Asteroid Astrometry by Stellar Occultations: Accuracy of existing sample from orbital fitting

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Abstract

Context: The technique of stellar occultations permits not only the determination of asteroid size and shape, but also the retrieval of very accurate astrometry, with a possible relevant impact on the study of dynamical properties. The use of Gaia as reference catalogue and the recent implementation of an improved error model for occultation astrometry offer the opportunity to test its global astrometric performance on the whole existing data set of observed events, dominated by minor planets belonging to the Main Belt.

Aims and Methods: We explore the performance on orbit accuracy brought by reducing occultations by stellar positions given in Gaia DR2 and EDR3, exploited jointly to the new occultation error model. Our goal is to verify that the extreme quality of DR2 and EDR3 brings a sensible progress in the exploitation of occultation astrometry with respect to previous catalogs. We also want to compare the post-fit residuals to the error model. We proceed by accurate orbit adjustment to occultation data, alone or joined to the other available ground-based observation, then analyze the orbit accuracy and the post-fit residuals.

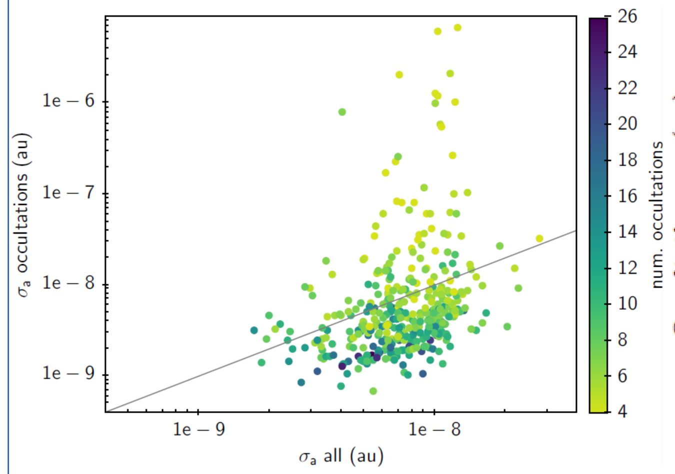
Results and Discussion: We find that Gaia EDR3 and DR2 bring a noticeable improvement to the accuracy of occultation data. This is particularly visible when occultations alone are used, resulting in very good orbits for a large fraction of objects. The joint use of archival data and occultations remains more challenging due to the higher uncertainties and systematic errors of other data.

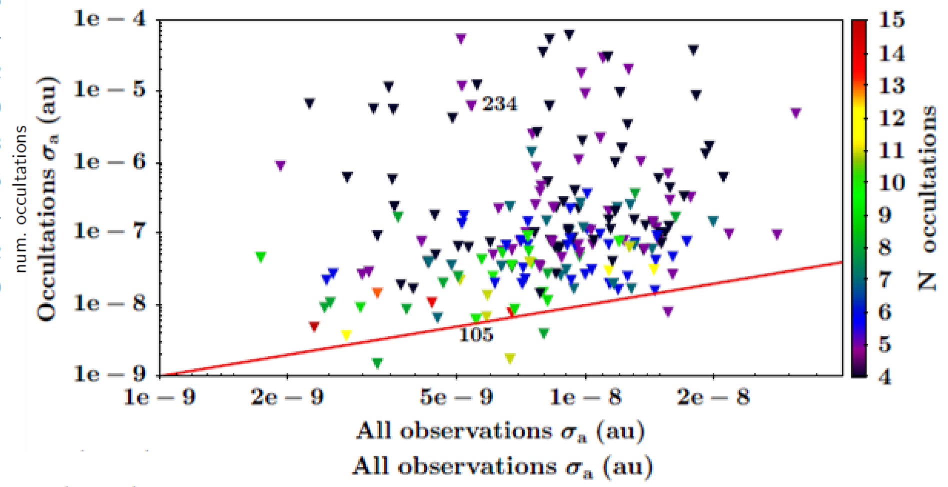
Orbital Quality: Semi-major axis uncertainty

