NPOESS Visible Infrared Imaging Radiometer Suite (VIIRS) Sensor Design and Performance

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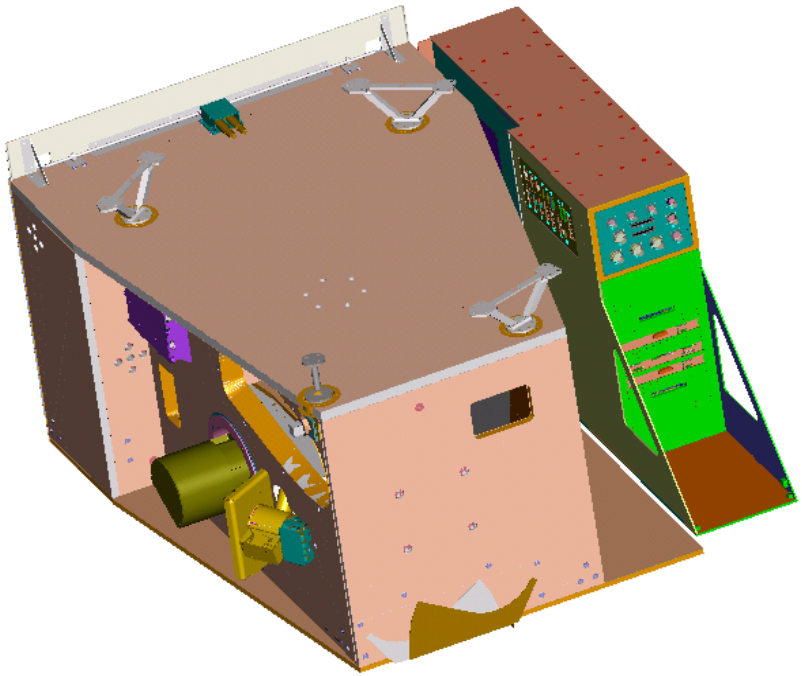
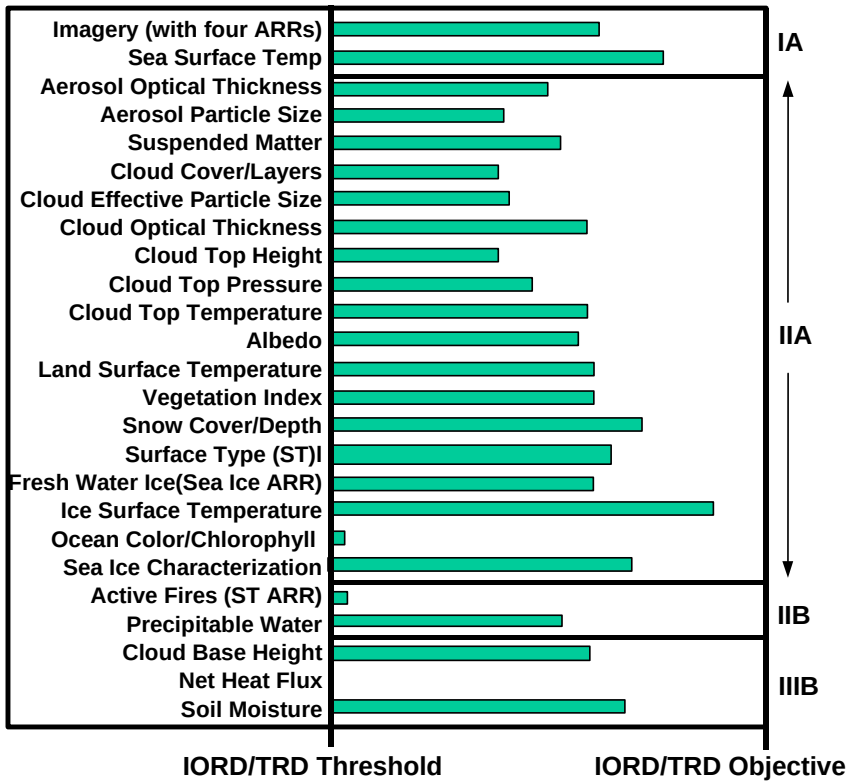
[2]Northrop Grumman Space Technology
[3]The Aerospace Corporation
[4]NPOESS Integrated Program Office (IPO)

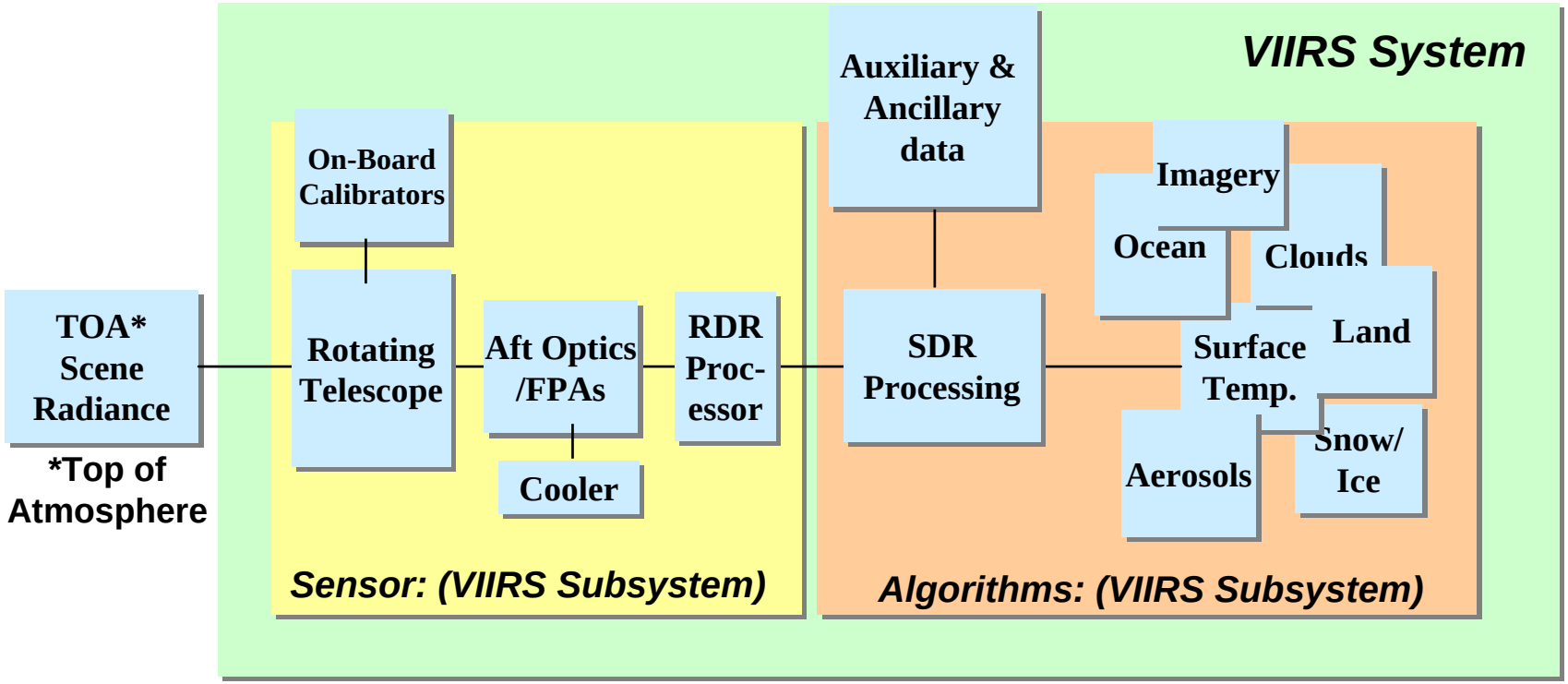
VIIRS System to Provide Excellent Environmental Data Records (EDRs)





