Airborne thermal infrared remote sensing using the Hyperspectral Thermal Emission Spectrometer (HyTES)

Presented at:
2017 Earth Science Technology Forum (ESTF2017)

Date: Wednesday 14 June 2017
8:30AM

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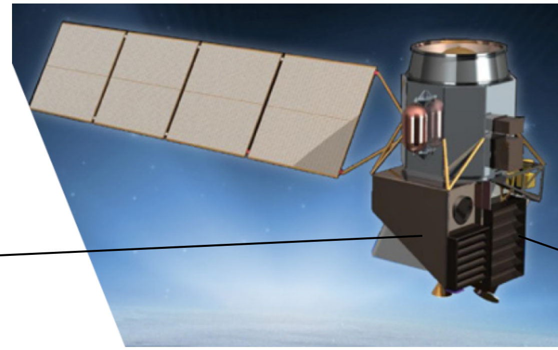
Outline

- **Brief background of the effort**
- **HyTES sensor description**
- **Recent campaigns**
- **Modified HyTES for both ER-2 and Twin Otter**
- **Concluding remarks**

HyspIRI Background

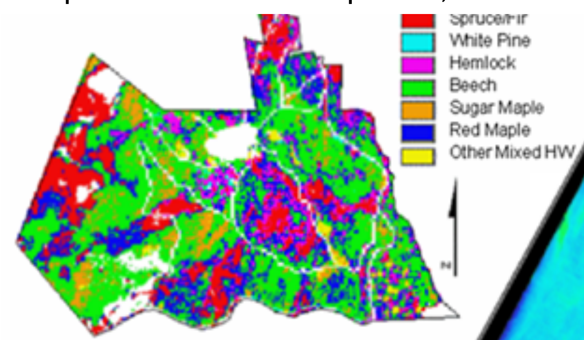
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

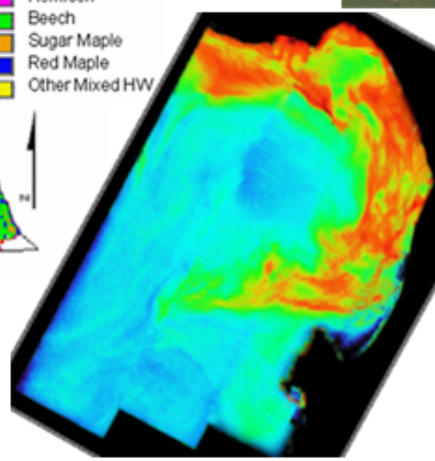


VSWIR: Plant Physiology and Function Types (PPFT)

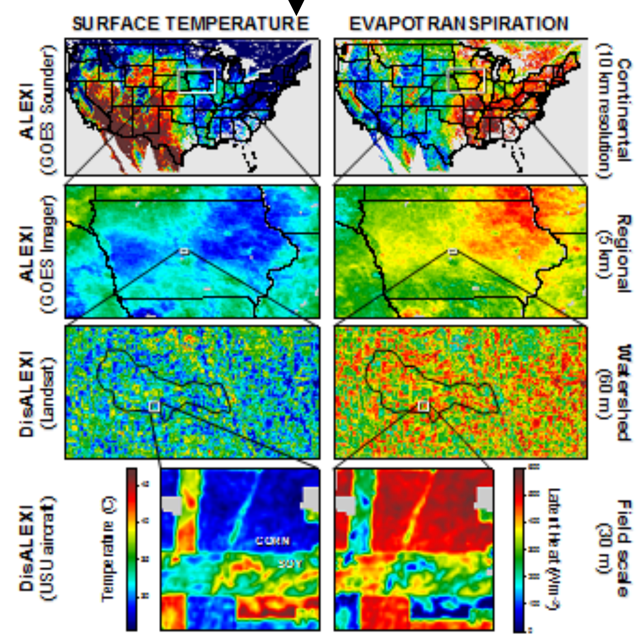
Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH



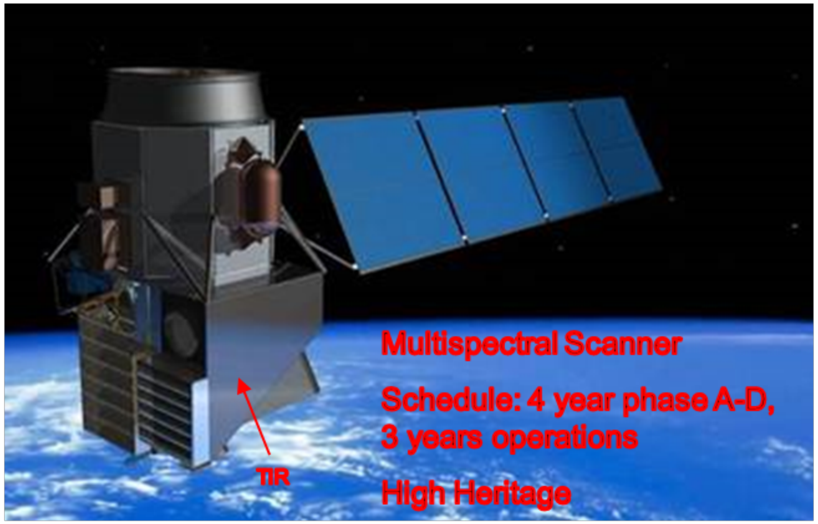


Red tide algal bloom in Monterey Bay, CA



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)*

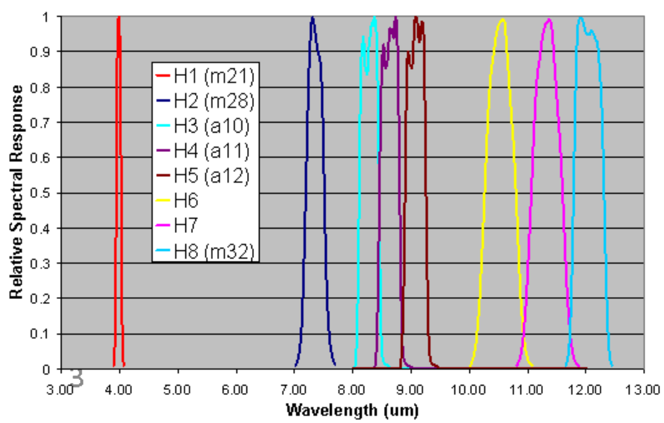
– *How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?*

- *TQ5. Earth surface composition and change, (AP,JC)*

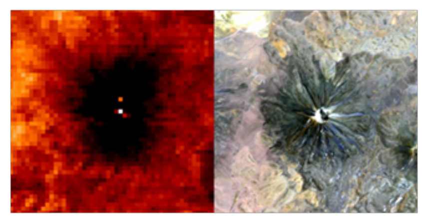
– *What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?*

Measurement:

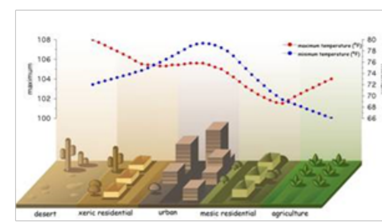
- 7 bands between 7.5-12 µm and 1 band at 4 µm
- 60 m resolution, 5 days revisit
- Global land and shallow water



Andean volcano heats up

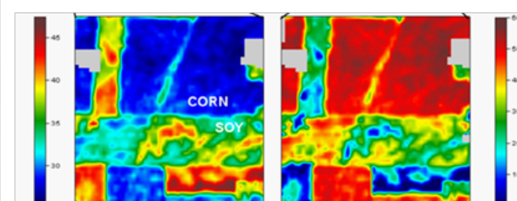


Urbanization



Volcanoes

Water Use and Availability



Surface Temperature

Evapotranspiration

ECOSTRESS Project Overview

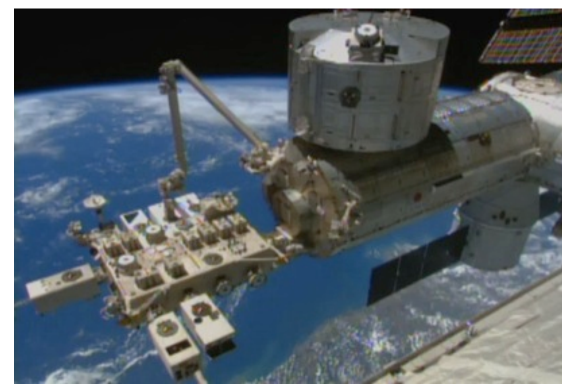
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) is an Earth Venture Instrument-2 on the ISS

