Evaluation of air-LUSI Measurements to Advance Lunar Modeling and the ROLO Lunar Calibration Reference

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The lunar calibration reference consists of a predictive model.
To improve its accuracy requires collecting new measurements of the Moon.

Why develop high-accuracy lunar calibration?

- Potential to achieve sub-1% absolute radiometric calibration for reflected solar sensors in orbit
  - SI traceable, referenced to solar spectral irradiance
- Accurate cross-calibration using a common, stable target
  - facilitates inter-operability of datasets from different instruments/platforms
  - critical for developing long-term data records, e.g. for climate applications
  - inter-calibration to benchmark reference instruments, e.g. CLARREO, TRUTHS
- Transfer of pre-launch calibration to on-orbit operations
- Ability to bridge a gap in otherwise continuous Earth observation records
  - requires that the Moon is viewed by instruments operating before and after the gap
  - the accuracy of the bridge calibration depends on the accuracy of the lunar reference

airborne Lunar Spectral Irradiance (air-LUSI)

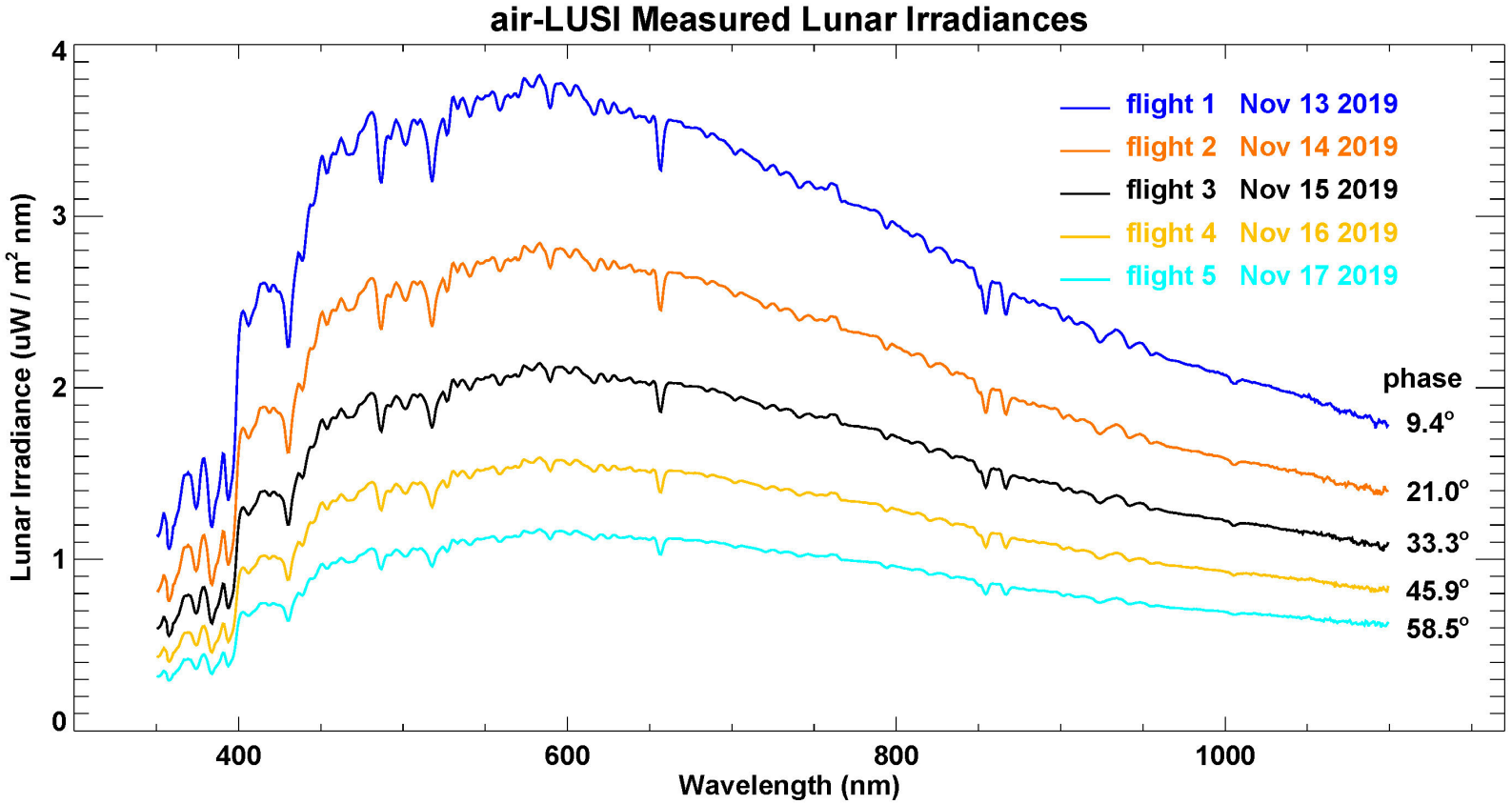
air-LUSI objective: dedicated measurements of lunar spectral irradiance

