Comparisons with Galaxy Models in the NGP Field

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Abstract. For the stellar data which we previously published in a field near the NGP, we revisit the limits on the systematic errors and report on new comparisons with the Besançon and IASG models.

1. Introduction

An investigation conducted in parallel with the construction of the second Guide Star Catalog (GSC–II; Lasker, et al. 1995) addresses galactic structure as determined from studies in the main meridional section of the Galaxy in the direction of the anticenter. Specifically, twelve fields have been selected for intensive study, with the goals being both the large scale parameterization of the Galaxy and the investigation of local structures.

The results from the first field, a 20 square degree area located near the NGP, have already been published (Spagna, et al. 1996, hereafter referenced as Paper I). This data is based on five plates (POSS–I, O and E, epoch circa 1950; Palomar Quick V, 1983; and POSS–II, J and F, 1990), with calibrations based on photometric CCD calibrations, with small-area ($\approx 1^\circ \times 1^\circ$) plate-to-plate astrometry for proper motion determinations, and with the proper motion zero points set by measurements of galaxies. The resultant catalogs contain 12708 photometric and 10230 astrometric measures of stars down to $V = 18.5$. In Paper I, these data were compared with that (in fields nearby) from other observers, ie., Stobie and Ishida (1987) and Soubiran (1992); and spatial and kinematical distributions of galactic stellar populations were studied in $(\mathbf{r}, \mathbf{v})$ space by means of photometric parallaxes.

The goals for this *Workshop* presentation are to elaborate on the control of systematic errors in that data set, particularly in the context of known microdensitometer properties, and to compare it to synthetic data from Galaxy models, specifically the Besançon model (Robin & Crézé 1986; Bienaymé, et al. 1987) and the IASG model (Ratnatunga, et al. 1989).

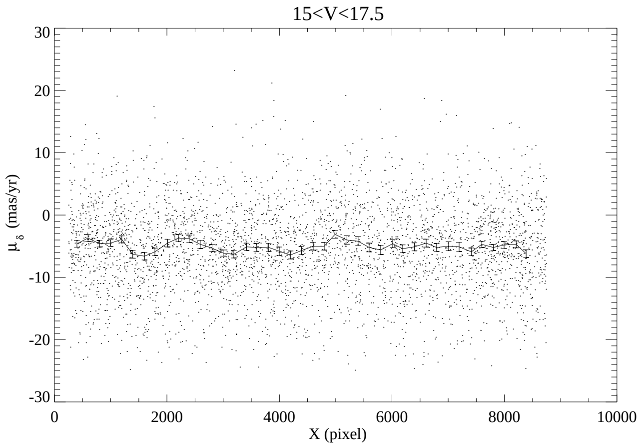

Figure 1. A plot of μ_δ against x for the NGP data from Paper I. The solid line, which gives the binned mean values and their errors, has a dispersion of about 1 mas yr^{-1}. The x scale is 1.7″ pixel^{-1}.

2. Control of Systematic Errors

In interpreting the astrophysical significance of our data, it is first appropriate to revisit the the matter of systematic errors and to report some studies done in conjunction with Paper I but not reported there.

We begin with the measuring process. Of particular interest is a well-known performance limitation of the microdensitometers (multi-channel laser-illuminated systems on a PDS mechanical substrate), ie., chopping[1]. This error, due to imperfect response in the servo system for the y (slow scan) axis, is generally a reproducible function of the x position. As such errors, propagated onto the corresponding plate axis, result primarily in a degradation in the measured declination, one searches for the effect in a plot of μ_δ against x (Figure 1). There the fluctuations are seen to be about $\sigma_\mu \sim 1.0$ mas (milli-arcsecond) yr^{-1}; and any effects due to chopping must be smaller than that.

If one assumes that the gradients in the proper motions within this small field are negligible, another, more global check on the quality of the proper motions is provided by examining the residuals with respect to the mean field proper motions. For 5918 stars in $15 < V < 18$, these data are given in Figure 2, which shows that the errors are small and randomly distributed. The scatter of these residuals is $\sigma_\mu \simeq 1.2$ mas yr^{-1} per component. As the proper motion scatter of the individual stars is about 10 mas yr^{-1} per component and as there are $n = 50 - 100$ stars in each area element of Figure 2, one would expect the dispersion among the cells to be about $\sigma_\mu/\sqrt{n} \sim 1 - 1.4$ mas yr^{-1}. Thus, statistical expectations are consistent with the measured scatter, and there is no evidence for a residual signal in the subfields.

