result were proven true beyond reasonable doubt, consequences for the physics of star formation and evolution of solar-type stars would be far-reaching, since arguments for the youth of a given stellar object relate primarily to its location in the vicinity of molecular clouds.

Four arguments are used to infer pre-main sequence status of a solar-type star:

- association with OB stars (e.g., in the Orion Trapezium region);
- association with dark or bright nebulosity (e.g., in the Taurus-Auriga region);
- location above the main-sequence in the Hertzsprung-Russell Diagram;
- presence in the spectrum of the λ6707 Å LiI resonance line (with equivalent width larger than in ZAMS stars of the same spectral type).

The first two criteria are straightforward: OB associations are short-lived, which guarantees the youth of associated low-mass objects, while physical association of a star with a cloud is either seen at the telescope when close reflection and emission nebulae are present – as is the case in the vicinity of many CTTSs – or inferred from kinematic studies (e.g. Jones & Herbig 1979).

The last two criteria above are more indirect. The location in the H-R diagram depends on the assumption made about the

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* Based on observations made with the ESA Hipparcos astrometry satellite

respective luminosities of photosphere and circumstellar matter in a given object (Kenyon & Hartmann 1990), as well as on the assumed distance. Lithium is, in theory, destroyed early in the star history, when the temperature at the bottom of the convection zone reaches about 2×10^6 K, but the lithium abundance may be dependent on variables other than age (cf., e.g., Ventura et al. 1998).

If some CTTSs appear to be located nearby, and thus far away from known star-forming region, as suggested by Favata et al. (1998), one must then choose between two equally unsettling possibilities: (a) either they are young stars, and one must explain how they arrived at their present location, or (b) they are field stars that mimic YSOs, and one must understand how this is possible. Needless to say, there are no obvious answers to these questions, and the entire picture of low-mass star formation would have to be fully revised in order to account for these observations.

This paper provides a detailed re-examination of Hipparcos satellite data for TTSs, focusing mainly on distances and binarity/multiplicity properties. Data are discussed in Sect. 2. Sect. 3 then examines the Hipparcos results relevant to YSO and molecular cloud distances, and concludes that Hipparcos distances for young stars are generally consistent with their expected physical association with molecular clouds. The same conclusion was reached independently by Wichmann et al. (1998), but we extend their analysis by providing new astrometric solutions for groups of TTSs in various star-forming regions. We then study the binarity/multiplicity Hipparcos data in Sect. 4. There, we discuss or improve the astrometric data reductions for several YSO systems, using Hipparcos intermediate astrometric data and, when available, taking advantage of recent spectroscopic information.

2. Hipparcos catalogue data for pre-main sequence stars

The sample of young stars contained in the Herbig & Bell (1988) Catalogue of Orion population objects with emission lines (HBC) and observed by the Hipparcos satellite is fairly limited:13 Herbig Ae/Be stars (7 of which have significant parallax values); 16 CTTSs, 10 of which have significant parallaxes; 7 WTTSs or SU Aurigae stars, 4 of them are positively detected; and 9 stars with uncertain pre-main sequence status, 4 of which have significant parallaxes.

Table 1 displays the TTSs found both in the HBC and in the Hipparcos Catalogue (ESA 1997). Column 1 gives the star name, while Columns 2 and 3 indicate its HBC and HIP number, respectively. Entries are in order of increasing α. Column 4 indicates the associated nebular region, and Column 5 indicates the object type according to the HBC nomenclature[1]. A CTTS is denoted ‘tt’, a WTTS is called ‘wt’, a member of the Herbig Ae/Be (HAeBe) group is noted ‘ae’, and a SU Aurigae-type star is marked ‘su’. A ‘?’ symbol indicates an uncertain type, while a ‘*’ symbol denotes uncertain pre-main sequence status. Column 6 gives the median Hipparcos magnitude, and Column 7 shows the Hipparcos parallax π in milliarcsecond (mas), with standard error σ as indicated in Column 8. Column 9 indicates the derived distance in pc for stars with $\pi \geq 2\sigma_\pi$ (marked ‘:’) and for stars with $\pi \geq 3\sigma_\pi$, with error bars corresponding to $\pm 1\sigma$. Column 10 gives the flag found in Field H59 (Double and Multiple Systems Annex flag) of the Hipparcos Catalogue, the meaning of which we now briefly describe.

For the majority of Hipparcos stars, the astrometric solutions were derived using a single star model, where the five astrometric parameters are the equatorial coordinates (α, δ), the proper motion components $(\mu_{\alpha *}, \mu_\delta)$ and the parallax π. However, detected non-single stars received different solutions, depending on the nature of their duplicity. Five different possibilities are noted in the H59 Field by different flags: either the system was resolved into several components with an assumed linear motion (component solutions, Flag C in Field H59), or an orbital solution could be computed (Flag O), or the duplicity was detected by a non-linear motion of the photocentre (acceleration solution, Flag G), or by the variability of one component, resulting in a specific motion of the photocentre (VIM solutions: Flag V), or by an excess scatter of the measurements possibly due to a short-period variation of the photocentre (stochastic solutions, Flag X). We emphasize here that the value of the derived parallax depends on the adopted astrometric model. It may happen, for example, that a single-star model was given in the Catalogue for a star which is now known to be a spectroscopic binary. One can then go back to the one-dimensional measurements archived in the Hipparcos Intermediate Astrometric Data, CD-ROM 5, in order to compute an orbital solution for this system, resulting in a presumably more accurate value of the parallax and other astrometric parameters. The reader is referred to ESA (1997) for a detailed explanation of astrometric solutions for non-single stars.

Cross-identification of the HBC and Hipparcos stars is in most cases obvious. Only 4 stars of Table 1 are not cross-identified in the SIMBAD database. They are the visual pair HIP 54738 and 54744, and the two single stars HIP 78053 and HIP 114995. The latter two stars are unambiguously identified as IM Lup and V628 Cas (MWC 1080) by inspection of the relevant sky regions. The situation is more confused for the HIP 54738 and 54744 pair, which is identified as CCDM J11125 -7644A/B in SIMBAD. Comparing the Hipparcos Input Catalogue (HIC, Turon et al. 1992) to the Hipparcos Catalogue, it seems that HIC 54738 was erroneously written down as HIP 54744. A careful examination of the sky atlas and arguments given in Sect. 4 lead us to propose the identification HIP 54738 = CV Cha and HIP 54744 = CW Cha.

In each star forming region (SFR), we searched for additional pre-main-sequence stars observed by Hipparcos and located in the vicinity of the stars given in Table 1, in order to improve the precision of the mean parallaxes. In addition to HBC stars, we thus considered HAeBe stars not found in the HBC but listed in the Thé et al. (1994) Catalogue along with young stars, mainly of WTTS type, which were discovered by the ROSAT satellite in the vicinity of star-forming regions or which form multiple systems with stars of Table 1. We restricted

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[1] Except for V773 Tau, which is a CTTS with forbidden line emission and sizable IR excess, and not a WTTS as indicated in HBC.

