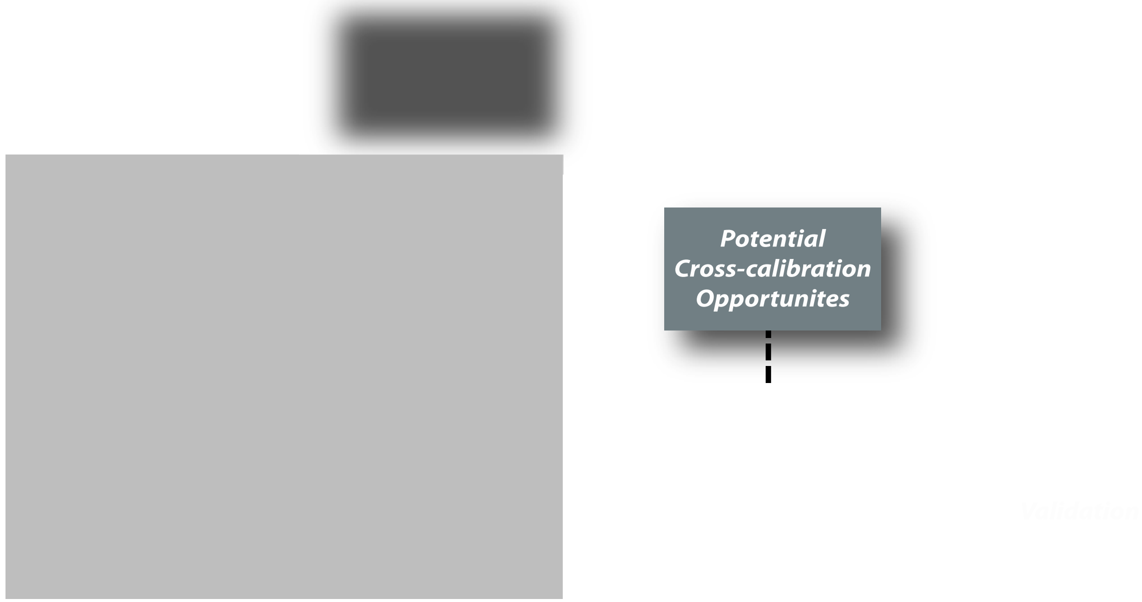
The analysis of improved laboratory measurements in the recalibration and reevaluation of the SORCE SIM data record

Erik Richard, Dave Harber, and Stéphane Béland
LASP

SIST Motivation

While the pre-launch SORCE SIM calibration efforts were limited in scope, largely due to insufficient calibration resources and schedule restrictions, continuous calibration refinements are required to improve data quality and further quantify uncertainty limits – <u>systematic uncertainties</u> (and potentially long-term trends)



SIST Analysis

Year 1 goals and achievements

- To adapt the existing resources used to develop the TSIS SIM optical-radiometric model to the SORCE SIM design and use new calibration and analysis data

  Data includes:

  Index of refraction (& temp. dep)
  Prism transmission
  Second-surface Alum. Reflectivity
  Photodiode rad. sens. (& temp. dep)

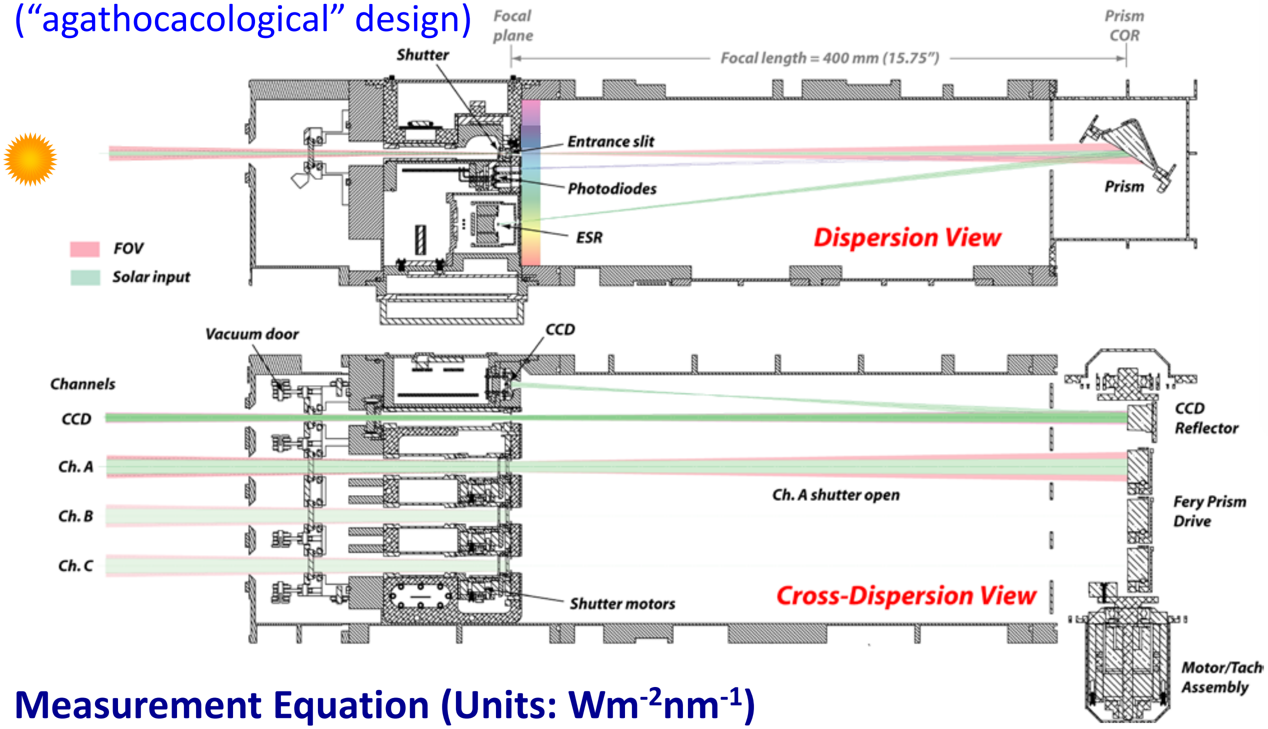
- Definition and refinement of the model will serve as a basis for elucidating systematic uncertainties and allow for evaluation of performance characteristics observed

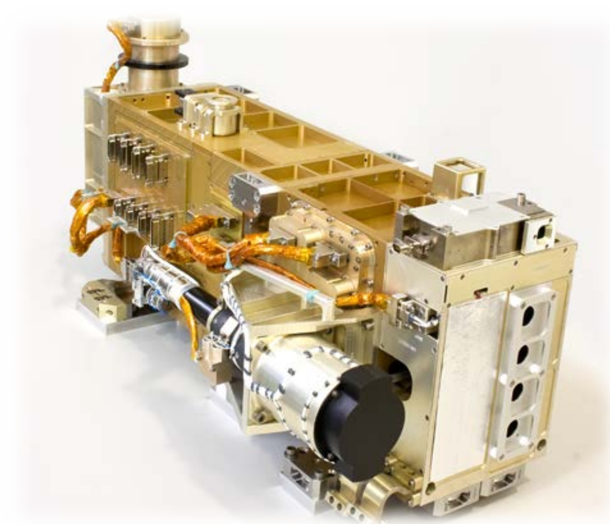
  IR issues – spectral profile intregral refinement

SIST
Solar Irradiance Science Team

TSIS SIM Overview

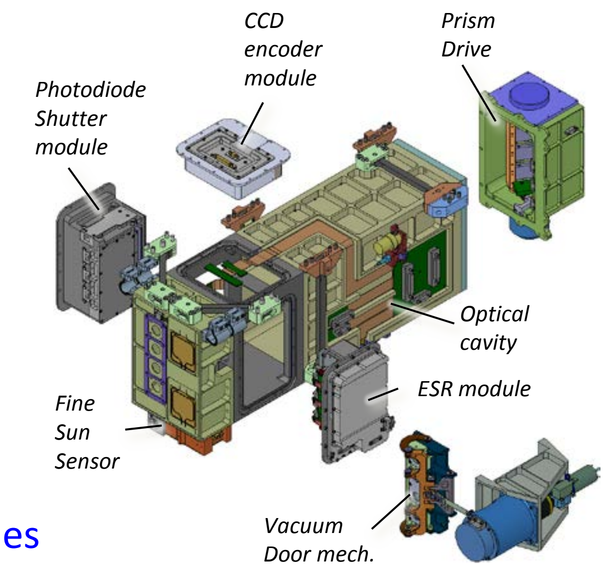
Féry prism spectrometer covering the full wavelength range from the UV to IR using <u>only one optical element</u> for spectral dispersion and image quality (“agathocacological” design)





Measurement Equation (Units: $Wm^{-2}nm^{-1}$)

$$\mathcal{E}_\lambda(\lambda_s) = \frac{\mathcal{P}_{ESR}(\lambda_s)}{A_{slit} \cdot \int \alpha_\lambda \cdot T_\lambda \cdot \phi_\lambda \cdot S(\lambda, \lambda_s)\ d\lambda}$$