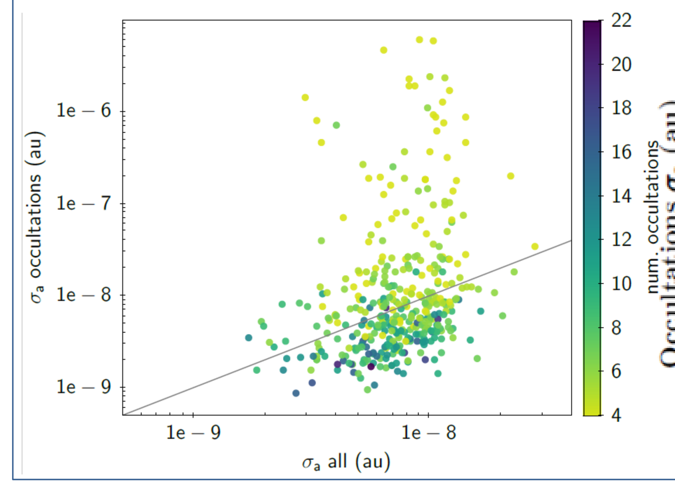
The data used in this work had several sources: the occultations archive[1], Gaia DR2[2] for asteroids and EDR3[3] for stars, JPL for radar observations[4], and astrometry from other methods was extracted from MPC[5]. The initial conditions for each asteroid's orbit were taken from AstDyS-2[6], and the orbital fit was made using OrbFit[7]. The error model used for occultation events was the one explained in Occult[1,8]

For both runs made, we checked in the post-fit analysis:

- The semi-major axis uncertainty (σ_a), comparing the results obtained with DR2 and EDR3 stellar astrometry versus using other sources[9];
- The residual value of each occultation compared to its expected astrometry based on the orbital solution.







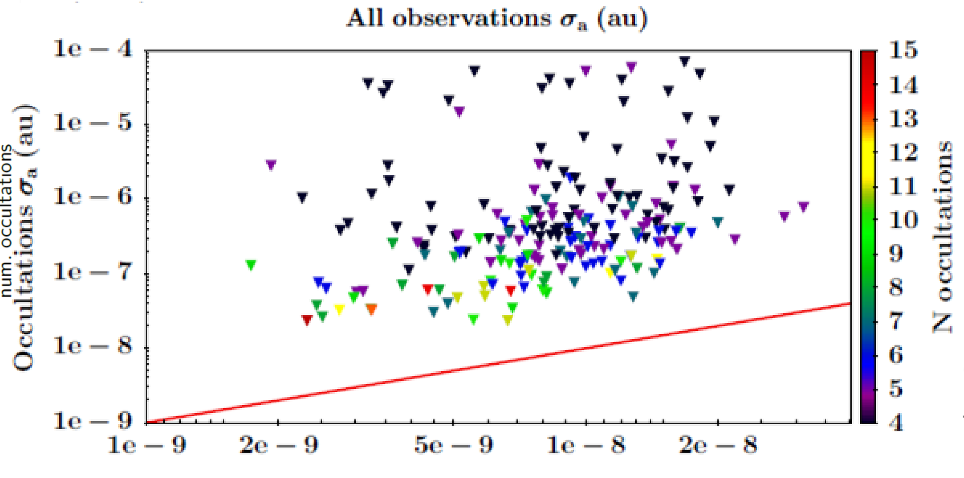


Fig. 4 (Top left) – Occultations vs other methods with EDR3 stellar astrometry. Half of the objects had better orbital quality based on the σ_a with only occultations.

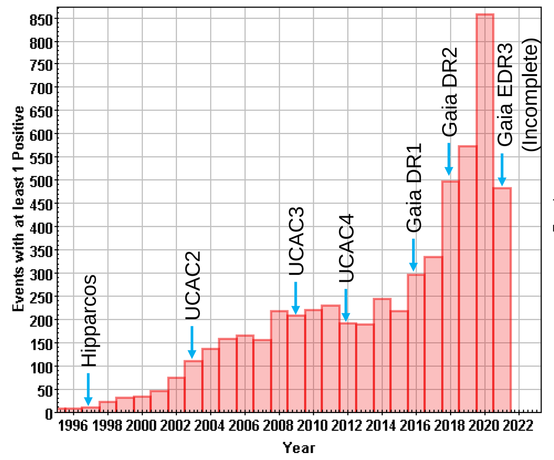
Fig. 5 (Bottom left) – Same analysis, with DR2 astrometry. Slightly worse performance.