- High accuracy — target uncertainty: 0.5% (k=1)
- SI traceability — through a chain of calibrations, traceable to NIST standards
- Spectrally resolved
  - 350-1100 nm range, ~4 nm resolution, 0.8 nm sampling
- Moon observations above most of the atmosphere
  - platform: NASA ER-2 aircraft, flies at 21.6 km (70,000 ft)
  - reduced uncertainty from atmospheric correction: min. transmission ~95%
- Definitive specification of absolute lunar irradiance

Application for lunar calibration: constrain the absolute scale and uncertainty of lunar models that constitute the lunar radiometric reference

air-LUSI irradiance measurements — November 2019

- 5 flights each acquired ~60 measurement sets over ~30 minutes on station
  - phase angles: 9.4° 21.0° 33.3° 49.5° 58.5°



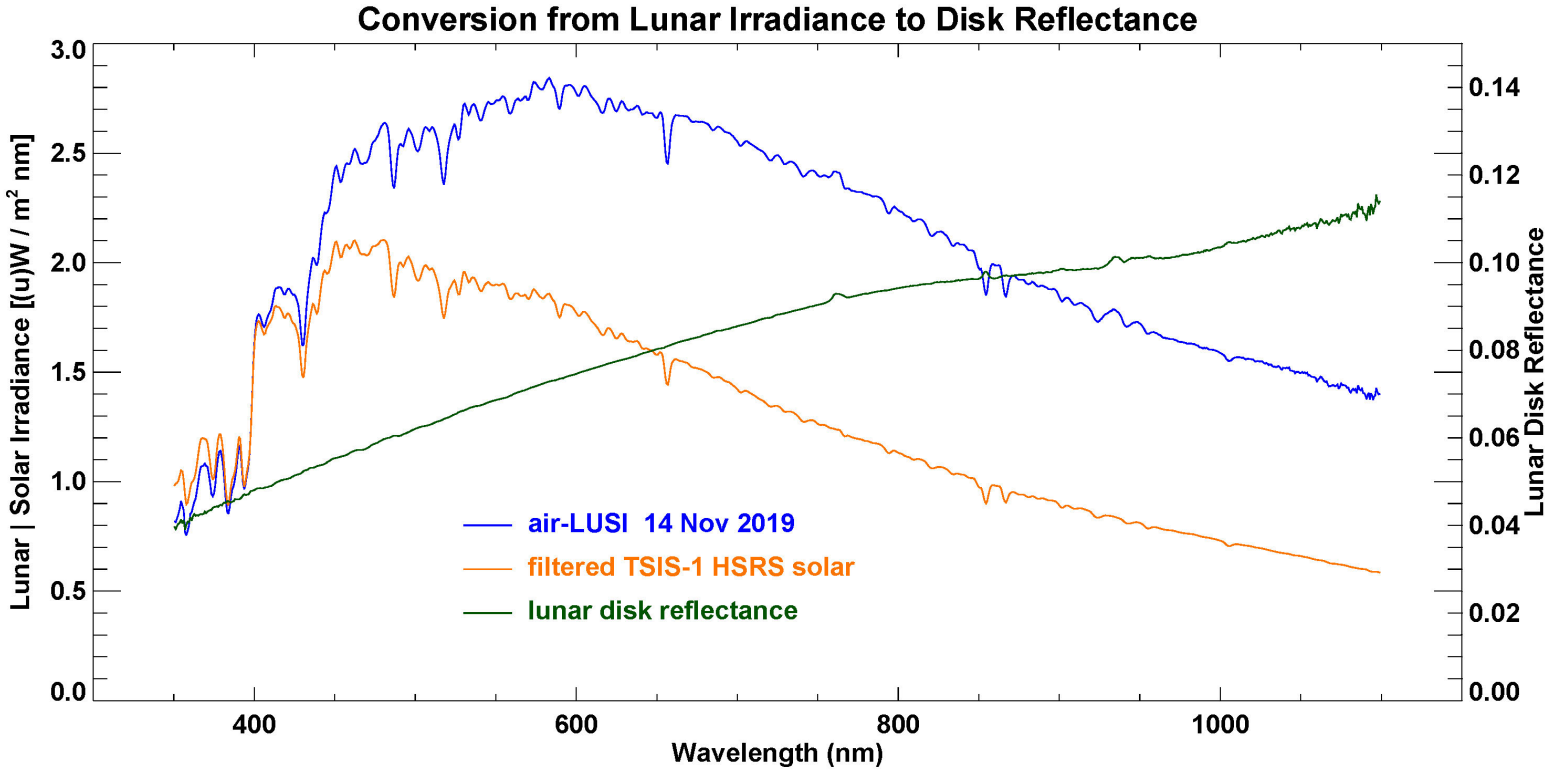
Representative spectra derived from median of measurement sets

Factors of 3 to 3.7 difference in absolute irradiance over this phase angle range, wavelength dependent

air-LUSI measurements — initial verification analysis

Conversion of air-LUSI irradiance measurements to lunar reflectance

- Goal: to check that the reflectance spectrum is smooth, as expected
- Used TSIS-1 HSRS solar spectrum, filtered to air-LUSI sensor line shapes



