One GHOTI, Two GHOTI, GHOTI, GHOTI

The GOES High-cadence Operational Total Irradiance project

Exploiting the EXIS Sun Position Sensors on the GOES-R Satellites for Solar Irradiance Studies

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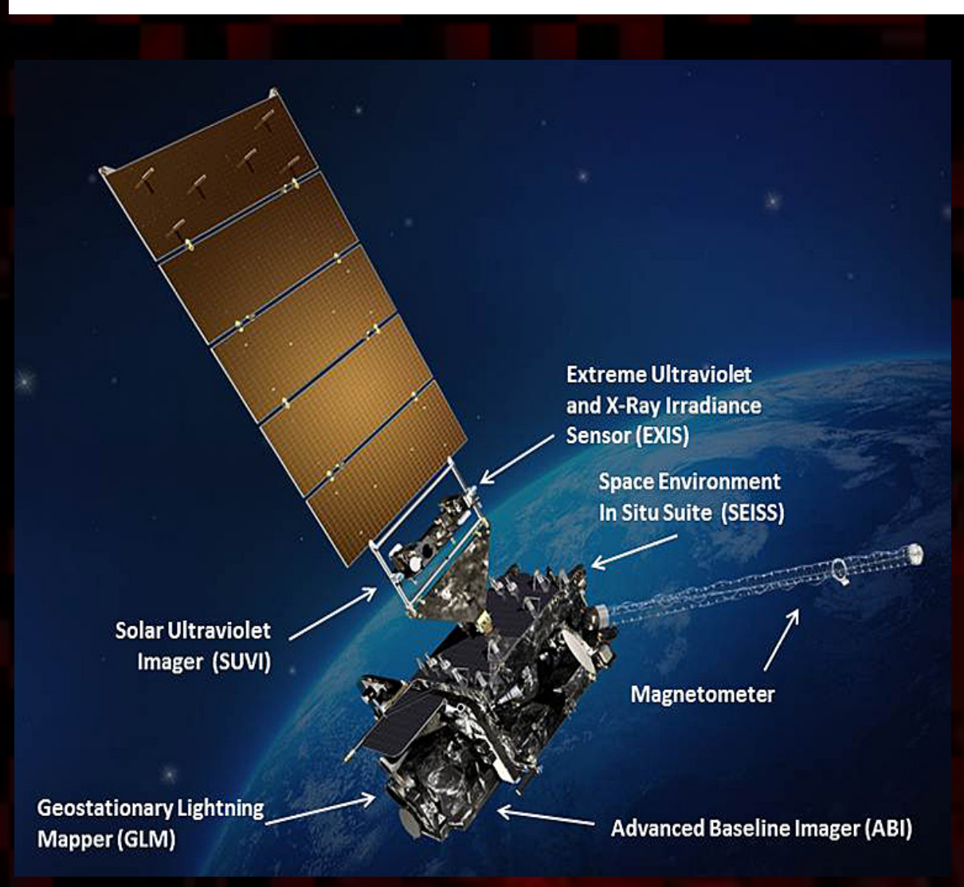


EXIS (Extreme ultraviolet and X-ray Irradiance Sensors) detectors on the GOES-R spacecraft (GOES-16, ~~17~~, and 18) use quad-diode (QD) Sun Positioning Sensors (SPS) to maintain precision pointing. The 4 Hz QD signal is high-precision, and we use this signal as a high-cadence proxy for Total Solar Irradiance, T🐡 (t). The QD signal must be calibrated for spacecraft velocity (1AU), instrument temperature, and diode degradation with usage. In our 4th year of this 4-year project, we report calibration and science goal progress.

What is the SPS?

The Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) on the GOES-R Series satellites (GOES-R/S/T/U) are used to monitor high-energy solar irradiance. GOES-16 & GOES-18 are currently operating. GOES-17(S) was safed on March 15, 2023 and GOES-U will launch no earlier than 30-Apr-2024.

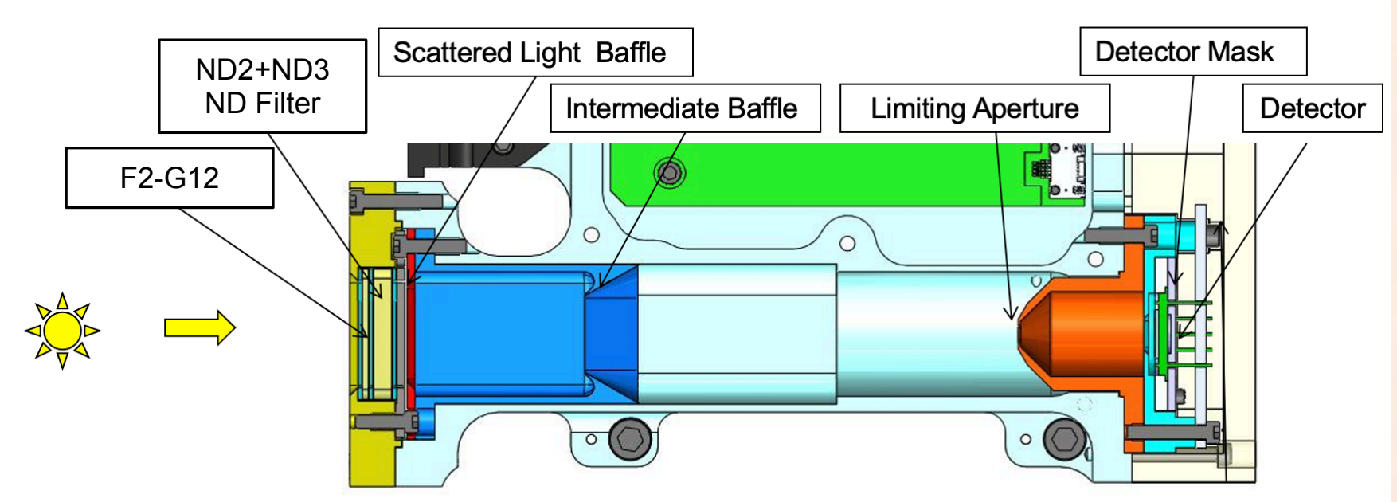
EXIS is described as having two detectors:

1) Extreme Ultraviolet Sensor (EUVS) : Monitors solar flares that can disrupt communications and degrade navigational accuracy, and

