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MEASUREMENT OF CFHT IMAGES II. ASTROMETRIC REDUCTION

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RESUMEN

Presentamos las evaluaciones de la reducción astrométrica de imágenes CFHT que serán usadas para la construcción de un catálogo profundo de la región ecliptical, usando UCAC3 como catálogo de referencia. Encontramos que el error de centrado promedio para objetos de apariencia estelar es de 0.012 pixel (2.2 mas), mientras que para objectos extendidos es de 0.037 pixel (6.9 mas). A partir de la comparación de mediciones hechas en dos filtros se detectó una fuerte aberración cromática que fue modelada y corregida. Tras dicha corrección las diferencias entre coordenadas instrumentales en ambos filtros son (-7 ± 11) mas y (-1 ± 12) mas en X e Y respectivamente, sin patrón sistemático evidente. Las diferencias entre coordenadas celestes obtenidas con los dos filtros son 15 mas en $\alpha \cos(\delta)$ y 26 mas en δ.

ABSTRACT

In this paper we present the evaluations of the astrometric reduction of CFHT images that are intended to be used for the construction of a deep ecliptic catalogue, using UCAC3 as reference catalogue. We find that the average centering error for star-like objects is 0.012 pixel (2.2 mas), but for extended objects it is 0.037 pixel (6.9 mas). By comparing measurements with two different filters a strong chromatic aberration was detected, that was modeled and corrected. After that correction the differences between instrumental coordinates in both filters are (-7 ± 11) mas in X and (-1 ± 12) mas in Y and no systematic pattern is apparent. The differences between celestial coordinates obtained with the two filters are 15 mas in $\alpha \cos(\delta)$ and 26 mas in δ.

Key Words: astrometry — methods: data analysis

1. INTRODUCTION

In the last year we have started a collaboration with the Laboratory SYRTE (Systèmes de Référence Temps-Espace, UM8630 of CNRS) at Paris Observatory for the exploitation of 1700 wide-field frames taken at the Canada-France-Hawaii Telescope (CFHT), each one covering a $1^\circ \times 1^\circ$ area with a mosaic of 36 CCD chips. These frames, covering a large band of the sky along the ecliptic, are already available as part of the CFHT Legacy Survey–Very Wide. The ultimate objective is the construction of a celestial catalogue called MEGACLIP much deeper and more accurate than other existing catalogues in the region concerned. For the same zone of the sky it will contain many more objects than these catalogues, as well as the output catalogue from GAIA (scheduled around 2017). Indeed the detection threshold from MEGACLIP is expected to be roughly $V \sim 23 - 24$ (Calderón & Bustos Fierro 2013) instead of $V \sim 20$ for this last mission. Moreover, the MEGACLIP catalogue, thanks to its high density and its accuracy with respect to the existing catalogues, will enable to determine GAIA's coordinates during its operational mission by giving the coordinates of reference stars with very good accuracy.

2. DETECTION AND CENTERING

The detection and centering of objects was performed with SExtractor (Bertin & Arnouts 1996) since besides the central coordinates of each detection it provides instrumental photometric magnitudes and some shape parameters that can be useful for the classification of detections into different types of objects (spurious, stellar or non-stellar) as mentioned in Calderón & Bustos Fierro 2013.

One of the main input parameters for the detection with SExtractor is the threshold in signal-to-noise ratio (S/N), that is, the minimum S/N value required for a number of connected pixels to be considered as an object instead of a random fluctuation of the background. In order to decide the optimum detection level we ran SExtractor on the same image with different thresholds, namely 3, 4, 5, 6, 7, 8, 9, 10 and 20, so we obtained nine catalogues of X, Y coordinates and star/galaxy classifier (output parameter CLASS in SExtractor catalogue). We considered as a star every detected object with CLASS ≥ 0.7 in all the catalogues where it was detected. For each

