New Horizons Cruise and Approach Phase 1 Photometry for Pluto and a Solar Phase Curve. Amanda M. Zangari[1], S. Alan Stern[1], Harold A. Weaver[2], Leslie A. Young[1], Kimberly Ennico[3], Catherine B. Olkin[1], Jeffrey M. Moore, [3] Richard P. Binzel[4], Marc W. Buie[1], Bonnie J. Buratti[5], Andrew F. Cheng[2], W. M. Grundy[6], Ivan R. Linscott[7], William B. McKinnon[8], Harold J. Reitsema[9], Paul Schenk[10], Mark R. Showalter[11], John R. Spencer[1], G. Leonard Tyler[12] [1]Southwest Research Institute, (1050 Walnut Street Suite 300, Boulder, CO 80302 (azangari@boulder.swri.edu), [2]Johns Hopkins University Applied Physics Lab, [3]NASA Ames, [4]Massachusetts Institute of Technology, [5]Jet Propulsion Laboratory, California Inst. of Technology, [6]Lowell Observatory [7] Stanford University, [8]Washington University in St Louis, [9]Ball Aerospace (retired), [10]LPI, [11]SETI Institute, [12] Stanford University

Introduction: Since the summer of 2013, Pluto and Charon have been resolved from one another in the New Horizons LOng Range Reconnaissance Imager (LORRI)[1]. These spacecraft-based images provide a perspective not seen from Earth. The Solar phase angle, or Sun-Observer-Target angle, as seen from New Horizons ranges from 11° to 15° between 2013 and encounter, while the Earth-based Solar phase angle is never greater than 2°. Further, from the perspective of New Horizons, the sub-spacecraft latitude does not change from +43° (north/positive pole lies in the direction of the angular momentum vector), providing a consistent view of Pluto compared to the northward creep of the sub-observer point currently seen from Earth.

In July 2013, on each of two different days, three LORRI images of Pluto-Charon were taken, and light curves and solar phase curves were made from these navigation images [2]. Successful results from these images prompted a larger program to be carried out the following year: a set of 5 images was taken 15 times throughout a single rotation during New Horizon's eighth annual checkout in July 2014 [3]. Due to a halving of Pluto-spacecraft distance between July 2013 and July 2014 (5.9 AU to 2.8 AU), the 2014 images were of significantly better quality. In late January 2015, when Approach Phase 1 LORRI imaging commences, the Pluto-spacecraft distance will have halved again to less than 1.4 AU. Throughout Approach Phase 1, which begins in mid-January and ends in April 2015, several additional series of LORRI images will be taken.

Calibration and Comparison to Previous measurements: Using color corrections and zero point LORRI calibrations supplied by the team (Weaver, personal communication 2013), LORRI "V" magnitudes of Pluto corrected to common distances of r = 39.5, Δ = 38.5 AU, and were used to create Pluto and Charon light curves (see Figures 1 and 2). Both the 2013 and 2014 light curves have shapes comparable to the light curve predicted from recent HST photometry and mapping efforts [4, 5].

Phase curve analogues: Phase curves from the 2013 and 2014 data are plotted for Pluto and Charon in Figures 3 and 4. Also plotted are previous Earth-based phase curves for Pluto and Charon [4,6], as well the phase curve approximations from GeoViz [7], and analogues of other icy moons such as Triton [8], Tethys [9] and Ariel [10]. Given the error bars for the Pluto and Charon photometry, all analogue phase curves, with the exception of the extrapolated linear phase curve from [6] agree with the measurements so far. A linear fit was made for the LORRI Pluto and Charon data, however, the large error bars cause very low linear correlation coefficients between magnitude and phase (R=0.30) and (R=0.21). The linear fit also disagrees with the Pluto and Charon analogues. The 2015 measurements, which will begin starting in late January, will have an improved Pluto-spacecraft distance that should result in higher signal-to-noise and more robust determination of the phase curve. We plan to report on the planned January data at LPSC.

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References: [1] Cheng, A. F. et al. (2008) Space Sci Rev, 140, 189–215. [2] Zangari et al 2013, DPS 45, # 303.08. [3] Zangari et al 2013, DPS 46, # 419.05. [4] Buie, M.W., Grundy, W.M., Young, E.F., Young, L.A., Stern, S.A., 2010a. Pluto and Charon with the Hubble Space Telescope. Astron. J. 139, 1117–1127. [5] Buie, M.W., Grundy, W.M., Young, E.F., Young, L.A., Stern, S.A., 2010b. Astron. J. 139, 1128–1143. [6] Buie, M.W., et al 1997, Icarus, 125, 233. [7] http://soc.boulder.swri.edu/nhgv/ [8] Buratti, B. J. et al 2011, Icarus, 212 835. [9] Buratti, B., Veverka, J. 1984, Icarus 58, 284. [10] Buratti, B. et al 1990, Icarus 84, 203.