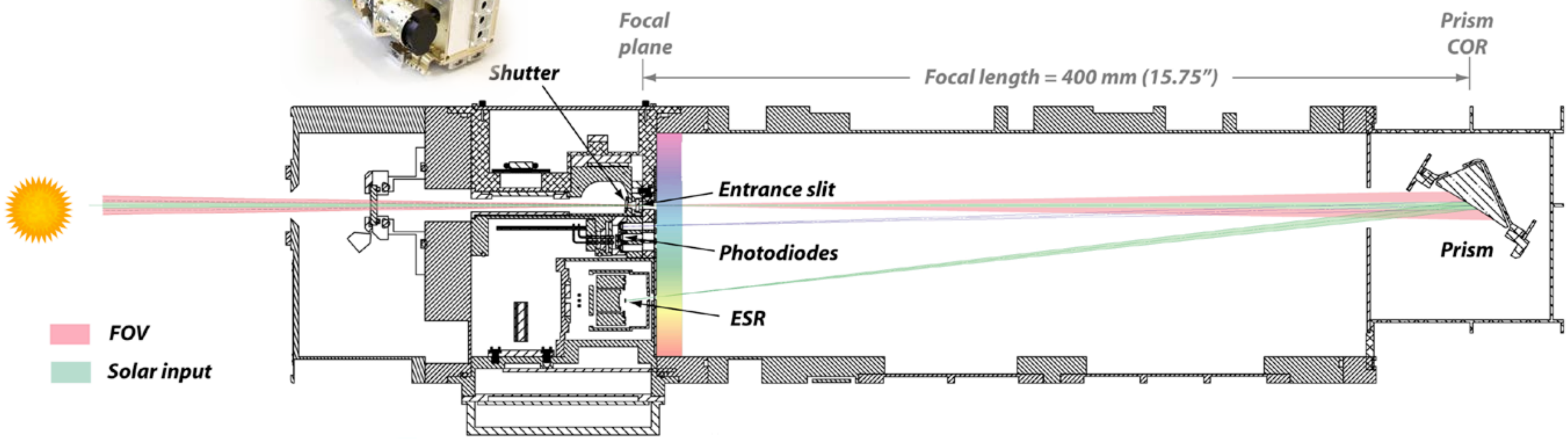


Modular design that allows for unit-level and sub-system performance characterizations and calibrations, also help to mitigate contamination issues

"TSIS to SORCE SIM"

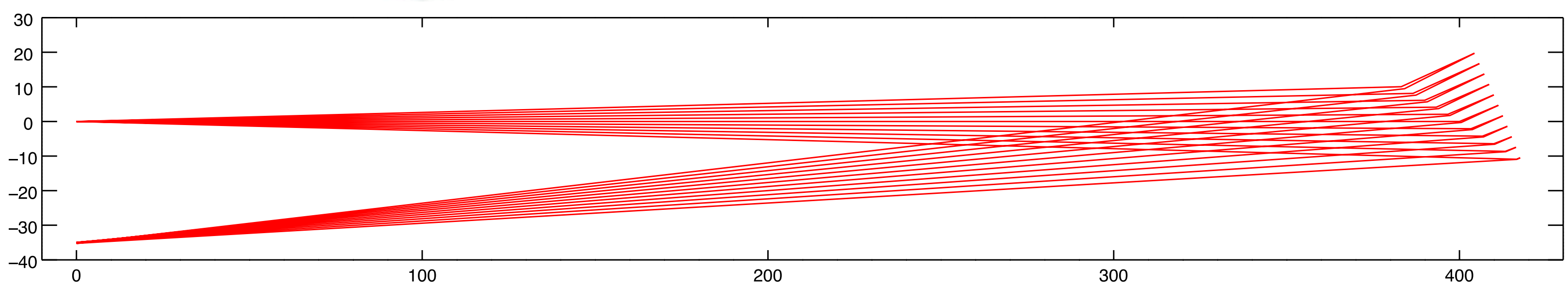
SIST Solar Irradiance Science Team

TSIS SIM



SORCE SIM

$$\mathcal{E}_{\lambda}(\lambda_s) = \frac{\mathcal{P}_{\mathrm{ESR}}(\lambda_s)}{A_{slit} \cdot \int \alpha_{\lambda} \cdot T_{\lambda} \cdot \phi_{\lambda} \cdot S(\lambda, \lambda_s)\; d\lambda}$$

