A new orbital concept for measuring passive volcanic degassing and small plumes

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INTRODUCTION:

Changes in volcanic gas and aerosol flux is important to understand the volcanic system and possibly forecast future eruptions. Detecting and quantifying volcanic gas flux has been accomplished using numerous techniques from direct sampling to orbital remote sensing. Remotely-measured data rely on the absorption properties of a gas species in a certain region of the electromagnetic spectrum. The most notable example is SO_2, measured using ground-based Fourier Transform Infrared (FTIR) spectroscopy and Differential Optical Absorption Spectroscopy (DOAS), for example. These approaches have been quite successful, but are not always practical nor affordable everywhere. Measurements from space or airborne sensors can be limited by the technical specification of the sensors, none of which were designed to detect and measure volcanic degassing and small passive plumes. The temporal, spatial and spectral resolution of these sensors is simply inadequate.

We have proposed an orbital concept designed to measure the global inventory of volcanic degassing on a repeated schedule. The mission concept named ICAPE and the instrument it carries called I-THEMIS would acquire high-spatial resolution multispectral thermal infrared data specifically tuned to detect SO_2, CO_2, H_2O, and solid phase SiO_2 (ash). With a planned a spatial resolution of ~ 30m/pixel and an SO_2 detection threshold better than 2 g/m^2, the data would allow passive degassing and proximal plumes to be studied globally. If selected and launched, I-THEMIS will allow us to quantify the mass and energy flux from these plumes and measure the globally-averaged gas, aerosol and mineral abundance injected by them into the lower atmosphere. The data will also provide TIR data continuity between current and future land imaging sensors.

Analysis of this potential future dataset has already begun with the development of a ground-based imaging sensor designed to replicate I-THEMIS (Figure 1). Data were acquired of the Kilauea plume in early 2017 as part of a NASA-sponsored airborne data campaign (Figure 2). The ultimate goal of this ongoing effort is to launch the first orbital instrument dedicated to accurately constraining the global flux of SO_2, other climate-relevant gases, and silicate aerosol flux from passive degassing and active systems. The overarching objectives are improved volcanic monitoring, eruption forecasting, and understanding of the linkage between these species to the regional to global climate.

Figure 1: Field image of the new miniature multispectral TIR camera (*MMT-Cam*) deployed at Kilauea caldera in January, 2017. The camera is capable of acquiring up to 6 wavelength channels at 7 Hz in the 8 – 12 µm region.

Figure 2: First light MMT-Cam data of the Kilauea summit plume acquired ~ 1 second apart. (left): 8.5 µm image showing absorption by the SO_2 plume (red arrows). (right): 11.3 µm image where SO_2 is non-absorbing and therefore transparent.

Constraining the global SO_2 and aerosol budget from plumes using an innovative thermal infrared imaging instrument

Primary Science Goal

- Quantify the mass and energy fluxes injected from plumes across the solid earth / atmospheric interface.

Primary Science Objective

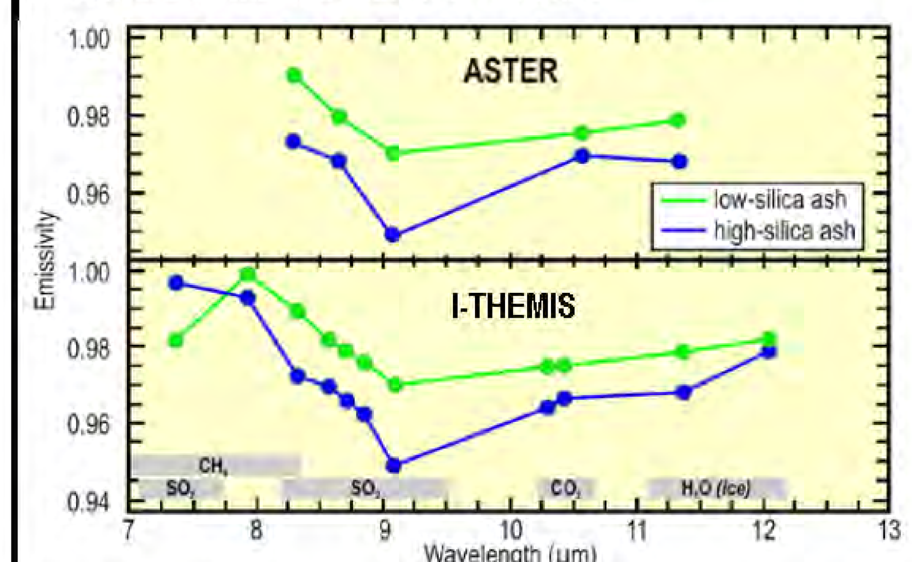
- Measure the globally-averaged gas, aerosol and mineral abundance injected into the lower atmosphere by both passive and active plumes.

