Status of HyTES/PHyTIR Concepts and Technologies being Validated for the HysplRI TIR Instrument Concept

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Outline

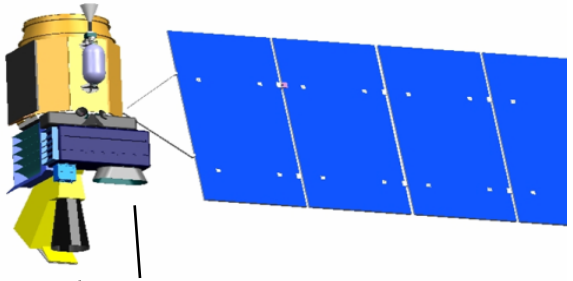
- HyspIRI Background
- Prototype Hyperspectral Thermal Infrared Radiometer (PHyTIR)
- Hyperspectral Thermal Emission Spectrometer (HyTES)
- Summary

HyspIRI Background

Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer

+

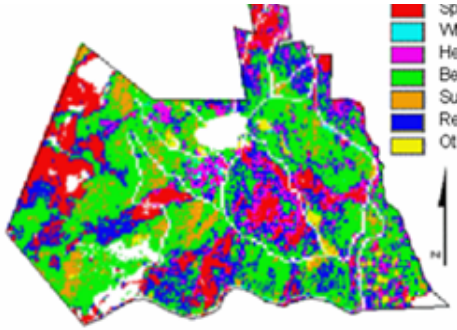
Multispectral Thermal InfraRed (TIR) Scanner

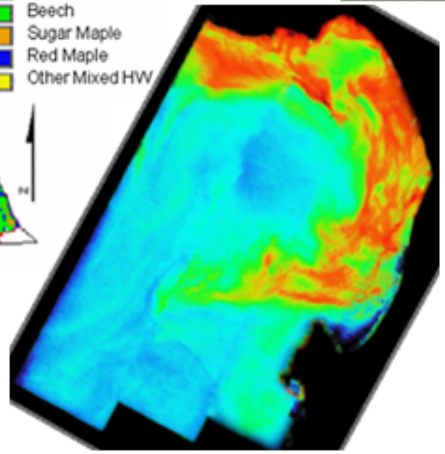


VSWIR: Plant Physiology and Function Types (PPFT)

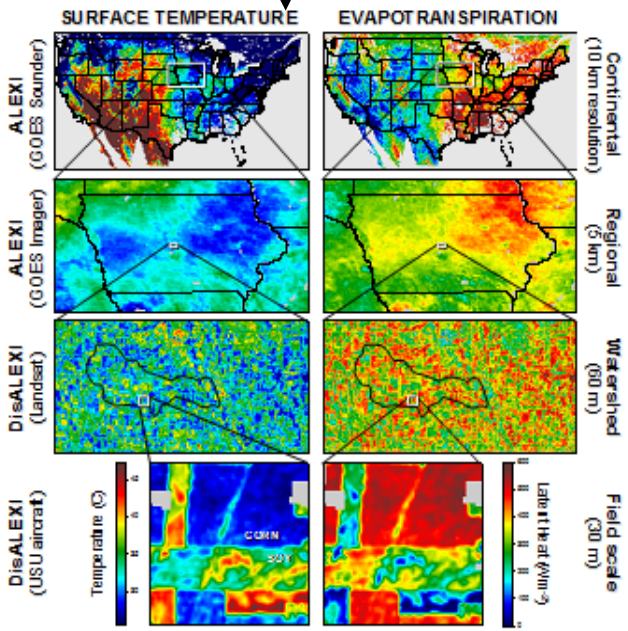
Multispectral TIR Scanner

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)

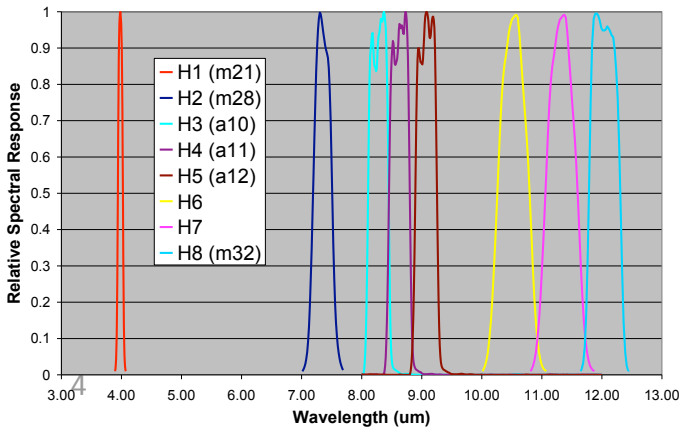
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

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

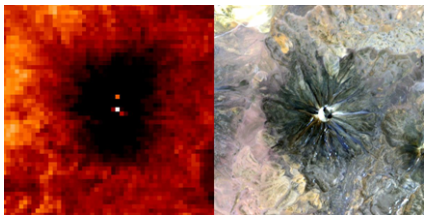
– What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

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

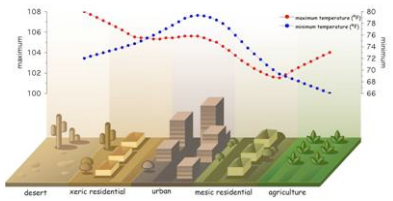


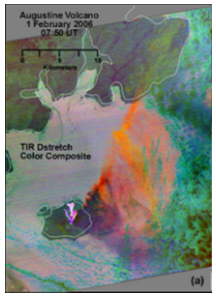
Andean volcano heats up



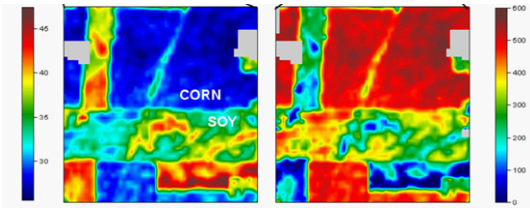
Volcanoes

Urbanization





Water Use and Availability



Surface Temperature

Evapotranspiration

HyspIRI-TIR Instrument Concept

Science Requirements
60 m Resolution
5-Day repeat

→

Instrument Requirements
~10,000 pixels cross track
~600 km swath
51° Cross-track swath

Whiskbroom (Push-Whisk)
- Single telescope with scanning mirror
- Single detector array with 256 pixels per band

Pushbroom
- ~10 detector arrays, each with ~1,000 pixels per band
- ≥3 telescopes

Science Requirements
0.5% Radiometric accuracy for 300 K scenes

→

Instrument Requirements
Frequent 2-point calibrations (space and blackbody)

Whiskbroom (Push-Whisk)
- Scanning mirror allows easy and frequent 2-point calibrations
- No mapping gaps

Pushbroom
- Calibration mechanism required – must enable multiple telescopes to view space and blackbody
- Gap in mapping during calibration

HyspIRI-TIR Instrument Concept

Science / Instrument Requirement
0.2 K resolution for 300 K scene

MCT Detectors
- Quantum efficiency ≥ 70%
- 0.06 K resolution at 60 K
  (69 W cooler power)

QWIPs
- Quantum efficiency ~3%
- > 0.3 K resolution at 40 K
  (225 W cooler power)

Uncooled Microbolometers
- Too slow for push-whisk method
- Even with pushbroom, resolution ~0.8 K

Science / Instrument Requirement
8 spectral bands 4-12 μm

MCT Detectors
- Single band-gap material can cover full spectral range

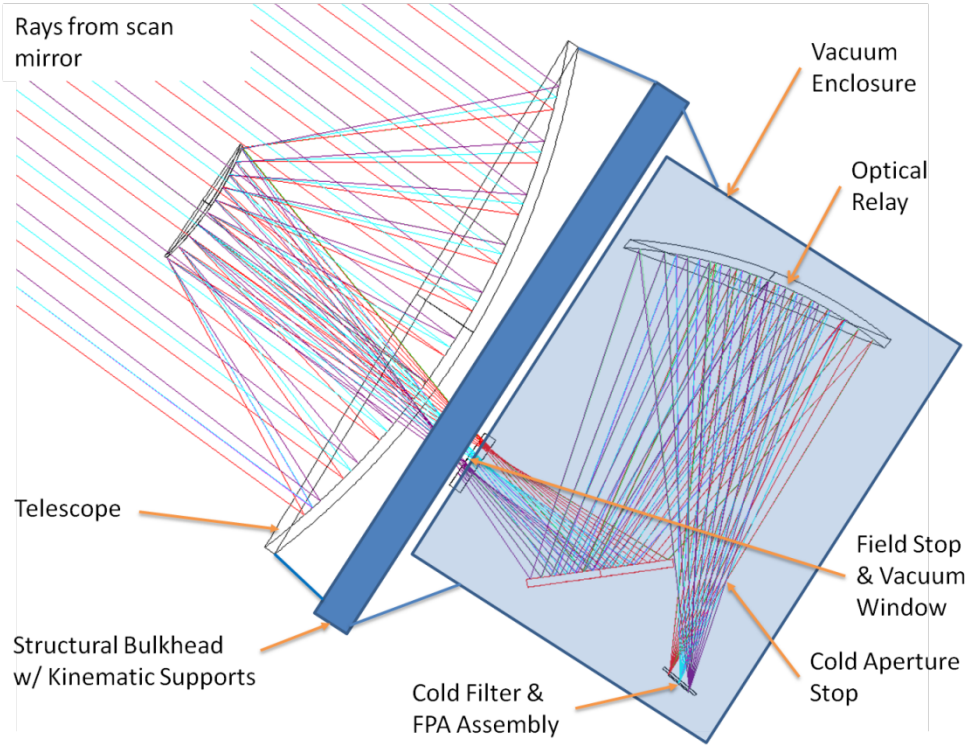
QWIPs
- Multiple arrays required to cover all bands