Finally, it is important to examine the errors that may be introduced by plate measuring processes that have systematic offsets as a function of magnitude. Data for about 700 galaxies in our NGP field are plotted as a function of

[1]The underlying process is called *autolock* in PDS engineering circles.

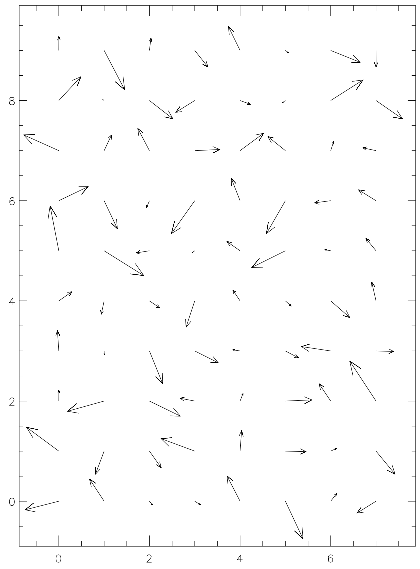

Figure 2. Vector residuals of μ_α versus μ_δ with the data binned into $0.5°$ cells over the $4° \times 5°$ NGP field. The longest vector corresponds to 2.8 mas yr^{-1}, and the σ are less than 1.5 mas yr^{-1} per axis.

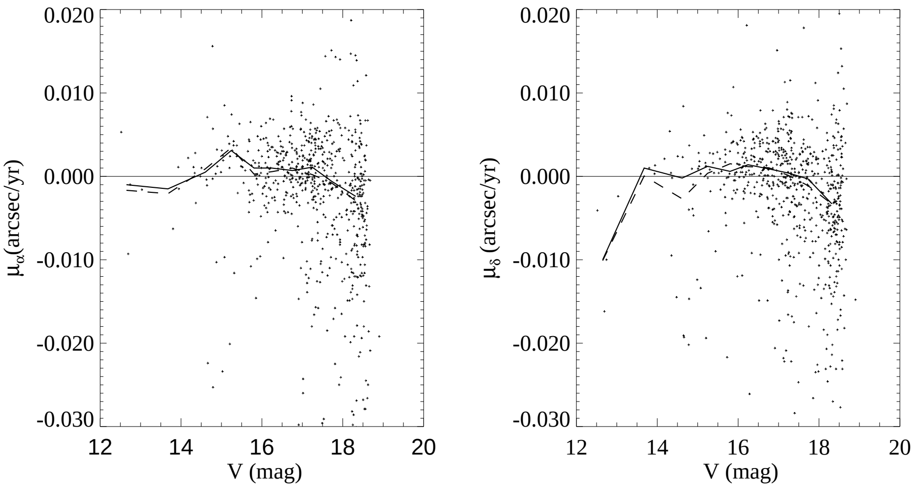

Figure 3. Proper motions as a function of magnitude for 700 galaxies in the NGP field. The solid line gives the means binned by magnitude (after rejecting outliers); and the dashed line, the medians.

magnitude in Figure 3. The result is virtually flat for $16 < V < 18$ and within 1 mas yr^{-1} of the expected zero value. One also notes that the objects outside this range are suspect because of centroiding issues on the brighter galaxies (ie., larger images) and because of contamination due to classification errors for the fainter ones (beyond $V \gtrsim 17$, many objects with large negative proper motions are surely stars).

While our interpretation of these plots must be moderated by two obvious caveats (1, the magnitudes are very rough because the photometric calibration, determined for stars, is not strictly applicable to galaxies; and 2, even for the small images that characterize this magnitude range, the image properties of galaxies and of stars differ), they do support the case that the proper motion zero point of the data is not a function of magnitude. Moreover, the positive offsets of the flat mean proper motion, $\Delta\mu_\alpha \simeq \Delta\mu_\delta \simeq 1$ mas yr^{-1}, provide an estimate for the accuracy of the absolute reference frame, which is affected by the star-galaxy misclassification.

In Paper I, a global residual of $\Delta\mu_\alpha = -4.3 \pm 0.9$ mas yr^{-1} was found with respect to the NPM1 catalog (Klemola et al. 1987). The 1 mas yr^{-1} error noted above reduces this to 3.3 mas yr^{-1}, a value which seems consistent with the Lick results when we consider the 2 mas yr^{-1} error for the absolute reference frame in an individual Lick field (Klemola et al. 1987, Hanson 1987).

