LONG-RANGE RECONNAISSANCE IMAGER ON NEW HORIZONS. A. F. Cheng[1], H. A. Weaver[1], S. J. Conard[1], J. R. Hayes[1], M. F. Morgan[1], M. Noble[1], H. W. Taylor[1], O. Barnouin[1], J. D. Boldt[1], E. H. Darlington[1], M. P. Grey[1], T. Magee[1], E. Rossano[1], C. Schlemm[1], K. E. Kosakowski[2], and D. Sampath[2], [1]The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, [2]L-3 Communications SSG-Tinsley, 65 Jonspin Road, Wilmington, MA 01887.

Introduction: The LOng-Range Reconnaissance Imager (LORRI) is the highest resolution imaging instrument on NASA's *New Horizons (NH)* mission to Pluto and the Kuiper Belt. *NH* is the first mission in NASA's New Frontiers program and was successfully launched on 2006-Jan-19 [1]. After a 9.5 year interplanetary journey, the NH spacecraft will fly ~12,500 km above the surface of Pluto in July 2012, providing the first in situ investigation of this fascinating system comprised of two dwarf planets (Pluto and Charon) and at least four small satellites (Nix, Hydra, P4, and P5). LORRI has the sensitivity and dynamic range required to image these multiple targets at illumination levels only 1/900th of those on Earth, and with a resolution of ~100 m during closest approach to Pluto.

Design: LORRI is a narrow angle (field of view=0.29°), high resolution (4.96 µrad pixels), Ritchey-Chrétien telescope with a 20.8 cm diameter primary mirror, a focal length of 263 cm, and a three lens field-flattening assembly (Fig. 1). LORRI's total mass and power draw are 9.0 kg and 4.6 W, respectively. A 1024 × 1024 pixel (optically active region), thinned, backside-illuminated charge-coupled device (CCD) detector from E2V is used in the focal plane unit and is operated in frame transfer mode. The design and fabrication of LORRI are described in Conard et al. [2].

LORRI provides panchromatic imaging over a bandpass that extends approximately from 350 nm to 850 nm. LORRI operates in an extreme thermal environment, situated inside the warm spacecraft with a large, open aperture viewing cold space. LORRI has a silicon carbide optical system, designed to maintain focus over the operating temperature range without a focus adjustment mechanism. Moreover, the spacecraft is thruster-stabilized without reaction wheels, placing stringent limits on the available exposure time and the optical throughput needed to satisfy the measurement requirements.

LORRI has flexible exposure control. Exposure times can be set either *manually*, using values between 0 and 30 s at 1 ms increments, or via *autoexposure*, in which the integration time is determined autonomously by the observed brightness of the target. During observations in the Jovian system, excellent imaging was obtained with exposure times of only a few milliseconds. Typical exposure times during the Pluto Encounter are 100-150 ms. In 2012 the LORRI flight software was modified to enable *trigger mode* operation, in which LORRI saves images during a pointing scan only when the target is within the field of view, reducing data volume requirements.

LORRI images can be taken at a maximum rate of once per second. LORRI images are digitized to 12 bits and can be stored and downlinked using either lossless or lossy compression.

Performance: LORRI underwent extensive ground testing and calibration prior to launch [3]. After launch, LORRI was commissioned for operations during the summer and fall of 2006, followed by annual performance monitoring [4]. The measurement requirements and scientific objectives of LORRI, and the processing steps required to calibrate LORRI data, are described in Cheng et al. [5].

LORRI has not shown any evidence of performance degradation since launch. The point spread function varies over the field of view but is stable over time (the best fit gaussian FWHM is 1.8−2.4 pixels in the row direction and 2.5−3.1 pixels in the column direction, depending on the location; the CCD's charge transfer efficiency is better in the row direction). The flat field and photometric sensitivity are stable over time to within a few per cent. The read noise is ~24 e, as it has been since pre-launch testing. There is no evidence of radiation damage to the CCD (*NH* is powered by a radioisotope thermoelectric generator), and only a handful of cosmic ray events are detected during typical exposures.