Primary Applications Goal

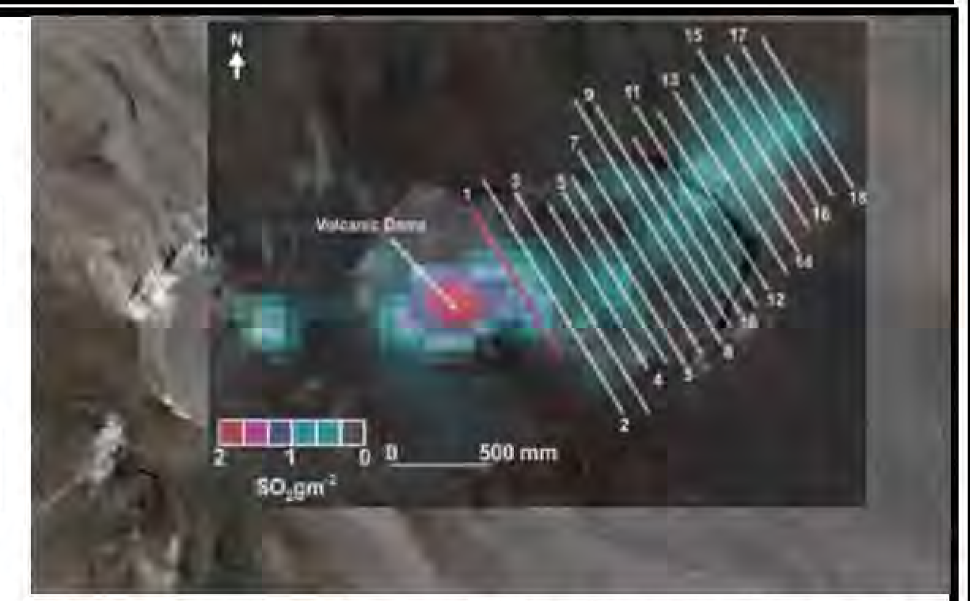
- Provide thermal infrared (TIR) data continuity in "global mapping" mode between current and future land imaging sensors using new and innovative technologies.

Primary Applications Objective

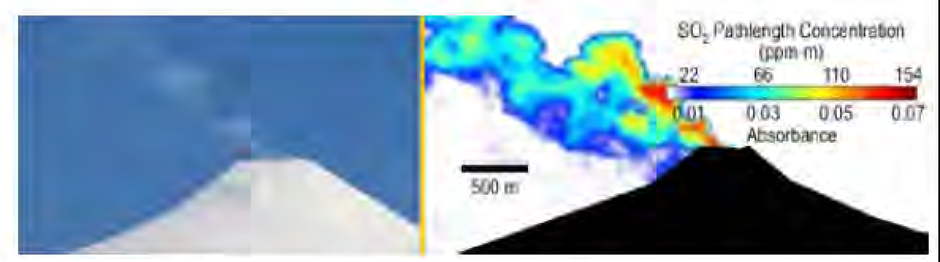
- Enable TIR data continuity with global partners for improved hazard analysis, refined climate modeling, and cross-correlation with international TIR data.



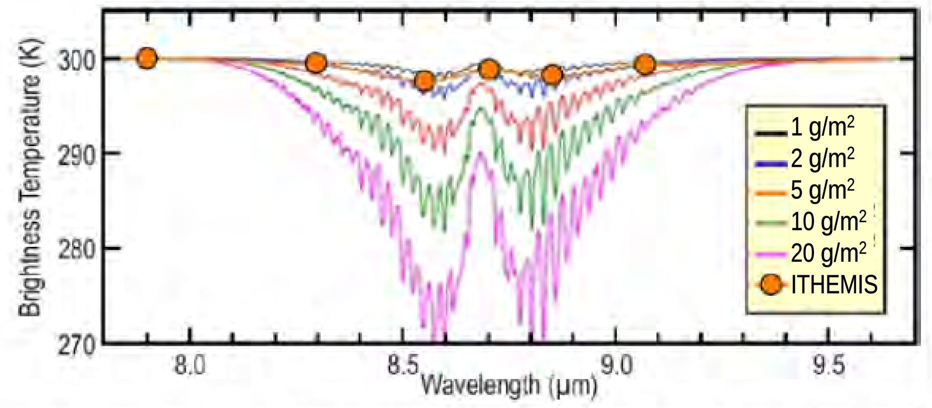
Laboratory TIR spectra of volcanic ash sieved to 25 µm and resampled to ASTER TIR and I-THEMIS resolutions. Also shown are regions of significant TIR absorption for the common emitted gas species found in volcanic and fire plumes. The spectral sampling of I-THEMIS was chosen specifically to provide greater fidelity in identifying these multiple gas species and range of possible silicate ash and dust compositions. This multi-component plume mapping capability leads to a better understanding of the ongoing geologic processes.



