GOES HES-DS (ABS): Interferometric and Grating Sensor Designs

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GOES R Industry Day

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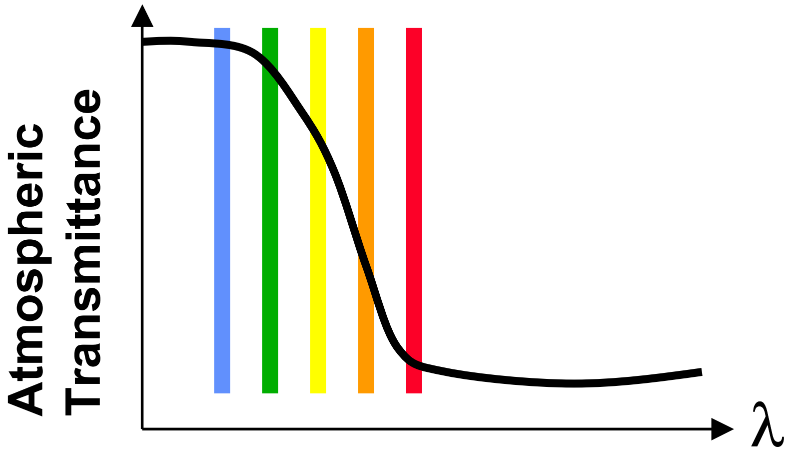
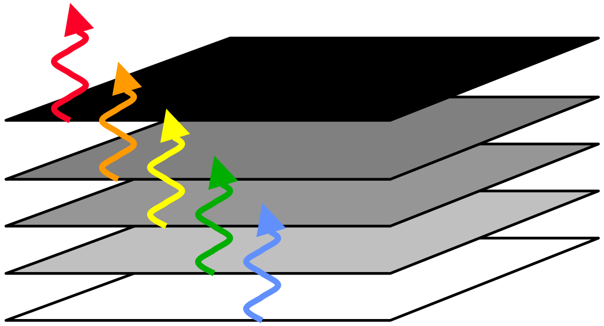
Outline

- Advanced Baseline Sounder (ABS) background
- ABS trade space analysis
- Conclusion

Atmospheric Sounding Review

- Extract vertical profiles of atmospheric temperature and water vapor from remotely-sensed measurements
  - Initialization of numerical weather prediction models
  - Derived product imagery (atmospheric stability and winds)
- Many narrow passive measurements of upwelling radiance along edge of molecular absorption spectral bands
- Radiance at band center is from top of atmosphere; radiance in window region from surface; measurements in-between give vertical structure

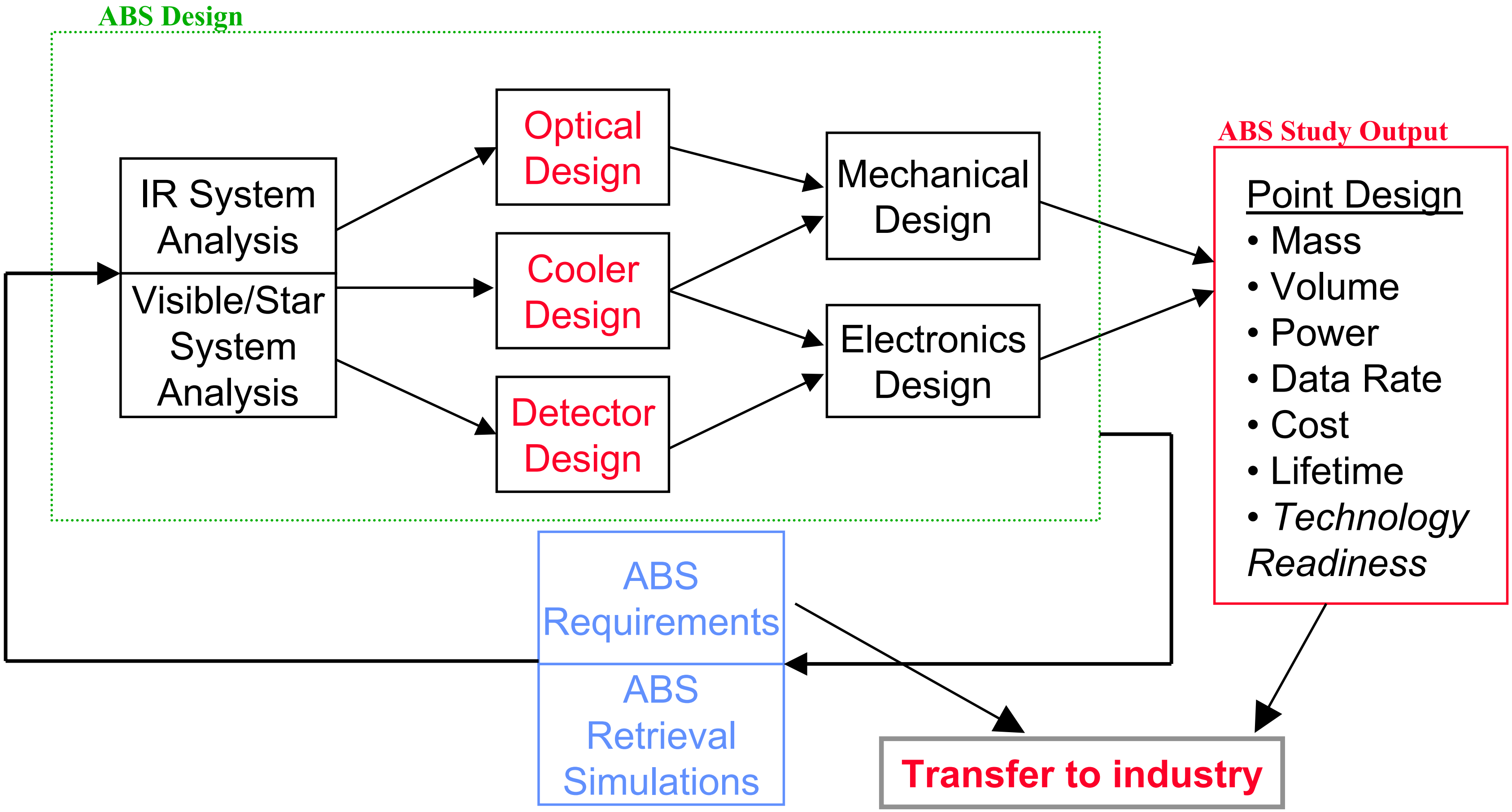




ABS Point Design Study

- Define a baseline instrument that meets NOAA requirements for an advanced sounder
  - Detailed requirement set for industry proposals
  - Trade-space analysis: define ABS architecture
  - Point design: produce viable instrument design
- MIT/LL has produced two potential ABS instrument designs
  - Fourier-Transform Spectrometer (FTS)
    - Spectral decomposition via interferometer
  - Diffraction grating Spectrometer
    - Spectral decomposition via grating

ABS Study Methodology



ABS Instrument Requirements

- **Study requirements set derived primarily from 1999 NWS GOES requirements document**
- **NWS wants finer vertical resolution and faster coverage, without sacrificing accuracy of retrieved profiles**

NWS Meteorological Requirements

Altitude Range	Observational Accuracy (RMS Error)		Vertical Resolution
	Temperature	Humidity	
Surface – 500 mb	$\pm$ 1.0 K	$\pm$ 10%	0.3 – 0.5 km layers
500 – 300 mb	$\pm$ 1.0 K	$\pm$ 10%	1 – 2 km layers
300 – 100 mb	$\pm$ 1.0 K	$\pm$ 20%	1 – 2 km layers
100 mb and above	$\pm$ 1.0 K	-----------	2 – 3 km layers