- VIIRS System Design based on integrated Sensor and Algorithms
- Engineering Development Unit (EDU) approaching integration
- EDR Science Algorithms developed, documented, and publicly released by Raytheon Technical Services Company (RTSC) Information Technology and Scientific Services (ITSS)

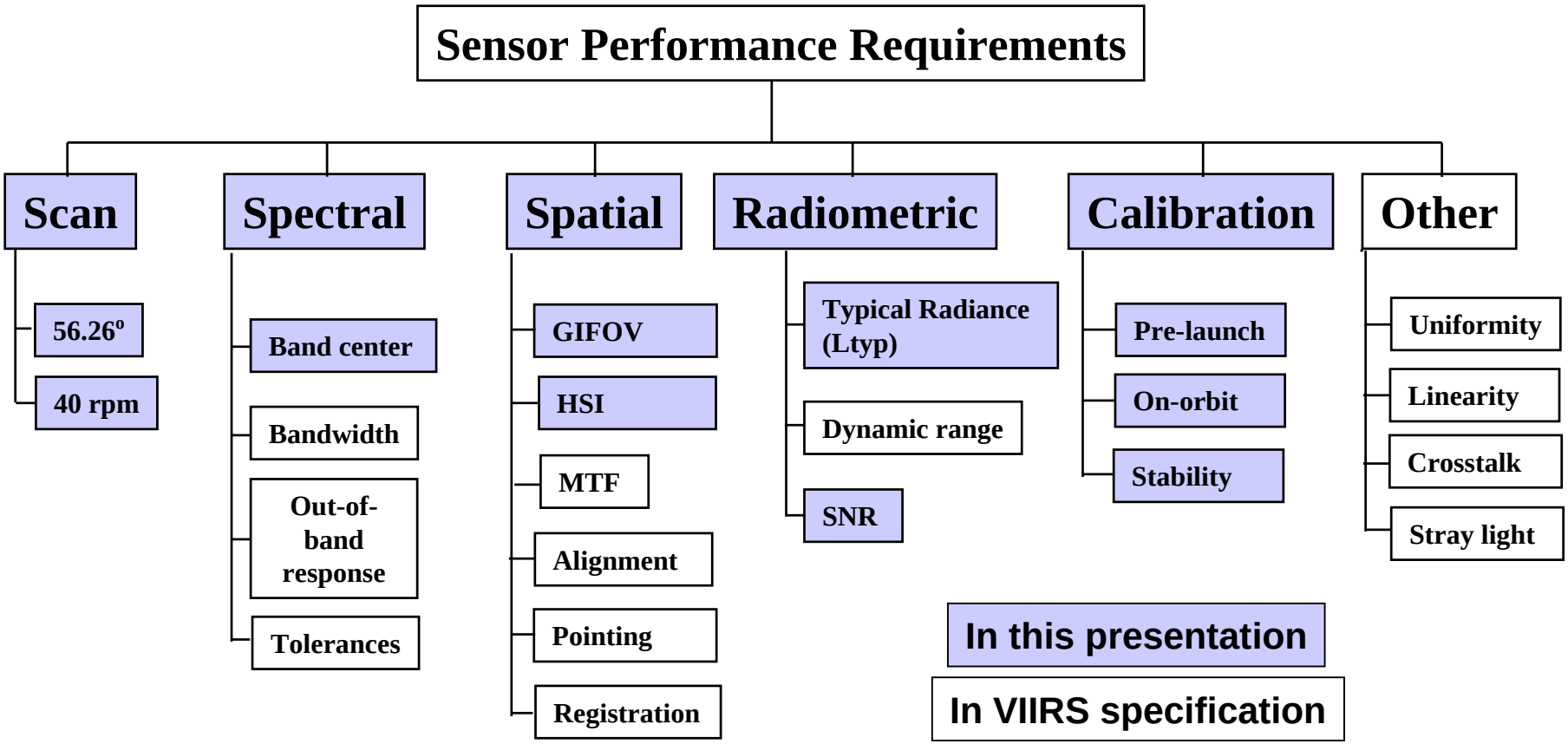
VIIRS Performance Verified by Hardware & Testbed



Closed the Loop!

