# TSIS SIM Solar Spectral Irradiance: First Light and Early Observations

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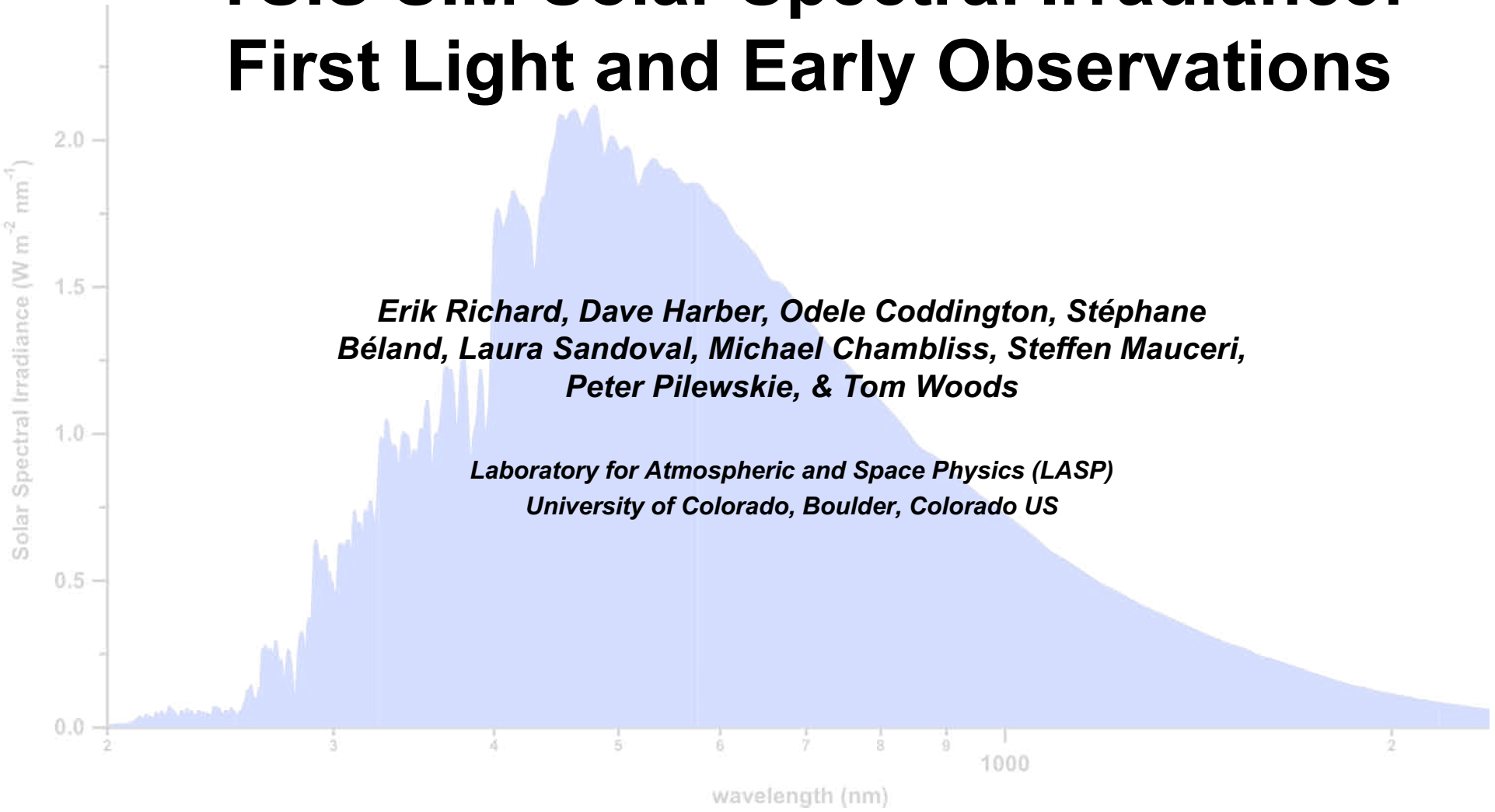
***Laboratory for Atmospheric and Space Physics (LASP)***
***University of Colorado, Boulder, Colorado US***




*"…When I say Me, I mean Us, and when I say us, I mean Them!"*

LASP
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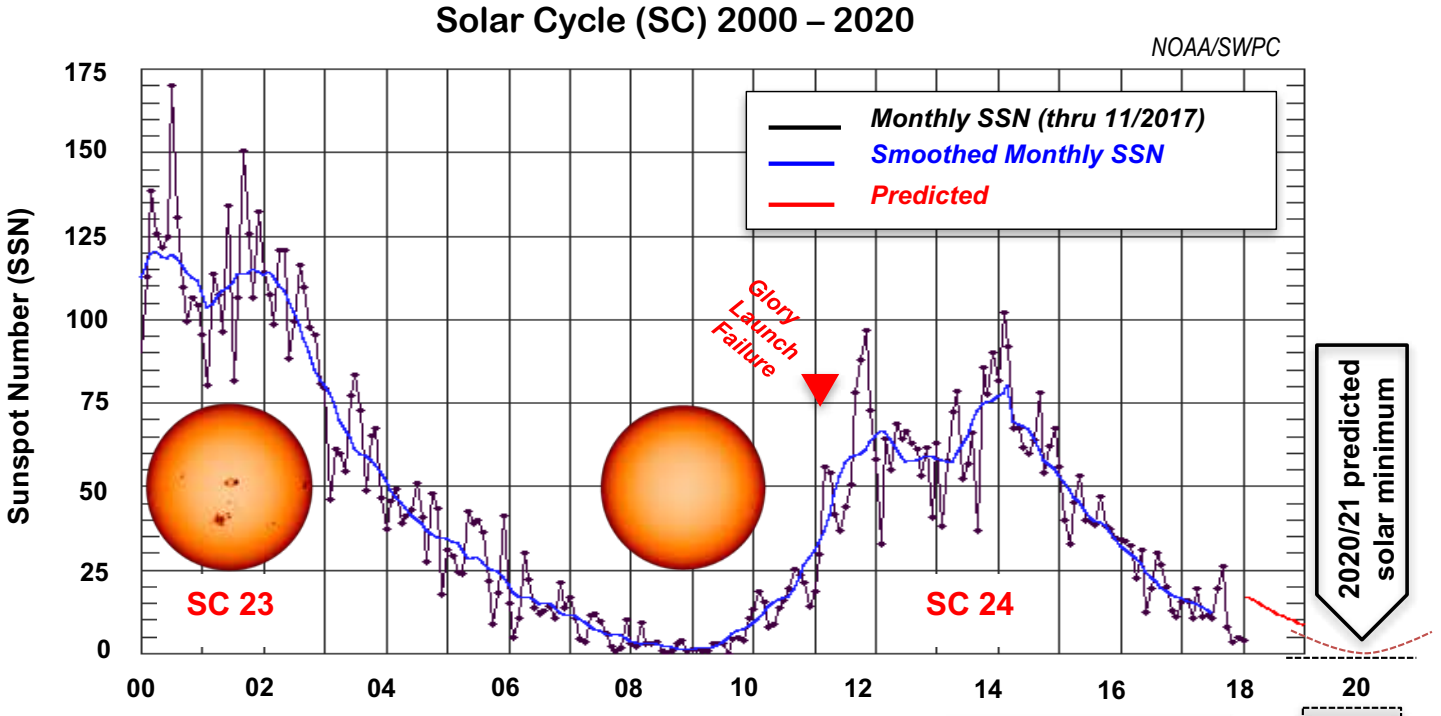
# TSIS Era Begins (Finally!)




*"Success is not final, Failure is not fatal: it is the courage to continue that counts"*

*- Winston Churchill*

# *"Per ardua ad astra"*

*(By striving we reach the stars)*

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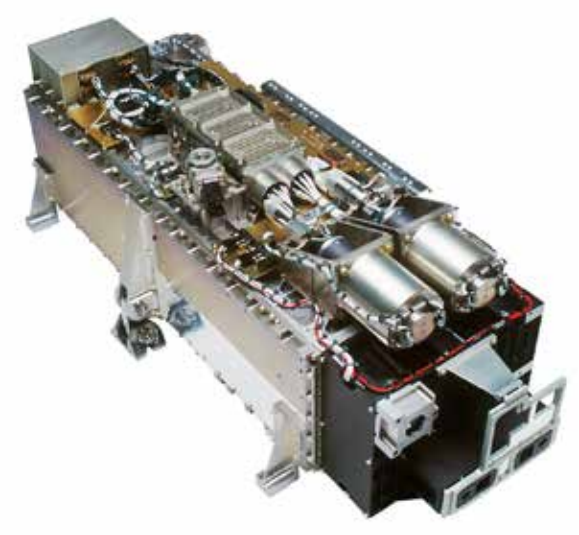
## TSIS SIM Timeline

**Launch…….. 15 December 2017**
**Turn-on……. 3 January 2018**
**Commissioning…... 4 Jan – 1 Mar. 2018**
**First Light……. 3-5 March 2018**
**Normal Ops……. 14 March 2018**

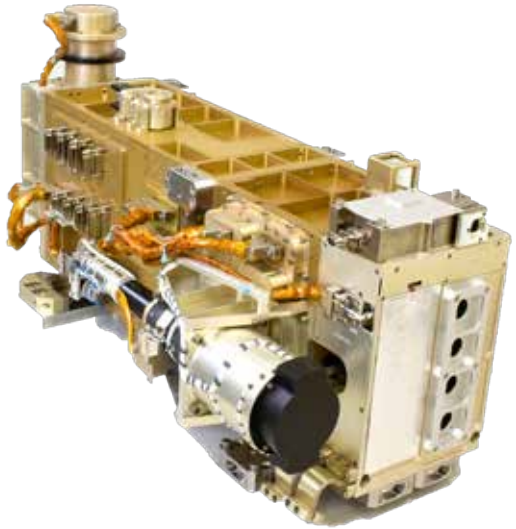
# Passing the SSI "Baton"



## SORCE SIM (launched 1/25/2003)

- Two channel instrument (duty-cycled for stability corrections)
- Absolute ESR detector (NiP bolometer)
  - First generation (nominal performance)
  - Diamond substrate
  - NiP black absorber
  - Kapton™ thermal link
- Abs. accuracy: 2-10% wavelength dependent (no-SI validation)

