Technology development in support of a future Earth Observing Nanosatellite-Infrared (EON-IR) atmospheric sounder

Advances in CubeSats and SmallSats to
Improve Earth Science and Weather Forecasting
AMS 97th Annual Meeting, Seattle, Washington
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IR Sounding legacy spans 4 decades

- **AIRS: Demonstration Mission**
  - Launched on Aqua on May 4, 2002: ECT: 1:30
  - First demonstration of hyperspectral infrared grating spectrometer for atmospheric sounding
  - Over 26 atmospheric and surface products
  - Over 860 Peer Reviewed Publications To Date
  - Over 900 Registered users worldwide
  - Science Topics: Weather related processes (transport, convection, extremes), climate science (ENSO, MJO, climate model validation), and applications (drought, vector borne diseases, flu, air quality)
- **IASI and CrIS: Data Continuity**
  - CrIS on Suomi NPP + 4 JPSS through 2036+
  - IASI on MetOp-A and MetOp-B today and beyond
  - AIRS, IASI, CrIS radiances agree to better than 0.2 K
- **High Value to Weather, Climate and Composition**
  - IR Sounder data and radiances used for science and weather prediction by users worldwide
  - IR Sounders have the highest impact of any single instrument type to operational forecast improvement. Second highest overall next to microwave

AIRS Instrument

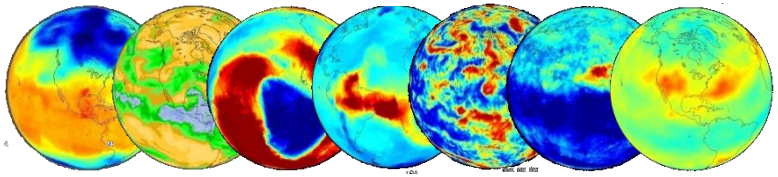
AIRS Technology Firsts

Split Sterling Pulse Tube Cryocooler (NG)

IR Grating Spectrometer 155K Operation

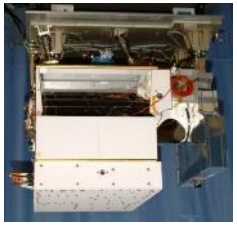
FPAs: PV HgCdTe to 13.7 µm, PC HgCdTe to 15.4 µm

AIRS Measures Key Climate Variables

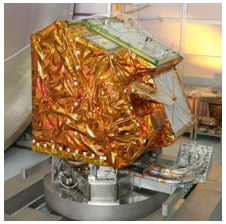


Temperature | Water Vapor | Ozone | Carbon Monoxide | Cloud Properties | Methane | Carbon Dioxide

