



The Hyperspectral Thermal Emission Spectrometer (HyTES): preliminary results

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Outline

- Introduction
- HypIRI Background
- HyTES and QWEST Instrument Specifications
 - Precursor Results (QWEST)
- HyTES System Technology Overview
 - Optics, Diffraction grating*
 - Quantum Well Infrared Photodetector (QWIP)*
 - Thermal Aspects, etc*
- Wrap up



Introduction

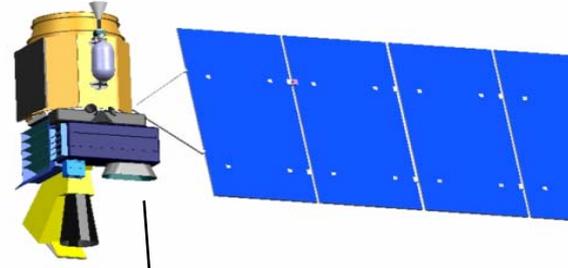
- Objective: Build an airborne Hyperspectral Thermal Emission Spectrometer (HyTES) with 512 spatial pixels across track and 256 spectral channels between 7.5 and 12 μm . Pixel sizes will be in the range of 5 to 50 m depending on aircraft flying height.
- Goal: Provide precursor high spectral and spatial resolution thermal infrared data for the (National Research Council) NRC Recommended HypsIRI mission and for use in Earth Science Studies.



HyspIRI Background

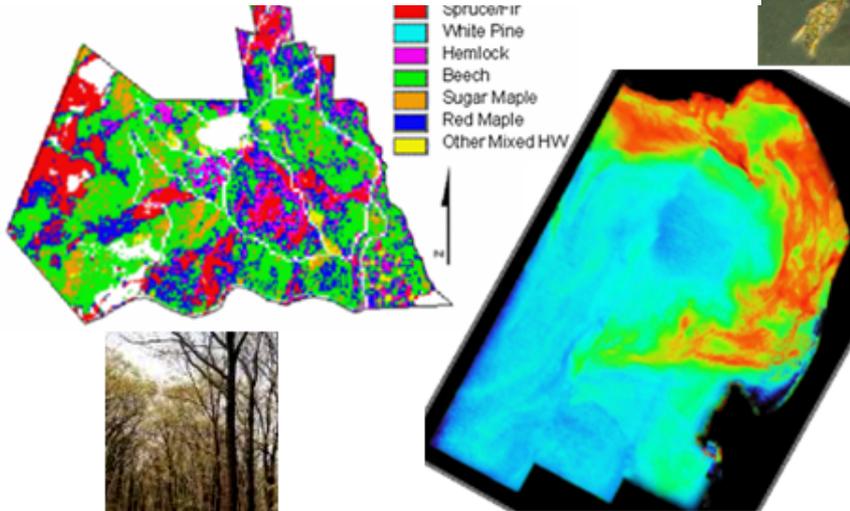
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer – AVIRIS-ng
+
Multispectral Thermal InfraRed (TIR) Scanner - HyTES

VSWIR: Plant Physiology and Function Types (PPFT)

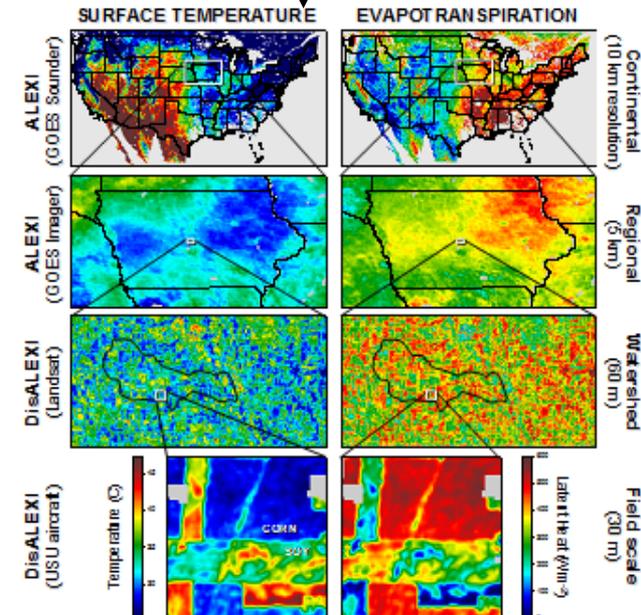


Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH



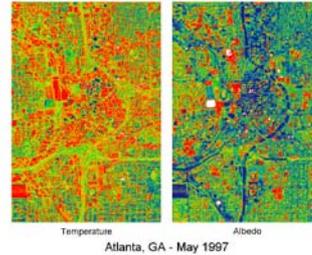
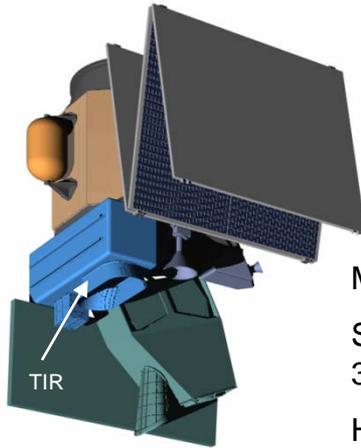
Red tide algal bloom in Monterey Bay, CA





HyspIRI-TIR Background

Thermal Imaging Spectroscopy



Multispectral Scanner

Schedule: 4 year phase A-D,
3 years operations

High Heritage

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)

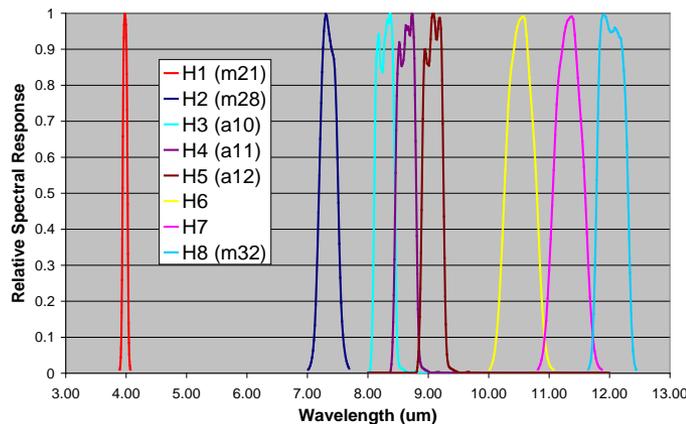
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

