A System for Pre-launch Characterization of Imaging Sensors using Tunable Laser Sources

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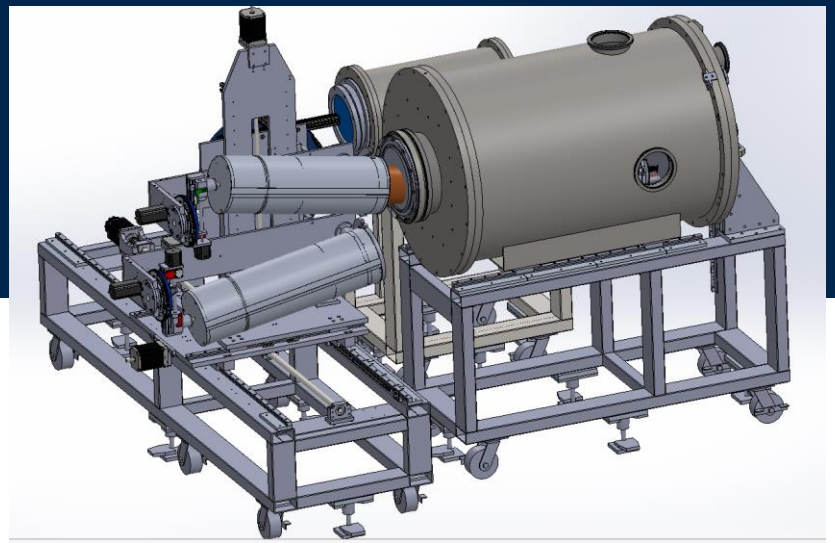

Calcon Technical Meeting, June 10, 2024

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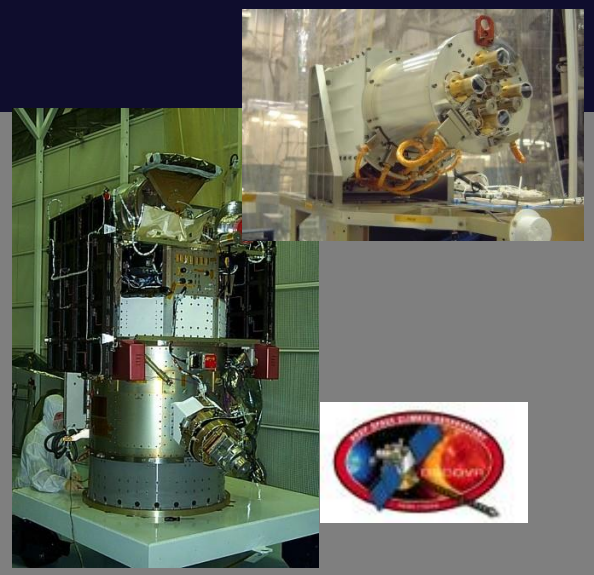

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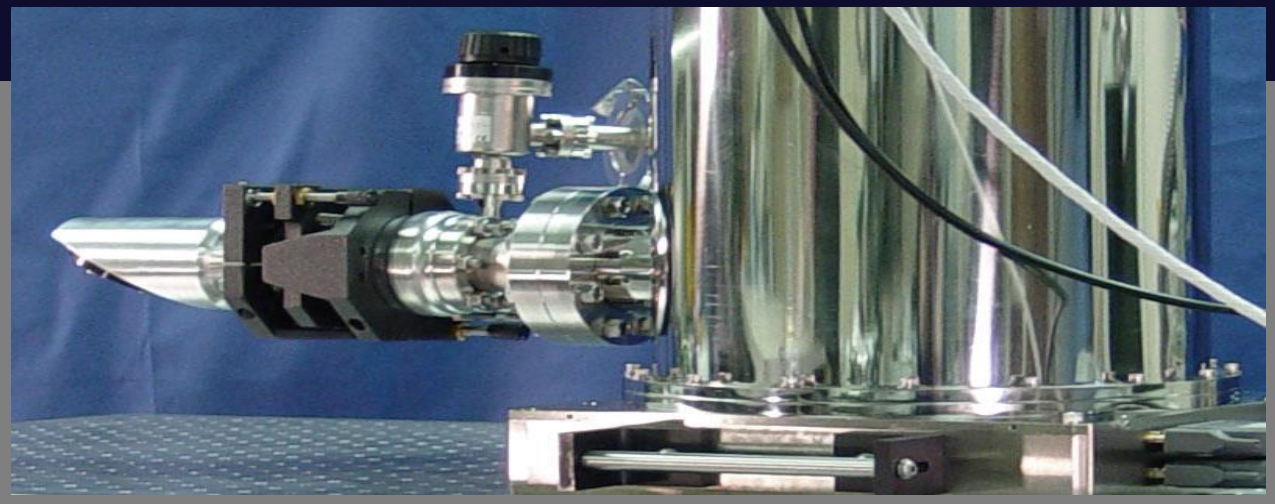

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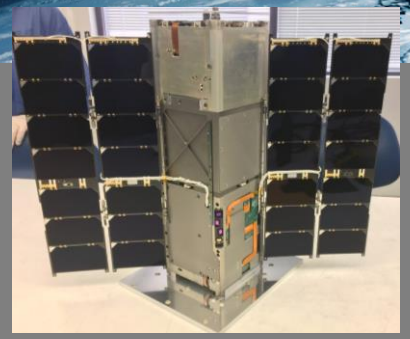

