Calibration Description: Lucy L'Ralph Multi-spectral Visible and Infrared Camera
Hannah Kaplan, March 5, 2024
Version 1.0

Introduction

The Lucy Mission to the Trojan asteroids in Jupiter's orbit carries an instrument named L'Ralph, a visible/near infrared multi-spectral imager and a short wavelength infrared hyperspectral imager. This document describes the Multi-spectral Visible and Infrared Camera (MVIC), half of the L'Ralph instrument that shares an optical path with the hyperspectral imager. MVIC has six independent time delay integration (TDI) charge coupled devices (CCDs) equipped with filters that span the panchromatic (pan, 350 – 950 nm), violet (375 – 480 nm), green (480 – 520 nm), orange (520 – 625 nm), phyllosilicate (625 – 750 nm), and near-infrared (750 – 950 nm). With TDI CCDs, the signal increases as the scene is scanned over the focal plane and charge is transferred between rows of pixels at the scan rate. MVIC has a cross-track width of 144 millirad (~8.25 degrees, 5024 pixels), which is scanned over the surface to build up large format images.

MVIC has several options to optimize integration times and returned data volumes. Each CCD has 5024 x 64 pixels, with an individual pixel size of ~29 microrad, and each CCD can be independently set to use either 4, 8, 16, 32, or 64 pixels in the TDI scan. Commanded integration time per TDI pixel is typically coordinated with scan mirror rate, both of which are recorded in the image header. The total integration time per pixel is a function of the integration time per TDI pixel and the number of TDI rows used in the observation. For every MVIC observation, all 6 channels (5 color + 1 panchromatic) are saved on the onboard memory, but individual channels may be disabled for playback so the retrieved dataset may have between 1 and 6 channels included. MVIC can perform analog pixel summing in the cross-track and/or along-track direction. This reduces the data volume and increases the SNR for an individual summed pixel but reduces the angular resolution. The number of pixels used in along-track summing and cross-track summing are defined by header keywords ATsum and XTsum where a value of 0 means no summing, a value of 1 means every 2 pixels were summed, and so forth. The two directions are set separately, but the nominal operation will use the same amount of cross-track and along-track summing. File size is dependent on summing and retrieved channels and will be: 5024/(XTsum+1) * AT/(ATsum+1) * N channels.

More instrument details can be found in Reuter et al. 2023 *Space Science Reviews* **219**, 69. DOI: 10.1007/s11214-023-01009-2.

The ground calibration pipeline converts the Level 0 data to physical units. Several processing and calibration steps are performed on the raw data to produce a Level 2 spectrum:

1. Subtract the average background (dark current) level.
2. If summing was employed, account for that with the calibration coefficients.
3. Calculate the actual integration time.
4. Convert to radiance units.

Calibrated data products produced by this calibration pipeline are indicated with a filename containing the filed “sci”, while level 0 products are indicated with “eng”. Further description of the MVIC pipeline and its products is provided in the Lucy MVIC SIS, Document 22668.07-MVIC-SIS-01_R0_C0.

1. Background Subtraction

Average background level can change throughout a mission. Deep space data acquired in the same observing mode, at similar detector temperature (and within the same scan, where operations permit), are used to calculate the average background level (Space File). As sequences are not calling separate observation blocks for this purpose, we take an average of 100 along-track rows of data for each channel to create an interim dataset size: 5024/(XTsum+1) * 1 * N channels. The 100 rows are taken from n1 to n2, where n1 is the number of TDI rows (e.g., 4, 8, 16, 32, or 64)+1 and n2 is n1+100 as long as that row occurs before the target has crossed the FOV. Outliers are removed from the average, and it is smoothed with a Savitzky-Golay filter with a window length of 11 and polynomial order of 3. This average row value is repeated for every along-track row to replicate the original data size. These corresponding space files are manually generated and validated to ensure that there is no target in the FOV. Corrected counts, $C_{i,j}$, are simply the raw counts $DN_{i,j}$, minus the average background $DNb_{i,j}$:

$$C_{i,j} = DN_{i,j} - DNb_{i,j}$$

The space data are saved into files with names matching the science file but denoted by “space". This file name appears in the headers, and the data are also written into the L2 file as an extension.

2. Sum Adjustment

If pixels have been summed onboard, the counts at level zero must be divided by the number of pixels used in the sum:

$$C_{i,j} = \frac{C_{i,j}}{(ATsum + 1) * (XTsum + 1)}$$

If summing was applied, then the radiometric coefficients are also summed by the relevant number of pixels designated by XTsum and ATsum and then divided by the total number of pixels in the sum.

3. Integration Time Calculation

Integration time per TDI row (VISINT) and total integration time (EXPTIME) are both included in the header and reported in microseconds. Total integration time can be calculated:

$$\text{EXPTIME} = \text{VISINT}*(\text{TDI}-1)$$

EXPTIME is divided by 1e6 to convert from microsecond to seconds and this value is used in the radiance unit conversion.

4. Radiance Unit Conversion

Corrected counts are converted to radiance units, $I_{i,j}$, in W/cm^2/sr/micron by first dividing by exposure time, *t*, to get counts/s. They are then multiplied by the appropriate calibration coefficients, $R_{i,j.}$ There is a unique set of calibration coefficients for each channel and each TDI setting (4, 8, 16, 32, 64), so for every channel the following calculation is performed:

$$I_{i,j} = \frac{C_{i,j}}{t} * R_{i,j}$$

The file name used in the pipeline is in the header, and the calibration coefficient are also written into a L2 file extension.

Data notes:

- There is currently no cosmic ray correction applied to these data.