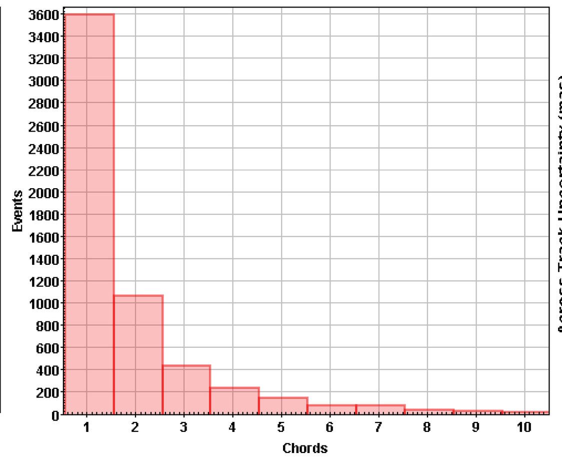
Fig. 6 (Top right) – Previous work done[9], using Gaia's DR1. Only 4 objects were better with only occultations, proving DR2 and EDR3 were major step ups in stellar astrometry.

Fig. 7 (Bottom right) – Same work[9], but with Pre-Gaia catalogues, showing that Gaia is what made occultations this reliable in terms of astrometric precision.

Occultation Census

We used the available archive of Stellar Occultations There are ~5 800 stellar occultations registered between 1961 and mid-2021[1], involving ~1 600 asteroids (occultations by planets and moons were excluded). Each event was fit with the OrbFit tool in two ways, once with only occultations used for the fit, and the other with all currently available observations. For this purpose, only asteroids with 4 or more occultation events have been registered (~500 objects).





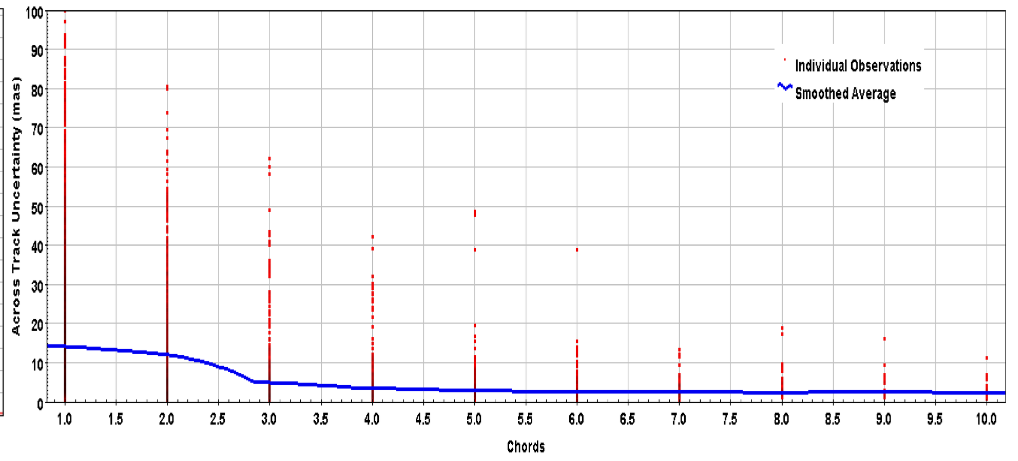


Fig. 1 (Left) – Occultation events in the past 25 years, identifying the release of major star catalogues.

Fig. 2 (Middle) – Number of events per number of chords. Events with more than 10 left out due to rarity.

Fig. 3 (Right) – Across-track (AC) uncertainty, in mas, as a function of the number of chords.

Post-Fit Residuals and Occultations vs Gaia

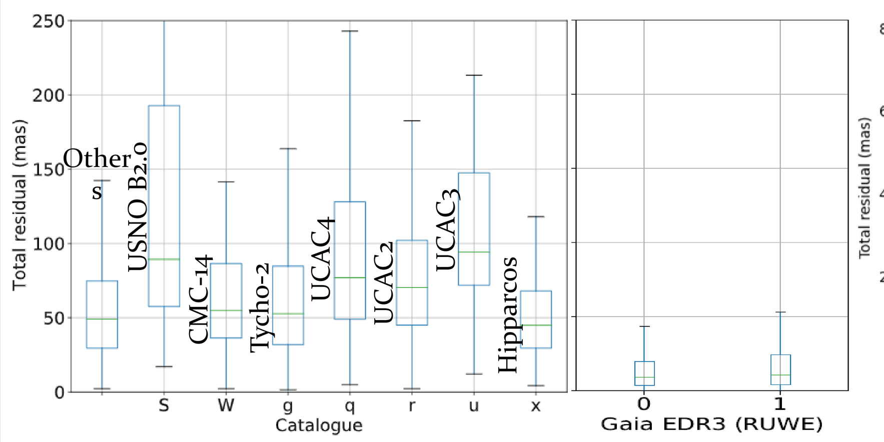


Fig. 8 – Post-fit residuals of occultations as a function of the original catalogue vs their equivalent EDR3 astrometry. EDR3 split between good and bad RUWE[10] (<1.4 and >= 1.4, respectively), a quality indicator that alludes to potential unknown problems in the catalogue.