- EDRs drive algorithm and raw sensor data requirements
- Sensor specification derived from EDRs with testbed
- Sensor performance verified by hardware risk-reduction demonstrations and analyses
- EDR performance verified by testbed with sensor models

VIIRS Sensor Performance Defined by Sensor Specification



- Northrop-Grumman Space Technology (NGST) contract to Raytheon Santa Barbara Remote Sensing (SBRS) based on sensor specification
- NPOESS Integrated Program Office (IPO) contract to NGST based on system specification including EDR performance

Photons to Digital Data: VIIRS Architecture Stable Since PDR

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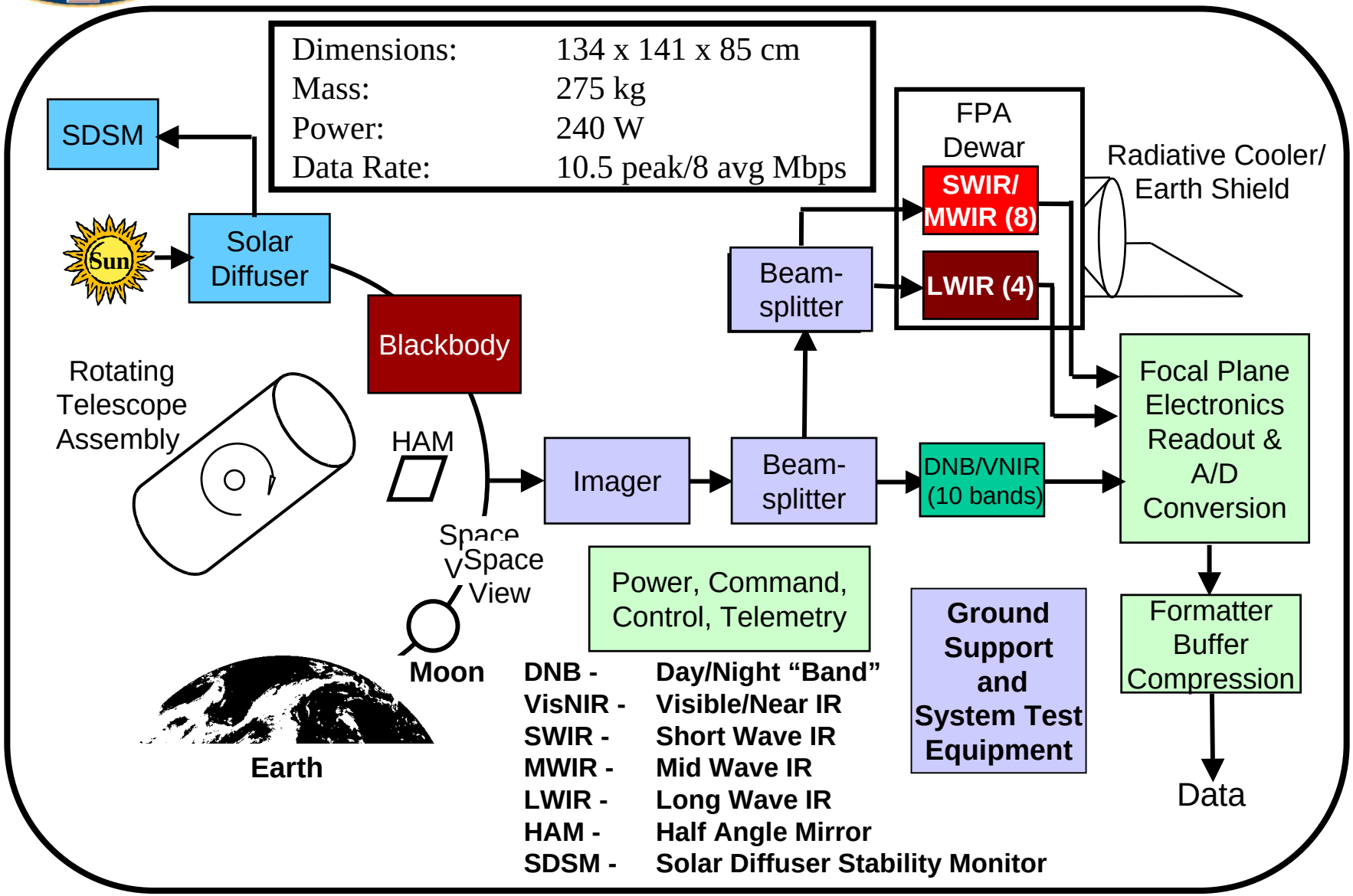

VIIRS Post-CDR Refinements Being Verified in EDU*

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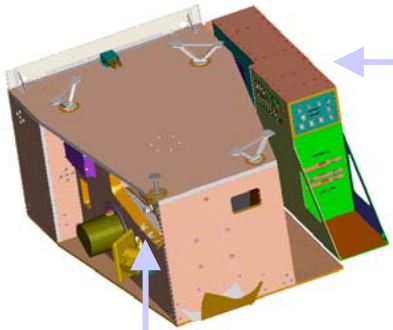
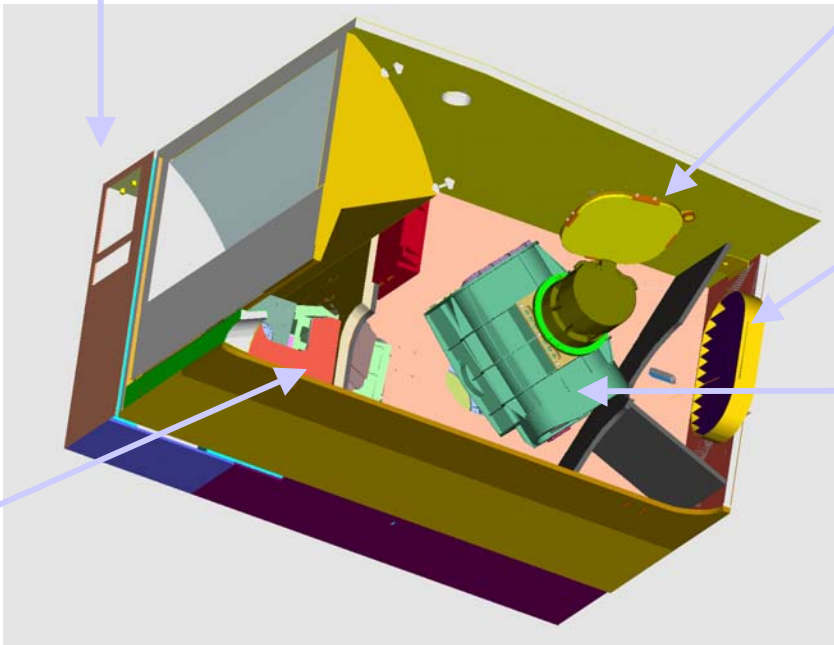
Raytheon



