Update on the a high-resolution, high-accuracy solar reference spectrum based on TSIS-1 SIM

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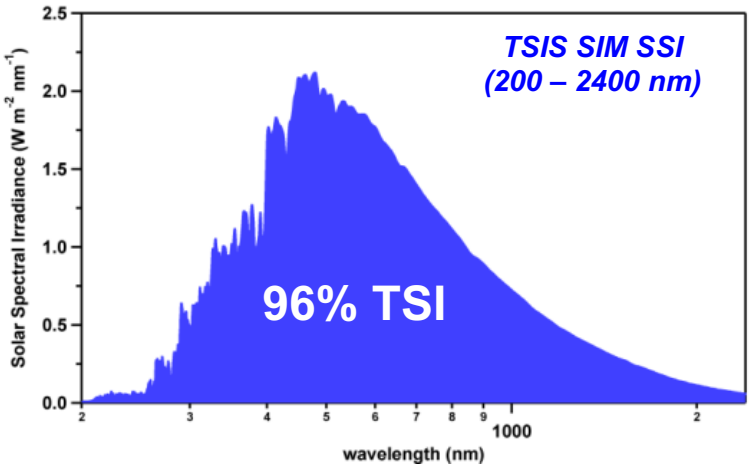
Outline

- Motivation
  - new, high-accuracy TSIS-1 SIM
  - Comparisons of TSIS-1 SIM to CSIM
  - Comparisons of TSIS-1 SIM to other common solar reference spectra
- Developing a high-resolution, high-accuracy solar reference spectrum
  - Methodology
  - Available high-resolution solar irradiance datasets
  - Example of re-calibrating a high-resolution dataset to TSIS-1 absolute scale

  New Results since the Sun-Climate Symposium (January, 2020)
  - Preliminary 'Hybrid' reference spectrum at 4 spectral resolutions
  - Preliminary validation results
- Next steps
  - Assess wavelength scale
  - Validation
  - Publish

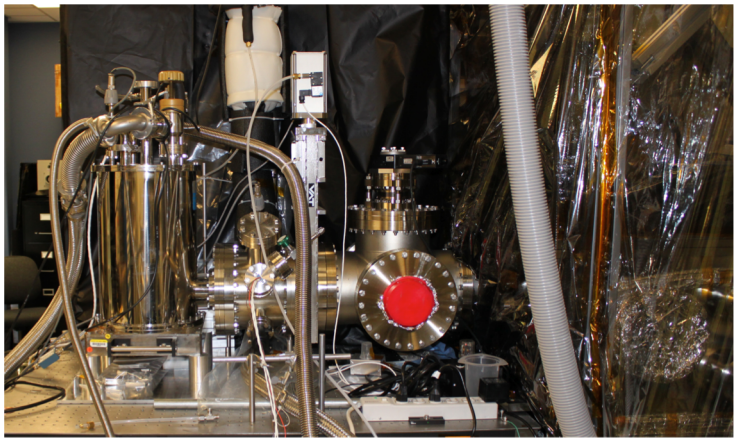
Motivation

- Knowledge of solar spectral irradiance (SSI) magnitude and variability is important for:
  - attribution of climate forcing,
  - solar irradiance variability modeling,
  - radiative transfer modeling,
  - conversion of measured satellite reflectance to radiance,
  - satellite calibration and on-orbit stability tracking
  - and much more.
- TSIS-1 SIM is designed, characterized, calibrated and validated to quantify and track SSI variability.
  - TSIS-1 SIM absolute accuracy *performance* is **<u>0.41% (uv) and 0.24% (vis/nir)</u>**
  - Pre-TSIS SSI absolute accuracy is **<u>2-8%</u>**



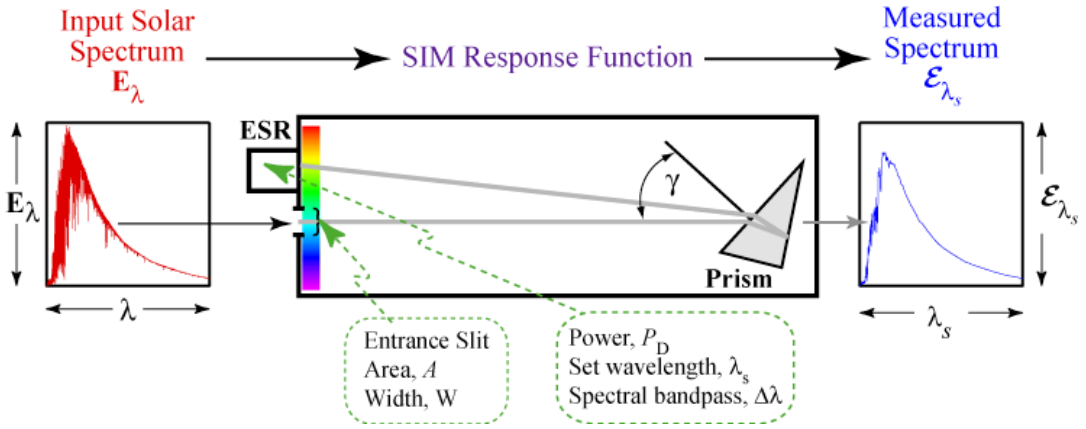
Detector-based calibration is key to high accuracy

- TSIS-1 SIM is the first, solar-viewing spectroradiometer using an electrical substitution radiometer that traces its accuracy to a primary detector-based standard.
  - detector-based radiometry allows for ~***5x improvement*** in accuracy (~0.05% unc) versus blackbody sources (~0.25% unc.) [*H. Yoon, Calcon, 2013*]
- For radiometric calibration, you can build a more accurate detector than a source (lamps, blackbodies, etc.).
  - LASP built the Spectral Radiometer Facility