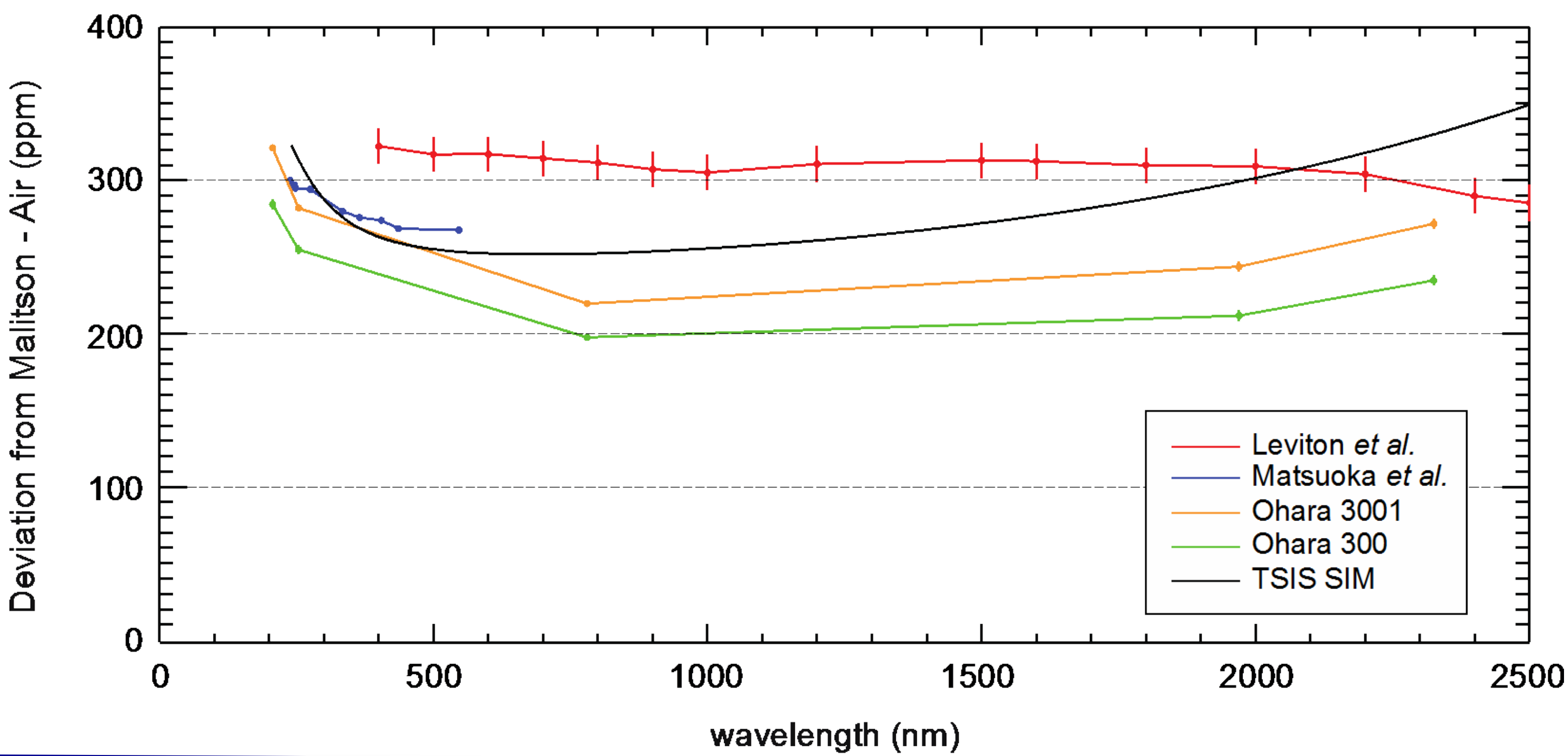


Refractive index refinement

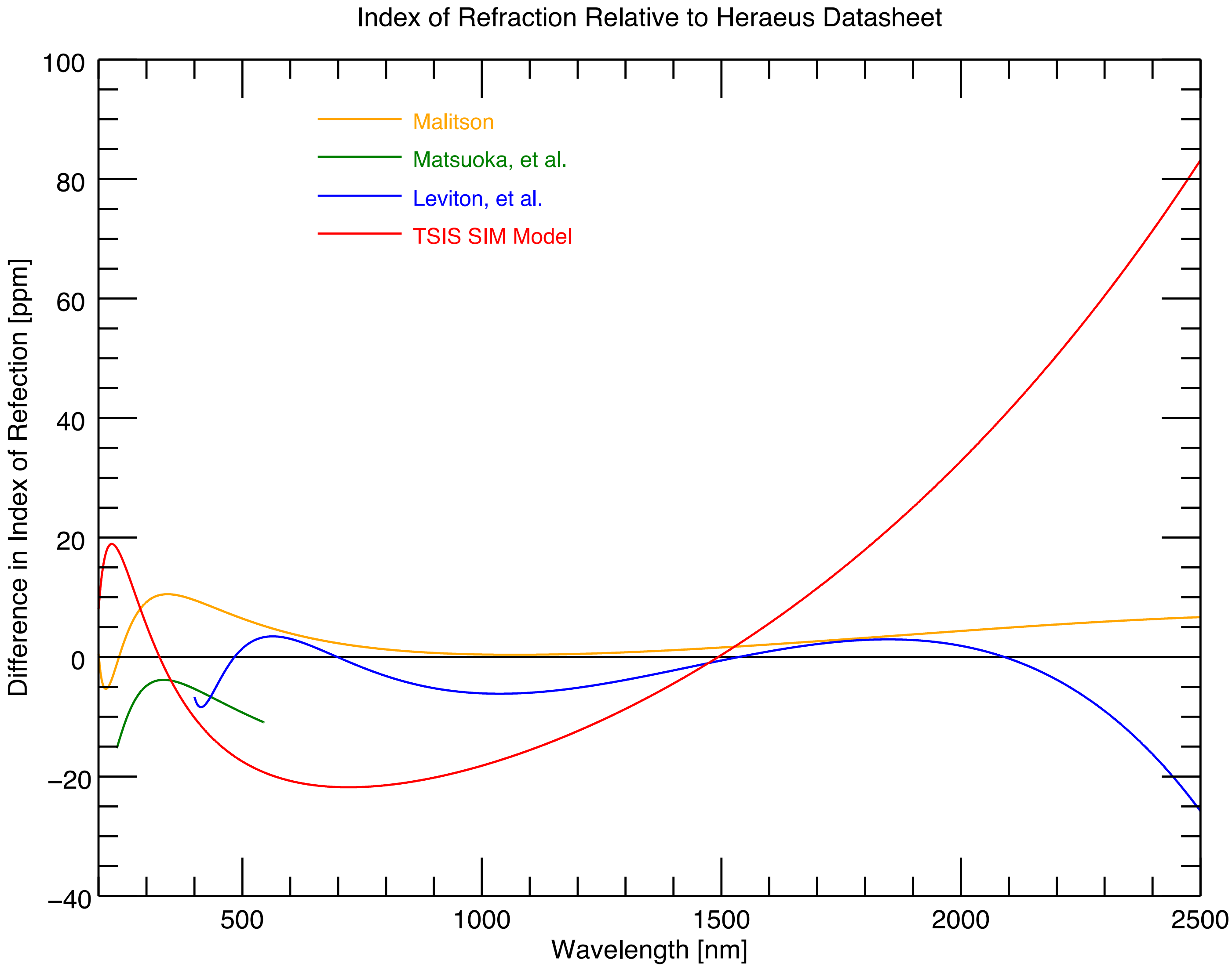
We propose to evaluate and to incorporate the updated fused silica (Suprasil 300 & 3001) vacuum index of refraction values and temperature dependent coefficients into the SORCE SIM wavelength scale processing and quantify the spectral trend dependencies and comparative uncertainties with the presently implemented wavelength adjustments.

Refractive index refinement

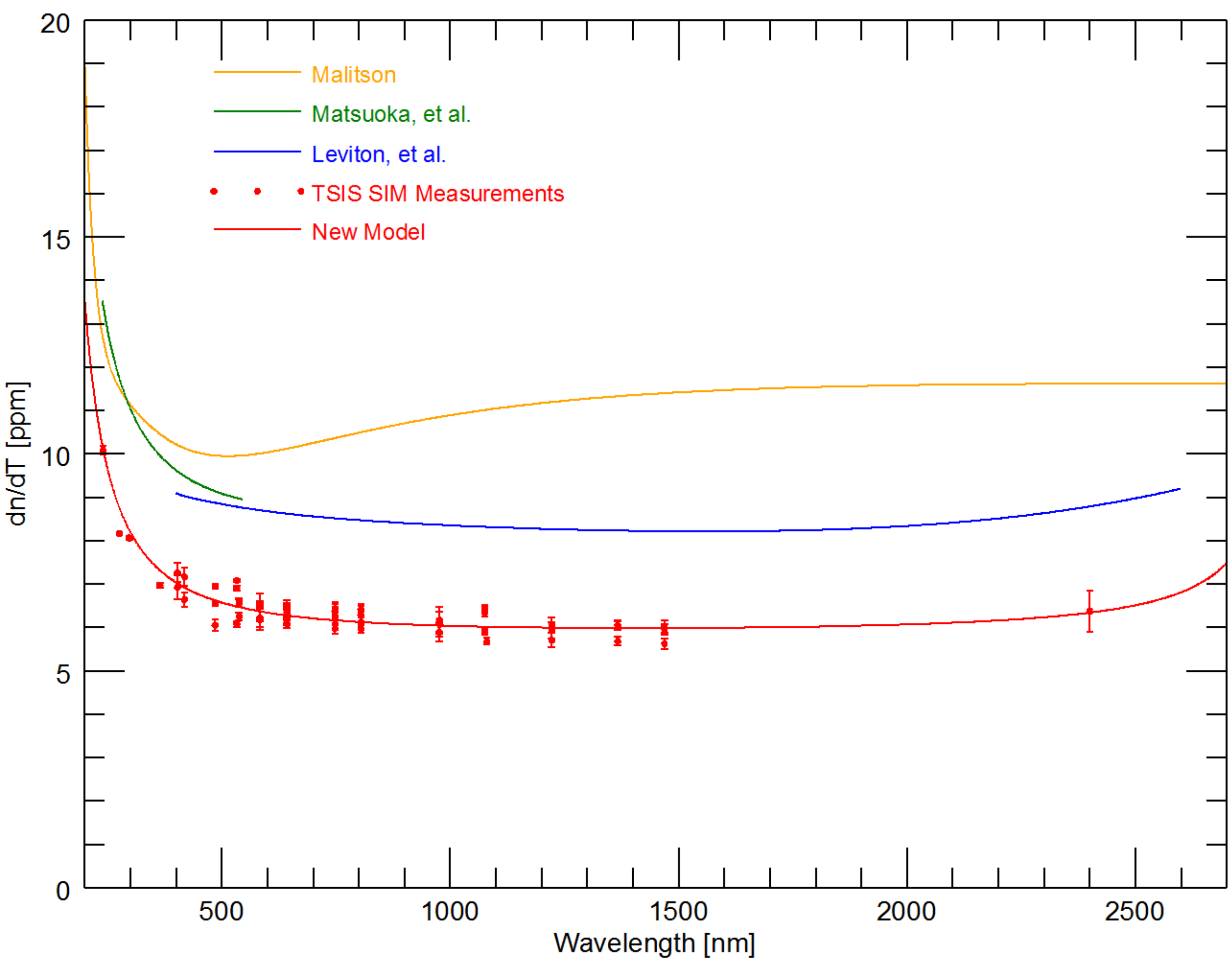
Plot shows index of refraction deviation from Malitson (1965). TSIS SIM the measurements were conducted in vacuum (black line is the resulting fit through 73 calibration wavelengths). The Ohara, Inc. results (vacuum corrected) were contracted and used flight witness samples for TSIS and SORCE fused silica.



Refractive index refinement



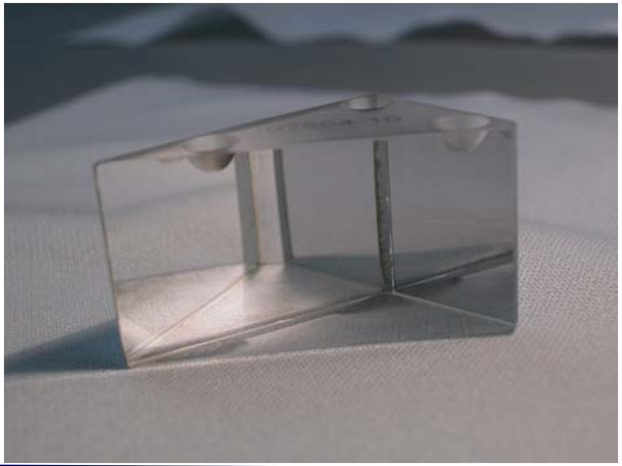
Refractive index temperature dependence (dn/dT)

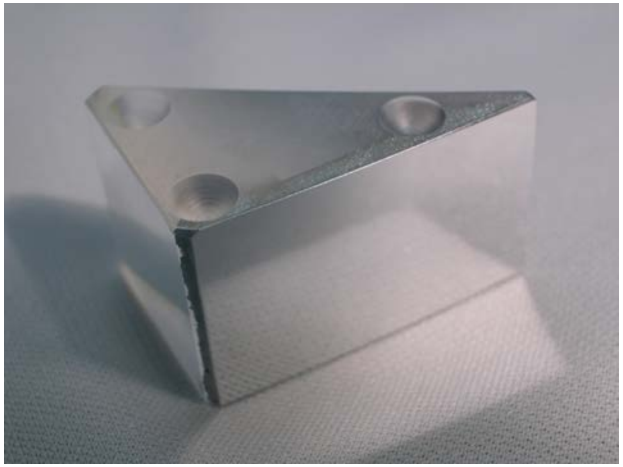


The TSIS measurements (Red) were completed in vacuum from 230 nm to 2400 nm over the temperature range of -10 to 40°C. Error bars represent the standard deviation of fit to the index to temperature slope over multiple temperature settings covering the full range. The yellow (Malitson) curve is used in SORCE SIM processing and differs by ~4ppm/°C through most of the near IR.

