GeoCarb Instrument Status

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June 2019

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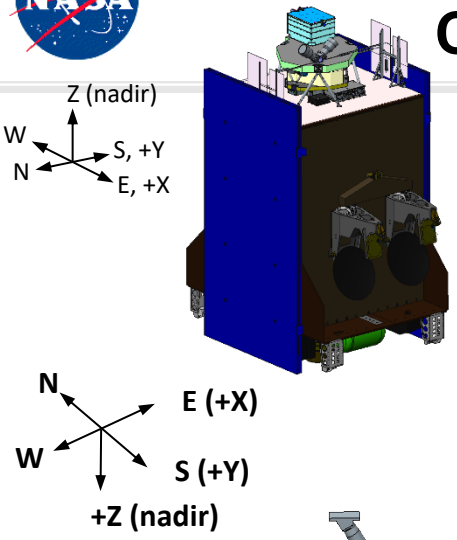
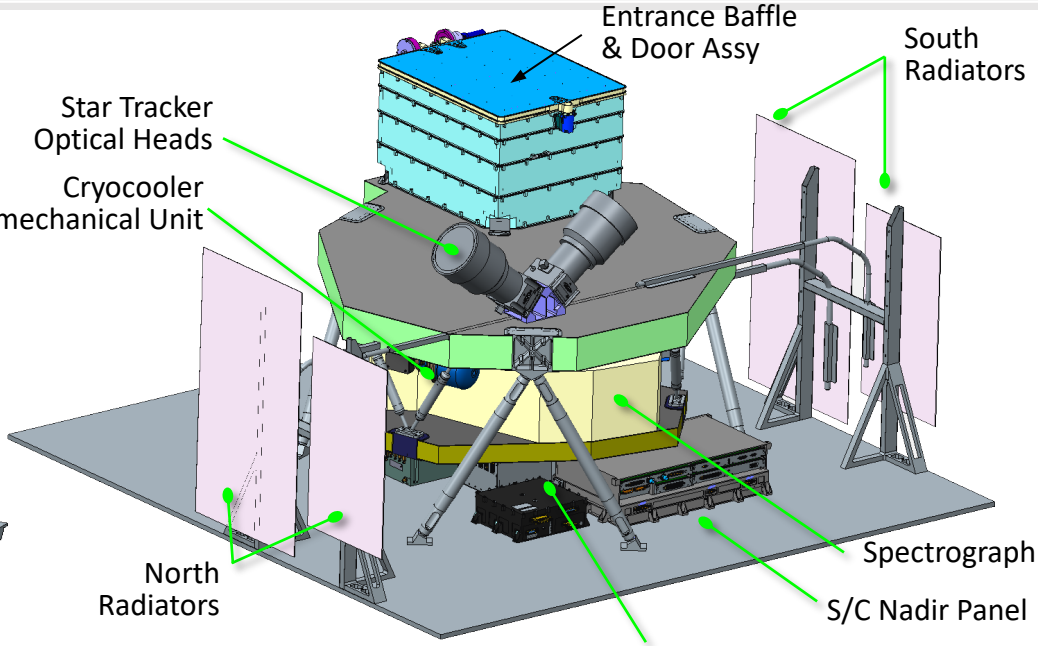
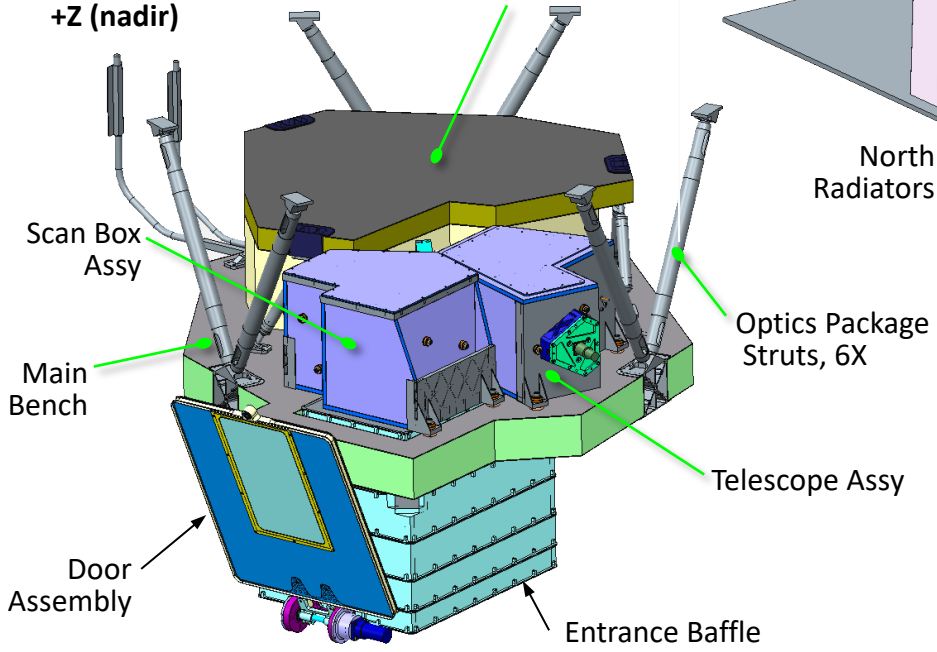
Government sponsorship acknowledged.

