Earth Observation NanoSatellite - Infrared (EON-IR) 2016 Study Kickoff

T. Pagano, D. Rider, A. Kummer, A. Andrade, D. Johnson, A. Lamborn

September 21, 2016

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Agenda

9:00	Introductions	
9:15	CIRAS Project Status	Pagano/Rider
10:00	EON-IR Study Plan / Phases	Pagano
10:15	Task 1: Electronics	Kummer
10:45	Task 2: Scanning Reqmts	Pagano
11:15	Task 3: Thermal	Andrade/Johnson
11:45	Task 4: Expanded Channels	Pagano/Lamborn
12:00	Adjourn	

CIRAS Project Status

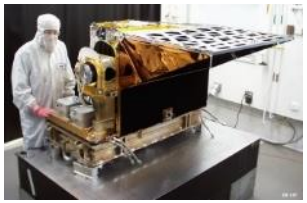
Part 1: Experiment Overview and Measurement

T. Pagano

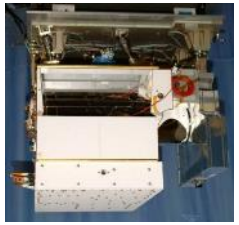
CIRAS Builds on the Success of Legacy Infrared Sounders; Prepares for Future Operational Use

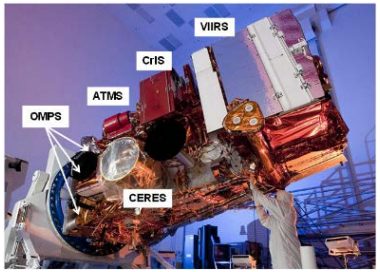
- Atmospheric Infrared Sounder (AIRS)
  - Launched May 4, 2002 on the EOS Aqua Spacecraft
  - Grating Spectrometer, Active Cryocoolers, HgCdTe
  - First to demonstrate high forecast impact from hyperspectral infrared sounders in space
  - Leading Data Set downloaded in Obs4MIPS for CMIP5 to Validate Climate Models
  - AIRS expected to be fully operational beyond 2022
- Crosstrack Infrared Sounder (CrIS)
  - CrIS on NPP and JPSS-1 and JPSS-2
  - Similar Performance to AIRS
- CubeSat Infrared Atmospheric Sounder (CIRAS)
  - NASA ESTO tech. demo. for IR sounding in a CubeSat (~$6M)
  - Meets sounding requirements in the lower troposphere
- Future: Earth Observation Nano-Satellite Infrared (EON-IR)
  - Reduce the cost of operational sounding (~$15M vs ~$200M)
  - Gap mitigation in the event of a loss of CrIS on JPSS
  - Can be used to add satellite soundings at new times
  - Constellation compatible for improved timeliness
  - Possible Extended spectral range to meet upper troposphere and/or atmospheric composition (12U)
  - Operational Quality (>2 year mission life).

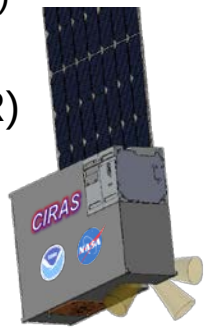
JPL/BAE AIRS



CrIS on JPSS



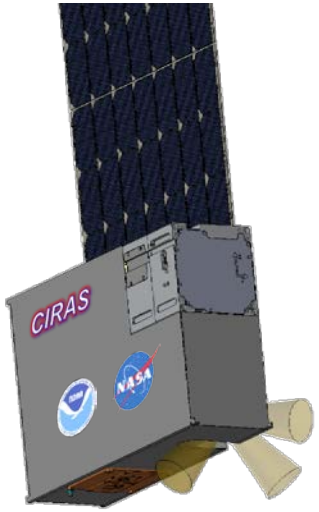




CIRAS Mission Overview

CIRAS is a ***technology demonstration*** mission to enable hyperspectral infrared atmospheric sounding on a CubeSat

- **Mission Objectives**
  - In-Space Technology demonstration for key infrared subsystems: JPL HOT-BIRD IR Detectors, JPL Grism Spectrometer, Black Silicon Blackbody
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Limited to mid to lower troposphere.
  - All technologies will be advanced to TRL 7 at the end of experiment
- **Implementation Summary**
  - 6U CubeSat (approx. 30 x 20 x 10 cm, <14 kg)
  - LEO Sun Synchronous Morning Orbit (400 km – 600km)
  - Minimum Mission Duration: 3 months
  - JPL Payload Development, Ball Optics, Commercial Spacecraft
- **Programmatic Summary**
  - Sponsored by NASA Earth Science Technology Office (ESTO) In-flight Validation of Earth Science Technologies (InVEST) Program, Awarded 2015
  - Design performed in collaboration with the NOAA Office of Projects, Planning, and Analysis (OPPA)
  - Selected on 2/18/16 for a launch opportunity by the NASA CubeSat Launch Initiative . Launch No Earlier Than June 2018.



CIRAS is Subset of Legacy Sounders Focus on MWIR for Temp, H2O in Lower Trop

	AIRS	IASI	CrIS	CIRAS	EON-IR
Spatial					
Orbit Altitude	705 km	817 km	824 km	600 km	600 km
Scan Range	±49.5°	±48.3°	±48.3°	±7.02°, ±49.6°	±49.6°
Spatial Resolution	13.5 km	12 km	14 km	3 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}	0.9 cm^{-1}	1.3-2.0 cm^{-1}	1.3-2.0 cm^{-1} MW 0.4-0.7cm^{-1}LW
0.4 - 1.0 µm	4	n/a	n/a	n/a	n/a
1.0 - 3.0 µm	n/a	n/a	n/a	n/a	n/a
3.0 - 5.2 µm	3.7-4.6 µm (514)	3.6-5.2 µm (3348)	3.9-4.6 µm (632)	4.08-5.13 µm (625)	4.08-5.13 µm (625)
5.2 - 8.2 µm	6.2-8.2 µm (602)	5.2-8.2 µm (2814)	5.7-8.2 µm (864)	n/a	n/a
8.2 - 12.5 µm	8.8-12.7 µm (821)	8.2-12.5 µm (1678)	9.1-12.0 µm (472)	n/a	8.0-11.6 µm (2000)
12.5 - 15.5 µm	12.7-15.4 µm (441)	12.5-15.5 µm (620)	12.0-15.4 µm (240)	n/a	n/a
Total Channels	2382	8460	2208	625	2625
Radiometric					
NEdT @ 250K	0.07-0.7K	0.25-0.5K	0.1-1.0K	< 0.2K	<0.2K
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	0.1 x 0.2 x 0.3 m^3	0.2 x 0.2 x 0.3 m^3
Mass	177 kg	236 kg	165 kg	14 kg	<50 kg
Power	256 W	210 W	117 W	40 W	180 W
Max Data Rate	1.3 Mbps	1.5 Mbps	1.5 Mbps	0.32 Mbps	TBD Mbps

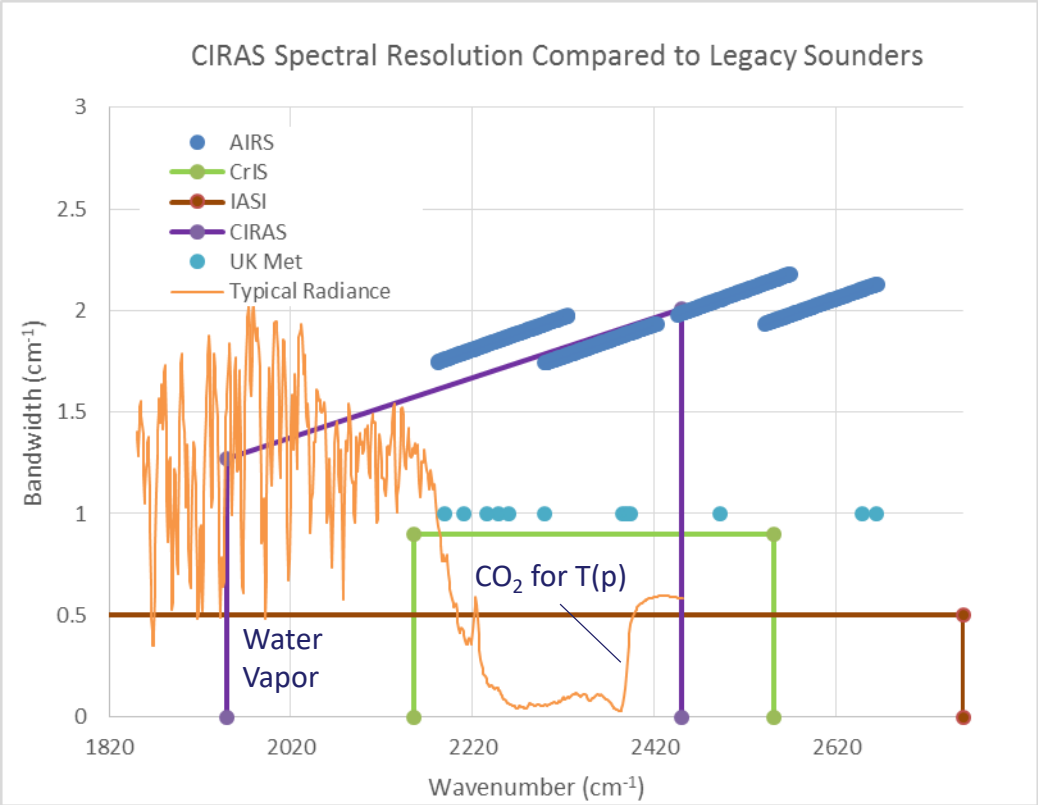
CIRAS Spectral performance comparable to AIRS in MWIR

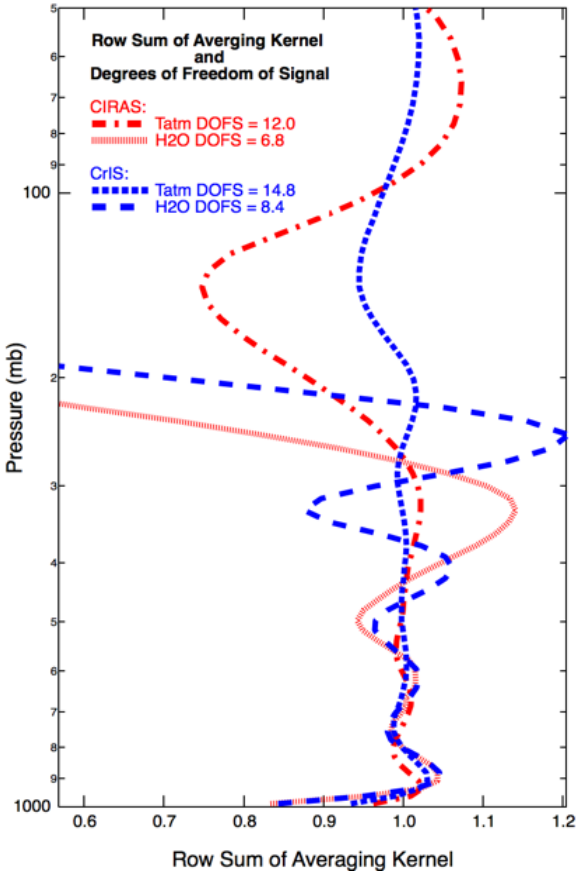
CIRAS Spectral like AIRS but Extends into Water Band

