IRRADIANCE RECONSTRUCTIONS

(WITH SATIRE, though not only)

N. Krivova

W. Ball, M. Dasi, S.K. Solanki, Y.C. Unruh

also thanks to Sasha Shapiro

MPS

Imperial College London

WHERE TO GO?

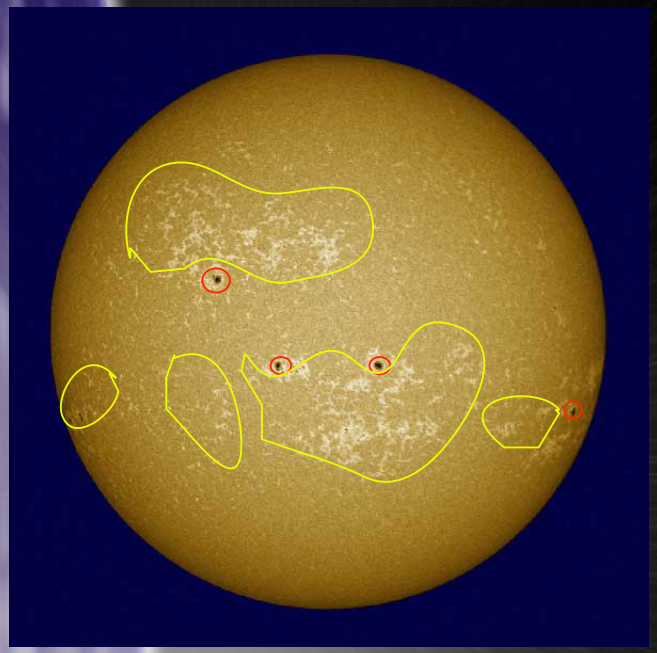
Satellite era:

- TSI – secular change and minimum 2008?
- SSI – SORCE vs. previous measurements and models

Past irradiance changes:

- Magnitude of the secular change

BASIC ASSUMPTION OF MODELS



All irradiance changes (TSI and SSI) are due to the evolution of the surface magnetic structures

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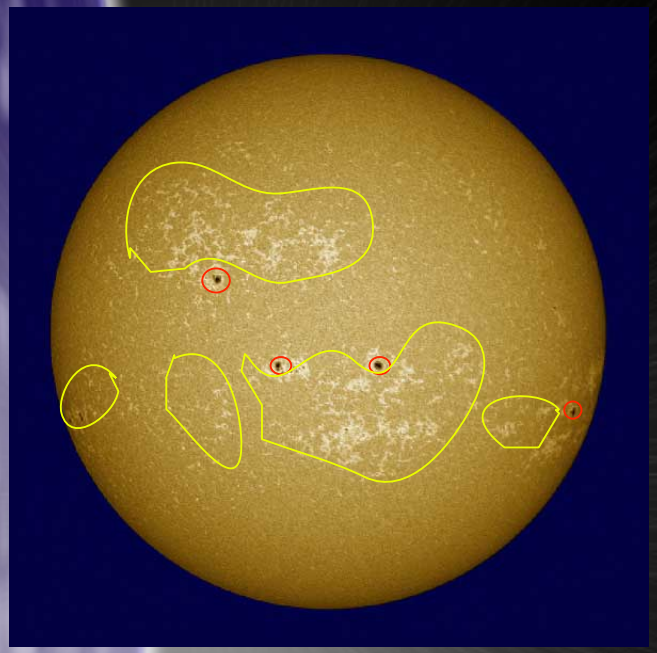


All irradiance changes (TSI and SSI) are due to the evolution of the surface magnetic structures

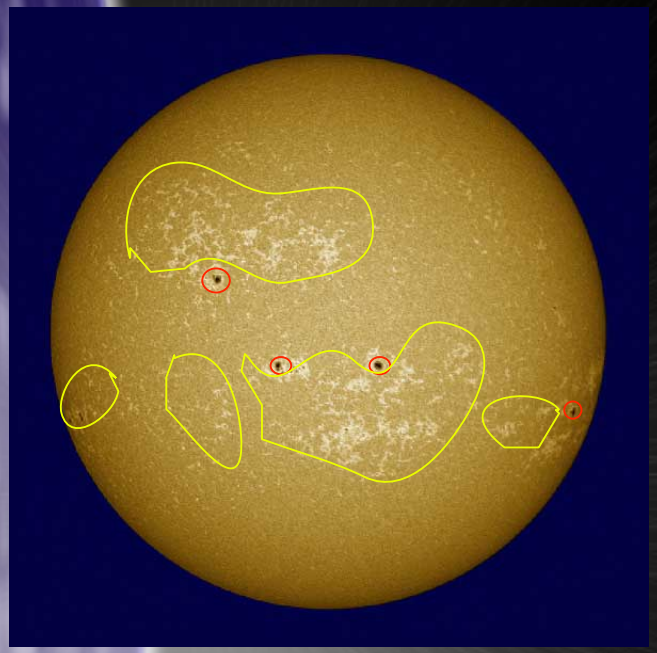
Irradiance = Quiet Sun brightness *(here QS means absolutely quiet, no MF)*

+ darkening due to sunspots

+ brightening due to faculae and the network:

$$S_{tot}(t) = S_{QS} + \Delta S_s(t) + \Delta S_f(t)$$

PROXY MODELS



Earlier simpler models *(e.g., NRLSSI)* combine sunspots darkening (e.g., PSI) with brightening due to faculae and the network (Facular Proxy, e.g. Mg index, Ca II, F10.7) using linear or multiple regressions:

$$S_{tot}(t) = S_{QS} + \kappa_1 PSI(t) + \kappa_2 FP(t)$$

PROXY MODELS

PROBLEM:

SSI

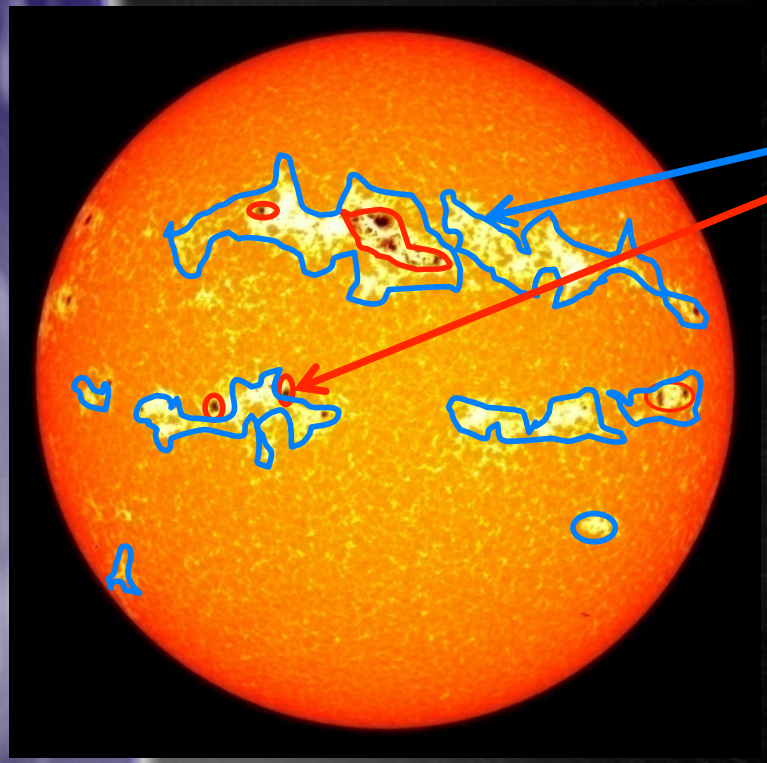
SOLUTION:

(1) Use reference spectra: e.g.,

- ATLAS spectra *(Thuillier et al. 2012*),
- SCIAMACHY *(Pagaran et al. 2009)*
- or combined – observed+theoretical *(NRLSSI - Lean 2000)*

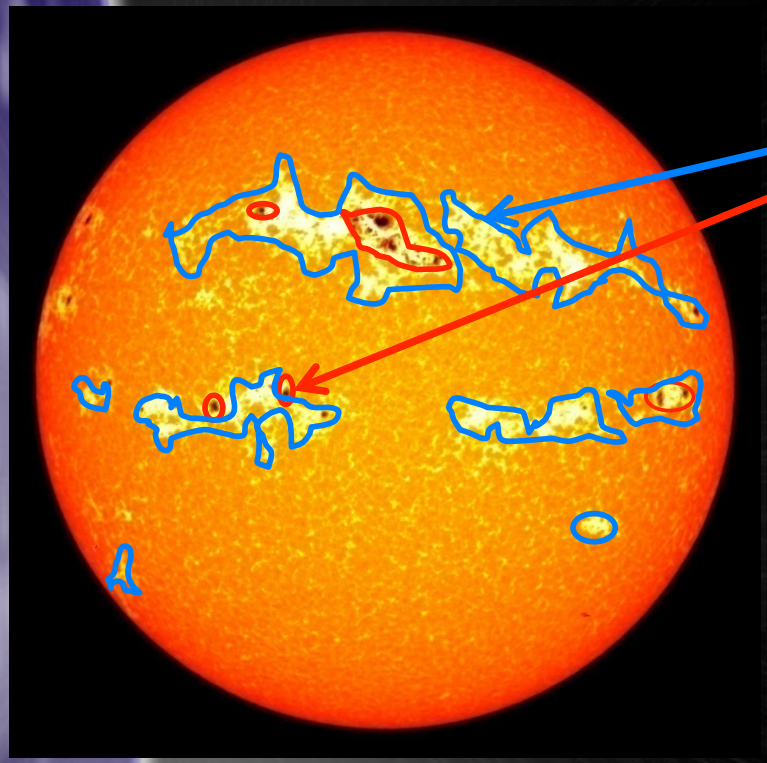
(2) Scale variability using proxies

SEMI-EMPIRICAL MODELS



1. Surface area coverage (filling factors) and possibly positions *(as a function of time)*

SEMI-EMPIRICAL MODELS



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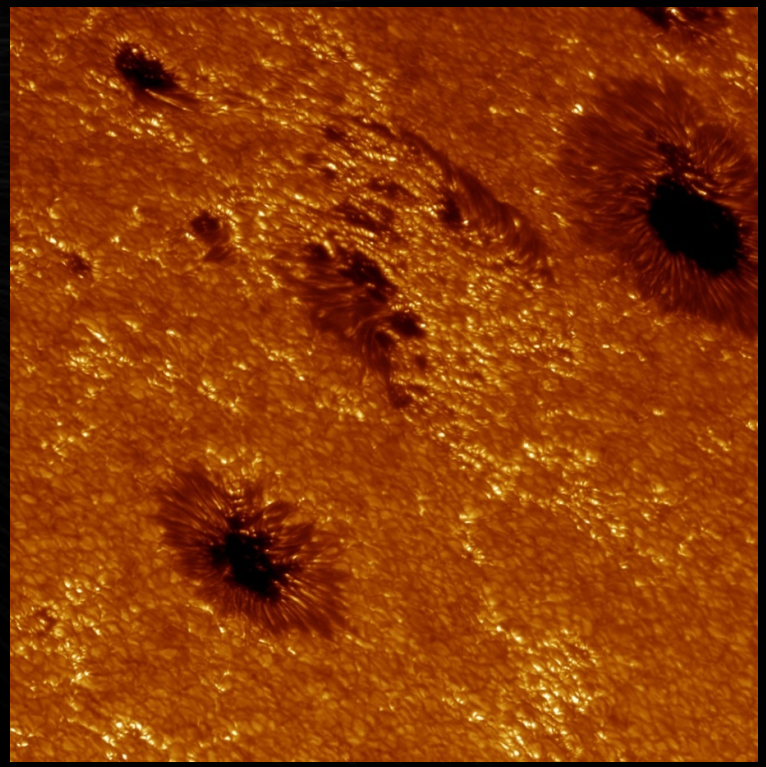
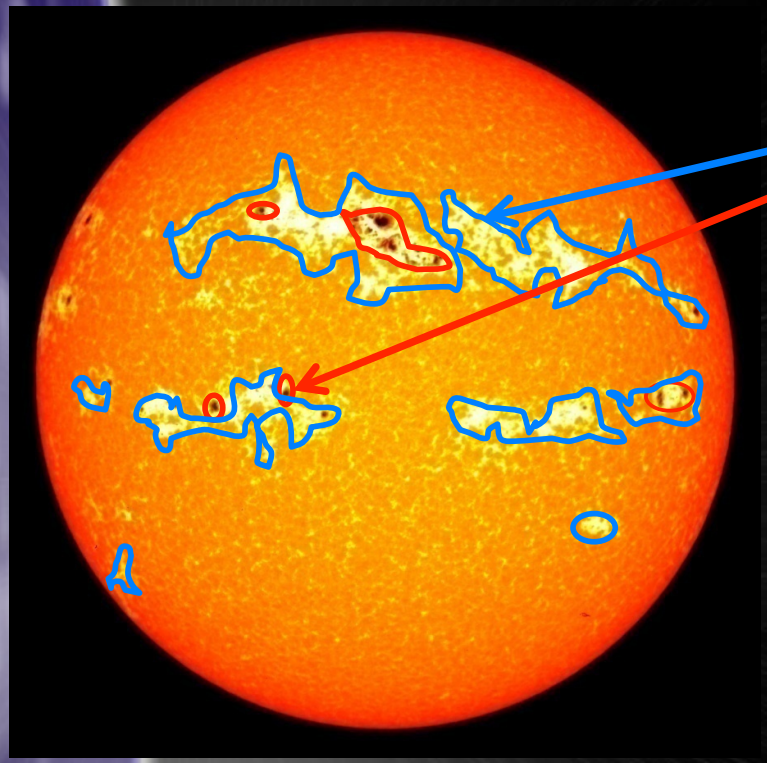


2. Brightness of each component *(as a function of wavelengths and disc position)*

SEMI-EMPIRICAL MODELS



1. Surface area coverage (filling factors) and possibly positions *(as a function of time)*

Can be:

disc-integrated, e.g. sunspot number, area, plage area, Mg index, Ca II, F10.7, ^{10}Be, ^{14}C....
(SATIRE-T & SATIRE-H – i.e. before 1974, Shapiro et al. 2012)

or spatially resolved maps of the full disc, e.g. magnetograms, continuum images, Ca II images etc. *(SATIRE-S, Fontenla et al. 2009, 2011)*