Table 1. Parallaxes and binary flags for young stellar objects in the HBC

Star (1)	HBC (2)	HIP (3)	Location (4)	Ty. (5)	$\overline{H_p}$ (6)	π (7)	σ_π (8)	D (9)	H59 (10)
V594 Cas	330	3401	L1291	ae	10.67	3.34	1.63	$299{:}^{+286}_{-98}$	-
XY Per	349	17890	L1449	ae	9.43	8.33	3.49	$120{:}^{+87}_{-35}$	C
V773 Tau	367	19762	B209	wt	10.86	9.88	2.71	101^{+39}_{-22}	V
V410 Tau	29	20097	B7	wt	10.91	7.31	2.07	137^{+54}_{-30}	-
BP Tau	32	20160	L1495	tt	12.12	18.98	4.65	53^{+17}_{-11}	-
RY Tau	34	20387	B214	tt	10.50	7.49	2.18	134^{+54}_{-31}	V
HDE 283572	380	20388	B214	su	9.16	7.81	1.30	128^{+26}_{-18}	-
T Tau	35	20390	L1546	tt	9.98	5.66	1.58	178^{+67}_{-40}	-
DF Tau	36	20777	L1521	tt	12.08	25.72	6.36	39^{+13}_{-8}	V
UX Tau A	43	20990	L1551	wt	11.17	-6.68	4.04	-	V
AB Aur	78	22910	L1517,19	ae	7.08	6.93	0.95	144^{+23}_{-17}	-
SU Aur	79	22925	L1517,19	su	9.40	6.58	1.92	152^{+63}_{-34}	-
UX Ori	430	23602	L1615?	?	10.70	0.61	2.47	-	V
RW Aur	80	23873	-	tt	10.30	14.18	6.84	$71{:}^{+65}_{-23}$	X
CO Ori	84	25540	anon	su	10.78	-1.82	2.80	-	G
AB Dor	435	25647	-	*	7.05	66.92	0.54	$14.9^{+0.2}_{-0.1}$	G
GW Ori	85	25689	B225	tt	10.00	3.25	1.44	$308{:}^{+245}_{-95}$	-
CQ Tau	464	26295	-	?	10.63	10.05	2.01	100^{+24}_{-17}	-
V380 Ori	164	26327	NGC 1999	ae	10.35	3.72	5.48	-	-
BF Ori	169	26403	L1640,41	?	10.18	-0.67	1.80	-	-
HD 250550	192	28582	L1586	ae	9.55	1.65	1.51	-	-
HD 259431	529	31235	NGC 2247	*	8.70	3.45	1.41	$290{:}^{+200}_{-84}$	-
Z CMa	243	34042	L1657	ae	9.78	-0.91	2.21	-	V
NX Pup	552	35488	CG1	ae	10.22	1.99	2.38	-	C
TW Hya	568	53911	-	tt	11.07	17.72	2.21	56^{+8}_{-6}	-
CR Cha	244	53691	Cha 1	tt	11.45	6.97	1.87	143^{+52}_{-30}	-
DI Cha	245	54365	Cha 1	tt	10.81	4.77	2.82	-	X
CU Cha	246	54413	Cha 1	ae	8.53	5.70	0.76	175^{+27}_{-20}	-
CV Cha	247	54738	Cha 1	tt	11.20	3.14	7.39	-	C
CW Cha	589	54744	Cha 1	tt	13.76	3.14	7.39	-	C
T Cha	591	58285	DCld 300.2-16.9	?	11.95	15.06	3.31	66^{+19}_{-12}	-
IM Lup	605	78053	Lup 3	wt	11.72	-4.77	13.79	-	C
RU Lup	251	78094	Lup2	tt	11.17	4.34	3.56	-	-
RY Lup	252	78317	Lup3,4	tt	11.56	9.26	2.83	108^{+48}_{-25}	-
V856 Sco	619	79080	Lup 3	ae	7.07	4.81	0.87	208^{+46}_{-32}	-
V1121 Oph	270	82323	L162	tt	11.42	10.51	2.77	95^{+34}_{-20}	-
AK Sco	271	82747	anon	tt	9.35	6.89	1.44	145^{+39}_{-25}	-
IX Oph	272	83963	B59	?	11.05	-0.26	2.64	-	V
FK Ser	664	89874	L405?	tt	10.75	9.42	6.17	-	C
R CrA	288	93449	NGC6729	ae	11.61	121.75	68.24	-	X
V1685 Cyg	689	100289	anon	ae	10.62	9.25	2.23	108^{+56}_{-21}	V
BD +41 3731	693	100628	L897,99	?	9.92	0.41	1.15	-	-
HD 200775	726	103763	NGC7023	ae	7.41	2.33	0.62	429^{+156}_{-90}	-
BD +46 3471	310	107983	IC5146	ae	10.22	-0.83	1.47	-	-
DI Cep	315	113269	-	tt	11.50	3.50	2.15	-	-
MWC 1080	317	114995	anon	*	11.56	-6.98	3.33	-	-

ourselves to those stars with confirmed pre-main sequence status discussed in the series of papers on ROSAT observations of SFRs (Neuhäuser & Brandner 1998, Krautter et al. 1997, Alcalá et al. 1995, Wichmann et al. 1996, Alcalá et al. 1997, Covino et al. 1997, Frink et al. 1998, Terranegra et al. 1999). Table 2 (with entries similar to Table 1) summarizes properties of these additional pre-main sequence stars.

Note that the Hipparcos data of a large sample of HAeBe stars, containing a number of likely members of the class in addition to those contained in HBC, were recently discussed by van den Ancker et al. (1997); we thus won't discuss them individually further here but will use them to compute mean parallaxes of YSO groups.

Table 2. Additional young stellar objects connected with the T associations and used in distance determinations

Star (1)	ROSAT (2)	HIP (3)	Location (4)	Ty. (5)	$\overline{H_p}$ (6)	π (7)	σ_π (8)	D (9)	H59 (10)
BD +11 533	RX J0352.4+1223	18117	Tau	wt	10.0	6.55	1.62	153^{+50}_{-30}	-
HD 284149	WKS96 6	19176	Tau	wt	9.71	6.43	1.84	156^{+62}_{-35}	-
HD 28150	-	20780	Tau	ae	6.96	8.04	1.53	124^{+29}_{-20}	C
BD+17 724B	WKS96 30	20782	Tau	wt	9.52	7.69	17.39	-	C
HD 283798	WKS96 50	21852	Tau	wt	9.69	8.68	1.35	115^{+21}_{-16}	-
HD 31648	-	23143	Tau	ae	7.79	7.62	1.18	131^{+24}_{-18}	-
HD 37061	-	26258	Orion Neb.	?	6.82	2.77	0.88	361^{+168}_{-87}	-
HD 97300	CHXR 42	54557	Cha 1	ae	9.06	5.33	1.01	188^{+44}_{-30}	-
HD 96675	RX J1105.9-7607	54257	Cha 1	ae	7.74	6.11	0.60	164^{+18}_{-15}	-
HD 104237	RX J1200.1-7811	58520	Cha 3?	ae	6.65	8.61	0.53	116^{+8}_{-7}	-
HD 102065	-	57192	DC 300-17	ae	6.64	5.95	0.52	168^{+16}_{-14}	-
V1027 Sco	KWS97 Lup 3 40	79081	Lup 3	ae	6.63	4.15	0.83	241^{+60}_{-40}	-

3. Parallaxes of TTSs and associated clouds

CTTSs and WTTSs observed by Hipparcos are among the brightest members of their respective classes, although they are some of the faintest stars in the Hipparcos Catalogue. Among the 31 stars with significant parallaxes in Tables 1 and 2, 14 are in the Taurus-Auriga star-forming region, 1 is located in Orion, 6 are associated with the Chameleon and 2 with the Lupus star-forming regions, 3 are within the Scorpius cloud complex, and the other ones are more isolated HAeBe stars and the nearby CTTS TW Hya.

