Enhancing the Ground Calibration in the Short-wavelength Region to Improve Traceability Within the Reflected Solar Bands of the CERES Instrument

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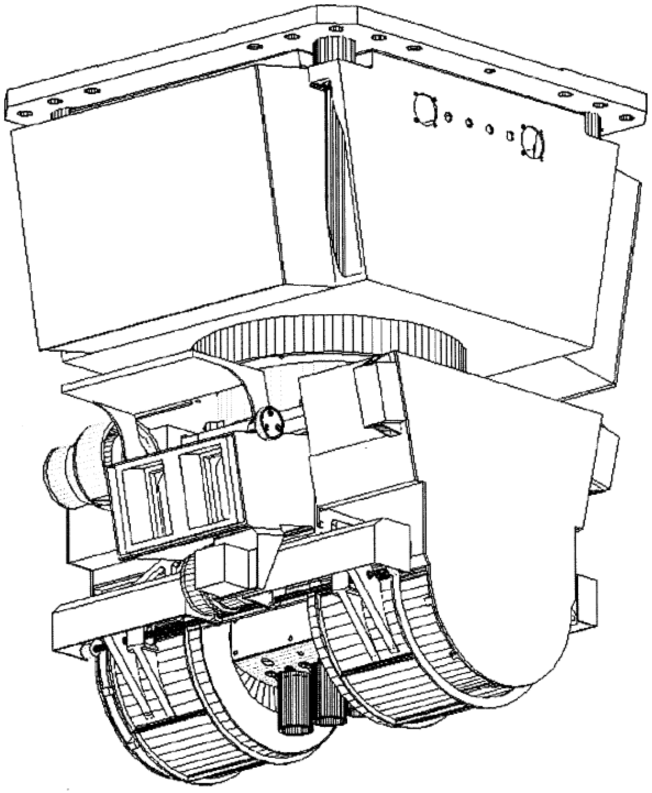
Overview

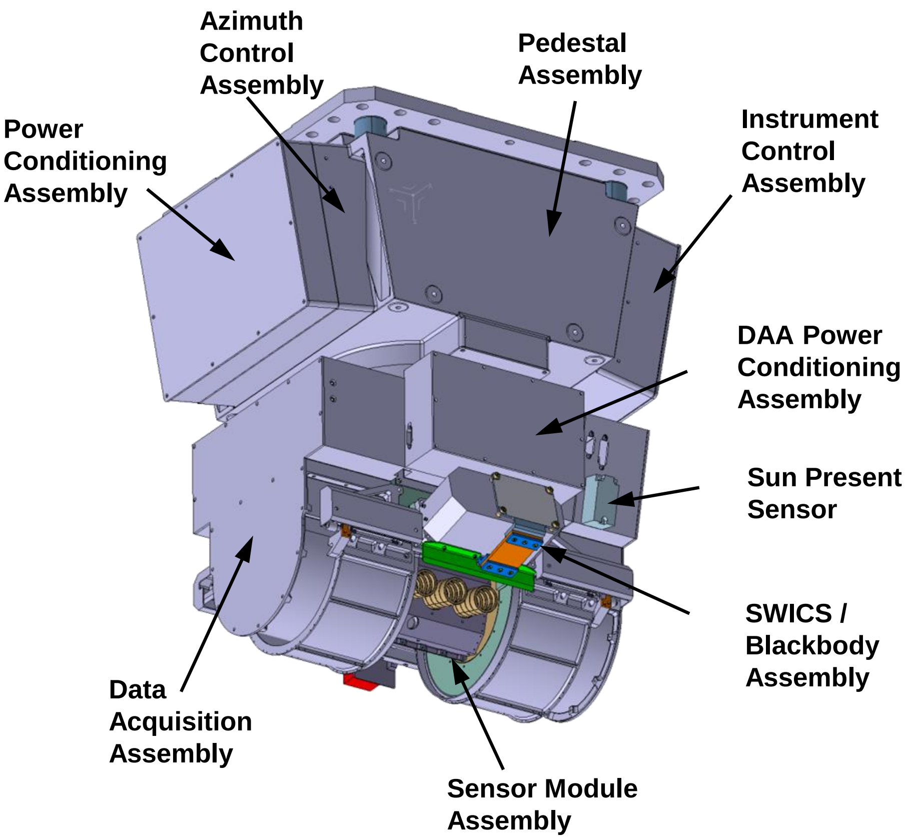
- **CERES instrument overview**
  - Measurement objectives
- **The need for calibration improvement**
  - SWRS spectral content
  - TACR telescope mirrors
- **Implementation of improvements**
  - Replace TACR Mirrors
  - Added additional shortwave sources
  - Improved TACR throughput measurements



CERES Instrument Overview

Clouds and the Earth's Radiant Energy System

- Designed, manufactured and tested by TRW (now Northrop Grumman Aerospace Systems)
- Contains three sensor assemblies with cassegrain optics and thermistor bolometer detectors
  - Shortwave: 0.3 µm to 5 µm
  - Total: 0.3 µm to >100 µm
  - Long wave: 5 µm to ~50 µm
- Sensors measure reflected solar and emitted thermal radiation in the visible through far-infrared spectral region
- The ICM is the internal calibration system for all three channels
- Calibration Accuracy Requirements in SOW - 0.5% LW, 1.0% SW
- Measurement Stability Goals - 0.02%/yr LW, 0.03%/yr SW



Radiometric Performance Requirements

CERES is defined as a class 'B' Mission

5-year design Lifetime

Spectral Region	Solar		Terrestrial		Atmospheric Window
Wavelengths	0.3 – 5.0 microns		5 – 200 microns		8-12 microns
Scene Levels	<100 wm^2/sr	>100 wm^2/sr	<100 wm^2/sr	>100 wm^2/sr	All Levels
Accuracy Requirements	0.8 w/m^2-sr	1.0 %	0.8 w/m^2-sr	0.5 %	0.3 w/m^2-sr
SOW Stability Requirements		0.14 %/yr		0.07 %/yr	
FM5 Accuracy Capability		1.7 %		0.7 %	
FM5 Stability Capability		0.32 %/yr		0.12 %/yr	
Climate Stability Goals		< 0.6 w/m^2/dec < 0.03 %/yr		< 0.2 w/m^2/dec < 0.02%/yr	

The current effort is focused on improving traceability within the reflected solar measurements (Short-Wave and Total channels) by enhancing the ground calibration in the short-wave region for FM-6.