LASP Spectral Radiometer Facility

TSIS SIM Measurement Principle

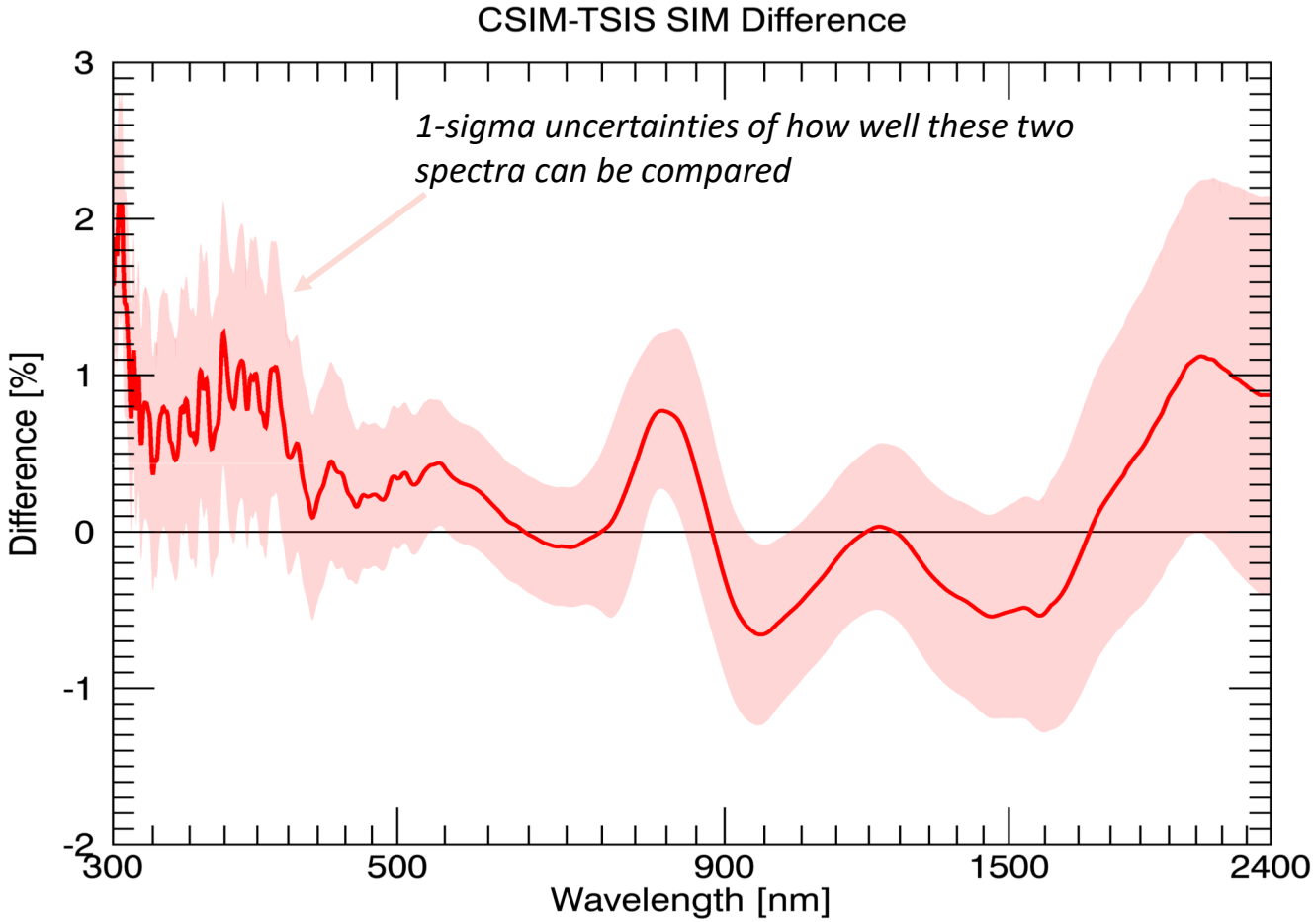


$$\mathcal{E}_\lambda(\lambda_s) = \frac{P_D(\lambda_s)}{A \cdot \Delta\lambda(\lambda_s)} \quad \text{units: } \frac{\text{W}}{\text{m}^2 \cdot \text{nm}}$$