3.1. Data quality

As a first check on data quality, we consider the standard error of the parallax measured by Hipparcos. While the derived parallax accuracy of the sample of young stars measured by Hipparcos depends on the median H_p stellar magnitude, it is typically less than about 2 mas, in agreement with the average accuracy of the Hipparcos Catalogue (cf. Fig. 1). The faintest stars of this sample, BP Tau and DF Tau, are those two CTTSs whose distances appear considerably lower than their associated clouds. The standard errors of their parallaxes is a factor 2 or more larger than standard errors of other stars in the YSO sample[2], which should be compared to parallax accuracies derived for the low-luminosity end of the Hipparcos Catalogue. Fig. 1 also displays (lower panel) parallax standard errors of the faintest stars with reliable parallaxes found in the Hipparcos Catalogue, which follows the $\propto 10^{\frac{H_p}{5}}$ law expected from photon noise only. It shows that DF Tau's parallax standard error is larger by a factor 1.5 than the standard error of stars with comparable magnitude, while BP Tau does not stand out in this sample. Except for DF Tau, then, the precision of parallaxes for the sample of positively detected YSOs appears to be of a quality consistent with Hipparcos data for stars of comparably low brightness.

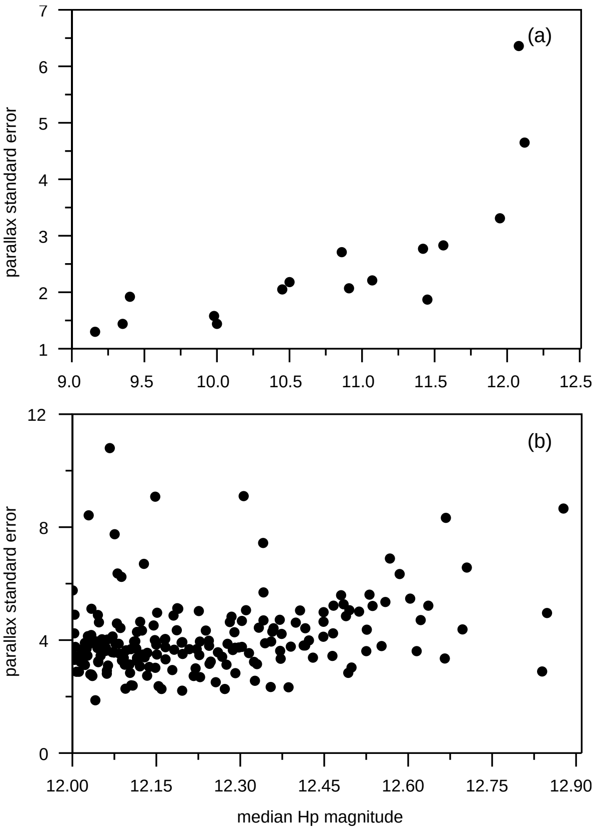

Fig. 1. Panel **a** Relationship between median Hipparcos magnitude $\overline{H_p}$ and parallax standard error σ for the pre-main sequence stars of Table 1. Only positively detected stars with $\pi \geq 3\sigma$ are plotted here. Panel **b** Same as Panel **a**, but for the low-luminosity end of the Hipparcos Catalogue.

3.2. Mean distances of T associations

In each T association, stars were grouped according to their positions and common motion. Mean parallaxes of these groups were then derived from the intermediate data (i.e., the abscissae on the Reference Great Circles of the satellite; cf. ESA 1997), using the method developed by Robichon et al. (1999) for com-

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[2] Note that RW Aur has a large parallax error in spite of its relative brightness. This is presumably due to the strong variability of this CTTS. Its measured parallax is only slightly above 2σ and cannot be considered significant.

Table 3. Distance indicators for the Taurus cloud

HD	HIP	π	σ_π	$\mu_{\alpha*}$	$\sigma_{\mu_{\alpha*}}$	μ_δ	σ_{μ_δ}	H59
26154	19634	6.19	1.13	-15.79	1.14	-25.53	0.89	C
28149	20789	7.86	0.75	-0.35	0.75	-13.25	0.70	-
30378	22314	5.10	1.02	5.12	0.99	-25.84	0.72	-
31293	22910	6.93	0.95	1.71	1.05	-24.24	0.69	-

puting the mean astrometric parameters of stellar groups. This method explicitly takes into account the fact that the Hipparcos parameters are correlated within a few square degrees.

3.2.1. Taurus-Auriga

The morphology and distance of the several molecular clouds forming the Taurus-Auriga complex is summarized by Ungerechts & Thaddeus (1987). They adopted a mean distance of 140 pc from previous analyses based on star counts, photometric distances of reflecting nebulae and reddening versus distance diagrams of field stars. Several of the young stars observed by Hipparcos in that region are located in the central part of Taurus, the distance of which was determined by Racine (1968) and Elias (1978) from the photometry of a few bright stars associated with nebulosity. By chance, all the calibrators used by Elias (1978) were observed by Hipparcos, and in Table 3 we give the Hipparcos astrometric parameters of these objects. The weighted average parallax $\sum\left(\pi_i/\sigma_i^2\right)/\sum\left(1/\sigma_i^2\right)$ and associated standard deviation $1/\sqrt{\sum\left(1/\sigma_i^2\right)}$ of these distance indicators is 6.78 ± 0.46 mas, corresponding to a distance of 147^{+11}_{-9} pc. This rough average Hipparcos parallax is thus in perfect agreement with previous estimates (cf. Kenyon et al. 1994).

The 17 stars selected in the Taurus-Auriga region were divided into 3 groups of respectively 5, 4 and 5 members. The 3 remaining stars HIP 18117, 20777 and 21852 are too isolated to be included in a group. The astrometric parameters of these stars and their mean values are summarized in Table 4. The term GOF there refers to the goodness-of-fit of the astrometric solution (cf. ESA 1997, p. 112).

Group 1 contains stars around the cloud L 1495. Their proper motions are quite similar and reinforce the hypothesis they are part of the same structure. The mean parallax of these 5 stars is 7.65 ± 0.98 mas and 7.97 ± 1.14 mas when removing the two VIMs HIP 19762 and 20387. Nevertheless, HIP 20160 (BP Tau), has an individual parallax 18.98 ± 4.65 mas, larger than these mean values. The mean parallax is 7.76 ± 1.15 mas using only the two single stars HIP 20097 and 20388, which each have an empty H59 field. BP Tau is then at more than 2σ from these values. It is unclear whether the star is a member of the group with a diverged parallax or is really closer than the group. In the latter case, it would be an unlikely coincidence that this star would be just in front of a T association with a similar proper motion but a distance less than twice as small. We shall discuss BP Tau in some detail in Sect. 4.

Group 2, in Auriga, contains HIP 22910, 22925, 23143, and 23873. The mean parallax is 7.08 ± 0.71 mas and 7.13 ± 0.75 mas when removing HIP 23873 which has a stochastic solution.