Uncooled Microbolometers
- Not sensitive to 4 μm band

HyspIRI-TIR Optical Assumptions

Optical Design Assumptions

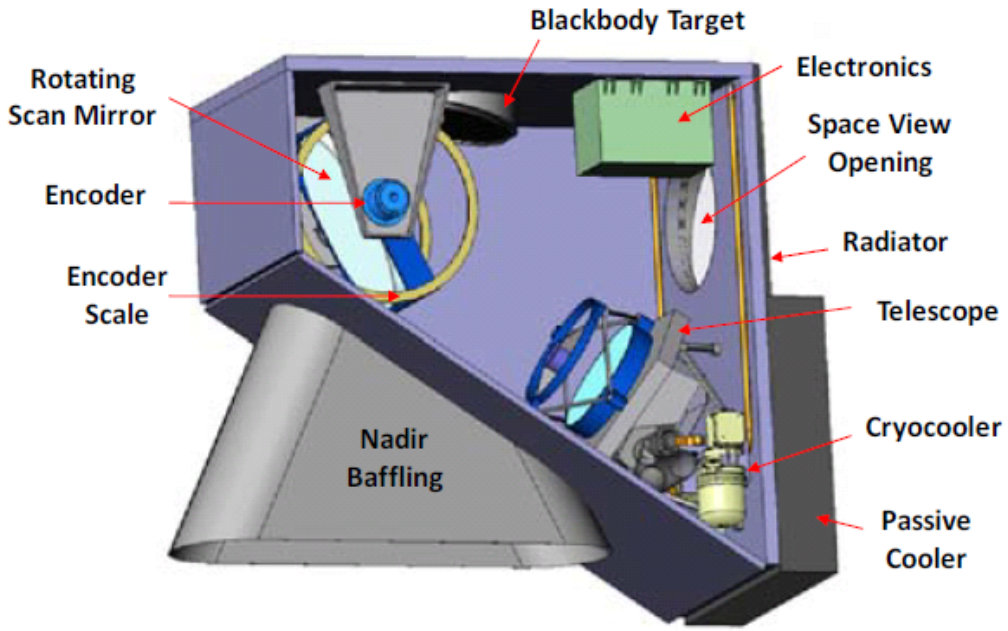
- Altitude: 623km (5-day repeat)
- Ground Sample Distance: 60m (@ NADIR)
- Pixel pitch: 40μm
- Aperture: F/2
- IFOV: 96.308 μrad
- FOV: 1.413° (along track)
- FOV: 51° (cross track scanning)
- Focal Length: 415.3mm
- Aperture Size: 207.7m
- Cross track pixels: 9242 pixels
- Swath: 600km (R_{earth} = 9378km)
- Swath overlap: 10% along track pixels
- Dwell time: 32microseconds
- Scan Mirror Rotation Rate: 14.15rpm (double sided scan mirror)
- Spectral coverage (Passband) = 4 to12mm
- $MTF_{Nyquist}$ = 60% for all fields and wavelengths
- Obscuration <15% (by area)
- 3 aspheric mirrors (telescope and relay)
- 2 flat mirrors (fold and scan)
- 2 transmissive elements (window and interference filter)
- chromatic aberration negligible

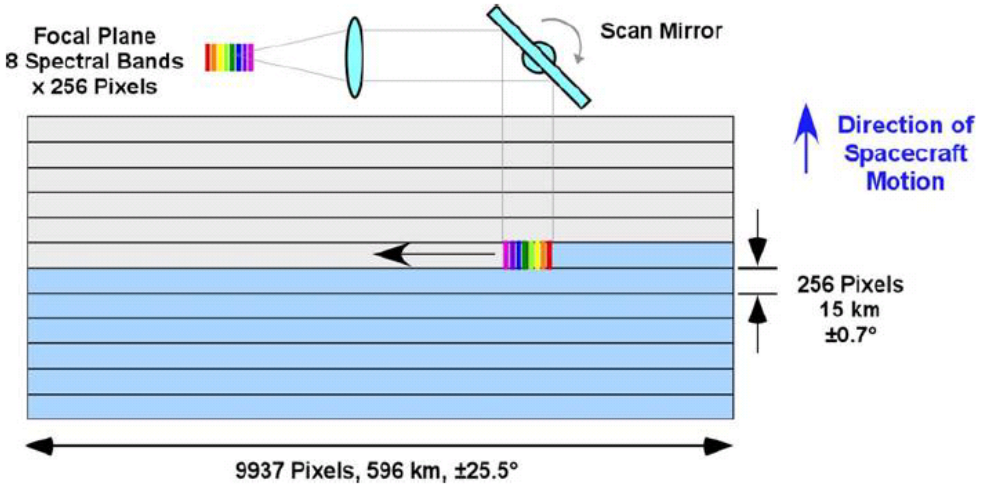


Summary

Parameter	Value
Aperture Size	208 mm (<10% obstruction)
F/#	2
Focal Length	416mm
Optical Throughput w/ Filters	66%

HyspIRI-TIR Instrument Concept



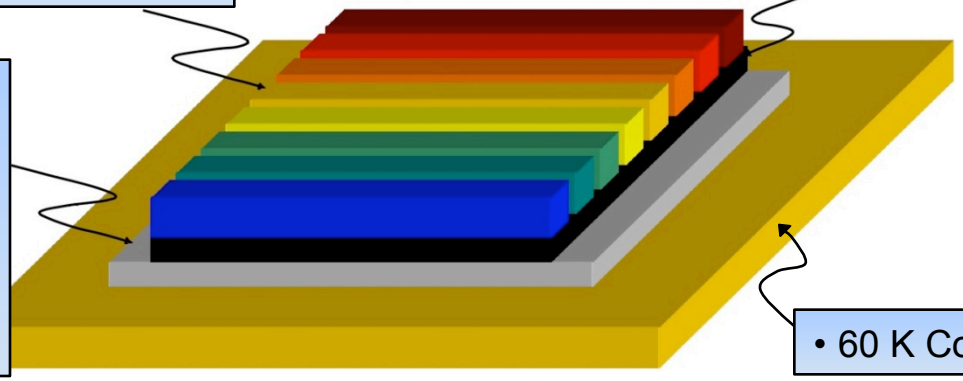


HyspIRI-TIR Instrument Concept

HyspIRI TIR Instrument Characteristics			
Spectral		**Spatial**	
Bands (8)	3.98 µm, 7.35 µm, 8.28 µm, 8.63 µm, 9.07 µm, 10.53 µm, 11.33 µm, 12.05 µm	IFOV	100 µrad; 60 m at nadir
Bandwidths	0.084 µm, 0.32 µm, 0.34 µm, 0.35 µm, 0.36 µm, 0.54 µm, 0.54 µm, 0.52 µm	MTF	>0.60 at FNy
Accuracy	<0.01 µm	Scan Type	Push-Whisk, 14.2 RPM mirror rotation
Radiometric		Cross-Whisk Samples	256
Temperature Range	Channel 1: 400-1200 K Channel 2–8: 200 K – 480 K	Samples in Whisk Direction (Cross Track)	9,300
Resolution	< 0.05 K, linear quantization to 14 bits	Cross-Whisk Swath Width	15.4 km (±0.7° at 623 km altitude)
Accuracy	< 0.5 K at 250 K	Swath Length in Whisk Direction	596 km (±25.5° at 623 km altitude)
Precision (NETD)	< 0.2 K	Band to Band Co-Registration	0.2 pixels (12 m)
Linearity	>99% characterized to 0.1 %	Pointing Knowledge	10 arcsec (0.5 pixels, 30 m)

- Butcher-Block Filter Assembly
- Baffles to Prevent Crosstalk Between Spectral Channels

- MCT Detector Array – 256 elements cross-sweep
- 1 Bandgap to Cover Full Spectral Range
- ≥ 4 Detector Columns per Spectral Channel to Allow Time Delay and Integration (TDI)

