DISCHARGE RATE AND COMPOSITION CONTROL ON THERMAL EMISSION FROM "OUTBURST" LAVA FLOWS ON IO. A.G. Davies[1], L. Wilson[2], J.W. Head[3], K. de Kleer[4] and I. de Pater[5]. [1]Jet Propulsion Laboratory-California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (Ashley.Davies@jpl.nasa.gov). [2]Lancaster University, Lancaster, Lancashire, UK. [3]Brown University, Providence, RI, USA. [4]California Institute of Technology, Pasadena, CA, USA. [5]University of California Berkeley, Berkeley, CA, USA.

Introduction: Io's powerful, voluminous "outburst" eruptions are characterised by lava fountains feeding extensive lava flows [1]. This eruption style is likely similar to that of ancient lunar eruptions [e.g., 2]. Eruptions that formed extensive, thick lava flows on the Moon and other bodies in their distant pasts are taking place now on Io. Io is the ideal location to observe and understand how these eruptions behave - it is the perfect laboratory for testing models and hypotheses.

Observations: Spacecraft observations, primarily from *Galileo*, have provided intermittent snapshots of this activity at moderate spatial resolution in the visible and infrared. Ground-based observations [3] (Figures 1 and 2) have provided more detailed temporal coverage. We are confident that these observations provide hard constraints on the emplacement mechanisms of lava flows, perhaps even to the extent of constraining the composition of the lava. Therefore, to maximize the extraction of information from these data we are developing physical models of eruptions in a vacuum to fit to the available data. The vast heat output from these most energetic eruptions is hard to understand unless high initial magma discharge rates generate fast-growing lava flows whose initial motion is fully turbulent.

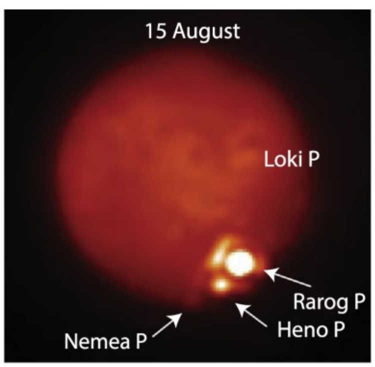

Figure 1. Two powerful (>10 TW) eruptions seen on Io on 2013 Aug 15 with the Keck telescope (shown at 2.2 μm) [3]. These high-volume eruptions exhibited an exponential decay in thermal emission and emplaced lava over hundreds of km² in a few days.

The Model: We have created and continue to refine a numerical model of flow emplacement (see Figure 3) called BOXCAR. In the last year, the model, initially developed in Excel, has been written in Harris Geospatial's IDL. We have begun runs of this model for end-member compositions: a terrestrial tholeiitic basalt; and a 32% MgO ultramafic komatiite. BOXCAR (a) is designed for Io environment conditions; (b) tracks the growth of phenocrysts and the progressive onset of non-Newtonian (presumed Bingham) rheology; (c) tracks the flow regime transition from turbulent to laminar using Reynolds and Hedstrom numbers; (d) is suitable for both basaltic and ultramafic compositions; (e) can be run for any fissure length; (f) can vary fissure length (e.g., decreasing as discharge decreases); and (g) incorporates user-defined initial peak discharge rate and subsequent temporal change (steady effusion rate or exponential decrease (see examples in Figure 4).

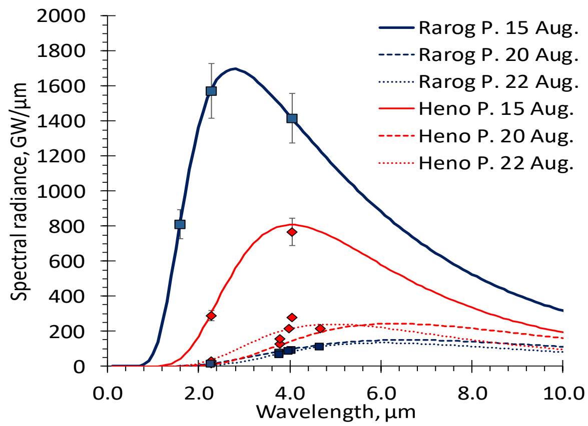

Figure 2. Evolution of the high-volume eruptions at Heno and Rarog Patera in August (after de Pater et al., 2014a). The temporal evolution of spectral radiance at different wavelengths constrains flow emplacement mechanisms – and possibly lava composition.

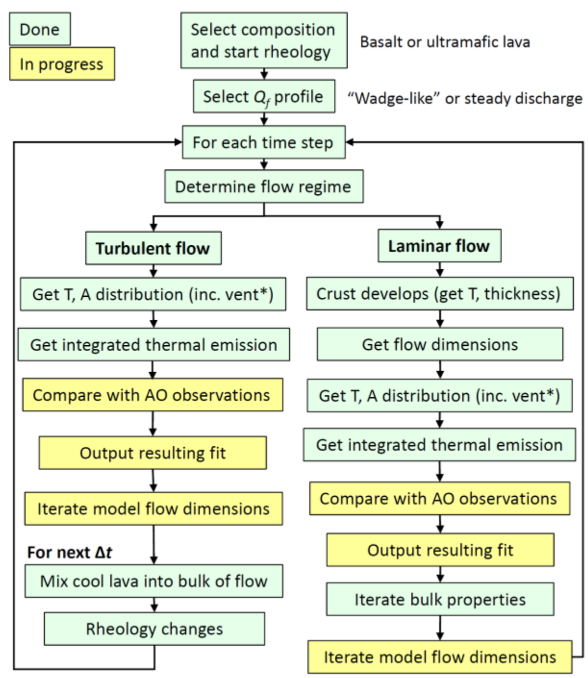

Figure 3. BOXCAR Model flow chart. (* *= optional*).

