The CubeSat Infrared Atmospheric Sounder (CIRAS), Pathfinder for the Earth Observing Nanosatellite-Infrared (EON-IR)

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IR Sounders Show High Impact to Operational Forecast. 2nd to Microwave Suite

- Microwave satellite measurements (AMSU-A) are responsible for 18% of the forecast error reduction
- Infrared measurements (AIRS and IASI) account for 12% each

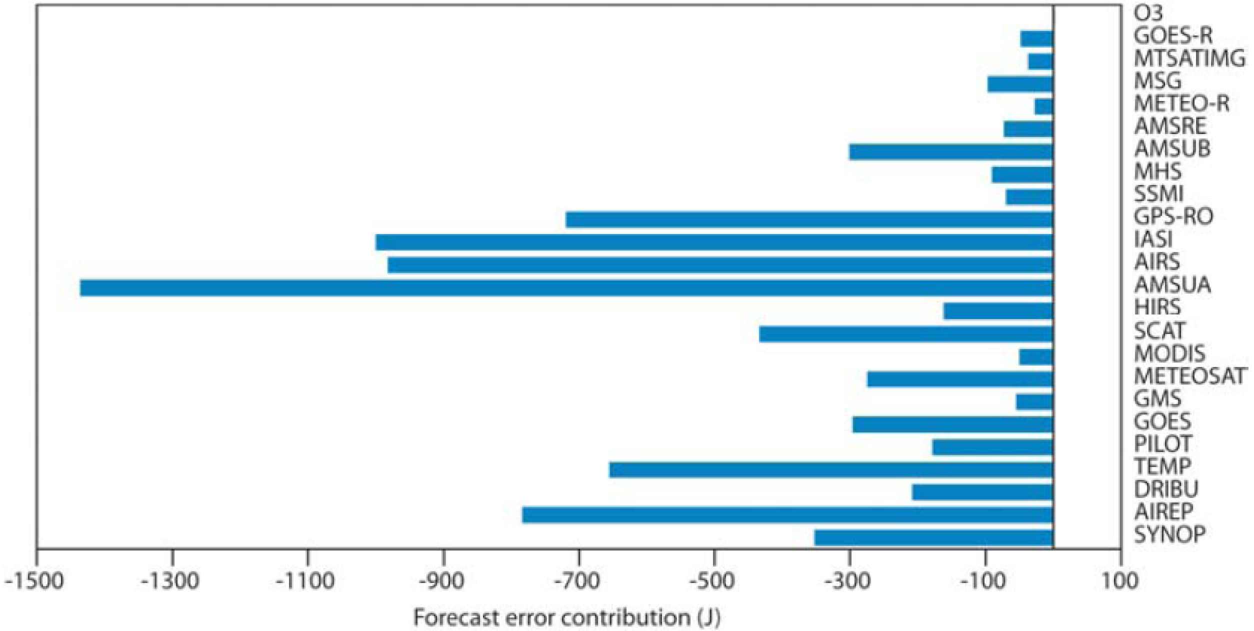
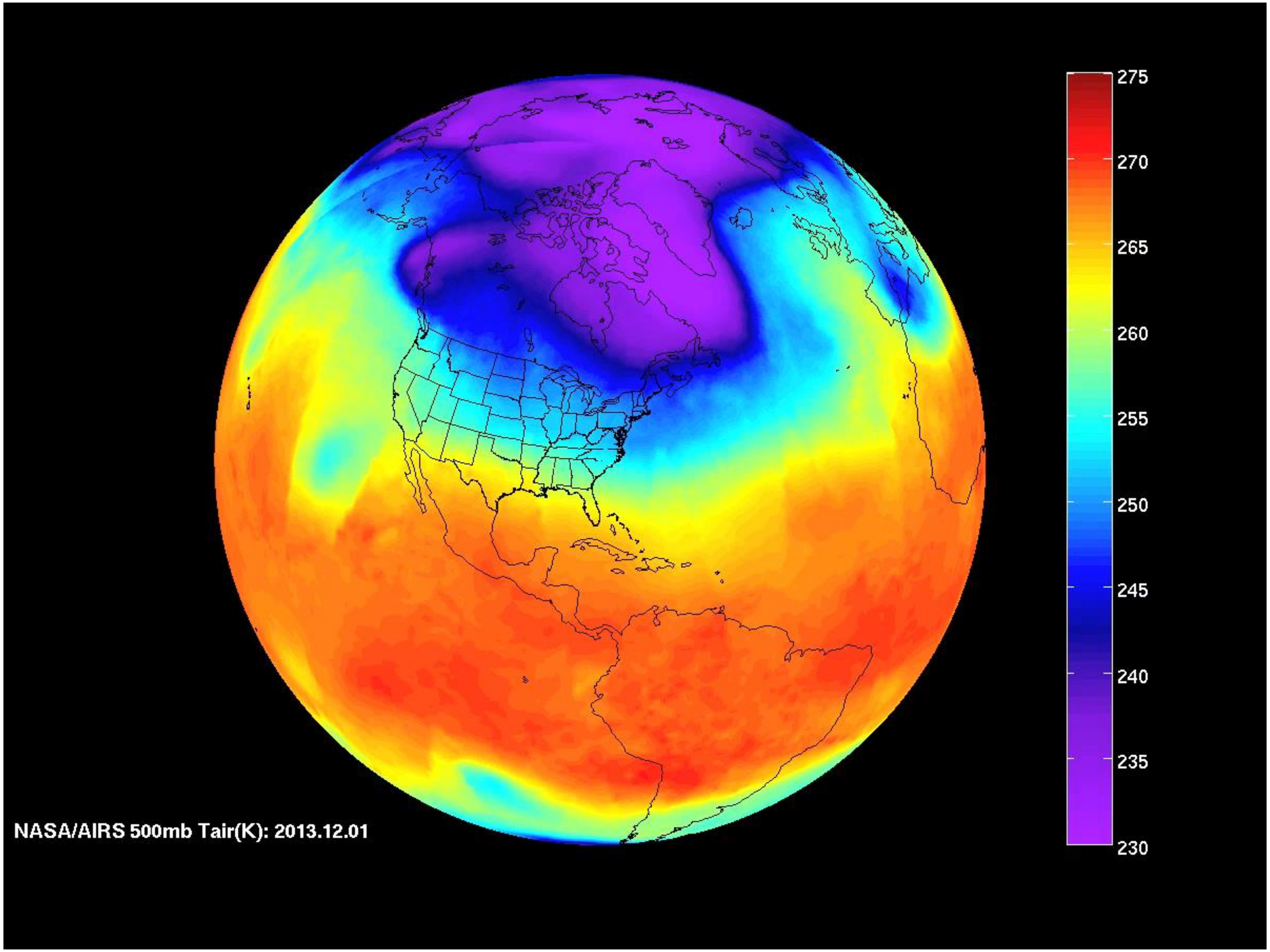


