Problems of Using Hipparcos Astrometry of Double Stars

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Abstract. The current optical realization of the International Celestial Reference System is the Hipparcos main catalog in its entirety. This paper demonstrates that a subset of the main catalog stars — specifically those marked as double ("C" stars), acceleration solution ("G"), variability induced movers ("V"), and stochastic solution stars ("X") — is of much lower quality than the majority of the catalog. Stars marked as suspected doubles ("S") were investigated and found to show few problems. The authors have put forth a resolution (Resolution 2, this conference) to remove the C, G, V, and X stars, in addition to the Hipparcos orbit stars ("O stars"), from the optical realization of the reference frame.

1. Introduction

IAU resolution B2 of the XXIII General Assembly (IAU 1998) specifies that the Hipparcos Catalog (ESA, 1997) is the optical realization of the ICRS. However, this includes a class of stars — those in multiple systems — having a significantly lower quality of proper motions on average than the majority of stars in Hipparcos.

In the following sections, the internal standard errors of the Hipparcos Catalog are utilized to show a clear difference between those stars believed to be single and those that are not. Additionally, comparisons utilizing the recently released Tycho-2 Catalogue (Høg *et al.*, 2000) show that the standard errors for the double stars may be underestimated by as much as 30%.

With these results, the authors propose to amend resolution B2 to eliminate known multiple systems and problem stars from the optical realization of the ICRS. The numbers of stars in each category are:

type	*H59 code (MultFlag)*	*number of stars*
All stars w/ astrometry	all	117,955
Suspected doubles	S (H61)	7,624
Double	C	13,211
Problem	G,V,X,O	4706

2. Data Utilized

In the following comparisons, those stars identified in both the Hipparcos main catalog and Tycho-2 catalog were used. Note that stars only appearing in the

Hipparcos annexes were excluded, as they are not covered by the IAU resolution. Additionally, stars in Tycho-2 whose proper motions were from photocenter data (blended images) were rejected. No stars identified as orbit stars in Hipparcos were included. The following table gives the number of stars used in the following comparisons. Note that Hipparcos observed a significantly higher number of double stars than are used in these comparisons. The greater resolution of the Hipparcos instrument over that of Tycho and the ground-based data used in the Tycho-2 proper motions resulted in many close doubles being photocenters in the Tycho-2 catalog. These are not included in the comparisons.

type	*H59 code (MultFlag)*	*number of stars*	$< B_T >$
Single stars	no code	92,316 stars	9.2 mag
Suspected doubles	S (H61), non-X	6556 stars	9.9 mag
Double stars	C	6707 stars	9.3 mag
Other problem stars	G, V, or X	4177 stars	9.4 mag

3. Comparisons

Hipparcos Quoted Errors For the four groups of stars (single, suspected double, double, problem), histograms of the Hipparcos proper motion errors have been plotted in Figure 1. Note that these are taken directly from the Hipparcos catalog; no external data are utilized. Clearly, there is a marked difference in precision between the single and suspected double stars versus the non-single stars.

Comparisons of Hipparcos Proper Motions with Tycho-2 For the four groups of stars (single, suspected double, double, problem), histograms of the differences between the Hipparcos proper motions and those of Tycho-2 have been plotted, as shown in Figure 2. Not surprisingly, the differences are much larger for the double and problem stars than for the single and suspected double stars.

For both the double and problem stars, significant portions of the data extend beyond the area covered by the graph. These amounts are displayed in the bars to the extreme right and left in the plots.

Comparisons of Hipparcos Proper Motion errors with those of Tycho-2 There is a clear difference between the internal errors quoted in Hipparcos for the single and the S stars versus the C, G, V, and X stars. An evaluation of the under- or over-estimation of those errors is warranted. Utilizing a technique recently used by Hoogerwerf & Blaauw (2000), we have compared the errors in proper motion of Hipparcos and Tycho-2 for the four groups.

To compare the errors, a normalized proper motion difference for each coordinate for each star in computed. This difference, Δ, is defined as:

$$\Delta = \frac{\mu_H - \mu_T}{\sqrt{\sigma^2_{\mu_H} + \sigma^2_{\mu_T}}}, \tag{1}$$

where μ_H and μ_T are the proper motions in Hipparcos and Tycho-2, and σ_{μ_H} and σ_{μ_T} are the errors in proper motion quoted in the two catalogs.

