



Laboratory for Atmospheric and Space Physics  
University of Colorado **Boulder**



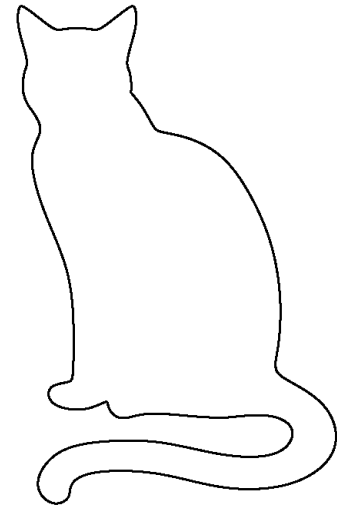
UNIVERSITY *of the*  
WESTERN CAPE

# SOLSTICE: Seventeen Years, Eighteen Versions

Marty Snow (SANSAS, LASP, UWC)  
Bill McClintock, Tom Woods, Josh Elliott (LASP)  
[msnow@sansa.org.za](mailto:msnow@sansa.org.za)

# Outline

- SOLSTICE Capabilities
- Inflight Calibration Techniques
  - Stellar Measurements
  - FOV Correction
- Final version uncertainties
- Final version results
  - Comparison to other measurements
  - Comparison to models
- Summary



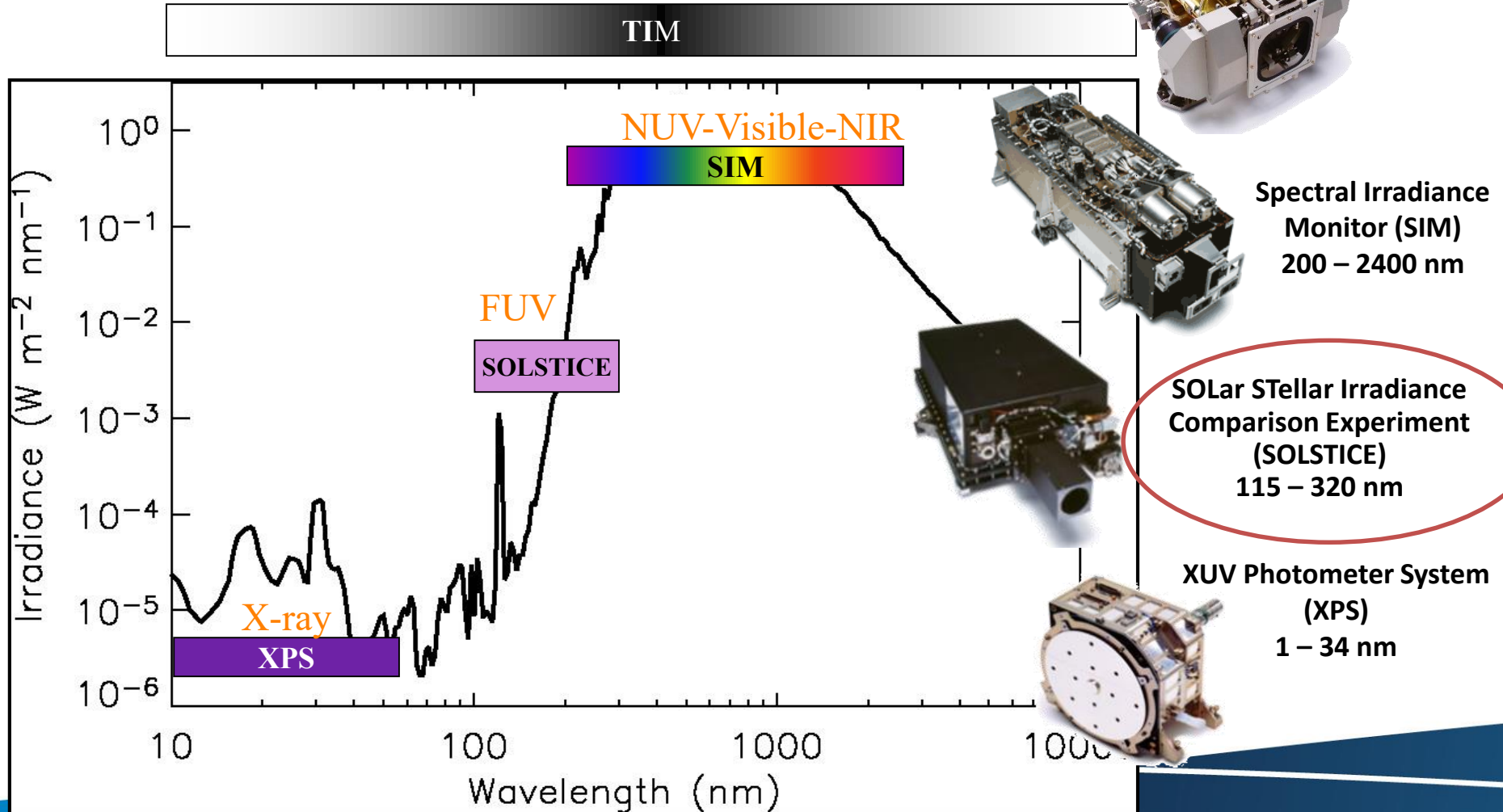
# References

- Snow et al. (2021) Algorithm Theoretical Basis Document – Post Launch update: SOLar-STellar Irradiance Comparison Experiment (SOLSTICE), Technical Report, University of Colorado Boulder, <https://doi.org/10.25810/meav-4g65>
- Snow et al. (2022) SOLar-STellar Irradiance Comparison Experiment II (SOLSTICE II): End-of-Mission Validation of the SOLSTICE Technique, Solar Physics, 297,55, <https://doi.org/10.1007/s11207-022-01984-9>
- Woods et al. (2021) Overview of the Solar Radiation and Climate Experiment (SORCE) Seventeen-Year Mission, Solar Physics, 296, 127, <https://doi.org/10.1007/s11207-021-01869-3>
- Woods et al. (2022) Solar-Cycle Variability Results from the Solar Radiation and Climate Experiment (SORCE) Mission, Solar Physics, 297, 43, <https://doi.org/10.1007/s11207-022-01980-z>



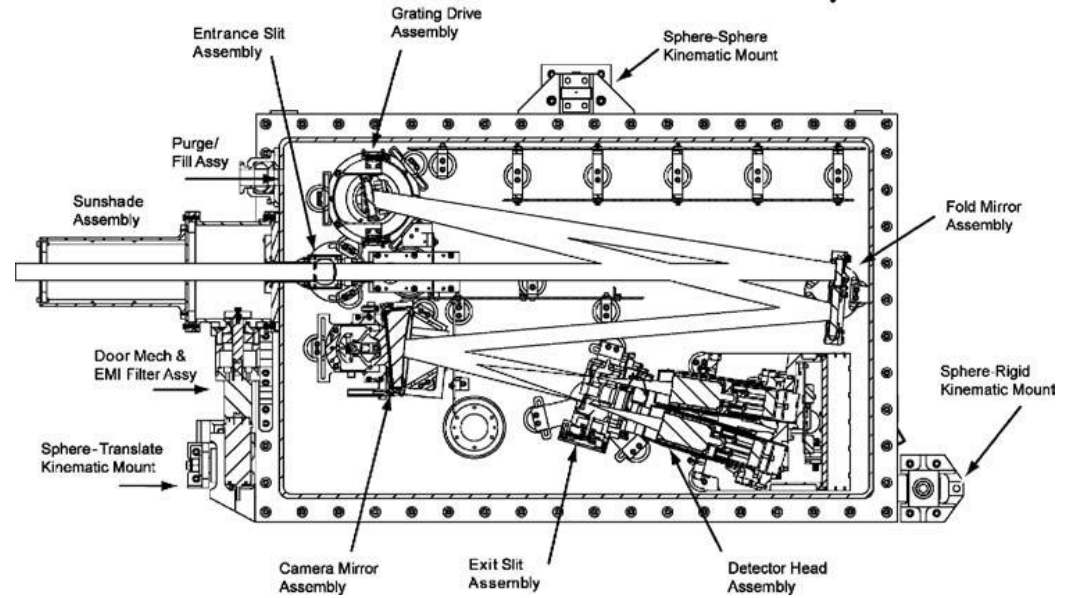
# Solar Radiation and Climate Experiment (SORCE) 2003-2020