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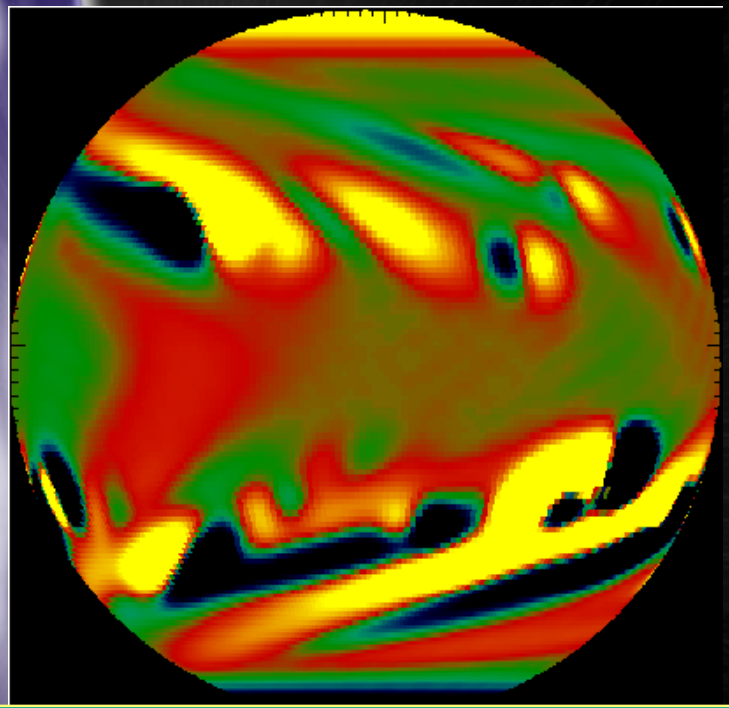

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or spatially resolved maps of the full disc, e.g. magnetograms, continuum images, Ca II images etc. *(SATIRE-S, Fontenla et al. 2009, 2011)*

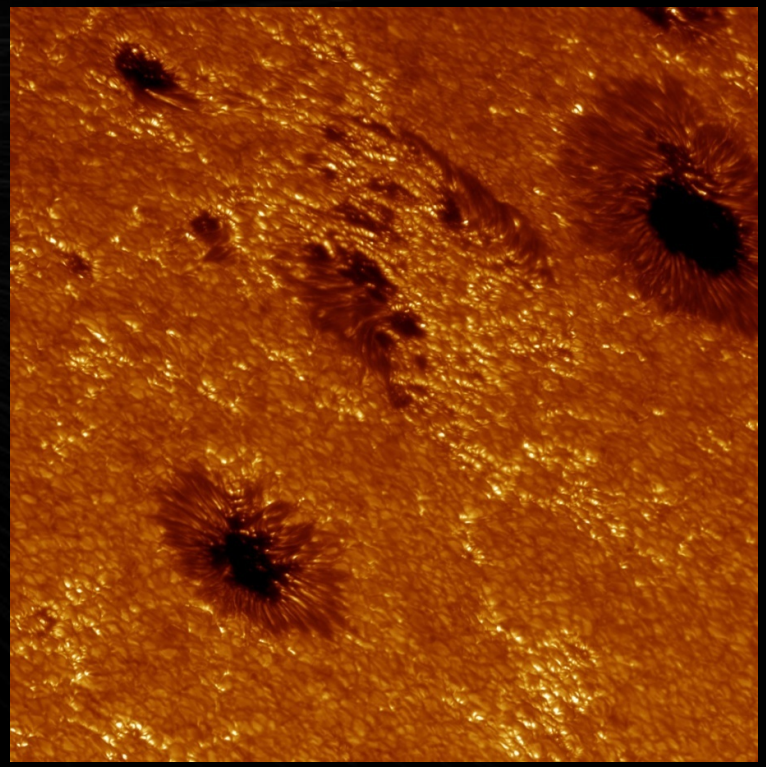
Do not need to be come from observations directly: e.g.

- Surface Flux Transport simulations *(Wang et al. 2005, Dasi 2012)*
- Monte Carlo simulations *(Crouch et al. 2008, Bolduc et al. 2012)*

SEMI-EMPIRICAL MODELS

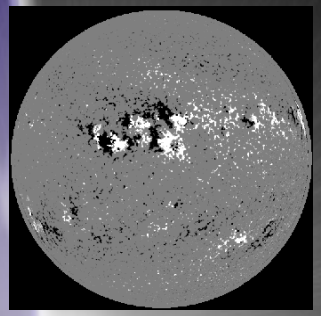
Calculated from semi-empirical models of the solar atmosphere
(e.g., Kurucz models, Fontenla et al. 1999, 2009, 2011; Unruh et al. 1999; Shapiro et al. 2010)
using spectral synthesis codes
(e.g., SRPM, COSI or ATLAS9, the latter uses LTE)

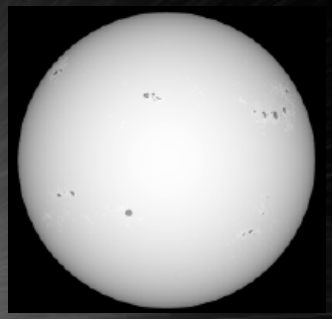
2. Brightness of each component *(as a function of wavelengths and disc position)*



SATIRE-S

(Spectral And Total Irradiance Reconstructions for the Satellite era)





Unruh et al. (1999); Fligge et al. (2000); Krivova et al. (2003); Wenzler et al. (2004, 2005, 2006); Ball et al. (2011, 2012)

Magnetograms and continuum images → Distribution of features on the solar surface

- changes with time

Semi-empirical model atmospheres → Brightness of features

- depends on the wavelength and the position on the solar disc (time independent!)

+

↓

IRRADIANCE

WHERE TO GO?

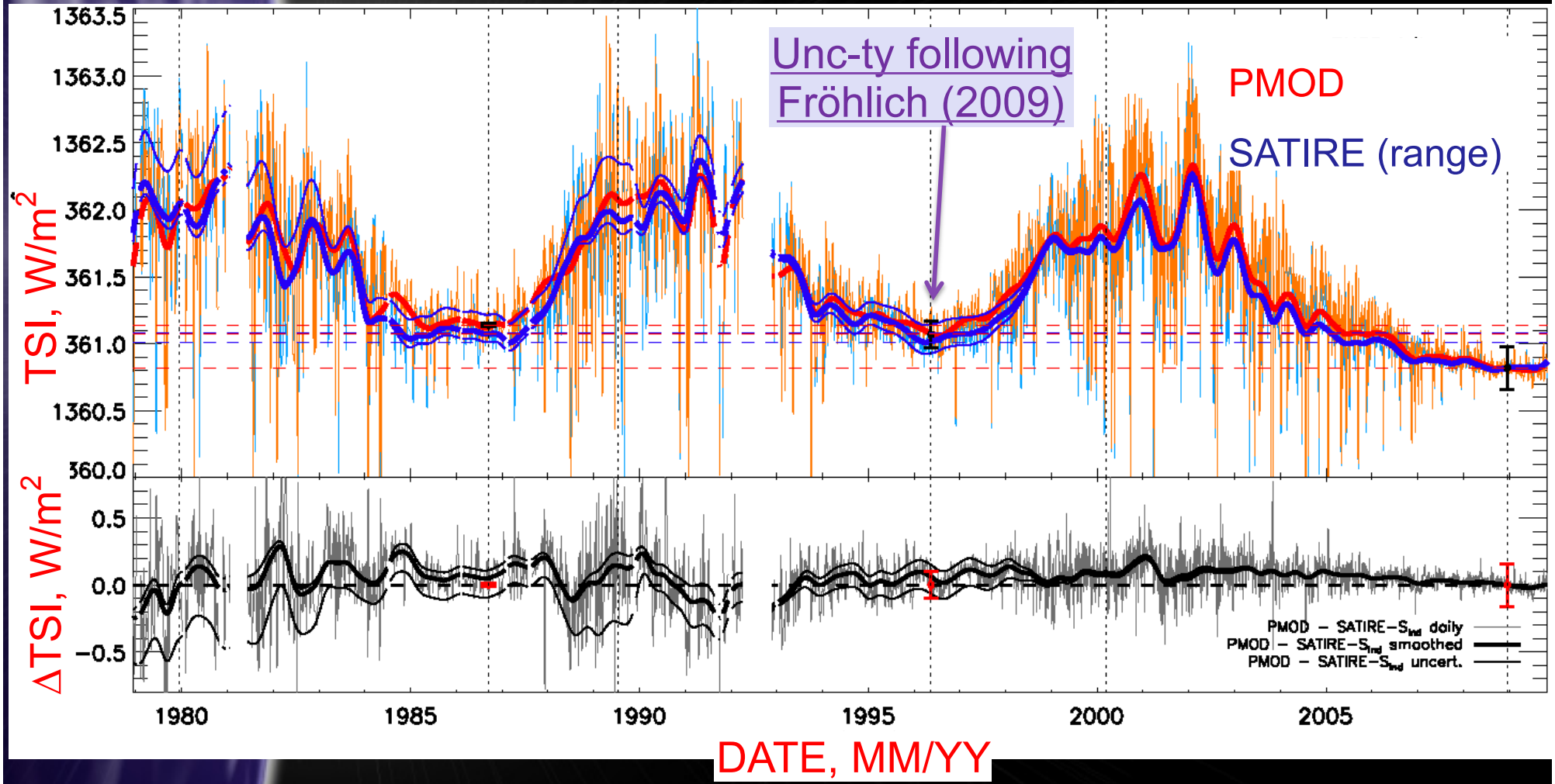
Satellite era:

- TSI – secular change and minimum 2008?
- SSI – SORCE vs. previous measurements and models

Past irradiance changes:

- Magnitude of the secular change

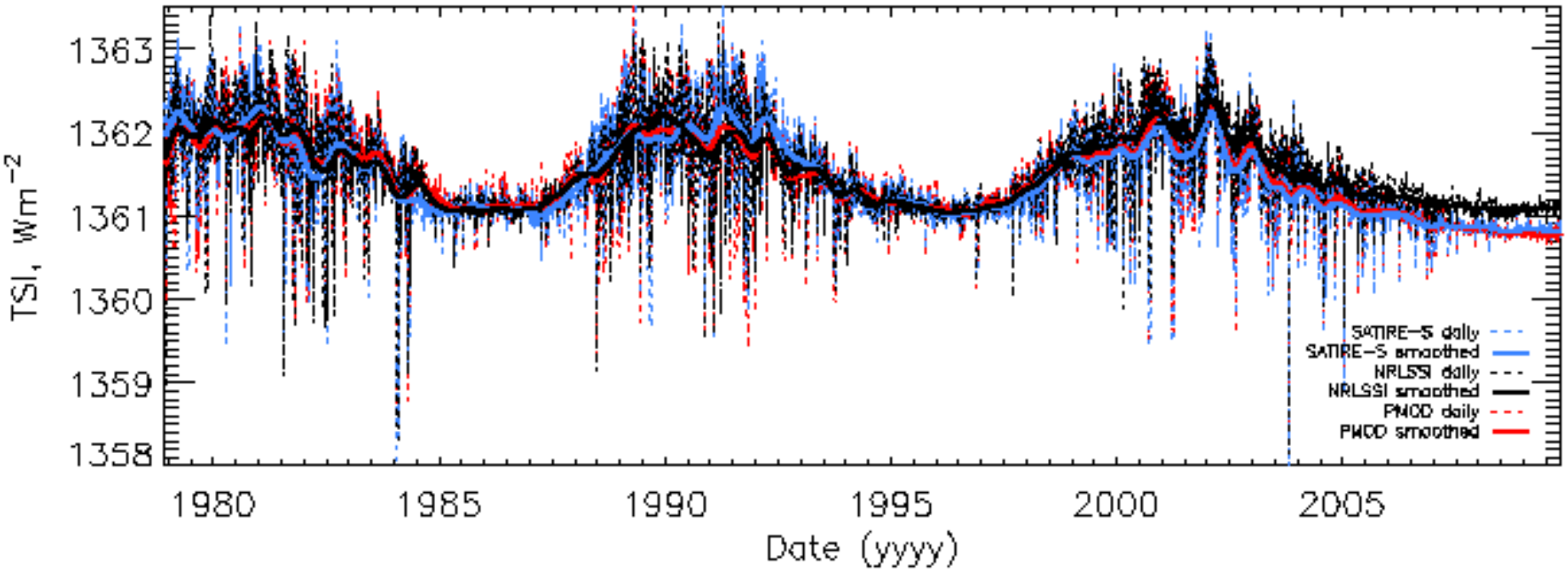
SATIRE-S VS. MEASUREMENTS: TSI 1978 - 2010



Rc=0.96

Ball et al, 2012

IRRADIANCE MODELS: TSI
NRLSSI and SATIRE vs. PMOD



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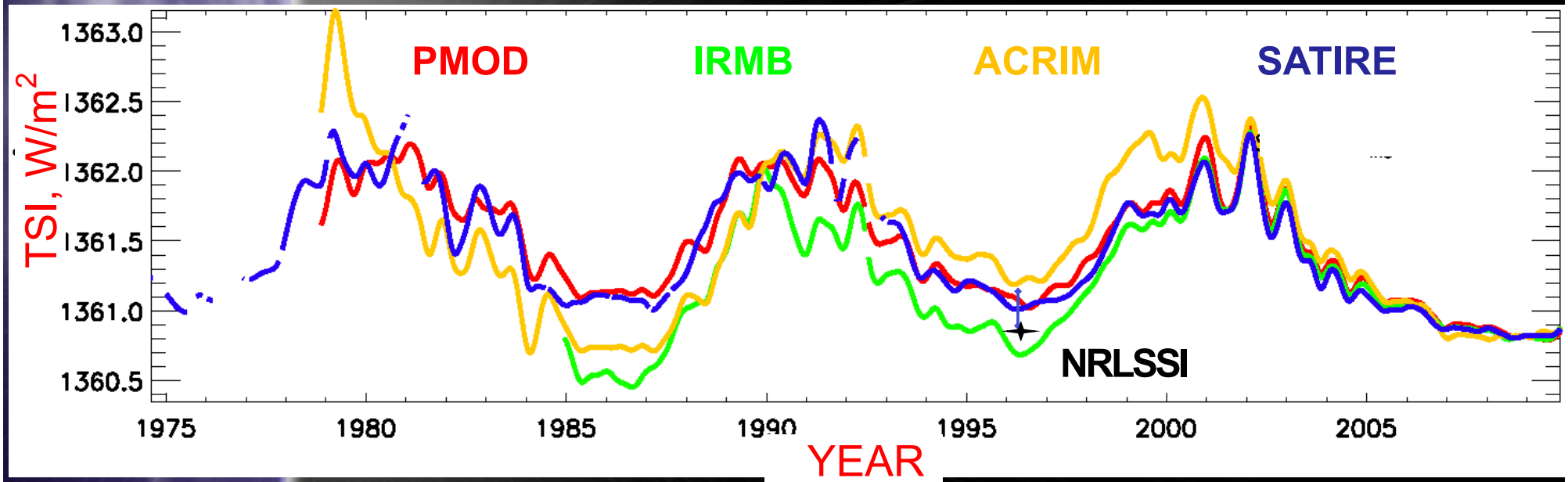

