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The future of stellar occultations by distant solar system bodies: Perspectives from the Gaia astrometry and the deep sky surveys

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ABSTRACT

Distant objects in the solar system are crucial to better understand the history and evolution of its outskirts. The stellar occultation technique allows the determination of their sizes and shapes with kilometric accuracy, a detailed investigation of their immediate vicinities, as well as the detection of tenuous atmospheres. The prediction of such events is a key point in this study, and yet accurate enough predictions are available to a handful of objects only. In this work, we briefly discuss the dramatic impact that both the astrometry from the Gaia space mission and the deep sky surveys – the Large Synoptic Survey Telescope in particular – will have on the prediction of stellar occultations and how they may influence the future of the study of distant small solar system bodies through this technique.

1. Introduction

Stellar occultation is a powerful technique that allows the determination of sizes and shapes of distant solar system objects with kilometric accuracy (Elliot et al., 2010; Sicardy et al., 2011a; Ortiz et al., 2012, 2017; Braga-Ribas et al., 2013; Gomes-Júnior et al., 2015; Braga-Ribas et al., 2014) (leading to albedos, densities), an investigation of their immediate vicinities (Ortiz et al., 2015, 2017; Braga-Ribas et al., 2014) (telling about the presence of rings, satellites, jets), and that may reveal tenuous - down to few nanobars - atmospheres (Sicardy et al., 2011a; Ortiz et al., 2012; Ortiz et al., 2017; Widemann et al., 2009).

Accurate predictions[1] of occultation events are the very first step for the full success in the use of the technique. The relevance of this step is such that its improvement inevitably – and positively – affects the future of the study of distant small solar system bodies through stellar occultations.

Thanks to the astrometry from the Gaia space mission and the deep sky surveys, a huge advance in this study is closer than ever. More specifically, the first will provide over 1 billion stars with unprecedented (sub milli-to micro-arcsecond) astrometric accuracy (see, for instance Mignard et al. (2005); Prusti et al. (2016)), while the latter, like the Large Synoptic Survey Telescope (LSST), will provide images from which short-term accurate ephemerides[2] of faint (down to $r \sim 24.5$ in the case of the LSST (Abell et al, 2009) solar system bodies can be determined. As a result, this will lead us to milli-arcsecond (mas) level - or better - predictions to tens of thousands of TNOs as explained in the next two sections.

2. The power of Gaia

Fig. 1 shows the improvement in accuracy, thanks to Gaia, of the ephemeris of (10199) Chariklo as determined by our orbit fitting tool NIMA (Desmars et al., 2015). In that figure, the most relevant difference between its upper and lower panels is that the first is based on pre-Gaia astrometry, whereas the latter is dominated by Gaia DR1 (Brown et al, 2016) -based positions (Lindegren et al., 2016) (but see also Katz and

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[1] Where and when, on the Earth, an occultation event can be observed.

[2] Ephemerides whose uncertainties, for 1–3 years after the most recent observation used in the determination of these ephemerides, are smaller than the angular size of the respective occulting bodies as seen from the Earth.

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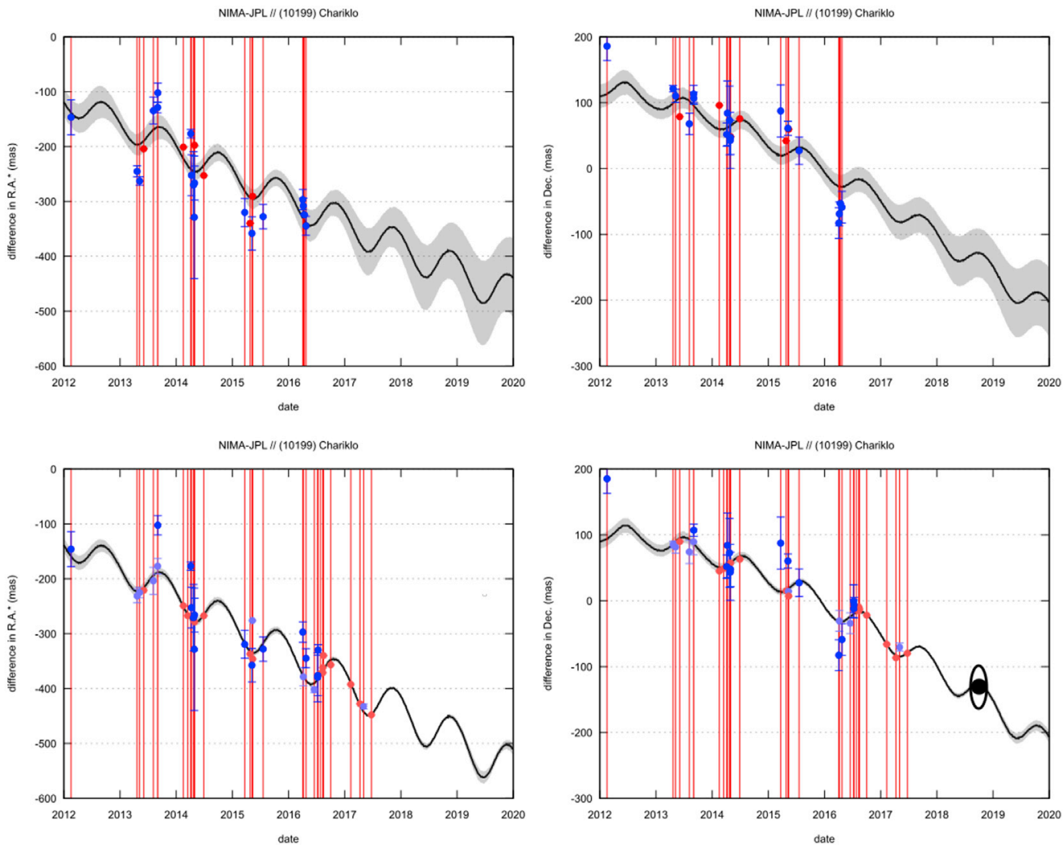