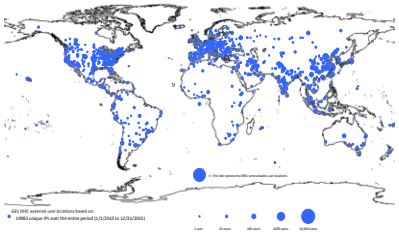
CrIS on JPSS



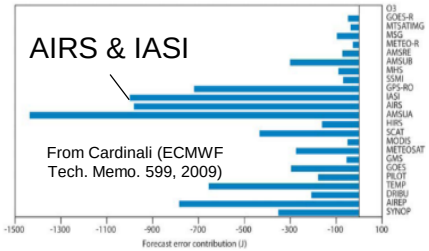
IASI on MetOp



AIRS Users Worldwide

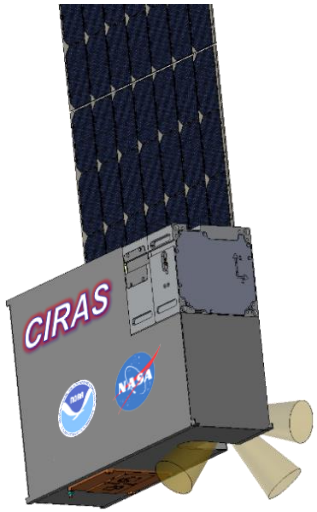


Sounders High Forecast Impact



CIRAS Mission Overview

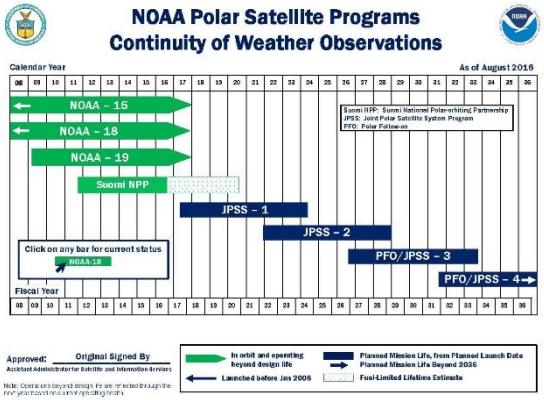
- **Mission Objectives**
  - In-Space Technology demonstration for key infrared subsystems: HOT-BIRD IR Detectors, Grism Spectrometer, Black Silicon Blackbody
  - Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Comparable to AIRS/CrIS in the lower troposphere.
  - All technologies will be advanced to TRL 7 at the end of experiment
- **Implementation Summary**
  - JPL Lead + HOTBIRD + Grism + 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

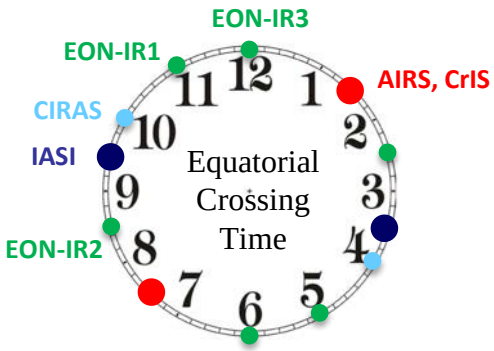


- **Programmatic Summary**
  - Sponsored by NASA Earth Science Technology Office (ESTO) In-flight Validation of Earth Science Technologies (InVEST) Program, Awarded 2015
  - Design performed in collaboration with the EON-IR Study sponsored by the NOAA Office of Projects, Planning, and Analysis (OPPA)
  - 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

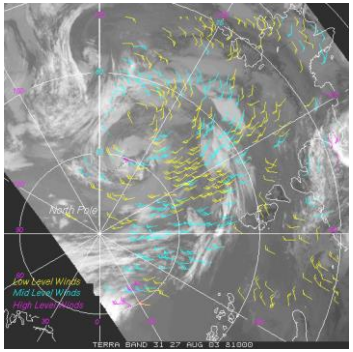
CIRAS Future Mission Concepts

- **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.
  - Cross-calibration of IR sounders shown to be better than 0.2 K (1σ) (Aumann, SPIE 2014) under most scene conditions.
- **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
  - CIRAS expected to be less capable/costly as MISTIC Winds

