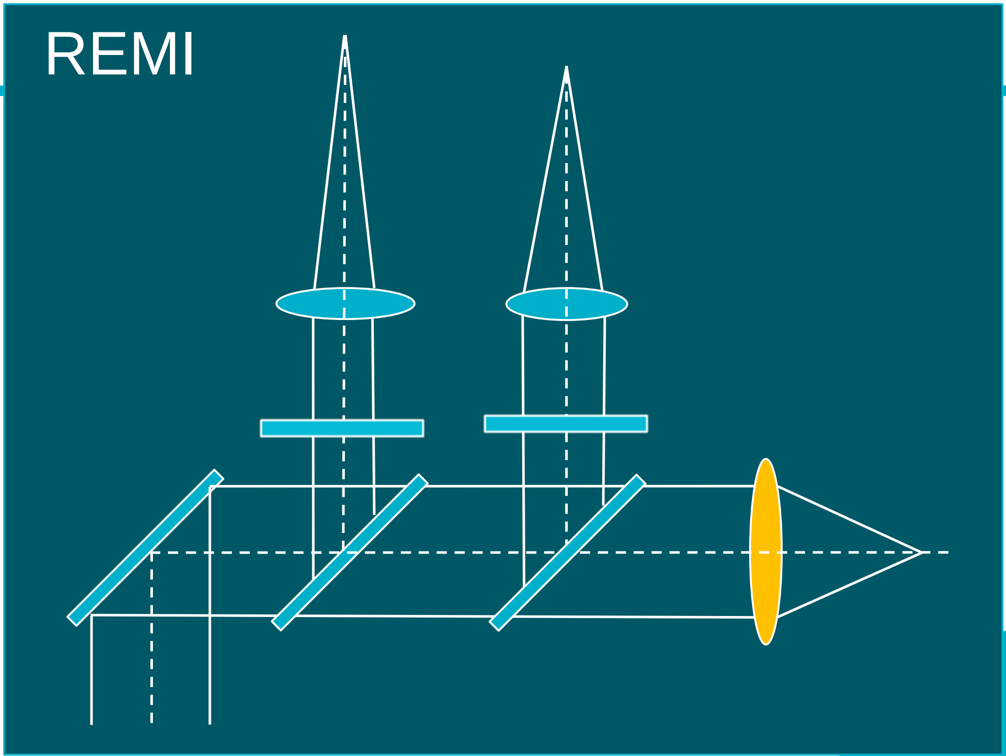
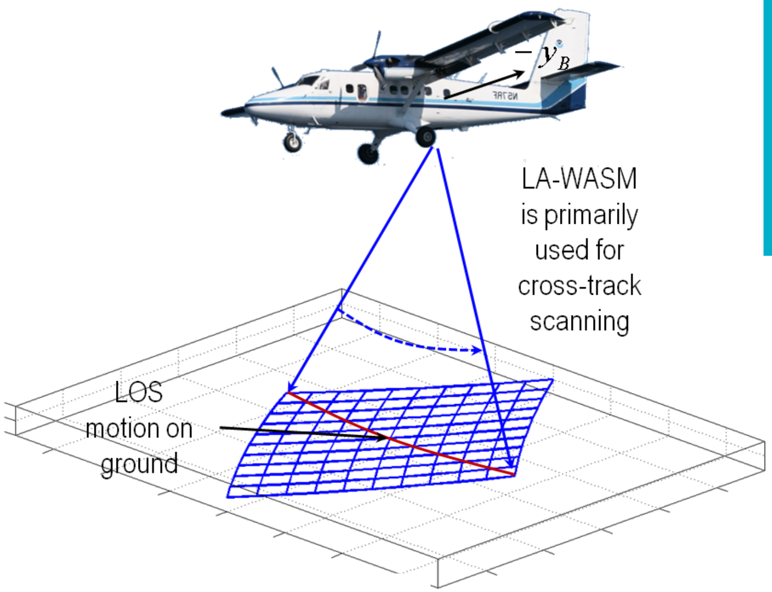


