Plume retrievals and transitioning to higher altitude platforms using the hyperspectral thermal emission spectrometer (HyTES)

Presented at:

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Paper 9976-2 of Session 1
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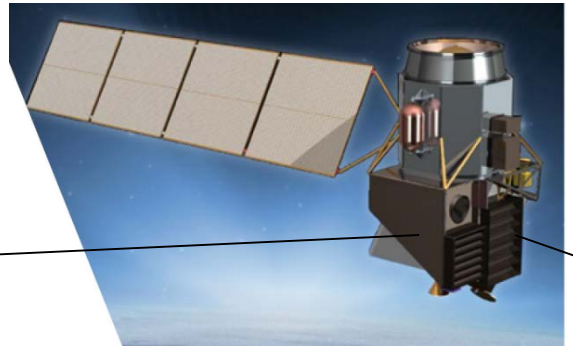
Outline

- **Brief background of the effort**
- **HyTES sensor description**
- **Recent campaigns**
- **Modified HyTES for the ER-2**
- **Transitioning to higher altitude platforms**
- **Concluding remarks**

HyspIRI Background

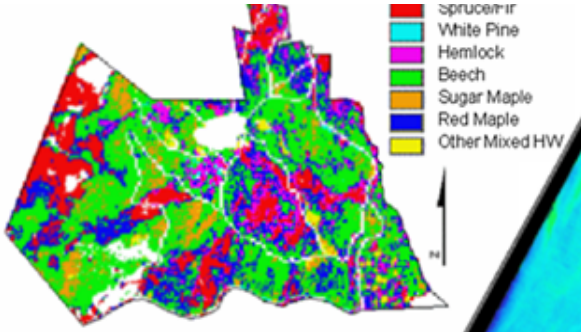
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

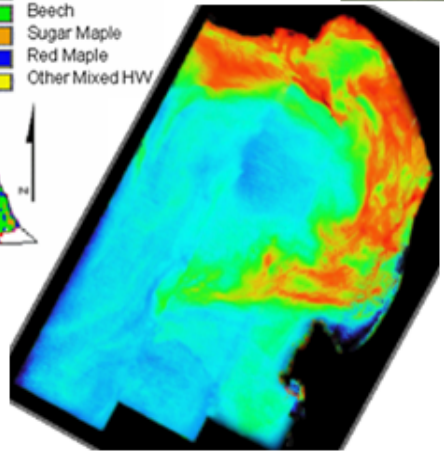


VSWIR: Plant Physiology and Function Types (PPFT)

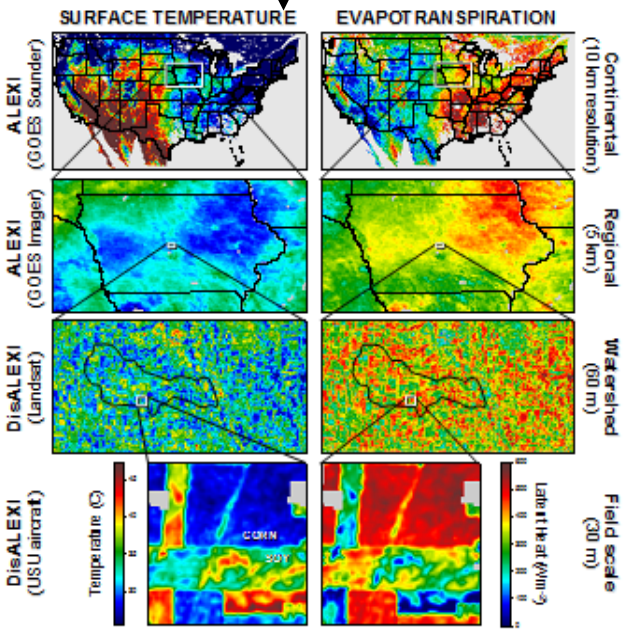
Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH





Red tide algal bloom in Monterey Bay, CA



http://hyspiri.jpl.nasa.gov/

HyspIRI Background

Science Questions:

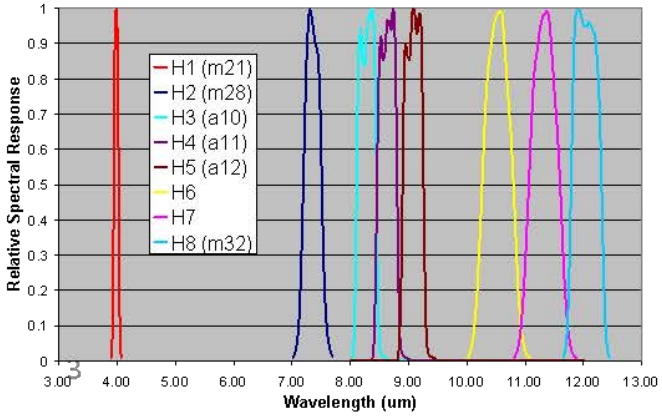
TQ1. Volcanoes/Earthquakes (MA,FF)

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

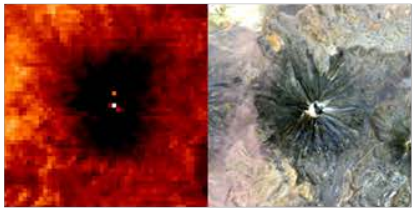
- *TQ2. Wildfires (LG,DR)*
  - *What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?*
- *TQ3. Water Use and Availability, (MA,RA)*
  - *How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?*
- *TQ4. Urbanization/Human Health, (DQ,GG)*
  - *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, (AP,JC)*
  - *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

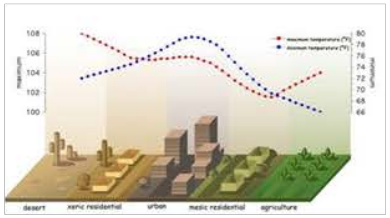


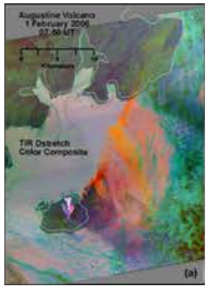
Andean volcano heats up



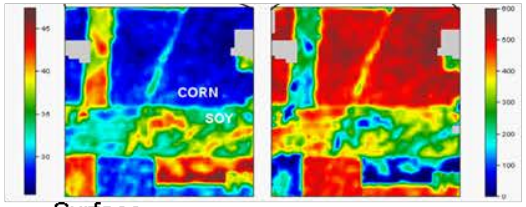
Volcanoes

Urbanization





Water Use and Availability



Surface Temperature

Evapotranspiration

ECOSTRESS Project Overview

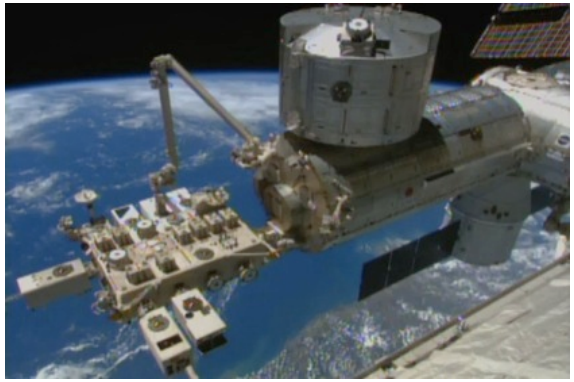
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) is an Earth Venture Instrument-2 on the ISS

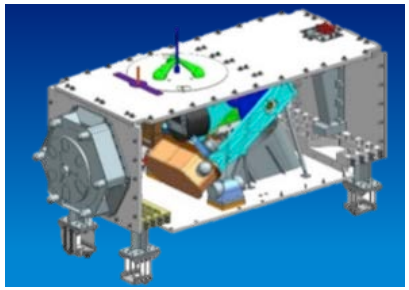
Primary Science Objectives

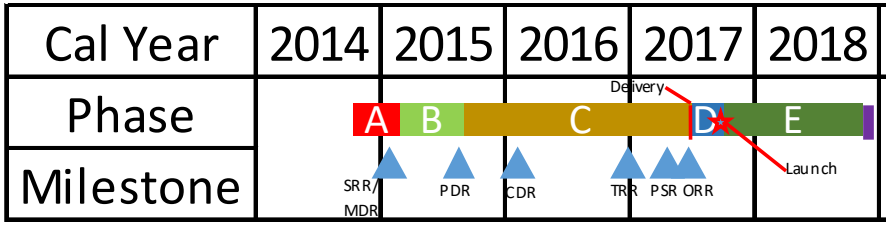
- Identify critical thresholds of water use and water stress in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant water uptake decline and cessation over the diurnal cycle
- Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

Features:

- 8–12.5 µm Radiometer with a 400km swath
- 5 TIR spectral channels, 1 SWIR band
- 2017 Payload delivery date
- Deployed on the ISS on JEM-EFU 10
- Measure brightness temperatures of Earth at selected locations
- Operational life: 1 year after 30 days on-orbit checkout



