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The Differential Astrometric Reference Frame on short timescales in the Gaia Era

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Abstract. We use methods of differential astrometry to construct a small field inertial reference frame stable at the micro-arcsecond level. Using Gaia measurements of field angles we look at the influence of the number of reference stars and the stars magnitude as well as astrometric systematics on the total error budget with the help of Gaia-like simulations around the Ecliptic Pole in a differential astrometric scenario. We find that the systematic errors are modeled and reliably estimated to the μas level even in fields with a modest number of 37 stars with G <13 mag over a 0.24 sq. degrees field of view for short timescales of the order of a day for a perfect instrument and with high-cadence observations. Accounting for large-scale calibrations by including the geometric instrument model over such short timescales requires fainter stars down to G=14 mag without diminishing the accuracy of the reference frame.

Keywords. astrometry, reference systems, methods: statistical

1. Modelling and Systematic Effects

In the presence of Earth's atmosphere, limitations to the differential astrometric precision are caused by effects such as refraction, turbulence, etc (Sozzetti, 2005). In its absence, for differential space-based measurements (based on reference objects that are all within a small field), we need to address effects such as: light aberration that is of the order of ~20 arcseconds to first order and a few mas to second order (Klioner 2003); gravitational deflection terms that lead to effects of several mas even at the Ecliptic Pole due to the monopole moment of the Sun (Crosta & Mignard, 2006); parallaxes and proper motions of stars that can be either removed apriori or accounted for in the model; and for changes in the geometric instrument model due to thermal variations and imperfections in the instrument that need to be efficiently calibrated (Lindegren *et al.*, 2012).

The simulation used was produced with AGISLab (Holl *et al.*, 2012) and takes advantage of the high-cadence observations of Gaia during the Ecliptic Pole Scanning Law to simulate the AL and AC field angles of stars taken from the IGSL catalogue (Smart & Nicastro 2014) that lie close to the North Ecliptic Pole (see Abbas *et al.* (2017) for details). In a nutshell, the observing times of the set of stars is restricted to within ± 15 seconds of the NEP t_{obs} for the same CCD column. Successive observations are separated by the time it takes the star to cross from one fiducial line to the next (approx. 4.42 secs). We then adopt the first configuration, i.e. t_{obs} of the NEP at the fiducial line of the first CCD column, on the first scan as the reference frame thereby obtaining the plate/CCD parameters that can transform coordinates on any other frame onto this reference.

The overlapping frames are solved using the Gaussfit software (Jefferys, 1988) through a differential procedure that involves determining the plate solution coefficients through a least squares adjustment and then applying the plate solution to obtain the corresponding coordinates of the target star on the frame. Gaussfit solves the set of equations through a least squares procedure that minimizes the sum of squares of the residuals constrained by the input errors alongwith appropriate constraints on the proper motions and calibration parameters. The distribution of residuals then informs us as to how well the model accounts for various physical or instrumental effects.

2. Results

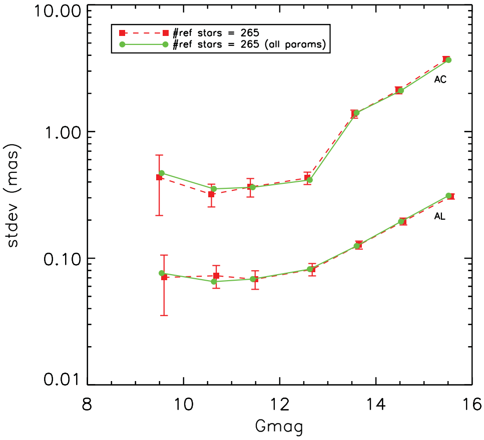

Figure 1. The standard deviations (in mas) from using a linear model to fit the overlapping frames of observations around the NEP in bins of the star's G-magnitude simulated with a perfect instrument and no proper motions (red dashed lines) superposed to the full linear model with all physical and instrumental effects included (green solid lines). The standard deviations shown in AL (lower) and AC (upper curve) have input errors that follow the standard CCD-level location estimation errors. The good agreement implies that a fully linear model is sufficient to describe the various physical and instrumental effects.

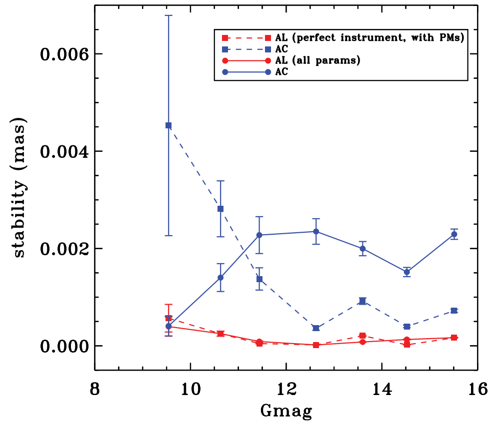

Figure 2. The absolute differences between the standard deviations of the estimated residuals and the input standard uncertainties of the Differential Astrometric Reference Frame in bins of the star's G-magnitude for different models in the AL and AC directions with poisson errors. The dashed lines are for a perfect instrument model (only physical effects included), whereas the solid lines are for the full linear model that involves the inclusion of 576 more unknowns and maintains the μas stability. Lower red lines and upper blue lines are for the AL and AC scan directions respectively. [Colour only in online version.]

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