Traceability to the GIRO and ROLO

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- **Potential Improvements of ROLO/GIRO Traceability and Accuracy (open discussion)**

Background

- **Objective**
  - Present ideas and concepts to ensure traceability for the ROLO model, the GIRO (that should follow the ROLO developments) and the traceability to MODIS within the context of inter-calibration / cross-calibration (*Wagner*)

- **Calibration and Traceability**
  - Calibration: comparisons with standards or references
  - Traceable calibration: calibration with traceable standards or reference materials from national or international standards institutes or laboratories
  - Traceability: an unbroken chain of comparisons with stated uncertainties (UC)
  - SI traceability (SI units: m, kg, s, A, K, mol, cd)

ROLO and GIRO Traceability

- **ROLO Traceability**
  - Tied to the ROLO measurements of the star Vega
  - Its UC includes UC for the Vega and that from atmospheric correction
  - Current UC of the ROLO absolute irradiance: 5-10%
  - *Future improvement (e.g. NIST and NASA effort)*

- **GIRO Traceability**
  - Tied to ROLO with an UC that includes ROLO UC and implementation error
  - Current UC should be at the same level of ROLO as the difference between ROLO and GIRO is very small (<1%?)
  - *Future improvement and alternative approach for the GSICS community*

See Tom's Presentations

MODIS Calibration Traceability

- **Calibration accuracy requirement: ±2% for reflectance factors and ±5% for radiances at typical scene radiances within a ±45^o scan angle range**
- **Reflectance based calibration via an on-board solar diffuser (SD)**
- **Key calibration parameters (methodology dependent)**
  - **Pre-launch (3 key parameters)**
    - SD BRF: characterized with traceability to NIST reflectance scale
    - Instrument temperature Effect: Characterized at 3 instrument temperature plateaus
    - Response versus Scan Angle (RVS): characterized over a number of scan angle (relative measurements)
  - **On-orbit (2 key parameters)**
    - SD BRF degradation: tracked by an on-board stability monitor
    - SD screen vignetting function: derived from observations during spacecraft yaw maneuvers

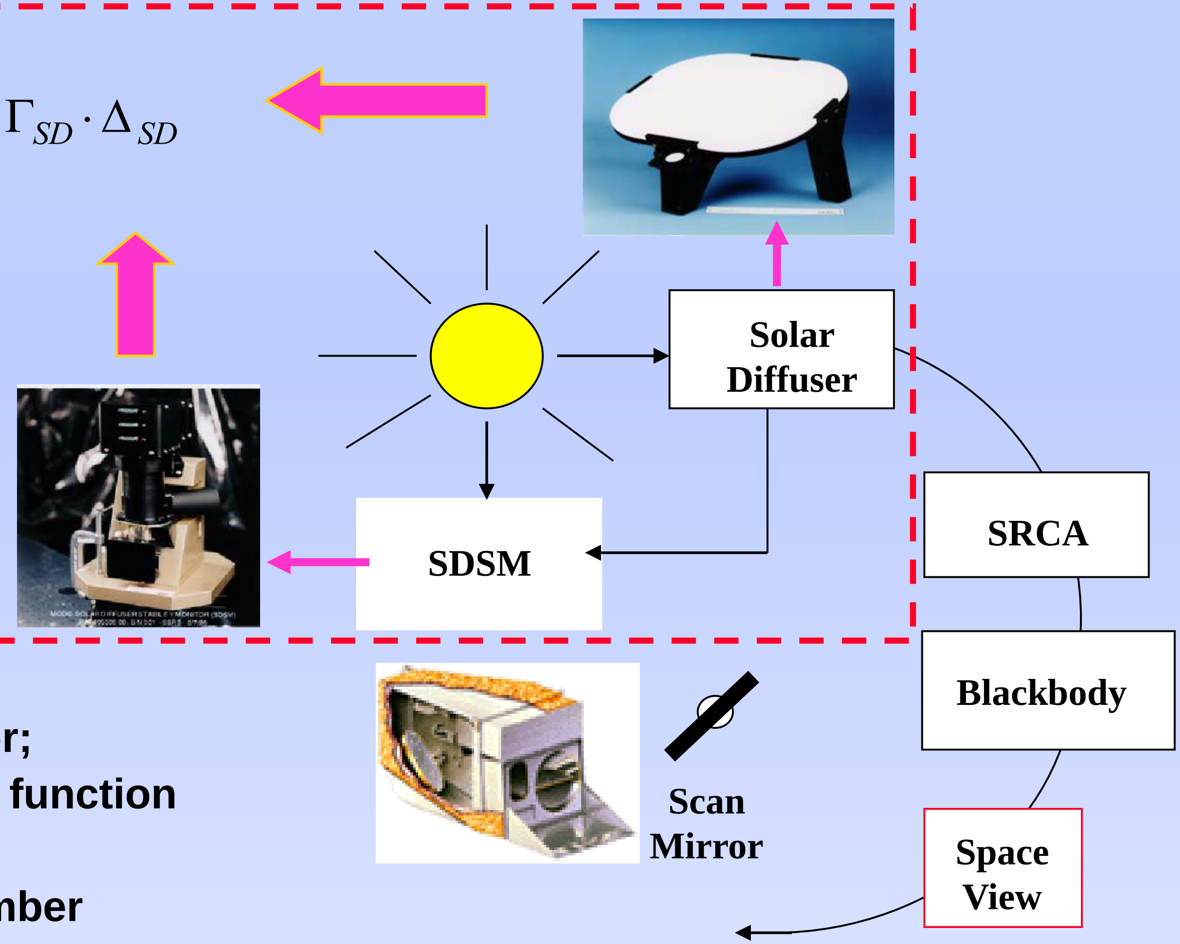
MODIS Calibration Methodology (RSB)

