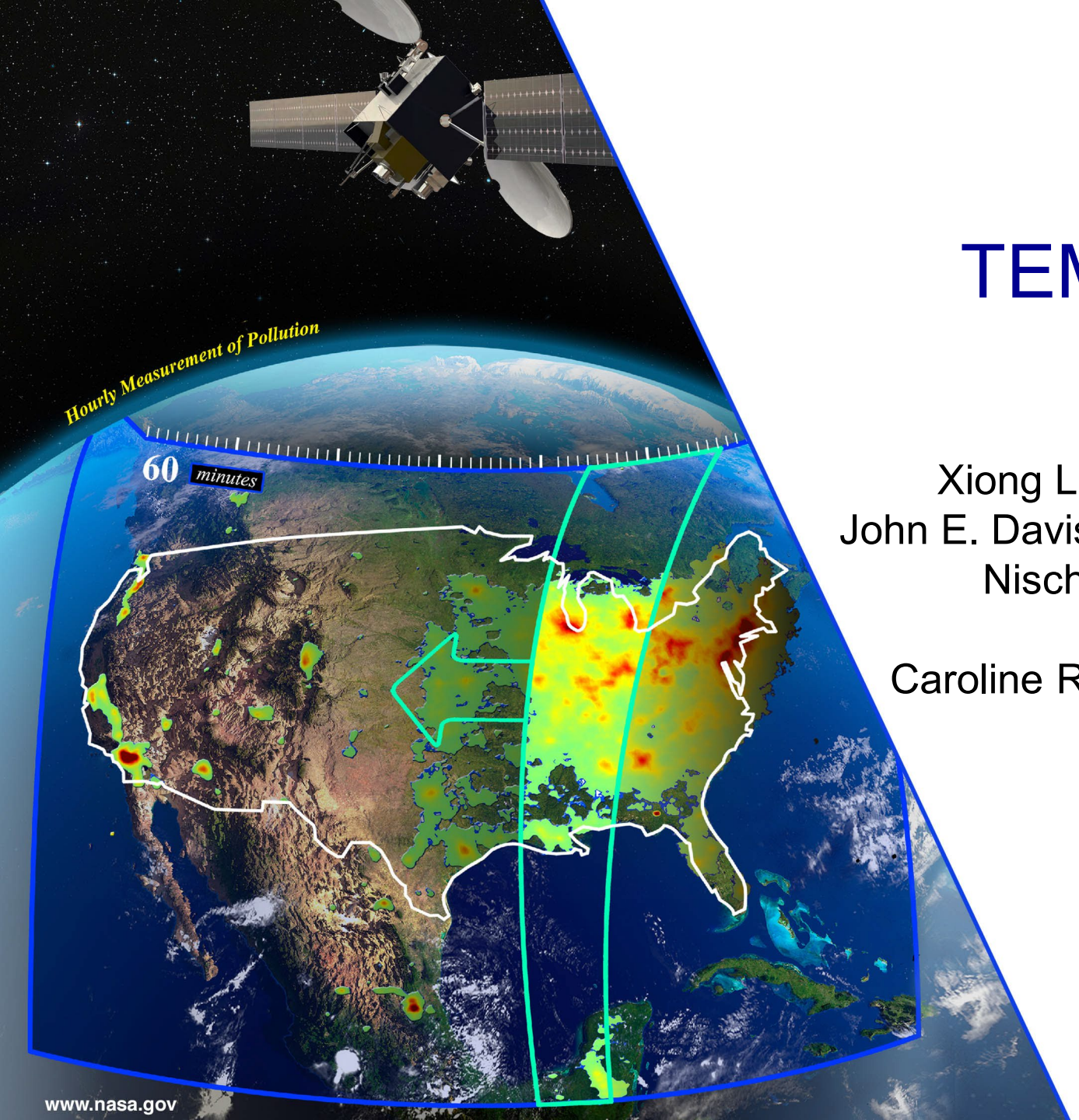


Tropospheric Emissions:
Monitoring of Pollution

TEMPO Calibration Status

David Flittner (NASA)

Xiong Liu, Heesung Chong, Weizhen Hou, John Houck, John E. Davis, James Carr, Raid M. Suleiman, Kelly Chance, Nischal Mishra, Brian Baker, Christopher Chan Miller, Marcellin Feasson, Gonzalo González Abad, Caroline R. Nowlan, Huiqun Wang, Ewan O'Sullivan, Jean Fitzmaurice, Zolal Ayazpour, Kang Sun, and the TEMPO Team

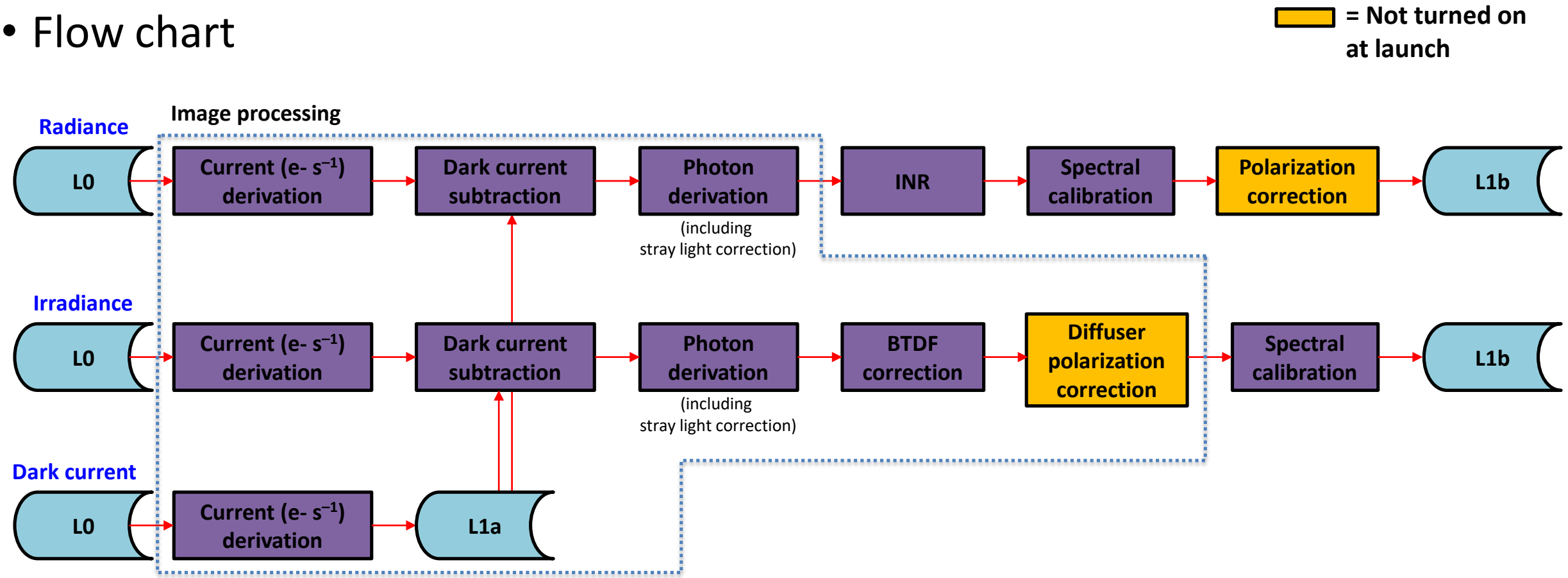
October 26, 2023

Introduction

- Level 0-1 Processing Scheme
- Modifications Since Launch
- Irradiance & Radiance Performance
- Summary and Outlook

TEMPO L0–1 processor

- Flow chart

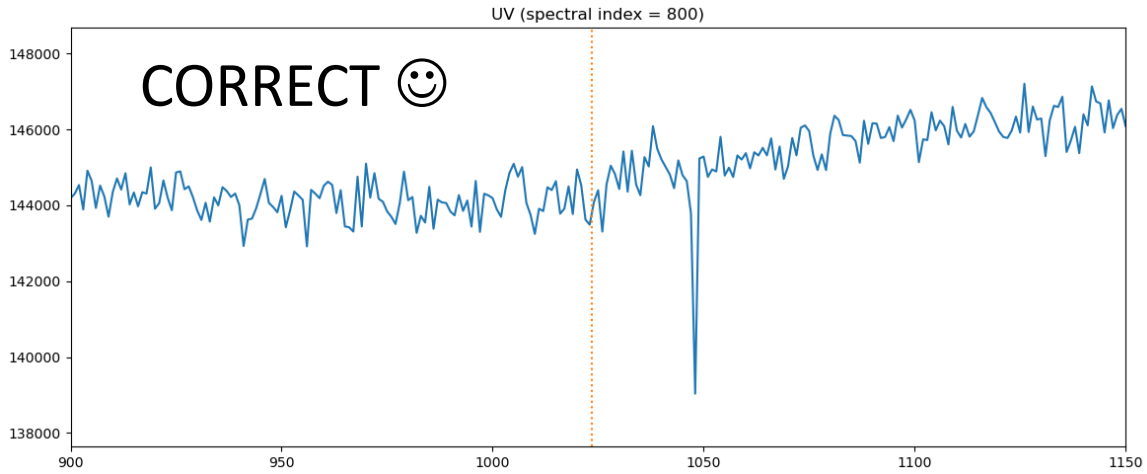


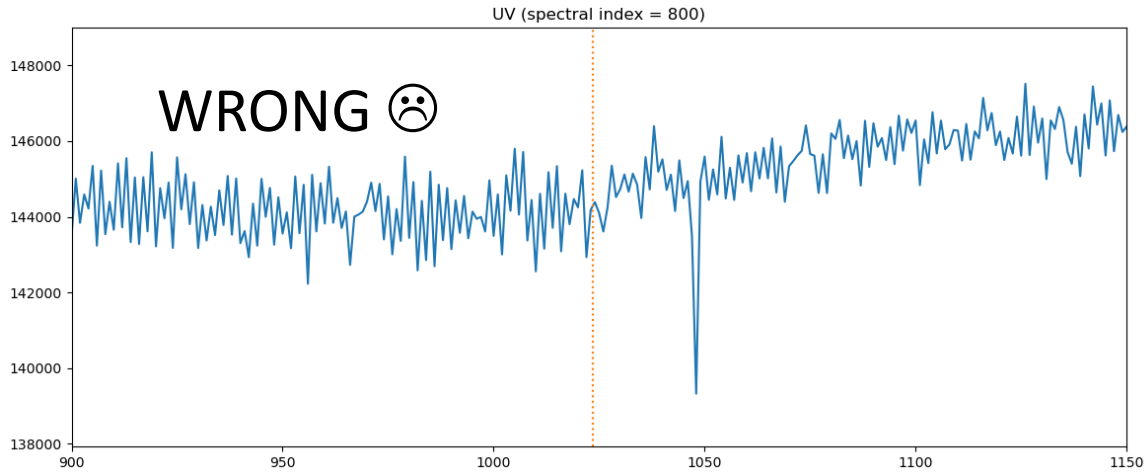
Approach for TEMPO adapts elements from GEMS, TropOMI, OMI

Updates since the first light

- **Calibration key data**
  - *Gain and nonlinearity* (derived from Ball Aerospace, consistent with the radiometric calibration coefficients)
    → It changes the radiance values by 3–5%.
  - *Bad pixel mask*
    (derived using dark current from July 28 + non-responsive N/S edge pixel flagging + improved saturation flagging)
  - *Pixel Response NonUniformity*

