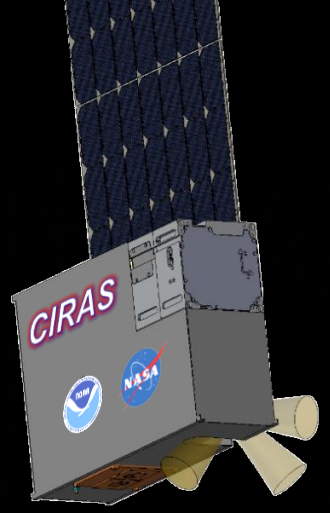

Technology advancements in the CubeSat Infrared Atmospheric Sounder (CIRAS)

Earth Science Technology Forum
Pasadena, California
Wednesday, June 15th, 2017

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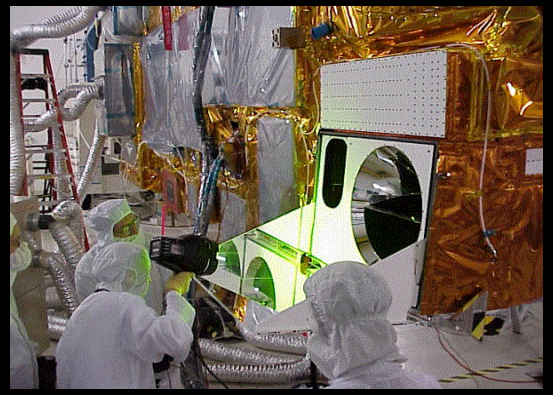
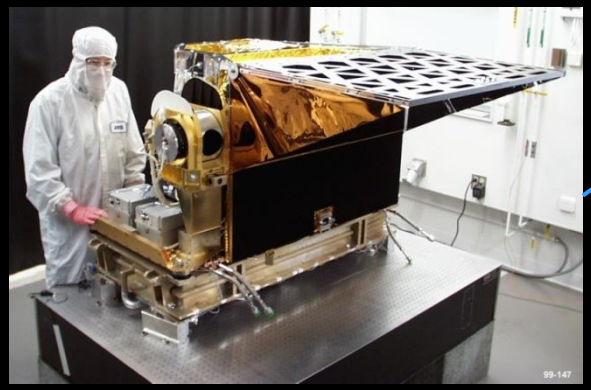
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Dr., Pasadena CA 91109; (818) 393-3917

The Aqua Spacecraft ("BigSat")