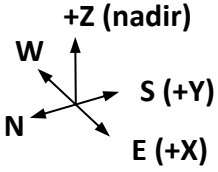
Instrument Implementation on a Commercial Communications Satellite at GEO





Nadir Panel Mounted Components
- GeoCarb Electronics Box (GEB)
- Focal Plane Electronics Box (FPE)
- Star Tracker Electronics Unit (STEU)
- Decoder Electronics Box (DEB)
- Cryocooler Electronics (CCE)





Coverage/Resolution Requirements

Requirements	Baseline	Threshold	Expected
North/South scan slit length at nadir: latitude extent or length	24.4° or ≥2700km	24.4° or ≥2700km	25.0° or 2800km
Space-based measurements shall have spatial resolution at the sub-satellite point (single sounding)	<30 km^2	<100km^2	5.4km (E/W)
Space-based measurements shall have spatial sampling at the sub-satellite point	<3 km	<5 km	3 km (E/W)
Space-based measurements shall have spatial Geolocation accuracy at sub-satellite point	<0.9 km	<1 km	0.53 km (E/W)
Retrieval estimates shall cover significant portions of Continental US, Central and South America to enable sub-daily soundings	>25M km^2 in ≤6 hrs	>25M km^2 in ≤6 hrs	37M km^2 in ≤6 hrs
East/West scan slit width at nadir	5.7 km	5.7 km	5.4 km

Instrument Spectral Requirements

- GeoCarb instrument is a 4-channel slit imaging spectrometer that measures reflected near-IR sunlight as follows:

Band	Central Wavelength (nm)	Required $\delta\lambda$ (nm)	Current Baseline $\delta\lambda$ (nm)	Required $R=\lambda/\delta\lambda$	Current Baseline $R=\lambda/\delta\lambda$	Required SNR	Current Baseline SNR (12 coadds)
O2A/SIF	765	0.0474	**0.044**	16139	**17556**	395	**424**
WCO2	1606	0.101	**0.091**	15901	**17592**	389	**426**
SCO2	2065	0.136	**0.114**	15184	**18082**	302	**388**
CH4/CO	2323	0.153	**0.129**	15183	**18044**	254	**280**