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

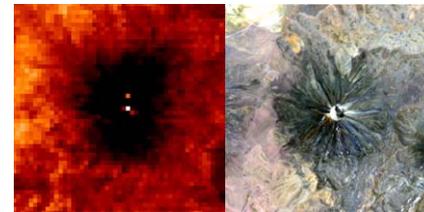
– What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

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

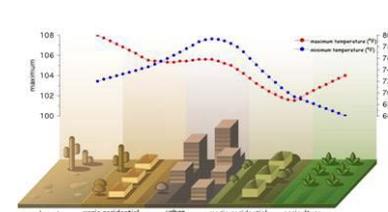


Andean volcano heats up

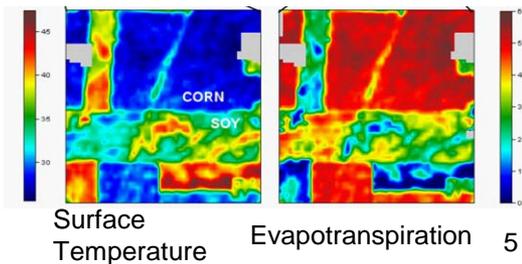


Volcanoes

Urbanization



Water Use and Availability



Next Generation Imaging Spectrometers

two in particular...

| Instrument Characteristic | QWEST | HyTES |
|--|-------------------------|-------------------------|
| Number of pixels x track | 320 | 512 |
| Number of bands | 64 | 256 |
| Spectral Range | 8-9 um | 7.5-12 um |
| Integration time (1 scanline) | 30 ms | 30 ms |
| Total Field of View | 40 degrees | 50 degrees |
| Calibration (preflight) | Full aperture blackbody | Full aperture blackbody |
| QWIP Array Size | 640x512 | 1024x512 |
| QWIP Pitch * | 25 um | 19.5um |
| QWIP Temperature | 40K | 40K |
| Spectrometer Temperature | 40K | 40K |
| Slit Width | 50 um | 39 um |
| Pixel size at 2000 m flight altitude | 4.5 m | 3.64 |
| Pixel size at 20,000 m flight altitude | 45 m | 36.4 |

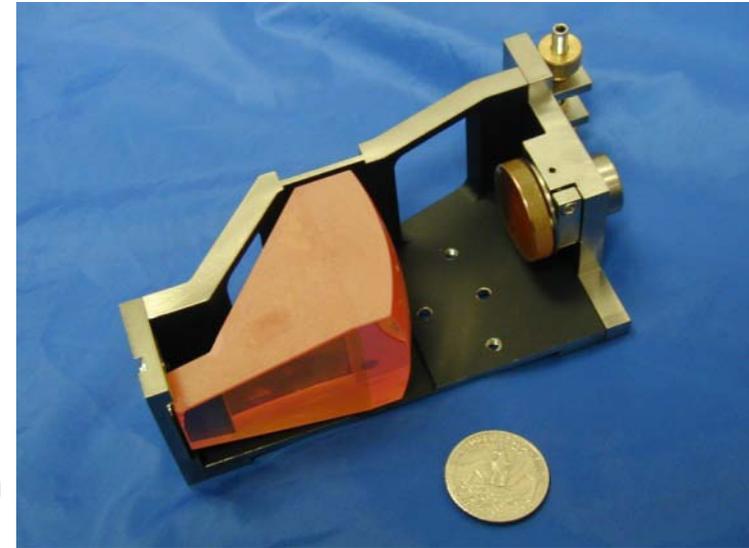
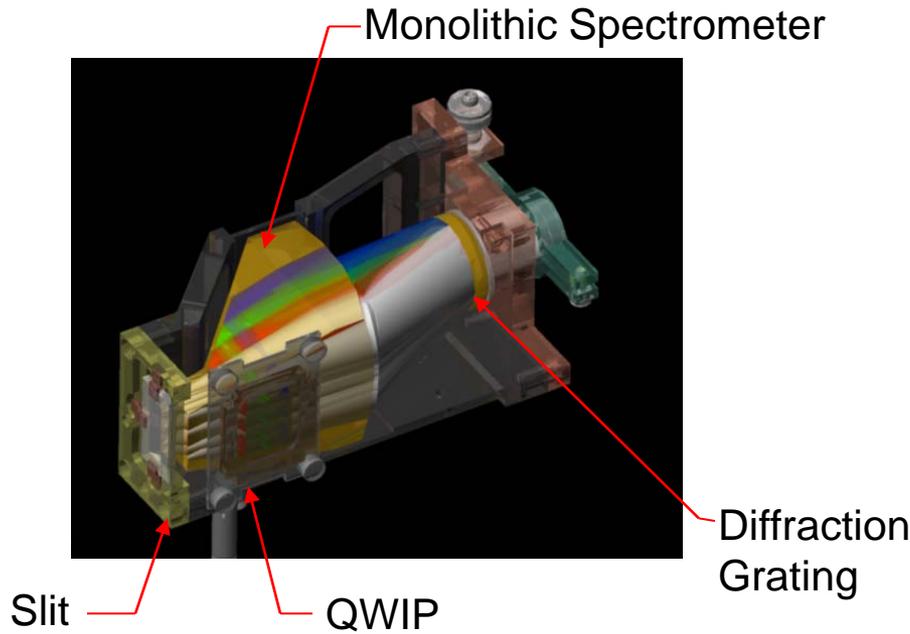
Operational