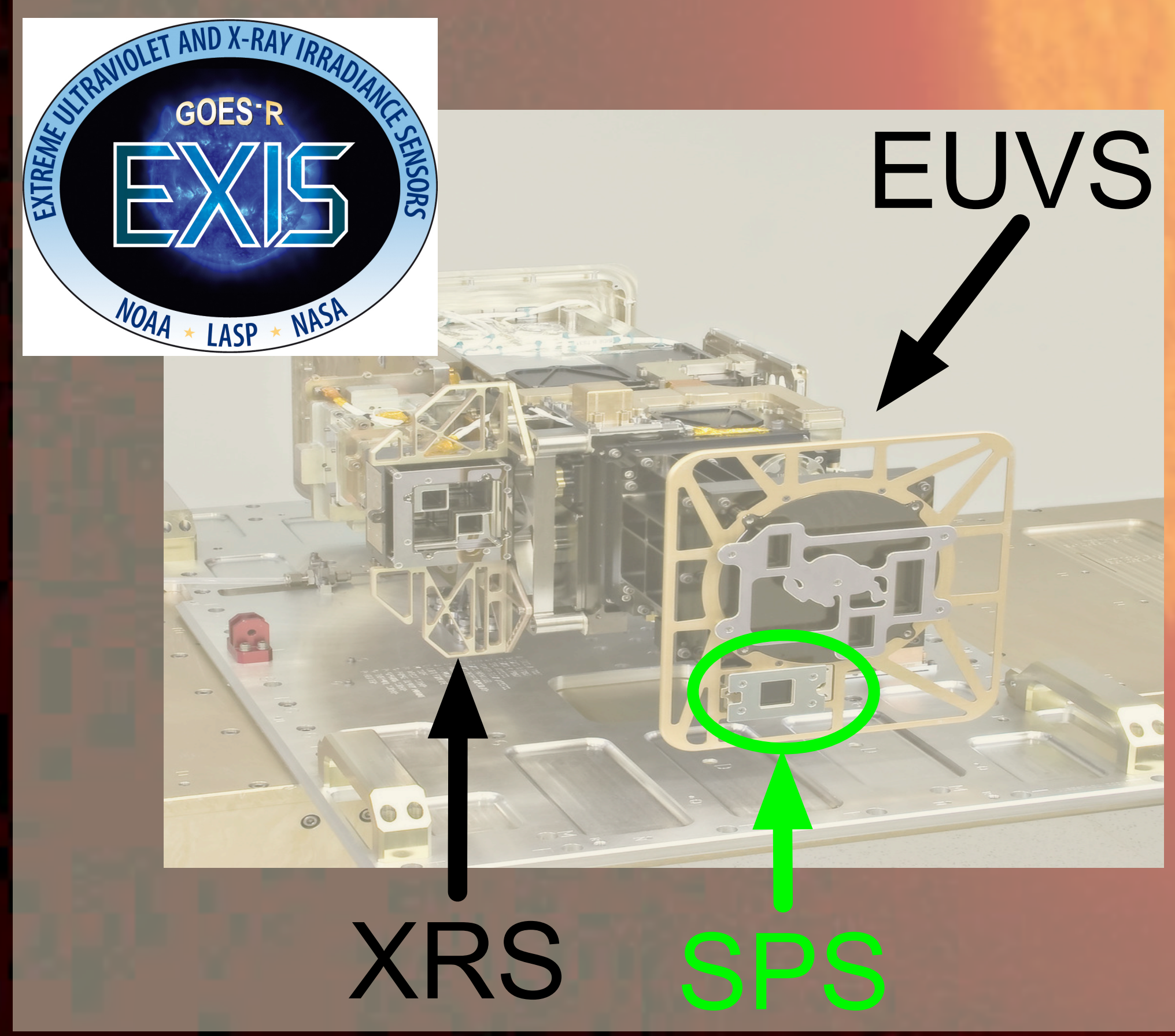
2) X-Ray Sensor (XRS): Monitors solar variations that directly affect satellite drag/tracking and ionospheric changes which impact communication and navigational operations.

However, there is a 3rd sensor, the Sun-Positioning Sensor (SPS), on that we are using as a broadband Solar monitor to develop a proxy for high-cadence Total Solar Irradiance (TSI), and to produce a high-cadence Solar Spectral Irradiance (SSI) estimate.

SPS is a set of 4 silicon diodes with a broad visible-light response (~300-700nm) with a cadence of 4 Hz. Operationally, solar illumination is used to monitor, and correct for, the pointing of EXIS.



SPS is a AXUV-PS6 quadrant photodiode detector behind radiation hardened glass (F2-G12) and ND3+ND2 filters. Each quadrant has a unique gain (Coulombs/DN), a 0.239 sec exposure time and 0.011 sec readout time, and records a solar signal at 4 Hz.



1AU Correction

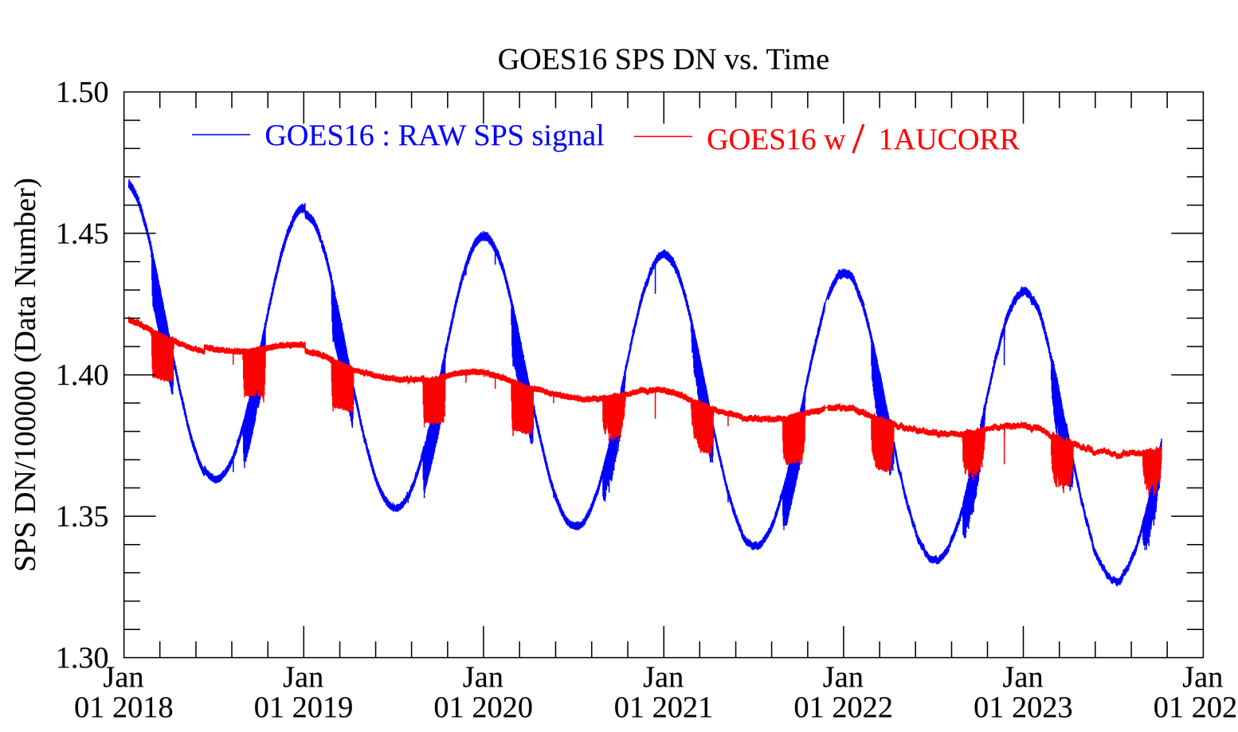
GOES-R satellites are in geosynchronous orbits, and thus, need a 1AU correction (1AUCORR) to correct for orbital distance from the Sun.

