Update on the GIRO Benchmark

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Some Preliminary Info

The GIRO (GSICS Implementation of the ROLO model) was developed by EUMETSAT, and provides access to the functionality of the ROLO lunar calibration model for the international community.

The GIRO benchmark was created to validate the GIRO against the ROLO reference, and to establish traceability of the GIRO to ROLO.

Approach: a reference dataset that covers the full parameter space of the ROLO model

- geometric — phase and libration angles viewable from Earth (orbit)
- spectral — range 350 nm to 2.5 μm

Primary application: to validate the GIRO operation against ROLO

- including any updates to ROLO that are propagated to the GIRO

Also, to validate any user's implementation of a lunar irradiance model against the GIRO (and thus ROLO)

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The GIRO Benchmark

A synthetic dataset developed for use with the GIRO

- comprises a set of GIRO input files
  - netCDF format
  - individual sets of SRFs and observations
- generated using python and shell scripts
  - varying the simulated observation parameters and SRFs to span the full valid range of observation geometry and spectral coverage of the ROLO/GIRO model

<u>Geometry Coverage</u>

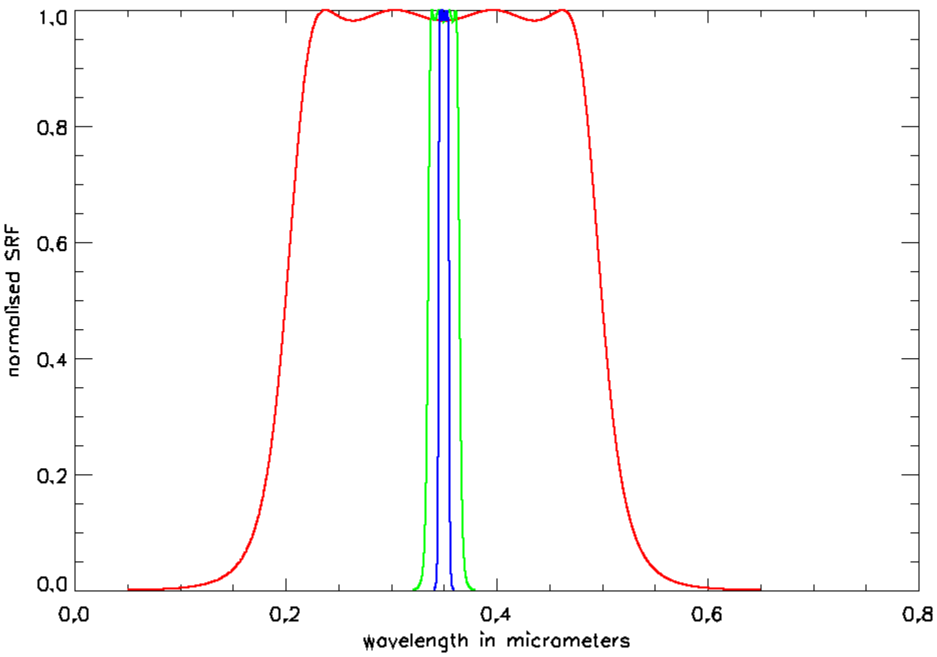
Accomplished by simulating a geostationary orbit at 0° longitude

