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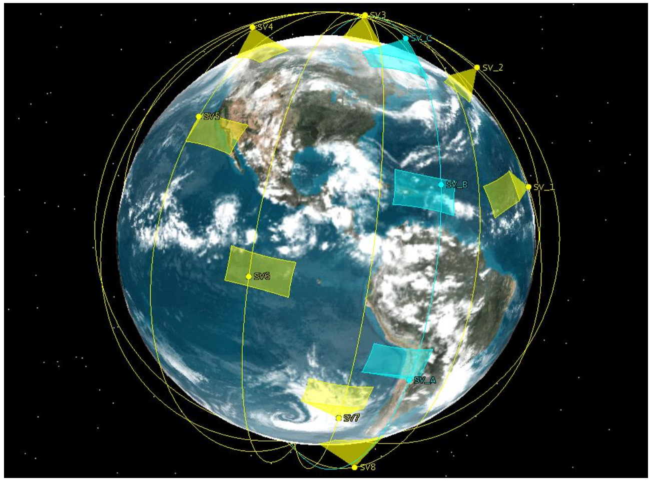
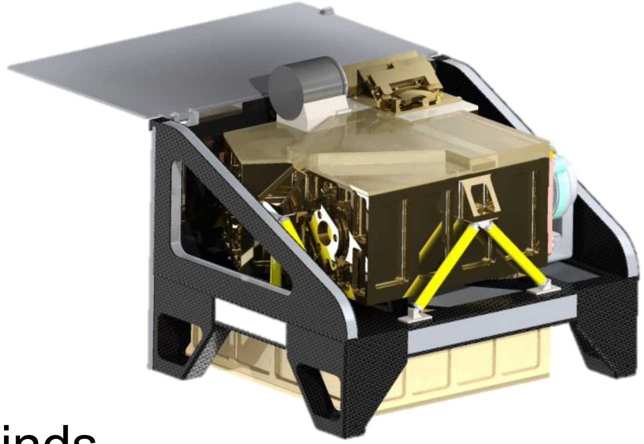
NASA Instrument Incubator Program (IIP)
MISTiC™ Winds
June 15, 2016

An Affordable System of Systems Approach for the Observation of Atmospheric Dynamics





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BAE Systems
Science Team:
H. H. Aumann JPL
J. Susskind NASA GSFC

MISTiC™ Winds

- Provides High Spatial/Temporal Resolution Temperature and Humidity Soundings of the Troposphere
  - Atmospheric State and Motion
  - Improved short term weather forecasting
- Enabled by:
  - LEO Constellation Approach
  - Micro-Sat-Compatible Instrument
  - Low-Cost Micro-Sat Launch

POC:kevin.maschhoff@baesystems.com

Topics

- Instrument Concept and Mission Concept Summary
- Instrument Physical Concept Update
- Risks Reduction Progress
  - FPA Radiation Test Summary
  - Airborne HSI AMV Winds Instrument Demonstration
    - Airborne Instrument Progress
- OSSE Plans
- Next Steps
- IIP Summary

MISTiC™ Winds- Two Affordable Measurement Concepts to Reduce Weather Forecasting Errors

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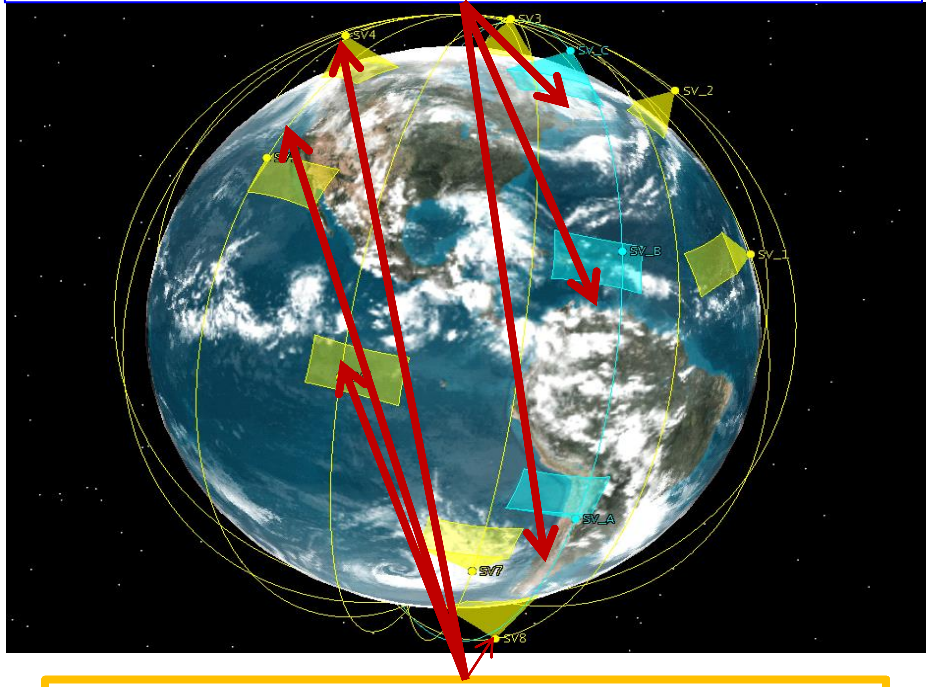
- MISTiC™ Winds Temperature and Humidity Sounding Constellation Options.
  1. Frequent-Sounding Constellation
     - e.g. 90 min refresh-globally.
  2. **Wind-Vector Formations**
     - **e.g. 4 3-Satellite Formations for Cloud-Drift and Water Vapor Motion-Vector Winds**
       - **Provide 3-Hr Refresh for 3D Winds *and* Atmospheric Soundings (T, H_2O)**

Miniature Spectrometers Operated in Constellations Offer Lower Cost /Lower Risk Approach than GEO for Frequent-Refresh IR Soundings & 3-D Winds

Motion-Vector Winds Formation (blue)



90 min Refresh of IR Soundings Provided by Spectrometers in 8 Orbital Planes (gold)

LEO orbit and SWIR/MWIR-only Spectra Enables MISTiC™ Instrument SWaP Reduction of 1-2 Orders of Magnitude

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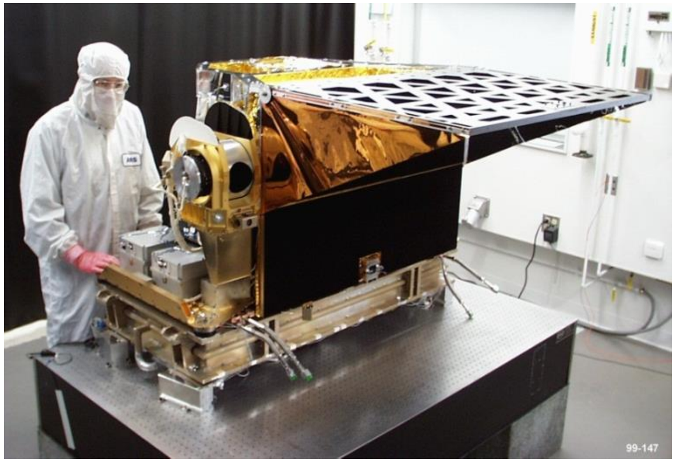
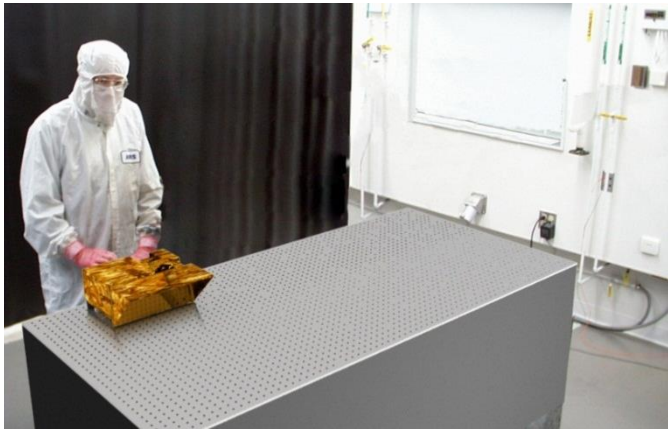
- Size Drivers
  - Geo-Stationary Imagers /Sounders Driven by Orbit Radius
  - IR Sounders Driven by # of Channels and LWIR Band Cooling
- **Moving MISTiC™ to a LEO orbit and eliminating LWIR channels enables massive reduction in SWaP**
  - Current concept is 60-125X less volume than Sounders proposed for GOES-R
  - Reduce power demand with an advanced FPA technology that won't require as much cooling
- IIP Instrument Concept Design
- Baseline envelope consistent with hosting on a 50 kg ESPA-Class Microsatellite
  - "Objective" Envelope consistent with 27U Cube sat Envelope (about 1 cubic foot of spacecraft volume)
- **Small instrument size depicted continues to be feasible as instrument concept fidelity increases**





Artist's Rendering Depicts a MISTiC™ Instrument, for Comparison to AIRS

Achieve Reduced SWaP by Reducing Number of Spectral Channels to the Mid IR only-*Sufficient to Sound the Dynamic Portion of the Atmosphere*

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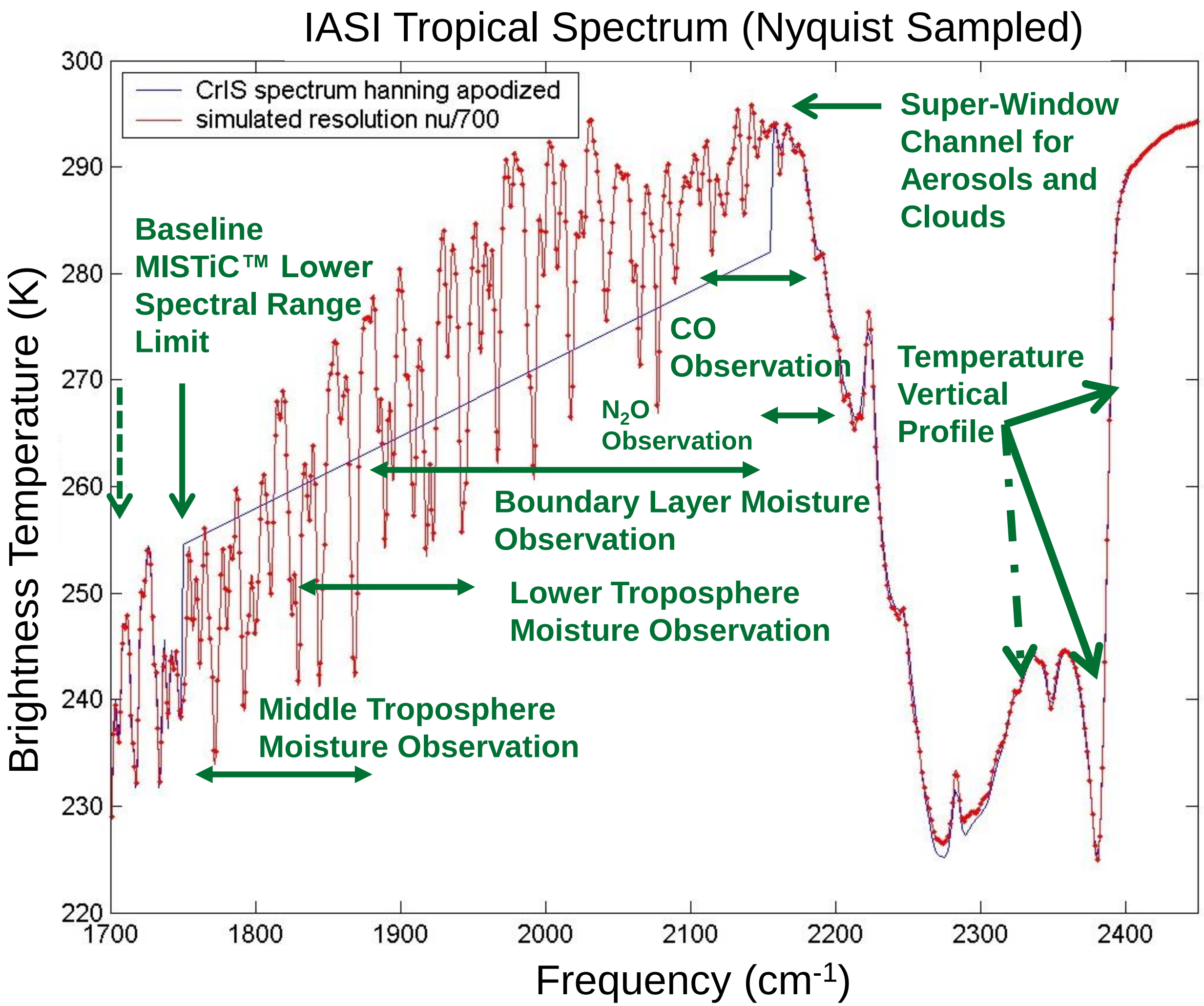

