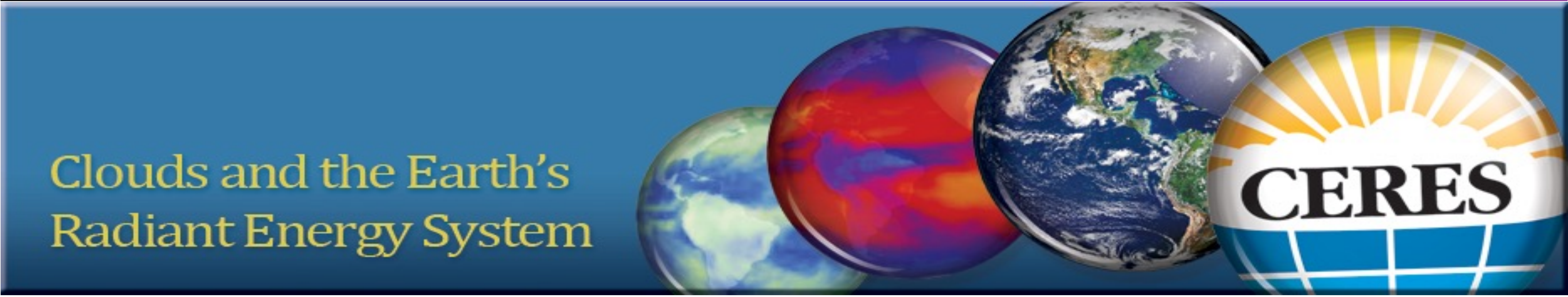


Experiments using CERES observations of the moon to supplement the Cal/Val protocol

Kory Priestley, *Janet Daniels*, Mohan Shankar

CERES Instrument Working Group

CERES Science Team Meeting
Virtual
October 13, 2021

Primary CERES Flight Radiometric Validation Protocol Activities

		Product Level	Spatial Scale	Temporal Scale	Spectral Weighting	Dynamic Range	Latitude Range	Radiometric Metric	Channel	Product
On-Board	Internal BB	Filtered Radiance	Full IFOV	Continuous Capability	290-320 K BB	Across	All	Absolute Accuracy, Stability	TOT, WN, LW	-
	Internal Lamp	Filtered Radiance	Full IFOV	Continuous Capability	17000, 2000, 2300 K BB	Across	All	Absolute Stability	SW	-
	Solar	Filtered Radiance	Full IFOV	1 per orbit capability	Solar	Fixed, High	N or S Pole	Relative Stability	TOT, SW	-
Vicarious	Theoretical Line-by-Line	Filtered Radiance	>20 Km	Instantaneous	Various Earth	Across	N/A	Inter-Channel Theoretical Agreement	TOT, WN, LW	-
	Unfiltering Algorithm Theoretical Validation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	TOT, SW, WN, LW	-
	Inter-Satellite (Direct Comparison)	Unfiltered Radiance	1-deg Grid	1 per crossing	Various Earth	Mid	All	Inter-Instrument Agreement, Stability	TOT, SW, WN, LW	OLR, RS
	Tropical Mean Geographical Average)	Unfiltered Radiance	20N-20S	Monthly	Tropical Ocean, All Sky	Mid	20N-20S	Inter-Instrument Agreement, Stability	TOT, WN	OLR
	DCC Albedo	Unfiltered Radiance	> 40 Km	Monthly	Cloud RS	High	All, Daytime	Inter-Instrument Agreement, Stability	SW	RS
	3-Channel Intercomparison	Unfiltered Radiance	>100 Km	Monthly	Various Earth	Across	All, Daytime	Inter-Channel consistency, Stability	TOT, SW, WN, LW	OLR, RS
	Time Space Averaging	Fluxes	Regional, Zonal, Global	Monthly, Yearly	Various Earth	Across	All	Inter-Instrument Agreement		OLR, RS
	Lunar Radiance Measurements	Filtered Radiance	Sub IFOV (7-10%)	1 day per lunar month	Lunar OLR and RS	Fixed, Low	N or S Pole	Relative Stability	TOT, SW, WN, LW	

At the end of the presentation we will compare results of the Internal Calibration Module and Lunar Observations

Executive Summary

The moon is NOT an adequate standalone calibration target for Spectrally broadband, Wide Angular Field of View, Absolute Radiometry sensors such as CERES.

However… It does play a role in the overall CERES Post Launch Cal/Val protocol

It presents itself as a highly unstable reflector (spatially nonuniform with insufficient spectral knowledge) calibration target that 'wobbles' in a galactic 'optical bench' where the key distances and illumination angles between source, reflector and measurement system vary rapidly and out of phase.

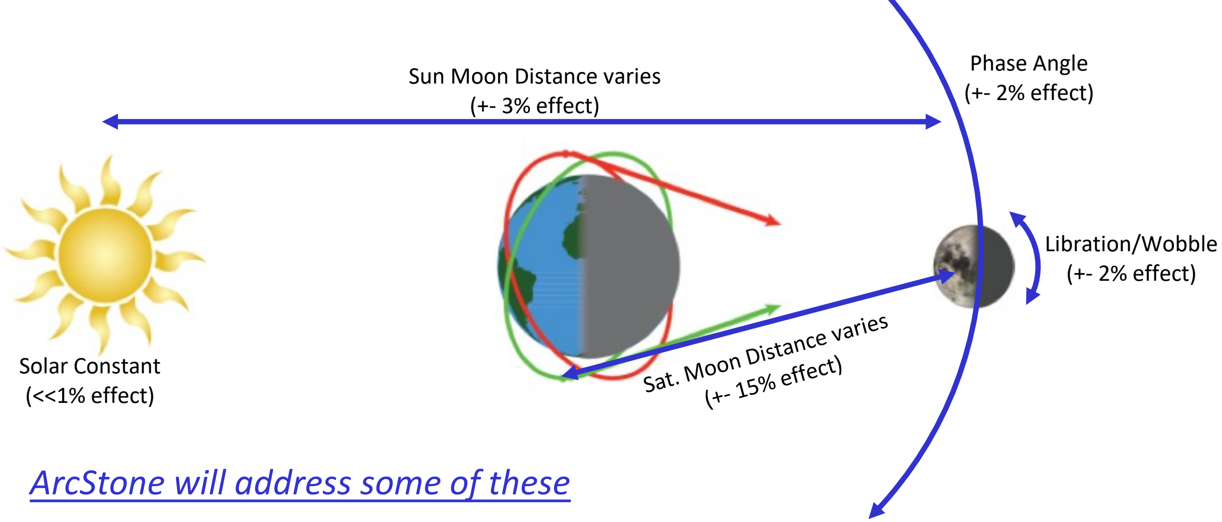
However… ROLO has, and ArcStone will in the future make important advances in characterizing these instabilities in the coming decade

Fully interpreted/corrected Lunar observations are consistent with all other elements of the cal/val protocol

1) Pointing Knowledge (supplements coastline detection experiment)
2) Co-alignment of the three science channels
3) Spatial/Angular uniformity of dynamic response in the sensor assemblies
4) Decadal trends consistent with those measured by onboard calibration sources (blackbodies and lamps)

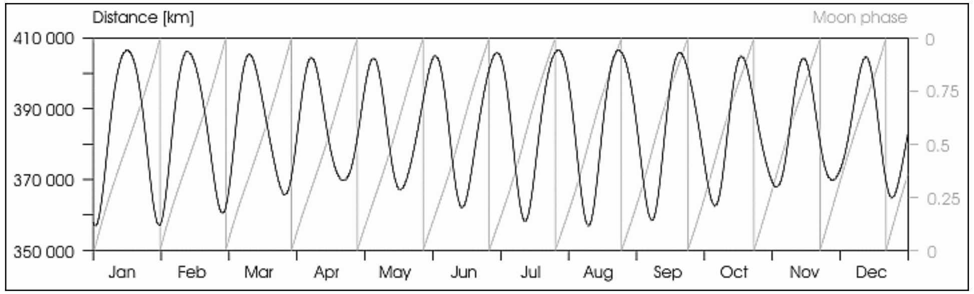
Lunar Cal Phenomena to be Untangled

Variation of illumination path lengths and angles



ArcStone will address some of these

Variation of Illumination Path Lengths and Angles all Have Unique Periodicity



The Sidereal and Synodic Months. The sidereal month is the time the Moon takes to complete one full revolution around the Earth with respect to the background stars. ... Thus, the synodic month, or lunar month, is longer than the sidereal month. **A sidereal month lasts 27.322 days**, while a synodic month lasts 29.531 days.

Mismatch of Lunar Disk Target Size to Optical system

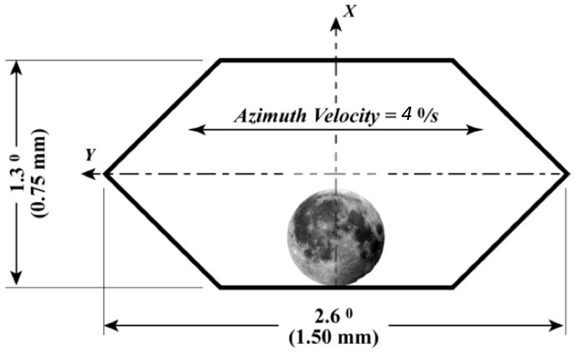
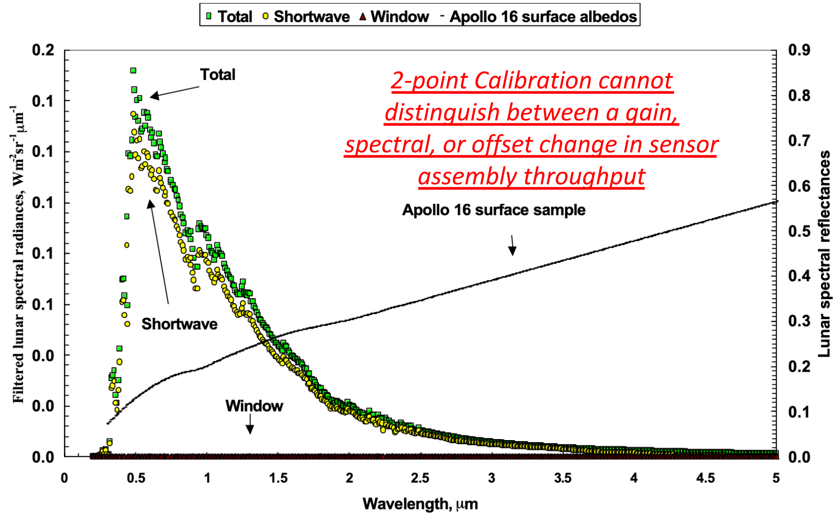


