MEETING THE CHALLENGE OF MEASURING IO'S LAVA ERUPTION TEMPERATURES.

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Introduction: It is a technological challenge to measure the temperature of erupting lava on the jovian satellite Io, even though Io has hundreds of currently active volcanoes [1,2]. Io's widespread, extreme level of volcanic activity is the result of extreme tidal heating [3]. Constraining eruption temperature is a long-desired goal. The result of an orbital resonance between Io, Europa and Ganymede, Io's tidal heating may be partitioned between mantle tidal heating and heating in a shallow aesthenosphere. 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. 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 eruption temperatures across Io may reveal spatial variations in heat production through tidal dissipation and suggest lateral variations in melt fraction [4].

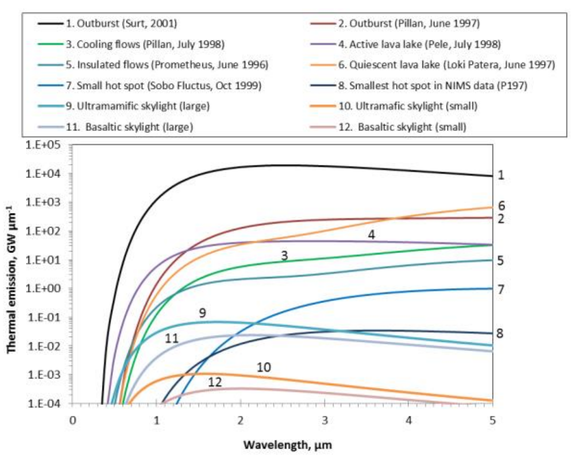

Figure 1. The range of thermal emission from Io's volcanoes. Different styles of volcanic activity yield different shapes of thermal emission spectra, with different magnitudes of thermal emission controlled by the areas of hot surfaces exposed. The most energetic eruptions (outbursts: 1 and 2) are also the rarest. The smallest, and possibly most common, thermal features are may be lava tube skylights (9-12). Base image from [8].

One method of determining lava eruption temperature of Io's dominant silicate lavas is by measuring radiant flux at two or more wavelengths and fitting a black-body thermal emission function. Only certain styles of volcanic activity are suitable, those where thermal emission is from a restricted range of surface temperatures close to eruption temperature. Such desirable processes include large lava fountains; smaller lava fountains common in active lava lakes; and lava tube skylights. 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. 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.

HOT-BIRD: Digital Formats: The "HOT" in HOT-BIRD refers to High Operating Temperature, and "BIRD" refers to Barrier Infrared Detector [5]. This infrared detector technology, which has recently been developed at NASA's Jet Propulsion Laboratory (JPL), is based on antimonide type-II superlattice (T2SL) infrared absorbers and the unipolar barrier device architecture [5]. The antimonide T2SL is an artificially engineered III-V semiconductor material capable of pervasive infrared detection coverage. The long-wavelength cutoff wavelengths can be continuously adjusted from anywhere between ~2 µm and beyond 14 µm.

Digital Read Out Integrated Circuit (D-ROIC): We emply a novel D-ROIC developed by MIT Lincoln Laboratory with the HOT-BIRD detector. An analog-to-digital converter and digital counter is placed in each pixel [6]. Theses digital-pixel readout integrated circuits (D-ROICs) store digital count values related to the photocurrent integrated by the detector. These digital counters do not saturate if their maximum count number (typically 2^{16} -1 or 2^{32} -1 counts) is exceeded. Instead, they "roll over" - in the same way a car's odometer would - and begin counting again from 0. In this manner, no information is lost, as when an analog array saturates, and the true count number can be recovered using real-time processing to correct for any rollovers [7]. Digitizing the signal in-pixel also offers other advantages, such as low-noise performance, wide dynamic range, and high frame rates. Using this technology prev ents digital focal plane array (FPA) saturation, overcoming one major hurdle encountered at Io. The detector can detect thermal emission from Io's volcanoes, large and small, at acceptable signal to noise ratios over a very broad span of distances to target without saturating the digital FPA, a necessary, vital requirement for observing Io's volcanoes.