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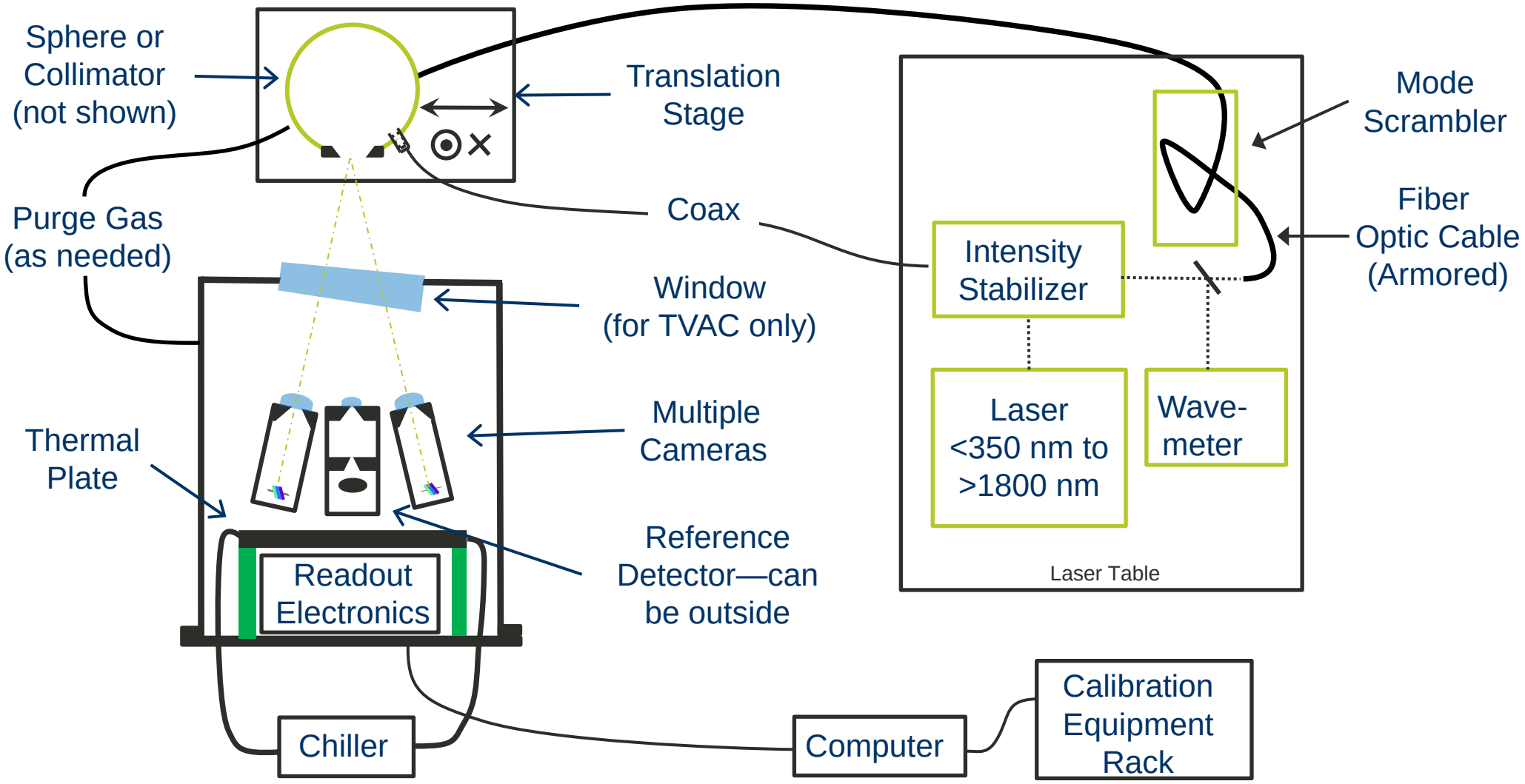
Overview

Calibration and characterization using detector-based radiometry with uniform tunable laser sources

- Same technique employed by national laboratories, e.g., NIST (SIRCUS facility) and NASA (GLAMR)
- Full aperture and field illumination—calibrate as the imager is used
- Absolute radiance responsivity vs wavelength—350 nm to 1800 nm (VNIR & SWIR)
- TVAC measurements for temperature dependence of response

Approximate uncertainty of band-integrated response (spectral responsivity): VNIR 0.5% (k=2) & SWIR & 1% (k=2)

Calibration Arrangement



Calibration Chain—SI Traceability (e.g., NIST)

- NIST calibrated L-1 built reference radiance meters
  - Calibrated at a discrete set of wavelengths
  - Interpolate radiance meter responsivity measurements to other wavelengths
- Laser wavelength measurements
  - Spectrographs calibrated with gas discharge lamps
  - Michelson Interferometer using He-Ne line as reference
- Radiance meter photocurrent measurements
  - L-1 built transimpedance amplifiers calibrated at L-1 with reference resistor traceable through accredited laboratory
  - Voltmeters calibrated at accredited laboratory

