New Horizons LEISA Instrument Overview

This document is an overview of the New Horizons' Linear Etalon Imaging Spectral Array (LEISA) Instrument. This LEISA description was originally adapted from Reuter et al. (2005), Reuter et al. (2008), and the New Horizons website. During migration to PDS4, this current copy was adapted from the PDS3 LEISA instrument catalog file, providing light edits to the text, format, and flow.

Instrument Overview

LEISA is a wedged etalon infrared spectral imager that operates in a push-broom mode. LEISA is part of the Ralph instrument package.

Specifications

NAME:	LEISA (Linear Etalon Imaging Spectral Array)
DESCRIPTION:	Infrared Imager
PRINCIPAL INVESTIGATOR:	Alan Stern, SwRI (Southwest Research Institute)
WAVELENGTH RANGE:	1250 - 2500 nm
FIELD OF VIEW:	15.9 x 15.9 mRad
ANGULAR RESOLUTION:	0.062 mRad
WAVELENGTH RESOLUTION:	6.3 nm/pixel (Full spectral range); 2.8 nm/pixel (2100 - 2250 nm)

Description

Ralph/LEISA operates at infrared (IR) wavelengths, and its etalon (a wedged filter with a narrow spectral bandpass that varies linearly in one dimension) is bonded to the illuminated side of the IR detector. As a result, each row of detector pixels receives only light of a particular wavelength. Spectral maps are produced by sweeping the Field of View (FOV) of the instrument across a scene, sequentially sampling each point in the scene at each wavelength. LEISA maps the distribution of frosts of methane (CH_4), molecular nitrogen (N_2), carbon monoxide (CO), and water (H_2O) over the surface of Pluto and the water frost distribution over the surface of Charon. LEISA data may also reveal new constituents on the surfaces that have never before been detected.

The LEISA filter comprises two bonded segments. The first, a high spectral resolution segment with Wavelength/ΔWavelength = 560 covering a wavelength range from 2100 to 2250 nm, provides surface temperature maps using temperature-dependent changes in the spectral structure of solid nitrogen near the alpha to beta phase transition at 35 K. The second, a low spectral resolution segment with Wavelength/ΔWavelength = 240 covering a wavelength range from 1250 to 2500 nm, provides information primarily for surface composition mapping. Though overlapping spectrally, the filter segments are separate and adjacent spatially. Plots of wavelength and Δwavelength per pixel row across the complete filter show discontinuities at the bond joint between the segments. See the Science Operations Center (SOC) Instrument Interface Control Document (ICD) for more information.

Scientific Objectives

- Hemispheric near-infrared spectral maps of Pluto and Charon at best resolution exceeding 10 km/pixel
- Hemispheric distributions of N_2, CO, CH_4 on Pluto at a best resolution exceeding 10 km/pixel.
- Surface temperature mapping of Pluto and Charon
- Phase-angle-dependent spectral maps of Pluto and Charon

Calibration

See Reuter et al. (2008) sections 5 & 6

Operational Considerations

LEISA images a scene through a wedged etalon (linear variable filter, Rosenberg et al. (1994)) placed about 100 micrometers above a 256x256 pixel Mercury Cadmium Telluride (HgCdTe) detector array (a PICNICarray). An image is formed on both the etalon and the array simultaneously (there is less than 5% spectral broadening by the f/8.7beam). LEISA forms a spectral map by scanning the FOV (Field-Of-View) across the surface in a push broom fashion, similar to the method of the MVIC (Multispectral Visible Imaging Camera) TDI (Time Delay and Integration) channels. As the spacecraft scans the target across the field of view, the spacecraft can reach the edge of a dead-band. This will cause thrusters to fire, putting the target closer to the desired location. As a result, the target can make a zig-zag pattern as it moves through the FOV. The frame rate is synchronized to the rate of the scan, so a frame is read out each time the image moves by the single pixel IFOV (Instrument FOV). The LVF (Linear Variable Filter) is fabricated such that the wavelength varies along one dimension, the scan direction.

