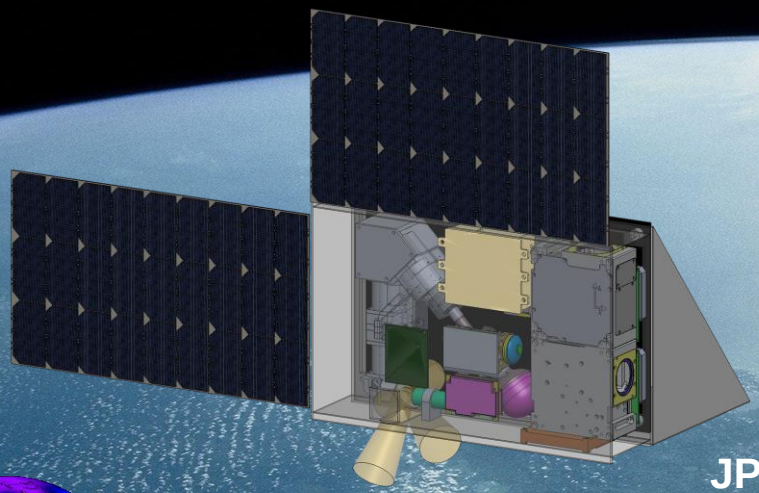
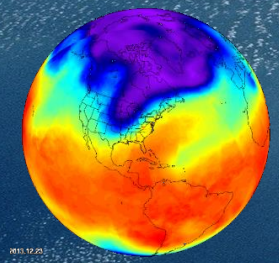
An Instrument Concept Study for an Advanced Imager-Sounder: Final Design Review

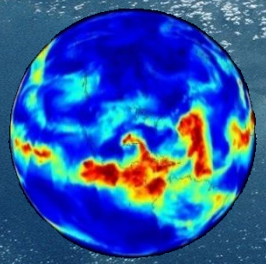
Sponsor: The National Oceanographic and Atmospheric Administration (NOAA)

Performed by: The NASA Jet Propulsion Laboratory

"The Goal of the study is to quantify the ability to meet the Cross-track Infrared Sounder performance requirements on a CubeSat platform."







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Jet Propulsion Laboratory,
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February 25, 2016

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Good participation from JPL Technologists, Management and NOAA

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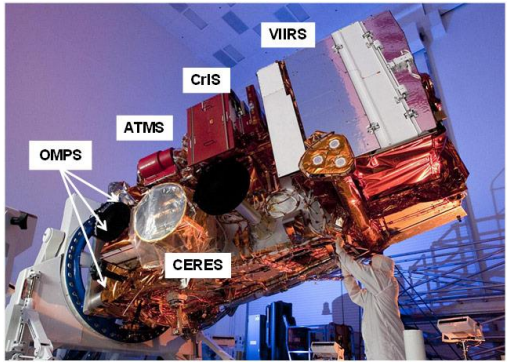
Agenda

- Study Overview
- EON-IR Design Overview: Requirements, Technical Approach, Schedule, Cost
- CIRAS NASA InVEST CubeSat Summary
- EON-IR Detailed Design
  - Orbital Analysis
  - Systems Engineering
  - Scanning System
  - Optical System
  - Detectors
  - Electronics
  - Thermal
  - Cryocoolers
- Summary and Conclusions

System Requirements

T. Pagano

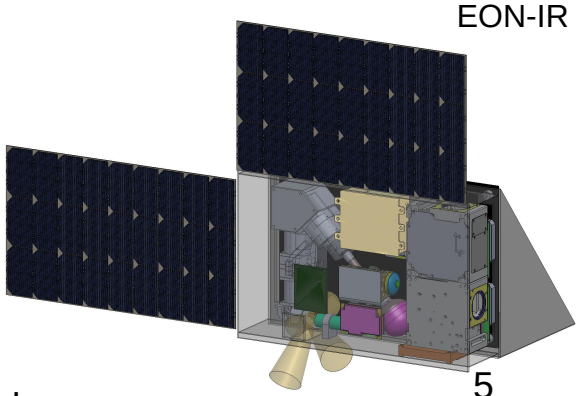
EON-IR Evolution



JPSS

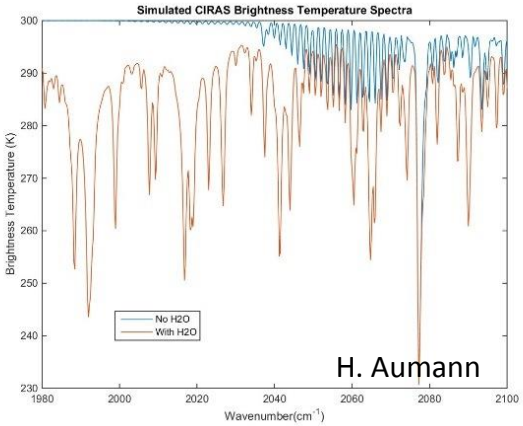
- CubeSat Infrared Atmospheric Sounder (CIRAS)
  - Technology Demonstration: 6U CubeSat IR Sounder
  - NASA InVEST Program (ESTO) Funded
  - Project Start: March 1, 2016. Launch in Late: 2018
  - **Orbit**: 400-800 km, Polar Sun Synch, 6am +- 3:30 hrs
  - **Spatial**: 13.5 x 0.32 km, No On-board Aggregation
    Limited Field of View (+/- 7.7°, 165 km)
  - **Spectral**: 4.8-5.1 µm, 625 Channels, Comparable to CrIS in Lower Trop (< 500mb)
  - **Radiometric**: NEdT of 0.25K. Comparable to CrIS on Average
  - **Limited Data:** <10 @ 165 km x 165 km granules per orbit
- Earth Observation Satellite – IR (EON-IR)
  - First NOAA operational unit with CrIS-like capability (in lower troposphere)
  - Expanded version of CIRAS InVEST (6U) with full CrIS spatial coverage
  - **Orbit**: Afternoon orbit operation: 1:30 am/pm JPSS
  - **Spatial**: Same as CrIS: 13.5 km Spatial Resolution,
    Wide field scanning (+/- 57°, 2200 km Swath)
  - **Spectral**: Same as CIRAS, 625 Channels
  - **Radiometric**: Same as CIRAS NEdT of 0.25K
  - **Full Data Download**: Data Compression and Multiple Stations
- Next-Gen EON-IR
  - Possible Higher Spatial Resolution and Extended Spectral Range
  - Larger Spacecraft (12U) to accommodate larger optics and focal plane

EON-IR

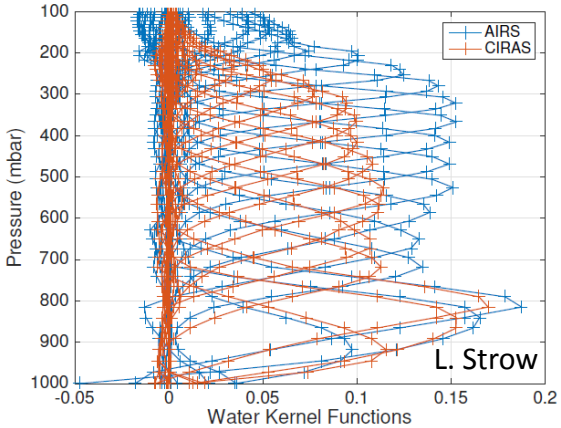


EON-IR Measurement Requirements

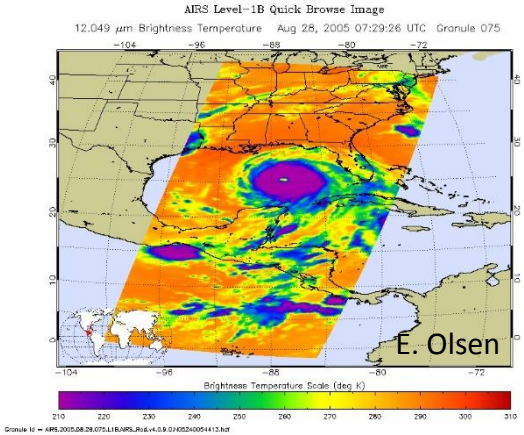
Measure Temperature and Water Vapor Spectrum 1965-2090 cm^{-1}



Sensitivity Comparable to Legacy Sounders in Lower Troposphere



Spatial Resolution and Coverage Comparable to Legacy Sounders: Global Daily Coverage at 13.5 km



Parameter	Legacy (CrIS) Performance	EON-IR Requirement	CBE	Margin
Orbit	824 km	600-850 km	600 km	Positive: 250 km
Vertical Range	1000-50mb	1000-500 mb	1000-400 mb	Positive: 100 mb
Temperature Profile	≤1.5 K/km	≤1.5 K/km	≤1.2 K/km	Positive: 0.3 K/km
Humidity Accuracy	15%/2km	20%/2km	15%/2km	Positive: 5%/2km
Spatial Res. (nadir)	13.5 km	13.5 km	13.5 km	N/A: By Design
Scan Range	2040 km	2040km	2040	N/A: By Design
Spectral Range	3.9-15.4μm	4.78-5.03μm	4.78-5.09μm	Positive: 0.06 μm
Spectral Resolution	0.625 cm^{-1}	1.0 cm^{-1}	0.5 cm^{-1}	Positive: 0.5 cm^{-1}
NEdT	<0.25 K	<0.35K	<0.25K	Positive: 0.1K

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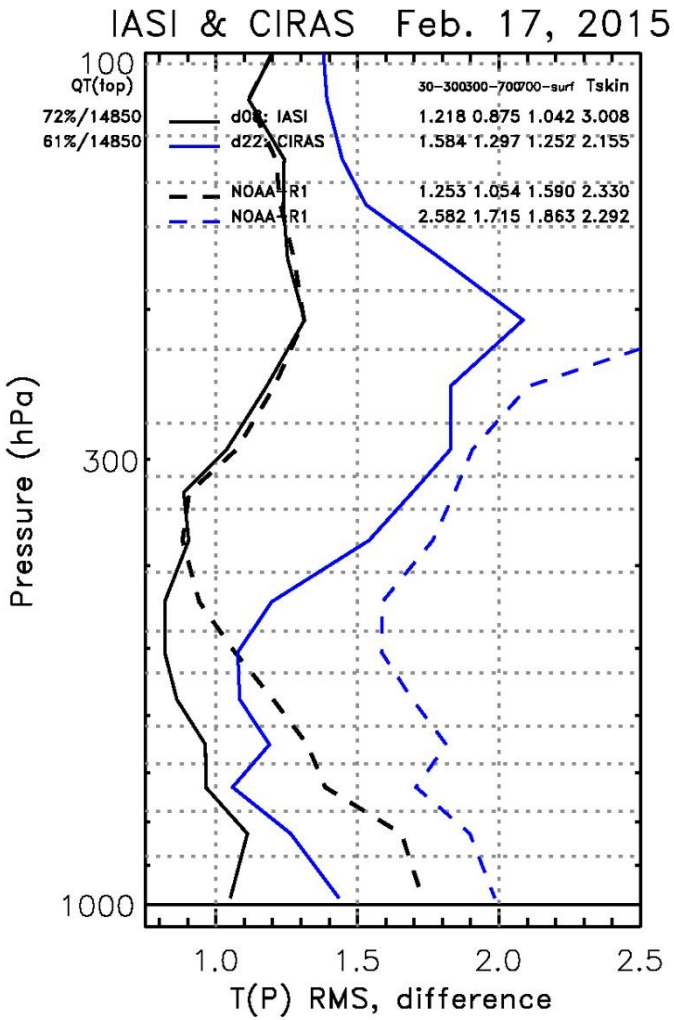
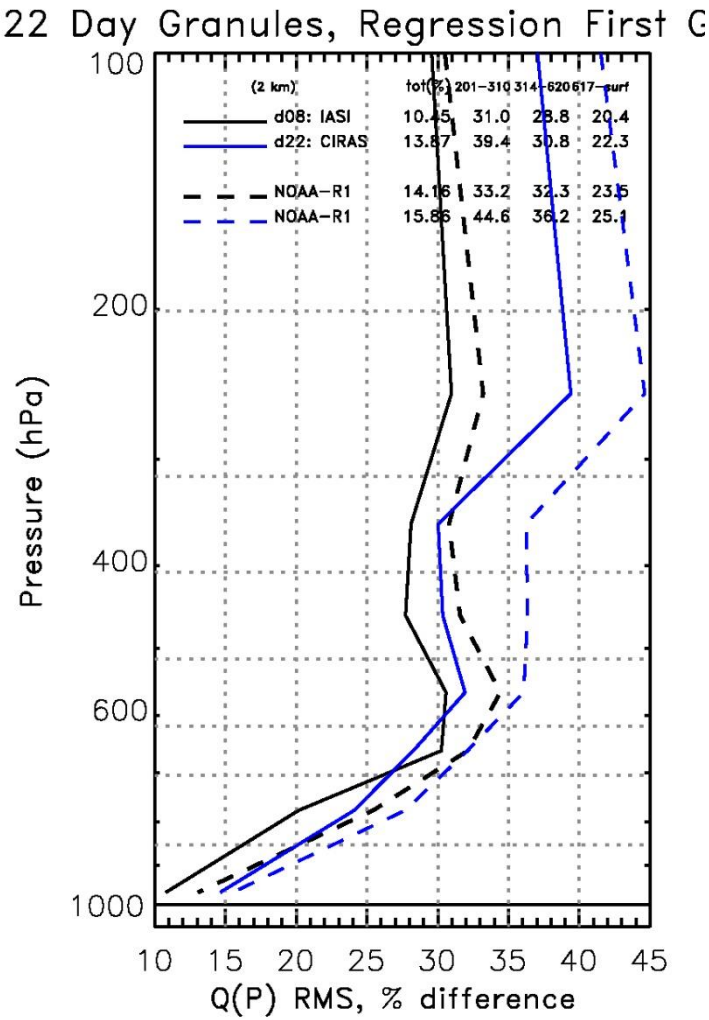
Temperature and water vapor retrievals using IASI data in only EON-IR band show good sensitivity in lower troposphere

Temperature



Water Vapor



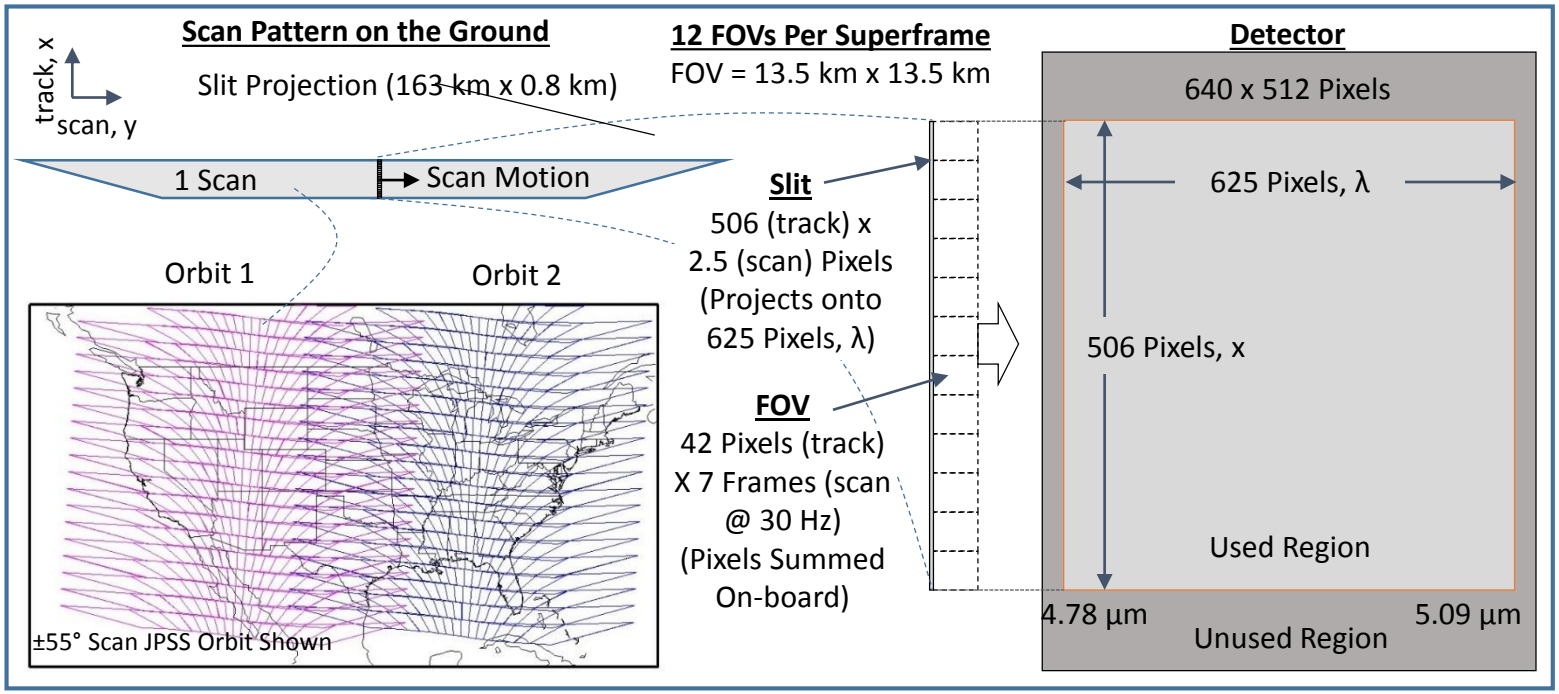
Relative to ECMWF

Chris Barnet, STC

EON-IR Compared to Legacy Instruments

Parameter \ Sounder	AIRS	IASI	CrIS	CIRAS	EON-IR
Spatial					
Orbit Altitude	705 km	817 km	824 km	600 km	824 km
Scan Range	±49.5°	±48.3°	±48.3°	±7.7°	±57°
Horizontal Resolution	13.5 km	12 km	13.8 km	13.5 km	13.5 km
Spectral					
Method	Grating	FTS	FTS	Grating	Grating
Nominal Resolution	0.5-2.5 cm^{-1}	0.5 cm^{-1}	0.625 cm^{-1}	0.5 cm^{-1}	0.5 cm^{-1}
Band 1	3.7-4.6 µm	3.6-5.0 µm	3.9-4.6 µm	4.78-5.09 µm	4.78-5.09 µm
Band 2	6.2-8.2 µm	5.0-8.26 µm	5.7-8.2 µm	n/a	TBD
Band 3	8.8-15.4 µm	8.2-15.5 µm	9.1-12.0 µm	n/a	TBD
Total Channels	2378	4230	1305+	625	TBD
Radiometric					
NEdT (@250K)	0.07-0.7K	0.05-1.0K	0.01-0.3K	0.25 K	<0.25K
Resources					
Size	1.4 x 0.8 x 0.8 m^3	1.2 x 1.1 x 1.3 m^3	0.9 x 0.9 x 0.7 m^3	6U Cubesat	6U Cubesat
Mass	177 kg	236 kg	145 kg	10 kg	< 14 kg
Power	256 W	210 W	105 W	35 W	<50 W
Data Rate	1.3 Mbps	1.5 Mbps	1.5 Mbps	0.2 Mbps	0.5 Mbps

EON-IR Scan Pattern and FPA Projection



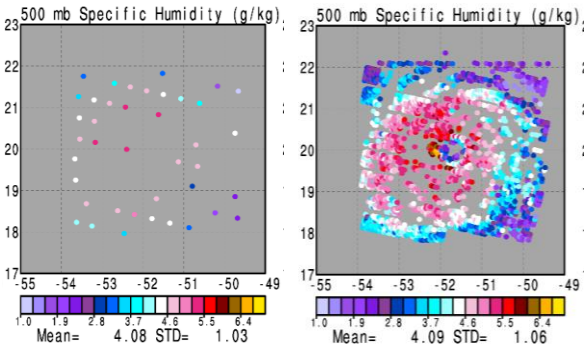
Global Daily Coverage
GSD = 13.5 x 13.5 km, FOR = 163 km x 2211 km
Regional Coverage
GSD = 3 x 3 km, FOR = 163 km x 63 km

Hyperspectral Infrared
1965cm^{-1} – 2090 cm^{-1},
(4.78-5.09µm), 0.5 cm^{-1}
625 ch