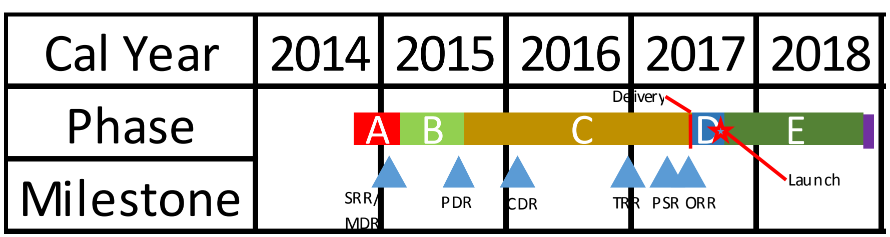
Primary Science Objectives

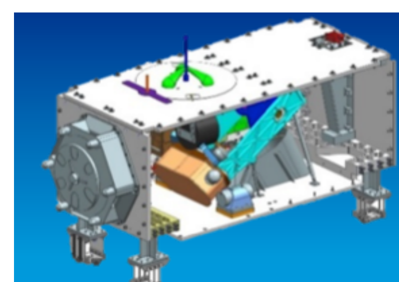
- Identify critical thresholds of water use and water stress in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant water uptake decline and cessation over the diurnal cycle
- Measure agricultural water consumptive use over the contiguous United States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

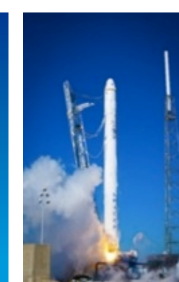
Features:

- 8–12.5 µm Radiometer with a 400km swath
- 5 TIR spectral channels, 1 SWIR band
- 2018 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





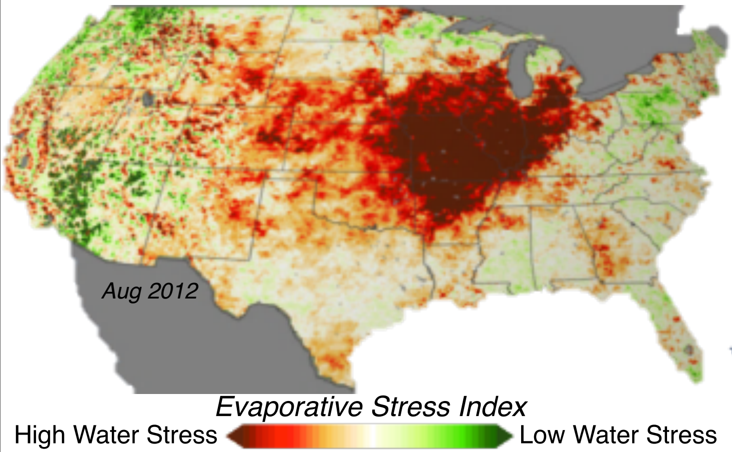




ECOSTRESS Science Overview

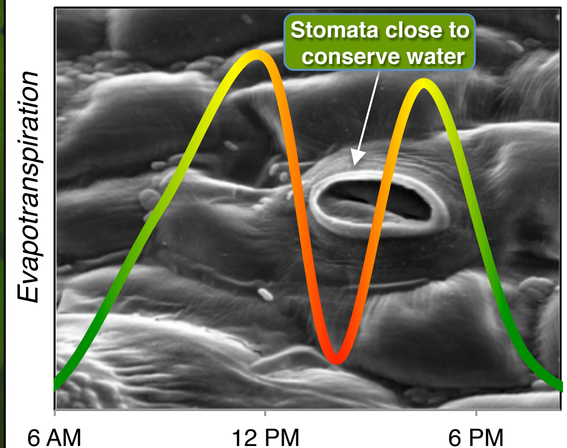
ECOSTRESS will provide critical insight into ***plant-water dynamics*** *and how* ***ecosystems change with climate*** *via* ***high spatiotemporal*** *resolution thermal infrared radiometer measurements of evapotranspiration (ET) from the International Space Station (ISS).*

Water Stress Threatens Ecosystem Productivity



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

Water Stress Drives Plant Behavior



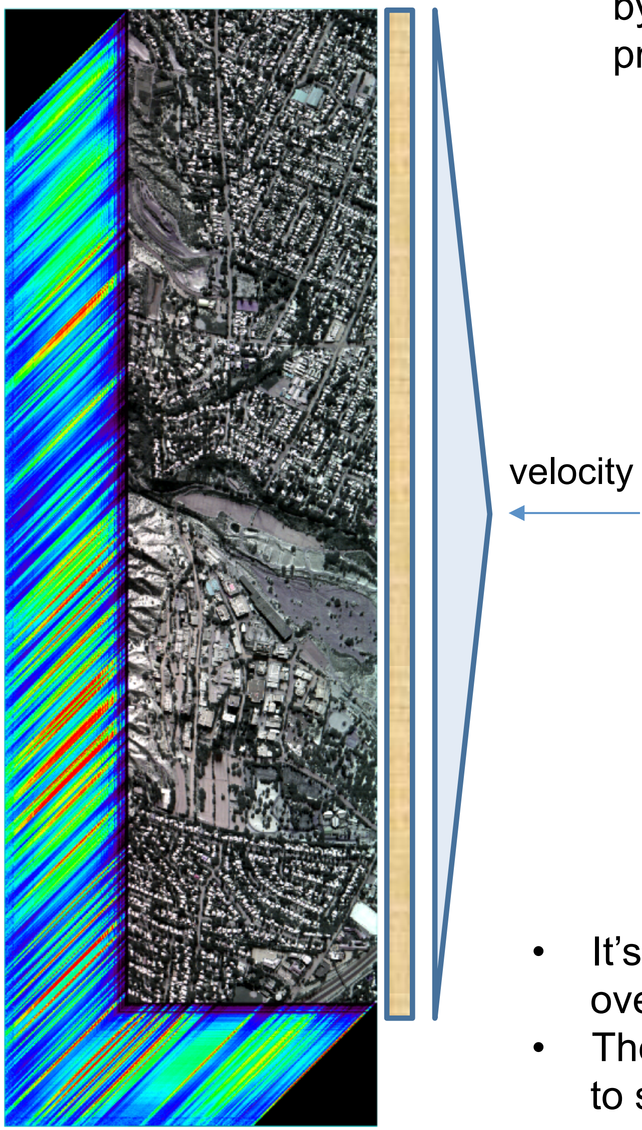
When stomata close, CO_2 uptake and evapotranspiration are halted and plants risk starvation, overheating and death.

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



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

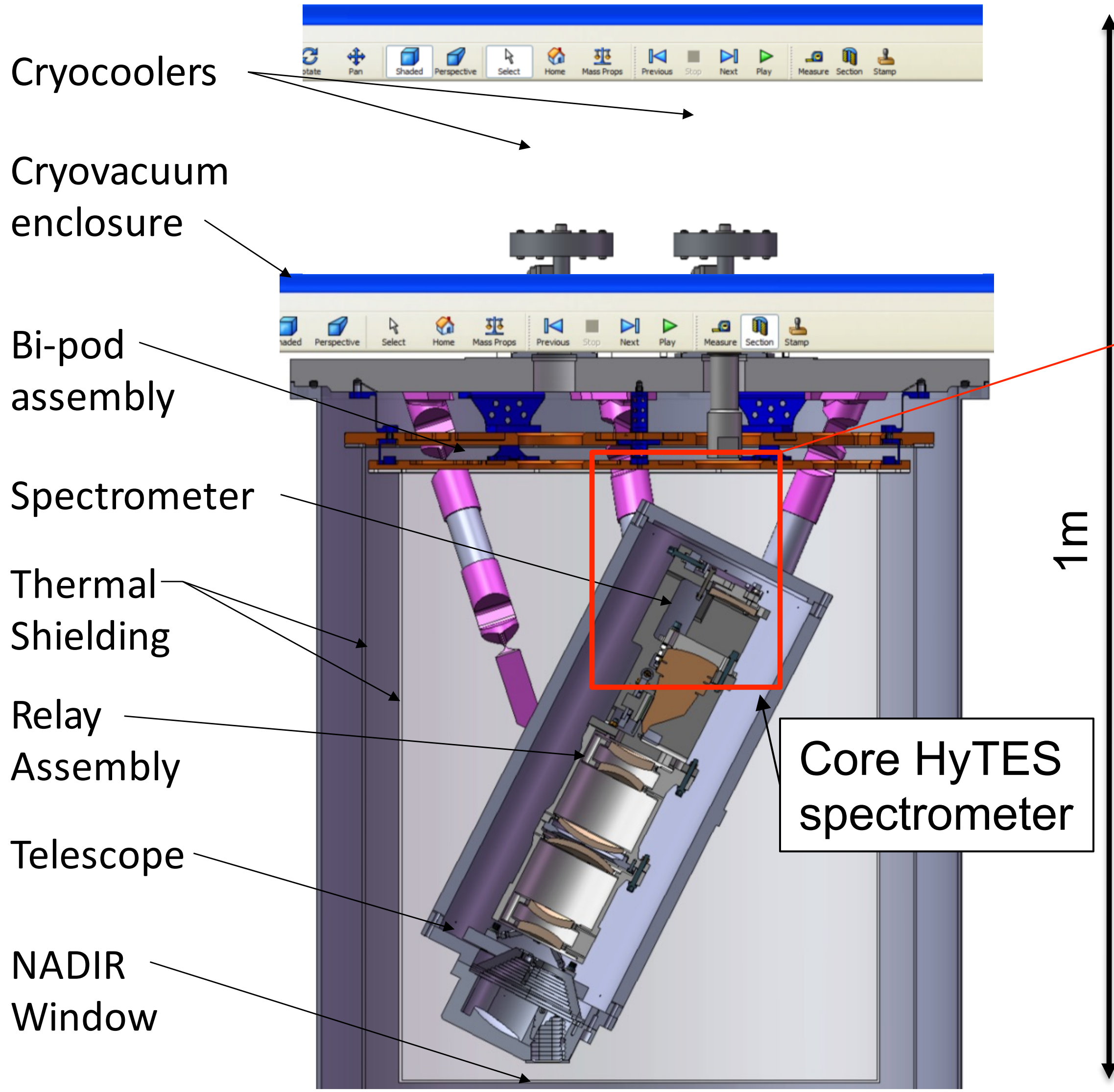
- HyTES was originally developed under an IIP to support HyspIRI by providing higher resolution *spatial and spectral* science products.

