THE NPM AND SPM CONTRIBUTIONS TO THE HIPPARCOS PROPER-MOTION LINK

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ABSTRACT

We describe the use of the Lick Northern Proper Motion (NPM) program and its southern-sky complement, the Yale/San Juan Southern Proper Motion (SPM) program to determine the Hipparcos proper-motion link to the extragalactic reference system defined by galaxies. Particular attention is given to the presence of systematic errors in the NPM and SPM proper motions which bias the spin solutions.

Key words: space astrometry; Hipparcos; proper motions; extragalactic link; catalogues.

1. INTRODUCTION

The all-sky Lick Observatory Northern Proper Motion program (NPM) and Yale/San Juan Southern Proper Motion program (SPM) are ideally suited for the purpose of determining the Hipparcos proper-motion link. The Lick NPM1 Catalog (Klemola et al. 1994) contains a relatively small number of the Hipparcos Input Catalogue (HIC) (Turon et al. 1992) stars or about 18 per cent of the HIC stars at $\delta > -23°$. This incompleteness is compensated by an excellent sky coverage, from the North celestial pole down to $\delta = -23°$, except for the galactic zone of avoidance. In contrast, the Yale/San Juan SPM fields (as of February 1996) cover only about 2000 square degrees on the sky but include virtually all HIC stars (over 4000) in that area.

For the Hipparcos link these two programs furnished by far the largest number of link stars and were expected to dominate in the final spin solution (i.e. finding the rotation of the coordinate frame defined by the Hipparcos data). However, the presence of systematic errors somewhat undermined these expectations. An attempt is made to remove the magnitude equation in the SPM data, and, subsequently, its effect on the spin solution.

2. NPM LINK SOLUTION

The Lick NPM1 Catalog contains 13 455 Hipparcos stars. The typical accuracy of the NPM1 absolute proper motions is 5 mas yr^{-1} derived from a single pair of blue plates. In total ~9100 Hipparcos stars were chosen for the link solution. Another ~4000 Hipparcos stars from the Lick NPM1 Catalog were not used for the reason explained below.

The definition of the proper-motion link equation is given elsewhere (e.g. Lindegren & Kovalevsky 1995). In accordance with this equation, an arbitrary spin can be split into three orthogonal rotations about the X,Y,Z axes: ω_X (X-axis towards $\alpha = 0^h$, $\delta = 0°$), ω_Y (Y-axis towards $\alpha = 6^h$, $\delta = 0°$) and ω_Z (Z-axis towards $\delta = 90°$). Figure 1 shows residual rotations of various spin solutions relative to the adopted system of the Hipparcos proper motions. The Lick solution is labeled by NPM. It can be seen that there is a large net rotation in ω_Z which indicates the presence of systematic errors.

The search for a possible type of systematic error resulted in finding a significant magnitude equation in both coordinates (Figure 2). This is not surprising since possible systematic errors had been anticipated in the NPM proper motions for stars with $B < 11$. In addition, the NPM proper motions have significantly larger magnitude equation in μ_δ for bright stars with $\delta < -2.5°$. To minimize the negative impact of these stars on the link solution it was decided, for the time being, not to use these low declination stars if they are brighter than $B = 10$. (Kovalevsky et al. (1997) have experimented with varying magnitude cutoffs in their NPM spin solutions and find the results sensitive to the exact value of the cutoff.) It should be also mentioned that the Hipparcos proper-motion accuracy rapidly deteriorates beyond $B > 11$ which then requires a large number of link stars. It is unfortunate that more of the fainter stars originally proposed to link with the NPM were not included in the Hipparcos Input Catalogue.

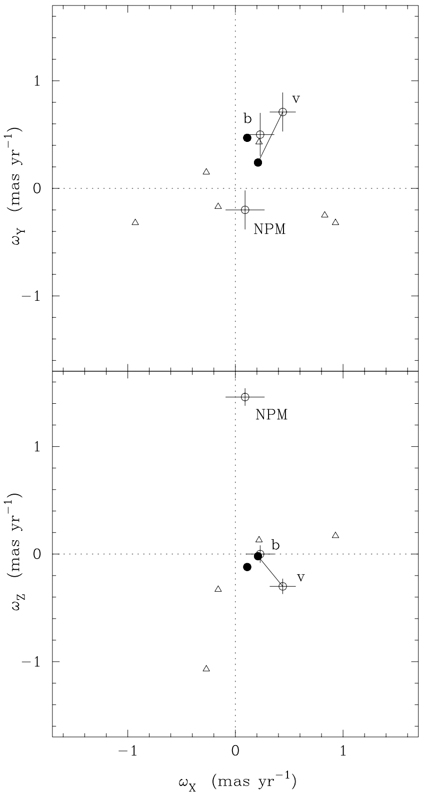

Figure 1. Spin solutions in (ω_X, ω_Y) and (ω_X, ω_Z) planes. Open circles are the adopted NPM and SPM (b – blue; v – visual) solutions. Error bars show the solution formal errors. Filled circles indicate the modified SPM solutions after an additional correction for the galaxy magnitude equation. For the sake of clarity, a line connects the 'old' and modified SPM$_v$ solutions. Triangles are other spin solutions from Kovalevsky et al. 1997.