Derived System Engineering Requirements (using instrument model and simulated retrievals)

- **NEdNs and spectral resolutions over relevant wavebands as delineated in previous talk**

Sensor Point-Design Options

- Very aggressive performance requirements lead to complex instrument designs
  - GOES is an operational system (24/7): risk-averse
- Requirements flow-down dictates high spectral resolution over wide spectral region
- This coverage, at rapid rate, necessitates large and complex sensors
- IR detector arrays are central to design trade-off analysis
  - Large photovoltaic HgCdTe LWIR arrays enable high coverage rates with many spectral bins
  - LWIR Detector cutoff wavelength > ~15 μm is a technological challenge and requires colder operating temperatures
  - Detector cooling dominates thermal budgets

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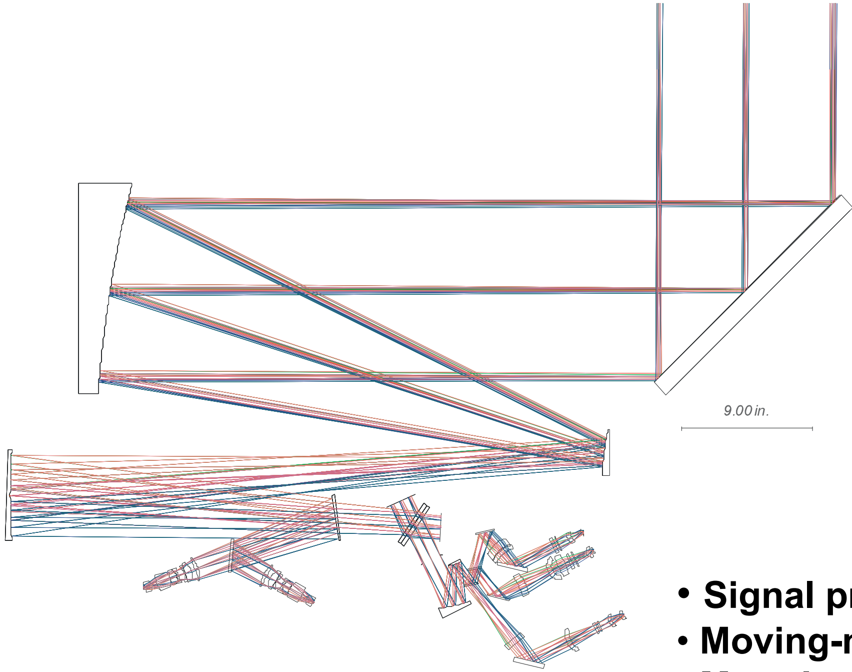
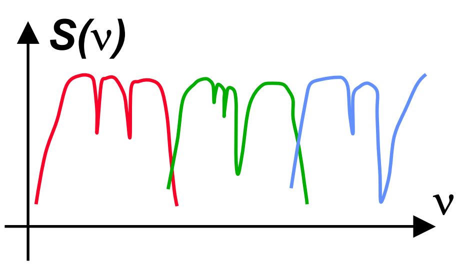
FTS-Based Instrument

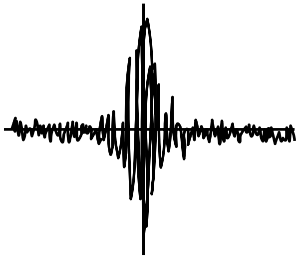


- Signal processing (FIR decimation filters)
- Moving-mirror servo (constant velocity)
- Metrology reference wavelength (laser)