## Total Solar Irradiance (TSI)



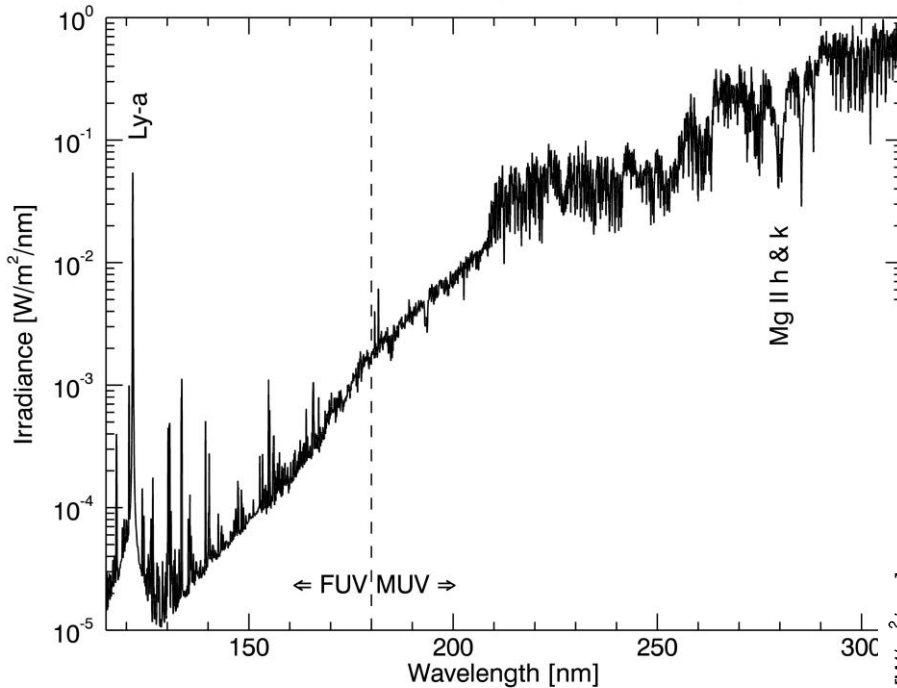
# SOLSTICE

- Grating spectrometer
- Two channels:
  - FUV (115-180 nm)
  - MUV (180-300 nm)
- Two redundant instruments
- Spectral resolution: 0.1 nm
- Preflight calibration at SURF
- In-flight calibration using stars



# SOLSTICE Measurements

SORCE SOLSTICE L3 Daily Spectrum 1 January 2004



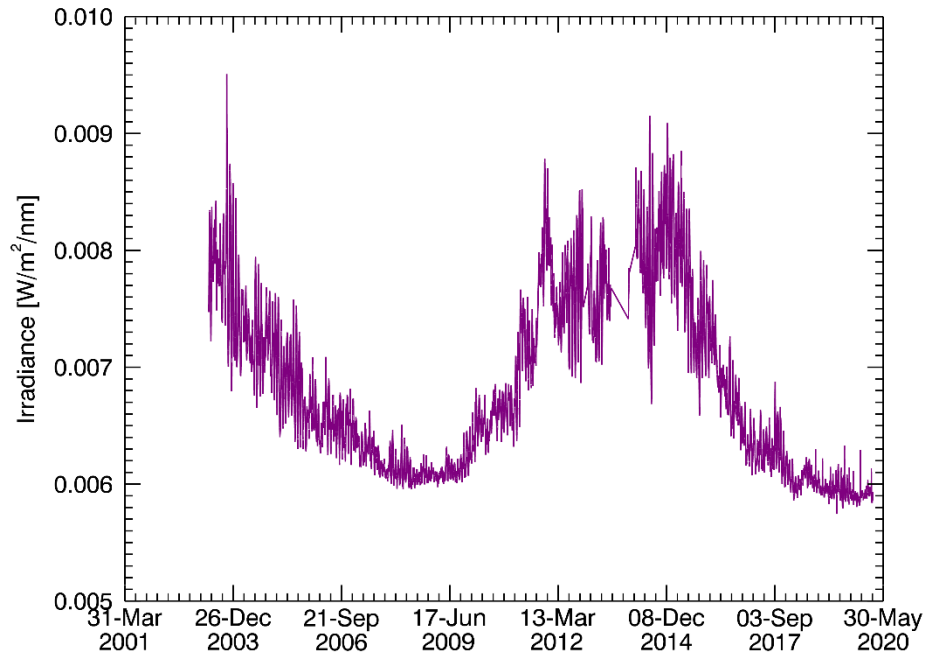
Daily SSI from 115-300 nm:

- Level 3: 1-nm binned
- Level 3: 0.1-nm native resolution sampled on a regular grid with 0.025 nm spacing

Additional:  
High cadence Lyman alpha scans

<https://lasp.colorado.edu/home/sorce/data/>

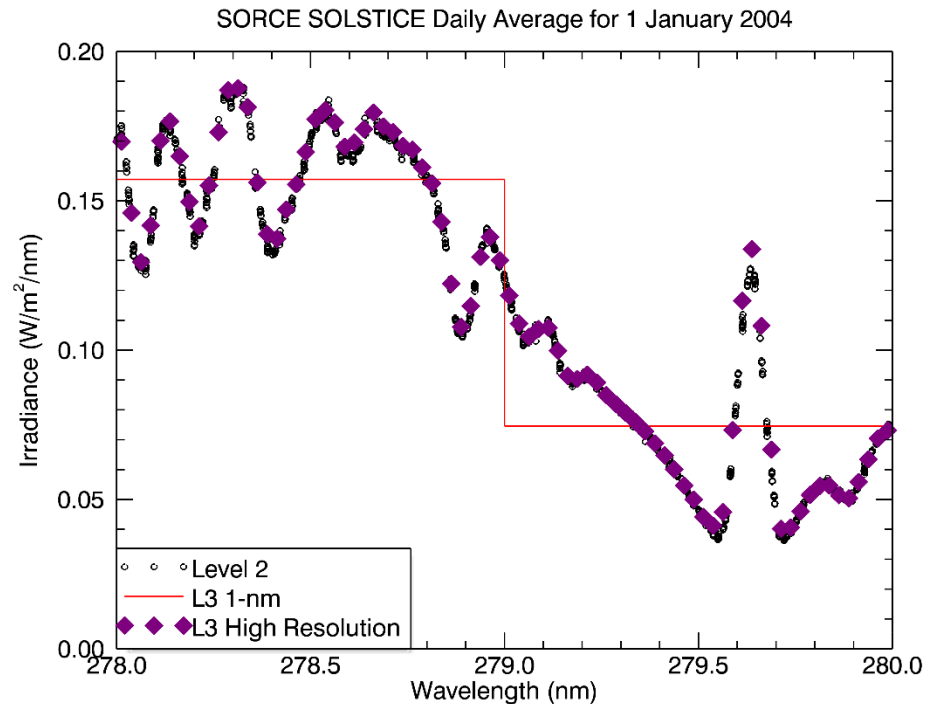
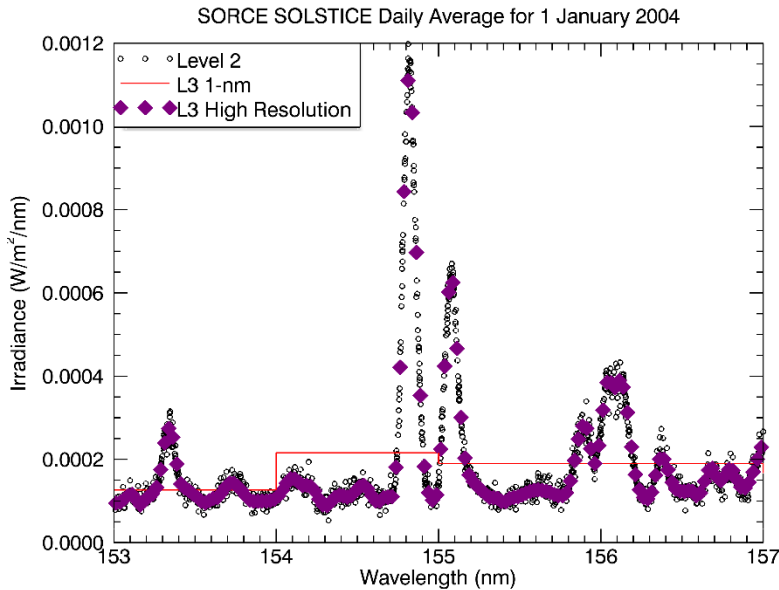
SORCE SOLSTICE Lyman-alpha