***"…15 years into a 5 year mission"***



## TSIS SIM (launched 12/15/2017)

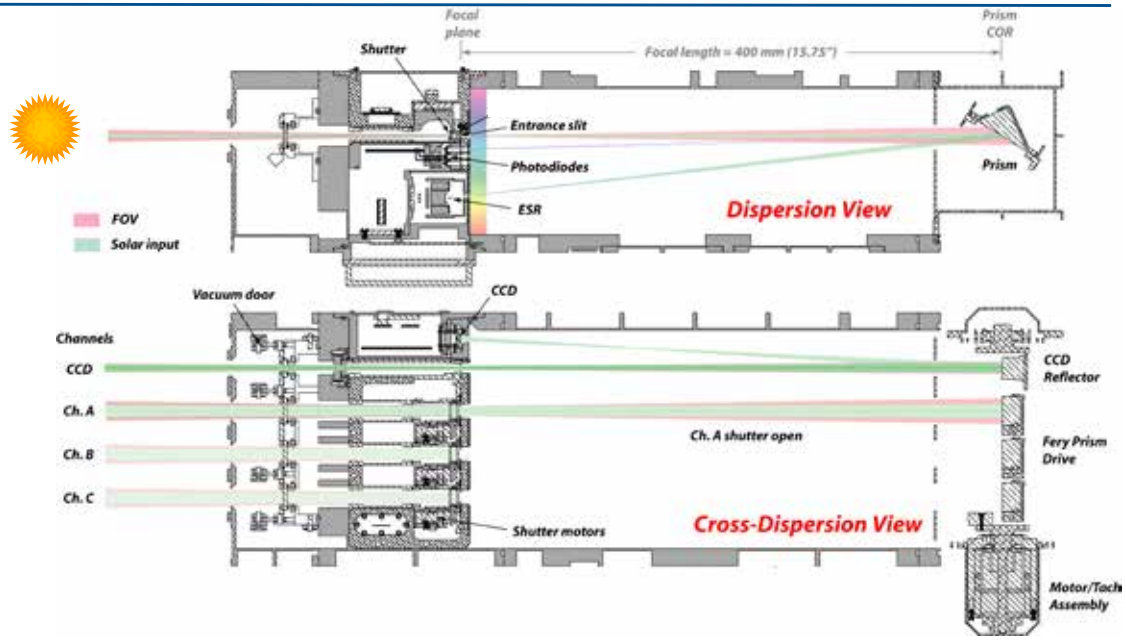
- ✓ Three channel instrument
  - For long-term stability validation of duty-cycling
- ✓ Absolute ESR detector (NiP bolometer)
  - Second gen. (improved noise performance)
  - Diamond substrate
  - NiP black absorber
  - Kapton™ thermal link
- ✓ Abs. accuracy – 0.2 % (SI-traceable validation)

***"…~2 weeks into a 5+ year mission"***

# TSIS Spectral Irradiance Monitor

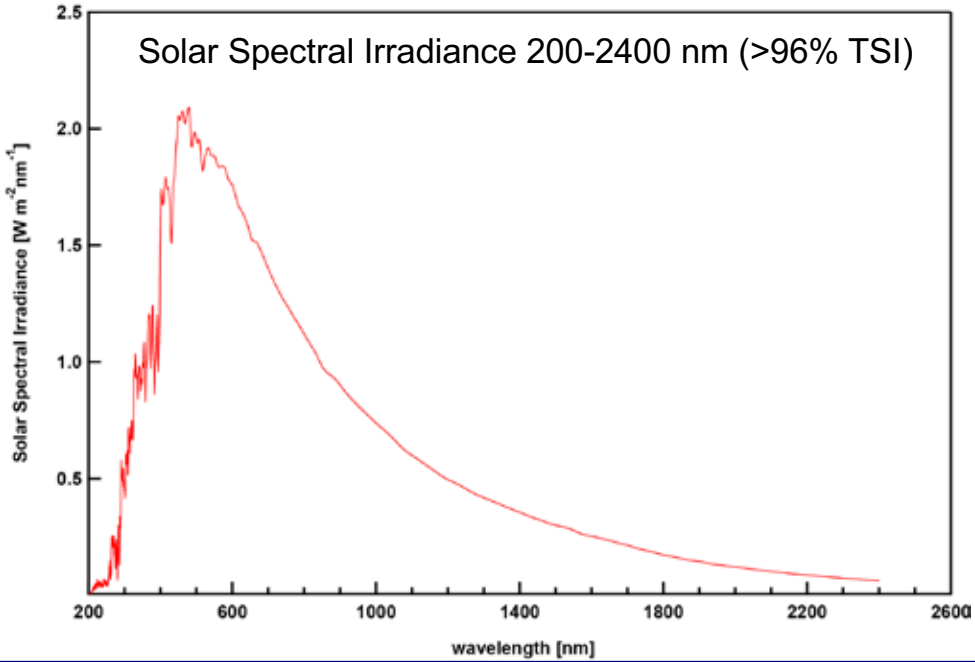
**3-channel SSI radiometer**
Each channel contains:

- Féry prism for dispersion
- 3 primary photodiode detectors
- Absolute ESR detector



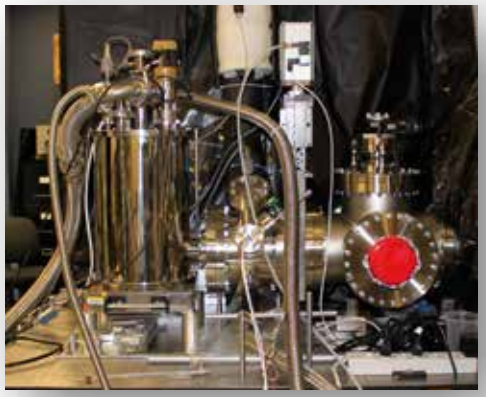

**Lessons learned from SORCE SIM**

- Establish consistent prism exposure plan
- Maintain constant exposure ratio between channels (target 10% duty cycle based on 7-year plan)
  - Expose B channel **daily** to experience same solar activity & contam. env't.
  - Scan ESR over limited wavelength regions for A/B (&C) comparisons (avoid disparate point scans )
  - Expose Channel C to same "optical" conditions (twice annually)

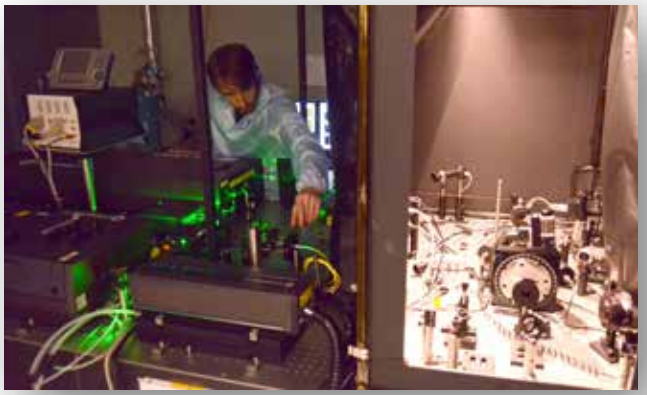


# Absolute Irradiance Scale (LASP-SRF)

L-1 Cyrogenic radiometer (NIST traceable)



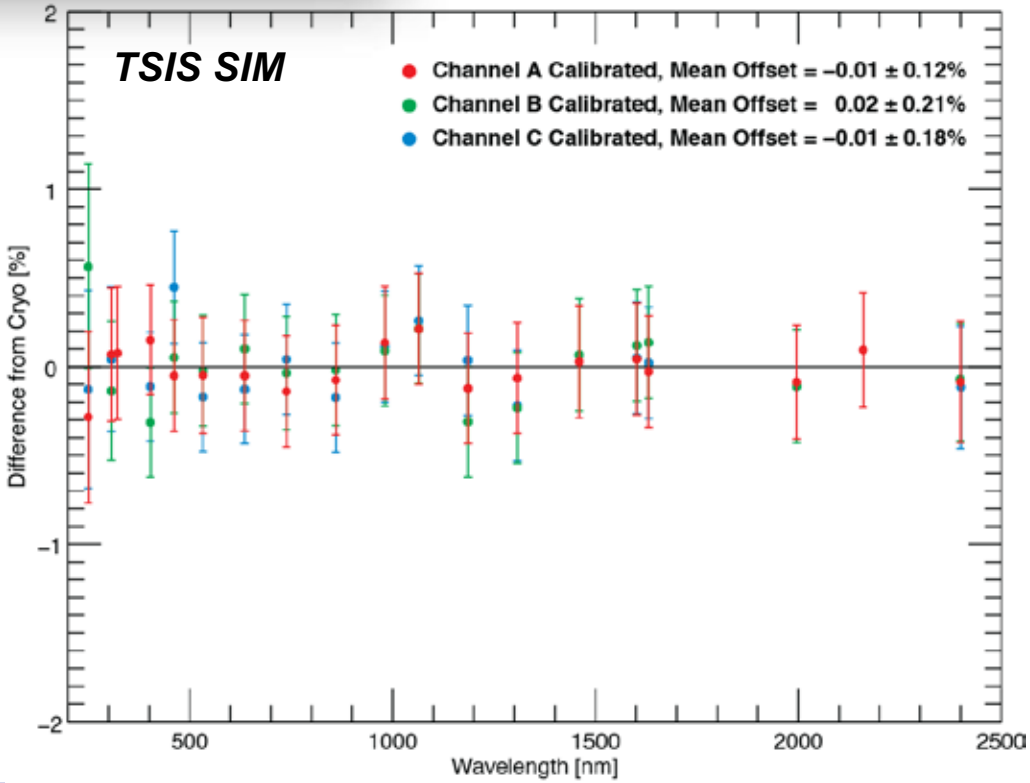
SRF "SIRCUS" Laser system (206 – 3000 nm coverage)



TSIS SIM

## TSIS SIM absolute calibration in the LASP SRF

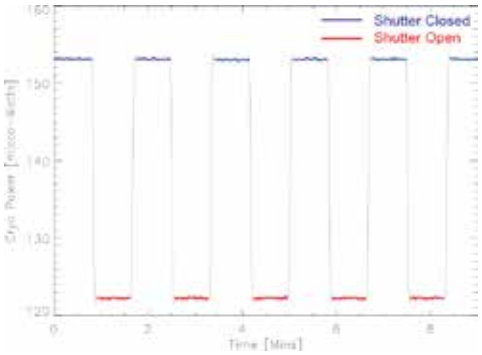
- SRF allows us to calibrate the instrument absolutely relative to the cryogenic radiometer and evaluate instrument optical performance as a function of wavelength
- ESR Calibration against the cryogenic radiometer is also part of the process as it provides the vacuum environment optimized for ESR noise testing
  - Get ESR vs Photodiode response
  - Get ESR noise floor performance
- Designed to achieve < 1% (0.2% goal) absolute accuracy uncertainty validation

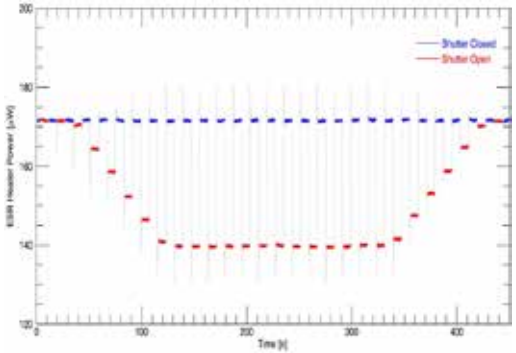


# Absolute Irradiance Scale (LASP-SRF)

## Cryogenic Radiometer Uncertainty Budget

| Parameter | Unit | % Effect | % Unc. (k=1) |
|---|---|---|---|
| Power | W | 100 | 0.015 |
| Cavity Reflectance | - | 0.01 | 0.004 |
| Cavity Non-Equiv. | - | 0 | 0.01 |
| Slit Area: Measured | $m^2$ | 100 | 0.05 |
| Slit Area: Contraction | - | 0.04 | 0.01 |
| Slit Area: Cosine effect | - | 0.02 | 0.01 |
| Slit Diffraction Loss | - | 0.13 | 0.02 |
| **Total** | | | **0.07** |



