Sensitivity of CLARREO Pathfinder Measurements of the Moon to Short-term Changes in Lunar Irradiance

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Overview and Motivation

The Moon is used as reference for on-orbit radiometric calibration of Earth observing instruments, such as MODIS, VIIRS, Landsat OLI, …

- The Moon is an ultra-stable diffuse reflector of sunlight (solar diffuser)
- This stability enables inter-calibration to a common reference

Using the Moon for a reference requires a numerical model, to predict the lunar intensity for an instrument's lunar observations

- A working lunar model has been developed by USGS: ROLO
- However, improvement in accuracy needed for an absolute reference
  - current absolute radiometric uncertainty is ~5–10%

CLARREO's radiometric accuracy capability will be leveraged to make new measurements of the Moon

- Initially from CLARREO Pathfinder RS
  - lunar calibration works at reflected solar wavelengths
- Used for inter-calibration and to improve the lunar reference

USGS is developing operational requirements for CPF Moon views to help assure that CLARREO lunar measurements approach its accuracy specs

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Considerations for Accuracy of CPF Lunar Measurements

The radiometric quantity used for lunar calibration is spectral irradiance

- For imaging instruments, found by spatial integration of Moon images:

$$E_{\mathrm{meas}} = \frac{\Omega_{\mathrm{p}}}{\eta} \sum_{i}^{N} L_i$$

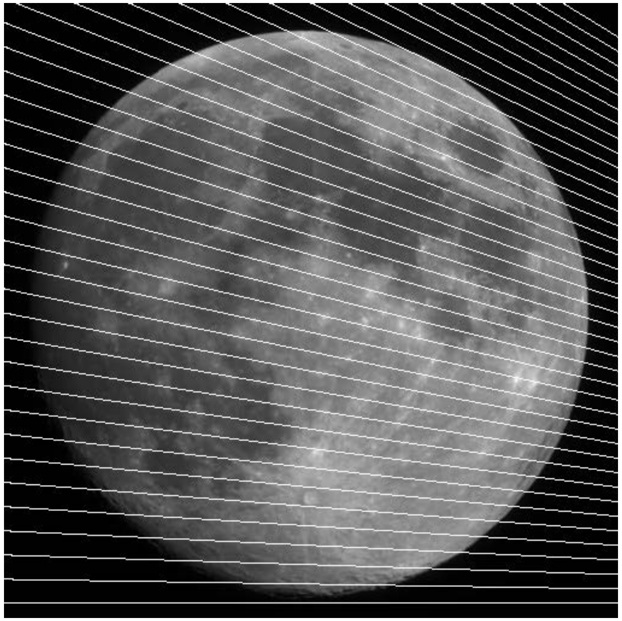
Ω_{p} = pixel IFOV (solid angle)
η = oversampling factor
L_i = pixel radiance
N = # of pixels on Moon

For CPF RS spectrometer, spectral images are built up from scan lines

- 2-axis gimbal means off-nadir scanning has a rotational component
  - thus differential sampling of the Moon disk
  - per-pixel oversampling must be determined from post-acquisition processing

$$E_{\mathrm{meas}} = \Omega_{\mathrm{p}} \sum_{i}^{N} \frac{1}{\eta_i} L_i$$

Ω_{p} = pixel IFOV (solid angle)
η_i = pixel oversampling factor
L_i = pixel radiance
N = # of pixels on Moon



- Discussed at the 2017 SDT Spring meeting

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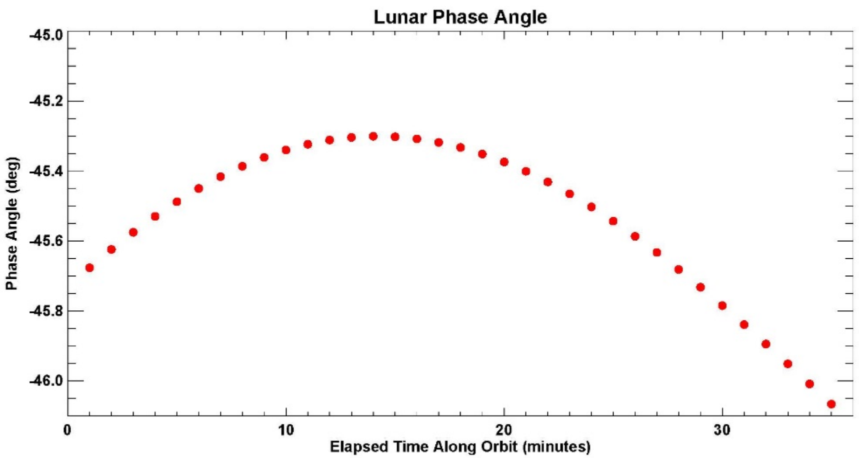
Considerations for Accuracy of CPF Lunar Measurements