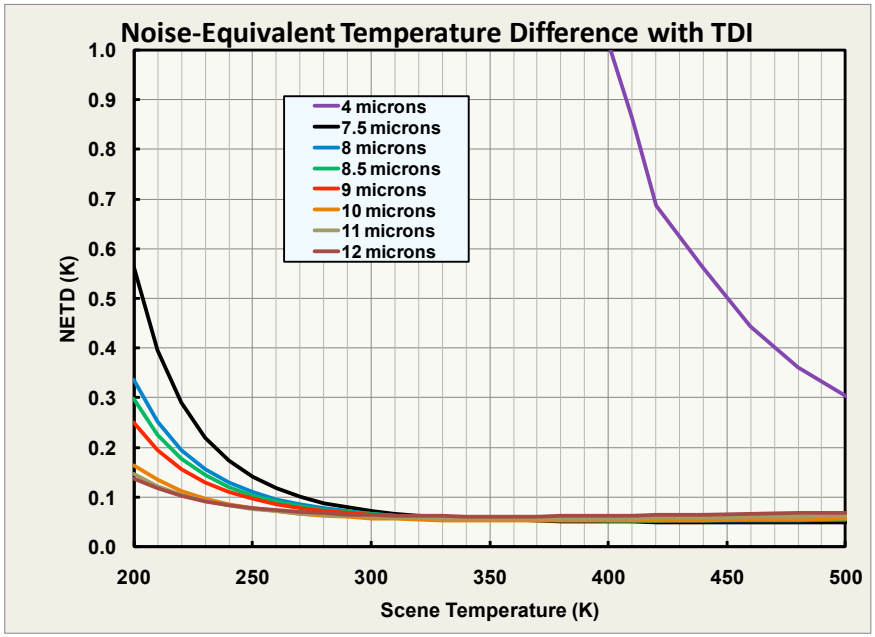


- CMOS Read-Out Integrated Circuit (ROIC)
- Multiple Output Signals to Enable Necessary Pixel Read Rate
- On-Chip Digitization Under Study

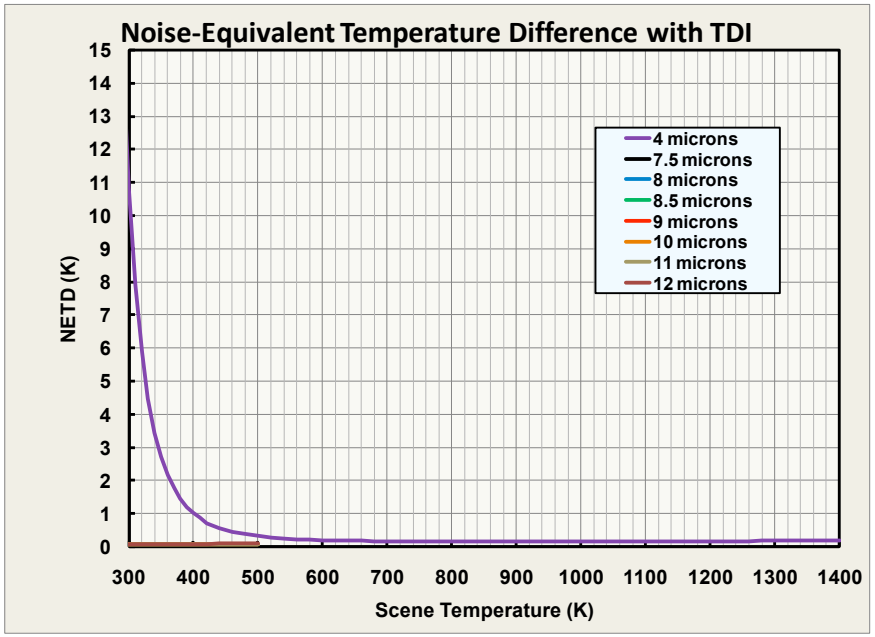
- 60 K Cold Tip of Cryocooler

HyspIRI-TIR will use a Butcher-block filter layout on top of focal plane. PHyTIR will not use focal plane filers but will spin a filter wheel in the optical path.

HyspIRI-TIR Instrument Concept

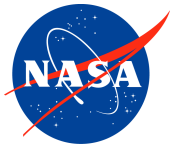


Expected HyspIRI-TIR Sensitivity Metric expressed as Noise Equivalent Delta Temperature (NEDT)



Expected HyspIRI-TIR Sensitivity Metric expressed as Noise Equivalent Delta Temperature (NEDT)

- Predicted sensitivity better than 0.2 K @ 300 K requirement.
- Good sensitivity in overlap region between channel 1 and channels 2-8.
- Expected saturation temperature of 1200K based on HyspIRI: Hot Target Saturation Subgroup (HTSS)

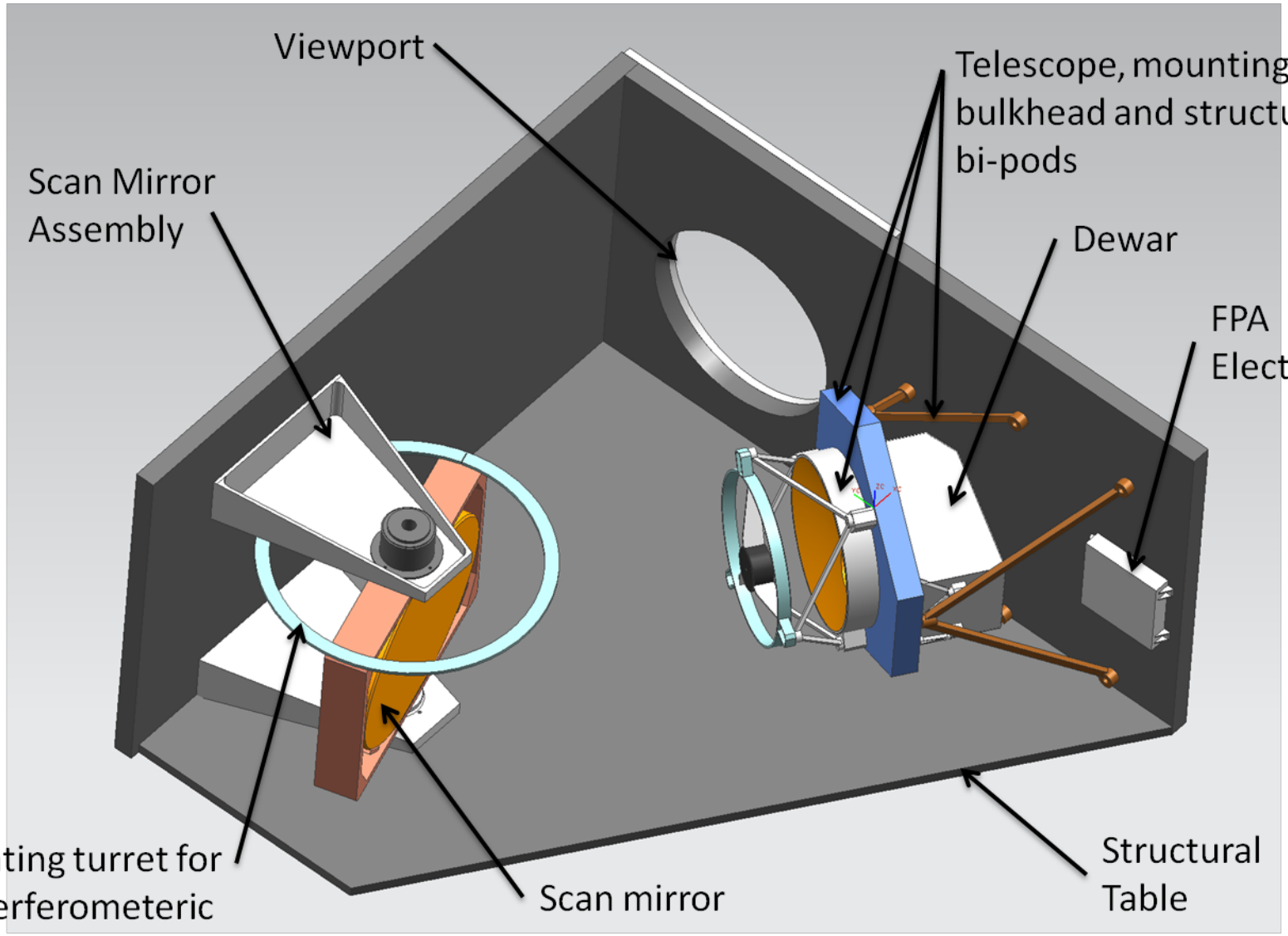


The Prototype HysplRI Thermal Infrared Radiometer (PHyTIR)