Radiometric Calibration Facility

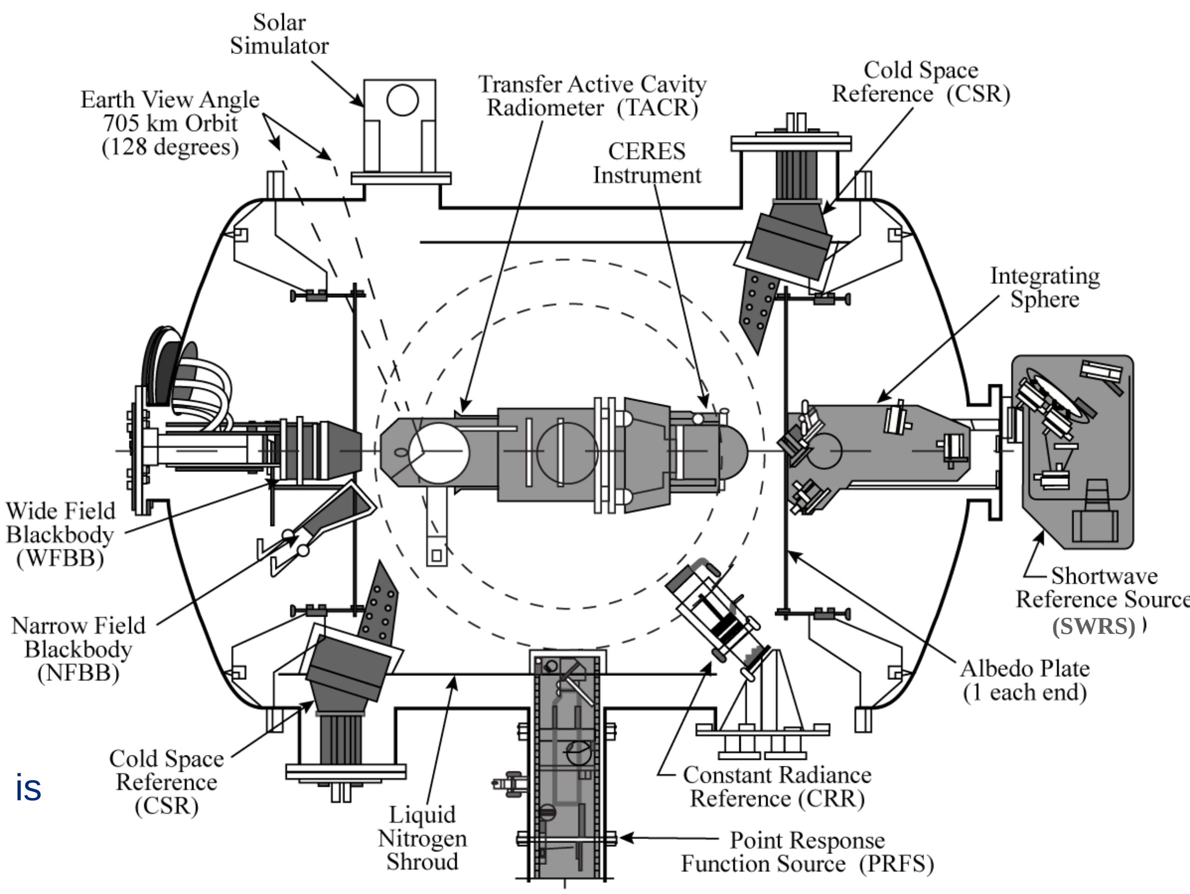
- Heritage ERBE calibration facility

Reflected Solar Bands

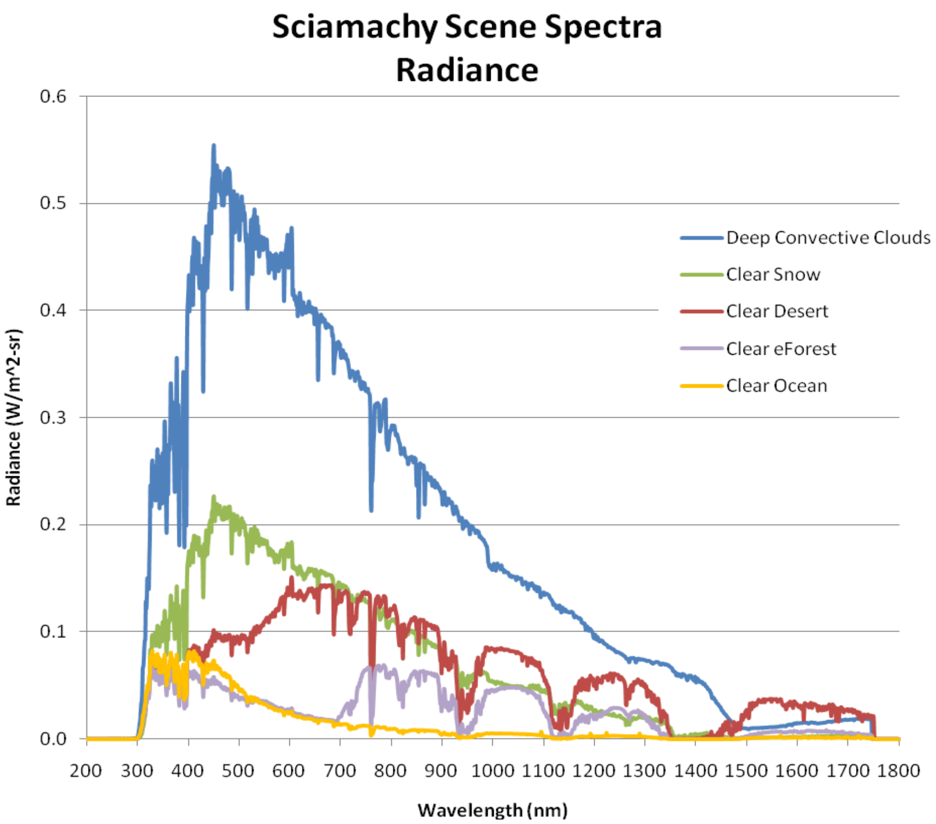
- SW reference source (SWRS) with spectral characterization capability
  - 13 discrete bands between 420 and 1960 nm
  - ***5 discrete 'monochromatic' LED's between 365 and 419 nm***
  - 5 cm integrating sphere with associated optics
- Cryogenically cooled Transfer Active Cavity Radiometer (TACR)
  - ***New Al Mirrors for FM6***

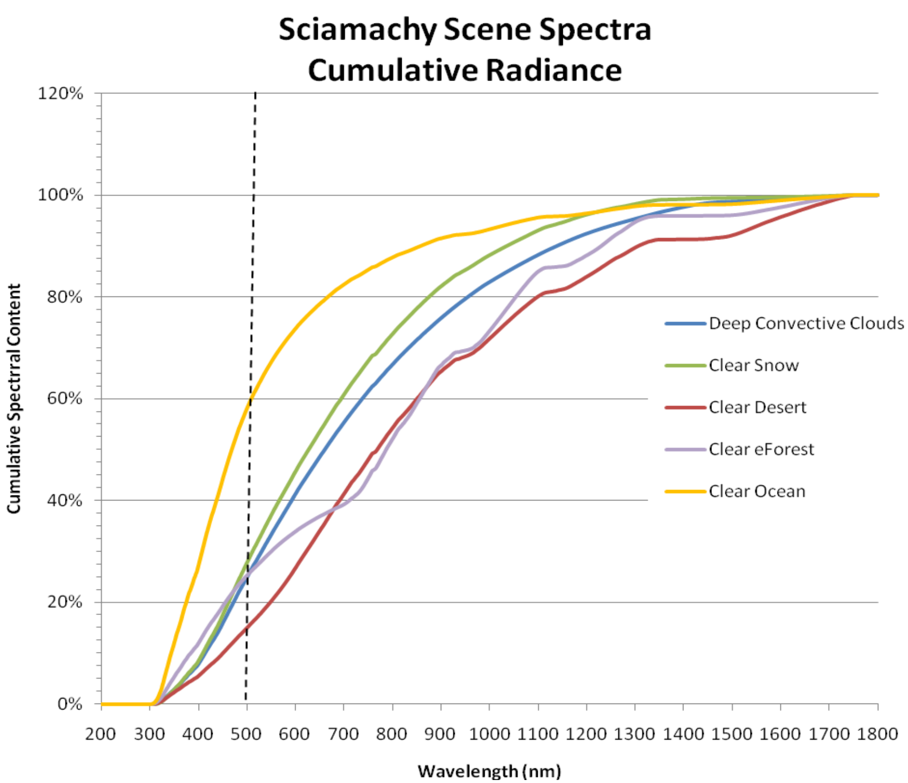
Thermal IR Bands

- Narrow Field of View Blackbody (NFBB) is primary standard (emissivity >0.9999)
- 12.5 cm Wide Field of View Blackbody (WFBB)
- Cold Space Reference (CSR) blackbodies