This correction shows both annual and daily variations. Our orbital distance correction is created by:

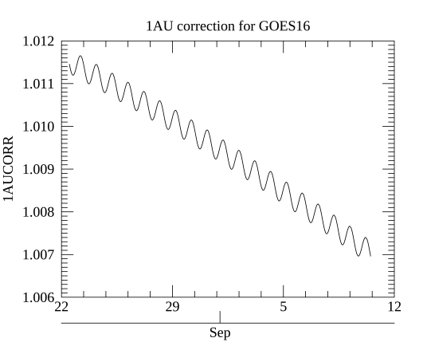
1) Download 2-line element files (tle) from https://www.space-track.org/

2) Using IDL ICY SPICE (N0066) to create Spice Kernel Files (spk)

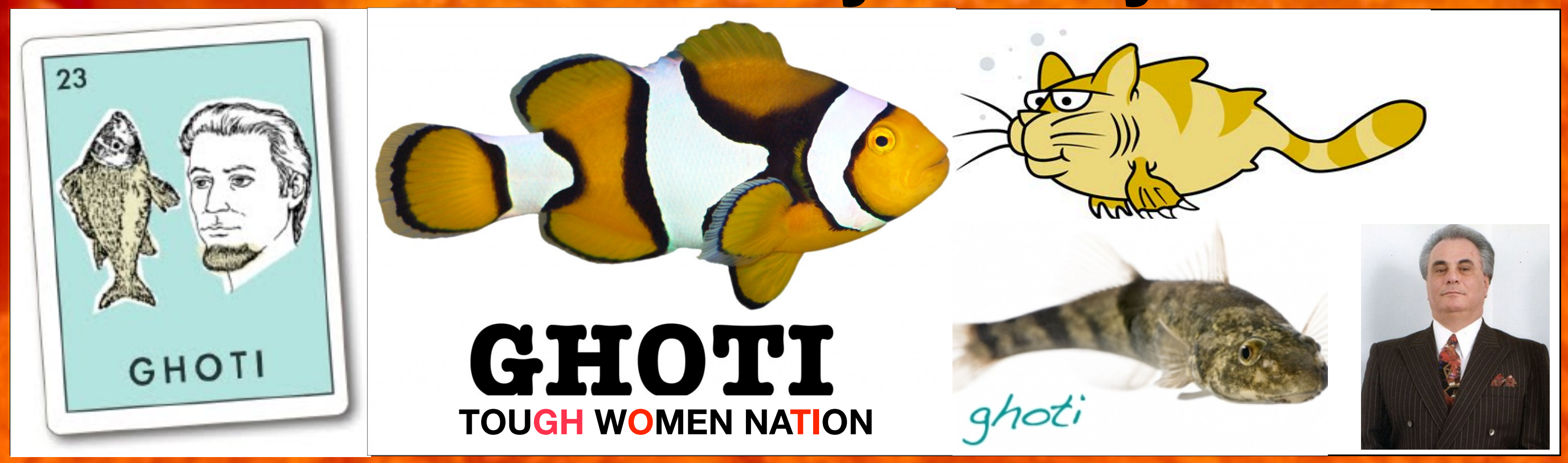
3) Apply the 1AUCORR to the quad-diode signal, measured in current, but expressed as DN (Data Numbers): DN_1AU = DN * (R/1AU)^2



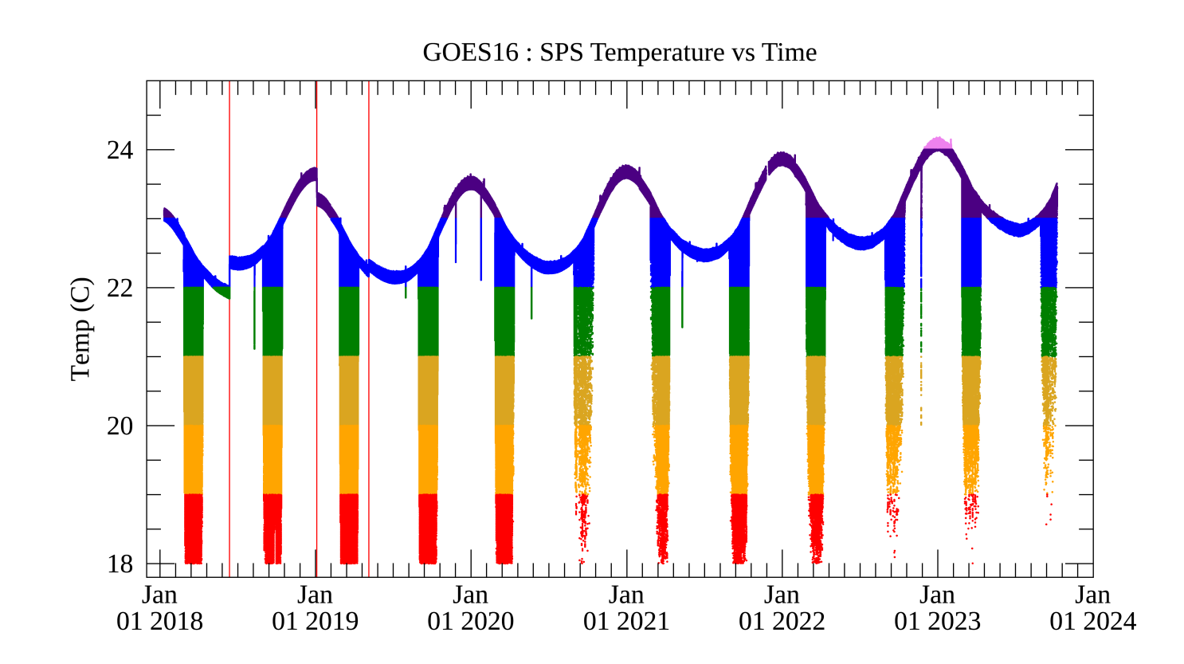
GOES16 SPS quad-diode signal in DN (Data Numbers) versus time before, in BLUE, and after applying 1AU correction, RED. Note the annual oscillation, as well as the bi-annual signal decreases during earth occultations (which also affect detector temperature). Figure to the right shows the daily 1AU corrections for Sept 2019.



