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# ASTROMETRIC REDUCTION OF CFHTLS-VW IMAGES: PRELIMINARY RESULTS

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RESUMEN

En este trabajo presentamos resultados preliminares de la reducción astrométrica de un conjunto de imágenes de la región ecliptical pertenecientes a la colección del CFHTLS-VW. Aquí discutimos la elección del modelo utilizado para la reducción y los criterios para la selección de las estrellas de referencia. Se discute la máxima precisión astrométrica alcanzada con esta elección a partir de imágenes tomadas con diferentes filtros en dos campos muy separados en el cielo. El propósito final de este trabajo es construir un catálogo profundo con información astrométrica, fotométrica y la clasificación estrella/galaxia/otro de las fuentes detectadas.

ABSTRACT

In this paper we show the results of the astrometric reduction of a set of images taken on the ecliptic region that belong to the CFHTLS-VW collection. We discuss the choice of the model used for the reduction and the criteria for the selection of the reference stars. Images of two fields widely separated in the sky that were taken with different filters were reduced in order to discuss the maximum achievable astrometric accuracy with the choice referred above. The final goal of this work is to build a deep catalog providing information on astrometry, photometry and object classification of the sources detected in the ecliptical zone.

*Key Words:* astrometry — methods: data analysis

## 1. INTRODUCTION

This work is the continuation of an ongoing investigation whose very first steps were presented in the 2012 ADeLA meeting (Bustos Fierro & Calderón 2014). The results obtained in that work were not satisfactory enough and we had to change the reference catalog and the procedures in order to obtain a more reliable astrometric reduction. The final goal of this project is to obtain an astrometric catalog with a precision limited by the accuracy of the reference catalog, and also providing photometry, a star/galaxy classification and morphometric data for the sources.

The images of the CFHTLS-VW cover a large fraction of the ecliptic plane inside a band of $\pm 2^\circ$ for a total area of 410 square degrees, avoiding the regions where it crosses the galactic plane. They were taken in three colours (g', r' and i') of the AB photometric system (Oke & Gunn 1983) with the wide field camera Megacam. This is the same photometric system of the Sloan Digital Sky Survey (Fukugita et al. 1996). Each image covers a field of view approximately $1^\circ \times 1^\circ$. The detector is a mosaic of 36 individual CCD $2048 \times 4612$ square pixels, 13.5 micron side corresponding to $0.187''$ in the sky. The images have bias, dark and flat field corrections and preliminary WCS and photometric calibrations. They can be downloaded from CADC as multiextension fits images.

## 2. SOURCES EXTRACTION

In our previous work we used SExtractor (SEx) version 2.0.0, converted to run under Windows, for detection and centering of potential sources, while in this work we use SEx version 2.19.5 for Linux (Bertin & Arnouts 1996). The main reason for the change was that with this version of SEx the precision in centroiding offered by "windowed" parameters is improved and very close to that of PSF-fitting on focused and properly sampled star images, and the author recommends its use whenever possible (E. Bertin, SExtractor v2.13 User's manual, Institut d'Astrophysique & Observatoire de Paris). We ran SEx with default detection parameters except DETECT_THRESH = 7 and DETECT_MINAREA = 12 pixels. We performed astrometric reductions based on centroids obtained with both versions of SExtractor and compared the results, but that comparison is not discussed in this contribution.

## 3. CLEAN LIST OF DETECTIONS

Before beginning the astrometric reduction it is necessary to clean the list of detections in order to

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remove spurious ones, as well as sources whose positions could be disturbed, so they would not be used as reference stars. For all sources detected, SEx provides centroids coordinates in pixels, instrumental photometric magnitudes and shape parameters, among others. It also provides an internal flag that informs about bright or close neighbours, truncated objects, objects originally blended, saturation, aperture data corruption and memory overflow. We rejected all sources with a non-zero flag, so assuring that the sources retained are not disturbed by any of the mentioned issues. In addition to that, we rejected sources with a FWHM too small or too large to be a star, retaining only those with Q01<fwhm<Q90, where Q01 and Q90 are the 1% and 90% percentiles of the distribution of FWHM. Finally, in order to use only widely separated sources as reference stars, we rejected those sources whose distance was smaller than six times the rms of a typical PSF. Results displayed hereafter were obtained from this cleaned list of detections.

## 4. REFERENCE CATALOG

The reference catalog in our previous work was UCAC3 (Zacharias et al. 2010). After its release, we started using UCAC4 (Zacharias et al. 2013) as it seemed dense enough for the reduction of CFHT images. Nonetheless we found that many UCAC4 stars were saturated in the CFHT images and some systematic differences among reductions in different colours remained, even when they were reduced with the same set of reference stars. Therefore we decided to try 2MASS (Skrutskie et al. 2006) although it is not an astrometric catalog.

According to Skrutskie et al. (2006), the 2MASS sources with $9 < K_s < 14$ have the lowest positional uncertainty around 70mas, so they are the best candidates for reference stars. However, we decided to use 2MASS sources in the range $13.3 < K_s < 15.5$ in order to avoid bright stars and to increase the density. In addition we rejected 2MASS sources with contamination flag, or extended-source flag, or more than one optical source around it.

