Quantifying active volcanic processes and mitigating their hazards with HyspIRI data

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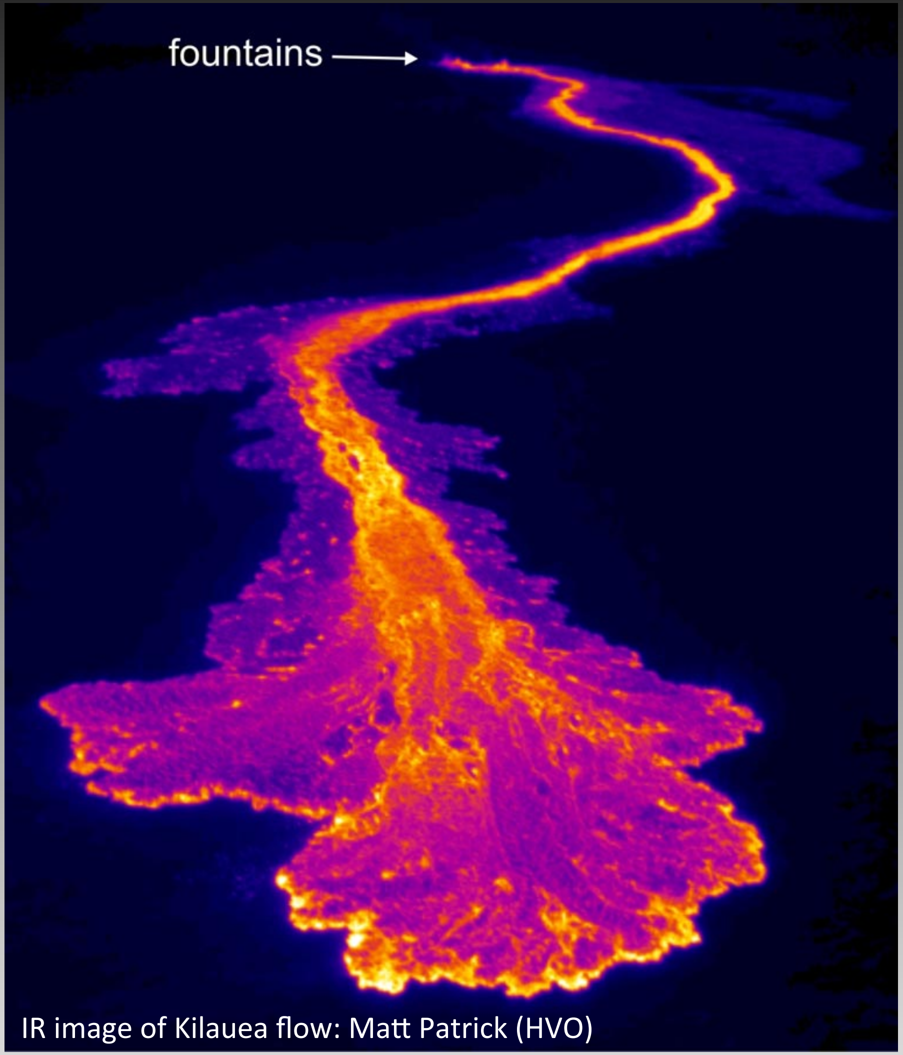
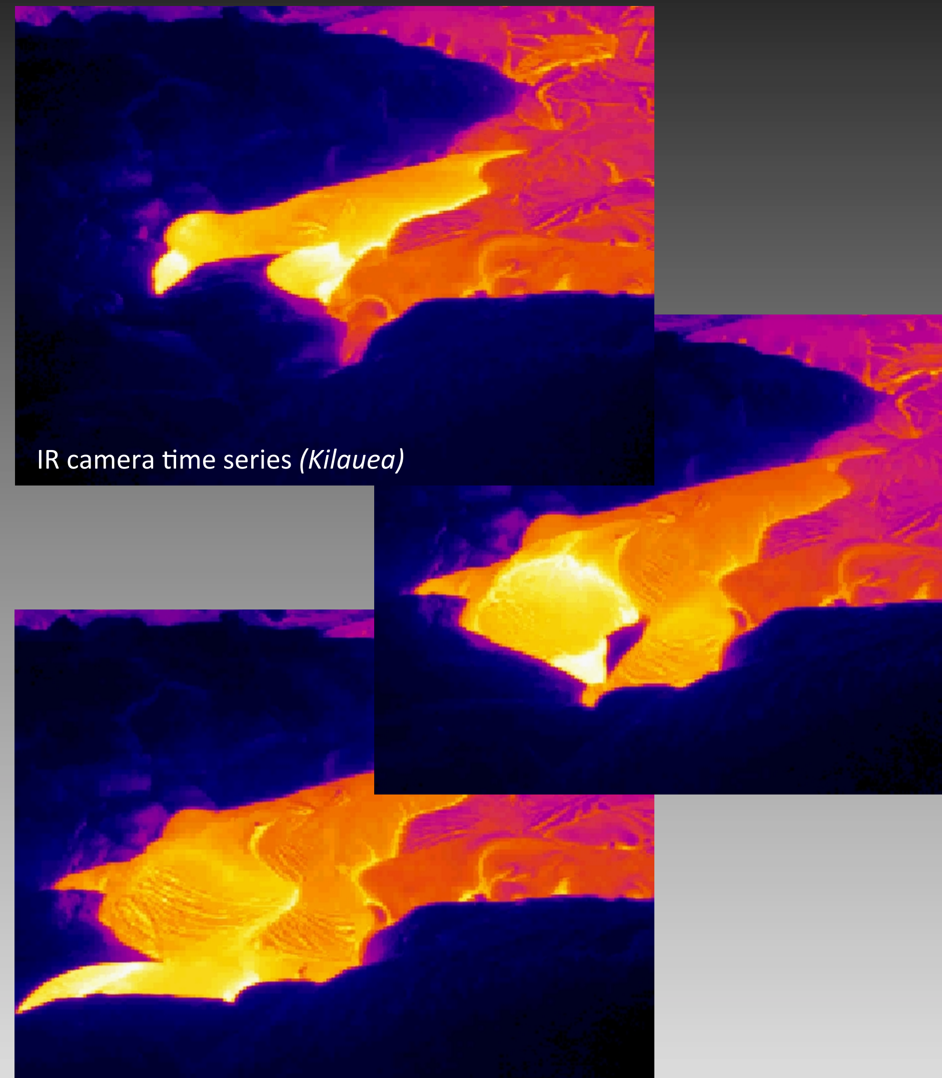