Detectors

The LEISA detector is a 1.25 to 2.5 micrometer HgCdTe PICNIC array, supplied by Rockwell Scientific Corporation of Camarillo CA. The array is a 256x256 pixel array and each pixel is 40x40 micrometers^2 in area. However, several modifications were made to the standard PICNICarray. The HgCdTe was grown on a CdTe substrate using Molecular Beam Epitaxy (MBE) to provide good lattice matching and low dark currents. The detector was bump bonded to a standard PICNIC multiplexer and the resulting hybrid was mounted to a molybdenum pad. This process reduces mechanical stress induced during cooling to operational temperature. It is estimated that the assembly can safely undergo at least 1000 thermal cycles.

See Reuter et al. (2008) for more detector details.

Electronics

See Reuter et al. (2008) section 4.0.

Filters

The filter, supplied by JDSU Uniphase/ Optical Coating Laboratories Inc. of Santa Rosa, CA, was made in two segments. The first, covering from 1.25 to 2.5 micrometers at a constant resolving power (constant delta-lambda/lambda) of about 240, provides information primarily for surface composition mapping. The second, covering from 2.1 to 2.25 micrometers at a constant resolving power of about 560, uses temperature dependent changes in the spectral structure of solid N2 near the alpha to beta transition at 35 K to provide surface temperature maps. In both segments, a constant resolving power is achieved by making the transmitted wavelength depend logarithmically on position. The two segments were bonded together to form a single filter element. This filter was, in turn, bonded into a holder and mounted such that the filter surface is about 100 micrometers above the surface of the array. The refractive index of the array is approximately 2.7 so that the total optical path between the filter and photo-active area of the array is less than 200 micrometers. In this distance, the f/8.7 beam spreads about 0.5 pixel, so when the focus position is optimized between the array and filter surface, the convolved image smear is about 0.04 pixel.

Optics

See Reuter et al. (2008) section 3.

Operational Modes

Readout modes

The array readout is performed in Read/Reset pairs. The accumulated charge is read, then the CCD (Charge-Coupled Device detectors) is reset and read immediately. Because it is read immediately, the Reset image has very little signal from the incoming scene and dark current and comprises mainly bias signal. The Read image comprises both bias plus time-proportionally more scene and dark current signal. After the integration time has expired, the readout cycle is repeated. The difference between the Read value and the previous Reset value is the charge accumulated during the integration time, plus and difference (noise) . LEISA has two recording modes. In the Subtracted mode the Reset value is subtracted from the Read value and the result is recorded. In the Raw mode the Read and Reset values are both recorded.

[N.B. We have not seen the fourth axis appear in the single lrw_ image taken so far - Archive team]

Mode	Prefix for FITS file	Dimensions of data FITS file
Subtracted	lsb_	(256 x 256 x N)
Raw	lrw_	(256 x 256 x N x 2)

N: number of image frames in the observation

Compression and downlink modes

While not a mode of the LEISA instrument, the processes by which the data are prepared on-board for downlink affect the products generated by the Science Operations Center (SOC), and so are covered here.