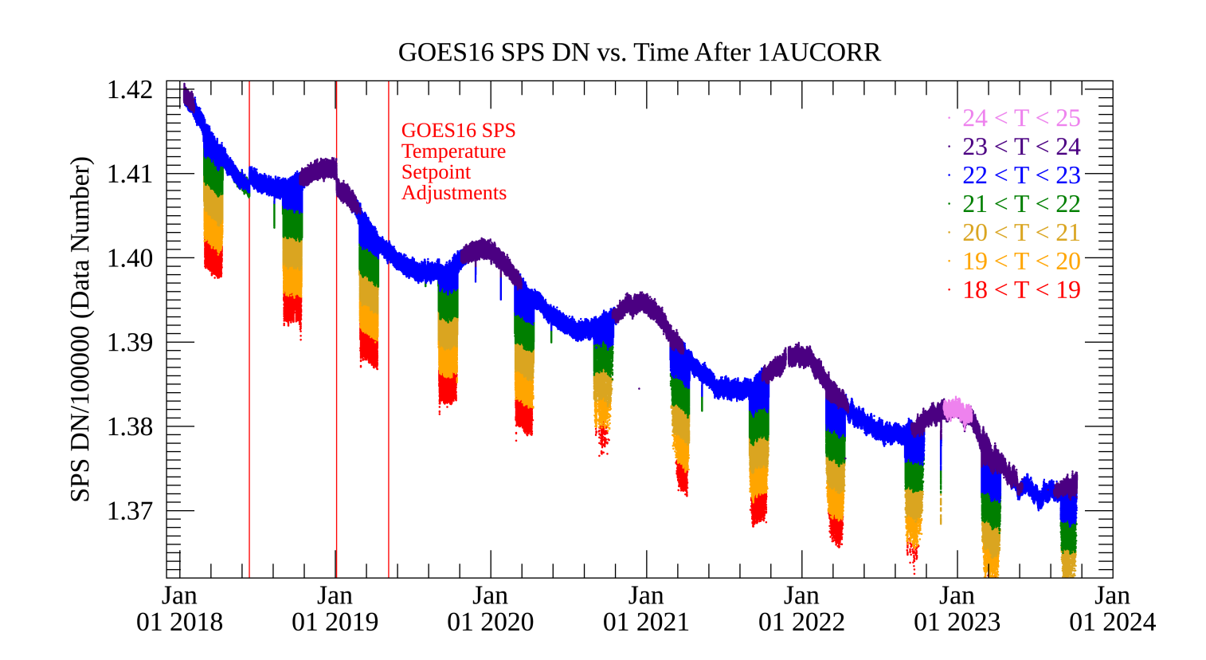
GHOTI : How do you say that ?



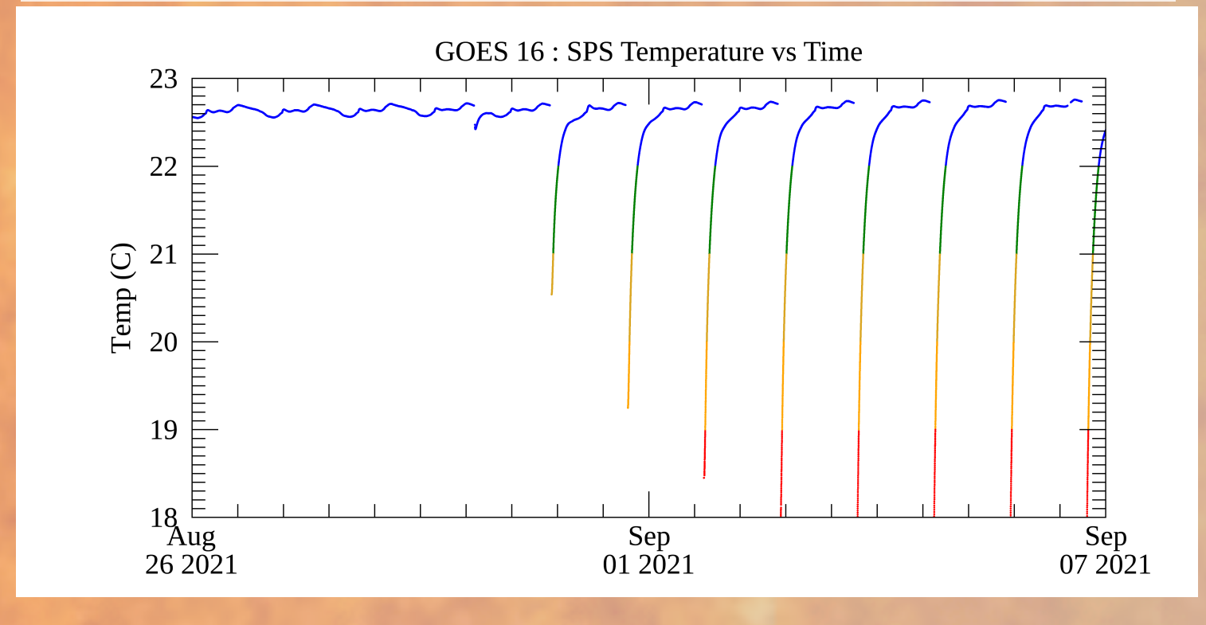
SPS Temperature Correction



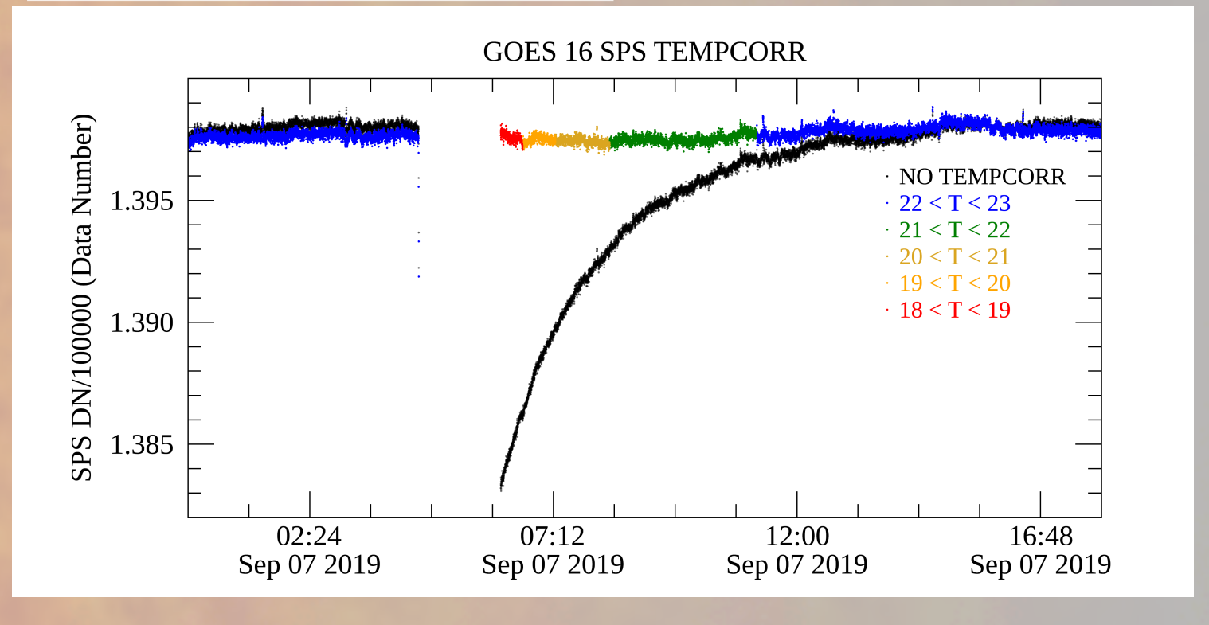
GOES16 SPS temperature, T(t), shows an increasing trend,+ an annual oscillation. Bi-annual eclipse seasons (occultations) cause dramatic T(t) drops. On 3 occasions (vertical lines), on-board heater set-points were adjusted.



