CubeSat Infrared Atmospheric Sounder (CIRAS)

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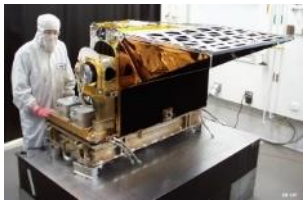
CIRAS Agenda

- Background
- Overview
- Experiment Objectives
- Measurement Requirements
- Measurement Approach
- Key Technologies
  - HOTBIRD Detectors
  - LM MPT Cryocooler
  - Immersion Grating Spectrometer
  - Black Silicon Blackbody
- Summary and Conclusions

CIRAS Builds on the Success of Legacy Infrared Sounders

- Atmospheric Infrared Sounder (AIRS)
  - Launched May 4, 2002 on the EOS Aqua Spacecraft
  - Grating Spectrometer, Active Cryocoolers, HgCdTe
  - Highest Forecast Impact of Any Single Instrument (tied with European IASI)
  - 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
  - Gap could happen if loss of JPSS-1 or JPSS-2
- CIRAS for NASA InVEST (ESTO)
  - Selected by **NASA InVEST** Program Sept. 2015
  - Project Start, April 1, 2016
  - Selected for Launch by the NASA CSLI in 2018/2019
  - Technology Development for Atmospheric Sounding
  - Lower Tropospheric Only. (MWIR Only)
  - Comparable Spatial Resolution to AIRS, CrIS
  - Constellation Compatible for Improved Timeliness

JPL/BAE AIRS



AIRS Shows High Forecast Impact

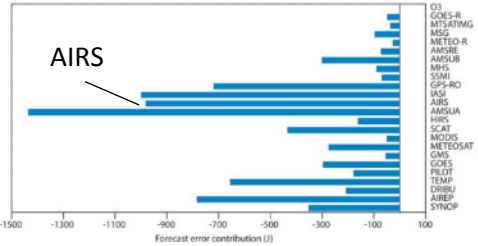
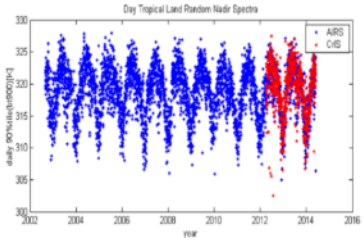


Figure 11. 24-hour forecast error contribution (Joule10^{-4}) of the components (types) of the observing system during September, October, November and December 2008. Negative (positive) values correspond to a decrease (increase) in the energy norm of forecast error.*

From Cardinali (ECMWF Tech. Memo. 599, 2009)

CrIS on JPSS

CrIS Continuity with AIRS Demonstrated for most scenes



CubeSat Infrared Atmospheric Sounder (CIRAS)

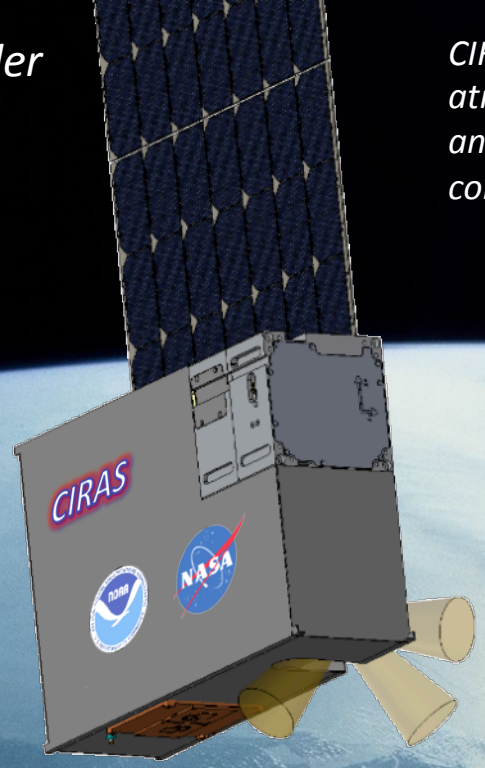
For NASA InVEST

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

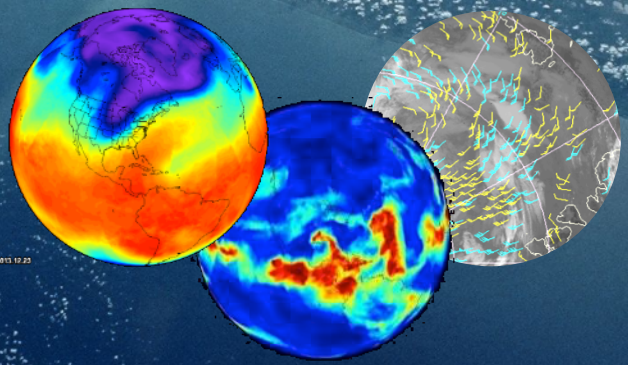
- *Demonstrate Key Technologies needed for Infrared Instruments on CubeSats*
- *Demonstrate fidelity of Hyperspectral Mid IR radiance measurements to retrieve Temperature and Water Vapor Profiles*
- *Fill Coverage Gaps and Improve Timeliness of Operational IR Sounders*
- *TRL in: 5-6, TRL out: 7*
- *Build: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