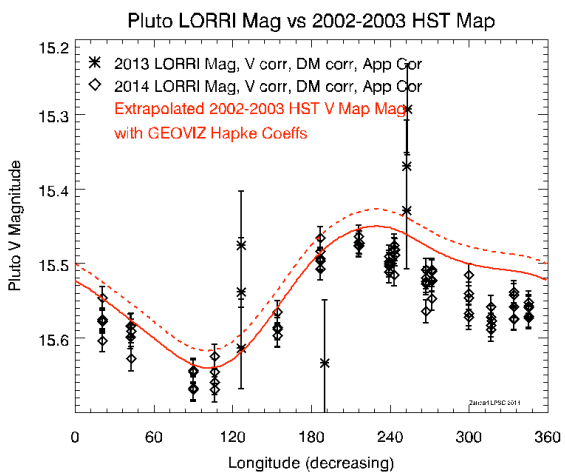

Figure 1: LORRI Pluto Light curve measurements from 2013 (X) and 2014 (diamonds) against extrapolated light curve based on HST measurements [4,5]. Light curves have been corrected to a common observer and sun distance, but not phase. The extrapolated light curves for 2013 and 2014 are represented by the dashed and solid red lines respectively The magnitude of the HST extrapolated light curve is determined by estimated Hapke coefficients [7]. There is no significant difference between the observed and extrapolated light curve shapes or the offset between the two.

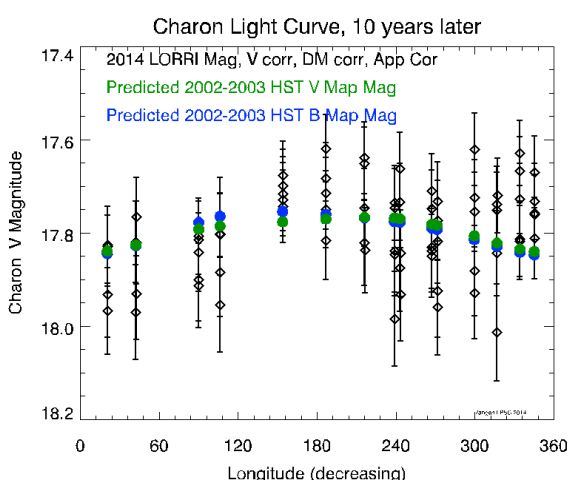

Figure 2: LORRI Charon light curve measurements from 2014 (diamonds) against a predicted light curve based on HST measurements (dots, blue = B, green = V) [4,5]. The magnitude of the predicted HST light curves plotted do not represent an offset calculated from analgoues, but rather a "light table" style shift to match up the HST light curve with the LORRI measurements. The shape of the LORRI Charon light curve is consitent with the shape predicted by HST, due to the large error bars.

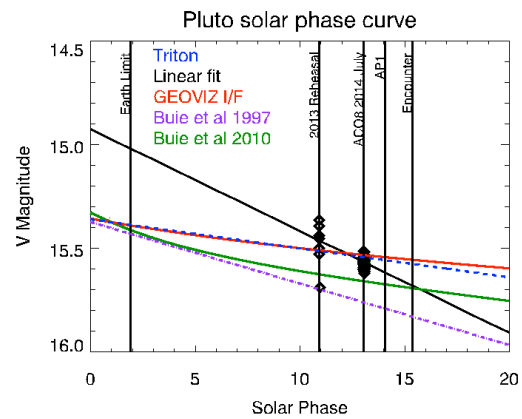

Figure 3: LORRI Pluto magnitudes plotted against solar phase angle for 2013 and 2014 LORRI data points. The data match well to all analogue light curves, save for Buie et al 1997 [6]. The linear fit matches the points, but not the other analogues and is driven by the high scatter from the 2013 points.

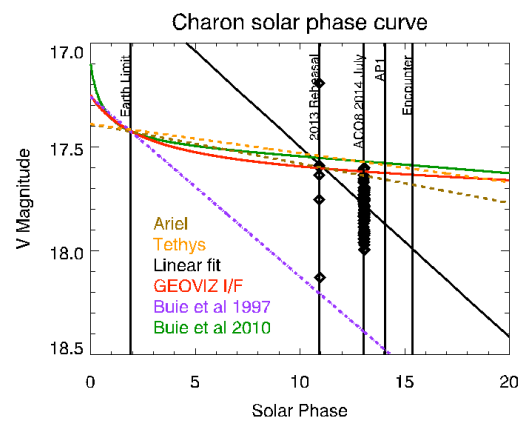

Figure 4: LORRI Charon magnitudes plotted against solar phase angle for 2013 and 2014 measures. The data match well to all analogue light curves, save for Buie et al 1997 [6]. The linear fit matches the points, but not the other analogues and is driven by the high scatter from the 2013 points.