GOES16 SPS quad-diode signal (DN) after 1AUCORR using the same color/temperature scheme. Our next calibration is to correct for the observed temperature dependency (TEMPCORR).

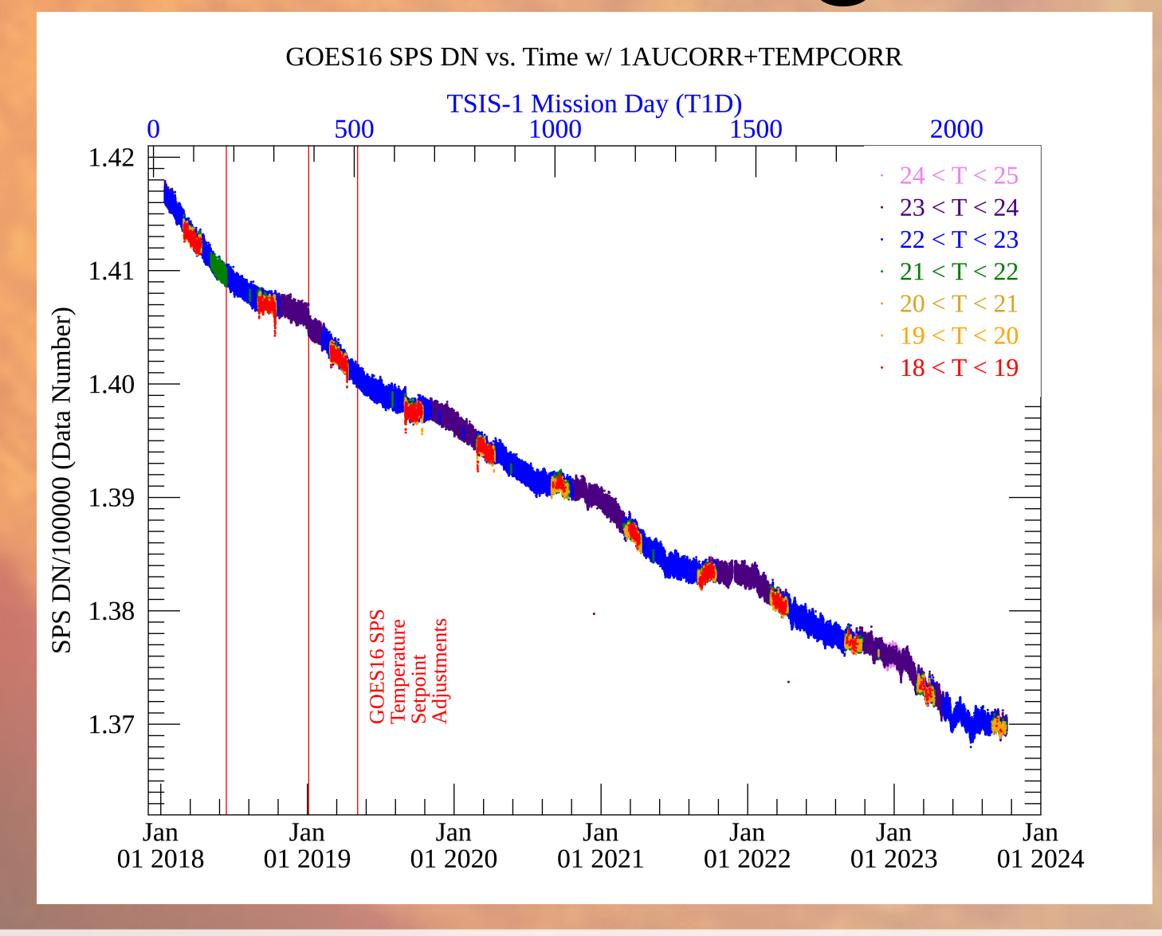


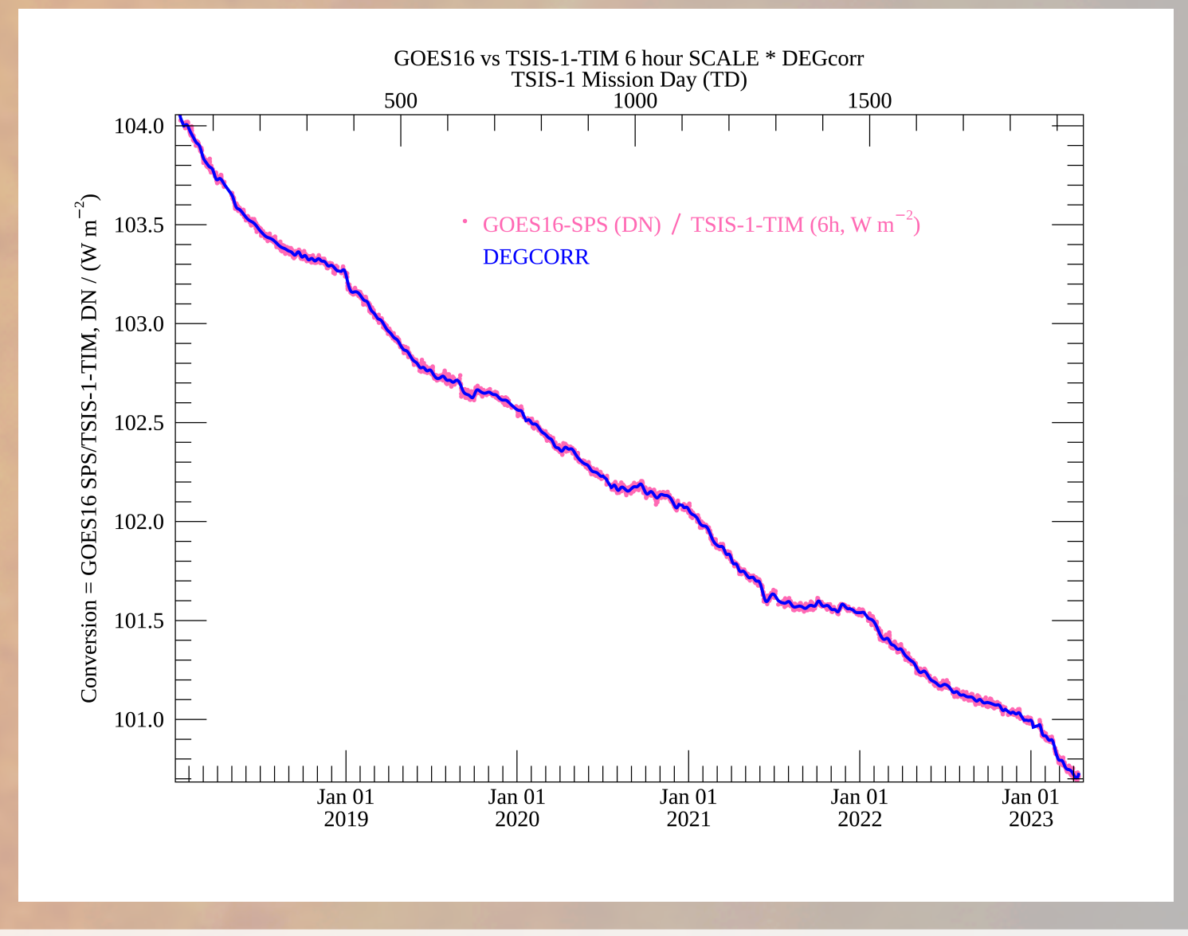
GOES16 SPS T(t) during the beginning of an eclipse season. Note that even without occultation, the temperature has a daily variance that needs addressing.