Primary Instrument Descopes

- Optical redesign: Reduce aperture area by half
  - reduction of SNR from - doubled stare time to meet SNR reqts
  - Areal coverage rate retained by removal of double sampling
- Removal of Secondary Solar Calibration Drum: redundancy to assess changes in primary diffuser – already planned lunar observations will be sufficient
  - Lunar observations will be used to assess changes in the calibration over time. This methodology has been demonstrated by OCO-2. Working with lunar cal experts to adapt the OCO-2 approach for GeoCarb sampling
- Removal of IMU: expected pointing knowledge is reduced by ~0.1km, but it still meets MDRA requirements

GeoCarb meets all Level 1 requirements and satisfies the mission hypotheses with the de-scoped project, though with reduced performance margin

Impacts of Instrument Descopes

- Reduced size of optics
  - Optical footprint areas average about 60% of former size
  - Reduces mass of most optics, especially those near pupils
- Throughput is halved
  - Accommodated by doubling of exposure time (see below)
- Beam speed from F/3.2 → F/4.5 (one “f-stop”)
  - Reduces errors due to geometric imaging
  - Relaxes fabrication tolerances
  - Increases diffraction limit by 40% (larger spots, still within req.)
  - Increases depth of field (slower beam, larger spot size)
- Improved clearances
  - Smaller optics and narrower beam
- Double exposure time
  - Essentially preserves signal-to-noise
    - Reduces coverage rate
  - Decreases contrast to thermal background (impacts S/N in CH4)
    - Reduces data rate

What Did Not Change

- Focal length/plate scale of telescope
  - Ground footprint of slit preserved
  - Field of view/field of regard preserved
- Overall layout of design
  - Initial view (previous slides) shows simple reduction of optics sizes, but redesign was looked into and performed (see next slide)
- Bandpasses/dispersion
  - Spectral coverage and resolving power preserved
- Gratings
  - Due to potential impacts on schedule, the gratings' sizes will remain as previously designed
  - No mass reduction
  - May require baffle mask

Instrument Optical Layout

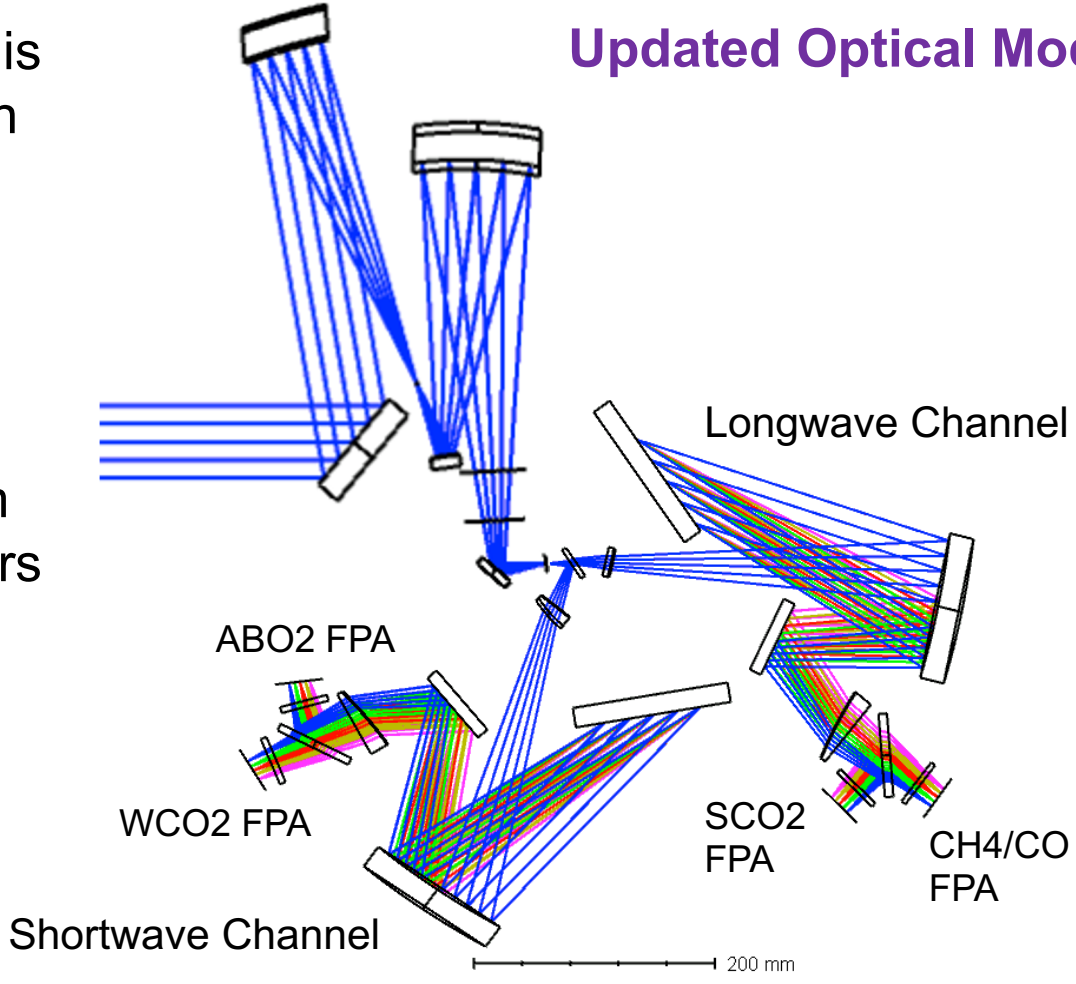
The GeoCarb instrument is a 4-Channel spectrograph split between:

- ABO2 +WCO2
- SCO2+CH4/CO

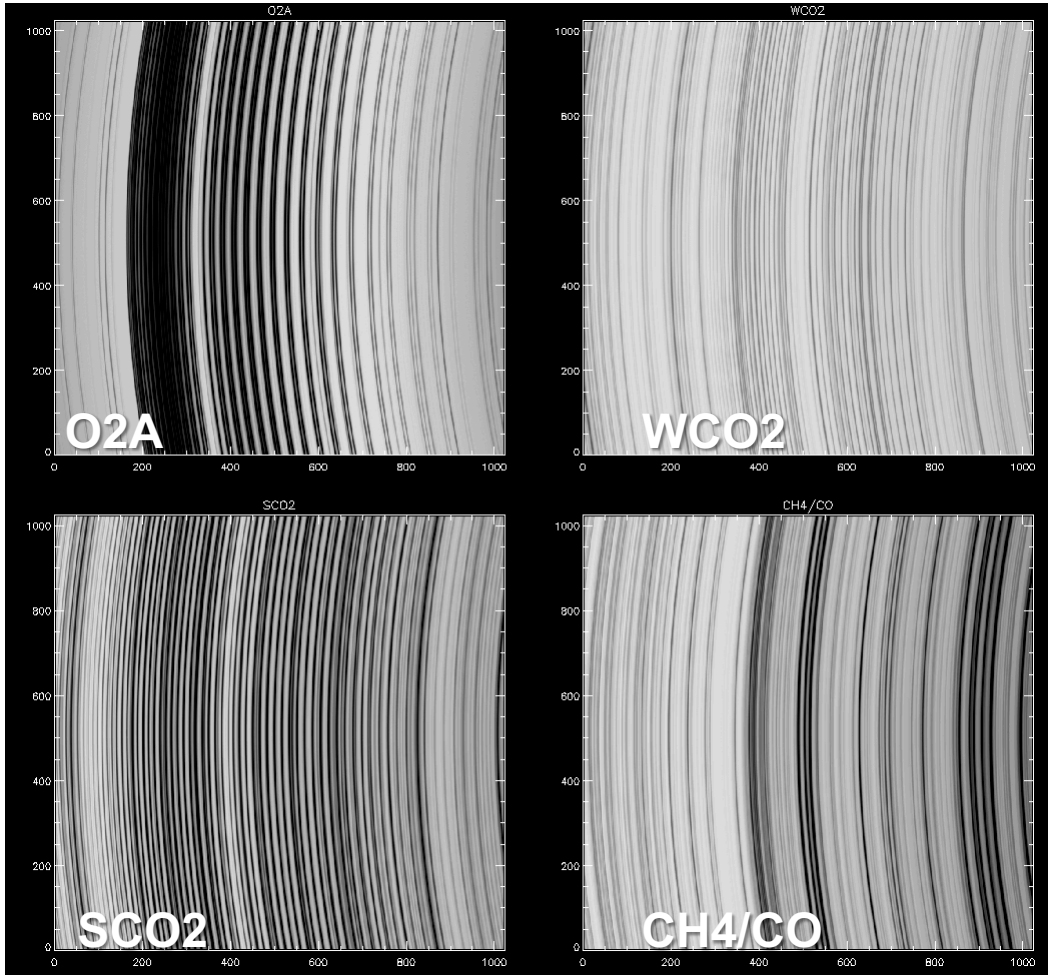
Echelle gratings used in multiple orders with beam splitters and blocking filters to isolate bandpasses.