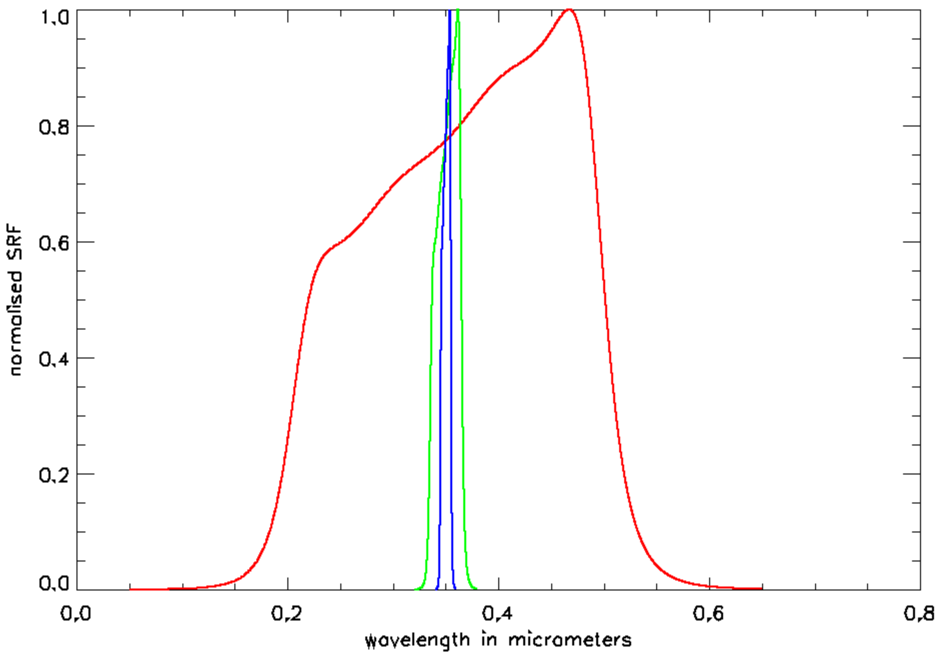
- fixed position: [42000, 0, 0] (km) in Earth-centered Earth-fixed frame
- various observation times and dates
  - starting January 2000, ending December 2017
  - 280 individual date/times, to adequately cover phase and libration space
  - also, one full Saros cycle (18.6 years) for one band (550 nm)

GIRO Benchmark Spectral Response Functions (SRFs)

Generated 3 different band widths and 3 different shapes, 9 total SRFs

- intended to be comparable to real instrument spectral responses
- narrow, medium and broad band widths
- "square" shape, and asymmetric with slope toward both short and long wavelengths





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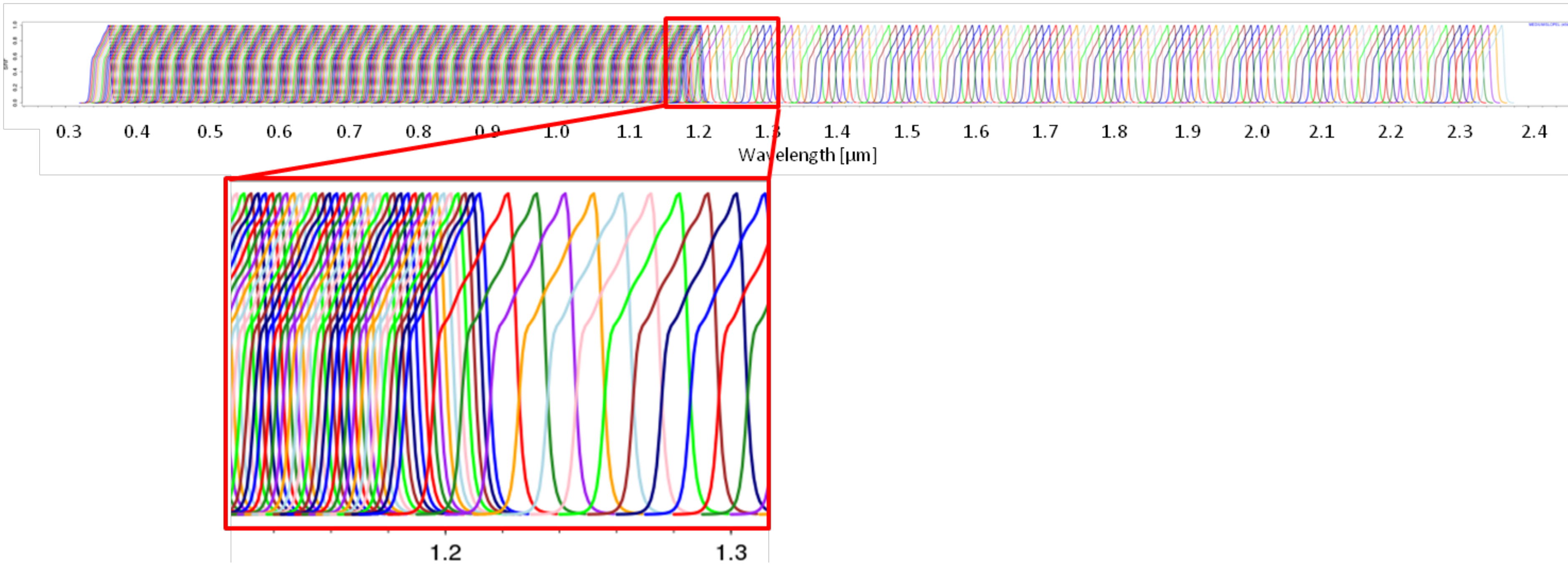
GIRO Benchmark Spectral Coverage and Resolution