- SWIR Coverage at NEΔT and $\Delta\nu$ Sufficient for CO_2 R-Branch Temperature Sounding of Surface to Upper Troposphere
  - Sharper Vertical Resolution using Line Wings
  - Spectral Resolution > 700:1 is Sufficient
- Mid-Trop. CO
- Mid-Trop. N_2O
- Moisture in Planetary Boundary Layer
- Moisture Profile in Lower and Middle Troposphere
  - WV Motion Vector Winds
- Clouds
  - Cloud MV Winds

Channels Below 1750 cm^{-1} Needed to Observ
in for Upper Troposphere—*but*, *UT is Observ*
Sufficient Frequency by CrIS/IASI and ATMS

MISTiC™ Winds Level 1 Instrument Performance Characteristics and Level-2 Sounding Data Quality (updated)

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MISTiC™ Key Instrument Performance Characteristics		
Characteristic	Value	Comments
Minimum Spectral Frequency	1750 cm^{-1}	5.72 μm
Maximum Spectral Frequency	2450 cm^{-1}	4.082 μm
Spectral Sampling	~ 2:1	<590 spectral samples
Spectral Resolution @ minimum	>700 :1	$\nu/\delta\nu$ ((comparable to CrIS-Apodized)
Spectral Calibration Knowledge	1/100,000	$\delta\lambda/\lambda$
Angular Sampling	1.6 mr (cross-dispersed)	1.38 km (@ Nadir)
Orbital Altitude and Orbit	705.3 km	Polar/Sun-Synchronous
Angular Range (cross-track)	1570 radians	90 Degrees—Same as AIRS
Spatial Resolution	<3.0 km (geometric mean)	@ Nadir
Radiometric Sensitivity	<200 mK (max)	(<150 mK @ 2380 cm^{-1})
Radiometric Accuracy	<1%	@ 300K Scene Background
Key Sounding Data Product Characteristics,		
Vertical Resolution—Temperature	~ 1 km	In Lower Troposphere
Layer Accuracy	~ 1.25 K	In Lower Troposphere
Vertical Resolution—Humidity	~ 2 km	In Lower Troposphere
Layer Accuracy—Humidity	~ 15 %	In Lower Troposphere

- MISTiC™ Data Quality Requirements Similar to those Demonstra-ted by NASA's Successful AIRS Instrument
  - Spectral Resolution
  - Spectral Calibration Stability
  - Radiometric Sensitivity/Accuracy
- Spatial Resolution Notably Finer than AIRS Resolution (13 km @Nadir for AIRS)
  - 3.0km @ Nadir
- Reduced Spectral Range Enables Major SWAP Reduction

MISTiC Winds IR Spectral Sounding Instrument Concept

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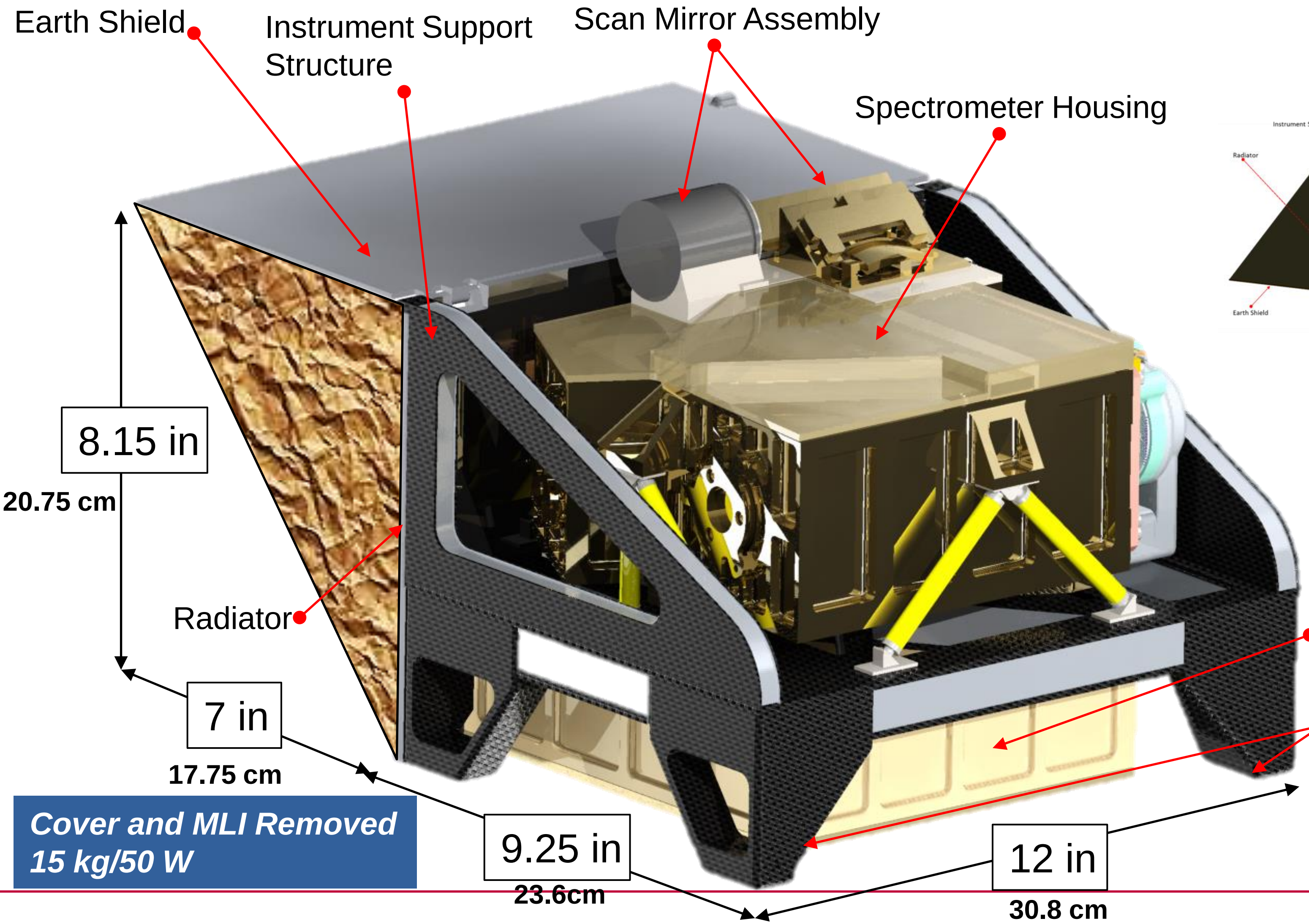
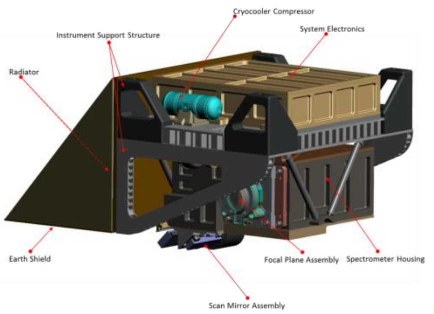
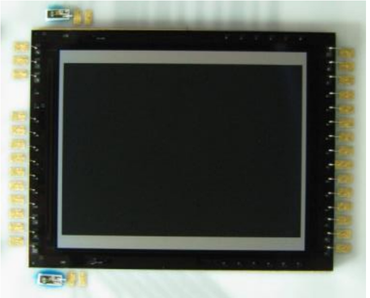


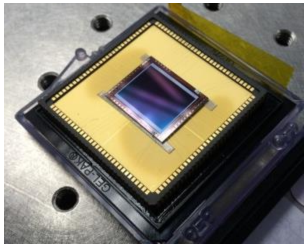


Cover and MLI Removed
15 kg/50 W

FPA Radiation Tolerance Risk and Risk Reduction Plan

- APD-Class SWIR/MWIR FPA Ionizing Radiation Tolerance Risk
  - High Sensitivity APD-Mode IRPFA Enables Higher Operating Temperature—Reducing Power Demand
  - Selected FPA Successfully Used Operationally in Airborne Hyperspectral Mission
  - ***Remaining Risk***: APD Array Not Yet Tested for Key MISTiC™ Conditions in Space Radiation Environment
    - Radiation Under Operating Bias
    - Evaluated for Low Frequency Operation (1/f knee <10 mHz)





The MWIR HgCdTe Avalanche Photodiode-based IR Focal Plane Array Detector selected for MISTiC™ allows high-sensitivity hyperspectral measurements at 90K

- Risk Reduction Plan
  - Proton Total Dose Testing of Engineering-Grade APDIS FPA (s)
    - Dose Applied Under Sufficient Bias for Gain > 100
      - λ_{co} similar to that needed for Temperature-Band
    - Includes Testing at Frequencies down to 10 mHz

Projected APD Detector Characteristics Meet MISTiC Updated Sensitivity(Dark Current) Requirements at 90K

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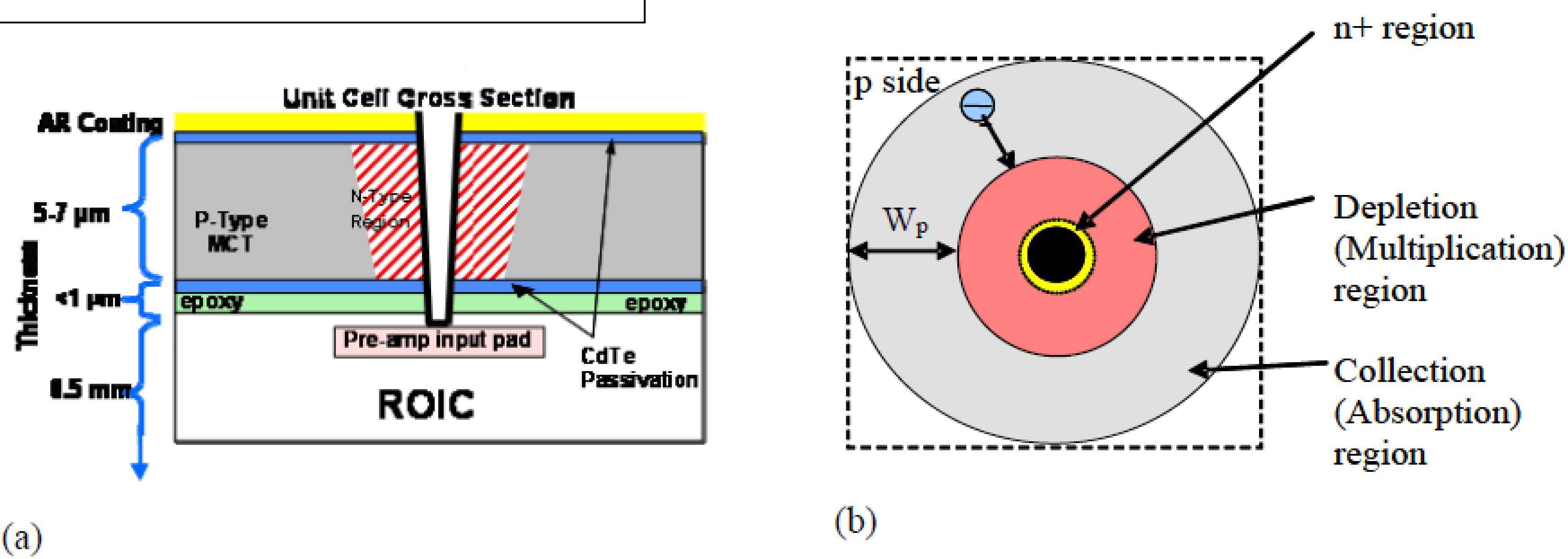
Updated Minimum Scene –Generated Photo-Current Density

- 8×10^{-10} A/cm^2 (Temperature Band)
- 2×10^{-8} A/cm^2 (Water Vapor Band)

DRS HDVIP Dark Current Density Model Estimates

Temp.	J_{dark} @ λ_{co}= 5.1 µm	J_{dark} @ λ_{co}= 6.4µm
85 K	1×10^{-11} A/cm^2	5×10^{-9}
90 K	4×10^{-11} A/cm^2 √	1×10^{-8} √
95 K	1×10^{-10} A/cm^2	5×10^{-8}



HDVIP® e-APD architecture.(a) Cross section of the HDVIP process. (b) Top-Side view

Ionizing Radiation Tests of HgCdTe APD FPA Demonstrate its Compatibility with Space Environment

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<u>Ionizing Radiation Test Background</u>:

- Test Performed by AFRL Infrared Radiation Effects Laboratory
- Test Type: Total Dose-Proton
  - 68 MeV Proton Energy
  - FPA Cooled/Under Operating Bias Voltages During Proton Irradiation
- FPA Radiometric Characterization Pre-Radiation and at 6 Dose Steps

<u>Key Test Results:</u>

- ROIC Essentially Unchanged to 70 krad
- Detector dark current (and noise) increase with dose, but acceptable rate
  - FPA Noise < Requirement at 20 krads Proton Dose\
  - Modest 1/f noise increase, at high APD gain at higher proton doses

Total Ionizing Dose (krad(Si))	Median Pixel Dark Current (A) (zero bias reference)
Pre-Rad	1.3×10^{-15}
1	1.26×10^{-15}
5	1.82×10^{-15}
15	3.5×10^{-15}
25	6.3×10^{-15}
35	8.0×10^{-15}
70	16.0×10^{-15}

Allocated Dark Current Rqmt. < 5 fA/Pix

HgCdTe 640x480-Format APD-Mode IR FPA Technology Readiness Level Advanced to 5

Primary Efforts under NASA IIP Address Instrument Concept, Technology and Measurement Challenges (Continued)

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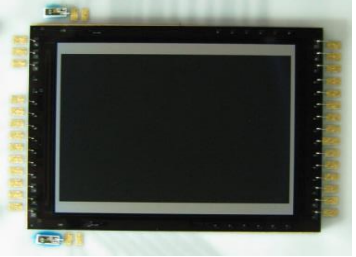
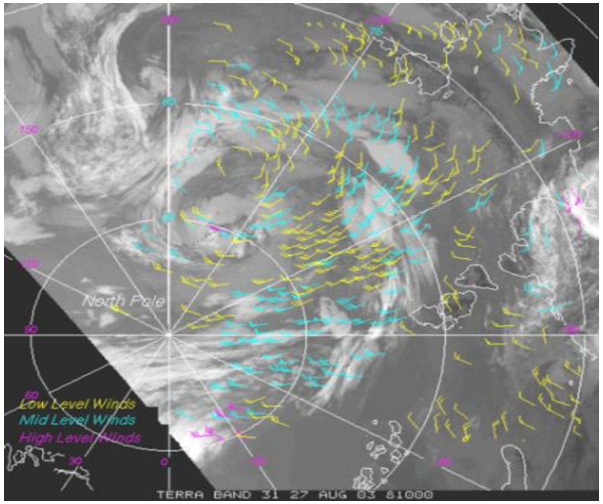
- ✓ Space Mission concept development
- ✓ <u>Technology Risk Reduction</u>

  Challenge: Get a higher operating temperature FPA in order to reduce cooler power
    - <u>Benefit</u>: Large reduction in SWAP
  - Approach: Use of new APD-Class MWIR FPA
    - <u>Risk</u>: APD Array Not Yet Tested in Space Radiation Environment
    - <u>Mitigation</u>: Radiation Testing on IIP *(by 9/15)*
- <u>Observation Method Risk Reduction</u>
  - Challenge: Application to Highly Vertically Resolved (3D) MV Winds is highly plausible-but not demonstrated
    - <u>Benefit</u>: MV Winds at Low Cost -> Better weather forecasting
    - <u>Risk</u>: Tracer De-correlation Behavior at finer vertical resolution unknown in detail
    - <u>Mitigation</u>: Airborne observations of Tracer De-Correlation Times & Behavior



The MWIR HgCdTe Avalanche Photodiode-based IR Focal Plane Array Detector selected for MISTiC allows high-sensitivity hyperspectral measurements at 85K



MISTIC™ Winds Tracers Features Would Have Better Vertical Resolution Than MODIS Winds

MISTiC™ Winds Airborne Test CONOPS Summary

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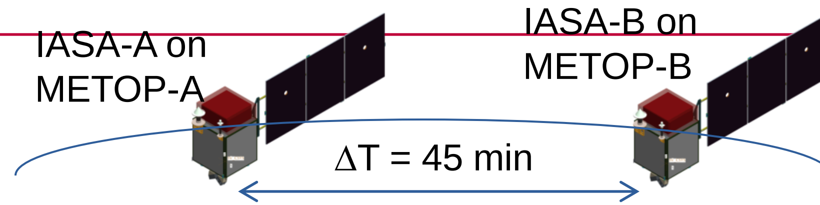
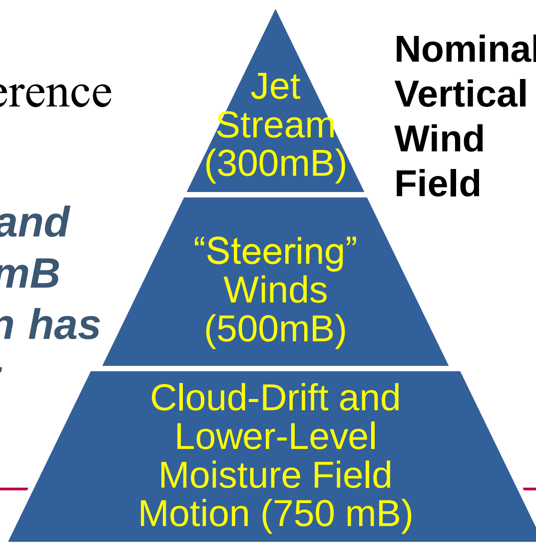
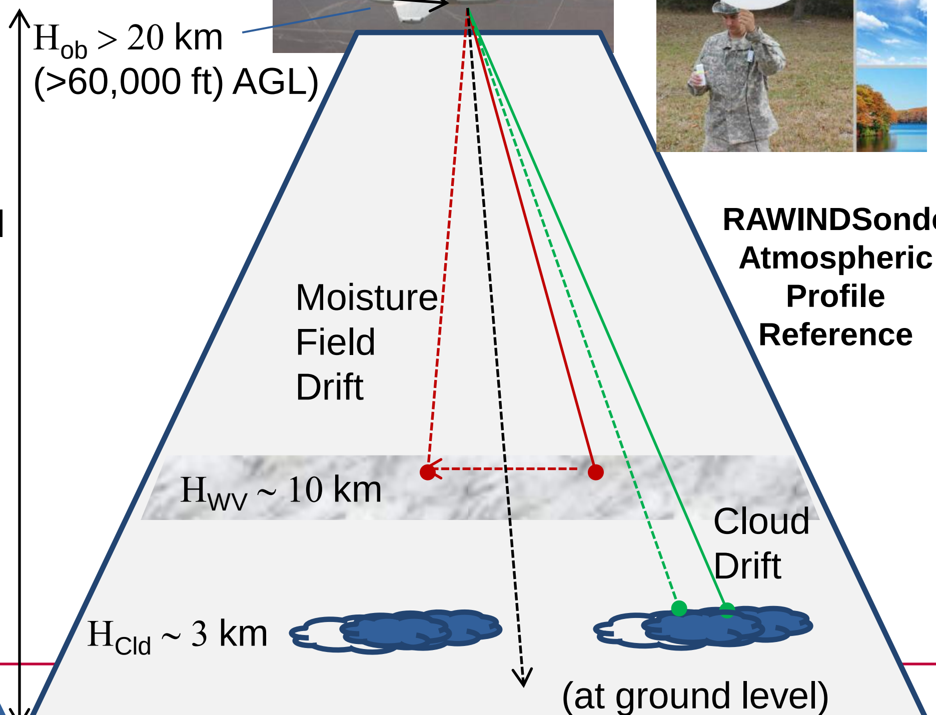
- *Test Objective*: Demonstrate Vertically-Resolved Moisture-Feature Tracking by an MWIR HSI Instrument for 500mB -Level Winds
- *Test Approach*:
  - Observe with Airborne MWIR HSI Instrument (MISTiC™ Airborne Moisture Tracking Demonstrator)
  - Under-fly METOP A and B to Correlate IASI Observations in MISTiC™'s Spectral Band
  - "SONDE" Reference



MISTiC Airborne Demonstrator





OSSEs by NASA and NOAA Show 500 mB Wind Assimilation has Greatest Weather Forecast Impact

Airborne Demonstration Instrument Status-Overview

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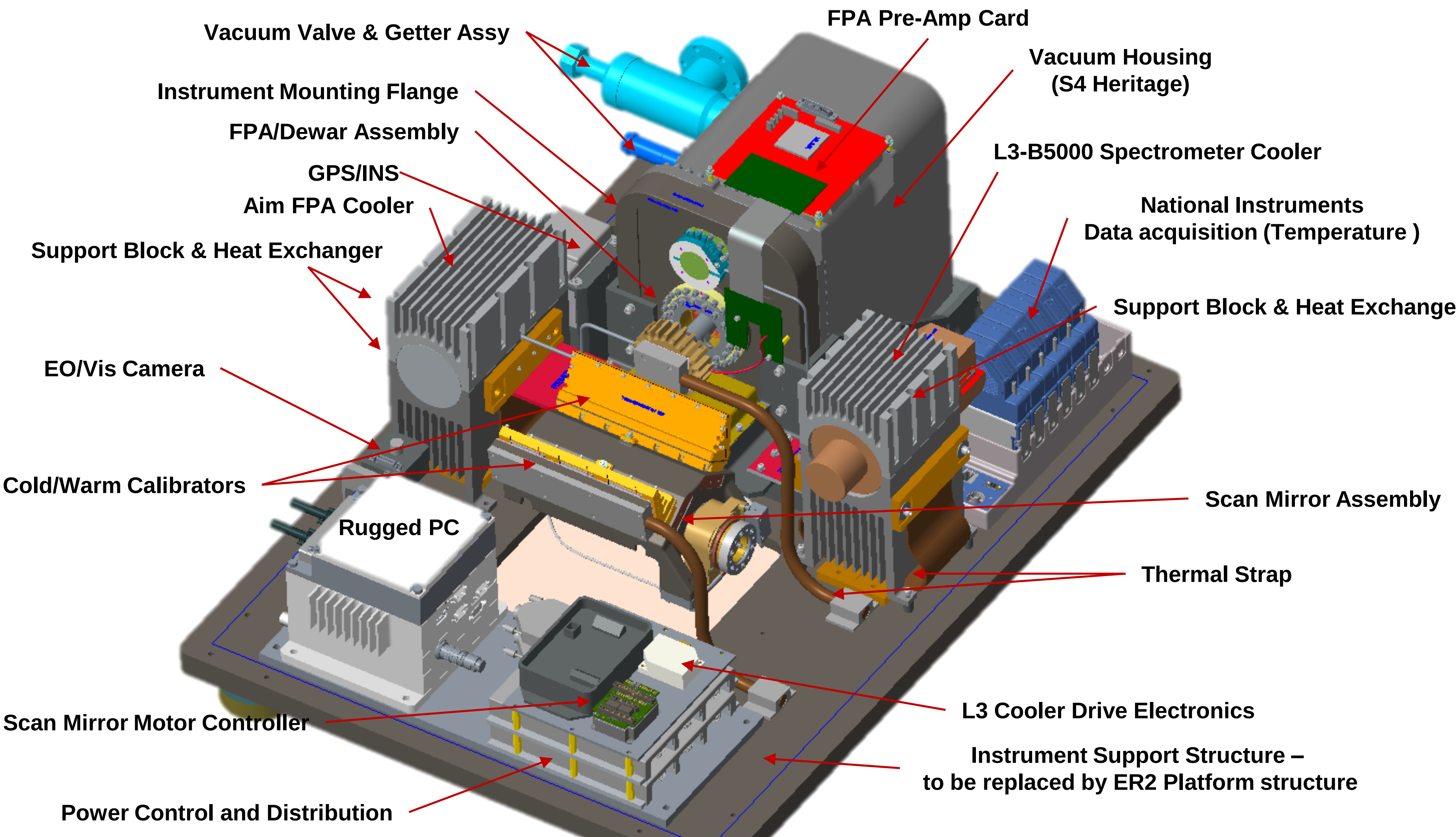

- Overall layout will be modified to accommodate ER2 I/F but all instrument components will be used.
- All Major subassemblies and components are either in house or on order.