Four (1024^2) HgCdTe H1RG detectors

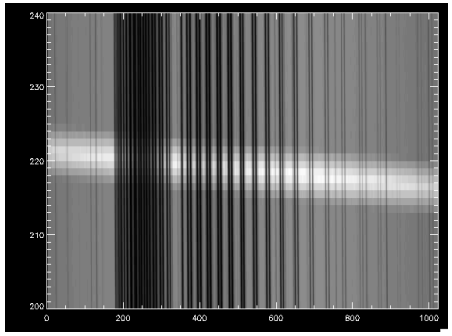
Updated Optical Model



Geometric Calibration



- Simplified because all light goes through a common slit
- Challenging because the slit image is strongly curved on FPA
  - ~40 pixels curvature at ends of slit
  - Mapping of slit to the FPA may change from channel to channel



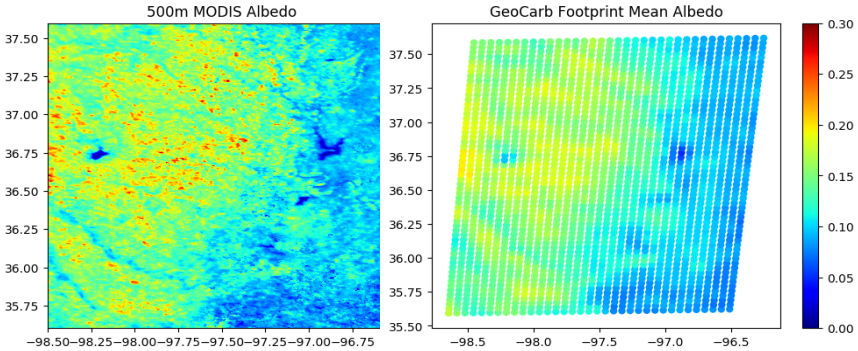
Significant Changes

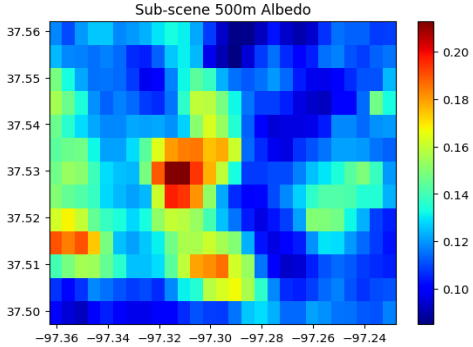
Item	PDR	DPDR	% change
Instrument Mass (CBE/MEV)	186 kg / 213 kg	157 kg / 183 kg	-16% / -14%
Instrument Power (CBE/MEV)	406 W / 538 W	393 W / 521 W	-3% / -3%
Data Rate	18.7 Mbps	9.3	-50%
Funded Schedule Reserve	71 days	71 days	0%

