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ASTEROID MASS ESTIMATION WITH MARKOV-CHAIN MONTE CARLO

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Abstract

1. Introduction

Estimates for asteroid masses are based on their gravitational perturbations on the orbits of other objects such as Mars, spacecraft, or other asteroids and/or their satellites. In the case of asteroid-asteroid perturbations, this leads to a 13-dimensional inverse problem at minimum where the aim is to derive the mass of the perturbing asteroid and six orbital elements for both the perturbing asteroid and the test asteroid by fitting their trajectories to their observed positions. The fitting is typically carried out with linearized methods, in particular the least-squares method. These methods need to make certain assumptions regarding the shape of the probability distributions of the model parameters to describe the parameters' uncertainties. This is problematic as these assumptions have not been validated and, in fact, are known to be misleading [2].

2. Algorithm

We have developed a new Markov-chain Monte Carlo-based algorithm for mass estimation [5, 6, 7] using asteroid-asteroid perturbations. We use the Adaptive Metropolis scheme [4] which constantly updates the used covariance matrices based on the chain itself in order to ensure suitable shapes for the proposal distributions. This algorithm is implemented into a fork of the OpenOrb asteroid-orbit-computation software [3]. We now extend the algorithm to use multiple massless test asteroids simultaneously. We also include a proper observational error model [1] in our calculations.

3. Results

We present results computed with our algorithms and compare them to published results for our chosen asteroids. Our results agree with the published nominal mass estimates, but suggest that the published uncertainties may be misleading as a consequence of using linearized mass-estimation methods. Fig. 1 shows example results for asteroid (19) Fortuna in the form of weighted histograms of all accepted masses in the chain for two separate runs with different test asteroids. This clearly showcases the systematic effect that the choice of test asteroid can have on the results: as the perturber is the same in both cases, it naturally follows that the correct mass is also the same. In practice, however, we get very different results with different test asteroids, though the correct mass remains within the uncertainties of both distributions. If both test asteroids were used at the same time, one would expect that the resulting distribution would be similar to the overlapping area of the two separate histograms, as the perturber mass would have to fit both objects at once.

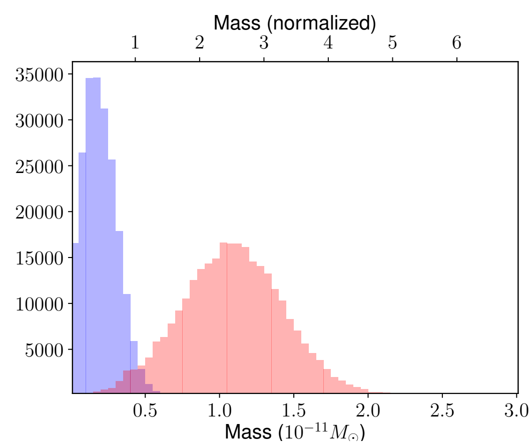

Figure 1: Results of the MCMC algorithm applied to asteroid pairs 19-3486 (blue) and 19-27799 (red). The lower x-axis represents mass in solar masses while the upper x-axis is normalized such that unity equals the weighted average of published values [2].

4. Summary and Conclusions

We have developed a new MCMC-based asteroid mass estimation algorithm, which gives results in line with previous literature values and suggests that uncertainties of prior estimates may be misleading as a consequence of using linearized methods. Future work includes further improvements to our algorithm (such as automated outlier rejection and accounting for systematic offsets in the astrometry) as well as application to Gaia Data Release 2 data to be released in April 2018.

Acknowledgments

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