$1950\ cm^{-1} – 2450\ cm^{-1}$

$\Delta v = 1.6\ cm^{-1}$, $N_{ch} = 625$

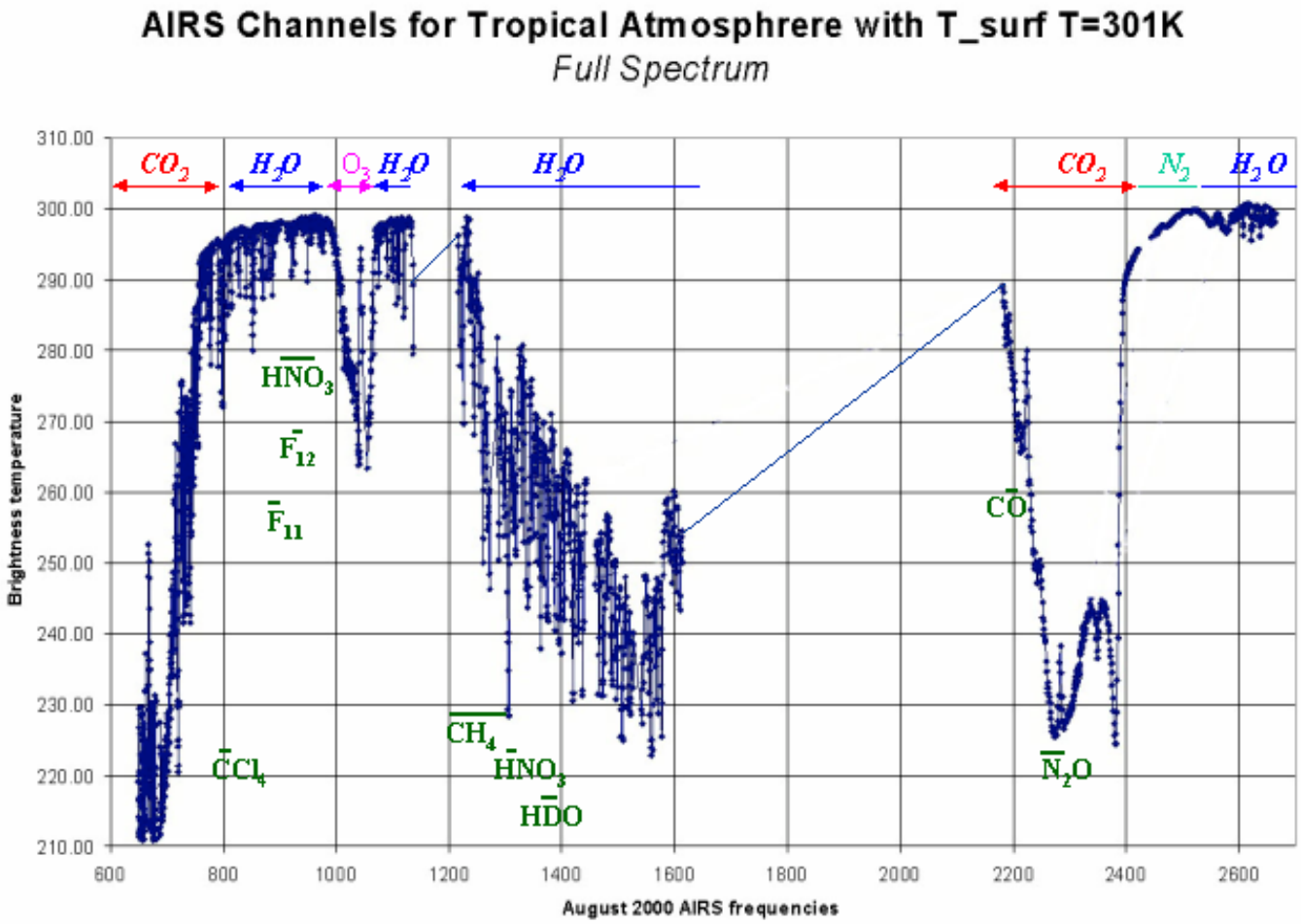
CIRAS Information Content Extends from Surface to >300 mb





Bill Irion (JPL)

AIRS Spectrum



CIRAS Band Sees Several Trace Gas Species

CIRAS Band: N2, CO2, N2O, CO, O3, H2O

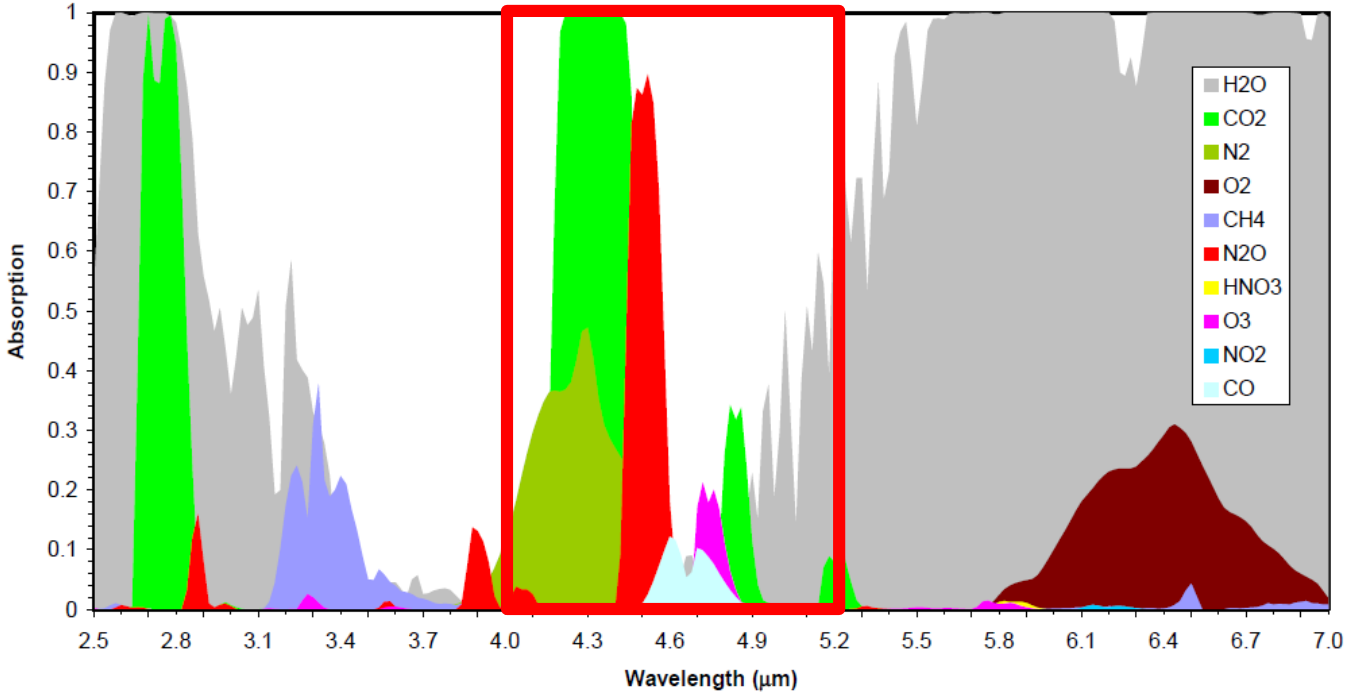
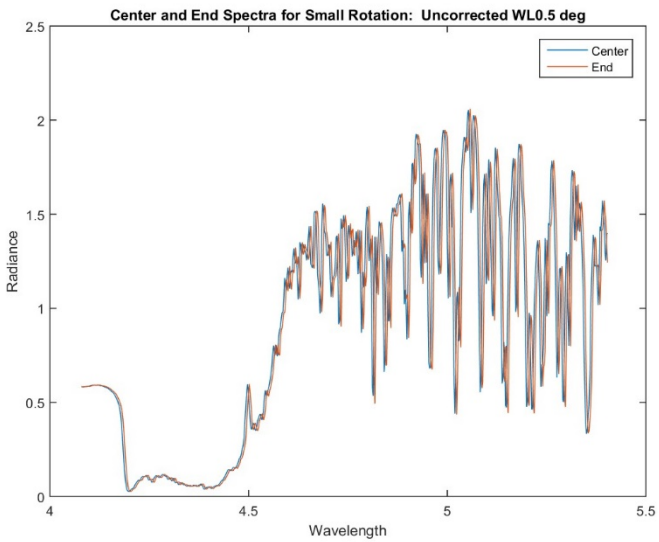


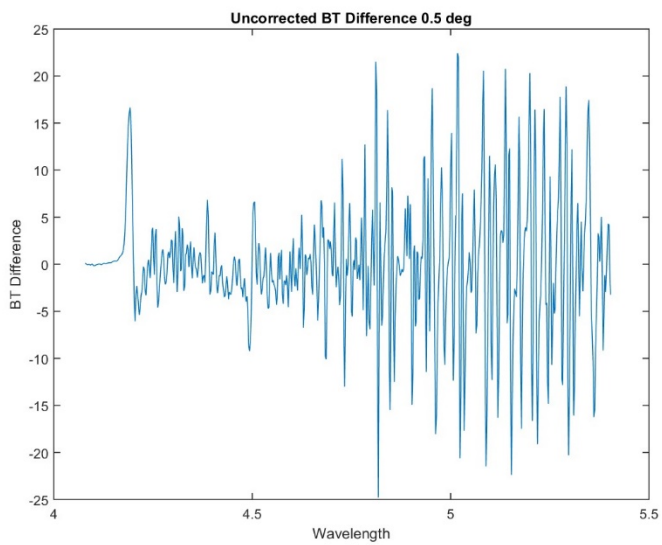
Figure 2. Plots of the nominal ambient atmospheric absorption for 10 molecular species that exhibit absorption features in the MWIR.

