SORCE SIM Instrument Highlights for Middle UV, Visible, and NIR

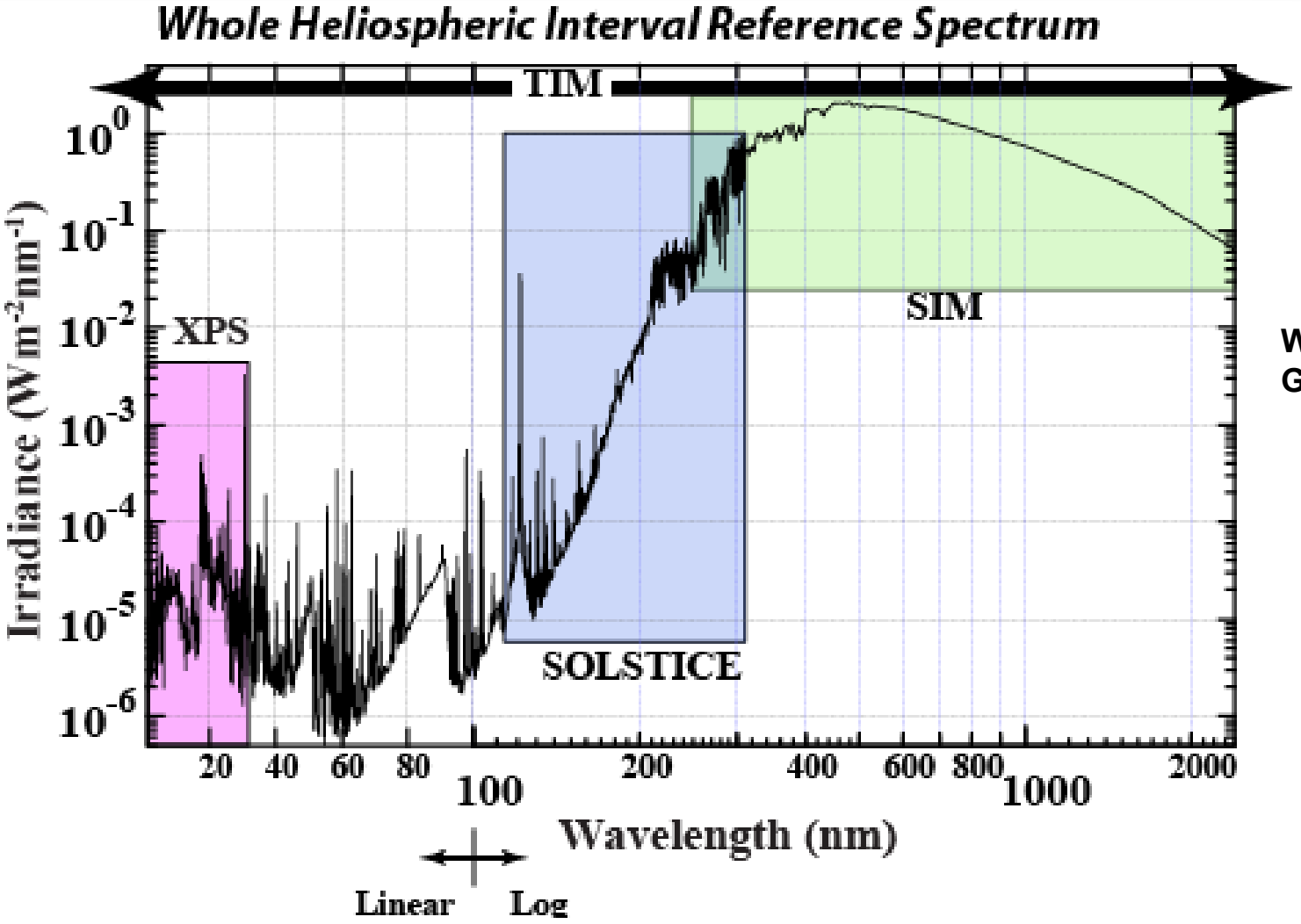
Jerald Harder, Stéphane Béland, Thomas Woods

Laboratory for Atmospheric and Space Physics, University of Colorado

Top Accomplishments for SORCE SIM: Past/Present/Future

1. First full spectral observations of solar spectral irradiance (SSI) with instrument-only degradation corrections
2. Input for models of solar irradiance
3. Input for chemistry/climate modeling efforts
4. Magnificent engineering
5. Into the future

Topic 1: First continuous SSI Record



Woods et al., GRL, 2009

- SORCE SIM
  - A full decade of wavelength coverage
  - A factor of 200 in dynamic range
  - Resolved spectrum-to-spectrum irradiance differences of ≈10^{-3}-5×10^{-4}

Topic 1: Degradation Measurement Equation

a) $$E(\lambda) = \frac{measuredDetectorCounts(\lambda)}{\int entranceApertureArea \times detectorResponseFunction(\lambda) \times spectralBandwidth(\lambda) \times OpticalTransmission(\lambda)\, d\lambda} \quad (\text{units of } Wm^{-2}nm^{-1})$$

b) $$E_{ESR}(\lambda_s, t) = \overbrace{\frac{1}{M}\frac{V_7^2 R_h}{(R_h + R_s)^2}\left\{\frac{1 + \tilde{G}(t)\ \vec{p}\bullet\vec{D}}{\tilde{G}(t)\ \ \vec{p}\bullet\vec{Q}}\right\}}^{\text{ESR Power (phase sensitive detection)}} \Big/ A_{slit}(T)\int \alpha(\lambda) Tr_0(\lambda)\Phi(\lambda) S(\lambda_s,\lambda)\, d\lambda \times \frac{1}{\left((1-a_{ESR})\exp(-\kappa(\lambda)C(t)) + (a_{ESR})\exp\left(-\frac{\kappa(\lambda)C(t)}{2}\right)\right)} \times \overbrace{\frac{1}{f_{1au}}\frac{1}{f_{doppler}}}^{\text{Orbit Correction}}$$