Sciamachy Scene Radiance

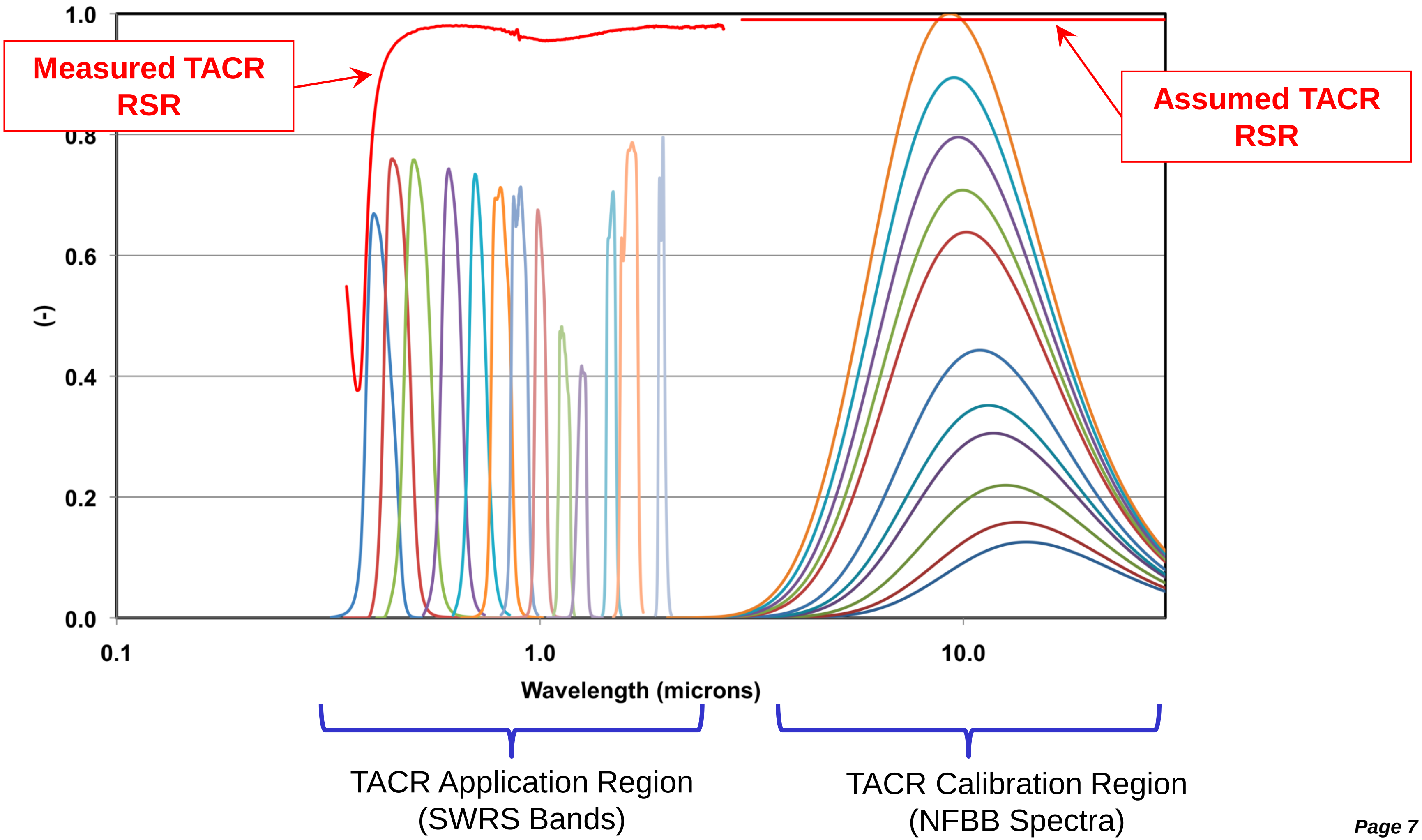




The globally averaged All Sky composite scene contains as much as 30% of its reflected solar radiance below 500nm

CERES Traceability

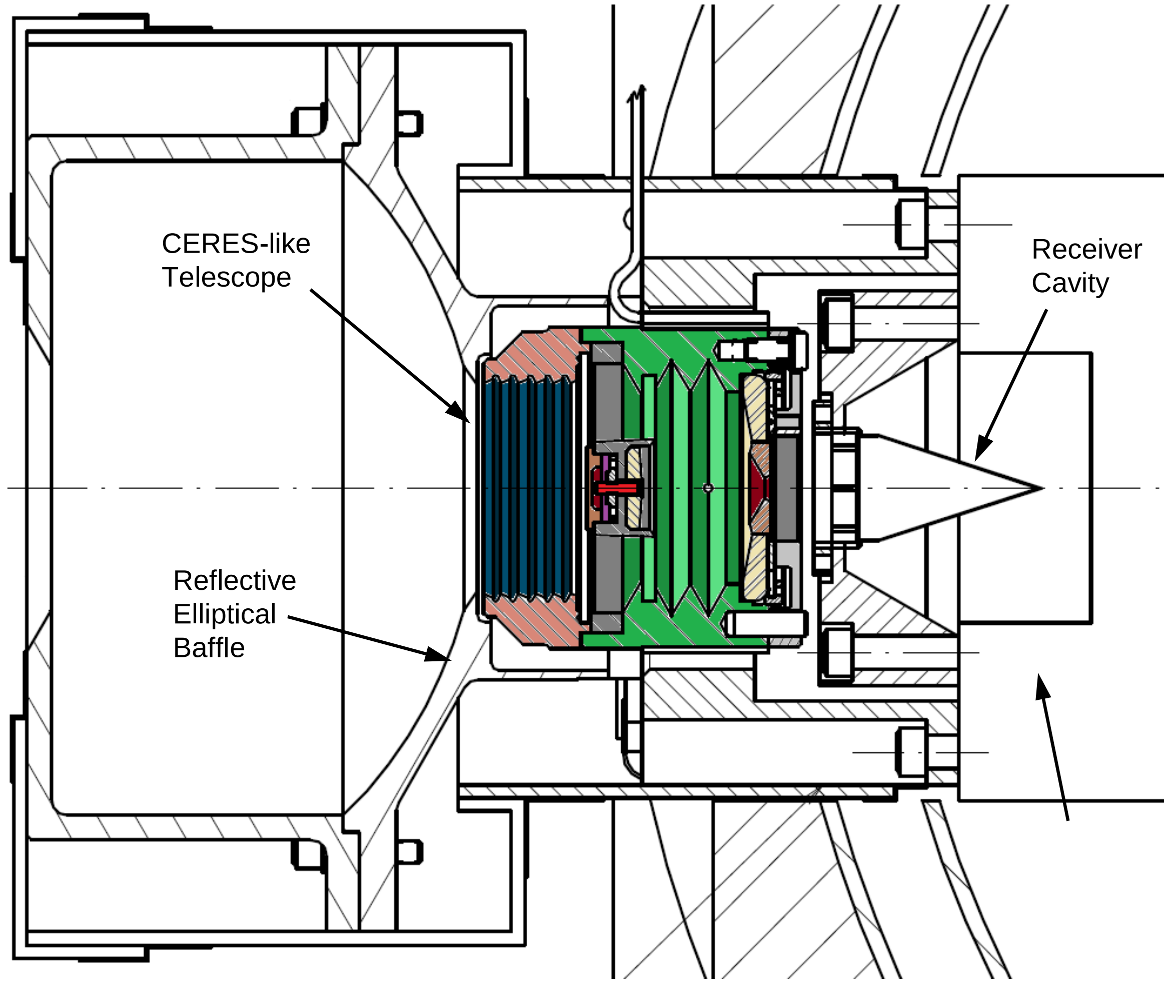
- NFBB is used for long-wave calibration at temperatures between 205 K to 318K
- Short-wave calibration is achieved by transfer of NFBB standard to SWRS via TACR



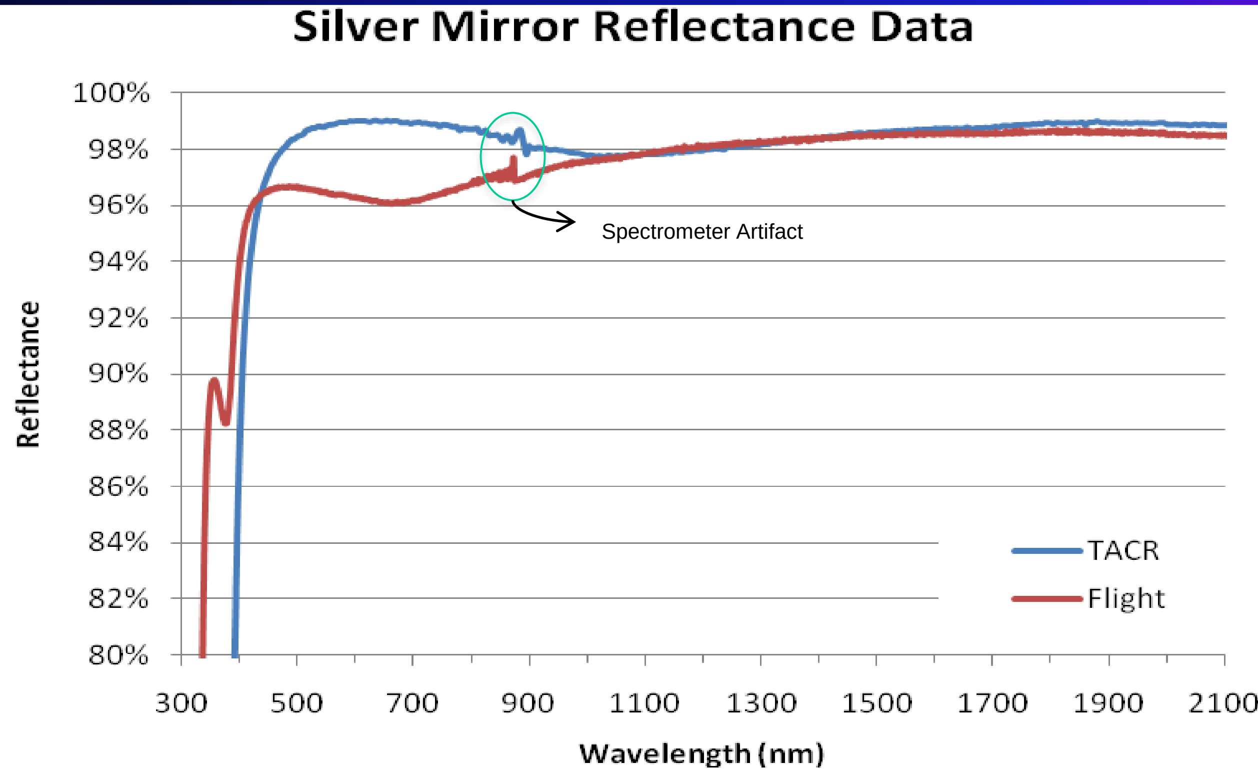
RCF Transfer Active Cavity Radiometer

TACR

- **Cryogenic receiver cavity**
  - Black copper cone, thermally sunk to a liquid He dewar
  - Absorptance >0.999 from visible to IR
- **TACR telescope**
  - CERES-like fore optics
  - Telescope housing and baffle are optically identical to flight configuration
  - Nickel mirrors with flight optical prescription
- **Elliptical reflective baffle**
  - Replaces sensor forward baffle
  - Provides radiance heat rejection
  - Increases thermal stability