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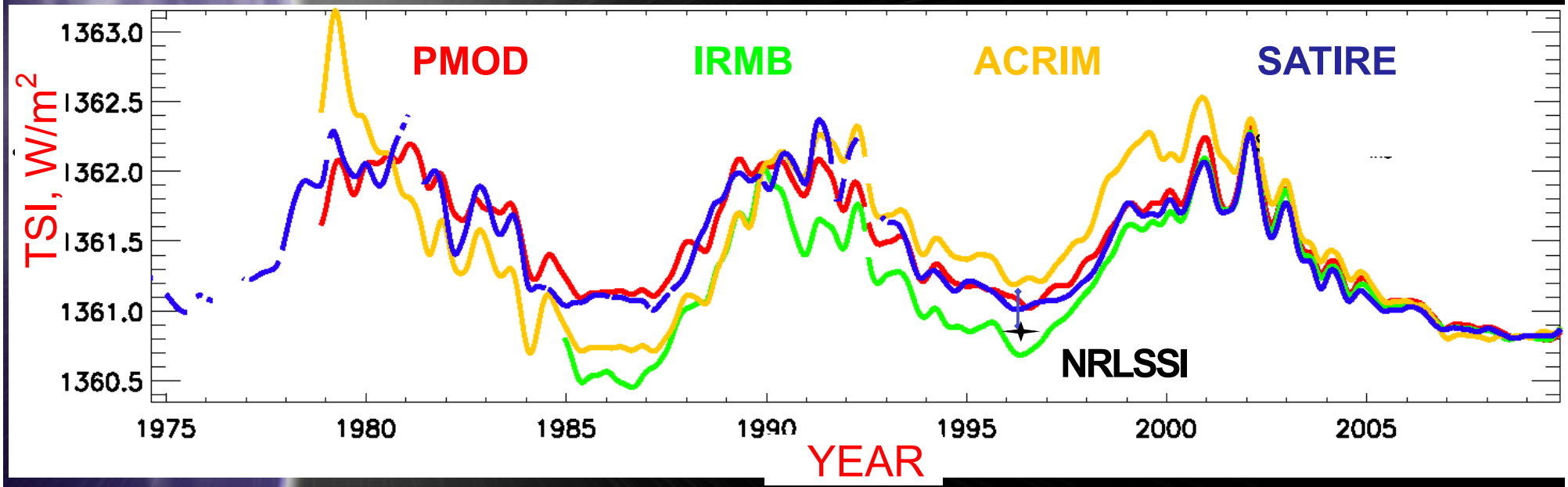

OAR *(Ermolli et al. 2011)* and Monte-Carlo models *(Bolduc et al. 2012)* also suggest a weaker, if any, decrease between 1996 and 2008 than in PMOD

Ball et al, 2012

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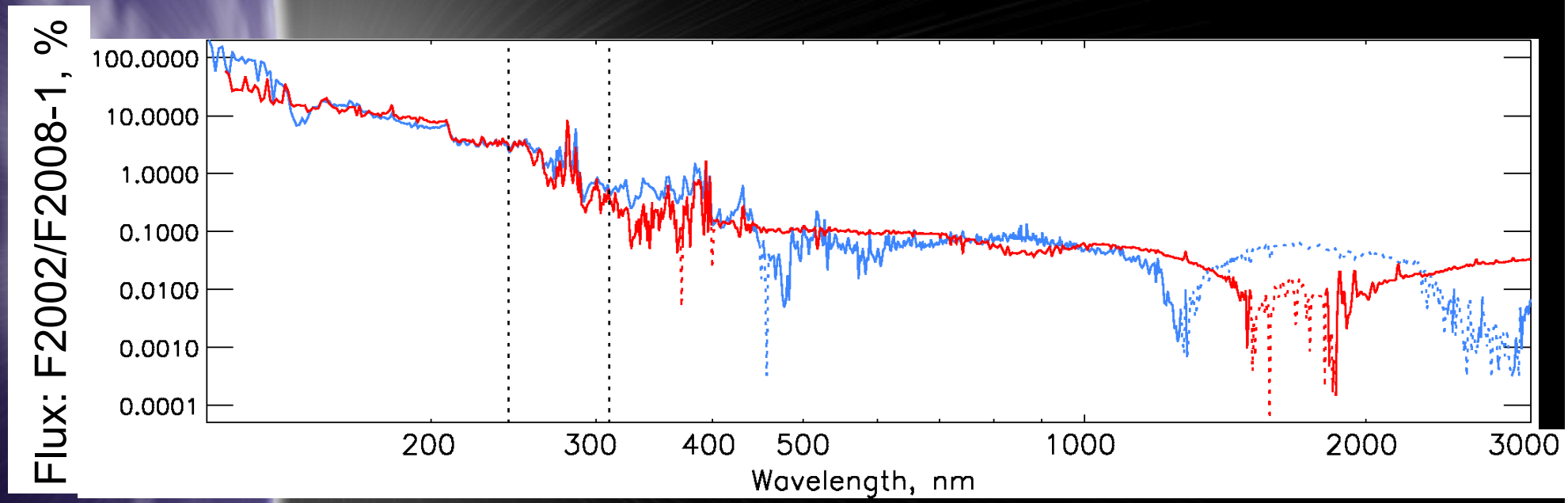
SPECTRAL IRRADIANCE MODELS: NRLSSI and SATIRE



Lean 2000; Lean et al. 2005

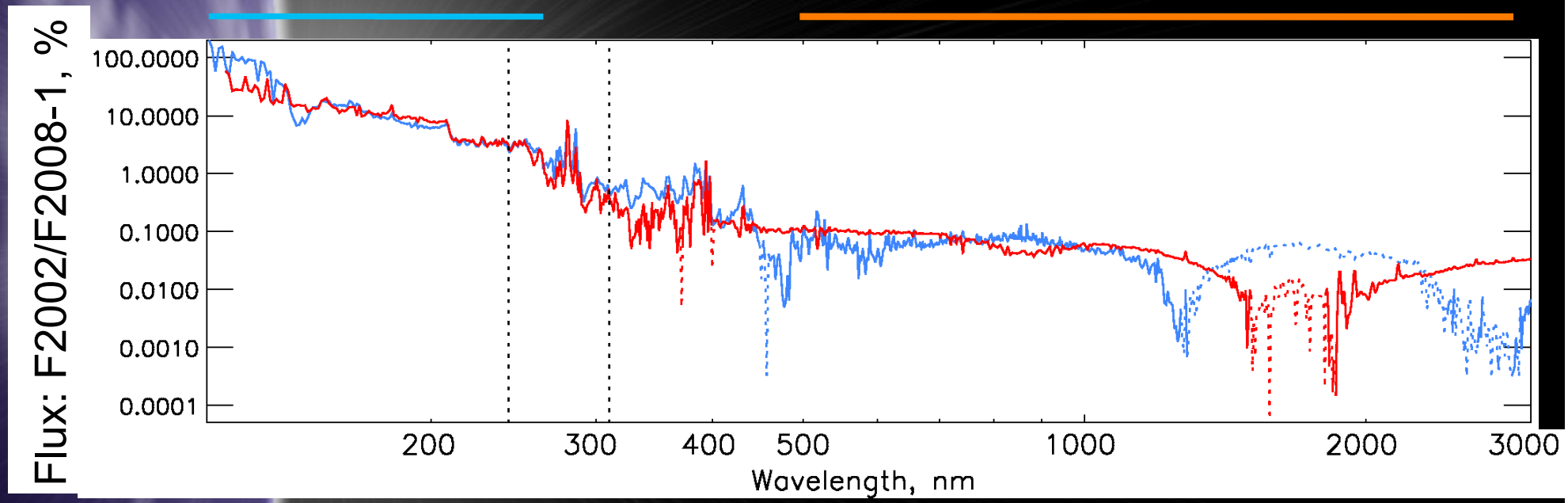
Ball et al., in prep.

SPECTRAL IRRADIANCE MODELS: NRLSSI and SATIRE

Both models use SSI measurements

SATIRE uses model atmospheres

Both use model atmospheres
Solanki & Unruh 1998
Unruh et al. 1999



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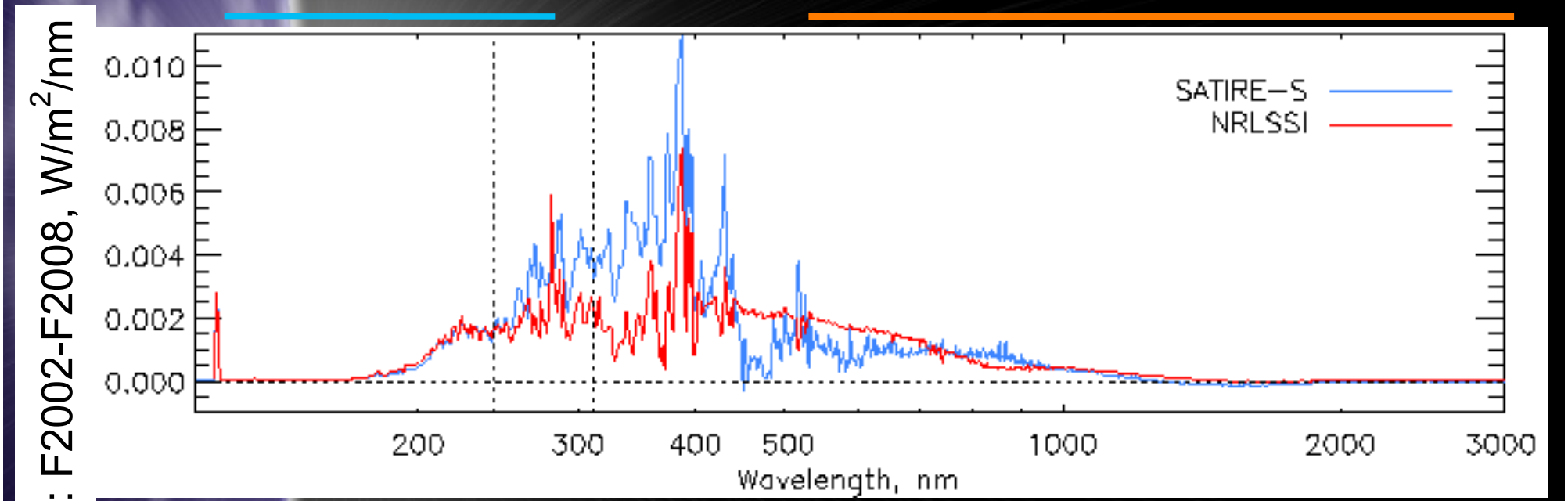

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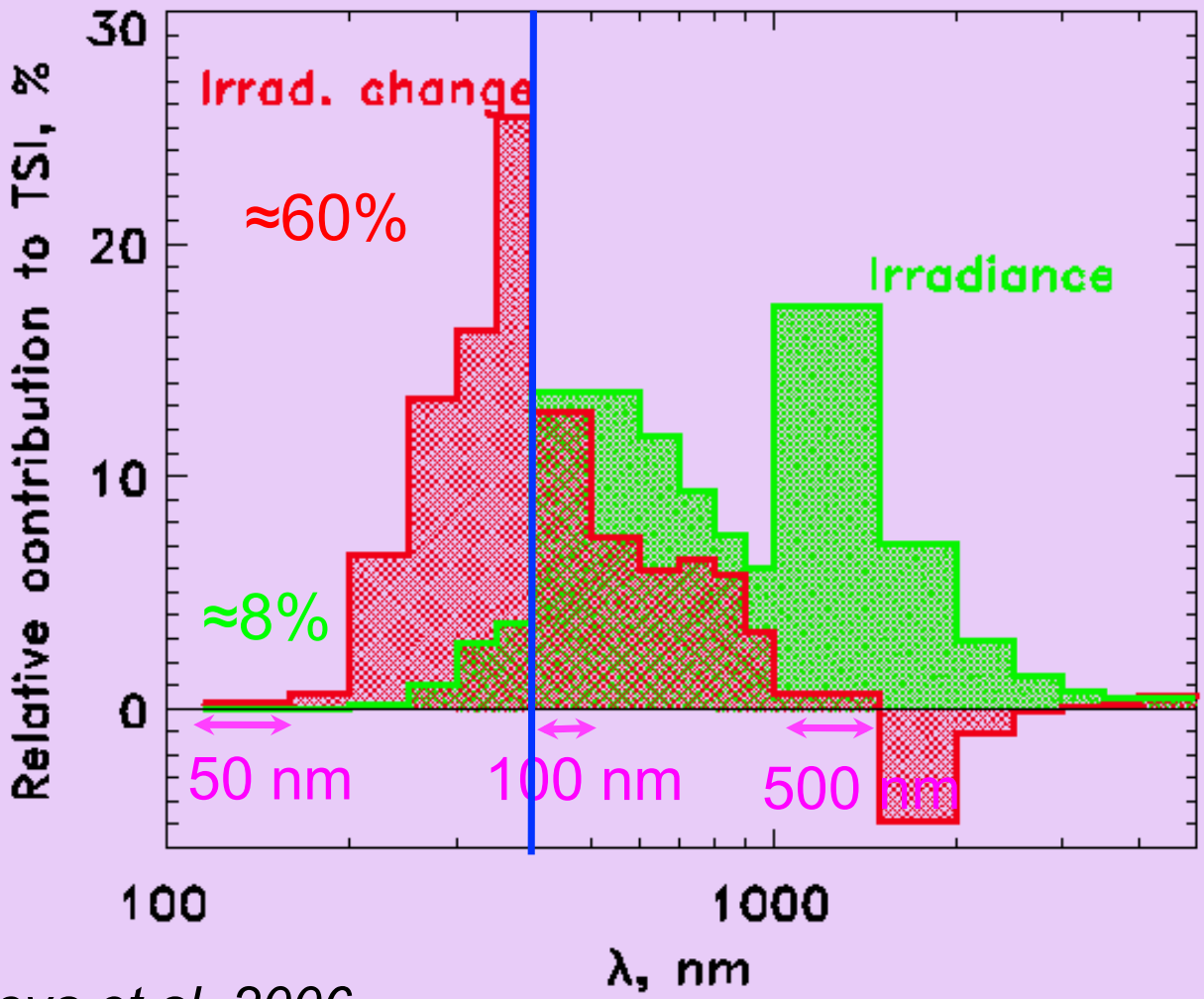
SPECTRAL IRRADIANCE: SATIRE



