New Horizons (486958) Arrokoth Encounter Surface Composition Maps – Overview

Note:

The information in the document is derived mainly from Grundy, et al. (2020). The data presented were also provided as supplementary material for that publication.

Some editing of the original PDS3 catalog file description has been done to provide better flow for readers in a PDS4 archive.

The Ralph Instrument

The Ralph instrument is a three-mirror anastigmat telescope with a 75 mm entrance aperture and 658 mm focal length. A dichroic beamsplitter feeds two focal planes, making it effectively two instruments in one: a color CCD imager (the Multi-spectral Visible Imaging Camera, MVIC) and an infrared spectral imager (the Linear Etalon Infrared Spectral Array, LEISA). See Reuter, et al. (2008) for additional details.

The Arrokoth MVIC Color Cube

Ralph's Multi-spectral Visible Imaging Camera (MVIC) focal plane consists of six time-delay integration (TDI) charge-coupled device (CCD) arrays and one frame transfer CCD. The TDI detectors have 32 rows to build up the integrated signal as the instrument field of view is scanned across the scene. In the cross-track direction, orthogonal to the 32 TDI lines, there are 5000 active pixels. Each pixel subtends 20 microrad for a cross-track field of view of 5.7 deg. Four of the six TDI detectors have broadband filters fixed to the detector assembly. The color filters are identified as "BLUE" (400-550 nm), "RED" (540-700 nm), "NIR" (780-975 nm) and "CH4" (860-910 nm). These detectors are operated simultaneously for color observations. It is not possible to operate the panchromatic detectors at the same time as the color detectors owing to data bus limitations.

CA05 observation

The highest spatial resolution MVIC color observation of Arrokoth, designated as CA05, was obtained on 2019 January 1 at 5:14 UTC (coordinated universal time), from a mean range of 17,200 km, at an image scale of 340 meters per pixel and phase angle 15.5deg. The scan rate was 800 microrad/s which corresponds to an integration time of 0.8 seconds. Comparing the observed signal for a well-lit portion of Arrokoth to the standard deviation in a sample of blank sky, we estimate the single pixel signal-to-noise ratios to be 60, 175, 148, and 57 in BLUE, RED, NIR, and CH4 filters, respectively.

MVIC cube construction

Each of the four color images was upsampled to three times its native pixel scale, and then the BLUE, RED, and CH4 images were degraded to match the PSF of the NIR image through convolution with Gaussian kernels. Each of the BLUE, NIR, and CH4 filter images was then transformed using a 3x3 transformation matrix to register it to the RED image.

The MVIC cube is provided as "ca05_mvic_cube.fit", with dimensions 300x300x4. The 300x300 dimensions are spatial, while the 4 dimension is spectral. The wavelengths are in the order listed earlier: BLUE, RED, NIR, CH4.

Caveats

Over the course of the CA05 scan, Arrokoth's orientation and range as seen from the spacecraft changed very slightly. The cube-building algorithm does not correct for these effects.

The Arrokoth LEISA Spectral Cube

Ralph's Linear Etalon Infrared Spectral Array (LEISA) focal plane consists of a Rockwell Scientific Corporation PICNIC array (a 256x256 pixel HgCdTe device) with two linear variable filters to disperse the light. The larger filter covers wavelengths from 1.25 to 2.5 microns with a resolving power (lambda/delta_lambda, where lambda is the wavelength) of ~240. The smaller filter covering 2.1 to 2.25 microns with a higher resolving power (~560) was not used in this product. The LEISA detector has a field of view of 0.9deg with both axes providing spatial data coupled with spectral dispersion along one axis.

CA04 observation

Ralph LEISA images its target scene through a linear variable filter. To capture each location at each wavelength of the filter, frames are recorded while the spacecraft scans LEISA's field of view across the scene. The highest spatial resolution LEISA observation, designated as CA04, was executed on 2019 January 1 around 4:58 UTC, from a phase angle 12.6 deg and mean range of 31,000 km, resulting in a mean image scale of 1.9 km per pixel. Panchromatic LORRI (LOng Range Reconnaissance Imager) images were also recorded during the CA04 scan, but they are provided elsewhere.