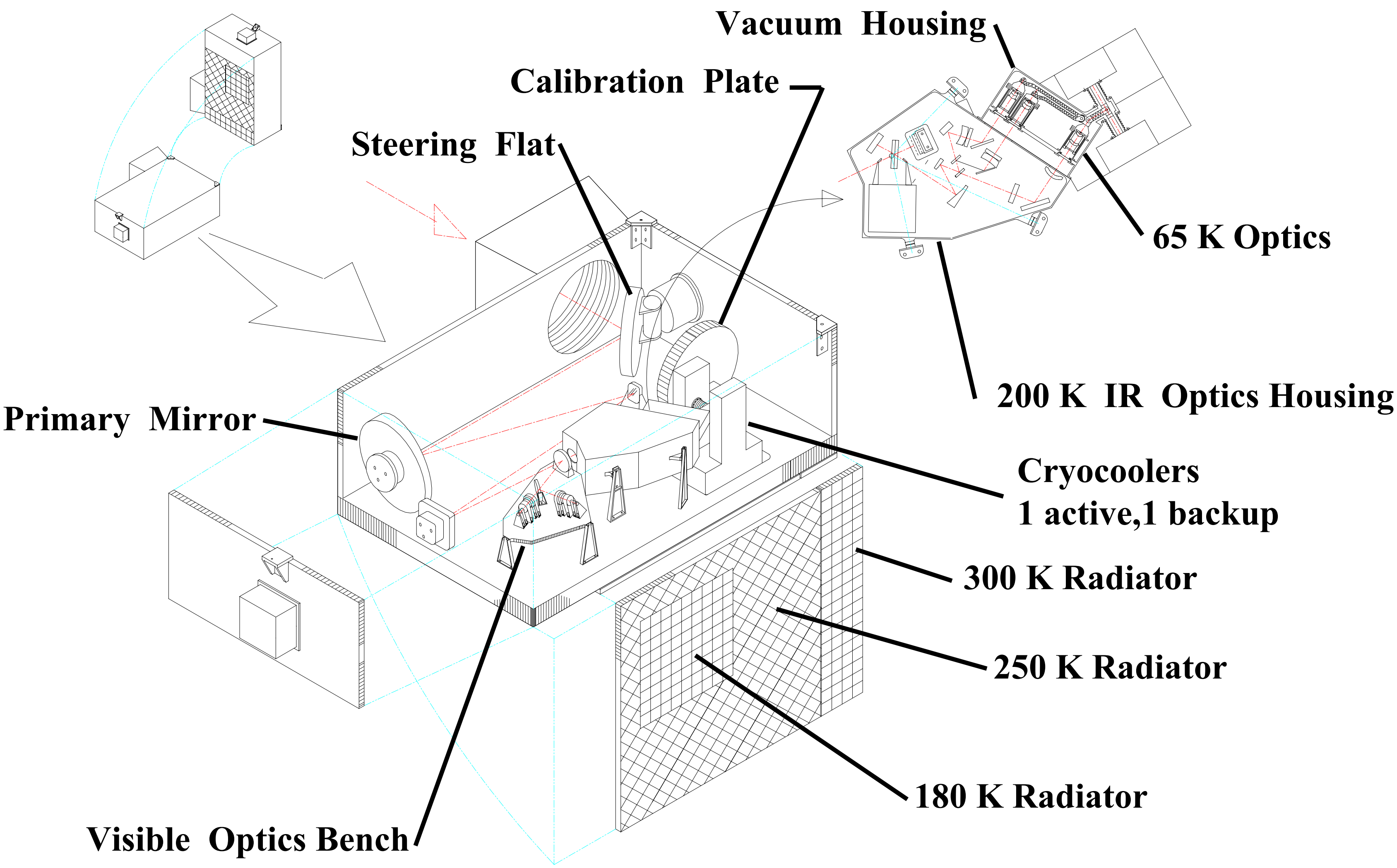
Spectrum of source

FFT

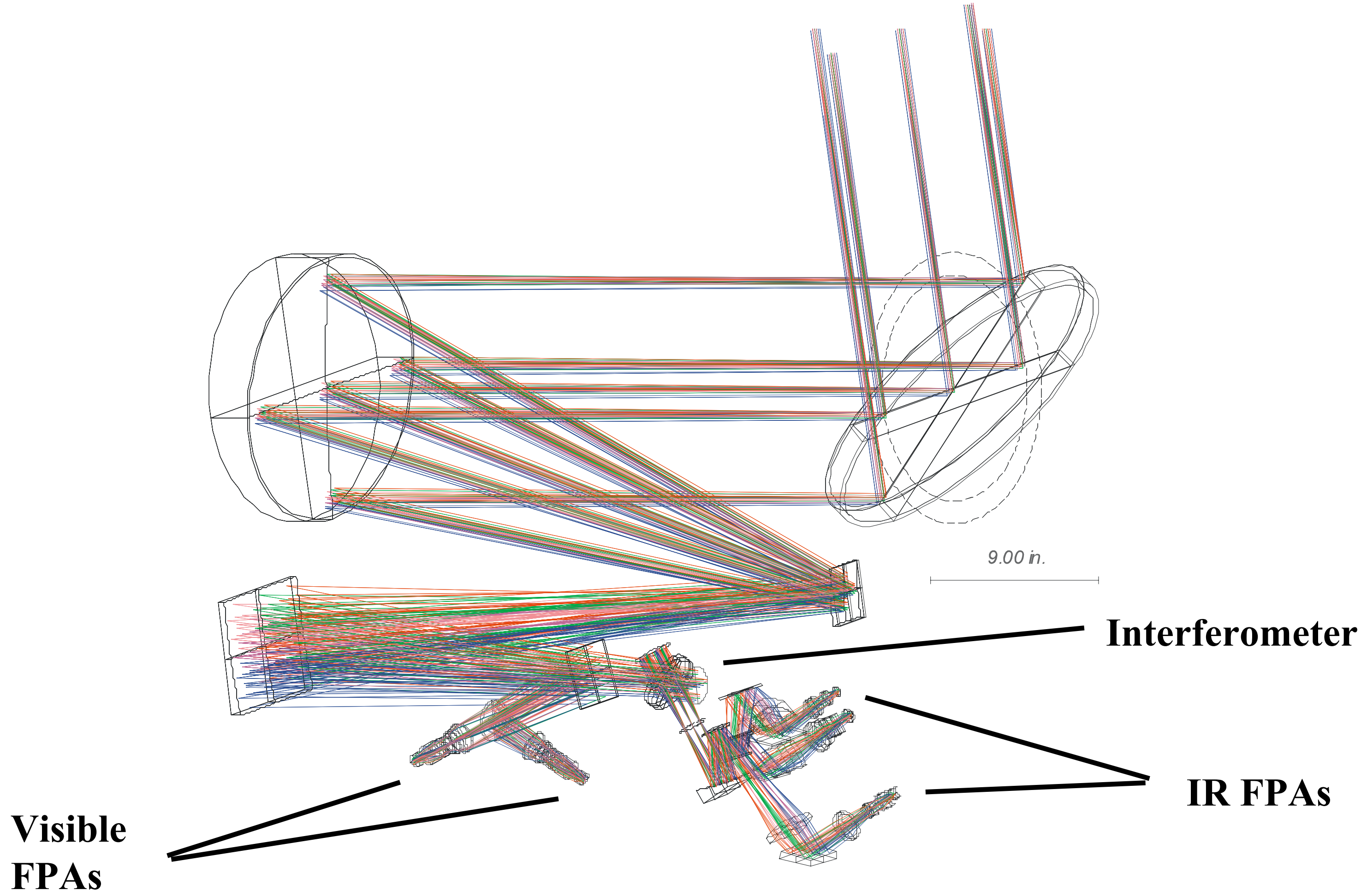


Interferograms

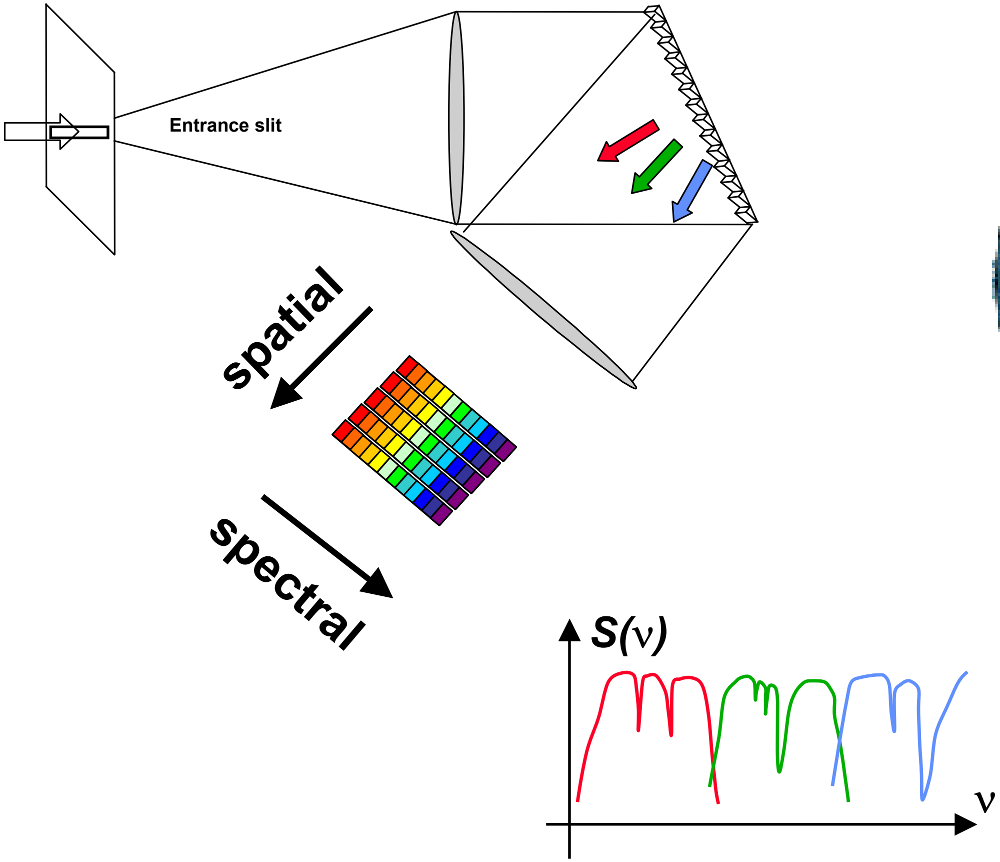
FTS Exploded View



FTS Optical Design (3d view)