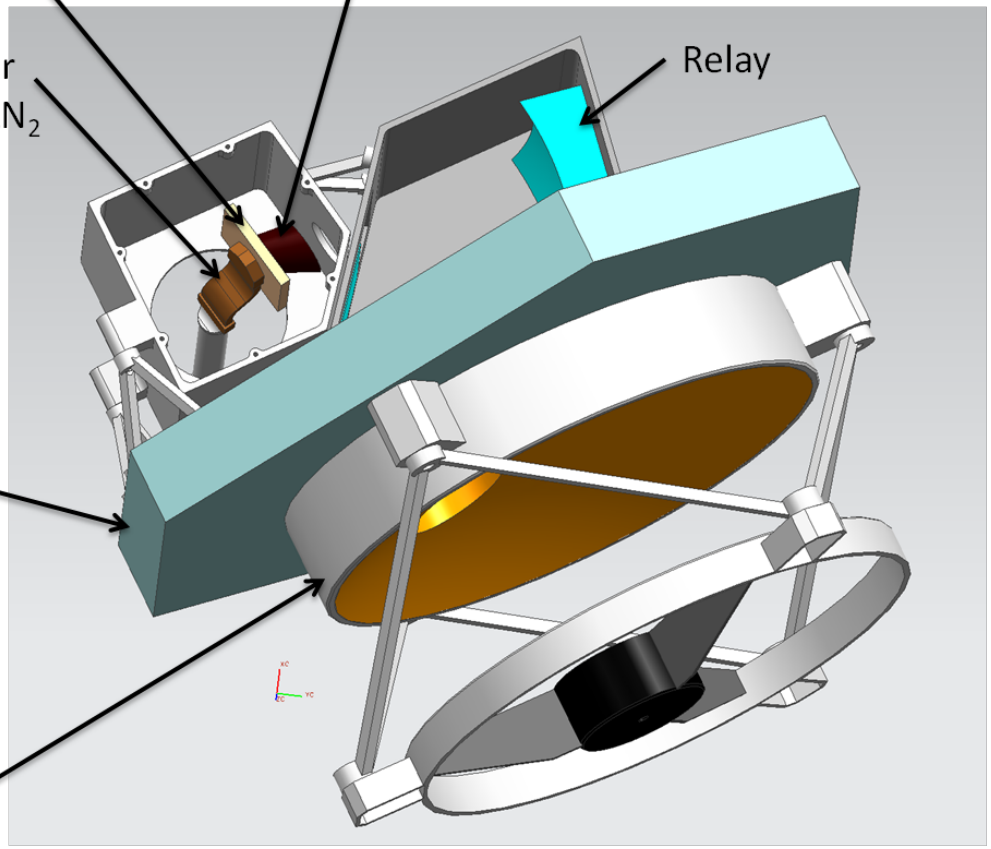
PHyTIR Rational

- HyspIRI-TIR requires a high throughput FPA and scanning approach to meet the revisit time (5 days), the high spatial resolution (60m), and the number of spectral channels (8).
- PHyTIR will demonstrate that:
  - The detectors and readouts meet all signal-to-noise and speed specifications
  - The scan mirror, together with the structural stability, meets the pointing knowledge requirements
  - The long-wavelength channels do not saturate below 480 K
  - The cold shielding allows the use of ambient temperature optics on the HyspIRI-TIR instrument without impacting instrument performance.

PHyTIR Implementation

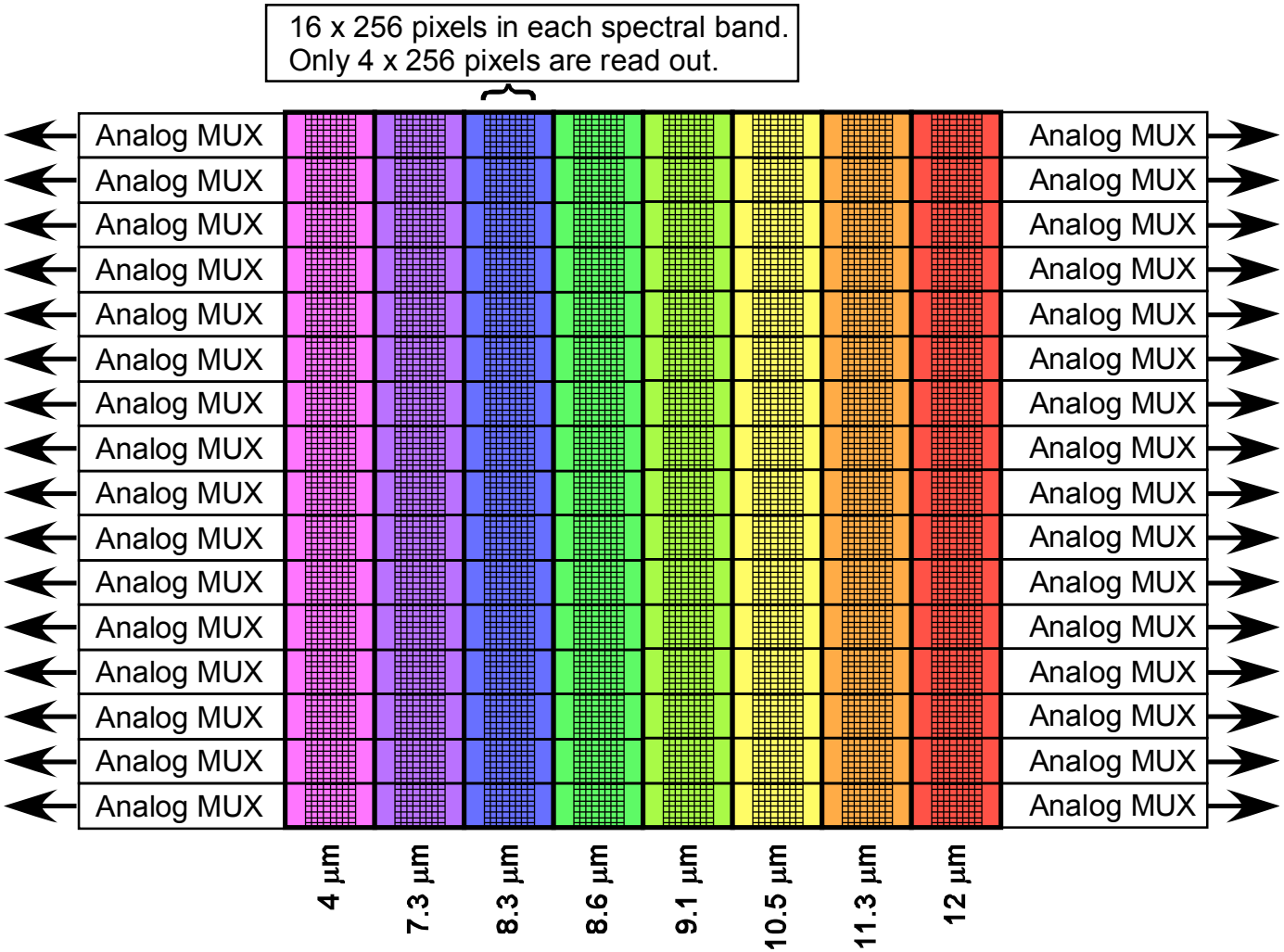


PHyTIR Implementation



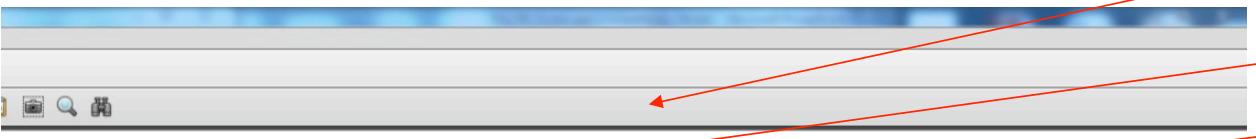
Dewar removed to show internal components

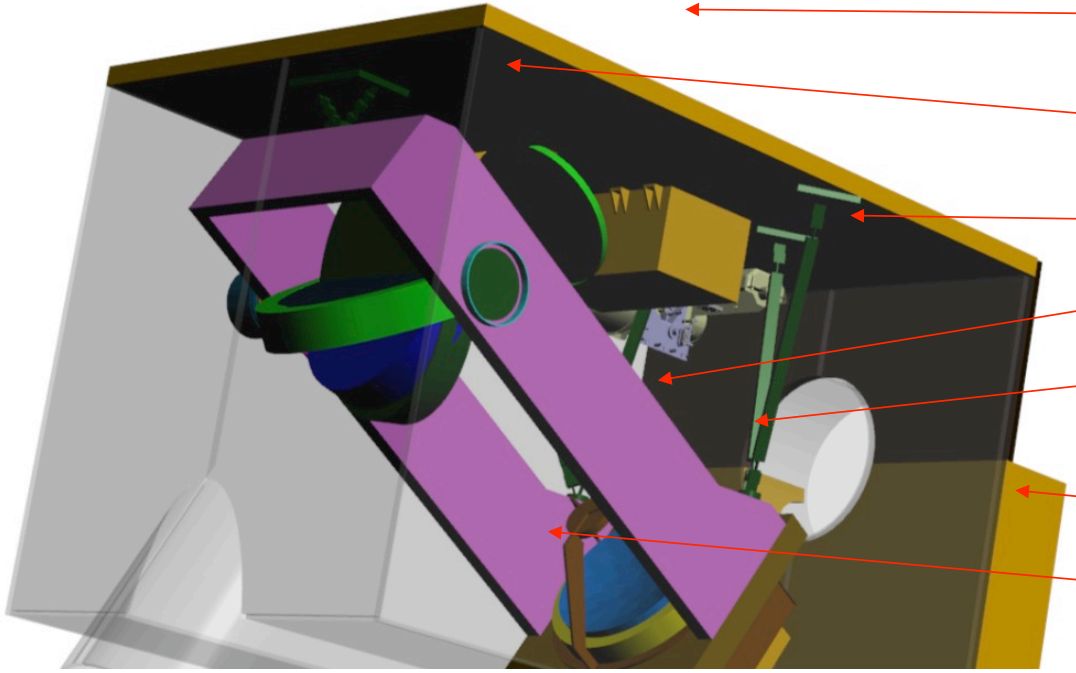
PHyTIR Implementation



PHyTIR will not have focal plane filters but will implement the identical ROIC design to HyspIRI-TIR.
32 parallel output at ≥ 10 MHz allow 32 µs frame times.