The combination of HOT-BIRD with the D-ROIC results in a powerful technology that can adjust to cope with the extreme variability and magnitude of Io's volcanic thermal emission.

Instrument Model: Our Excel instrument model allows different instrument parameters (including mirror diameter, number of signal splits, exposure duration, filter band pass, and optics transmissivity) to be tested so as to determine eruption detectability. We find 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 uncertainties in accurate determination of the highest lava surface temperatures exposed. Examples of the extreme ends of the scale of volcanic activity on Io suitable for the purposes of deriving lava eruption temperature are the large thermal outburst eruptions and lava tube skylights, and SNR values are shown in Figure 2.

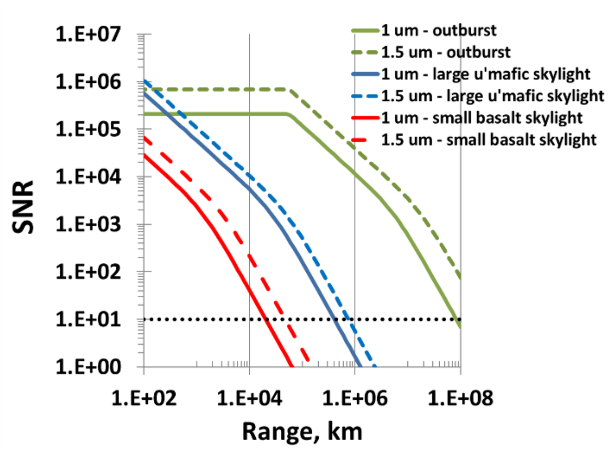

Figure 2. Signal to Noise Ratio (SNR) at 1 and 1.5 μm as a function of range for extreme ends of the scale of volcanic activity on Io, from the largest thermal outburst to likely small lava tube skylights. All of these eruption scenarios are detectable at acceptable SNR values (>10) over a wide range of distances to target.

Derivation of lava eruption temperature: We find that observations at 1 and 1.5 μm are sufficient for this purpose. Even with a ten-way beam split, instrument through-put generates acceptable signal to noise values (Figure 2) even for the smallest targets. Figure 3 shows the expected range of the 1.5:1.0 ratio expected for small skylights expopsing basalt (blue) and ultramafic lavas (red), with the overlap shown in purple. The ratios are derived from an active skylight thermal emission model [4]. 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 [4].

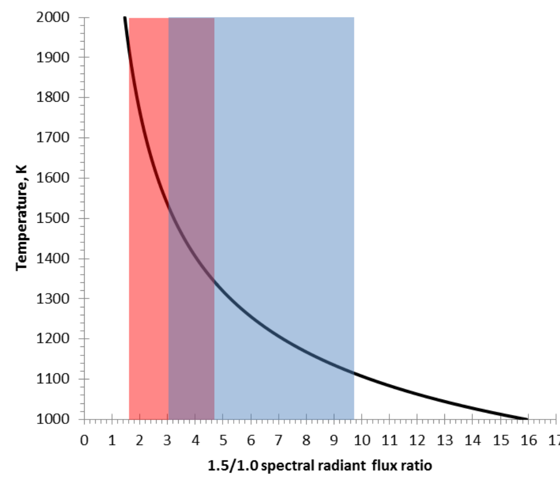

Figure 3. 1.5-μm:1.0-μm radiant flux ratio as a function of temperature using the model described in [4]. Overlap between basalt and ultramafic compositions occurs between ratios of 3.4 and 4.76. Ratio values larger than 3.4 can be indicative of either basaltic or ultramafic lavas. Ratios less than 3.4 are diagnostic of ultramafic composition. The limiting (maximum) size of a skylight is ~5 m x 5 m.

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