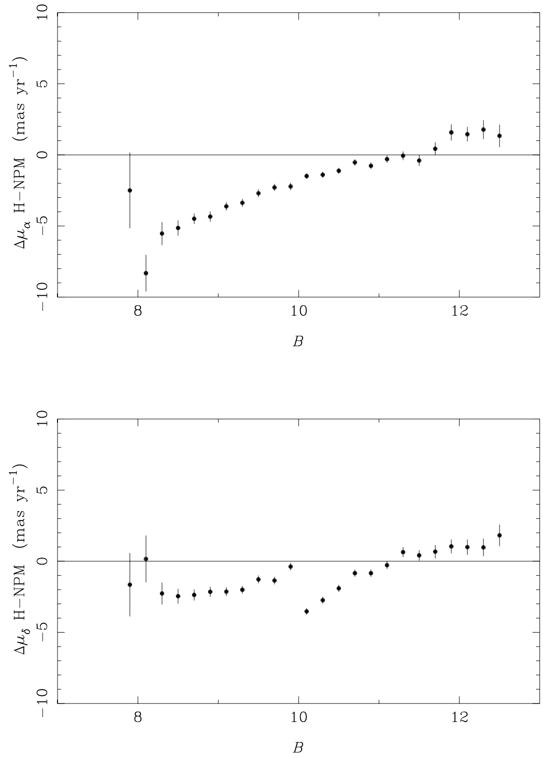

Figure 2. Binned Hipparcos (H) proper motions minus NPM as a function of B magnitude. Error bars represent error of the mean in each magnitude bin. The NPM proper motions have a more pronounced magnitude equation in μ_δ for bright stars with $\delta < -2.5°$ and, thus, these low declination stars have been excluded for $B < 10$. This explains the break in the $\Delta\mu_\delta$ plot at $B = 10$.

Note that a magnitude equation in right ascension produces a spurious rotation mainly appearing in ω_Z, exactly what we see in Figure 1.

One way of correcting the NPM proper motions would be to use some external catalog (like the PPM Star Catalogue) solely for the purpose of removing the magnitude equation for the stars with $B \leq 11$. While in principle this could be done, in practice no such catalogs are available. Even the most comprehensive PPM catalog is affected by a magnitude equation (Lindegren et al. 1995).

Whatever the cause of the magnitude equation for the bright stars (e.g. grating-image blending, instrumental effects, etc.), extensive tests have shown that the Lick NPM1 Catalog is systematic-error free for the stars with $B > 12$ mag on which the galactic structure and kinematic studies are based. The Lick astrometry group, however, intends to re-examine all brighter stars and the link problem as soon as the Hipparcos data are fully released.

3. YALE/SAN JUAN SPM LINK SOLUTION

The SPM program, though similar to the NPM, also has a few important differences, such as an additional visual plate-pair for astrometry, several measurable grating images for bright stars and a considerably larger number of program stars measured per field including all Hipparcos stars. For bright stars the proper-motion accuracy is about 2–3 mas yr^{-1}. Since the SPM is an ongoing project, only 4100 HIC stars were available (as of February 1996) for the Hipparcos proper-motion link.

The residual rotation in the SPM solutions can be seen in Figure 1, where 'b' denotes the officially adopted blue-plate-based solution and 'v' the visual plate solution. There is a clear net rotation in the SPM proper motions especially in ω_Y, well exceeding formal errors. As it follows, a likely explanation of this offset is again the magnitude equation.

From earlier studies we knew that the SPM positions and consequently the proper motions might have considerable magnitude equation changing from plate to plate (Platais et al. 1995). A procedure was developed to correct for the magnitude equation in the coordinates using the positional differences between the grating images (Girard et al. 1997). As a result, the SPM proper motions seem to be well corrected for the magnitude equation. The plots similar to Figure 2 show no trend with magnitude. However, a somewhat different picture emerges when examining the mean-per-field offsets 'Hipparcos-SPM'. The distribution of these offsets is not random. It turned out that there is a correlation between these offsets and the corrections applied for magnitude equation (Figure 3). A closer look at the offsets showed that the star-image positions have been corrected for magnitude equation adequately but this is not quite true for the reference galaxies. Thus, if the magnitude-equation corrections are not varying randomly from field to field (i.e. emulating noise) they might introduce bias in the proper motions and, consequently, in the spin solution. An aggravating factor for the spin solution is the rather scattered spatial distribution of the SPM fields (Kovalevsky et al. 1997).

