First flight of the Hyperspectral Thermal Emission Spectrometer (HyTES) airborne Instrument

Presented at:

2012 HysplRI Workshop
Washington, DC USA.

Simon Hook & The HysplRI/HyTES/PHyTIR Team(s)
Organization: NASA/Jet Propulsion Laboratory

Outline

- Introduction
- Instrument design and characteristics
- Laboratory testing and results
- Airborne testing and results
- Summary and Conclusions
- Future Plans

HyspIRI-TIR Quad Chart

Science Questions:

TQ1. Volcanoes/Earthquakes

– How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

- *TQ2. Wildfires*

– What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

- *TQ3. Water Use and Availability*

– How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?

- *TQ4. Urbanization/Human*

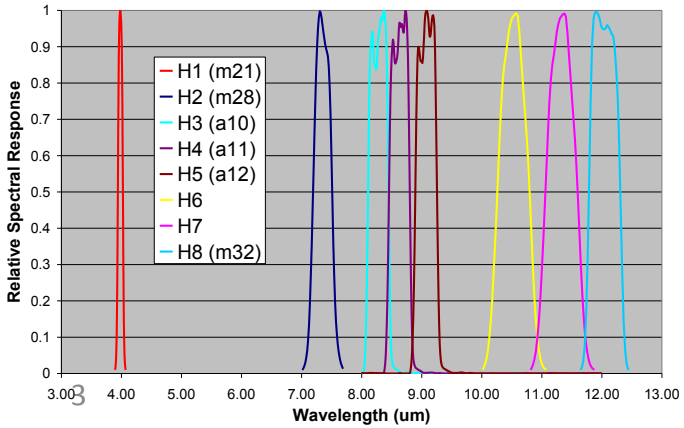
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

- *TQ5. Earth surface composition and change*

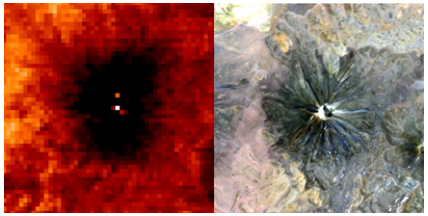
– What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

Measurement:

- 7 bands between 7.5-12 μm and 1 band at 4 μm
- 60 m resolution, 5 days revisit
- Global land and shallow water

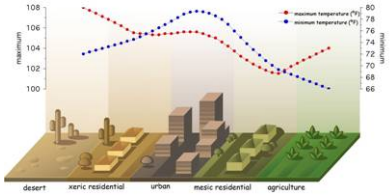


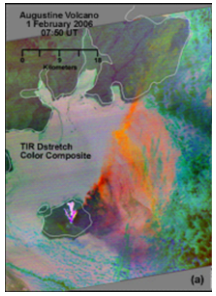
Andean volcano heats up



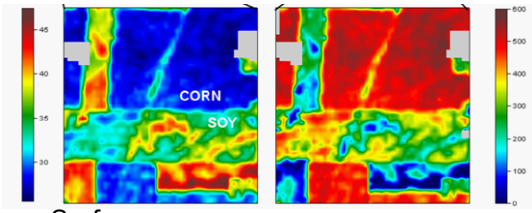
Volcanoes

Urbanization





Water Use and Availability



Surface Temperature

Evapotranspiration

HyspIRI, HyTES and PHyTIR

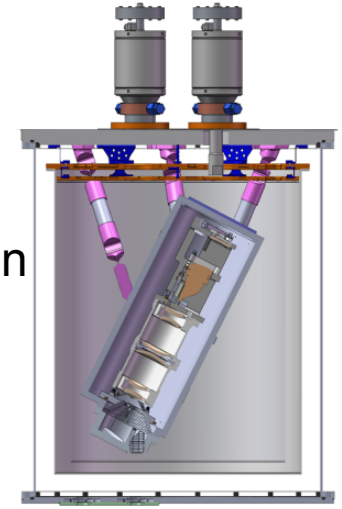
VSWIR

TIR

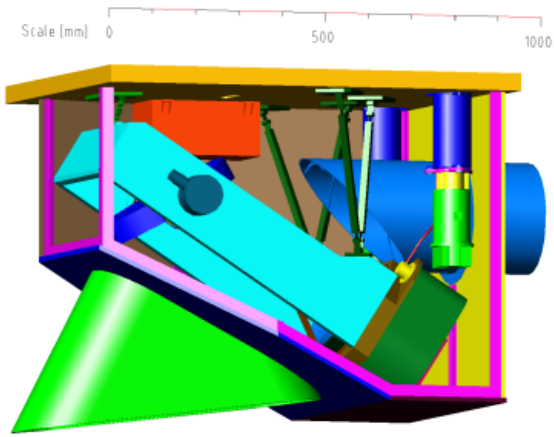
Hyperspectral Infrared Imager (HyspIRI)

Science Risk Reduction

Hyperspectral Thermal Emission Spectrometer (HyTES)



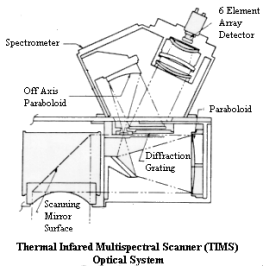
Engineering Risk Reduction

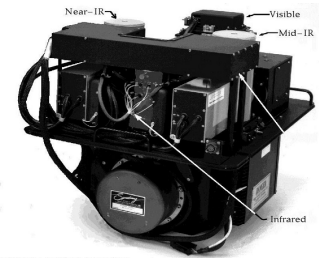


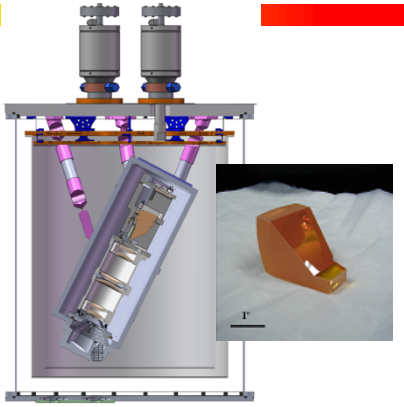
Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)

HyspIRI, HyTES and PHyTIR

Airborne Instruments

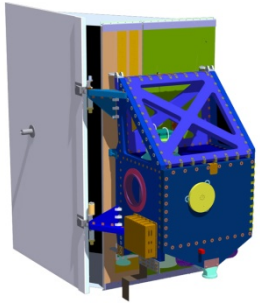


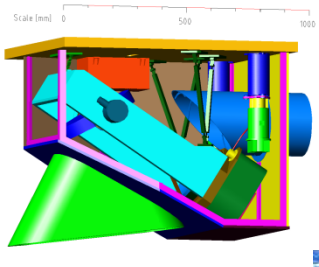




Airborne Name	TIMS	MASTER	QWEST	HyTES
First Year of Operation	1980	1998	2008	2012
Number of TIR Bands	6	10	56	256

Spaceborne Instruments (incl. lab prototypes)





Spaceborne Name	ASTER	Landsat 8 (LDCM)	PHyTIR	HyspIRI-TIR
First Year of Operation	1999	2013	2014	2020
Number of TIR Bands	5	2	8	8
Swath Width	60 km	185 km	600 km	600 km
Pixel Size	90m	100 m	60 m	60 m

Overall Science Goal and Objective

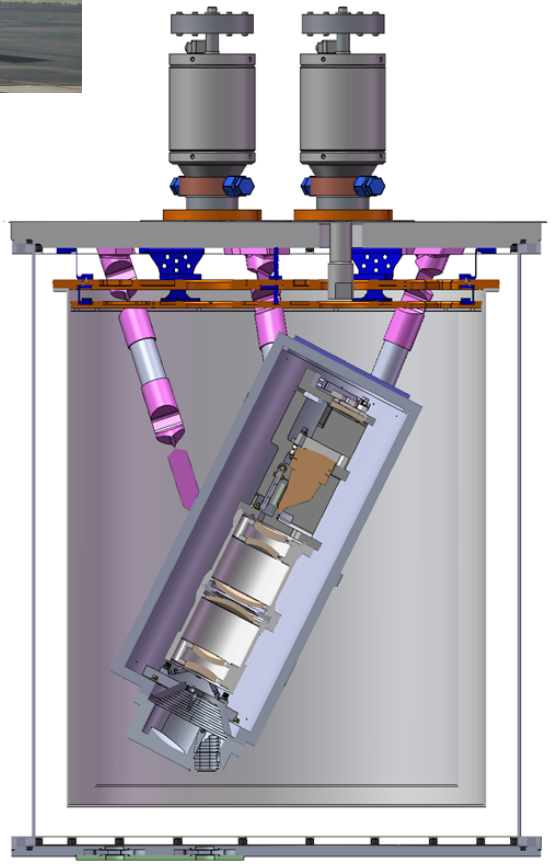
- Provide precursor high spectral and spatial resolution thermal infrared data for the NRC Recommended HyspIRI mission and for use in Earth Science Studies.

- Build and deploy an airborne Hyperspectral Thermal Emission Spectrometer (HyTES) with 512 pixels across track with pixel sizes in the range of 5 to 50 m depending on aircraft flying height and 256 spectral channels between 7.5 and 12 µm.


HYPERSPECTRAL THERMAL EMISSION SPECTROMETER
HyTES
NASA • JET PROPULSION LABORATORY

Hyperspectral Thermal Emission Spectrometer (HyTES)

First Flights in July 2012

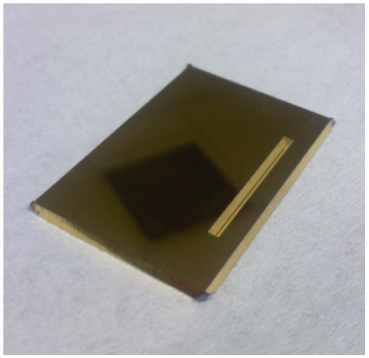


Instrument Characteristic	HyTES
Mass (Scanhead)[1]	12kg
Power	400W
Volume	1m x 0.5m (Cylinder)
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 μm
Frame speed	35 or 22 fps
Integration time (1 scanline)	28 or 45 ms
Total Field of View	50 degrees
Calibration (preflight)	Full aperture blackbody
Detector Temperature	40K
Spectrometer Temperature	100K
Slit Length and Width	20 mm x 39 μm
IFOV	1.7066
Pixel Size/Swath at 2000 m flight altitude[2]	3.41m/1868.33m
Pixel Size/Swath at 20,000 m flight altitude[2]	34.13m/18683.31m

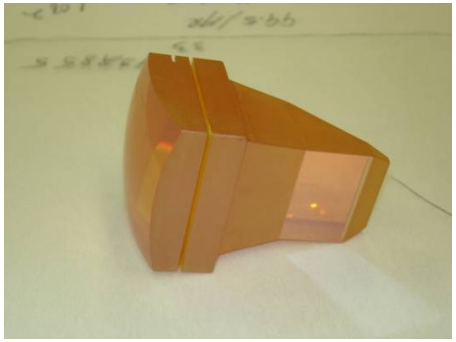
1. Does not include 1 rack of electronics to operate instruments; 2. Includes ~27 calibration pixels

Key JPL developed technologies

- Current instruments provide high spectral and low spatial OR high spatial and low spectral resolution in thermal infrared. HyTES provides BOTH high spectral and spatial resolution. New design can be made very compact.