IR image of Kilauea flow: Matt Patrick (HVO)

Outline

overview | background | examples | results | summary

- **Overview**
- **Background**
  - high temperature emissivity
    - prior findings
    - analysis/impact of the VSWIR?
- **Modeling/Analysis Results**
  - Tolbachik, Russia
  - Kilauea, HI
  - other examples
    - ***constrain flow conditions***
- **Summary**

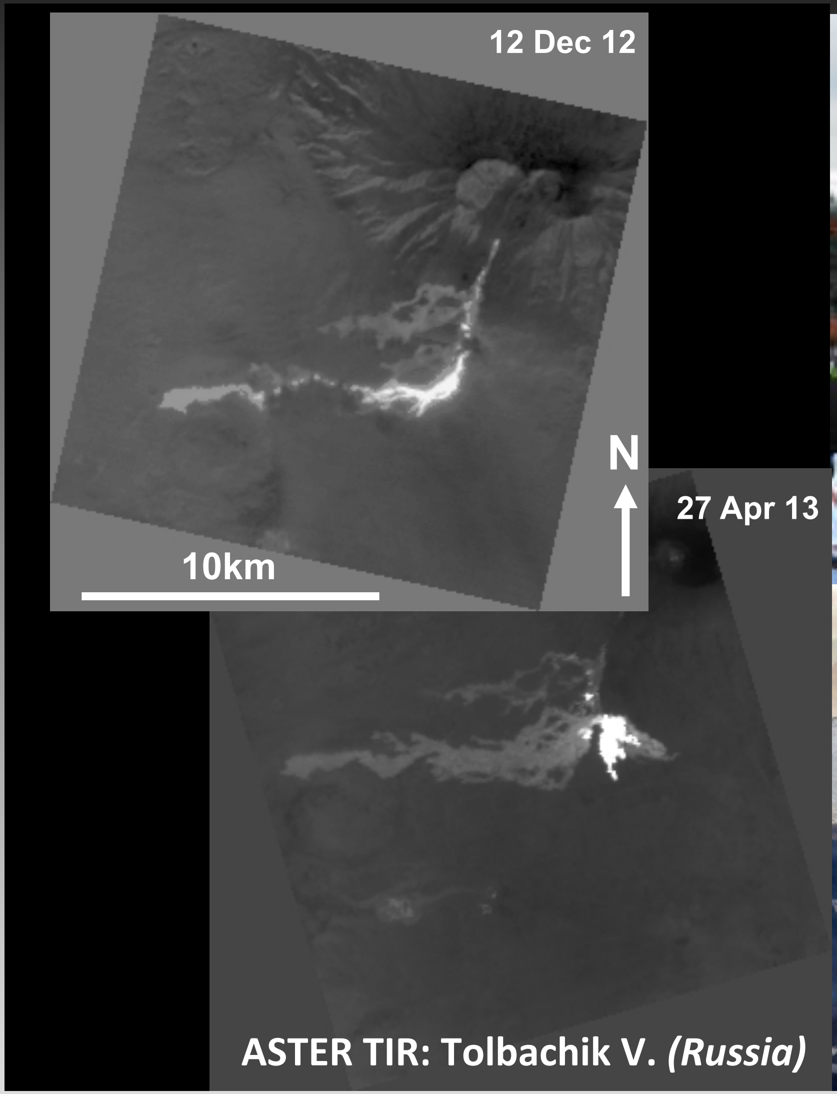

IR camera time series *(Kilauea)*

Studies of Lava Flows

❖ Bigger Picture

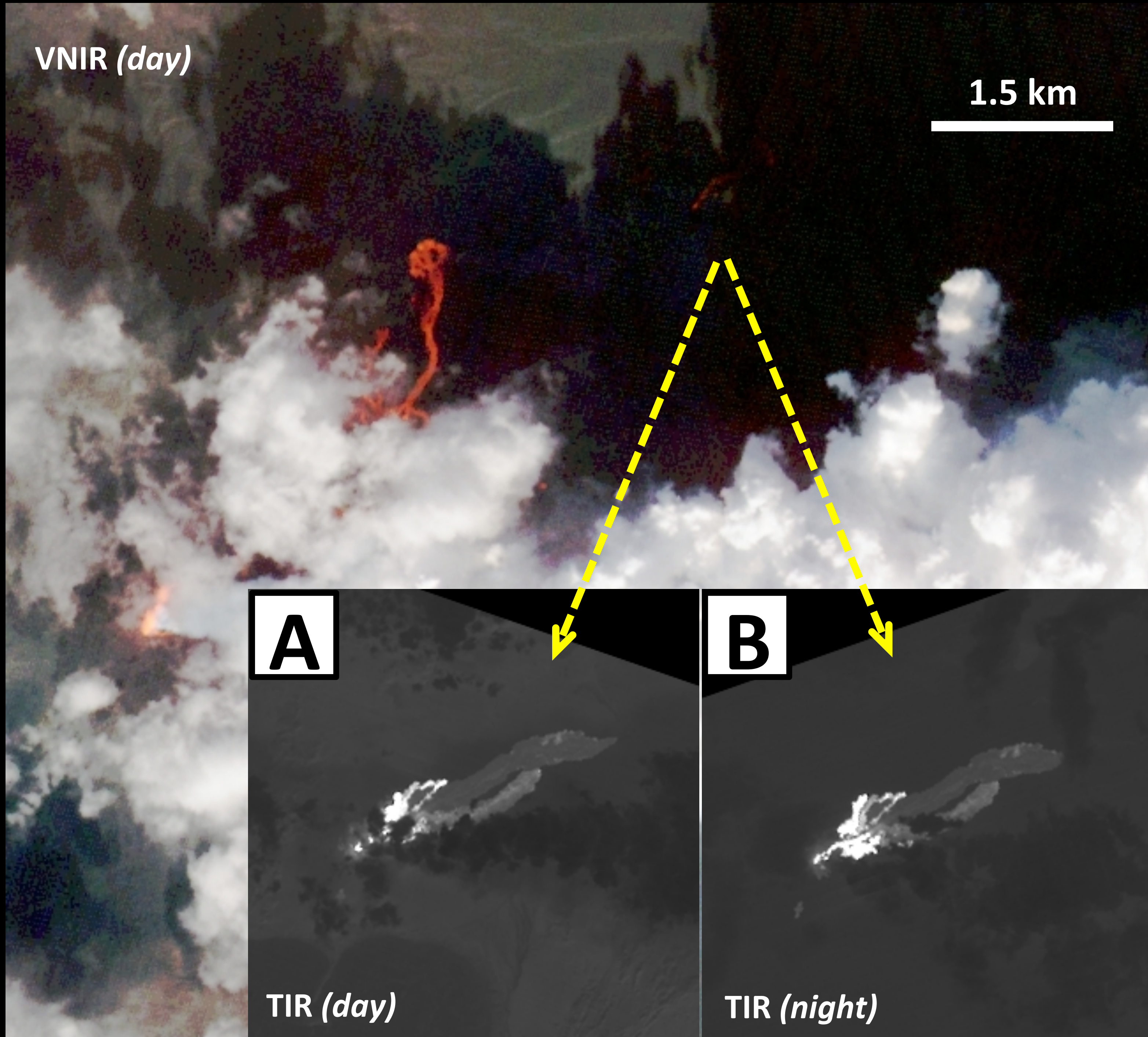
- large lava flows are quite common
  - threaten property and impact airspace
  - e.g., Kilauea, (Hawaii); Eyjfjallajökull and Bardarbunga (Iceland); Nyiragongo (DR Congo), Etna (Italy)

- captured dozens of these flows with ASTER over the past 15 yrs.
  - data provide a unique opportunity to examine the TIR response over time and model the flow paths



ASTER URP: Bardarbunga Iceland

(23 Sept 2014)



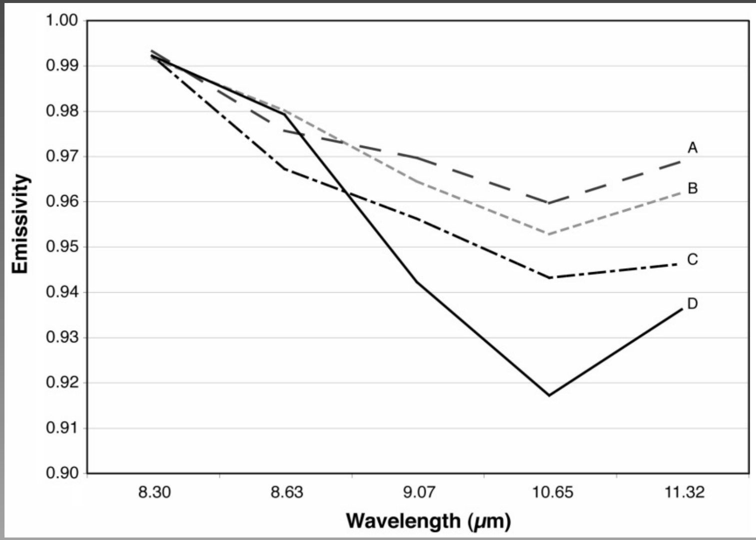
❖ Recent Work