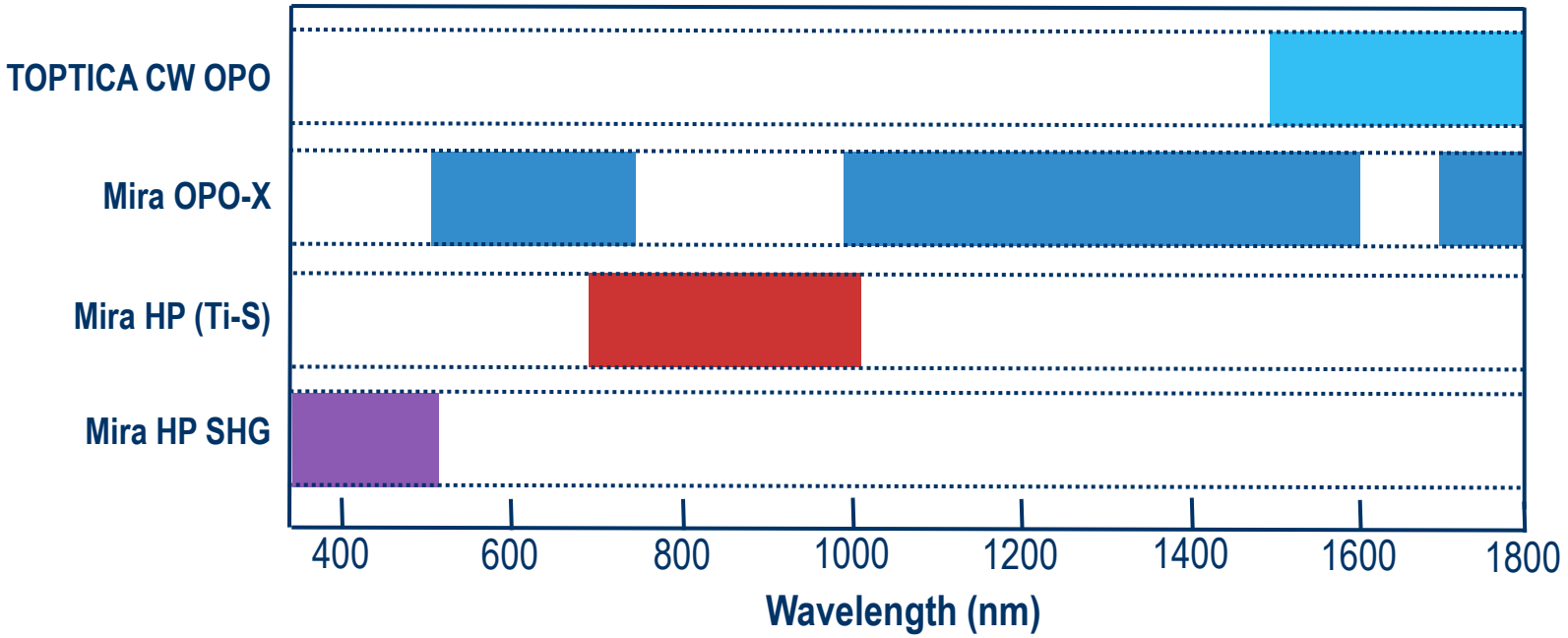
Wavelength Coverage

Tunable Lasers (<300 nm to >1800 nm)

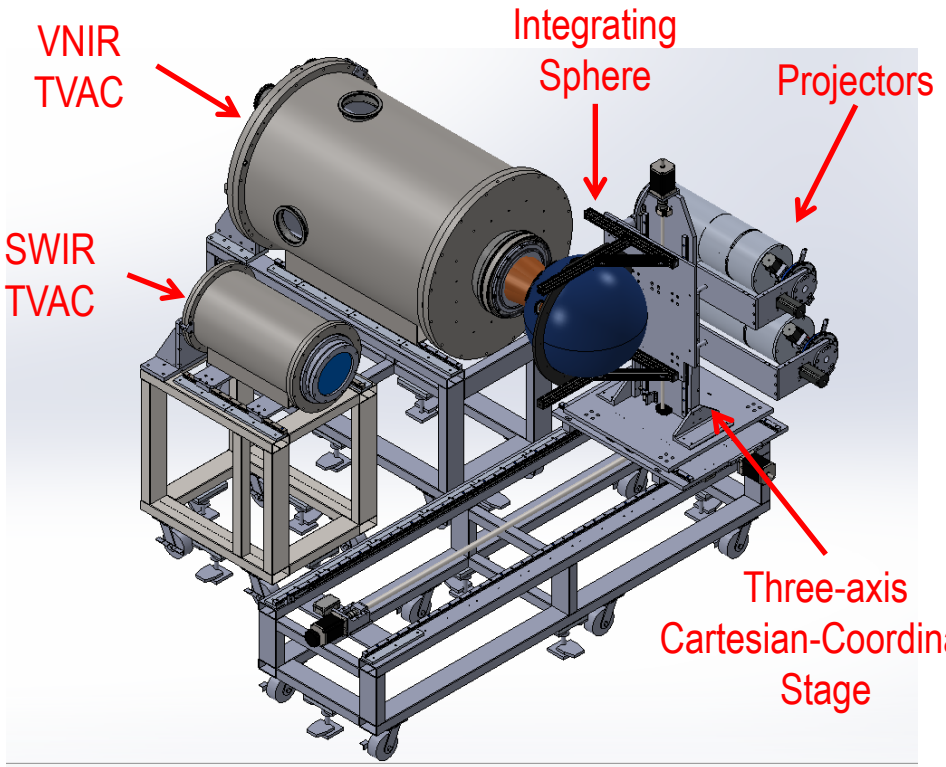
- Coherent: Mira HP (Ti:S) with SHG,
- Mira OPO-X (with intra Cavity SHG)
- TOPTICA CW OPO

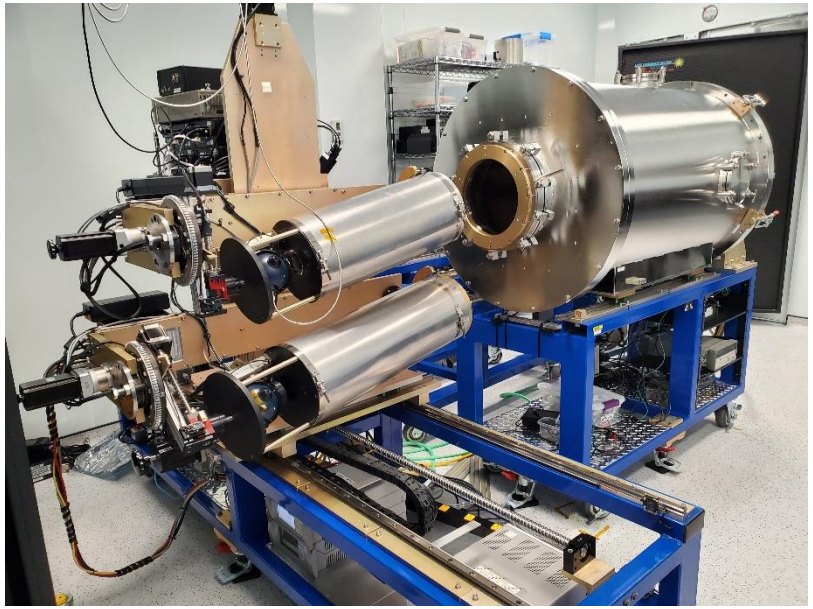
Reference Detectors

- NIST calibrated responsivity: 350 nm to 1800 nm
- Temperature stabilized Si and InGaAs photodiodes
- Fore optic: entrance pupil Dia. ≈13 mm; ≈ 1º FOV