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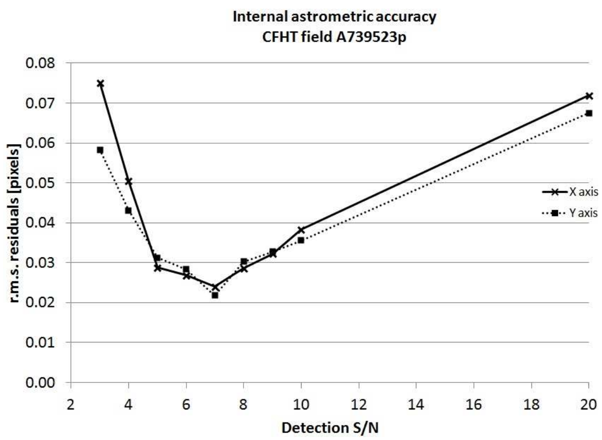

Fig. 1. R.m.s deviation from average position at different S/N detection levels.

star we computed the average position of all its detections and the residuals of every single position from the average position. We computed the r.m.s. of all the residuals for each S/N threshold, named *internal astrometric accuracy* at that S/N threshold. Figure 1 shows that the minimum r.m.s. of the residuals is about 0.025 pixel at the detection threshold S/N=7 for the field 739523p, but similar results were obtained with other fields. Therefore all the measurements were performed at the detection level S/N=7.

The first indicator of the accuracy of the positions is provided by SExtractor itself. It is the error of the centroids derived by the software assuming photon noise in the counts of every pixel. The average error for the whole sample was 0.029 pixel (5.4 mas), with noticeable differences between 'stars' (objects with CLASS ≥ 0.7) and extended objects (with CLASS < 0.7) as shown in Figure 2. The average error for stars is 0.012 pixel (2.2 mas), while for extended objects it is 0.037 pixel (6.9 mas).

3. ASTROMETRIC REDUCTION

We chose UCAC3 (Zacharias et al. 2010) as reference catalogue due to its high density –about 1000 stars per square degree– and its astrometric accuracy. In the field 739523p there are nearly 1500 UCAC3 stars that could be used as reference stars, that is an average of more than 40 reference stars per frame. Therefore it is possible to perform the astrometric reduction of each single frame independently from the others.

In the first astrometric reduction, for every frame two linear transformations between instrumental coordinates (X, Y) and standard coordinates (ξ, η) in

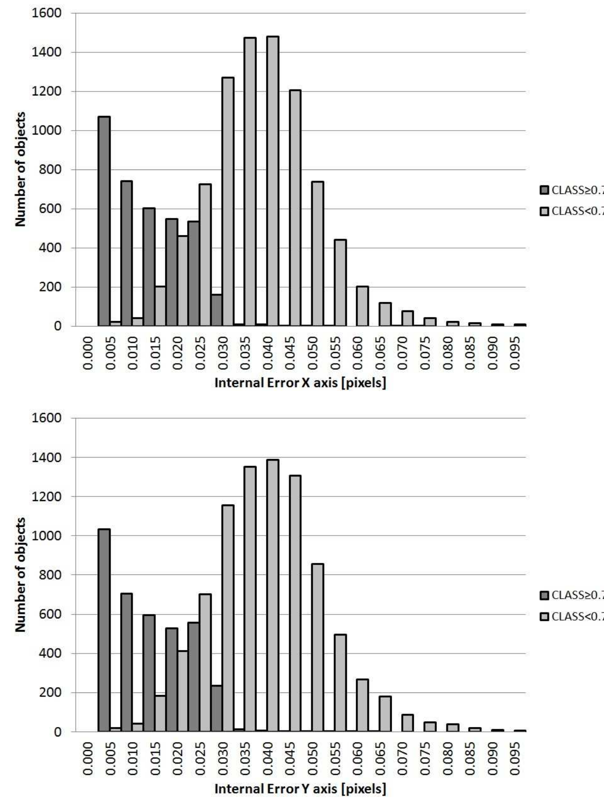

Fig. 2. SExtractor centering errors.

a plane tangent to the celestial sphere were fitted by least squares: one for the ξ coordinate and one for the η coordinate. The r.m.s. residual of the fitting in η (2.5 pixel) is clearly larger than in ξ (1.4 pixel).

