Astrometric calibrations of the HST images in the era of Gaia

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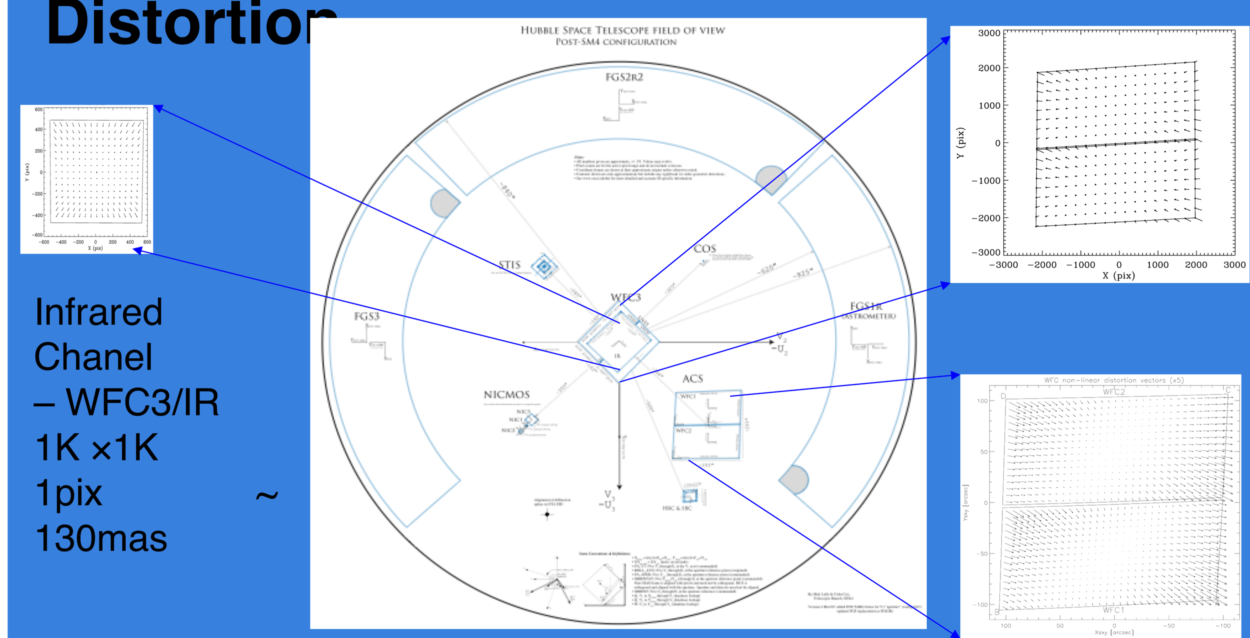
INTRODUCTION

It is well-known that HST images, taken with ACS/WFC and WFC3/UVIS, have substantial geometric distortion. Knowledge of accurate distortion is important not only for science with precision astrometry, it is important for many applications with the HST images. Over the years our knowledge about this distortion has been vastly improved. Nevertheless, in certain applications it may not be good enough. Preliminary results of comparison state-of-the-art HST astrometric standards and the Gaia DR2 indicate significant offsets, global rotation and scale difference in the HST data. However, in terms of positional precision the HST images are not surpassed yet. The release of Gaia DR2 is used to finalize and improve the HST astrometric calibrations down to 0.5 mas or better.

