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Solar phase functions of cometary nuclei

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Abstract

Relatively few measurements of the solar phase function of cometary nuclei exist, despite the importance of this parameter in determining accurate sizes and its use in modeling surface properties. We make use of robotic telescopes and service mode observing to monitor cometary nuclei over months at a time, combining intensive observations at a single epoch with regular short light-curve segments to efficiently account for brightness changes due to both nucleus rotation and changing solar phase angle. We present our latest results on comets 8P/Tuttle, 14P/Wolf, 67P/Churyumov-Gerasimenko and 110P/Hartley 3.

1. Introduction

As with all Solar System bodies, the observed brightness of cometary nuclei varies with the phase angle α at the time of observations. This angle is the Sun-Object-Earth angle, which changes for a given object with time due to the orbital motions of the object and the Earth. This causes a variation in the amount of sunlight reflected back to the Earth due to geometric effects (as are visible to the eye in the changing phases of the Moon), but also depending on the surface properties of the object concerned. Very rough surfaces are more phase darkened (i.e. reflect less light at greater phase angles) than smooth ones. Theoretical models describe how surfaces reflect at a range of phase angles. These models can adopt a number of parameters for individual surface particles, such as the size, albedo and porosity. With a good measurement of the variation of brightness with phase, these models can be applied to obtain estimates of these surface properties. The particle size is important as it tells us about the surface composition; is the surface made up of large boulders, as may be expected for a rubble pile, or is it relatively smooth, as may be expected for an eroded nucleus?

A phase function is used to describe the variation in measured brightness with phase angle; this function can then be used to convert measurements made at a given phase angle to the magnitude that would be measured at $\alpha = 0$, and therefore measure a true absolute magnitude and therefore size of the object. The dependence of size on the phase function also means that the choice of function affects the measured size distribution. The size distribution for any population is of critical importance in assessing its total population and collisional history; our recent work shows that the choice of phase function is the source of considerable uncertainty on the size distribution gradient measurement [2]. Measurement of the phase function is therefore necessary to measure accurate sizes.

The two common types of phase function used are linear, with the change in observed magnitude $m_R(\alpha) \propto \beta\alpha$, and the H-G formalism used in asteroids [4]. This is linear at large phase angle, but accounts for the opposition surge which causes a non-linear brightness increase at $\alpha \leq 2°$. Observations are required with higher cadence phase coverage to allow fitting of an H-G type function: For this reason the majority of comet nuclei phase laws are given simply as linear functions, due to having relatively few measurements. When it has been possible to make an estimate, comets have been shown to have a very weak (or non-existent) opposition surge [3].

2 Previous studies

Phase functions for comets are difficult to measure, since it is necessary to obtain light-curves at multiple epochs to remove rotational variations from the photometry and leave the variation due to changing phase angle. Even relatively well measured phase curves, such as that for 28P/Neujmin 1 [5], are still uncertain despite observations at 6 epochs with $0.8 \leq \alpha \leq 8°$ using the ESO 2.2m and NTT telescopes, with further data from other observations over a number of years. Table 1 and fig. 1 (taken from [2], see this paper for references to individual studies) show a summary of previous estimates of β, including some measured us-

Table 1: Phase function measurements for JFCs.

Comet	β	Comet	β
2P	0.053 ± 0.003	45P	~ 0.06
9P	0.046 ± 0.007	47P	0.083 ± 0.006
10P	0.037 ± 0.004	48P	0.059 ± 0.002
19P	0.043 ± 0.009	67P	0.076 ± 0.003
28P	0.025 ± 0.006	81P	0.0513 ± 0.0002
36P	0.060 ± 0.019	143P	0.043 ± 0.001

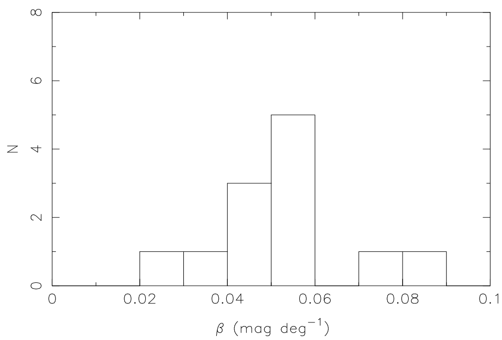

Figure 1: Histogram of previous β estimates.

ing only 3 phase angles (3 point straight line fits [6]). It is noticeable that the measured phase functions are generally steeper than the normally assumed values of $\beta = 0.035$ or 0.04 mag deg^{-1}; the mean value is 0.053 $\pm$ 0.016 mag deg^{-1}. This is due to a number of recent measurements of steep phase functions, while the larger (brighter, easier to observe) nuclei observed previously all had shallower slopes. This suggests a correlation between size of nucleus and phase function, but when we tested this we found that there is no statistically significant link.

3 Our observations

We have begun a campaign using robotic telescopes and queue scheduled (service mode) observations at the ESO VLT to measure more phase functions for cometary nuclei. Our strategy is to obtain a single good quality light-curve at a single epoch and short segments covering parts of the light-curve at other phase angles throughout the observable period for each comet. We then match the short segments to the template light-curve to correct for any variation in the observed brightness due to rotation, allowing us to measure the variation due to changing phase angle. We have selected nuclei that already have a reasonable rotation period determination, to be sure of getting a decent sampling with the short segments. We also make use of further independent observations of each target, for example those collected by the SEPPCoN survey [7, 8], to refine the phase function measurement. Care must be taken to ensure that other changes in the viewing geometry do not mask the phase function signal when using data taken in different years.

The comets in our survey are (so far) 8P/Tuttle, 14P/Wolf, 67P/Churyumov-Gerasimenko and 110P/Hartley 3. 67P already has a phase function determination [9], but we have obtained further data at very low phase angle to search for any opposition surge.

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