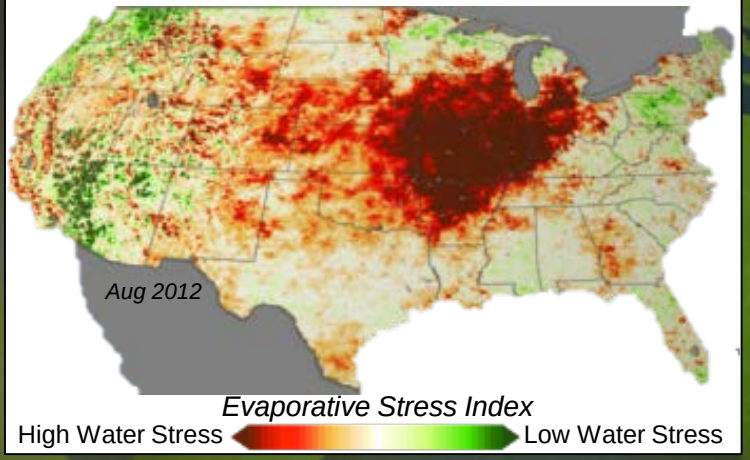




ECOSTRESS Science Overview

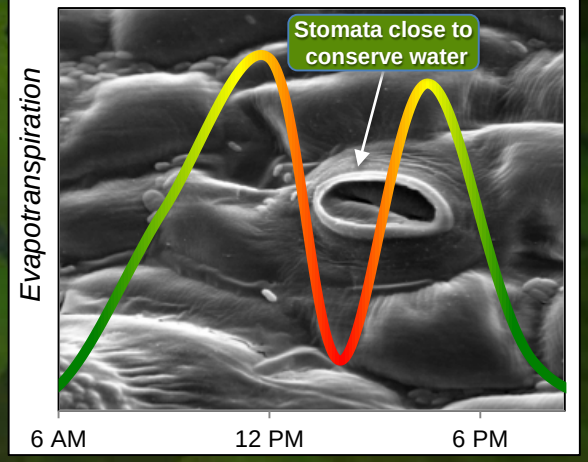
*ECOSTRESS will provide critical insight into **plant-water dynamics** and how **ecosystems change with climate** via **high spatiotemporal** resolution thermal infrared radiometer measurements of evapotranspiration (ET) from the International Space Station (ISS).*

Water Stress Threatens Ecosystem Productivity



Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

Water Stress Drives Plant Behavior



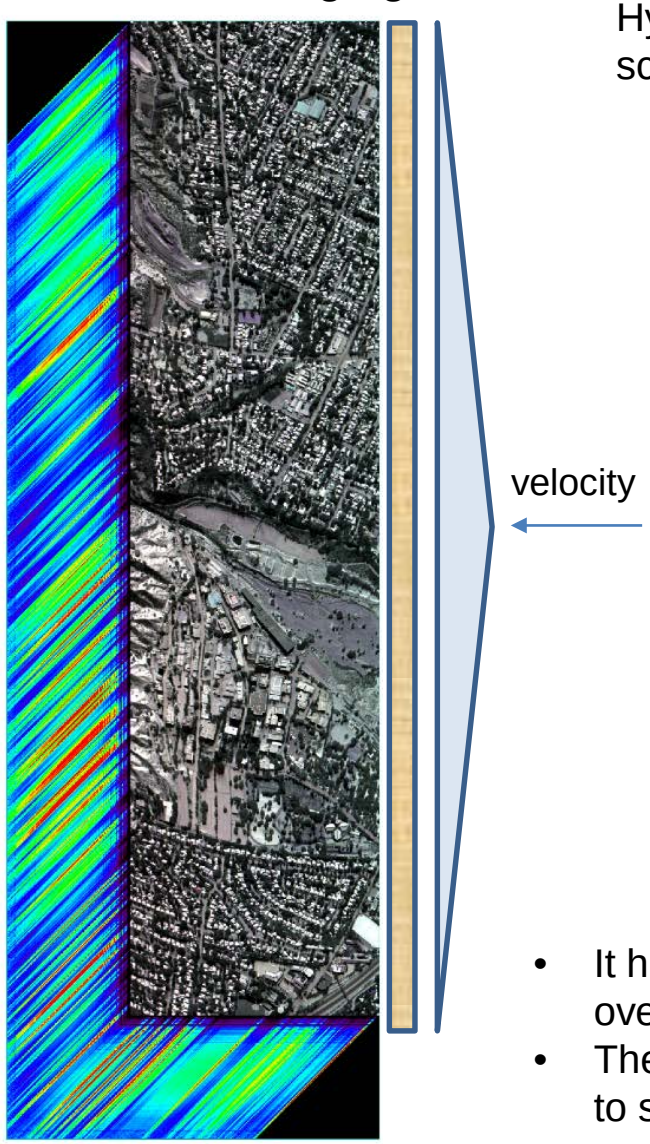
When stomata close, CO_2 uptake and evapotranspiration are halted and plants risk starvation, overheating and death.

Science Objectives

- Identify **critical thresholds of water use and water stress** in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant **water uptake decline** and/or cessation over the **diurnal cycle**
- Measure **agricultural water consumptive use** over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy

HyTES Instrument

Push broom imaging



velocity

HyTES Image cube of JPL flyover, Summer 2014.
L1A: bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm), displayed at RGB

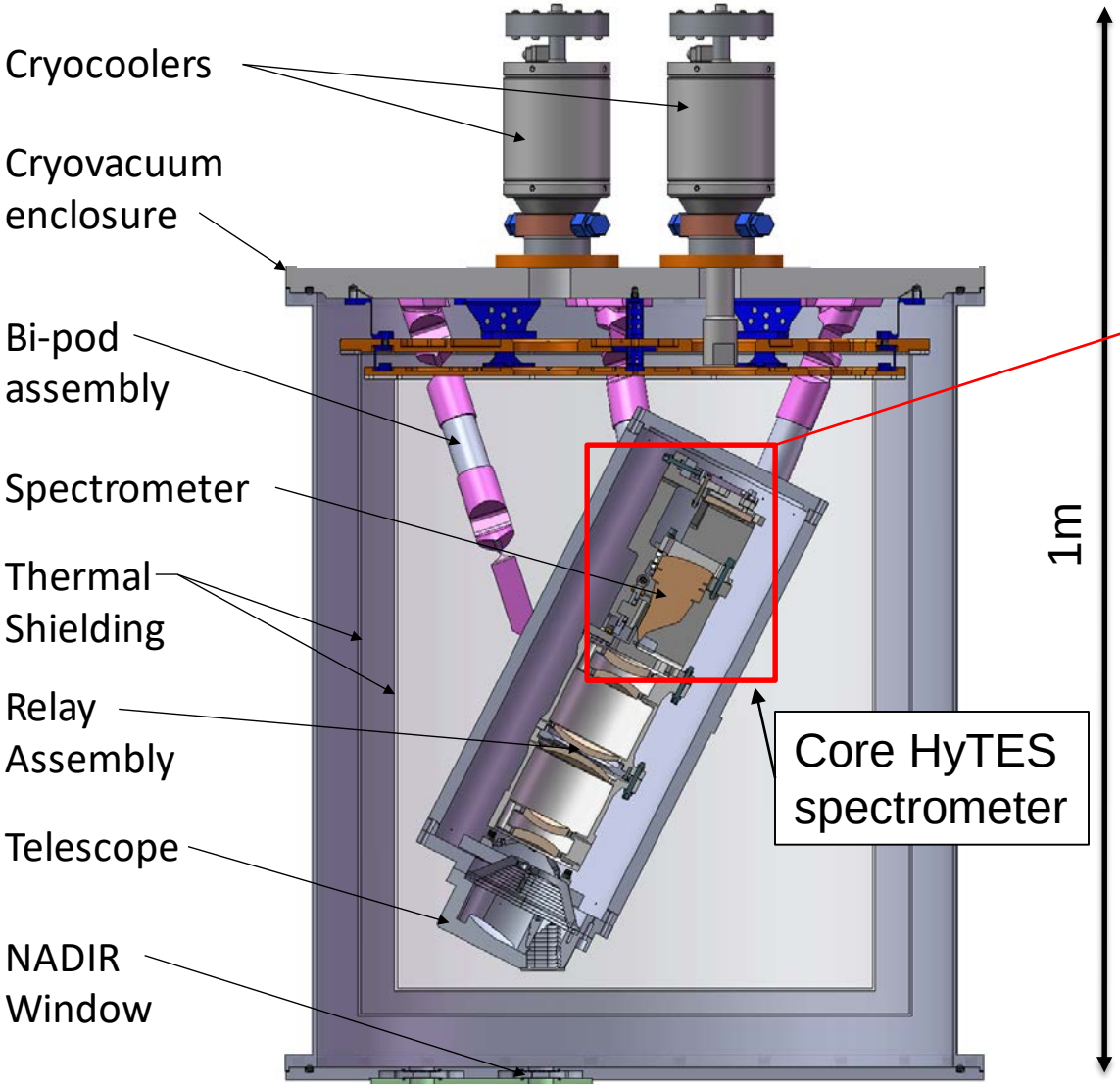
- HyTES was originally developed under an IIP to support HyspIRI by providing higher resolution *spatial and spectral* science products.

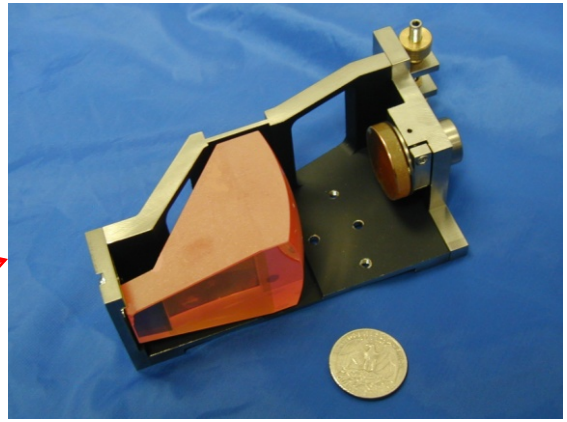
Basic Instrument Parameters

Volume (scan head)	0.6m x 0.4m + peripheral struts
Number of spatial pixels x track	512
Number of spectral channels	256
Spectral range	7.5 - 12μm
Frame Speed	35 or 22 fps
Total field of view	50deg
Calibration	Full aperture blackbody
Detector temperature	40K
Optics temperature	100K
NEΔT	200mK
IFOV	1.7066 mrad
Low Altitude pixel size/swath	2m/1Km
High Altitude pixel size/swath	20m/10Km

- It has also been used to spatially map trace gas plume signatures over targets of interest.
- The HyTES cryosat system has undergone a design modification to support operation in the ER-2 under the AITT program.

