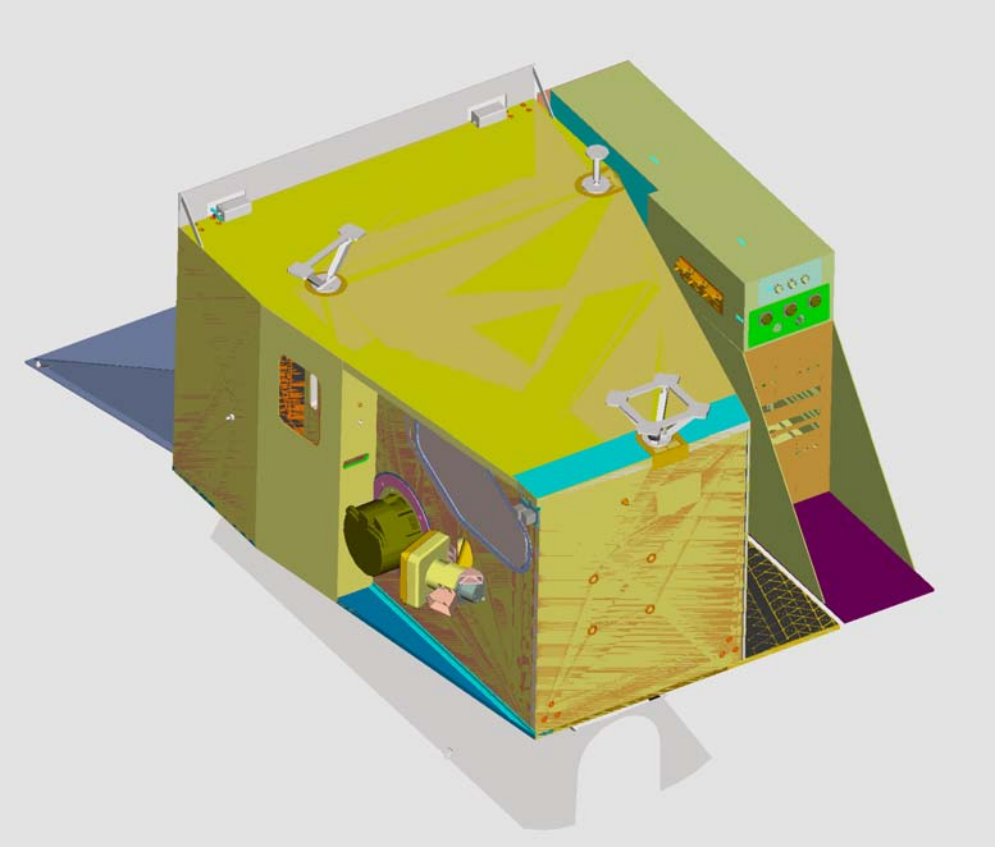
NPOESS VIIRS: Overview & Status



2002 IEEE International Geoscience And Remote Sensing Symposium
Toronto, Ontario Canada
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Major Carol Welsch, USAF

Agenda

- VIIRS Requirements
- Acquisition and Design Approach
- Sensor Overview
- Status
- Role of Science Community

The VIIRS Sensor

- Primary NPOESS imaging sensor
- Produces over 50% of total NPOESS weather data (63.6 Gbits/orbit/satellite)
- Primary sensor for satisfying 26 Environmental Data Records (EDRs) and 2 Key Performance Parameters
- Designated a “critical sensor”
- Prime contractor: Raytheon Santa Barbara Remote Sensing (SBRS)--Goleta, California

VIIRS Mission Requirements

- Better than heritage (DMSP OLS and POES AVHRR) performance
- Increased Emphasis on Environmental Monitoring
- New/Emerging Weapon Systems
- Operationalizing Climate Mission
- Advances in NWP
- Disaster support

"The mission of the VIIRS is to provide high quality imagery and radiometric data within the visible and infrared spectral regions to support worldwide DoD and civilian operations and high-priority programs"

VIIRS EDRs

KEY
Imagery
Sea Surface Temp

Atmospheric
Aerosol Optical Thickness
Aerosol Particle Size
Suspended matter

Earth Radiation
Albedo

Cloud
Base Height
Cover/Layers
Effective particle Size
Optical Thickness
Top Properties (z,T,P)

Land
Surface Temp
Vegetation Index
Snow Cover
Surface Type
Active Fire

Ocean
Ice Surface Temp
Net Heat Flux
Ocean Color
Sea Ice
Fresh Water Ice

A New Design Approach for VIIRS

- The VIIRS EDRs are the ultimate deliverables to the user community
  - For each EDR, a set of attributes were developed by the user community; some attributes may have a minimum performance level (Threshold) and a goal performance level (Objective)
- In Phase 1, the Contractors' sought to optimize their design to
  - Meet EDRs with better than threshold performance
  - Accommodate the IPO's priorities
  - Meet costs and schedule with minimum risk
- In Phase 2, a set of performance specifications (systems, sensor, algorithm, and interfaces) were developed with guaranteed levels of performance for final acceptance and validation

VIIRS EDR Priorities & Performance

Imagery (with four ARRs) Sea Surface Temp	IA
Aerosol Optical Thickness Aerosol Particle Size Suspended Matter Cloud Cover/Layers Cloud Effective Particle Size Cloud Optical Thickness Cloud Top Height Cloud Top Pressure Cloud Top Temperature Albedo Land Surface Temperature Vegetation Index Snow Cover/Depth Surface Type (ST)l Fresh Water Ice(Sea Ice ARR) Ice Surface Temperature Ocean Color/Chlorophyll Sea Ice Characterization	IIA
Active Fires (ST ARR) Precipitable Water	IIB
Cloud Base Height Net Heat Flux Soil Moisture	IIIB

IORD/TRD Objective

IORD/TRD Threshold

EDR Attributes Flowed Down to Sensor Performance Requirements

Specification Top Down Derivation

Via EDR Sensitivity Studies using Radiative Transfer Models

Algorithm/ Sensor IPTs

EDRs (23+6 ARRs)*

Algorithm IPT

Algorithm Data Definition**

Sensor IPT

Sensor Performance Requirements

Sensor Module Specifications

- **HCS/HRI/VCS/VRI**
- **Hor/Vert Coverage**
- **Measurement Range**
- **Meas Accy/Prec/Unc**
- **Long-term Stability**
- **Mapping Uncertainty**
- **Min Swath Width**

