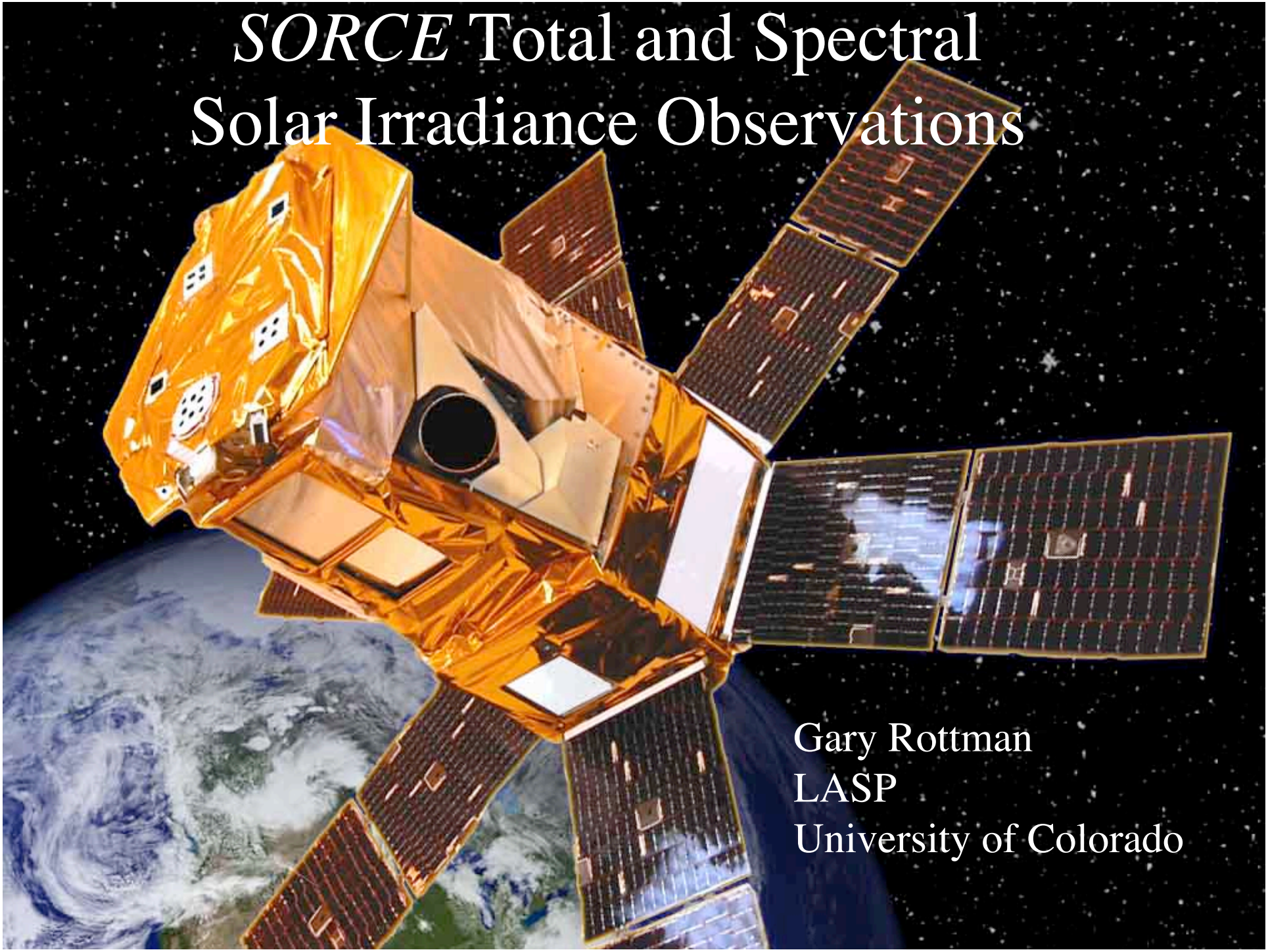
SORCE Total and Spectral Solar Irradiance Observations



Gary Rottman
LASP
University of Colorado

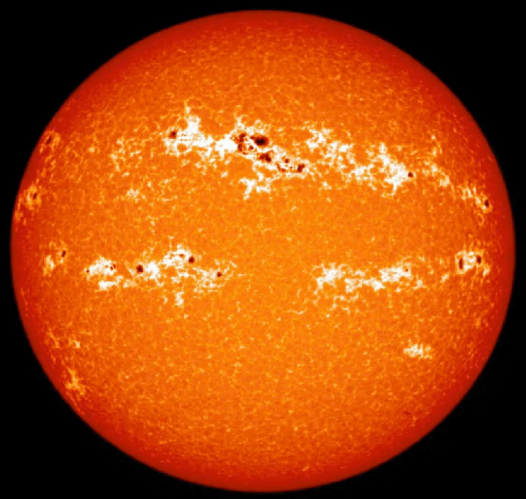
The *SORCE* Mission

The *SORCE* mission is one element of NASA's Earth Science Enterprise. *SORCE* is dedicated to the measurement of solar irradiance — both total and spectral irradiance.

- The *SORCE* has four solar irradiance instruments designed and built at LASP.
- The *SORCE* spacecraft was developed by Orbital Sciences Corporation.
- The *SORCE* was launched on a Pegasus XL rocket on January 25, 2003, and is in a 40° inclination orbit at an altitude of 620 km.
- The *SORCE* is operated from a control center at LASP.

Postcards from *SORCE*

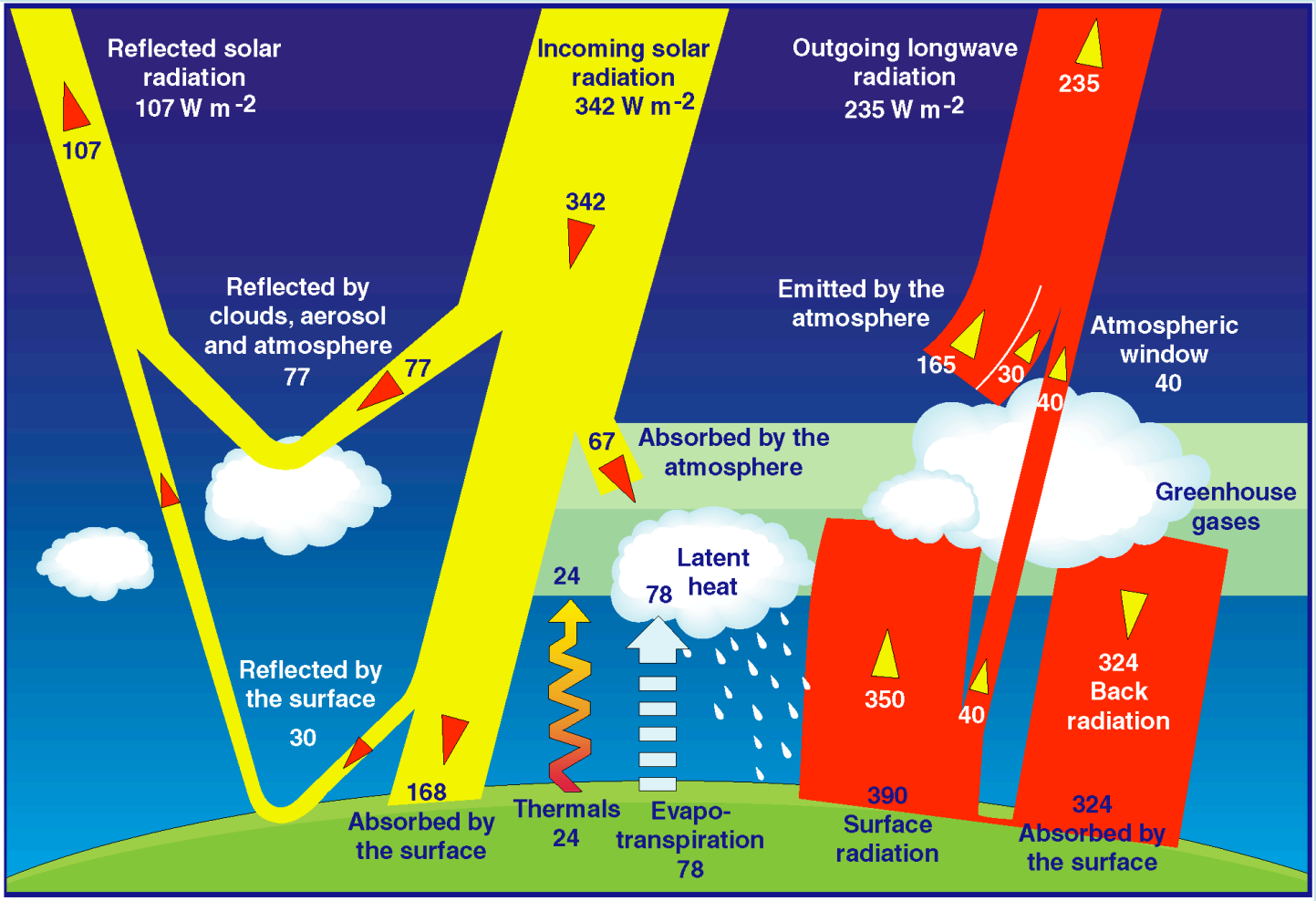
Observation of Climate State Variables



- Total Solar Irradiance
- Spectral Solar Irradiance
- Particles and fields

- Clouds
- Water
- Greenhouse gases
- Shortwave and Longwave surface radiation
- Snow/Ice Cover
- SST and SAT
- Ocean Salinity
- Ocean Topography
- Soil Moisture
- Costal Zones and Margins
- Vegetation
- ….. + many others

The Earth's Radiation and Energy Balance

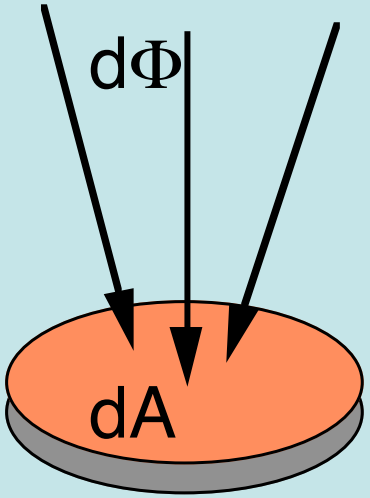


Radiation Balance of the Earth (Jeffrey T. Kiehl)

Basic Radiometic Measurements

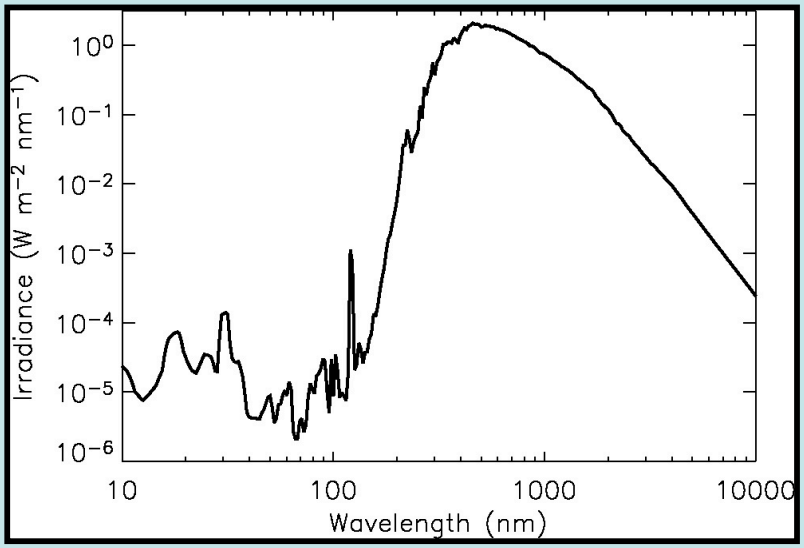
The *total irradiance* or *radiant flux density* is the radiant flux across a surface element, d*A* :

$$E = \frac{d\Phi}{dA} \qquad \{W / m^2\}$$



The *spectral irradiance*, E_λ, is the radiant flux density per unit wavelength interval:

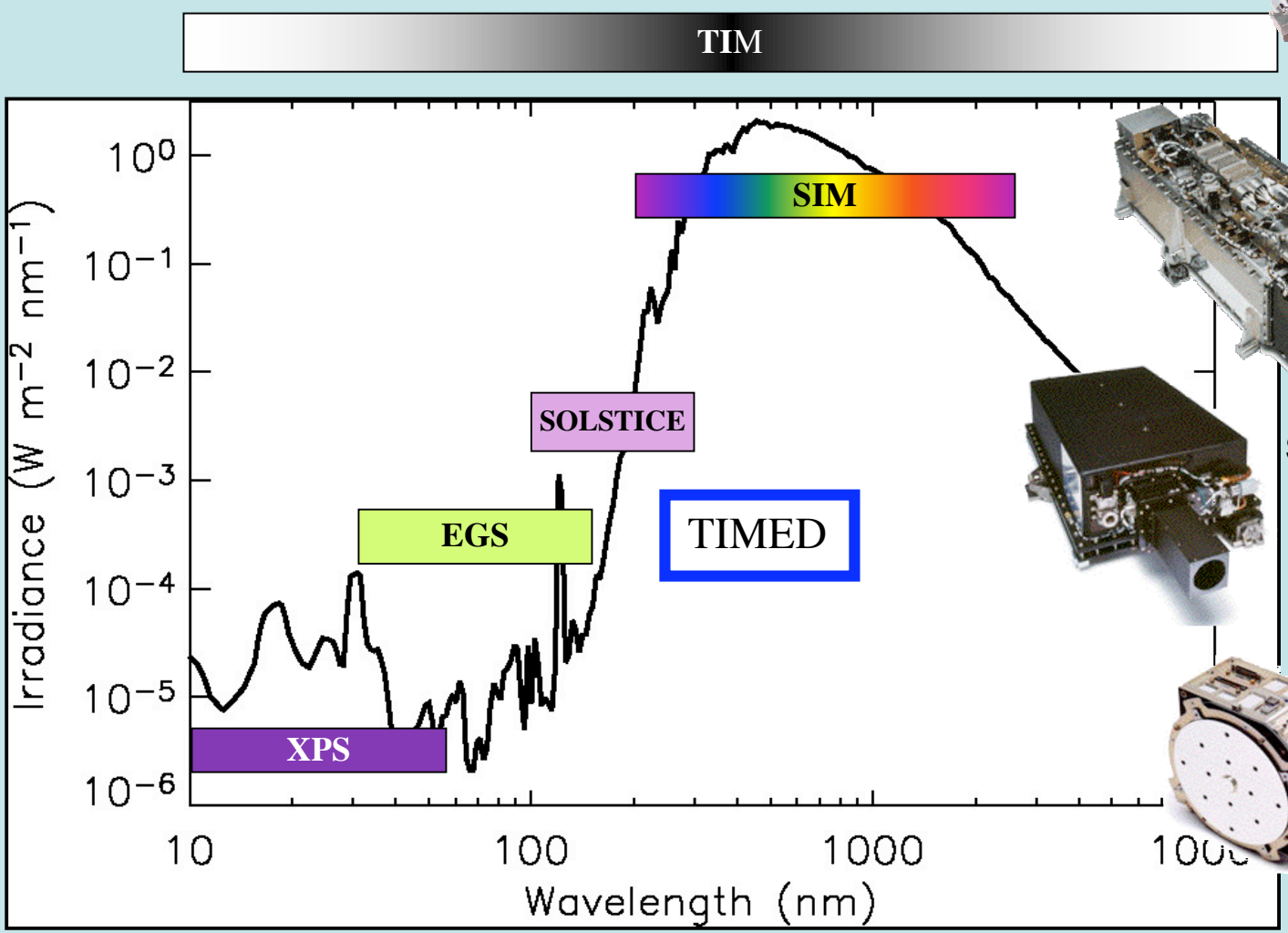
$$E_\lambda = \frac{d^2\Phi}{dA d\lambda} \qquad \{W / m^3\}$$

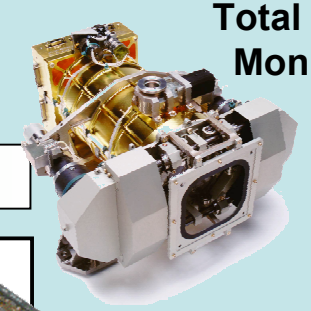


<u>NOTE</u>: the *Total Solar Irradiance, TSI,* is the integral over all wavelengths of the Solar Spectral Irradiance.

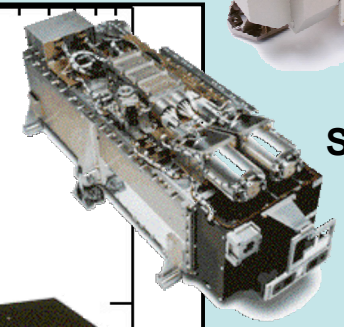
$$E = \int_{\lambda=0}^{\infty} E_\lambda \, d\lambda$$

SORCE Instruments



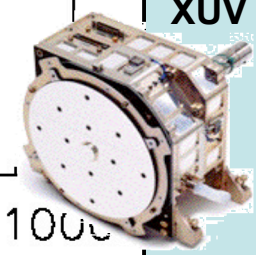


Total Irradiance Monitor (TIM)



Spectral Irradiance Monitor (SIM)
200 – 2000 nm

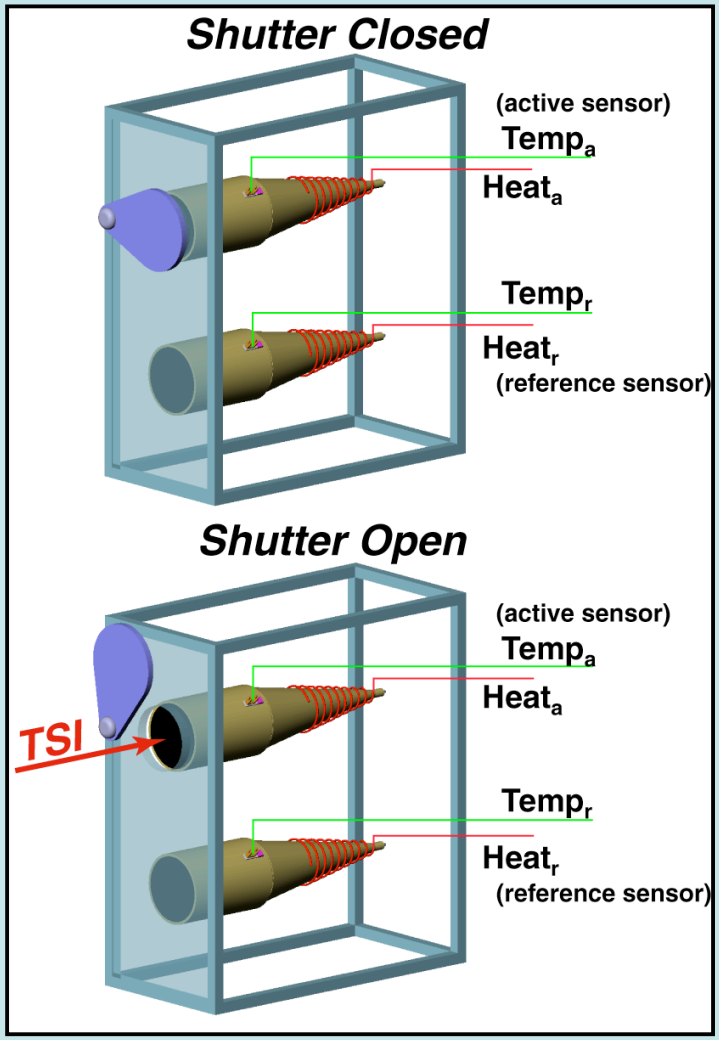
SOLar STellar Irradiance Comparison Experiment (SOLSTICE)
120 – 300 nm



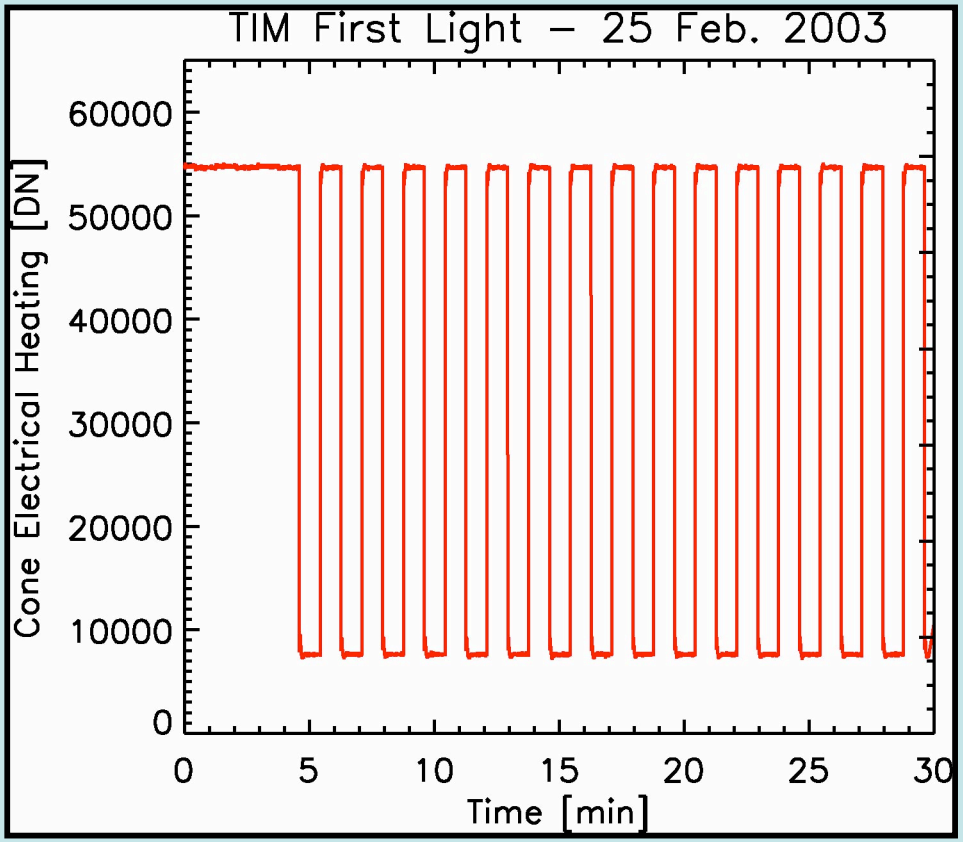
XUV Photometer System (XPS)
1 – 34 nm

Concept of Electrical Substitution Radiometers

- Based on the measurement of heat flux. Two identical sensors, one active and the other used as a reference, are connected so that they are in the same thermal environment.
- Joule heat is supplied to each sensor by an "actively controlled" heater circuit so that they attain the same temperature.
- These sensors have high *absorptance* in order to efficiently collect radiation. Photon energy is *completely* converted to heat.
- A shutter opens and solar radiation is allowed to fall on the active sensor — a corresponding amount of Joule heat must therefore be removed from the active sensor in order to maintain the heat flux balance. The change of Joule heat to the active sensor is *equivalent* to the amount of radiation now incident upon it.