## 5. ASTROMETRIC REDUCTION: PROCEDURE AND RESULTS

In order to start the astrometric reduction, it is necessary to identify some reference stars. For this preliminary identification we used the WCS information in the header of the images. In some cases, we have found headers that do not provide the WCS for all CCDs, those are not considered for the results presented in this paper, since an additional treatment is required to find preliminary reference stars.

As in Bustos Fierro & Calderón (2014), we performed the astrometric reduction of each single frame independently from the others and we followed the same iterative procedure outlined in that paper, but in the present work we adopted a complete quadratic model in both coordinates. For every image the output of this procedure consists of one single catalog with all the detections in the 36 frames with their right ascensions and declinations, and one single list of the reference stars in the last iteration of every frame.

If there are $n$ images of every field, there are also $n$ different catalogs and $n$ different sets of reference stars. As noticed in Bustos Fierro & Calderón (2014), systematic differences are observed when comparing celestial coordinates obtained from reductions with different reference stars, therefore the same set of reference stars should be used in every image of a single field. This was done by retaining only the reference stars that were common to all the lists that resulted from the astrometric reduction of the single frames. After that a final least squares fitting is performed for every image of the field, using only the common reference stars. Then we get $n$ different catalogs without systematic differences, thanks to having a common set of reference stars.

One final position in each colour was computed by averaging the positions in the individual catalogs in that colour. The final catalog of the field was constructed by averaging the final positions in all the colours available for that field.

This procedure was applied on two fields: the first one (Field 1) was selected at random. It is centered at RA 04h 42m 17.28s, DEC $+22°35'14.0''$(J2000). The images of this field are: 827155 and 827164 (g' filter), 827156 and 827162 (r' filter), 827157 and 827163 (i' filter). They were taken on December 1st 2005. Exposure time was 200 seconds. The second one (Field 1+180) was selected 180 degrees from Field 1, it is centered at RA 16h 38m 13.22s, DEC $-21°13'21.4''$(J2000). The images of this field, their filter, their observation date and exposure time in seconds, are: 931130 (r'; July 28; 180), 931408, 931423 and 931438 (r'; July 30; 180); 934668 (g'; August 9; 110), 934970 (g'; August 11; 110), 935275 and 935292 (g'; August 13; 180). All images were taken on 2007.

*Results for Field 1*: The final least squares fittings for this field were performed using 1917 reference stars common to the six images, their r.m.s. residuals were in the range 73 − 81mas. The differences in coordinates obtained from the two images in every filter were computed (see Table 1, rows 1

TABLE 1

MEAN AND RMS DIFFERENCES IN MAS

| Difference | $\Delta\alpha cos\delta$ | $\Delta\delta$ | Sources |
|---|---|---|---|
| 827157 - 827163 (i') | $1 \pm 12$ | $0 \pm 9$ | 18586 |
| 827156 - 827162 (r') | $0 \pm 9$ | $0 \pm 7$ | 14833 |
| 827155 - 827164 (g') | $0 \pm 16$ | $0 \pm 9$ | 11431 |
| Mean r' - Mean i' | $1 \pm 8$ | $0 \pm 6$ | 13902 |
| Mean r' - Mean g' | $0 \pm 11$ | $0 \pm 6$ | 10832 |
| Mean g' - Mean i' | $0 \pm 11$ | $0 \pm 7$ | 10443 |
| Mean i' - Final | $0 \pm 5$ | $0 \pm 4$ | 14124 |
| Mean r' - Final | $0 \pm 5$ | $0 \pm 3$ | 14513 |
| Mean g' - Final | $0 \pm 7$ | $0 \pm 4$ | 11054 |
| 931438 - Mean r' | $1 \pm 7$ | $0 \pm 6$ | 35500 |
| 935292 - Mean g' | $1 \pm 12$ | $0 \pm 11$ | 34371 |
| Mean r' - Mean g' | $2 \pm 27$ | $3 \pm 19$ | 35148 |

to 3). The differences in average coordinates obtained with the three different filters were computed (see Table 1, rows 4 to 6). As explained, final positions were computed by averaging the individual coordinates of each filter, mean and r.m.s. differences between final positions and positions in different colours were also computed (see Table 1, rows 7 to 9, and Figure 1).

*Results for Field 1+180*: The final least squares fittings for this field were performed using 3690 reference stars, their r.m.s. residuals were in the range $73 - 81$mas. The differences in coordinates obtained from single images with the average coordinates through the corresponding filter were computed, and the differences between average coordinates through both filters were also computed. As an example the mean and r.m.s differences with mean positions in two colours and differences between means in each colour for images 931438 (r') and 935292 (g') are shown in Table 1, rows 10 to 12, and Figure 2.

## 6. CONCLUSIONS

The procedure we developed for the astrometric reduction seems to be suitable for an automated massive reduction. However some previous steps require human attention and work, for instance the preliminary identification of reference stars. Although the comparison is not shown here, the use of the latest available version of SExtractor (version 2.19.5) and the windowed centroiding parameters produced a noticeable improvement in the internal errors.