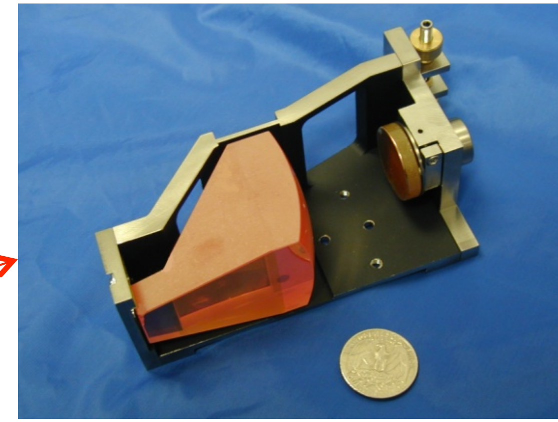
Basic Instrument Parameters

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's 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





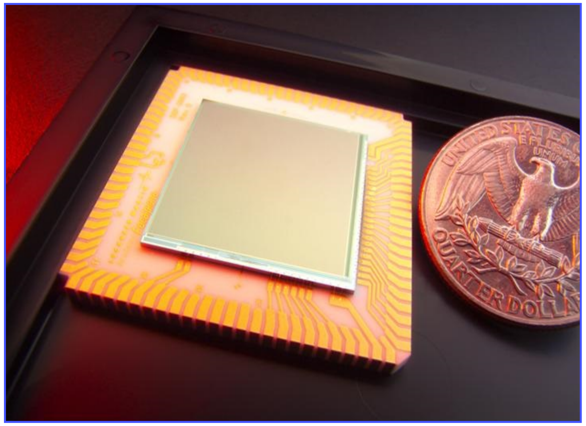
- HyTES flew its last campaign with this cryovac configuration in January 2016.
- It has been transitioned to an even smaller configuration for higher altitude deployment.
- The new smaller design still works on the twin otter.
- The new cryovac configuration was flown on the ER-2 in December 2016 and early 2017.

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

QWIP Technology

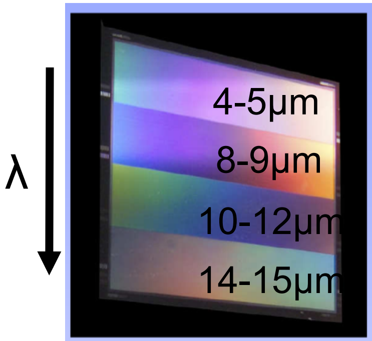
Quantum well infrared photodetector (QWIP) developed at JPL

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

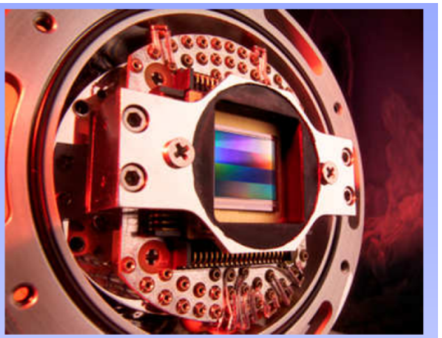


1024x1024 pixel single-band QWIP FPA

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



Four-band FPA

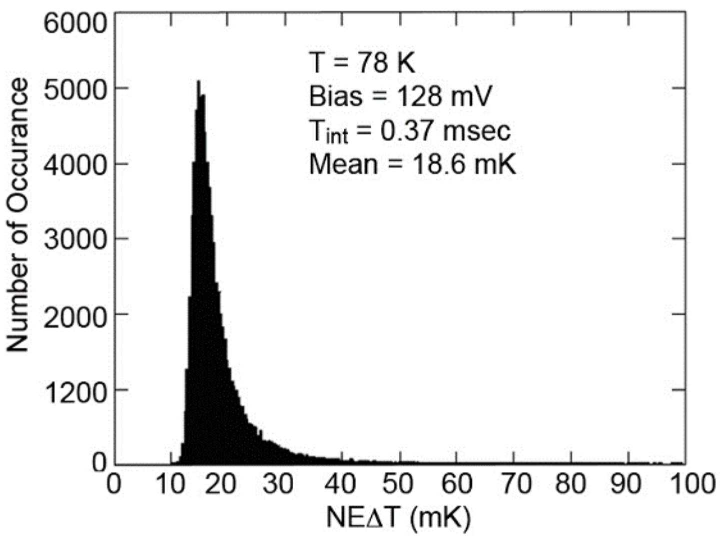


Four-band FPA in Dewar

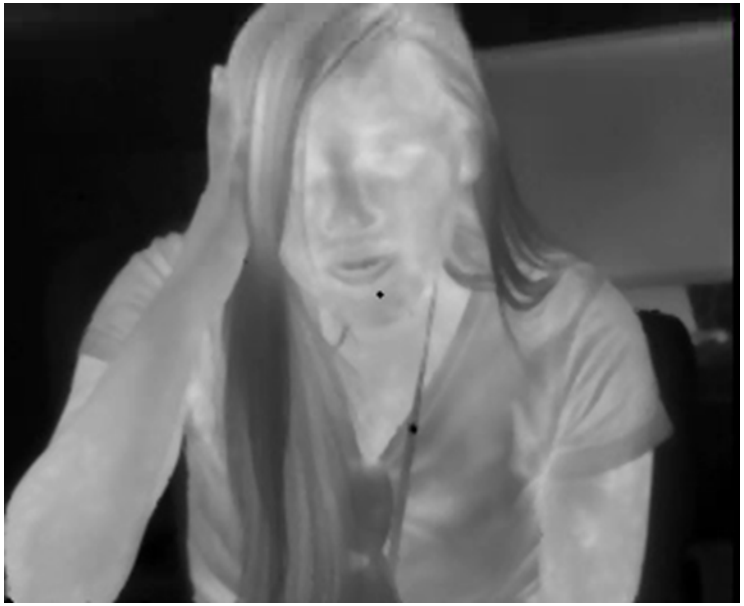
CBIRD Technology

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



HyTES Operating with BIRD Array

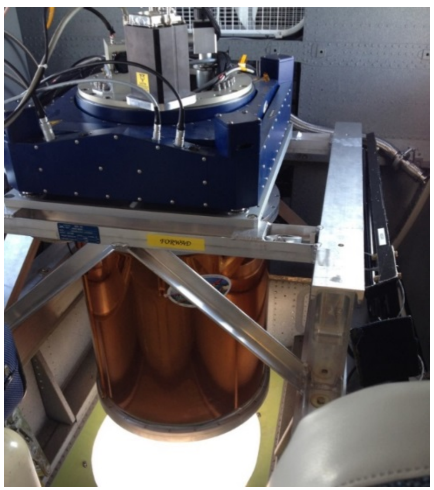
APPLIED PHYSICS LETTERS 95, 023508 (2009)

A high-performance long wavelength superlattice complementary barrier infrared detector

