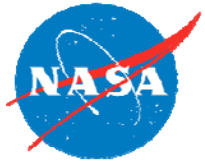

Results of NASA/NOAA HES Trade Studies

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NOAA Satellite Hyperspectral Spectrometer Workshop
March 29-31, 2011
Miami, Florida

Hyperspectral Environmental Suite (HES)

HES requirements originally called for two distinct sets of capabilities

1) IR hyperspectral sounder designed for flight on GEOS-R with comparable spectral and radiometric performance to AIRS/CrIS

   Provides information about surface and atmospheric temperature, water vapor, and clouds

2) Inclusion of visible channels to measure ocean color

   Requirement 2) was eliminated as part of trade studies designed to minimize HES cost and risks

Three vendors BAE, BALL, and ITT were selected to conduct the HES Trade Studies

All vendors were required to evaluate both Dispersive (AIRS-like) and Interferometric (CrIS-like) approaches for the HES IR Sounder

All vendors were also required to perform risk reduction studies

Fabricate detector arrays and laboratory spectrometers which meet HES spectral, radiometric, operability, distortion, and crosstalk requirements

Trade Studies

The vendors were required to conduct 11 Trade Studies

The goal of the trade studies was to minimize instrument cost and risk while producing scientifically useful products

Trade Study requirements were based on a dialogue between vendors and Government Scientists

- Requirements had to be achievable from the vendor perspective
- Requirements had to be compatible with at least minimal scientific needs

Trade Study 1 involved a wish list of things scientists would like from GEO orbit

- All vendors showed that these would result in a very high cost/high risk instrument

Trade Study 11 was for a Reduced Accommodation Sounder (RAS)

- **RAS Accommodation constraints**
  - Mass, power, volume, and data rate for RAS were compatible with flight on GEOS-R
- **RAS Technical constraints**
  - RAS Spectral and radiometric requirements, as well as spatial and temporal coverage, would result in useful scientific products

All vendors had low technical risk instrumental designs compatible with RAS constraints

Accommodation Constraints for RAS for Flight on GEOS-R Spacecraft

	RAS	ORIGINAL
Mass	210 kg	315 kg
Power	285 W	550 W
Volume	150 cm x 100 cm x 150 cm	170 cm x 170 cm x 150 cm
Data Rate	6.6 MBPS	66.6 MBPS

RAS instrument is smaller than originally planned

A smaller aperature results in higher noise, everything else remaining constant

HES Spectral coverage, spectral resolution, radiometric accuracy requirements were not relaxed for RAS

Spatial coverage and revisit time requirements were all relaxed for RAS to maintain HES radiometric accuracy

Minimal RAS requirement 3000 km x 3000 km, 10 km spatial resolution, 70 minute revisit time – maintains current GOES Sounder coverage

HES AIRS/CrIS Like Spectral Requirements

AIRS covers the spectral ranges 650 cm^{-1} – 1600 cm^{-1} and 2180 cm^{-1} – 2667 cm^{-1}

AIRS resolving power $\nu/\Delta\nu \approx 1200$

AIRS Spectral resolution ranges from 0.5 cm^{-1} at 650 cm^{-1} to 2.2 cm^{-1} at 2667 cm^{-1}

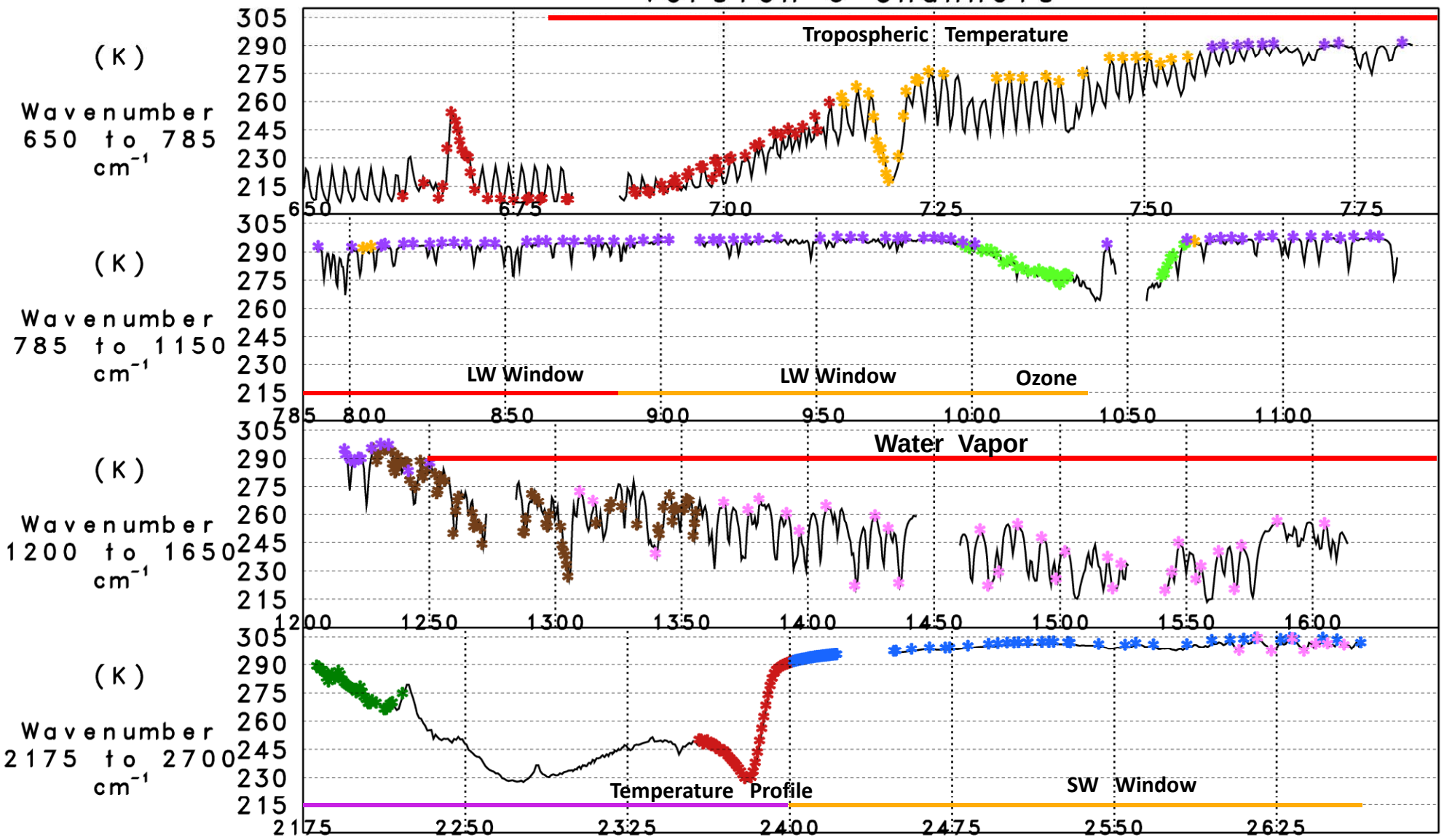
CrIS spectral coverage and spectral resolution are similar to AIRS

