THE THERMAL SIGNATURE OF VOLCANIC ERUPTIONS ON IO AND EARTH – IMPLICATIONS FOR A FUTURE MISSION TO IO.

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Introduction: High-temperature silicate volcanic activity has been identified on Io and Earth (see summary in [1]). We present a new spectrum-based technique [2] to identify the style of active volcanic eruptions on Jupiter's moon Io. Thermal remote sensing of Io has had to rely primarily on low-spatial-resolution data, similar to low-spatial-resolution satellite data applied to detecting and charting the temporal evolution of terrestrial hot spots. These terrestrial analyses use data from sensors designed primarily to monitor the weather and sea surface temperature. On Io, such low-spatial-resolution data are used to classify eruption styles (modes of emplacement) by means of a number of criteria related to the temporal evolution of the infrared spectrum associated with the eruptive activity at each hot spot, which we term “thermal signature." We find that the ratio of the emission at 2 µm and 5 µm, and how this ratio changes with time, is often diagnostic of eruption style, even in low-spatial-resolution data. Tests using thermal data for terrestrial “ground truth” cases show that our classification system is valid on Earth. The results of our analysis can be used to aid in the design of future space-based instruments that can be used for volcano monitoring on Io, as well as Earth. Additionally, we have identified the optimum wavelengths for determining eruption style for future mid to thermal infrared instruments on future missions to Io, such as the proposed Discovery-class *Io Volcano Observer* [3, 4].

Classification based on thermal spectrum: Constraining ionian eruption style using *Galileo* NIMS (0.7 to 5 µm) low-spatial resolution data has proved successful in predicting emplacement style, for example, at Prometheus (insulated flows), Pele (lava lake) and Pillan 1997 (lava fountains) [e.g., 5, 6] before high-resolution data were obtained [e.g., 7]. Figure 1 shows a plot of 2-µm and 5-µm thermal emission for a selection of ionian and terrestrial volcanoes. For each style of eruption activity different characteristics emerge. For example:

Lava fountains and open channel flows: The large Pillan eruption of 1997 [6, 7] has increased 2-µm emission due to lava fountains and the emplacement of open-channel flows. As time passes the 2-µm flux drops rapidly as lava fountaining ceases and the emplaced flows transition to insulated flows, with cooler surfaces. Finally, activity ceases and the emplaced surfaces cool further.

Active lava lake: Pele exhibits the characteristics of an active, overturning lava lake, with a 2-µm intensity that can match the 5-µm intensity. Pele is the only volcano on Io that persistently exhibits this behaviour. 2-µm/5-µm ratios are similar to those of terrestrial active lava lakes [2].

Paterae: Ionian paterae such as Culann Patera and Tupan Patera have 2/5-µm ratios (Figure 1) similar to those of insulated flows [2]. These features may be resurfaced by flows [8] or may be lava lakes [9]. However, no Pele-like (active lake) ratios are seen in data analysed so far. Although the magnitude of activity changes, the 2-µm/5-µm ratio does not. This indicates a change only in area of activity, not style of emplacement.

Discussions and conclusions: Different effusive eruption styles display characteristic trends in their thermal radiance evolution, as well as in spatial distribution and intensity of radiant heat flux, and therefore can be classified according to their spectral character. As seen by *Galileo* NIMS, for example, different effusive and explosive eruption styles on Io have characteristic “spectral signatures” that can be used for constraining eruption style.

Even with the low-spatial-resolution data currently available of Io’s volcanic activity it is possible to constrain and classify eruption style from the shape of integrated thermal emission spectrum as well as the ratio of the 2:5 µm emission. This classification is borne out by consideration of similar data for volcanic activity on Earth. We find that data collected at two wavelengths is sufficient if (1) the wavelengths are carefully selected from the 1-2 µm and 4-5 µm regions, and (2) temporal resolutions are sufficiently high to allow the change in fluxes at these wavelengths to be observed. The measurement of the 2:5 µm ratio is particularly sensitive to changing style of emplacement. For terrestrial data, and when using terrestrial telescopes to image Io, the 4.8-µm window has an atmospheric transmission of better than 70%, and there is little difference in between thermal emission at 4.8 µm and 5 µm. Ideally, an observation in the thermal infrared (8-12 µm) would also be obtained to improve constraint on temperature model fits to the data [10,11].

Even when an entire volcano is reduced to one pixel, the thermal signature provides insight into the eruption style. Whereas the most vigorous mafic eruptions (generating the proportionally largest areas at high temperatures) generally do not last longer than a few hours to days, low effusion rate activity can persist for years to decades. Observations should ideally be made on time scales an order of magnitude less than the time scale of the phenomenon. A lava fountain, for example, should therefore be imaged on a time scale of minutes. Other examples are given in [1]. Finally, we suggest that the optimum wavelength set for a thermal imager for constraining eruption style on both Io and Earth are 2, 5, 8, and 12 µm [1]. Additional constraints on model fits can be obtained with additional bands at 3 µm and 20 µm.