- modified version of an invited talk I gave at the IUGG Meeting in June
- mostly geared toward a terrestrial volcanology crowd
  - but was a joint planetary/terrestrial session
- modeling work has grown out of current ongoing (NSF-funded) laboratory analysis of emissivity changes in molten silicates
  - now incorporating that data into flow propagation models for terrestrial hazard studies *(work with A. Harris in France)*
  - extended the results/model in a reverse application to flow fields on Mars *(work with D. Crown in Tucson, AZ)*
    - use morphometric data from THEMIS, CTX and HiRISE to estimate flow eruption parameters

(Ramsey et al., 2015)

❖ TIR Data

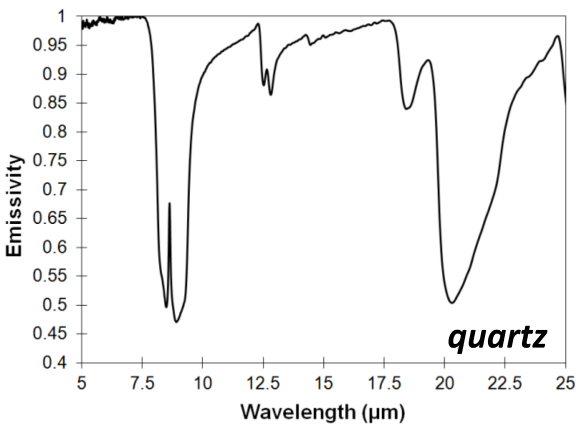
- at the pixel-scale
  - anisothermality results in significant errors in the derived TIR emissivity spectra
    - ➢ due to assumptions during separation of emissivity and temperature combined with the non-linearity of the Planck curve

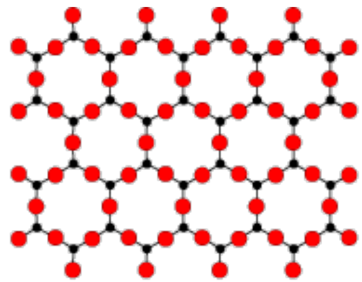


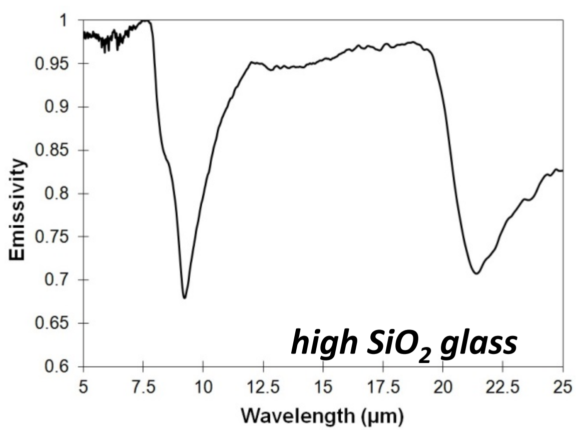
(Rose et al., 2013)