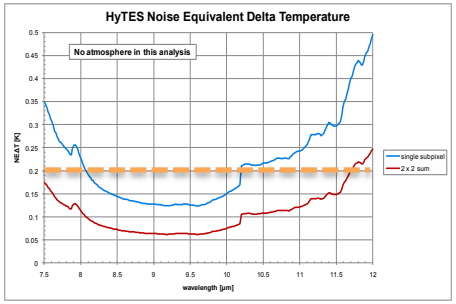
Long, straight slits:
Victor White

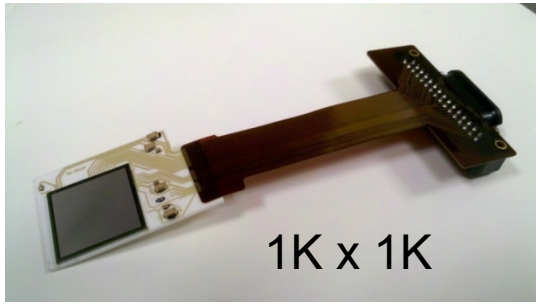


Compact Dyson Spectrometer:
Zakos Mouroulis

Concave E-beam diffraction Grating:
Dan Wilson

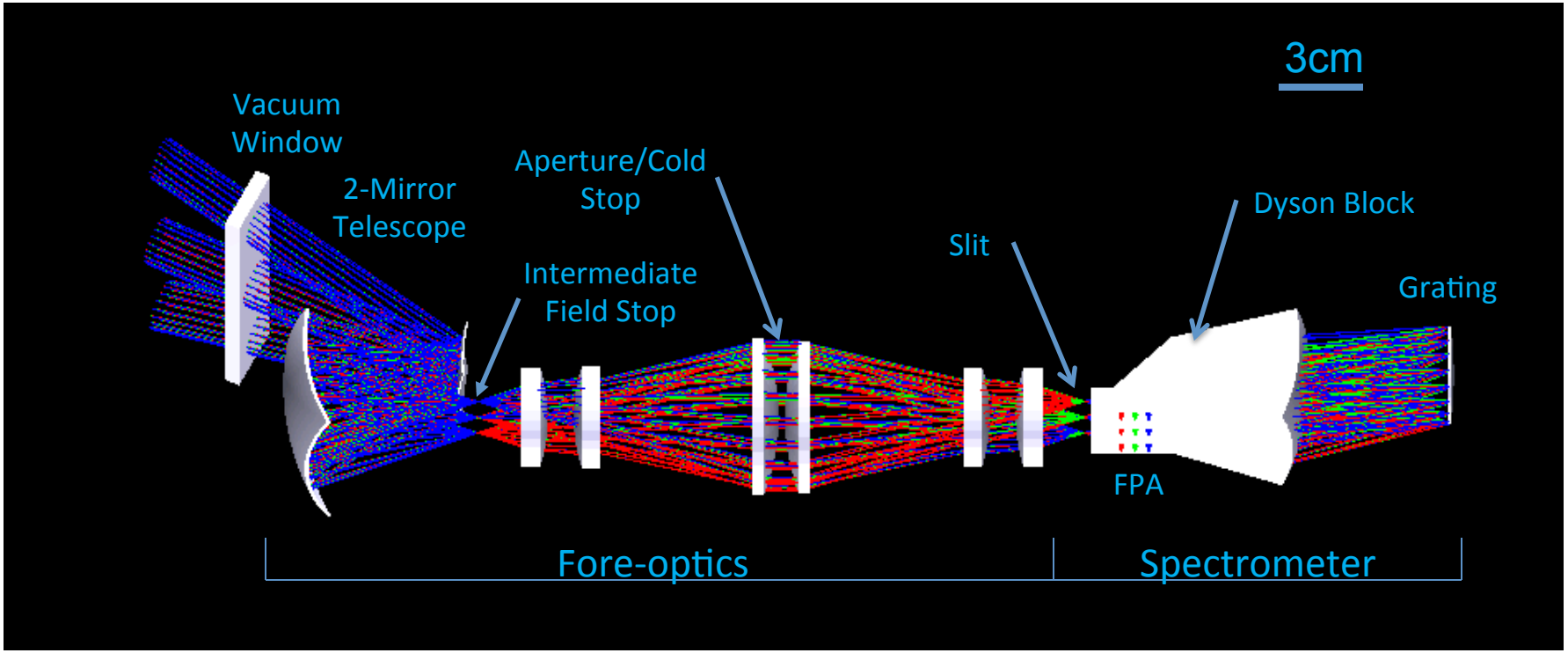
Advanced Designs:
William Johnson





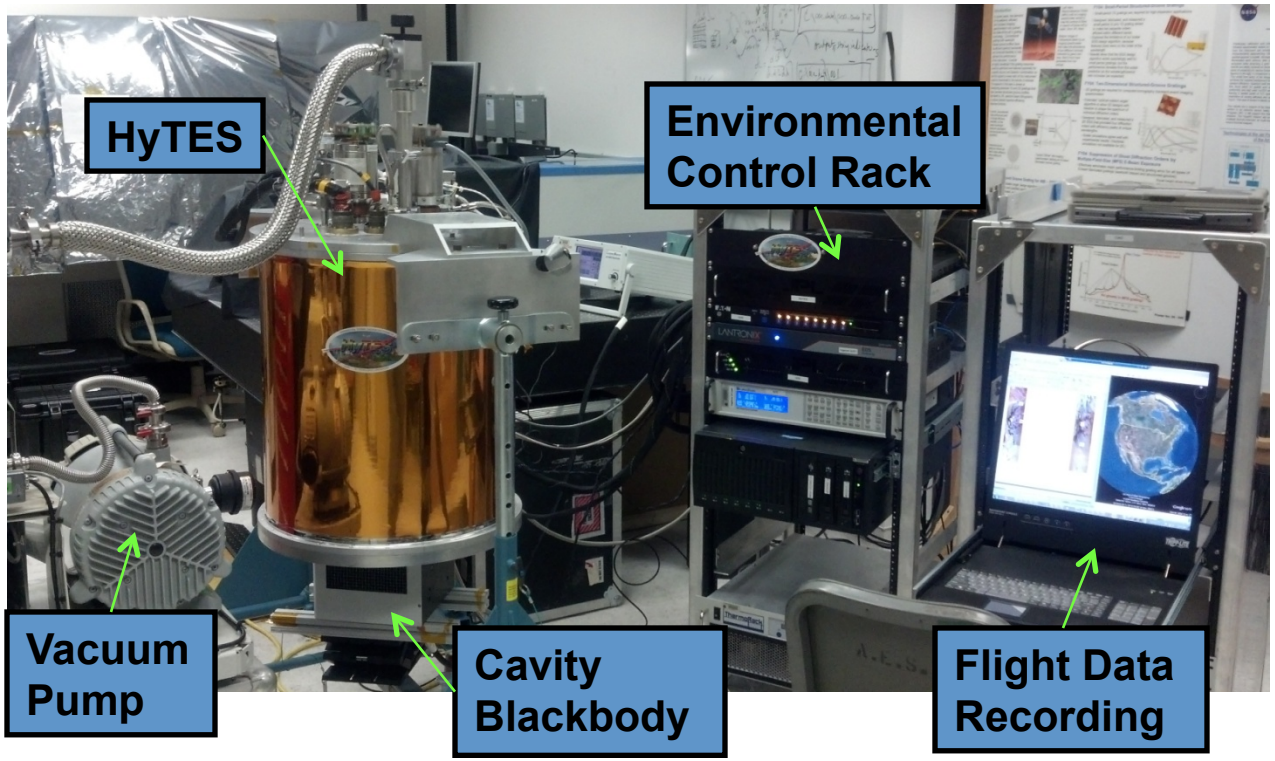
Multi-stack large format QWIP arrays: Sarath Gunapala

HyTES Optics



HyTES Optical Layout
(The entire system is cold, so there's no real "cold stop" in the traditional fashion)

HyTES Laboratory Setup

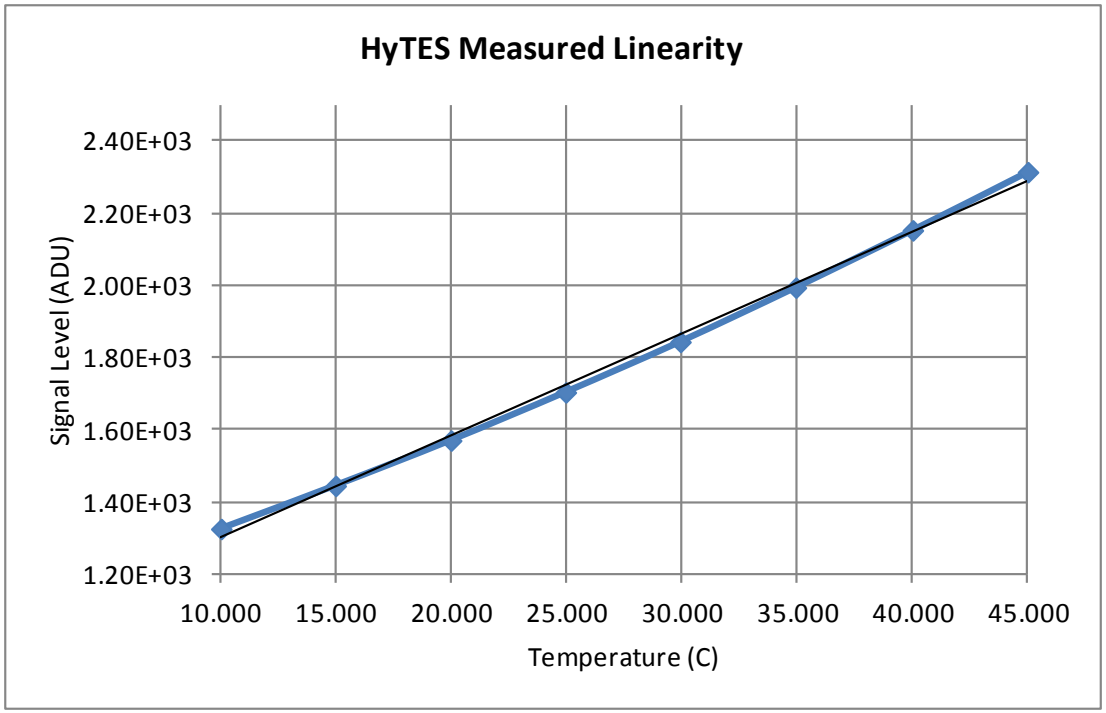


Lab Test Procedure

- **Cycle Blackbody Through Temperatures of 5, 10, 15, 20, 25, 30, 35, 40 and 45 °C**
- **Blackbody DN's at 5 and 45 °C used to Calculate 2-Point Calibration Coefficients**
- **Calculate Radiance and Brightness Temperature for Blackbody at 25 °C.**

HyTES shown with high accuracy cavity blackbody. This is the set-up used for measuring system linearity, brightness temperature and NEDT.