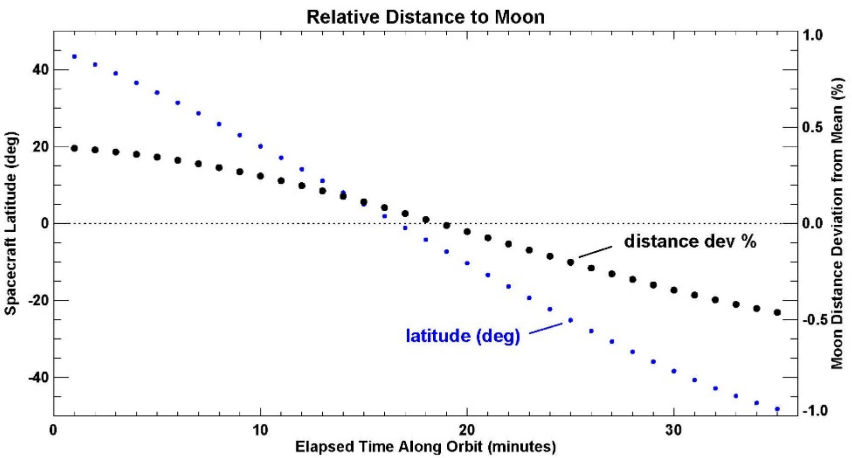
Uncertainties of each factor must be evaluated to get combined uncert

- per-pixel oversampling η_i, pixel IFOV Ω_p, net radiance $\boldsymbol{L_i}$

Another contribution to irradiance measurement uncertainty: **the Moon target changes brightness with time**

- due to lunar phase change and orbital motion of the sensor platform
  - lunar reflectance (thus irradiance) is strongly dependent on phase angle
  - phase angle changes with platform (ISS) position along its orbit track
  - irradiance has $1/r^2$ dependencies on Sun-Moon and Moon-sensor distance
  - Moon-sensor distance changes with platform position along its orbit track



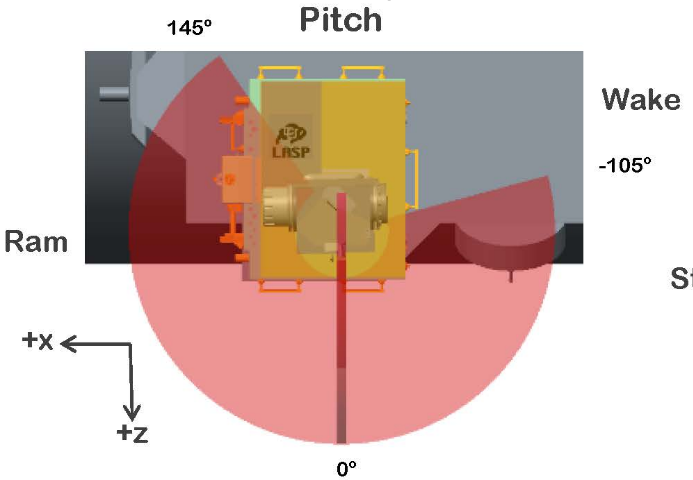


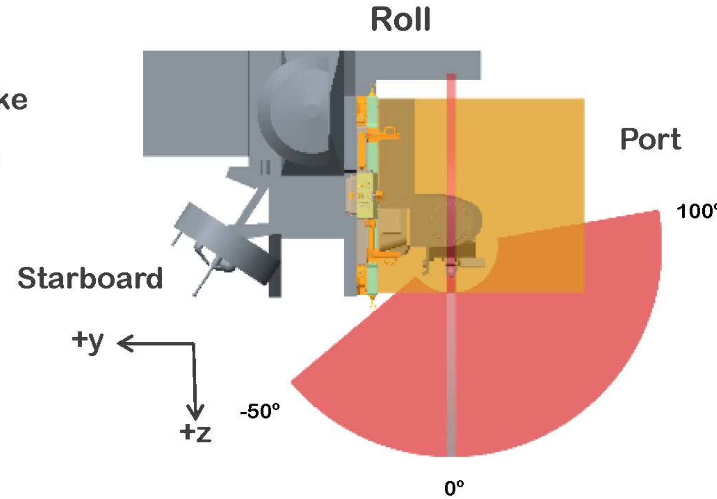
Current USGS study to evaluate these effects