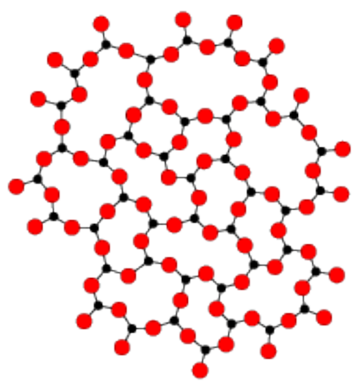
- at the lab-scale
  - $T_{lava} > T_g$ *(glass transition)* also affects the TIR emissivity
  - results in the ability to extract Si:O bonding information

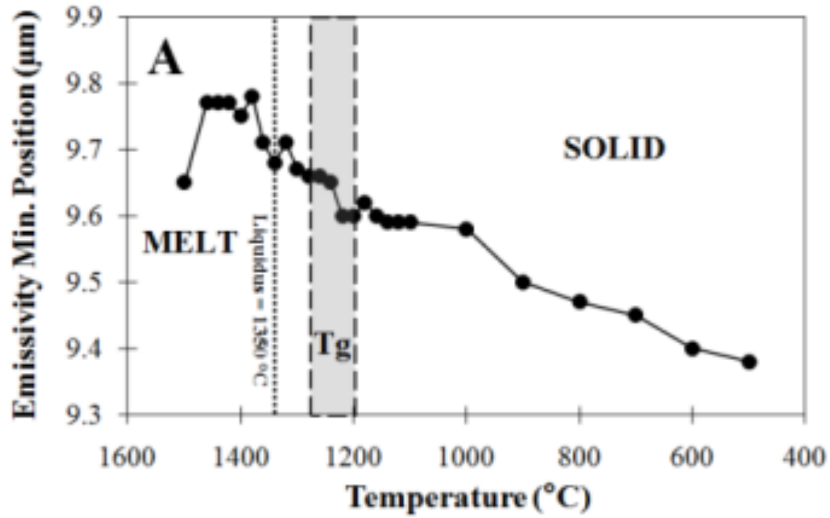
Thermal Analysis of Melts

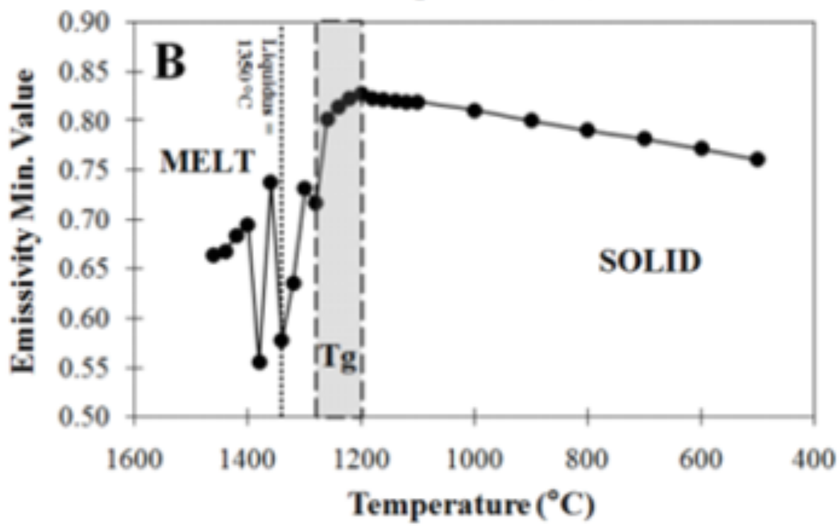












(Lee, 2011; Lee et al., 2013)

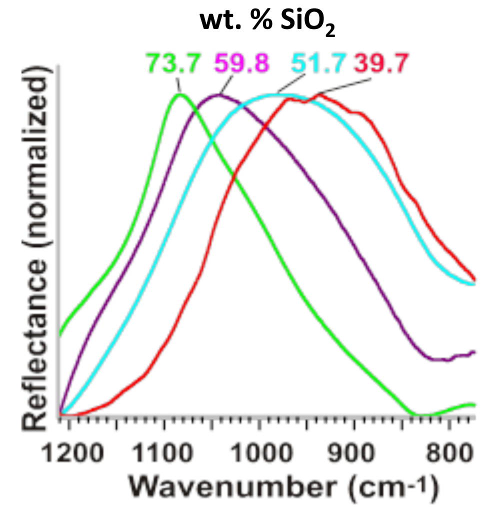
Thermal Analysis of Melts

❖ Composition

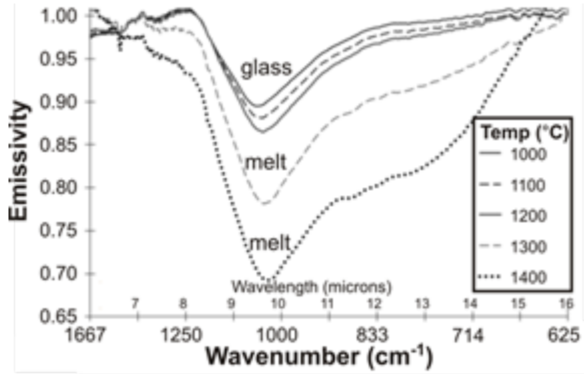
- presence of different minerals
- wt. % SiO_2 of glassy lavas

❖ Silicate Bond Structure

- changes to the mineral/glass structure alters bond lengths and strengths
  - emissivity increases as a lava cools through the T_g
  - impacts remote determination of:
    - lava composition
    - accurate surface temperatures
    - down-flow cooling, viscosity, from thermorheological models