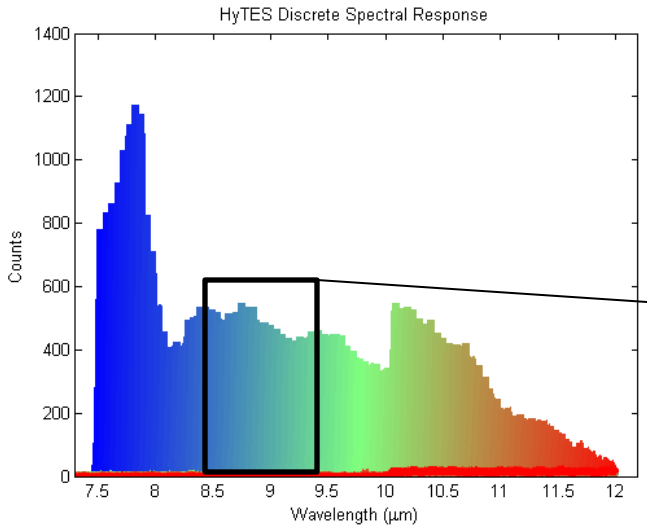
HyTES Temperature Linearity



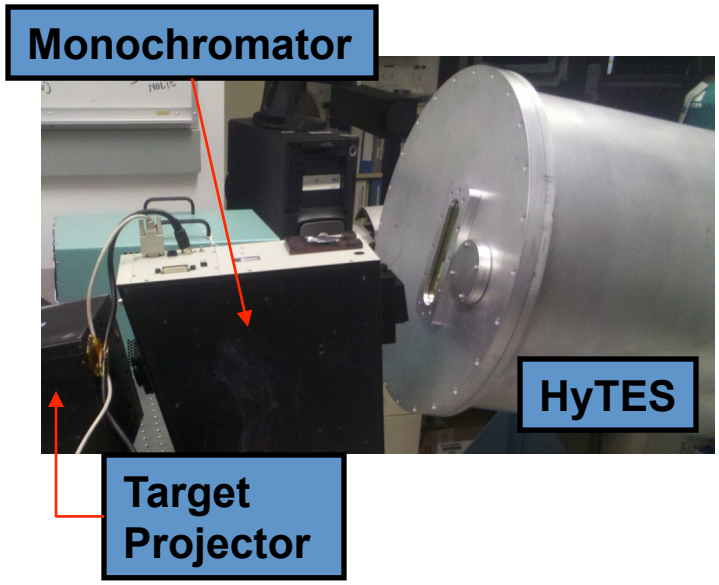
Actual Temp (C)	Measured Temp (C)	ΔT (C)
45	45.00	0
40	40.01	0.0054
35	34.94	-0.0594
30	29.92	-0.0769
25	24.95	-0.05225
20	19.97	-0.02695
15	14.96	-0.03695
10	10.00	0

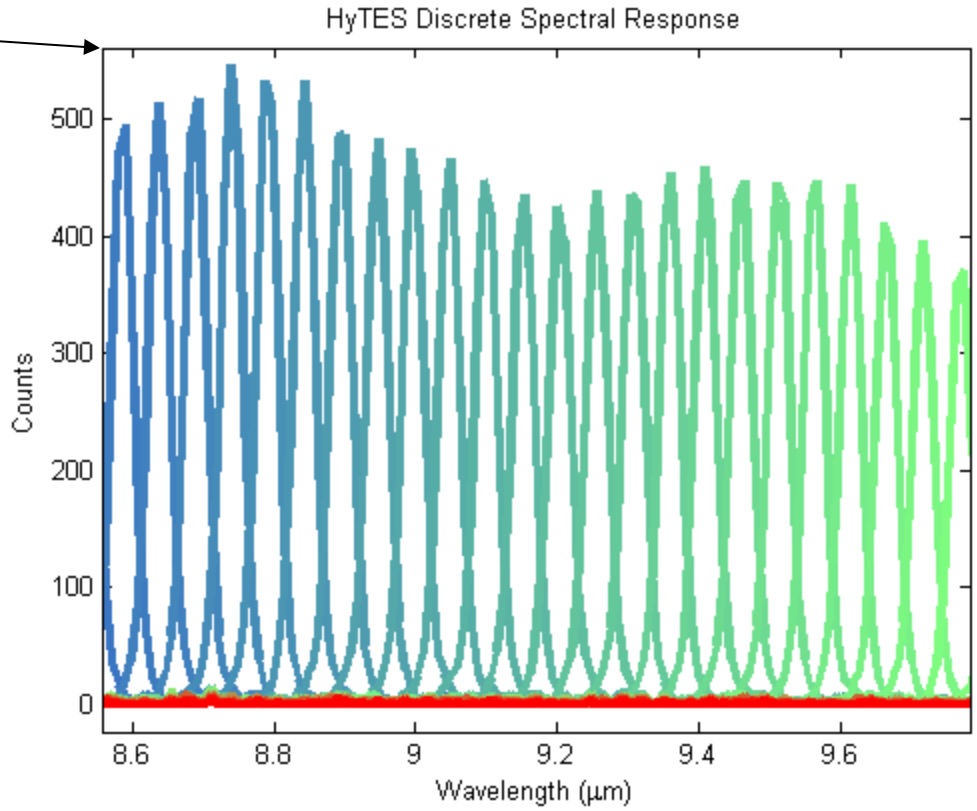
Excellent linearity measured (<+/- 0.1C)

HyTES Spectral Response



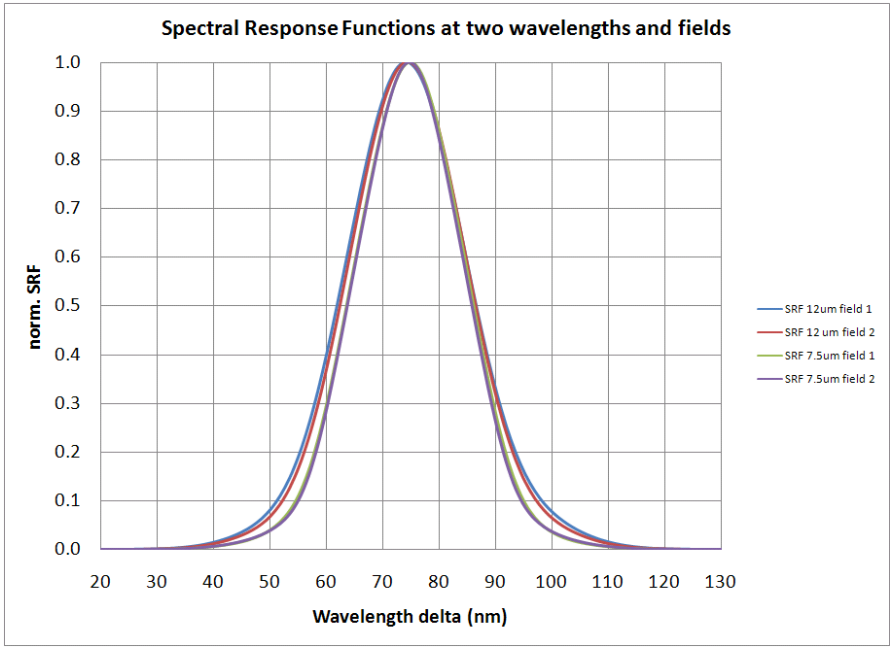
HyTES measured spectral response. A monochromator was cycled through each spectral band while positioned at the entrance aperture.



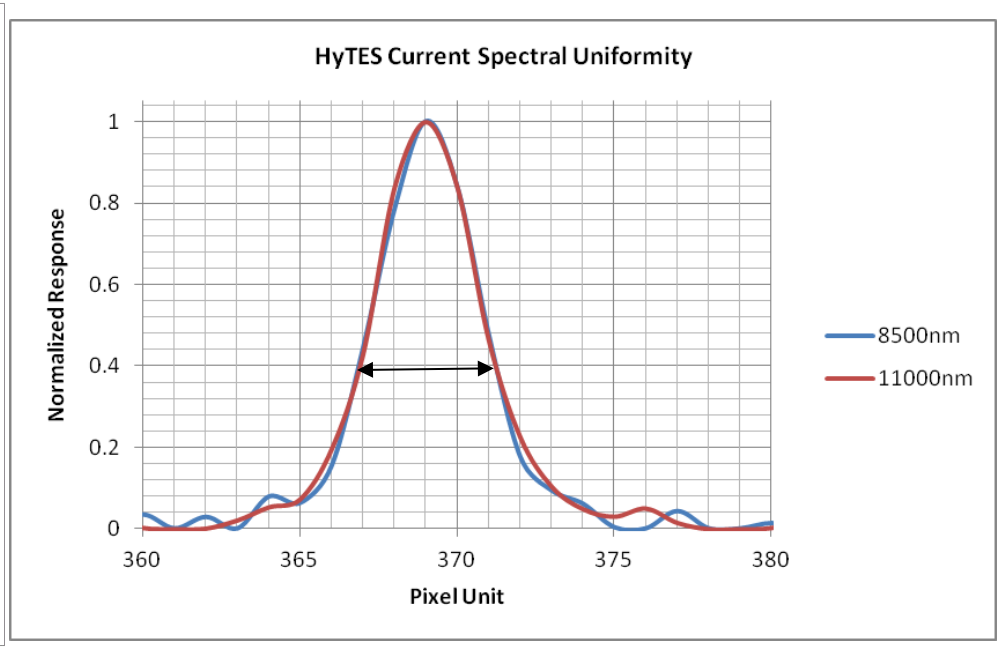


HyTES Spectral Response

Predicted spectral response

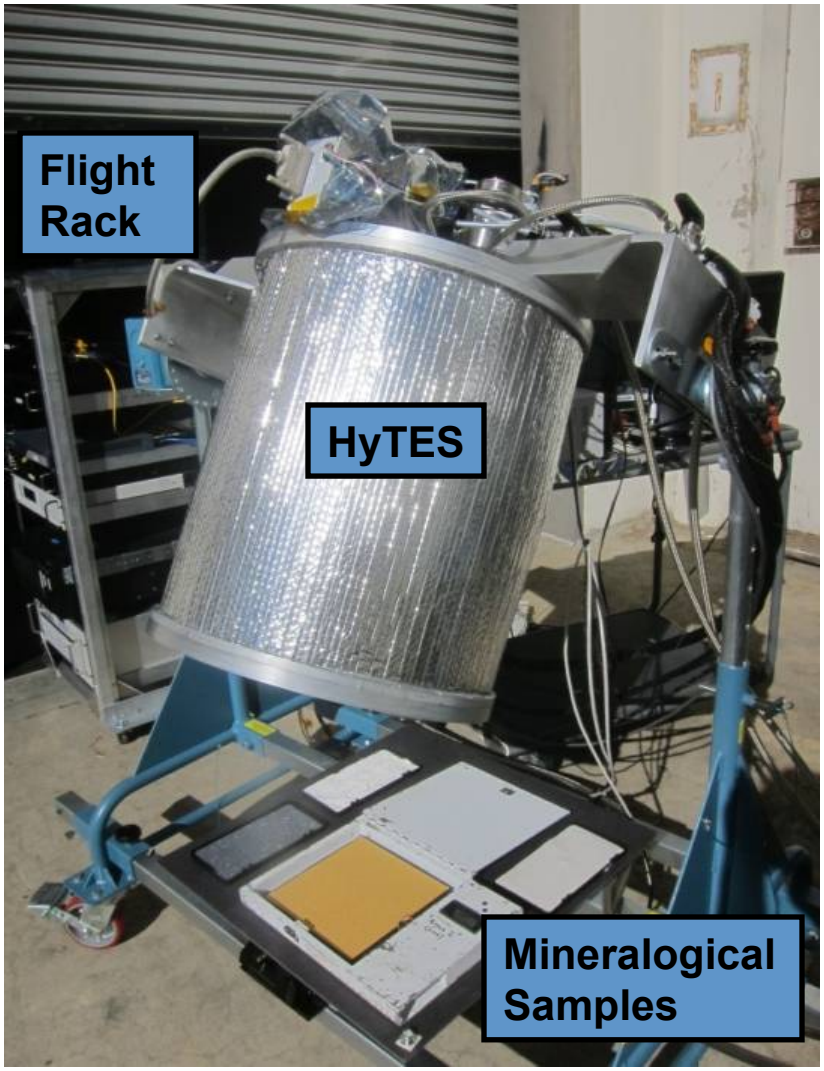


Measured spectral response



Arrow on measured response shows a FWHM of about 4 pixels (or 2 effective pixels) which is 35.2nm.