Descope efforts have significantly increased the financial health and key contingencies of GeoCarb while maintaining performance that satisfied the Level 1 Requirements and mission objectives

Impacts of Non-uniform Illumination

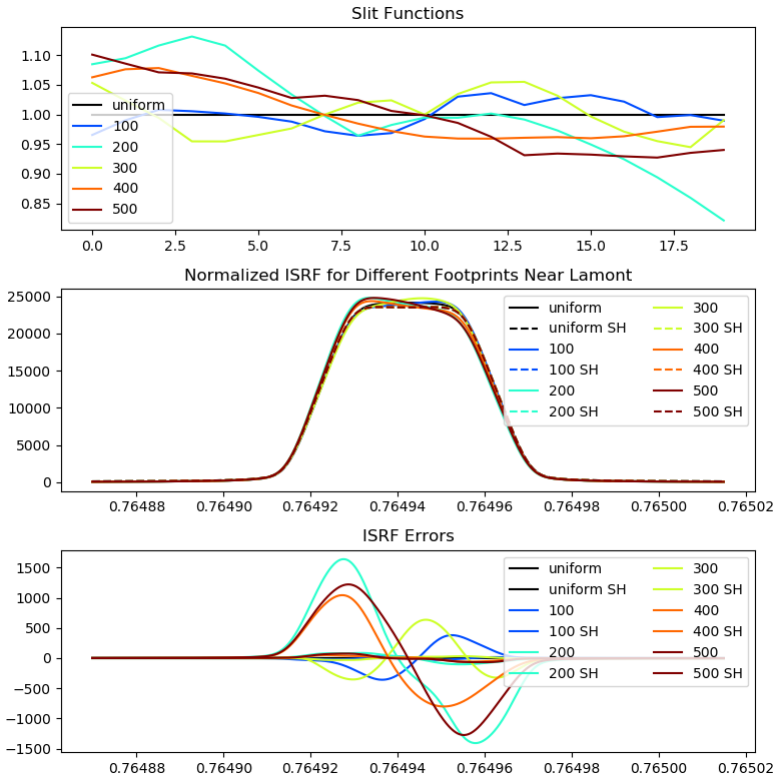
- Spatial variations in illumination across the slit introduce biases by modifying the instrument line shape (ILS)
- Modification of ILS tested using 500m MODIS albedo variations for a 2°x 2° degree region around Lamont, OK