HyTES Instrument





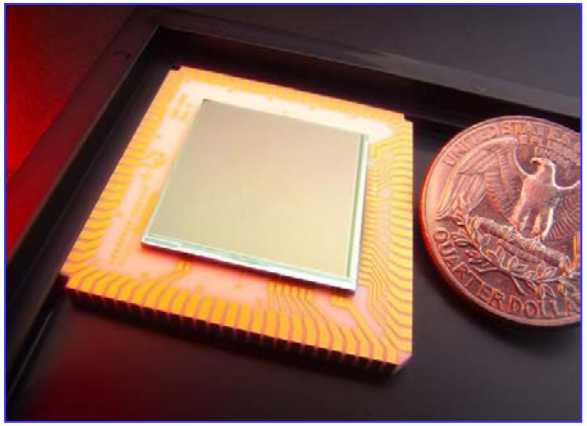
- HyTES flew its last campaign with this cryovac configuration in January 2016.
- It has been transitioned to an even smaller configuration for higher altitude deployment.
- The new smaller design still works on the twin otter.

http://airbornescience.jpl.nasa.gov/hytes/

QWIP Technology

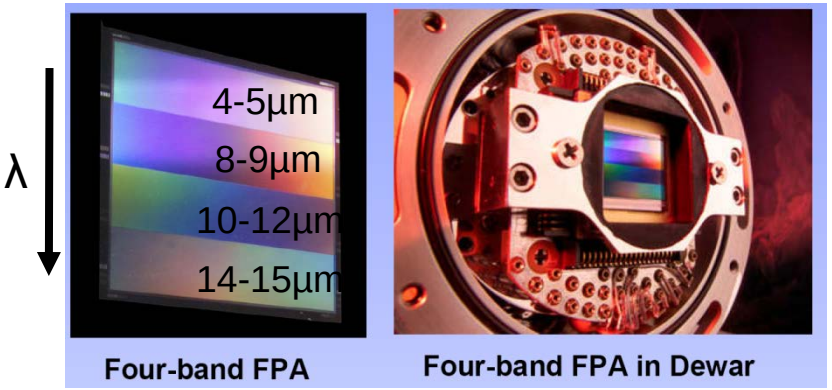
Quantum well infrared photodetector (QWIP) developed at JPL

- Detector Material - Spatially separated 2-color QWIP
- Array Size - 1024x1024 pixels
- Pixel Pitch - 19.5 microns
- Wavelength - 7.5-12 microns; three spectral bands
- Input Circuit - Direct Injection
- Integration Type - Snap Shot mode
- Integration Time - Adjustable integration time > 10 μs
- Integration Modes - Integrate-While-Read & Integrate-Then-Read
- Well Depth - 8.1×10^6 electrons



1024x1024 pixel single-band QWIP FPA

2-point corrected image of focal plane array used in HyTES.

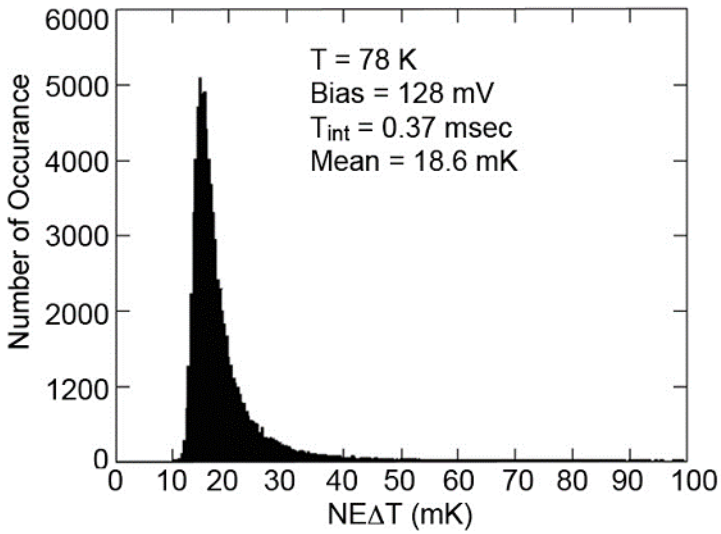


CBIRD Technology

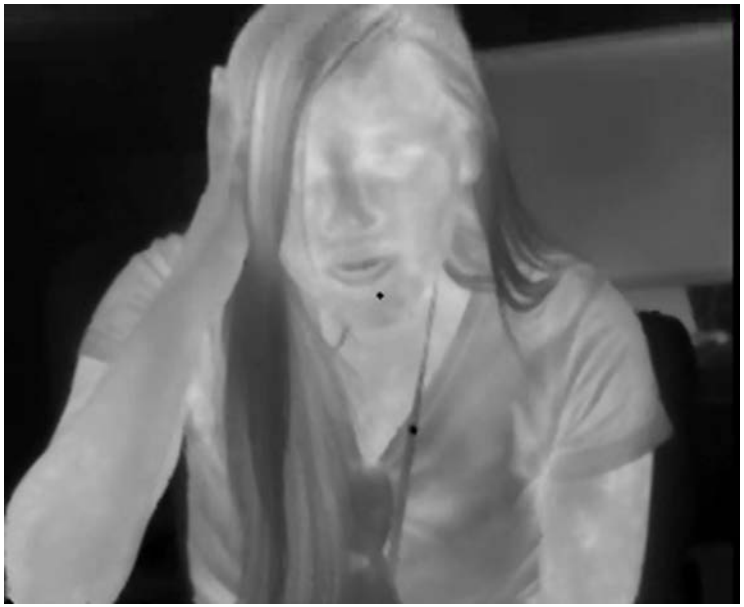
New infrared detector technology for future pushbroom hyperspectral sensors:

- Antimonide superlattice based long-wavelength infrared photodetectors using a complementary barrier infrared detector (CBIRD) design offers the possibility of stabilized, uniform arrays with low dark current, higher operating temperature than QWIP and higher QE.

- Antimonide-based superlattice infrared absorbers can be customized to have cut-on wavelengths ranging from the short-wave infrared (SWIR) to the very long-wave infrared (VLWIR).



Format	– 320x256
Pixel pitch	– 30 μm
ROIC	– ISC 0903 DI
Pixels	– Fully reticulated
Pixel Size	– 26x26 μm^2
Polarity	– N on P
Cutoff wave.	– 10 μm
Oper. temp.	– 78 K
QE (8-9.2 μm)	– 54% (without A/R)
NEΔT	– 18.6 mK with f/2 300K
Substrate	– Removed
Temp. Cy	– 29



HyTES Operating with BIRD Array

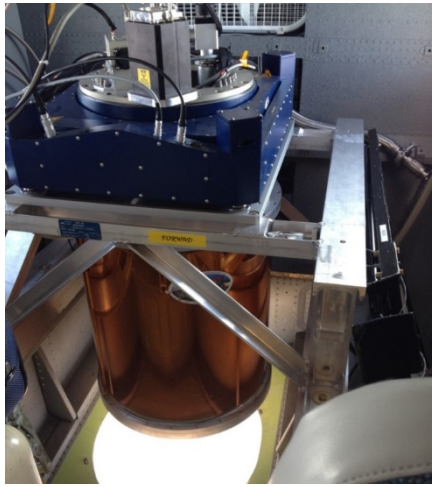
APPLIED PHYSICS LETTERS **95**, 023508 (2009)

A high-performance long wavelength superlattice complementary barrier infrared detector