HES spectral requirement trade studies

- 650 cm^{-1} – 680 cm^{-1} Measures mid-upper stratospheric temperature
  Detector performance is high risk for all designs
  Spectral coverage in this region was dropped as a HES requirement in early trade studies
- 680 cm^{-1} – 882 cm^{-1} Measures tropospheric temperature and longwave window
  Required for HES
- 882 cm^{-1} – 1040 cm^{-1} Measures ozone and longwave window
  Desirable but dropped as a requirement for HES
- a) 1210 cm^{-1} – 1645 cm^{-1} Measures water vapor

  OR
- b) 1689 cm^{-1} – 2150 cm^{-1} Measures water vapor (not on AIRS/CrIS)
  a) or b) required on HES
- 2150 cm^{-1} – 2400 cm^{-1} Measures temperature profile
  Technologically more challenging for interfermeter
  Very desirable but not required for HES
- 2400 cm^{-1} – 2660 cm^{-1} Shortwave window
  Desirable but not required for HES

Sample AIRS Cloud Free Brightness Temperature Version-6 Channels



*Cloud Clearing *Temperature Profile * Surface Skin
*Water Vapor *Ozone * CO
* CH_4 *LW Emissivity

Required for RAS **Very Desirable for RAS** **Desirable for RAS**

Brief Overview of Vendors Trade Study 11 Designs

BAE

Dispersive Design

Covers 680 cm^{-1} – 1040 cm^{-1}, 1689 cm^{-1} – 2410 cm^{-1}

BALL

Dispersive Design

Covers 680 cm^{-1} – 893 cm^{-1}, 1689 cm^{-1} – 2439 cm^{-1}

ITT

Interferometer

Covers 680 cm^{-1} – 1040 cm^{-1}, 1210 cm^{-1} – 1645 cm^{-1}

All designs meet or exceed accommodation and technical requirements for RAS

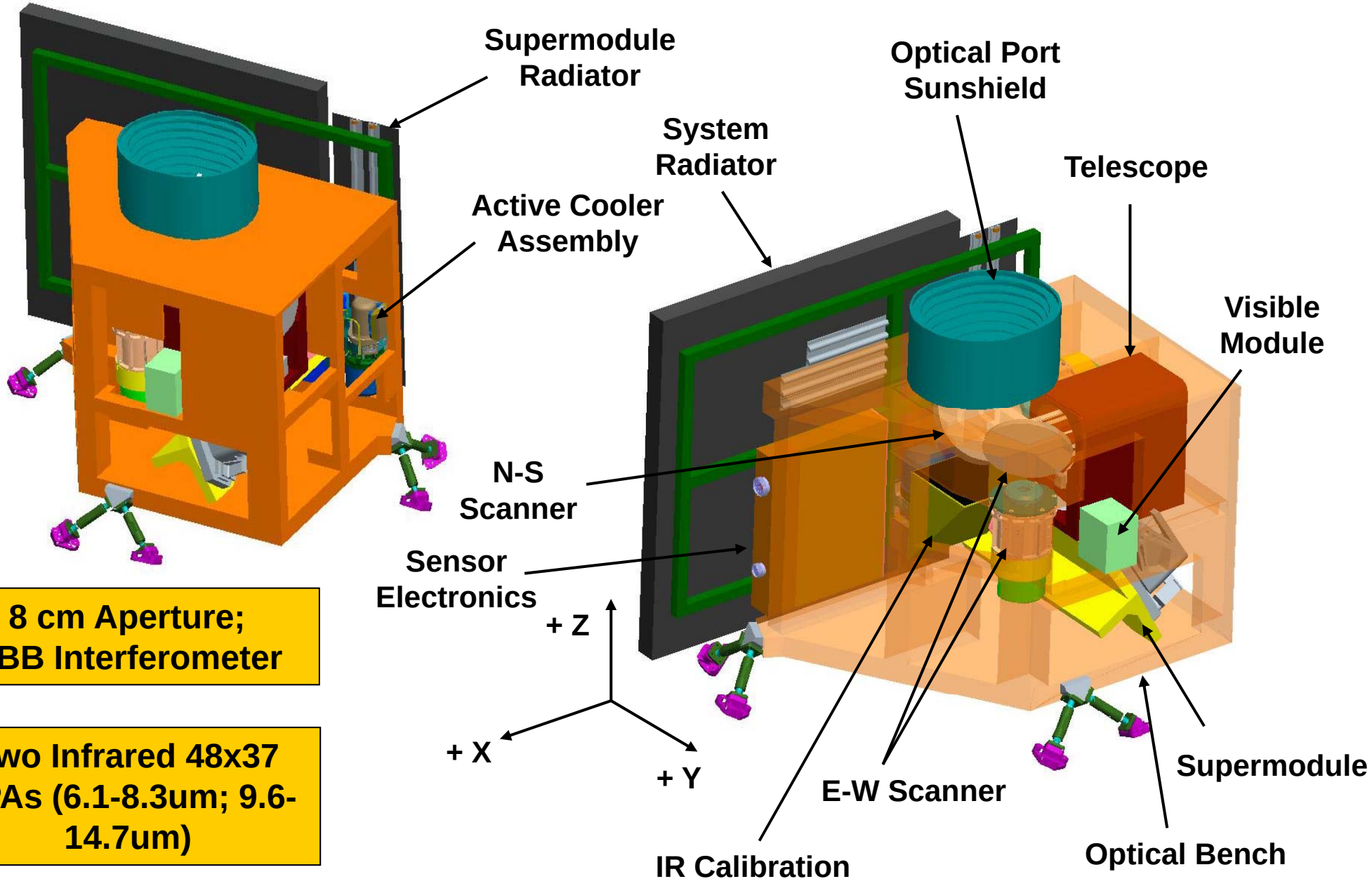
Should provide AIRS quality soundings with at least 10 km resolution