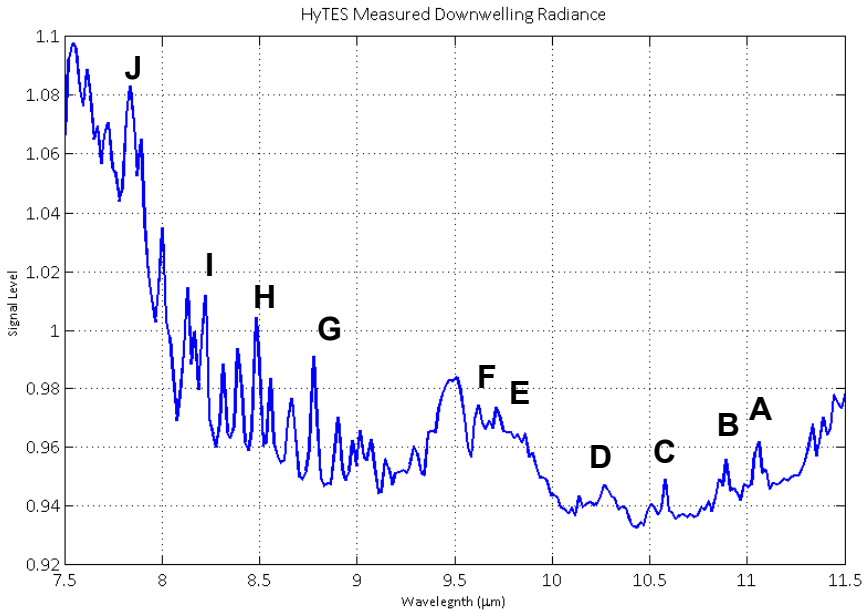
HyTES Outside Setup

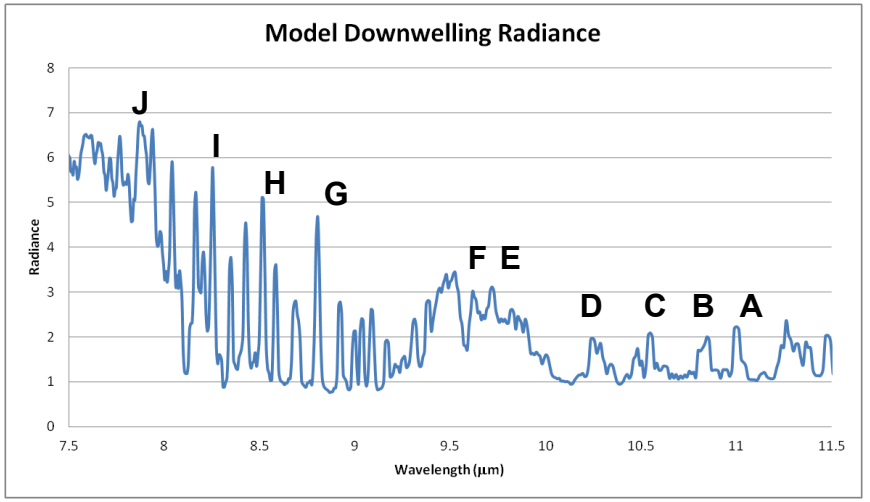


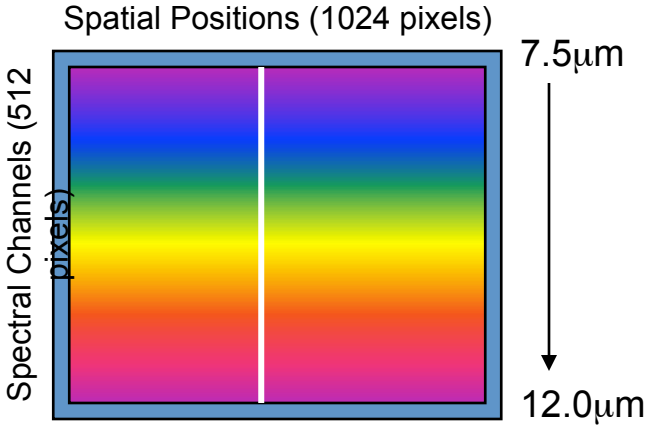
Test Procedure in Direct Sunlight

- Obtain spectral calibration from downwelling radiance using diffuse gold.
- Observe mineralogical species: Quartz, Silicon Carbide

HyTES Spectral Accuracy







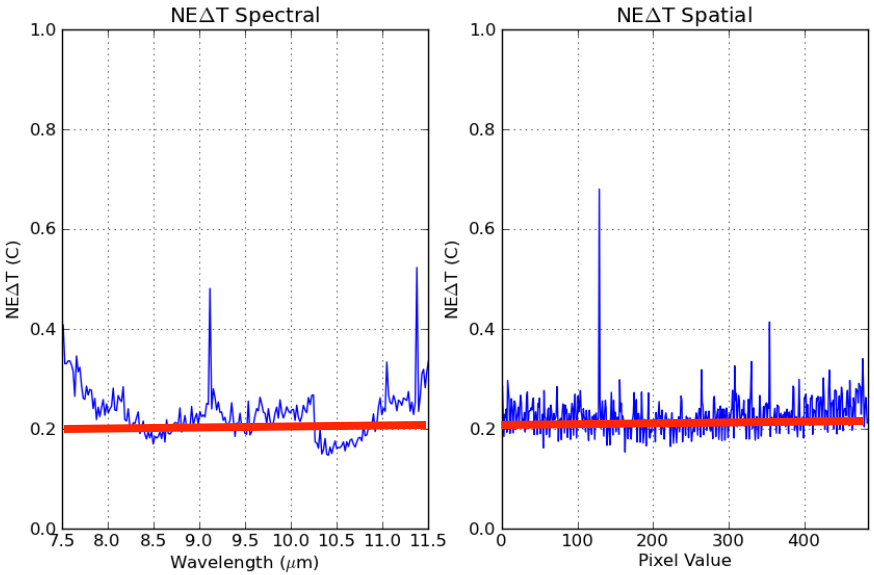
HyTES spectral calibration is very good. Wavelength determination for each features is well within one bandwidth.

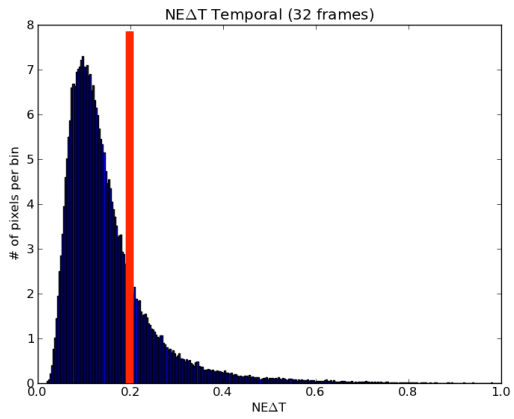
	Model	HyTES	Δλ
A	11.0010	11.01	-0.009
B	10.8460	10.853	-0.007
C	10.5485	10.5404	0.0081
D	10.2459	10.237	0.0089
E	9.7180	9.7246	-0.0066
F	9.6150	9.6125	0.0025
G	8.8028	8.8051	-0.0023
H	8.5106	8.5105	0.0001
I	8.2508	8.2524	-0.0016
J	7.8740	7.875	-0.001

HyTES NEDT

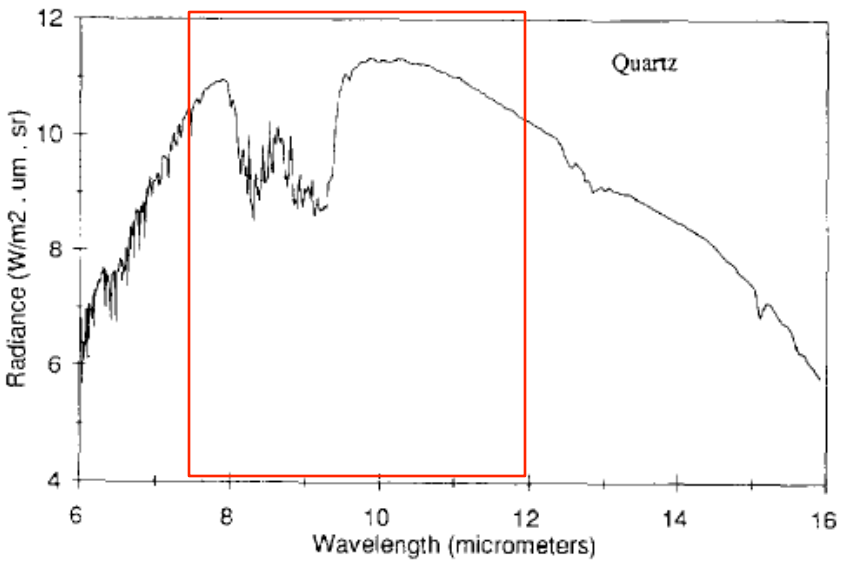
Field Test Results
16 July 2012

- **Brightness Temperature Within 0.5 °C of 25 °C (Black-body Set Point)**
- **Sensitivity (NEDT, Modeled as Standard Deviation) Better than 0.2 °C Between 7.5 – 11.5 µm**
- **Two-Layer QWIP Detector Array**