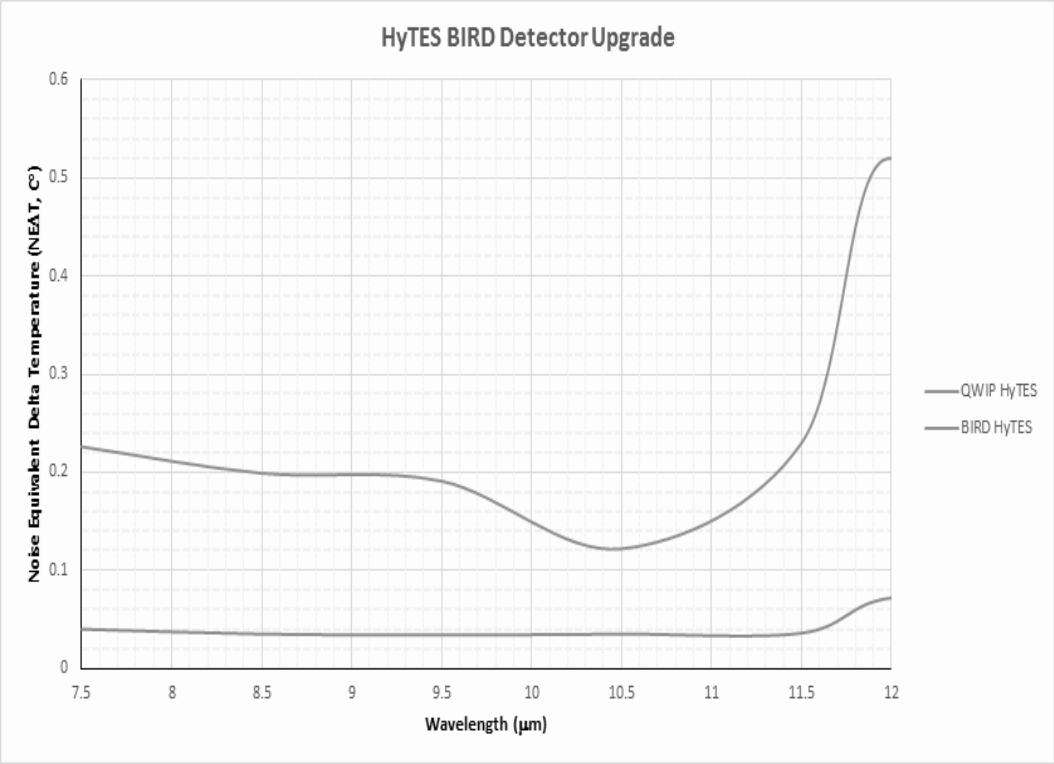
David Z.-Y. Ting,[a] Cory J. Hill, Alexander Soibel, Sam A. Keo, Jason M. Mumolo, Jean Nguyen, and Sarath D. Gunapala
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA

(Received 8 April 2009; accepted 23 June 2009; published online 16 July 2009)

We describe a long wavelength infrared detector where an InAs/GaSb superlattice absorber is surrounded by a pair of electron-blocking and hole-blocking unipolar barriers. A 9.9 μm cutoff device without antireflection coating based on this complementary barrier infrared detector design exhibits a responsivity of 1.5 A/W and a dark current density of 0.99×10^{-5} A/cm^2 at 77 K under 0.2 V bias. The detector reaches 300 K background limited infrared photodetection (BLIP) operation at 87 K, with a black-body BLIP D^* value of 1.1×10^{11} cm Hz$^{1/2}$/W for $f/2$ optics under 0.2 V bias. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3177333]



The HyTES airborne imaging spectrometer mounted on the Twin Otter Aircraft.



Comparison of detector NEdT for QWIP and BIRD arrays. Lower NEdT is better. Performance for the BIRD array was computed using a 44 ms integration time, 60K detector temperature, 20% QE, and the expected 5X MCT dark current. QWIP detector performance was simulated for a 40K detector temperature and 44 ms integration time based on current best estimate parameters for dark current and QE.

HyTES Flights

HyTES has been flying campaigns since 2012

- Notable calibration targets have been Cuprite, Death Valley, Salton Sea and Tahoe.
- Specific gas retrieval targets include: 4-Corners campaign, SoCal Gas Porter Ranch Leak

All flights have been out of Grand Junction Colorado on a low altitude Twin Otter aircraft.

HyTES is scheduled to have its first high altitude flight on NASA's ER-2 in 2016.

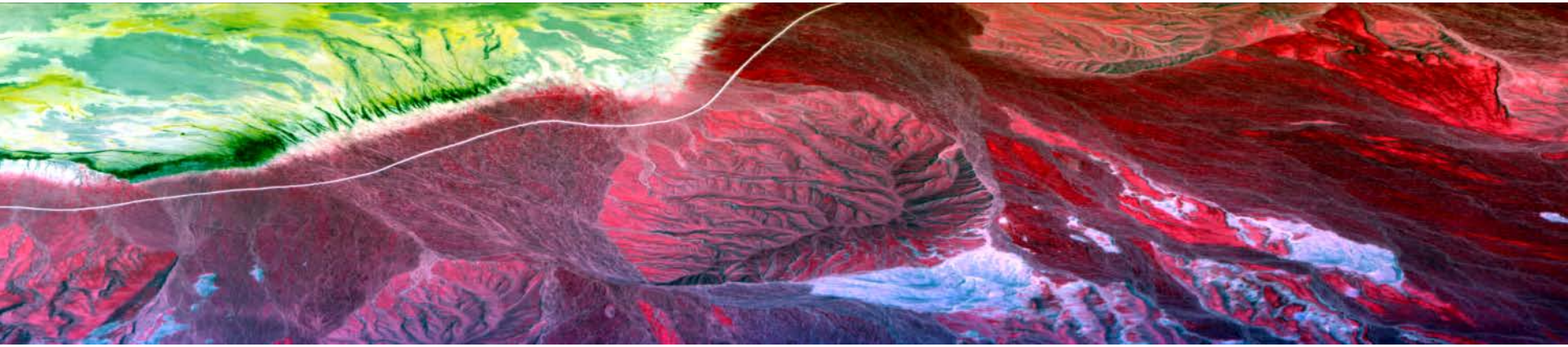
HyTES flight team

HyTES instrument team

HyTES Campaign Products

Death Valley, CA

Quartz alluvial fan

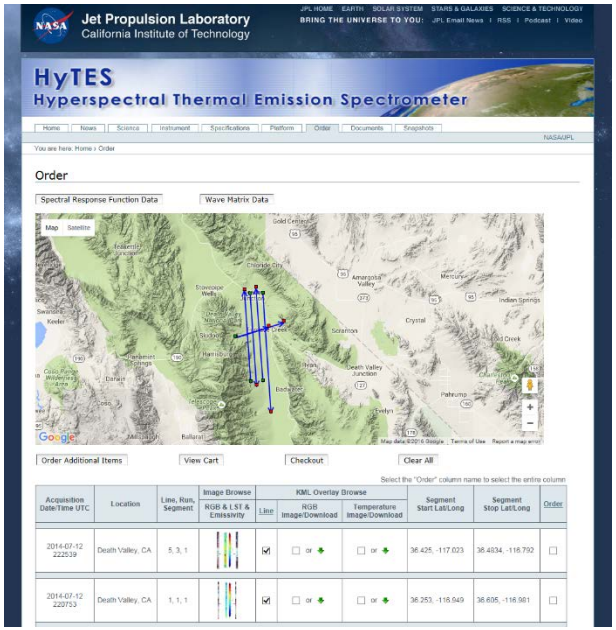


Carbonate

Basalt

HyTES image of Death Valley
L1A: bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm), displayed at RGB

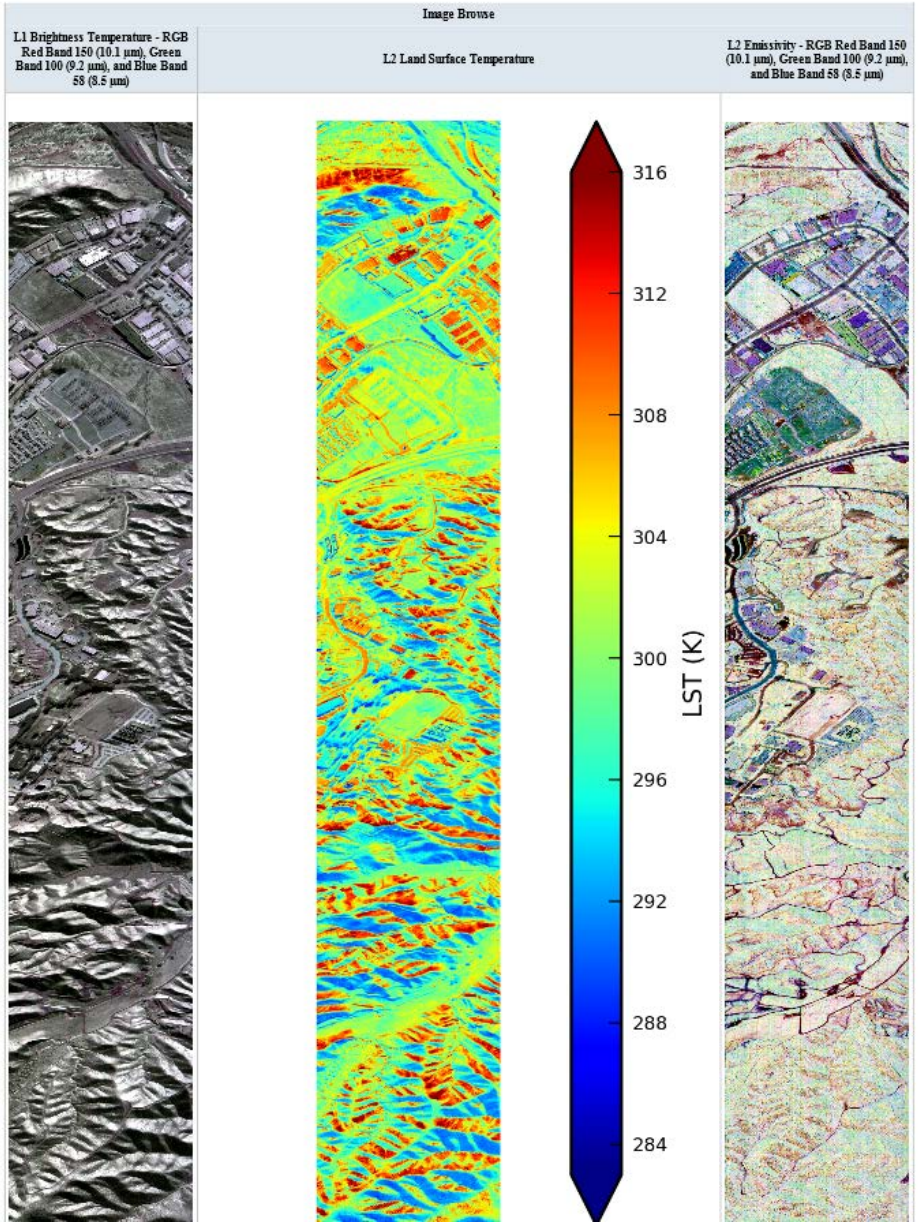
- Data from all previous flights can be found at the web portal shown to the right.
- One can browse quick looks and order higher level products.
- ATBD documentation is available from L1 to L3



