TSIS-1 SIM Science Data Processing Update

Penton, Béland, Brooks, Chambliss, Charbonneau, & Peck

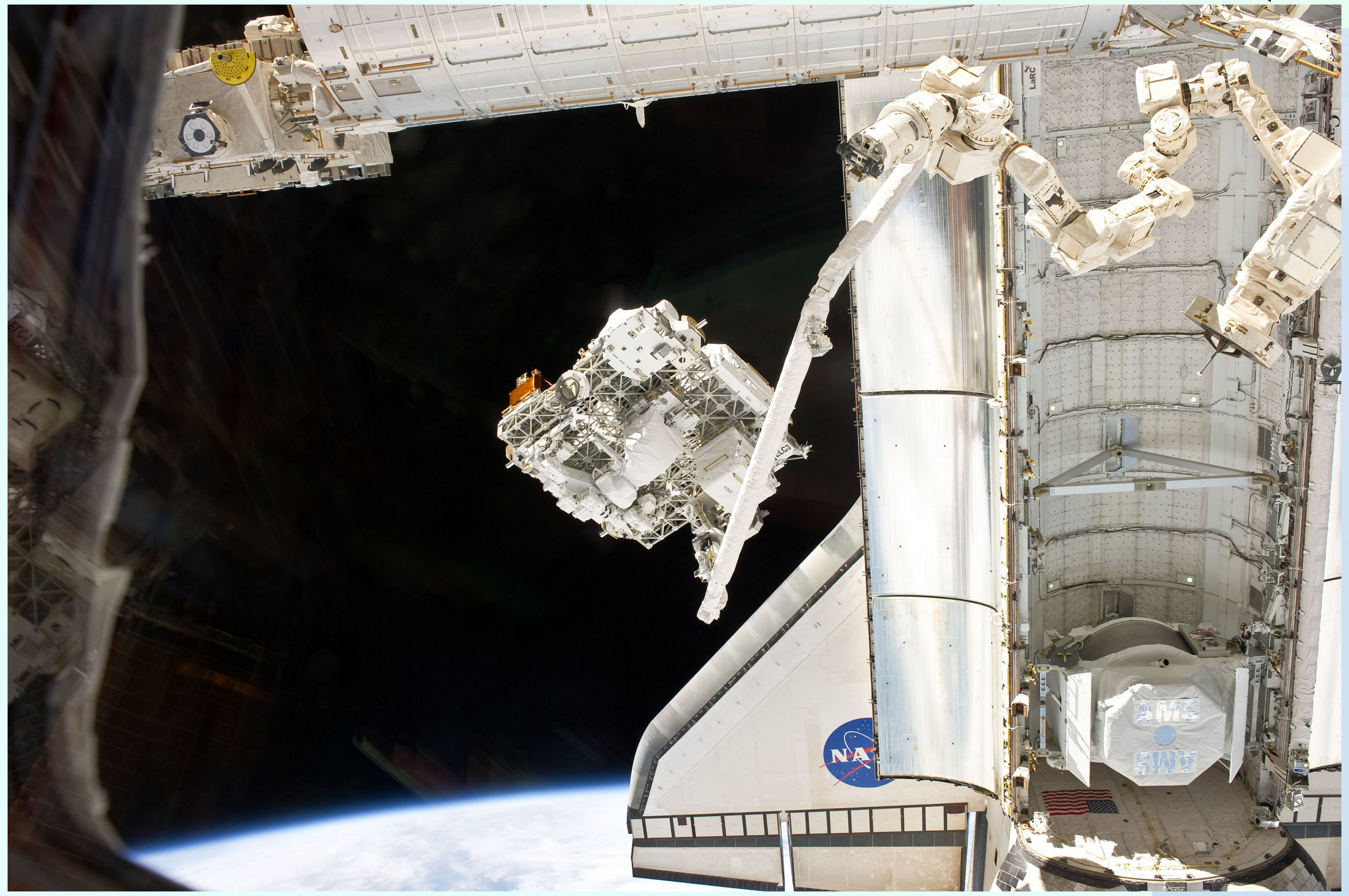
TSIS-1 PI : Tom Woods

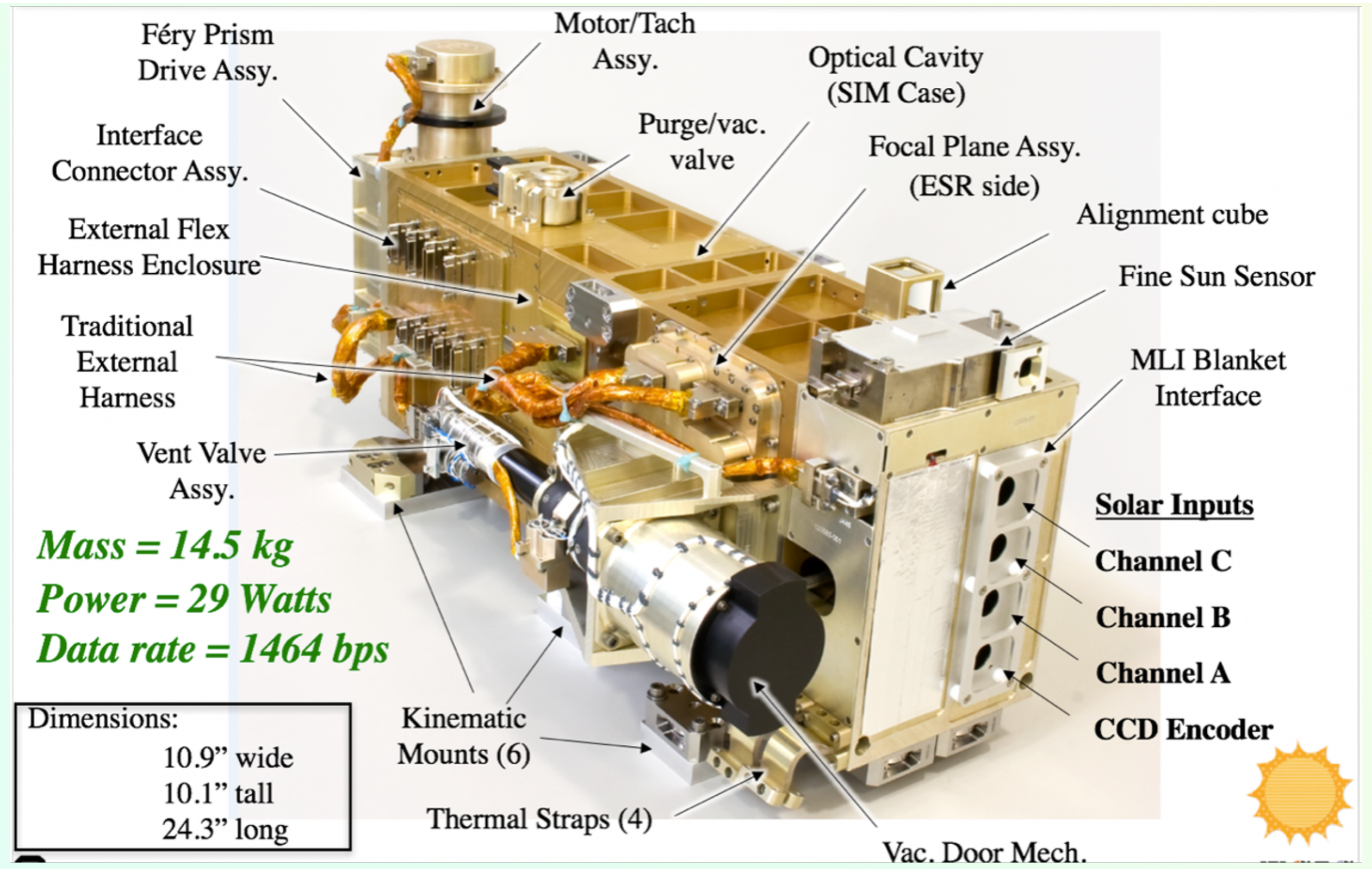
TSIS-1 SIM Instrument Scientist : Erik Richard

Introduction to TSIS-1 SIM

The Total and Solar Irradiance Sensor (TSIS-1) operates on the International Space Station (ISS) from the ELC-3 (ExPRESS Logistics Carrier, STS-134). TSIS was launched on Dec 15, 2017 on a SpaceX Falcon 9.

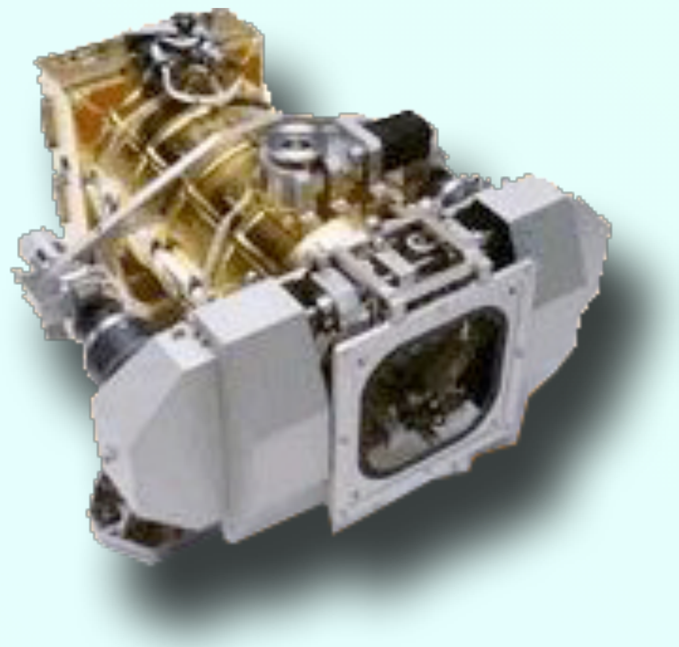
TSIS-1 measures TSI with the TIM (Total Irradiance Monitor) and SSI with SIM (Spectral Irradiance Monitor).



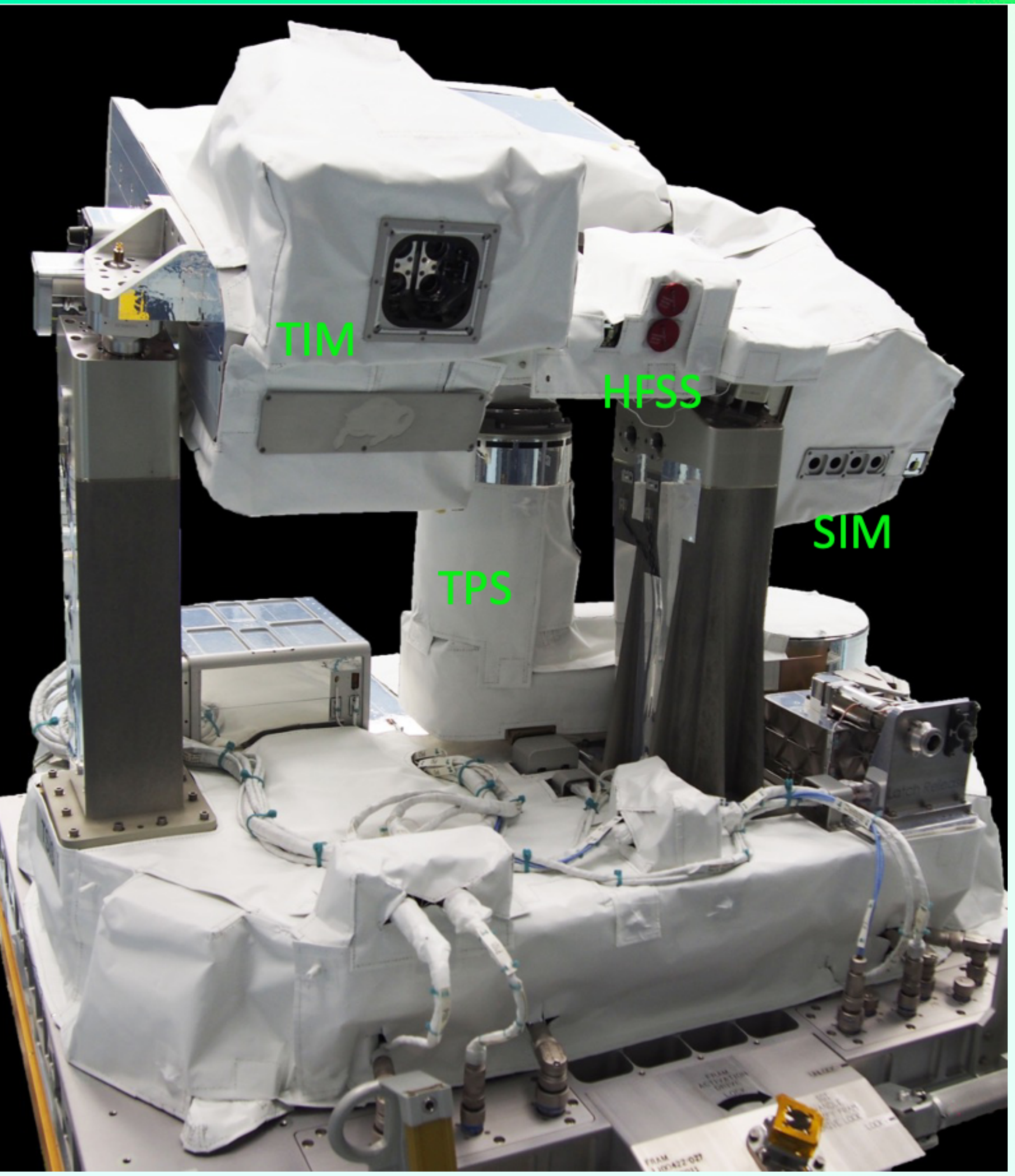


SIM

TIM

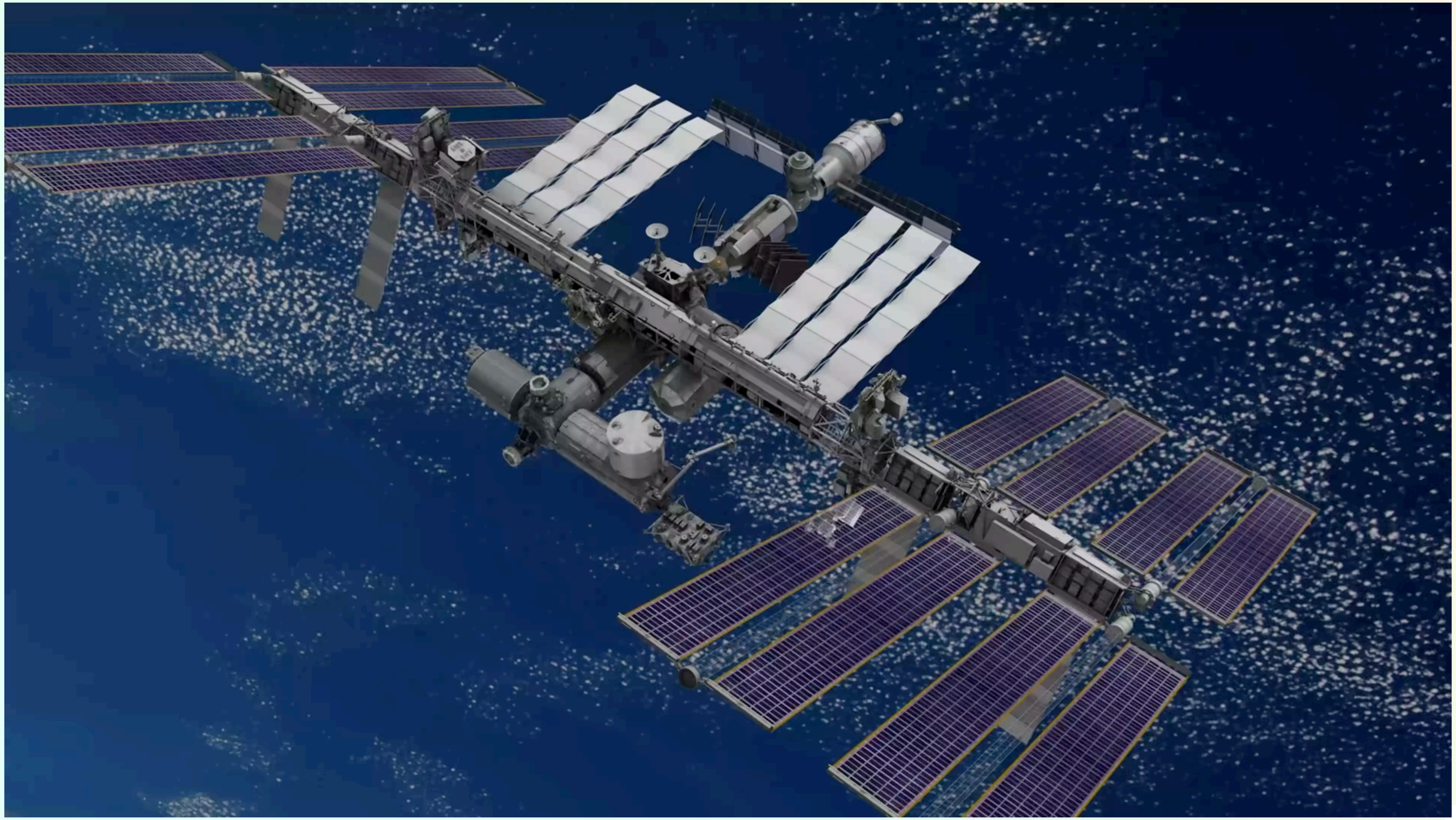


Introduction to TSIS-1



The TIM+SIM optical bench is mounted on a two-axis gimbal known as the thermal pointing system (TPS).

