GOES-R Calibration & Validation Update

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GOES-R PSE Calibration Coordination Team Lead

GLM Science Meeting

September 20, 2012

Outline

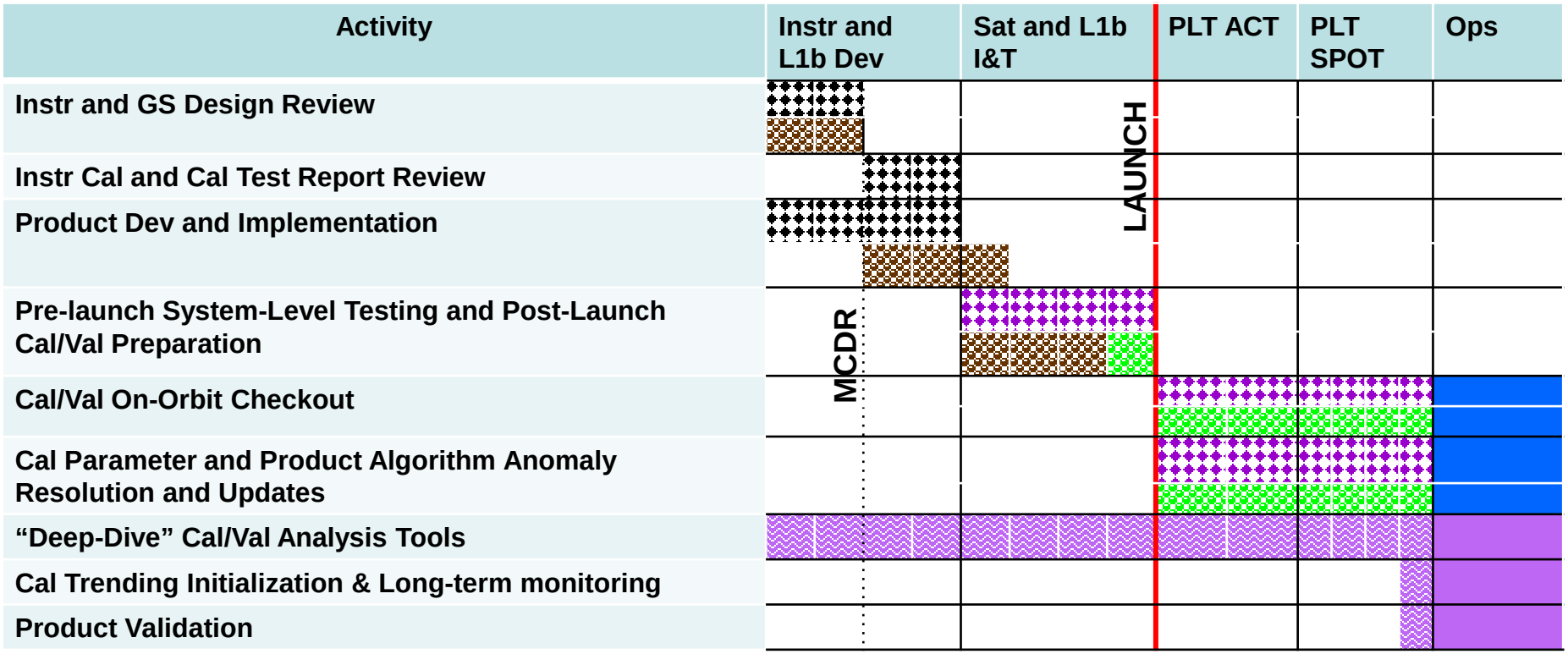
- **GOES-R program-level cal/val scope and overview**
- **Cal/Val Updates**
  - **ABI**
  - **GLM**
  - **Space Weather Instruments**
  - **Ground Segment**
- **Summary**

GOES-R Cal/Val Scope

- Ensure instrument calibration requirements are met
- Enhance data integrity by leveraging NIST SI-traceable calibration standards, and testing capabilities and procedures
- Reduce risks associated with possible operational failure of on-board calibration systems
- Prepare NOAA satellite calibration scientists and engineers for monitoring, analyzing and maintaining GOES-R series instrument calibration and product integrity
- Support product validation to determine the degree to which GOES-R science data meets user needs

GOES-R Program commitment to cal/val enhances understanding of data quality, and encourages “Day-1” readiness and long-term user confidence.

GOES-R Cal/Val Overview



Space Segment Development

- Flight Oversight
  CCT/CWG/OSPO Support
  Instr. Vendor Responsible
- Flight/MOST Responsible
  CCT/CWG/OSPO Support
  Instr. Vendor Support

Ground Segment Development

- GSP Oversight
  CCT/CWG/AWG/OSPO Support
  GS Vendor Responsible
- GSP/MOST/DOST Responsible
  CCT/CWG/AWG/OSPO Support
  GS Vendor Support

Long-term Cal/Val Readiness

- PSE CCT/CWG/AWG Responsible
  MOST/DOST Support
- STAR/NGDC/MSFC Responsible

- OSPO Responsible
  STAR/NGDC/MSFC Support
  Vendor Support as Requested

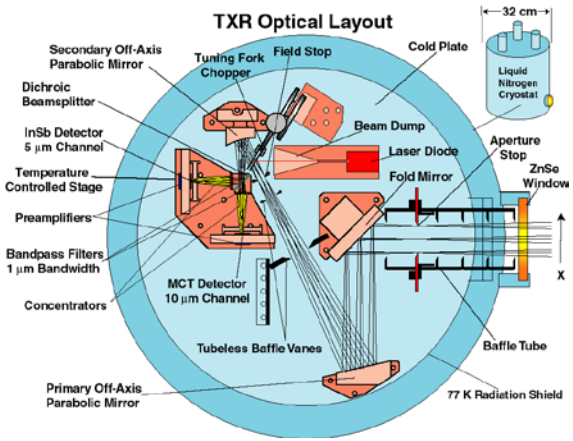
ABI Cal/Val Updates

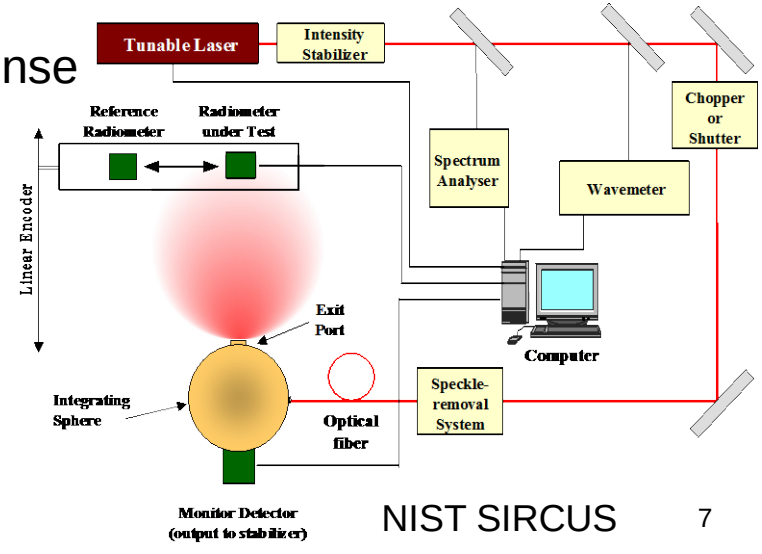
Test Activities: ABI Vendor (ITT Exelis)

- *Proto-Type Model (PTM)*
  - Formal testing period complete
  - Retested on an as-needed basis to learn about instrument behavior
  - PTM not used to verify performance specifications
- *Proto-Flight Model (PFM)*
  - Bench Testing
    - Revealed a ghosting issue that has been resolved.
    - Other tests show ABI meets requirements with few exceptions.
  - Pre-Environmental Review set for 16-18 October

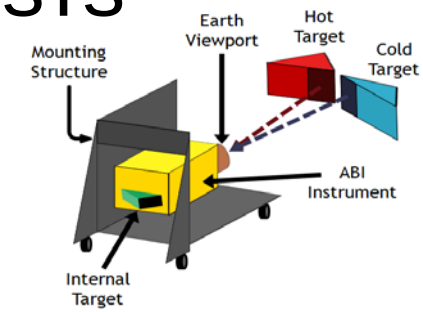
Test Activities: NIST

- Completed Testing
  - Instrument-level testing using NIST Traveling Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS)
    - Irradiance to radiance transformation validation
    - Spectral response validation
  - Small integration sphere characterization at the NIST FAcility for Spectroradiometric CALibrations 2 (FASCAL 2)
  - External blackbody characterized using the NIST Thermal Transfer Radiometer (TXR)
  - Exelis FEL lamp calibration process validation and spatial uniformity test
- Coming in FY '13
  - Large integration sphere radiance scale validation using the NIST Visible Transfer Radiometer (VXR)
  - Determination of witness filter spectral response