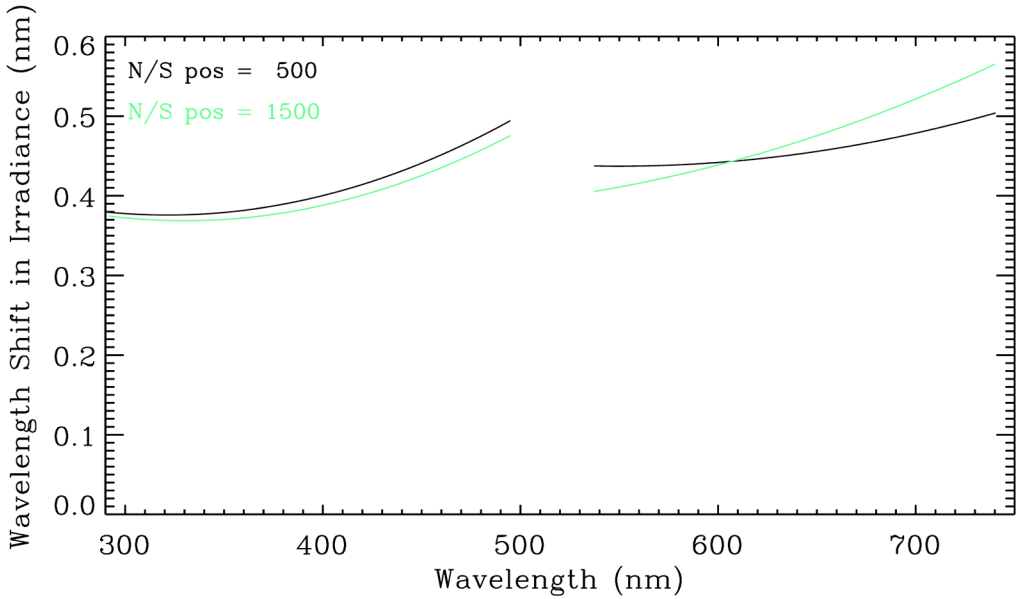
- **Identification of analog-to-digital configuration**
  - Refine algorithm for determining correct gain configuration for each image - reduces striping

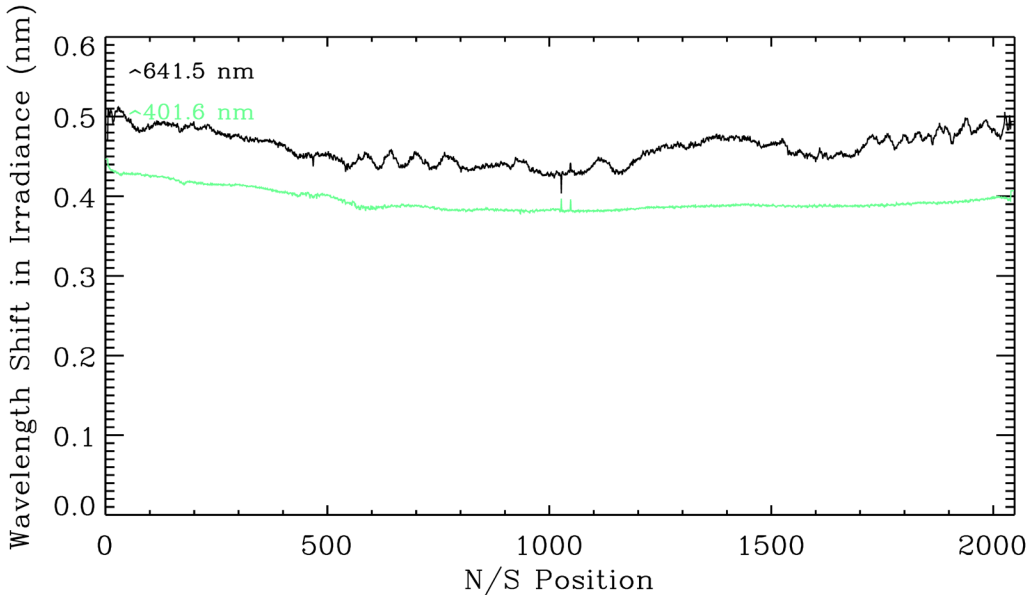




Wavelength Shift from Pre-launch

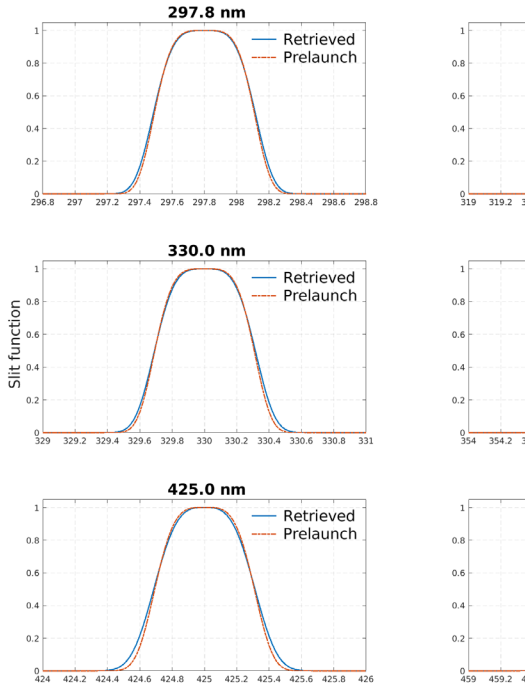
- **Large wavelength shifts from pre-launch characterization.**
  - **Adjustment of nominal wavelength table**
  - **Possibly indexing error with instrument delivery**
- **Level 1 and 2 baseline algorithms register wavelength scale of each image.**

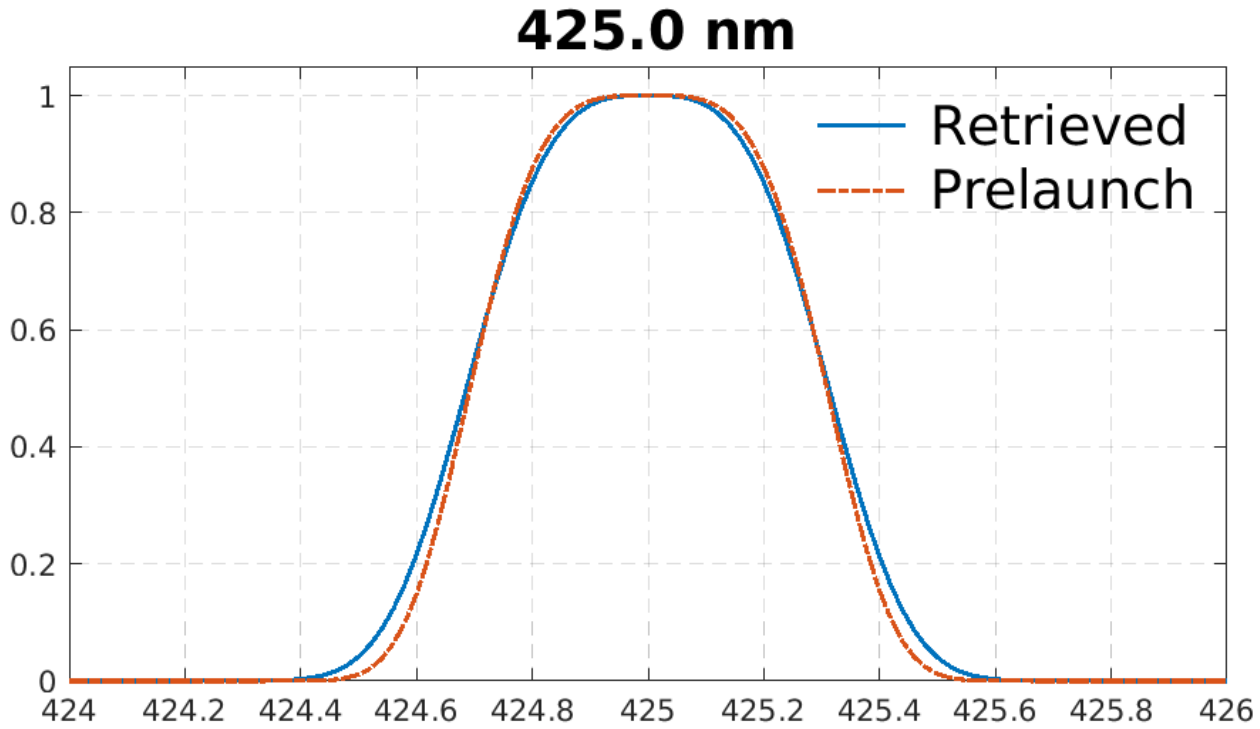


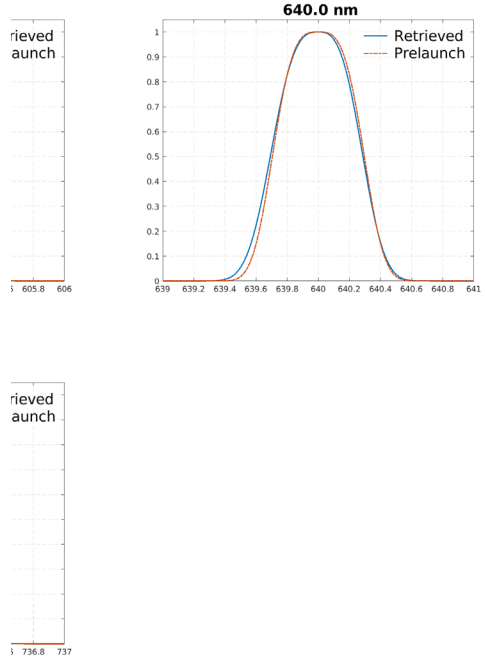


Spectral bandpass calibration

- Deriving in-flight spectral response function assuming asymmetric super Gaussian – wings slightly wider than prelaunch