The following material was made available by each vendor for this presentation

Two ITT HES Design Concepts Examined in Detail

- **"Reduced Accommodations" HES Sounder**
  - **Small, reduced-aperture system (8 cm)**
  - **ABB cornercube interferometer system (similar to GFI)**
  - **Two infrared bands with 48x37 FPAs (DRS)**
  - **Active cooling of FPAs**
  - **Significant reuse of ABI components and design approaches**
  - **Interferometer and FPAs demonstrated as part of the Hyperspectral Imaging Test Bed (HITB) risk reduction program**
- **"Maximum ABI Reuse" HES Sounder (a.k.a. "ABX")**
  - **Essentially an ABI instrument with aft optics module removed and replaced with an interferometer and new FPAs**
  - **Larger volume and mass (27 cm aperture)**
  - **Despite larger size, instrument cost and risk are actually lower than the "Reduced Accommodation" design, due to drastic reduction in non-recurring engineering**

Reduced Accommodations HES Design



8 cm Aperture; ABB Interferometer

Two Infrared 48x37 FPAs (6.1-8.3um; 9.6-14.7um)

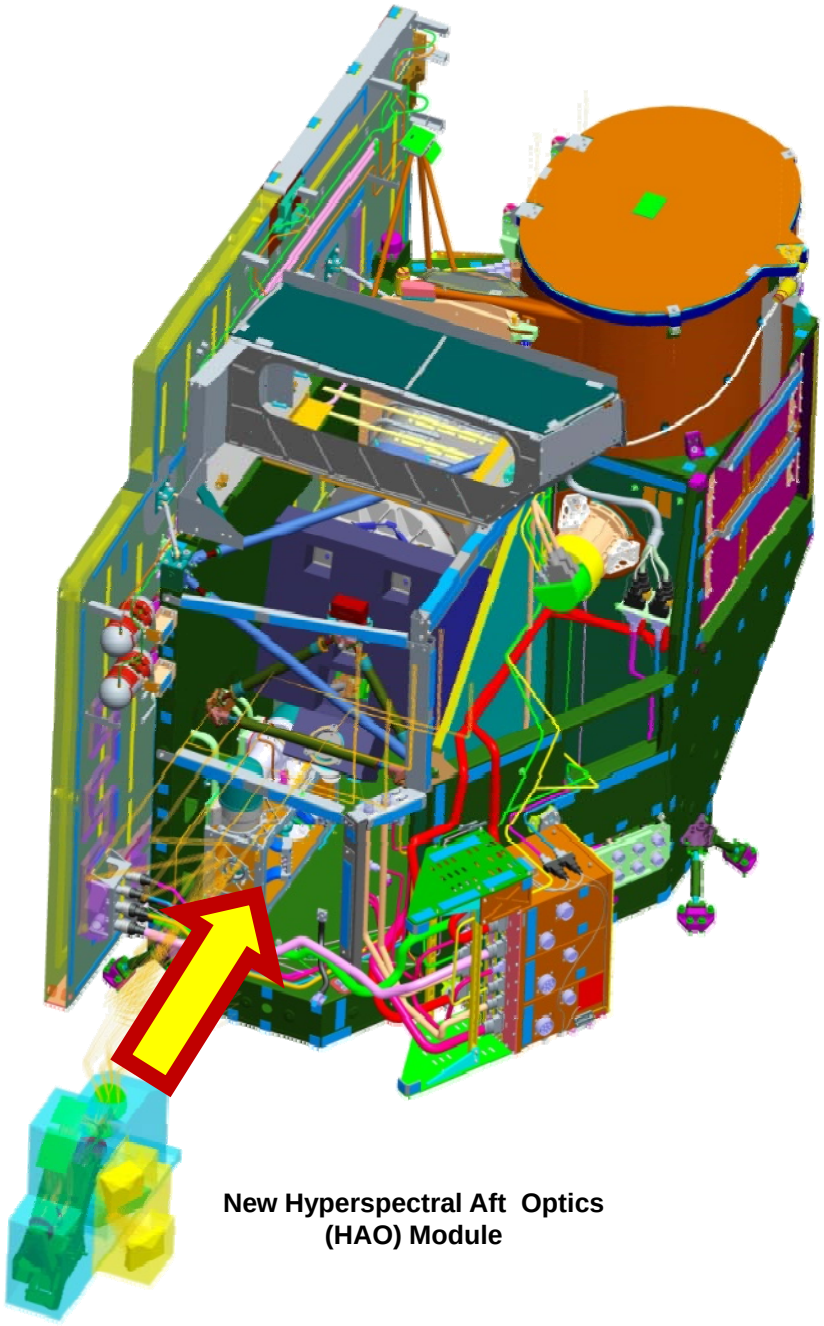
ITT

Reduced Accommodation Design is Compliant With All Requirements

Requirement	Units	Required Value
Data Rate (w/ uncertainty)	Mbps	≤6.6
Power, Average Operational	watts	≤285
Mass	kg	≤210
Width (E-W, X)	cm	≤150
Height (N-S, Y)	cm	≤100
