

**How do
Active Region Magnetic Fields
Affect
Solar Irradiance?**

Dora Preminger, Dibyendu Nandi
Piet Martens and Gary Chapman

Objectives

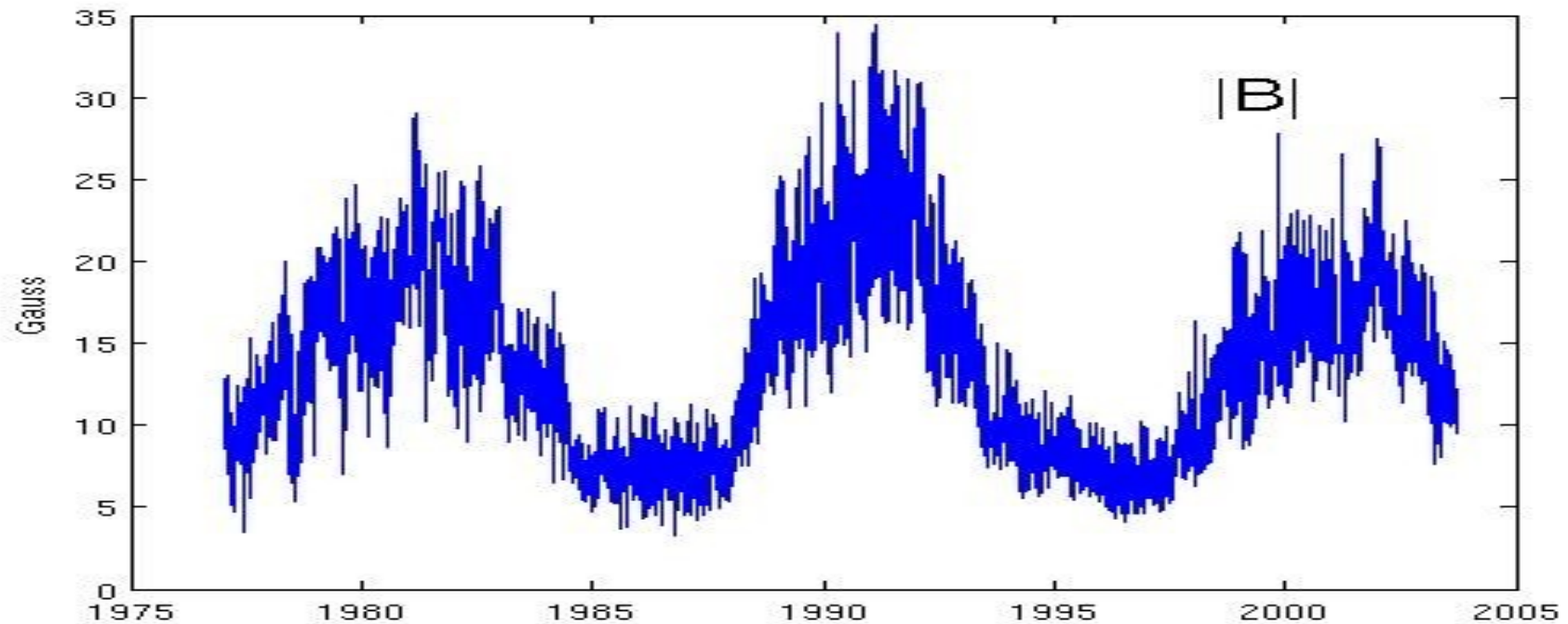
- Compare $|B|$, the full-disk average magnetic flux from Kitt Peak, with the disk-integrated spectral irradiance at different wavelengths.
- Quantify the relationship
- Analyze its temporal nature.
- Provide constraints for physics-based models of energy transfer in active regions?

Data

- Daily, disk-integrated solar data measuring the variability of:
 - 1) Magnetic flux
 - 2) Total Irradiance, TSI
 - 3) Spectral Irradiance, SSI
 - (a) Continuum radiation from bottom of Photosphere
 - (b) Spectral lines from Photosphere, Chromosphere and Transition region
 - (c) Spectral lines from Corona