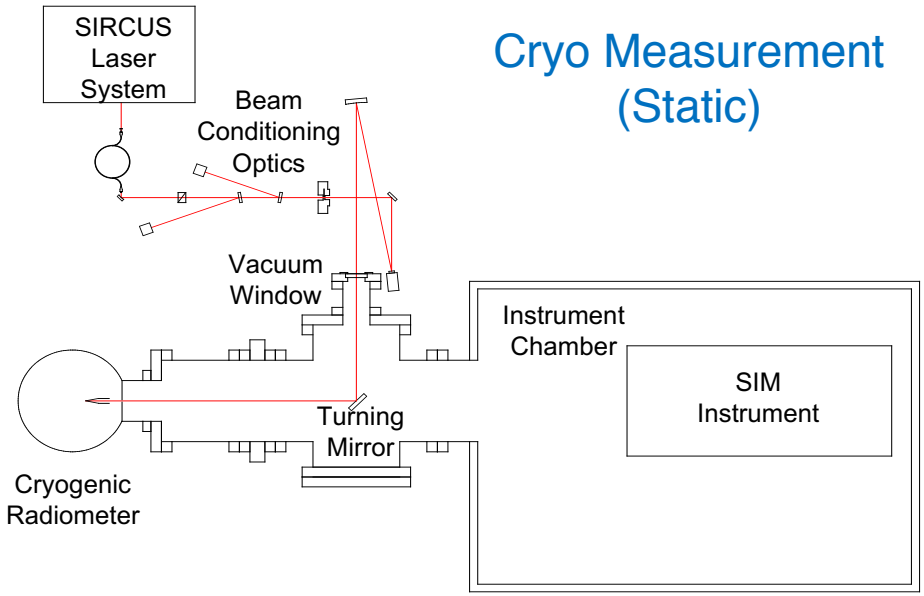
$$I_0 = \frac{DN(\lambda_0)}{AD(\lambda_0)C(\lambda_0)\bar{G}(\lambda_0,p)}$$

$$I_0 = \frac{\int DN(c)dc}{AD(\lambda_0)T(\lambda_0,p)\bar{G}(\lambda_0,p)\Delta W(c)}$$

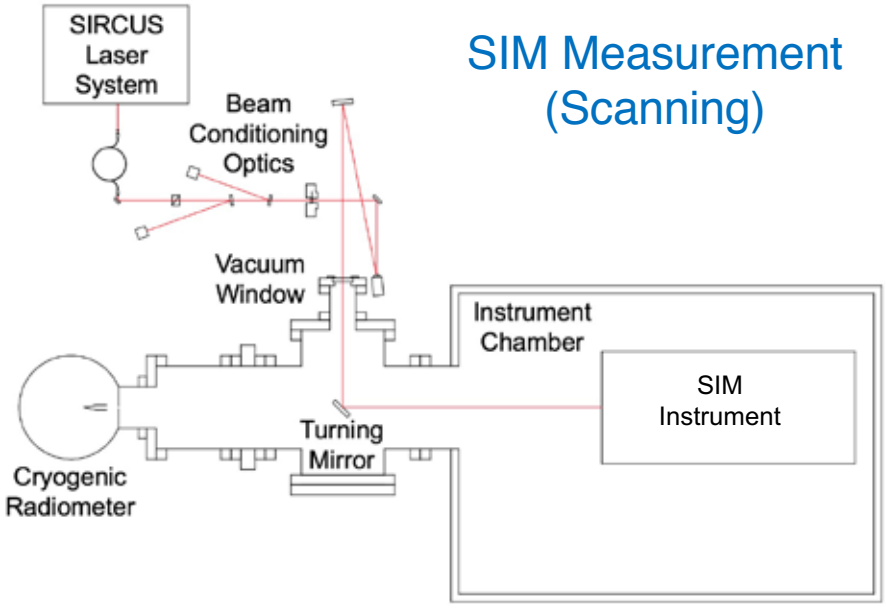
## LASP SRF End-to-End Uncertainty Budget

| Parameter | Unit | % Effect | % Unc. (k=1) |
|---|---|---|---|
| Cryo Measurement | $W/m^2$ | 100 | 0.07 |
| Turning Mirror Repeatability | - | 0 | 0.004 |
| Laser: Stability | - | 0 | 0.060 |
| Laser: Pattern Uniformity | - | 0 | 0.023 |
| Path Length Correction | - | 0 | 0.0002 |
| CSIM Spectral Integration | $W/m^2$ | 100 | 0.1 |
| **Total** | | | **0.14** |

## Cryo Measurement (Static)




## SIM Measurement (Scanning)



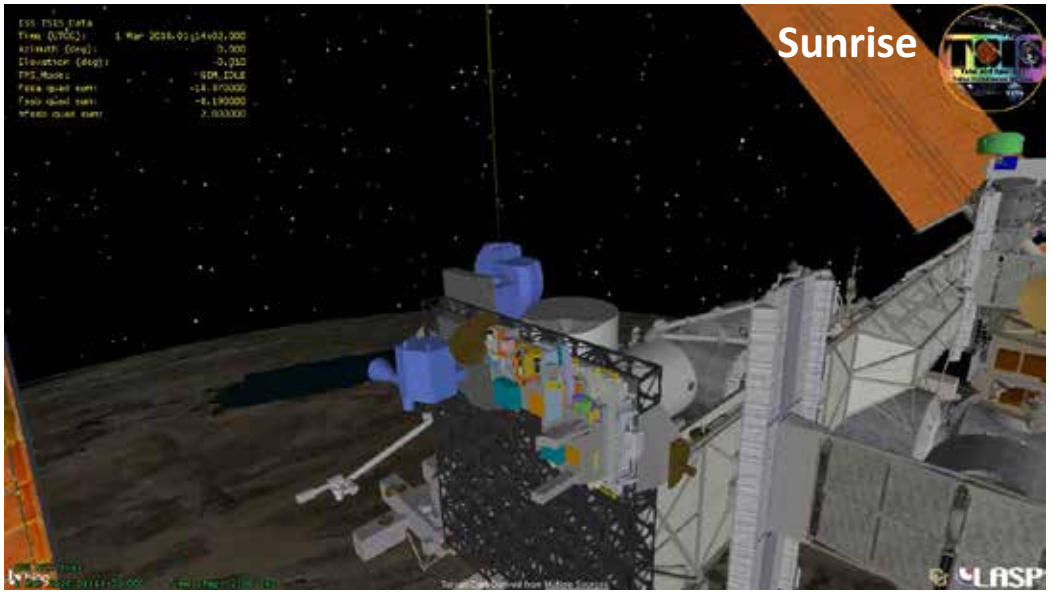
# TSIS-1 on ISS


SIM
SSI
TIM
TSI
TSIS is an operational sensor on ISS.
(provides a daily TSI and SSI data record)
Located on ELC-3 site 5 in order to track the sun