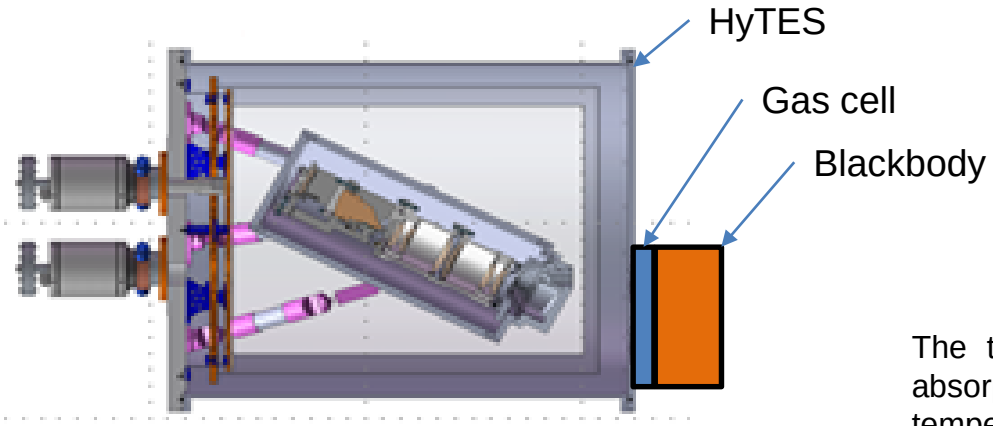
Web portal at *hytes.jpl.nasa.gov*

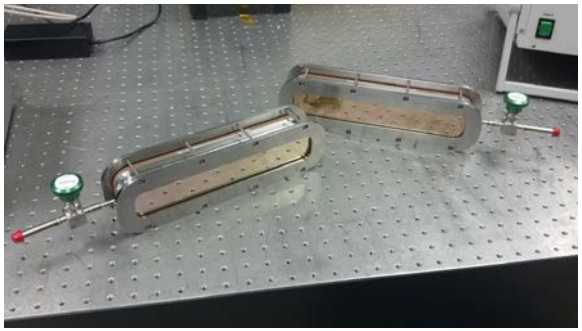
Temperature Emissivity Separation

- Example of HyTES L2 products displayed side by side with L1 brightness temperature.
- For HyTES a modified version of the in-scene atmospheric correction (ISAC) approach initially developed for the SEBASS airborne hyperspectral sensor (Young et al. 2002) was implemented.
- Temperature Emissivity Separation (TES) algorithm (Gillespie et al. 1998)

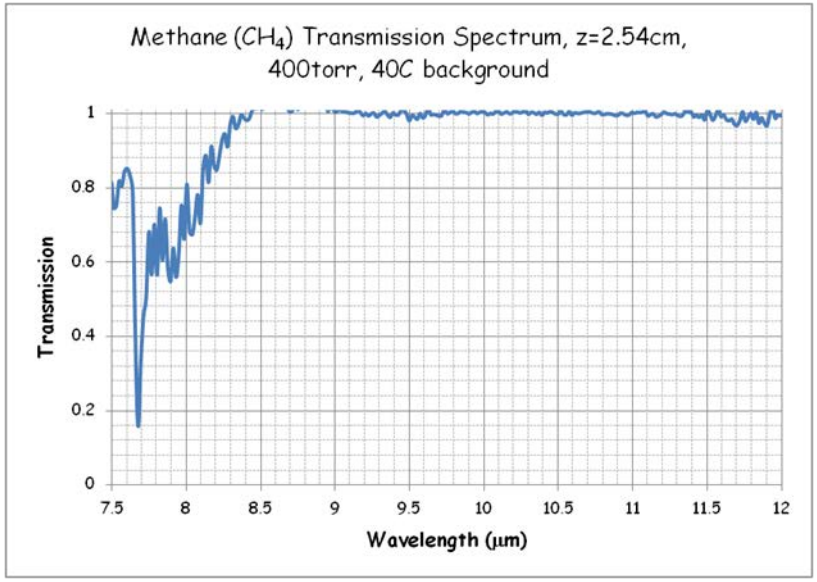


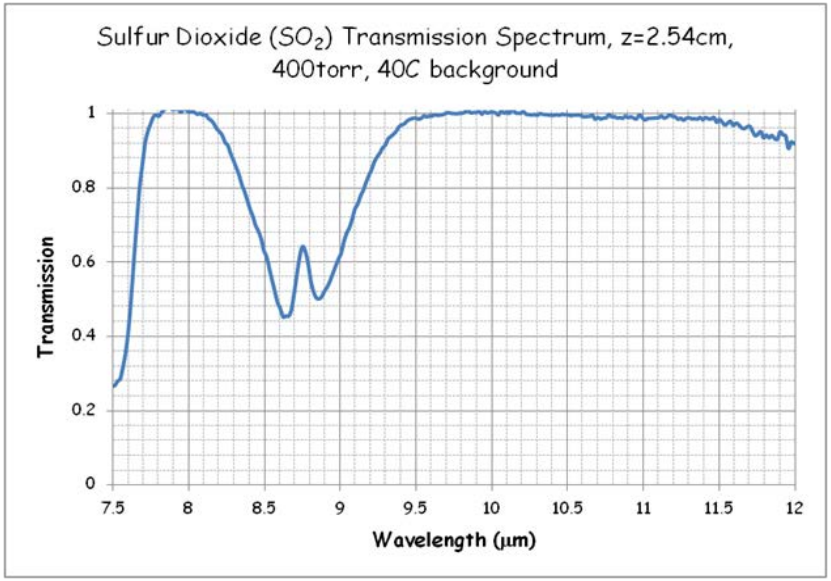
Sensor Calibration



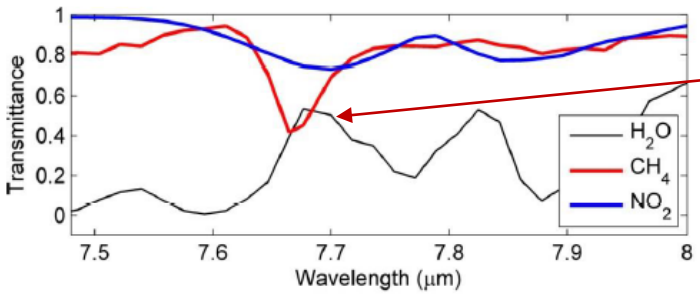


The typical observation technique is to image either in absorption or transmission mode using a variable temperature blackbody behind the gas cell. The gas cell is positioned in front of the entrance aperture of the vacuum housing.

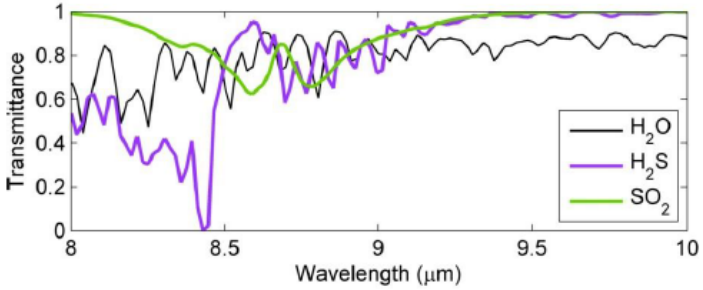




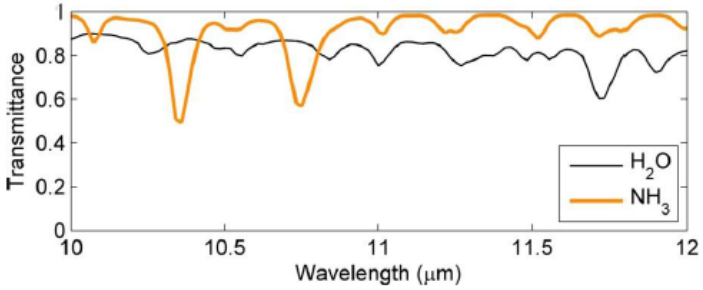
Plume retrievals and spectra



Need accurate atmospheric correction to remove water vapor absorption effects from signal