ASTER-based retrieval of the smallest recorded passive SO_2 plume from Lascar Volcano, Chile (from Henney et al., 2012). Detection of such small, low gas flux plumes is only possible with high-spatial, high-SNR, multispectral TIR data, which would be routine with I-THEMIS.



SO_2 plume from the ground at Villarica Volcano, Chile as seen in the visible (left) and as a concentration map (right) (from Bluth et al., 2007).



SO_2 absorption at difference concentration levels measured as a function of detection temperature difference (a proxy for spectral difference in the TIR). For the first time, I-THEMIS will have the detection sensitivity and spectral resolution to measure column concentrations as low as 2 g/m^2.

NASA Relevance

- Accurately constrain the global flux of SO_2 and other climate-relevant gases (from passive degassing systems), as well as the silicate aerosol flux (from active volcanic and aeolian systems) with the overarching objective of studying the interaction of the solid Earth with the lower atmosphere.
- Provide a cost-effective Class-C instrument that acquires high-spatial resolution, multispectral TIR data, recommended in the 2007 NRC Decadal Survey, and which addresses two NASA focus areas: **1)** Climate Variability/Change and **2)** Earth Surface/Interior.
- Engage international partners with a critically-needed dataset for hazard risk mitigation strategies and ensuring data continuity.

Notional Mission Overview

- **I-THEMIS** would be placed in a sun-synchronous polar orbit at an altitude between 500 – 800 km either as a free-flyer or co-manifest on Landsat-9 or Sentinel-3c. It will provide greatly improved TIR detection capability over current instruments such as ASTER or TIRS while maximizing detection of SO_2, CO_2, CH_4, as well as silicate and ice aerosols, at the ~100m spatial scale.

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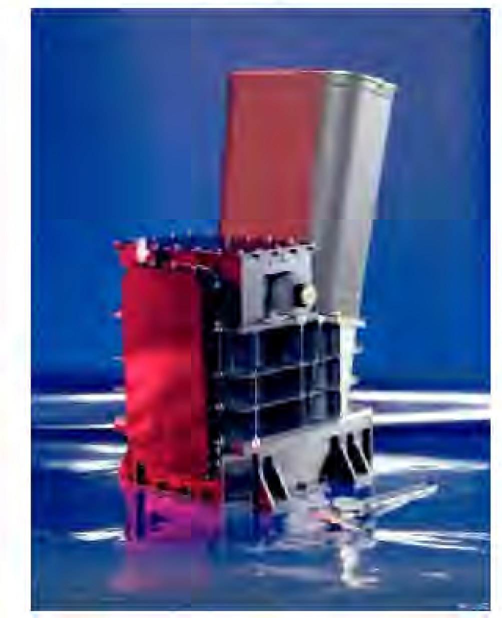
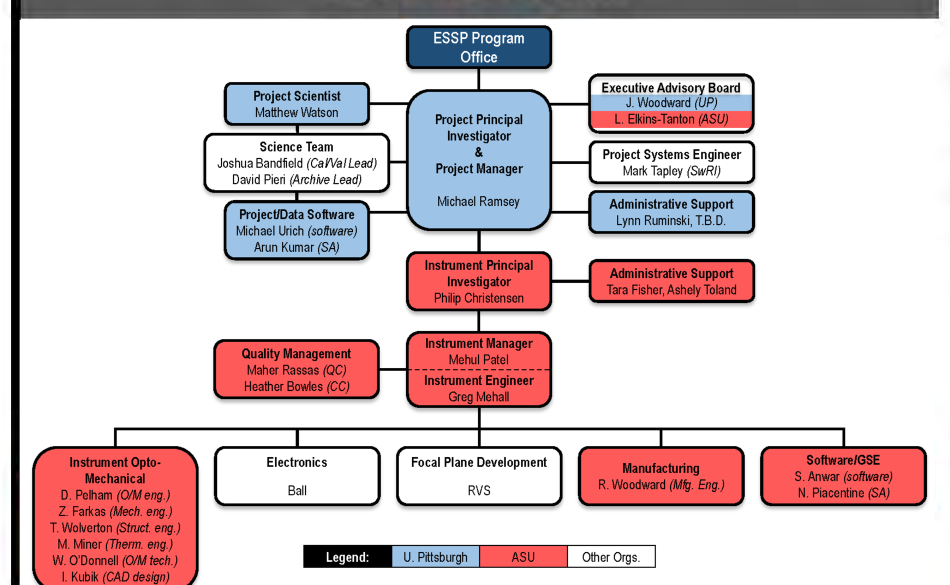
I-THEMIS Flight Instrument



