Calibration Acquisitions of the Moon by CLARREO Pathfinder

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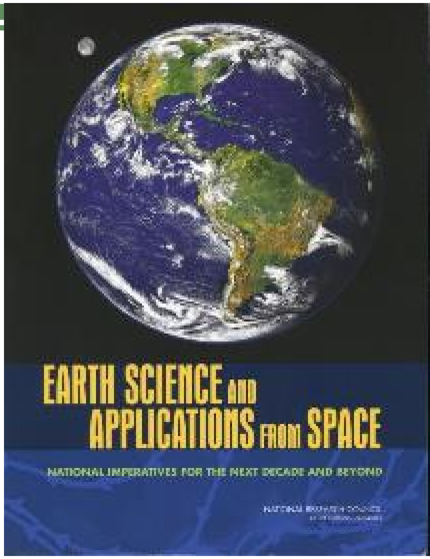
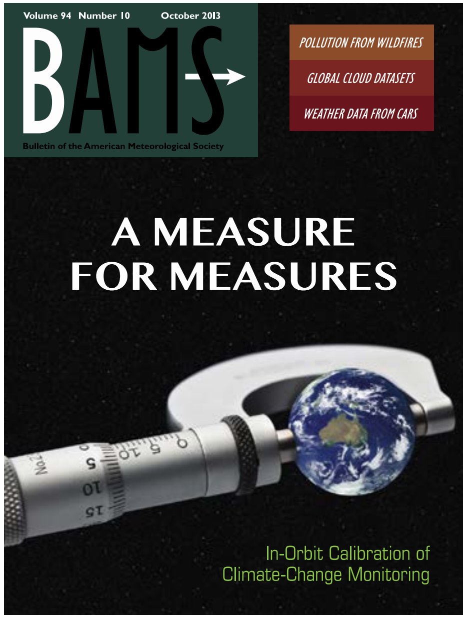
Introduction: CLARREO mission

- CLARREO = Climate Absolute Radiance and Refractivity Observatory
- Calibration Reference Spectrometers for national and international climate observing systems in orbit (Tier 1 Decadal Survey Mission)
- Reflected solar and infrared spectrometers enabling calibration across the entire solar and infrared spectrum of space instruments (e.g. CERES, VIIRS, CrIS, Landsat, geostationary imagers and sounders)
- Advance accuracy a factor of 5 to 10 for observing global climate change from space (e.g. climate sensitivity/cloud feedback)
- Higher accuracy enables earlier more accurate predictions of future climate change (15 to 20 years)
- Reduced prediction uncertainty leads to better societal decisions and economic outcomes.
- CLARREO will be a critical calibration anchor of the first international climate observing system (currently we have none)
- *Economic value of a more accurate climate observing system using CLARREO as the example estimated at $10 Trillion U.S. dollars (Cooke et al., 2014). ROI $50:$1 if triple global climate observation effort (true climate observing system)*





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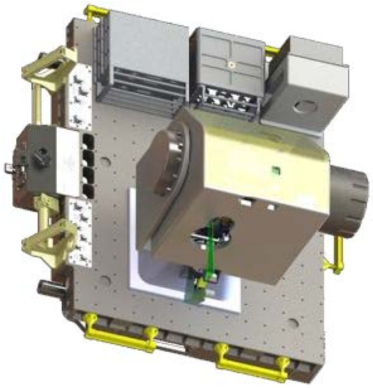
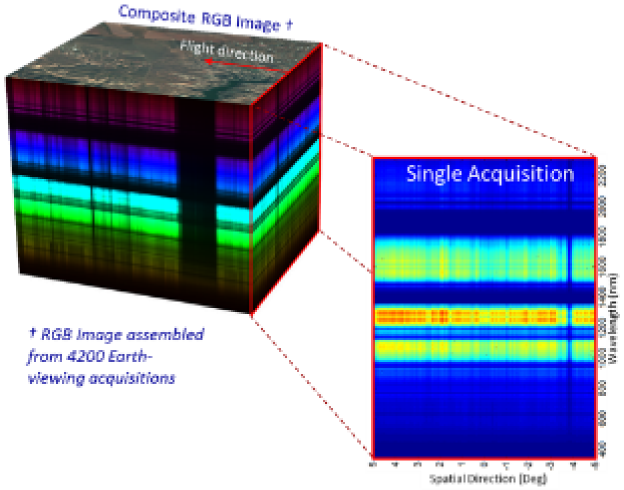
http://clarreo.larc.nasa.gov/