Parameter	CIRAS
Spatial	
Orbit Altitude	600-850 km
Pushbroom SW	163 km
Horizontal Res'n	13.5 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*

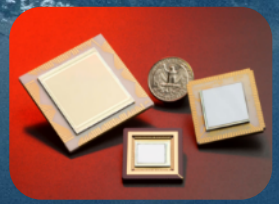


CIRAS Technologies

Micro Pulse Tube Cryocooler (Lockheed Martin)

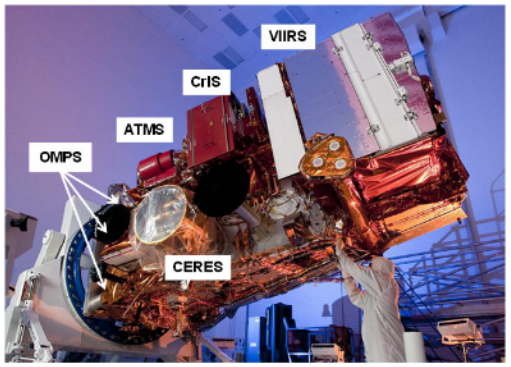
JPL GRISM Spectrometer

JPL HOT-BIRD Detector



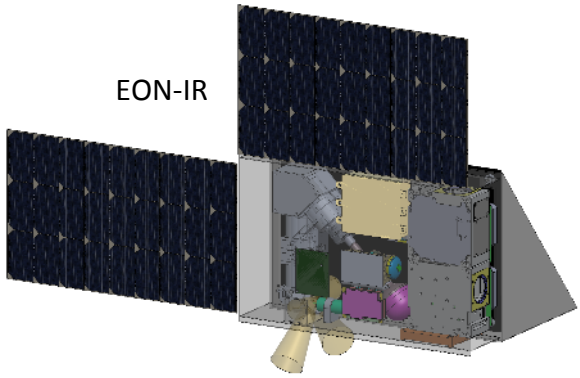
CIRAS is Path to EON-IR for NOAA

- CubeSat Infrared Atmospheric Sounder (CIRAS)
  - **Technology**: 6U CubeSat IR Sounder
  - **Sponsor**: NASA InVEST Program (ESTO)
  - **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)
  - **Technology**: Expanded version of CIRAS with full CrIS Capability
  - **Sponsor**: First NOAA operational unit
  - **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)
    Zoom Mode: 3km Spatial Resolution (+/-8 °, 170 km)
  - **Spectral**: Same as CIRAS, 625 Channels
  - **Radiometric**: Same as CIRAS NEdT of 0.25K
  - **Full Data Download**: On-board Binning, 350 channels, and 2X Data Compression