We used a slower scan rate (60 microrad/s) than had previously been used at Pluto to partly compensate for the lower light levels at Arrokoth's extreme distance from the Sun (43.28 AU at the time of the encounter) and its low albedo. This low scan rate led to substantial motion distortion as numerous thruster firings occurred during the course of the scan to maintain the target within pointing deadbands. The duration of the scan was such that the spacecraft-target range also changed over the course of the scan, resulting in changes in the scale and resolution.

Flat field

We used three LEISA scans of Charon taken during the Pluto encounter to construct a flat field for the LEISA observation. Charon was used for this purpose because of the lack of spectral diversity across its surface, unlike Pluto. The three highest spatial resolution scans of Charon (90) were used in order to check for consistency. These are identified as C_LEISA_HIRES, C_LEISA_LORRI, and C_LEISA. In each of these scans, Charon passed through the center of the field of view with the C_LEISA_HIRES scan subtending the greatest area of the detector. Charon did not completely fill the detector in any of these scans, so there are regions around the frame edges which have not been corrected, but Arrokoth was not imaged in these uncorrected regions.

Using the frame data (spatial vs. spatial-spectral format), a mask was constructed to isolate Charon from the background. The average signal was then calculated for each pixel when it was illuminated by Charon. This produced a 256x256 pixel array (with pixels set to zero if never illuminated by Charon) with the mean spectrum of Charon still present. That was removed by robust fitting (i.e., with rejection of outlier points) of a single-order polynomial to each row (wavelength) of the frame. The results from each of the Charon scans were then combined where they overlap. The result is the ratio of the new flat to the old flat with which the Charon data had already been processed by the standard pipeline. After multiplying by the old flat, the new flat was obtained. This file is provided as "leisa_charon_flat.fit".

LEISA cube construction

The LEISA data were processed into a spectral cube, with spatial dimensions along two axes and wavelength along the third axis. The cube-building algorithm we adopted accounts for the motion distortion from thruster firings as well as changes in spacecraft range over the course of the CA04 LEISA scan. To extract the spatially-registered spectra of Arrokoth from the LEISA data frames, a frame-by-frame pointing solution was determined. The changing spacecraft-to-target range during the LEISA scan resulted in a spatial scale that changed from 2.0 to 1.8 km/pixel over the time the scan, with the closer range coinciding with longer wavelengths. The range was taken from predicted SPICE kernels for the observation time of each frame and used to construct a scaled model image of Arrokoth (two sky-plane circles connected by a rectangular neck). The focal plane center of figure, mean albedo, and the full width at half maximum of a Gaussian point spread function was varied until the mean squared difference between a given frame and the model was minimized. Parameter optimization was achieved with simplex minimization. The position angle of the neck and two spheres was assumed to be fixed in all frames. In the case where a pointing solution failed (such as when the target was crossing the edge of the focal plane), the position was estimated via linear interpolation from the nearest successful solutions.

Pixel coordinates in each plane were then converted into a physical frame relative to the center of figure using the range prediction. The [*delta_x* (km), *delta_y* (km), *lambda* (microns)] coordinates of each pixel were stored, where *delta_x* and *delta_y* are distance from the center of figure along the axes of the detector array, along with the I/F measured by that pixel. A mask of hot pixels and cosmic rays was applied at this stage, and flagged pixels were removed from this data structure. A nearest-neighbor interpolant was constructed to interpolate these

I/F measurements over these coordinates. The final spectral cube was constructed by constructing a (*delta_x*, *delta_y*, *I/F*) plane from this interpolant sampled over a spatially-uniform grid sampled at 10 times the average native spatial resolution at each unique wavelength sampled by the measurements.

The LEISA cube is provided as "ca04_leisa_cube.fit", with dimensions 47x47x197. The 47x47 dimensions are spatial, while the 197 are spectral. A separate file "ca04_leisa_wavelengths.tab" contains the wavelengths associated with each of the 197 spectral planes.

Caveats

Over the course of the CA04 scan, Arrokoth's orientation as seen from the spacecraft changed slightly. The cube-building algorithm does not correct for the effects of that rotation.

References

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