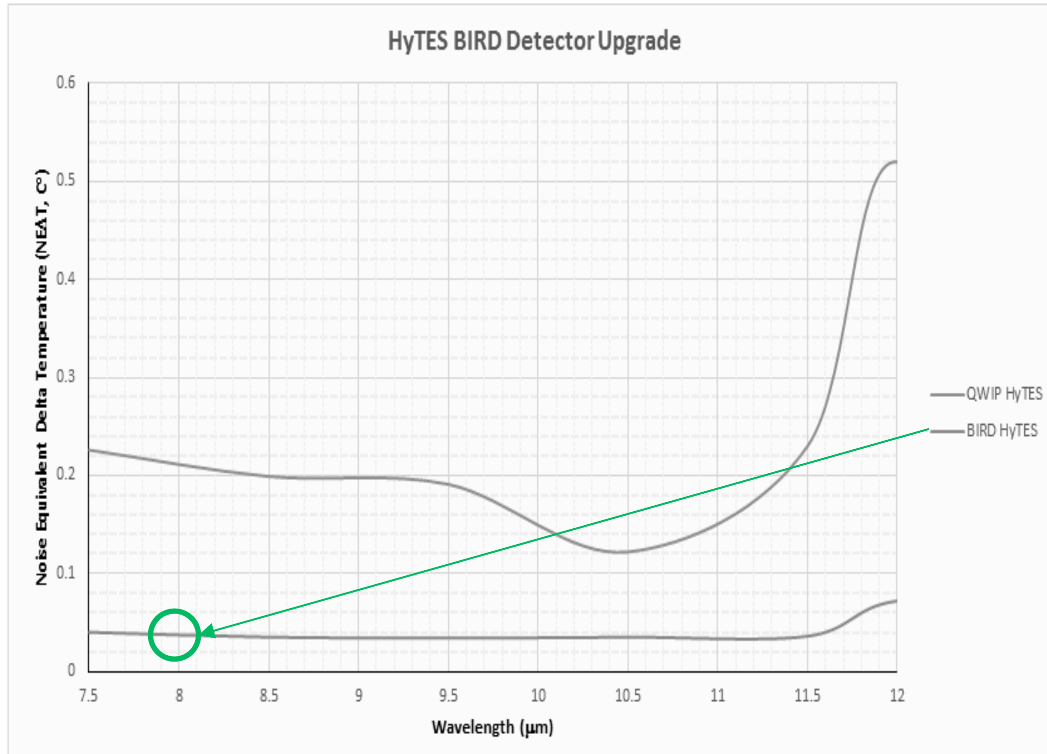
David Z.-Y. Ting,[a] Cory J. Hill, Alexander Soibel, Sam A. Keo, Jason M. Mumolo, Jean Nguyen, and Sarath D. Gunapala
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA

(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 campaigns since 2012:
- Notable calibration targets have been Cuprite, Death Valley, Salton Sea and Tahoe.
- Specific gas retrieval targets include: 4-Corners campaign, Porter Ranch Gas Leak

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

Recently, HyTES flew its first high altitude mission on NASA's ER-2
- Geometrical calibration targets
- Goldfield/Alkali mineralogical site

As of June 14, 2017, HyTES is flying on the Twin Otter with its modified scan head

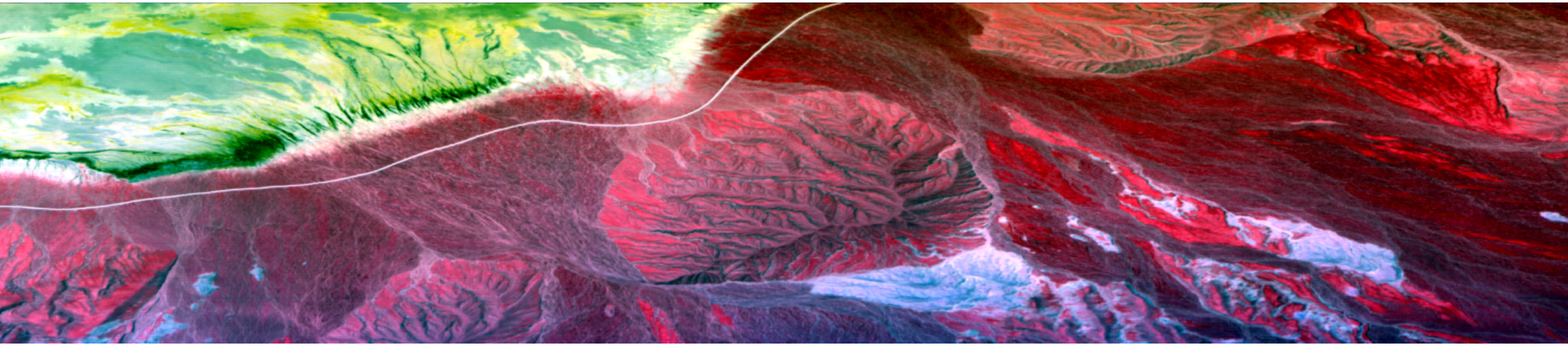
HyTES flight team

HyTES instrument team

HyTES Campaign Products

Death Valley, CA

Quartz alluvial fan



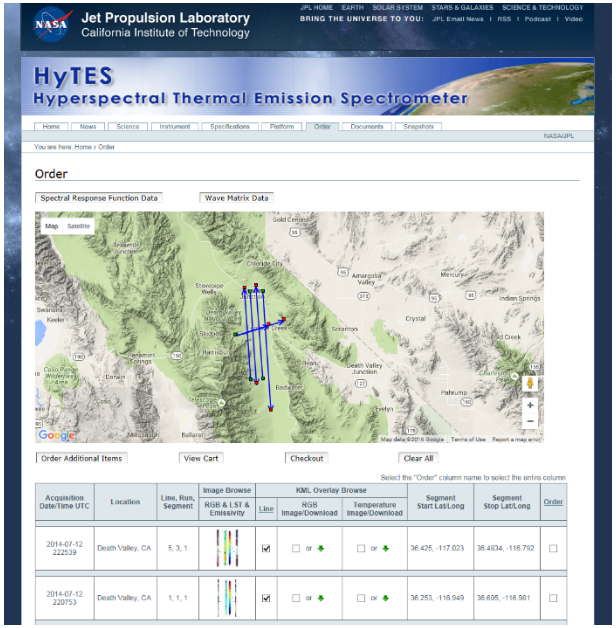
Carbonate

Basalt

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

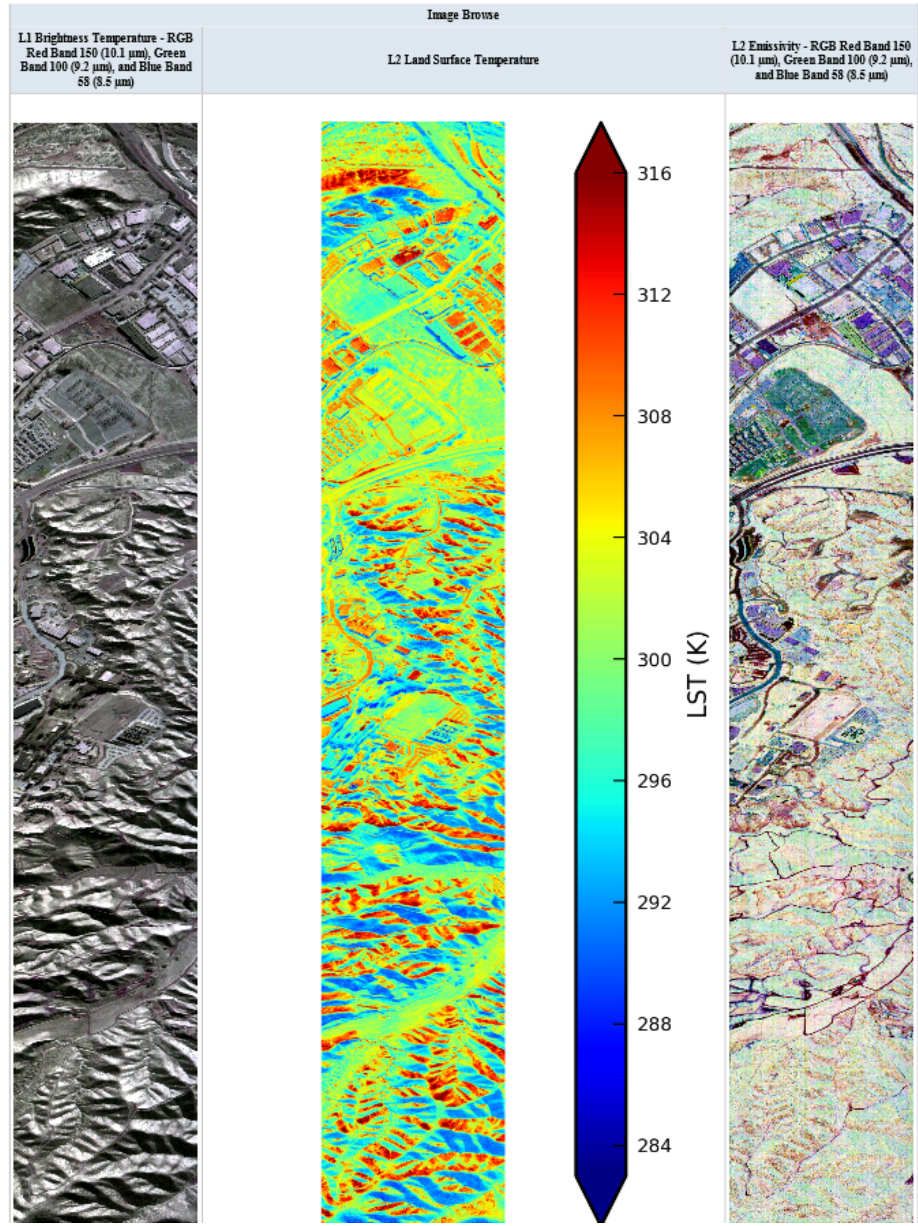
- Processed data from all previous flights can be found at the web portal shown to the right.
- One can browse quick looks and order higher level products.
- ATBD documentation is available from L1 to L3

