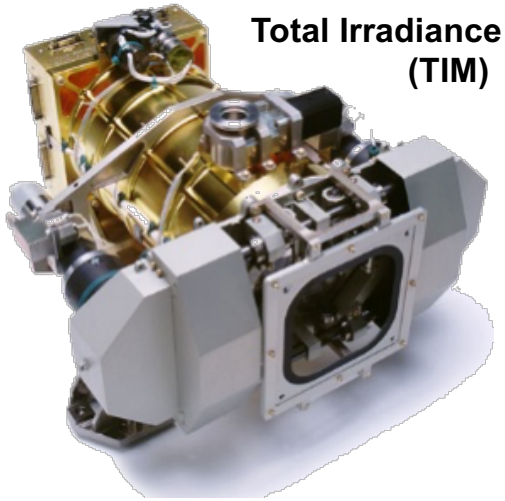
Implementation of Solar Irradiance Measurements on the International Space Station (ISS): The TSIS-1 Mission of Total and Spectral Solar Irradiance Observational Continuity

Erik Richard, Greg Kopp, & Peter Pilewskie
University of Colorado – Boulder
Laboratory for Atmospheric and Space Physics (LASP)

TSIS Makes Two Measurements

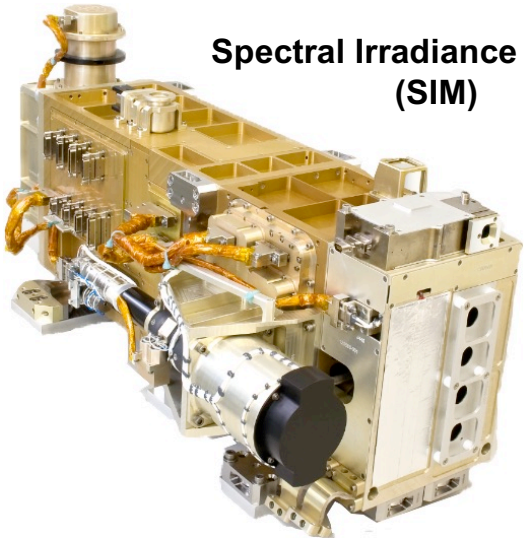
The Total and Spectral Solar Irradiance Sensor-1 (TSIS-1) provides two measurements critical for understanding solar influences on Earth climate.



Total Irradiance Monitor (TIM)

Total Solar Irradiance (TSI) [Wm^{-2}]

- Earth's predominant energy source.
- The TSIS-1 Total Irradiance Monitor (TIM) will continue a 40-year long uninterrupted measurement record of TSI.



Spectral Irradiance Monitor (SIM)

Solar Spectral Irradiance (SSI) [$Wm^{-2}nm^{-1}$]

- Measured by the TSIS-1 Spectral Irradiance Monitor (SIM). Continuous wavelength range 200 -2400 nm.
- Identifies the regions of atmosphere that are affected by solar variability and the mechanisms of response.

Solar Irradiance Requirements

Level 1 Performance Requirement Parameter	TIM Requirement	SIM Requirement
Spectral Range	Total-spectrum integrated	200-2400 nm (96% TSI)
Uncertainty	0.01%	0.2%
Measurement Stability	0.001% per year	0.05%/yr (≤ 400 nm) 0.01%/yr (> 400 nm)
Spectral Resolution	N/A	2 nm: (< 280 nm) 5 nm: (280 to 400 nm) 45nm: (>400 nm)
Reporting Frequency	4 six hour averages per day	2 spectra per day
Data processing approach	Consistent with SORCE/TSIS-1 approach for continuity	Consistent with SORCE/TSIS-1 approach for continuity