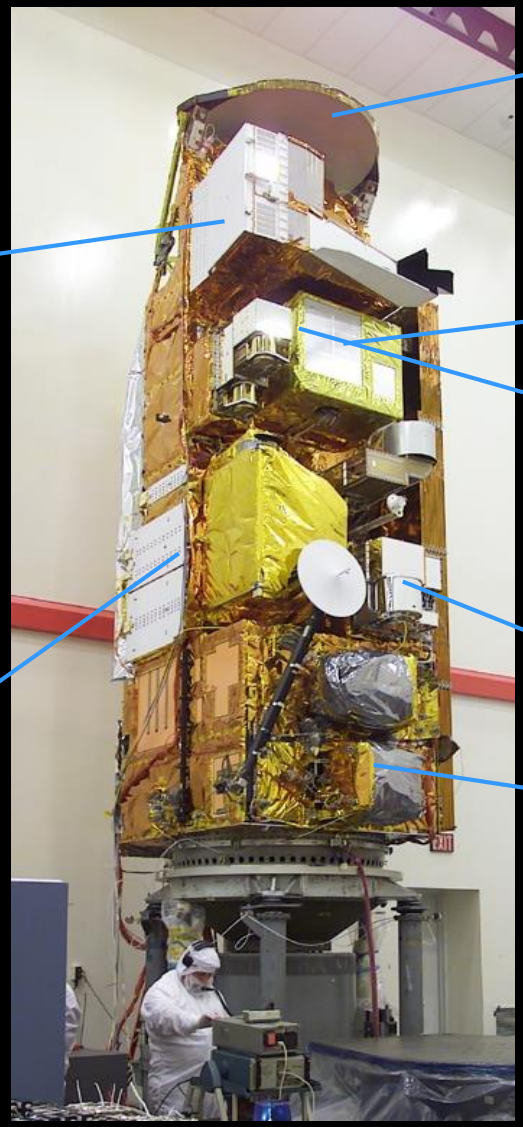
Launched May 4, 2002



Moderate Resolution Imaging Spectroradiometer (MODIS)
GSFC/Raytheon

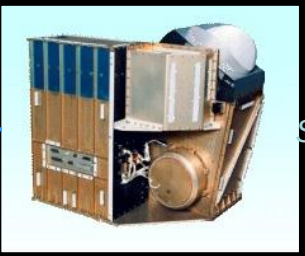


Atmospheric Infrared Sounder (AIRS)
JPL/BAE SYSTEMS

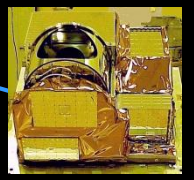


AQUA Spacecraft
GSFC/NGST

Advanced Microwave Scanning Radiometer (AMSR-E)
MSFC/JAXA



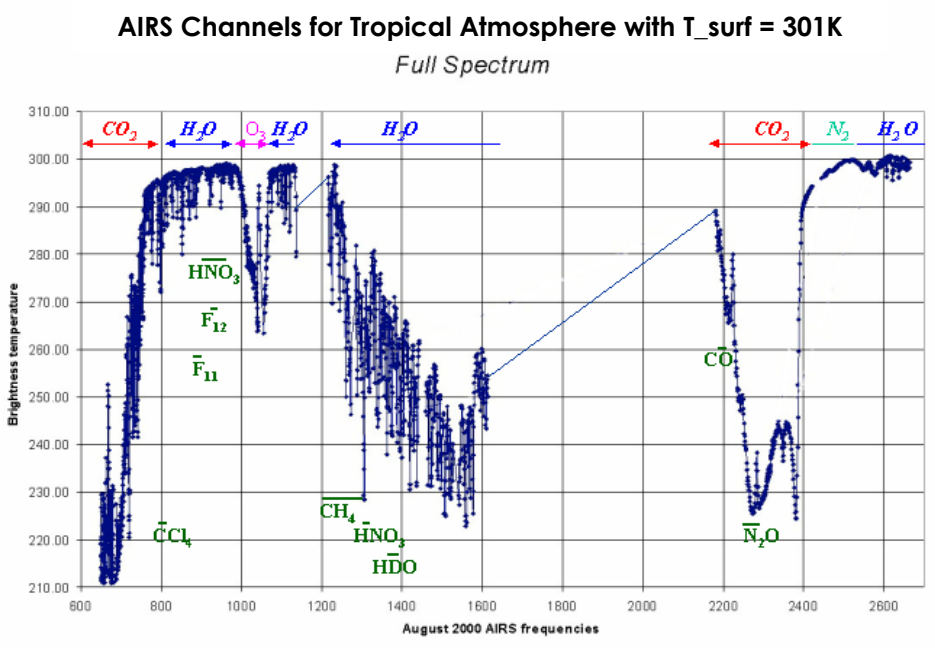
Advanced Microwave Sounding Units (AMSU-A/B)
JPL/Aerojet

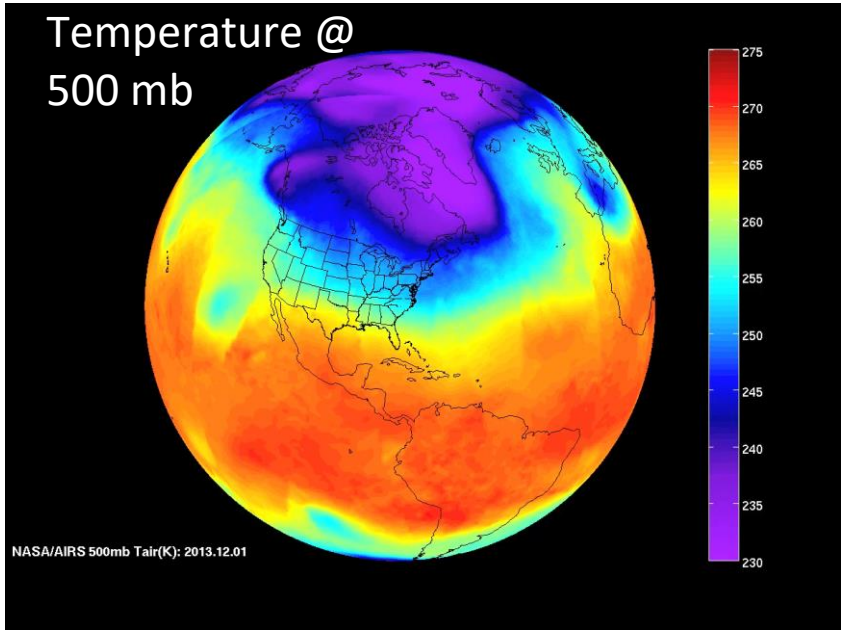


Humidity Sounder from Brazil (HSB)
JPL/Aerojet

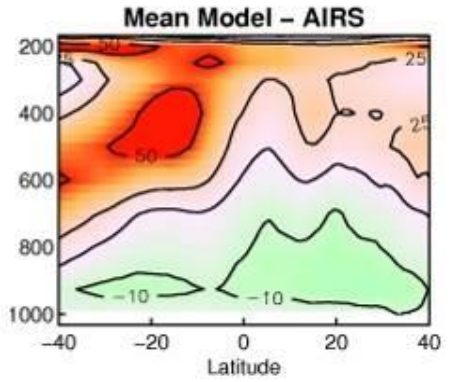
Clouds and Earth Radiant Energy System (CERES)
$_2$LaRC/NGST