MODIS-heritage Solar Diffuser Stability Monitor refined to improve performance

Electronics module (EM) & cables refined to minimize EMI

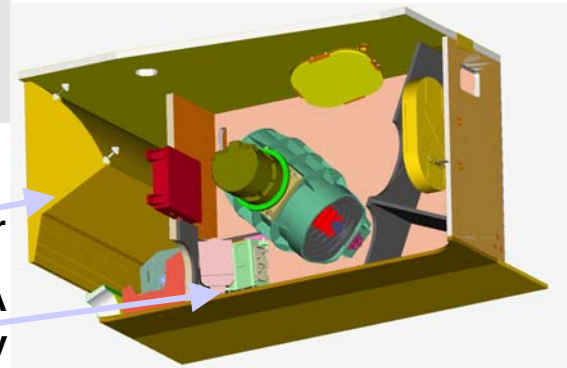


MODIS-heritage Solar Diffuser screen redesigned to minimize solar modulation

MODIS-heritage blackbody relocated to minimize Earth shine

3-Mirror Anastigmat Rotating telescope refined to eliminate modulated instrument background (MIB)

4-mirror anastigmat All-reflective Aft optics imager



Passive Cryoradiator

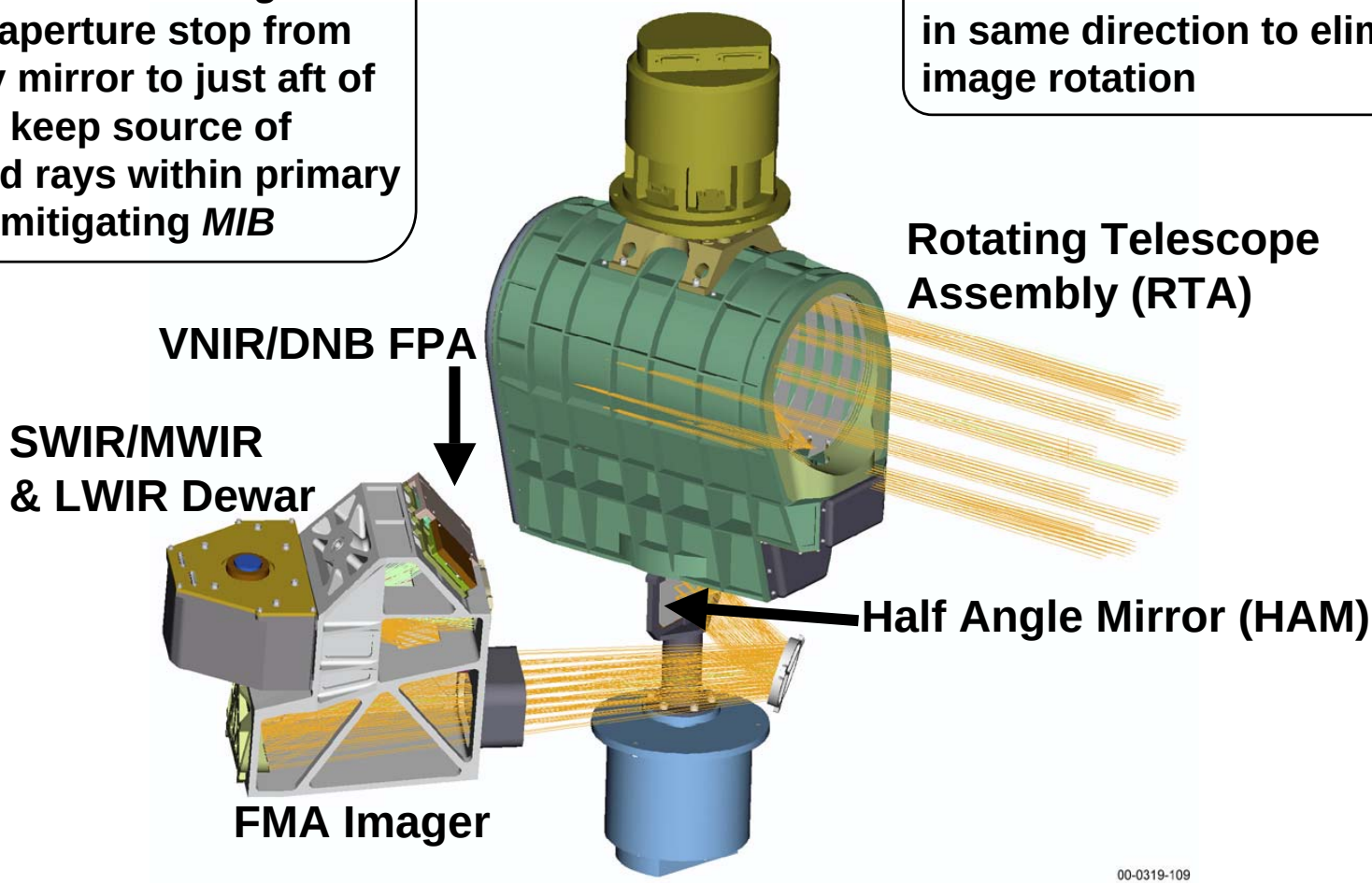
Cold FPA Dewar Assembly

- Constant-speed rotating telescope
- Simple all-reflective diamond point turned bolt-together optics
- Proven emissive/reflective calibration

VIIRS Compact, All Reflective Non-Image Rotating Optical Design

Key post-CDR redesign:
Moved aperture stop from primary mirror to just aft of HAM to keep source of detected rays within primary mirror, mitigating *MIB*

HAM rotates at half RTA speed in same direction to eliminate image rotation



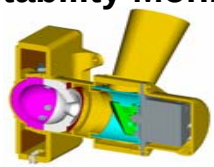
Follow the Photon!

