National Aeronautics and Space Administration

Radiation Budget Instrument Status

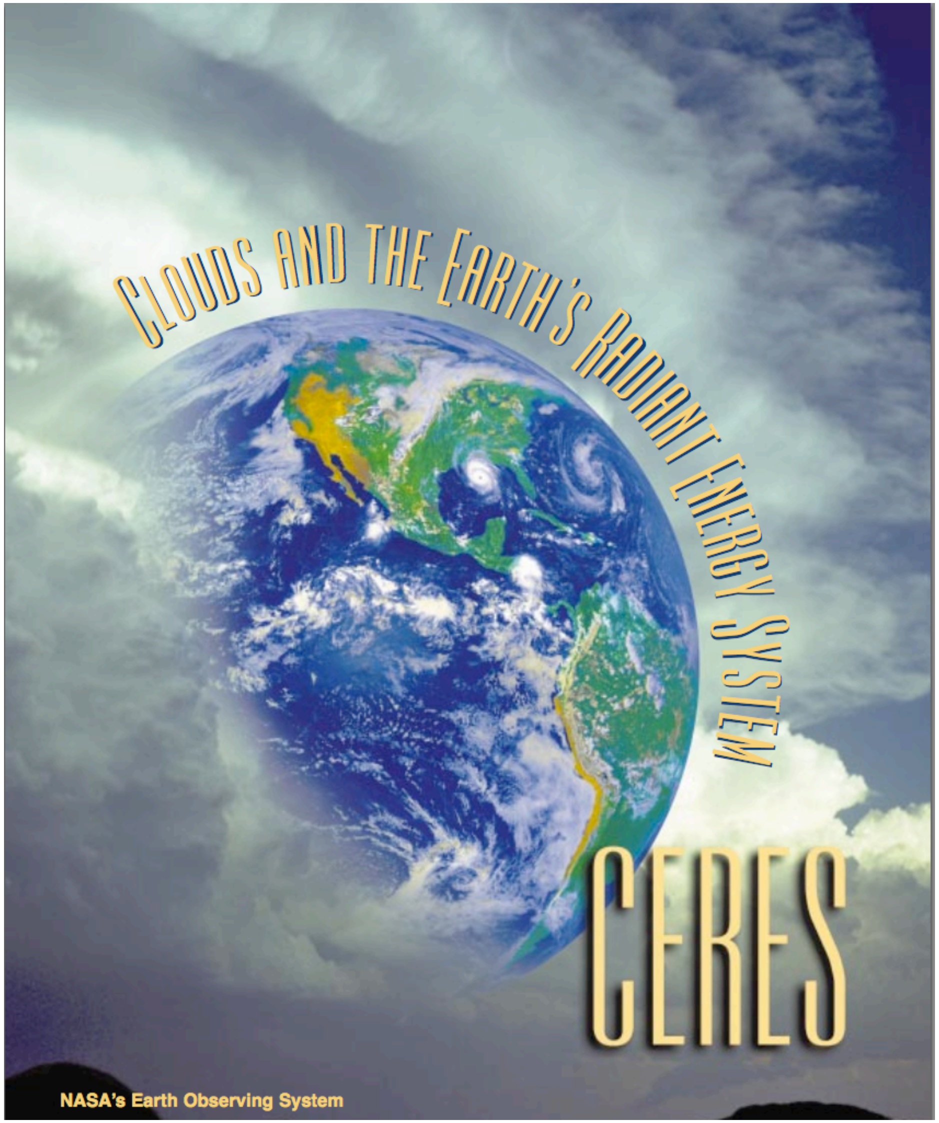
Radiation Budget Instrument

Anum Barki, *Deputy PS – Modeling*

Kory Priestley, *Project Scientist*
Mohan Shankar, *Deputy PS - Calibration*

www.nasa.gov

Discussion Topics

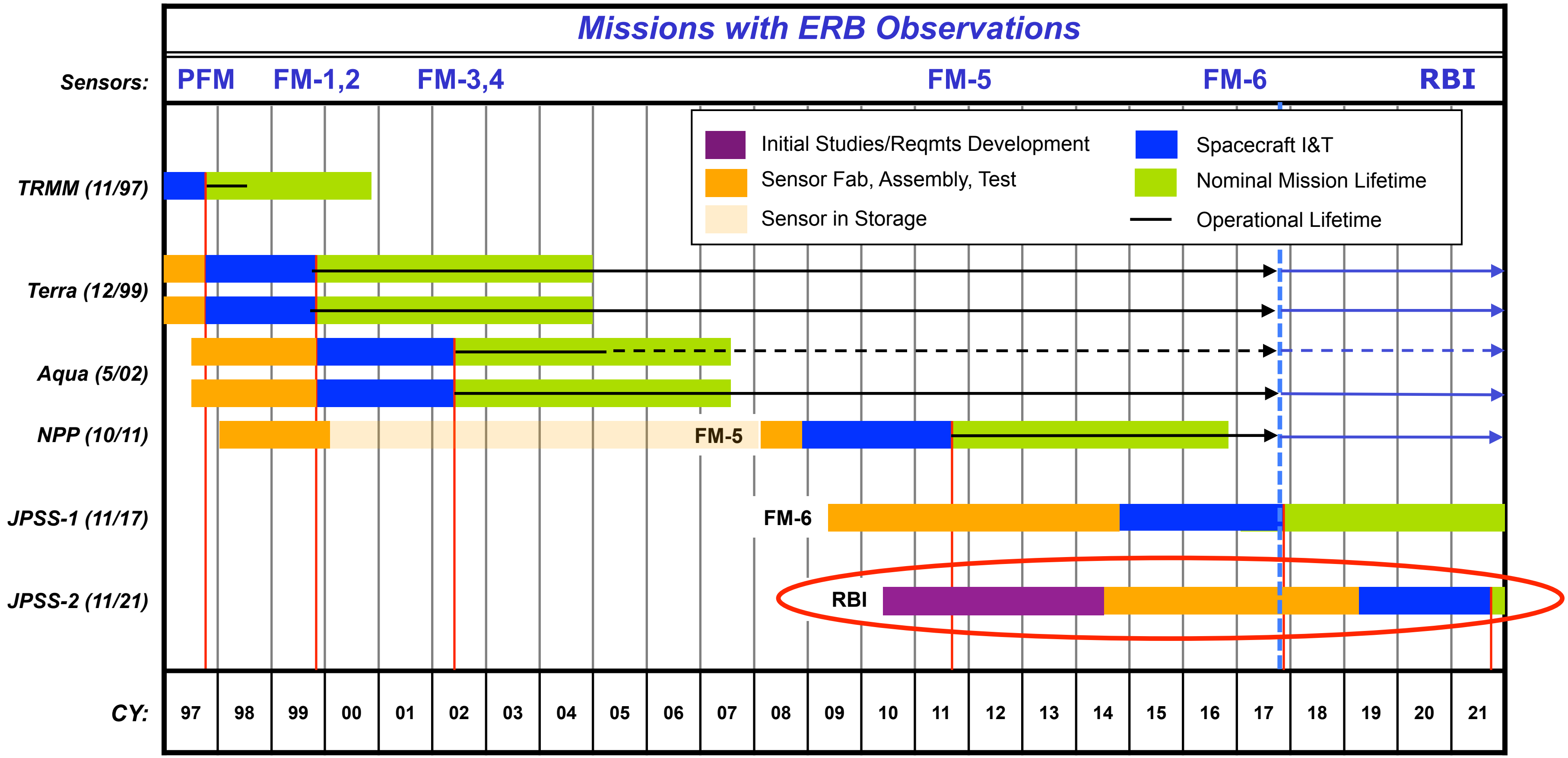


- **RBI Goals, Objectives, Mission Success**
- **Key requirements for RBI Mission**
- **RBI Overview and Scope**
- **Instrument Architecture**
- **EDU Bench Test Results**
- **Predicted Performance**
- **RBI Summary**

ERB Climate Data Record Continuity

Clouds and the Earth's Radiant Energy System

Missions for which LaRC is responsible for ERB Mission Operations and Data Analysis (MO&DA)



We now have over 65 years of flight experience with the CERES instruments

RBI Goals, Objectives, and Success

- **Project Goal**
  - Provide an instrument that enables continuity of Earth Radiation Budget (ERB) observational record.
- **Science Objectives**
  - Collect the observations necessary to seamlessly continue the ERB Climate Data Record (CDR) by:
    - Measuring the temporal and spatial distribution of outgoing thermal and reflected solar radiation from the Earth, allowing investigation of the Earth's radiation budget when combined with measurements of solar irradiance
    - Tying the RBI observations to those of CERES through intercalibration while aiding in the development of a quantitative understanding of the links between the radiation budget and the properties of the atmosphere and surface that define it, and improve models of Earth's climate system
- **Mission Success**
  - RBI provides measurements of the reflected solar and emitted radiances from the top of the Earth's atmosphere that continue for at least six (6) years post launch, with accuracy, precision, extent, and frequency sufficient to continue this radiation budget climate data record with similar accuracy and precision