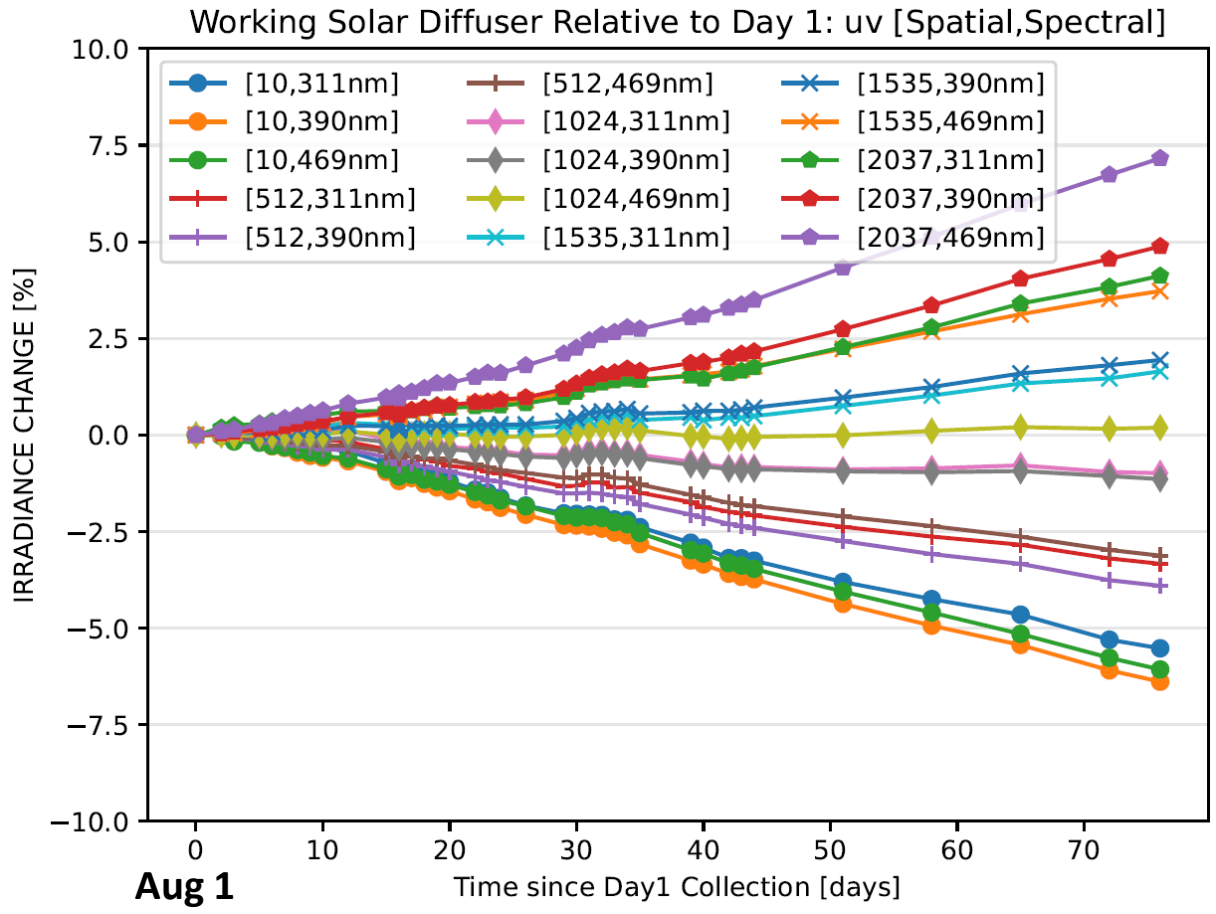


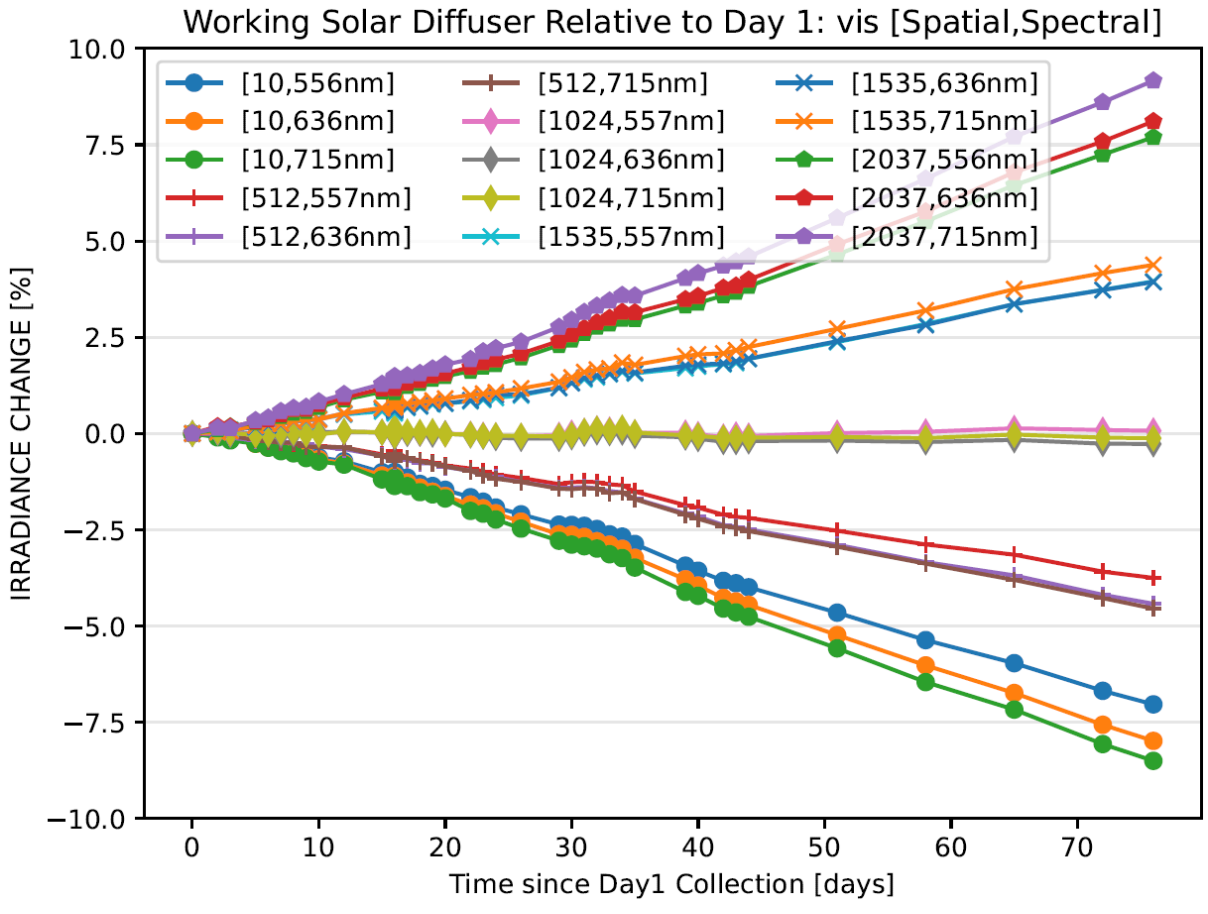




Angular dependence of BTDF - 1

- Temporal irradiance changes (as expected from GEMS measurements)



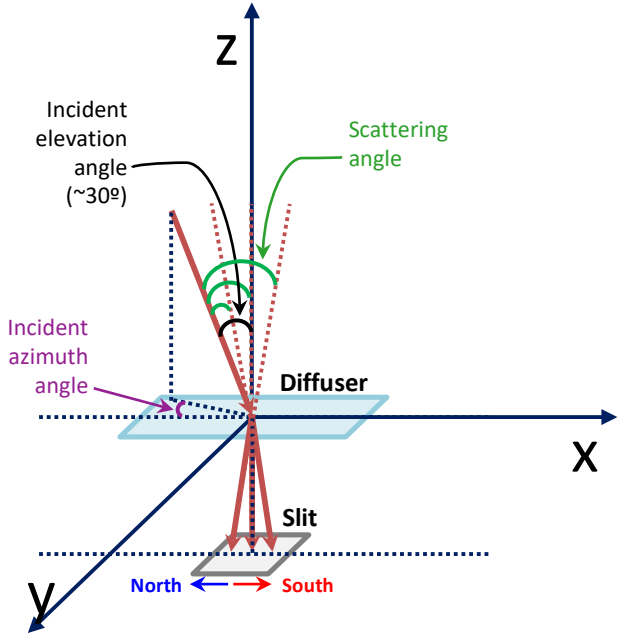


BTDF = Bidirectional Transmission Distribution Function

Correcting angle-dependence of BTDF -2

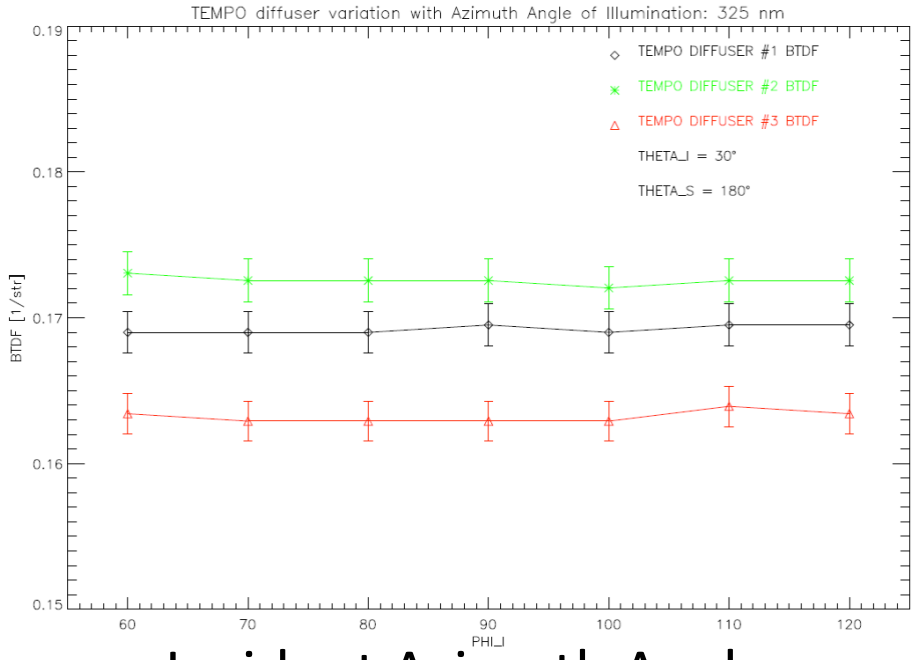
- First-principle correction using 'scattering angles' will be implemented.

Geometry of solar cal.



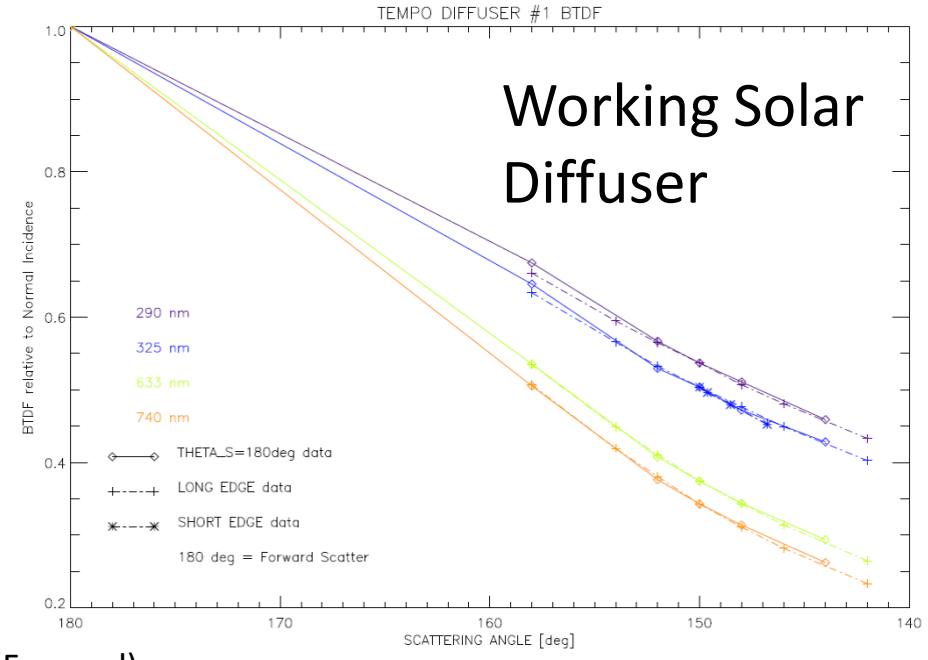
[Credit: Heesung Chong]