After analyzing the residuals in η a systematic trend of those residuals was noticed depending on Y, which suggested that a linear transformation was not good enough, probably due to the rectangular shape of the CCDs that are twice larger in Y than in X.

The second astrometric reduction was performed by fitting a linear transformation in ξ and a quadratic one in η. The r.m.s. residuals were reduced to 1 pixel in both coordinates.

4. ONE FIELD, TWO FILTERS

The mosaics 827155p and 827156p cover the same field –centered in $\alpha = 70.572°$, $\delta = 22.58722°$– with two filters: g' and r' respectively. SExtractor detected 11595 objects in the first and 16562 in the last one. Both mosaics were independently reduced by fitting the same transformations mentioned in the last section. In mosaic 827155p, 1525 stars from UCAC3 were used as reference, while 1495 stars were used in mosaic 827156p.

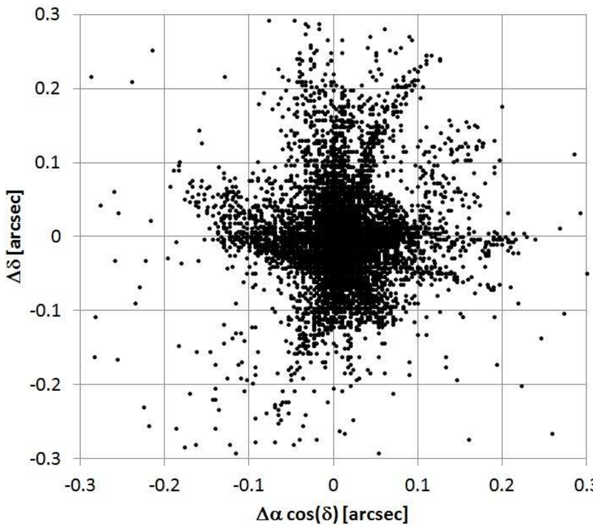

Fig. 3. Differences between coordinates obtained in two filters (g' and r').

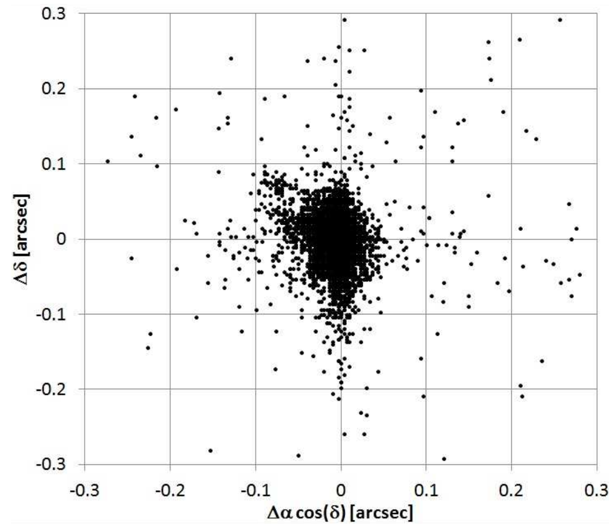

Fig. 4. Differences between coordinates obtained in two filters, using the same set of reference stars in both filters.

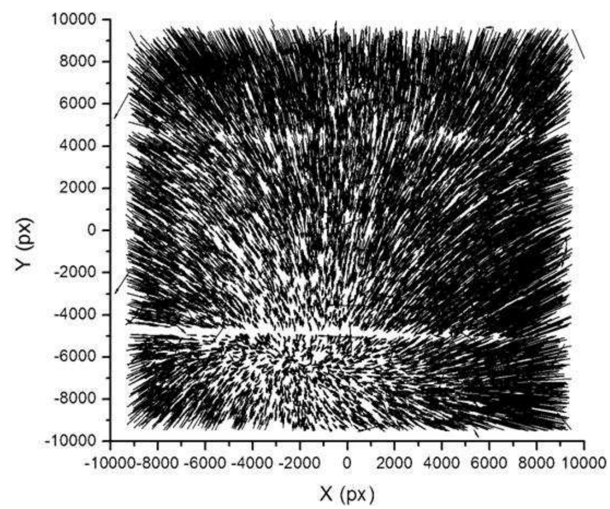

Fig. 5. Differences between instrumental coordinates obtained with SExtractor in two filters. Vectors enlarged 1000 times.