Griffin, 2004

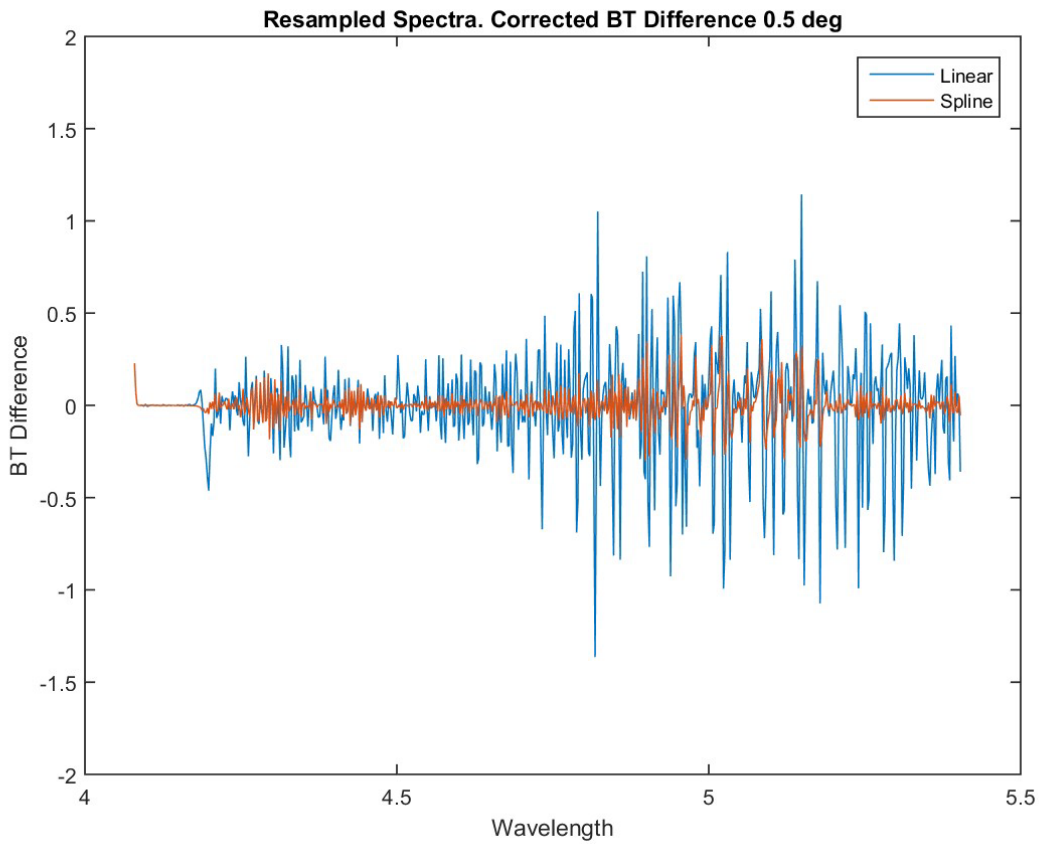
Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery X, edited by Sylvia S. Shen, Paul E. Lewis, Proceedings of SPIE Vol. 5425 (SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.543526

Resampling Errors Expected to Be <200 mK



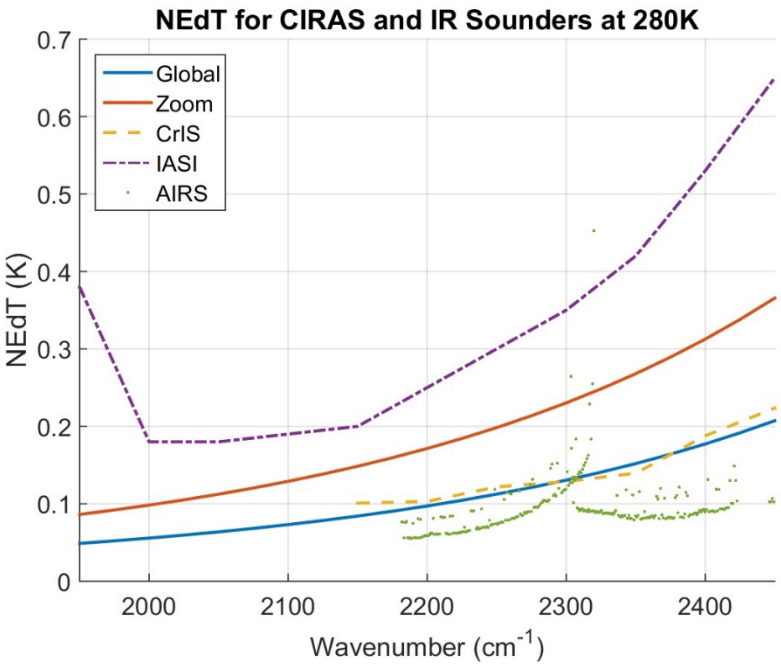


- Convolved LBL spectra with CIRAS PSF
- Projected spectrum onto FPA grid
- Rotated FPA
- Resampled spectrum to common grid
- Residual errors calculated at Tsc

