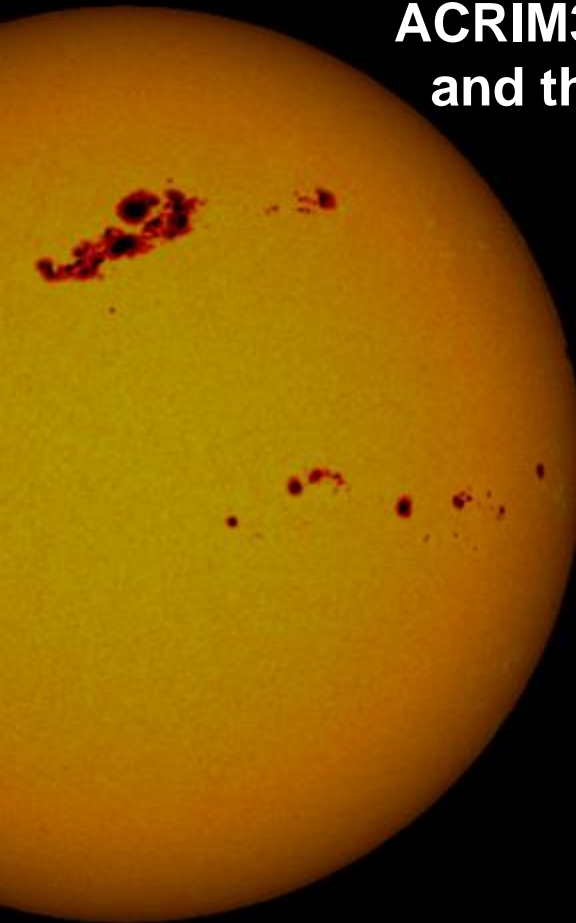


# ACRIM3 Characterization by the LASP/TRF and the Total Solar Irradiance Database



## ACRIM3 SCIENCE TEAM

**Dr. Richard C. Willson**  
**ACRIM**  
**Principal Investigator**

**Dr. Nicola Scafetta**  
**Duke University**  
**Co-Investigator**

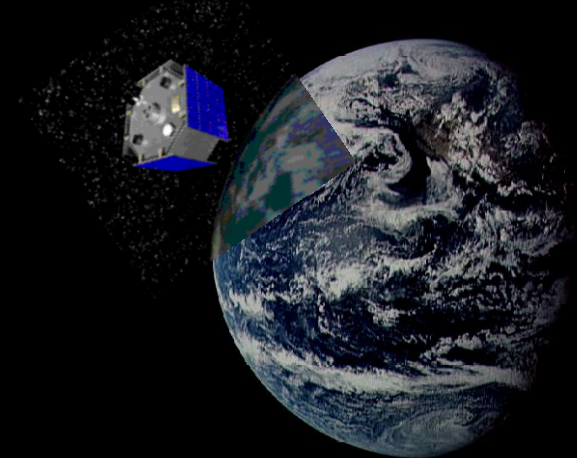
**Dr. J.M. Pasachoff**  
**Williams College**  
**Co-Investigator**

**Roger Helizon**  
**Instrument Consultant**

## ACRIMSAT PROJECT

**Sandy Kwan**  
**JPL**  
**Project Manager**

ACRIMSAT/ACRIM3



# ACRIM3 Testing and Characterization at the LASP/TRF <sup>1</sup>

- Tested the ACRIM3 flight backup instrument

Fabricated during the ACRIM3 flight instrument build  
Representative of ACRIM3 flight instrument performance

- Test Plan

Compare ACRIM3 self-calibration with TRF cryo-radiometric scale  
Conduct diagnostic testing to characterize ACRIM3 scattering and diffraction effects  
Compare alternate 20 minute exposures between ACRIM3 and the TRF cryo-radiometer  
Comparisons used a laser transfer system calibrated by the TRF cryo-radiometer  
TRF cryo-radiometric scale traceable to NIST <sup>2</sup> standards

- Participants

LASP/TRF – Greg Kopp – TRF Operations  
ACRIMSAT/ACRIM3 – Richard Willson – ACRIM3 Science Team PI  
NRL<sup>3</sup> – Jeff Morrill – Independent test oversight and testing/modeling

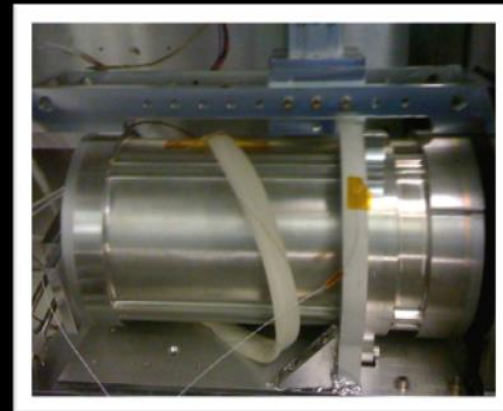
<sup>1</sup> Laboratory for Astronomy and Space Physics (LASP) Total Solar Irradiance Radiometer Facility (TRF)

<sup>2</sup> National Institute of Standards and Technology

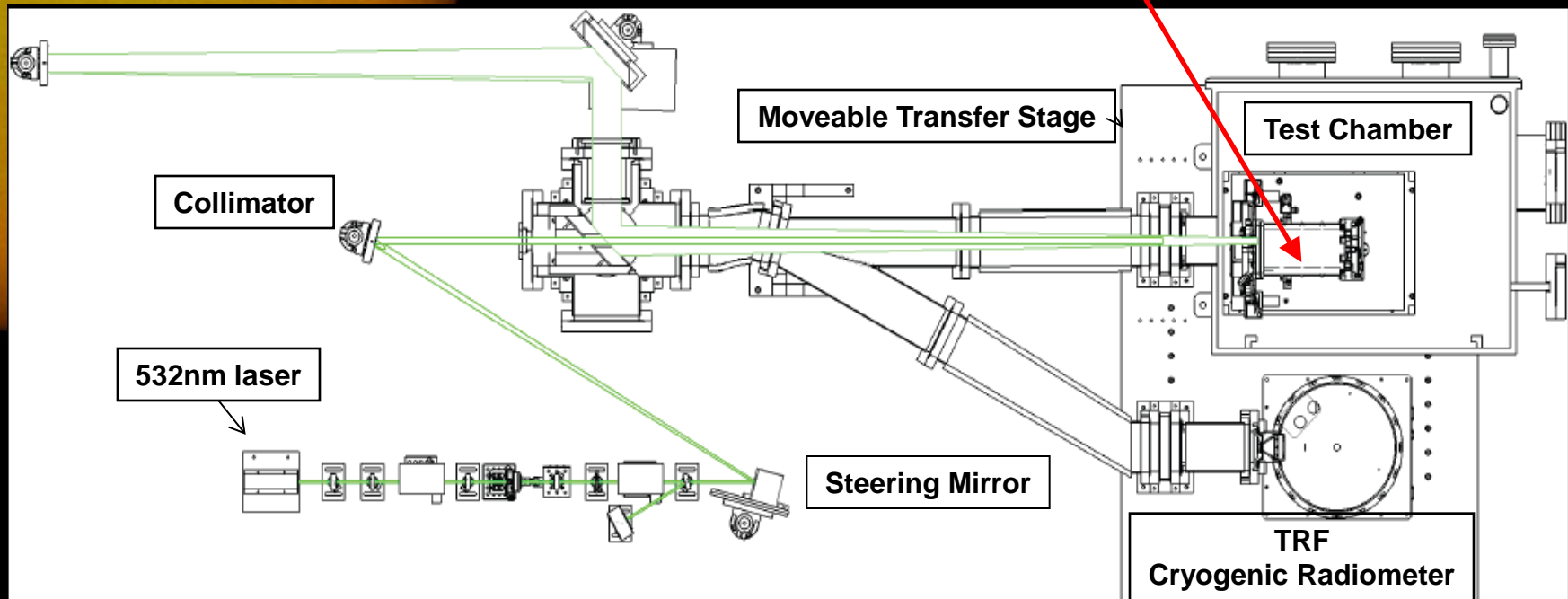
<sup>3</sup> Naval Research Laboratory (NRL)



**ACRIM3 test setup**  
**Laboratory for Atmospheric  
And Space Physics (LASP)**  
**Total Solar Irradiance  
Radiometer Facility (TRF)**



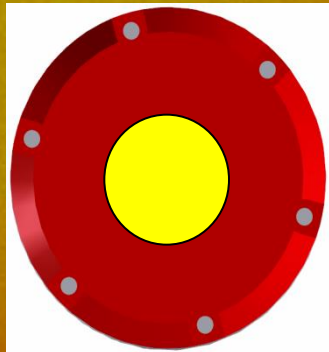
**ACRIM3  
Engineering Model**



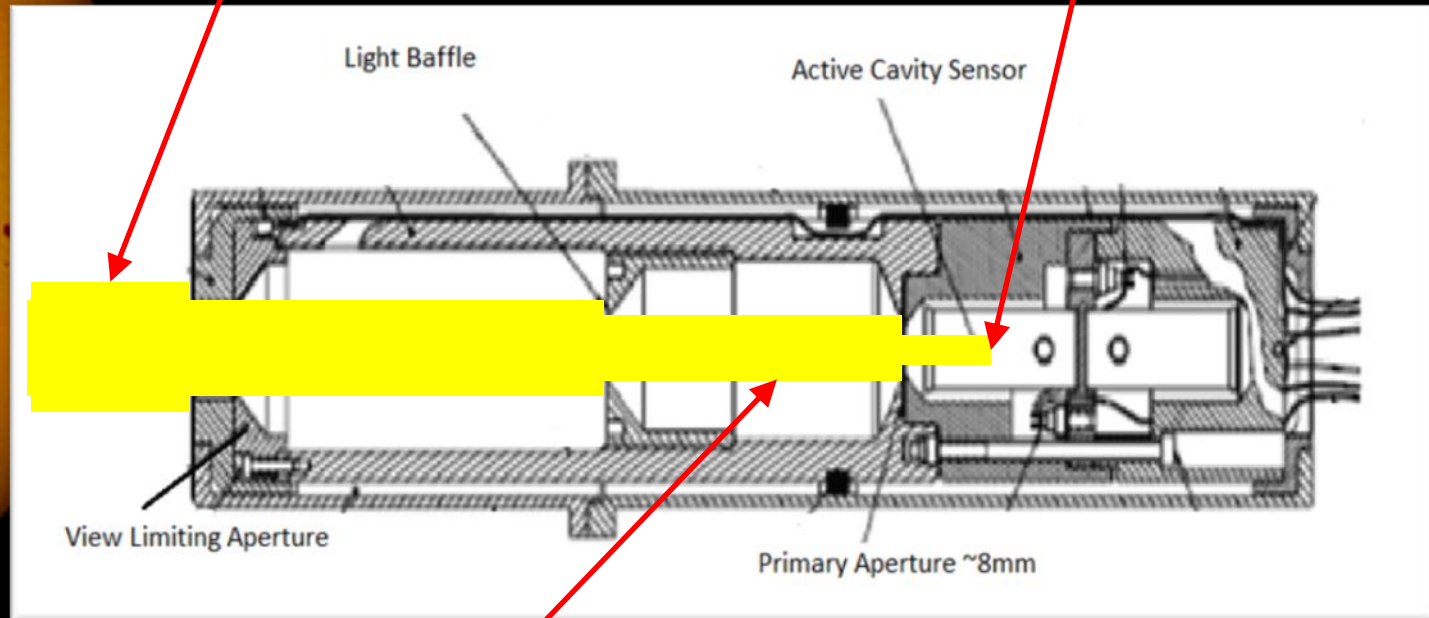
# ACRIM3 Sensor Module and Irradiance Testing Modes