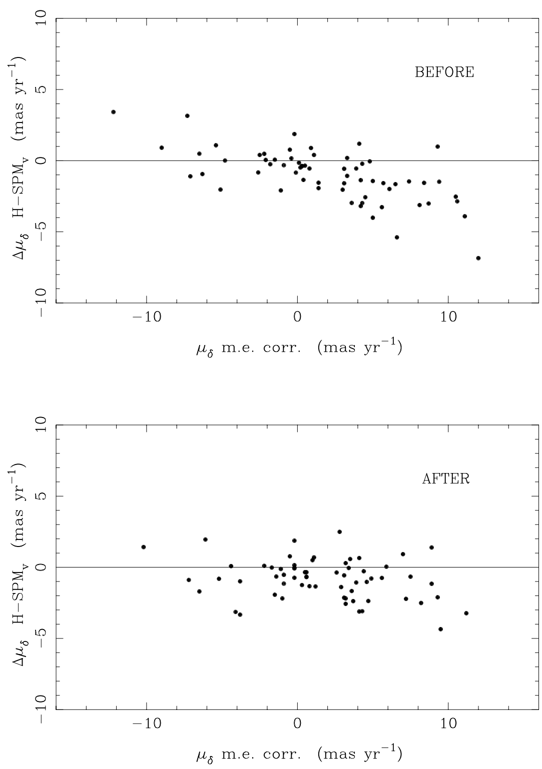

Figure 3. Hipparcos (H) proper motions minus SPM visual mean proper motions per field plotted as a function of the magnitude-equation corrections. The lower panel shows the improvement after the additional magnitude recalibration of galaxies.

These findings point to a very touchy issue: should the stars and galaxies be corrected for the magnitude equation similarly? It is well-known that the shapes of galaxies vary considerably and are non-stellar which makes the galaxy magnitude estimates (Platais et al. 1993), and similarly the magnitude-equation corrections somewhat dubious. It is nearly impossible to establish an independent magnitude equation for the galaxies due to much larger errors in their 'proper motions' and their short span of apparent magnitudes. This is why we apply the corrections, derived from the star images, to both stars and galaxies. Trial solutions applying no corrections to the galaxis lead to obviously poorer results.

Since the galaxy magnitudes are not reliable we may ask the legitimate question: what if we change them? Actually, this can be done empirically by minimizing trends in the differences in zero-point correction to absolute proper motions derived from the blue- and visual-plate pairs (Girard et al. 1997). This yields a correction to the galaxy magnitudes $\Delta m_g = -0.7$ mags. It means that all galaxies must be brightened by that amount *before* applying the magnitude equation correction. The positive effect of this procedure can be noticed in Figure 3. In addition, the residual rotation seen in Figure 1 is also smaller (denoted by filled circles).

4. IMPLICATIONS FOR THE LINK AND GALACTIC STRUCTURE STUDIES

It is fair to say that the magnitude equation has been haunting astrometrists since the beginning of time. In some special cases, for instance using star-cluster members, it is possible to eliminate the magnitude equation in relative proper motions, however, large surveys like the NPM and SPM do not have this advantage. The grating-image method can take out the bulk of the magnitude equation, although there can be a residual magnitude equation related to the galaxy appearance. If it were not for the Hipparcos data, we would not have detected this effect. In turn, for the sake of the Hipparcos proper-motion link, we still can correct the SPM proper motions *independently* and contribute to the link. The modified SPM link solution (using the data as of February 1996) indicates that the Hipparcos proper-motion system is rotating no more than $\sim$0.2 mas yr^{-1}. It is expected that upon completion of the SPM program the link solution can be improved by a factor of five in accuracy. Numerical values of the NPM and SPM spin solutions adopted in the Hipparcos proper-motion link to the extragalactic reference system and full analysis of the link are given in Kovalevsky et al. (1997) and Platais et al. (1997).

We expect that our experience will alert others to check for possible magnitude equations in all photographic surveys targeted towards galactic kinematic studies. Even a couple of mas yr^{-1} offset in the proper motions can do irreparable damage to Galaxy modeling and its reliability, especially for the fainter, more distant stars which are not covered by the Hipparcos mission.

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