(King et al., 2011)



(Lee, et al. 2013)

Development of New Tools

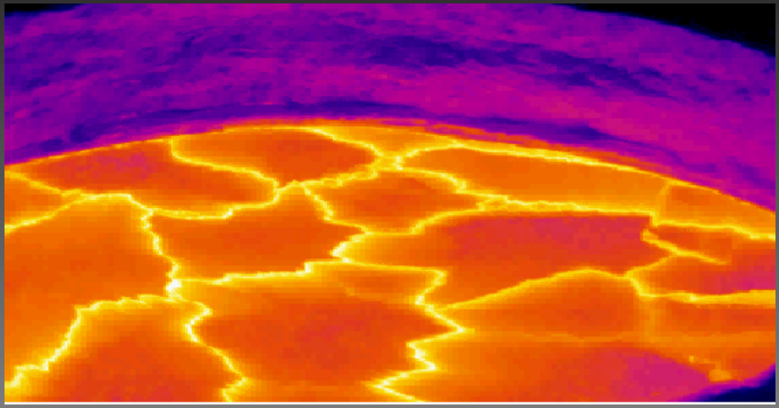
❖ Field Multispectral FLIR

- new adaptation to a FLIR camera to measure *in situ* emissivity for the first time
  - six wavelength filters fabricated to replicate ASTER, MODIS, MASTER and HyspIRI channels
    - acquire ≈ 3 frames/filter pass
    - slow process of post-processing
    - automated, smaller version now in development
      - should allow for remote, autonomous deployment

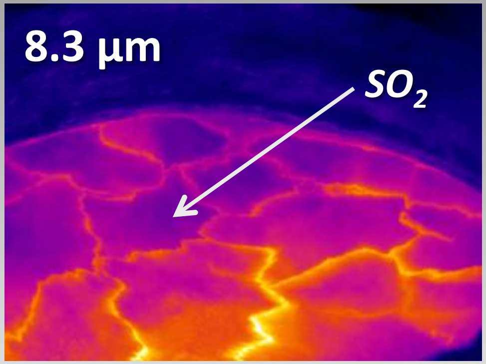
Development of New Tools

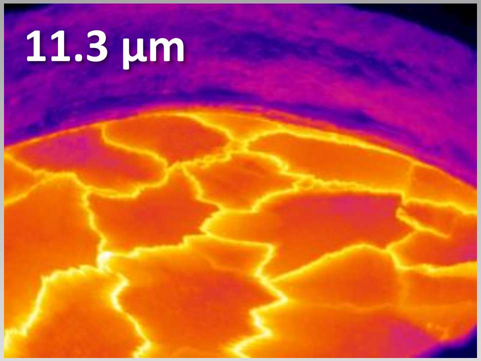
❖ Field Multispectral FLIR

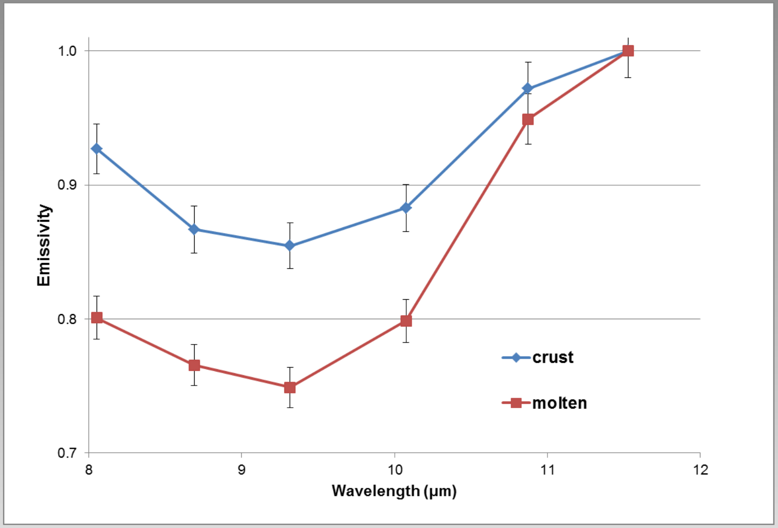
- tested at Kilauea's Halemaumau lava lake *(August 2014)*
- concept appears to work although more calibration is needed
  - detected SO_2, glassy surfaces and basaltic mineralogy
  - confirmed avg. 7% emissivity drop in molten basalt (max = 12%)



FLIR filter sequence of Halemaumau crater lava lake spanning ≈ 20 seconds *(Aug 2014)*





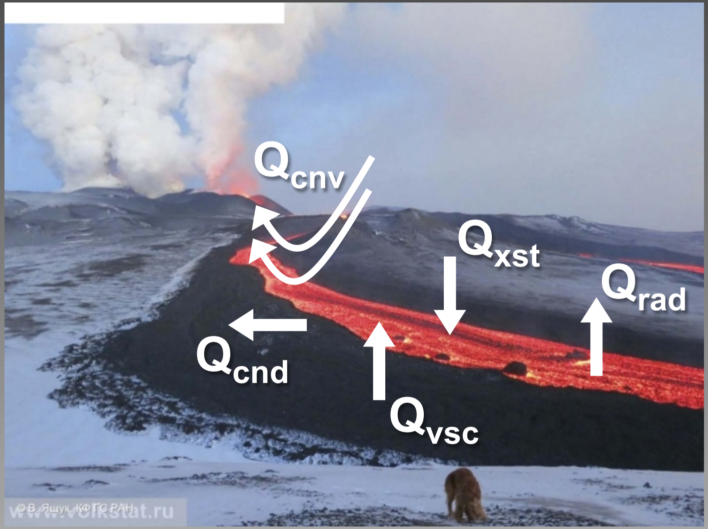


Cooling & Emissivity at the Flow-Scale

overview | background | **examples** | results | summary

❖ Thermorheological Flow Modeling

- apply FLOWGO for channelized flows and vary the emissivity
  - track the heat gains and losses of an element of lava flowing down a natural or user-defined channel
    - cooling-limited *(open-channel)* rather than supply-limited
    - temperature-dependent viscosity
    - recalculation of the thermal and petrological conditions of the lava