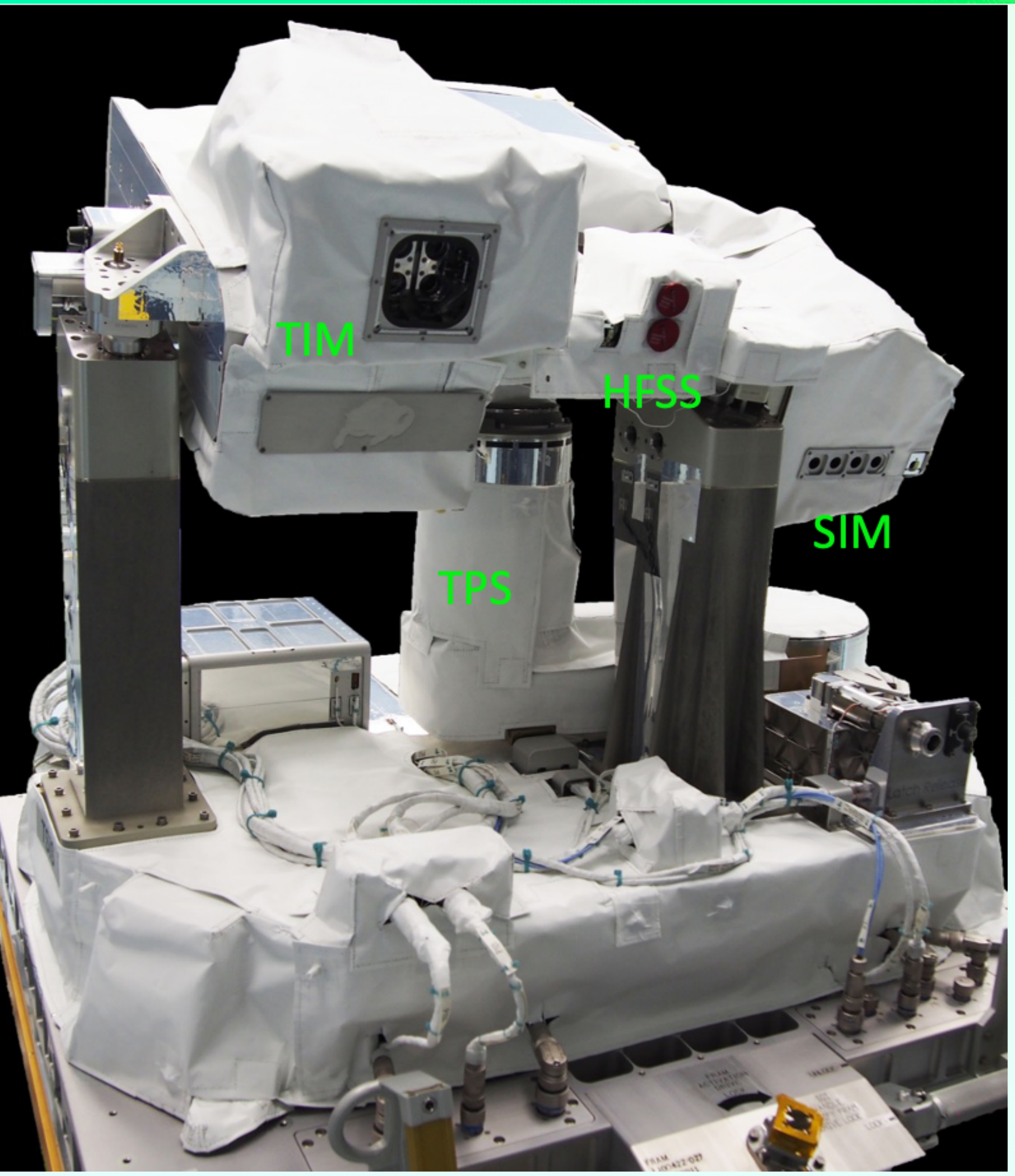
Solar pointing is controlled by 1 of 2 High-rate Fine Sun Sensors (HFSS)



ISS orbits the Earth ~15.5 times a day

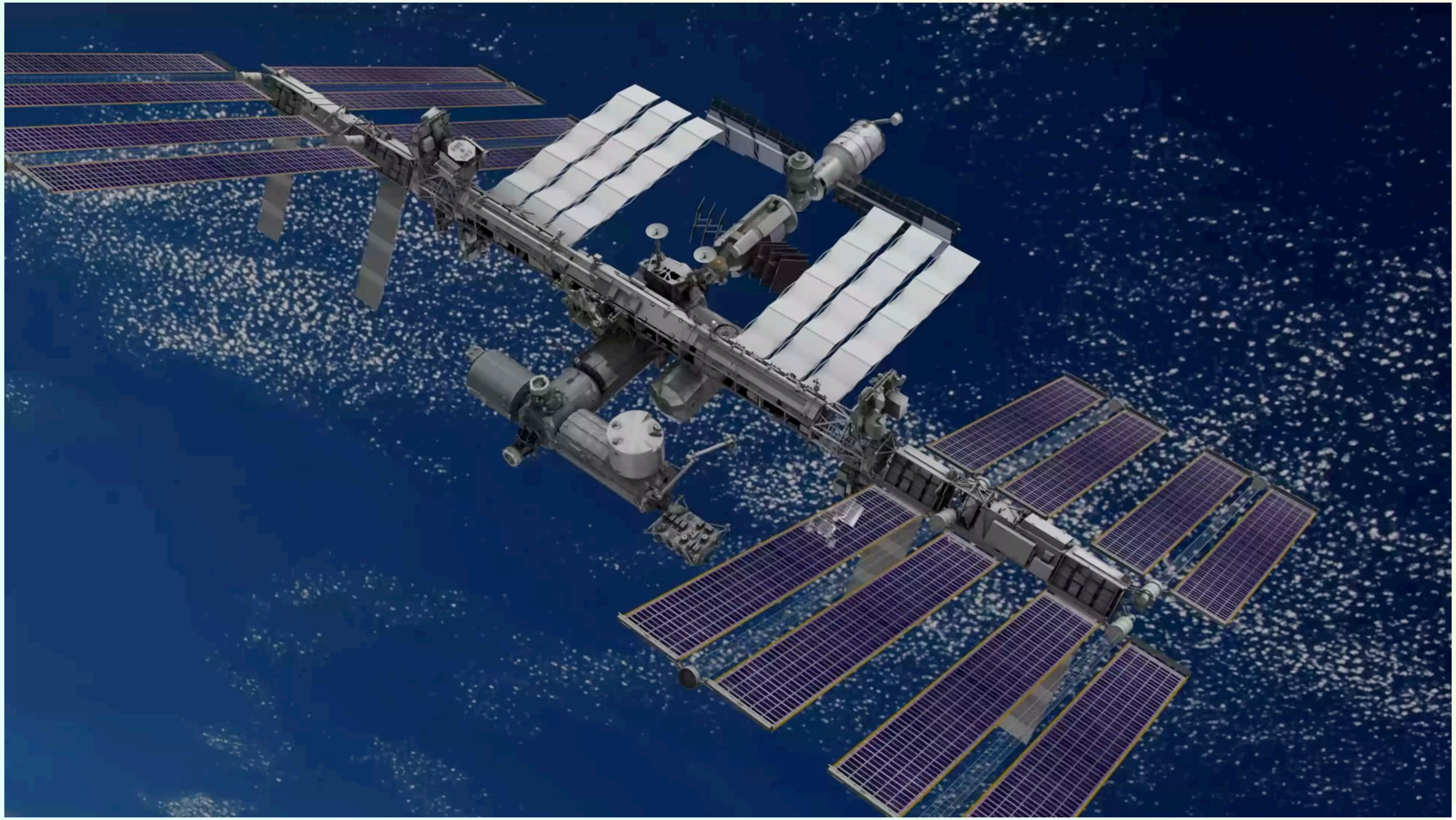
~45 min/orbit for science

Introduction to TSIS-1



The TIM+SIM optical bench is mounted on a two-axis gimbal known as the thermal pointing system (TPS).

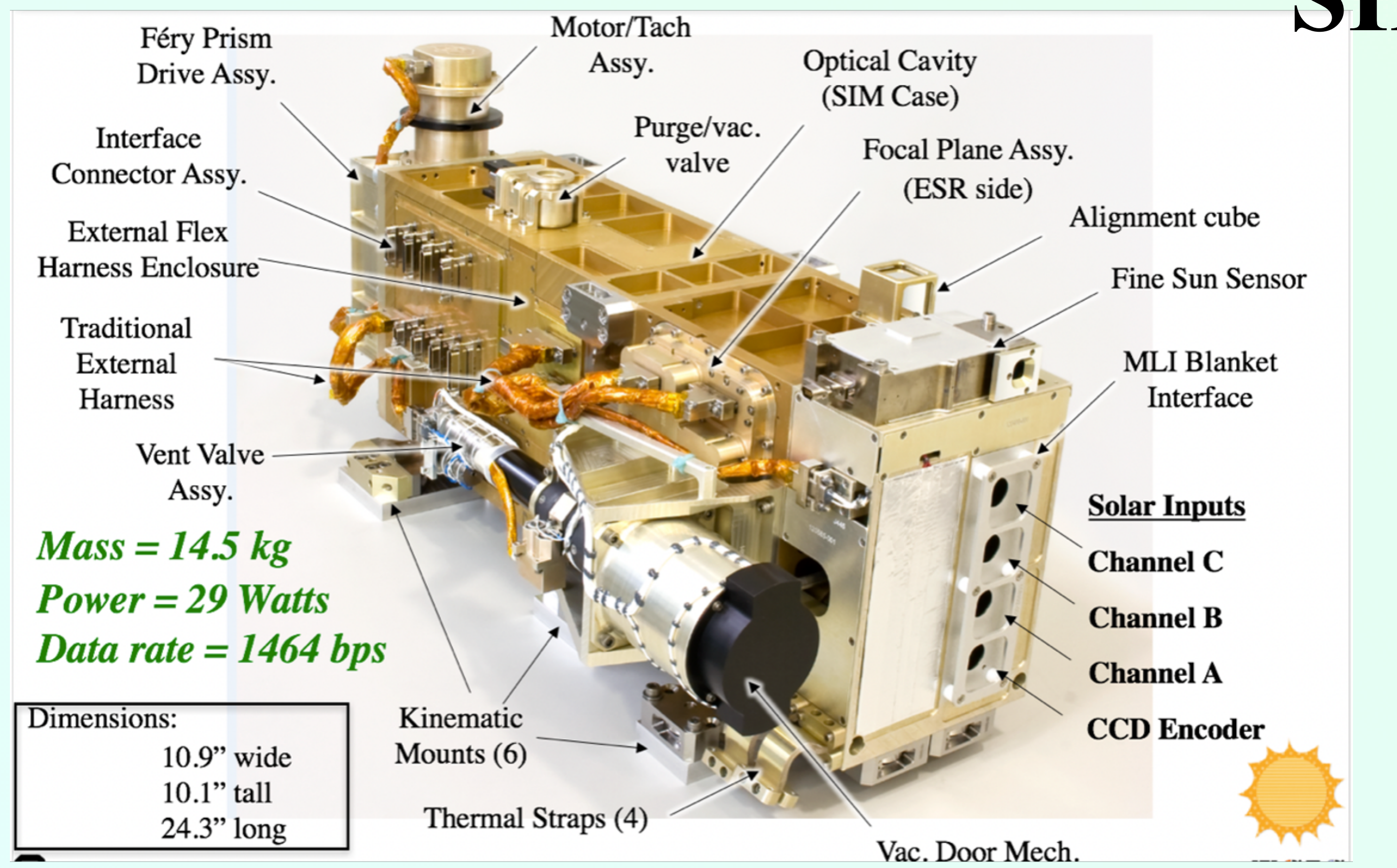
Solar pointing is controlled by 1 of 2 High-rate Fine Sun Sensors (HFSS)



ISS orbits the Earth ~15.5 times a day

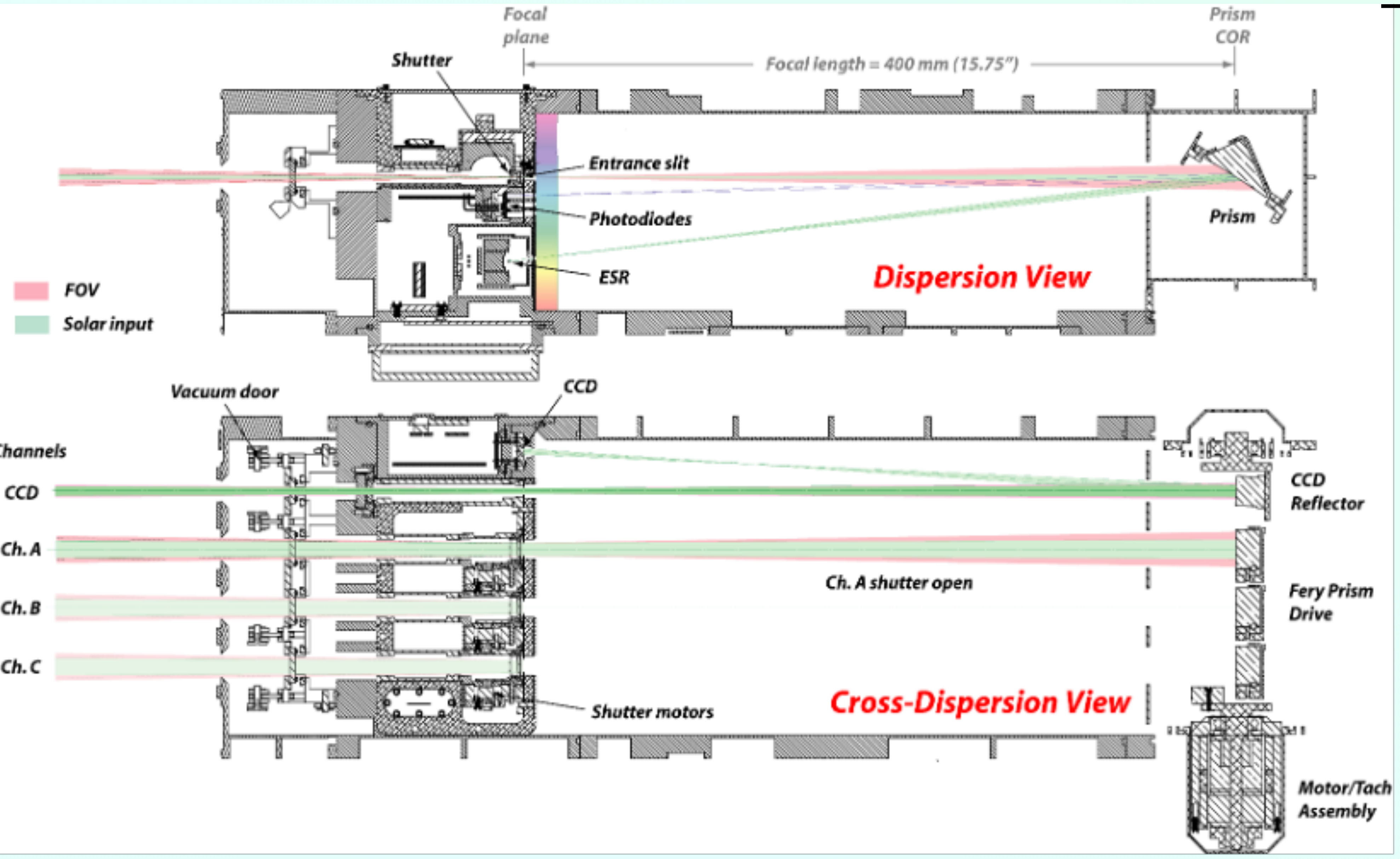
~45 min/orbit for science

Introduction to TSIS-1 SIM



SIM is a 3-channel Spectrometer (1 wavelength at a time). Each channel contains:

- **UV diode (200 - 312 nm)**
- **VIS diode (312 - 950 nm)**
- **IR diode (950 -1620 nm)**
- **ESR (Electronic Substitution Radiometer) 1620-2402 nm**
- **A Féry Prism that degrades (becomes opaque) with usage**

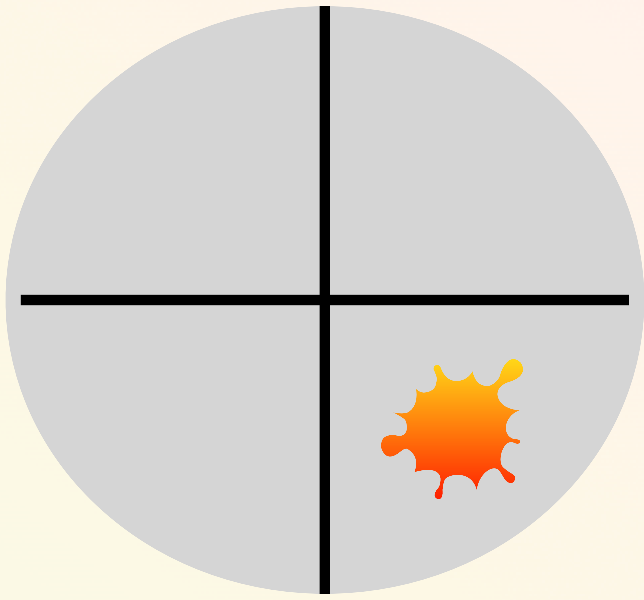


- **ChA is the prime channel and takes 2 full spectra a day**
- **ChB and C are used to monitor ChA degradation**
- **ChB takes a full spectrum every 3-4 weeks**
- **ChC takes a full spectrum twice a year when the Earth is at 1AU (early April and early October)**
- **Each ChC spectrum triggers a recalibration of the entire mission, and an new data release**
- **Observing schedule is limited by ISS operations/obstructions**

Since last Sun-Climate Symposium (May 2022)

On 2022-03-19, contamination from Soyuz MS-21 docking reduced counts on the HFSS-B quad diode

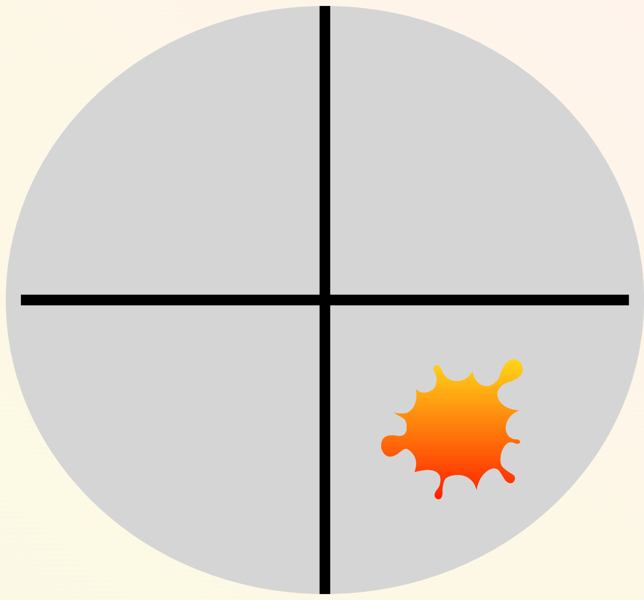
- Resulted in all SIM observations from 2022-03-19 to 2022-05-19 being offset by 1 arcmin
    - This included the Apr 2022 ChC observations (unusable)
- TSIS-1 SIM V07 data release was halted, and no data published after 2022-03-19
- On 2022-05-19, pointing was switched to the backup HFSS (HFSS-A)



Since last Sun-Climate Symposium (May 2022)

On 2022-03-19, contamination from Soyuz MS-21 docking reduced counts on the HFSS-B quad diode

- Resulted in all SIM observations from 2022-03-19 to 2022-05-19 being offset by 1 arcmin
  - This included the Apr 2022 ChC observations (unusable)
- TSIS-1 SIM V07 data release was halted, and no data published after 2022-03-19
- On 2022-05-19, pointing was switched to the backup HFSS (HFSS-A)



In June 2022, we commissioned a series of recovery exposures to derive a spectral correction for the off-pointed data

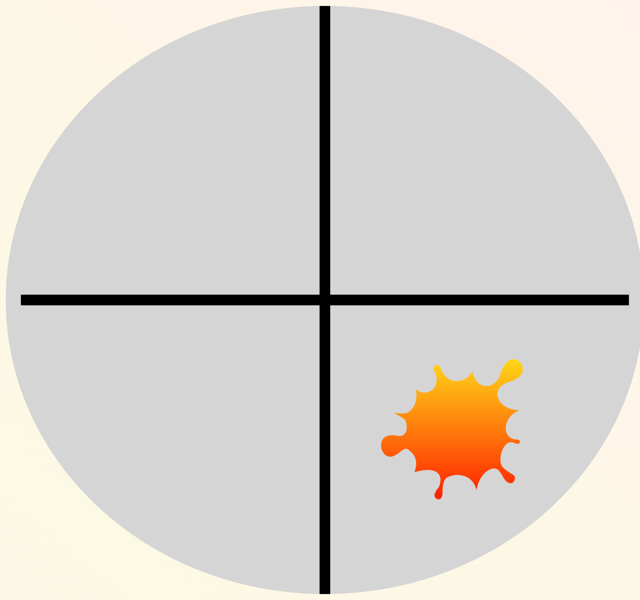
- 2 sets of back-to-back HFSS-B(OFF) and HFSS-A ChA/ChB spectra, 2 weeks apart to quantify solar variability
- On 2022-08-11, TSIS-1 SIM V08 was released, with HFSSB-B(OFF) data fully corrected for off-pointing
  - Adds L3 data quality flags (including one for HFSS-B(OFF) spectra) & adds baseline (filtering) spectrum (safety net)
- On 2022-08-18, another contamination event affected HFSS-A (just after RS EVA-54 and SpX-25 thruster test)
  - minor (5 arcsecond) compared to HFSS-B offset (60 arcseconds), ok to proceed, but correction desired

---

Since last Sun-Climate Symposium (May 2022)

On 2022-03-19, contamination from Soyuz MS-21 docking reduced counts on the HFSS-B quad diode

- Resulted in all SIM observations from 2022-03-19 to 2022-05-19 being offset by 1 arcmin
  - This included the Apr 2022 ChC observations (unusable)
- TSIS-1 SIM V07 data release was halted, and no data published after 2022-03-19
- On 2022-05-19, pointing was switched to the backup HFSS (HFSS-A)



In June 2022, we commissioned a series of recovery exposures to derive a spectral correction for the off-pointed data

- 2 sets of back-to-back HFSS-B(OFF) and HFSS-A ChA/ChB spectra, 2 weeks apart to quantify solar variability
- On 2022-08-11, TSIS-1 SIM V08 was released, with HFSSB-B(OFF) data fully corrected for off-pointing
  - Adds L3 data quality flags (including one for HFSS-B(OFF) spectra) & adds baseline (filtering) spectrum (safety net)
- On 2022-08-18, another contamination event affected HFSS-A (just after RS EVA-54 and SpX-25 thruster test)
  - minor (5 arcsecond) compared to HFSS-B offset (60 arcseconds), ok to proceed, but correction desired

---

After ChC scans in 2022-10, the TSIS-1 SIM V09 data release of 2022-11-15 added a new column to the data record

- ADDITIONAL_UNCERTAINTY : reports the uncertainty associated with the HFSS-B(OFF) spectral corrections

V08/09 : Correcting the HFSS-B(OFF) pointed SIM data in V07

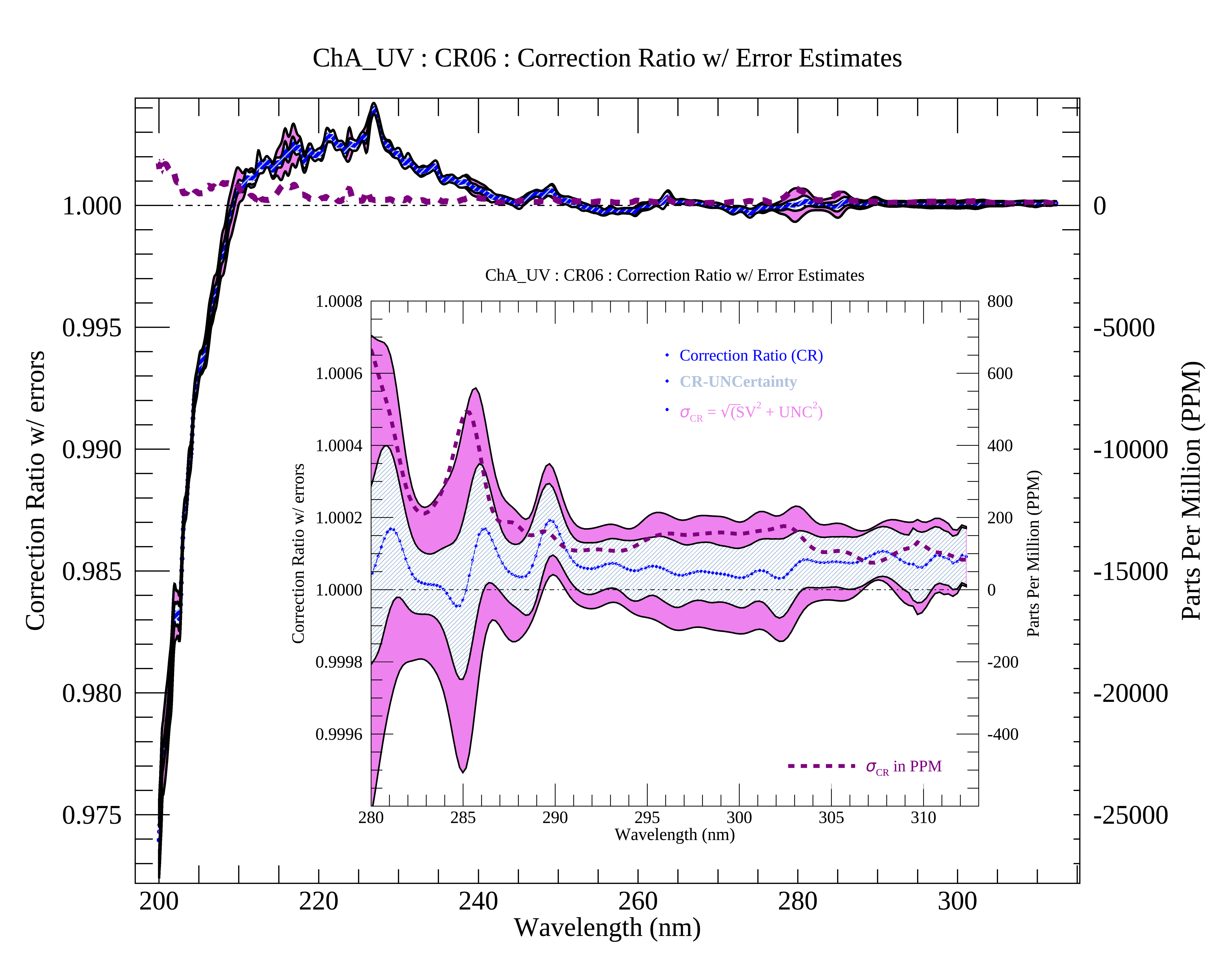
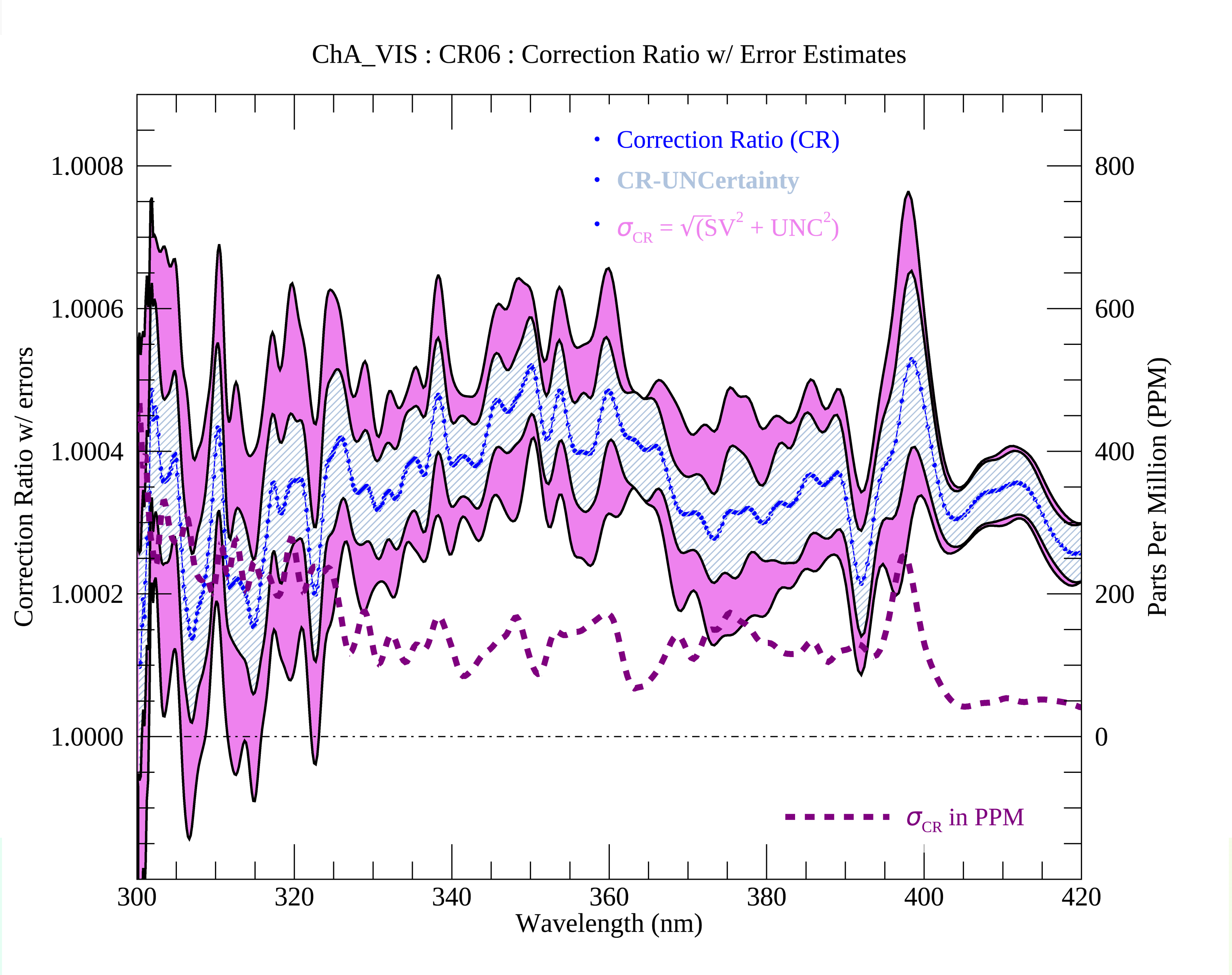


Figure shows the HFSSB-(OFF) pointing SSI correction and uncertainty for the UV diode of TSIS-1 SIM Channel-A .