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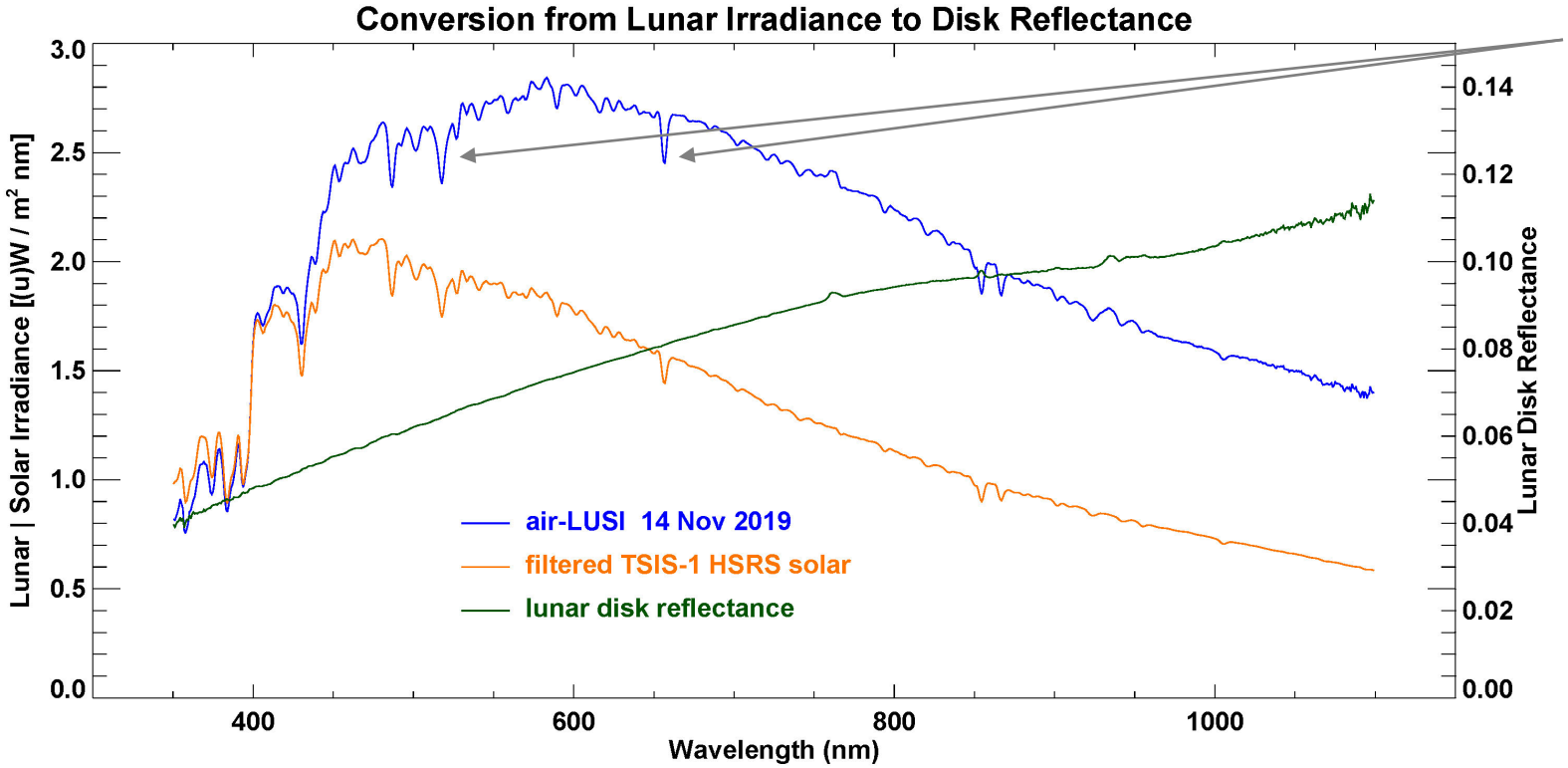

Fraunhofer structure in the air-LUSI irradiance spectrum is effectively offset

- well-matched wavelengths and line strengths
- reflectance spectrum shows a reasonable shape for the Moon