RBI is a Data Continuity Mission

Key Performance Requirements

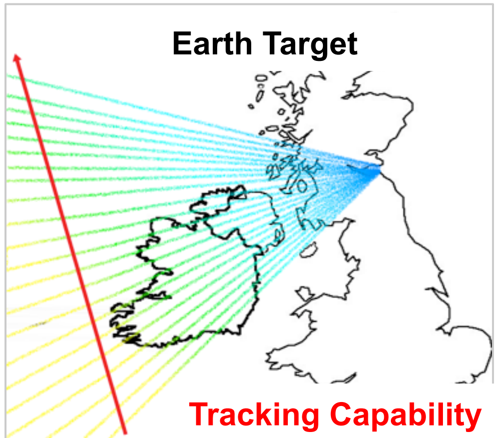
Clouds and the Earth's Radiant Energy System

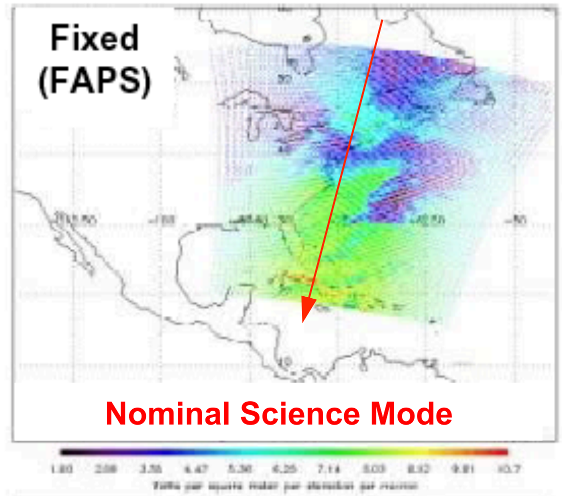
Key Performance Requirements	Baseline Values	Threshold Values
Total Spectral Range	0.3 to 100+ microns	0.3 to 50+ microns
Shortwave Spectral Range	0.3 to 5 microns	0.3 to 5 microns
Longwave Spectral Range	5 to 50+ microns	5 to 35+ microns
Total Channel Absolute Radiometric Accuracy	≤ Larger of 0.575 W/m^2-sr or 0.5% (k = 1)	≤ Larger of 0.575 W/m^2-sr or 0.75% (k = 1)
Shortwave Channel Absolute Radiometric Accuracy	≤ Larger of 0.75 W/m^2-sr or 1.0% (k = 1)	≤ Larger of 0.75 W/m^2-sr or 1.25% (k = 1)
Longwave Channel Absolute Radiometric Accuracy	≤ Larger of 0.575 W/m^2-sr or 0.5% (k = 1)	≤ Larger of 0.575 W/m^2-sr or 0.75% (k = 1)
Total Channel Radiometric Precision	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	≤ 0.2 W/m^2-sr + 0.1% (k = 2)
Shortwave Channel Radiometric Precision	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	≤ 0.2 W/m^2-sr + 0.1% (k = 2)
Longwave Channel Radiometric Precision	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	≤ 0.2 W/m^2-sr + 0.1% (k = 2)
Total Channel Linearity	≤ 1.5 W/m^2-sr	≤ 2.5 W/m^2-sr
Shortwave Channel Linearity	≤ 1.28 W/m^2-sr	≤ 2.13 W/m^2-sr
Longwave Channel Linearity	≤ 0.54 W/m^2-sr	≤ 0.9 W/m^2-sr
Point Spread Function	Within 95% of CERES	Within 90% of CERES

RBI Baseline Science Requirements Match CERES

RBI Continues CERES Operational Scanning Capabilities

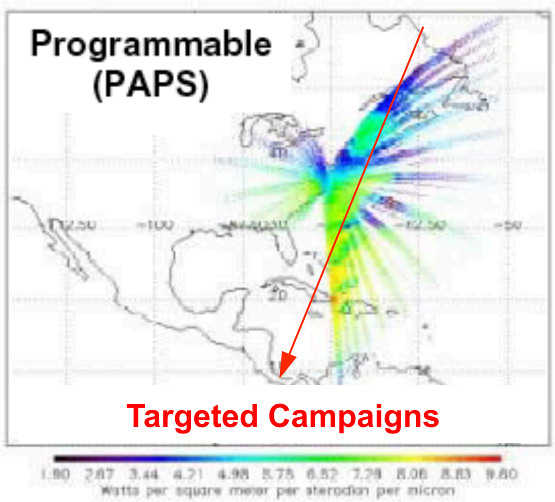
Enabling Inter-mission Continuity

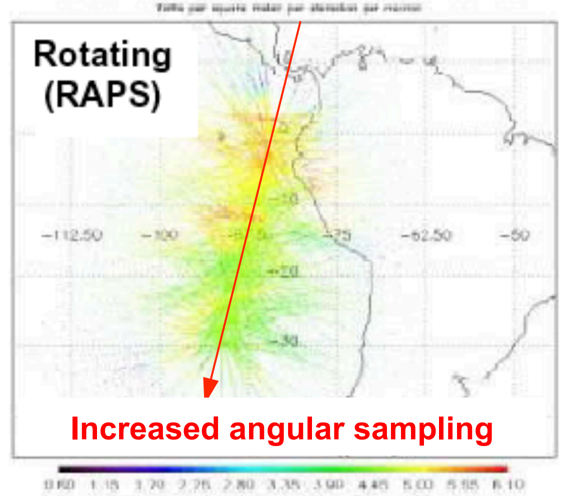




Fixed Azimuth Plane Scan

Programmable Azimuth Plane Scan

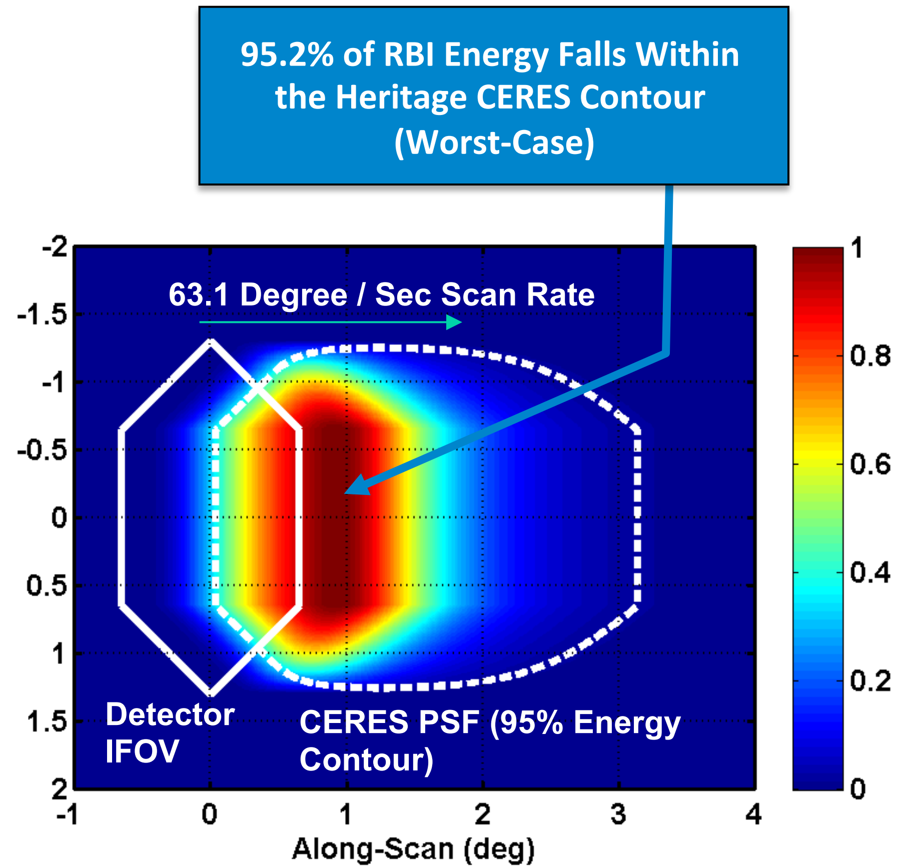




Rotating Azimuth Plane Scan

CERES-Like Point Spread Function Supports Data Continuity

- **Use of CERES-shaped detector and heritage scan rate provides best PSF match**
- **RBI PSF is required to be smaller than CERES, referenced to 95% energy contour**
  - i.e., over 95% of RBI energy must be within the CERES 95% energy contour
- **Close match to CERES PSF supports data continuity value**