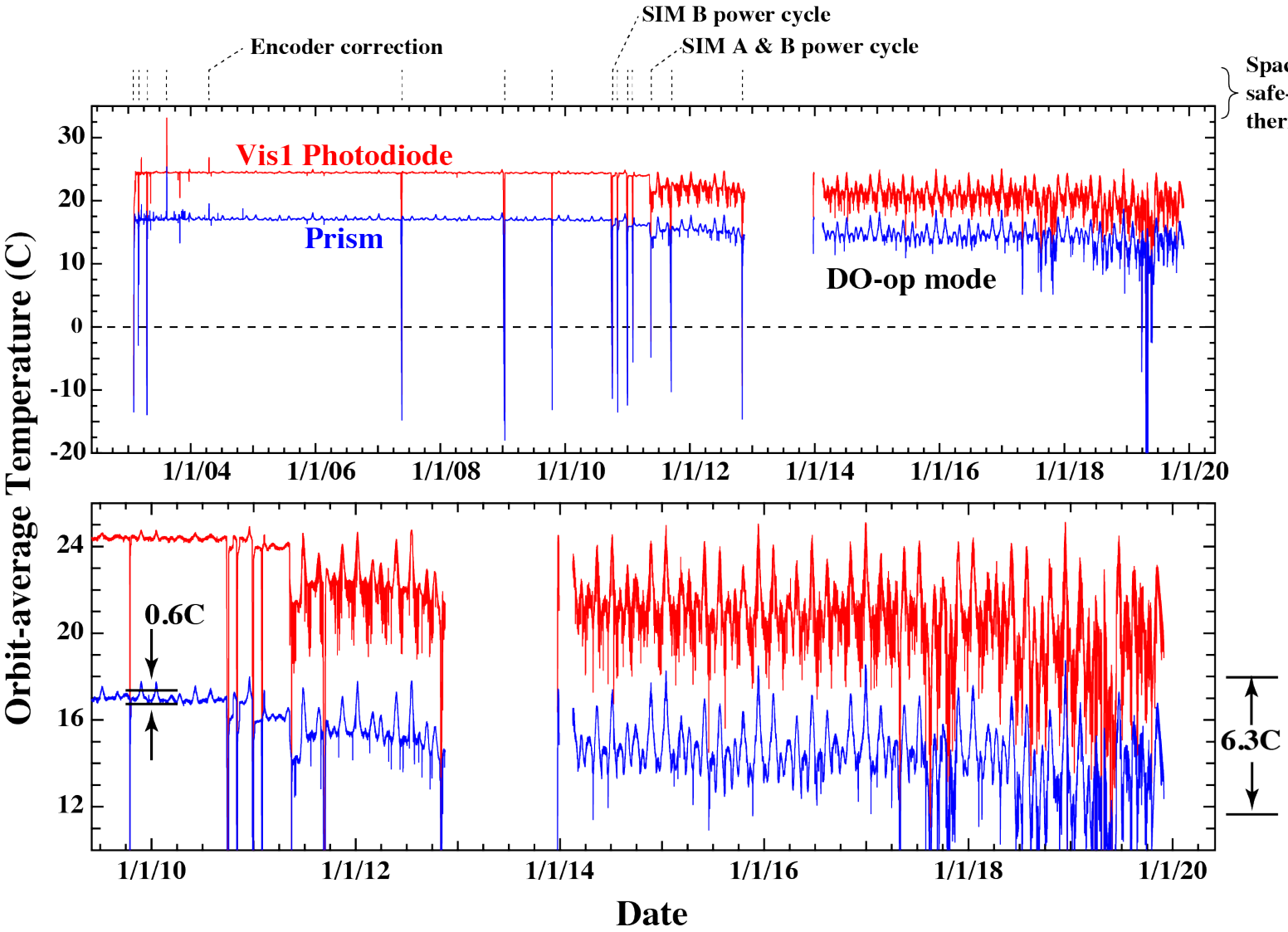
ESR Gain (non-exposure degradation)

c) $$E_{Diode}(\lambda_s, t) = \frac{\overbrace{\frac{V_{\max}}{M}\left\{\frac{D - D_0}{R_f}\right\}}^{\text{Detector photocurrent}}}{\underbrace{A_{slit}\int RS(\lambda, t, T) Tr_0(\lambda)\Phi(\lambda) S(\lambda_s,\lambda)\, d\lambda}_{\text{Profile Integral}}} \times \underbrace{\frac{1}{\left((1-a_{diode})\exp(-\kappa(\lambda)C(t)) + (a_{diode})\exp\left(-\frac{\kappa(\lambda)C(t)}{2}\right)\right)}}_{\text{Prism Transmission Degradation Factor (Exposure related degradation)}} \times \frac{1}{f_{1au}}\frac{1}{f_{doppler}}$$

Photodiode radiant sensitivity (non-exposure degradation)