EV Reflectance $$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun}$$

$$m_1 = \frac{BRF_{SD} \cdot \cos(\theta_{SD})}{< dn^*_{SD} > \cdot d^2_{Earth-Sun}} \cdot \Gamma_{SD} \cdot \Delta_{SD}$$

$$dn^* = dn \cdot (1+k \cdot \Delta T)/RVS$$

$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}}$$



Δ_{SD}: SD degradation factor;
Γ_{SD}: SD screen vignetting function
d: Earth-Sun distance
dn*: Corrected digital number
dc: Digital count of SDSM

Inter-calibration Using Lunar Observations

- **Most activities have been limited to comparisons and inter-comparisons**
- **ROLO model is used to correct differences due to viewing geometries, including oversampling if necessary, and SRF (or RSR)**
- **MCST effort includes inter-comparisons with a number of sensors**
  - Terra (Aqua) MODIS, TRAM VIRS, SeaWiFS, MISR, S-NPP VIIRS, Pleiades-A (-B), …
  - Support from USGS (ROLO)
- **Examples → Lessons**

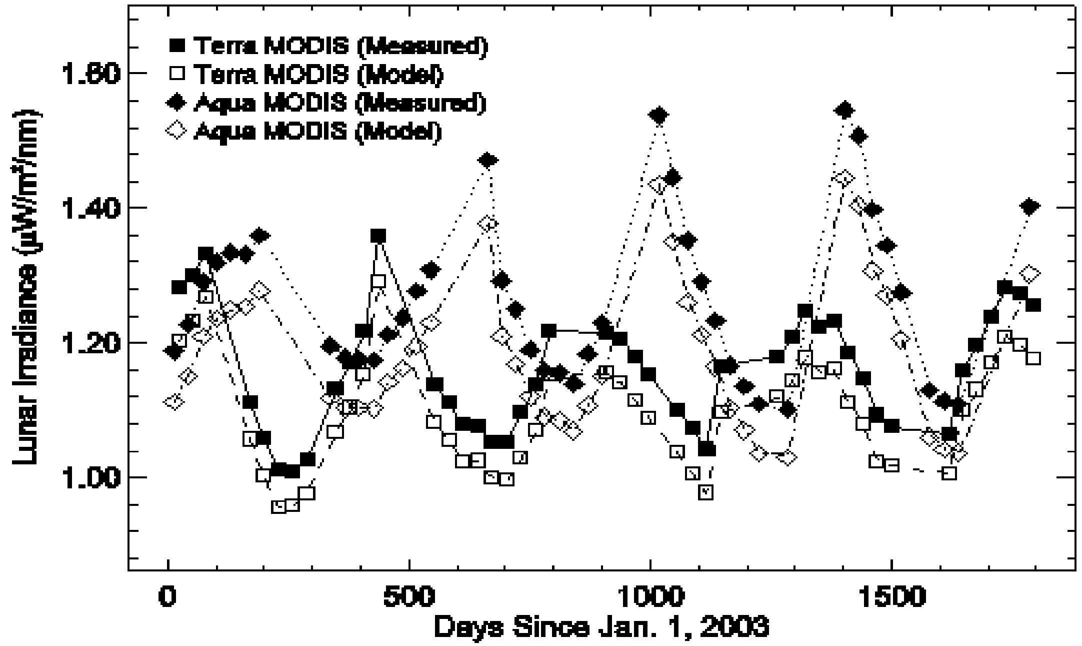
Inter-Comparison of MODIS and SeaWiFS Lunar Calibration

Comparison of MODIS viewing the Moon at 22° phase angle and SeaWiFS at 23° phase angle (data collected during April 14, 2003 Terra Pitch Maneuver)

SeaWiFS				MODIS				
Band No.	Wavelength (nm)	Measured I μW/m^2/nm	Model I μW/m^2/nm	Band No.	Wavelength (nm)	Measured I μW/m^2/nm	Model I μW/m^2/nm	Ratio
1	412	1.790	1.757	8	412	1.805	1.714	0.97
2	443	2.190	2.130	9	442	2.143	2.026	0.97
				3	466	2.465	2.316	
3	490	2.574	2.437	10	487	2.526	2.319	0.97
4	510	2.589	2.458	11	530	2.617	2.463	0.99
5	555	2.776	2.631	12	547	2.704	2.523	0.98
5	555	2.776	2.631	4	554	2.663	2.539	1.01
				1	647	2.596	2.512	
6	670	2.744	2.556	1	647	2.596	2.512	1.04
7	765	2.480	2.266					
8	865	2.009	1.886	2	857	1.974	1.855	1.00
				17	904	1.912	1.705	
				18	935	1.822	1.574	
				19	936	1.815	1.572	