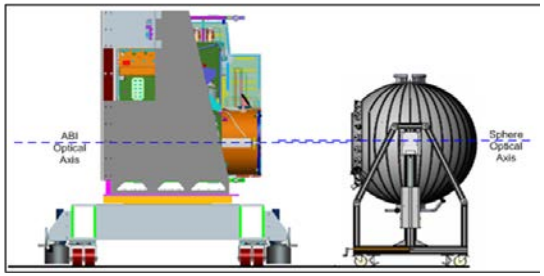


Test Activities: Government Witness and Analysis

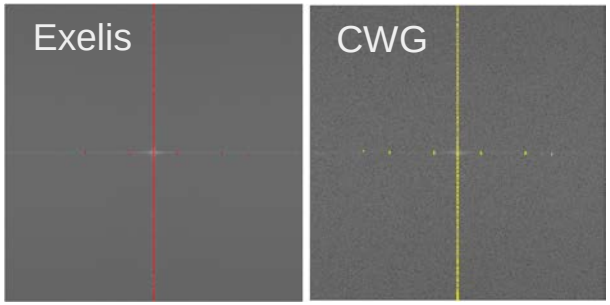


Calibration Working Group (CWG) conducted detailed data analysis on pre-launch tests for **proto-type model (PTM)**

- Reflective and emissive channel calibration
- Coherent noise; irradiance calibration; and MTF-focus-registration



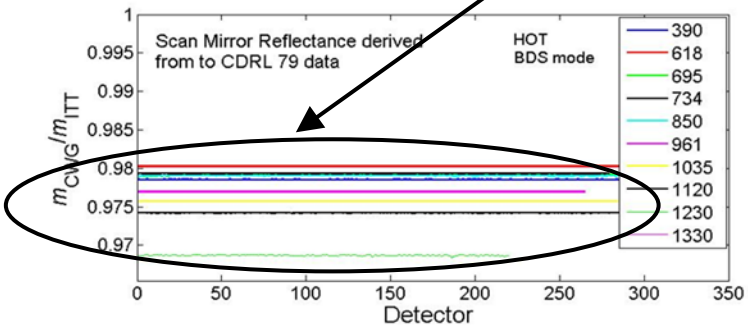
Emissive (top) and Reflective (bottom) channel calibration test arrangement

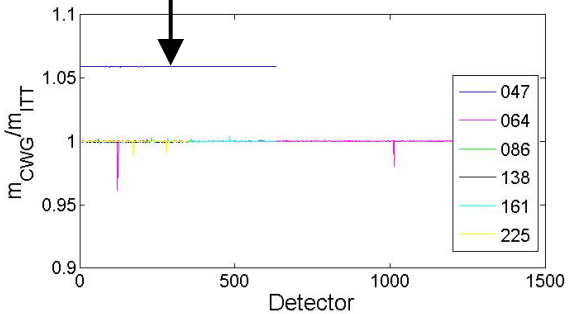


Coherent noise test results - exceedances for 2.25 µm channel

Anomalies caused by not using actual scan mirror reflectance values

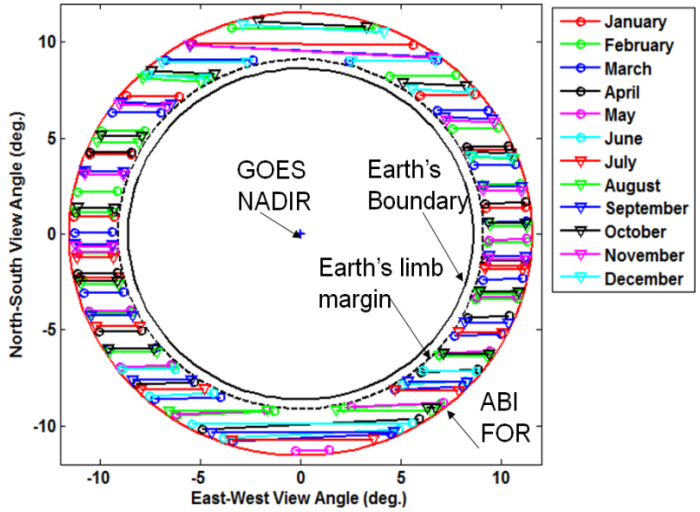
Anomalies caused by incorrectly reported sphere level





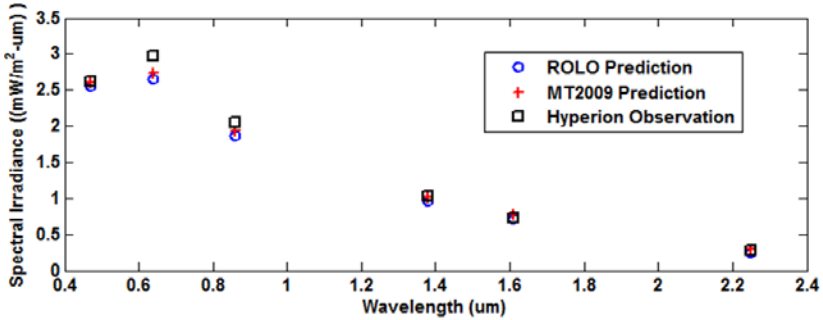
Emissive (left) and reflective (right) channel calibration test results - ratio of CWG to Exelis cal coefficient

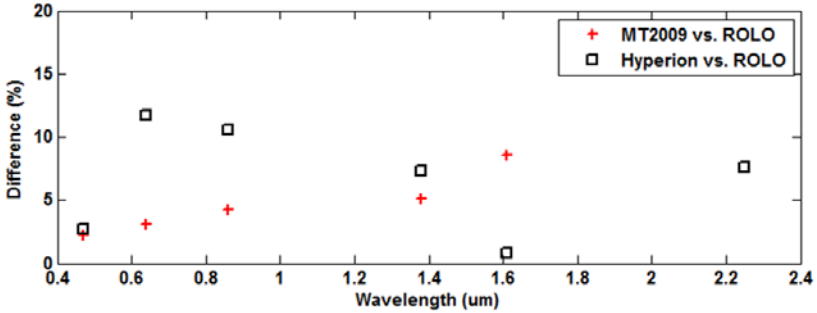
Post-Launch Cal/Val Support Readiness: Lunar cal method implementation



Prediction of lunar imaging windows of opportunity for GOES-EAST for year 2016, lunar phase < ±60°.

Synthetic ABI 0.47 µm channel lunar observation derived from Hyperion observations.

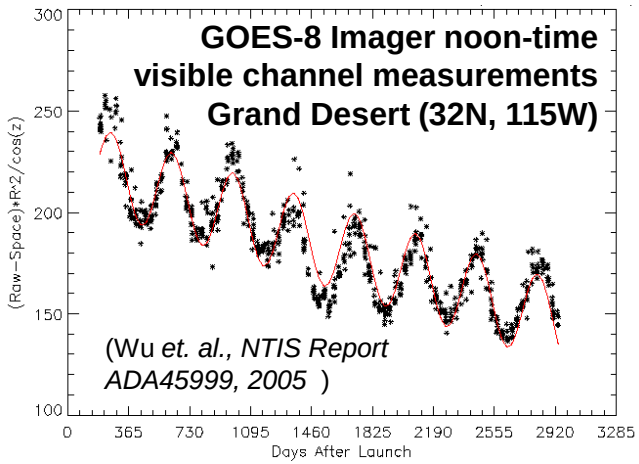




Simulated ABI Lunar irradiance inter-comparisons using Hyperion data and ROLO and Miller-Turner Lunar Models

NIST currently has a proposal out to improve the calibration of ROLO measurements

Post-Launch Cal/Val Support Readiness: Desert target BRDF determination



Measurements – *corrected to nadir sun angle and average earth-sun distance* – reveal seasonally-variant anomalies that could be reduced with knowledge of surface bi-directional reflectance distribution function (BRDF).