REMI - Reduced Envelope Multi-Spectral Imager for Sustained Land Imaging



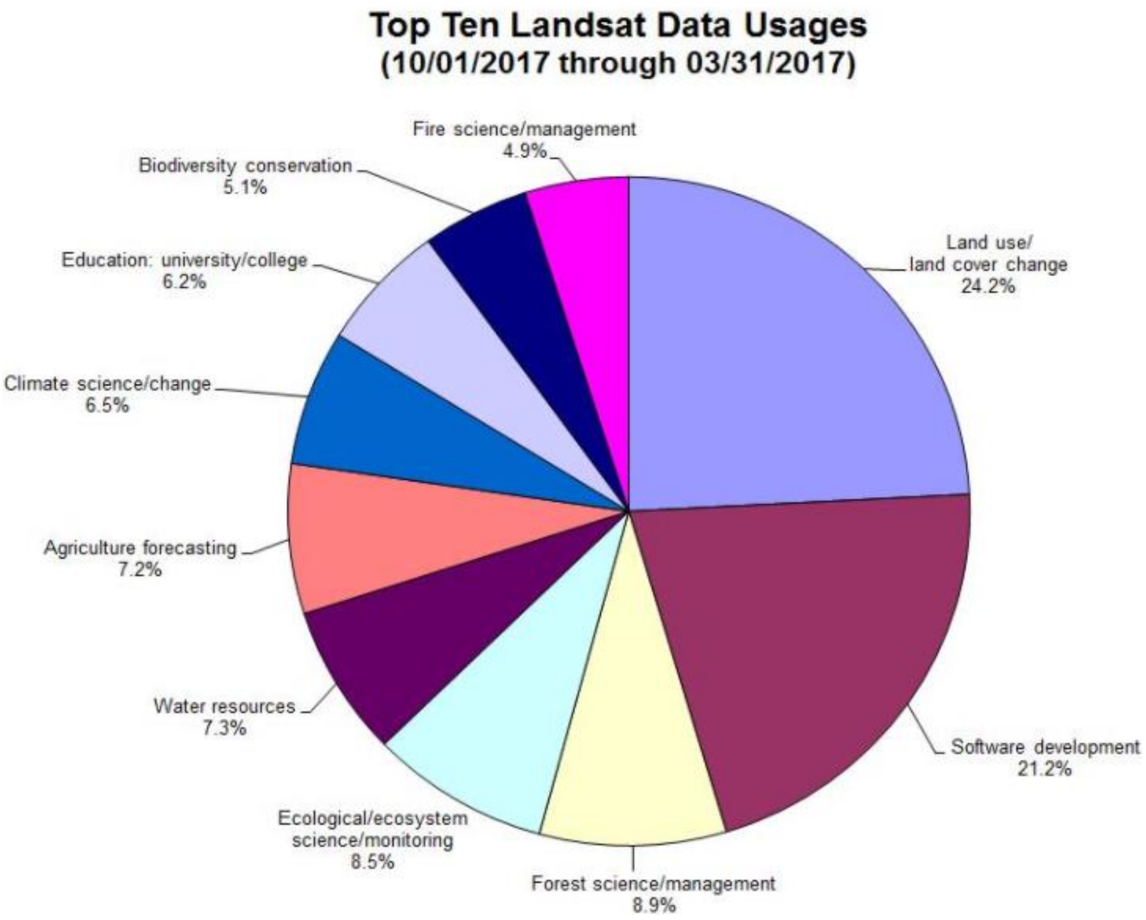
Paula Wamsley, PI
A. Scotty Gilmore, PM

Earth Science Technology Forum

June 2017

LandSat: An Early & Enduring Earth Observation Mission

Landsat Data are Widely Distributed for Use in Science Research and Applications

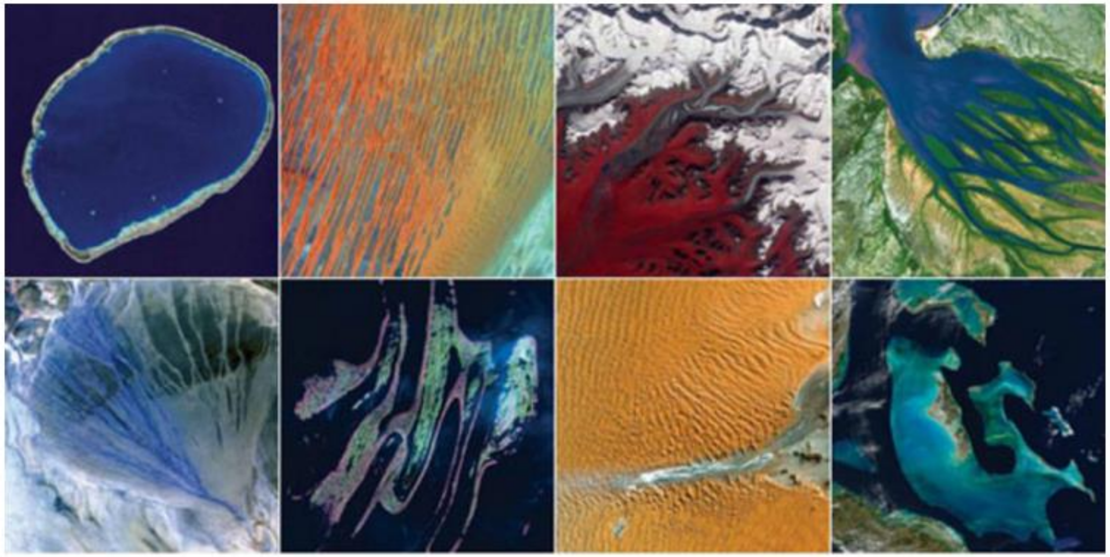


https://landsat.usgs.gov/top-ten-uses

376 Abstracts for 2016 AGU Fall Meeting

5,270 entries in Google Scholar for 2017

Sustainable Land Imaging Program



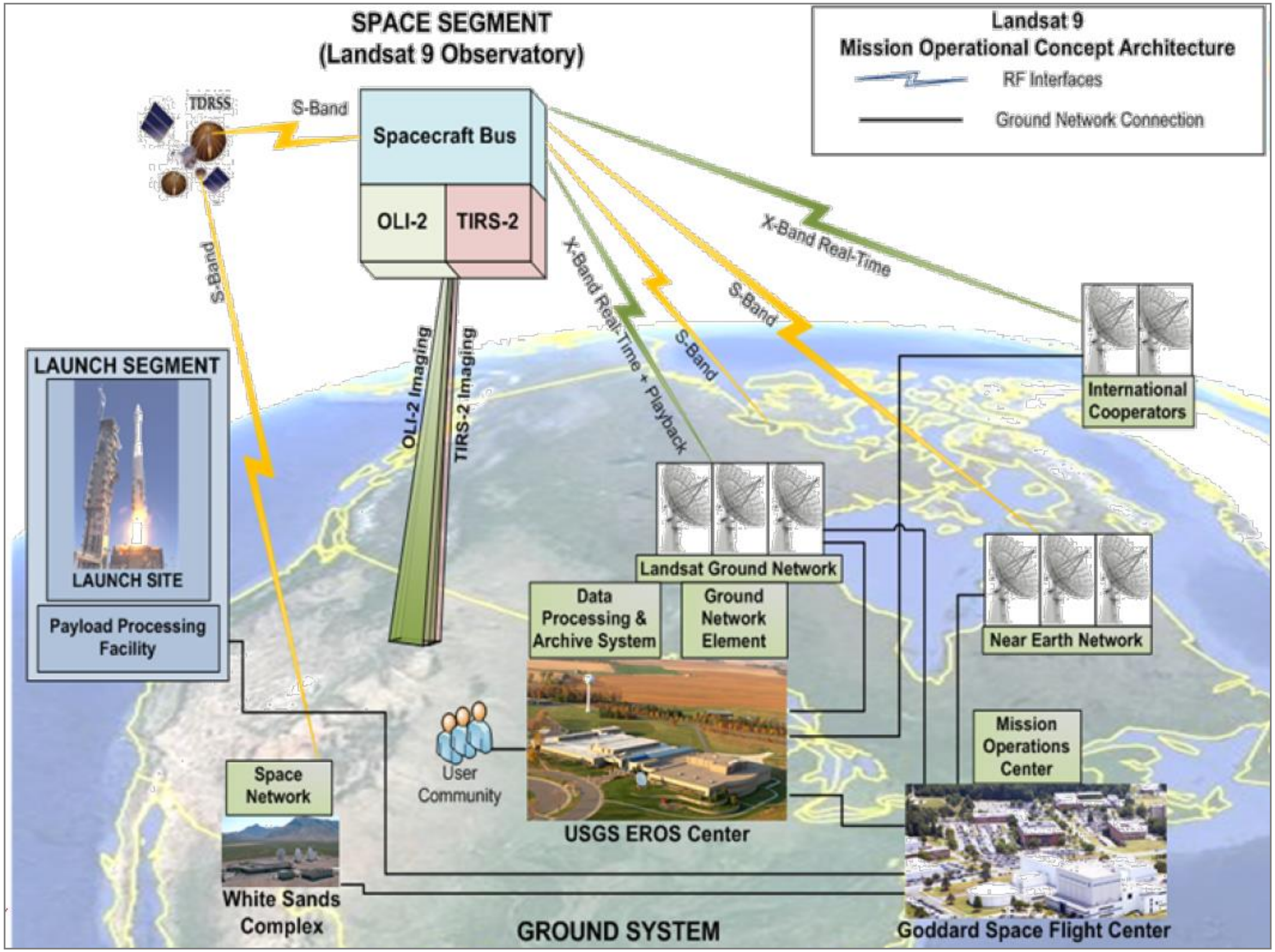
- ❑ **Sustainability**
- ❑ **Continuity**
- ❑ **Reliability**

The goals of the SLI-T program are to research, develop, and demonstrate new measurement technologies that improve upon the Nation's current land imaging capabilities while at the same time reducing the overall program cost for future SLI measurements.

The SLI-T program seeks to:

- Reduce the risk, cost, size, volume, mass, and development time for the next generation SLI instruments, while still meeting or exceeding the current land imaging program capabilities;
- Improve the temporal, spatial, and spectral resolution of SLI measurements; and
- Enable new SLI measurements that can improve the program's operational efficiency and reduce the overall costs of the Nation's land imaging capabilities.

Landsat 8/9 Top Level Architecture



Landsat Mission Operations Request for Information Industry Day, Floyd, V. & Nelson, J., USGS 2/2/2016.

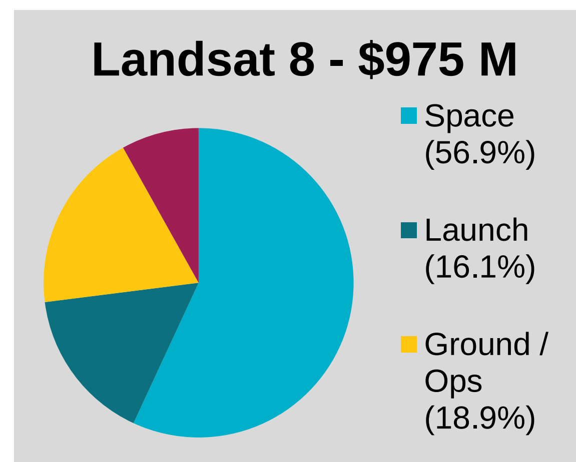
Landsat 8 Space Segment - Sensors

Parameter	OLI	TIRS
Mass (kg)	470	236
Envelope Vol. (m^3)	6.5	2.0
GSD (m)	30 (15 PAN)	100
Sensor Type	Pushbroom	Pushbroom
X-track Angular FOV (°)	15 (185 km)	15 (185 km)
Wavelength (mm)	0.4–2.4	10–13
FPA	SiPIN (VNIR), HgCdTe (SWIR)	QWIP (Thermal), Actively cryo-cooled
Primary Calibration	On-board solar diffuser	On-board blackbody

LandSat 8		
Segment	Price	% of Mission
Space	$555.1M	56.9%
Launch	$157.1M	16.1%
Ground / Ops	$184.3M	18.9%
Mgmt	$78.2M	8.1%
Total	**$974.7M**	**100%**

