FAINT THERMAL SOURCES ON IO. G. J. Veeder[1], A. G. Davies[2], D. L. Matson[2] and T. V. Johnson[2], [1]Bear Fight Institute, 22 Fiddler's Rd., Winthrop, WA, 98862, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Introduction: We report the identification of nine faint thermal sources on Io from further examination of *Galileo* NIMS (Near Infrared Mapping Spectrometer) data. All of these hot spots are associated with dark material in small paterae. We have analyzed the thermal emission of each of these individually and quantified their total volcanic thermal power.

Many hot spots of thermal emission and volcanic features on Io have been catalogued and mapped [1-4]. Hot spots are well correlated with dark paterae and large flow fields. All large dark volcanic features contain hot spots but only some of the many small visual features have been detected in the infrared.

We have previously analyzed [5-7] hot spots detected by *Voyager* IRIS (InfraRed Interferometer Spectrometer) and *Galileo* NIMS and PPR (Photo-Polarimeter Radiometer) [3,4,8-14] and established that hot spots associated with dark paterae are the largest component of Io's heat flow. We have estimated the contribution to Io's global heat flow from known hot spots as well as other dark volcanic features, but have been unable to account for ~40% of Io's global heat flow [5-7].

Search for Faint Thermal Sources: The *Voyager* IRIS and *Galileo* NIMS and PPR data on Io are limited by the spatial resolution and sensitivity of the infrared instruments. An examination of the spectral slope for each pixel in a *Galileo* NIMS observation from orbit C3 (November 1996) led to the concept of numerous 'myriads' of sub-pixel infrared anomalies [15]. Such faint hot spots were subsequently identified in later high resolution *Galileo* NIMS data with limited areal coverage [12,13].

We are pursuing a suggestion [16] to examine the infrared spectral slope of pixels in high resolution NIMS data with a technique previously used for the C3 low resolution *Galileo* NIMS observation [15]. However, to mitigate against strong SO_2 absorption near 4 microns we co-add the NIMS flux in the three longest wavelength bands available, co-add the intensities in three bands just above 3 microns and then ratio these co-additions for each pixel. The resulting ratio images are stretched between low and high cut-offs to discriminate for pixels with infrared color temperatures of ~200-400 K. Strong hot sources are intentionally saturated compared to the corresponding 4.7 micron intensity images [12,13] to optimize the contrast for faint sources [17].

We have generated infrared color ratio images for regional and targeted NIMS data in the anti-Jovian hemisphere from I24, I25, I27, I31 and I32 [e.g., 17]. These ratio images reveal nine faint hot spots as summarized in Table 1. Although all of these hot spots are associated with small dark paterae, note that some dark spots have much smaller areas than enclosed by the rims of their associated paterae [1,2]. Moreover, we have specifically examined 24 additional small (diameter less than ~100 km) dark paterae identified in *Galileo* visual SSI (Solid State Imaging) images [1]. Most of these have also been mapped as 'PF_d' (Patera Floor, dark) units [2]. Although scanned by NIMS at relatively high spatial resolution (order of ~25 km/pixel), these 24 small dark paterae did not show significant volcanic thermal emission.

Number of Faint Hot Spots: All nine faint NIMS hot spots in Table 1 are associated with small dark paterae catalogued and mapped from *Galileo* visual SSI images [1,2]. In contrast, none are associated with bright paterae. Furthermore, none are associated with mapped small (diameter less than ~100 km) 'F_d' (Flow, dark) units [2].

The coverage of our infrared ratio images in the anti-Jovian hemisphere of Io includes a relative maximum in the surface density of volcanic hot spots as well as paterae [1,2,7,18-21]. An additional complication is that the surface distributions of paterae and flow fields are different [2,5,6]. However, a straight geometric extrapolation of nine faint hot spots from our ~30% surface coverage over Io implies that there are only ~30 similar hot spots globally near the best *Galileo* NIMS detection limit.

