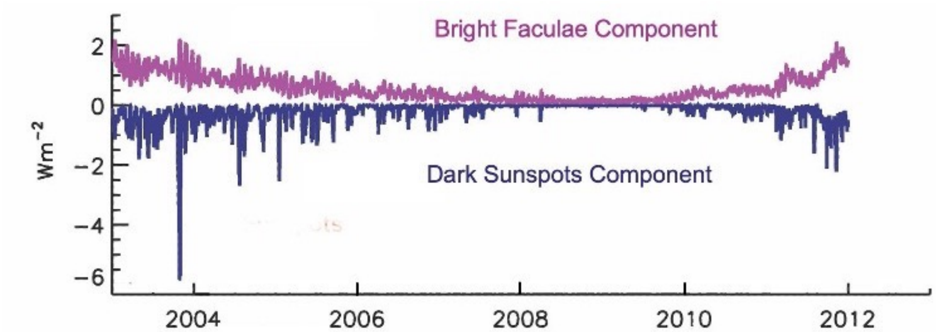
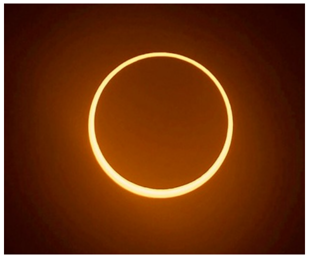
Painted Desert Pueblo
Summer Solstice Marker



Oct 14 Eclipse



Next-generation Irradiance Proxies using TSIS-1 Data

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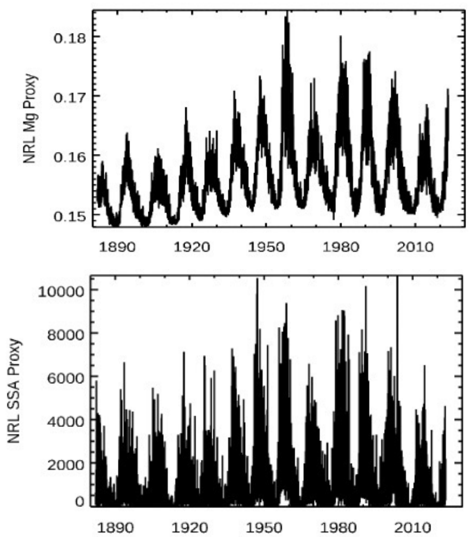
Why do we need new proxies?

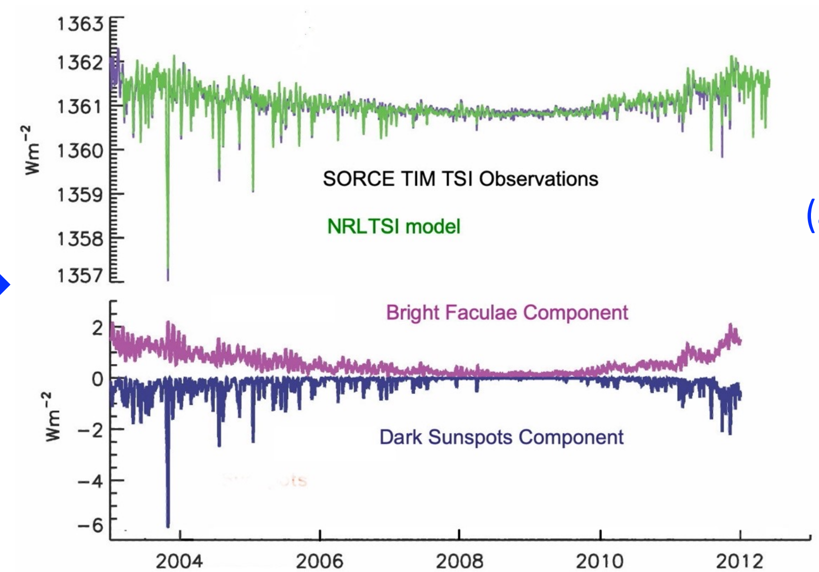
Mg Index

+

Sunspot Area



2-Component Proxy Model



NRLTSI (and NRLSSI) Model of Solar Irradiance Variability

- **Sources for current solar variability proxies are from senior instruments**
  - NRL models currently depend on Bremen Mg II C/W ratio composite and SOON sunspot area
    - Bremen Mg index composite data are from ESA's GOME-2 that launched in 2006
    - SOON data are from Air Force instruments with some dating back to 1981
  - SATIRE models currently depend on magnetograms from SDO HMI
    - SDO launched in 2010; there are no replacements for HMI planned for near-future NASA missions
    - GONG is other option; dates back to 1995; next-generation GONG is planned, but it is just concept now

Talk Outline

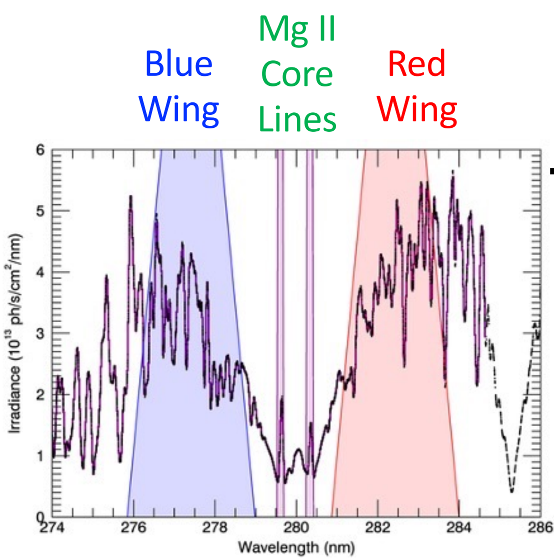
- Next Generation Mg II Core-to-Wing Ratio (Mg index)
  - Goal is to extend 40+ year record of Mg II C/W ratio
  - New Mg II C/W ratio from TSIS-1 SIM instrument

- Next Generation Sunspot Area proxy
  - Goal is to extend 140+ year record of sunspot area
  - New Total Solar Irradiance (TSI) component proxies from TSIS-1 TIM and SIM instruments

- Solar Spectral Irradiance (SSI) modeling with next generation (NG) proxies
  - Improvements over the SORCE results