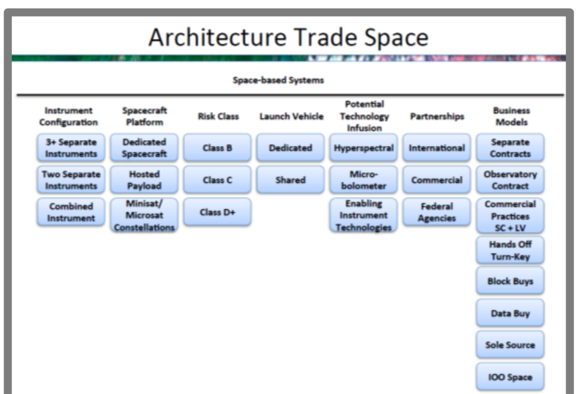
Ball Aerospace

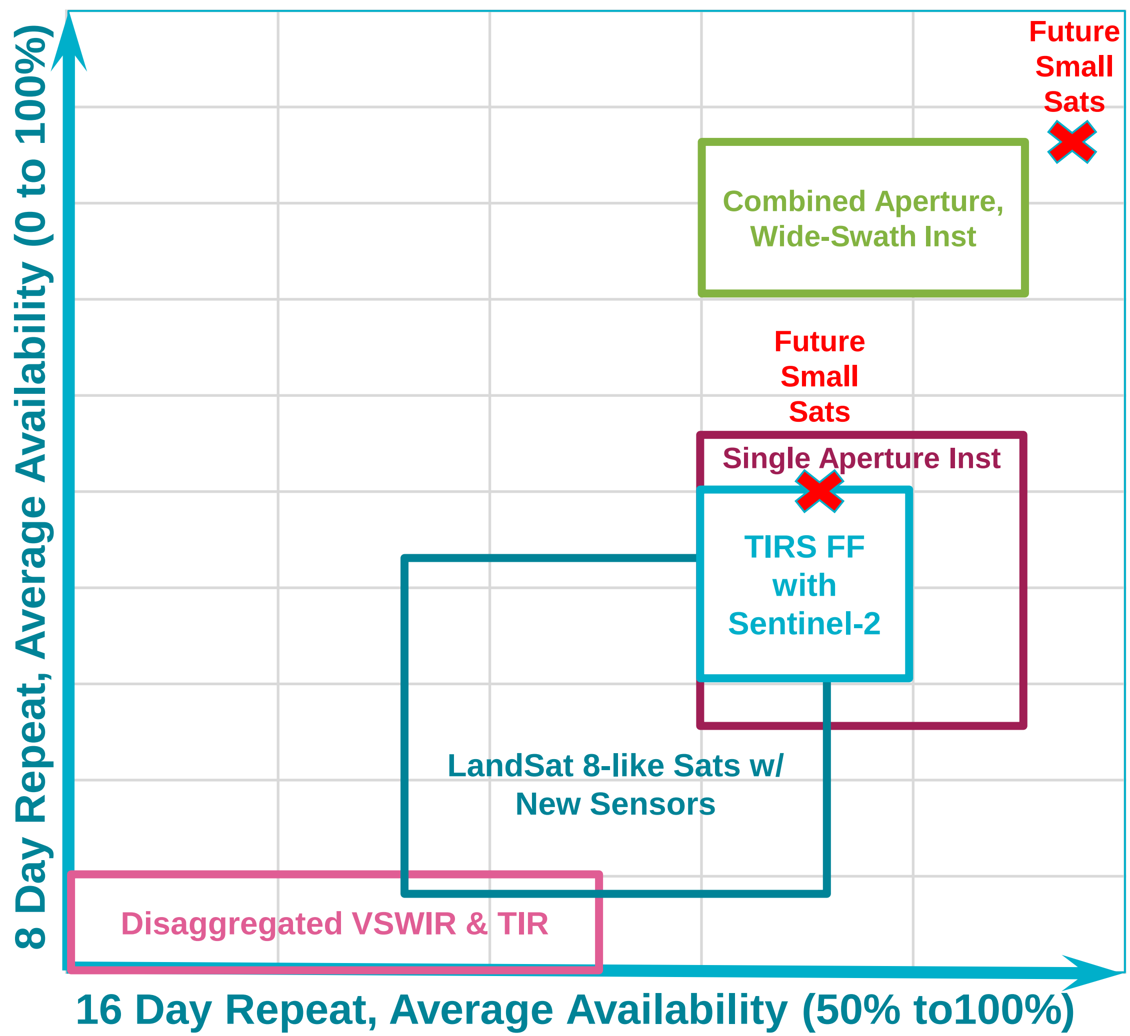
NASA



REMI Design Concept Guided by NASA/USGS Architecture Studies

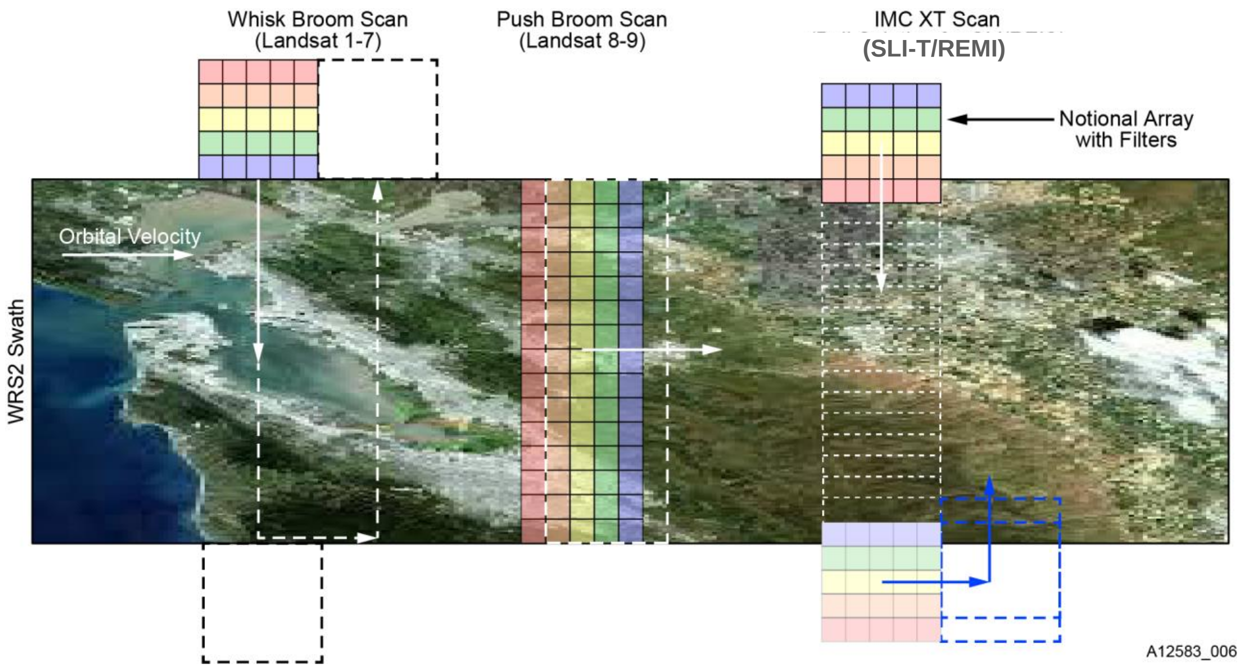
What is an Architecture?
Payload
Spacecraft
Launch
Technology Infusion Plan
Mission Risk Class
Org Partnerships
Procurement Approach





