DISTRIBUTION OF IO'S VOLCANIC THERMAL EMISSION FROM *GALILEO* AND GROUND-BASED DATA

G. J. Veeder[1], A. G. Davies[2], D. L. Matson[2], T. V. Johnson[2], D. A. Williams[3] and J. Radebaugh[4];
[1] Bear Fight Institute, 22 Fiddler's Rd., Winthrop, WA, 98862; [2] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA; [3] Arizona State University, Phoenix, AZ; [4] Brigham Young University, Provo, UT.

Introduction: Detections of Io's hot spots and identification of volcanic features have been catalogued by various workers [e.g., 1-4]. However, to understand the role played by volcanism in global heat transport, thermal emission from Io's volcanoes has to be quantified, locally, regionally and globally. Only then can robust estimates be made of volcanic advection, which may reveal internal heating patterns controlled by the evolving tidal resonance between Io, Europa and Ganymede. We have completed an analysis of all suitable spacecraft data and, using additional ground-based data, have quantified the thermal emission from all of Io's volcanoes during the *Galileo* epoch down to the limit of detection [5-7]. *Galileo* identified many dark features on Io that did not exhibit obvious anomalous thermal emission, yet their low albedo suggested that these features were at least warm (cool, high albedo sulphurous deposits had not formed on them). We used dark areas identified from the recently-published Io Global Map [3] and a knowledge of the detection limit of the *Galileo* NIMS instrument to quantify the thermal emission from these areas. In all, our analysis includes 240 individual thermal sources (Figure 1) yielding ~60 TW. Our "snapshot" of global volcanic activity shows that Io's paterae yield ~80% of this amount, with a preponderance of thermal emission emanating from the northern hemisphere. This is strongly biased by Loki Patera and, to a lesser extent, by recent outburst locations. Of the remaining identified hot spot thermal emission (Table 1), ~15% comes from active or recent lava flow fields, and the remaining 5% comes from massive outburst eruptions (some in paterae) and very small hot spots. The energy accounted for makes up ~62% of Io's total thermal emission of ~100 TW [8]. It is possible that a multitude of very small hot spots beneath instrument detection limits, and/or cooler, secondary volcanic processes involving sulphurous compounds may be responsible for the unaccounted heat flow.

Methodology: Data sources were primarily *Galileo* NIMS and PPR data and analyses, analyses of ground-based observations and analyses of *Voyager* data. *Galileo* SSI data were used to pinpoint the location of active features [e.g., 3,4]. We used the USGS Io Global Mosaic [10] and the Io geological map of Io [3] to derive an estimate of the maximum possible contribution from even smaller dark areas not detected as thermally active but which nevertheless must be warm so as to avoid being covered by plume deposits. We utilize a trend analysis to extrapolate from the smallest detectable volcanic heat sources to these smallest mapped dark areas. We used the limit of detection of NIMS and areas of low-albedo features [3, 5-7] to ascertain minimum effective temperatures to estimate power output for small dark features that cover a summed area of ~27,000 km^2. We extend the discussion of a multitude of very small ("myriad") hot spots in [13] and also include the heat from estimates for "outburst" eruptions in Table 1.

Table 1. *Volcanic Heat Flow*. From [7].

	Power [a] 10^{12} W	No. Sources
Dark Paterae [c]	31.9	132
Loki Patera	9.6 [b]	1
'pfd' units [d]	2.7	50
Dark irregular paterae [e]	0.8	3
Six small dark paterae [f]	0.3	6
subTotal: dark paterae	**45.3**	**192**
Bright paterae [g]	2.6	11
subTotal: all paterae	**47.9**	**203**
Dark Fields [h]	5.6	28
Other sources [i]	3.8	9
Total	**57.3**	**240**
Myriads [j]	2.5 [k]	250 [k]
Outbursts [l]	1.7 [m]	25 [n]
Grand Total Power [o]	**61.5**	~

Notes
a Also percentage Io's global heat flow (10^{14} W [8]).
b Average for 'magma sea' model [12].
c Excluding Loki Patera [6].
d Additional mapped small dark paterae (see [7], [3]).
e Low albedo irregular paterae [7].
f Other very small dark paterae [7].
g High albedo paterae [7].
h See Table A2 in [5].
i Other sources of thermal emission [7].
j See Section 4.3 of [7] and especially [13].
k Geometric extrapolation of NIMS coverage for 'small hot spots' in [1], [11] and also [14].
l [15].
m [1] and [11].
n Estimated events per year on Io (cf., [15]).
o Estimated power including myriads and outbursts.