P_D is the optical power directly measured by the SIM ESR

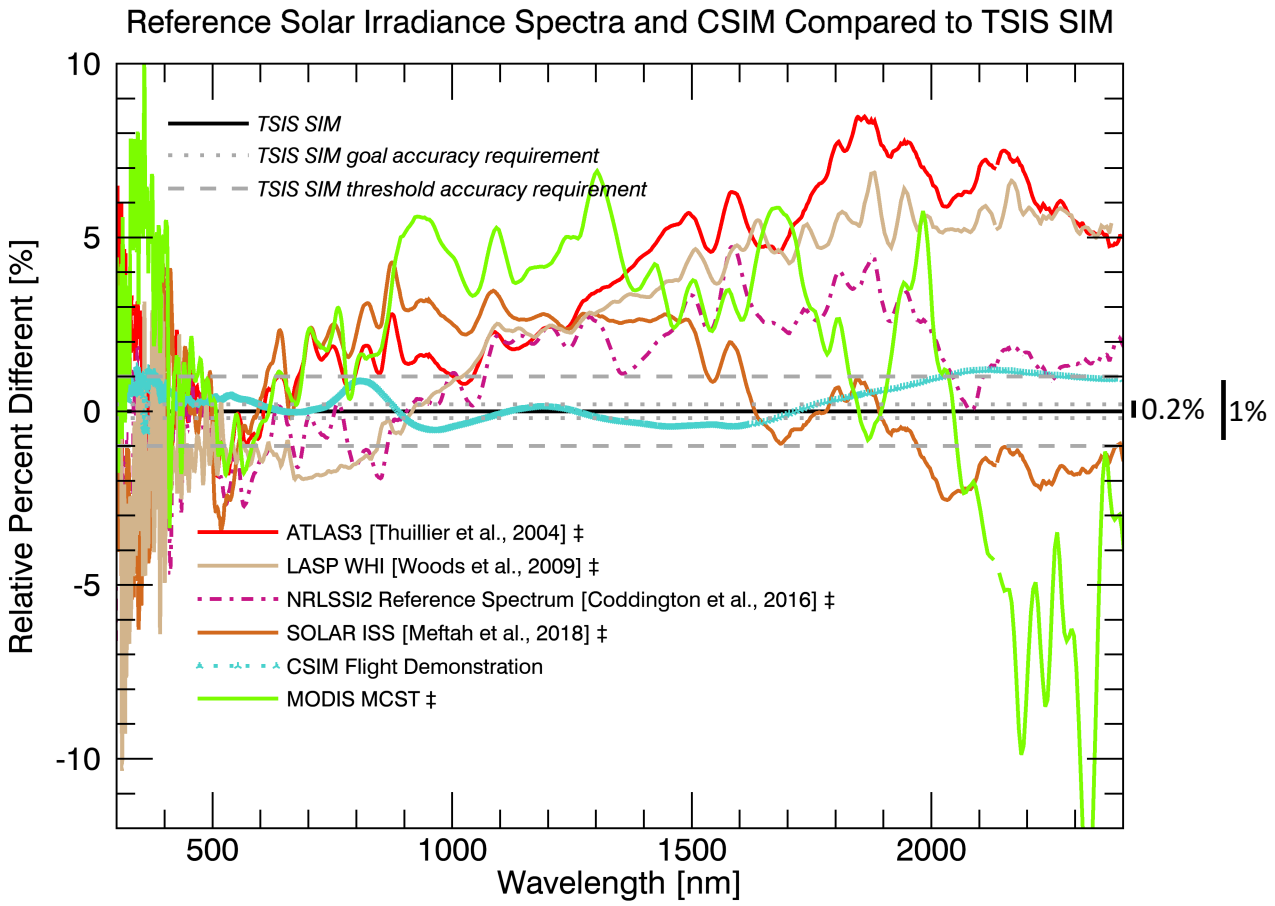
CSIM and TSIS-1 SIM Difference

- The Compact SIM (CSIM) technology demonstration mission (launched early 2019) shows on-orbit agreement to TSIS-1 SIM to 1%.



*CSIM measures a broader spectral range than TSIS-1 SIM. CSIM will be used to extend the hybrid reference spectrum past 2400 nm.

TSIS-1 SIM sets a new standard for SSI accuracy

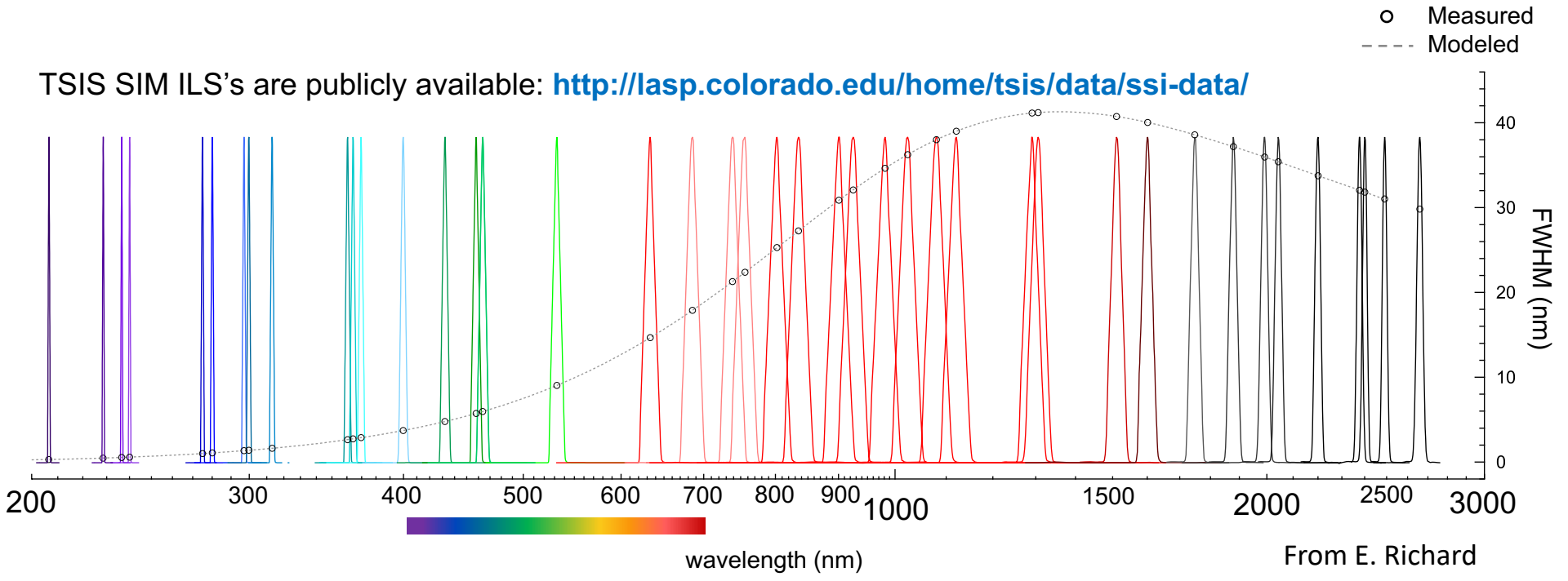


*All datasets have been convolved to TSIS SIM resolution.