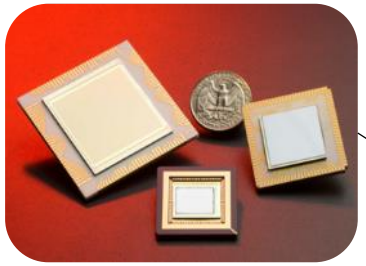




MODIS AMV Winds



CIRAS Instrument

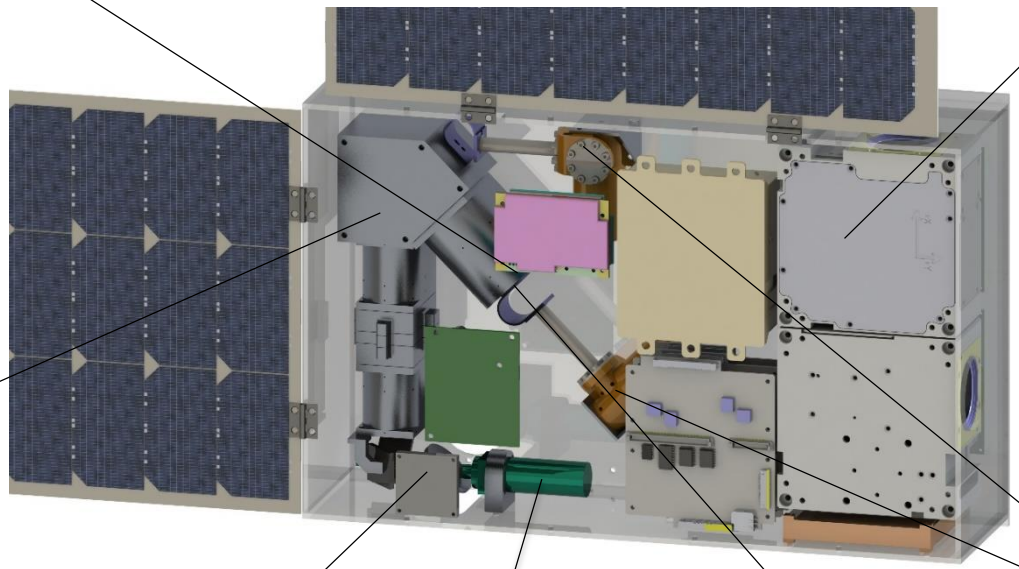


Detectors and FPA
HOTBIRD
(JPL)

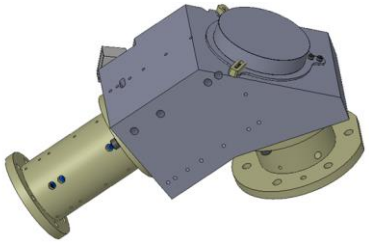
Size	*6U Cubesat*
Mass	*14 kg*
Power	*37.5W*
Data Rate	*0.3 Mbps*

7 Major Subsystems

Blue Canyon Technologies
Spacecraft

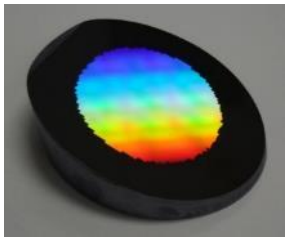


Optics Assembly
Telescope/MGS
(Ball)

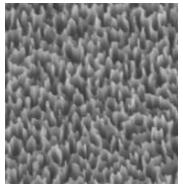


Payload Electronics
(JPL) +
Camera Electronics
(IR Cameras)

Immersion Grating

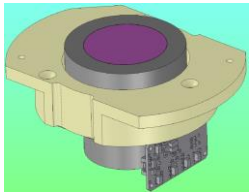


Blackbody
Assembly
Black Silicon



Scan Mirror Assy
Commercial Stepper
Motor + Electronics

Dewar (IDCA)
(IR Cameras)



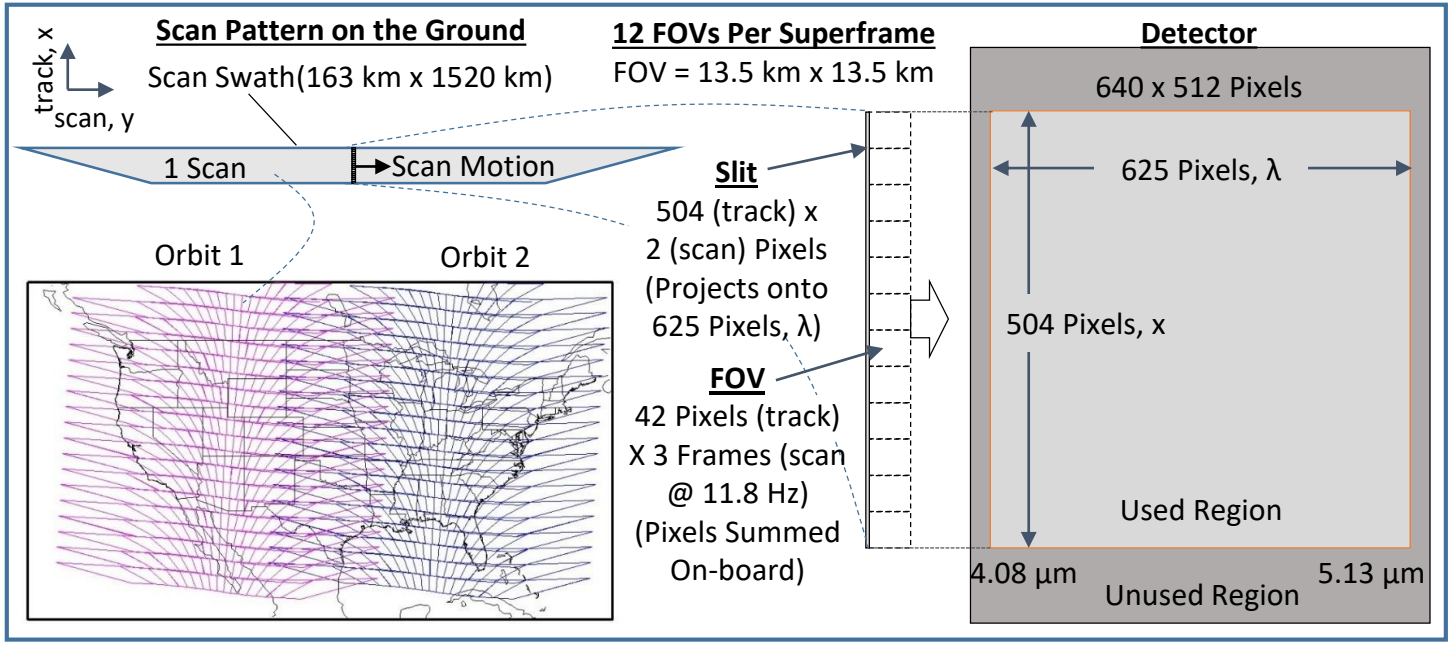
Cryocoolers +
Electronics
(Ricor K508)