Sensor Models Being Verified by Engineering Development Unit (EDU) Tests

Legend	Model Description
A	Signal to Noise Ratio (SNR)
B	Modulation Transfer Function (MTF)
C	Polarization Performance
D	Sequential Ray Trace
E	Non-sequential Ray Trace
F	Thin Films Design and Performance
G	Structural Design and Performance
H	Thermal Design and Performance
I	Electronics Simulation
J	Focal Plane Array (FPA) Performance

Solar Diffuser

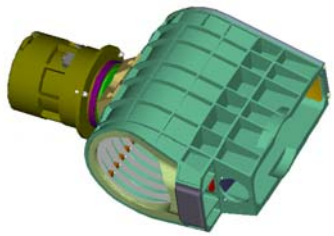
Solar Diffuser Stability Monitor



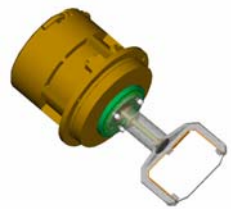
Blackbody Reference

On-Board Calibration Mechanisms: *A*

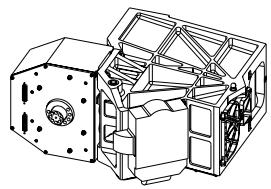
All Optics: *C,D,E,F,H*



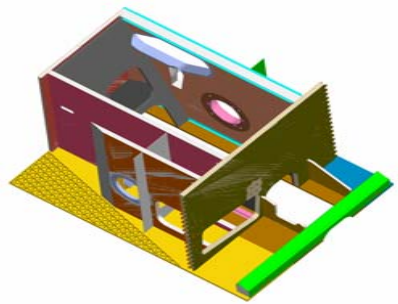
Rotating Telescope: *A, B*



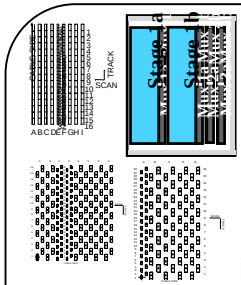
Half-Angle Mirror: *I*



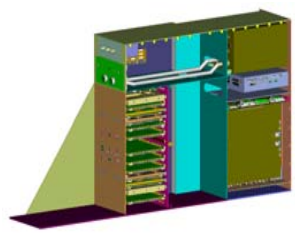
Aft Optics: *A, B*



Mainframe: *G, H*



Focal Planes (FPAs): *J*



Electronics Module (EM): *G*

FPAs & EM: *A,B, H, I*

Spectral, Spatial & Radiometric Attributes of 22 VIIRS Bands

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		Band No.	Wave-length (μm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp	Signal to Noise Ratio (dimensionless) or NEΔT (Kelvins)		
				Nadir	End of Scan				Required	Predicted	Margin
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	44.9	352	441	25%
						Aerosols	High	155	316	807	155%
		M2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	40	380	524	38%
						Aerosols	High	146	409	926	126%
		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	32	416	542	30%
						Aerosols	High	123	414	730	76%
		M4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	21	362	455	26%
						Aerosols	High	90	315	638	102%
		I1	0.640	0.371 x 0.387	0.80 x 0.789	Imagery	Single	22	119	146	23%
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	10	242	298	23%
						Aerosols	High	68	360	522	45%
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6	199	239	20%
		I2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25	150	225	50%
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	6.4	215	388	81%
						Aerosols	High	33.4	340	494	45%
CCD		DNB	0.7	0.742 x 0.742	0.742 x 0.742	Imagery	Var.	6.70E-05	6	5.7	-5%
S/MWIR	PV HgCdTe (HCT)	M8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4	74	98	32%
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6	83	155	88%
		I3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3	6.0	97	1523%
		M10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3	342	439	28%
		M11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12	10	17	66%
		I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K	2.500	0.486	415%
		M12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K	0.396	0.218	82%
		M13	4.05	0.742 x 0.259	1.60 x 1.58	SST	Low	300 K	0.107	0.063	69%
						Fires	High	380 K	0.423	0.334	27%
LWIR	PV HCT	M14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K	0.091	0.075	22%
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.070	0.038	85%
		I5	11.450	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K	1.500	0.789	90%
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.072	0.051	42%

Finer Sampling, Spatial Resolution & Better Sensitivity

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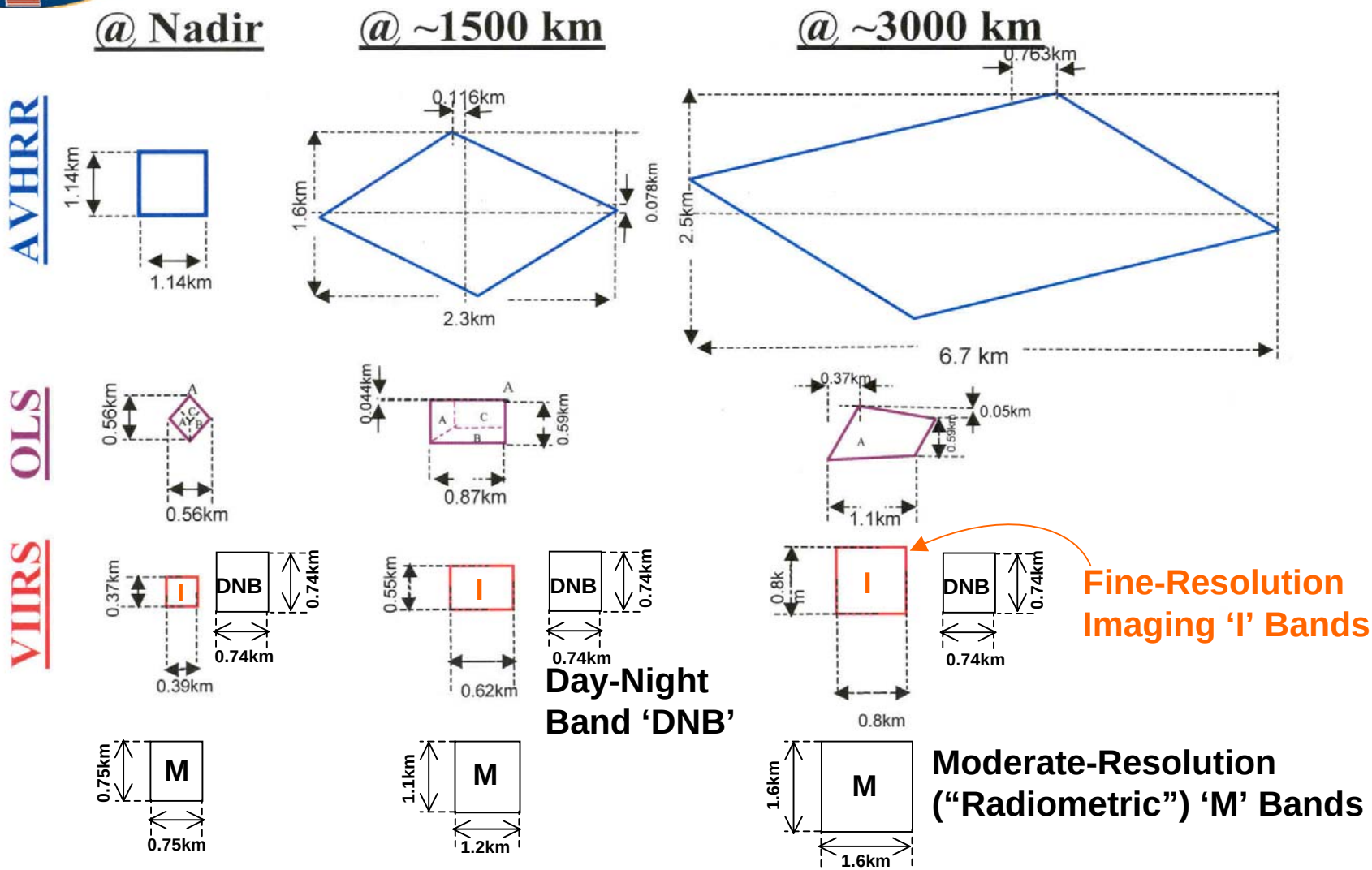