*VIIRS System Specification

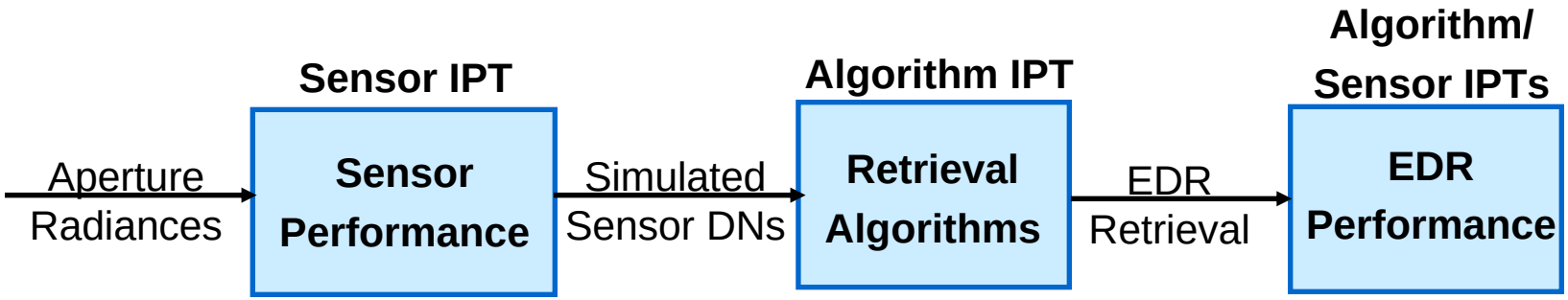
- **Auxiliary/Ancillary Data**
- **Geolocation, Pointing, Scan**
- **Bnd Cntr Wavelength/Bandpass**
- **Band Co-Registration**

- **Horzntl Smplg Interval (HSI)**
- **Horzntl Spatial Resolution (HSR)**
- **Dynamic Range/Sensitivity**
- **Calibration Accuracy/Stability**

All but Aux/Anc Data & Geolocation in Sensor Specification

** Algorithm Data Definition (ADD) Documents (Y2371-- Y2384), ATBDs, and Algorithm Subsystem Specification

Sensor Specification Verified via Simulation of Test Data Response*



- **Pointing, Scan**
- **Band Cntr Wavelength & Bandpass**
- **Band Co-registration**
- **Horzntl Smplg Interval (HSI)**
- **Horzntl Spatial Resolution (HSR)**
- **Dynamic Range/Sensitivity**
- **Calibration Accuracy/Stability**

- **RDRs (Sensor DNs/Telemetry)**
- **Geolocation**
- **Auxiliary/Ancillary Data**
- **Algorithm Theoretical Bases**
- **Research Grade Code**

- **HCS/HRI/VCS/VRI**
- **Hor/Vert Coverage**
- **Measurement Range**
- **Meas Accy/Prec/Unc**
- **Long-term Stability**
- **Mapping Uncertainty**
- **Swath Width**

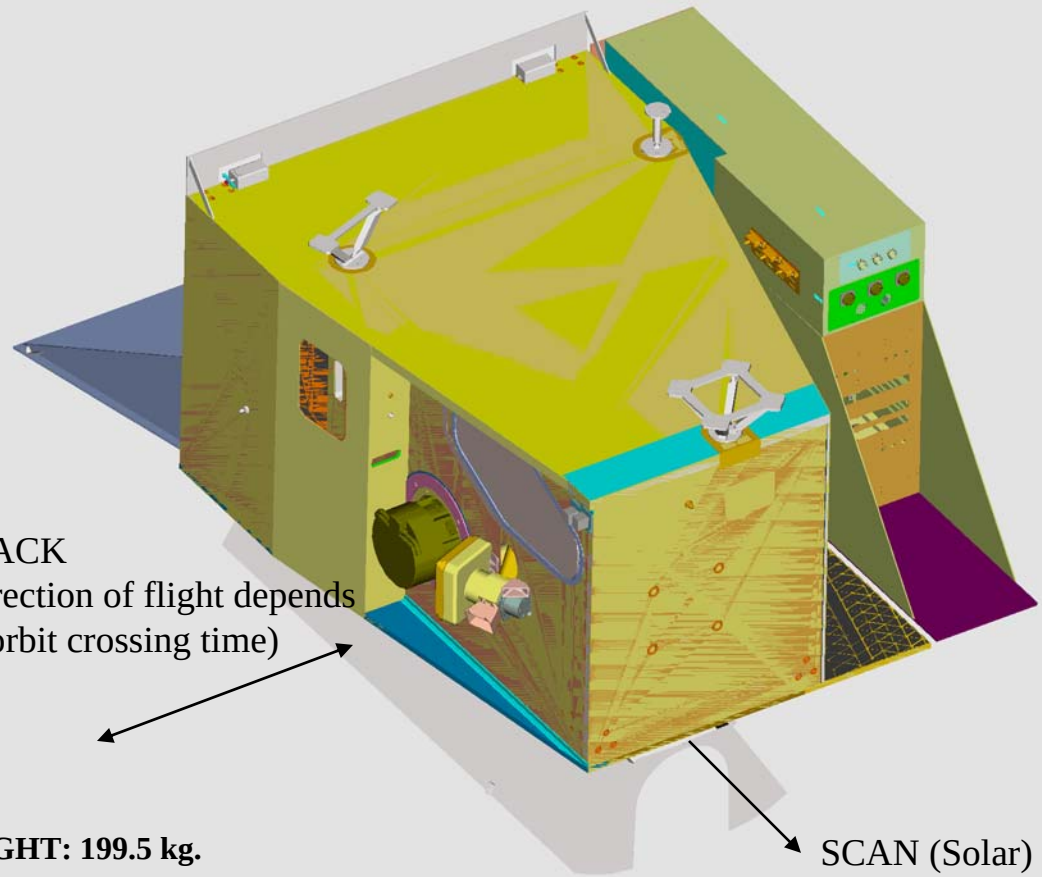
Specification Bottom Up Verification

* Y5308 Specification Verification Report & Y3249 Appendix A Error Budgets

Major Design Drivers

- High resolution Imagery with near constant resolution across scan
- Increased Accuracy/ Resolution of Sea Surface Measurements
- Disaster Monitoring (Volcanic ash, Suspended Matter, Floods, Fires)
- Increased Accuracy/resolution on Aerosols and Cloud Properties
- Climate Related Accuracies

VIIRS Sensor Design At CDR Level Maturity



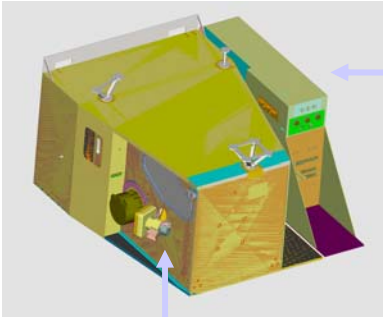
WEIGHT: 199.5 kg.

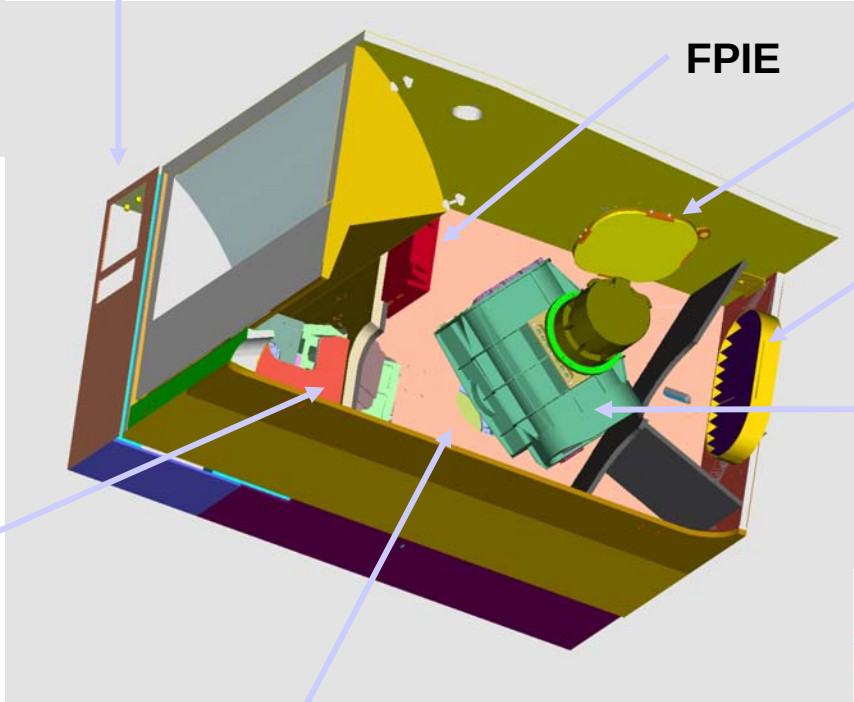
DATA RATE: 5.8 Mbps average, 10.50 Mbps peak