JPL MDL Technologies

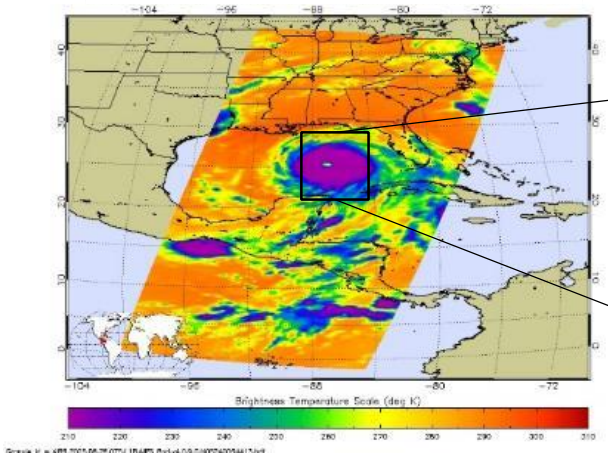
CIRAS spatial resolution comparable to AIRS, CrIS + Zoom

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

CIRAS Binning Scheme (600 km Orbit)

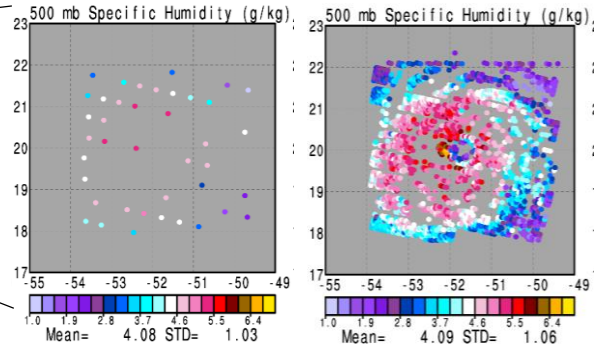


AIRS Global Mode



Simulated Sounder Yield

Global Mode 13.5 km GSD | **Zoom Mode 3 km GSD**



Susskind (GSFC)