Day-Night Band 'DNB'

Fine-Resolution Imaging 'I' Bands

Moderate-Resolution ("Radiometric") 'M' Bands

SNR predicted and specified at worst-case edge of scan:
~60% better nadir SNR *and* finer spatial resolution

VIIRS Provides Operational Data Continuity in Many Areas, Including Ocean Color*

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Commercial & Research

SeaWiFS (1997)

- 5 year mission – aproaching 6 years
- Verified ocean color benefits
- Eight bands

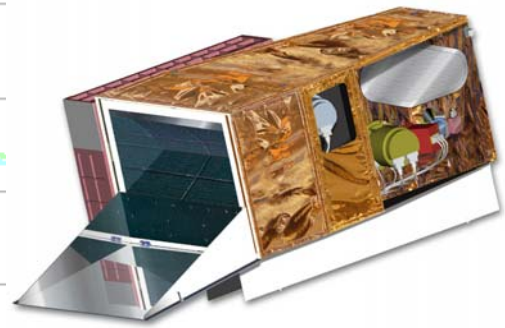
Research

NASA EOS MODIS (1999)

- 5 year life
- Nine ocean color bands
- Ocean color one of many applications

Operational

NPOESS VIIRS (2006 NPP)



- 7 year life
- Seven ocean color bands
- Ocean color supports other VIIRS EDRs

*With VIIRS improvements: e.g., dual-gain, finer spatial resolution, better sensitivity, etc.

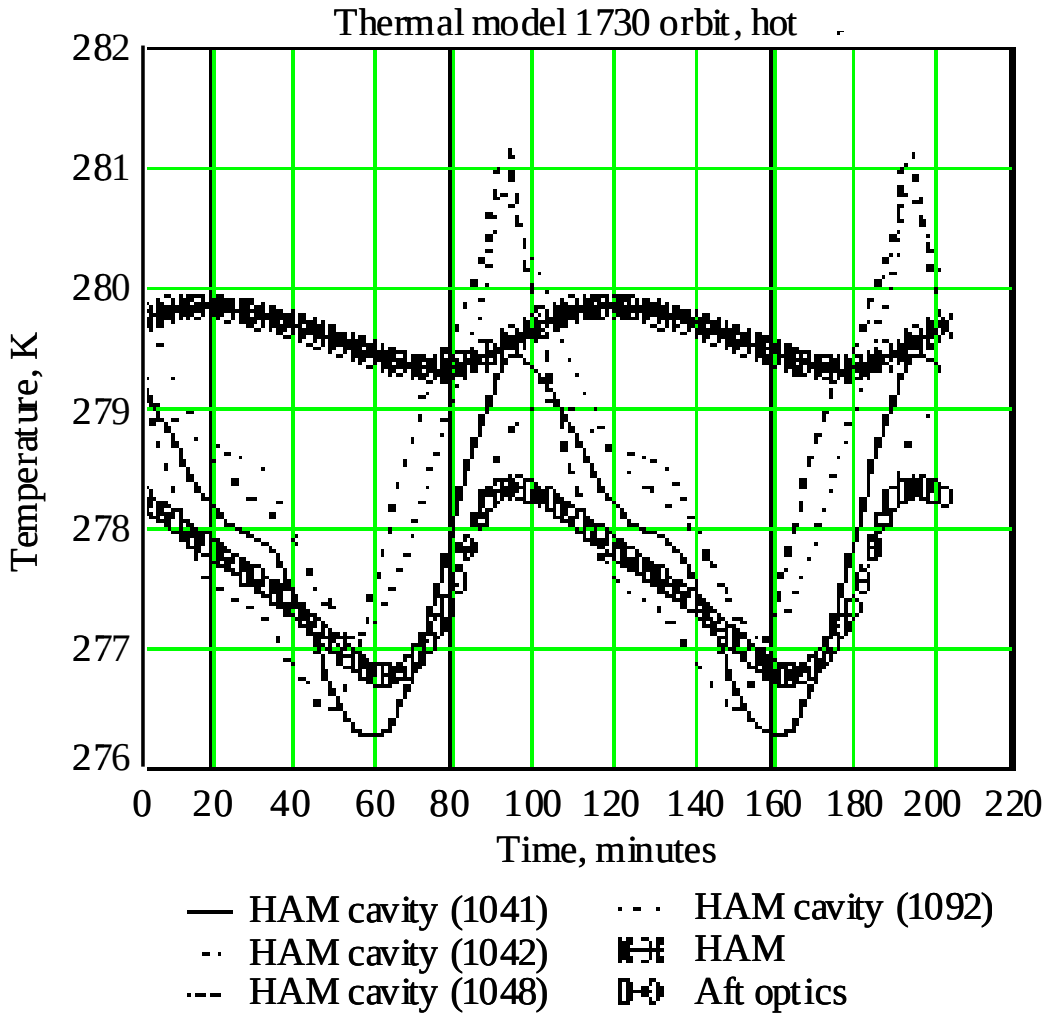
VIIRS Model Predicts Excellent Polarization Sensitivity Margin

VIIRS Band	Bandcenter (nm)	Polarization Specification (%)	-45 degrees	Zero degrees	+45 degrees
M1	412	3.0	1.30	2.00	2.90
M4	555	2.5	0.50	0.30	0.60
I2 & M7	865	3.0	0.70	0.04	0.02