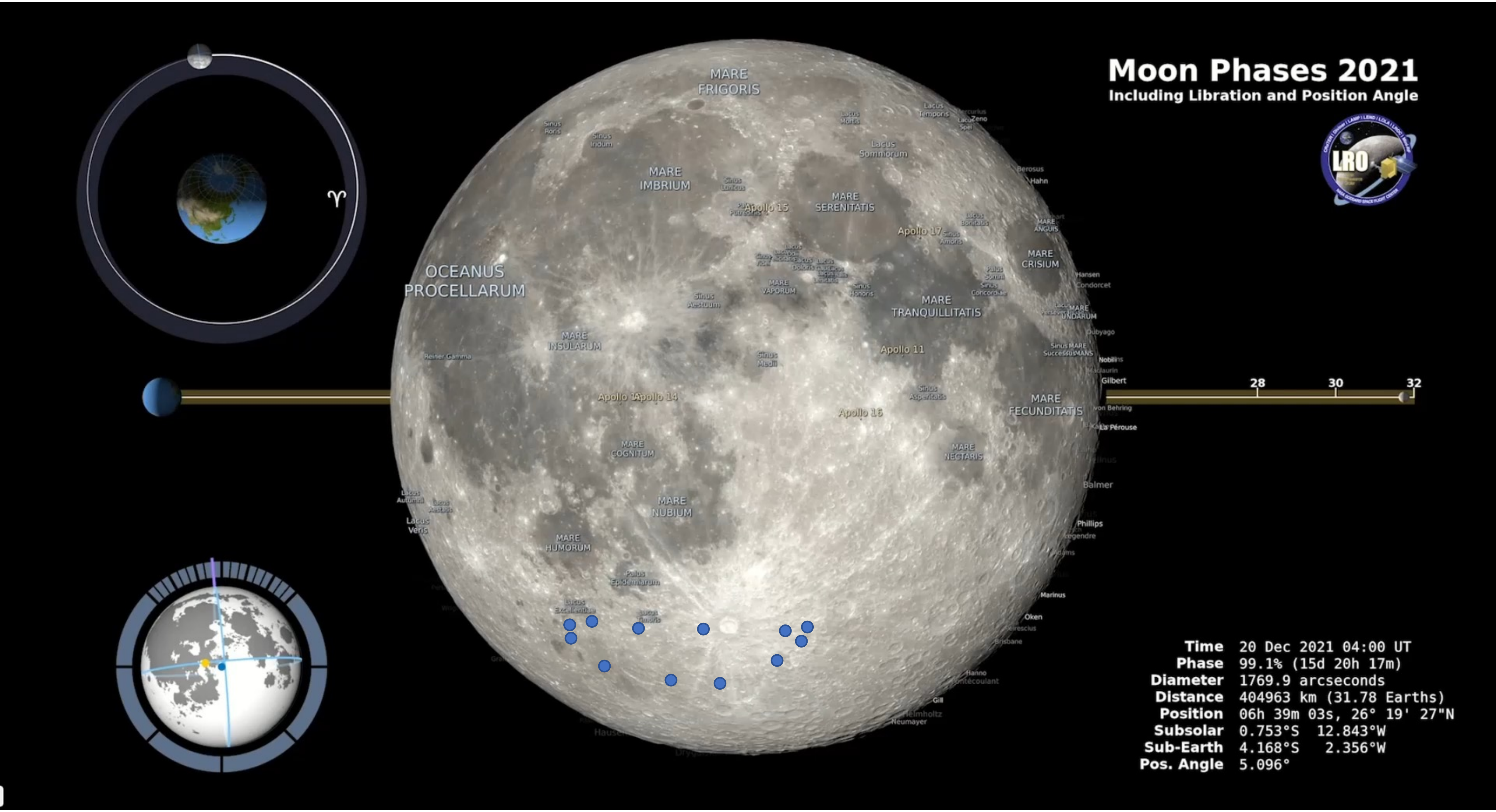
Fig. 3. Moon in CERES field of view

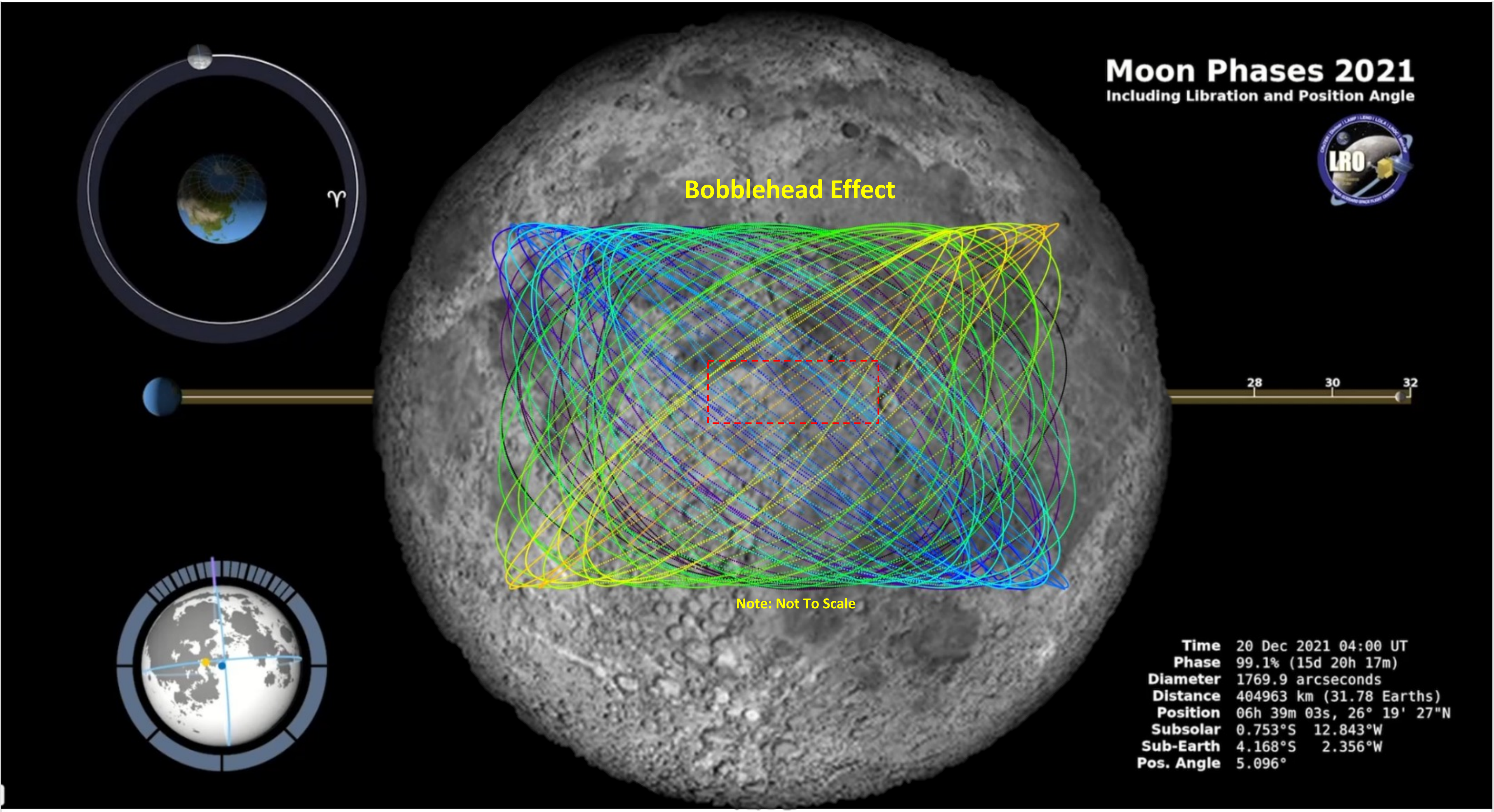
- Moon fills 7.4% of ceres FOV at perigee and 9.7% at apogee
  - yields time varying Solid angle of source illumination.
- >90% System etendue is 2K deep space background.
  - Yields Very low signal

Presents Minimal Variation in Integrated Spectral Radiance



~ A Case Study in how not to design a calibration experiment ~


Moon Phases 2021
Including Libration and Position Angle
LRO
MARE FRIGORIS
MARE IMBRIUM
MARE SERENITATIS
MARE CRISIUM
MARE TRANQUILLITATIS
OCEANUS PROCELLARUM
MARE INSULARUM
MARE FECUNDITATIS
MARE COGNITUM
MARE NECTARIS
MARE NUBIUM
MARE HUMORUM
Apollo 15
Apollo 17
Apollo 11
Apollo 14
Apollo 16
28
30
32
Time 20 Dec 2021 04:00 UT
Phase 99.1% (15d 20h 17m)
Diameter 1769.9 arcseconds
Distance 404963 km (31.78 Earths)
Position 06h 39m 03s, 26° 19' 27"N
Subsolar 0.753°S 12.843°W
Sub-Earth 4.168°S 2.356°W
Pos. Angle 5.096°


Moon Phases 2021
Including Libration and Position Angle
LRO
Bobblehead Effect
Note: Not To Scale
28
30
32
Time 20 Dec 2021 04:00 UT
Phase 99.1% (15d 20h 17m)
Diameter 1769.9 arcseconds
Distance 404963 km (31.78 Earths)
Position 06h 39m 03s, 26° 19' 27"N
Subsolar 0.753°S 12.843°W
Sub-Earth 4.168°S 2.356°W
Pos. Angle 5.096°

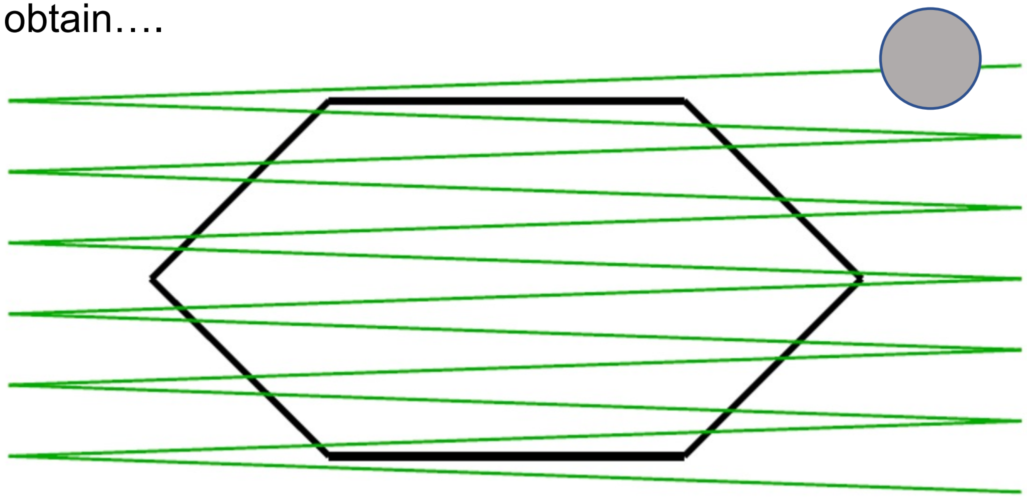
Lunar Observation Experimental Design

Objective: Utilize the moon as a quasi-point source to complete a near steady-state raster scan across the CERES FOV to support Cal/Val activities

Goals

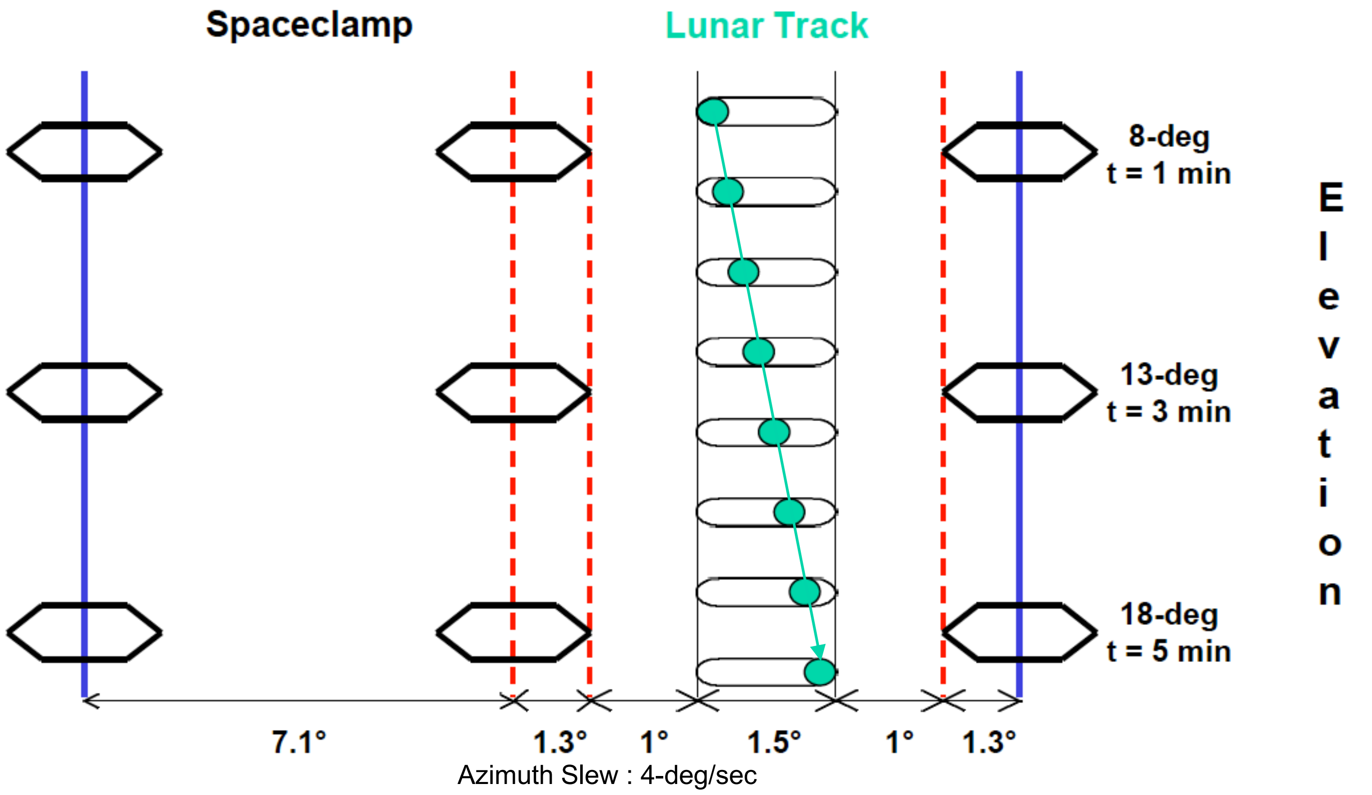
- Validate pre-launch alignment measurements ***(dedicated observations began in April 2001)*** ***(Ipod released May 2001)***
- Measure inter-channel relative pointing accuracy, (i.e. co-registration of telescopes)
- Map out system level spatial non-uniformities in the CERES Optics/Detectors
  - Detector Requirement is +-10% from raster scan focused spot across the detector (component test)
  - This type of mapping is not performed ***under vacuum*** prior to launch
- Develop data set for long term stability measurements utilizing lunar radiances (***stable protocol since 3/2006***)

By combining knowledge of the motion of the moon relative to the spacecraft and the programmability of the CERES Instruments we obtain….