# Example Full-resolution spectra

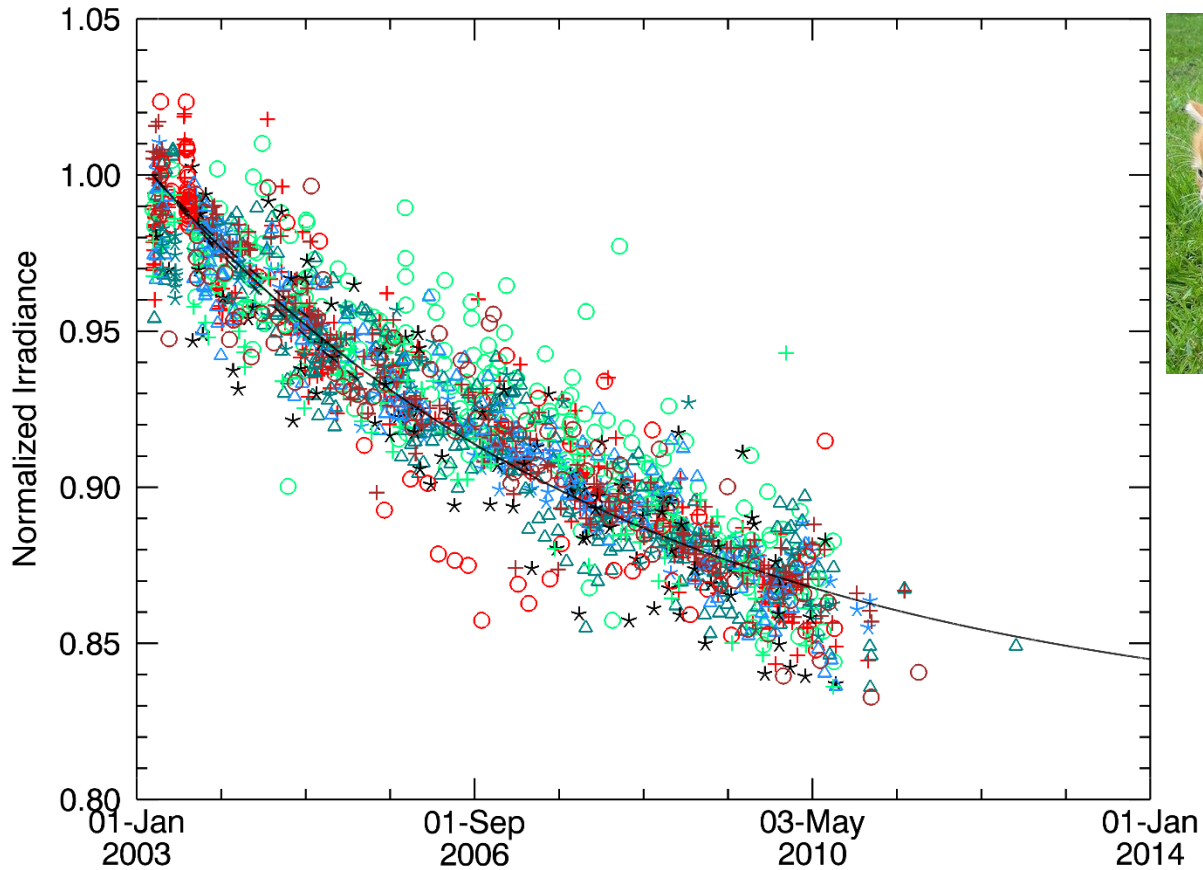
1-nm data product compatible with legacy datasets, but full-resolution spectra are recommended.

Long-term trends are identical. 1-nm product is numerically integrated from high-res



# Stellar Observations

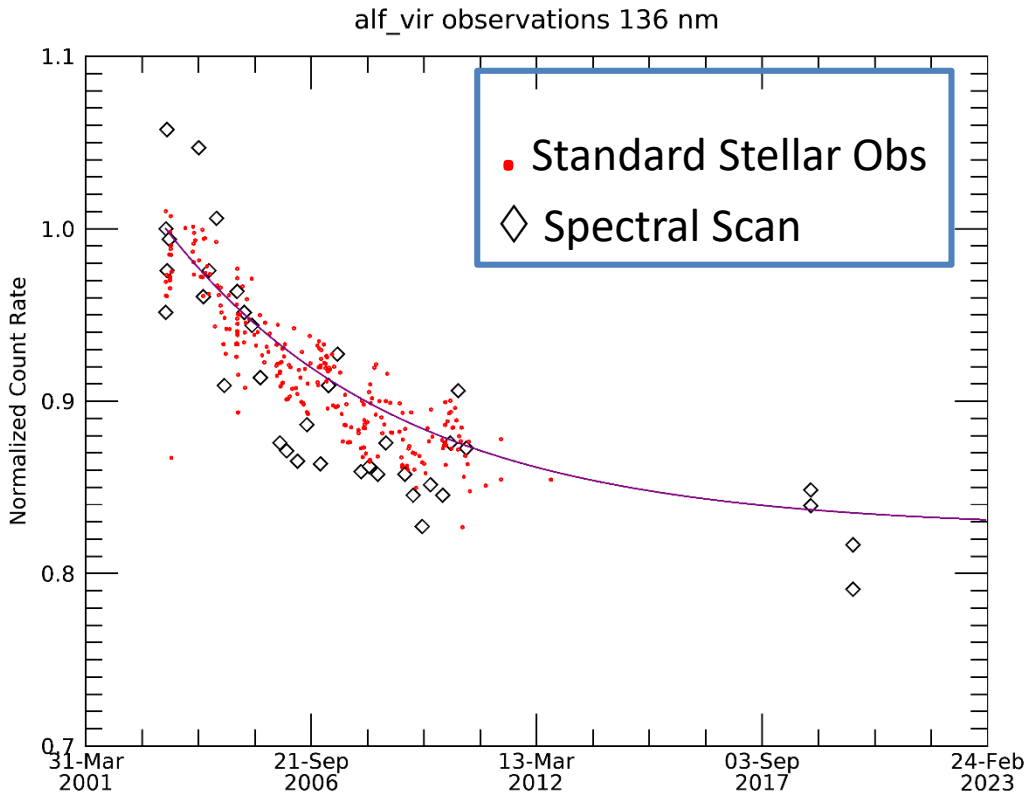
Fit After Removing Outliers



|   |         |       |
|---|---------|-------|
| + | ALF_CMA | 312.  |
| * | ALF_CRU | 1624. |
| o | ALF_PAV | 263.  |
| △ | ALF_VIR | 1061. |
| + | BET_CEN | 1521. |
| * | BET_CMA | 419.  |
| o | DLT_SCO | 289.  |
| △ | ETA_UMA | 236.  |
| + | SIG_SGR | 251.  |
| * | TAU_SCO | 338.  |
| o | ZET_CEN | 281.  |