Krivova et al. 2006

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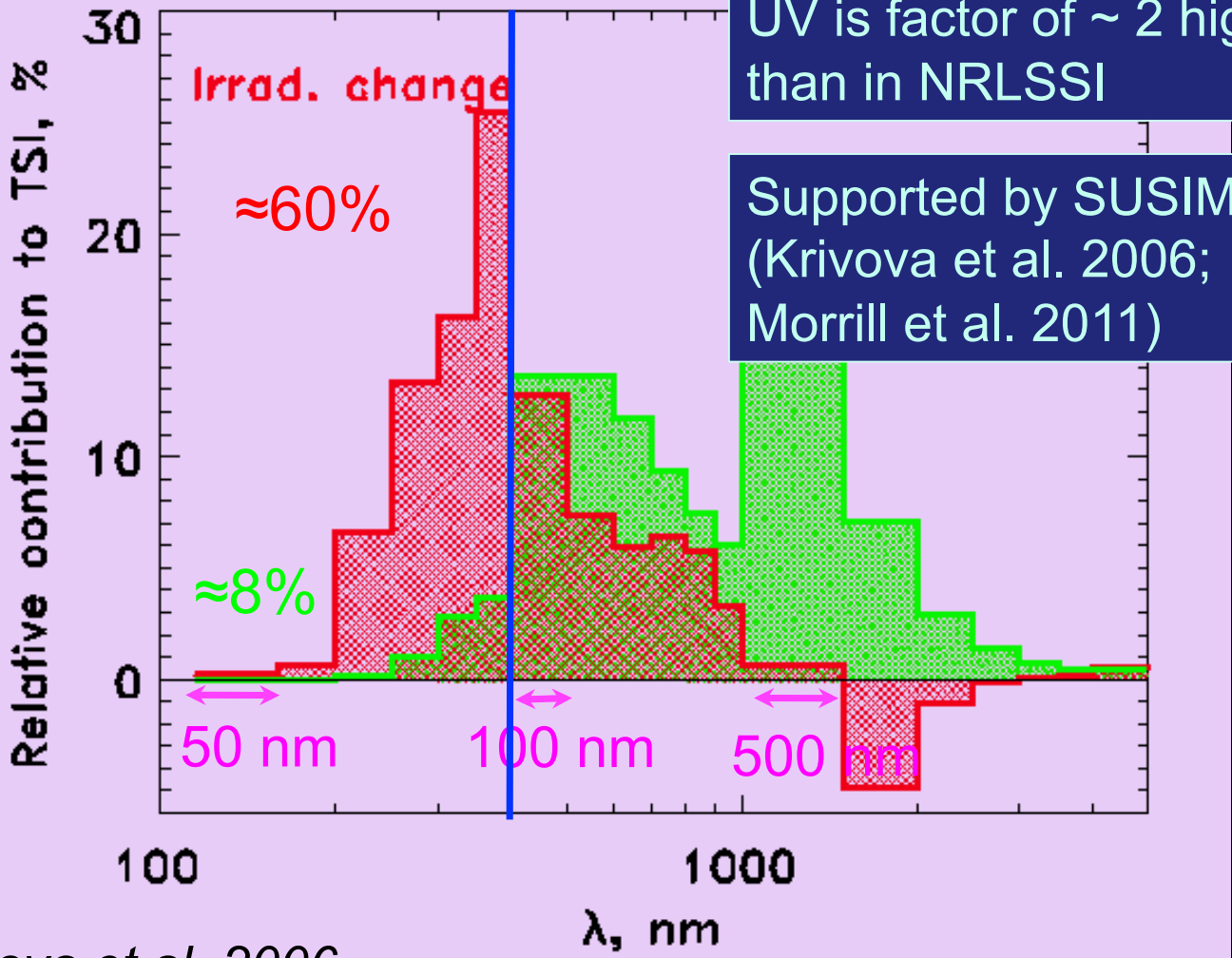
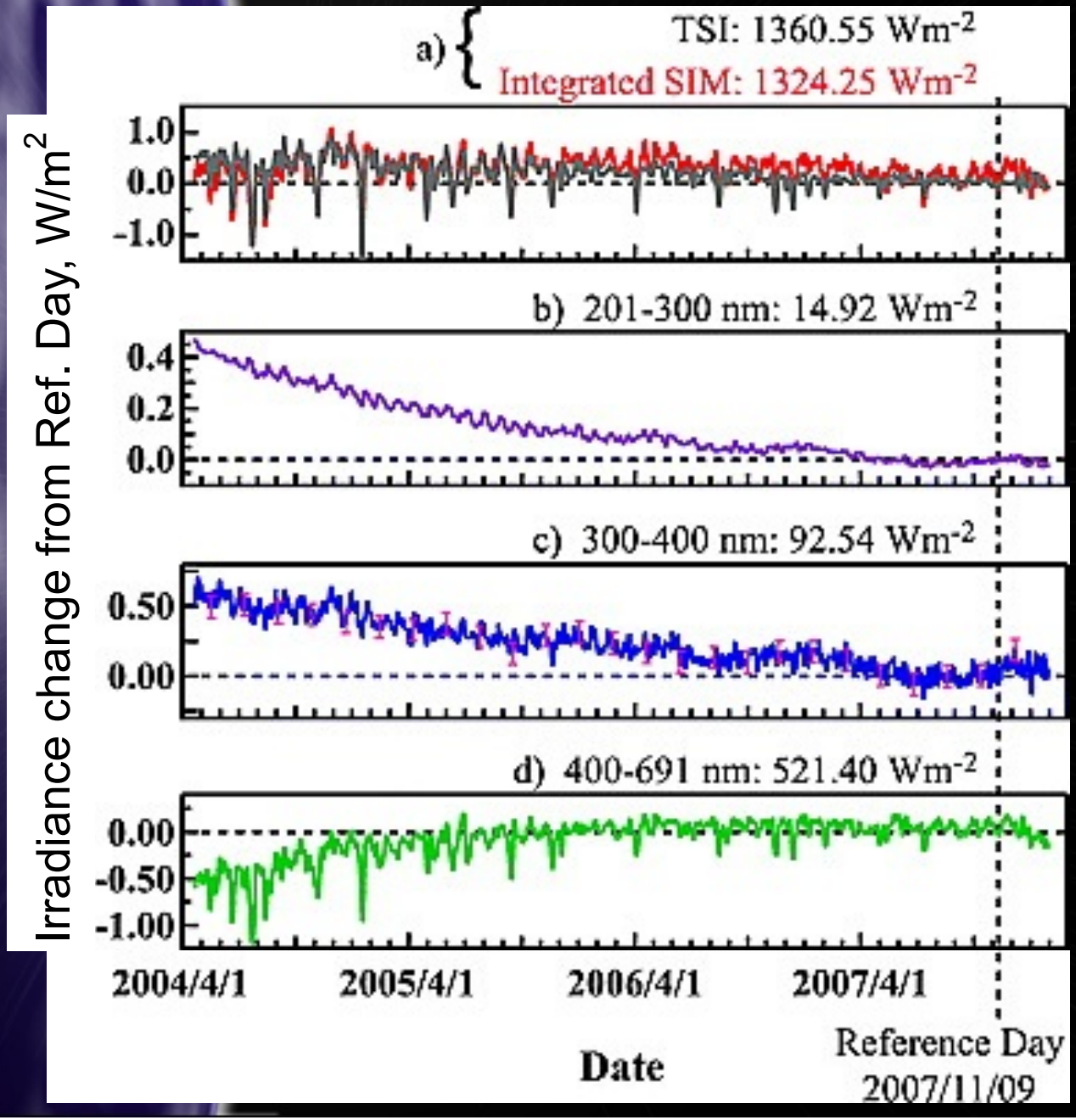


Krivova et al. 2006

The contribution of the UV is factor of ~ 2 higher than in NRLSSI

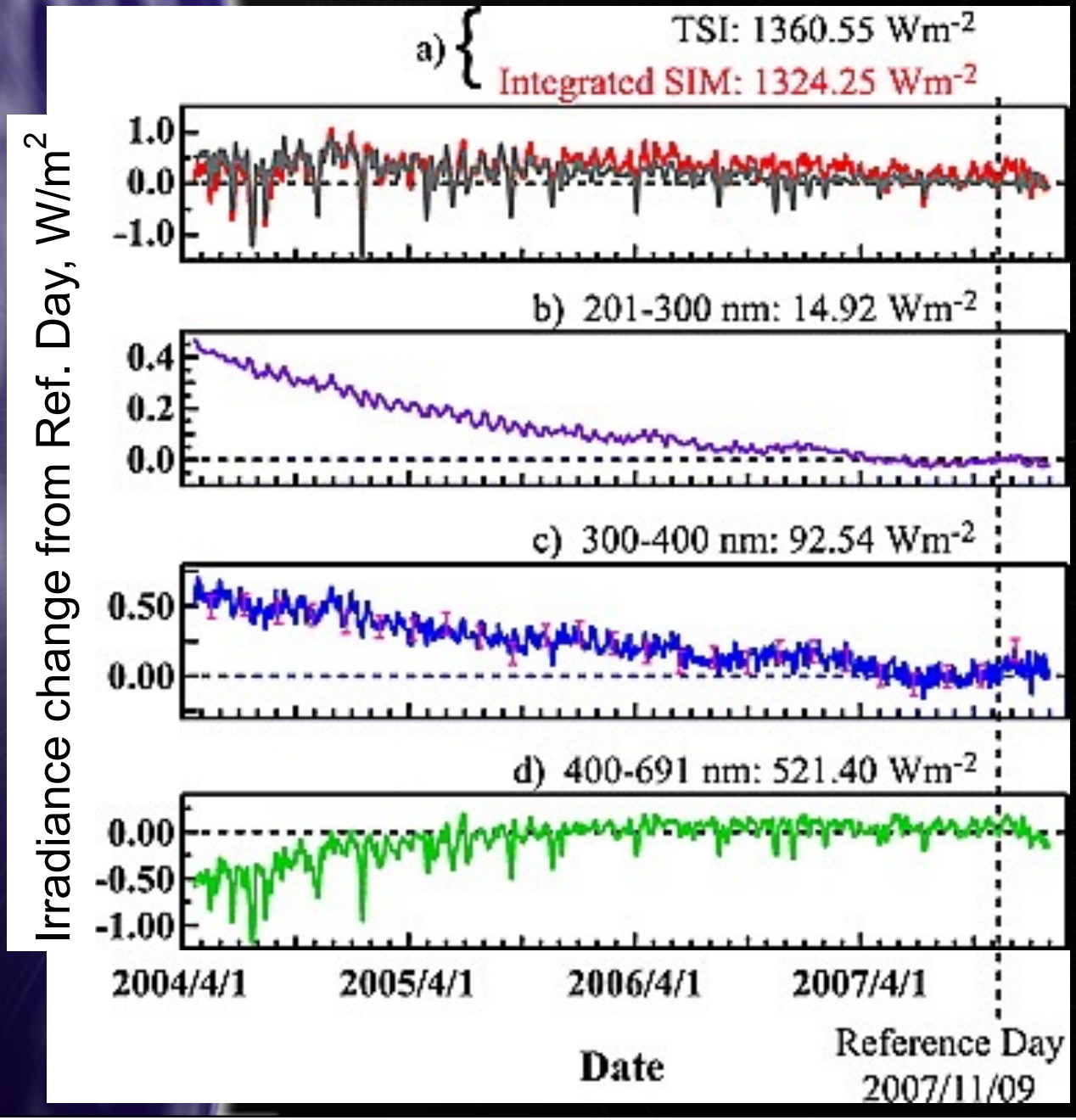
Supported by SUSIM data (Krivova et al. 2006; Morrill et al. 2011)

NOW COMES SORCE/SIM...



Harder et al, 2009

NOW COMES SORCE/SIM...

