THE NEW HORIZONS PHOTOMETRIC PHASE ANGLE SURVEY OF DEEP OUTER SOLAR SYSTEM OBJECTS: FROM THE KUIPER BELT TO THE SCATTERED DISK. A. J. Verbiscer¹, S. B. Porter², S. D. Benecchi³, J. J. Kavelaars⁴, W. C. Fraser⁵, L. Peltier⁶, D. Gerdes⁷, H. W. Lin⁸, K. Napier⁹, H. A. Weaver⁷, M. W. Buie², P. Helfenstein⁸, F. Yoshiida⁹, T. Ito¹⁰, T. Terai¹⁰, S. A. Stern², J. R. Spencer², J. W. Parker², K. N. Singer², P. Brandt², and the New Horizons KBO Search and Planetary Science Theme Teams. ¹University of Virginia (P.O. Box 400325, Charlottesville, Virginia 22904-4325; av4n@virginia.edu), ²Southwest Research Institute, ³Planetary Science Institute, ⁴National Research Institute of Canada, ⁵Herzberg Astronomy and Astrophysics Research Centre, ⁶University of Michigan, ⁷Johns Hopkins University Applied Physics Laboratory, ⁸Cornell University, ⁹University of Occupational and Environmental Health, ¹⁰National Astronomical Observatory of Japan.

Introduction: Since its launch in 2006, NASA’s New Horizons spacecraft has observed more than 36 KBOs [1,2] and dwarf planets [3] from its trajectory through the solar system. While most of these objects appear to New Horizons’ LOnge Range Reconnaissance Imager, LORRI [4,5] as unresolved point sources, the unique geometries from which they are observed enable the analyses of their surface microphysical properties, shapes, and rotation poles. The large heliocentric distances at which these objects orbit the Sun preclude observations of them from 1 au at solar phase angles greater than 2⁰; however, New Horizons can access nearly the full range of phase angles, from 0⁰ to 180⁰.

New Horizons has observed KBOs from all dynamical classes, including 14 classical, 9 scattered disk, 3 resonant, and 5 large KBOs, as well as 3 dwarf planets and 2 Centaurs at phase angles between 8⁰ and 153⁰.

Prime and First Kuiper Extended Mission Results: Rotation Light Curves: Rotation light curves acquired by New Horizons show that these rotation periods range from 5 to 49 hours, and the amplitudes of many of these rotation curves increase with increasing phase angle, likely due primarily to their non-spherical shapes rather than surface albedo variations. Applying the DAMIT light curve inversion code [6] to these rotation curves reveals that many KBO shapes are flattened and elongated like that of Arrokoth and they have rotation poles with high obliquities [7].

Solar Phase Curves: Combining the high phase angle observations of these KBOs from New Horizons with Earth-based observations acquired at low phase angles enables both the construction of whole-disk solar phase curves with broad phase angle coverage and fits to these phase curves using the Hapke photometric model [8]. These photometric model fits enable comparisons between the surface scattering properties of different dynamical classes using parameters including the single scattering albedo, macroscopic surface roughness, and directional scattering properties in addition to parameters that describe the phase curve behavior near opposition at small phase angles. Our pilot Hapke analysis [5] of nine large KBOs and dwarf planets, for example, reveals a significant correlation between their implied relative regolith maturities and their corresponding regolith particle albedos. The small, dark KBOs, like Arrokoth, have steep solar phase curves and small phase integrals, much like those of other small, dark asteroids, comet nuclei, and satellites [4]. Larger KBOs and dwarf planets with volatile ices on their surfaces have shallower solar phase curves with large phase integrals.

Figure 1: Perihelion vs. aphelion distances for objects observed by or yet to be observed by New Horizons. Black dots represent classical Kuiper belt objects; blue dots are resonant objects; red dots are objects from the scattered disk. Scattered disk objects 2020 KH42, 2020 KV11, and 2020 KS11 have aphelia beyond the heliosphere’s termination shock (between 75-90 au) and the latter two have aphelia beyond the heliopause (at 123 au). New Horizons is the only facility currently capable of obtaining ‘high phase’ observations of these objects which have spent significant fractions of their lifetimes beyond the heliopause, with their surfaces exposed to galactic cosmic rays.

Second Kuiper Extended Mission Opportunities: Primarily using the Subaru Telescope, operated by the National Astronomical Observatory of Japan, the New
Horizons team continues to search for new targets for LORRI to observe, either as point sources or even via close flyby [9,10]. As New Horizons travels beyond the classical Kuiper belt (Figs 1, 2), LORRI will observe more KBOs from the scattered disk population and more distant KBO populations. Going forward, owing to their increasing distance from the Sun, New Horizons KBO targets will be somewhat biased toward larger KBOs that have longer observation windows, and thereby broader phase angle coverage from which to measure their surface scattering properties. New Horizons will be able to obtain, for the first time, high phase angle observations of these small bodies whose orbits extend beyond the heliosphere’s termination shock and even beyond the heliopause.

Figure 2: Locations (dots) and orbits (lines) of objects observed or so far planned to be observed by New Horizons. Orange dots (Pluto and Arrokoth) have had close flybys; Blue dots are objects observed as point sources. Black dot is the location of the New Horizons spacecraft in October 2023. New Horizons observed Scattered Disk Object (SDO) 2020 KS11 in September 2023 and will be closest to SDO 2020 KV11 in 2027.

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