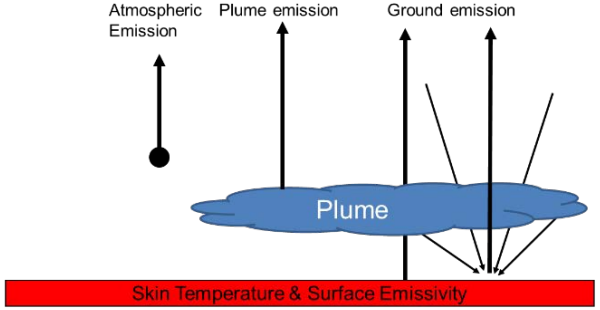


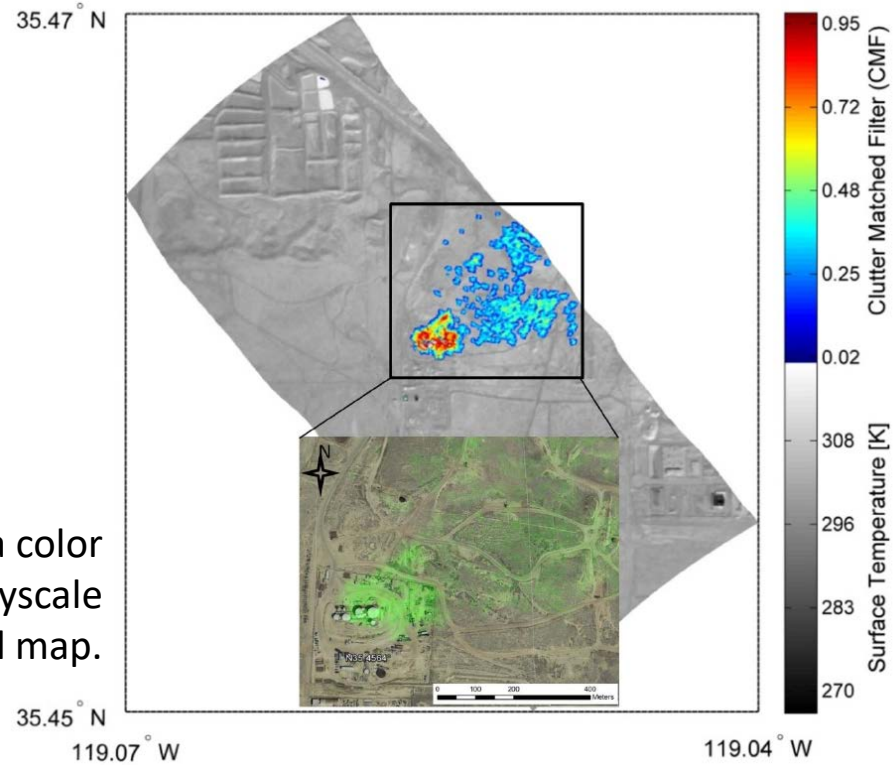
Spectral retrieval of various trace gas species



Sensor Radiance

$$L_i(\theta) = \underbrace{L^{path}}_{\text{Atmospheric Emission}} + \underbrace{L^{plume}\tau^{atm}}_{\text{Plume emission}} + \underbrace{L^{gnd}\tau^{atm}\tau^{plume}}_{\text{Ground emission}}$$





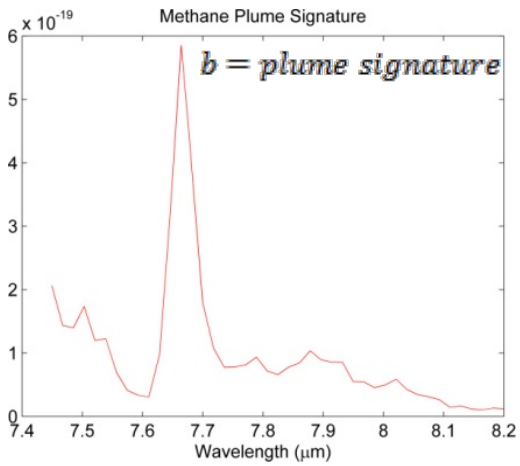
Higher-level plume visualization images showing a color Clutter Matched Filter (CMF) algorithm overlay on grayscale surface temperature image on a geospatial map.

Plume Detection: Cluster-Tuned Matched

1. HyTES datacube of radiances, ***R***

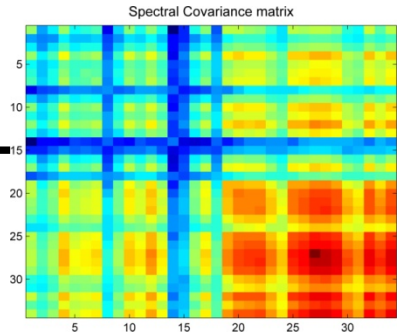
$R \in (N,n)\ N = pixels, n = bands$

2. Search for spectral signature, ***b***, assumed to be linearly superimposed on background clutter. Gas signature ***b*** is extracted from Hitran database.



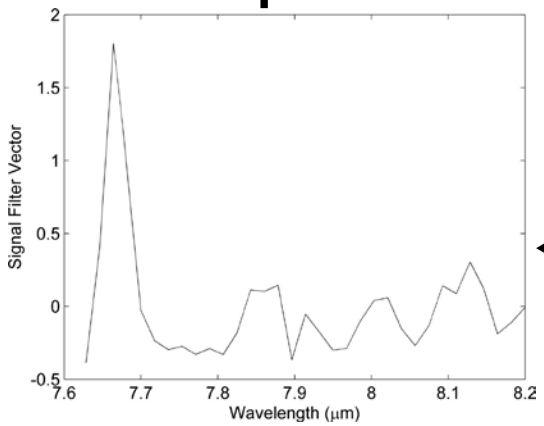
3. Calculate the spectral covariance matrix of input radiances, ***K*** :

$$K = \frac{1}{N} R R^T,$$

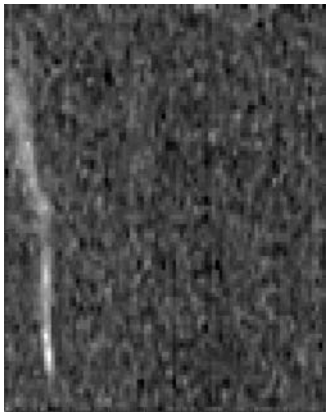


4. Compute signal filter vector, ***q***:

$$q = \frac{K^{-1} b}{\sqrt{b^T K^{-1} b}}$$



$$Plume = q^T R$$

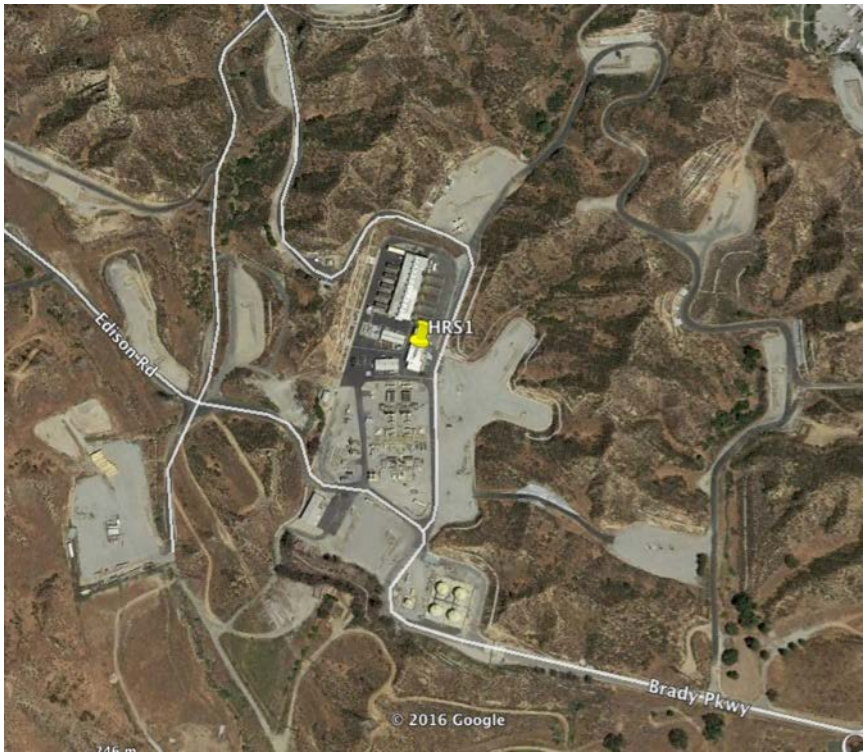


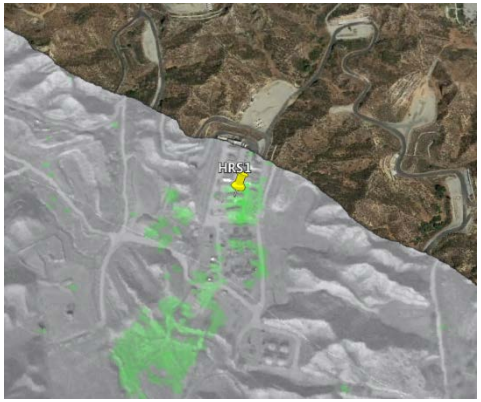
5. Applying signal filter vector to datacube, ***R*** produces plume signature image.

Honor Ranch Leak Discovery

SoCalGas Honor Rancho Facility is located within the Santa Clarita Valley, California.

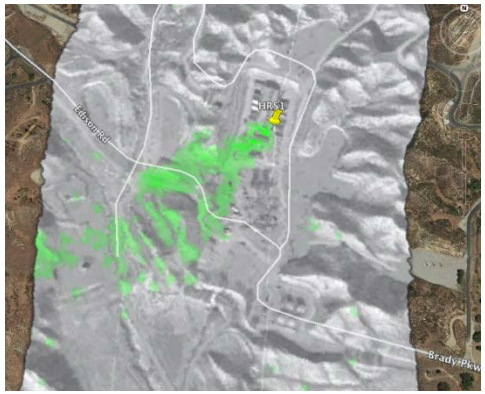
The facility is about one-fourth the size of the Aliso Canyon storage area.