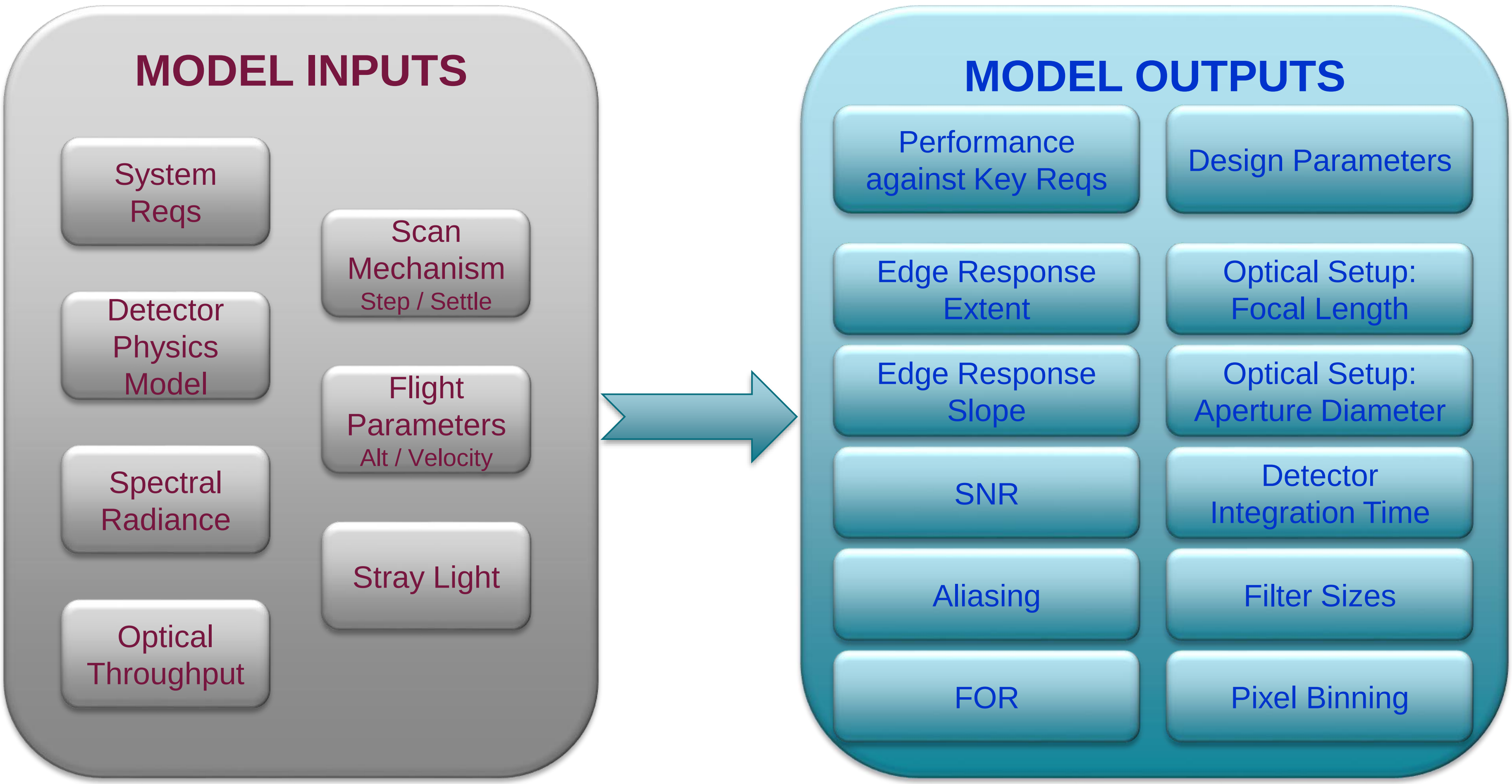
Scan Approach Opens the Design Space

- **Whisk Broom: LandSat 1-7**
- **Push Broom: LandSat 8 & 9**
- **Step-Stare with Image Motion Correction: SLI-T/REMI**



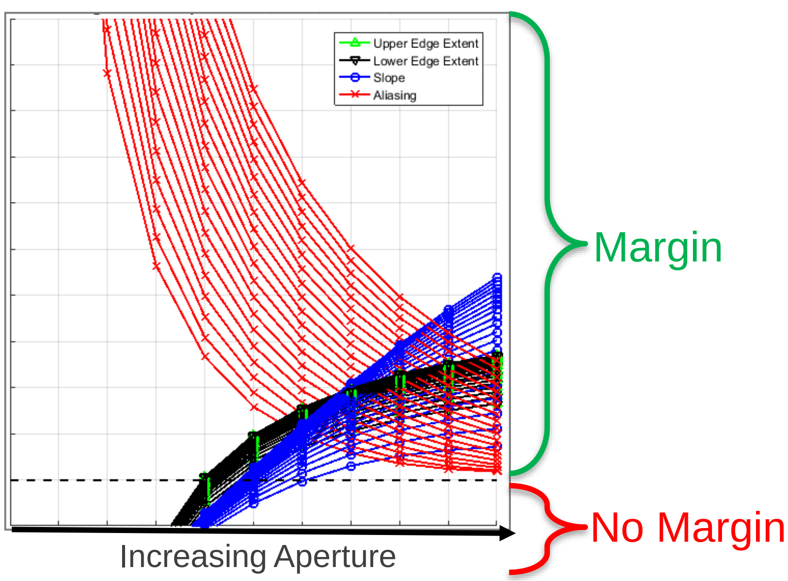
Comparison of three different scan methodologies: Whisk Broom, Push Broom, and Step-Stare.

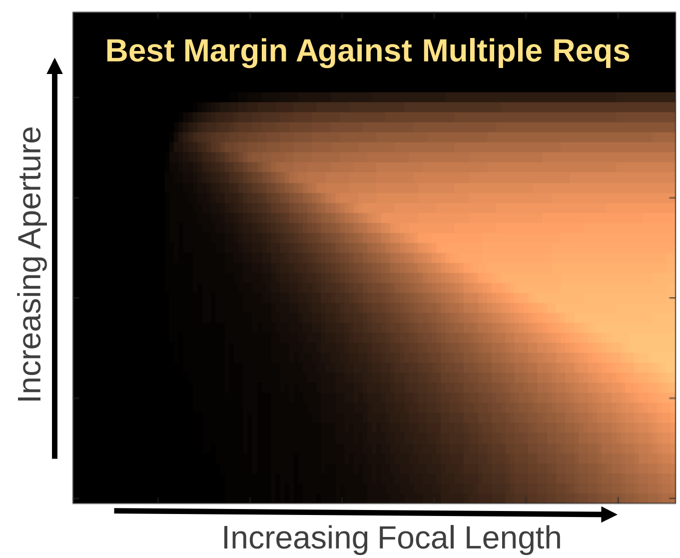
Performance Model Developed to Guide Design Trades



Derivation of REMI Reqs from SLIT RMA

	SLIT Requirements from Reference Mission Architecture						REMI Requirements (4,000 m AGL)							
Band #	Band Name	Nominal GSD (m)	Min Edge Slope (m^{-1})	Min Edge Slope (μrad^{-1})	Max Half Edge Extent (m)	Max Half Edge Extent (µrad)	Nominal GSD[1] (m)	Predicted GSD[1] (m)	Equivalent GSD[1] (m)	Min Edge Slope[2] (m^{-1})	Min Edge Slope[2] (μrad^{-1})	Max Half Edge Extent[2] (m)	Max Half Edge Extent[2] (µrad)	Max Aliasing[4]
1	Coastal Aero	30	0.027	0.0190	23.0	32.6	0.168	0.069	12.1	4.7588	0.0190	0.13	32.6	1.0
2	Blue	30	0.027	0.0190	23.0	32.6	0.168	0.069	12.1	4.7588	0.0190	0.13	32.6	1.0
3	Green	30	0.027	0.0190	23.0	32.6	0.168	0.069	12.1	4.7588	0.0190	0.13	32.6	1.0
4	Red	30	0.027	0.0190	23.5	33.3	0.168	0.069	12.1	4.7588	0.0190	0.13	33.3	1.0
5	NIR	30	0.027	0.0190	24.0	34.0	0.168	0.069	12.1	4.7588	0.0190	0.14	34.0	1.0
6	SWIR 1	30	0.027	0.0190	28.0	39.7	0.168	0.168	29.6	4.7588	0.0190	0.16	39.7	1.0
7	SWIR 2	30	0.027	0.0190	29.0	41.1	0.168	0.168	29.6	4.7588	0.0190	0.16	41.1	1.0
8	Pan	15	0.027	0.0190	14.0	19.9	0.168	0.069	12.1	4.7588	0.0190	0.08	19.9	1.0
9	Cirrus	30	0.027	0.0190	27.0	38.3	0.168	0.168	29.6	4.7588	0.0190	0.15	38.3	1.0





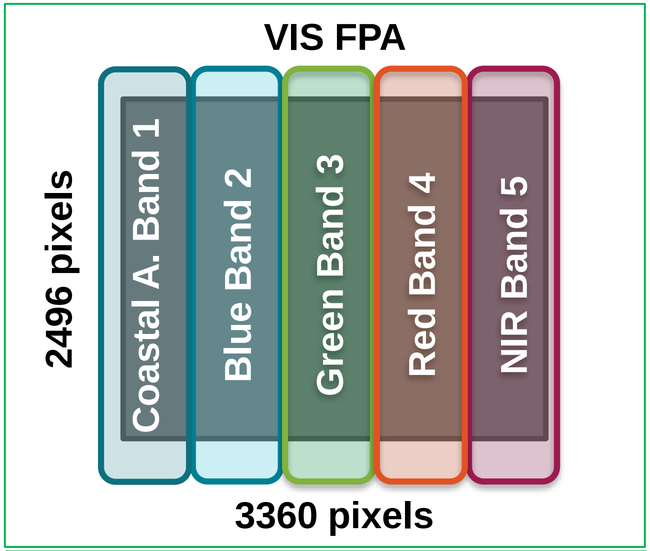
All VSWIR Spectral Bands Demonstrated

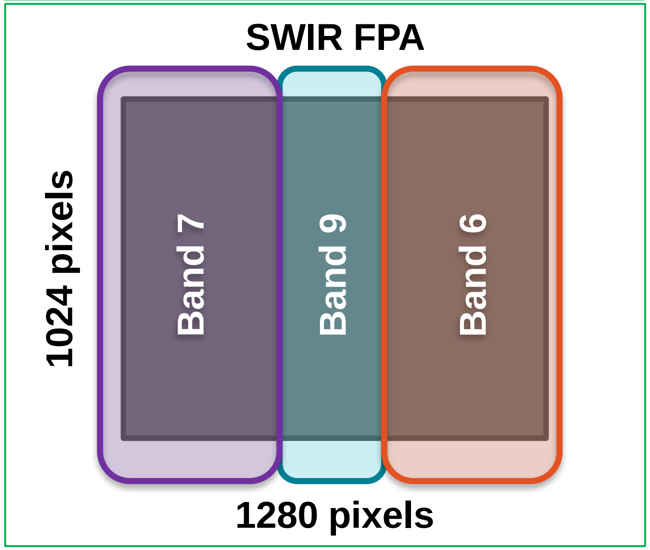
Full VSWIR optical solution for SLI-T demo