BTDF at center of diffuser (aka middle of N-S slit) independent of azimuth angle



Incident Azimuth Angle

BTDF has robust dependence on scattering angle



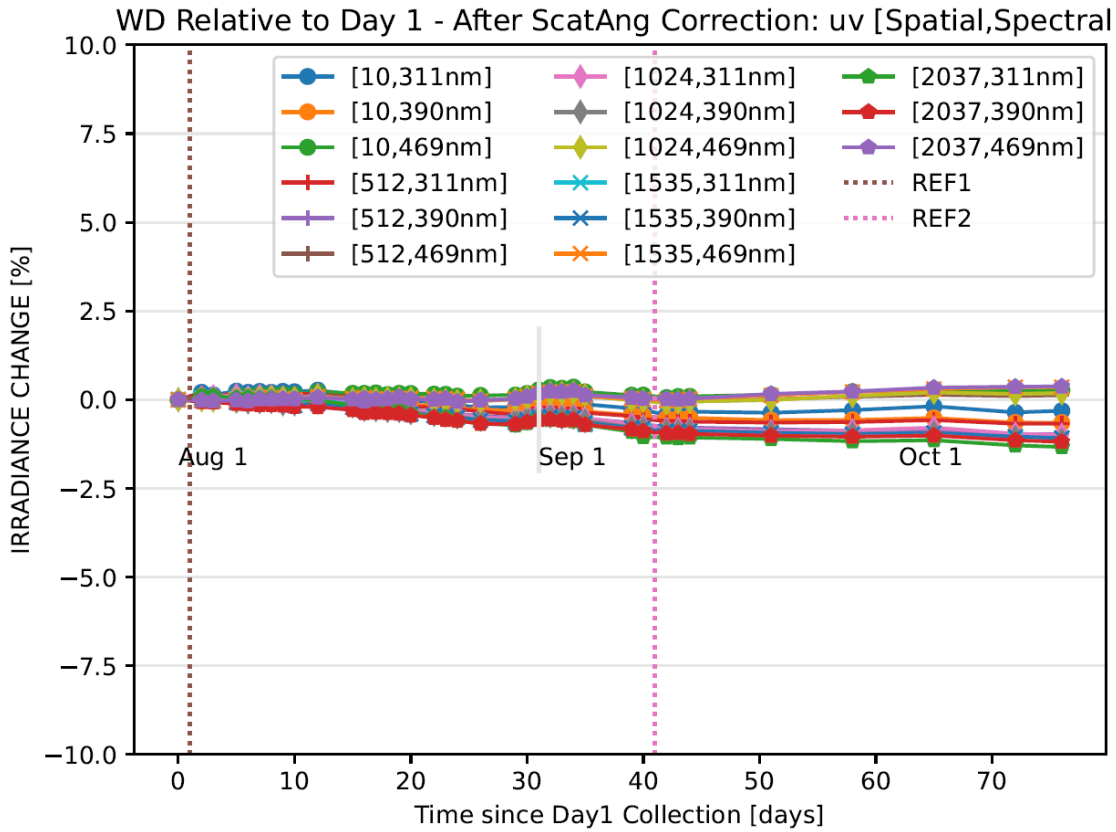
(Forward)

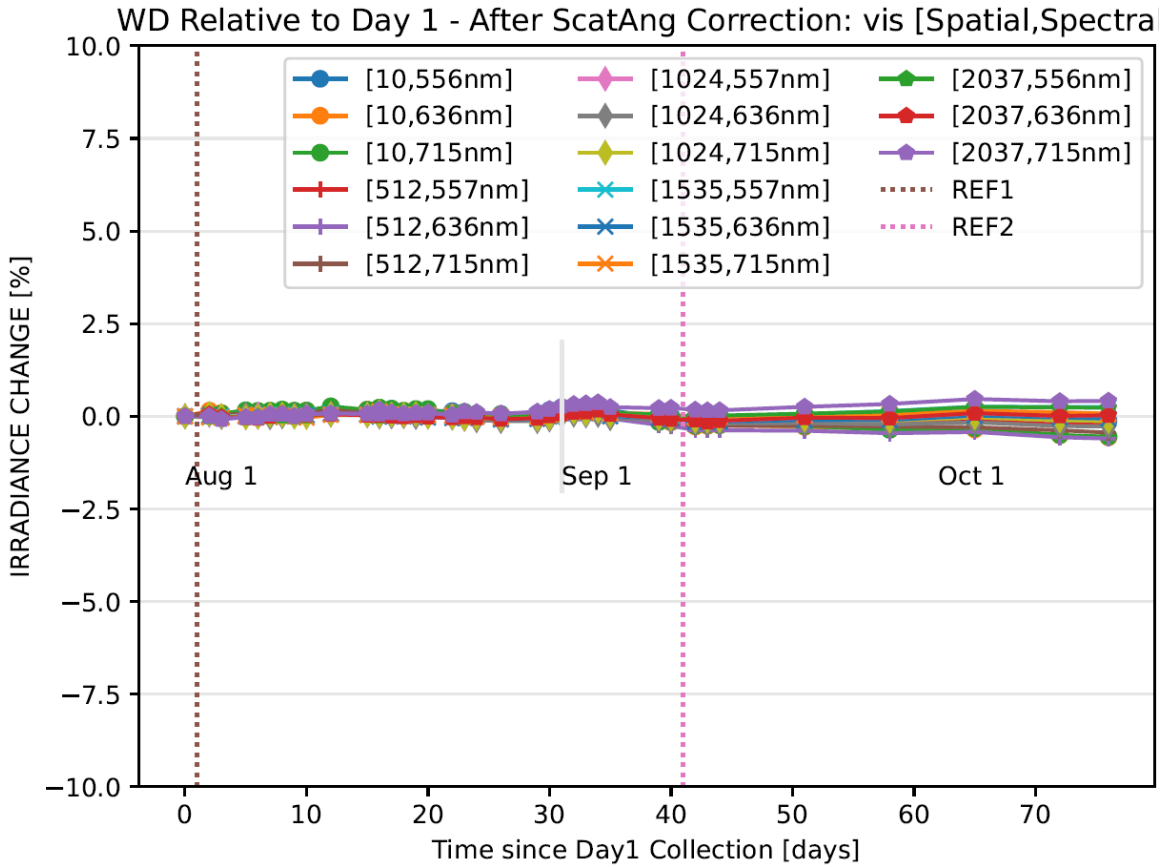
Scattering Angle

BTDF = Bidirectional Transmission Distribution Function

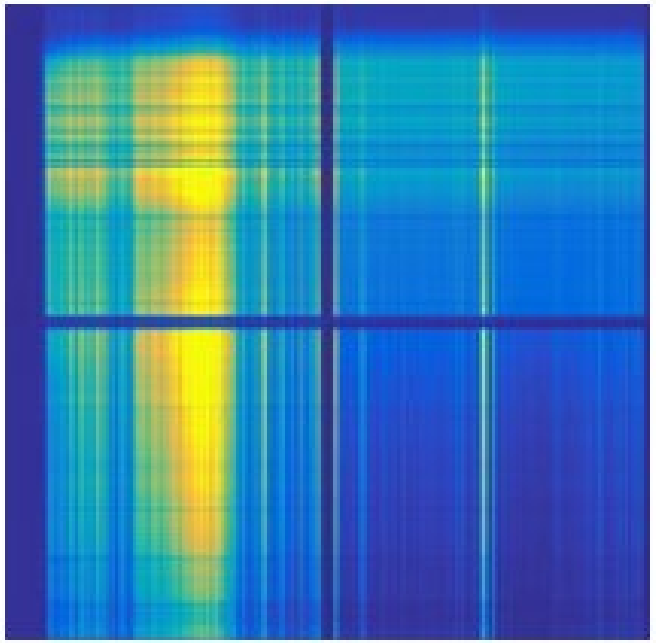
Correcting angle-dependence of BTDF - 3

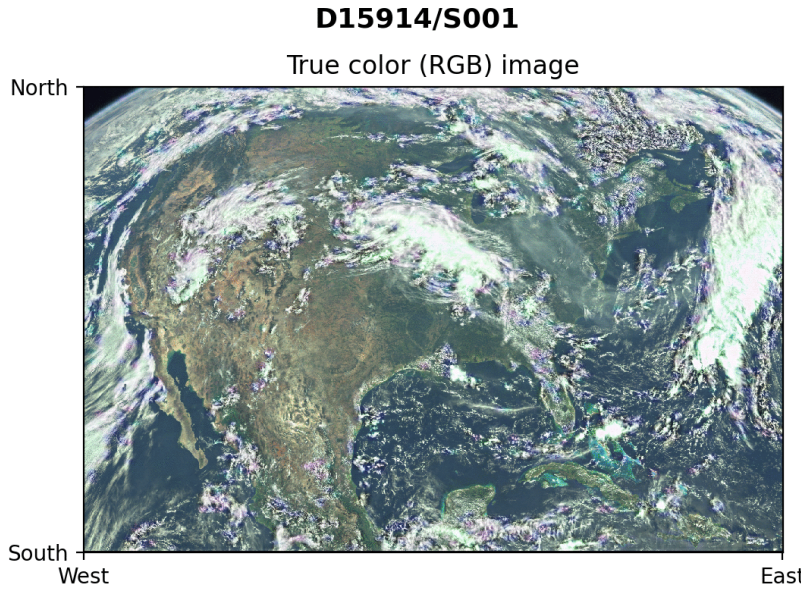
- After applying scattering angle correction, trend is significantly reduced

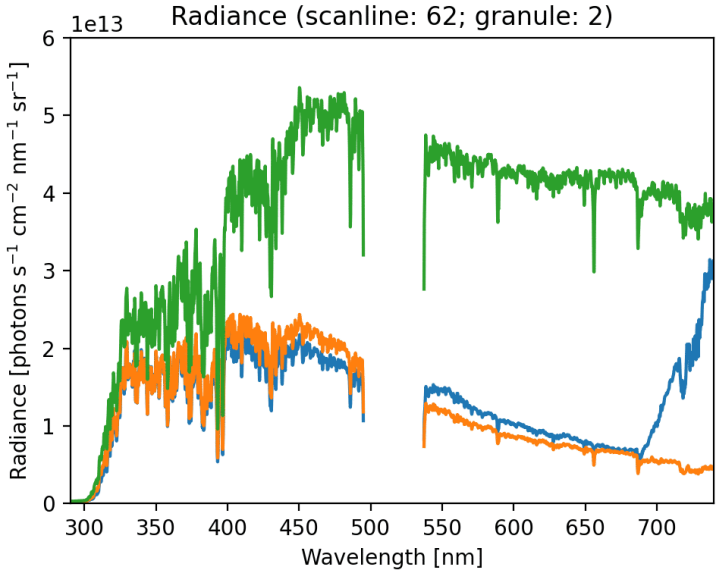


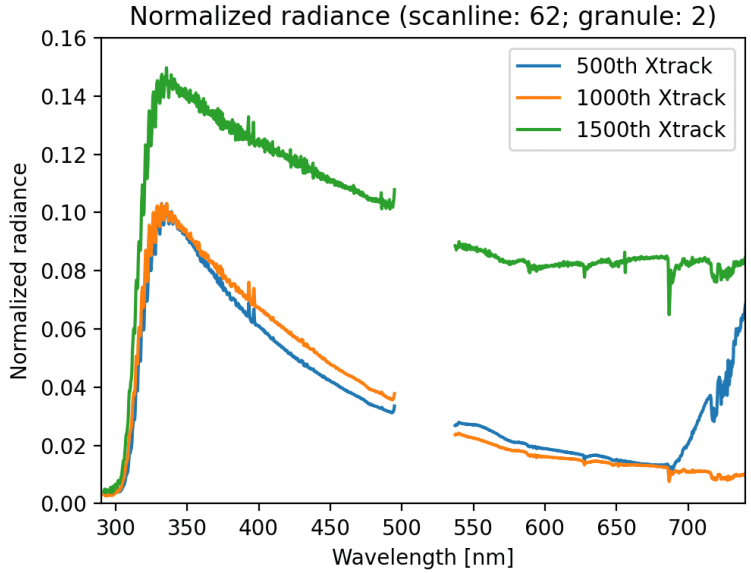


First Light: Earth Imaging
Started @11:13 ET, August 2, 2023









Instrument SNR Requirements

- Instrument performance requirements were derived from L1 precision requirements
- Signal to Noise Ratio (SNR) is the dominant factor for instrument performance