Airborne Instrument Progress and Status – Spectrometer Fabricated

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Key Metrology Data

Airborne Spectrometer Design and Materials Identical to Space Instrument Design

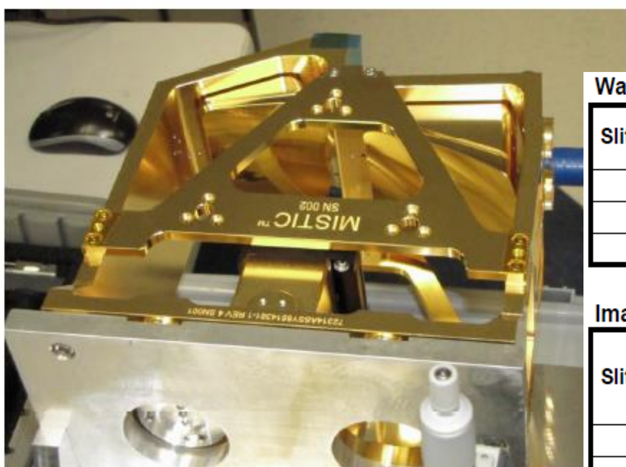
Optical Element	Surface Roughness Spec (RMS)	Actual	Mirror reflectance Spec: Rx > 97% (4.0-6.0 um)	
M1 Mirror	< 45 A	41	99.40%	
M3 mirror		45	99.02%	
M2 -Grating	< 20A	16	98.91%	
			S1 Rx	1.44%
			S2 Rx	4.20%
			Matl % Tran	94.87%
			Based on avg AOI Angles	

Slit Dimensions	Spec	Actual
Slit Width (um)	50 +0/-2	49.8
Slit Length (mm)	12.00 +1.0/-0	12.004

- Surface finish and slit dimensions meet spec with margin.
- Machining quality is exquisite.

Housing with grating and lens sub-assembly installed. Alignment mirrors covered for protection.

- Spectrometer optical performance interferometrically tested @3.39um in 2X pass
- Wavefront spec @3.39um in 3rd and 4th Order corresponds to MTF performance required usable MISTiC Orders. Very slightly out of spec for the off axis position.



Fully assembled with Surrogate Slit on holding fixture.

Key Performance Metrics – Pre/Post thermal Cycle

Wavefront Error @ 3.39µm

Slit Location	Spec (wv. RMS) 3rd Order	Spec (wv. RMS) 4th Order	Pre Thermal 3rd Order	Pre Thermal 4th Order	Post Thermal 3rd Order	Post Thermal 4th Order	Vignetting?
Top	0.04	0.039	0.042	0.04	0.039	0.042	No
Center	0.041	0.047	0.036	0.03	0.034	0.034	No
Bottom	0.04	0.039	0.055	0.045	0.055	0.048	No

Image Plane Location (*mm*) Relative to Slit Center, 3rd Order (3.39µm)

Slit Location	Pre Thermal 3rd Order X	Y	Z	4th Order X	Y	Z	Dispersion 144(nm/mm)	Post Thermal 3rd Order X	Y	Z	4th Order X	Y	Z	Dispersion 144nm/mm
Top	0.008	-5.986	-0.008	11.687	-5.986	0.005	145	0.010	-5.991	-0.047	11.695	-5.991	-0.036	145
Center	0.000	0.000	0.000	11.680	0.008	0.005	145	0.001	0.000	0.013	11.681	0.000	0.020	145
Bottom	-0.011	5.989	0.010	11.659	5.996	0.022	145	-0.010	5.986	0.027	11.666	5.989	0.033	145

- Dispersion 144 nm/mm => 3.6 nm/pixel 2nd order : Measured 145 nm/mm => 3.625 nm/pixel
- Excellent dispersion performance

Instrument Progress and Status – Scan Mirror Assembly Fabricated

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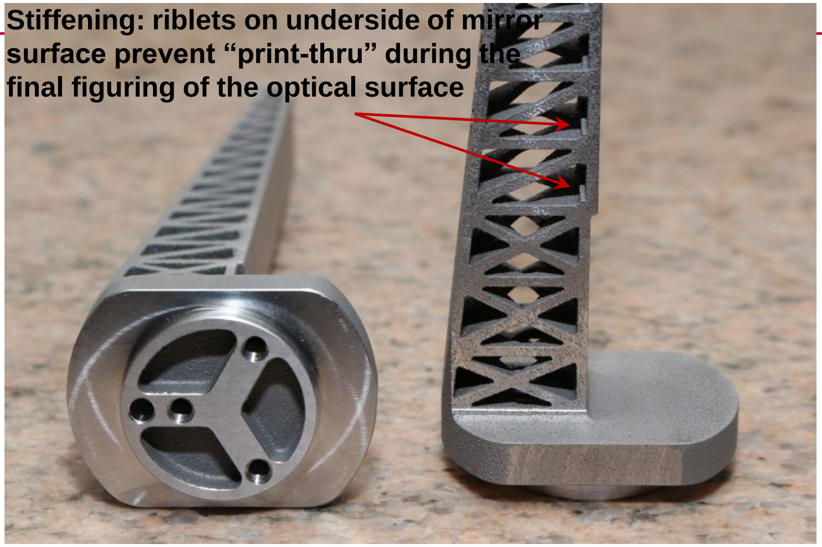
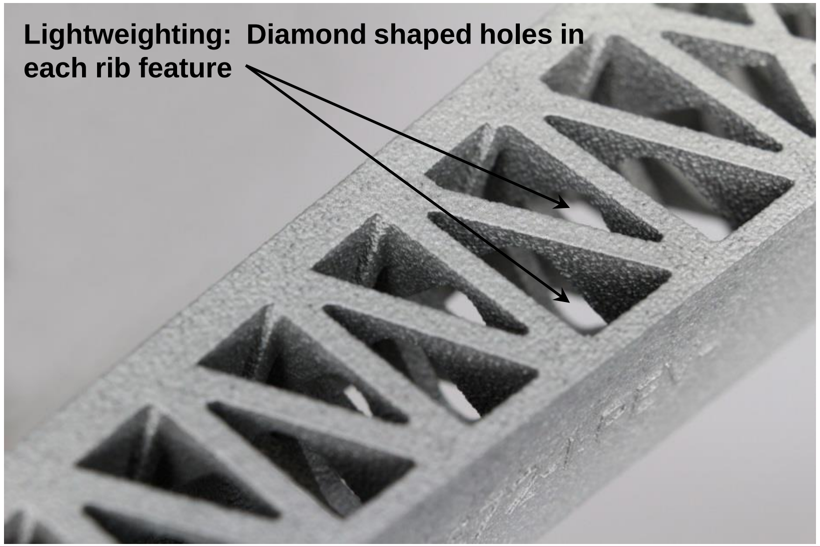
Technology Development:
Scan Mirror fabricated using additive manufacturing aka "3D Printing " Technology.

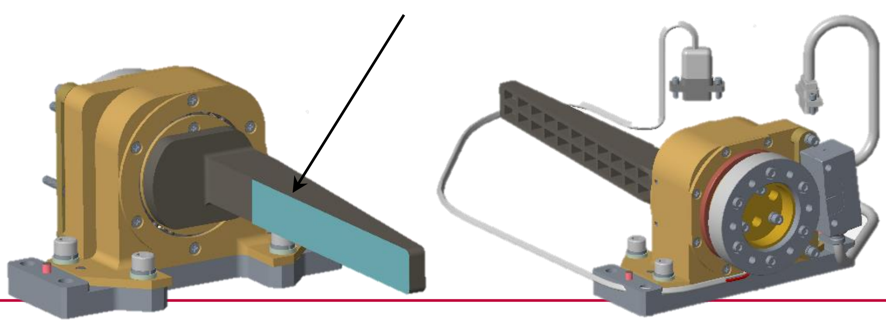
Working with General Dynamics we fabricated a unconventional lightweighted MISTiC Scan mirror.

This method of manufacture could Benefit future MISTiC efforts to reduce payload SWaP and system manufacturability.

Part can be fabricated batches of A dozen or more.







Airborne Instrument Progress and Status – Integrated Dewar/Cryocooler Assembly Fabricated

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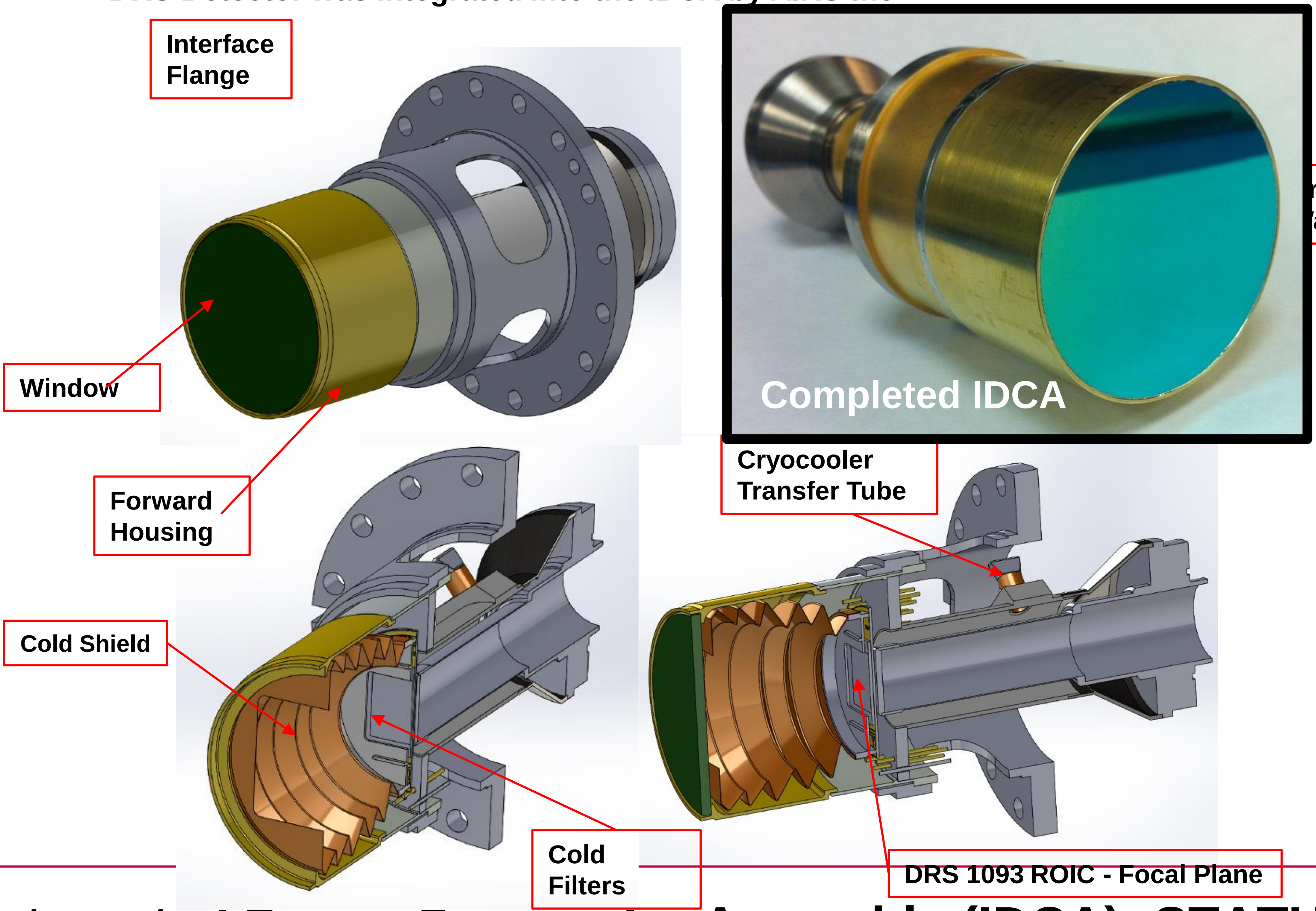
DRS Detector was integrated into the IDCA by AIRS Inc



Integrated Dewar Cryocooler Assembly (IDCA) -STATUS

DRS 1093 ROIC – APD-Mode Focal Plane Array

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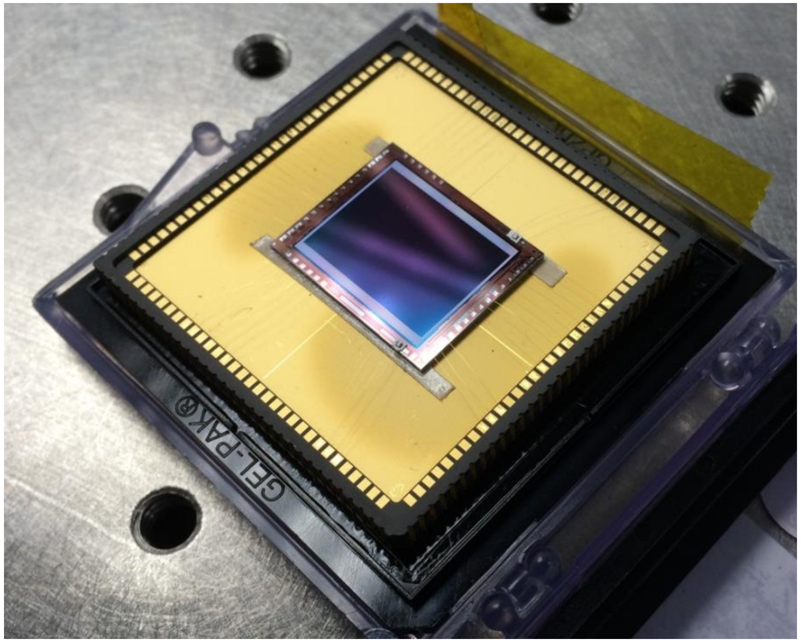
- 640 x 480 Array of APDs
- 25µm Pixel Pitch
- Frame rate 30Hz
- Master clock 12MHz.
- 77K Nominal Operating Temperature
  - Space Instrument Operating Temp 90K
  - Airborne Demo Temp 60K
- Active Power 200 mW
- 46 bond pads, 32 are to be bonded
  - 4 detector
  - 2 video output
  - 7 power
  - 8 ground and substrate
  - 3 external biases (2 tactical)
  - 6 digital inputs (5 tactical)
  - 10 internal bias overrides
  - 1 digital test out
  - 1 analog test out
  - 2 temp pads (4 temp wires)
  - 2 test diodes (not included in pad count)