Some examples of LORRI's in-flight imaging performance are shown in the figures. Remarkably, LORRI produced superb images of objects in the Jovian system (Figs 2 & 3) even though those bodies are ~35 times brighter than the targets LORRI was *designed* to observe in the Pluto system. LORRI's exceptional sensitivity is demonstrated by the long exposure of the Pluto approach field, where stars as faint as V≈18 are detected (Fig. 4). LORRI's optical design is not optimized for scattered light rejection, but LORRI produced exciting scientific results during high solar phase angle observations in the Jovian system

References: [1] Stern, S. A. (2008) Space Sci Rev, 140, 3–21, DOI: 10.1007/s11214-007-9295-y. [2] Conard, S. et al. (2005) Proc. SPIE 5906, 407–420, DOI: 10.1117/12.616632. [3] Morgan, F. et al. (2005) Proc. SPIE 5906, 421–432, DOI: 10.1117/12.616880. [4] Noble, M. W. et al. (2009) Proc. SPIE 7441, DOI: 10.1117/12.826484. [5] Cheng, A. F. et al. (2008) Space Sci Rev, 140, 189–215, DOI: 10.1007/s11214-007-9271-6.

Fig. 1: Photograph of LORRI during laboratory testing prior to integration into the New Horizons spacecraft.

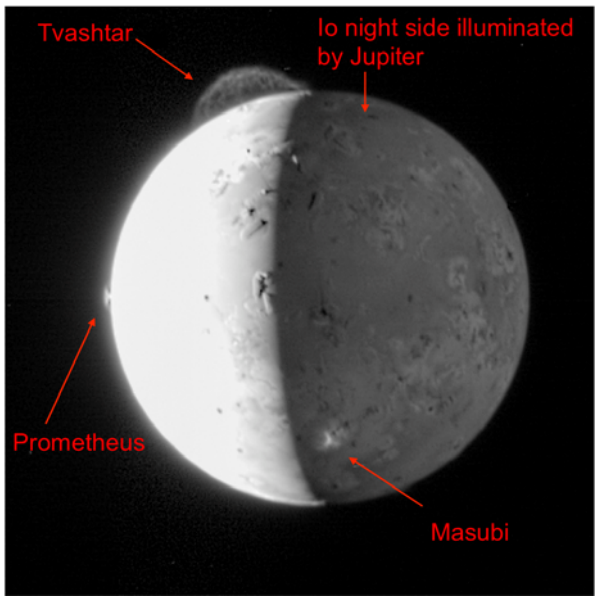

Fig. 2: During the New Horizons flyby of Jupiter, LORRI captured many spectacular images of active volcanos on Io. The above LORRI image was taken on UT 2007-Feb-28 11:04 at a range of 2.4 million km, a phase angle of 102 deg, and a resolution of 12 km. LORRI captured a 5-frame sequence of a Tvashtar eruption over an 8-min period, providing the most detailed view ever obtained of the dynamics of an extraterrestrial volcano.

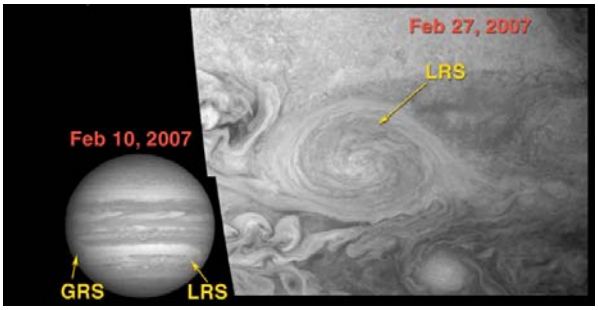

Fig. 3: LORRI made the highest resolution observations of the Little Red Spot on Jupiter, allowing a detailed mapping of the winds in this giant hurricane.

Fig. 4: Composite of five LORRI images taken on 2012 June 1 during a New Horizons annual checkout. Each LORRI image had an exposure time of 10 sec and was obtained in 4x4 format (i.e., on-chip binning over 16 pixels during CCD readout). This star field is centered near the expected location of Pluto during the entire period from January 2015 until approximately 1 month prior to closest approach. In fact, Pluto is already seen within the LORRI field of view during this observation 3 years before closest approach (Pluto is circled in red). This deep exposure reaches down to V≈18. The black tails to the right of the bright, saturated stars are caused by amplifier undershoot.