PHyTIR Current Design





Common spacecraft interface

Bi-pod struts

Kinematic yoke mounting

Onboard blackbody

Electronics

Fine and coarse encoding scan mirror

Space view port

Telescope

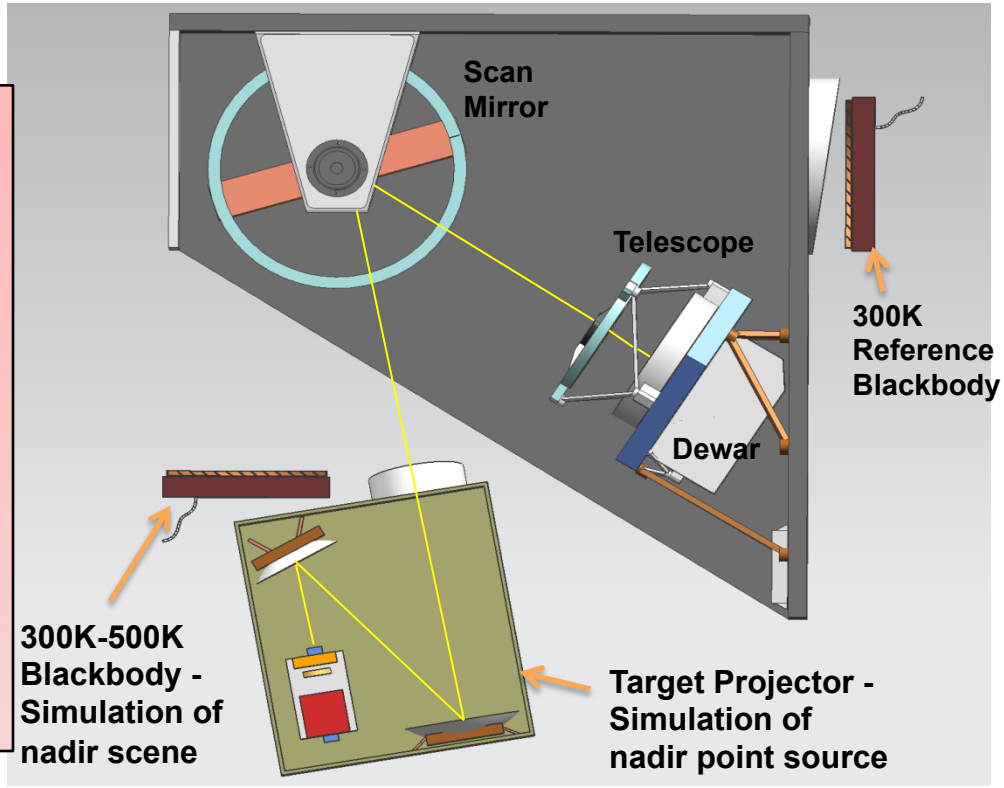
Relay optics enclosure

Passive radiator/cooler

Baffling

PHyTIR Testing

- PHyTIR Prototype Consists of
  - Full HyspIRI TIR MCT detector array
  - Spectral range 4-12 μm (TIR spectral range)
  - Scan mirror prototype with precise encoder
- Testing of PHyTIR Prototype
  - Measuring response to two blackbody targets, combined with detector noise, will provide S/N (tested at full frame rate)
  - Imaging of target-projector slit while inducing T gradients will test pointing stability
  - Increasing blackbody T will determine saturation T and high-T S/N
  - Measuring background, noise, and drift will show effects of uncooled optics



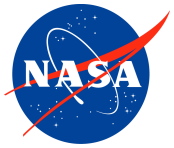
PHyTIR Summary

The following steps are currently being undertaken to build PHyTIR:

1) Design and Build the Scan Mechanism
2) Design and Build a Scan Mirror
3) Integrate the Spectral Filters with Focal Plane Array and ROIC
4) Assemble the Dewar with external telescope, internal relay and focal plane assembly
5) Build the prototype Electronics
6) Assemble PHyTIR

Once PHyTIR is assembled it will be used to retire the four key risks as noted earlier. A key part of this effort is the final testing to prove these four key risks.

a) **Detectors and readout meet all signal-to-noise and speed specifications.**
b) **Scan mirror and structure meet pointing knowledge requirements.**
c) **Long-wavelength channels will not saturate below 480 K.**
d) **Background from ambient temperature optics does not affect instrument performance.**

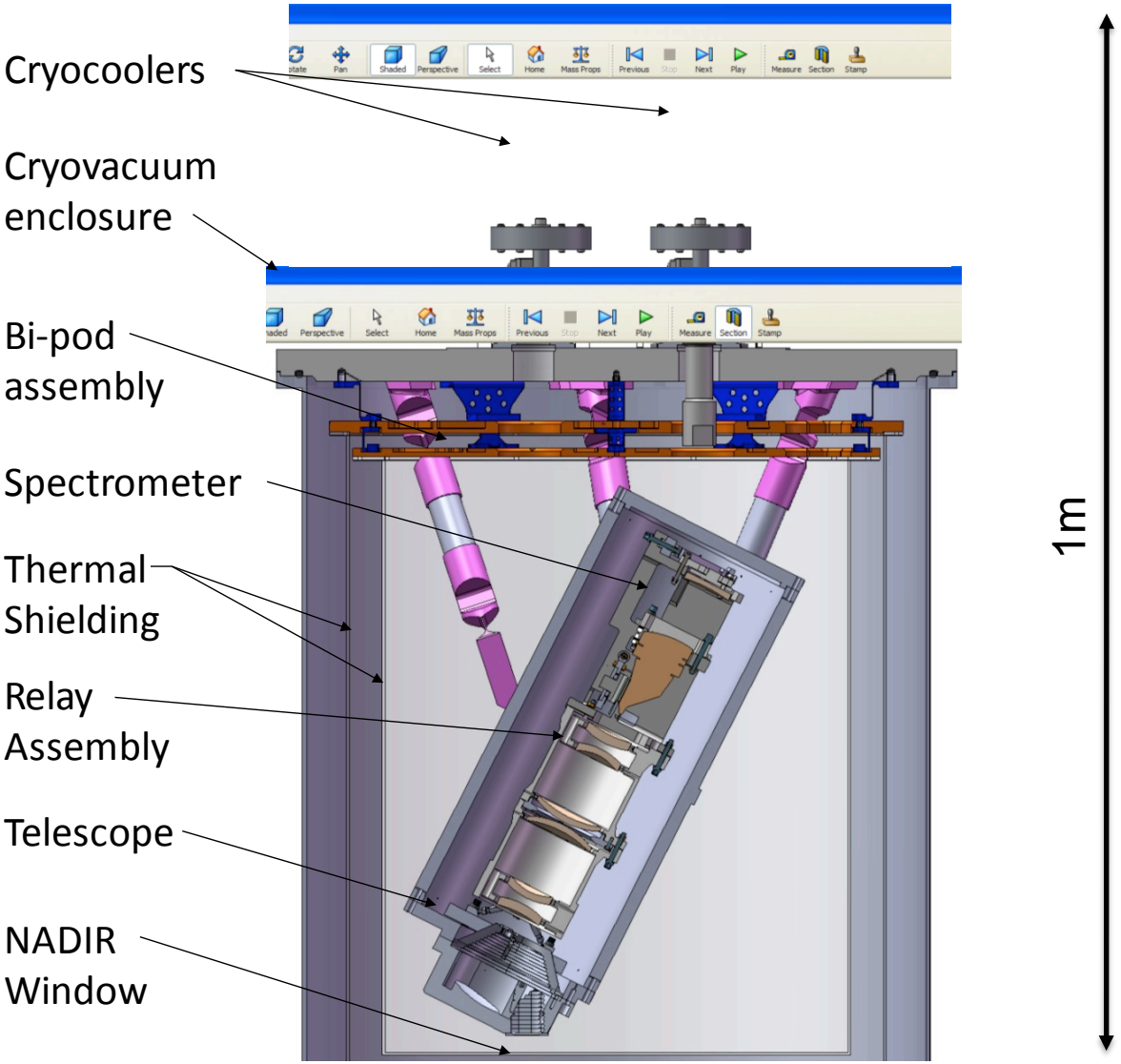


The Hyperspectral Thermal Emission Spectrometer (HyTES)

HyTES Rational

- Determine of the optimum position for the band filters for HyspIRI
- Provide antecedent data for testing HyspIRI algorithms
- Provide a new measurement capability, with high spectral and spatial imaging data useful for a range of applications such as volcanic gas detection
- Capitalize on the Quantum Well Earth Science Testbed (QWEST) an internally funded laboratory demonstration system for component testing, e.g. Detectors (QWIP), diffraction gratings, and slits at the system level.