Major Improvement of the TIM ESR



Major

- Phase sensitive detection at the shutter fundamental frequency
- Pulse width modulation of the heater power
- Use of Nickel-Phosphide, NiP, black absorber

TIM Measurement Equation

Use the Real Part

On-Sun, Off-Sun (Dark) Data Numbers

Feedforward Data Numbers

$$E_0 = \mathrm{Re}\left\langle \frac{dP}{dDN} \bullet \frac{-\left(\boldsymbol{DN}_{Sun} - \boldsymbol{DN}_{Dark}\right)\left(1 + \frac{1}{\boldsymbol{G}}\right) + \frac{\left(\boldsymbol{FF}_{Sun} - \boldsymbol{FF}_{Dark}\right)}{\boldsymbol{G}}}{A_P\, \alpha\, \boldsymbol{\Psi}\, f_{point}\, f_{degrade}\, f_{Doppler}\, f_{AU}} \bullet \frac{\boldsymbol{Z}_H}{\boldsymbol{Z}_R} \right\rangle$$

Aperture

Efficiency Factors

Shutter Waveform

Absorptance

Equivalence Ratio

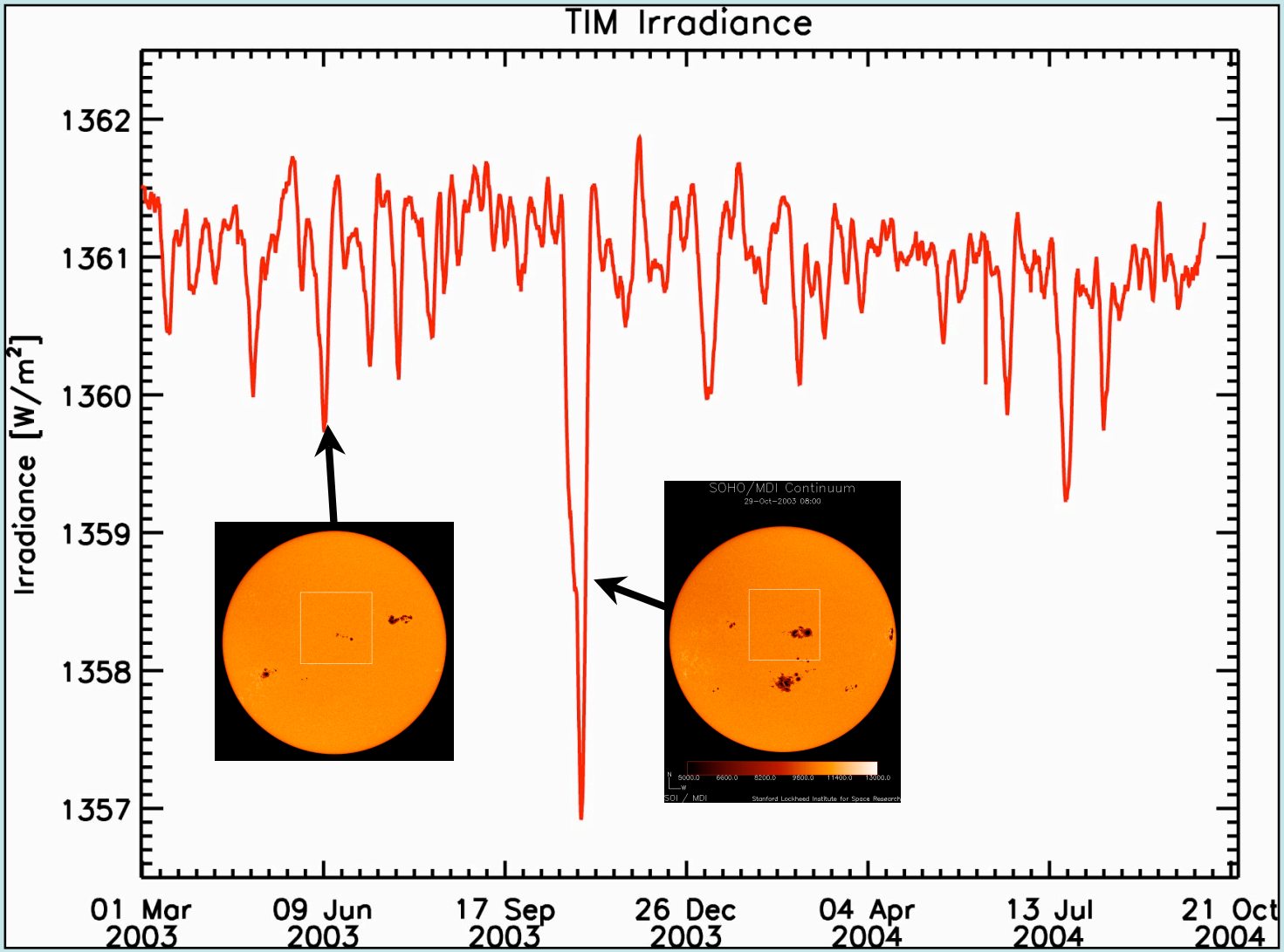
$$\frac{dP}{dDN} = \frac{V^2}{M\, R'}$$

Standard Watt

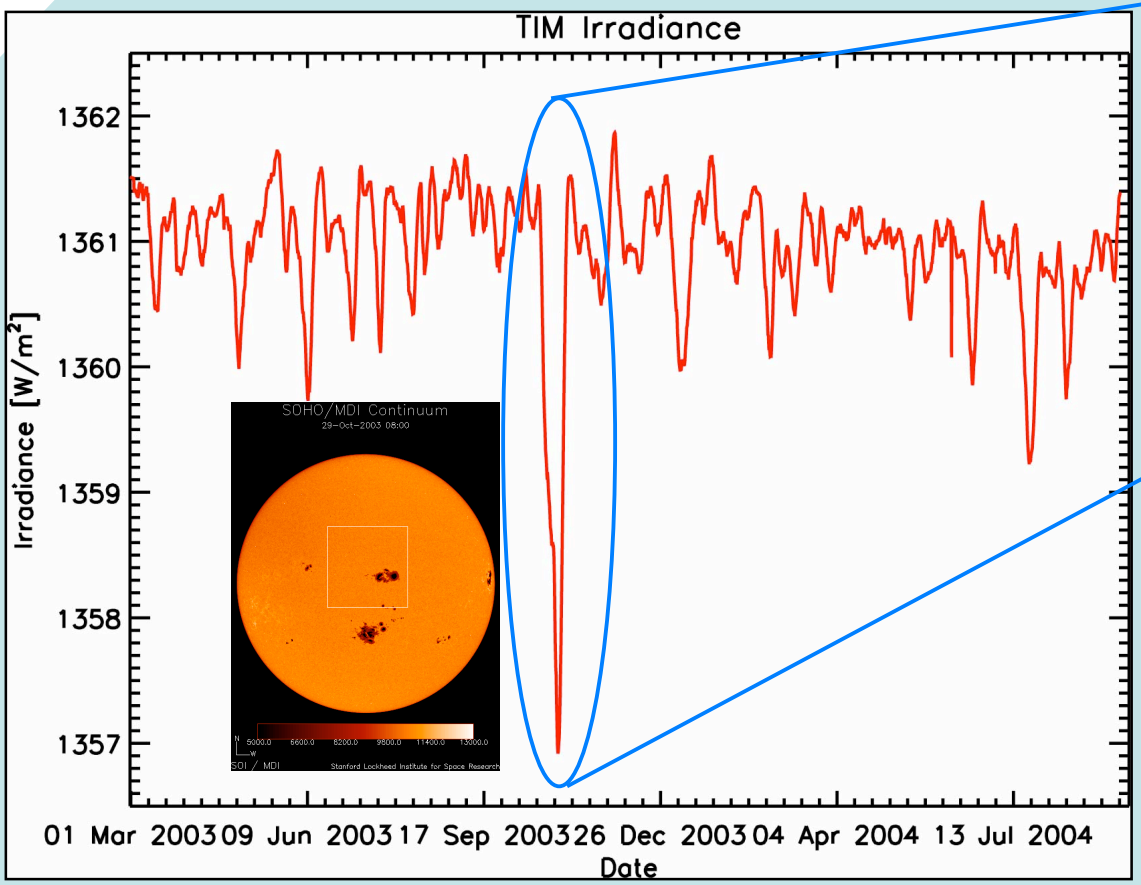
M = Full Scale Count =64000 {not 2^{16}}

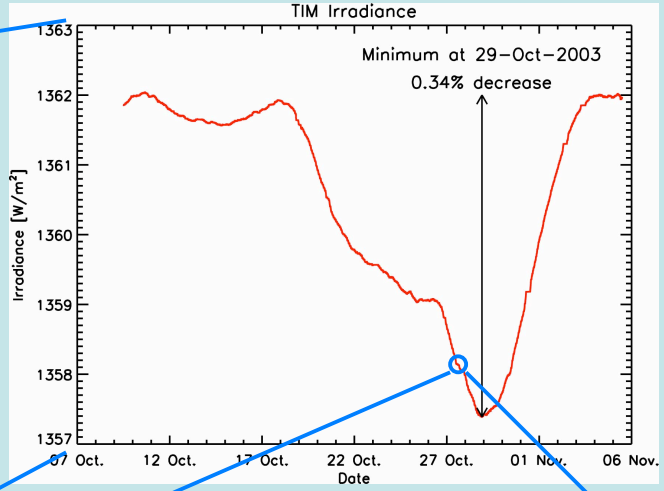
Bold type denotes phasors.