Prerequisite: Simulation of CPF Moon Viewing Opportunities

Objective: to find times when the Moon is observable from ELC-1 Site 3

- Investigation of view geometries having clear line of sight to the Moon
  - based on an ephemeris for the Moon, a simulated ISS orbit, and CPF RS gimbal constraints
  - instrument mounting on ELC constrains RS views above the horizon:





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

- One-year simulation (nominal CPF mission), starting 22 Sept 2021
  - outcome was list of times when the Moon potentially is observable by RS
  - used as the basis dataset for the current study of Moon target variability

Current: Computing Changes in Lunar Irradiance with Time

Objective: determine the rate at which the Moon's brightness is changing

- rate of change determines the max RS scan time to capture the Moon

The USGS lunar irradiance model (ROLO) was used as a proxy

- spectral irradiances computed for times of CPF Moon view simulation
- nominal wavelength 500 nm, monochromatic
  - other wavelengths also run, but results were found negligibly different
- model outputs included distance corrections: Sun-Moon, Moon-ISS

The CPF Moon view simulation was conducted in 1-minute time steps

- lunar irradiance predictions E_{M} were generated for each time step
- collated into contiguous view opportunities with ≥4 minutes duration
- differentials computed from simple differences of adjacent time steps:

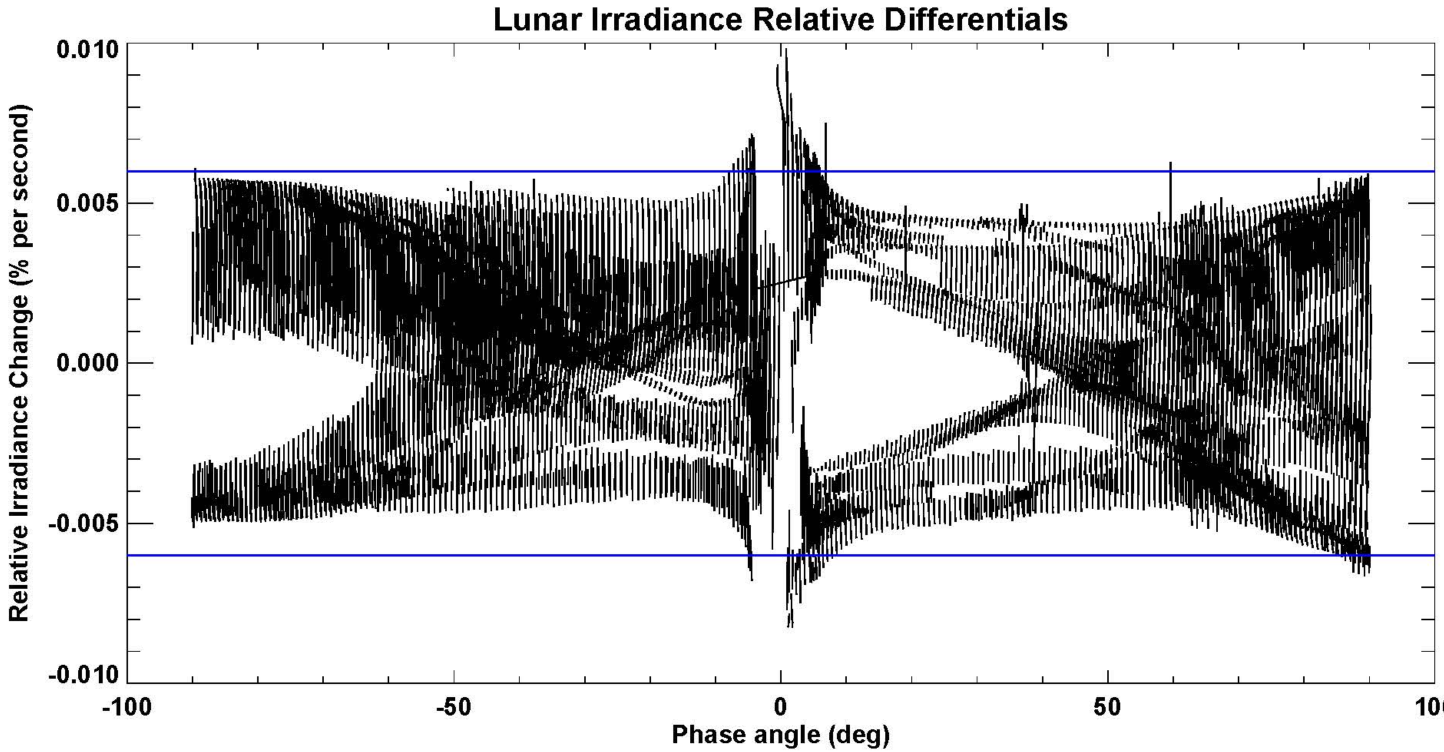
$$\Delta E_{\mathrm{M}}/\Delta t = (E_i - E_{i\text{-}1}) \;/\; 60 \text{ seconds}$$