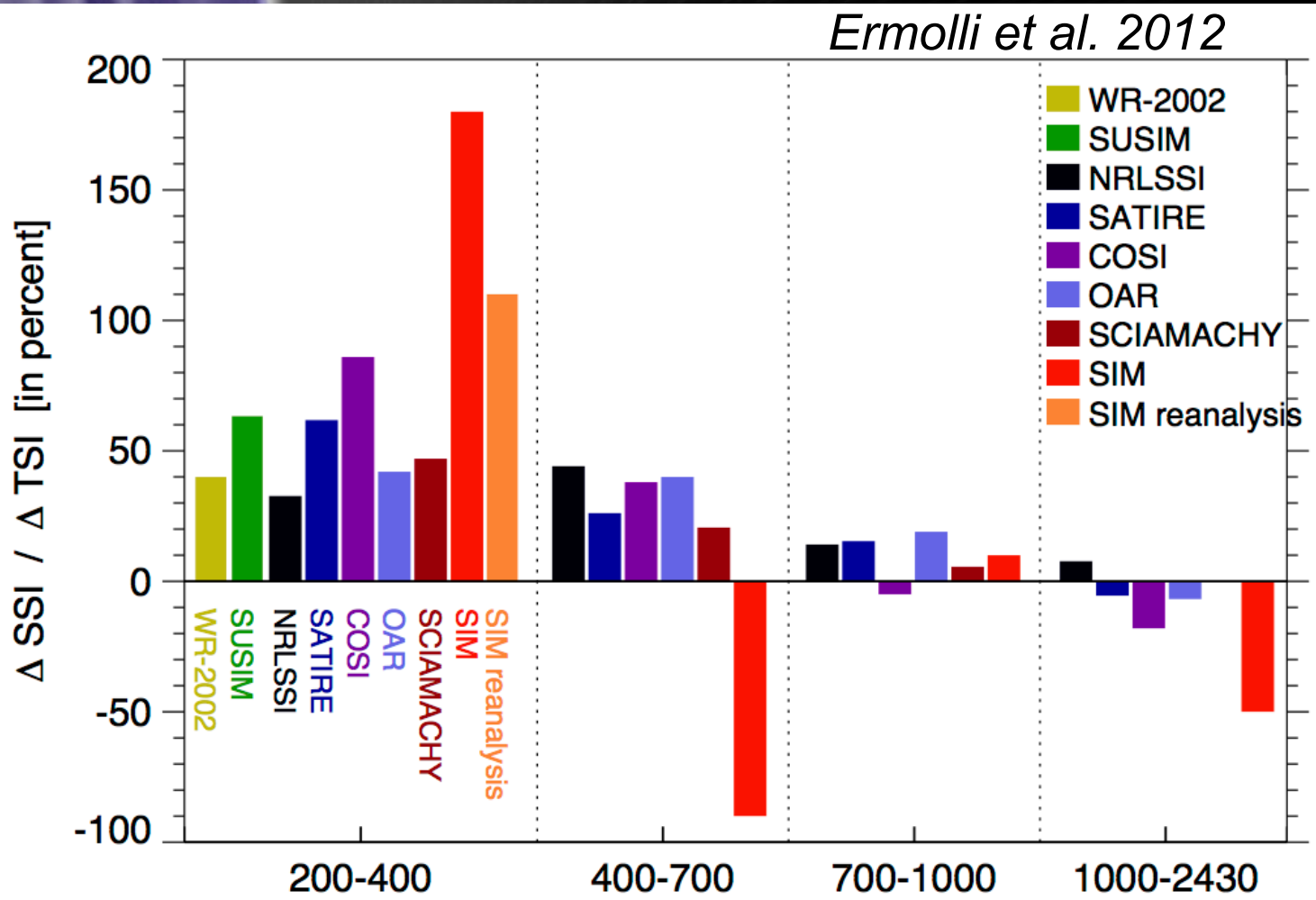


Significantly stronger change at 200-400 nm

... Compensated by the oppositely directly change in the VIS

Harder et al, 2009

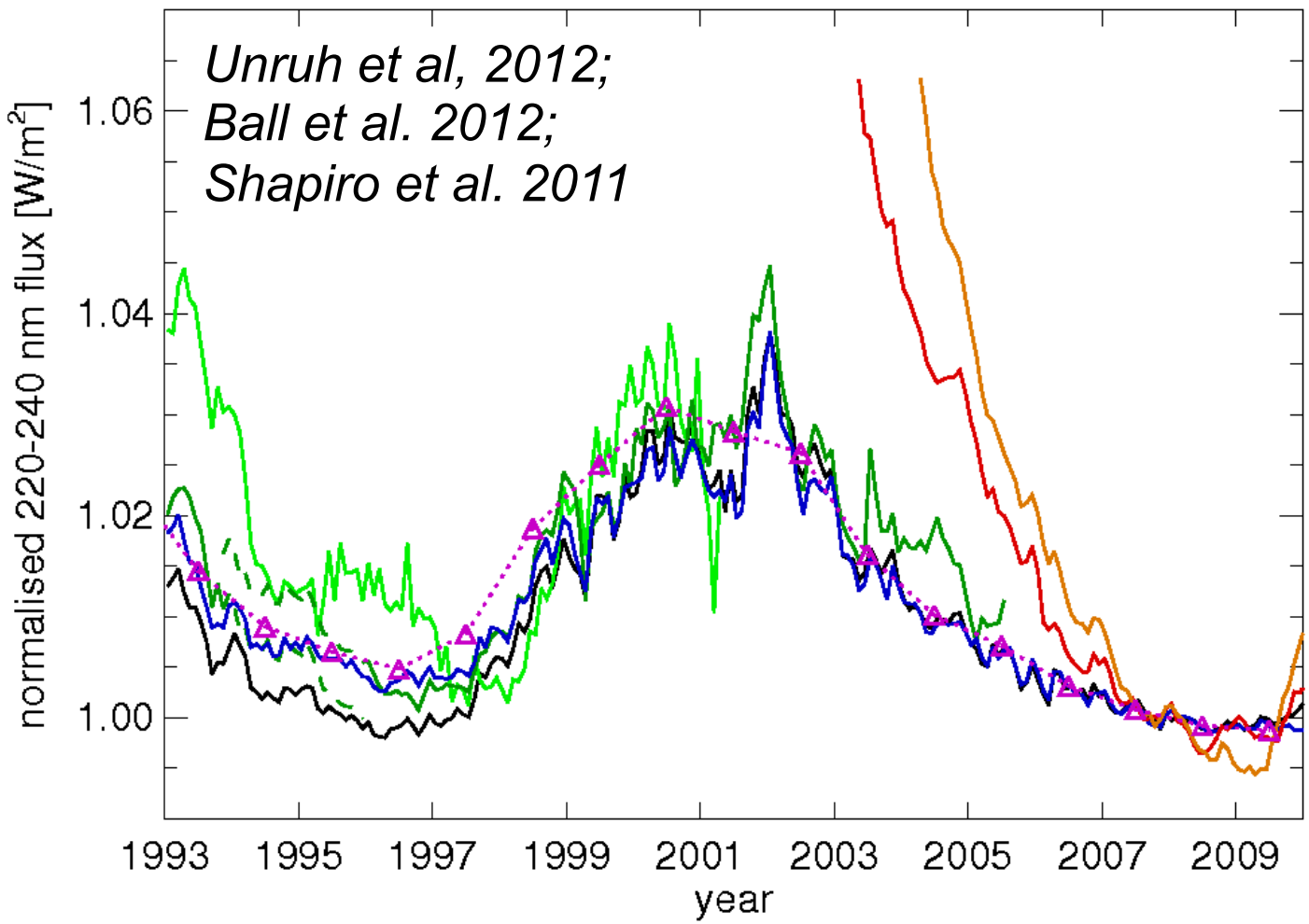
SSI VARIABILITY 2003-2009



NB: SCIAMACHY values must be corrected by roughly 25% (sum over all wavel. is only 76%)

SPECTRAL IRRADIANCE: DATA & MODELS

NRLSSI, SATIRE, COSI, SUSIM, UARS/ SOLSTICE, SIM, SORCE/SOLSTICE



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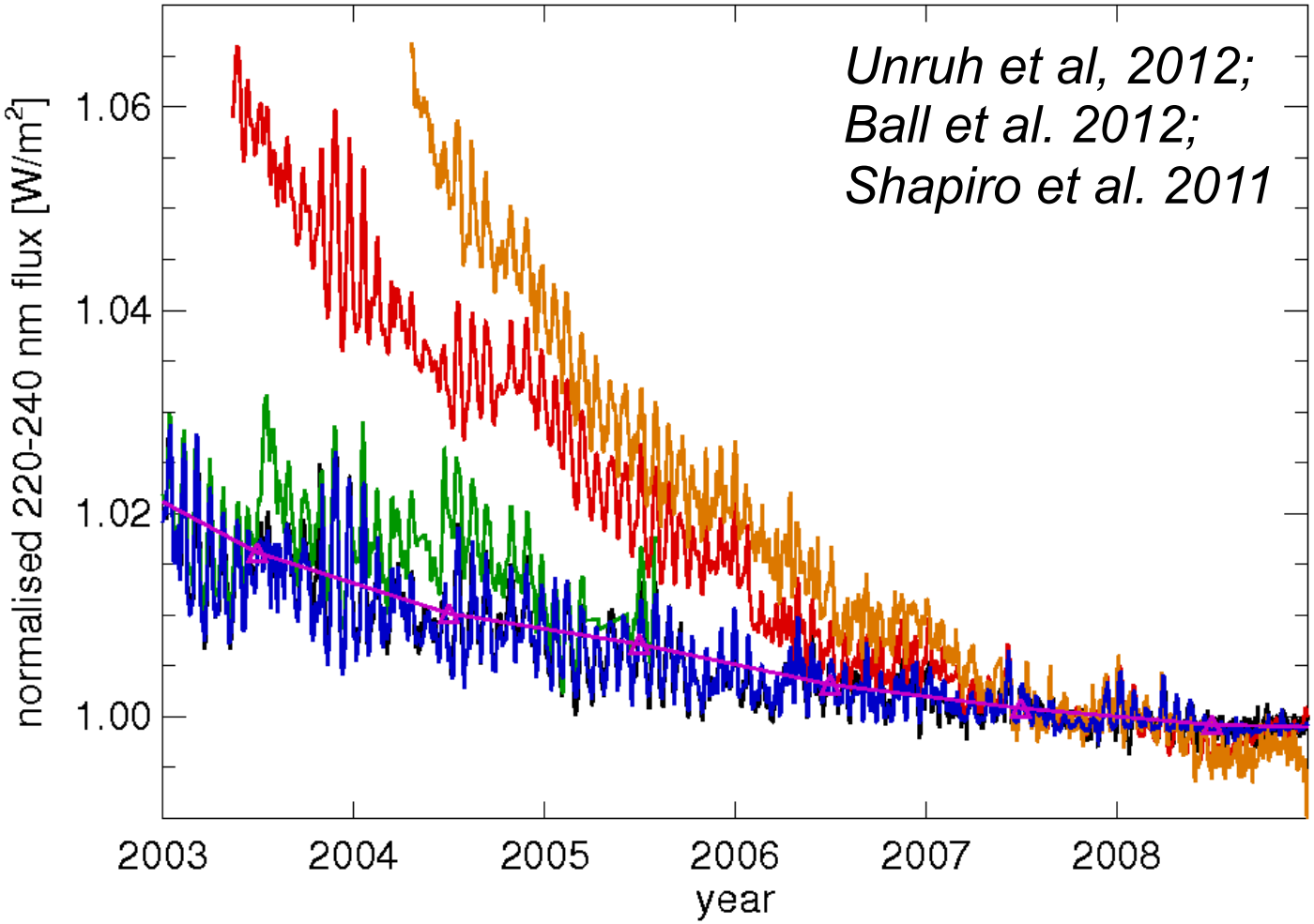
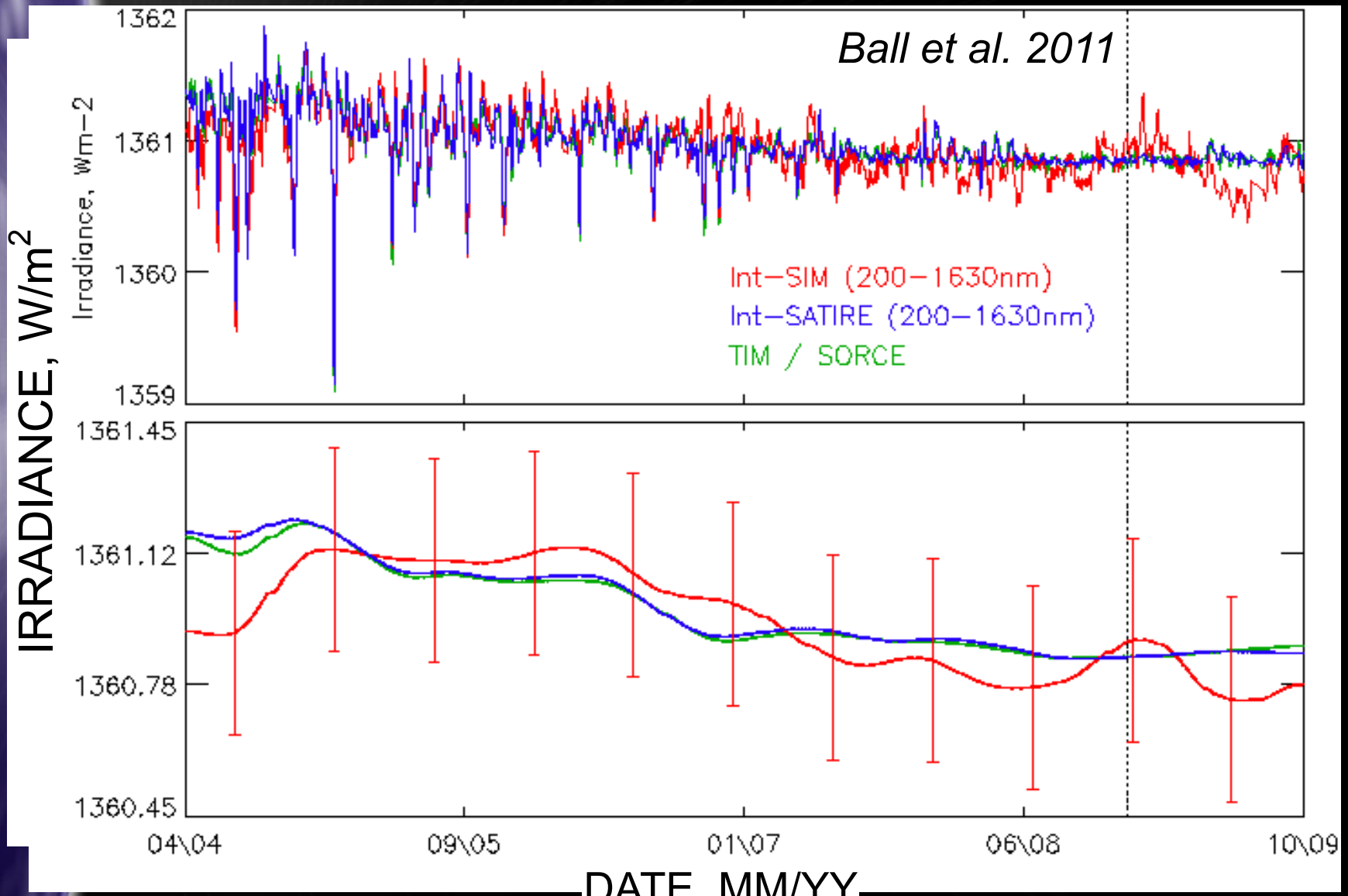


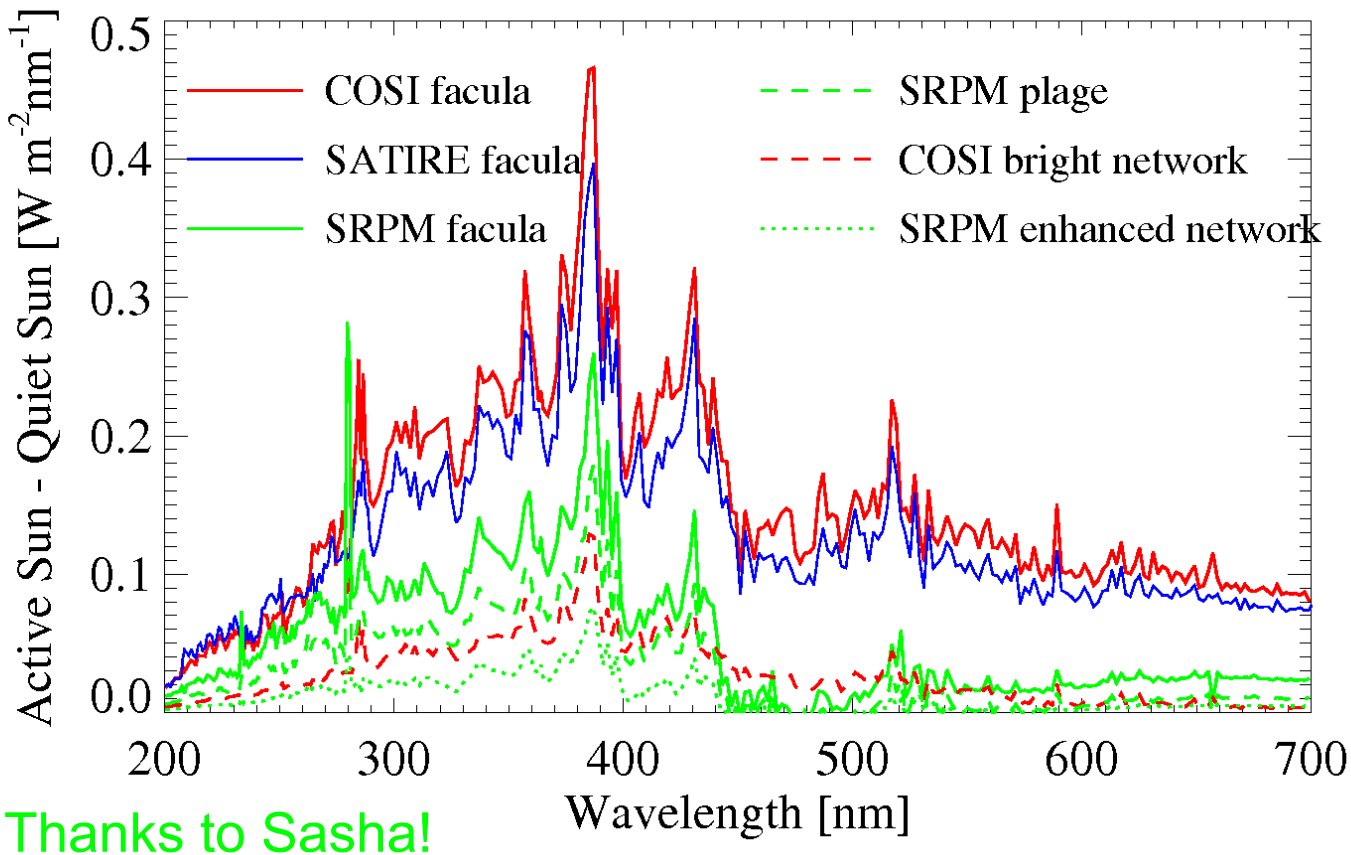
SORCE/SIM VS. SORCE/TIM
SATIRE VS. SORCE/TIM



SEMI-EMPIRICAL ATMOSPHERIC MODELS

How reliable they are?

