THE MAPPING IMAGING SPECTROMETER FOR EUROPA (MISE) ON-INSTRUMENT DATA PROCESSING FOR RADIATION NOISE MITIGATION. F. P. Seelos[1], J. Hayes[1], C.A. Hibbitts[1], R. Redick[2], and D. L. Blaney[2], [1]Johns Hopkins Applied Physics Laboratory (frank.seelos@jhuapl.edu), [2]Jet Propulsion Laboratory, California Institute of Technology.

Introduction: The Mapping Imaging Spectrometer for Europa (MISE) [1] is a hyperspectral infrared push broom imaging spectrometer that will fly on the Europa Clipper mission [2]. MISE has spectral range of 800 – 5000 nm with 10 nm spectral sampling (421 bands). The 250 μrad IFOV and 300 cross-track scene pixels yield a cross-track FOV of ~4.3 degrees. A scan mirror that operates in the along-track direction allows MISE to sample the surface of Europa with the appropriate scan rate over a wide range in spacecraft (S/C) altitude – from active scanning at 40,000 km to high rate image motion compensation (IMC) at 25 km.

The energetic particle flux and energy distribution at Europa's orbital distance is a significant operational consideration with regard to both the radiation budget (total integrated dose (TID)) and radiation-induced noise in the acquired science data [3]. The MISE approach to radiation noise mitigation has three key components: (1) Shielding of the focal plane to reduce the energetic particle flux; (2) Operational best practices that include: (a) a short exposure time (53.5 ms) to limit the accumulation of radiation noise in any individual frame; (b) along-track oversampling of the surface using the scan system to recover the required signal; (c) frequent acquisition of dark frame stacks which sample the instrument state and variable radiation noise environment; and (3) On-instrument processing of the acquired dark frames and oversampled scene data to minimize the effects of radiation noise and maximize the SNR in the frame-aggregate image cubes that are sent to the S/C for downlink (D/L). Here we report on the MISE instrument Data Processing Unit (DPU) data handling which allows MISE to meet the investigation science requirements while adhering to mission, S/C, and instrument resource constraints.

Background: The MISE DPU features a rank-order hardware accelerator that can sort up to 32 samples and calculate the mean and/or median from a selected continuous subset of the rank-ordered elements (high- and/or low- tail exclusion). The DPU data processing capability design target is an assumed 15% per frame radiation noise event probability above the signal-independent instrument noise envelope, with reference to a radiation noise DN distribution traceable to beam line testing and integrated instrument radiation transport modeling.

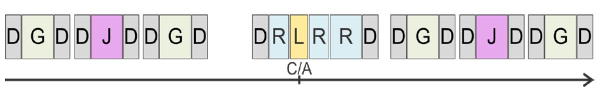


Figure 1. *MISE reference Europa encounter data acquisition scenario. Each global [G] and joint scan [J] observation (40000-1200 km altitude) is bracketed dark frame stacks [D]. Observing time surrounding closest approach (C/A) is limited so dark frame stacks bracket rather than interleave the regional [R] and local [L] observation set (<1200 km altitude).*

MISE Reference Encounter Science Data Handling: An illustration of the MISE 10-scene reference Europa encounter scenario is shown in **Figure 1**. Every stack of dark frames [D] is processed to generate a set of D/L products consisting of: (1) a single radiation noise mitigated aggregate dark frame that is used in the MISE ground radiometric calibration; and (2) a dark-corrected dark frame stack histogram that supports the evaluation of instrument performance and the characterization of the radiation noise environment. Selected dark frame stack processing results also inform the scene data processing. Every global [G], joint scan [J], and regional [R] oversampled scene image cube is processed to generate D/L products consisting of: (1) a radiation noise remediated and spatially regularized aggregate spectral image cube; and (2) an optional bookkeeping image cube that records additional information about the as-acquired scene data and the DPU data processing.

Dark Stack Processing: The data processing objectives for each stack of dark frames (nominally 320 frames) acquired before and after each scene or as close in time (in as comparable a radiation environment) as possible are: (1) generate a single aggregate dark frame; (2) gather instrument and radiation noise statistics; and (3) calculate an effective radiation noise hit rate table for the observed radiation noise distribution. Each $[x_i,\lambda_j]$ element in the aggregate dark frame is a 'cascade median' of the corresponding elements in the input frame stack – that is the median of a set intermediate median frames with the maximum sub-stack size set by the hardware accelerator capacity. Each frame in the dark stack is subtracted by the aggregate dark frame, and a histogram of the dark-corrected dark stack data distribution is constructed. An effective hit rate table – that is the fraction of pixels in the frame stack that experienced a radiation noise event at a given DN level or above – is calculated as the reverse cumulative distribution of the isolated radiation noise distribution.

Scene Image Cube Processing: The data processing objectives for each oversampled scene image cube (nominally 6000 frames; 300 lines at 20x oversampling) are: (1) generate an aggregate regularly sampled image cube where each subset of spatially oversampled frames $[x,\lambda,t_a:t_b]$ have been combined to produce an aggregate frame $[x,\lambda,t_k]$ that maximizes the

SNR and minimizes the influence of radiation noise on the aggregate result; (2) optionally generate bookkeeping information that records additional information about the acquired oversampled data, the algorithm processing, and/or the aggregate result.