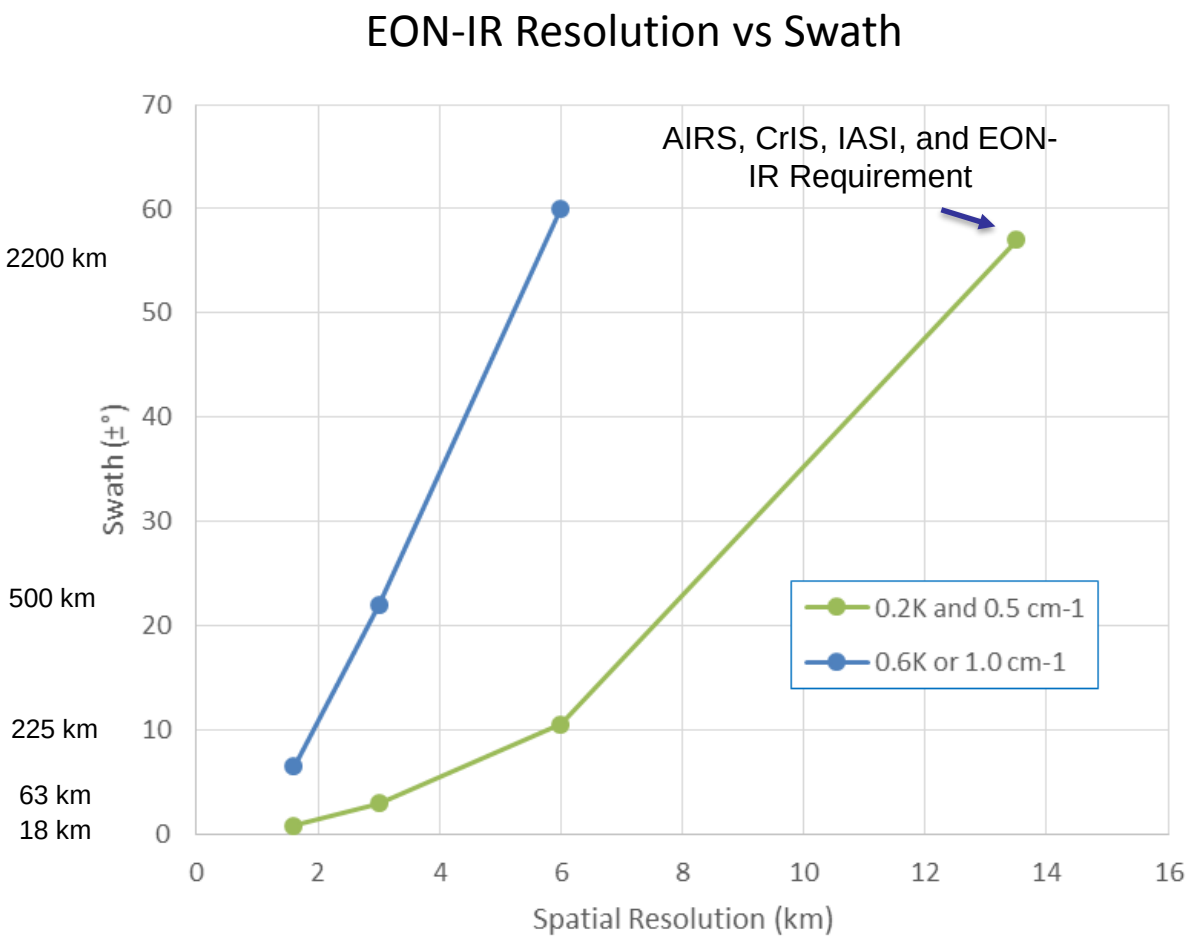
EON-IR Can Improve IR Sounding Yield in Critical Areas

- Higher spatial resolution improves yield in high cloud regions
- Simulation on HWRF (Atlas) nature run and AIRS retrieval system (Susskind)

13.5 km GSD 2 km GSD



- Native resolution of EON-IR is 1.6 km
- EON-IR bins pixels and multiple frames while scanning to achieve desired spatial resolution
- Pixel binning scheme and scan rate are programmable while in orbit
- Changing scan range (and rate) and pixel binning can improve spatial resolution at the expense of coverage (see right)



EON-IR Data Rate Meets Full Data Downlink Capacity

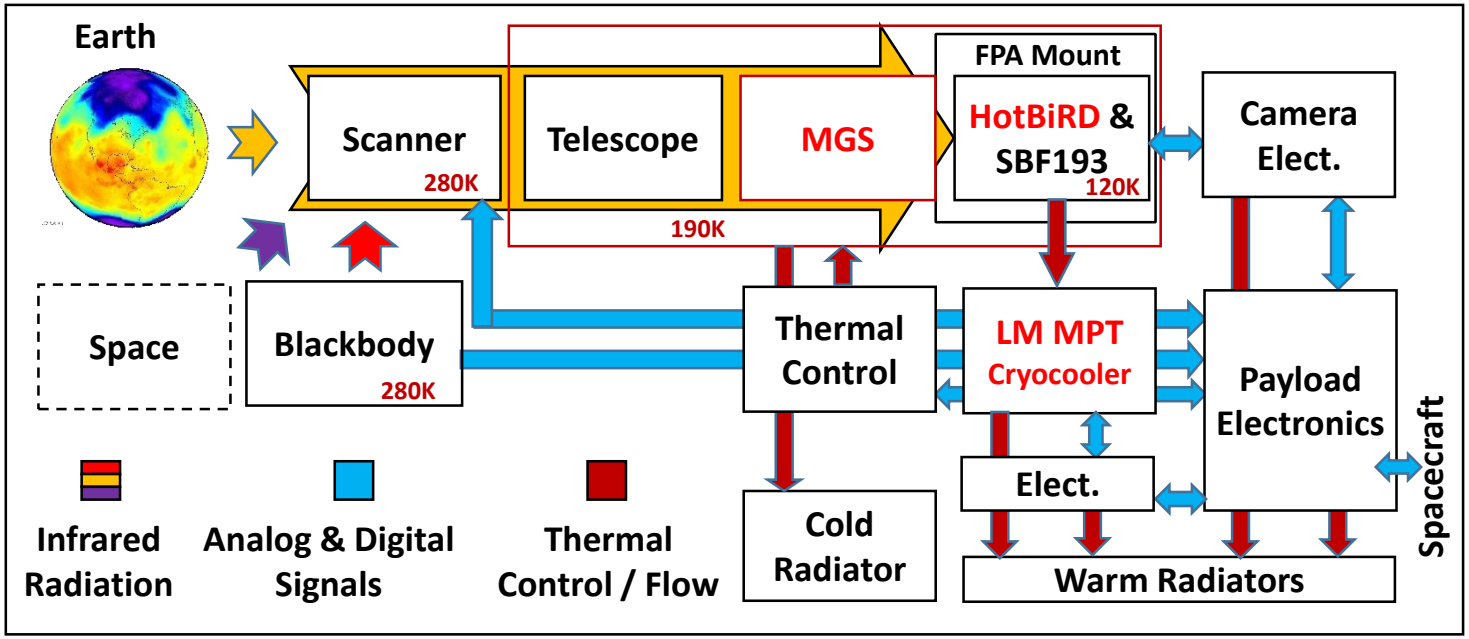
Parameter	13.5 km	3 km
Number of Spectral Channels	625	625
Number of Spatial Pixels	506	506
Dwell Time (s)	0.03333	0.03333
Quantization Bits	14	14
Raw Data Rate (Mbps)	**132.9**	**132.9**
Number of Superpixels Along Track	12	54
Number of Channels to Download	350	45
Oversample Factor	7	4
Telemetry & Overhead (Mbps)	0.10	0.10
Aggregated Data Rate (Mbps)	**0.35**	**0.35**
Data Compression Factor	2.00	2.00
Orbit Period (s)	5792.3	5792.3
Data Volume Per Orbit (Gb)	**1.02**	**1.01**
Downlink Time / Pass (min)	6	6
Downlink Rate (Mbps)	3	3
Downlink Capacity Per Pass (Gb)	**1.08**	**1.08**
Passes / Orbit Needed	**0.94**	**0.94**

- Design meets orbital downlink capacity for
  - 13.5 km Spatial Resolution
  - 2211 km Swath (±57.7°)
  - 100% duty cycle
  - 350 Channels (of 625)
  - 2x Data Compression

EON-IR Design Approach

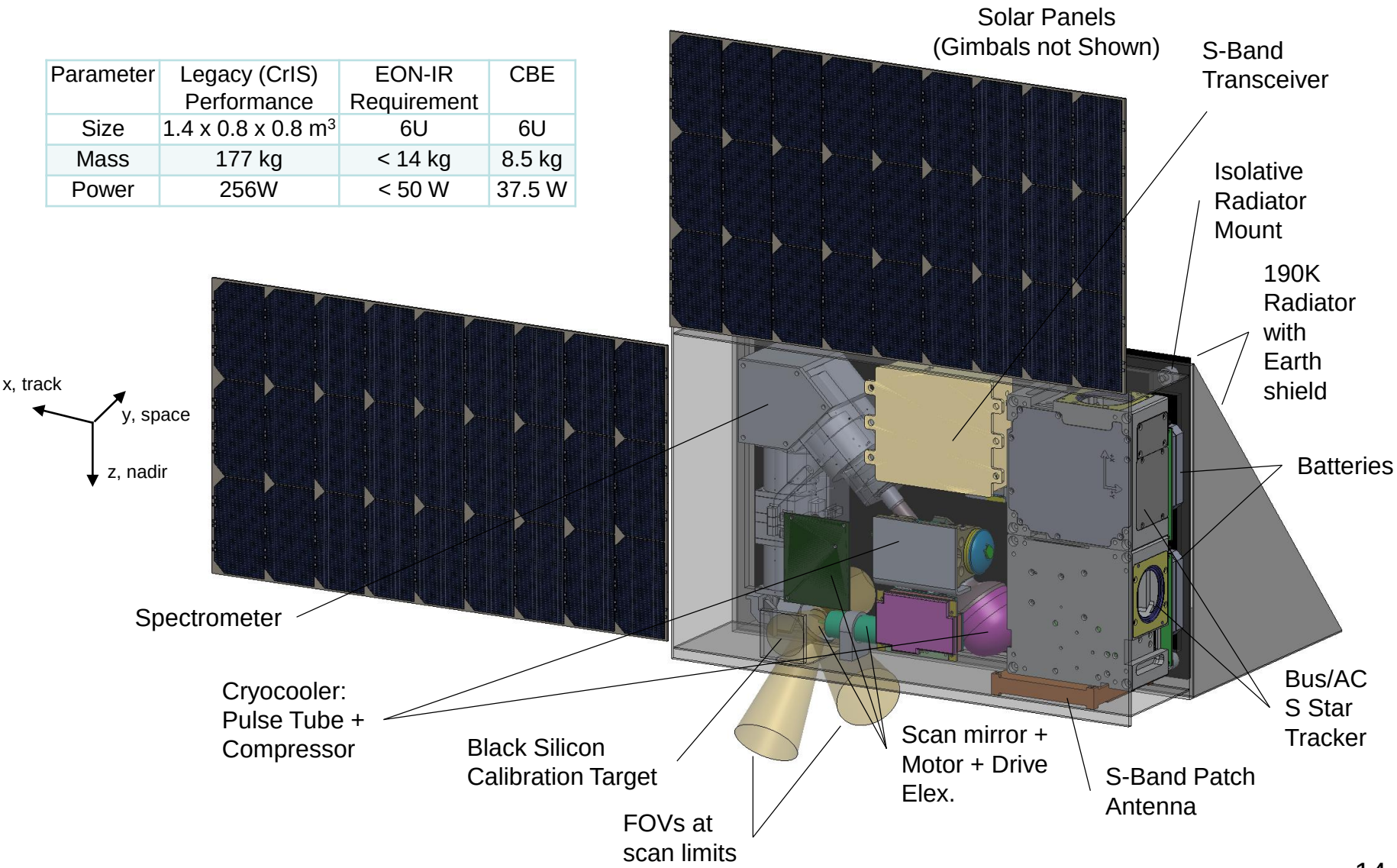
T. Pagano

EON-IR Payload Block Diagram



EON/IR Configuration

Parameter	Legacy (CrIS) Performance	EON-IR Requirement	CBE
Size	1.4 x 0.8 x 0.8 m^3	6U	6U
Mass	177 kg	< 14 kg	8.5 kg
Power	256W	< 50 W	37.5 W

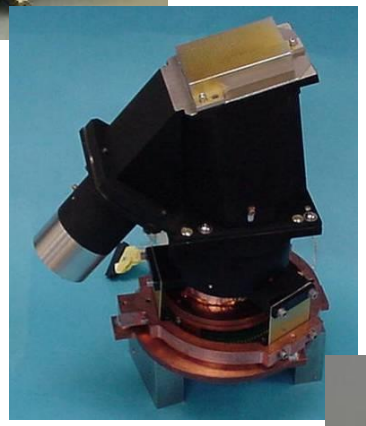


EON-IR Uses Compact Immersed Grating Spectrometer

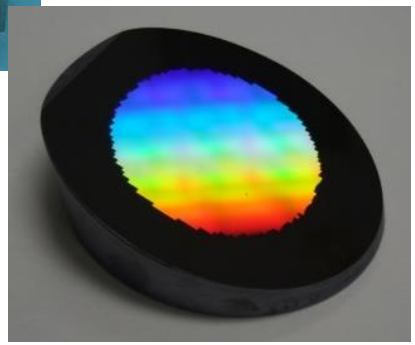
- EON-IR Optics Have Simple Design
  - All Silicon Materials
  - All Spherical Surfaces
  - 3 Lens Groups Identical
  - Immersion Grating Reduces Size
  - JPL Black Silicon Slit
- EON-IR optics have good heritage
  - JPL
    - OCO-2 Refractive High Dispersion Spectrometers
    - Wide Field OCO Immersion Grating RTD Spectrometers
  - Ball
    - SIRAS ESTO IIP-1 (JPL Lead)
    - SIRAS-G ESTO IIP-3
    - HES Tech Demo for NOAA GOES-R
    - Wavelengths: 12-15 µm, 3-5 µm, 3-5 µm

JPL OCO-WF Immersion Grating Spectrometers

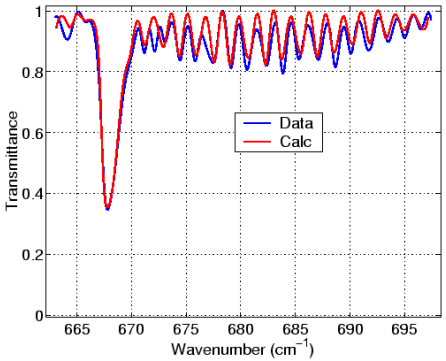
OCO-2



Ball SIRAS 12-15 µm



JPL Immersion Grating

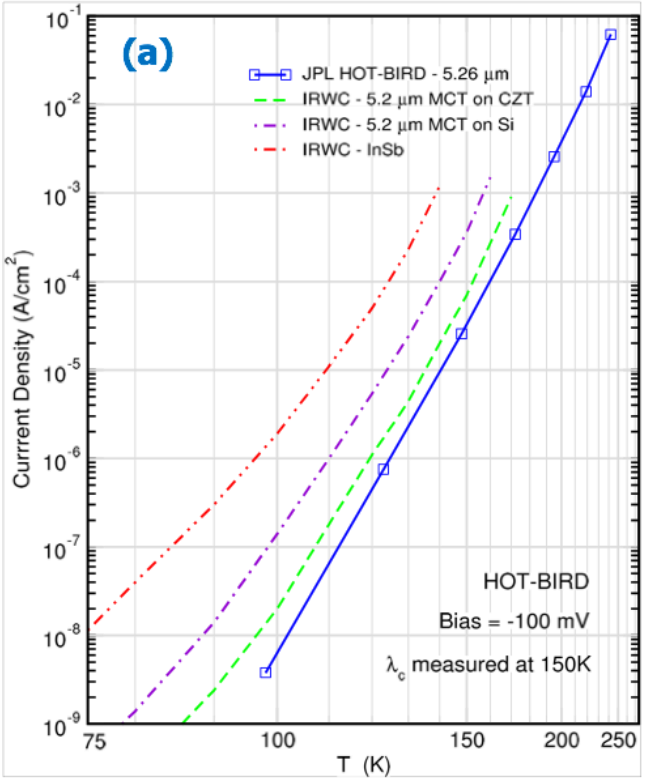


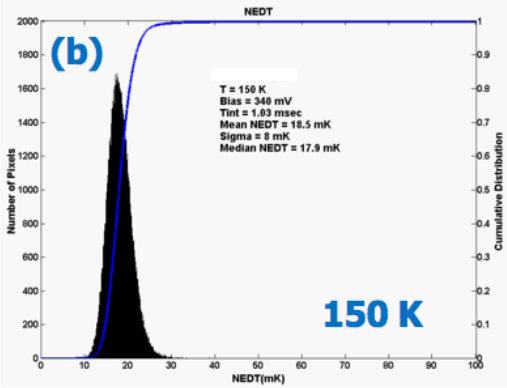
SIRAS Lab Spectra

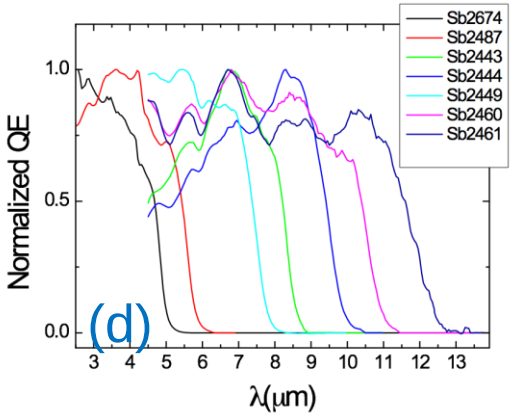
Jet Propulsion Laboratory
California Institute of Technology

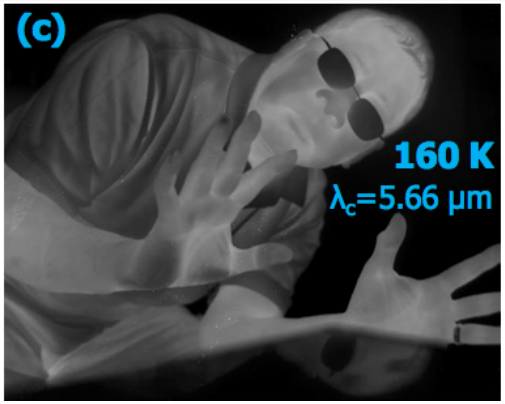
EON-IR Uses JPL High Operating Temperature Barrier IR Detector (BIRD) Technology

High performance MWIR (2-5µm) and LWIR (2-14 µm) Barrier IR (BIRD) detectors have been demonstrated at JPL



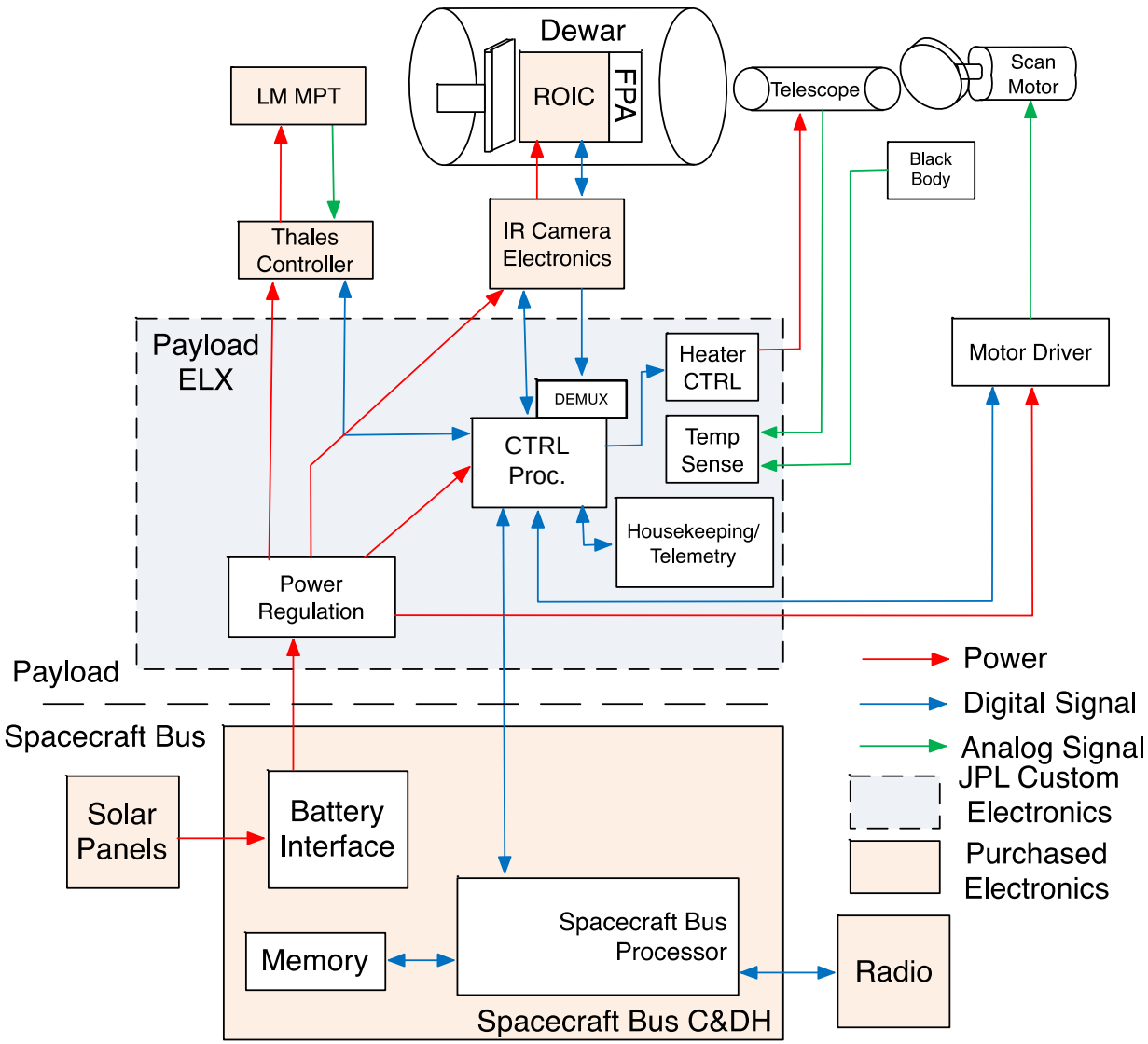




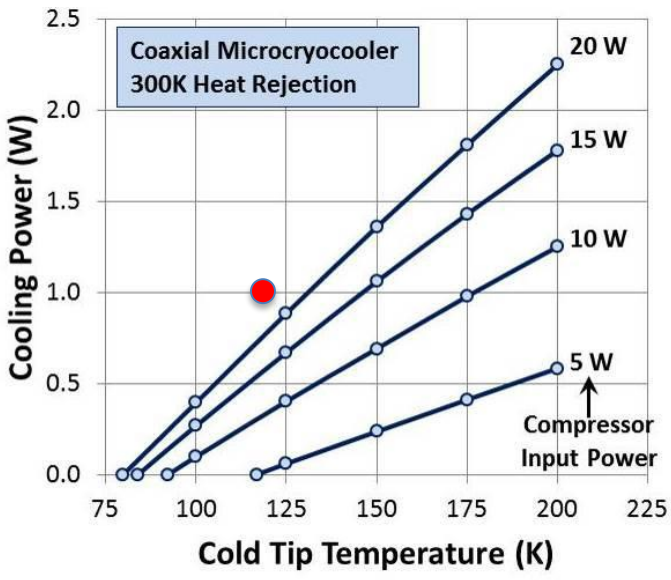


(a) The left panel shows the dark current density temperature dependence for a JPL HOT-BIRD device. Commercial InSb, MCT on Si substrate, and MCT on CZT substrate results taken from the Raytheon Infrared Wall Chart (IRWC) are shown for comparison.
(b) The top middle panel shows the NEDT distribution for a 640x512 FPA made from the HOT-BIRD material.
(c) The bottom middle panel shows an image taken with the FPA.
(d) The top right shows normalized spectral response of MWIR and LWIR HOT-BIRD detectors
(e) The top bottom shows an image taken with the 1344x784 LWIR FPA.