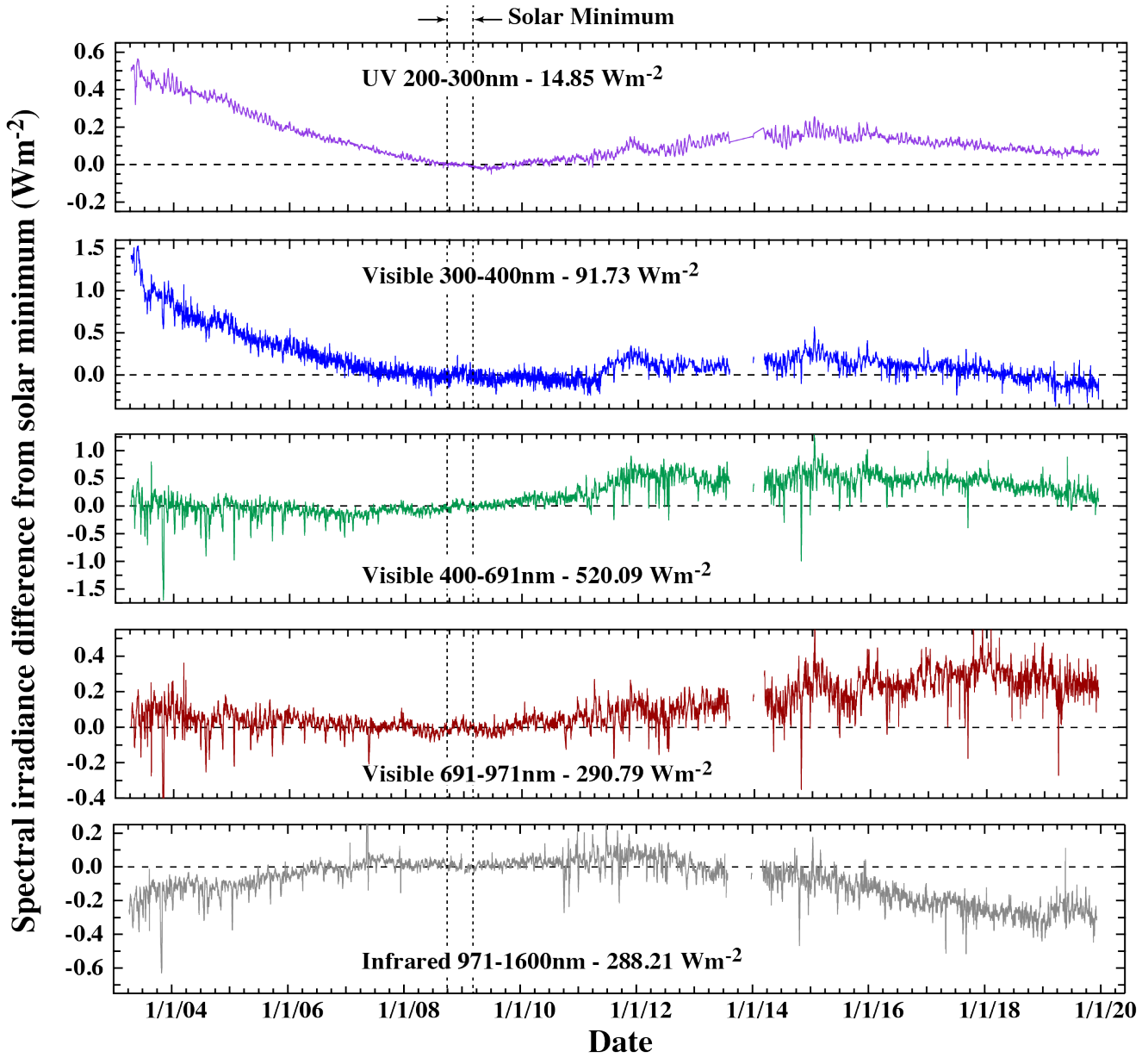
- **SORCE SIM applies instrument-only degradation corrections**
- **Corrections are based on comparisons of two independent SIM channels**
- **Time dependent degradation function found by tracking both clock time and solar exposure time related changes in instrument sensitivity**

Topic 1: SORCE SIM Temperature Record



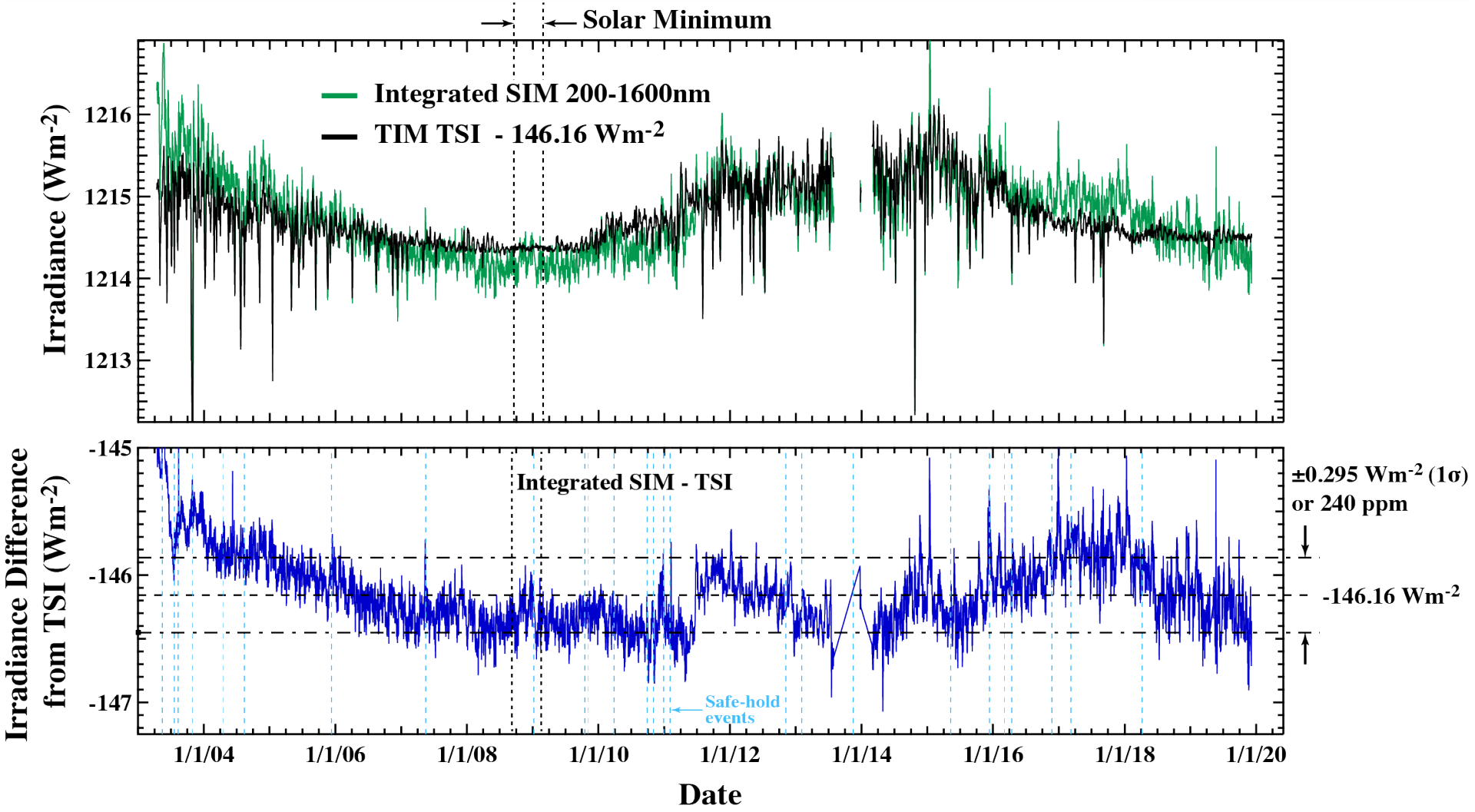
- Temperature control less reliable in the latter part of the mission
- Adds additional uncertainty absolute accuracy
- Long term secular drift in temperature also noted