Late 2011





HyTES Precursor: QWEST Technology Demo

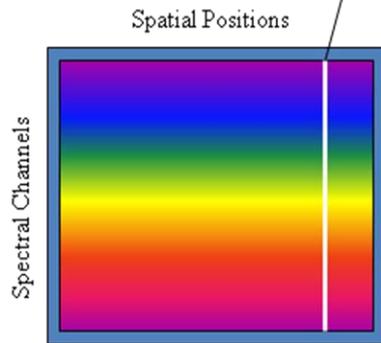
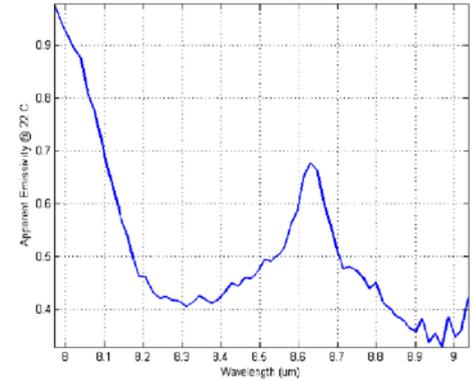
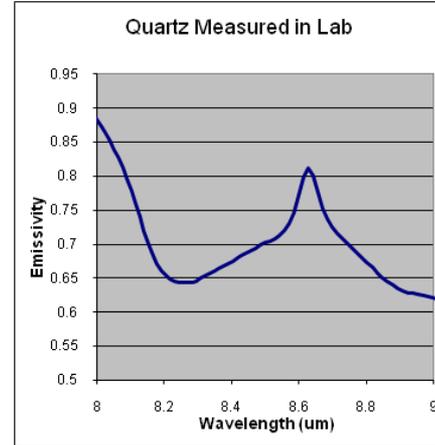
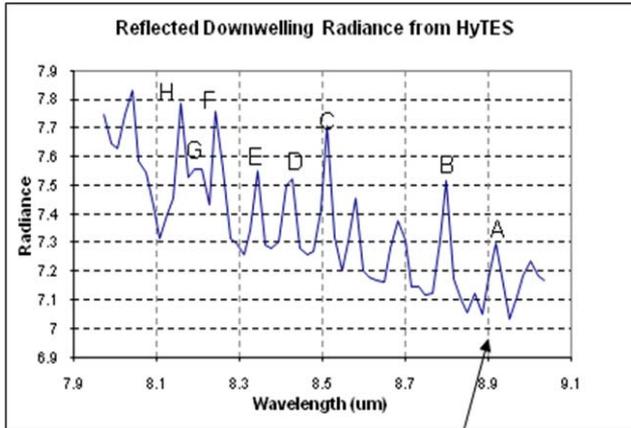


Compact Thermal Spectrometer Designs and Hardware

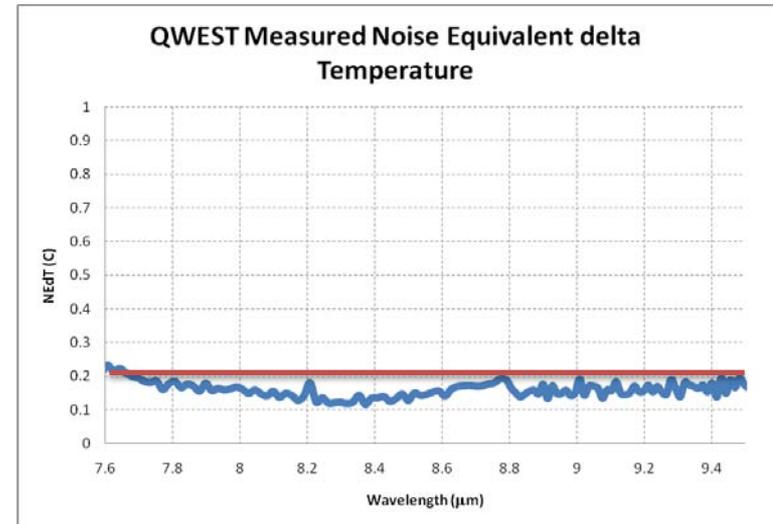


QWEST Results: Data Train

Thermal Imaging Spectroscopy

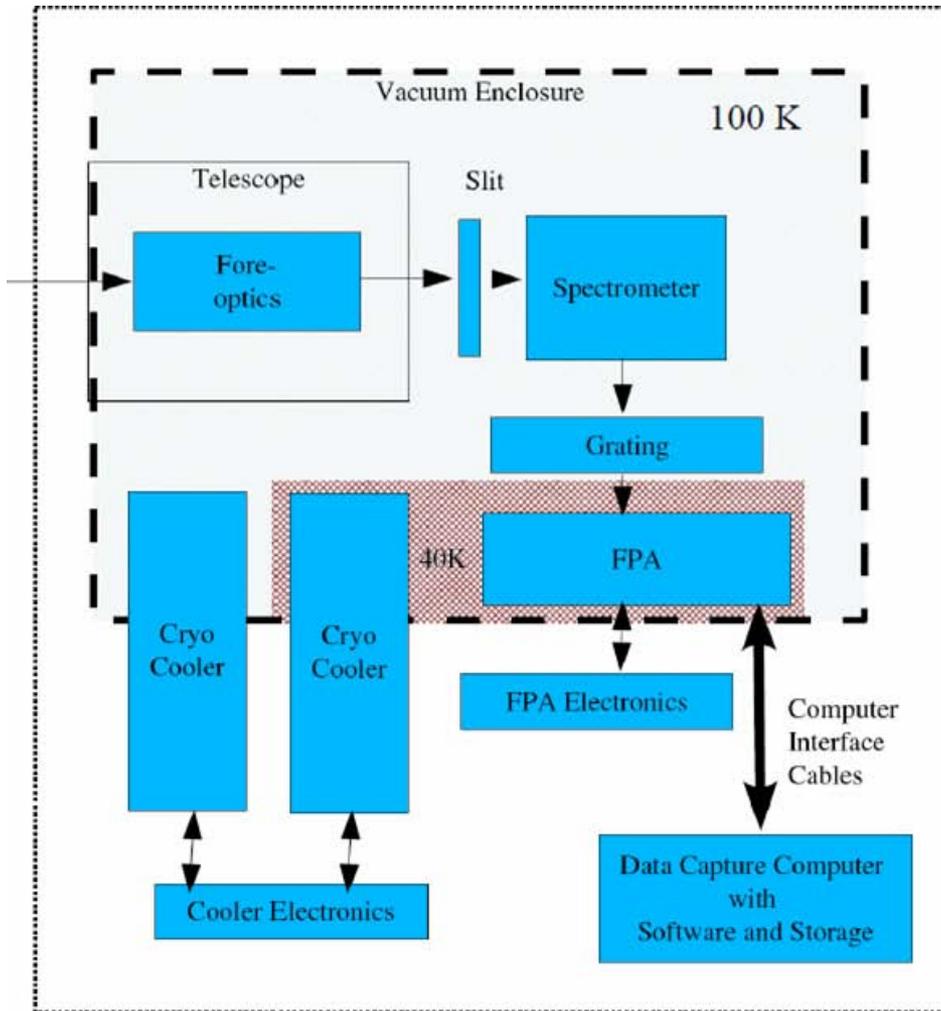


| | Model | QWEST | Delta |
|---|---------|--------|----------|
| A | 8.92061 | 8.9179 | 0.00271 |
| B | 8.79894 | 8.7995 | -0.00056 |
| C | 8.51426 | 8.5121 | 0.00216 |
| D | 8.4246 | 8.4276 | -0.003 |
| E | 8.34725 | 8.3431 | 0.00415 |
| F | 8.25082 | 8.2418 | 0.00902 |
| G | 8.20345 | 8.208 | -0.00455 |
| H | 8.16327 | 8.1573 | 0.00597 |