Heat Flow: Our thermal models for the nine faint NIMS hot spots in Table 1 yield a total volcanic power of 0.55×10^{12} W. Analysis of our ground-based hemispheric observations at the IRTF (InfraRed Telescope Facility) [22] has indicated that Io's global heat flow is ~10^{14} W. Thus, the extrapolated thermal emission of an estimated 30 faint hot spots is able to contribute less than 2% of Io's global heat flow. This is comparable to our estimate for all dark paterae that have not (yet) been detected in the infrared, but is much less than the unidentified ~40% of Io's global heat flow [5-7].

Conclusions: (1) Near infrared ratio images are a useful technique for identifying faint hot spots with small volcanic features on Io. (2) Faint hot spots continue to be associated with the darkest material within small paterae, but are not likely to out number small dark volcanic features on Io. (3) The small size and finite number of faint thermal sources limit their contribution to Io's total heat flow.

Table 1. *Faint Thermal Sources on Io*.

	Area [a] km^2	T_{eff} K	Power [b] GW
P225 [c]	255	256	62
At'am Patera [d]	550	220	73
Shango Patera	777	230	123
P165 [c]	139	199	12
P151 [c]	7	368	7
P150 [c]	53	305	26
P89 [c]	372	197	32
Wabasso Patera [e]	355	316	201
P13 [c]	4	450	10

Notes

[a] Dark surface material.

[b] Volcanic thermal emission excluding solar insolation.

[c] *Galileo* identification [1].

[d] *Galileo* P41 [1] and see also [23].

[e] 'L' in [24].

References: [1] Radebaugh J. (2005) Univ. Arizona, PhD Thesis. [2] Williams D. A. *et al.* (2011) *Icarus*, 214, 91-112. [3] Davies A. G. (2007) *Volcanism on Io*, Cambridge. [4] Lopes R. M. C. and Spencer J. (2007), *Io after Galileo*, Springer. [5] Veeder G. J. *et al.* (2009) *Icarus*, 204, 239-253. [6] Veeder G. J. *et al.* (2011) *Icarus*, 212, 236-261. [7] Veeder G. J. *et al.* (2012) *Icarus*, 219, 701-722. [8] Pearl J. C. and Sinton W. M. (1982) In: Morrison, D. (Ed.), *Satellites of Jupiter*, Univ. Arizona Press, 724-755. [9] Pearl J. C. (1985) *Bull. Am. Astron. Soc.* 17, 691. [10] Pearl J. C. (1988) *Bull. Am. Astron. Soc.* 20, 818. [11] McEwen *et al.* (1992) *LPS, XXIII*, abstract #881. [12] Lopes R. M. C. *et al.* (2001) *J. Geophys. Res.*, (Planets) 106 (E12), 33053-33078. [13] Lopes R. M. C. *et al.* (2004) *Icarus*, 169, 140-174. [14] Rathbun J. A. *et al.* (2004) *Icarus*, 169, 127-139. [15] Blaney D. L. *et al.* (2000) *LPS, XXXI*, abstract #1617. [16] Davies A. G. *et al.* (2007) *LPS, XXXVIII*, abstract #1849. [17] Veeder G. J. *et al.* (2013) *LPS, XLIV*, abstract #1320. [18] McKinnon W. B. *et al.* (2001) *Geology* 29, 103–106. [19] Schenk P. *et al.* (2001) *J. Geophys. Res.*, (Planets) 106 (E12), 33201–33222. [20] Kirchoff M. R. and McKinnon W. B. (2009) *Icarus*, 201, 598–614. [21] Hamilton C. W. *et al.* (2013) *Earth Planet. Sci. Lett.*, 361, 272-286. [22] Veeder G. J. *et al.* (1994) *J. Geophys. Res.*, (Planets) 99 (E8), 17095-17162. [23] Bunte *et al.* (2008) *Icarus*, 207, 868-886. [24] Marchis *et al.* (2005) *Icarus*, 176, 96-122.

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