Topic1: SIM Irradiance Time Series



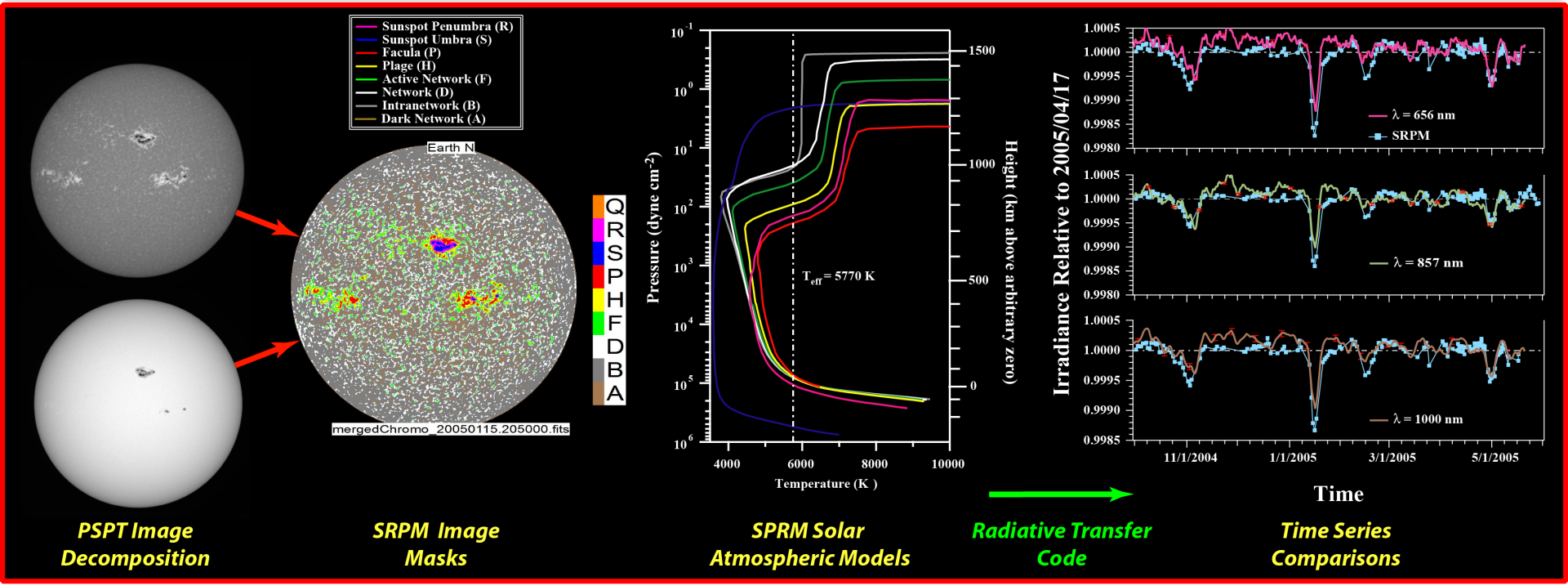
- **Both in-phase and out of phase components appear in the time series**
- **Uncertainties higher after onset of power cycling & the DO-op mode.**

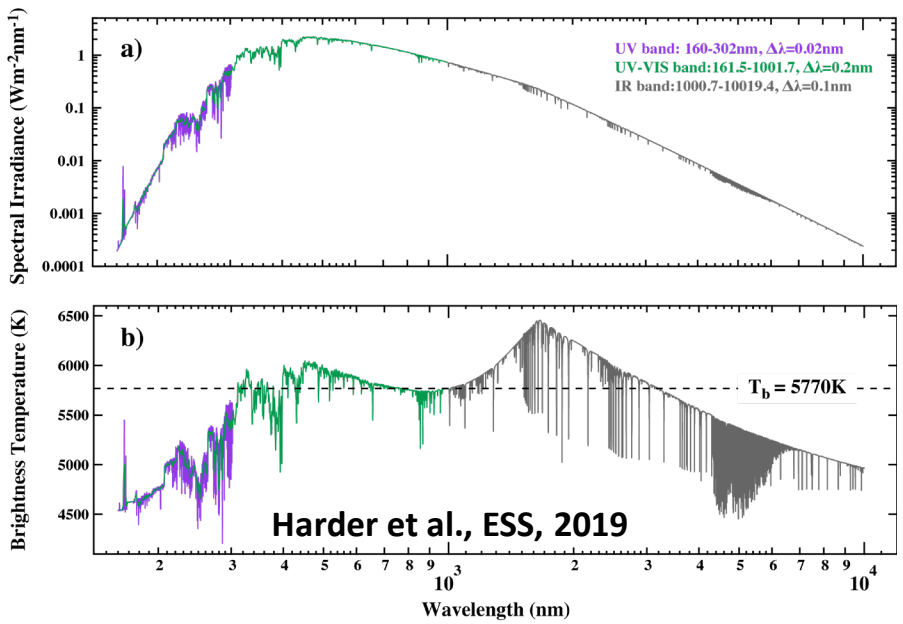
Topic1: Integrated SIM versus TSI

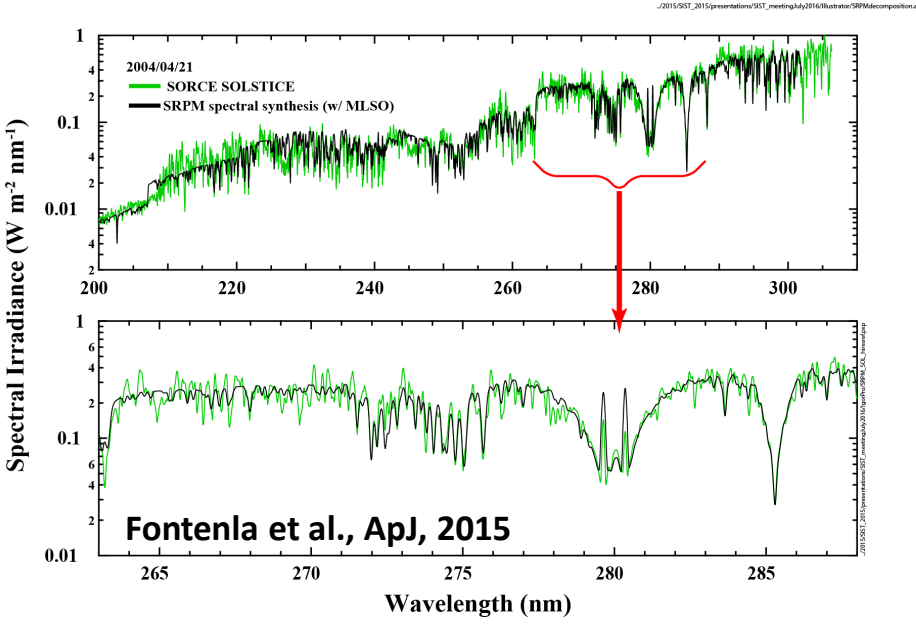


- **Majority of structure seen in residual occurs at boundaries of safe-hold events**