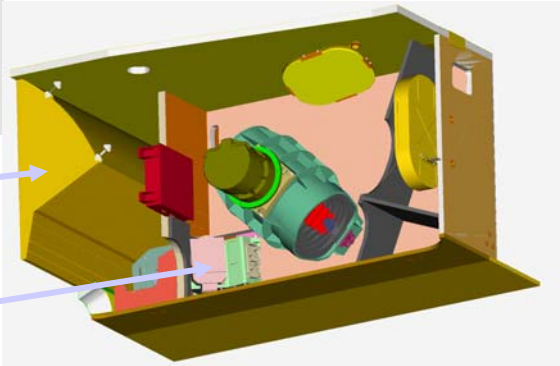
POWER: 133.3 W Operational, 280 W peak in Outgas mode

SIZE:130.3 (Velocity) x 141.2 x 82.1 (nadir, including kinematic mounts) cm

VIIRS Sensor Subsystems







Separately Mounted Electronics Module

Solar Diffuser

FPIE

Blackbody

Solar Diffuser
Stability Monitor

3-Mirror Anastigmat
All reflective
Rotating telescope

4-Mirror Anastigmat
All Reflective
Aft Optics Imager

Cryoradiator

Half-angle Mirror

Cold FPA
Dewar Assembly

EDR Spectral Requirements

Required Band **Fine HSR** **EDR Deleted from IORD Since PDR**

2:1 Nadir to Edge-of-Scan HSI Driver

Emissive NEdT & Calibration Driver

Fine Resolution 1.61 μm Driver

VNIR Driver

All-Band* Co-registration Driver

DNB	M1	M2	M3	M4	I1	M5	M6	M7	I2	M8	M9	M10	I3	M11	M12	I4	M13	M14	M15	I5	M16	PDR FINAL 23APR00
DNB	Cl2w2	2	chlor8	4	5i	OC2	OC3	6	6i	cloud1	7	8	8i	9	10	10iw	sst2	sst4	11	12iw	12	
700	412	445	488	555	640	672	746	865	865	1.24	1.378	1.61	1.61	2.25	3.7	3.74	4.05	8.55	10.76	11.45	12.013	Band position
400	20	18	20	20	100	20	15	39	39	0.02	0.015	0.06	0.06	0.05	0.18	0.38	0.155	0.3	1	1.9	0.95	Band width
																						Imagery
																						SST
																						Soil Moisture
																						Cloud Base Height
																						Cloud Cover/Layers
																						Cloud Particle Size
																						Cloud Thickness
																						Cloud Top Height
																						Cloud Top Pressure
																						Cloud Top Temp.
																						LST
																						FIRE
																						Vegetation Index
																						Snow Cover(Binary)
																						Snow Cover(Fraction)
																						Vegetation/ Type
																						Albedo
																						Fresh Water Ice
																						IST
																						Littoral Transport
																						Net Heat Flux
																						Ocean Color/chl_A
																						Sea Ice age/ motion
																						Mass (turbidity)
																						Ocean Currents
																						Aer Opt T (Ocean)
																						Aer Opt T (Land)
																						Aer Part Size (Ocean)
																						Aer Part Size (Land)
																						Suspended Matter
																						Total Pre. Water
																						Cloud mask

DNB/VNIR Focal Plane (Two FPAs)

SWIR Focal Plane (One FPA)