RBI Overview and Scope

Partnerships and Teams

- **NASA/NOAA Partnership**

–NOAA accommodates RBI on the JPSS-2 satellite

–NASA provides RBI instrument and support through spacecraft I&T and launch/activation

- **NASA Langley**

–Manages prime contractor development of RBI instrument, provides management, technical, and mission assurance insight and oversight; provides support to spacecraft I&T thru launch and early on-orbit checkout (thru Phase D); develops L0-L1 science algorithms

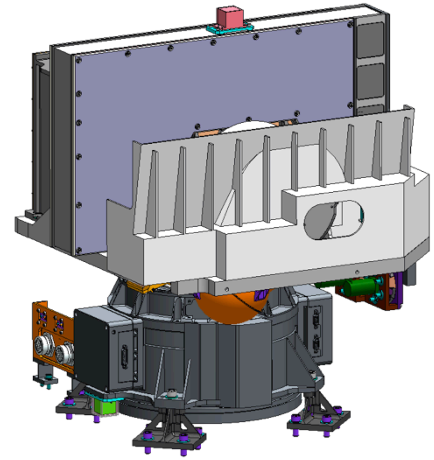
–Hand-over and release of RBI instrument ownership by RBI Project occurs at the JPSS-2 Operational Hand-over Review (OHR)

- **Harris**

–RBI prime contractor with sub-contractors providing key elements and support (SDL for Calibration, JPL for Thermopile Detectors, Sierra Nevada for Azimuth Rotation Module)

RBI scanning radiometer measuring three spectral bands at top of Atmosphere (TOA)

- Total 0.3 to > 100+ μm
- Shortwave 0.3 to 5.0 μm
- Longwave 5.0 to 50+ μm



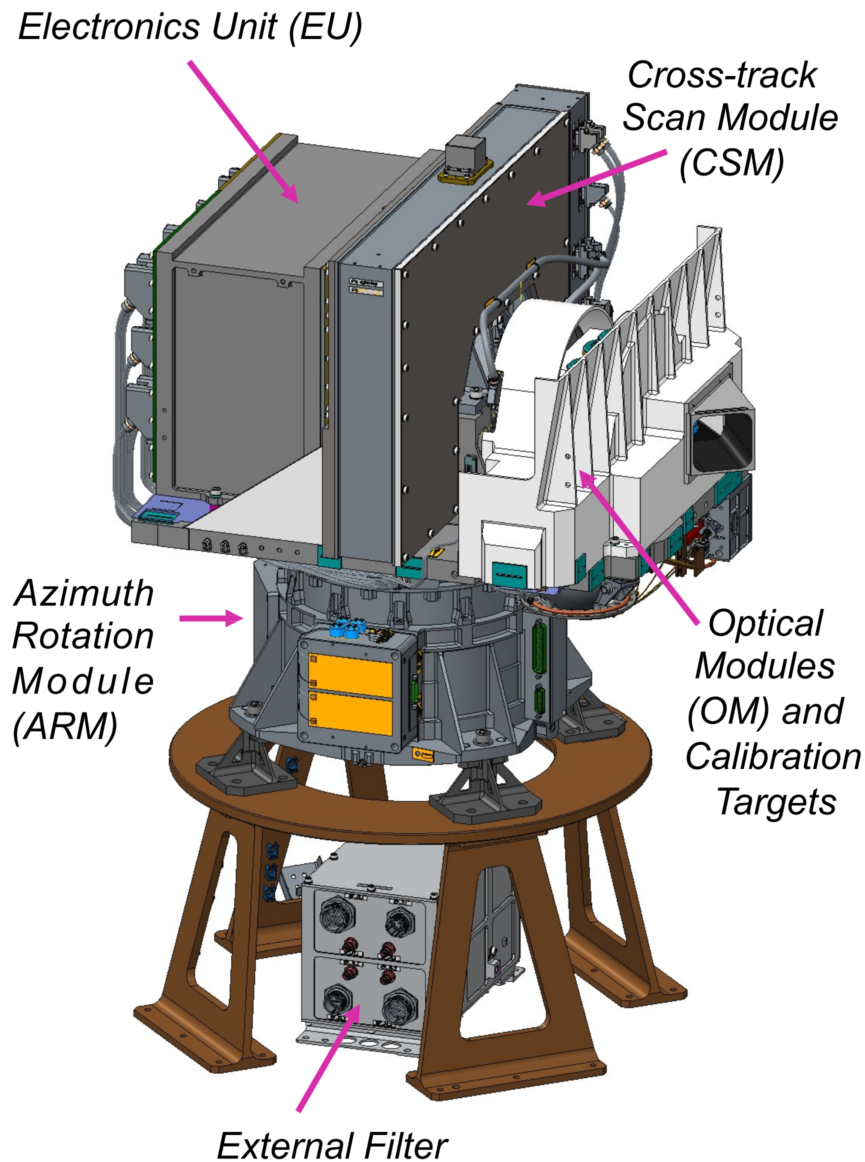
Science Goal

- Provide an instrument to support global climate monitoring by continuing the sequence of Earth Radiation Budget (ERB) measurements obtained by NASA and NOAA over the past thirty years

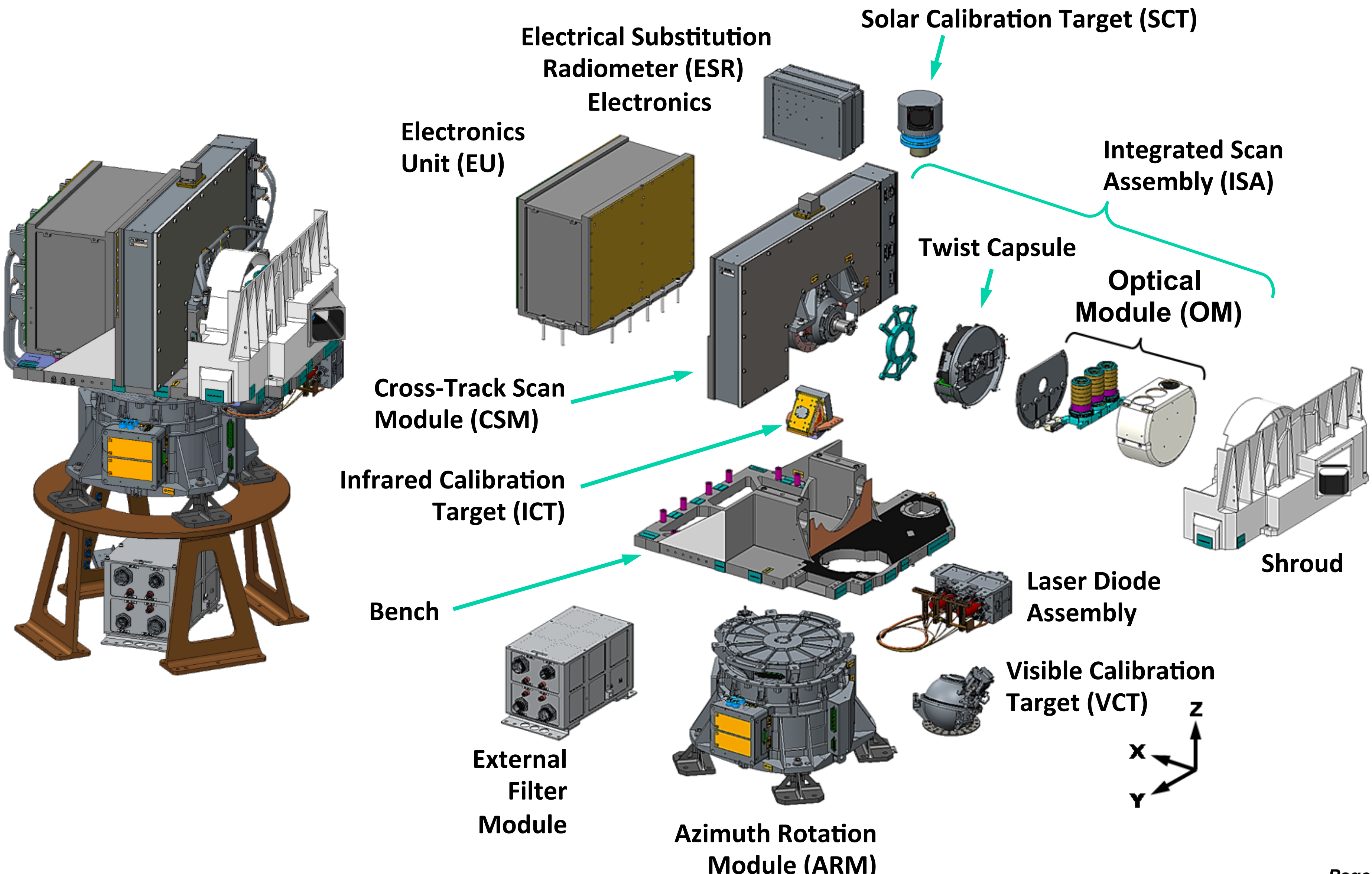
- **Phase:** Final Design and Fabrication (C)
- **Critical Design Review** : 9/26-28/2017
- **Flight Instrument Delivery:** Q3 FY19
- **JPSS-2 Launch:** Q4 FY21
- **Life:** 7 years

