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The Shape and Pole of (486958) 2014 MU_{69}

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Abstract

On January 1, 2019, NASA's *New Horizons* spacecraft flew past (486958) 2014 MU_{69} (MU69) [1], a cold classical Kuiper Belt Object (KBO). Here we present our work to fit the shape and pole of MU69. This work expands on prior shape fitting efforts for Pluto's satellites Nix and Hydra. We find that MU69 has a bilobate shape, with one larger flattened lobe and one smaller, more spherical lobe. The pole of MU69 is highly inclined to both its orbit and the spacecraft approach vector, making shape-fitting challenging.

1. Shape and Pole Fitting Process

Because MU69 cannot be resolved except in New Horizons images, the major constraints on the pole are the same images that are used to fit the shape. Solving for shape is thus a degenerate with solving for the poles. We will show results of our combined shape and pole fitting method. This method forward-models all the available images with a given rotational pole, rotational phase, parametric model shape, and rough photometric model. The shape is parameterized with two lobes that use the octantoid formalism [2], with a regularization to minimize shape detail in the unimaged areas. This forward modeling is performed in GPU using OpenGL, much faster than would be possible in CPU. We then convolve the rendered image with the point-spread function (PSF) of the image, allowing us to compare directly to the images of MU69 obtained by New Horizons LORRI. We calculate the sum of square of the difference of the real images with the forward-modeled images to provide a $\chi 2$ for a given parameter set. We then optimize the pole, shape, and photometric parameters to minimize $\chi 2$ and produce the best-fit model for the shape and pole. This model was originally developed for Nix and Hydra with a single lobe [3], refined for 2014 MU69 with the addition of the two-lobe parameterization.

2. Initial Results

The rotational pole of MU69 is RA = 317.5°, Declination = -24.89°, with an approximate uncertainty of 0.5°. This is inclined 99.3° to MU69's heliocentric orbit plane, making it a highly-inclined retrograde rotator. In addition, the pole is inclined 39.4° to the *New Horizons* approach vector, meaning that most images were obtained at a sub-solar latitude of -50.6°. The rotational period of MU69 is 15.918 hours. This is similar to published cold classical KBO periods [4]. Because of the highly-inclined pole, we were not able to detect the lightcurve of MU69 in either HST observations [5] or from unresolved spacecraft images. Instead, we had to use the initial resolved spacecraft images to derive a rotational period. We then combined those with the ground-based occultation profiles to provide a long rotational baseline.

Our current best-fit shape is shown below in Figure 1. As hinted at by the ground-based occultations, the shape of MU69 is a contact binary, with two roughly ellipsoidal lobes. Its overall dimensions are 36.0 x 18.0 x 10.0 km, with a total volume equal to a sphere of diameter 18.3 km. Because the flyby primarily imaged the southern half of the object, the uncertainty for these dimensions is roughly ±0.5 x ±0.5 x ±2.0 km. The larger lobe has a volume equal to a sphere of diameter 15.9 km, while the equivalent diameter for the smaller lobe is 12.9 km. This equates to volume ratio of 1.90:1 for the best-fit solution, making the larger lobe roughly twice as massive as the smaller. From ground-based lightcurves, [4] suggest that ~10-15% of cold classical KBOs may be equal-mass contact-binaries, though this number could be higher for 2:1 mass ratio contact binaries.

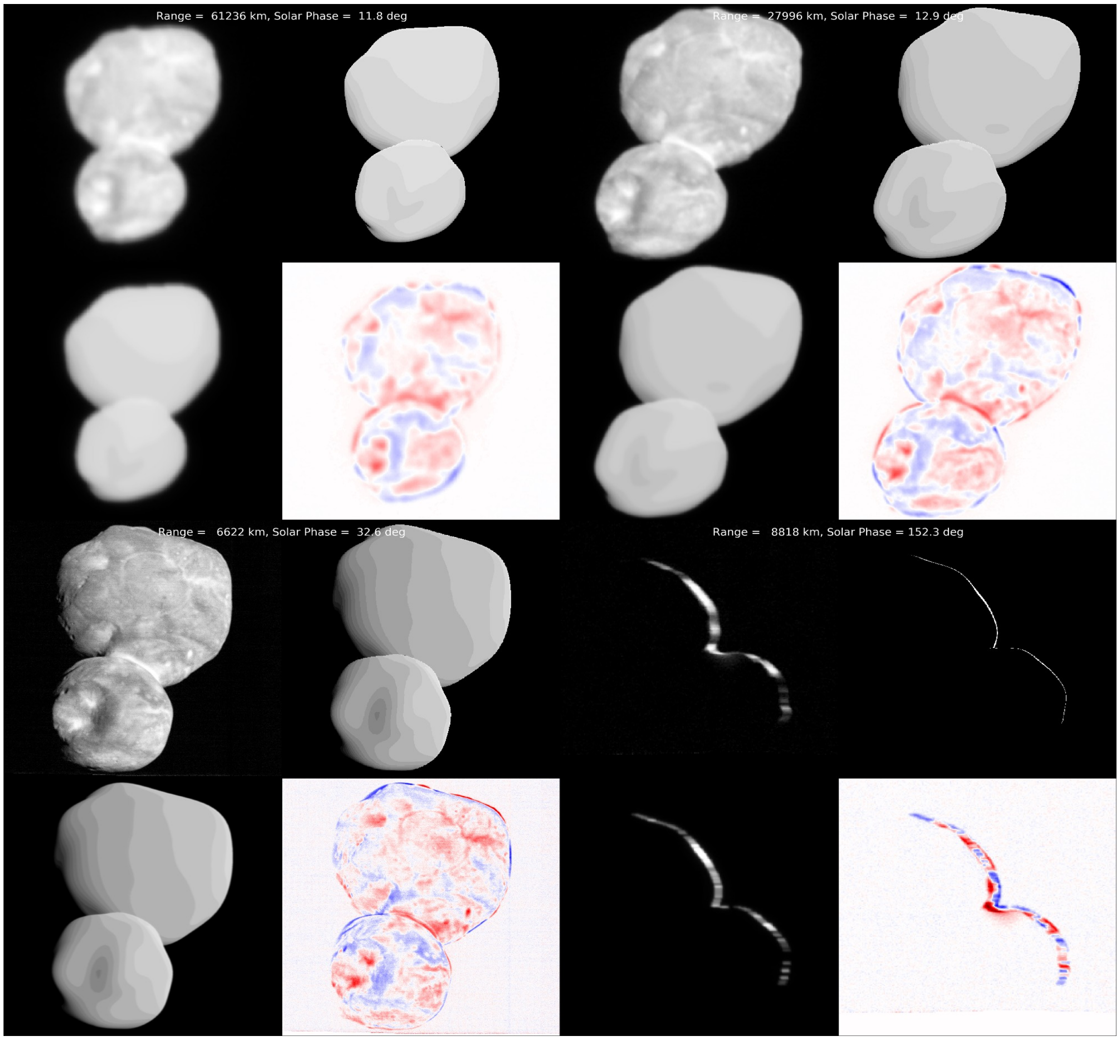

Figure 1: Quad charts showing the model fit for the three highest signal-to-noise observations of MU69. The observations are, clockwise from top left, CA01, CA04, CA07, and CA06. For each observation, the LORRI image is top left, a high-resolution rendering of the model is top right, a rendering of the model at camera resolution is bottom left, and difference between the rendering and real image is bottom right. Because the model assumes uniform albedo and has low spatial resolution, the residuals are dominated by albedo features and small-scale terrain.

Acknowledgements

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