Figure 11. 24-hour forecast error contribution (Joule10^{-4}) of the components (types) of the observing system during September, October, November and December 2008. Negative (positive) values correspond to a decrease (increase) in the energy norm of forecast error.*

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

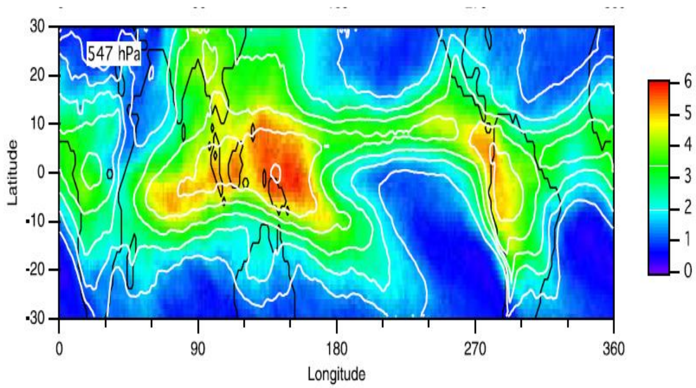
See also, Cardinali, C, Monitoring the observation impact on the short-range forecast, Q. J. R. Meteorol. Soc. 135: 239–250 (2009)

IR Sounders Capture Severe Weather Events (Polar Vortex of 2013/2014)

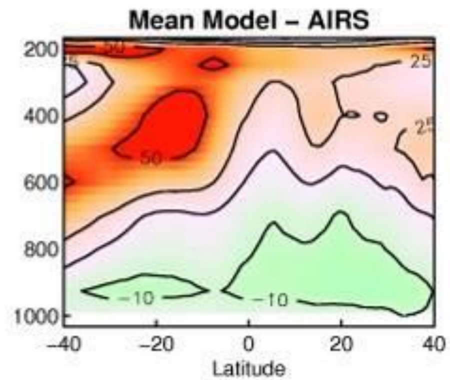


Dec 4, 2013: Denver weather: Temperature hits minus 13 — record low for the date
Dec 24, 2013: Record Low Tied at Cedar Rapids This Morning | Iowa Weather Blog
Jan 6, 2014: Chicago Record Low Temperature: City Hits -16 Mark To Kick Off ...
Jan 29, 2014: Atlanta, Georgia, historic weather for the past week

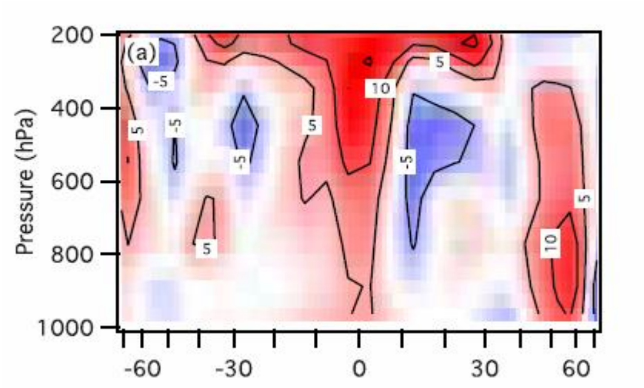
IR Sounders Support
Climate Research and Model Validation



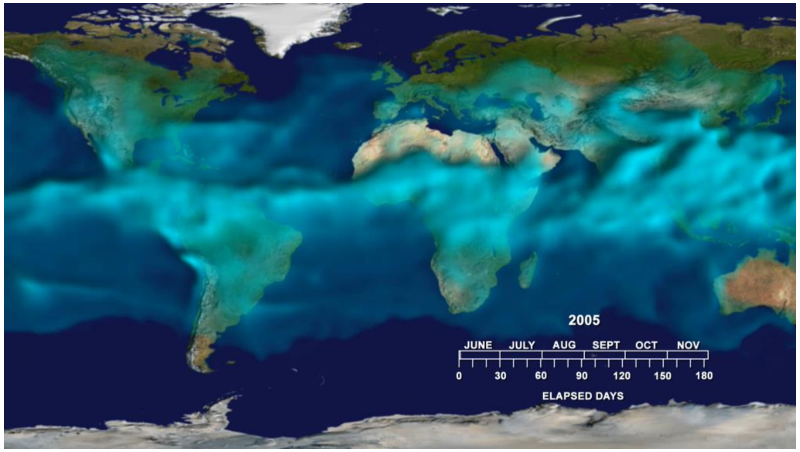
Water Vapor Transport
(Dessler, Texas A&M, 2007)



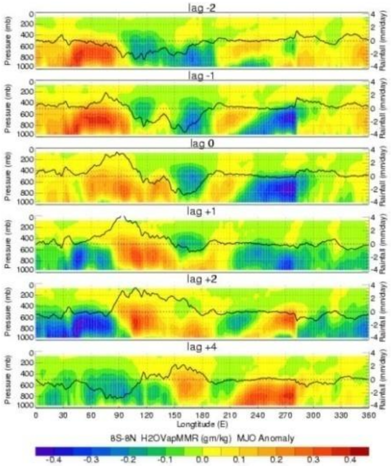
Water Vapor Climatology
(Pierce, Scripps, 2006)



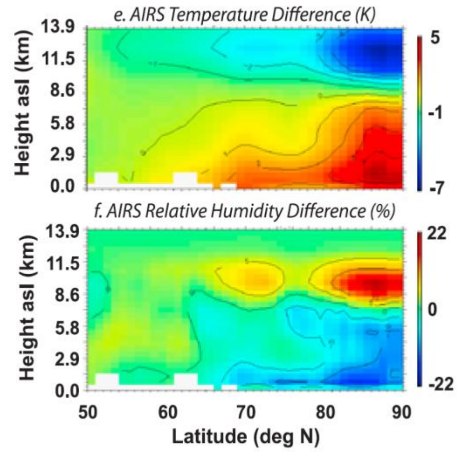
Water Vapor Feedback
(Dessler, Texas A&M, 2008)



AIRS Water Vapor Isosurface (5kg H2O /kg Dry Air)
V. Realmuto, C. Thompson, T. Pagano, S. Ray NASA/JPL



Madden Julian Oscillation
(Tian, JPL, 2006)

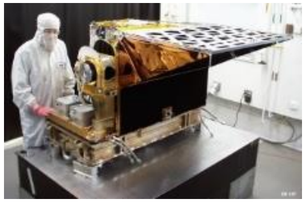


Polar Warming/Drying 2007
(Kay, J. E., 2008)

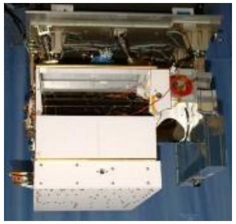
CIRAS Builds on the Success of Legacy Infrared Sounders; Prepares for Future Operational Use

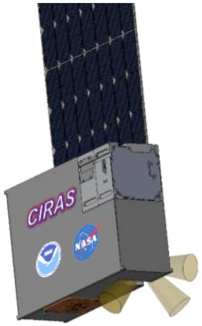
- Atmospheric Infrared Sounder (AIRS)
  - Launched May 4, 2002 on the EOS Aqua Spacecraft
  - Grating Spectrometer, Active Cryocoolers, HgCdTe
  - Highest Forecast Impact of Any Single Instrument (tied with European IASI)
  - Leading Data Set downloaded in Obs4MIPS for CMIP5 to Validate Climate Models
  - 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
- CubeSat Infrared Atmospheric Sounder (CIRAS)
  - NASA tech. demo. for IR sounding in a CubeSat (~$6M)
  - Meets sounding requirements in the lower troposphere
- Future: Earth Observation 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
  - Extended spectral range to meet upper troposphere and/or atmospheric composition (12U)
  - Operational Quality (>2 year mission life).