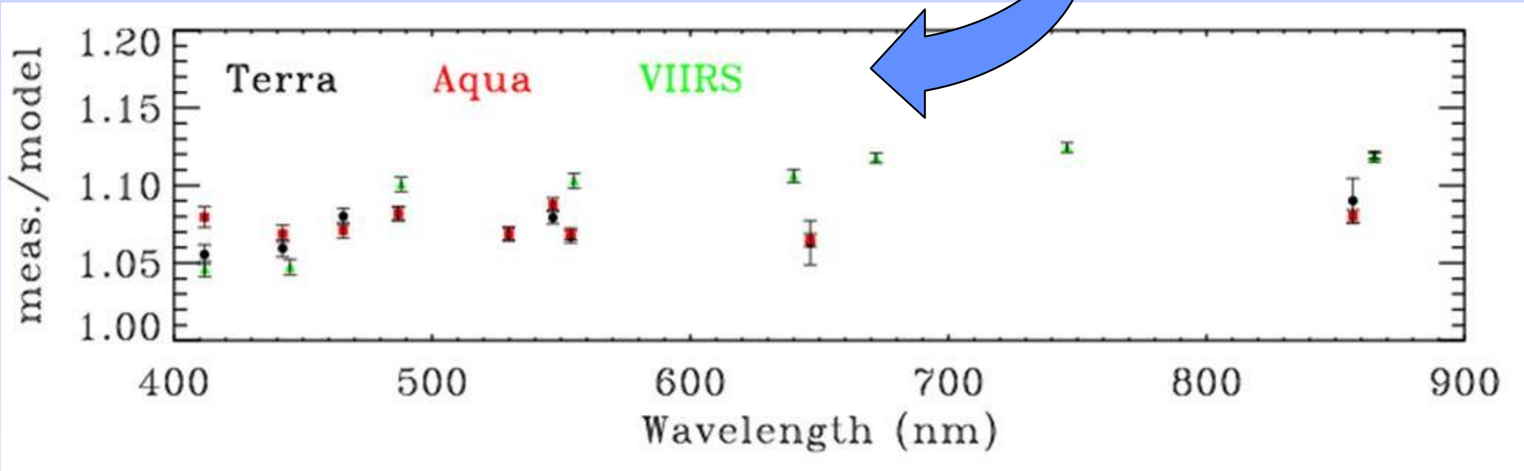
Barnes WL, Xiong X, Eplee R, Sun J, and Lyu CH, "Use of the Moon for Calibration and Characterization of MODIS, SeaWiFS, and VIRS," *Earth Science Satellite Remote Sensing: Data, Computational Processing, and Tools*, Vol. 2, Chapter 6, 98-119, Springer, 2006

Inter-Comparison of MODIS and VIIRS Lunar Calibration

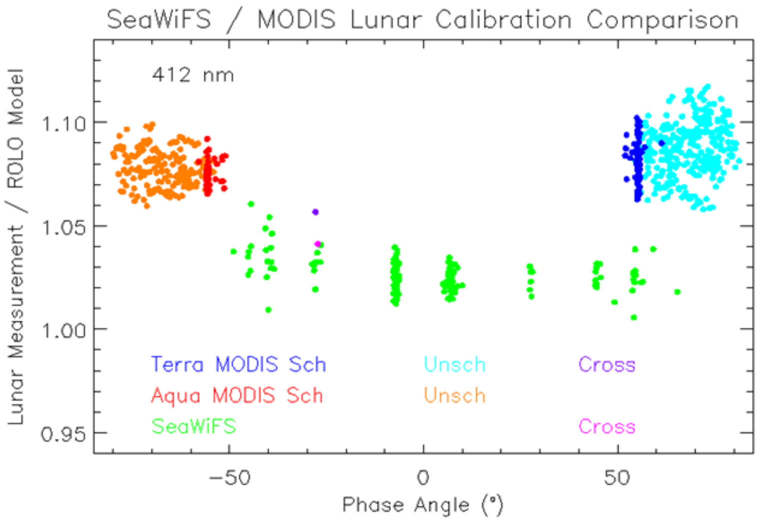


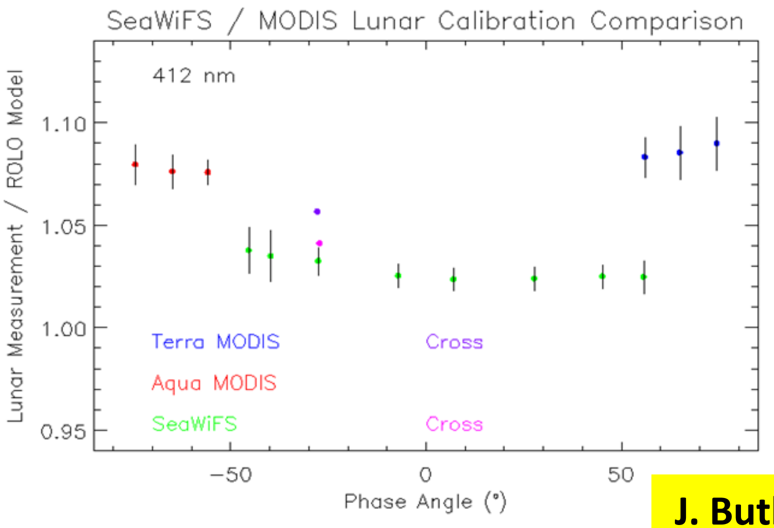
Xiong, Sun, and Barnes, GRSL 2009, Terra and Aqua MODIS Band 1