Introduction: CLARREO Pathfinder Mission

- ***CLARREO Pathfinder will demonstrate essential measurement technologies for the Reflected Solar portions of the CLARREO Tier 1 Decadal Survey Mission***
  - Demonstrate on orbit, high accuracy, SI-Traceable calibration
  - Demonstrate ability to transfer this calibration to other on-orbit assets
- **Formulation, implementation, launch, operation, and analysis of measurements from a Reflected Solar (RS) Spectrometer, launched to the International Space Station (ISS)**
- **Category 3 / Class D Mission, nominal 1-year mission life + 1 year science data analysis**
- **Targeted for launch to ISS in early CY2021**



Instrument Payload



Spectrally-Resolved Earth Reflectance

CLARREO Pathfinder is not the end, it is a critical step along the way to a full CLARREO Mission.

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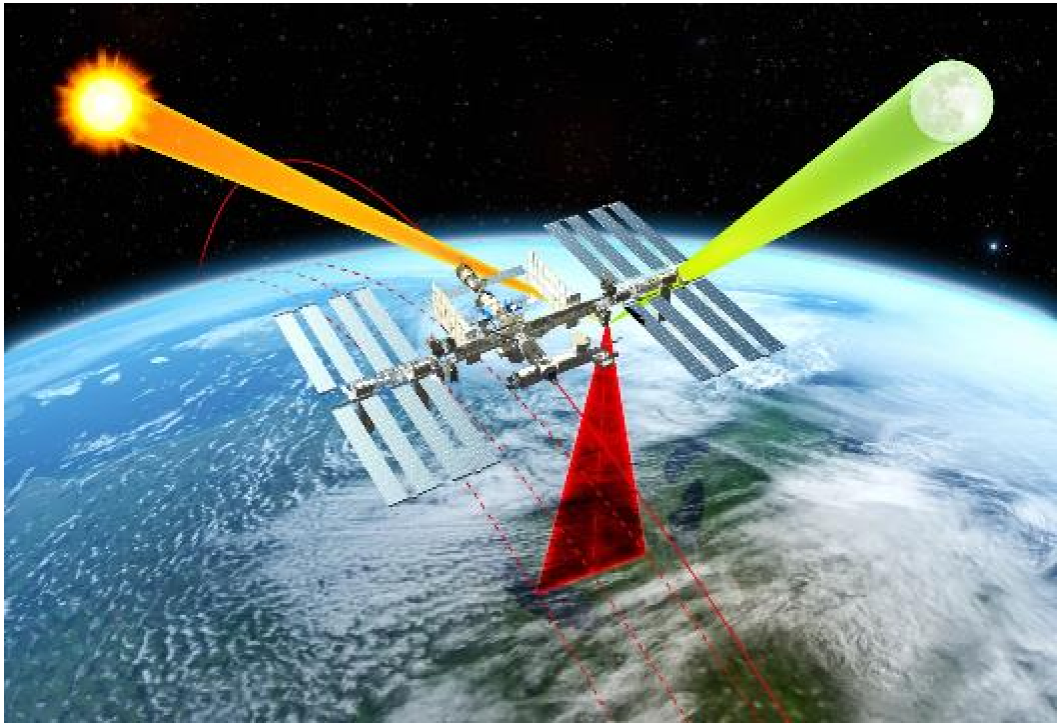
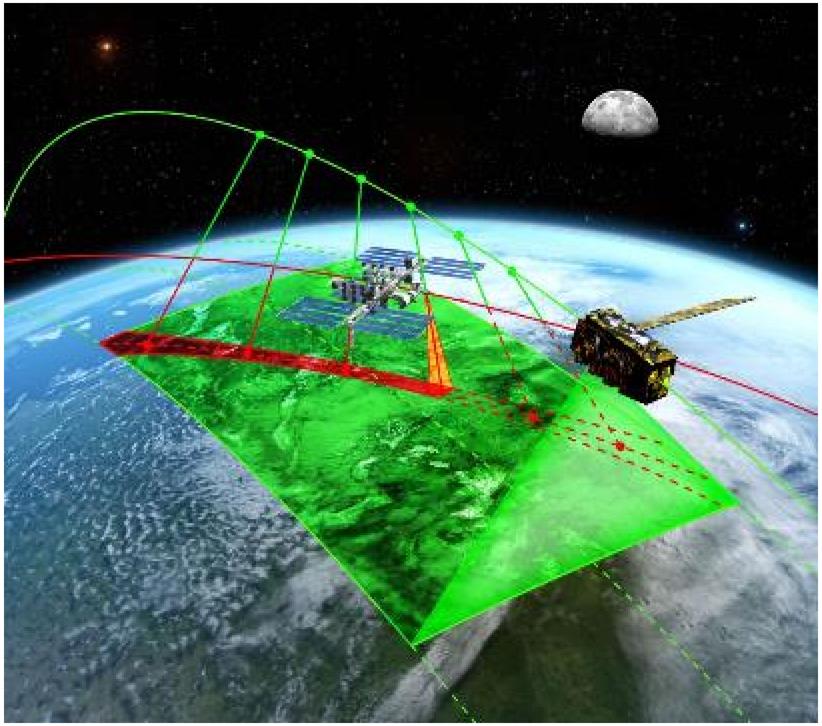
CLARREO Pathfinder — Baseline Mission Objectives