Detectors view of the moon passing through the FOV

Lunar Observation Experimental Design



Elevation Gimbal is fixed at one of three pre-determined angles above the earth's limb

Elevation Gimbal completes an out and back rotation in 6.6 second data packet

Earth Limb

Operation is completed for the five orbits before and after full moon each lunar month

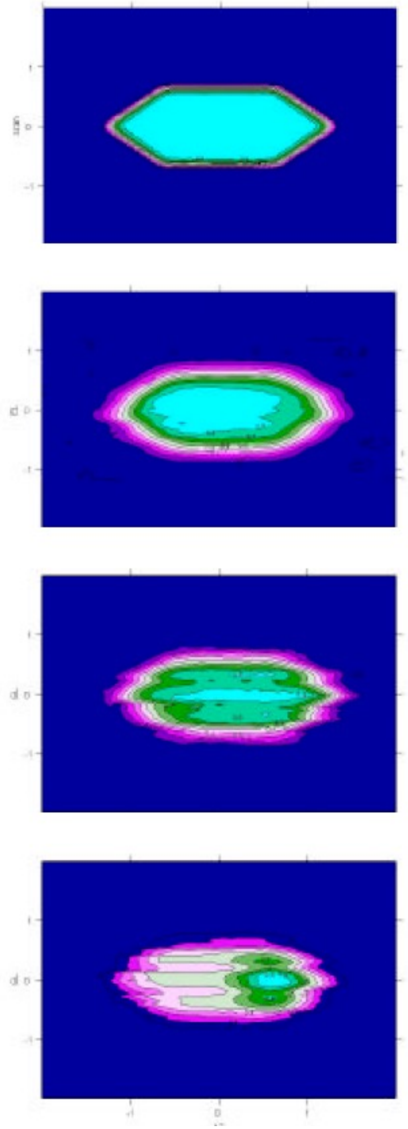
Lunar Scanning Results – CERES Optical Transfer Function

Monte-Carlo Ray Trace (FELIX)

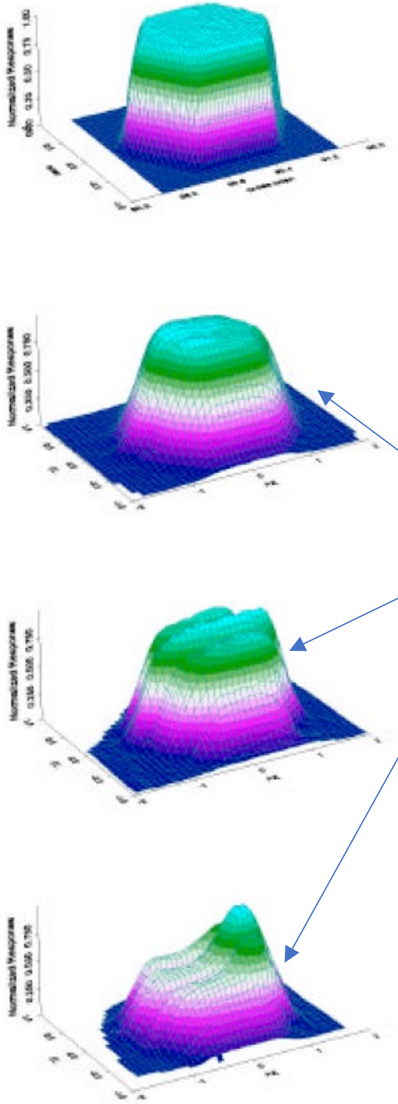
FM-2 Total

FM-2 Shortwave

FM-2 Window



Confirms alignment and co-registration



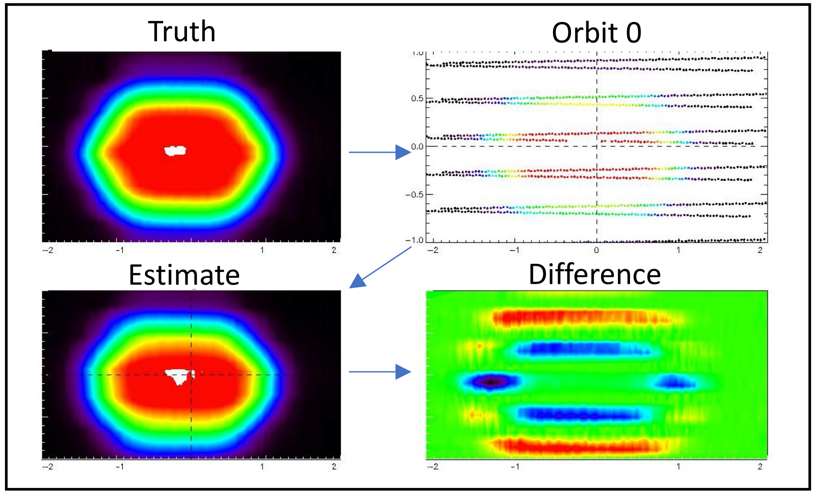
Displays non-uniformity in Response

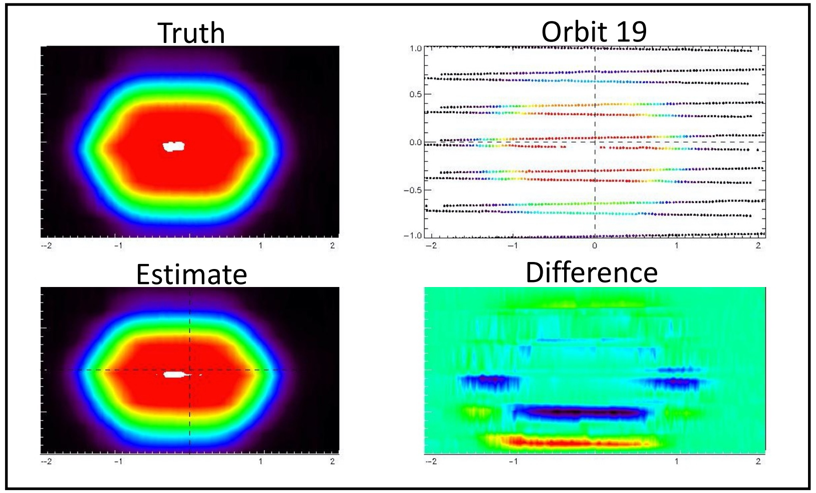
Integrating across the transfer function provides an estimate of full-field lunar signal

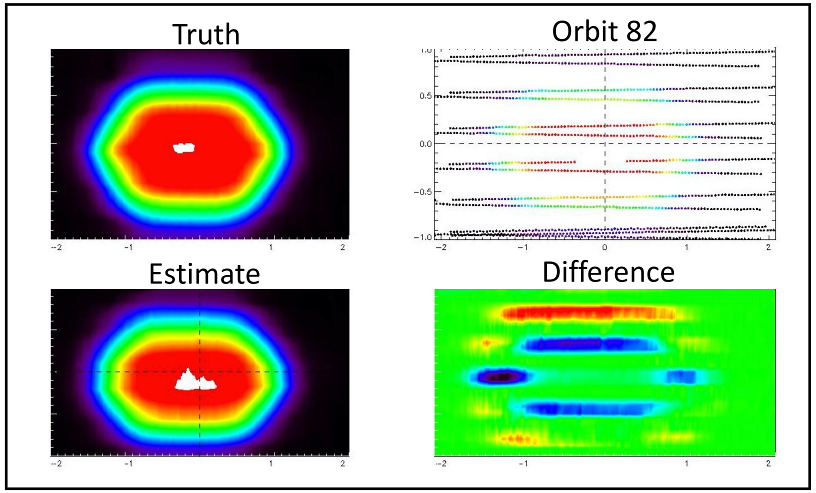
How accurately can this be accomplished with sparsely sampled data?

Lunar Observation Angular Sampling Study

Study to quantify the impact of sampling pattern on estimating equivalent full field lunar radiance

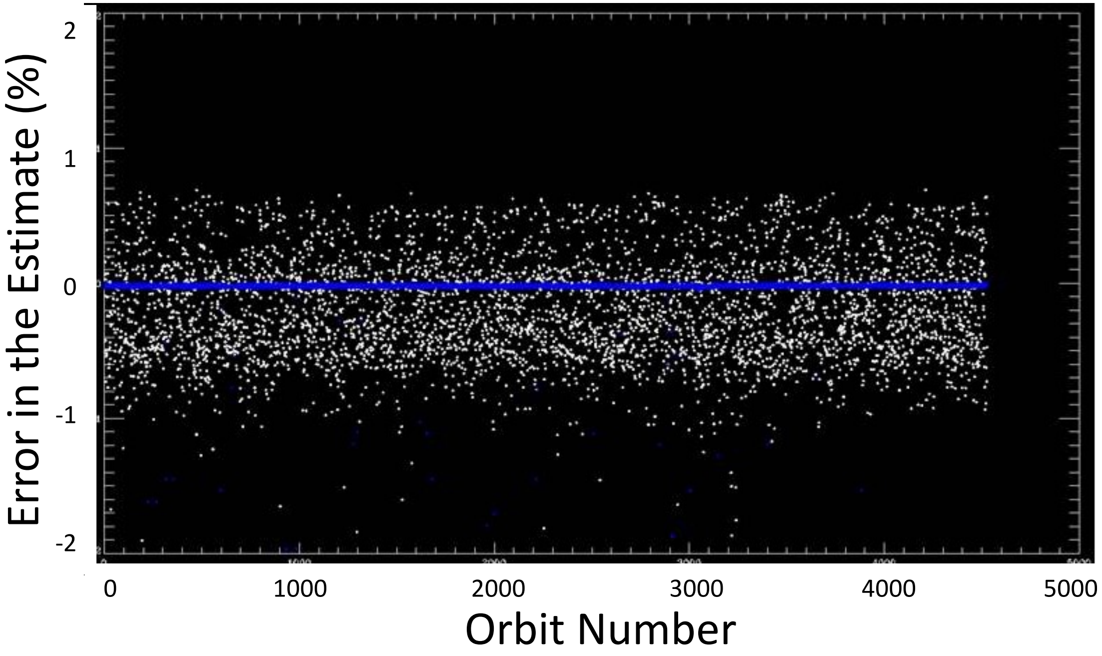






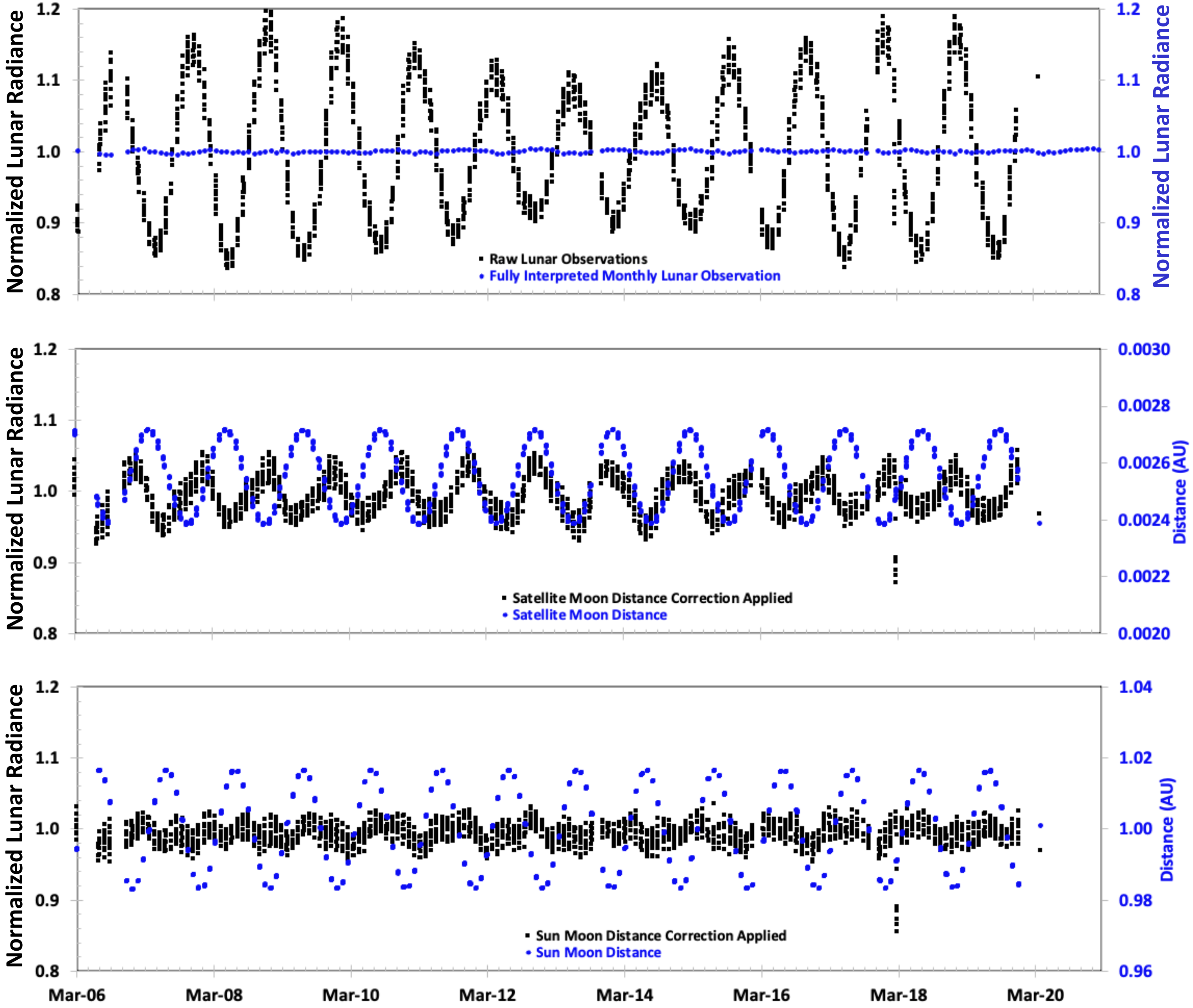
Error in the process of Estimating equivalent Full Field Observed Radiance from a sub Full Field Raster Scan

~+-0.3% (k = 1)