This paragraph provides a brief and general background about data handling on the spacecraft. There are two types of data, low-speed data and high-speed data, that are stored by the Command and Data Handling (CDH) system, which takes data from the instruments and other subsystems and stores them on the Solid State Recorder (SSR). Only low-speed data are ready for downlink (transmission) to Earth via the telecommunication subsystem. Low-speed data comprise the following: science observation data from the low-speed instruments (PEPSSI, SDC and SWAP); engineering telemetry from all instruments (status, instrument parameters and settings, sensor measurements, times when observations start, etc); telemetry from other spacecraft subsystems (attitude, thruster firings, etc.). High-speed data comprise the science observational data from the high-speed instruments (Alice, LEISA, LORRI, MVIC and REX). High-speed data may not be directly downlinked, but must first be converted to low-speed data packets before downlink is possible. The conversion of high-speed data to low-speed data occurs via a process of either data compression or data packetization, both of which convert the high-speed data to packets ready for downlink. In data packetization, the high-speed data are converted directly to low-speed packets with no reduction in data volume. In data compression, the volume of the data is reduced by one of two entropy-aware algorithms. One data compression algorithm is **lossless**, meaning no information is lost and the original data can be recovered exactly, bit-for-bit. The second data compression algorithm is **lossy** and is similar to the commonly used JPEG compression for images. Lossy data compression trades downlinked data quality (fidelity to the original high-speed observation data) for large reductions, by an order of magnitude or more, in data volume, which in turn translates into reduced downlink time per observation. This was a key consideration when transmitting data at the low maximum rates feasible when 30-40 AU from Earth. This allowed a crucial subset of the Pluto encounter observations, designated the 'First Look' dataset as it would be the first data to be published in the public press, to be downlinked to Earth within weeks of encounter, while the downlink of all encounter data would take over a year. The First Look data set was carefully chosen to meet mission science requirements, so lossy compression was a mission-enabling technique in that it increased the likelihood of overall mission success against the chance of catastrophic spacecraft failure in the months after encounter before all the data were downlinked. A further level of data volume reduction is available in that a (sub-)window or sub-frame of an observation's high-speed data can be selected for conversion to low-speed data and downlinked; LEISA-specific details are below. The conversion of high-speed to low-speed data is commonly referred to simply as 'compression' or 'on-board compression' even though in some cases (data packetization) no actual data volume reduction takes place. The same convention will be adopted here, with the phrases 'data compression' and 'data packetization' used when necessary to distinguish between the actual conversion algorithm used. Which conversion algorithm and which CDH Side (CDH 1 or CDH 2) were selected is indicated by the Application (Process) ID (ApID). The ApID is available in the filename and elsewhere.

The LEISA ApIDs, the algorithm, and whether the data are stored on SSR1 by CDH 1 or on SSR2 by CDH 2 are shown in the following table:

CDH 1 ApID	CDH 2 ApID	Compression Algorithm
0x53c	0x54b	Lossless
0x53e	0x54d	Lossy
0x53d	0x54c	Packetized

For LEISA and other high-speed instruments, other than the ApID assigned to a data product, which CDH (and thus SSR) is selected will have no effect on the data compressed and downlinked. A key point to keep in mind is that the high-speed data are the same, no matter what conversion algorithm is selected, and that the same data may be downlinked multiple times. Also note that, for Pluto encounter data, the Project made the policy decision that, although some data will be initially compressed and downlinked using the **lossy** data compression algorithm and/or sub-frames, all encounter high-speed data will eventually be converted and downlinked with **lossless** or **packetized** algorithms, and without any sub-framing (windowing).

LEISA has two kinds of windowing: fixed windows and sliding windows. All windowed data are compressed with the lossless data compression algorithm. Windowing is only a technique to limit the downlink bandwidth of First Look data; in all LEISA observations the full 256x256 spectral and spatial extents of the observation will remain in spacecraft memory for later downlinks.

Fixed windows are in the same location and have the same extents (spatial and spectral-spatial) on the detector in every frame. Typically the spacecraft will scan such a fixed window, providing a limited spectrum of an extended swath across an intended target much larger than the LEISA field of view (e.g. Pluto near the time of closest approach); in an extreme case, the fixed window could be a single line in the spectral-spatial direction, effectively converting the multi-spectral LEISA instrument as a monochromatic line camera for those downlinked data.

A sliding window has a fixed extent (size), but the location of the sliding window moves across the detector along the spatial-spectral dimension, and only portions of the sliding window that intersect the detector will return data. A sliding window starts by covering one line at one spatial-spectral end of the 256x256 LEISA detector for the first frame with the rest of the window 'off' the detector. The window then shifts 0, 1 or several spatial-spectral lines per frame, initially shifting more of the window onto the detector, and then shifting the window off the opposite end of the detector, until the window covers only one line at the opposite end of the detector. Typically, the spacecraft will scan the LEISA boresight in a direction opposite to the motion of a sliding window and at a speed that leaves that sliding window pointing in a constant direction in space or with respect to an intended target smaller than the LEISA field of view (e.g. the Pluto system days before the flyby encounter, or one of Pluto's smaller satellites, or a calibration star field); this downlink technique provides the full LEISA spectrum of the intended target. The extent of the sliding window in the spatial-spectrum direction is chosen to increase the likelihood of capture of the target, based on an a priori estimate of the trajectory and pointing uncertainties.

Note that there is no guarantee that any intended target object will be in a downlinked window, whether fixed or sliding.