Depth (Nadir-Zenith, Z)	cm	≤150
ZRDQ Operational Zone Inner Boundary: IR-pixels	degrees	≤10
ZRDQ Operational Zone Inner Boundary: Vis-pixels	degrees	≤10
ZRDQ Restricted Zone Inner Boundary: IR-pixels	degrees	≤3
Coverage Time: CONUS Region	minutes	≤70
Long Wavelength Resolution	cm^{-1}	0.875
Mid Wavelength Resolution	cm^{-1}	1.75
Maximum GSA at SSP for DS-IR Bands	μrad	≤280
Maximum GSA at SSP for DS-VIS Band	μrad	≤35
DOEE: DS-IR - Weighted Minimum Band	%	≥70
LW Band NEdN - Minimum Margin	%	≥30
MW Band NEdN - Minimum Margin	%	≥30
Adjacent Pixels Simultaneity, CONUS	minutes	≤10
Absolute Radiometric Accuracy (Max of LW or MW)	K	≤1 or Derived NEdT
Sounder Spectral Stability over any 24 hr period - Maximum	% channel width	<2
Sounder Spectral Bands Simultaneity (Vis to IR)	seconds	≤10

“Maximum ABI Reuse” HES Design

ABI Aft Optics Module is Replaced by a Hyperspectral Module (Interferometer or Dispersive Technologies Are Both Compatible)



New Hyperspectral Aft Optics (HAO) Module

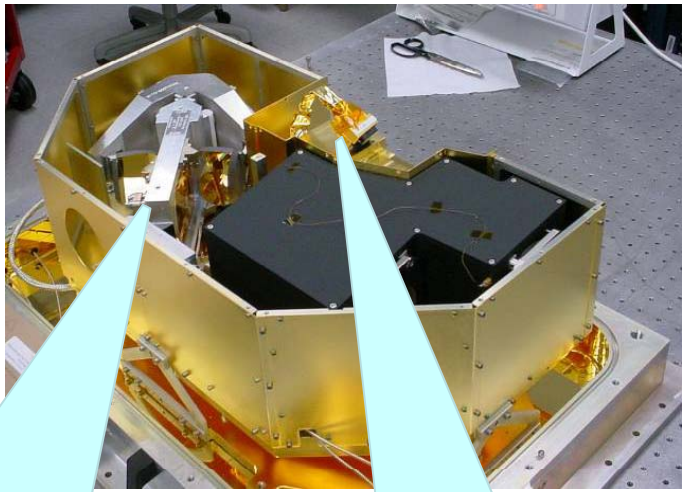
Virtually No Other Changes to ABI Design or Hardware

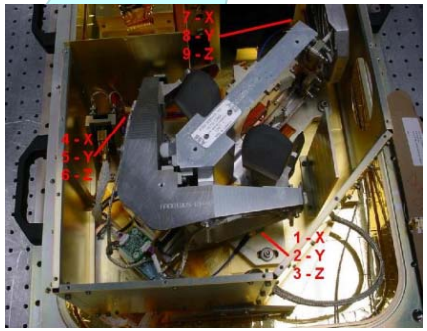
27 cm Aperture, Two Infrared 96x96 FPAs

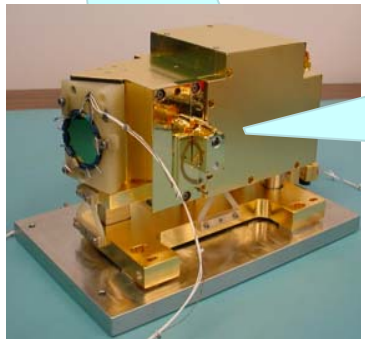
Performance is Superior to Reduced Accommodation Design

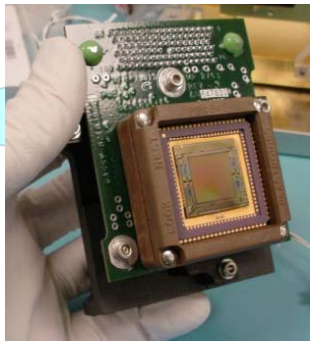
Risk Reductions Eliminated Key Risks for Both Designs