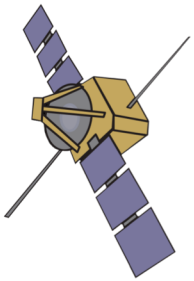
Results updated to include comparison to MCST reference spectrum

Methodology

- Spectral ratio method [e.g. Dobber et al. 2008; Kang et al., 2017]
- Scaling factor = the ratio of the low resolution dataset to the high-resolution dataset (convolved to the resolution of the low resolution, but higher accuracy, dataset)
- Modification: for our work, we also derive the spectral ratio, but at ***even lower*** resolution than that of the low resolution, high accuracy, dataset
- Validation of results: Convolution of the hybrid spectrum with the TSIS-1 SIM instrument line shape, followed by comparison to TSIS-1 SIM. Requires good knowledge of TSIS-1 SIM instrument line shape (ILS)



SPTS (empirical)

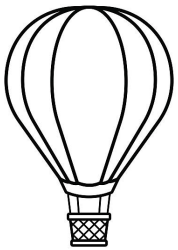


ATMOS

ACE

GOSAT

Which high-resolution data sets to use? So many choices!



AFGL

MKIV

TCCON

CAVIAR2 (has gaps)

QASUME/FTS

KPNO (solar irradiance atlas)

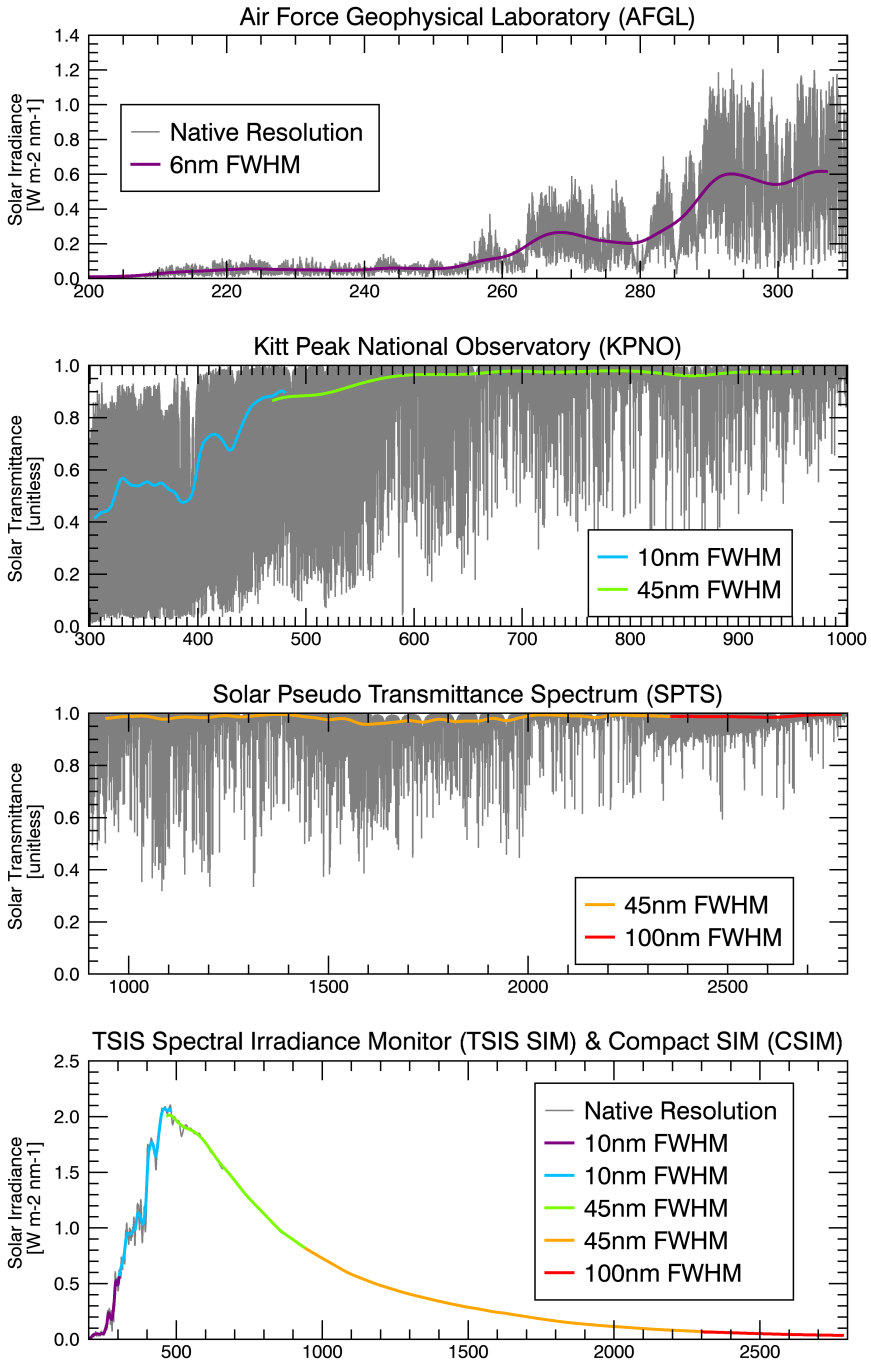
KPNO (solar flux atlas)