Starting with the initial delivery of data from the Pluto mission phase in March, 2016, the SOC provided a table defining the location and extent of all windows (fixed and sliding) in each frame of LEISA data in each data set. This was only provided for the Pluto mission phase.

The sliding window (DARK_SKY) process is shown in the sequence of diagrams below.

Frame 0

Start of DARK_SKY compression (sliding windows)

- Only one line of this frame is compressed and downlinked

```
             <----->  Spectral-spatial dimension of detector
             <-----   Direction of LEISA boresight motion
                        during scan

             +----------------+       ^
             |                |       |
    ***********               |       | Spatial dimension of detector
    *        |*               |       |
    *        |*               |       v
    ***********               |
      ^      |                |
      |      +----------------+
      |             ^
      |             |
Sliding             Detector 256x256
 Window

 ----->  Direction of motion of sliding window wrt detector
```

Frames 1 through N1

Progression of sliding window onto detector

- more lines are compressed and downlinked with each frame
- N1 is a number dependent on the DARK_SKY setup

```
       +---------------+
       |               | Frame 1
***********            |
*      |  *            |
*      |  *            |
***********            |
       |               |
       +---------------+
```

```
       +---------------+
       |               | Frame n1
  ***********          | Where 1 < n1 < N1
  *    |     *         |
  *    |     *         |
  ***********          |
       |               |
       +---------------+
```

```
       +---------------+
       |               | Frame N1
       ***********     |
       *         *     |
       *         *     |
       ***********     |
       |               |
       +---------------+
```

Frames N1+1 through N2

The sliding window is completely on the detector and moves across the detector

- all lines in the window are compressed & downlinked w/each frame, but which lines those are on the detector changes with each frame.

```
       +---------------+
       |               | Frame N1+1
       |***********    |
       |*         *    |
       |*         *    |
       |***********    |
       |               |
       +---------------+
```

```
       +---------------+
       |               | Frame N2
       |     ***********
       |     *         *
       |     *         *
       |     ***********
       |               |
       +---------------+
```

Frames N2+1 through N3

The sliding window moves off of the detector, until there is only one line of intersection at frame N3.

- fewer lines are compressed and downlinked with each frame
- At N3, the DARK_SKY compression is complete

```
+-----------------+
|                 | Frame N2+1
|        ***********
|        *        |*
|        *        |*
|        ***********
|                 |
+-----------------+

+-----------------+
|                 | Frame N3
|                 ***********
|                 *         *
|                 *         *
|                 ***********
|                 |
+-----------------+
```

The details of the DARK_SKY compression algorithm parameters will not be covered here, and depending on the parameters selected, the sliding window can be wider than the detector, but the same 1-line conditions will define the start and end of the compression. The parameters also control the rate at which the sliding window moves across the detector. The on-board implementation uses integer arithmetic, and the average rate of the sliding window may be anywhere from less than 1 line per frame to several lines per frame; for rates less than 1 line per frame the location of the sliding window will not change between some pairs of successive frames.

Finally, note that the location and extent of the sliding window in the spatial dimension does not change.

Measured Parameters

Radiance in units of [erg s^{-1} cm^{-2} $Angstrom^{-1}$ $steradian^{-1}$].

References

Reuter, D., A. Stern, J. Baer, L. Hardaway, D. Jennings, S. McMuldroch, J. Moore, C. Olkin, R. Parizek, D. Sabatke, J. Scherrer, J. Stone, J. VanCleeve, and L. Young, Ralph: a visible/infrared imager for the New Horizons Pluto/Kuiper Belt Mission, Proc. SPIE 5906, Astrobiology and Planetary Missions, 59061F, 2005. https://doi.org/10.1117/12.617901

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Further Reading

Rosenberg, K.P., K.D. Hendrix, D.E. Jennings, D.C. Reuter, M.D. Jhabvala, and A.T. La, Logarithmically variable infrared etalon filters, Proc. SPIE 2262, Optical Thin Films IV: New Developments, 7 September 1994. https://doi.org/10.1117/12.185804

SOC Instrument Interface Control Document (ICD): urn:nasa:pds:nh_documents:mission:soc_inst_icd, NASA Planetary Data System.