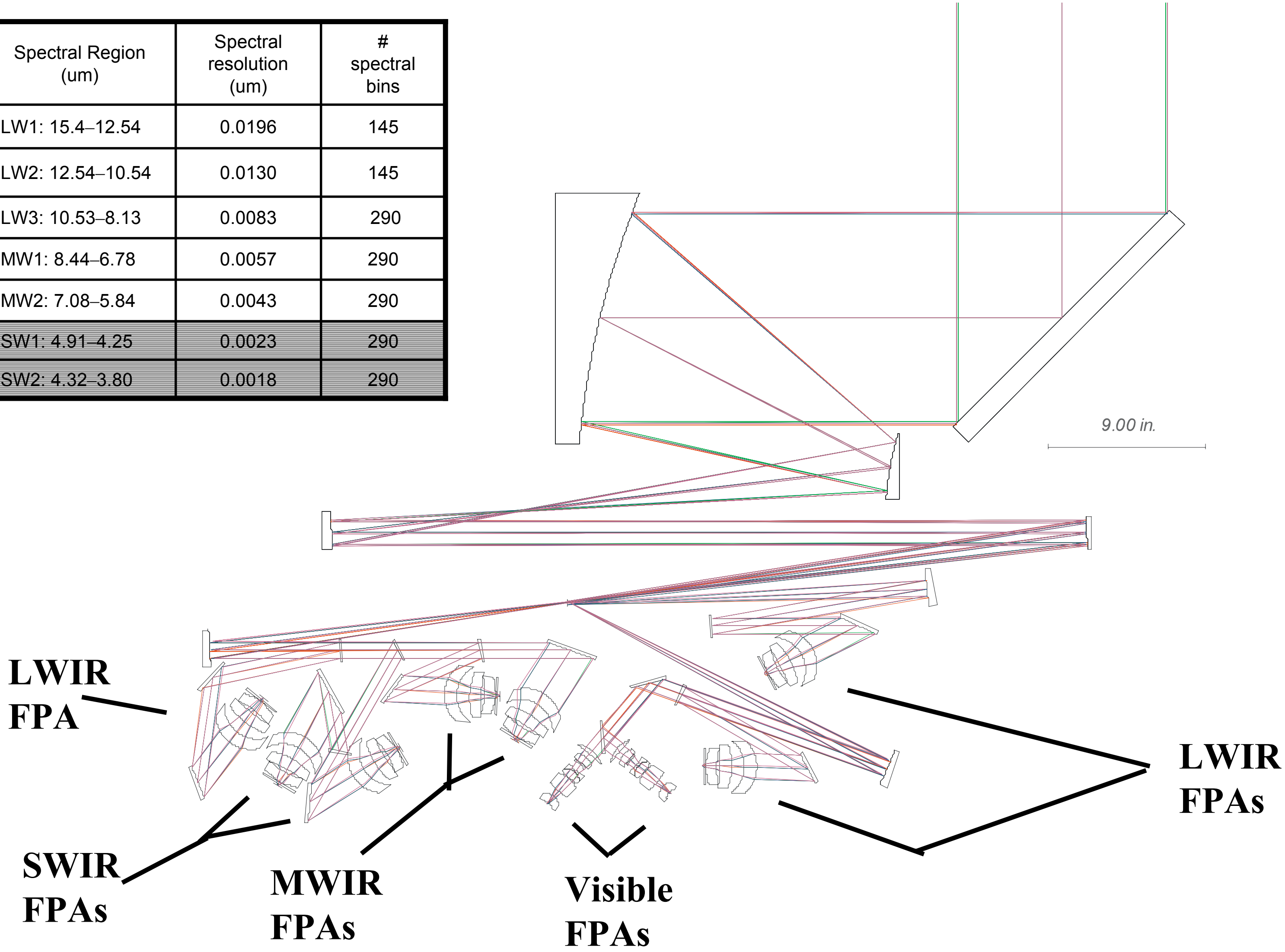
Grating-Based Instrument



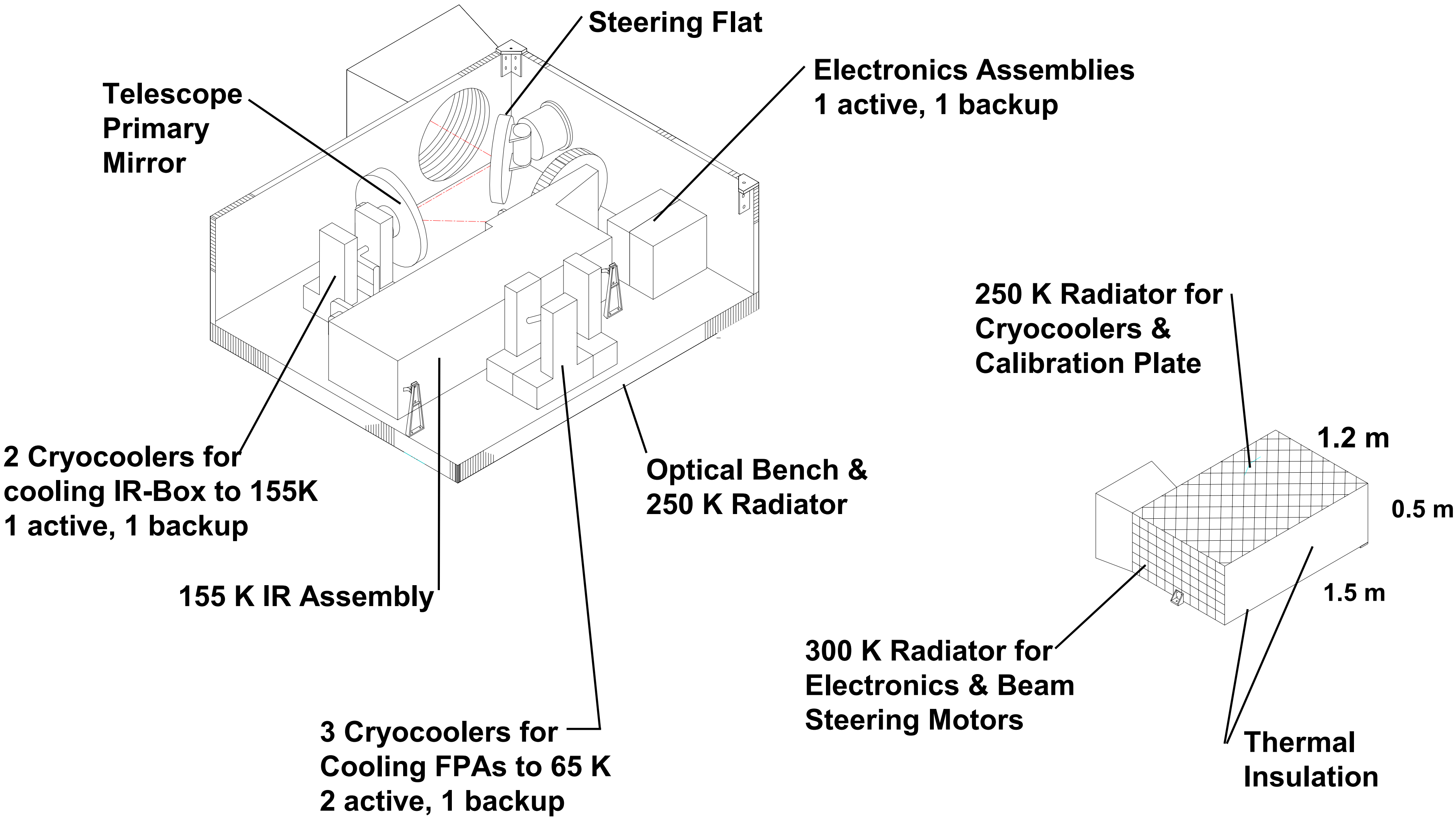
Spectrum of source

ABS Grating Baseline Optical Design

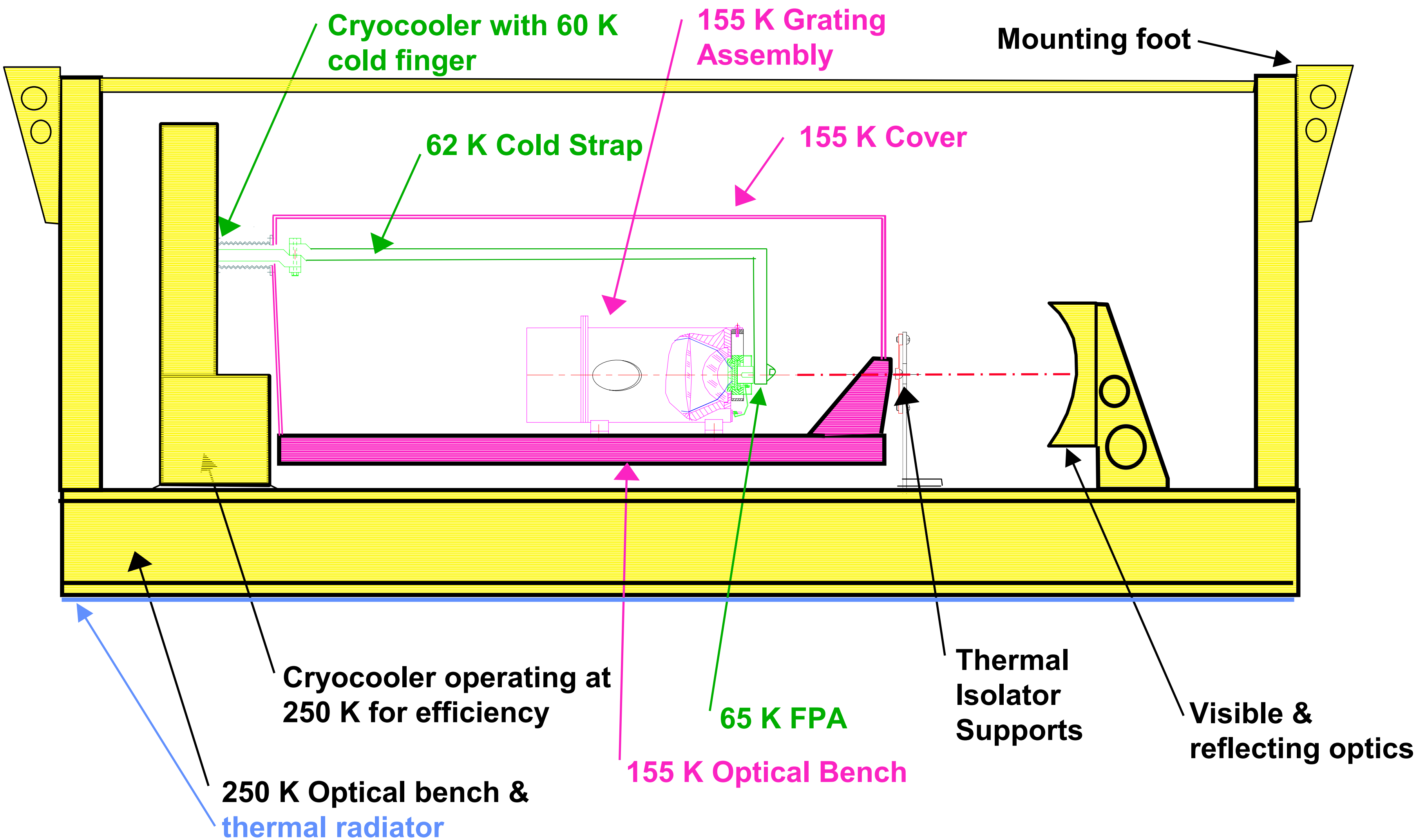
Spectral Region (um)	Spectral resolution (um)	# spectral bins
LW1: 15.4–12.54	0.0196	145
LW2: 12.54–10.54	0.0130	145