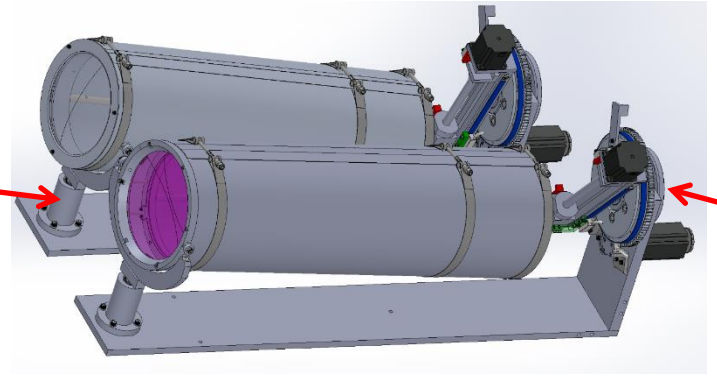


Calibration Equipment



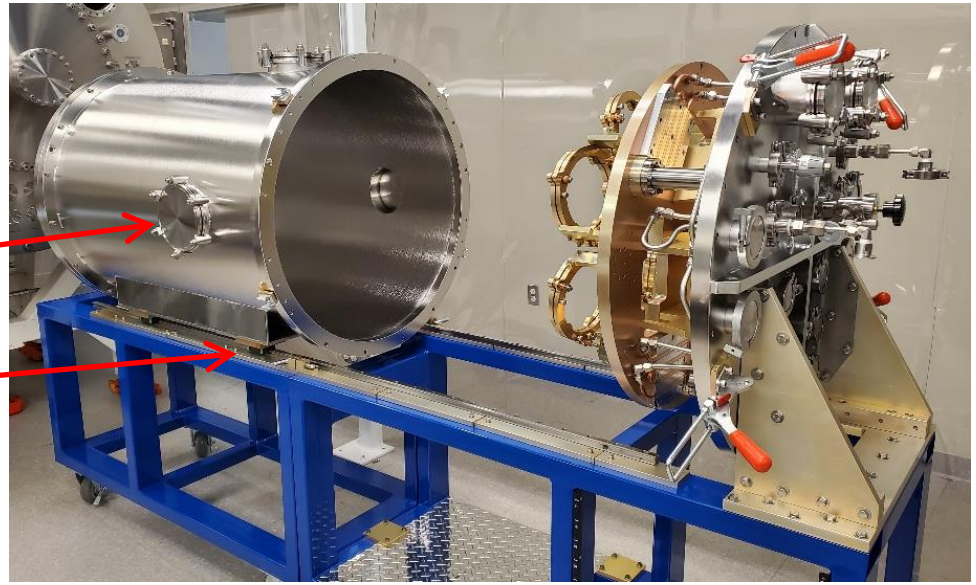


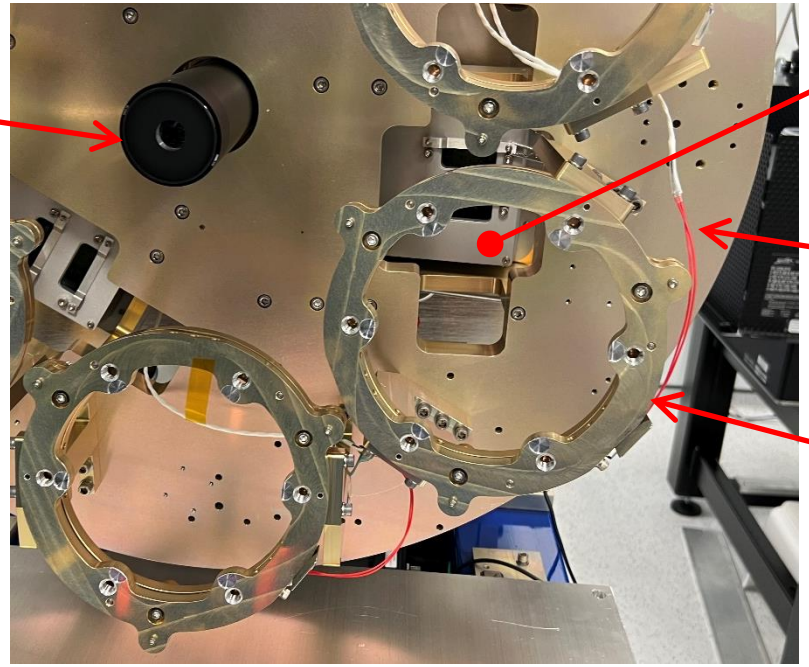
Projector/Collimator Pair on Rotation Stages

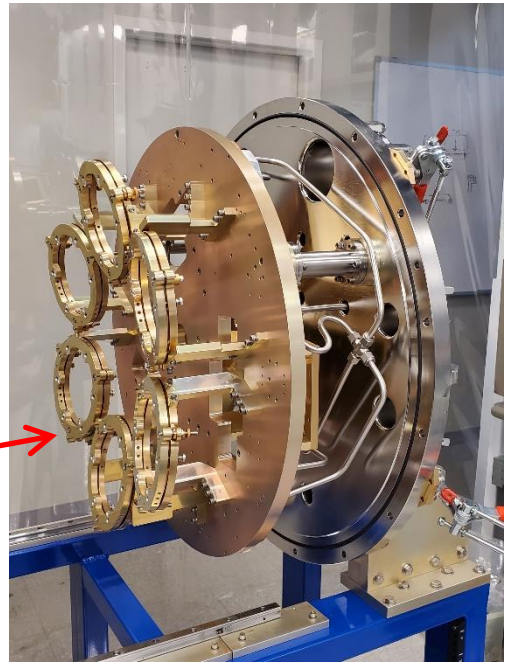


VNIR Chamber

- Current configuration supports up to six imagers mounted off-axis—**adaptable as needed**
- Support flange has numerous standard ports for electrical and thermal circuit feedthroughs
- AR coated window 380 nm to 950 nm, wedged and tilted
- Thermal plate has 3 heat exchangers for thermal control
- Compatible with high-vacuum

