MULTI-WAVELENGTH QUANTIFICATION OF IO'S VOLCANIC HEAT FLOW AS OBSERVED BY *GALILEO* NIMS: PRODUCT SELECTION AND PROCESSING METHODOLOGY. A. G. Davies[1] and G. J. Veeder[2]. [1]Jet Propulsion Laboratory – California Institute of Technology, Pasadena, CA 91109, USA. Email: Ashley.Davies@jpl.nasa.gov. [2]Bear Fight Institute, Winthrop, WA 98862, USA

Introduction: Funded by NASA's PDART Program, we are systematically processing all Io data obtained between 1996 and 2001 by the *Galileo* spacecraft Near Infrared Mapping Spectrometer (NIMS) [1]. We are deriving at-surface leaving radiances in the range 0.7 to 5.2 µm for over 1000 detections of thermal emission from Io's active volcanoes. The resulting products will be made available via NASA's Planetary Data System (PDS). Here, we report on progress in processing all suitable NIMS Io "tube" products to identify, process, and model thermal emission from Io's volcanoes.

***Galileo* NIMS data:** *Galileo* NIMS data contain the highest spatial and spectral resolution data of thermal emission from Io's active volcanoes [2] but historically have been hard to access and process. Recently, however, data access has been improved [3]. Now, by generating fully processed NIMS hot spot spectra, we will ensure wider planetary community access to an invaluable resource: an extensive set of Io's volcanic thermal emission spectra. NIMS was particularly well suited to observing thermal emission from ongoing or recent high-temperature (silicate) volcanic activity [2]. The NIMS wavelength range (0.7 to 5.2 µm) meant that it was sensitive to a wide range of surface temperatures (>1000 K to ~220 K) and lava surface exposure times (seconds to days) [4]. A detailed description of NIMS Io data is found in [2]. Each NIMS product contains valuable metadata (range to target, observation time, emission angle, etc.) and each is available from the NASA Planetary Data System. NIMS Io data have a wide range of spatial resolutions, a function of range to target. Most tube data have spatial resolutions from ~100 to ~400 km/pixel. Temporal resolution of individual targets was also highly variable. During *Galileo* orbit E4, the Loki Patera region was observed 15 times in less than a day [5]. On some other orbits only single observations of Io were obtained. The maximum number of wavelengths was 408. From October 1999 wavelengths were restricted to 12 or 15 distributed across the NIMS wavelength range. These latter data are still suitable for temperature fitting. Io longitudinal coverage was highly variable over the course of the mission, with most regional (resolution ~100-300 km/pixel) and global observations (>300 km/pixel) of the anti-Jovian hemisphere.

Processing data: "tubes" and "cubes": The NIMS Io dataset in the PDS can be summarized as follows: 190 NIMS Io "tube" observations of spectral radiance were obtained and converted into 181 "cube" products (Figure 1). NIMS tube hot spot data for sub-pixel sources are processed by adding spectra from two adjacent pixels (see Figure 2) in the mirror sweep direction (along a single line) to account for the NIMS point-spread function. A tube includes a 50% swath overlap (Figure 1), and contains accurate, unaltered radiance values. The swath overlap is removed during generation of cube products, which are re- navigated and contain the most accurate hot spot location data.

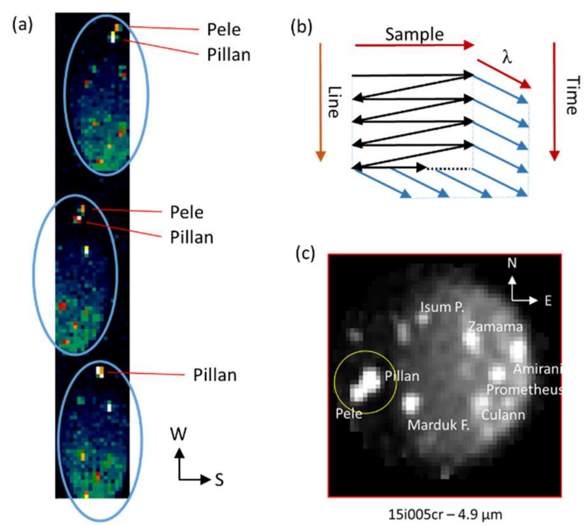

Figure 1: NIMS tube (a) *and cube* (c) *product comparison for observation 15i005tr, obtained 1998 May 31. The tube* (a) *contains multiple observations of Io.* (b) *shows the tube data acquisition sequence. All of the tube data are resampled for incorporation into the cube* (c)*, a process that changes radiance values and can cause merging of hot spots, as seen here with Pele and Pillan.*

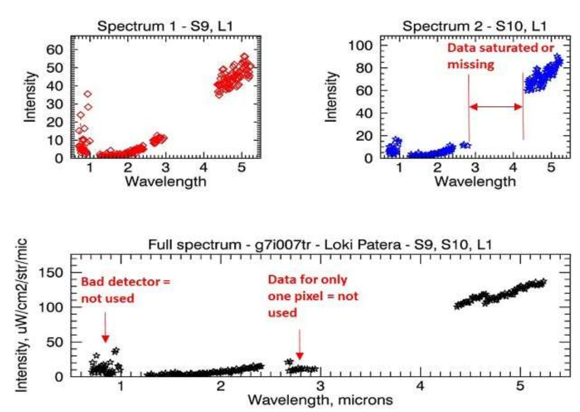

Figure 2: Example of a PDART interim product: the addition of NIMS tube radiance spectra (g7i007tr) of Loki Patera. The added spectrum, once anomalies are removed, is used to derive spectral radiances, temperatures, areas, and total radiated power (see [5]*).*