**15mm Circular Beam**  
Over-fills View Limiting aperture  
Calibrates total scattering, diffraction, scale

**5mm Circular Beam**  
Under-fills Primary aperture  
Basic scale comparison in SI Units



**Front View of  
Sensor Module**



**10mm Circular Beam**  
Over-fills primary aperture, Under-fills View Limiting aperture and Baffle  
Calibrates scattering in lower view limiting assembly



# Summary of ACRIM3 TRF Testing and Algorithm Updates

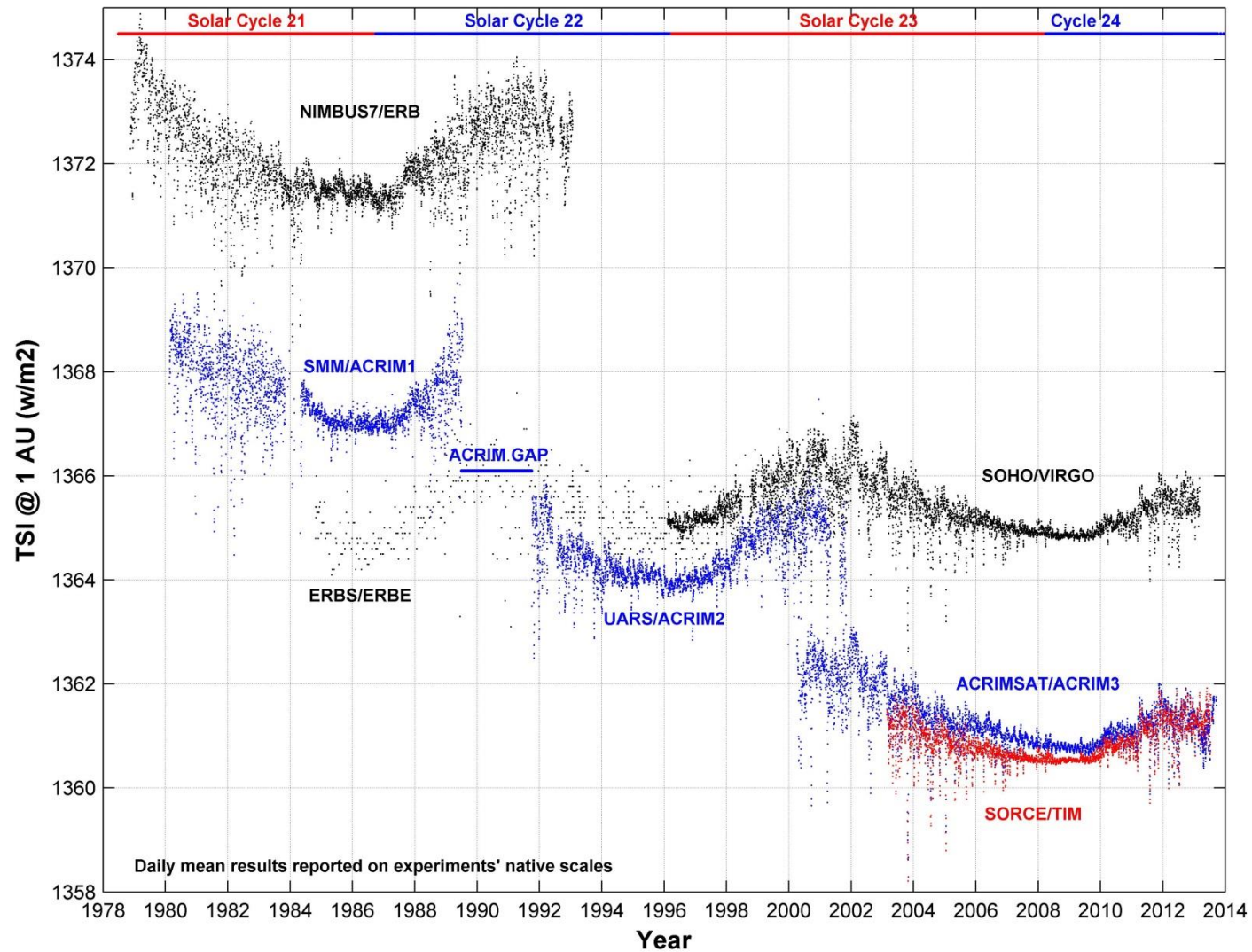
- ACRIM3 and TRF scales agree within test uncertainty ( $\pm \sim 300$  ppm)
- Combined ACRIM3 scattering and diffraction effects:  $\sim 5000$  ppm (+/-  $\sim 500$  ppm)
- ACRIM, LASP and NRL analyses of TRF data agree within test uncertainties
- ACRIM3 flight data algorithm updated

ADC temperature dependent reference voltage corrections updated  
Shutter cycle data parsing updated  
Sensor degradation self-calibration updated

- Effects of TRF corrections and algorithm updates

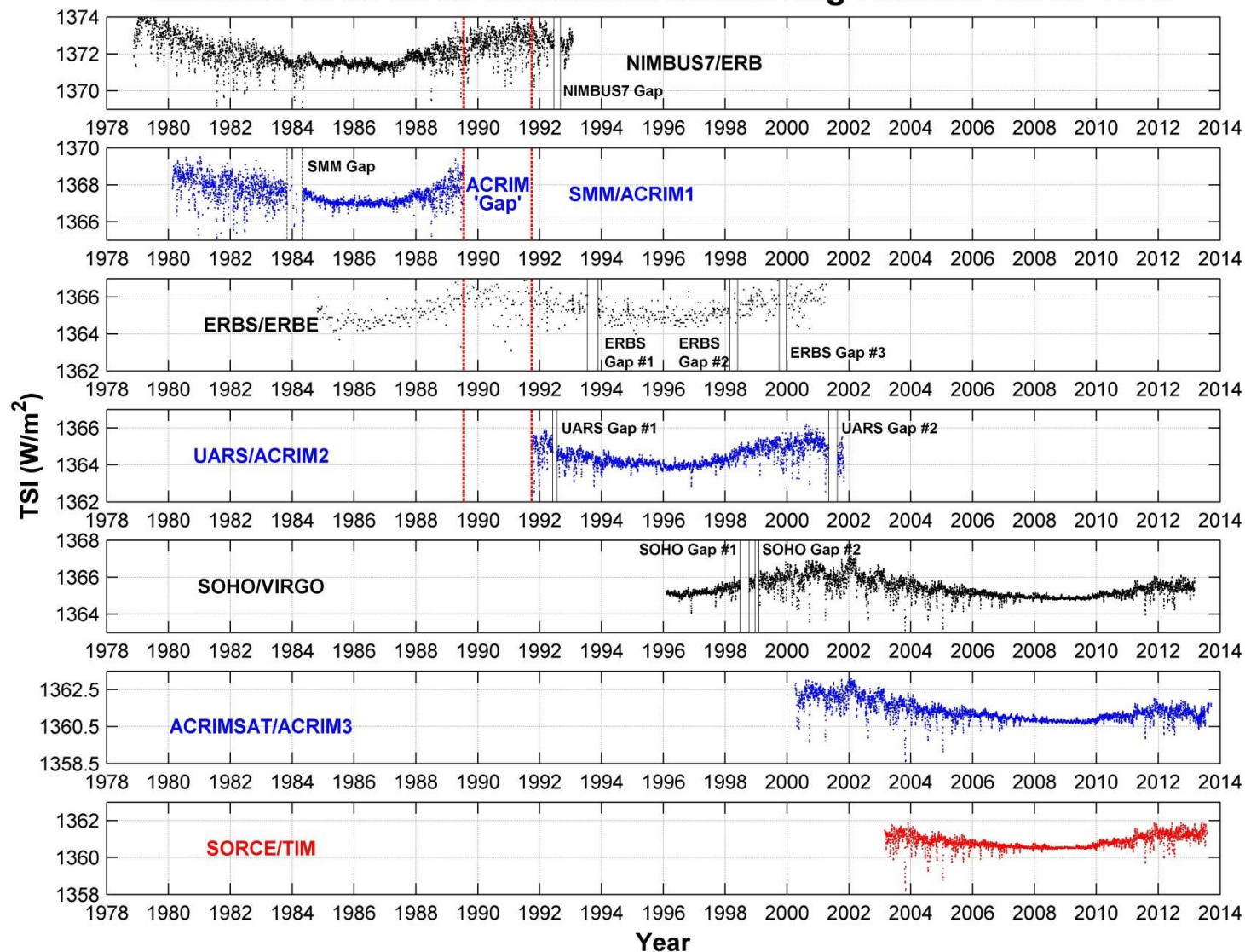
An annual thermal component in ACRIM3 results removed ( $\sim 300$  ppm)  
ACRIM3 and TIM results agree more closely in scale  
ACRIM3, VIRGO and TIM show close agreement in detected TSI variations

## TOTAL SOLAR IRRADIANCE MONITORING RESULTS: 1978 to Present



RC Willson, earth\_obs\_fig1 12/05/2013

# Satellite Total Solar Irradiance Monitoring Results Since 1978

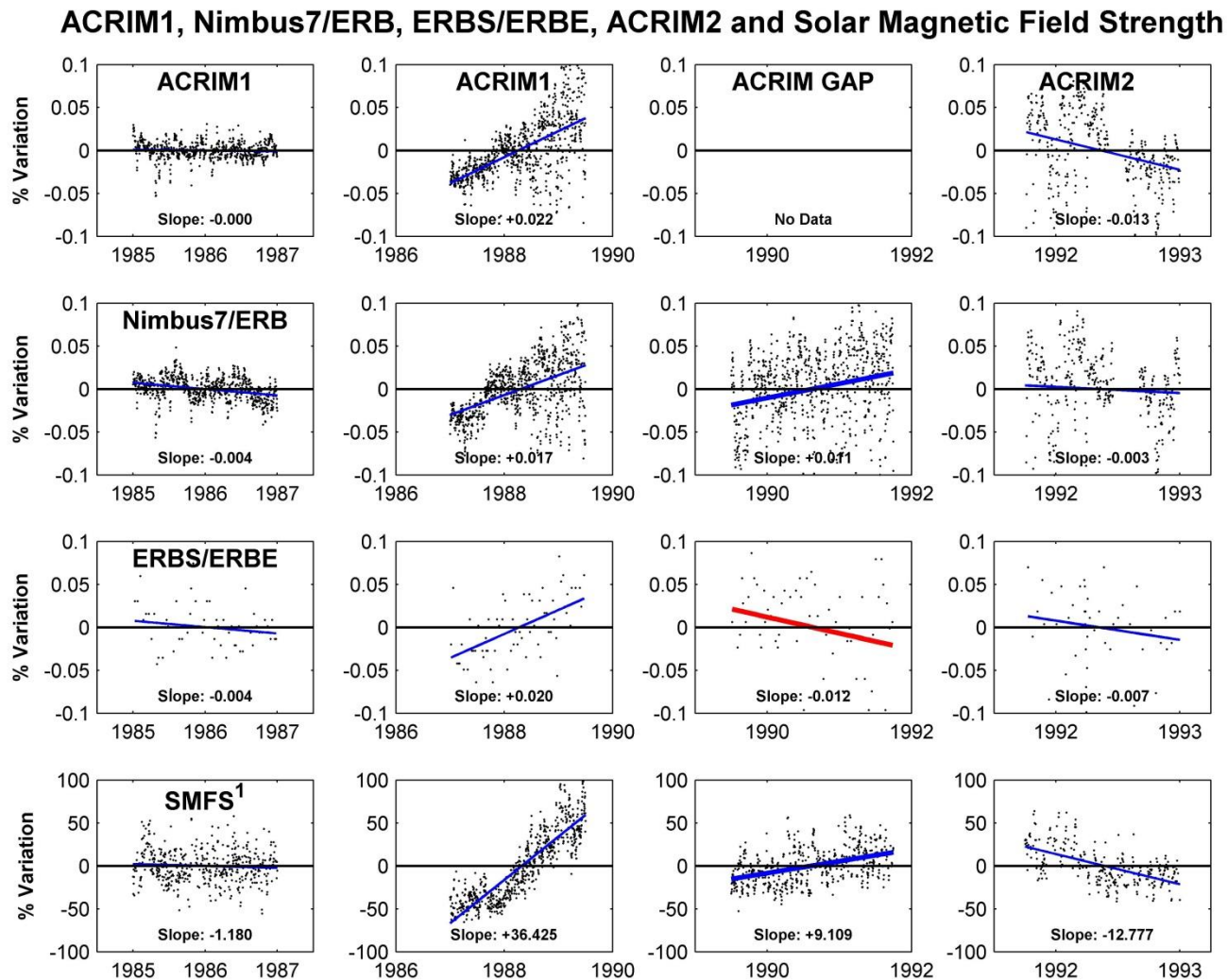


Daily mean results reported on "native" scales of experiments (W/M<sup>2</sup> @ 1 AU)