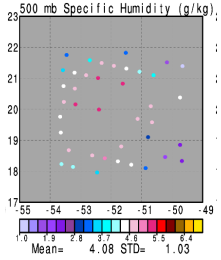
JPSS

EON-IR

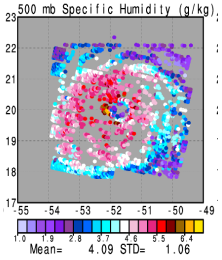


EON-IR Zoom Mode Improves Yield in Critical Areas

13.5 km GSD

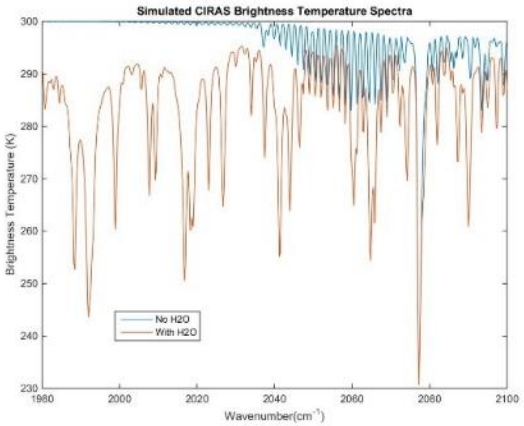


3 km GSD

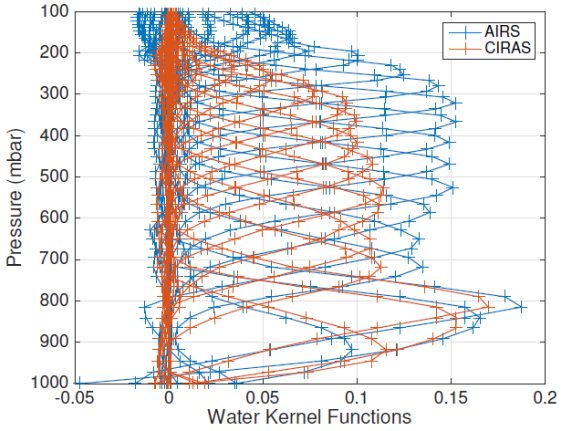


CIRAS will demonstrate IR Sounding in a CubeSat

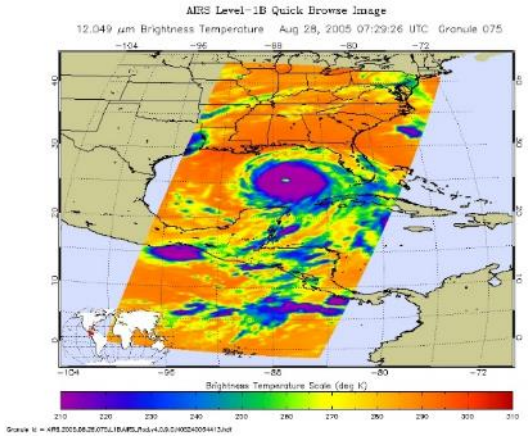
Measure Temperature and Water Vapor Spectrum 1965-2090 cm^{-1}



Sensitivity is Comparable to Legacy Sounders in Lower Troposphere



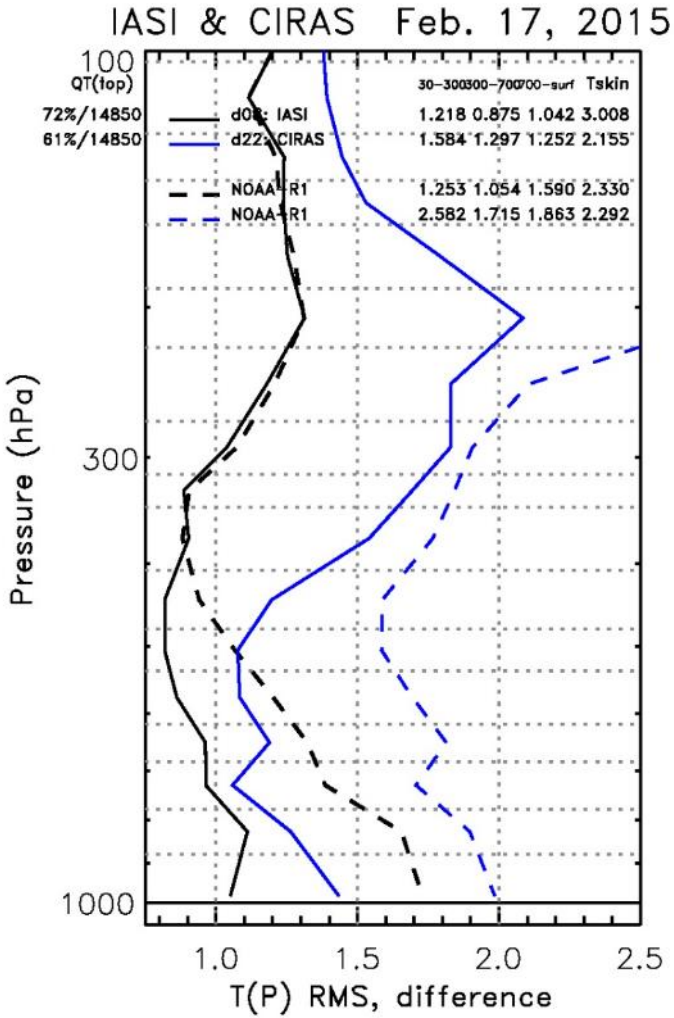
Spatial Resolution Comparable to Legacy Sounders and Coverage only limited by data downlink