JPL/BAE AIRS



CrIS on JPSS

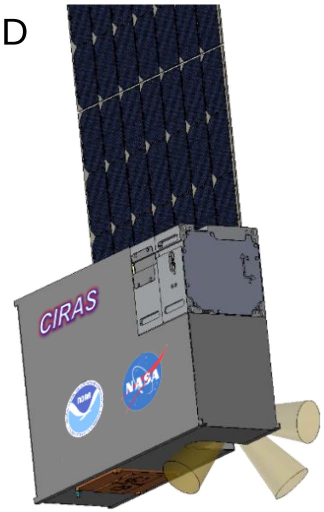




CIRAS Mission Overview

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

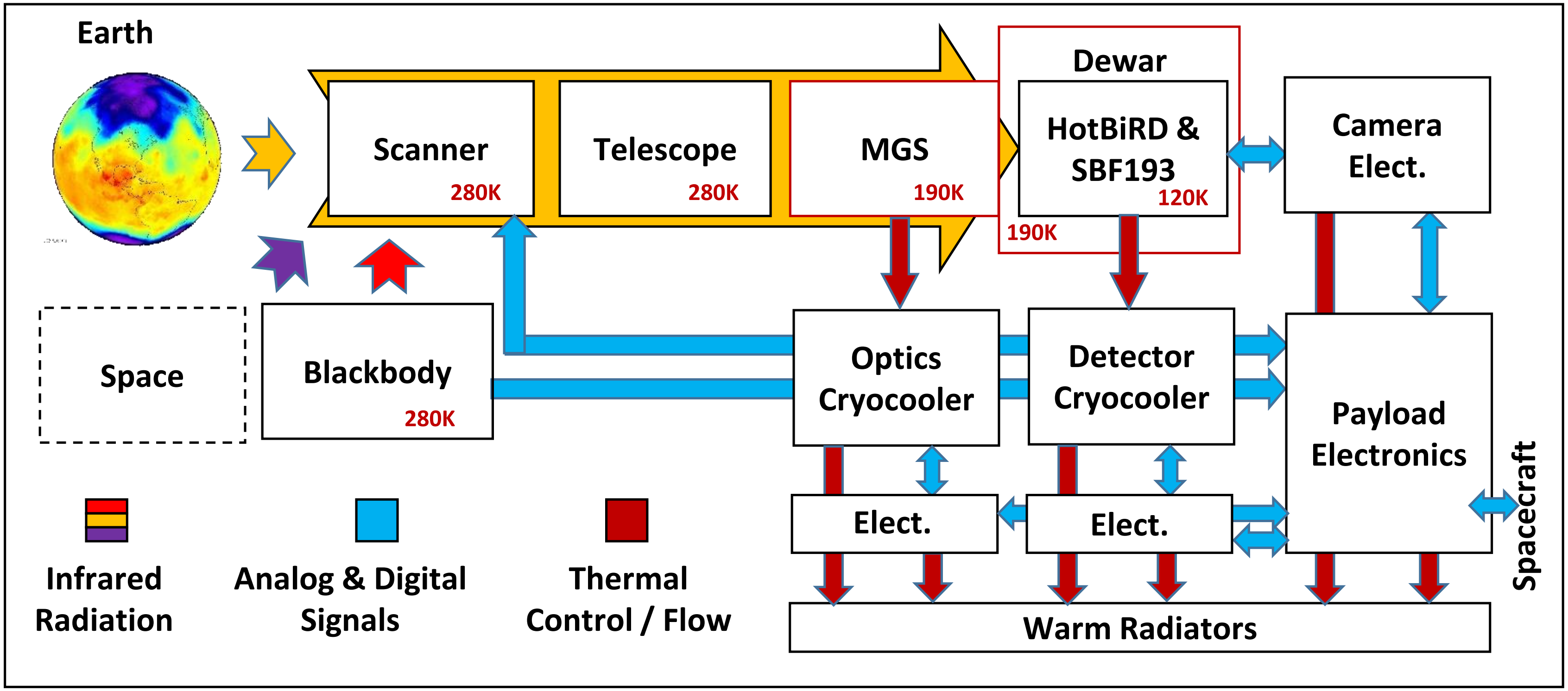
- **Mission Objectives**
  - In-Space Technology demonstration for key infrared subsystems: JPL HOT-BIRD IR Detectors, JPL Grism Spectrometer, Black Silicon Blackbody
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Limited to mid to lower troposphere.
  - All 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 – 850km)
  - Minimum Mission Duration: 3 months
  - JPL Payload Development, Ball Optics, Commercial Spacecraft
  - CubeSat Launch Initiative for Launch Services
  - 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, H_2O in Lower Trop

	AIRS	IASI	CrIS	CIRAS
Spatial				
Orbit Altitude	705 km	817 km	824 km	450-600 km
Scan Range	±49.5°	±48.3°	±48.3°	±6.2°, ±41.6°
Spatial Resolution	13.5 km	12 km	14 km	3 km, 13.5 km
Spectral				
Method	Grating	FTS	FTS	Grating
Nominal Resolution	0.5-2.5 cm^{-1}	0.5 cm^{-1}	1.0-5.0 cm^{-1}	1.3-2.0 cm^{-1}
0.4 - 1.0 μm	4	n/a	n/a	n/a
1.0 - 3.0 μm	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)
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
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
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
Total Channels	2382	8460	2208	625
Radiometric				
NEdT @ 250K	0.07-0.7K	0.25-0.5K	0.1-1.0K	0.2K - 0.6K
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
Mass	177 kg	236 kg	165 kg	14 kg
Power	256 W	210 W	117 W	40 W
Max Data Rate	1.3 Mbps	1.5 Mbps	1.5 Mbps	0.32 Mbps