RC Willson, earth\_obs\_fig5 01/26/2014



# ACRIM Gap 'Bridge' Database Selection Criterion

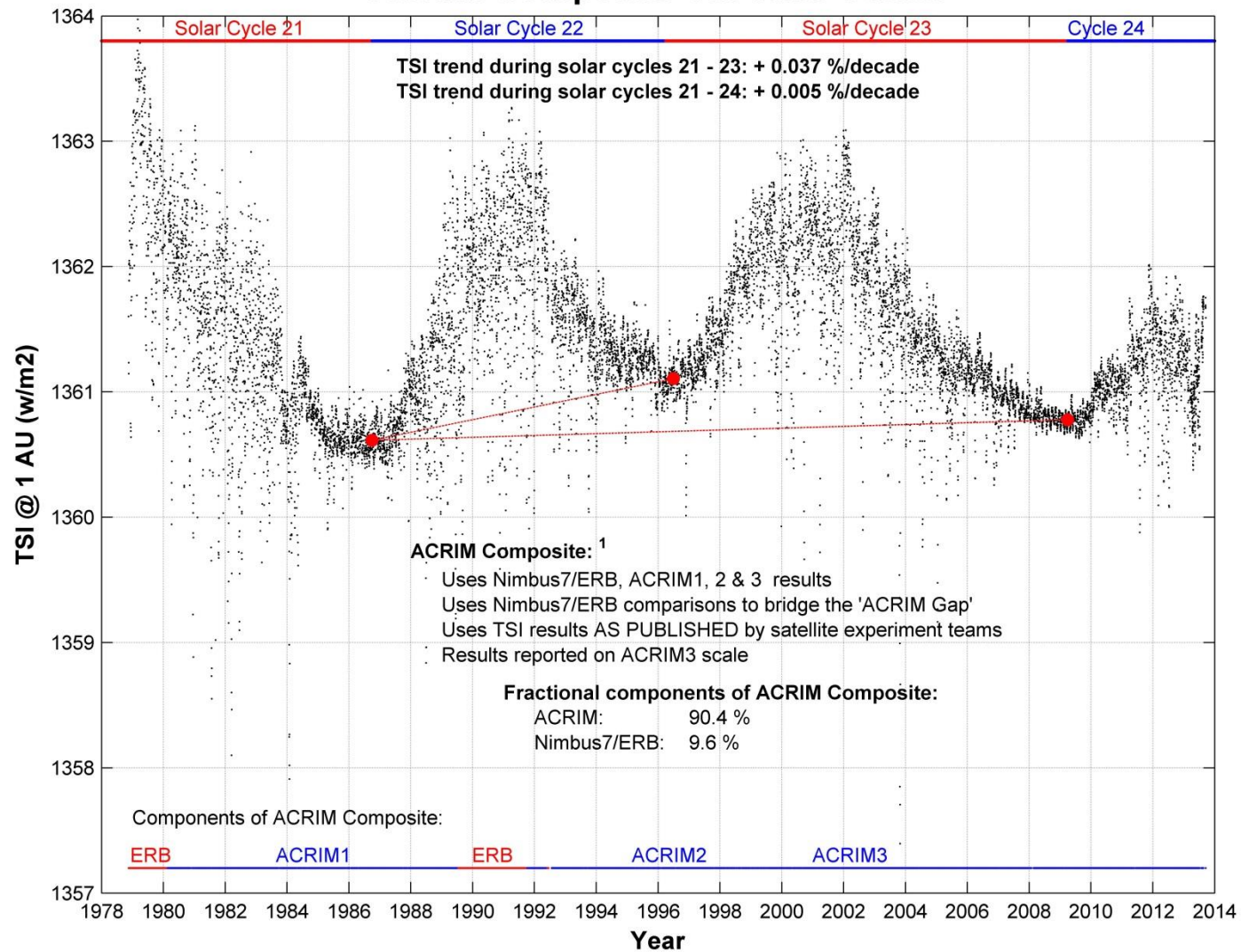


<sup>1</sup> NSO/Kitt Peak Solar Magnetic Field Strength

RC Willson, ACRIM\_Gap\_4p\_smfa 01/28/2014



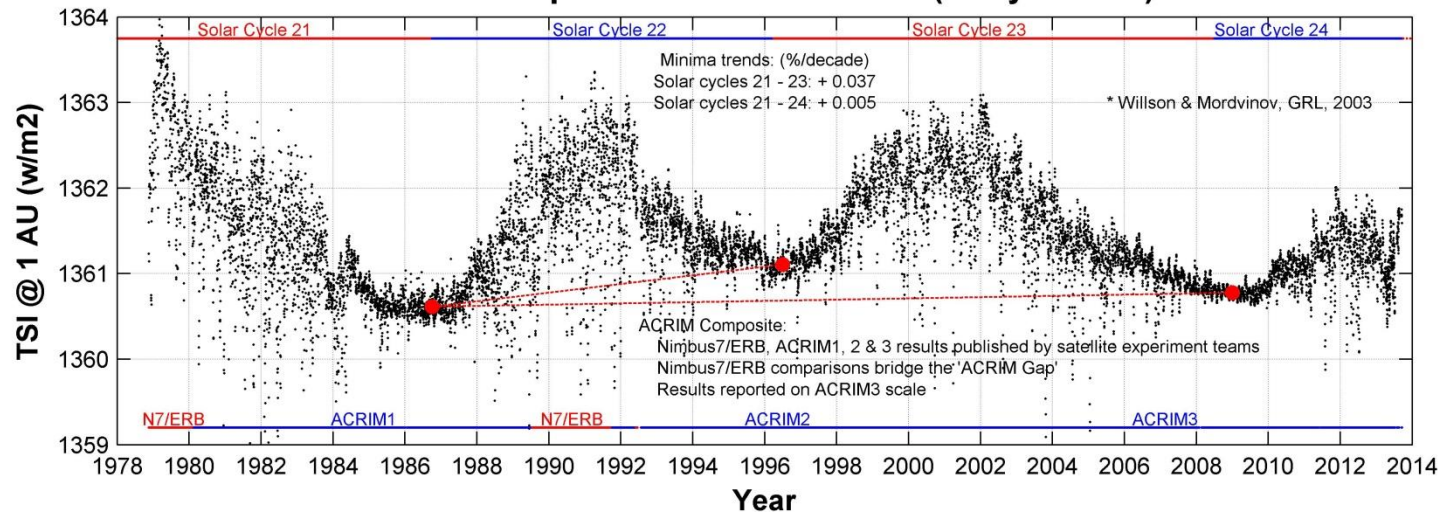
# ACRIM Composite TSI Time Series



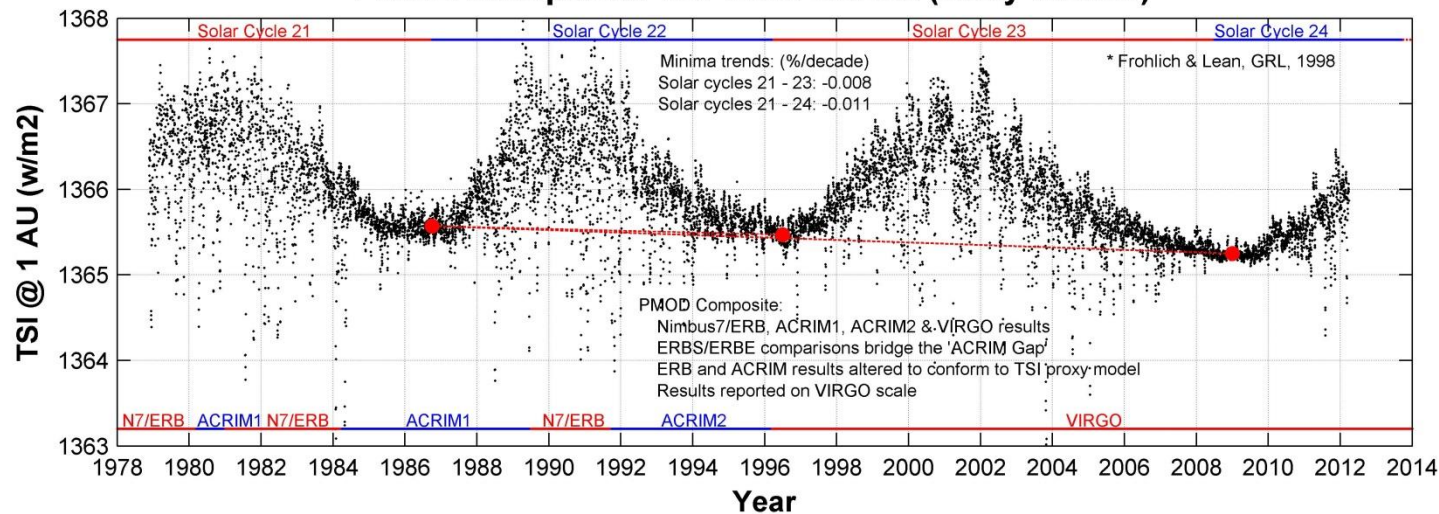
<sup>1</sup> Willson & Mordvinov, GRL, 2003