MWIR Focal Plane

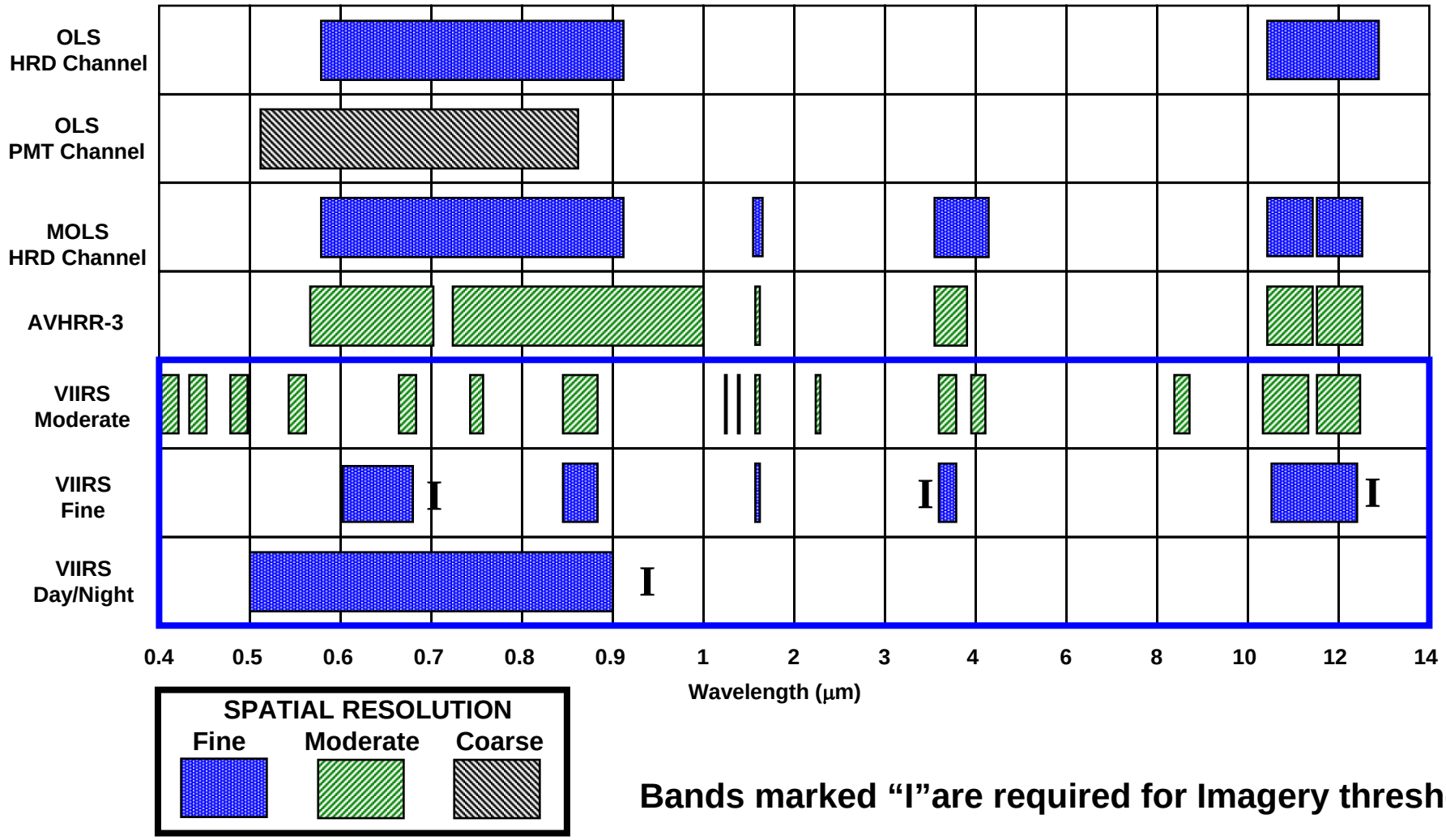
LWIR Focal Plane

*Except DNB

DNB FPA | 9 VNIR Bands FPA | 5 SWIR | 3 MWIR | 4 LWIR

All on one FPA

Imagery EDR Benefits from True Multispectral Capability

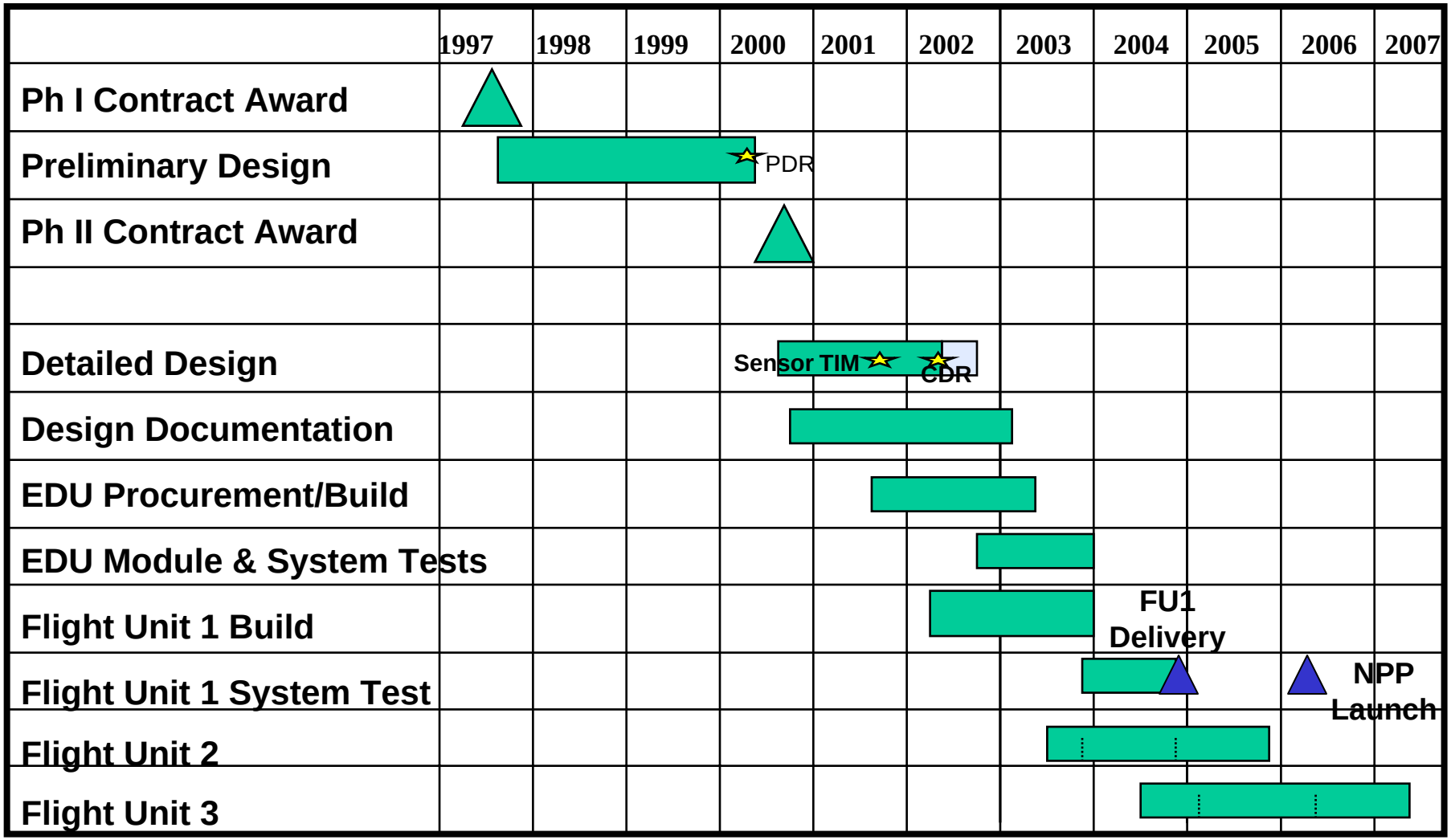


Bands marked "I"are required for Imagery thresholds

Imaging Sensor Comparison

Capability	POES/AVHRR	DMSP/OLS	NPOESS/VIIRS
Imagery Resolution (km)	1-7	0.5-1.1	<0.4-0.8
# of Channels	6	2	22
Low Light Visible	No	Yes	Yes
Ocean Color	No	No	Yes

VIIRS EDU and Flight Units on Track



Science Interactivity Approach

- Operators and scientists involved throughout program
  - Definition of original requirements
  - Continuing role in VOAT (VIIRS Operational Algorithm Team)
  - Will participate in Cal/Val
- Participants in sensor/system procurement actions
  - Attend and provide technical assessment of contractor performance
- Participate in technology transition programs
- Input and peer review for algorithm upgrades
- VIIRS ATBDs available for review on the WWW
  - http://npoesslib.ipo.noaa.gov