Image courtesy the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

Detailed Thermal Modeling Predicts On-orbit Temperature Variations

- **Detailed VIIRS thermal model predicts sensor structure and optics element temperatures vs. orbit and time: *Greatest variations in 1730 (terminator) orbit***
- **Detailed calibration model uses results to predict emissive band radiometric accuracy: *Model predicts specification margin in all bands***



Detailed SST-band Error Budget with On-orbit Temperature Variations

Parameter	VIIRS Center Wavelength (μm)				
	3.70	4.05	8.55	10.76	12.01
Ttypical (K)	270	300	270	300	300
Temperature knowledge effect (%)	0.32	0.24	0.14	0.09	0.08
Wavelength knowledge effect (%)	0.20	0.20	0.04	0.03	0.04
Integrated out-of-band effect (%)	0.30	0.30	0.20	0.10	0.10
Response vs. scan angle knowledge (%)	0.20	0.20	0.60	0.20	0.20
Response vs. scan angle pedestal knowledge	0.20	0.20	0.60	0.20	0.20
Emittance knowledge (%)	0.20	0.20	0.20	0.20	0.20
Electronic crosstalk (%)	0.20	0.20	0.20	0.20	0.20
Ghosting (%)	0.24	0.24	0.24	0.24	0.24
Polarization knowledge effect (%)	0.01	0.01	0.10	0.10	0.10
Earthshine effect (%) (Tearth=343K)	0.029	0.025	0.009	0.008	0.007
Solar diffuser screen emission (%) (Tinst=285K)	0.0293	0.0245	0.0091	0.0076	0.0071
Solar diffuser Sunlight Scatter (%)	0.128	0.110	0.047	0.041	0.038
Blackbody Skin Temp Effect (%) (Tinst=275K)	0.014	0.003	0.0	0.0	0.0
Surround Correction Effect (%) (Tinst=285K)	-0.031	-0.028	-0.013	-0.011	-0.01
Radiometric Calibration Model σ (%)	0.68	0.62	0.55	0.35	0.35
Allocation Requirement (%)	0.7	0.7	0.6	0.4	0.4

MODIS SST image courtesy NASA @http://visibleearth.nasa.gov/data/ev2/ev284_global_SST_sm.jpg

Engineering Development Unit (EDU) Approaching Integration Phase

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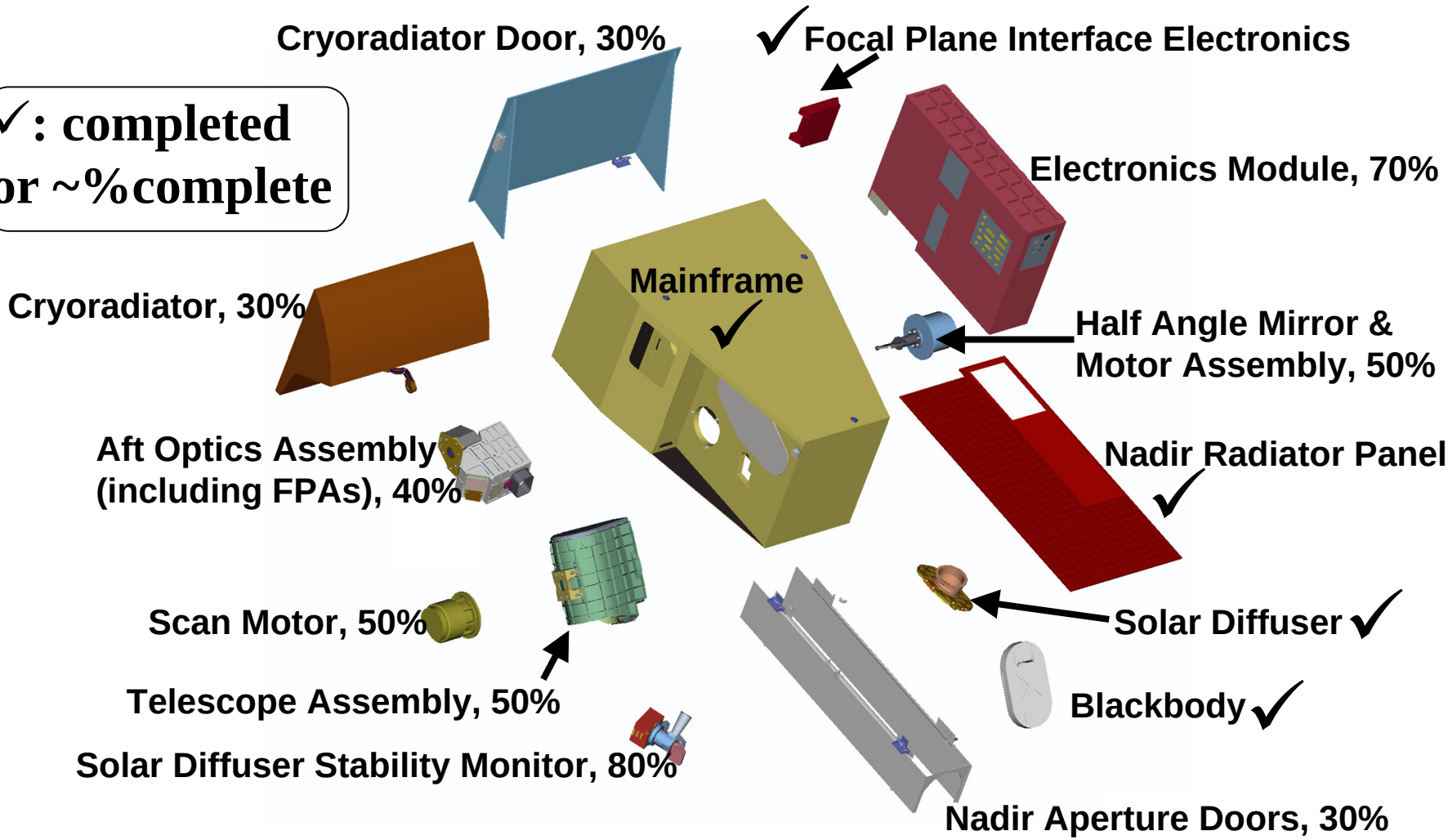
✓: completed
or ~%complete