Applying the TEMPCORR calculated on 9/5/2019 to the SPS DN signal does a good job of correcting the temperature dependence of the diodes.

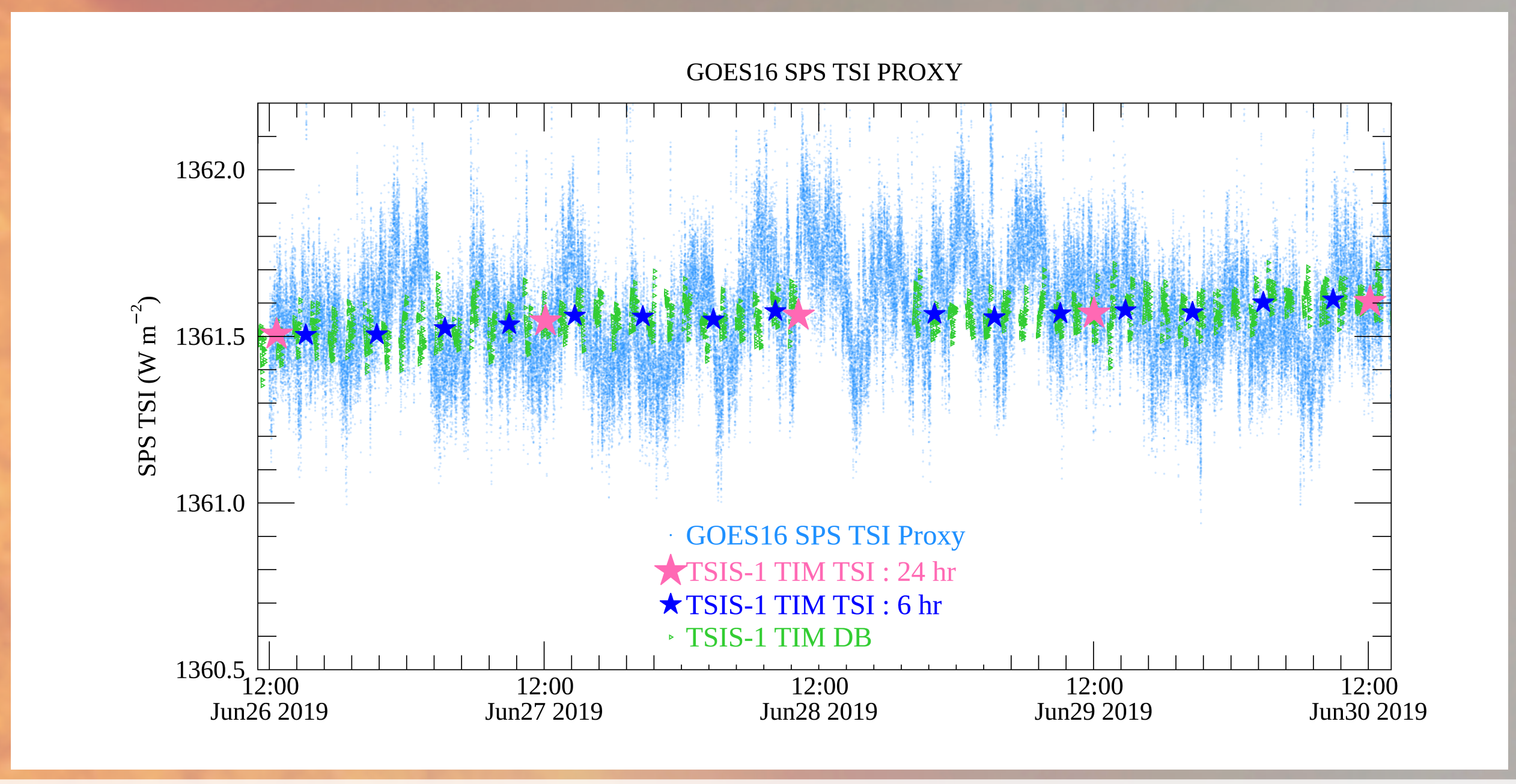
SPS Degradation Correction



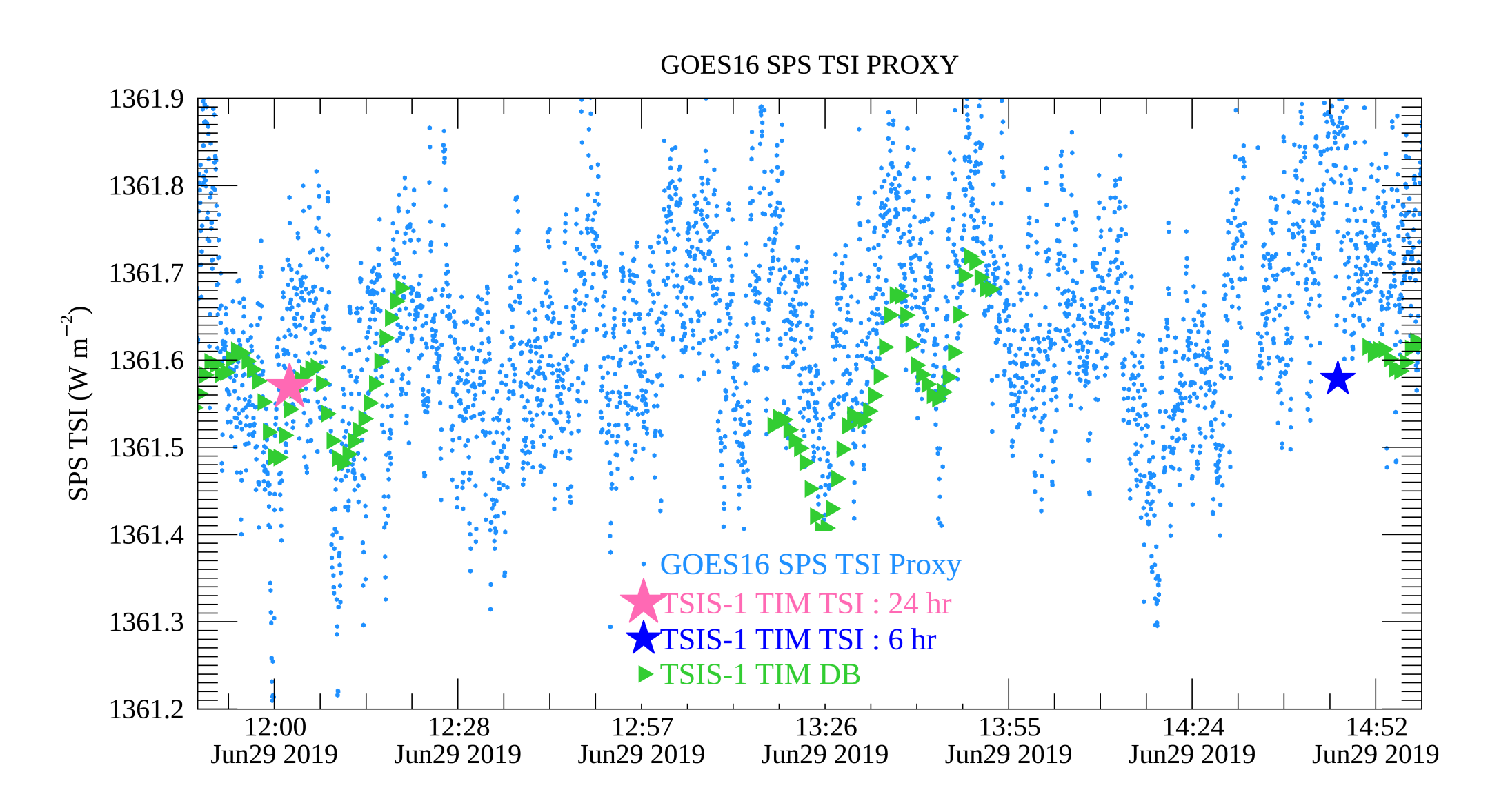


SPS filter throughput, and diode efficiency, decrease with time. Left figure shows the GOES16 SPS signal after 1AUCORR and TEMPCORR. We use TSIS-1 TIM Total Solar Irradiance (TSI) 6h measurements to model this degradation.The right figure