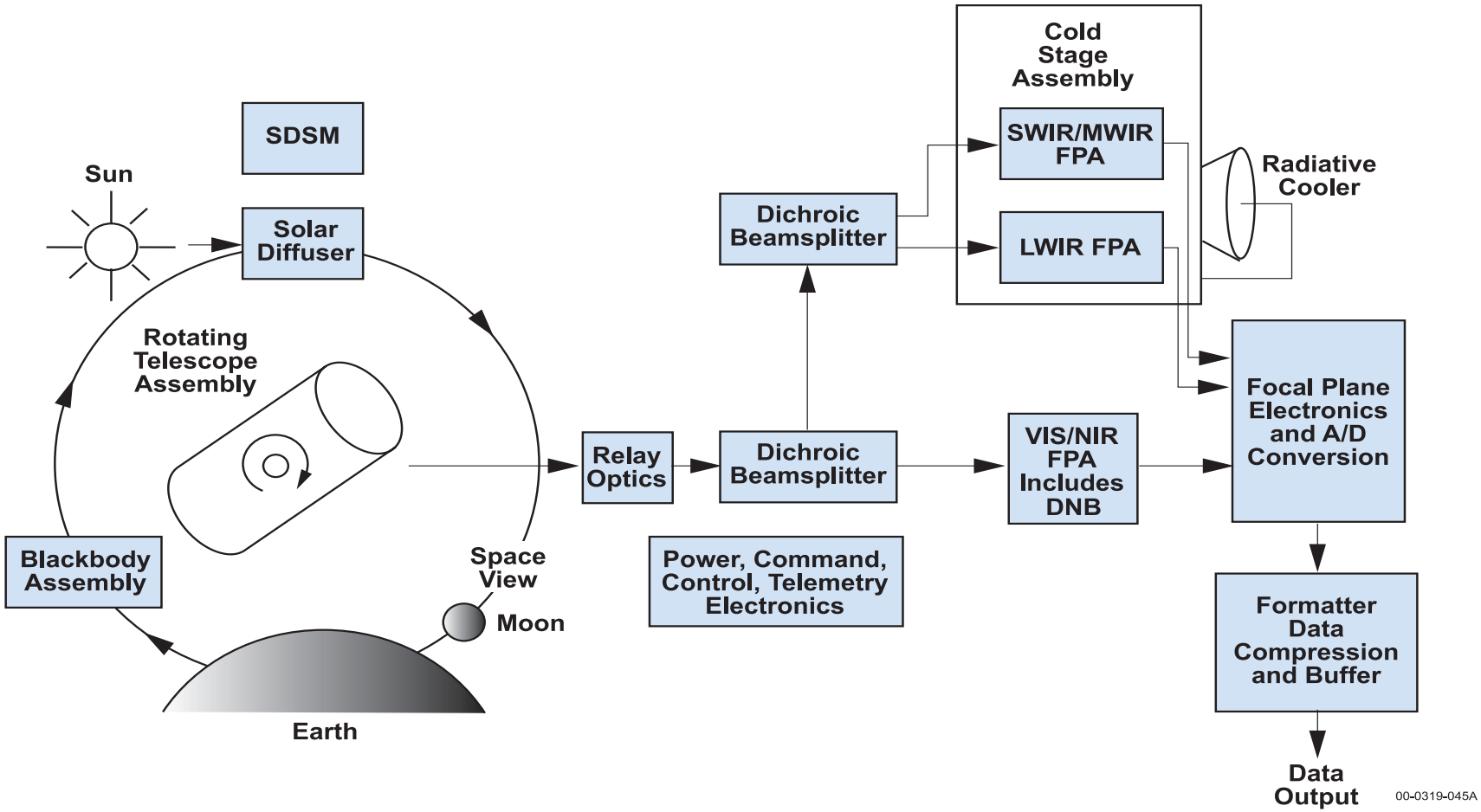
Some Final Thoughts

- Making the transition from research to operations
- Science-quality data at operational refresh rates
- Science and research applications largely unexplored
- Capabilities in combination with other NPOESS sensors

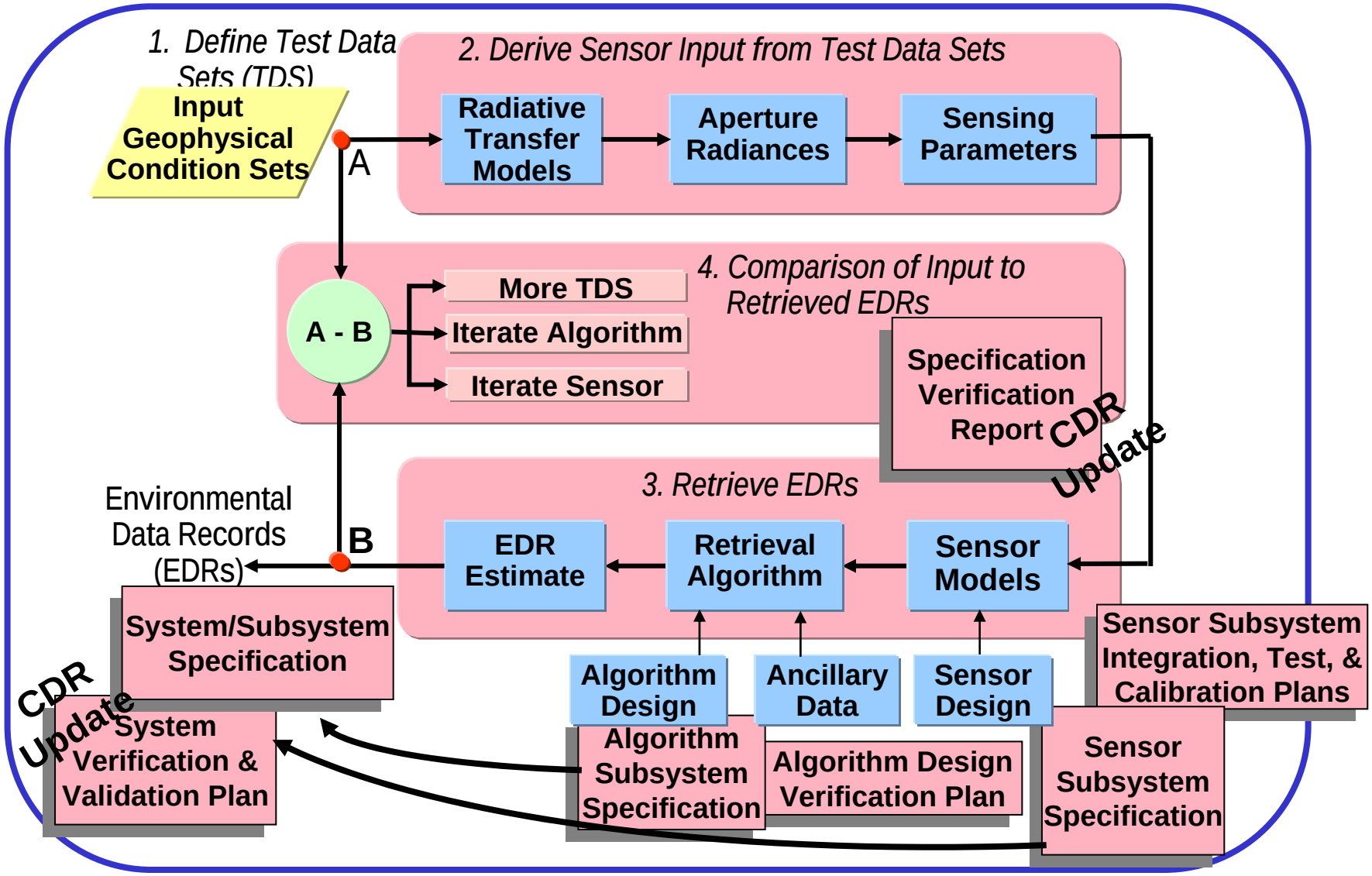
Look at the possibilities!