Electronics Block Diagram



LM Micro Pulse Tube (MPT) Cryocooler Offers Sufficient Cooling Capacity in Small Package



JPL Qualified
Thales Electronics

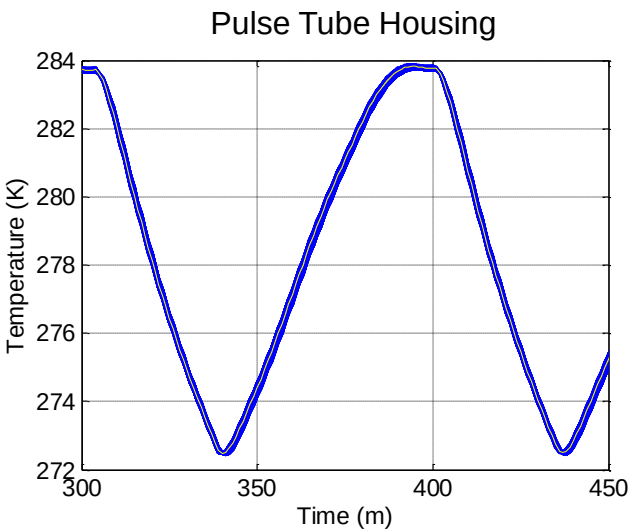
Design Maturity and Capabilities

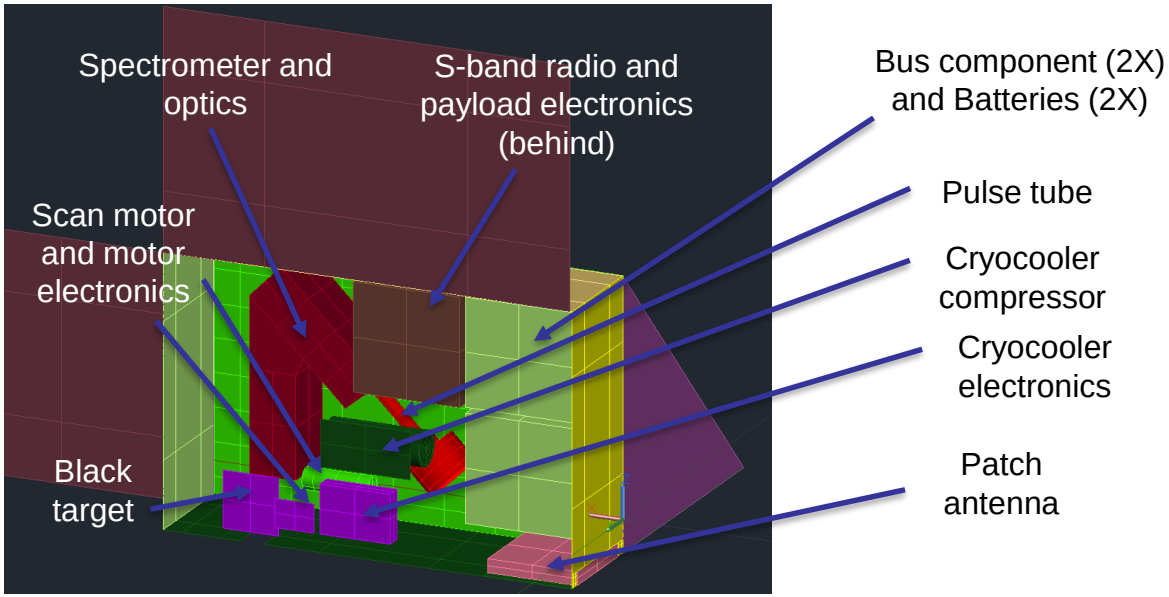
- EON-IR has high TRL for all critical components
- All Subsystems at TRL 7 or Higher After Launch

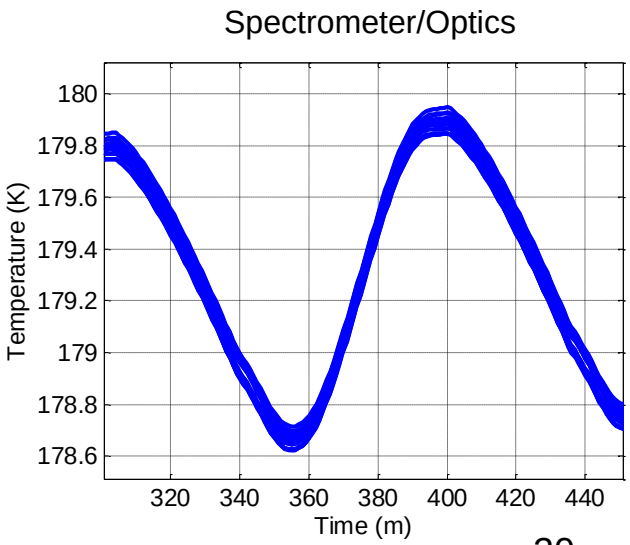
Assembly	Component	TRL	
		Current	At Launch
BCT XB1 Bus	Unit	5	6/7
	Reaction Wheels	6	7
	Batteries	9	9
	Star Tracker	6	7
HOT-BIRD Detector	Unit	6	6
Cryocooler	LM MPT	6	6
Electronics	Electronics	6 (TBR)	6
MGS	Spectrometer	5	6
Scanner	Motor & Electronics	6	6
Black Si Blackbody	Unit	5	6
Camera Electronics	Unit	6	6

Thermal Design Meets Requirements

- Spectrometer Temperature: 190K +/- 50 mK
- Detector Temperature: 120K
- Instrument Temperature: < 285K
- Assumptions
  - Component power dissipation approximated (total < 62 W)
  - Component masses approximated (total mass = 11 kg)
  - Thermal conductance values estimated and modeled
  - Aluminum properties for all components (specific heat, density, emissivity)
  - $\epsilon^* = 0.05$ multilayer insulation on inner surface of low-temperature radiator and outer surface of spectrometer







EON-IR Cost and Schedule

T. Pagano

CubeSat Infrared Atmospheric Sounder (CIRAS)

Overview

PI: Tom Pagano (JPL)
Sponsor: NASA ESTO, InVEST Program

February, 25, 2016

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Jet Propulsion Laboratory
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CubeSat Developments at JPL
(CIRAS not shown)

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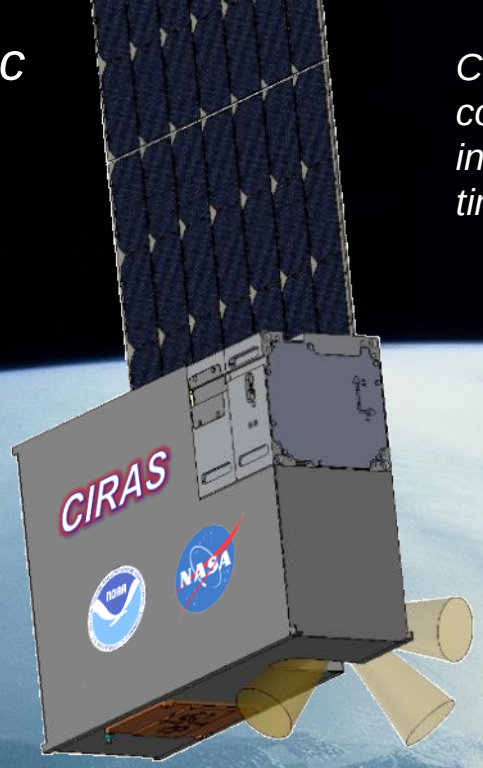
CubeSat Infrared Atmospheric Sounder (CIRAS)

For NASA InVEST
PI: Tom Pagano (JPL)
Sponsor: NASA ESTO



CIRAS will significantly reduce the cost of atmospheric sounding in the infrared and enable improved timeliness through constellations

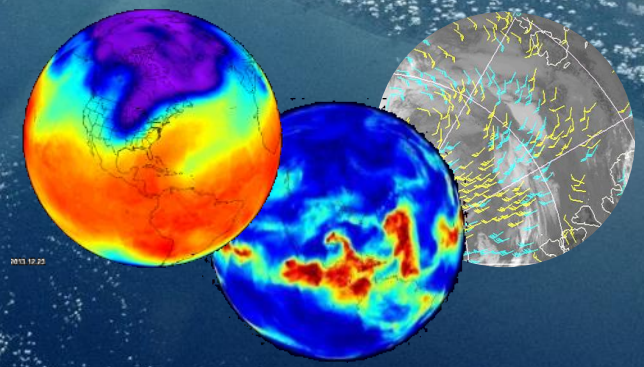
CIRAS Mission

- *Demonstrate Key Technologies needed for Infrared Instruments on CubeSats*
- *Demonstrate fidelity of Hyperspectral Mid IR radiance measurements to retrieve Temperature and Water Vapor Profiles*
- *Fill Coverage Gaps and Improve Timeliness of Operational IR Sounders*
- *TRL in: 5-6, TRL out: 7*
- *Build: 2016, 2017. Launch 2018 (TBD)*

Parameter	CIRAS
Spatial	
Orbit Altitude	600-850 km
Pushbroom SW	163 km
Horizontal Res'n	13.8 km
Spectral	
Method	Grating
Band 1	4.78-5.09 µm
Res'n / Sampling	0.5 / 0.2 cm^{-1}
Total Channels	625
Radiometric	
NEdT (@250K)	<0.25 K
Resources	
Size	6U Cubesat
Mass	8.5
Power	37.5
Data Rate	2 Mbps

CIRAS Measurements

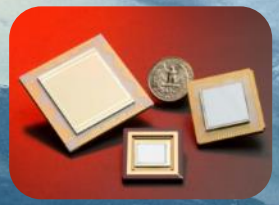
- *Lower Tropospheric Temperature Profiles*
- *Lower Tropospheric Water Vapor Profiles*
- *Goal: Experimental Demonstration of 3D Winds*



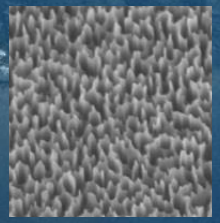
CIRAS Technologies

JPL/Ball GRISM Spectrometers

JPL HOT-BIRD Detectors



JPL Black Silicon Blackbody



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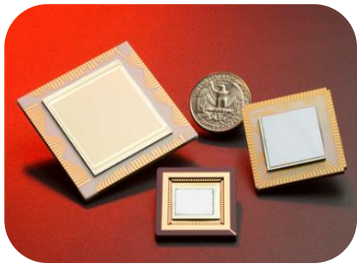
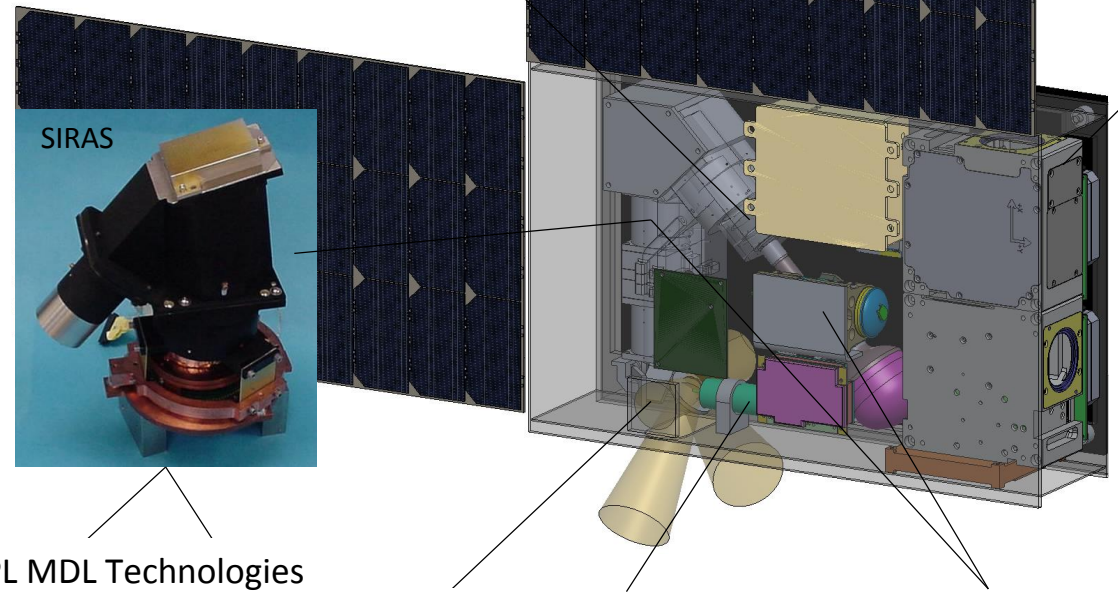
**Patent Pending*

CIRAS Technologies

JPL
HOTBIRD
Detectors

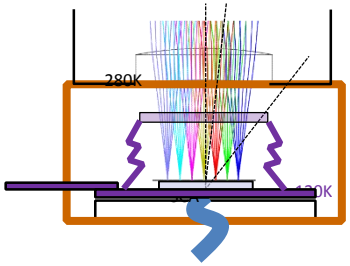


Commercial
Spacecraft



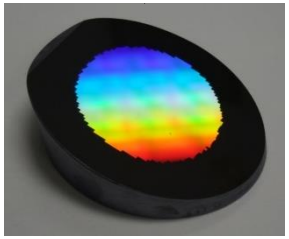
JPL/BALL
Midwave Infrared
Spectrometer

Custom Detector and
Cold Filter Mount

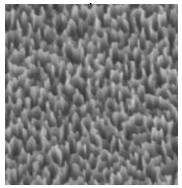


JPL MDL Technologies

Immersion Grating



Black Si.
Blackbody & Slit



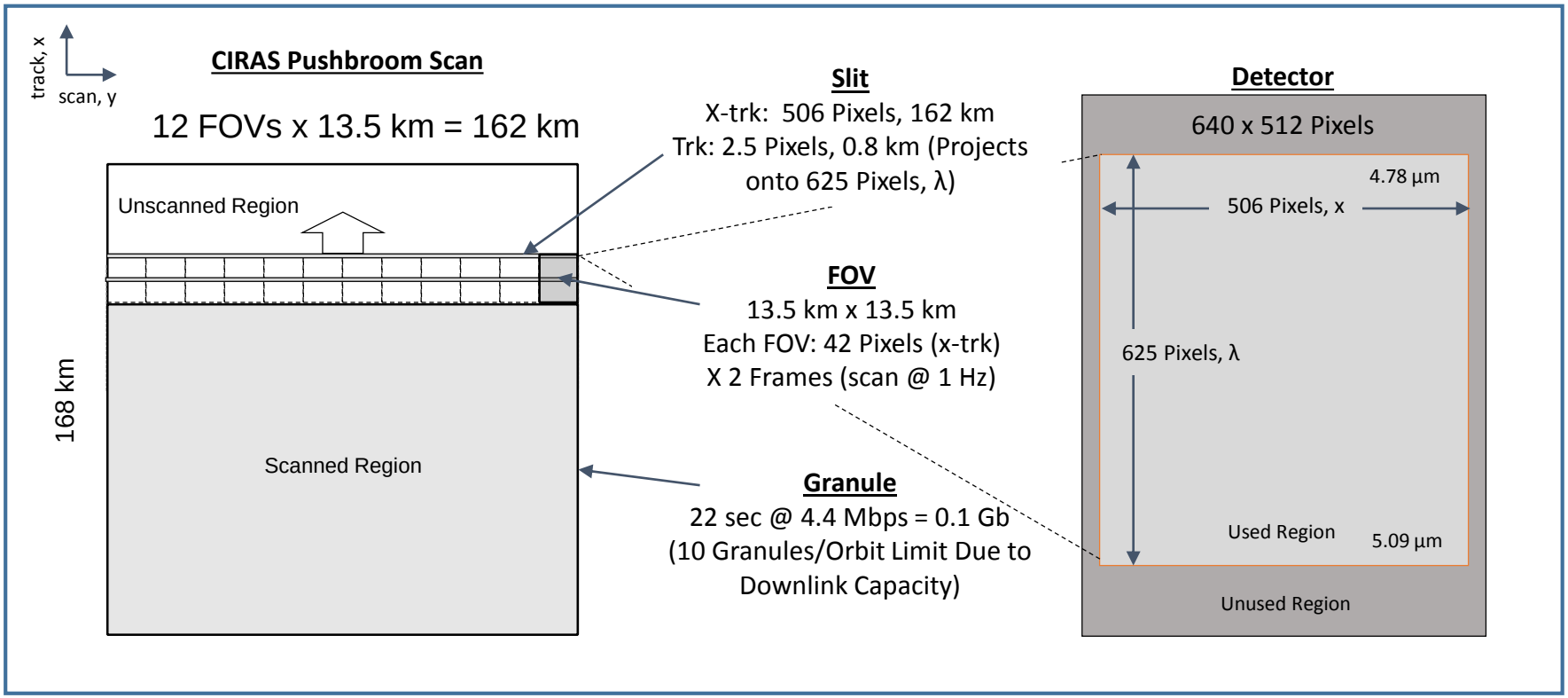
3-position Pointing
Mirror Assy Commercial
Stepper Motor + Elex

Ricor K562S Rotary
Stirling cooler + Elex

IR Cameras
SBF193 Electronics

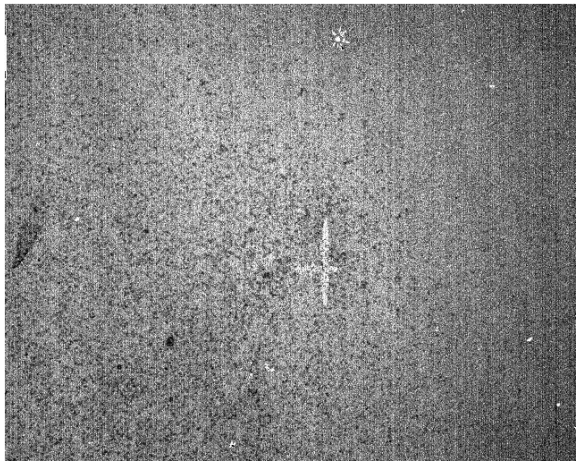
This document contains export-restricted data.

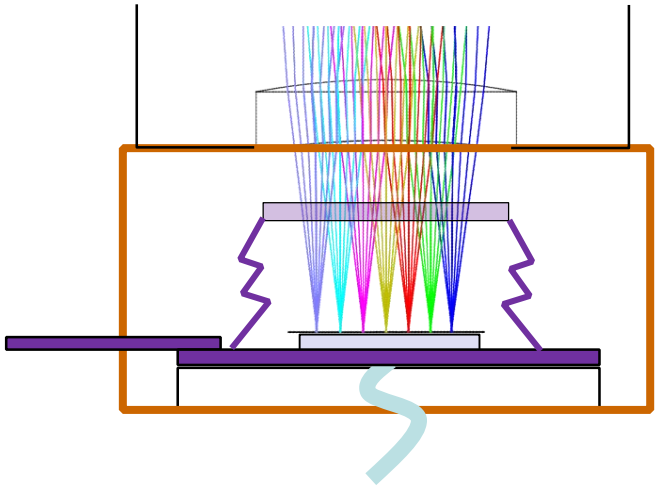
CIRAS Scan and Focal Plane Geometry



CIRAS uses existing Focal Plane Assembly

- Sensor Chip Assembly
  - JPL has existing HOTBIRD detector / SBF193 ROIC as proposed for CIRAS: 640 x 512 @ 24µm
  - Array fully characterized during EON-IR Study for NOAA. Meets requirements.
  - Risk associated with use of only one detector.
- Motherboard, Cable, Electronics
  - IRCameras in Santa Barbara to provide
    - Detector Cable Assembly
    - Camera Electronics Board
- Cold Shield and Window
  - JPL scope includes FPA mount, pedestal, cold shield, cold filter
  - JPL to integrate and test





CIRAS Summary

- CIRAS is an ESTO funded task as part of the In-space Verification of Earth Science Technologies (InVEST) program
- Key Technologies to Demonstrate:
  - IR Immersion Grating Spectrometer
  - HOTBIRD Infrared Detectors
  - Black Silicon Blackbody
- Reduced spatial coverage
- 18 month schedule
- Cost-driven project with a $4.2M total budget
- No science and 3 mo in-orbit lifetime requirements
- CIRAS technology is high TRL or commercial
- CIRAS will demonstrate a fully functional temperature and water vapor IR sounder in space in a CubeSat configuration
- Expected Launch Date: Late 2018/Early 2019

Things we've learned from the EON-IR Study for CIRAS

- Measurement Requirements
  - Retrieval in this band will provide good soundings
- Payload design models developed
  - Radiometric, spectral, optical, thermal
- Detailed Design and Trade Studies
  - Scanner Assembly
  - Optical Design, Alignment, Fab, Tolerances
  - Electronics and Spacecraft Interfaces
  - FPA mounting approach
- Performance Testing
  - EON-IR Tested CIRAS Flight Detector
  - Tested and Identified high EMI from LM MPT Cryocooler
  - Grating performance vs ruling approach. Blazed is best.