Without correction, V07 SSI measurements were off by as much as 2.5% (25,000 ppm)

Uncertainties are a combination of based of published V08 SSI uncertainties + solar variability between calibration observations



VIS-B Correction

V08/09 : Correcting the HFSS-B(OFF) pointed SIM data in V07

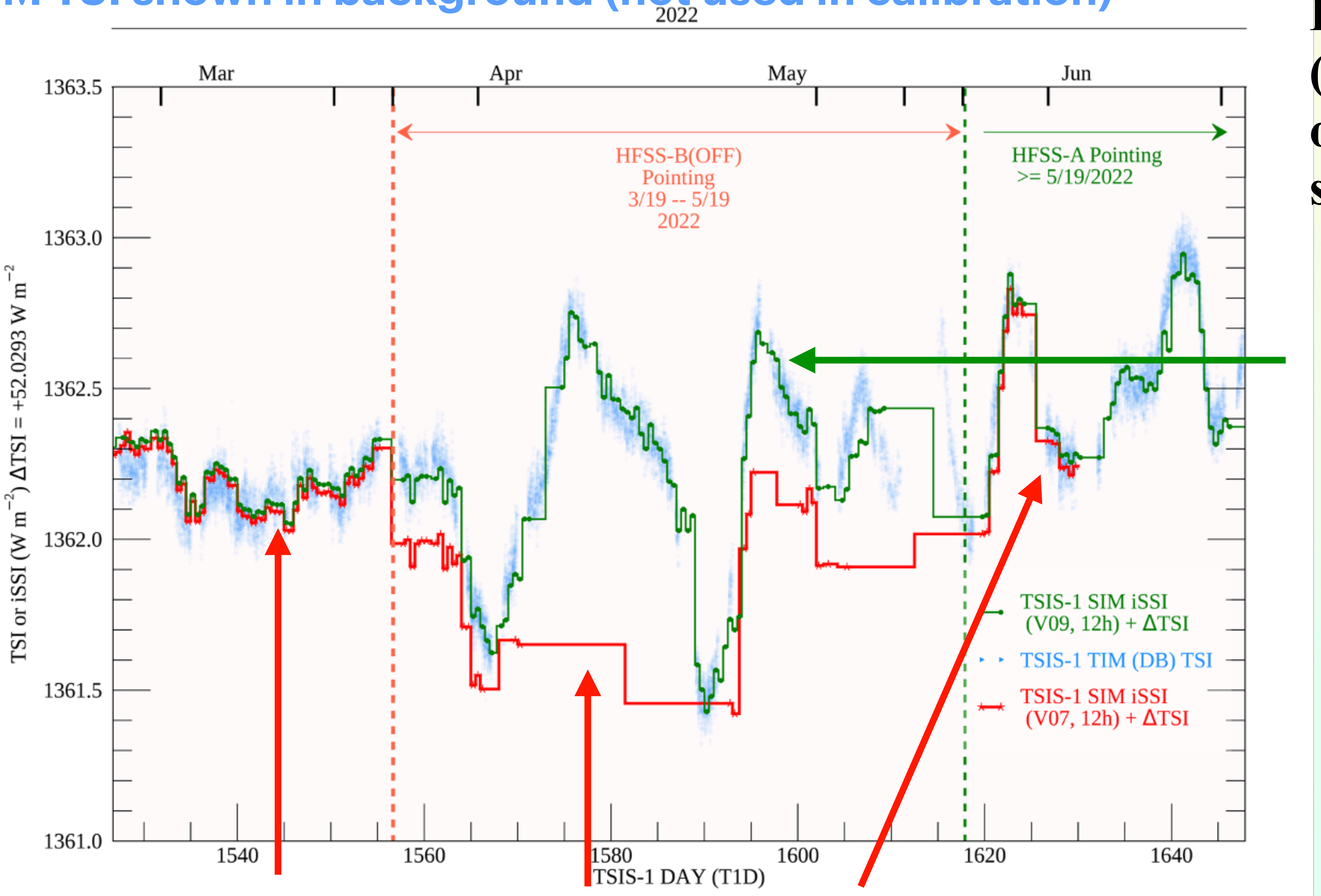
TIM TSI shown in background (not used in calibration)

TSIS-1 SIM V09 @ 366 nm tracks TSI during contamination, HFSS-B(OFF) pointing.

V07 @ 366 nm tracks TSI before contamination, significantly offset during, recovers after.

V08/09 : Correcting the HFSS-B(OFF) pointed SIM data in V07

TIM TSI shown in background (not used in calibration)



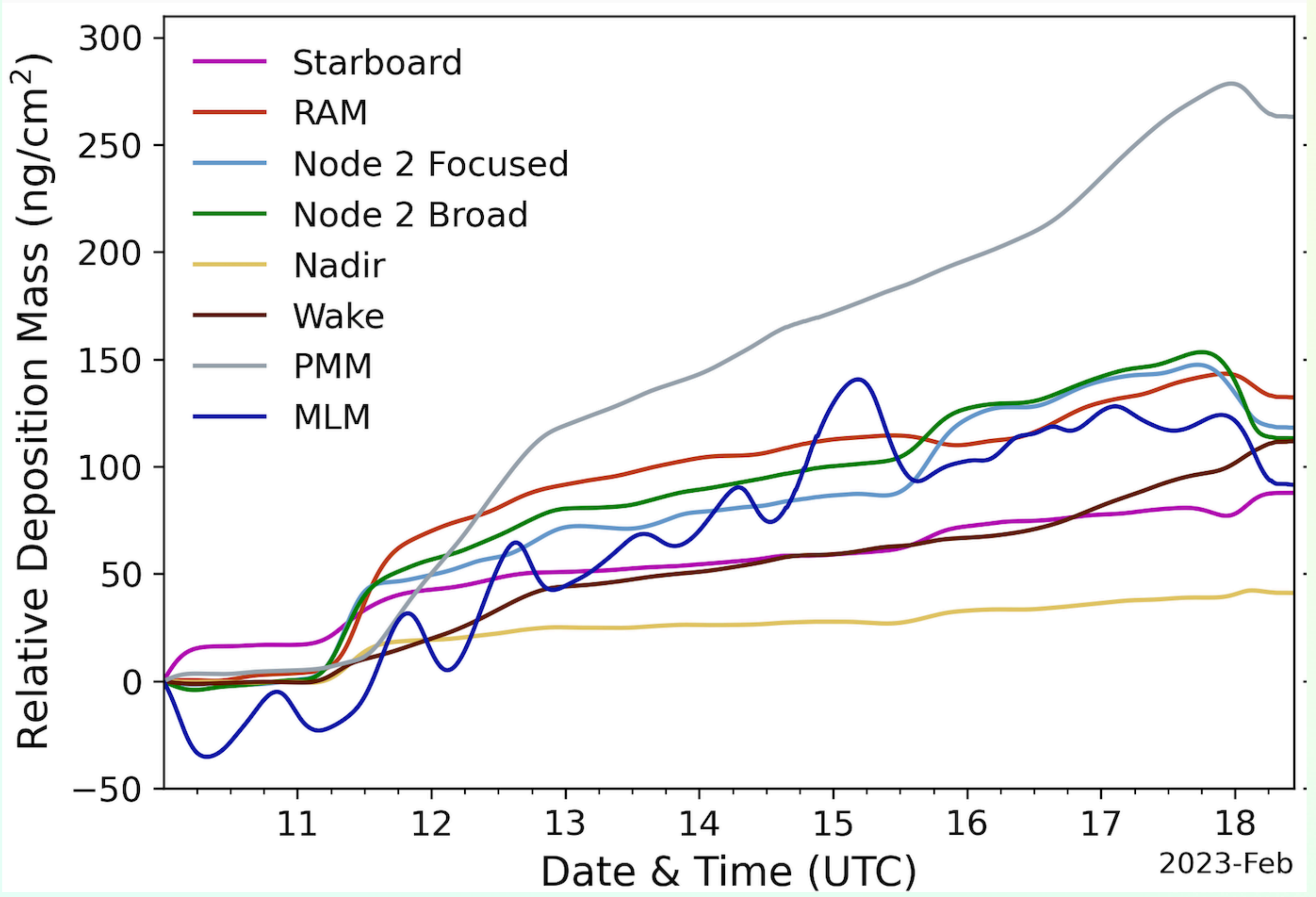
Integrating SSI from 200-2402 nm (iSSI) allows the best comparison of the effectiveness of the V08/V09 spectral corrections.

TSIS-1 SIM V09 iSSI tracks TSI during contamination, HFSS-B(OFF) pointing.

V07 @ 366 nm tracks TSI before contamination, significantly offset during, recovers after.

TSIS-1 SIM Update for Fall 2022 / Spring 2023

- 2022-11-15 : V09 released
- 2022-12-15 : MS-22 major leak
  - Fortunately, no SIM impact
- 2023-02-09 : HFSS-A/B realigned
  - HFSS-B now a viable backup
- 2023-02-11: Another MS-21 Leak
  - Fortunately, no SIM impact
- 2023-04 : Successful ChC Scans
- 2023-05-31 : V10 released
  - ESR (> 740 nm) wavelength alignment now uses IR prism offset corr.
  - Updated IR prism degradation corrections for 950-1620 nm
  - New prism degradation correction for ESR 1620–1845 nm
  - Updated baseline (filtering) spectrum using V10 data



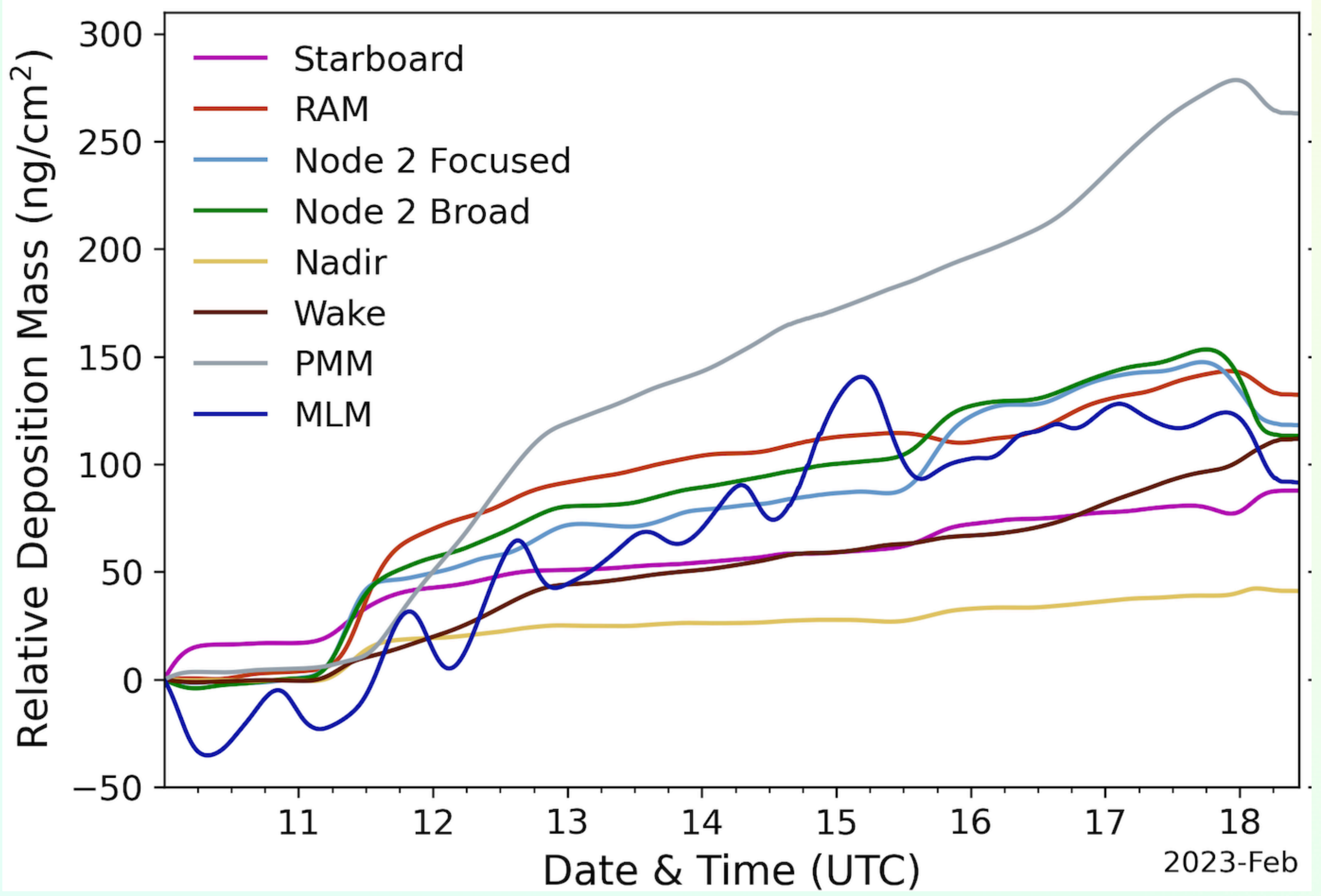
SAGE III (ELC-4

Monitored signific
contamination on t
panels facing
multiple directions

Up to 300 ng/cm²

TSIS-1 SIM Update for Fall 2022 / Spring 2023

- 2022-11-15 : V09 released
- 2022-12-15 : MS-22 major leak
  - Fortunately, no SIM impact
- 2023-02-09 : HFSS-A/B realigned
  - HFSS-B now a viable backup
- 2023-02-11: Another MS-21 Leak
  - Fortunately, no SIM impact
- 2023-04 : Successful ChC Scans
- 2023-05-31 : V10 released
  - ESR (> 740 nm) wavelength alignment now uses IR prism offset corr.
  - Updated IR prism degradation corrections for 950-1620 nm
  - New prism degradation correction for ESR 1620–1845 nm
  - Updated baseline (filtering) spectrum using V10 data



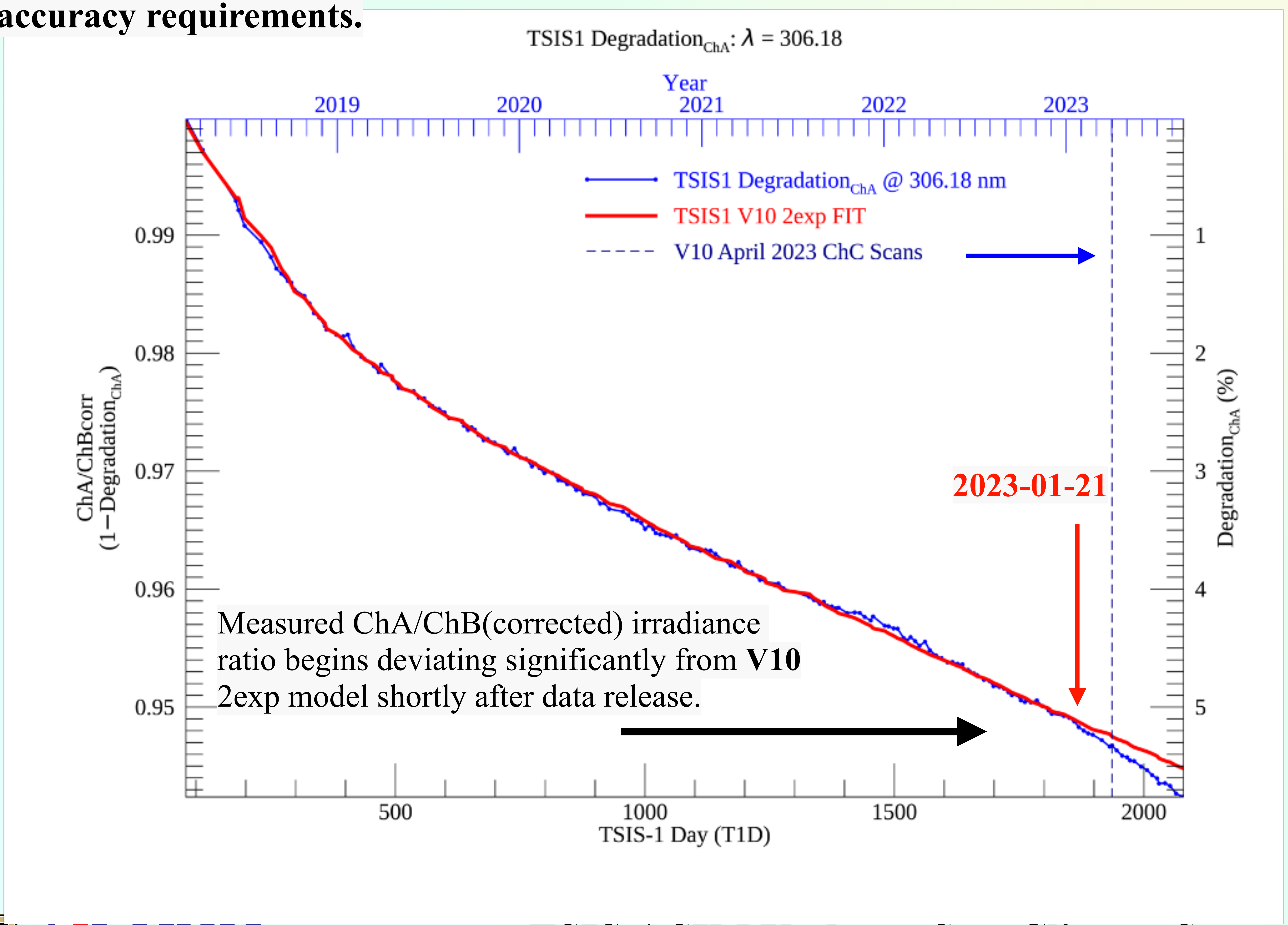
SAGE III (ELC-4

Monitored signific
contamination on t
panels facing
multiple directions

Up to 300 ng/cm²

TSIS-1 SIM V10 halted on 2023-08-10

Shortly after V10 release, the observed ChA/B irradiance ratios slowly deviated from the **V10** 2-term exponential prism degradation models used to **extrapolate** between semi-annual ChC scans. **Action was needed to prevent reported irradiances from exceeding accuracy requirements.**