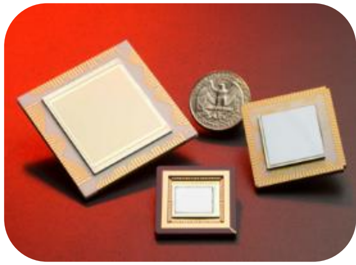
CIRAS Payload Block Diagram



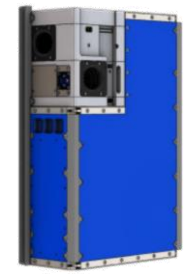
CIRAS Instrument

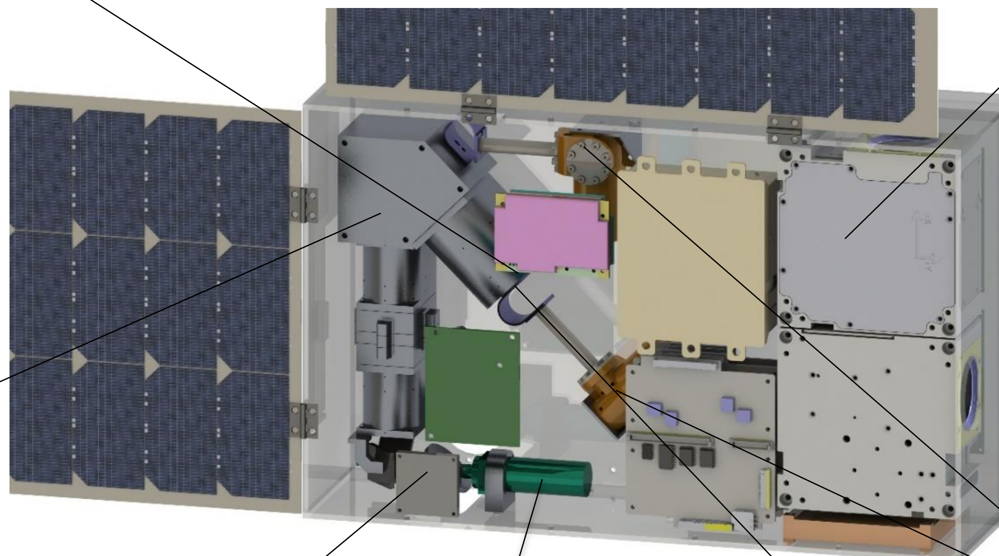
Size	6U Cubesat
Mass	8.5 kg
Power	37.5W
Data Rate	2 Mbps

JPL
HOTBIRD
Detectors



Commercial
Spacecraft



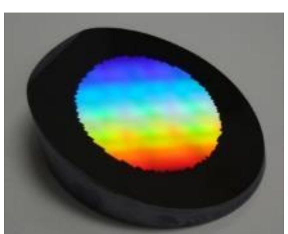


JPL/BALL
Midwave Infrared
Spectrometer

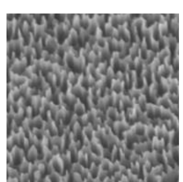
IR Cameras
SBF193 Electronics

JPL MDL Technologies

Immersion Grating

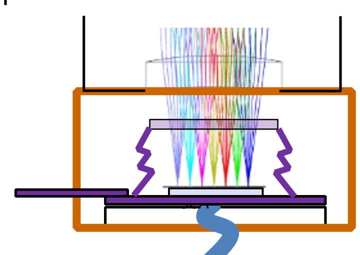


Black Si.
Blackbody & Slit



Scan Mirror Assy
Commercial Stepper
Motor + Elex

Custom Detector
and Cold Filter
Mount

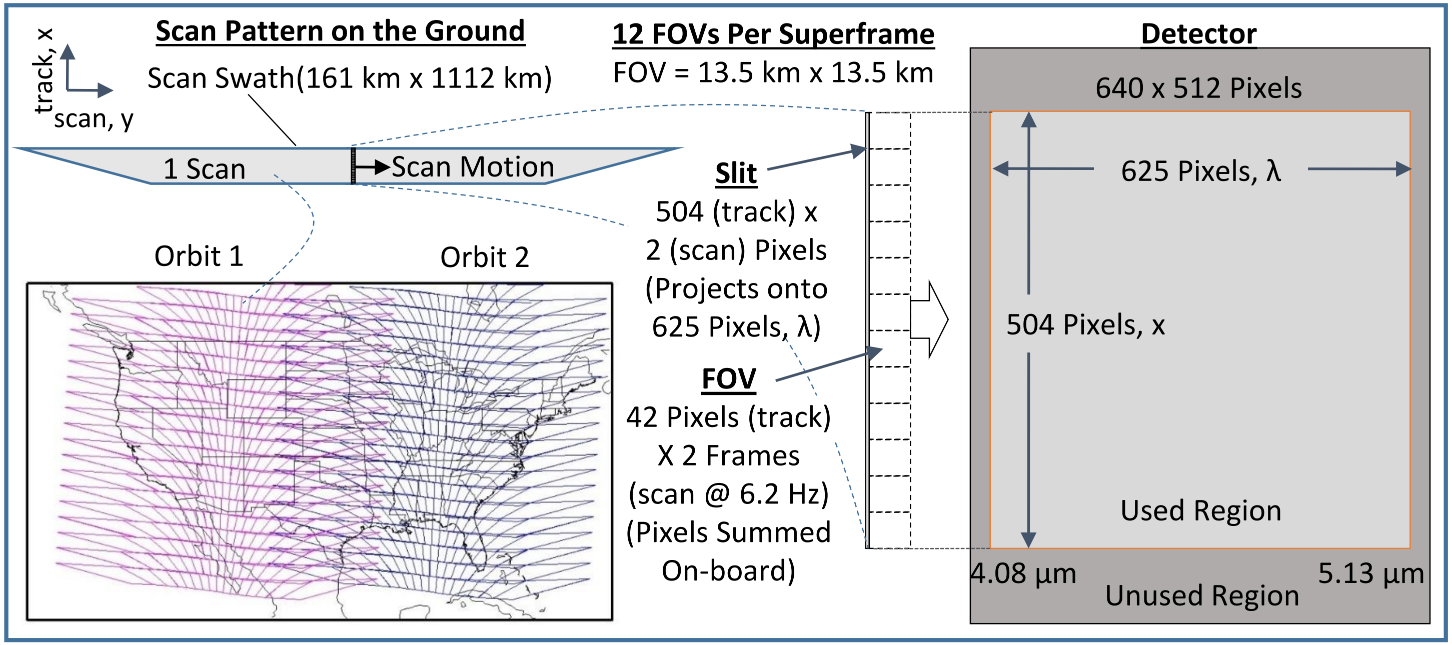


Ricor K562S
Cryocoolers + Elex

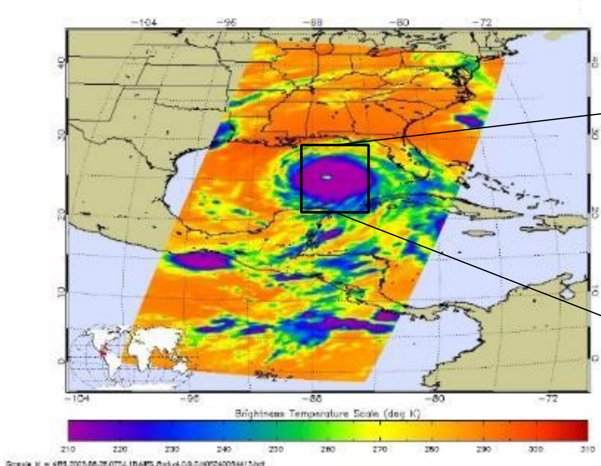
CIRAS Spatial Requirements comparable to AIRS, CrIS + Zoom