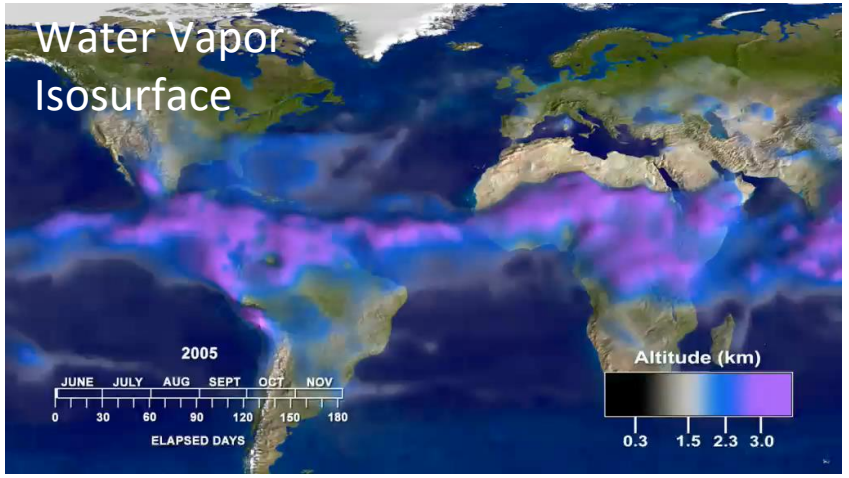
IR Sounders Support Weather Forecasting and Climate Science



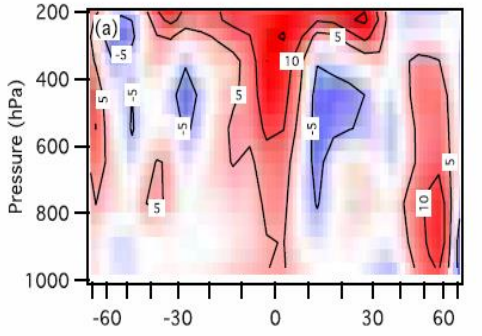


Water Vapor Climatology
(Pierce, Scripps, 2006)





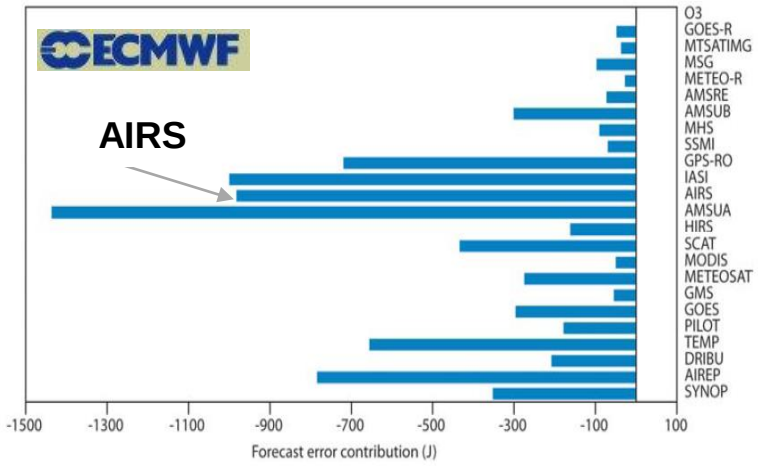
Water Vapor Feedback
(Dessler, Texas A&M, 2008)