- normalized to give relative irradiance differentials in % per second:

$$\text{differential} = \frac{\Delta E_{\mathrm{M}}/\Delta t}{E_{\mathrm{M}}} \times 100\%$$

Results: Lunar Irradiance Differentials

Distribution by lunar phase angle, 1-year simulation



- each "vertical" line represents a view opportunity, 2745 total
- fiducial lines at ±0.006% sec^{-1} show approximate max differential
  - includes most data for phase angles larger than ~8°
  - lunar "opposition effect" at narrower phases should be avoided

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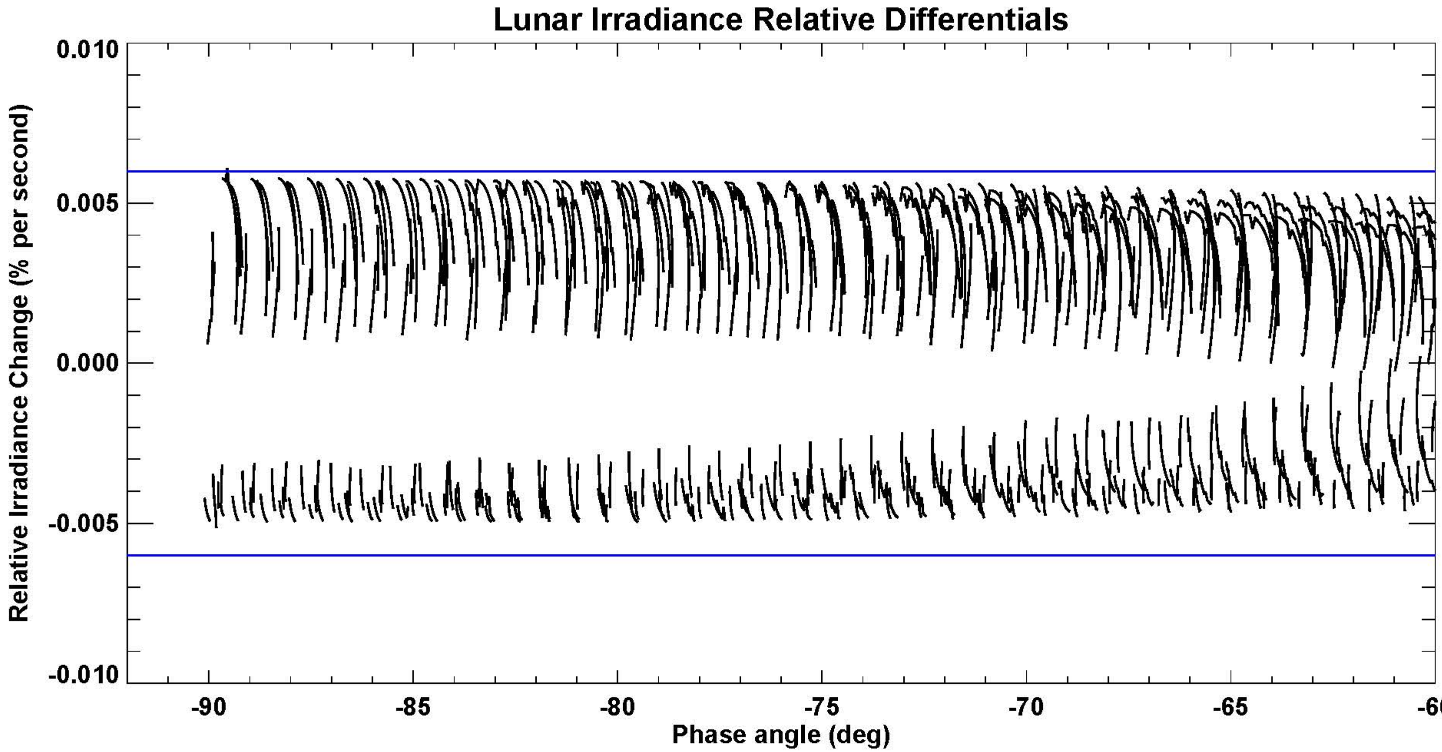
Results: Lunar Irradiance Differentials

