PLUTO'S SMALL SATELLITES. H. A. Weaver[1], S. B. Porter[2], M. W. Buie[2], J. C. Cook[3], W. M. Grundy[4], A. J. Verbiscer[5], D. P. Hamilton[6], T. R. Lauer[7], M. R. Showalter[8], J. R. Spencer[2], S. A. Stern[2], K. Ennico[9], C.B. Olkin[2], L.A. Young[2], and the *New Horizons* Science Team. [1]Johns Hopkins Applied Physics Laboratory (hal.weaver@jhuapl.edu), [2]Southwest Research Institute, [3]Pinhead Institute, [4]Lowell Observatory, [5]University of Virginia, [6]University of Maryland, [7]National Optical Astronomy Observatory, [8]SETI Institute, [9]NASA Ames Research Center.

Introduction: The Pluto system is comprised of the Pluto and Charon binary pair and four much smaller satellites: Styx, Nix, Kerberos, and Hydra, in order of increasing distance from Pluto [1]. In this invited talk, we review the properties of the small satellites and how they inform our understanding of the origin of the Pluto system.

Orbital and Rotational Properties: The orbits of the small satellites are remarkable in that the orbit planes are nearly coincident with Pluto's equatorial plane, and their orbital periods (20.16 d, 24.85 d, 32.17 d, 38.2 d) fall nearly in the 3:4:5:6 mean motion resonances (MMRs) with Charon [2]. Although the MMRs are regions of dynamical stability, attempts to model the orbital evolution of the small satellites from formation in a presumably more compact (around Pluto) configuration to their current locations (with orbital semi-major axes of 42,660 km, 48,694 km, 57,780 km, 64,738 km) have been largely unsuccessful [3]. While Pluto and Charon are in synchronous rotation (period=6.4 d) and have rotational poles aligned with their orbital poles, all of the satellites have rotational periods (3.2 d,1.83 d, 5.3 d, 0.429 d) much shorter than their orbital periods and rotation poles oriented nearly perpendicular to their orbital planes, suggesting that impacts may have dominated their rotational properties.

Physical Properties: Nix and Hydra are approximately the same size, with effective spherical diameters of ~35 km. Styx and Kerberos are much smaller, with effective spherical diameters of ~10 km for both. All of the small satellites are highly aspherical (Fig.1), with primary axes ratios ranging from 1.6 to 2.4 [4]. All of the small satellites have highly reflective surfaces, with *V*-band geometric albedos in the range 0.5-0.9 [1]. The phase curves of Nix and Hydra are similar and modeling suggests relatively smooth, forward-scattering surfaces [5]. The masses derived from dynamical models [6] are highly uncertain (~50-100%), but using the nominal mass values for Nix and Hydra, and the latest shape models [4], the bulk densities are ~1.9 g/cm^3 for Nix and ~2.3 g/cm^3 for Hydra, suggesting they are *not* highly porous objects and/or a significant amount of rocky material has been incorporated into their interiors.

Color and Composition: The surfaces of Nix and Hydra have mostly neutral (i.e., solar-like) colors [1], but Hydra's surface is slightly bluer than Nix's. The large crater on Nix is slightly (~10%) redder than the rest of the surface (Fig. 1), perhaps revealing either previously buried material, or retained impactor material that has different properties than the typical surface material. Near infrared spectra of Nix and Hydra [7; see Fig. 2] reveal deep water ice absorption bands, mostly crystalline in nature, and another band near 2.21 μm that may indicate the presence of an ammoniated material (e.g., ammonium chloride, ammonium nitrate, or ammonium carbonate, but *not* ammonia hydrate). Perhaps significantly, the strength of the ammonia-containing material appears to be weakest at the location of the slightly reddish large crater on Nix [7]. Weak spectral bands near 2.42 μm and 2.45 μm may due to absorption by hydrocarbon or tholins [7].