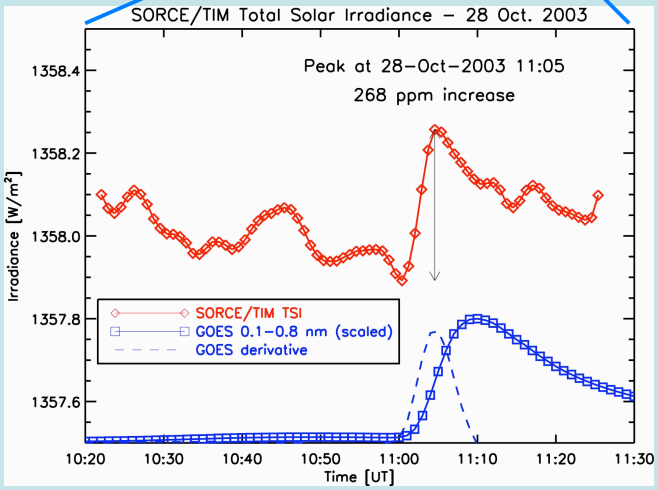
TIM TSI Record



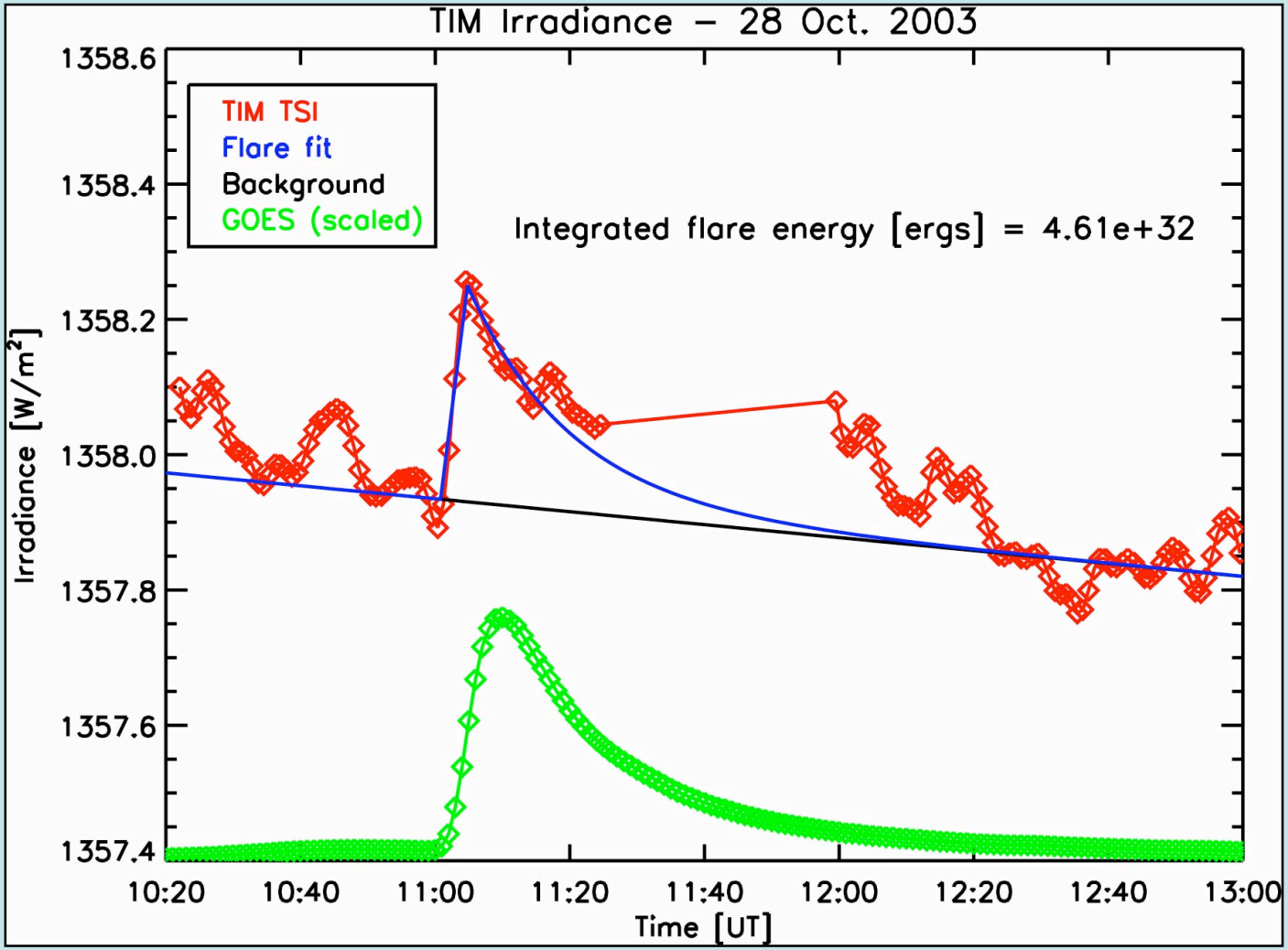
The TIM Measurements Are Very Precise



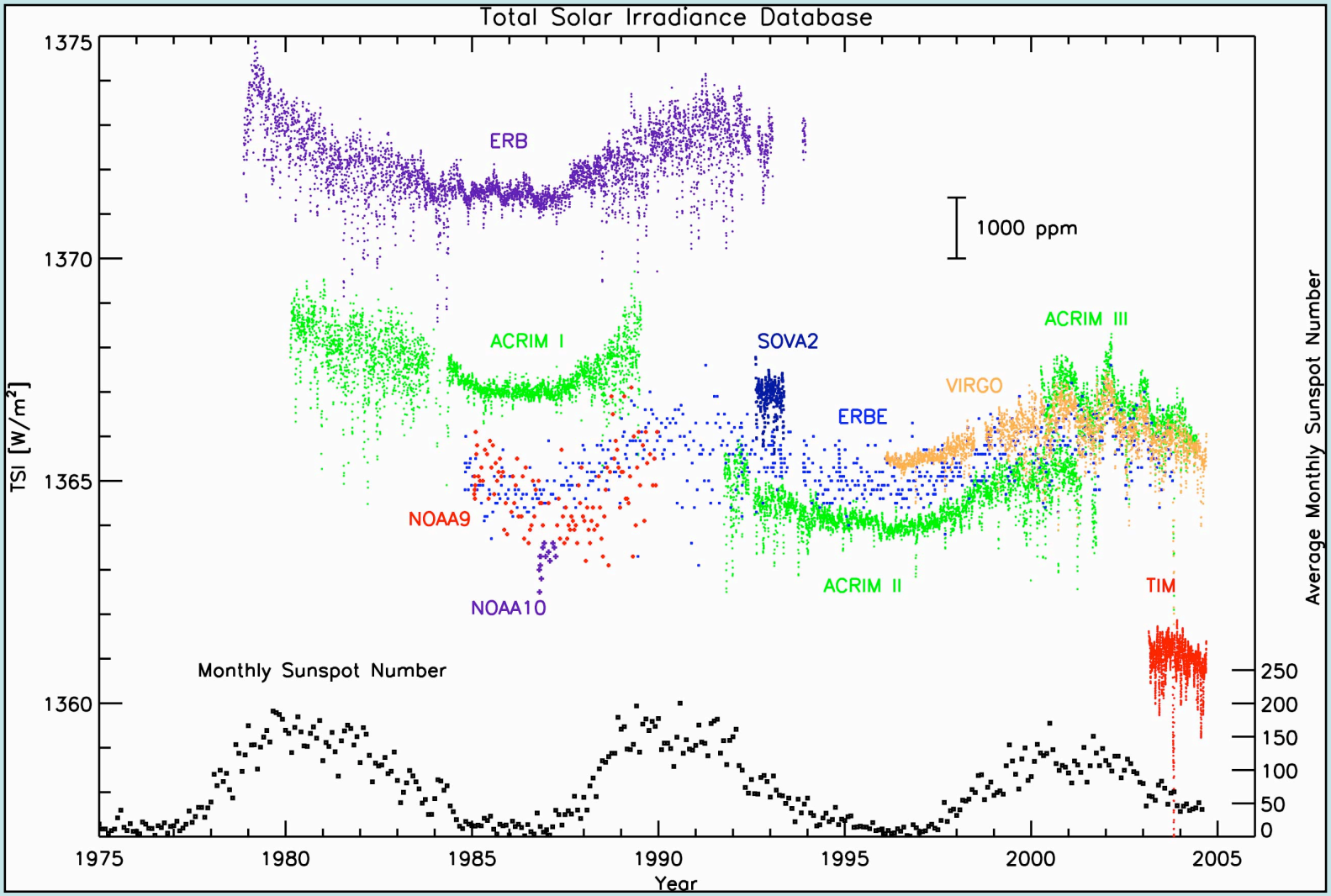




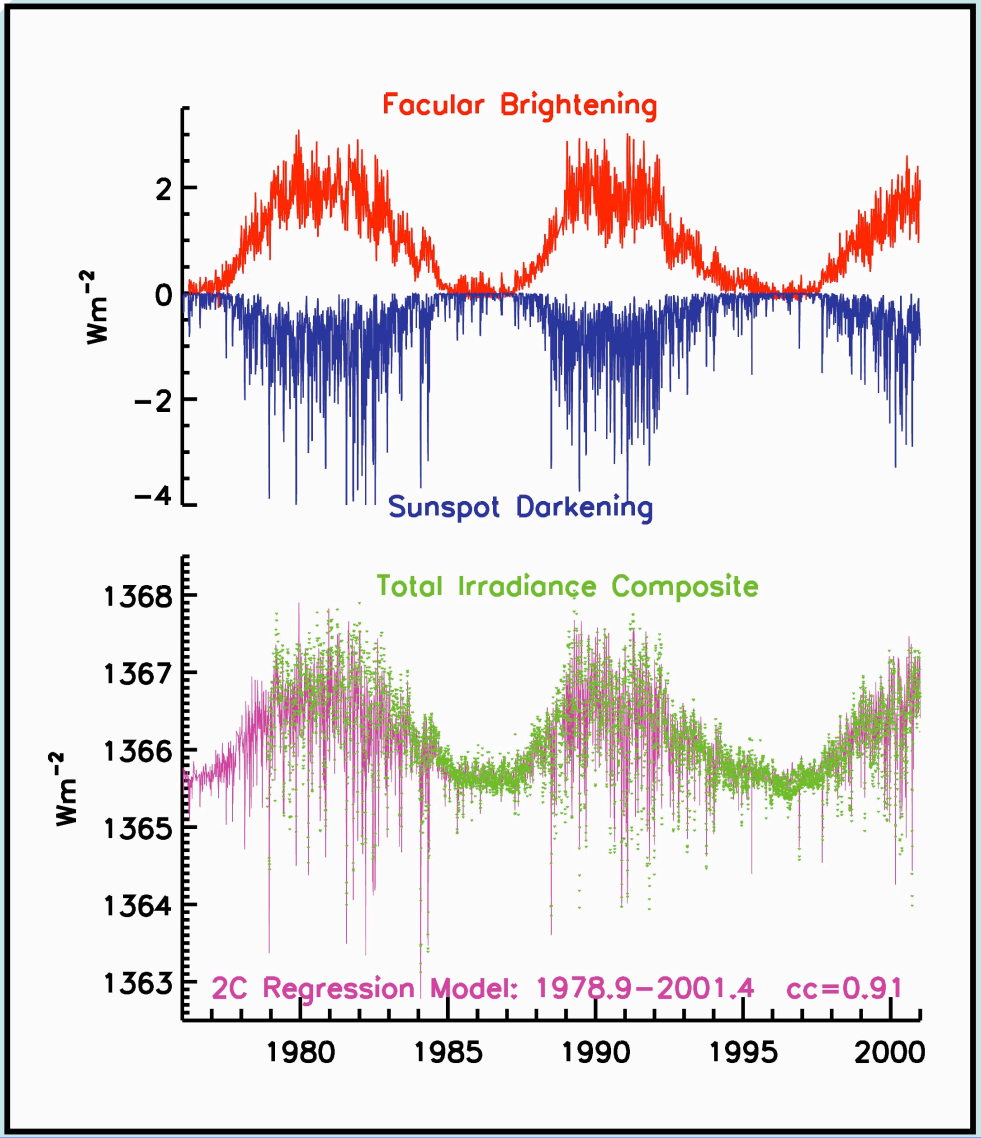
TSI Flare Observations Measure Total Flare Energy

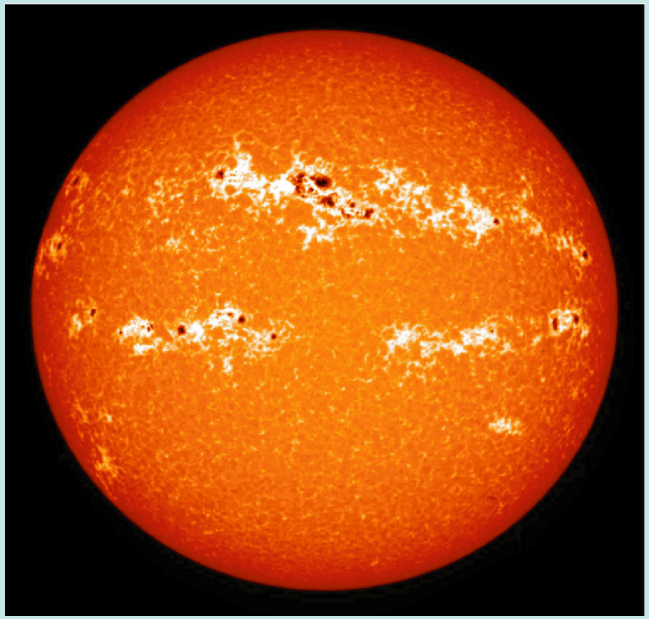


TSI Record


Total Solar Irradiance Database
TSI [W/m²]
1375
1370
1365
1360
ERB
1000 ppm
ACRIM I
SOVA2
ACRIM III
VIRGO
ERBE
NOAA9
NOAA10
ACRIM II
TIM
Monthly Sunspot Number
250
200
150
100
50
0
Average Monthly Sunspot Number
1975
1980
1985
1990
1995
2000
2005
Year