Prism transmission

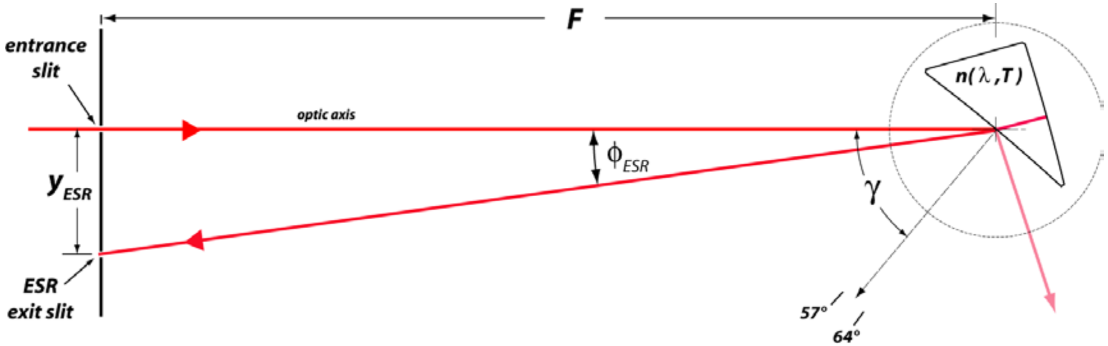
Fully analyze the existing SORCE SIM transmission measurements using proven algorithms developed for TSIS SIM and incorporate the results into the SORCE SIM optical-radiometric model and data processing.



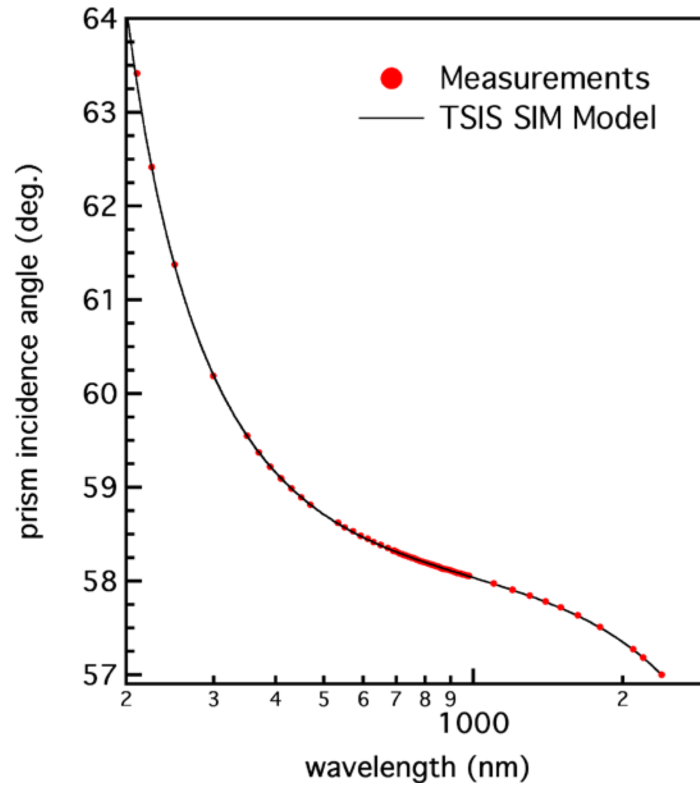


Full spatial & spectral transmission mapping

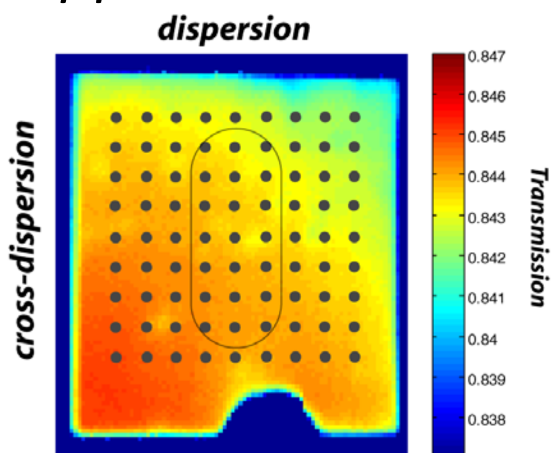
Prism measurement geometry is for ESR optical path
Stabilized SIRCUS lasers cover 211 – 2400 nm range

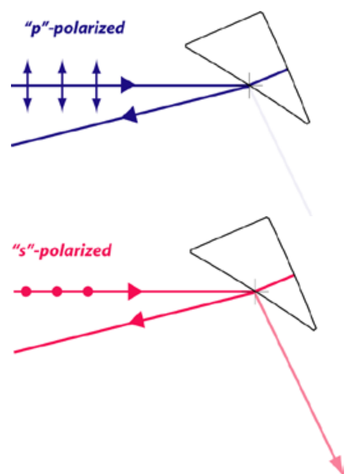


Refraction vs. wavelength
(Suprasil 300 & 3001 fused silica)