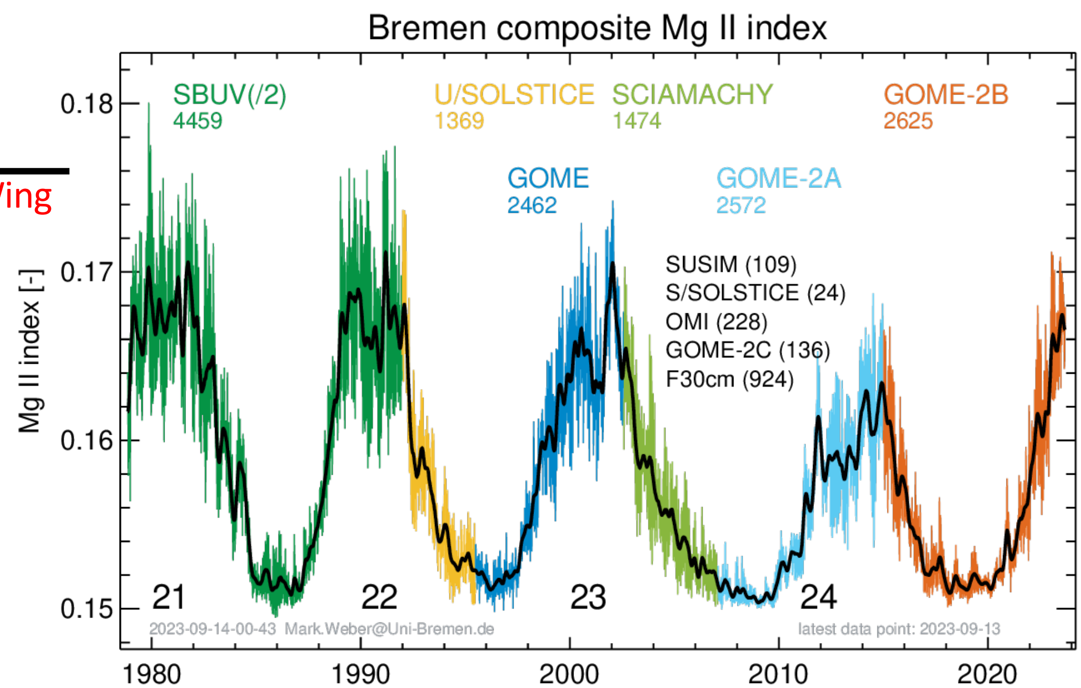
40+ Year Record of Mg II Core-to-Wing Ratio

- Composite Mg index record has been developed with solar spectral irradiance data of the Mg II line (280 nm) dating back to 1978
  - Composite made with several satellites: SBUV, UARS, GOME, SORCE, SCIAMACHY, GOME-2
  - Bremen Mg index composite data are now from ESA's GOME-2 that launched in 2006



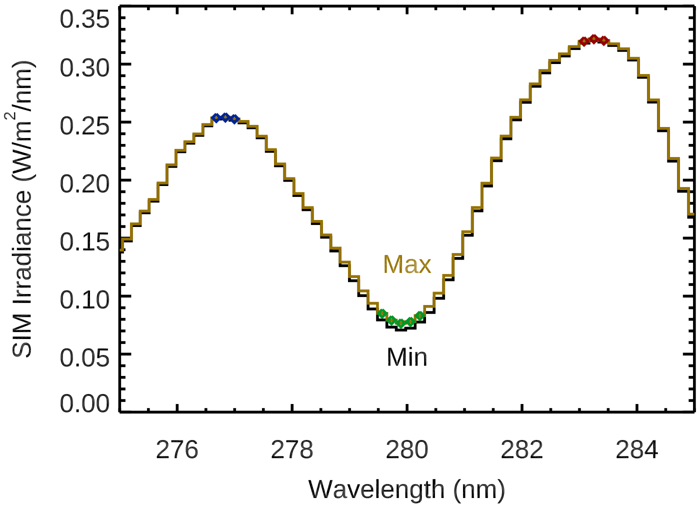
SORCE SOLSTICE spectra
(Figure 2 from Snow et al., 2019)

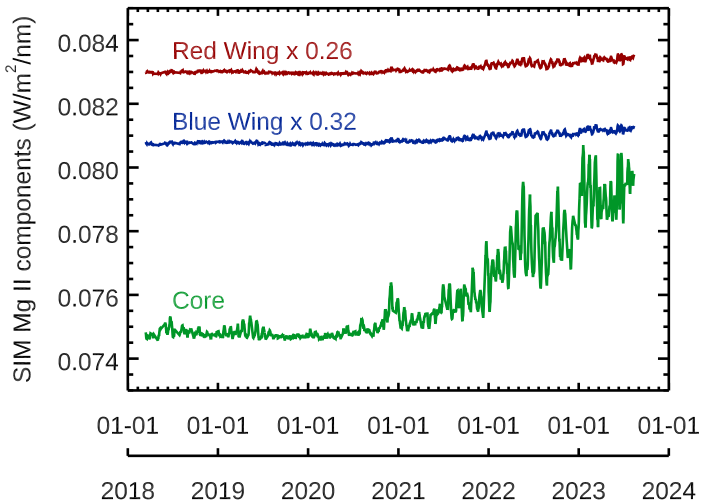
$$\frac{\text{Core\_Lines}}{\text{Blue\_Wing} + \text{Red\_Wing}}$$



Bremen Composite Figure is from https://www.iup.uni-bremen.de/UVSAT/Datasets/mgii

TSIS-1 SIM Mg II Core-to-Wing Ratio

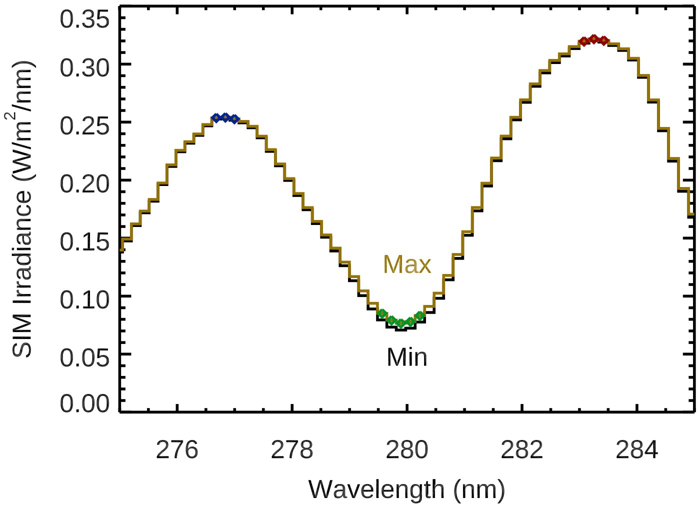


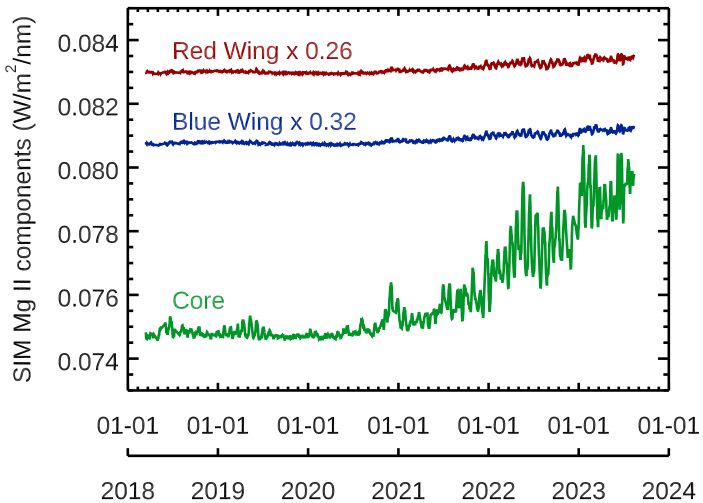


- SIM Mg index is calculated with 5 core points and 6 wing points
- Wing variability ~0.5%
- Core variability ~7%

$$\text{Mg Index} = \frac{\text{Core\_Lines}}{\text{Blue\_Wing} + \text{Red\_Wing}}$$