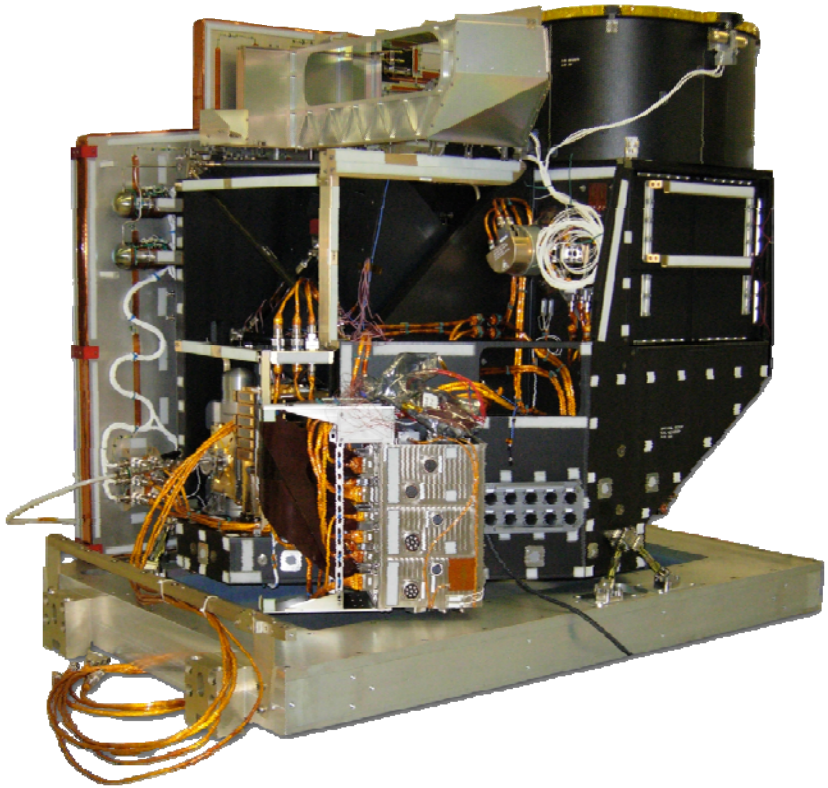
HITB Demonstrated 96x96 FPAs, Cooled Cornercube Interferometer, New Aft Optics, and New Signal Processing Electronics Design











ABI PTM Has Demonstrated Active Coolers, Scanner, Fore-Optics, Structure, Control Electronics, and GEO Thermal Control

Ball Aerospace Baseline Design - Spacecraft Resources

Spacecraft Resource	Simplified Sounder Allocation	Compliant With Margin
Mass (Mature)	<210 kg	Y
Power (Mature)	<285 W	Y
Data Rate (No compression)	<6.6 Mbps	Y
Sensor Unit Envelope	<1.1 x 1 x 1.5 m^3	Y

Ball Aerospace Design Meets the Reduced Capability Spacecraft Accommodations with Margin

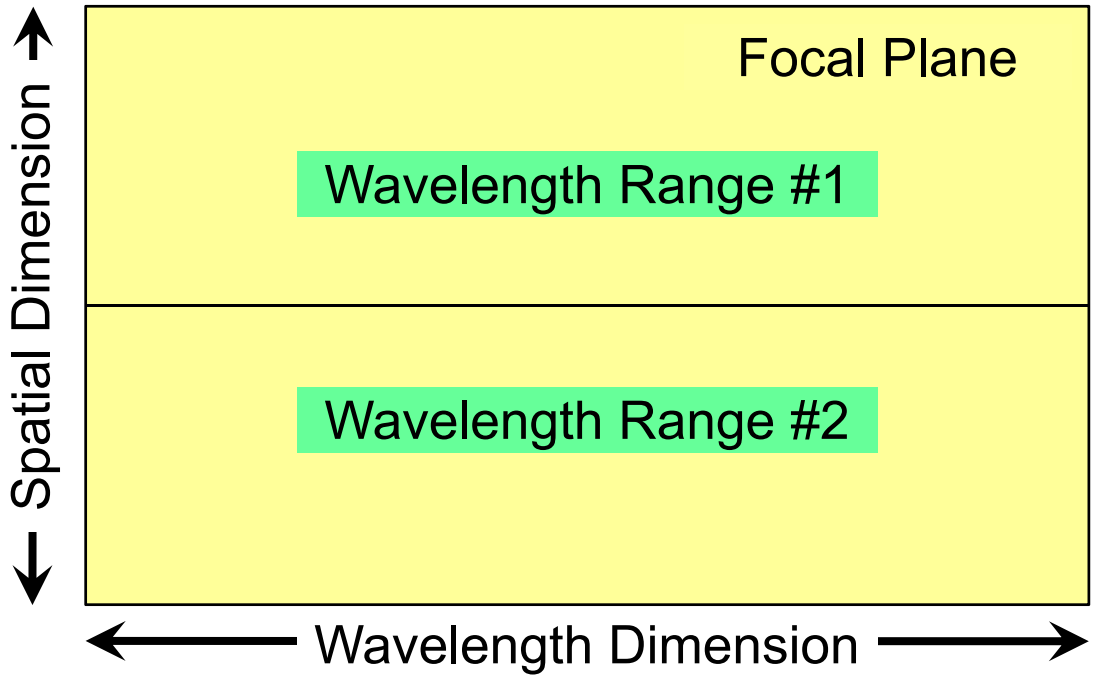
Ball Aerospace Simplified Sounder Design - Performance Against Driving Requirements

Drivers	Requirement	Compliant With Margin
Coverage Time (CONUS)	< 70 minutes	Y
Co-Reg Channel Overlap	> 90%	Y
Ground Sample Distance	< 10 x 10 km^2	Y
Spectral Range	11.34-14.7 μm AND 4.64-5.92 μm OR 6.08-8.26 μm	Y
NEdT (@12.5μm)	< 0.18 K	Y
Absolute Accuracy	< 1 K	Y
Spectral Resolution (@ 12.5μm)	< 14.59 nm	Y
DOEE	> 70%	Y

Ball Aerospace Design Meets all Performance Driving Requirements with Margin

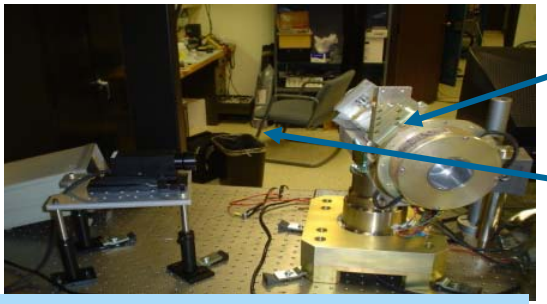
Ball Aerospace Simplified Sounder Concept