Group 3, around T Tau itself, contains HIP 20780, 20782, 20990 to which one could attach HIP 19176 and 20390 which are a few degrees beside them. Unfortunately, only HIP 19176 and 20390 have an empty H59 field. HIP 20780 and 20782 form a two-pointing double system (C in H59) in the Hipparcos Catalogue. HIP 20780 has a reliable solution while HIP 20782 is 3 magnitudes fainter and has a very uncertain solution. HIP 20990 is a faint VIM with an unreliable solution. The mean parallax of these 5 stars is 5.66 ± 0.88 mas. It is 5.80 ± 0.90 mas using the three reliable stars HIP 19176, 20390 and 20780 and 5.96 ± 1.20 mas using only the two single stars HIP 19176 and 20390.

Putting the 8 single stars (H59 empty) together, we obtain a mean parallax of the Taurus-Auriga complex of 7.21 ± 0.49 mas corresponding to a distance of 139^{+10}_{-9} pc. Using the most reliable parallax value for each group (those obtained with the single stars only), the three groups are respectively at 125^{+21}_{-16}, 140^{+16}_{-13} and 168^{+42}_{-28} pc. These values, although statistically in agreement, could reflect real distance differences of about the angular size of the complex.

3.2.2. Orion

Orion is a very large complex of molecular clouds with several distinct regions (cf. Maddalena et al. 1986). The complex has practically no tangential reflex solar motion so that YSOs are impossible to separate from field stars using astrometric parameters. The only star with detected (marginally significant) parallax in the Table 1 sample is GW Ori. It is associated with molecular clouds surrounding the HII region excited by the O8 star λ Ori, HIP 26207, at a distance of 324^{+109}_{-65} pc; and the derived distance of GW Ori is consistent with this value. The star CO Ori is also in the same vicinity, but it is fainter with parallax standard error comparable to its expected parallax.

In addition to the stars listed in Table 1, 15 presumably young Orion stars are found in the Hipparcos Catalogue: the HAeBe stars HIP 24552, 25299, 25546, 26594, 26752 and 27059 (from van den Ancker et al. 1997), and 9 stars detected by ROSAT in the Orion Nebula cluster (Gagne et al. 1995) – HIP 26220, 26221, 26224, 26233, 26234, 26235, 26237, 26257 and 26258. Only the last of these stars has a (marginally) significant parallax. Two other Orion stars detected by Rosat, HIP 26081 and 26926 are foreground stars according to their Hipparcos parallaxes: respectively 59.45 ± 3.88 mas and 19.94 ± 0.83 mas. The Orion nebula cluster is probably not a bound cluster but part of a 80 pc long structure connected with the Orion OB1 association (Tian et al. 1996). Among the Hipparcos-detected stars in this cluster, only HIP 26258 has an empty H59 field. HIP 26220, 26221 and 26224 are three components of a quadruple system, HIP 26233, 26234, 26235 and 26257 are also flagged C in H59, while HIP 26237 has a stochastic solution. No mean parallax could therefore be determined for these objects. HAeBe stars

Table 4. Astrometric parameters of stars in the Taurus-Aurigae complex. For each group, two mean values, with their standard errors and goodness-of-fit (GOF), are indicated. The first has been computed using all the stars, while the second considers only single stars (i.e., stars with an empty H59 field).

Name (1)	HIP (2)	π (3)	σ_π (4)	$\mu_{\alpha*}$ (5)	$\sigma_{\mu_{\alpha*}}$ (6)	μ_δ (7)	σ_{μ_δ} (8)	H59 (9)
Isolated stars								
BD+11 533	18117	6.55	1.62	6.37	1.79	-16.60	1.50	-
DF Tau	20777	25.72	6.36	14.48	6.25	-26.38	4.26	V
HD 283798	21852	8.68	1.35	-0.70	1.35	-20.56	1.04	-
Group 1 (L1495 region)								
V773 Tau	19762	9.88	2.71	0.65	2.55	-24.89	1.89	V
V410 Tau	20097	7.31	2.07	6.04	2.38	-27.44	1.77	-
BP Tau	20160	18.98	4.65	5.28	5.43	-33.13	3.94	-
RY Tau	20387	7.49	2.18	9.08	2.62	-23.05	1.89	V
HDE 283572	20388	7.81	1.30	7.52	1.57	-27.45	1.14	-
Mean (all stars)		$\pi = 7.65 \pm 0.98$		GOF=1.32				
Mean (single stars)		$\pi = 7.97 \pm 1.14$		GOF=0.76				
Group 2 (Auriga region)								
AB Aur	22910	6.93	0.95	1.71	1.05	-24.24	0.69	
SU Aur	22925	6.58	1.92	0.17	2.24	-21.69	1.28	
HD 31648	23143	7.62	1.18	6.25	1.22	-23.80	0.91	
RW Aur	23873	14.18	6.84	9.69	7.36	-21.92	3.91	X
Mean (all stars)		$\pi = 7.08 \pm 0.71$		GOF=5.39				
Mean (single stars)		$\pi = 7.13 \pm 0.75$		GOF=0.63				
Group 3 (south Taurus)								
HD 284149	19176	6.43	1.84	6.00	1.65	-15.40	1.24	-
T Tau	20390	5.66	1.58	15.45	1.88	-12.48	1.62	-
HD 28150	20780	8.04	1.53	2.83	2.18	-17.77	1.85	C
BD+17 724B	20782	7.69	17.39	-5.93	25.67	-33.28	20.88	C
UX Tau A	20990	-6.68	4.04	8.59	5.08	-27.42	3.78	V
Mean (all stars)		$\pi = 5.66 \pm 0.88$		GOF=3.27				
Mean (single stars)		$\pi = 5.96 \pm 1.20$		GOF=-0.13				
All stars								
Mean (single stars)		$\pi = 7.21 \pm 0.49$		GOF=0.83				

Table 5. Distance indicators for the Orion R1 and R2 associations (Racine 1968)

HD/BD	HIP	π	σ_π
36540	25954	1.79	1.19
-06 1253	26327	3.72	5.48
37674	26683	3.08	1.07
37776	26742	1.96	0.98
38087	26939	5.02	1.89

outside the Orion nebula cluster are more isolated and cannot be grouped to compute mean parallaxes.

We can nevertheless derive a new, post-Hipparcos estimate of the distance to the Orion A and B clouds by considering the distance indicators of Racine (1968), which are members of the Orion R1 and R2 associations. Among the 8 stars studied by Racine, 5 were observed by Hipparcos. Their parallaxes are given in Table 5. All these stars are single with empty H59 and H61 fields, except for HD 38087, a double with published component solution. The mean weighted parallax of the Orion distance indicators, to which we add the star HIP 26258 discussed above, is 2.63 ± 0.49 mas. This corresponds to a distance of 381^{+86}_{-59} pc, to be compared to the value of 600 ± 50 pc derived by Racine.

3.2.3. Chamaeleon

The Chamaeleon, Lupus, and Scorpius clouds have spatial velocities close to that of the Sco OB2 (Scorpius-Centaurus-Lupus-Crux) association, around $(U, V, W) = (0, -12, 0) \pm (5, 5, 5)$ km s^{-1}. The histories of these SFRs are certainly connected even if their present ages, motions and distances are not exactly the same.