JPL/GSFC

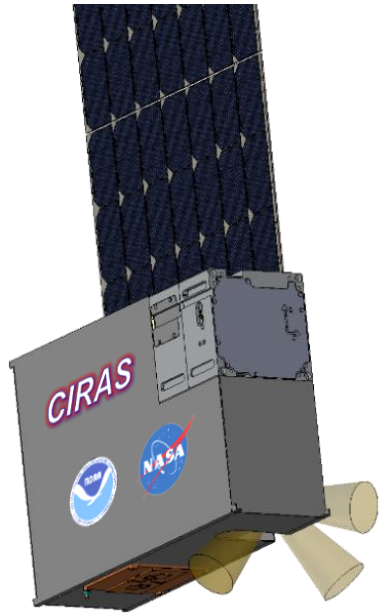
NOAA
NESDIS/NCEP

JCSDA



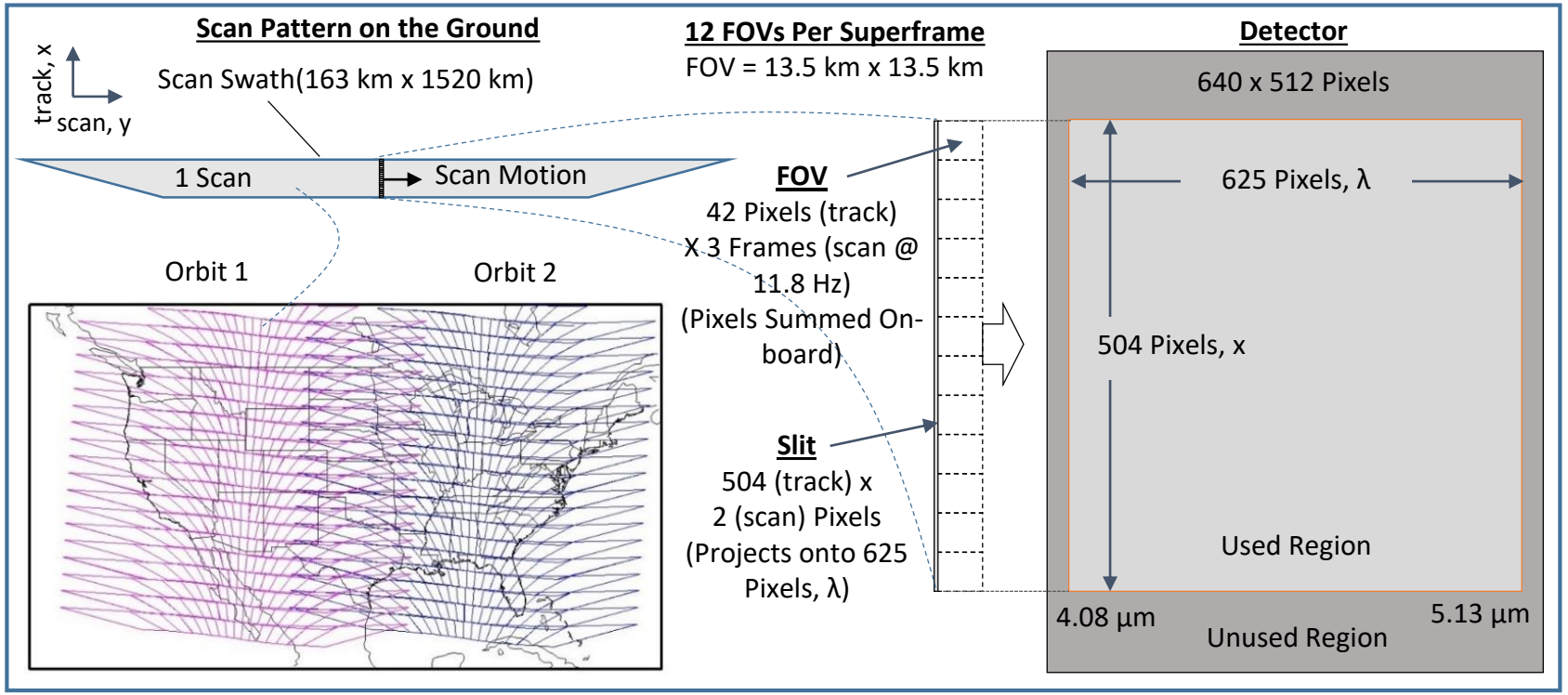
CubeSat Infrared Atmospheric Sounder (CIRAS) Mission Overview

- Mission Objectives
  - In-Space Technology demonstration for key infrared subsystems: HOT-BIRD IR Detectors, Immersion Grating Spectrometer, Black Silicon Blackbody
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Comparable sensitivity to AIRS/CrIS in the lower troposphere.
  - All technologies will be advanced to TRL 7 at the end of experiment
- Implementation Summary
  - JPL Lead + HOTBIRD + Immersion Grating + Black Si, Ball Optics, IR Cameras Camera, Blue Canyon Technologies (BCT) Spacecraft
  - 6U CubeSat (approx. 30 x 20 x 10 cm, <14 kg)
  - LEO Sun Synchronous Morning Orbit (450 km – 600km)
  - Minimum Mission Duration: 3 months
- 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 EON-IR Study sponsored by the NOAA Office of Projects, Planning, and Analysis (OPPA)
  - Selected on 2/18/16 for a launch opportunity by the NASA CubeSat Launch Initiative .
  - Interim Review 1 on February 10, 2017
  - Launch no earlier than January 2019