(Harris & Rowland, 2001)

  - allows determination of flow parameters such as:
    - viscosity, cooling rate, crystallinity, …

$$(Q_{vsc} + Q_{xst}) = (Q_{cnd} + Q_{cnv} + Q_{rad})$$

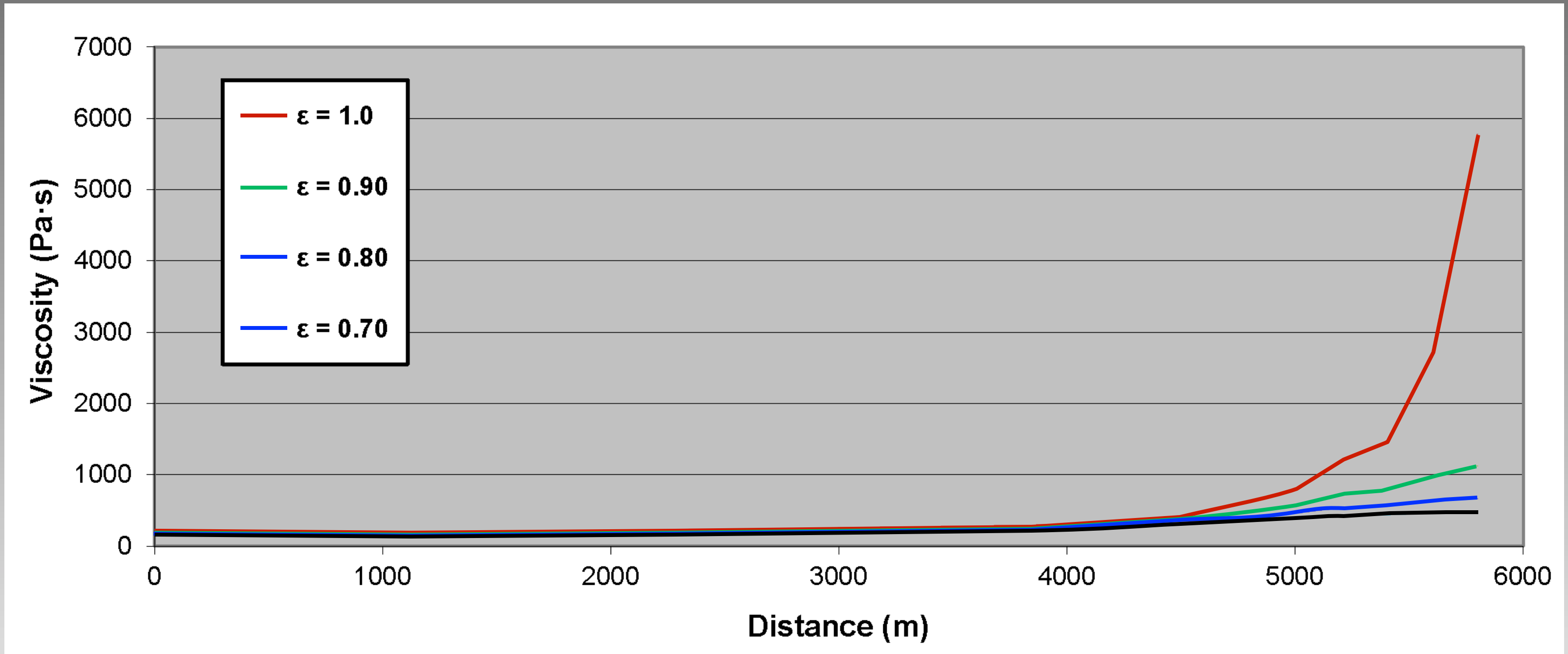
* time-average discharge rate = $A_{lava} \cdot [(Q_{cnd} + Q_{cnv} + \varepsilon Q_{rad}) / \rho (C_p \Delta T + C_L \Delta \phi)]$

