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Asteroid Phase Curves Seen by Pan-STARRS 1

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Abstract

The Pan-STARRS1 survey made 19 million optical observations of more than half a million main-belt asteroids in 2010-2016, creating an exceptionally rich dataset for understanding asteroid reflectivity in the $433 - 815$ nm bandpass w_{P1} across varying geometry. Deriving measurements of the absolute magnitude H and slope parameter G from well-sampled phase curves for large sets of asteroids has only become possible with the advent of systematic wide-field surveys. We consider the asteroid photometry from the Solar System Survey dataset of Pan-STARRS1 in the wide-band w_{P1} filter. We provide H, G phase curve information sampled over a seven-year span for more than half a million $H_r > 13$ asteroids with well-determined orbits, and map these against the dynamical populations of the main belt. Our asteroid set doubles that of Vereš et al. (2015), who considered the first 15 months of PanSTARRS1 data, and improves on the 421,496 asteroids measured with sparser data by Muinonen et al. (2010); Oszkiewicz et al. (2011).

Introduction

Phase curves and their residuals provide critical information about the surface reflectance properties, shapes, and sizes of minor planets (Bowell et al., 1989; Oszkiewicz et al., 2012). Two parameters defining the physical properties of a minor planet can be derived from a phase curve. The absolute magnitude H, as measured within a given wavelength range, provides a luminosity, often used as an albedo-dependent proxy for size. The slope parameter, G, encodes bulk information about an unresolved minor planet's reflectivity, with an observed correlation with albedo.

The relationships with H, G and orbital parameters can provide insight into the formation and evolution of minor planet populations. Yet, despite over 791,274 minor planets reported to the Minor Planet Center as of 2019 January 29, only a small fraction currently have quantified slope parameters. Small datasets exist where targeted observations have been made (e.g Carbognani et al., 2019), but full population estimates require extensive multi-opposition calculations of H and G. The near-Earth asteroids have been assessed in their entirety by Valdes (2019) from MPC-listed observations, but this small population number only 18,355 NEOs. The lack of high-precision absolute magnitudes for a majority of the population affects estimates of asteroid sizes, and propagates through to other aspects, such as the membership and estimated ages of dynamical families (e.g. Milani et al., 2014; Nesvorný et al., 2015).

Observations and analysis

The Panoramic Survey Telescope and Rapid Response System 1 Survey (PS1) has made two wide-field Northern sky surveys: the 3π survey (Chambers et al., 2016) and the ongoing Solar System Survey (hereafter, S3). The 3π observations we use were acquired after the telescope was refit and the software overhauled, from 2010 through to its end in mid-2014. The S3 observations were made between 2012 June and 2016 October. While the PS1 imager is equipped with six filters: a Sloan-like $grizy$ set and a wide-band w filter, which approximates the gri passband (Tonry et al., 2012), the majority of the PS1 observations are in w_{P1}.

We develop criteria for suitable densities of sampling of cadence, phase angle α and magnitude m_w for the multi-opposition asteroids that provide high-quality fits for H, G: $m_w \leq 20.0$, m_w measurements numbering ≥ 24 in ≥ 12 epochs with ≥ 2 epochs at $\alpha \leq 5°$; 22% of our sample meet these 'A'-grade criteria. Both the 'A'-grade and, with larger spread, the lower quality 'B'-grade fits confirm previous expectations for median G of 0.2, and median

$H_w(\text{PS1}) - H_w(\text{MPC}) = 0.25$.

Asteroids with $m_r < 16$ will saturate in the imaging of the upcoming LSST survey; thus, this dataset of physical parameters will remain useful in that era, complementing the phase curves that will be measured with *Gaia* (Oszkiewicz et al., 2017) and by other, brighter wide-field surveys such as ATLAS (Tonry et al., 2018a,b) and ZTF (Graham et al., 2019).

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