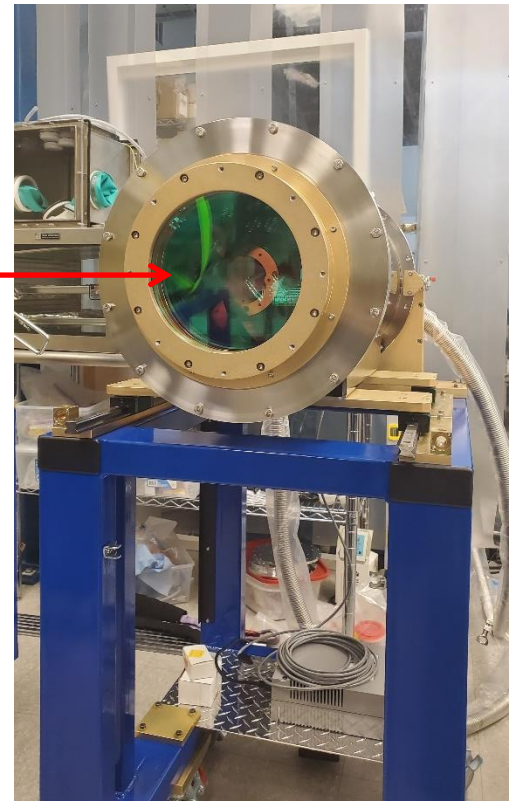


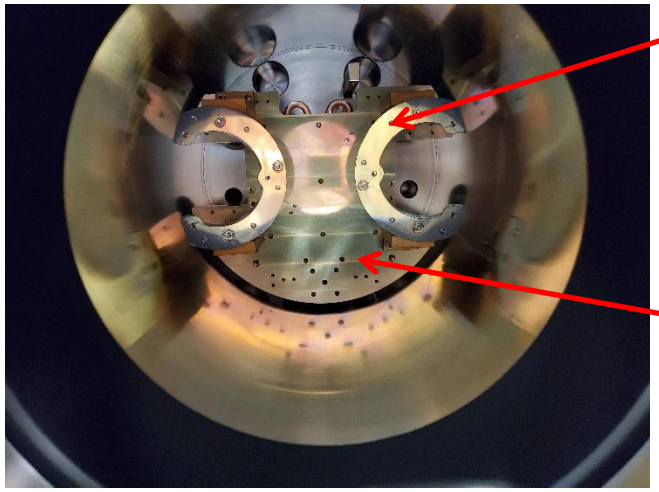


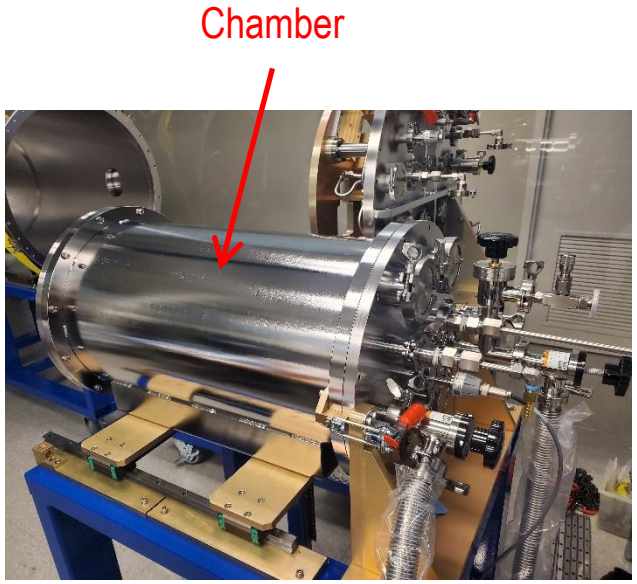


SWIR Chamber

- Smaller version of VNIR chamber—smaller with IR AR coated window
- Current configuration supports up to 2 imagers mounted off-axis—**adaptable as needed**
- Support flange has numerous ports for electrical and thermal feedthroughs
- AR-coated window 900 nm to 1800 nm
- Compatible with high-vacuum