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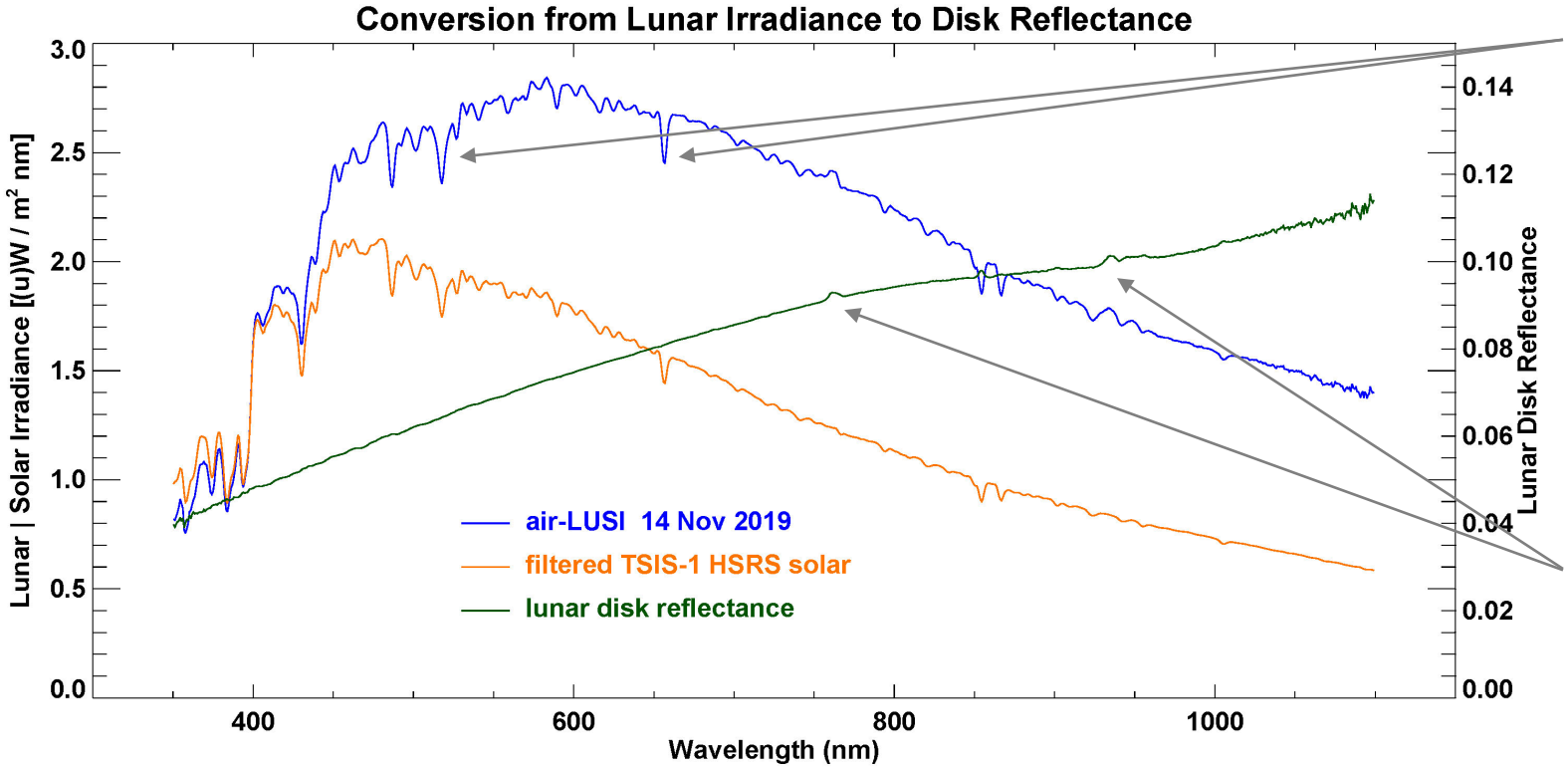