Origin: The dynamical, physical, and compositional properties of the small satellites are consistent with a giant impact origin of the system [8], in which two Pluto-sized objects experienced a glancing collision producing the Pluto-Charon binary and a debris disk in their equatorial plane where the small satellites subsequently formed. The debris disk was likely comprised primarily of mantle material from the two large, and probably partially differentiated impactors, which could explain why the small satellites have bright, icy surfaces and relatively low bulk densities. The retention of high albedo surfaces over the age of the solar system also suggests that impacts on the small satellites were primarily destructive (i.e., resulted in a net loss of material, including that of the impactors) and that the small satellites have icy material throughout their interiors. The properties of the small satellites of the Pluto system can inform our understanding of other KBO satellite systems that also resulted from giant impacts. But we do not expect the properties of Pluto's small satellites to be similar to those of the typical small KBOs (i.e., objects that are *not* satellites of Dwarf Planets).

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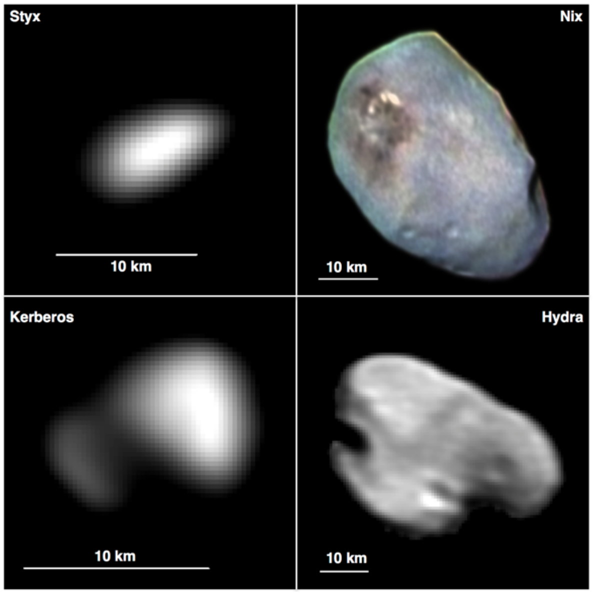

Fig. 1: Resolved images of Pluto's four small moons taken during the *New Horizons* flyby in July 2015. Celestial north is up and east is to the left. All images were deconvolved to recover the best available resolution. Panchromatic LORRI images were used for Styx, Kerberos, and Hydra, while an enhanced color image combining both MVIC and LORRI data was used for Nix. Some surface features on Nix and Hydra are impact craters. The largest crater on Nix is slightly darker and redder than the rest of Nix's surface. (Adapted from [1].)

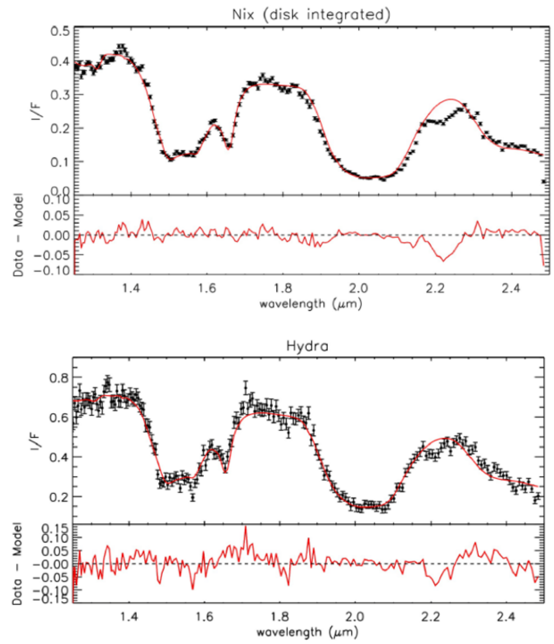

Fig. 2: *New Horizons* LEISA near-infrared spectra of Nix (top) and Hydra (bottom). Both spectra (black symbols with error bars) show deep absorption bands centered near 1.5, 1.65, and 2 μm associated with crystalline water (H_2O) ice. The over-plotted red curves are from model fits that include only crystalline water ice. The residuals (plotted below the main spectra) show that both Nix and Hydra have an additional absorption feature near 2.2 μm that may be associated with an ammonia-bearing species (Adapted from [7].)

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