Ratio change is due to increased ChA prism transmission loss, due to increased Solar activity during solar maximum

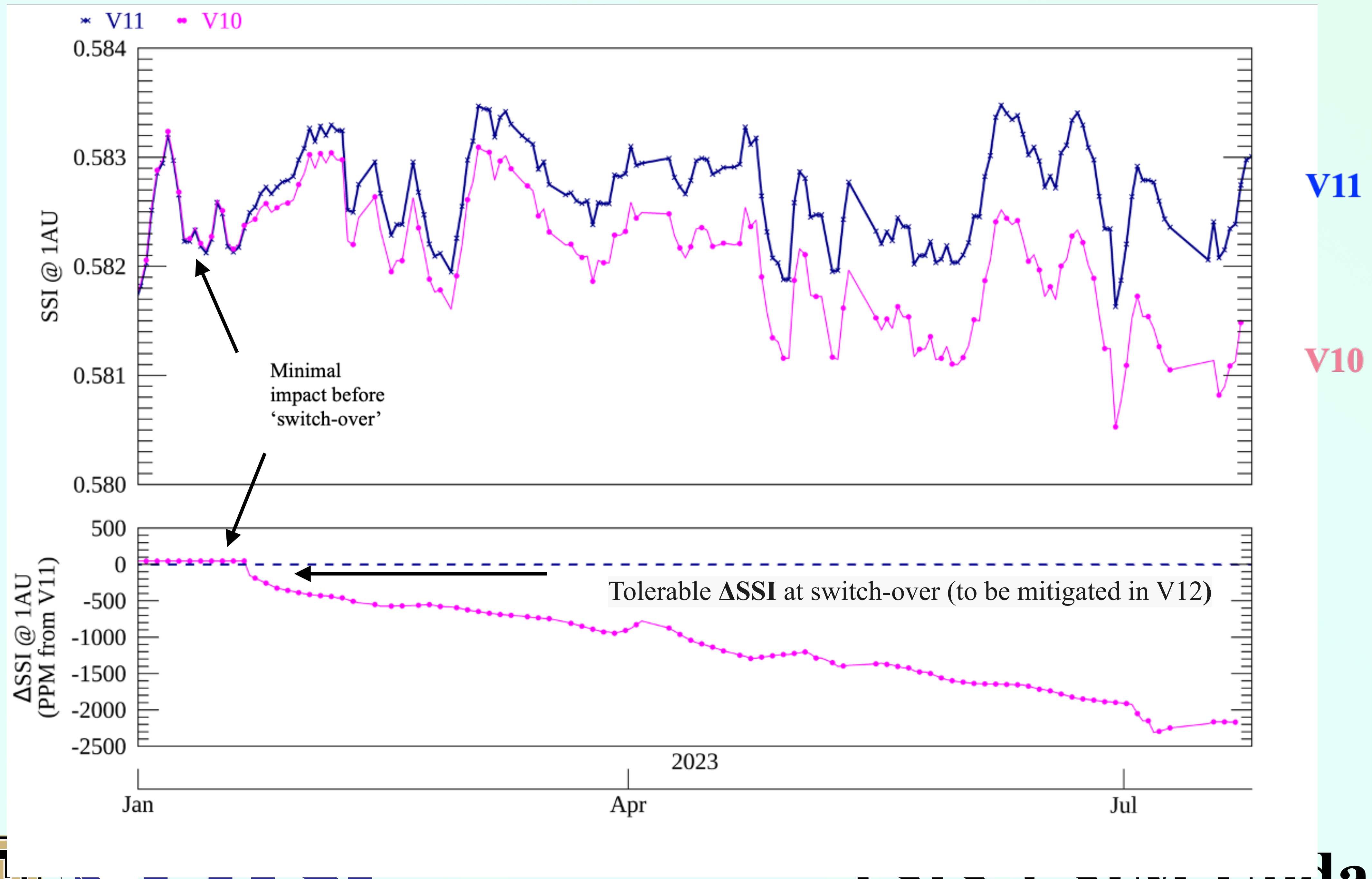
Currently only seen for $\lambda < 800$ nm on the most used channel, ChA.

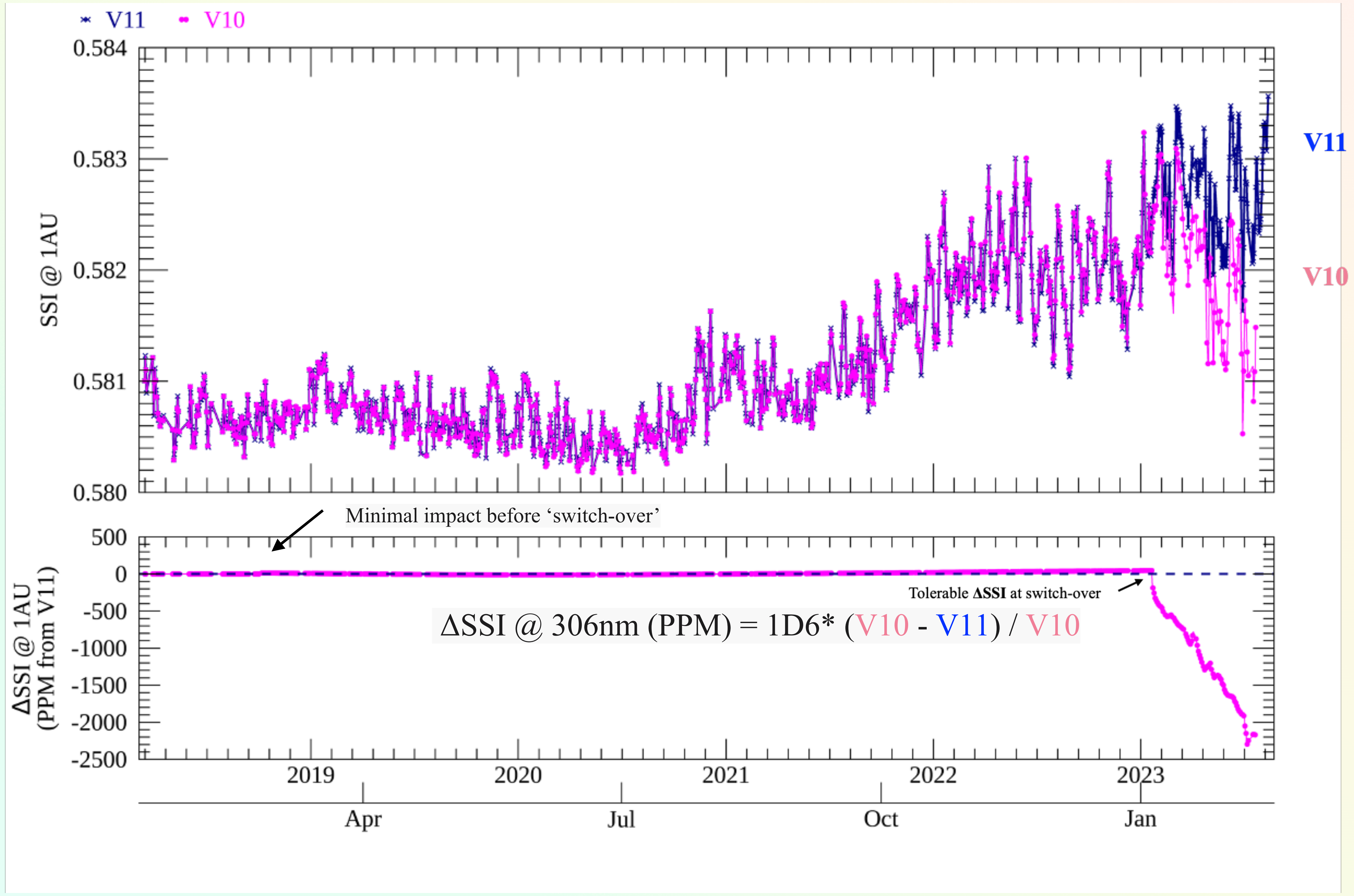
Mitigated in V11 by ending degradation model extrapolation on 2023-01-21, replaced by actual measurements (‘piece-wise’ linear, ~ the blue data)

V11 : Mitigating the V10 Prism Degradation Issue (306 nm)

V11 Timeline

- **2023-08-10** - V10 issue discovered
- **2023-08-17** - V10 data release halted
  - Alert published on all data delivery portals
  - Published data rolled back/truncated to 2023-03-07 (date at which ½ accuracy requirement exceeded)
- **2023-08-30** - V11 replaces V10
  - V11 replaces extrapolation with 'piece-wise' linear (actual measurements) after 2023-01-21

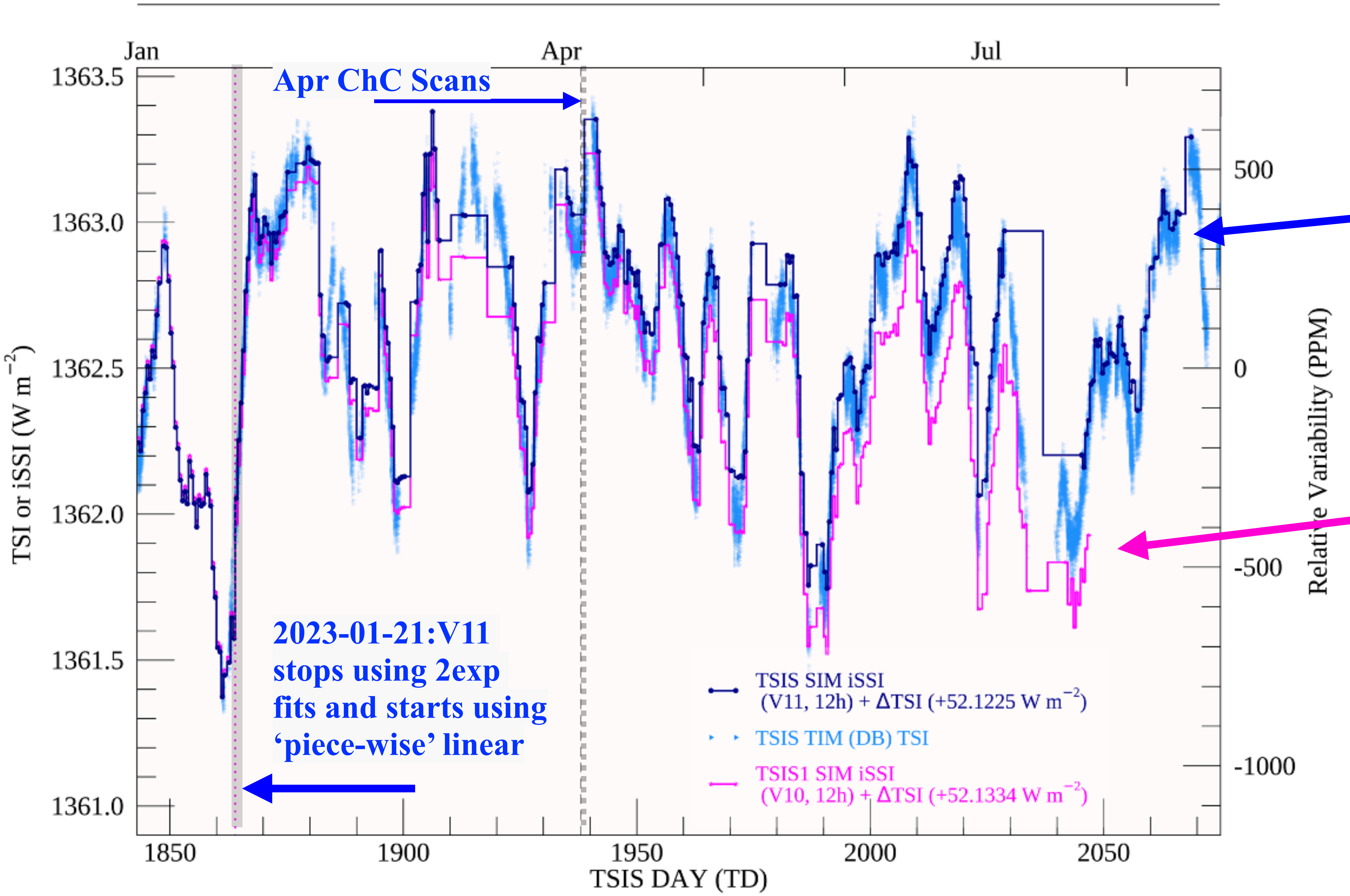




V11 alleviates the V10 prism degradation rate change issue

V11 : Mitigating the V10 Prism Degradation Issue (iSSI vs TSI)

TIM TSI shown in background (not used for calibration)



V11 iSSI tracks TIM-TSI extremely well

V10 iSSI increasingly divergent from TIM-TSI: -400 PPM on 2023-08-10

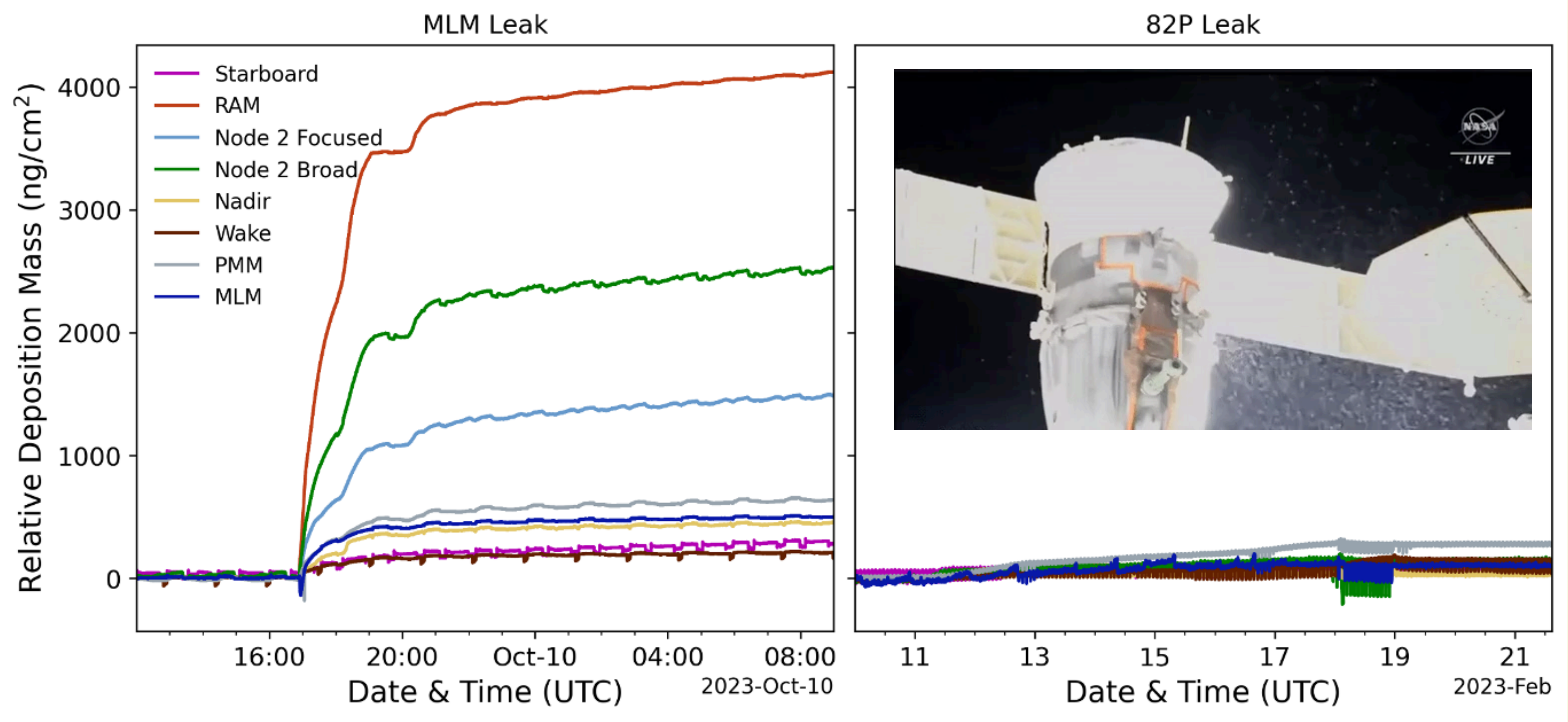
TSIS-1 SIM update for September/October 2023

- 2023-09-02 : SIM DSP (digital signal processor) hang halts SIM science operations
  - non-stop telemetry indicates instrument is otherwise healthy (temps and voltages)

- 2023-09-29 : Mission Extension Approved (at 50% budget)
  - Includes exploring an 2400-2800 nm extension