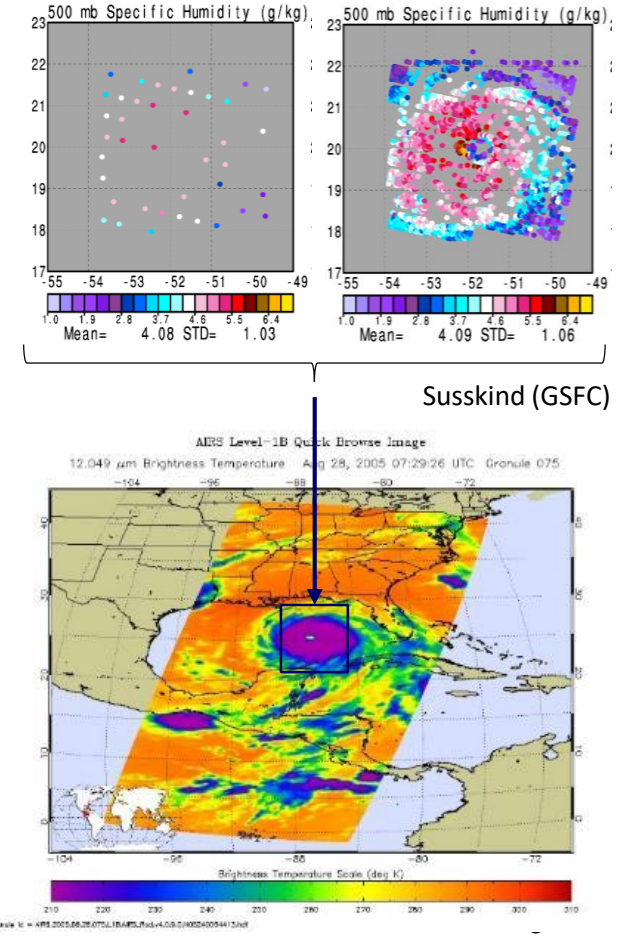


CIRAS spatial resolution comparable to AIRS, CrIS + Zoom

- **Programmable Pixel Binning and Scan Rate Allow Global and Zoom Modes**
- **CIRAS Binning Scheme (600 km Orbit):**



Zoom Mode Improves Yield



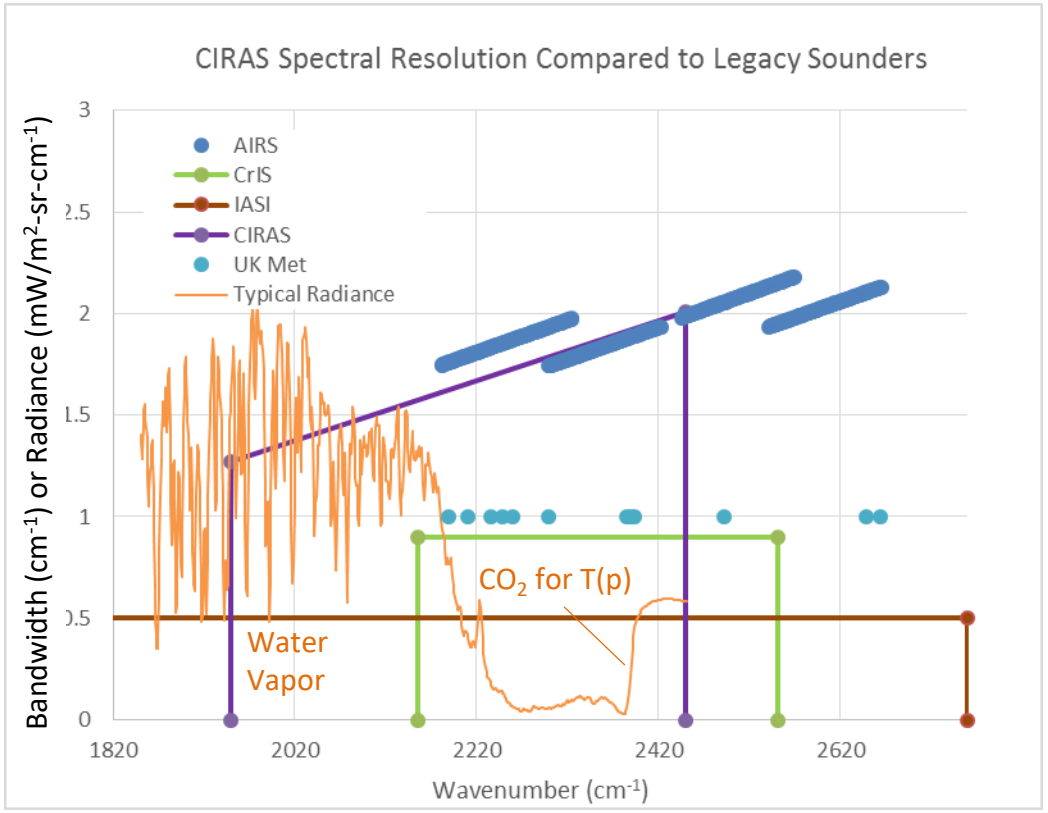
AIRS Global Mode

CIRAS spectral performance comparable to AIRS in the MWIR

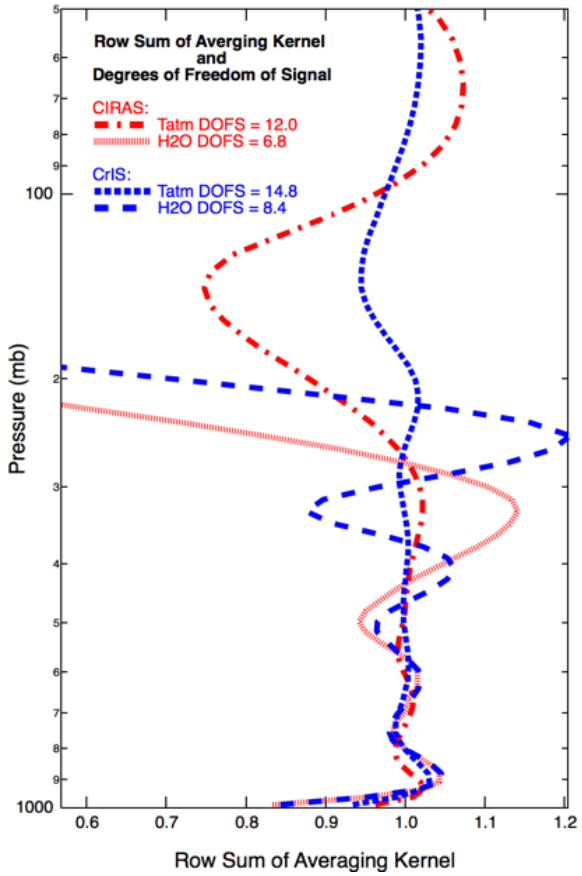
CIRAS Spectral like AIRS but Extends into the Water Band