TSIS-1 SIM Mg II Core-to-Wing Ratio





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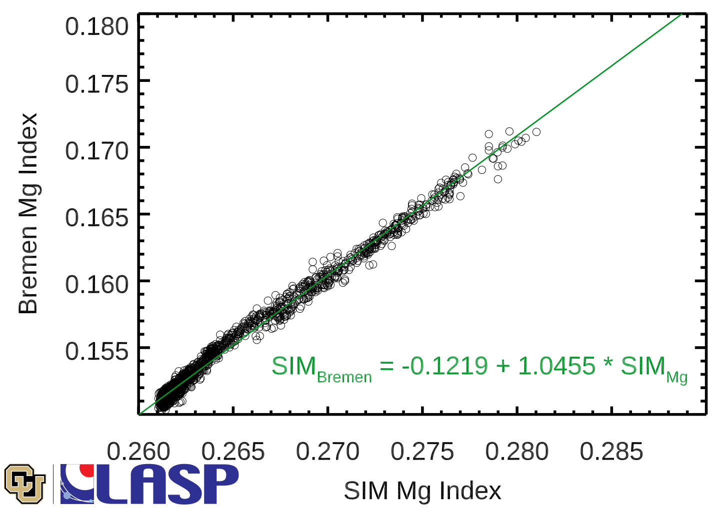
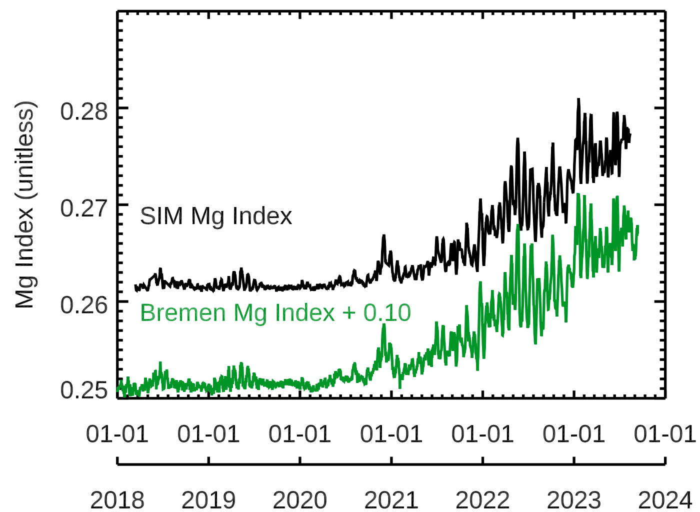


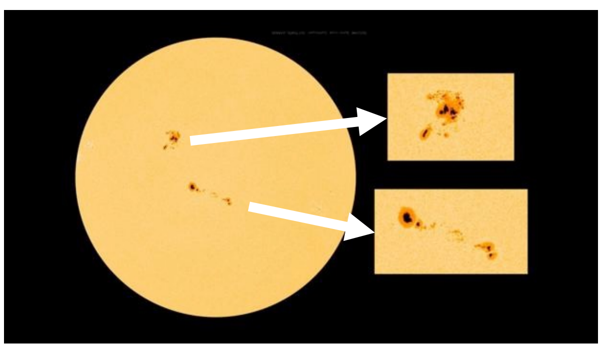


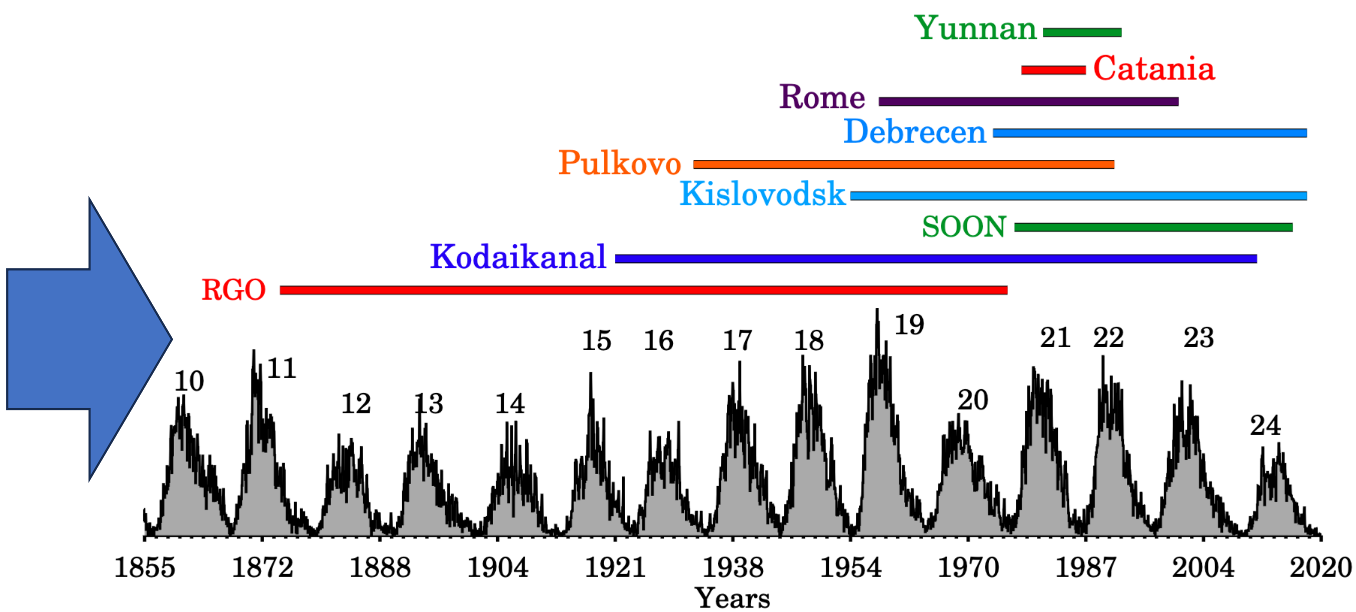
- TSIS-1 SIM Mg index has very linear relationship with Bremen Mg index
  - R = 0.996

140+ Year Record of Sunspot Area

- Sunspot Area (SSA) data extends back to 1874 [Mandal et al., *A&A*, 640, A78, 2020]
- Sunspot Area (SSA) record has been generated for NRL solar irradiance models using Solar Optical Observing Network (SOON) data [e.g., Lean et al., 2022; Coddington et al., 2017]
  - SOON data are from Air Force ground-based instruments with some dating back to 1981
  - SOON sunspot area data sometimes have 50% errors (Meadows, *MNRAS*, 497, 1110, 2020)

Sunspot Area includes umbra and penumbra regions.