Fig. 1. Orbit improvement for Chariklo. Versions 8 (2016/JUN, upper panels) and 13 (2017/JUL, lower panels, the most recent one on the date this paper was written) of Chariklo's orbit as determined by NIMA. In all plots we have: differences in right ascension and declination (black curves) in the sense NIMA ephemeris minus the Jet Propulsion Laboratory (JPL) ephemeris (version: JPL20); 1-σ uncertainty (grey area) of NIMA ephemeris; red points: differences between positions obtained from stellar occultations and those from the JPL ephemeris; dark/light blue points: differences between positions obtained from direct imaging of Chariklo and those from the JPL ephemeris; red vertical segments are provided for an easier visual correspondence between the dots and the dates associated to them; error bars represent the standard deviation of the observational residuals from the same night and same observatory. Red dots, in particular, represent one observation each so that no error bar is attributed to them. In the upper panels, all positions are based on pre-Gaia astrometric catalogues. In the lower panels, red and light blue points are now Gaia DR1-based. Some of these light blue points are a re-reduction of the non Gaia-based dark blue points in the upper panels. Note how well the Gaia-based positions agree with the orbit. Chariklo and its rings are also roughly represented in the lower right panel. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Brown (2017) for a foretaste of the impressive data that will be delivered by the Gaia Data Release 2 from April 2018).

It should be noted that the uncertainty in the most recent version[3] of that ephemeris (lower panels) is significantly smaller than the angular size of Chariklo throughout 2018. And there are more accurate data and orbits to come! Note that all positions of Chariklo used here are from ground-based observations and that Gaia DR1 does not provide positions of small solar system bodies. Thousands of them, however, will be available in Data Release 2 (Katz and Brown, 2017; Tanga, 2017).

Currently, orbits determined by NIMA discriminates observational data (positions) of solar system bodies between those obtained from direct imaging and those obtained from occultations. It also discriminates between Gaia- and non Gaia-based positions. In the lower panels of Fig. 1, Gaia-based positions are given by the red and light blue points whereas non Gaia-based positions are given by the dark blue points. These discriminations are expressed in terms of weights.

Fig. 2 indicates the different weights attributed to the positions mentioned above. Astrometric data from an occultation is obtained from the relative position of the occulting body with respect to that of the occulted star. This relative position is determined with mas level accuracy (see, for instance Sicardy et al. (2011b)). Therefore, accurate stellar

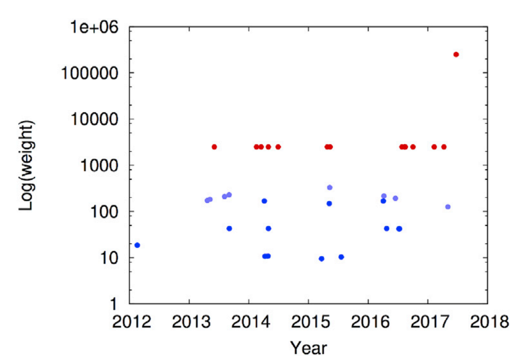

Fig. 2. Logarithm of the weights (σ^{-2}) attributed to the points shown in the lower panels of Fig. 1. The same colour code is used. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

positions, as those given by the Gaia mission, provide mas level accurate positions of the occulting (solar system) body. In this context, it is natural that these points (red dots in Fig. 2) have the largest weights.

Table 1 quantifies the effect of the weighing scheme (see Desmars et al. (2015) for more details), that results in an orbit heavily dominated by the Gaia-based positions with emphasis to those from occultations.

[3] On the date this paper was written.