The distance of Chamaeleon clouds has been a topic of controversy for a long time; earlier estimates ranged from 115 to 215 pc for Cha 1, and from 115 to 400 pc for Cha 2. From a recent re-investigation of the reddening with distance over a large area around the clouds, Whittet et al. (1997) conclude that the most probable distance of Cha 1 is 160 ± 15 pc, and that of Cha 2 is 178 ± 18 pc. A similar analysis using Hipparcos distances gives essentially the same result (Knude & Høg 1998).

We can use 10 stars to compute mean parallaxes of groups in the Chamaeleon region. In Cha 1 there are four CTTSs: HIP 53691, 54365 and the pair HIP 54744 and 54738. The two Herbig Ae/Be stars HIP 54413 and HIP 54557 are usually associated with Cha 1 because of their reflecting nebulosities. Inclusion of HIP 54257 is more speculative, since it is a B star not known as a Herbig star but detected by ROSAT. On the basis of its Hipparcos proper motion and parallax, Terranegra et al. (1999) believe that it is a probable member although Gry et al. (1998) place it just behind the Cha 1 complex. The mean parallax of these 7 stars is 5.86 ± 0.45 mas, whereas it is 5.96 ± 0.45 mas when considering only the four stars with an empty H59 field, corresponding to our best estimate of 168^{+14}_{-12} pc for the Cha 1 distance. Note that the group mean parallax is only 5.71 ± 0.62 mas when also removing the possibly dubious member HIP 54257, which rules out that this star is located behind the cloud, since its individual parallax is 6.11 ± 0.60 mas.

The other subgroups of the Chamaeleon region have few Hipparcos stars. There is the WTTS HIP 58285 in Cha 3, the B star HIP 57192 just in the head of DC 300–17, and the HAeBe star HIP 58520 at less than 1 degree from the head of DC 300-17 but connected to Cha 3 in the literature. In addition, the B star HIP 57192 is placed just behind the DC 300-17 cloud by Gry et al. (1998). Its parallax is 5.95 ± 0.52 mas, in perfect agreement with the mean parallax of Cha 1. HIP 58520 ($\pi = 8.61 \pm 0.53$ mas) is definitely closer than the Cha 1 cloud. HIP 58285 is faint with a large parallax error ($\pi = 15.06 \pm 3.31$) but its astrometric parameters are closer to those of HIP 58520 than to those of HIP 57192. HIP 58520 and 58285 are members of a presumed moving group of young stars described in Frink et al. (1998) and Terranegra et al. (1999). Two other Hipparcos WTTSs belong to this proposed group, the reality of which is difficult to demonstrate. Its spatial velocity is small and is noticed mainly because of its reflex motion with regard to the Sun. Note that one can find many stars with the same motion in the Hipparcos Catalogue, in a distance range of 50–200 pc, which were not detected by Rosat. While some of them may form a moving group with the WTTSs mentioned above, it is also conceivable that this apparent group is an artifact caused by the limiting magnitudes of Hipparcos and ROSAT.

To summarize this section, the only firm evidence concerning the Chamaeleon complex is that Cha 1 is at a distance of about 170 pc, in agreement with recent estimates by Whittet et al. (1997) and Knude & Høg (1998).

3.2.4. Lupus

Re-assessing association membership from Hipparcos results, de Zeeuw et al. (1999) find a mean distance of 140 pc for the Upper Centaurus Lupus association. From the angular extent of the association (about 27°), and assuming that it is nearly spherical, the distances of individual members are expected to range from about 110 to 190 pc. Two positively detected stars of our sample (RY Lup and V856 Sco) are apparently associated with clouds of the Lupus star-forming region, and their distances are compatible with the above range.

Six stars connected with the Lupus complex can be used for computing mean parallaxes: HIP 77157, 78094, 78317, 79080, 79081 and 78053. HIP 77157, 78094 and 78317 are TTSs in Lupus 1, 2 and 4 respectively. HIP 79080 and 79081 are the brightest stars of a quadruple system (at least) in Lup 3. HIP 79080 is a Herbig Ae star and 79081 a peculiar B star. HIP 78053 is a WTTS in Lupus 3 with a poor Hipparcos solution and a flag C in field H59. We don't include six other WTTSs discovered by ROSAT (Krautter et al. 1997 and Wichmann et al. 1997) and discussed by Neuhäuser & Brandner (1998) because they have proper motions not exactly in agreement with CTTSs, so that it is quite impossible to decide whether they are members of the T association, the OB association or are young field stars instead.

The mean parallax computed for the 5 stars with an empty H59 field is 4.77 ± 0.61 mas, a small value compared to the previous estimates quoted above. However, it results mainly from the brightest stars HIP 79080 and 79081, which have small errors on their parallaxes. If we remove these stars and consider only HIP 77157, 78094 and 78317, we obtain a larger value of 6.79 ± 1.50 mas – in agreement with previous determinations of the Lupus SFR distance, but with a large uncertainty – and a value of 4.38 ± 0.67 mas for HIP 79080 and 79081. The explanation could be either that HIP 79080 and 79081 are not members of Lupus 3 or that this cloud is farther away than the other associations.

3.2.5. Scorpius

This is another association studied by de Zeeuw et al. (1999), who find a mean distance of 145 pc, in agreement with previous work by Racine (1968). The parallax distribution width is approximately 1 mas, corresponding to distances from 127 to 170 pc. While the parallax of AK Sco is consistent with this result, the fainter CTTS V1121 Oph may be located somewhat closer to us. Note that the quadruple system ϱ Oph[3], associated with the dense parts of the cloud where vigorous star formation is currently taking place, is at a distance of 128^{+12}_{-10} pc, i.e., on the front side of the Upper Scorpius association.

3.2.6. The TW Hya association

TW Hya, the closest CTTS, has long been considered to be isolated but is now known to be part of the closest T association (cf. de la Reza et al. 1989, Gregorio-Hetem et al. 1992, Kastner et al. 1997, Jensen et al. 1998, Sterzik et al. 1999 and Webb et al. 1999). The most recent list of members reports 13 pre-main sequence systems in the vicinity of TW Hya for a total of

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[3] ϱ Oph AB = HIP 80473, ϱ Oph C = HIP 80474, ϱ Oph D = HIP 80461

Table 6. Hipparcos-detected members of the TW Hya association)

Name	HIP	π	σ_π
HD 98800	55505	21.43	2.86
CD -36 7429	57589	19.87	2.38
HD 109573	61498	14.91	0.75

at least 20 objects ranging from an A star to a possible brown dwarf (Sterzik et al. 1999).

Four of these objects are in the Hipparcos Catalogue: HIP 53911 (TW Hya itself) and the three objects given in Table 6. Their parallaxes lead to a depth of 20 pc, comparable to the angular size of the association. We didn't compute a mean parallax because the method is not suited to such a nearby group where the depth is not small in comparison to the formal parallax errors.

3.2.7. Conclusion

In most cases, we confirmed that the Hipparcos distances to young solar-type stars are comparable to the distances of molecular clouds and/or OB stars with which they appear associated, as anticipated from a large body of earlier work. There are, however, two discrepant individual cases: BP Tau and DF Tau. These are among the most investigated CTTSs, so one may argue that a good part of what we know about the T Tauri phenomenon is based on these stars. On the other hand, there are a few CTTSs that are found outside of molecular clouds, such as RW Aur or, as seen above, TW Hya. Perhaps such cases are not so rare? Before we start to speculate, it appears quite important to convince ourselves that the Hipparcos results for BP Tau and DF Tau are valid. A possible bias can be due to undetected binarity, and we shall examine in the next section the evidence for binarity in Hipparcos data for YSOs.