Solar Irradiance Requirements

Quantifiable Goals

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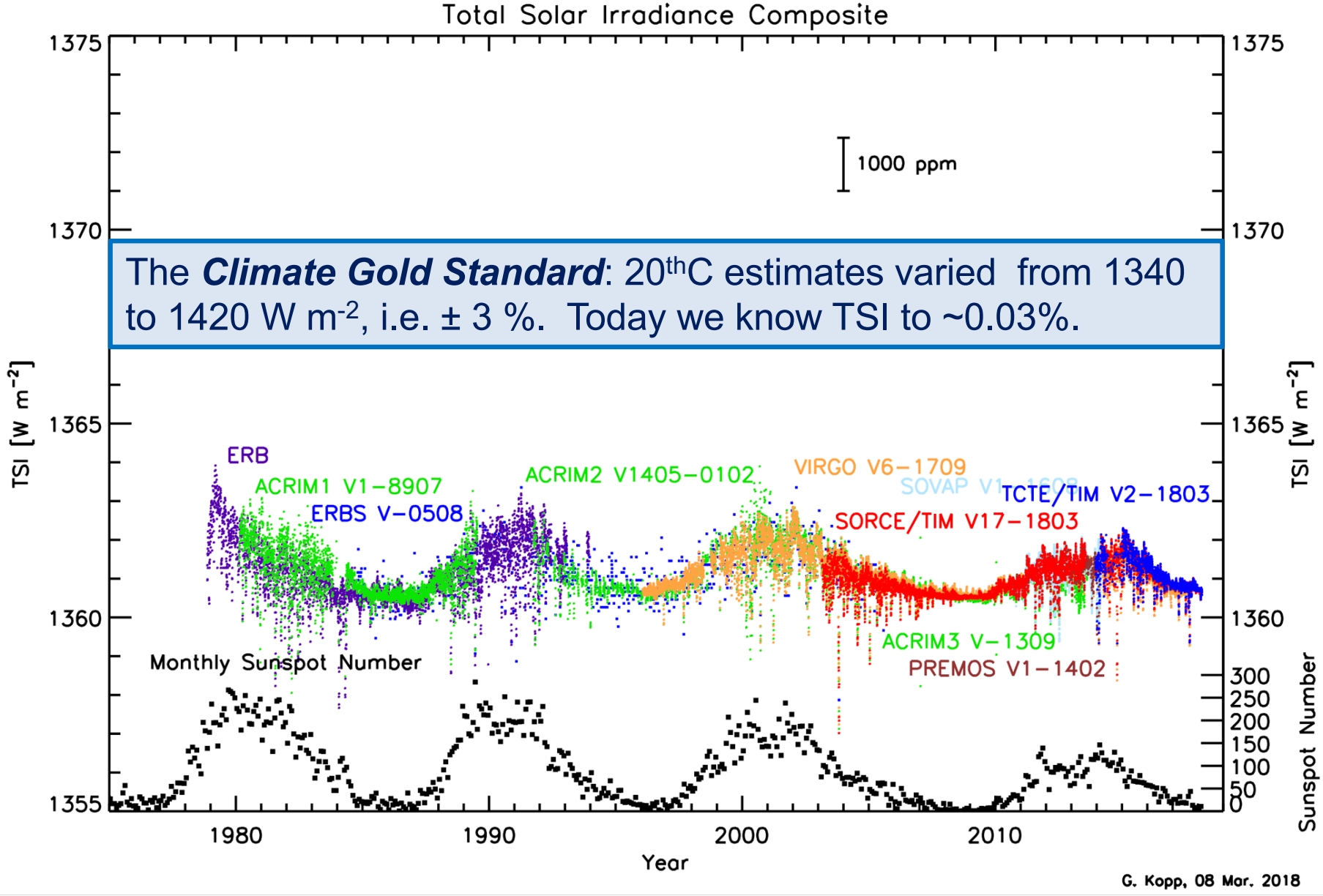
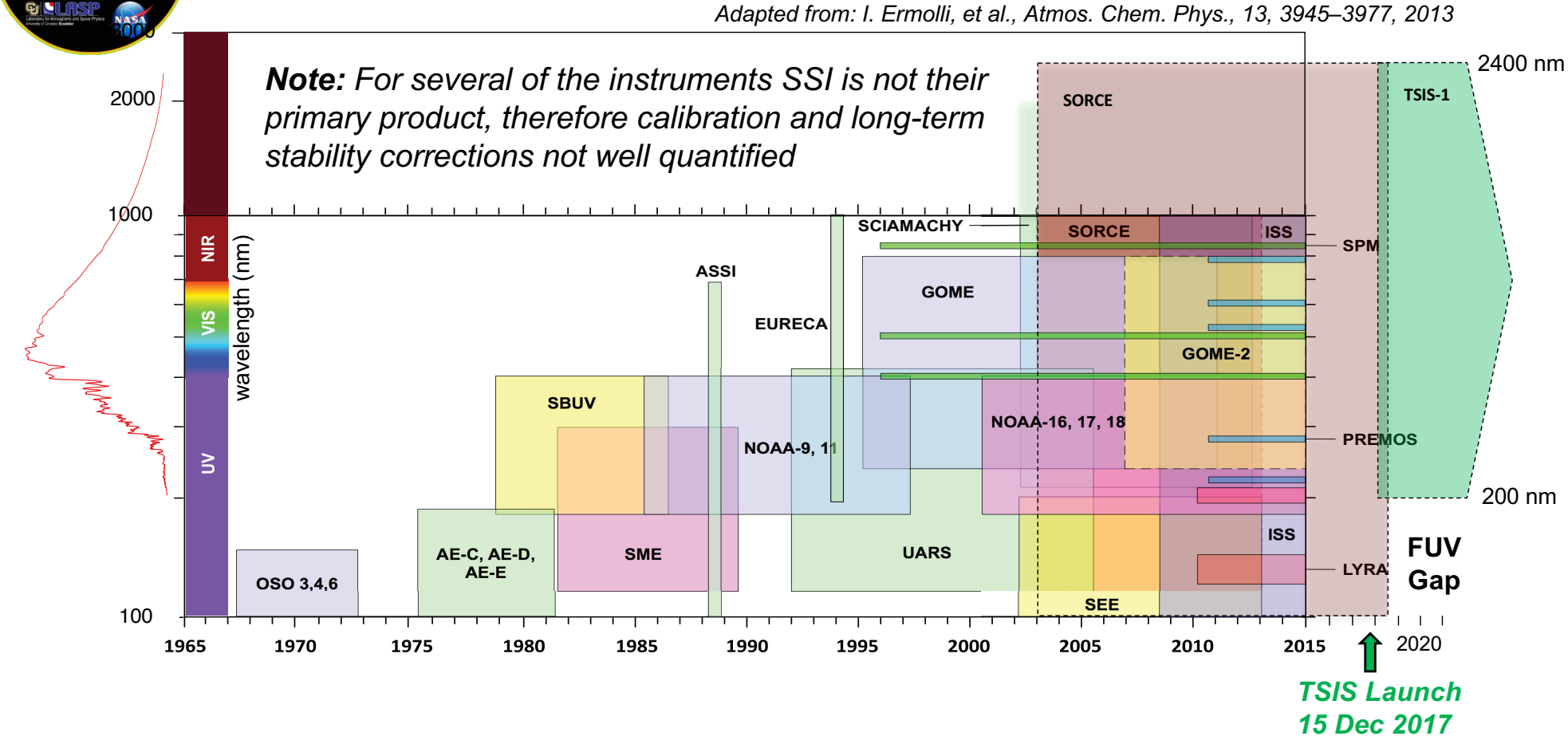
Hypothesis: *Solar activity influences climate circulation patterns. To monitor such changes in solar radiative forcing, determine Total Solar Irradiance to an SI-traceable absolute accuracy of 100 ppm and stability of 10 ppm/yr [NRC, 2013]. Determine Solar Spectral Irradiance to an absolute accuracy of 0.5% and stability of 0.05% /yr. TSI and SSI observations sufficient to determine monthly averages at the traceable accuracy and stability indicated above.*