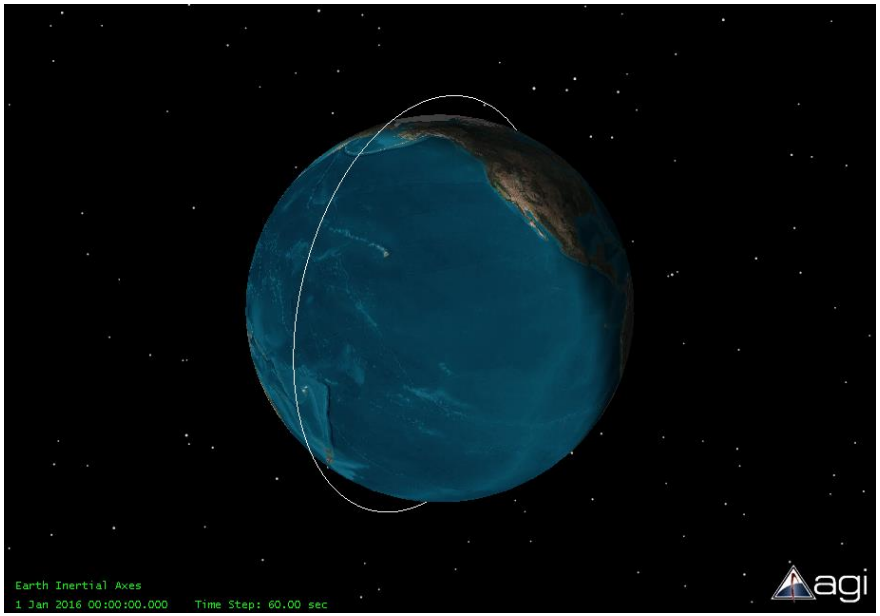
EON-IR Detailed Design

Orbit Analysis

Sarah Spangelo

Orbit Assumptions

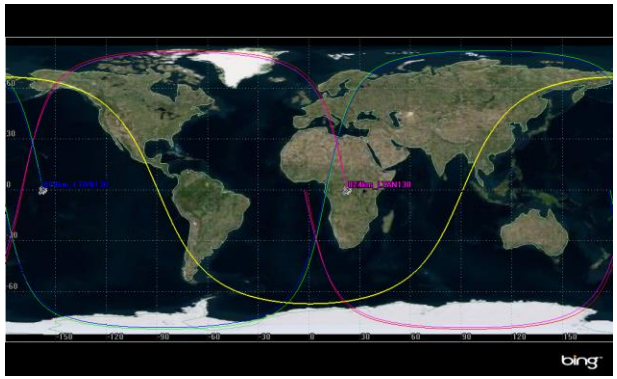
- Sun Synchronous Orbits with LTAN: 1:30pm ±10 minutes
  - 600km (Period = 96.7 min) and 97.87°, 824 km (Period = 101.4 min) and 98.7°
  - LTAN: 1:30pm : Legacy requirement for atmosphere meteorology to maintain climate record
- Launch: scheduled for Q2 2017 on a Delta-2 vehicle of ULA from VAFB, CA
- Analysis with J2 Perturbation orbital propagator assumed for STK analysis

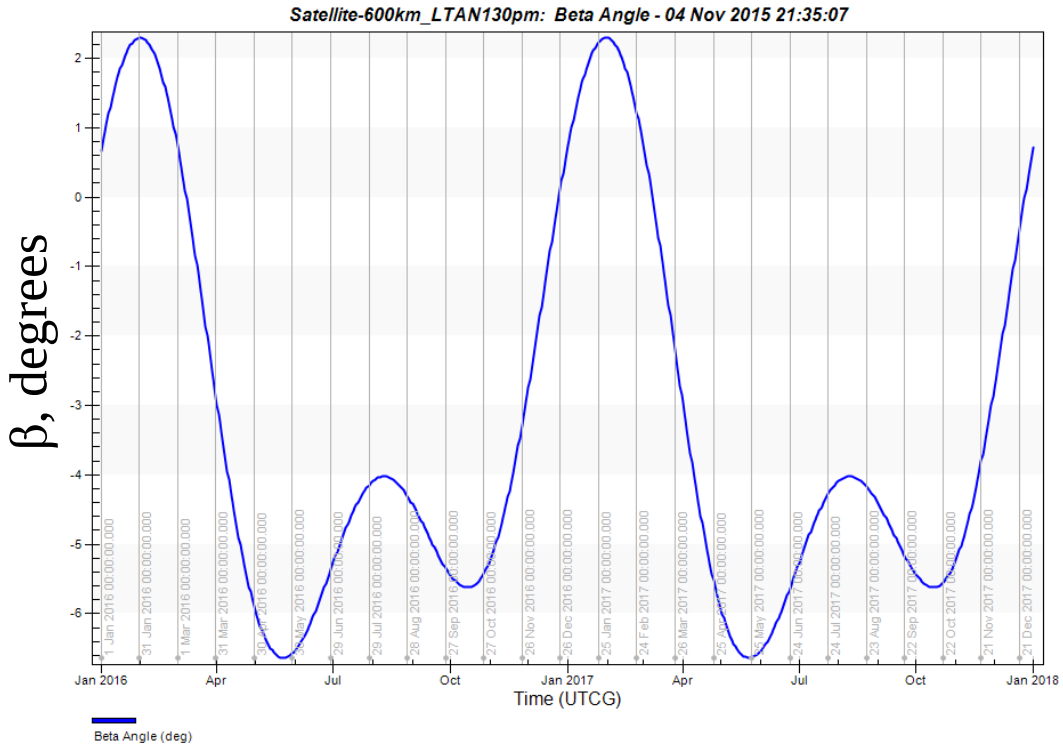


Representative orbit on Jan 1, 2017 from STK

Solar and Eclipse Trends

- Beta angle (β): Angle between orbital plane and Sun vector
  - Note absolute values of β plotted
  - β angle close to ~0 degrees throughout year
    - Orbit always orthogonal to vector to Sun
- Eclipses are ~35.4 min every orbit year-round (all orbits)

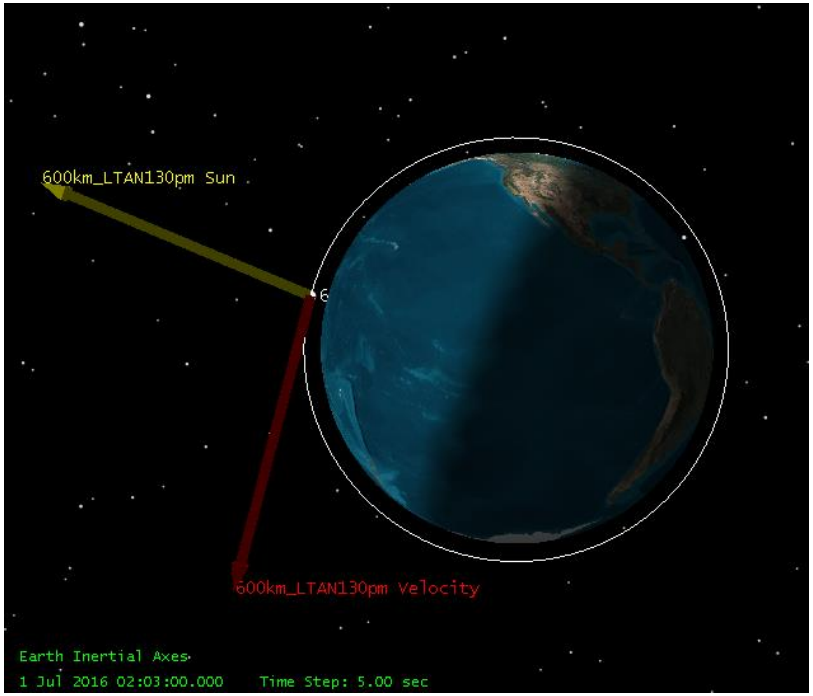




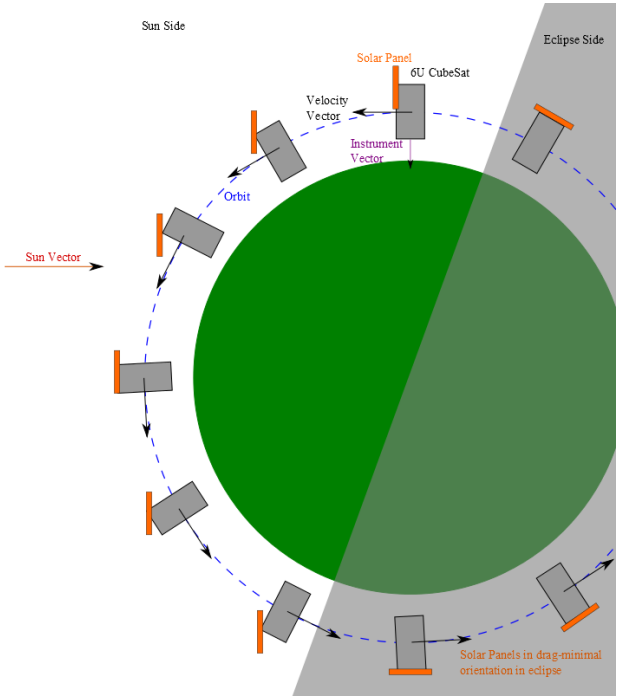
Results will be similar regardless of launch year (actual launch will be in 2017 or later)

Orientation & Power Collection

- Solar power pointing scheme to maximize power collection:
  - Adjust the solar panel angle for the best illumination geometry (see figure on right below)
  - With this approach, max power when in Sun (63.4% of orbit for 600 km)
- If articulated solar panels (in 2 directions) are not feasible for Sun tracking, significantly larger solar arrays and body-fixed arrays may be required to achieve power requirements
  - Given orbit lifetime results on following slide, this may not be overly problematic
- Different orbit (e.g. Sun sync ~6hr/18hr orbit) would help maximize power w constant angle and no/min eclipses



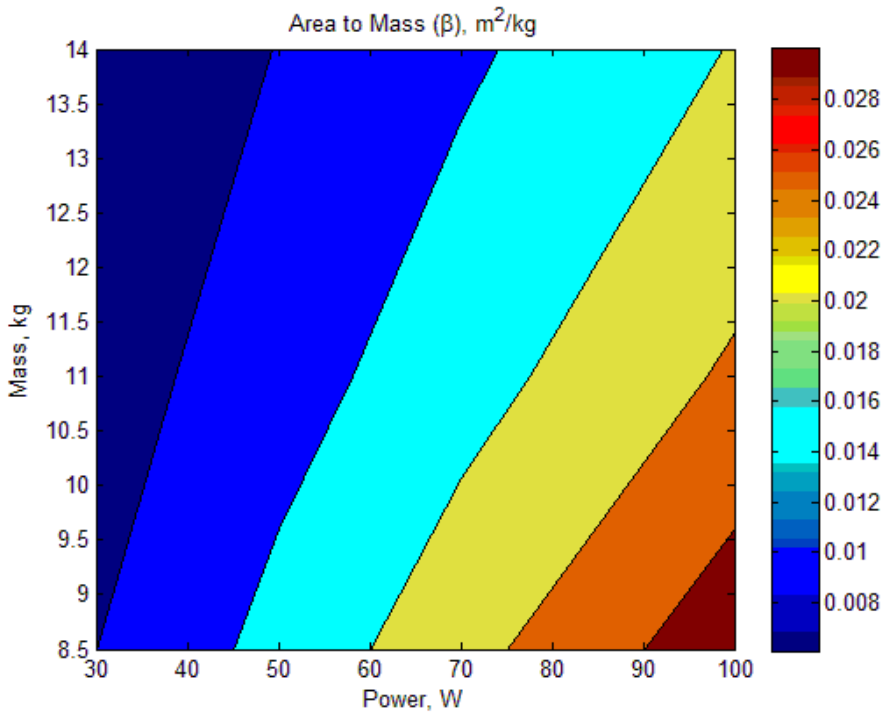
Representative orbit on June 1, 2017 from STK



Solar panel orientation throughout orbit to maximize power collection.

Lifetime Analysis

- Lifetime depends on β: relationship between mass and area in the velocity direction (a function of power)
  - Assume max solar panel area for ~20% of orbit, drag min for remaining 80% of orbit (ConOps on previous slide)
  - Range of mass and power values (on left plot) represent possible values for EON mission
- Lifetimes for different altitudes and β values (right plot)
  - Analysis with NASA DAS Lifetime Tool (standard approach), assume launches in 2017, Sun-sync orbits
  - 600 km orbits de-orbit in >>5 years and <25 years (required for orbital debris)
  - 824 km orbits do not orbit within 50 years, even with max solar panel area (2.8E-2 m^2/kg)→ not recommended



Orbit Altitude km	Max β m^2/kg	Lifetime years
600	4.00E-03	38.2
600	7.00E-03	20.2
600	1.00E-02	17
600	2.80E-02	7.1
824	4.00E-03	>100
824	7.00E-03	>100
824	1.00E-02	>100
824	2.80E-02	84.07

Instrument Systems

Pamela E. Clark

All slides from this section have been removed for public release

Scanner Requirements

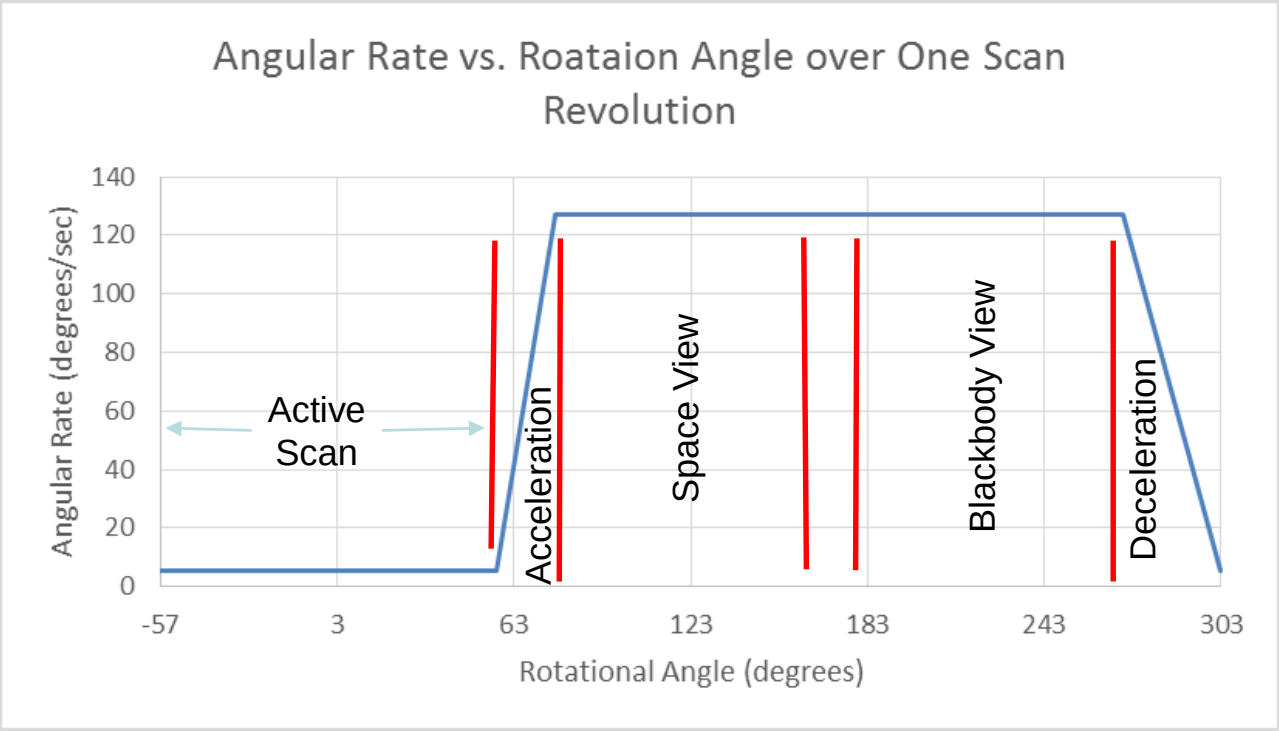
Michael R. Johnson

Summary of Mirror Actuator Requirements

- Minimum rotation rate of 0.9 RPM
- Maximum rotation rate of 21.2 RPM
- Continuous rotation
- Support mirror for launch
- Rotate at slow speed for 20.89 seconds over 114 degrees of rotation
- Rotate at 21.2 RPM over 193 degrees of rotation
- Accelerate between minimum and maximum rotation rates in remaining angle
- Total time for 246 degrees of rotation is 2.32 seconds, including speed-up and slow-down periods
- Operate from single power bus
- Interface with system over serial bus communication (RS-485 or CAN-Open)
- Provide angular feedback knowledge resolution of 0.4 degrees of the mirror, minimum (630 pulses per revolution at the encoder assuming 10:1 gearbox over one sample period)

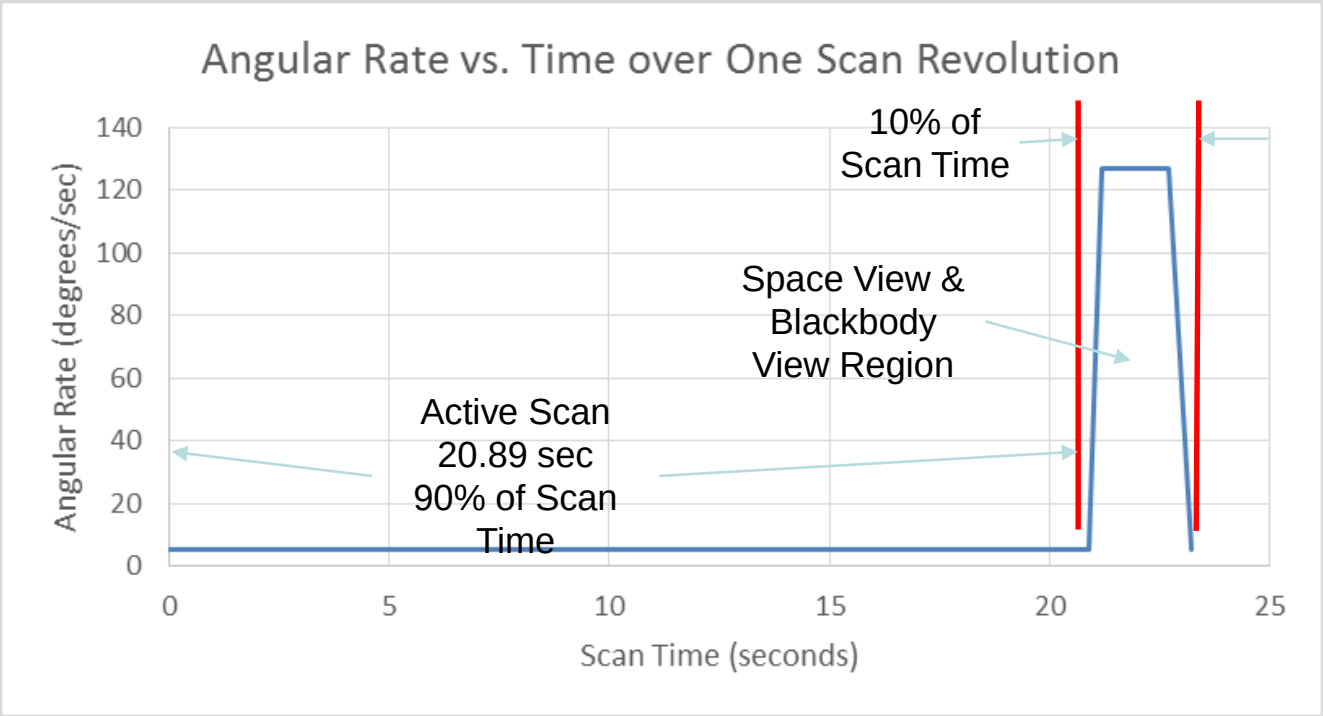
Rotational Rate Requirement

- Active Scan angle is ± 57 degress for a total angle of 114 degrees
- Space View and Blackbody View are both 90 degrees of rotation
- This corresponds to 21 sample periods of 33 milliseconds each, or three super frames of seven sample periods per super-frame



Rotational Rate Requirement (continued)

- Active Scan time is 20.89 seconds
- Active scan time is 90% of total time for one revolution
- Backscan time is 10% of total time for one revolution

