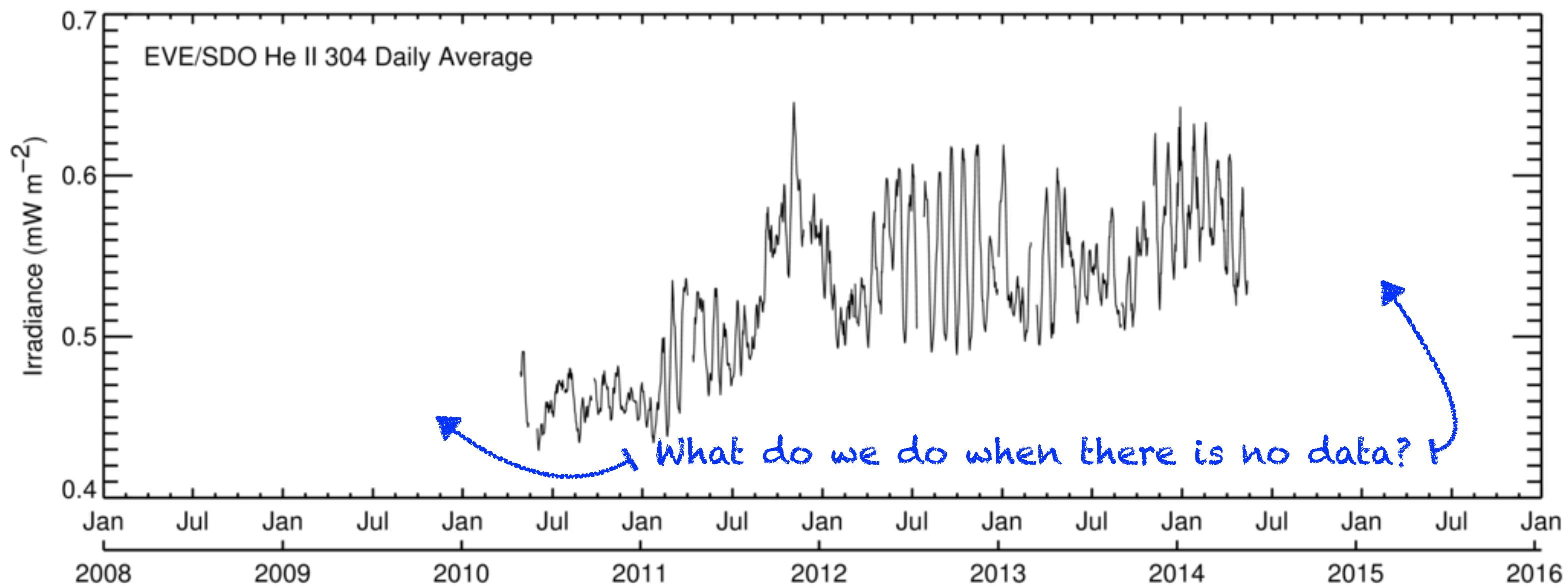
# Outline

- Total Solar Irradiance
  - Measurements
  - Application to climate change
- Solar Spectral Irradiance
  - The Solar Atmosphere
    - Soft X-rays
    - Extreme Ultraviolet
    - Ultraviolet
    - Visible/Infrared
  - Overview of observations
  - Application to satellite drag

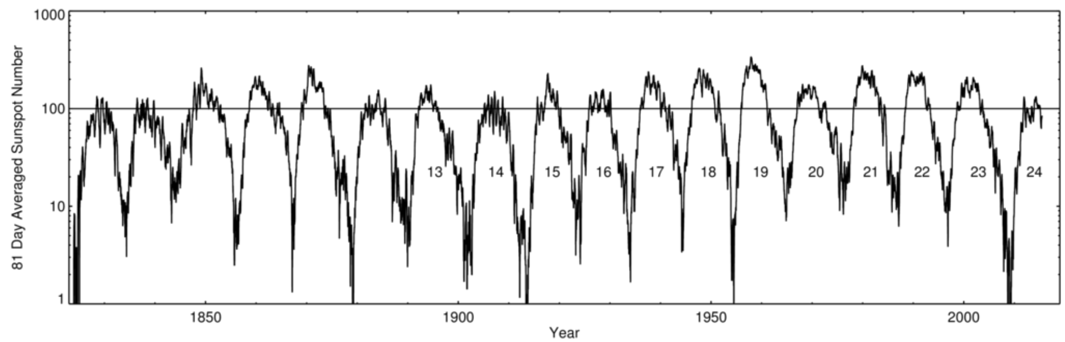
maybe the second half will be better . . .

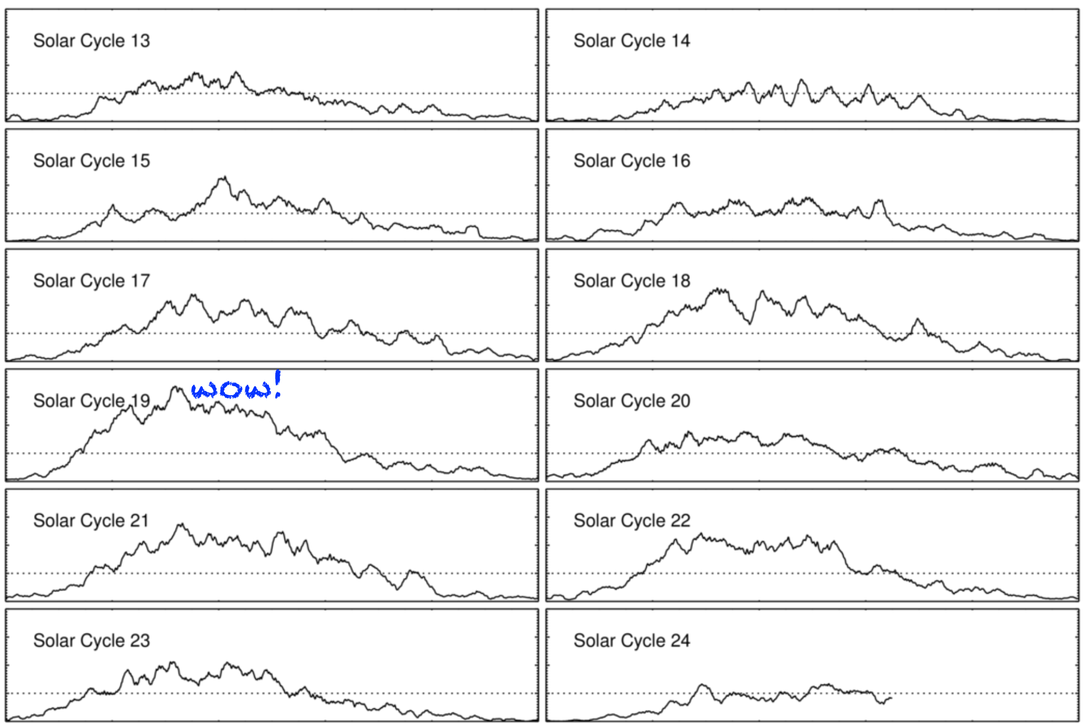
- Common proxies for solar activity
- Proxy irradiance models
- A quick note on regression
  - Training/Test/Validation
  - Gaussian Process Regression
- The magnetic flux as a proxy
- Forecasting solar activity
  - Autoregression
  - Magnetic flux transport
- Emission processes
  - Optically thin line emission
- Semi-empirical models
  - Differential emission measure
- My 2 cents on useful tools and skills