From T/A MODIS to SNPP VIIRS



Phase Dependence of MODIS Terra/Aqua and SeaWiFS Lunar Measurements





- Inherent scatter in a series of lunar measurements at 412 nm (top plot)
  - SeaWiFS uncertainty primarily due to oversampling correction
  - MODIS uncertainty primarily due to lower lunar signal at higher lunar phase
- Binned residuals plotted as means with standard deviations at 412 nm (bottom plot)
  - Phase dependence (phase angle):
    - MODIS Aqua: 1.1% from -80 to -51 deg.
    - SeaWiFS: 1.7% from -45 to -6 deg. & 5 to 56 deg.
    - MODIS Terra: 1.5% from 52 to 82 deg.
- An uncertainty of 1.7% is a robust estimate of the lunar model phase dependence from -80 to -6 deg. and from 5 to 82 deg using these MODIS and SeaWiFS data.
  - USGS estimate of lunar model phase dependence: 1% from a much larger database of lunar measurements from the ground

J. Butler, 2012 NIST Lunar Workshop

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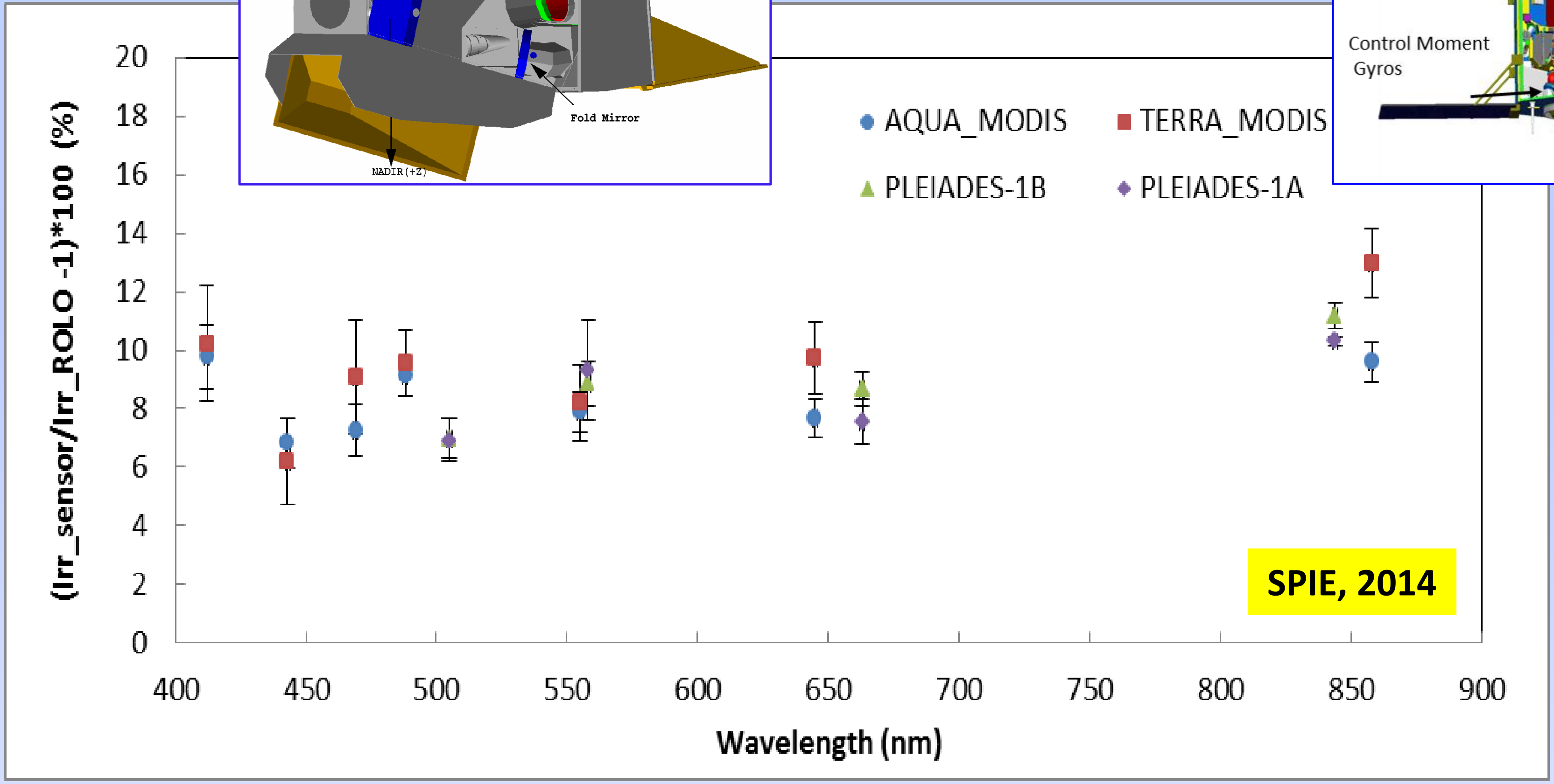
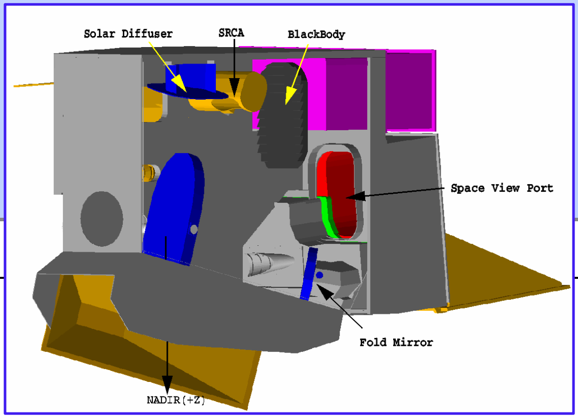
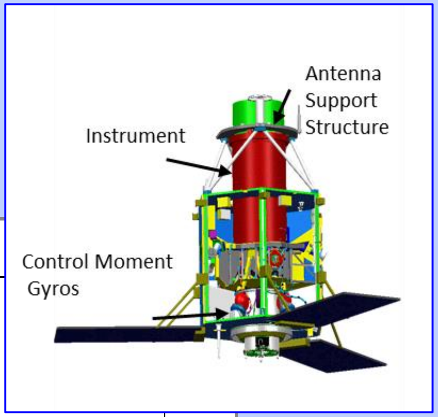
R. Eplee, Jr., J. Sun, G. Meister, F. Patt, X. Xiong, C. McClain, "Cross calibration of SeaWiFS and MODIS using on-orbit observations of the Moon," Applied Optics, 2011