Demonstrate high accuracy SI-Traceable Calibration



Objective #1: Demonstrate the ability to conduct, on orbit, SI-Traceable calibration of measured scene spectral reflectance with an advanced accuracy over current on-orbit sensors using a reflected solar spectrometer flying on the International Space Station.

Demonstrate Inter-Calibration Capabilities



Objective #2: Demonstrate the ability to use that improved accuracy to serve as an in orbit reference spectrometer for advanced intercalibration of other key satellite sensors across the reflected solar spectrum (350-2300 nm).

CLARREO Pathfinder (CPF) Specifications

- Spectrally resolved Earth reflectance (350 – 2300 nm) measurements
  - SI-Traceable, referenced to spectral solar irradiance
  - Uncertainty requirement: ≤ 0.3% (k=1) baseline, ≤ 0.6% (k=1) threshold

    Baseline requirement is within a factor of 2 of full CLARREO Tier-1 Decadal Survey Mission Requirements

- On-orbit inter-calibration with CERES/RBI short wave channel and VIIRS reflectance bands
  - Uncertainty requirement: ≤ 0.3% (k=1) baseline, ≤ 0.6% (k=1) threshold

    Threshold requirement is a factor of 2 (CERES) to 4 (VIIRS) better than current capabilities

<u>Prototype Instrument</u>: LASP HyperSpectral Imager for Climate Science (HySICS)

Spatial Resolution:	2.5 arcmin
Field of View (cross-track):	10°
IFOV:	0.2°
Wavelength Range:	350–2300 nm
Wavelength Resolution:	6 nm, constant, Nyquist sampled
Nominal frame rate:	15 Hz

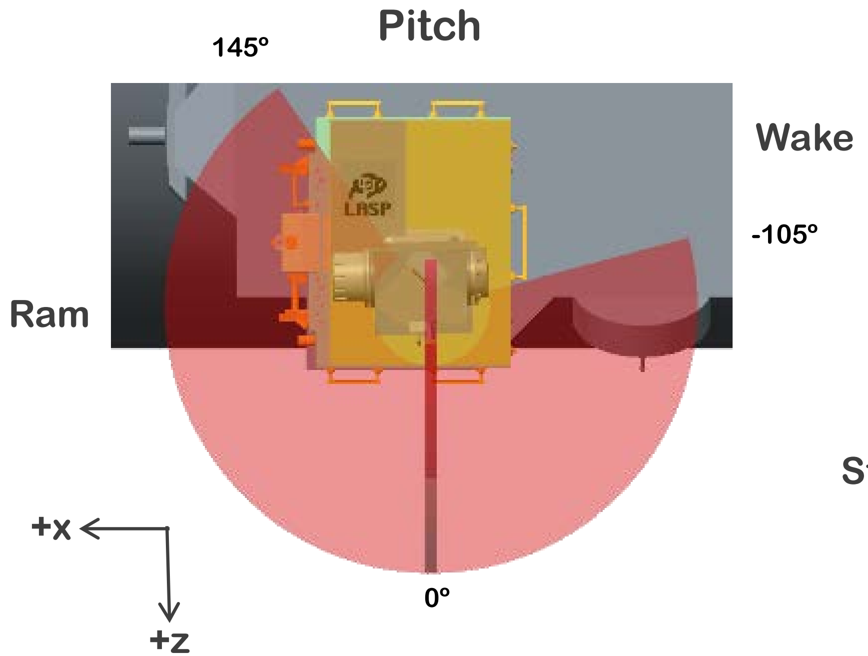
CPF Reflected Solar (RS) Instrument Accommodation on ISS