# Proxies for Solar Activity

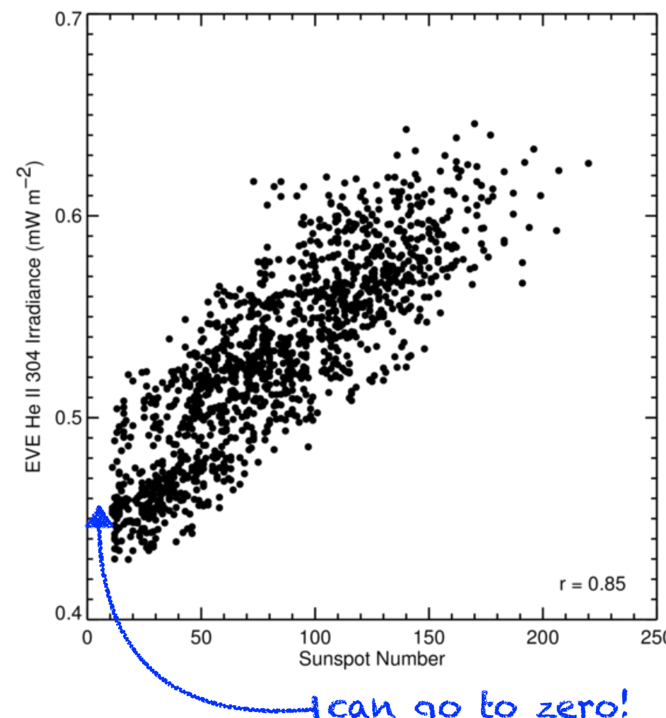


# Proxies for Solar Activity: Sunspot Number



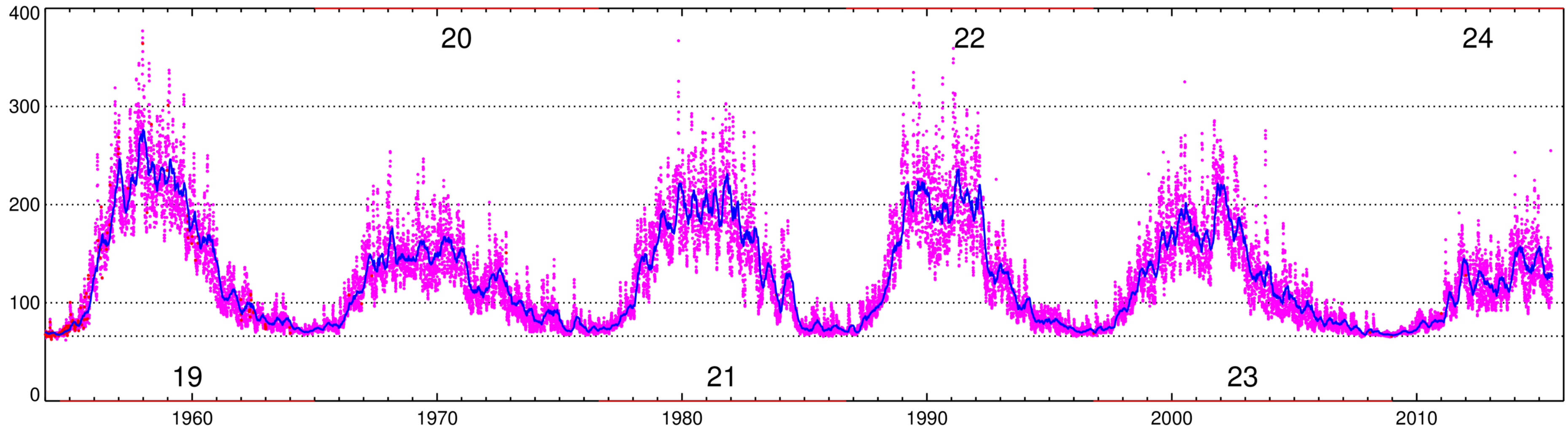




- Very extensive database
- Noisy; modest correlation with irradiance observations
- Recent Reference
  - Clette et al, SSR, 2014

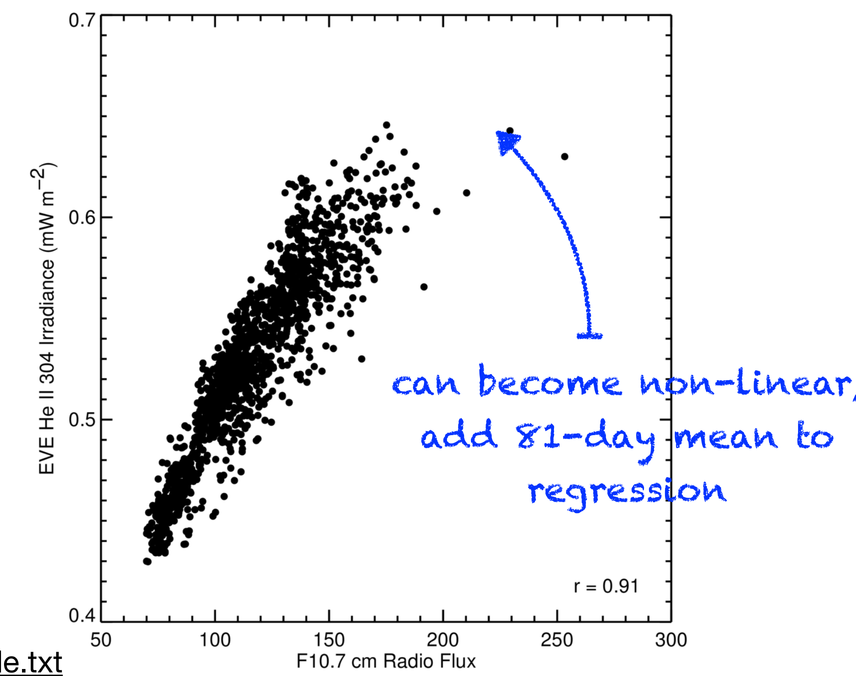



source: WDC-SILSO, Royal Observatory of Belgium, Brussels
http://sidc.be/silso/home

# Proxies for Solar Activity: F10.7 cm Radio Flux




- Extensive database (from 1932)
- Good correlation with irradiance observations




- References
  - Tapping, Space Weather, 2012
  - Tapping, JGR, 1987

source:ftp://ftp.geolab.nrcan.gc.ca/data/solar_flux/daily_flux_values/fluxtable.txt

# Problem: F10.7 is too popular! Atmospheric Models Often Use F10.7 as an Input

Community Earth System Model CESM

## How is the solar spectrum specified?

- Namelist variables point to 2 files specifying solar forcing
  - `solar_parms_file`: F10.7, $K_p$, $A_p$ only F10.7 can be input; not the spectral irradiance
    - solar and geomagnetic parameters used for aurora, UBCs, and wavelengths shorter than Lyman-α

```
> grep solar_parms_file CaseDocs/atm_in
 solar_parms_file = '/fis/cgd/cseg/csm/inputdata/atm/waccm/phot/wa_smax_c100517.nc'
```

  - `solar_data_file`: tsi, ssi, tsi_ref, ssi_ref
    - Covers wavelengths longer than Lyman-α
    - Time-variation of total solar irradiance, as well as variability with λ