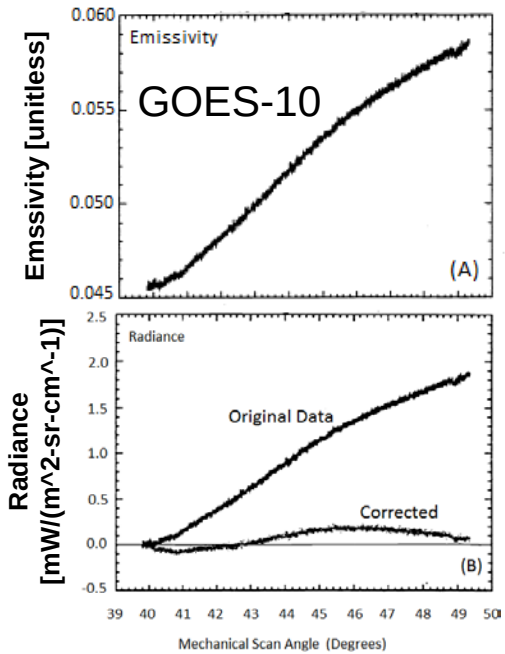
ER-2 AVIRIS/MASTER Flight Acquisitions Completed:

- **White Sands Missile Range (WSMR) (May 23, 2011)**
- **Sonora Desert (June 10, 2011)**
- **Underflights of GOES-11/13, Metop-A, EOS-Aqua/Terra and NOAA-19**

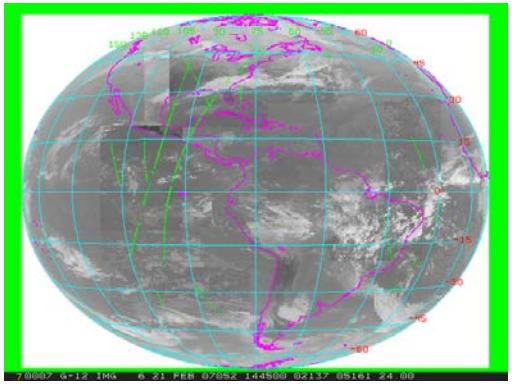
Sonoran Desert and WSMR BRDF data analyses to be performed starting 2013 by a UMD Graduate Student

Post-Launch Cal/Val Support Readiness: Post-launch test (PLT) preparation

- **GOES-R PLTs being created based on GOES-R Cal/Val Plan Vol. 1: L1b Data**
- **ABI scan angle dependent response test being developed**
- **Success of NPP VIIRS and CrIS instrument supports ABI proxy data generation for testing, as well as providing a standard for cross-comparison after launch**



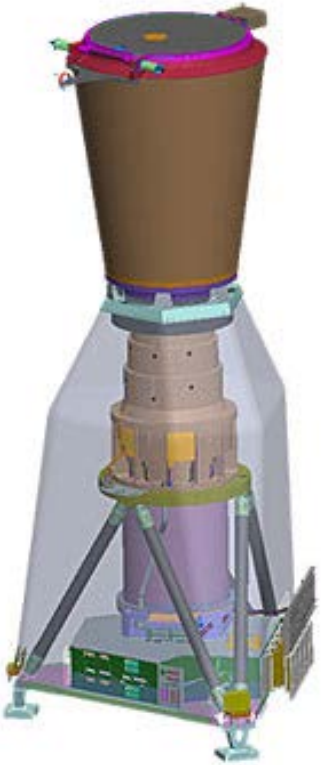
GOES-10 Ch. 4A (Top) Mirror emissivity vs. scan angle and (Bottom) Corrected and uncorrected Radiance vs. scan angle. (Beaucom *et al.*, Proceedings of SPIE, 1999)



GOES-AIRS collocated pixels for 21 February 2007 used for infrared channel inter-comparisons. AIRS is a proxy instrument for JPSS CrIS.

Sample NPP VIIRS data projected over a "full-disk" view. (*Image courtesy of NASA Ocean Color Team)*

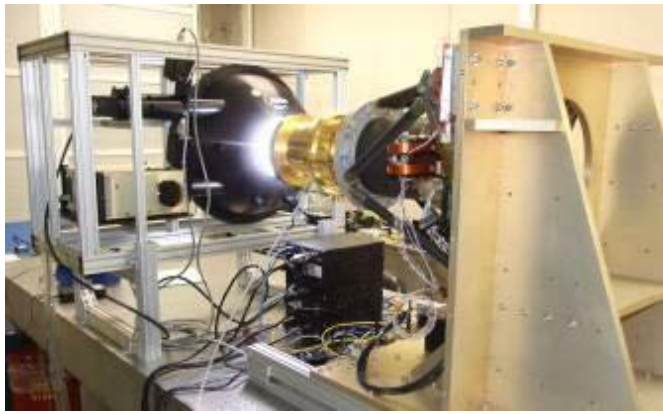
GLM Cal/Val Updates



Test Activities: GLM Vendor (Lockheed-Martin ATC)

The GLM characterization and calibration activities consist of observatory-level checks designed to investigate the following:

- static linearity response and uniformity;
- transient response;
- performance;
- field of view;
- spectral response;
- effects of spacecraft motion and jitter; and
- solar intrusion.

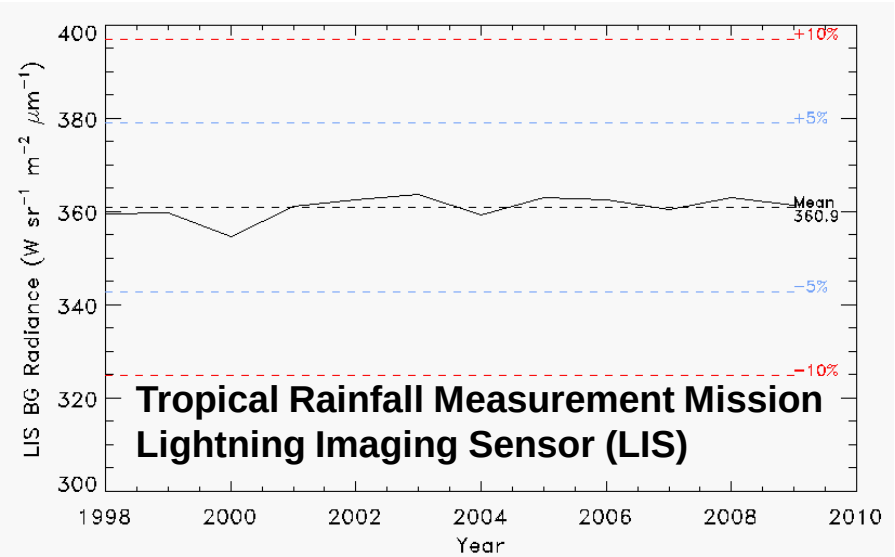


Test Activities: Engineering Development Unit (EDU)

- *Testing philosophy*: EDU testing is a proof-of-concept of testing procedures, and helps to define realistic algorithm parameters to support algorithm implementation.
- Testing of EDU does not verify performance specifications.
- Calibration Working Group (CWG) member Harold Peterson spent a week in Palo Alto this past July to observe EDU testing.
- Current EDU testing helping to iron out testing procedures for FM1.

