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Asteroid phase-curves from Gaia-calibrated data

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Abstract

We use asteroid differential photometry gathered in the past decades together with the Gaia stellar catalogue (as photometric standards) to obtain relative magnitudes. The obtained magnitudes are then used to fit the multi-opposition phase curves in several ways depending on data quality.

1. Introduction

Modern CCD photometric observations of asteroids are traditionally done using differential photometry. That is only the differences between the asteroid and a comparison star are obtained without placing the measurements on a standard photometric system. Differential photometry has been used for decades and is sufficient for a variety of applications, like determining the rotational period, spin axis orientation and shape. It is however not very useful for determining asteroid absolute magnitudes and phase curve parameters, where relative magnitudes are required.

Obtaining relative photometry is typically avoided due to lack of photometric standards in the field of view and/or lack of photometric weather during observations. Thus not many accurately determined phase curves based on dense data (such as those in for example [1] [2]) are available (low accuracy phase curves are available for several hundreds of asteroids [3], [4]).

This problem can be completely solved with the Gaia mission catalogue. Gaia is a space observatory launched in 2013 by the European Space Agency [5] [6]. The ongoing mission is currently cataloging approximately 1 billion astronomical objects. The first catalogue (DR1) was released in 2016. Subsequent releases are planned in stages with the last, fifth (containing asteroid data) planned in 2022. Due to the number of stars, high photometric precision and accuracy, the stars measured by Gaia are suitable to use as photometric standards. Most of the historical CCD images contain Gaia photometric stars, making it possible to re-measure asteroid magnitudes from the images and by placing them on a standard photometric system obtain relative measurements.

2. Data

We have gathered a substantial 7.26 TB of possible data to use in the project. In Table 1 we summarize the data available for this project. The data secured stretch decades of observations (from 1992 until now) and contain multiple lightcurves for thousands of asteroids. Most photometric observations in our datasets were taken with a Cousins R filter, but some with Johnson V filter, Sloan r', or a wide-band VR filter. Data obtained at the RBT telescope are obtained mainly in the wide-band L (luminosity) filter. Some observations are done in so called Open filter (unfiltered) and those might be challenging to convert to relative photometry. However those constitute a small fraction of our entire dataset. It is possible to include further datasets if available during the course of the project.

Telescope	Aperture	Instrument	Institute
PTP	0.4m	SBIG	PO
RBT	0.8 m	SBIG	PO
various	various	various	CSSS
31-inch	0.8m	nasa31	LO
Hall	1.1m	nasa42	LO
Perkins	1.8m	prism	LO

Table 1: Telescope data available for this project. Abbreviations: PO- Institute Astronomical Observatory, Adam Mickiewicz University in Poznań, LO- Lowell Observatory, CSS - Center for Solar System Studies.

3. Relative magnitude calibration

We will perform standard photometric reductions with bias and flat-field correction followed by ordinary aperture photometry. We will use the Gaia catalogue to obtain the G nightly zero-points. The G magnitude relates to Sloan r' linearly: $r'_{Sloan} = G + 0.066$. We will use two or more comparison stars in each field, of much higher signal-to-noise than the target (when possible). When possible we will select the comparison stars to have near-asteroidal colors. For asteroids near their stationary points, we might be able to use the same comparison star sets on multiple nights. The measuring apertures will be adjusted depending on each image quality.

4. Phase curve fitting

For asteroids with data from a single opposition we will use the standard Fourier fitting to determine magnitude shifts between the different lightcurves. Those will then be directly used to fit phase curves and obtain absolute magnitudes. For multi-opposition data we can use two approaches. First for asteroids with limited data we would use approach similar to [3] where average aspect corrections were adopted. For sparse and low quality objects modified phase functions [9] will be used. For asteroids with larger amounts of data we will use more accurate brightness model, where apparent magnitude is given by [7]:

$$V(\alpha, \eta) = 5\log_{10}(r\Delta) + f(\alpha, H, G_1, G_2) + 2.5\log_{10}(\Delta S(P, \lambda_p, \beta_p, a/b, b/c, \phi_0)) \quad (1)$$

where r is the asteroid - Sun distance, Δ is the asteroid-Earth distance, α is the phase angle (Sun-Asteroid-Earth angle), and η denotes the vector of unknown parameters in the model $\eta = [P, \lambda_p, \beta_p, a/b, b/c, \phi_0, H, G_1, G_2]$. The parameters are: P - rotational period, (λ_p, β_p) - rotational pole coordinates, (a/b, b/c) - shape axis ratios, ϕ_0 - initial rotational phase, H is absolute magnitude and (G_1, G_2) are phase curve parameters. For the phase function $f(\alpha, H, G_1, G_2)$ we use H, G_1, G_2 function developed by [8] and adopted by the IAU in 2015.

5. Summary and Conclusions

The Gaia mission will provide data for asteroids at large phase angles. Due to small range of the phase angle covered the Gaia data on their own are insufficient to fit phase curves and calculate asteroid magnitudes. However the Gaia stellar catalogue can be used as a photometric standard catalogue. By combining the Gaia catalogue with the historical asteroid differential photometry we can derive relative magnitudes and fit thousands of asteroid phase curves.

Acknowledgements

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