# Late-mission stellar observations



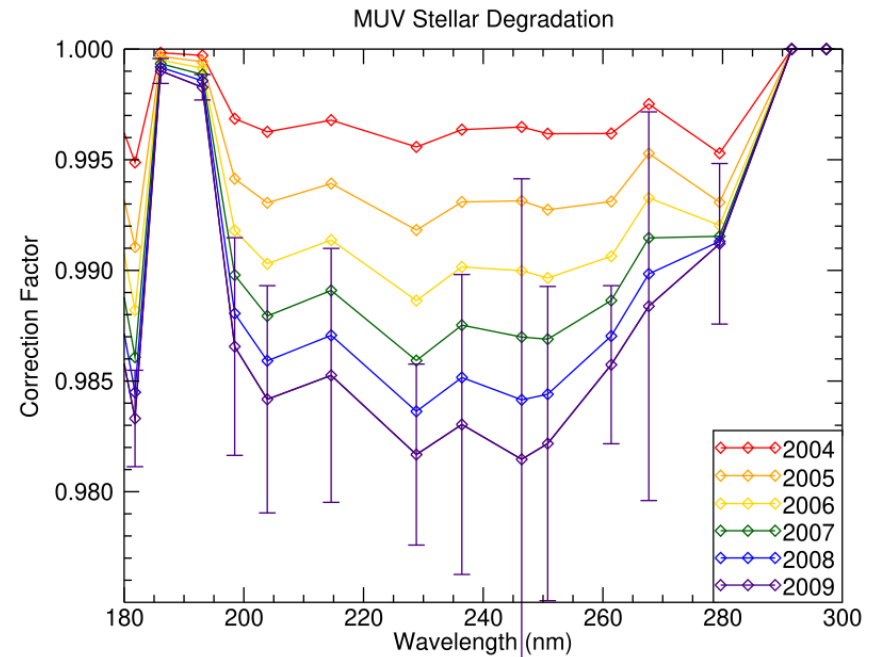
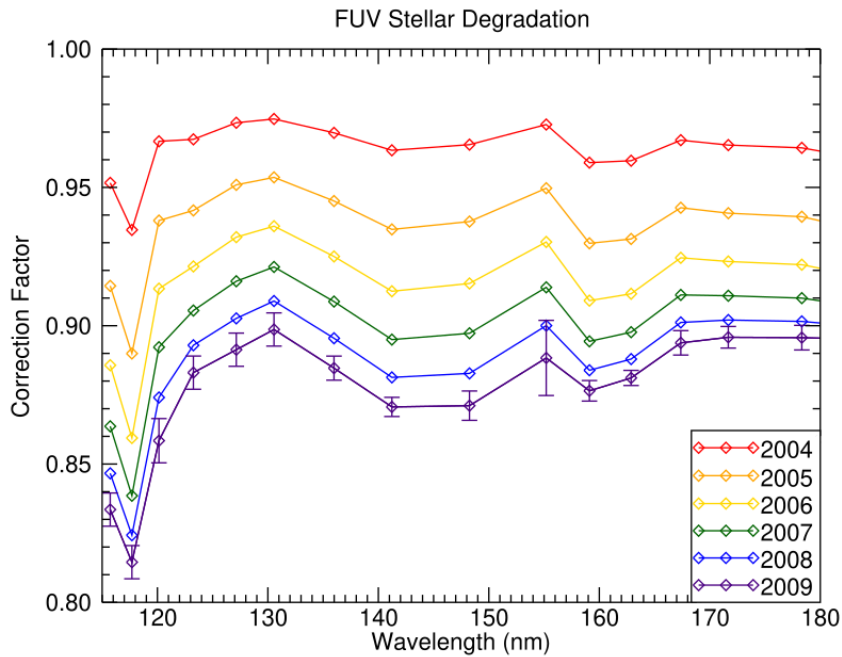
Battery degradation prevented standard eclipse activity. Stellar degradation trends were extrapolated after 2011.

Late in the mission, two daytime stellar observing campaigns in the FUV confirmed that prior extrapolation was reasonable.

Too few observations to warrant new curve fit.



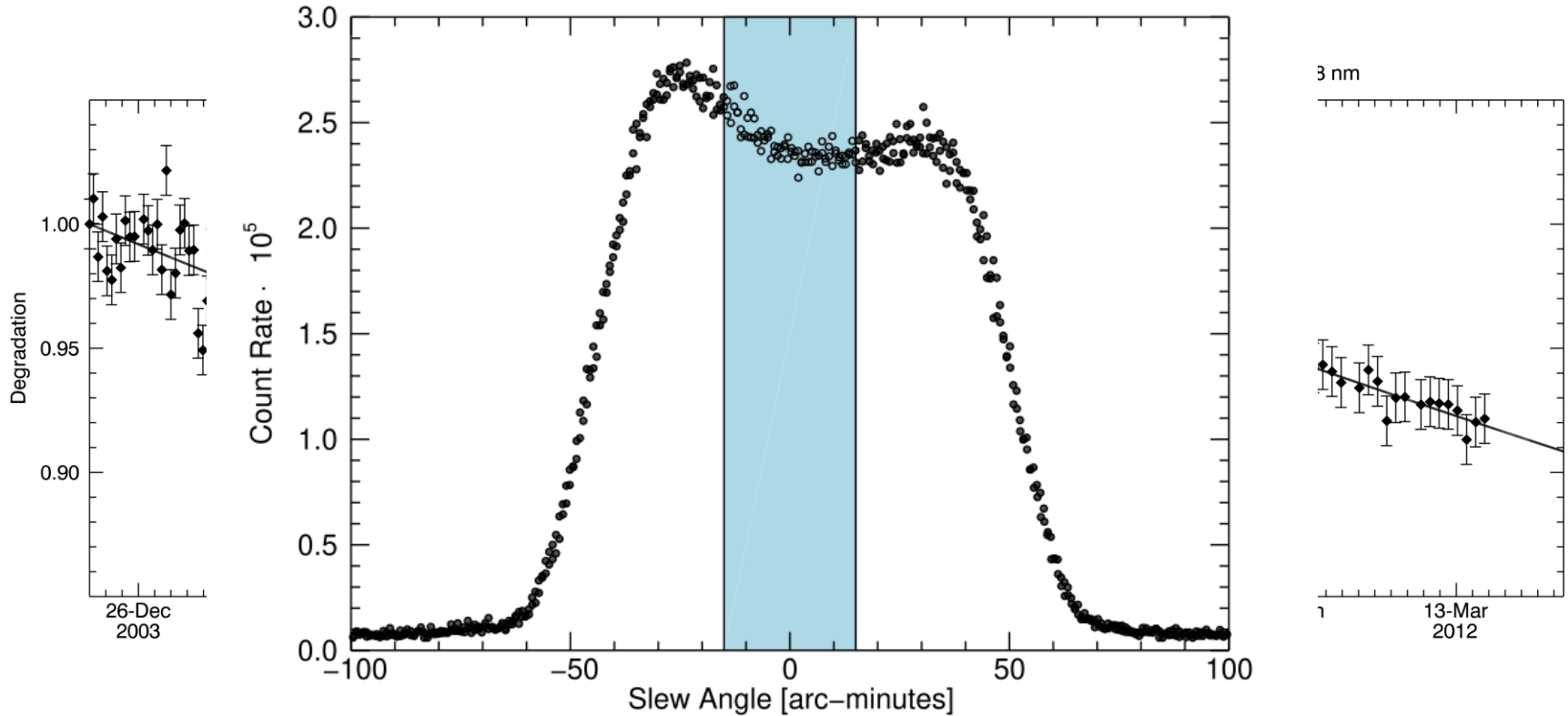
# Summary of Stellar Trending



For clarity, error bars are only included on 2009 curves.