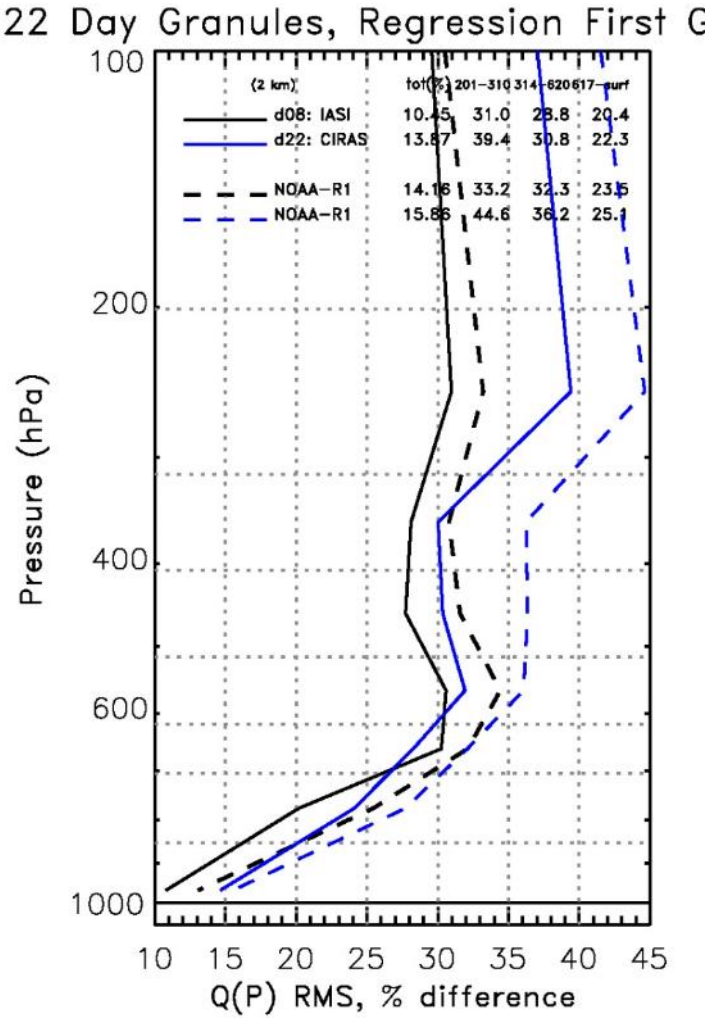
Parameter	Legacy (CrIS) Performance	CIRAS Requirement	CBE	Margin
Orbit	**824 km**	**600-850 km**	**450 km**	**Positive: >150 km**
Vertical Range	1000-50mb	1000-500 mb	1000-300 mb	Positive: 200 mb
Temperature Profile	**≤1.5 K/km**	**≤1.5 K/km**	**≤1.2 K/km**	**Positive: 0.3 K/km**
Humidity Accuracy	15%/2km	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	165 km	165 km	**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**

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

Temperature



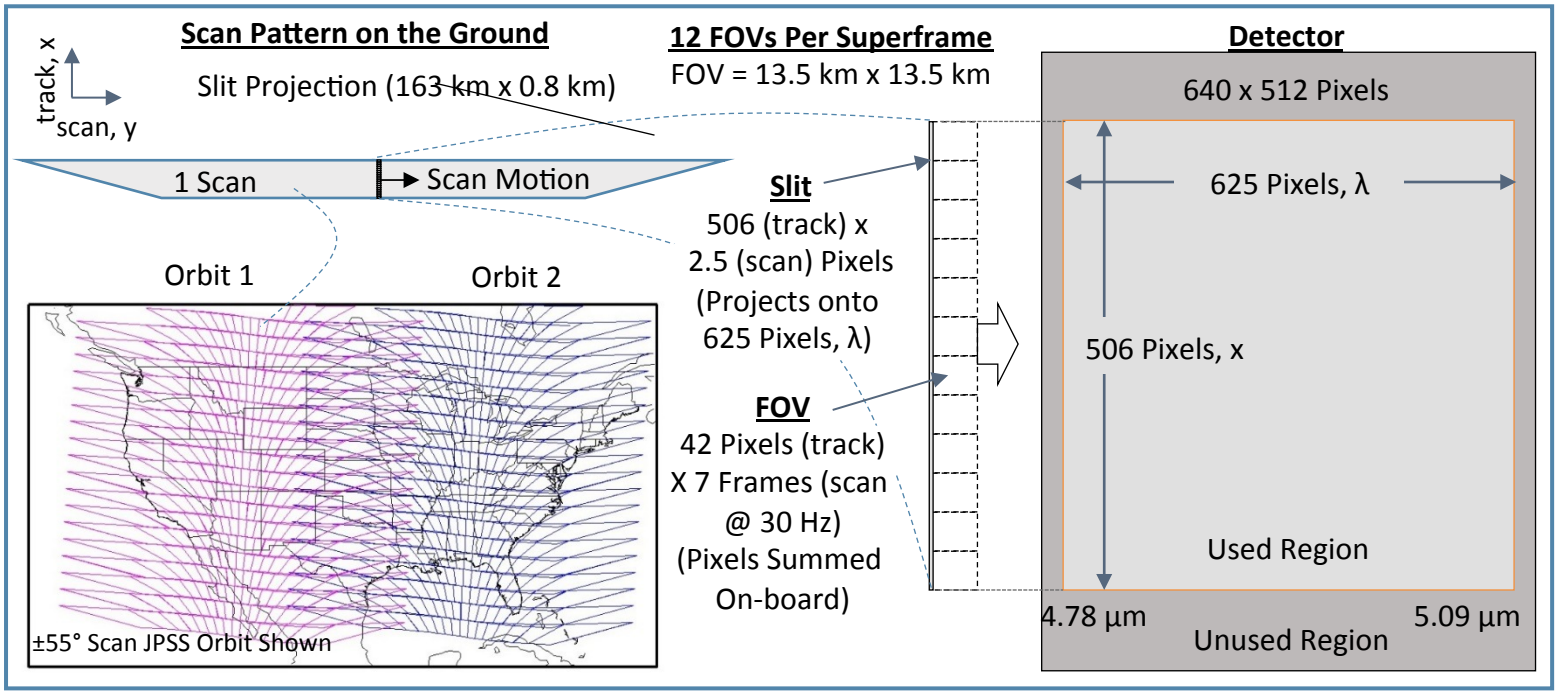
Water Vapor



Relative to ECMWF

Chris Barnet, STC

CIRAS Scan Pattern and FPA Projection



Resolution and coverage depend on on-board computing capability and downlink speed