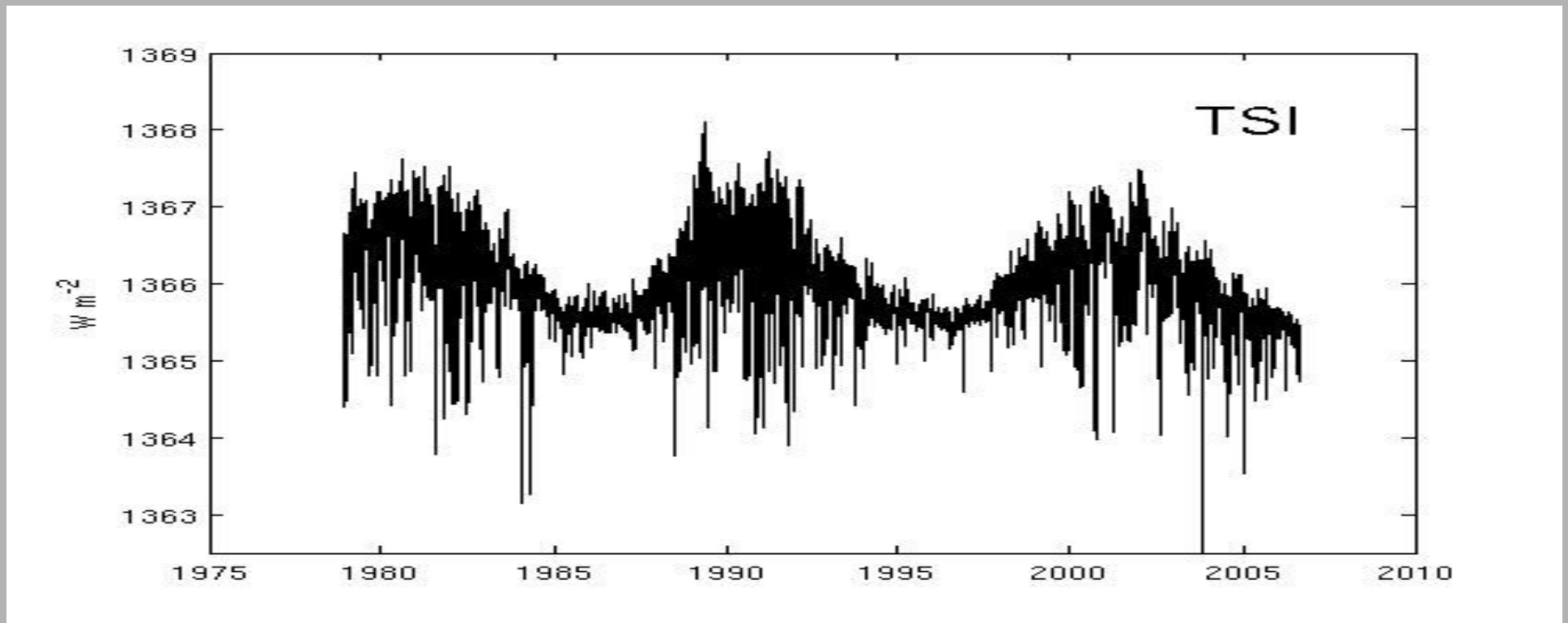
Magnetic Field data

- $|B|$: Average unsigned magnetic flux from Kitt Peak, in Gauss. The absolute value of the line-of-sight magnetic field strength observed with 1 arcsec pixel size, averaged over the full disk. Data is best with spectromagnetograph installed, 1992 - 2003



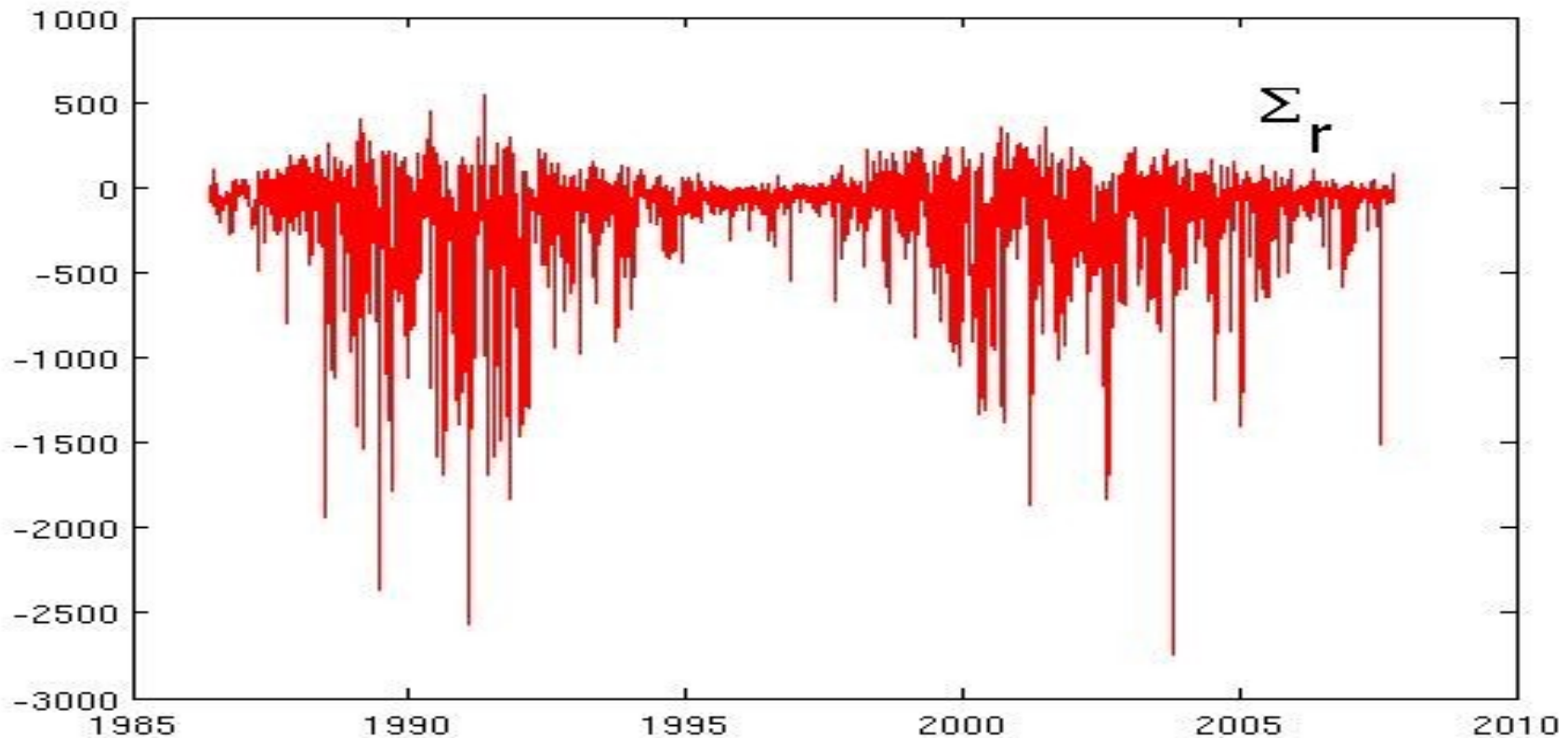
Total Solar Irradiance data

- TSI : Composite total solar irradiance at 1 AU, in Wm^{-2} , compiled from spacecraft measurements by Frohlich and Lean (1998, 2004)