# Solar/Stellar Correction (FOV)



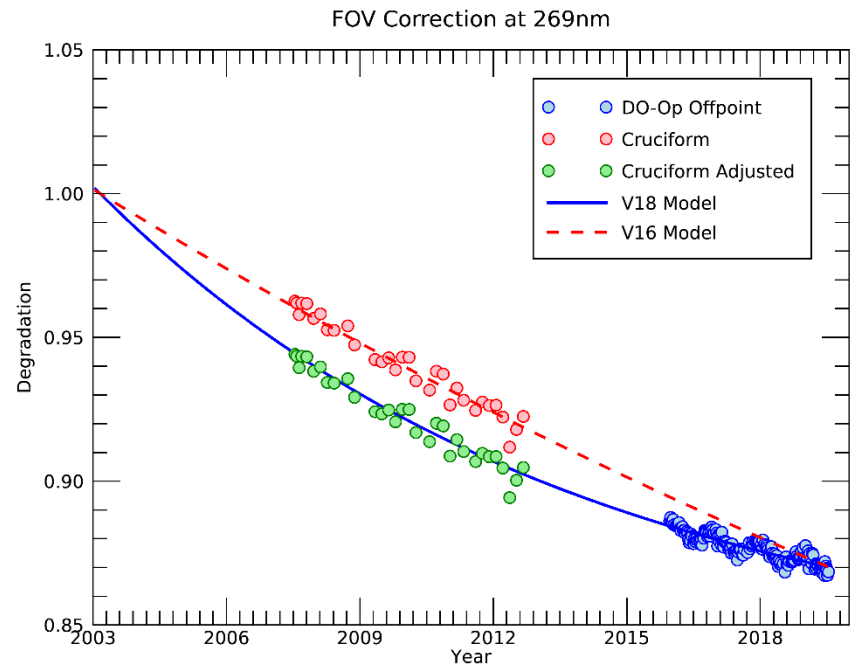
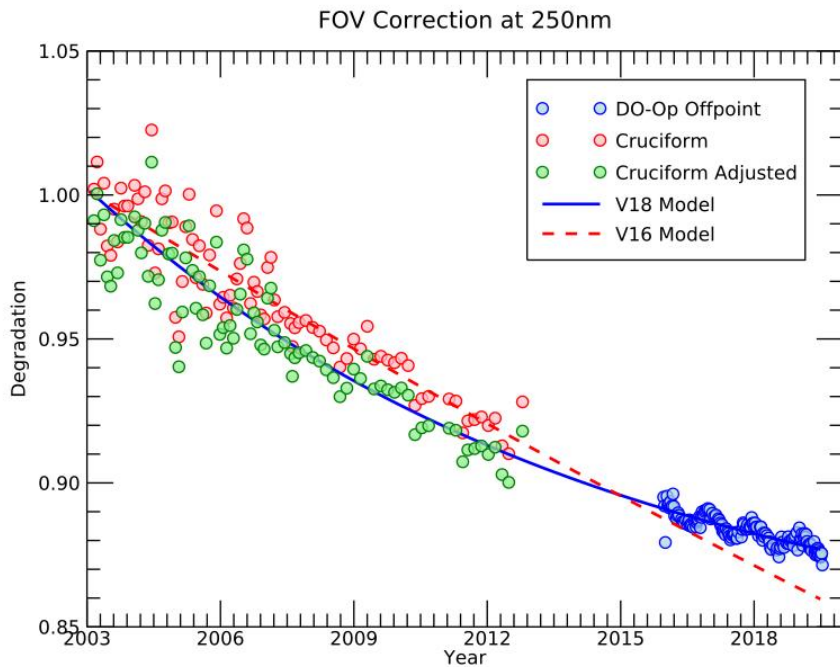
Observations at some wavelengths began in 2003, other wavelengths began later in the mission. Illumination on primary mirror and grating is not the same for solar and stellar modes. Ratio of center of FOV to edge was normalized to beginning of the mission up to version 16. An additional degradation correction from field-of-view measurements is required.

# Needed to revise for DO-Op

- Spacecraft operation starting in 2014 changed dramatically.
- Day Only Operation (DO-Op, Woods et al. 2021)
- Weekly spacecraft slews were no longer possible.
  
- Replacement operation was to offpoint the spacecraft and take an entire spectrum.
- Con: only sample one spot on the “haystack”
- Pro: measure entire wavelength range rather than 4 or 8 discrete wavelengths



# DO-Op trend did not match...



Red dashed line is a fit to the earlier observations.

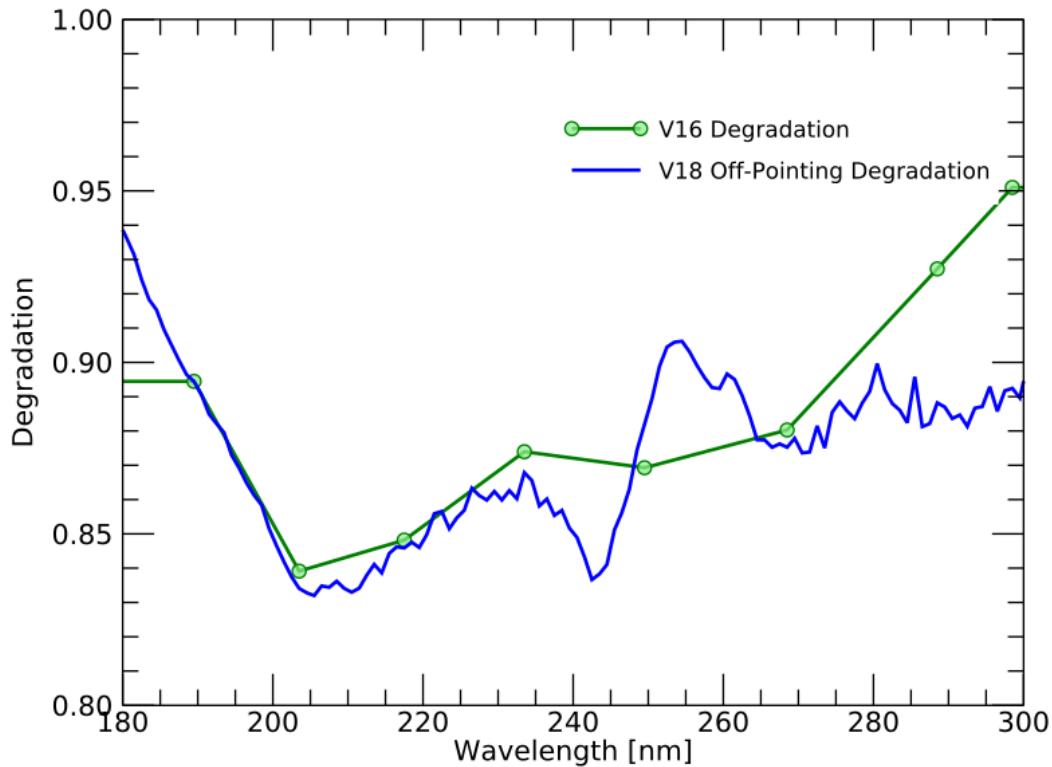
Does not agree with DO-Op measurements (blue).

Remember: Data was arbitrarily normalized to be unity at the start of the mission.

Allowing that scaling factor to be a fitting parameter produces the blue curve that fits all of the data.

# Summary for V18

Field of View Correction



**Table 1.** Estimates of uncertainty in SOLSTICE degradation correction as a function of time for the MUV channel. The uncertainty in comparing any two SOLSTICE measurements depends on the time interval between them.

| Component of degradation                          | Estimated trend uncertainty |
|---|-----------------------------|
| Stellar correction                                | ~0.1%/year                  |
| FOV correction                                    | ~0.2%/year                  |
| AB-Comparison correction<br>(SOLSTICE A MUV Only) | ~0.2%/year                  |
| Combined uncertainty:                             | ~0.3%/year                  |

FUV stability 0.1%/year  
MUV stability 0.3%/year



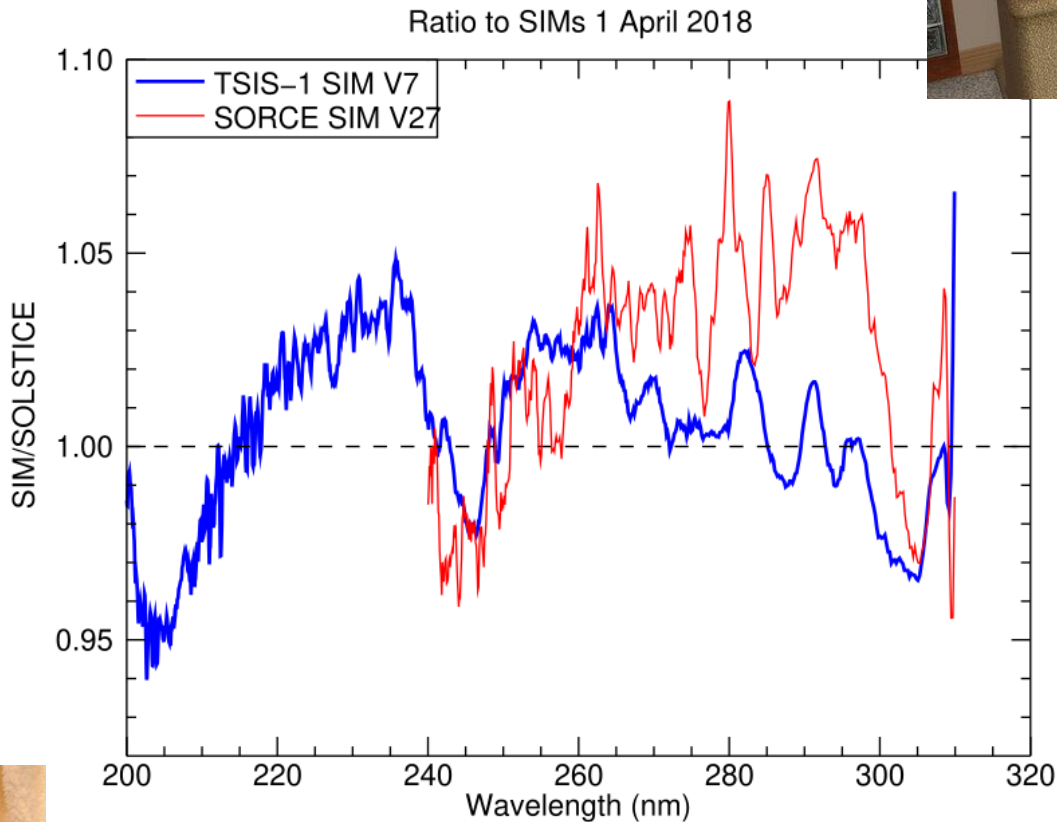
# Validation of Final Version!