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



Temperature Emissivity Separation

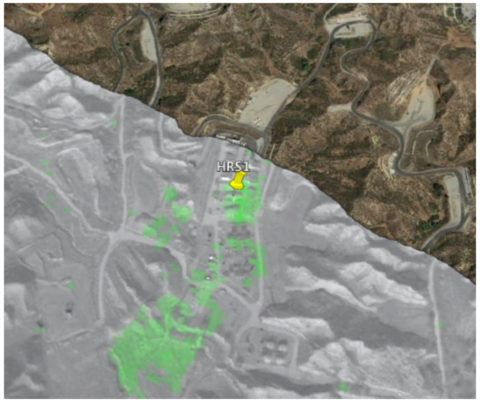
- Example of HyTES L2 products displayed side by side with L1 brightness temperature.
- For HyTES a modified version of the in-scene atmospheric correction (ISAC) approach initially developed for the SEBASS airborne hyperspectral sensor (Young et al. 2002) was implemented.
- Temperature Emissivity Separation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



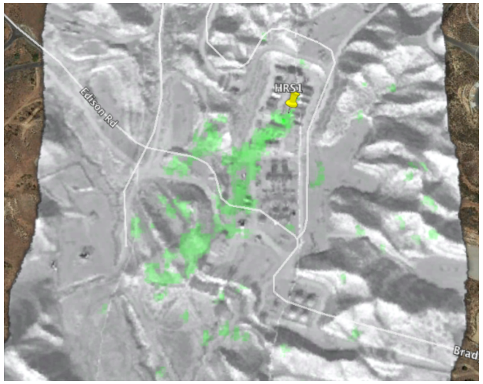
Honor Ranch

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

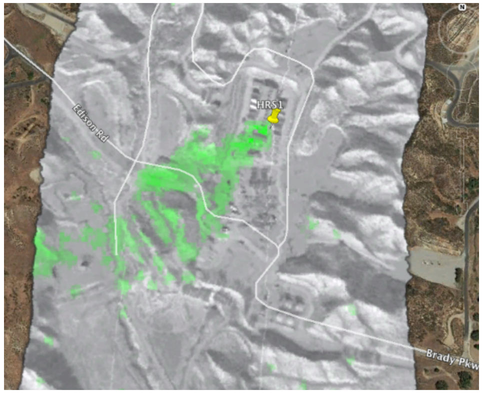
The facility is about one-fourth the size of the Aliso Canyon storage area.



Jan 21

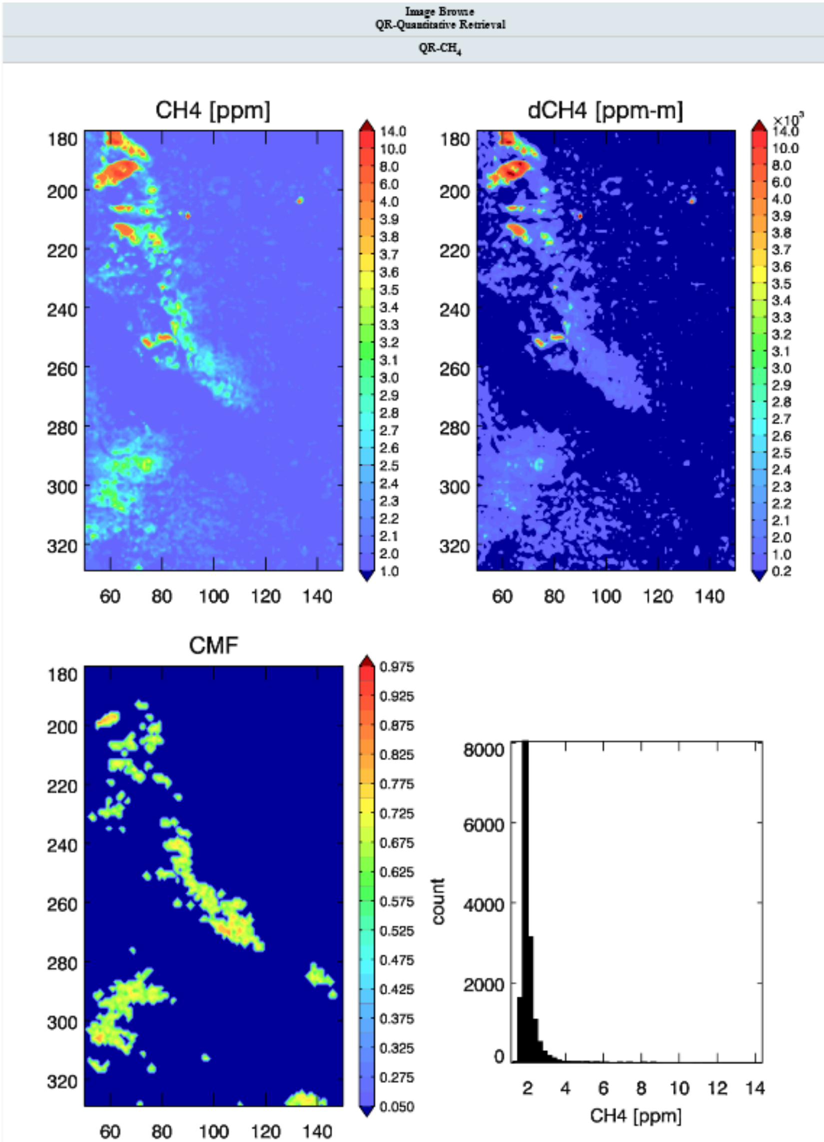


Jan 26, run 1



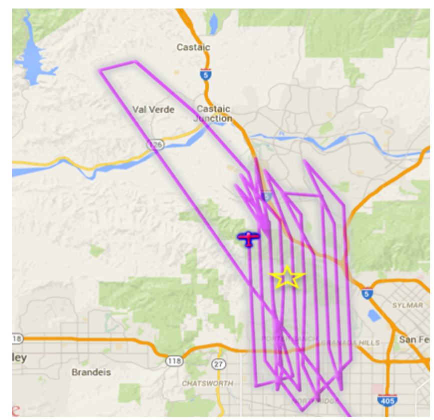
Jan 26, run 2

Aliso Canyon: Porter Ranch

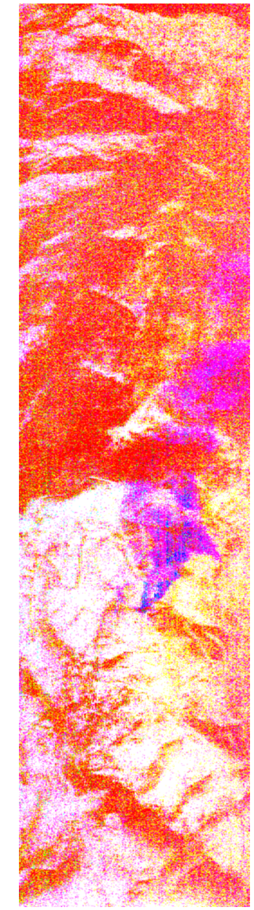


Quantitative retrievals (QR) of methane concentration

- 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)



