## Towards Improved Detection Capabilities: The MMT-Cam

The miniature multispectral thermal camera (MMT-Cam) was developed to measure the accurate temperature and emissivity of high-temperature volcanic surfaces *[7]*. A commercial FLIR A65 camera is paired with a seven-position filter wheel containing six wavelength filters and an open port (Fig. 11). Data are acquired in one of two gain settings nearly simultaneously (~ 1 sec) in image cubes of 640 × 512 pixels.

The instrument is calibrated over the full range of expected scene temperatures using a laboratory high-accuracy blackbody temperature plate. Corrections are made for internal temperature drift, geometric, and self-reflectance effects. A primary second-order polynomial calibration is made for every pixel of each band to convert measured counts from the camera core to calibrated scene radiance, correcting for optical attenuation and instrument noise.

A modified version of the ASTER temperature emissivity separation (TES) code is implemented for atmospheric correction to produce surface temperature and emissivity.

Over the range of temperatures from 283 K to 958 K, the MMT-Cam achieves a signal to noise (SNR) from 600 to 1400 K, a noise equivalent delta temperature (NEΔT) of 0.4 to 0.7 K, and a total error (%) of 2 to 3.5, respectively.

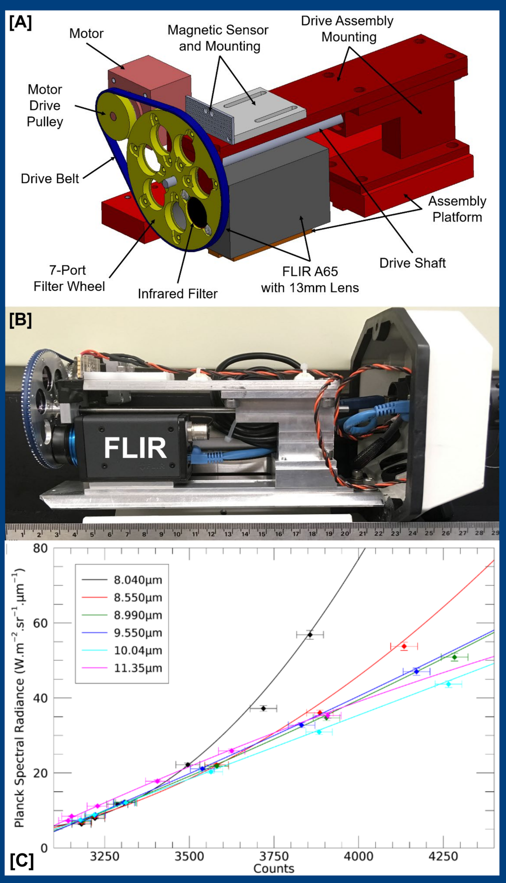


***Figure 11.*** *MMT-Cam design and development. [A] Initial CAD model. [B]Completed instrument with housing removed. [C] Per-pixel/per-band calibration from the measured camera counts to final spectral radiance.*

## Deployment

The MMT-Cam was deployed three times to Hawaii in 2017-2018 prior to and following the 2018 lower East Rift Zone (LERZ) eruption *[8]*. Data were acquired of active flows and the Halema`uma`u Crater's lava lake/$SO_2$ plume. During the LERZ eruption, the camera was paired with a gimbal system for helicopter-based data collection (Fig. 12).

***Figure 12.*** *MMT-Cam deployment at Kilauea volcano (HI) from 2017 to 2018.*

## Results

MMT-Cam data acquired during the first two deployments to Hawaii provided well-calibrated images of the lava lake and active pahoehoe flow surfaces (Fig. 13). Retrieved emissivity showed clear spectral change as the basalt cooled from the molten state. The 2018 LERZ eruption deployment allowed airborne data collection for the first time (Fig. 14), which enabled observations of active fire fountaining and flowing channels. From those data, the emissivity, the per-pixel fraction of molten temperatures, and total heat flux were retrieved for improved lava flow modeling *[9]*.