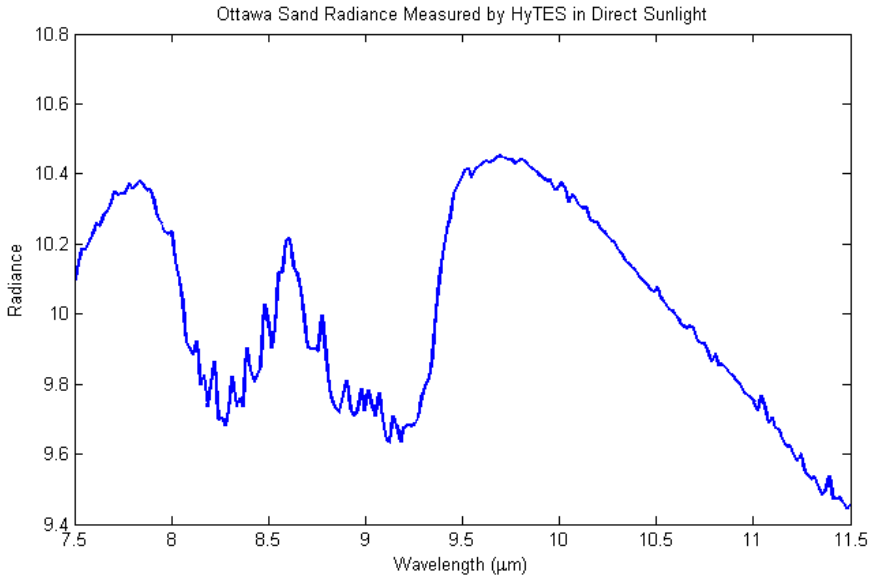




HyTES Measured Spectra



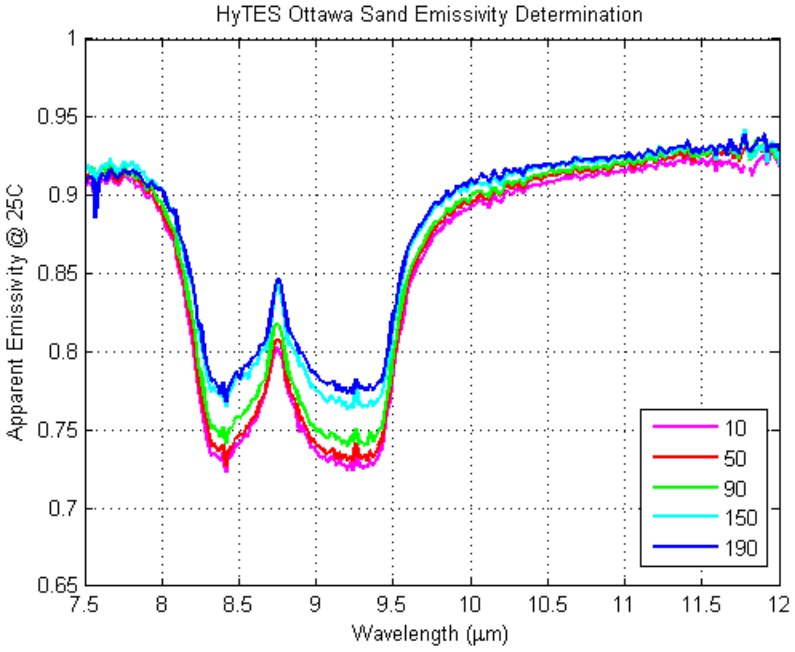
Previously measured field radiance of Quartz (micro-FTIR)

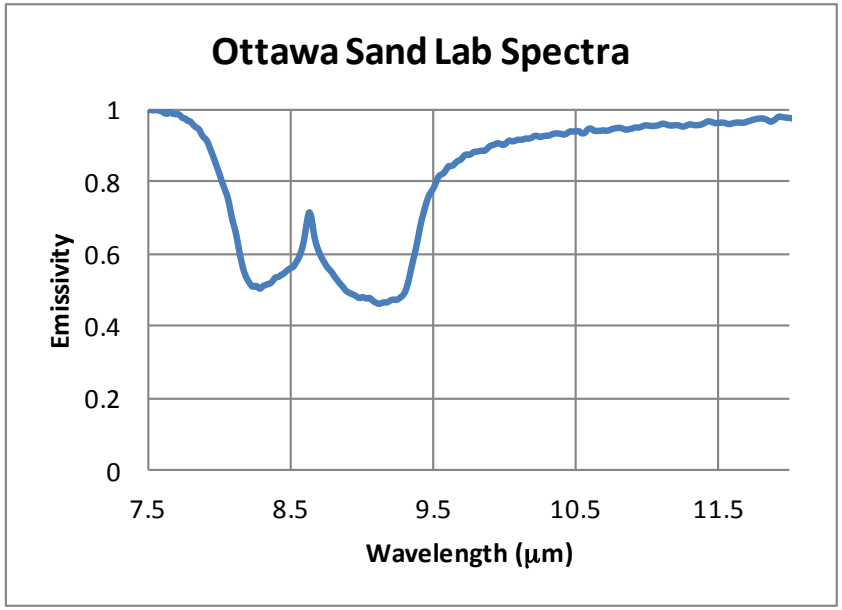


HyTES radiance measurement of Ottawa sand in direct sunlight.

HyTES Measured Spectra

Similar mineralogical species shown at different spatial locations (same temperature assumed for all spatial samples).

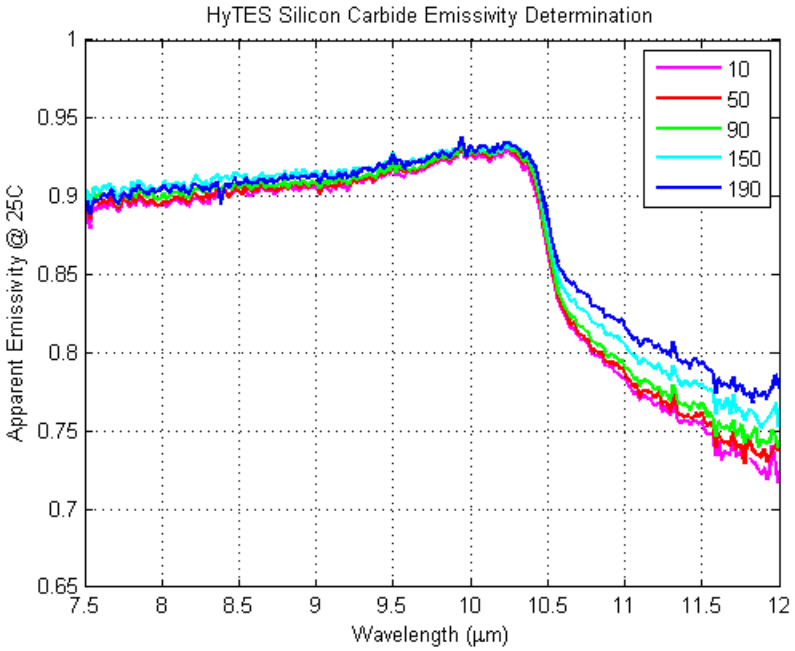


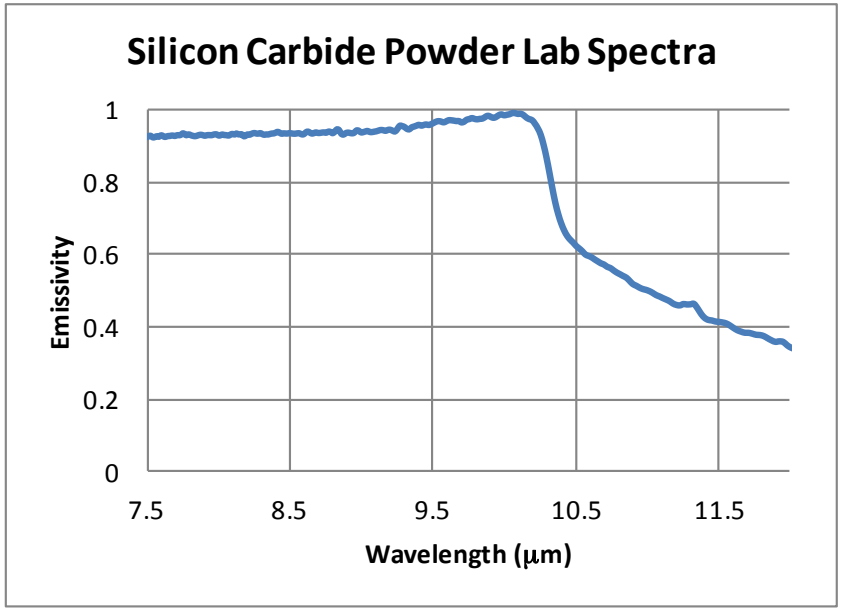


Excellent shape agreement.

HyTES Measured Spectra

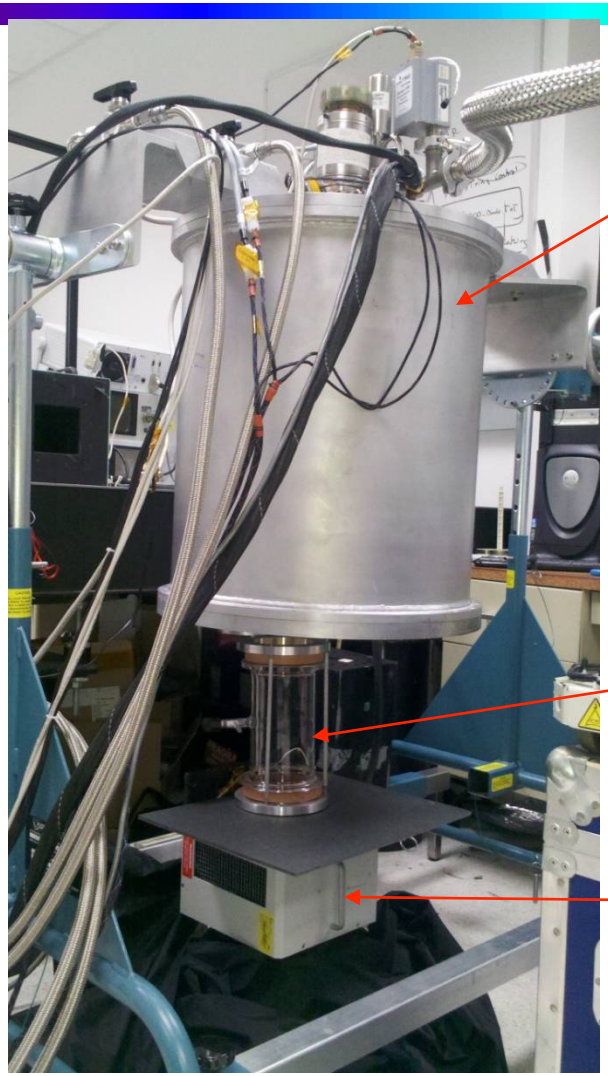
Similar mineralogical species shown at different spatial locations (same temperature assumed for all spatial samples).





Excellent shape agreement.