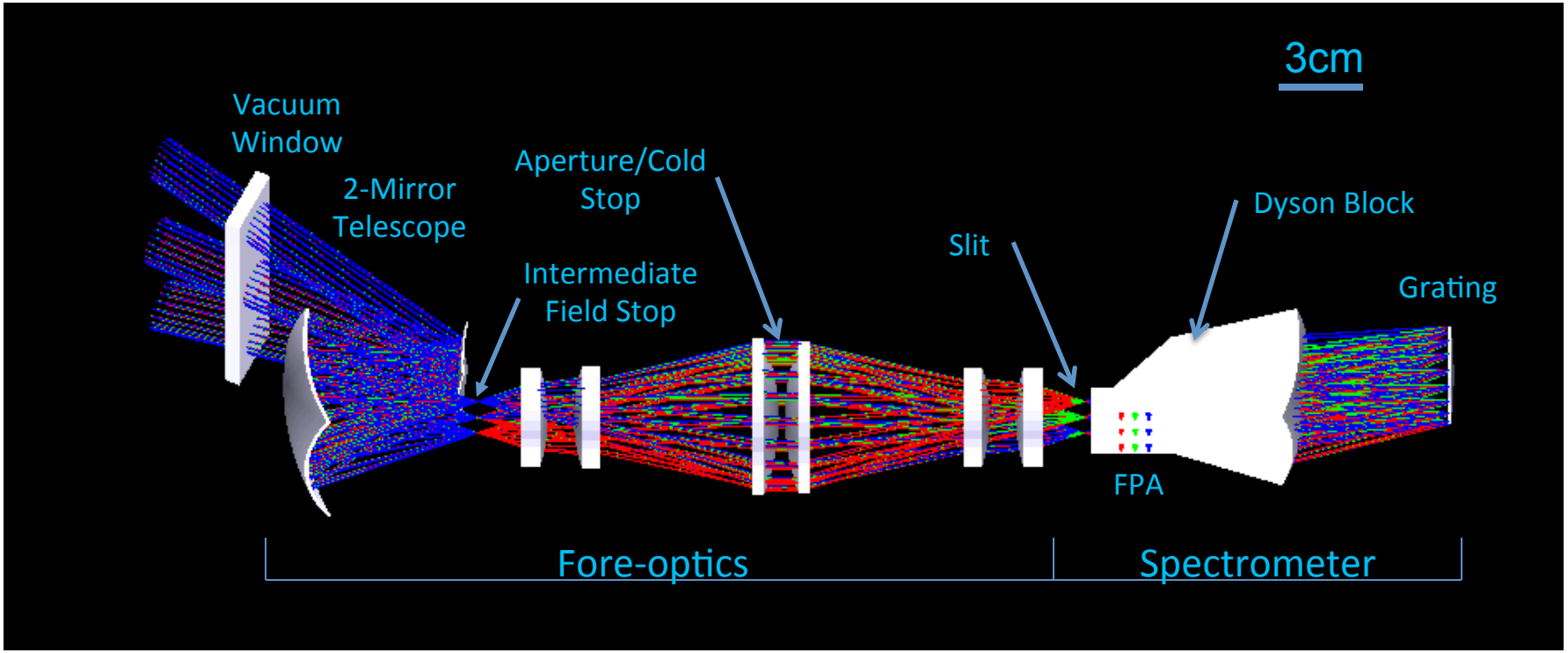
HyTES Instrument Design



HyTES & QWEST Characteristics

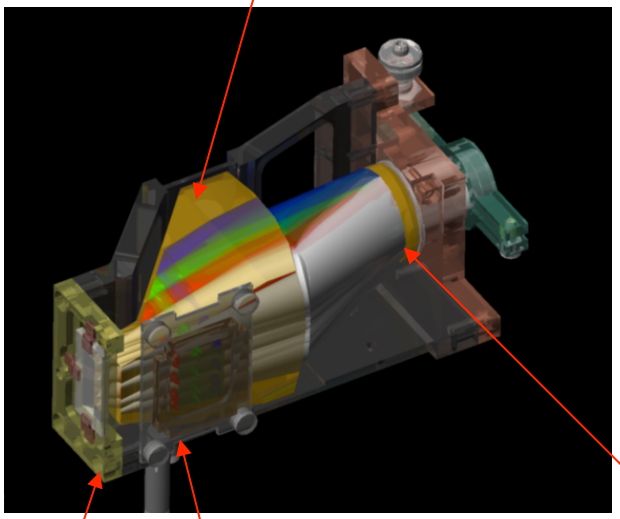
Instrument Characteristic	QWEST	HyTES
Number of pixels x track	320	512
Number of bands	256	256
Spectral Range	8-12 um	7.5-12 um
Integration time (1 scanline)	30 ms	30 ms
Total Field of View	40 degrees	50 degrees
Calibration (preflight)	Full aperture blackbody	Full aperture blackbody
QWIP Array Size	640x512	1024x512
QWIP Pitch *	25 um	19.5um
QWIP Temperature	40K	40K
Spectrometer Temperature	40K	100K
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**

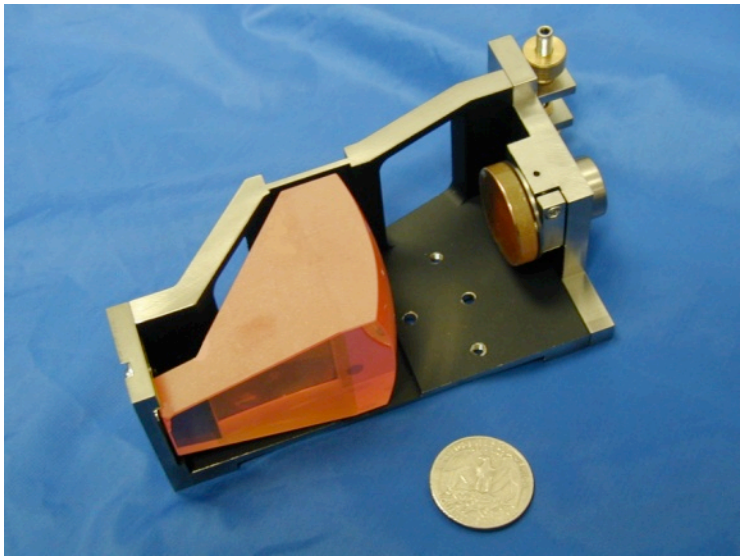
HyTES Optics



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

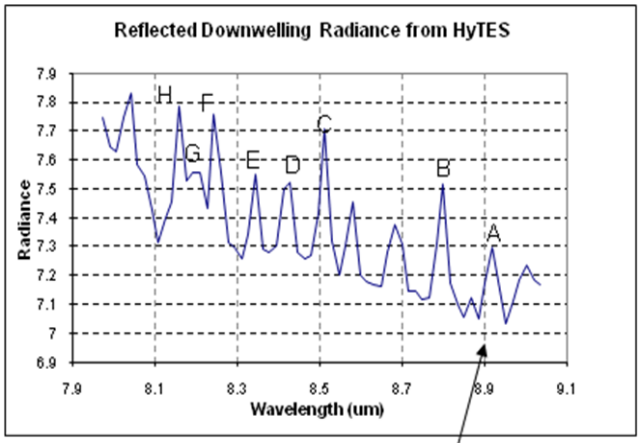
HyTES Precursor: Technology Demo

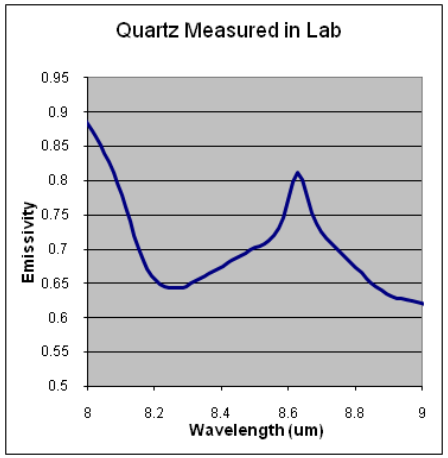


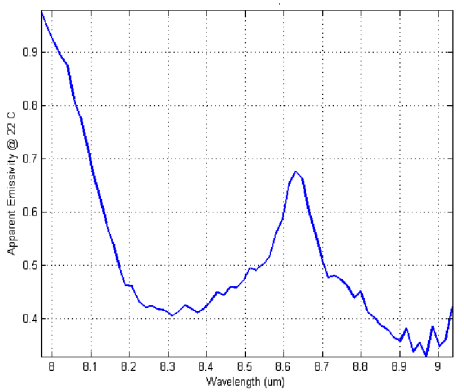


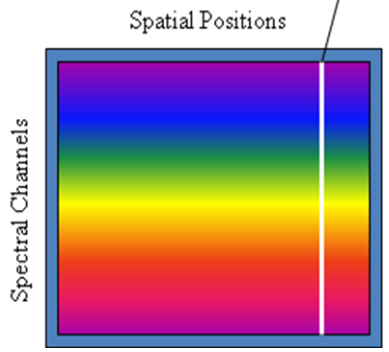
Compact Thermal Spectrometer Designs and Hardware

