Uncovering the shapes of comets from the ground: The nucleus of comet 162P/Siding-Spring

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1. Motivation

- Our knowledge of the shapes of comet nuclei has resulted primarily from a small number of in situ missions to short period comets (Figure 1) and from one radar detection [1].
- These observations revealed that ~70% of the seven comet nuclei have a bilobed shape (i.e. appear to be made up of two distinct lobes). In comparison, it is estimated that only 20% of approximately 1000 near-Earth asteroids are in such "contact binary" configurations.
- Can we therefore deduce that comets undergo some unique process which leads to the formation of bilobed shapes? The present sample size of seven comets with well-constrained shapes is much too small to draw any such conclusions about the population.

Aim: Develop a method to identify the shapes of comet nuclei using solely ground-based observations.

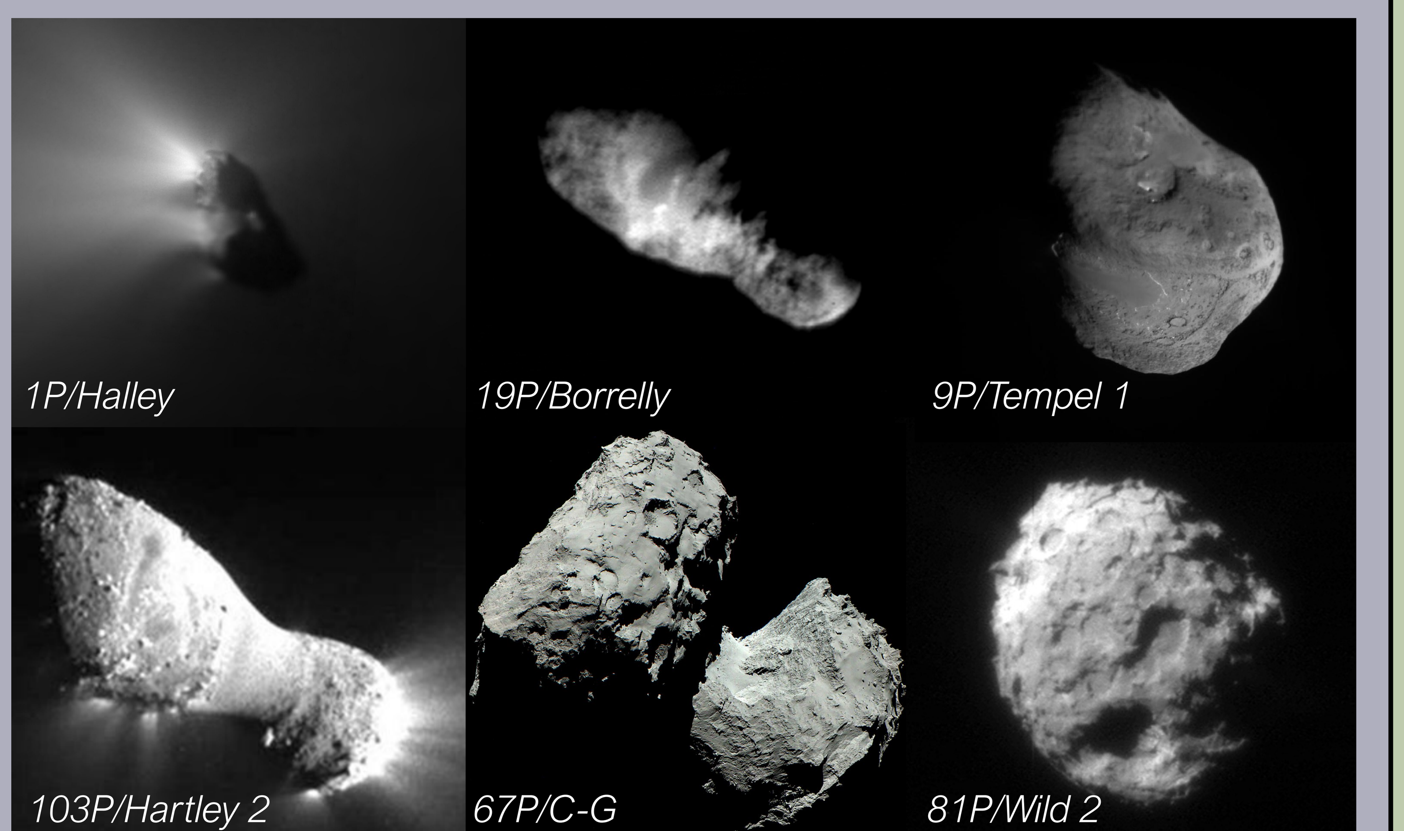

Figure 1.* The six comets imaged by spacecraft. Four of these comets (1P, 19P, 103P and 67P) have a bilobed shape.