1950 cm^{-1} – 2450 cm^{-1}

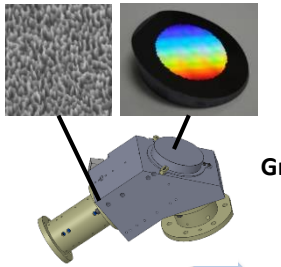
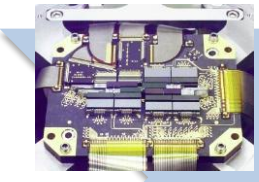
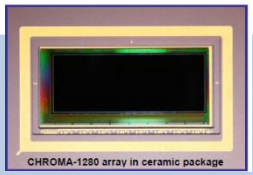
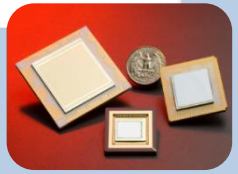
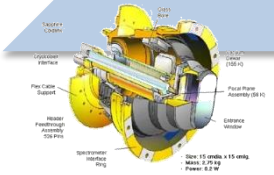
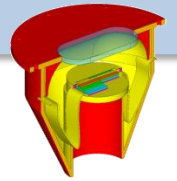
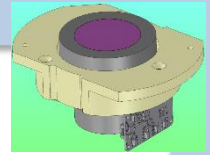
$\Delta\nu$ = 1.2-2.0 cm^{-1} , N_{ch} = 625



CIRAS Information Content Extends from the Surface to 300 mb

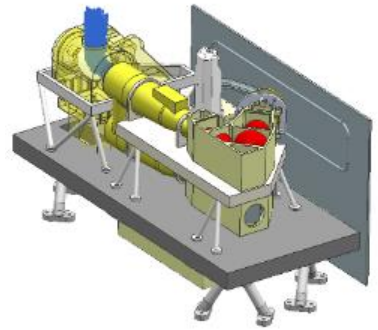


Infrared Grating Spectrometer Atmospheric Sounder Technology

	AIRS	MIRIS	CIRAS
		ESTO	ESTO
Spectrometers	 AIRS BAE Systems Pupil-Imaging Grating Spectrometer FOV = 1.1° D = 2 mm	 SIRAS, SIRAS-G Ball Aerospace Imaging MWIR Grating Spectrometer FOV = 16° D = 25 mm	 CIRAS Ball Aerospace / JPL Imaging MWIR Immersion Grating Spectrometer FOV = 16° D = 15 mm
Detectors	 AIRS BAE Systems PV/PC HgCdTe 17 modules 2 x ~180 100 x 50 um	 CHROMA Teledyne PV HgCdTe 13.5 um Cutoff 480 x 1280 30 x 30 um	 HOTBIRD JPL 5.5 um Cutoff 640x512 24 x 24um
Dewars	 AIRS BAE Systems Cryo Dewar	 SIRAS Ball Aerospace Reflecting Warmshields	 CIRAS IR Cameras IDCA
Cryocoolers	 AIRS Northrop Grumman Pulse Tube Cryocoolers	 ABI / OCO-2 Northrop Grumman Smaller Pulse Tube Cryocoolers	 Ricor K508 Integral Sterling Cryocooler

AIRS 2002

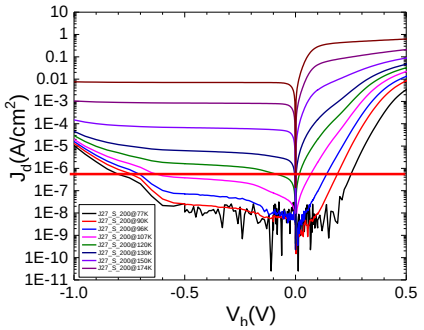
MIRIS 2010 (Concept)

