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On-sky verification of the 6-h periodic basic angle variations of the Gaia satellite

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Abstract. A Basic Angle (BA) of 106.5° separates the view directions of Gaia's two fields of view (FoV). A precise determination of the BA variations (BAV) is essential to guarantee a correct reconstruction of the global astrometric sphere, as residual systematic errors would result in, e.g., a bias in the parallaxes of the final Gaia catalog. The Basic Angle Monitoring (BAM) device, which provides a reliable and accurate estimation of BAV, shows that there exists a ∼1 mas amplitude, 6-h period BA oscillation. It's essential to verify to what extent this signal is caused by real BAV, or is at least in part an effect of the BAM device itself. Here, we propose an astrometric on-sky approach to re-determine the 6-h periodic BAV. The results of this experiment, which treated a full day (17 Oct 2016) of Gaia astrometric data, recover a value for the 6-h oscillation of 1.856±0.857 mas. This is consistent, within the errors, with the BAM finding for that day.

Keywords. periodic basic angle variation, astrometric method, validation

1. Introduction

An early discovery in the Gaia data was that there exists a ∼1 mas amplitude, 6-h period oscillation in the BAM data (Mora *et al.* 2014). An immediate question was whether this signal is caused by a real variation of the BA, or an effect in the BAM device itself. Here, we discuss a method based solely on astrometric measurements of transiting stars to validate whether that 6-h periodic BAV is seen on sky.

2. Astrometric Method

Gaia measures the crossing time of the target image center transiting the CCD fiducial lines (Prusti *et al.* 2016). The proposed method is to analyze the difference of the time required for two targets, coming from the two FoVs and quasi-simultaneously entering the common astrometric focal plane, to cross two consecutive fiducial lines. The quasi-simultaneous entering ensures that the two targets share the same attitude, while the BAV effect will be left in the time difference since they come from different FoVs.

As seen from the left panel of Fig. 1, the transiting time interval of star S_1 from PFoV and star S_2 from FFoV to cross two consecutive fiducial lines can be written as:

$$\Delta t = t_2 - t_1 = \Delta t_\eta + \delta t^{S_1}_{att} + \delta t^{S_1}_{noise} + \Delta t_{f_0} \quad \text{and} \quad \Delta T = T_2 - T_1 = \Delta T_\eta + \delta T^{S_2}_{att} + \delta T^{S_2}_{noise} + \Delta T_{f_1} \tag{2.1}$$

The differential of their transiting time intervals can be written as:

$$\Delta t - \Delta T = (\Delta t_\eta - \Delta T_\eta) + (\delta t^{S_1}_{att} - \delta T^{S_2}_{att}) + (\Delta t_{f_0} - \Delta T_{f_1}) + (\delta t^{S_1}_{noise} - \delta T^{S_2}_{noise}) \tag{2.2}$$

where $(\Delta t_\eta - \Delta T_\eta)$ is the effect of the proper distance along scan difference between two fiducial lines (that we consider constant within 24h); $(\delta t^{S_1}_{att} - \delta T^{S_2}_{att})$ is the effect of differential attitude

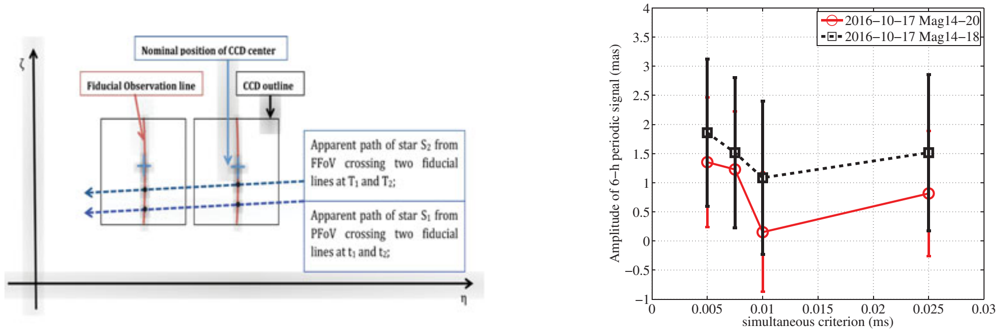

Figure 1. Left: Schematic illustration of quasi-simultaneous observations. The dashed lines are the apparent path of two targets from the two FoVs crossing two fiducial lines at (t_1,t_2) and (T_1,T_2), respectively. Right: The results of the amplitude of the 6-h periodic signal under different simultaneity criterions for day 17 Oct 2016; two magnitude ranges, ($14 \leqslant G \leqslant 20$) and ($14 \leqslant G \leqslant 18$), are compared. The results show that with a larger quasi-simultaneity criterion, the signals become less significant, and, with more bright stars, the SNR is better.

noise. Quasi-simultaneous observations ensure the two targets S_1 and S_2 share the same attitude, so that $(\delta t_{att}^{S_1} - \delta T_{att}^{S_2})$ can be eliminated, at least the low frequency terms; $(\Delta t_{f_0} - \Delta T_{f_1})$ is the effect of the two lines of sight change, which is treated as the basic angle variation effect between t_1 and t_2, that is $\frac{\Delta\Gamma(t_2)-\Delta\Gamma(t_1)}{\Omega} = (\Delta t_{f_0}^{S_1} - \Delta T_{f_1}^{S_2})$. $\delta t_{noise}^{S_1}$ and $\delta T_{noise}^{S_2}$ are the measurement noise effect of the image location estimation of S_1 and S_2, respectively. Of course, the brighter the stars, the better the noise. To least-square the data, we use the following functional form:

$$\Delta\Gamma(t) = \sum_{k=1}^{8} [A_k \cos(k\Omega t) + B_k \sin(k\Omega t)] \tag{2.3}$$

Where A_k and B_k are the coefficients of the periodic variation terms, Ω is the satellite spin angular velocity. $\Delta\Gamma(t)$ represents only the time variations caused by the periodic BAV components. A secular term is present in the data, and was taking into account in the reduction, but it's not shown here.

3. Results and Conclusions

The right panel of Fig. 1 shows the fitting results of the selected data set under different quasi-simultaneity criterions. The results show that the optimal simultaneity criterion is 0.005ms, and the best magnitude range is to G magnitude 18. A 6-h periodic component with an amplitude of 1.856±0.857 mas is found, which is compatible with the BAM results within the errors for that day. The SNR of the result is low and we'll try to improve it by using a data set with a higher density and larger number of bright stars (G magnitude $\leqslant 16$), such as when the satellite is scanning the disk of the Milky Way.

However, the results might be telling a more interesting story, as the lines of sight change measured by this approach represents an average over the whole focal plane; by contrast, the BAM results only represent a specific part of the focal plane. Also, our results are affected by the focal length changes and optical distortion in the two different telescopes.

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