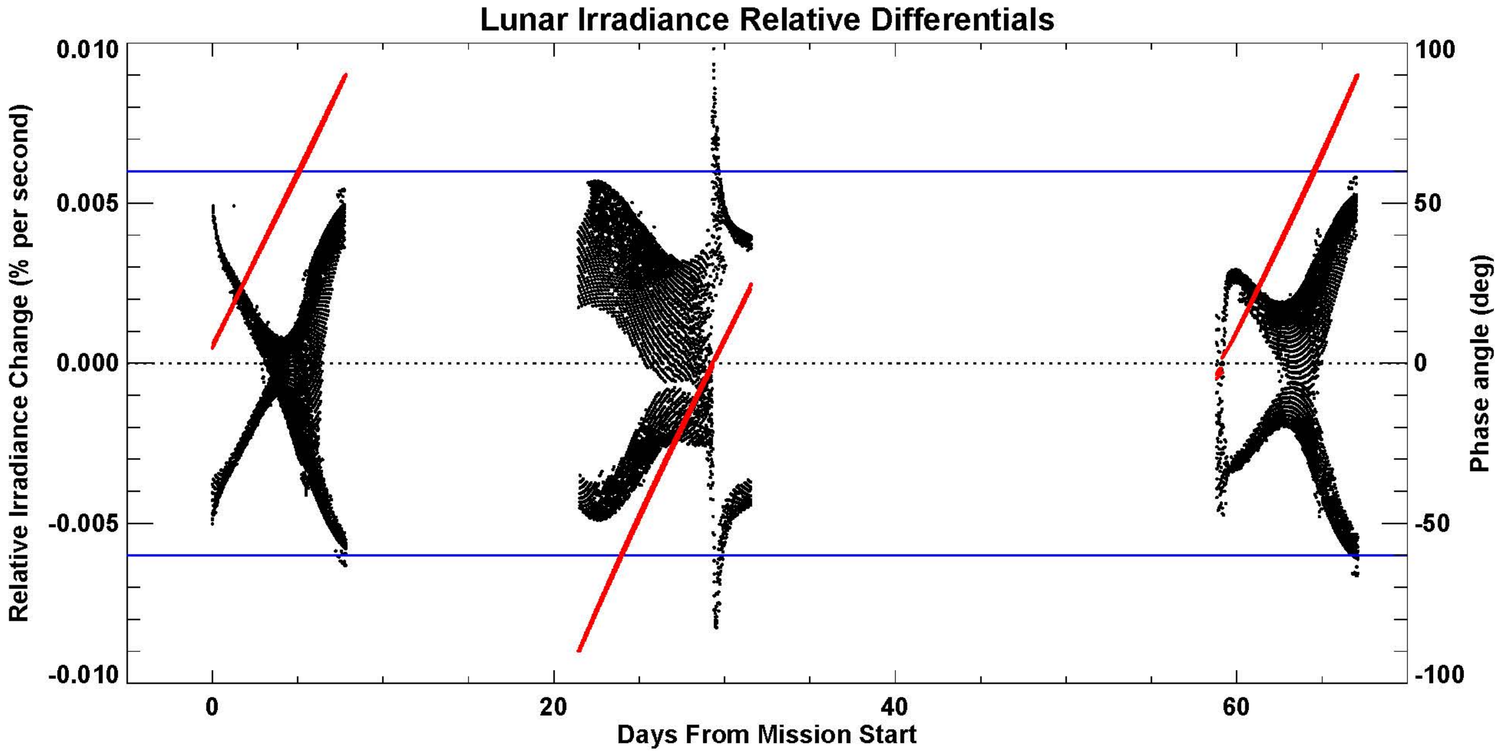
Distribution by lunar phase angle, expansion of range -90° to -60°



- typically a range of differentials within a view opportunity
- we are interested to find conditions when differentials are smallest
  - allows more time to scan the Moon

Results: Lunar Irradiance Differentials

Distribution with time — first three lunations



- phase angles indicated in red (scale on right)
- distinct patterns suggest favorable times with small irradiance changes
  - led to search for predictors: correlations with various obs parameters
  - the two primary drivers are phase angle and distance correction