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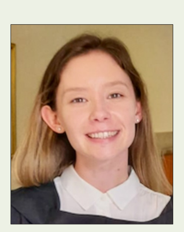
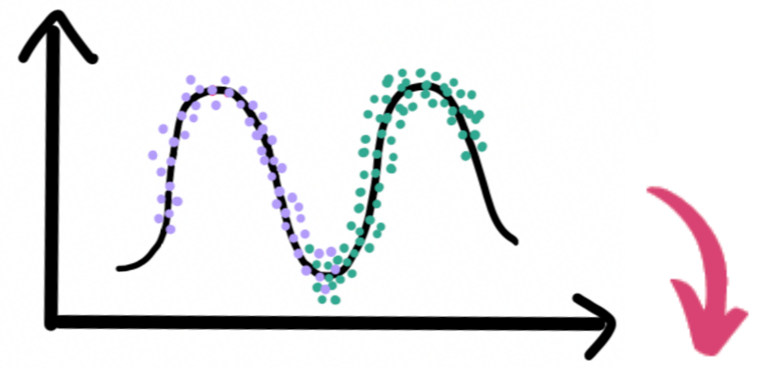
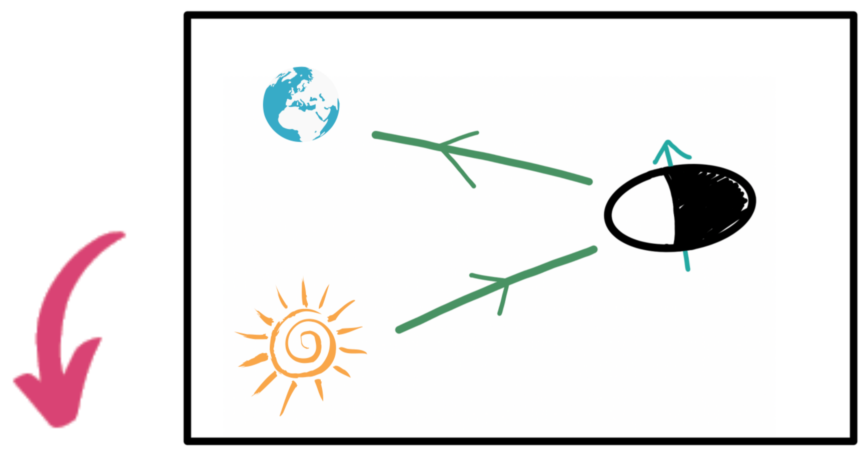


2. What can we learn from nucleus photometry?

1. **Estimate rotation period** from a few nights of targeted monitoring:



2. Combining observations at different solar phase angles allows us to **fit a phase function:**



3. With enough lightcurves covering a wide range of observing geometries, we can fit a model for the **shape of the nucleus:**

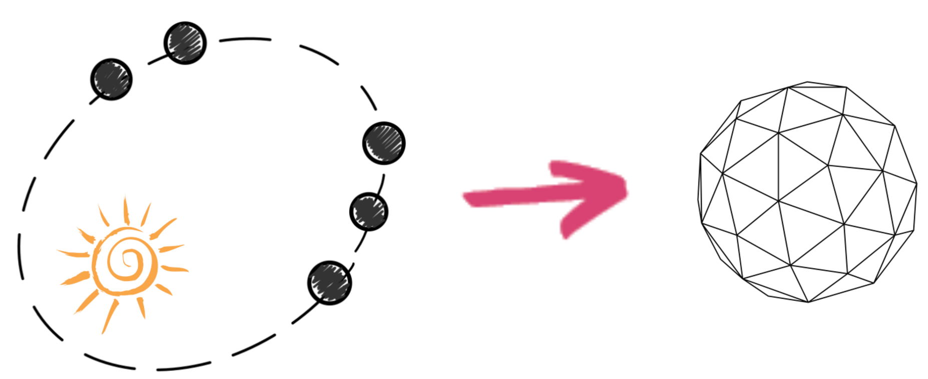


Figure 2.