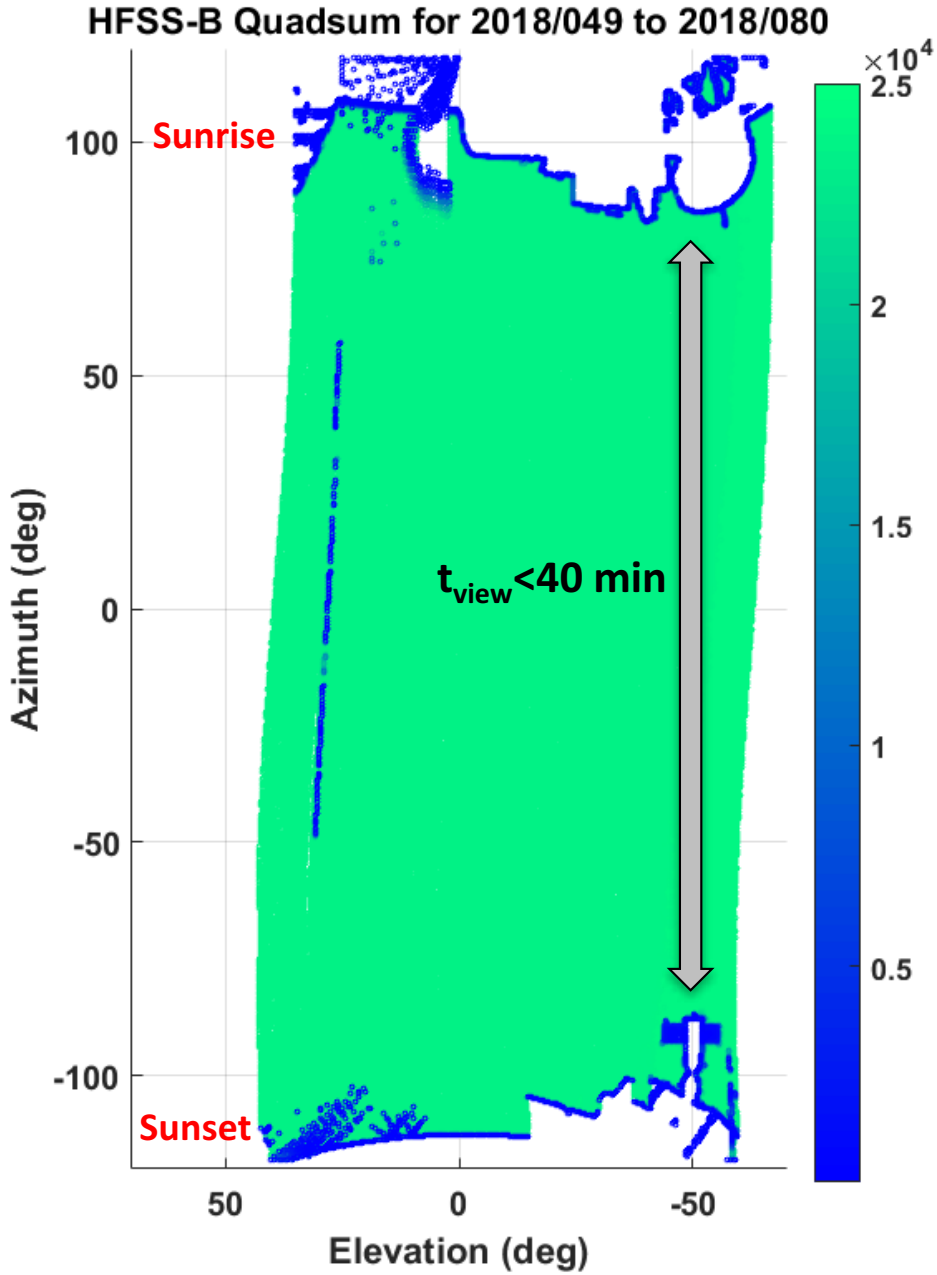
# TSIS-1 on ISS

## Deployed 31 Dec. 2017

# ISS Obscurations: *"vita sine Sole"*





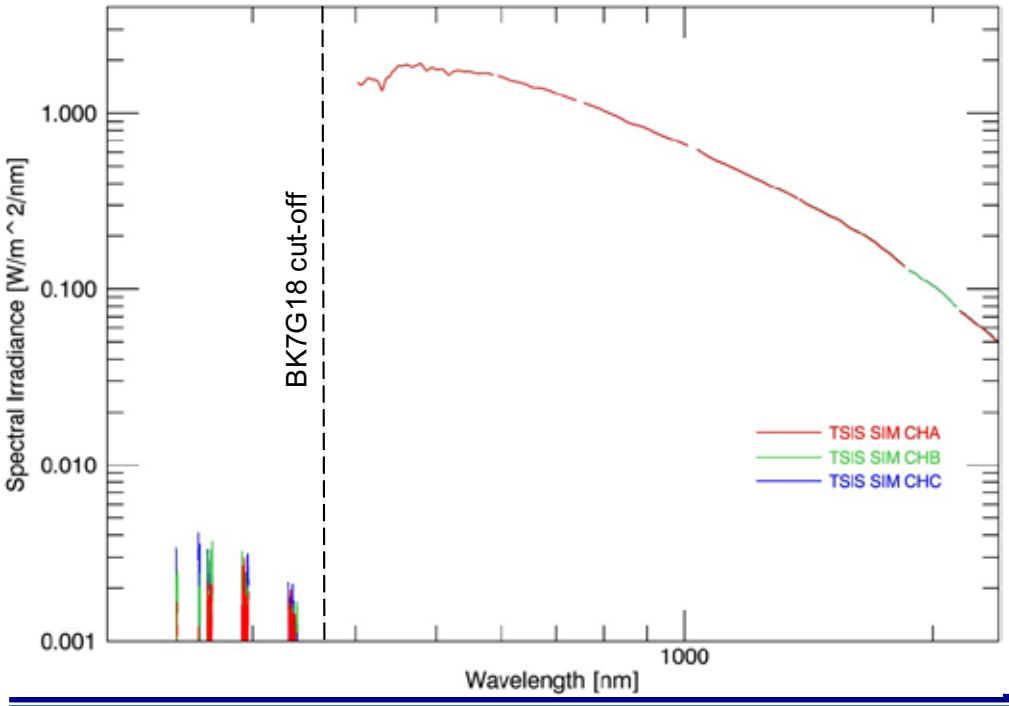


# Performance Summary: SSI Spectrum

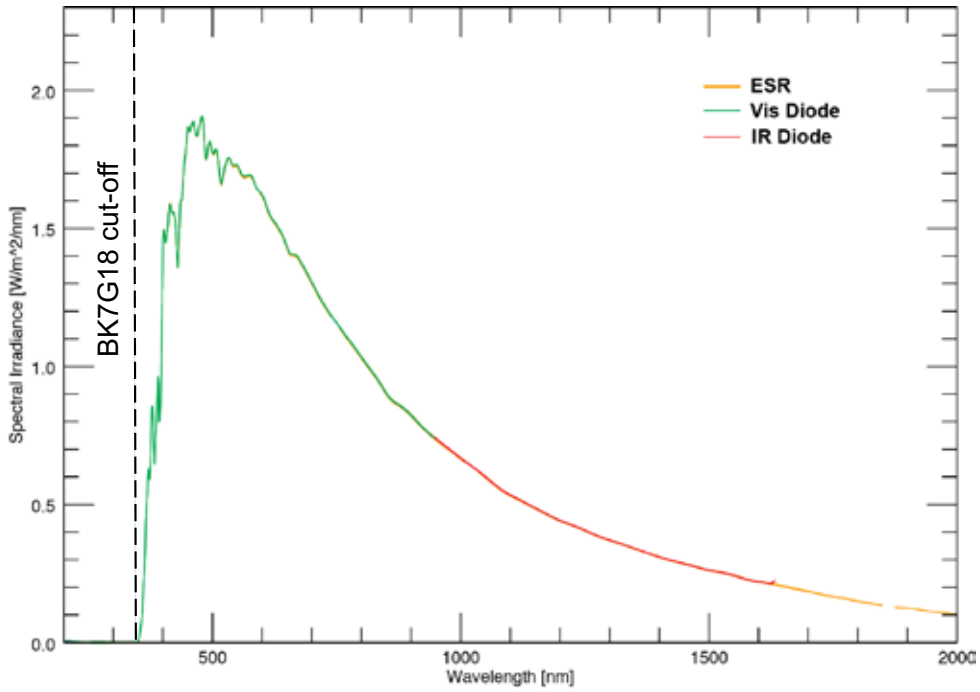
## Commissioning

- Performed dry-run Full Scans (vac. door closed, through BK7G18 window). ESR & PD scans
- No UV solar signal (< 350 nm) through BK7G18, allows for quantification of background signal (stray & scattered light, In-Field/Out-of-Band)

