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Testing the inversion of the asteroids' Gaia photometry

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Abstract

We have generated photometric simulations for Gaia-like observations for 10.359 objects having a triaxial ellipsoid shape, with their spin axis directions homogeneously distributed. Using a genetic algorithm we have performed the inversion of this dataset and we analysed the results obtained. The reliability of the inversion performance presents a correlation with the asteroid pole latitude and the body elongation.

1. Introduction

The potential of the sparse photometric data to provide physical information about asteroids has been extensively proved by several authors. The main challenge to be solved when inverting sparse data is the correct determination of the rotation period. One possible approach to solve this issue is to fit an asteroid model on a given period interval (Kaasalainen 2004). Using a convex representation of the asteroid's body shape, some authors have successfully used this technique to solve the inversion problem for a couple of hundreds of asteroids (e.g. Durech et al. 2008 or Hanus et al. 2013). If any "dense" lightcurve is available for the object, the interval is reduced to some boundaries around the observed period, saving a lot of computational time and increasing the solution reliability. But unfortunately obtaining full lightcurves of asteroids is a highly time consuming task, thus such observations are actually available only for 4.000 asteroids (stored in the Minor Planet Lightcurve Database). It is estimated that the ESA Gaia mission will produce photometric measurements for a number of the order of 100.000 asteroids, which means that for the majority of inversion trials the period scanning shall be extended to all the possible period values, namely from 2 to 100 hours. However, the inversion technique specifically developed to invert the Gaia sparse data of asteroids (Cellino et al. 2006), is based on a genetic algorithm, for which the solution of the inversion problem is the best fit of a set of parameters that have been obtained by means of several random variations during a "mutation" process. This solution is more efficient in terms of CPU time and its capability to derive the correct inversion solution have been shown in some experiments with Gaia simulated observations and also with real data collected during the ESA Hipparcos mission (Cellino et al. 2009). On the other hand, adding existing ground-based observations for a given asteroid is not speeding up the performance of this method (in fact the inversion became slower as greater the number of observational points is) and whether such observations can improve or not this method performance is a topic that needs to be studied. Now that all the parameters of the Gaia scanning law are fixed, we are able to predict exactly the observation sequence for SSO. This means that we can plan to observe from the ground at the same time as Gaia. For example, we can very easily add a full rotational (dense) lightcurve around (or very close to) an isolated observation by Gaia. The link between the two data sets would then be very strong, as a single Gaia measurement provides a very precise absolute measurement of brightness that can be used to calibrate a ground-based lightcurve obtained at the same epoch. The question is: how many such lightcurves we need (per object) to obtain a substantial improvement of the inversion? Maybe a single one? Or more? Therefore, our work is thought to address such questions and lay the foundations for a collaboration involving coordinated observations from the ground. Moreover, we focus on assessing the reliability of the solutions derived with the Gaia inversion method under all the possible asteroids' pole situations, different rotation periods and checking the impact of "realistic" asteroids simulations with nonconvex shapes representation. Such work is necessary to correctly analyse the results that will be generated at the end of Gaia's mission, when asteroids' photometric observations will be available.

2. Inversion test with simulations

With the aim of testing the performance of the inversion algorithm, we simulated Gaia-like observations for 10.359 objects having a triaxial ellipsoid shape, with their spin axis directions homogeneously distributed. In order to generate the observational epochs for each object, we have used the Gaia mission simulator developed by F. Mignard and P. Tanga at the Observatoir de la Cote d'Azur, with the majority of asteroids having a typical main belt orbit, but also with some Trojans and NEAs. The population period distribution was generated following a Maxwellian distribution like the one described in Pravec, Harris Michalowski (2002) for asteroids with larger diameter than 40 km. The disk-integrated photometry simulations have been generated using a Z-Buffer standard graphic method described by Catmull (1974). We note that more simple and efficient methods exist to generate the brightness of a triaxial ellipsoid, but the main objective of that test is to ensure that the algorithm which will be later used to generate photometric simulations for nonconvex shapes is well performing and we are not adding any bias in our analysis. The inversion run with the 10.359 objects was executed using the Poznań's observatory cluster that consists of 27 workstations equipped with a 6 core AMD processor (3 GHz), and the outcome was obtained after one full day of computations. Finally, we contaminated our photometric simulations with a Gaussian noise for different values of σ, and we repeated the inversion process for each case.

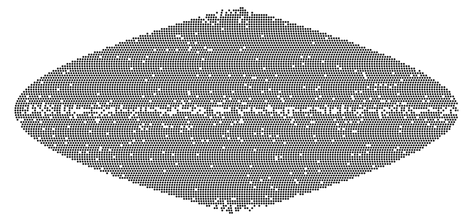

Figure 1: Sinusoidal projection showing the distribution of the "warnings" (white points, not accepted solutions) received from the inversion algorithm.

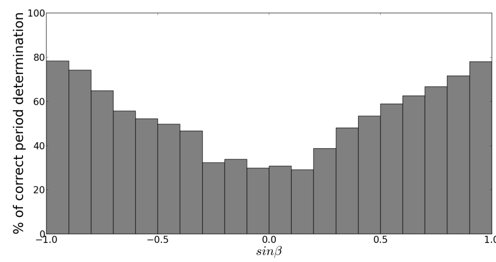

Figure 2: Histogram showing the percent of correct period determinations within a 0.01% accuracy as a function of the pole latitude. The simulations were generated using triaxial ellipsoids and a Gaussian noise with $\sigma = 0.1$.

3. Preliminary results

We have detected a correlation between the inversion reliability and the pole latitude of the asteroids. In particular, the solutions not accepted by the algorithm are mainly concentrated for asteroids with low latitude poles, as can be seen in Fig.1.

On the other hand, the accepted inversion trials of the simulation data with Gaussian noise are better as greater is the latitude pole. As an example, the histogram in Fig.2 is showing the percent of correct inversion solutions when feeding the algorithm with noisy simulations ($\sigma = 0.1$).

The results are also showing a relation between the asteroid shape and the inversion reliability: the results are better as more elongated the body is. All these results might be explained in terms of distribution of the photometric measurements for a given asteroid: when one approaches a pole-on view (what is only possible for asteroids with low pole latitudes) the resulting lightcurve is almost flat, thus the quantity of physical information collected for the sparse-in-time observations might be restricted under such configurations.

4. Conclusions and future work

This preliminary results suggest that the Gaia asteroids catalogue might be biased. In particular, the inversion algorithm will tend to miss solutions for nearly spherical objects and low pole latitudes. The reliability of the derived solutions will also depend on the pole latitude and the asteroid brightness. In order to minimize such effects we propose to combine ground-based photometric observations with the Gaia sparse-in-time measurements and study their impact on the inversion results for the problematic cases.

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