LW3: 10.53–8.13	0.0083	290
MW1: 8.44–6.78	0.0057	290
MW2: 7.08–5.84	0.0043	290
SW1: 4.91–4.25	0.0023	290
SW2: 4.32–3.80	0.0018	290



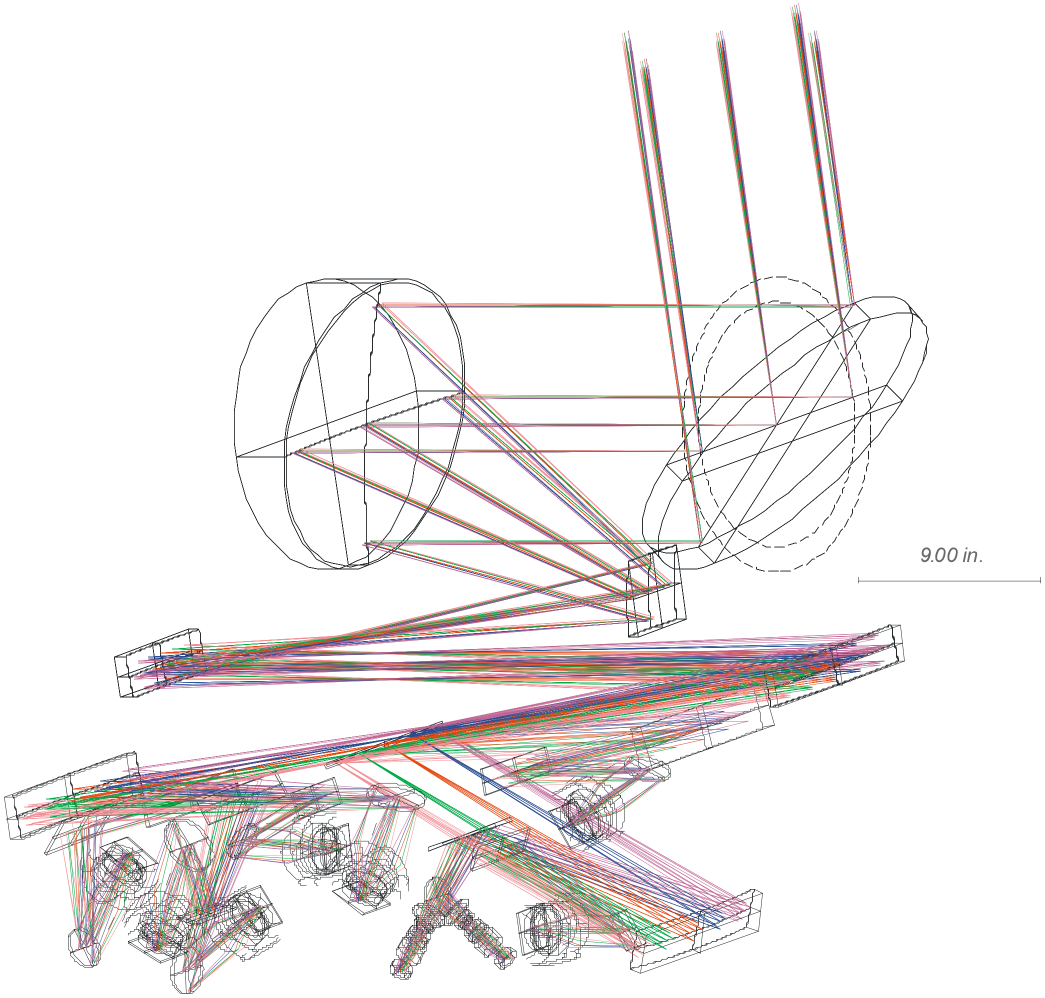
Grating Exploded View



Grating Mechanical & Thermal Concept

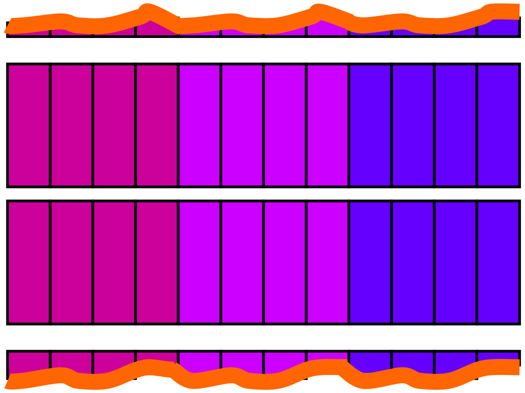


ABS Grating Optical Design (3d view)