Earth-View TEMPO Signal to Noise Ratio (SNR) Verification Summary

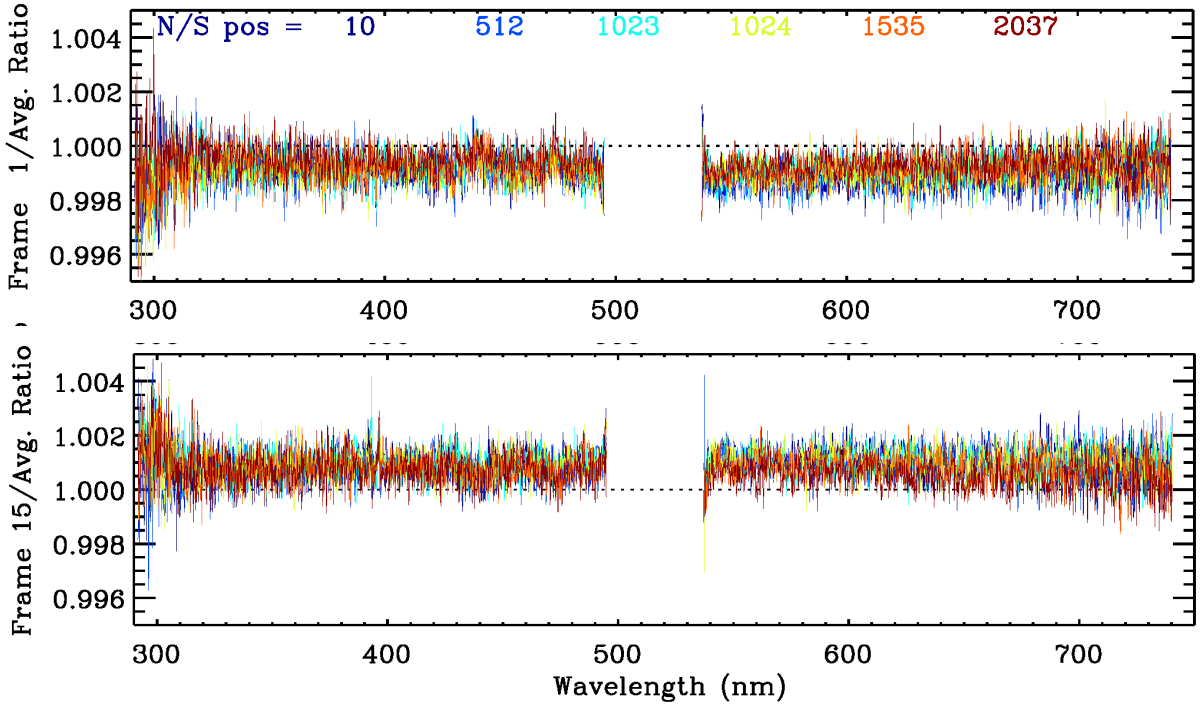
Req Number	Requirement			BOL SNR		EOL SNR	
	Atmospheric Constituent	Wavelength (nm)	SNR Requirement e- / e-	As-Measured SNR	Margin	Predicted EOL SNR	Margin
IRD-320 TSS-59	O3	290	19.6	N/A	N/A	N/A	N/A
	O3	300	46.1	49	5.4%	45	-2.4%
	O3	305	161.9	191	17.8%	178	10.1%
	O3	310	377	471	24.9%	447	18.5%
	O3	320	1220	1664	36.4%	1621	32.8%
	O3, H2CO	330	2003	2829	41.2%	2779	38.7%
	O3, H2CO, Cloud	340	2013	2867	42.4%	2827	40.4%
	H2CO, Cloud	350	1414	2717	92.1%	2685	89.9%
	NO2	420	836	2138	155.8%	2127	154.4%
	NO2	430	675	1681	149.0%	1670	147.4%
	NO2	450	733	1875	155.8%	1865	154.4%
	Cloud	490	1176	1886	60.4%	1879	59.8%
	O3	540	1109	1813	63.5%	1806	62.9%
	O3	600	987	1577	59.8%	1571	59.1%
	O3	650	898	1383	54.0%	1376	53.2%
	Cloud	690	820	1195	45.8%	1188	44.9%

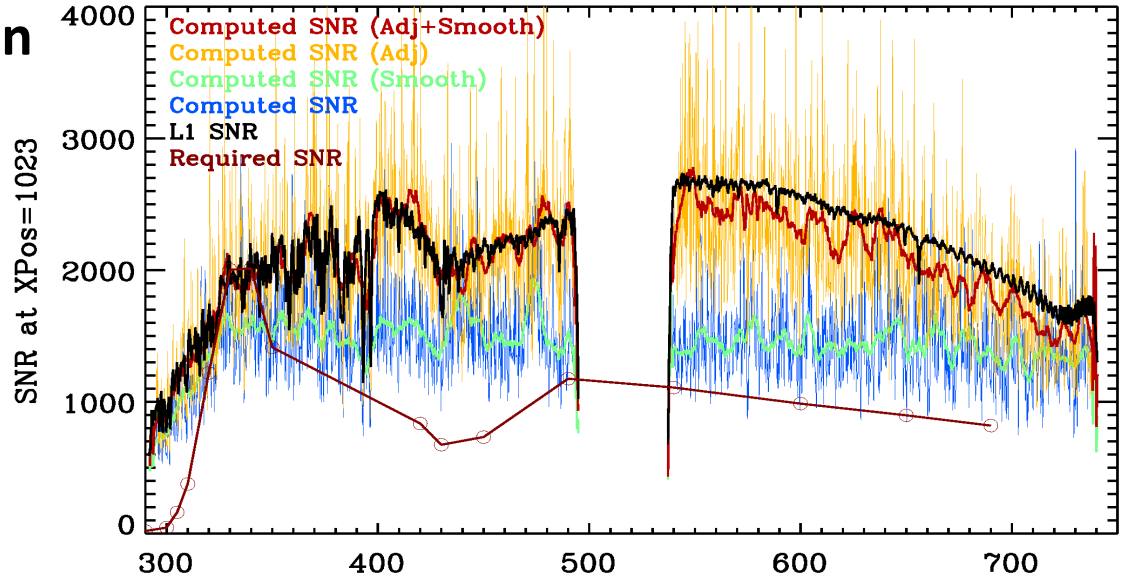
Table of radiance SNR requirement and with Beginning of Life (BOL) as-built performance (4 Pixels coadded)

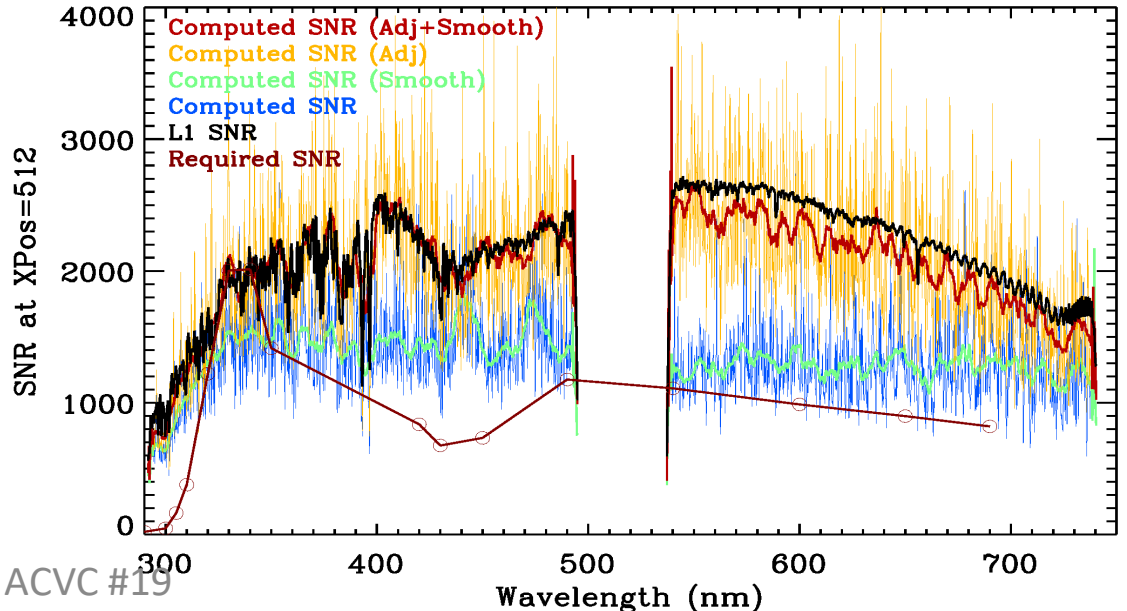
- The Instrument shall meet the SNR requirements in Table for the provided nominal spectral radiances when measuring every point in the entire FOR in a revisit time of 1 hour or less, by binning no more than 4 spatial pixels.
- The Instrument shall perform solar calibration measurements with SNRs greater than or equal to 2 times those for the nominal radiances.

Solar Irradiance SNR

- **15 frames of working solar diffuser measurements on 8/17/2023 for SNR verification.**

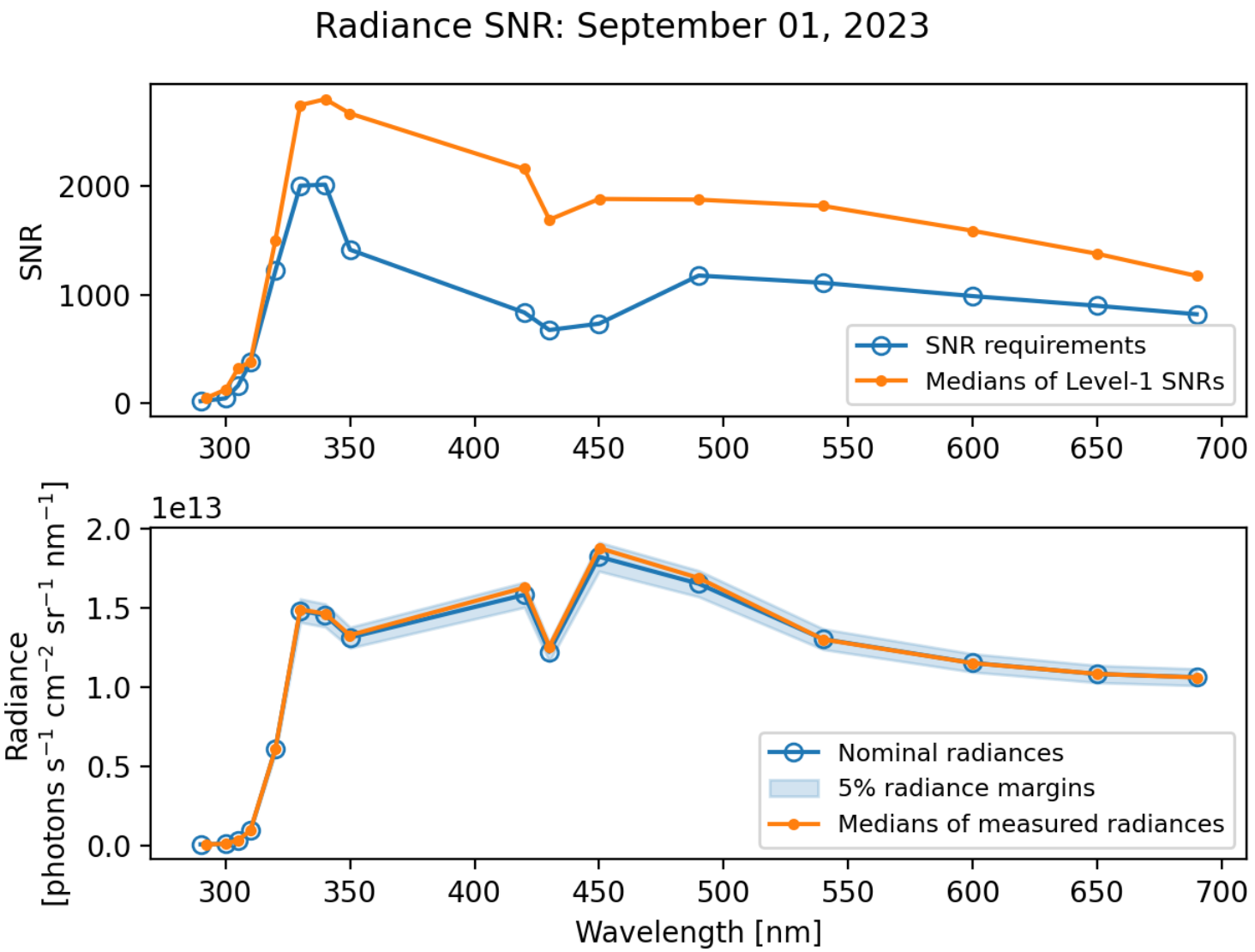






- **After accounting for variation, we verify :**
  - ✓ L1 Signal to Noise Ratio (SNR) calculation is correct
  - ✓ We can meet the solar SNR requirement.