Radiation Budget Instrument

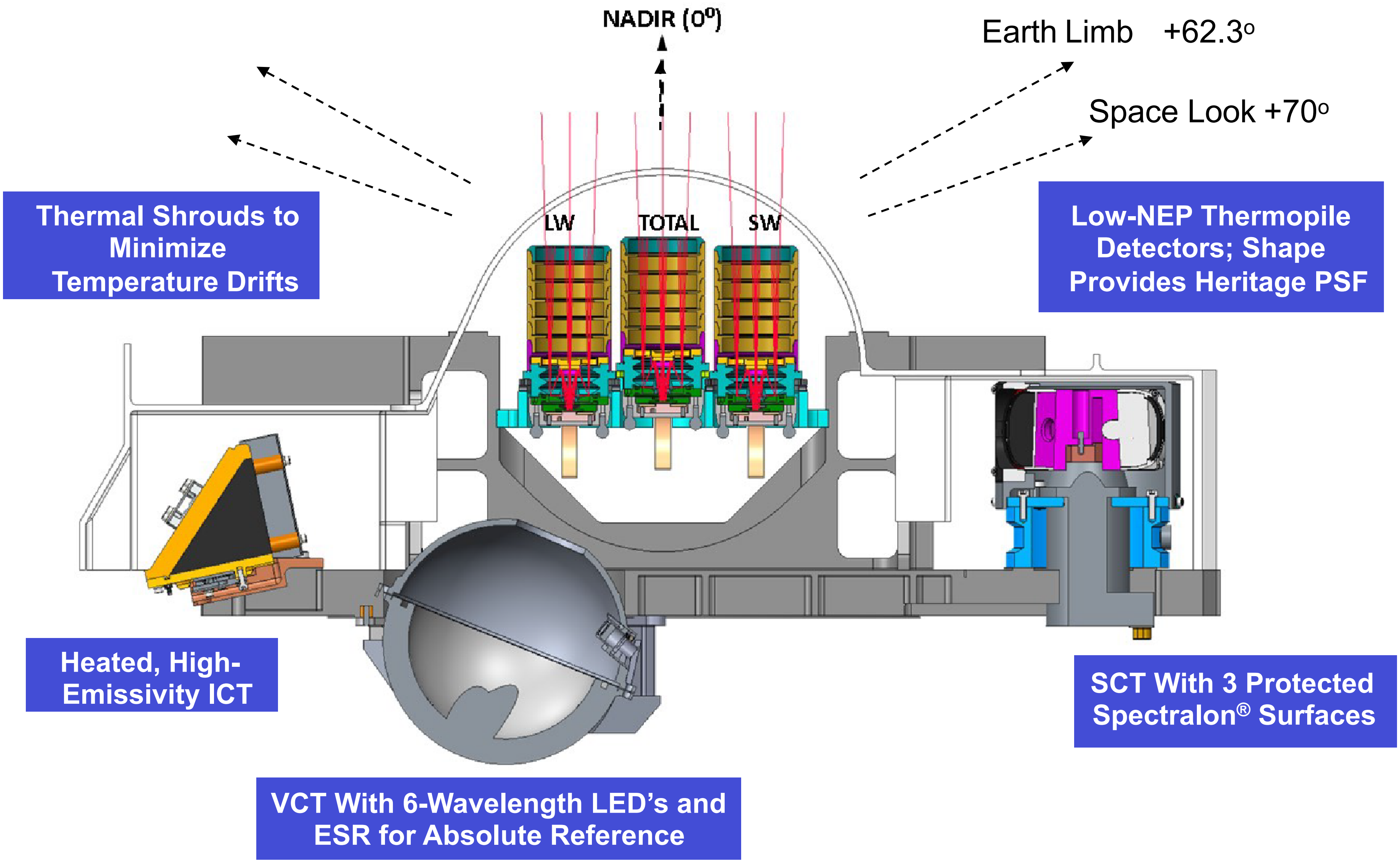
- **Collects upwelling earth radiance over a wide spectral range**
  - Ultraviolet to far-infrared (100um)
  - Continuous cross-track scans
- **Three spectral bands**
  - Shortwave: reflected solar energy
  - Longwave: emitted earth energy
  - Total: Sum of reflected and emitted
  - One telescope per band simplifies detectors and operations
- **Very precise calibration**
  - Extensive ground calibration program sets the calibration
  - Multiple onboard targets maintain calibration over mission life



RBI's Modular Architecture

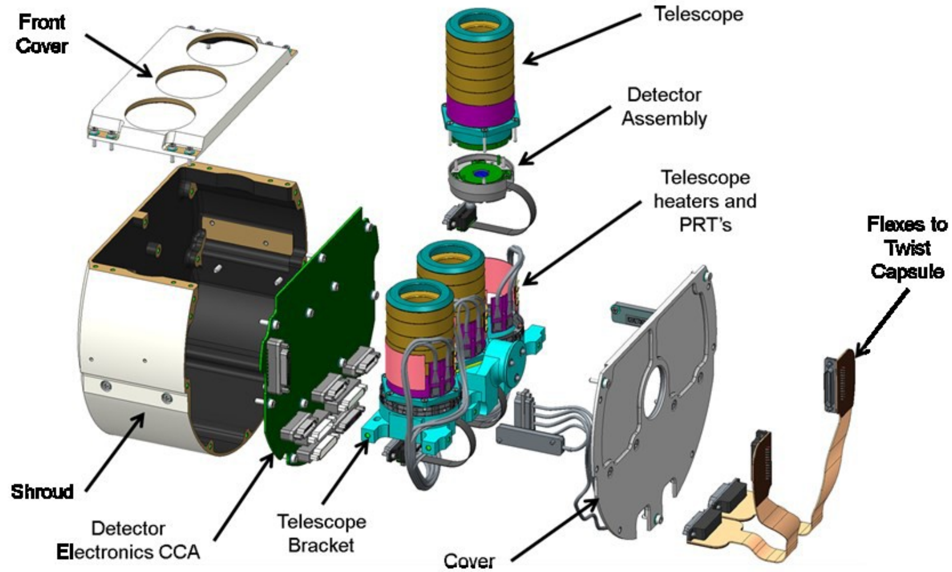


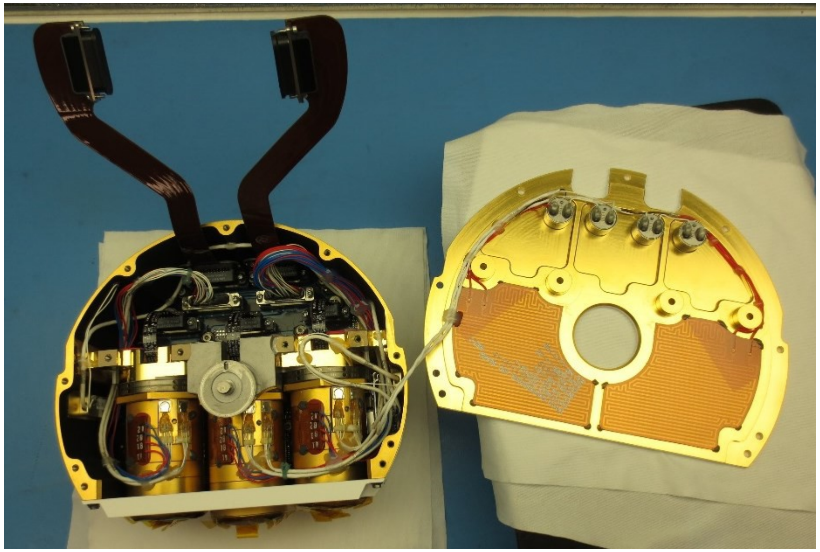
Optical Module and Targets Designed for Stability and Accuracy