Post-Launch Cal/Val Support Readiness: Cal monitoring tool development

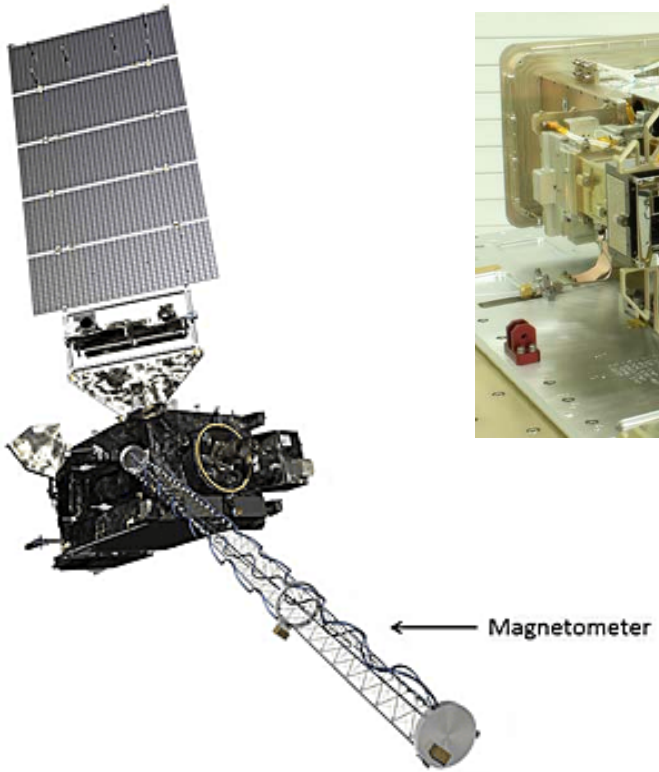
Paper was accepted by *Atmospheric Research*: "Assessing the performance of the Lightning Imaging Sensor (LIS) using Deep Convective Clouds" by *Dennis E Buechler; Dennis Buechler; William J Koshak; Hugh J Christian; Steven J Goodman*



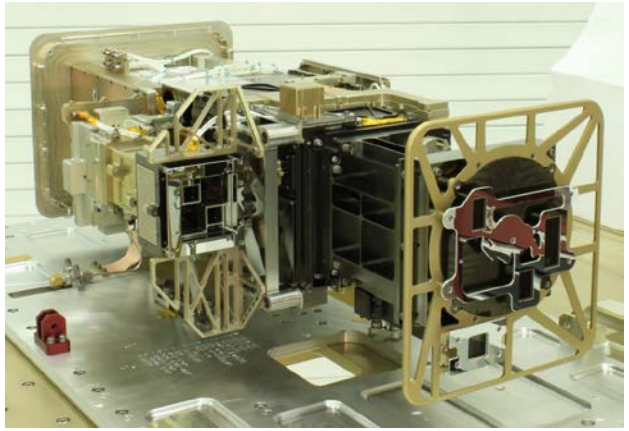
Application of GLM Long-term Radiometric Performance tool to LIS.

Cal/Val Updates

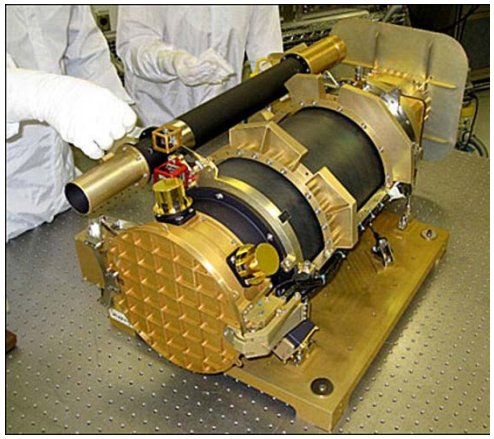
Space Weather Instruments



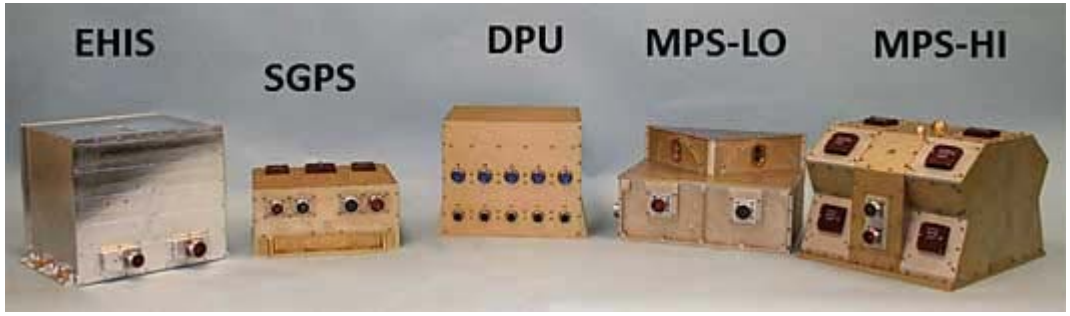
EXIS



SUVI



SEISS



Test Activities: SEISS (Assurance Technology Corp)

SGPS:

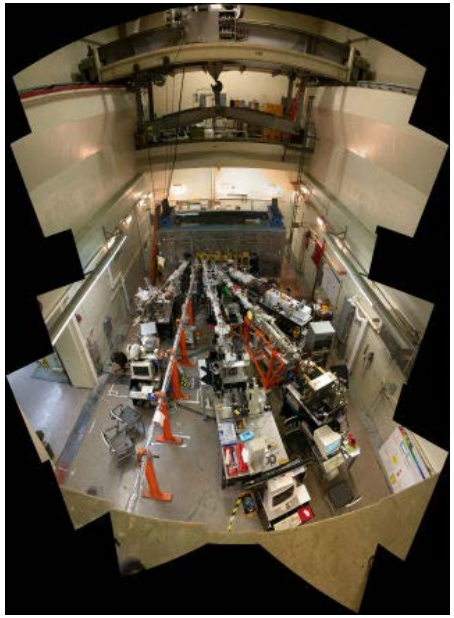
- Tested at Mass General Hospital Proton Therapy Center in May 2012.
- Later vibration test revealed a mechanical issue that, after fixing, will require later re-calibration.

MPS-HI:

- Tested at MIT van de Graaf electron accelerator in June (good data and no runs repeated) and NASA GSFC in July. Some unexpected variability between telescopes may warrant expanded testing of later units.
- The sensor is currently in storage awaiting it's final calibration run at GSFC. The low energy accelerator at GSFC was down for maintenance during calibration of MPS-HI in early August.

Test Activities: EXIS (Lab for Atmospheric and Space Physics)

- Tested in July at NIST Synchrotron Ultraviolet Radiation Facility III (SURF-III).
- Extensive data are still to be analyzed.
- NIST staff continue to improve the SURF beam uniformity, stability, characterization accuracy, and ease of use.
- LASP scientists and engineers have taken full advantage of the SURF improvements.
- Calibration data has less scatter due to these improvements.
- Calibration data supports more detailed system models.
- The GOES-R team is performing an EXIS calibration that will increase the accuracy of solar data input to climate models.



NIST SURF-III Facility

Test Activites: SUVI and MAG (Lockheed-Martin)