- **Single slit, reflective grating spectrometer**
- **Unique folding of two spectral regions onto a single focal plane using a spatial-split dichroic assembly**



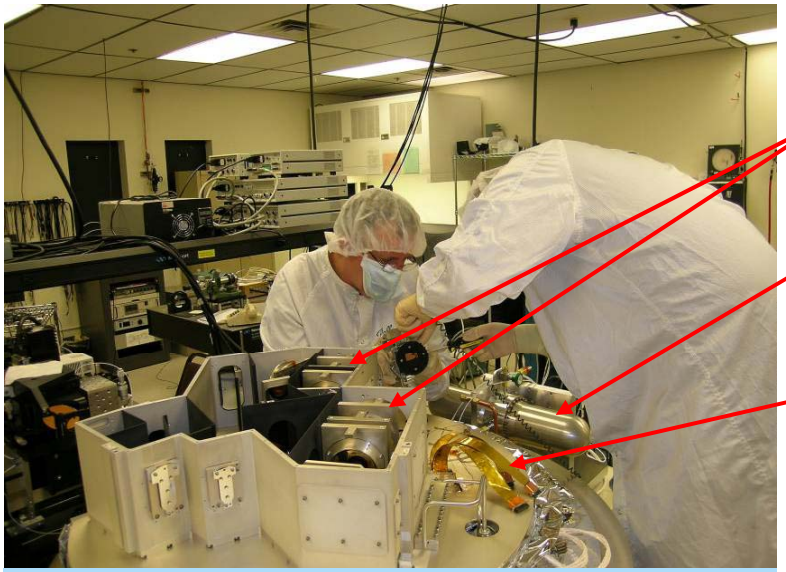
Applicable Ball Aerospace Technology Demonstrations

BB H/W & Test

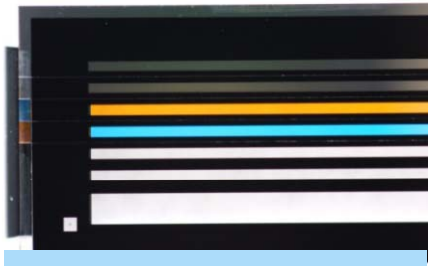


Scan Mech H/W & Test

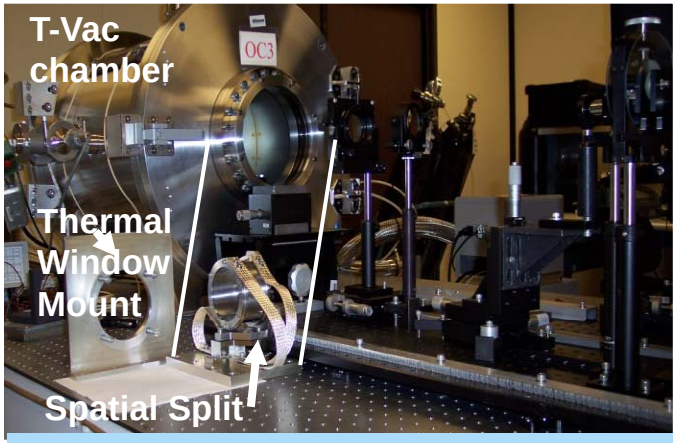
Focal Plane Electronics H/W & Test



Guinness spectrometer H/W & Test



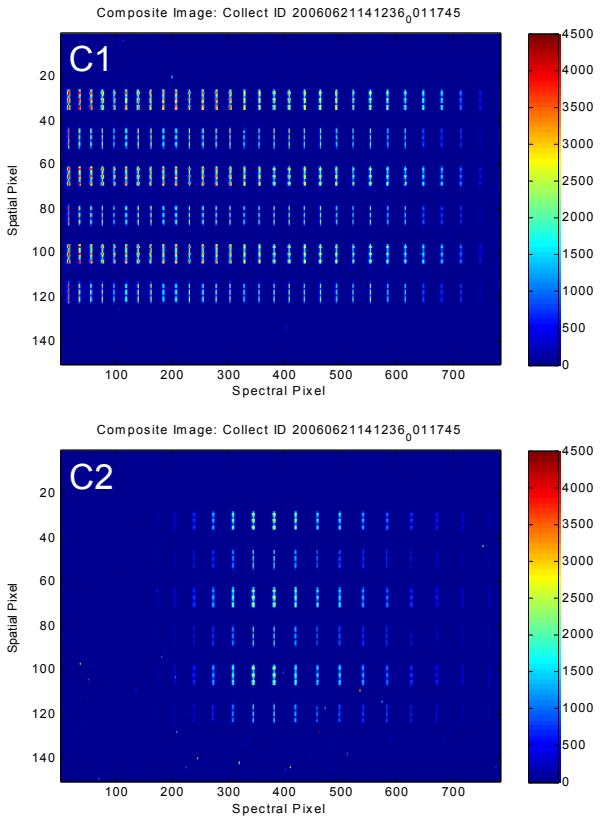
Filter Assembly Test



Optical Component H/W & Test

Project Guinness Highlights

- Guinness is a demo of critical components for a multi-channel imaging spectrometer (9-14 μm)
- Project started in April 2005 – Testing completed June 2006 (15 months)
- Demonstrates an IR imaging spectrometer operating at cryogenic temperatures with critical components
- Primary motivation: Burn down percieved technical risk of co-registration between multiple spectrometer channels