Grating design FPA Format

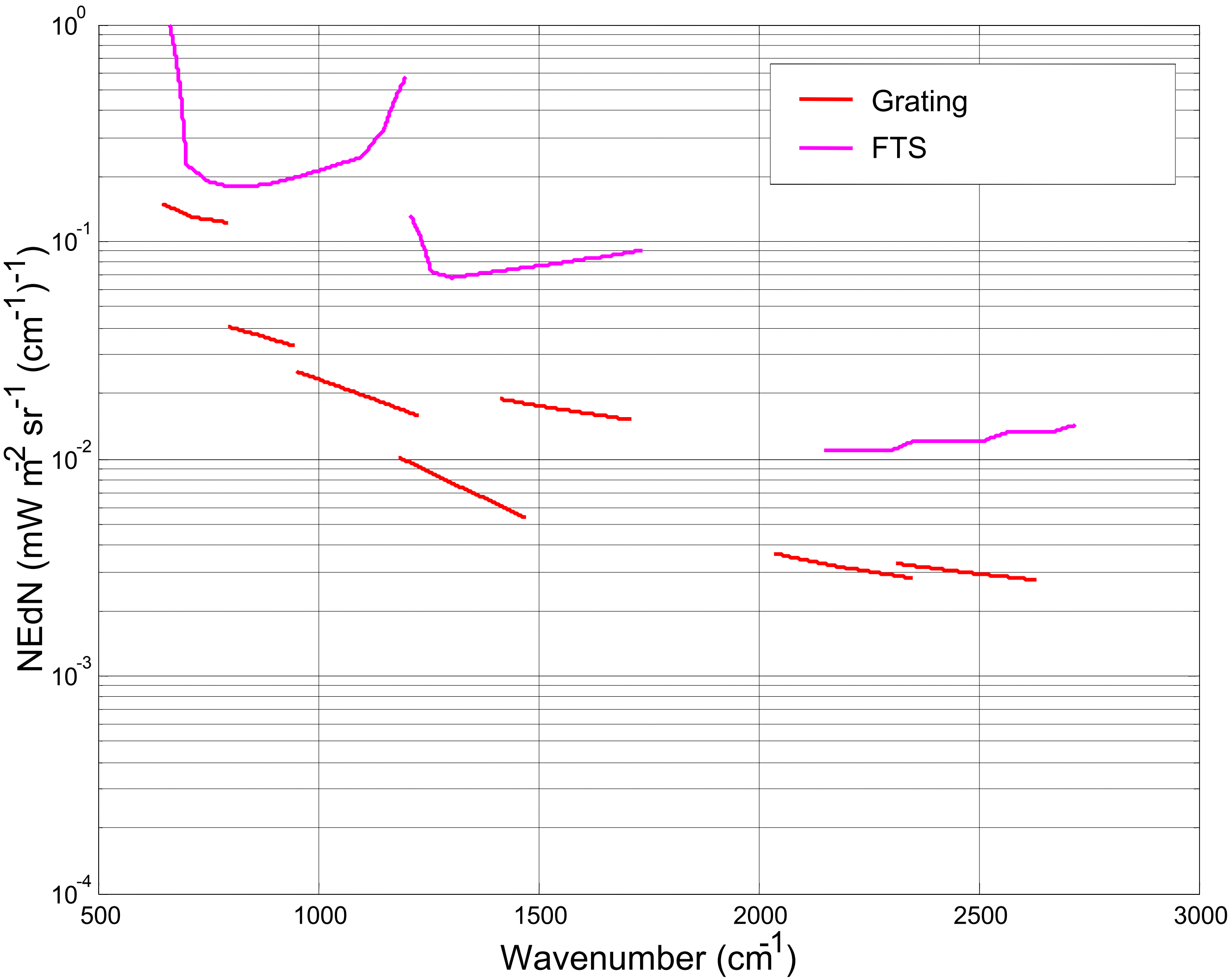
- FPA format
  - 8 pixels per resolution element (ground FOV)
  - Improves spectral purity
  - Multiple pixels in each resolution element facilitate sampling the curvature of slit images along the length of the array