Model of TSI

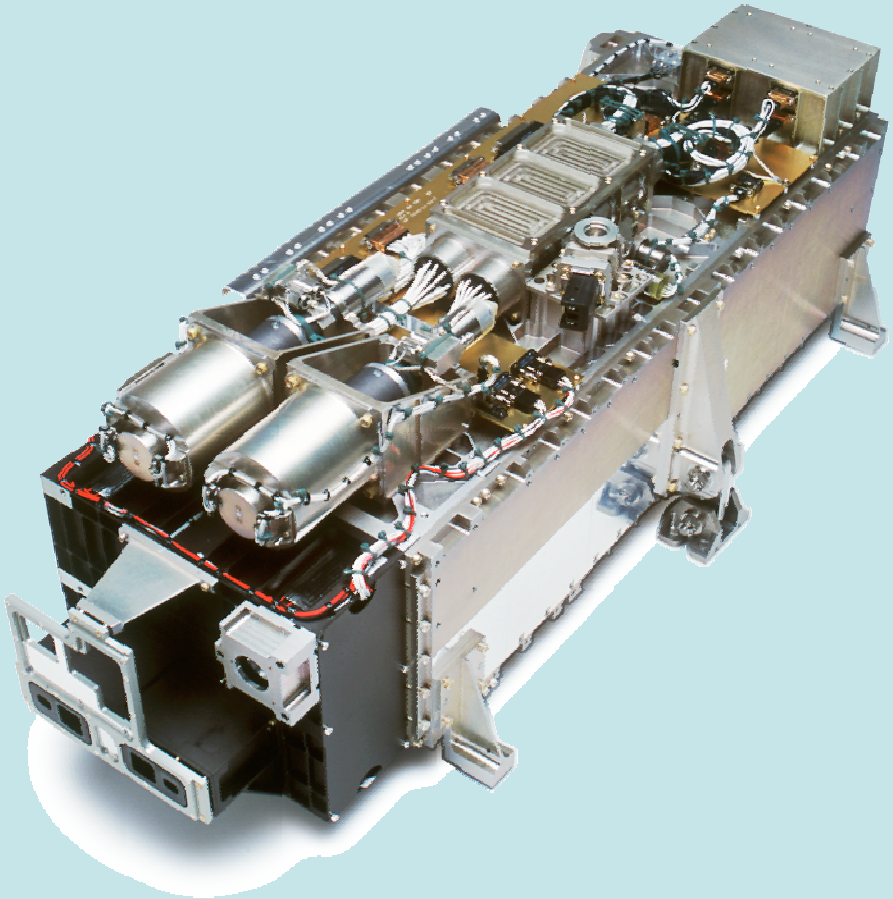




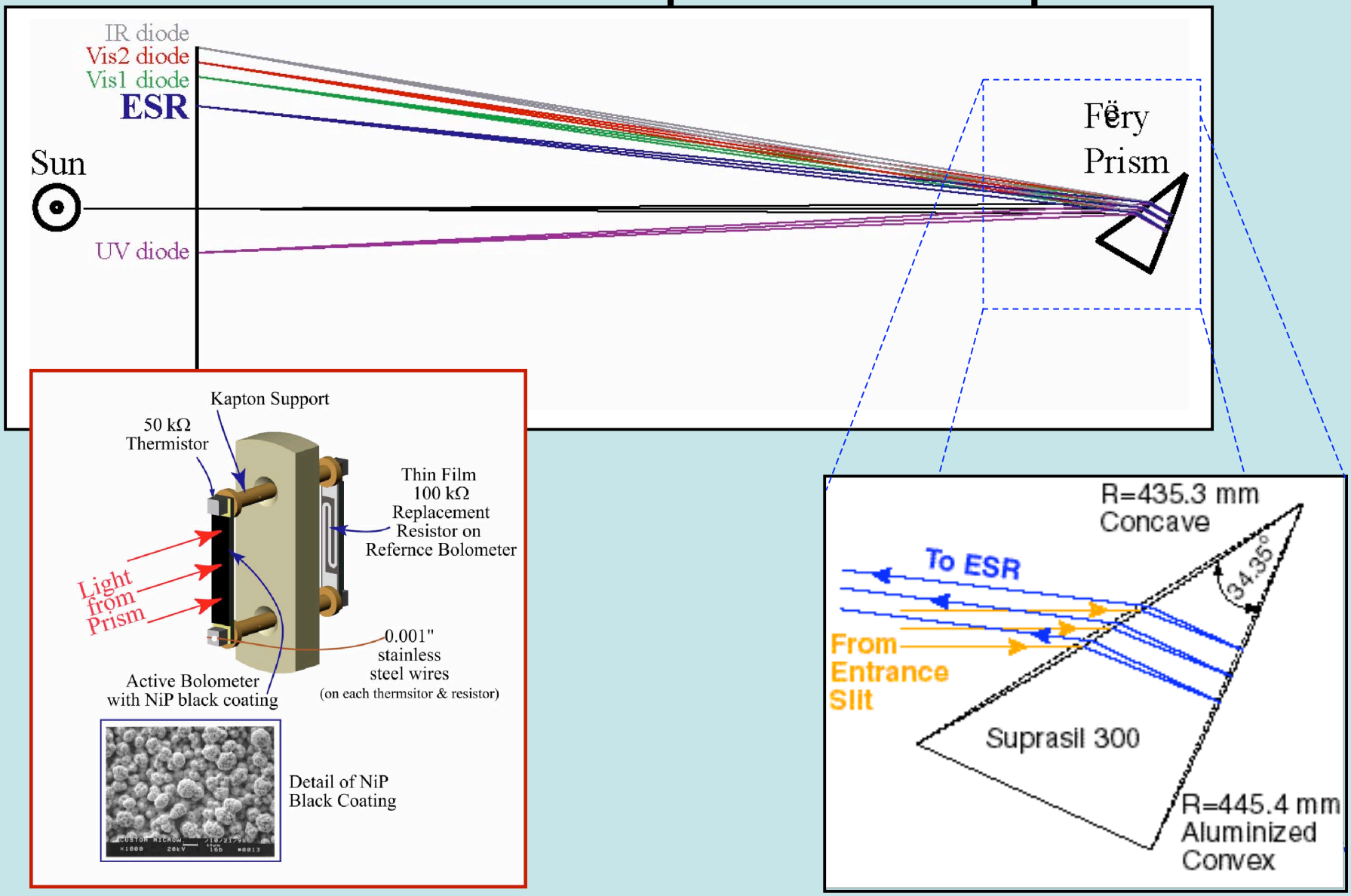
Solar variability on all temporal and spatial scales is intimately connected with variations of the solar magnetic field

Spectral Irradiance Monitor — SIM

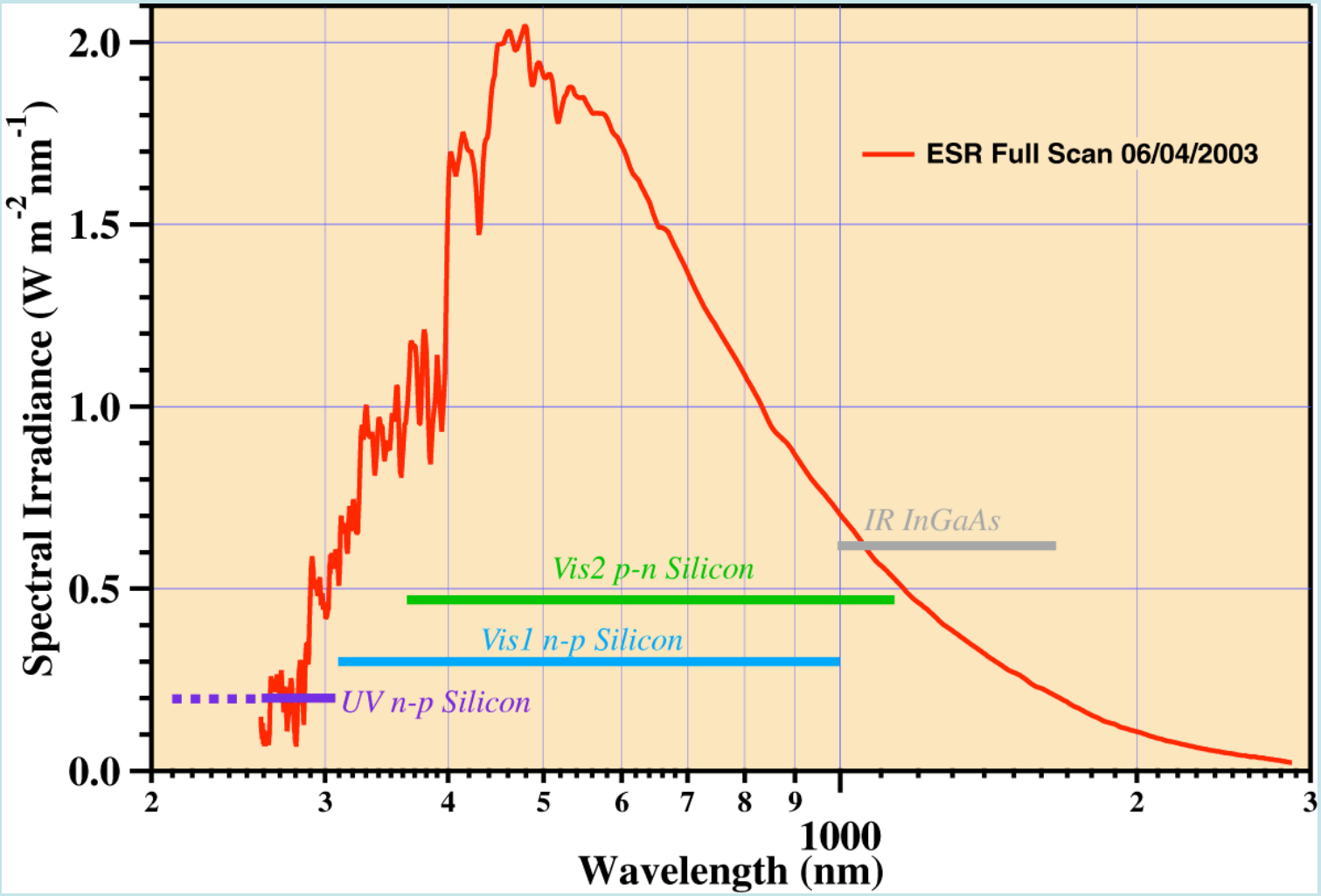
- Instrument Type: Dual Féry Prism Spectrometer
- Wavelength Range: 200-3000 nm
- Wavelength Resolution: 0.25-33 nm
- Optics: Suprasil 300 prism
- Detectors: ESR, 5 diodes
- Absolute Accuracy: 300 ppm
- Relative Stability: 100 ppm/year
- Field of View: 1.5° x 3.5 °
- Mass: 22 kg
- Orbit Average Power: 25.3 W



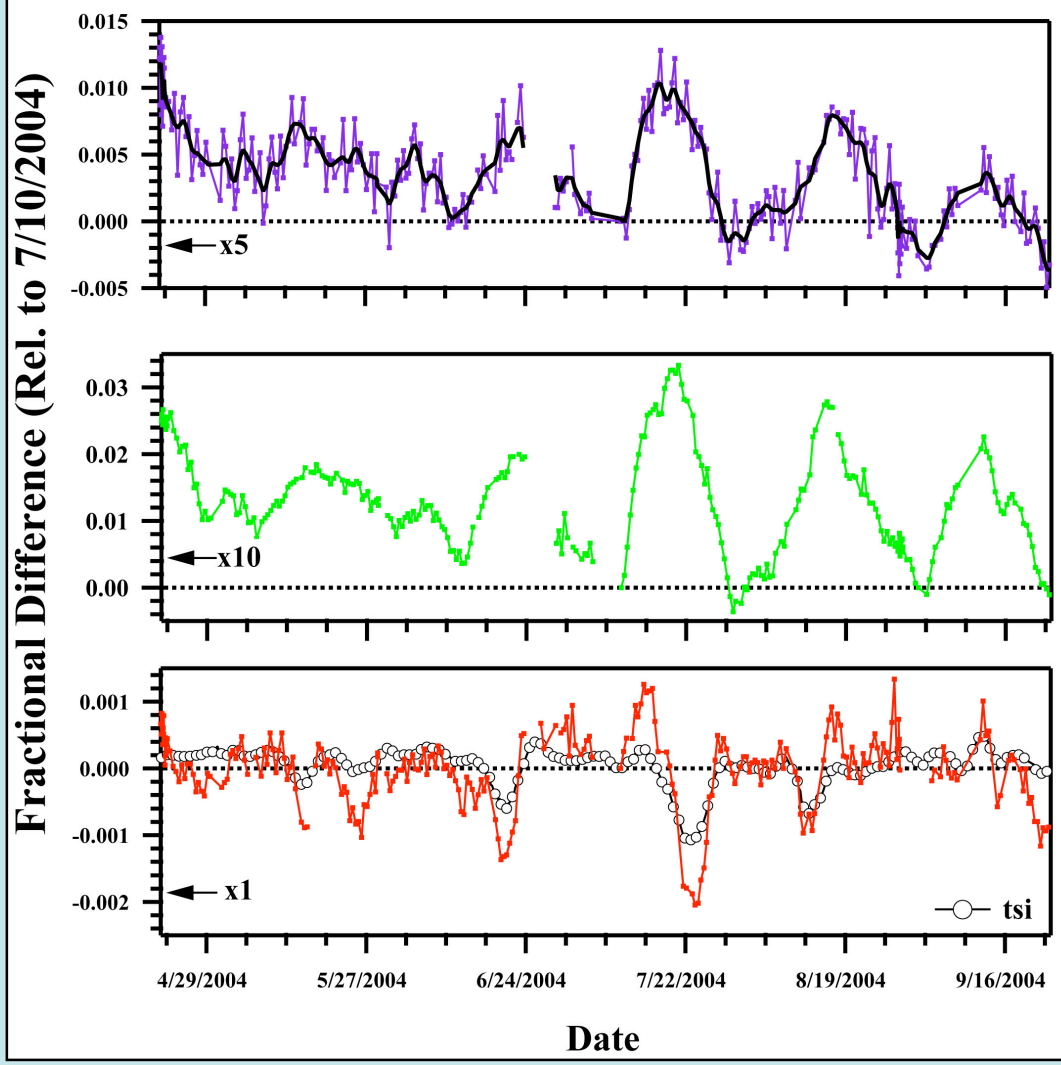
SIM Optical Concept



SIM ESR Irradiance Spectrum



Solar Variability in the Ultraviolet



250 nm: UV Pseudo-Continuum

- *Formed from continuum flux from the top of the photosphere and densely spaced spectral lines in the lower chromosphere.*
- *Continuum contribution decreases with sunspot blocking, lines increase intensity due to presence of plage.*
- *Chromospheric component tends to dominate.*