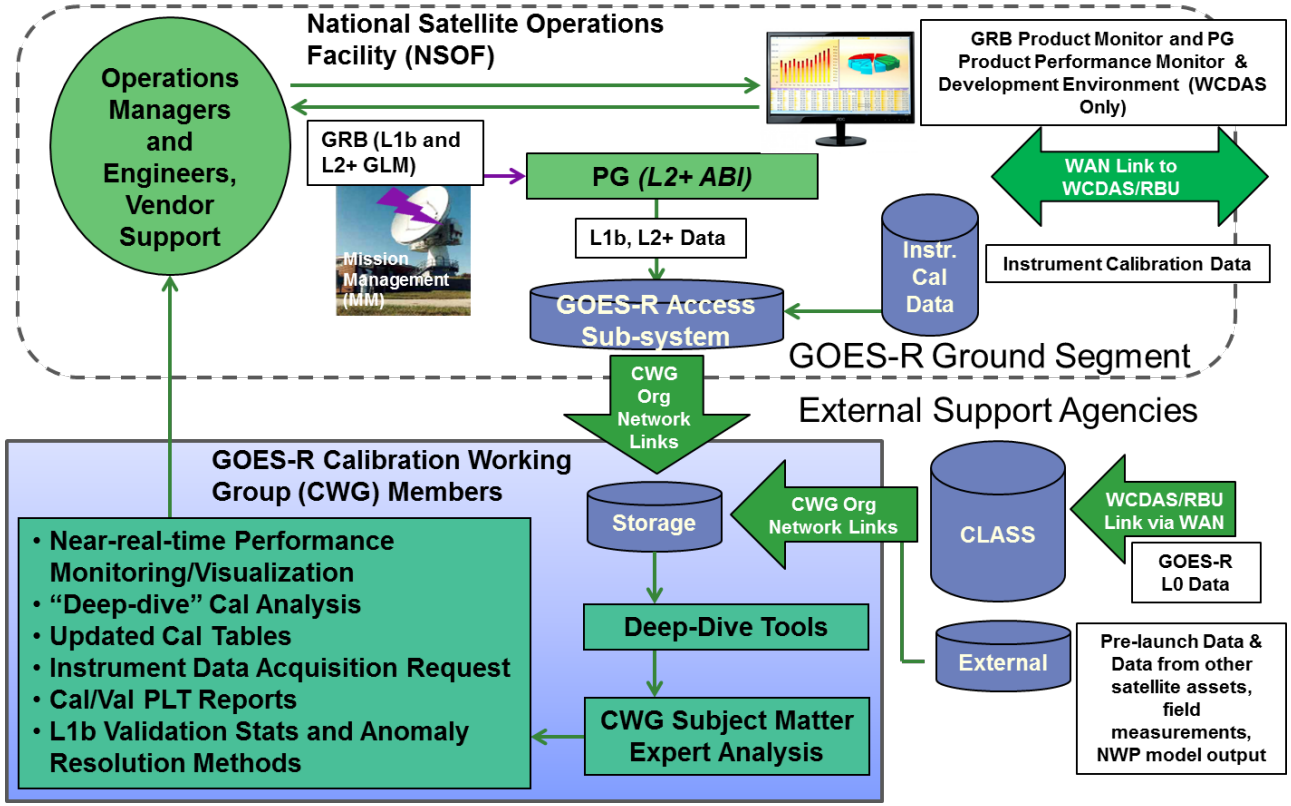
SUVI

- Performance testing of instrument components supports analytical inference of system-level instrument performance.
  - Mirror reflectance measured at LBNL.
  - Transmission of SUVI filter witness samples will be measured by NIST to validate vendor model estimates.
  - CCD calibration at vendor based on new NIST calibrated transfer detector.
  - Vendor X-Ray test underestimates CCD charge spreading. Investigating repeating test at EUV.

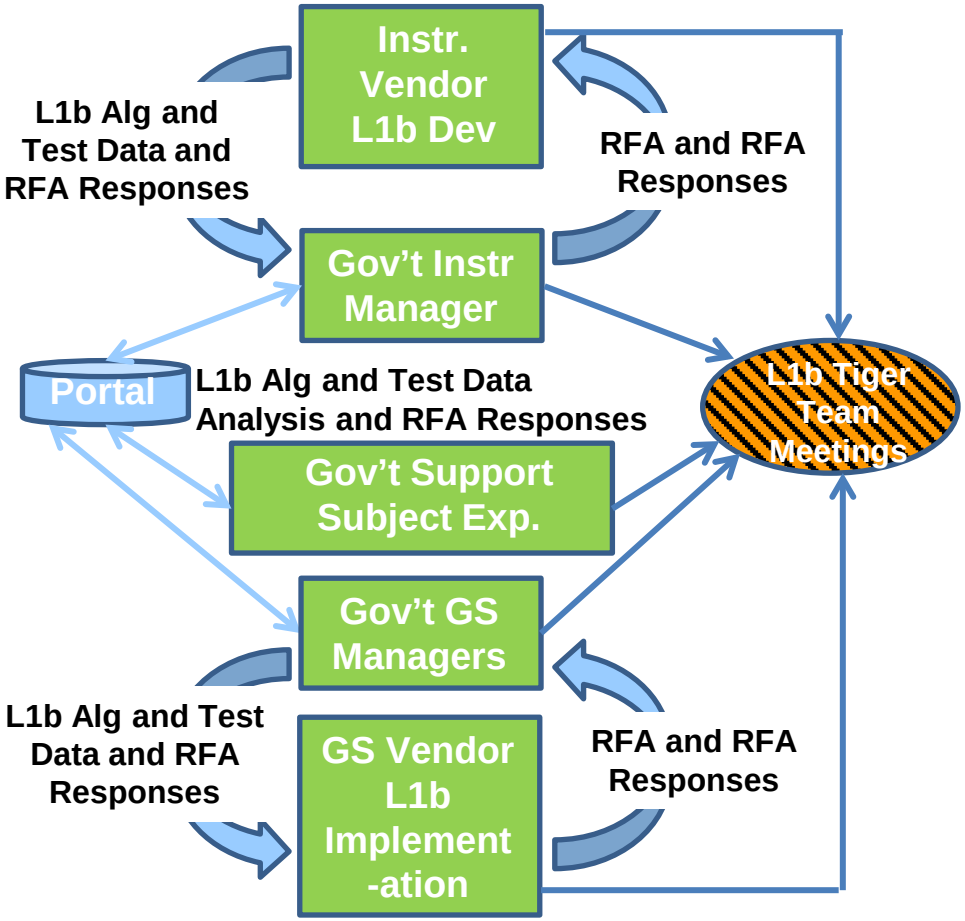
MAG

- No current testing.
- Test will be performed using well characterized sources at vendor facilities.

Ground Segment Cal/Val Updates



L1b Dev and Implementation



L1b Tiger Team Mandate
Proactively identify and mitigate risks associated with implementing GFP L1b algorithms

Key activities

- Evaluate L1b algorithm completeness to support upcoming development phases
- Identify specific issues to be resolved by the L1b algorithm developer
- Use TIMs to obtain technical data from L1b algorithm developer
- Develop product metadata definition and processing
- Address algorithm OPSCON issues specific to Harris GS design
- Track algorithm interdependencies with other algorithms/sensors and with spacecraft

ABI Lunar Image Ground Processing Operational Concept Finalized

- *Mission Management* predicts, schedules and collects ABI Mode 3 Lunar ‘meso’ images
- *Product Generation* extracts the Lunar ‘meso’ data using scene pointing information in the science data, and then L1b Processing applies the ABI calibration to the data
- *Product Distribution* packs the Lunar data into Instrument Calibration Data files
- *Operational Support Organization* processes and trends the lunar data over mission

Instrument Calibration Data

- Instrument Calibration Data are needed to evaluate, monitor, and trend sensor performance, and to perform calibration anomaly resolution
- Instrument Calibration Data contains:
  - Raw sensor calibration data
  - Engineering data and sensor parameters
  - Derived sensor performance statistics
  - Intermediate calibration products
  - Final sensor calibration coefficients
- Before launch, careful checks are made by the GOES-R CWG to ensure that Instrument Calibration Data meet post-launch ‘fitness-for-purpose”