RC Willson, earth\_obs\_ACRIM\_Composite 01/25/2014

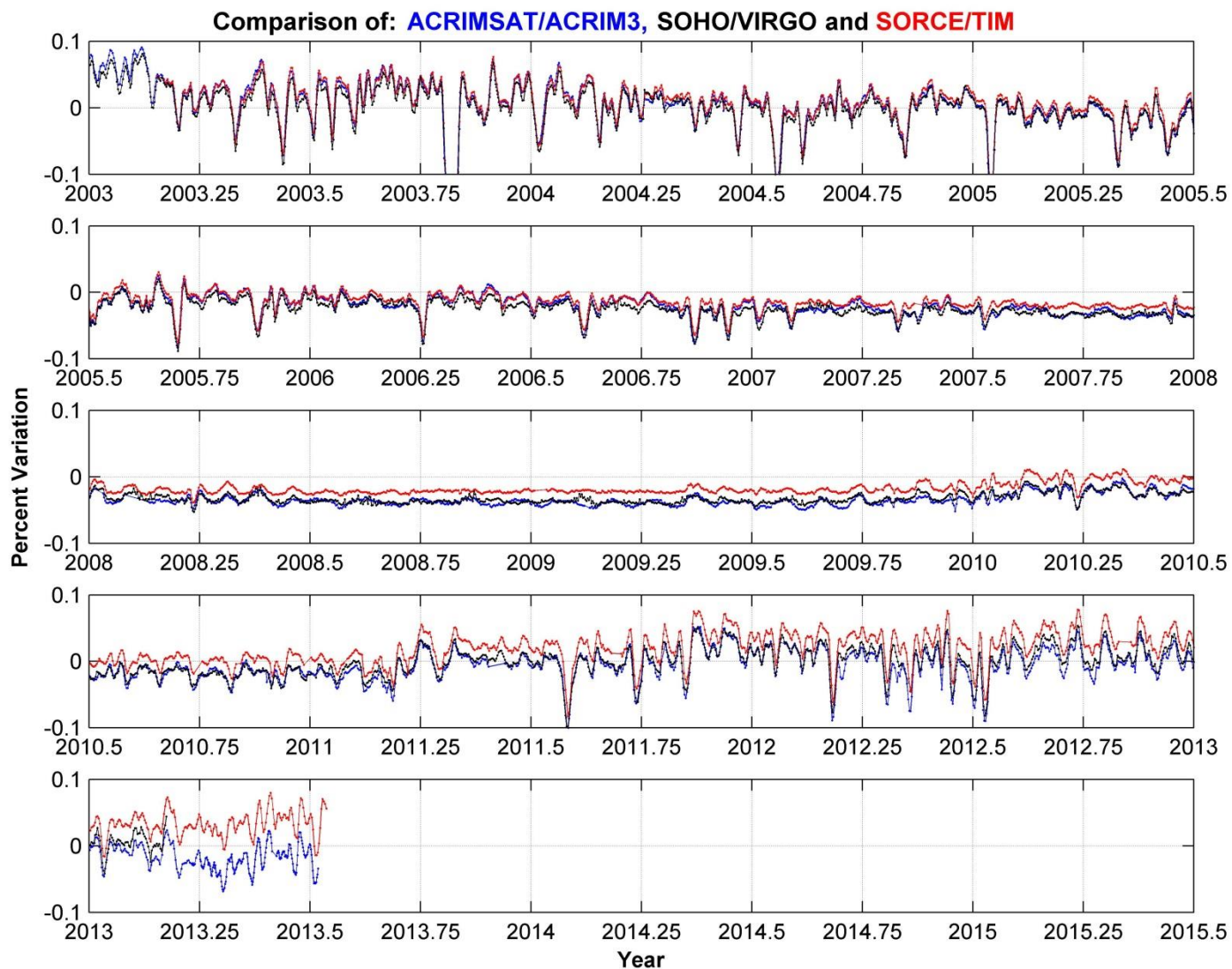
## ACRIM Composite TSI Time Series (Daily Means) \*



## PMOD Composite TSI Time Series (Daily Means) \*



RC Willson, ACRIM and PMOD Composites 01/25/2014



RC Willson - hi\_res\_avt\_pv 01/08/2014





**1. The harmonic components of the ACRIM3,  
VIRGO and TIM results**

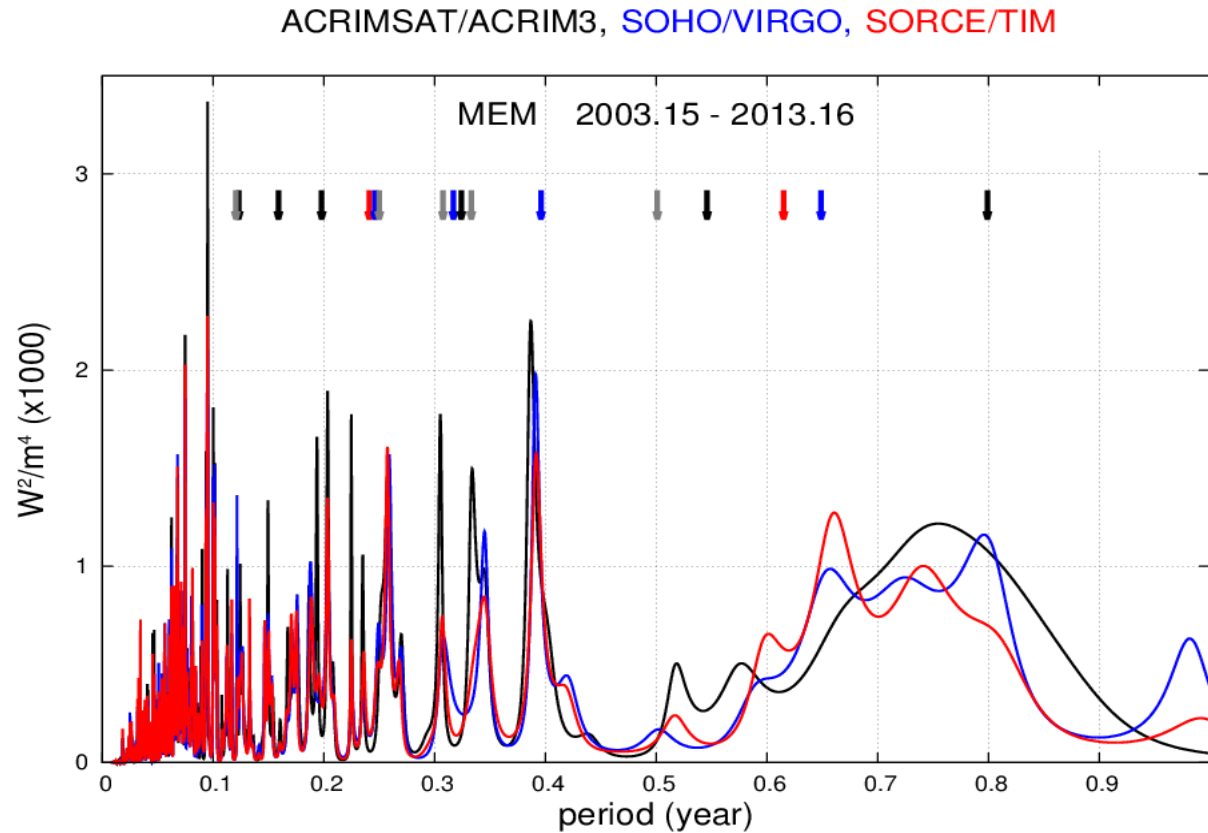
**2. The harmonic components of the  
ACRIM & PMOD composite TSI**

**3. The validation of ACRIM Composite TSI  
by the solar magnetic proxy models**

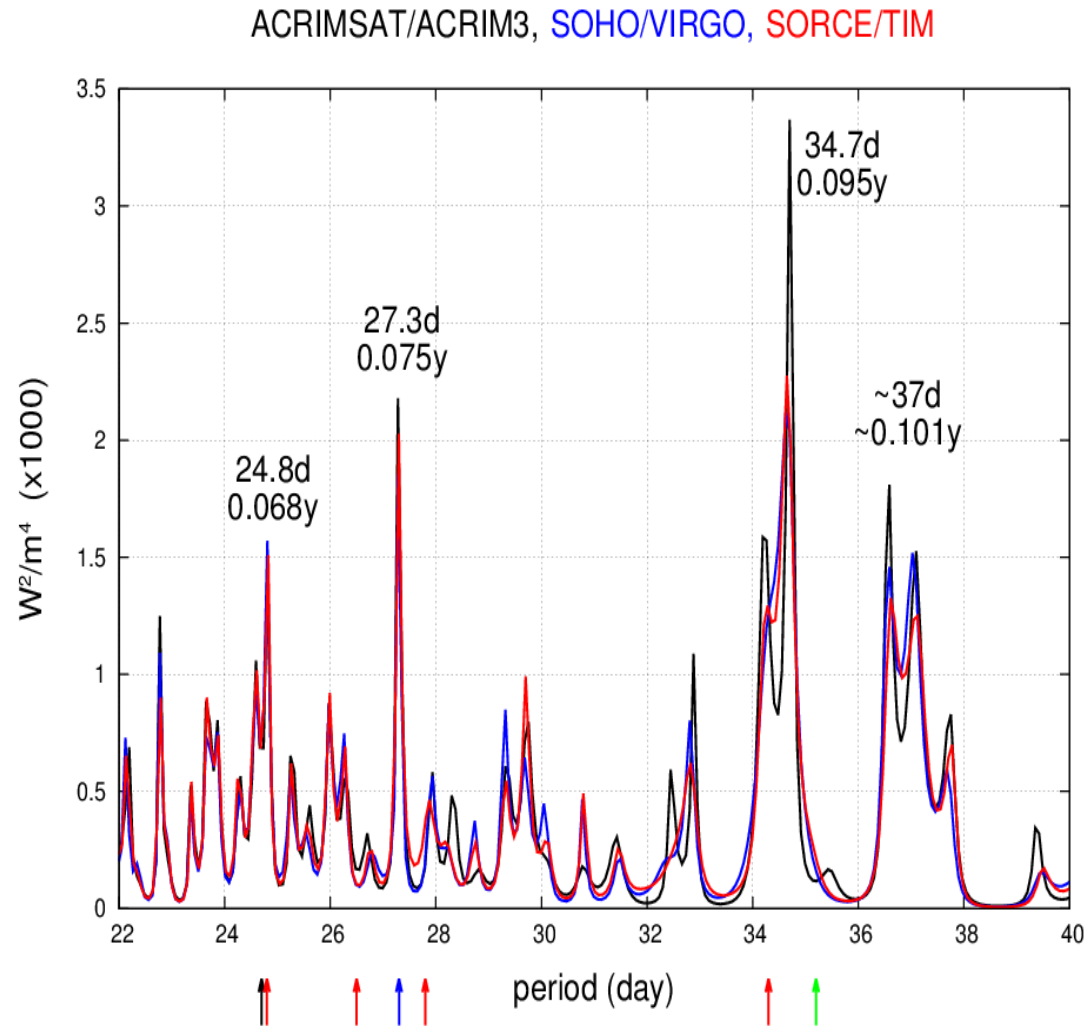




# Power Spectrum Comparison



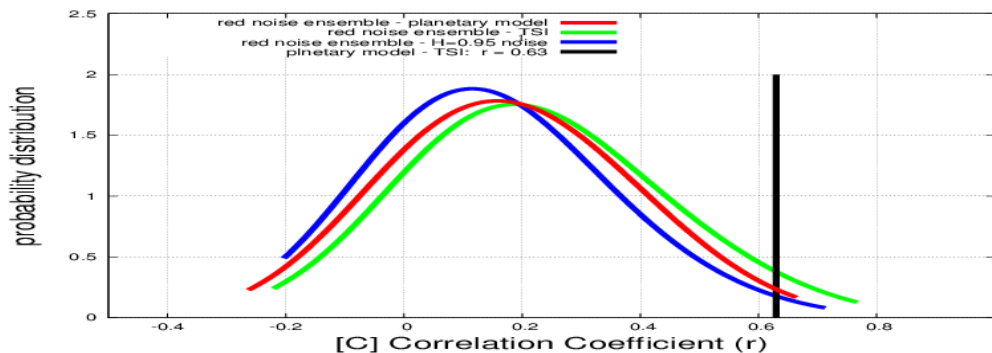
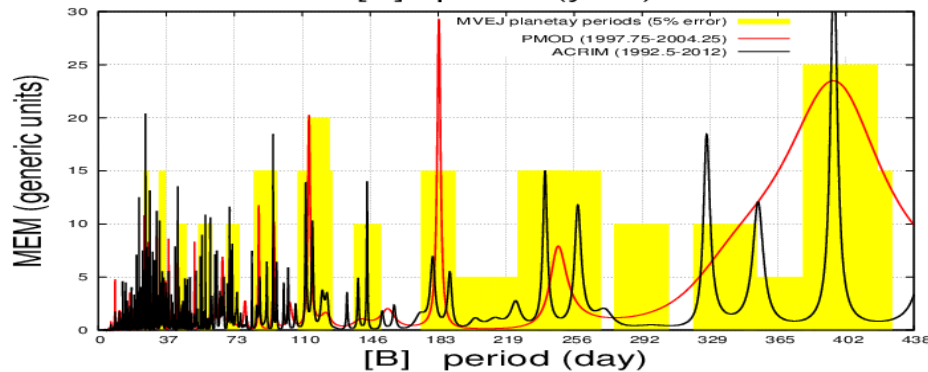
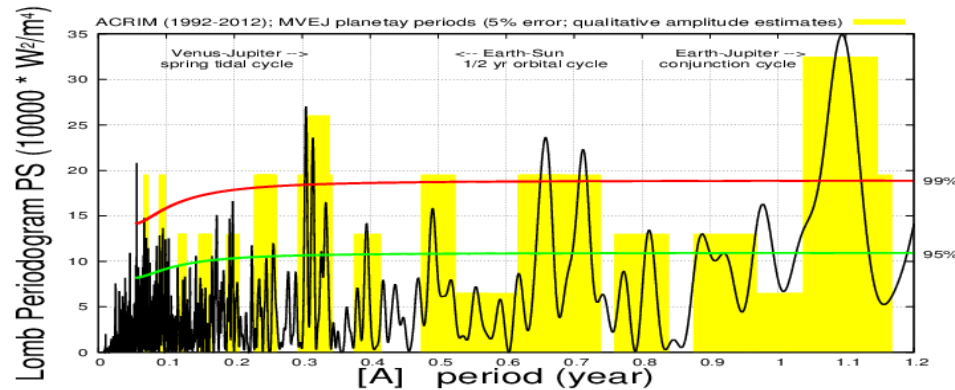
# Solar Rotation Range