APD IRFPA Demonstrated in Operational (Airborne) Hyperspectral Imaging Applications

Airborne Instrument Progress and Status - Spectrometer Vacuum Housing

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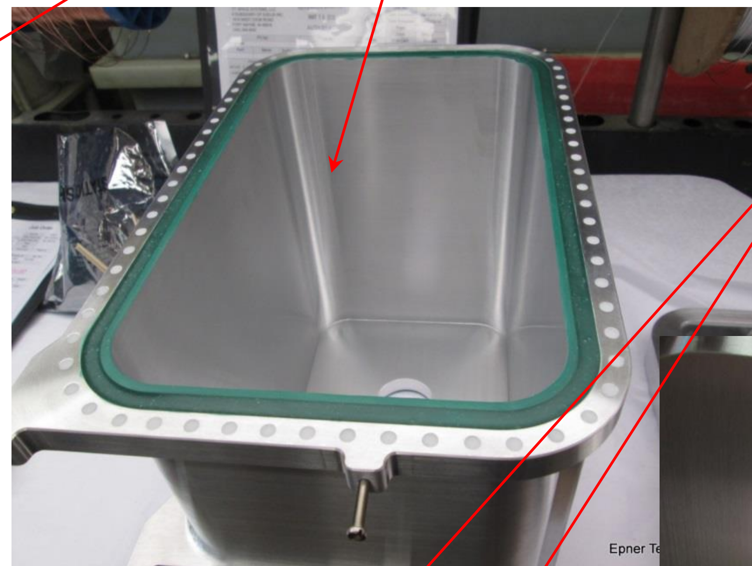
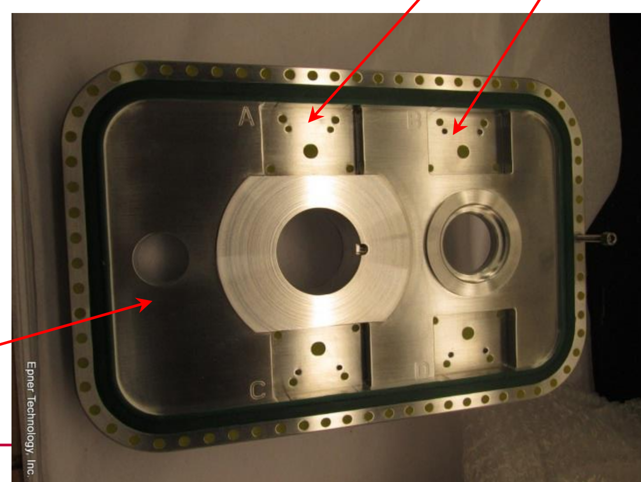
Housing is in electroplating @ Epner

Spectrometer Vacuum Housing

Spectrometer Mount Locations

Hermetic Feed thrus (Temp Sensors)





Vacuum Flange – Spectrometer Mounting Structure

Airborne Instrument Progress and Status – Fore Optics Fabricated

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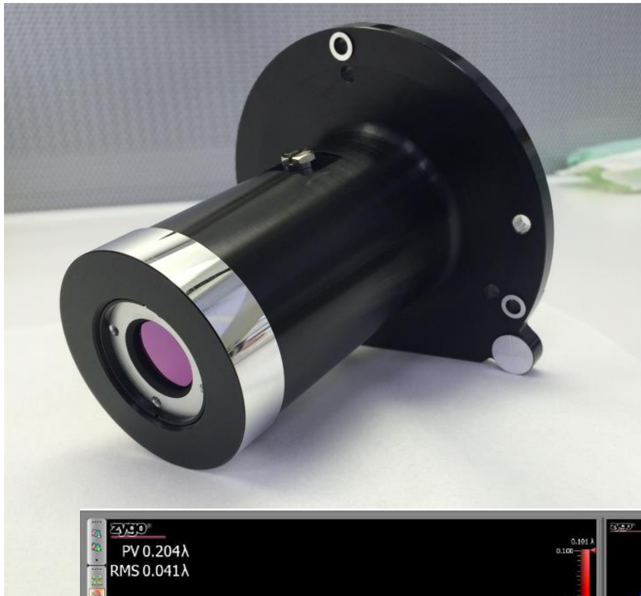

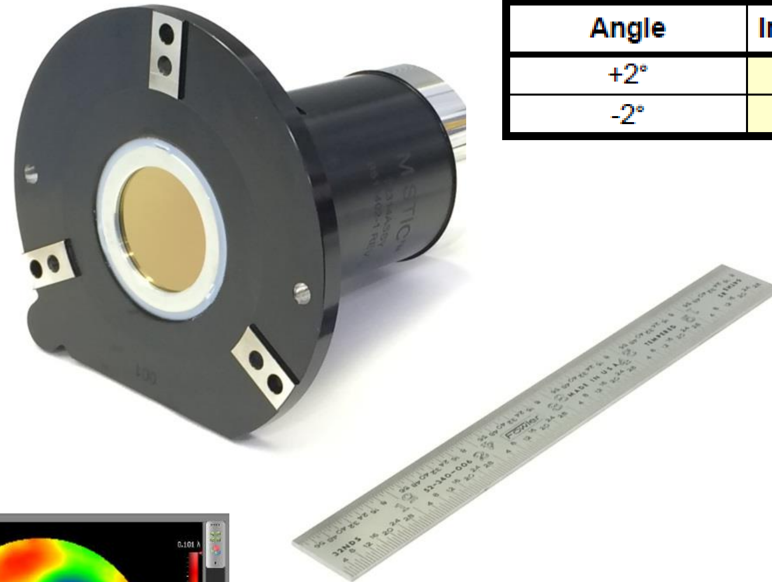

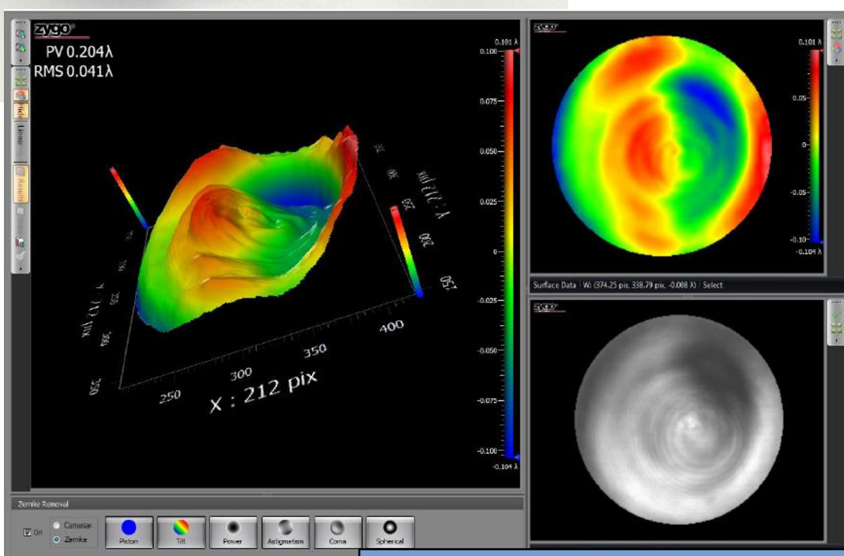

Average Effective Focal Length (mm)

Angle	Image Height	EFL
+2°	0.351	10.037
-2°	0.351	10.038
	Spec	10mm +/- 0.5%
	AVG	10.037

RMS Wavefront Error @ 3.39µm

Field Point (Image Height)	Spec	Pre Thermal	Post Thermal
Axis	0.072	0.041	0.041
+3.8mm	0.100	0.067	0.066
-3.8mm	0.100	0.088	0.077

System Transmission

System Transmission
Trans ≥ 85% @4.06- 5.88µm
96.4%

Fore Optics Meets all Performance Requirements

Ionizing Radiation Tests of HgCdTe APD FPA Completed

Ionizing Radiation Test Background:

- Test Performed by AFRL Infrared Radiation Effects Laboratory
- Test Type: Total Dose-Proton
  - 68 MeV Proton Energy
  - FPA Cooled/Under Operating Bias Voltages During Proton Irradiation
- FPA Radiometric Characterization Pre-Radiation and at 6 Dose Steps

Key Test Results:

- ROIC Essentially Unchanged to 70 krad
- Detector dark current (and noise) increase with dose, but acceptable rate
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Allocated Dark Current Rqmt. < 5 fA/Pix

HgCdTe 640x480-Format APD-Mode IR FPA Technology Readiness Level Advanced to 5

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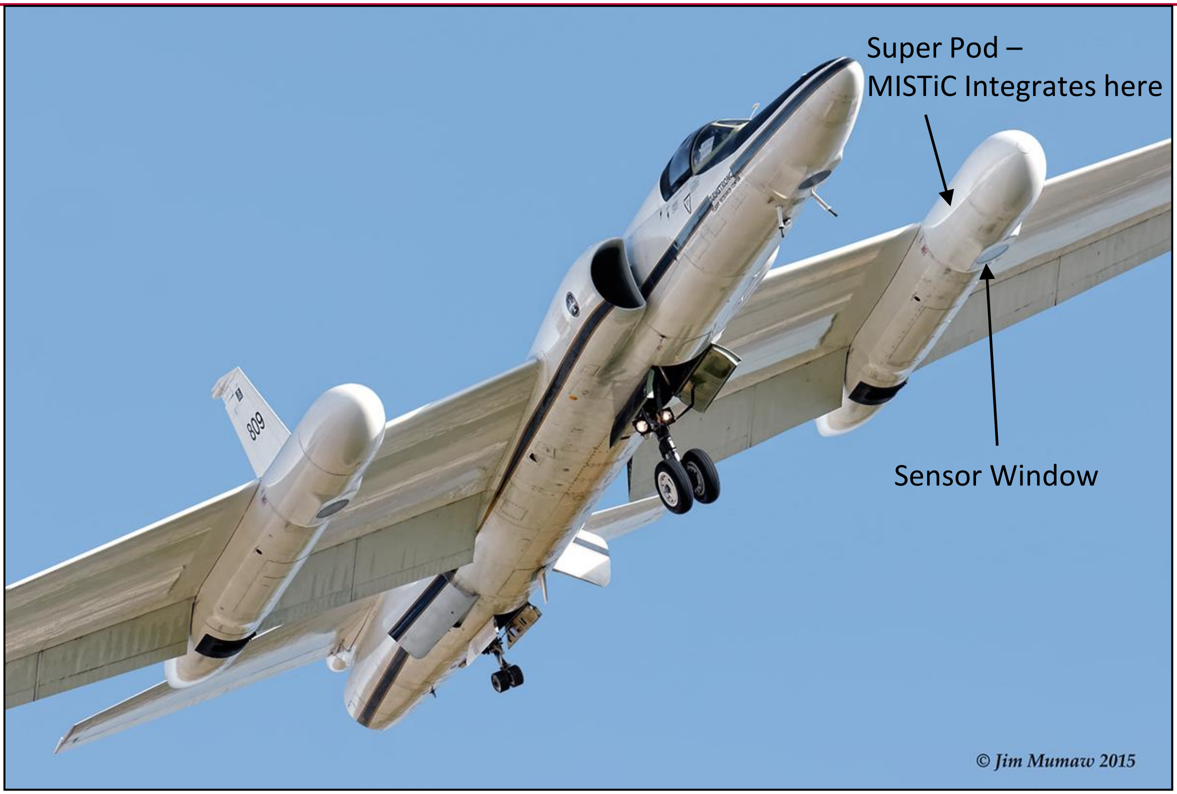
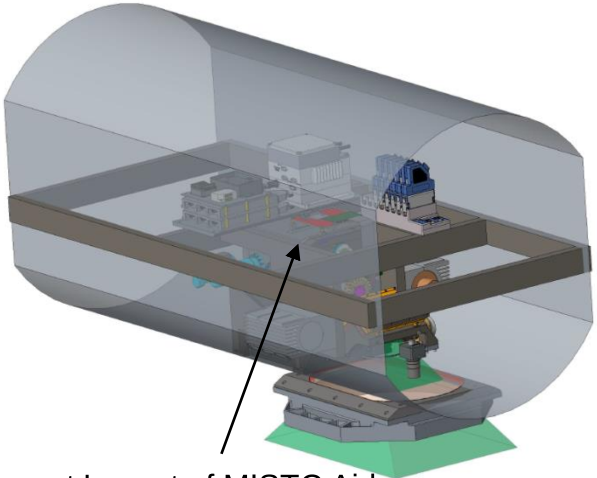
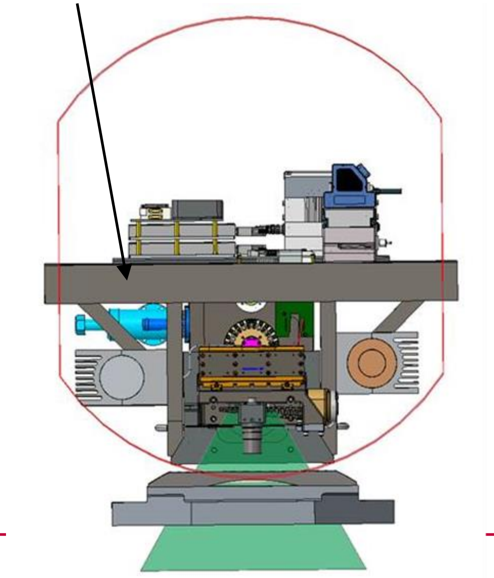
Airborne Testing Migrating to NASA ER2 Platform