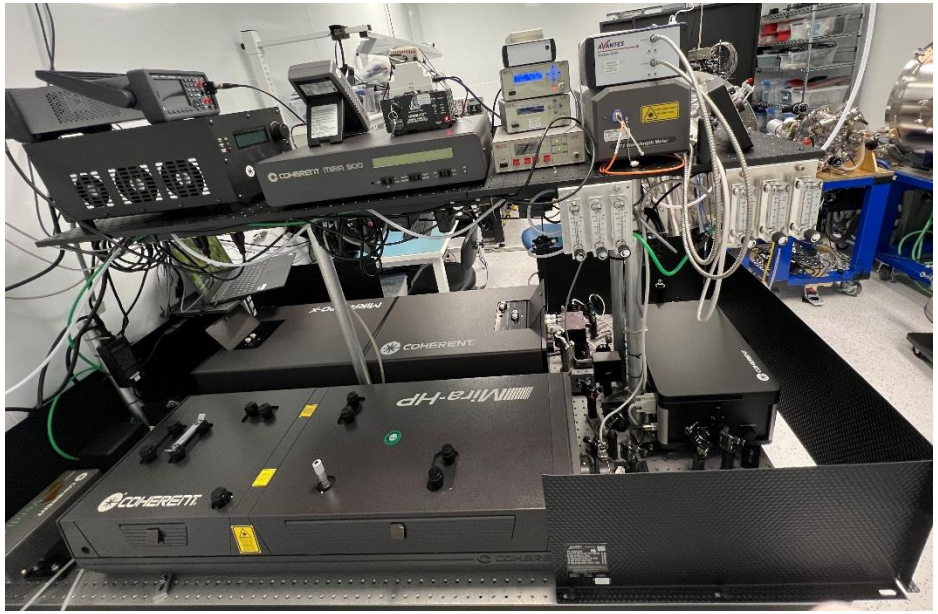


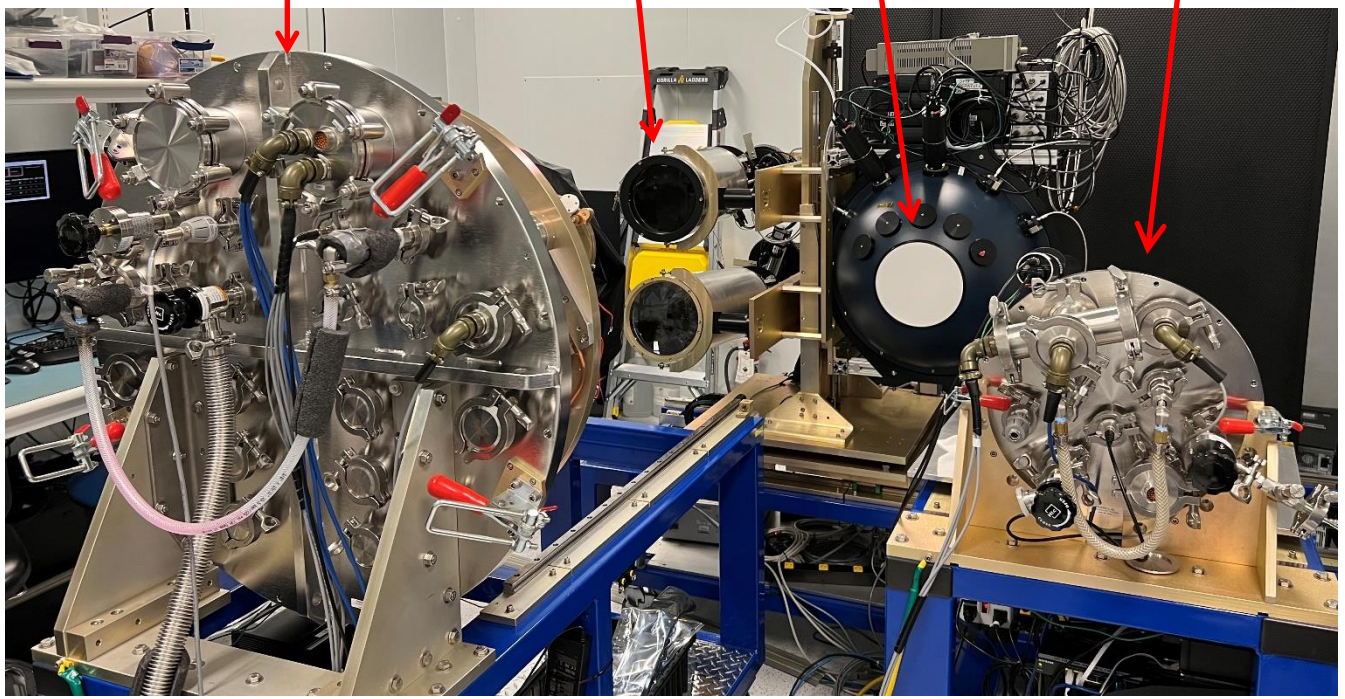


System Set-up for EarthDaily Pre-launch Calibration

- VNIR and SWIR chambers aligned with sources
- CW OPO Laser not shown

Coherent Laser Table:
Ti-Sapphire, OPO-X, and
Harmonic Generator





Basic Tests Performed

All measurements are on a per-pixel basis and are dark corrected

- Linearity of response: $DN_{LIN} = \mathcal{L}_i(DN_i)$, where DN_i are the counts for the i[th] pixel

- Absolute radiance responsivity, $R_i(\lambda_k)$, at discrete wavelengths, λ_k, in units of [DN_{LIN} m^2 sr / W] after illumination with radiance, L_s

$$R_i(\lambda_k) = \frac{\mathcal{L}_i(DN_i)}{L_s}$$

- Integrate, $R_i(\lambda)$, over wavelength to determine the spectral responsivity, SR_i [DN_{LIN} m^2 sr μm / W]
  - High density of, λ_k, integrate using discrete sampling, $R_i(\lambda_k)$
  - Or combine fewer $R_i(\lambda_k)$ with model

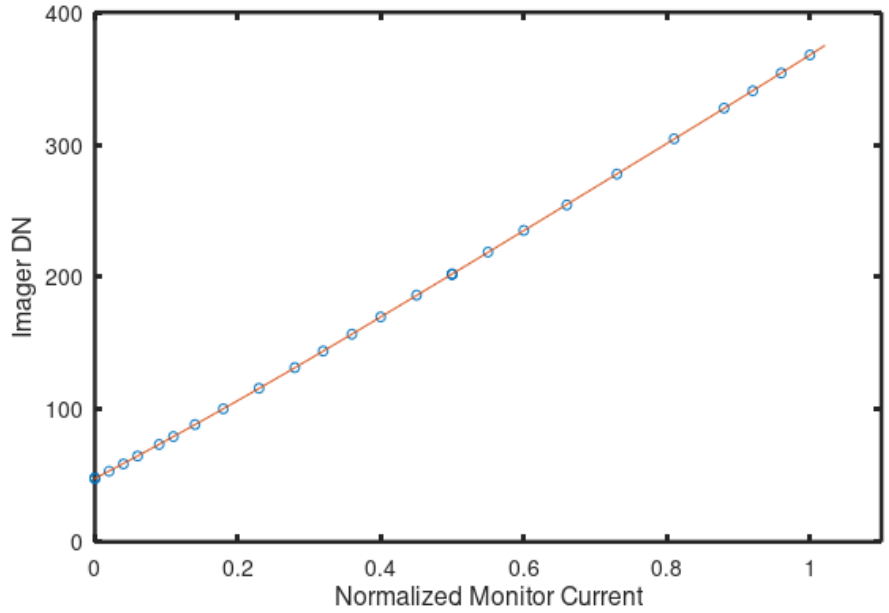
- TVAC testing through a window is treated as a relative response measurement referenced to ambient temperatures.
  - Linearity & changes in absolute response.
  - A few points, $R_i(\lambda_k)$, per band