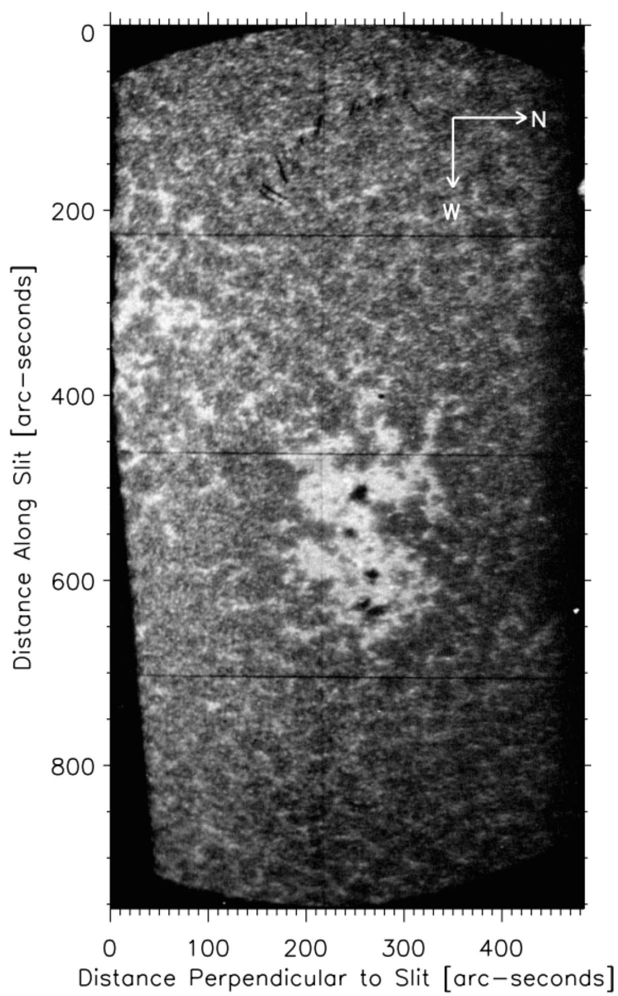
```
> grep solar_data_file CaseDocs/atm_in
 solar_data_file = '/fis/cgd/cseg/csm/inputdata/atm/cam/solar/
spectral_irradiance_Lean_1610-2009_ann_c100405.nc'
```

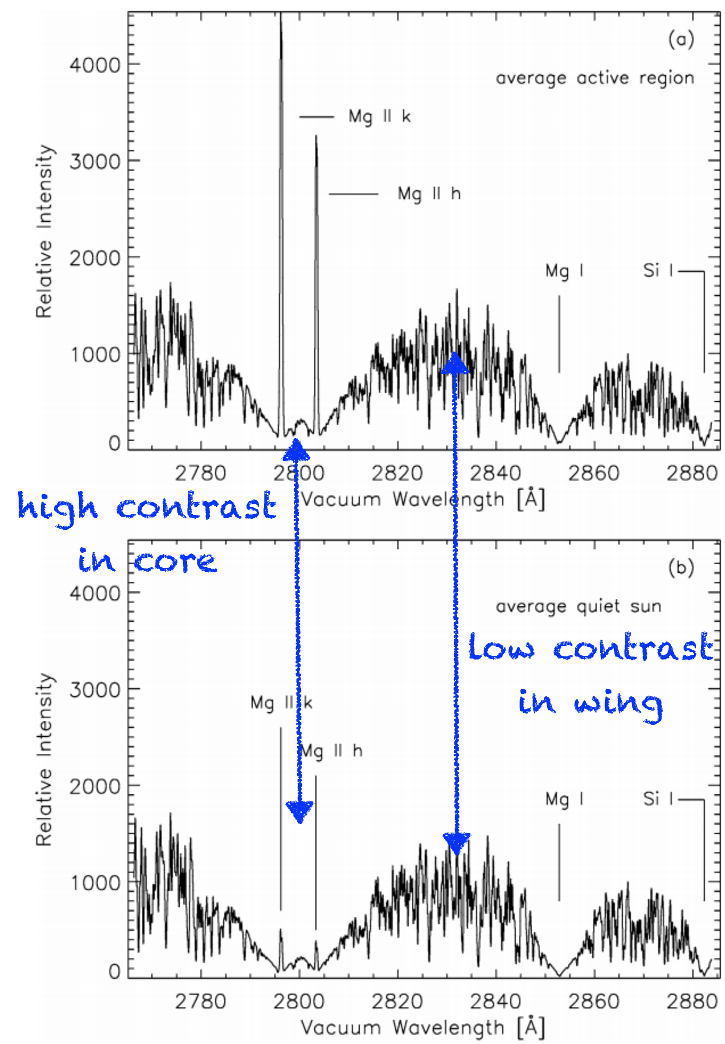
spectral irradiance does go here

NCAR WACCM Whole Atmosphere Community Climate Model

**Dan Marsh, Mike Mills/NCAR**

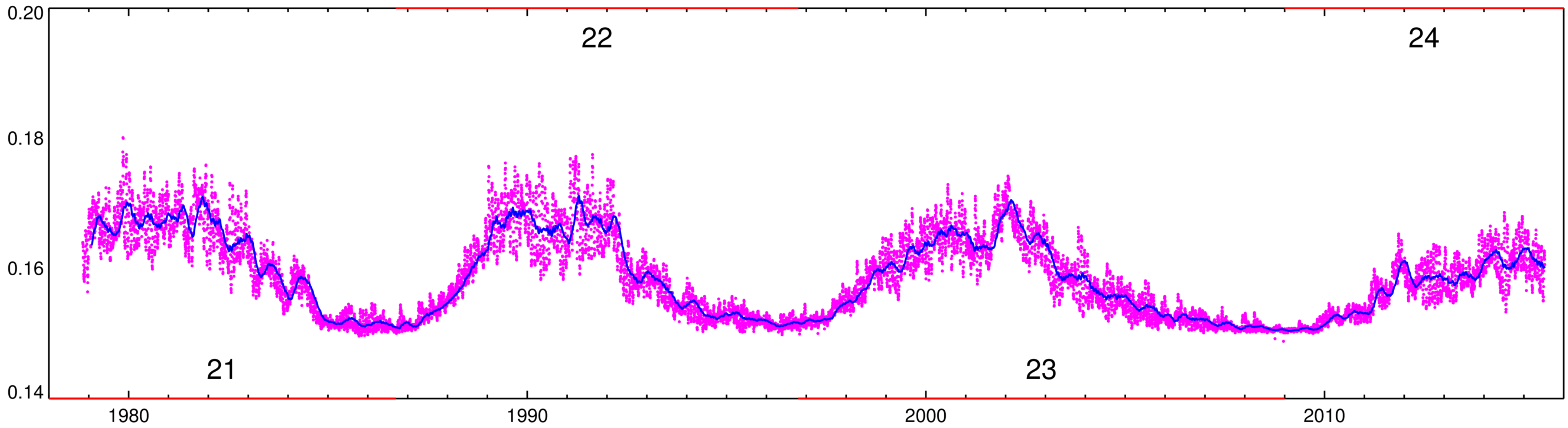
# Proxies for Solar Activity:
# Mg Core-to-Wing Ratio



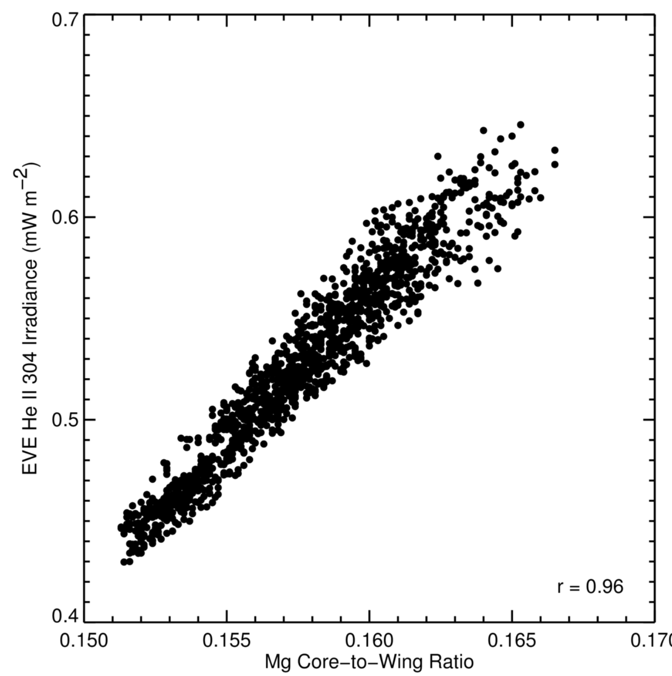




Morrill et al. 2008, 2011a,b [HRTS9/NRL]