ESR Solar Spectral Irradiance

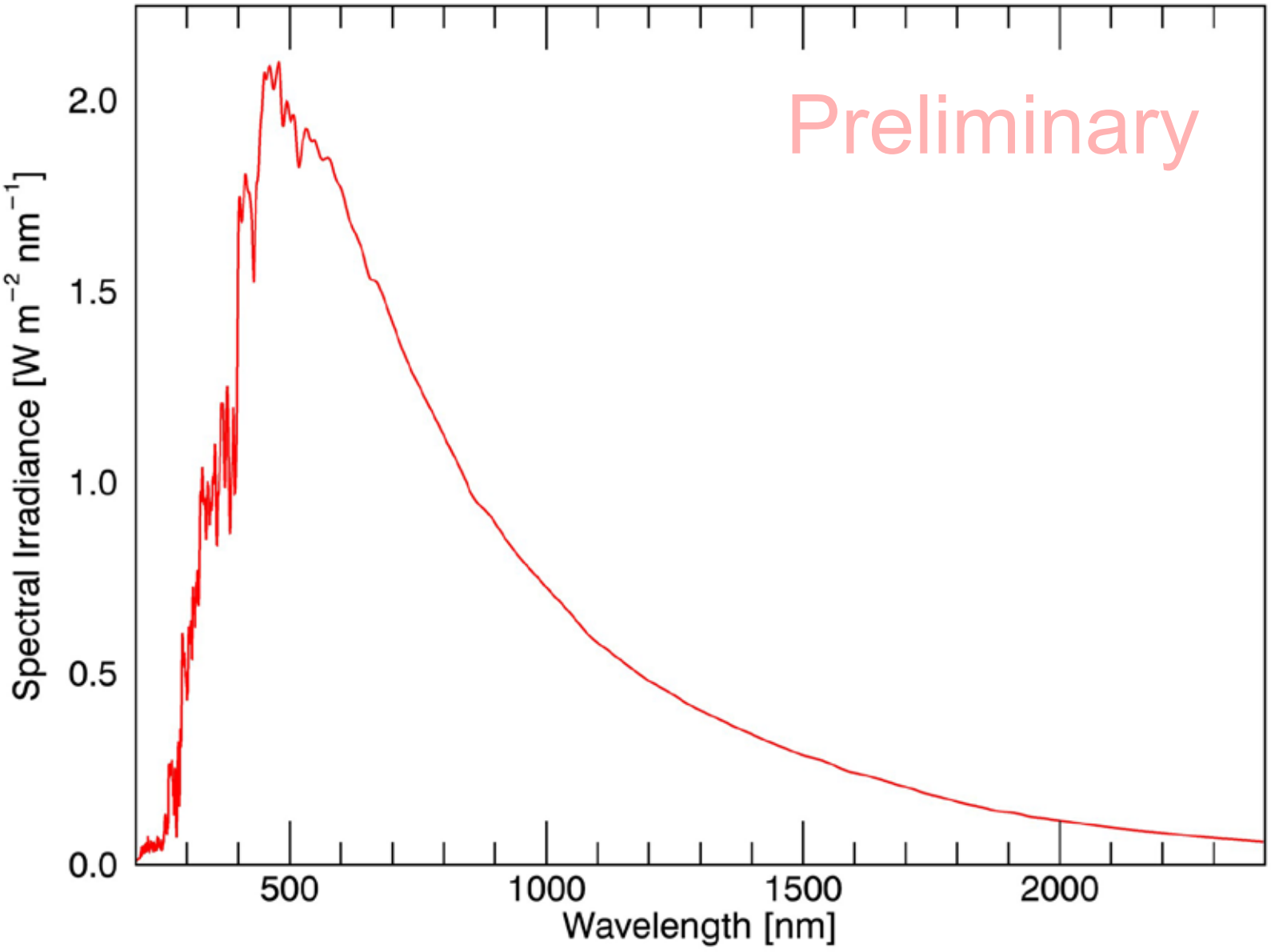



ESR & PD Solar Spectral Irradiance



# First Light SSI spectrum (200 – 2400 nm)

3-5 March 2018



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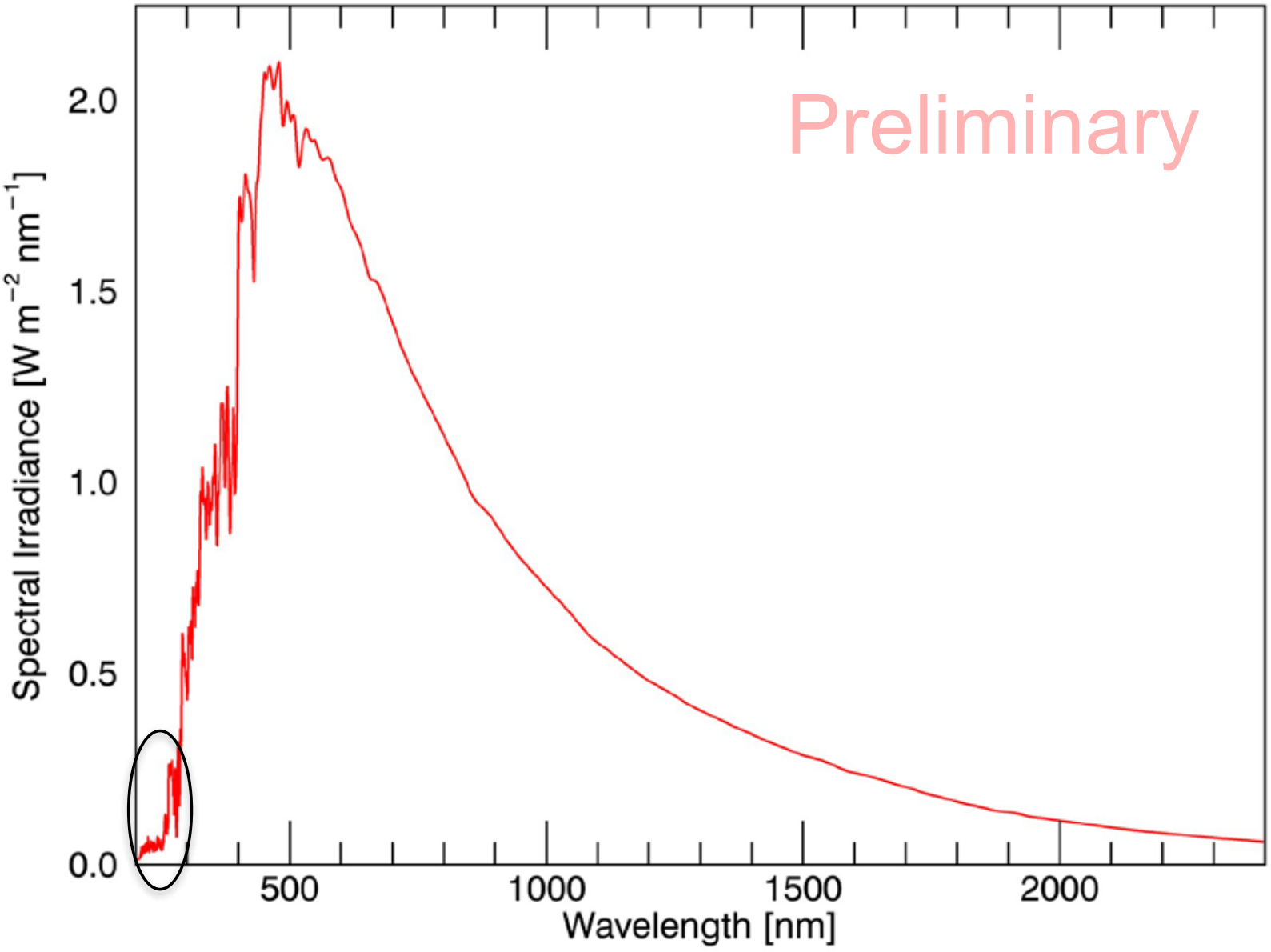
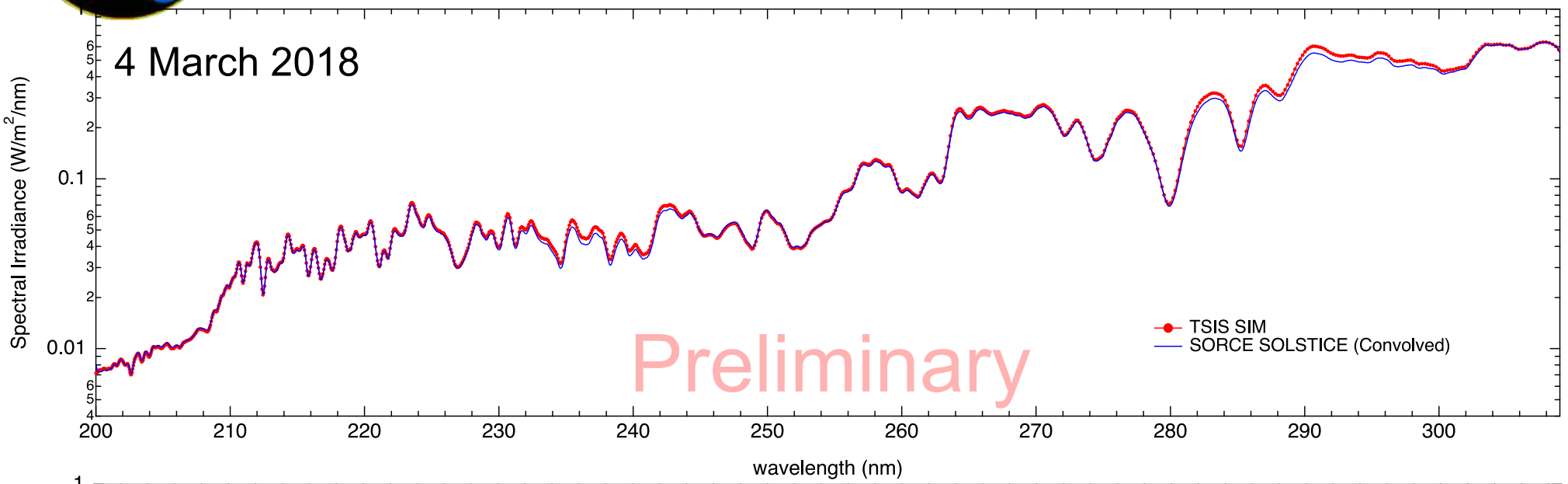
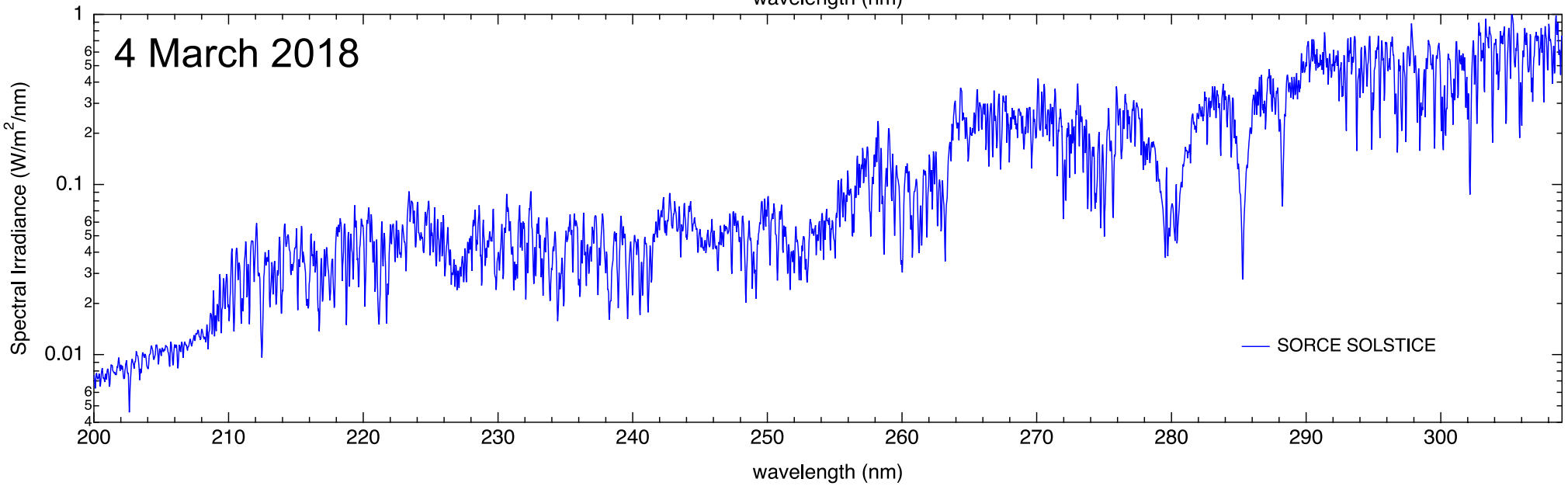
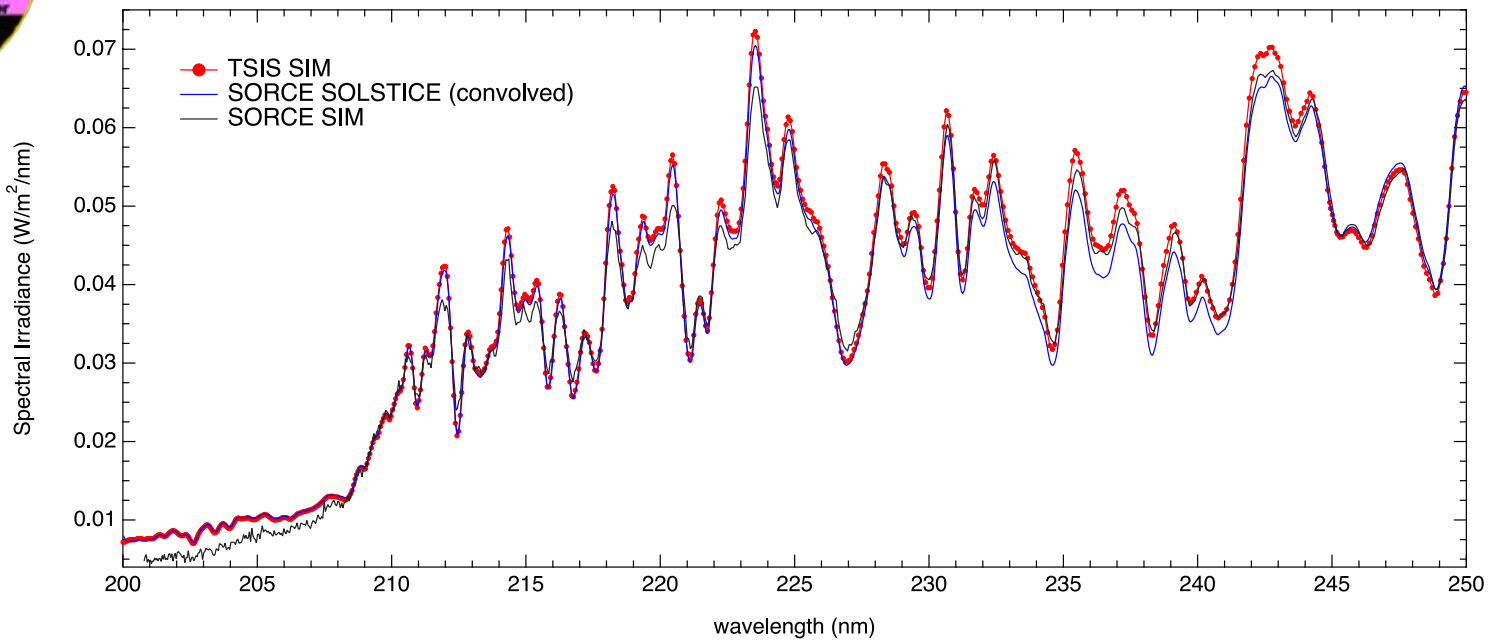


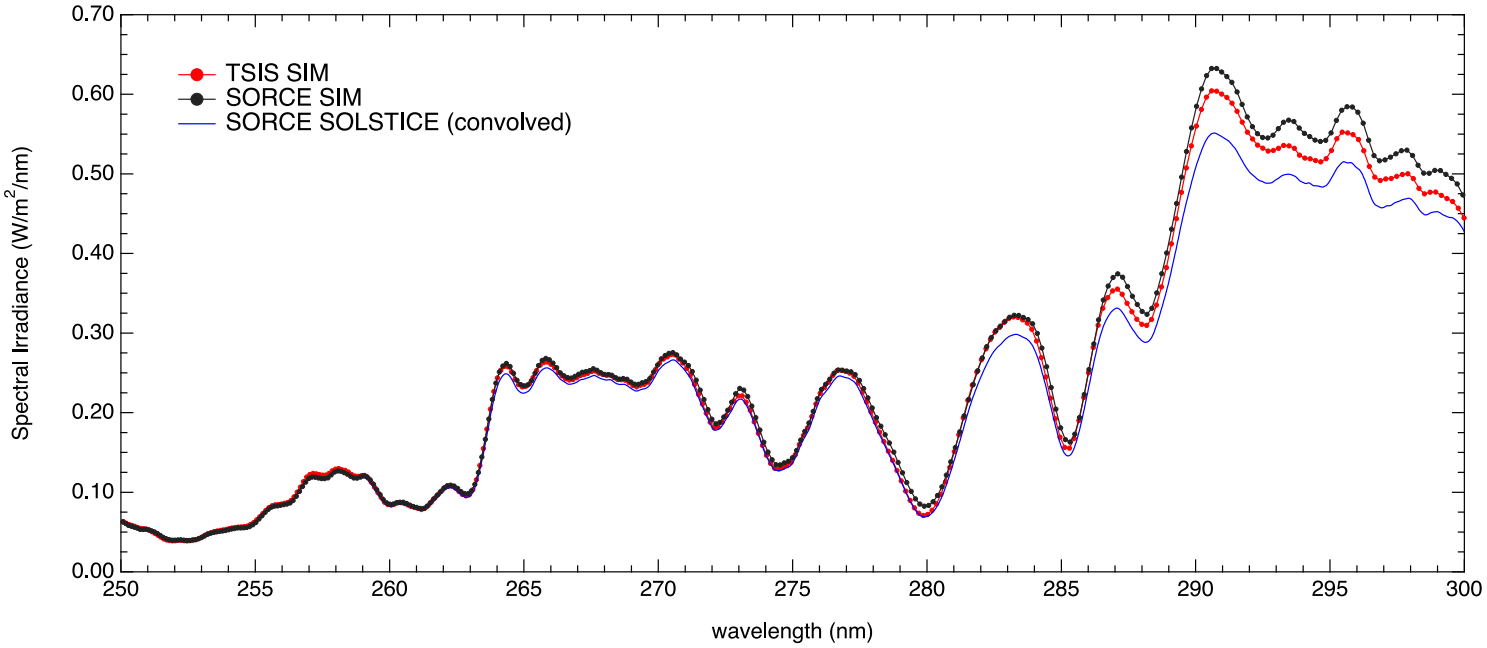
# First Light SSI spectrum (200 – 310 nm)