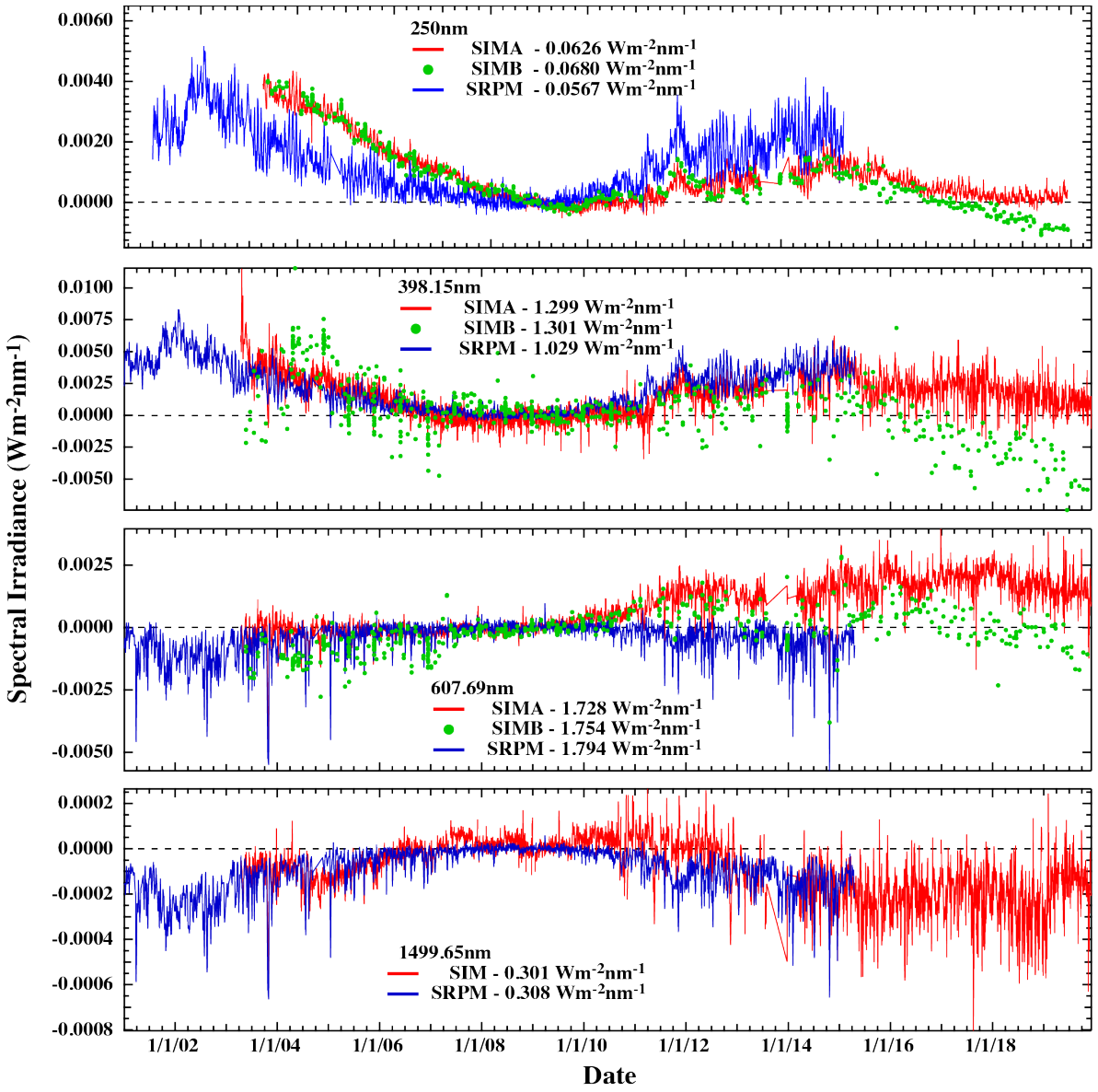
Topic 2: Input for solar irradiance models







Topic 2: SRPM/SIM Comparison



UV:

SIM generally reports larger variations in the descending phase of SC23

Near UV:

Reasonable agreement at most wavelengths

Visible:

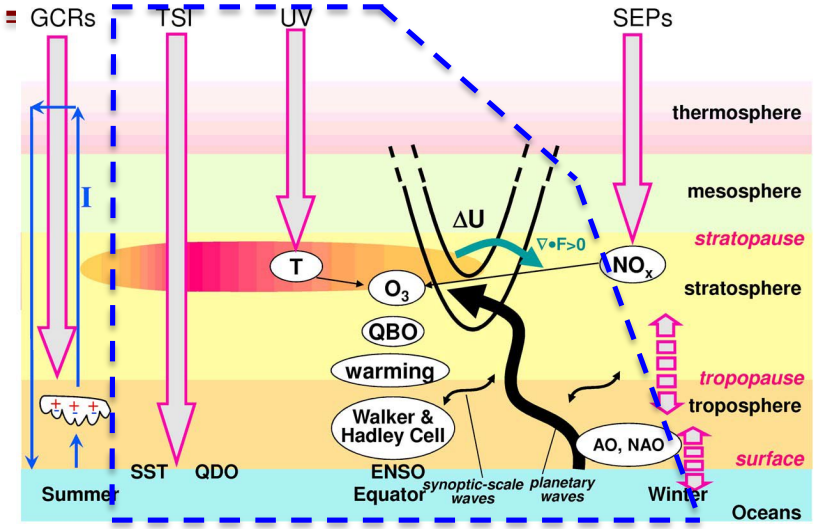
Good agreement in descending phase of SC23

Systematic differences appear after power cycling

IR:

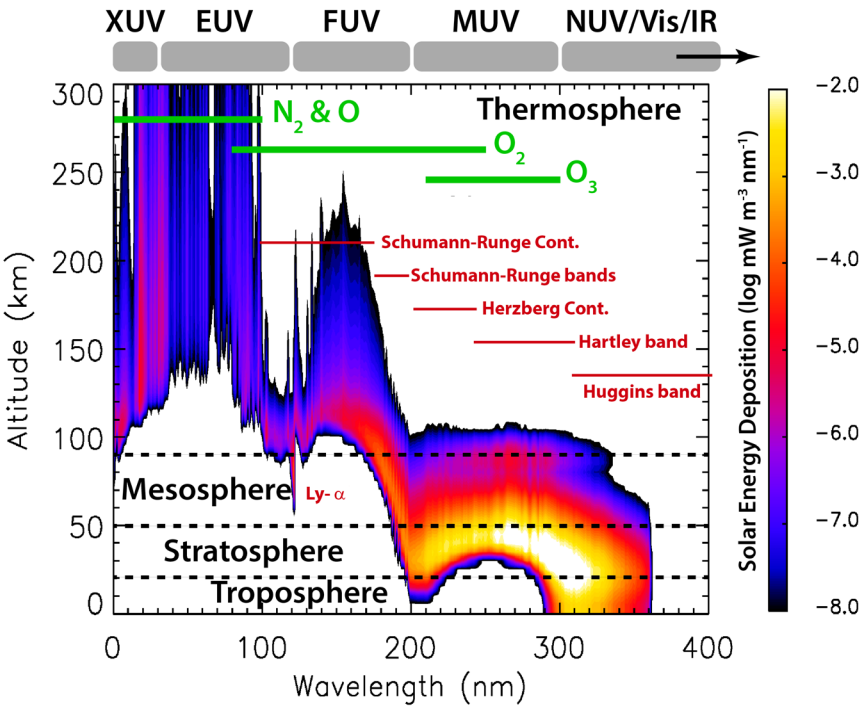
Good agreement throughout showing distinct solar cycle variations

Topic 3: Input for chemistry/climate modeling

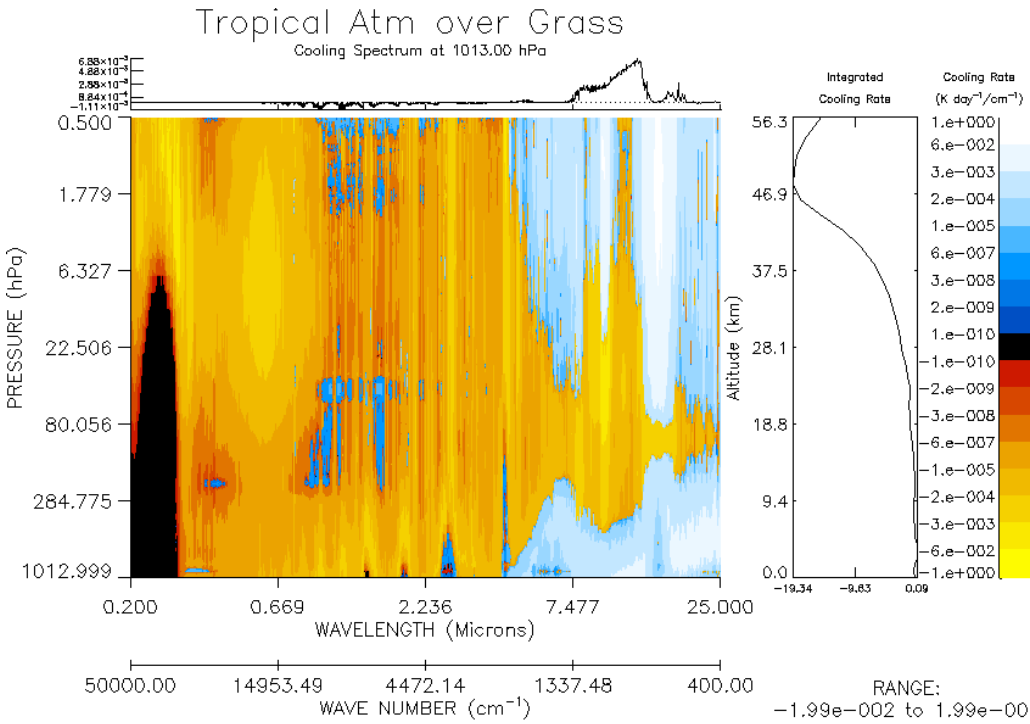


Gray et al., *Rev. Geophys.*, **48**, 2010

- **Earth's atmosphere responds to changes in the distribution of SSI**
  - **Both photochemical and dynamical responses are expected.**
  - **Atmospheric response is strongly wavelength and altitude dependent**
  - **Climate models now require accurate spectral variability**



Courtesy of Stan Solomon HAO



Berk *et al.*, *Proc. SPIE*, 2006 (MODTRAN)

