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Validation of the Absolute Proper motions Outside the Plane catalog (APOP)

with the Praesepe Open Cluster

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Abstract. Our understanding of very low-mass stellar astrophysics will benefit greatly from Gaia's new astrometry, which is expected to deliver sub-mas accurate parallaxes and proper motions down to the 20th magnitude limit, and possibly beyond. At this faint limit, Gaia's proper motions should still be better than those delivered by dedicated ground-based efforts; accordingly, results from the latter can be exploited, for example, to tune up astrophysically-driven test cases on data quality. APOP is the first version of an absolute proper motion catalogue achieved using the Digitized Sky Survey Schmidt plate material outside the galactic plane ($|b| \geq 27^o$). After a brief overview of APOP's catalogue data, this paper presents an analysis of its proper motions in the field of the Praesepe open cluster. This kind of validation is one of the prime quality assurance tests being planned for Gaia's absolute proper motions.

Key words. Astrometry: absolute proper motions, open clusters

1. Introduction

Gaia is expected to provide high-accuracy positions, proper motions and distances of a complete magnitude-limited sample reaching out to a significant portion of our Galaxy. Such a wealth of data will help address outstanding Brown Dwarf questions such as the formation mechanism of these sub-stellar objects and the determination of their masses and ages. In particular, the availability of accurate proper motions will be decisive for finding brown dwarfs in binary systems, hence allowing us to infer their age from that of the companion. Detailed kinematics of these objects will also permit us to identify their presence in nearby moving groups, and trace back their space motion to derive precious information on their origin. Finally, being able to determine the sky path of brown dwarfs with high accuracy can lead to the prediction of future microlensing events of background stars, and therefore to a direct measurement of the lens' mass.

Since the quality of Gaia's proper motions for the faintest brown dwarfs is expected to improve upon ground-based dedicated work, we believe it is particularly important that currently available data be used to test significant science cases, where Gaia's foreseen results could give a definitive answer. A recent catalog of absolute proper motions being applied to this kind of research is the Absolute Proper motions Outside the Plane (APOP) catalogue derived from the Guide Star Catalogue (Lasker et al. 2008) plate material which is being compared to recent infrared proper motion surveys (e.g. Smith 2014). The construction of the APOP catalogue, the astrometric calibrations, and the external comparisons with the QSO sample are described in details by Qi et al. (2014, submitted). The APOP catalogue covers about 22,525 square degrees outside the galactic plane ($|b| \geq 27^o$), for a total 100,777,385 objects, and a magnitude limit of $R_F \sim 20.8$. An accuracy analysis via Quasi-stellar objects (QSOs) in APOP gives a zero-point error in the absolute proper motions of less than 0.6 mas/yr, and a precision of better than 5.0 mas/yr for objects brighter than $R_F = 19.0$, rising to 10.0 mas/yr for magnitudes $19.0 < R_F < 20.0$. In the following, we briefly review the principle of catalogue construction, then discuss the proper motion results in the Praesepe cluster (M44, NGC2632, $RA = 130^o.02$, $Dec. = 19^o.68$) as a check of APOP's data quality.

2. The construction of APOP

The observational data come from the STScI Catalogue of Objects and Measured Parameters from All-Sky Surveys (COMPASS), containing the measured astrometric, photometric and geometric parameters for all detections on the digitized scans of 7000+ all-sky survey Schmidt photographic plates used to build the Guide Star catalogues and the Digitized Sky Survey. The derived absolute proper motions rely on a novel calibration method which iteratively uses the stellar and galaxy images on each plate in order to eliminate all the systematic errors in the rectification of the plates.

Under the hypothesis that objects (stars and galaxies) physically close on a photographic plate and with similar magnitudes/colors have similar systematic errors, and that the absolute proper motions of galaxies are always zero, i.e. not dependent on their plate position, magnitude or color, we can rely on the galaxies present on each plate for the calibration of magnitude- and color- dependent errors (MdE and CdE, respectively) in the plate-to-plate transformation.

In synthesis, the principal calibration steps are:

1. Removing the position-dependent systematic errors (PdE) with a moving-mean filter using stellar objects with good image quality;
2. Selecting galaxies from non-point-like sources (non-stars) via their common null-motion characteristics;
3. Calibrating the MdE and CdE and the residual PdE of all objects with reference to the galaxies;
4. Calculating the absolute proper motions from all-epoch plate data.

3. Quality assurance

Since the field of view of Schmidt plates is quite large ($6^o.5 \times 6^o.5$) the mean proper motion of stellar objects varies across the plate simply due to the mean Galactic motion; therefore, special attention must be paid at eliminating systematic errors in the plate-to-plate transformation while preserving genuine proper-motion signatures.

More specifically, in the presence of an open cluster covering a significant part of the photographic plate, Step 1 has the net effect of removing also the true common proper motion for this group of objects, if we select cluster members as reference stars. Theoretically, we believe our procedure returns the intrinsic mean proper motions to these stellar groups with Step 3. As an example, we took the Praesepe open cluster, whose basic parameters from two other catalogues Boudreault et al. (2012) and van Leeuwen (2009) are listed in Table 1. The diagram shown in Figure 1 presents the vector point diagram (VPD) of the absolute proper motions for all APOP objects with magnitude $R_F < 20$ in the area of the cluster. A tight group (314 objects within the red ring) indicates the location of Praesepe

Table 1. Summary data for Praesepe.