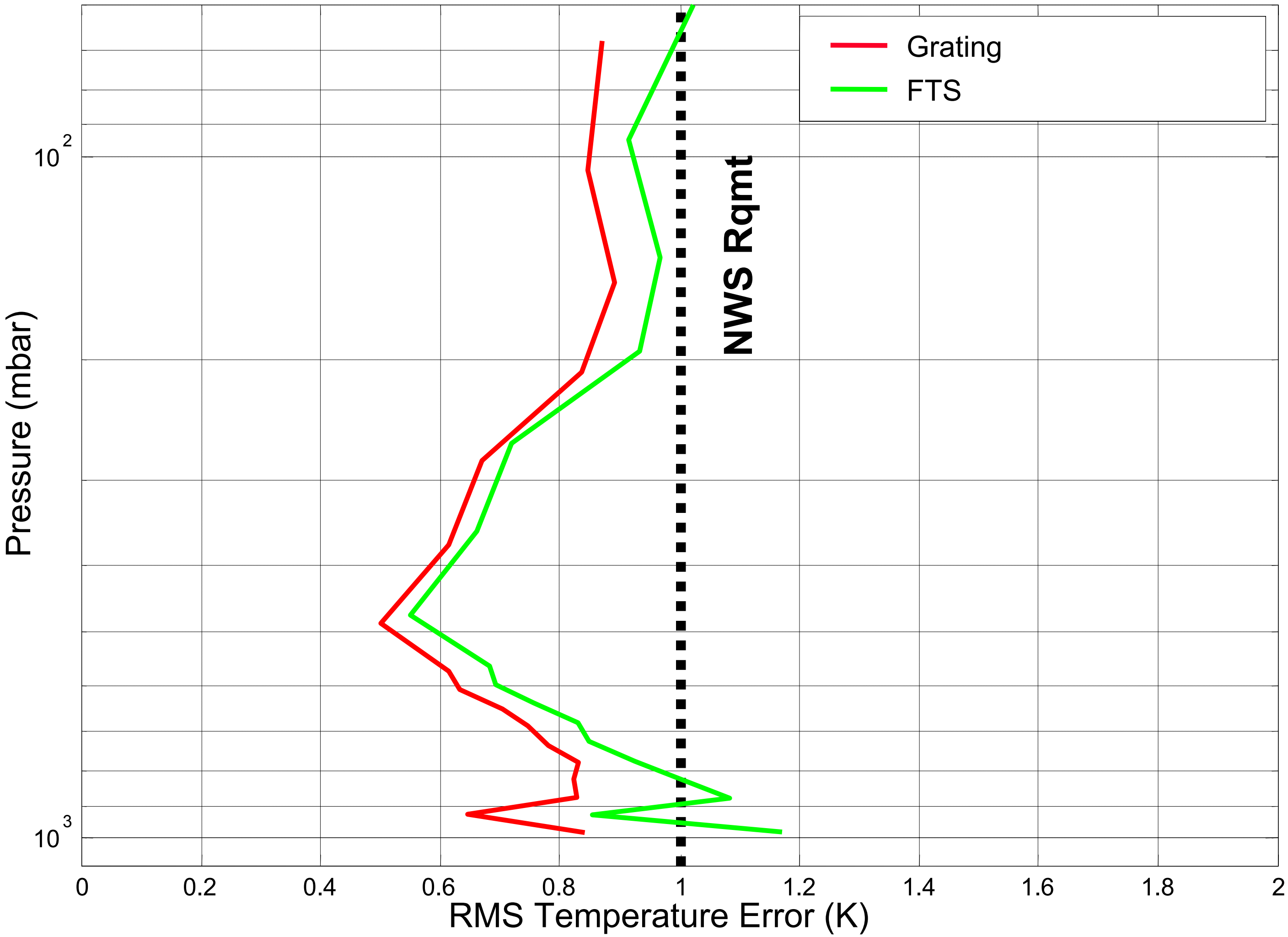
Design Performance Validation

- **Use sounding retrieval modeling to evaluate instrument performance**
- **"Forward" models simulate sensor measurement data from ensemble of various atmospheric observations**
- **Retrieval modeling then estimates vertical profiles of temperature and water vapor from measurement data**
- **Flexible diagnostic approach that permits exploring parametric sensitivities, design-space excursions, etc**