- 2023-10-04 : October ChC scans aborted

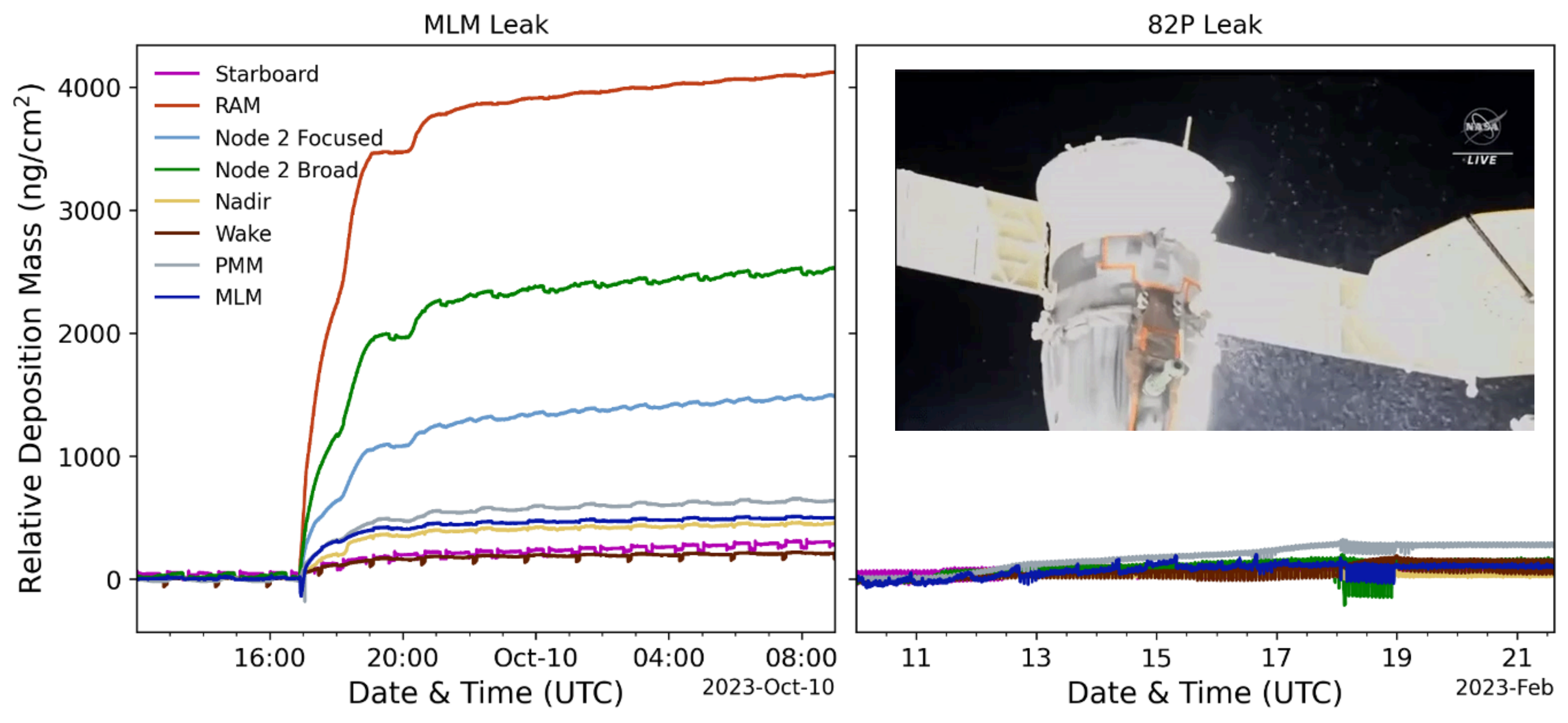
- 2023-10-09 : Major MLM Leak
  - Multipurpose Laboratory Module = Nauka
  - Up to 4000x worse than MS-22 (82P) leak !
  - 70+ liters of coolant
  - Amazingly, no SIM impact detected (FSSs or CCD)



- 2023-10-14 : SIM DSP ‘un-hung’
- 2023-10-17 : 3 days ago - SIM Dark exposures successfully executed - full functionality
- 2023-10-18 : 2 days ago - SAGE III shows contamination down to acceptable levels
- 2023-10-20 : Today - SIM resumes science operations at 12:16 PM MT

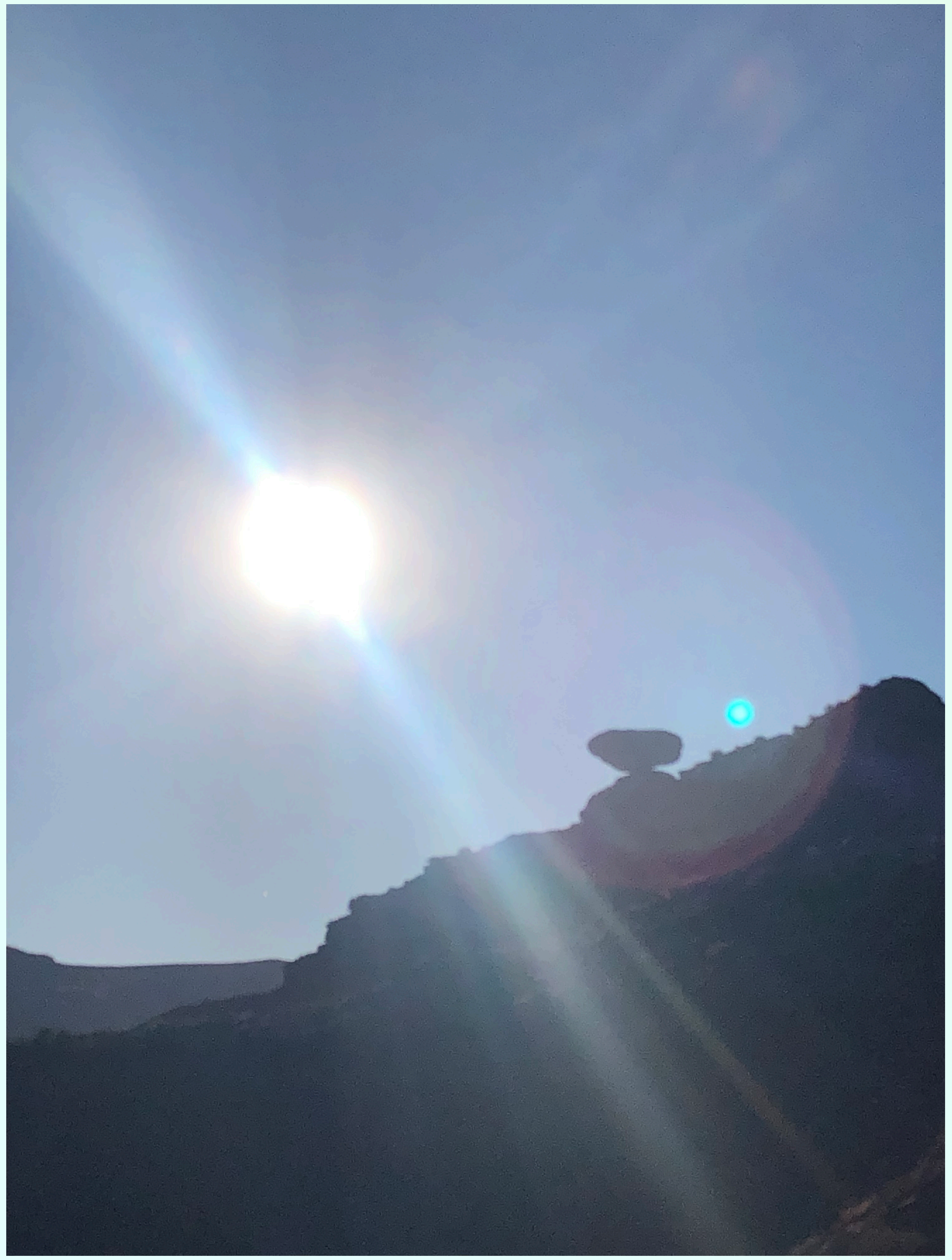
TSIS-1 SIM update for September/October 2023

- 2023-09-02 : SIM DSP (digital signal processor) hang halts SIM science operations
  - non-stop telemetry indicates instrument is otherwise healthy (temps and voltages)
- 2023-09-29 : Mission Extension Approved (at 50% budget)
  - Includes exploring an 2400-2800 nm extension
- 2023-10-04 : October ChC scans aborted
- 2023-10-09 : Major MLM Leak
  - Multipurpose Laboratory Module = Nauka
  - Up to 4000x worse than MS-22 (82P) leak !
  - 70+ liters of coolant
  - Amazingly, no SIM impact detected (FSSs or CCD)



- 2023-10-14 : SIM DSP 'un-hung'
- 2023-10-17 : 3 days ago - SIM Dark exposures successfully executed - full functionality
- 2023-10-18 : 2 days ago - SAGE III shows contamination down to acceptable levels
- 2023-10-20 : Today - SIM resumes science operations at 12:16 PM MT

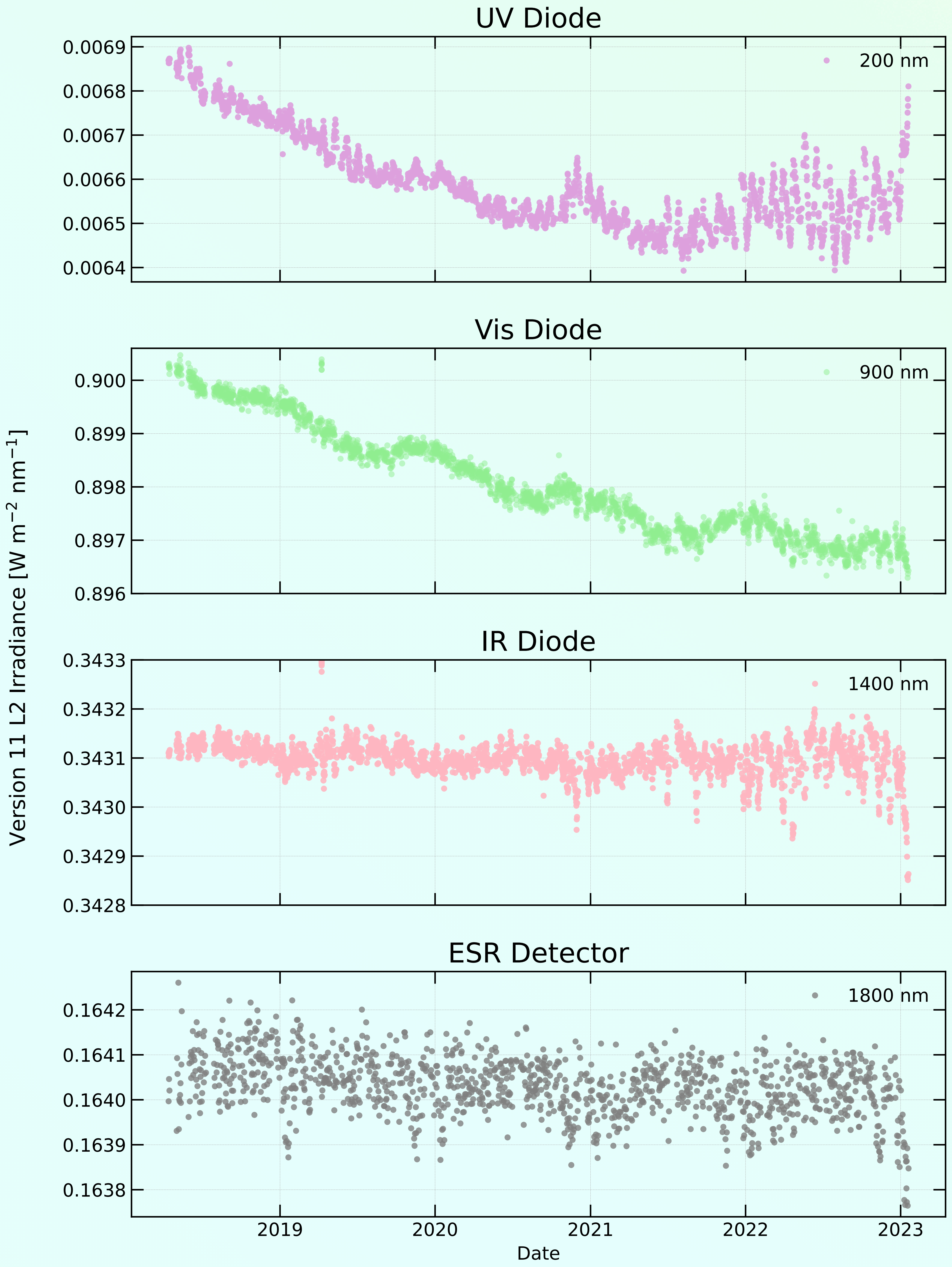
What's next ? Plans for TSIS-1 SIM V12



1. Remove the need to extrapolate prism degradations (in time)
   A. Replace 2-exponential models with polynomials or separate fits over independent time epochs (in development)
   B. After the latest ChC scan, only actual measurements will be used - 'piece-wise' linear interpolation
2. Report 'TRUE_EARTH' irradiance
   A. Current irradiance is '1AU' normalized to highlight solar variability
   B. Irradiance @ Earth important for climate studies/earth science
   C. TSIS-1 TIM already provides similar TSI data product (w/uncertainties) - Implementation will mirror TSIS-1 TIMs
3. Continued evolution of software for multi-mission use (TSIS-2)
4. Continued mitigation of annual signals seen in time series

V12 : Investigating Removal of Instrumental Annual Oscillations

V11



Investigating two main improvements:

1) Improving diode temp. dependence, dR/dT

2) Improving the diffraction correction using the true solar radius instead of the average

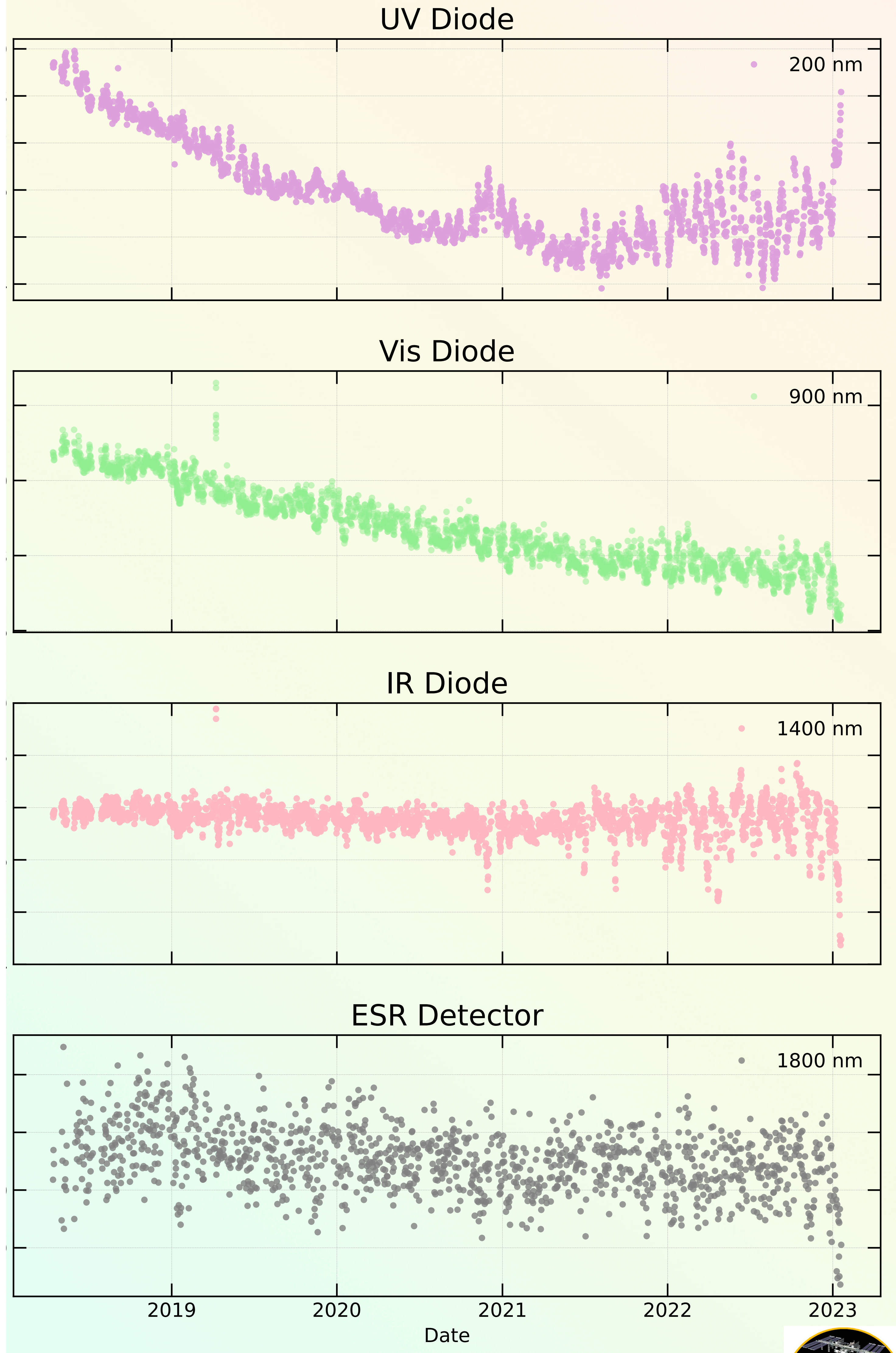
L2 data shown in figures
(no prism degradation correction)