200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800

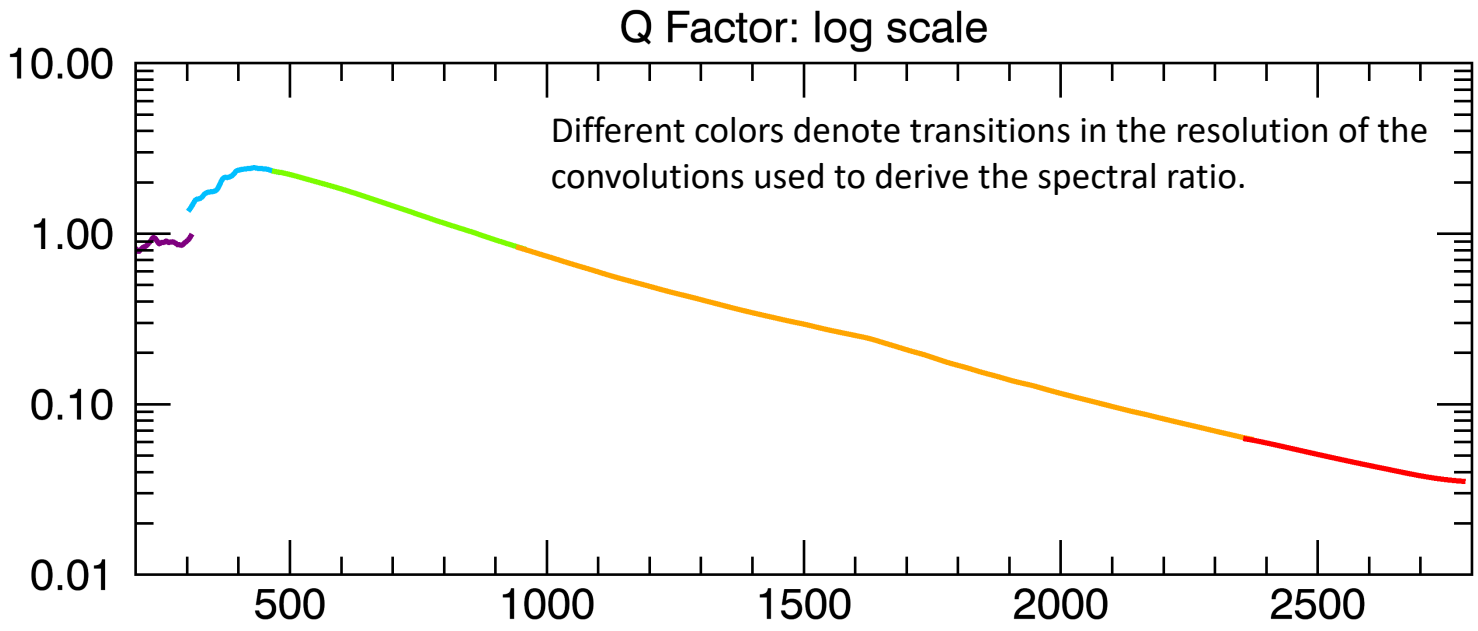
(nm)

All Datasets used in the Hybrid Spectrum

Different colors denote transitions in the resolution of the convolutions used to derive the spectral ratio.



Spectral Ratio, ‘Q-Factor’

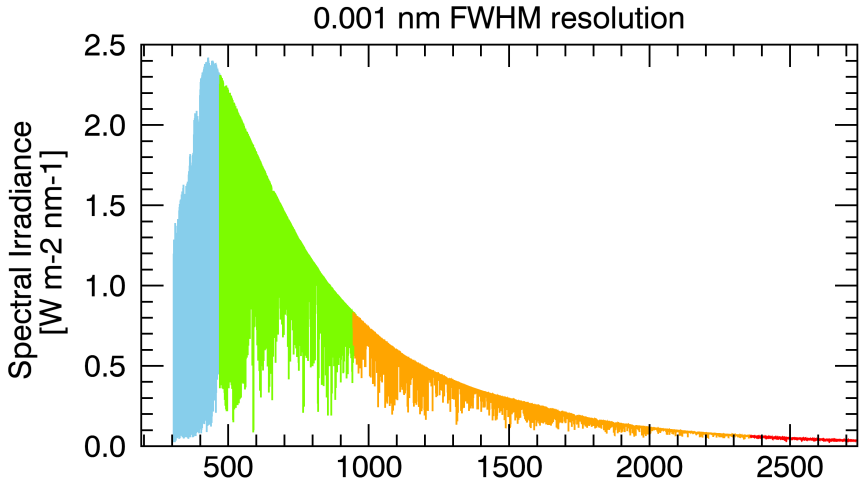


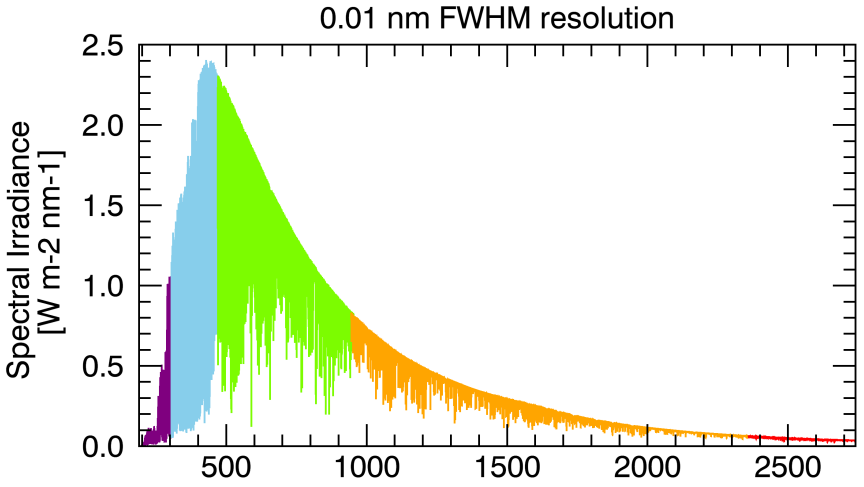
The Q-Factor is used to re-calibrate the high resolution datasets (multiplicative factor).