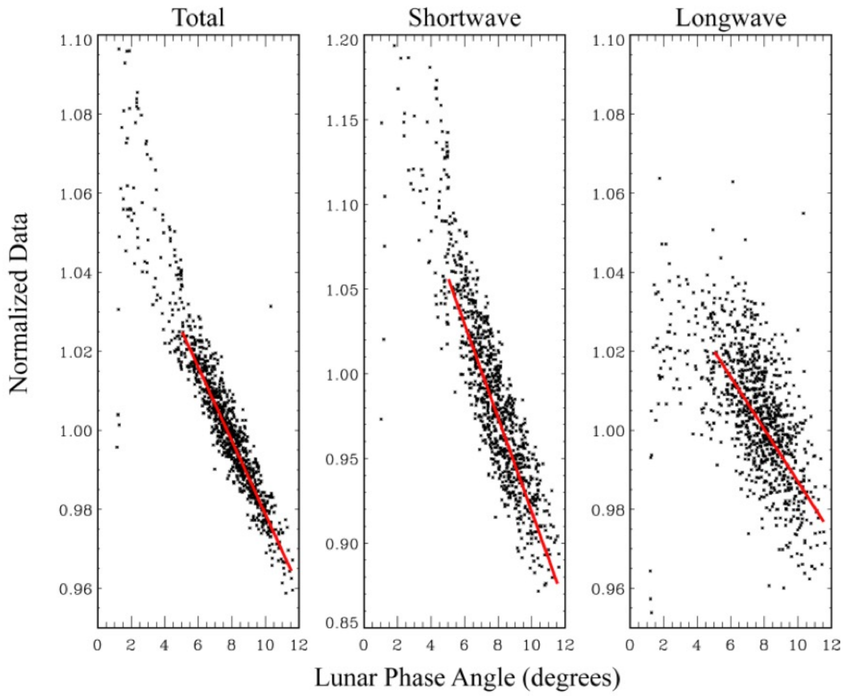
FM1 Total Channel : 2006 to 2021

Moon presents itself to CERES as a time varying target of ~+-20%



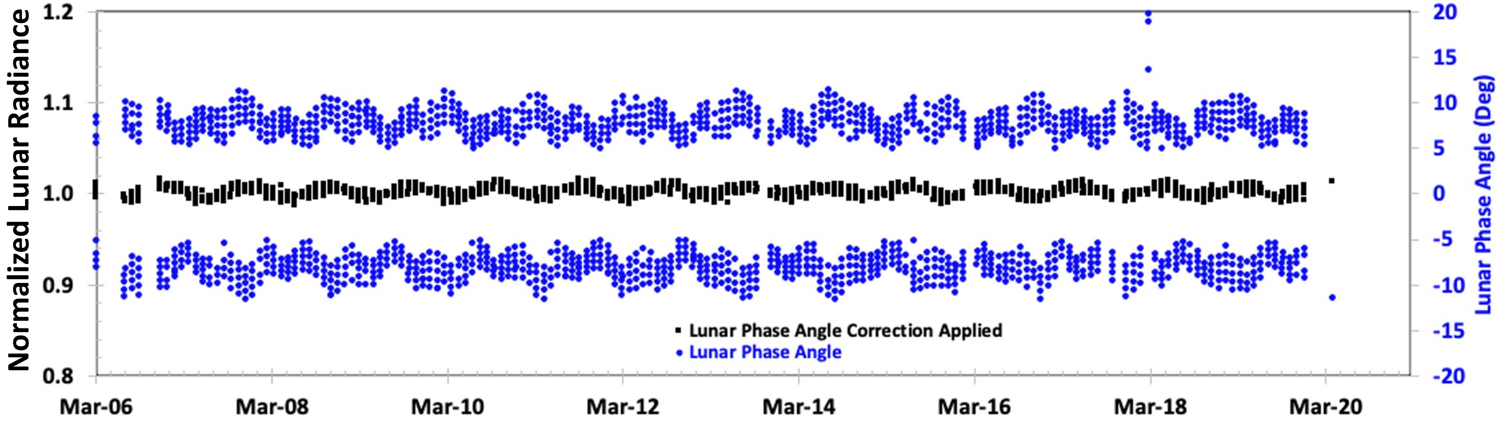
Once Fully Interpreted Variability is at ~+-1%

FM1 Total Channel : 2006 to 2021

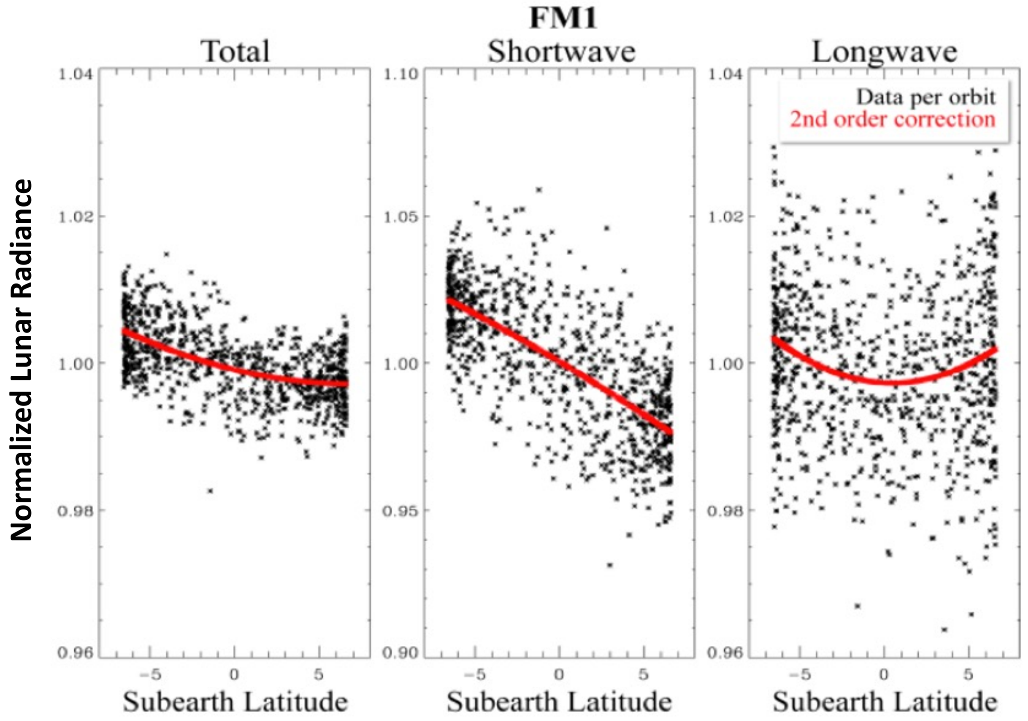


Shortwave Channel Sensitivity to Lunar Phase Angle 2X Total and Longwave

Correct Lunar Observations to an 8-deg Lunar Phase Angle



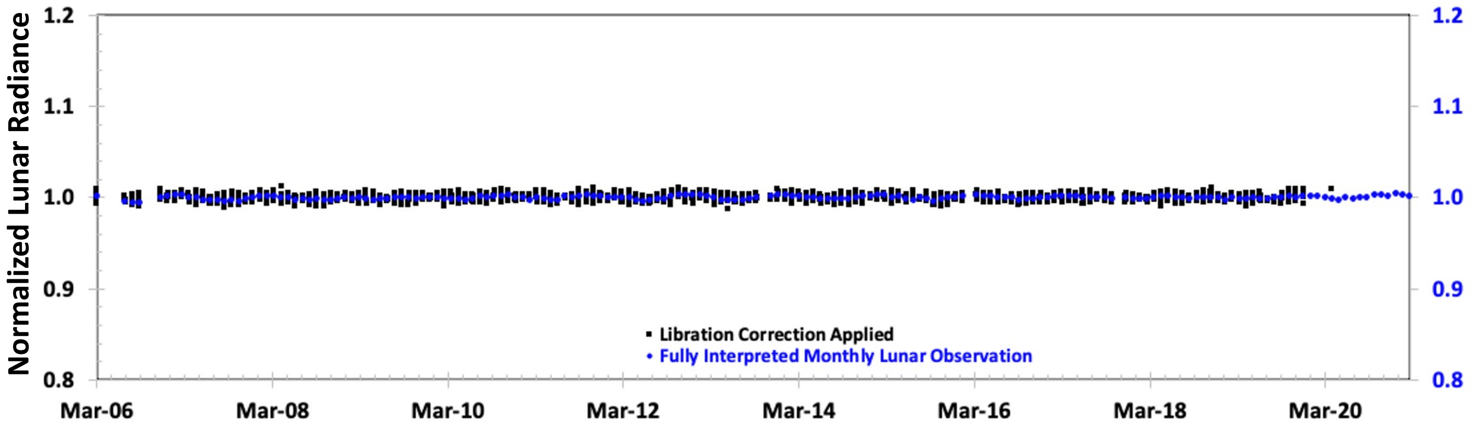
FM1 Total Channel : 2006 to 2021



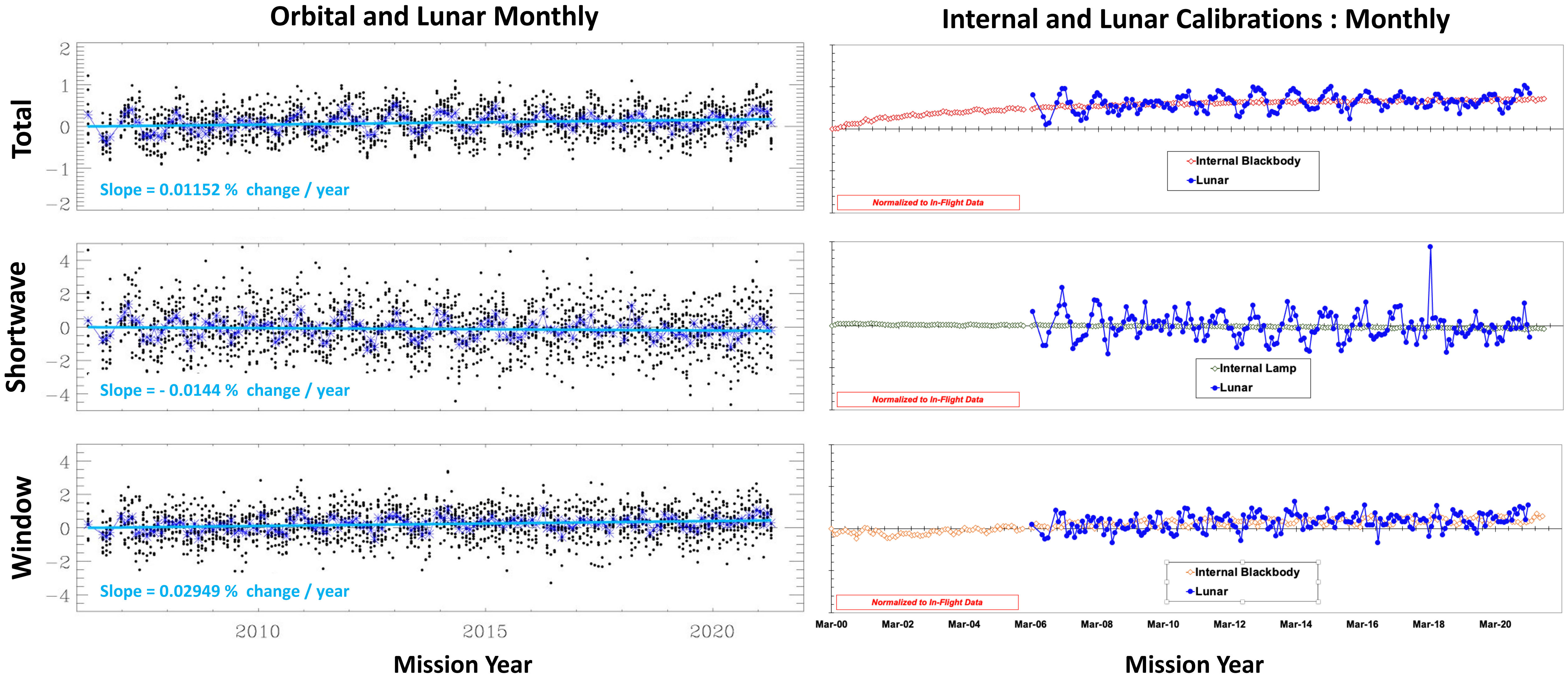
Shortwave Channel Sensitivity to Lunar Libration 2X Total and Longwave

