SHAPES OF TNOS FROM NEW HORIZONS LIGHTCURVES. S. B. Porter[1], A. J. Verbiscer[2], H. A. Weaver[3], J. R. Spencer[1], J. J. Kavelaars[4], K. N. Singer[1], J. W. Parker[1], S. A. Stern[1], and the *New Horizons* Geology, Geophysics, and Imaging (GGI) Team. [1]Southwest Research Institute (Boulder, CO; porter@boulder.swri.edu), [2]University of Virginia (Charlottesville, VA), [3]Johns Hopkins University Applied Physics Laboratory (Laurel, MD), [4]National Research Council of Canada (Victoria, BC) & Department of Physics and Astronomy, University of Victoria (Victoria, BC).

Summary: NASA's *New Horizons* spacecraft has traversed approximately the inner half of the Kuiper Belt over the past few years. In addition to the flybys of the Pluto system and Arrokoth (formerly 2014 MU_{69}), the spacecraft has observed 5 dwarf planets and 17 smaller trans-Neptunian objects (TNOs) at unique solar phase angles not attainable from Earth. Rotational lightcurves of the smaller TNOs at high solar phase angles provides a unique test of the shapes of TNOs. Initial analysis of these lightcurves shows that most, but not all, of the TNOs smaller than dwarf planets are elongated. Since the one small TNO with a known shape, Arrokoth, is a contact binary [1], this observation may imply that contact binaries are common in the Kuiper Belt.

New Horizons High-Phase Observations: The primary long-range imaging instrument on the *New Horizons* spacecraft is LORRI (LOng Range Reconnaissance Imager), a 20.8 cm telescope with an unfiltered CCD with 1024x1024 ~1 arcsecond pixels. For exposures longer than a few seconds, these images are binned 4x4 to make 256x256 ~4 arcsecond pixel images [2]. For objects other than Pluto and Arrokoth, these 4x4 images are at lower spatial resolution than that achievable from Earth-based facilities. However, owing to the size of the Earth's orbit, Earth-based observatories can only ever see TNOs at a Sun-Target-Observer (solar phase) angle less than about two degrees. From its unique vantage point within the Kuiper Belt, *New Horizons* can observe TNOs at any solar phase angle, and is chiefly limited by the sensitivity of LORRI and flight rules which prohibit pointing LORRI near the Sun. Using LORRI in 4x4 mode, *New Horizons* has observed TNOs at phase angles greater than 120 degrees. Observations with solar elongations less than 30 degrees have been attempted, but were generally unsuccessful due to the solar scattered light swamping any signal from the TNO. In addition, *New Horizons* observed five objects at their brightest with LORRI in unbinned 1x1 mode, to maximize spatial resolution in order to search for closer binaries than can be observed from Earth or Earth orbit near 1 AU.

High-Phase TNO Lightcurves: Many TNOs show high-amplitude lightcurves that are independent of wavelength, and therefore could be due to shape rather than albedo [3]. Indeed, some TNOs display a distinct V-shaped low-phase lightcurve that could be indicative of a contact-binary shape [3]. However, the limited solar phase angles available from Earth make the determination of the shape of a TNO very difficult without stellar occultations (which successfully detected Arrokoth's contact-binary shape prior to the flyby [4]).

For most of the brighter TNOs that *New Horizons* has flown near to (V<19 from the spacecraft), LORRI obtained lightcurve observation at a cadence of one hour for typically 16 hours. These lightcurves allow a rough determination of rotational period, and if that period is less than the observation period, the amplitude of the lightcurve. As shown in the figure below, the amplitude of the lightcurve variation increased for most objects at higher phase angles. In particular, 2011 HK_{103} and 2011 HF_{103} showed very large variation in brightness at solar phase angles greater than 90 degrees. These two objects are the best candidates for being Arrokoth-style contact binaries. In contrast, 2011 JY_{31} shows very little variation in brightness across all phase angles at which it was observed by *New Horizons*. Since an object cannot be pole-on at many-different phase angles, 2011 JY_{31} is unlikely to be very elongated, and may be closer in shape to the smaller lobe of Arrokoth. 2014 OS_{393} shows even higher flux variation than 2011 HK_{103} and 2011 HF_{103}, but this object appears to possibly be a separated binary in the highest-resolution 1x1 LORRI images. However, the large brightness variation of 2014 OS_{393} meant that it was not visible in one of the two 1x1 epochs, making confirmation of its binary nature difficult without future ground based occultation data.