Cycle	Type	P (day)
Sun	equ-rot	24.7
Sun - Ju	equ-rot	24.8
Sun - Ea	equ-rot	26.5
Sun - Ea	Car-rot	27.3
Sun - Ve	equ-rot	27.8
Sun - Me	equ-rot	34.3



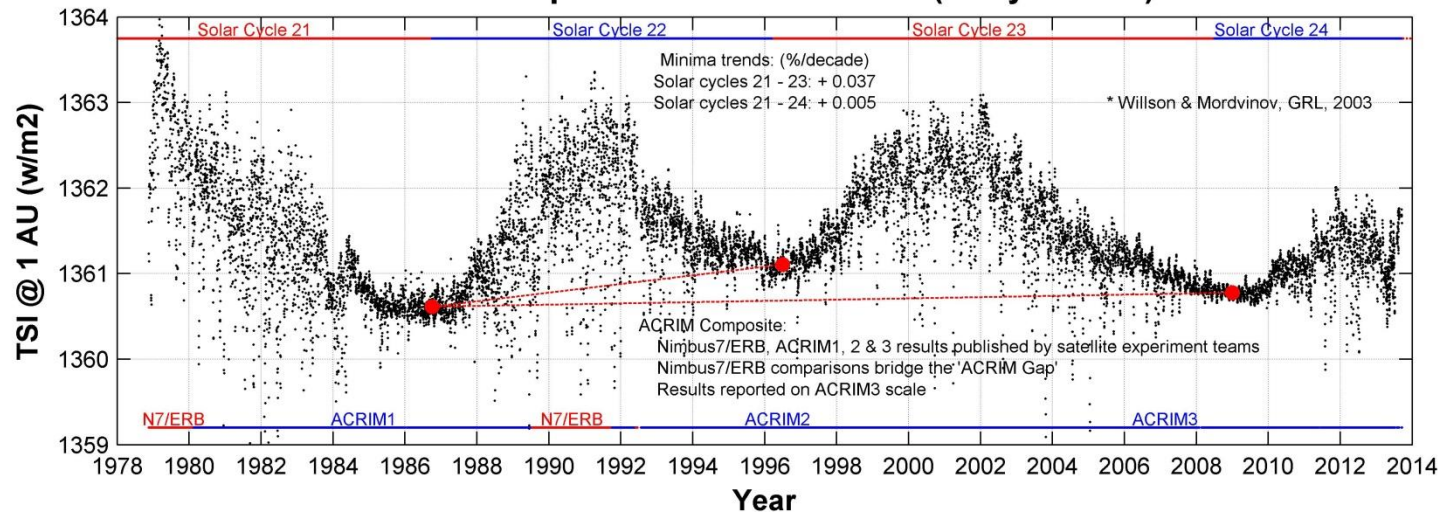
# Power Spectrum Estimates of ACRIM and PMOD



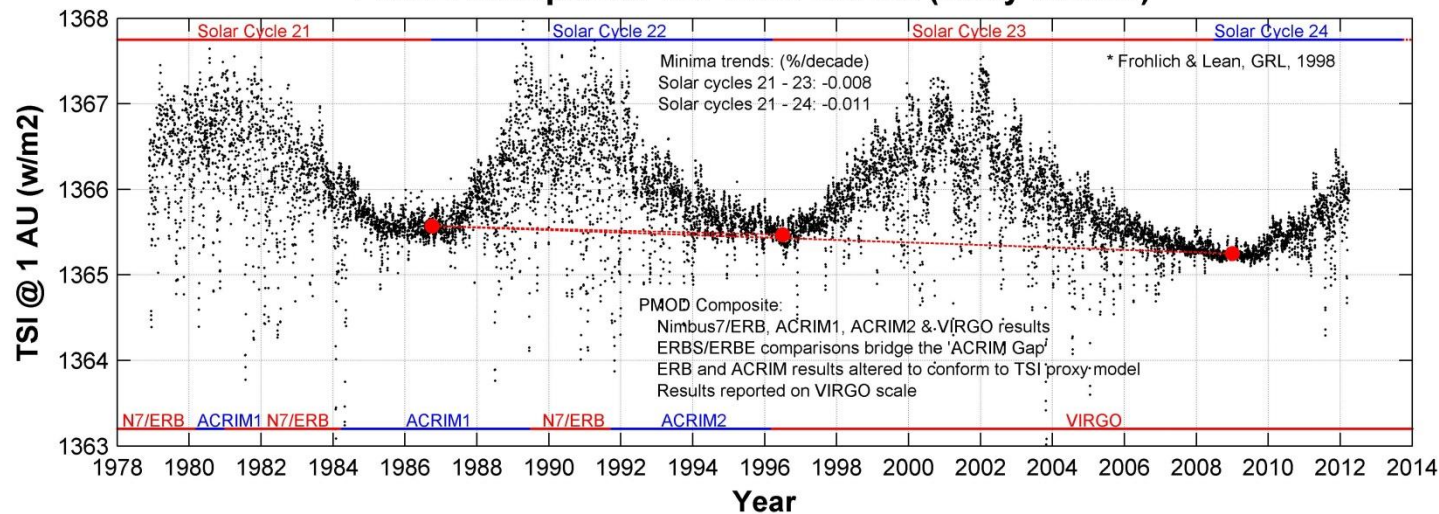
## Main planetary periods

Cycle	Type	$P$ (year)
Me	$\frac{1}{2}$ orbital	$0.120 \pm 0.000$
Me-Ju	spring	$0.123 \pm 0.024$
Me-Ea	spring	$0.159 \pm 0.027$
Me-Ve	spring	$0.198 \pm 0.021$
Me	orbital	$0.241 \pm 0.000$
Me-Ju	synodic	$0.246 \pm 0.002$
Ea	$\frac{1}{4}$ orbital	$0.250 \pm 0.000$
Ve	$\frac{1}{2}$ orbital	$0.307 \pm 0.000$
Me-Ea	synodic	$0.317 \pm 0.024$
Ve-Ju	spring	$0.324 \pm 0.003$
Ea	$\frac{1}{3}$ orbital	$0.333 \pm 0.000$
Me-Ve	synodic	$0.396 \pm 0.033$
Ea	$\frac{1}{2}$ orbital	$0.500 \pm 0.000$
Ea-Ju	spring	$0.546 \pm 0.010$
Ve	orbital	$0.615 \pm 0.000$
Ve-Ju	synodic	$0.649 \pm 0.004$
Ve-Ea	spring	$0.799 \pm 0.008$
Ea	orbital	$1.000 \pm 0.000$
Ea-Ju	synodic	$1.092 \pm 0.009$
Ea-Ve	synodic	$1.599 \pm 0.016$

## ACRIM Composite TSI Time Series (Daily Means) \*



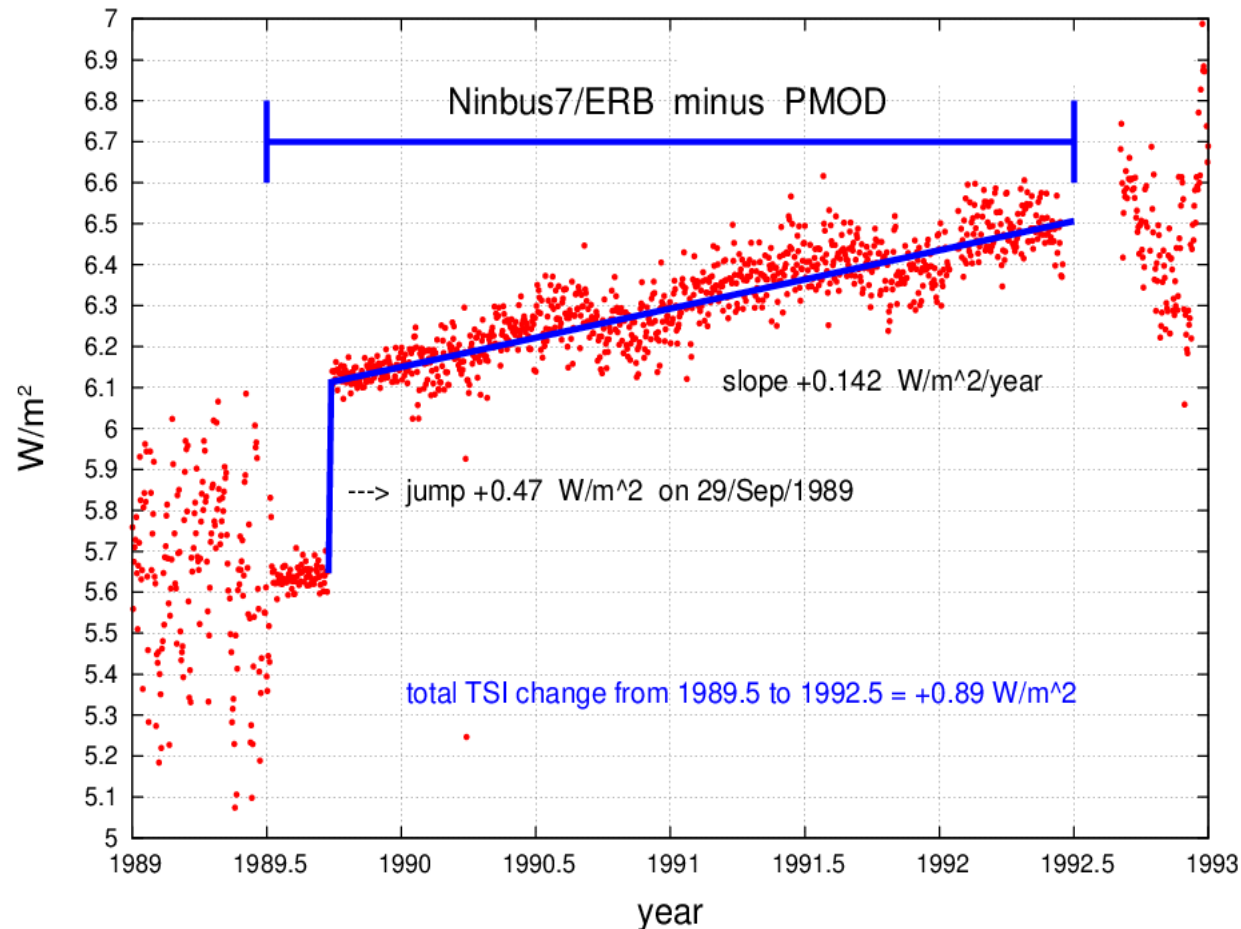
## PMOD Composite TSI Time Series (Daily Means) \*