VIS diode improvement is ~100% via dR/dT

IR and **ESR** improvements are mainly from diffraction correction

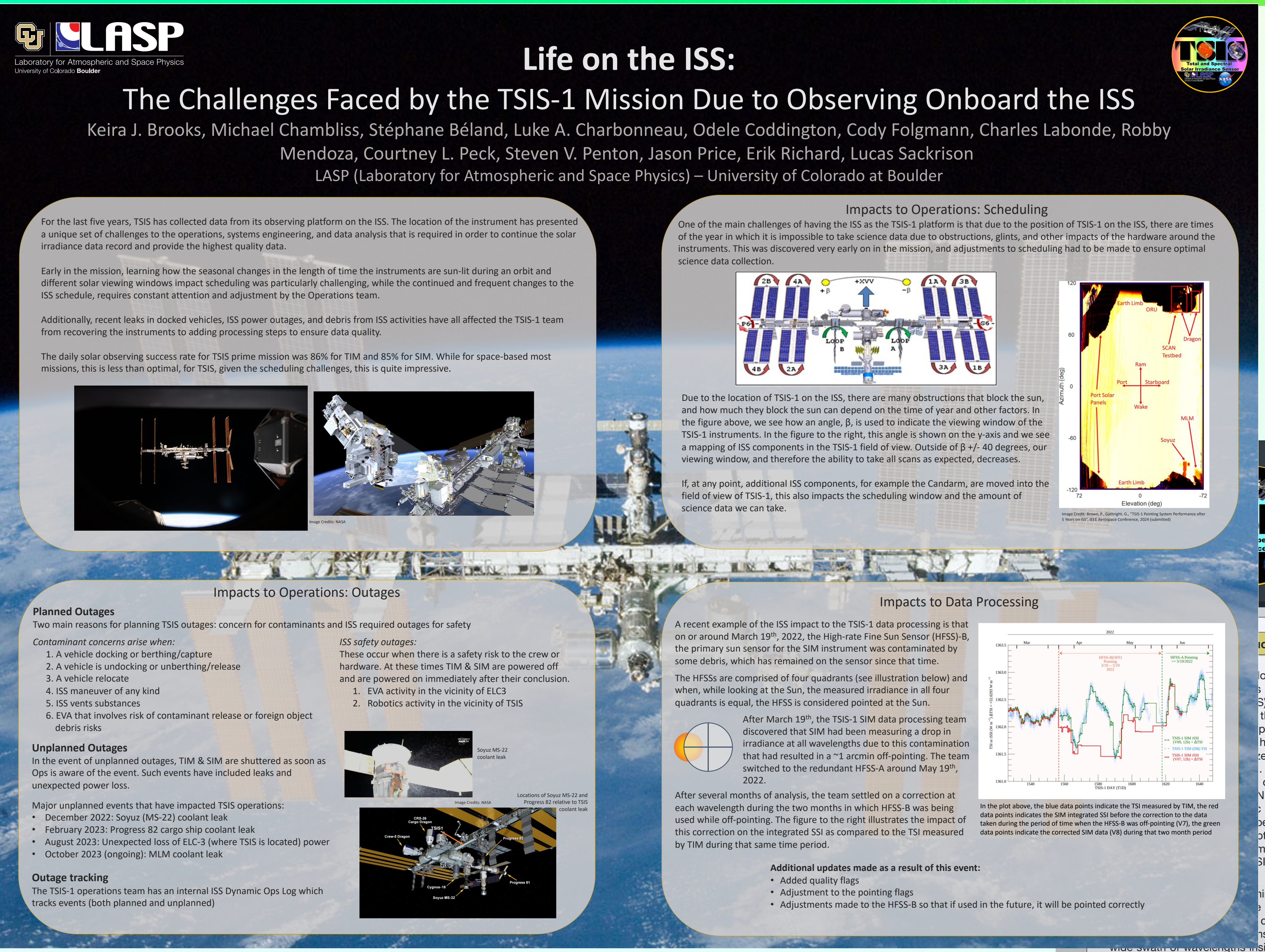
There is almost no change to the **UV**, but future improvements to dR/dT should help.

V12beta

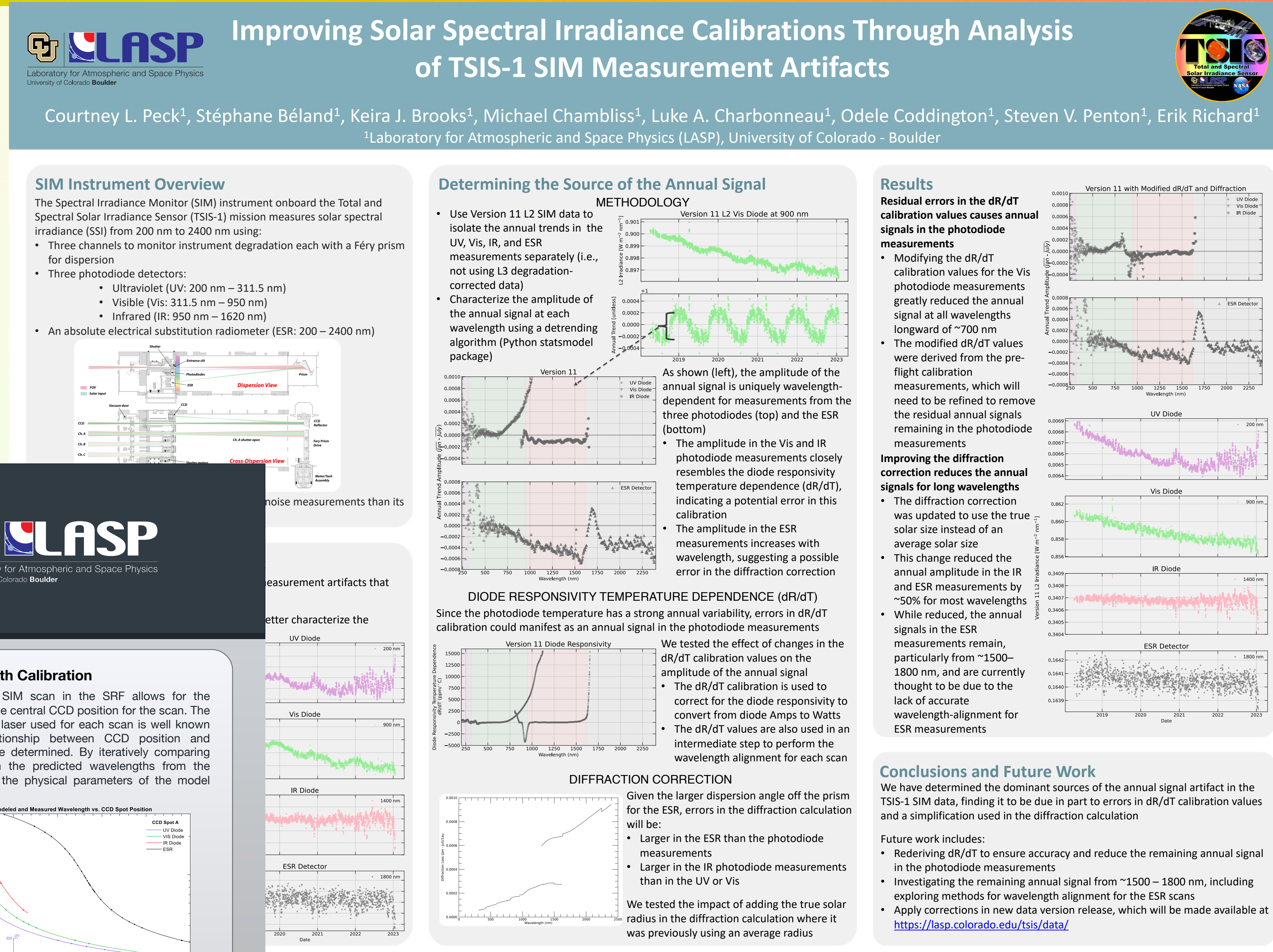


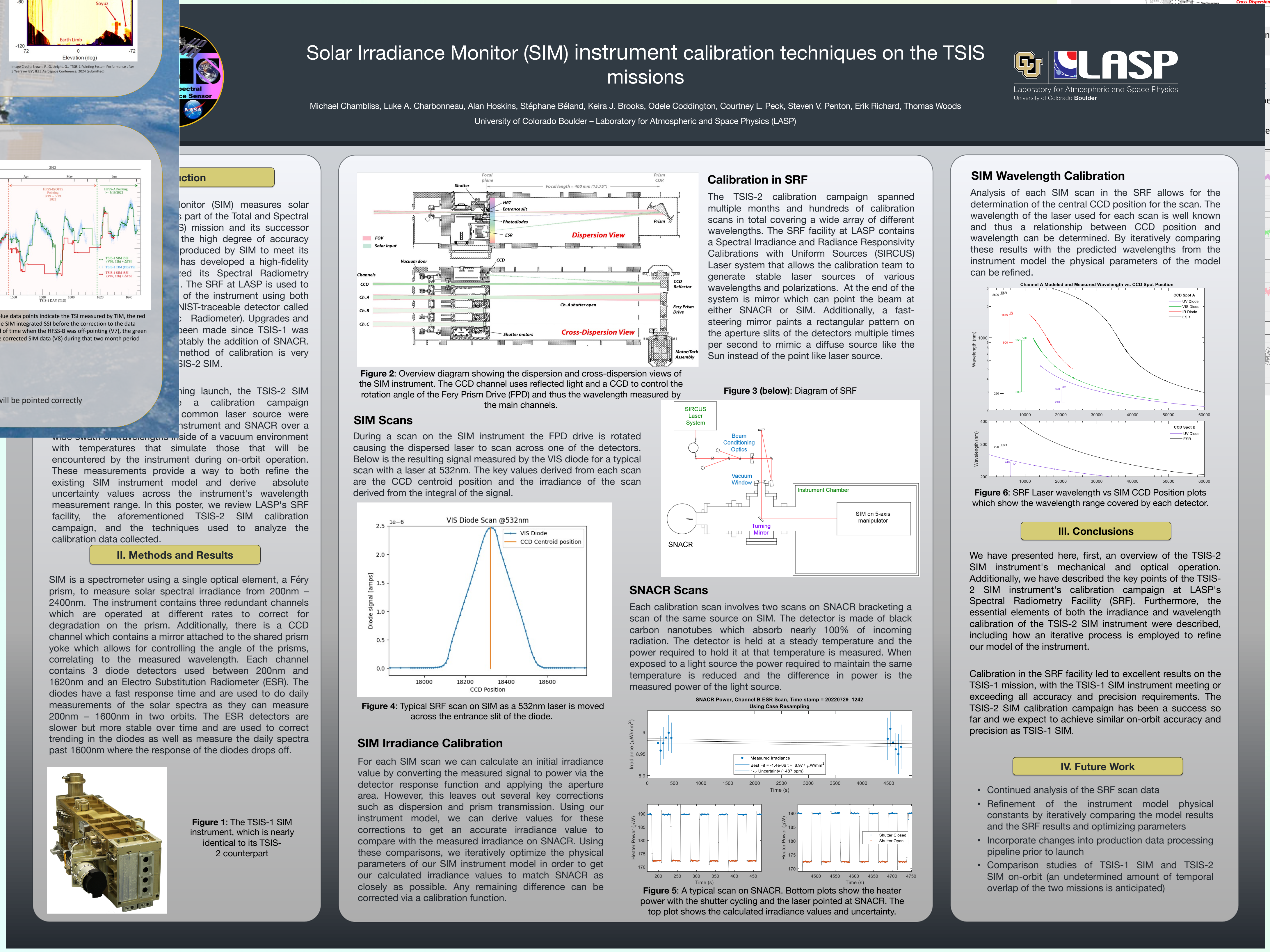
From Poster by Courtney Peck, et al.