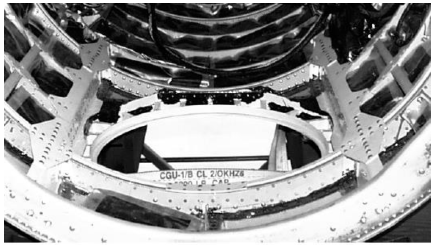


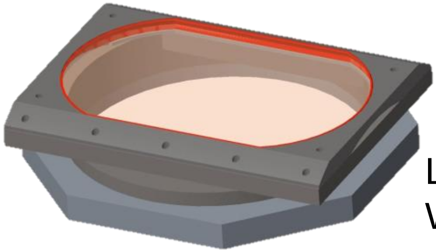


Concept Layout of MISTC Airborne Payload in ER2 Superpod Volume



ER2 Window Frame



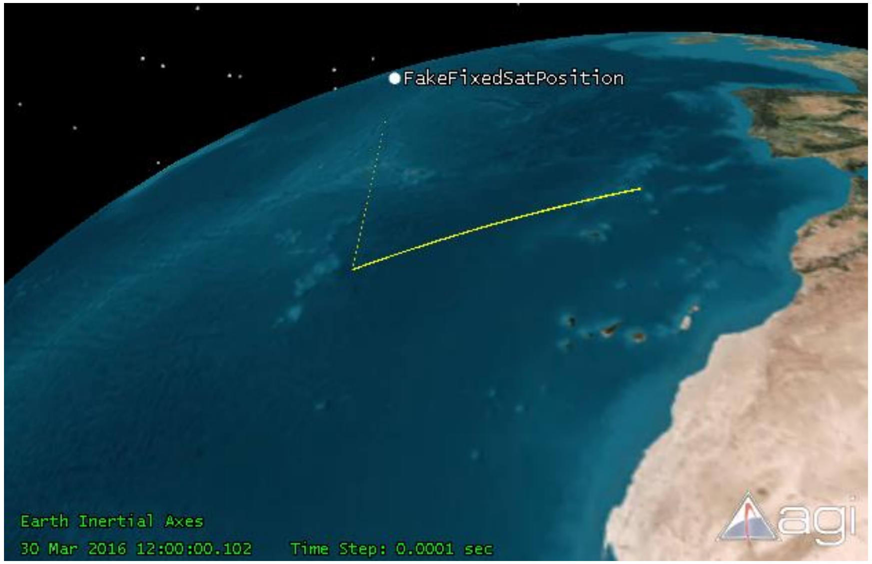


Legacy ZnS Window

Key MISTiC Winds Observation Method Inputs Provided to GSFC/GMAO for Hyperspectral AMV (MISTiC Winds) OSSE

BAE SYSTEMS

- Information Provided to NASA GSFC GMAO Includes:
  - Spectral Channels and Resolution
  - Spatial Sampling Positions and Spatial Resolution Across Swath
  - Orbit Descriptions (STK)
    - For a 4-Triplet Constellation (Sun-Sync/705 km orbit)
- Fidelity to Actual Instrument Design
  - Orbits Identical to Current Design
  - Current 590 Spectral Channel (Sample) List Provided for MISTIC 2-order Spectrometer)
    - (At spectrometer field center)
  - Spatial Scan Simplified to Push-Broom (Matching Average Swath)
    - Actual sampling/resolution similar, but more complex



For OSSE, MISTiC Area Coverage Simplified to a Push-Broom Geometry Providing Similar Cross-Track Spatial Resolution and Sampling to MISTiC's Cross-Scan Coverage

(Avoids Complexities due to Overlaps, Along-Track Res/Samp Variations, Cal)

BAE SYSTEMS

Broader Objective and Next Steps:

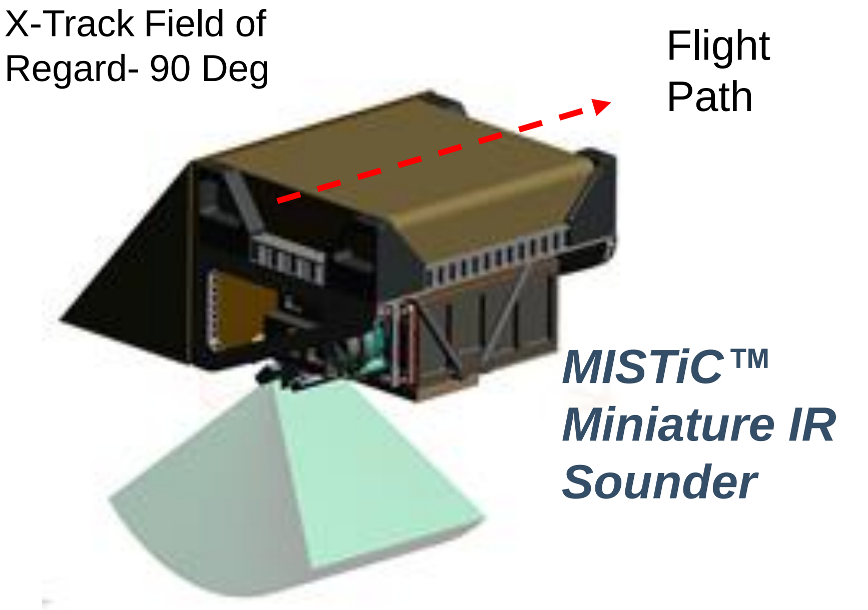
- Objective: Affordable Means to Improve Fine Scale/Short Term Weather Forecasts
  - Societal Benefits Include:
    - Airlines and Air Traffic Control-- having greater knowledge of weather 3 hours out to reduce flight delays
    - Improved Power Grid Load Forecasts (and more)
- Next Steps to Operational System
  - NASA IIP continues to mitigates risks
    - Spectral Sounding and AMV Feature-Tracking Demonstration
      - Airborne Instrument Being Integrated
      - BAE/ NASA Armstrong ECO Flight Test Planning Under Way
      - ER2 Hosted Flight Planned for 2016/17
  - OSSE Modeling to Evaluate Impact on Numerical Weather Prediction
    - IR Hyperspectral AMV OSSE in Progress at NASA/GMAO (4/16-3/17)
  - MISTiC Winds Formation (Wind Triplet) Demonstration in Space

Miniature Spectrometers Operated in LEO Constellations Offer Affordable/Lower Risk Approach for Improved Short Term/Fine Scale Weather Forecasting

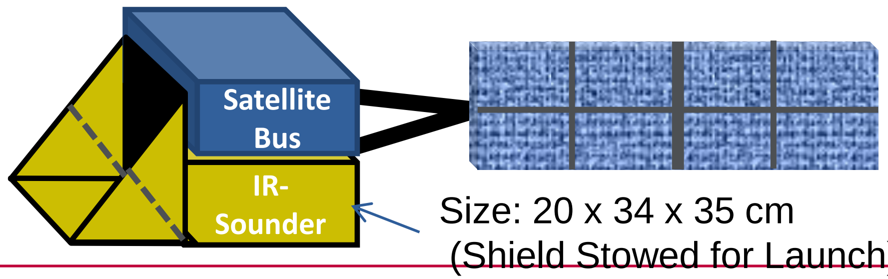
MISTiC™ Winds-A Miniature High Vertical Resolution Infrared Sounder for 3D Winds and Frequent IR Soundings

BAE SYSTEMS

- Miniature Spectrometers Enabled by:
  - Optimized Low-Impact Spectral Channel Selection Proven through a Decade of NASA's AIRS Experience
  - Innovative Opto-Mechanical/Thermal Design Minimizes S/C Resources Needed to Cool IR Spectrometer
  - Advanced Large-Format IRFPA, Miniature Cryocooler, and Electronics
    - *All Technologies TRL-5 or Higher*
- Compact IR Sounder Design, Mature Algorithms and Technologies Enable:
  - Payload Hosting on a Micro-Satellite for a Low-Cost Total IR Sounding Mission
  - ~1 km Vertical & ~3 km Horizontal Resolution (@Nadir) in the Troposphere
    - Temperature, Moisture, Wind Profile



Micro-Sat with Miniature IR Sounder Payload



Supplemental Material

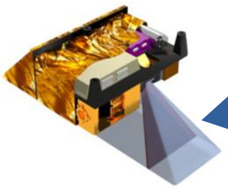
MISTiC Winds: Midwave Infrared Sounding of Temperature and humidity in a Constellation for Winds

BAE SYSTEMS

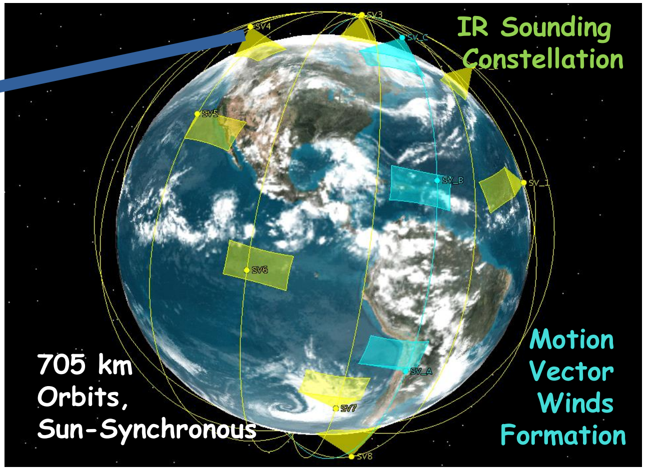
PI: Kevin R. Maschhoff, BAE Systems

Advance the readiness of a miniature, high resolution, wide field, thermal emission imaging spectrometer to measure vertically resolved tropospheric profiles of temperature and humidity for deriving global 3-D wind measurements.

- Provide ~ 2-3 km spatial resolution temperature and humidity soundings of the troposphere using an AIRS-like (Atmospheric Infra-red Sounding) method.
- Enable a LEO constellation approach that provides 3-D Wind field measurements and atmospheric state and transport observations at low system cost.
- Reduce technology risks with the Infrared Focal Plane Array (IRFPA) and spectrometer technologies critical for significant instrument size, weight and power reduction (20 x 30 x 30 cm, 15 kg, 50 W).



MISTiC Instrument will fit on a 27U CubeSat or a ESPA-Class Micro-Sat



- Optimize and refine space-based measurement approach based on experience with AIRS, AIRS-Light and small satellite provider experiences.
- Demonstrate calibration stability of miniature MWIR spectrometer (4.08 - 5.8 um) in ground testing.
- Demonstrate robustness of spectrometer by performing space level thermal fluctuation testing and vibration testing to launch levels.
- Verify instrument measurement capability of 3-D cloud-drift and water vapor motion vector winds on high altitude balloon or high-altitude fixed-wing platform.
- Demonstrate IRFPA space radiation tolerance (> 25 krad).