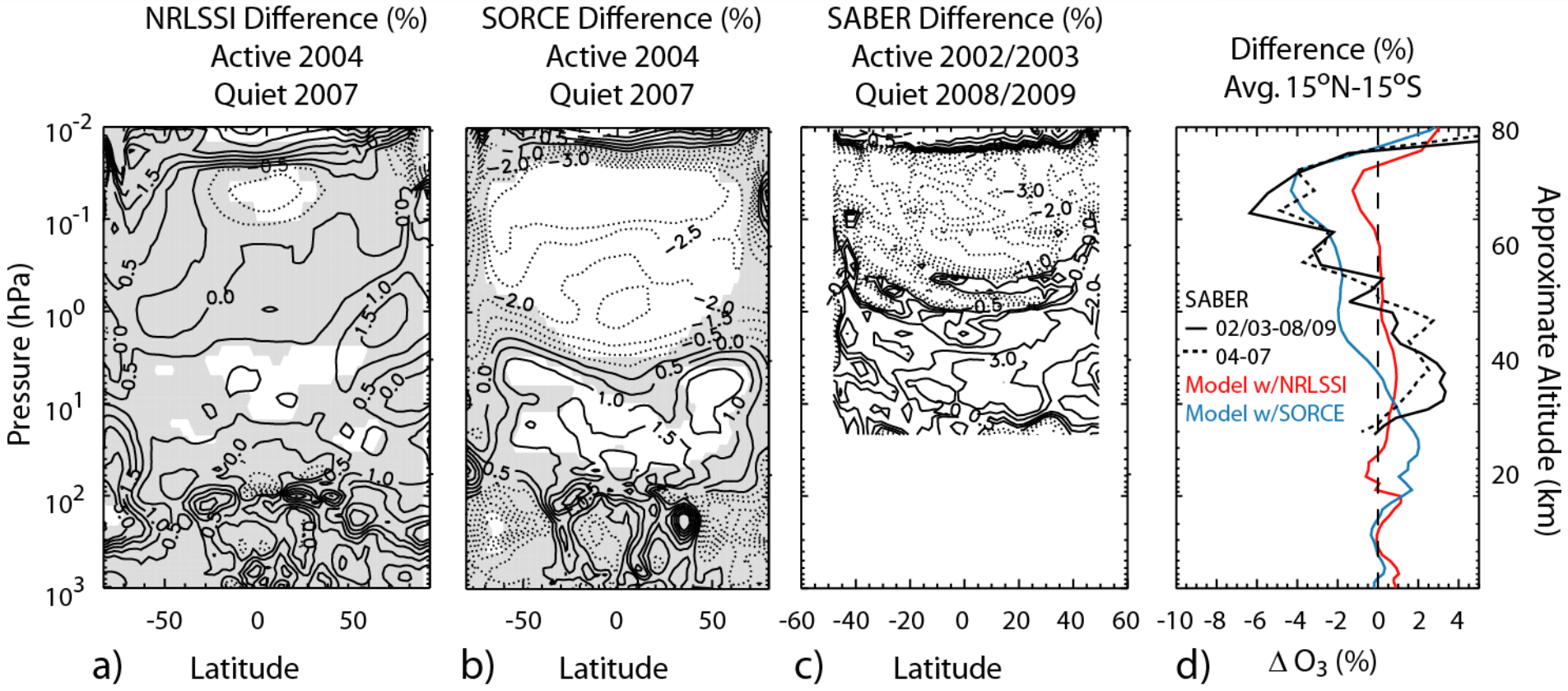
Model Studies Using SORCE Input (just a sampling…)

Author	Reference	Model/Topic
Haigh *et al.*	Nature, 2010	IC2D model/SC Ozone
Cahalan *et al.*	GRL, 2010	GISS ModelE/Trop. Temp.
Merkel *et al.*	GRL, 2011	WACCM/SC ozone & TIMED SABER
Ineson *et al.*	Nat. Geosci., 2011	HadGEM3/NAO
Oberländer *et al.*	GRL, 2012	EMAC-FUB/Strat. temp
Swartz *et al.*	ACP, 2012	GEOS CCM/ Strat. Ozone & temp
Wang *et al.*	PNAS, 2013	WACCM/MLS & grnd based OH
Shapiro *et al.*	JGR, 2013	SOCOL/SC response
Wen *et al.*	JGR, 2013	GISS ModelE/Temp. response
Ineson et al.	Nature Comm., 2015	HadGEM3/NAO/CMIP5 study, Maunder Minimum response
Maycock et al.	JGR, 2105	Impacts of grand minima on future climate
Matthes et al.	Geosci. Model Dev., 2017	Solar forcing for CMIP6

Modeling studies focusing on SSI implications:

- Photochemistry
- Radiative response
- Circulation - NAO
- "Top down" vs "Bottom up"

SORCE/WACCM/SABER Comparison



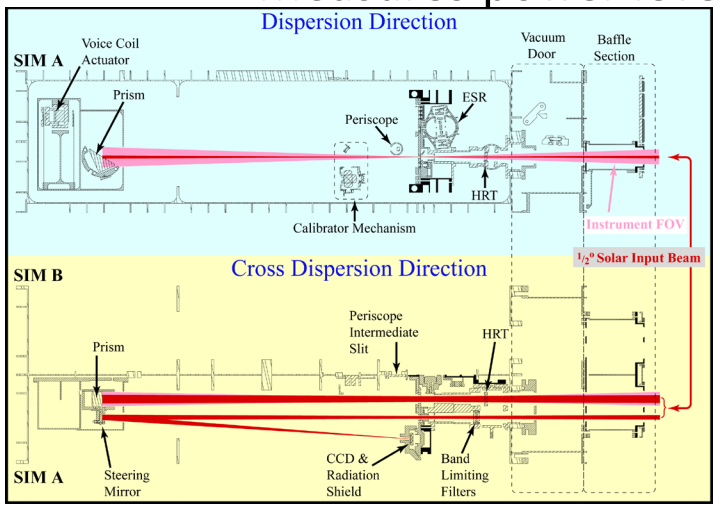
Merkel et al., *GRL*, **38**, L13802, 2011

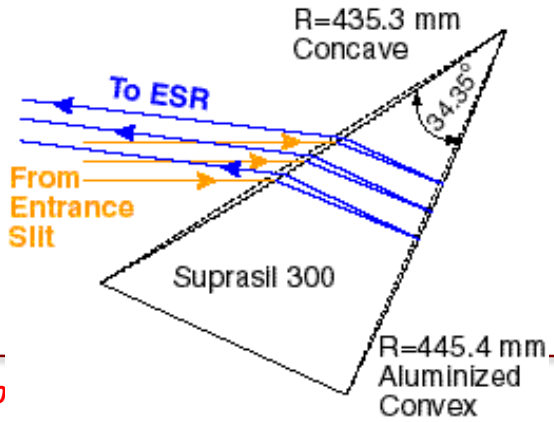
J2 Rate: $O_2 + h\nu \rightarrow 2O$

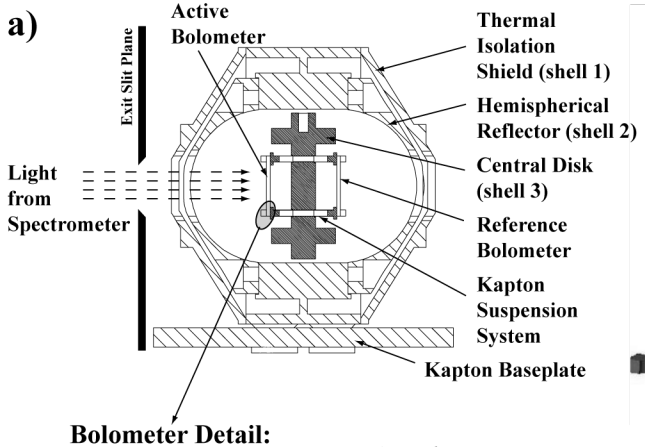
J3 Rate: $O_3 + h\nu \rightarrow O(^1D) + O_2$

