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Properties of long-period asteroids from simultaneous optimisation using visible and thermal data

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Slow rotators among asteroids

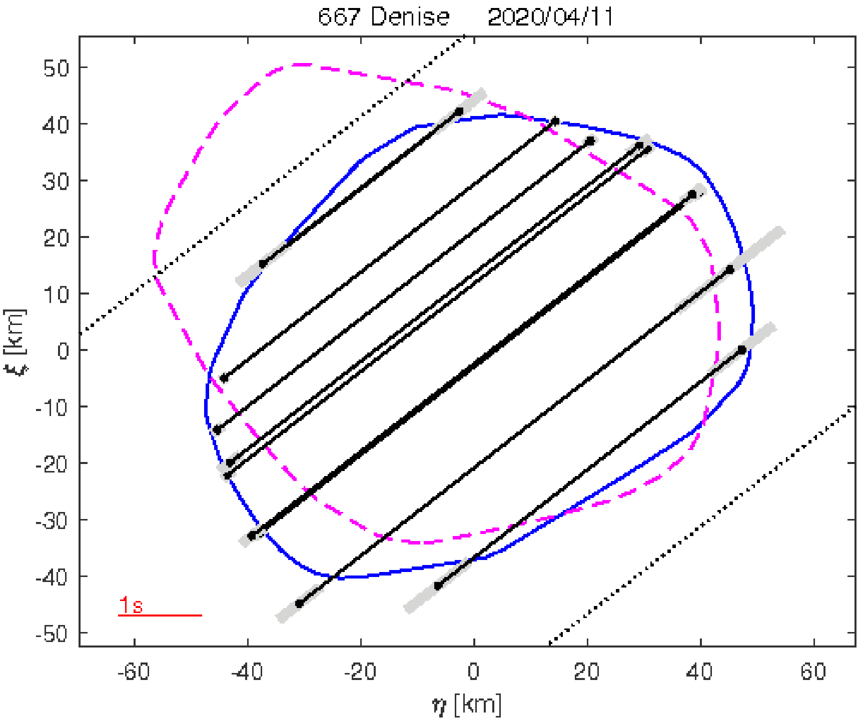
Recently published results from Kepler and TESS space missions (Molnar 2018; Pal et al. 2020) revealed surprisingly large numbers of slow rotators (P>12 hours) among main belt asteroids. Previous, ground-based surveys usually disfavoured them, so they also lacked dense lightcurves from multiple apparitions, essential for the spin and shape reconstruction. Such targets are also poorly studied in the thermal infrared range, because thermophysical modelling (TPM) requires spin and shape model as input. However slow-rotators are particularly interesting on that matter, due to their expected larger skin depth able to probe their denser or more conductive layers underneath the upper regolith (Harris & Drube 2016, 2020)

Our ongoing survey (see e.g. Marciniak et al. 2015; and 2019) is targeted at slow rotators to decrease this bias, and complement our knowledge of various properties of these objects. We gather dense lightcurves using a rich network of small ground-based telescopes, supplementing the data with the results from TESS and Kepler spacecrafts, where available.

