POST-LAUNCH CHARACTERIZATION AND CALIBRATION OF THE OPTICAL NAVIGATION INSTRUMENTS FOR NASA'S LUCY MISSION

Eric Sahr[1*], Erik Lessac-Chenen[1], John Pelgrift[1], Derek Nelson[1], Coralie Adam[1], and Dale Stanbridge[1]; [1]KinetX Aerospace, 21 W Easy St Suite 108, Simi Valley, CA 93065, [*]Eric.Sahr@kinetx.com

Abstract. *The Lucy spacecraft is currently in its Outbound Cruise phase, on the way to the first exploration of Jupiter's Trojan asteroids. Successful navigation of the spacecraft to its Trojan targets will require optical navigation to satisfy requirements. The use of optical navigation necessitates precise characterization of various aspects of the imaging systems. This paper will present the observation planning efforts and results of the Outbound Cruise activities that captured the images necessary for imager characterization and the results of the geometric distortion characterization for the L'LORRI and TTCAM imagers.*

Introduction. The Lucy Jupiter-Trojan mission launched in October 2021, marking the beginning of a 12-year mission to perform the first-ever exploration of the Trojan asteroids of Jupiter. Between June 2027 and November 2028, the spacecraft will perform five close flybys in the L4 cluster of Jupiter. The spacecraft will then cruise for five more years before performing a flyby of a binary Trojan asteroid system in Jupiter's L5 cluster in 2033. The spacecraft will also perform a flyby of the main-belt asteroid 52246 Donaldjohanson in 2025. The close flybys of these targets will require robust optical navigation (OpNav) capabilities in order to facilitate the precise and accurate navigation of the spacecraft relative to the flyby targets. [1]

The Lucy Long-Range Reconnaissance Imager (L'LORRI) and the two Terminal Tracking Cameras (TTCAMs) [2] will be used for optical navigation prediction and reconstruction of each Trojan encounter. To this end, known potential sources of error in the imager systems must be understood and reduced prior to being used for navigation. For each of these imagers, the geometric distortion of the optical system must be calibrated, the photometric qualities of each imager must be modeled, and the alignment of each imager to the Lucy Instrument Pointing Platform (IPP) must be characterized.

At approximately 120 days after launch (i.e. L+120d) the first of the planned instrument calibration activities was performed in order to begin characterizing the optical instruments' photometric and geometric behavior. Initially planned solely as an instrument-to-IPP alignment calibration, the scope was expanded during the initial planning process to include geometric distortion and photometric modeling of the L'LORRI and TTCAMs instruments.

IPP-Gimbal-Angle-Based Instrument Pointing Simulator. The OpNav Team faced significant challenges to planning the initial IPP movement requirements for the navigation-driven characterization of the L'LORRI and TTCAM imagers. The scope of the L+120d characterizations was expanded to include characterizations of other aspects of the imagers, such as stray light sensitivity and pointing stability. Fitting in these additional observation goals imposed added complexity to ensuring that the requirements of all stakeholders were met. To assist in the planning for meeting these requirements, an IPP-Gimbal-Angle-Based Instrument Pointing Simulator was developed by the OpNav Team in order to search the problem space for the optimal imaging targets. An example of the output of this tool appears in Figure 5.

L'LORRI Distortion Calibration Overview. As part of the larger L+120d Checkout observations, a total of 65 L'LORRI images were taken at exposure times ranging from 2 to 10 seconds. These images were processed through the KinetX Image Processing Suite (KXIMP) [3] using a pre-fit OpenCV geometric distortion model, with all terms set to 0 and the focal length set to a pre-launch measured value. The resulting residuals of observed star positions vs. expected star positions in each image were used to estimate the geometric distortion of the L'LORRI imager. The pre-fit star residuals were very close to zero-mean, but with standard deviations exceeding two pixels. A pre-fit quiver plot of these residuals (a plot showing the residuals at the star locations in the field of view) showed a pattern that was indicative of a focal length error in the pre-fit camera model. An OpenCV distortion model was estimated in a least-squares sense using these star residuals. The resulting geometric distortion solution was fed back into KXIMP where the images were re-processed, and the process was iterated until a final geometric distortion solution was converged upon. The final geometric distortion solution using this dataset also had zero-mean star residuals, but with a standard deviation on the order of hundredths of a pixel. A quiver plot of this solution is shown in Figure 1, accompanied by a plot of star residuals vs. apparent magnitude in Figure 2. As more L'LORRI images become available throughout the mission, further characterization of the distortion model will be performed, including characterization of any temperature dependence of the focal length. A Simple Imaging Polynomial geometric distortion model was also estimated in a similar manner, and will be discussed at greater length in the conference presentation of this work.