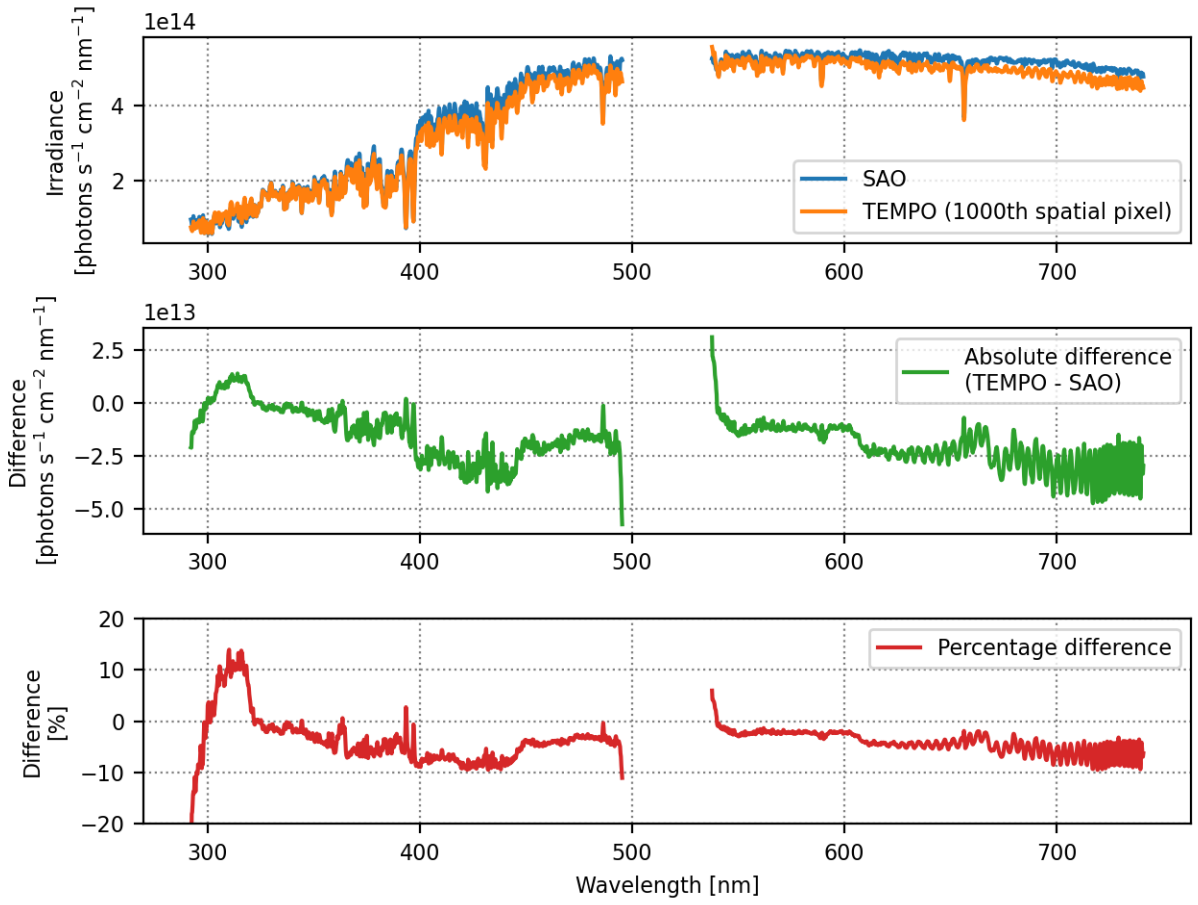
Radiance SNR



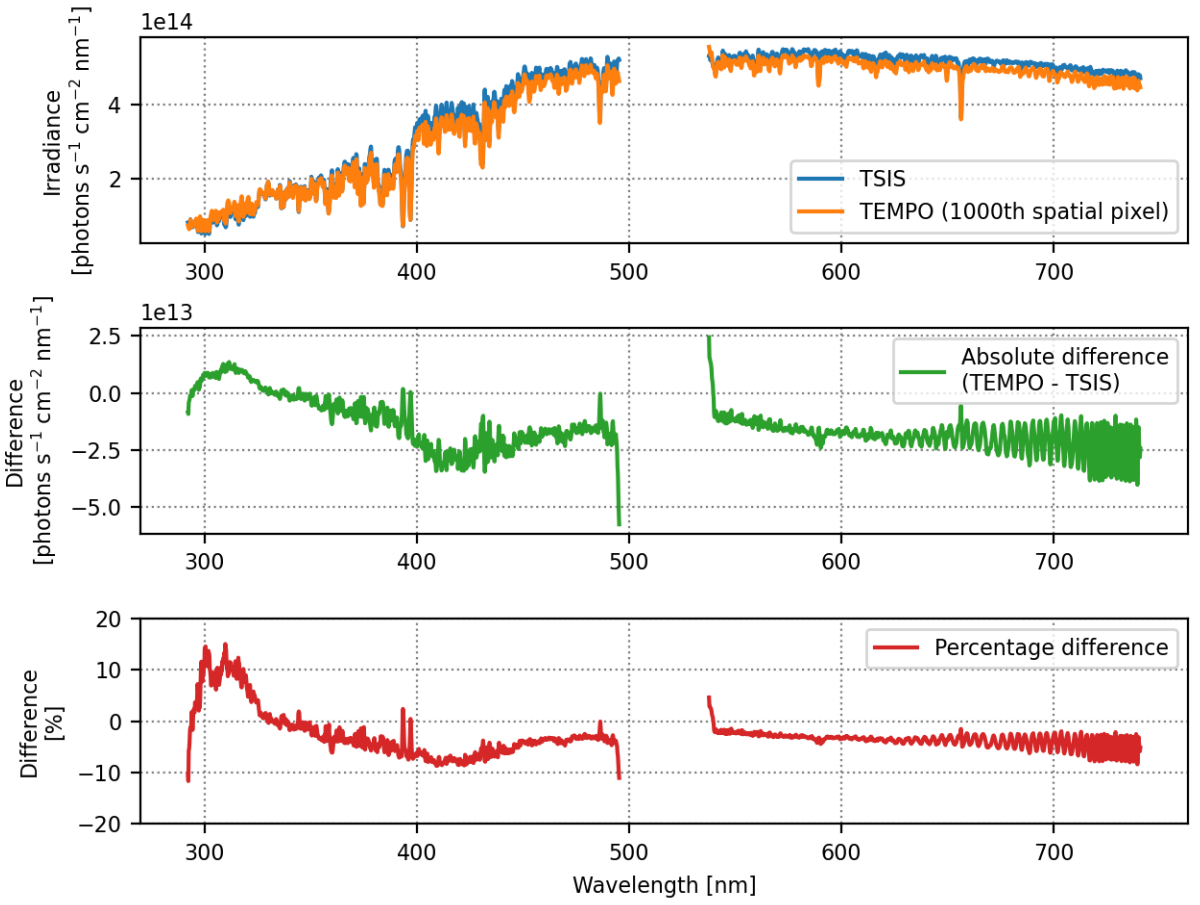
- **Used radiance data from all thirteen scans on September 1.**
  - ✓ For each nominal wavelength, select pixels within +/-5% of the nominal radiance.
  - ✓ Calculate median of SNRs for the searched pixels for each wavelength (upper panel).
  - ✓ Calculate the median of radiances for the searched pixels for each wavelength (lower panel).

Irradiance Comparison

TEMPO vs. SAO (Chance & Kurucz 2010)



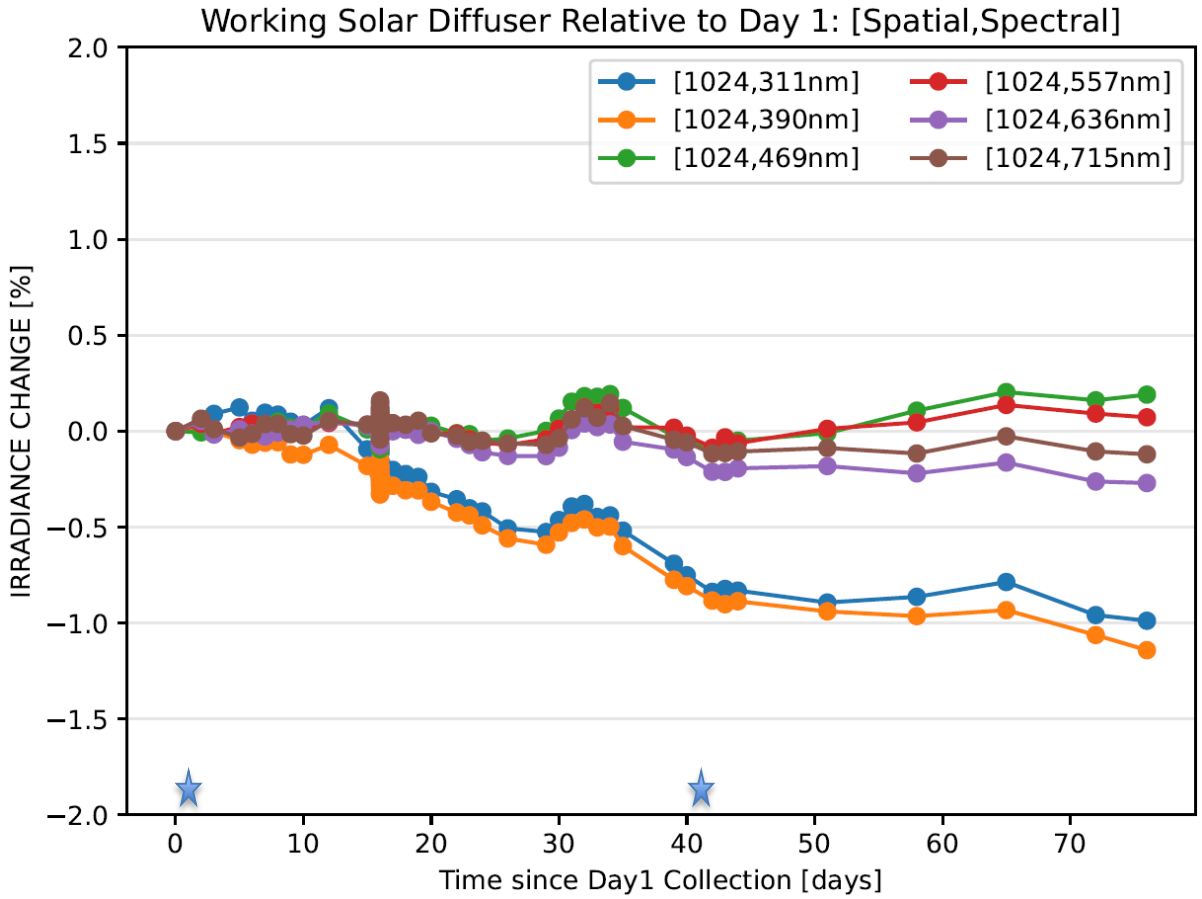
TEMPO vs. TSIS (Coddington et al. 2021)