The celestial coordinates obtained from the CFHT images were compared with two catalogues: UCAC3 and USNO-B1 (Monet et al. 2003). The standard deviations of the differences with UCAC3 are about $0.23''$ in both coordinates, while with USNO-B1 they are about $0.34''$.

When computing the differences between coordinates obtained in both filters, their averages and standard deviations are small: (8 ± 44) mas in $\alpha\cos(\delta)$ and (-1 ± 58) mas in δ, but their distributions are not symmetrical and they are strongly dependent on the frame (chip on the mosaic) as shown in Figure 3.

In order to reduce the possibility of differences between the fittings in different filters, new astrometric reductions were performed using as reference stars those UCAC3 stars that were identified in both mosaics only, that is using the same set of reference stars in both filters. The averages and standard deviations of the differences between coordinates obtained in both filters were reduced to (-6 ± 22) mas in $\alpha\cos(\delta)$ and (-1 ± 31) mas in δ and their distributions were consequently improved, but they are still not symmetrical, as shown in Figure 4.

The SExtracted X, Y instrumental coordinates were compared. In the absence of any chromatic aberration these coordinates should present random differences. Instead of that, they have large means and standard deviations – $(-0.03 \pm 0.12)''$ in X, $(-0.10 \pm 0.09)''$ in Y – and they show an approximately radial pattern as seen in Figure 5.

The pattern found could not be satisfactory modeled with polynomials up to the third degree, so it was averaged with a weight function (Stock & Abad 1988) and subtracted from one of the mosaics (827155p). After that subtraction the differences are greatly reduced –(-7 ± 11) mas in X and (-1 ± 12) mas in Y– and the systematic pattern disappears.

The corrected mosaic (827155p) was re-reduced and the differences between celestial coordinates obtained with the two filters were re-calculated. Their standard deviations were slightly reduced to 15 mas in $\alpha \cos(\delta)$ and 26 mas in δ, but their distributions remained unchanged.

5. CONCLUSIONS

The best centering accuracy with SExtractor is achieved with the detection threshold at S/N=7. In this case the average centering error provided by SExtractor for 'stars' is 0.012 pixel (2.2 mas), while for extended objects it is 0.037 pixel (6.9 mas).

The density of UCAC3 allows every single chip to be astrometrically reduced independently of the others. After performing this reduction by fitting a linear transformation in ξ and a quadratic one in η, the r.m.s. residuals in both coordinates were 1 pixel ($0.187''$).

The comparison of coordinates obtained in the same field with two different filters showed an approximately radial pattern that could not be satisfactory modeled with polynomials up to the third degree, so it was averaged with a weight function and subtracted from one of the mosaics. After that substraction the differences are greatly reduced and the systematic pattern disappears.

After correction of the chromatic aberration, the mosaics in both filters were re-reduced and celestial coordinates of objects were re-calculated. The differences in those coordinates have larger standard deviations in δ than in $\alpha \cos(\delta)$. We think that it may be due to the reference stars, and it will be studied in the future.

This work is based on observations obtained with MegaPrime/MegaCam, a joint project of CFHT and CEA/DAPNIA, at the Canada-France-Hawaii Telescope (CFHT) which is operated by the National Research Council (NRC) of Canada, the Institut National des Science de l'Univers of the Centre National de la Recherche Scientifique (CNRS) of France, and the University of Hawaii. This work is based in part on data products produced at TERAPIX and the Canadian Astronomy Data Centre as part of the Canada-France-Hawaii Telescope Legacy Survey, a collaborative project of NRC and CNRS.

This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France (Ochsenbein, Bauer, & Marcout 2000).

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