# Proxies for Solar Activity: Mg Core-to-Wing Ratio

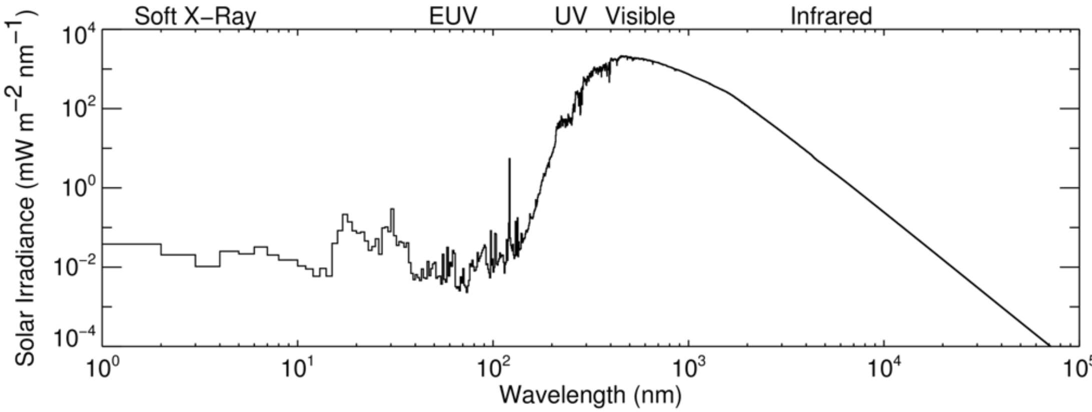



- More limited database (from 1978)
- High correlation with irradiance observations
- Must be observed from space → composite time series
- References
  - DeLand & Marchenko, JGR, 2013
  - Viereck & Puga, JGR, 1999
  - http://www.iup.uni-bremen.de/UVSAT/Datasets/mgii




source: http://www.iup.uni-bremen.de/gome/solar/MgII_composite.dat

# Proxy Irradiance Models: NRLSSI



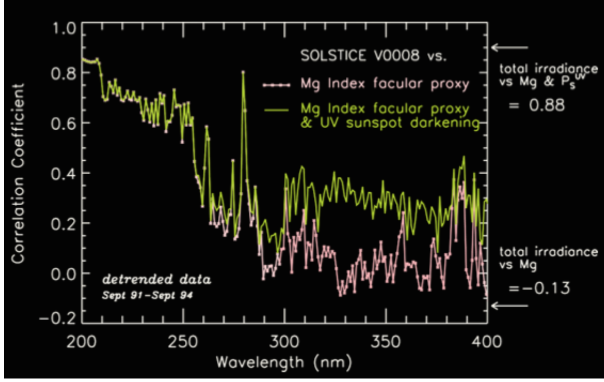

## References

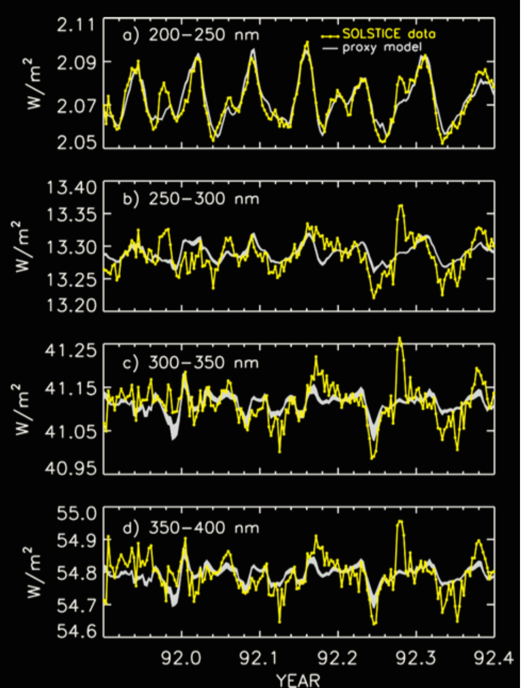
- Lean et al. 2011
- Lean 2000
- Lean et al. 1997

*Lean et al., JGR 1997*
*Lean, GRL, 2000*

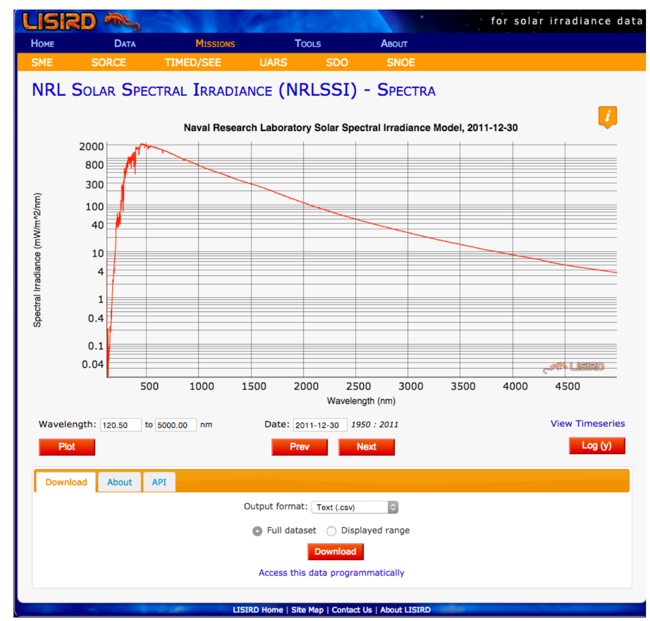
$$F(\lambda,t)/F(\lambda)_{ref} - 1 = a(\lambda) + b(\lambda)\times[Mg(t)/Mg_{ref} - 1] + c(\lambda)\times[SB(t)/SB_{ref} - 1]$$

with the coefficients a(λ), b(λ) and c(λ) determined from multiple linear regression of detrended time series



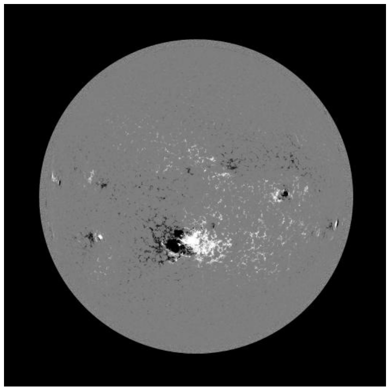

1950-2011



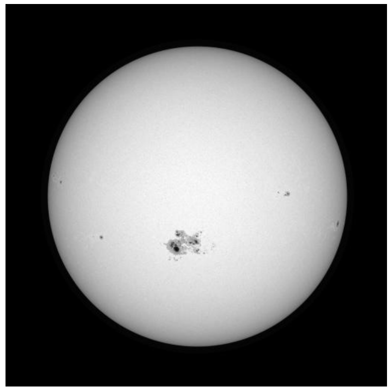

http://lasp.colorado.edu/lisird/nrlssi/

# Proxy Irradiance Models: SATIRE-S

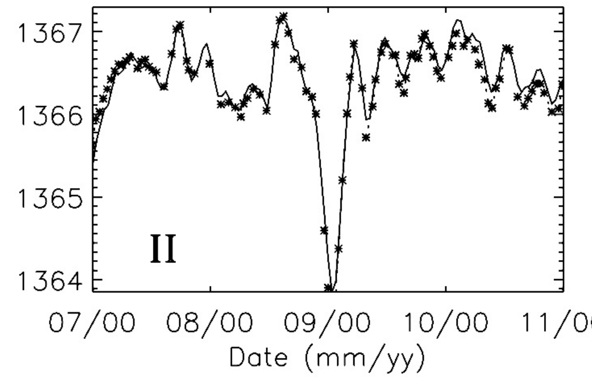
Yeo et al. 2014; Ermolli et al. 2013; Unruh et al. 2012; Ball et al. 2012; Krivova et al. 2011