4. Binarity of YSOs in the Hipparcos catalogue

A few known young binary systems (FK Ser, etc.) were included in the Hipparcos observation program, but most of the discoveries of close T Tauri systems result from recent progress in high-resolution interferometric and imaging techniques, after the Hipparcos launch. This fast moving research field opens the exciting prospect of understanding the molecular core fragmentation process and the relationship between the formation of binaries and disk (cf. Mathieu 1994).

The theoretical angular resolution of Hipparcos is 0.45 arcsec, but double stars with a moderate brightness ratio ($\Delta H_p <\approx 2$) separated by 0.10–0.13 arcsec already produce a measurable broadening of the diffraction peak (Lindegren 1997). Unresolved systems with separation below this limit (and below about 0.3 arcsec for larger brightness ratios) were seen by Hipparcos as single point sources located at the photocentre of the system. Both orbital motion and light variability of at least one of the system's components can lead to deviations of the photocentre's path from its expected uniform motion, giving rise to the suspicion that the star is an unresolved binary. As explained above, if an astrometric solution for a binary system could be derived by the Hipparcos data reduction teams, it is indicated in the Hipparcos Catalogue (Field H59, cf. Column 10 of Table 1). Table 1 shows that Hipparcos observations resulted in several detections of astrometric binaries in the small YSO sample that was observed.

Table 7. VIM solutions for Young Stellar Objects

Star (1)	$\Theta_C \pm \sigma_{\Theta_C}\,(^\circ)$ (2)	$\rho_{\min}$ (mas) (3)
V773 Tau	118.08 ± 9.54	119.4
RY Tau	316.61 ± 37.59	19.5
DF Tau	307.08 ± 17.70	80.2
UX Tau A	253.90 ± 5.53	204.7
UX Ori	257.42 ± 18.42	21.8
Z CMa	135.30 ± 20.27	80.1
IX Oph	244.59 ± 13.65	56.9
V1685 Cyg	22.94 ± 11.71	140.6

We went back to the intermediate astrometric data of these objects and of other young stars for which the astrometric solutions derived by the Hipparcos teams did not take into account newly discovered information, notably as far as binarity is concerned. We tried on a star-by-star basis to explore alternative astrometric solutions, and we discuss below those systems where an improvement has been obtained, in order of increasing α for each type of double star distinguished in Hipparcos astrometric solutions.

4.1. Variability-induced movers

Since TTSs are variable stars, it is not surprising to find that several of them are called Variability-Induced Movers (VIMs, Field H59=V), for which Wielen (1996) derived astrometric solutions based on the assumption that one star in the binary system is variable, while the other one is constant. Since the photocentre varied back and forth between the two components, both the position angle Θ_C (with its standard deviation σ_{Θ_C}) and a lower limit $\rho_{\min}$ of the separation can be found in this way. The results for the 8 VIMs among our TTS sample are given in Table 7, and we discuss each of these objects briefly in turn.

4.1.1. V773 Tau

This is a triple system made up of a double line spectroscopic binary star (Welty 1995) and a third component which has been resolved at several optical and IR wavelengths (cf. Ghez et al. 1997a and references therein). The position angle of V773 Tau C ranges from 295° in 1990 to 320° in 1994, and the separation is about 115 mas until 1993, then decreasing to about 60 mas from 1993 to 1995. This is in good agreement with the VIM solution given in Table 4. Note that the position angle Θ_C refers to the constant component of the binary (as assumed in the VIM formalism) with respect to the variable component, while it refers to the primary component in Ghez et al. (1997a). The phase shift of π between the two position angle values thus confirms that V773 Tau C is more variable than V773 Tau AB, as observed by Ghez et al. (1997a). It is therefore likely that the two flares recorded by Hipparcos in its photometric database originate from V773 Tau C.

There is an unmodelled scatter in the astrometric data residuals of the Hipparcos solution, which could be due to the motion of the photocentre of the two-lined spectroscopic binary. However, if one uses the luminosities of the components from Ghez et al. (1997a) and the masses ($\times \sin i$) given by Welty (1995), the semi-major axis for the motion of the photocentre is ≈ 5% of the semi-major axis of the relative orbit, i.e., around 0.15 mas. This is too small for detection by Hipparcos, and even if the secondary had a much smaller luminosity, the effect would be negligible compared to the VIM effect (≈ 58 mas variation of the photocentre between the minimum and maximum luminosity of the system).

Recently, Lestrade et al. (1999) determined the astrometric parameters of V773 Tau using high precision VLBI astrometry, and found a parallax of 6.74 ± 0.25 mas. The derived parallax and proper motion agree within 2σ with Hipparcos results. The fact that the position angle of V773 Tau C changed during the mission has an influence on the astrometric parameters: constraining the position angle to vary linearly with time during the 3-year mission with $\theta = 6.33t + 118°$ gives a parallax of 8.74 ± 3.19 mas, closer to the VLBI value but with a large uncertainty.

4.1.2. RY Tau

This star has long been suspected of being a binary (Herbig & Bell 1988) based on apparent changes in the stellar radial velocity, and Hipparcos confirmed this suspicion.

A new VIM solution was computed, using all available intermediate data, and slightly improving the published solution. The position angle is $304 \pm 34°$ and the lower limit on the separation is 23.6 mas. This is compatible with the lack of detection of this system in current high angular resolution observations. The projected minimum distance between the two components is 3.27 AU.

4.1.3. DF Tau

The binarity of DF Tau was first detected in a lunar occultation (Chen et al. 1990), and was observed on several occasions since then. Available data are summarized by Ghez et al. (1997a), who find that the position angle decreases from $328°$ in 1990 to $297°$ in 1995, while the separation stays approximately constant over this time, at about 90 mas. The position angle from the Hipparcos VIM solution is consistent with these values and indicates that the primary is the variable component. This is also suggested by Ghez et al. (1997a), who note that both components display infrared excess but that the UV excess, which signals accretion activity, is much stronger in the primary than in the secondary. The VIM formalism (used to derive DF Tau's parallax in the Hipparcos Catalogue) assumes uniform orbital motion, which is obviously not the case here. We tried to improve the astrometric solution in two ways.

1. Assuming that the VIM formalism is correct, i.e. that the variability-induced photocentre motion dominates the orbital motion, we derived a new VIM solution using a linear change of the position angle during the mission duration. The parallax in this case is 18.52 ± 8.61 mas, which confirms that the derived value depends critically on the assumed astrometric model.
2. We then tried to obtain a new astrometric solution by assuming that the observed motion is orbital, i.e., by neglecting the variability-induced photocentre motion. In support of this procedure, one can argue that the H_p magnitude should always be dominated by the primary, since the contrast between the two components ranges from 3.4 in the HST F439W B-like filter to 1.9 in the HST F555W V-like filter, and the primary is also the most active component, as discussed above. We thus used the (admittedly preliminary) orbital parameters determined by Thiébaut et al. (1995) to compute a new astrometric solution, and found a parallax value of 14.06 ± 9.06 mas.