Optical Module Overview

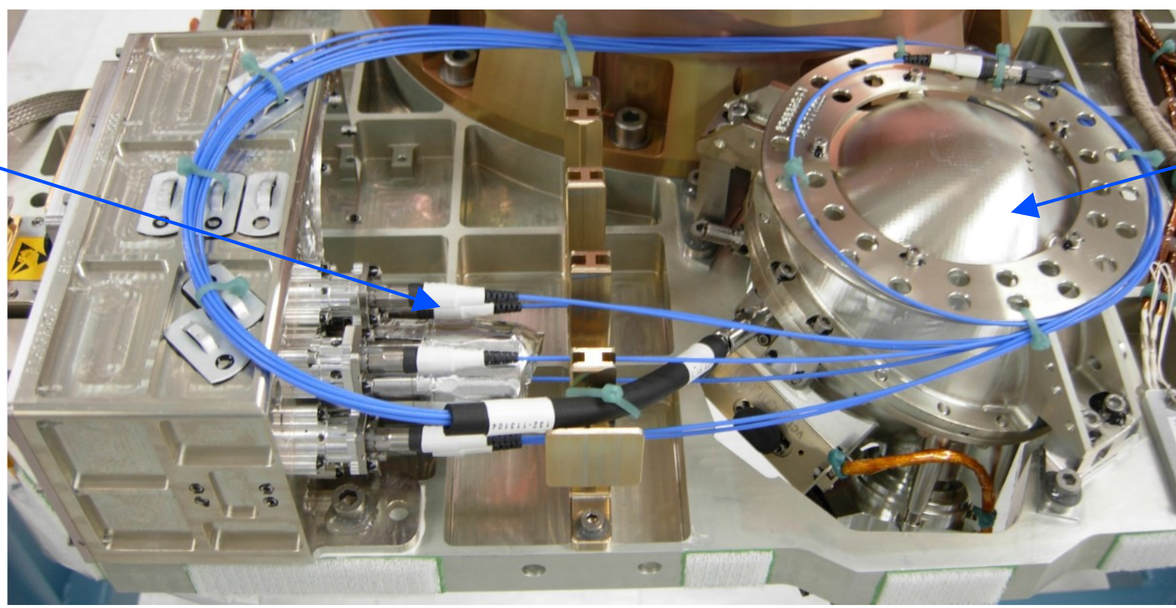
- **Focuses photons on the detector and converts to bits**
- **Minimizes stray light**
- **Provides low noise linear conversion of radiance to bits**
- **Athermalized design provides a stable uniform environment for low noise detectors**
- **Provides spectral selection into three bands**
- **Thermal control provides for long term stable environment**





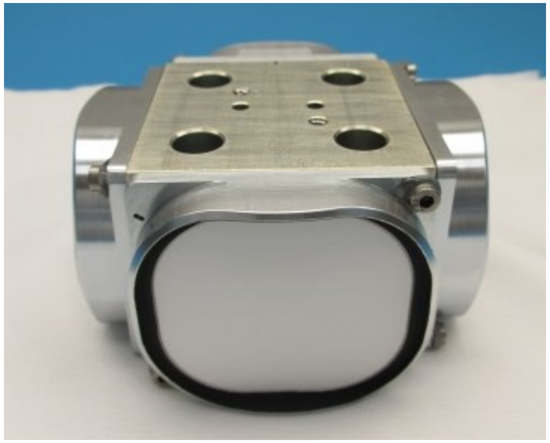
Visible Calibration Target (VCT)
Provides Radiance Standard for Reflected Solar Bands

- **Provides 6 narrow band Laser-diode sources: 375, 405, 445, 680, 915, 1470 nm for the TOT and SW channels**
- **Si and InGaAs photodiodes monitor sources and provide quick radiance reference**
- **Electrical Substitution Radiometer (ESR) provides stable, long term, absolute, NIST-traceable measurements**
    - Used monthly to calibrate monitoring photodiodes
- **Neutral density filters mounted in filter wheel enable flux level adjustment**
- **Thermal stability achieved by remotely locating and fiber coupling the laser diodes**



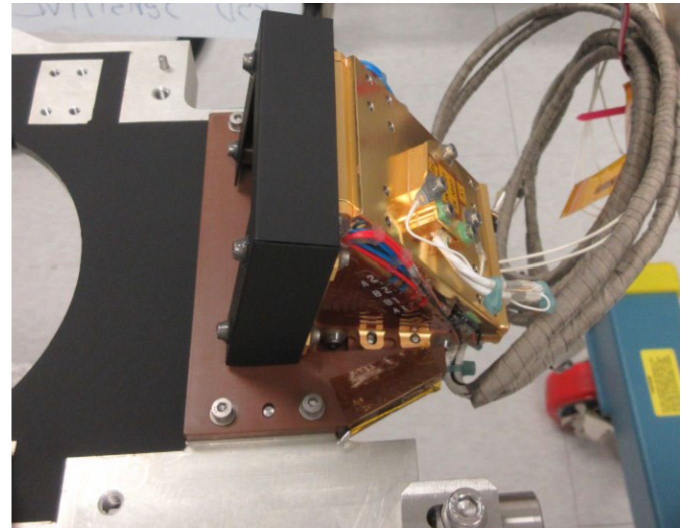
Solar Calibration Target (SCT) Provides Indirect Solar Illumination to RBI

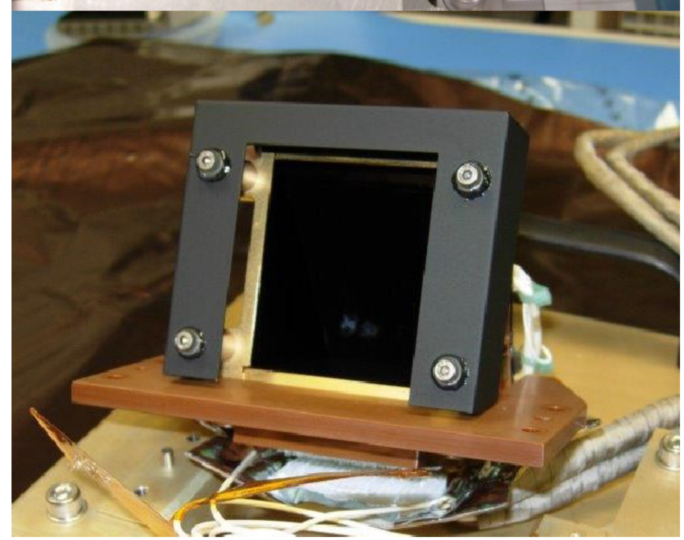
- **Provides a secondary calibration monitor for reflected solar bands (TOT & SW channels)**
- **Three Spectralon diffusers used with different frequencies to monitor reflectance degradation over mission life**
    - Bi-weekly, Quarterly, & Yearly
- **Shroud encapsulates and protects Spectralon surfaces from contamination**
- **Provides a full aperture source of diffusely reflected solar spectral irradiance**



Infrared Calibration Target (ICT) Provides Radiance Standard for Infrared Bands

- **Onboard infrared radiance standard for LW and Total channels**
- **Geometry and optical surface ensure a highly, stable emissivity that, when combined with known surface temperature, provides a stable, known radiance, resulting in low radiometric uncertainty**
- **Heaters provide an accurate, stable and controllable (23-42ºC) source for daily calibration and monthly linearity testing**
- **NIST traceable standards**
    - Platinum Resistance Thermometers (PRTs) calibrated to ITS-90 scale
    - ICT paint calibrated to gold reference standard





RBI Calibration Cadence Ensures Performance Compliance Over Mission Life

Daily: quantify short-term repeatability

- Total and SW channels view VCT (single LD, one illumination level)
- Total and LW channels view ICT (fixed point temperature)