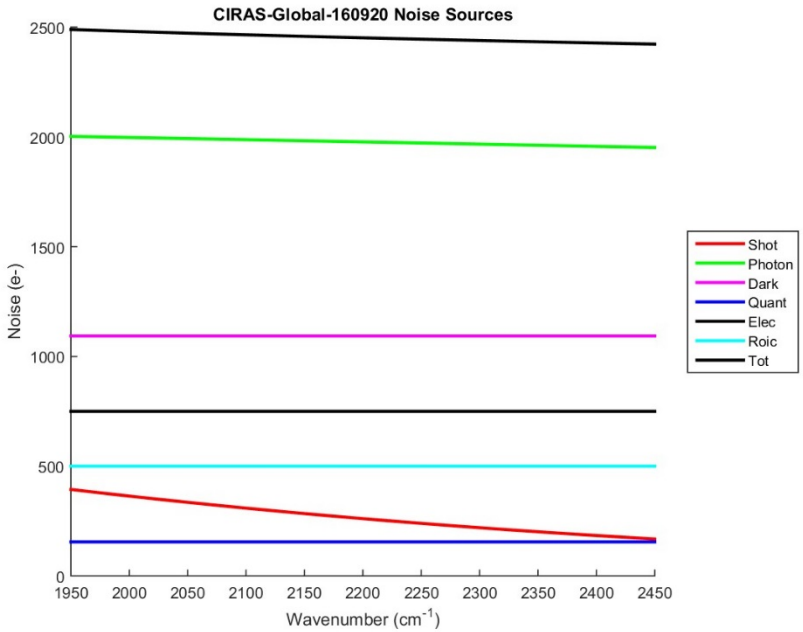


CIRAS Radiometric Sensitivity (NEdT) Comparable to Legacy Sounders

CIRAS & Legacy Sounders NEdT



CIRAS Noise Sources



CIRAS Project Status

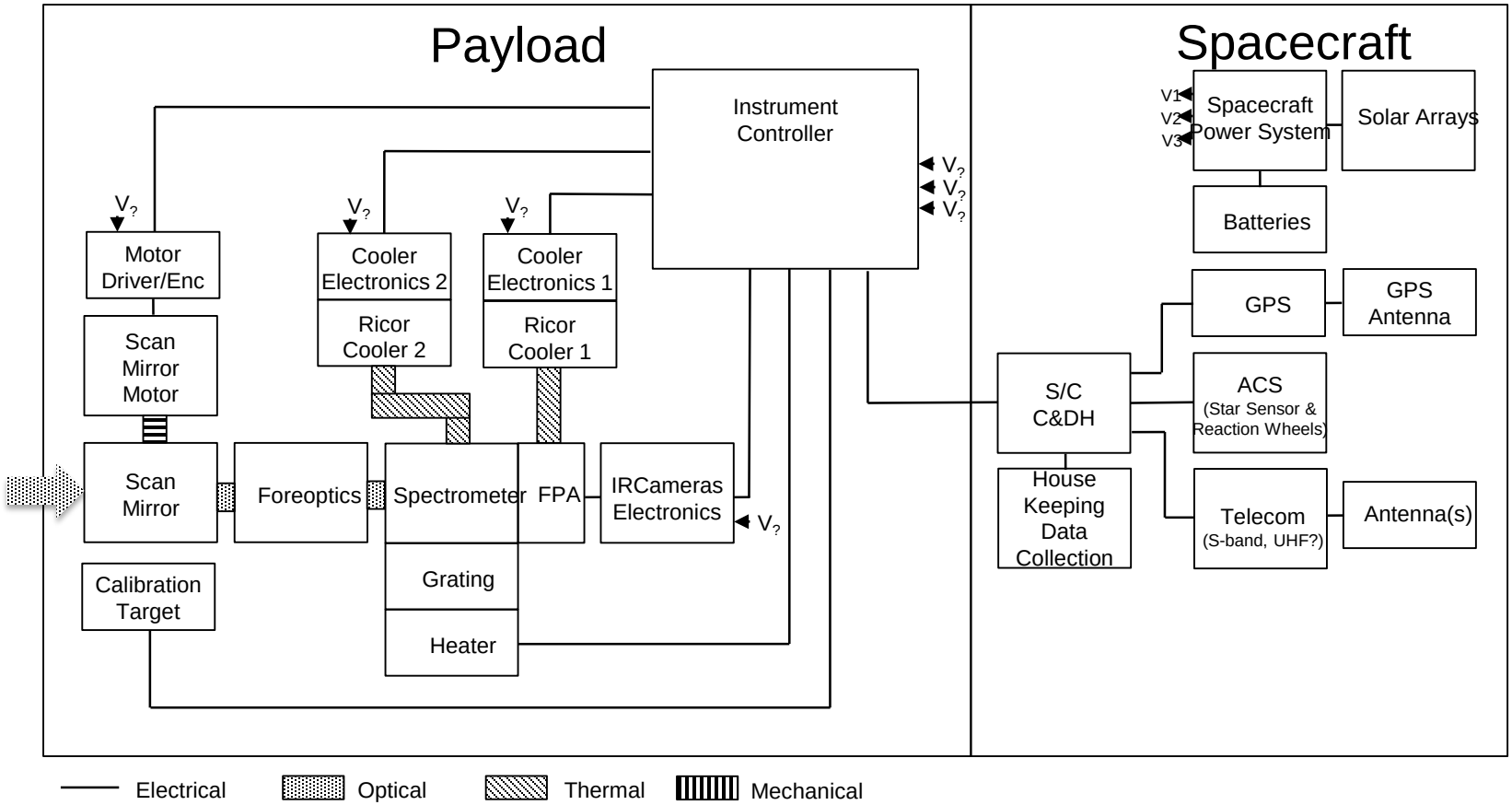
Part 2: Design Status

D. Rider

Jet Propulsion Laboratory
California Institute of Technology

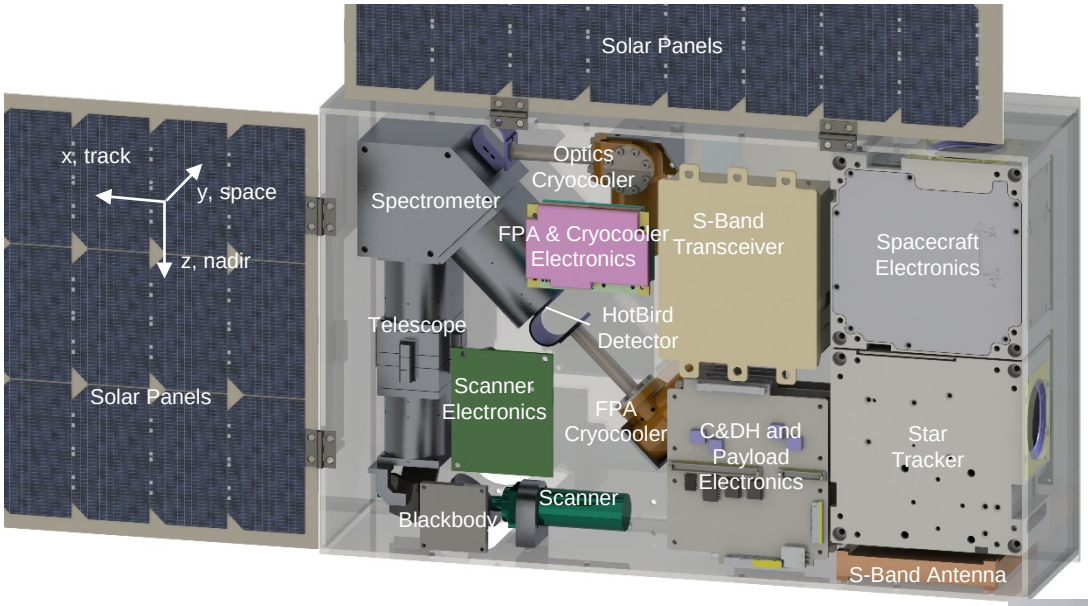
CIRAS Block Diagram

V0.1, 6/30/16

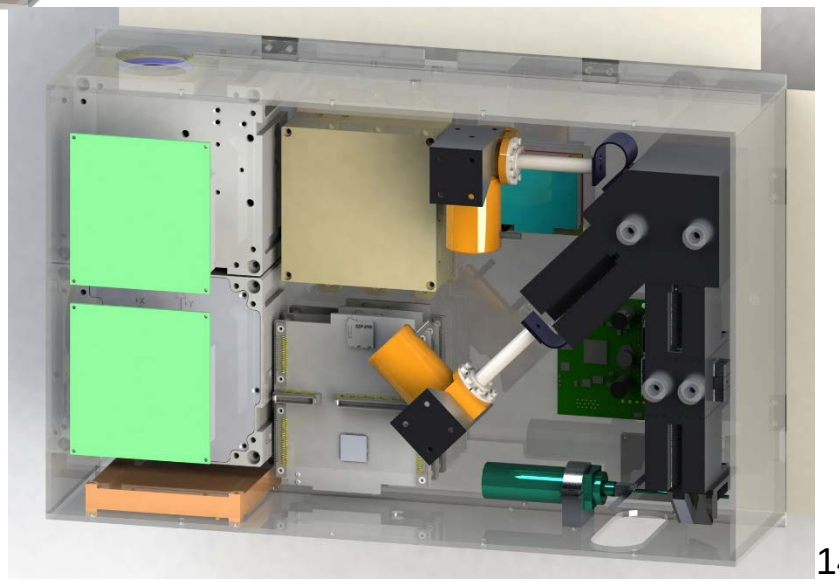


CIRAS Layout Version 0

Front View



Back View



CIRAS Status
9/21/16

- NASA ESTO Funds on contract in June, 2016
  - Most of the effort in the last few months have focused on building a team and developing requirements
- Spectrometer
  - Study/Design contract with Ball Aerospace is in place
  - A preliminary optical design is nearly complete
  - Transition final design and build phase in early 2017
- Blue Canyon Technology is selected just this week as the spacecraft contractor
  - Will have a contract in place by the end of the year
- Selected the JPL Sphinx CubeSat flight computer for the instrument controller and C&DH
  - An engineering model was developed and tested with internal JPL funds.
- IR Cameras is on contract to provide Focal Plane Assembly (FPA) control and interface to the instrument controller and to help develop the FPA to spectrometer opto-mechanical interface and FPA thermal control
- Received read out integrated circuits for the FPA.
  - Detector material growth will be started this fall.

EON-IR Task 1

A. Kummer

EON-IR Study 2016: Task 1

Task 1: Mission Reliability Improvement

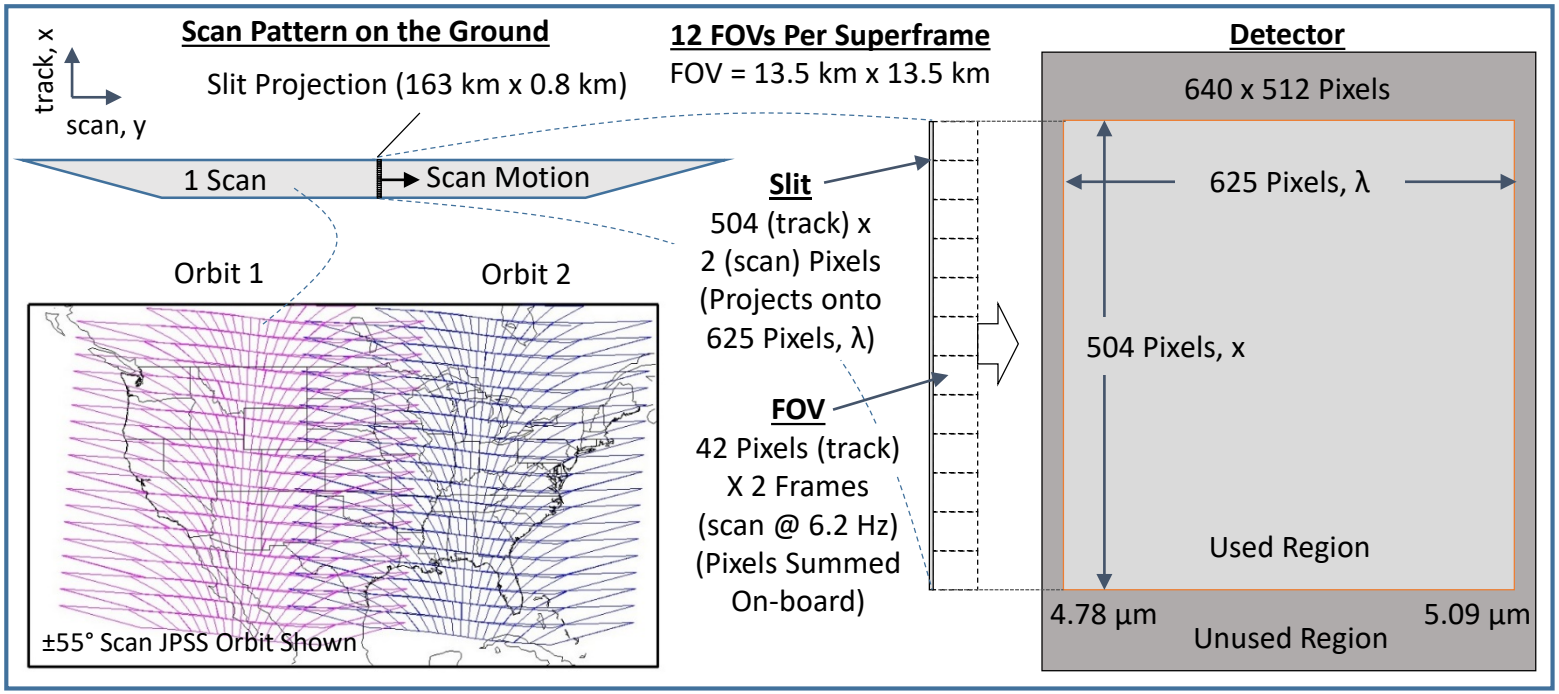
- Improve the design of EON-IR to increase reliability commensurate with a mission of two years in length or longer. This task will examine the reliability and mission assurance of the EON-IR and its subsystems, primarily electronic, including the spacecraft.

An EON-IR Study of 2015 [2] concluded with identification of the key and driving requirements, an electronics block diagram for the payload, a description of the FPGA design, and identification of the pin-out interface requirements of the spacecraft.

For Task 1, JPL will do the following

- Review the preliminary design of the MWIR portion of the EON-IR presented in 2015. The design included extensive use of commercial hardware with limited custom circuitry.
- Perform a detailed design of the EON-IR payload electronics subsystem maximizing the use of COTs electronics to reduce instrument cost. Identify commercial and custom circuit boards, interfaces, rates, and overall functionality and anticipated performance.
- Perform tests on commercial and custom electronics (to be loaned by the CIRAS project) to measure performance and interface capabilities to confirm viability of the design.
- Perform a first order assessment of the reliability of the EON-IR payload. This will include identification of high risk parts and subsystems and areas of unknown reliability. This will include reliability of full scan capability. It will also recommend tests to be performed during an EON-IR build to determine reliability of commercial subsystems.
- Contact a candidate 6U spacecraft vendor to identify lifetime limitations on the spacecraft in terms of a 2 year or longer project, and their recommendations for extending life of the system.

Modest Processing Requirements



EON-IR Task 2

T. Pagano

EON-IR Study 2016: Task 2

Task 2. Full Swath Scanning Study

- This task will explore the ability to scan the EON-IR to achieve full swath as currently obtained from the operational sounders. Model the scanning mechanism and impacts on the sensor collection as well as the dwell times.

The EON-IR Study of 2015 included definition of the scan rate and coverage requirements and concluded that a commercial encoder and drive electronics can meet the requirements of the EON-IR.