# The SIMs

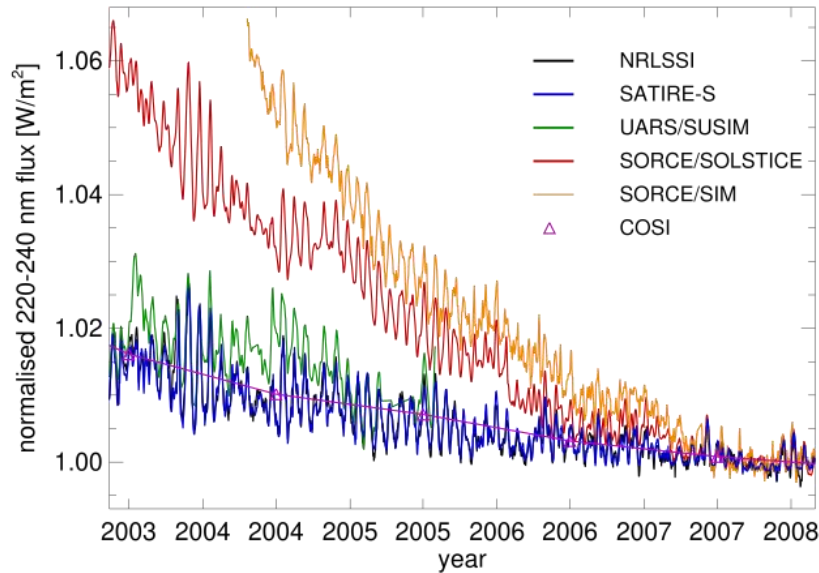
Uncertainty in SOLSTICE stability after 15 years is about 5%, so this agreement is well within the combined uncertainty.

Uncertainty of TSIS/1 SIM on this date is very small.

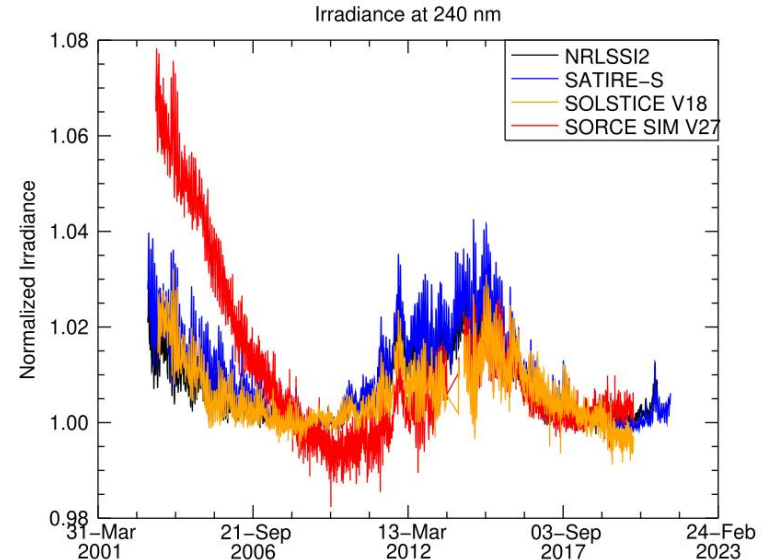




# UV Time Series



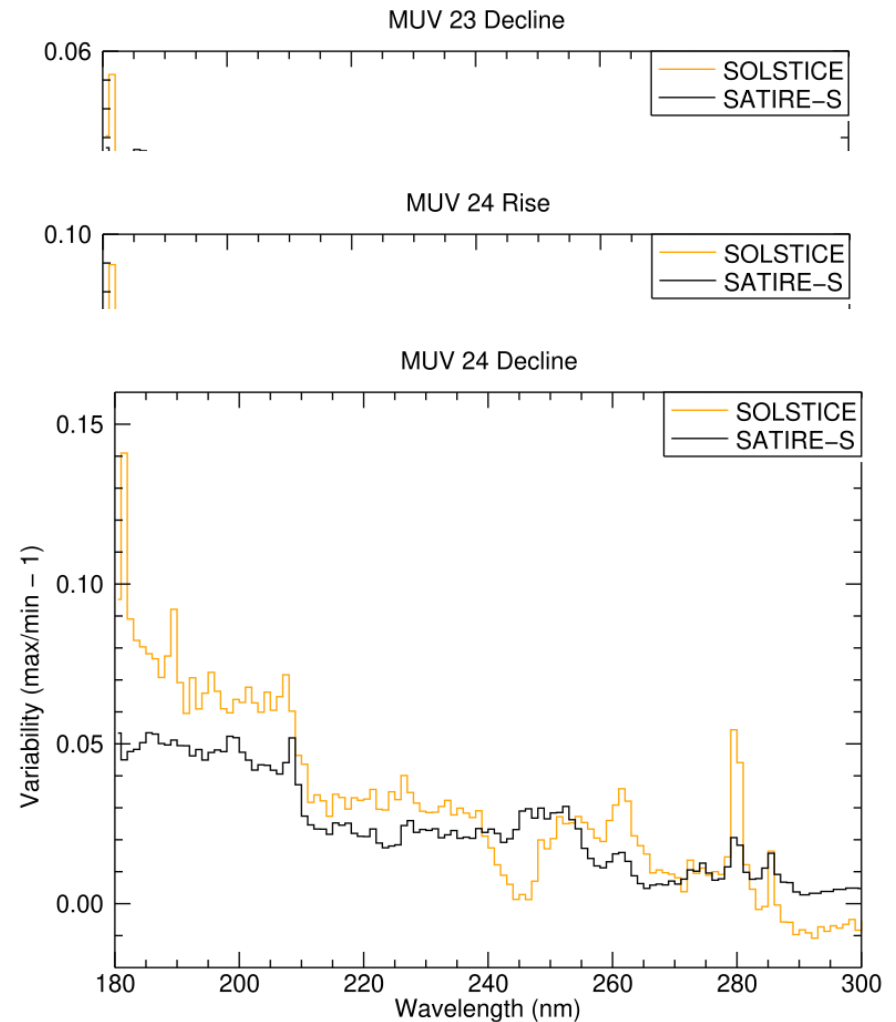
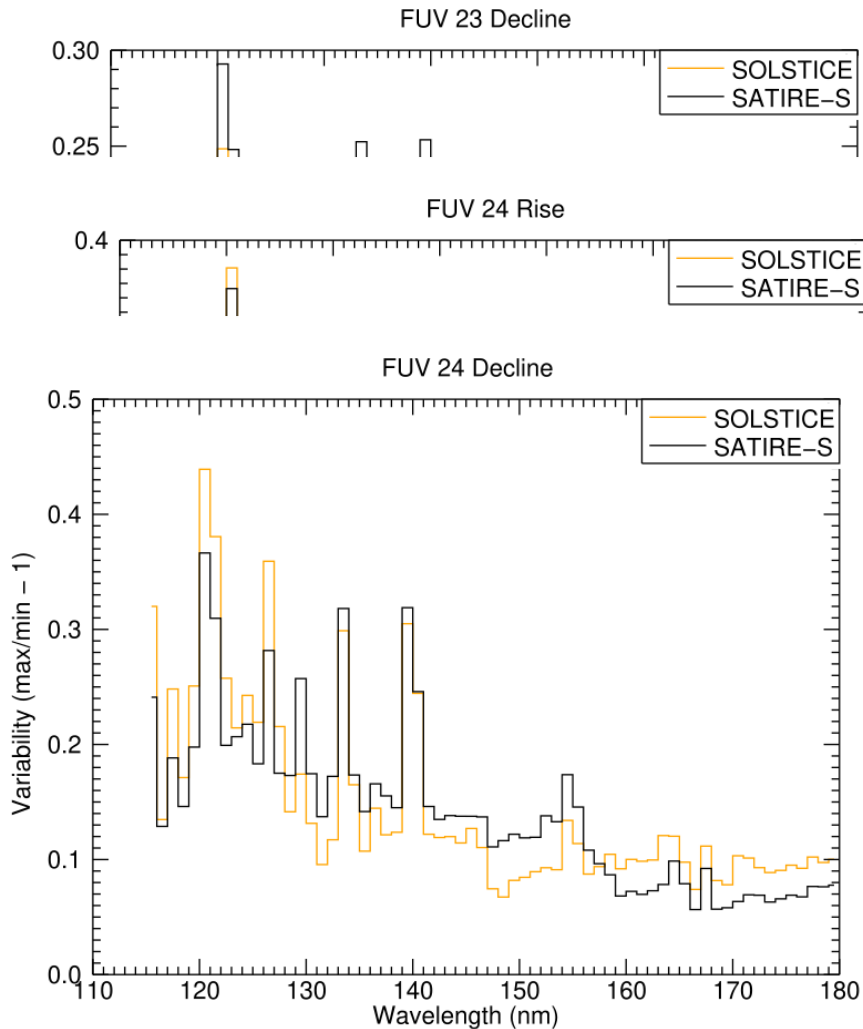
From Ermolli et al. (2013)



