HIPPARCOS EXTRAGALACTIC LINK: THE POTSDAM CONTRIBUTION

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ABSTRACT

The Potsdam group was involved in the link of the Hipparcos proper motion system to an extragalactic reference system. Absolute proper motions were derived from measurements of photographic plates taken mainly with the Tautenburg Schmidt telescope (134/200/400 cm). In 24 fields included in different Potsdam proper motion programmes and well distributed over the northern sky, 360 Hipparcos stars were measured. In each field of about 10 square degrees a large number of galaxies was used for the link. Detailed investigations showed that the proper motion determination of bright stars is affected by systematic magnitude dependent errors. Therefore, only the 256 stars with $B \geq 9.0$ were used to determine the spin parameters of the Hipparcos system. The accuracy of our final results is 0.5 mas/yr for all three spin parameters. The results are in good agreement with the VLBI link parameters and the synthesized solution by Kovalevsky et al. (1997).

Key words: Hipparcos; galaxies; extragalactic link.

1. INTRODUCTION

The ESA satellite Hipparcos measured positions, proper motions and parallaxes of more than 100 000 stars in a homogeneous system with a high internal accuracy. Nevertheless, the Hipparcos reference frame needed a link with regard to an inertial system. There are different methods to link the Hipparcos reference frame to extragalactic objects (Lindegren & Kovalevsky 1995). One possibility is to use photographic astrometry with deep Schmidt plates.

24 fields with Tautenburg Schmidt plates (see Figure 1) from different Potsdam proper motion programmes were selected for the Hipparcos link. The sample of Hipparcos link fields consists of 7 fields from the MEGA programme (Schilbach 1988), 7 fields with globular clusters and 9 other fields with a sufficient number of galaxies as reference points. The results for one field (3c345) were kindly provided by Tucholke (1995) who also used deep Tautenburg plates. Each link field covers about 10 square degrees.

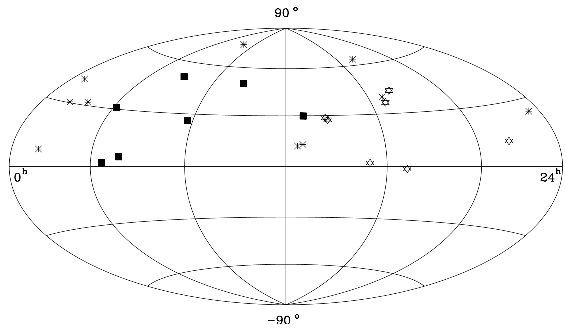

Figure 1. Distribution of the link fields in equatorial coordinates. Filled squares: MEGA fields, stars: globular cluster fields, asterisks: other fields.

2. DETERMINATION OF ABSOLUTE PROPER MOTIONS

For the Potsdam programme of linking the proper motions of the provisional Hipparcos catalogue H37cr to an extragalactic reference system we used exclusively deep Schmidt plates (Table 1). The majority of the Schmidt plates were fully scanned by the automated measuring machines APM (Kibblewhite et al. 1984) at Cambridge, MAMA (Guibert 1983) at Paris and PDS (Horstmann et al. 1989) at Münster.

For most of the link fields two plate pairs, i.e. two first epoch plates and two second epoch plates were measured. For details on the reduction within the MEGA programme, see Schilbach & Scholz (1991) and Kharchenko et al. (1994). The reduction of the globular cluster fields is described in Scholz et al. (1994, 1996a, 1996b). The proper motion determination in all these fields was based on independent plate-to-plate solutions using polynomials of up to fourth order (according to the number of reference objects used) and the method of stepwise regression of Hirte et al. (1990).

With epoch differences of about 20 to 40 years an internal accuracy of 3 to 5 mas/yr was achieved for undisturbed (by overlapping images) and relatively faint ($B > 9$) Hipparcos stars. From 664 Hipparcos stars in all 24 fields H37cr data of 610 (92 per cent) stars were provided for the link. From all measured H37cr stars we excluded those stars which showed large errors in their proper motions because of bad

Table 1. Link fields.