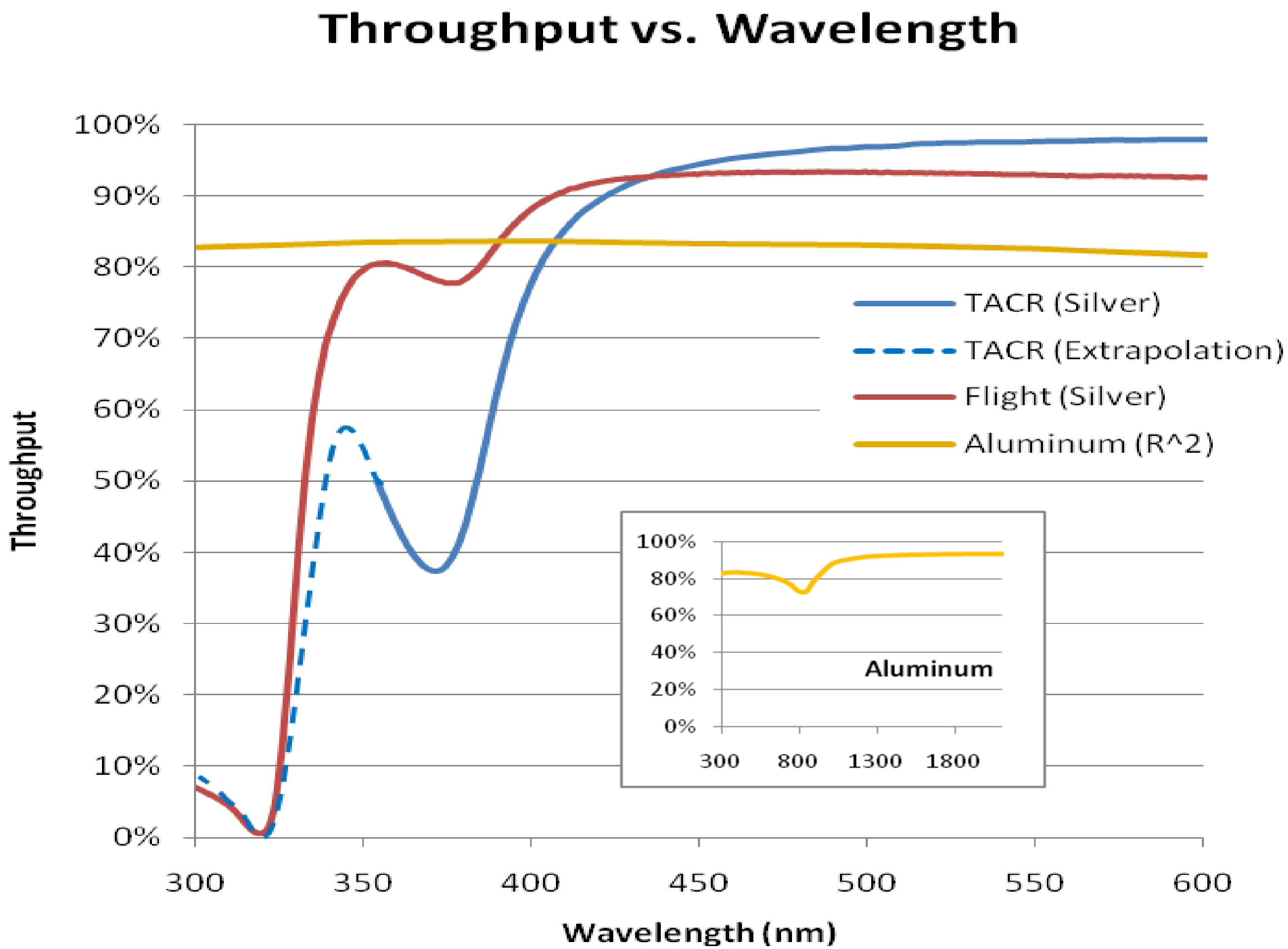
TACR Limitations



- Legacy TACR mirror spectral reflectance differ from the flight mirrors which adds higher than desirable uncertainty in the shortwave
- The roll off in the short wavelength region introduces a source of error and reduces the signal-to-noise ratio in the TACR
- Measurements of Legacy inferred by **witness samples** rather than true spectral response of the telescope

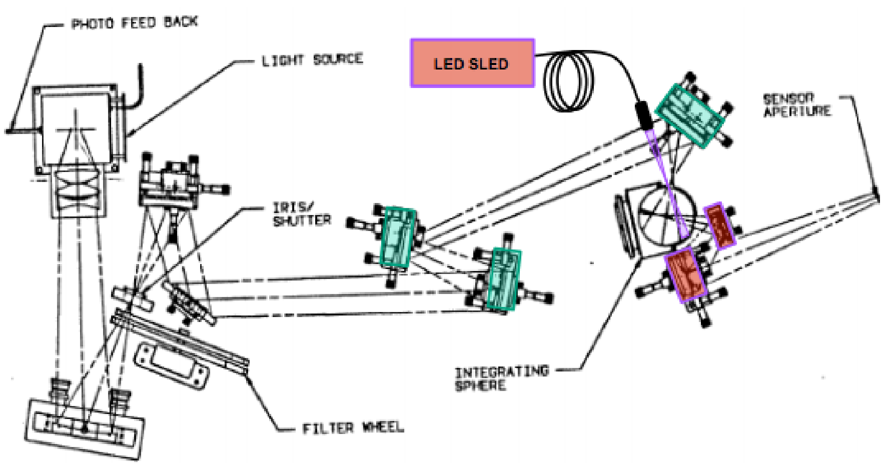
TACR vs. Flight Witness Samples

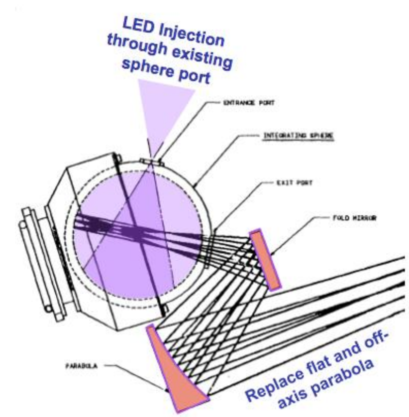
The TACR telescope throughput roll off impacts shortwave measurements. A flatter reflectance spectrum is desirable.



Uncertainty of the RCF Shortwave Reference Source

- **The SWRS consists of a stabilized Quartz-Tungsten- Halogen lamp fed into the RCF via optical train with**
  - 8 mirrors, 1 triplet lens set,13 filters in a filter wheel, an iris aperture, a vacuum window and an integrating sphere