HST Focal Plane: ACS/WFC and WFC3 Large-scale Distortion



Ultraviolet-Visible Chanel WFC3/UVIS 2 4K × 2K CCDs, 1pix ~ 40mas

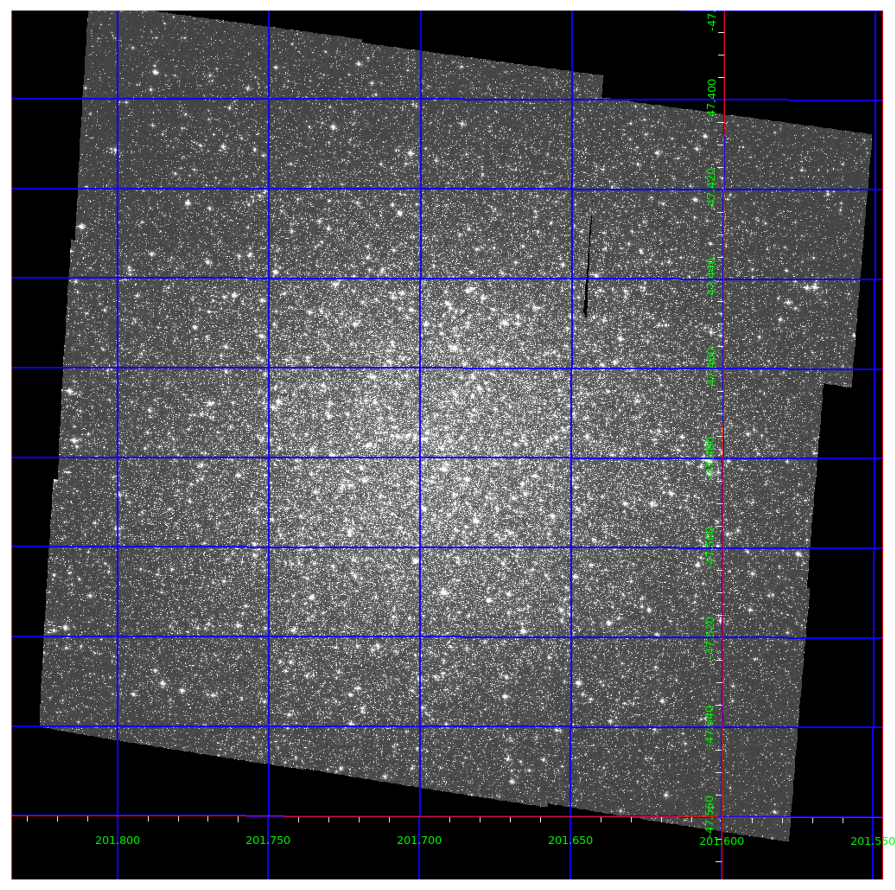
Wide Field Chanel – ACS/WFC 2 4K × 2K CCDs, 1pix ~ 50mas

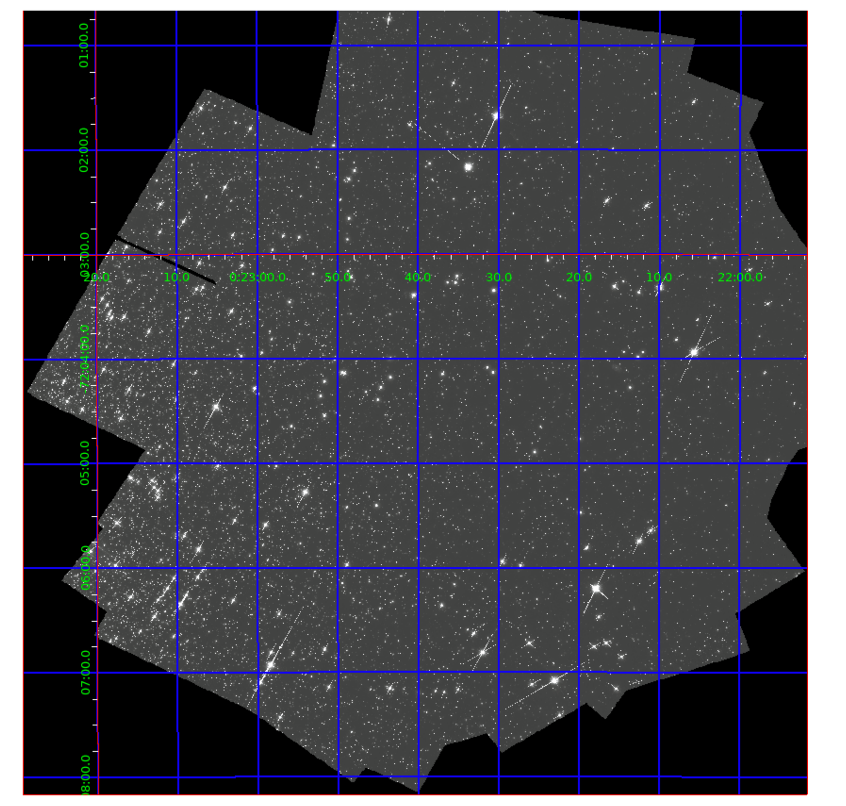
The geometric distortion of the HST/WFC3, and ACS/WFC instruments is characterized by large-scale distortions due to the complexity of the HST optical assembly and can be modeled by a high-order polynomials.