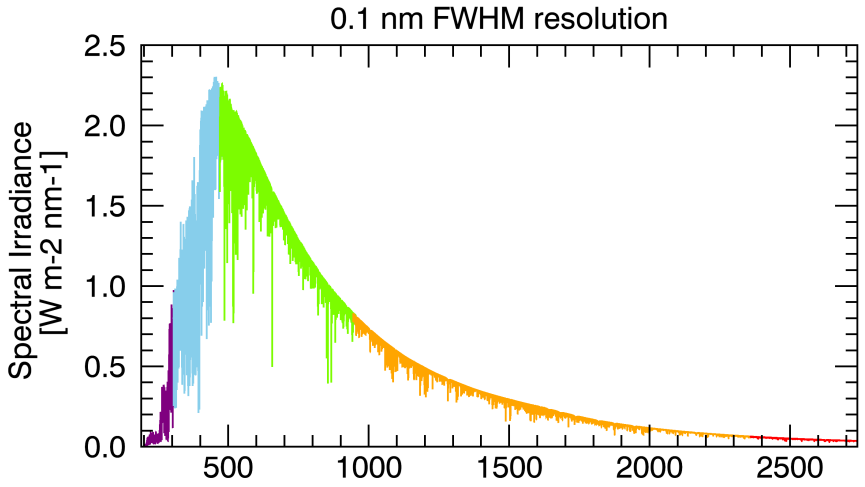
The Q-Factor corrects underlying calibration, **with no changes to the spectral lines of the high-resolution datasets**.

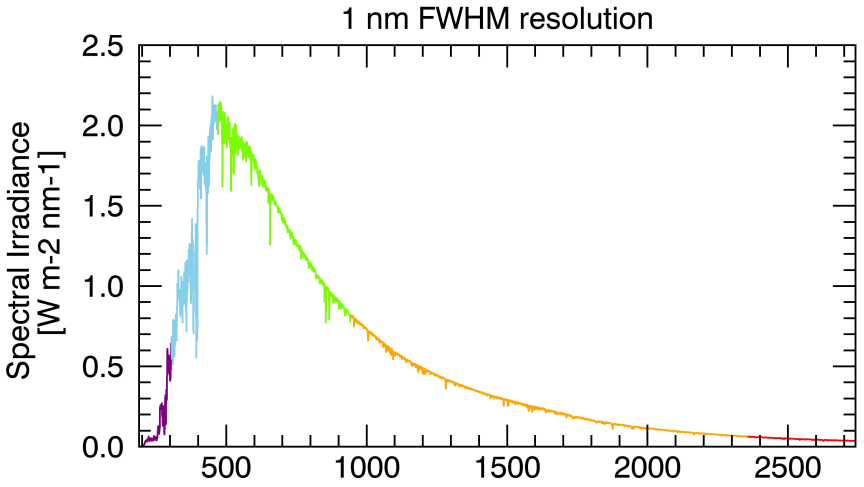
Hybrid Reference Spectrum (prelim): 4 resolutions

*Coarser resolutions obtained by convolving 0.001 nm spectrum with Gaussian kernel of specified FWHM.