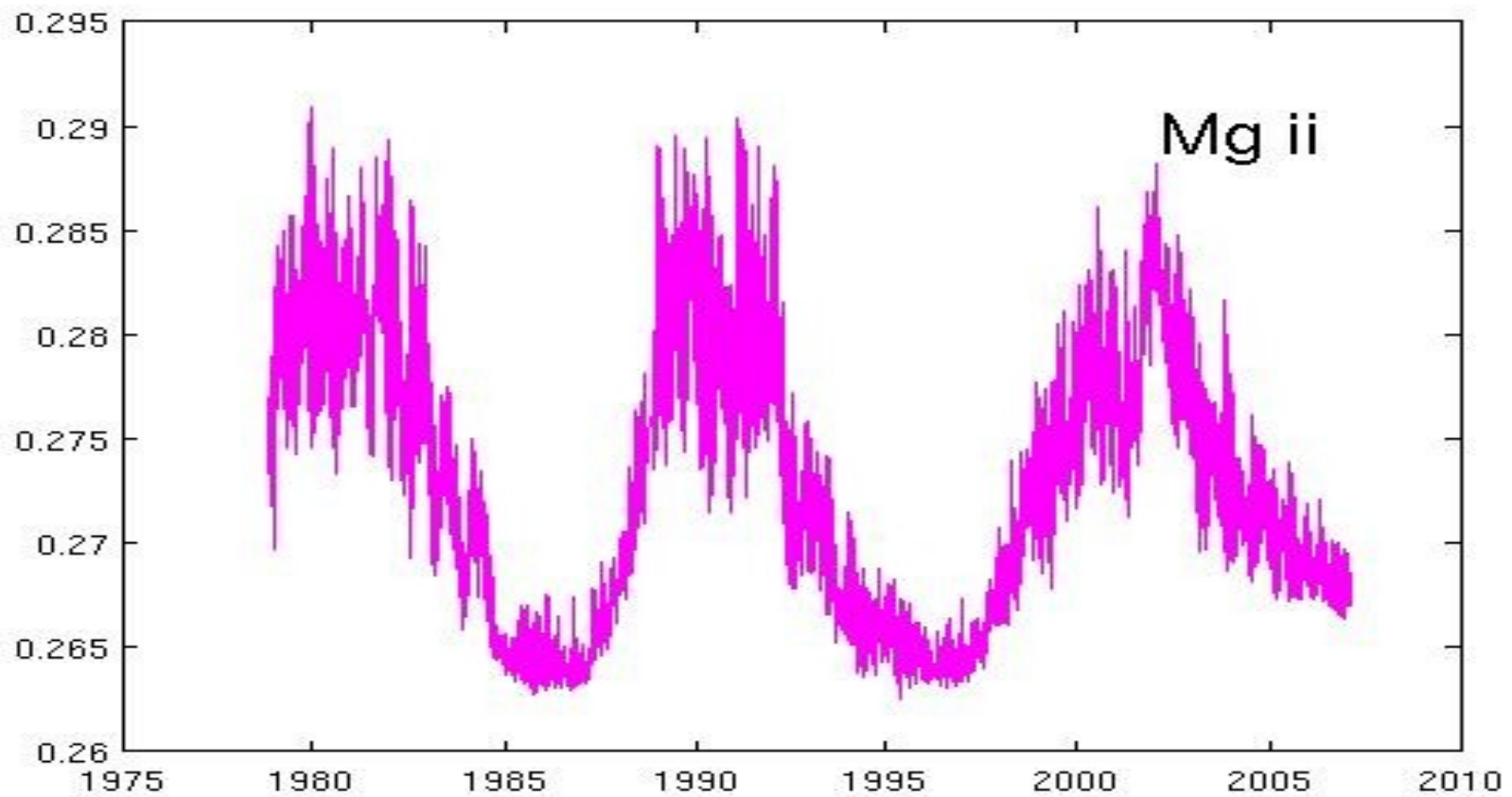
Variability of Continuum Radiation from Photosphere

- Σ_r : Relative change in the intensity measured on broadband red images from SFO, includes dark and bright features
- Remarkably flat over the solar cycle (maybe even anticorrelated)



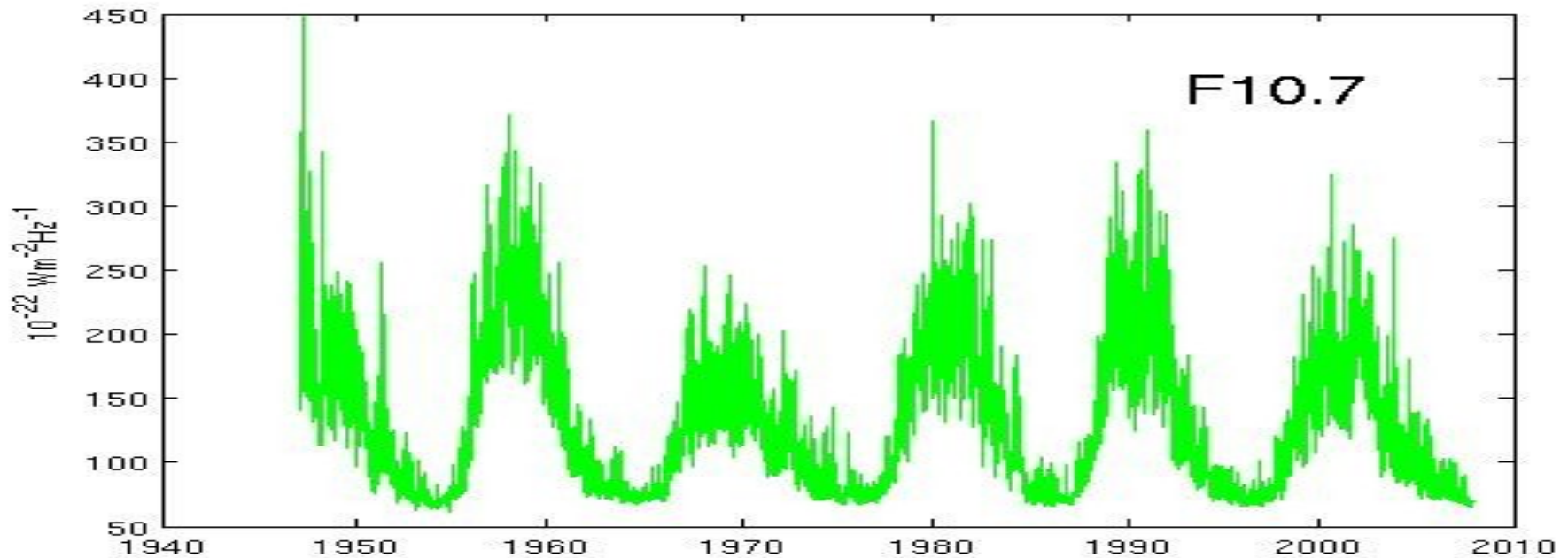
Spectral line radiation from Chromosphere and Transition Region