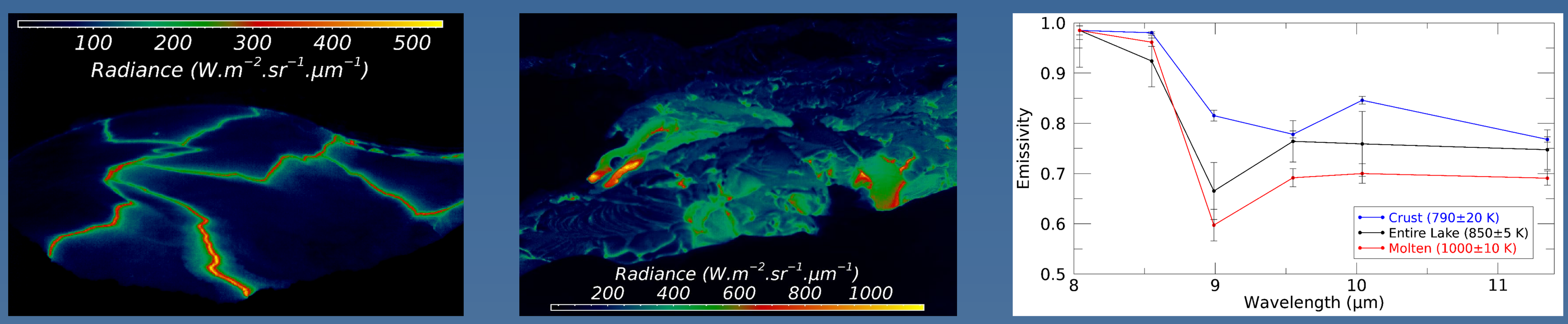


***Figure 13.*** *MMT-Cam calibrated surface radiance of the 2017 lava lake, inflating pahoehoe lava flow, and the emissivity extracted from the lava lake data showing the spectral change with temperature [8].*

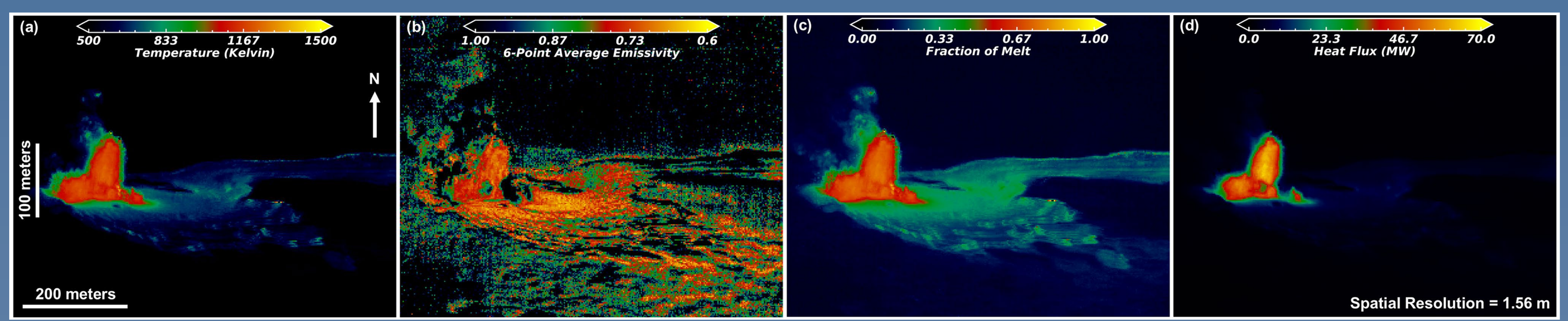


***Figure 14.*** *Helicopter-based MMT-Cam results of the Fissure 8 fire fountain and perched lava channel acquired during the 2018 LERZ eruption [9].*

## Phase 2: The MMT-gasCam

The MMT-gasCam was proposed and funded by NASA's Earth Surface and Interior Program (projects: 80NSSC-21K0840 and -24K0669).

