CRATER MAPPING CAMPAIGN FOR THE PLUTO-CHARON SYSTEM. S.J. Robbins[1], K.N. Singer[1], V.J. Bray[2], P. Schenk[3], A. Zangari[1], W.B. McKinnon[4], L.A. Young[1], K. Runyon[5], R.A. Beyer[6,7], S. Porter[1], T.R. Lauer[8], J.M. Moore[7], R.P. Binzel[9], M.W. Buie[1], B.J. Buratti[10], A.F. Cheng[5], W.M. Grundy[11], I.R. Linscott[12], H.J. Reitsema[13], M.R. Showalter[6], J.R. Spencer[1], G.L. Tyler[12], H.A. Weaver[5], C.B. Olkin[1], K. Ennico[14], S.A. Stern[1]. [1]Southwest Research Institute, 1050 Walnut Street, Suite 300, Boulder, CO 80302. [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. [3]Lunar and Planetary Institute, Houston, TX. [4]Washington University in St. Louis, St. Louis, MO. [5]The Johns Hopkins University, Baltimore, MD. [6]Sagan Center at the SETI Institute. [7]NASA Ames Research Center. [8]National Optical Astronomy Observatory, Tucson, AZ. [9]Massachussetts Institute of Technology, Cambridge, MA. [10]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. [11]Lowell Observatory, Flagstaff, AZ. [12]Stanford University, Stanford, CA. [13]Ball Aerospace [retired], Boulder, CO. [14]NASA Ames Research Center, Moffett Field, CA 84043. stuart@boulder.swri.edu

Introduction: NASA's New Horizons mission successfully made its closest approach to Pluto on July 14, 2015, at 11:49A.M. UTC. The flyby nature of the mission, distance to the system, and multiple planetary bodies to observe with a diverse instrument set required a complex imaging campaign marked by numerous trade-offs; these lead to a more complicated crater population mapping than a basic orbital mission. Here, we discuss the imaging campaign and methods we are using to map impact craters across the bodies in the Pluto-Charon system.

Mission Profile: *New Horizons* is in the midst of its 360-day encounter of the Pluto-Charon system. The initial approach used imaging almost exclusively for optical navigation. In late May, LORRI (LOng-Range Reconnaissance Imager, an 20.8-cm diameter telescope with a 1024×1024 pixel CCD [1]) was able to resolve Pluto as more than 10 pixels, making them the best images ever taken of the system. Twenty-one days from closest approach (≈3 Pluto/Charon rotations/orbits), a cadence of more than daily imaging of the system commenced. The "core" load began 7 days out and lasted through 2 days after closest approach. The pixel scale of Pluto changed from 41 km/px to almost 70 m/px during this core load – over a factor of 500 change. The trajectory took the spacecraft 12,500 km from Pluto's surface (~5000 km from Charon's orbit, though Charon was on the opposite side of the system during the closest approach to Pluto).

Imaging Sequence of Pluto: The Pluto imaging campaign was full-disk until ≈8.5 hours before closest approach, at which point the full-disk was imaged via mosaicking until ≈3.5 hrs before closest approach when the pixel scale was 0.9 km/px. After this, two LORRI-specific imaging campaigns were conducted of the partial disk and six of the full crescent, and three were conducted in strips as ride-alongs with other instruments. These should supply partial coverage at up to 70–80 m/px (Fig. 1a; Table 1). There is additional MVIC (Multi-spectral Visible Imaging Camera [2]) color and pan-chromatic imaging at up to 0.3 km/px of the encounter hemisphere.

Imaging Sequence of Charon: The Charon imaging campaign was full-disk until ≈9 hours before closest approach, at which point the full-disk was imaged via mosaicking until ≈3.5 hrs before closest approach when the pixel scale was 0.9 km/px. After this, two LORRI-specific imaging campaigns were conducted of the partial disk and five of the full crescent; Plutoshine on Charon was also attempted with LORRI, and there were two high-resolution ride-alongs with other instruments that will provide coverage at up to 160 m/px. Fig. 1b summarizes this coverage.

Imaging Sequence of Small Moons: The discovery of Nix and Hydra in 2005 was early enough that plans were developed to image them. The best observations of each have pixel scales of 0.3 and 1.5 km/px. Nix was the better imaged of the two due to its proximity to the spacecraft's path. Kerberos and Styx were discovered in 2011 and 2012, respectively, which was too late in the mission planning to design imaging campaigns. Built into the core sequence were four "retargetables," and these were used for Kerberos and Styx for maximum pixel scale of ≈3 km/px and the data will not be downlinked for several months.

Data Downlink Plan: Before the core load, there was little data backlog, though critical navigation images were top priority (along with hazard searches) and these could be used for cartography and crater identification (the first control network was produced 11 days before closest approach). The core load filled 60 Gbit of data which will require an estimated 16 months to send to Earth. Several LORRI images were included in the "browse" dataset which were lossy-compressed at a 6:1 ratio, introducing significant compression artifacts. The downlinked lossy images included the last full-frame images of Pluto (3.8 km/px) and Charon (2.3 km/px) of the encounter hemispheres, a 2.3 km/px mosaic of Pluto, 7 of the 15 images at 0.4 km/px of images intended for stereo construction of the topography of the equatorial region of Pluto, and two 0.4 km/px images of Charon which were part of a LEISA ride-along. (See Table 1.) The best images of the non-encounter hemispheres of Pluto and Charon are approximately 21 km/px (taken midnight July 10-11).