From Snow et al. (2022)

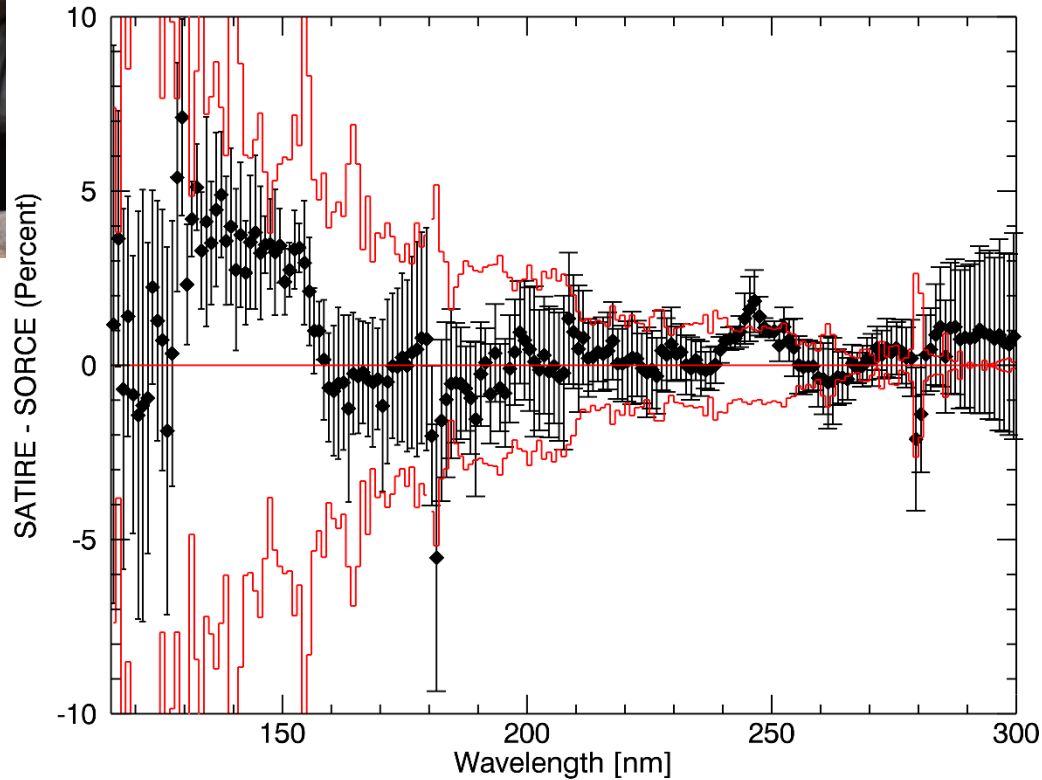
Controversy over long term trends early in the SORCE mission has now been reduced due to improved FOV correction.

# Comparison to SATIRE-S



# SATIRE-S Summary (S<sup>3</sup>)

Variability Difference



Black points are average difference between SOLSTICE and SATIRE-S for the three intervals from the previous slide. Error bars are the standard deviations. The red curve shows the solar cycle variation. Differences are smaller than the SC variation below about 260 nm.

# Summary

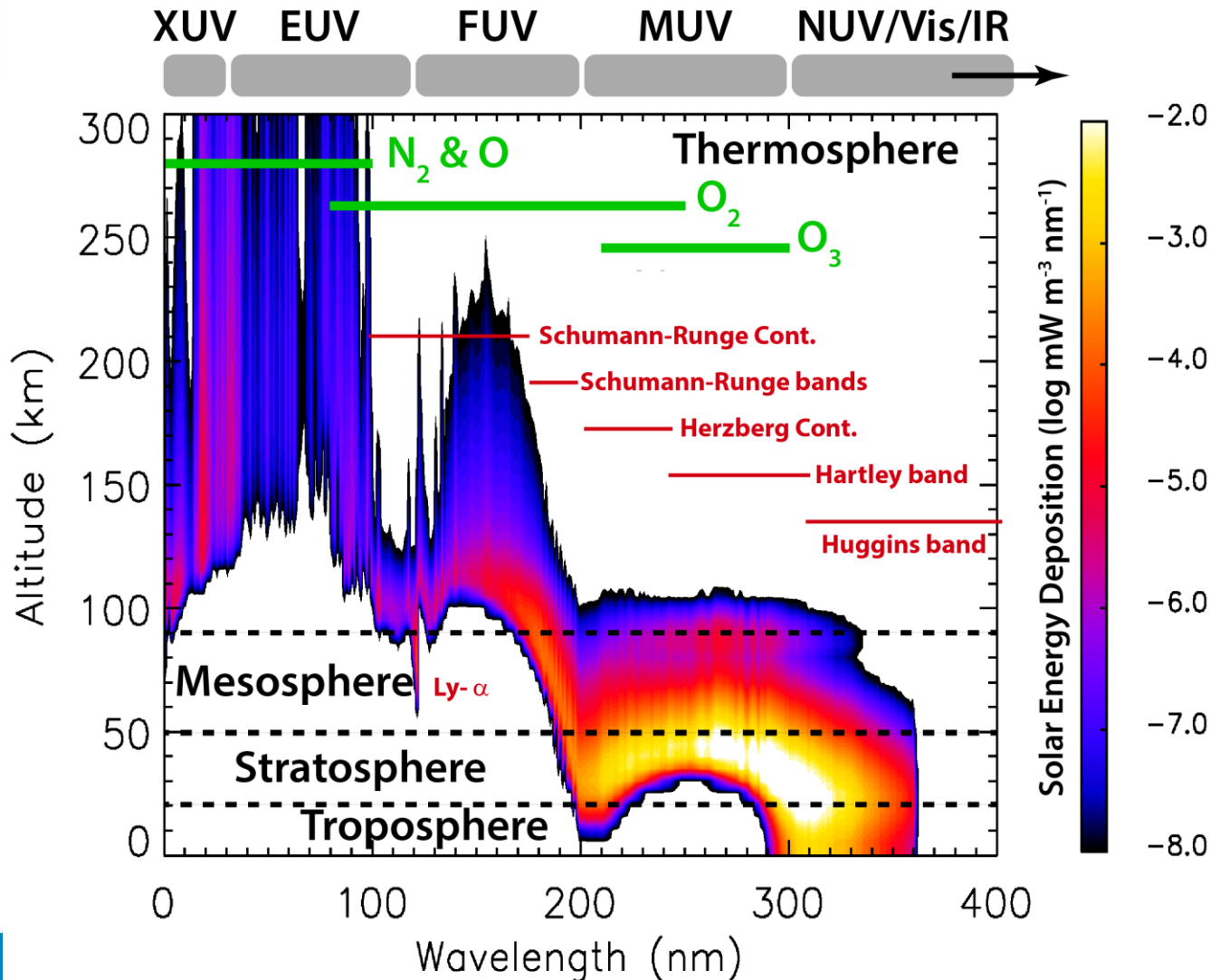
- SOLSTICE successfully measured UV SSI throughout the SORCE mission
- Version 18 degradation corrections solve the previous controversies
  - Good agreement with simultaneous measurements
  - Good agreement with empirical models
- Results now published!