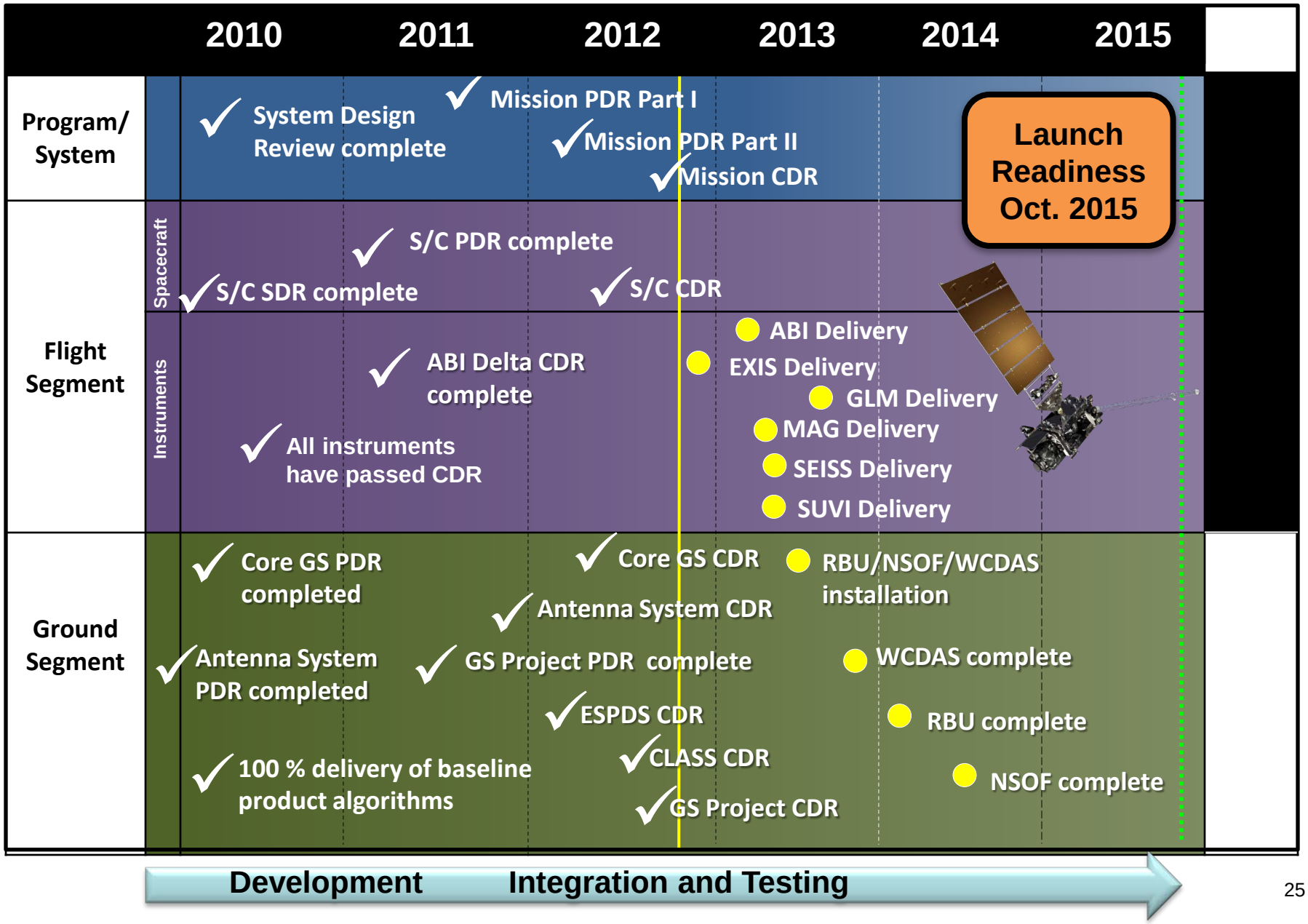
Validation Field Campaigns

Current Recommendations have been made by the Science Community to fly:

- **GLM Airborne Simulator**
  - Build an airborne detection system that will make high resolution optical measurements as a GLM simulator.
  - Deploy on aircraft (e.g., ER2) to observe cloud-top lightning pulses.
- **MODIS Airborne Simulator (MAS)**
  - An airborne scanning spectrometer that acquires high spatial resolution imagery of cloud and surface features from its vantage point on-board a NASA ER-2 high-altitude research aircraft.
  - Similar channels as GOES-R ABI

It is also recommended that GOES-R leverage upon JPSS underflights for the purpose of instrument post-launch validation.

GOES-R Pre-Launch Milestones

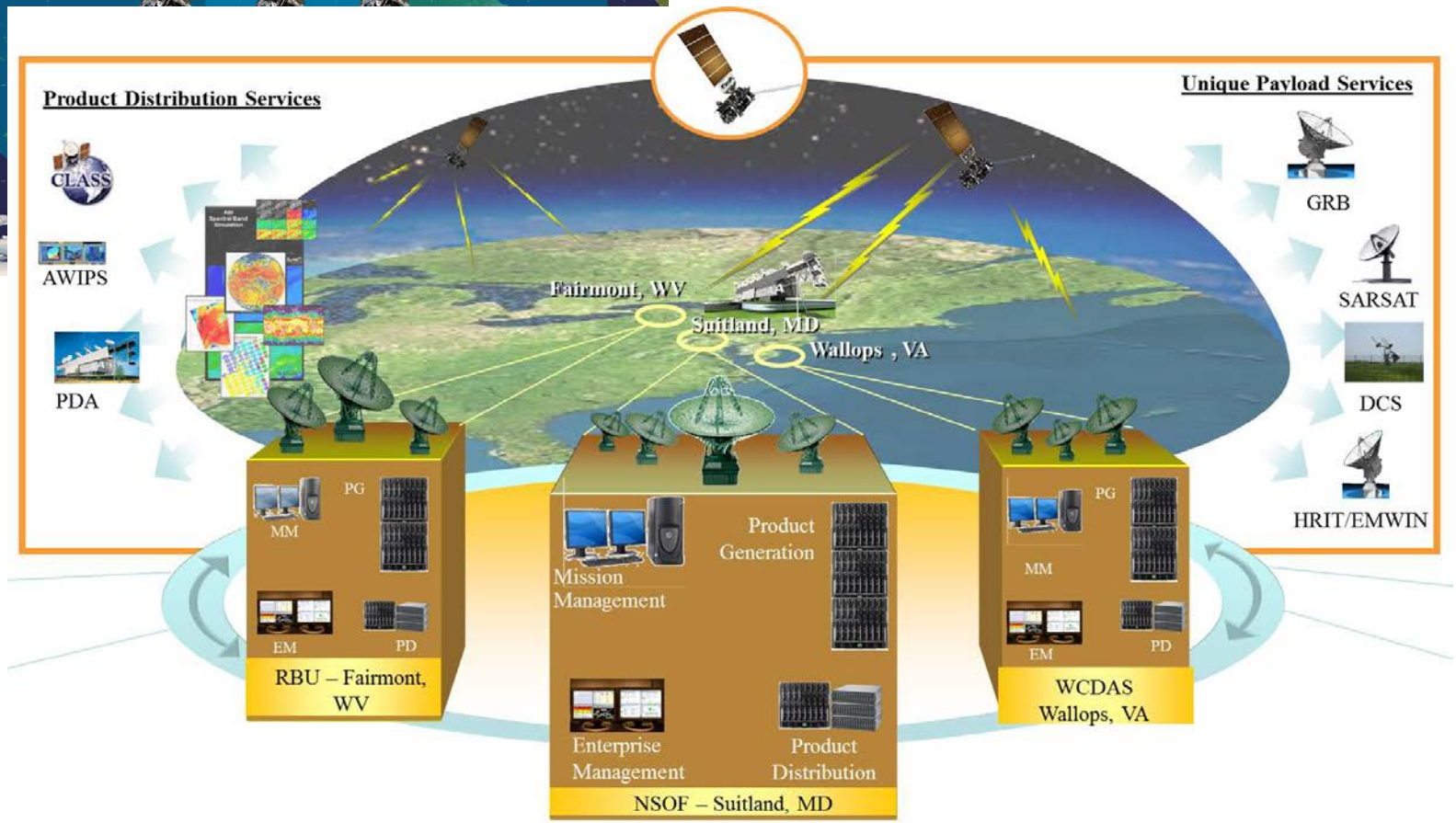


Summary

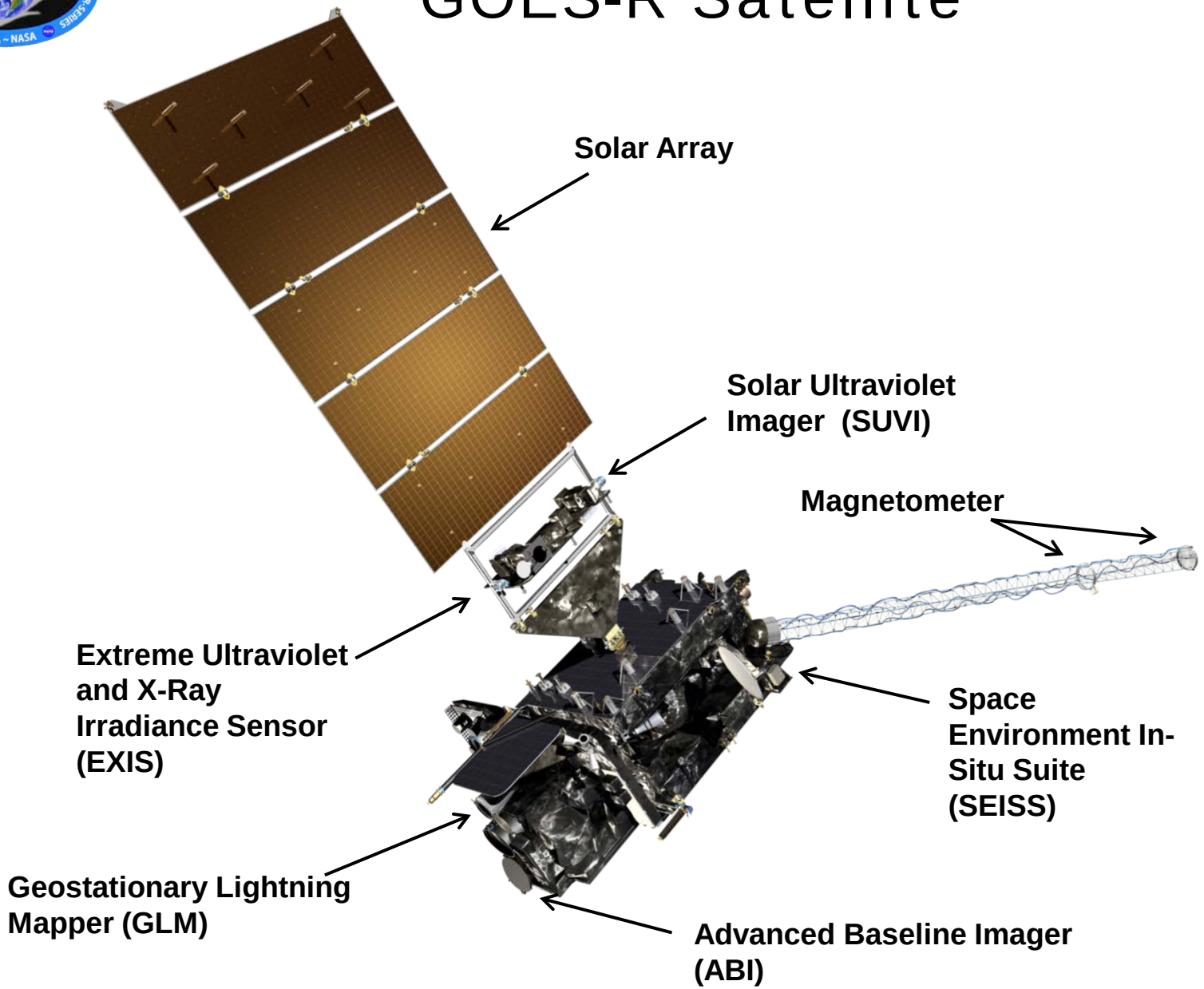
- GOES-R is post-CDR, and all instruments and the ground segment are in the process of fabrication, assembly, integration, and test
- GOES-R leveraging diverse complementary technical capabilities and resources for cal/val
- There is a life cycle cal/val plan to support a successful GOES-R program