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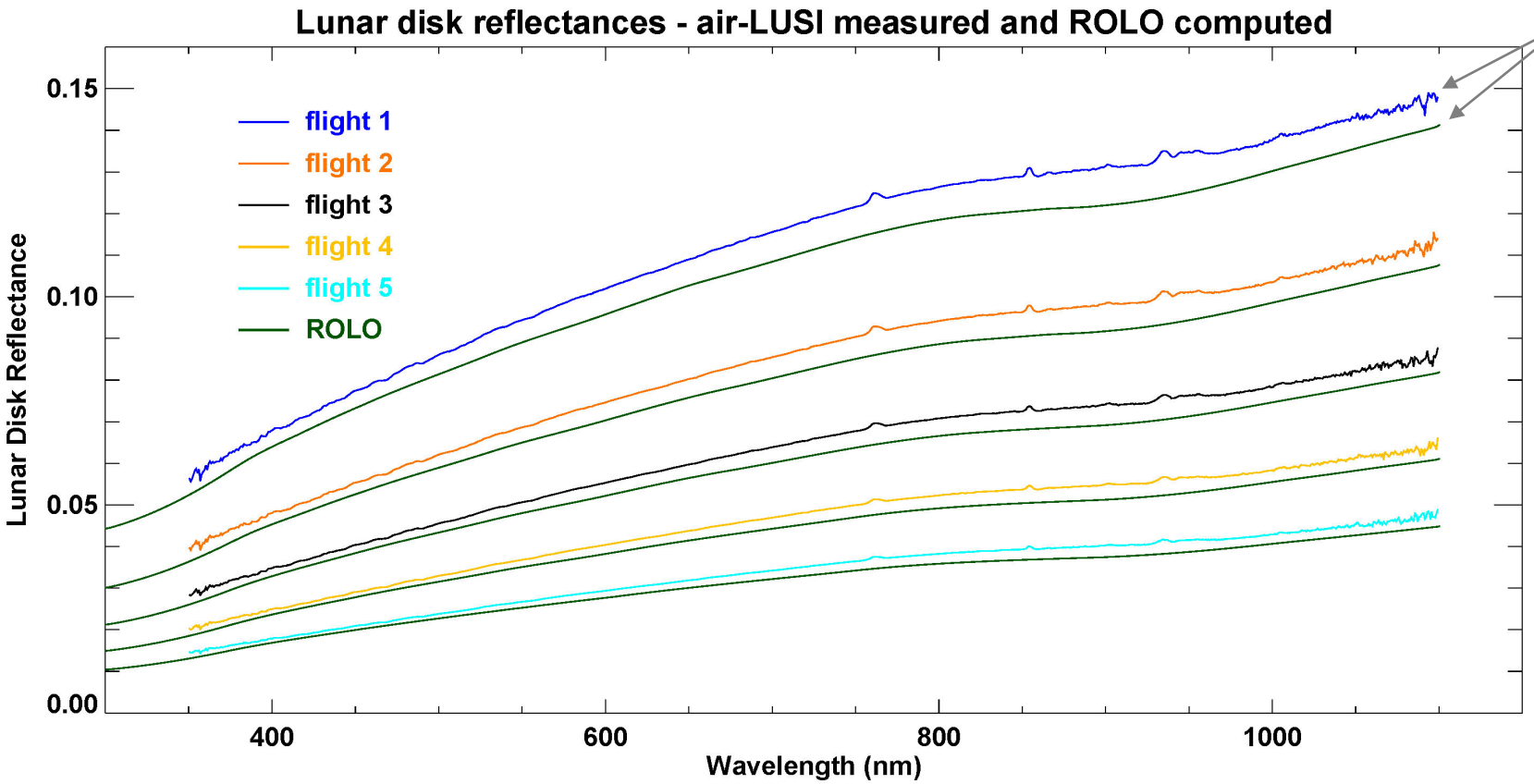
Small residual atmospheric signatures: O_2 A-band, H_2O

- instrument calibration during campaign: integrating sphere at 15 m distance

air-LUSI measurements — comparisons to ROLO

Reflectance conversions for the 5 nights of the Nov. 2019 campaign



Differences from ROLO are consistent at 4% to 7%

- wavelength dependent
- in line with ROLO model estimated uncertainties

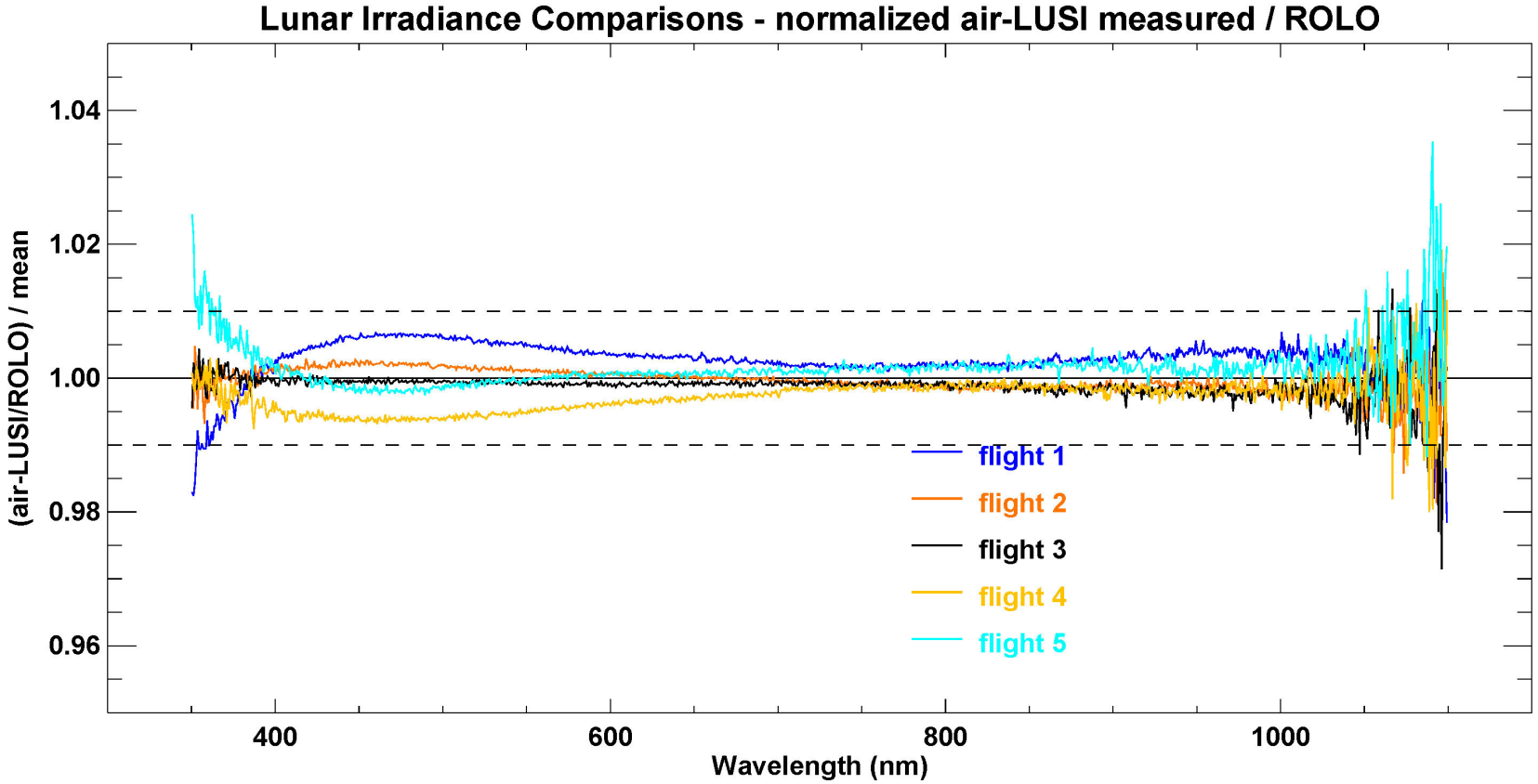
Still characterizing some Type B measurement errors in the air-LUSI data