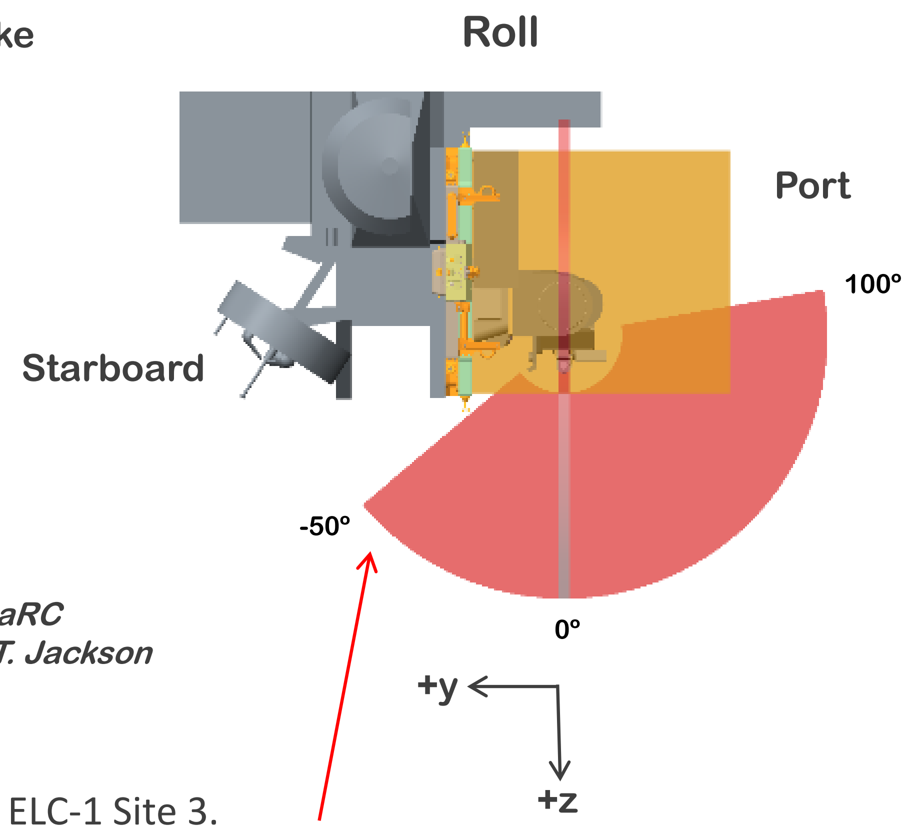
ExPRESS Logistics Carrier ELC-1 Site 3:

ISS port side nadir location, outboard-facing pallet

RS Instrument Field of Regard:
Pointing for Solar, Lunar, Inter-calibration

Accommodations on ISS at Express Logistics Carrier #1 (ELC-1) Site 3 provides adequate viewing to meet CLARREO Pathfinder mission objectives.





Accommodation studies by the NASA LaRC Engineering team: J. Leckey, C. Boyer, T. Jackson

- Gimbal configuration: pitch - roll
- Approximate gimbal range of motion at ISS ELC-1 Site 3.
- Not all pointing angles are available due to ISS accommodation.