Backup Slides

GOES Fleet and GOES-R Architecture



GOES-R Satellite

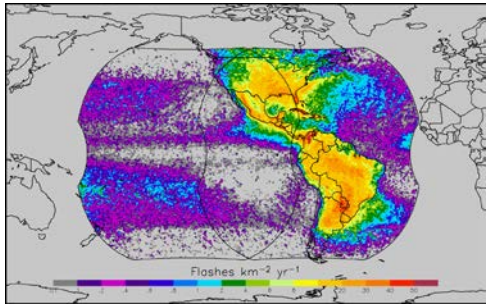


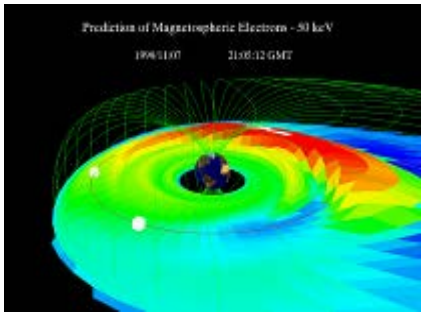
Instrument Overview

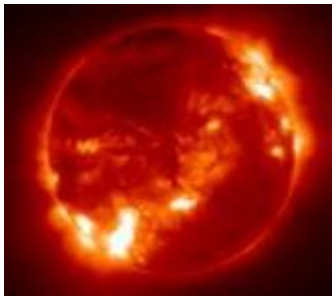
GOES-R supports NOAA mission to provide forecasts and warnings for the United States, its territories, and adjacent waters for the protection of life and property and the enhancement of the national economy.

GOES-R is the next generation of GOES satellites that will provide a major improvement in quality, quantity, and timeliness of data collected.

Earth Pointing		In-Situ	Sun Pointing
ITT EXELIS	LOCKHEED MARTIN	Assurance Technology Corporation	LOCKHEED MARTIN LASP
Visual & IR Imagery	Lightning Mapping	Space Weather Monitoring	Solar Imaging







- *Advanced Baseline Imager (ABI)*

- *Geostationary Lightning Mapper (GLM)*

- *Space Environment in-Situ Sensor Suite (SEISS)*
- *Magnetometer*

- *Solar Ultra-Violet Imager (SUVI)*
- *Extreme UV/X-Ray Irradiance Sensors (EXIS)*

New and improved capabilities for:

- increased lead times for severe weather warnings
- better storm tracking capabilities
- solar, space weather, and climate analyses
- advanced products for aviation, transportation, commerce

GOES-R Data and Product Overview

GOES-R Products

L1b →

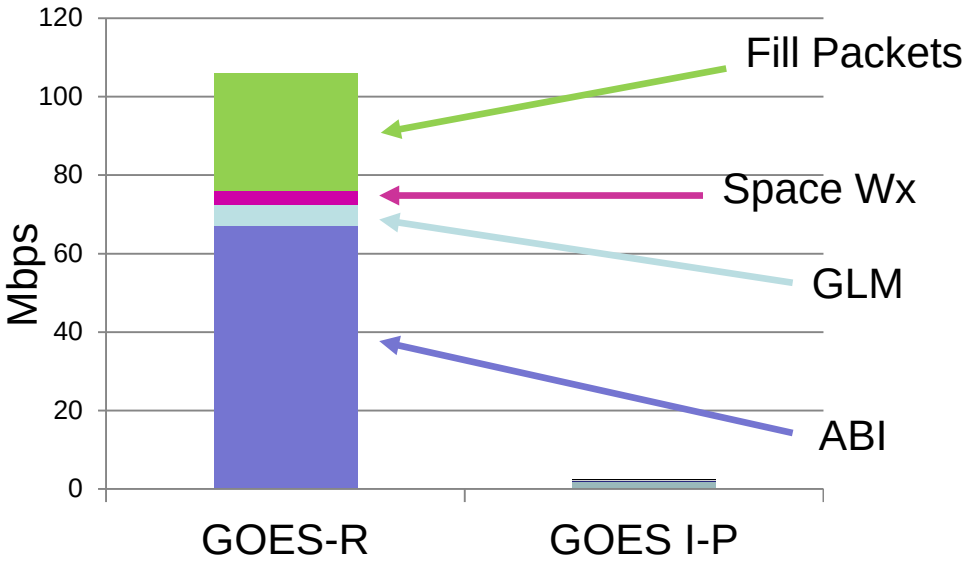
Radiances*	Cloud and Moisture Imagery (KPP)
Solar Imagery: X-ray*	Rainfall Rate / QPE
Energetic Heavy Ions*	Legacy Vertical Moisture Profile
Magnetospheric Electrons and Protons: Low Energy*	Legacy Vertical Temperature Profile
Magnetospheric Electrons and Protons: Medium and High Energy*	Derived Stability Indices
Solar and Galactic Protons*	Total Precipitable Water
Geomagnetic Field*	Clear Sky Masks
Solar Flux: EUV*	Downward Shortwave Rad.: Surface
Solar Flux: X-Ray*	Fire / Hot Spot Characterization
Lightning Det: Events, Groups, Flashes*	Land Surface (Skin) Temperature
Aerosol Detection (Including Smoke & Dust)	Sea Surface Temperature (skin)
Aerosol Optical Depth	Reflected Shortwave Rad.: TOA
Volcanic Ash: Detection & Height	Snow Cover
Cloud Optical Depth	Derived Motion Winds
Cloud Particle Size Distribution	Hurricane Intensity
Cloud Top Phase	Cloud Top Pressure
Cloud Top Height	Cloud Top Temperature

ABI	GLM
SEISS	EXIS
SUVI	Magnetometer

* Included in GRB

L2+ Products are remainder outside of oval

GOES-R Raw Data Throughput



ABI provides 3x spectral, 4x coverage, and 5x temporal resolution of current imager

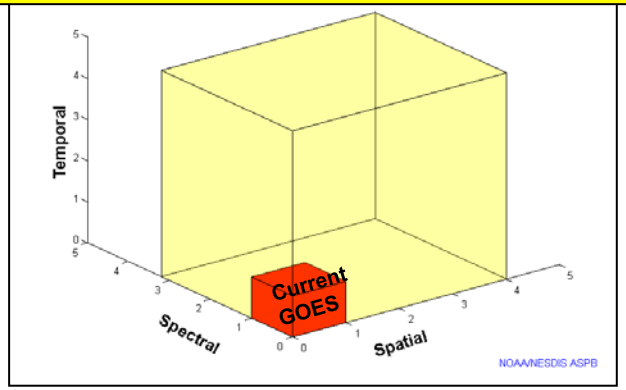
GOES-R product requirements drive instrument performance requirements, which often are the same as, or more strict than, heritage GOES.