- Proposal: 4 visible bands and 2 SWIR bands
  - Demonstrate step-stare approach
  - Multiple optical paths with single aperture
- Baseline: Enable all 5 visible bands, the Cirrus band and both SWIR bands

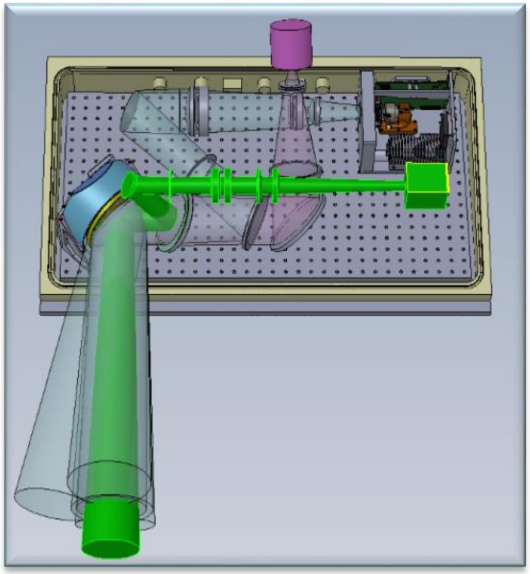
TABLE A.2 SLI-T REFERENCE MISSION SPECTRAL IMAGE PERFORMANCE REQUIREMENTS

Band #	Band Name	Band #	Center Wavelength (nm)	Center Wavelength Tolerance (nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)
1	Coastal Aerosol	1	448	2	443	453
2	Blue	2	482	5	450	515
3	Green	3	562	5	525	600
4	Red	4	655	5	630	680
5	NIR	5	865	5	845	885
6	SWIR 1	6	1610	10	1560	1660
7	SWIR 2	7	2200	10	2100	2300
8	Panchromatic	N/A	590	10	500	680
9	Cirrus	9	1375	5	1360	1390
10	Thermal 1	N/A	10800	200	10300	11300
11	Thermal 2	N/A	12000	200	11500	12000

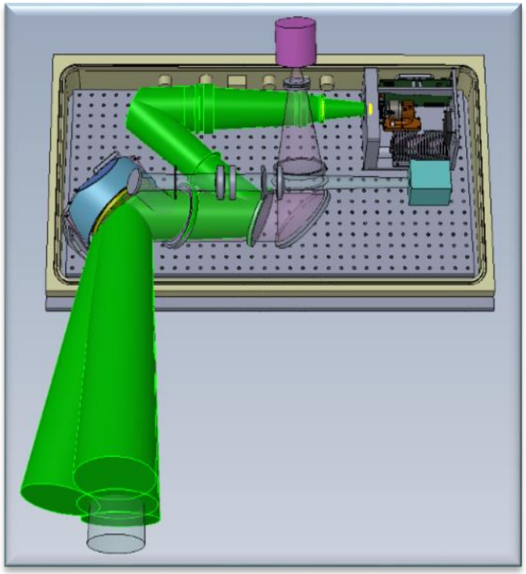




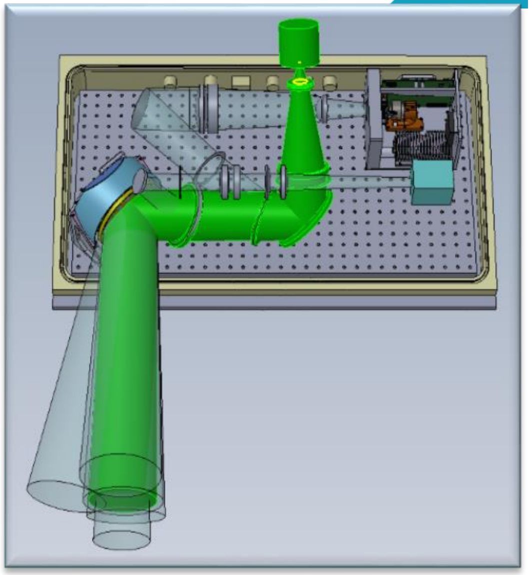
Mechanical Packaging Concept Complete



VNIR Optical Path



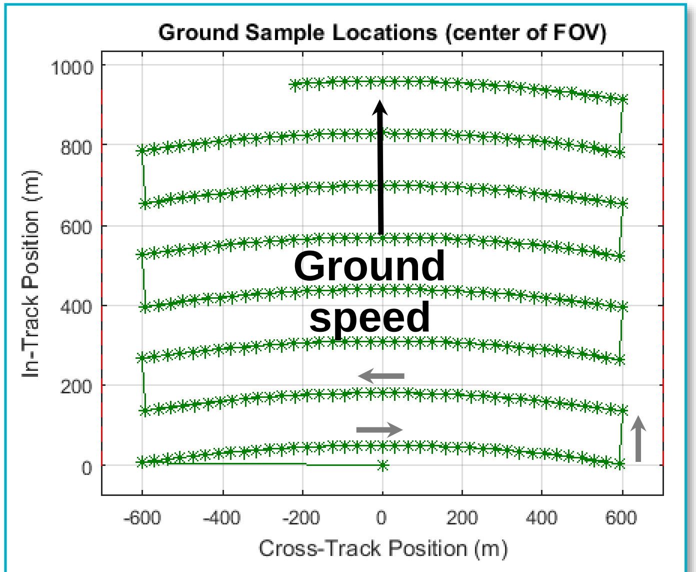
SWIR Optical Path

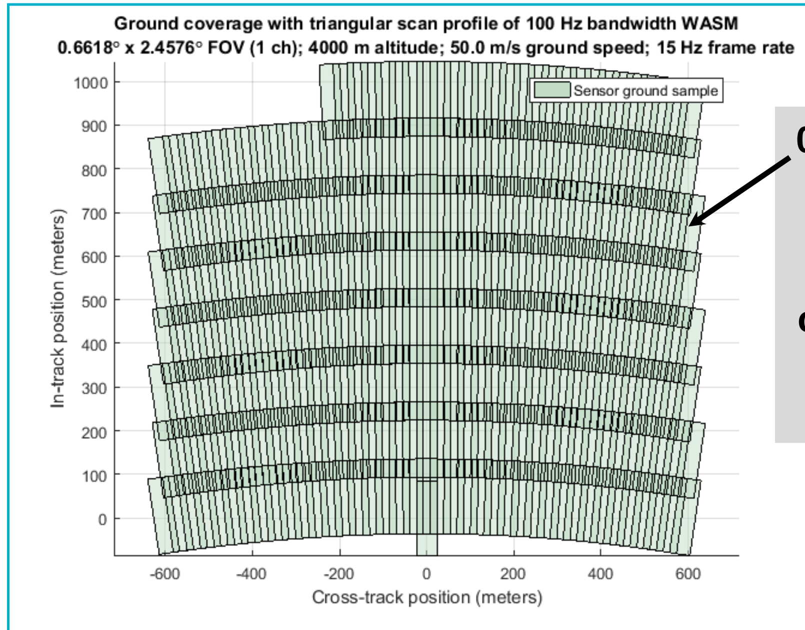


TIR Optical Path

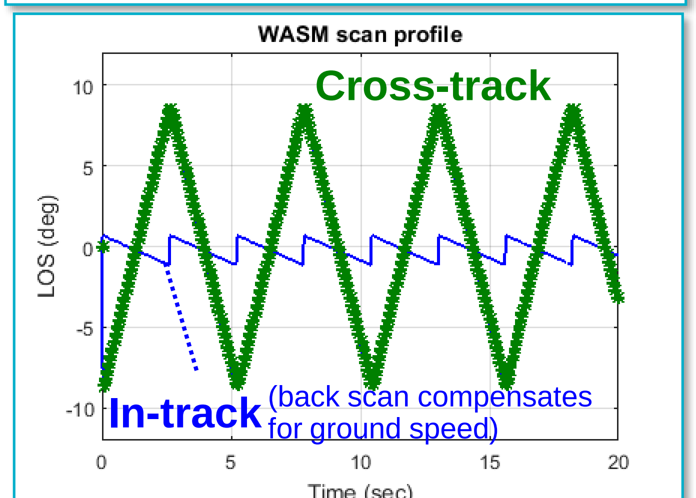
- Initial packaging complete
- The VNIR and SWIR channels can be packaged within the allocated volume.
- Inclusion of the TIR Channel will likely cause the system to exceed the space allocation and may require a larger baseplate to hold all three channels (still a manageable option)