**Weatherhead, Wielicki, Ramaswamy et al., Designing the Climate Observing System of the Future, 2017*

The Total Solar Irradiance Data Record



The Solar Spectral Irradiance Data Record

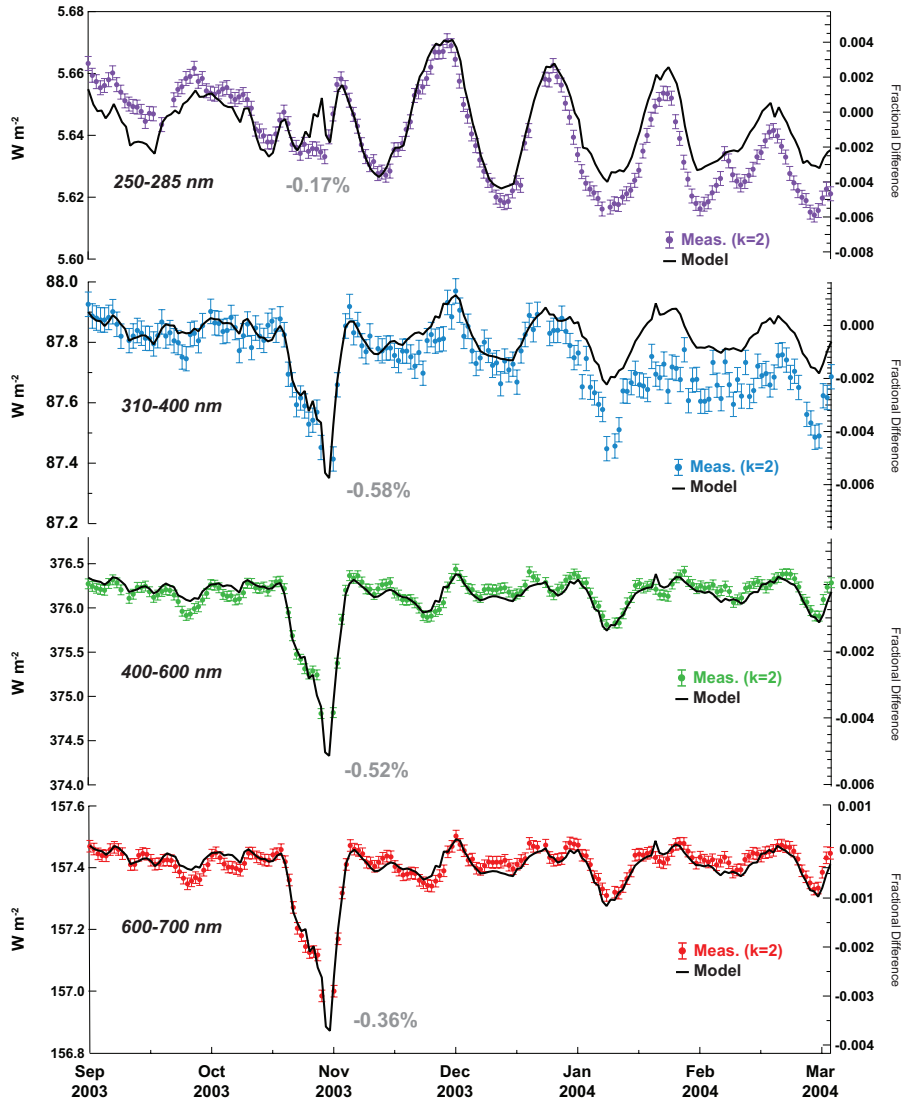


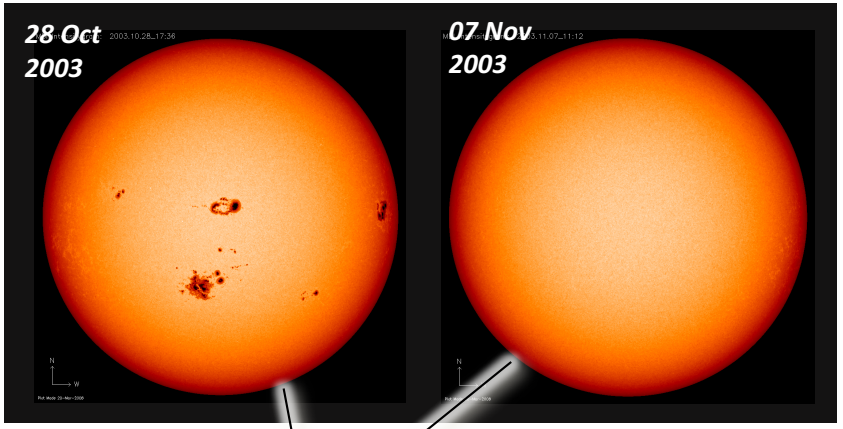
SSI validation presents a different challenge than TSI:

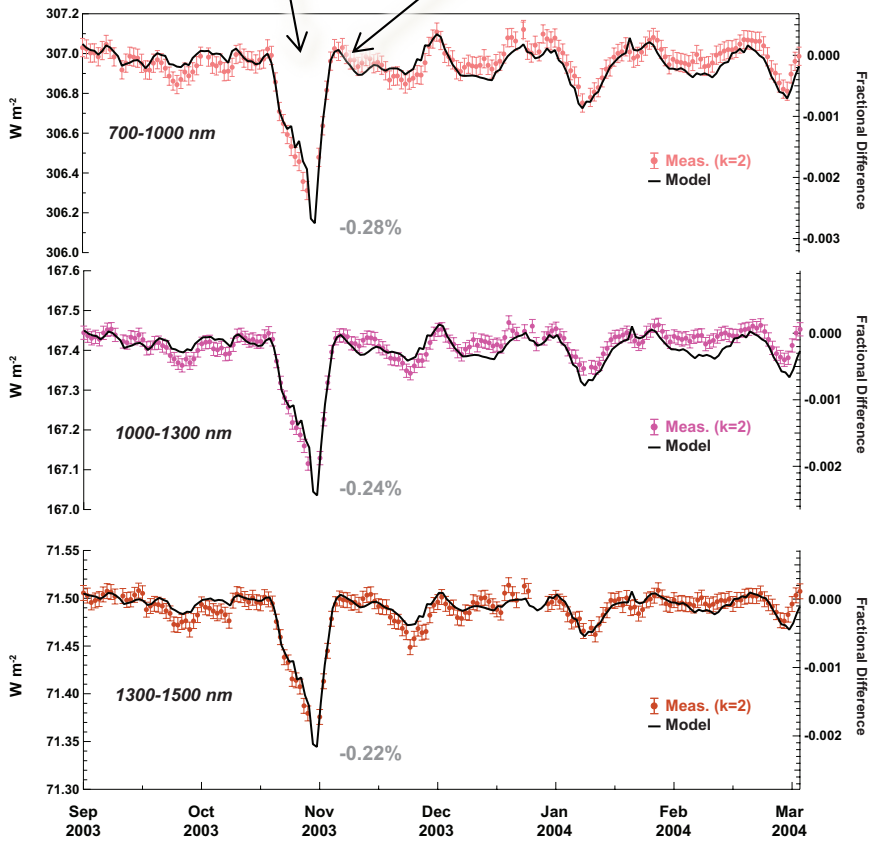
- Requires overlap in time and wavelength.
- Record shows overlap in time but spotty overlap in spectral domain.
- Other challenges include spectral sampling and resolution.