shows the GOES16 SPS degradation correction (DEGCORR) in units of SPS DN/(W/m2).

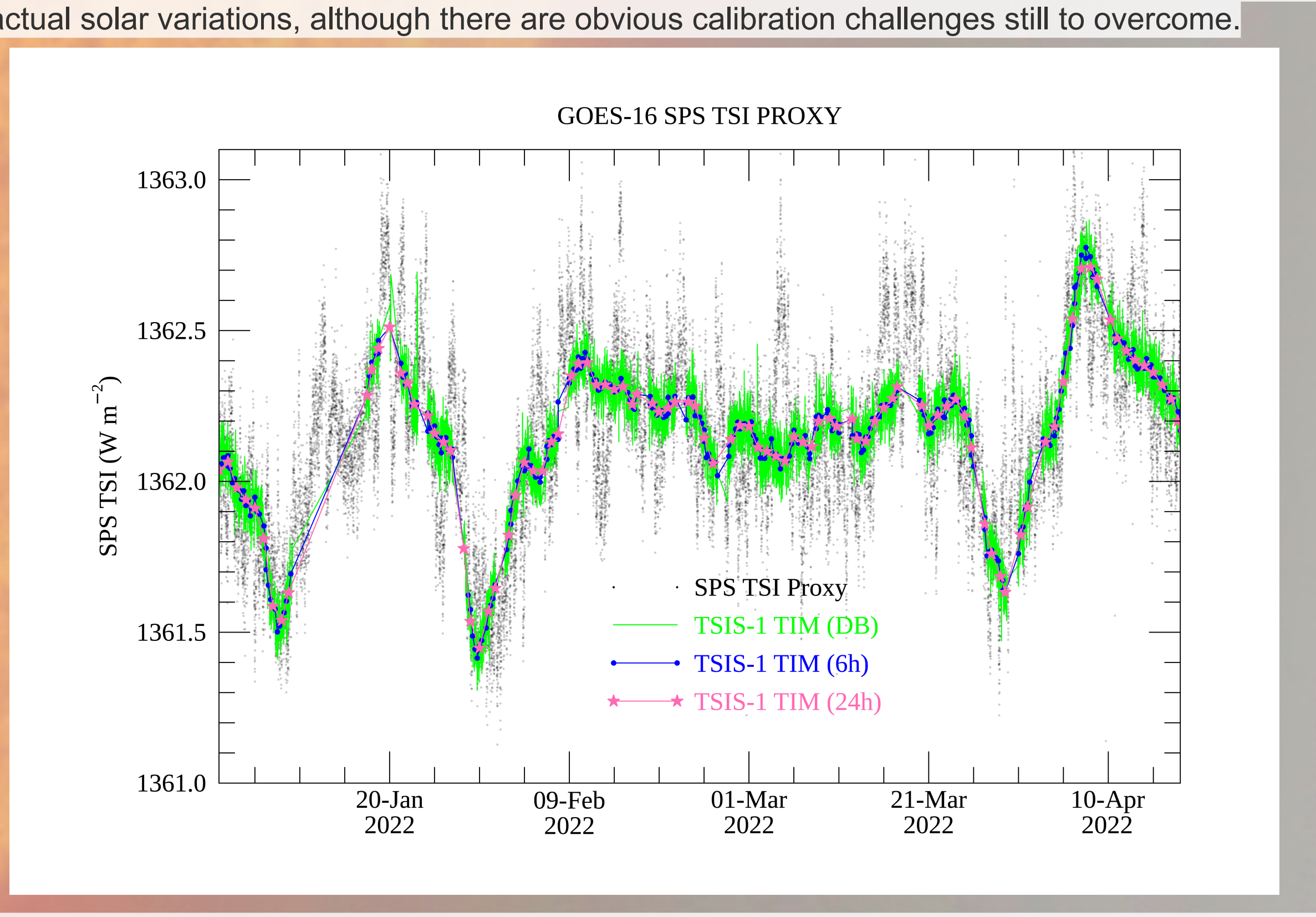
GOES16 SPS as a TSI PROXY



Applying our DEGCORR to the SPS signal gives our 3s SPS TSI Proxy. Our TSI Proxy shows considerable structure not seen in the 6/24-hour TSIS-1 TSI datasets. If this is indeed Solar signal (and not an existing calibration issue), our high cadence (3s) long-term (4+ years) TSI proxy seems not only viable, but extremely scientifically useful.