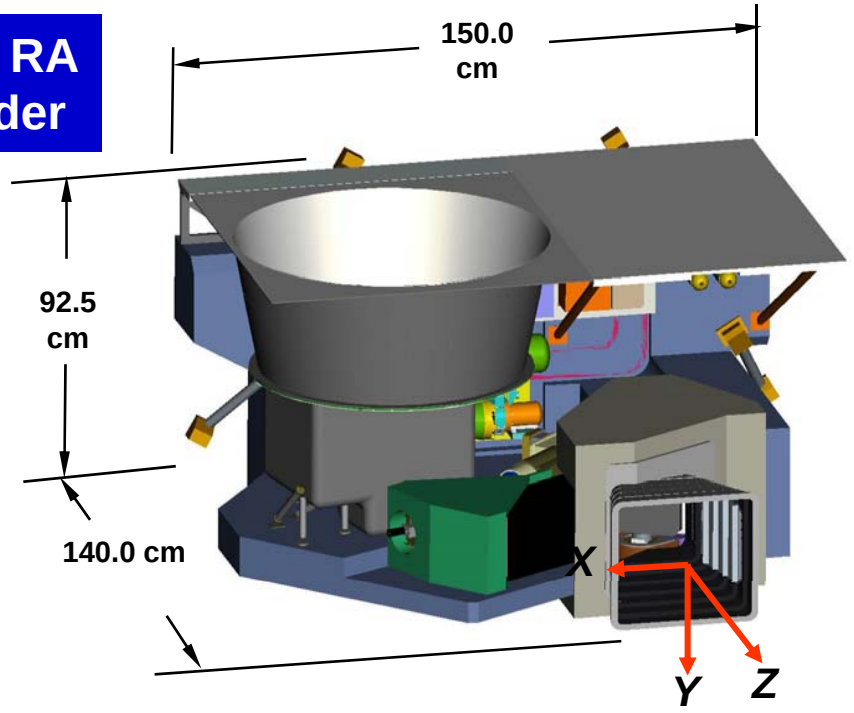
H/W designed, developed, & tested in 15 months

Test set and methodology developed concurrently for rapid & accurate performance testing of imaging spectrometers

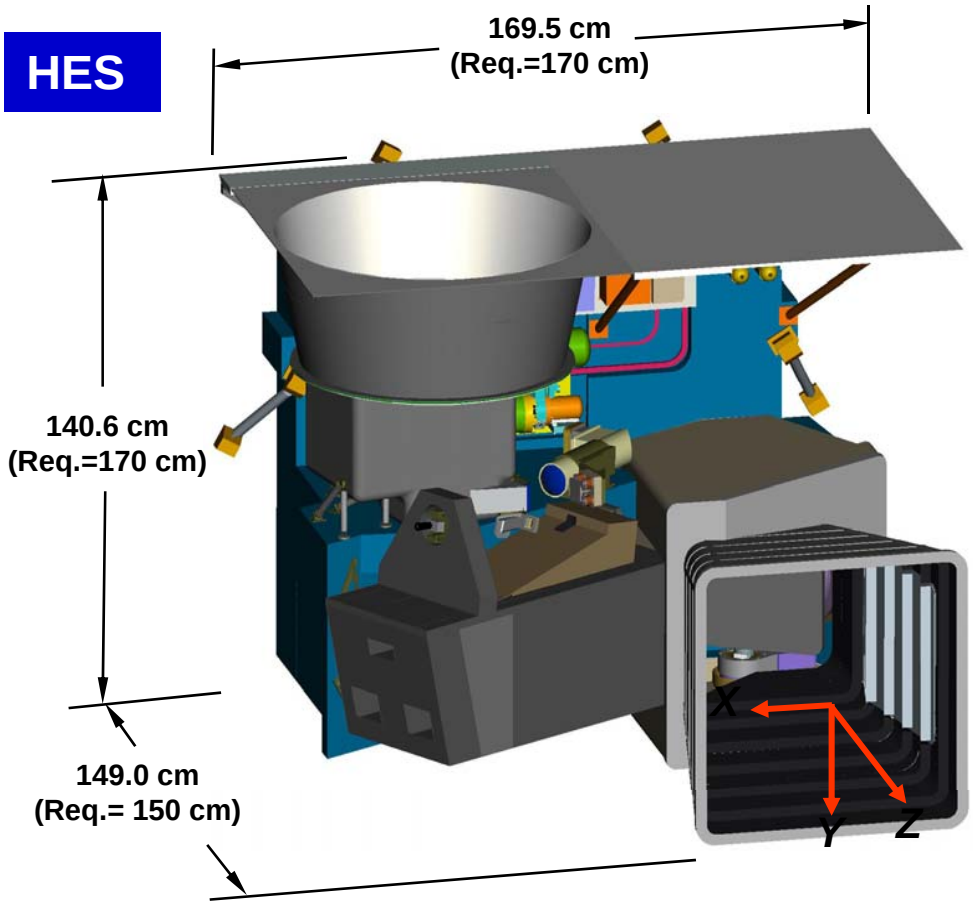
Co-registration of 0.06 pixels between 2 spectrometer channels attained

