LUNAR RECONNAISSANCE ORBITER CAMERA (LROC): READY FOR ROCKS. M. Tschimmel[1], M. S. Robinson[1], D. C. Humm[2], B. W. Denevi[1], S. J. Lawrence[1], S. Brylow[3], M. Ravine[3] and T. Ghaemi[3], [1]School of Earth and Space Exploration, Arizona State University, P.O. Box 873603, Tempe, AZ 85287 (martin@ser.asu.edu), [2]Space Instrument Calibration Consulting, Annapolis, MD, [3]Malin Space Science Systems, San Diego, CA

The NASA Lunar Reconnaissance Orbiter Camera (LROC) is comprised of three cameras (Figs 1 and 3): a Wide-Angle Camera (WAC) and two identical Narrow Angle Cameras, called NAC-L and NAC-R. The instruments and electronics were built by Malin Space Science Systems with heritage from the successful cameras MARCI and CTX onboard MRO [1].

The WAC is a push-frame camera with two UV and five visible wavelength filters (321, 360, 415, 566, 604, 643 and 689 nm). Its visible and the UV channels have separate optics providing a spatial resolution of 100 m/pixel and 400 m/pixel, respectively. The focal lengths are 6.0 mm (visible) and 5.04 mm (UV), the F/# is 5.06 for the visible and 5.66 for the UV. The system modulation transfer function (MTF) is 0.3.

The WAC will be operated in two modes: multicolor for mineralogical mapping and monochrome to provide a global large-incidence angle basemap and a time-lapse movie of illumination conditions at the poles [2]. Ground calibration was performed to characterize the system response for each camera and a calibration pipeline is now awaiting data from the Moon.

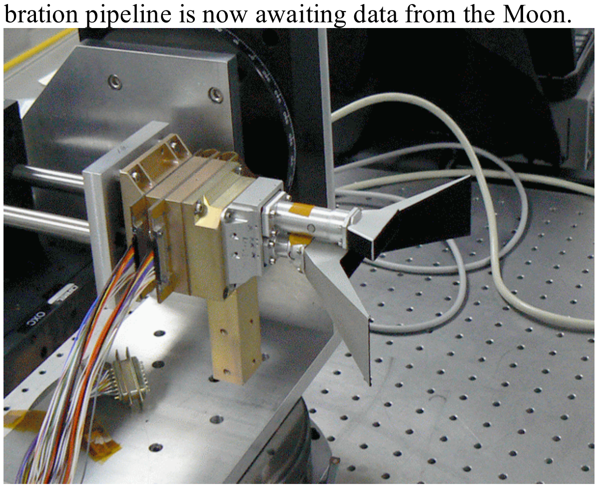

Figure 1: The WAC during lab calibrations. For scale, the holes on grid are 1” apart.

The WAC CCD is highly linear and has a gain of 26.3 e^-/DN. The read noise is 72 e^- and the fullwell capacity is 47,000 e^-. The signal-to-noise ratio in each band is higher than 145. The system spectral response (Fig. 2) was calculated from component measurements due to the low angular resolution and the small CCD fill factor (~20%). Absolute calibration from lab measurements is estimated to be better than 20% with expected improvement to 10% with in-flight data. Dark response and system non-uniformity were characterized during lab calibration. However, both measurements will be improved with in-flight data.

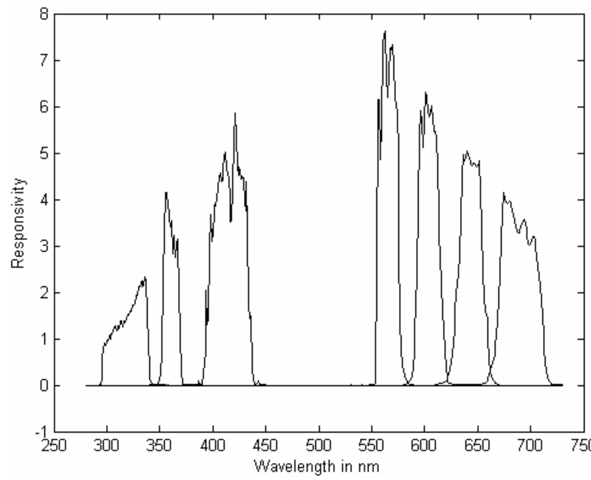

Figure 2: System spectral response for the WAC as derived from component measurements.

The two NACs are monochrome pushbroom scanners capable of 50 cm/pixel resolution from a 50-km orbit. As the NACs are mounted side-by-side the combined images have a swath width of 5 km and a maximum downtrack length of 26 km. The purpose of the NACs during the primary mission is to fully characterize future human and robotic landing sites in terms of scientific and resource merit, trafficability, and hazard assessment. The North and South poles will be mapped at 1-meter-scale poleward of 85.5 degrees latitude [2]. Stereo coverage is achieved by pointing the NACs off-nadir, which requires planning in advance [3, 4].

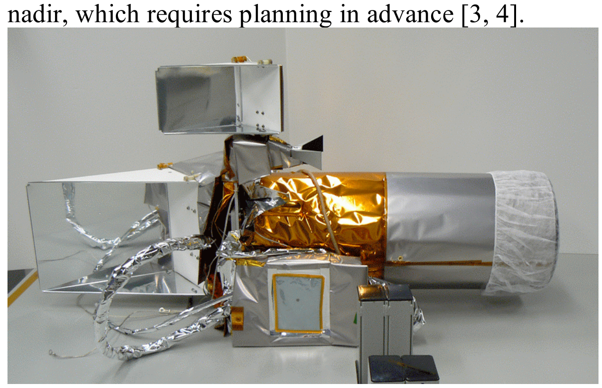

Figure 3: The NAC-L before thermal vacuum tests with radiator attached (left). The WAC is mounted on top, including its radiator. The electronics box (SCS) is in front of the NAC.