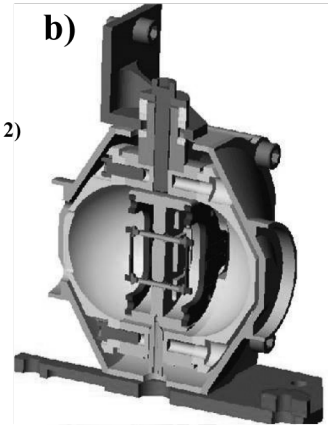
- More UV radiation is transmitted to lower levels
  - Greater O_2 photolysis produces more O_3
- 2.5% increase in intensity in 210-242nm band
  - Increased J2 rate from 4.5% to 7%
  - Increased J3 rate from 3% to 3.5%
- Altitude of sign change depends on J2 &J3 rate

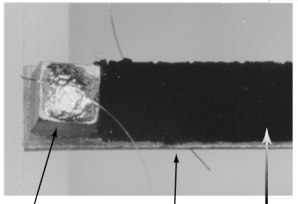
- **SIM contributions to spectral radiometry:**
  - **Single optical element Fèry prism design**
    - Focuses and disperses light with only 1 optical element
  - **Electrical substitution radiometer for SSI measurements**
    - Measures power levels ≈1000x smaller than TIM

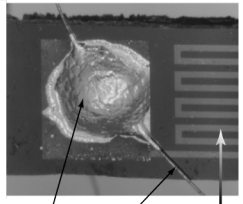


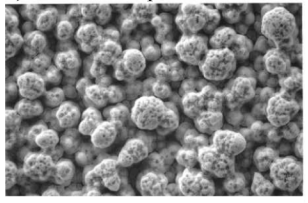






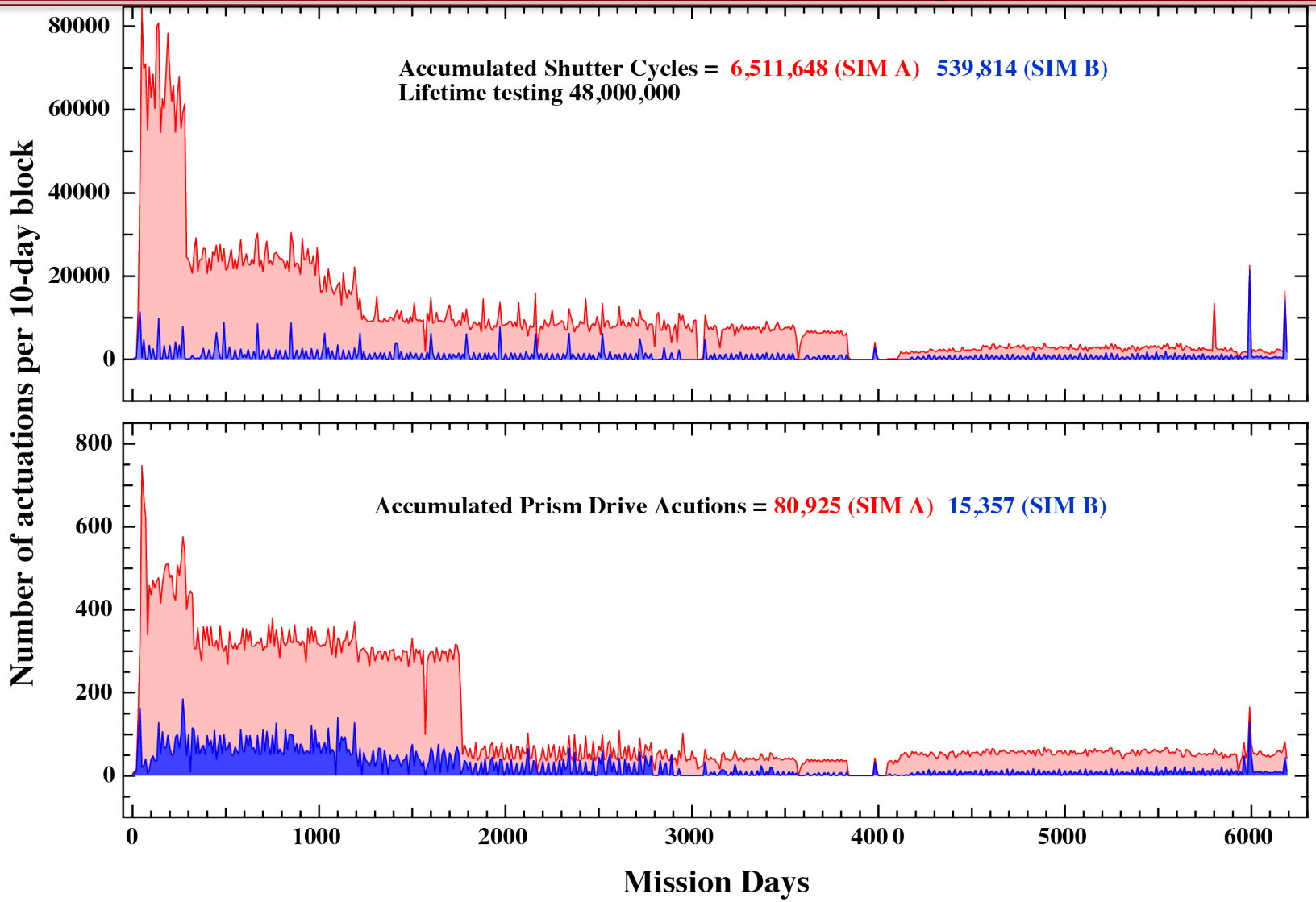






Harder et al., *Solar Physics*, **230**, 2005

SIM Mechanism Usage



- **Relative usage:**
  - **SIM A / SIM B: Shutter ~12:1, Prism drive ~1:1**
    - SIM B usage of these mechanisms is not insignificant
  - **SIM A / Lifetime Test: Shutter=14%**

Into the Future

We're Not Done Yet!

Topic	Participants
SORCE/TSIS Intercomparison (stability &absolute scale adjustment)	S. Béland, E. Weatherhead, E. Richard (funded through SIST)
Final ATBD delivery (NASA requirement)	SORCE SIM Data Processing Group
Peer Reviewed paper on SORCE SIM on-orbit performance	J. Harder + many others
Continued analysis of SORCE SIM data (pending available funding)	Usual suspects…

Questions?