α [deg]	δ	l [deg]	b	*Diam.*[*deg*]	μ_α^* [mas/yr]	μ_δ	Dist. [pc]
130.02	19.68	205.87	32.42	4.5	−35.81	−12.85	181.5

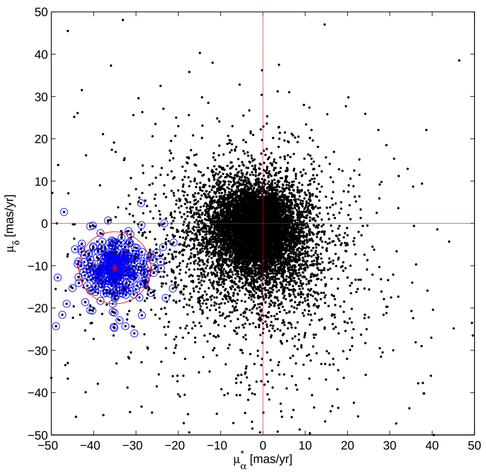

Fig. 1. Absolute proper motion vector-point diagram (VPD) for all APOP objects with magnitude $R_F < 20$ in the area of the Praesepe cluster. The 344 objects with the filled blue circles are cluster members with membership probability higher than 60% by cross-matching with the catalogue made by Boudreault.

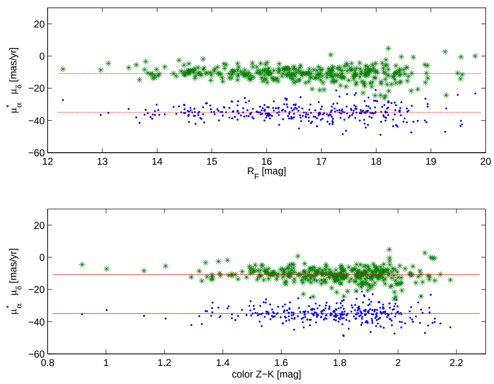

Fig. 2. Absolute proper motion of the objects with filled blue circles in Figure 1 as a function of magnitude and color. For these 344 objects (with membership probability higher than 60%) we find the mean absolute proper motion, μ_α^*=-34.96±0.24 mas/yr, μ_δ=-10.85±0.23 mas/yr, with the dispersion of $\sigma_{\mu_\alpha^*}$=4.39±0.17 mas/yr, σ_{μ_δ}=4.27±0.16 mas/yr.

and permits a segregation between cluster and field stars. The mean absolute proper motion of the cluster is estimated at μ_α^*=-34.93±0.22 mas/yr, μ_δ=-10.71±0.21 mas/yr, which is quite close to the Hipparcos value for Praesepe: μ_α^*=-35.81±0.29 mas/yr, μ_δ=-12.85±0.24 mas/yr (van Leeuwen 2009). Therefore, we confirm that the true proper motion of the cluster has been recovered by the overall APOP procedure, which sets the absolute proper motions via the galaxies present on each plate, with a systematic zero point error not exceeding 1 mas/yr and 2 mas/yr on μ_α^* and μ_δ, respectively.

If we assume the tangential velocities have the same dispersion as the radial velocities in combination with a distance to Praesepe we can find the predicted (intrinsic) proper motion dispersion. Adopting a distance to Praesepe of 181.5pc (van Leeuwen 2009) and a radial velocity dispersion of 0.79 km/s (Mermilliodet al. 2009) we predict a proper motion dispersion of around 1 mas/yr. On the other hand, we compute a dispersion of $\sigma_{\mu_\alpha^*}$ = 4.00 ± 0.16 mas/yr and σ_{μ_δ} = 3.72 ± 0.15 mas/yr for objects with membership probability higher than 60% in APOP, this provides an independent estimation of the APOP random errors. Actually, this larger dispersion in APOP (around 4 mas/yr) is the observed proper motion dispersion, which also include the errors from the measurements. In fact, detecting such small (1 mas/yr) dispersion is often below the capacity of Schmidt photographic surveys.

In fact, Step 3 not only removes the MdE and CdE between the program and reference

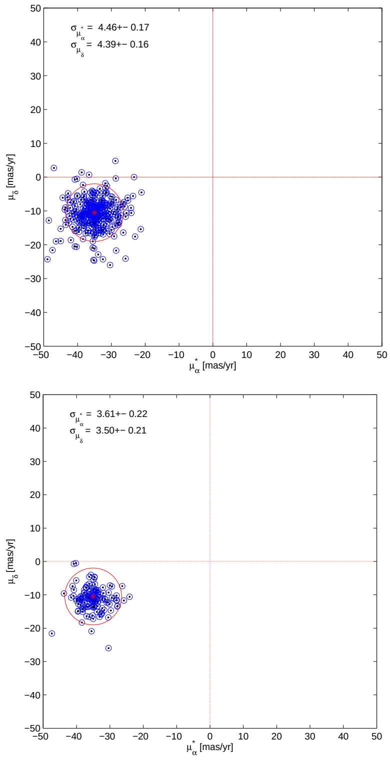

Fig. 3. Absolute proper motion vector point diagram (VPD) objects with membership probability hight than 10% (Top panel, 355 objects) and 90% (Bottom panel, 139 objects).