HyTES Precursor: Data Train

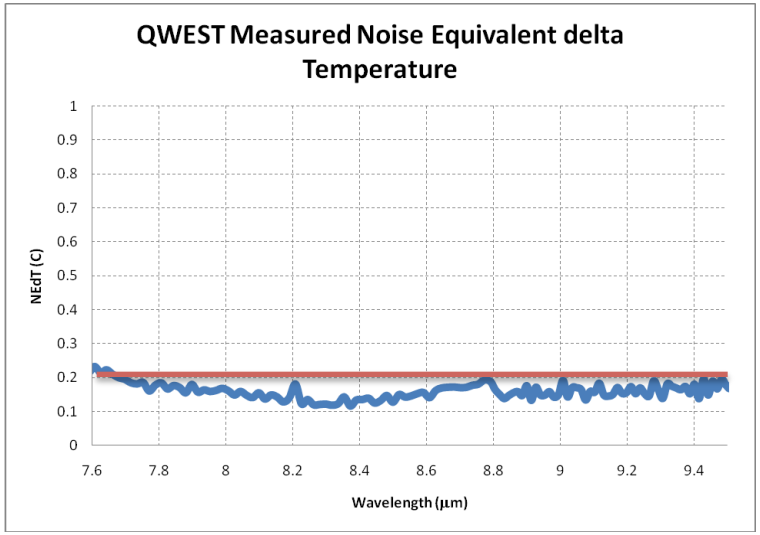






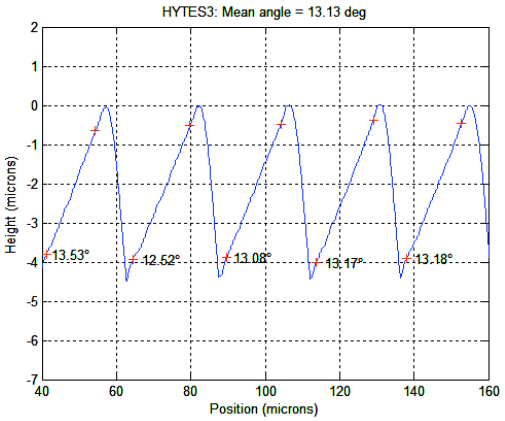


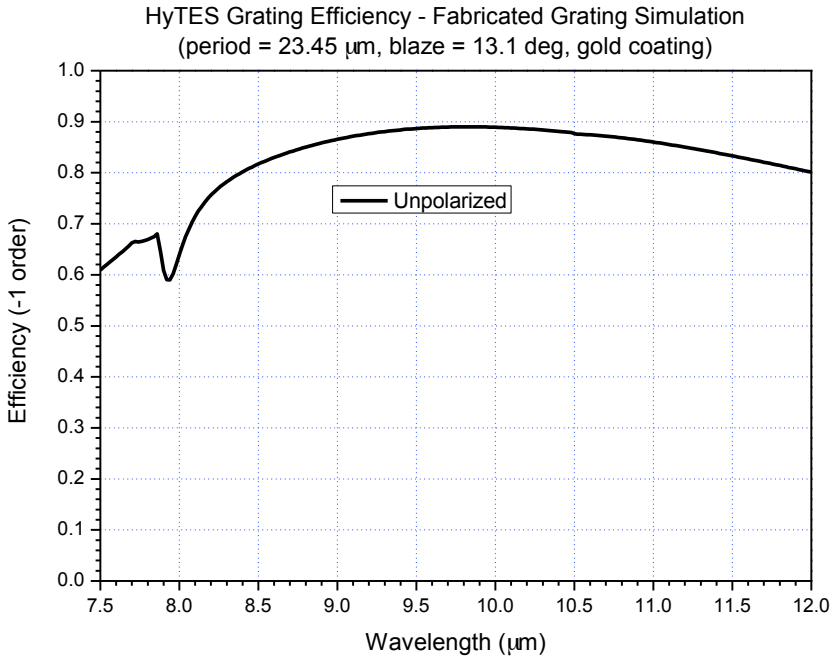
	Model	QWEST	Delta
A	8.92061	8.9179	0.00271
B	8.79894	8.7995	-0.00056
C	8.51426	8.5121	0.00216
D	8.4246	8.4276	-0.003
E	8.34725	8.3431	0.00415
F	8.25082	8.2418	0.00902
G	8.20345	8.208	-0.00455
H	8.16327	8.1573	0.00597



HyTES Diffraction Grating

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

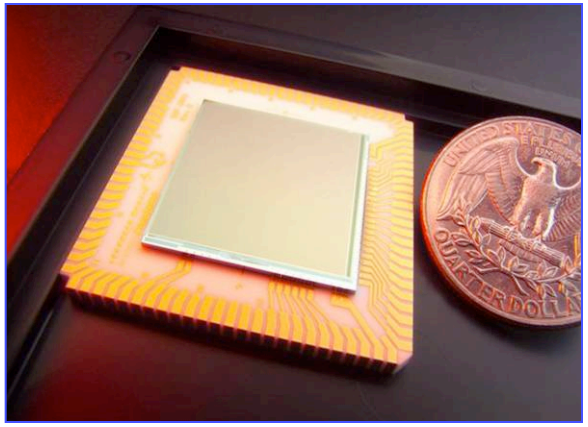




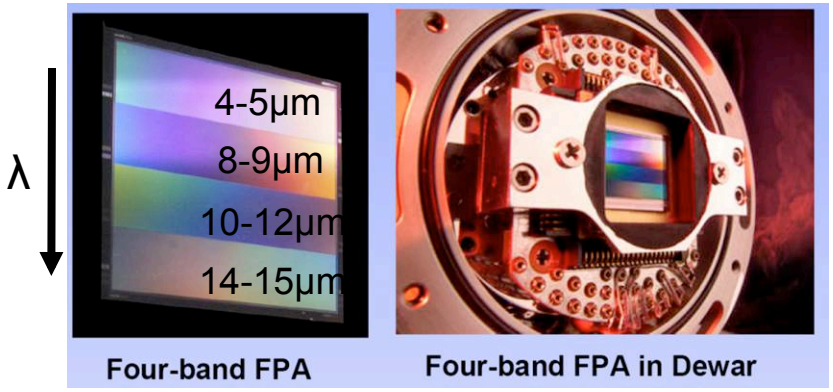
- Measured blaze angle is 9% deeper than 12° design – will decrease efficiency at 7.5 µm and increase efficiency at 12 µm as simulated above

HyTES Focal Plane Array

- HyTES will use a 1024x1024 pixel array covering the 7.5-12μm 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 7.5-12μm band the NEDT is less than 200 mK



1024x1024 pixel single-band QWIP FPA

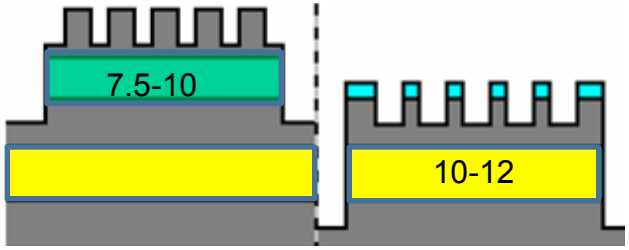


Four-band FPA

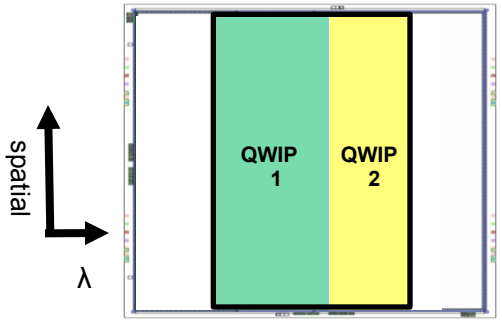
Four-band FPA in Dewar

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 7.5-10µm 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 7.5-12µm operation



HyTES pixel design – cross-sectional zoom at the transition point, showing two bands with ¼ lamda gratings on each

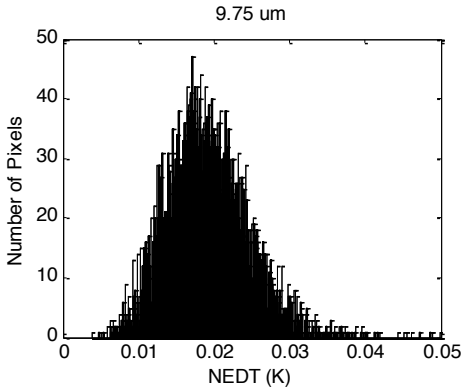


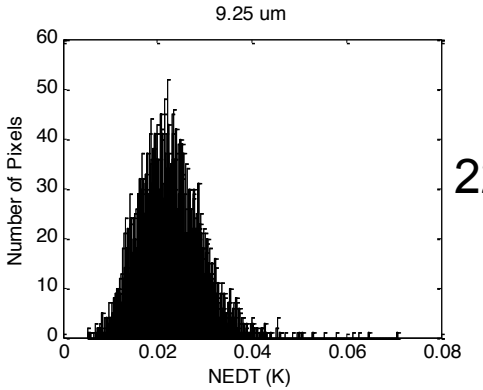
Top-down view of FPA
Illuminated area shown in green and yellow

HyTES Focal Plane Array

Measured noise equivalent delta temperature (NEΔT) for existing focal plane array. Single pixel data.