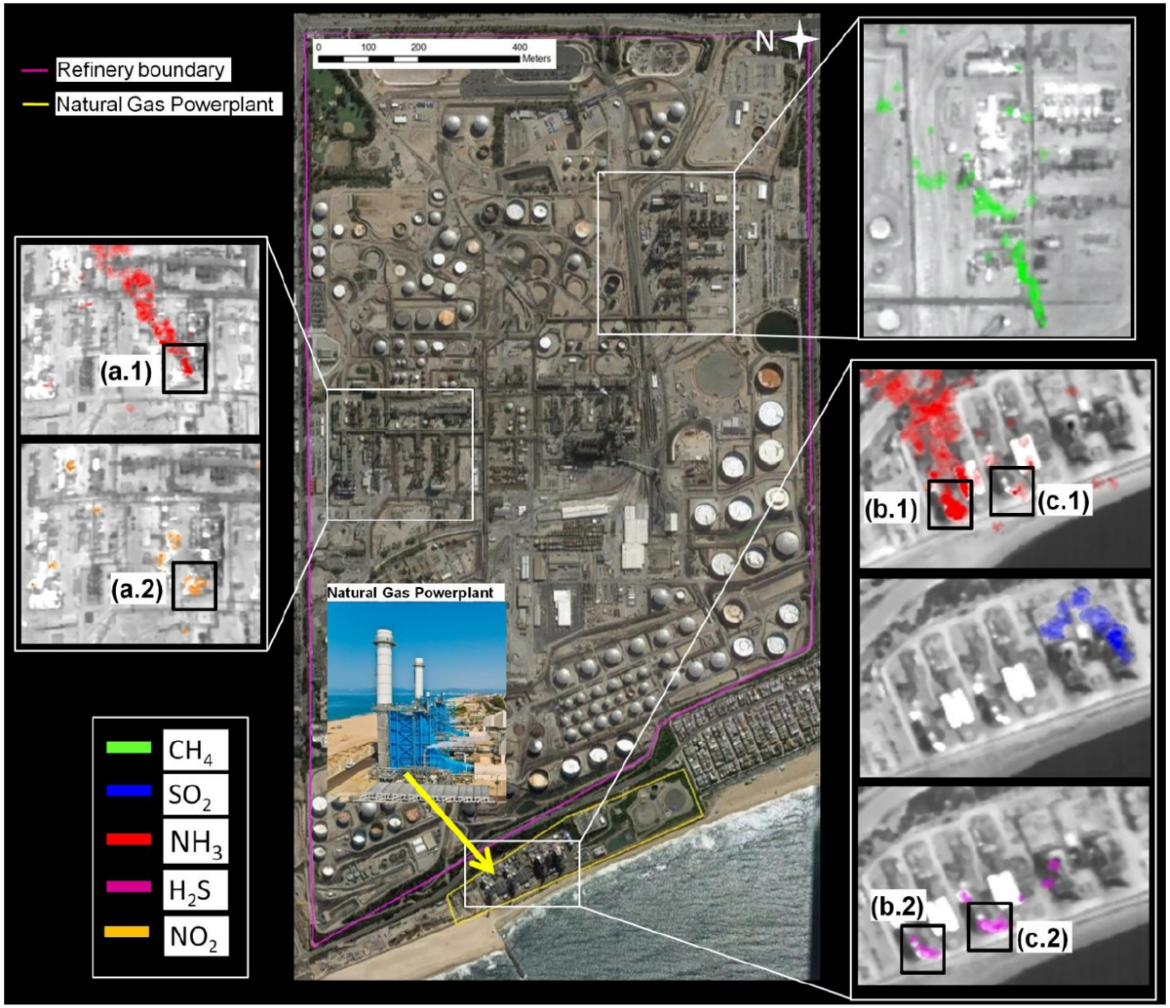
Flight lines



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.

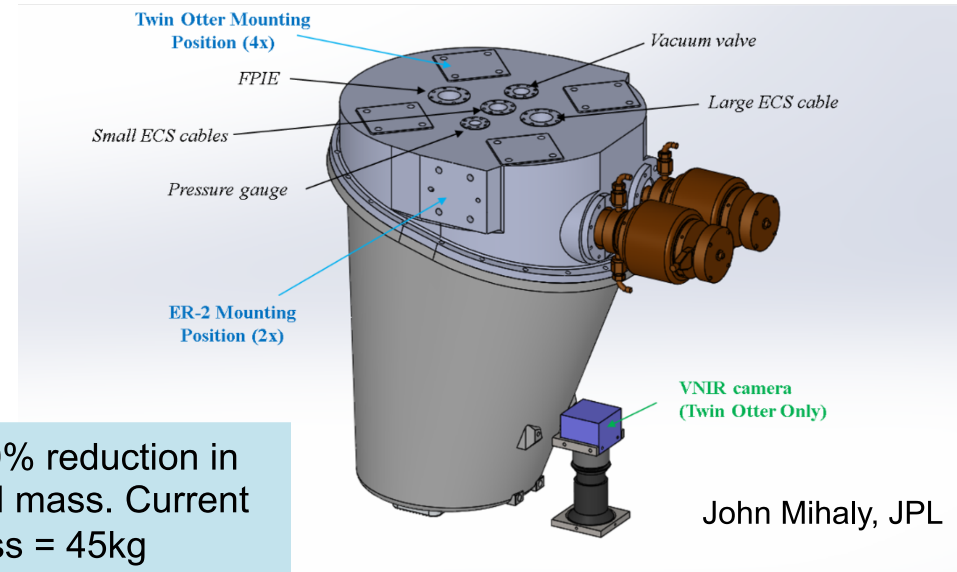
Multi-species



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.

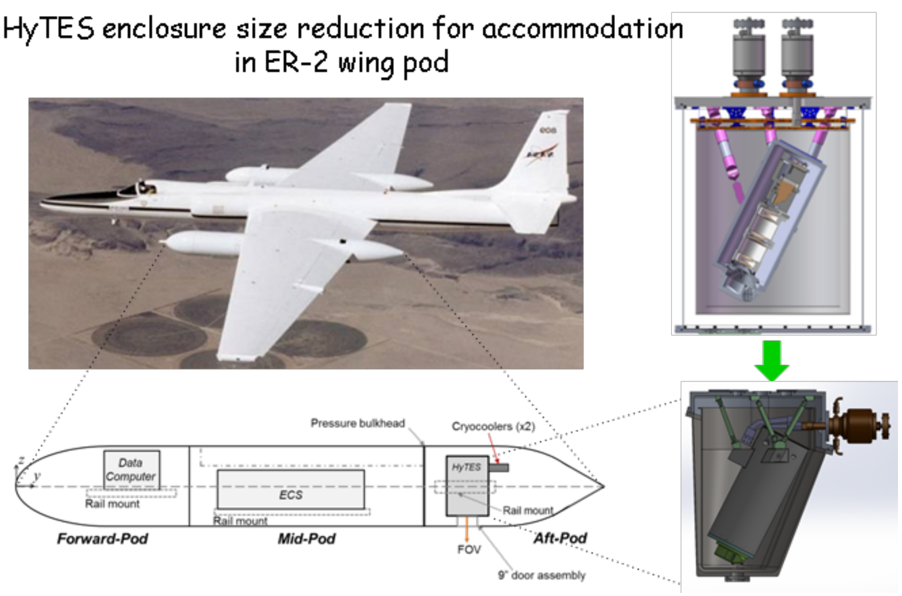
New ER-2 Platform



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

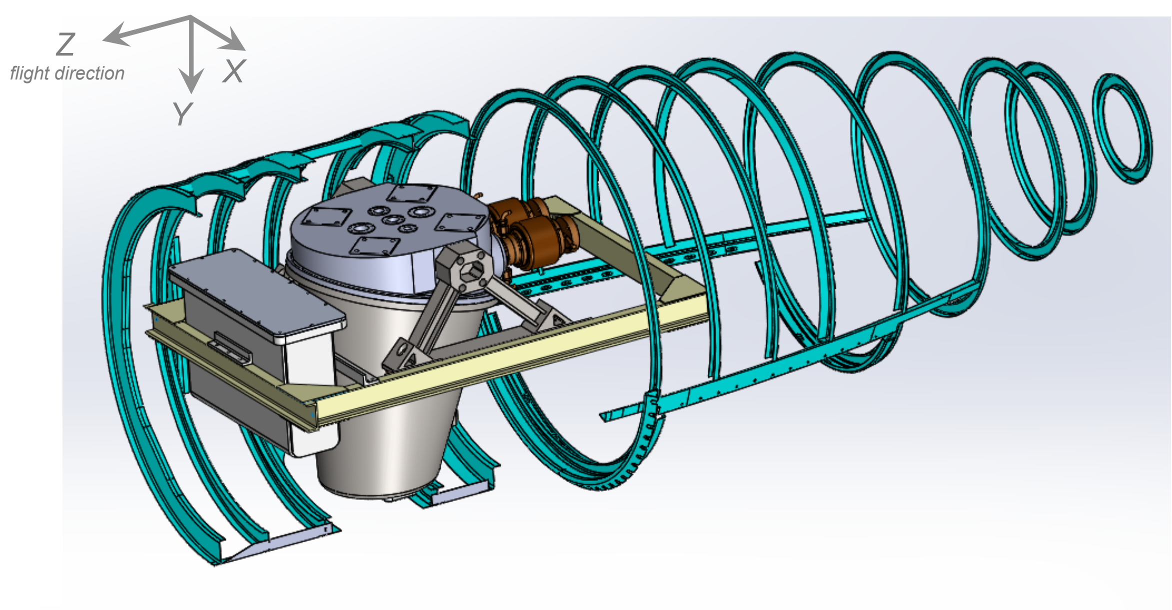
John Mihaly, JPL

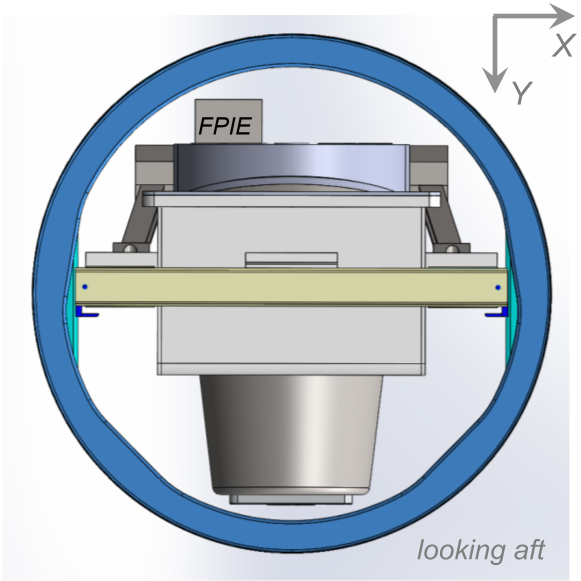
HyTES enclosure size reduction for accommodation in ER-2 wing pod