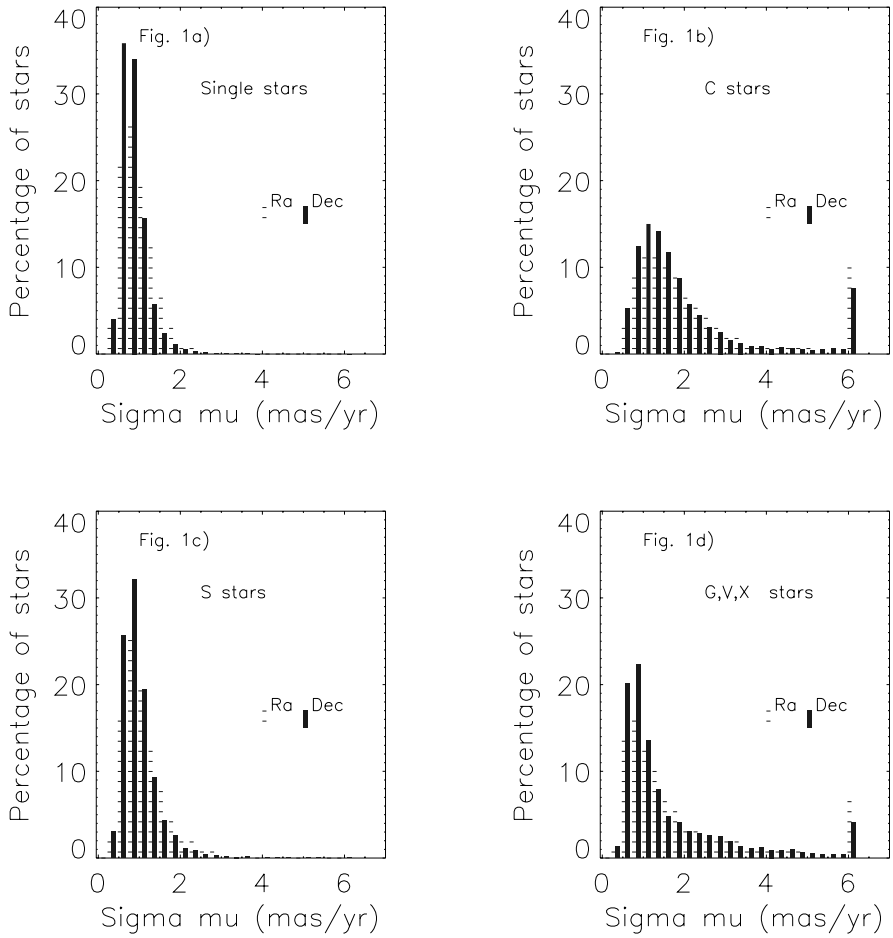

Figure 1. Percentage of stars by quoted Hipparcos standard error.

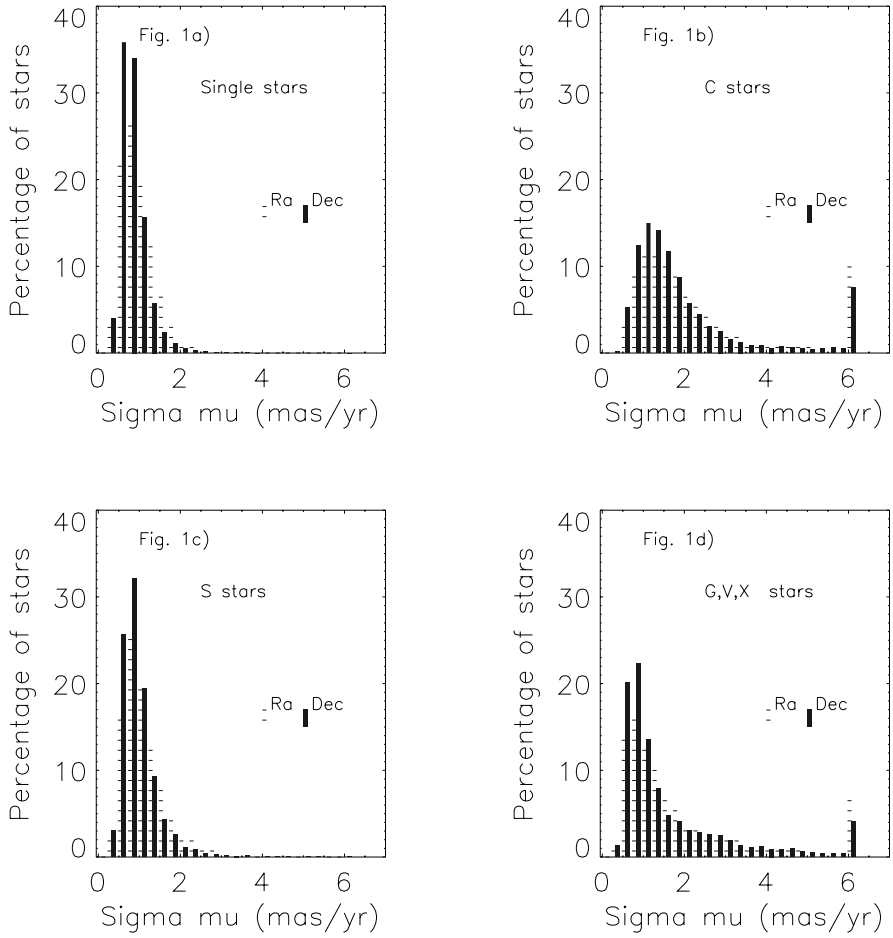

Figure 2. Difference between Hipparcos and Tycho-2 proper motions. Note the large wings on the double and G, V, and X stars.