+

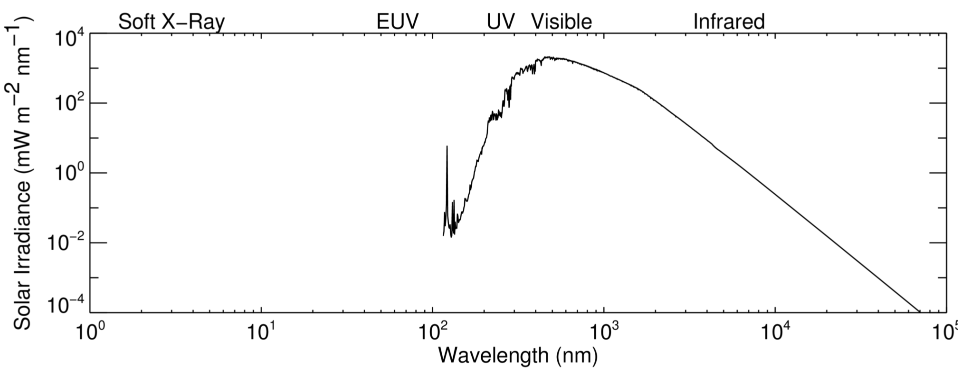


+ model spectra center-to-limb =




SATIRE-S uses full-disc magnetograms and continuum images of the Sun to quantify the fractional disc area coverage by different surface components (quiet Sun, sunspot umbrae, sunspot penumbrae, faculae and network) as well as their spatial distribution.

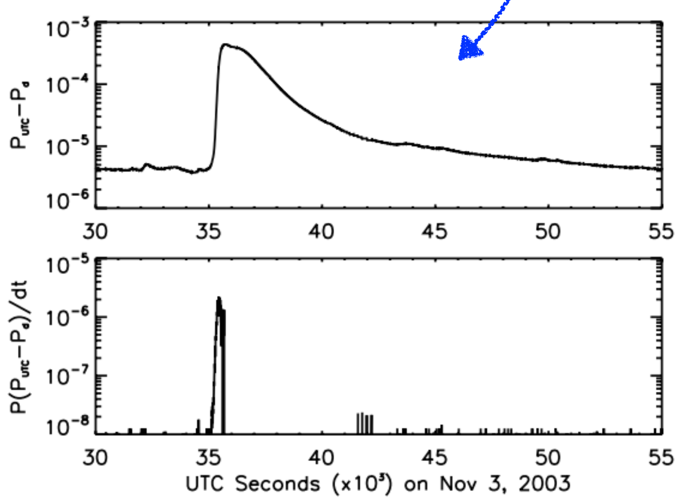
The most recent version of the model uses the data from the NSO KP (1974-1999), SoHO/MDI (1999-2009) and SDO/HMI (since 2010)




http://www2.mps.mpg.de/projects/sun-climate/data.html

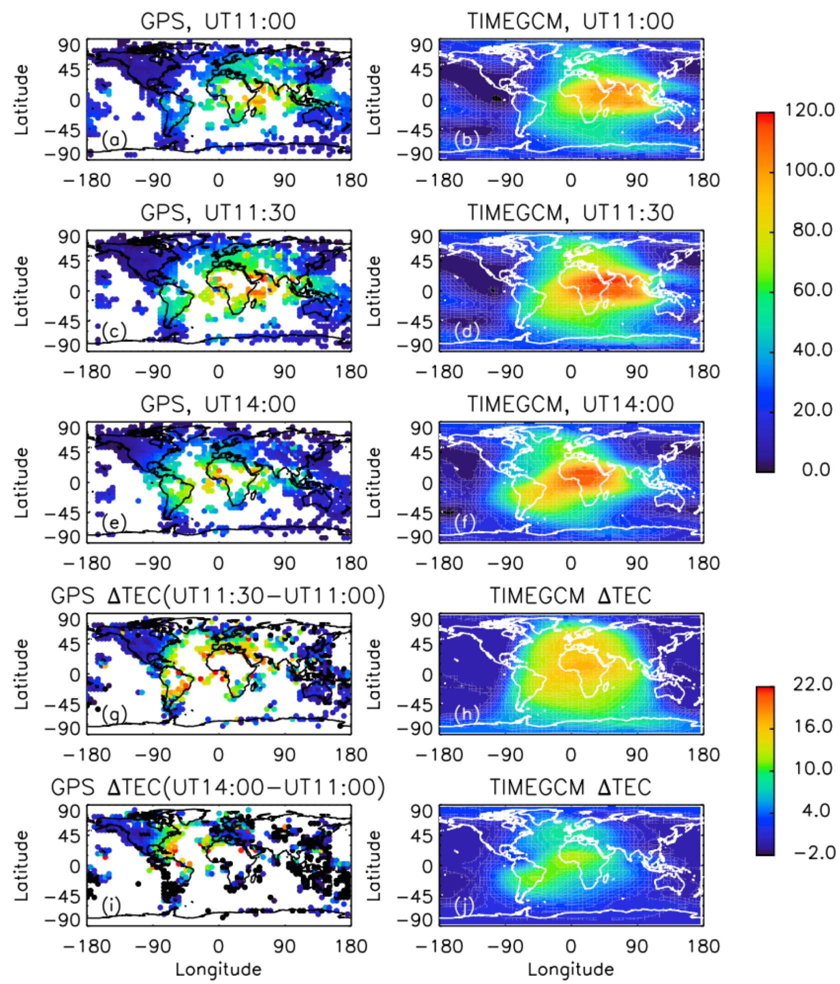
# Proxy Irradiance Models: FISM

- Based mainly on SEE/TIMED observations
- GOES SXR light curves are used to generate a flare component
- References
  - Chamberlin et al, 2007, 2008a,b




estimate HXR burst from SXR derivative

Example Application to Total Electron Content




Qian et al. 2008

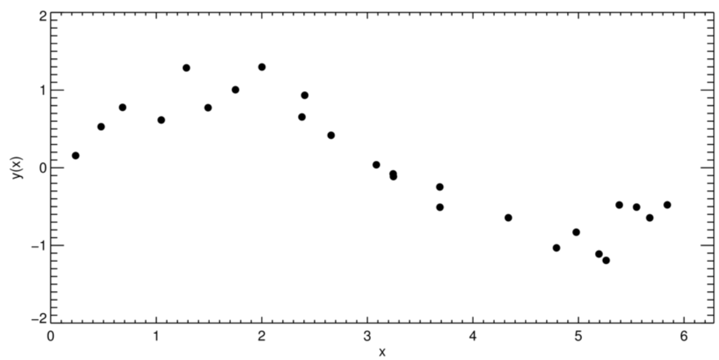
# A Quick Comment on Regression

*A good regression doesn't provide the lowest $\chi^2$,*
*it returns probabilistic results*

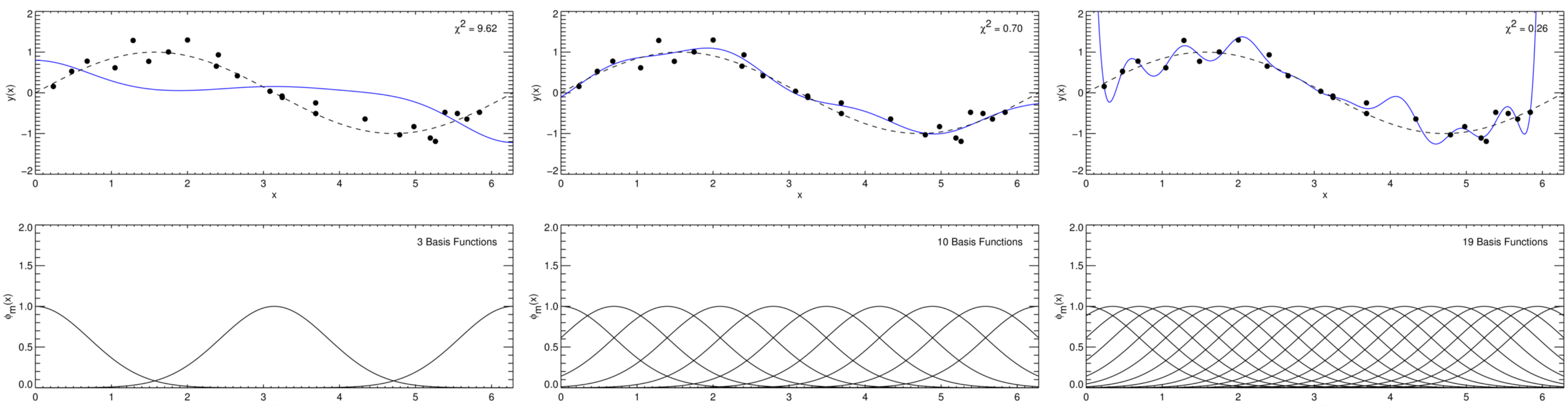
how do I represent y(x)
as a smooth function?