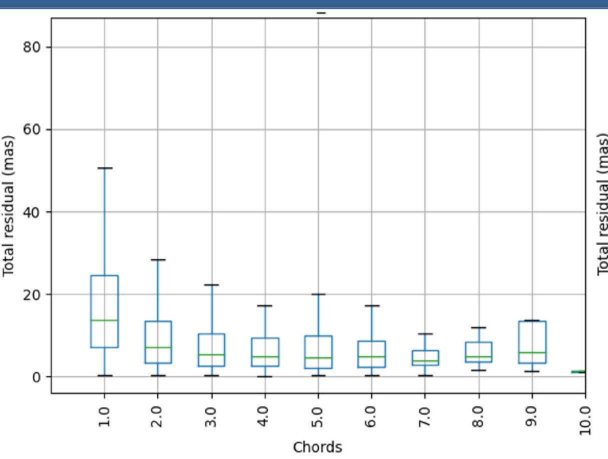


Fig. 9 – Residuals as a function of the number of chords, which shares the behaviour of the error model[8], showing it is well implemented.

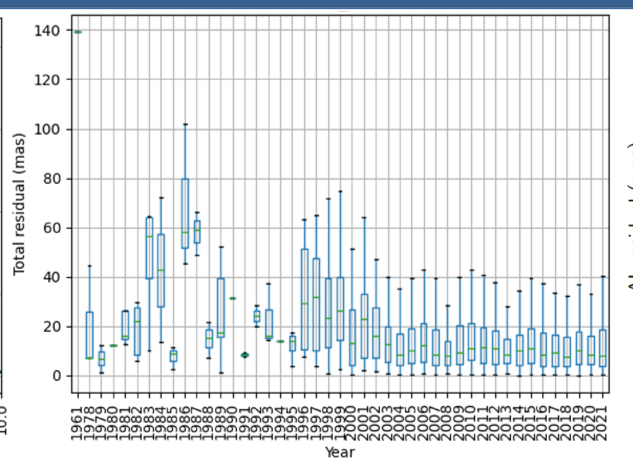


Fig. 10 – Residuals as a function of observation year. Stabilisation in past two decades due to normalization of the use of CCD/CMOS with GPS timing.

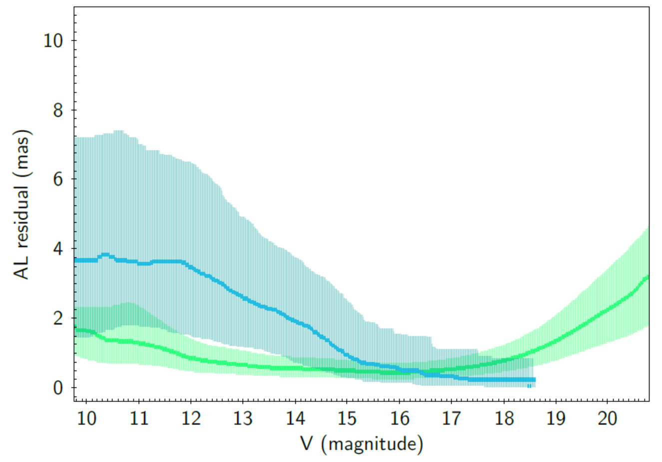


Fig.11 – Occultations are good complement to Gaia, as they reach similar levels of precision, and show an inverse behaviour with asteroid magnitude Instead of Gaia's direct relation.

Conclusions

Gaia has brought a new level of reliability to occultations, including older ones with the star's Gaia solution propagated.

We also verified that Gaia and occultations complement each other well in terms of magnitude ranges for the asteroids, and occultations can provide Gaia-level measurements beyond the mission's end[11].

An occultations campaign can go a long way to improve the orbital knowledge of asteroids, so it is a good method to study objects from interesting groups, like NEA or TNO[12].

The results from this work were written by all the authors into a paper, which is currently under revisions.

References

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11. Gaia mission ends in 2024. Expected Gaia Data Releases: https://www.cosmos.esa.int/web/gaia/release;
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