THE SHAPES AND POLES OF NIX AND HYDRA FROM NEW HORIZONS. S. B. Porter[1], M. R. Showalter[2], H. A. Weaver[3], J. R. Spencer[1], T. R. Lauer[4], A. J. Verbiscer[5], W. M. Grundy[6], S. A. Stern[1], L. A. Young[1], C. B. Olkin[1], K. Ennico[6], and The New Horizons Geology, Geophysics, and Imaging Team. [1]Southwest Research Institute, (Boulder, CO; porter@boulder.swri.edu), [2]SETI Institute (Mountain View, CA), [3]Johns Hopkins University Applied Physics Laboratory (Laurel, MD), [4]National Optical Astronomy Observatory (Tucson, AZ), [5]University of Virginia (Charlottesville, VA), [6]Lowell Observatory (Flagstaff, AZ), [7]NASA Ames Research Center (Moffett Field, CA).

Background: The four small satellites of Pluto form a fascinating circumbinary system that is unique in the solar system in both its architecture and the fact that has been visited by a spacecraft [1]. The four small satellites Styx, Nix, Kerberos, and Hydra are all on circular, roughly coplanar orbits around the central Pluto-Charon binary. The rotation rates of the small satellites are all significantly super-synchonous, but similar to small KBOs [1]. All of them are smaller than 52 km. Because of their circular, coplanar orbits, the small satellites are likely fragments from the original giant impact that formed Charon [2]. This is supported by the spectral similarities between Charon and the small satellites [3]. Nix and Hydra were discovered right after New Horizons launched, and were imaged at a few epochs during the New Horizons flyby, at sufficient resolution to resolve their rough shape and spectra. Styx and Kerberos were both discovered after the New Horizons flyby sequence had already been planned, and so had to be imaged with the backup "retargetable" observations. This meant that only two low-resolution observations of Kerberos were obtained by New Horizons LORRI, and only one low-resolution observation of Styx. It is thus very hard to restrict the shape and pole of Styx and Kerberos. In this talk, we will provide the best estimates for the shape and pole of Nix and Hydra.

Shape and Pole Fitting: Because Nix and Hydra 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 the octantoid formalism [4], 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-spead function (PSF) of the image, allowing us to compare directly to the images of Nix and Hydra 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 χ^2 for a given parameter set. We then optimize the pole, shape, and photometric parameters to minimize χ^2 and produce the best-fit model for the shape and pole. This model was originally developed for Nix and Hydra [5], refined for 2014 MU69, and now re-applied to Pluto's satellites.

Nix: Nix was resolved in eight LORRI approach images, one MVIC PAN frame at closest approach, and one very faint crescent LORRI image. It has a rotational period of 43.9 hours, and its pole was pointing 73° from the New Horizons approach vector. This gave good coverage of most of the surface. Nix appears to be a single elongated body with best-fit dimensions 48x32x30 km, and equal volume to a sphere with a diameter equal to 36.5 km. With the best-fit Nix mass in [6], this results in a density of 1.8 g/cm^3. The equatorial profile of Nix is roughly trapezoidal. The limb profile of Nix is curiously angular, but the resolution is not sufficient to tell the exact geologic reason for this. Nix's pole is inclined 125° to Pluto's pole, making a super-synchronous retrograde rotator.

Hydra: Hydra was resolved in seven LORRI visits. It has a rotational period of 10.3 hours, and its pole was pointing roughly 24° from the direction of the spacecraft on approach. This meant that only the northern half of Hydra was imaged, and the rotation of Hydra could be seen between images of the last two LORRI epochs. The best-fit dimensions for Hydra roughly 51x37x21 km, and equal volume to a sphere with a diameter equal to 35.0 km. With the best-fit Hydra mass in [6], this results in a density of 2.1 g/cm^3. However the smallest axis is poorly constrained due to the encounter geometry. Hydra has an irregular shape, consisting of a large main body (~40 km diameter), and a smaller extension (~10 km long). Hydra's pole is inclined 64° from Pluto's pole, and the combination of this with Hydra's rapid rotation rate should cause its pole to precess over time.