HyTES System Block Diagram



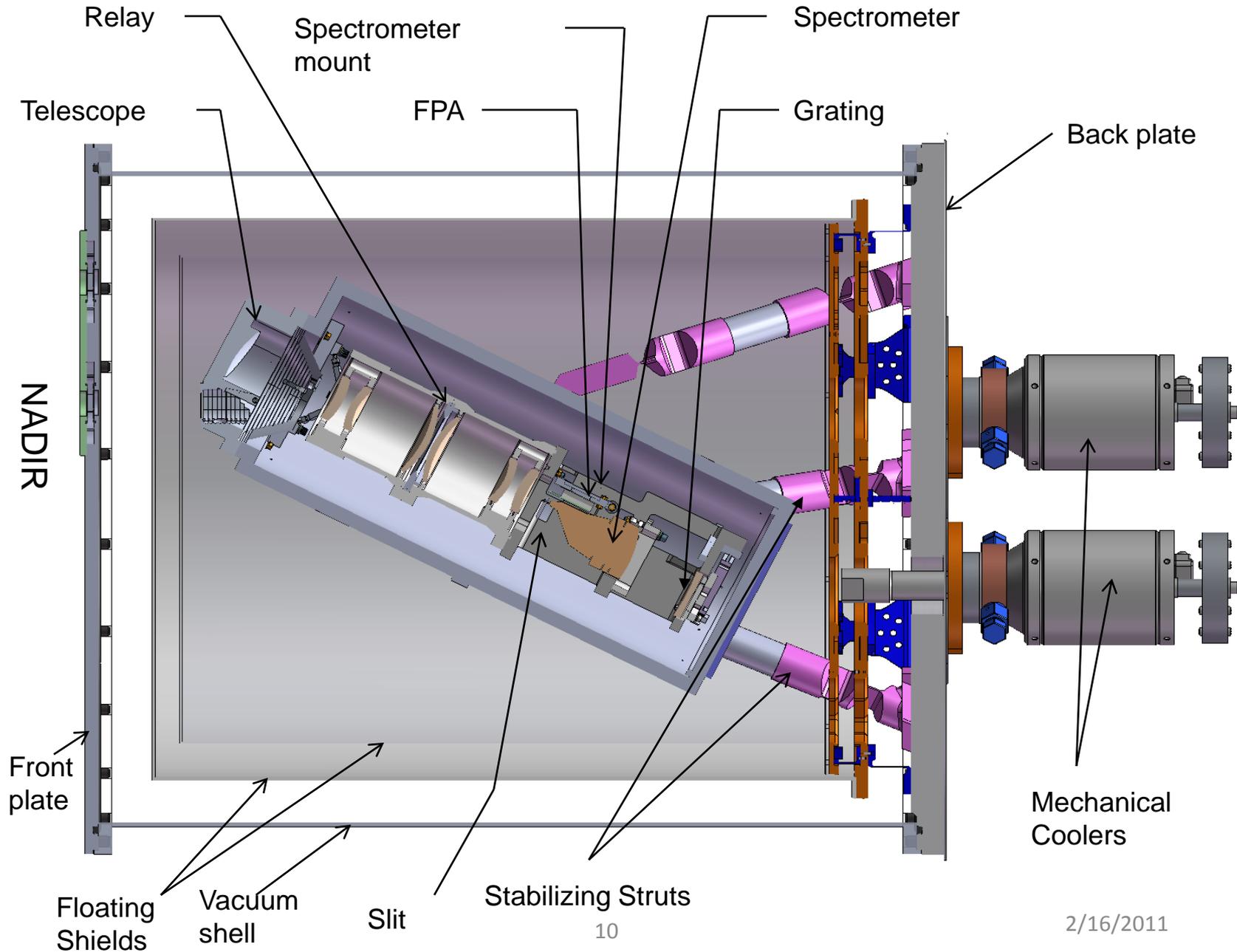
The HyTES airborne instrument is a mechanically cooled system consisting of a vacuum chamber, cryocoolers, thermal radiation shields, telescope/relay, and spectrometer

