**IO: HEAT FLOW FROM DARK PATERAE** G. J. Veeder, D. L. Matson, A. G. Davies, T. V. Johnson, and J. C. Castillo-Rogez, Jet Propulsion Laboratory, California Institute of Technology, ms 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109-8099 (Glenn.Veeder@jpl.nasa.gov).

**Introduction:** Io is the most active volcanic body known in our Solar System. The global heat flow of Io derived from Voyager IRIS, IRTF and Galileo PPR far infrared observations is much more than predicted from tidal dissipation models [*e.g.*, 1-7]. The spacecraft and ground-based data sets compliment each other. The IRTF observations measure the daytime and eclipse hemispheric emission, span a decade in time and cover all longitudes of Io. The spacecraft data yield high resolution (in both latitude and longitude) snapshots of Io's stronger sources within limited regions during either daytime or nighttime. Io's poles have not yet been well covered.

Much of the heat flow from Io is from a few tens of relatively large, active paterae. Loki Patera, a possible magma 'sea', contributes approximately 10% of Io's total heat flow from less than 1% of Io's surface [5-8]. Global mosaic maps show that Loki Patera is unique [*e.g.*, 9-14]. Moreover, the distribution of paterae is relatively uniform in both longitude and latitude [*e.g.*, 15-16]. This supports straightforward geometric scaling from limited spatial coverage. Galileo visual SSI [*e.g.*, 9-16] and near infrared NIMS [*e.g.*, 17-19] data contain additional information which can constrain the thermal models and refine the estimated heat flow.

*Global model sources*. The total heat flow of Io is significantly larger than the sum of its known hot spots. In search of an explanation for this discrepancy, we have considered the following classes of sources. 1) large dark paterae 2) many additional small dark paterae 3) dark lava flow fields 4) NIMS [20] and SSI hot spots. Here we focus on the heat flow contribution from the small dark paterae relative to that from the large dark paterae. The size distribution of paterae extends beyond the limiting resolution of the infrared observations. The distinction between large and small paterae is somewhat arbitrary. The relevant comparison is between the strong sources detected by Galileo's PPR and the larger number of weaker sources which were not individually detected. One piece of the puzzle is an explicit bias correction of the PPR sample within the context of a global thermal model. Another is whether an accounting of the heat flow from small paterae, dark lava flow fields and NIMS hotspots can constrain the possible, residual heat flow due to conduction through the rest of Io's surface.

**Large Dark Paterae:** The dark material within Loki Patera has an average temperature of ~240-273°K [6] and an area of somewhat more than ~20,000 km$^2$. Other dark paterae detected by PPR total ~114,000 km$^2$. Loki Patera and the other mapped PPR sources extrapolate to ~50% of Io's heat flow if Loki itself is held to be unique (*i.e*., ~1 out of ~2 w m$^{-2}$) [7]. At shorter wavelengths, NIMS points to ~30% of Io's thermal output [20]. For sources isolated, but not resolved, by PPR, we have estimated each dark area from SSI maps [*e.g*., 9-16] and assigned an effective temperature to yield the observed infrared flux. These effective temperatures range from ~100 to ~300°K relatively independent of size. (Pele is yet another special case.) Some sources seen in the PPR map did not result in tabulated flux measurements [7]. For example, the moderately strong SW Mazda source falls on a boundary between regions of different scan resolutions. These sources may skew the bias corrections if ignored.

**Small Dark Paterae:** We have identified ~36 small dark paterae not detected within the region mapped by PPR [7]. Some of these have been listed previously from Voyager and Galileo visual data [*e.g.*, 2, 4, 15, 17-19]. We have inspected these small dark paterae individually on SSI maps [*e.g*., 9-16] and estimated the area of dark material associated with each. These range in size from ~7800 down to less than 100 km$^2$. The total area of these is ~66,000 km$^2$ or equivalent to about three times the area of Loki Patera's dark material. PPR also obtained an important high resolution N-S scan at a longitude of ~100°w (*i.e*., outside the PPR map) [7]. This scan detected three small paterae directly and provides a calibration reference for the temperatures of small paterae.

**Spatial Distribution of Dark Paterae:** The visual maps of Io can be used to correct for the limited sampling of the Voyager IRIS and Galileo PPR infrared observations. Previous literature has discussed the number density of paterae with respect to longitude and latitude. For the present purposes, we require the distribution of areal density of dark material for the refinement of our global model. We have identified ~100 dark paterae outside of the PPR map coverage with a total area of ~165,000 km$^2$ or equivalent to about seven times the area of Loki Patera's dark material. Many, but not all, of these have been listed previously [*e.g*., 2, 4, 15, 17-19]. Fortunately, the areal distribution appears to be relatively uniform in both longitude and latitude. Thus, one important result expected from our model of the paterae population is the total area of dark paterae on Io.

**Temperature Distribution of Dark Paterae:** The distribution of effective temperatures for the identified paterae is required along with their areal distribution to calculate the total global power driving Io's heat flow. SSI and NIMS hot spots have high color temperatures within both dark patera and dark flow fields [*e.g*., 9, 17-20]. Loki Patera is the largest; but not the hottest spot on Io. However, it is so large that it does make the largest contribution to Io's heat flow. The small paterae in the high resolution PPR scan appear to be cooler than Loki Patera but warmer than larger lava flow fields [7]. However, in general there is no correlation between effective temperature and size for dark paterae.

**Global Heat Flow:** A number of different volcanic components with different properties have been identified on Io which imply that different processes are at work [20-22]. In particular, some NIMS hotspots within paterae suggest cracks in the crust of lava lakes (*e.g*., Pele). Other NIMS hotspots within large extended flow fields suggest lava breakouts. Especially in the cases of extensive lava flows, somewhat cooler material surrounding the active center is expected to radiate significantly more power at longer wavelengths due to a larger surface area. Model extrapolation to include these cooler areas of NIMS sources has been discussed previously [23].

A pair of high resolution PPR scans across part of Lei Kung Fluctus suggests that large areas are at an intermediate temperature (~130ºK) between active, large and small, paterae and the background passive surface (~95ºK) [7]. Amirani is one of the few large flow fields which has been well mapped with derived temperatures and areas (thus power) [24].

Polar regions may make some additional contribution to Io's heat flow because the surface temperature between identified sources does not fall off with latitude as expected (~ $\cos^{1/4}$) [6, 7, 25]. The maximum possible heat flow from polar regions is also constrained by eclipse cooling observations. It is unlikely to be more than ~0.5 watt $m^{-2}$ because the polar caps, where observational coverage is poor, have only a limited area [25].

**Conclusions:** The infrared observations of Io show that the thermal emission comes from a variety of sources. We have identified many small dark paterae not detected in the Galileo PPR map. The total area of small dark paterae and their surface distribution is constrained by global mosaics from Voyager and Galileo images. Altogether, small dark paterae are a significant component of the heat flow of Io. Separate and detailed accounting for the thermal emission from each class of heat sources on Io within an inclusive model helps to clarify the different contributions to Io's global heat flow.

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