Spectral shape traces reasonably well over most of the wavelength range

air-LUSI measurements and ROLO — relative comparisons

Comparisons of air-LUSI measurements to ROLO model outputs

- Shown as ratios to the mean (air-LUSI/ROLO) spectrum over the 5 flights



air-LUSI/ROLO comparisons are consistent within ±1%, despite ≥3× difference in the observed lunar irradiance

No clear phase trend in absolute scale differences

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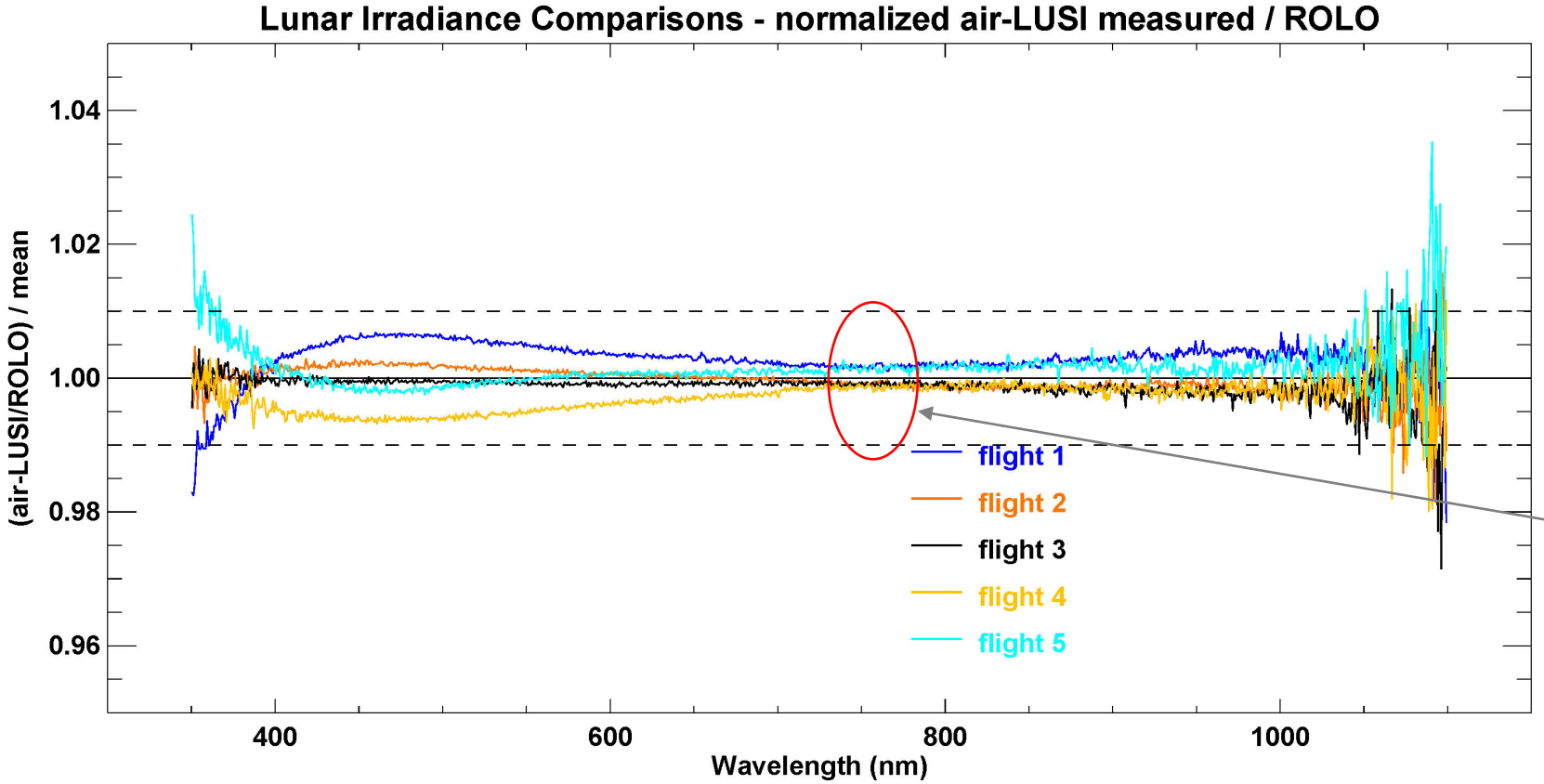