Comparison of MODIS and PLEIADES Lunar Observations

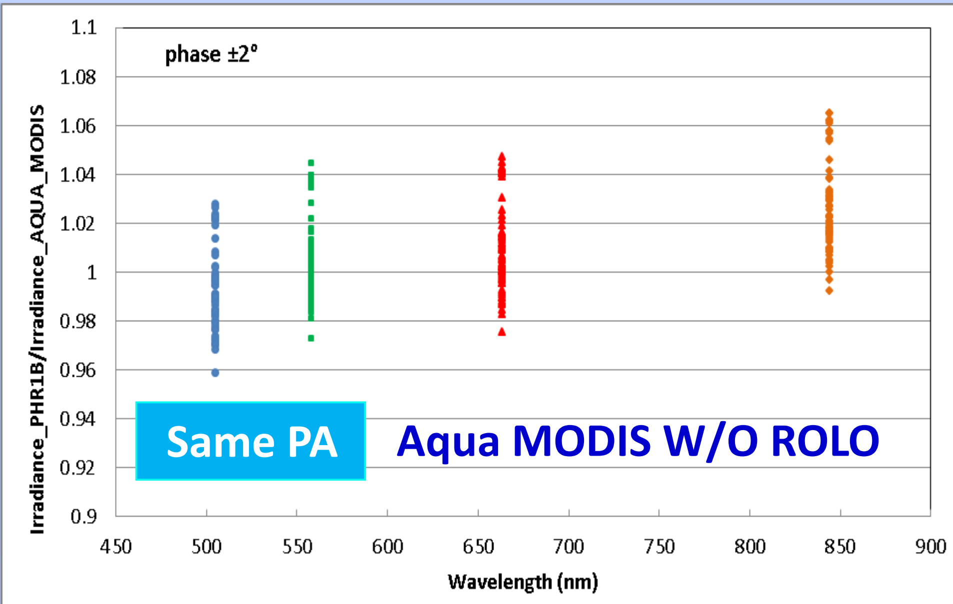


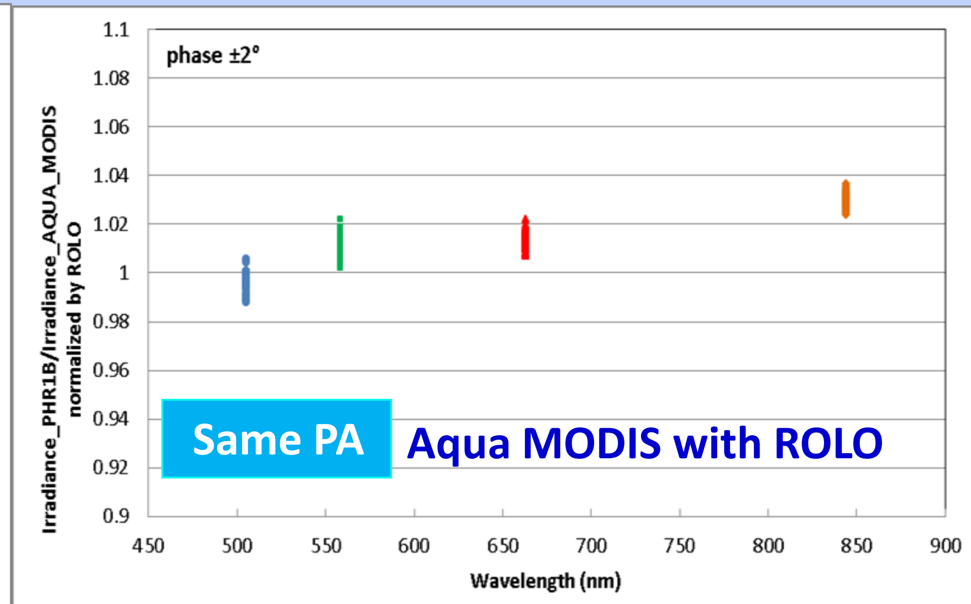


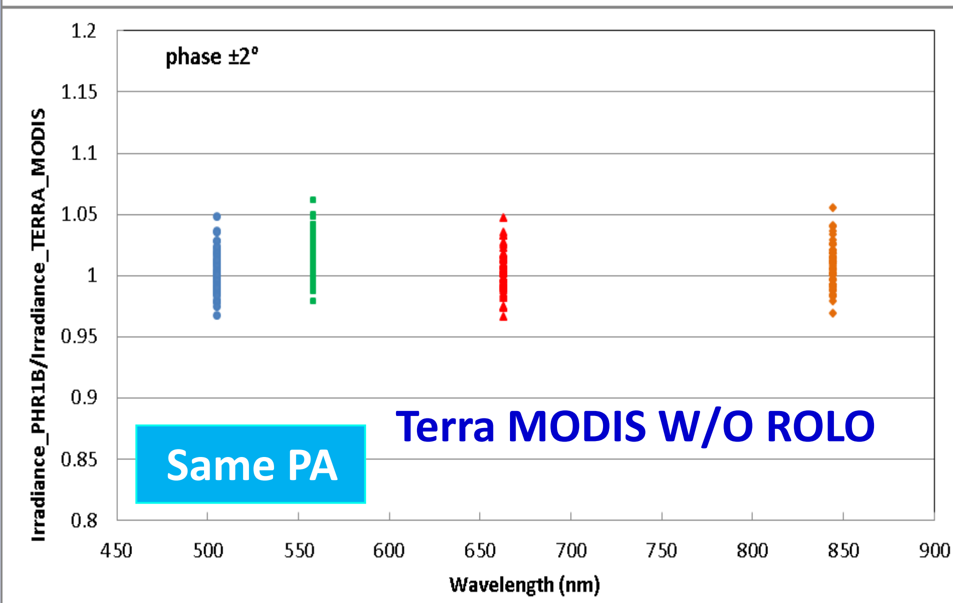


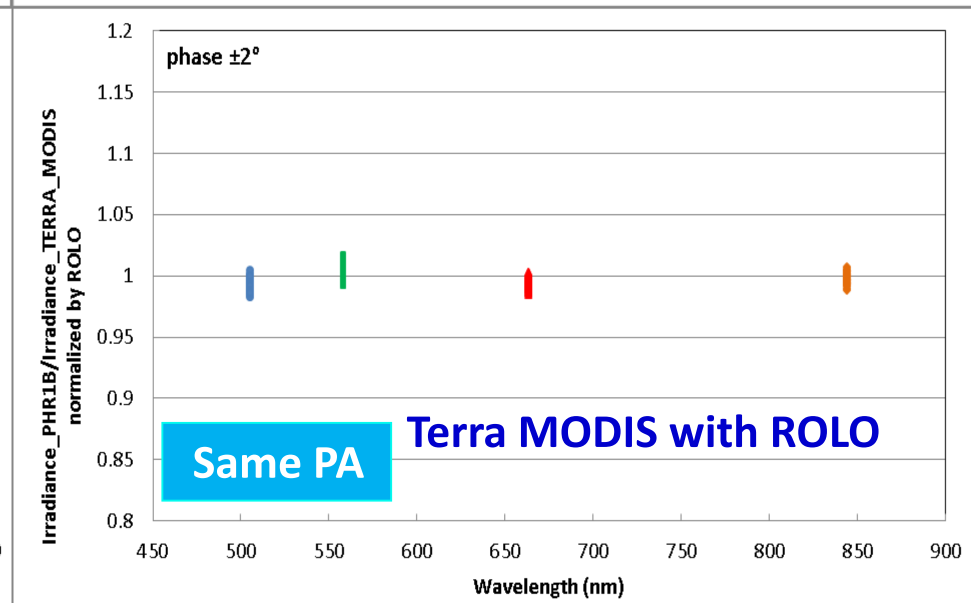
Limited to the same phase angles: ±55.5°
Referenced to the ROLO model

Direct comparison of Aqua MODIS and Pleiades calibration
(same phase angles, not constraint to SLO)







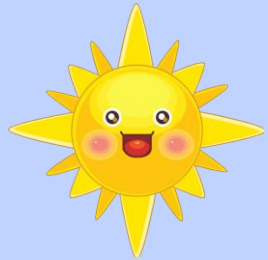


Establish Lunar Calibration Traceability

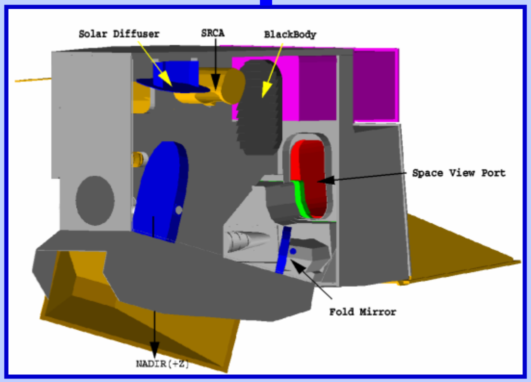
What's next?