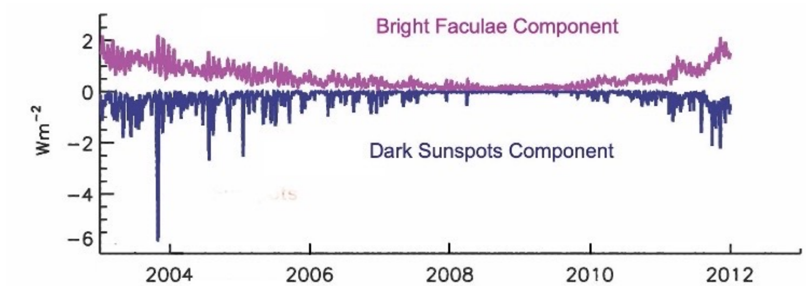




Sunspot Area Provides “dark component” for TSI-SSI

- TSI and SSI in NUV, Visible, and NIR have two primary variability components
  - Bright component represents bright faculae contributions (proxy is Mg index)
  - Dark component represents dark sunspots contributions (proxy is SSA)

TSI Variability =



- Our next-generation sunspot area proxy is the TSI Dark Component
  - That is, TSI = TSI_bright + TSI_dark

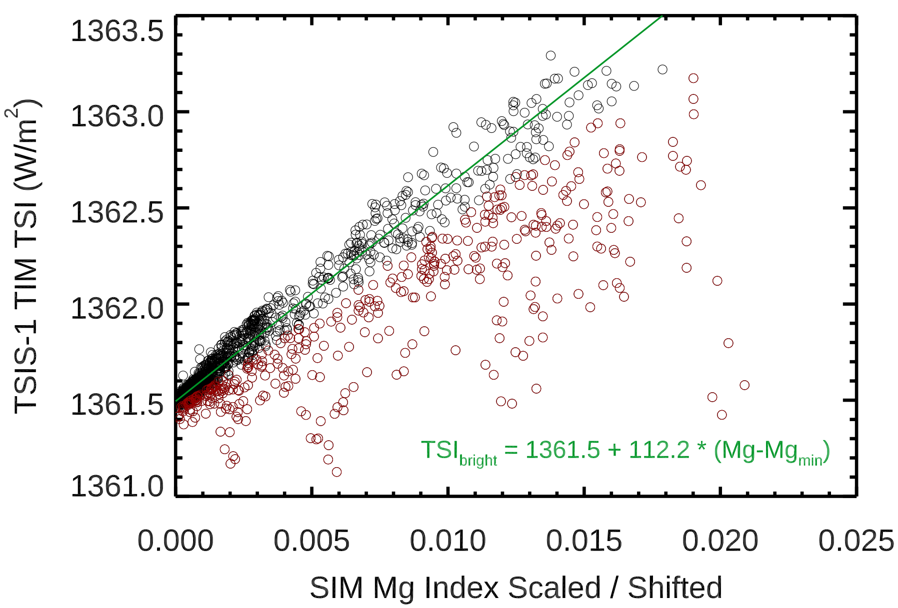
  where TSI_Bright is Mg index scaled to TSI units

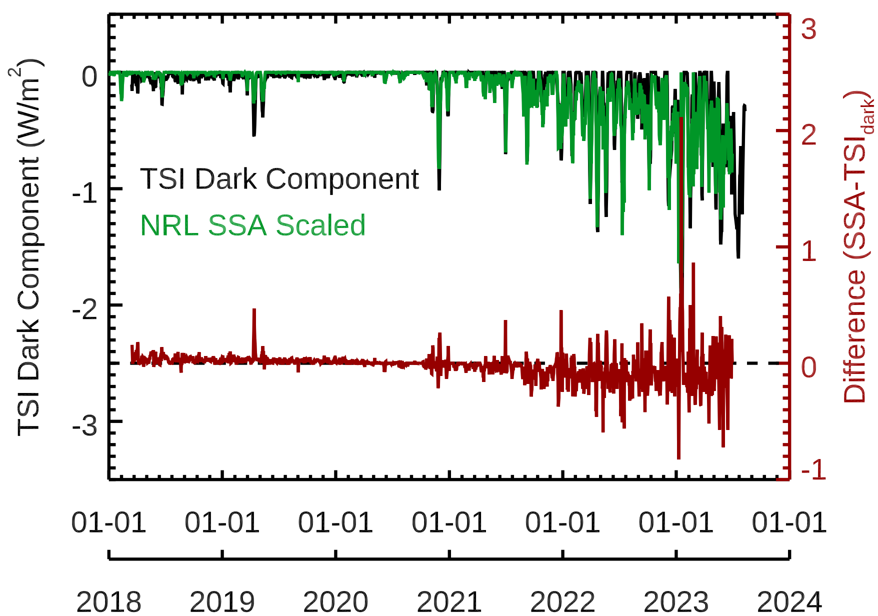
  and we derive TSI_Dark = TSI_measurement – TSI_Bright

  Then we scale the TSI_Dark to SSA units.

New Sunspot-Darkening Proxy with TSIS-1 Data

- *LEFT*: The TSI-Bright Component (green line) is derived with TSIS-1 TSI and SIM Mg index (scaled to Bremen-scale), which have been filtered to remove the dark sunspot data points (red). *Woods et al. [2022] shows TSI is dominated by Bright Component 86% of the time.*
- *RIGHT*: The TSI-Dark Component (black) is compared to the scaled sunspot area proxy used in the NRLTSI / NRLSSI model (green). The difference between these two proxies is shown in red.





TSIS-1 SIM SSI Modeling with new NG-Proxies

- Two Components (2C) model linear regression includes TSIS-1 SIM Level 3 Version 11 spectra, facula-brightening proxy, and sunspot-darkening proxy
  - ***Heritage***: empirical (proxy) 2-component modeling
    - For example, TSI modeling [Chapman et al., *Solar Phys*., 2012], SSI modeling [Woods & DeLand, *E&SS*, 2021], and the NRLTSI and NRLSSI models [Lean et al., *E&SS,* 2022]
  - ***New***: Version 11 of the TSIS-1 SIM Level 3 product
  - ***New*** : TSIS-1 SIM Mg II core-to-wing ratio (Mg index) for facula-brightening proxy
  - ***New*** : TSIS-1 TSI minus "TSI-bright" component (Mg index) for sunspot-darkening proxy