Bi-weekly: quantify short-term repeatability

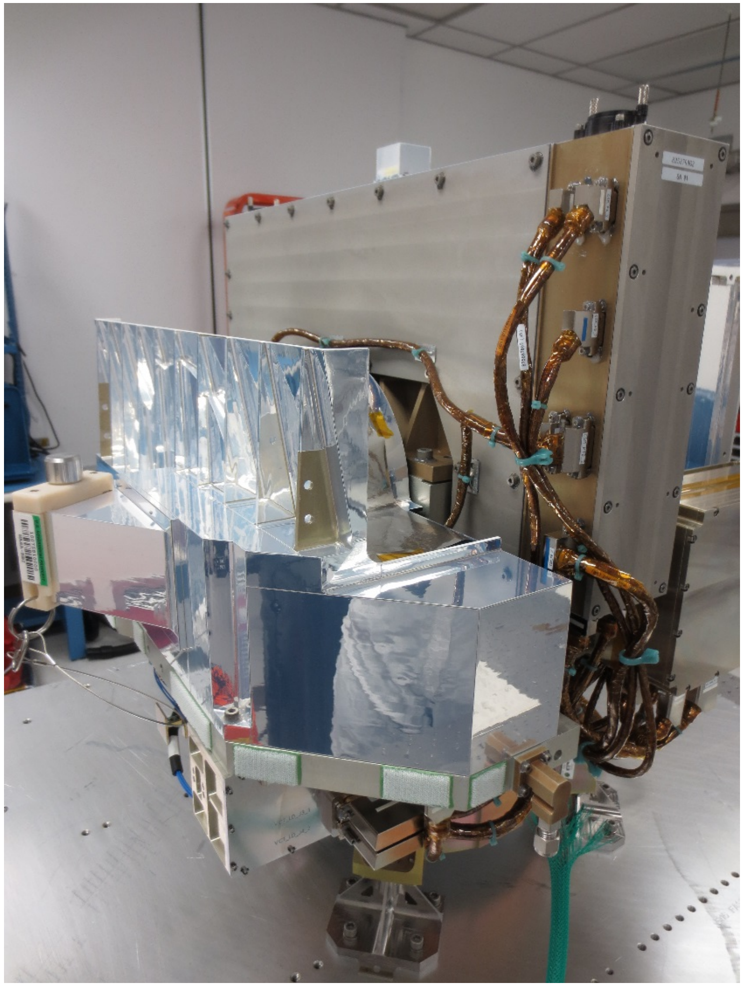
- Total and SW channels view SCT

Monthly: quantify long-term uncertainty

- Multiple illumination (ND filter) levels using one laser diode source are used to characterize linearity/gain for Total and SW
- Laser diodes at multiple wavelengths are used to characterize the spectral response of the Vis/NIR portion of the Total and SW
- ESR calibrates Photodiodes in VCT
- Multiple ICT temperature levels used to characterize linearity/gain for Total and LW

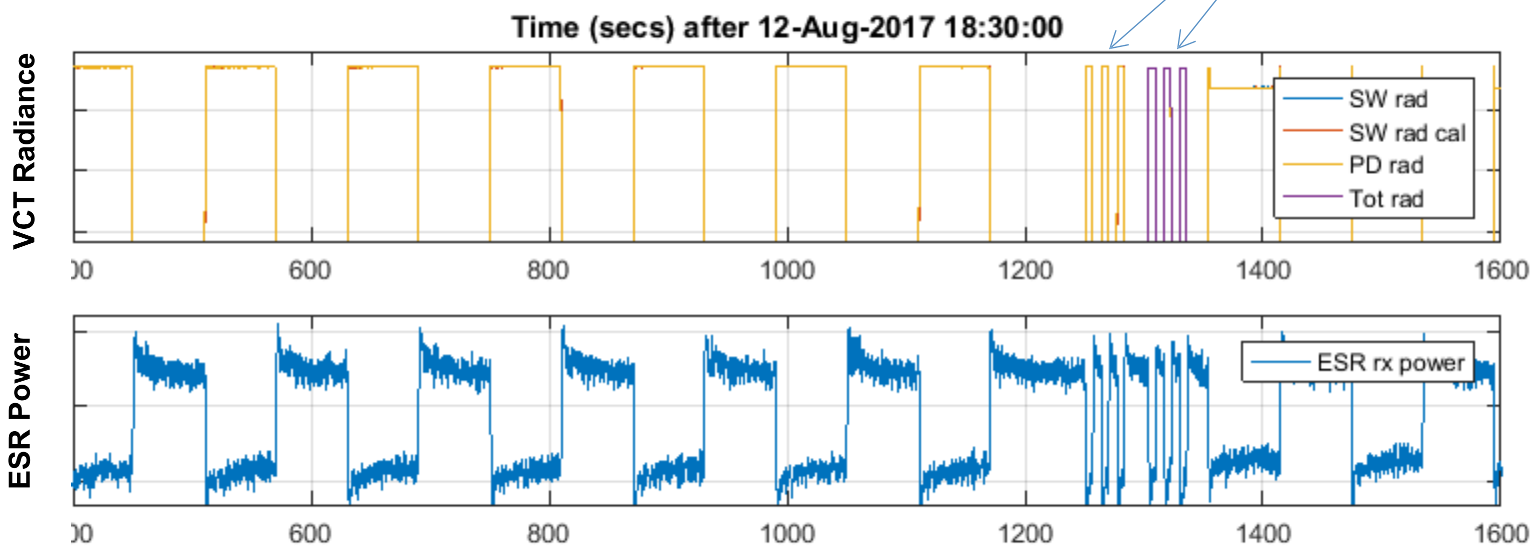
Engineering Development Unit Under Test at SDL

- **EDU is a pathfinder for:**
- **Calibration**
  - Radiometric design is virtually identical to RBI flight design
  - Manufacturing processes are validated
  - Performance requirements are demonstrated
  - Calibration approach is demonstrated
- **Test execution**
  - "Dry Run" of TVAC test program/GSE
- **Flight build and test**
  - Design team has incorporated all EDU lessons learned in the flight design
- **EDU TVAC testing is underway**



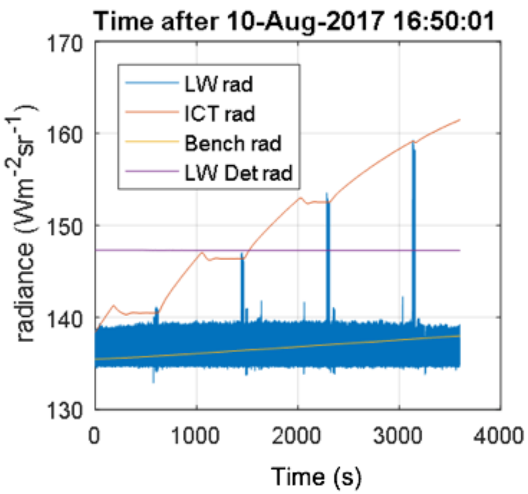
VCT Performance Is As Expected

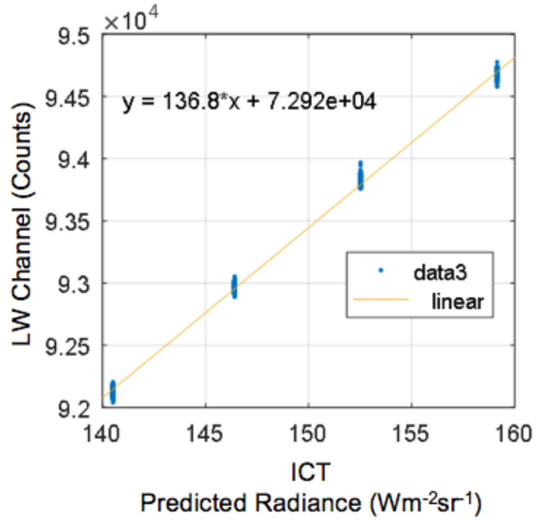
Photodiode radiance agrees very well with TOT and SW



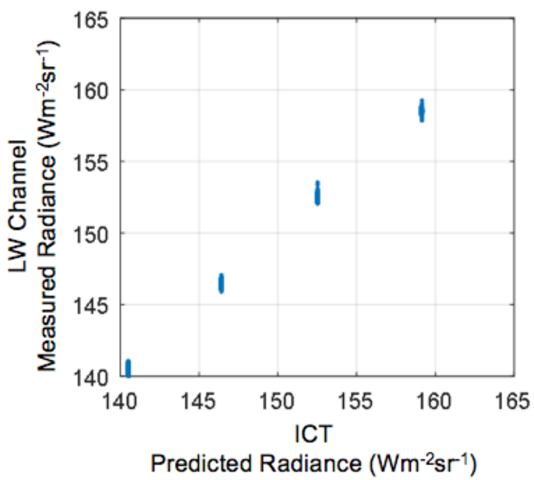
All measured responses are as expected

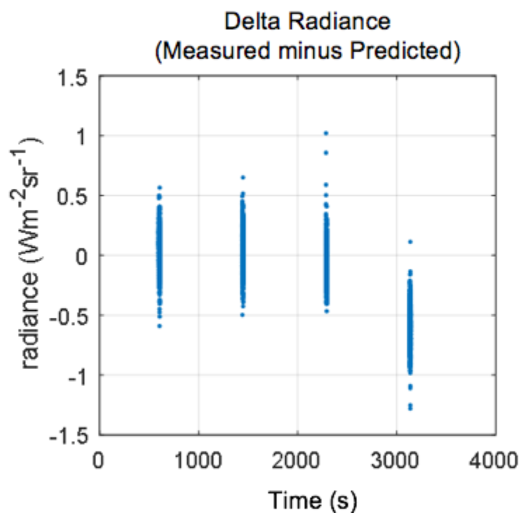
Linearity Performance Is As Expected Using ICT