All images will be eventually downlinked lossless (regardless of whether they have already been transmitted as lossy-compressed) which will greatly increase ability to map impact craters. Table 1 shows the list of targeting campaigns, pixel scale, and percent of the lit disks that should be covered.

Complications— Pixel Scale, Solar Incidence: Unlike orbiters where most terrains can be imaged at multiple ranges and lighting conditions, we are constrained by the best pixel scales and incidence angles at which images were taken during the flyby. While most high-resolution imaging by quantity has been done over areas of variable solar incidence as the spacecraft passed by Pluto and Charon, these cover a relatively small fraction of the bodies and most coverage has been done at near-noon sun. This makes crater identification difficult.

Complications— Cartographic Network: The initial cartographic network, until a week before closest approach, was based on stellar alignments of images at the sub-pixel level. One week out, imaging was approximately 40–50 km/px, and a cartographic control network was begun using the USGS's Integrated Software for Imagers and Spectrometers (ISIS). As each new image set is returned, these are incorporated into the existing control network for Pluto and Charon (and lossy images will be replaced with lossless). As such, the control networks are in flux which makes mapping difficult and subject to change. However, control of images is necessary such that, *i.e.*, a crater in one image will not be identified as a different crater in a different image, despite them being the same feature.

Crater Mapping Approach— Images: The highest pixel scale images currently returned as lossless were navigation images, returned July 12, at 13 km/px. All other images currently available are lossy compressed. Several different image processing techniques have been employed by the Geology and Geophysics Investigation team, including basic image stacking, super-sampling, deconvolution to remove the ~2-pixel point-spread function, and Fourier Transform clipping to try to remove compression artifacts.

Crater Mapping Approach— Cartographic Control: Because the cartographic system is currently in flux, Robbins has been mapping impact craters on individual unprojected images that are part of the control network. This is done in pixel space and ISIS can use the information contained in the image to project into decimal degrees. As the cartographic network is updated, the information in the image file is also updated and the pixels can be reprojected into the new system. This prevents excessive duplicated effort.

Singer and Bray are using projected map products to map impact craters. Runyon is using the Small Body Mapping Tool [3] to measure crater diameters on the multi-resolution controlled mosaics. Robbins plans to also do a final global catalog to compare. Other team members may use additional tools throughout this work, and during this process we are including a subjective "confidence" of how certain they are that a feature is an impact crater. A consensus catalog will be made from everyone's identifications.

Crater Mapping Approach— Progress: With several researchers involved, we have been able to keep up with the returned images and plan to continue to do so. At this preliminary stage, the images show a variety of crater densities over both bodies indicating there is a range of geologic ages, potentially a variety of endo- and exogenic geologic processes, and the crater populations will not be as simple to interpret as many had anticipated. This is important because we will directly test different model impactor populations [*e.g.*, 4,5,6], and crater retention/preservation models [*e.g.*, 7]. Based on the imagery on the ground as of early August, 2015, it is too early to make any broad conclusions about crater morphology, or even to say that we see a large variety of morphologies.

References: [1] Cheng, A.F. *et al*. (2008). [2] Reuter, D.C. *et al*. (2008). [3] http://sbmt.jhuapl.edu [4] Schultz, P.H. & D.E. Gault (1985). [5] Bierhaus, E.B. & L. Dones (2015) doi:10.1016/j.icarus.2014.05.044. [6] Greenstreet, S. *et al.* (2015) doi:10.1016/j.icarus.2015.05.026. [7] Melosh (1989).

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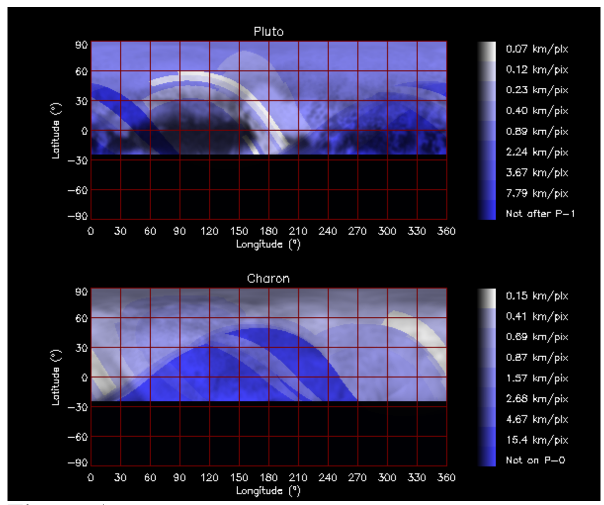

Figure 1: Expected resolution maps based on the most recent reconstructed spacecraft trajectory of (a) Pluto and (b) Charon over basemaps as of July 13, 2015.

Table 1: Pluto image campaign summary (non-exhaustive).

Name / Description	# Images	Px Scale	**Planet** Coverage*‡
N/A (non-encounter)	*several*	>15 km	38%
Full Disk Mosaic (encounter hemisphere)	20	0.9 km	26%*
Stereo Mosaic	15	0.4 km	2.1%*
LEISA Ride-Along	23	0.26 km	1.2%
MVIC Ride-Along	70	0.13 km	5.2%
Closest Approach	130	0.09 km	2.8%
High-Phase High-Res	60	0.08 km	0.7%
Soonest Crescent	6	0.8 km	~few%

*Areas covered at higher pixel scale are removed from this calculation.

‡Approximately 25% of the bodies were in permanent shadow during the flyby.