Note: Longitude Correction Not Shown

Correct Lunar Observations to an 8-deg Lunar Phase Angle

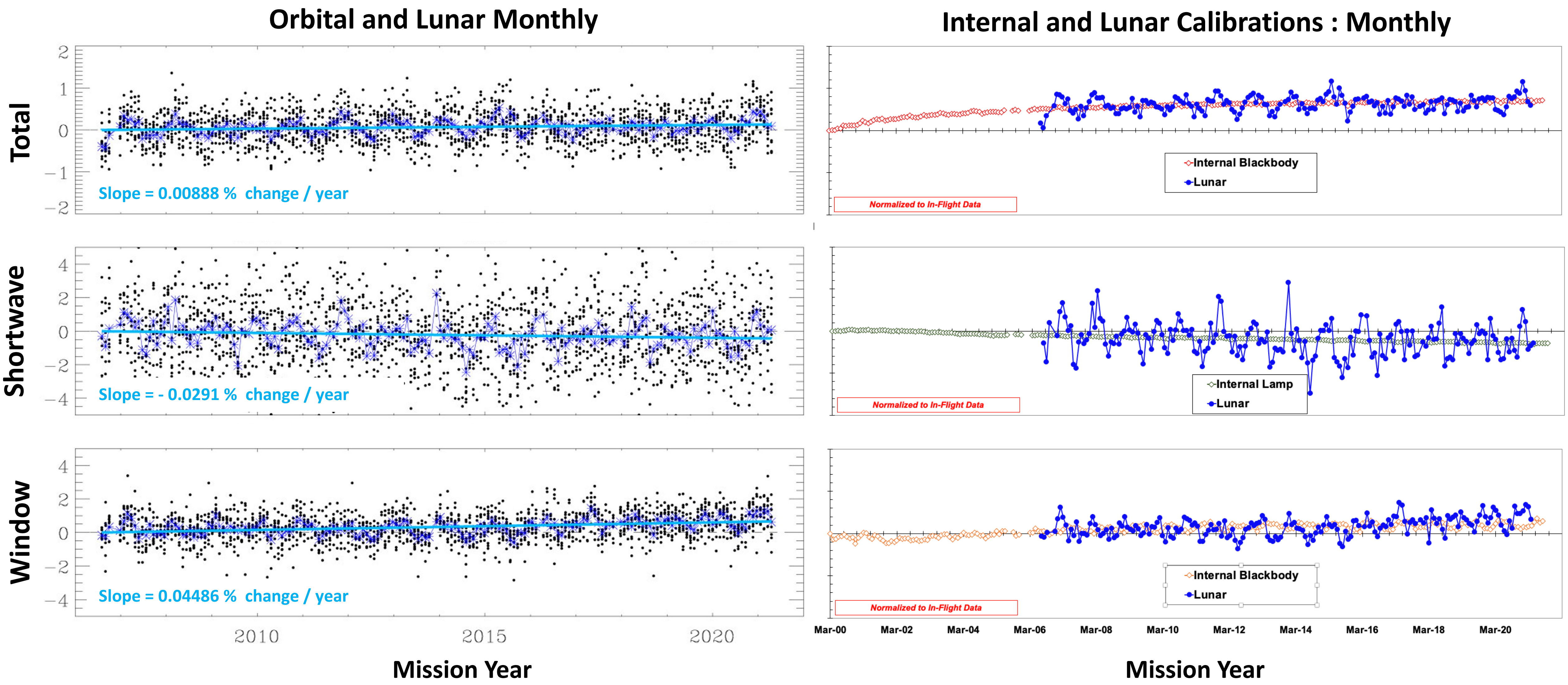


FM-1 Lunar and Internal Calibration
Normalized Trend Comparison (%)



Results display instrument artifacts that have been removed in the Edition-4 Products

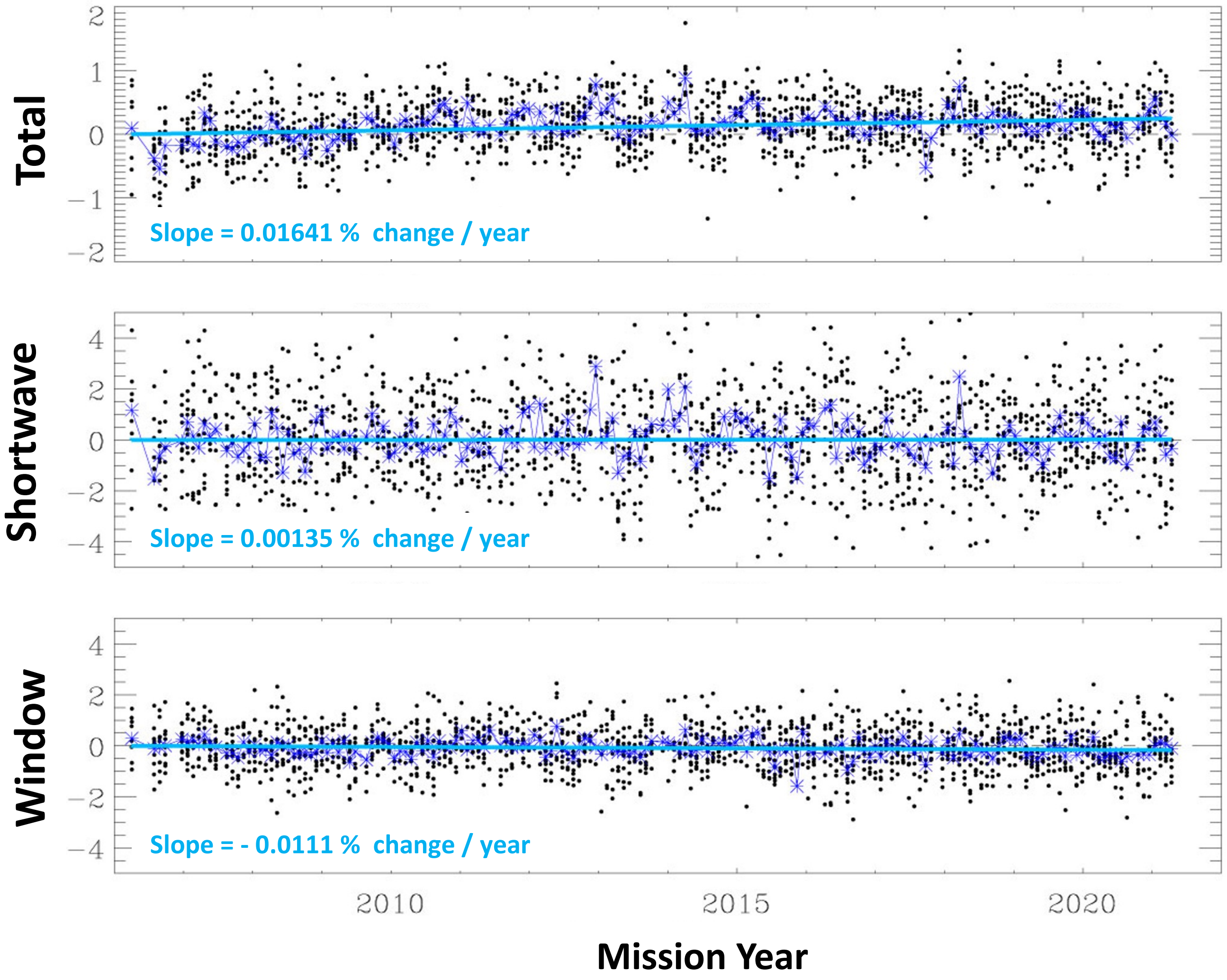
FM-2 Lunar and Internal Calibration
Normalized Trend Comparison (%)



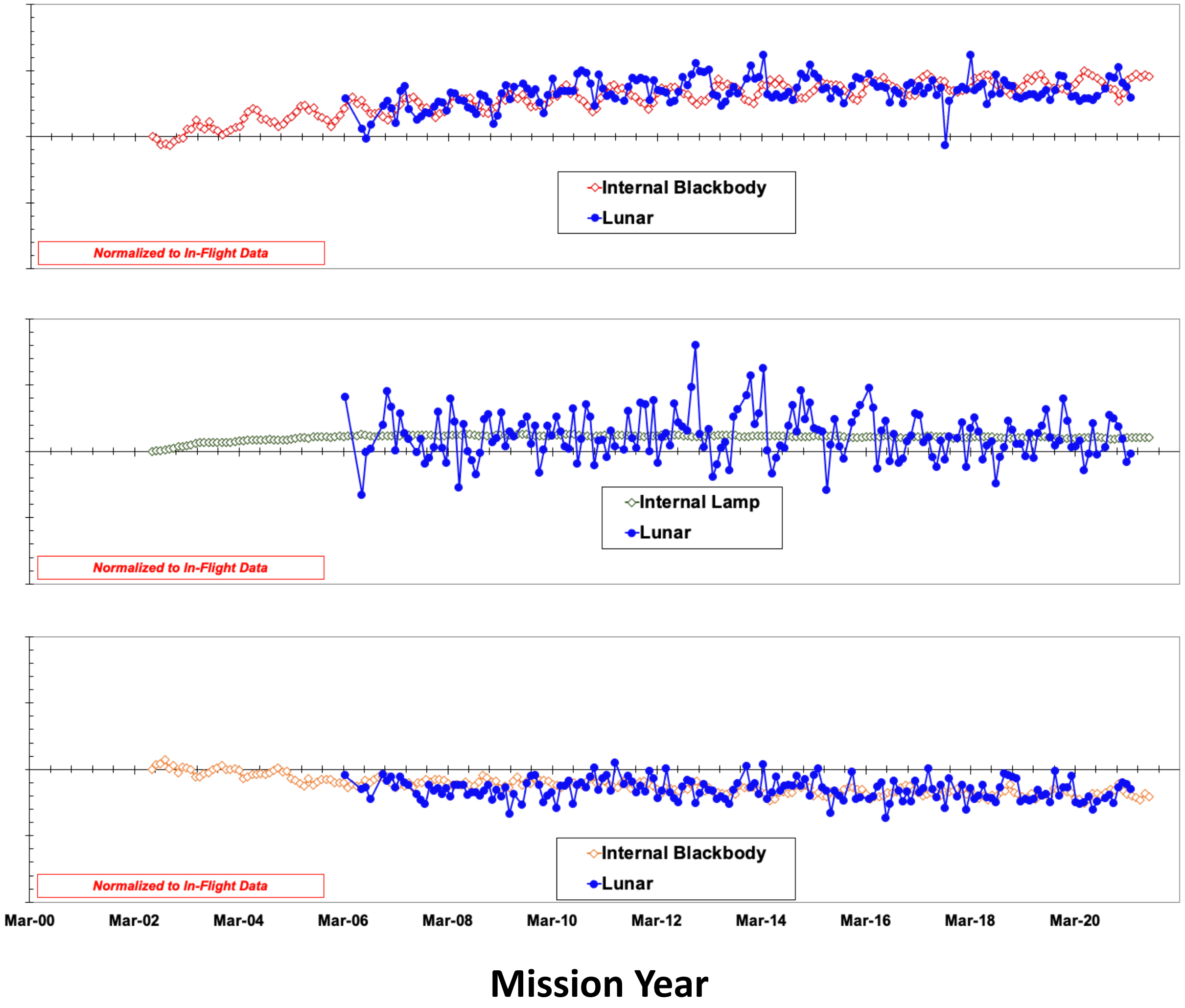
Results display instrument artifacts that have been removed in the Edition-4 Products

FM-3 Lunar and Internal Calibration
Normalized Trend Comparison (%)

Orbital and Lunar Monthly

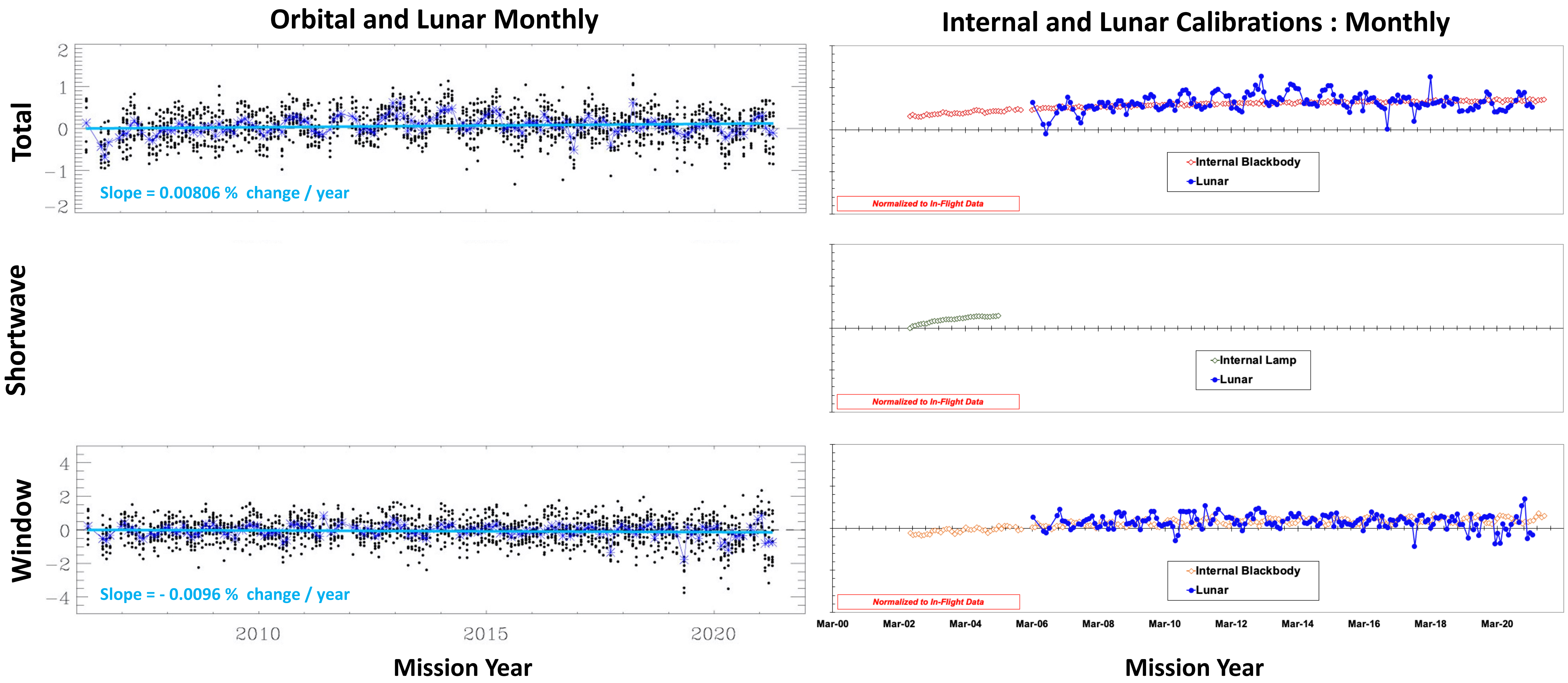


Internal and Lunar Calibrations : Monthly



Results display instrument artifacts that have been removed in the Edition-4 Products