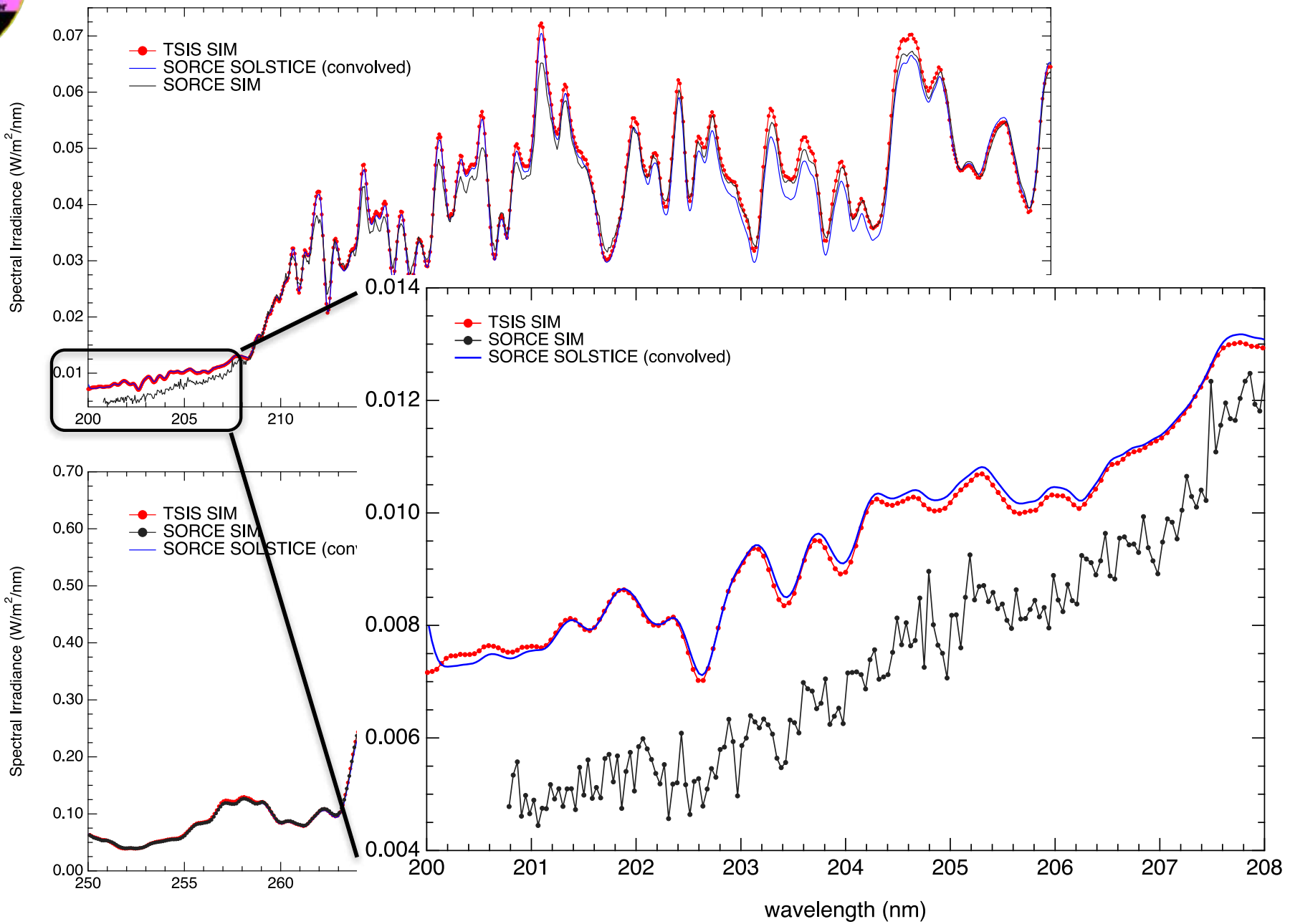



# First Light SSI spectrum (200 – 300 nm)

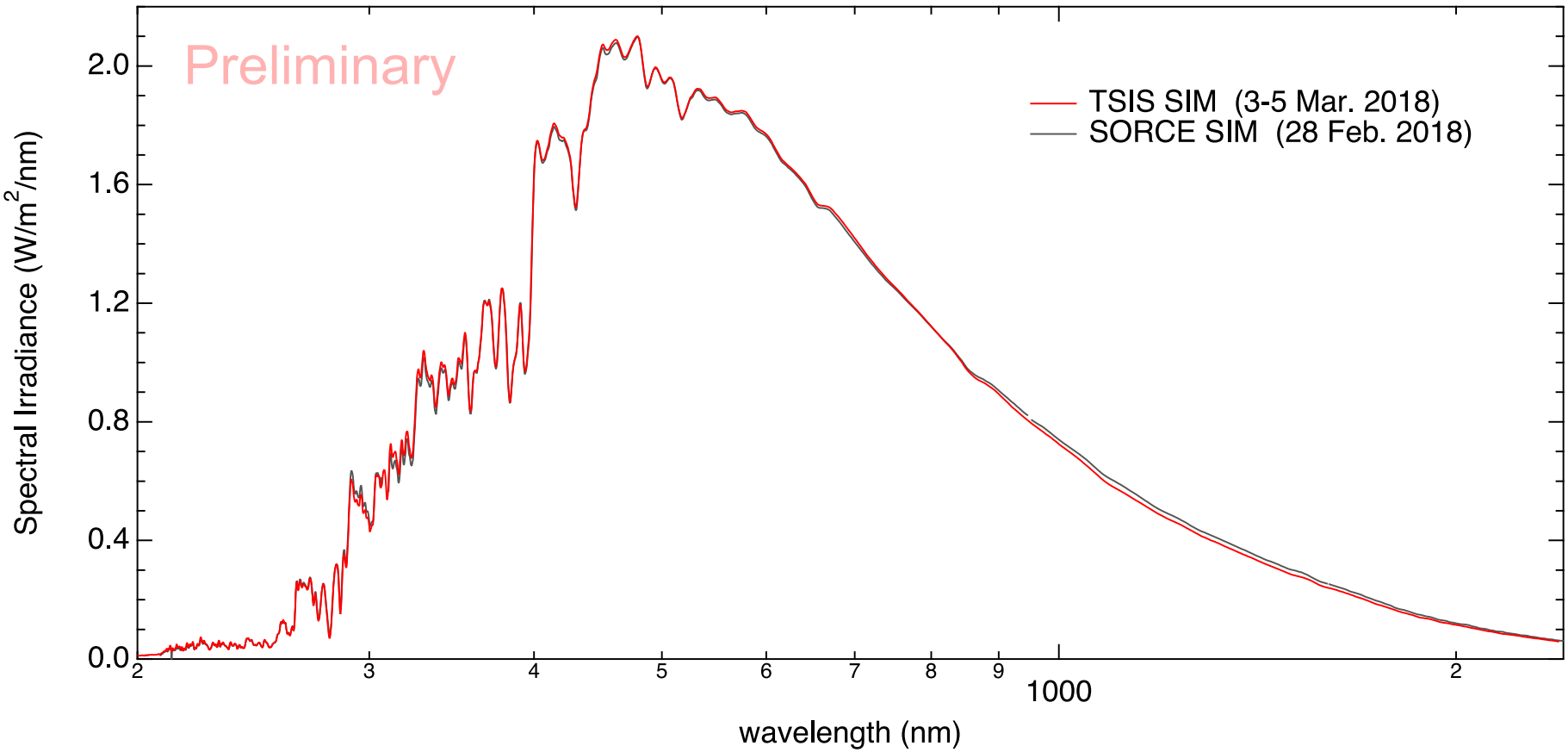


# First Light SSI spectrum (200 – 208 nm)



# First Light SSI Spectrum Comparison



# First Light SSI Integral Comparison to TSI

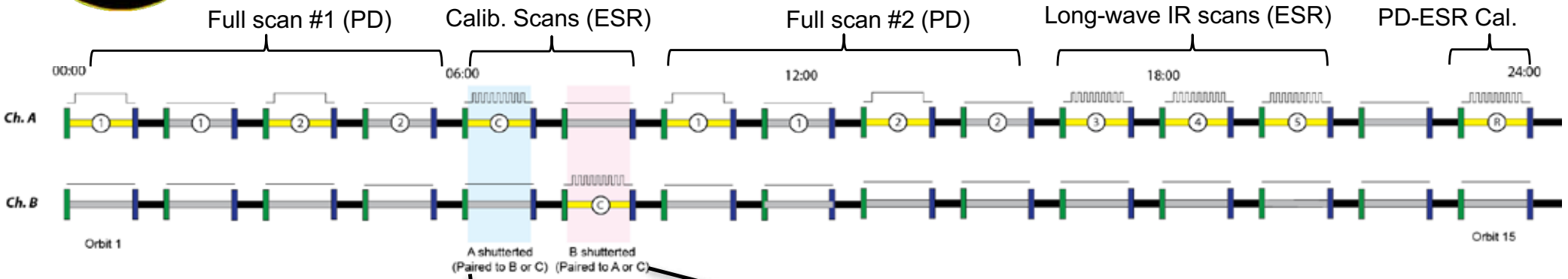
Uncorrected reference spectra integrals (relative comparison)

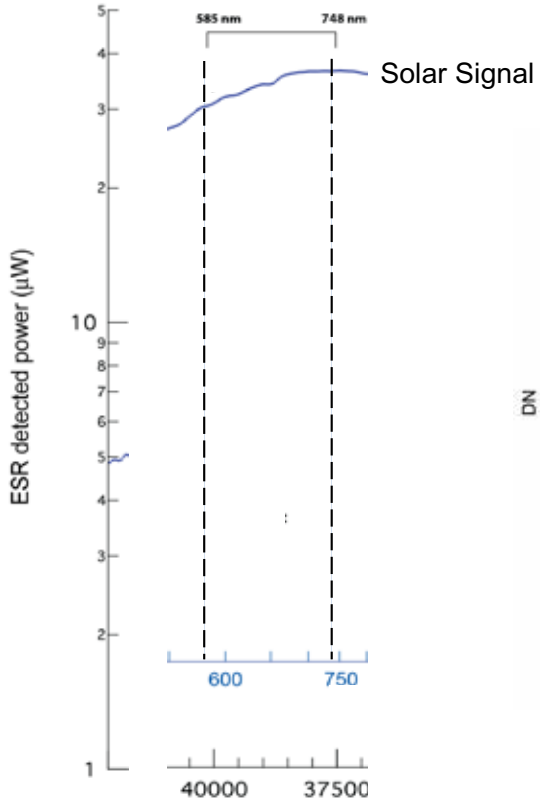
| Spectrum | 205-2390 ($W/m^2$) (96% TSI) | + 52 ($W/m^2$)* | TIM TSI ($W/m^2$) | % Diff. |
|---|---|---|---|---|
| ATLAS-3 | 1333 | 1386 | 1362-1360 | +1.76-1.88 |
| SIRS-WHI | 1323 | 1375 | 1362-1360 | +0.95-1.1 |
| **TSIS SIM** | **1307.6** | **1359.6** | **1360.6** | **-0.08** |

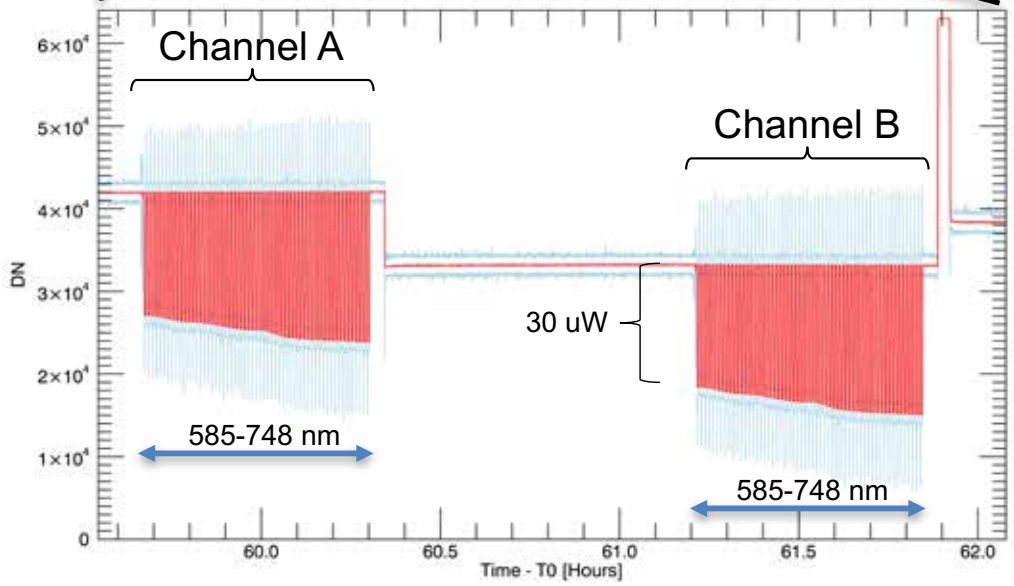
*Integrated SSI contribution outside 205-2390 nm