3. Tests against Galactic Models

We have compared our NGP data with the IASG and Besançon Galaxy models, which provide both photometric (magnitudes and colors) and astrometric (proper motions) predictions. Besançon synthetic data were derived by the version of 1994 November 16. The IASG model used the default parameters for the thin disk and halo; and a thick disk was included with $h_z = 750$ pc, $\rho/\rho_0 = 0.10$, and a 47 Tuc population.

A first comparison between data and models is provided by the starcounts in Figure 4. There is good general agreement to intermediate magnitudes, $V \simeq 15$.[2] However, at fainter magnitudes, the Besançon model underestimates the starcounts by about 10-20% in the range $15 < V \leq 18$, while the IASG overestimates them by an even larger (20-45%) amount. As our data compare (cf. Paper I) reasonably with those of Stobie & Ishida (1987), it seems that the models (or their parameters) need improvement at these magnitudes. A range of IASG models with $600 \leq h_z \leq 1500$ pc and $2 \leq \rho/\rho_0 \leq 10\%$ was also tried, but with little improvement in the quality of the fit.

A more delicate test is provided by the color distributions as a function of magnitude. The $B - V$ distributions are given in Figure 5 for selected intermediate ($14 < V \leq 15$) and faint ($17 < V \leq 18$) magnitude ranges.[3] At the intermediate magnitude, models and observations agree as to the position of the

[2] Observed counts are underestimated at bright magnitudes ($V < 12$) because of processing difficulties associated with their very heavily saturated images.

[3] Note that Besançon distributions include a 0.1 mag error on both V and B–V, while the IASG distribution does not.

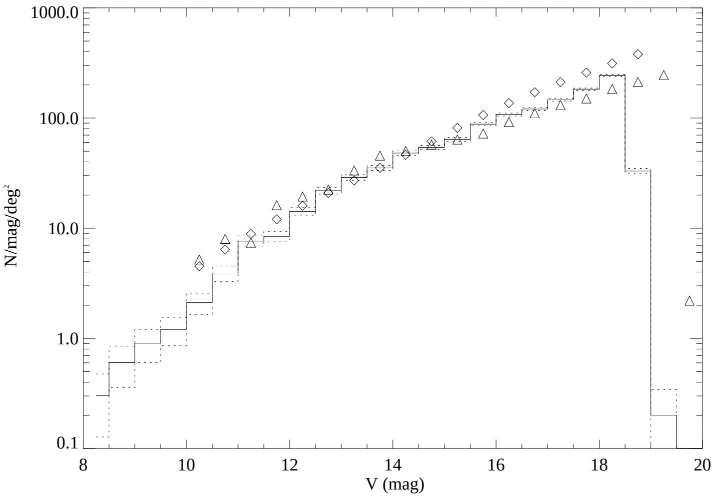

Figure 4. NGP starcounts (*solid* line) and $\pm 1\sigma$ limits (*dotted* line), compared with Besançon (*triangles*) and IASG (*diamonds*) predicted counts.

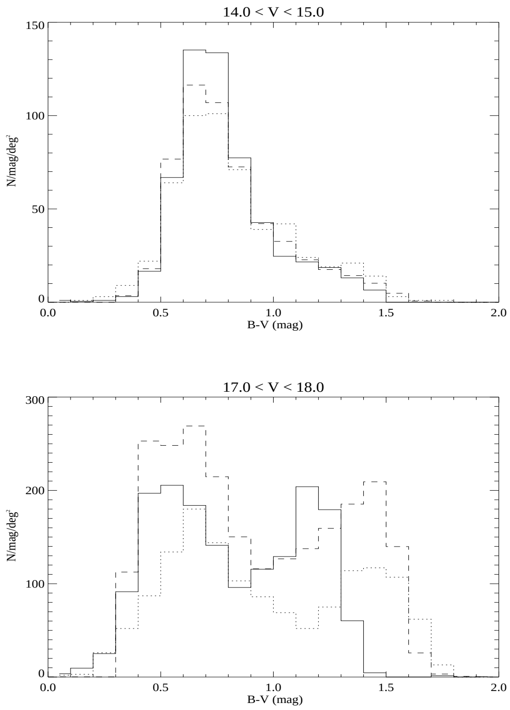

Figure 5. NGP color distribution (*solid* line), for $14 < V \leq 15$ (top) and $17 < V \leq 18$ (bottom), compared with Besançon (*dotted* line) and IASG (*dashed* line) predictions.