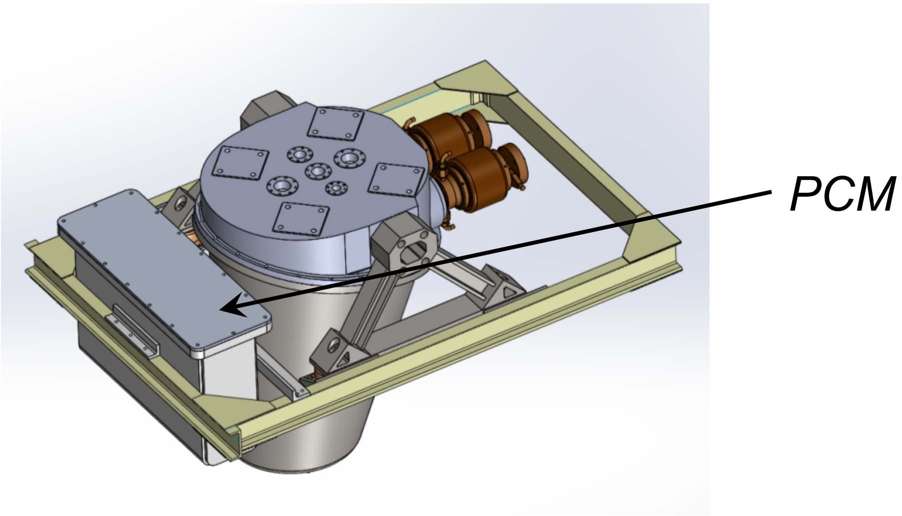


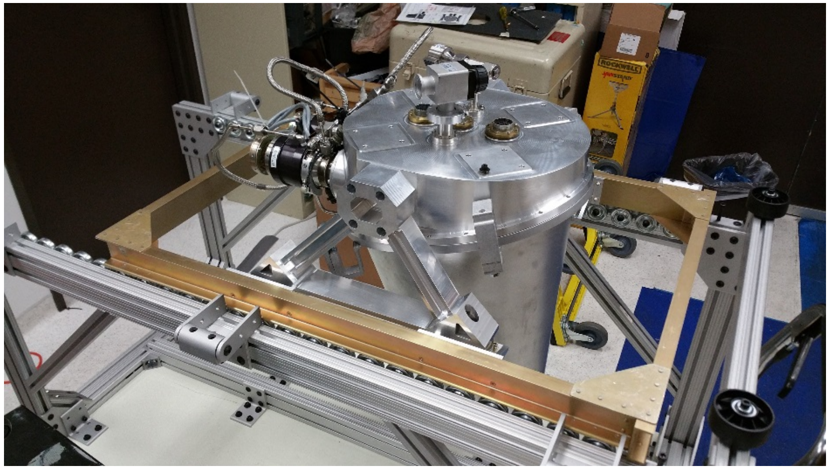
HyTES on the ER-2
Swath = 17km
GSD = 34m pixels
NEDT = 0.1C (with BIRD)

New ER-2 Platform









HyTES new scan head design in ER-2 Aft rail

New ER-2 Platform

GSE used to keep the scan head cold during transition.

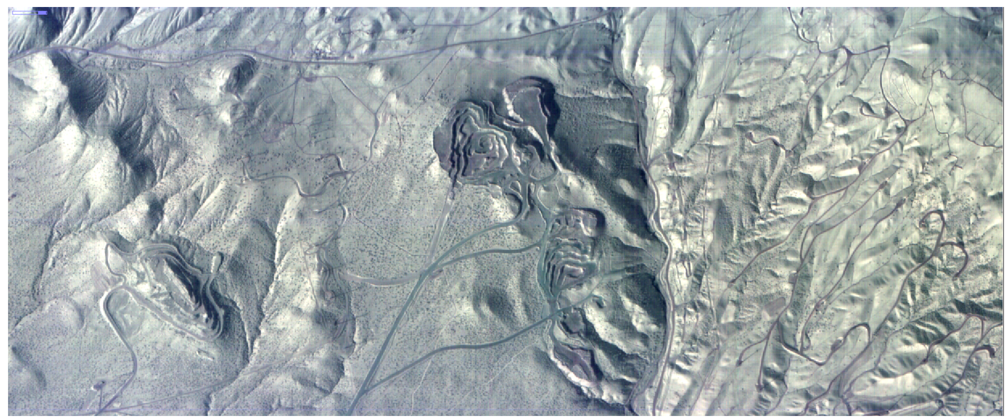
Installing the aft scan head pod going on

Installing the fore-body pod

New ER-2 Platform

Right after take off, Lancaster, CA

Altitude 15 ft



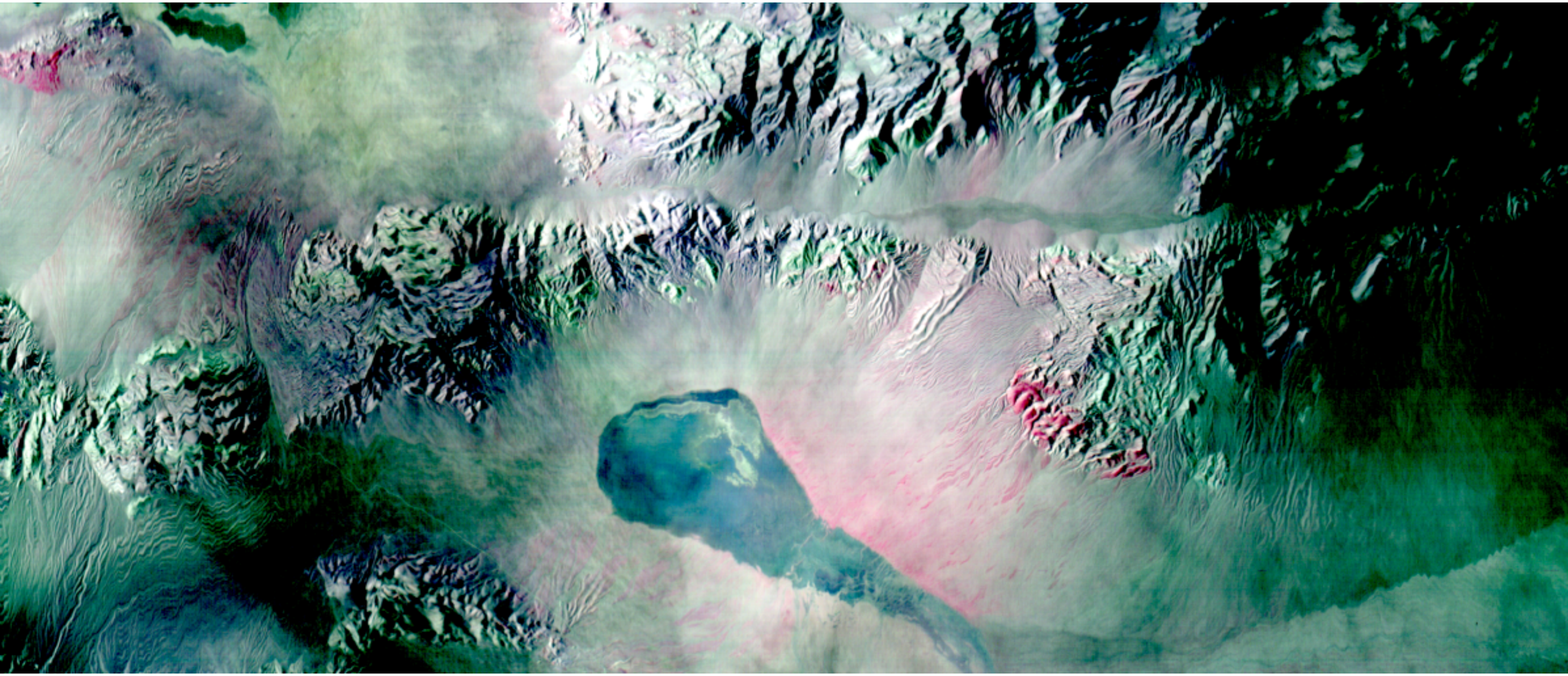
Near Tehachapi, CA

Altitude 25K ft

Alkali Lake, NV (geological depression)