Short-term spectral variability

6-month spectral variability around 2003 "Halloween Storms"

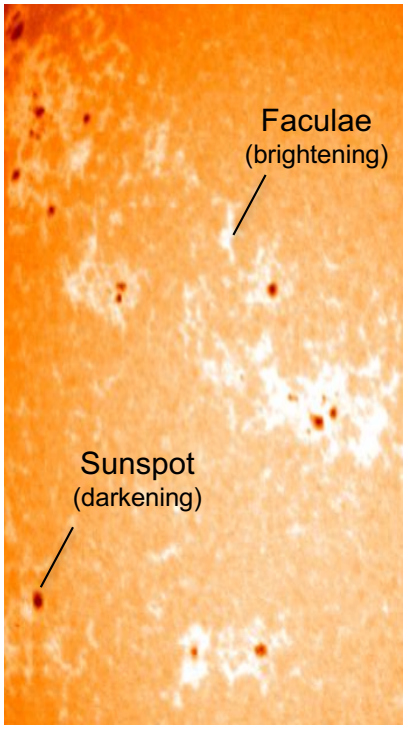


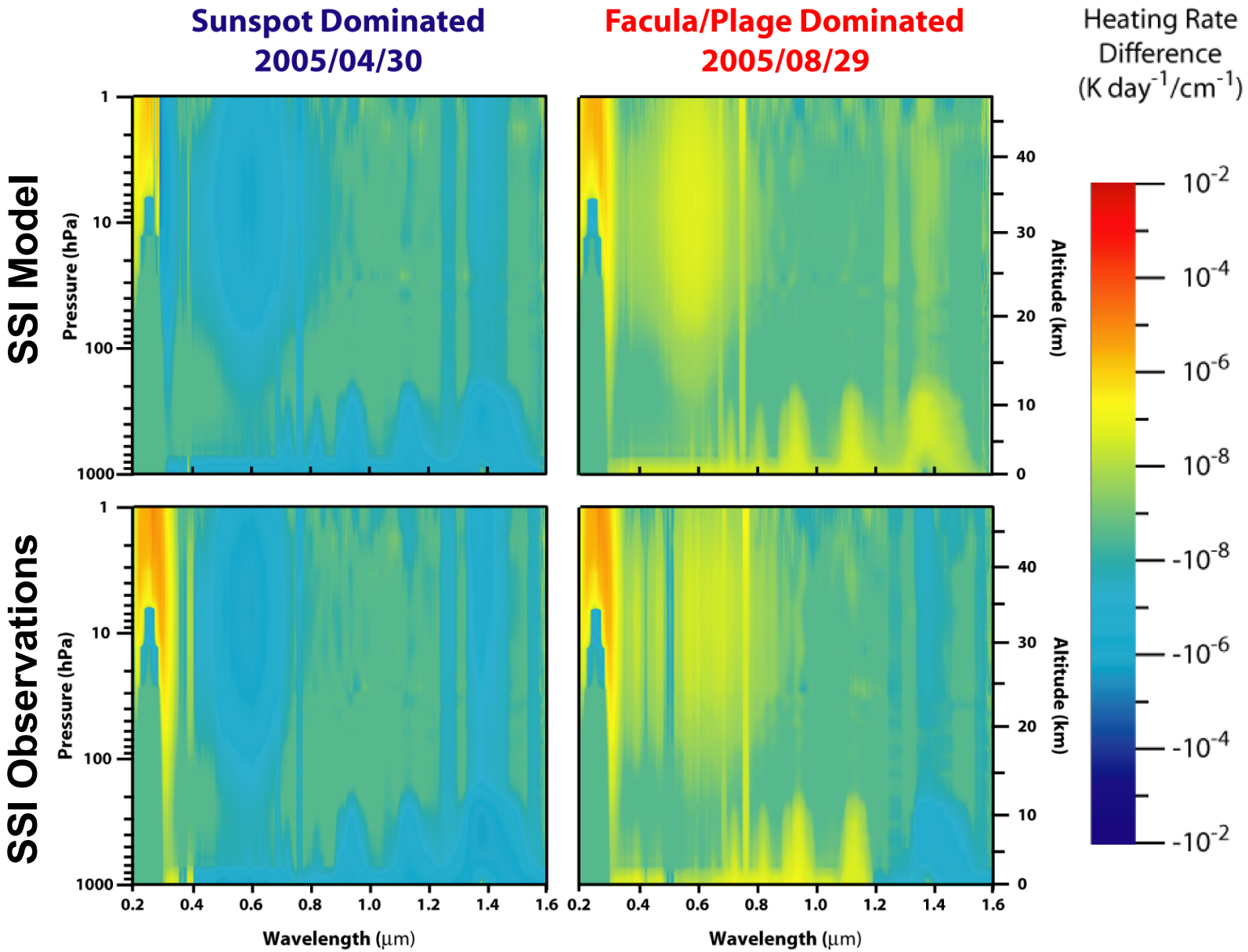




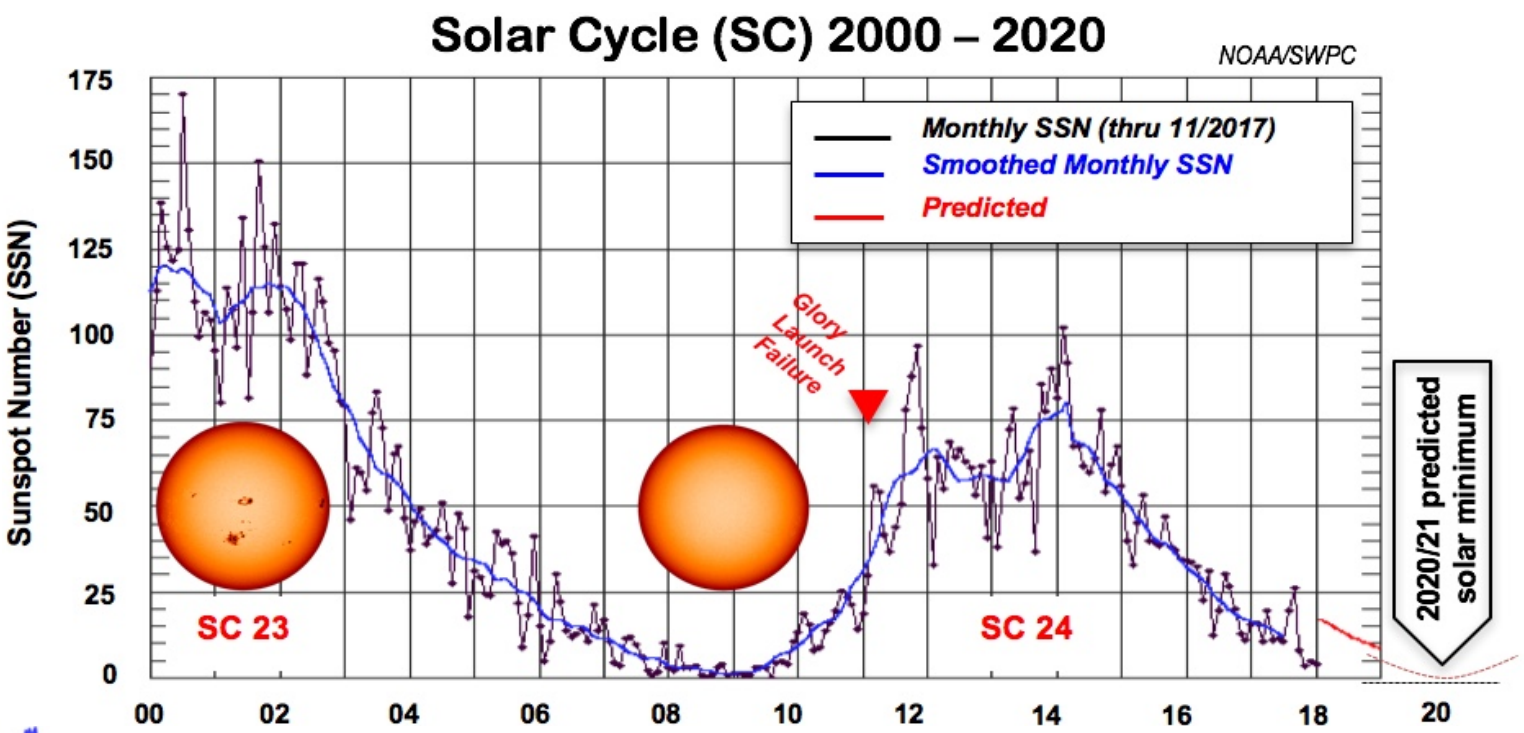
Instantaneous Spectral Heating Rate Differences