- Instrument science and payload requirements review 10/14
- Instrument science and payload concept review 12/14
- Airborne demonstration plan review 06/15
- Detector/ROIC radiation test/analysis complete 09/15
- Calibration stability test complete 07/16
- Airborne instrument design/build complete 10/16
  - Airborne demonstration complete 2/17
  - Airborne demonstration data analysis complete 4/17

Co-Is/Partners: J. Susskind, NASA GSFC; H. Aumann, JPL

TRL_{in} = 4 **$TRL_{current}$ = 5**

IIP-13-0004

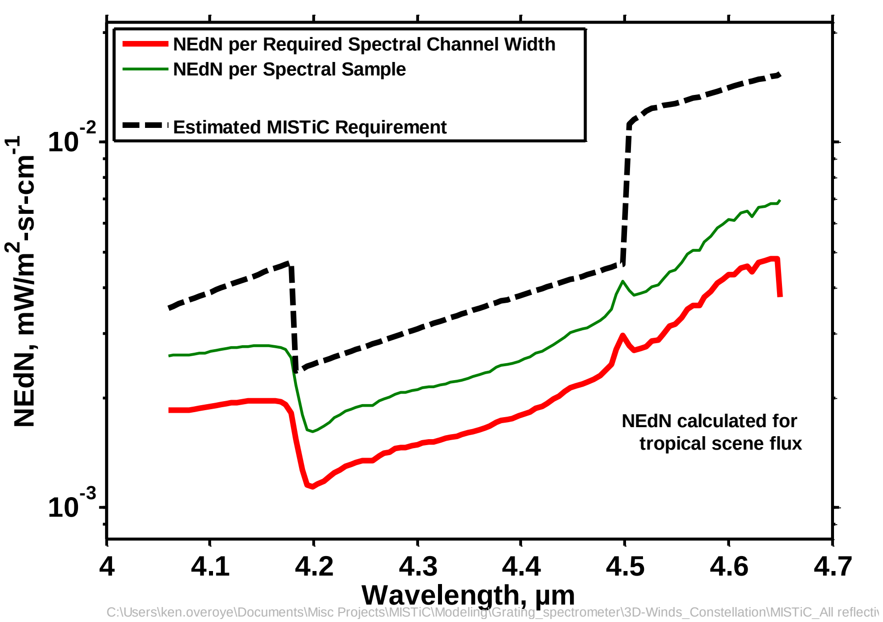
GOES-R Advanced Baseline Imager, AIRS, and CrIS

- Size of Geo-Stationary Imagers/Sounders Driven by Orbit Radius
- Size of IR Sounders Driven by # of Channels and LWIR Band Cooling

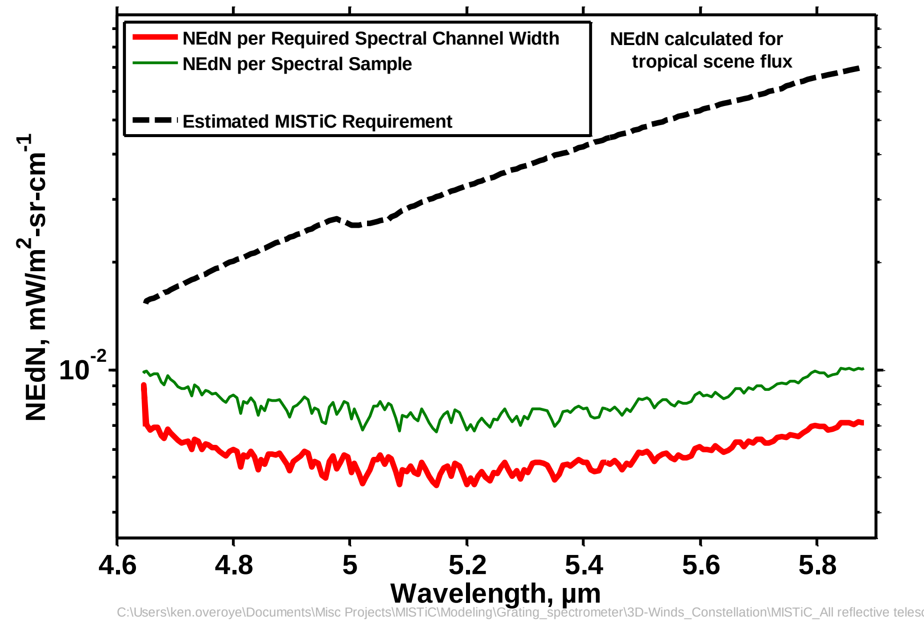
MISTiC™ Winds Instrument Radiometric Sensitivity Performance Estimates Show Solid Margin Against Requirements

BAE SYSTEMS

Sounding NEdN vs Wavelength:



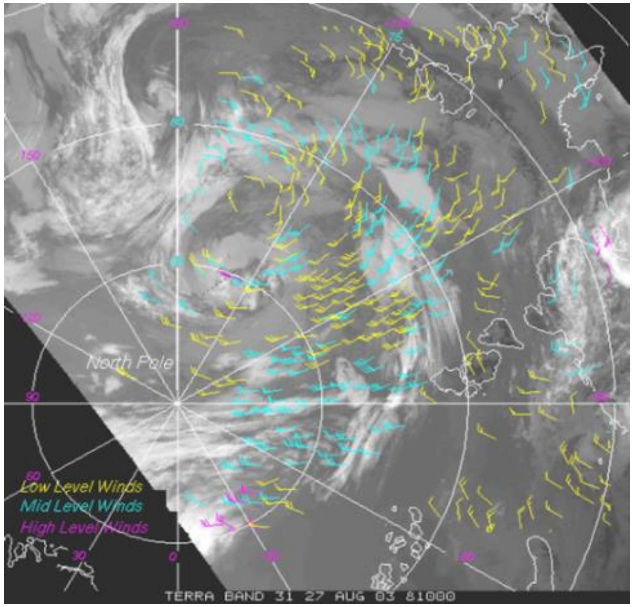
Sounding NEdN vs Wavelength:



- Spectrometer Radiometric Modeling Methods Developed for AIRS, GOES-R HES, etc used to Estimate MISTiC™ Winds Instrument Sensitivity
- Sensitivity Similar to AIRS (<200 mK @ 250K Scene) for low brightness temperature regions near 4.2 μm
- Updated APD detector noise modeling still be included in system model
  - APD FPA Vendor-modeled dark current and noise are in acceptable range for MISTiC™ at 90K

MISTiC Winds Observes the 3D Vector Wind Profile

- MISTiC Winds Observes 3D Atmosphere at 3 closely spaced times to Produce Multi-Altitude Motion-Vector Winds
  - Projected Wind Speed Error ~ 2 m/s rms
    - ~3x better than projected for GOES-R
  - SWIR/MWIR Imaging/Sounding Provides Much Better Tracer Height Assignment than GOES
    - 1K/1 km Temperature Sounding Enables Separation of Temperature and Moisture Concentration Contributions to Radiance
  - Both Moisture and Cloud Motion Vector Winds Observed by MISTiC
- OSSE's Show that 3D-Winds Observations Would Have the Largest Impact on Short Term Weather Forecast of Any New Observation
  - MISTiC Observes Thermodynamic State *and* Mass-Field Motion



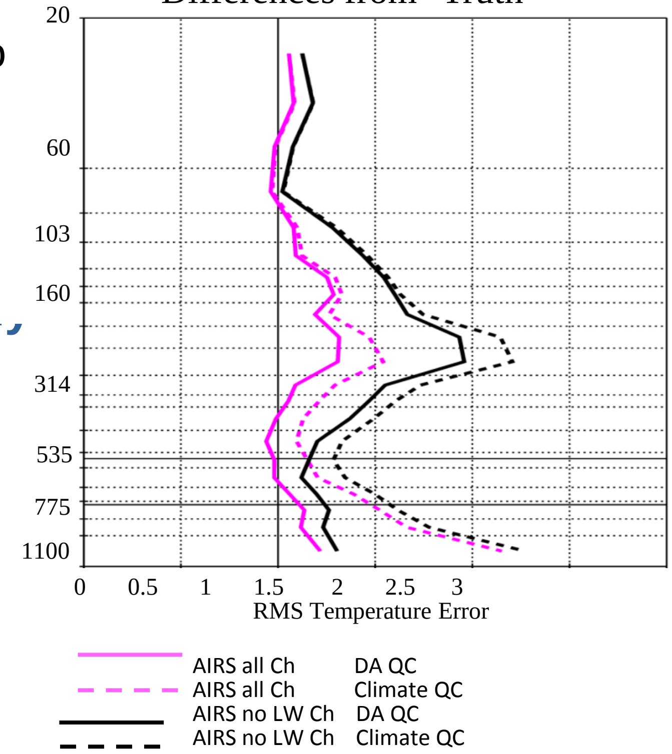
MISTIC Winds' Tracers Features Would Have Better Vertical Resolution Than MODIS Winds (shown) and GOES Imagers

MISTiC™ Winds' Concept Based on Proven Science From Current Flight Instruments

BAE SYSTEMS

- **MISTiC™ Winds' Vertical Temperature Profile Retrieval Comparable to AIRS & CrIS in Lower Troposphere**
  - Vertical Temperature Profile Retrieval Accuracy for Two Different Quality Control Thresholds Shown
    - Using All AIRS Channels—solid curves
    - Using SWIR/MWIR-Only –dashed curves
- **Additional Error experienced is modest using on SWIR/MWIR Channels**
  - ≤ 0.1K Added Error in Lower Troposphere
  - NOTE-AIRS Version 6 Algorithm Primarily uses /SWIR MWIR Channels for Sounding, using LWIR Channels **only for Cloud-Clearing**
- **<u>Fine spatial resolution</u> (~ 3 km @ nadir)a new benefit**
  - Yield of Cloud-Clear Observations much higher for MISTiC than for CrIS, IASI, and AIRS
  - Increased Cloud Contrast in Partly Cloudy Scenes

AIRS/AMSU Retrievals
Global Cases for July 10, 2012
Layer Mean RMS Temperature (K)
Differences from "Truth"



(from Joel Susskind NASA GSFC)

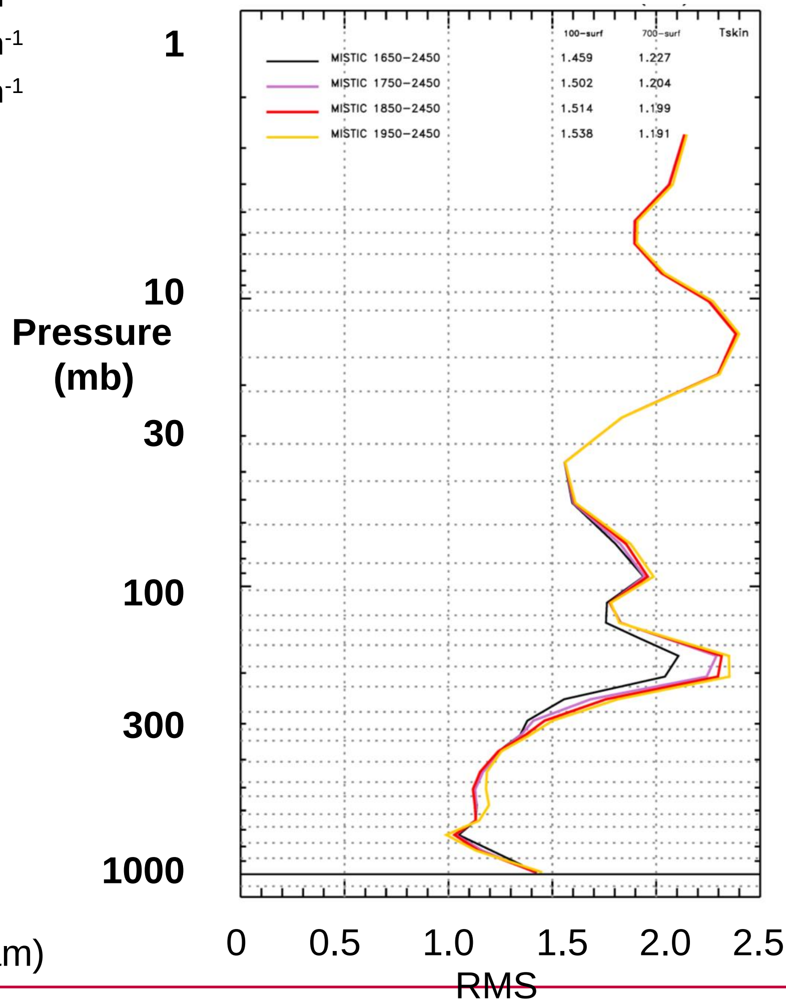
MISTiC™ Winds Retrieval Simulation Validates Chosen Spectral Range