Calibration shows that the CCDs of the NACs are linear above 400 DN. The dark noise is below 2 DN. For NAC-L the gain is 69.3 e^-/DN yielding a read noise of 76 e^- and a fullwell of about 260,000 e^- (cf. Fig. 4). For NAC-R the gain is 71.1 e^-/DN resulting in a read noise of 74 e^- and a fullwell of approximately 271,800 e^-. The focal lengths are 699.6 mm (NAC-L) and 701.6 mm (NAC-R). The system MTF is 0.23 for both NACs and thus meets the requirements. Signal-to-noise ratio for both NACs is at least 46 (terminator scene) and can be higher than 200 (high-sun scene). Both NACs exhibit a minor straylight feature, which is caused by out-of-field sources and is of a magnitude of 1-3%. However, this feature is well understood and can be mitigated with on-ground processing. Dark response and system non-uniformity were characterized during lab calibration, however both measures will be improved with in-flight data.

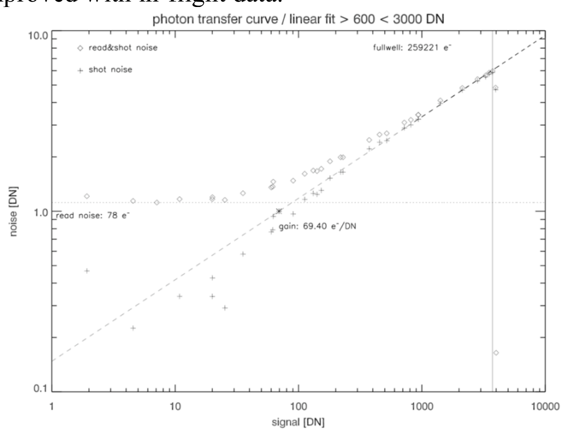

Figure 4: Photon transfer curve analysis of NAC-L linearity images yielding gain, read noise and fullwell.

The NAC calibration pipeline is developed and reviewed (see Fig. 5). One particular feature is the correction of non-linearity at low signal levels with a logistic function $\frac{1}{a \cdot b^x + c}$ (Fig. 6). This correction will be applied for DN values below 400 DN.

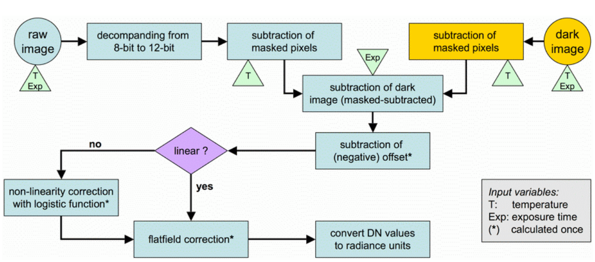

Figure 5: NAC calibration pipeline: depending on the focal plane temperature "T" and the exposure time "Exp" the parameters of the calibration will vary. Each NAC line has several masked pixels that are used to subtract the offset, which varies from image to image.

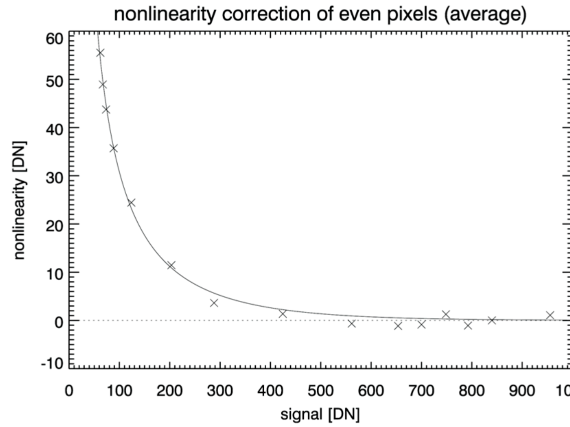

Figure 6: Nonlinearity correction for NAC-R even pixels with a logistic function..

As part of the imaging process the original 12-bit data of the NAC (11-bit for the WAC) are companded to 8 bits. While the WAC uses a lookup table the NAC companding has to utilize piecewise linear functions due to fast pixel readout. There are 6 functions available (composed of 5 linear pieces) that are optimized to the expected brightness conditions (Fig. 7). After companding the LROC Sequence and Compressor System (SCS) with a 256 MB memory compresses the images without loss by a factor of 1.7 and transfers them to the LRO solid state recorder.

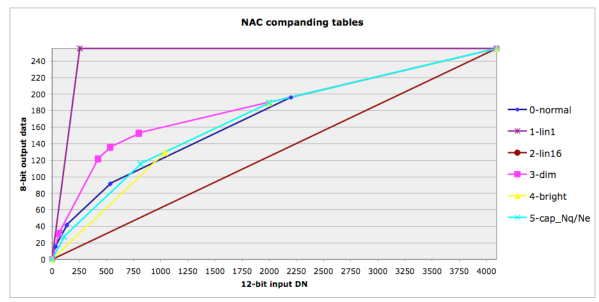

Figure 7: The available NAC companding tables are optimized to various illumination conditions.

During the nominal mission LRO will complete 12.7 orbits per day. On each orbit an average of 12 NAC pairs are taken, which results in an expected datarate of 450 Gbits per day. Therefore, at the end of the one-year primary mission there will be 20 TB of high-resolution images of the Moon that will pave the way for future lunar science and exploration.

References: [1] Robinson M. S. et al. (2005) *LPS XXXVI*, Abstract #1576. [2] Chin G. et al. (2007) *Space Science Reviews, 129*, 391-419. [3] Jolliff B. L. et al. (2009), *LPS XL*. [4] Lawrence S. J. et al. (2009), *LPS XL*.