OPTIMAL WAVELENGTHS FOR STUDYING THERMAL EMISSION FROM ACTIVE VOLCANOES ON IO.

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Introduction: Our goal is to identify the optimal wavelengths for studying volcanic activity on Io. While better temporal, spatial, and spectral resolution is always desired, practical limitations lead one to limit both the wavelength range and spectral resolution of an observation. Our primary motivation is to assist the development of future spacecraft observations, but these results are also relevant to Earth-based telescopic observations of Io.

We focus on the Io Volcano Observer (IVO) concept [1]. IVO is proposed to study Io from the vantage point of a highly inclined elliptical orbit around Jupiter with close Io flybys every 30-200 days. While data collection at closest approach will be limited by the blistering ~18 km/s ground speed, more distant monitoring is planned over a ~2 day encounter period.

The two instruments that would observe thermal emissions are the radiation-hard camera (RCam) and Thermal Mapper (ThM) [1]. RCam is planned to have a 10 μrad IFOV, giving better than 10 m/pixel at closest approach and ~1 km/pixel for the more distant, global observations. Lava fountains above fissure vents would be spatially resolved near closest approach, but the global synoptic views would spatially resolve only large lava flow fields and paterae. ThM should have a spatial resolution of about 10 km/pixel global and better than 1 km/pixel over selected targets. This should allow different parts of a lava flow field to be spatially resolved near closest approach, but most active volcanic centers will be contained in a few pixels in the global views.

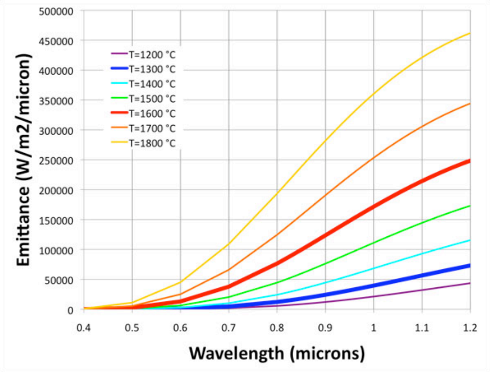
While the approximate spatial resolution is known, the choice of spectral bandpasses is ongoing [1].

Science Questions: The science questions related to thermal emissions are (1) what is the eruption temperature of the lava, (2) what are the different styles of eruption on Io, and (3) what is the global heat flow.

Eruption temperature is important to measure because it provides the best constraints on lava composition and the state of Io's mantle [2]. If, as intially suggested by Galileo SSI data, the eruption temperature can exceed 1600 °C, then the upper mantle is largely molten and Io should contain a magma ocean [3]. Such a magma ocean would imply that Io is far from thermal equilibrium because tidal dissipation within the ocean would be much less than the observed heat flow [4]. Reanalysis of the uncertainties in the *Galileo* data suggests that eruption temperatures could be closer to 1400 °C [5]. More and better observational data are essential in order to answer fundamental questions about the basic nature of Io's interior. The least adulterated view of erupting lava is provided by spatially resolved images of skylights or lava fountains obtained in darkness.

Constraining Peak Temperature (RCam): The peak temperature is best determined by measuring the steep short wavelength side of the Planck Function (Fig. 1). Cooler emitting surfaces have a relatively weak effect on this part of the spectrum. Furthermore, this part of the emission spectrum is nearly linear, so its slope (and thus the temperature) can be well constrained with limited spectral resolution.

Figure 1. Plank function for emissivity of 1.



The most critical goal is to determine if eruption temperatures are ≥1500 °C or ≤1300 °C. These temperatures can be clearly distinguished by ratioing high SNR observations through effective bandpasses near ~0.8 μm and ~1.0 μm, within the sensitivity range of silicon-based detectors. It would be prudent to be able to measure lava temperatures up to ~1800 °C, since such temperatures would have very important implications for Io's interior. This could be accomplished if measurements were also collected with a bandpass that excludes light beyond ~0.8 μm. A >1.1 μm cutoff filter would theoretically be useful for measuring lower temperatures but may be rendered impractical by low detector sensitivity beyond 1 μm.

Skylights in a lava tube would provide the most straightforward estimates of lava temperature [6]. Skylights on Earth are typically only a few meters across and are usually surrounded by cool surfaces. An Io skylight on the same scale would expose a temporally stable narrow range of very high temperature surfaces. Therefore, 2- (or 3-) color brightness temperatures, or more sophisticated cooling model fits to data, even from unresolved skylights, might provide our best temperature estimates. Close flyby observations of insulated flow fields fed by lava tubes would be desirable, especially at night or in Jupiter's shadow [6].