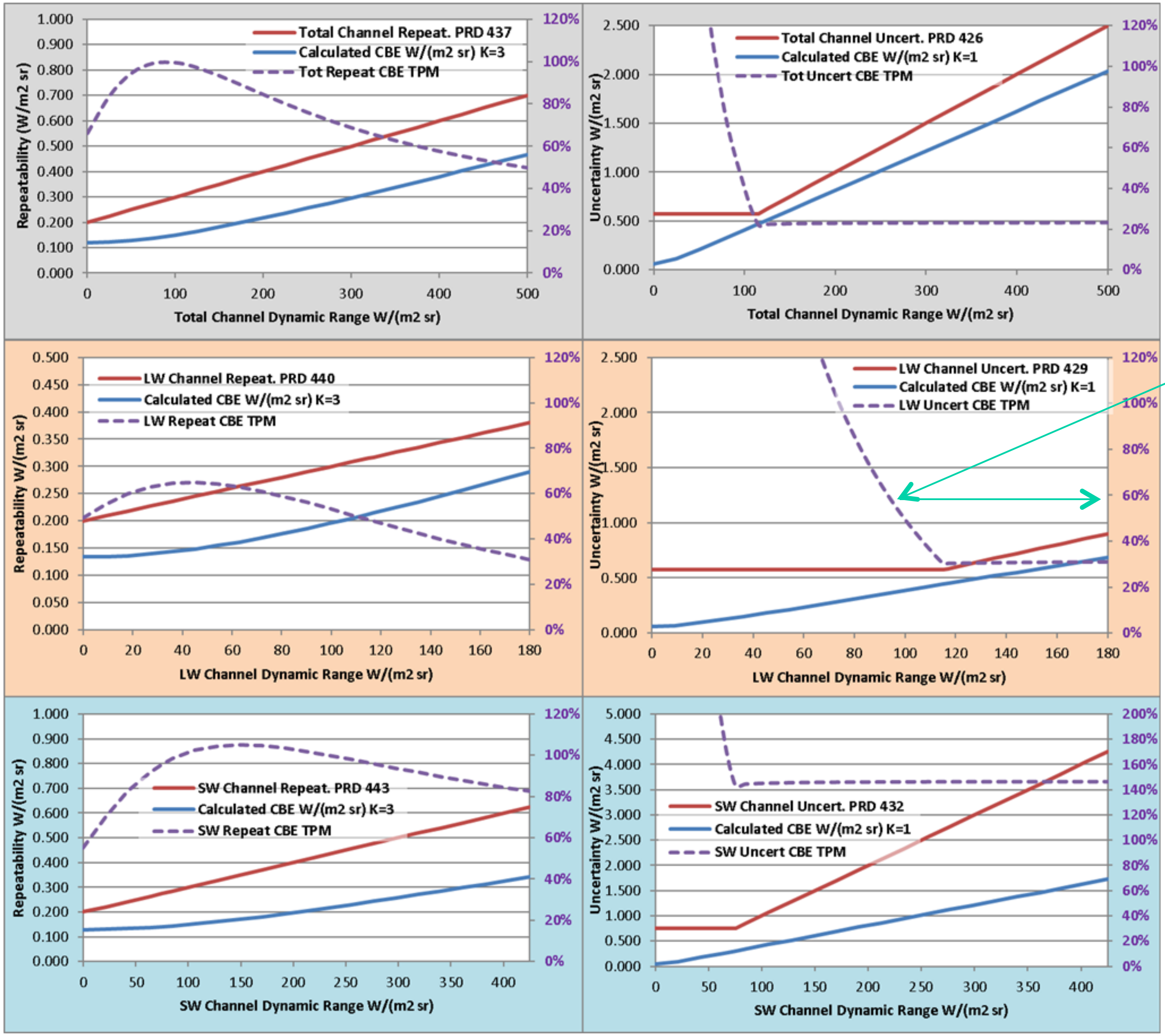
Instrument Response is Very Linear





<0.5 $Wm^{-2}sr^{-1}$ (3-sigma) Agreement is Very Good

Estimated Radiometric Performance Meets Requirements with Margin



Margin using allocations: use RHS scale

Requirement

Current Best Estimate

RBI Summary

- PDR was held May 2016, KDP-C approved July 2016
- CDR occuring currently
- Flight delivery in mid-2019
- Instrument flies on JPSS-2, launch 2021

- RBI will continue the important ERBE and CERES data records
  - PSF and spectral coverage traceable to CERES
  - RBI has an enhanced shortwave calibration source providing accurate multi-wavelength sources with a NIST-traceable reference detector

Program is on Track for Successful Delivery of RBI FM1

Back-Up

EDU Bench Test Performance Indicates Readiness To Proceed to TVAC Testing

	TOT	SW	LW
Responsivity (DN / r.u.)	182*	282	272
Noise (DN) viewed at park	20	20	20
NER (r.u.) unfiltered at ambient	0.11	0.071	0.071
NER (r.u.) unfiltered expected**	<0.19	<0.12	<0.12
NER (r.u.) unfiltered in TVAC (est.)	0.033	0.021	0.021

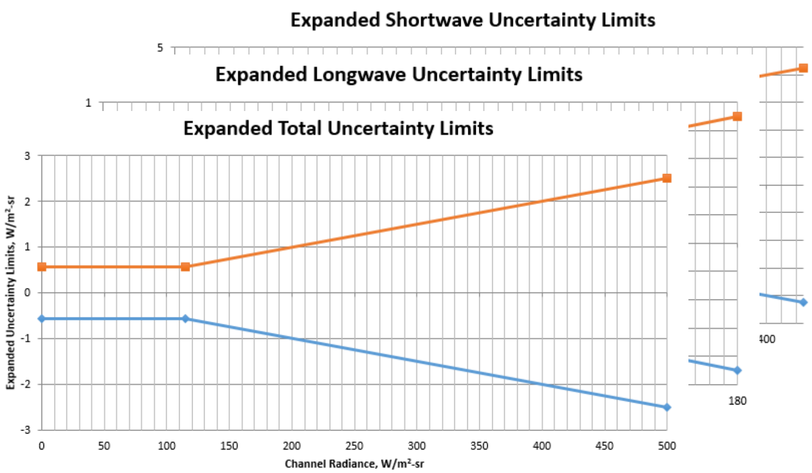
* Total channel intentionally has lower responsivity since it has a larger dynamic range requirement
** Based on RTM testing in TVAC and at ambient pressure

All measured responses and noise levels are as expected

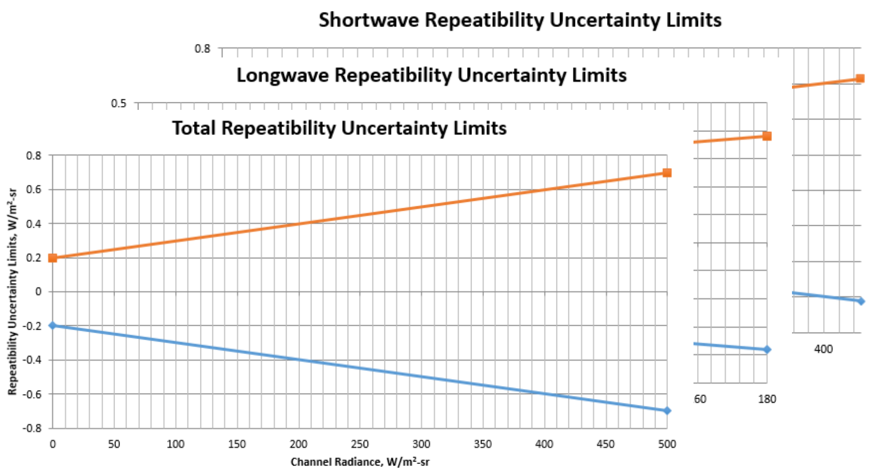
Key Requirements Drive Calibration and Traceability to CERES

- Radiometric Uncertainty (SW, LW and Total channels)

Long Term Uncertainty



Repeatability



- Relative Spectral Response by channel
  - SW: 0.2 μm – 5 μm; LW: 5 μm – 50 μm; Total: 0.2 μm – 100 μm
- Point Spread Function (PSF) 95% match to CERES
- Channel to channel registration of 98%
- Calibration sources for SW, LW and solar calibration