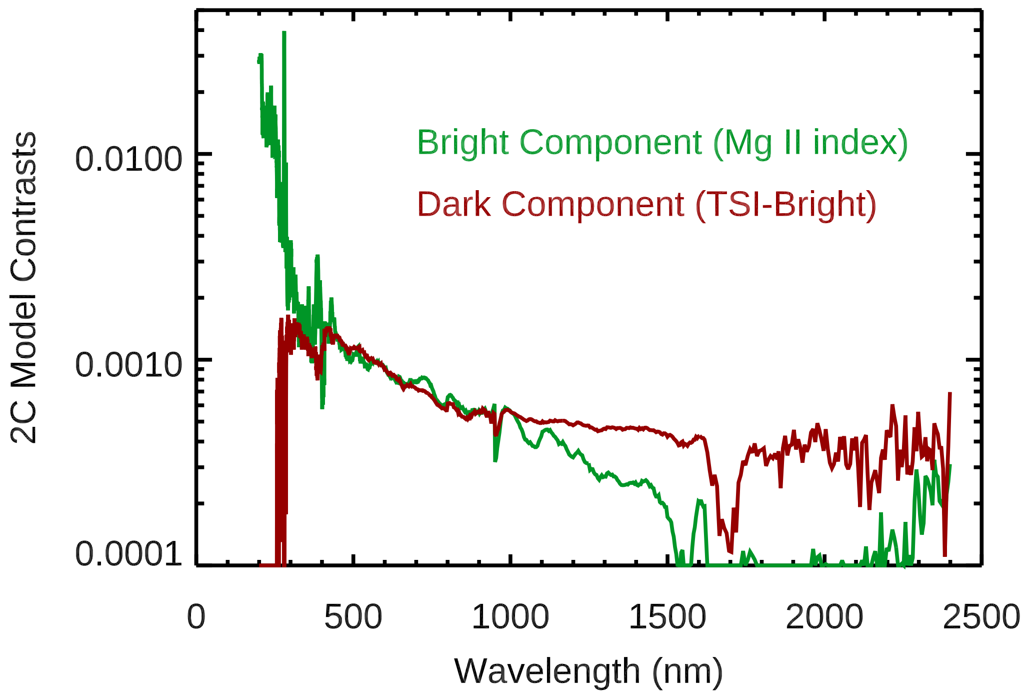
- <u>Key Result</u>
  - TSIS-1 SIM Model fits have correlations that are 2 times better than SORCE SIM similar-type modeling

- ***Note that this modeling approach is only for SSI variability and is not appropriate for TSI modeling because the TSI measurements are part of the "TSI-dark" proxy.***

Two-Component (2C) Model: Proxy Contrasts

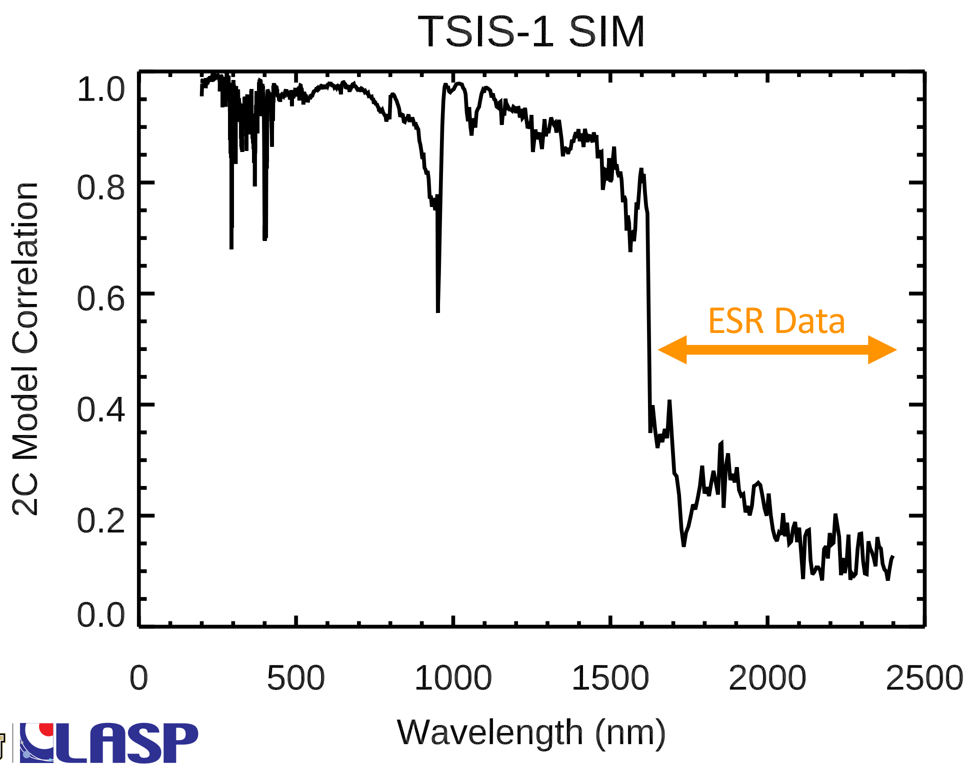
- The contrast values are derived as a linear regression of the TSI_bright (Mg index) and TSI_dark proxies with the TSIS-1 SIM SSI at each wavelength between 200 nm and 2400 nm.
- The bright component dominates for wavelengths shorter than 320 nm, and the dark component dominates for wavelengths longer than 1000 nm.

Proxies are in TSI variability units (W/m^2), so contrast values are relative to TSI variability.

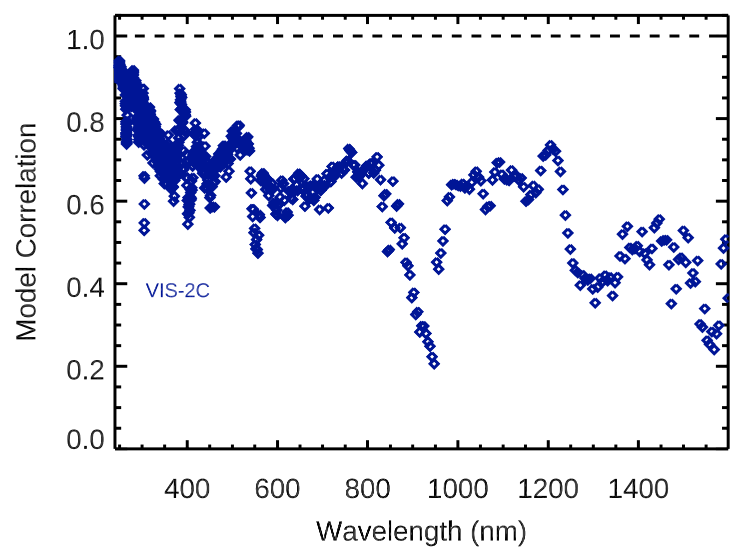


Two-Component (2C) Model: Correlation

- The two-component (2C) model fit correlation is shown as a function of wavelength. These correlations are significantly improved compared to SORCE SIM 2C Model.
- The low correlation values at wavelengths longer than 1600 nm can be improved by data averaging (time & wavelength). SIM data for > 1600 nm are from ESR only.



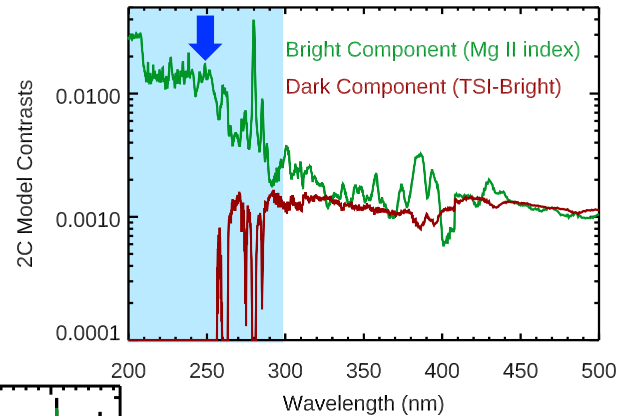
SORCE SIM 2C Model has about factor of two lower correlation than TSIS-1 SIM 2C model.