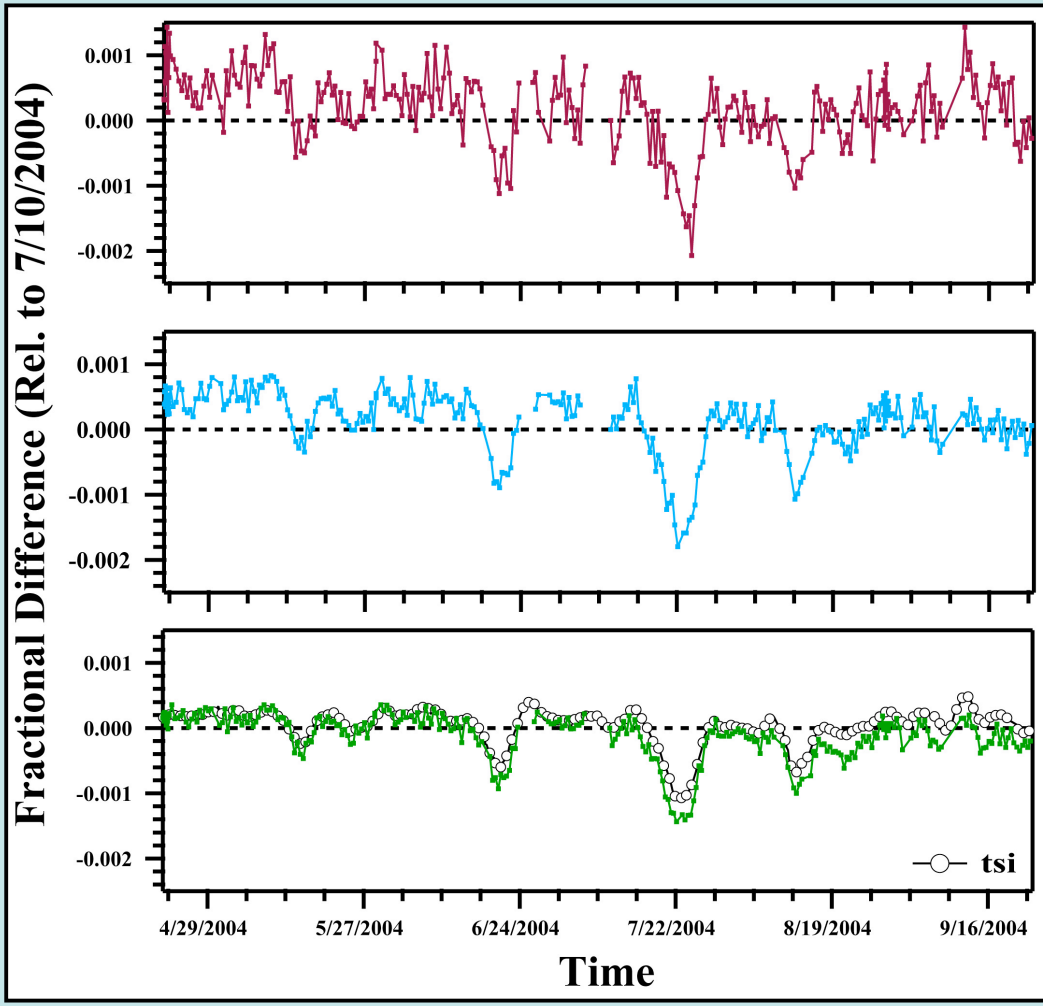
280 nm: Mg II

- *Resolution 1.1 nm, so contains pseudo-continuum & the cores of the Mg II lines.*
- *280 nm peaks when the plage areas are the largest.*
- *Flux is affected by the presence of active network structures.*

304 nm: Near-UV Pseudo-Continuum

- *Continuum formed in deeper layers of the photosphere with less densely spaced lines than at 250 nm.*
- *Time series resembles TSI and is more photospheric in nature than chromospheric.*
- *A factor of ~2x contrast inhancement compared to TSI*

Solar Variability in the Visible – Short Wavelengths



430 nm: G Band

- *Formed from densely spaced spectral lines; CH molecular, Fe I resonance and H Balmer γ (434.25 nm)*
- *Molecular lines formed at the top of the photosphere and bottom of chromosphere.*
- *Time series resembles TSI but about 2x more contrast*

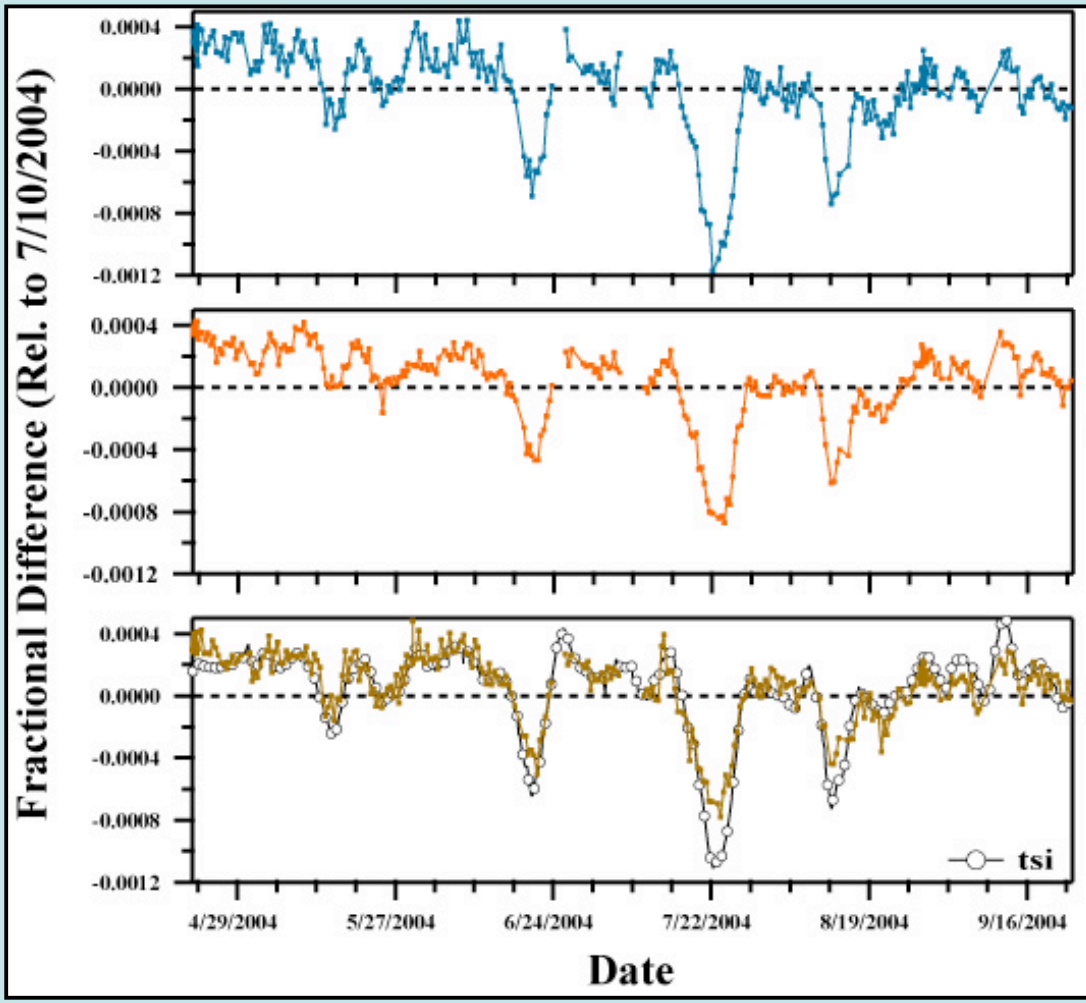
480 nm: Irradiance Peak

- *Predominately Continuum with low density atomic lines*
- *Photosphere in character*
- *Time series resembles G Band*

589 nm: Na I D

- *Na I D lines formed in the lower chromosphere but with large departures from LTE and do not display emission at the core.*
- *Very similar in character to TSI, but broader in extent.*

Solar Variability in the Visible – Long Wavelengths

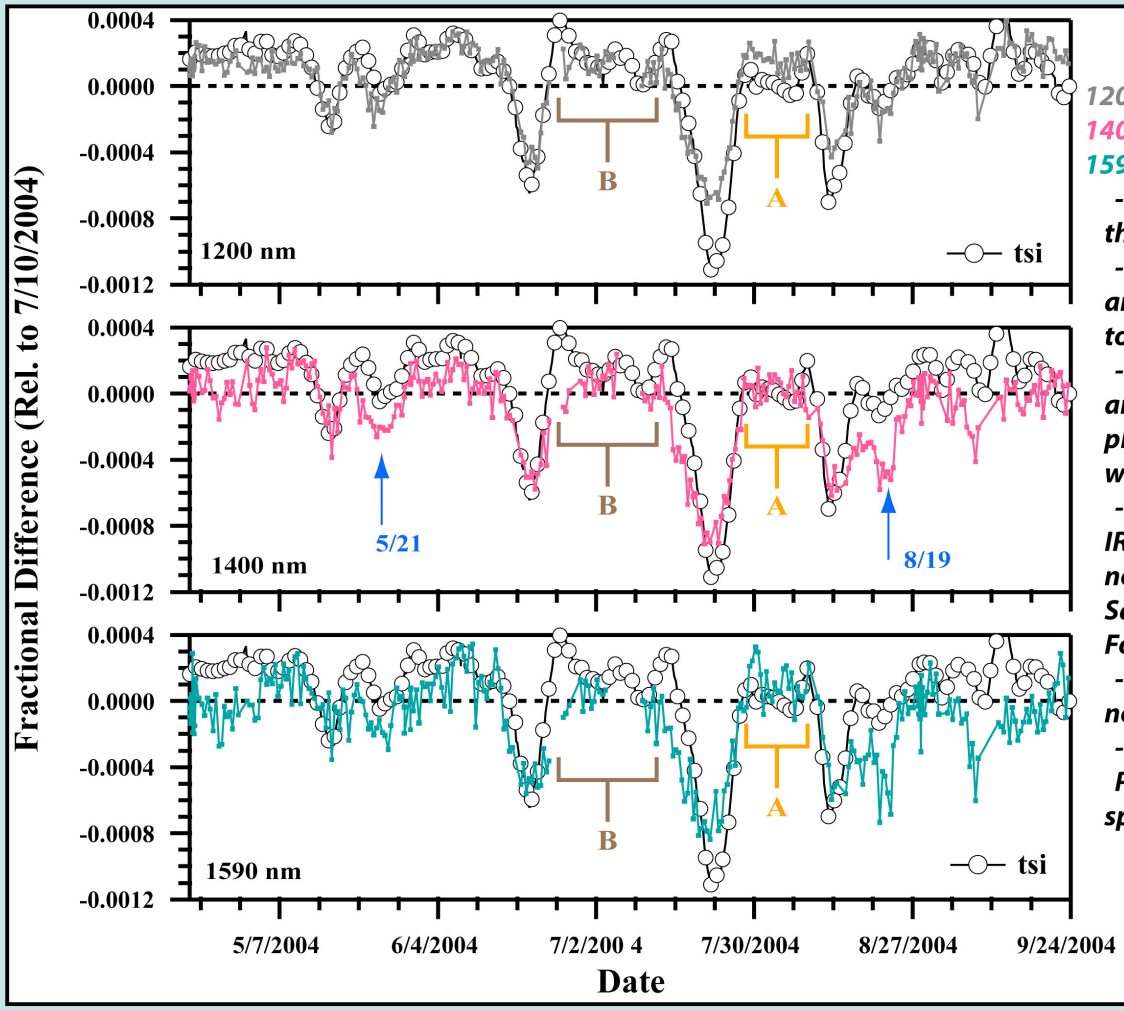


656 nm: H α
- *Instrument function ~15 nm FWHM at this point so time series contains continuum contribution*
- *Almost indentical in character to TSI*

857 nm: Ca II Triplet
- *Instrument function ~25 nm FWHM*
- *Contrast is now less that for TSI*

1000 nm: Ca I Resonance
- *Facular brightening on the limb just barely compensates for sunspot areas still on the disk at this wavelength*