$$y(x) = \sum_{m=1}^{M} w_m \phi_m(x)$$

$$\phi_m(x) = \exp\left[-\frac{(x - x_m)^2}{r^2}\right]$$

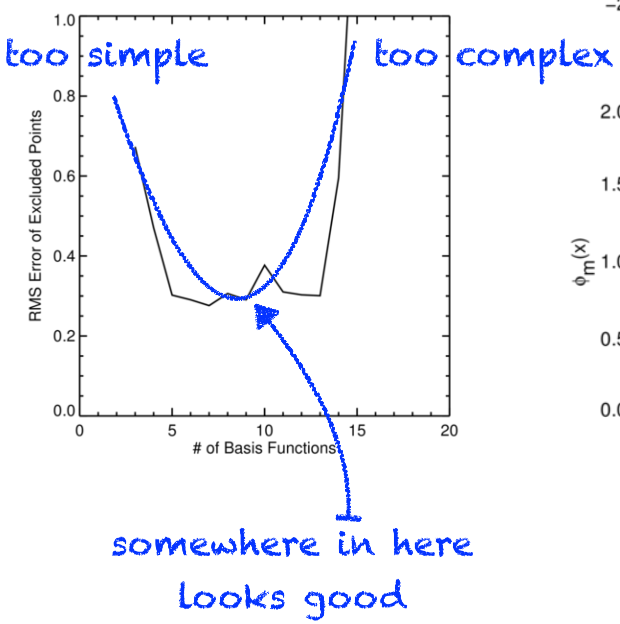


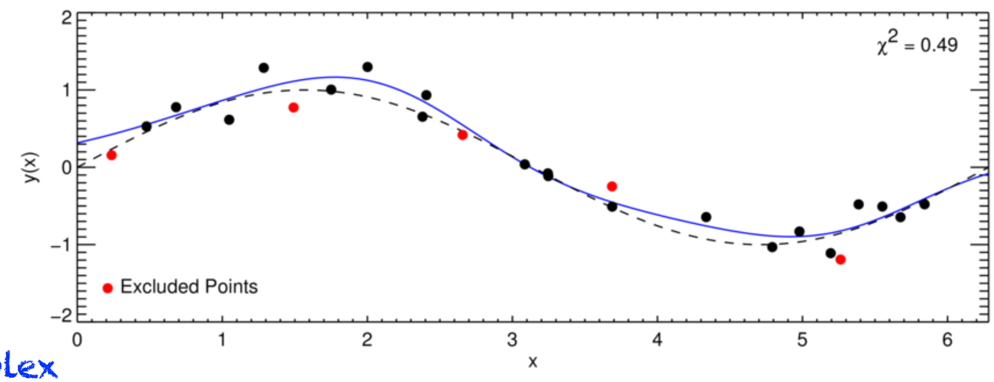

emphasis on chi-squared
encourages overfitting

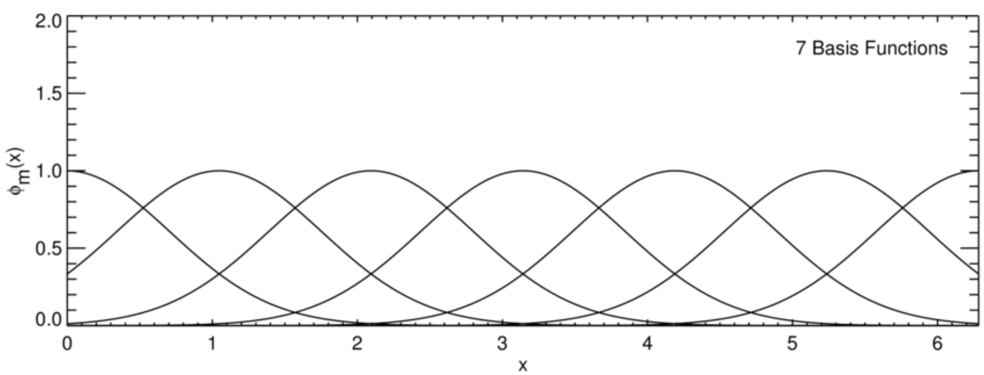


# A Quick Comment on Regression

- Determine optimal model complexity by considering points <u>excluded</u> from determining the fit parameters

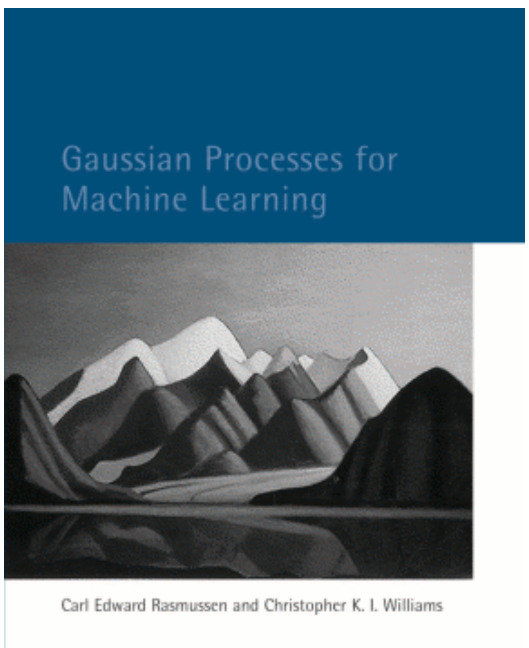


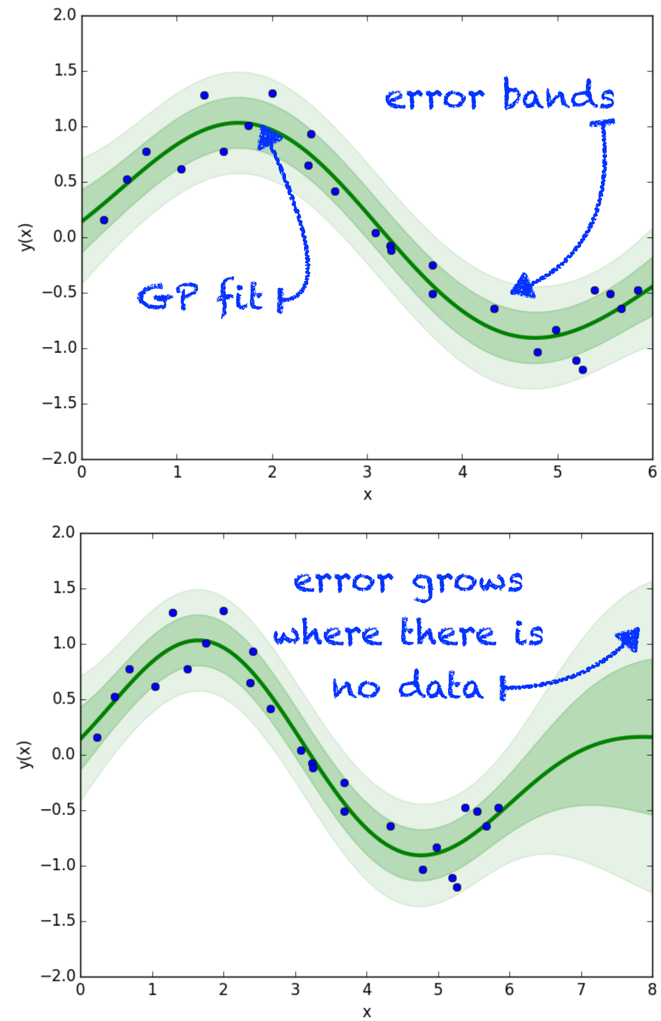



# A Better Way: Gaussian Process Regression

- Gaussian Process Regression
  - Non-parametric; use covariance to describe the model
    $$K_{i,j} = \sigma_f^2 \exp\left[-\frac{(x_i - x_j)^2}{2\ell^2}\right]$$
  - Bayesian: probabilistic predictions
- Reference:

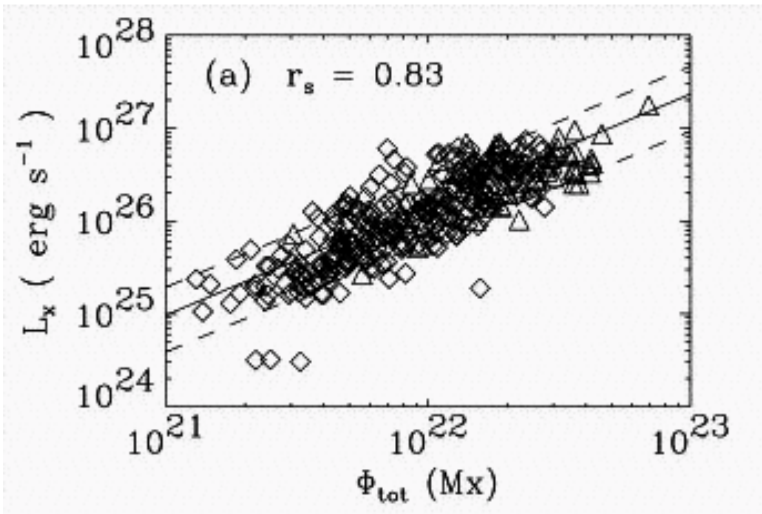



http://www.gaussianprocess.org/
http://videolectures.net/

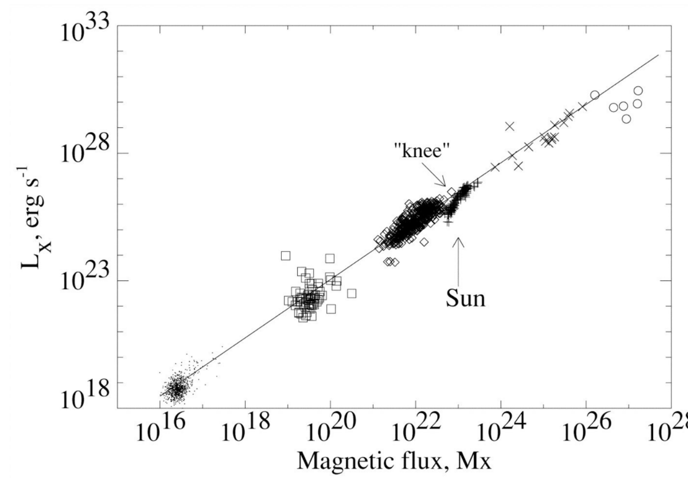



pyGPs - A Package for Gaussian Processes

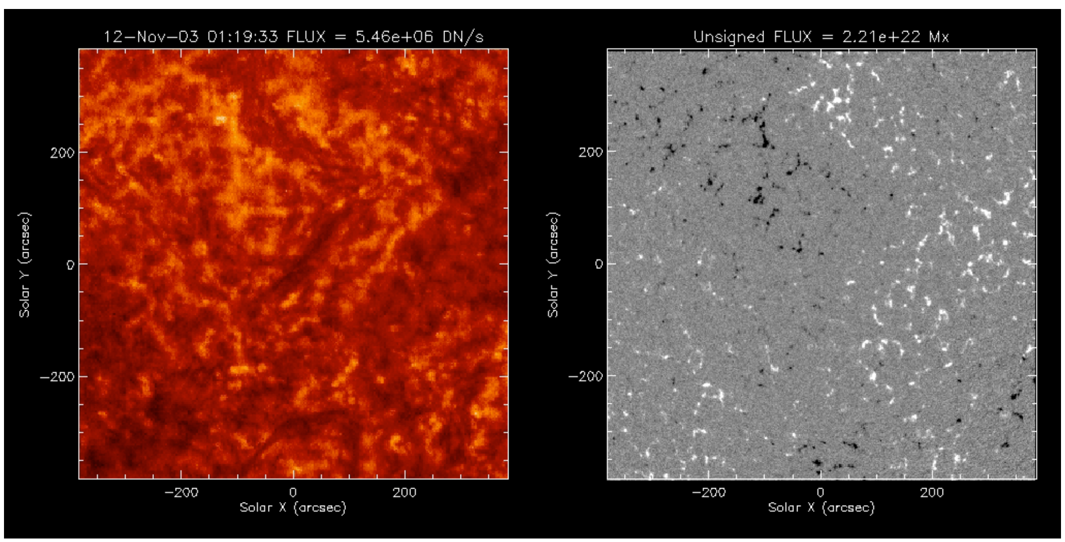
# Proxies for Solar Activity: Total Unsigned Magnetic Flux

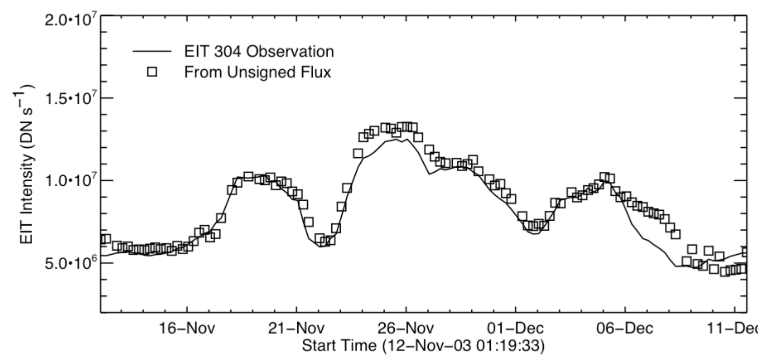



Fisher et al., ApJ (1998)



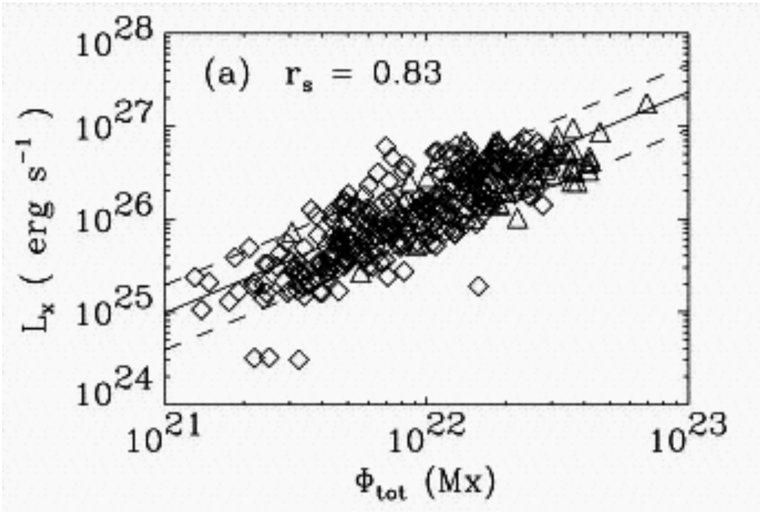

Pevtsov et al., ApJ (2003)



