

TOWARDS UNDERSTANDING IO'S HEAT FLOW: THE INCORPORATION OF MULTI-WAVELENGTH IRTF IO DATA INTO THE PDS. A. G. Davies¹ and G. J. Veeder², ¹Jet Propulsion Laboratory-California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (email: Ashley.Davies@jpl.nasa.gov). ²Bear Fight Institute, 22 Fiddler's Road, Winthrop, WA 98862, USA.

Introduction: The jovian moon Io is the most volcanically active body in the Solar System. This strong volcanic activity is driven by tidal dissipation within Io [1-3]. Variations in the magnitude and distribution of Io's volcanic and background (non-volcanic) heat flow are so extreme that they can be detected using telescopes on Earth. Between 1983 and 1993, hundreds of infrared observations were made of Io at 4.8, 8.7, 10 and 20 μm using NASA's InfraRed Telescope Facility, located on Mauna Kea, HI (Figure 1). The measured spectral radiances were published by Veeder et al. in 1994, in the *Journal of Geophysical Research* [4]. These data remain, to this day, as the best record of Io's volcanic thermal emission at TIR wavelengths. However, these data existed only in printed form (i.e., [4]). We have converted the data into electronic products which are archived in NASA's Planetary Data System (PDS).

Incorporation of IRTF data into the PDS: Under the auspices of an award from the NASA Planetary Data Archiving, Restoration and Tools (PDART) Program, we have completed the task of incorporating the spectral radiance data in Veeder et al. (1994) [4] into easily accessible electronic format, using NASA Planetary Data System PDS4 standards. By March 2019, these products will be available from the NASA PDS Planetary Atmosphere Node at New Mexico State University, Las Cruces, NM (<https://pds-atmospheres.nmsu.edu/>).

Io's heat flow: Over 250 active volcanic sources have been identified on Io [5-7]. The short-wavelength thermal emission from Io's active volcanoes has been quantified from spacecraft and ground-based telescope data, yielding about 55% of Io's total thermal emission [5,6]. Yet the largest uncertainty in Io's total heat flow is the contribution from the ~98% of Io's surface that is not covered by active thermal sources, "hot spots", due to volcanic eruptions and recently exposed and emplaced lava. Quantifying Io's "non-hot-spot" heat flow is possible by examining Io's thermal emission at multiple infrared wavelengths and incorporating recent mapping efforts [7, 8]. Understanding Io's total heat flow requires sampling the full range of its thermal emission from both the day and night sides. Short-wavelength-infrared ($\leq 4.8 \mu\text{m}$) data are sensitive to exposed lava and active volcanic vents; 8.7- μm data to warm dark paterae and flows, while long-wavelength (20- μm) data are sensitive to cooled lava surfaces, plume deposits and the thermal inertia of the extensive passive surface areas (the Io non-volcanic background). In addition, multi-

ple-wavelength measurements are essential for evaluating the balance between reflection and absorption of solar insolation during the daytime on Io. Since strong volcanic sources on Io are known to be variable, it is necessary to follow their evolution over an extended time. The large multi-spectral 1983-1993 IRTF dataset complements *Voyager* Infrared Imaging Spectrometer (IRIS) and *Galileo* Solid State Imager (SSI), Near Infrared Mapping Spectrometer (NIMS) and Photo-Polarimeter Radiometer (PPR) results (these observations are summarised in [9]), but the IRTF data were not available in an accessible electronic format for use in ongoing analyses of Io's heat flow. For example, we recently analyzed *Voyager*, *Galileo* and other spacecraft data [5,6,11,12] and additional Keck Observatory telescope data to create the first global map of volcanic heat flow from 242 individual thermal sources on Io [7]. That map was created mostly from short-wavelength-infrared data at wavelengths shorter than 5.2 μm (the longest NIMS wavelength). The heat flow map *assumes* a background (non-volcanic) heat flow of about 1 W m², and highlights the need for modelling Io's background thermal emission using global observations at wavelengths sensitive to thermal emission from the low-temperature surfaces. The IRTF data at 8.7, 10, and 20 μm are the most useful data for this purpose, hence our effort to make them available in an accessible electronic format.