1650-2450 cm-1
1750-2450 cm-1
1850-2450 cm-1
1950-2450 cm-1

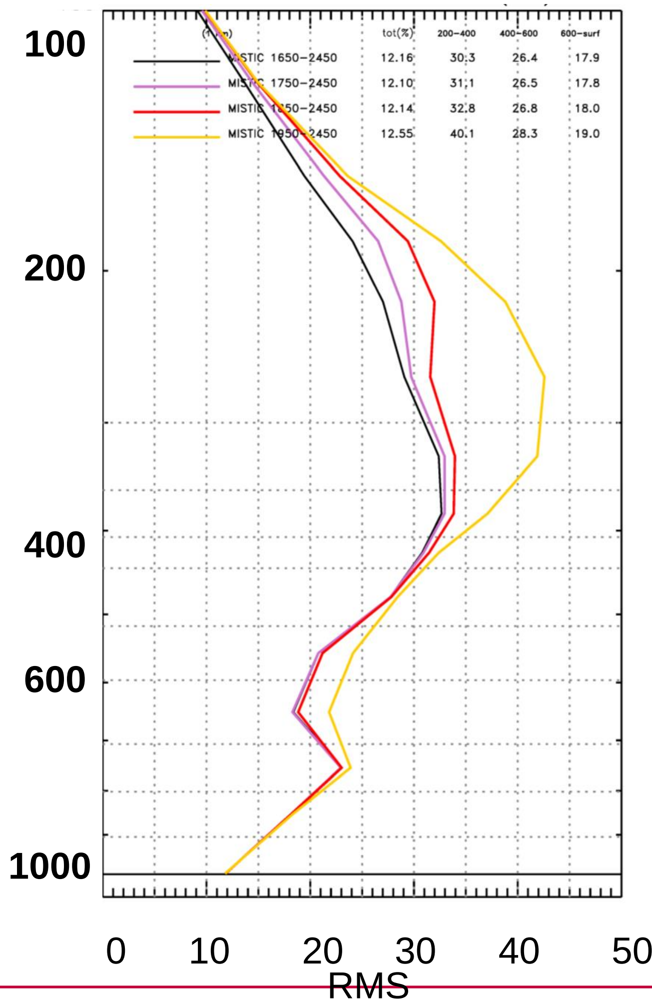
- Reasonably accurate temperature sounding can be done, using just the 4.2 micron band of CO_2, up to about 200 mb
- Water vapor retrieval accuracy best at1650 cm-1 but good enough at 1750 cm-1 spectral cut-off validating MISTiC™ Winds spectral range selection

(from NASA GSFC Sounder Research Team)

1 Km Layer Temperature (K)
RMS Differences from Truth



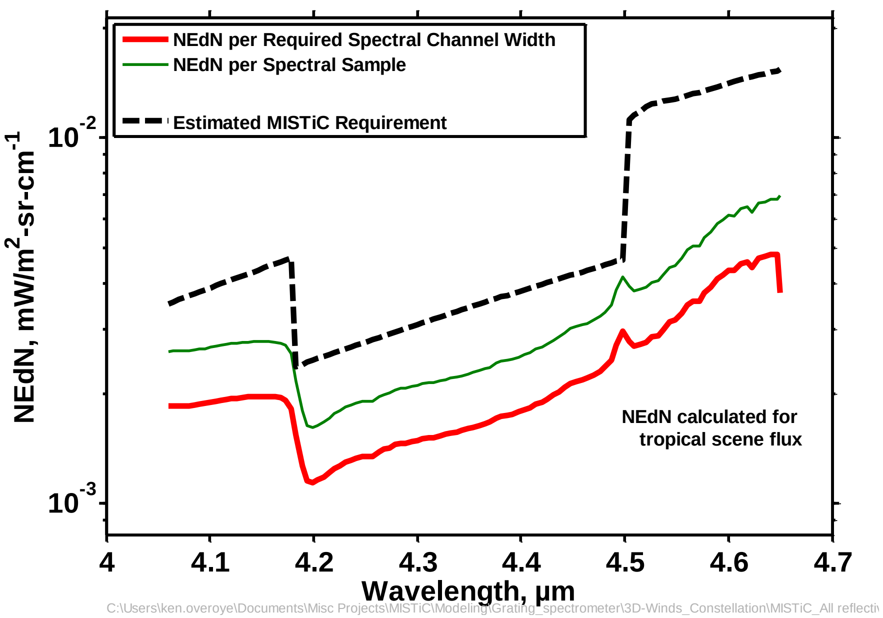
1 Km Layer Precipitable Water RMS
% Differences from Truth



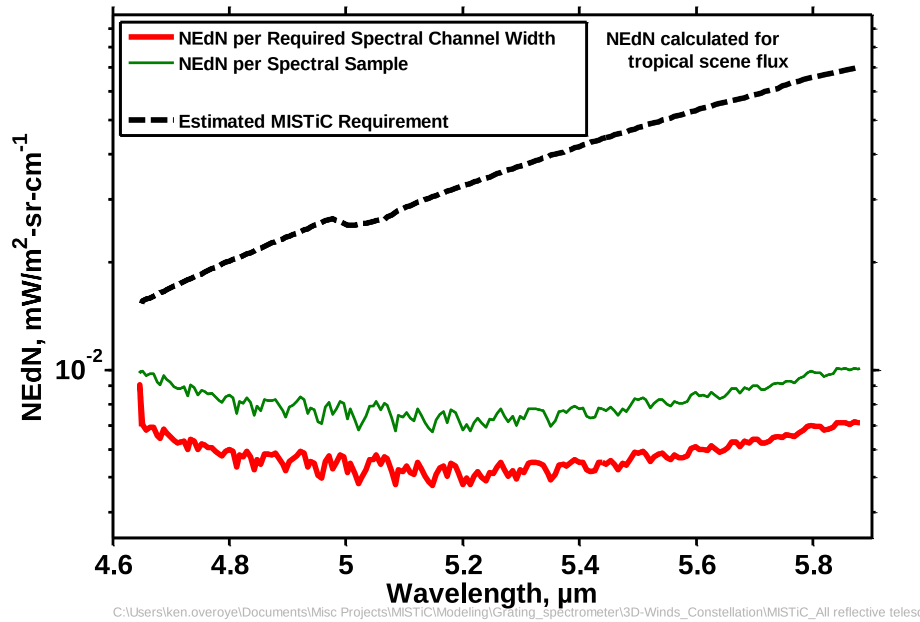
Truth = AIRS Retrievals version 6 - Ocean 50°N to 50°S December 4, 2013

MISTiC™ Winds Instrument Radiometric Sensitivity Performance Estimates Show Solid Margin Against Requirements

Sounding NEdN vs Wavelength:



Sounding NEdN vs Wavelength:



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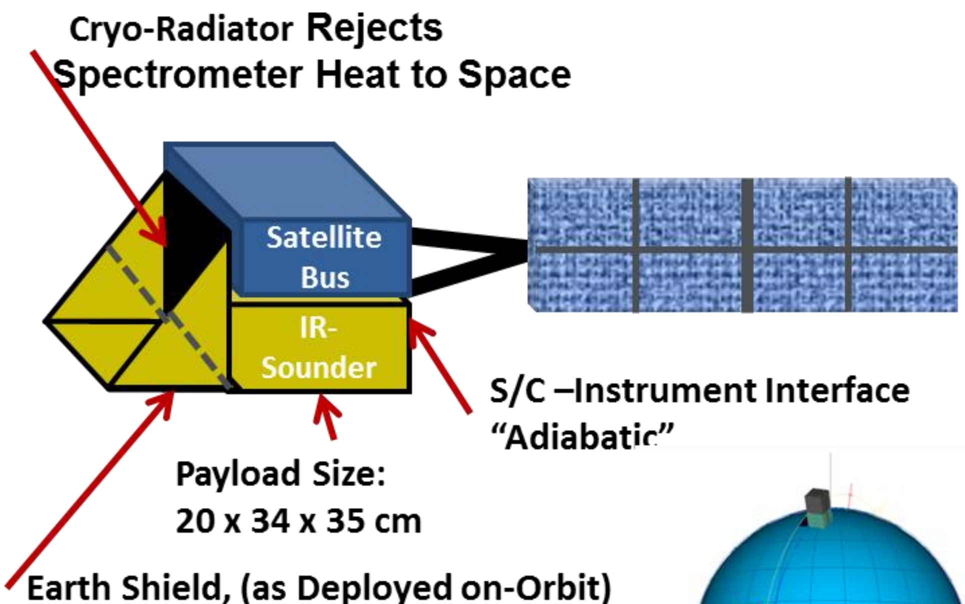
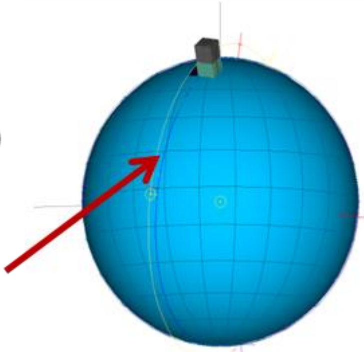
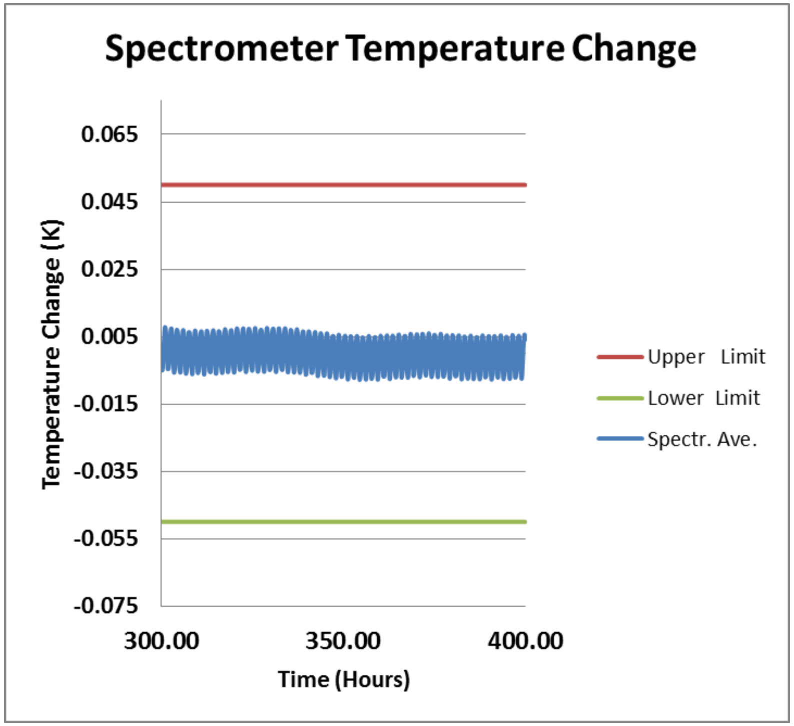
- Updated APD detector noise modeling still be included in system model
  - APD FPA Vendor-modeled dark current and noise are in acceptable range for MISTiC™ at 90K

Spectrometer Temp. Variation in Worst-Case Orbit is Small



Earth Shield Blocks some, but Not All
Solar Illumination of Cryo-Radiator in
1:30 PM Orbit (Worst Case Orbit)





1000+-node Thermal Model Assessment

→MISTiC Meets Stringent IR Sounder Spectral Calibration Stability Requirements Within Envelope/Mass Limits of a Small Micro-Satellite

BAE SYSTEMS

Key MISTiC 3D Winds System (of Systems) - Level Performance Requirements (draft)

KPP	KPP Attribute	Requirement
3D Motion Vector Winds (Moisture and Cloud Motion Vectors)	Layer Wind Speed Uncertainty	< 2 m/s rms
	Layer Wind Direction Uncertainty (above 10 m/s)	< 10 degrees rms
	Layer Height Pressure Height Assignment Error	<30 mB
	Layer Effective Vertical Thickness	<100 mB
	Minimum Pressure of Highest Pressure-Level	<350 mB (MMV) <500 mB (CMMV)
	Tracer Potential Density (Cloud-Free Conditions for MMV, Cloud Contrast for CMV)	>1 per 6 km sq per vertical layer :
Temperature Vertical Profile	Layer Effective Vertical Thickness	>100 mB (~ 1 km)
	Layer Temperature Accuracy	>1 K
	Sounding Measurement Potential Density	> 1 per 6 km sq
ObsFrequency	Observation Refresh Period	<3 hours (4 planes)

MISTiC Winds Observes both Total Wind Velocity Vector and the (via IR Sounding) the Geostrophic/Gradient Wind Vector Component in ≥ 6 Layers