Solar Variability in the Infrared

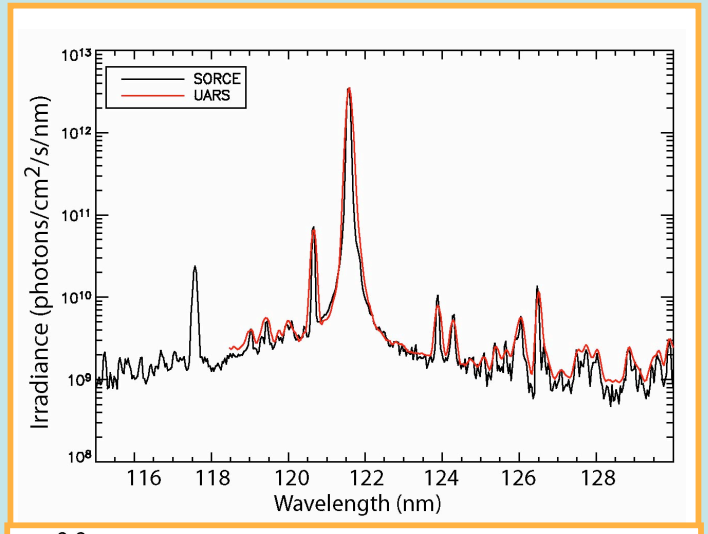


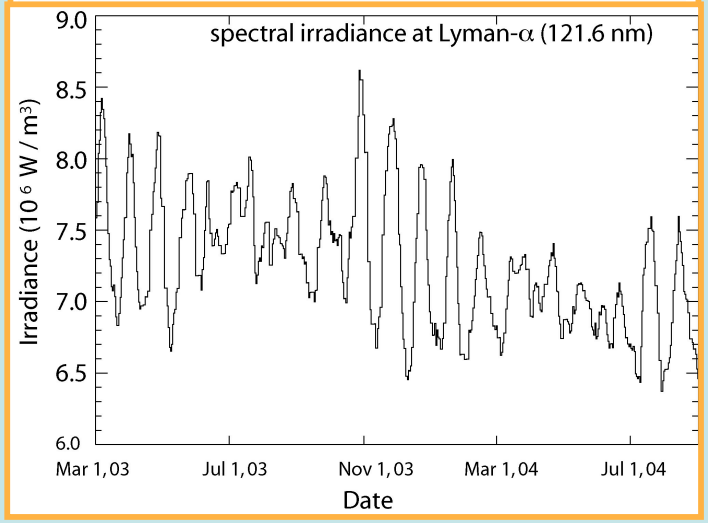
1200 nm
1400 nm
1590 nm : H^- Opacity Minimum

- *In all cases, less sunspot contrast than TSI.*
- *For 1400 & 1590 nm traces, no apperance of brightness inhancements due to presence of plage on the solar limbs.*
- *On 5/21 and 8/19 differences from TSI are attibutable to the appearance of plage structures on the limb from other wavelengths.*
- *Feature A shows an enhancement of IR brightness above that of TSI that is not present at the visible wavelengths. Same observation as discussed in Fontenla et al.*
- *Notice that the enhancement does not appear time period B.*
- *What is the nature of Feature A? Possibly an extended deep photospheric feature with very low contrast.*

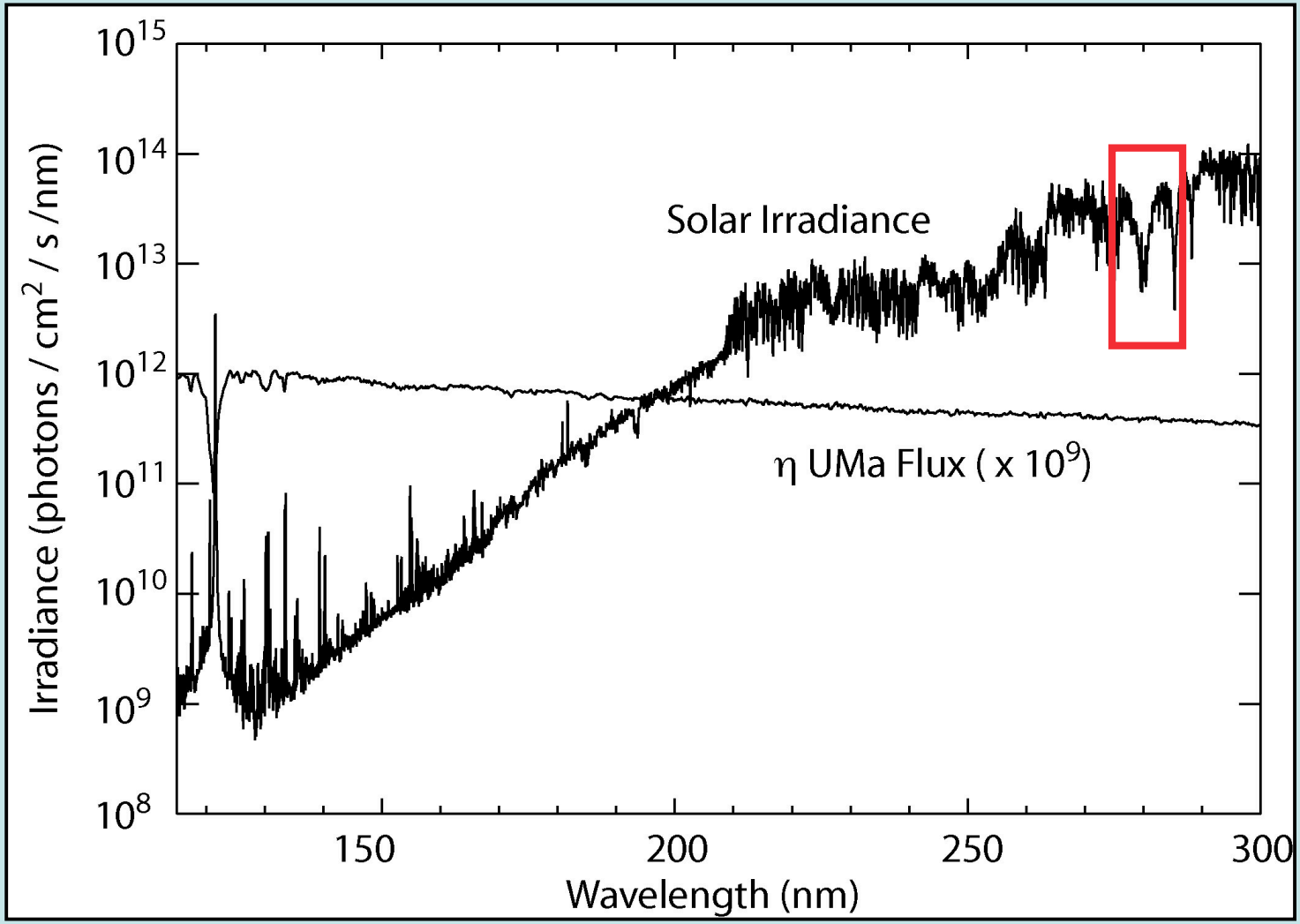
SORCE SOLSTICE

SORCE SOLSTICE continues the UARS data base. There are improvements in all aspects — stellar calibration, spectral resolution, and overall instrument performance.