Linearity Measurements—Example

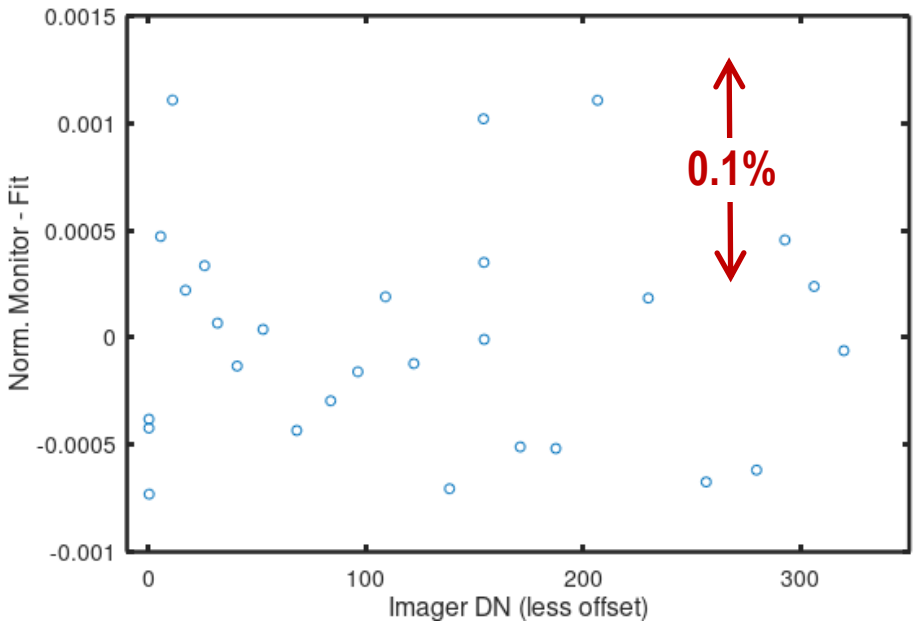
Linearity measurement using large integrating sphere

- Linearity measured to about 0.1%—better than the absolute scale
- Imager DNs are an average across the band
- Monitor current fit to imager DN: data (blue) and fit (red) on right, fit residuals on left