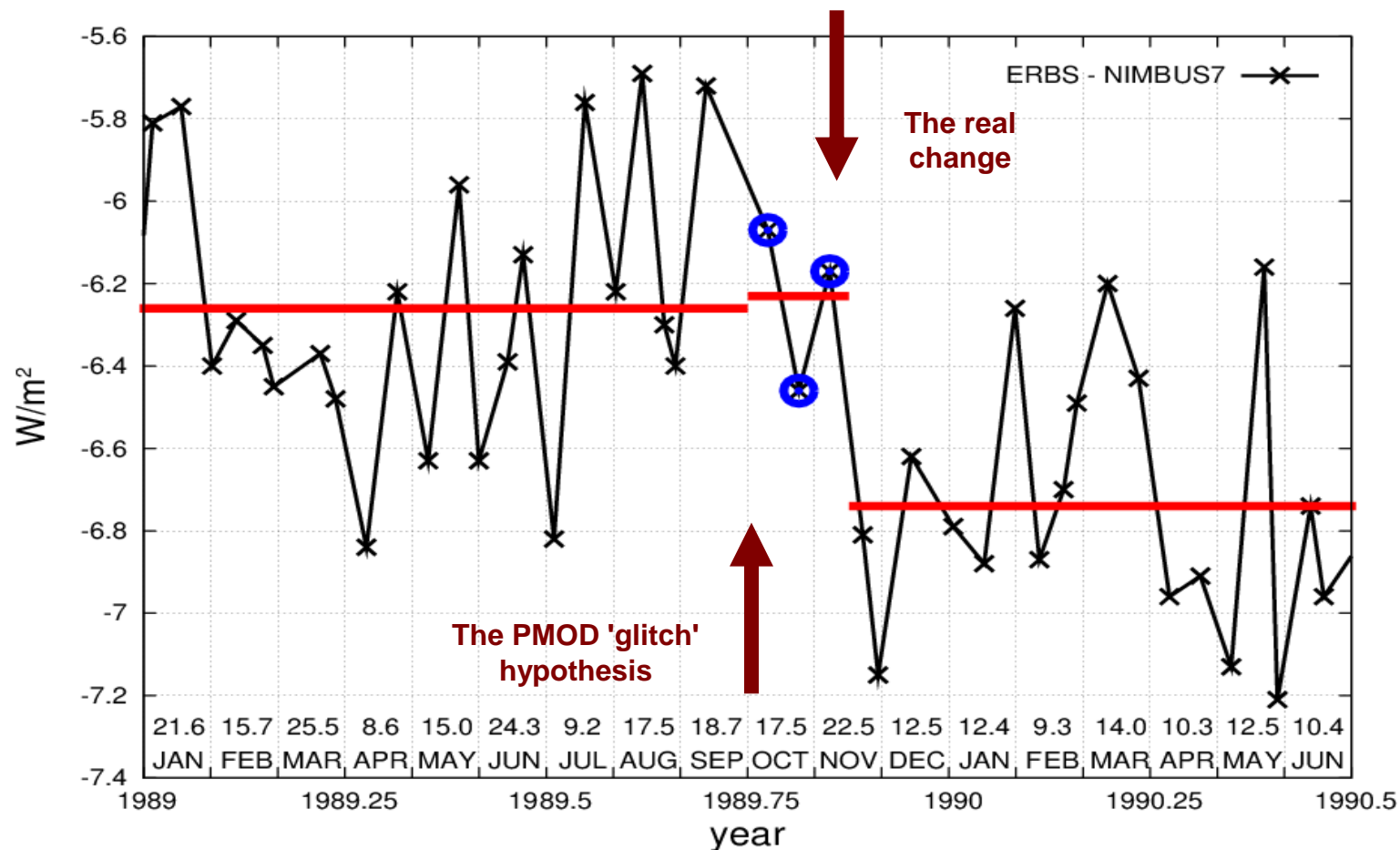
RC Willson, ACRIM and PMOD Composites 01/25/2014



# PMOD Alterations of Nimbus7/ERB



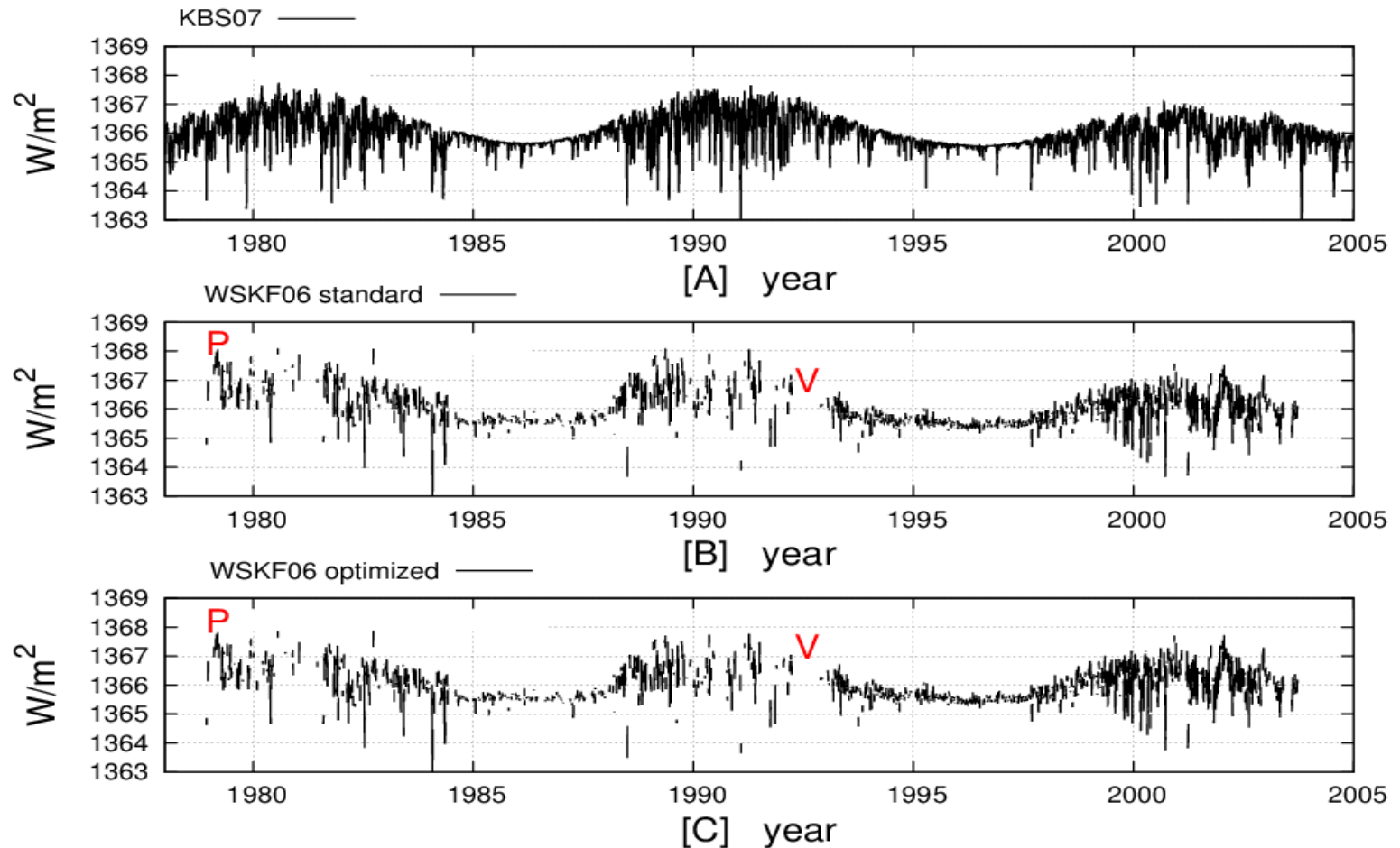
# Nimbus7/ERB - ERBS/ERBE Divergence



# Douglas Hoyt's statement on Nimbus7/ERB accuracy during the ACRIM-Gap

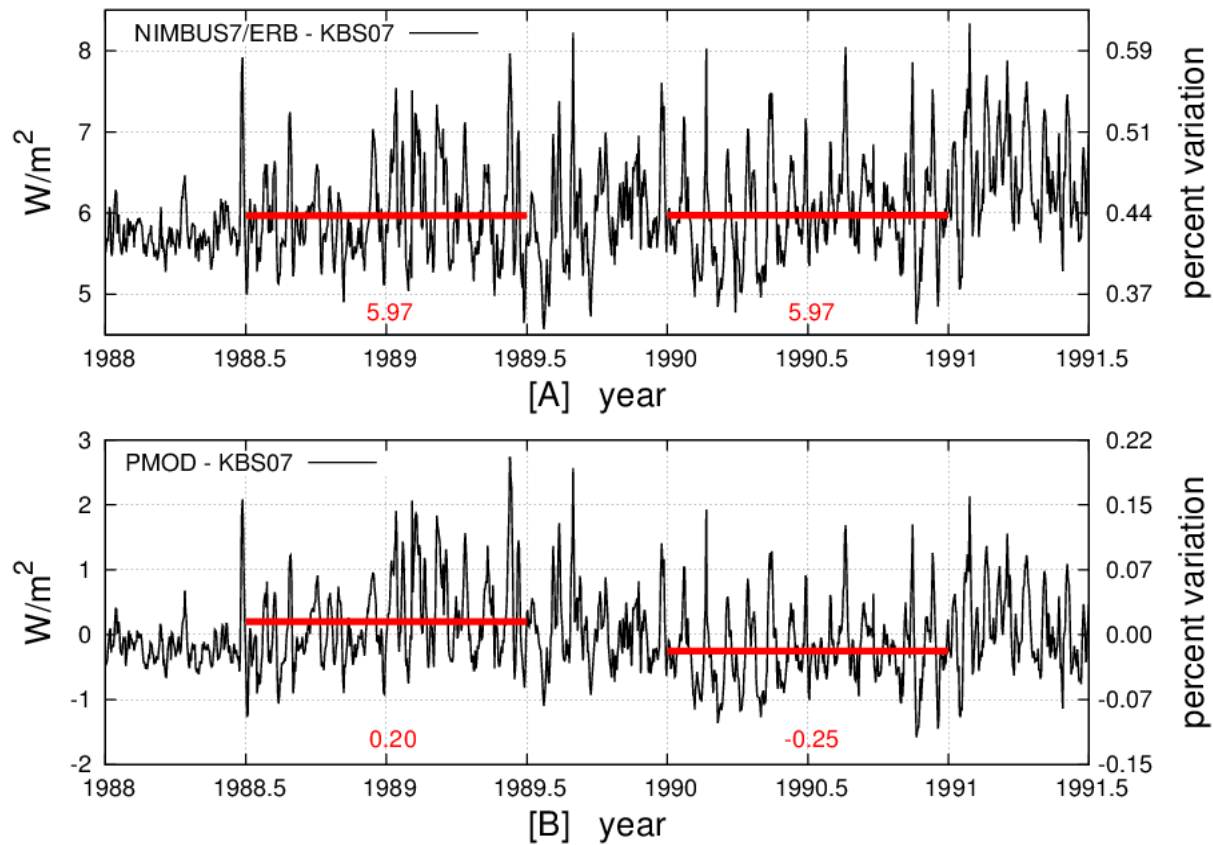
1. *There is no known physical change in the electrically calibrated N7 radiometer or its electronics that could have caused it to become more sensitive. At least neither Lee Kyle nor I could never imagine how such a thing could happen and no one else has ever come up with a physical theory for the instrument that could cause it to become more sensitive.*
2. *The N7 radiometer was calibrated electrically every 12 days. The calibrations before and after the September shutdown gave no indication of any change in the sensitivity of the radiometer. Thus, when Bob Lee of the ERBS team originally claimed there was a change in N7 sensitivity, we examined the issue and concluded there was no internal evidence in the N7 records to warrant the correction that he was proposing. Since the result was a null one, no publication was thought necessary.*
3. *Thus, Fröhlich's PMOD TSI composite is not consistent with the internal data or physics of the N7 cavity radiometer.*