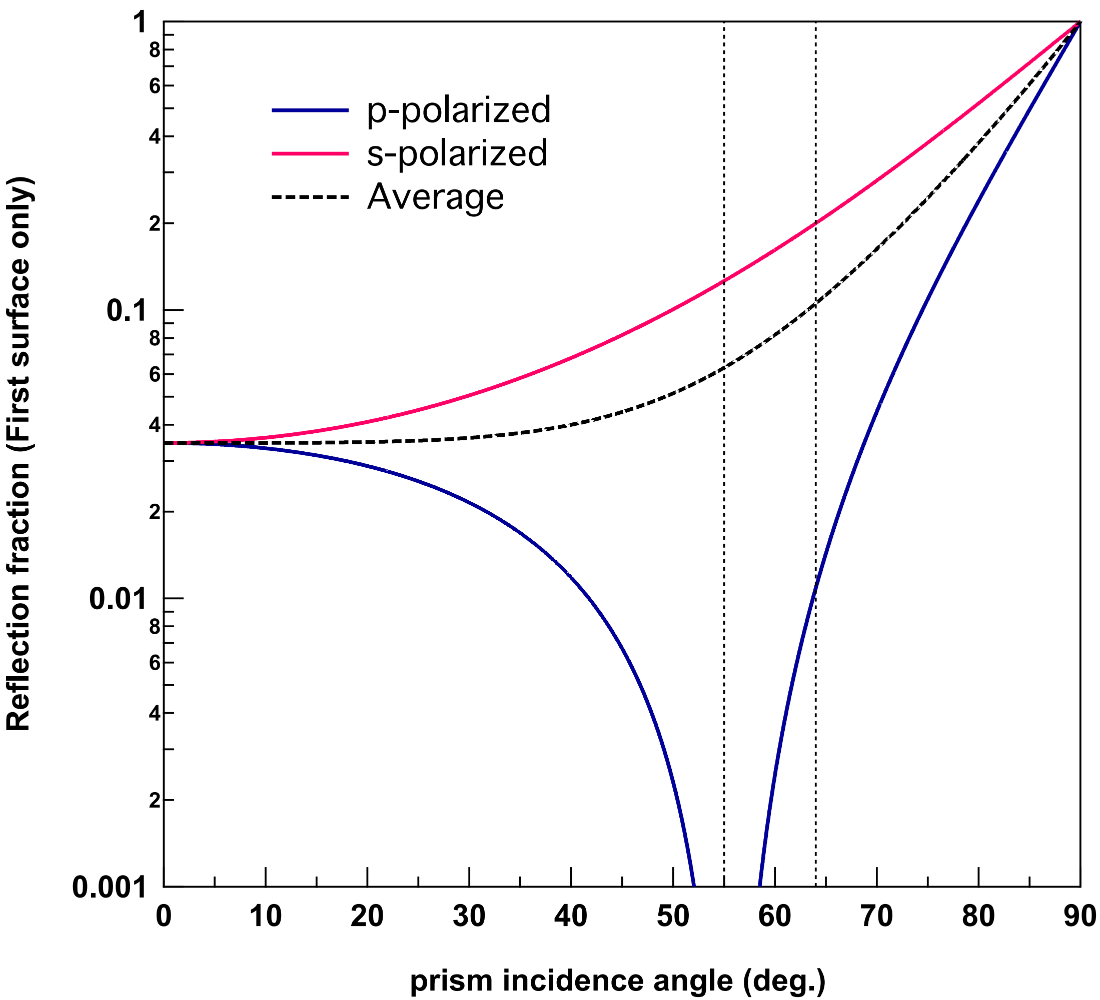


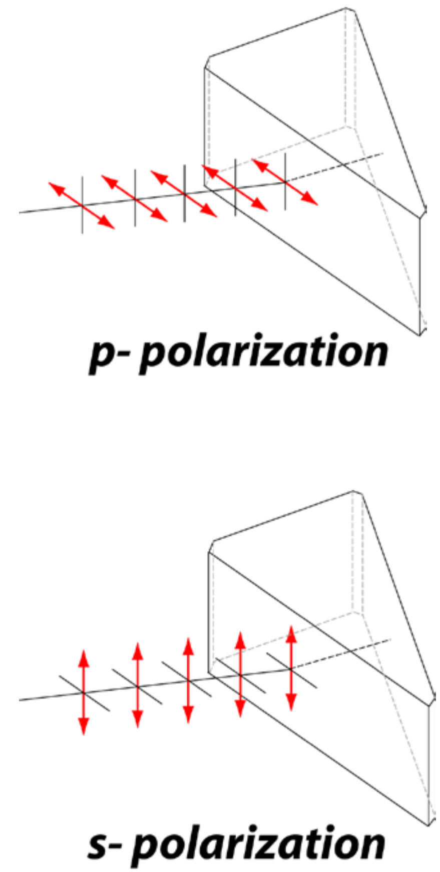
Transmission measured over 10 x 10 grid for both s and p-polarizations



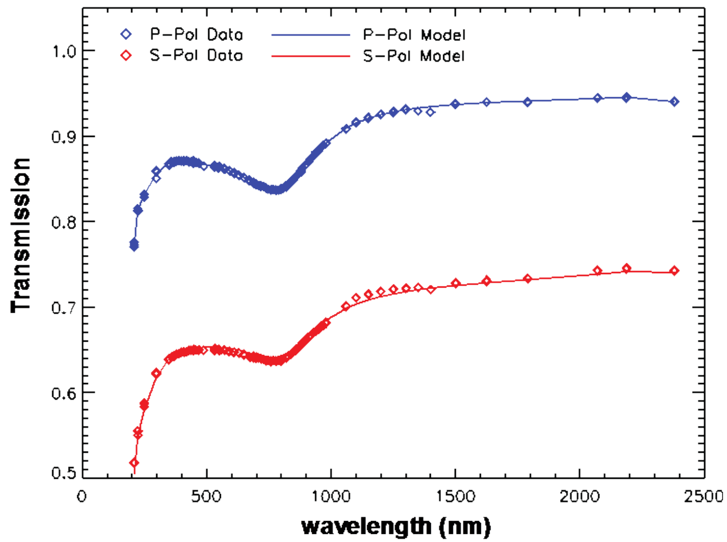


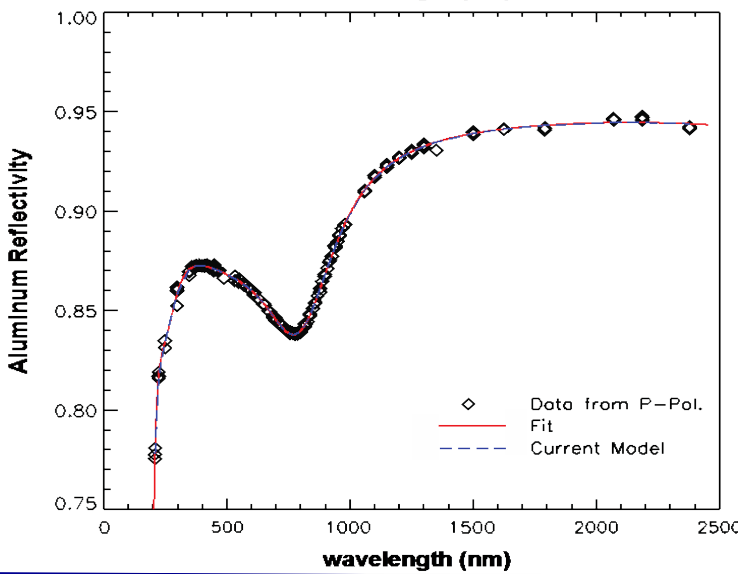
Fresnel coeff. review





Prism transmission

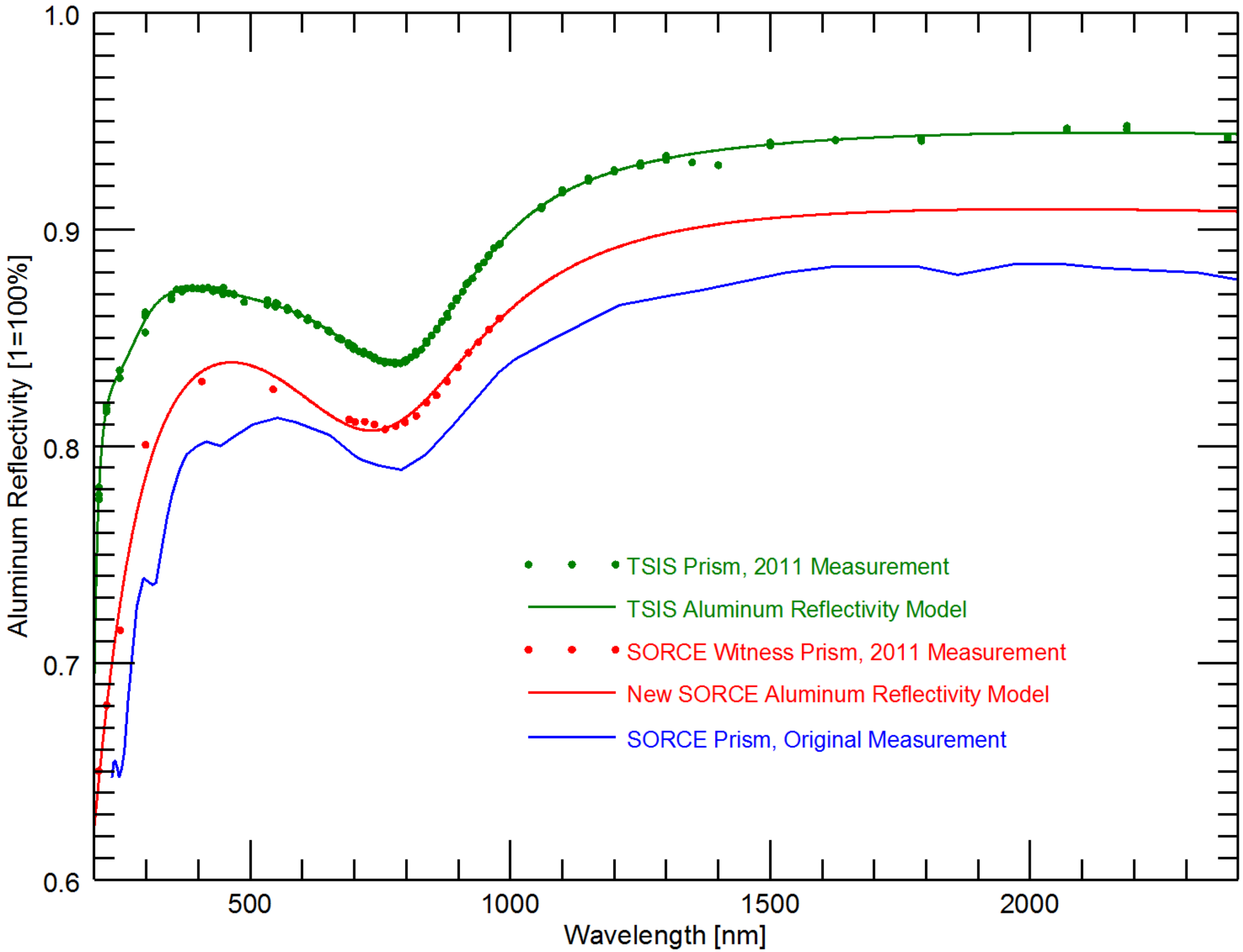




Laboratory measurements of fused silica prism transmission for both both horizontally (p) and vertically (s) polarized laser light. The solid lines are calculated curves based on complex refractive index data for both fused silica and second-surface aluminum. Data shown here is for TSIS SIM Féry prisms measured in the LASP SRF for the wavelength range 210-2400 nm. The same experimental setup was used for measurements on the SORCE SIM ground witness Féry prism.

Fused silica prism second-surface aluminum reflectivity derived from removing Fresnel reflection contributions as a function of prism incidence angle. Black diamonds show data for horizontally polarized laser light (where Fresnel reflection coefficients are smaller than vertically polarized light). Reflectivity data includes minor first surface scatter and bulk loss contributions. Also shown are the best fit to the current model result based on second-surface SiO_2-aluminum complex refractive index calculation.