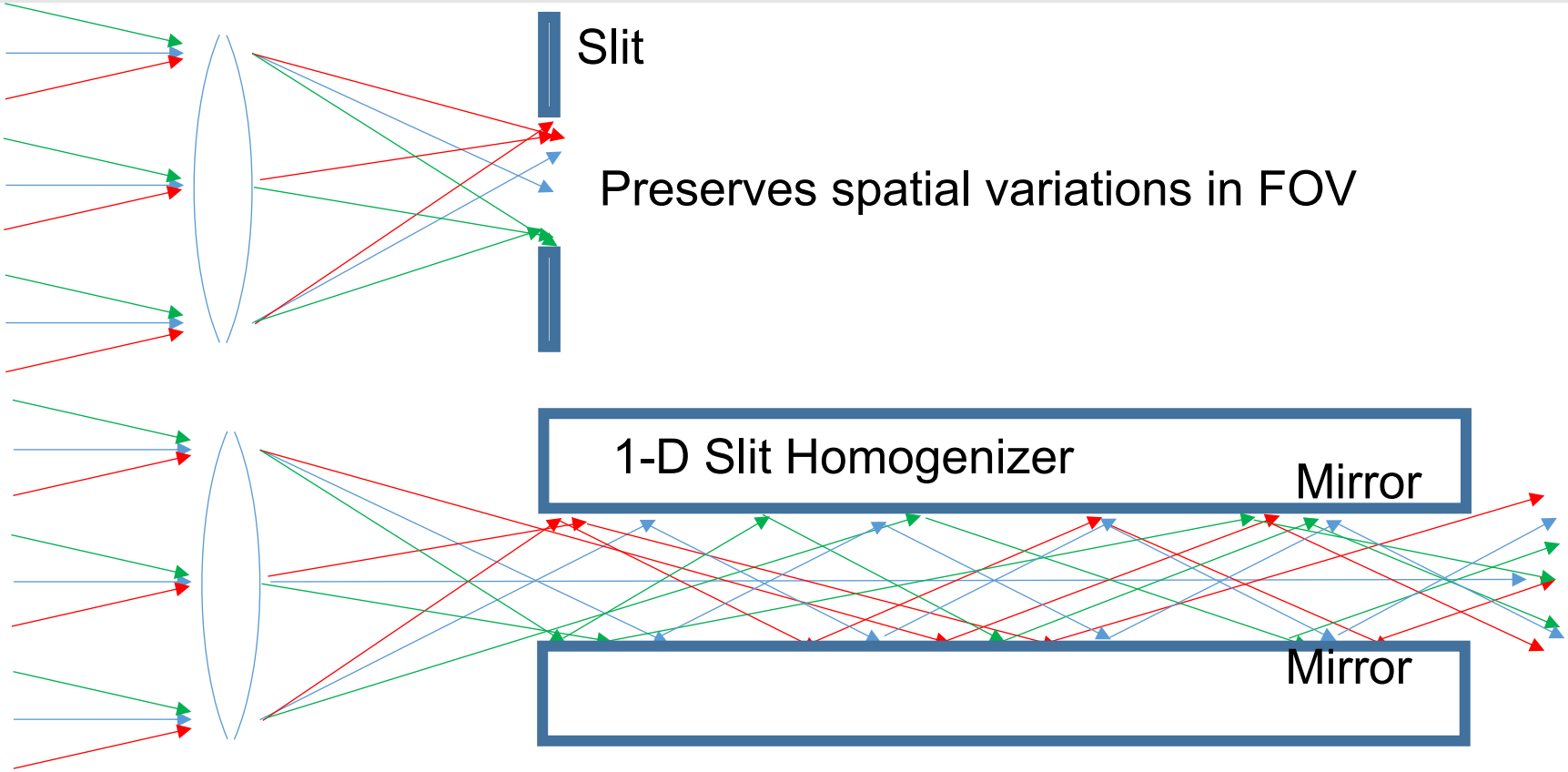


Albedo Variations within a Footprint

Sample ILS with and w/o a 1-D slit homogenizer for different variations in albedo across the slit