# Surface Magnetic Indices TSI Proxy Models

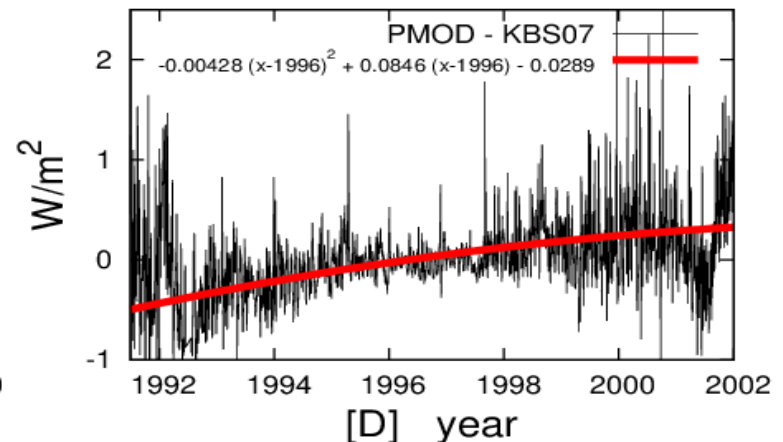
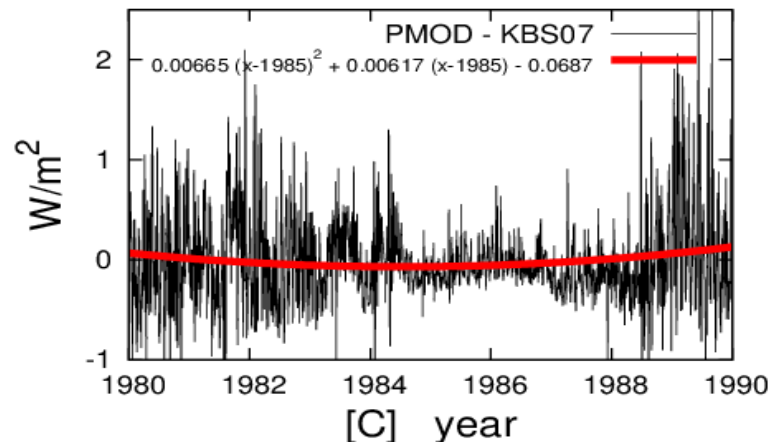
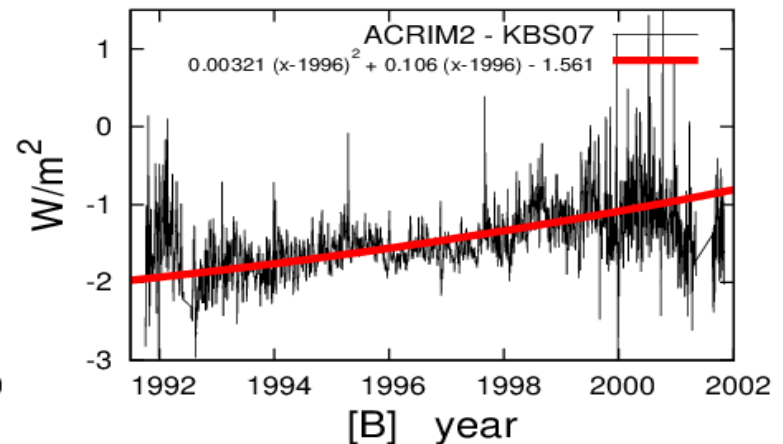
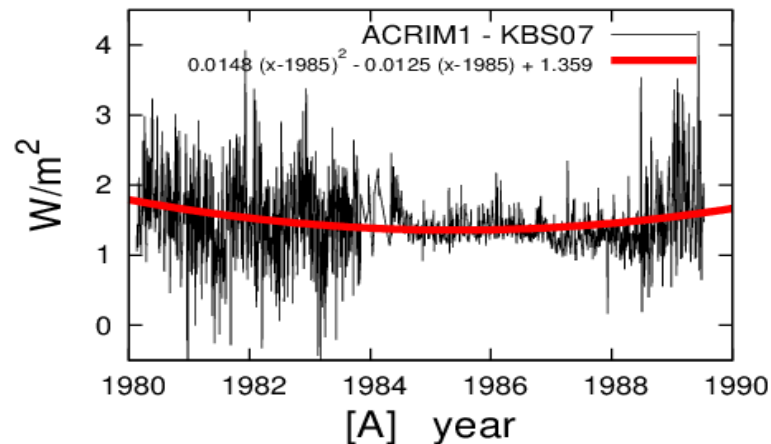




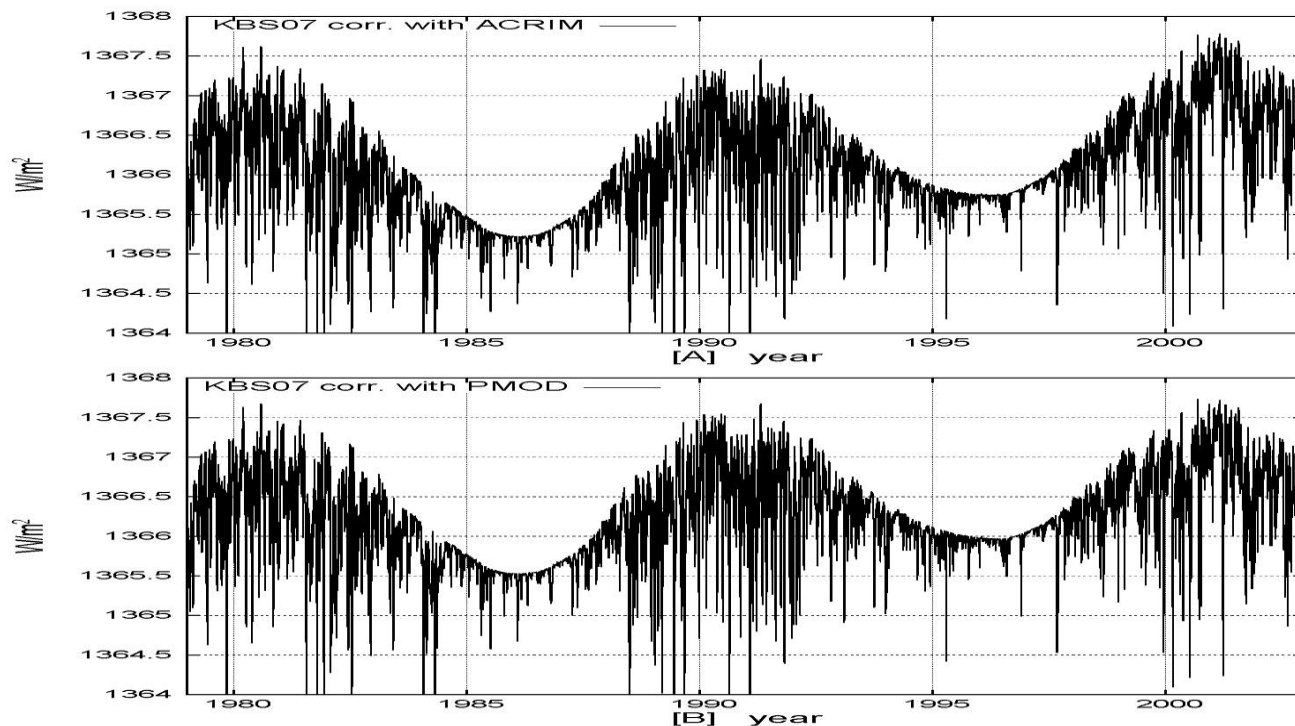
# Nimbus7/ERB & PMOD - KBS07



# ACRIM1, ACRIM2 & PMOD - KBS07

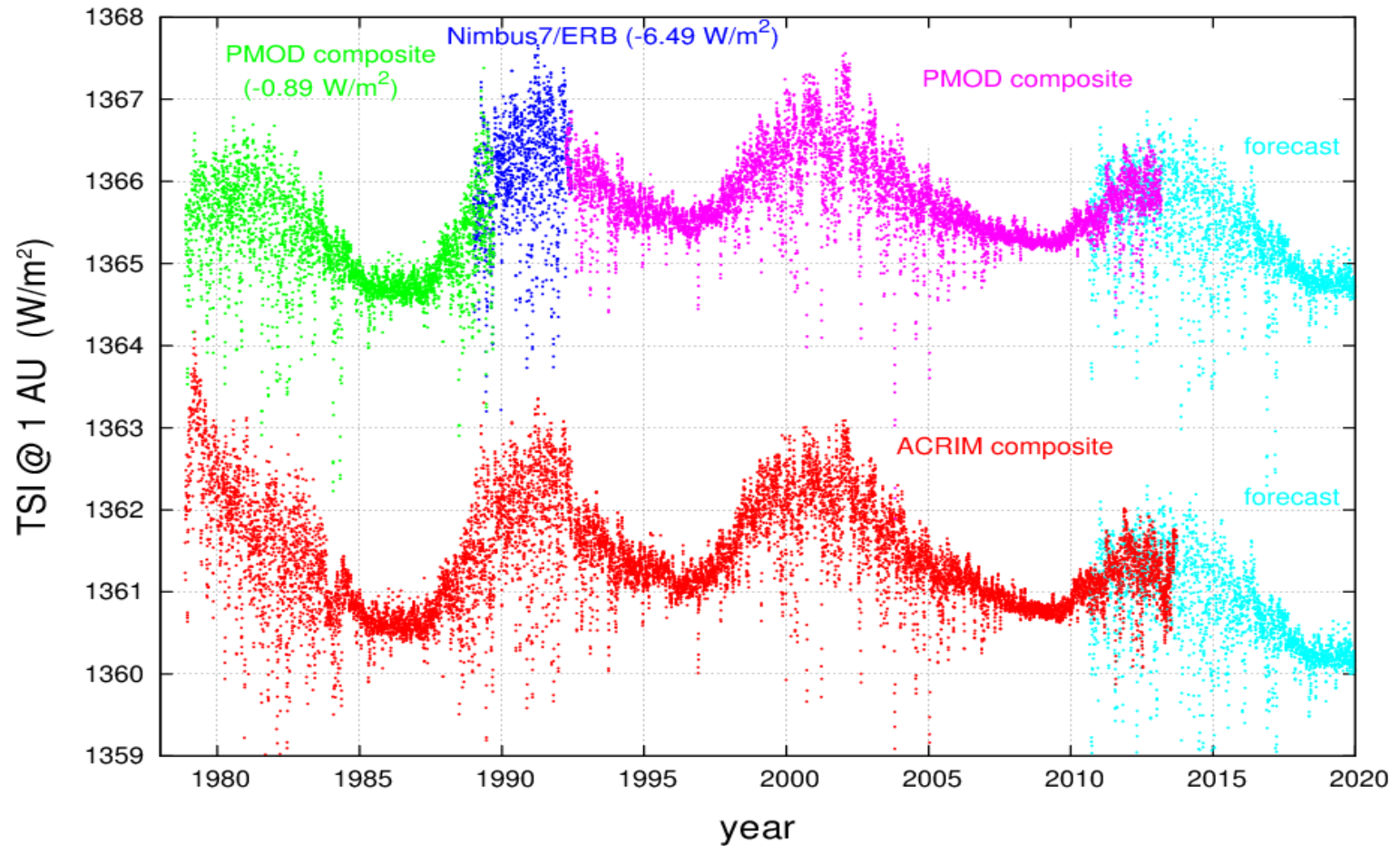


# ACRIM and PMOD TSI composites recalibrated using surface magnetic field TSI proxy model of Krivova et. al.



- ACRIM and PMOD TSI Composites calibrated during 1980-1989.5 and 1992.5-2001 using Krivova et. al. solar surface magnetic field proxy model instead of Nimbus7/ERB or ERBS/ERBE results
- The TSI trend from 1980-2000 of the recalibrated ACRIM and PMOD composites are similar in timing and amplitude to the trend in the original ACRIM composite.