field	R.A.	Dec.	number of plates	measuring device	baseline [years]	number of galaxies	all Hipparcos stars	reliably measured H37cr stars	finally used stars ($B \geq 9$)
	J1991.25								
M31	10.7	40.9	8T	PARSEK	25	70	36	32	20
A193	21.4	7.9	4T	PDS	21	150	23	13	11
M33	23.1	30.4	4T	ASCORECORD	18	60	26	23	10
SNHoffm	37.2	31.6	4T	PDS	29	30	23	15	4
MEGA01	62.0	30.9	4T	MAMA	25	270	23	10	7
MEGA02	67.5	2.0	4T	MAMA	19	120	22	12	11
MEGA04	78.5	5.1	4T	MAMA	25	70	33	20	10
MEGA07	90.0	51.3	4T	MAMA	25	130	30	20	14
Mrk4	100.4	74.9	4T	PARSEK	22	100	33	17	10
MEGA10	116.6	26.1	4T	MAMA	24	30	15	10	5
MEGA11	144.9	49.7	4T	MAMA	19	190	32	15	13
Virgo2	186.9	12.0	4T	APM	25	540	21	11	8
Virgo3	190.2	12.9	4T	APM	24	680	32	10	10
MEGA14	191.3	29.9	4T	MAMA	25	600	30	18	14
M3-Z	205.5	28.6	53T	APM	30	1600	34	14	14
M3-IV	206.8	27.4	4T	APM	22	1050	32	6	6
M5	229.7	2.0	2P, 1UK, 5T	APM	38	1160	38	15	14
M13	250.4	36.6	4T	ASCORECORD	21	50	36	25	20
3C345	250.6	39.8	11T	PDS	20	120	28	17	16
M12	252.3	- 1.4	2P, 1UK, 2T	APM	43	1380	24	7	6
A2255	258.8	63.9	4T	PARSEK	18	190	25	14	7
M92	259.4	43.3	10T	APM	26	2300	27	7	7
M15	322.3	12.2	6T	APM	24	510	28	11	11
Mrk319	351.2	24.4	4T	PDS	21	50	28	21	11
total							664+	360*	256*

T - Tautenburg (134/200/400), P - Palomar (122/183/307), UK - AAO-Schmidt (120/180/306) plates
(In parentheses the aperture / diameter of the mirror / focal length are given in cm.)
+ there are 15 common stars in the overlapping field of M3-Z and M3-IV, * 3 stars were measured in M3-Z and M3-IV

measurements or non-stellar image classification. 360 stars remained for the determination of the link.

Due to the large number of galaxies, the formal zero point error in a given field is usually less than 1 mas/yr. However, in a few fields with globular and open clusters systematic magnitude dependent errors in the proper motions were detected and removed (Scholz & Kharchenko 1994, Kharchenko & Schilbach 1995). In some of the link fields this kind of error was also found and corrected for. But it cannot always be detected so that on the average, residual systematic errors of about 2 mas/yr per field may be expected.

3. DETERMINATION OF THE SPIN PARAMETERS

The systematic part of the difference between the Hipparcos positions and positions in an inertial reference system can be described by a rotation. The differences in proper motions are represented by the spin, the time derivative of the rotation. Assuming $\Delta\mu_\alpha$ and $\Delta\mu_\delta$ are the proper motion differences in the sense Hipparcos minus absolute, α and δ are the equatorial coordinates of the link stars we used the following basic equations for the determination of the spin vector $\omega = (\omega_x, \omega_y, \omega_z)$:

$$\begin{aligned} \Delta\mu_\alpha \cos\delta &= -\omega_x \cos\alpha \sin\delta - \omega_y \sin\alpha \sin\delta + \omega_z \cos\delta \\ \Delta\mu_\delta &= +\omega_x \sin\alpha \qquad - \omega_y \cos\alpha \end{aligned}$$

The indices x to z refer to a right-handed triad with the x-axis pointing towards the vernal equinox and the z-axis towards the north equatorial pole. The $\omega_x, \omega_y, \omega_z$ were computed from both components of the proper motion differences, i.e. from the least-squares solution of $2n$ equations, where n is the number of link stars. This is called the 'star solution'.

The proper motion differences $\Delta\mu_\alpha \cos\delta, \Delta\mu_\delta$ in a given field may be correlated due to a systematic error of the extragalactic link in each field. Therefore, we used the average proper motion differences for each field in a second least-squares solution of $2m$ equations, where m is the number of link fields. This is called the 'field solution'. Both star and field solution should be identical if the stars are homogeneously distributed in the fields with the same weights and if the fields are homogeneously distributed over the sky. This is not the case, therefore the solutions will differ. Formally, the rms error of the star solution is smaller than that of the field solution because of the greater number of equations.

4. INVESTIGATION OF MAGNITUDE DEPENDENT ERRORS

Figure 2 and Figure 3 show the proper motion differences H37cr–absolute for all 360 selected Hipparcos stars before the determination of the spin parameters. The data were binned in five intervals, with 27, 77, 145, 84 and 26 (from bright to faint) stars, respectively.