** need accurate thermal parameters for the lava (emissivity, temperature)*

Cooling & Emissivity at the Flow-Scale

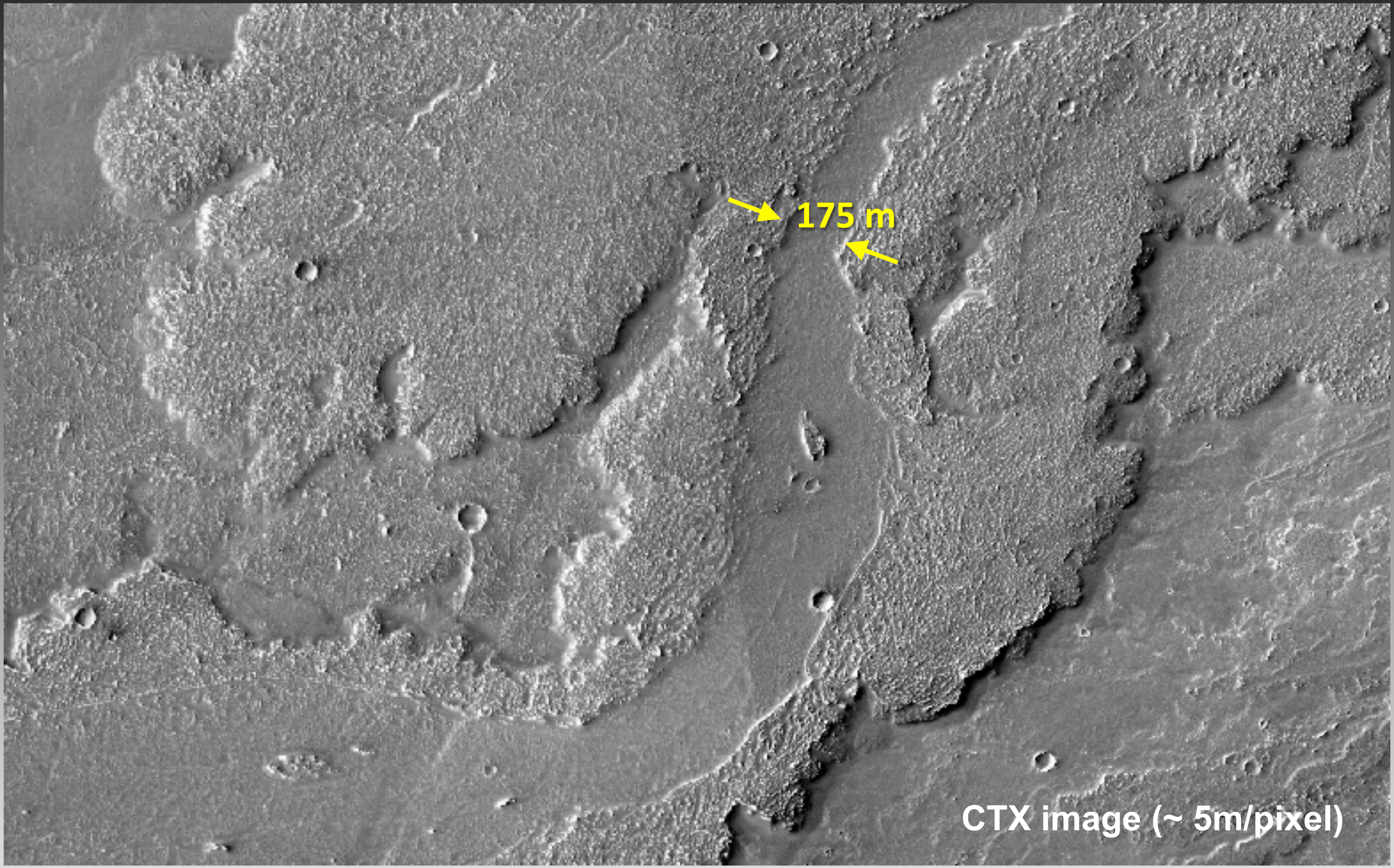
❖ Thermorheological Flow Modeling

- typically, emissivity and vesicularity are assumed constant:
  - ε ≈ 0.95 – 0.98; ζ ≈ 0.92
  - these were varied for a prior FLOWGO run of a channel in the 1972 Mauna Ulu flow field (Harris et al., 2009)



Example: *Arsia Mons*

overview | background | examples | **results** | summary



Example: *Arsia Mons*

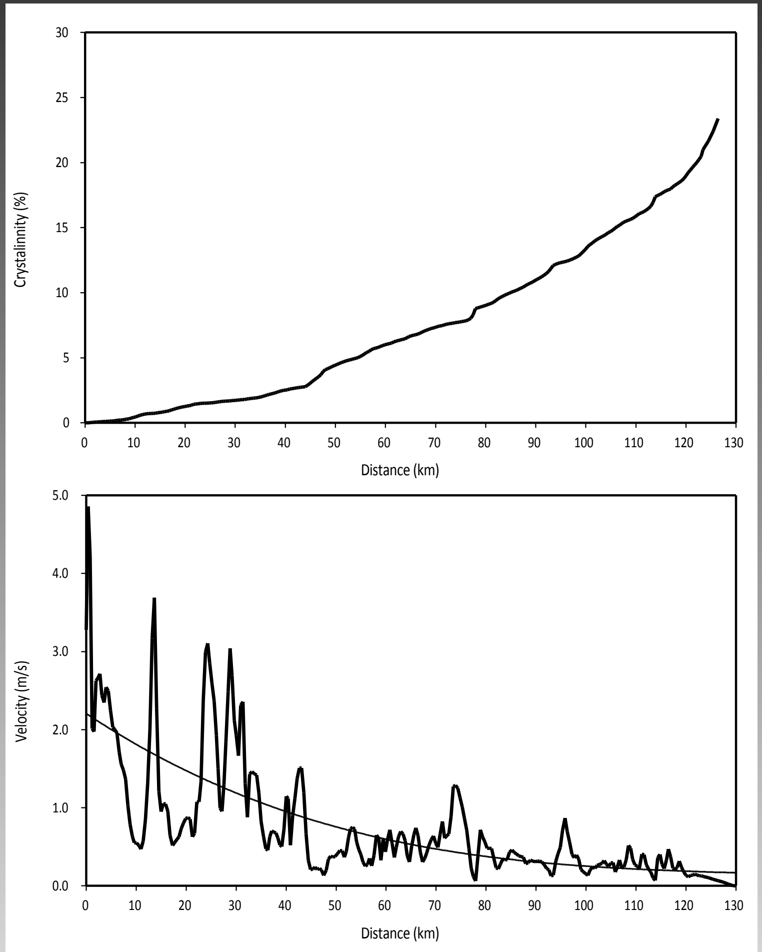
❖ First, Estimate the TADR

- using certain starting assumptions
- calculate initial viscosity
- flow area proportional to TADR:
  - TADR = 0.90 – 7.80 x 10^3 m^3/s
    - *similar range of* 3.4 – 13.0 x 10^3 m^3/s

(Wilson & Mouginis-Mark, 2001)