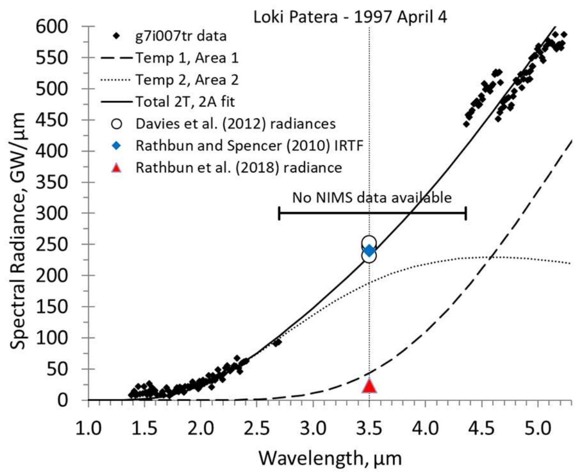

Figure 3: 2-Temp, 2-Area fit to partially-saturated NIMS tube data (interpolated to 3.5 µm) of Loki Patera by [5] *for g7i007tr and two other observations (circles). Blue diamond = contemporaneous IRTF data* [10]. *Red triangle = result from* [6] *using cube data.*

As cube production involves averaging radiance values from adjacent pixels in both line and sample space, the resulting radiance values should not be used for quantifying thermal emission from sub-pixel sources without considerable care so as to yield robust products. A recent analysis [6] that used only cube data for extracting 3.5 µm spectral radiances underestimated the spectral radiances from Io's most powerful hot spots – Loki Patera (Figure 2) (compare with [5]); Pele and Pillan (compare with [7]); and Amirani (compare with [8]) – by up to five orders of magnitude, partly due to the incorporation of saturated (null value) 3.5 µm data. For many other volcanoes, [6] generated large uncertainties that are in part due to the presence of spectral anomalies caused by (for example) boom hits and instrument jitter. The 3.5 µm radiances in [6] are often smaller, and uncertainties larger, than those previously extracted from NIMS data [e.g., 5, 7-9] and from InfraRed Telescope Facility (IRTF) observations [10] (see Figure 3).

Production workflow: Given the variability of spectra in the NIMS dataset, with varying numbers of wavelengths, differing amounts of radiation noise, other artifacts (e.g., boom hits and excessive jitter), and effects of instrument degradation (e.g., Figs. 2, 4), there is no "one size fits all" methodology for fitting even nighttime data. We have instead separated the data into different classes based on their complexity and the presence of anomalies, and have developed a specific production workflow for each class. These spectra have enabled systematic processing with minimal user input, yielding robust estimates of thermal emission, generally with tightly constrained model fits to the data. An existing database of 4.8 and 5 µm spectral radiance data (the NIMS Io Thermal Emission Database, or NITED – e.g., [5]) has been imported into an Interactive Display Language (IDL) structure. The full NIMS Io data collection has also been ingested into IDL data structures. The entire production workflow is within the IDL environment. Results are written into other IDL data structures. This process allows the results to be written into any desired format for ingestion into PDS4 products, as defined using the latest PDS standards and XML product templates [11]. We continue to work closely with staff at the PDS to establish final product format and facilitate streamlined product generation. At all stages of the workflow, careful checks are made to ensure the products generated at that stage are accurate. After correcting the data for range and emission angle, and assuming Lambertian emission, other IDL code is utilized to model the spectra (Fig. 3). The resulting temperature and area fits yield robust estimates of spectral emittance and total thermal emission. Once completed, these products will be a valuable resource for quantifying Io's volcanic activity and for comparison with other data, both from spacecraft and from ground-based telescopes.

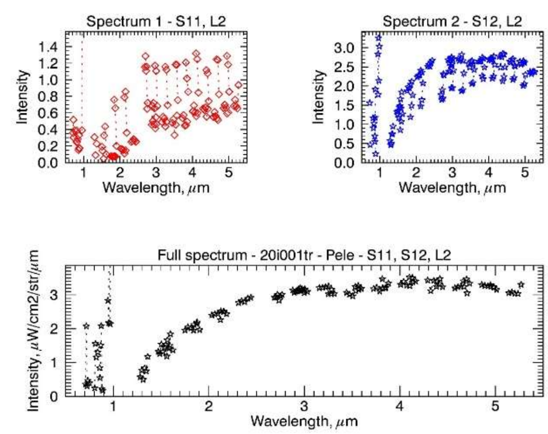

Figure 4. Pele tube spectra. Note how the apparently noisy spectra yield a clean, smooth spectrum when added. Data <1 µm are not used (bad detector).

Acknowledgements: We thank the NASA PDART Program and the PDS Node at the University of New Mexico, Las Cruces, NM, for their invaluable support. This work was performed at JPL-Caltech and BFI under NASA contract.

References: [1] Carlson, R. et al. *Space Sci. Rev*., 60, 457-502. 1992. [2] Davies, A. G. *Volcanism on Io,* CUP, 372 pages. 2007. [3] Cahill, J. et al., 3rd Plan. Data Workshop, abs.7071. 2017. [4] Davies, A. G. et al. *JVGR,* 194, 75-99. 2010. [5] Davies, A. G. et al. *GRL*, 39, L01201. 2012. [6] Rathbun, J., Lopes, R. et al. *Astro. J*. 156, 5, 207. 2018. [7] Davies, A. G. et al. *JGR*, 106, E12, 33,079-33,104. 2001. [8] Davies, A. G. et al. *Icarus*, 241, 190-199. 2014. [9] Lopes-Gautier, R. et al. *GRL*, 24, 2439-2442. 1997. [10] Rathbun, J. and Spencer, J., *Icarus,* 209, 625-630. 2010. [11] PDS4_DataProvidersHandbook_20160223.pdf.