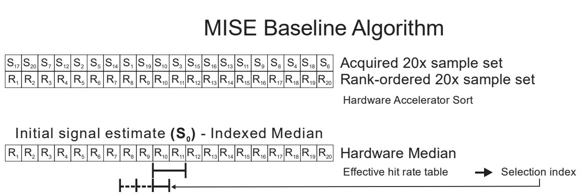
The frame-to-frame variability of the radiation noise, the governing distributions for the radiation noise event probability and amplitude, and relatively large (20x) nominal oversampling factor allow each aggregate element $[x_i,\lambda_j,t_k]$ to be a function of a subset of continuous samples in the acquired data cube $[x_i,\lambda_j,t_a{:}t_b]$ traceable to the corresponding individual detector element $[x_i,\lambda_j]$. The evaluation of each 1D sample set is supported by a collection of statistical and instrument characterization look-up tables calculated in advance that are stored in the instrument memory, plus the associated effective hit rate table and aggregate dark frame derived on board. The extensive use of look-up tables expedites the data processing by minimizing the number of required DPU software calculations.

The sample set evaluation progresses through a 3-part series of increasingly rigorous estimates of the radiation noise remediated aggregate result. Uncertainty in the result can be traded against processing time by truncating the calculation at an intermediate step. An overview of the scene processing is shown in **Figure 2**. The initial signal estimate (S_0) is the median of the sample set calculated using only the hardware accelerator. This initial signal level is dark-corrected using the aggregate dark frame and the corrected value along with a specified sigma level indexes an instrument radiometric model noise table to establish the instrument noise envelope. The width of the noise envelope in turn indexes the effective radiation noise hit rate table to establish the effective radiation noise event probability for the sample set. This sample-set-specific event probability along with a specified tolerance then indexes a binomial distribution table which returns the number of samples that are expected to be unaffected by a radiation noise event in excess of the noise envelope to the specified tolerance. This series of table look-ups allows for the calculation of an order-statistics model signal (S_1) as the best linear unbiased estimate (BLUE) of the location parameter (μ) for a Type II censored sample set [4]. The normal order statistics BLUE coefficients for the set of possible censored sample set configurations are also stored in look-up tables. With the model estimates of the radiation-noise-free sample set mean and standard deviation, an outlier threshold is calculated by looking up the one-sided Grubbs' test statistic [5] in a table indexed by sample size and a specified confidence level. Returning to the rank-order hardware accelerator, the mean of all samples less than the outlier threshold is returned as the final result (S_2). Simulation of MISE acquired dark frame stacks, oversampled scene data, and the corresponding resultant data products has demonstrated that the aggregate science data product requirements (SNR, data volume) are met with the available processing resources (energy, time).

Data Processing Bookkeeping: The variation in the number of acquired data samples participating in the calculation of a given aggregate element means the SNR will vary element-to-element in the aggregate cube, and the variation in the index position of the participating data samples means the effective along-track spatial sampling function will also vary. This interesting characteristic of the MISE aggregate data motivates a set of bookkeeping products which record additional information about each aggregate element at different levels of detail. The bookkeeping options include: (1) flag cube (boolean) - records if the number of samples that contributed to each aggregate element exceeds a given threshold (typically corresponding to the SNR requirement); (2) count cube (integer) - records the number of samples that contributed to each aggregate element (per-element SNR); (3) vector map (long integer) - documents which samples were excluded (per-element along-track sampling function).

Summary: The roster, content, and data volume of the science data products MISE sends to the S/C for D/L are a function of how the data are acquired and how they are processed and handled by the DPU. The MISE DPU data processing capabilities support a large and flexible data product and data volume option space that will allow the MISE investigation to meet science requirements and objectives while respecting mission, S/C, and instrument operational resource constraints.

References: [1] Blaney, D. L. et al. (2017) *LPSC*, 2244. [2] Howell S. H. and Pappalardo R. T. (2020) *Nat Commun*, 11, 1311. [3] Man K. F. (2018) *ASCE Earth and Space*, CL17-4965. [4] Gupta A. K. (1952) *Biometrika,* 39, 4, 260-273. [5] Grubbs, F. (1969) *Technometrics*, 11, 1-21.



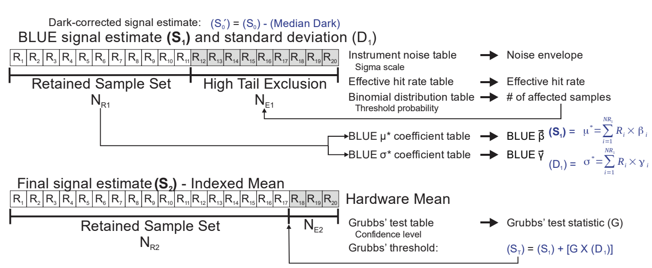


Figure 2. *MISE baseline frame-aggregation and radiation noise mitigation sample set data processing.*