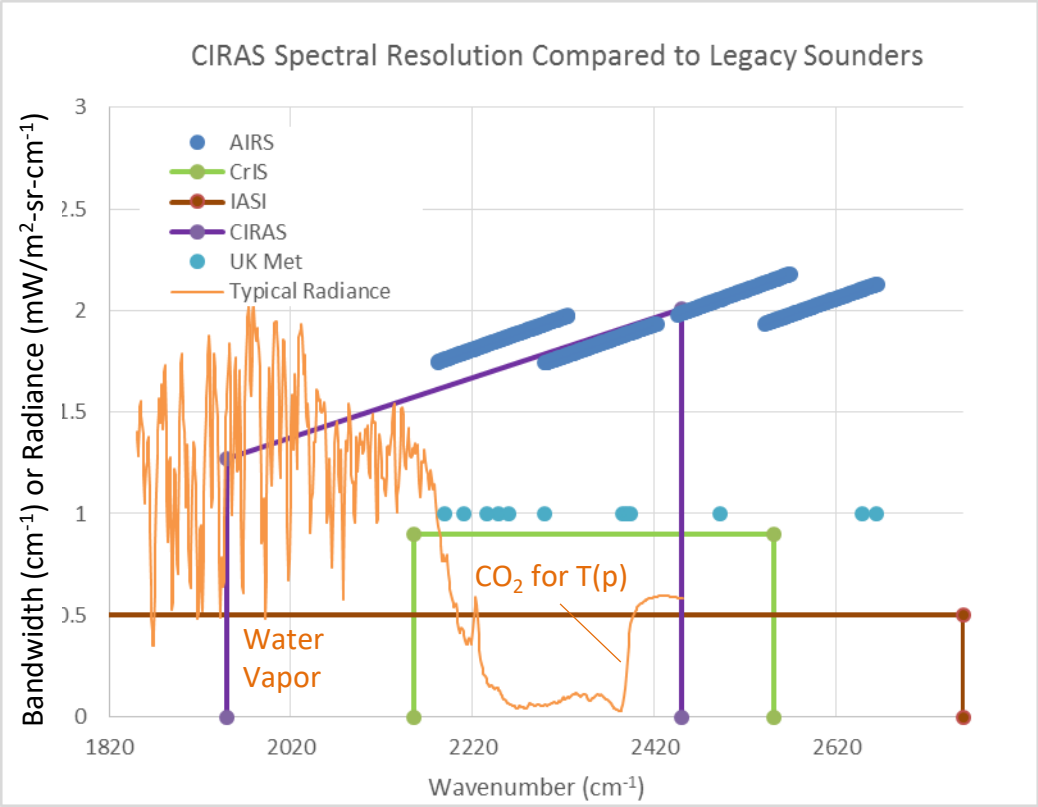
CIRAS Spectral performance comparable to AIRS in the MWIR

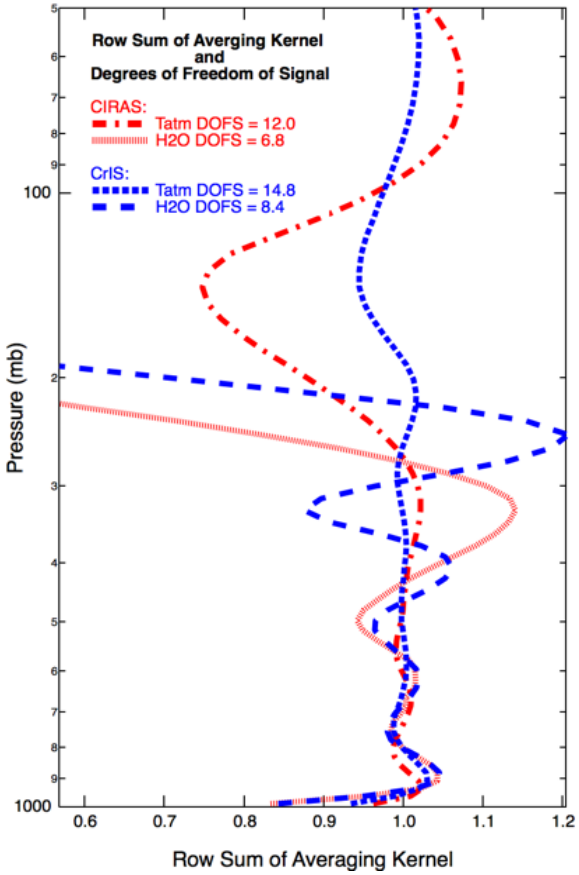
CIRAS Spectral like AIRS but Extends into the Water Band