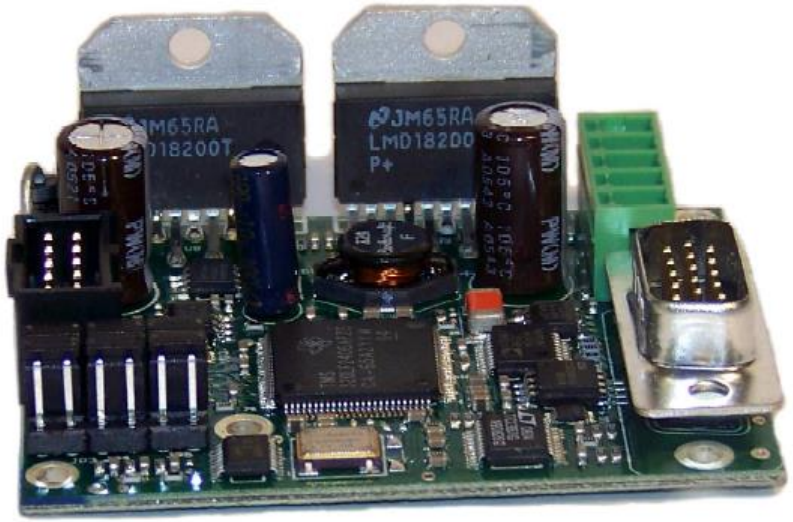


Scan Mirror Actuator and Drive

- Scan mirror is driven by a two-phase stepper motor with a planetary gearbox
- Output rotation rate is 0.9 RPM during the active scan and speeds up to 21.2 RPM for the backscan portion
- Encoder mounted to the motor provides rotor position feedback for the motor drive electronics
- COTS industrial encoder planned to be used (Dynapar, BEI, etc.)
- Mirror is attached directly to output shaft
- No launch restraint required for the mirror or actuator

Scan Mirror Actuator Drive Electronics

- Motor is driven by a servo drive electronics available as a COTS product from Quicksilver Controls in San Dimas, CA
- Core of motor driver is a DSP designed for motor operation
- Product is mature with over a decade of production
- Driver uses components that have pin-for-pin flight versions available, if desired
- Multiple serial bus interfaces present on-board



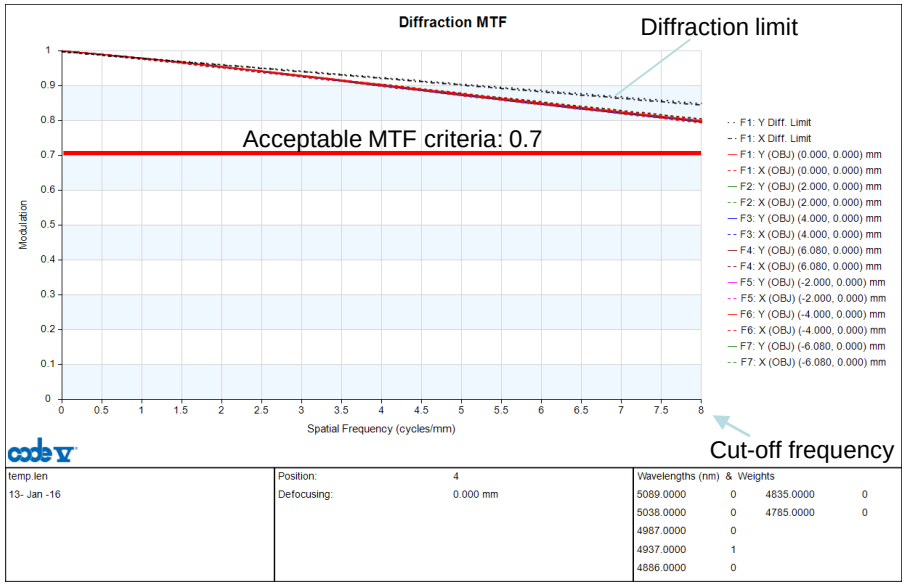
Items to Work

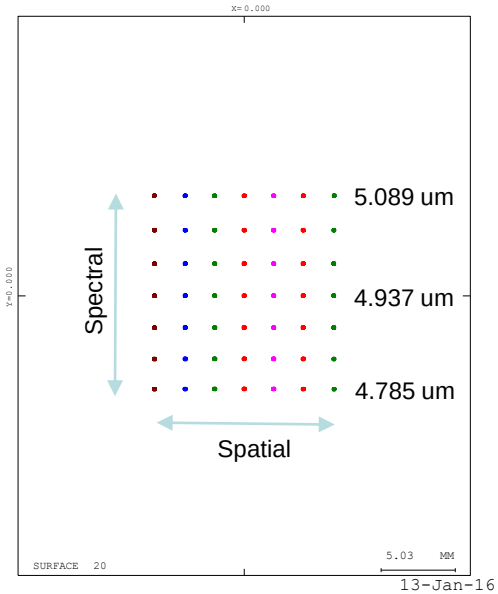
- Rotational drift of spacecraft during high speed operation of scan mirror
- Capacity of reaction wheels to respond to the momentum changes
- Consideration of momentum compensation mechanism design (equivalent inertia rotating in opposite direction to cancel momentum changes)

Optical Design

M. Rud, D. Wilson, N. Raouf

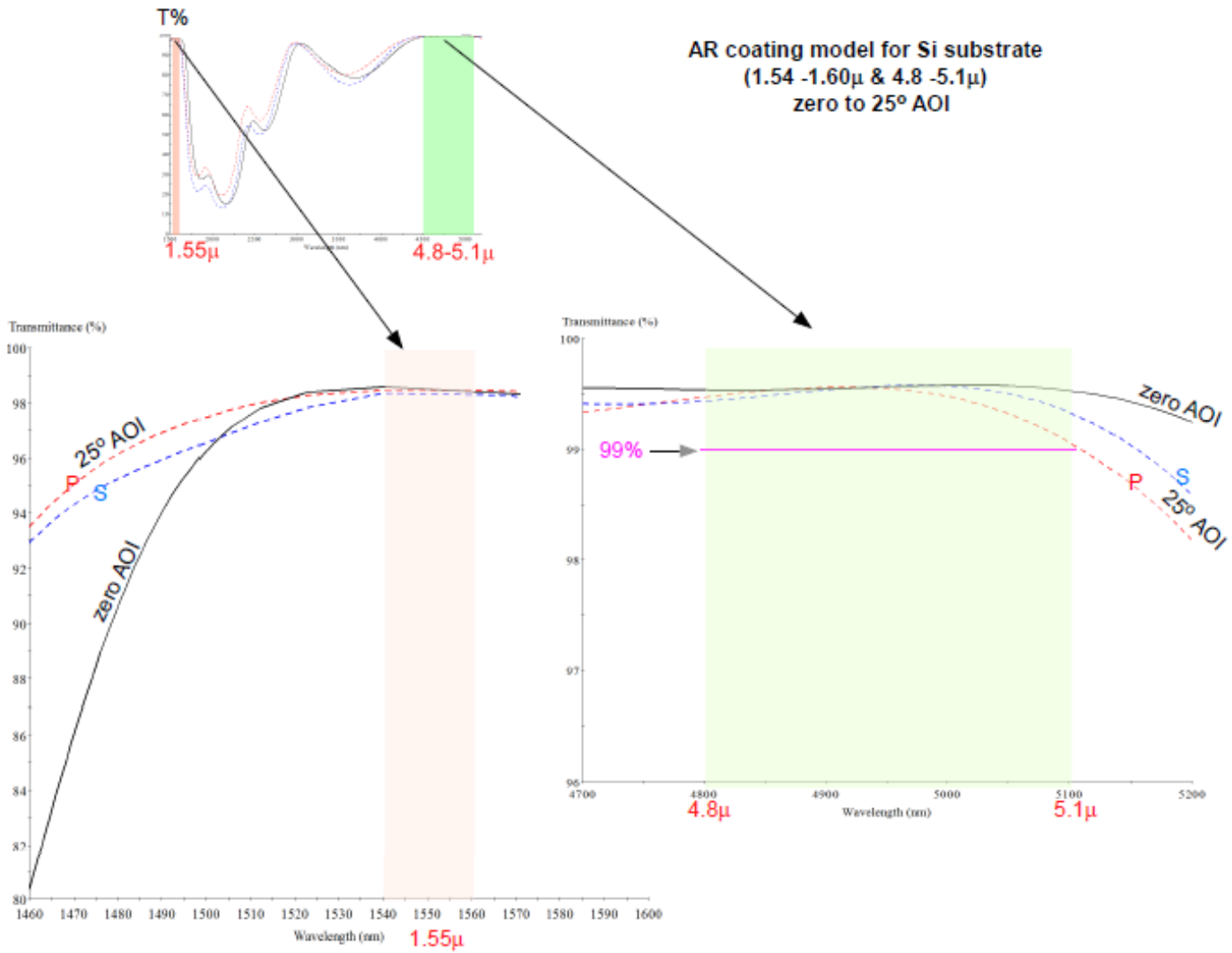
As-Designed Diffraction MTF Meets Requirements





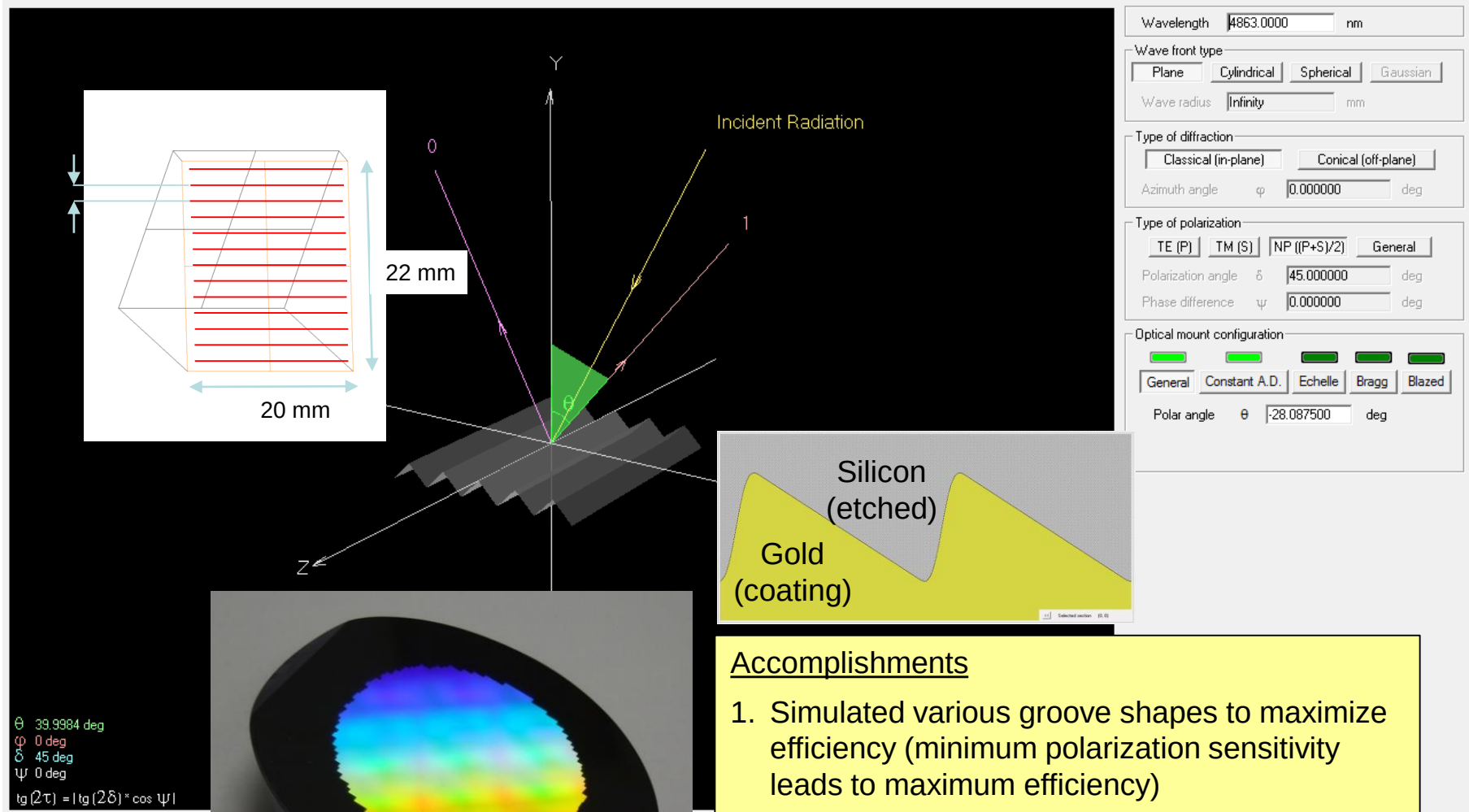
- Super-pixel in spectral direction is defined as a slit width: 24 um/pixel x 2.5 = 60 um
- Cut-off frequency (Nyquist): 8.33 cy/mm
- **Highest Resolution Mode requirement: MTF 0.7 @8.33 cy/mm**

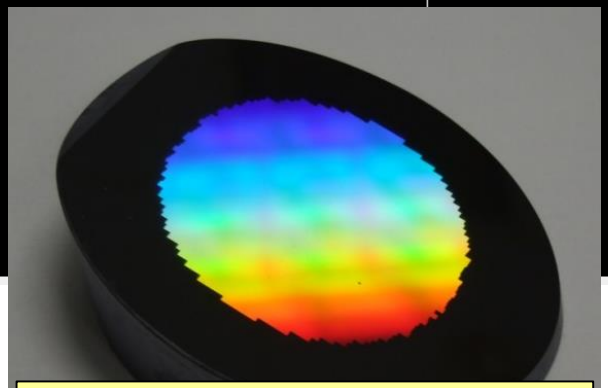
AR Coatings Meets Requirements



N. Raouf

EON-IR Silicon Immersion Grating



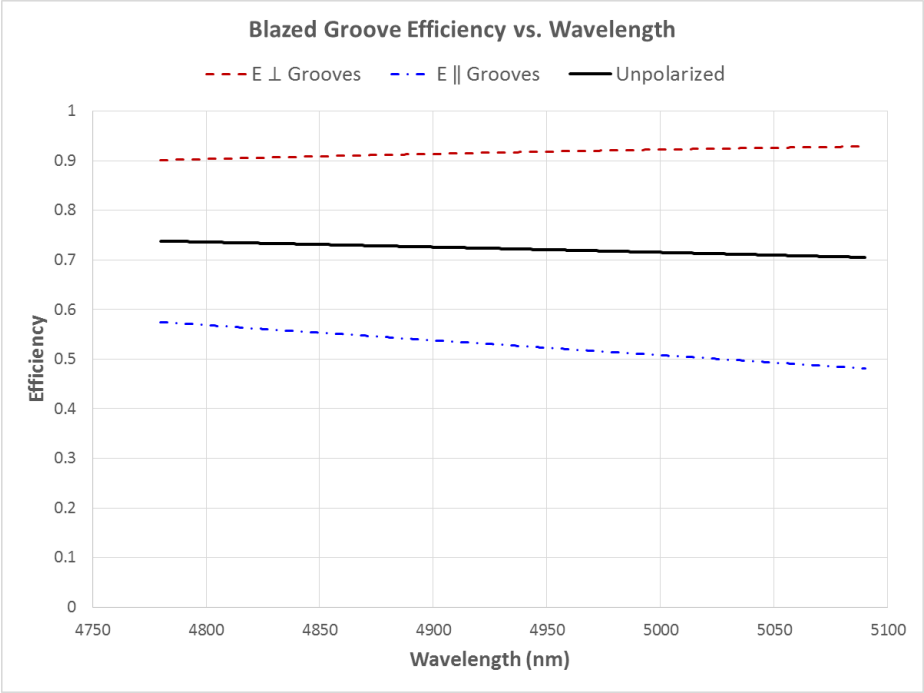


Grating for previous project: E-beam fabricated silicon grating for λ=2 μm (55 mm diameter grating)

Accomplishments

1. Simulated various groove shapes to maximize efficiency (minimum polarization sensitivity leads to maximum efficiency)
2. Fabricated test gratings on silicon wafers, then measured grooves (atomic force microscope) and simulated efficiency.

Blazed Groove Grating Simulation

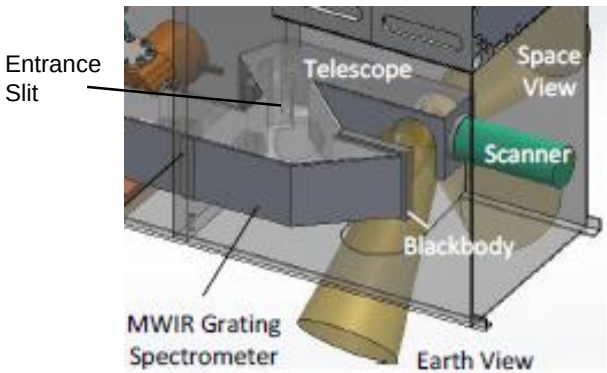


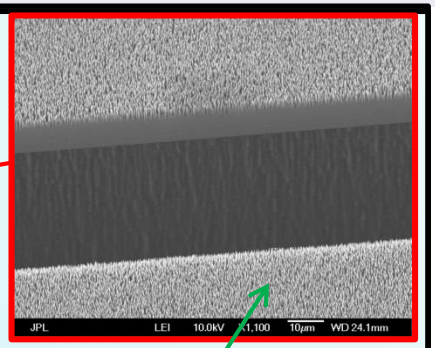
Blackbody & Slit Requirements

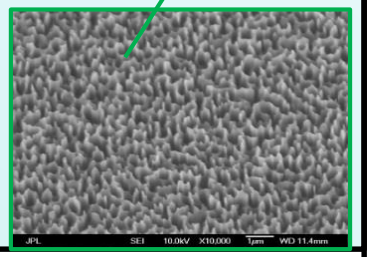
Karl Yee

EON-IR will use 'Black Silicon' for Entrance Slit and IR Blackbody

Jet Propulsion Laboratory
California Institute of Technology



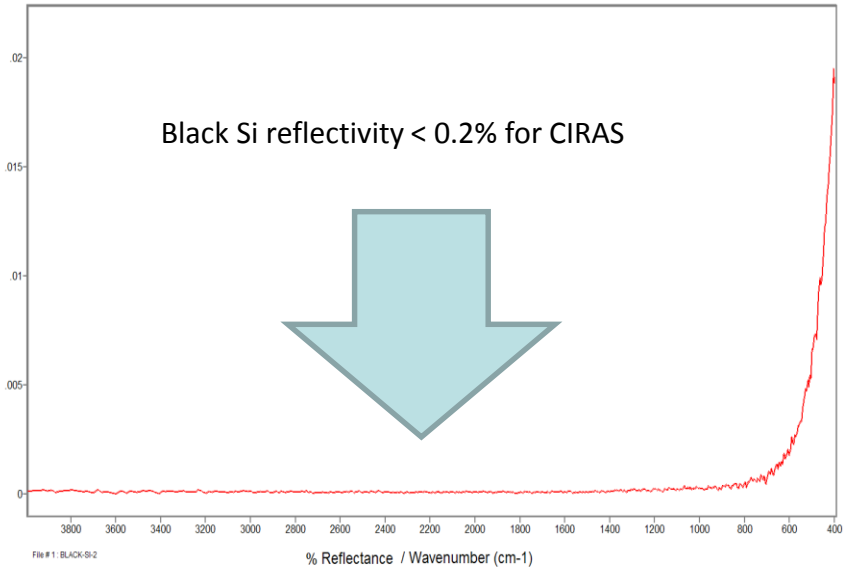




Lithographically defined spectrometer slit with black Si anti-reflection surface fabricated for OCO2

Black Silicon Uses for CIRAS:

- Blackbody Surface
  - <1" Diameter (Max target size manufactureable is ~5.5" diameter wafer)
  - Surface is robust under shock / vibration, and is compatible with liquid cleaning
- Entrance Slit
  - Lithographically defined, precision micro machined slit with smooth sidewalls
  - Knife edge geometry with black silicon anti-reflection surface texturing for reduction of stray light
  - Flight heritage: JPL instruments utilizing slits of this type include: HyTES, AVARIS, UCIS, HyspIRI, MaRS2, PRISM, NEON

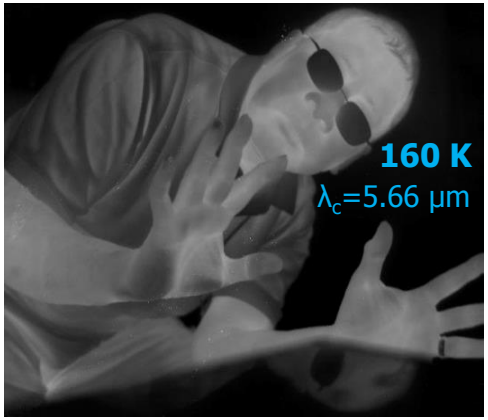


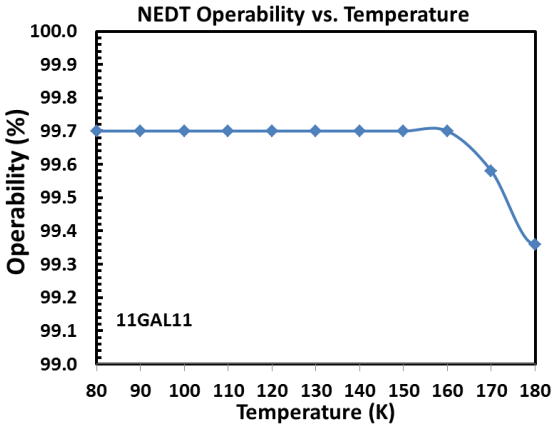
HOT-BIRD MWIR Noise Measurement Detail Design Review