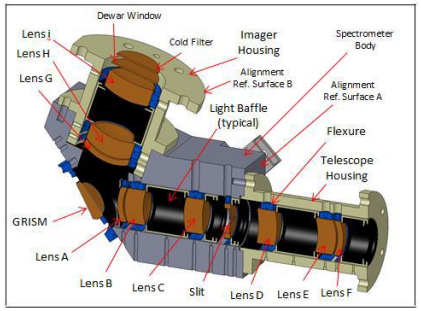


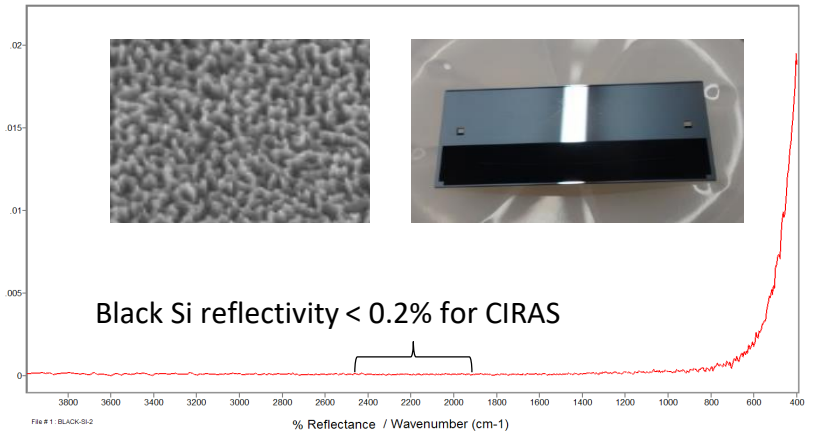
CIRAS 2019

CIRAS Key Technologies Development Status

- **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 low 1/f noise.
  - Detector/ROIC (Sensor Chip Assembly, SCA) complete. SCA's under test.
- **MWIR Grating Spectrometer (MGS) (TRL 5)**
  - All refractive grating spectrometer with a 16 degree Field of View. Covers 4.08-5.13 µm and 625 channels. MGS design complete. Build by Ball Aerospace with immersion grating and slit by JPL.
  - MGS in final design and parts procurement phase at Ball. Slit in design, procuring immersion grating substrate.
- **Black Silicon IR Blackbody (TRL 5)**
  - A cryo-etched silicon surface that exhibits less than 0.2% reflectance across a broad spectral band. Developed at JPL
  - CIRAS Black Si Slit and Blackbody currently in the design phase.
- **All technologies will be advanced to TRL 7 at the end of the spaceflight mission**

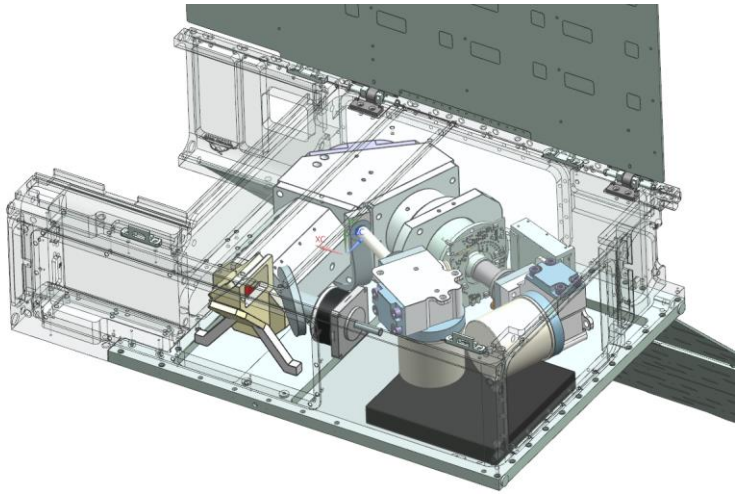


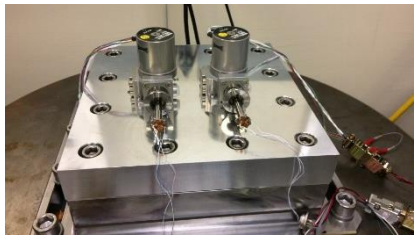


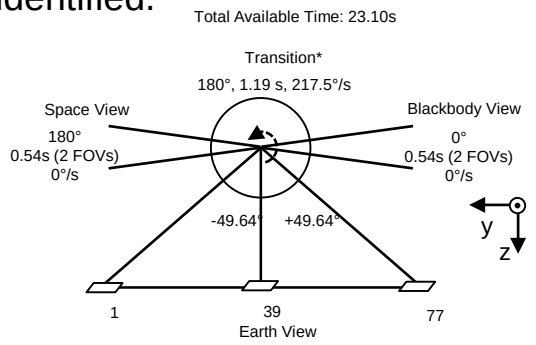


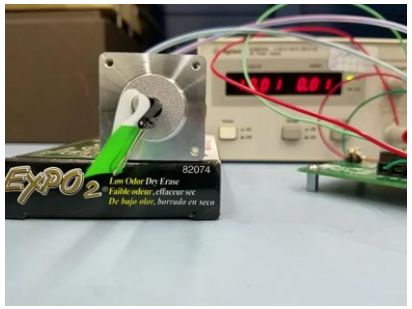
CIRAS Project Status

- Management
  - Project completed SRR. PDR/CDR in August 2017
  - On schedule for May 2018 Payload Delivery.
- Systems Engineering
  - System Requirements Review complete. All trades complete.
- Optics
  - Ball under contract for phase 2, optics development.
- Mechanical
  - Preliminary packaging complete. Interfaces, structural analysis and mounts in progress.
- Thermal
  - Dynamic thermal model of payload complete. Thermal isolation requirements defined. Vibration levels of coolers measured
- Electrical
  - Commercial camera boards procured. Latchup sensitive parts identified. Payload controller PWB board procurement in place. Mechanical packaging requirements identified. Scan motor procured. Required profile demonstrated.
- Detectors and Dewar
  - SCA Fab complete, SCA's in Test. IDCA procurement in place.
  - Commercial IDCA by IR Cameras.
- Spacecraft
  - Contract established with BCT for September 2018 spacecraft delivery.