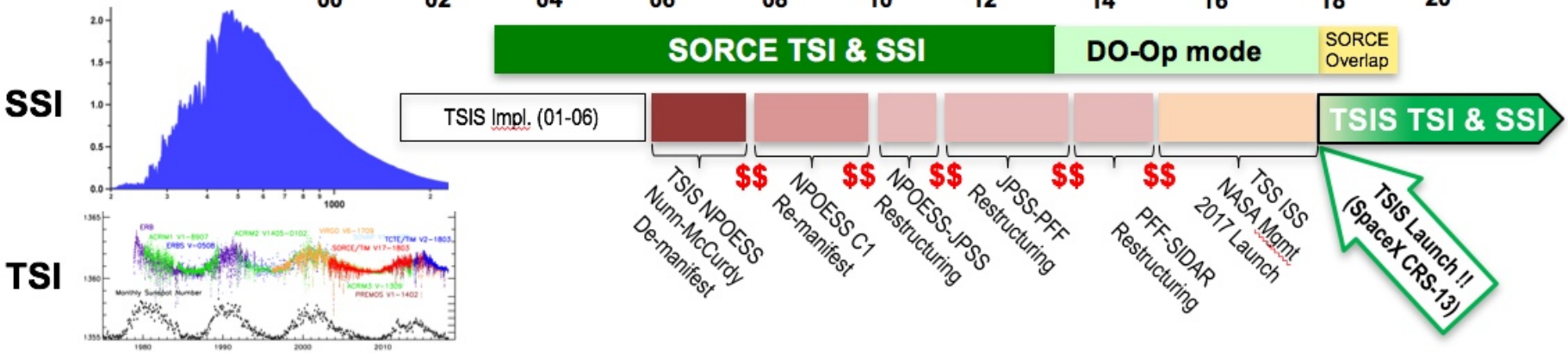
Solar activity features





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”

(Through adversity to the stars)

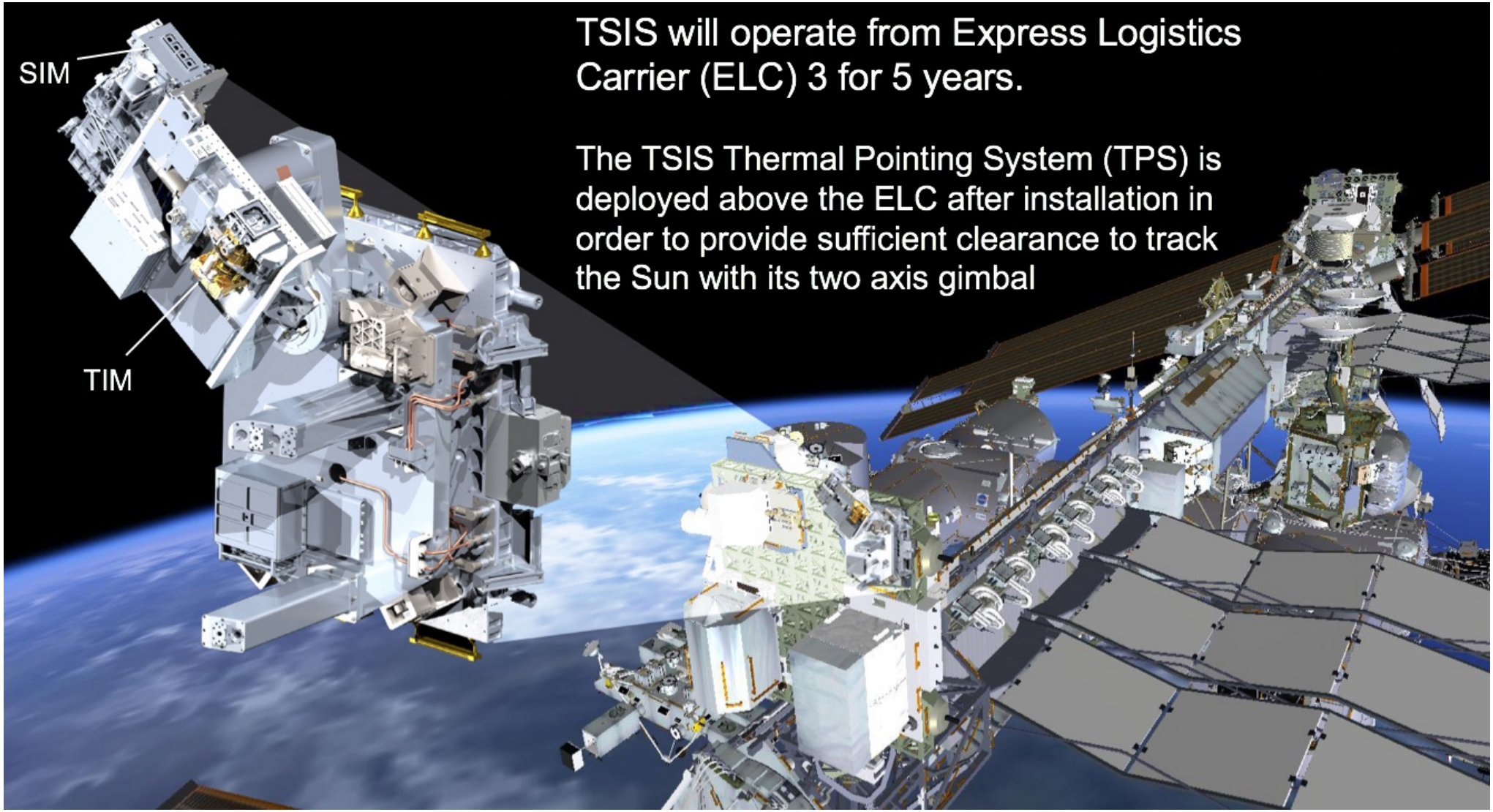
Laboratory for Atmospheric and Space Physics
University of Colorado Boulder