Best Case:

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

Coverage: Global Daily

Hyperspectral Infrared

1965cm^{-1} – 2090 cm^{-1}, 0.5 cm^{-1}

(4.78-5.09µm), 625 ch

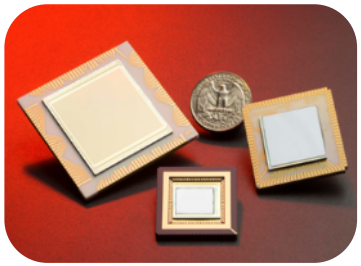
Worst Case:

GSD = 13.5 x 13.5 km, FOR = 163 km x 163 km

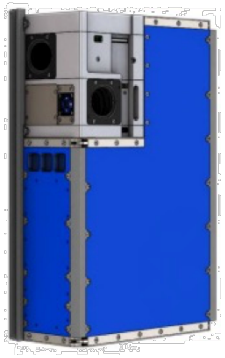
Coverage: 10 Granules (12 x 12 FOVs) acquired per orbit

CIRAS Technologies

JPL HOTBIRD Detectors

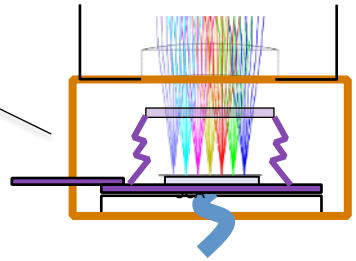


Commercial Spacecraft



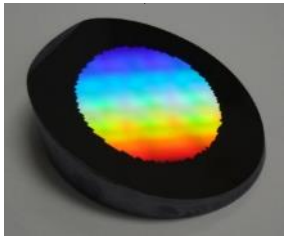
JPL/BALL Midwave Infrared Spectrometer

Custom Detector and Cold Filter Mount

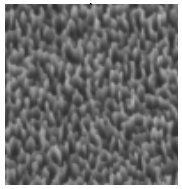


JPL MDL Technologies

Immersion Grating



Black Si. Blackbody & Slit



3-position Pointing Mirror Assy Commercial Stepper Motor + Elex

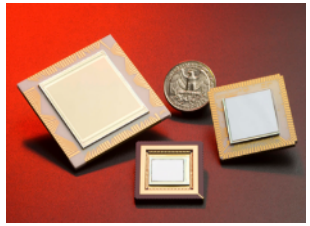
Ricor K562S & LM MPT Cryocoolers + Elex

IR Cameras SBF193 Electronics

CIRAS Key Technologies to Demonstrate

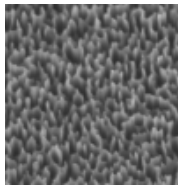
- CIRAS Demonstrates In-Space Key Technologies Required for Hyperspectral Infrared Measurements
  - **HOT-BIRD Detectors (TRL 6):** The new High Operating Temperature Barrier Infrared Detector (HOT-BIRD) detector materials developed at JPL provide superior uniformity and operability, higher operating temperature, and lower 1/f noise with comparable performance as HgCdTe at these wavelengths, and can be made at a significantly reduced cost.
  - **Coaxial Micro Pulse Tube (MPT) Cryocooler (TRL 6):** The Lockheed Martin (LM) built active MPT cryocooler used in CIRAS is the smallest flexure-bearing cooler available, built for low vibration and long life and ideal for Earth science missions requiring multi-year data sets.
  - **MWIR Grating Spectrometer (MGS) (TRL 5):** The CIRAS MGS is a high dispersion immersion grating spectrometer enabling IR remote sensing of atmospheric temperature and water vapor profiles in a CubeSat package.
  - **Black Silicon IR Blackbody (TRL 5):** A cryo-etched silicon surface that exhibits less than 0.1% reflectance across a broad spectral band
- Extensive use of commercial technologies
  - Camera electronics, scan motor and controller, cryocooler, cryocooler electronics, and spacecraft
- All technologies will be advanced to TRL 7 at end of experiment

JPL HOT-BIRD Detector



Micro Pulse Tube Cryocooler (Lockheed Martin)