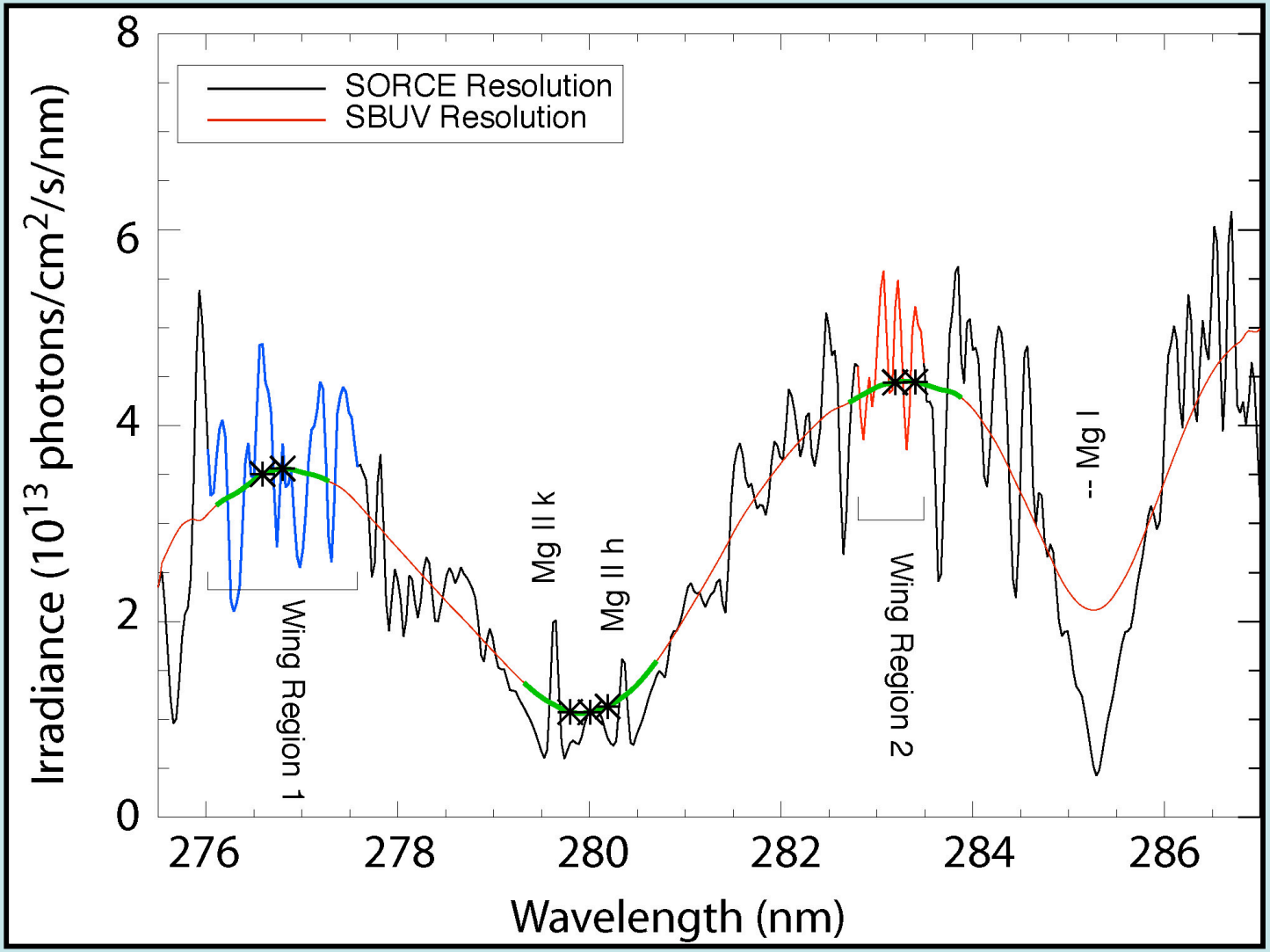




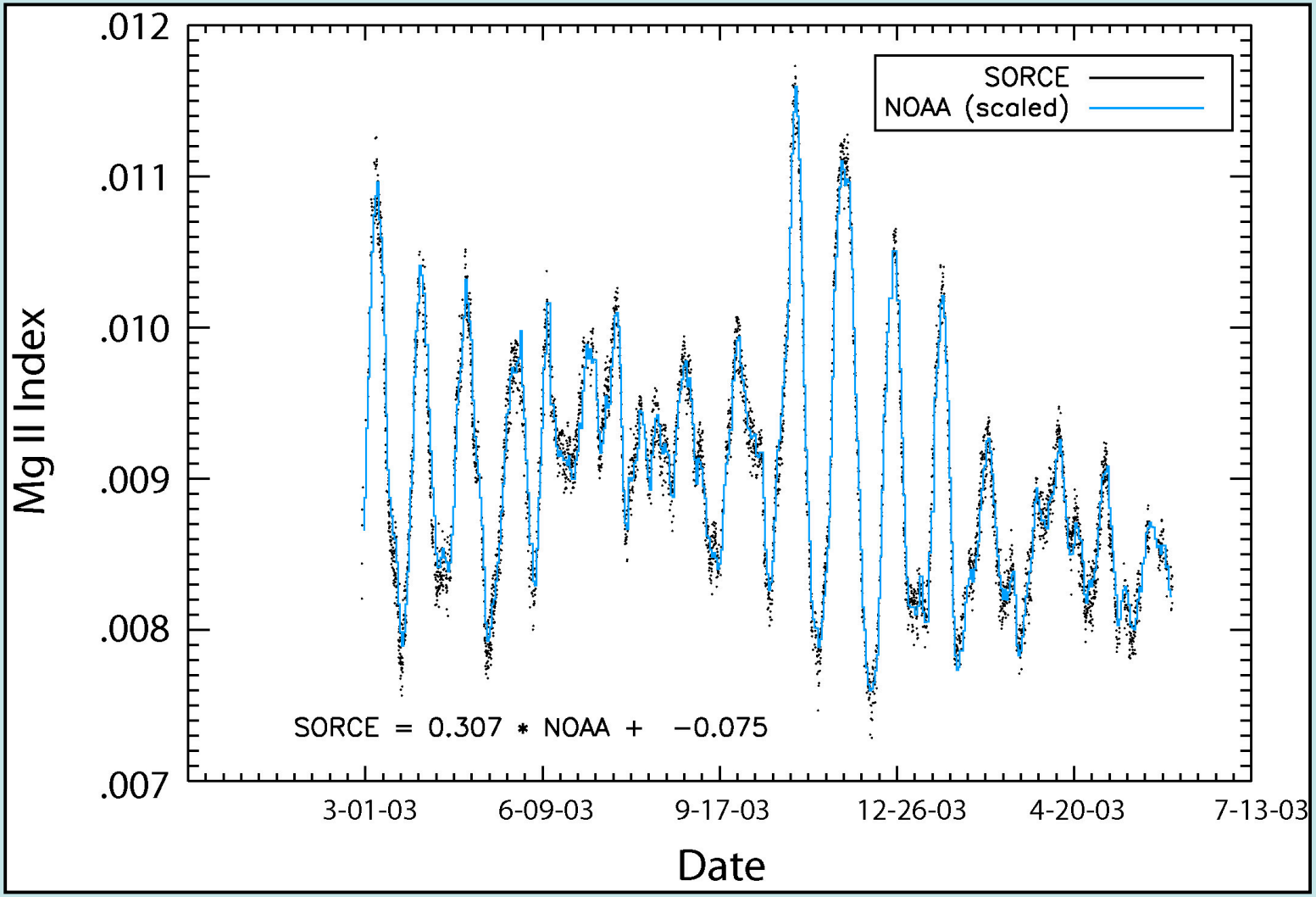
Solar Stellar Comparison



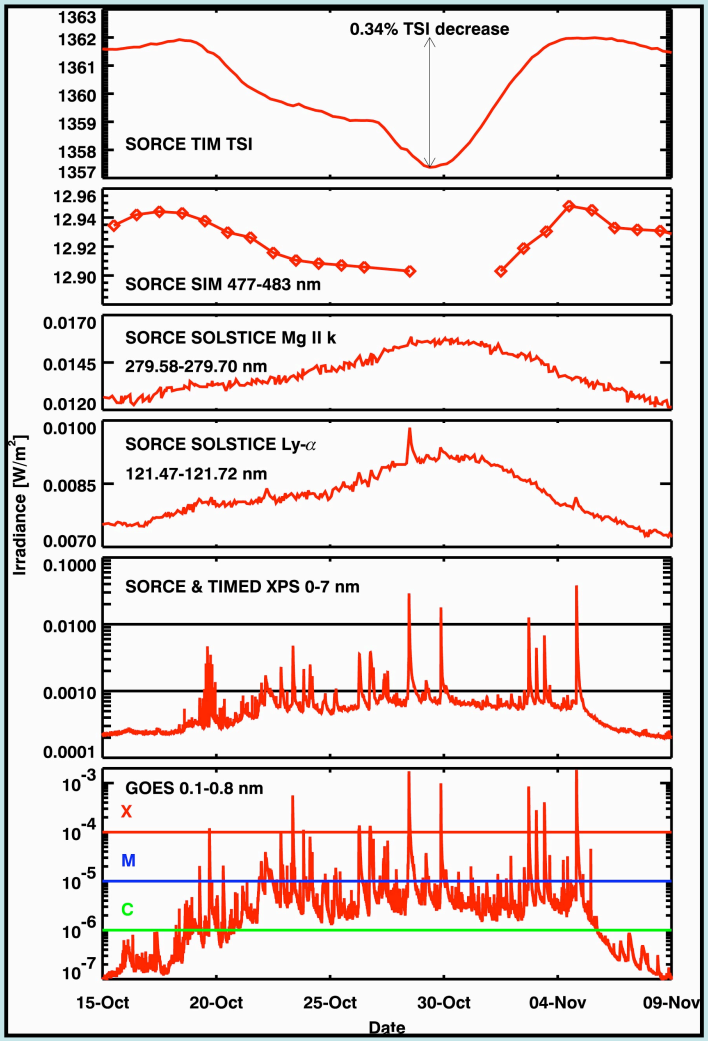
Magnesium II Index

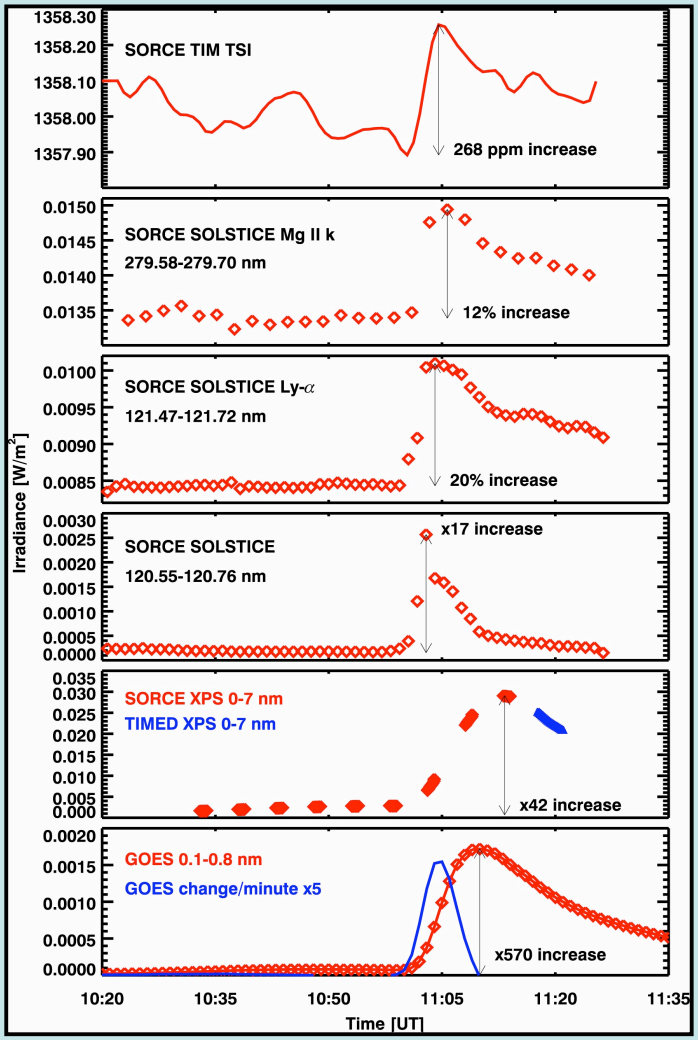


Mg II Time Series



Light Curves of the October Activity and X17 Flare





Follow-On to *SORCE (after 2008)*

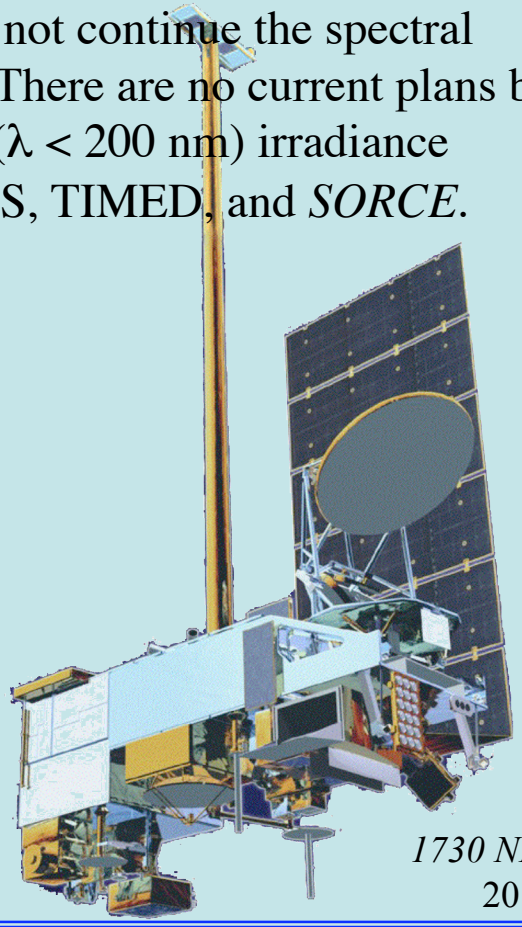
2007 to 2011

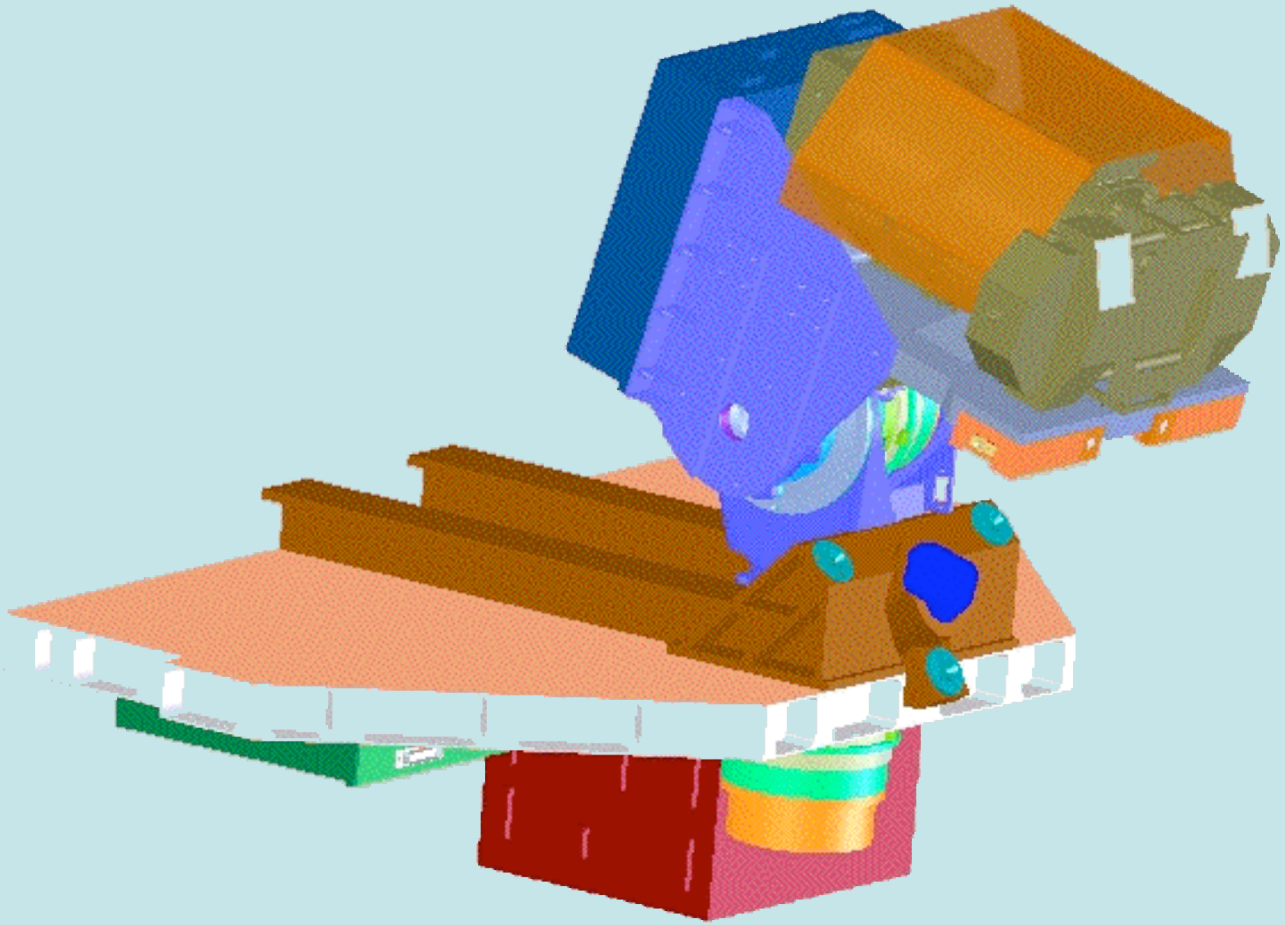
GLORY 12/06

NASA plans a Solar Irradiance Gap Filler (SIGF) that will be partially accomplished by placing a LASP TIM on the GSFC GLORY Mission. This will continue the long-term data record of TSI, but will not continue the spectral measurements of *SORCE*. There are no current plans by NASA to continue the UV ($\lambda < 200$ nm) irradiance observations of SME, UARS, TIMED, and *SORCE*.

2013 to 2020 ++++

NOAA/DOD/NASA will conduct the NPOESS (National Polar Orbiting Operational Environmental Satellite System) from 2010 onward. The payload will include the TSIS (Total and Spectral Irradiance Sensor) which includes a TIM and SIM instrument and a pointing platform. LASP is under contract with NGST to provide TSIS for a series of NPOESS spacecraft. There are no plans for the UV spectral irradiance to be provided on the future missions.



1730 NPOESS
2013

TIM May Be Flying on *Glory*?