Standard Astrometric Catalogs

Two standard astrometric catalogs (SAC) were used to calibrate the ACS/WFC and WFC3 (Kozhurina-Platais, 2009, 2015).

Right: Astrometric catalog in 47Tuc, (Anderson,2007). FOV ~7″x7″, through F606W ACS/WFC filter.
53K tangential-plane positions on the system of 2MASS.
μ_x, μ_y - proper motions (Anderson, 2015).
ACS/WFC distortion *w.r.t* 47Tuc SAC

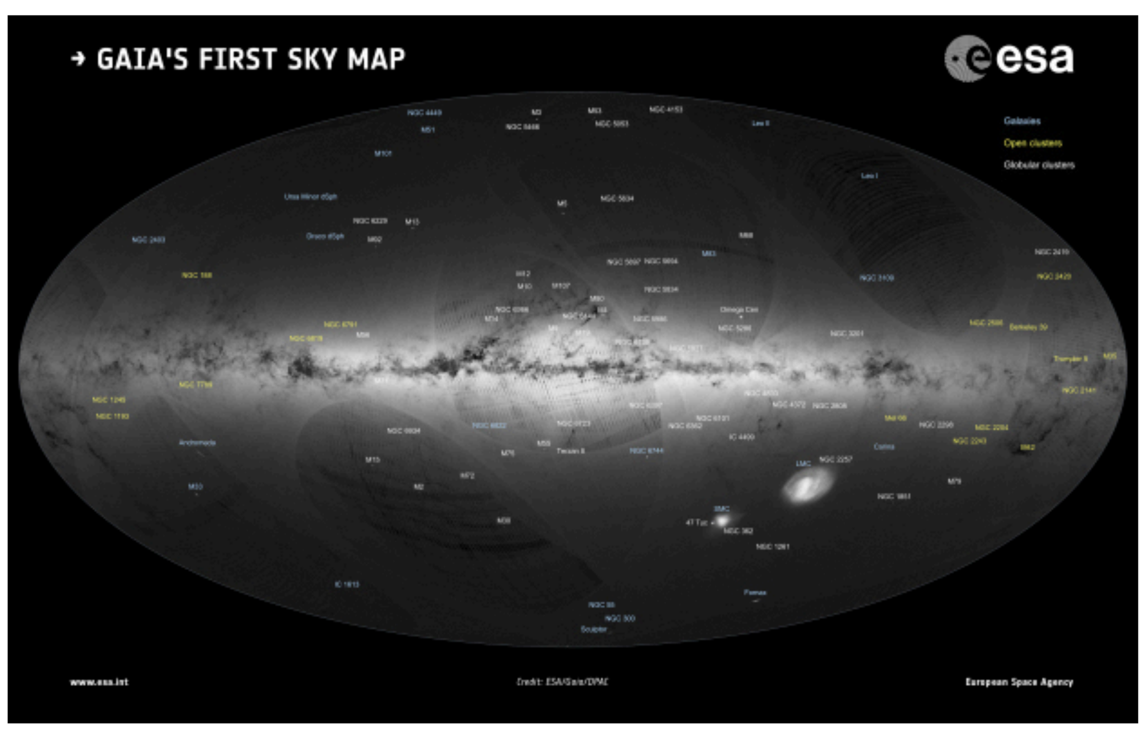




Left: Astrometric catalog (ω Centauri, Anderson & van der Marel, 2010). FOV 10′x10′, through F435W and F625W ACS/WFC filters.
960K tangential-plane positions on the system of 2MASS.
Internal velocity dispersion of ω Centauri σ= 0.9 mas/yr appears as a random noise.
WFC3/UVIS & IR distortion *w.r.t* ω Centauri.

Gaia - Data Release 2

The second Data Release 2 (DR2) of the Gaia mission is an all-sky catalog of positions for 1.1 billion sources (Gaia wide band G mag down to 20.7) from 22 months of observations (Gaia Collaboration et al., 2016a; Gaia Collaboration et al. 2016b). Each source in the catalog has a large number of parameters that fully characterizes its positional accuracy at the epoch of 2015.5



All Gaia sources in DR2 from the Gaia Archive Core System located at European Space Agency (ESA) Center, were retrieved in the vicinity of 47 Tuc and ω Centauri. The Gaia DR2 sources with positional errors < 1 mas were used for comparison between the HST Standard Astrometric Catalogs and Gaia/DR2.

The evaluation of the HST catalog was done by employing the linear transformation of X,Y catalog positions into the system of tangent-plane U,V Gaia positions. Then the linear terms in this transformation between two coordinate systems are used to detect possible residual systematics in the catalog positions and characterize its accuracy:

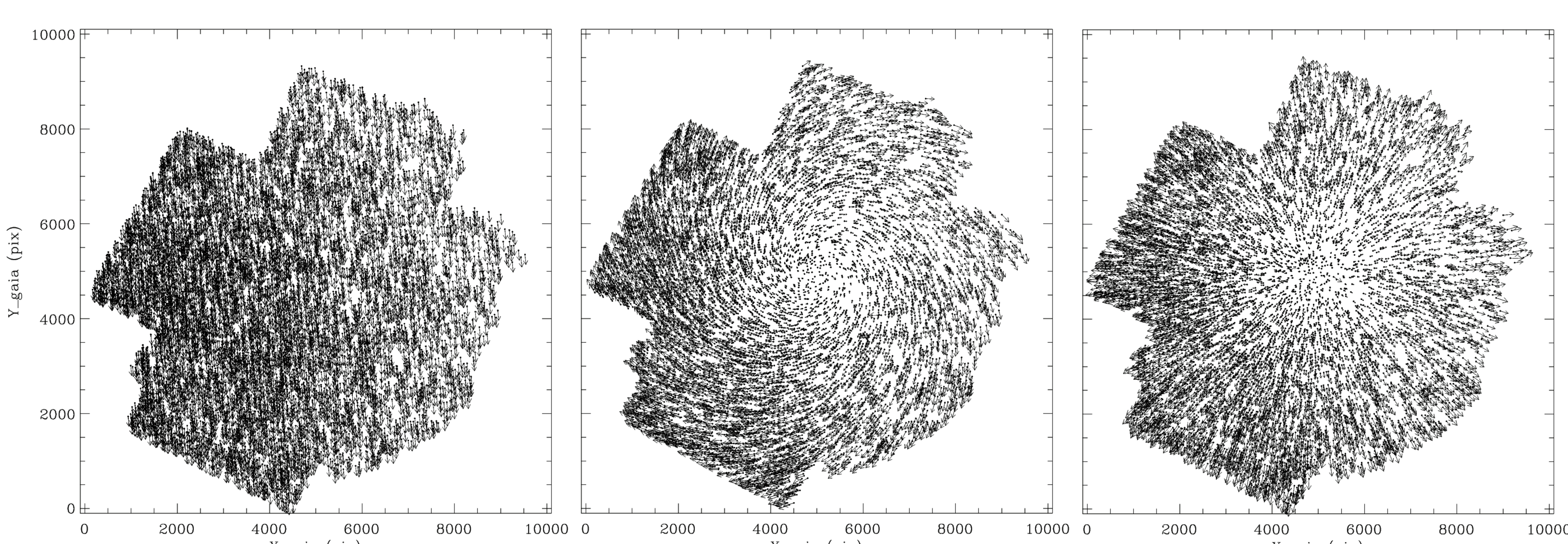
$$U = A_1 + A_2X + A_3Y \quad \text{(Eq.1)}$$

