Uncertainties in determining asteroid rotational periods

Karolina Dziadura[1] and Dagmara Oszkiewicz[1]

1. Institute Astronomical Observatory, Adam Mickiewicz University, Sloneczna 36, 60-286 Poznań, Poland

The goal of this work is to estimate the relationship between asteroid rotational period uncertainty and following quanatities: lightcurve amplitude, number of nights the object was observed, photometric uncertainty of a single measurement. Assessing these relationships is crucial for planning future observations.

1 Introduction

The asteroid rotational period is a fundamental parameter used to study properties and evolution of asteroid populations. The spin state distribution is used to study spin evolution of asteroids, and the spin-state limit (so-called spin barrier) provides context for understanding asteroid internal structures (monoliths, fractionated bodies, rubble piles) (Warner et al., 2009). Those are then of great importance for problems such as for example predicting Earth impact consequences or understanding formation of binary asteroids. Small asteroids ($<$ 50 km in diameter) are thought to be affected by so-called YORP effect (thermal effect of increasing or decreasing of the asteroid periods and modifying the rotational pole coordinates), whereas large asteroids are thought to have preserved primordial (from the time when the asteroids were formed) spin states. Additionally, direction of rotation (prograte vs. retrograde) determines the dynamical migration of asteroids via so-called Yarkovsky effect. Small, prograde rotating asteroids migrate outwards the Solar System, whereas retrograde – inwards. Understanding of the rotational period uncertainties and what influence them is therefore crucial for correct interpretation of key topics in planetary science. In this work we study the influence of timing of observations, lightcurve amplitudes and observing noise on the rotational period uncertainty.

2 The data simulation

Asteroid rotational periods are typically calculated from lightcurves. We have simulated asteroids lightcurves as a sinusoids, assuming rotational period, lightcurve amplitude, photometric uncertaninty of a single measurement, number of observing nights, frequency of exposures and frequency of observations. The simulated lightcurves were then used to compute asteroid rotational periods and uncertainties using standard Fourier series fitting. This way of simulating lightcurves does not take into consideration how the lightcurve morphology changes with the phase angle (Dziadura, 2017). The assumed parameters are also considered to be uncorrelated.

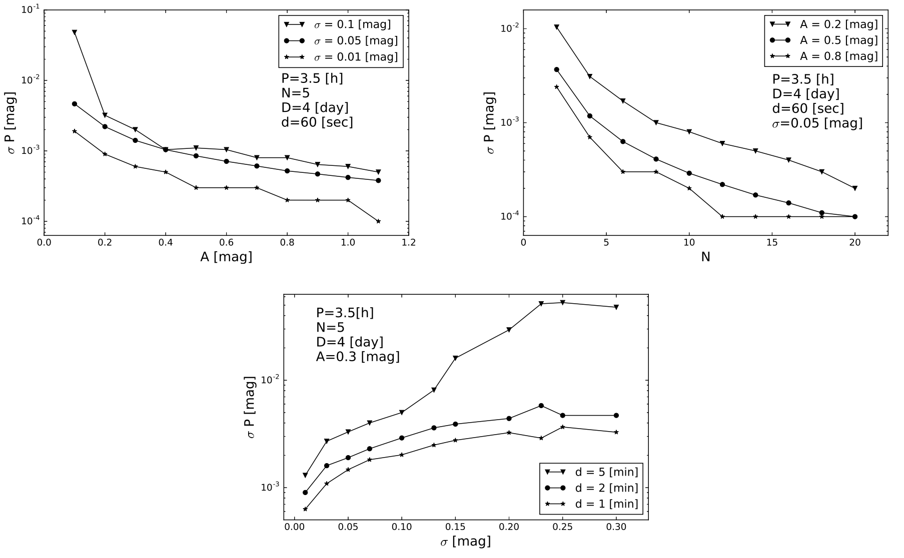

Fig. 1: The dependence of asteroid rotational period uncertainty and: lightcurve amplitude (top left), number of observation nights (top right), and photometric uncertainty of a single measurement (bottom). Simulated rotational period P, number of lightcurves N, frequency of observations D, frequency of exposures d, amplitude A and photometric noise σ are labeled in each panel.

3 Determination of rotation period

Assuming that the lightcurves are periodic and do not change their shape, the rotation of the asteroid can be determined using a Fourier series (Pravec et al., 2000; Kwiatkowski et al., 2009):

$$V(t) = C_0 + \sum_{n=1}^{m} C_n \cos\frac{2\pi n}{P}(t - t_0) + S_n \sin\frac{2\pi n}{P}(t - t_0), \tag{1}$$

where: C_0, C_n, S_n – are coefficients of Fourier series, t – time of observation, t_0 – zero-point time (epoch), m – Fourier series order, and P – rotational period.

Coefficients C_0, C_n, S_n are determined for assumed period P, next the model brightness is calculated for each observation time $t_1 ... t_N$. Then χ^2 function is calculated to measure the deviation of the Fourier series from the points of observations.

The determination of Fourier series coefficients is repeated for different period values P (in interval $P_1 ... P_k$ with a step δP). This results in periodogram – the dependence of period P from χ^2. The best solution can be found in the minimum of periodogram (the lowest χ^2, the lowest deviation of the model from observations).

To determine the uncertainty of the result, our code calculates the probability density function. Then the code determines interval of periods covering 99.7300028% probability mass using the 3σ criterion (Dziadura, 2017).

4 Results

To determine the uncertainty of the rotation period from observational parameters, datasets of different elements were simulated. Then the rotation period and its uncertainty were determined using a Fourier series for each dataset.

Our results are presented in Fig. 1. In the left figure we present the calculated rotational period uncertainty as a function of asteroid lightcurve amplitude (from 0.2 to 1.2 mag) and assumed photometric uncertainty of a single measurement (from 0.01 to 0.1 mag). As expected, the rotational period uncertainty decreases with increasing lightcurve amplitude. The trend is similar for the different photometric uncertanty assumed. The largest photometric uncertainty results in the largest rotational period uncertainty.

In the right figure we present the calculated rotational period uncertainty as a function of the number of nights the object was observed (from 2 to 20) and assumed the lightcurve amplitude (from 0.2 to 0.8 mag). As expected, the rotational period uncertainty decreases with the number of observing nights. The trend is similar for the different lightcurve amplitude assumed. The largest lightcurve amplitude results in the smallest rotational period uncertainty.

In the bottom panel, we present the calculated rotational period uncertainty as a function of photometric uncertainty of a single measurement (from 0.01 to 0.3 mag) and the assumed length of exposure (from 1 to 5 min). As expected, the rotational period uncertainty increases with photometric uncertainty. The trend is similar for the different lightcurve amplitude assumed. The largest lightcurve amplitude results in the smallest rotational period uncertainty.

5 Conclusions

To obtain higher accuracy of the synodic period in the simulated data, it is recommended to reduce photometric uncertainty, increase the number of lightcurves, increase the interval between successive lightcurves, and reduce intervals between successive exposures. The minimum exposure time is related to the diameter of the telescope and the maximum acceptable noise. In practice, reducing the distance between exposures may not be possible. Exposure time may be increased to reduce the photometric uncertainty. The maximum exposure time is limited by the seeing and movement of the asteroid in the sky plane and is only modifiable to a certain degree. The best strategy for achieving the lowest uncertainty of the rotation period is therefore to obtain more light curves and increase observing baseline (time period covered by observations).

References

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