DETECTABILITY OF CRYO-VOLCANISM WITH THERMAL INFRARED SPECTROSCOPY
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Introduction: Active cryovolcanic processes were been observed in the Neptune [1] and Saturn [2] systems, and are considered a possibility within the Jupiter system. In particular for Europa, cryovolcanism would provide a mechanism that brings interior material to the surface, potentially including evidence of biological activity [3], to the surface. Thus, detection of ongoing or recent cryovolcanic activity would not only be of geologic interest for future missions such as the Europa Orbiter [4], but a compelling target for landed missions. Surface temperature can be most directly measured from remote sensing in the mid (5-40 μm) and far infrared (40-350 μm), where ice is nearly a black body and temperature can be fit to a Planck curve using Wein’s Law, with lower temperatures peaking at longer wavelengths. As a guide to instrument design for future missions, this study modeled the thermal emission of putative cryovolcanic features to determine the minimum requirements of resolution and spectral range for the detection of cryovolcanism.

Previous Work: The possibility of using infrared spectroscopy to detect cryovolcanic thermal emission has been considered previously [5, 6]. However the evolution of the thermal signature for a putative cryovolcanic feature, and the requisite instrument sensitivity and resolution to detect it has not been explored. Infrared radiometers have been used to explore the Jovian system since the first fly-bys with Pioneer 10 and 11 [7], followed by the Infrared Interferometer Spectrometers (IRIS) on board Voyager 1 and 2 [8], which were the first to image Jovian moons and had a maximum spatial resolution of 900 km [9]. Galileo arrived in 1995 and carried two infrared instruments, the Near Infrared Mapping Spectrometer (NIMS) and the Photopolarimeter-Radiometer (PPR). NIMS had a lower limit of 180 K for its detection of thermal emission of an object in its field of view [10]. The PPR was tasked to map day and night time surface temperatures in order to understand spatial variations in thermophysical properties on Europa, such as endogenic thermal activity [11]. It imaged Europa with a spatial resolution of 80-200 km, and a spectral range from 0.35 to 100 μm, and no hotspots were detected even in its most sensitive and highest resolution data [6].

Approach: This study focused on lenticulae, dome-like features on Europa [12], which are proposed as potential cryovolcanic analogs to terrestrial silicate lava domes, as reviewed and modelled by [13]. Our initial work focused on the most extreme case of cryovolcanism for Europa, pure water (i.e., a liquidus temperature of 273 K) erupting at the surface, in order to define the required level of instrument sensitivity for unambiguous detection of this event.

Combining the modelled emplacement rates [13], with a thermal model of a quenching and surface cooling of an erupted cryolava [14], the smallest dome considered in [13] would cover 11.3 km² after 5.3×10⁶ s at the fastest possible emplacement rate. For this study, the emplacement was segmented into ten discrete time/area steps, each with different start and end times of emplacement. Different resolutions are simulated by taking the emission from the dome and averaging it against a pixel area with only background temperature emission. The result for the pure water case at the moment emplacement stops (e.g. before solidification and subsequent cooling) is shown in Figure 1.

Analysis: At a spatial resolution of 10 km or lower, the hot spot, at peak emission during emplacement, is hardly distinguishable from diurnal variations. However, an instrument with 5 km or higher resolutions could distinguish the hot spot from the background surface. Because the variation between the peak thermal emission of the hotspot and a passive surface in the day is only on the order of 1.5 Wm⁻²m⁻¹ at 15 μm, the instrument would need to be sensitive on the order of 0.1 Wm⁻²m⁻¹ to detect a hotspot at its peak emission.

One important consideration is the Sun, which emits essentially a black body curve for 5780 K, peaking at 0.5 μm. At the Sun-Jupiter distance of 5.2 AU, the magnitude of this peak is 65 Wm⁻²m⁻¹, a much larger peak (albeit at a shorter wavelength) than the ~22.0 to ~32.0 μm peaks of the day-time (120 K) and night-time (100 K) average surface temperatures. At wavelengths greater than around 5 μm, the reflected sunlight is much smaller than the surface thermal emission, even for total reflection from a high albedo surface. Nonetheless, it is desirable to perform searches for cryovolcanic “hot spots” in night-time data and thus remove reflected light from the equation.

Future Work: Any thermal anomaly on Europa will persist after emplacement due to the slow conduction of heat in an airless environment. Further work will model thermal emission through the solidification of the cryolava dome and subsequent cooling to ambient surface temperatures, which will quantify how long such a thermal hotspot will remain detectable as differ-
ent resolutions. Other effects to consider are shifts in the liquidus temperature due to saline compositions, or if the lenticulae are emplaced as ductile ice [12] rather than cryolava.

Conclusions: Cryolava is warmer than the background surface on a body like Europa to a degree sufficient for thermal infrared spectrometry or radiometry to detect. In principle, this is no different than the detection of volcanism from the contrast between lavas and background emission of the surface of a volcanically active body such as the Earth or Io.

A multi-spectral instrument spanning 5-50 μm would cover the range of likely temperatures for any endogenic activity, and 0.1 Wm⁻²μm⁻¹ sensitivity would be sufficient to resolve the surface temperatures to the order of a degree Kelvin, enabling not just searches for endogenic activity, but also mapping of surface thermophysical properties. The main requirement for a robust search for endogenic activity is higher resolution, on the order of 1-5 km/pixel.


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Figure 1. Planck curves for a 11.3 km² hot spot at simulated resolutions from 1 to 200 km resolution, compared to thermal emission curves for day and night-time temperatures when no hot spot is present.