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

CIRAS Binning Scheme (600 km Orbit)

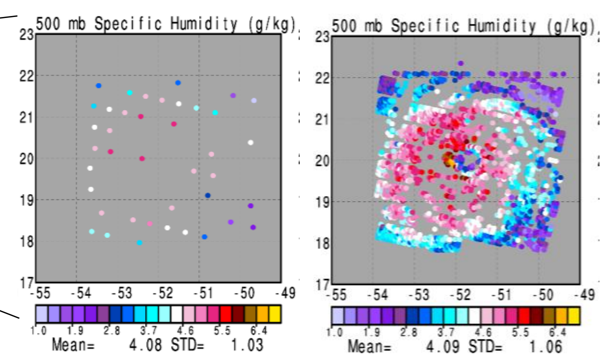


AIRS Global Mode



Simulated Sounder Yield

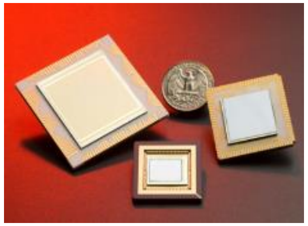
Global Mode 14 km GSD | **Zoom Mode 3 km GSD**



CIRAS Key Technologies to Demonstrate

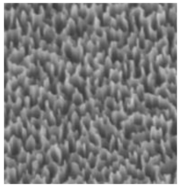
- CIRAS Demonstrates In-Space Key Technologies Required for Hyperspectral Infrared Measurements
  - **HOT-BIRD Detectors (TRL 6):** The new High Operating Temperature Barrier Infrared Detector (HOT-BIRD) detector materials developed at JPL provide superior uniformity and operability, higher operating temperature, and lower 1/f noise with comparable performance as HgCdTe at these wavelengths, and can be made at a significantly reduced cost.
  - **MWIR Grating Spectrometer (MGS) (TRL 5):** The CIRAS MGS is a high dispersion immersion grating spectrometer enabling IR remote sensing of hyperspectral radiances with no moving parts, at low cost, in a CubeSat package. To be built by Ball Aerospace.
  - **Black Silicon IR Blackbody (TRL 5):** A cryo-etched silicon surface that exhibits less than 0.2% reflectance across a broad spectral band
- Extensive use of commercial technologies
  - Camera electronics, scan motor and controller, cryocoolers, cryocooler electronics, and spacecraft
- All technologies will be advanced to TRL 7 at the end of the spaceflight mission

JPL HOT-BIRD Detector



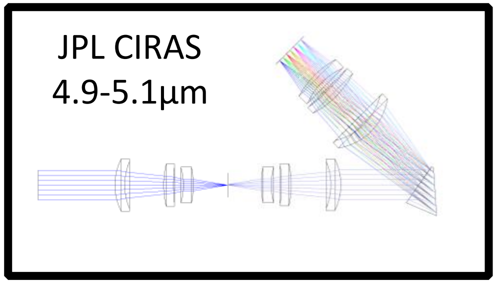
CIRAS optics based on SIRAS developed in IIP 2000 and 2007

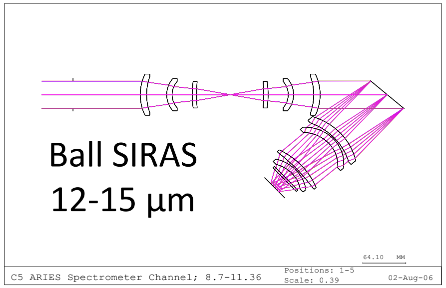
Black Si. Blackbody & Slit

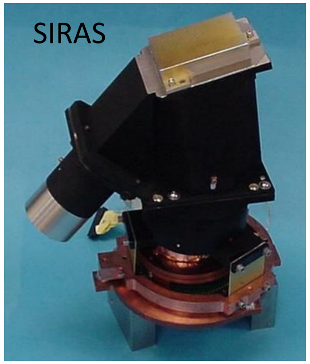


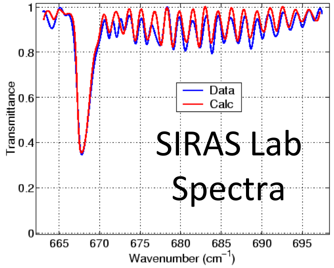
CIRAS Optics Based on NASA IIP Technologies

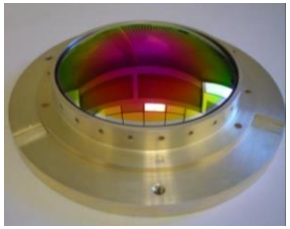
- Wide Field of View: Allows wide swath for slow scan
- All refractive optics with multiple surfaces enable good image quality across the field and high spectral resolution
- High degree of commonality. Telescope uses same optics as collimator
- JPL Immersion grating: Reduces size of spectrometer and reduces distortion
- JPL Black silicon slit: Low stray light
- Ball has history of development of wide field refractive IR spectrometers for JPL, ESTO and NOAA
  - SIRAS ESTO IIP-1 (JPL Lead)
  - SIRAS-G ESTO IIP-3
  - Wavelengths: 12-15 µm, 3-5 µm