Reduced-Accommodations IR Sounder and HES Comparison

GOES RA Sounder



HES



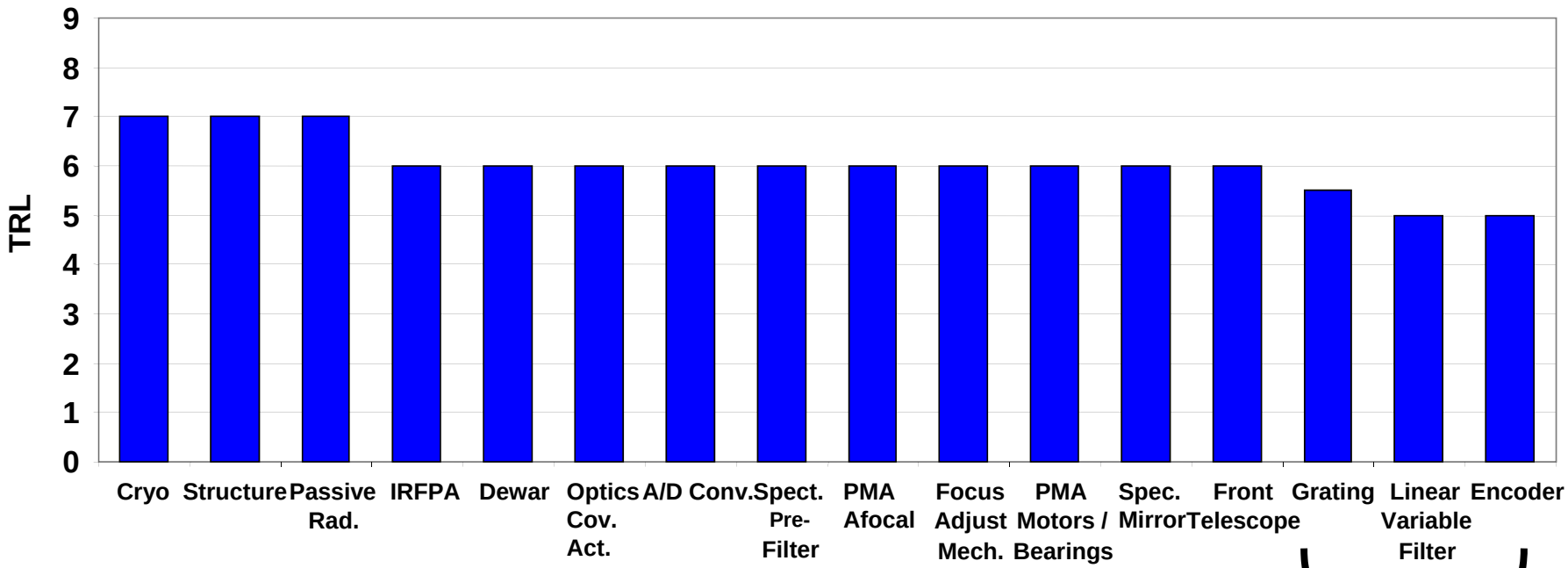
GOES-R Sounder Characteristics
- Mass: 169 kg
- Power: 223 W
- Data Rate: 1.8 Mbps
- CONUS Sounding Coverage Rate:
  - CONUS/hr @ 10 km GSD (Can Provide 2x CONUS/Hr also)
- Disk Sounding Coverage Rate:
  - 62 Deg. Disk/hr @ 20 km GSD
- Meso-scale Demonstration @ 5 km

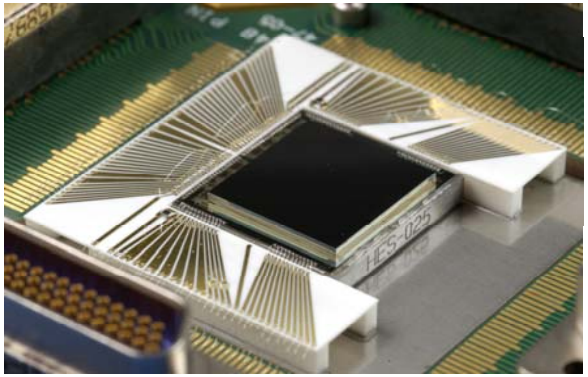
Shared Characteristics
- Spectral Coverage:
  - 4.165-5.92 μm (1689-2400 cm^{-1})
  - 9.65-14.7 μm (680-1036 cm^{-1})
- Spectral Resolution: λ/δλ>1000
- NEΔT: 0.2K
- Spectral Stability: <0.01 δλ

HES Characteristics
- Mass: 214 kg
- Power: 326 W
- Data Rate: 7.3 Mbps
- SW/M Coverage Rate:
  - CONUS/hr @ 5 km GSD
- Disk Sounding Coverage Rate:
  - 62 Deg. Disk/hr @ 10 km GSD

Key TRL Assessment Summary @ HES FPCCR

-All Technologies at Level Needed For Low-Risk HES Development





Fully-Compliant Flight-Like VLWIR FPA Demonstration Has Retired the Technology Risk for the HES Flight FPA

Technology Area	Technology Maturation Plan
Special Grating	End-to-end cryo-testing in Sounder Spectrometer
Special FPA Optical Filter	Build and test HES Prototype (“smile”, off-axis rejection, radiation etc.)
PMA Encoder	Test in Pointing Stability test bed to validate performance at low angular rates

Summary

- NASA/NOAA HES Trade studies were completed in 2007

  Three vendors each had low technical risk, affordable cost designs for a

  Reduced Accommodation Sounder (RAS) compatible with flight on GOES R-U

  RAS would deliver AIRS quality soundings with spatial and temporal coverage at least as good as now achieved with the current IR Geo Sounder

- NASA was prepared to down select to a single vendor to proceed to CDR
- NOAA terminated the study because of instrument cost and risk concerns

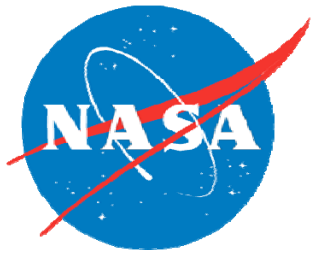
  NOAA also considered the ground system very high risk for HES

  RAS data rate requirement is now 6.6 MBPS compared to 66.6 MBPS as originally specified

  This data rate is only slightly larger than AIRS data rate

  Ground system should not be a concern

The three vendors are all enthusiastic about continuing work to design and build HES


NASA