The MIDAS instrument design and characterization. C. I. Honniball, R. Wright, and P. G. Lucey, Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa (1680 East-West Road, POST 517 Honolulu, HI 96822; cih@higp.hawaii.edu)

Introduction: Remote sensing in the mid-wave IR (MWIR) from 3–5 μm can provide essential information for a range of Earth and planetary science applications for both gaseous and solid targets. For example thermal observations of lava lakes on Io, the most volcanically active body in the solar system, will aid in defining their dynamics and origin as well as their compositions [1]. Applications for Earth science include the detection of CH_4 from industrial gas leaks and the remote measurements of the energy at 4 μm emitted by wildfires. The energy emitted is used to quantify fire radiative power, which is a quantitative measure of global biomass burning that can be used to estimate the amount of carbon liberated into the Earth's atmosphere, and is thus an essential climate variable [2]. Many atmospheric species exhibit strong absorption features in the MWIR region. Although there are several good reasons to make scientific measurements at these wavelengths, there are also challenges to working in the MWIR.

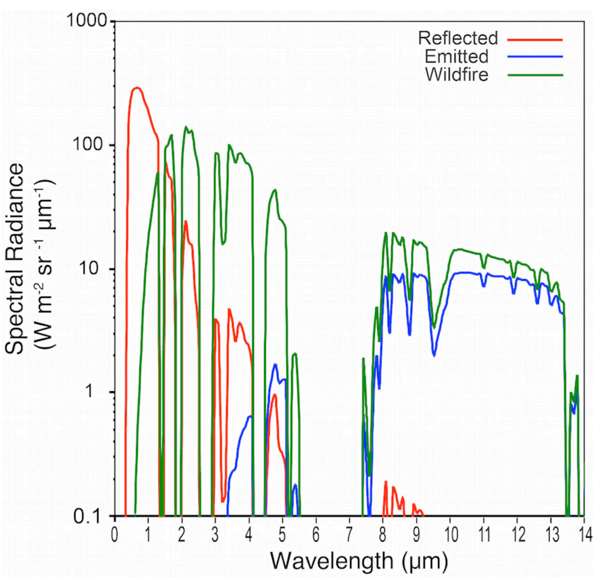

Figure 1. Spectral radiance levels (measured in units of W m^{-2} sr^{-1} μm^{-1}) available for measurement at the top of Earth's atmosphere. The red, blue, and green curves show the at-satellite spectral radiance from the Sun (assuming reflectivity of 1.0), from a 300K surface, and from a wildfire at 1400K [1] (where the flame occupies 1% of the instantaneous field of view and the remainder—99%—is occupied by the ground at 300K). A model atmosphere was assumed for all calculations.

Compared with the long-wave IR (LWIR) spectral region (8–14 μm), there is significantly less light available to measure in the MWIR (for surfaces at, near, or below Earth's ambient temperature). For instance, the availability of light over the IR region for both reflected (red line) and emitted (blue line) light is shown in Figure 1. To overcome this lack of signal, it is typically necessary to cool MWIR instruments. Such cooling, however, causes the instruments to consume substantial amounts of power, which leads to large masses and volumes. However, emerging interferometric techniques allow uncooled microbolometer arrays to be used for hyperspectral imaging. This is primarily a result of the higher signal-to-noise ratio attainable with an interferometer when compared to a dispersive spectrometer, allowing for higher signal-to-noise even when using relatively insensitive microbolometers. Moreover, uncooled microbolometers require much less power than cooled photon-detecting arrays. This makes them attractive candidates for imaging instruments on small satellites.

The Instrument: At the University of Hawai'i we have developed the Miniaturized IR Detector of Atmospheric Species (MIDAS) to demonstrate the utility of microbolometers for the detection of gaseous constituents for Earth and planetary atmospheres. MIDAS is a MWIR hyperspectral imager, which can be seen in Figure 2 outlined in blue. The instrument consists of an uncooled microbolometer that is coupled with a Sagnac interferometer and a set of three lenses – an objective, a collimator, and an imaging lens. MIDAS operates as a conventional remote sensor with a large distance between the sensor and target. However, removing the objective allows MIDAS to be used as a microscope with 1:1 magnification.