HyTES Gas Measurement Set-up

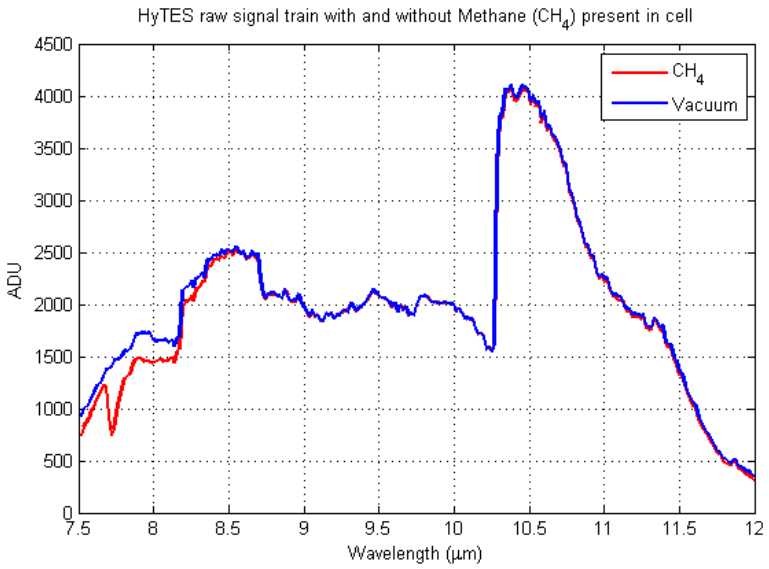


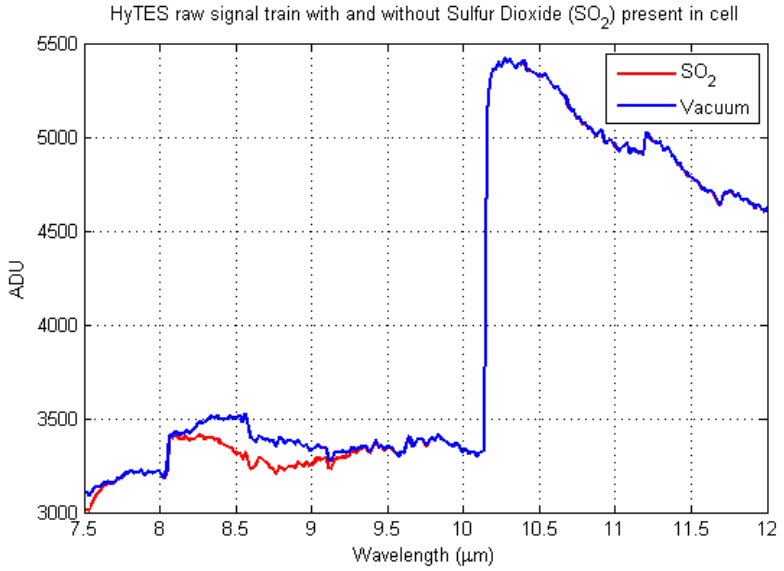
Custom cell housing

- **200mm cell length**
- **ZnSe transmission optics with anti-reflection coatings for maximum transmission.**
- **All gas species are held at 50torr pressure**

HyTES Gas Measurement

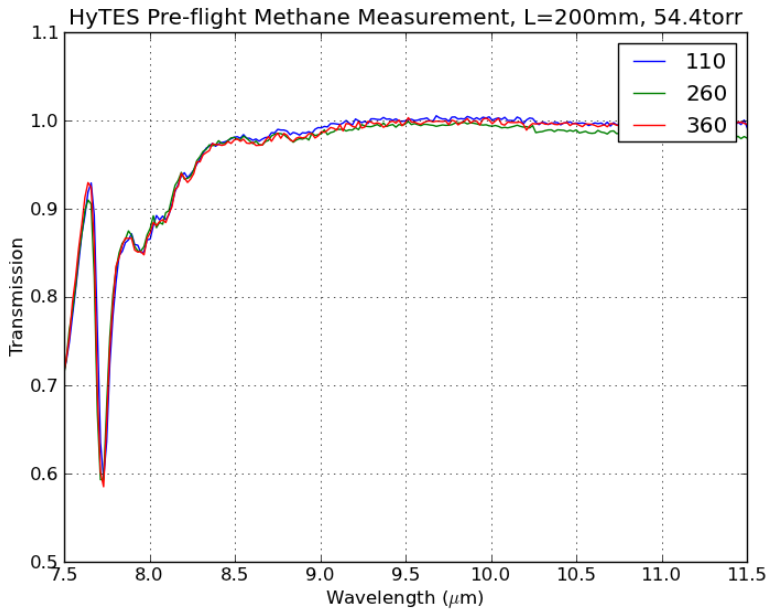
CH_4 and SO_2 raw signals measured in the field and in the lab before flight.

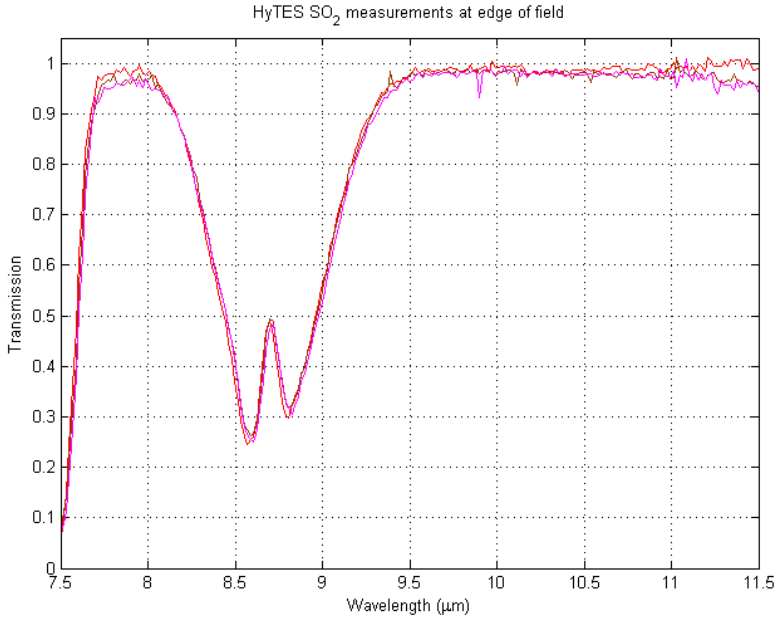




HyTES Gas Measurement

CH_4 and SO_2 raw signal converted to transmission spectra. Absorption spectra agree with spectra in NIST and PNNL databases





Airborne Testing

- Platform: Twin Otter
  - Flight at 2000-4000m
  - Frame rate = variable 15 to 30 FPS
  - Swath Width = 1.8km-3.6km
  - Pixel size = 2.9-5.8m

  Operator has console to monitor instrument status, change frame rate, start and stop acquisition

  Data are stored on removable hard drives.