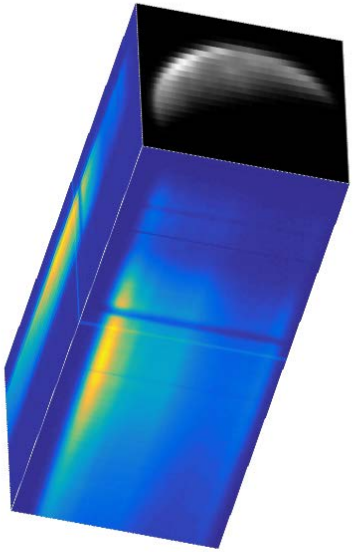
CPF RS Views of the Moon

On ISS, the RS spectrometer slit will be oriented perpendicular to the roll or elevation gimbal axis

- aligned with the ISS ±Y body axis (starboard/port) when nadir-viewing
- to accommodate primary mission objective: pushbroom imaging of Earth

Two scanning modes will be used for RS lunar views:

- along-slit scans
  - to sample the same slice of the Moon with all detectors in the spatial direction, for flatfielding
  - accomplished with elevation (roll) gimbal movements
- across-slit scans
  - to build spectral images, for lunar radiometry
  - accomplished with azimuth (pitch) gimbal movements
  - CPF applications of lunar radiometry:
    - inter-calibration with other instruments, using the Moon as a common reference target
    - contributing to a database of high-accuracy lunar radiometric measurements, to refine and constrain the lunar calibration reference



HySICS spectral image acquired 18 Aug. 2014 on high-altitude balloon

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Challenges for CPF RS Lunar Radiometry

Spatial Sampling

Typical lunar calibration activities utilize the spatially integrated quantity of spectral irradiance. For imaging instruments, this involves summing radiance pixels over the Moon image:

$$E_\lambda = \frac{1}{\eta} \sum_{i=1}^{N_\mathrm{p}} \Omega_i \, L_{i,\lambda}$$

η = oversampling factor
Ω_i = pixel solid angle
$L_{i,\lambda}$ = pixel radiance
N_p = # of pixels on Moon

For reliable lunar irradiance measurements, a critical parameter is accurate knowledge of the oversampling *of the Moon disk*

The 2-axis gimbal of CLARREO Pathfinder, combined with the fixed orientation of the slit, means across-slit scanning (by azimuth slewing) will trace a curved path for off-nadir view directions.

Thus for off-nadir across-slit scans, the slit projection on the target will rotate with the azimuth gimbal movement.

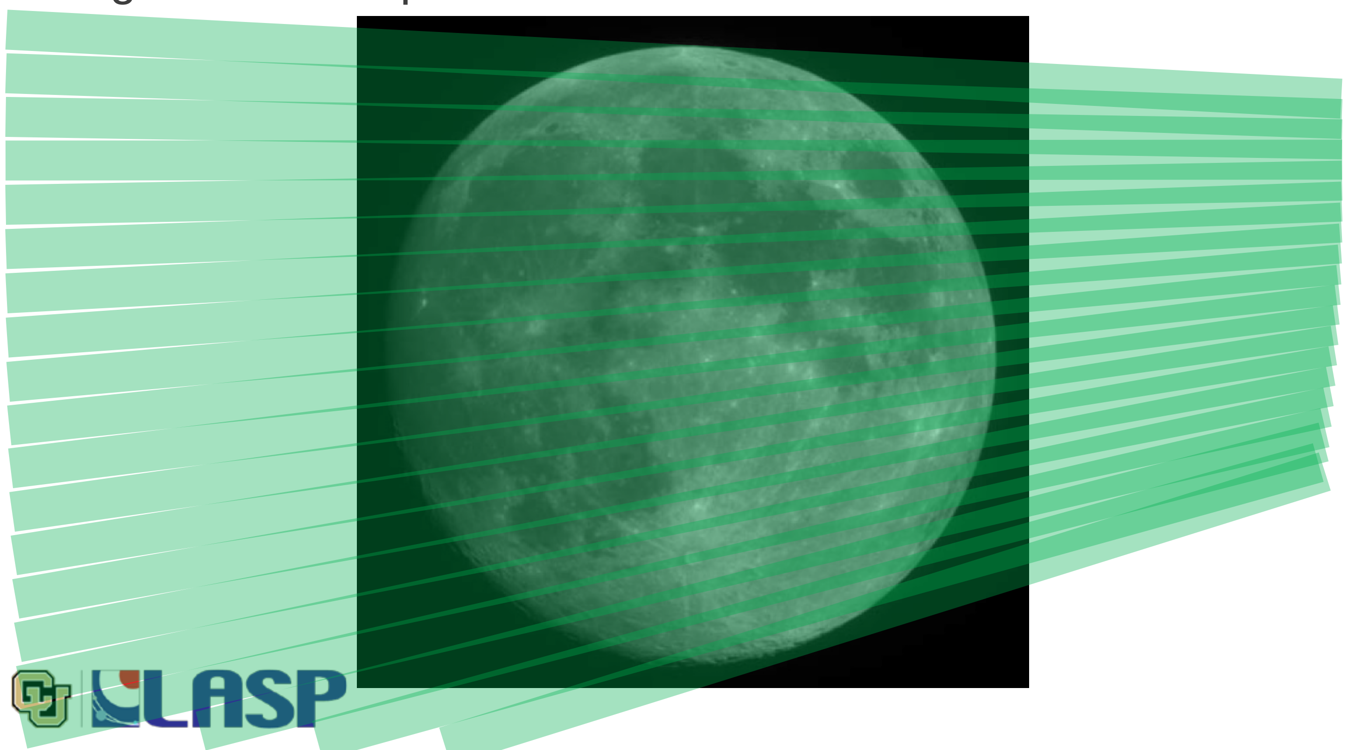
Spatial Sampling Issue for CPF RS Lunar Radiometry