Historical value of these data: Apart from the need to quantify any multi-decadal variation in Io's volcanic activity, the Veeder et al. IRTF dataset is of great historical significance as it contains the first multi-spectral detections of what are now known to be the most powerful class of ionian eruptions – so-called "outburst" eruptions (see Fig. 1 for locations), consisting of fountains of lava often gushing forth at extremely high ($>10^5 \text{ m}^3/\text{s}$) discharge rates [e.g., 12]. IRTF data collected in 1986 and 1990 and included in this dataset were the first data to unambiguously identify active volcanism at molten silicate temperatures [12-14]. Other high-discharge rate outburst events were observed by the *Galileo* spacecraft [15,16] and with the powerful Keck Observatory and Gemini N telescopes on Mauna Kea, HI [17-19]. The data collected by [4] include outbursts in 1986 and 1990. Given recent advances in modelling volcanic eruptions [e.g., 20], the IRTF data can be revisited using new, more sophisticated techniques than were available in 1994. The new PDS products will enable the investigation of further constraints on the characteristics and

distribution of the ensemble of detected, but not yet located, thermal sources and non-volcanic background heat flow that, when combined, may account for up to 45% of Io's integrated heat flow [5, 6].

The value of this work is in creation of products for the planetary community to allow modelling of Io's thermal emission, and, in particular, the background thermal emission best seen at 10 and 20 μm . Io is identified in the most recent Planetary Science Decadal Survey [21] as a candidate target for a New Frontiers-class mission (cost \sim \$1B). A lower-cost Discovery-class mission (*Io Volcano Observer*) [22] has been proposed (cost \sim \$500M), and may be proposed again. Io's heat flow magnitude and distribution reflects the current state of the tidal heating mechanism and of Io's interior. Also of great interest is the effect a possibly evolving Jupiter-Io-Europa tidal resonance might have on Europa, now the target of a major NASA Flagship-class mission: *Europa Clipper* (cost $>$ \$2B). To understand the nature of Io's extraordinary tidal heating, and, by extension, tidal heating of other bodies, it is therefore important to establish the long-term stability of Io's heat flow, and the IRTF data are crucial for this task. Yet, until now, these data were not in an easily accessible form. This situation has now been remedied.

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Acknowledgements: We gratefully acknowledge the invaluable help of Prof. Nancy Chanover, Dr. Lynn Neakrase and Mr. Lyle Huber, of the Planetary Atmospheres Node of the PDS at New Mexico State University, Las Cruces, NM. The authors thank the NASA PDART Program and Program Manager Sarah Nobel for support under award WBS 811073.02.37.01.64. This work was performed at the Jet Propulsion Laboratory-California Institute of Technology and the Bear Fight Institute, under contract to NASA. © 2019 Caltech.

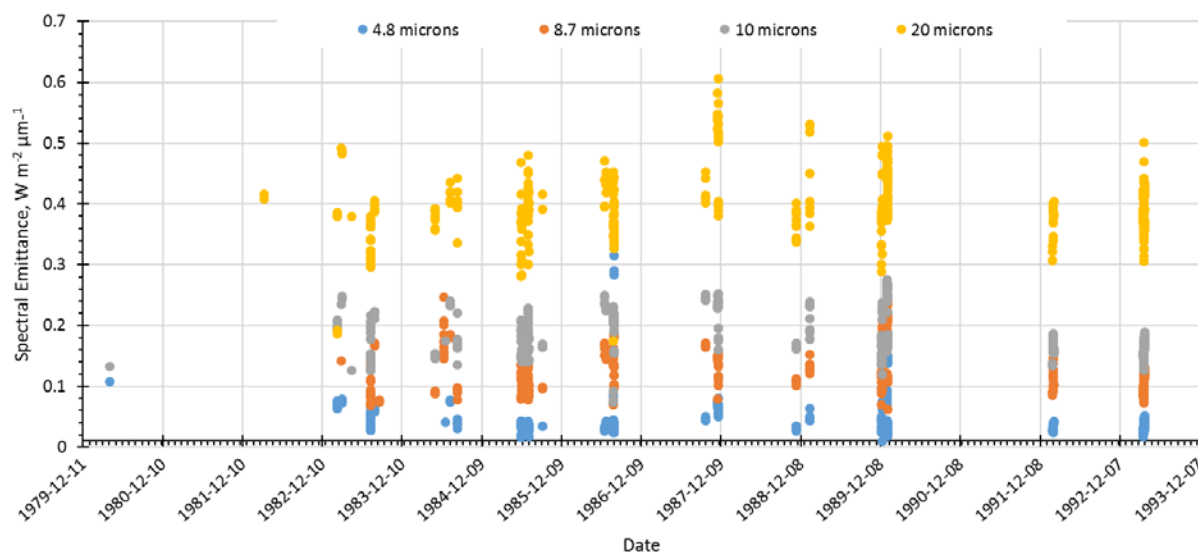


Figure 1. Io spectral emittances measured with the IRTF at different wavelengths. These data, now incorporated into PDS4 products, are from Veeder et al (1994) [4]. The 4.8 μm data include a reflected light component. The 8.7 and 10 μm data are most sensitive to volcanic thermal emission. The 20 μm data are most sensitive to thermal emission from Io's non-volcanic background (98% of Io's surface) [7].