FM-4 Lunar and Internal Calibration
Normalized Trend Comparison (%)



Results display instrument artifacts that have been removed in the Edition-4 Products

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2) **Co-alignment of the three science channels**
3) **Spatial/Angular uniformity of dynamic response in the sensor assemblies**
4) **Decadal trends consistent with those measured by onboard calibration sources (blackbodies and lamps)**

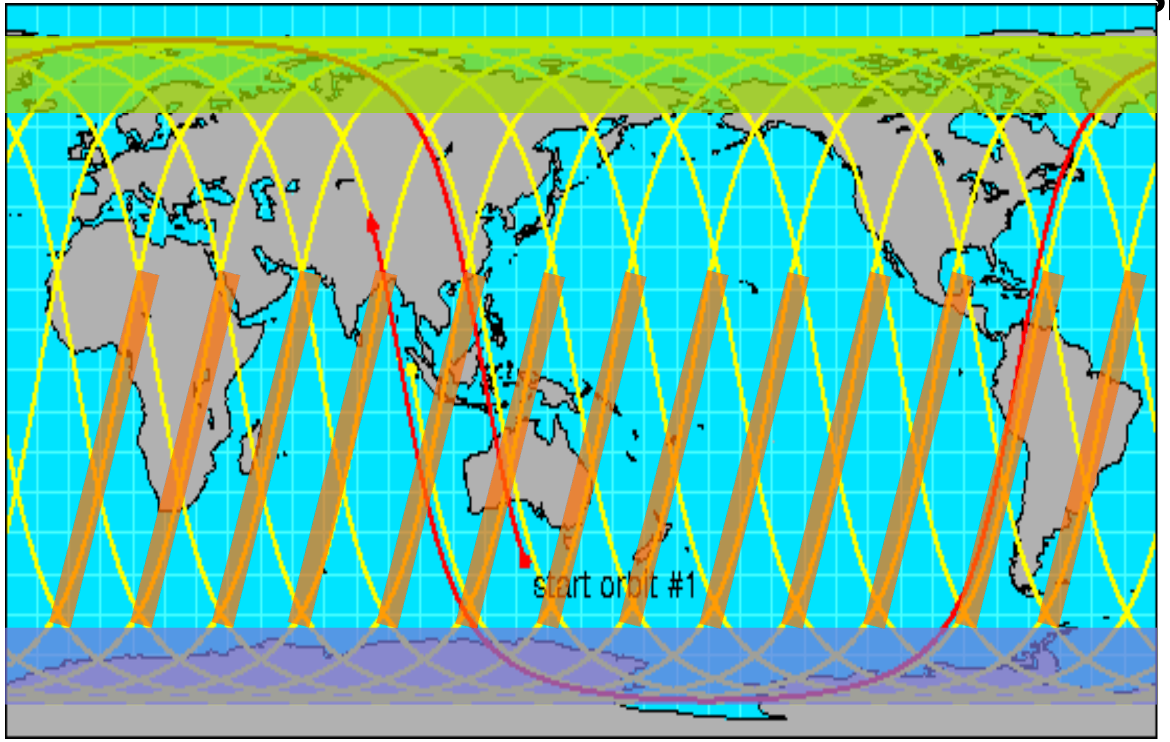
Back-up

Flight Cal/Val Locations

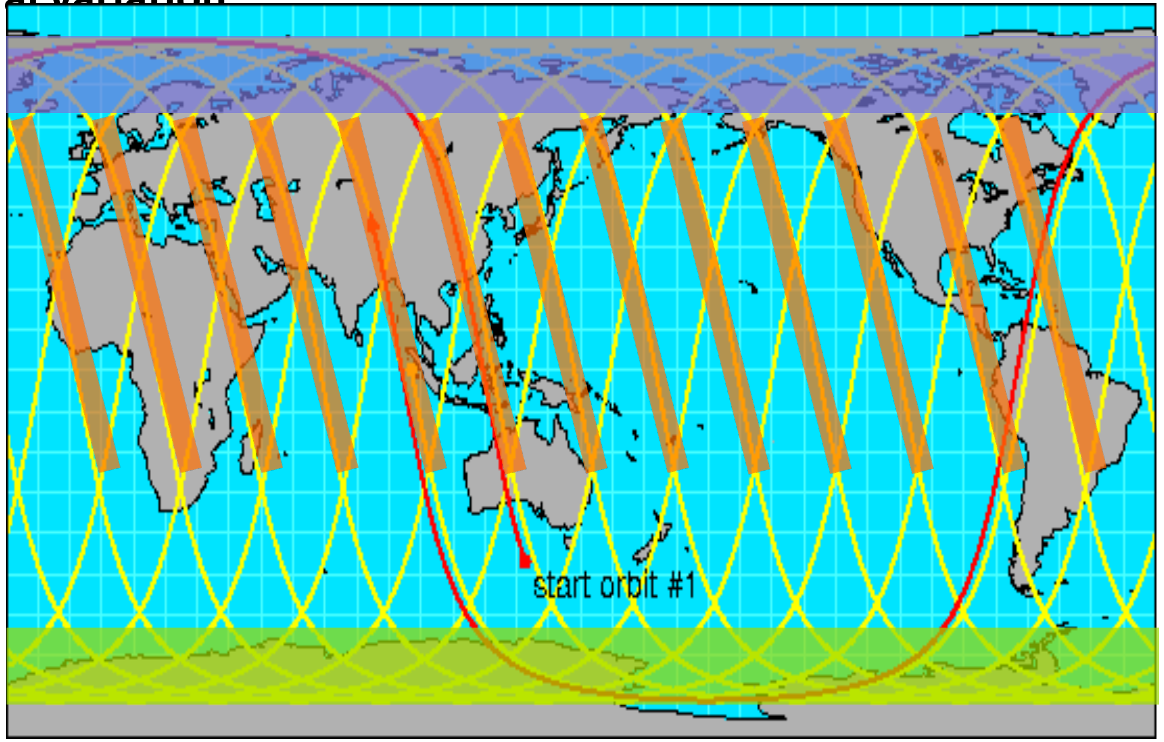
Still not corrected for:

Spectral variation

Aqua

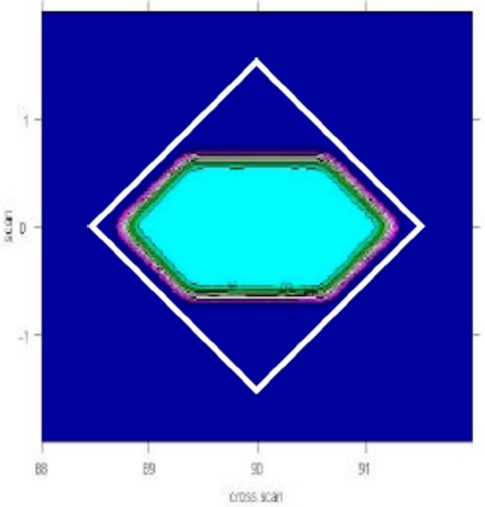


Terra



- Lunar Observations
- Solar Calibrations
- Internal Calibration Sequence

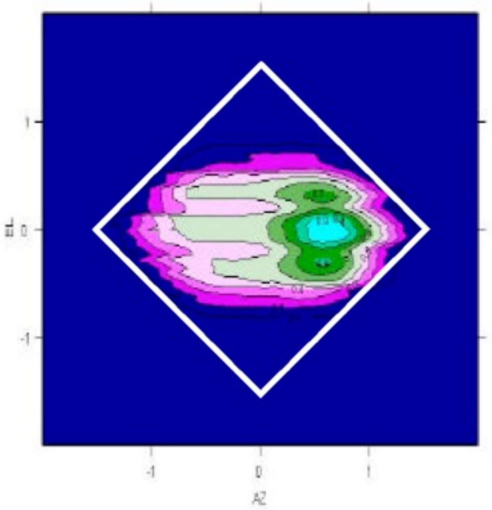
Monte-Carlo Ray Trace



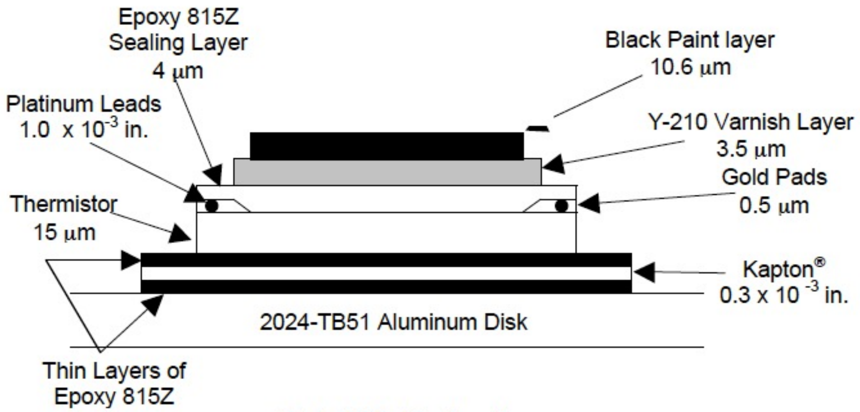
FM-2 Window Channel

- **One quadrant of detector has an extremely high responivity**
- **Probably due to localized delamination of detector due to air-bubbles in the lower Epoxy layers.**
  - Consistent with known fabrication problems at the time these detectors were made.
- **The resulting void would provide a higher local thermal impedance**
  - Inducing higher temperatures in thermistor layer
  - Result in a slower time constant
  - Much longer air-to-vacuum stabilization time

FM-2 WN Channel

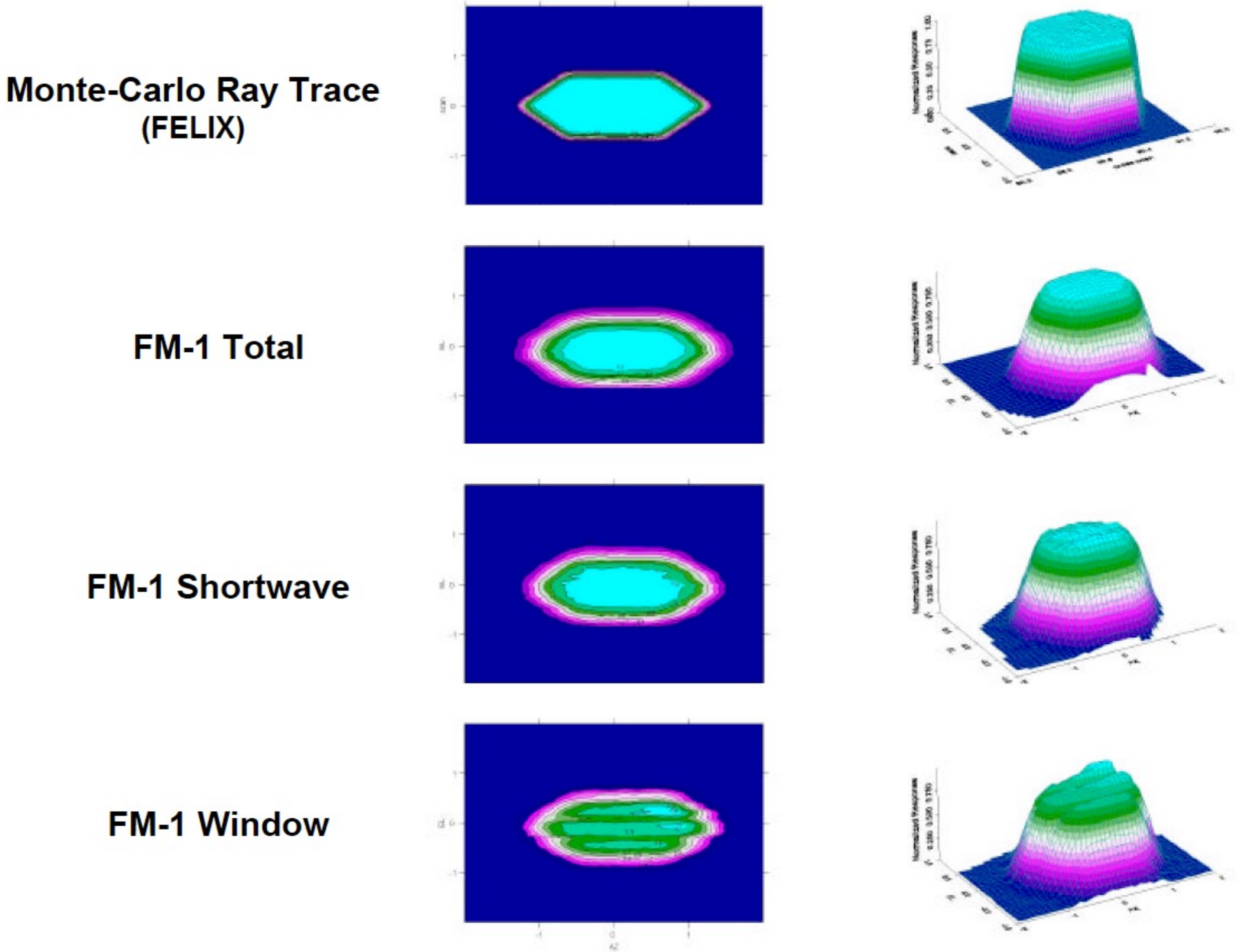


Very stable radiometric performance on orbit!!!!!