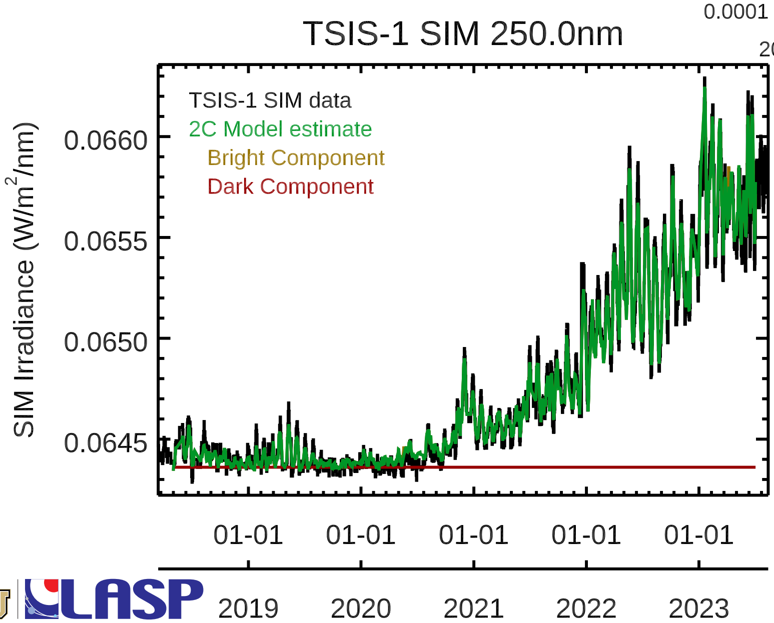
SORCE SSI Variability: Woods et al., *Solar Phys.*, 297, 2022]

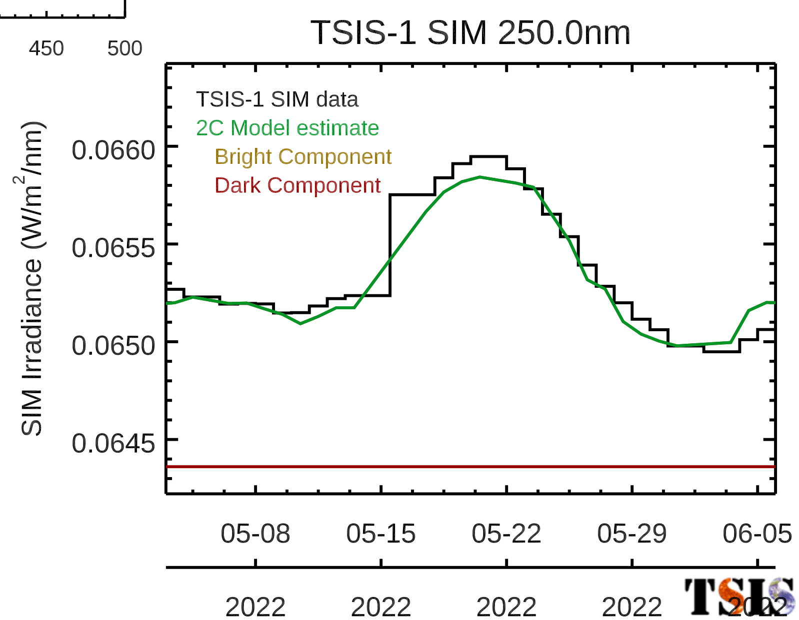
Two-Component (2C) Model: UV Example

- The Bright Component dominates in the middle ultraviolet (MUV: 200-300nm)



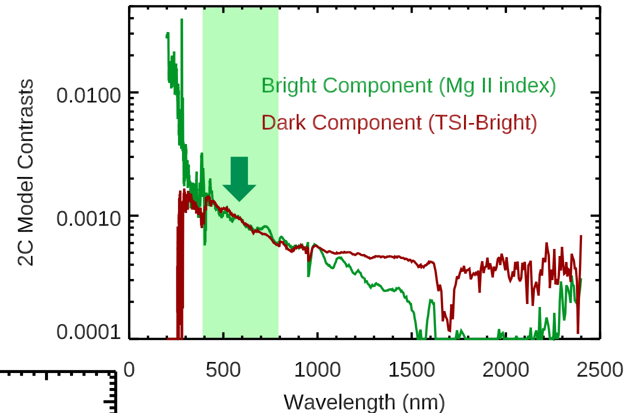
Only the Bright Component is needed for λ < 256 nm.





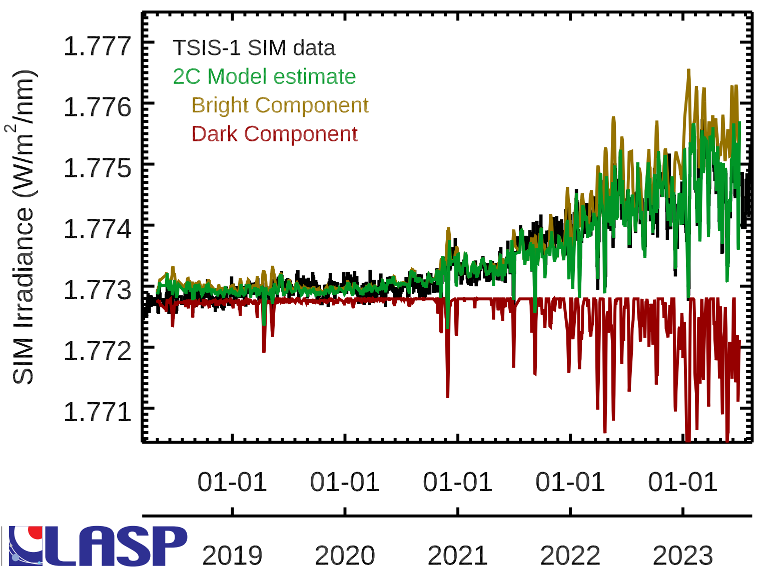
Two-Component (2C) Model: VIS Example

- The Bright and Dark Components are about equal for Visible (VIS: 400-800nm)

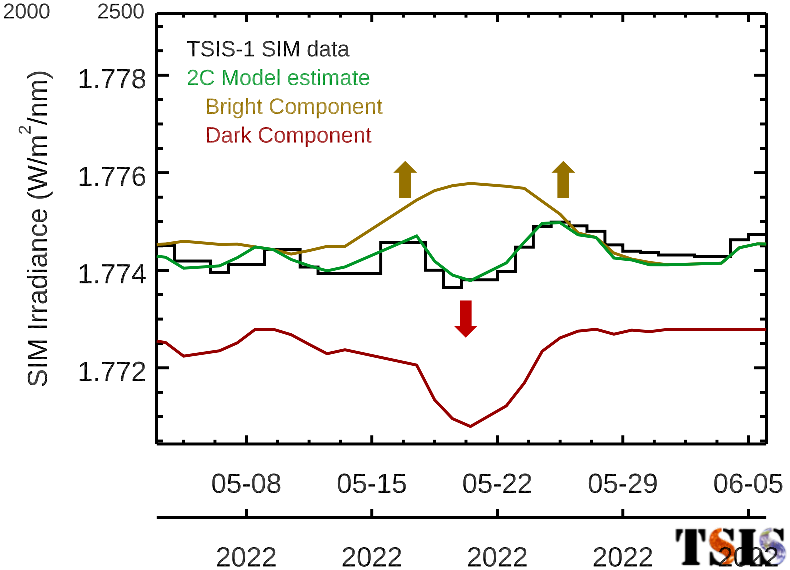


Bright and Dark Components are more obvious during 27-day solar rotations.