plates, but also sets the star's absolute proper motions via the galaxies present on each plate. Since *bona fide* cluster members will exhibit the same proper motion, irrespective of their magnitude and color, we can use the proper motion dispersion to evaluate catalogue quality, checking for the presence of residual MdE and CdE. Results for stars with membership probability higher than 60% are given in Figure 2. Objects fainter than $R_F \sim 14$ do not show evident systematic errors in absolute proper motion as function of magnitude and color (i.e., neither MdE or CdE are present). However, for objects brighter than $R_F \sim 14$, we find a significant MdE, around 3-5 mas/yr, the causes of which are under investigation.

Finally, the potential user of this catalogue must keep in mind that for objects brighter that $R_F \simeq 14$, the proper motion accuracy is degraded by image saturation on the plate (resulting in larger centroiding error) and by the fact that the number of bright galaxies on a plate is generally very few, making the calibration of the magnitude error less robust at the bright end.

In addition to the above, we checked the dispersions of absolute proper motions for objects with different membership probability. Figure 3 shows the VPD of APOP objects with membership probability higher than 10% (355 objects) and 90% (139 objects), separately. It is evident that the spatial concentration on proper motions in the VPD is higher when the probability of membership is increased, and there is no distinct change in the mean absolute proper motion of the cluster. The diagrams shown in Figure 4 present the same data as in Figure 3 but as a function of magnitude and color.

The results are very nice for objects with membership probability higher than 90%: no MdE and CdE are found, and the precision of absolute proper motions is better than 3.6 mas/yr. However, when the membership probability gets lower, very bright and very faint objects are included, and the global performance is poorer. In this respect, we want to emphasize that the measurement errors of the images on the plates is limited by the intrinsic noise of photographic plates, which we could not work to improve.

4. Conclusions

APOP is an absolute proper motion catalogue based on the Digitized Sky Survey Schmidt plate data outside of the galactic plane $|b| \geq 27^o$. We have analyzed the proper motions of this new catalogue in the region of the Praesepe open cluster taking membership probabilities from literature work. The cluster is very well segregated from the field stars, though the accuracy of proper motions shows a deterioration towards the bright and faint plate magnitude limit.

Given that the true proper motion dispersion of M44 should be less than 1mas/yr, and even smaller for more distant clusters, this kind of test will be an extremely valuable tool for

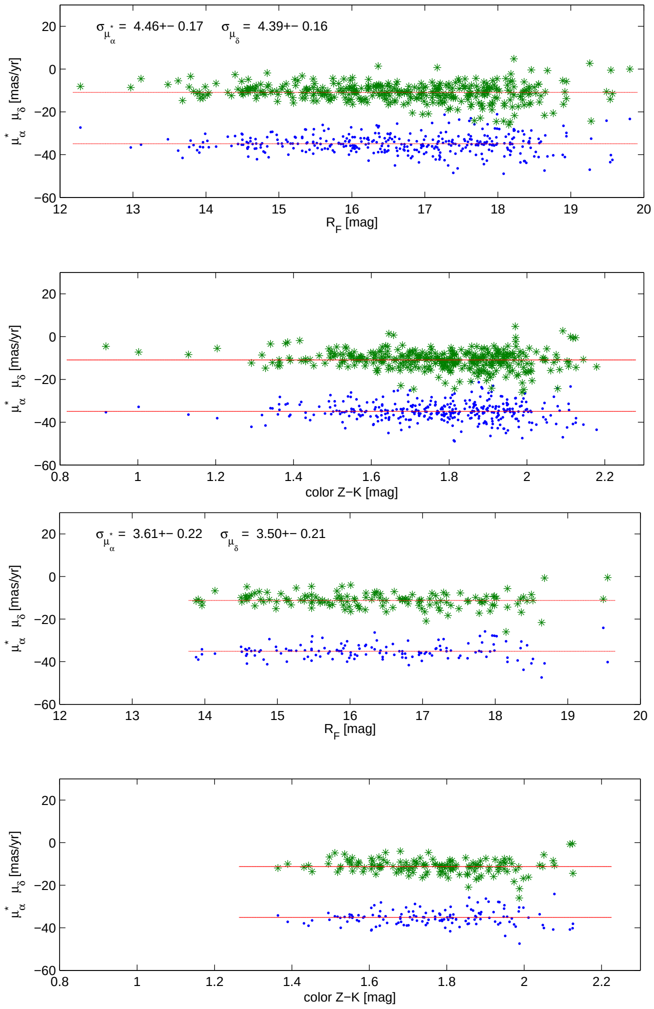

Fig. 4. Absolute proper motion of the objects with membership probability hight than 10% (Top two panels) and 90% (Bottom two panels) as a function of magnitude and color.

evaluating the quality of the proper motions delivered by Gaia.

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