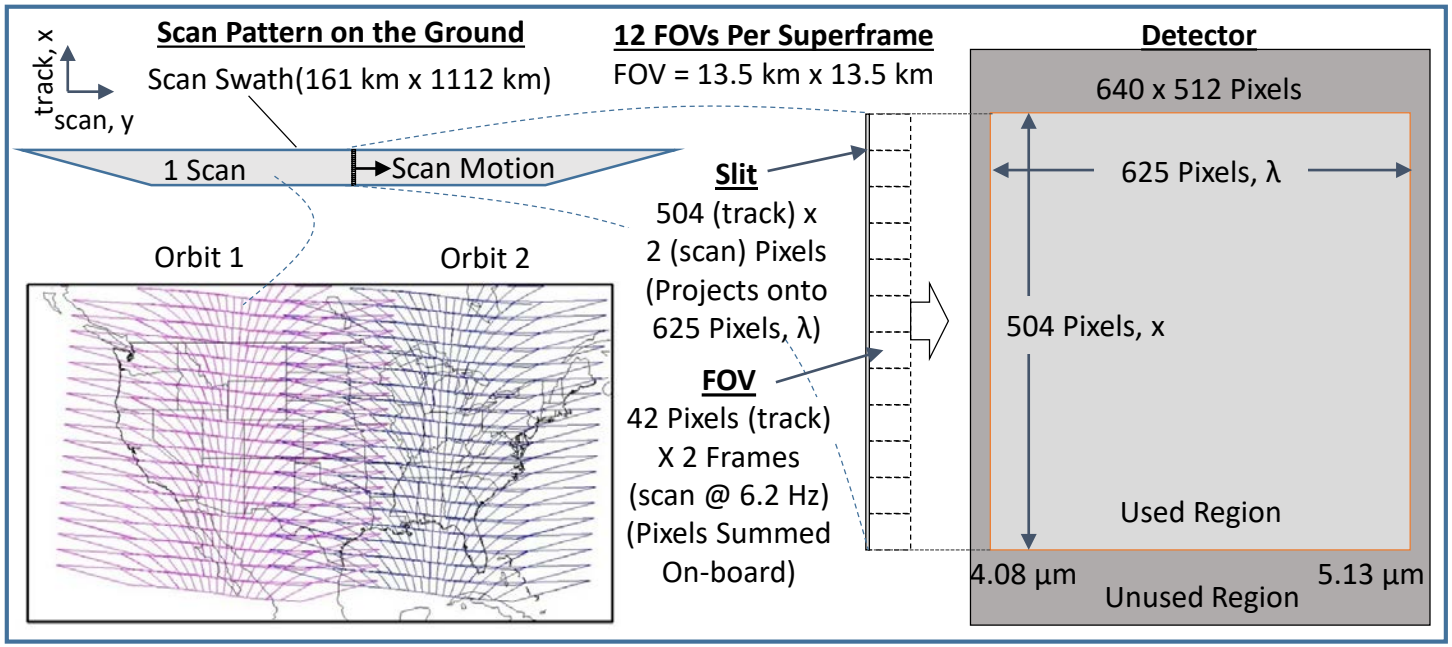
For Task 2, JPL will do the following

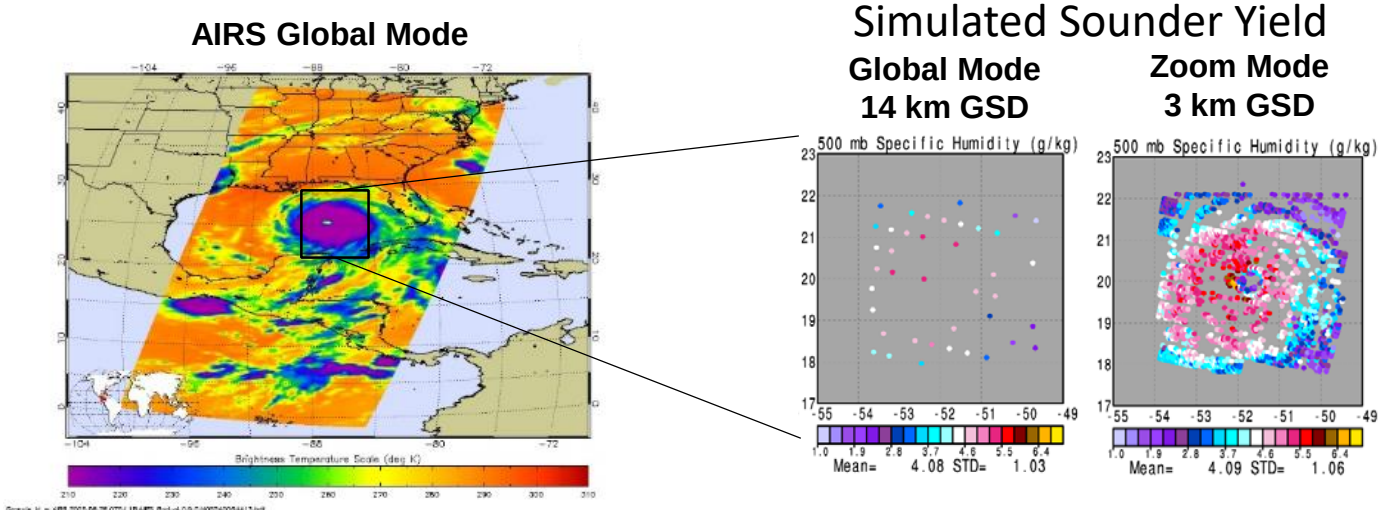
- Review the scan rate requirements and selection of commercial hardware defined in the EON-IR 2015 study. Modify as needed to account for orbit flexibility and footprint size control.
- Design the end-to-end scan system including motor/encoder, scan controller, and software necessary to perform EON-IR scanning to meet requirements
- Perform tests on commercial parts (if available from CIRAS project) to measure performance and interface capabilities to confirm viability of the design.

CIRAS Spatial Requirements comparable to AIRS, CrIS + Zoom

- Programmable Pixel Binning and Scan Rate Allow Global and Zoom Modes

CIRAS Binning Scheme (600 km Orbit)





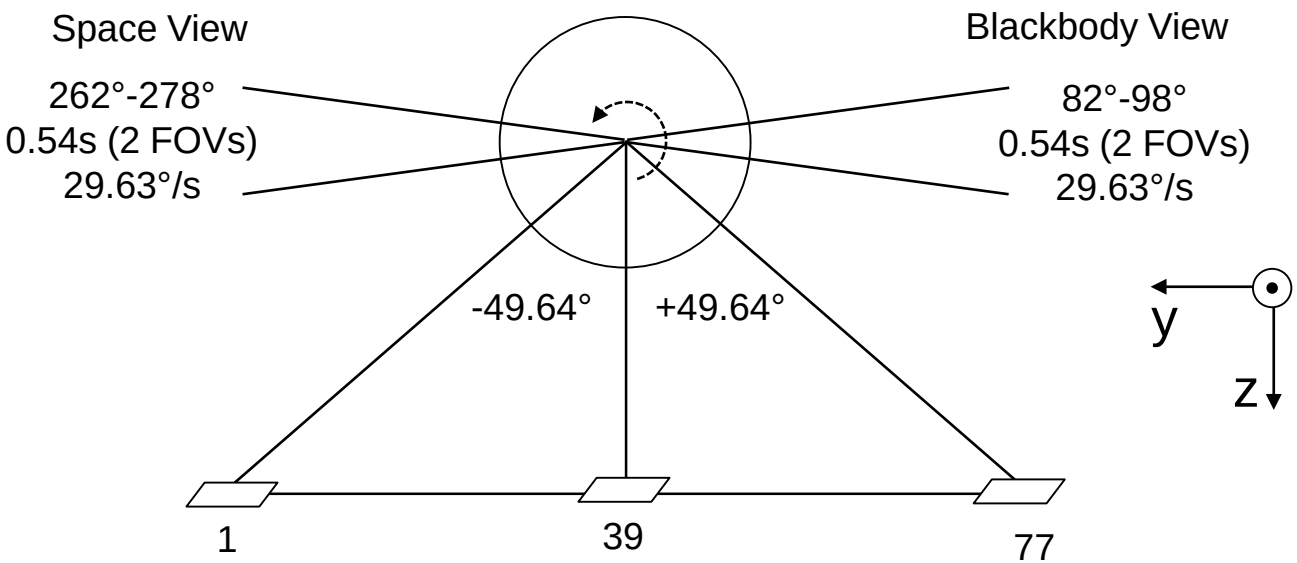
Susskind (GSFC)

CIRAS/EON-IR-MW Global Mode
600 km Orbit, 13.5 km GSD

Total Available Time: 23.10s

Transition*

228.73°, 1.23s, 185.95°/s



Earth View

1520 km, 99.28°, 20.79s, 4.77°/s

*Transition time for contiguous swaths along track
Longer times possible with associated gap in coverage

CIRAS/EON-IR-MW Zoom Mode (Goal)
600 km Orbit, 3 km GSD

Total Available Time: 23.10s

Transition*

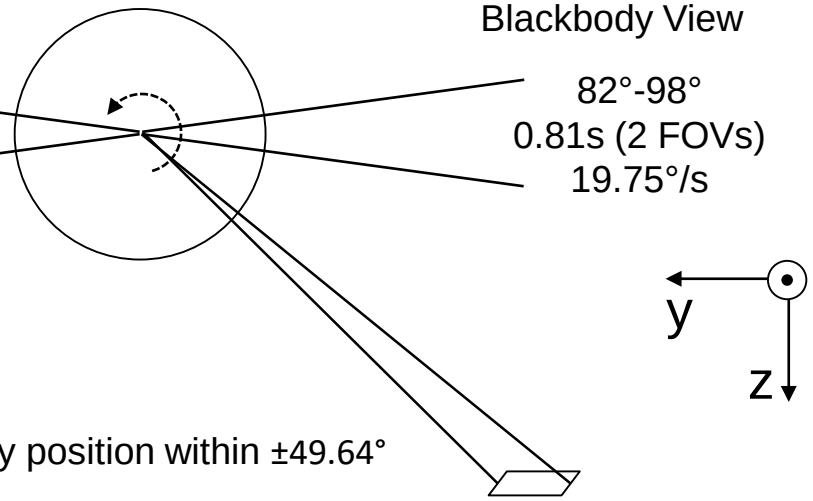
313.96°, 1.64s, 191.44°/s

Space View

262°-278°
0.81s (2 FOVs)
19.75°/s

Blackbody View

82°-98°
0.81s (2 FOVs)
19.75°/s



Any position within ±49.64°

1-49

Earth View

148 km, 7.02°, 19.84s, 0.707°/s

*Transition time for contiguous swaths along track
Longer times possible with associated gap in coverage

CIRAS/EON-IR-MW Preliminary Scanning Requirements Defined

Scanning	Global: 13.5 km	Zoom: 3 km
Scan Eff	0.9	0.859
Swath trk (km)	161	161
Swath xtrk (deg)	49.6	7.02
Swath xtrk (km)	1.52e+03	148
N_Pixels xtrk	77	49
Time in Earth View (s)	20.8	19.8
Scan Rate in Earth View (r/s)	0.0833	0.0123
Number of Calibrators	2	2
Time on each Cal Views (s)	0.54	0.81
FOV of On-board Cals (deg)	16	16
Scan Rate in Cal View (r/s)	0.517	0.345
Time in Transition (s)	1.23	1.64
Scan Rate in Transition (r/s)	3.25	3.34
Tdwell (s)	0.27	0.405
Integr. Time (s)	0.135	0.135

EON-IR Task 3

A. Andrade, D. Johnson

EON-IR Study 2016: Task 3

Task 3. Improve the MWIR portion of EON-IR Thermal/Mechanical Design

- Improve the EON-IR thermal/mechanical design. Model designs for a Focal Plane Assembly (FPA) mount and cold shield/filter for EON-IR with sufficient fidelity to estimate total photon flux at the detector for accurate predictions of noise performance, and estimate total thermal load at the detector cryocooler cold finger. Provide a better estimate of the amount of heat needed to dissipate by the cryocoolers and radiators.