TSIS-1 SIM SDP Posters Presented at SCS 2023



Life on ISS in tough - K. Brooks





Further improvements are on the way - C. Peck

How we calibrate - M. Chambliss and L. Charbonneau

TSIS-1 SIM Update : Sun-Climate Symposium 2023

TSIS-1 SIM Update : Sun-Climate Symposium 2023

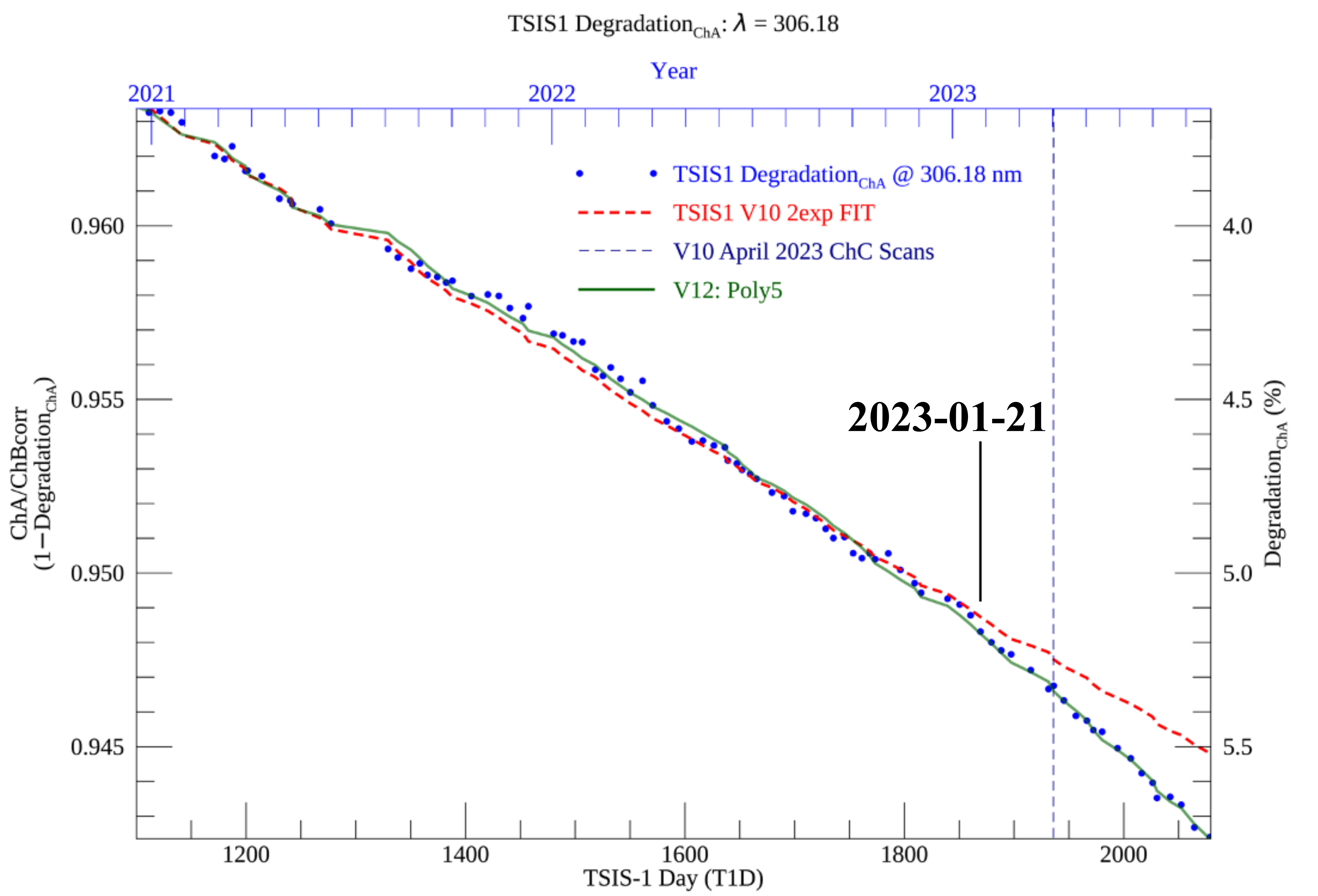
BACKUP SLIDES

V12 : Changes to Prism Degradation Models to handle V10/11 Issues

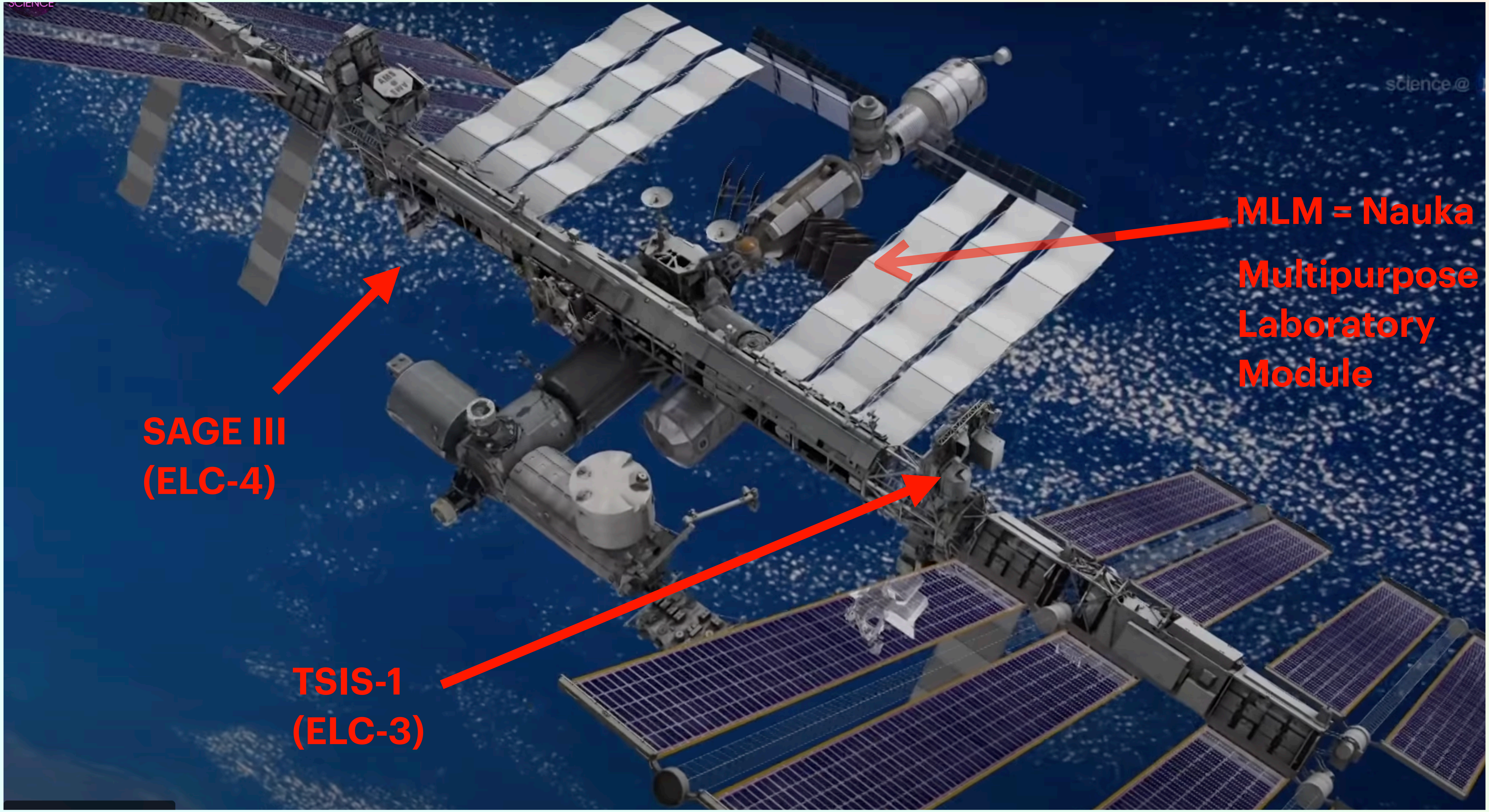
Example for wavelength < 800 nm, after :
ChA(uncorrected)/ChB(corrected) Prism Degradation Correction

	V10	**V11**	**V12 (beta)**
Data up to latest ChC Scan (or 2023-01-21, V11)	2-term exponential model	2-term exponential, BUT only < 2023-01-21, where model deviates from ChA/B measurements	Polynomial fits (N<6) and/or fits over multiple time ranges
Data after latest ChC Scan (or 2023-01-21, V11)	**Extrapolation** of 2-term exponential model after latest ChC	Uses ChA/ChB measurements (piece-wise linear) AFTER 2023-01-21	Uses ChA/ChB measurements (piece-wise linear) AFTER last ChC (no extrapolation)

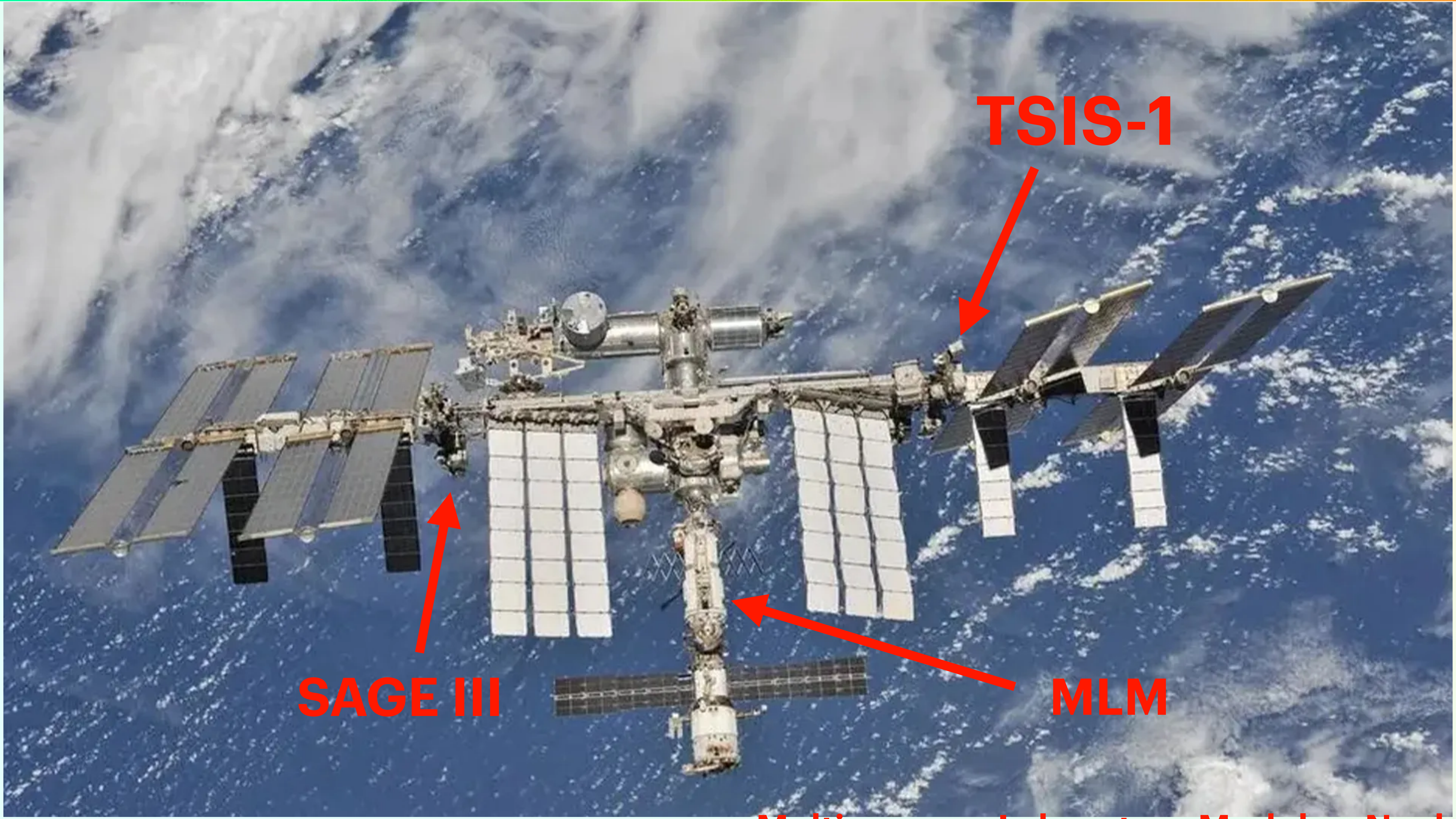
V12 : Example of Polynomial ChA Prism Degradation Fit* at 306 nm



*Polynomial (n=5) fit is made as a function of solar exposure, but displayed here vs calendar time/ TSIS-1 Day

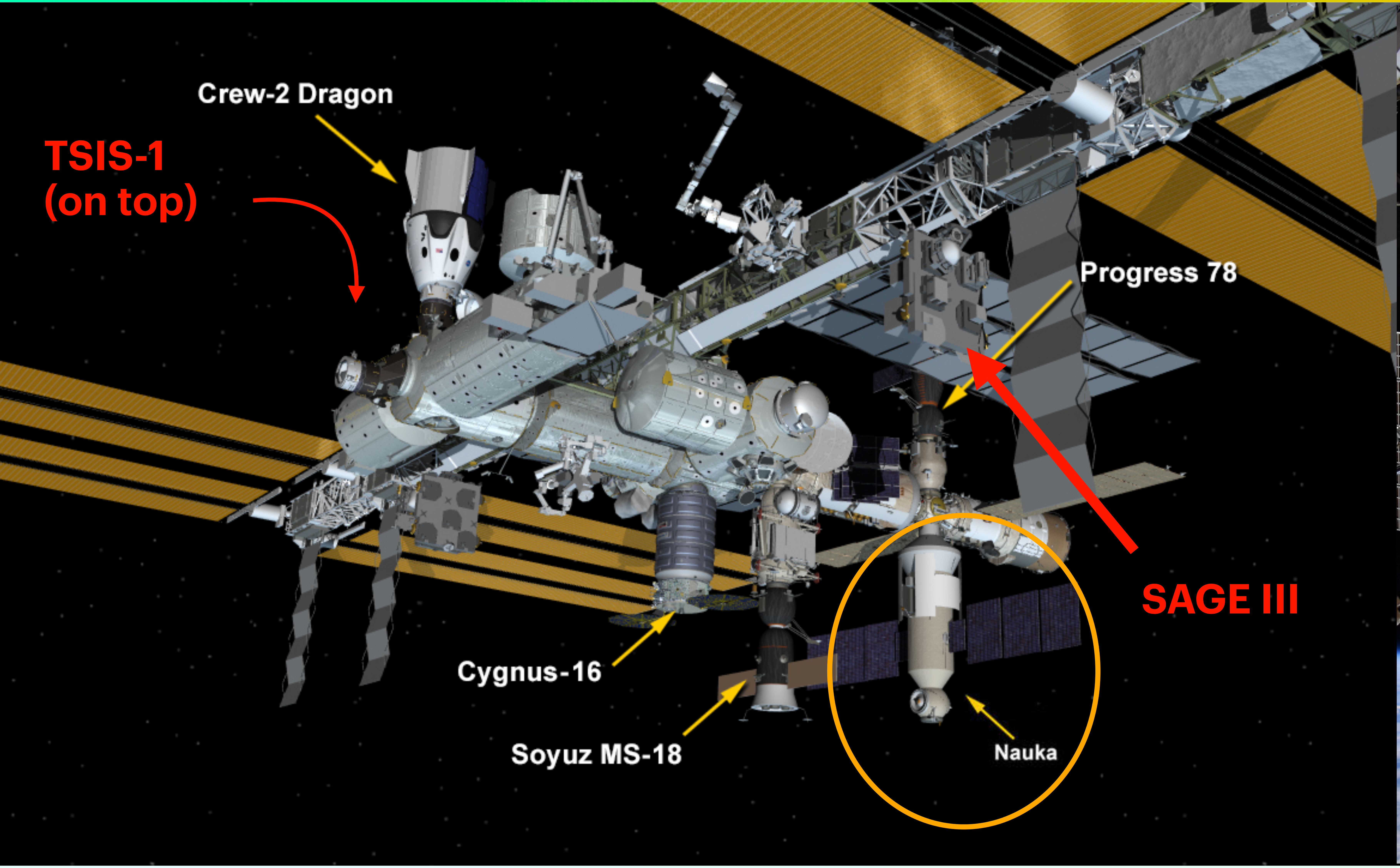

MLM = Nauka
Multipurpose Laboratory Module
SAGE III (ELC-4)
TSIS-1 (ELC-3)

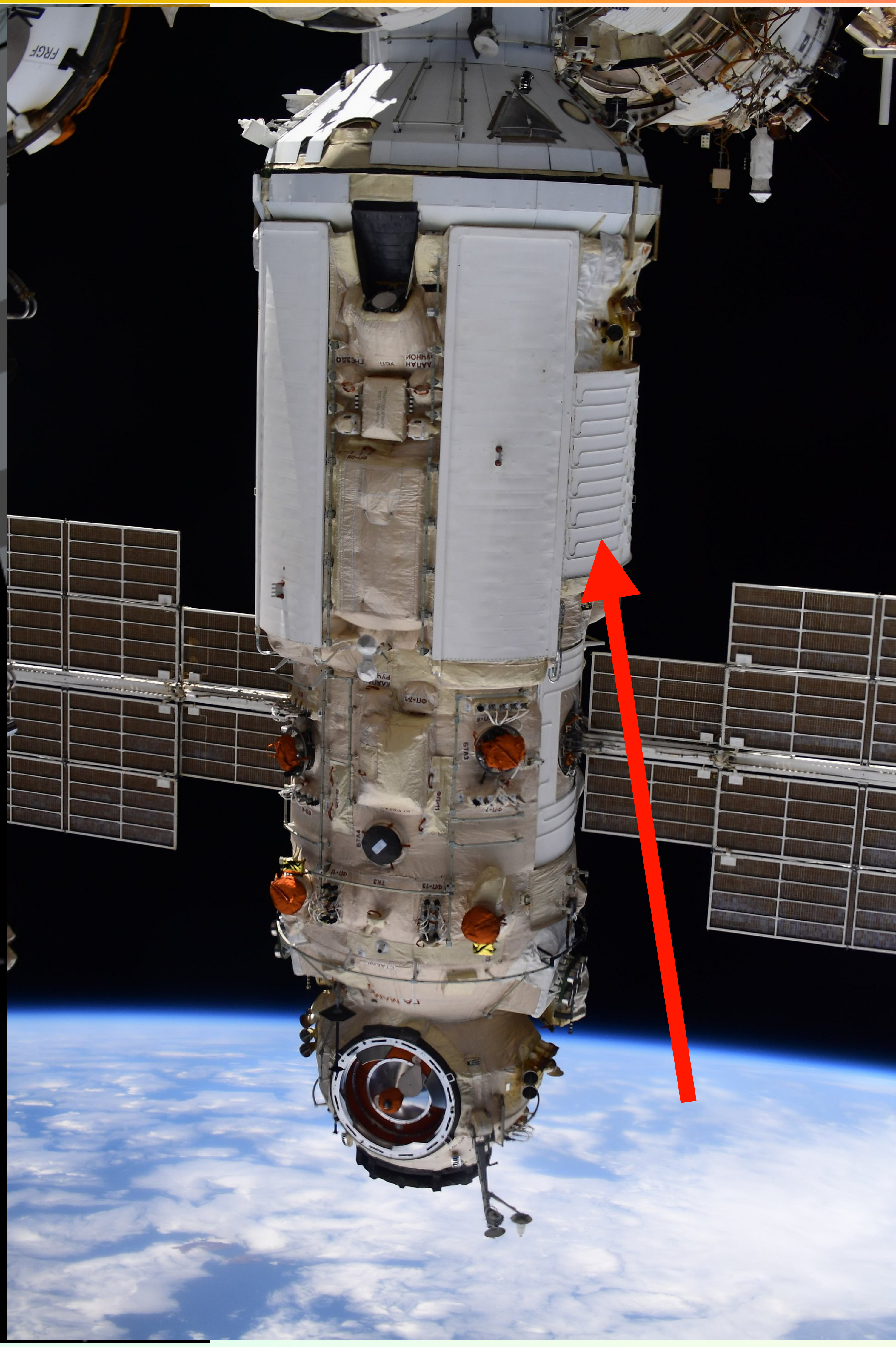
TSIS-1 & SAGE III in relation to the MLM (Nauka)



Multipurpose Laboratory Module = Nauka

TSIS-1 & SAGE III in relation to the MLM (Nauka)





TSIS-1 & SAGE III in relation to the MLM (Nauka)

Multipurpose Laboratory Module (MLM) Spare Radiator External Coolant Leak Radiator was installed during RS EVA #56 summer 2022, but was not in use at the time.