- Design based on the Mars Odyssey THEMIS instrument
- Enhanced uncooled microbolometer detector array
- Three-mirror anastigmat telescope (*f/1.6, 3.5° x 4.5° FOV*)
- Mass: 9.4 kg (*CBE*)
- Power: 13.1 W (*CBE*)

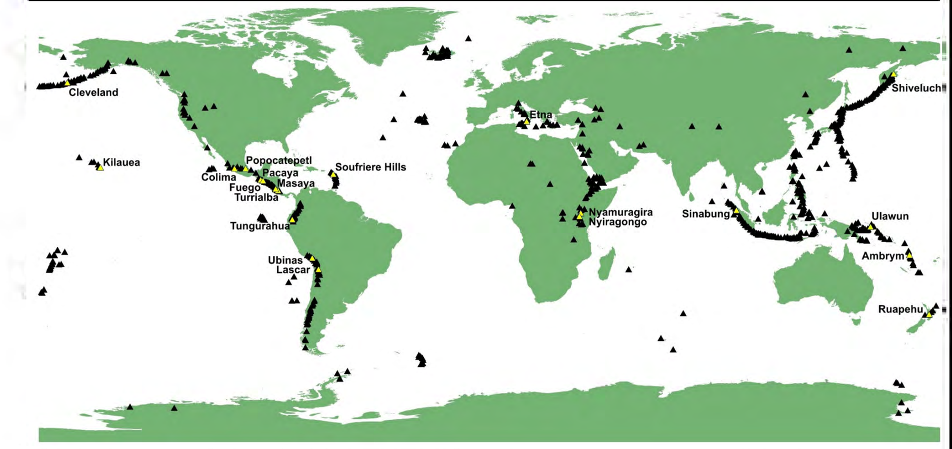
I-THEMIS Team



- The I-THEMIS science and instrument teams are comprised of leading experts in atmospheric science; TIR data analysis and calibration; volcanic and mineral dust plume science; as well as TIR instrument technology, design, construction and systems engineering,

Co-Manifest Mission Concept

		Sentinel-3c	Landsat-9
proposed launch:		2020	2023
altitude:		814.5 km	705 km
equatorial crossing:		10:00 am	10:15 am
I-THEMIS	*spatial res:*	51 m x 122 m	44 m x 115 m
	swath width:	65.5 km	56.6 km



Global map of the 1560 I-THEMIS point-source targets (black triangles) including the primary SO_2 science calibration targets (yellow triangles).

Free-Flyer Mission Concept

- Nominal orbit: 500 km altitude, sun-synchronous orbit
- Maximum spatial resolution: 31 x 102 m (*lower SNR*)
- Mapping mode spatial resolution: 94 x 102 m (*higher SNR*)
- Swath width: 40 km
- Estimated 60,000 to 80,000 clear images of volcanic plumes during year 1 of the mission

Ground track (in green) for I-THEMIS at a 500 km altitude (yellow) showing a 10 am local time overflight of the Cayambe Volcano. Successive ground tracks are spaced ~24 degrees apart in longitude.

Schedule Summary and Mission Cost [in millions of $FY20 ($RY)]

Phase	Phase A		Phase B		Phase C/D		Phase E		Phase F		Total	
	FY$	RY$	FY$	RY$	FY$	RY$	FY$	RY$	FY$	RY$	FY$	RY$
Instrument Costs	0.77	0.73	4.65	4.48	14.12	14.12	0.41	0.45	0.07	0.08	21.76	21.69
PI Managed Costs	1.12	1.07	6.11	5.88	19.18	19.17	4.15	4.59	1.93	1.93	38.34	39.06
Reserves	0.18	0.17	0.88	0.84	2.78	2.78	1.14	1.26	0.84	0.84	8.11	8.42
Total NASA Costs	1.14	1.08	6.17	5.94	19.36	19.36	4.19	4.64	1.95	1.95	38.73	39.45

*** I-THEMIS Science Team:**

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