- Daily data : CaK, Mgii, He1083, Ly α , UV200
- Example: mg ii c/w ratio:



Spectral Line Radiation from Corona

- Fe XIV green line : Coronal Index
- X-ray flux from SXT (0.8 - 2nm)
- F10.7 cm flux (corona and chromosphere)
- example: F10.7



Method

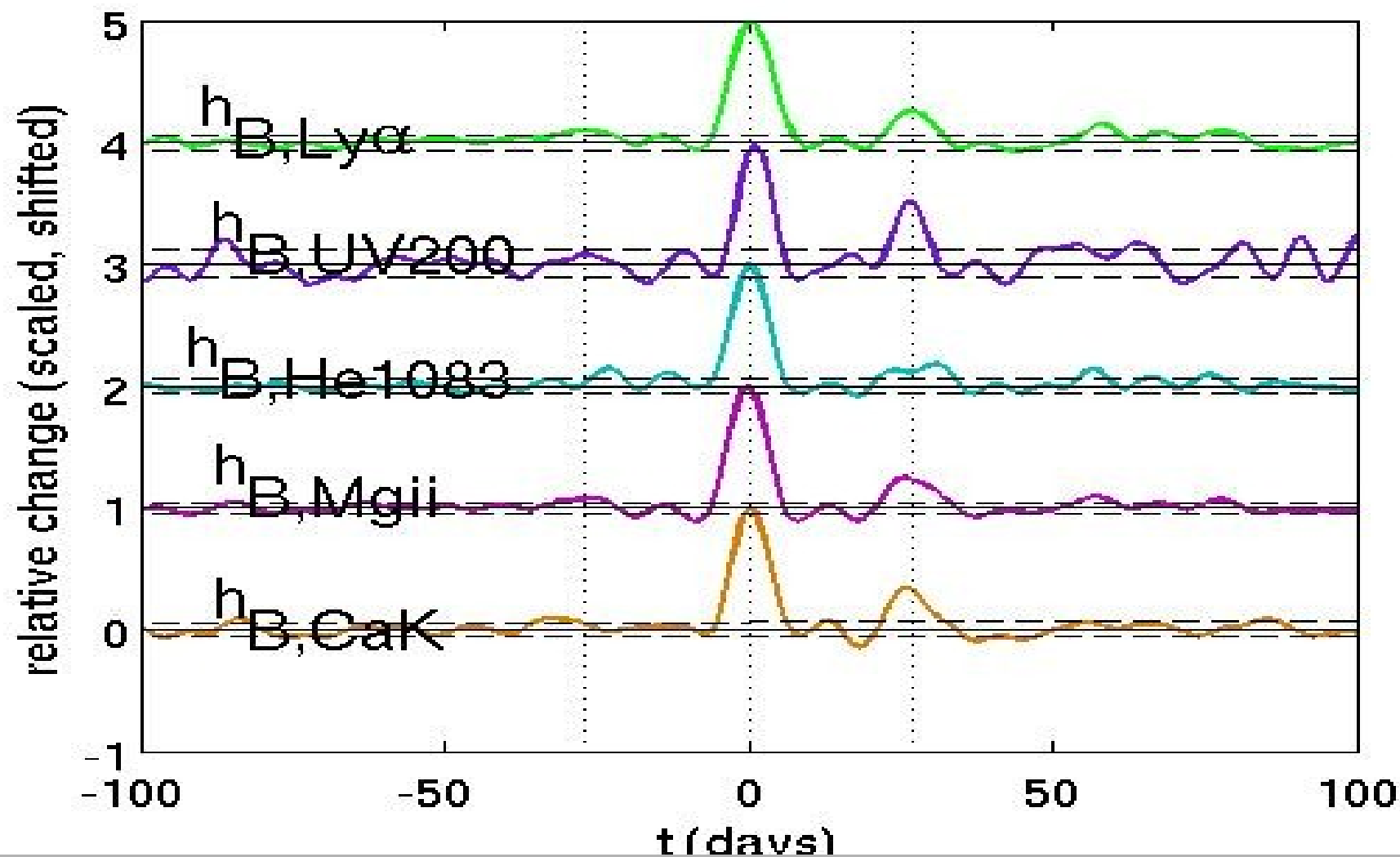
- Assume sun is a linear time-invariant system, Quiet Sun is the equilibrium state.
- Change in $|B|$ is the input to the system
i.e. the emergence of active region magnetic flux is an event that affects the equilibrium of the system
- The change in irradiance $X(t)$, from its quiet sun value, is the output of the system
- $X(t) - X_{QS} = (B(t) - B_{QS}) * h_{B,X}(t)$ * Denotes convolution
- $h_{B,X}(t)$ is the impulse response function that characterizes the system: it is the output caused by a brief input signal at $t=0$, a B “event”. Evaluate $h(t)$ with Fourier methods

Results

- The impulse response functions, $h_{B,X}(t)$
 - Contain information about how a B event affects X
 - Can be used to reconstruct $X(t)$, for any $B(t)$
 - Are a statistical average, strongly weighted by large active regions with strong magnetic flux
 - Are a little hard to interpret because $|B|$ is influenced by dark and bright active regions and is not impulsive by nature