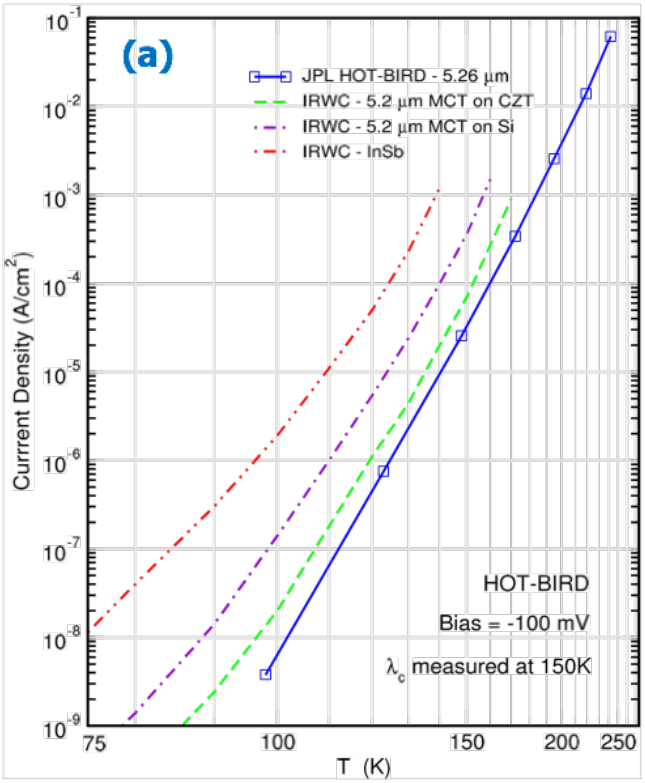
Black Si. Blackbody & Slit

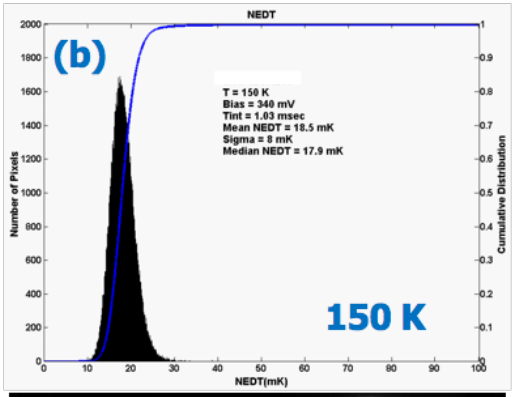


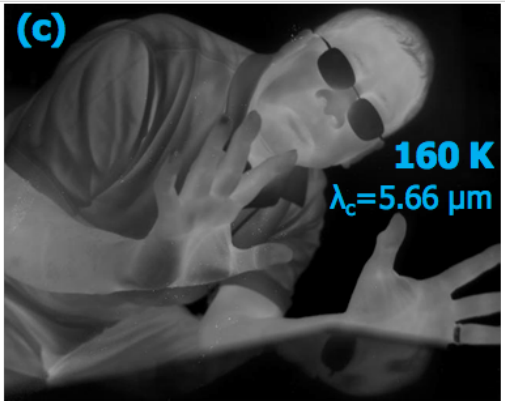
JPL Telescope and MGS (Based on OCO-WF)

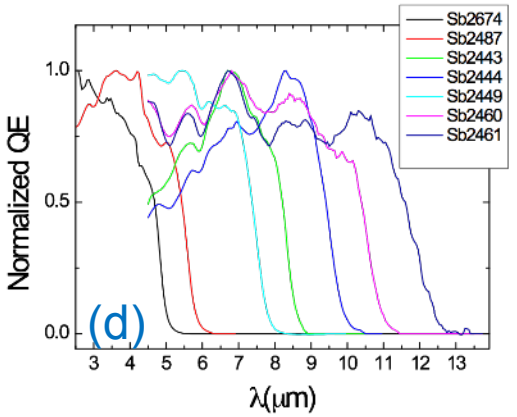
CIRAS Uses JPL High Operating Temperature Barrier IR Detector (BIRD) Technology

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.

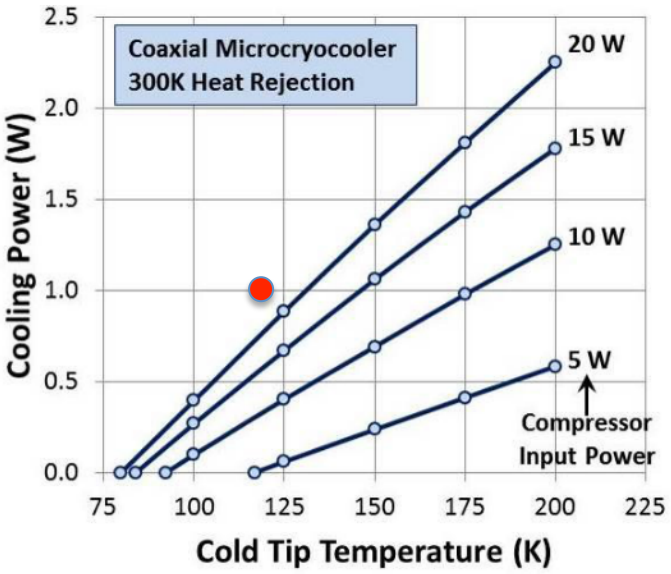
(b) The top middle panel shows the NEDT distribution for a 640x512 FPA made from the HOT-BIRD material.