❖ Next, use modeled TADR to initiate the FLOWGO model

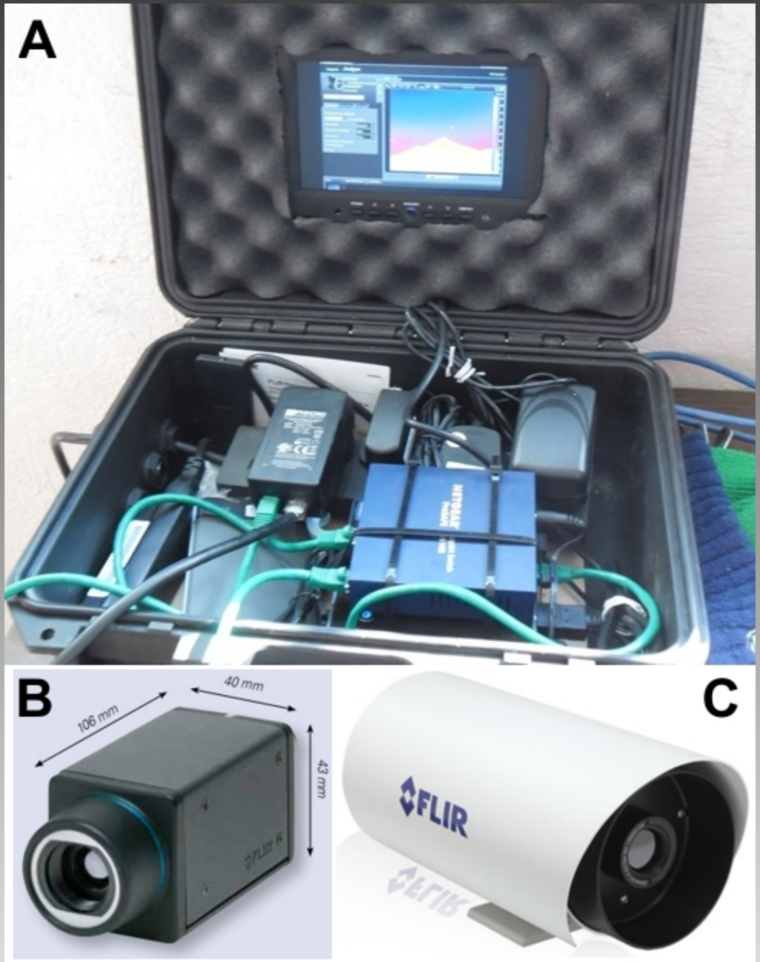
- under Martian conditions using properties of terrestrial flows
  - model down-flow crystallinity, viscosity, velocity, temperature until flows "stops"



(Ramsey et al., 2015)

HyspIRI: *Proposed Work*

- ***Quantifying active volcanic processes and mitigating their hazards with HyspIRI data***
  - Proposed Tasks
    - Task 1: Quantify the magnitude of temperature-dependent emissivity change for active basaltic surfaces using *in situ* field and laboratory IR data *(fundamental science)*
      - development of the new miniature multispectral IR camera
      - *in situ* data collection



HyspIRI: *Proposed Work*

❖ ***Quantifying active volcanic processes and mitigating their hazards with HyspIRI data***

- Proposed Tasks
  - Task 2: Determine the accuracy of high-temperature emissivity extraction at potential HyspIRI spatial resolutions and its impact on modeling of flow advance *(applied science)*

    - ➢ spatial analysis of the HyspIRI analog data
    - ➢ integrated IR measurements and FLOWGO modeling

Conclusions

❖ What Can We Say About TIR Data of Lava Flows?

- provide a synoptic view of volcanic activity at many scales
- critical ground- and lab-based studies continue to validate the orbital data and modeling approaches needed for scaling over orders of magnitude resolution differences
- quantitative information on temperature and emissivity
  - able to derive composition/structure of silicate phases; vesicularity; thermal fractions using the data
  - more accurate modeling of lava flows on Earth and Mars
- newly-funded work for HyspIRI
  - multi-scale approach to test how the accuracy of HyspIRI data will affect thermal models of eruption rate and flow propagation,
    - ➢ directly related to hazard assessment and eruption forecasting

Questions?

❖ Collaborators:

- J. Byrnes, *Oklahoma State University, USA*
- D. Crown, *Planetary Science Institute, USA*
- A. Harris, *Clermont Université, France*
- P. King, *Australia National University, Australia*
- R. Lee, *SUNY Oswego, USA*
- M. Patrick, *Hawaii Volcano Observatory, USA*

❖ Prior Students and Post-Docs:

- A. Steffke, *University of Hawaii, USA*
- A. Carter, A. Harburger, R. Lee, S. Rose, *University of Pittsburgh, USA*

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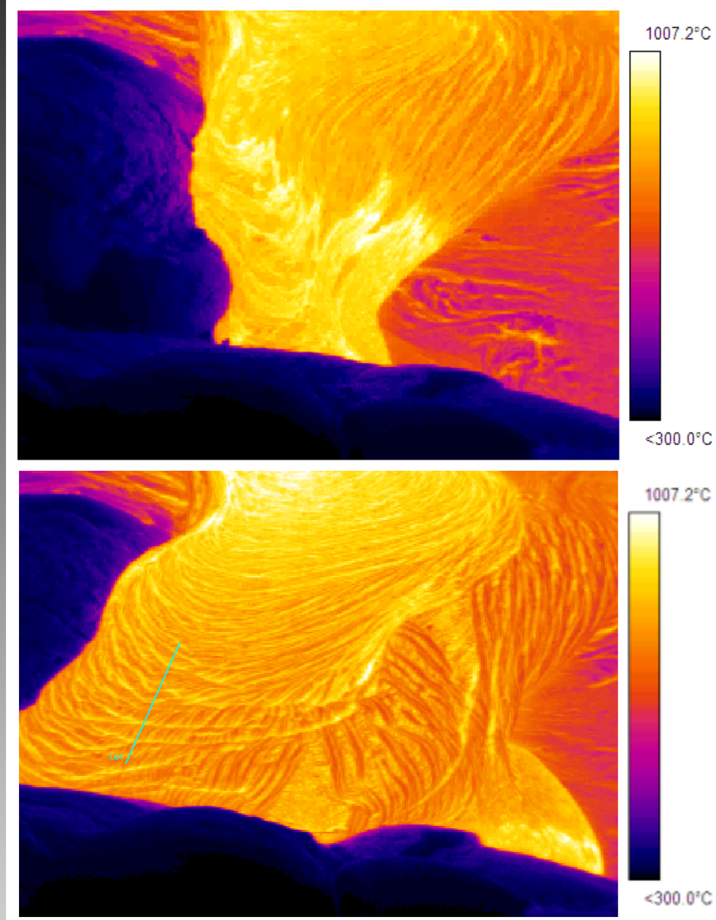

(Harburger and Ramsey, 2011)