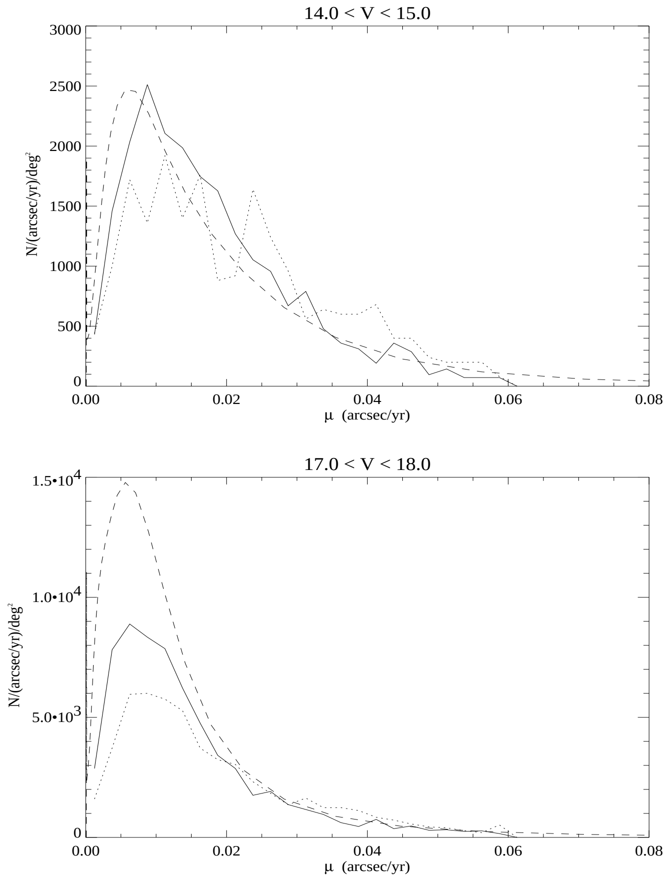

Figure 6. NGP total proper motion distribution (*solid* line) for $14 < V \leq 15$ (top) and $17 < V \leq 18$ (bottom), compared with Besançon (*dotted* line) and IASG (*dashed* line) predictions.

peak ($B-V \simeq 0.7$); and the main difference lies in the density normalization. However, fainter than $V = 16$ (bottom panel), the discrepancies are too large to be explained by the known photometric deficiencies.[4]

Finally, IASG and Besançon proper motions have been compared to NGP astrometric data. In Figure 6, the distributions of total proper motion[5] μ are shown for the $14 < V \leq 15$ and the $17 < V \leq 18$ intervals. The main features (e.g., the peak position and the wings) are consistent in both data sets, although, as noted above, the total starcounts are significantly different at faint

[4] We recall that the color calibration is limited by the lack of photometric standards with $B-V > 1.3$ mag and by the extrapolation of the photometric transforms for $B-V \geq 1.46$ (Paper I, Table 3). Moreover, at these faint magnitudes, our red-peak counts are partially incomplete because of the magnitude limit of the blue plates.

[5] Besançon proper motions include an error of 2 mas yr^{-1}per component, which increases their dispersion slightly, while IASG does not.

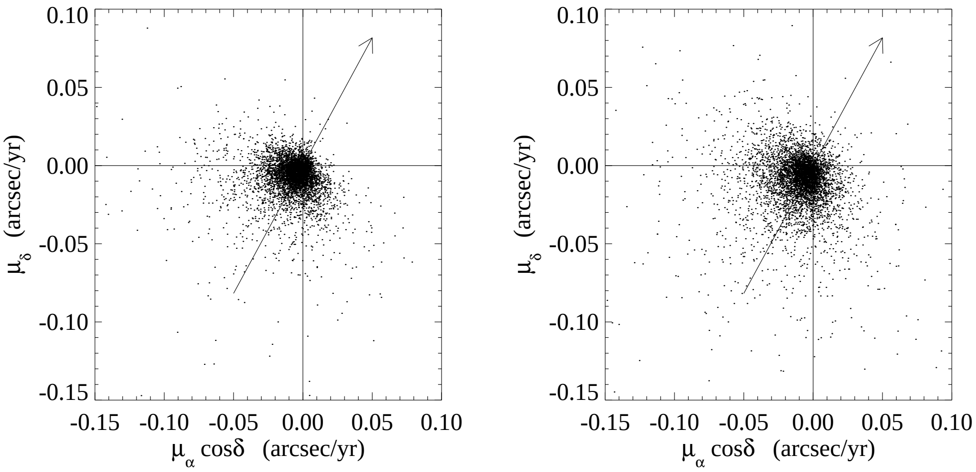

Figure 7. Vector Point Diagrams of the observed NGP (*left*) and Besançon simulated (*right*) catalogs for $10 < V \leq 18.5$. Arrows indicate the direction of the rotation velocity of the Galaxy.

magnitudes. However, this astrometric test shows quite clearly that the inconsistencies in starcounts are associated with *low* proper motion stars ($\mu \lesssim 20$ mas yr^{-1}), while the high proper motion tails for both the data and the models look similar (except for a slightly larger dispersion in the Besançon at intermediate magnitudes). The distributions of the proper motion components, μ_α, μ_δ, were also investigated for the Besançon model; these are consistent with the previous statement.