(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.

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



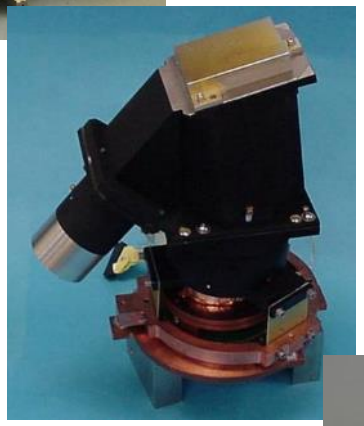
JPL Qualified
Thales Electronics

CIRAS Uses Compact Immersed Grating Spectrometer

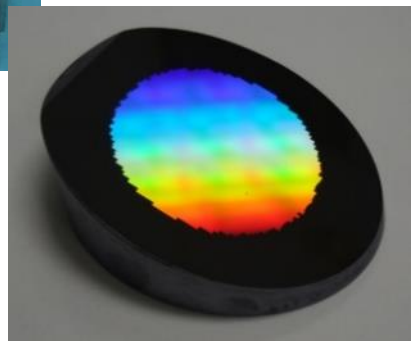
- CIRAS Optics Have Simple Design
  - All Silicon Materials
  - All Spherical Surfaces
  - 3 Lens Groups Identical
  - Immersion Grating Reduces Size
  - JPL Black Silicon Slit
- CIRAS optics have good heritage
  - JPL
    - OCO-2 Refractive High Dispersion Spectrometers
    - Wide Field OCO Immersion 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