Backup Charts

VIIRS Sensor
Photons In to Digital Data Out



End-to-End Testbed Proven in Phase I: Specification Flowdown & Verification



EDR CAIV Example: Ocean Aerosol Optical Thickness at High Range

IPO

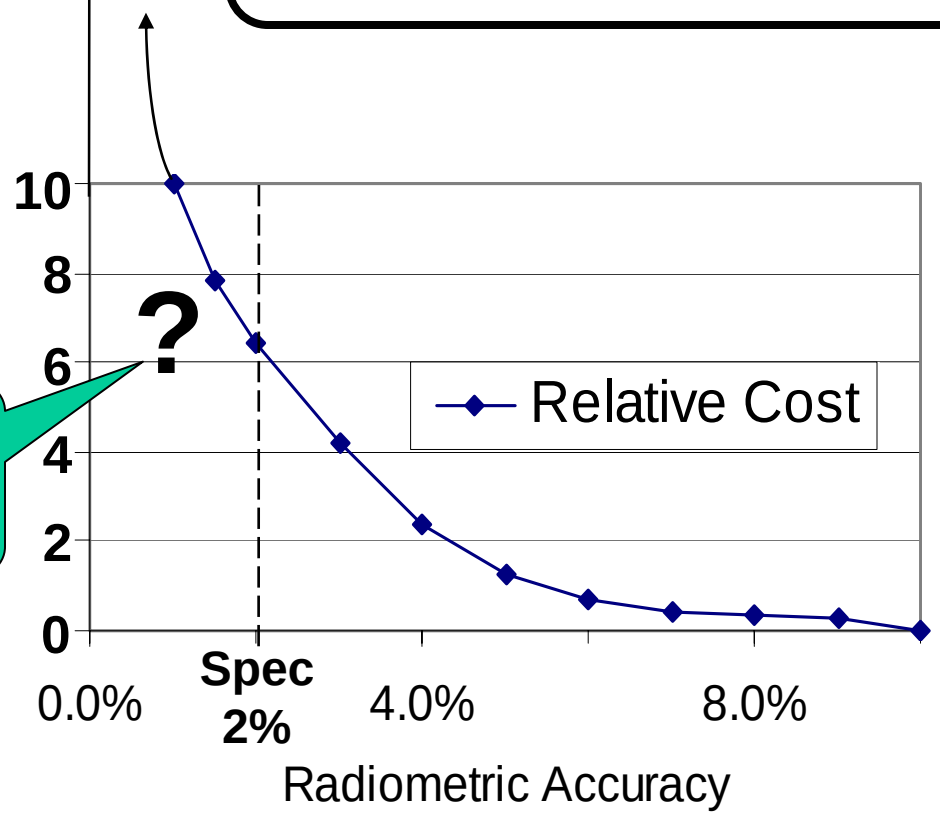
EDRs

Cost

CAIV

***SRD*: AOT Range 0 - 2: Threshold < 0.03**

***CAIV* Specification:** **< 0.02; AOT < 0.5**
linear ramp; AOT > 0.5



< 2%: Cost & Risk Difficult to Estimate

Partial Compliance Compelling Benefits:

- **MODIS Specification**
- **Bounded Cost & Risk**
- **Excellent Accuracy for 99% of Cases**

VIIRS Sensor Bands

Band Name	λc(nm)	Δλ(nm) **	Wavelength Type	Radiance Type	Spatial Resolution Type	Focal Plane Assembly
M1	412	20	VIS	Reflective	Moderate	VISNIR
M2	445	18	VIS	Reflective	Moderate	VISNIR
M3	488	20	VIS	Reflective	Moderate	VISNIR
M4	555	20	VIS	Reflective	Moderate	VISNIR
M5	672	20	VIS	Reflective	Moderate	VISNIR
M6	746	15	NIR	Reflective	Moderate	VISNIR
M7	865	39	NIR	Reflective	Moderate	VISNIR
M8	1240	20	SWIR	Reflective	Moderate	SMWIR
M9	1378	15	SWIR	Reflective	Moderate	SMWIR
M10	1610	60	SWIR	Reflective	Moderate	SMWIR
M11	2250	50	SWIR	Reflective	Moderate	SMWIR
M12	3700	180	MWIR	Emissive	Moderate	SMWIR
M13	4050	155	MWIR	Emissive	Moderate	SMWIR
M14	8550	300	LWIR	Emissive	Moderate	LWIR
M15	10763	1000	LWIR	Emissive	Moderate	LWIR
M16	12013	950	LWIR	Emissive	Moderate	LWIR
DNB	700	400	VIS	Reflective	Imaging	DNB
I1	640	80	VIS	Reflective	Imaging	VISNIR
I2	865	39	NIR	Reflective	Imaging	VISNIR
I3	1610	60	SWIR	Reflective	Imaging	SMWIR
I4	3740	380	MWIR	Emissive	Imaging	SMWIR
I5	11450	1900	LWIR	Emissive	Imaging	LWIR

Excellent Spatial Performance Over Range (Imagery, Aerosols, and Clouds)

EDR	HCS/HRI		**Range**		**Ptype**	
	Spec	Pred Perf	Spec	Pred Perf	Spec	Pred Perf
Imagery	0.4-0.8/0.74km	0.37-0.8/0.74km			n/a	n/a
Cloud cover	2.4 km	1.6 km	0-1 x 0.1	0-1 x 0.1	n/a	n/a
Cloud Type	2.4 km	1.6 km	14 types	Clr,Obs,ST,CU,C	85%	95%
Ice Edge	n/a	n/a	n/a	n/a	n/a	n/a
Ice Conc	0.8 km Nadir	0.75 km nadir	0-1	0-1	n/a	n/a
SST	3.2/1.3* km	3.2/1.3* km	271-313 K	271-313K	n/a	n/a
Soil Moisture	1.6 km EOS	1.6 km EOS	0-100 cm/m	0-100 cm/m	n/a	n/a
AOT (=0.3)						
AOT (ocean)	1.6 km	1.6 km	0.0 - 2.0	0 - 2.0	n/a	n/a
AOT (land)	9.6 km	9.6 km	0.0 - 2.0	0 - 2.0	n/a	n/a
Prtcl Size (AOT=0.3)						
Particle Size (ocean)	1.6 km	1.6 km	-1 to +3	-1 to +3	n/a	n/a
Particle Size(Land)	9.6 km	9.6 km	-1 to +3	-1 to +3	n/a	n/a
Susp Matter	1.6 km	1.6 km EOS		Classify SM	0.85	0.85
Cloud base	10 km	10 km	0 - 20 km	0 - 15 km	n/a	n/a
Cover/Layers	25 km/pixel*	25 km/pixel*	0-1/cld no cld	0-1/cld no cld	see Spec	see ATBD
Particle size	25/5* km	25/5* km	0-50 micron	0-50 micron	n/a	n/a
Optical thick	25/5* km	25/5* km	0.1-64	0.1-64	n/a	n/a
Top Height	25/5* km	25/5* km	0-20 km	0-20 km	n/a	n/a
Top Pressure	12.5/5* km	12.5/5* km	50-1050 mb	50-1050 mb	n/a	n/a
Top Temp	25/5* km	25/5* km	190-310K	180-310K	n/a	n/a

Excellent Spatial Performance over Range (Albedo to Precipitable Water)