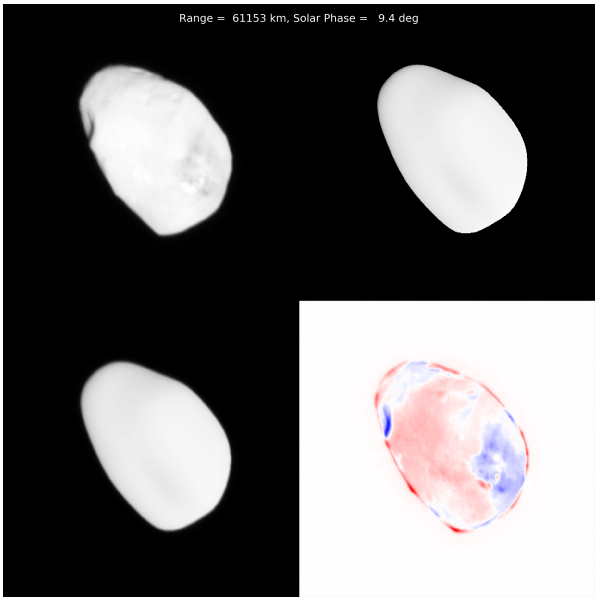

Figure 1: Example solution for the high-resolution LORRI image of Nix. The quadrants are top left: real image, top right: high-resolution rendering of the model, bottom left: rendered image convolved with the LORRI PSF, and bottom right: the difference of the data and convolved rendered image. Note that the difference image clearly shows the albedo feature associated with the large crater on Nix, as well as the divot in the top left of the data, which is below the parametric shape model's spatial resolution.

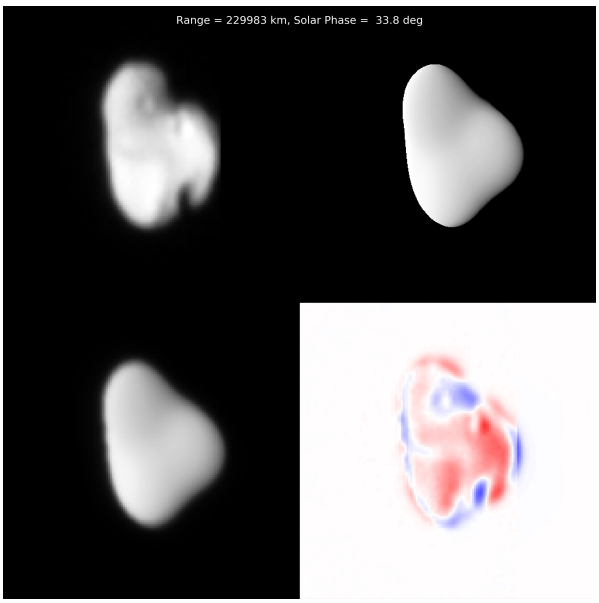

Figure 2: Example solution for the high-resolution LORRI image of Hydra. The quadrants are the same as Fig. 1. Hydra has a more complex shape that Nix, but was imaged less, and with much worse latitudinal coverage. It is thus much more challenging to fit a shape pole and to, and the shortest axis of the model is poorly constrained. However, even with these problems, we are able to estimate the bulk shape and volume of Hydra.

Implications for Pluto and KBO formation: Both Nix and Hydra have elongated shapes, rapid rotation rates, and poles that are highly inclined to the plane of their orbits around the central Pluto-Charon binary. This may imply that they have been bombarded by sufficient impacts since formation to increase their rotation rate and incline their poles. Alternatively, they could have excited into high rotation rates and inclinations by spin-orbit interactions, though it may be hard to produce the retrograde rotation of Nix by that process. Neither Nix nor Hydra is a contact binary in the style of 2014 MU69, implying that the formation of Nix and Hydra around Pluto could have been a very different process to KBO formation from the circumsolar disk.

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