In principle they can be tuned to match SIM variability qualitatively *(Fontenla et al. 2011 vs. Fontenla et al. 2009)*. But this is still not enough though causes problems with TSI *(SRPM – Fontenla et al. 2011 vs. OAR – Ermolli et al. 2012)*



Thanks to Sasha!

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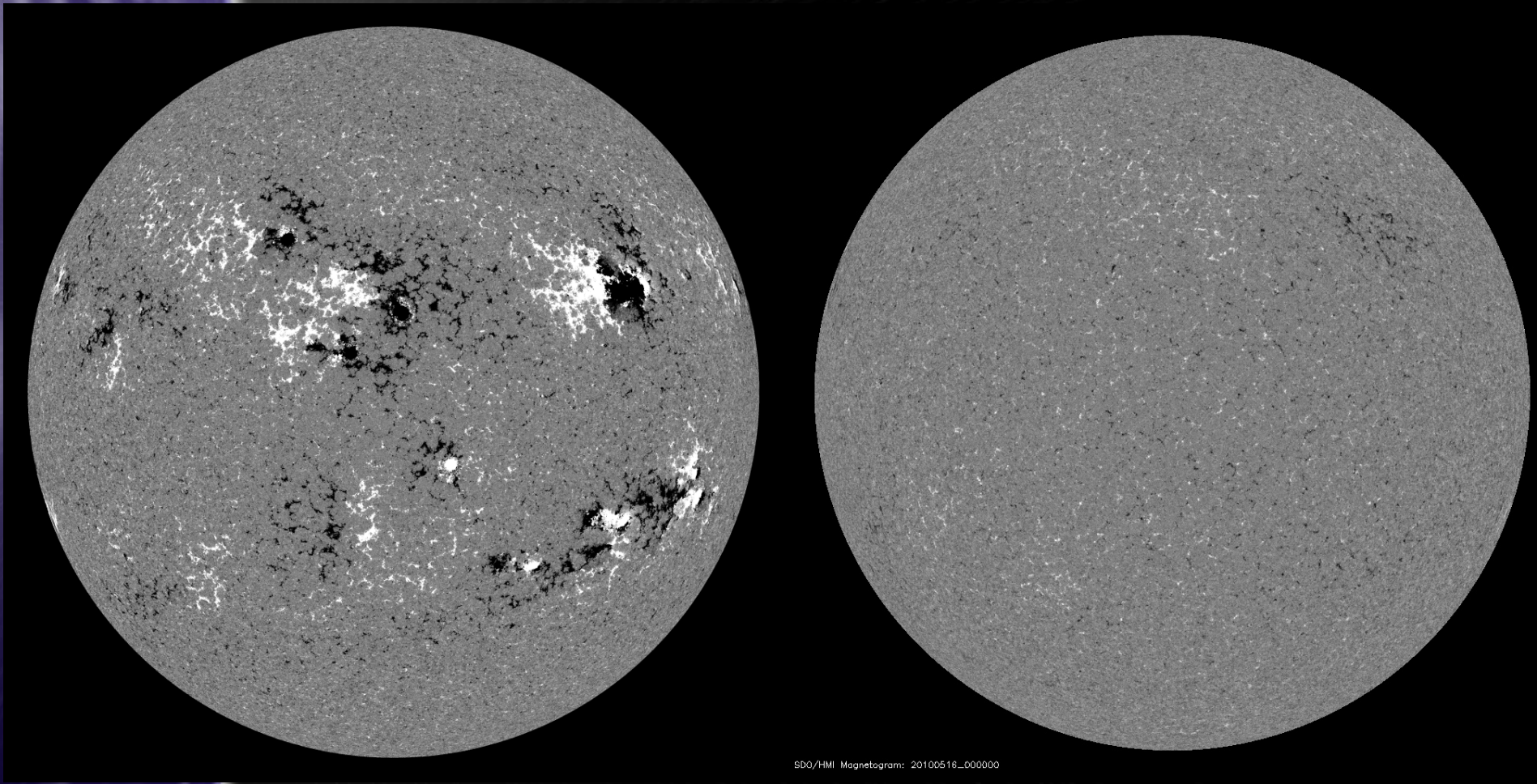
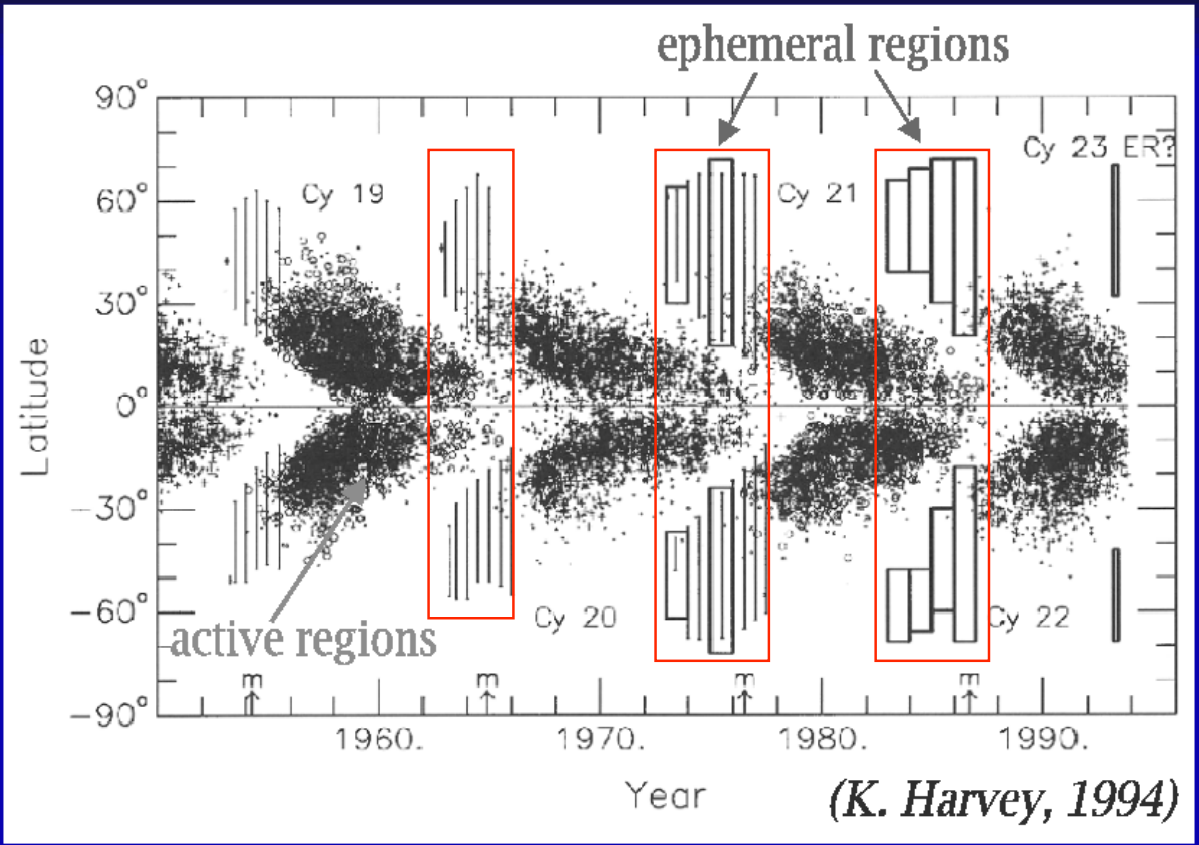
SOLAR MAGNETIC FLUX
Secular change



11.11.11 SDO/HMI 16.05.10

SOLAR MAGNETIC FLUX
Secular change

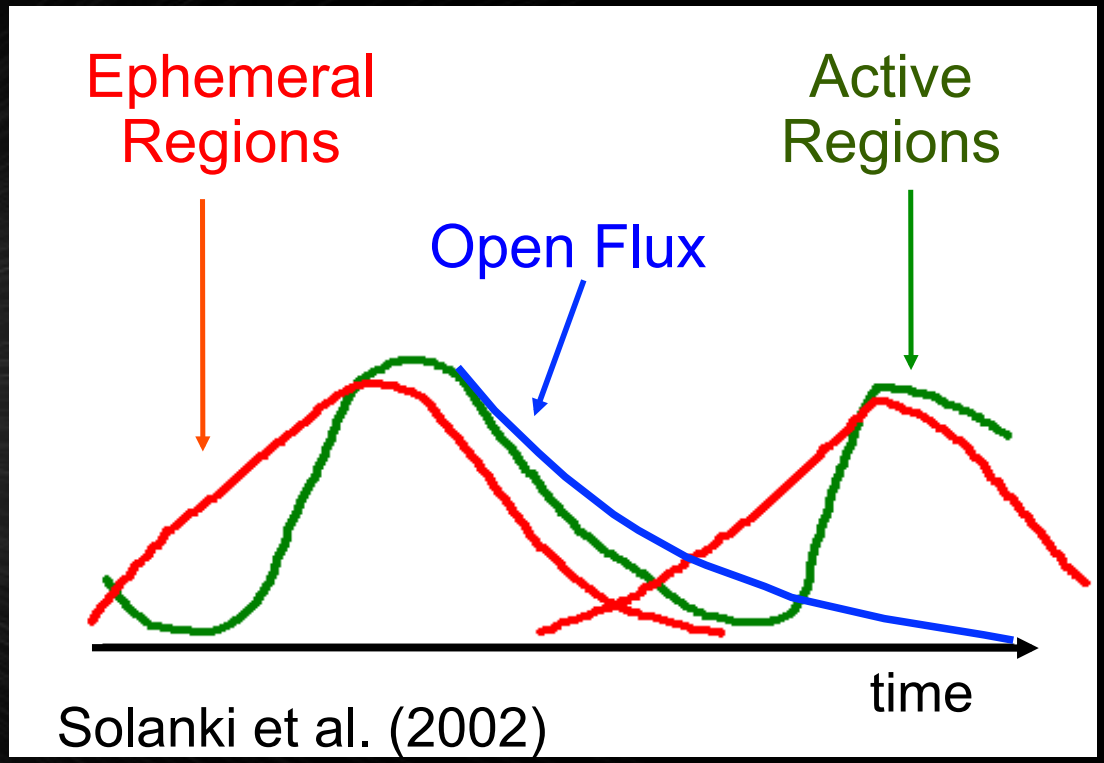
SOLAR CYCLE & EPHEMERAL REGIONS



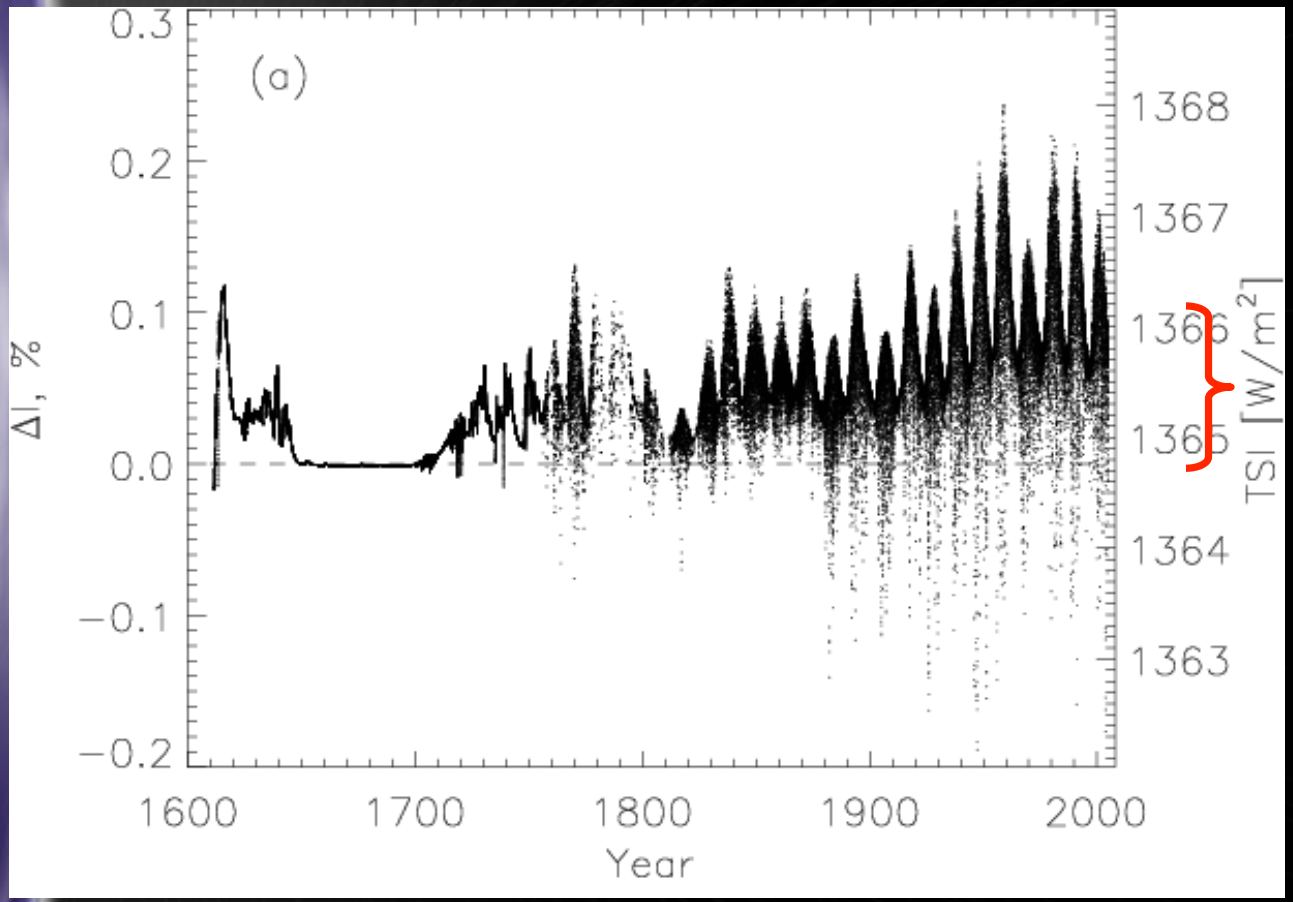
(K. Harvey, 1994)