The rotation of the slit projection on the target means spatial sampling will be non-constant, and dependent on the spatial pixel position.

To determine oversampling of the Moon disk will require:

- knowledge of the slew rate, sampling rate, and the elevation gimbal angle
  - ➢ to determine the geometric oversampling for each spatial pixel
- knowledge of the location and extent of the Moon slice in each scan frame
  - ➢ to map the target onto the spatial dimension

Simulated curved scan showing differential oversampling of the Moon disk

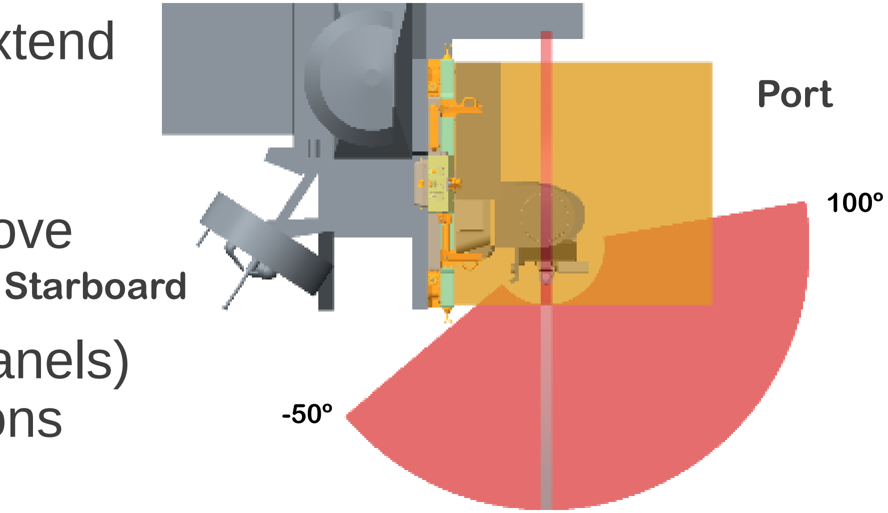


Challenges for CPF Lunar Radiometry

Moon Viewing Constraints

The instrument location on the nadir side of the ISS restricts views above the horizon.