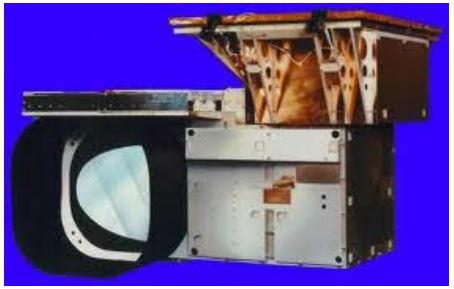
ABI Comparison to Current GOES Imager

	ABI	Current
Spectral Coverage	16 bands	5 bands
Spatial resolution		
0.64 μm Visible	0.5 km	1 km
Other Visible/near-IR	1.0 km	n/a
Bands (>2 μm)	2 km	4 km
Spatial coverage		
Full disk	4 per hour	every 3 hr
CONUS	12 per hour	~4 per hour
Mesoscale	30 sec (typical)	n/a

ABI provides 3x spectral, 4x coverage, and 5x temporal resolution of current imager

GOES-R ABI





GOES Imager

Importance of Calibration & Validation (Cal/Val)

Calibration: *The process to determine factors for converting and correcting raw detector measurements into science data units (e.g., radiance) with the specified level of accuracy.*

Calibration is applied to GOES-R raw instrument data to transform them into L1b measurements … the fundamental building blocks for all L2+ products.

Validation: *The process of determining that the deliverable item satisfies its intended use in its intended environment.*

Validation provides user confidence that GOES-R data can be used for their intended purpose, .e.g weather forecasting or numerical weather prediction.

GOES-R Program Calibration and Product Validation Strategy

Effective Date: 06-19-2009
Expiration Date: 06-19-2014
Responsible Organization: GOES-R/417

P417-R-CALVAL-0192
Version: 1.0

Geostationary Operational Environmental Satellite (GOES)

Calibration and Product Validation Strategy

June 19, 2009

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)

***Describes*:**

- Scope of effort
- Organizational elements and working groups
- Activities, and roles and responsibilities, for each mission phase
- Resources
- Schedules

GOES-R Program Cal/Val Plans

Effective Date: date of last signature
Expiration Date: five years from Effective date
Responsible Organization: GOES R Program/Code 410

410-R-PLN-0101
Version 2.0

GOES-R Series Calibration/Validation Plan
Volume 1: Level 1b Data

July 2012

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
NOAA Environmental Satellite, Data, and Information Service (NESDIS)
National Aeronautics and Space Administration (NASA)

THIS DOCUMENT IS SUBJECT TO ITAR CONTROL, AND MAY CONTAIN INFORMATION PROPRIETARY TO GOES-R VENDORS.
Check the VSDE at https://goesv3.ndc.nasa.gov to verify correct version prior to use

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GOES-R Series Calibration/Validation Plan Volume 2: Level 2+ Product Validation

May 2012

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
NOAA Environmental Satellite, Data, and Information Service (NESDIS)
National Aeronautics and Space Administration (NASA)

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Describe cal/val methods and processes as a function of mission phase

GOES-R Cal/Val Collaborators

Collaborator	Main Responsibilities	Cal	L1b Prod Val	L2+ Prod Val
Flight Project	Oversee SC/Instr. Design, Fabr., Integ., and Test	✓	✓	
SC/Instr Vendors	SC/Instr. Design, Fabr., Integ., and Test	✓	✓	
Ground Segment (GS) Project	Oversee GS Design, Fabr., Integ., and Test	✓	✓	✓
GS Vendor	GS Design, Fabr., Integ., and Test	✓	✓	✓
Mission Ops Support Team	Gov't SC/Instr/GS Test	✓	✓	✓
Data Ops Support Team	Gov't GS Test	✓	✓	✓
Cal Coordination Team (CCT)	PSE Coordination Support to GOES-R Instr. Cal & L1b Val	✓	✓	
Cal Working Group (CWG)	PSE Technical Support to GOES-R Instr. Cal & L1b Val	✓	✓	
Algorithm Working Group (AWG)	L2+ Product Dev and V&V			✓
NESDIS Office of Satellite and Product Operations (OSPO)	Ops Support to Cal/Val	✓	✓	✓

GOES-R Cal/Val Resources

Resource	Pre-Launch	Post-Launch Testing	Mission Operations
Data and Tools			
Cal/Val, L0, L1b Data Archive/Storage	✓	✓	✓
Models/Analysis Tools	✓	✓	✓
GOES-R Portal and Web Sites	✓	✓	✓
Facilities and Equipment			
Vendor Offices, Manufacturing Centers, Test Labs/Equipment	✓	✓	
NIST Test Labs/Equipment	✓		
NASA Offices & Test Labs/Equipment	✓	✓	
NOAA Offices	✓	✓	✓
Independent Test Facilities	✓		
Field Campaign Assets	✓	✓	✓

Instrument Calibration: ABI

Radiometric Characterization & Calibration	Spectral Response	Image Navigation & Registration	Spatial Resolution & Response
• System linearity and dynamic range • Signal-to-Noise, NEDN, and Coherent Noise • Pixel-to-pixel, swath-to-swath, channel-to-channel-, image-to-image, and blackbody calibration-to-calibration repeatability • Irradiance to radiance transfer (VNIR) • External/Internal calibration target comparison (TIR) • Polarization (VNIR) • Channel-to-channel and within channel optical cross talk • Electronic cross talk • In-flight electronic calibration • Blooming • Quantization step size • Hot, marginal and dead pixels	• Spectral response envelope • Spectral response uniformity over the focal plane detector array • Out-of-band response • Evaluation of spectral response function uncertainty • Inference of possible spectral shifts • Consistency between system-level and integrated component-level spectral response functions	• Navigation (including star sensing) • Frame-to-frame, within frame, swath-to-swath, and channel-to-channel registration	• System modulation transfer function • Spatial response uniformity (e.g., response vs. scan angle) • Ringing from a sharp edge • Near field scatter • Far field scatter • Ghosting • Pointing knowledge

On-Orbit Instrument Calibration

Instrument	On-Board Cal Devices	Vicarious Targets	Inter-Calibration with Other Satellite Assets
Advanced Baseline Imager (ABI)	***IR Cal (NEDT[@300K]: 0.1K all but 13.3 μm, 0.3K for 13.3 μm)*** – Blackbody; ***VNIR Cal (5%)*** - Solar Diffuser; ***Self-Emission*** - Space View; ***Electronics Linearity*** - Electronic Stimulus	***VNIR Cal*** - Moon, Stars, Deserts, Test Sites, Deep Convective Clouds (DCCs), Rayliegh Scattering, etc; ***MTF, B2B Reg*** - Moon	***VNIR/IR Cal*** - GEO and LEO Imagers; ***Spectral Cal*** – Hyperspectral Imagers
Geostationary Lightning Mapper (GLM)	*None*	***Response Cal*** - DCCs, Deserts, Sun-glint	***Response Cal*** - GEO and LEO Imagers
Extreme Ultraviolet and X-Ray Irradiance Sensor (EXIS)	***Response Linearity*** - Light Sources; ***Dark Measurements and Flatfields*** - Off-point Mechanism; ***Electronics Linearity*** - Electronic Stimulus	***Response Flatfield*** - Sun	***Response Cal*** – GEO Solar Sensors (e.g., SDO/EVE)
Solar Ultraviolet Imager (SUVI)	***Aliveness*** - Light Source; ***Dark Measurements and Flatfields*** - Off-point Mechanism; ***Out-of-band Rejection*** - Glass/Analysis Filters; ***Electronics Linearity*** - Electronic Stimulus	***Response Flatfield*** - Sun	***Response Cal*** - EXIS and other GEO Solar Sensors (e.g., SDO/EVE)
Space Environment In-Situ Suite (SEISS)	***Electronics Linearity*** - Electronic Stimulus	*None*	***Response Cal*** – GEO Particle Sensors
Magnetometer (MAG)	***Electronics Linearity*** - Electronic Stimulus	*None*	***Response Cal*** - GEO Mag Sensors