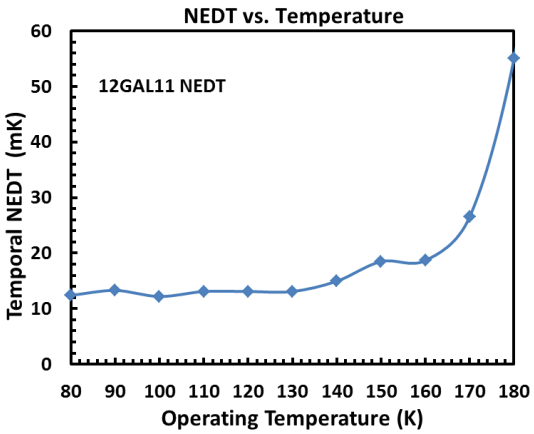
Don Rafol, Dave Ting & Sarath Gunapala

HOT MWIR Detector Development Led to Breakthrough IR Detector Technology

- InSb: MWIR (λ_c ~5.2 μm) FPA volume market leader
  - III-V semiconductor based, good manufacturability & low cost
  - Very large format capability, high uniformity and operability
  - But with much lower operating temperature (~80K) than MCT
- MWIR MCT single pixel operates at 150K, but, FPAs operate at 110K
- A high operating temperature (HOT) III-V alternative?
- HOT MWIR detector with λ_c >5 μm demonstrated at JPL in July 2010
  - High operating temperature (HOT) barrier infrared detector (BIRD)
  - Based on type-II strained layer superlattice (T2SLS) & Unipolar barriers
    - Adjustable cutoff wavelength, ranging from λ_c =4 μm to λ_c >14 μm







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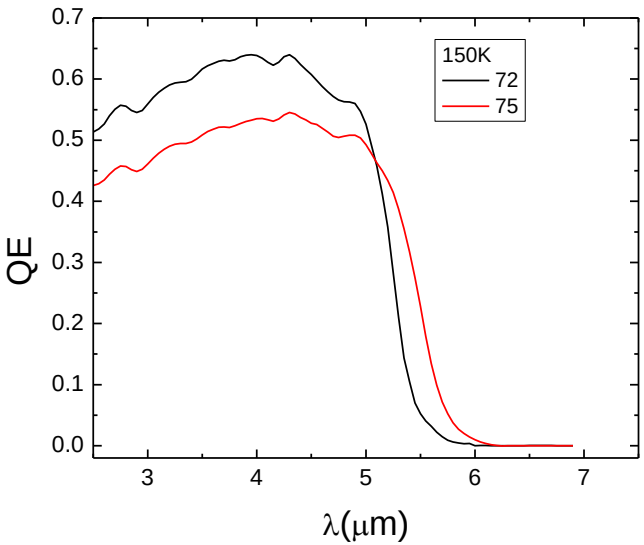
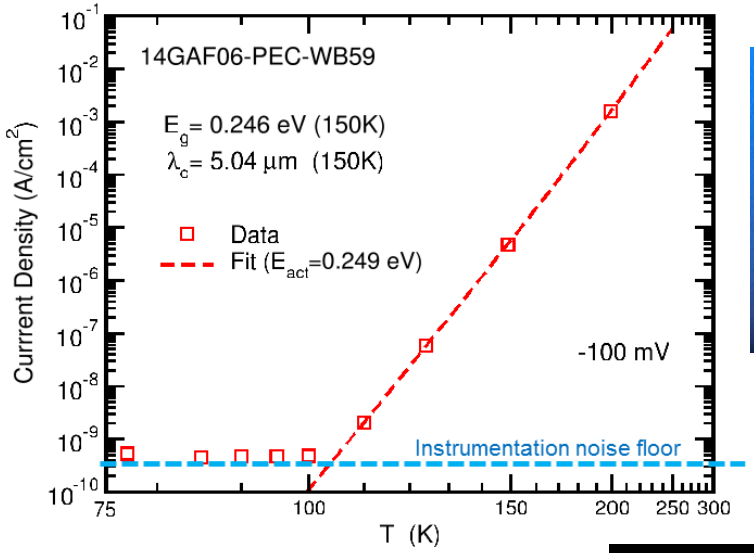
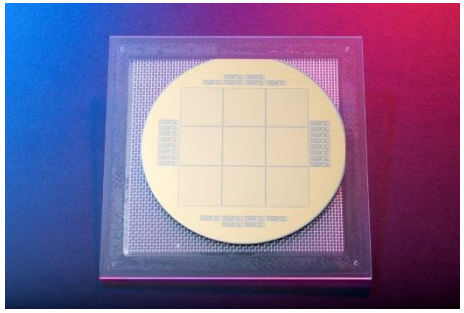
California Institute of Technology

JPL HOT-BIRD MWIR FPA

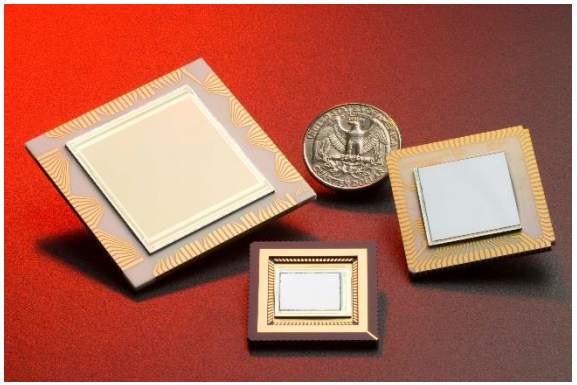






Nine megapixel FPAs on 4-inch wafer

- T= 150K, F/2 optics, 300K background
- Pixel Operability = 99.9%
- Mean NEΔT = 18.5 mK
- Operating at T=150-160K
- External Mean QE = 76%



Megapixel to VGA format FPAs

Boeing 737 during landing

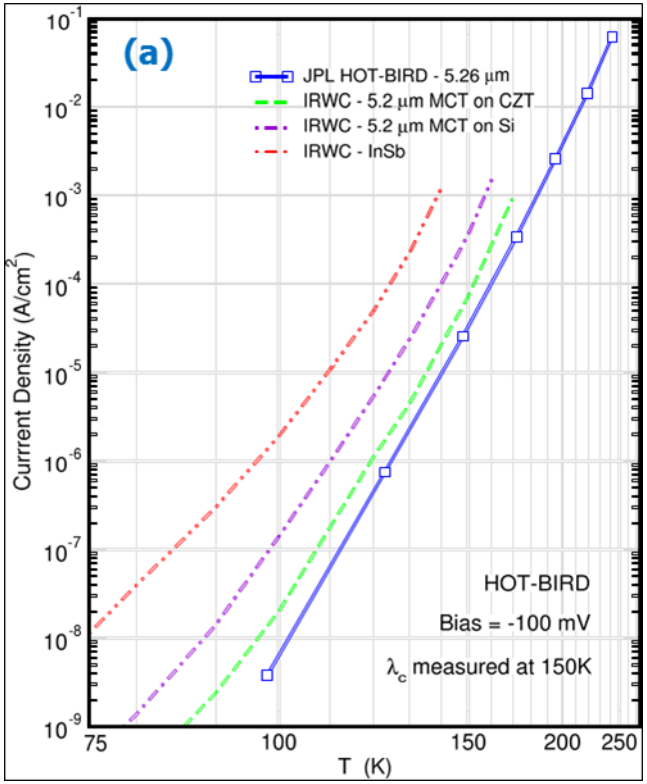
Pasadena City Hall

MWIR HOT-BIRD FPA SNR Experimental Study for EON-IR

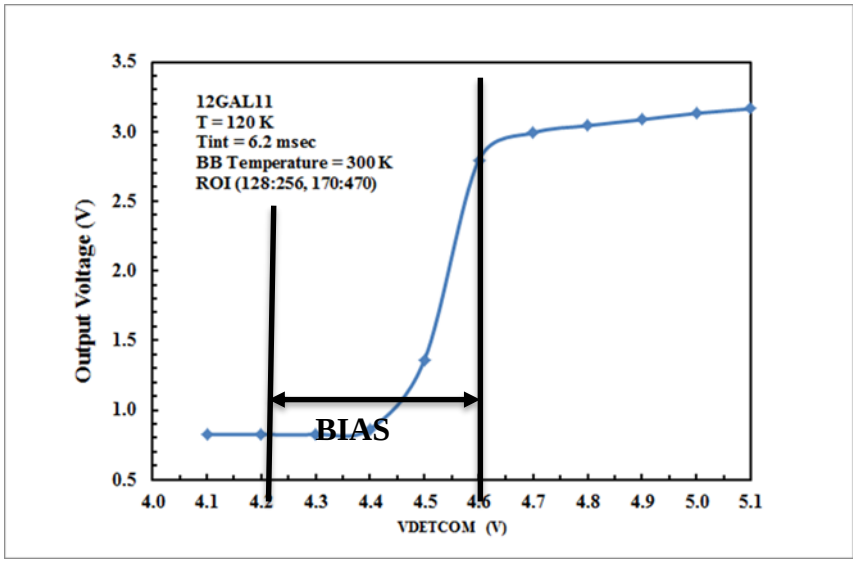
- Objective: Validate dark current @ 120 K, Electronics and Photon Noise
- Test requirement on a real HOT-BIRD FPA from NRO Program
- Test Condition
  - Noise Measurement on two FPA at temperatures120 K and 130 K
    - > 1014 Photons/sec/cm2
    - > 1013 Photons/sec/cm2
    - > 1012 Photons/sec/cm2
  - 5 Watt L3 Cryocooler/Dewar and SEIR small electronic
    - adjustable temperature (> 50 K)
  - Band pass filter 4.7 mm to 5.7 mm (Detector Cut offs at ~5.2 mm)
  - Cold Long Pass filter 4.4 mm
  - High f/Number
- Results show detectors behave as expected and meet requirements.

Dark Current Density & Biasing

- Dark Current Density

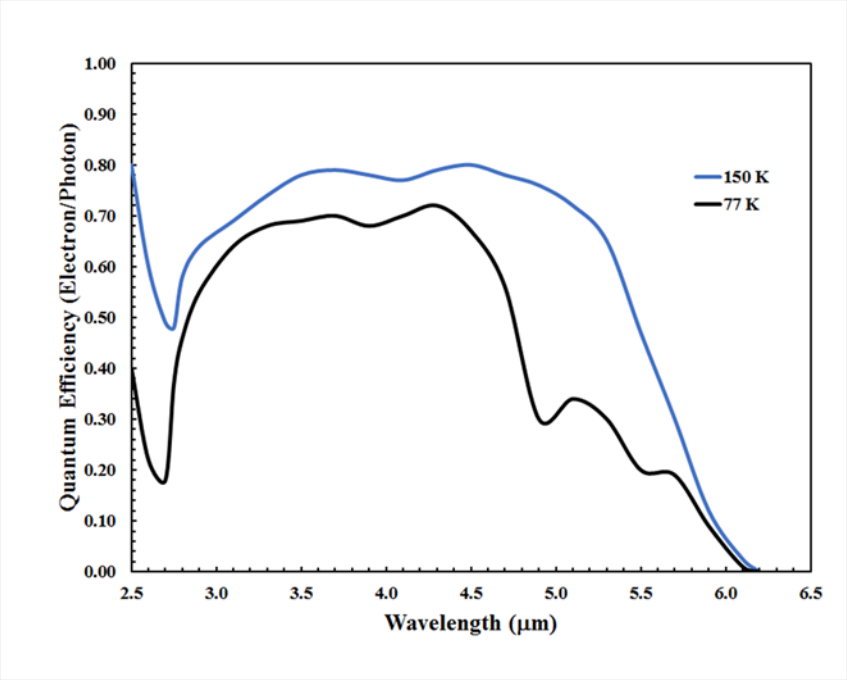


- Bias at the Plateau region, ~ 340 mV

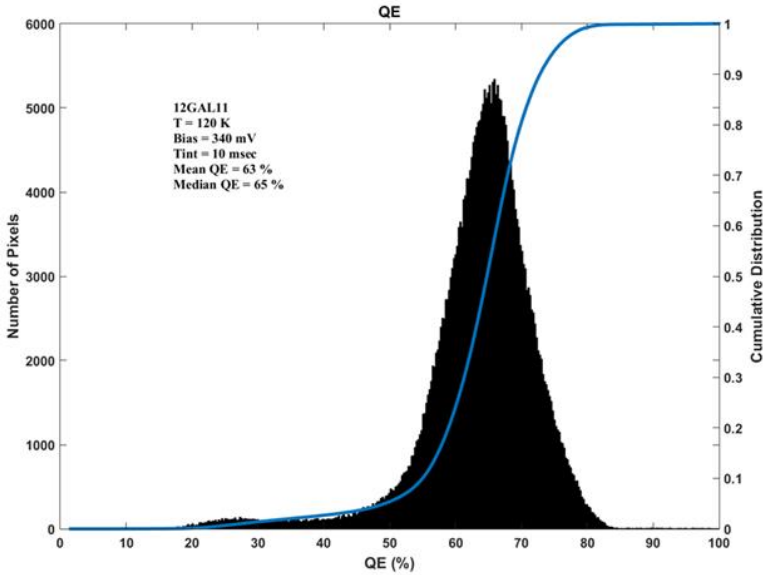


QE

- Single Element External Quantum Efficiency, NO-AR Coating

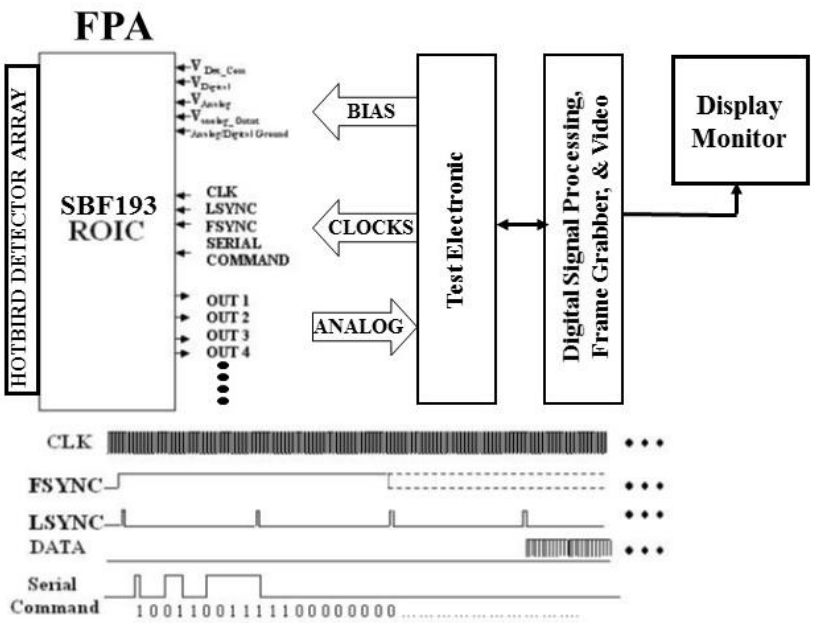


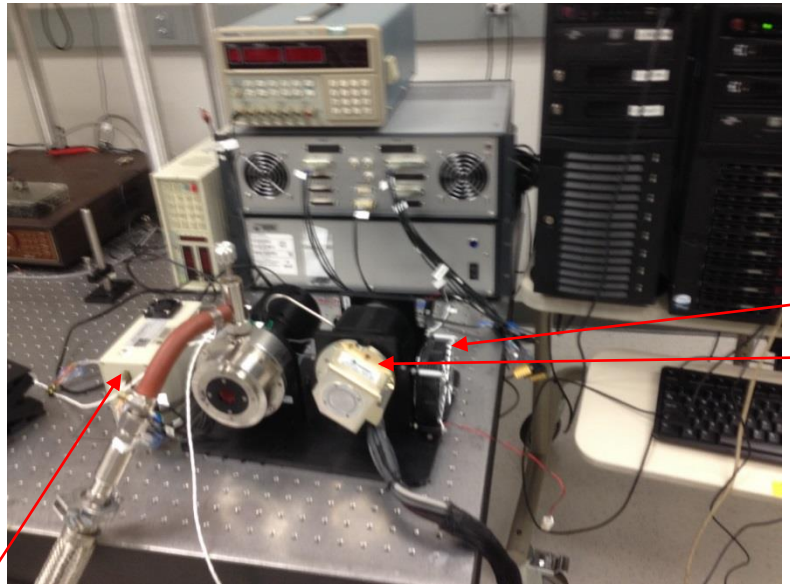
- Band Pass Filter 4.7-5.3 mm, No AR-Coating
- Agrees with single element measurement



SEIR Test System & Cooler Interface

- SEIR Test System





Cooling Fan

Cooler Electronics

SEIR Electronics

Dark Noise Measurement: Integration time chosen to match background noise measurement

- The same integration time for Dark and Background noise measurement.
- Integration time determine from well fill 2/3
- Cooler/Fan contributes to noise ~ 900 electrons
  - Minimum 733 electrons/count
- **Electronic noise > 800 Electrons higher than budget**
- Better agreement when cooler/fan noise is subtracted out
- Dark Current shot noise estimate, used full noise bandwidth ~ 1/Tint

FPA @ 120 K				
Tint (msec)	3.94	33.37	33.37	Comments
Measured ROIC and Electronic Noise (Electrons)	962	996	996	Bias Off, Cooler Off, Fan Off
Measured ROIC, Electronic, Cooler/Fan Noise (Electrons)	1332	1327	1327	Bias Off, Cooler On, Fan On
Measured Dark Current, ROIC, Electronic and Cooler/Fan Noise (Electrons)	1368	1891	1891	Bias On, Cooler on, Fan On
Estimated Electronic Noise (Electrons)	822	861	861	Assume ROIC ~ 500 Electrons
Estimated Induced Noise (Electrons)	921	877	876	Noise from Cooler/Fan
Estimated Dark Current Noise (Electrons)	312	1347	1347	Dectector Dark Current Noise Only
Calculated from Dark Current Noise (Electrons)	377	1550	1550	Shot Noise from Dark Current

Dark Current Noise as expected for 120K

Instrument Electronics

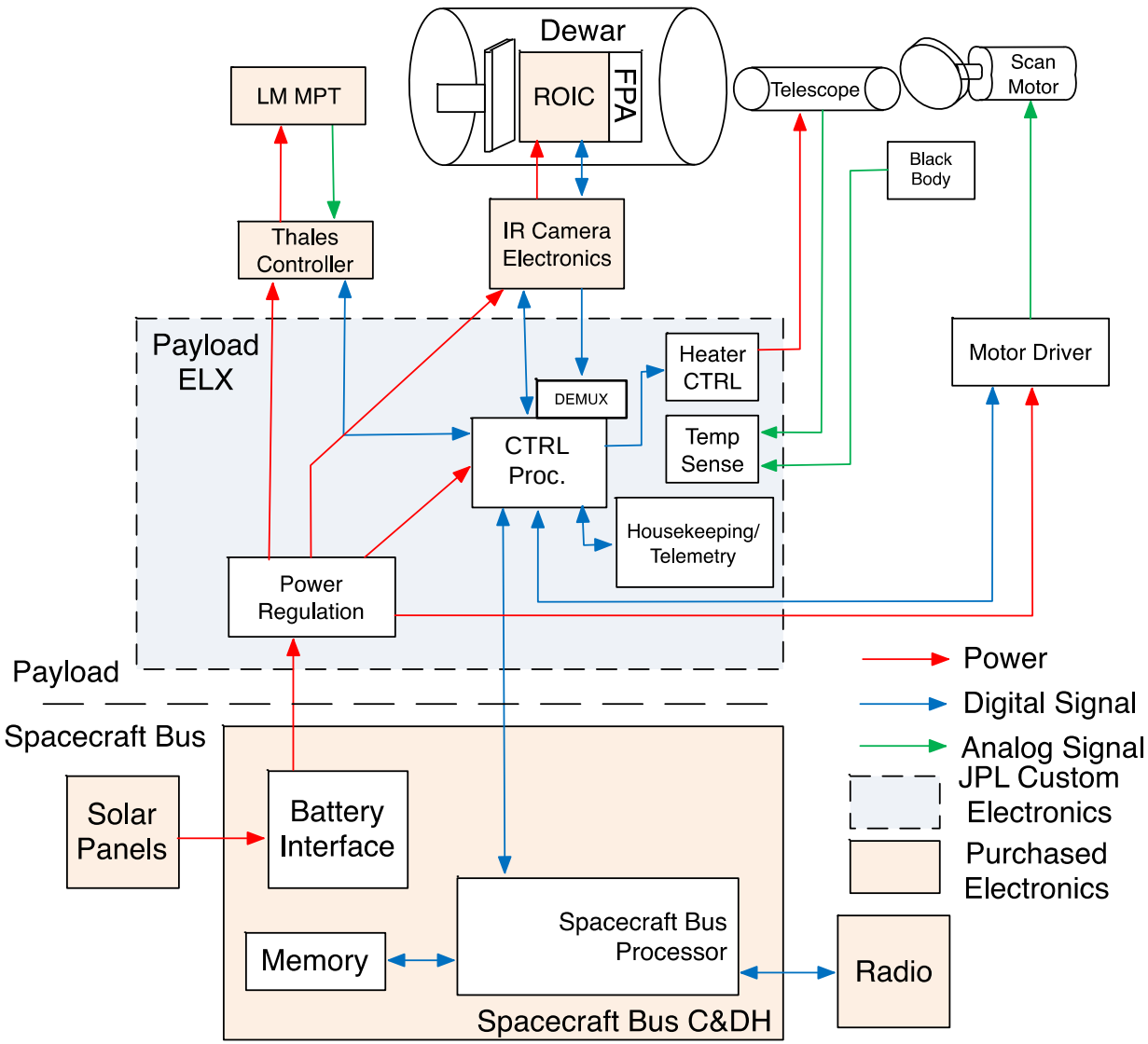
Allen Kummer

1/29/2016

Key and Driving Requirements

- Camera interface
  - IR Cameras output is camera link
- Spacecraft vendor flexibility
  - Requires maintaining two different interfaces, LVDS and SPI, through the hardware design cycle to be down selected late in development
- Flexibility of Real-time Image processing
  - Desired flexibility is up to no integration of images, meaning images streamed in real time as they are received. Drives data link requirements with the spacecraft
- Power generation for cryo cooler
  - Requires 18 V minimum input
- Thermal control at 50 mK accuracy
  - Drives precise knowledge and control circuit designs