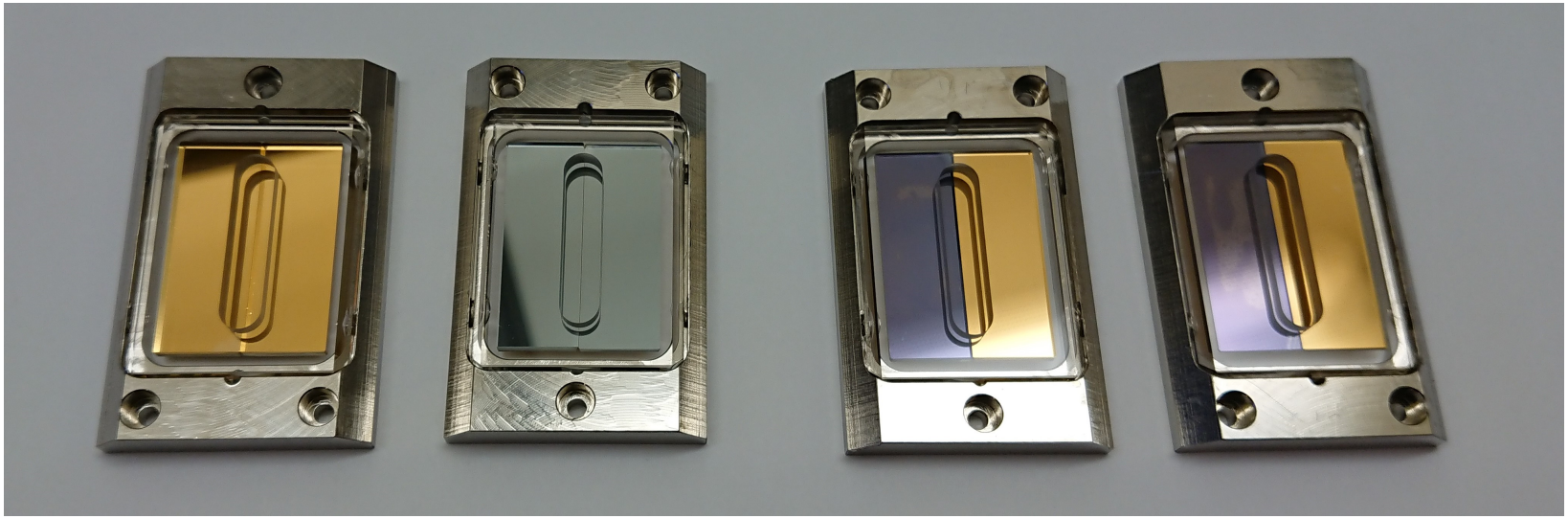


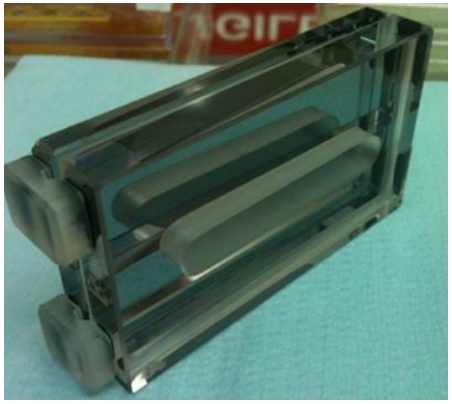
1-D Slit Homogenizers



Side (or top) of a 1-d slit homogenizer. Rays focused on the same field positions at the entrance emerge at different field positions at the exit (… pardon hand drawn rays …) but preserve the F/#.

Slit Homogenizer Development





- Non-flight 1-d slit homogenizers have been fabricated by two vendors and shipped to ITO for testing (3 depths X 2 from each)
- Initial quality checks look good
- Slit widths 33-34 um
- Flight models will be ordered by end of June

Calibration

Similar approach as used for OCO-2

- Pre-flight characterization and calibration
  - Performed with instrument in vacuum using an integrating sphere
  - Zero-level offset (bias)
  - Gain and gain linearity
  - Integrated radiometric efficiency
  - Geometric calibration
- In-flight Calibration
  - Radiometric Calibration
    - Solar Calibration (primary and secondary diffusers)
    - Lunar calibration (throughput of Science optical path)
  - Spectroscopic calibration
    - Solar and telluric lines
  - Geometric calibration
    - Moon and stars

Summary

Instrument:

- GeoCarb has a highly optimized, compact optical design, Optical performance, by design, meets all driving requirements
  - Spatial resolution, spectral resolution, and signal-to-noise all have margin
- Slit homogenizer accommodated with astigmatism introduced in a single flat fold mirror

Calibration and Characterization planning underway

- Comprehensive ground testing sets baseline for instrument calibration
  - Informs alignment, integration, and test planning
  - Test as we build approach reduces risk
- Builds on heritage from OCO-1/2/3 experiences
  - Overlapping science teams, calibration expertise
- Concept of Operations defines on-orbit calibration monitoring
  - Frequent calibration observations interwoven with science observations will allow for most accurate science products possible