HyTES Aircraft Hardware

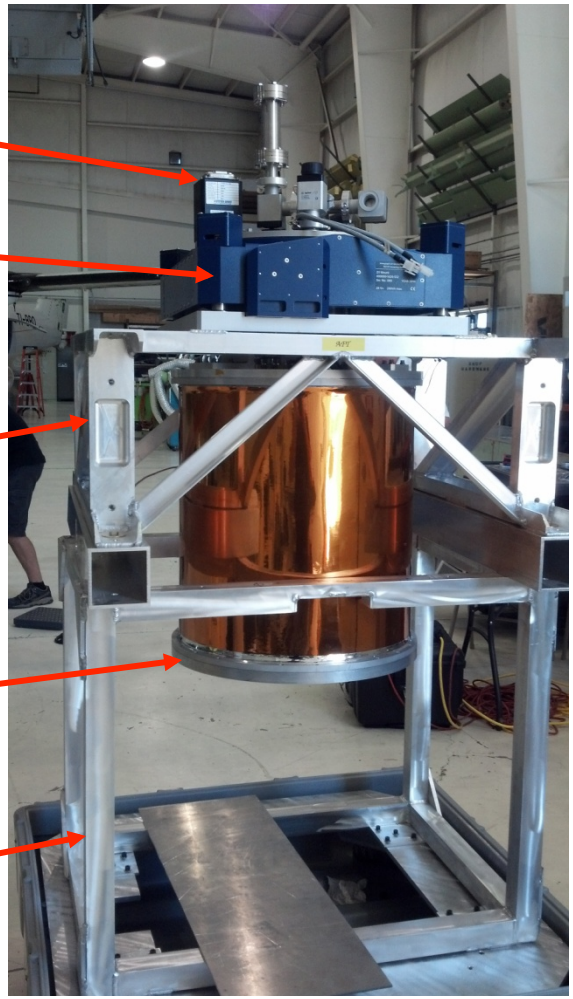
CMIGITS

Z/I Gyro-Stabilization Mount

Twin Otter Aircraft Mount

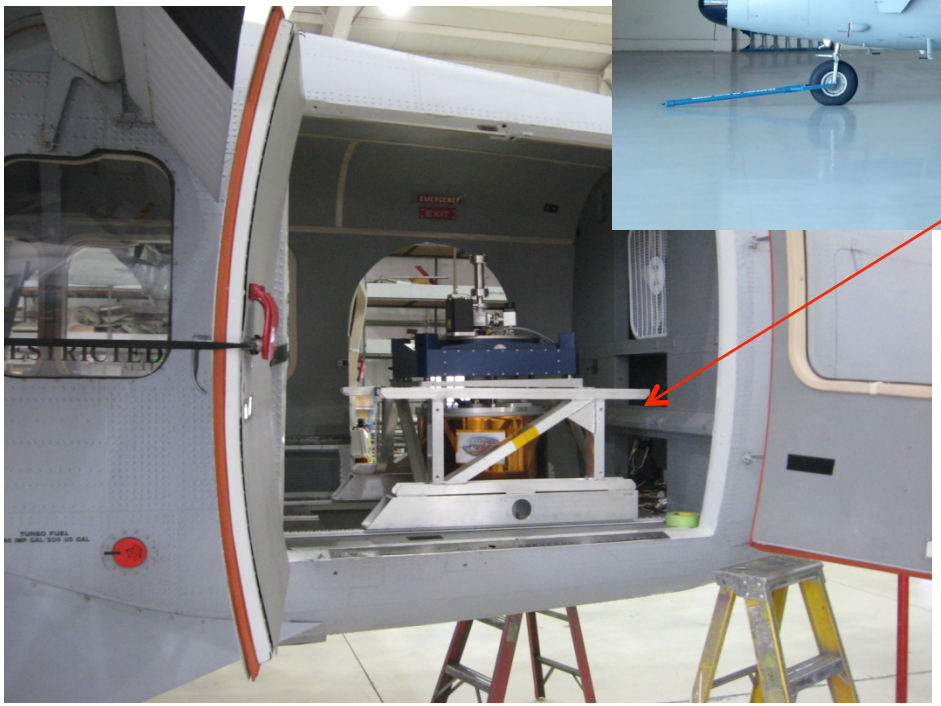
HyTES Scan head

Shipping mount



Twin Otter 300 Series with NADIR View Port

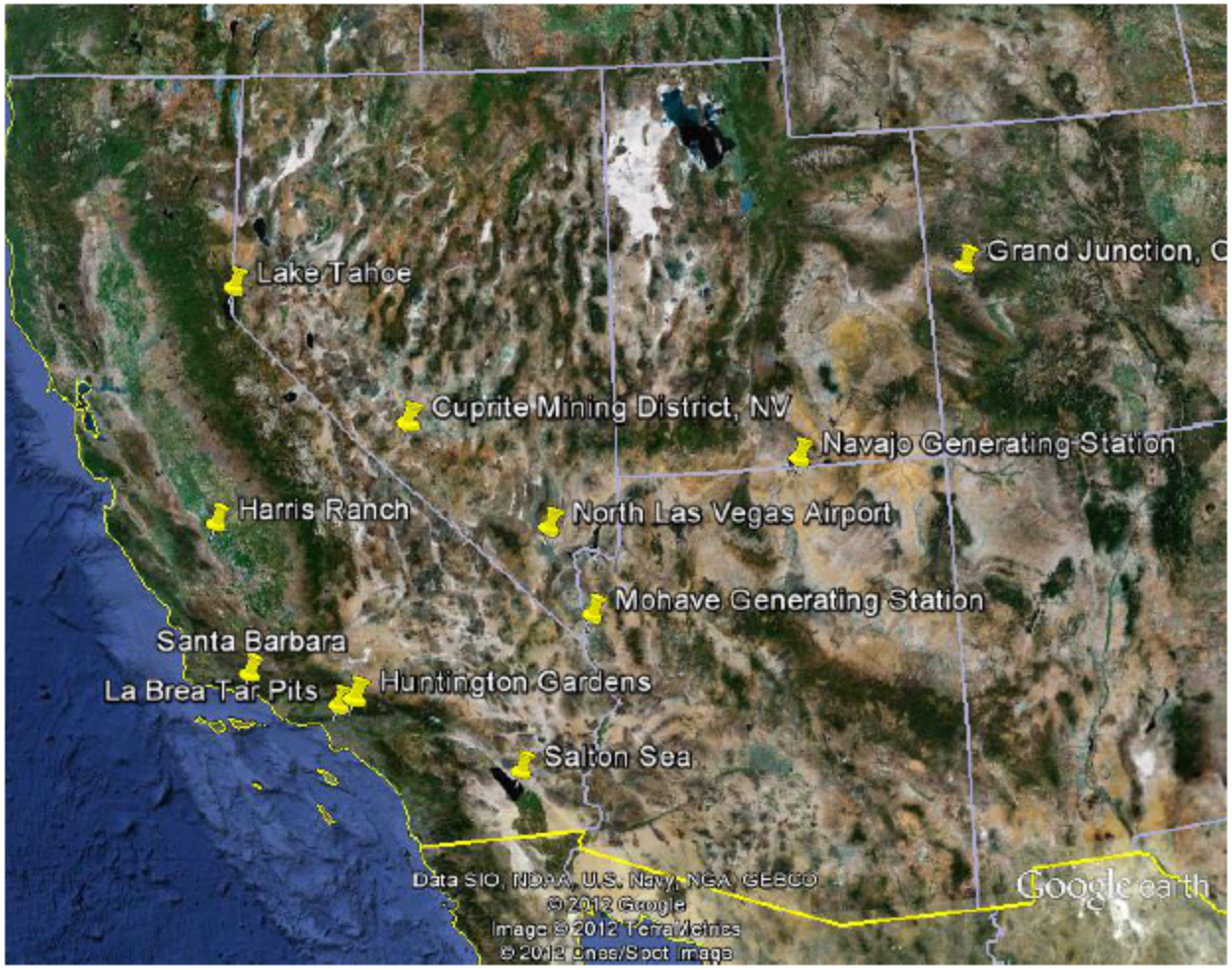
Arriving at Grand Junction



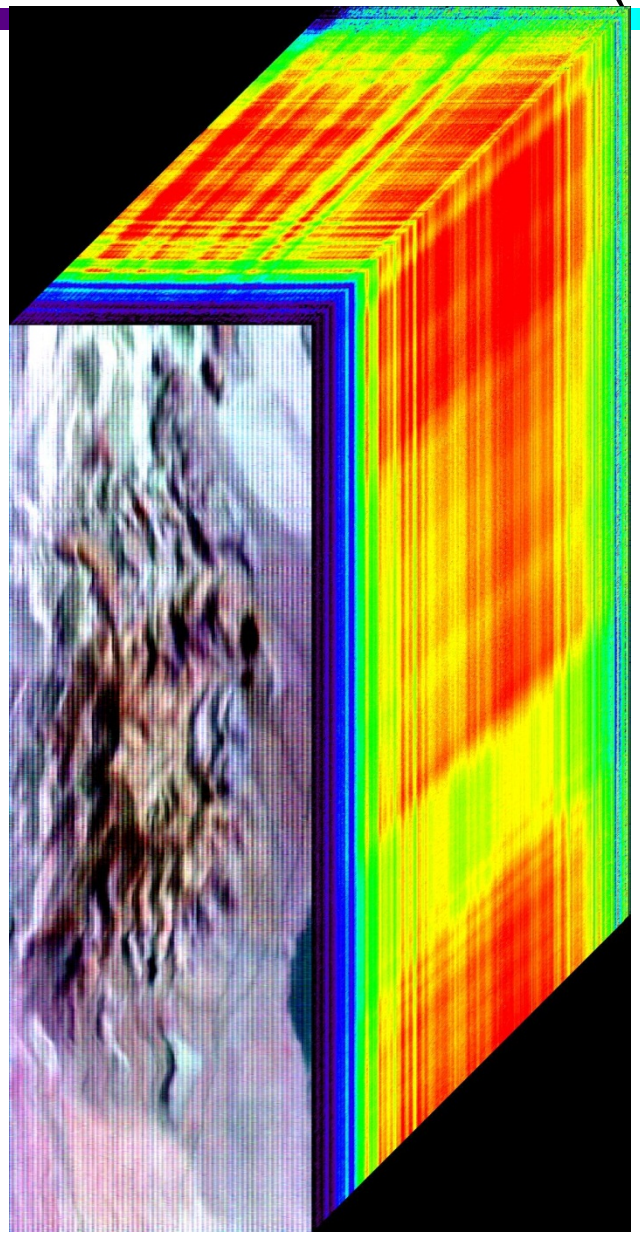
Test Sites and Purpose

Sitename	Purpose
La Brea Tarpits	Urban/Methane
Salton Sea	Calibration/Ammonia
Huntington Gardens	Ecosystems
Cuprite	Surface Composition
Death Valley	Surface Composition
Navajo Generating Station	Sulfur dioxide

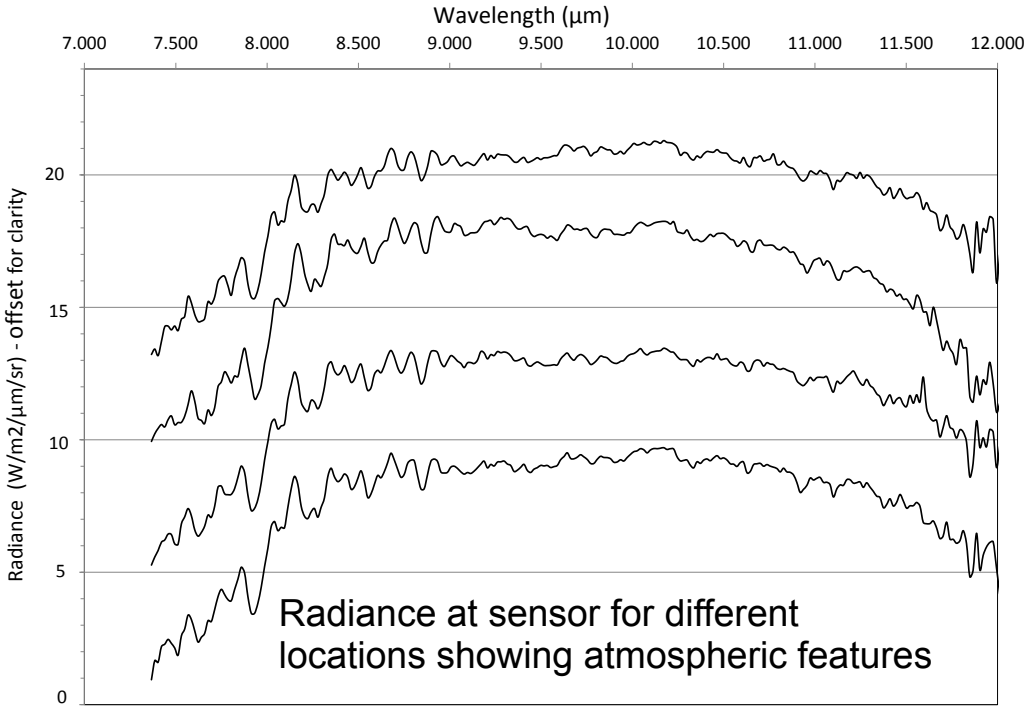
Sites…


Lake Tahoe
Grand Junction, C
Cuprite Mining District, NV
Navajo Generating Station
Harris Ranch
North Las Vegas Airport
Mohave Generating Station
Santa Barbara
La Brea Tar Pits
Huntington Gardens
Salton Sea
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Google
Image © 2012 TerraMetrics
© 2012 Cnes/Spot Image
Google earth
Google earth
miles
km
500
900

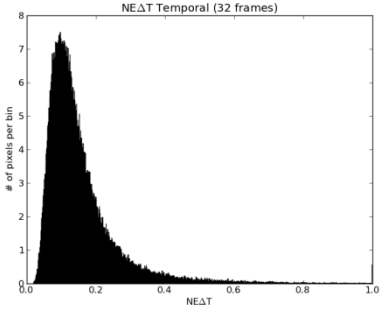
Hyperspectral Thermal Emission Spectrometer (HyTES) First Flights



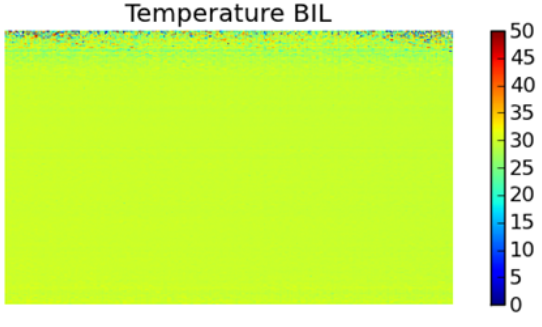
Left: Cuprite, NV 2012-07-20, bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm) displayed as RGB respectively as image cube.



