EPSC Abstracts
Vol. 12, EPSC2018-193, 2018
European Planetary Science Congress 2018
ⓒ Author(s) 2018

How to Measure Io’s Lava Eruption Temperatures with a Novel Infrared Detector and Readout Circuit

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1. Introduction

In the wake of NASA’s *Galileo* mission to the Jovian system, perhaps the most important question that remains from the detailed investigation of Io concerns the composition of Io’s dominant erupting lavas [1,2]. Measuring eruption temperature would help constrain lava composition, but this measurement is technically challenging using remote sensing, even though Io has hundreds of currently active volcanoes [3,4]. Io’s widespread, extreme level of volcanic activity is the result of tidal heating [5], the result of an orbital resonance between Io, Europa and Ganymede. Internal heating and volcanic advection result from a complex interplay of processes dependent on internal viscosity and variability of viscosity, and therefore on composition and temperature. The mapping of eruption temperatures across Io may reveal spatial variations in heat production through tidal dissipation and suggest lateral variations in melt fraction [6].

Only certain styles of volcanic activity are suitable for determining eruption temperature remotely, those where thermal emission is from a restricted range of surface temperatures close to eruption temperature and filling an area large enough to be detected [2]. Such desirable processes include large lava fountains; smaller lava fountains common in active lava lakes; lava tube skylights; and transient but powerful explosive events [7].

Problems that must be overcome to obtain usable data are: (1) the rapid cooling of the lava between data acquisitions at different wavelengths; (2) the often unknown magnitude of thermal emission (see Figure 1) at any given time, which has often led to detector saturation; and (3) thermal emission changing on a shorter timescale than the observation integration time – newly exposed lava cools extremely fast from eruption temperature [2]. We can overcome these problems by using the HOT-BIRD detector and a novel, advanced digital readout circuit (D-ROIC) which saturates only under such extreme conditions that they are unlikely to be encountered on Io.

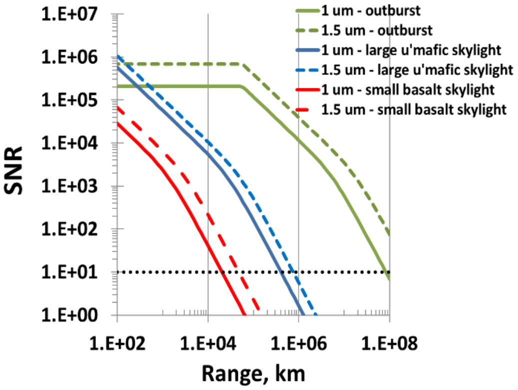

Figure 1. Signal to Noise Ratio (SNR) at 1 and 1.5 µm as a function of range for a large thermal outburst and small lava tube skylights. These eruptions are detectable at SNR values (>10) over a wide range of distances to target. From [2].

1.1 HOT-BIRD and D-ROIC

The “HOT” in HOT-BIRD refers to High Operating Temperature, and “BIRD” refers to Barrier Infrared Detector [8]. This infrared detector technology was recently developed at JPL [8]. We use a novel D-ROIC developed by MIT Lincoln Laboratory with the HOT-BIRD detector. An analogue-to-digital converter and digital counter is placed in each pixel [9]. These digital-pixel readout integrated circuits (D-ROICs) store digital count values related to the photocurrent integrated by the detector. The digital counters do not saturate if their maximum count number is exceeded. Instead, they “roll over” and begin counting again from zero. In this manner, no information is lost; the count number are recovered using real-time processing to correct for rollovers [10]. The combination of HOT-BIRD with the D-ROIC results in an imaging system technology that can cope with the extreme variability, unpredictability and unknown magnitude of Io's volcanic thermal emission without saturation.

2. Instrument model

Our Excel-based instrument model [2] demonstrates that a short-wavelength infrared instrument on an Io flyby mission can achieve simultaneity of observations by splitting the incoming signal for all relevant eruption processes and still obtain data fast enough to remove uncertain-ties in accurate determination of the highest lava surface temperatures exposed. Examples of SNR values for extreme (both big and small) thermal sources are shown in Figure 1.

3. Deriving eruption temperature

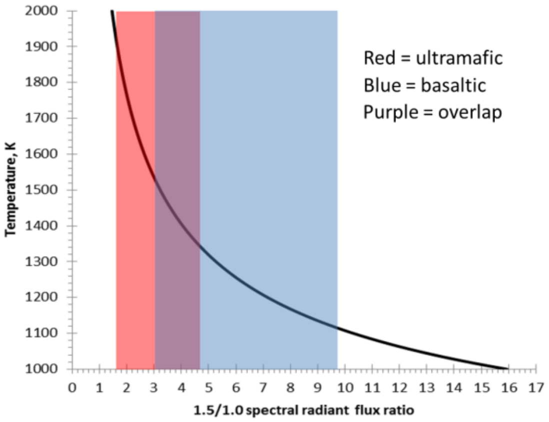

Figure 2. Skylight 1.5-µm:1.0-µm radiant flux ratio as a function of temperature [see 6]. The red area is exclusively ultramafic. Adapted from [2].

We find that observations at 1 and 1.5 µm are sufficient for determining eruption temperature. Even with a ten-way beam split, instrument throughput generates acceptable signal to noise values (Fig. 1) even for the smallest targets. Fig. 2 shows the expected range of the 1.5:1.0 ratio expected for small skylights exposing basalt (blue) and ultramafic lavas (red), with the overlap shown in purple. The ratios are derived from an active skylight thermal emission model [6]. Lava eruption temperature determinations are, of course, also possible with a visible wavelength detector so long as data at different wavelengths are obtained simultaneously and integration time is very short, so as to "freeze" the lava cooling or heating process. This is especially important for examining the thermal emission from lava tube skylights due to rapidly changing viewing geometry during close flybys [6].

Acknowledgements

This work was performed at the Jet Propulsion Laboratory – California Institute of Technology, under contract to NASA. SG thanks the JPL Fellows Fund for support. We thank the NASA PICASSO and Outer Planetary Research Programs for support. © 2018 Caltech.

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