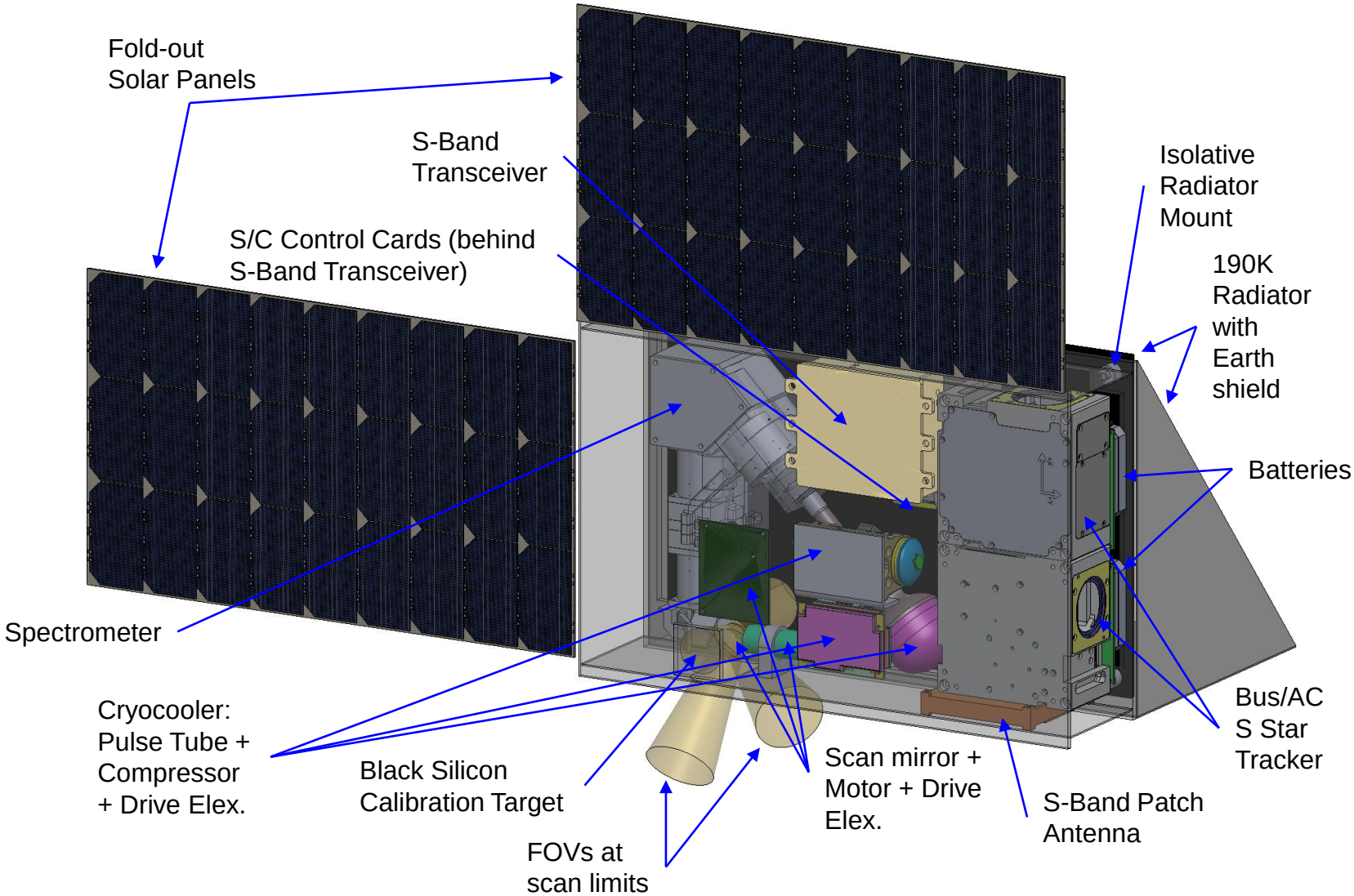
Electronics Block Diagram



Mechanical Design

Marc Lane, Tom Disarro

EON/IR Configuration



Primary Mechanical Components

- **Main Structure** to support the instrument, cryocooler, radiator, electronics, and other components. Interfaces with a 6U cubesat dispenser.
  - Integrated structure required to support thermal design.
  - Design for the Planetary Systems Corp. Canisterized Satellite Dispenser (CSD).
  - Box covers/closeouts provide radiation shielding.
- **Opto-mechanical Structure**
  - Housing to support optics (telescope and spectrometer). Simple housing, no kinematic mounting.
  - Includes calibration target.
- **FPA Mount**
  - Keeps FPA at 120° K via thermal straps from cooler.
  - Must have “soft” mechanical and “hard” thermal connection between cryocooler cold tip and detector.
  - Simple mount (not a Moore mount).
- **Blackbody Calibration Target**
  - Mounts at a point in the 360° scan circle. Must be thermally stable.
  - Aluminum substrate with embedded temperature sensor mounted on black silicon (provided by project).
- **Radiator with Earth Shield**
  - Large flat plate radiator (210 x 350mm) passively cools the spectrometer and telescope optics.
  - An Earth shield will be required.
  - Radiator is thermally isolated from rest of spacecraft. (100° K temperature difference, <1 watt heat flow).
- **Scan Mechanism and its Support Electronics**
  - Use COTS stepper motor with COTS controller. Motor and controller costs included.
  - Scan mirror rotates continuously in one direction at varying speed.
- **All Cables**

Key/Driving Requirements

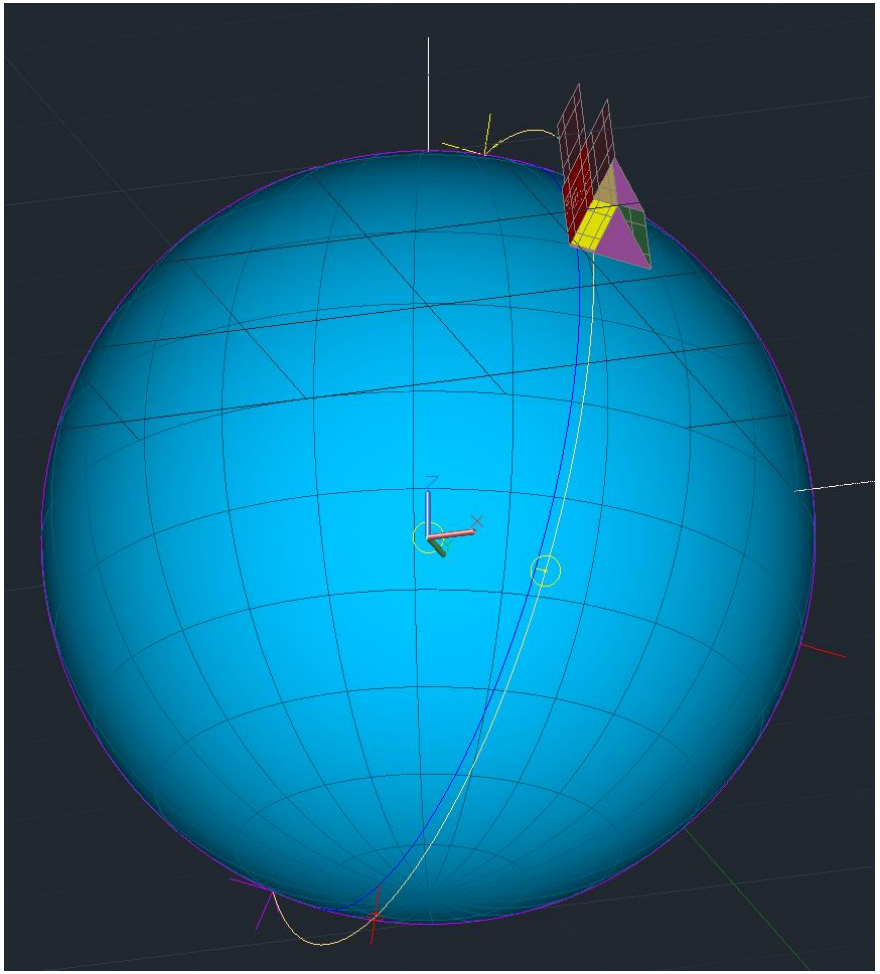
- Keep detector at 120K
  - Means we must use a cryocooler and take on significant thermal requirements.
  - Cryocooler attachment to detector is hard thermal/weak mechanical connection, and must be thermally attached to “warm” radiator part of spacecraft.
  - Employ mechanical isolators if possible to minimize vibration.
- Keep optics at 190K
  - Spectrometer optics and housing must be held at 190K.
  - Thermal design requires large thermal inertia to stabilize temperature across day & night of morning sun synchronous orbit.
  - Large, heavy radiator and optics housing + MLI blankets must be supported on spacecraft but thermally isolated. $\Delta T = 100^\circ$ C, $Q \leq 1$ Watt. Fiberglass spacers with Ti bolts **won’t** cut it.
  - Refractive design except for diffraction grating mirror.
  - **Assume** relatively easy optical alignment requirements – simply mounted optics in barrel.
- Keep rest of spacecraft at 290K
  - Cryocooler & rest of heat generating electronics dissipate through exterior of spacecraft.
- COTS scan mechanism and electronics
  - Current baseline is Quicksilver Controls design.
  - Loose scan mirror pointing requirements.
- Mission duration
  - ≥ 3 months.

Thermal Design

Colin Smith

Orbit, Attitude, Environment

View from sun



Orbit and attitude

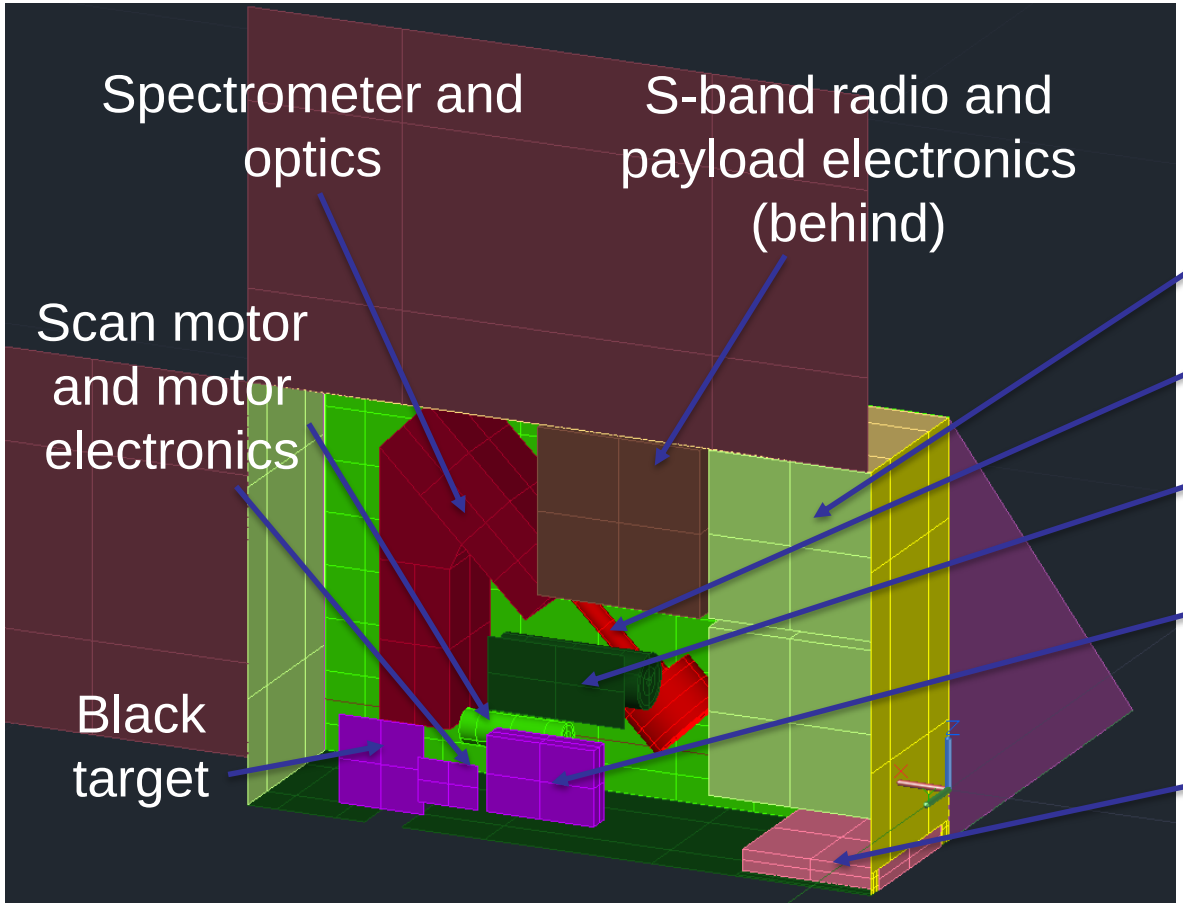
- 1:30 am/pm sun-synch, 600 km
- Beta angle: 17º
- One 20 cm X 30 cm side of spacecraft never has direct view of sun

Environmental heat loads

- Direct solar
- Earth IR
- Earth albedo

Thermal model – internal view

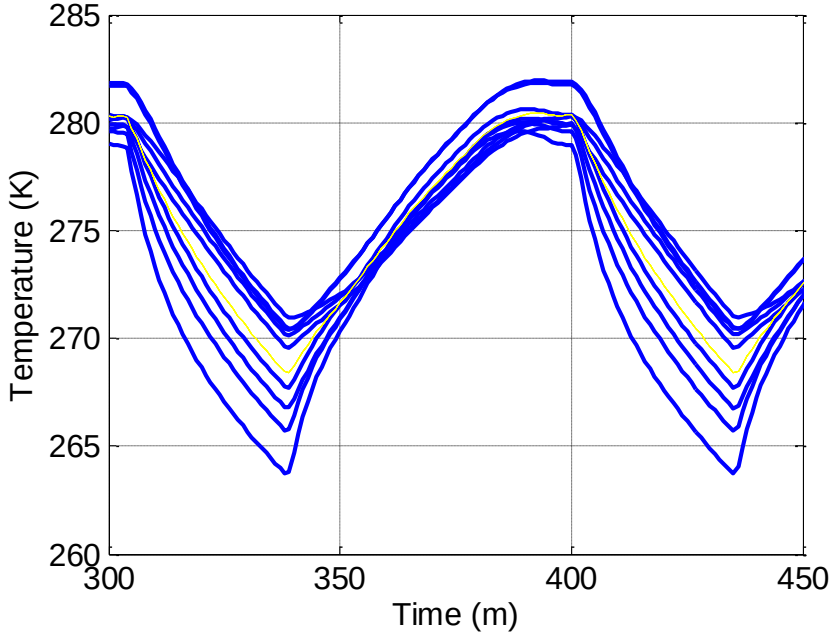
- Component power dissipation approximated (total = 62 W)
- Component masses approximated (total mass = 11 kg)
- Thermal conductance values estimated and modeled
- Aluminum properties for all components (specific heat, density, emissivity)



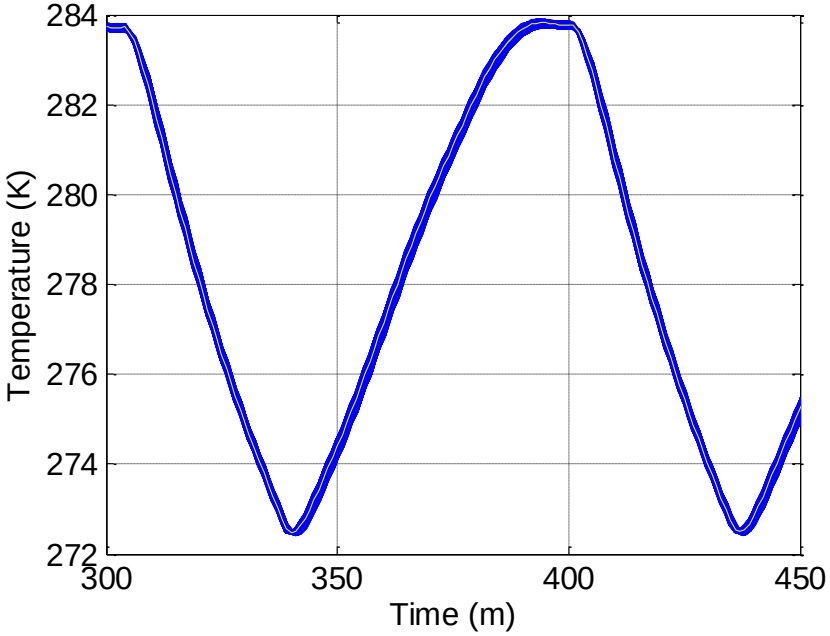
Model results – warm components

- The spacecraft structure stays between about 265 and 280 K with 62 W of power dissipated internally
- The pulse tube is the component with the highest power dissipation, and it is tied to the main warm radiator with 5 W/K; other components have lower peak temperatures

Main warm radiating surface



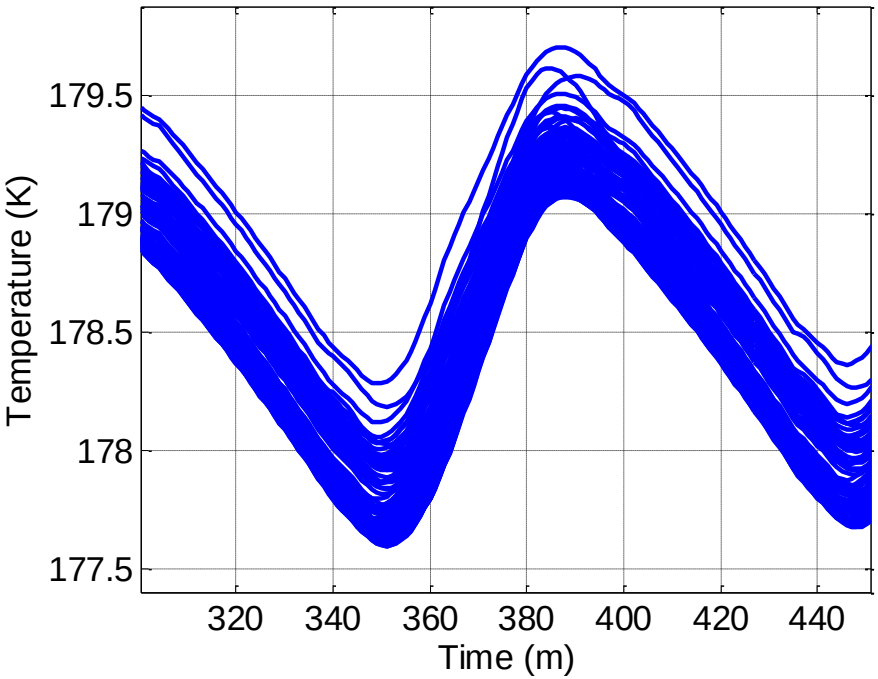
Pulse tube



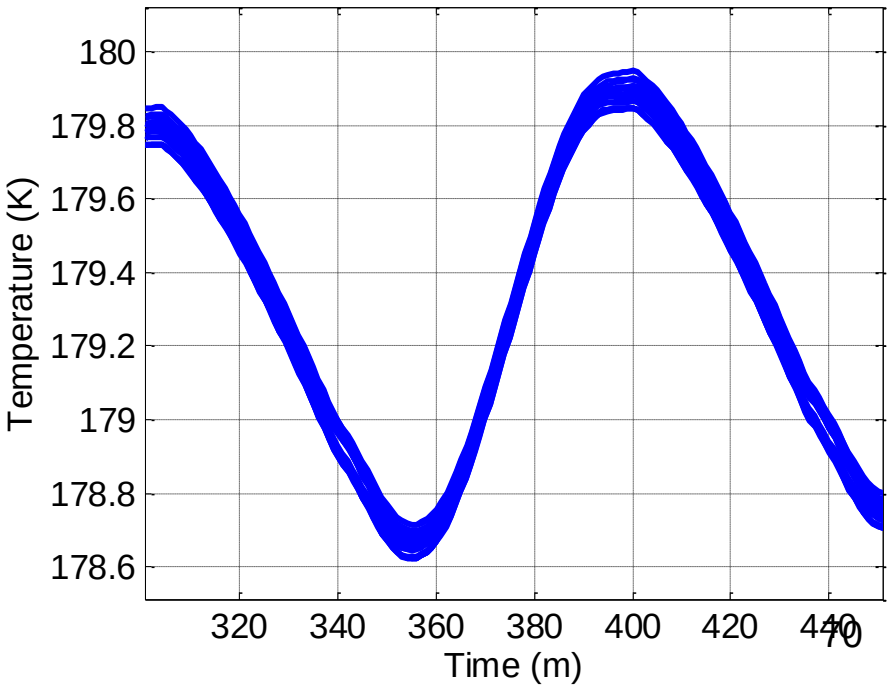
Model results – radiator and spectrometer