Second-surface Al reflectivity



Photodiode performance analysis

We propose to finalize the detailed analyses of the SORCE SIM witness photodiode measurements and use them to refine the SORCE SIM radiometric model.

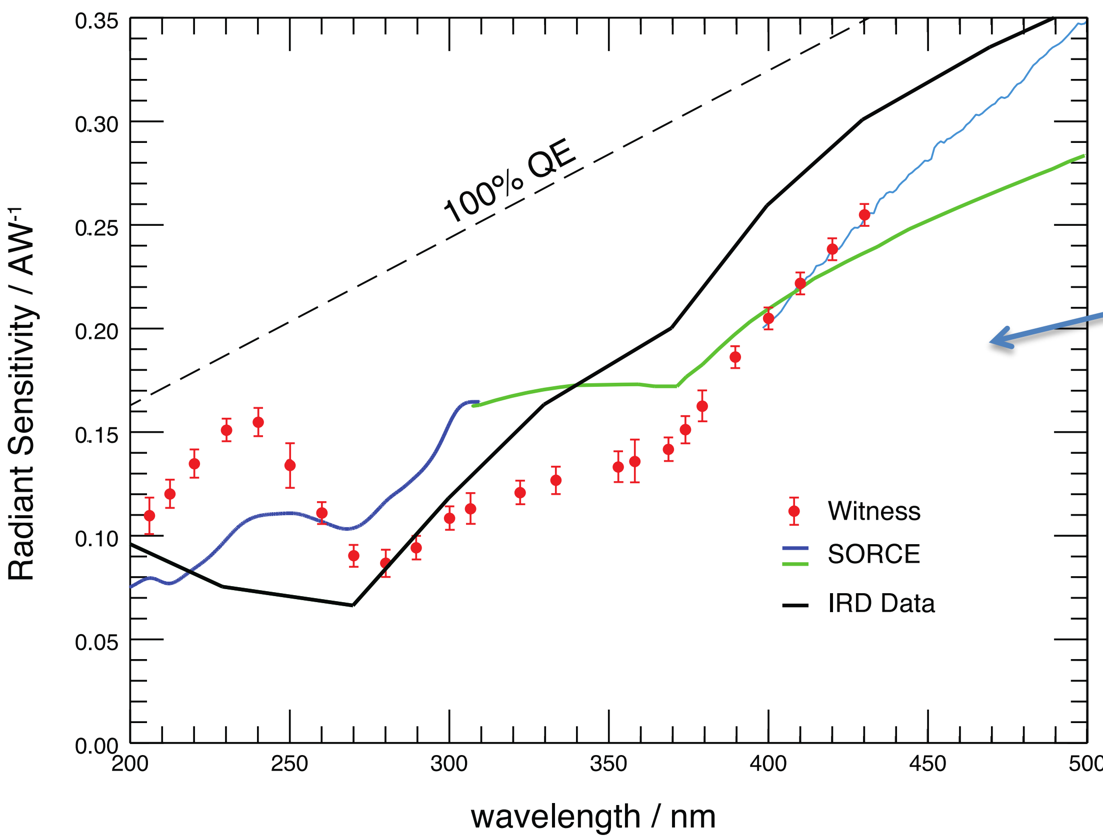
The final data will be ingested into the SORCE SIM processing code and direct comparisons will be made via comparative uncertainty assessments with the present SIM data version irradiance data.

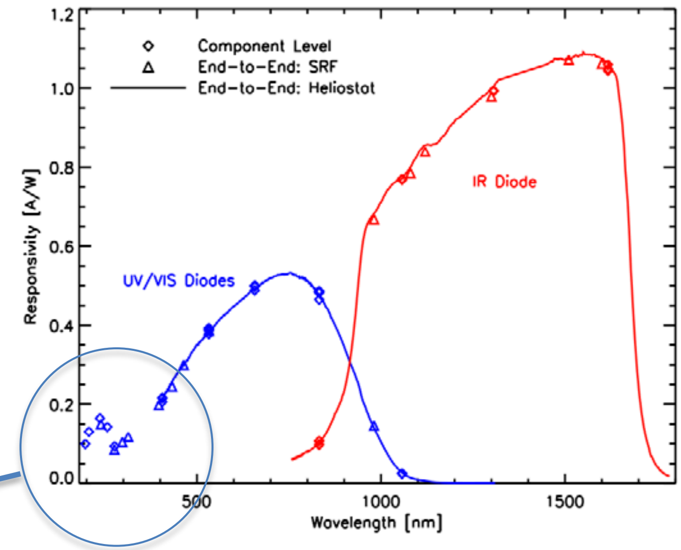
Analysis includes:

- ***Radiant sensitivities (A/W)***
- ***Temperature coefficients (ppm/°C)***

Photodiode Radiant Sensitivities

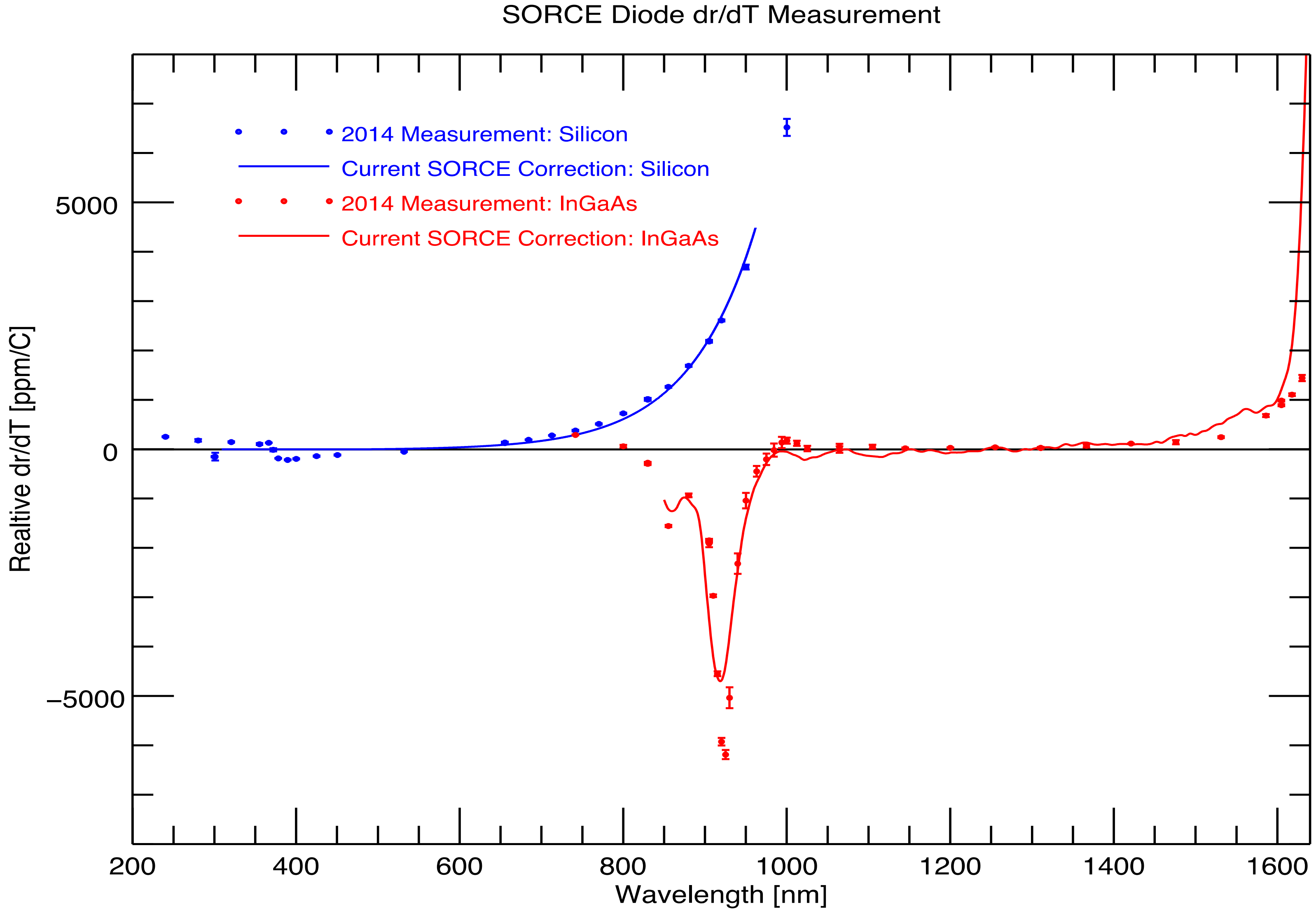
UV Photodiode Radiant Sensitivity Comparisons





These values are tied to the LASP SRF cryogenic radiometer that has its absolute calibration tied directly to the NIST cryogenic radiometer. Notice that in the 200-250 nm region the new values are ~30-35% higher than previous and in the 270-400 nm region they are lower. The cyan colored curve between 400 – 500 nm shows TSIS SIM data measured in the LASP Solar Heliostat where the radiant sensitivities where derived from the internal ESR showing the excellent agreement between different calibration methods.