The mechanical coolers are a design change from the original proposal



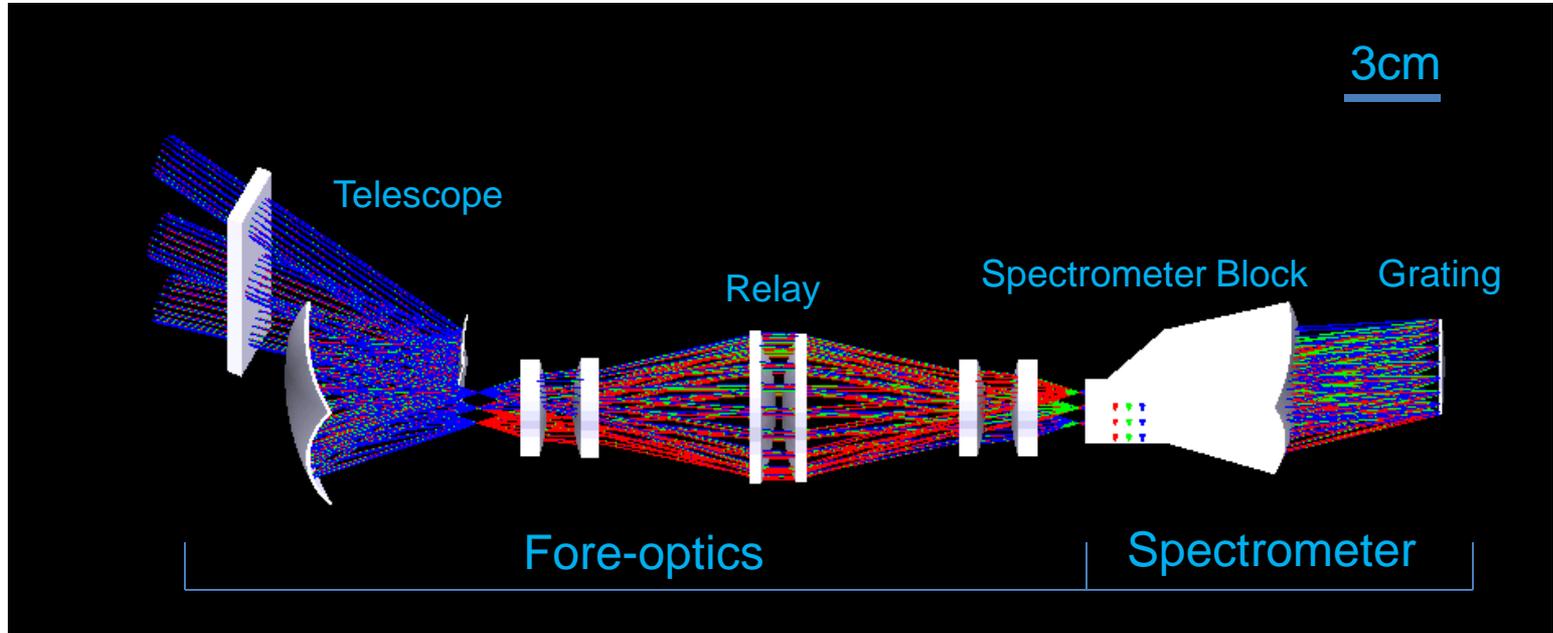
HyTES Instrument

Thermal Imaging Spectroscopy





HyTES Optics

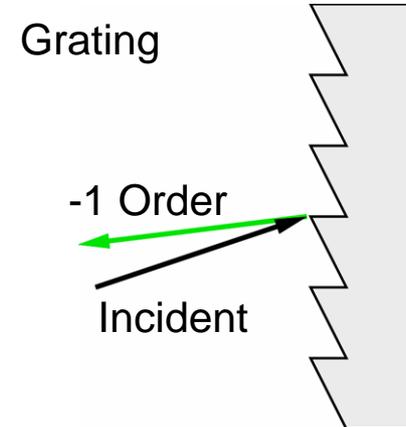


HyTES Optical Layout



HyTES Diffraction Grating

HyTES Ray Trace



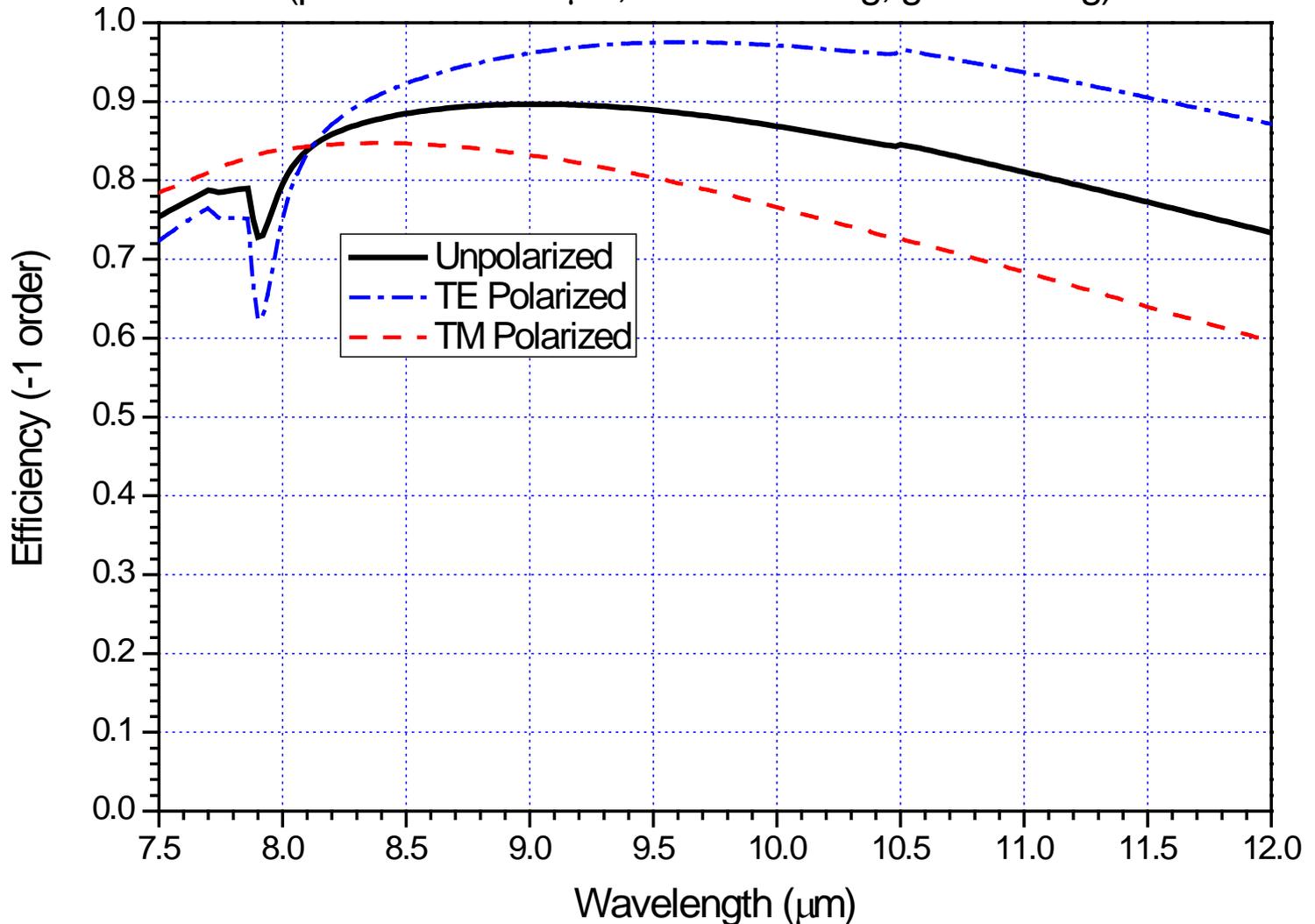
Requirements and Design

| | |
|-------------------------|--|
| Wavelength Range | 7.5 to 12 μm |
| Incident angle | ~ 20 deg |
| Diffraction order | -1 |
| Period | Design: 23.462 μm Actual (E-beam pattern): 23.450 μm (-0.051% error) |
| Groove shape | Triangular, 12.3° blaze angle |
| Substrate | Diameter: 38.53 mm Radius of curvature = 121.396 mm |
| Grating area | Diameter = 32.53 mm Sag = 1.0946 mm |
| Materials / Fabrication | Diamond turned ZnSe concave substrate PMMA resist (~ 7 μm thick, grooves etched by E-beam lithography & development) Cr/Au reflective coating (~ 80 nm thick gold by electron-beam evaporation) |