By adding a second filter wheel, the spectral resolution is doubled (12 bands), with those bands centered on specific gas, aerosol, and ash compositions. For improved precision and stability, the two-wheel belt drive system of the MMT-Cam is replaced by direct-drive, single filter wheels and the foreoptics changed from the 13 mm (45° x 37°) FLIR lens to a 25 mm (25° x 20°) lens for narrower field of view (FOV) and a higher at-target spatial resolution.

The filters were again fabricated by Andover Corporation (USA), with the design, build, and calibration conducted at the University of Pittsburgh.

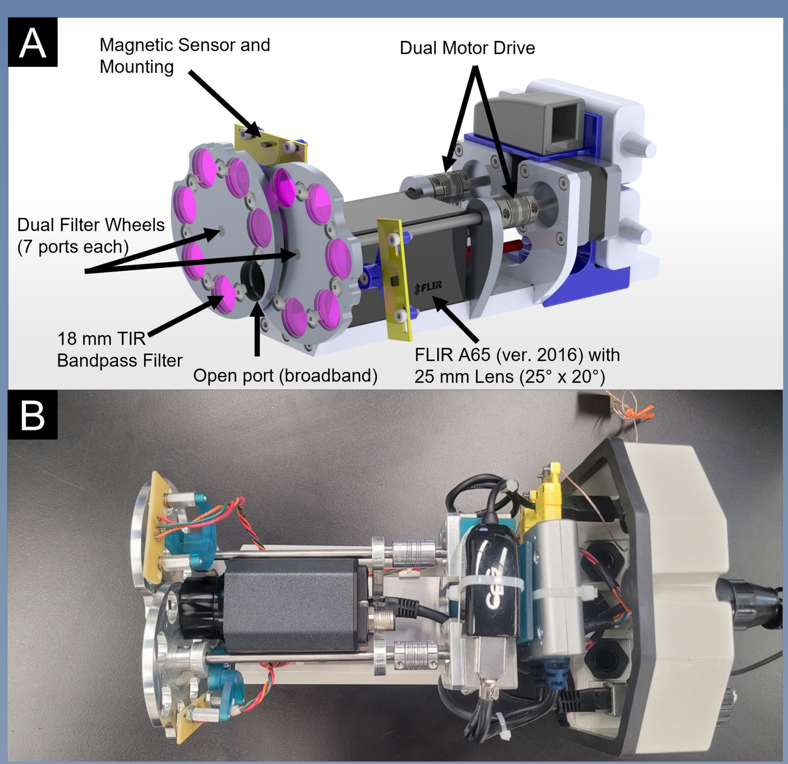


***Figure 15.*** *MMT-gasCam design and development. (A) Initial CAD model showing the two direct-drive filter wheels (different than the MMT-Cam). (B) Completed instrument.*

## Development and Calibration

The 12 MMT-gasCam filters are designed to capture the spectral features of several gas and particulate species commonly found in volcanic plumes such as $SO_2$ gas, sulfate aerosols and silicate ash (Figs. 16 & 17). In addition to the detailed calibration of the instrument response performed for the MMT-Cam, additional calibration is carried out for the gasCam by injecting the target species in the FOV (e.g., $SO_2$ in Fig. 18). This calibration is performed with both cooler and warmer background temperatures to quantify the response of the instrument to the presence of each gas.

A custom retrieval algorithm is being developed to estimate the plume temperature and the concentration of the various species of interest in both emission (a warm plume against a colder sky) and transmission (a cold plume against a warmer surface) geometries. The increased number of spectral channels allows for the simultaneous retrieval of multiple plume components (Figs. 17 & 18).