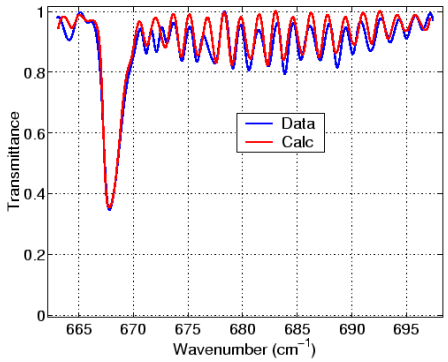
OCO-2



Ball SIRAS 12-15 μm

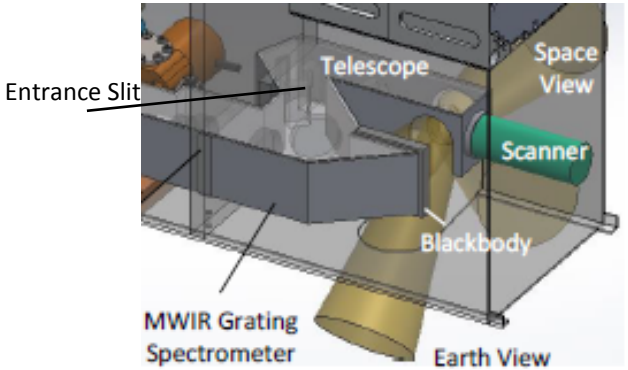


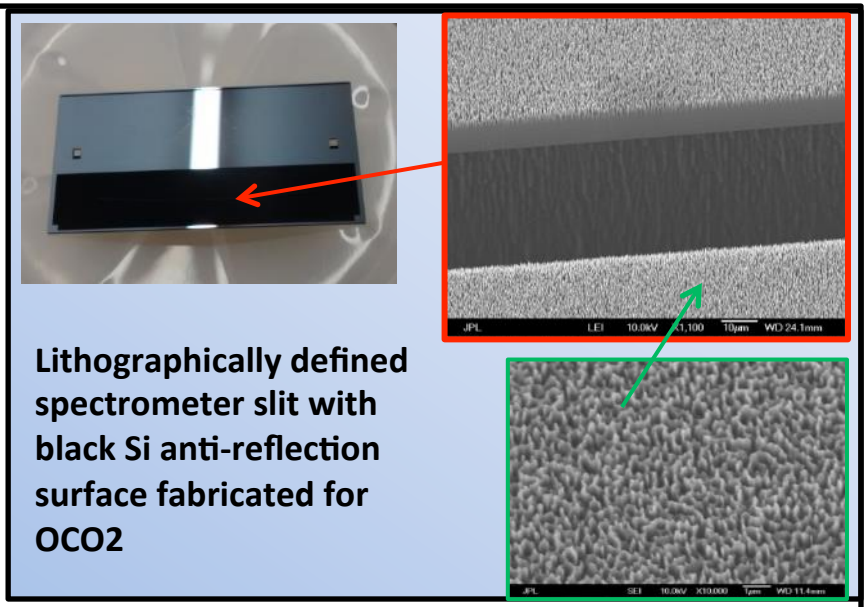
JPL Immersion Grating



SIRAS Lab Spectra

CIRAS will demonstrate an IR Blackbody using Black Silicon in space

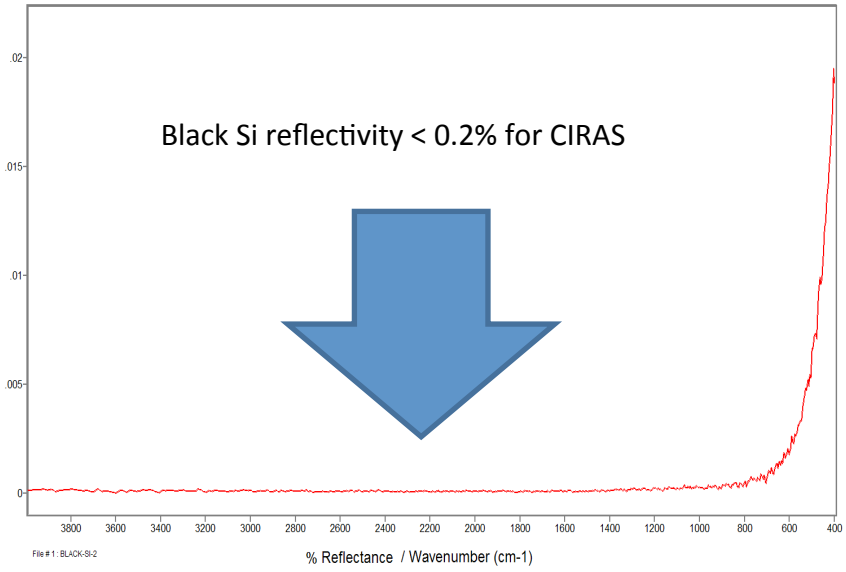




Lithographically defined spectrometer slit with black Si anti-reflection surface fabricated for OCO2

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



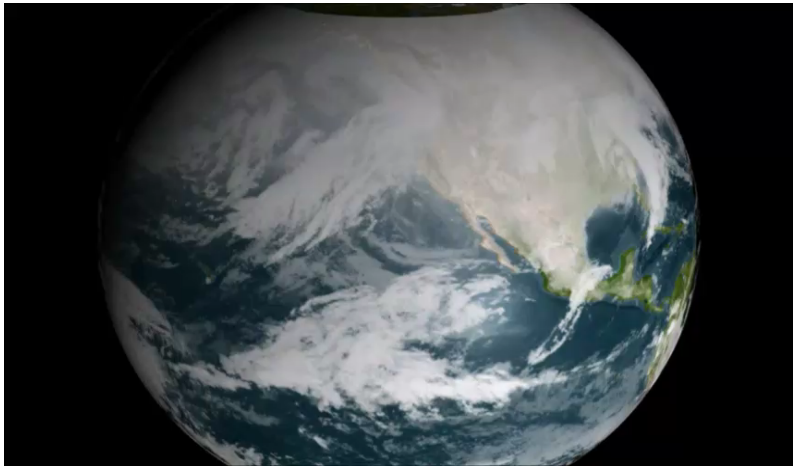
Summary and Conclusions

- CubeSat Infrared Atmospheric Sounder (CIRAS) Selected for development by the NASA InVEST Project
- CIRAS Selected by the CubeSat Launch Initiative. Requested Launch in 2018/2019 Timeframe
- Development starts April 1, 2016
- CIRAS demonstrates 4 Key Technologies for IR Spectroscopy in a CubeSat from space.
- CIRAS is a technology demonstration. Limited operations budget with no science objectives
- CIRAS will acquire hyperspectral infrared atmospheric radiances suitable for retrieval of temperature and water vapor in the lower troposphere from a CubeSat platform

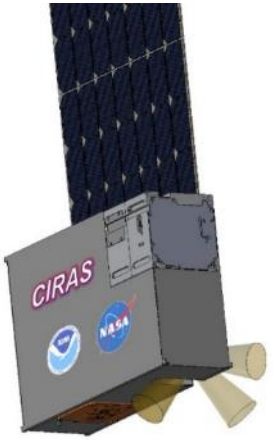
CIRAS Objectives and Mission Summary

CIRAS is a ***technology demonstration*** mission to enable hyperspectral infrared atmospheric sounding on a low-cost, quick-turnaround platform.

- **CIRAS Objectives**
  - In-Space Technology demonstration for key infrared subsystems: LM MPT Cryocooler, JPL HOT-BIRD IR Detectors, JPL Grism Spectrometer
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Limited to mid to lower troposphere. Supports operational weather prediction and scientific research on the atmosphere
- **Implementation Summary**
  - 6U CubeSat (approx. 30 x 20 x 10 cm, 9 kg)
  - Deployed into LEO Sun Synchronous Morning Orbit (400 km – 850km)
  - Minimum Mission Duration: 3 months
  - JPL Builds Payload
  - Subcontract for 6U spacecraft and I&T
  - CubeSat Launch Initiative for Launch Services
  - Launch-ready June 2018



AIRS 3D Water Vapor



CIRAS 6U CubeSat