Implications for Contact Binary Fraction: Ground-based observations of TNOs have identified several that appear to show contact-binary lightcurves, and have been used to estimate the contact-binary fraction as ~10-25% for the classical Kuiper Belt [5]. However, a contact-binary needs to be almost equator-on to display such a lightcurve. Despite being an obvious contact binary, Arrokoth displayed no lightcurve variation in *Hubble Space Telescope* observations [6]. Ground-based estimates of the contact binary fraction are thus limited to lower limits.

In contrast, the *New Horizons* results sample the solar phase angle space much more thoroughly, and can identify very elongated objects much readily than from the ground. But, unlike ground-based surveys, the

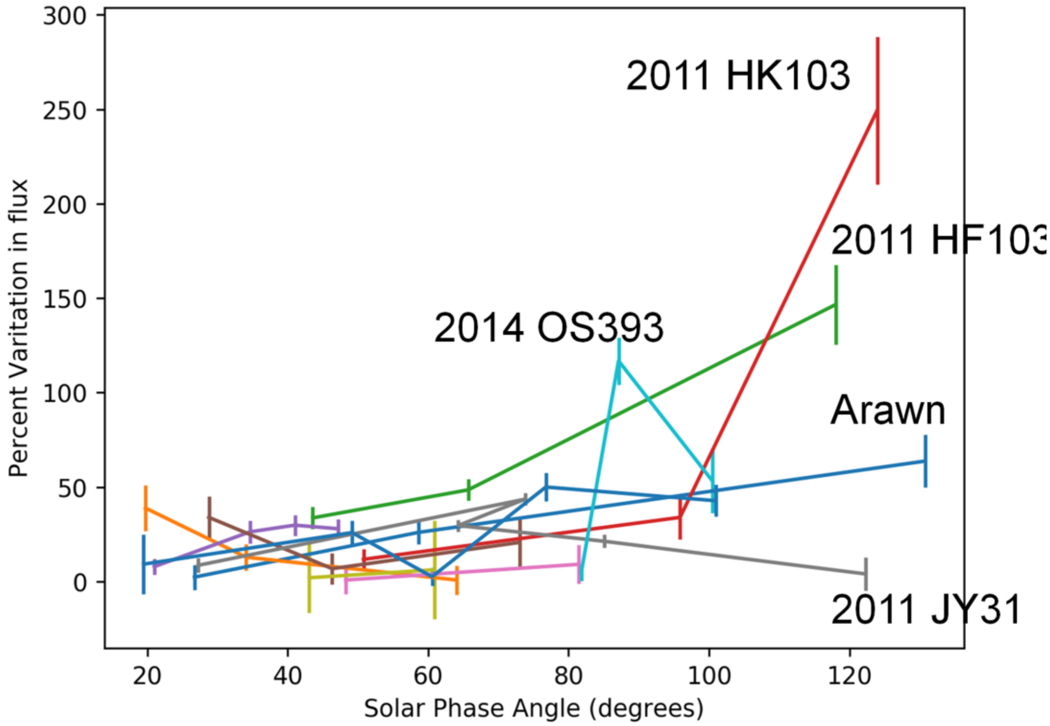

Figure 1: Brightness variation of TNOs seen from *New Horizons* as a function of solar phase angle. Each color shows a different object observed by *New Horizons* at least twice, and which are not dwarf planets (H_V>6).

New Horizons observations are limited to the finite number of objects that were bright enough for LORRI to observe. The *New Horizons* results thus must be combined with Earth-based TNO lightcurve surveys to provide the best estimate of the contact binary fraction. Upcoming TNO lightcurve surveys and ground based stellar occultations by KBOs will be very helpful increasing this number. LSST will be useful in particular, as all of the New Horizons high-phase targets are in the southern hemisphere.

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