# A 2014-2020 TSI Tentative Forecast





# Conclusions

- Correction of ACRIM3 results for scattering and diffraction is required

Scattering+diffraction correction  $\sim -5000$  ppm

Produces closer agreement of TSI results between ACRIM3 and SORCE/TIM

- ACRIM3, TIM and VIRGO results observe the same TSI variability

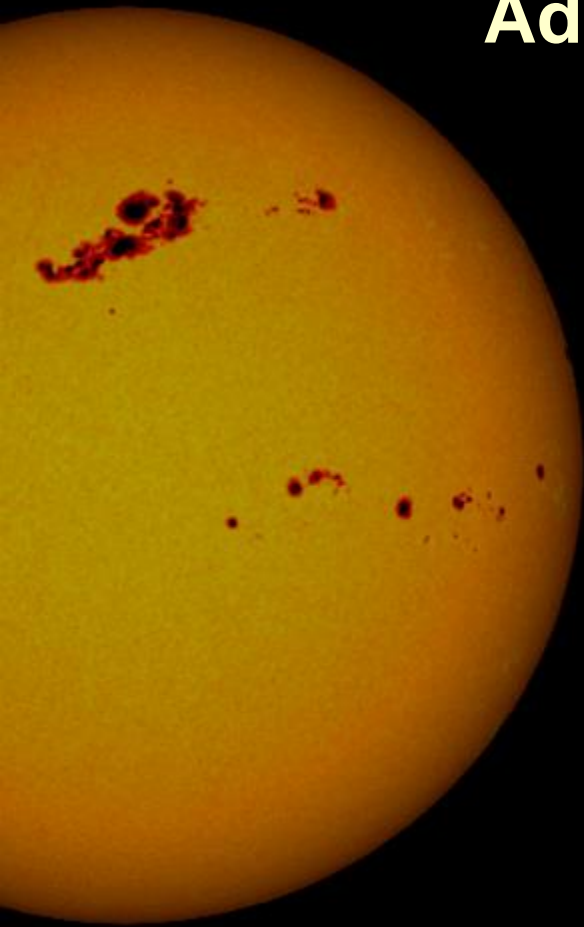
Fine detail reveals periodic variations detected by all three data sets

Largest signal is near the rotation rate of the primary solar magnetic latitudes

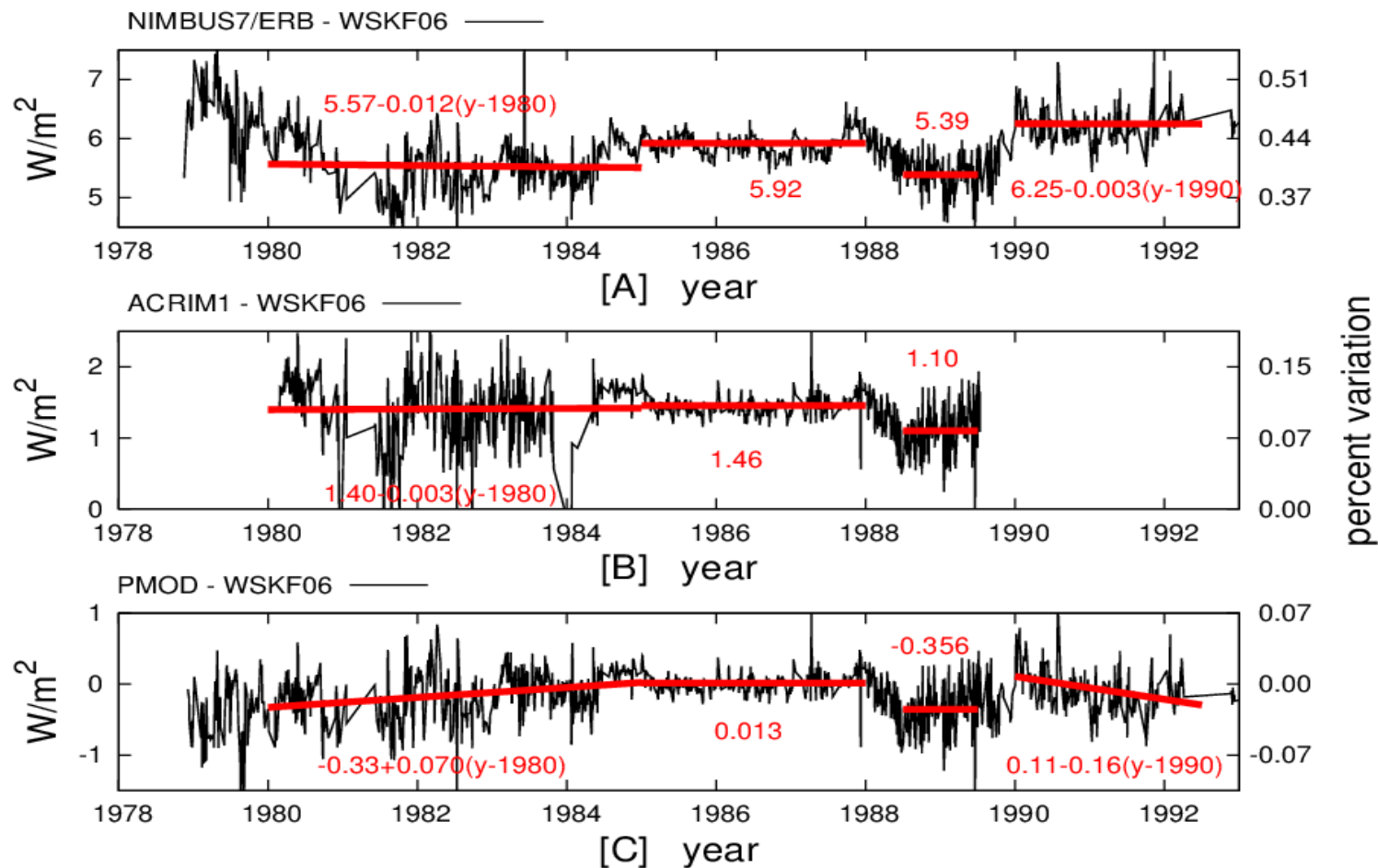
- ACRIM Composite TSI finds a  $+0.04$  %/decade trend during solar cycles 21 – 23

ACRIM Composite trend supported by Kitt Peak solar magnetic field strength proxy  
PMOD Composite trend likely an artifact of ERBE uncorrected degradation

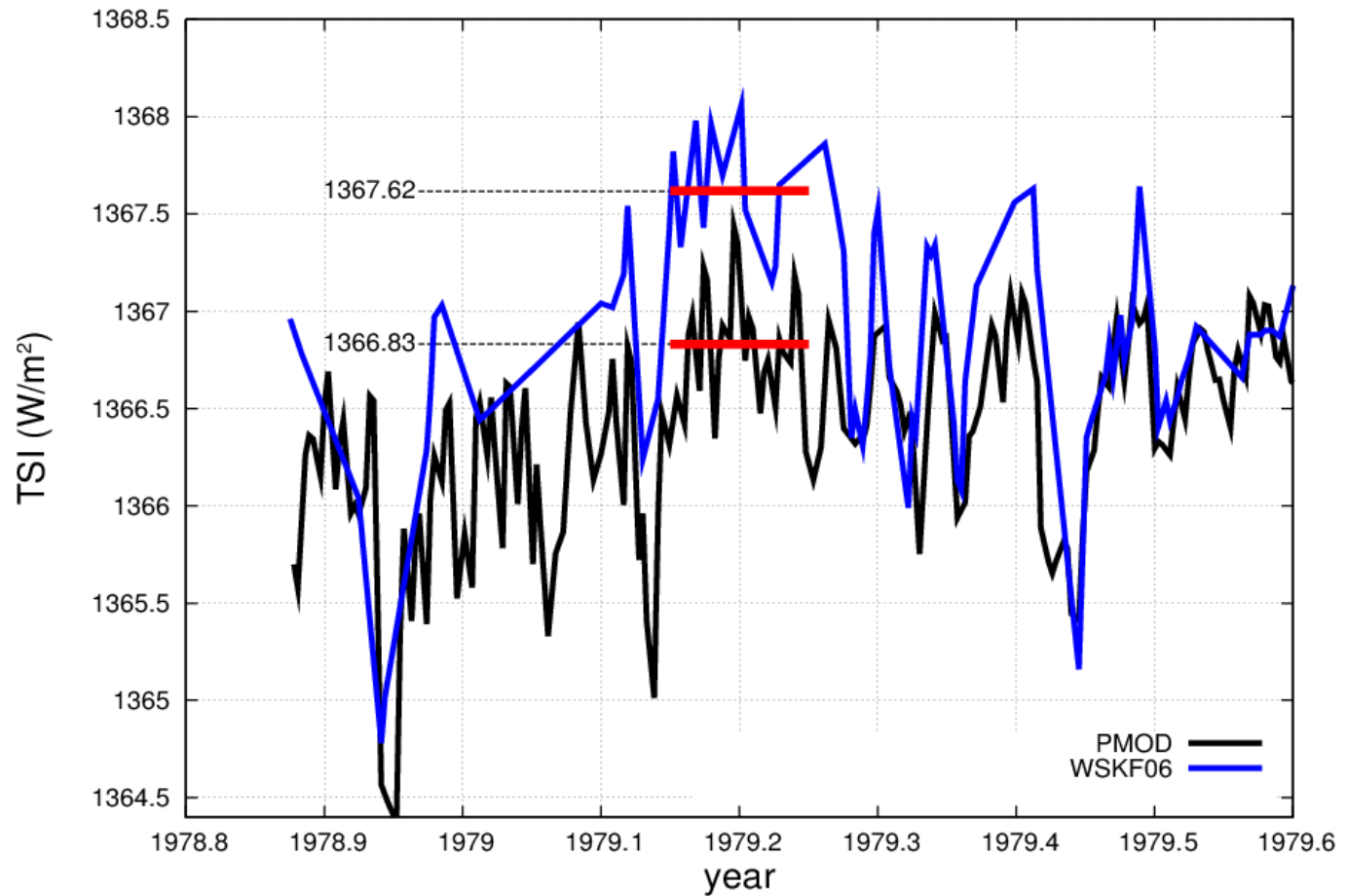
# Additional Slides for Q & A



# Nimbus7/ERB - ACRIM1 - PMOD - WSKF06



# WSKF06 - PMOD: The TSI Peak in 1979.2





# ACRIM - PMOD - SATIRE