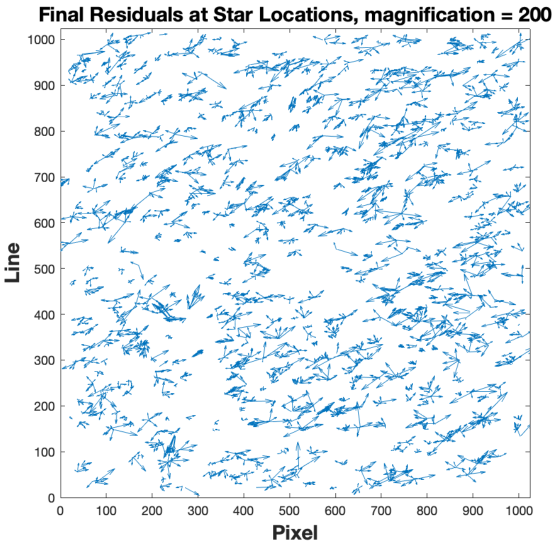

Figure 1. L'LORRI Post-Fit Residual Quiver Plot

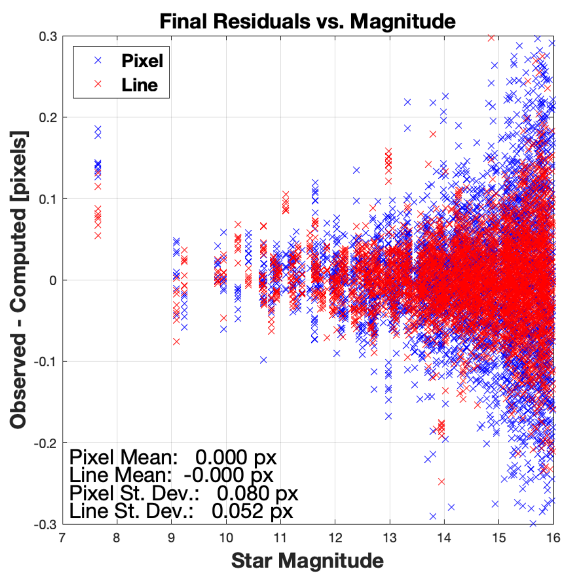

Figure 2. L'LORRI Post-Fit Residuals vs. Apparent Magnitude

TTCAM Distortion Calibration Overview. Characterization of the geometric distortion of the two TTCAM imagers was also performed. 32 images were captured during the L+120d Checkout campaign, with 2 images captured for each TTCAM imager at each of 8 IPP pointing positions. These images were processed through KXIMP using a pre-fit OpenCV geometric distortion model, with all terms set to 0 and the focal lengths set to a pre-launch measured value. For each imager, OpenCV distortion models were estimated in the same manner as L'LORRI. The pre-fit geometric distortion solution had zero-mean star residuals for both imagers. However, residual standard deviation exceeded two pixels for TTCAM1 and half a pixel for TTCAM2. A pre-fit quiver plot of these residuals showed a pattern that was indicative of a focal length error in the pre-fit camera model for TTCAM1, and a radial error in TTCAM2. After the final geometric distortion solutions for each imager were estimated, the star residuals were zero-mean, with residual standard deviations of about one-tenth of one pixel. A quiver plot of the TTCAM1 solution is shown in Figure 3, accompanied by a plot of star residuals vs. apparent magnitude in Figure 4. As with L'LORRI, the geometric distortion model will be continuously updated as more images become available throughout the mission.

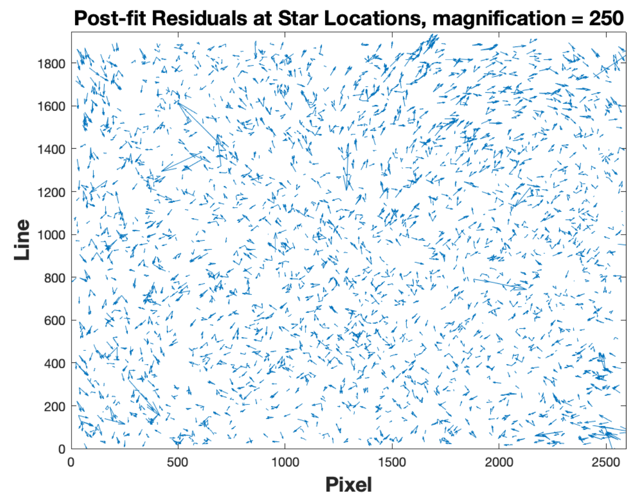

Figure 3. TTCAM1 Post-fit Residual Quiver Plot

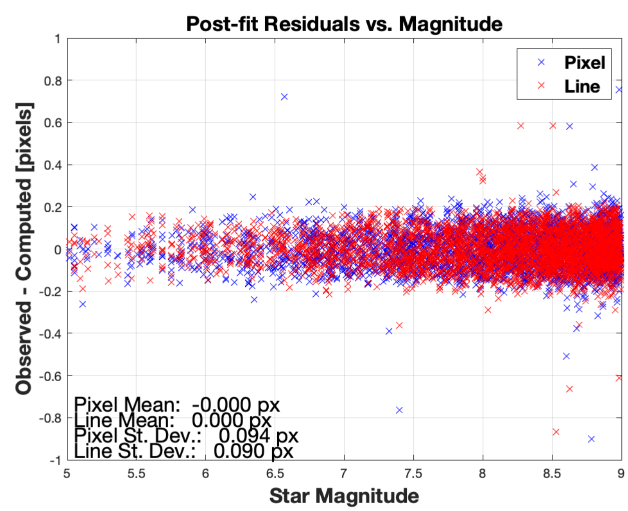

Figure 4. TTCAM1 Post-fit Residuals vs. Apparent Magnitude

References.