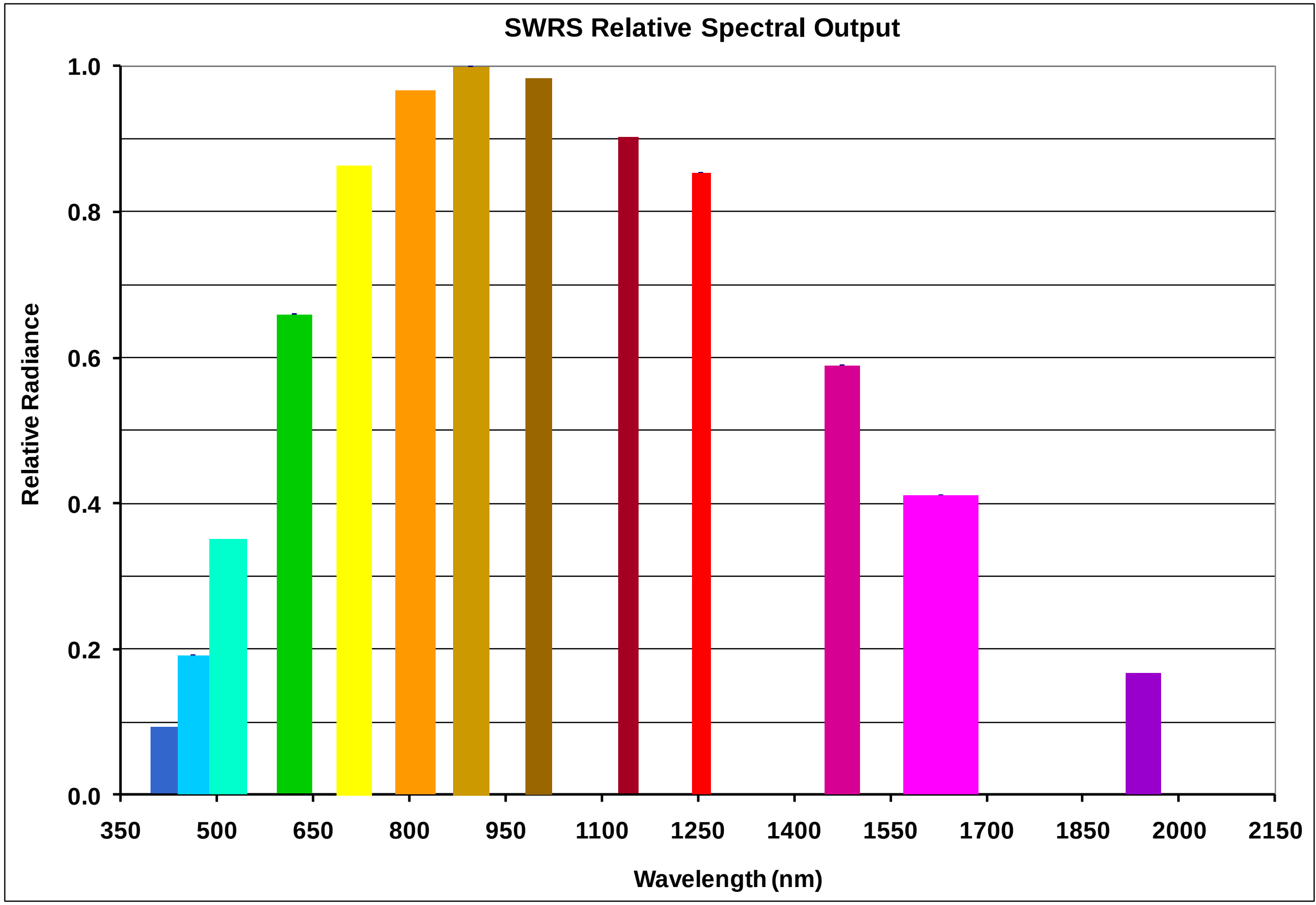




PARAMETER	VALUE
Filters used for CERES Calibration (center wavelengths in μm)	0.42, 0.46, 0.51, 0.62, 0.71, 0.81, 0.90, 1.00, 1.15, 1.25, 1.35, 1.63, 1.94
Broadband Radiance Range (W/m^2/sr)	13 to 2500
Exit Port Angular Subtense (degrees): cross-scan; in-scan	3.5; 7.8
Radiance Uniformity (peak to valley): aperture; field angle	± 0.5%; ± 1.5%
Radiance Fluctuation (0.01 sec. to hours)	< ± 0.1% (1-sigma)
Thermal Stability and Uniformity (Kelvin)	± 0.5
Sphere Operating Temperature (Kelvin)	< 85

SWRS Spectral Content

- Spectral content in the blue-visible region is limited, which impacts calibration for this region
- Intra-band knowledge assumes spectral shapes of filters and source only and does not include the optical train spectral profile
- No filter bands below 420nm, where there is known reflected solar radiation collected by the CERES sensor



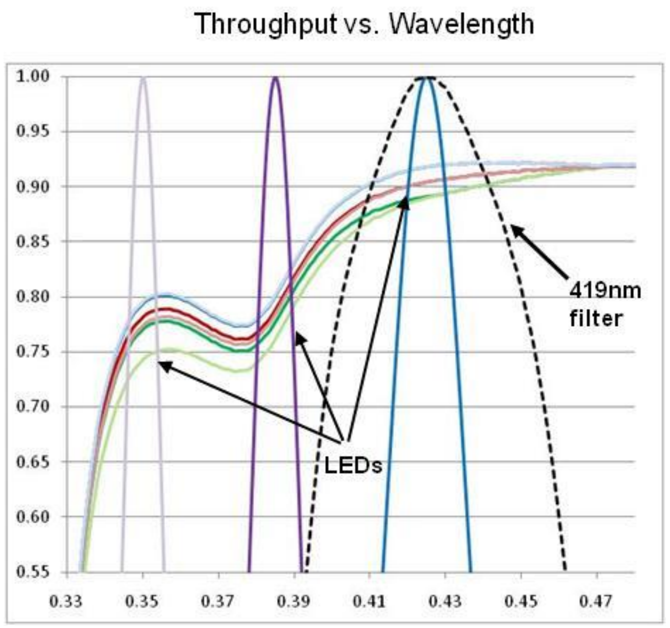
RSB Calibration Improvements

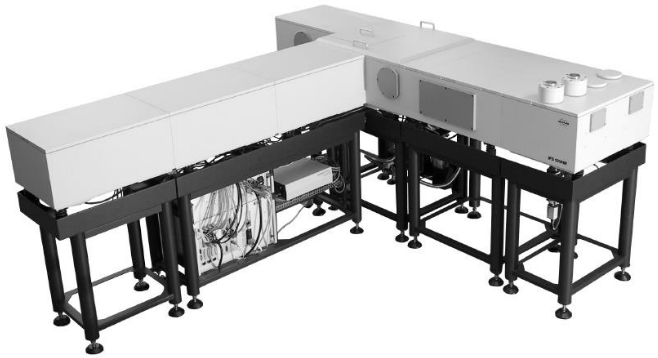
SWRS Improvements

- **Characterize legacy SWRS throughput**
- **Supplement SWRS for increased throughput at the shorter wavelengths**
  - Discrete LED sources
- **Replaced Reflective Exit Optics to increase throughput**

TACR Improvements

- **Construct new TACR telescope with aluminum mirrors**
  - characterize telescope with Bruker FTIR system
- **Characterize legacy TACR telescope throughput with Bruker FTIR system**
  - Shortwave spectral uncertainty <0.25% between 1 um and 5 um .