L. Dame, *"New Solar Reference Spectrum SOLAR-ISS"*
Session 2: 5:30

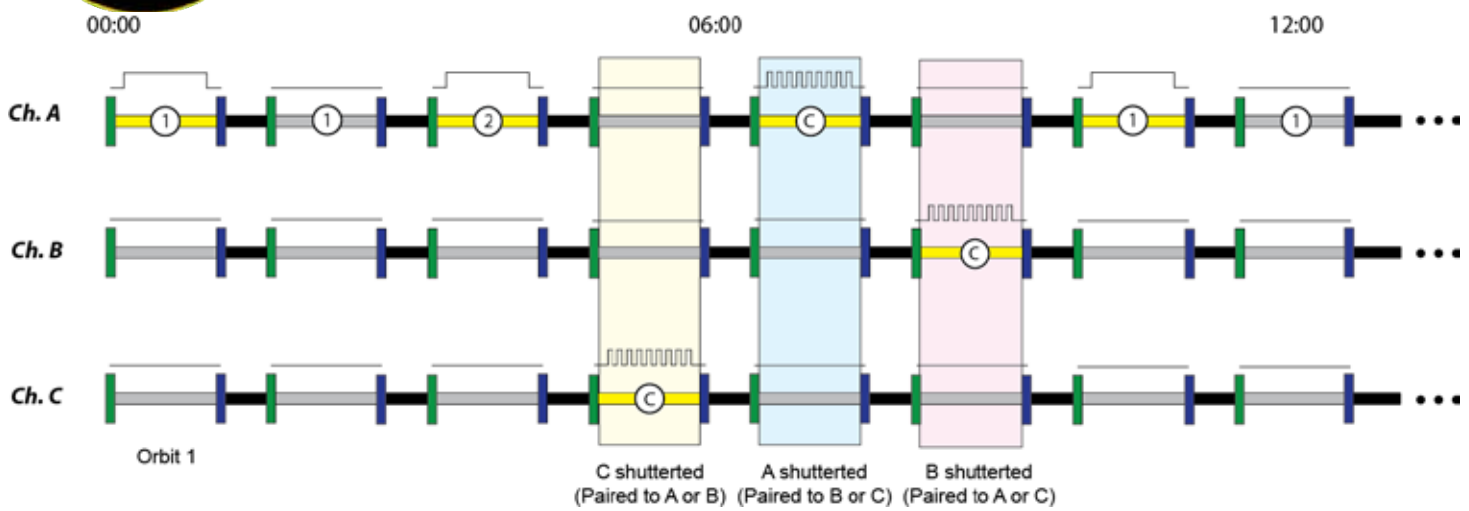
# Normal Operations Plan (Daily Schedule)



# Timeline for Channel C Calibrations




Enter Sun
Exit Sun
Eclipse (bearing roll / reset)
Normal Science (Solar viewing)
Normal Science (PD Dark & ESR Gain meas.)

Shutter state
Open (Photodiode only)
Closed
Cycled (ESR only)

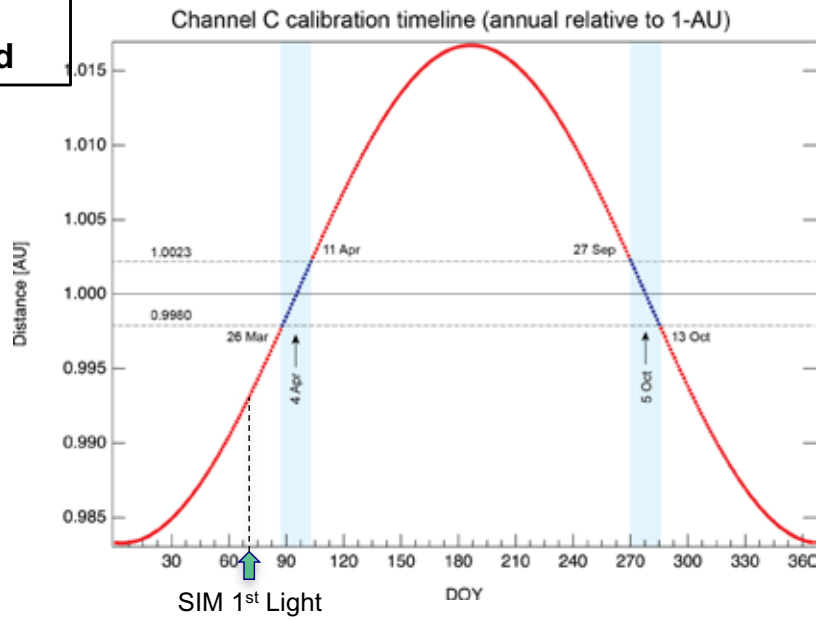
**Acivity**
① UV diode scan (200-260 nm) - 26 min.
② Full diode scan (250-1695 nm) - 34 min.
Ⓒ ESR Variable Scan* (Inter-channel calib.)
Includes diode scans 1 & 2 (at end)

**Note: Addition of Ch. C interleaved calibration does not affect the nominal Ch. A & B operational timeline (exposure cadence undisturbed**

The Channel C calibration activities occur <u>twice per calendar year</u> and require 17 days (like channel B) centered at common 1-AU times (4/4 & 10/5).

The reason for this timing relates to guaranteeing common:

- **Field-of-view** (similar solar image in prism)
  - Want to match degradation spot on prism
- **Solar flux** (similar distance correction)
  - 6.7% **irradiance** change over 6 months, therefore different correlation to exposure time between 17 days in January and 17 days in July



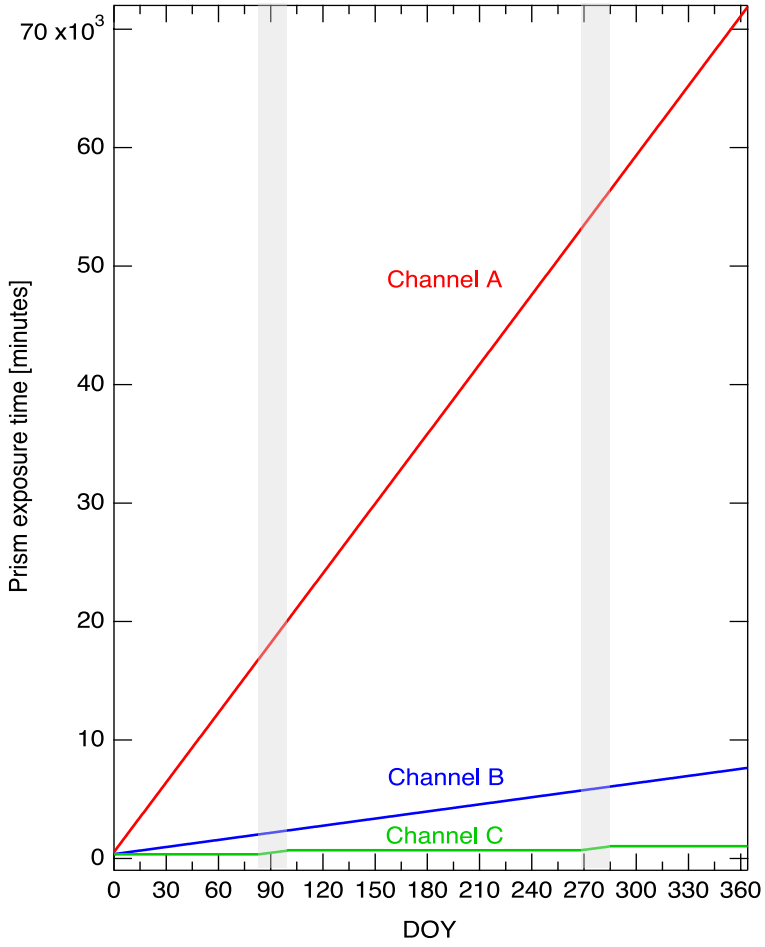
# Annual Solar Exposure Totals

## Total prism exposure for all SIM channels

| Calibration Totals | Prism – Solar exposure totals | | | |
|---|---|---|---|---|
| | Daily (min.) | 17-day Cal. (min.) | Annual (min.) | Annual (days) |
| Channel A | 196 | 3332 | 71540 | 49.68 |
| Channel B | ~20 | 345 | 7245 | 5.03 |
| Channel C | - | 345 (every 6-months) | 690 | 0.48 |