Scan Profile for (Airborne System)





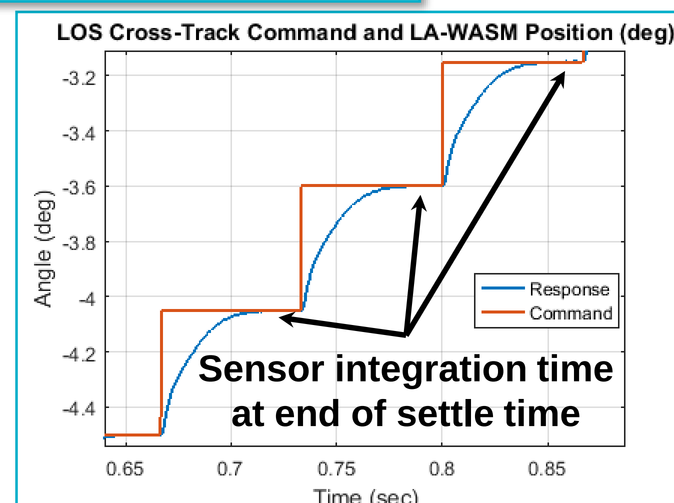
0.45° cross-track step of 0.66° filter width provides 32% cross-track scan overlap. In-scan overlap = 24%.



0.45° cross-track step size at 15 Hz step rate;

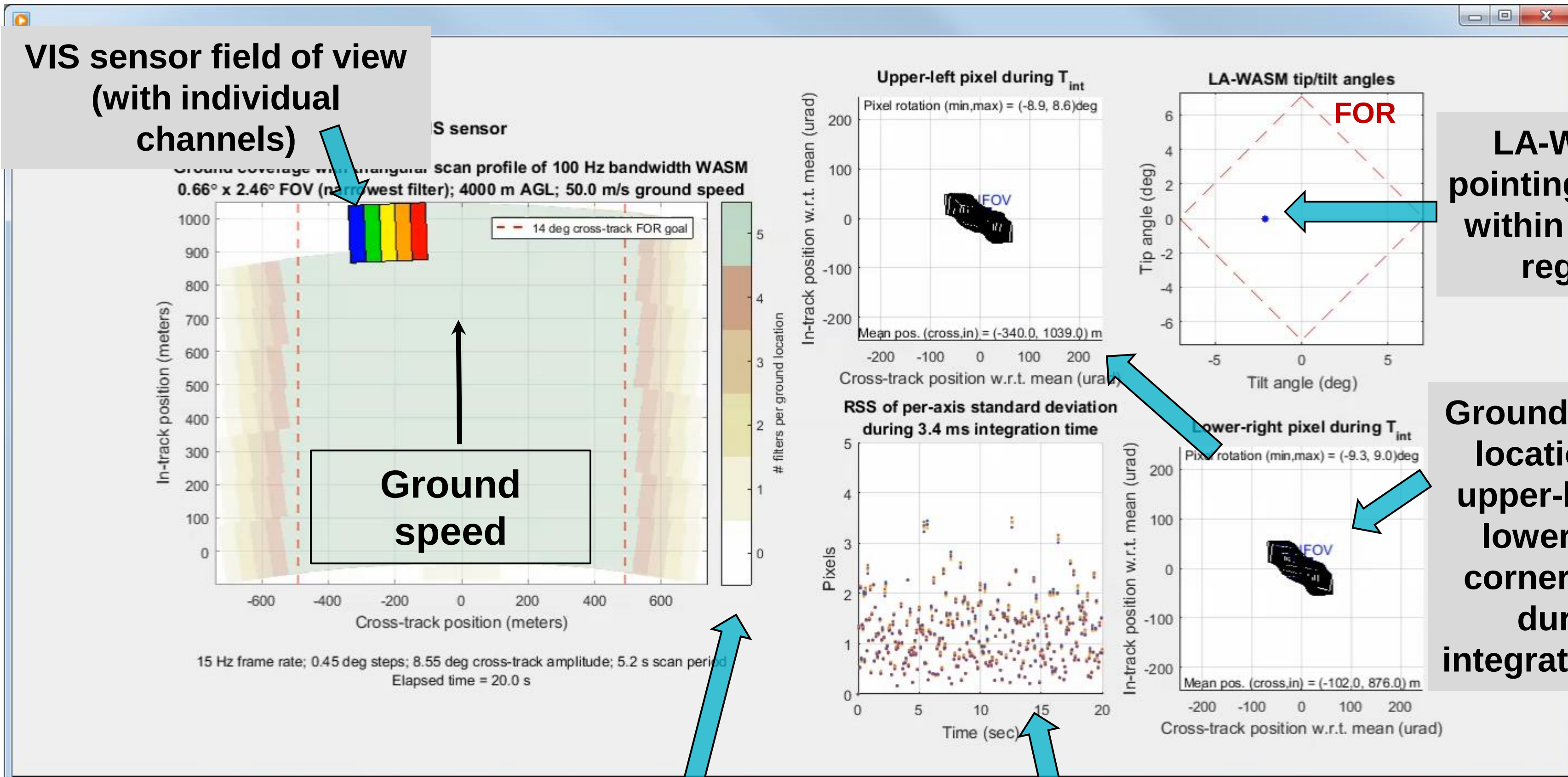
5.2 s scan period; 4000 m AGL;

50 m/s ground speed



Scan Modeling (Airborne System)

(OLI equivalent VIS IFOV = 42 urad)



VIS sensor field of view (with individual channels)

Ground speed

LA-WASM pointing angles within field of regard

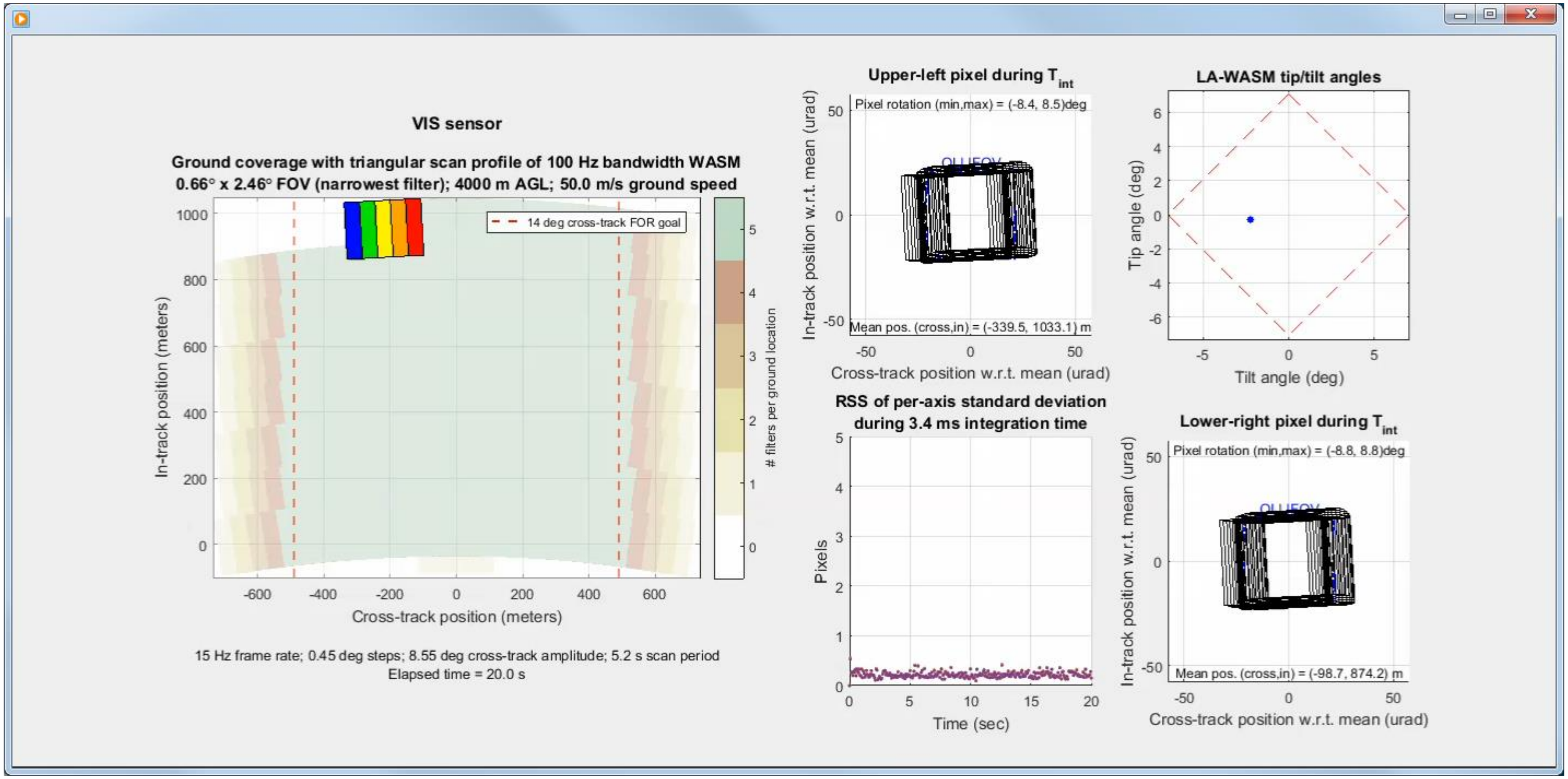
Ground sample locations of upper-left and lower-right corner pixels during integration time