TSIS-1 SIM 600.1nm



TSIS-1 SIM 600.1nm



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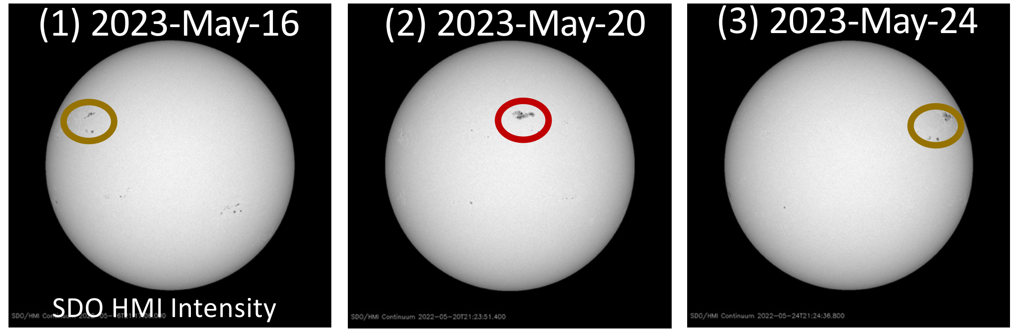
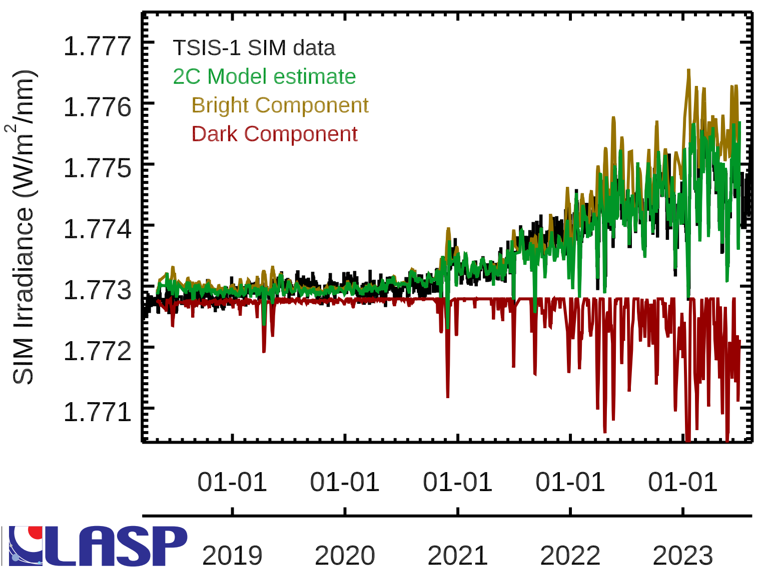
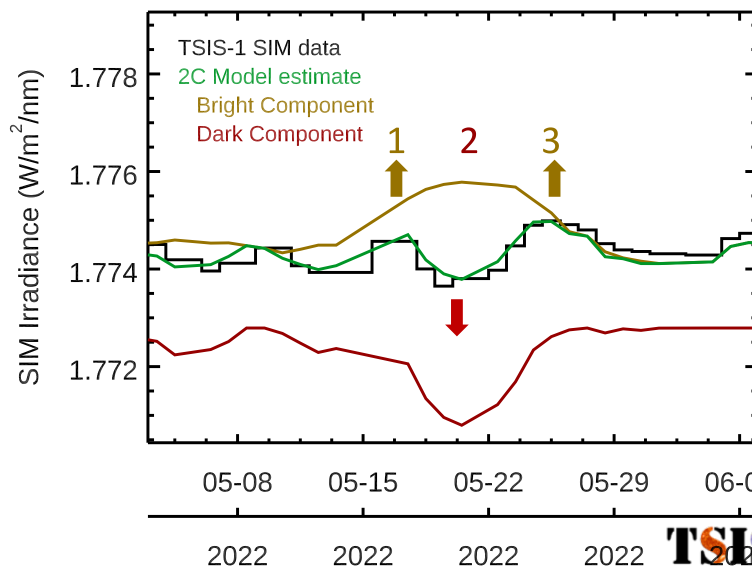