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Acknowledgements: This work was carried out at the Jet Propulsion Laboratory-California Institute of Technology, under contract to NASA. AGD and LPK are supported by grants from the NASA PG&G and OPR programs.

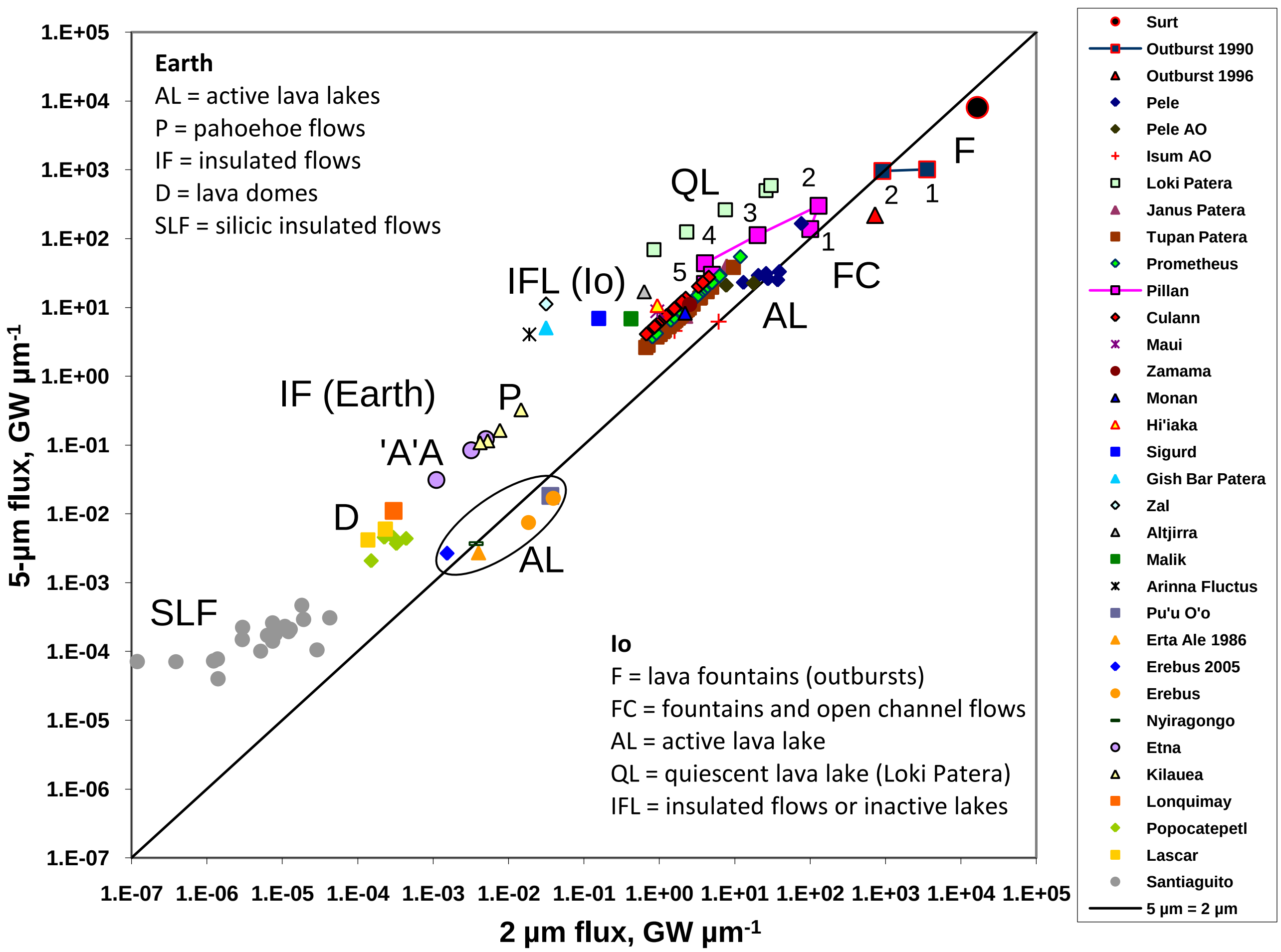

Figure 1. Radiative fluxes at 2 and 5 µm for different volcanoes on Io and Earth [1] with rough groupings by lava emplacement mode shown. The distance from the 2-µm = 5-µm flux line is an indication of the thermal intensity of volcanic activity: lava fountains and vigorously-overturning lava lakes are close to or on the line, whereas insulated flows are further from it. Eruptions located to the left of the 2-µm = 5-µm flux line have a decreasing ratio of hot surfaces to cool surfaces, and by implication the vigour of the eruption, with increasing distance from the line. To the right of the line, eruption vigour increases with increasing distance from the line. Effusion rate increases with distance from the origin. Data from [2].