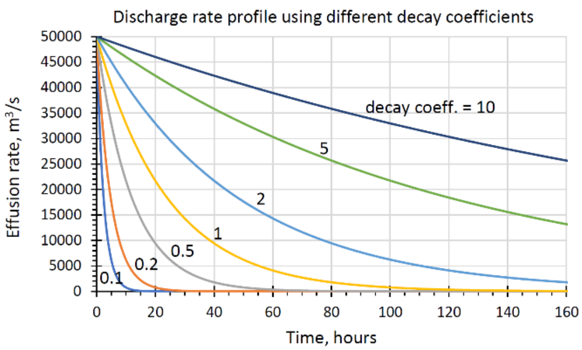

Figure 4. Example of how one variable – the decay coefficient – affects lava discharge rate with time.

Model results: Figure 5 shows an initial example of model output which broadly approximates both the magnitude and temporal evolution of the AO data from Rarog Patera [3].

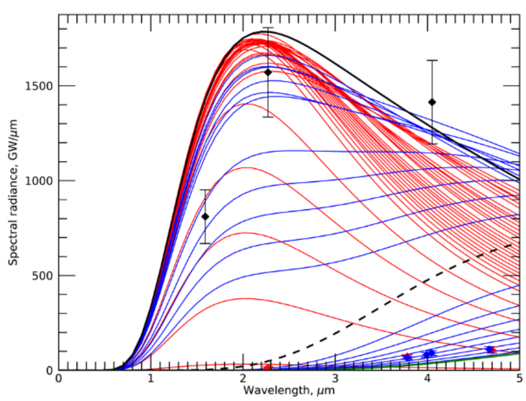

Figure 5. BOXCAR model output for the following case: Composition: tholeittic basalt; eruption temperature = 1430 K; initial effusion rate = 95,000 m/s; discharge decay coefficient = 0.1; fissure length = 95 km (this assumes two flows, each flowing away perpendicular to the fissure; this could also be multiple en echelon *fissures); duration of model run = 10 days; peak thermal emission is reached after 50 minutes; flow emplacement stops after 1.8 days. Length of flow =15 km. Final flow thickness at head of flow = 3.1 m, where flow surface temperature = 348 K. Total volume erupted is 6.8 km³. The lava that erupted at peak discharge rate was turbulent for about 10 minutes before transitioning to laminar flow (when bulk temperature reached 1417 K) at which point a crust began to form on the lava flow.*

In Figure 5, the red spectra are where thermal emission (from channel and levees) is waxing – the black line represents the peak of thermal emission, reached in 50 minutes.

- Blue spectra are where thermal emission is waning.
- The black dashed line is the thermal emission profile at the point where the effusion rate has dropped to the level that flow emplacement stops. The blue spectra below this line are from the cooling, crusted-over flow surfaces and levees.
- The green line is thermal emission after 10 days.
- The AO data for Rarog Patera on 2013 Aug 15 (black diamonds), Aug 20 (red diamonds) and Aug 22 (blue diamonds) are also plotted, with their uncertainties.
- Further parameter modification will yield the best fit to the Rarog Patera data, followed by fitting of the Heno Patera data.

Discussions and conclusions so far:

1. Initial BOXCAR runs find that a transition to laminar flow is required relatively quickly, otherwise the thermal emission will peak at shorter wavelengths than observed. It is apparent that the eruption was likely to have been observed within a few hours of initiation.

2. A rapid transition to laminar flow within the channel (within a few km of the vent) coupled with a rapid drop in effusion rate allows formation of broad expanses of crusted-over lava that cool quickly in an ionian environment, reducing the spectral radiance to the relatively low levels (Figure 5) observed on 20 Aug 2013 and 22 Aug 2013.

3. For the same effusion rate, komatiites generate an order of magnitude more thermal emission (also peaking at shorter wavelengths) than tholeiitic basalt.

4. Crucially, the AO data strongly confine eruption parameters. The need to rapidly decrease thermal emission at short wavelengths suggests that transition to laminar flow is early in the eruption, limiting the volume erupted per unit of fissure length. However, to reach the magnitude of thermal emission observed, this requires a length of fissure (or fissures) 95 km long, in this example, assuming flows move away in two directions perpendicular to the fissure. We are examining the implications of this requirement for magma transport by dikes on Io.

In conclusion, our initial model runs suggest that lava composition and thermo-physical characteristics, combined with a discharge rate profile, provide strong constraints on the resulting spectral radiance peak and spectral emission evolution. Further analysis should yield robust compositional constraints.

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References: [1] Davies, A. G. (1994) *Icarus*, 124, 45-61. [2] Wilson, L. and Head, J. W. (2018) *GRL*, 45, 5852–5859. [3] de Pater, I. et al. (2014) *Icarus*, 242, 352-364. 2132.