Thank You

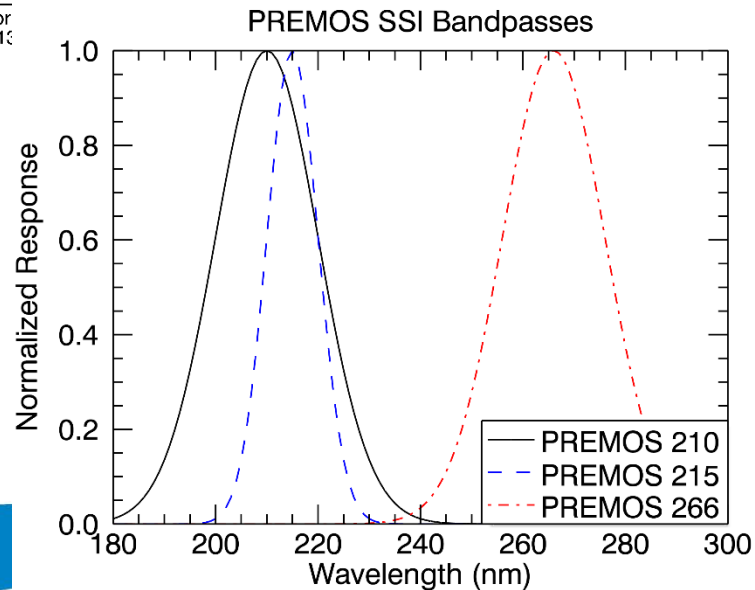
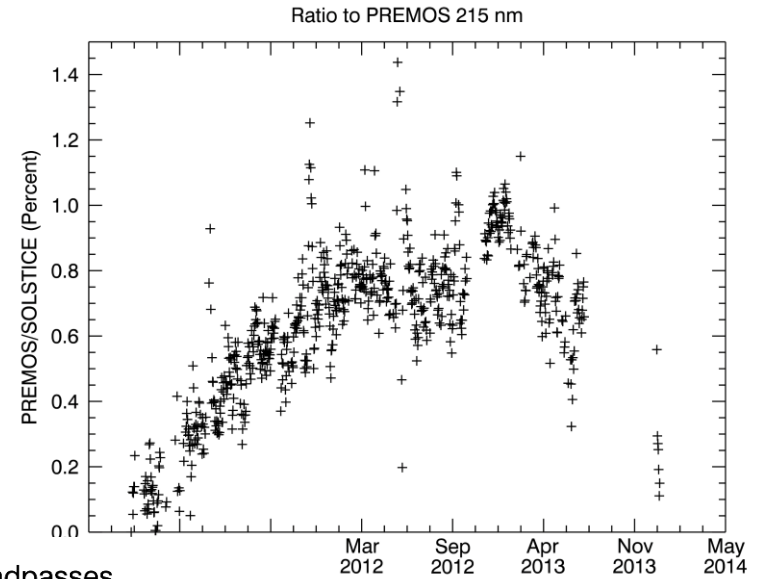
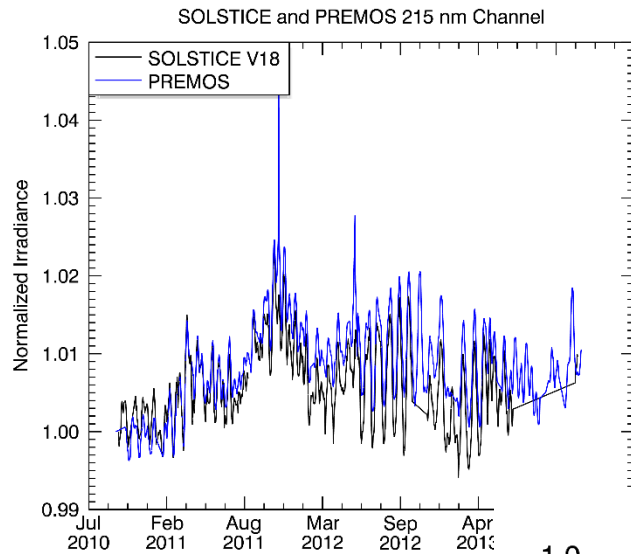
# Why make these measurements?



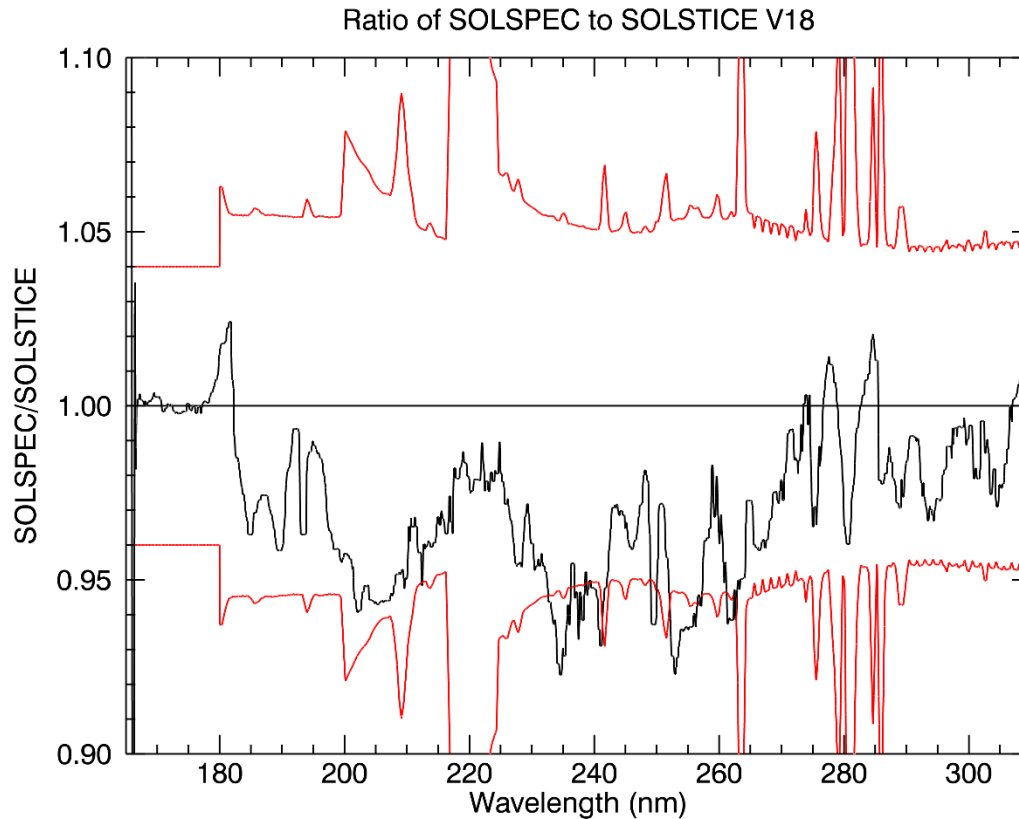
January 25, 2003



# Picard/PREMOS



# SOLAR/SOLSPEC



Ratio of SOLSTICE to “first light” SOLSPEC spectrum April 2008  
Red curves mark upper and lower uncertainty envelopes.



# Future SOLSTICE Projects

- Progress in Understanding Ultraviolet iRRadiance (PUURR), part of the SIST-3 program.
- Lyman alpha high cadence observations from SOLSTICE
- Radiation Environment Observed by SOLSTICE

