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Optimal strategy for KBO lightcurve studies from the ground

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Abstract

We conducted a magnitude-limited survey of 35 Kuiper Belt Objects (KBOs) and Centaurs, observed as part of a Large Program at the 3.6-m ESO New Technology Telescope (NTT) between 2014 and 2016. This is the first survey with a 4m telescope conducted in an entirely homogeneous manner (using the same telescope, the same observing strategy, and the same data analysis). The 2-year span of the program allowed repeated observations of the same targets during multiple observing runs at different phase angles, and prompted the development of a technique that would allow simultaneous determination of the rotational lightcurves and the phase functions of the objects. Here, we present the results from the program and give special emphasis on the strategies used to obtain and interpret the observations. In particular, we use the lessons learned from this program to propose optimal strategies for observation planning and data analysis, which would facilitate the efficient characterisation of larger samples of KBOs in the future.

1. Introduction

Many questions related to the formation and subsequent evolution of KBOs can be answered with targeted photometric studies of their physical and surface characteristics. Ground photometric observations can be used to reveal their colours, surface spots, phase functions and albedos. Photometric time-series with sufficient signal-to-noise ratio can be used to derive the object's lightcurve period and peak-to-peak range (Δm) which can constrain the KBO's spin rate and shape. Lightcurves are therefore powerful tools to compare different populations [1, 2] and to study individual objects in detail [3, 4, 5].

Previous lightcurve observations have been reported for roughly 100 KBOs [6, 7, 8]. The majority of them have been obtained with smaller 1-m or 2-m class telescopes and do not have rotation period solutions, nor useful upper limits to the variability. Furthermore, the available sample of known rotation properties may be biased towards elongated KBOs [9], as authors tend to report lightcurve detections, while publications of cases with no detected variability are less frequent.

2. Observing program

Our program was awarded 48 nights to study the lightcurves of Centaurs and KBOs from all dynamical classes. Despite losing over 40% of the awarded time due to bad weather, we obtained r'- and g'-band photometry of 35 objects (Fig. 1). Our analysis aimed to: 1) measure their spin periods, as well as to constrain their shapes and bulk densities; 2) identify objects with extreme shapes or spins and possible contact-binaries; 3) study surface colour variations, including the presence of surface spots; 4) obtain a sample of absolute magnitudes and optical colours protected from light curve variation; 5) measure solar phase functions for the entire sample.

3. Observing strategy

In order to address the survey goals defined above, we had to fulfil the following requirements:

- Study a large sample of objects which includes different size ranges and covers all dynamical classes in order to compare the physical proprties of the different populations.
- Detect the brightness variation of slow-rotating objects (P>20 hours) since these lightcurves have been missed by previous surveys consisting of short observing runs.
- Determine the lightcurves of objects with small Δm<0.2 mag, as these were not accessible to previous studies with smaller telescopes.
- Observe the targets at different phase angles in order to determine their phase functions. Phase functions are considered useful in two ways: 1) they enable the comparison of the microscopic

surface properties of different objects; 2) they allow an accurate determination of the absolute magnitude of the objects, and therefore improve the geometric albedo estimates.

4. Data analysis

Deriving the rotational lightcurves of faint targets and objects with small brightness variation required very precise magnitude measurements. In addition to this, combining data from different observing runs required reliable magnitude calibration. We therefore developed a technique for absolute photometric calibration using multiple comparison stars from the Pan-STARRS catalog in each frame (see [10]). Without the small absolute-calibration uncertainties of this method (down to 0.01 mag), deriving the lightcurves of objects with small Δm would not have been possible.

Another very important aspect of the data analysis in this work is the simultaneous determination of the object's phase-function slope and lightcurve period (Fig. 1). This is implemented through a modified version of the Monte Carlo method adopted in [10]. This technique ensures that the complete range of possible solutions for both parameters is explored and provides reliable uncertainty ranges on the reported values. The combination of period-fitting algorithms (Lomb-Scargle periodogram and string-length minimisation) was carefully selected in order to distinguish between single and double-peaked lightcurves, as well as to guarantee that the best periods are also found in the extreme cases of asymmetric lightcurves or lightcurves with sharp minima.

5. Summary

This paper will present the results from our large photometric survey of 35 KBOs and Centaurs. We will highlight the most interesting discoveries and will compare our results to previous studies. We will discuss the benefits of the observing strategy adopted in this work. We will also emphasise the benefits of 1) performing absolute calibration using all-sky photometric catalogues, 2) careful selection of the period-fitting algorithms used, 3) simultaneous phase-function and ligthcurve fitting, and 4) methodological inspection of the determined rotation periods and phase-function slopes. These insights from our program will be highly beneficial for the planning of future photometric surveys of the Kuiper belt.

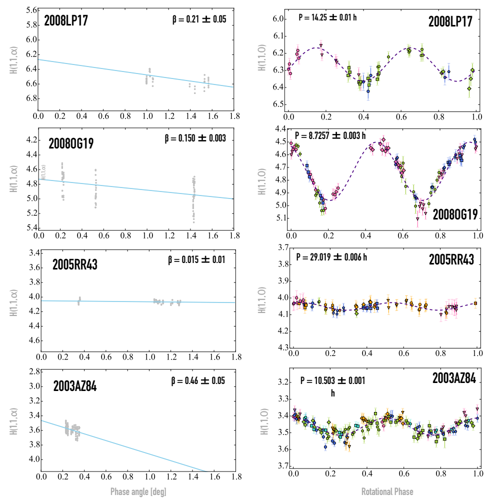

Figure 1: Phase functions (left) and rotational lightcurves (right) of selected KBOs from our survey. The different colours of the points correspond to different observing epochs. This selection of objects highlights the great variety of lightcurve shapes and phase-function slopes that our survey was able to determine.

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