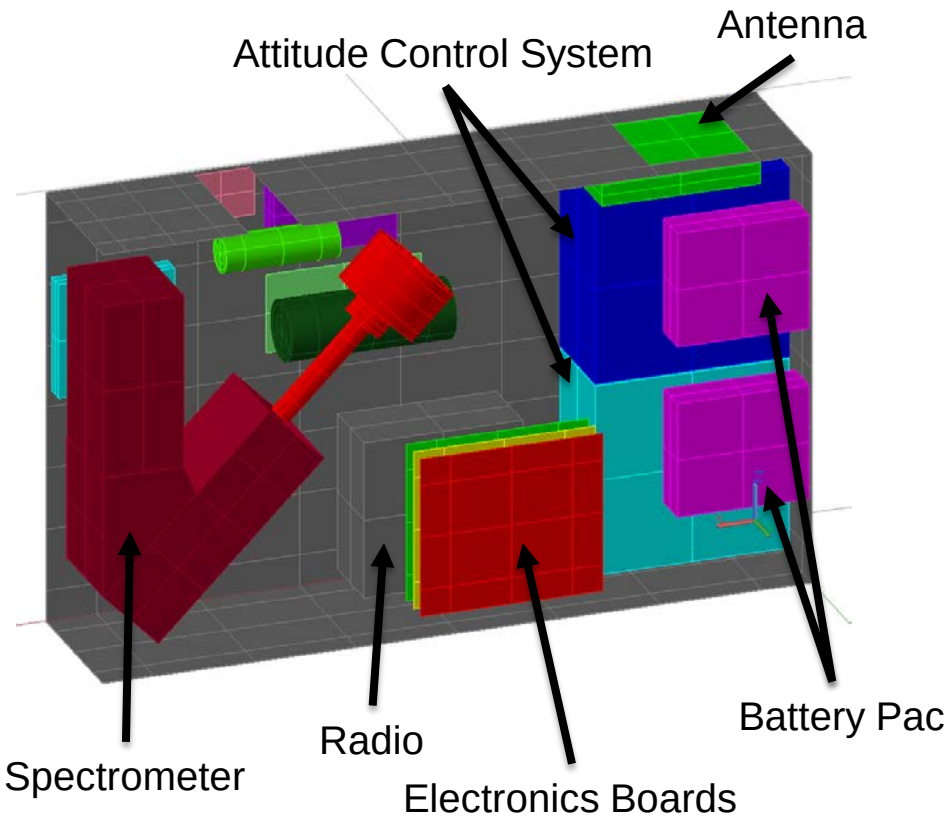
The EON-IR study of 2015 did not examine the thermal and radiant photon flux loads at the detector. Sufficient uncertainty exist in the design in this area that could lead to increases in cooling requirements and a corresponding increase in required power and radiator surface area.

For Task 3, JPL will do the following

- Design the FPA mount, cold shield/filter and dewar design for the EON-IR
- Develop a radiant loads model of the optical system to estimate the photon flux at the detector and cold finger
- Develop a thermal model of the EON-IR opto-mechanical assembly to estimate thermal conductive and radiant loads on the optics. Estimate optics cryocooler requirements
- Develop a thermal model of the EON-IR dewar assembly system to estimate the thermal loads on the cold finger. Estimate detector cryocooler requirements.
- Estimate total thermal loads on the system and design a heat transfer approach and radiators suitable in size and location for dissipating all required heat from the system at any sun synchronous orbit.

CIRAS Preliminary Thermal Model

- Cullimore and Ring Technologies' Thermal Desktop.
- Thermal Desktop runs as an AutoCAD application.
- Thermal Desktop's integrated RadCAD module calculates radiation exchange factors and orbital heating rates which then are combined to form the inputs for SINDA/FLUINT, C&R Tech's thermal/fluid analyzer.



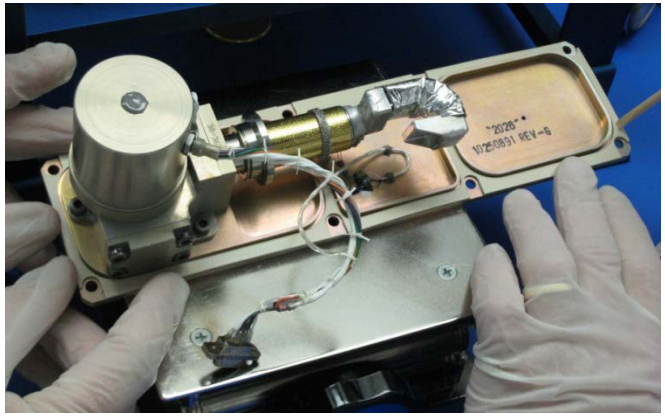
Cryocooler Options for EON-IR

- Investigating use of an Integrated Dewar Cryocooler Assembly to minimize contamination potential of focal plane
- CIRAS, with limited funds, elected to pursue the Ricor K508 rotary Stirling cooler – one for 120K focal plane, and one for 190K spectrometer optics
  - Rotary Stirling; fixed stroke with variable drive frequency to meet load demand
  - Efficient thermal performance
  - Flight heritage
  - Limited life (8,500 – 12,000 hour MTTF) or 1 to 1.5 years
- EON-IR would use one cooler for focal plane, and a passive cooler for the spectrometer
  - Pulse tube cooler; fixed frequency and variable stroke to meet load demand
  - With 2+ year operation life, we will seek to use miniature pulse tube cooler from Lockheed Martin (TRL 6)
  - Lockheed high power micro cryocooler selected for **EUROPA/MISE**
  - Reliable: larger coolers in space with over 14 years life without performance degradation

Cryocooler Options for EON-IR

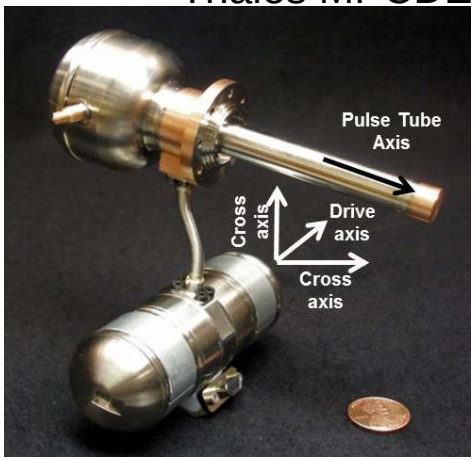
CIRAS

- Ricor K508 amenable to IDCA
- Mass: 450 gms
- Photos below from MSL/CheMin

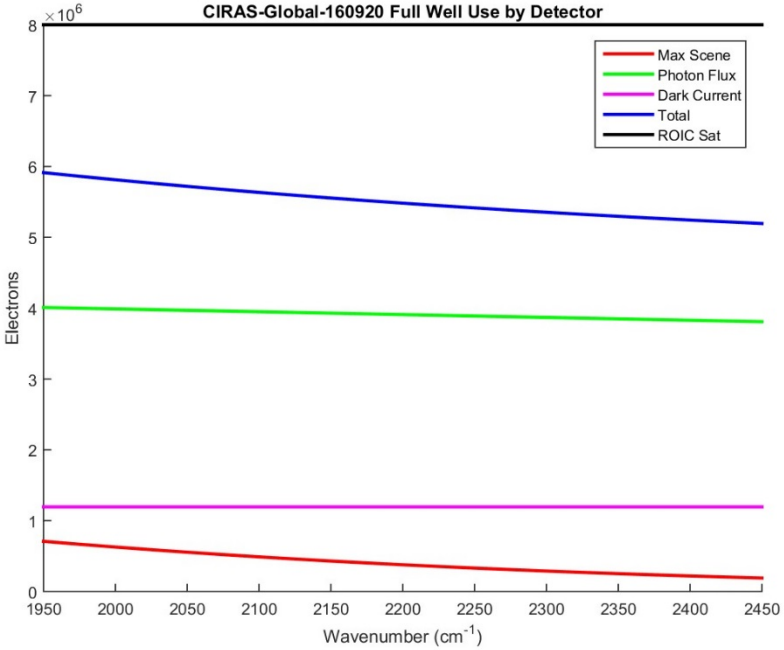


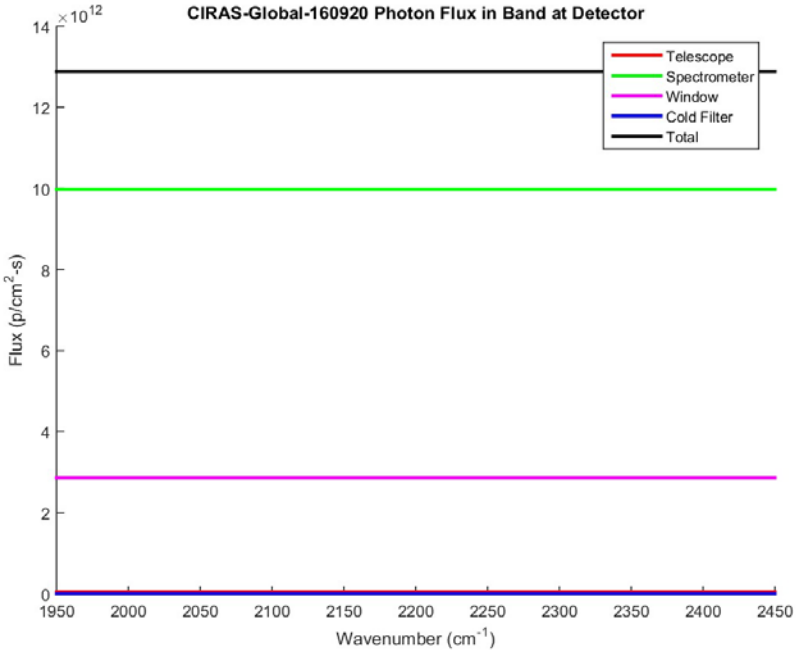
EON-IR

- Lockheed microcoolers amenable to IDCA
  - "Standard" 20W micro pulse tube cooler; mass:~350 gms
  - High power 60W micro pulse tube cooler; mass:~450 gms
  - JPL evaluating both units
- Drive electronics options:
  - Iris Technology 35W mini LCCE or
  - Thales MPCDE 2450