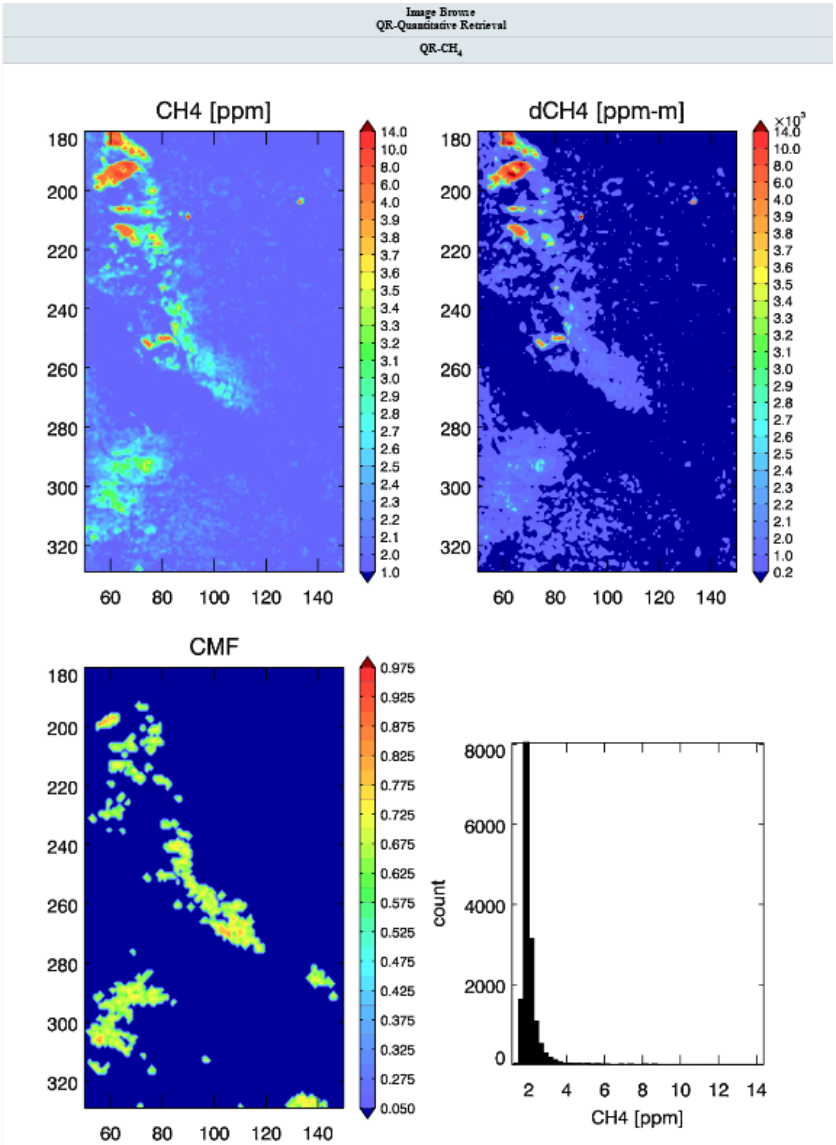
Jan 21

Jan 26, run 1



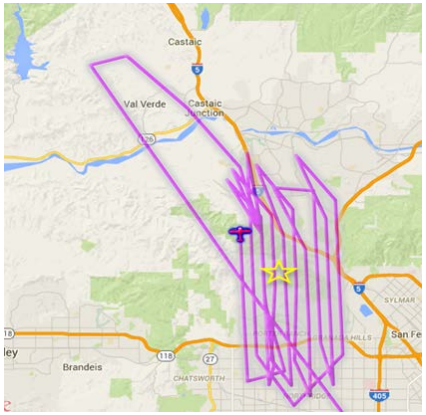
Jan 26, run 2

Aliso Canyon: Porter Ranch

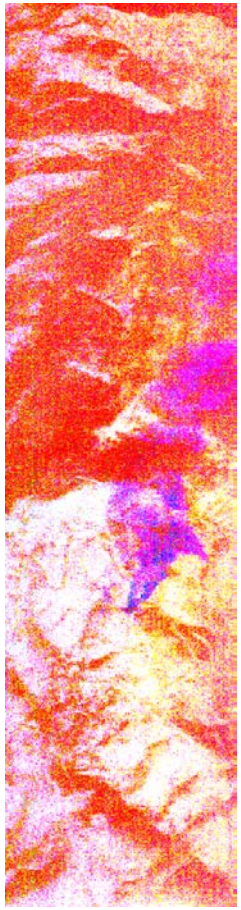


Quantitative retrievals (QR) of methane concentration

- Began Oct 23; plugged on Feb 11
- Complex, highly variable methane source
- Megacities Carbon Project: sustained monitoring of LA basin methane emissions (pre-leak, ongoing)



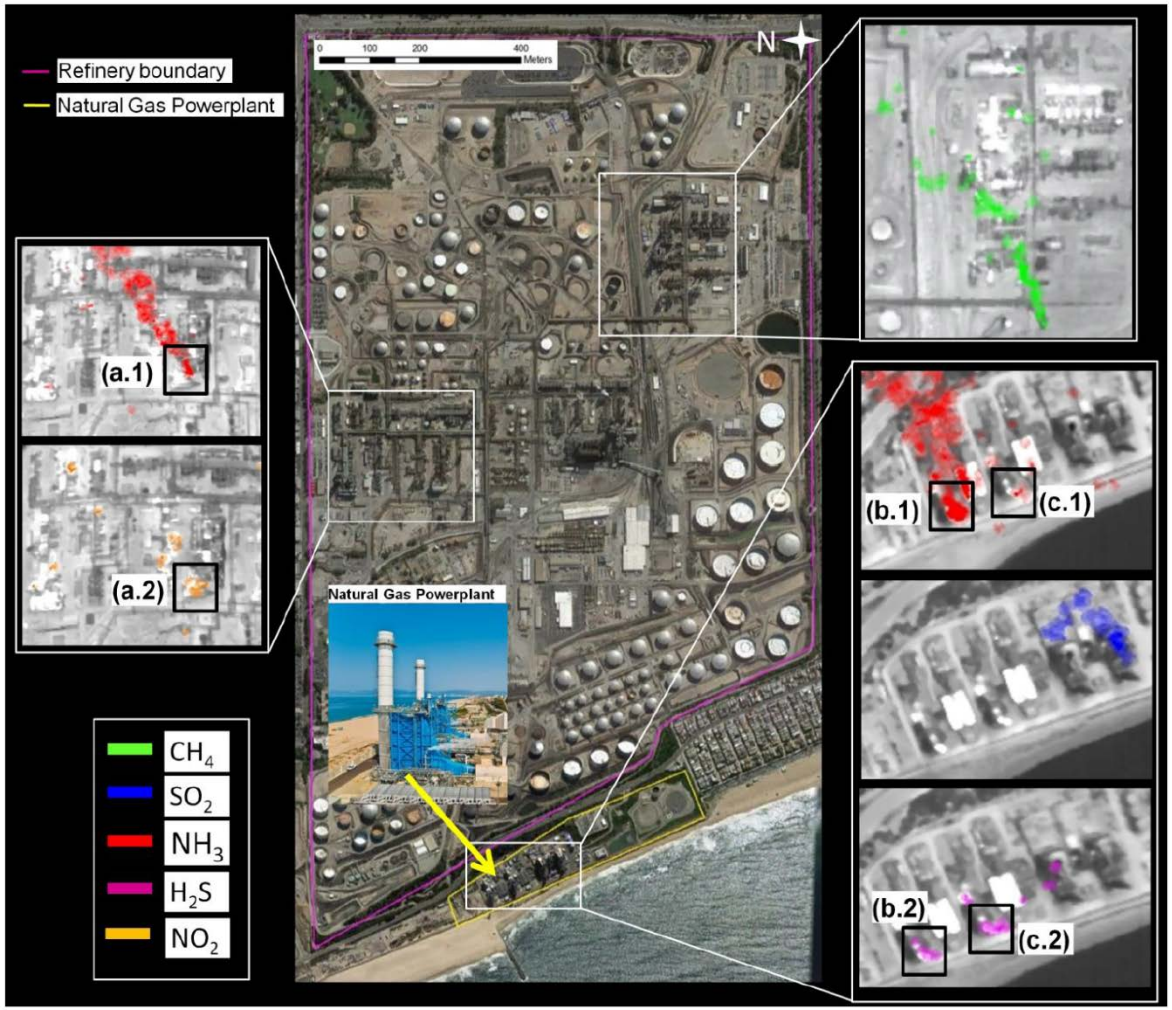
Flight lines



Simple 3-band PCA

Kuai, Le, et al. "Characterization of anthropogenic methane plumes with the Hyperspectral Thermal Emission Spectrometer (HyTES): a retrieval method and error analysis." *Atmospheric Measurement Techniques* 9.7 (2016): 3165-3173.