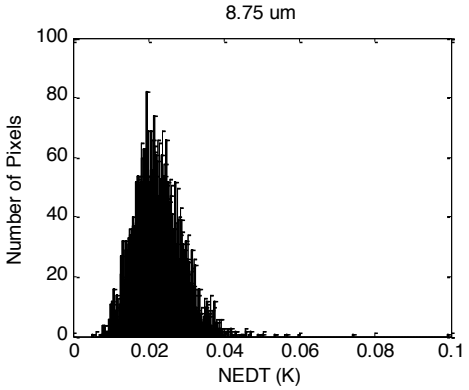
19.2 mK

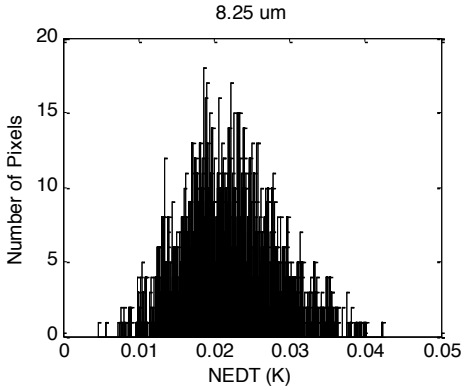




22.5 mK

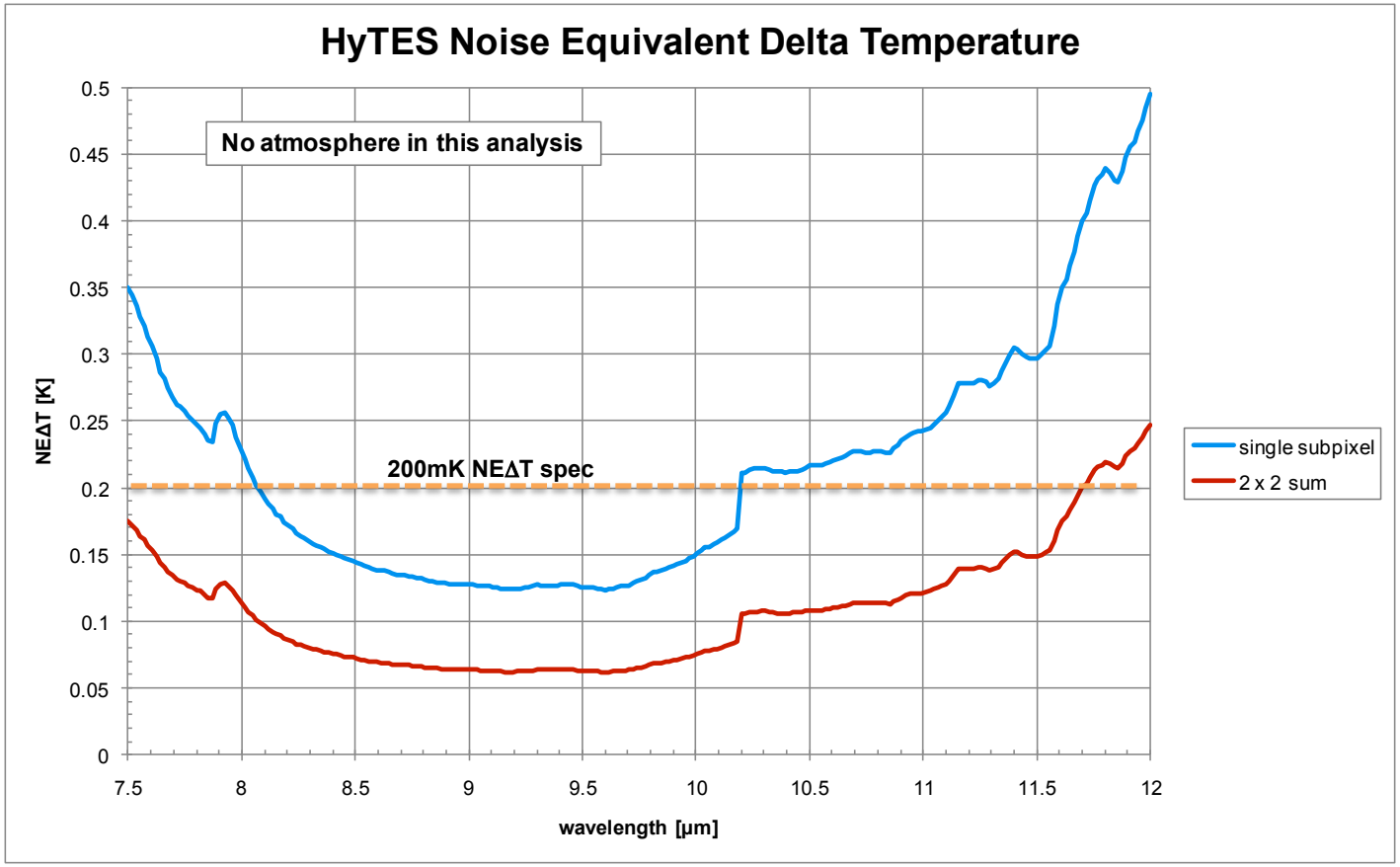
22.7 mK





22.0 mK

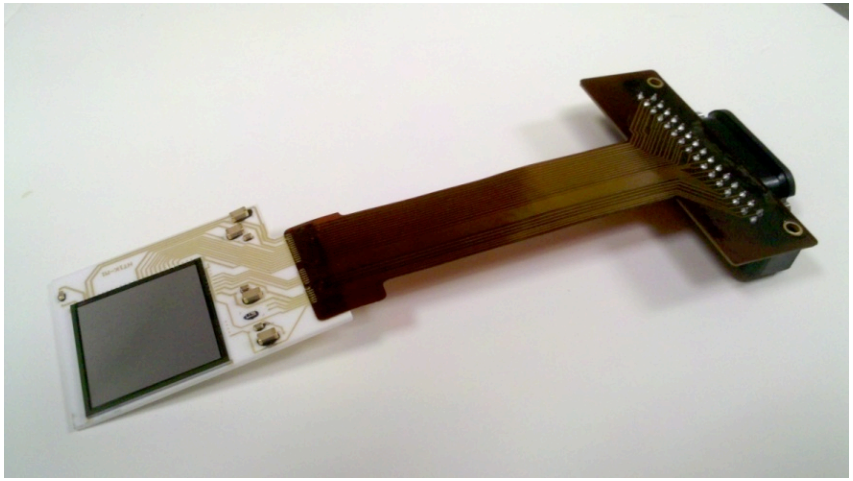
HyTES Sensor Modeling



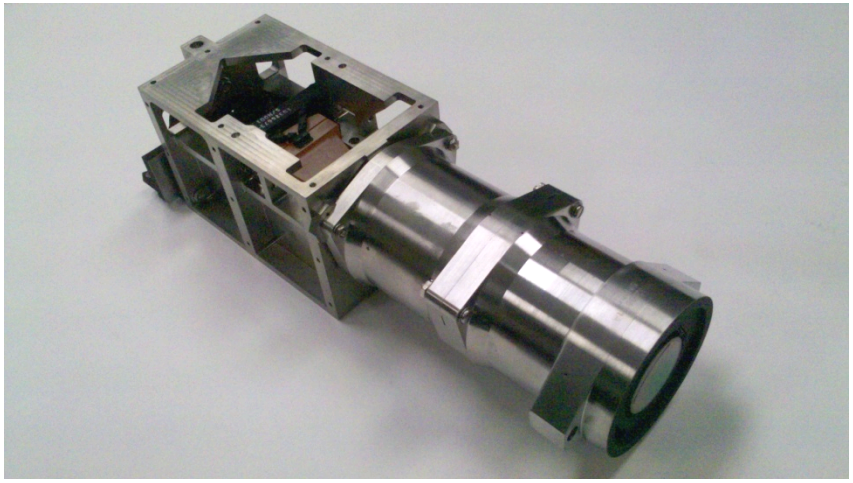
- The final design exhibits a smoother transition between bands than the original three-color version and meets spec (2x2 pixel summation NEΔT < 200mK) in nearly all of the 7.5-12µm band

HyTES System

Focal Plane Electronics



Spectrometer housing and Relay Assembly



Airborne Cryovacuum Enclosure

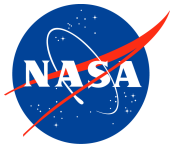
Various delivered hardware. The current effort is focused on integration and testing.

HyTES Summary

- HyTES will allow the determination of the optimum position for the band filters for HyspIRI
- HyTES will provide antecedent data for testing HyspIRI algorithms
- HyTES will provide a new measurement capability, with high spectral and spatial imaging data useful for a range of applications such as volcanic gas detection
- HyTES instrument laboratory testing will begin in the next few weeks
- HyTES airborne flights are planned for mid 2011

Overall Summary

- Exciting technology development and risk reduction underway for the HyspIRI-TIR program
- PHyTIR provides instrument risk reduction for key components of HyspIRI-TIR in particular the scan mirror and detectors
- HyTES provides science risk reduction for HyspIRI-TIR by allowing the optimum band positions to be determined as well as providing antecedent data at higher spectral and spatial resolution for algorithm development



Backup

PHyTIR Summary

This activity will benefit the development of any airborne or spaceborne system that will utilize a high speed scanning mirror coupled with a MCT detector array to obtain a wide swath width, high spatial resolution, thermal infrared measurement with an NEΔT of approximately 0.2K.

Similar systems have been used in the Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS), Advanced Spaceborne Thermal Emission Radiometer (ASTER) and Landsat (TM5/ ETM+) instruments (Barnes et. al. 1998; Mitchel 2008; Ohmae and Kitamure, 1994; Barsi et al. 2003).

However, none of these existing systems has sufficient performance to meet the measurement requirements of the HyspIRI-TIR instrument. PHyTIR will demonstrate that HyspIRI-TIR required high accuracy measurements can be made and help enable both the HyspIRI-TIR instrument as well as other future instruments built by Governments or Commercial Companies that utilize similar technology.

HyTES Diffraction Grating