Radiant Sensitivities – Temp. Dependence



SIST Solar Irradiance Science Team

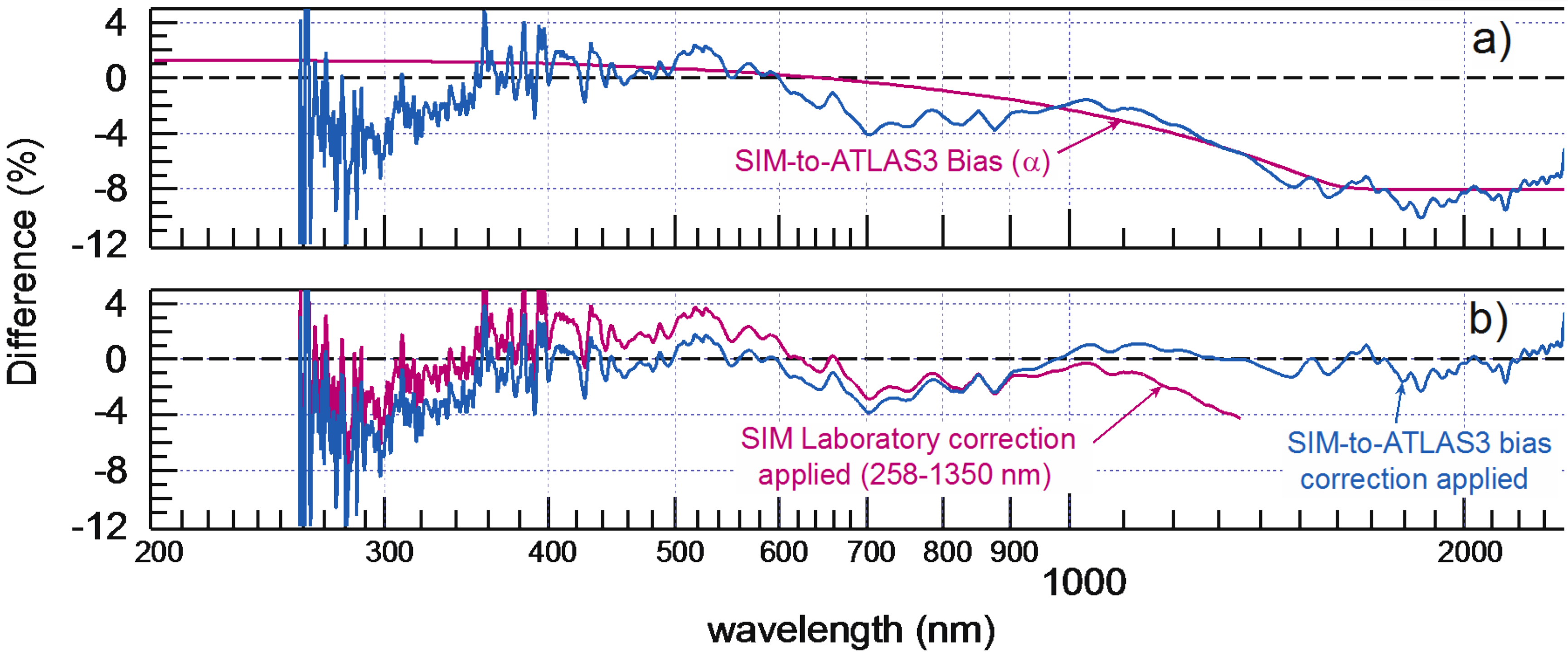
Profile integral refinement

$$\mathcal{E}_\lambda(\lambda_s) = \frac{\mathcal{P}_{\mathrm{ESR}}(\lambda_s)}{A_{slit} \cdot \int \alpha_\lambda \cdot T_\lambda \cdot \phi_\lambda \cdot S(\lambda, \lambda_s)\, d\lambda}$$

We propose to reanalyze the SORCE SIM spectral point spread functions based on existing NIST SIRCUS laboratory measurements on the SORCE SIM brass-board and recent TSIS SIM calibrations in the LASP SRF.

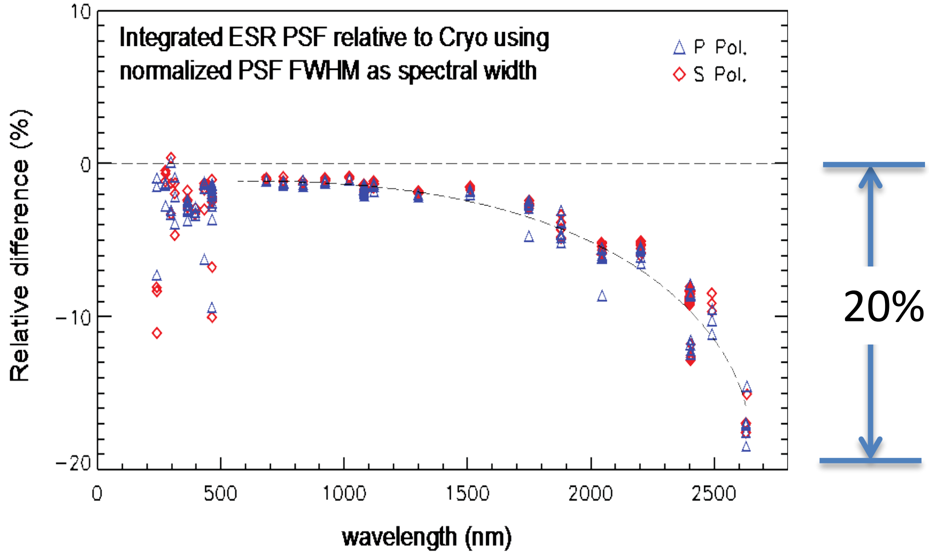
GOAL: Implement the results into SORCE SIM spectral profile integral processing to the investigate causes of calibration bias observed in the near IR region of the spectrum and provide correct spectral PSF parameterization in data processing.

The "IR" issue



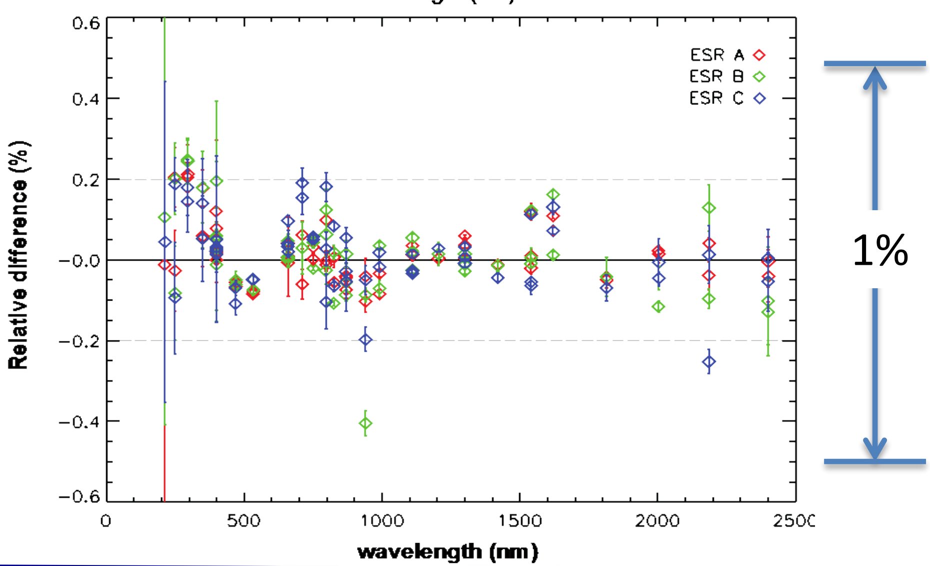
***(a)** Percent difference between SORCE SIM and ATLAS3 over the wavelength range 258-2400 nm, showing increasing systematic bias at wavelengths greater than 1000 nm where SIM irradiance is lower by as much as 10% near 2000 nm. The **pink alpha-curve** is a functional bias correction applied to SORCE SIM to correct the spectrum to ATLAS3 absolute irradiance. **(b)** Percent difference between SORCE SIM and ATLAS 3 after bias correction **(blue curve)**.*

Spectral response function – profile integral refinement (test study)



$$\int D(\lambda)\cdot T(\lambda,p)\cdot I_s(\lambda,c_s)d\lambda$$

Relative difference between the spectral irradiance measured by the SI-traceable cryogenic radiometer and those derived by SIM through integration of a normalized spectral point spread function using the FWHM defined spectral width. A growing systematic bias is present in the near IR exceeding a 10% deficiency near 2400 nm