to make lunar calibration results meaningful and useful

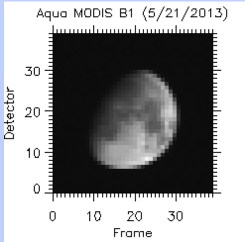
- **Unbroken chain of comparisons**
  - Establish methodology
  - Identify key parameters (error sources)
- **Stated UC budget (sensor dependent)**
  - Sensor measurement error
    - SNR, stability, …
  - Image processing error
    - Offset, oversampling, …
  - Other calibration error
    - SRF knowledge, nonlinearity, temperature sensitivity, …



☺ You have done this before



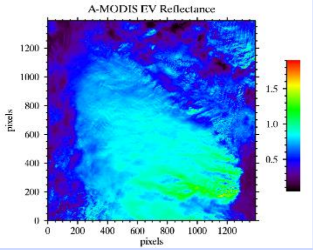
Ref Sensor "CLARREO"



GIRO/ROLO
POLO

Sensor to be calibrated

SNO



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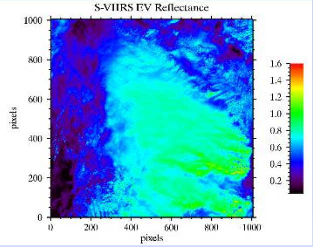


SNO

Ground Reference Targets: PICS (Pseudo Invariant Calibration Sites)

Potential Improvements of ROLO/GIRO Traceability and Accuracy

From stability monitoring to accurate calibration

Near future effort:

- Adjustments to the existing GIRO irradiance output?
- Determination and implementation of the adjustments?
- Traceability and accuracy after adjustment?
- Issues to be considered
  - Spectral coverage
  - Accuracy and traceability
  - Data availability, …

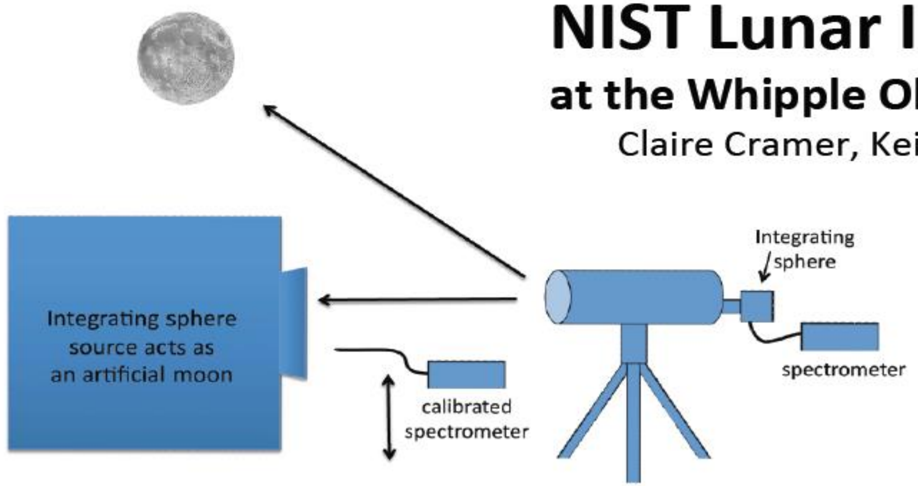
Future effort and activities (NIST and NASA):

➢ Could significantly improve the traceability and absolute accuracy for ROLO and GIRO

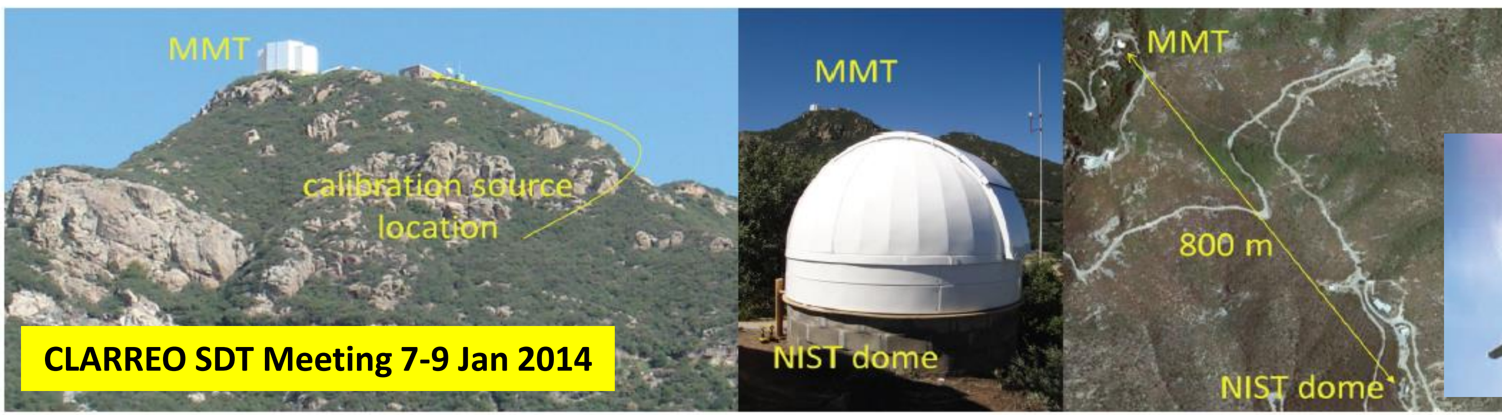
NIST Lunar Irradiance Program

at the Whipple Observatory, Mt. Hopkins AZ

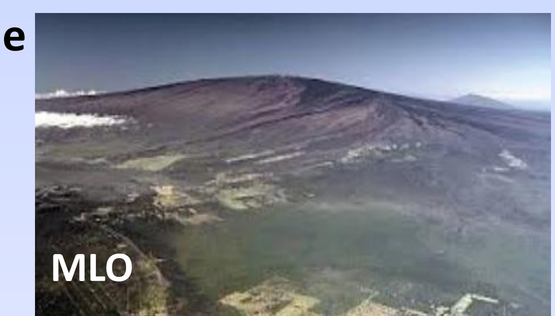
Claire Cramer, Keith Lykke and John Woodward