TSIS-1 Timeline

Launch…….. 15 December 2017
Turn-on……. 3 January 2018
Commissioning……. 4 Jan – 1 Mar. 2018
TIM First Light…….. 11 Jan 2018
SIM First Light……. 3-5 March 2018

TSIS on the International Space Station

- TSIS delivered to KSC in July 2017 with launch to ISS and deployment in Dec. 2017.
- TSIS launched in the SpaceX-13 Dragon trunk an Express Pallet Adapter (ExPA) using a Flight Releasable Attachment Mechanism (FRAM).

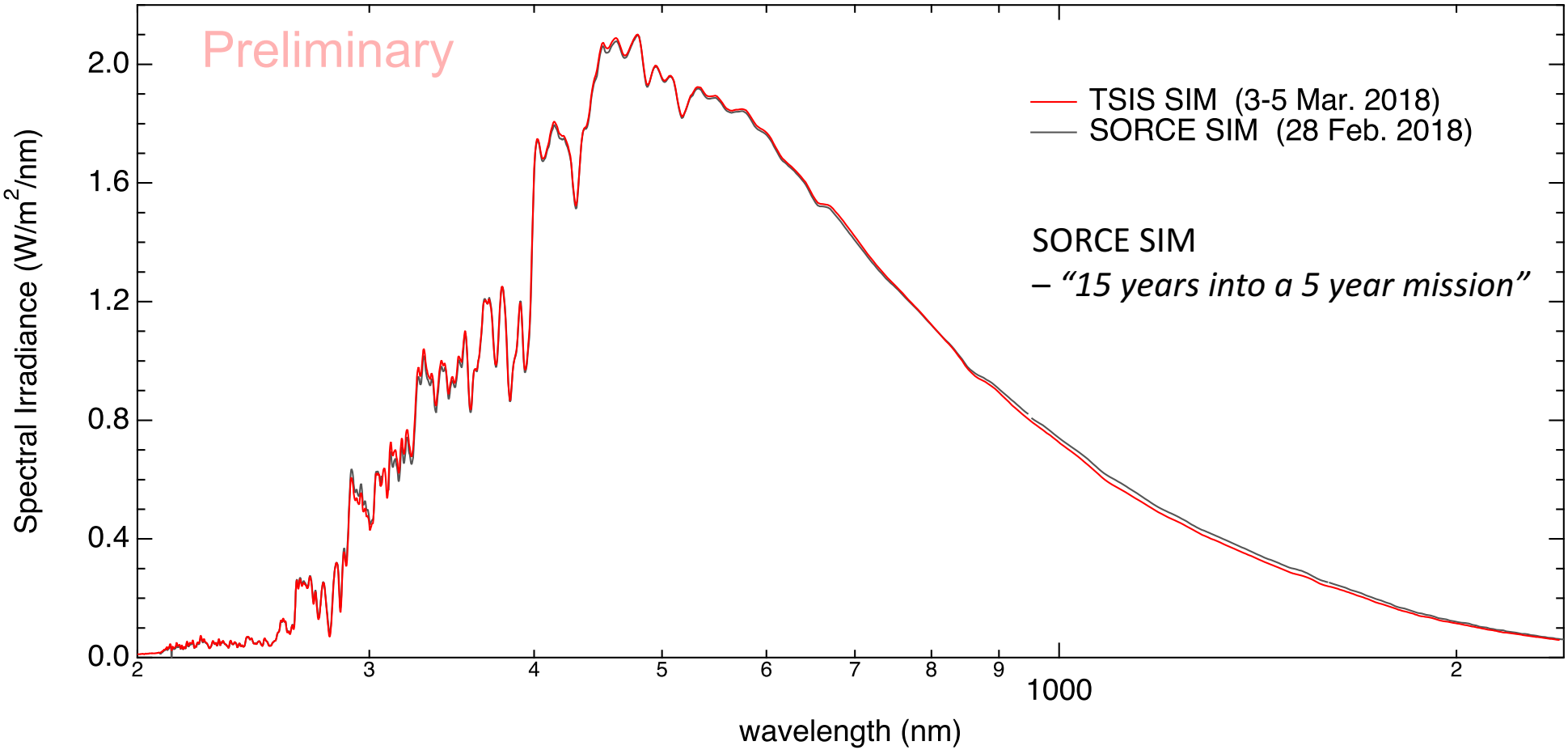


TSIS-1 on ISS

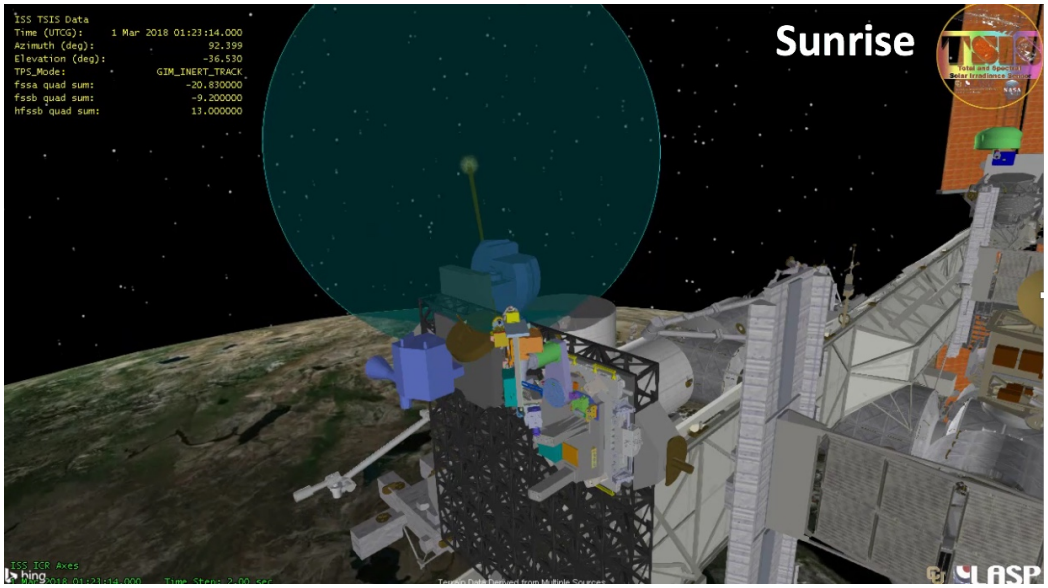
Full system deployed 31 Dec. 2017

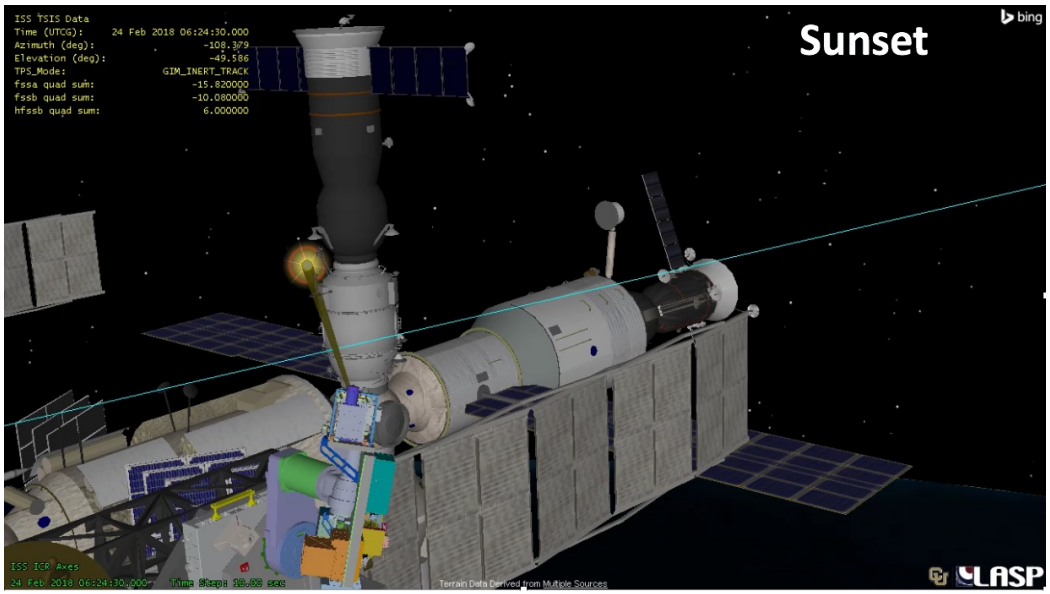
First Light SSI Spectrum Comparison

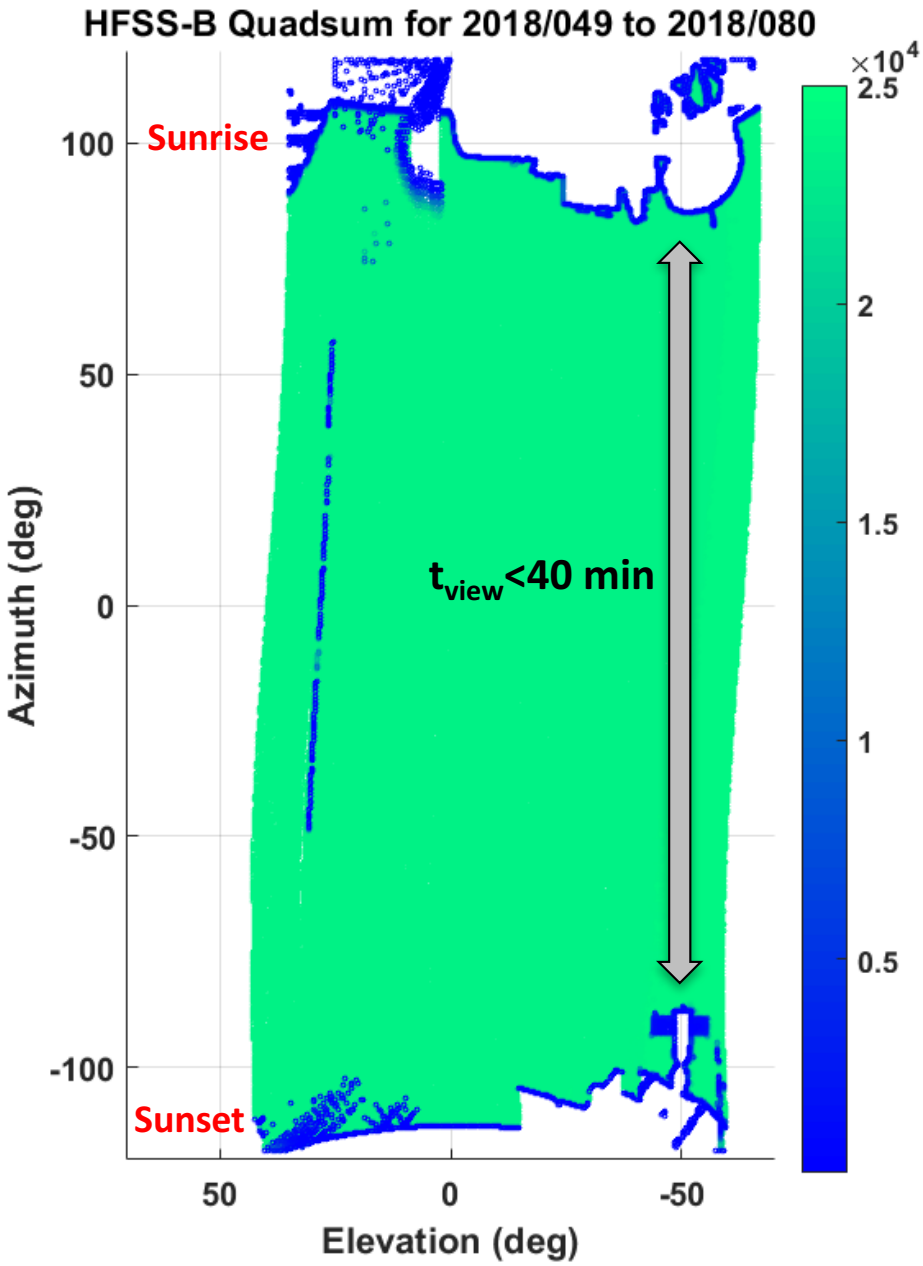
TSIS & SORCE SSI overlap began March 2018 and will continue for 1 year (SORCE EOM scheduled 2019)