Channel B-to-A duty cycle = 10.1%
Channel C-to-B duty cycle = 9.5%

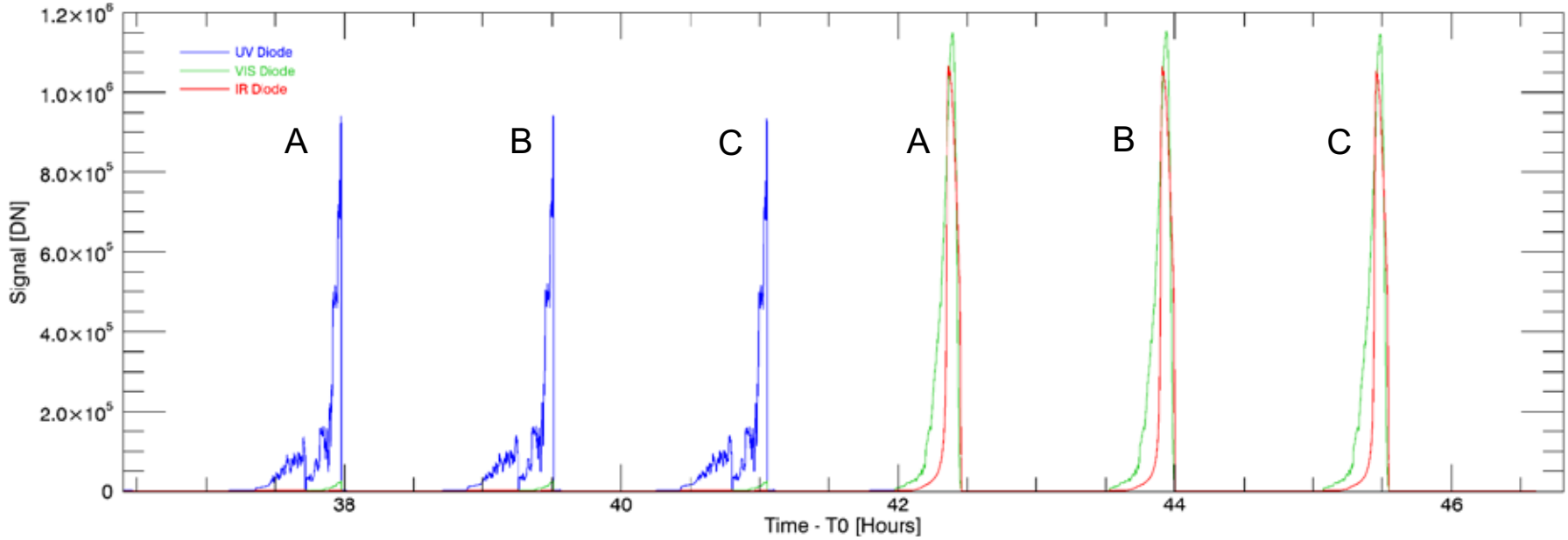
Annual SIM exposure time

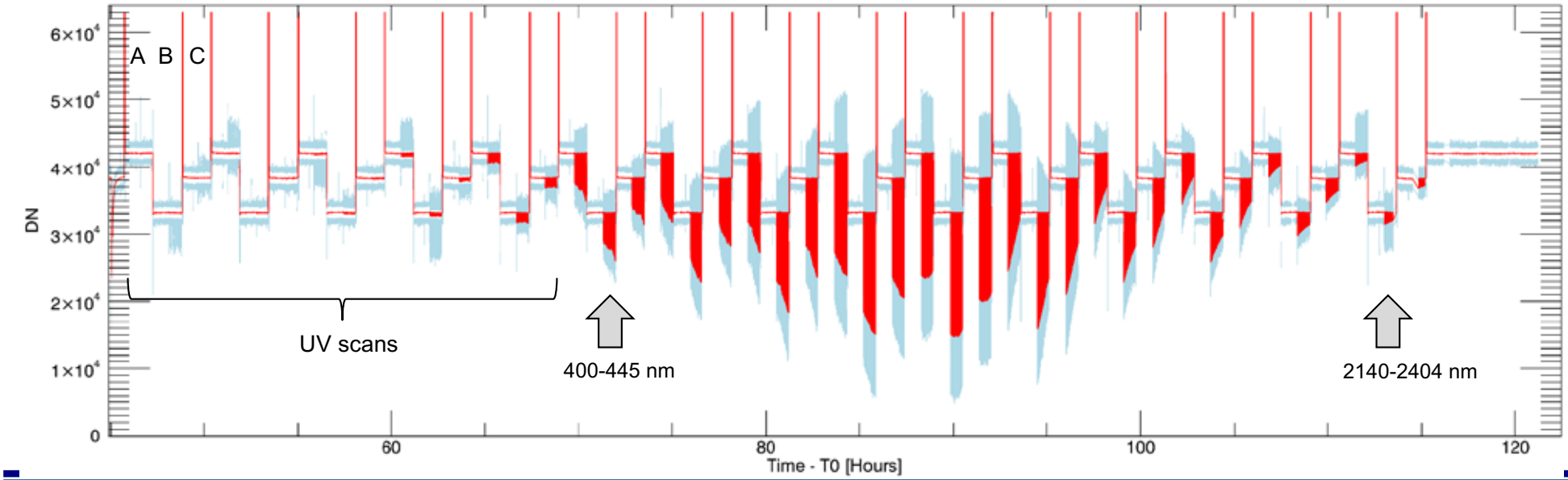





# BACK UP SLIDES

# First Light All Channels



# Wavelength Dependent Responses

## Photochemistry

### EUV (Ionosphere):

$N_2 + h\nu\ (\lambda < 80nm) \rightarrow N_2^+ + e^-$

$O_2 + h\nu\ (\lambda < 103nm) \rightarrow O_2^+ + e^-$

$O + h\nu\ (\lambda < 92nm) \rightarrow O^+ + e^-$

### FUV (Ozone creation):

$O_2 + h\nu\ (\lambda < 242nm) \rightarrow O + O$

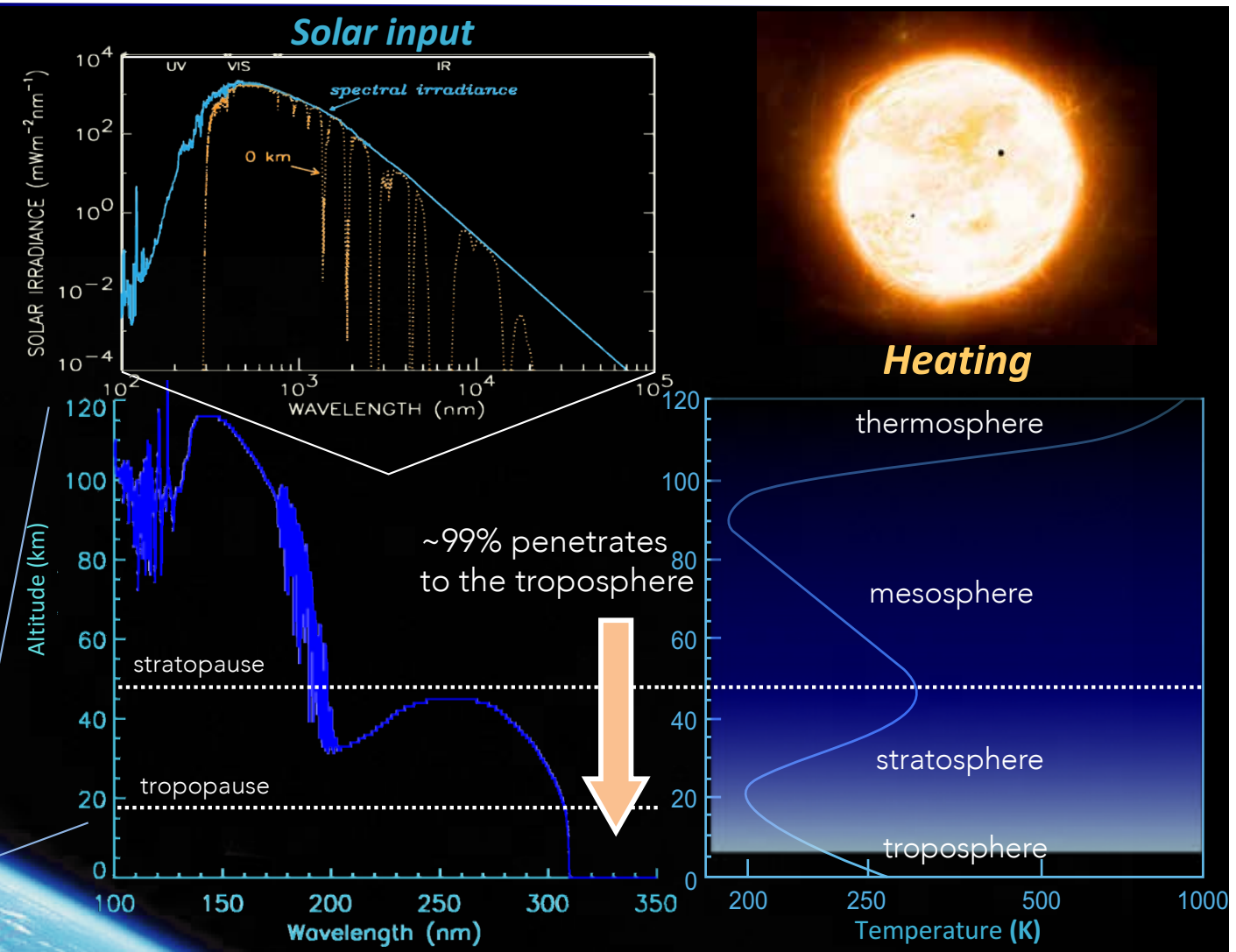
$O + O_2\ (+M) \rightarrow O_3$

### MUV (Ozone Destruction):

$O_3 + h\nu\ (\lambda < 310nm) \rightarrow O_2 + O$

### Visible-IR:

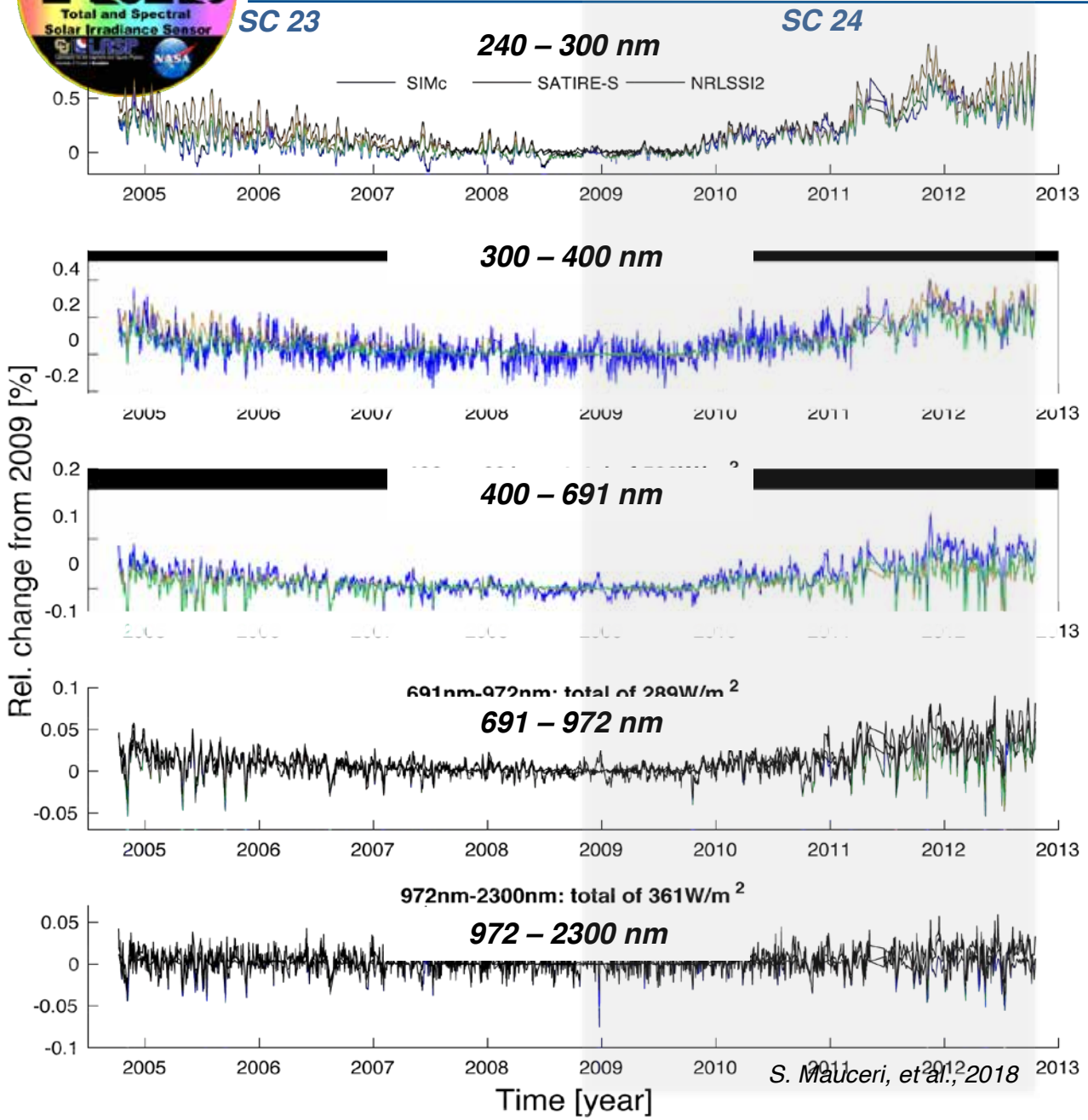
$H_2O$, $CO_2$, aerosol,
Land – Ice – Ocean




**The measurement of TSI alone provides no information about the spectral content of the irradiance variability**

| | | | | |
|---|---|---|---|---|
| $\lambda < 120$ nm | = 0.003 | ± 0.001 | $Wm^{-2}$ | (0.0002%) |
| 120 -300 nm | = 14.9 | ± 0.1 | $Wm^{-2}$ | (~1%) |
| $\lambda \geq 300$ nm | = 1346 | ± 0.5 | $Wm^{-2}$ | (~99%) |

# SSI "Long-term" Record (~ 1 decade)




S. Mauceri, et al., 2018

$$\sum_{240}^{2300} SIM = 1254\ Wm^{-2}\ (92\%\ TSI)$$