Goal: a lunar irradiance measurement with k=2 uncertainties of 1 % or less over the spectral range from 400 nm to 1000 nm

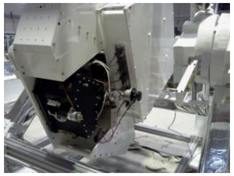


2 lunar irradiance data sets with UC of 1% (k=2) from 500 to 920 nm
Setting up a facility at the Mauna Loa Observatory (MLO) to provide low UC phase and libration data; Working on development of a high-altitude flight campaign to provide model tie points
- Goal: UC of 0.5% (k=2) from 380 to 980 nm
Extend spectral coverage from 380 to 2400 nm.



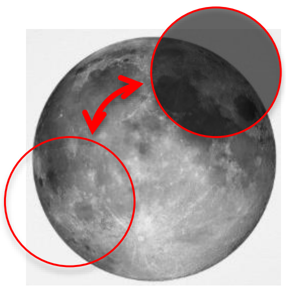
HyperSpectral Imager for Climate Science (HySICS)

PI: Greg Kopp, University of Colorado, LASP

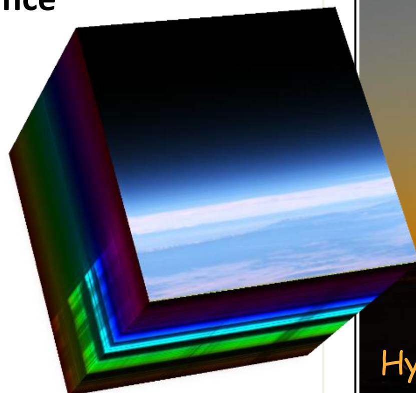


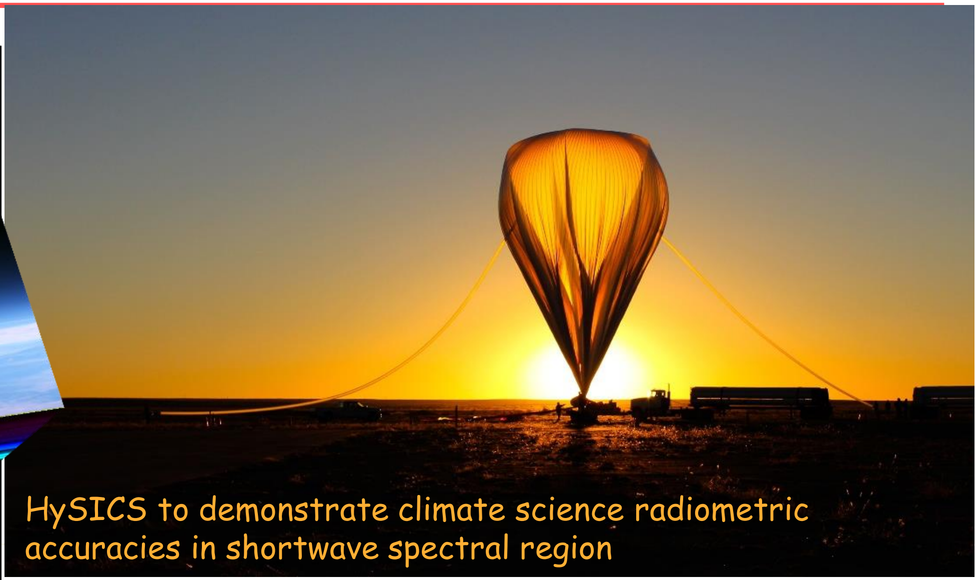
Purpose

- **Primary purpose is to cross-calibrate Earth scenes off of the Sun's accurately known irradiance**



Filter Calibration from Moon





TRL_{in} = 3 **$TRL_{current}$ = 6**

Objective

Build and flight test a hyperspectral imager with improved radiometric accuracies for climate science

- **350-2300 nm with single FPA to reduce cost & mass**
- **<0.2% (k=1) radiometric accuracy**
- **<8 nm spectral resolution**
- **0.5 km (from LEO) IFOV and >100 km FOV**
- **<0.13% (k=1) instrumental polarization sensitivity**

Perform two high-altitude balloon flights to demonstrate solar cross-calibration approach and to acquire sample Earth and lunar radiances

Approach

Single HgCdTe FPA covers full shortwave spectral range with reduced mass, cost, volume, and complexity

Incorporate solar cross-calibration approaches demonstrated on prior IIP to provide on-orbit radiometric accuracy and stability tracking

Orthogonal configuration reduces polarization sensitivity

No-cost balloon flights from experienced team at NASA WFF demonstrate on-orbit capabilities

Co-I – Peter Pilewskie / LASP
Balloon Flight Manager – David Stuchlik / WFF