Obviously, a solution combining both orbital motion and VIM is necessary for this object, but this is impossible without more precise information, notably about the orbital parameters. None of the above derived parallaxes is significant, and the published parallax should obviously be considered with caution. Can we conclude that a location of DF Tau outside of the Taurus cloud is ruled out by our analysis? Not definitely. We have merely shown that the derived parallax in the Hipparcos Catalogue is probably not significant, and that its standard error is so large that DF Tau's weight in mean parallax derivations is very low. The only firm conclusion that we can draw is that, as a group including DF Tau, the TTSs associated with Taurus are indeed located at the cloud's distance; as for DF Tau, its location remains uncertain.

4.1.4. UX Tau A

Prior to Hipparcos launch, this object was a known triple system (1979). UX Tau A and B components are WTTSs, while UX Tau C is a low-mass object with Hα emission. The astrometric companion found by Hipparcos is most likely the B component. Table 8 summarizes the current position angles and separations of components B and C with respect to A.

Table 8. The triple system UX Tau

UX Tau	p.a. (°)	ρ (")
B	269	5.9
C	181	2.7

4.1.5. UX Ori

Binarity of this star was first detected by Hipparcos. The small minimum separation found in this VIM solution may explain why this star has not been detected in IR with the shift-and-add technique (Pirzkal et al. 1997). It has been argued that the observed variability of this star and of BF Ori (also suspected of binarity by Hipparcos) is due to violent comet-like activity (Grinin et al. 1994, de Winter et al. 1999).

4.1.6. Z CMa

This star was already known as a binary with position angle around $120°$ and separation 100 mas (Koresko et al. 1991, Leinert et al. 1997). The Hipparcos solution is in agreement with these solutions. In the optical range, the variable component is the primary.

4.1.7. IX Oph

The evolutionary status of this F star is not entirely clear, and it appears to have attracted little observational attention so far. The detection by Hipparcos of its binary nature is a new development. An improved VIM solution gives a position angle $243 \pm 10°$ and minimum separation of 46.84 mas.

4.1.8. V1685 Cyg

Although the minimum separation, according to Hipparcos, is rather large, the binarity of this Herbig B2,3e star was detected neither in high angular resolution IR observations (Pirzkal et al. 1997), nor by speckle-interferometry (Leinert et al. 1997). However, the region around this star is a small stellar cluster with a molecular outflow oriented north-south (Palla et al. 1995), with V1318 Cyg and V1686 Cyg located south of BD +40 4124, which could explain why a VIM solution was found with a position angle $20 \pm 11°$.

4.2. Component solutions

4.2.1. XY Per

This binary has a 1.331 ± 0.01 arcsec separation, 76.3° position angle with 0.88 H_p magnitude difference. This is consistent with the results of Pirzkal et al. (1997), who find respectively 1.2 arcsec and 255°. Hipparcos thus resolves the 180° ambiguity noted in Pirzkal et al. (1997) and caused by the nearly equal brightness of the components.

4.2.2. NX Pup

This is a HAeBe star whose binary nature was discovered with the HST Fine Guidance Sensor giving $\rho = 0.126 \pm 0.007$ arcsec, $\theta = 63.4 \pm 1.0$, with a 0.64 ± 0.07 magnitude difference (Bernacca et al. 1993). Hipparcos found consistent but less precise estimations, respectively 0.140 ± 0.026 arcsec, $\theta = 74°$, and $\Delta H_p = 0.44 \pm 1.10$ mag.

4.2.3. CV Cha

CV Cha and CW Cha are the two components of an optical binary T Tauri system with separation equal to 11.4 arcsec and p.a. $105°$ (Reipurth & Zinnecker 1993). HIP 54744 is identified as CCDM J11125-7644A in SIMBAD, while HIP 54738 is identified as CCDM J11125-7644B. The component solution derived in the Hipparcos Catalogue gives a separation equal to 8.48 arcsec and a position angle of $275°$. The solution quality is given as poor (‘C’), and the Hipparcos solution is not consistent with the images obtained by Reipurth & Zinnecker (1993). However, we note that the Hipparcos-derived position angle would be consistent with observations, if HIP 54738 were in fact CV Cha and if HIP 54744 were CW Cha. Given the weakness of CW Cha, the separation derived by Hipparcos is likely to be inaccurate. As discussed also in Sect. 2, we conclude that there is a misidentification in the Hipparcos Catalogue, and we believe that HIP 54738 = CCDM J11125 -7644A = CV Cha, while HIP 54744 = CCDM J11125 -7644B = CW Cha. A single star astrometric solution for CV Cha gives the following results: $\pi = 7.60 \pm 2.10$ mas, $\mu_\alpha \cos\delta = -21.00 \pm 2.19$ mas/yr, and $\mu_\delta = 0.38 \pm 1.94$ mas/yr (Falin, priv. comm.). Results given for HIP 54744 in the Hipparcos Catalogue should be discarded.

4.2.4. FK Ser

This visual binary was found by Herbig to be a possible post-T Tauri system (Herbig 1973). Hipparcos measured a separation of 1.118 ± 0.025 arcsec, and the position angle of the secondary is 14°. These values can be compared to those given by Herbig for the date 1972.5: separation of 1.32 arcsec, p.a. 11.5°.

4.3. Acceleration solutions

An acceleration solution, using either a quadratic or cubic motion with respect to time, was applied to all stars not having a ‘component solution’, and only the stars with significant nonlinear terms were retained. The acceleration effect may be interpreted as the signature of binaries with an intermediate period (more than about 10 years).

4.3.1. CO Ori

This star has been detected as a binary by Reipurth & Zinnecker (1993), who mention a 280° position angle and 2.0 arcsec separation. Given the distance of Orion and the very long period, it is unlikely that the acceleration term may be significant, so that the detected variation of the photocentre with time is probably an artifact due to the configuration of the system and the scanning law of the satellite.

If a stochastic solution (see below) is applied instead of an acceleration solution, the cosmic error is 4.31 ± 1.34 mas, i.e., with the same significance as a Gaussian 2σ level. From this cosmic error a magnitude difference $\Delta H_p = 3.19 \pm 0.3$ mag is estimated, consistent with the 0.07 flux ratio in the Gunn z band. If a VIM solution is computed, the astrometric elements of the

Table 9. The triple system RW Aur

RW Aur	p.a. (°)	ρ (”)
B (wrt A)	255	1.417
C (wrt B)	111	0.120

VIM motion are not significant at more than a 1σ level, but it should be noticed that the position angle found, $301 \pm 30°$, is also consistent with the Reipurth & Zinnecker 1993 observation.

4.3.2. AB Dor

The combination of Hipparcos and VLBI data allowed the determination of a dynamical mass of about 0.09 solar mass for the low-mass companion of this ZAMS star (Guirado et al. 1997). The Hipparcos data cover only a small fraction of the period, but the curvature of the photocentre motion was nevertheless clearly detected.

4.4. Stochastic solutions

These solutions were applied as a last resort during the Hipparcos data reduction, when all other solutions failed to give an adequate astrometric fit. A so-called cosmic error ϵ was added to the abscissae standard error, representing the unmodelled photocentre variations. Although the photocentre displacement may be due to short-period astrometric binaries (e.g. HIP 39903, Arenou 1998), it may also be caused by undetected long-period binaries, with separation of a few arcseconds. It may also be that a stochastic solution simply reflects bad abscissae measurements, without any binarity indication.