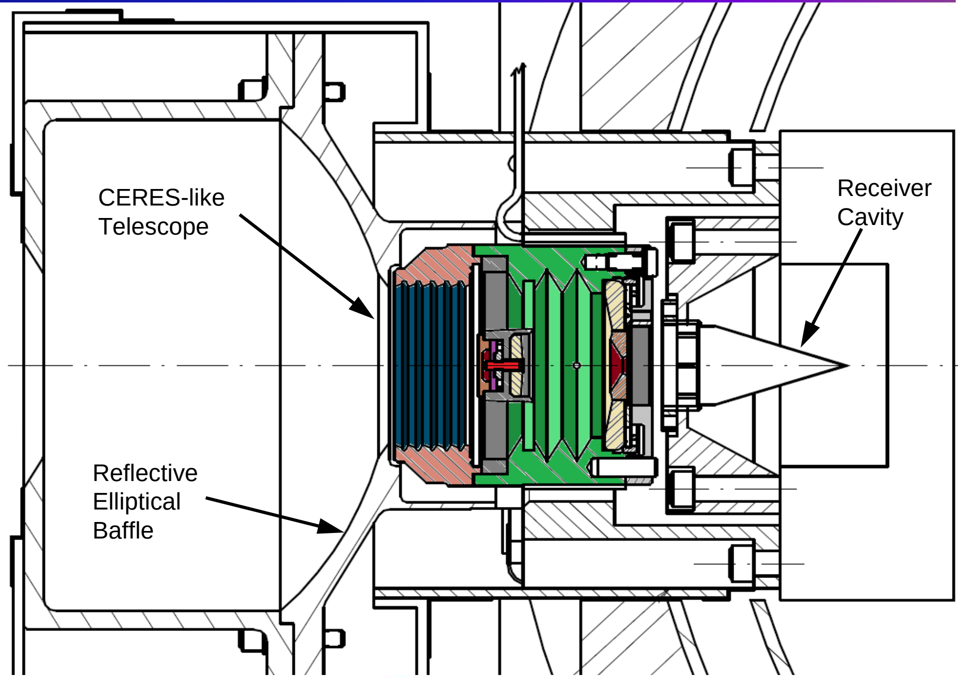


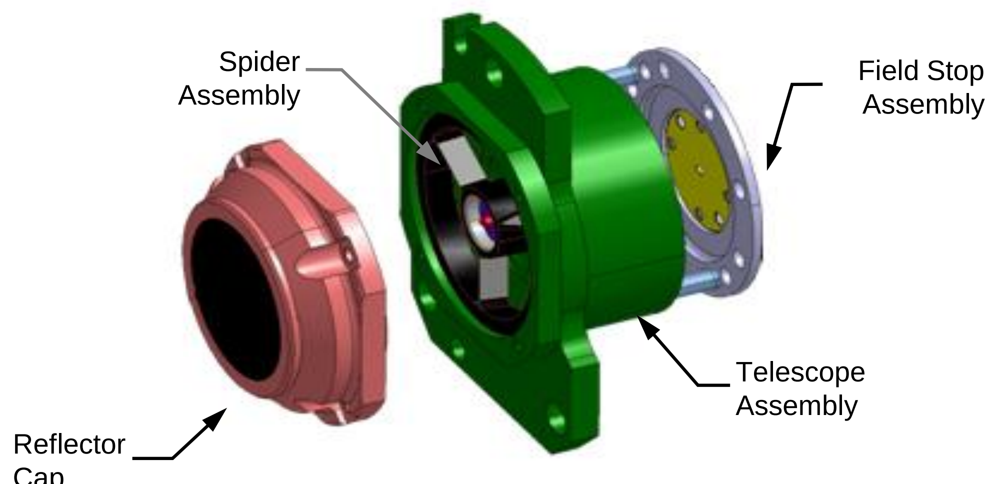


FM 6 Ground Calibration Improvements

TACR Improvements

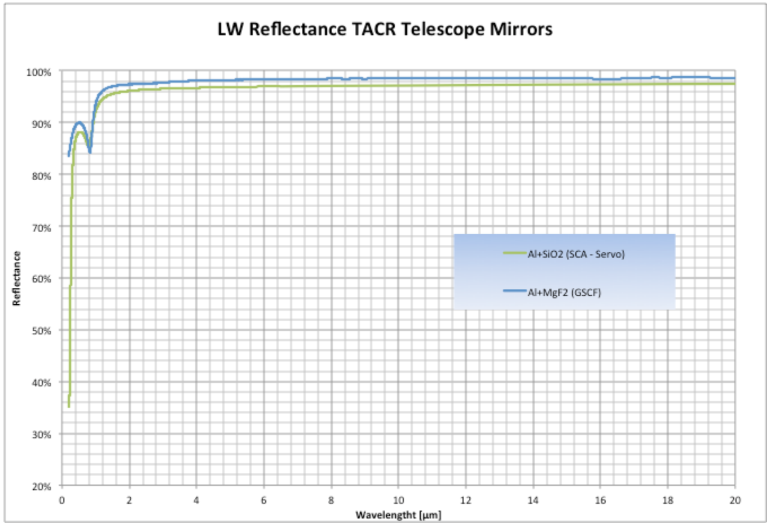
- **Install new CERES-like front end with aluminum telescope mirrors**
  - Replaced silver mirrors with aluminum mirrors
  - Telescope geometry and optical prescription remains identical to flight
  - Ambient and cryogenic reflectance measurements from 0.3 to 100 µm on witness samples (TBC)
  - Telescope throughput measurements from 0.3 to 100 µm
  - Baseline gain, out-of-field contribution and linearity tests were run in calibration chamber
- **Remove and characterize legacy TACR telescope**
  - Determine total throughput to better than 0.15% from 0.3 to 100 µm
  - Compare with heritage reflectance measurements



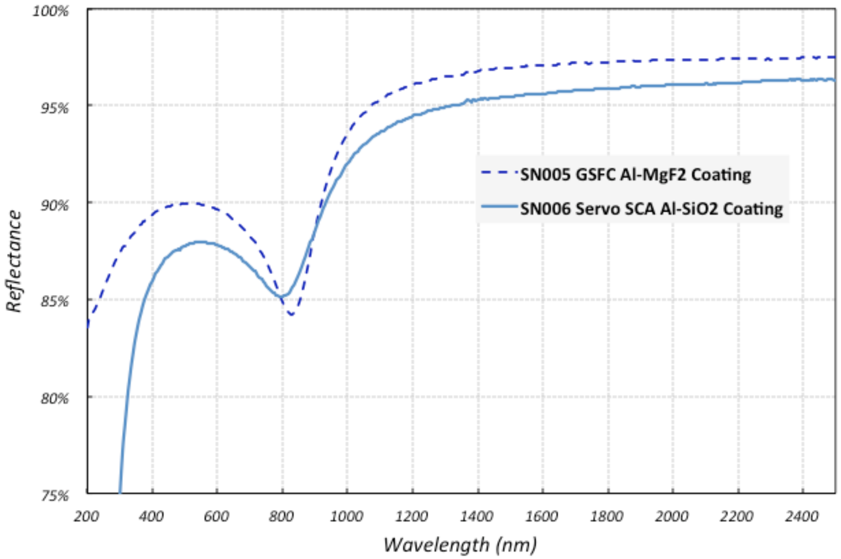


New TACR Mirror Trade Study

- **New TACR Telescope mirrors are made of nickel substrates with protected Al coating.**
  - Trade #1: Aluminum with Magnesium Fluoride coating
  - Trade #2: Aluminum with Silicon dioxide coating
- **Spectral response of the witness samples from the two coatings were measured and compared**