EDU Focal Planes
Verified Design

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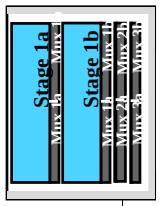
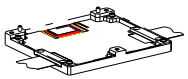
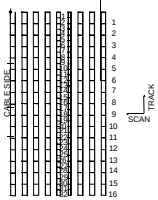
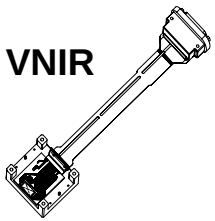


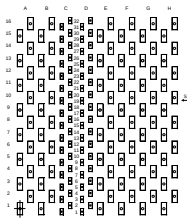


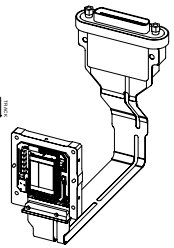
DNB



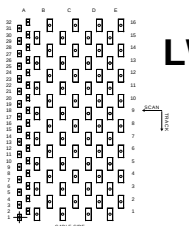


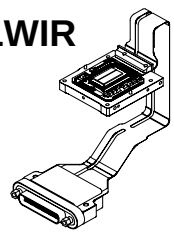
VNIR





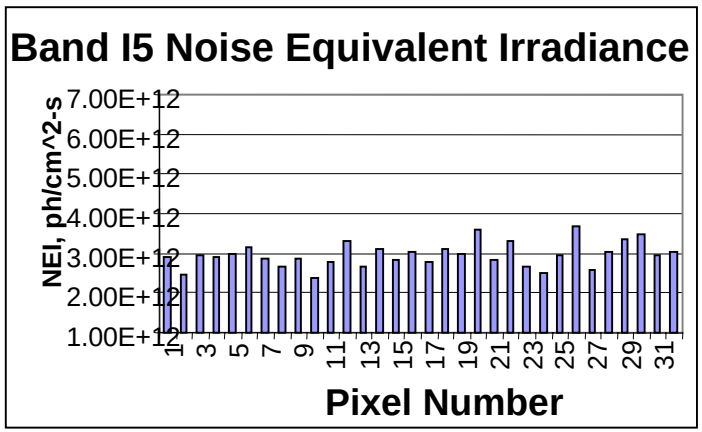
SW/MWIR

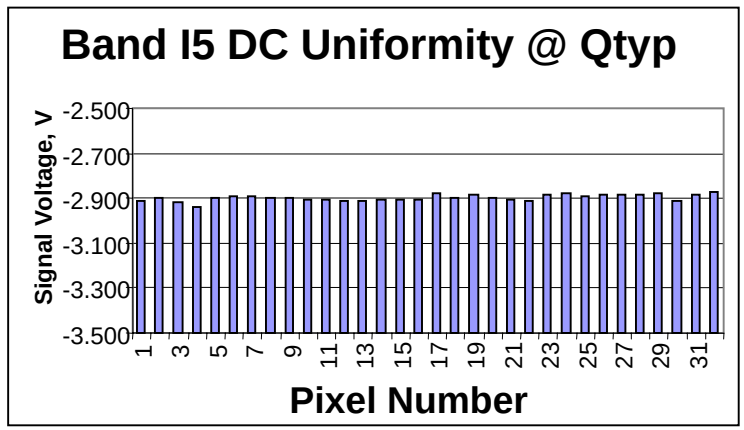




LWIR

- All EDU FPAs assembled and tested, including detectors & read-out integrated circuits (ROICs)
- S/MWIR & LWIR FPAs: Photovoltaic (PV) HgCdTe with integrated “Microlens” technology to reduce background noise
- All PV HgCdTe allows LWIR time-delay and integration (TDI) and lowers crosstalk
- Optical alignment of all FPAs provides optimum band-band registration





EDU Testing Lowers Risk for Flight Unit Integration & Test

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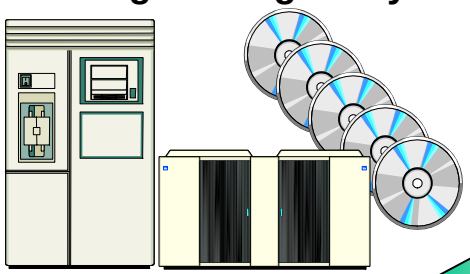
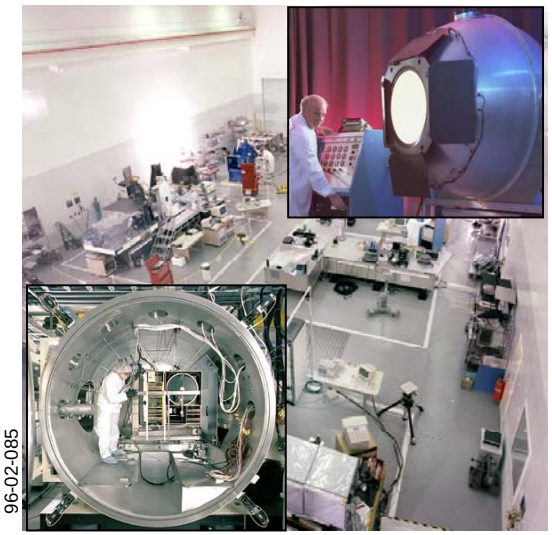
Software, Documentation, and Engineering Analysis



Ground Support Equipment



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Engineering Development Unit

- Calibration and Test
- Performance Assessments

EDU Lessons Learned

First Flight Unit

- Integration
- Calibration and Test
- Performance Assessments

Shipping/ Storage

Flight Instruments

NPP model (2005)
C1 model (2006)

. . .

VIIRS on-track to EDU Integration & NPP Flight Unit Development

- National Polar-orbiting Operational Environmental Satellite (NPOESS) Visible Infrared Imaging Radiometer Suite (VIIRS) approaching Engineering Development Unit (EDU) integration
  - Several design refinements lowered EDU and flight unit development and test risks
  - Principal post-CDR optics design change to correct modulated instrument background (MIB) approved
  - Sensor specified for excellent EDR performance: Refined design offers margin to sensor specification
  - Detailed quantitative sensor performance modeling completed and partially verified by EDU hardware tests
  - Remaining EDU fabrication and testing will verify models or identify corrective action
- First flight unit for NPOESS Preparatory Project (NPP) scheduled for completion in 2005 for 2006 launch
- Second flight unit for NPOESS initial operational launch in 2130 orbit scheduled for completion in 2006 for 2009 launch