CERES Detector

Lunar Scanning Results – CERES Optical Transfer Function



- No longer have working group meetings at Science Team so thought we would initiate individual focused presentations on each of the cal val activities
- Recognize arcstone selection
- Provide inputs to costy and Cindy on CERES perspective
- Timeline of when and why we executed lunar scanning

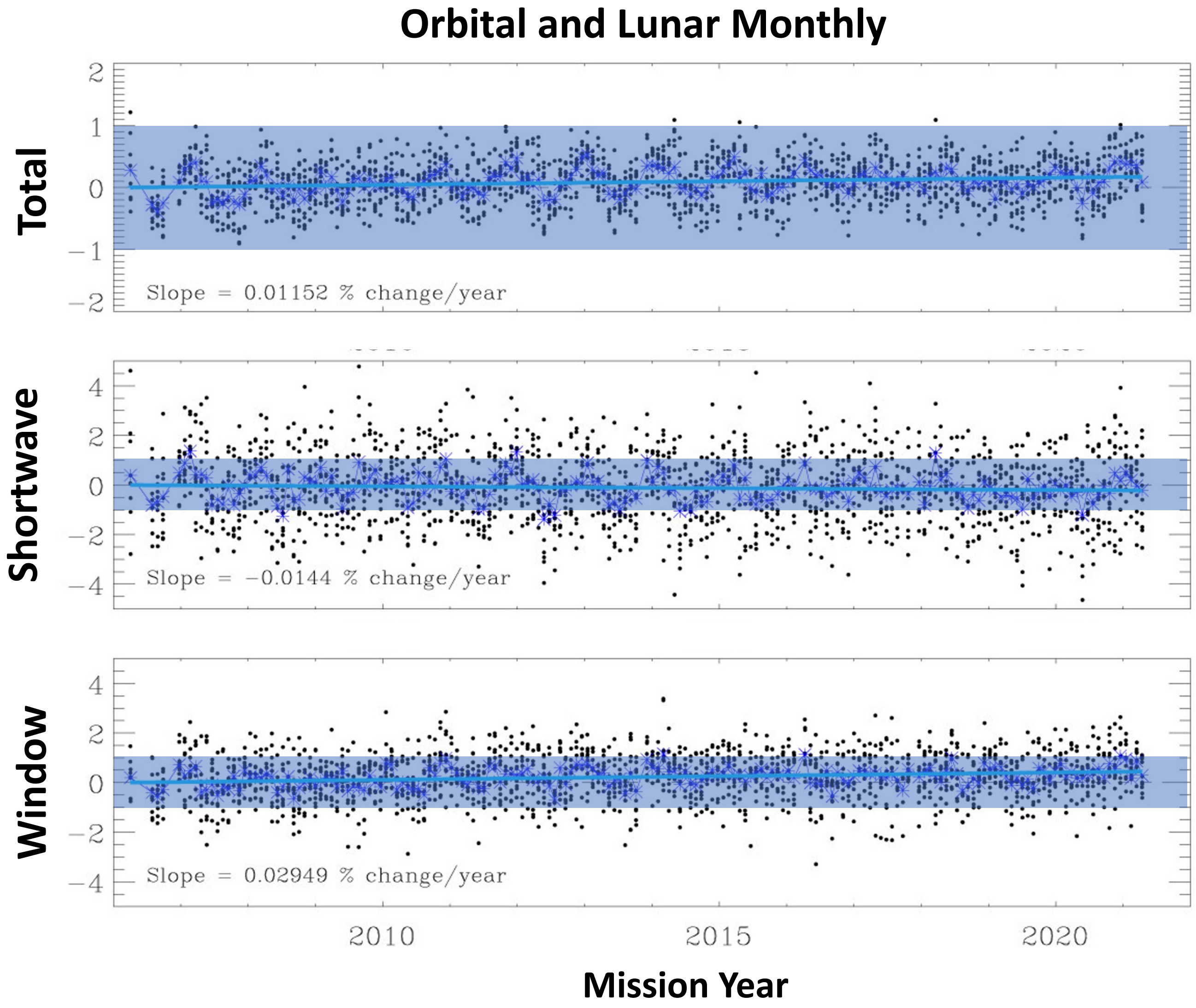
- Wide field telescope introduces it's own uniqueness vs imagers with much smaller IFOV

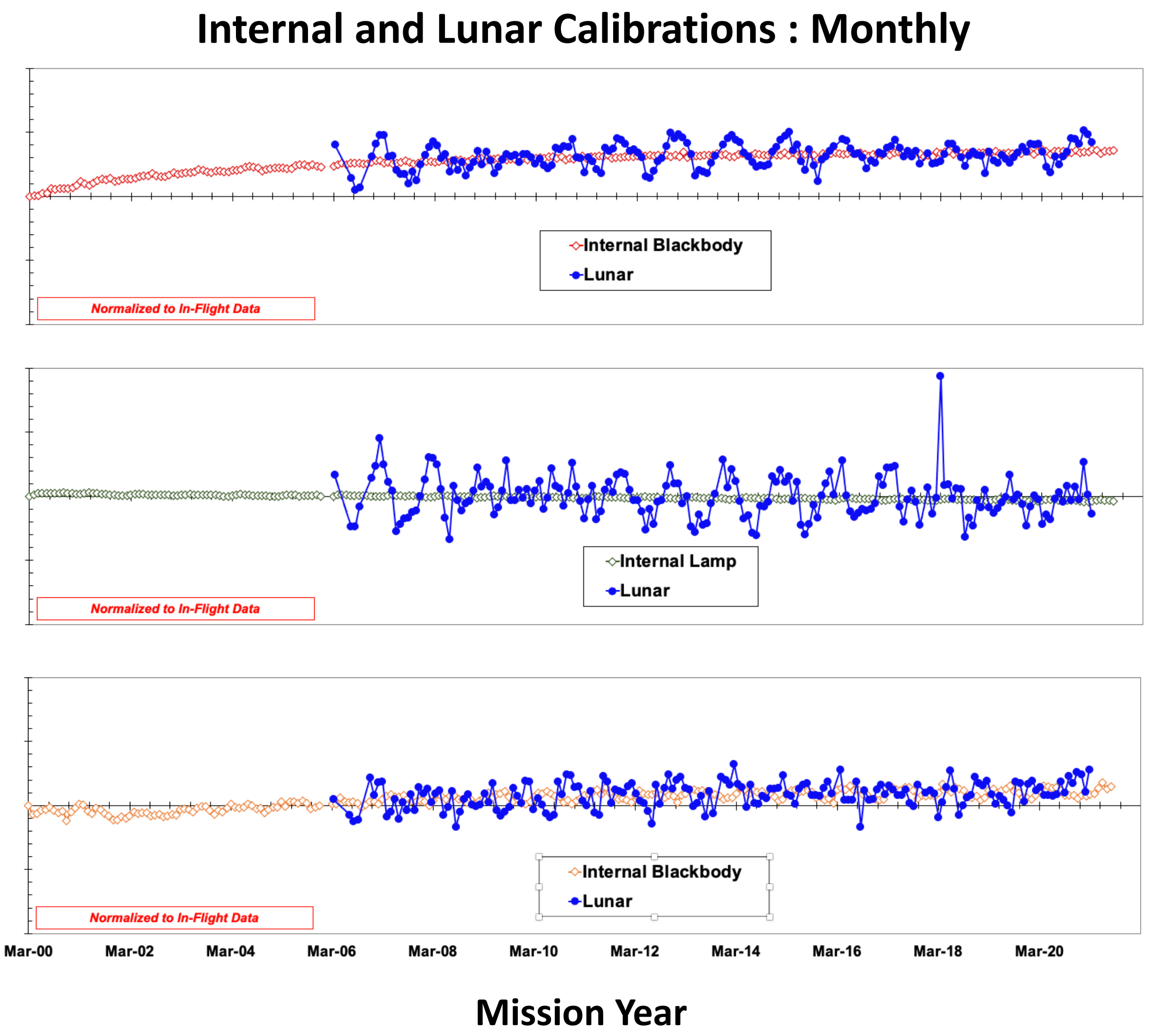
- Phases of experiment
- Operations to sample
- Analysis of collected data (Arcstone may help here)
- Comparison to other cal/val experiment results

- Lunar reflectance plot
-

  Time scales…. Lunar is one data point per month
- See calcon plot for where calibrations occur
- The moon is okay for what it is, but it's really only one element in an overall cal/val protocol

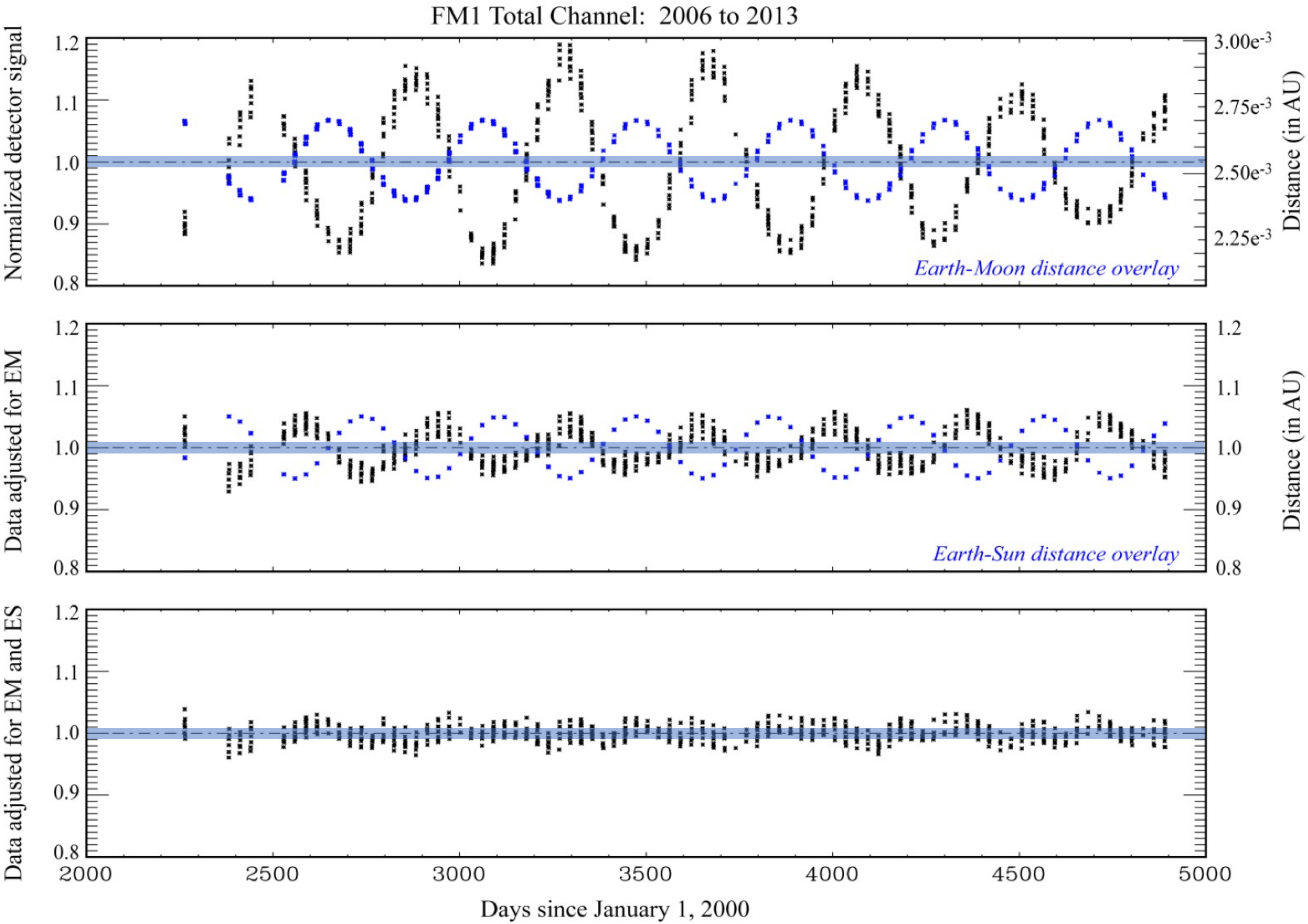
FM1 Lunar and Internal Calibration Trend Comparison (%)





Moon presents itself to CERES as a time varying target of ~+-20%

To be useful peak to peak variability/noise must be reduced to better than +-1%.