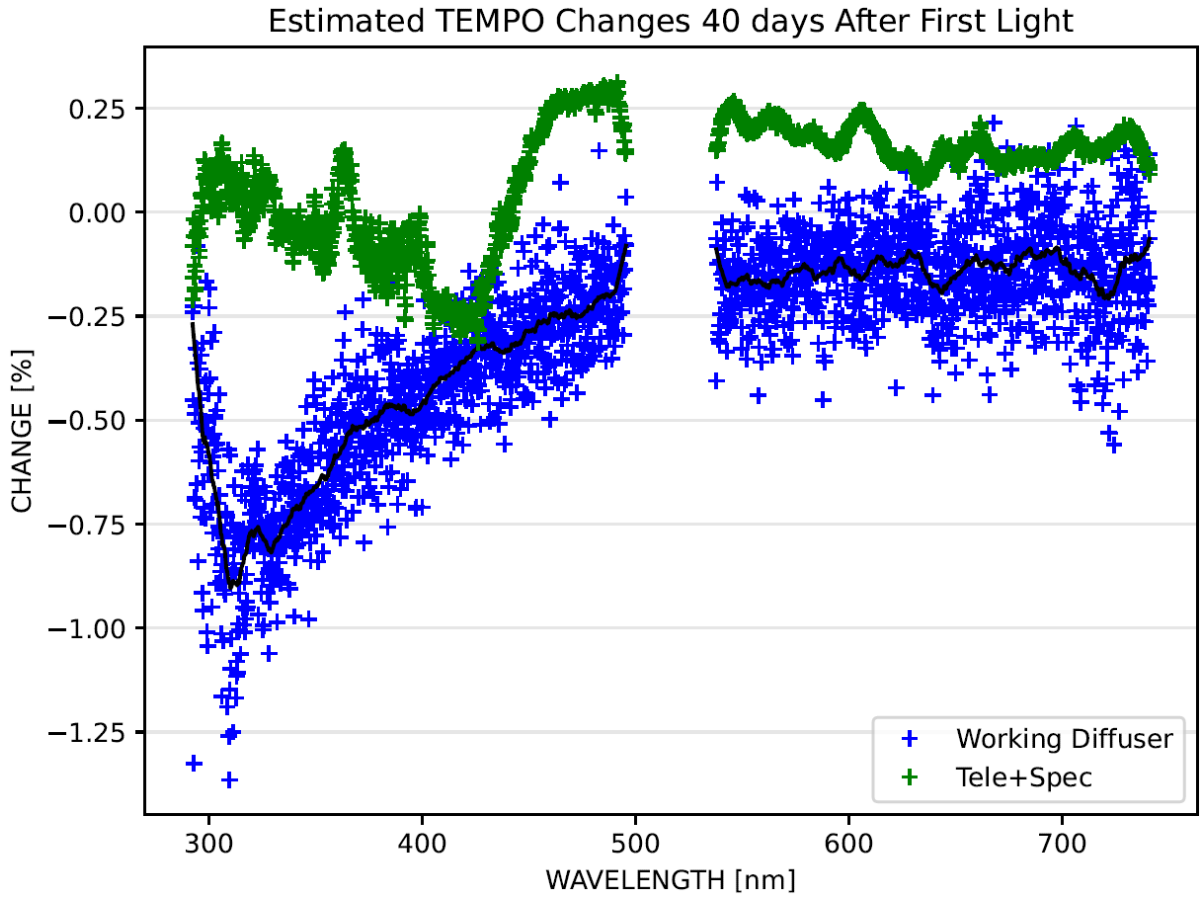


[Credit: Heesung Chong]

- TEMPO first light irradiance biased low (0-10%) above 320 nm
- Below 320 nm biased high (0-10%)

Sensor Response Evolution



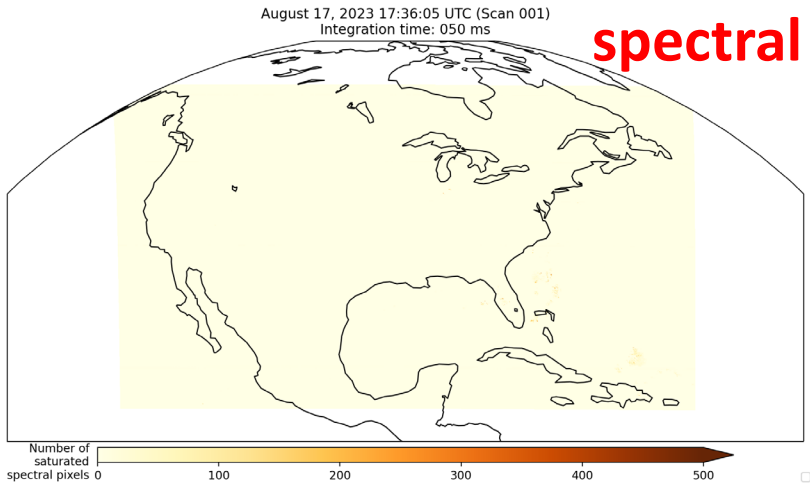


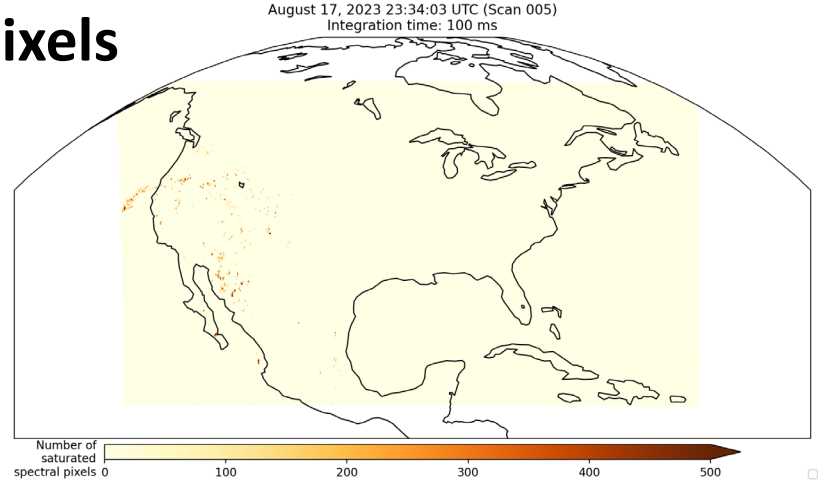
Reference Solar Measurements = ★
(Aug 2, 2023; Sep 11, 2023)

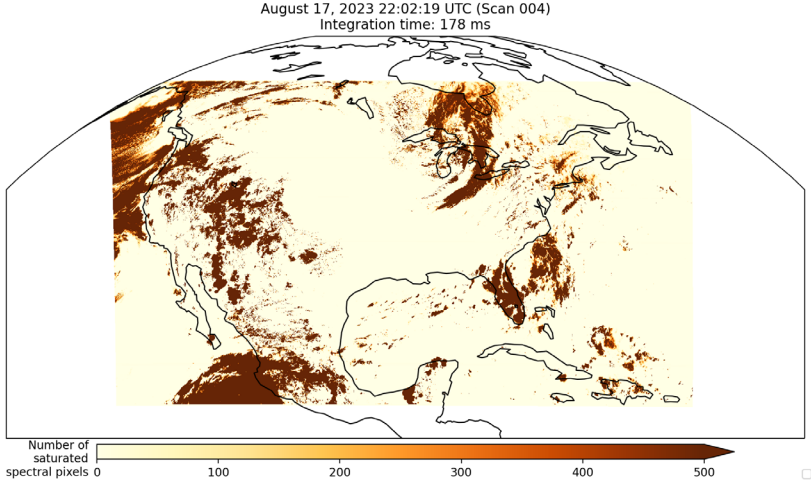
Saturation

50 ms **Number of saturated** 100 ms 178 ms

spectral pixels



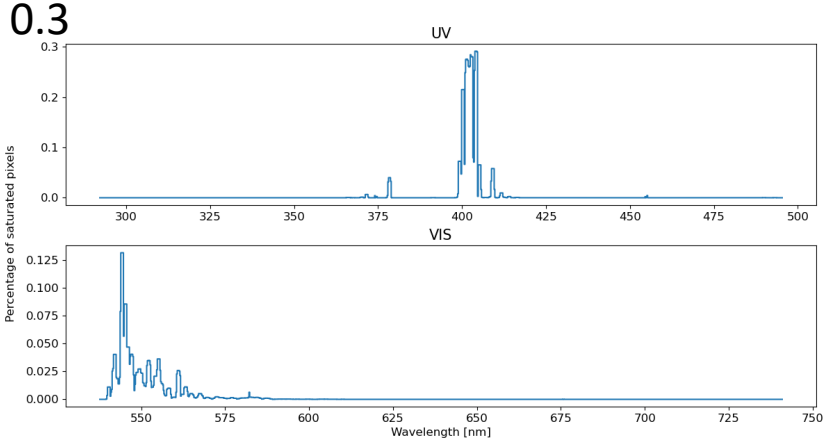


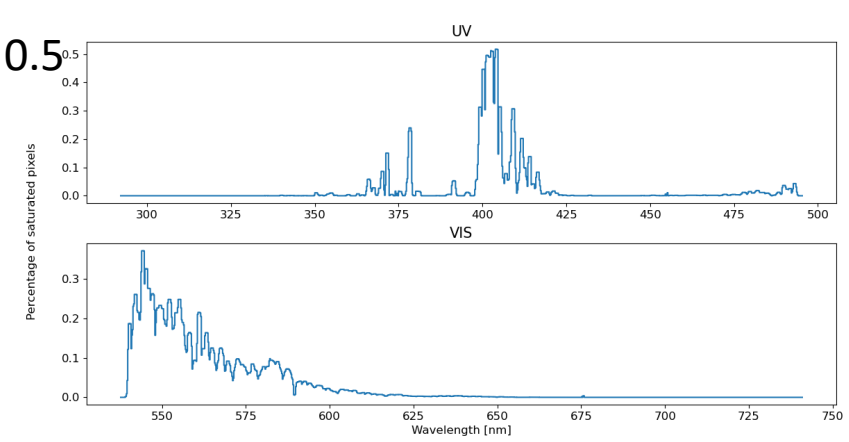


[Credit: Heesung Chong]

<u>Percentage of saturated spatial pixels, as a function of wavelength (excluding bad pixels)</u>