1950 cm^{-1} – 2450 cm^{-1}

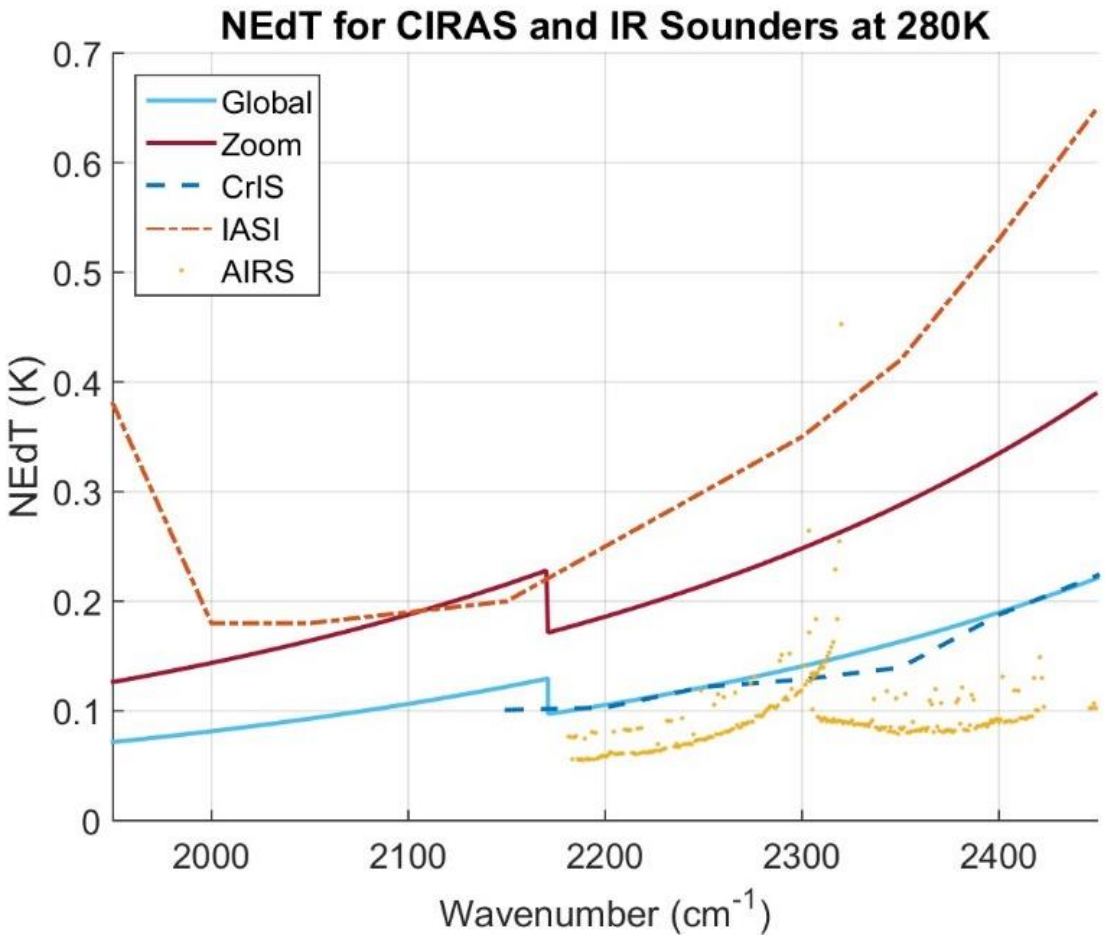
$\Delta\nu$ = 1.2-2.0 cm^{-1} , N_{ch} = 625

CIRAS Information Content Extends from the Surface to 300 mb





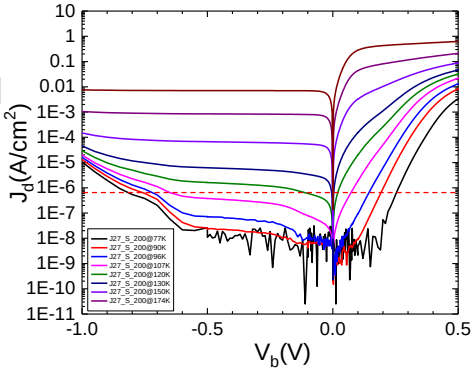
CIRAS Noise Equivalent Differential Temperature (NEdT) Comparable to Legacy Sounders



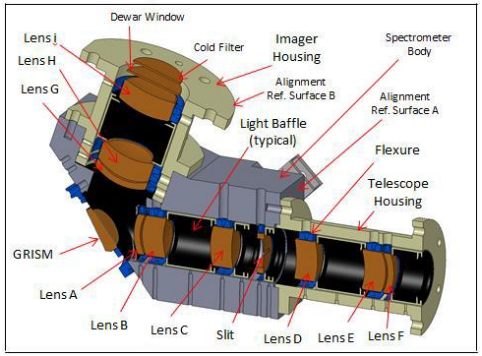
CIRAS Key Technologies in Development

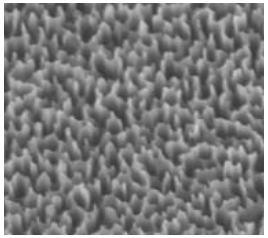
- **HOT-BIRD Detectors (TRL 6)**
  - The new High Operating Temperature Barrier Infrared Detector (HOT-BIRD) detector materials developed at JPL provide superior uniformity and operability, higher operating temperature, and low 1/f noise. Detector material fabricated. Next step is pixel delineation.
- **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 grism and slit by JPL.
- **Black Silicon IR Blackbody (TRL 5)**
  - A cryo-etched silicon surface that exhibits less than 0.2% reflectance across a broad spectral band. To be built at JPL.
- **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**