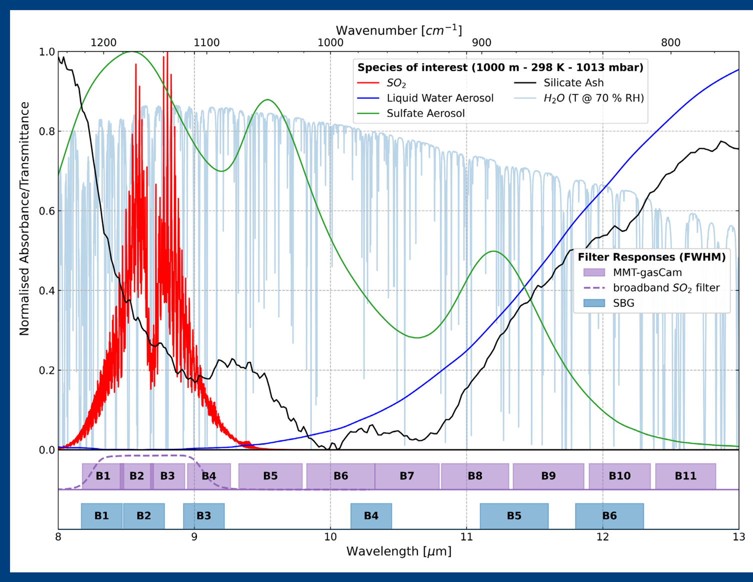


***Figure 16.*** *Absorbance spectra of $SO_2$ and $H_2O$ gas, $SO_4^{2-}$ and $H_2O$ aerosols, and the emissivity spectrum of silicate ash in the TIR window. Band positions of the MMT-gasCam and future SBG TIR instrument are shown.*

| Filters (μm) | |
|---|---|
| 8.3 | 10.1 |
| 8.6 | 10.6 |
| 8.7 * | 11.1 |
| 8.8 | 11.6 |
| 9.1 | 12.1 |
| 9.6 | 12.6 |

***Figure 17.*** *MMT-gasCam filter wheels shown with germanium cover window removed. The filter wavelength centers are shown in the table.* **broadband (1.0 μm) $SO_2$ filter.*

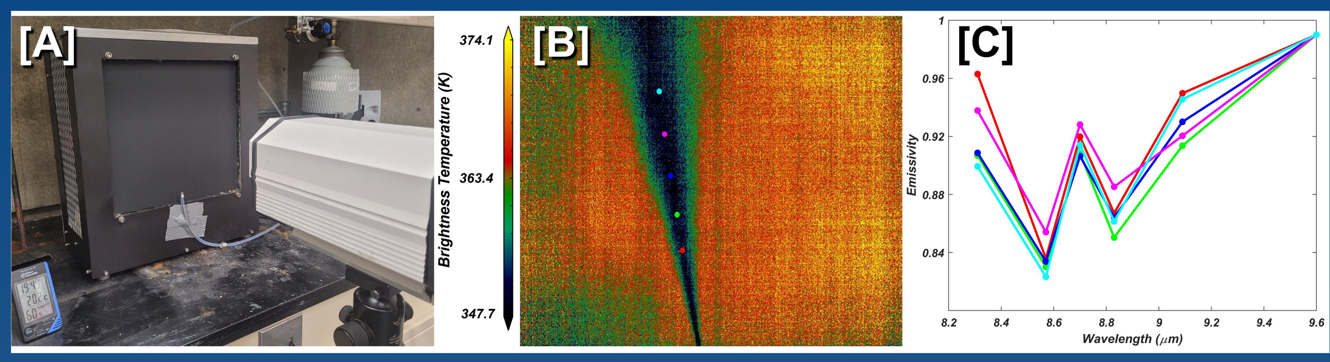


***Figure 18.*** *[A] Laboratory calibration using the blackbody target plate with a controlled $SO_2$ release. [B] Temperature image of the plume with dots showing the retrieved spectra shown in [C].*

## First Deployment

The first field test deployment of the MMT-gasCam took place in February 2024 following the Cities on Volcanoes Conference in Guatemala. The camera is field portable consisting of two cases (camera head & electronics/power). Despite cloudier than expected conditions, data were acquired of Pacaya and Fuego volcanoes. A period of clearing at Pacaya allowed the summit and $SO_2$ plume to be imaged (Fig. 19). Several small eruptive ash-rich plus $SO_2$ plumes were also imaged at Fuego (Fig. 20). The camera performed well, and the data are currently being reduced/analyzed.