50 ms 100 ms 178 ms





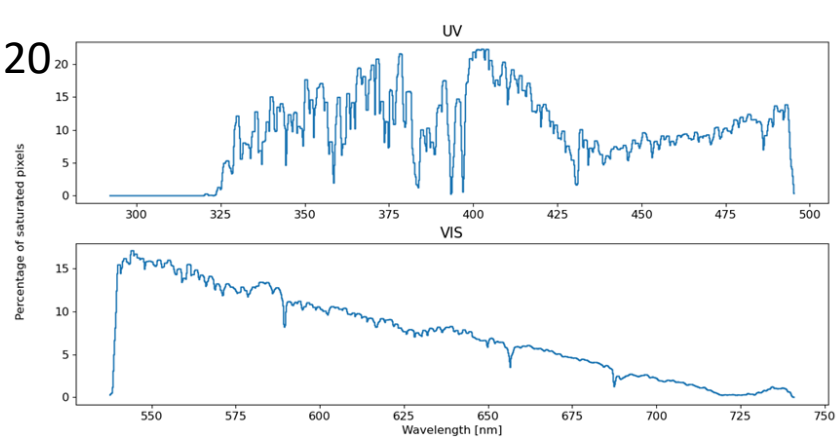
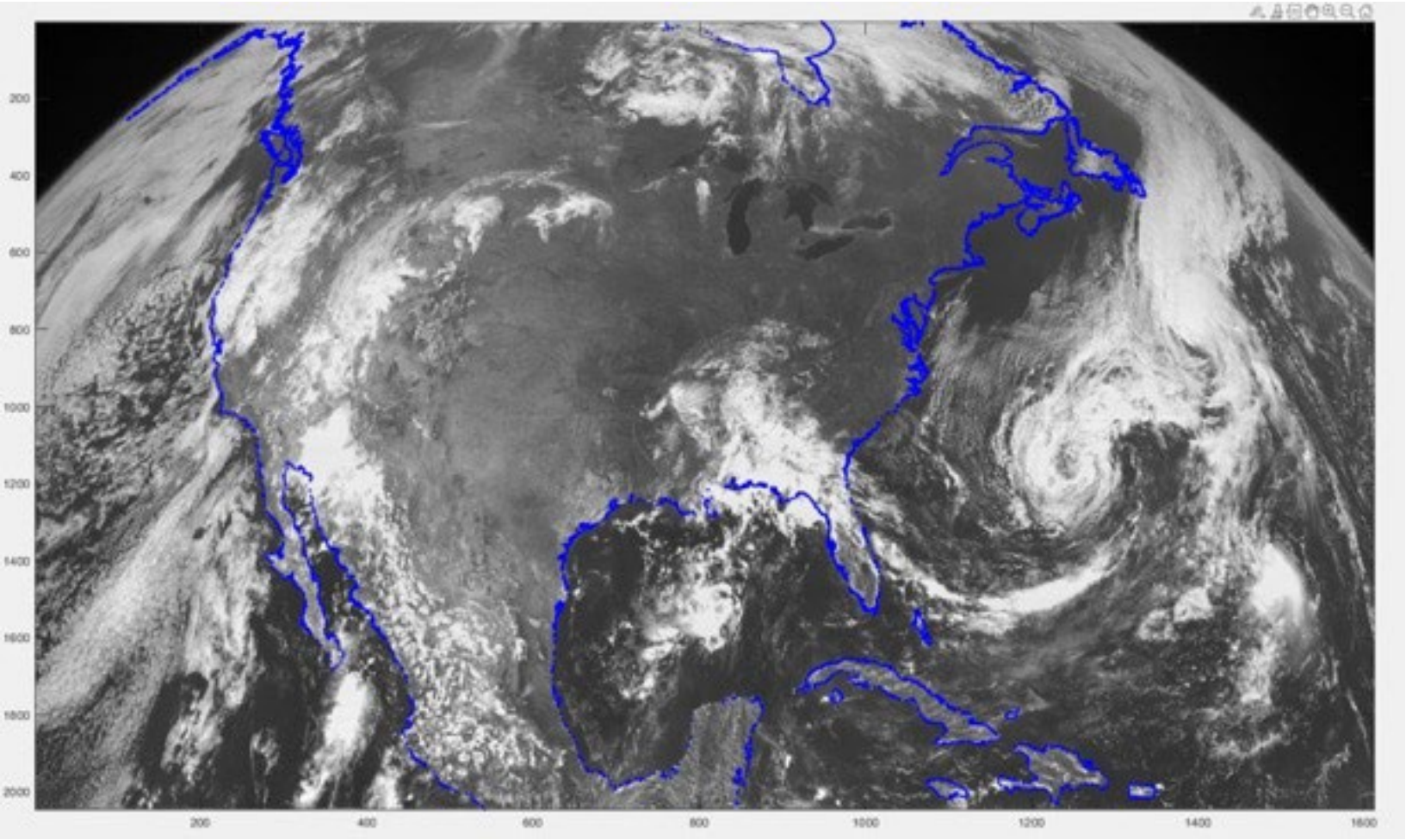
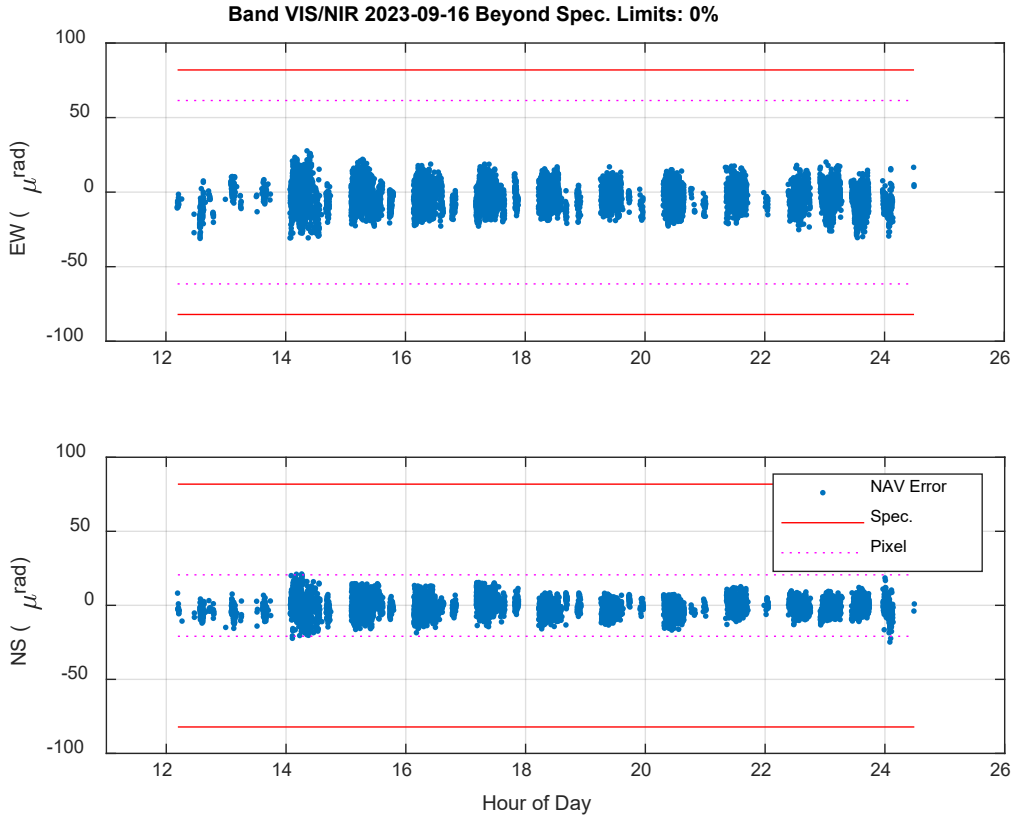


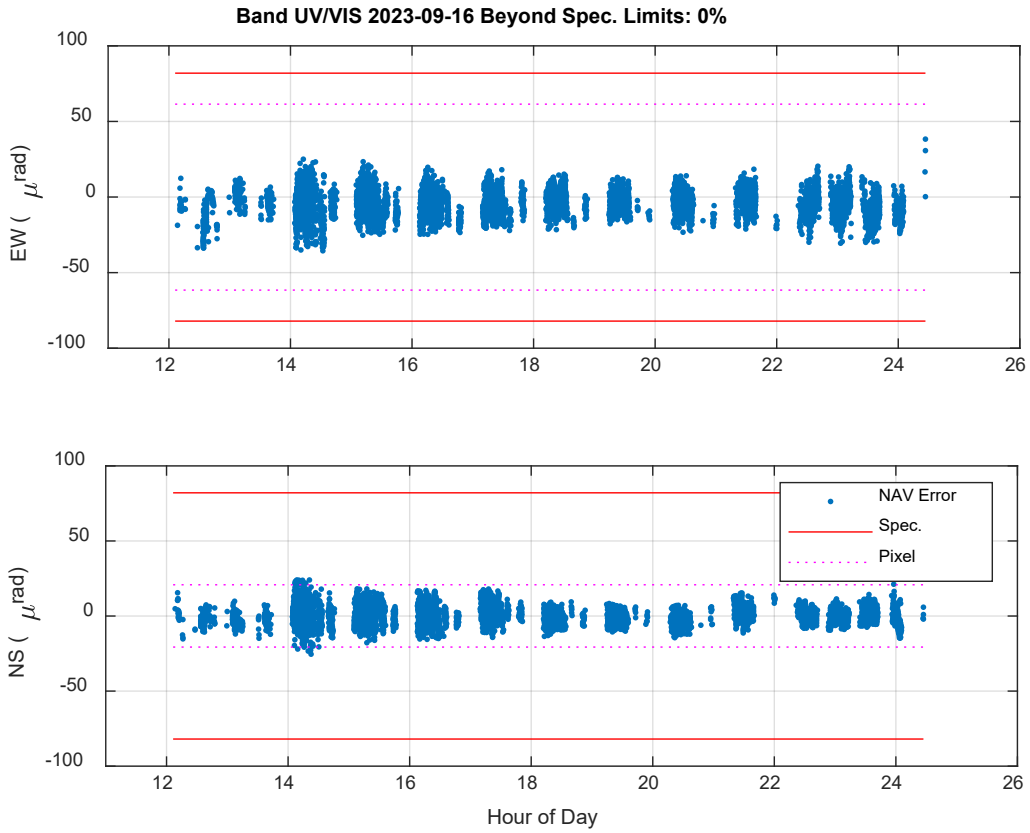
Image Navigation and Registration Status



- **INR Requirements are Met**
  - ✓ Navigation error limits exceeded = 0% (3s) of evaluations (Pass)
  - ✓ Optimized scanning performs worse at start of day
- **Tuning efforts aim to improve start-of-day performance**
  - ✓ Illumination is very low for earliest scans
  - ✓ May have separate tunings for Optimized and CONOPS scanning
- **Consistent NS biases observed in UV/VIS**
  - ✓ Not a specification compliance issue
  - ✓ Should investigate and correct in any case

Optimized Scanning (GPSR): September 16 Next INR Release





- **Registration meets < 4km requirement; Effective jitter much smaller than requirement**

[*urad*]

	EW Mean	EW Std	NS Mean	NS Std	Out of Limit
VIS/NIR	-2.0981	6.0594	-1.4832	4.1732	0
UV/VIS	-3.3226	6.1935	-0.128	4.3225	0

Calibration and L1b Validation

- Verify and update image correction steps in the L0-1 processing during Commissioning Phase and Nominal Operation
  - System linearity, zero-input, relative gains, saturation blooming, dark current variation and temperature-dependent correction, check quality flags, evolution of solar diffuser, noise calculation, straylight
- Assess wavelength calibration and its performance
  - Will assess performance of routine processing (wavelength calibration in both L0-1b & L1-2 via high-resolution solar reference and atmospheric absorption)
  - Pre-launch measured instrument line shape will be compared with that derived from solar irradiance
- Assess radiometric calibration using a multi-pronged approach
  - Internal assessment of images, assess performance of routine processing
  - Comparison solar irradiance with solar reference and correlative contemporaneous sensors (e.g., OMPS, TROPOMI, GOME-2, EPIC, MODIS, VIIRS)
  - Comparison with radiative transfer simulation
- Assess and improve INR accuracy
  - Alignment issue, ephemeris reliability, IRU time synchronization, scan tailoring verification
  - Different configuration for special observation

Summary and outlook

- Initial look has been done for each core element of Level 1b cal/val plan
- Image processing
  - Calibration key data and octant phase identification have been updated since the first light.
  - Refining image processing steps (e.g., electronic offset removal, smear correction, and dark current correction to account for temperature dependence), dynamic bad-pixel flagging, and updating other quality flags are underway.
- BTDF
  - A scattering-angle-based correction will be implemented.
- Spectral calibration
  - Wavelength grids have been updated and are being optimized using Chebyshev polynomials.
  - Plans for radiance calibration
    (a) Use actual solar irradiances measured from TEMPO for reference spectra.
    (b) For each CCD, derive a single shift against the irradiance grids from a small fitting window to speed up the process.
- Testing for stray light and polarization corrections is currently underway.
- INR
  - Verified using GEOS-E/W with terrain correction, INR meets the requirements.
  - Further updates are ongoing to optimize the performance and make it more robust.
- Level 1b to be released February 2024


TEMPO

Backup

Solar Calibration Geometry