Altitude 65K ft

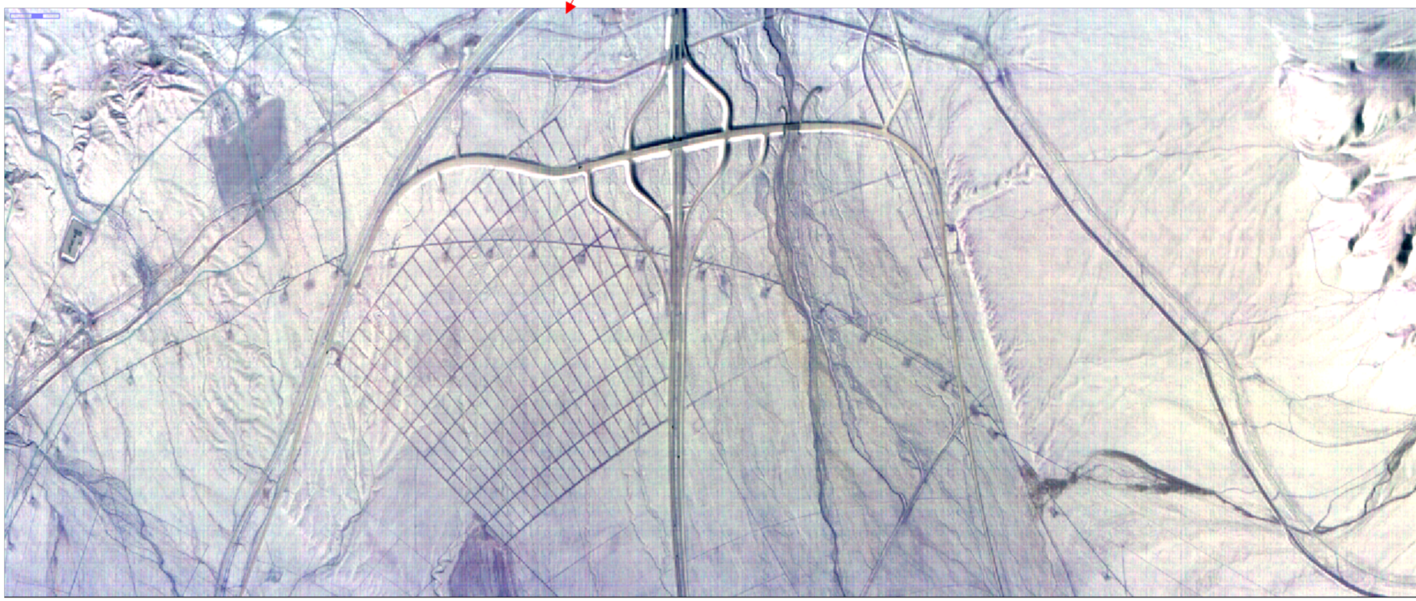
New ER-2 Platform

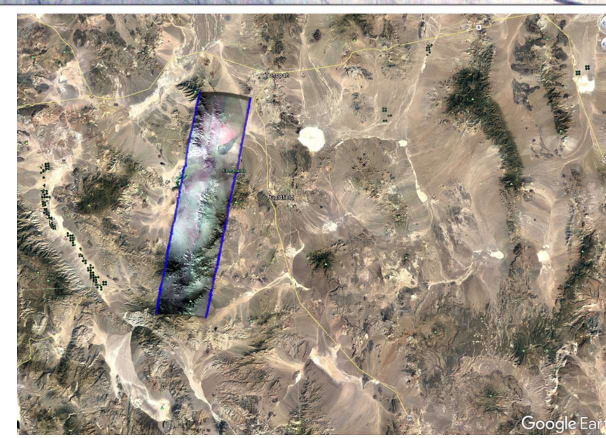


Alkali Lake, NV near Esmeralda and Cuprite
(geological depression)

New ER-2 Platform

Spatial calibration target near Mojave, CA

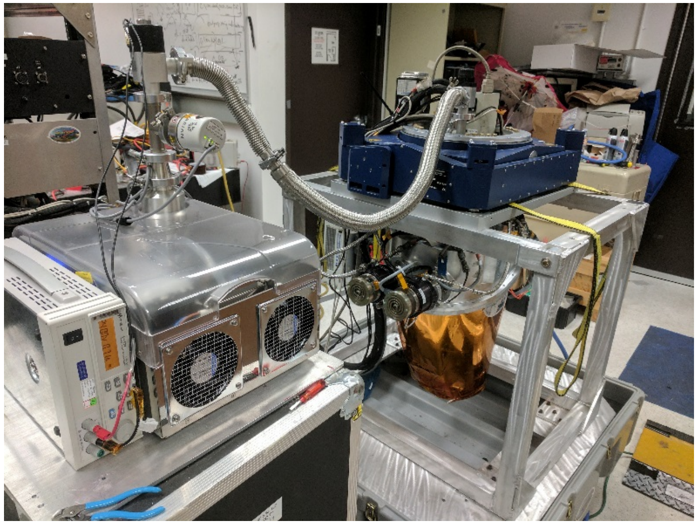




L1 product of Goldfield, NV overlaid on to google earth.

HyTES Back on the Twin Otter

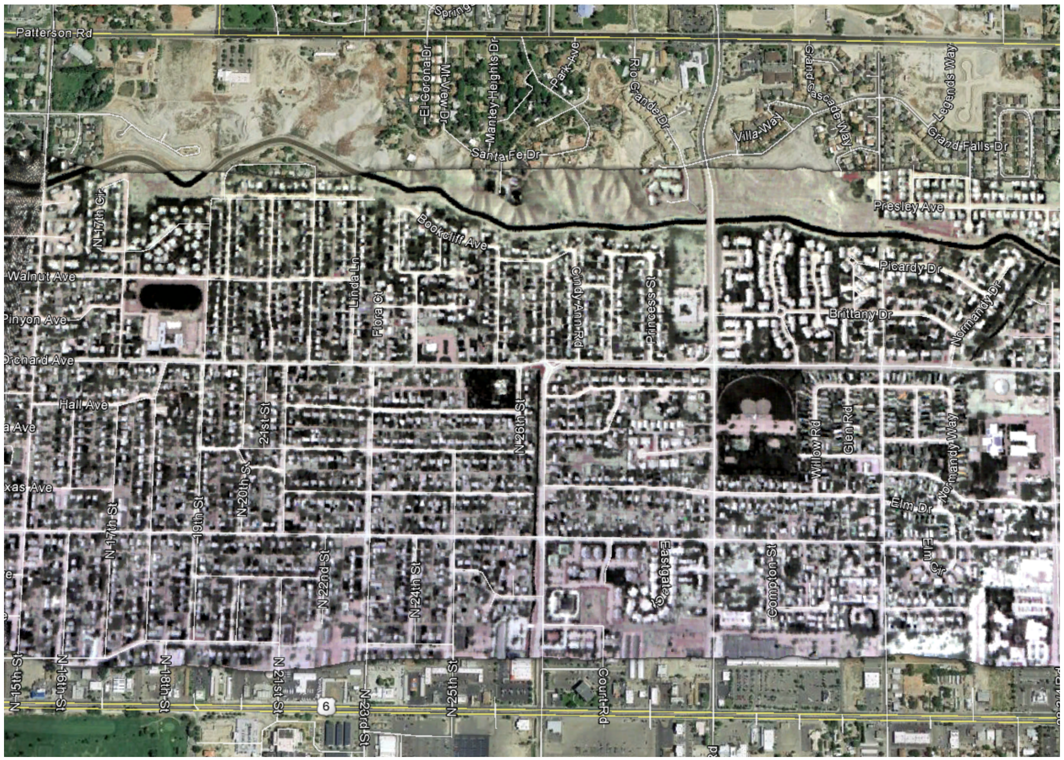
HyTES currently in Burbank for local flights



HyTES new cryo-vacuum system with a scanhead ~ ½ its former mass.

HyTES being loaded onto forklift while cold. HyTES ships cold from JPL to Colorado for integration on the Twin Otter.

HyTES Back on the Twin Otter



Preliminary geolocation check-out from 6-7-2017 from the twin otter.

Superimposed thermal imagery overlaid with Google Earth

HyTES got the okay to fly the Bakersfield lines for SoCal gas sensing experiment.

HyTES Summary

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

- HyTES is capable of imaging from the ER-2. More testing is needed to improve the calibration of the sensor at full altitude.

- HyTES is currently flying in modified form on the Twin Otter.

- Future high altitude flights (during and beyond 2017) 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.

The author would like to acknowledge Marco Hernandez, Luis Rios, Scott Nolte, and the rest of the JPL AVIRIS group for their tremendous help in supporting HyTES. QWIP and CBIRD contributions from Drs. David Ting and Sarath Gunapala of JPL.