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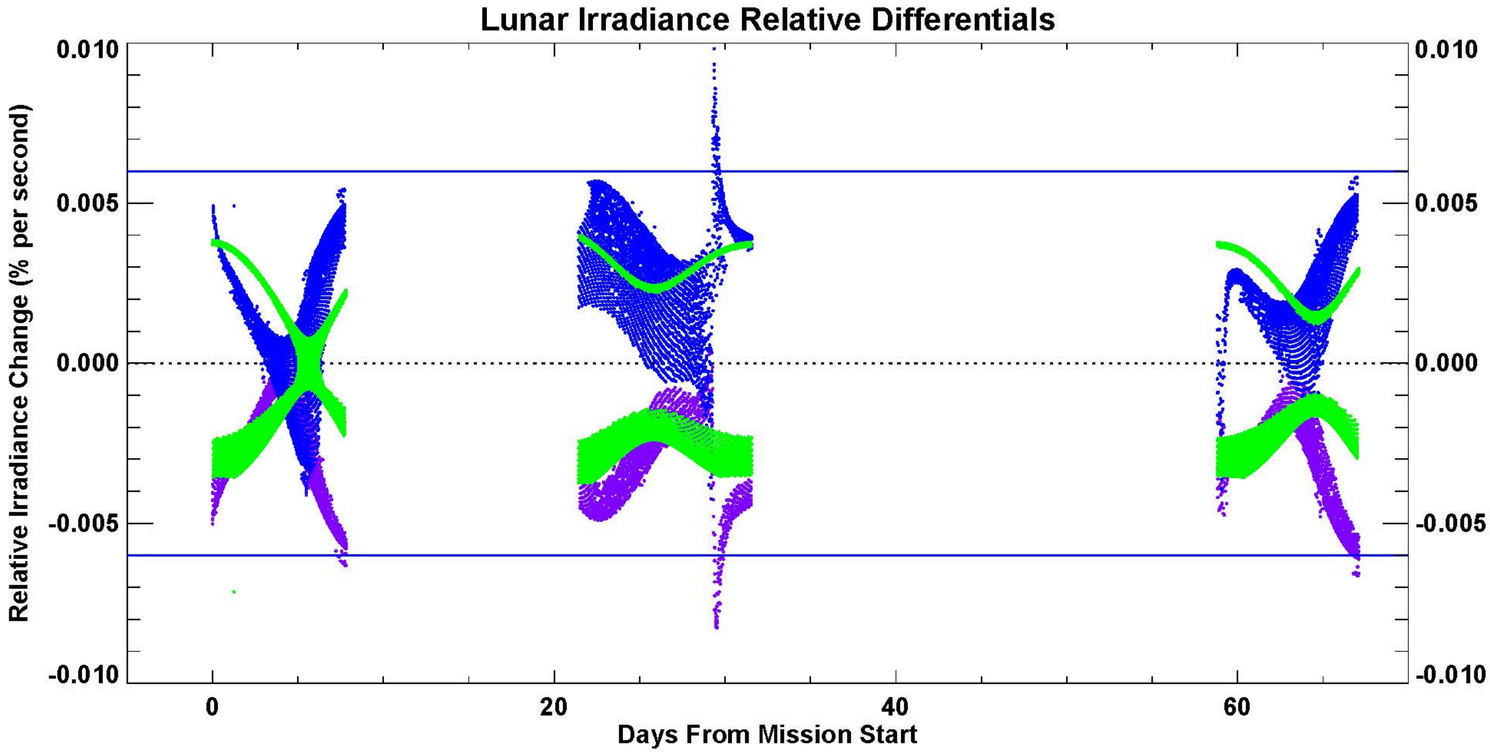
Results: Lunar Irradiance Differentials

Distribution with time — first three lunations



- differentials of distance corrections indicated in green
  - correlation ~0.7, but the patterns are not aligned temporally
- other observation parameters were found to exhibit large variations over the lunation periods

Conclusion and Outcome

Conclusion: the temporal patterns of irradiance differentials arise from a more complex function of observation parameters in the lunar model

– thus some form of the lunar model must be operated to find the smaller irradiance changes

Alternatively, an operational requirement can be derived from the min/max values that encompass most of the irradiance differentials

- fiducial lines in the earlier plots, at ±0.006% sec^{-1}

Given a threshold of allowable variability in the lunar brightness during a measurement, can compute the maximum time to scan the Moon

Example: given a specification that the Moon's brightness can change no more than 0.1% during the measurement, the lunar disk must be scanned within 16.7 seconds:

$$0.1\% \,/\, 0.006\%\ \text{sec}^{-1} = 16.7\ \text{sec}$$

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Thank You!