HyTES Diffraction Grating

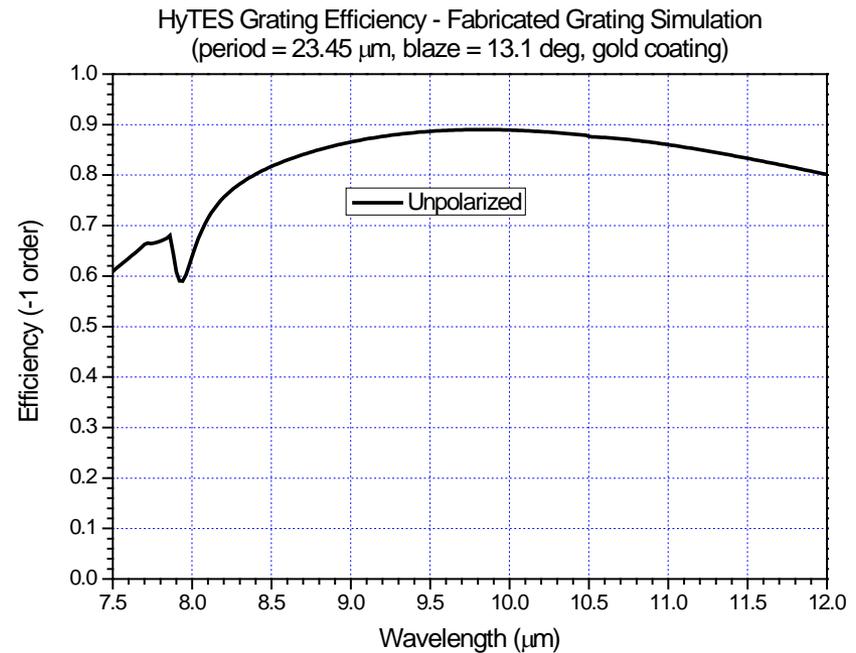
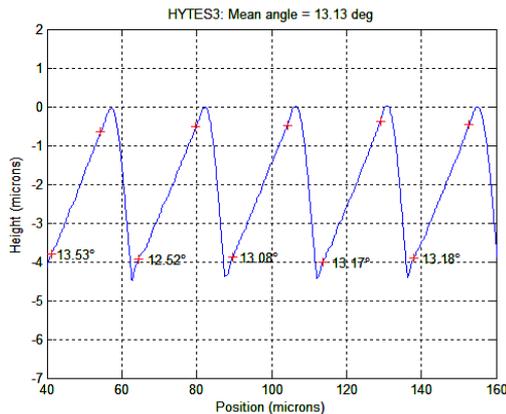
HyTES Grating Efficiency - Design Simulation
(period = 23.462 μm , blaze = 12 deg, gold coating)





HyTES Diffraction Grating

- Grating successfully fabricated (ZnSe substrate, grooves etched in PMMA resist, gold reflective coating)

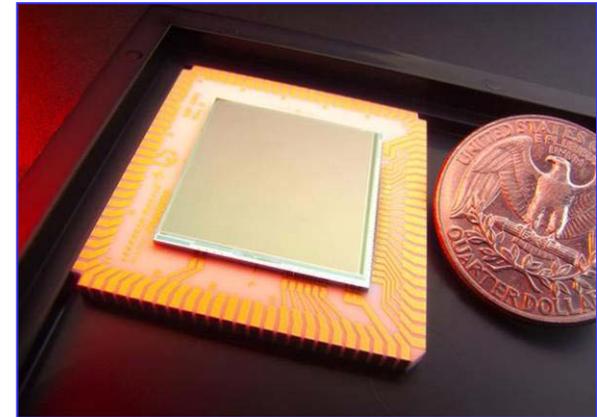


- Measured blaze angle is 9% deeper than 12° design – will decrease efficiency at 7.5 μm and increase efficiency at 12 μm as simulated above

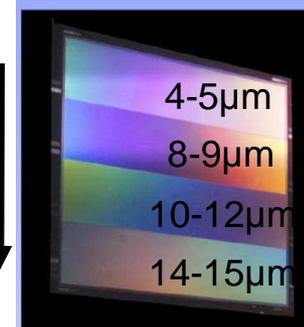


HyTES Focal Plane Array

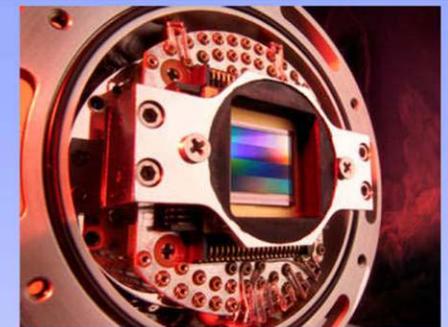
- HyTES will use a 1024x1024 pixel array covering the 7.5-12 μ m spectral band (typical array package shown at top right)
- JPL has fabricated and delivered similar large area and multi-band (dual color, three color and four color) arrays in the past
- This is not a commercially available technology, and only JPL delivers large format, high performance multi-band QWIP arrays
- The detector array has the following requirements:
 - 1kx1k format, SBF 184 ROIC
 - Operating temperature 40K
 - Performance such that in each of the 2x2 superpixels in the 7.5-12 μ m band the NEDT is less than 200 mK



1024x1024 pixel single-band QWIP FPA



Four-band FPA



Four-band FPA in Dewar

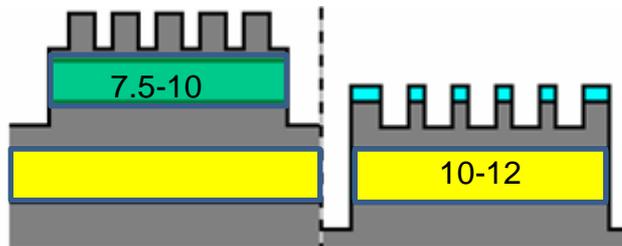
λ

4-5 μ m
8-9 μ m
10-12 μ m
14-15 μ m

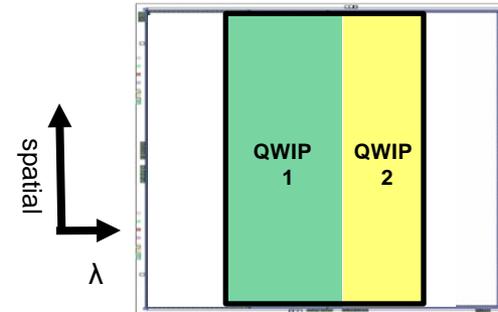


HyTES Focal Plane Array

- A cross section of the two-band quantum well infrared photodetector (QWIP) used as the detector material is shown below
- This is similar to the previous three-band design but much simpler to process
- Roughly half of the illuminated area of the array will respond in the 7.5-10 μm range, and the other half will cover the 10-12 μm range
- Different fabrication approaches on each half of the array are required to achieve the 7.5-12 μm operation