For resolved binary systems, there is a correlation – depending weakly on separation – between the magnitude difference of the two components ΔH_p and the cosmic error ϵ that would result if a stochastic solution was computed instead of a component solution (Arenou 1997). Using all Hipparcos component solutions with separation, e.g., between 1.3 and 1.5 arcsec, the magnitude difference ΔH_p can be calibrated against the cosmic error ϵ, leading to

$$\Delta H_p \approx (-0.90 \pm 0.01) \ln \epsilon + 4.50 \pm 0.04$$

This relationship allows us to estimate the magnitude difference between components when Hipparcos does not resolve a binary system.

4.4.1. RW Aur

This is a triple star (Table 9; cf. Ghez et al. 1997a) with the A component separated by 1.4 arcsec from the BC binary (0.12 arcsec separation), which probably perturbed the Hipparcos observations.

No significant VIM solution can be found, but it is sufficient to reject the bad abscissae to obtain a better astrometric solution $\pi = 7.98 \pm 3.15$ mas, $\mu_{\alpha*} = 3.26 \pm 3.44$ and $\mu_\delta = -23.03 \pm 2.00$ mas/y. This justifies the use of this star for computing a mean distance of the Taurus-Auriga region. Estimated magnitude difference between BC and A is $\Delta H_p = 2.08 \pm 0.07$ mag, not far from the 2.3 ± 0.08 bolometric magnitude difference given by Ghez et al. (1997a).

4.4.2. DI Cha

Although the binarity of this object is not detected, e.g., in the infrared DENIS survey (Cambrésy et al. 1998), it is clear from Reipurth & Zinnecker (1993), Chelli et al. (1995), and Ghez et al. (1997b) that this is a binary of separation 4.9 ± 0.3 arcsec and position angle $202 \pm 3°$.

However, the binarity has probably not perturbed the Hipparcos astrometry too much. Indeed, if this star was reduced as a single star, its parallax would be 5.16 ± 1.54 mas, close to the stochastic solution, although with a 1.21 normalized χ^2.

Using the same method as above, the calibrated relation between cosmic error and magnitude difference is also valid for separation between 4 and 6 arcsec, so that the magnitude difference for DI Cha components is $\Delta H_p = 2.54 \pm 0.09$ mag. Note that the primary is redder than the secondary with a difference of about 4 mag in the K band (Chelli et al. 1995).

4.4.3. R CrA

The Corona Australis molecular complex is at a distance of about 130 pc (Marraco & Rydgren 1981), which is corroborated by the parallax 7.35 ± 1.15 mas of HD 176386 (HIP 93425). R CrA is surrounded by several other YSOs (Wilking et al. 1997), which probably explains why the Hipparcos observations have been perturbed, leading to a stochastic solution. Although the error bar on the parallax prevents any safe distance to be derived, it is clear that the Hipparcos astrometric solution for this star should be completely discarded.

Once a VIM solution was attempted, the parallax shifted from 121 ± 68.24 to 36.7 ± 91 mas. Even constraining the parallax to the expected parallax of Corona Australis does not give a satisfactory solution (in the sense of obtaining significant values of astrometric or orbital parameters). We conclude that the astrometric intermediate data are clearly useless for this star.

4.5. Other astrometric solutions

4.5.1. V410 Tau

This is a triple system (Table 10, Ghez et al. 1997a), undetected by Hipparcos, apart from the ‘suspected non-single’ flag in the Hipparcos Catalogue H61 field. The AB pair is not resolved by the HST either (Ghez et al. 1997a). There is no evidence in the Hipparcos astrometric intermediate data that a double solution can be obtained, and the published solution cannot be improved.

4.5.2. BP Tau

This is one of the few objects in Table 1 that Hipparcos did not flag as a suspected binary star. That it is single down to 0.01 arcsec is further confirmed by HST observations (Bernacca et al. 1995). Closer binarity would obviously not be detected by Hipparcos, and we can rule out variability-induced motions of the photocentre to explain the parallax found in the standard data reduction. An undetected orbital motion cannot be an explanation either, although a one-year orbital period would obviously result in a confusion between the orbital and the parallactic motion. We checked that this assumption would imply unreasonably large masses (on the order of $15\mathrm{M}_\odot$) for the two components.

Because the star is apparently single, we cannot dismiss BP Tau's apparent parallax easily. We do not believe, however, that it should be taken at face value for the following reason. The solution published in the Hipparcos Catalogue represents the best astrometric fit with normalized χ^2 equal to 1.1. If we now compute a solution where we constrain the parallax to be that of the Taurus stars, we get a fit with normalized χ^2 equal to 1.2. In other words, the solution is only marginally worse than the published solution, and a true parallax at 2σ from the published parallax is not unlikely. Also, one should note that the star, although it would be located in front of the Taurus group if the Hipparcos parallax were correct, has the same proper motion as confirmed members of the Taurus SFR. This casts additional doubt on the published parallax value.

Assuming for the moment that the Hipparcos parallax is correct, is it plausible that the current location of BP Tau could be explained by its relatively large heliocentric radial velocity, $14.0 \pm 3.0\,\mathrm{km\,s^{-1}}$ (Barbier-Brossat & Figon 1999)? This velocity translates to a LSR velocity of about +5 km s^{-1}. Given the LSR radial velocity of the local molecular cloud of +7.1 km s^{-1} (Herbig 1977), the radial velocity of BP Tau with respect to the cloud is about -2 km s^{-1}. The radial displacement of the star in its estimated lifetime of 1 Myr (Siess et al. 1999) is thus about 2 pc. This is obviously not consistent with location of BP Tau in the molecular cloud at birth.

There is no obvious reason to dismiss the Hipparcos parallax for this star, but conversely, there is no strong reason to believe it either; the large statistical error on the result precludes a firm conclusion. The reason for this large error is not obvious either. Most likely, the culprits are the faintness of BP Tau and its intrinsic variability. As in the case of DF Tau, the conclusion is somewhat frustrating, as no clear-cut answer can be given to the question of these stars' distance. A major conclusion that was drawn, however, is worth being repeated here: whereas distances of individual TTSs must be viewed with caution, the distance of Taurus TTSs *as a group* is entirely consistent with the molecular cloud distance.

4.5.3. GW Ori

One of the brightest CTTSs, GW Ori was found to be a single-lined spectroscopic binary by Mathieu et al. (1991), who give its orbital parameters. Because of the large distance of this star, the astrometric perturbation due to orbital motion (reflex motion ≈ 0.5 mas) is too small for Hipparcos to detect it.

Table 10. The triple system V410 Tau

V410 Tau	p.a. (°)	ρ (")
B	182	0.074
C	132	0.287

4.5.4. AK Sco

This is a SB2 system with well-defined orbital parameters (cf. Andersen et al. 1989). Unfortunately, the two components have nearly equal masses and luminosities, so that the photocentre orbital motion is not significant, precluding a computation of the other orbital elements from Hipparcos data.

4.6. Conclusion

Astrometry turned out to be a powerful tool for detecting the binarity of variable stars using the variability-induced motion of the photocentre (Wielen 1996). In spite of the limitations of the method, which must assume that only one component is variable and neglects all other causes of photocentre motions, the binary parameters derived for VIM systems are in remarkable agreement with other observations. VIM detection of the RY Tau binarity is a long awaited, but somewhat unexpected result of the Hipparcos mission.

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