Each synthetic SRF set has 456 channels

- channel spacing is 2.5 nm for 350–1200 nm, 10 nm for 1200–2500 nm
- spectral sampling is 0.1 nm for all channels
- number of samples in a band is 200 for narrow width, 600 for medium, 6001 for broad



Initial Testing at USGS

Objective is to compare GIRO and ROLO outputs for the same inputs
- this is the primary validation task

GIRO output files contain all the data needed to run the ROLO model
- benchmark output files were provided to USGS by EUMETSAT

The GIRO outputs require some pre-processing to generate ROLO inputs
- conversion of spacecraft position from ECEF to J2000 inertial frame
- conversion of observation times from UNIX time to Julian Days
- check on ephemeris data: phase and librations, Sun and Moon positions

ROLO standard ancillary SRF files built from benchmark SRFs

Initial test used one SRF set (NARROW+SQUARE) and one observation data set
- 6 date/times
- phase angles: 73.8°, 74.2°, 77.9°, 79.7°, 80.0°, 86.6°

Initial Testing at USGS

First test: validation of the lunar disk reflectance model

- kernel of the ROLO system, Eq. 10 in Kieffer&Stone (2005):

$$\ln A_k = \sum_{i=0}^{3} a_{ik} g^i + \sum_{j=1}^{3} b_{jk} \Phi^{2j-1} + c_1\phi + c_2\theta + c_3\Phi\phi + c_4\Phi\theta$$

$$+ d_{1k} e^{-g/p_1} + d_{2k} e^{-g/p_2} + d_{3k} \cos((g - p_3)/p_4)$$

- for input phase (g) and librations (Φ, φ, θ) generates disk reflectance A_k for the 32 ROLO bands k
  - these 32 values are provided in the GIRO output files
  - *ROLO values were found to be identical, to within machine precision*

Second test: comparing the GIRO output lunar irradiances with computations of ROLO model:

discrepancy = (GIRO/ROLO – 1) × 100%

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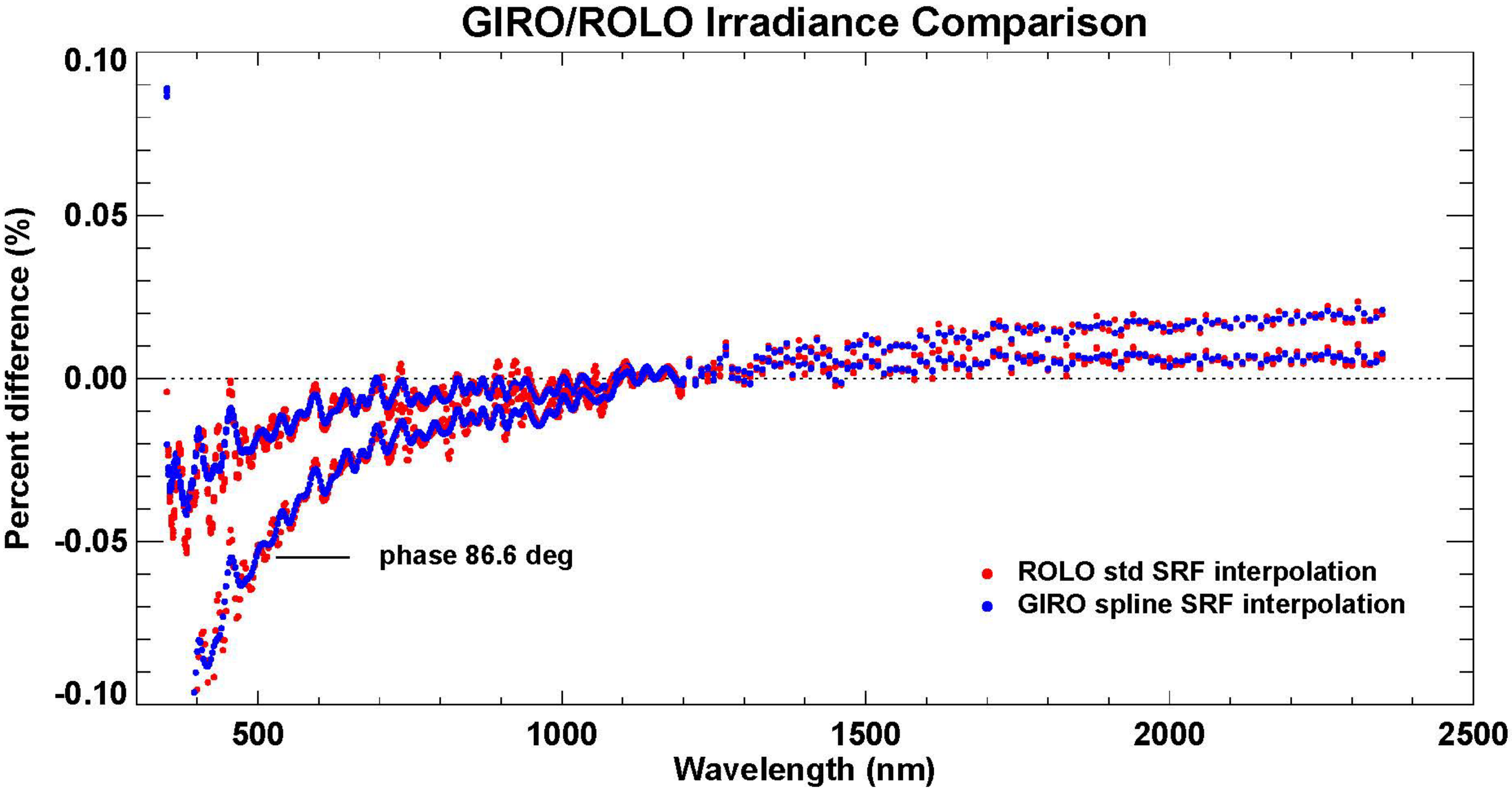
Results of First Comparisons of GIRO Benchmark to ROLO