Imager Response vs Monitor Current



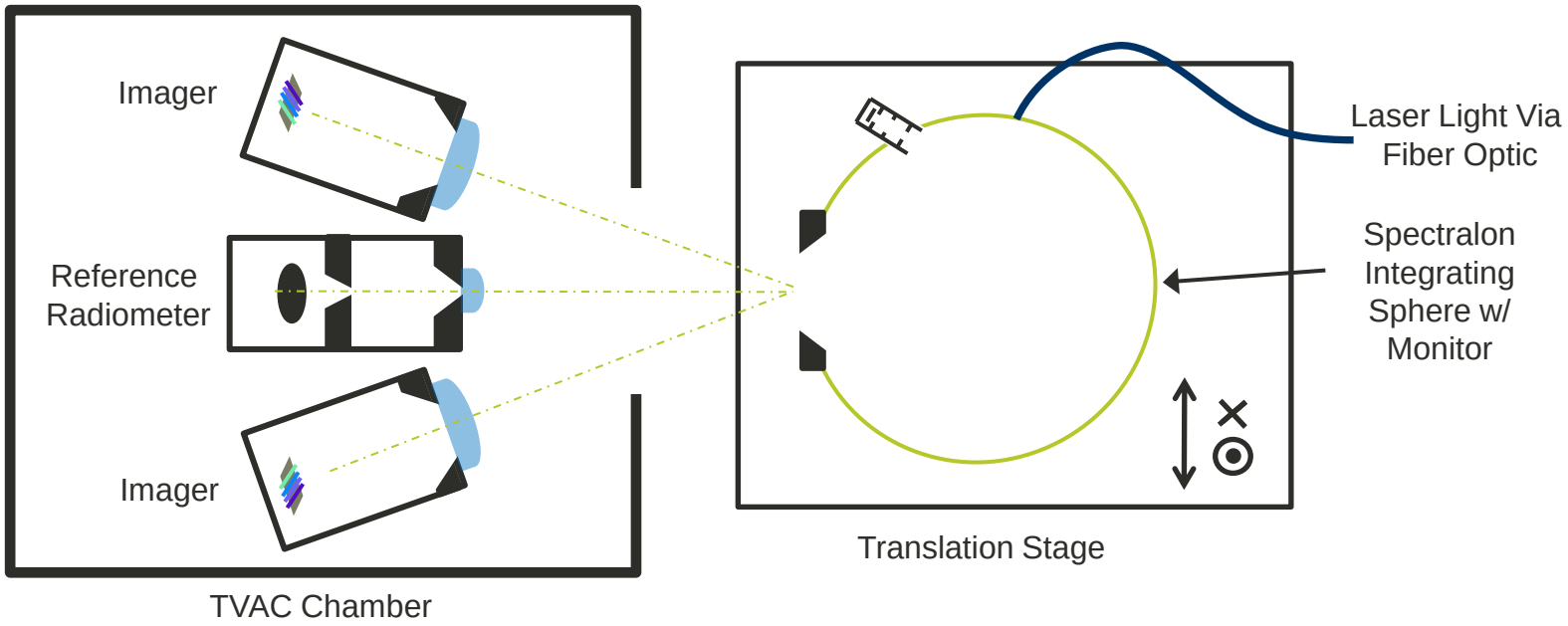
Residuals of Fit vs Imager DN



In-band Responsivity Measurements

Provides low-uncertainty responsivity vs wavelength for each pixel

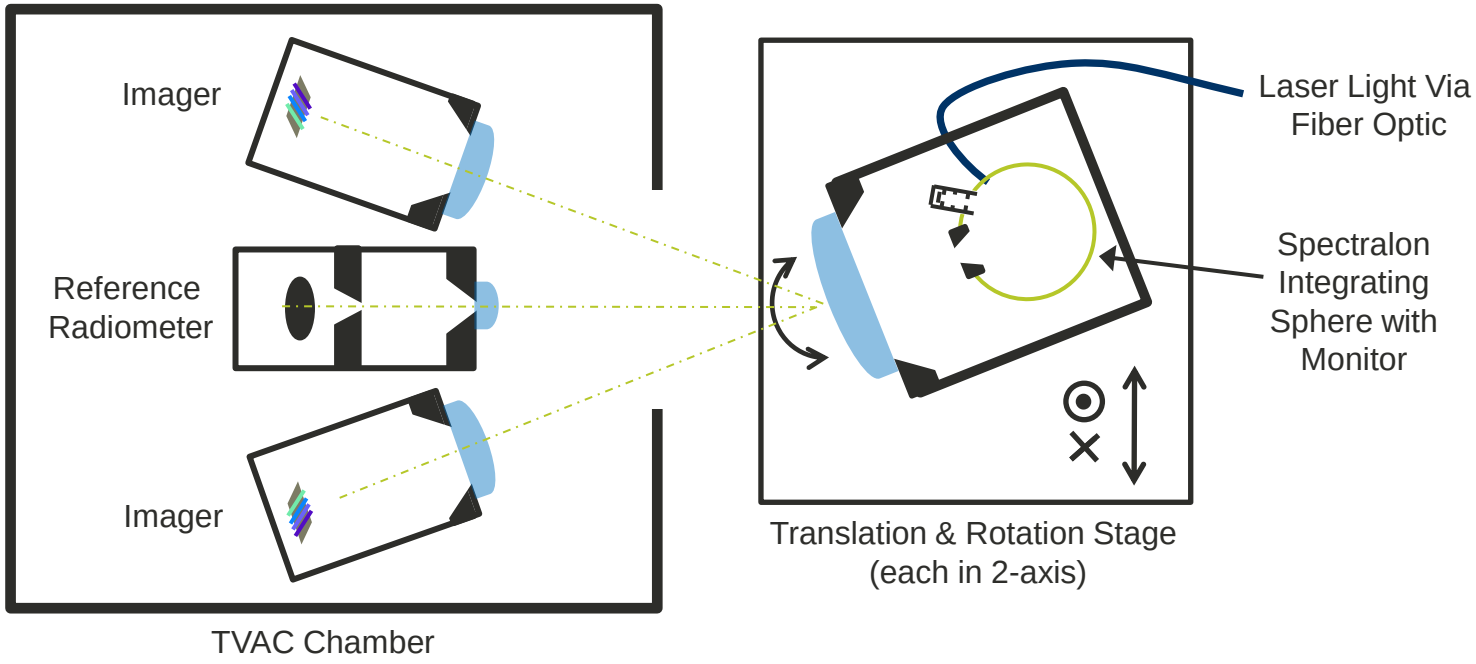
- Use aperture filling integrating sphere with 180 mm diameter exit port
- Reference detector measures sphere radiance
- Sphere uniformity ~0.1%, even off-axis
- N_2 purge sphere and TVAC chamber (**no window**) at atmospheric water bands



Out-of-band Responsivity and Linearity

Collimator/projector when high radiance required, otherwise, use sphere

- Small, 75 mm Dia., sphere feeds projection optics
- Illuminates imagers one at a time with more than 10x sphere radiance
- Linearity of source monitor detector ~0.01% (as with large sphere) supports SNR limited imager linearity measurement
- Linearity can be done with window



Calibration Radiance Levels—Tunable Lasers

- Pixel-level linearity measurements require excitation of the sensor at or above the max DN for a band
  - Expect projectors to reach max DN for moderate aperture imagers and typical bands
  - Sphere may reach max DN at the highest laser powers, 700 nm to 1000 nm and above 1500 nm

$$L_{\lambda}^{Band\ Max} \frac{\int rsr_i(\lambda) d\lambda}{rsr_i(\lambda_k)} = L_{laser}^{Max}(\lambda_k)$$

- Spectral response measured with sphere, if DNs are too low → map spectral response at longer integration times and transfer to calibration to short integration time using projector as a transfer source

Uncertainty of In-band Responsivity Measurements

Band spectral responsivity uncertainty budget showing *approximately* 0.5% (k=2) uncertainty in the VNIR (wavelength dependence ignored). Similar analysis gives *approximately* 1% (k=2) for SWIR wavelengths.

	Standard Uncertainty (k=1)		
	Type A	**Type B**	**Combined**
Reference Detector			
Responsivity VNIR	-	0.10%	
Photocurrent	-	0.01%	
Integrating Sphere			
Uniformity		0.05%	
Source Noise	0.05%	-	
Wavelength (spectrograph)	-	0.03%	
Monitor Noise/Stability	-	0.05%	
Camera			
Noise	0.1%	-	
Total (single wavelength in-band)	0.11%	0.13%	0.17%
Linearity Correction	-	0.1%	
Wavelength Sampling In-band (TBD)	<0.03%	0.15% (Budgeted)	
Out-of-band (TBD)	-	0.1%	
Total Band Integrated (TBD)	0.03%	0.24%	0.24% (0.49%, k=2)

Thank You