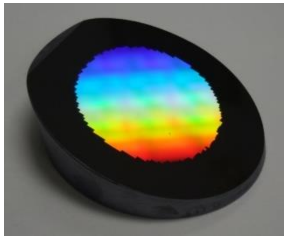








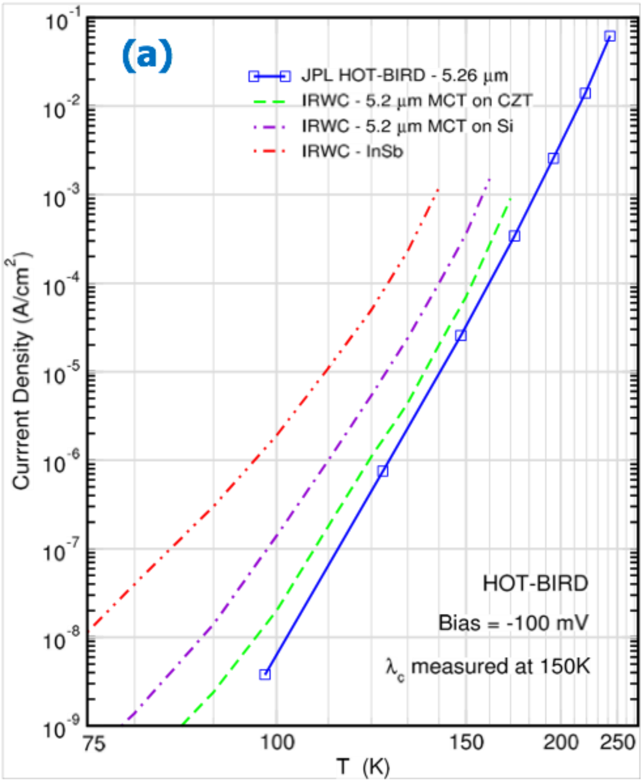


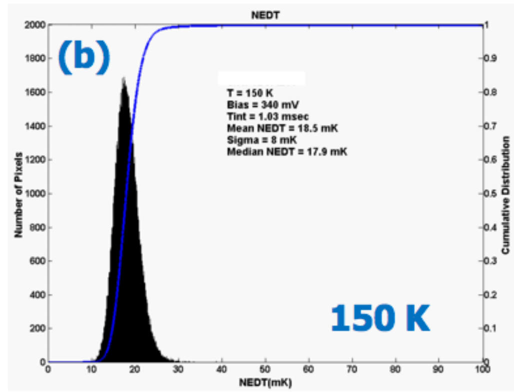


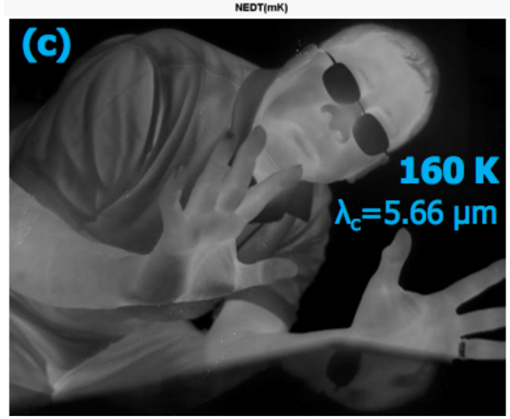
JPL Immersion Grating

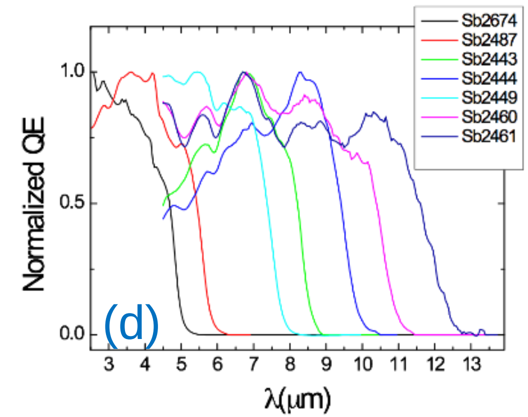
CIRAS Uses JPL High Operating Temperature Barrier IR Detector (BIRD) Technology

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







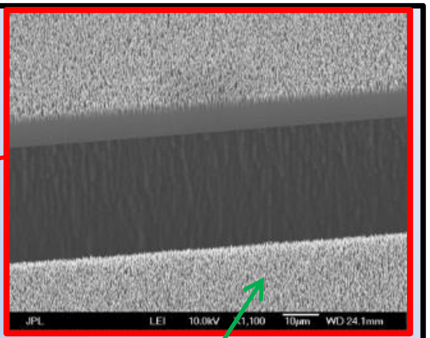


(a) The left panel shows the dark current density temperature dependence for a JPL HOT-BIRD device. Commercial InSb, MCT on Si substrate, and MCT on CZT substrate results taken from the Raytheon Infrared Wall Chart (IRWC) are shown for comparison.
(b) The top middle panel shows the NEDT distribution 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.

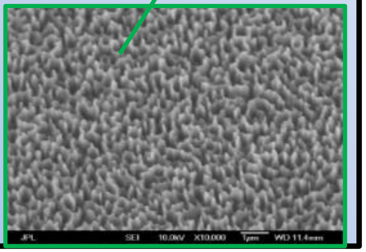
CIRAS will demonstrate an IR Blackbody using Black Silicon in space

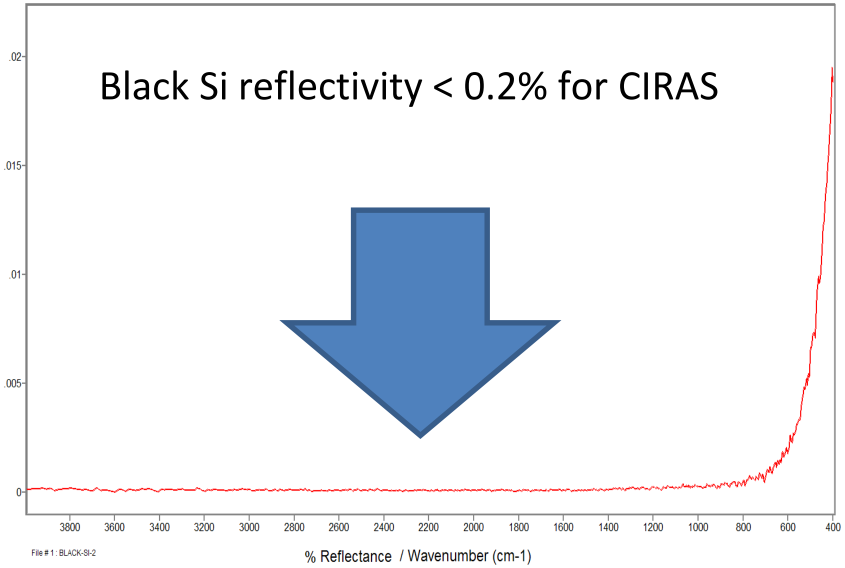
Black Silicon Uses for CIRAS:

- Blackbody Surface
  - <2” Diameter (Max target size manufacturable 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