Integrated Team Supports RBI Development

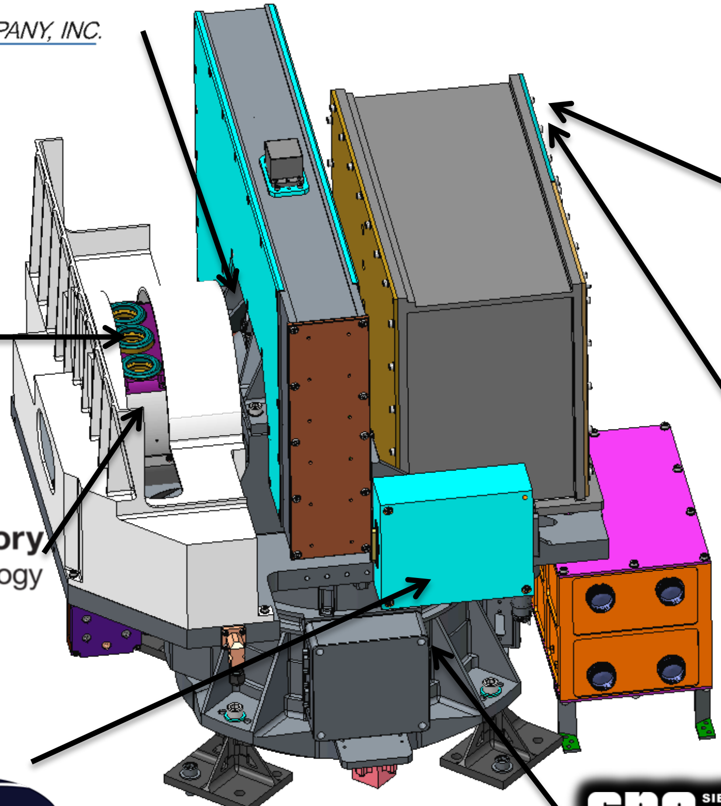
Clouds and the Earth's Radiant Energy System

HARRIS
Radiation Budget Instrument (RBI)

BEI PRECISION SYSTEMS & SPACE COMPANY, INC.
Cross-track Scan Module (CSM) and
Encoder Electronics

GENERAL DYNAMICS
Global Imaging Technologies
Telescopes

Jet Propulsion Laboratory
California Institute of Technology
Thermopile Detectors



Space Dynamics Laboratory
Utah State University Research Foundation
TVAC and Calibration

Microsemi
Electronics Unit (EU) Power Supply

Maxwell Technologies
Electronics Unit (EU) Single Board Computer

L-1
Visual Calibration Target (VCT)

SNC Sierra Nevada Corporation
Space Systems
A WORLD CLASS LEADER IN SPACE SYSTEMS & TECHNOLOGIES
Azimuth Rotation Module (ARM)

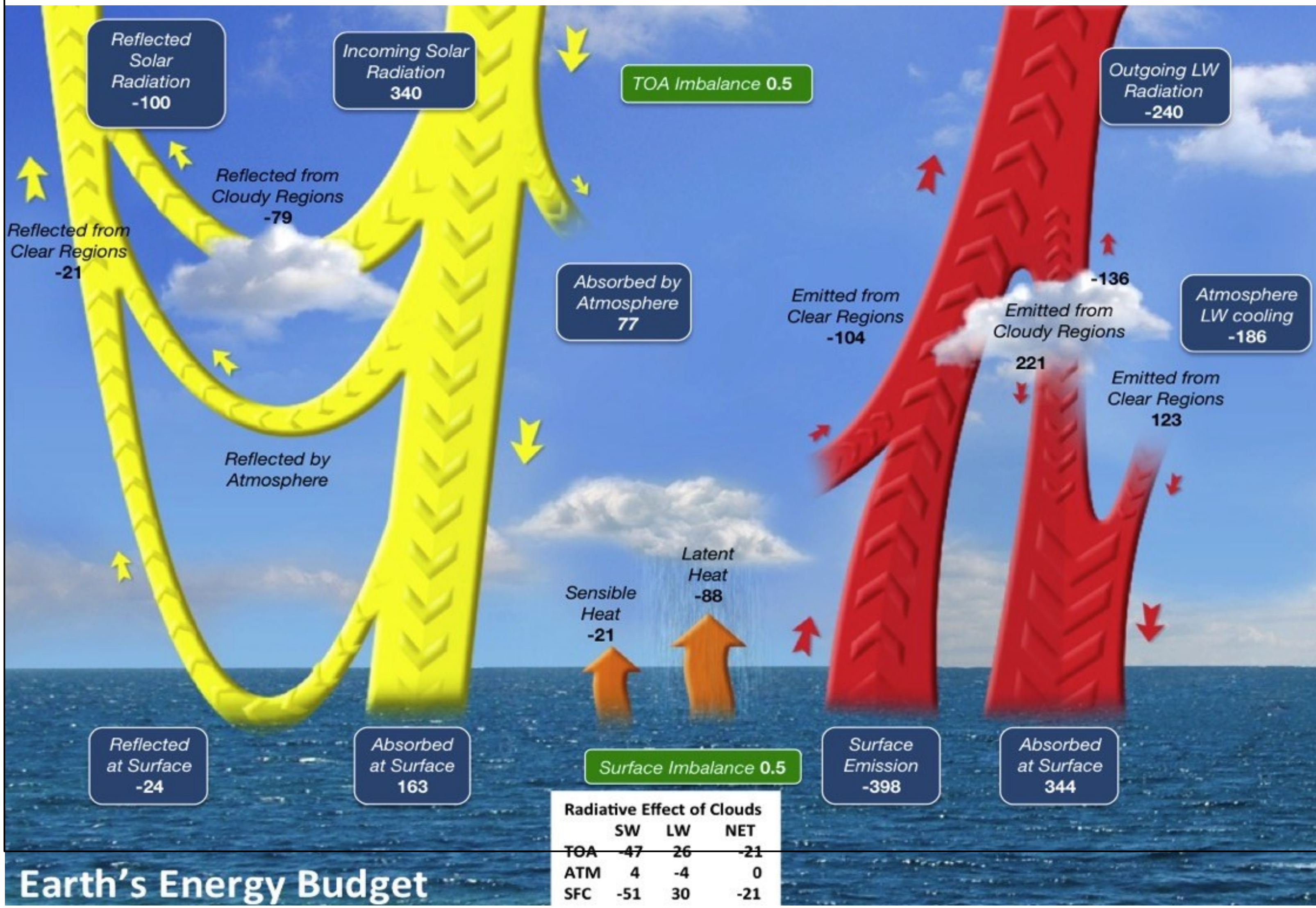
Enhancements to RBI Design Since 2016

PDR Design	CDR Design	Benefit of Change
PDR Telescope Baffle Design	Improved Baffle Design; Z306 Paint With Micro-Balloons	Better Stray Light rejection. Improved radiometric uncertainty to allow compliance with margin.
Aperture stop at edge of primary mirror surface	Changed to physical baffle aperture (telescope metering structure T4) in close proximity to the primary mirror surface	Physical aperture is a more robust and controllable stop
Heritage Gold Black Coating	Improved Gold Black Deposition Process With Revised Thickness Spec	Improved repeatability and better resistance to solar glints. Also enables better electrical grounding.
CSM Bearing Fixture OM Restraint	CSM magnetic-lock launch restraint	Secure restraint of telescopes during launch and transfer orbit preventing solar exposure
No ICT Baffle	Thermally Isolated Baffle Added	Better thermal isolation from a potential space view. Black-painted baffle interior minimizes stray light
ICT Single-Piece Titanium Mount	Improved Mount Design Including Vespel Material	Design accommodates new baffle, reduces mass, and provides better thermal isolation
660nm VCT Diode	Changed to 680 nm	680 was chosen for its availability and offers improved radiometric uncertainty, spectral correction
ARM ECU	Revised FPGA Code and ECU design	Improved torque margin performance

Changes Improve Mission Performance, Reduce Complexity, and Better Support

RBI's Mission: Earth's Radiation Budget Measurement Continuity

Clouds and the Earth's Radiant Energy System



Radiative Effect of Clouds

	SW	LW	NET
TOA	-47	26	-21
ATM	4	-4	0
SFC	-51	30	-21

Lessons-Learned During EDU Build and Test

Discovery	Changes to Design to Resolve Discovery
FPM to filter housing spacing	Change to Filter ring mount in Flight design
CSM free rotation	Magnetic launch lock design
FPGA sync, detector noise	Fix implemented on EDU
Flight SW elevation drop outs	Noise eliminated on EDU/Flight
SW integration, set points, coefficient and telemetry issues	Resolved Flight SW to EU/FPGA interfaces
Test processes/equipment debug and integration	Test procedures and work instructions are being updated and made ready for Flight
VCT temp sensitivity	Flight fix
MIL-STD-1553 test software implementation issue	Test set issue resolved to support EDU/Flight testing
ARM flex design issues	Flight fix
CSM control system	Optimized for requirements set