Define $F_H(\mu_H)$ which gives the probability of observing proper motion μ_H when the real proper motion is $\hat{\mu}_H$, and the real proper motion error is $\hat{\sigma}_{\mu_H}$. A similar function is defined for the Tycho-2 proper motions and errors.

Assuming that the two catalogs are independent, the mean of Δ should be zero, because

$$\overline{\Delta} = E(\Delta) = \frac{\hat{\mu}_H - \hat{\mu}_T}{\sqrt{\sigma^2_{\mu_H} + \sigma^2_{\mu_T}}}, \tag{2}$$

and $\hat{\mu}_H = \hat{\mu}_T$ since they are defined as the real proper motion of the same star. The variance of Δ is

$$\sigma^2_\Delta = E([\Delta - E(\Delta)]^2) = \frac{\hat{\sigma}^2_{\mu_H} + \hat{\sigma}^2_{\mu_T}}{\sigma^2_{\mu_H} + \sigma^2_{\mu_T}}. \tag{3}$$

If the quoted standard deviations are correct, then σ_Δ, should be unity.

The value of σ_Δ can be below 1.0 if the catalogs are correlated or the errors in one or both catalogs are over-estimated. Similarly, σ_Δ will be above 1.0 if one or both of the catalog errors are under-estimated.

σ_Δ	reasons
Less than 1.0	catalogs correlated
Less than 1.0	quoted errors over-estimated
Greater than 1.0	quoted errors under-estimated

4. Discussion

The following table shows the standard deviations of the normalized differences for each of the four groups of Hipparcos stars as compared with Tycho-2. A three sigma outlier removal was made.

type	σ_Δ
Single	0.91
Suspected double; S	1.00
Double; C	1.54
Problem; G, V, and X	2.01

The single stars have a standard deviation below one, most likely due to the two catalogs not being truly independent. (This correlation is a result of utilizing the Hipparcos data to reduce all of the catalogs used to compute the Tycho-2 proper motions.) The suspected doubles have a standard deviation of one, indicating a non-significant underestimation of errors. Both the doubles and the G, V, and X group show that either Hipparcos, Tycho-2, or both catalogs' proper motion errors are underestimated for the non-single stars. The combined underestimation is significant; values of 50% for the C stars and 100% for the G,V, and X stars are indicated (and this does not account for the fact that the Tycho-2 and Hipparcos catalogs are correlated, which should lower the standard deviation).

It is impossible to tell if only one of the catalogs is to blame. When selected double stars are used, as shown in the table below, the underestimation factor is still large. It is suspected that the contributions to the underestimation of the errors are probably not due to one class of star, nor are they from only one of the catalogs.

Some causes can be assumed. With better *a priori* information, Falin & Mignard (1999), Söderhjelm (1999), and Fabricius & Makarov (2000) have all recently re-analyzed some Hipparcos double stars, quite often changing the proper motions by over 100 mas/yr. It is also known that for stars with orbital periods of a few decades, the 3.5-year observing span of Hipparcos is insufficient in duration to adequately separate proper motion from that of orbital motion. Additionally, astrometry from transit circles and photographic plates becomes very questionable for double stars with separations of a few arcseconds and smaller.

It is the authors' intention to continue this investigation to try to uncover some of the reasons for these results. However, in view of these results and those shown in Figure 1, there is no question that the representation of the optical reference frame is best made by avoiding the non-single stars.

Selected double stars The following table shows the standard deviations for the normalized differences of selected groups of Hipparcos double (C) stars. As stated earlier, if quoted errors in Hipparcos and Tycho-2 are correct, the standard deviation should be 1.0. The amount above 1.0 is the underestimation factor. These values are computed after a removal of outliers at the 3 σ level. The last line in the table gives the most selective group, that is stars that should have few problems in either Tycho-2 or Hipparcos. All stars have 5 or more positions going into the Tycho-2 motions, are in widely separated pairs, and have low quoted errors in both catalogs. Even so, underestimation in one or both of the catalogs amounts to nearly 30%.

Catalog positions used in Tycho-2	*Separation of components*	*limits on errors* (mas/yr)	# stars	σ_Δ	σ^2_Δ
5 or more	all	none	4637	1.44	2.00
5 or more	> 5.0	none	1692	1.35	1.82
5 or more	> 5.0	2.5(H) 3.5(T)	1195	1.27	1.62

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