Simultaneous optimisation

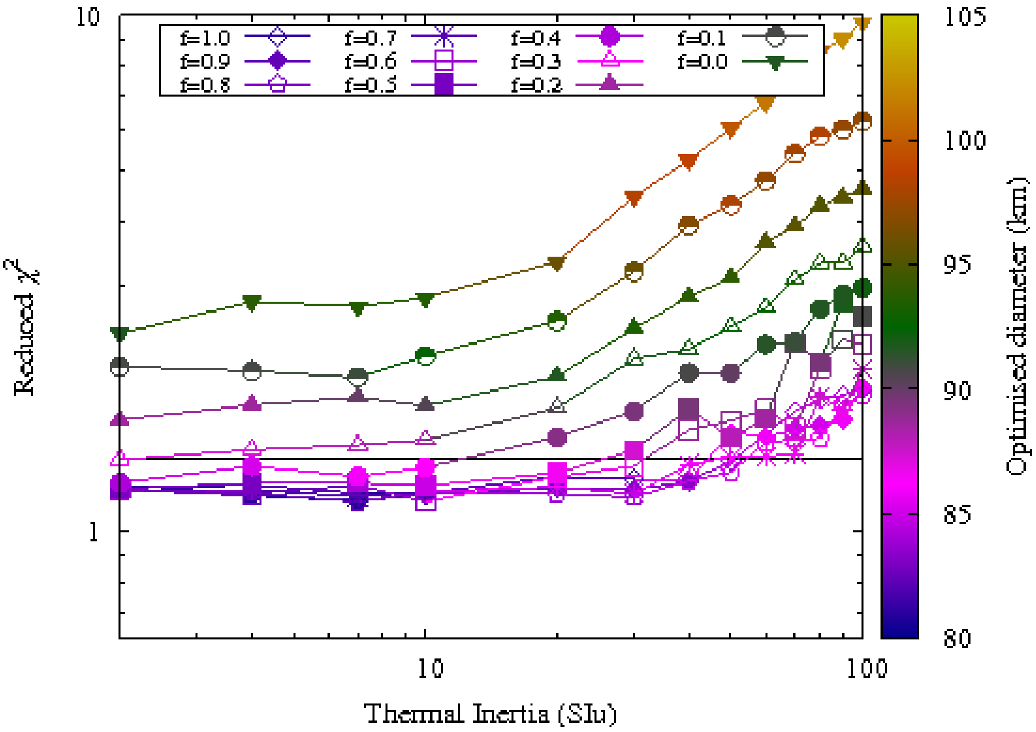
For the modelling we are using a novel approach to simultaneously optimise model spin, shape, size and thermal inertia using both visible lightcurves mainly from our survey, and thermal data from the infrared satellites, primarily WISE (Wright et al. 2010), IRAS (Neugebauer 1984), and AKARI (Usui 2011). The method joining the two approaches is Convex Inversion Thermophysical Model (CITPM, Durech et al. 2017). As a result we get size-scaled shape models which fit both data types very well. This is often not the case when shape models from lightcurve inversion only are a posteriori used in the TPM. However their slight alteration, eg. via bootstrapping the lightcurves can improve the reduced χ^2 substantially (Hanus et al. 2015; 2018). With the CITPM method the thermal data are allowed to alter the shape models on the fly, instead of the two-step approach used in previous studies (see e.g. our benchmark studies within SBNAF project, Muller et al. 2018).

In cases where rich stellar occultation timings were available in the PDS (Herald et al. 2019), we also fit the obtained shape models to occultation chords, obtaining independent size determinations, consistent with the sizes from CITPM. This step also validates shape model topographic features, and in some cases allows to break the degeneracy between two mirror-pole solutions (see figure below). Sizes from CITPM and occultation fitting are in good agreement. In the figure below two contours represent shape models for two mirror pole solutions, while black lines mark occultation shadow chords from occultation timings. Negative (no occultation) chords are marked with dotted lines. North is up and west is right. One of the pole solutions fits much better than its mirror counterpart.



Thermal inertia and sizes

With this approach we recently obtained detailed models for 16 slow rotators (Marciniak et al., submitted). Figure below shows example thermal inertia vs reduced χ^2 curves (target: 667 Denise), where the range of solutions with low χ^2 values allows to define the range of possible thermal inertias. The solution also constraints the best size range, coded with colour scale, and gives some constraints on surface roughness coded with symbols (f being the percentage of coverage with hemispherical craters, while their opening angle was also optimised in the process).



Results

We substantially enlarged the sample of modelled and precisely scaled slow rotators with available thermal inertia, and validated the approach of simultaneous fitting two different types of data. Determined sizes are on average accurate at 5% precision level, with the diameters in the range from 25 to 145 km. Thermal inertia reaches wide range of values, from 2 to < 400 SI units, with inevitable degeneracy with surface roughness.

Overall, we found no common features or trends among our targets, in particular no trend with the rotation period. The reason might be still small size of the available sample, or the relatively small thermal skin depth (l_s) of even the slowest rotators in our sample, where targets with periods up to 59 hours have l_s in a few millimetre range.

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