HyTES pixel design – cross-sectional zoom at the transition point, showing two bands with $\frac{1}{4}$ lambda gratings on each

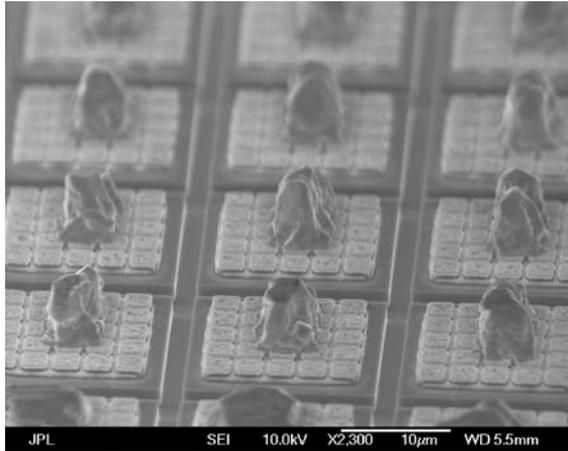


Top-down view of FPA
Illuminated area shown in green and yellow

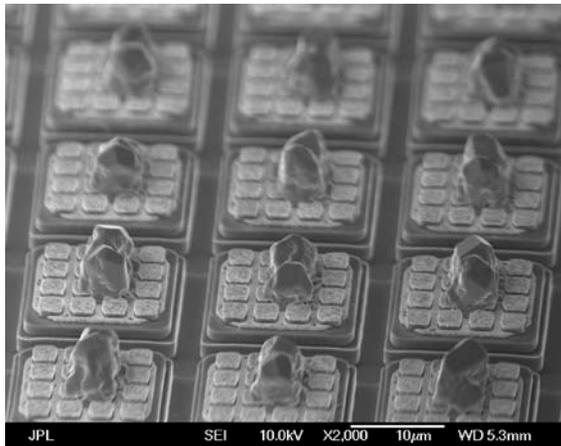


HyTES Focal Plane Array

Thermal Imaging Spectroscopy

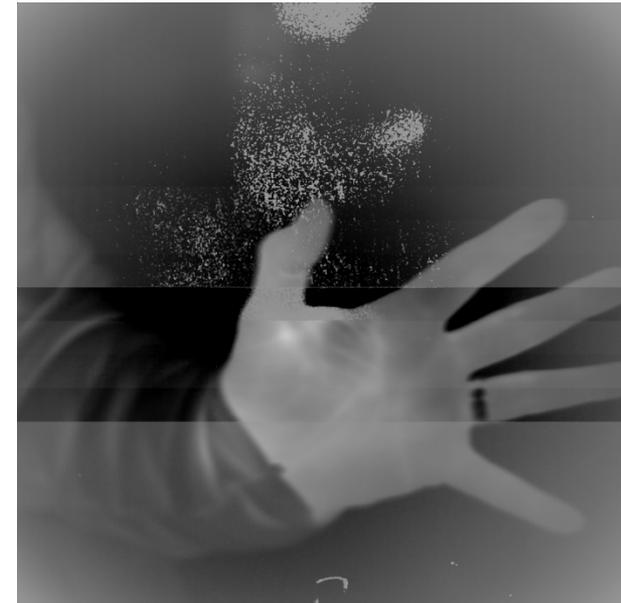


MW



LW

SEM images of indium bumps on QWIP gratings



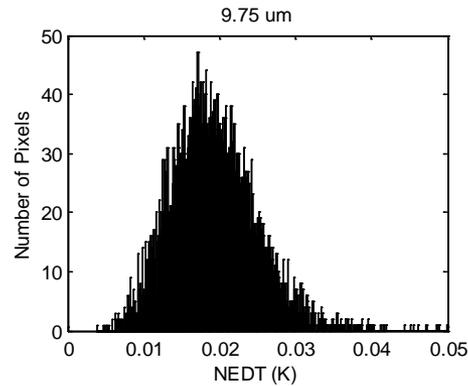
Recent image from test QWIP



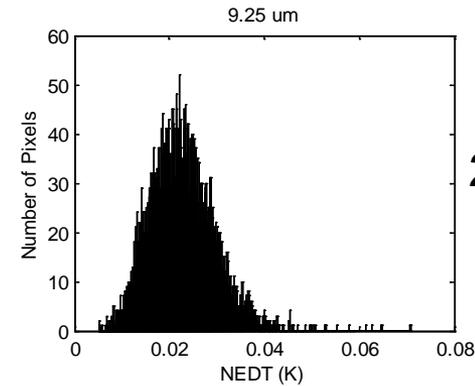
HyTES Focal Plane Array

Measured noise equivalent delta temperature ($NE\Delta T$) for existing focal plane array. Single pixel data.