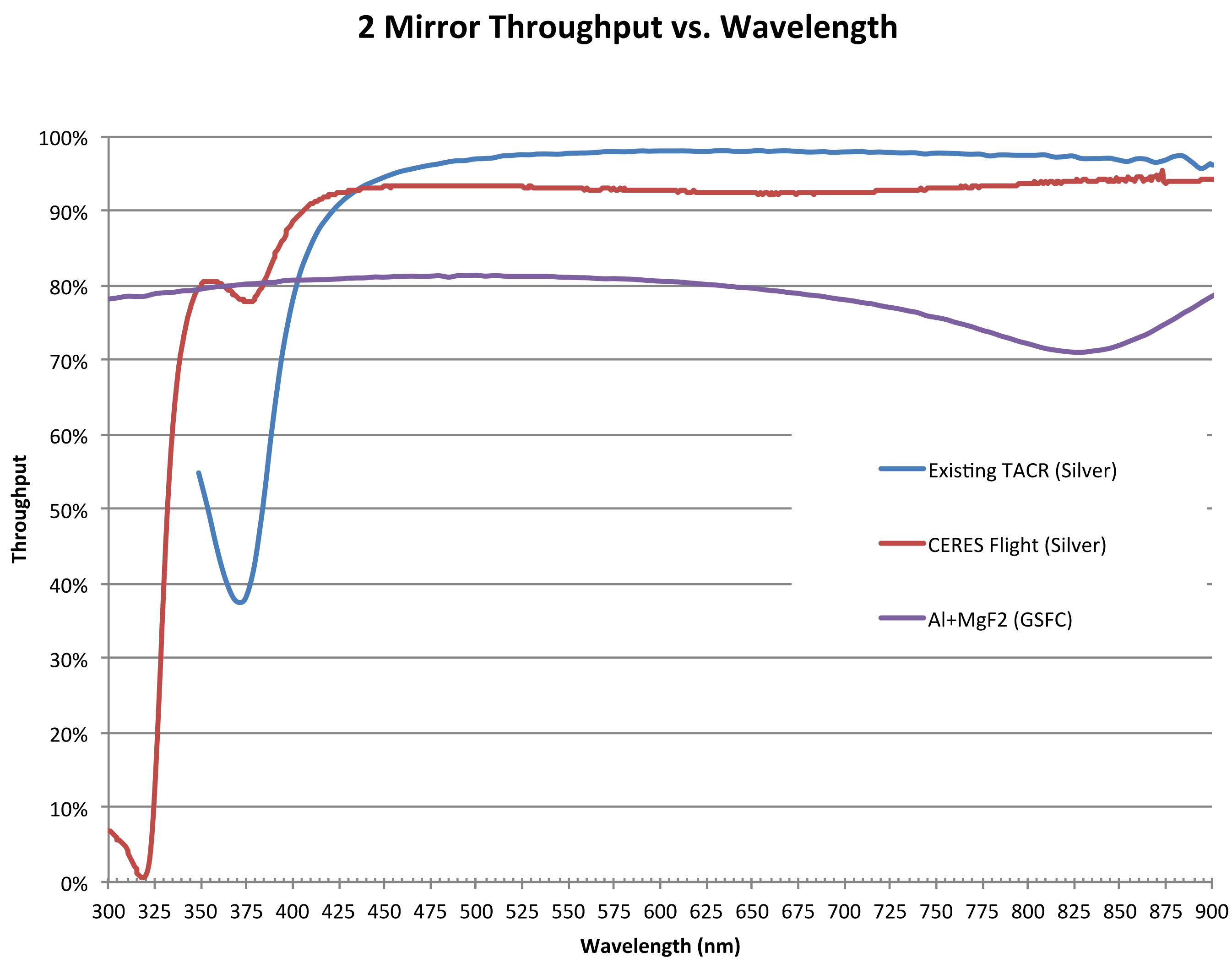


Comparison of TACR Mirror Coatings

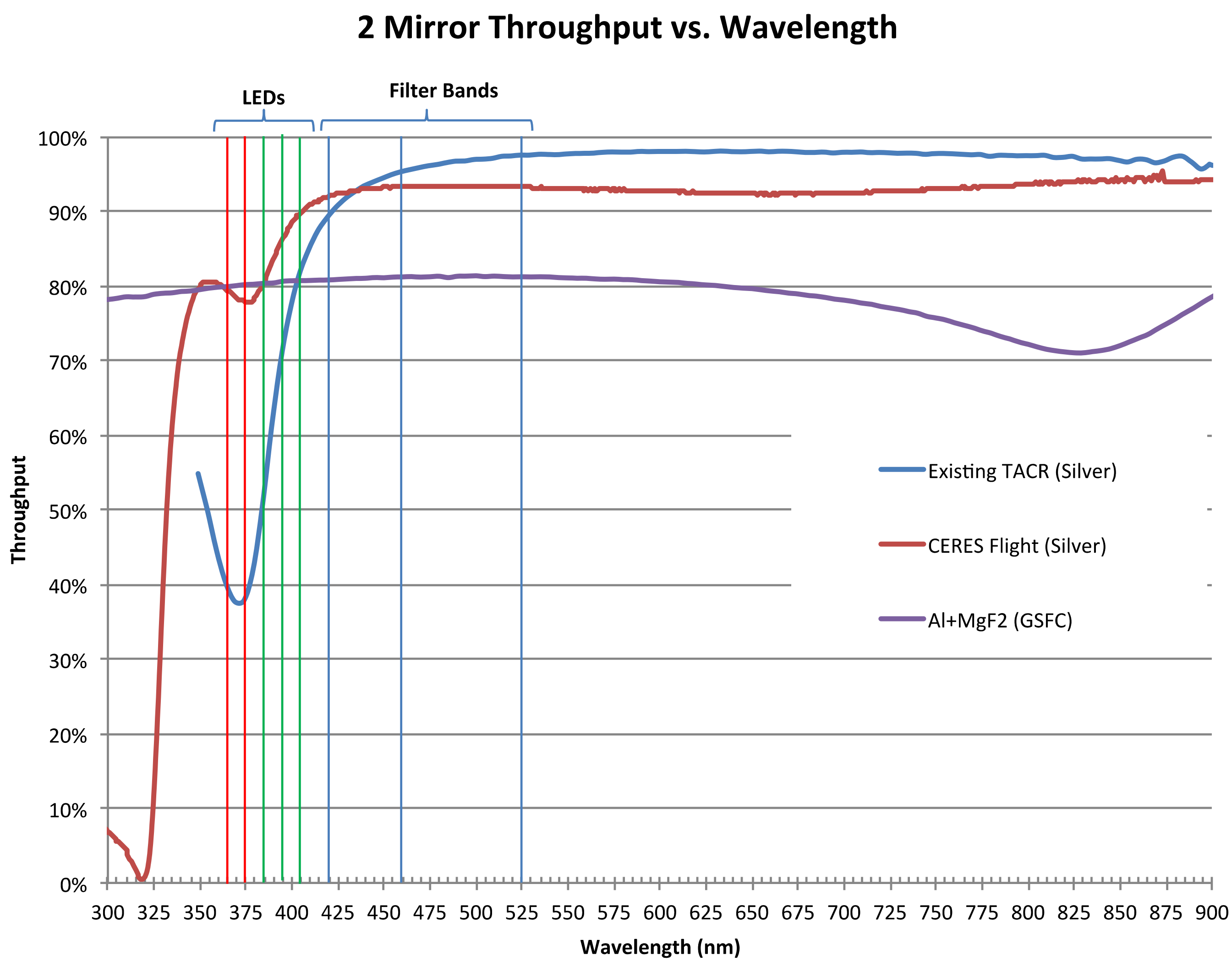


Relative Spectral Response Functions

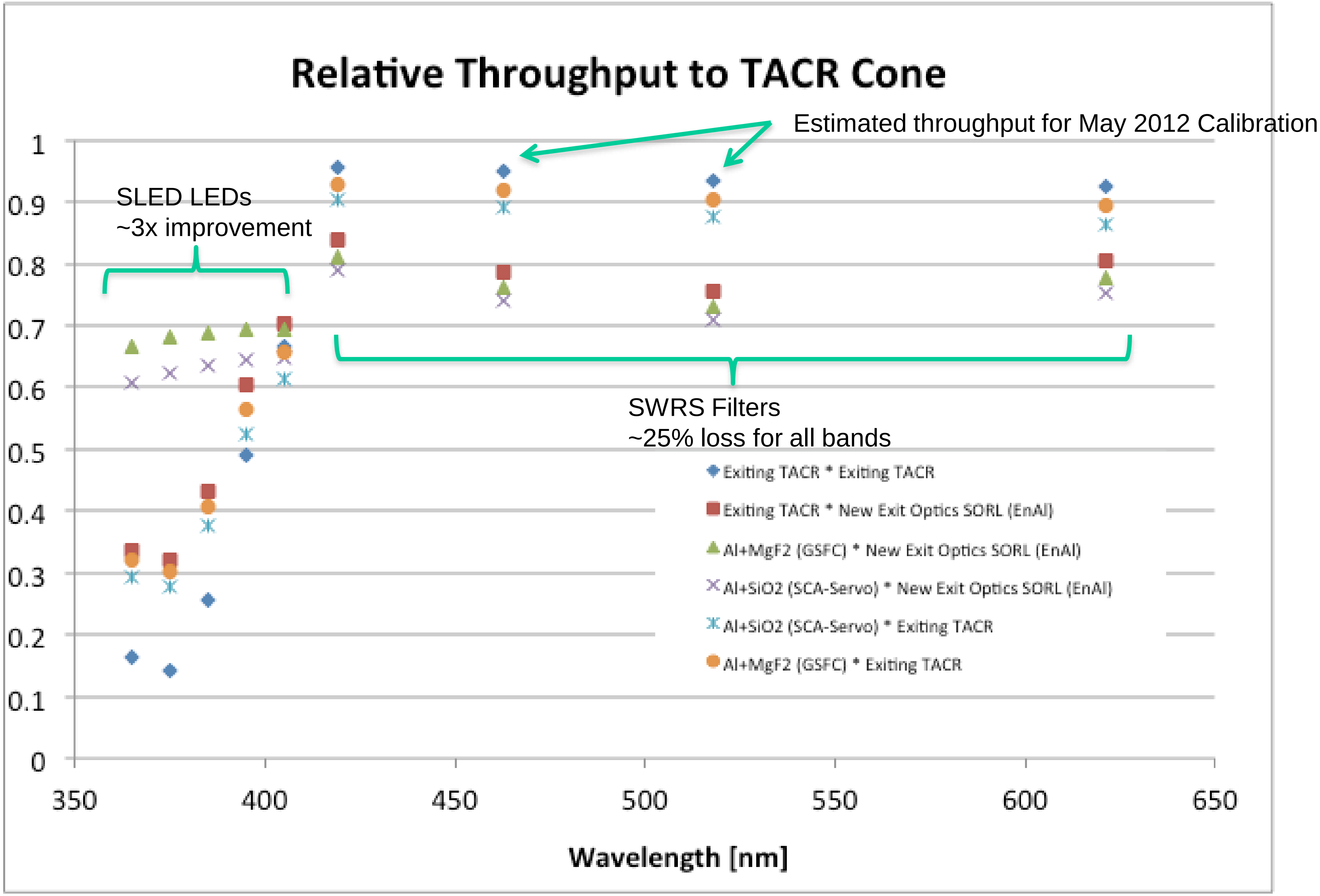
Clouds and the Earth's Radiant Energy System