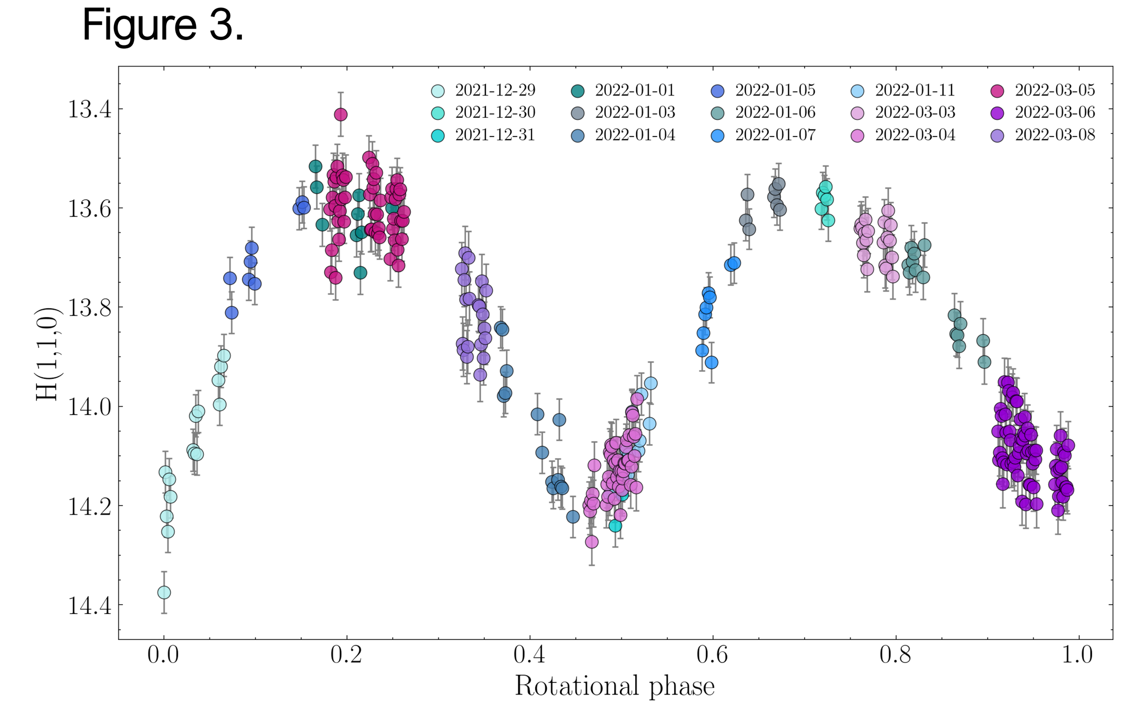
3. Modeling shapes from lightcurves

- The lightcurve of a small body is highly dependent on its shape and aspect [2,3] meaning that shape information can be extracted from even sparse-in-time surface photometry.
- Convex lightcurve inversion (CLI) is a technique used to construct a convex "hull" of an object from lightcurves collected over multiple epochs and viewing geometries [4,5].
- We use the software *convexinv* [6] for CLI. For a given rotational period (which can also be fitted using the software), *convexinv* optimises the shape, pole solution and scattering parameters.

4. Application of convex lightcurve inversion to 162P/Siding-Spring

- We obtained new lightcurves of low-activity comet 162P in January & March 2022 (Figure 3). In total, we have collected 33 absolutely-calibrated lightcurves of this comet made up of ~1000 data points between 2007-2022.
- We applied CLI to these lightcurves to identify the shape model and rotation pole orientation that most closely reproduced them. The distribution of poles and final shape model are shown in Figures 4 and 5.

Figure 3.