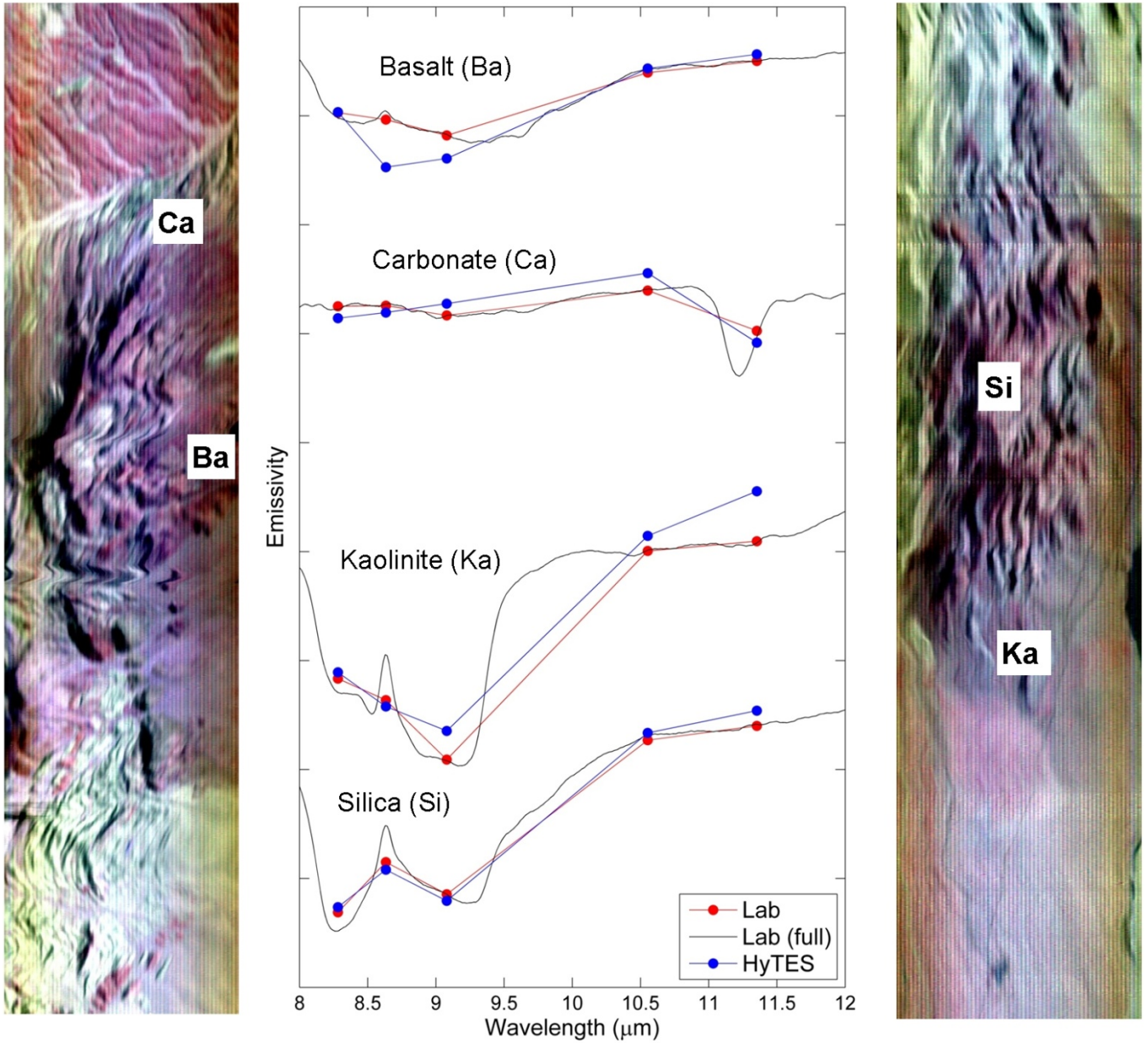
Noise Equivalent Delta Temperature (NEdT) ~0.2K



Blackbody Cross track uniformity

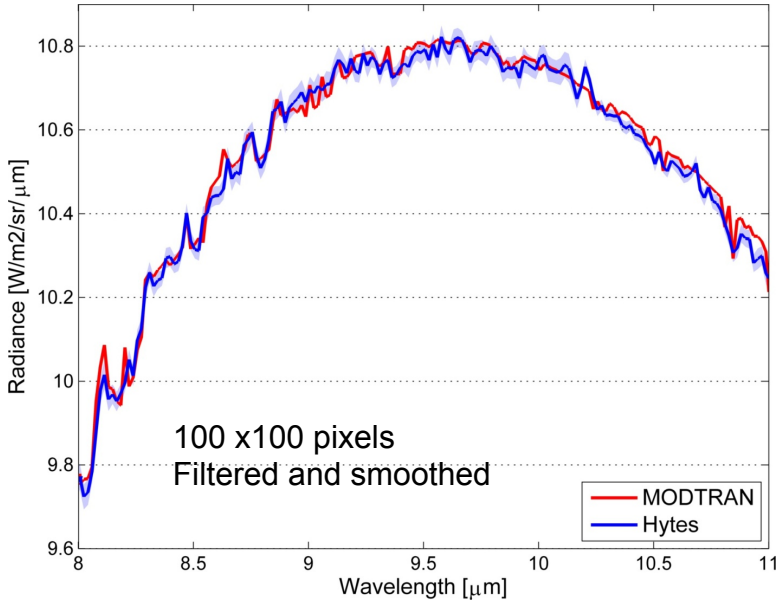


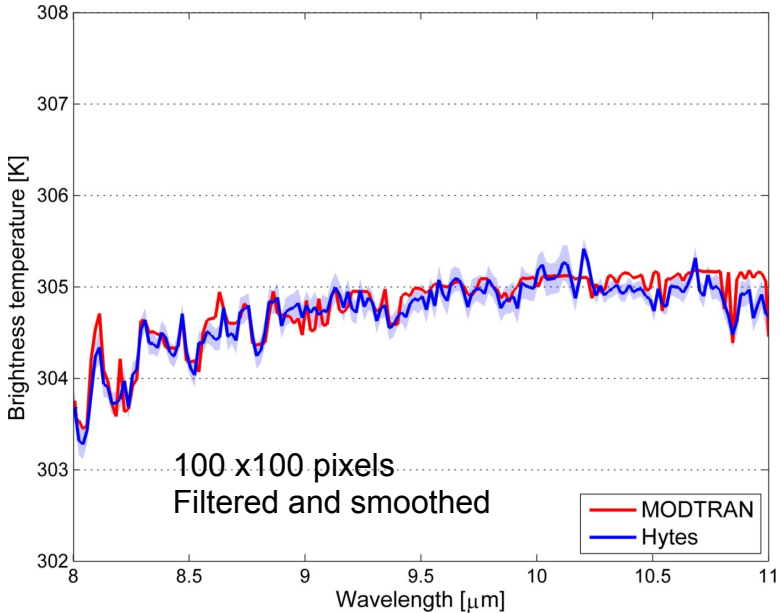
HyTES and Laboratory Spectra – Cuprite, NV



Salton Sea Matchups

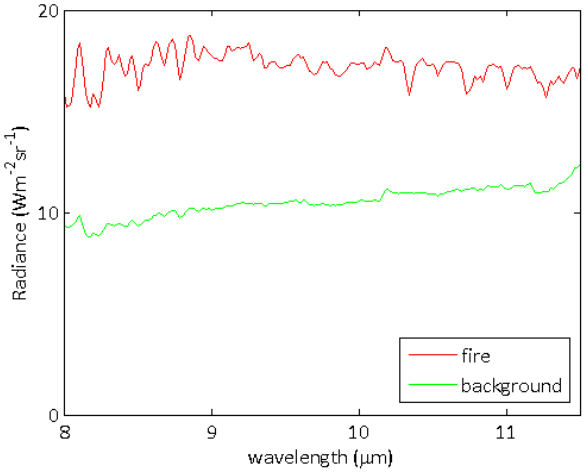
In situ skin temperature = 305.88 K (32.73 C)
HyTES skin temperature = 306 K (32.85 C)
RMSE = 0.18 K
MODTRAN run at 1 wavenumber with NCEP profile then resampled to HyTES wavelengths





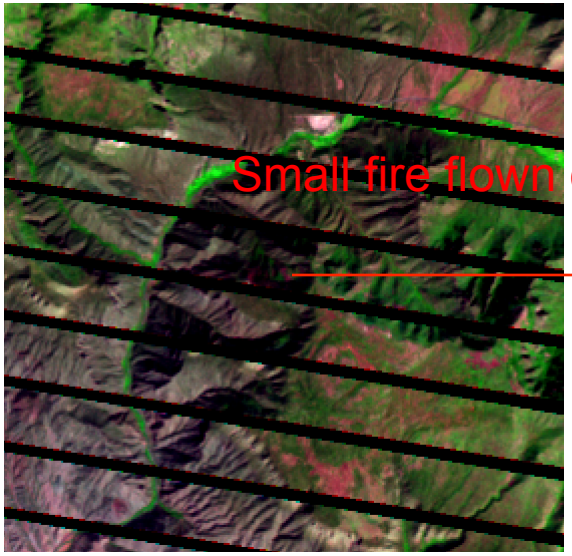
HyTES fire scene

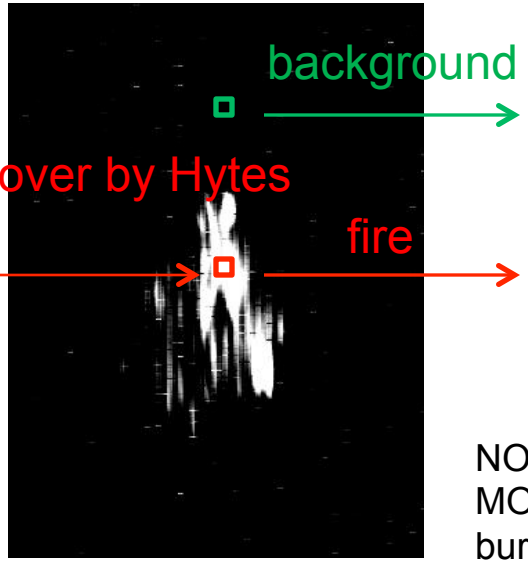
2012 Colorado fires (pictures from the Denver Post)

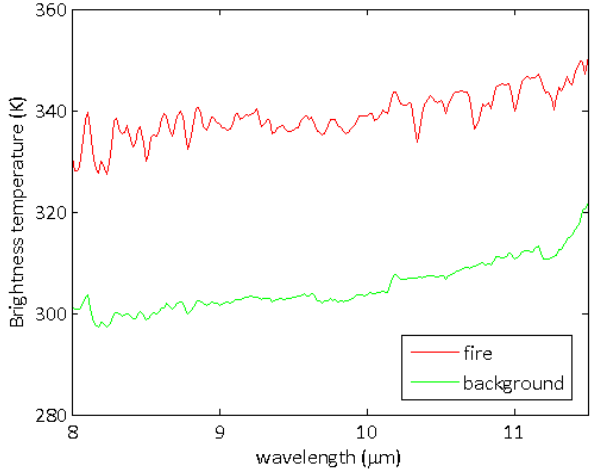


Post-fire Landsat 7 scene (RGB-743)

HyTES scene (11 μm) acquired on July 22, 2012







NOTE: the small fire was not detected by the MODIS active fire product (MO(Y)D14) nor the burned area product (MCD45)

Summary and Conclusions

- HyTES allows the determination of the optimum position for the band filters for HyspIRI
- HyTES provides antecedent data for HyspIRI and other Earth Science studies
- HyTES first airborne flights took place in July 2012. Airborne engineering flights identified various issues that are being addressed including:
  - Controlling focal plane temperature
  - Geolocation hardware issues

Next Steps

- Near-Term – Science Flights
  - Address issues from engineering flights, new coolers, new backup supply, improve thermal control, fix geolocation
  - Undertake science flights early 2013
- Longer-Term - Make HyTES-campaign ready
  - Integrate on a high altitude platform
  - Enable in-flight and field data evaluation
  - Use spares to make an extra FPA
- Find out more at: http://hytes.jpl.nasa.gov