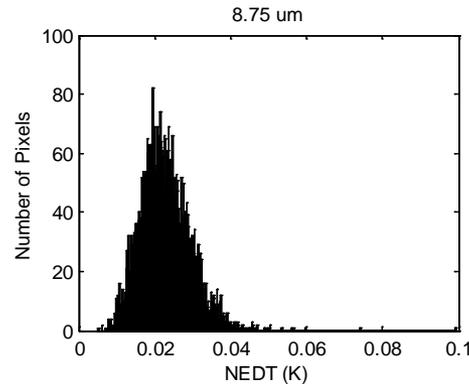
19.2 mK



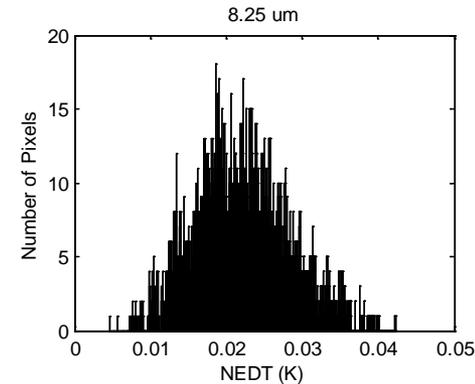
22.5 mK



22.7 mK

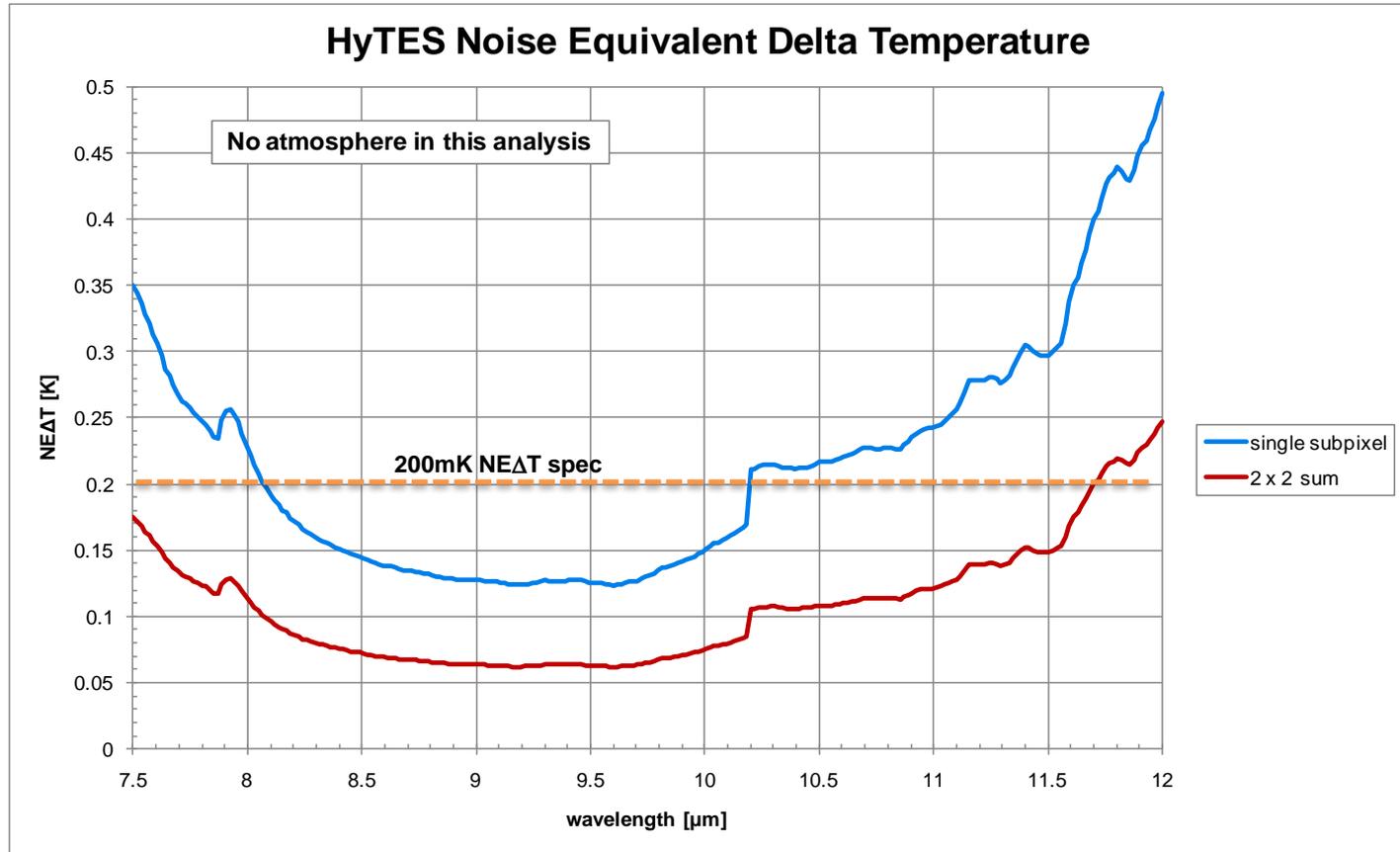


22.0 mK





HyTES Sensor Modeling

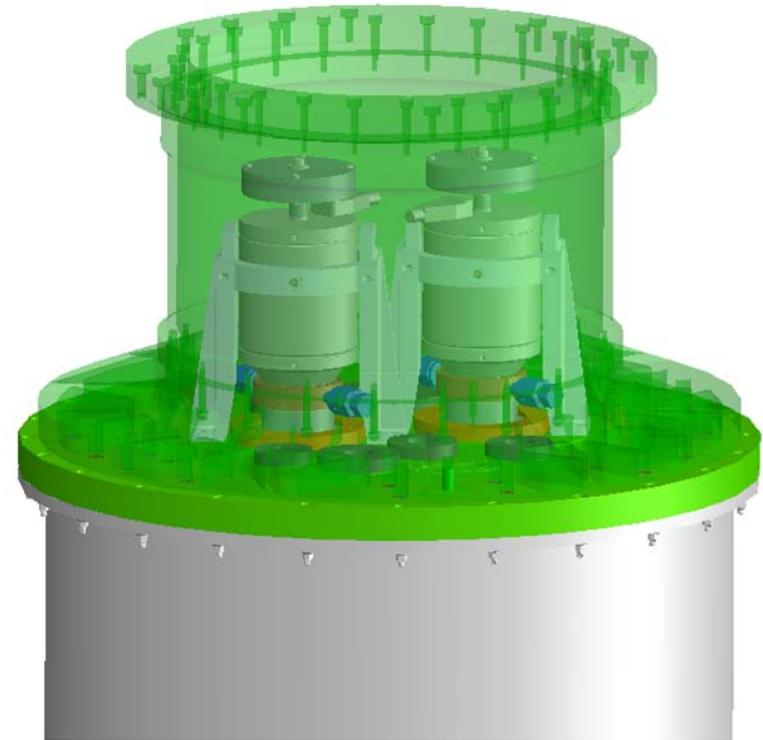


- The final design exhibits a smoother transition between bands than the original three-color version and meets spec (2×2 pixel summation $NE\Delta T < 200\text{mK}$) in nearly all of the $7.5\text{-}12\mu\text{m}$ band



HyTES Cryovacuum Enclosure

- Cryovacuum enclosure received from vendor. Vacuum components are fully installed and passed leak checks.





HyTES System

Airborne Cryovacuum Enclosure



Focal Plane Electronics



Spectrometer housing and Relay Assembly



Various delivered hardware. The current effort is focused on integration and testing.



Wrap Up

Summary

- QWEST has demonstrated all the vital technology to date. The testing was done on an end-to-end system built at JPL.
- HyTES is nearing completion and should be tested by the end of 2011.