MODEL OF THE ER MAGNETIC FLUX

- Take sunspot number as a `proxy´
- ER start earlier
- Open flux decays slowly
- More extended cycles



SATIRE-T
(Spectral And Total Irradiance Reconstructions for the Telescope era)



ΔS_{MM}
$\sim 1.25 W/m^2$

Krivova et al. (2007, 2010)

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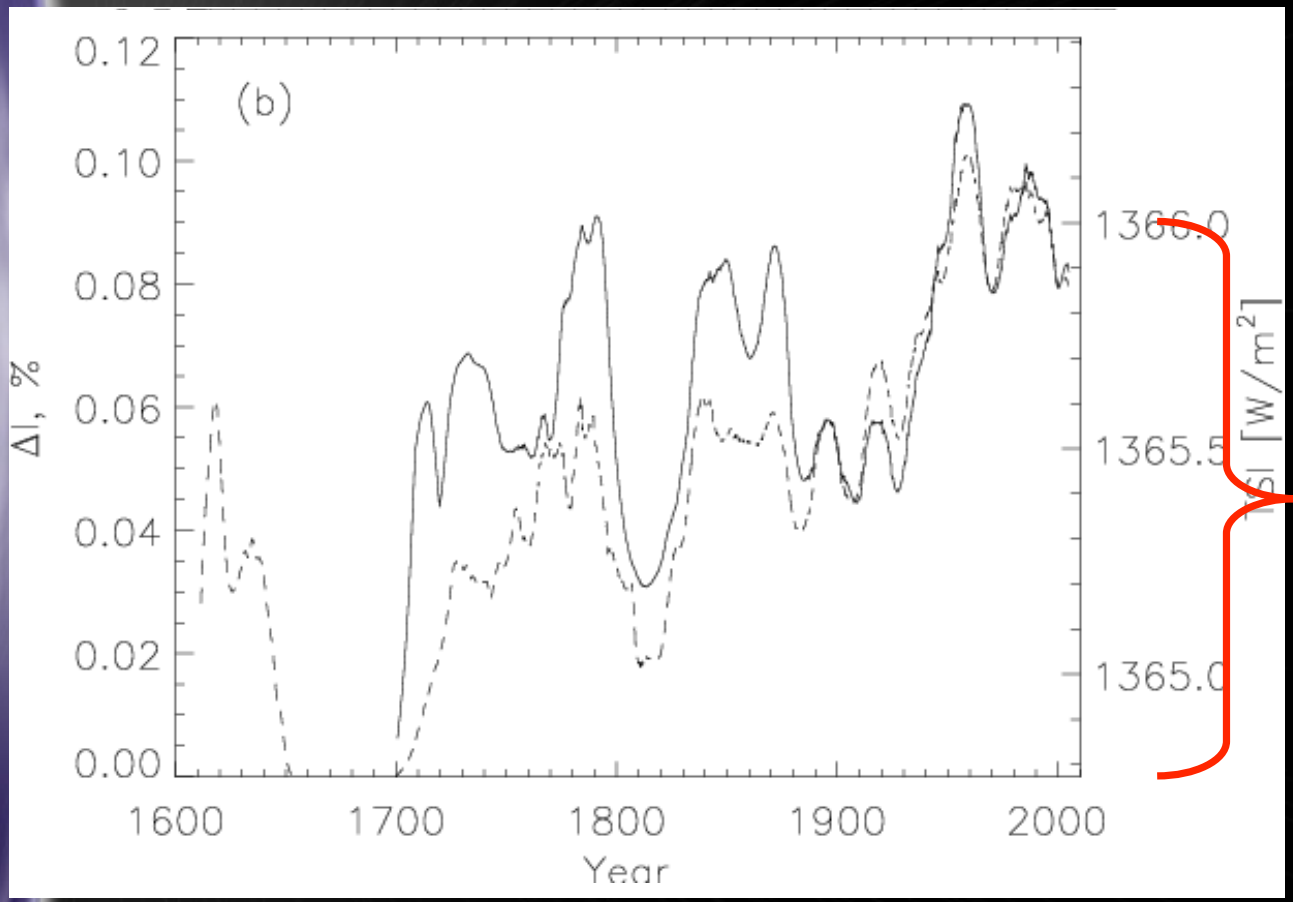

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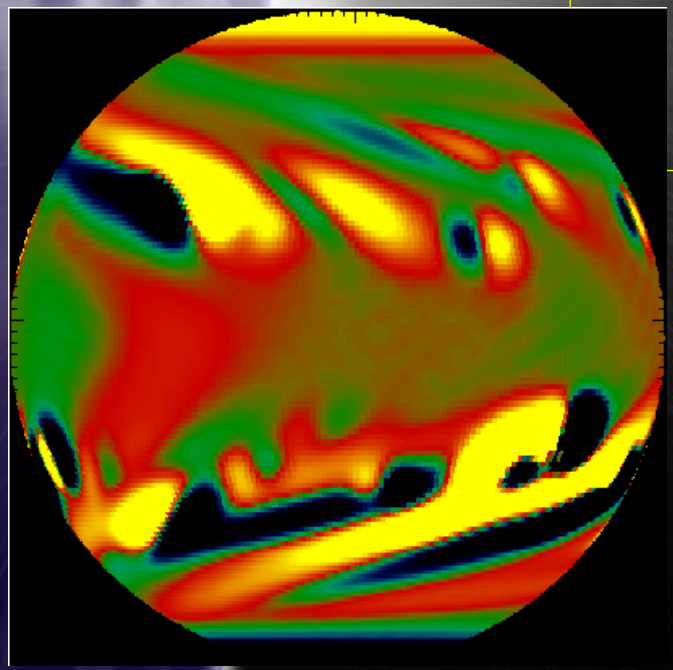
SATIRE-T: A NEW APPROACH

Since 1878

SATIRE-S + Surface Flux Transport:

- Sunspot positions and areas as input to an SFT model *(Jiang et al. 2010)* -> simulated full-disc magnetograms, describing active regions and open flux.
- Simulated magnetograms are used in combination with semi-empirical spectra to calculate TSI and SSI

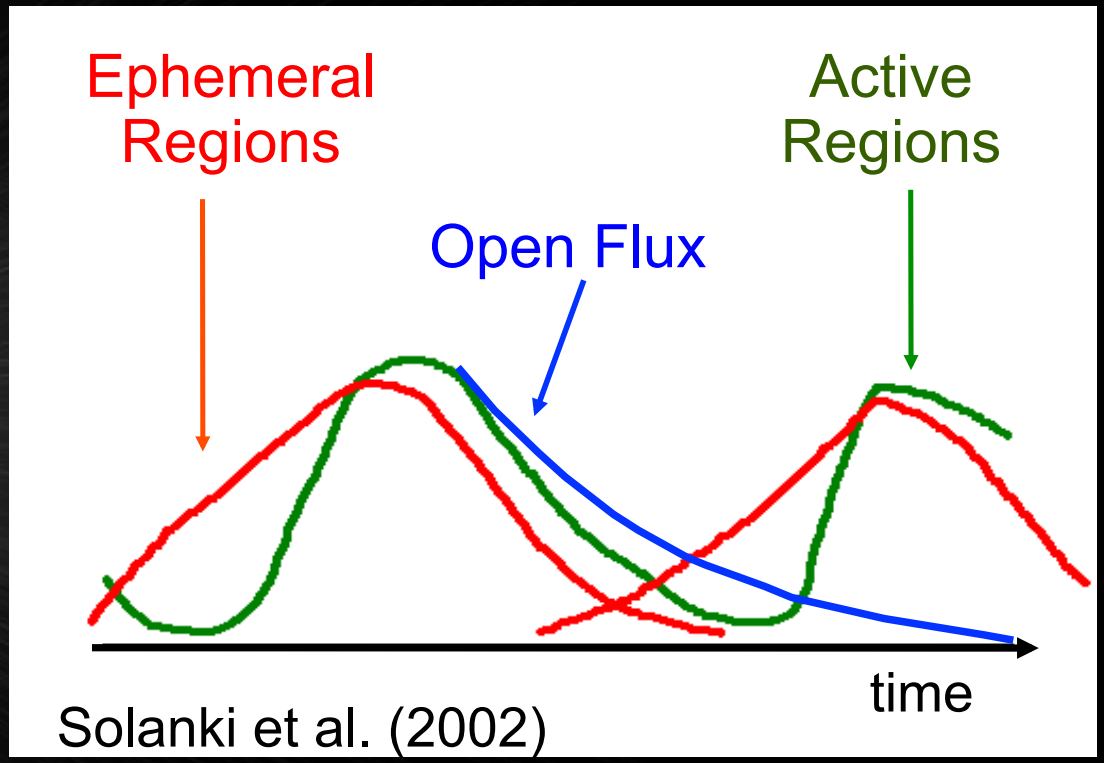


- Spatial resolution of the magnetic features -> improved days to months time scales.
- ER flux is considered separately.

SATIRE-T: A NEW APPROACH

Model of ER magnetic flux

- Active Region flux and Open Flux included in the SFTM
- ER considered separately as in the model of Solanki et al. (2002).



Surface Flux Transport Models

(Wang et al. 2005; Jiang et al. 2011)

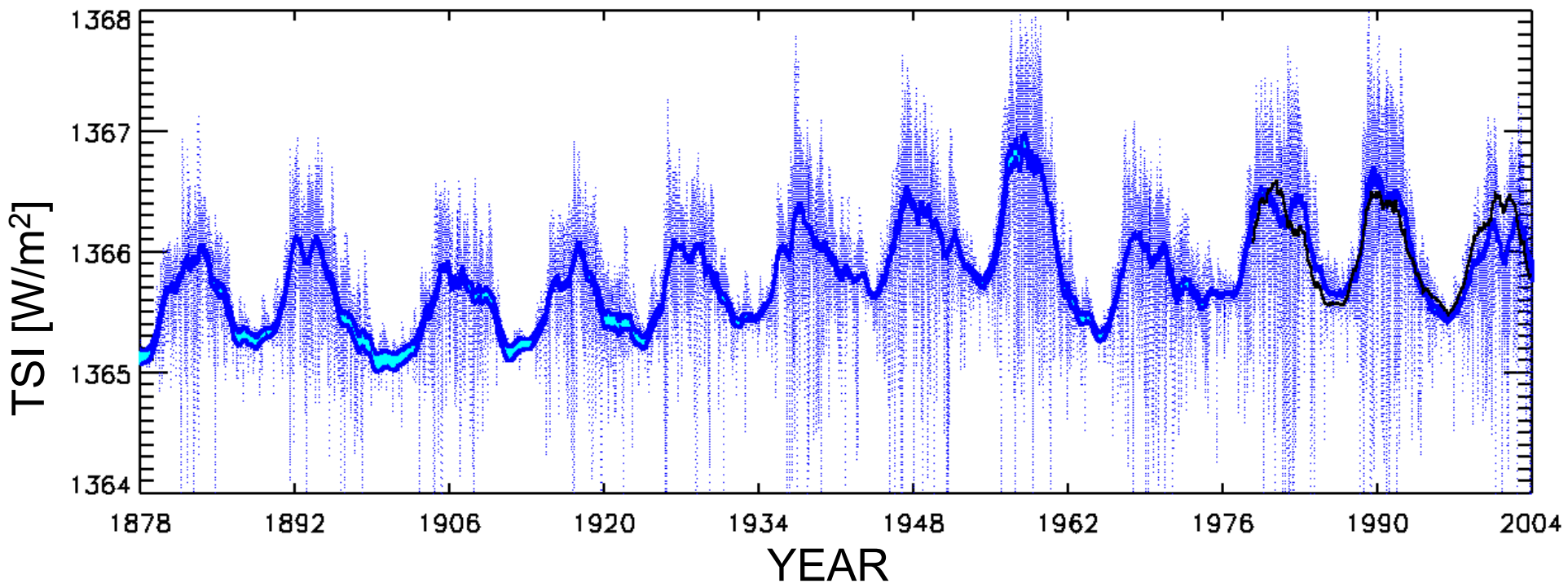
Slow decay of OF: YES

Overlap of ER: NO

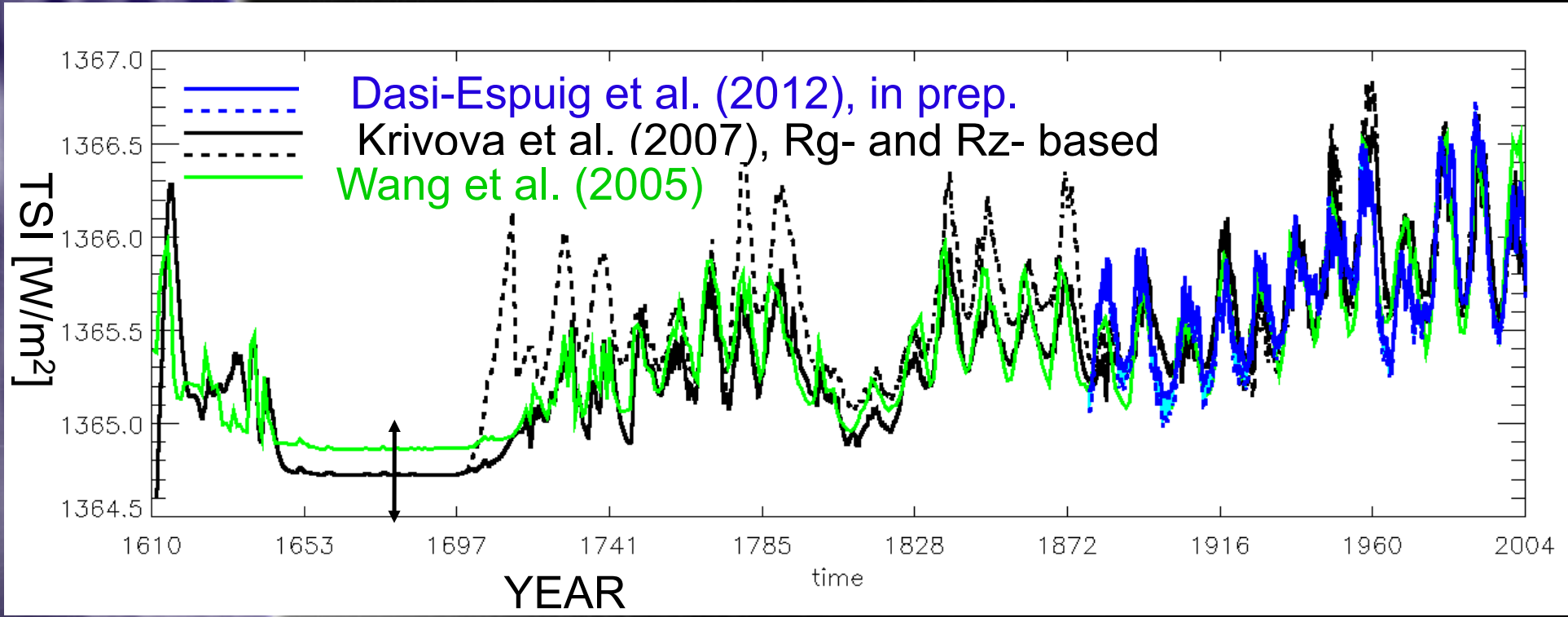
SATIRE-T: SATIRE-S + SFT + ER FLUX

Since 1878

Dasi-Espuig (2012, PhD Th.)
Dasi-Espuig et al. (in prep.)