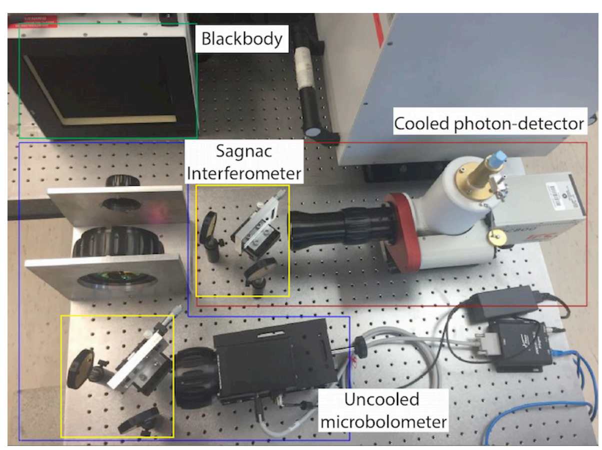

Figure 2. Benchtop setup of the MIDAS instrument

(outlined in blue). In this configuration, MIDAS is positioned to look through the Sagnac interferometer (outlined in yellow) and lenses to a hot blackbody (outlined in green). The cooled photon detector looking through the Sagnac interferometer is outlined in red.

Measured light is decomposed into its component frequencies by the Sagnac interferometer, which comprises a beam splitter and two mirrors. An interference pattern is thus generated, which we then sample and process (using standard Fourier transform techniques) to derive a calibrated radiance spectrum for each scene element. The configuration of the mirrors and beam splitter causes the optical path to vary linearly across the detector array. The interferometer allows us to leverage the well-known multiplex advantage, allowing for higher signal-to-noise when compared to the more common dispersive methods for acquiring spectral data when employing read-noise limited detectors such as microbolometers [3]. Part of our research will be to determine whether the signal-to-noise advantages that accrue from this interferometric approach allow us to make valid science measurements in the MWIR using uncooled microbolometers.

Instrument characterization: To quantify the precision and accuracy with which MIDAS can quantify thermal emission in the MWIR, it will be benchmarked against a cooled photon-detector used in the same Sagnac interferometer configuration. Both systems are subjected to numerous standard characterization procedures—including, but not limited to, the determination of noise equivalent differential temperature, signal-to-noise ratios, and spectral response. For most of the characterization tests, the use of a standard large format blackbody and a high temperature cavity radiator as our target allows for accurate temperature variation; providing information on which temperature ranges MIDAS is best suited for.

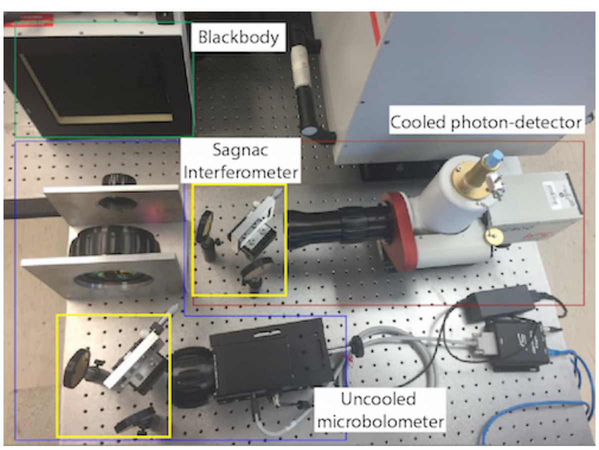

Figure 3. Cooled photon-detector system set up to look through a gas cell at a large format blackbody.

In addition to benchtop characterization we will also quantify the performance of MIDAS by simulating the aforementioned science cases. Both MIDAS and the cooled photon-detector system will look through gas cells filled with known concentrations of gases, such as CO_2 and CH_4, at a large format blackbody, an example setup can be seen in Figure 3. This will allow us to simulate the performance of MIDAS for gas detections (and fire and active lava measurements) under representative field conditions. Detection of CH_4 from industrial gas leaks depends on the contrast between the background and the plume. There are two ways MIDAS may look for CH_4 leaks, the first by looking at the plume in absorption with the ground as the background and the second by looking at the plume in emission with the sky as the background. Detection of CH_4 may prove to be difficult in the MWIR if the temperature of the plume and the background are similar. The remote detection of lava lakes on Io and wildfires on Earth are targets for which MIDAS is not signal limited. Wildfires reach temperatures of 1400 K [2] and emit substantial levels of energy in the MWIR, with a peak emission around 5 μm while measured temperatures for Pele on Io have been up to ~1700K [4].

Summary: Due to the lack of moving parts in the Sagnac interferometer and the minimal power requirements of uncooled microbolometers, MIDAS is well suited for adaption to small satellite platforms such as CubeSat's. For this presentation we will present results from benchtop characterization testing.

References: [1] Lopes, R.M.C. et al. (2004) Icarus, 169, 140-174. [2] Wooster, M., Zhukov, B., and Oertel, D. (2003) Remote Sens. Environ. 86, 83–107. [3] Griffiths, P. and De Haseth, J. (1986) Fourier Transform Infrared Spectroscopy, Wiley. [4] Lopes, R.M.C. et al. (2001) J. Geophys. Res. 106, 33053–33078.

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