Ground coverage plot (color indicates # of VIS channels that sampled point on ground)

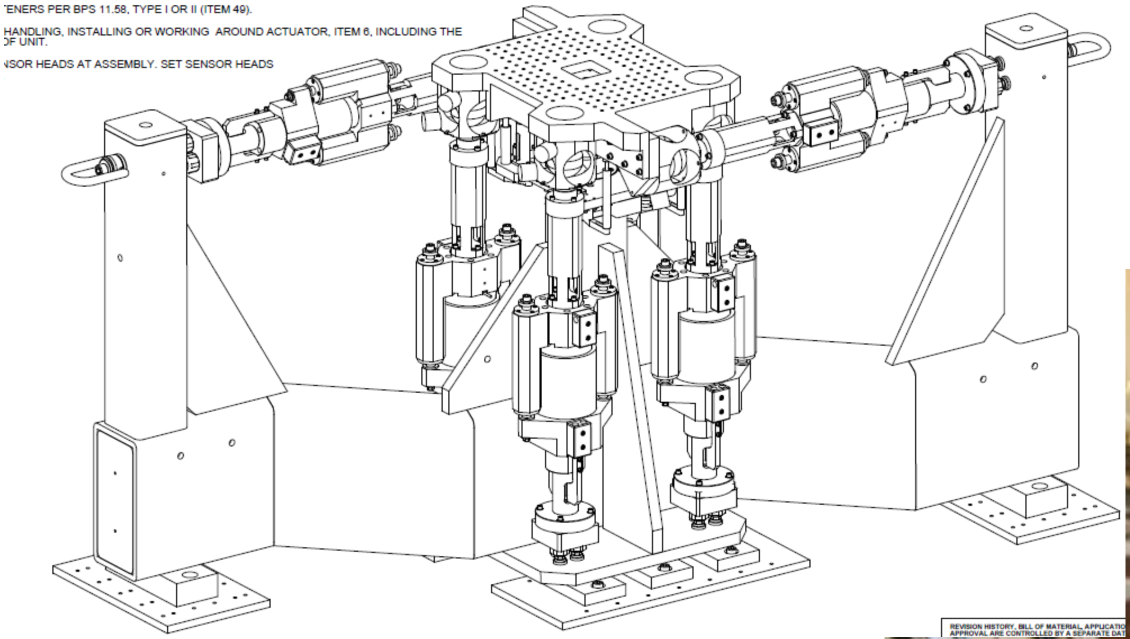
RMS motion of corner pixels during integration time

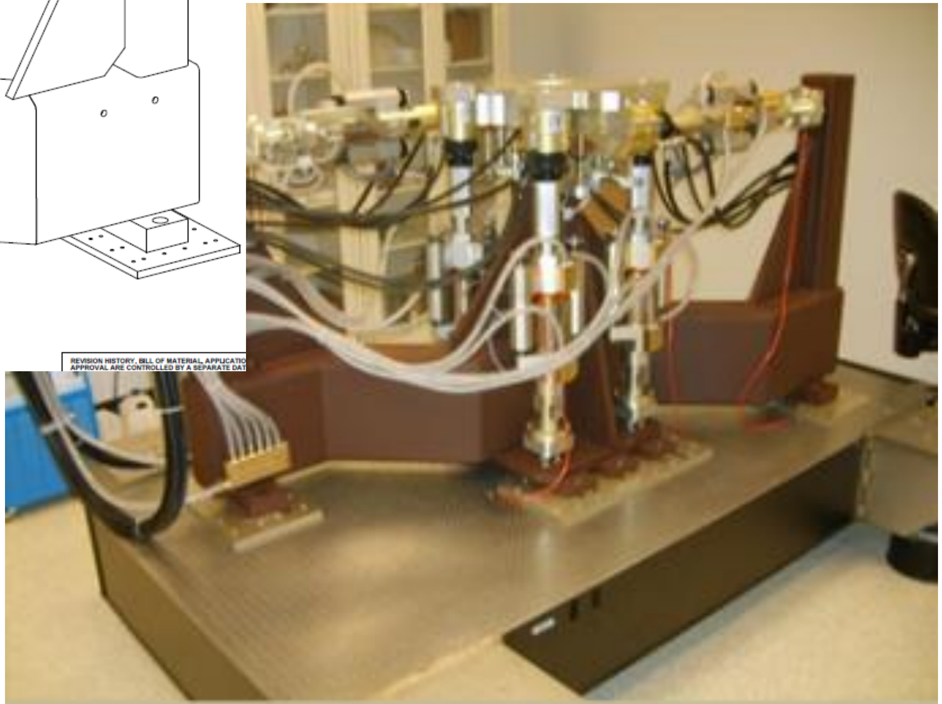
Scan Modeling (On-Orbit Case)

(OLI equivalent VIS IFOV = 42 urad)



Rate Table for Simulating Spacecraft Motion





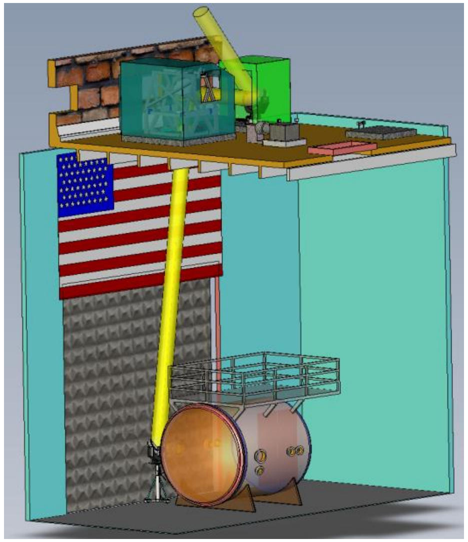
3-axis angular vibration and rate table

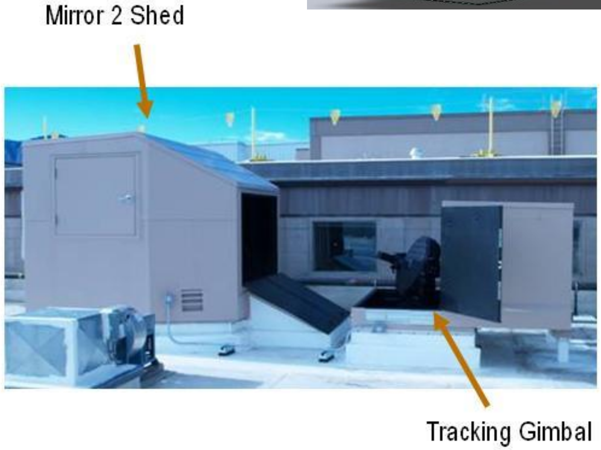
Calibration Approach

- Absolute calibration performed during ground testing with NIST traceable sources (blackbody & lamps)
- Relative calibration in airborne configuration that has been scaled against absolute calibration on ground
- Heliostat testing (fall 2018) for direct comparison to OLI2 (LandSat9)

Heliostat Testing Provides Direct Comparison with OLI

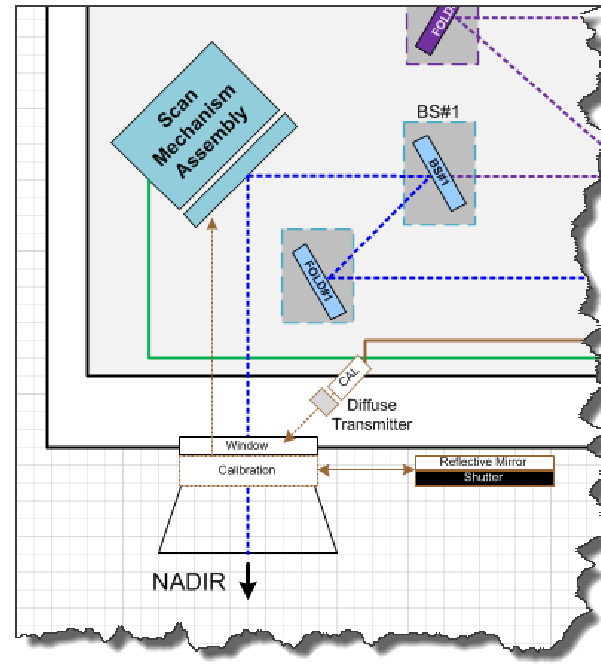
- Solar source provides realistic spectral profile for direct comparison between REMI and OLI
- OLI planned Heliostat testing is Fall 2018
- REMI positioned outside the chamber so that the beam is folded the opposite direction for testing without cleanliness and feedthrough requirements
- University of Arizona is contracted for OLI to perform atmospheric transmission measurements during Heliostat testing from roof