Response of chromospheric line radiation to a B event

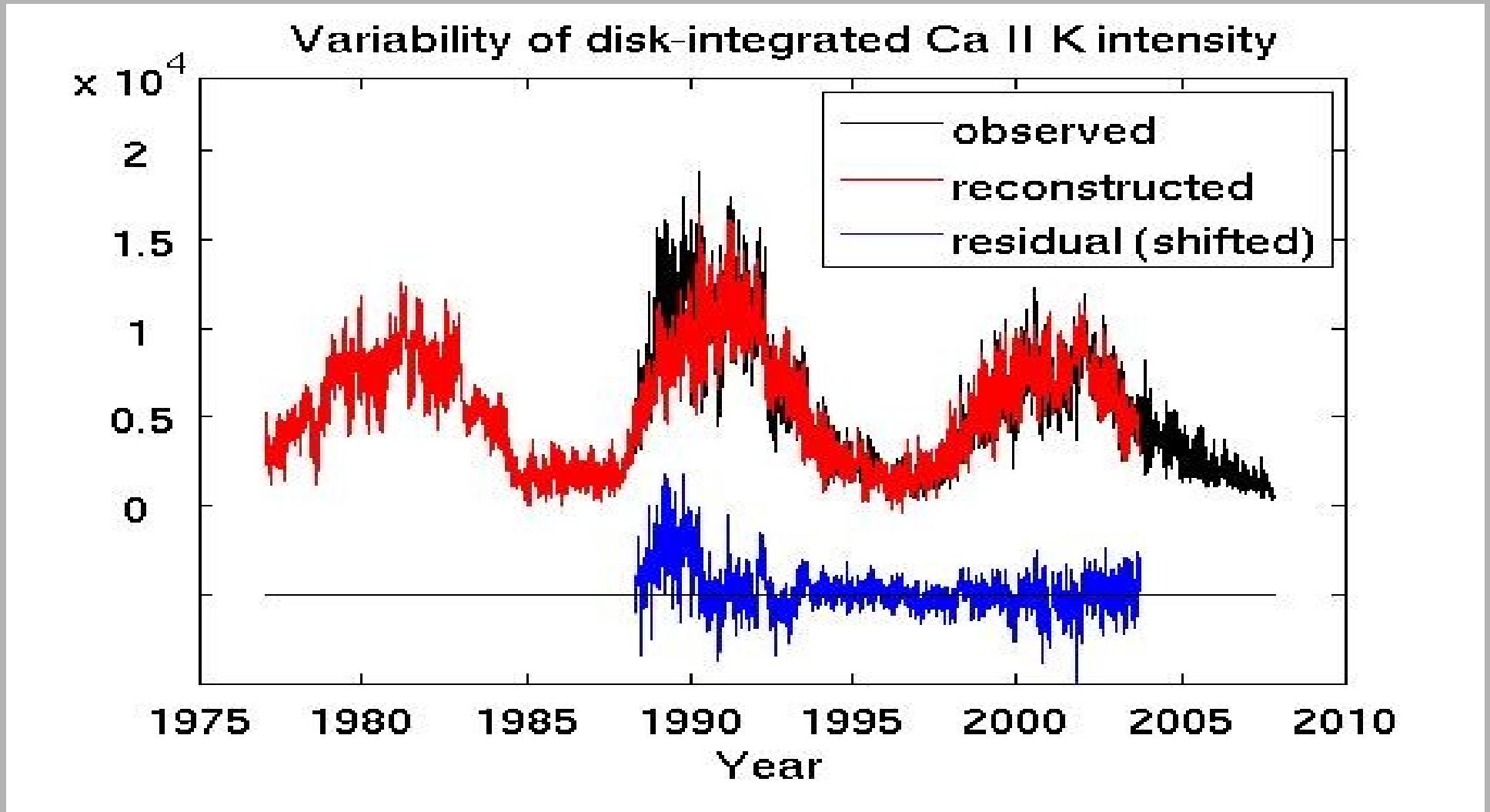
- strong peaks are caused by rotational modulation of spatially concentrated active regions



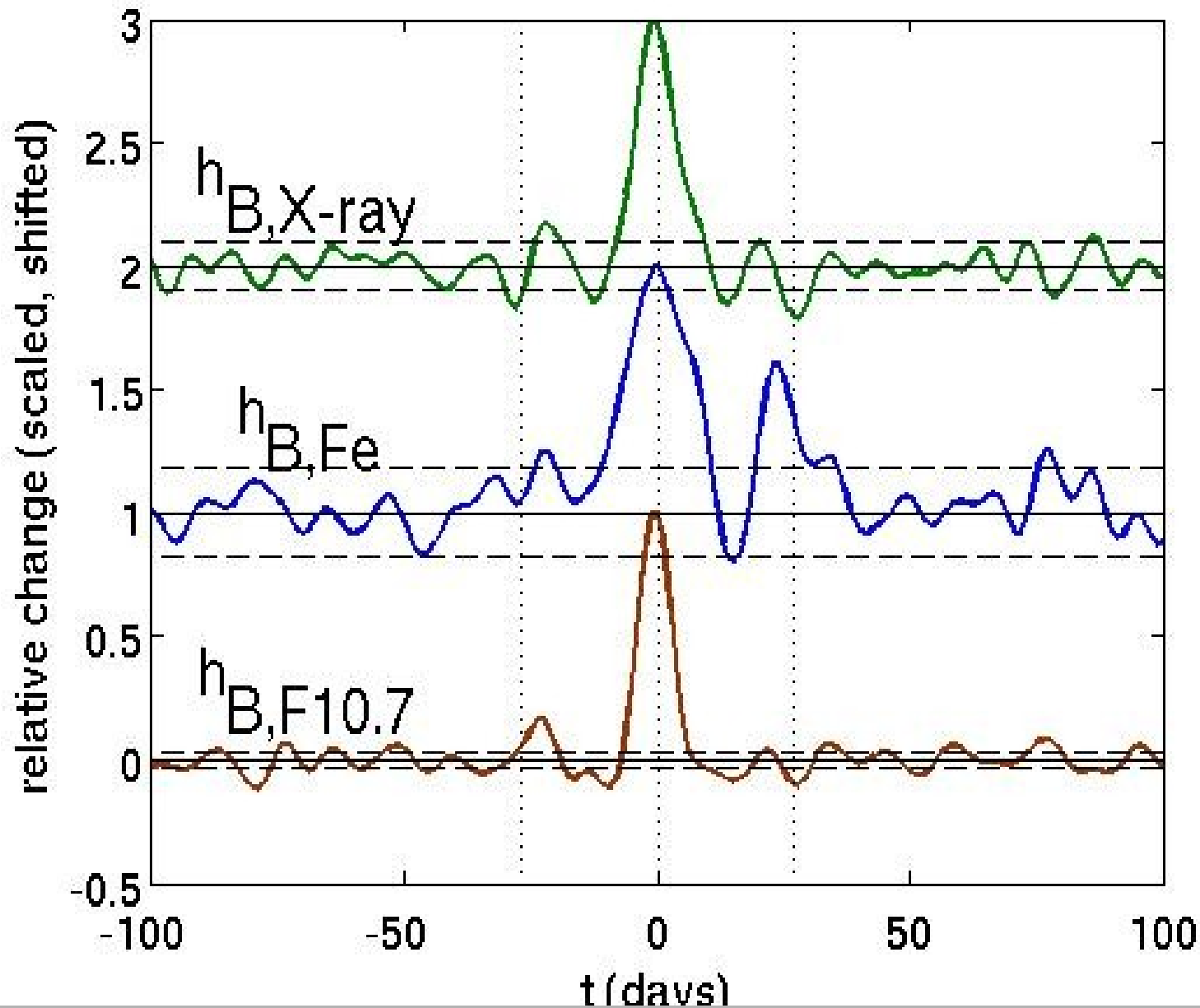
Note: the $h(t)$ have been smoothed slightly