CIRAS Photon Flux Dominates Full Well Use





Driven by spectrometer temperature

EON-IR Task 4

T. Pagano / A. Lamborn

EON-IR Study 2016: Task 4

Task 4. Expand the EON-IR Channel Capability

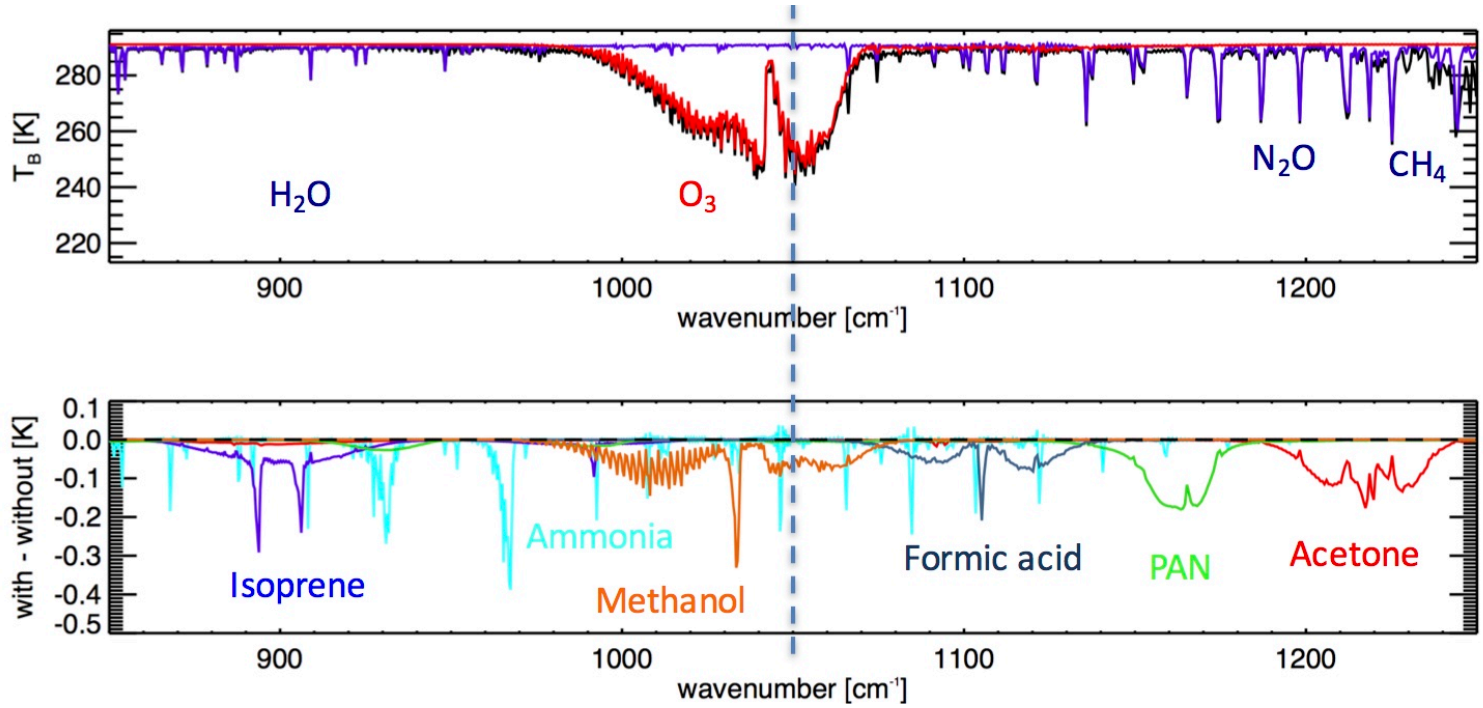
- Identify drivers and limitations to expand the EON-IR pathfinder channel capability to the Crosstrack Infrared Sounder (CrIS) sensor capabilities. The objective is to determine if there are viable options to expand EON-IR beyond the Mid-wavelength Infrared (MWIR) to include Long-wavelength Infrared (LWIR). This task should look at thermal impacts as well and also possible increase in CubeSat size to accommodate additional capability.

The EON-IR Study of 2015 did not include a design for the LWIR spectrometer. However, a prior study for NOAA in 2013 by JPL for a larger more capable sounding instrument included a design for the LWIR spectrometer [3].

For Task 4, JPL will do the following

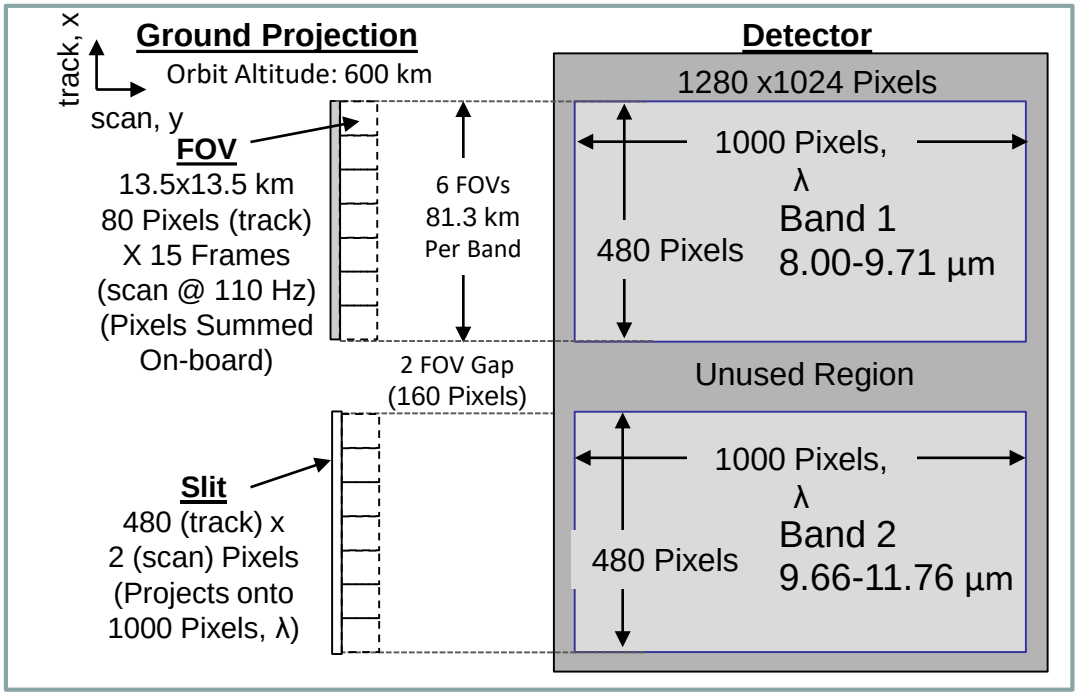
- Define the system level performance requirements to meet the requirements of the LWIR spectral range between 8-15 microns of the CrIS. This band is primarily used for temperature sounding, surface temperature, ozone concentration and other trace gas species.
- Identify the key requirement drivers
- Develop an optical design for this system and estimate its performance. The design can build upon work from the 2013 NOAA study.
- Define the requirements for and estimate the current capabilities of a suitable detector array including operating temperature, quantum efficiency and dark current. Include selection of a suitable Readout Integrated Circuit (ROIC).
- Select a suitable cryocooler for the system and estimate its loads.
- Examine first order thermal loading of the system and required radiator approach and area.
- Perform a first order opto-mechanical design of the LWIR-1 payload giving size and mass.
- Estimate payload power, data rate and reliability for a 2 year mission.
- Perform a Team-X costing exercise for the LWIR-1 payload

EON-IR LW Band Targets Surface and Trace Gases

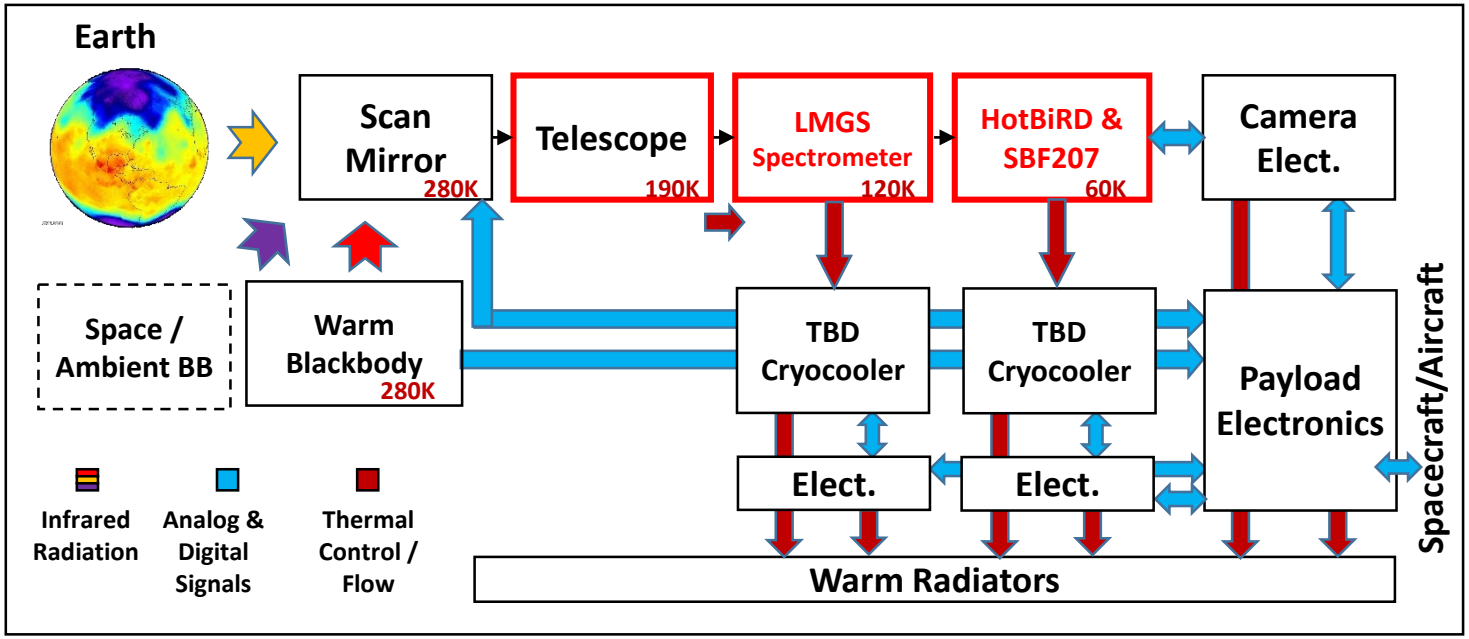


Molecular signatures of the key trace gases measured by INCAS. The dashed line indicates the cutoff between the two bands. (Top) Typical spring simulated radiance with the primary absorption bands. (Bottom) Difference in radiances when depicted minor trace gas is absent from radiance calculation.