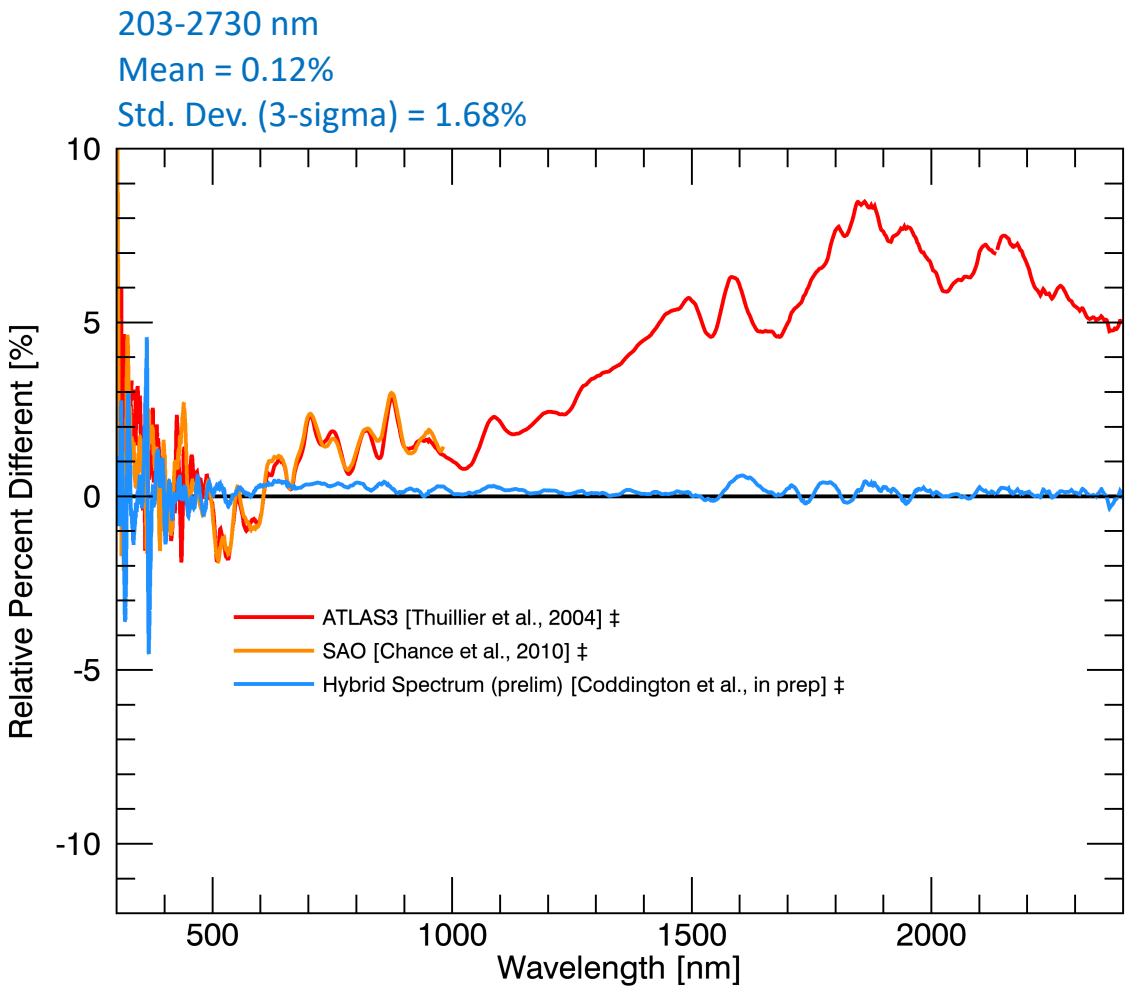








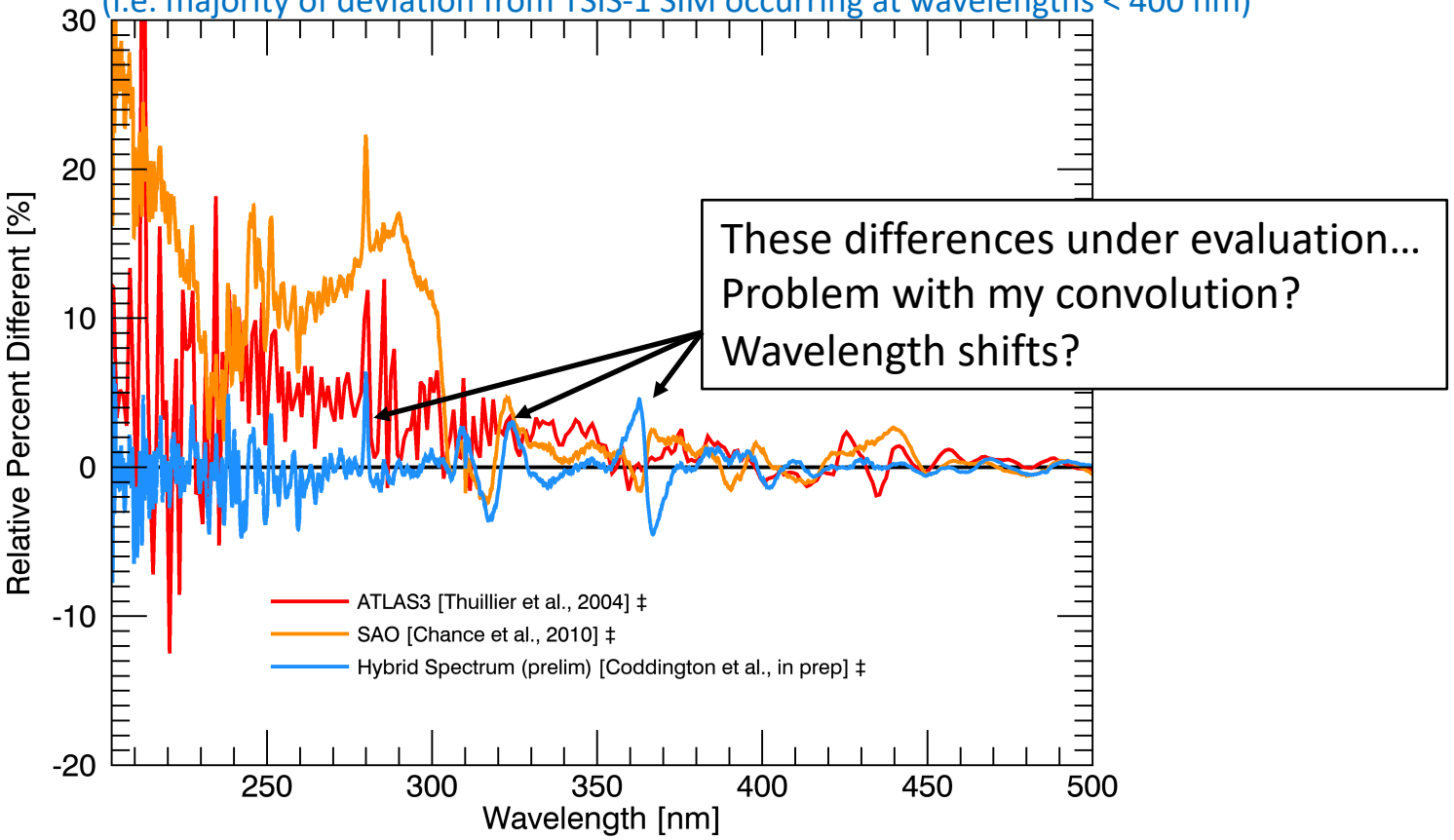
Validation (203nm-2730 nm):



*All datasets have been convolved to TSIS SIM resolution.