Reconstructions of Chromospheric indices

- Reconstructions using the portion of $h(t)$ near $t=0$ account for $\sim 86\%$ of the variability



Response of coronal line radiation to a B event



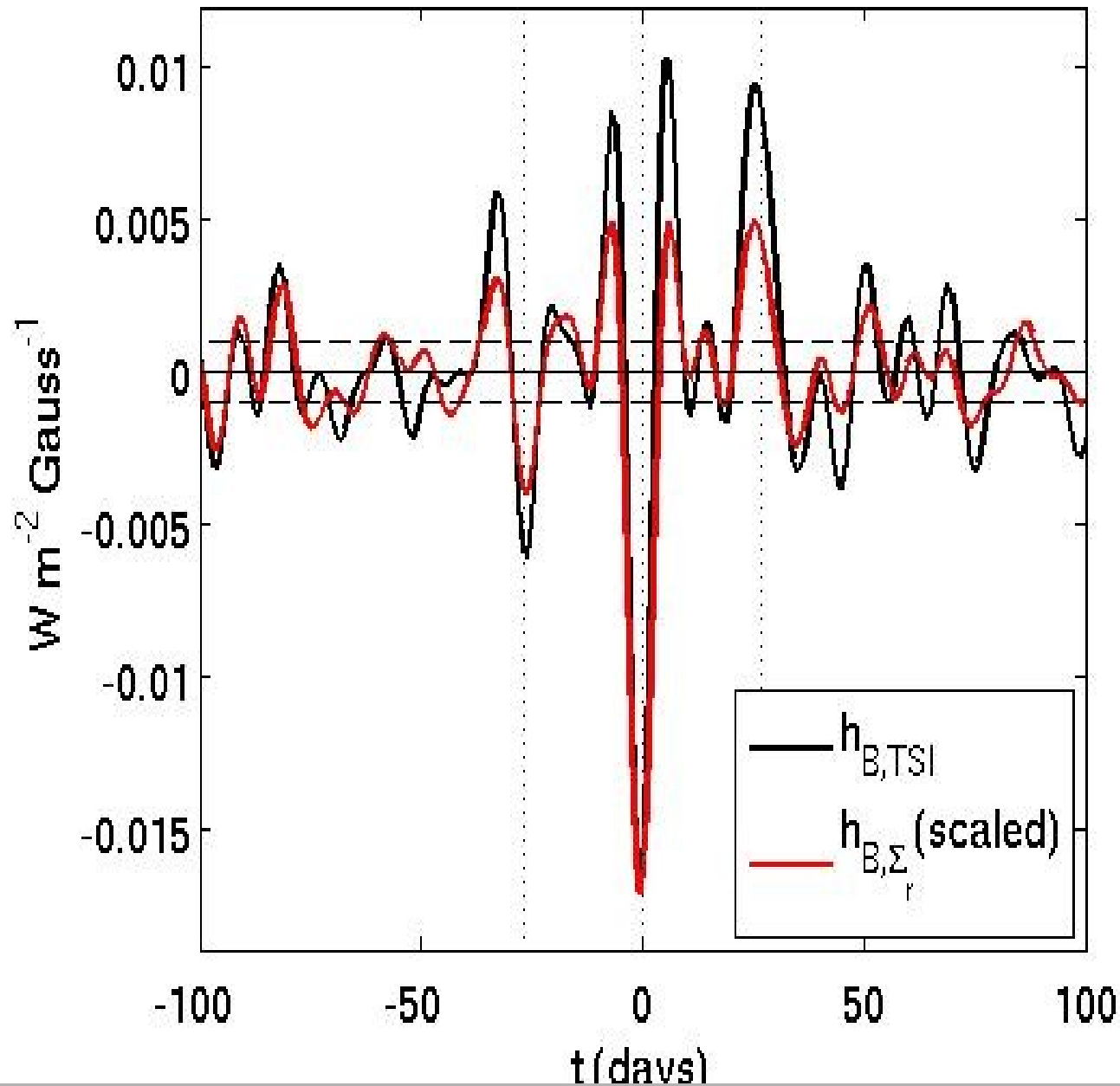
**% variability
accounted for
by the model**