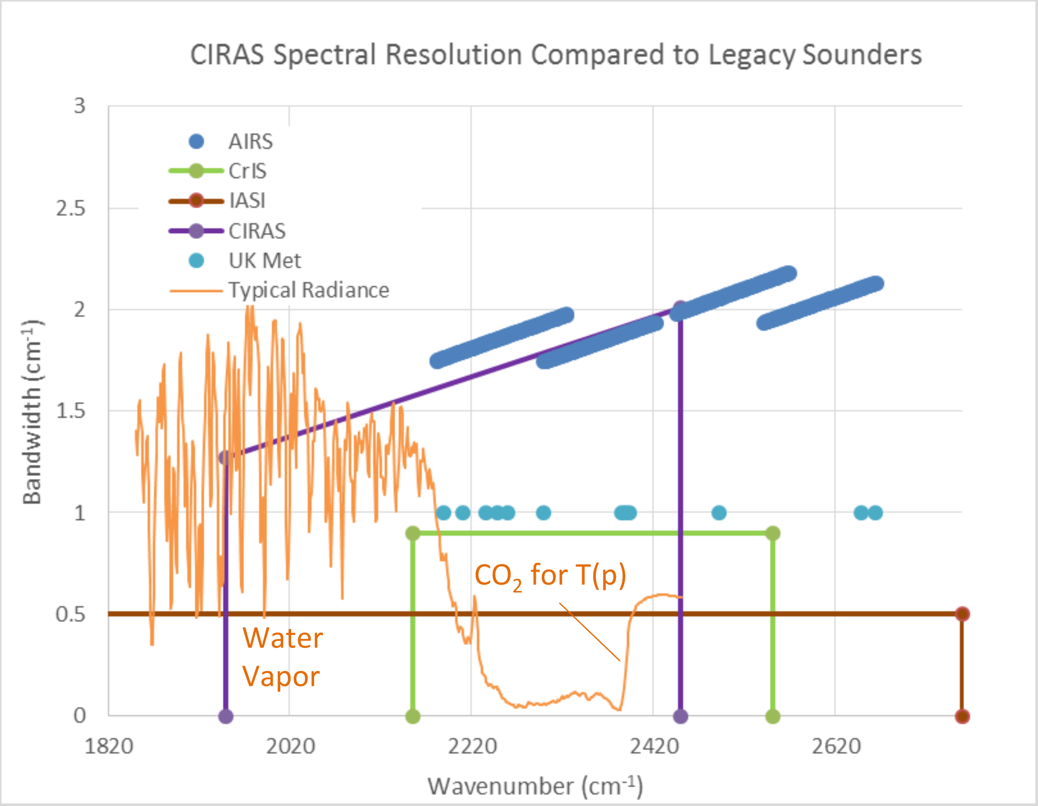
Lithographically defined spectrometer slit with black Si anti-reflection surface fabricated for OCO2



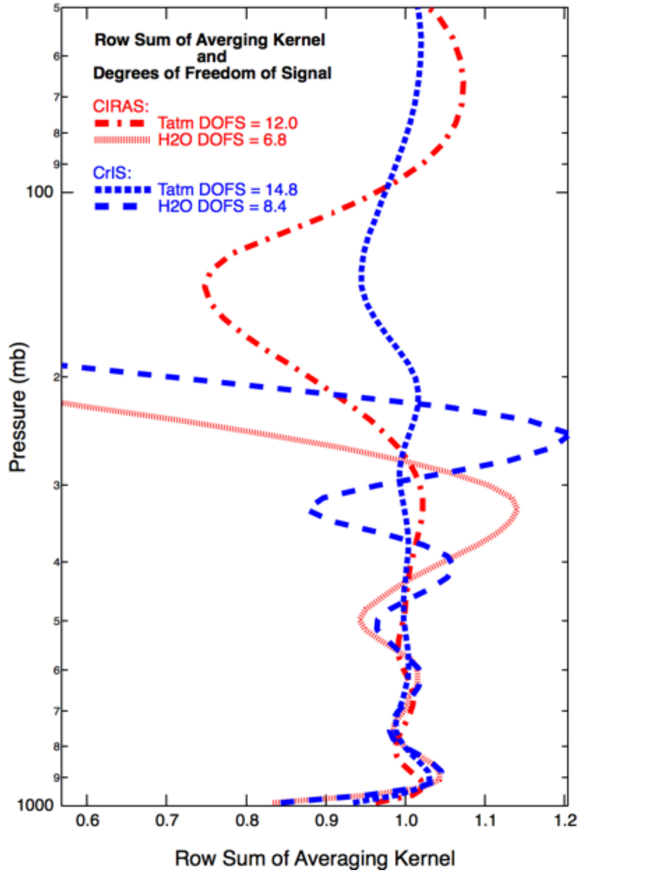


CIRAS Spectral performance comparable to AIRS in MWIR

CIRAS Spectral like AIRS but Extends into Water Band
$1950\ cm^{-1} – 2450\ cm^{-1}$
$\Delta\nu = 1.6\ cm^{-1}$, $N_{ch} = 625$