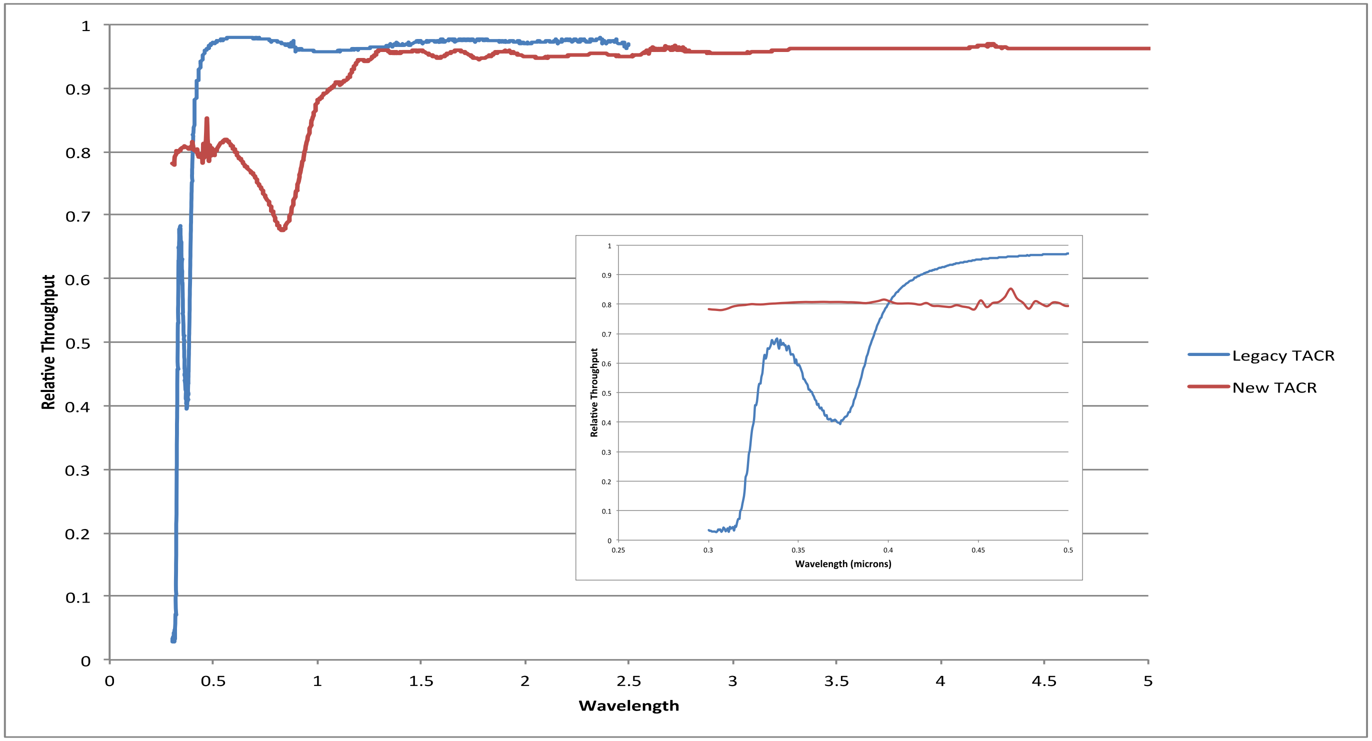
Relative Spectral Response Functions



Throughput in Filter Bands is traded for SLEDs



Relative Throughput of TACR Telescope



- Initial characterization of the Legacy TACR telescope and the New TACR telescope measured with the Bruker FTIR system.

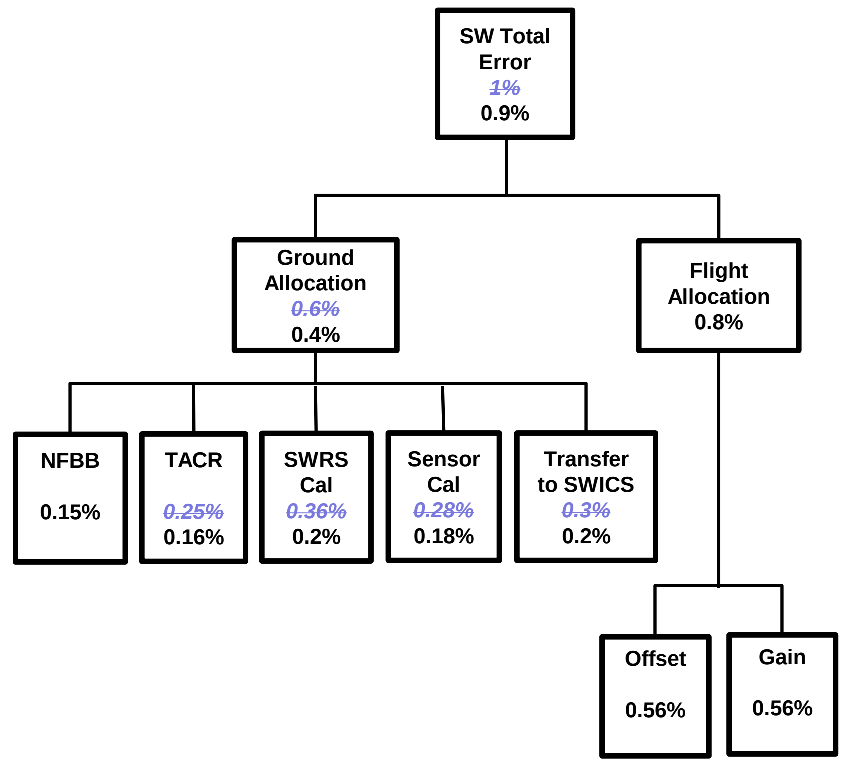
- Traded off the lower signal at the 850 nm band for a higher throughput in the UV region.

Traceability Improvements

- SW Ground Calibration error allocation is 0.6%
  - The proposed improvements will provide capability of 0.4% accuracy or better through
    - TACR spectral reflectance
    - SWRS Calibration
    - Sensor Calibration
    - Transfer to SWICS
  - Spectral response uncertainty below 500nm can be reduced from 3% to less than 0.25%
    - Additional sources to measure SW spectral response
    - Larger throughput to TACR receiver cone – improved signal-to-noise performance in SW bands
    - Bypassing optical filters improves spectral stability in SW bands
  - Anticipated reduction in uncertainty for all sky filter radiance of better than 0.1%

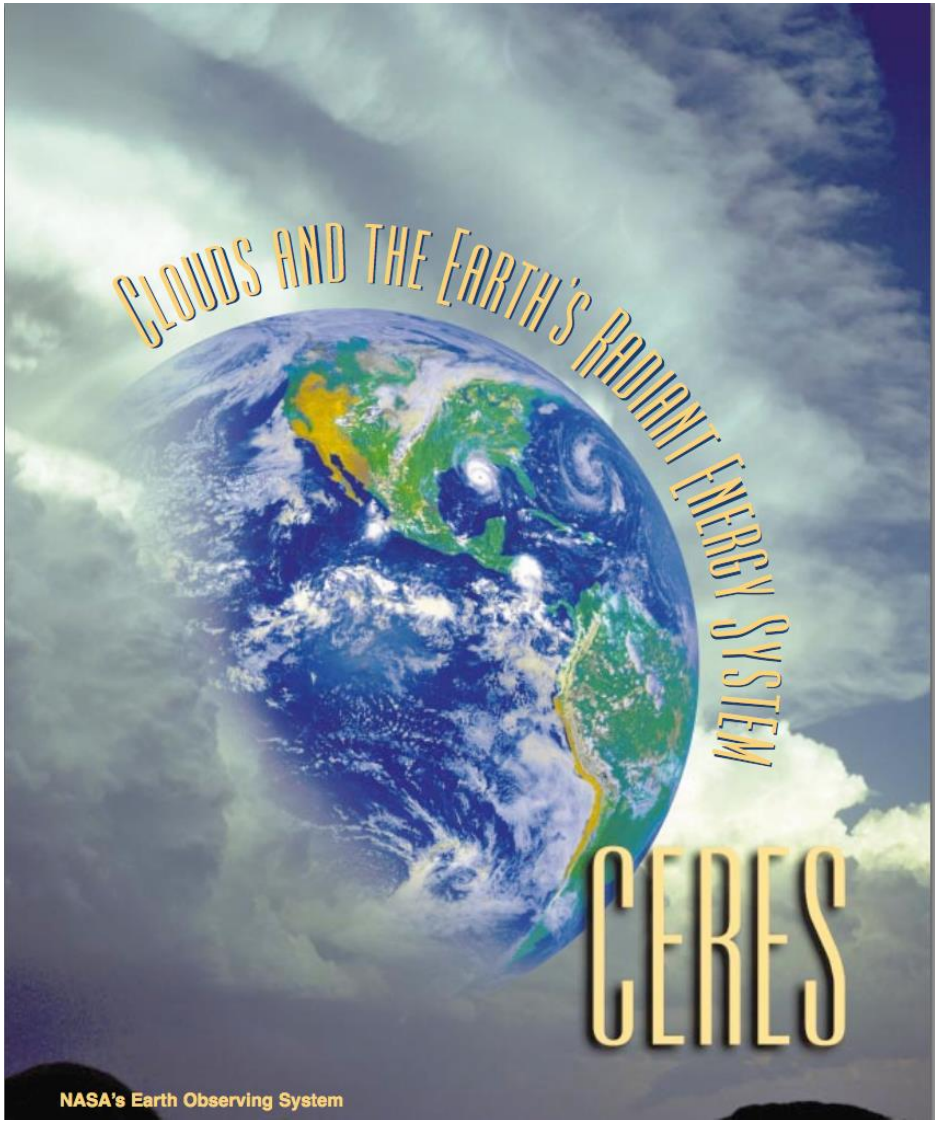
FM-6

Short-wave Channel Error Allocation



- Expected improvement in traceability – better than 0.9% total accuracy for SW for FM6
- Legacy traceability improvements continues to be assessed

Summary



- **Reflected Solar Spectra**
  - Up to 60% of clear ocean scene content is below 500nm
  - Up to 30% of all sky content is below 500nm
- **SW Calibration Limitations**
  - SWRS band shifting and low output in the UV-blue create sizeable uncertainly in calibration bands below 500nm
  - No response measurements taken below 420nm, which forces extrapolation of spectral response to SW sensor limit
- **CERES Ground Calibration Improvements**
  - New TACR front-end with improved throughput in the UV-blue region
  - Full spectral characterization of legacy TACR telescope optics provide insight to former Cals
  - New sources improved throughput for SWRS in the UV-blue region
- **Traceability of CERES FM6**
  - FM6 will be the most highly characterized CERES instrument to date.
  - Improvement in SW accuracy – 0.9% predicted