A significant complication in interpreting data from a lava fountain is that the effusion from a fountain is often expected to be variable on a time scale of seconds with distinct pulses or bubble bursts. The best fountain temperature estimates would be derived by resolving the products of a single batch of pyroclasts. While we expect differences in the fountain dynamics on Earth and Io, terrestrial experience suggests that a batch of pyroclastics is likely to begin with a scale of ~10 m (the size of a bursting lava bubble or the throat of a vent) and expand to a few hundred meters before being mixed with other batches. Alternatively, fountains can produce relatively stable jets for several seconds, producing a continuous temperature distribution spread across ~1 km. Thus, at closest approach, RCam has the potential to spatially resolve either individual batches of pyroclasts or the temperature distribution across a fountain. In either case, it is critical to obtain the data at the two (or more) different wavelengths nearly simultaneously because the temperature of the pyroclasts changes very rapidly. Preliminary modeling shows that pyroclasts will cool 100 °C in 0.2-0.4 seconds [5]. <0.1 s between acquisition of data in the different colors is the recommended design goal. Another design constraint is to not saturate even at the highest temperatures (1300-1800 °C) while providing useful data at ~1000 °C.

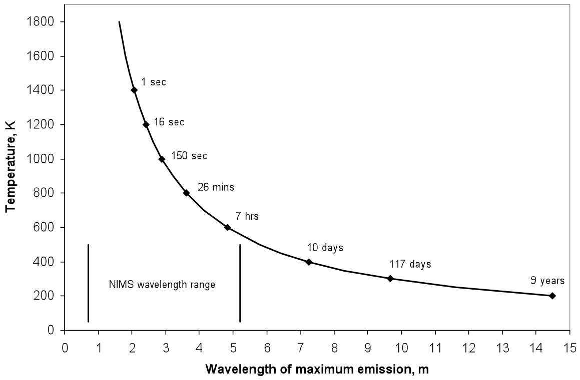
When the hottest lava component is not spatially resolved, thermal models must be used to estimate the eruption temperature from the mixed surface temperatures. The difference between assuming a small pyroclast and a thick lava flow can result in eruption temperature estimates differing by hundreds of degrees.

Constraining Eruption Style (ThM): In addition to being a critical part of estimating eruption temperatures, determining the distribution and temporal evolution of different styles of volcanism is a central goal of observing Io. Since volcanism is proceeding at a much larger scale on Io than on the Earth, Io provides a unique opportunity to observe active flood volcanism – a process that has played an important role in the formation of the surfaces of all the terrestrial planets.

While a few individual eruptive centers could be examined with high spatial resolution imaging from IVO, the global monitoring will must rely on ~10 km per pixel data. The preliminary ThM design can collect data in up to 10 bands (including repeats via neutral density filters to avoid saturation), so the selection of wavelengths needs to be made with some care.

We suggest selecting the wavelenths by considering the timescales of volcanic activity that should be monitored. These timescales can then be translated into expected surface temperatures and peak emission wavelengths (Fig. 2). The very shortest timescales (<1 s) are best dealt with using RCam as discussed in the previous section. At the timescale of seconds, we wish to observe the variability in eruption rates at the vent and instabilities in open channel flow. The next set of processes, including breakouts from insulated flows, spill overs from channels, and overturns of lava lakes typically take tens of minutes. At the next scale, major episodes of eruption and changes in eruptive style (e.g., from open to insulated flow) typically take several days. Finally, we will collect data on the timescale between flybys (i.e., a few months).

Figure 2. Peak emission wavelength as a function of time. Calculated for an eruption temperature ~1200 °C and an insulating lava flow/quiescent lava lake [7].



The desired wavelengths are approximately 2, 3, 4, 6 and 8 microns. If only 3 bands were available, 2, 5, and 8 microns would provide the best compromise.

Constraining Global Heat Flow: Another of the major goals for IVO is to better constrain global heat flow. While the bands discussed above would well-constrain the silicate volcanic activity, there may also be significant secondary sulfurous volcanism, perhaps driven by shallow intrusions [2], and we must measure the passive background temperatures. Sulfur will boil at ~450 °C and solidify at ~115 °C, with corresponding peak thermal emission at 4.0 and 7.3 µm, requiring no additional ThM bands. However, the triple point for SO_2 is just under 200 K, with peak thermal emission at 14.7 µm. Thus, if technically feasible, a 15 µm band could be useful. For passive background temperatures a bandpass at 20 µm or longer is needed.

References: [1] McEwen et al. (2009) *LPS 40*, Abstract #TBD. [2] Keszthelyi et al. (2004) *Icarus, 169*, 271-286. [3] Keszthelyi et al. (1999) *Icarus, 141*, 415-419. [4] Moore (2001) *Icarus, 154*, 548-550. [5] Keszthelyi et al. (2007) *Icarus, 192*, 491-502. [6] Davies (2008) *AGU Fall Meet.*, Abstract #P43A-1389. [7] Davies et al. (2009) *JVGR.*, in prep.