There is a deviation of the mean differences H37cr–absolute from zero seen in Figure 2, and especially in

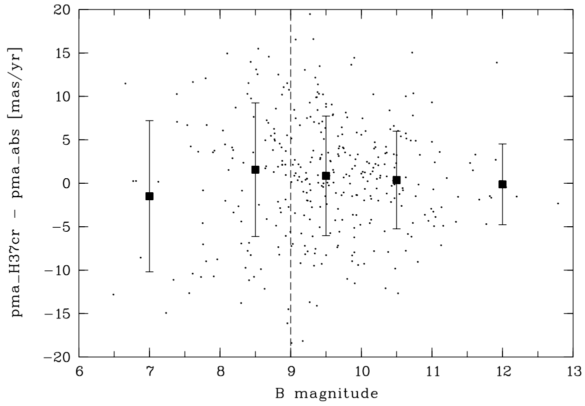

Figure 2. Proper motion differences H37cr–absolute in $\mu_\alpha cos\delta$ over the B magnitude. All 360 stars with reliable measurements are plotted. Filled squares with error bars show the mean differences and their dispersions in five intervals: $B < 8$, $8 \leq B < 9$, $9 \leq B < 10$, $10 \leq B < 11$ and $B \geq 11$. Only the stars on the right side of the dashed line ($B \geq 9$) were used in the final solution.

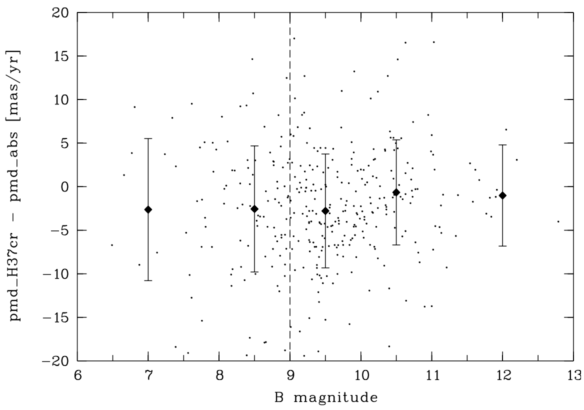

Figure 3. Same as Figure 2, but for proper motion differences μ_δ. Filled rhombs and error bars show the mean proper motion differences and their dispersions over the B magnitude.

Figure 3 for the bright stars. This possible systematic error in the obtained absolute proper motions of bright stars makes an exclusion of these stars from the final link plausible. A further argument for their exclusion is their non-uniform distribution over the link fields (compare the last two columns in Table 1) which may lead to systematic effect in the determination of the spin parameters.

For an investigation of magnitude dependent effects, the bright stars were successively omitted from the solution in steps of 0.1 mag (see Figure 4). Due to the relatively small number of bright stars (only 27 stars with $B < 8$), there are almost no changes in the left part of the diagrams in Figure 4. But from $B_{\text{limit}} = 8$ to $B_{\text{limit}} = 9$ a trend can be seen, i.e. the bright stars increase the values of ω_x and ω_y systematically. The number of stars per field (see lower right diagram of Figure 4) decreases rapidly for $B_{\text{limit}} > 9$.

Table 2. Residual spin parameters (mas/yr) referred to the final Hipparcos system (see Section 5).

star solution	field solution
$\Delta\omega_x = -0.22 \pm 0.52$	$\Delta\omega_x = -0.07 \pm 0.83$
$\Delta\omega_y = +0.43 \pm 0.50$	$\Delta\omega_y = +0.19 \pm 0.80$
$\Delta\omega_z = +0.13 \pm 0.48$	$\Delta\omega_z = +0.60 \pm 0.75$
rms of solution	
6.5 mas/yr	3.1 mas/yr
correlation coefficients	
$r_{xy} = +0.20$	$r_{xy} = +0.21$
$r_{xz} = -0.04$	$r_{xz} = -0.04$
$r_{yz} = -0.04$	$r_{yz} = -0.01$

From $B_{\text{limit}} \geq 9.4$ there are only one or no stars in some of the link fields, i.e. the solution becomes unstable. Therefore, the selected value $B_{\text{limit}} = 9.0$ represents a compromise between a sufficient number of stars (per link field) and a minimum influence of bright stars affected by larger (and possible systematic) proper motion errors. The final solution for the spin parameters was obtained with 256 stars with $B \geq 9.0$ distributed over 24 link fields. The minimum number of stars per field was 4.

The star solution and the field solution show the same behaviour in Figure 4 although the errors of the spin parameters from the field solution are larger. In every case, the star solution and the field solution agree within their errors (Table 2).

5. DISCUSSION OF THE RESULTS

All determinations of the spin parameters were carried out by the use of H37cr data. In order to express our results in the final Hipparcos system, we compared them with the composed solution of Kovalevsky et al. (1997) based on different programmes and techniques. In this synthesized solution the Potsdam star solution with 256 stars was included. The residual spin parameters of the Potsdam solution in the final Hipparcos system were obtained by subtracting the composed solution of Kovalevsky et al. (1997) from the Potsdam solution with H37cr. Table 3 from Kovalevsky et al. (1997) shows the residual spin parameters for the different programmes used in the synthesized solution. The high quality of the Potsdam contribution is underlined by its increased weight in the process of the synthesized solution by Kovalevsky et al. (1997) and the relatively small deviation from the VLBI data. From the comparison with the results presented in Kovalevsky et al. (1997) we may conclude that the small internal errors of the Potsdam spin parameters (≈ 0.5 mas/yr) correspond to the real errors.