$$V = B_1 + B_2X + B_3Y \quad \text{(Eq.2)}$$

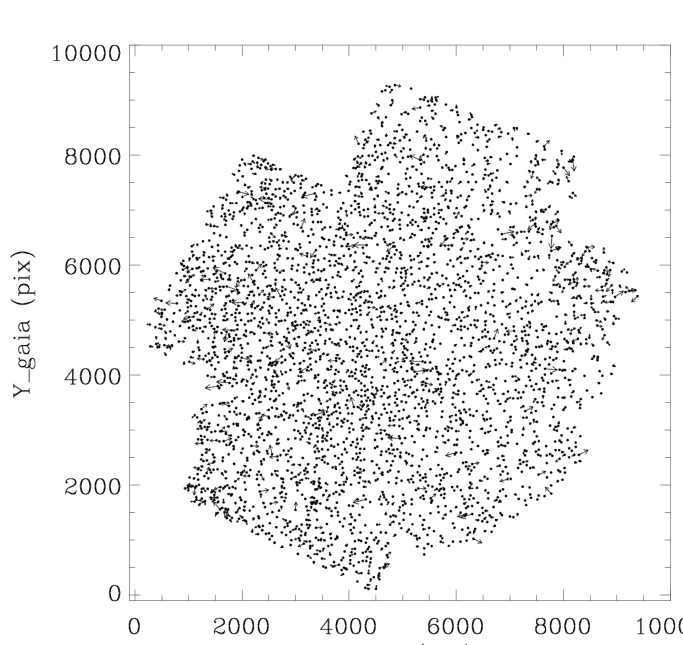
A_1 and B_1 are the constant terms representing an arbitrary offset between two sets of coordinate systems;
A_2, A_3, B_2, B_3 are the linear terms characterizing the scale & rotation between two coordinate systems.

47Tuc SAC *vs* Gaia/DR2

A total of ~6000 common sources between Gaia/DR2 and 47Tuc SAC were used for linear transformation (Eq.1-2). The solution provides an RMS of 0.85 mas in X , and 0.75 mas in Y. This transformation indicates global shifts & rotation and scale difference between two catalogs.