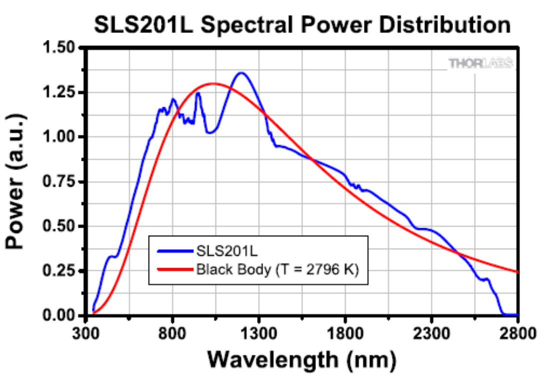


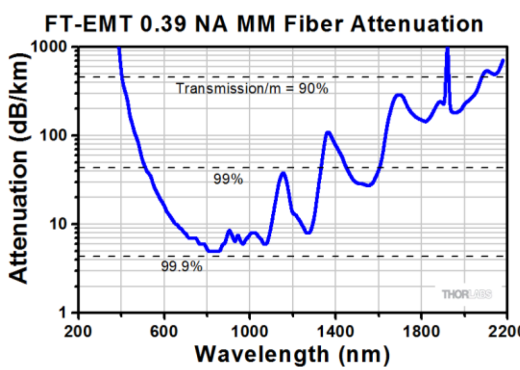


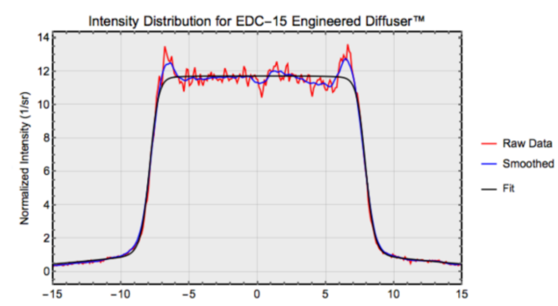
Airborne Stability Monitoring

- Broadband light source & fiber optic
- Diffuse Lambertian light from engineered diffusor
- Mirror on back of external shutter in “closed” position
- Relative calibration in-flight (stability)

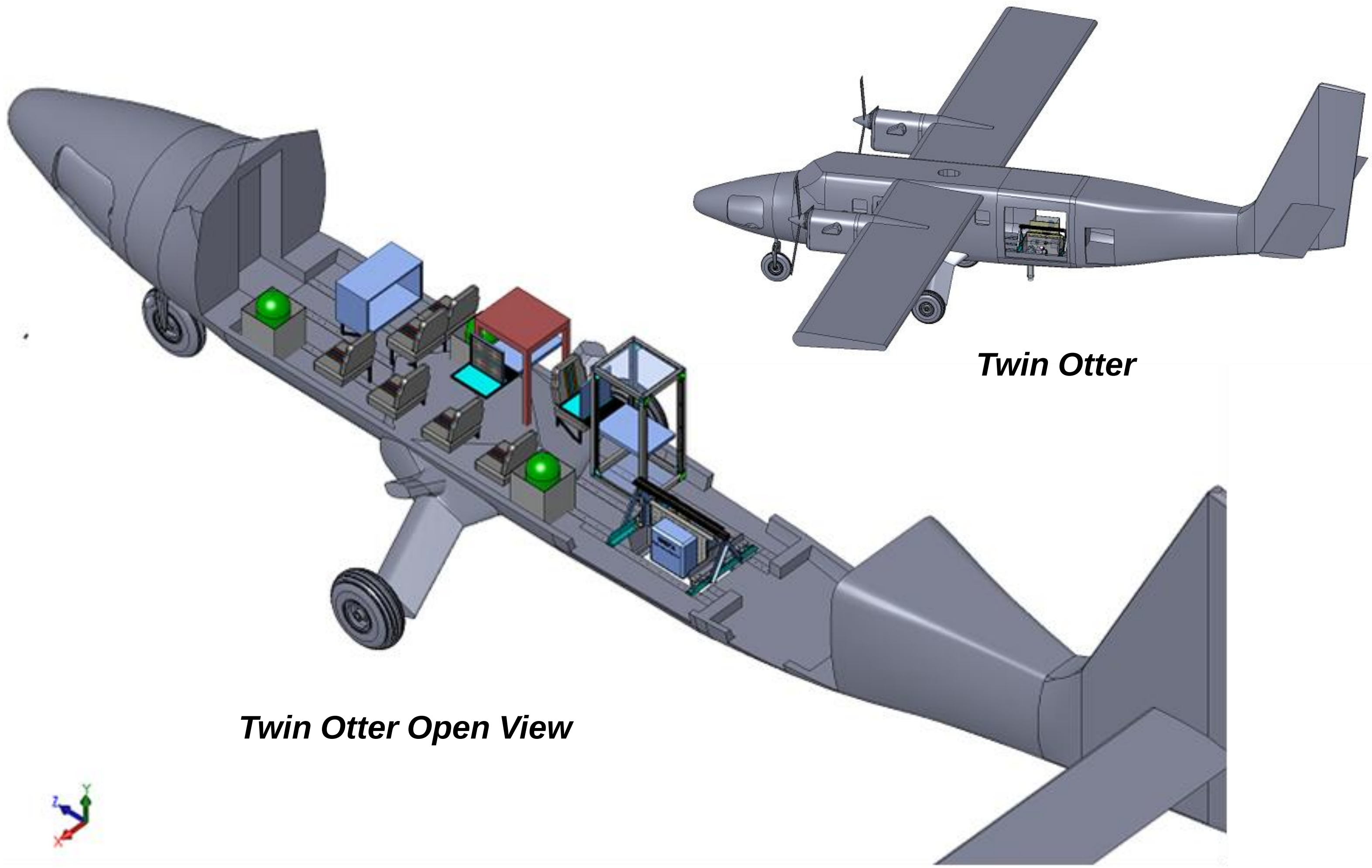








Mechanical Layout in Twin Otter



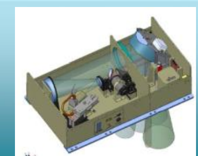
Twin Otter

Twin Otter Open View

Flight Plans

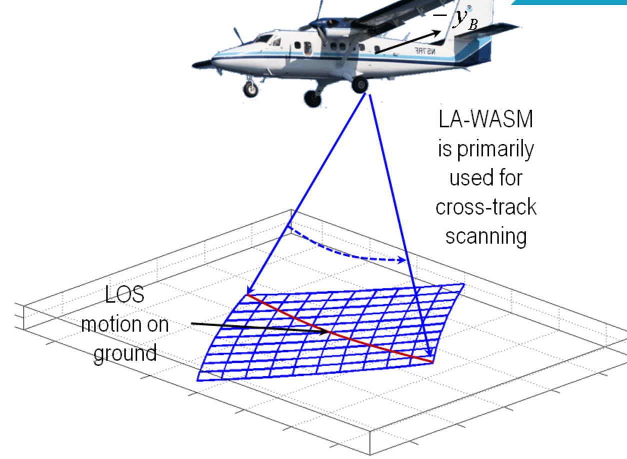
2017Q4
Lab Testing
Rate Table

2018Q1/2
Eng. Flight
VSWIR Bands



2018Q3/4
Data Flight
VSWIR Bands

2019Q2/3
Science
Flights



- <u>Eng. Flights</u> ensure proper interfacing and functionality while airborne
- <u>Data Flights</u> used to generate data used to validate concepts
- <u>Science Flights</u> used to acquire data of specific interest to the science community

Acknowledgements

- Funding from ESTO/SLI-T, Contract No. NNX16AP63G
- Ball Team:
  - Tom Kampe, Optics
  - Bob Warden, Mechanical
  - Kyle Solander, Electronics
  - Jonathan Fox, Software
  - Homero Gutierrez, Scan Mechanism
  - Lyle Ruppert, L1B Data Processing
  - Bill Good, Aircraft Ops

THANK YOU!