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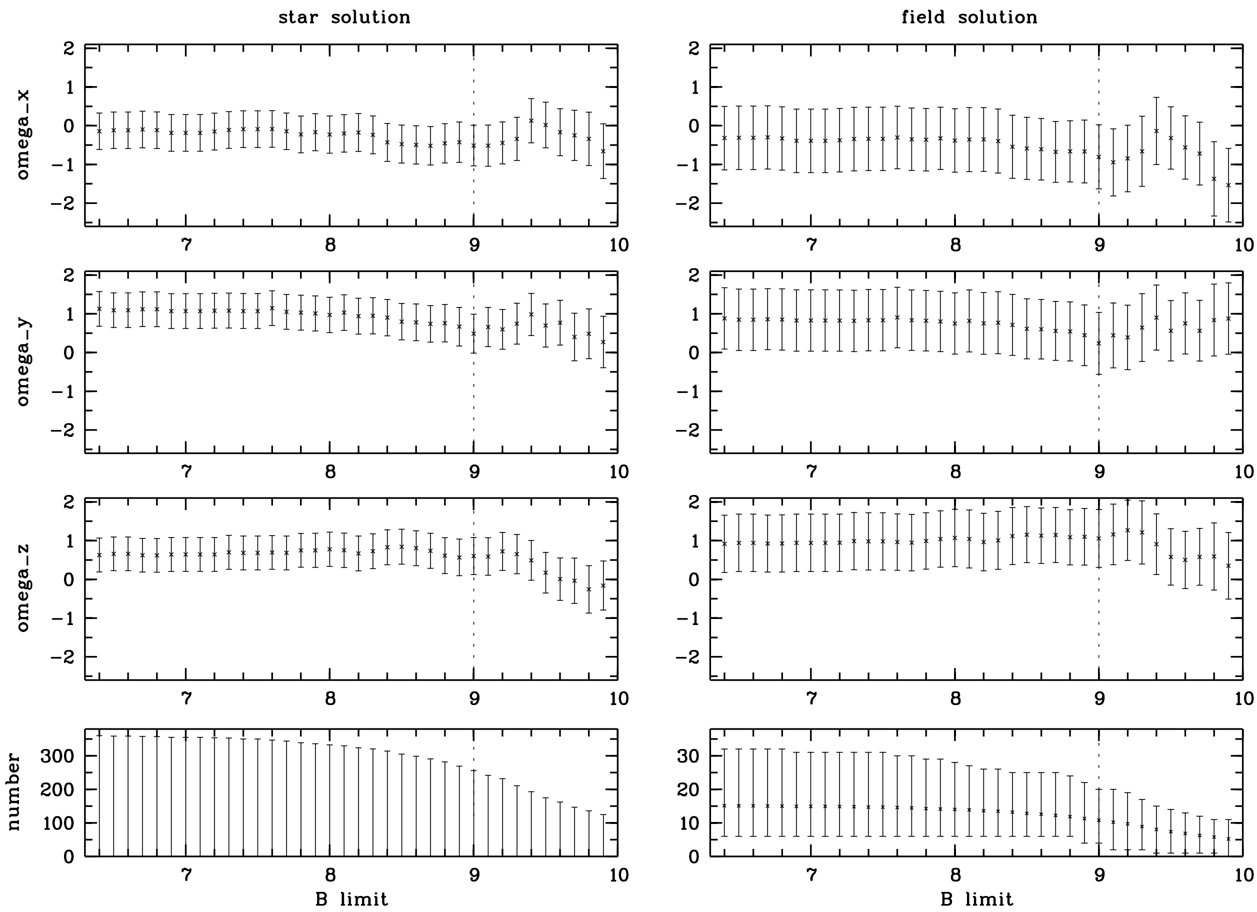

Figure 4. Values of ω computed from all stars with $B \geq B_{limit}$. The lower diagrams show the number of stars included (left), the range of the number of stars per field and as crosses the mean number over all fields (right).

(IoA, Cambridge), MAMA (Observatoire de Paris), PDS (University Münster), PARSEK (Main Astronomical Observatory of Ukrainian Academy of Sciences, Kiev) and ASCORECORD (Technical University Dresden) measuring machines. We thank H.-J. Tucholke for providing his results in the field of 3c345 for this work.

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