***Figure 19.*** *MMT-gasCam deployment (Pacaya Volcano).*

Small modifications to the design are underway prior to the next deployment to Italy in June 2024.

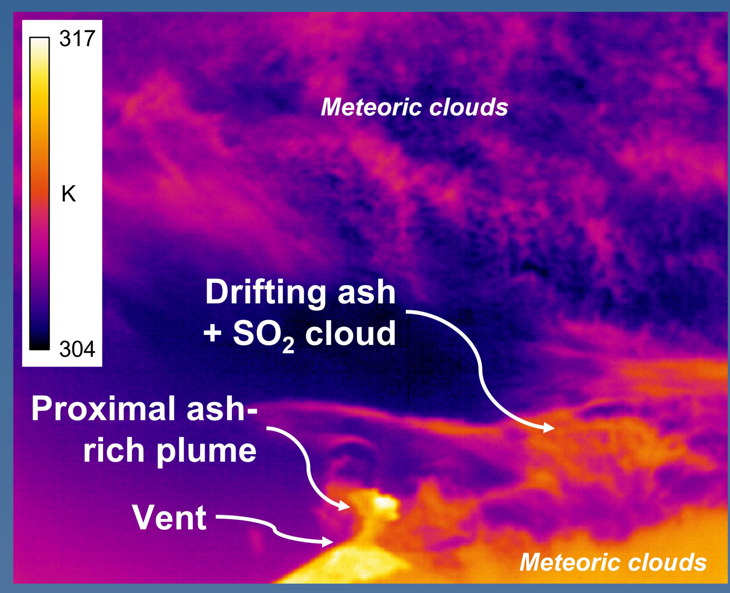


***Figure 20.*** *MMT-gasCam "first light" temperature image of an eruptive ash/$SO_2$ plume (Fuego Volcano).*

## Future Work and SBG

In preparation for the SBG mission's launch in 2028 and the SBG Volcanic Activity (VA) data product, we have developed the MMT-gasCam, a low-cost, ground-based, multi-wavelength TIR sensor. NASA has funded a new three-year study to use this instrument for measuring small, passive plumes in emission to determine the detection threshold of $SO_2$ in the TIR, its conversion to sulfate aerosol, its detectability in the presence of ash, and the temperature of the emissions. Results will help to validate the future VA data product. The first field campaign to Italy in collaboration with INGV will commence in June 2024 focusing on Etna, Vulcano, and Stromboli (Fig. 21).

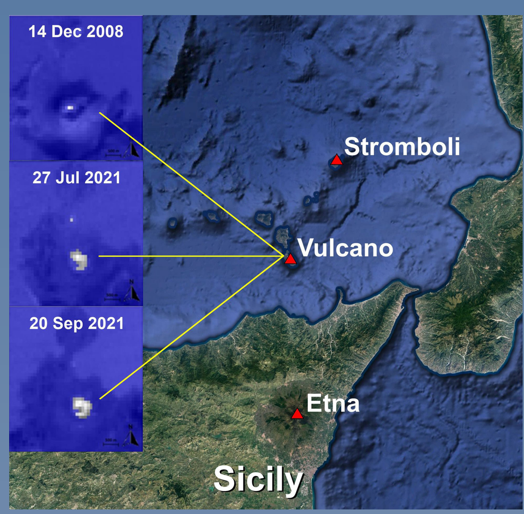


***Figure 21.*** *Target volcanoes of the 2024 field campaign.*

## References


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