Overplotting the individual TSIS-1 TIM measurements that go into the 6 and 24 hour TSIS-1 TIM L3 data measurements (GREEN points labeled DB, database) over a shorter time range, we see that we are indeed appear to be tracking actual solar variations, although there are obvious calibration challenges still to overcome.



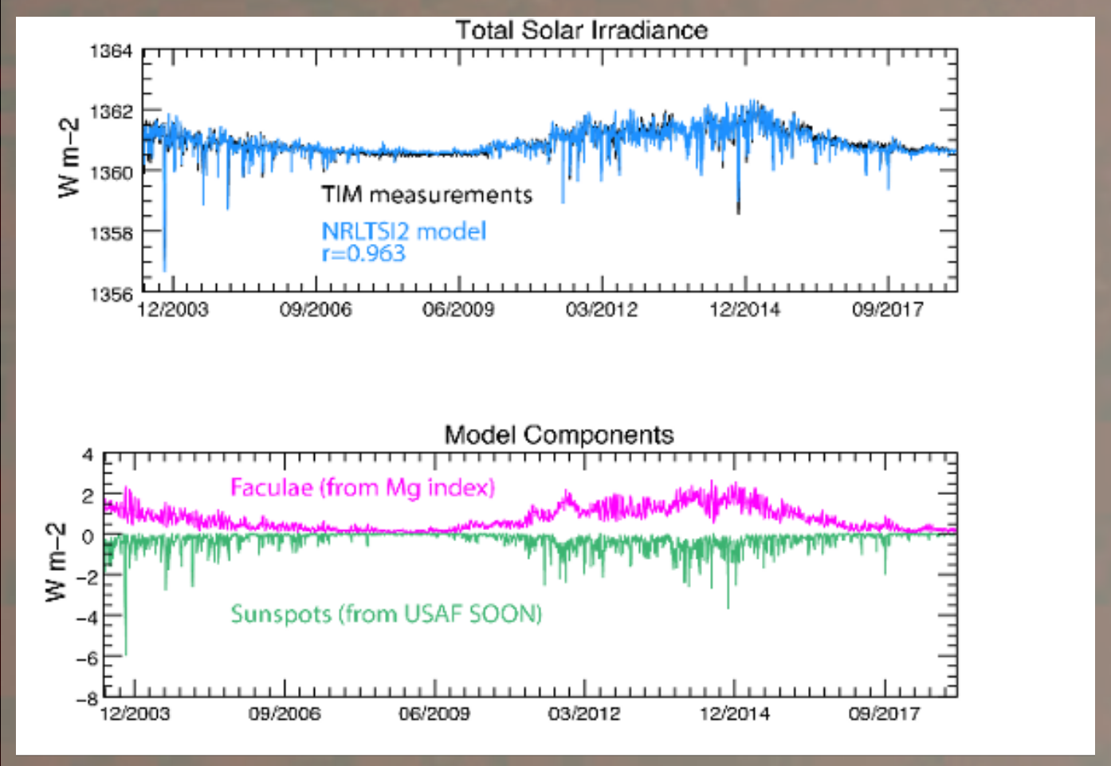
Our spring 2022 SPS TSI-Proxy is plotted here (BLACK) versus the TSIS-1 TIM TSI from the DB (GREEN), 6-hr (BLUE) and 24-hr (PINK). The solar variability can be increasing seen as the cadence of the TSI increases. Our TSI-proxy can also be used to fill in temporal gaps in TSIS-1 TIM measurements.

Future Work:

We are in the final year of our project, with most efforts devoted to SPS signal analysis and calibration. Our year 4 goals (in addition to further enhancing our SPS TSI Proxy calibrations) are:

1) Use GOES-17/18 to assist in the GOES-16 SPS calibration.
2) Switch to using TSIS-1 TIM V04.
2) Expand our TSI analysis to the GOES-18 spacecraft.
3) Combine our SPS TSI Proxy with the Magnesium II index (EUVS-C),

to create an additional high-cadence (3s) UV-IR spectrum, I🐡 (λ,t)



The NRLSSI/2 (Coddington et al. 2016) model uses a linear combination of the Magnesium II index and sunspot areas to create the solar irradiance spectrum from 115 nm to 100 microns. We adapt the algorithm to use the EUVS-C MgII measurements (cadence 3 sec), and our 3s SPS TSI proxy, T🐡 (t).

Modeling the solar spectrum: The NRLSSI and NRLTSI models use linear combinations of facular brightening, $\Delta T_F(t)$, and sunspot darkening, $\Delta T_S(t)$, relative to a Quiet Sun reference spectrum (T_Q, Coddington et al. 2016, Coddington and Lean 2015). We can infer the sunspot darkening from TSI(t) :

$$TSI(t) = T_Q + \Delta T_F(t) + \Delta T_S(t)$$

$$\Delta T_F(t) = a_F + b_F \times [F(t) - F_Q] \quad ; F_Q = \text{Facular Brightening at Solar Minimum}$$

$$\Delta T_S(t) = a_S + b_S \times [S(t) - S_Q] \quad ; S_Q = \text{Sunspot Darkening at Solar Minimum}$$

S(t) is the sunspot darkening, **F(t)** is the facular brightening, and for TSI, we use our GHOTI TSI-proxy (***T***🐡). Other constants are described in Coddington and Lean (2015). Solving for S(t):

$$S(t) = S_Q + \frac{\boldsymbol{T}_{🐡} - T_Q - \boldsymbol{\Delta T_F(t)} - a_S}{b_S}$$

F(t) is determined from EUVS-C MgII observations. Knowing S(t) and **F(t)** at high cadence, we compute the high-cadence spectrum, $I_{🐡}(\lambda, t)$, according to Coddington and Lean 2015:

$$I_{🐡}(\lambda, t) = I_Q(\lambda) + \Delta I_F(\lambda, t) + \Delta I_S(\lambda, t)$$

$$\Delta I_F \propto \boldsymbol{F(t)} \qquad \Delta I_S \propto S(t)$$

bold indicates measured quantities

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