EDR	HCS/HRI		Range		Ptype	
Albedo	1.6/0.75* km	1.6/0.75* km	0 - 1.0	0 - 1.0	n/a	n/a
LST	1.6/0.75* km	1.6/0.75* km	213 - 343 K	213 - 343 K	n/a	n/a
Veg Index						
NDVI	0.8/0.375* km	0.8/0.375* km	(-1) to 1	(-1) to 1	n/a	n/a
EVI	0.375 km*	0.375 km*	(-1) to 1	(-1) to 1	n/a	n/a
Snow Cover/Depth						
Binary Map	0.4-0.8 km	0.4-0.8 km	snow/no snow*	snow/no snow*	0.95	0.97
Fraction	0.8-1.6 km	0.8-1.6 km	0 - 1	0 - 1	n/a	n/a
Surface Type	1/1* km	1/1* km	17 IGBP,0-100%	17 IGBP,0-100%	0.88	0.88
Active Fires						
Subpixel Temp	1.6 km EOS*	1.6 km EOS*	800-1200 K*	800-1200 K*	n/a	n/a
Subpixel Area	1.6 km EOS*	1.6 km EOS*	1000m^2-50xGSDscan*	1000m^2-50xGSDscan	n/a	n/a
IST	10 km*	10 km*	13-275 K Ice cov. land/wat	13-275 K Ice cov. Land/wat	n/a	n/a
Net Heat Flux	20 km	20 km	0 - 2000 W/m^2	0 - 2000 W/m^2	n/a	n/a
Ocean color	2.6/1.0* km	2.3/1.0* km	0.05-50 mg/m^3	0.05-50 mg/m^3	n/a	n/a
Sea Ice Characterization					n/a	n/a
Ice Age	2.4 km EOS	2.4 km EOS	New or Young,FY,MY	New or Young,FY,MY	0.75	0.77
Ice Edge Motion	2.4 km EOS	2.4 km EOS	0-100 km/day	0-100 km/day	n/a	n/a
Fresh Water Ice					n/a	n/a
Concentration	1.6 km EOS	1.6 km EOS	0.1 - 1	0.1 - 1	n/a	n/a
Edge Boundary	n/a	n/a	n/a	n/a	n/a	n/a
Prec Water	0.75 km*	0.75 km*	0 - 100 mm*	0 - 100 mm*	n/a	n/a

Excellent APU (Accuracy, Precision, Uncertainty) Performance (Imagery, Aerosols, and Clouds)

EDR	Uncertainty		Accuracy		Precision		Stability
	Spec	Pred Perf	Spec	Pred Perf	Spec	Pred Perf	Spec
Imagery	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cloud cover	0.1	0.06	n/a	n/a	n/a	n/a	n/a
Cloud Type	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ice Edge	1 km	0.65 km	n/a	n/a	n/a	n/a	n/a
Ice Conc	0.1	0.085	n/a	n/a	n/a	n/a	n/a
SST	0.35 K	0.32 K	0.2 K	0.19 K	0.27 K	0.26 K	n/a
Soil Moisture	5 cm/m	4.5 cm/m	n/a	n/a	n/a	n/a	n/a
AOT (=0.3)					.03-.2		
AOT (ocean)	n/a	0.028	0.02	0.02	0.02	0.019	0.01
AOT (land)	.05+0.2tau =0.11	0.082	0.1	0.067	0.1	0.038	0.01
Prtcl Size (AOT=0.3)			0.3 - 1		0.3 - 1		
Particle Size (ocean)	n/a	0.078	0.3	0.076	0.3	0.018	0.1
Particle Size(Land)	n/a	0.5	0.6	0.5	0.6	0.015	0.1
Susp Matter	0.5	0.5	n/a	n/a	n/a	n/a	n/a
Cloud base	2 km	1.5 km	n/a	n/a	n/a	n/a	n/a
Cover/Layers	n/a	n/a	0.1	0.09	0.15	0.14	n/a
Particle size	12/2.5	11/2	8/2	7.9/1.35	2/1	1.6/0.70	0.02
Optical thick	10%/0.30*	5.38%/0.27	10%/0.28	8.5%/0.25	5%/0.10	2.5%/0.08	0.02
Top Height	0.5/2 km*	0.4/1.4 km	0.5/2 km	0.35/1.0	0.3 km	0.25	0.2 km
Top Pressure	30/130 mb*	20/125 mb	30-100 mb	20-90 mb	13/25 mb	7/15 mb	5-10 mb
Top Temp	5K*	3K	2-6K	1.6-5.3 K	1.5K	1.0K	1K

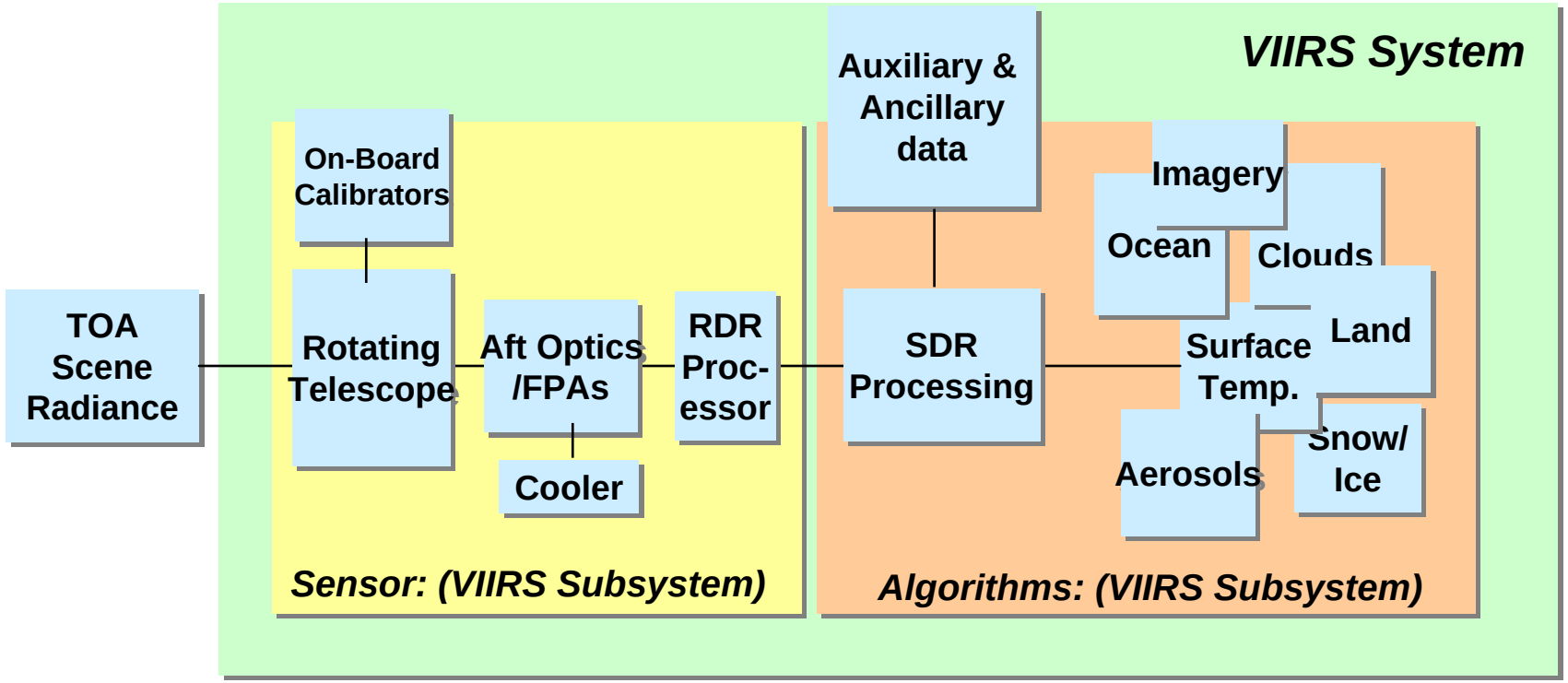
Excellent APU Performance (Albedo to Precipitable Water)