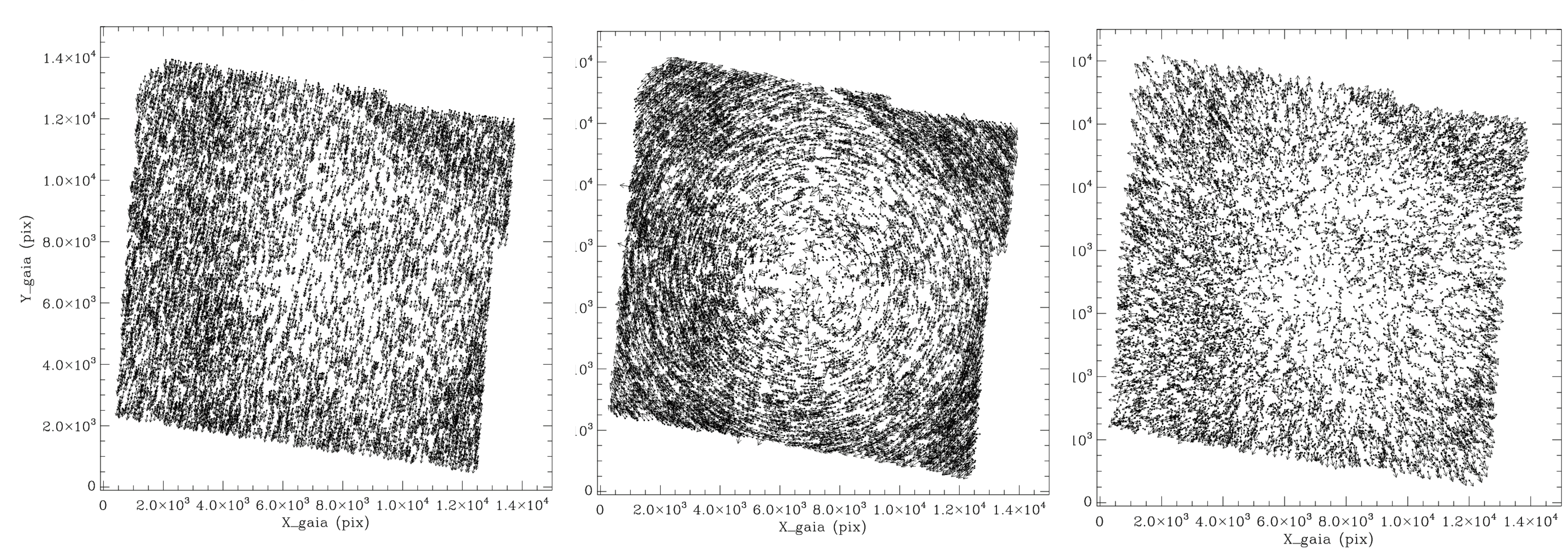
Differences in positions between the Gaia and 47Tuc SAC.
From left to right: Effect of the global offsets in X&Y positions before applying the shifts of ~0.1″ & 0.7″ in **α** and **δ** respectively; Effect of global rotation ~ 0.009° after subtraction of X&Y shifts; The post-correction for global shifts & rotation reveals significant scale difference by 0.004 mas introducing systematic offsets at the far edge of the catalog by 20 mas (0.4 pixels).



The difference between the Gaia and SAC after accounting for global shifts, rotation & scale. Residuals are random now with the largest accidental vector of ~0.15pix, magnified by 1000.

ω Centauri SAC *vs* Gaia/DR2

A total of ~8000 common sources between Gaia/DR2 and ω Centauri SAC were used for linear transformation (Eq.1-2). The solution (LSM) provides an RMS of 8 mas in both X &Y. Main contribution to larger RMS is due to the internal velocity dispersion of over 12 yr ~ 9.6mas (~0.16 pix), and appears as random noise. Similar to 47Tuc, transformation indicates global shifts & rotation and scale difference between two catalogs.



From left to right: Insignificant global offsets in **α** and **δ** << 0.1″ respectively; Effect of global rotation ~0.1° ; The scale difference by 0.003 mas introduces systematic offsets in positions at the far edge (11000 pix) of the catalog by 33 mas (~0.6 pixels).

Similar to 47Tuc SAC, ω Centauri SAC have been corrected for all systematic errors based on Gaia/DR2 down to 0.5 mas.

Afterwards

Finalizing the components of low-order distortions in the HST standard catalogs & improving its accuracy down to the level of 0.5 mas or better, will simultaneously improves the HST astrometric calibration to the true level of 1 mas. Consequently, the improved astrometric calibration of the HST ACS/WFC and WFC3/UVIS instruments will finally eliminate existing uncertainties in several steps of HST images manipulation:

- accurate stacking of various HST images taken with different dither patterns and at different orientations and crossed-instruments;
- cosmic-ray rejection with high accuracy and precision in the drizzled-combined HST images;
- enhancement of the spatial resolution in the HST images;
- deepening of the detection limit.

REFERENCES

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