[1] D. Stanbridge, K. Williams, B. Williams, C. Jackman, et al, "Lucy: Navigating A Jupiter Trojan

Tour", AAS 17-632, AAS/AIAA Astrodynamics Specialist Conference, Stevenson, WA, August 2017.

[2] E. J. Lessac-Chenen, C. D. Adam, D. Nelson, J. Pelgrift, E. Sahr, L. K. McCarthy, D. Stanbridge and K. Berry. "Optical Navigation Operations and Preparations for the Lucy Trojan-Asteroid Mission," AIAA 2022-1226. *AIAA SCITECH 2022 Forum*. January 2022.

[3] C. D. Jackman and P. J. Dumont, "Optical Navigation Capabilities for Deep Space Missions", Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, February 2013.

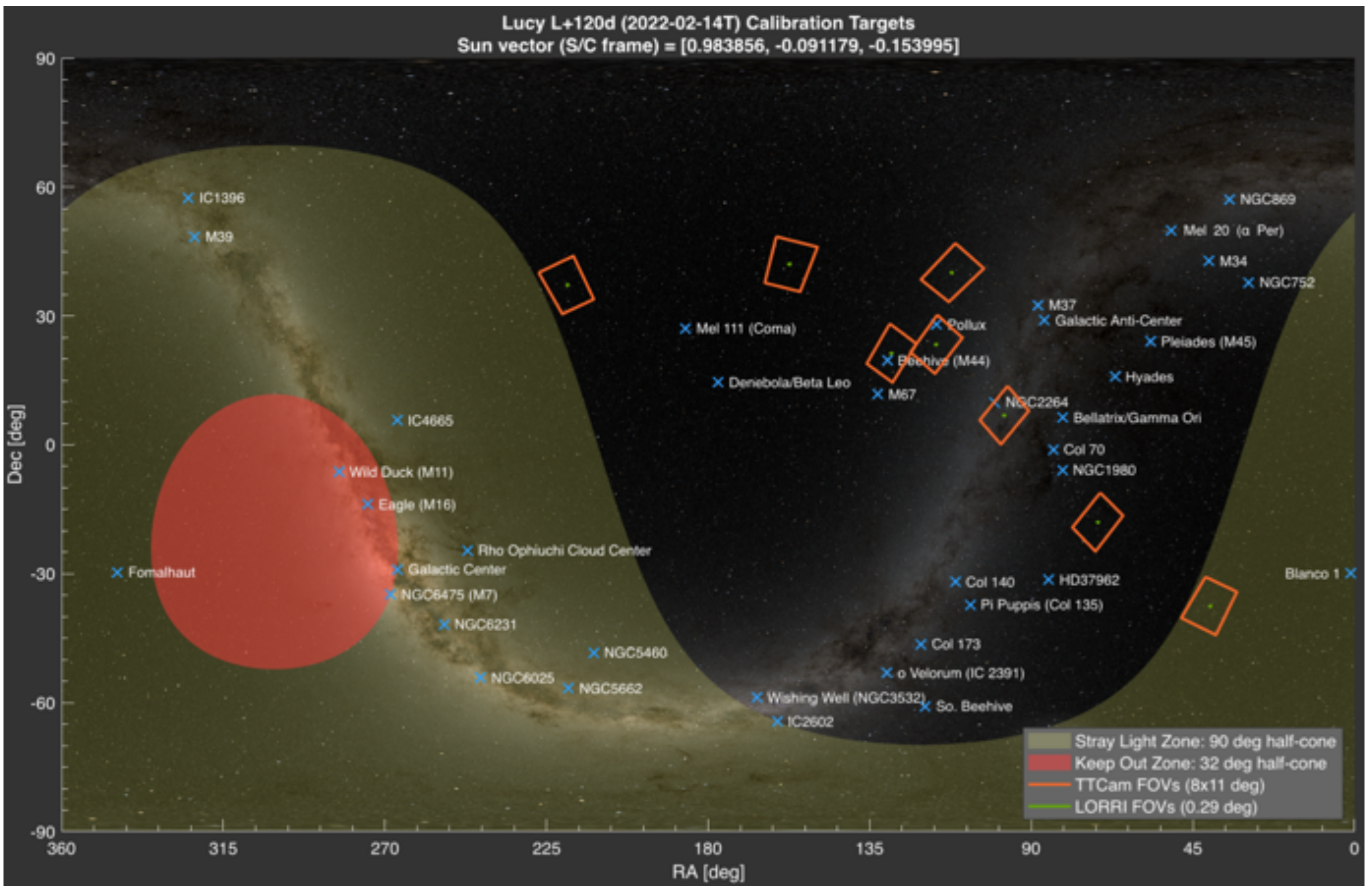

Figure 5. TTCAMs and L'LORRI fields of view for IPP Alignment and Instrument Geometric Distortion Activities