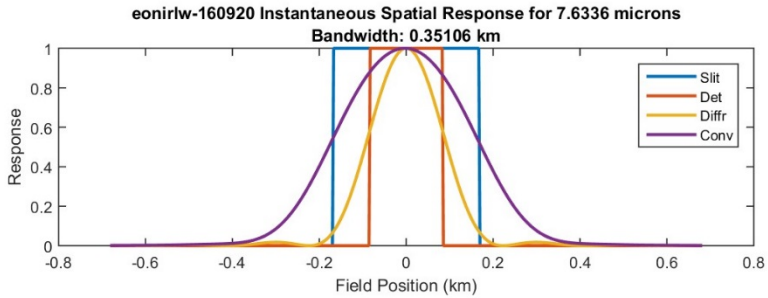
2-Band Spectrometer Imaging

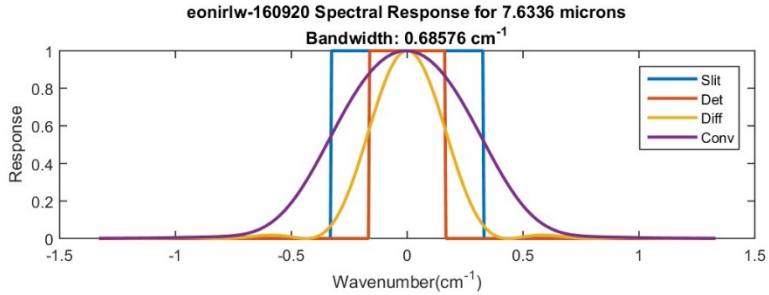


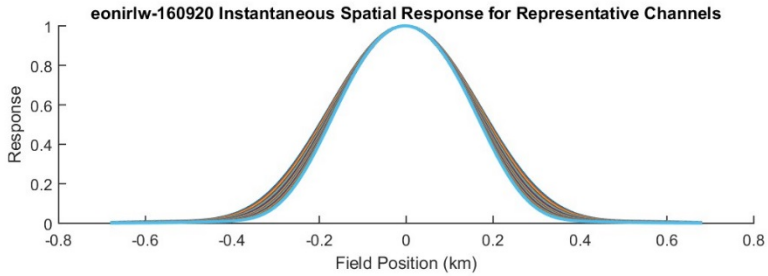
EON-IR LW Block Diagram

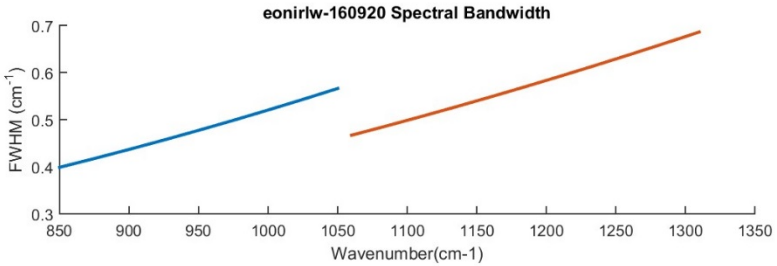


Angular Response Function Impacts Spatial and Spectral Bandwidth

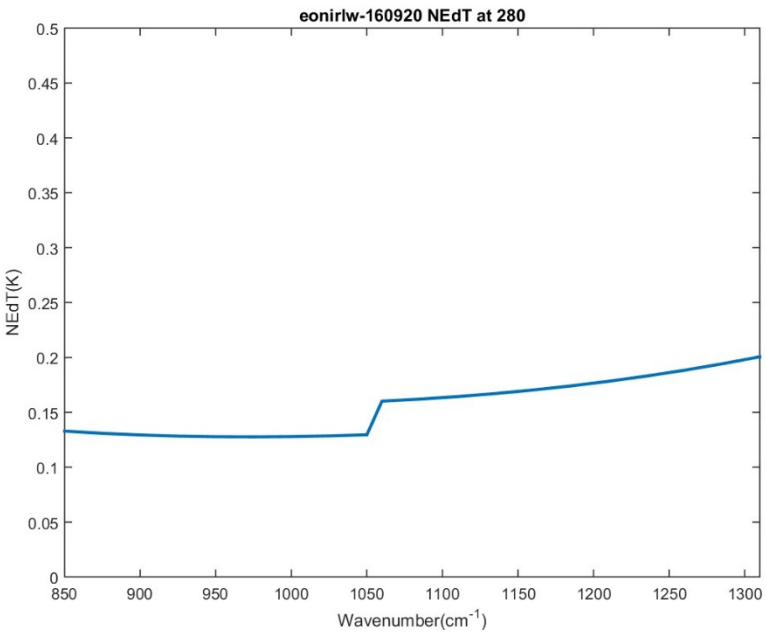


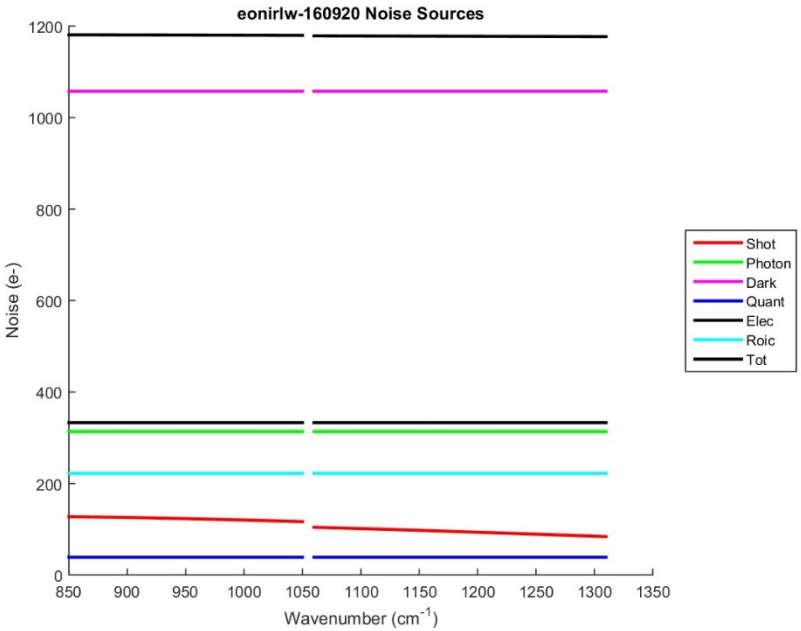
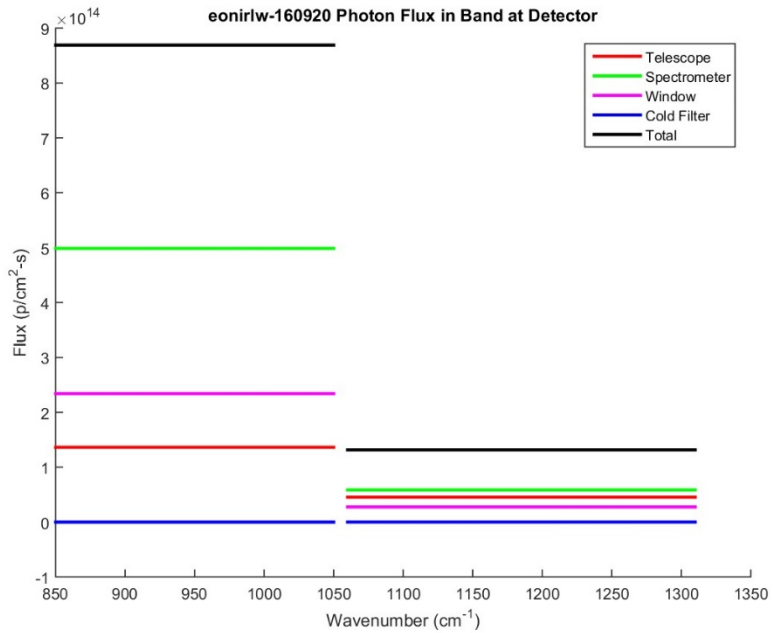
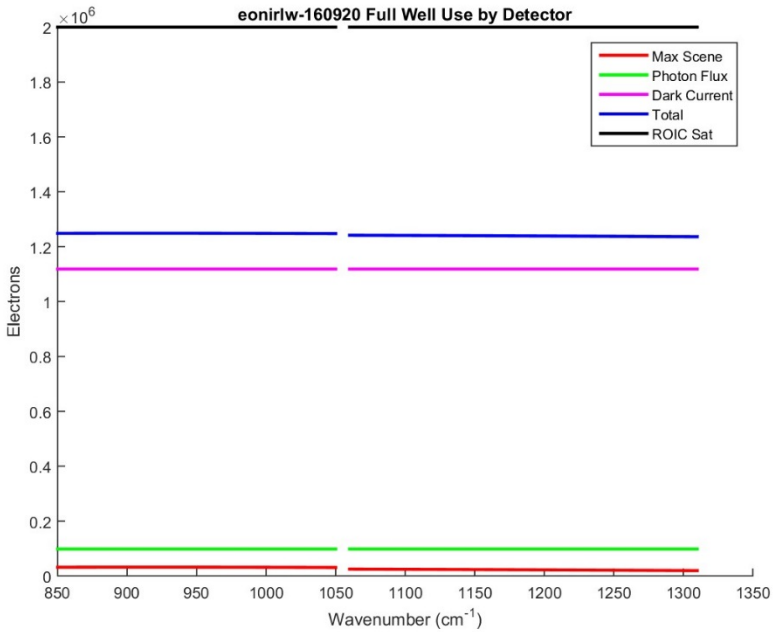






EON-IR-LW NEdT
Limited by Dark Current at 65K





EON-IR-LW Full Well Driven by Dark Current