CIRAS Detector Material Meets Spec



CIRAS All Refractive Grating Spectrometer

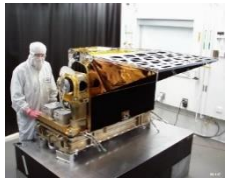
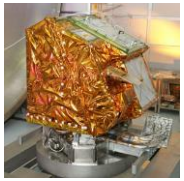
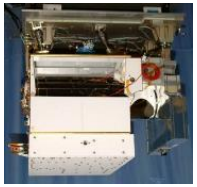
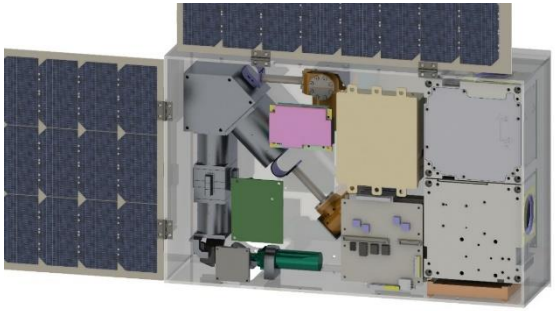
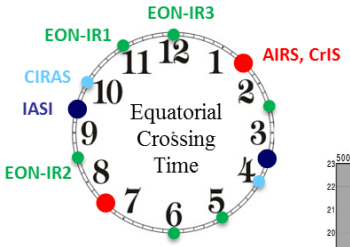
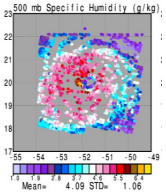




Black Silicon Blackbody & Slit

Questions remain and work to be done

- **Questions remain:**
  - Is the impact of CIRAS sufficiently positive to make it worth the cost to NWP centers?
  - Is the information content in the MWIR band sufficient to capture the key IR sounder climate variables: T(p), q(p), clouds, trace gases?
  - Are the radiances of sufficient accuracy and stability to complement the climate record?
- **Work to be done:**
  - Successful implementation of CIRAS will help answer some of these questions.
  - Requires support from the IR sounding community, NASA, NOAA and NWP centers worldwide is essential
    - Additional technology demonstration to support operational implementation of CIRAS (towards an EON-IR). Thermal control, extended life, higher duty cycle, etc.
    - Cross-calibration demonstration with CIRAS, AIRS, IASI, CrIS
    - Radiative transfer improvement in the MWIR
    - Data assimilation studies (e.g. OSSEs)
    - Sensor simulation studies: Effects of sensor performance on measurement objectives. (NEdT, Spectral Resolution, Spatial Resolution, etc.)
    - Mission planning and architecture studies (e.g Orbits, Sensor Web)
    - International participation will promote development of a low cost constellation

Summary and Conclusions

- **Legacy IR Sounding**
  - Hyperspectral Infrared atmospheric sounders measure the upwelling Earth radiances with high spectral and radiometric resolution, precision and accuracy
  - IR Sounder data show high impact to operational forecast and support premier atmospheric process and climate science
  - The future of IR Sounders is assured with AIRS, CrIS and IASI
- **The CubeSat Infrared Atmospheric Sounder (CIRAS)**
  - Tech demo under development at JPL with Ball, IR Cameras, and BCT
  - Sponsored by the NASA InVEST program
  - Scheduled for launch in early 2019 timeframe
- **CIRAS is cheap. How can we make use of this asset?**
  - Gap mitigation, additional orbits, 3-satellite constellation for AMV Winds
  - Zoom mode (3km) will help focus on critical areas
- **CIRAS is highly synergistic**
  - Existing IR Sounders (AIRS, CrIS, IASI)
  - Microwave CubeSat sounders (e.g. MicroMAS, TEMPEST-D)
- **Community participation needed**
  - Tech demos, RTA development, OSSEs, cross-cal, architecture studies, product development, etc.