84%

73%

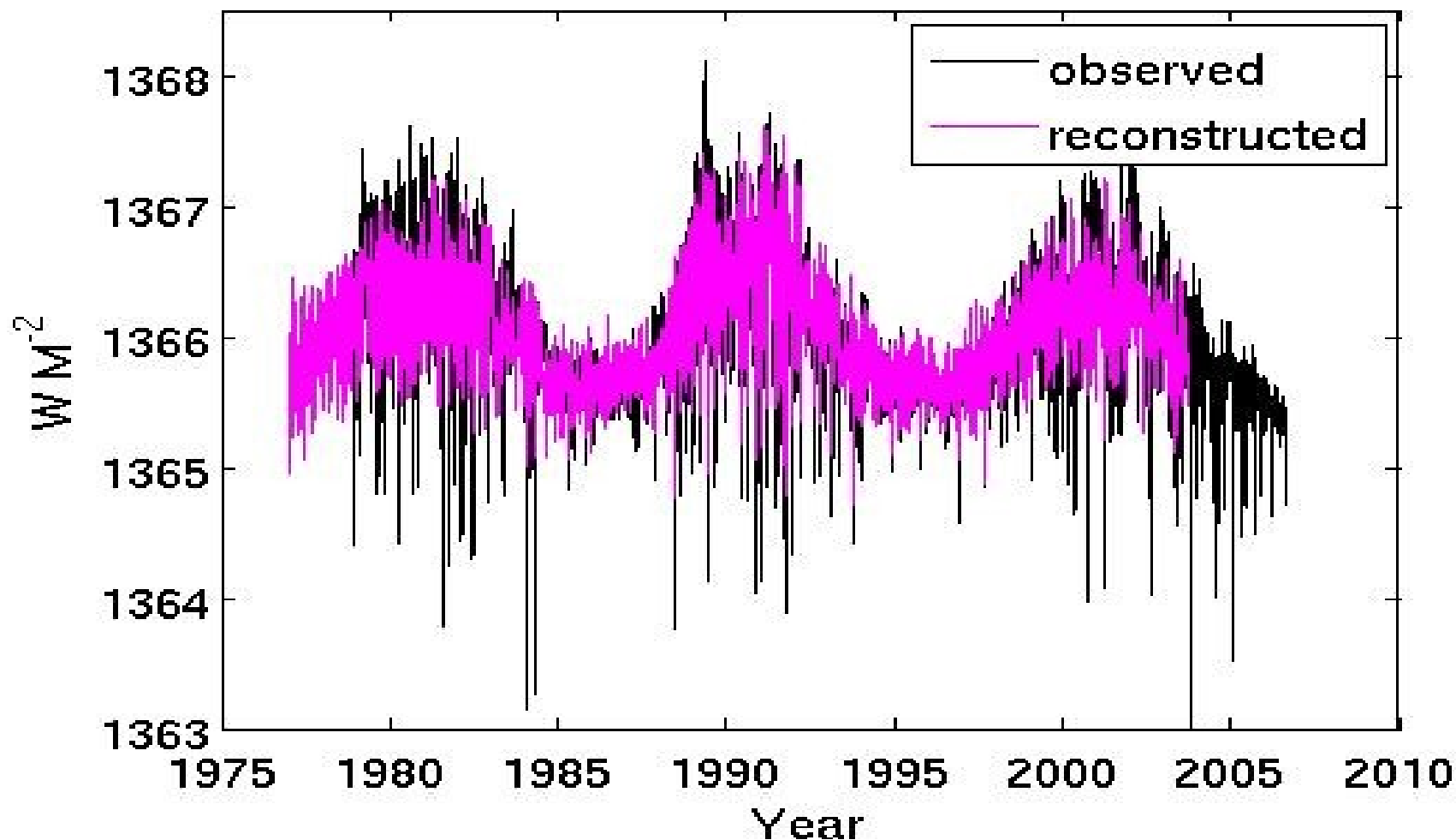
85%

Response of TSI and red Continuum radiation to a B event



- Dip at $t=0$: strong flux blocks continuum radiation and therefore reduces TSI
- Peak at $t=27$ days: no more strong flux, active region is bright
- Dip at $t=-27$ days: active region detected in TSI and continuum image before affecting $|B|$ noticeably??

Reconstruction of TSI



Reconstruction - not so good:

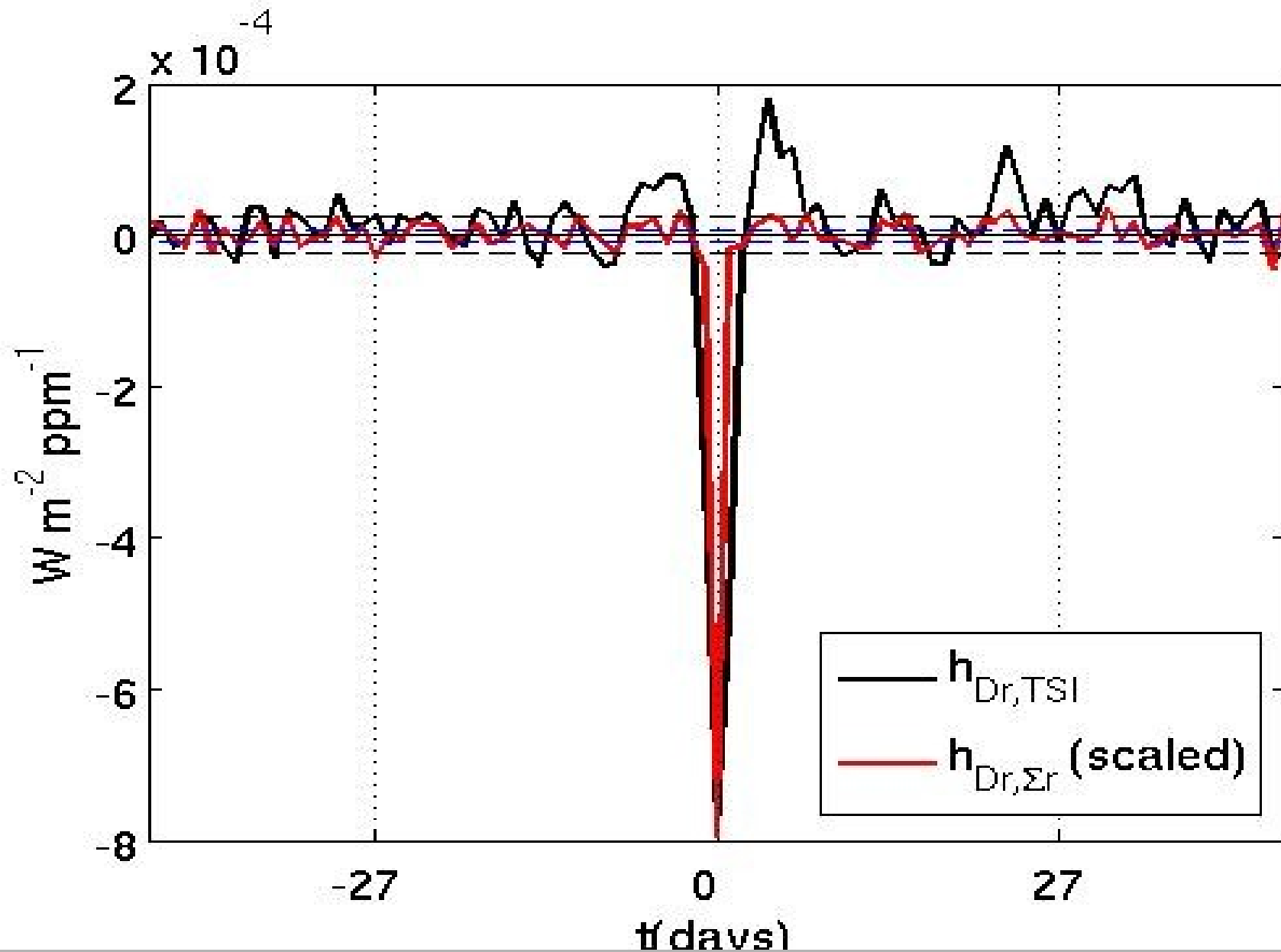
$R^2 = 0.57$ (using all h)