TSI SINCE THE MAUNDER MINIMUM



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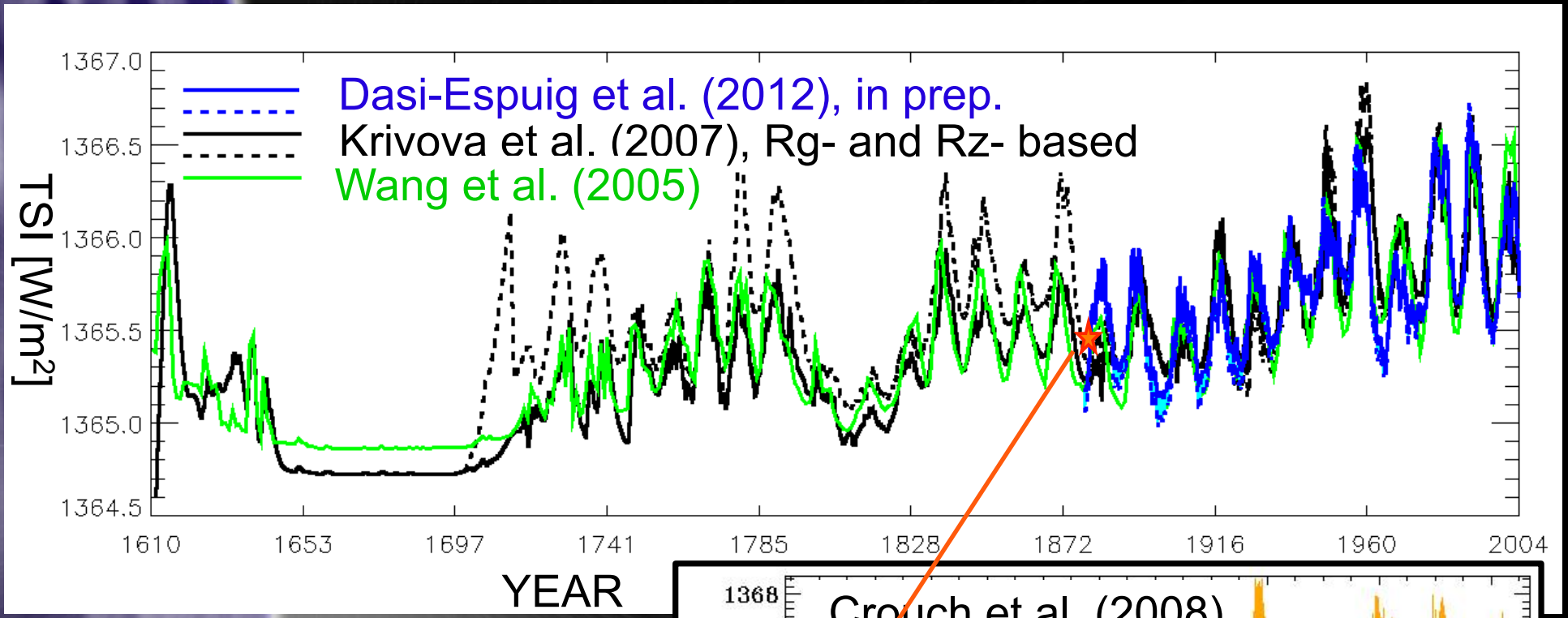

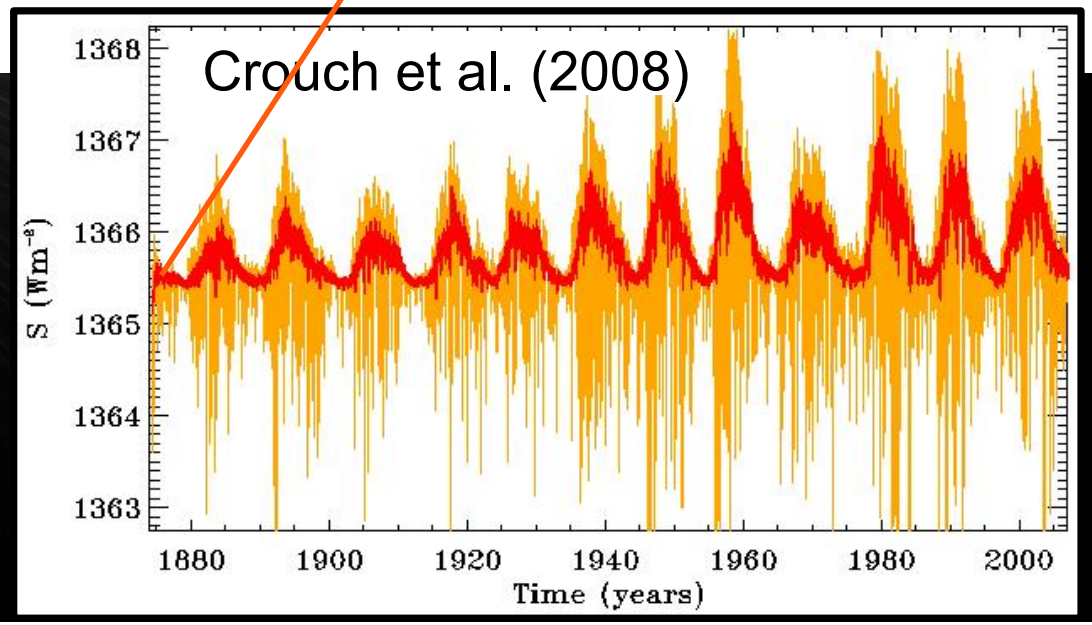

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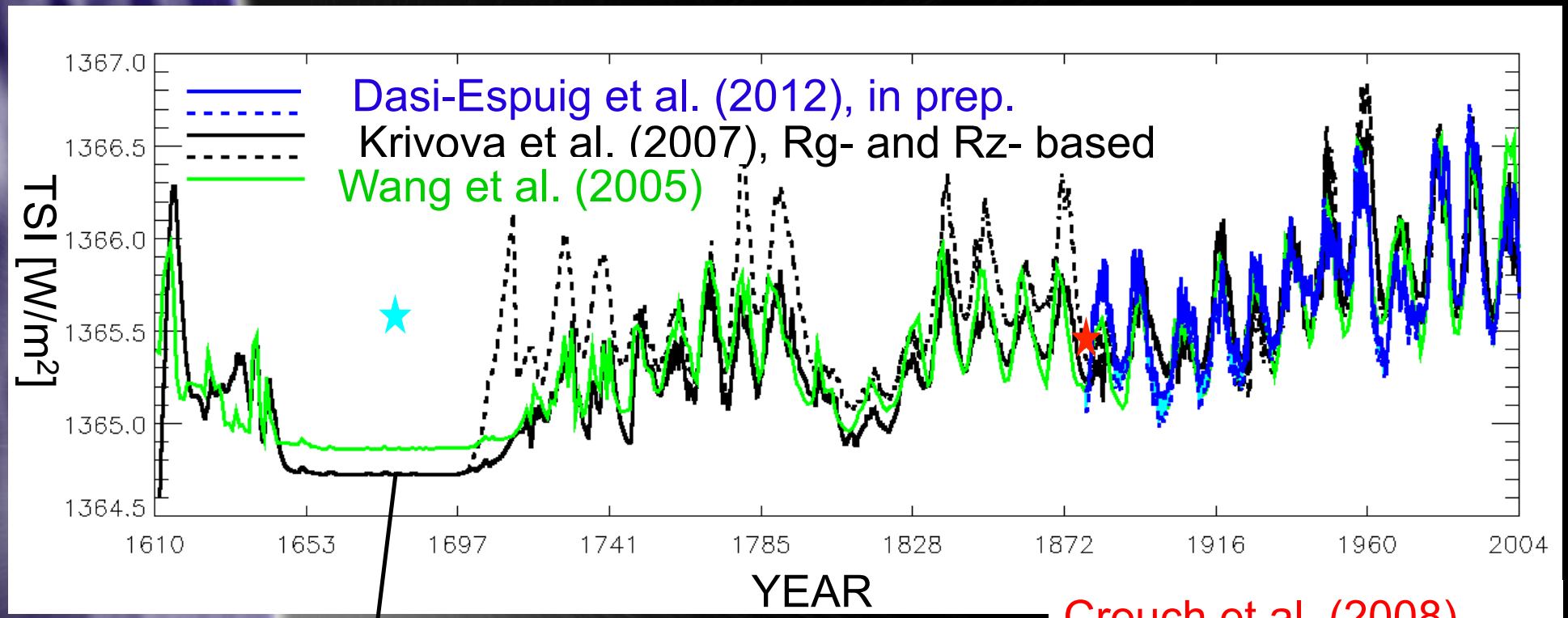
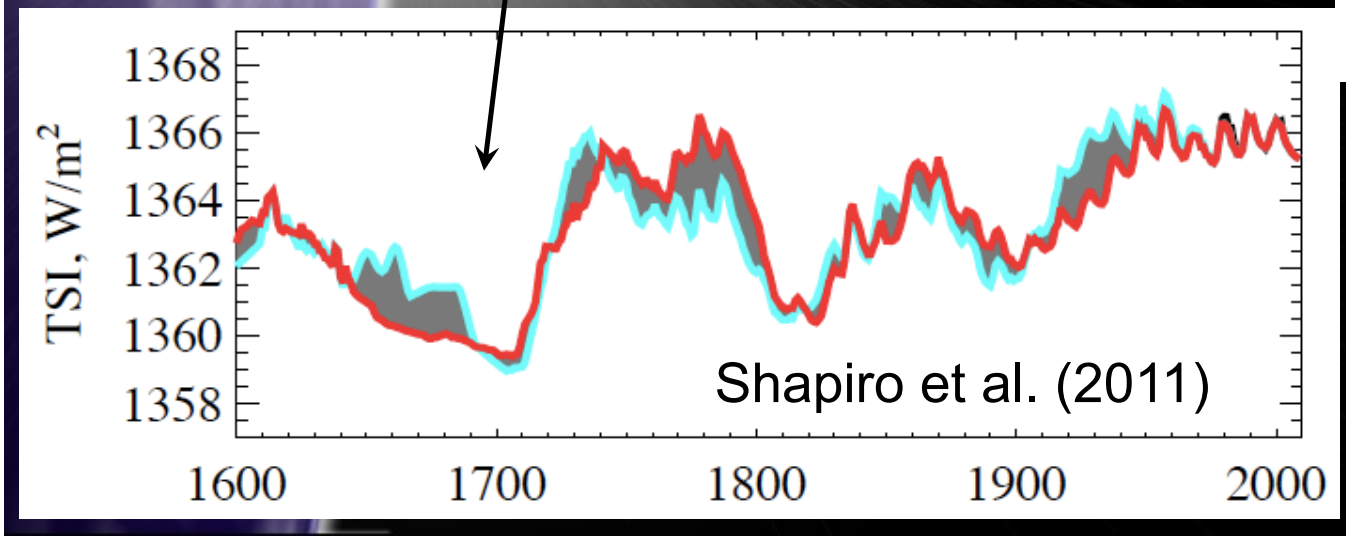


Crouch et al. (2008)
Schrijver et al. (2011)



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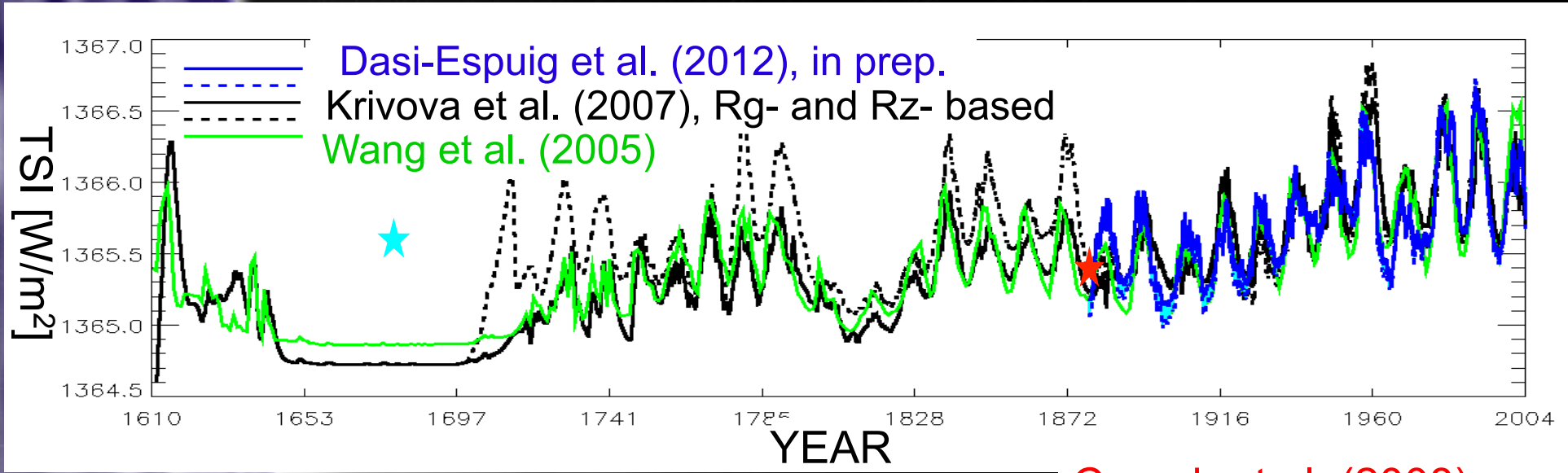

Crouch et al. (2008)
Schrijver et al. (2011)
Shapiro et al. (2011)

Judge et al. (2012)

SUMMARY

- TSI exhibits a slight decrease to essentially no change over the last 3 cycles
- SSI:
  - ✓Good agreement between SATIRE SSI, other models and measurements on rotational time scales *(see also DeLand & Cebula 2012)*
  - ✓Good agreement between SATIRE SSI and UARS measurements on longer time scales
  - ✓There are some quantitative differences between models (e.g., factor of ~2-3 for variability at 250-400 nm
  - ✓Difference between SORCE/SIM results and models is qualitative and is not understood
- Secular change:
  - ✓Most models converge to roughly 0.1% since MM, but unc-ty range remains huge (between 0.2 and 6 [3] W/m^2)