EDR	Uncertainty		Accuracy		Precision		Stability
Albedo	0.03	0.03	0.025	0.025	0.02	0.02	0.01
LST	2.50 K*	2.14 K	2.4 K	2.1 K	0.5K	0.42 K	n/a
Veg Index							
NDVI	0.02	0.014	0.016	0.006	0.02	0.013	0.008
EVI	0.11	0.1	n/a	n/a	n/a	n/a	n/a
Snow Cover/Depth							
Binary Map	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Fraction	0.1	0.1	n/a	n/a	n/a	n/a	n/a
Surface Type	n/a	n/a	0.2	0.2	0.1	0.1	n/a
Active Fires							
Subpixel Temp	50 K*	50 K*	n/a	n/a	n/a	n/a	n/a
Subpixel Area	30%*	30%*	n/a	n/a	n/a	n/a	n/a
IST	0.5 K	0.35 K	n/a	n/a	n/a	n/a	n/a
Net Heat Flux	n/a	n/a	10Wm2	10Wm2	25Wm2	25Wm2	n/a
Ocean color	30%*	27%*	30%	27%	30%	28%	n/a
Sea Ice Characterization							
Ice Age	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ice Edge Motion	.8 km/day	.7 km/day	n/a	n/a	n/a	n/a	n/a
Fresh Water Ice							
Concentration	0.1	0.085	n/a	n/a	n/a	n/a	n/a
Edge Boundary	1 km	0.65 km	n/a	n/a	n/a	n/a	n/a
Prec Water	32%/1.5 mm	32%/1.5 mm	n/a	n/a	n/a	n/a	n/a

VIIRS Baseline Orbital Parameters

ORBIT	**833 km, sun synchronous, nominal 13:30, 17:30, 21:30, must be capable of any orbit crossing time**
SWATH	**± 56.063°, 3040 km scan**
IFOV	**0.890 mr track x 0.382 mr scan for moderate bands** **0.445 mr track x 0.114 mr scan for imaging bands** **0.890 mr track x 0.890 mr track for DNB**
HSI	**0.742 km track x 0.259 km scan at nadir** **1.600 km track x 1.579 km scan at EOS**

System-level Simulations Demonstrate End-to-End Performance



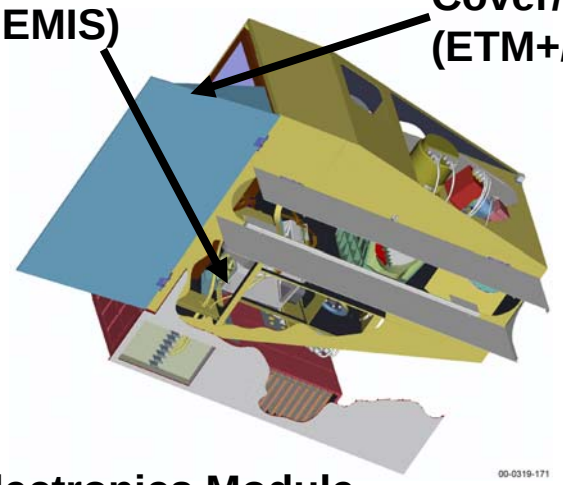
- System test-bed includes important Sensor effects
- EDR Algorithms verified with Research-grade code

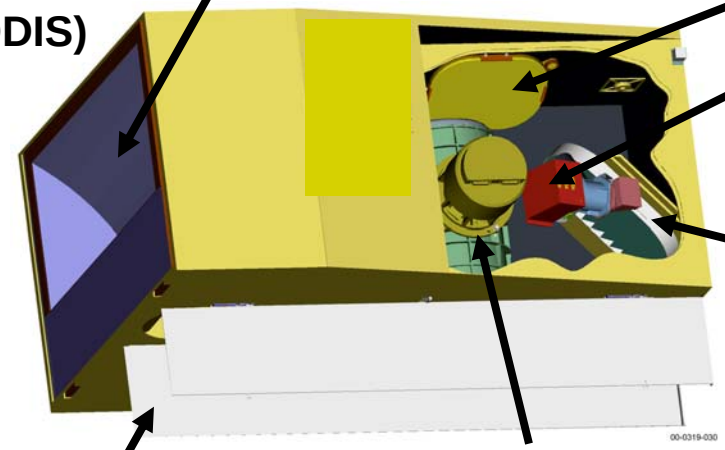
Best Value
Single Sensor Design

- Multi-Orbit Operational Flexibility only Limited by Solar Diffuser View Angle
- Terminator Orbit Sun-Glare Mitigation without Spacecraft Glare Obstructor
- Superb Imagery, SST, and many other EDRs

Aft Optics (THEMIS)

Passive Radiative Cooler Cover/Earth Shield (ETM+/MODIS)





Solar Diffuser (MODIS)

Solar Diffuser Stability Monitor (MODIS Redesign)

Blackbody to be more Vertical to Mitigate Earthshine (MODIS/VIRS)

Electronics Module (ETM+/MODIS/SeaWiFS/VIRS)

Rotating Telescope (MODIS/SeaWiFS/THEMIS)

Nadir Aperture Cover/ Doors/Sun Glare Shields (ETM+/MODIS)

- Constant-Speed Rotating Telescope
- All-Reflective Diamond Point Turned Bolt-together Optics
- Improved Emissive/Reflective Calibration

Significant Design Changes Since PDR - 1 Of 2

- Overall Z dimension increased from 65 to 75 cm (ICSR G1040401), then to 85cm via GIID ECP
- Angular Momentum Compensator deleted, Max. Momentum requirement in x-axis increased to 1.0 N-m-s (G1061401)
- OPERATIONAL/Terminator mode deleted - terminator orbiting sensor to operate in Day mode (G1062001A)
- Band I1 spectral requirements changed from center wavelength of 645nm (50 nm wide) to 640nm (80nm wide) (G1062701)
- Band M6 center wavelength changed from 751nm to 746nm (Rev. - Specification)
- Low Rate Data (LRD) requirements deleted for EDU and FU1 sensors - updated requirements being negotiated with SSPRs for FU2 and subsequent (G1071801)
- Spacecraft to provide a 60 Watt (at 10°C) cold plate interface for the Electronics Module (ICSR G1090501)

Significant Design Changes Since PDR - 2 Of 2

- HAM motor/encoder changed from SeaWiFS type to same MODIS type design as Rotating Telescope
  - Provides better angular resolution, reduces cost via commonality, and makes use of MODIS bearing life tests
- SW/MWIR detector sizes optimized for SNR performance
- Uncompensated disturbance torque limit increased to 0.2 N-m, allowing telescope stow within 45 second period
- Lossless data compression technique modified to include spectral subtraction and backup prioritized data trimming
- Blackbody relocated and reoriented to minimize earthshine exposure
- Baffling and coatings refined to improve DNB scattered light performance