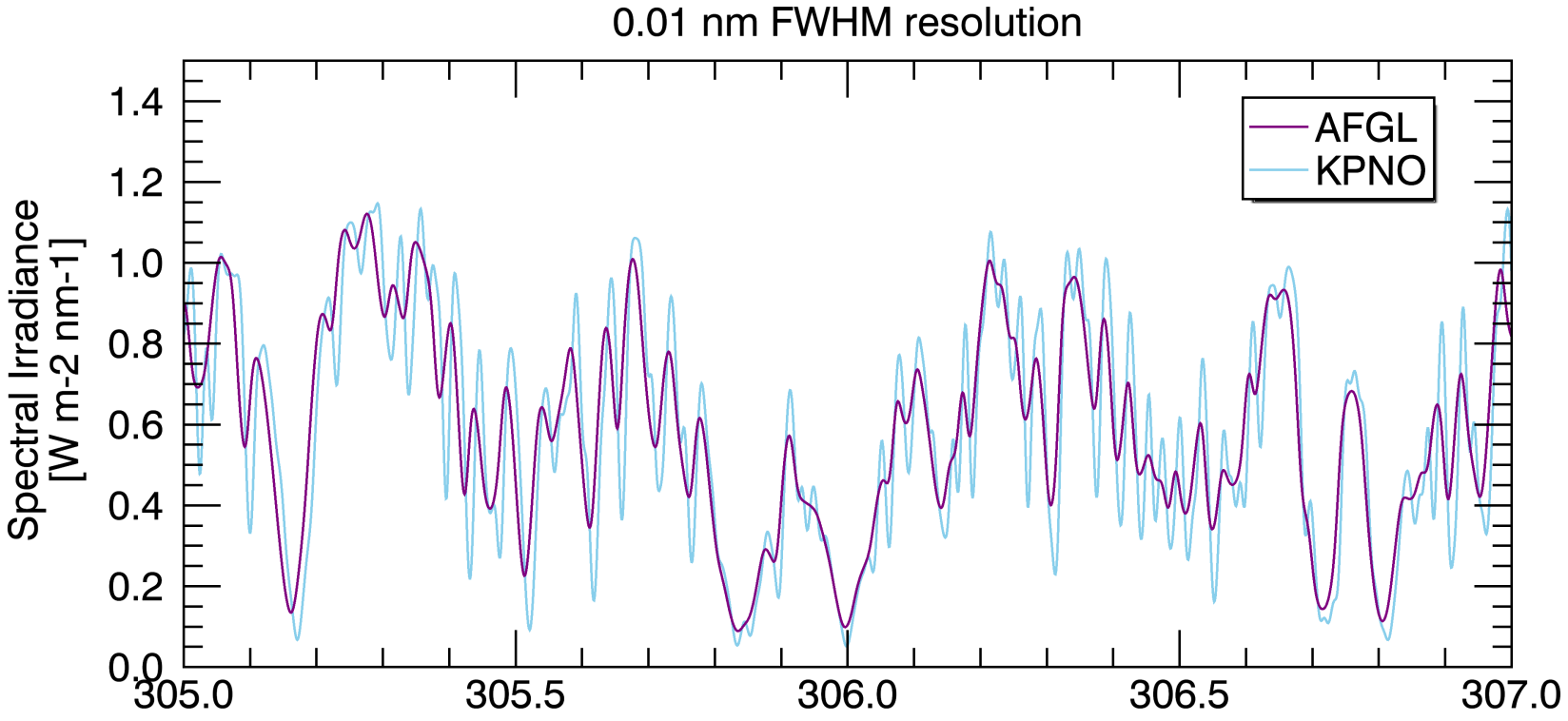
Validation (203-500 nm):

203-500nm
Mean = -0.10%
Std. Dev. (3-sigma) = 4.35%
(i.e. majority of deviation from TSIS-1 SIM occurring at wavelengths < 400 nm)



*All datasets have been convolved to TSIS SIM resolution.

Wavelength scale



Currently re-assessing:

*my conversion from air to vacuum wavelengths for AFGL data.

*my convolutions.

*Further comparisons of the position of spectral features in the hybrid-spectrum against *independent* higher resolution datasets, such as GOSAT, OCO, QASUME-FTS, SCIAMACHY, etc.

Next Steps

- Validation of the high-resolution hybrid reference spectrum at TSIS-1 SIM irradiance scale:
  - 203-2730 nm (extended from 2400 nm with CSIM
  - 4 spectral resolutions (0.001 nm, 0.01m, 0.1, and 1 nm).
  - Evaluate wavelength scale: re-assess air-to-vacuum conversion, correction to underlying dataset(s) needed?
- Our Sun is a variable star
  - TSIS-1 SIM launched near to solar minimum ("first light" spectrum)
  - The 'WHPI campaigns' show we've entered the next solar cycle. "Quiet" Sun periods occurred during 2019 to early 2020.
- Define uncertainties, wavelength-dependent, with contributions from:
  - TSIS-1 SIM accuracy
  - The small offset needed to scale CSIM to TSIS-1 SIM at 2400 nm.
  - A metric of how well the re-calibration of the high-resolution data to TSIS SIM scale can be performed across the spectrum
    - currently at 0.12% and 1.86% (mean and 3-sigma std. dev.)
  - Uncertainties in wavelength scale (propagated into irradiance)
- Publish