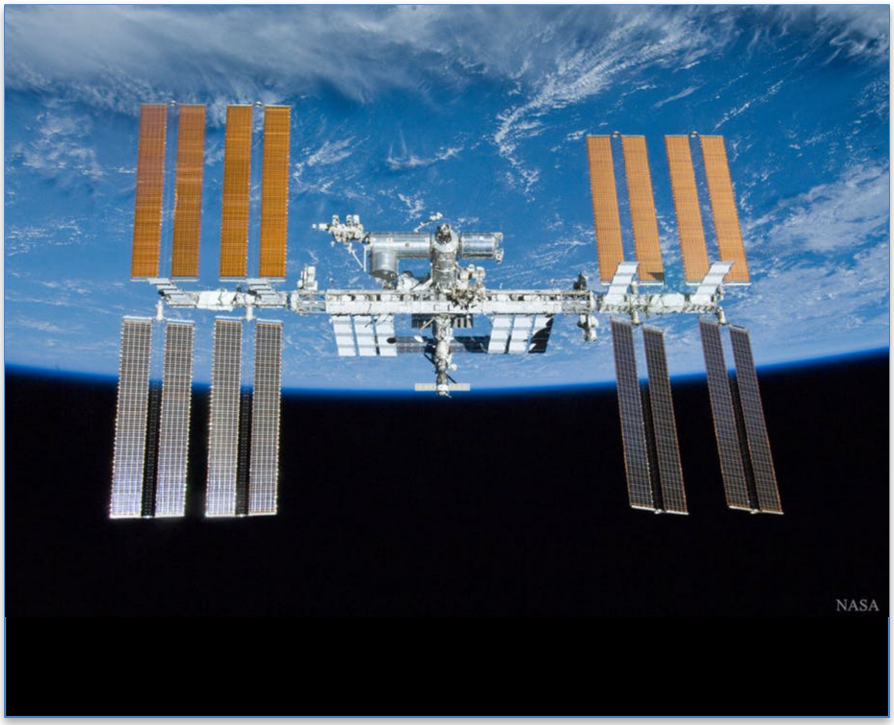
ISS Obscurations: *"vita sine Sole"*







ISS Platform for Long-term Science Operations



Pros…

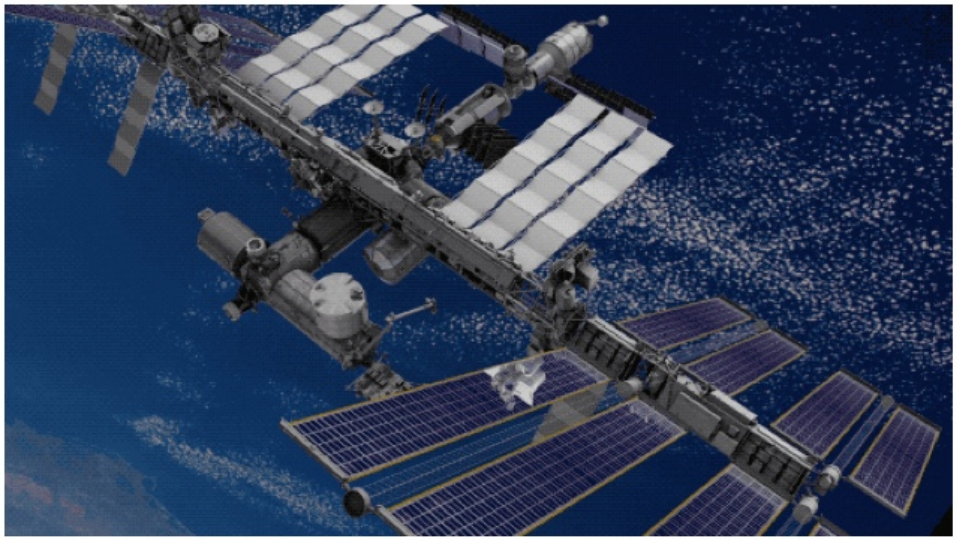
- Lots of available uplink time
- Near-constant downlink
- Essentially Free launch
- Reliable, high priority platform

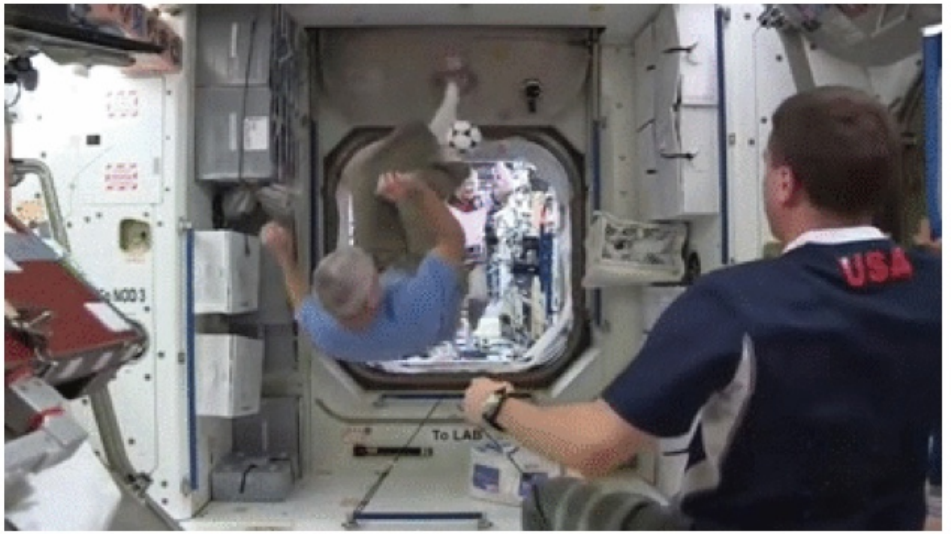
Cons…

- Evolving contamination environment
  - Visiting vehicles
  - ISS “re-boosts” occur multiple times per year
  - New payloads added all the time
- Non-Earth viewing is challenging
  - ISS structure gets in the way
  - Off-nominal attitudes happen occasionally
  - Solar arrays are held fixed some times, rotating most of the time
  - ISS structure is evolving with visiting vehicles, new payloads, etc.
  - Predicting and determining times when structure will be/was in field of view is a complex problem
  - EVAs and robotics activities can cause obstructions
- Complex troubleshooting environment
  - No single source of knowledge about all ISS and payload operations
- Additional developmental obstacles
  - Limitations on testing with flight FRAM (Flight Releasable Attachment Mech.)
  - FRAM handling
- Large team with lots of stakeholders
  - Complex troubleshooting environment - no one organization has all the information
- Visiting vehicles, EVAs, EVRs that affect operations can be delayed at the last minute

Observations on a “shared” Platform

Must design for broad range of environmental influences, including low frequency disturbances and interferences





Gap Filling and the Future

Compact solar irradiance monitors open opportunities, increase mission flexibility and reliability of long-term data record stewardship.