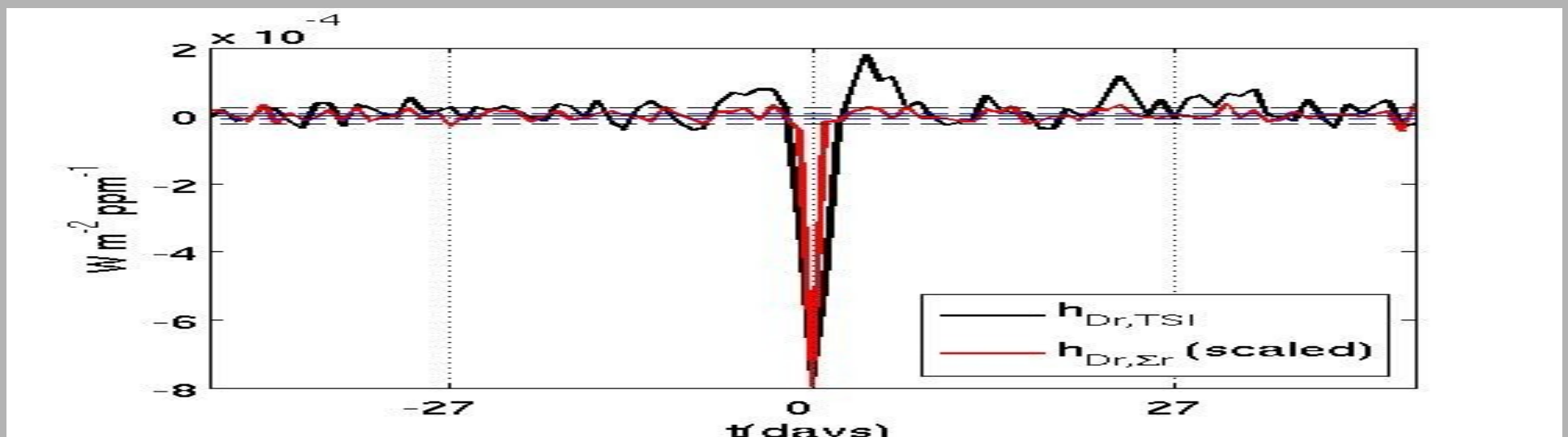
$R^2 = 0.45$ (using portion near $t=0$)

Reality check

- $h_{B,X}(t)$ does not reproduce the extreme dips in TSI and Red Continuum radiation
- Therefore, do not analyze it too much!
- Better model would use sunspot magnetic flux as the input signal
- Proxy: Sunspot Deficit, D_r
- Use D_r to model TSI and Red Continuum radiation – check results

Response of TSI and red Continuum radiation to Dr (no smoothing)





Energy Changes (J m^{-2} per ppm)

	Very short-term	Short-term	Long-term
	$\int h(t)$ [rotation 0]	$\int h(t)$ [rot 0,1,2]	$\int h(t)$ [all t]

TSI	-70 ± 10	70 ± 10	220 ± 10
Continuum	-63 ± 10	-60 ± 10	-50 ± 10

- Total Energy blocked by active region's sunspot is released within 2 solar rotations

Discussion

- Response to emergence of strong magnetic flux (sunspot)
 - $\int h(t)$ [for all t] is slightly negative for continuum radiation output, but is positive for TSI and for all spectral line output
 - The overall result of the event is a net increase in the total amount of radiation emitted
 - Therefore, magnetic field does not inhibit energy output (except over very short timescales)
 - Rather, magnetic field enhances emission of energy (cf. Parker 1974)
 - Contradicts the idea of sunspots as simple thermal plugs

Discussion of Energy Balance

- Response to the emergence of strong magnetic flux (sunspot)
 - During the event:
 - TSI, Continuum radiation: blocked
 - Line radiation: enhanced
 - Shortly after the event:
 - Energy output enhanced (all)
 - An amount of energy equal to the blocked energy is released within two solar rotations of the emergence of the sunspot
 - Over the long-term:
 - More energy is emitted than blocked
 - Question: Where did the energy come from?

THE END