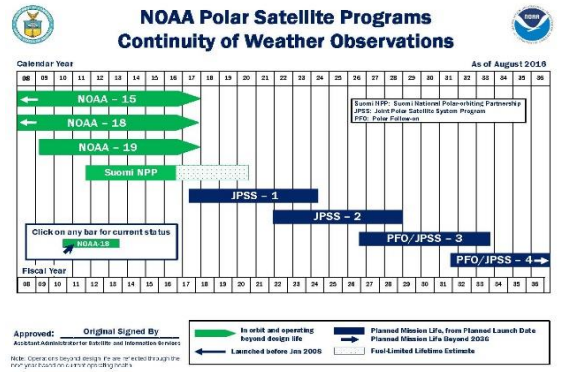


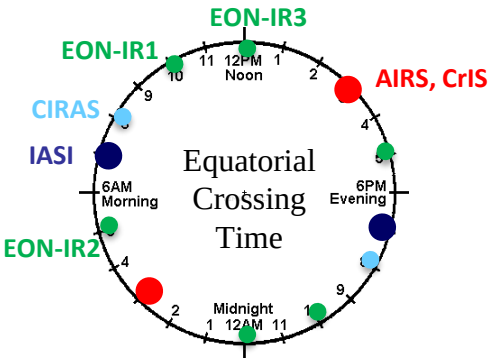


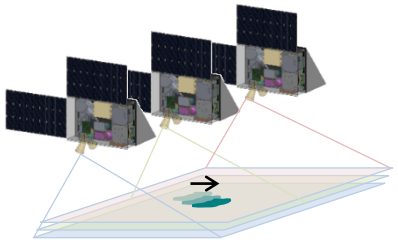


CIRAS Future Mission Concepts

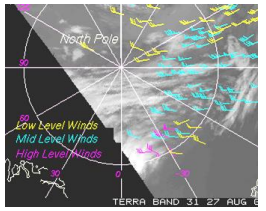
- **Gap Mitigation**:
  - Support the NOAA Joint Polar Satellite System (JPSS) project as a gap mitigation of infrared sounding in the event of a loss of the Cross-track Infrared Sounder (CrIS) instrument.
  - NOAA has identified the Earth Observation Nanosatellite-Infrared (EON-IR) as a potentially valuable instrument for gap mitigation
  - CIRAS is a technology pathfinder for EON-IR
- **Improved Timeliness**:
  - Low cost of CIRAS lends itself to placement in orbits to complement existing sounders and improve revisit time
  - This application could be used to improve Numerical Weather Prediction worldwide, or to study the diurnal properties of hydro-thermodynamic processes in the lower troposphere.
- **3D AMV Winds**:
  - Each CIRAS sounder provides imagery of water vapor in 3D since each horizontal pixel contains a vertical sounding profile.
  - 3 CIRAS instruments flown in formation and separated in time by 15 min – 1 hr would allow measurement of the data needed to produce 3D Atmospheric Motion Vector (AMV) winds
- **AIRS Pollution Studies**
  - The CIRAS band from 1950-2450 cm^{-1} can measure lower tropospheric Carbon Monoxide (CO)



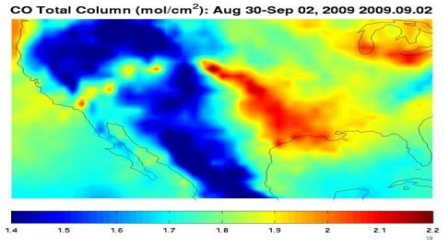




MODIS AMV Winds



AIRS Carbon Monoxide



Summary and Conclusions

- The CubeSat Infrared Atmospheric Sounder (CIRAS) is a 6U CubeSat under development at JPL sponsored by the NASA ESTO In-Flight Validation of Earth Science Technologies (InVEST), 2015
- CIRAS undergoing detailed design. Major procurements in place.
- Extensive use of commercial technologies including the camera boards, Ricor K508 cryocoolers, LIN engineering scan motor with TI controller, Blue Canyon Technologies spacecraft technologies.
- Key technologies progressing well: HOTBIRD SCA's fabricated, spectrometer design complete and procurements in place, black silicon slit and blackbody in design phase
- Project PDR/CDR in August with I&T starting in January. Payload complete in May 2015.
- Spacecraft procurement in place. Expect delivery of completed CIRAS spacecraft with integrated payload ready for launch in September 2018.
- Design will meet all major technology demonstration objectives and function as a good IR sounder.
- Several possible applications with this technology including gap mitigation, improved timeliness, 3D IR AMV winds, atmospheric composition