Plot of lunar irradiance comparison: (GIRO/ROLO – 1) × 100%

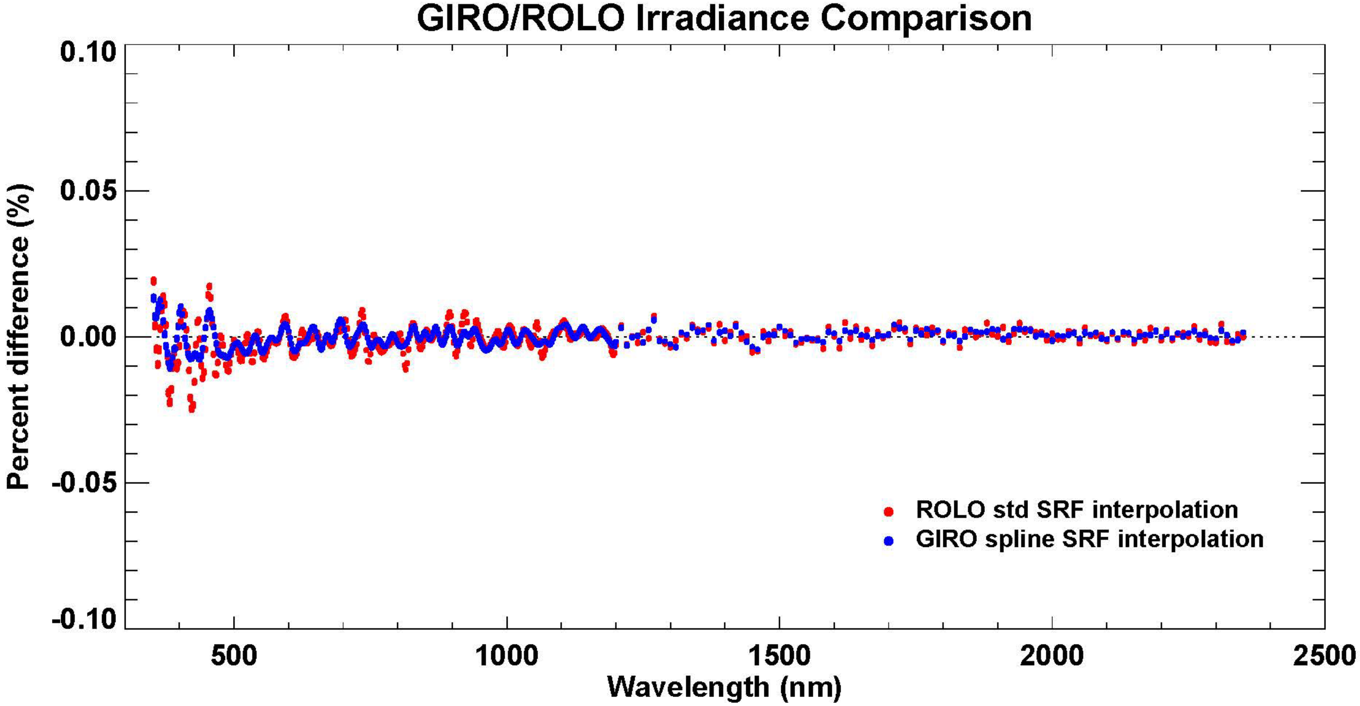
- differences up to 0.14% seen
- spectral trends and spectral structure seen
- GIRO spline interpolation method implemented in test (blue points)



Tracing the Source of the Anomalies

<u>Investigation of differences in algorithm implementations</u>:

- solar spectrum, used for conversion of disk reflectance to irradiance
  - Wehrli (1985) PMOD-WRC spectrum, Gaussian filtered to SRFs
- spectral smoothing of disk reflectance model outputs A_k
  - *found to be the source of the spectral trend anomaly*
- spectral interpolation and convolution with SRF and solar spectrum



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Mitigation Strategy

Constraints:

- both ROLO and GIRO are quasi-operational systems
- making significant modifications to ROLO means changing many years of results for many spacecraft instruments
  - will happen when a new major version of the ROLO model is released
- GIRO is written in C language
  - there are fundamental differences from ROLO in terms of algorithm implementation — ROLO is written in IDL

Examining code differences

- sources of both the spectral trend and spectral structure anomalies have been found
  - discrepancies between GIRO and ROLO ancillary parameters: easy to fix
  - discrepancies in algorithm implementation: must be reconciled between USGS and EUMETSAT
  - discrepancies in software operation: must be handled by reconciling code implementation between USGS and EUMETSAT

Conclusions and Next Steps

- The GIRO benchmark is a comprehensive synthetic dataset
  - intended to exercise the full range of the lunar irradiance model
  - remainder of cases need to be run: phase and libration geometries, SRFs
- Initial testing with the benchmark started, for validation against ROLO
  - has revealed variations in algorithm implementation and operation between the software systems
    - an outcome of the comprehensive nature of the benchmark dataset
- Continuing collaboration between USGS and EUMETSAT is essential
  - to reconcile code differences and algorithm implementation
  - to assure consistency of ROLO and GIRO systems, to the extent possible
- Implementing improvements to the ROLO model, propagated to GIRO
  - minor upgrades can be done now
  - a major version update may/will require substantial re-coding of the GIRO

The GIRO is recommended to be used by the GSICS and CEOS-IVOS Lunar Calibration communities

Thank You!