The vector point diagrams in Figure 7 show the observations and a simulated Besançon catalog down to $V = 18.5$ mag. The agreement is quite clear, especially in the outer regions, although there is a slightly larger dispersion in the Besançon proper motions. The asymmetric drift along the rotation direction of the Galaxy is evident.

With the large sample available, the mean proper motions ($\langle\mu_\alpha\rangle$, $\langle\mu_\delta\rangle$) have been investigated in detail as a function of magnitude. This is shown in Figure 8, where the mean proper motions and their errors are plotted by magnitude bin for all the stars and for a "blue" subset with $0 \leq B - V \leq 0.9$ (bottom). There is a fair agreement between the slopes of the full samples (except for the brightest μ_α bin), and it improves at the faint magnitudes if stars redder than $B - V = 0.9$ are excluded. An offset of about $2 - 4$ mas yr^{-1} remains, although this decreases when only the blue samples is used. We also note that this difference would decrease even more if we removed the ~ 1 mas yr^{-1} error in the absolute zero point, as discussed in Section 2.

4. Conclusions

On the purely technical side, we have argued against the presence of magnitude-dependent astrometric errors for $V > 13$ and have shown that the absolute

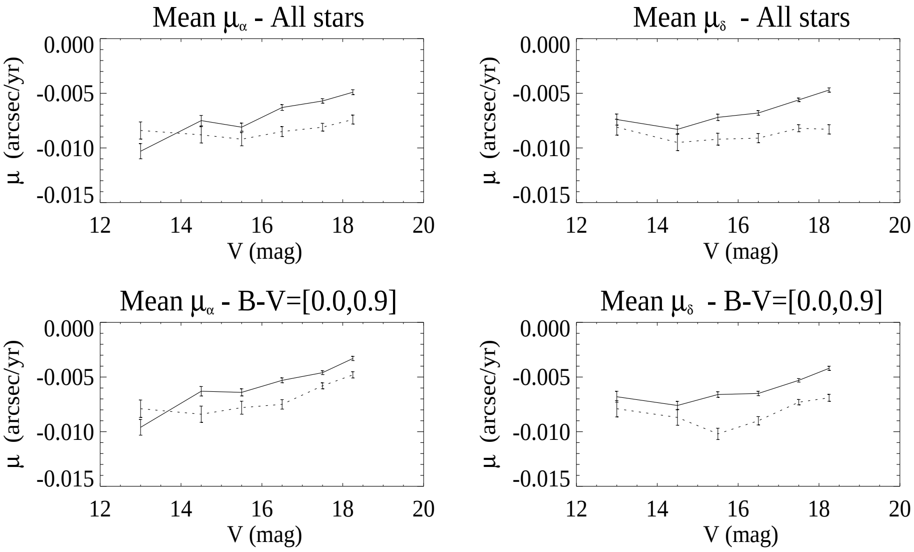

Figure 8. Mean μ_α, μ_δ for bins of the magnitude, V =[12, 14, 16, 17, 18, 18.5], of NGP data (*solid* line), and Besançon model (*dotted* line).

reference frame is reliable to $1-2$ mas yr^{-1} and that no metrology effects are detectable at that level. Additionally, we note that the kind of care required to obtain such results may be regarded as a risk in an environment of massive all-sky processing (eg., GSC–II).

Galactic models are powerful tools for studying galactic structure and kinematics but require the widest variety of observable parameters for checking and calibration. Classical starcounts are always a fundamental test for any prediction, although photometric and astrometric information can both improve the tests significantly and support the interpretation of discrepancies.

The more powerful tests based on color distributions are currently limited by the deficiencies of our color transformations for $B-V>1.3$. However, critical tests are also provided by the kinematics. The Besançon model gives a "fair" fit, although some questions of amplitude and zero point remain. The large overestimation of faint counts, particularly for stars of low proper motion, appears to be the main problem with the IASG model – at least in the configuration we used.

Further progress in these comparisons will require a better understanding of the differences in the models, as well as refinements to the stellar populations used in the multiparametric analysis of this four dimensional space (V, $B-V$, $\vec{\mu}$).

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