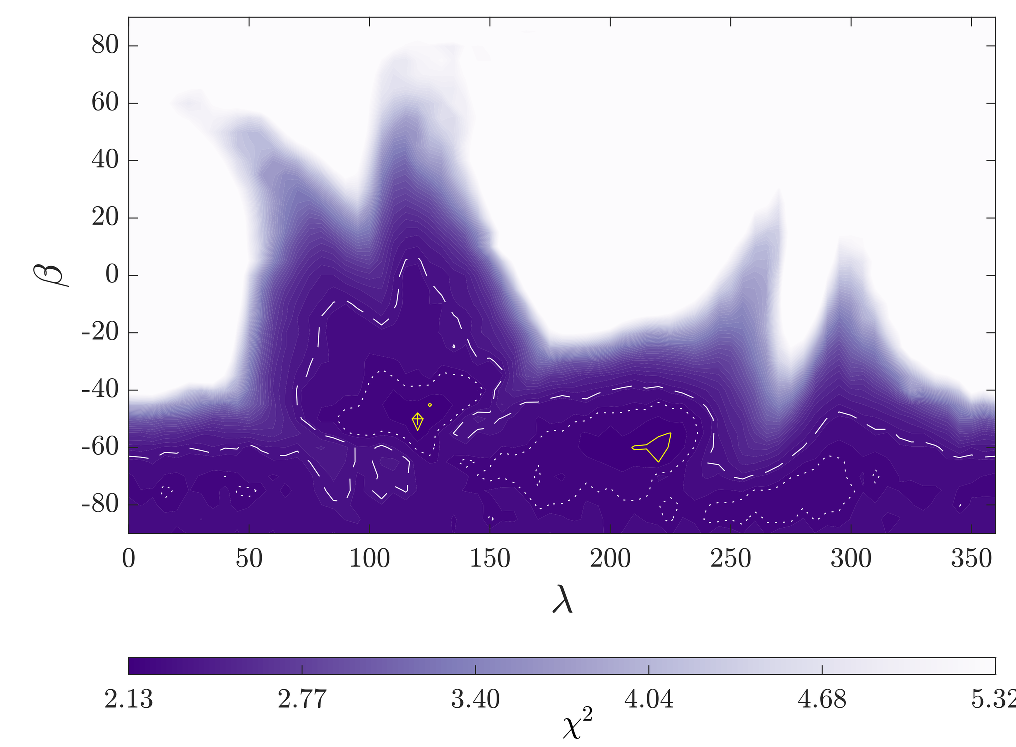


Figure 4. X^2 distribution from a grid search over all ecliptic latitude (λ) and longitude (β) for the direction of the model rotation pole. The solution that minimizes X^2 occurs at (λ, β) = (118, -50)°.

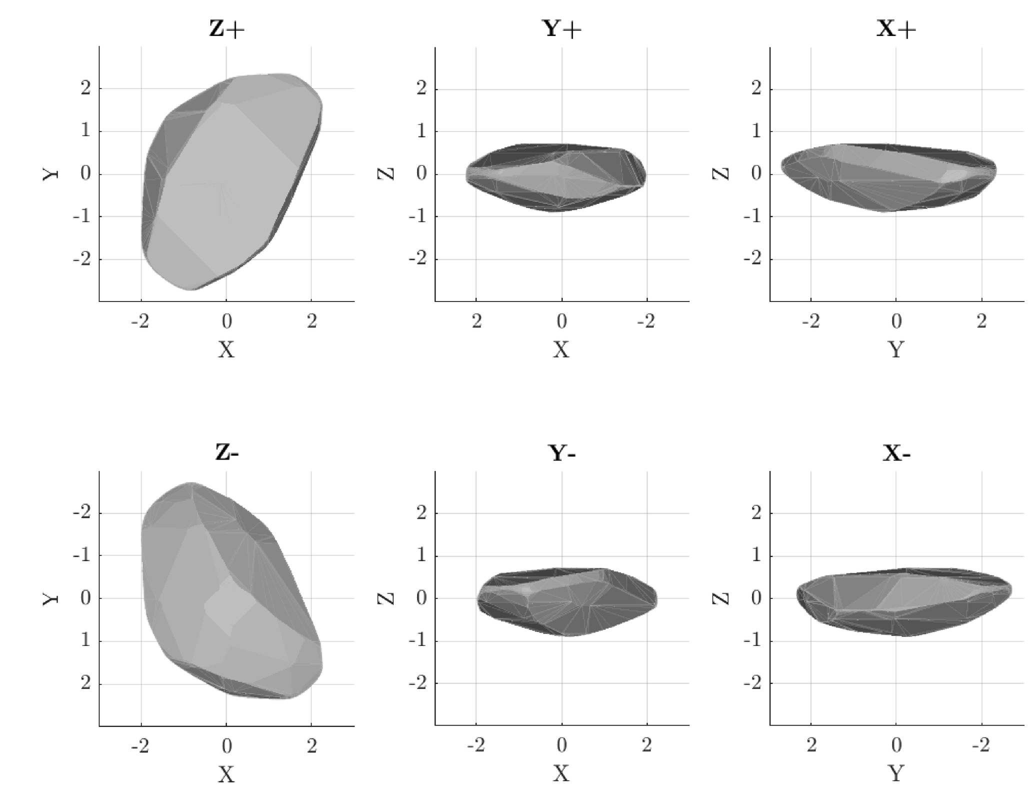


Figure 5. Best-fit convex shape model of 162P, viewed along three orthogonal directions. The model z-axis is aligned with its axis of rotation, as defined by the best fit pole coordinates in Figure 4.

5. Discussion and scope for future work

- The large, flat facets on the shape model can be interpreted as tentative evidence for a bilobed structure – CLI cannot replicate the concavities that result from this morphology, instead it 'covers' them with flat regions.
- The final model is dependent on phase function. Therefore, we can use the shape model to correct for the effects of rotation in the lightcurves and search for a cometary opposition effect by comparing models developed with different phase functions.
- CLI is challenging to apply to comets: not only is there a more limited range of viewing geometries available for orbits confined largely to the Ecliptic plane, but the nucleus can also only reliably be observed when inactive.
- Upcoming surveys (e.g. LSST) may provide increased coverage of viewing geometries. Potential then to streamline the modelling process for a greater number of comets and acquire a larger sample of shapes.

References: [1] Harmon et al. (2010); [2] Karttunen (1989); [3] Karttunen & Bowell (1989); [4] Kaasalainen & Torppa (2001); [5] Kaasalainen et al. (2001); [6] Durech et al. (2010)

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