- starboard-side views will not extend to space
- port-side views will be partially obstructed by the ISS truss above 100° from nadir
- moveable objects (e.g. solar panels) will cause temporary obstructions



A simulation of potential Moon view opportunities provided preliminary data on possible lunar acquisitions

- ISS in stable circular orbit at 51.6° inclination, LVLH attitude: +XVV
- space-viewing constraints imposed as limits on gimbal motions
- no accommodation for temporary obstructions or attitude variations
- simulation was run for one-year flight (nominal CPF mission)

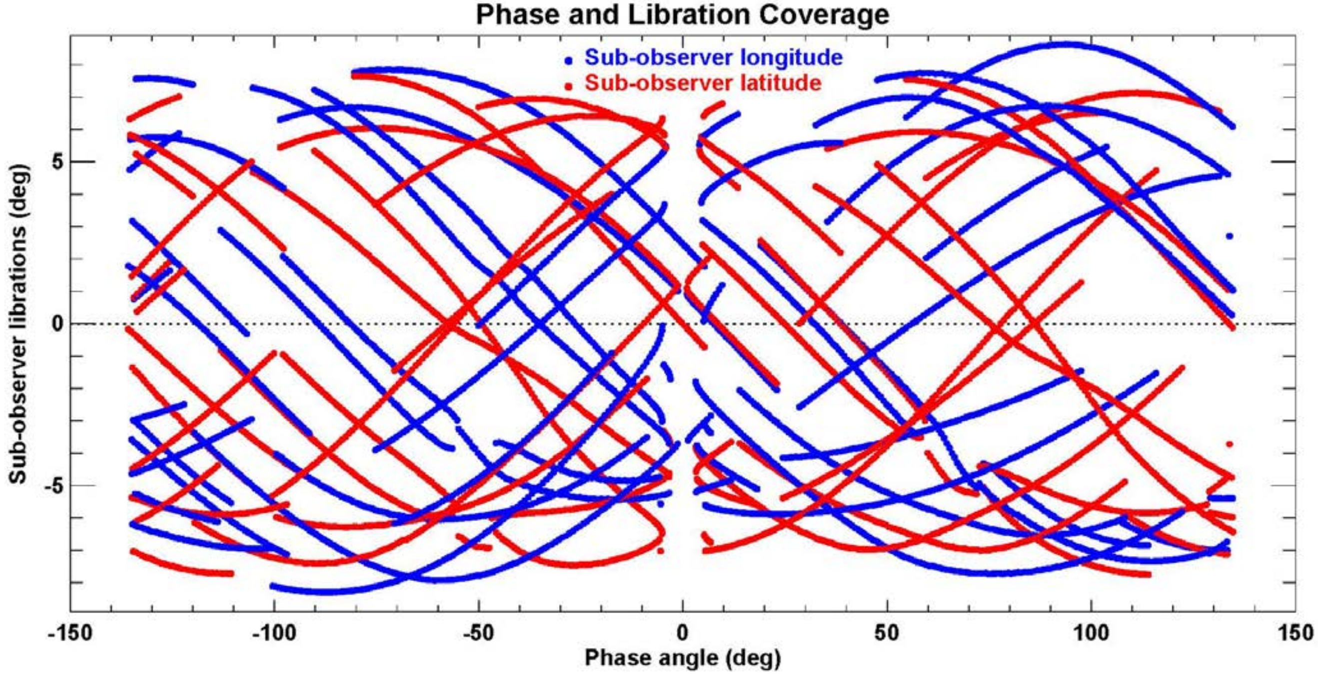
Moon Viewing Opportunities for CPF RS

To build a database of lunar measurements for a calibration reference, extensive coverage of the geometric parameter space (phase angles and lunar librations) is essential.

Preliminary results from the CPF Moon view simulation:

3502 points = view opportunities with > 4 minutes duration

>80% have less than 10 minutes duration



Substantial coverage in one year !

– plot shows all potential opportunities; not likely actual Moon acquisitions

Summary

- CLARREO Pathfinder has the potential to acquire high-accuracy lunar spectral irradiance/disk reflectance measurements
  - useful to constrain and/or refine the lunar calibration reference
  - potential for inter-calibration of other sensors that view the Moon
- Addressing the rotating spatial sampling and its impact on lunar measurements (disk oversampling) will require post-processing of the lunar spectral images; methodology is currently under development
- Observability of the Moon from CPF location on ISS has constraints
  - some view obstructions from ISS structural components, both fixed and moveable (temporary)
  - simulation shows numerous potential view opportunities, but short time windows

The CLARREO Pathfinder team is enthusiastic about the potential to collect a lunar measurement database useful for calibration applications.

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Thank You!