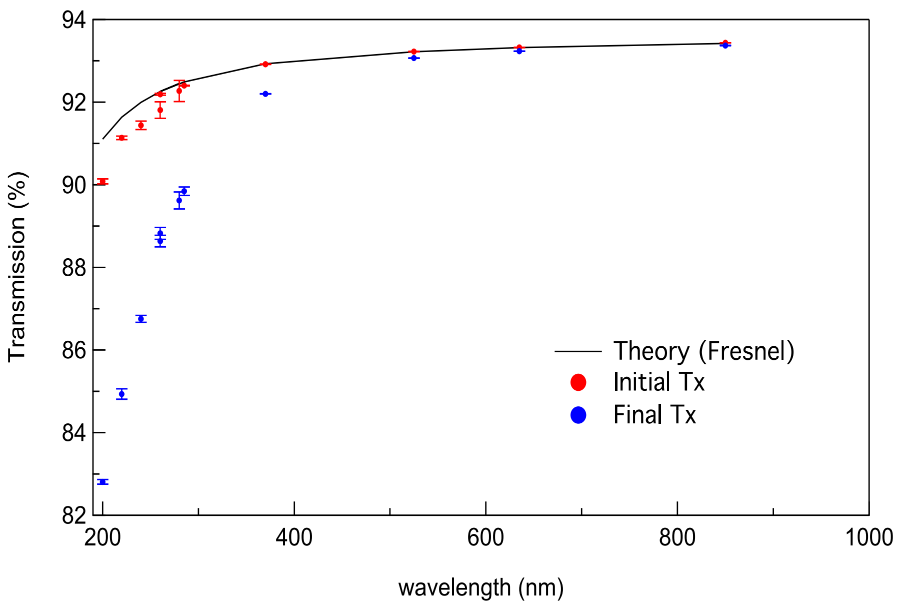


Relative difference between the spectral irradiance measured by the SI-traceable cryogenic radiometer and those derived by SIM through integration of the fully measured spectral point spread function. The PSF's were not normalized and fully modeled incorporating all diffraction corrections and optical coma and astigmatism. Absolute agreement to the cryogenic radiometer is within ±0.2% over the full spectrum for all TSIS SIM channels.

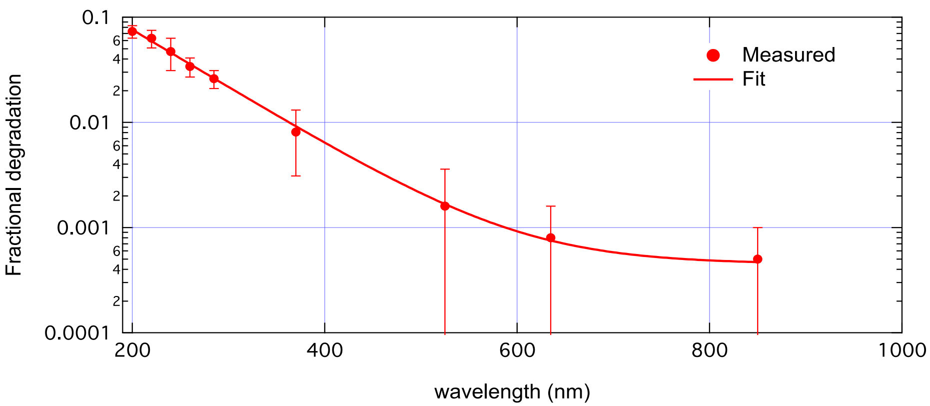
Long-term degradation analysis

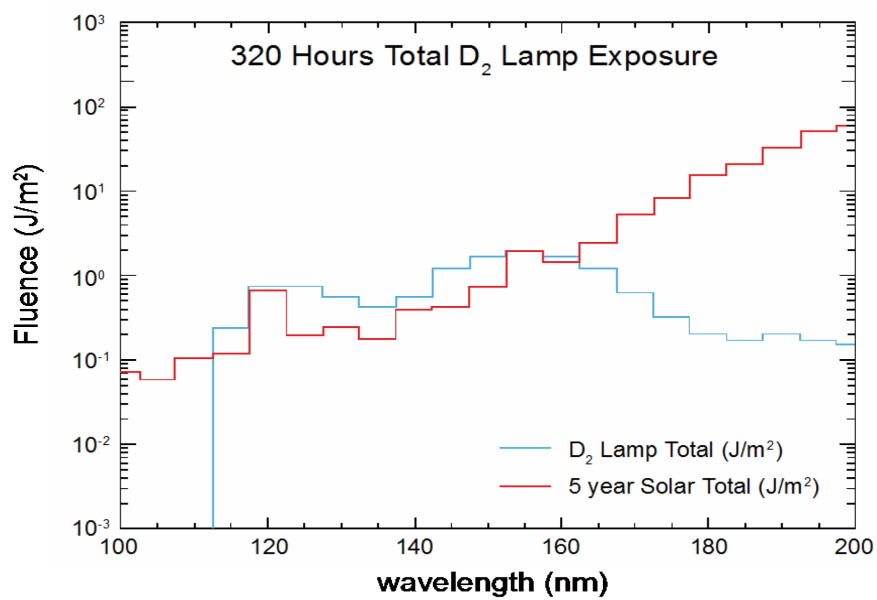
We proposed to undertake a comparative degradation analysis using a Lyman-a dose weighted solar exposure in the SORCE SIM degradation analysis model rather than solely exposure time and provide an assessment of the trending differences to the current long-term SSI variability results.

Laboratory degradation analysis

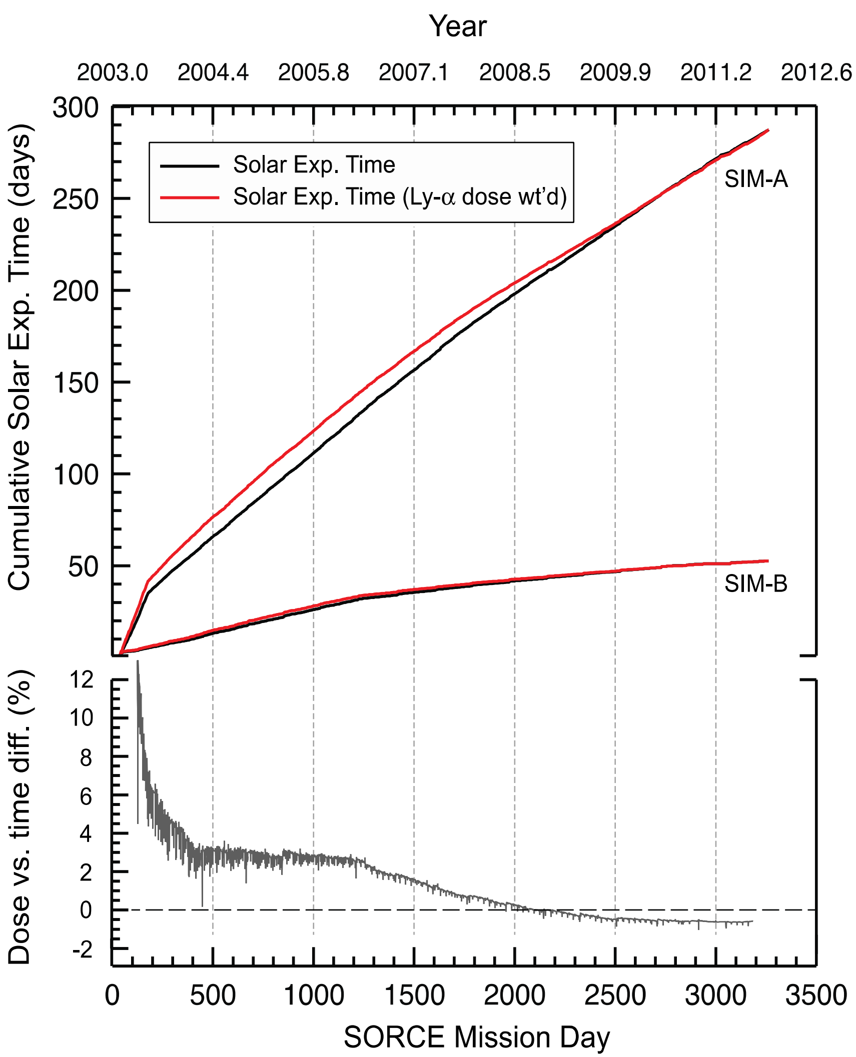


Laboratory study of the long-term exposure related optical transmission degradation of fused silica (Suprasil 3001). **Top Left** shows the resulting transmission loss after 320 hours exposure to FUV. **Bottom Left** shows the derived wavelength dependent fractional degradation with 8% degradation at 200 nm decreasing to ~0.05% (near measurement limit) in the near IR. **Plot below** shows the 320 hour fluence of the D_2 lamp related to the 5-year solar equivalent.





Long-term degradation analysis



Top panel shows the cumulative solar exposure for the prisms in SIM-A and SIM-B. The black curve is the actual time (in days) of direct exposure and the red curve is the Ly-a weighted exposure (in days) based on the Lyman-a dose experienced during the time of exposure (normalized here to the first mission day exposure). This is meant to provide a more realistic exposure estimate for the damaging radiation causing the prism optical degradation and folds in corresponding solar activity levels. The **bottom** panel shows the relative difference in the SIM-A to SIM-B ratios based on dose vs. time exposure. Note the larger exposure contribution early in the mission. The net effect will produce a larger degradation rate for SIM-A where degradation increases more rapidly than SIM-B early in the mission.