Conclusions: We have examined the thermal emission from 240 volcanic features on Io and quantified the magnitude and distribution of volcanic heat flow during the *Galileo* epoch. We account for 61.5 x 10^{12} W (or ~61.5%) of Io's total thermal emission including the heat from estimates for "outburst" eruptions and for a multitude of very small ("myriad") hot spots. Loki Patera contributes 9.6 x 10^{12} W (or 9.6%) of Io's total thermal emission (see also [9]). Dark paterae contribute 45.3 x 10^{12} W (or ~45.3%). Although dark flow fields cover a much larger area than dark paterae, they contribute only 5.6 x 10^{12} W (or 5.6%) of Io's heat flow. Bright paterae contribute 2.6 x 10^{12} W (or 2.6%). Io's global volcanic heat flow is not uniformly distributed. We find a bimodal longitudinal distribution with maxima at ~315 °W and ~105 °W for dark paterae (excluding Loki Patera). Thermal emission from dark flows peaks between 165 °W and 225 °W. There is a significant regional minimum in all thermal emission (other than Loki Patera) at around 200 °W (almost at the anti-jovian longitude).

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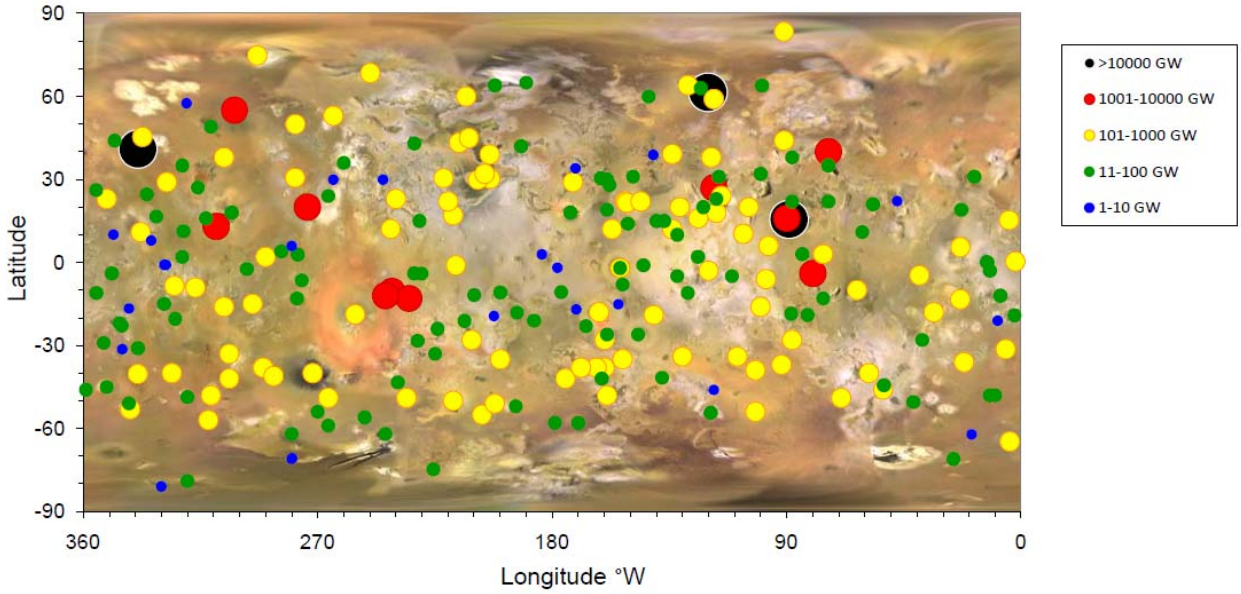

Figure 1: Volcanic thermal sources on Io. A logarithmic scale is used to classify hot spots on the basis of thermal emission. All of the thermal measurements and estimates are from [5-7]. A wide range of thermal emission is covered, ranging from small hot spots seen only in high spatial resolution data and emitting ~1 GW to massive outbursts emitting nearly 80 TW. Most hot spots plotted here are in the 11 to 1000 GW range. The most powerful hot spots are in red and black. Loki Patera (red) emits 9.6 TW on average. Three examples of outbursts are plotted (black), at Tvashtar Paterae, Surt 2001, and the North Amirani region.