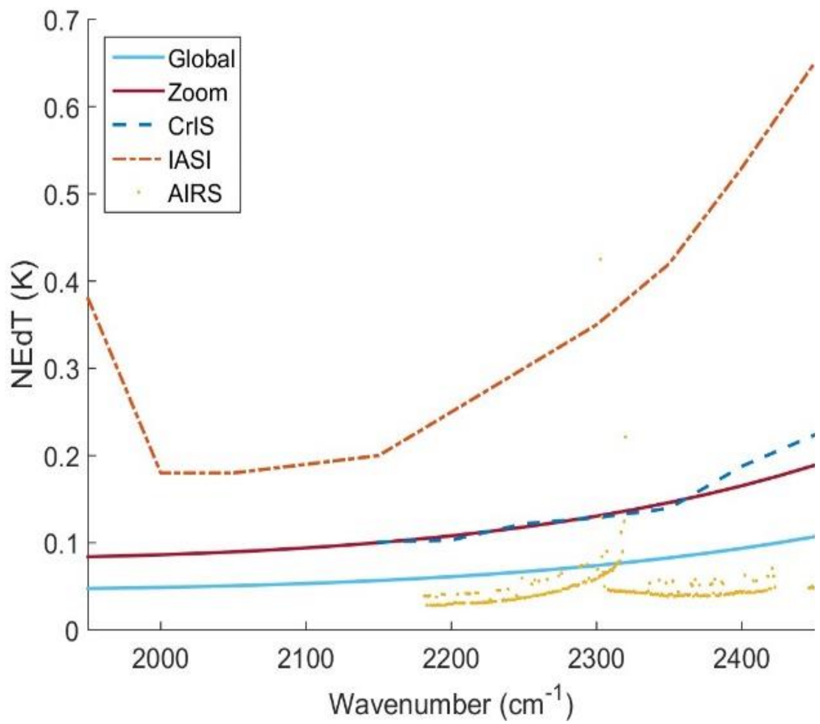


CIRAS Information Content Extends from Surface to 300 mb

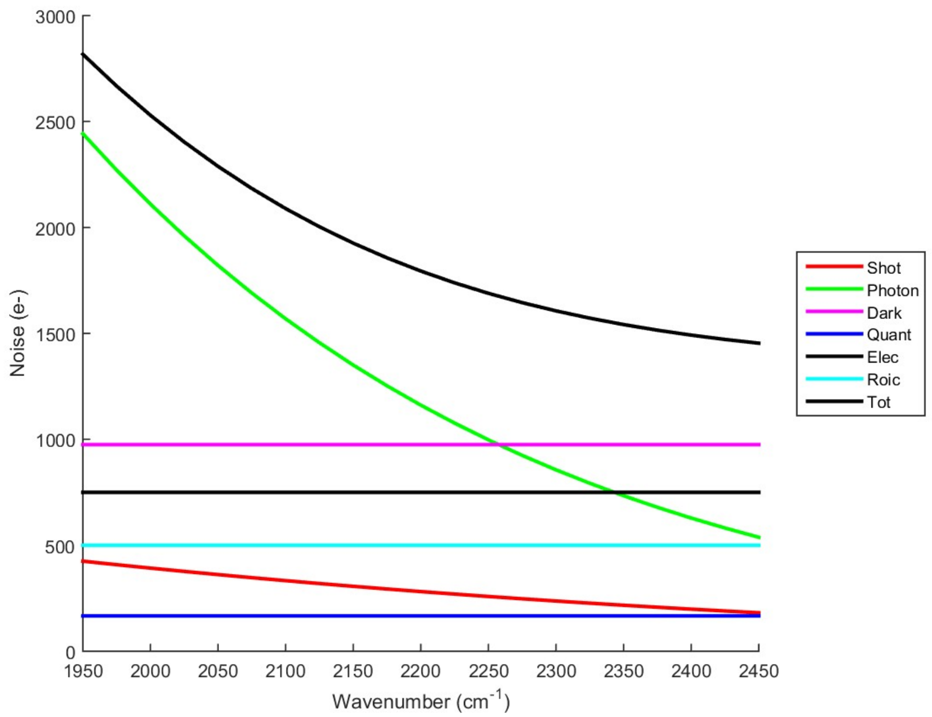


CIRAS Noise Equivalent Differential Temperature (NEdT) Comparable to Legacy Sounders

CIRAS & Legacy Sounders NEdT

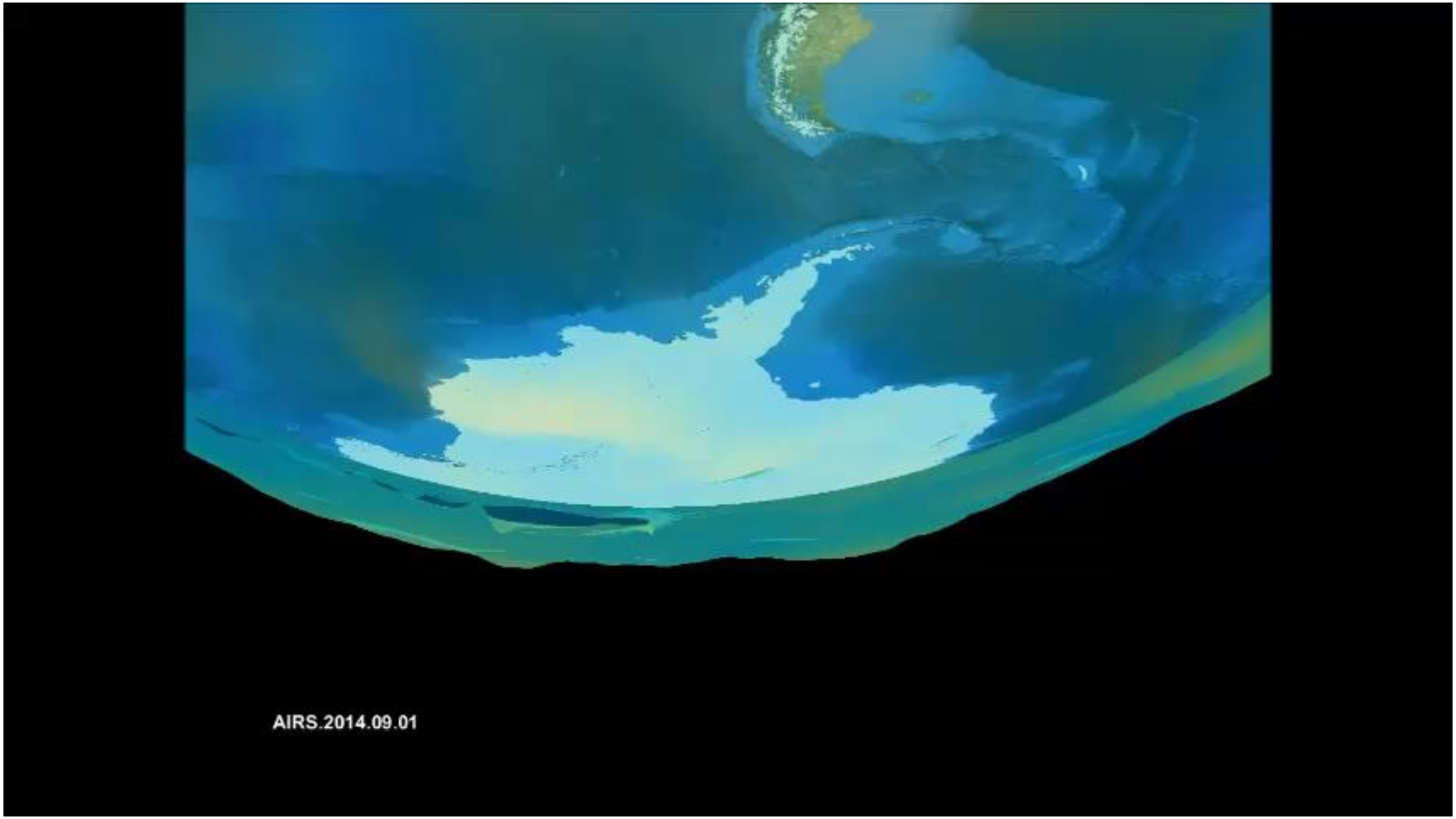


CIRAS Noise Sources



AIRS 3D O_3 12 Hr Over Poles Demonstrates Value of Improved Timeliness. EON-IR will enable trace gases.

AIRS O_3 Isosurface, Sept, 2014



AIRS O3_VMR, 2014. Isosurface at 5 x 10^{-7} ppmv. Altitude Scale: 100, Altitude Offset: 10 km, Max Altitude (above which transparent): 18 km

Summary and Conclusions

- Infrared atmospheric sounders measure hyperspectral infrared radiances with high precision and accuracy
- IR sounder radiances provide high impact to operational forecast
- IR sounders provide valuable information for climate science
- CIRAS provides IR sounding using the MWIR with sensitivity to temperature and water vapor profiles in the lower troposphere
- CIRAS can be used to mitigate a loss of operational IR sounders, add orbit times and improve timeliness
- CIRAS will demonstrate higher spatial resolution IR sounding (3 km vs legacy capability of 14 km)
- CIRAS to be built at JPL with Ball optics, and commercial technologies
- CIRAS to procure a commercial spacecraft
- CIRAS scheduled for launch in mid 2018 to early 2019 timeframe
- CIRAS is a pathfinder to a future operational mission, EON-IR enabling legacy capability at 1/10th the cost of today's IR sounders