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- ratios match within ±0.3% at 750 nm

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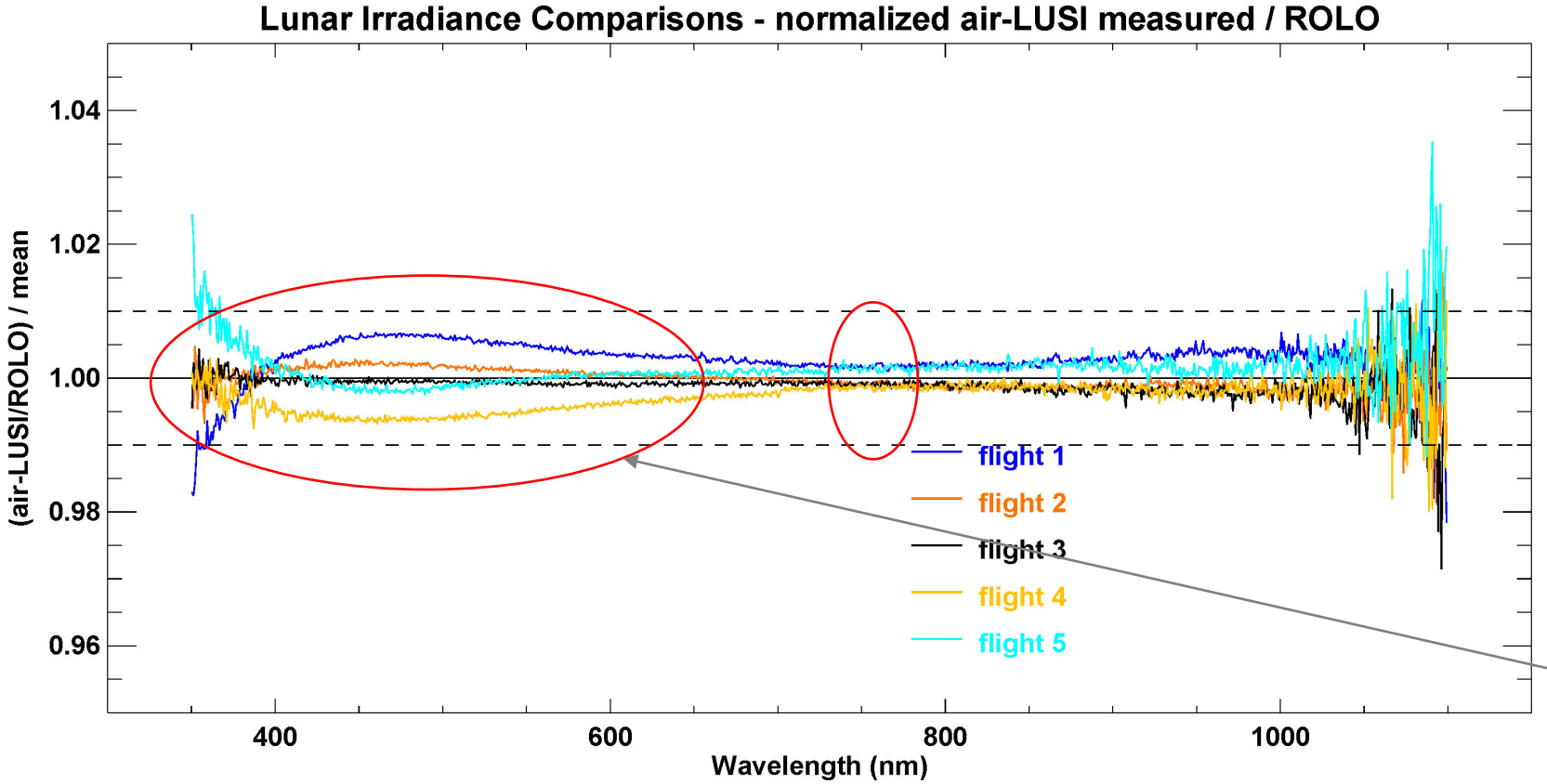

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Spectral excursions toward short wavelengths, monotonic with phase angle