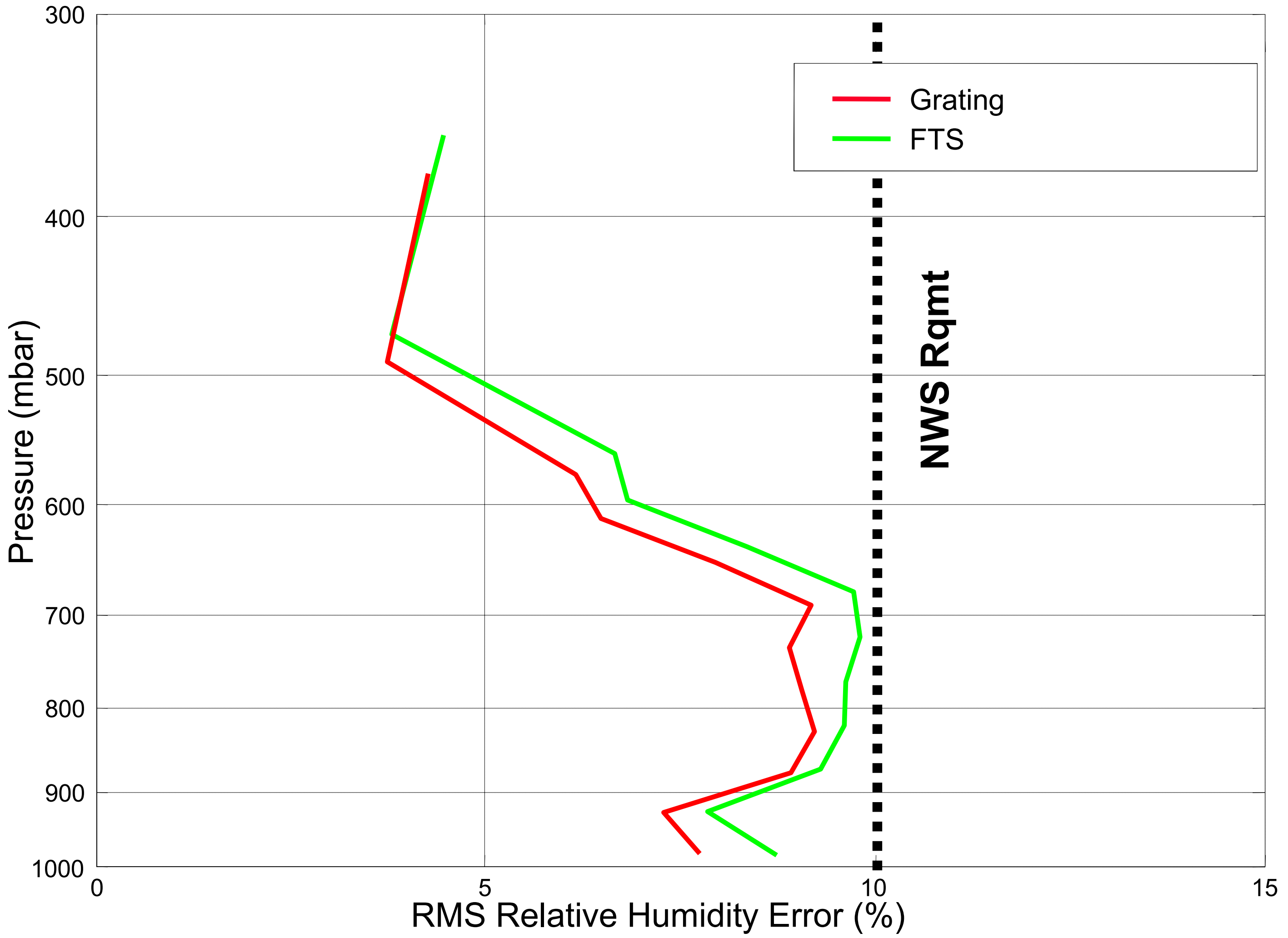
Radiometric Modeling Results



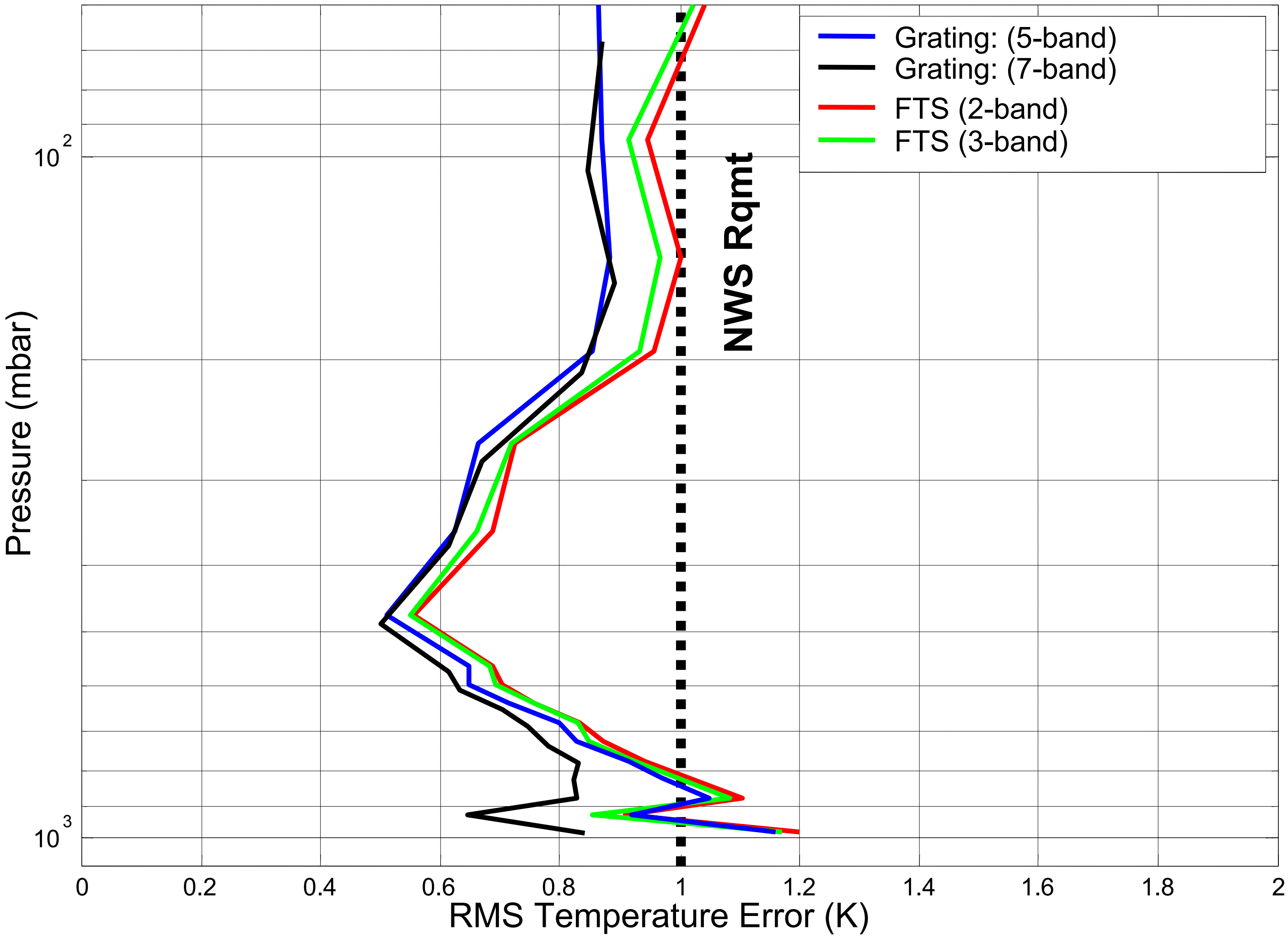
Temperature Retrieval Performance



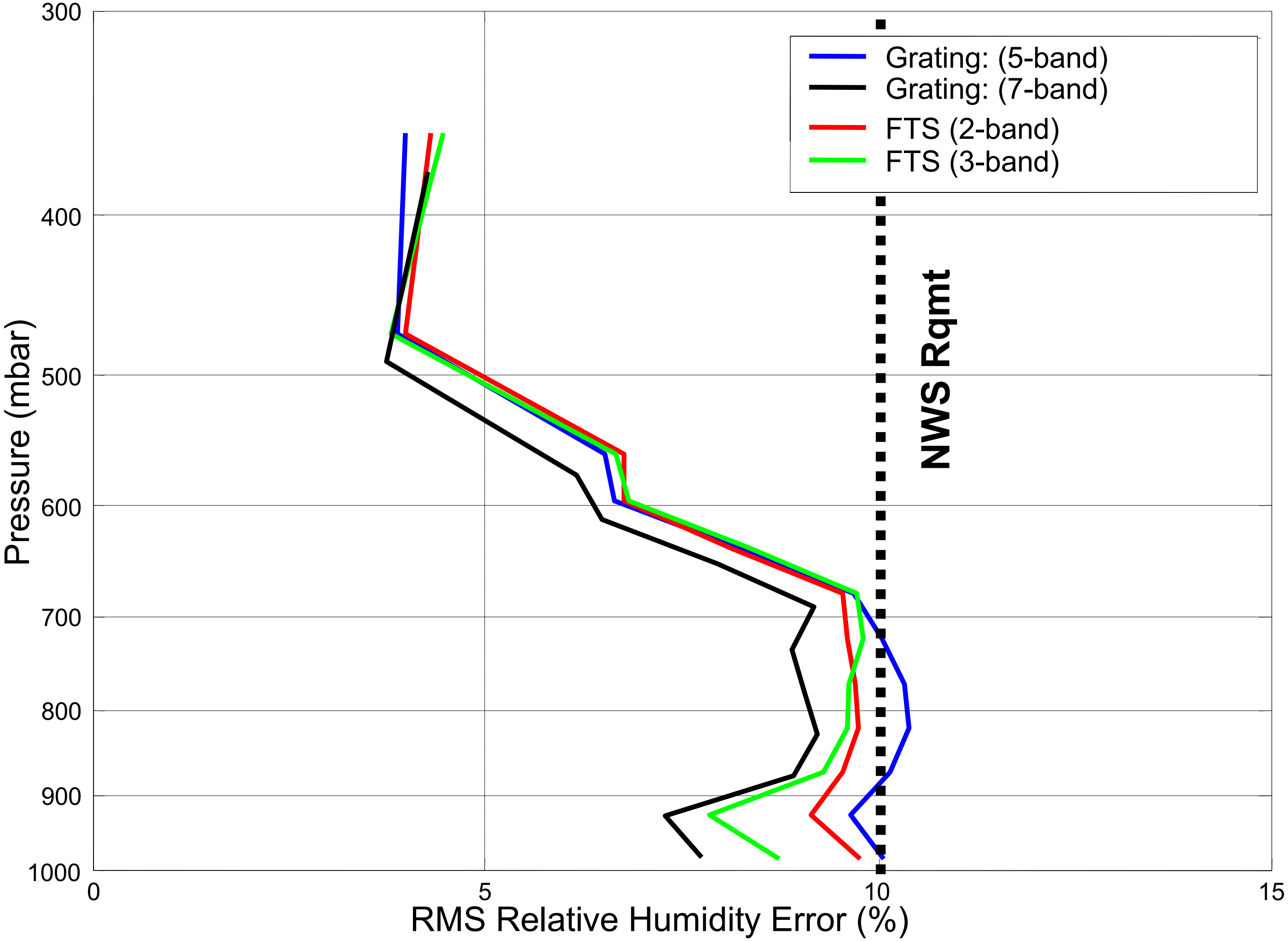
Water Vapor Retrieval Performance



Impact of Shortwave Bands on Temperature Retrieval



Impact of Shortwave Bands on Water Vapor Retrieval



Design Approach Comparison

	FTS	Grating
Advantages	• Relatively compact aft-optics • Viable thermal-mechanical design • Fewer detectors	• Excellent radiometric performance • Nominally stable operation once aligned • More robust to pixel failures
Disadvantages	• Interferometer moving mirrors • Metrology laser lifetime • Signal processing electronics	• Enormous number of detectors • Very challenging thermal-mechanical & optical designs • Susceptibility to 1/f noise (requires chopper in LW)

ABS Summary

	FTS	Grating	Current GOES sounder
Mass (kg)	190	212	126
Sensor Volume	0.9 m^3 1.5m x 1m x 0.6m	1 m^3 1.5m x 1.2m x 0.5m	0.8 m^3 1.4m x 0.8m x 0.8m
Power (W)	235	450 - 526	106
Data Rate (Mbps)	11	15	0.04
Aperture (cm)	30	30	30
FPA Format	22 x 48 PV	626 x 192 PV	2 x 2 PC
Detector Cooling	Active, 65K	Active, 65 K	Passive, 94 K
IR Channels	1540	~ 1800	18 (Filter Wheel)
Coverage	~ 7E7 km^2, 60 min	~ 7E7 km^2, 60 min	3000 x 3000 km, 45 min

Conclusion

- The HES-DS (ABS) will greatly improve current GOES atmospheric soundings
  - ~5x faster coverage, ~100x spectral resolution, improved S/N
- MIT/LL has developed two instrument point-designs capable of this advanced performance
  - Fourier Transform Spectrometer
  - Diffraction grating Spectrometer
- Point designs represent sensor “existence proofs”, not necessarily recommendations for actual construction/flight
  - Work is particularly valuable for risk mitigation