The choice of 2MASS as reference catalog and the selected magnitude range $13.3 < K_s < 15.5$ seems to be appropriate. The use of the same reference stars in the reduction of all the images of a given field is necessary for internal consistency.

In Field 1 the internal accuracy estimated from Table 1 (rows 1 to 6) is around 10 mas in both coordinates in colours i' and r' and slightly larger in right ascension in g' colour. This larger dispersion could be due to guiding error. From the comparison in Table 1 (rows 7 to 9) the internal accuracy of the final positions ∼5 mas can be evaluated. Since this corresponds to approximately 3% the pixel size, we foresee that CFHT images will be useful for accurate astrometric measurements, at least if the quality of most of the images of the collection is similar to that of Field 1.

In Field 1+180 the internal accuracy estimated from Table 1 (rows 10 to 12) is around 7 mas in r' and 12 mas in g'. This larger dispersion could be due to the poorer signal-to-noise ratio of the images in g', as can be readily noticed from visual inspection.

The strong influence of the images quality on the results can also be seen in the difference Mean r' - Mean g' ∼25 mas, noticeably larger than in Field 1. It can also be noticed by comparing Figure 1 and Figure 2 even though they do not show exactly the same type of differences.

The maximum achievable accuracy in final positions can be inferred from internal errors ∼5 mas in i' and r' colours, but the actual accuracy is limited by the reference catalog ∼80mas in this work. When a dense and accurate (1 mas) catalog be available (e.g. Gaia first release), internal errors and proper motions will limit the accuracy. In this case the resulting catalog from this project will provide an extension to fainter magnitudes.

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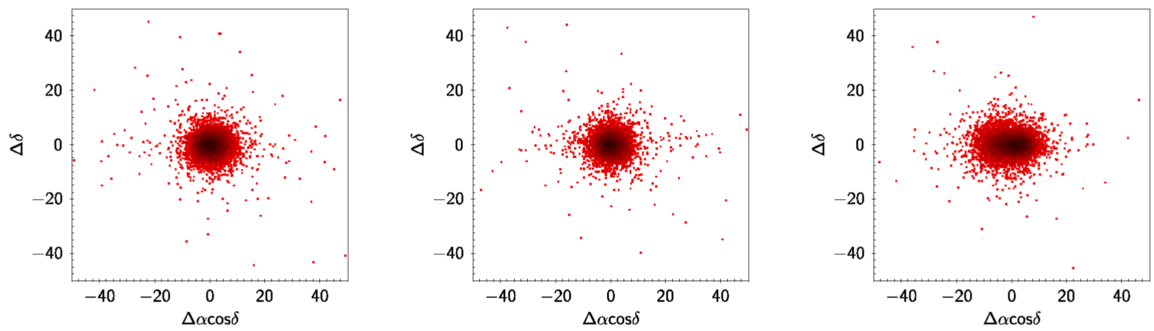


Fig. 1. Field 1 Differences between coordinates measured in every colour and final coordinates. Left: Mean i' - Final. Middle: Mean r' - Final. Right: Mean g' - Final.

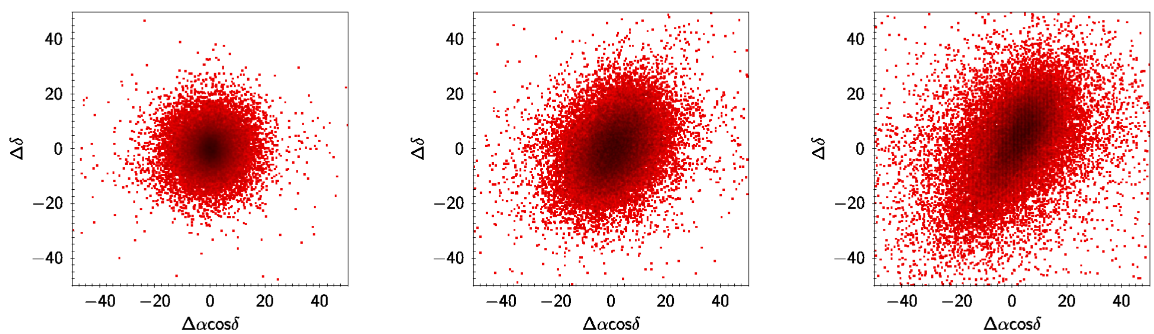


Fig. 2. Field 1+180 Differences with mean positions in two colours and differences between means in each colour. Left: 931438 - Mean r'. Middle: 935292 - Mean g'. Right: Mean g' - Mean r'.

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## REFERENCES

Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393

Bustos Fierro, I. H., & Calderón, J. H. 2014, RMxAC, 43, 47

Fukugita, M., Ichikawa, T., Gunn, J. E., et al. 1996, AJ, 111, 1748

Ochsenbein, F.; Bauer, P. & Marcout, J. 2000, A&AS, 143,23

Oke, J. B., & Gunn, J. E. 1983, ApJ, 266, 713

Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163

Zacharias, N., Finch, C., Girard, T., et al. 2010, AJ, 139, 2184

Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, AJ, 145, 44