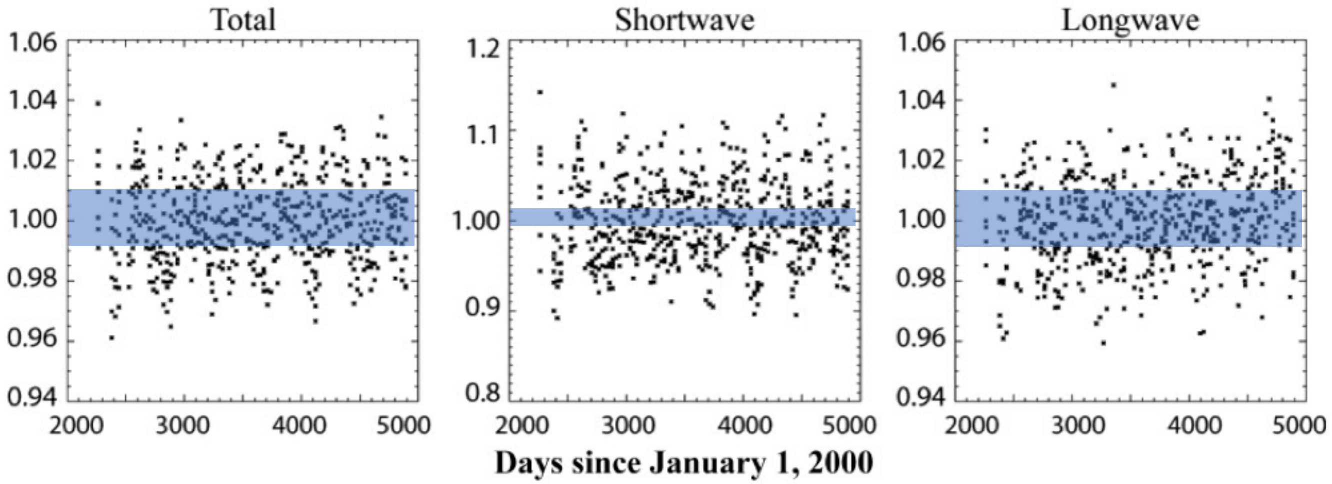


Fig. 11. CERES FM-1 detector response before lunar phase angle adjustment.

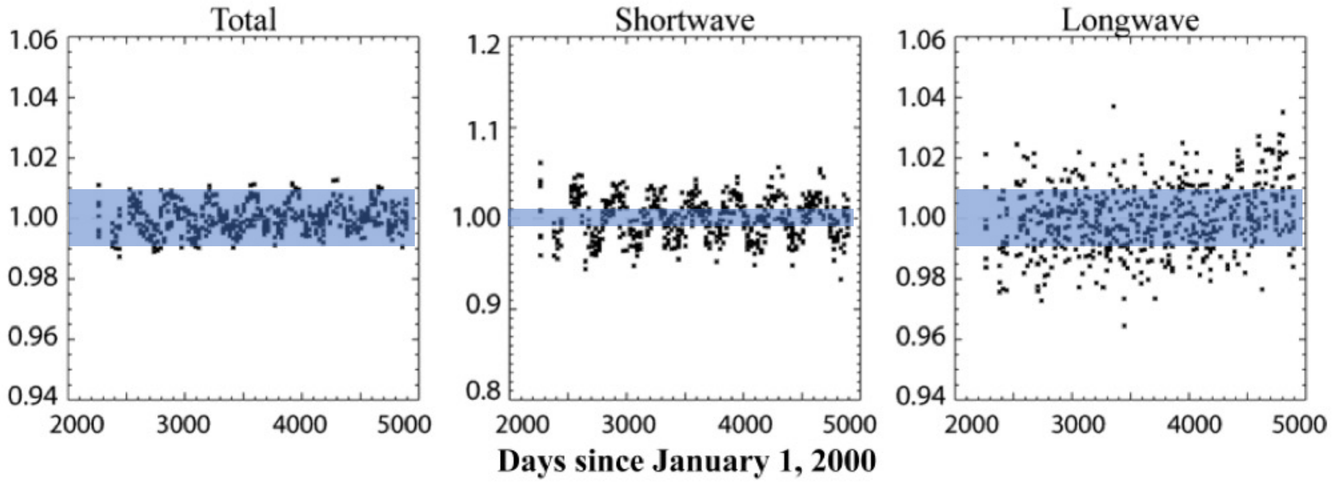


Fig. 12. CERES FM-1 detector response after lunar phase angle adjustment.

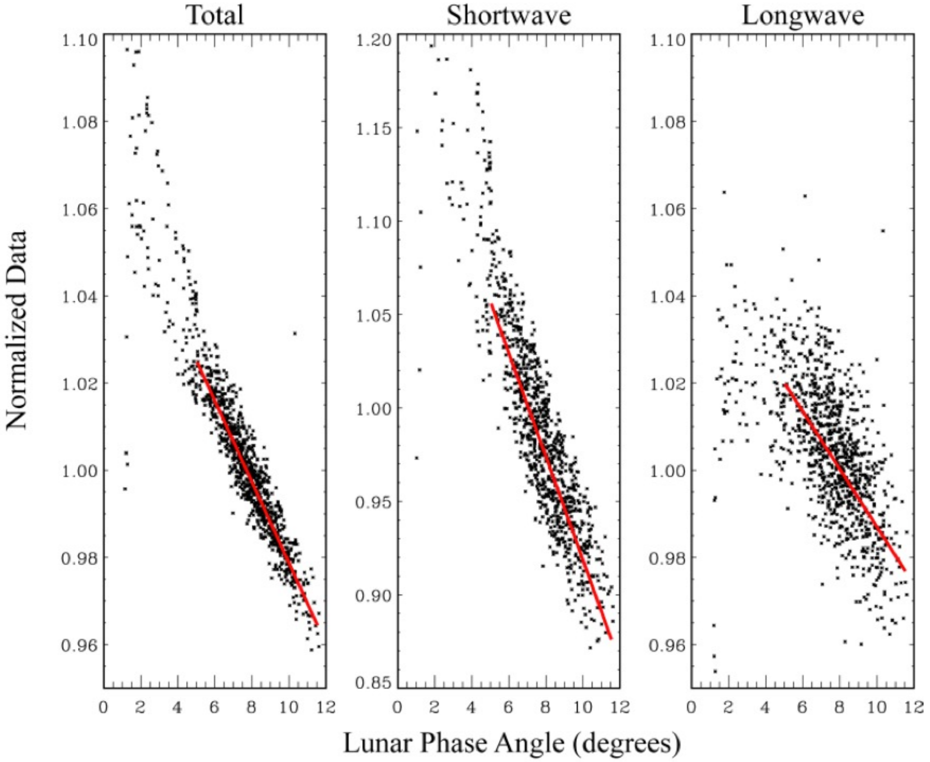


Fig. 10. Lunar Phase Angle and CERES detector response

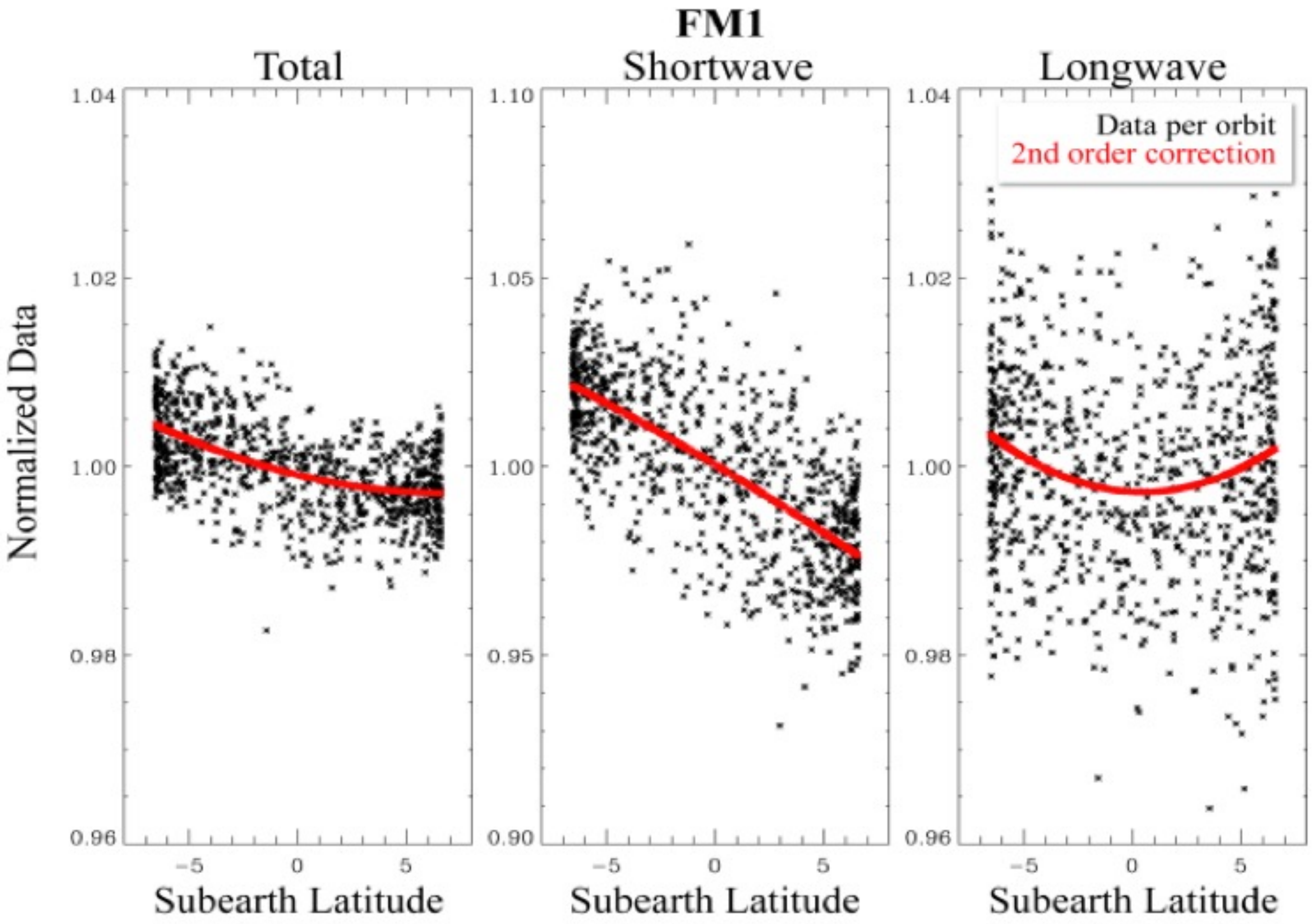


Fig. 14. FM-1 detector output versus lunar libration latitude.

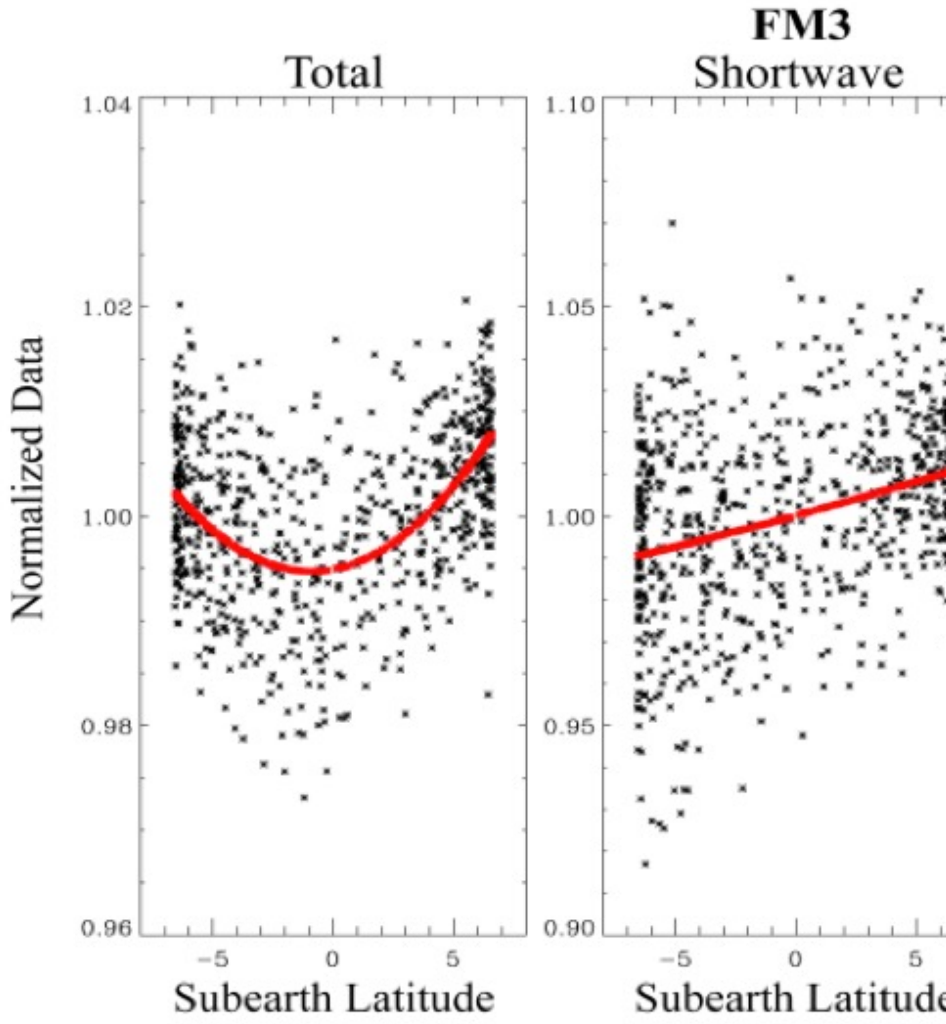


Fig. 15. FM-3 detector output versus lu