TSIS-1 SIM 600.1nm



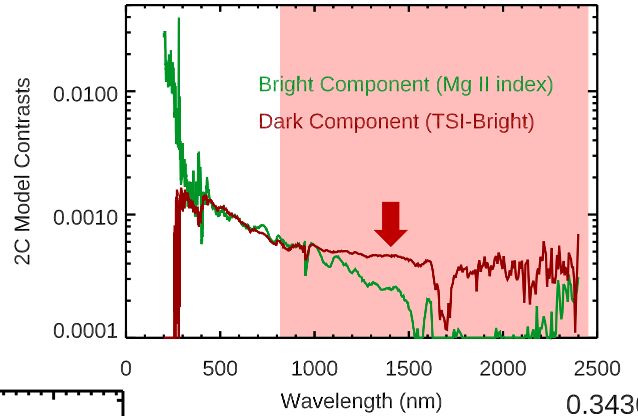
TSIS-1 SIM 600.1nm

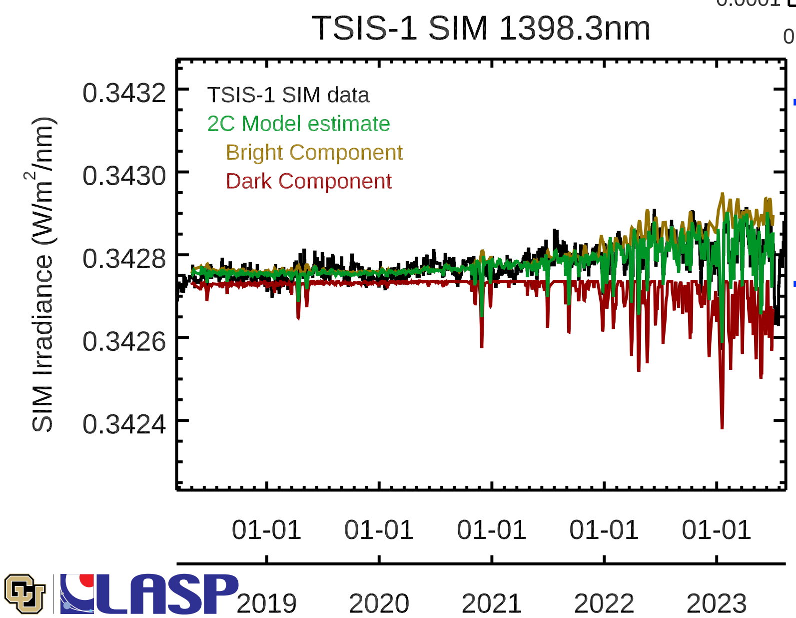


Two-Component (2C) Model: NIR Example

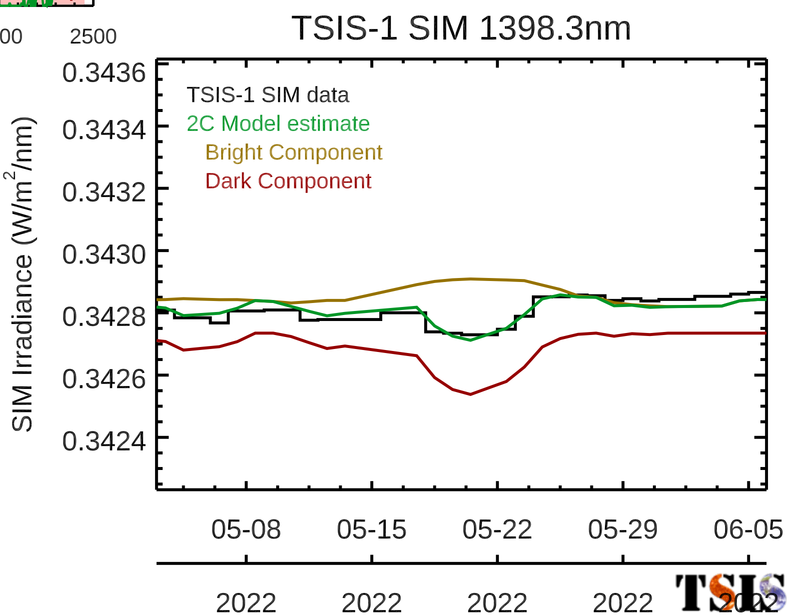
- The Dark Component dominates for the near infrared (NIR: 800-2500 nm)

NIR solar cycle variability is smaller than the visible variability.





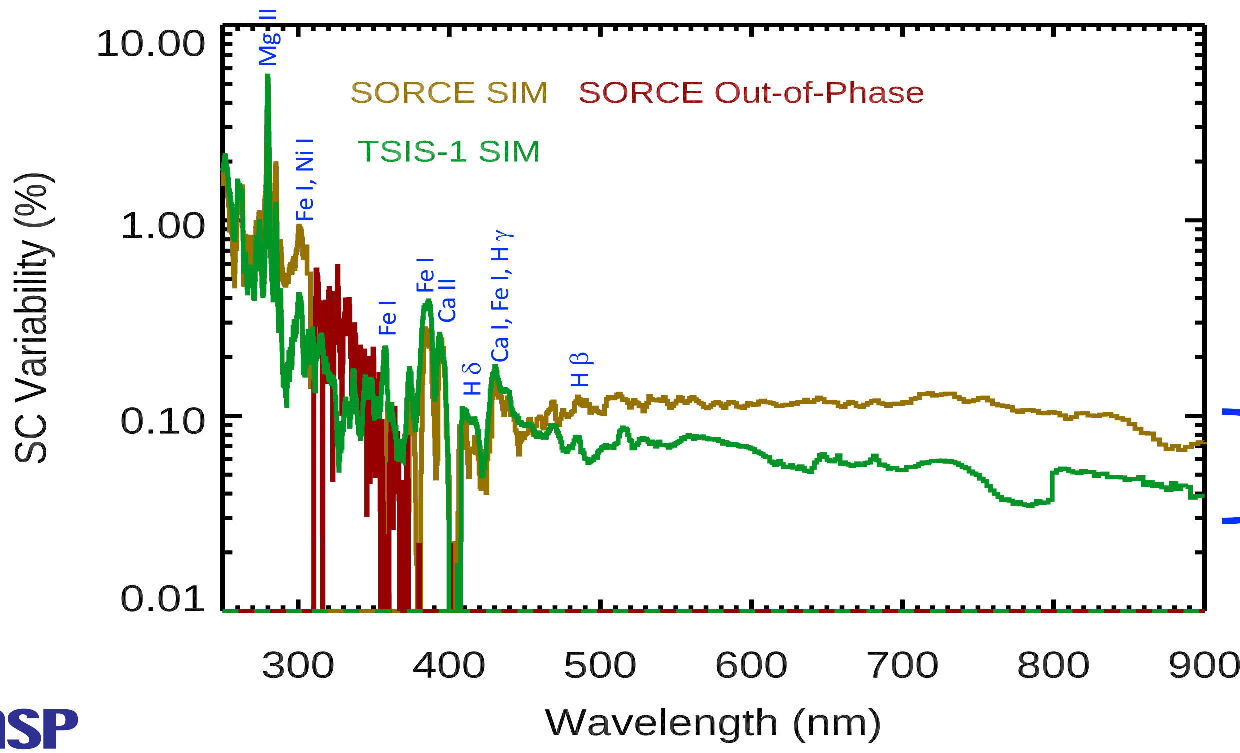
Relative variability for 600 nm



Solar Cycle SSI Variability Comparison for TSIS-1 and SORCE

- Solar Cycle 24: SORCE SIM (2008/315 to 2011/351) with **x 1.55** for Mg II 280nm agreement
- Solar Cycle 25: TSIS-1 SIM (2020/001 to 2023/001)
  - **AGREEMENTS**: λ < 286 nm and between 373 nm and 457 nm
  - **DIFFERENCES**: 286-373 nm ➔ SORCE SIM has out-of-phase variability

    λ > 457 nm ➔ TSIS-1 SIM has about 2 times lower variability



500-900 nm Difference
This could just be scaling difference between chromosphere variability and photosphere variability for these dates.

Summary

- TSIS-1 SIM is providing highly accurate next-generation Mg II C/W ratio results
  - Because TSIS-1 SIM spectra are very precise, and
  - Because SIM degradation trends are tracked extremely well with 3 SIM channels
- TSIS-1 TIM TSI data combined with SIM Mg index are providing highly accurate TSI_dark results, which are used for the next-generation sunspot area proxy
  - TSI_bright component is SIM Mg index scaled to TSI units
  - TSI_dark component (in TSI units) can be scaled to SSA units for NRLTSI/NRLSSI models
  - These two components are then used for modeling the SSI variability.
- SIST-4 Proposal (CATNIP) is pending to further expand this NG-proxy research
  - Combine TSIS-1 next-generation proxies into historical proxy composite records
  - Improve <u>operational</u> GOES EUVS-C Mg index results with more accurate SIM Mg index