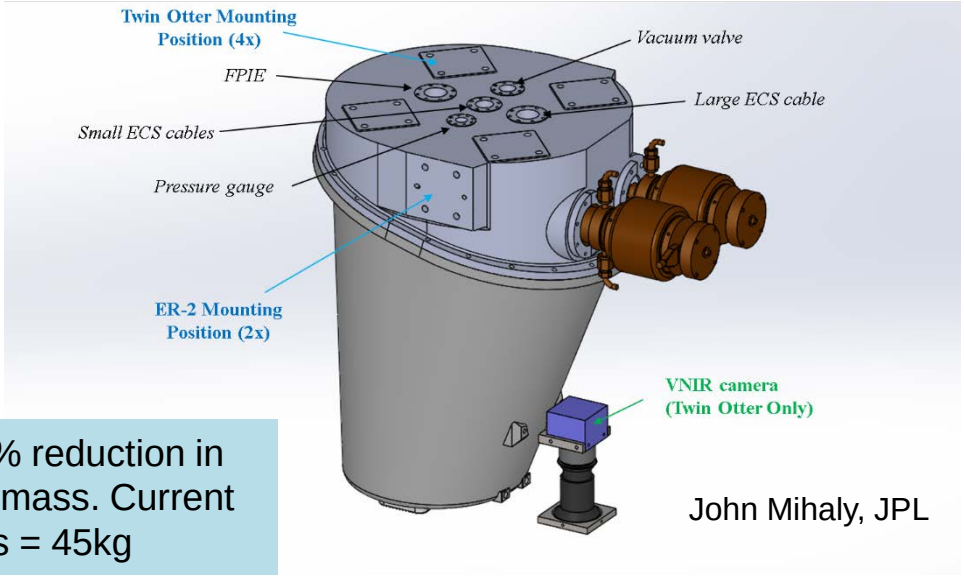
Multi-species



A HyTES Multi-species gas detection example showing a Google Earth image (center) of the area covered by a HyTES flightline over a refinery (magenta outline) and a natural gas powerplant (yellow outline) near El Segundo, CA. The insets show HyTES imagery of five detected trace gases (CH4, NO2, NH3, H2S, and SO2) highlighted in different colors and overlayed on retrieved surface temperature data in grayscale.

Hulley, Glynn C., et al. "High spatial resolution imaging of methane and other trace gases with the airborne Hyperspectral Thermal Emission Spectrometer (HyTES)." Atmospheric Measurement Techniques 9.5 (2016): 2393-2408.

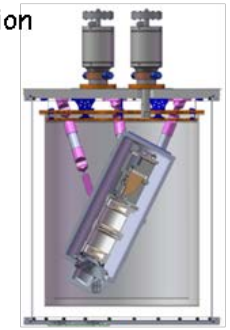
HyTES New ER-2 Platform

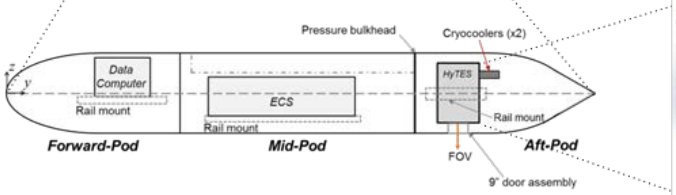


Nearly 50% reduction in scan head mass. Current mass = 45kg

John Mihaly, JPL

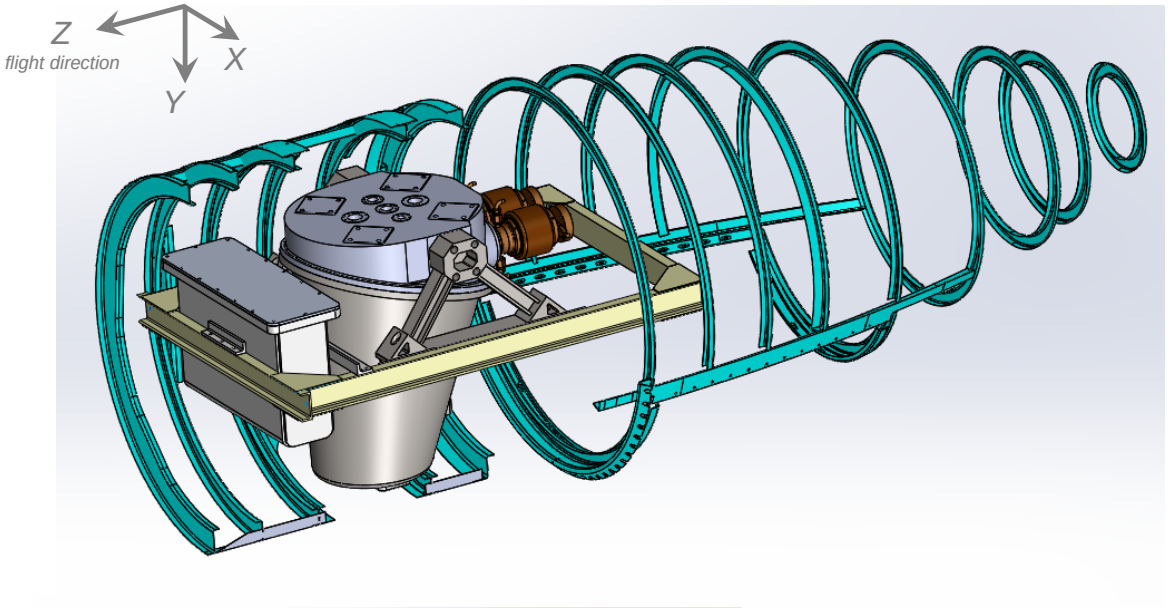
HyTES enclosure size reduction for accommodation in ER-2 wing pod

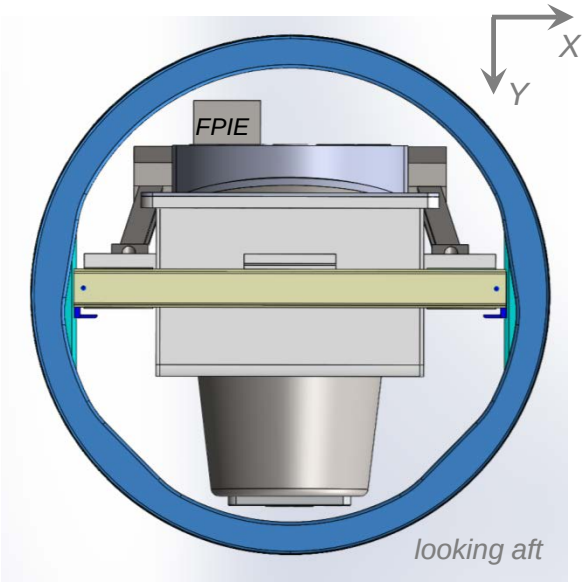


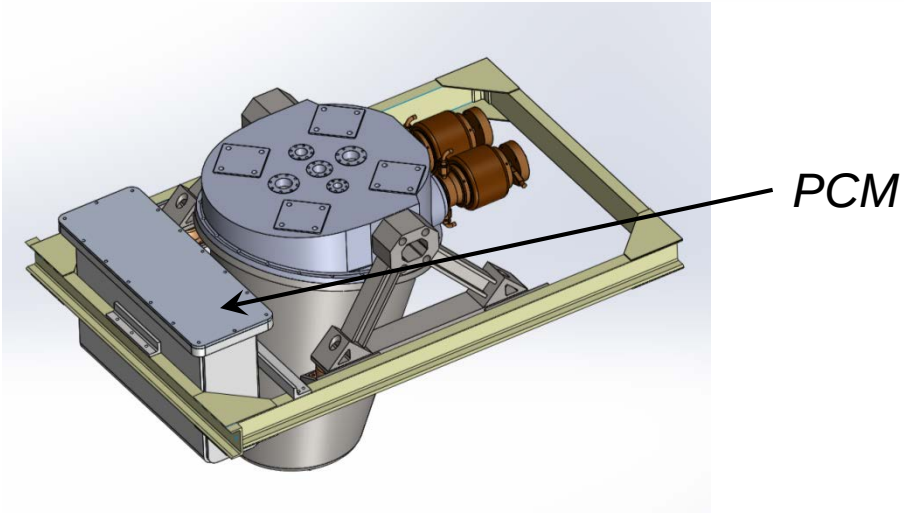


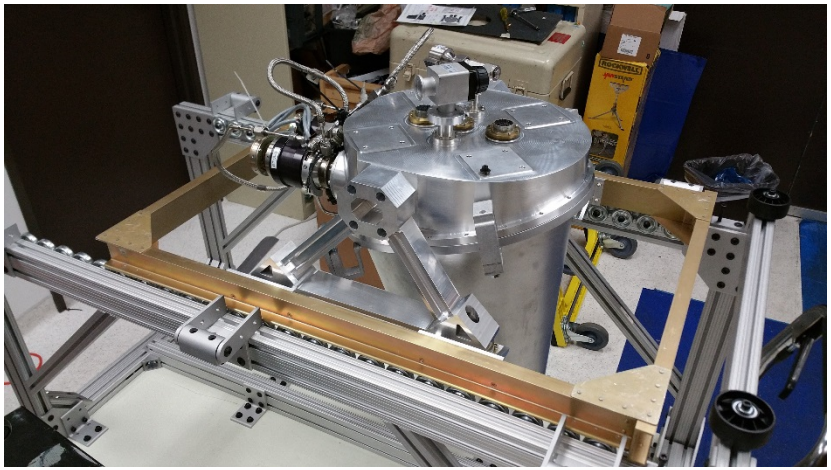
HyTES on the ER-2
Swath = 17km
GSD = 34m pixels
NEDT = 0.1C (with BIRD)

ER-2 Implementation









HyTES new scan head design in ER-2 Aft rail

HyTES Summary

- HyTES has proven to be effective at spatially mapping trace gas plumes from low altitude.

- The HyTES platform modification is complete. It's now ready to fly on the ER-2 (scheduled for November 2016).

- Future high altitude flights (beyond 2016) as well as low altitude Twin Otter flights will benefit from the BIRD higher sensitivity detector technology. It's also hoped that improving the detector sensitivity will translate into refining our quantitative trace gas retrievals.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

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