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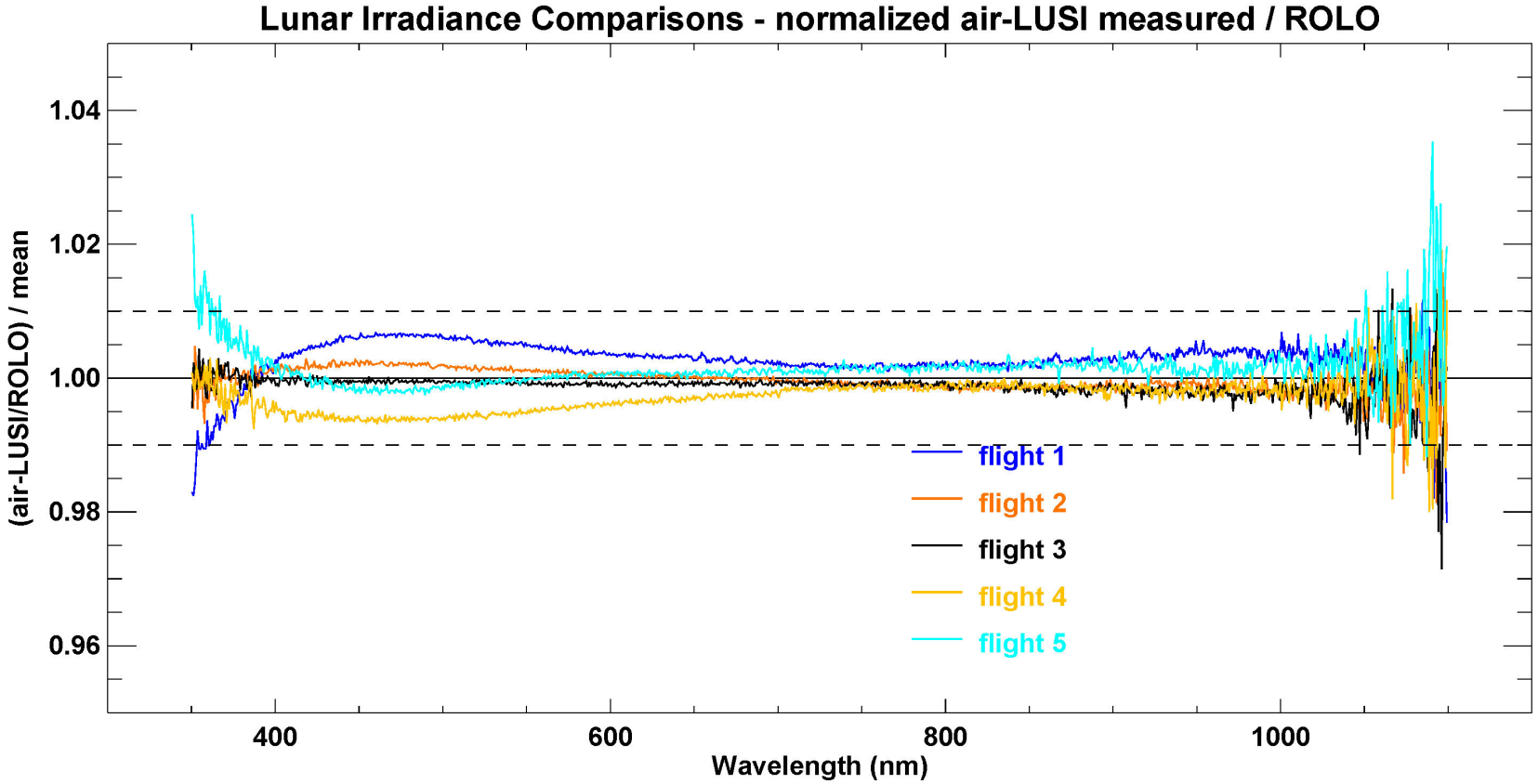

Spectral excursions toward short wavelengths

- origin not clear at present
- monotonic behavior with phase angle suggests actual changes in lunar reflectance with phase
- indicates how air-LUSI measurements can be used to constrain the lunar calibration reference

Take-aways and implications for lunar calibration

Impact on lunar models and advancing lunar calibration development

- air-LUSI measurements are high accuracy, low uncertainty and SI traceable
  - potential definitive specifications of absolute lunar spectral irradiance
- fulfills requirements for new measurements to advance lunar modeling efforts
  - acquired from above most of the atmosphere
  - spectrally resolved
- quantifies the uncertainty (bias) in the ROLO model
  - validates previous 5-7% uncertainty estimates
- defines the spectral content of lunar disk-equivalent reflectance
  - potential to define phase-dependent variations in the lunar reflectance spectrum

Take-aways and implications for lunar calibration

Impact on lunar calibration users

- air-LUSI results can constrain absolute differences in instruments' lunar measurements comparisons to the ROLO model
  - looking to gather ROLO–collaborating instrument teams for discussion of implications
- also constrains potential phase dependence in the ROLO model
  - perceived by some lunar calibration users, e.g. geostationary imagers
  - within the current phase angle range of air-LUSI acquisitions: +9.4° to +58.5°
  - additional flights planned for February 2022, targeting phase angles before Full Moon

Thank You!