- The low-temperature radiator stays under 180 K with no active temperature control

Low-temperature radiator



Spectrometer/Optics



Conclusions / Further work required

- The passive cooler design is feasible with the following key design components
  - High emissivity surface and large area
  - Highly-specular earthshade
  - Low-conductance mounting
  - Multilayer insulation on the internal side of the radiator and the spectrometer housing
- The current model has many assumptions and must be updated as the mission and configuration are better defined
  - Orbit parameters
  - Power, mass and thermal properties for each component
  - Thermal conductance (W/K) of interfaces
- The focal plane mounting is important; the connection between the focal plane (120 K) and the spectrometer (190 K) must be low-conductance
- The temperature control of the spectrometer will require detailed design
  - A requirement for temperature uniformity needs to be developed
  - The spectrometer might need to be somewhat isolated from the low-temperature radiator to reduce the amplitude of the variation
  - 50 mK control is not trivial in a cubesat

CRYOCOOLER STATUS

Dean Johnson

EON-IR Cryocooler System Hardware

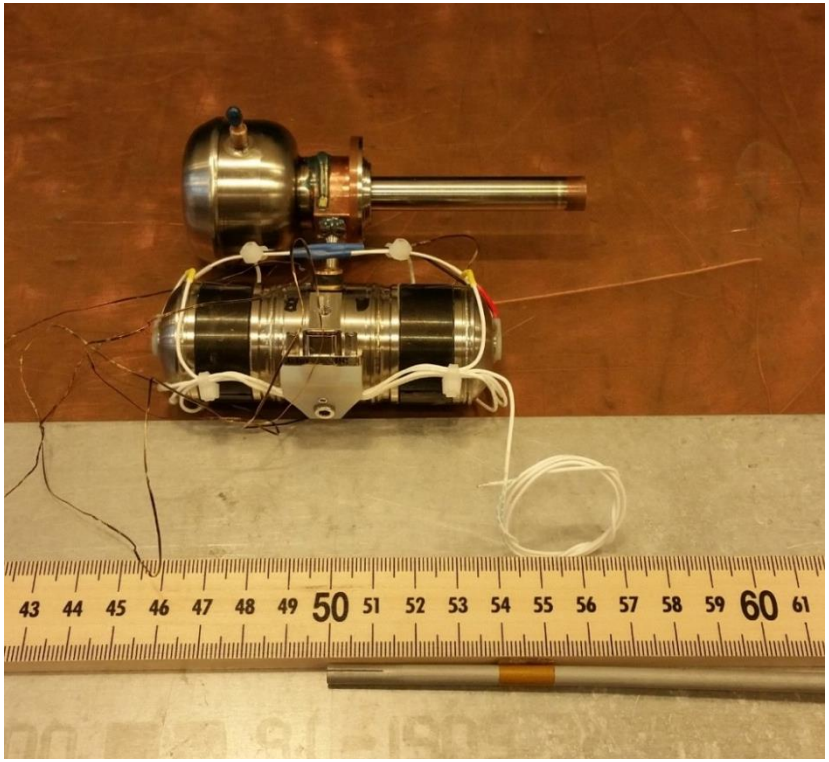
Detector will be cooled to 120K using the Lockheed Martin Standard micro pulse tube cooler and the Thales cooler drive electronics

Cryocooler Activity Highlights

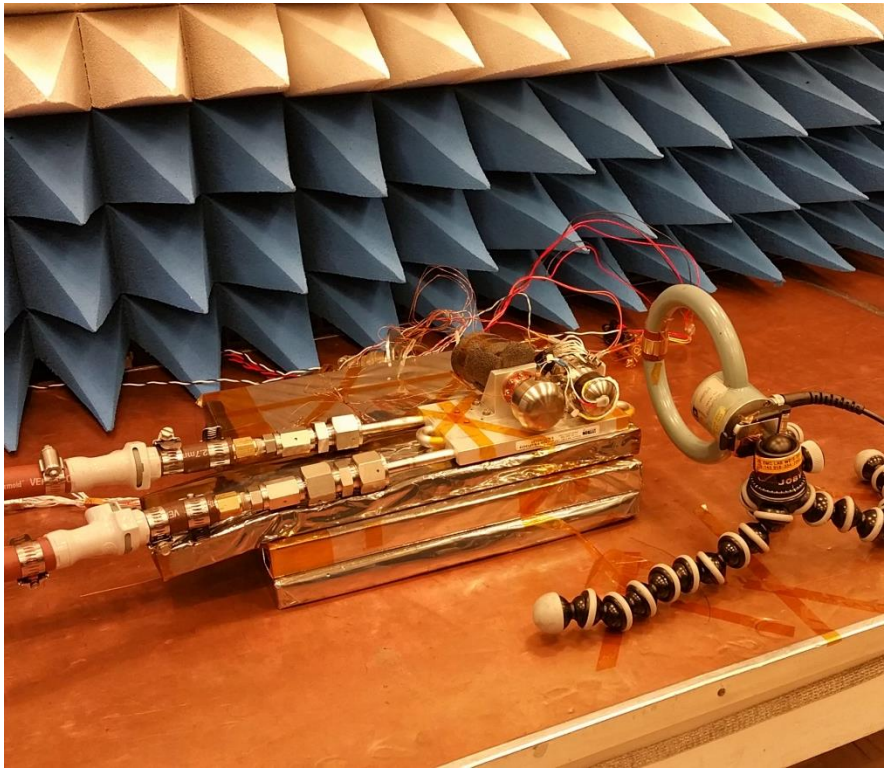
- This cooler was procured on a Matisse program, which gave us the opportunity to characterize the cooler
  - Cost sharing for test activities covered by several programs that plan to use this cooler
- Performed thermal characterization testing in thermal vacuum environment
  - This cooler optimized for 150K; EON-IR cooler will be optimized for 110K to provide additional refrigeration
- Conducted DC and AC magnetics measurements with the Lockheed micro pulse tube cooler
- Measured the exported vibration from cooler with and without vibe control
- Initiated SOW and SSJ in preparation for Lockheed cooler procurement contract; in discussions with Lockheed about details
- Initiated discussions with magnetic materials company regarding magnetic shielding

Electromagnetic Compatibility

- DC magnetic testing in EMC lab at JPL

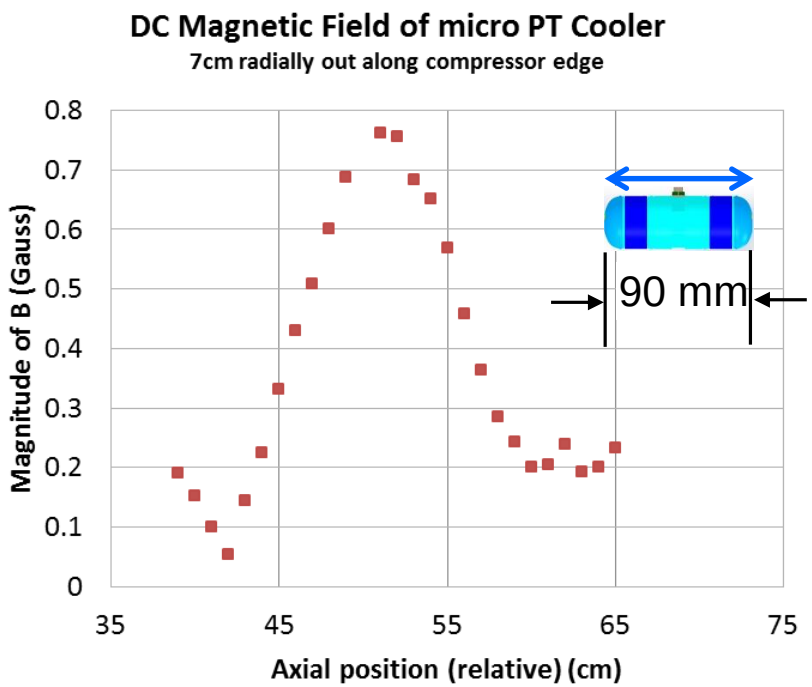


- AC magnetic testing in EMC lab at JPL

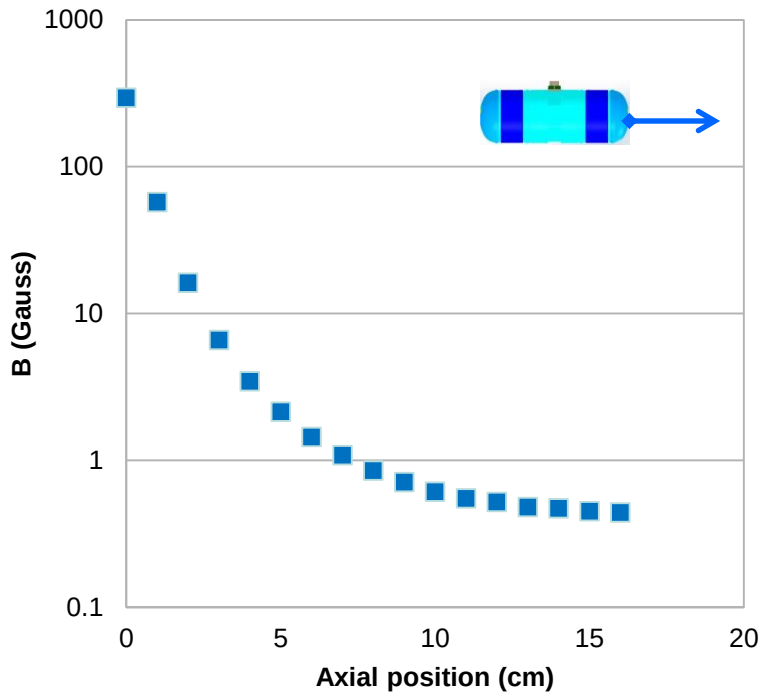


DC Magnetics Test Results

- Magnitude of magnetic field measured along compressor length at 7 cm distance from compressor edge

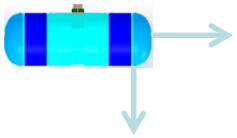


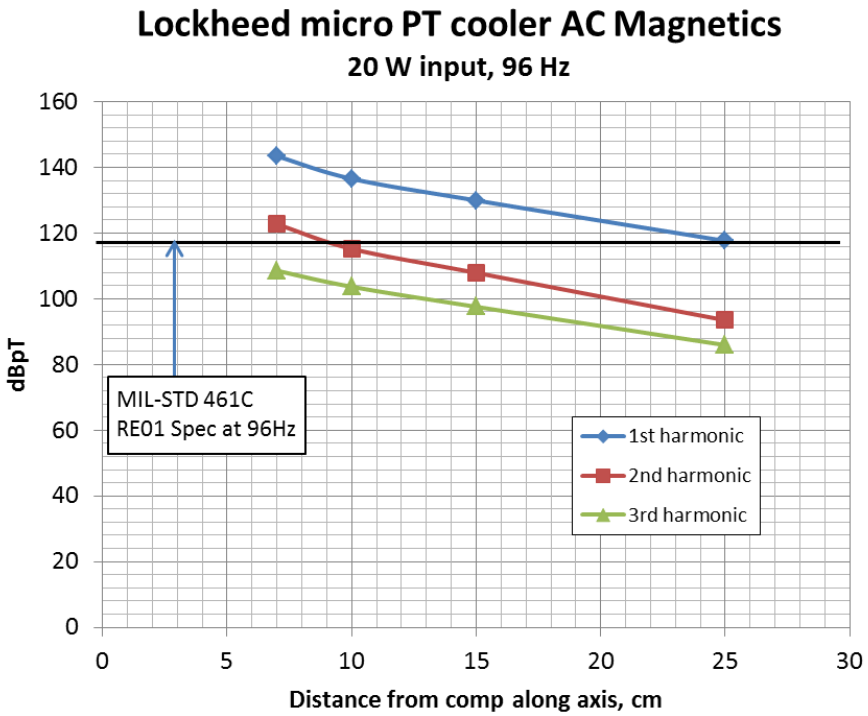
- Magnitude of magnetic field measured from the compressor endcap along compressor axis

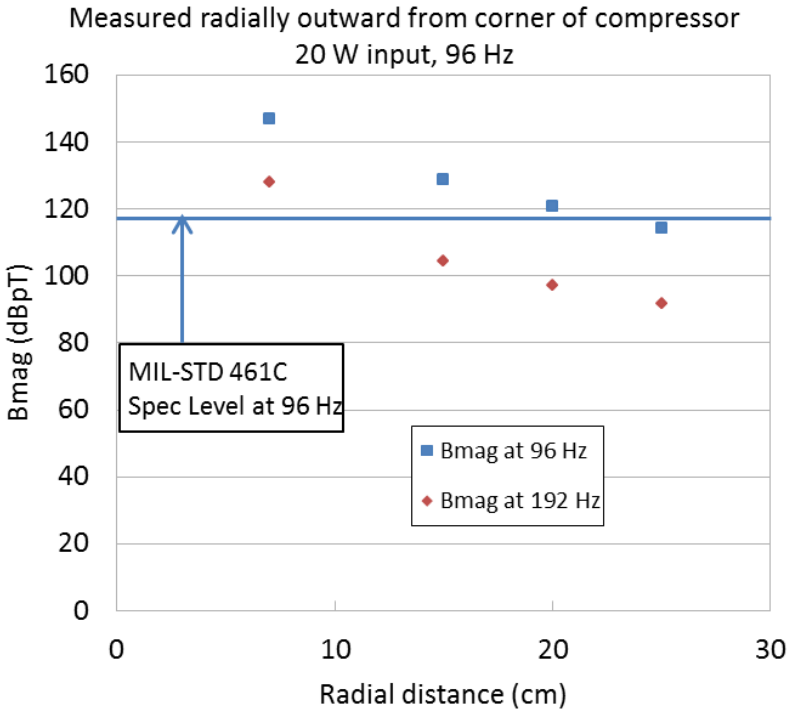


AC Magnetics Test Results

- AC along compressor axis
- AC radially out from side of compressor
- AC at 7cm along side of compressor (not shown)

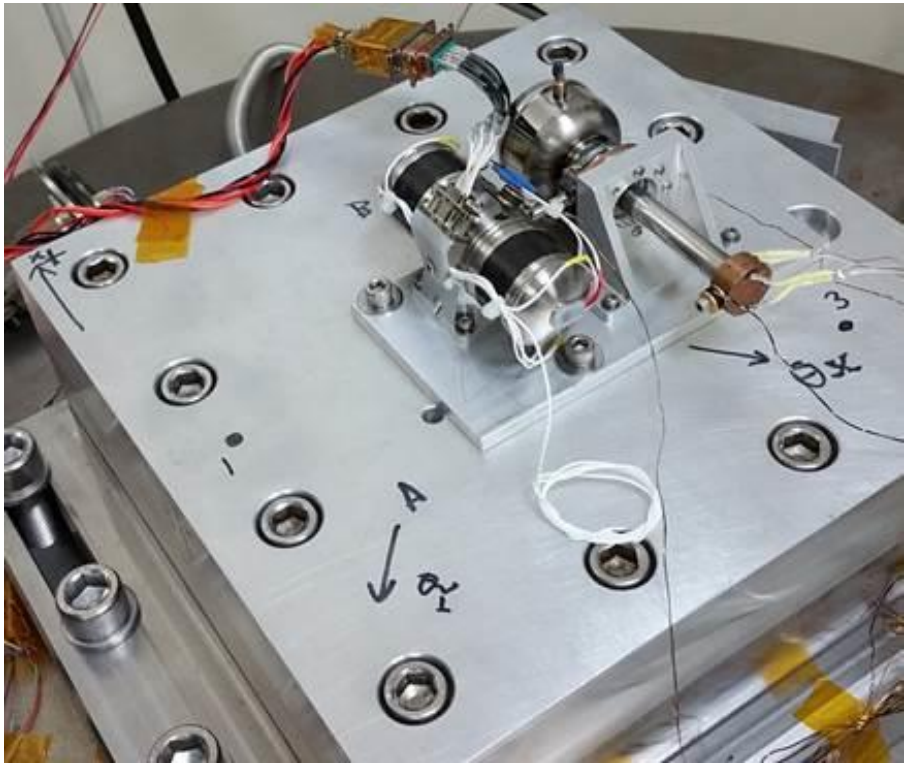






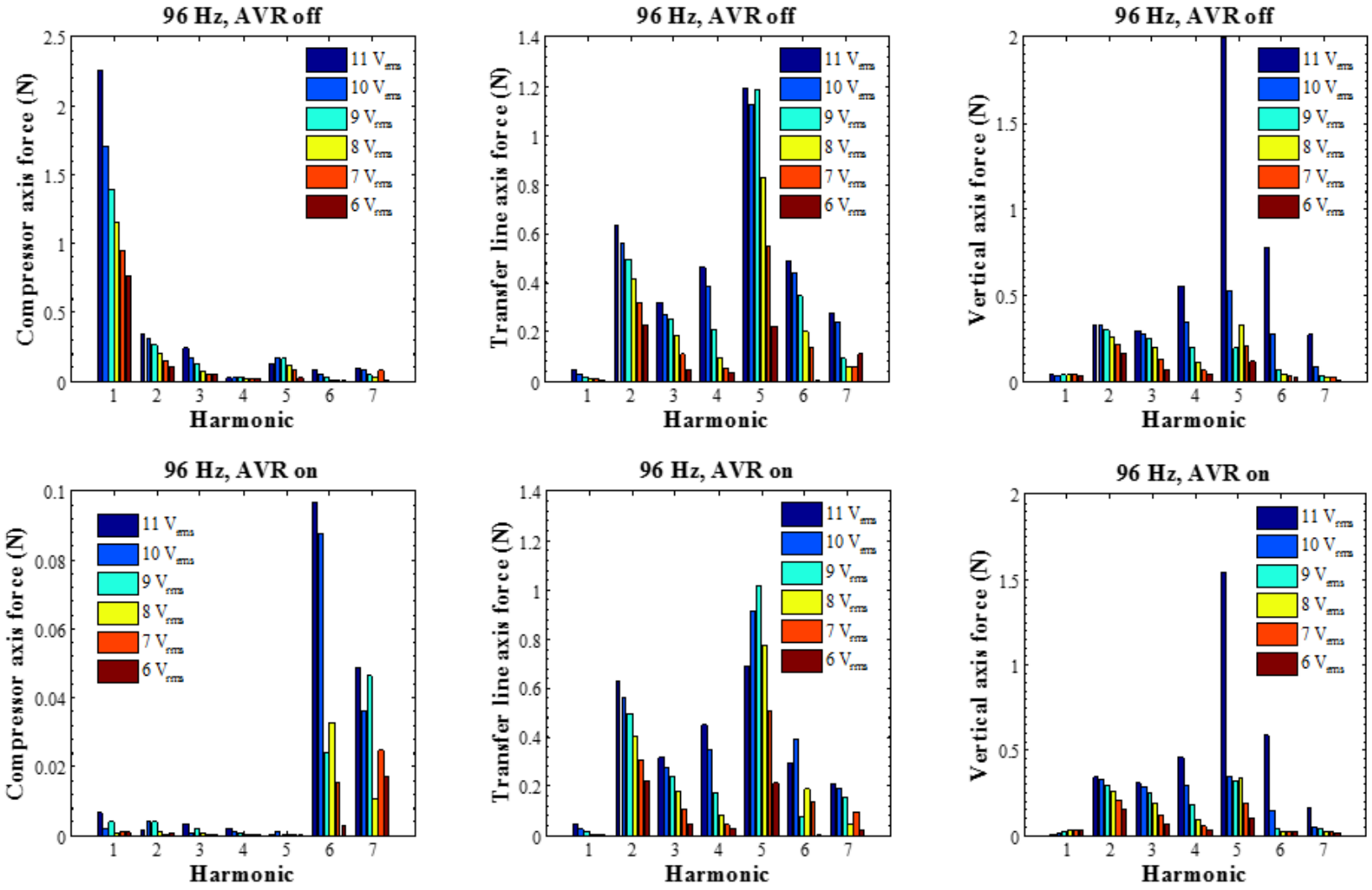
Exported Vibration Testing of the Lockheed micro Pulse Tube Cooler

Thales CDE7232 Cooler Drive Electronics with Auto vibration reduction (5 harmonics)



Thales MPCDE2450 Cooler Drive Electronics

Preliminary Exported Vibration from Cooler



Summary and Conclusions

- A detailed design study was performed for an Advanced Infrared Sounder in a CubeSat configuration: Earth Observation Nanosatellite Infrared (EON-IR)
- The study covered requirements and architecture trades, orbit analysis, systems engineering, scanning, optics, grating design, slit and blackbody material, detector testing, electronics, mechanical and thermal design, and cryocooler testing.
- Results show that a 6U cubesat can perform atmospheric sounding with the same horizontal resolution, coverage, and vertical resolution as the current operational IR sounders.
- EON-IR can be developed in a 26 month period for about $16M
- The EON-IR has the ability to program the spatial resolution to improve yield in critical areas.
- A constellation of EON-IR sounders will improve temporal coverage
- The EON-IR study helped prepare for the NASA CIRAS InVEST development task