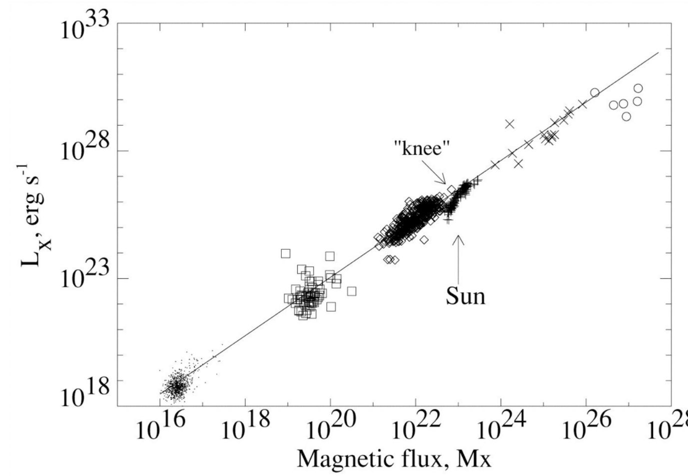




Example from EIT and MDI on SoHO

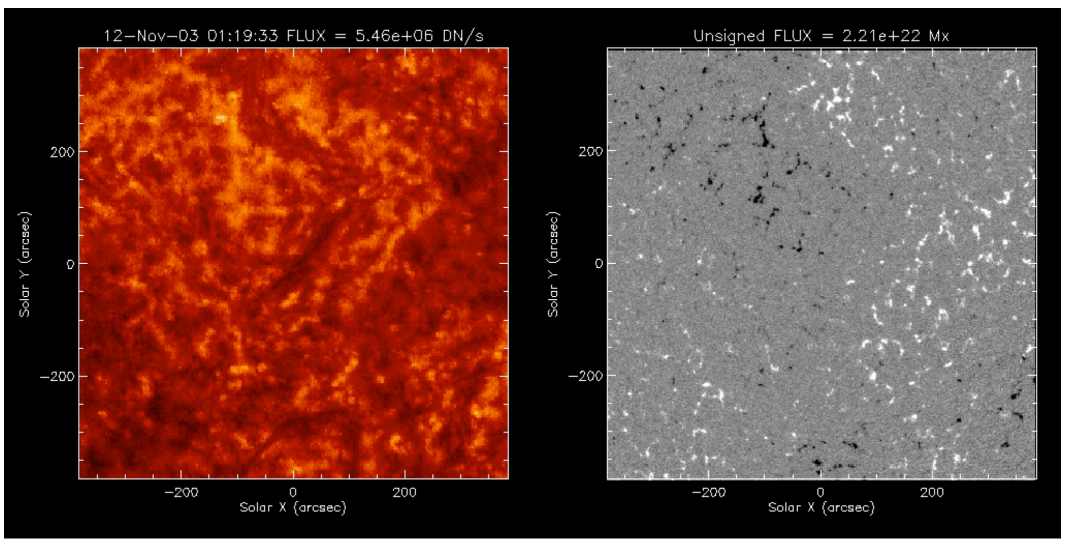
# Proxies for Solar Activity:
# Total Unsigned Magnetic Flux

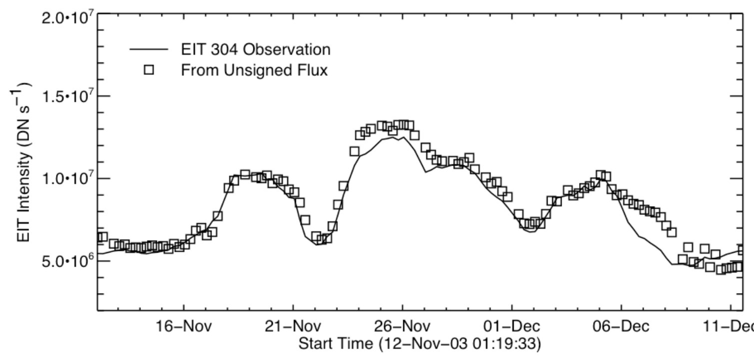



Fisher et al., ApJ (1998)

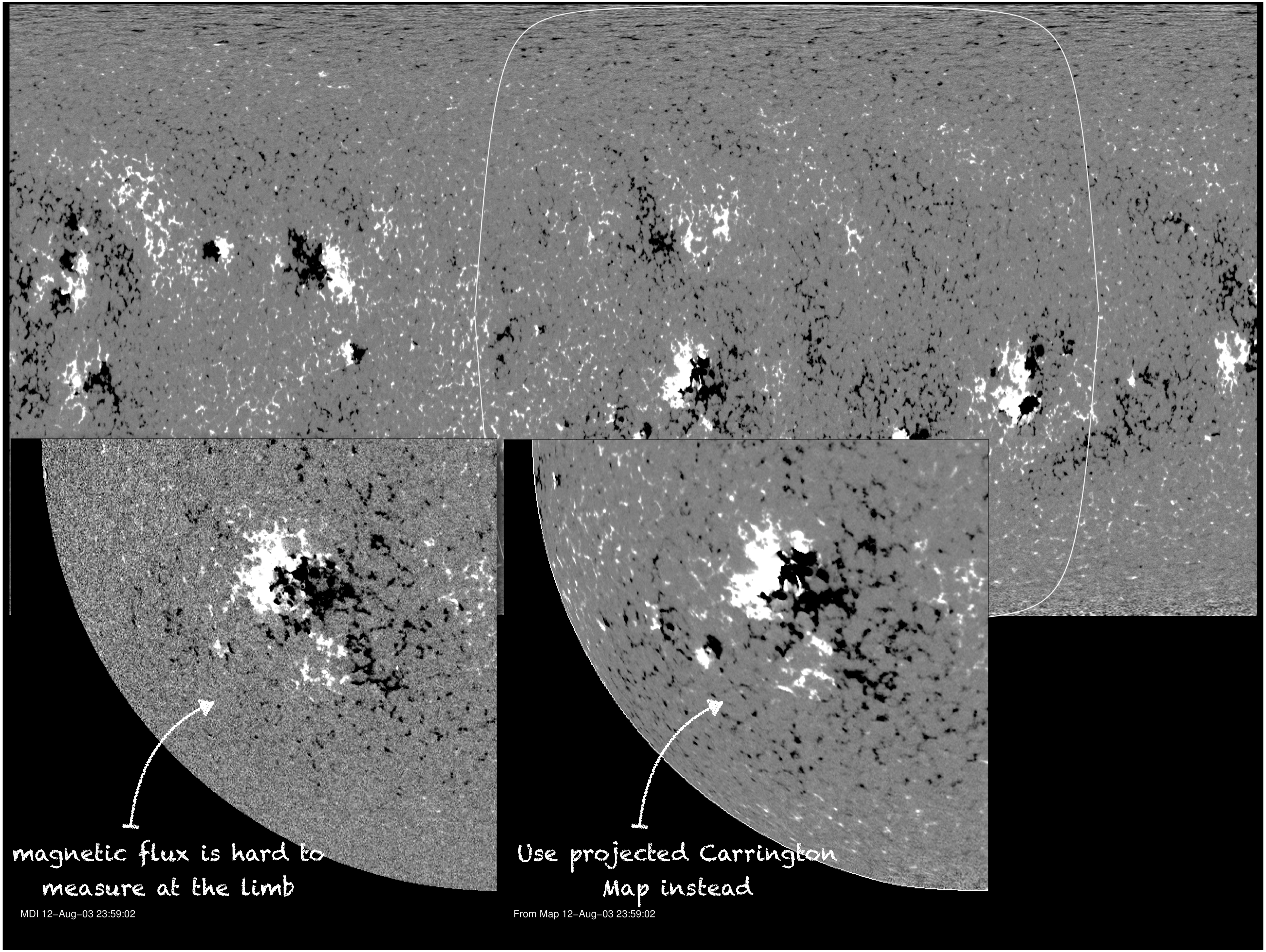



Pevtsov et al., ApJ (2003)

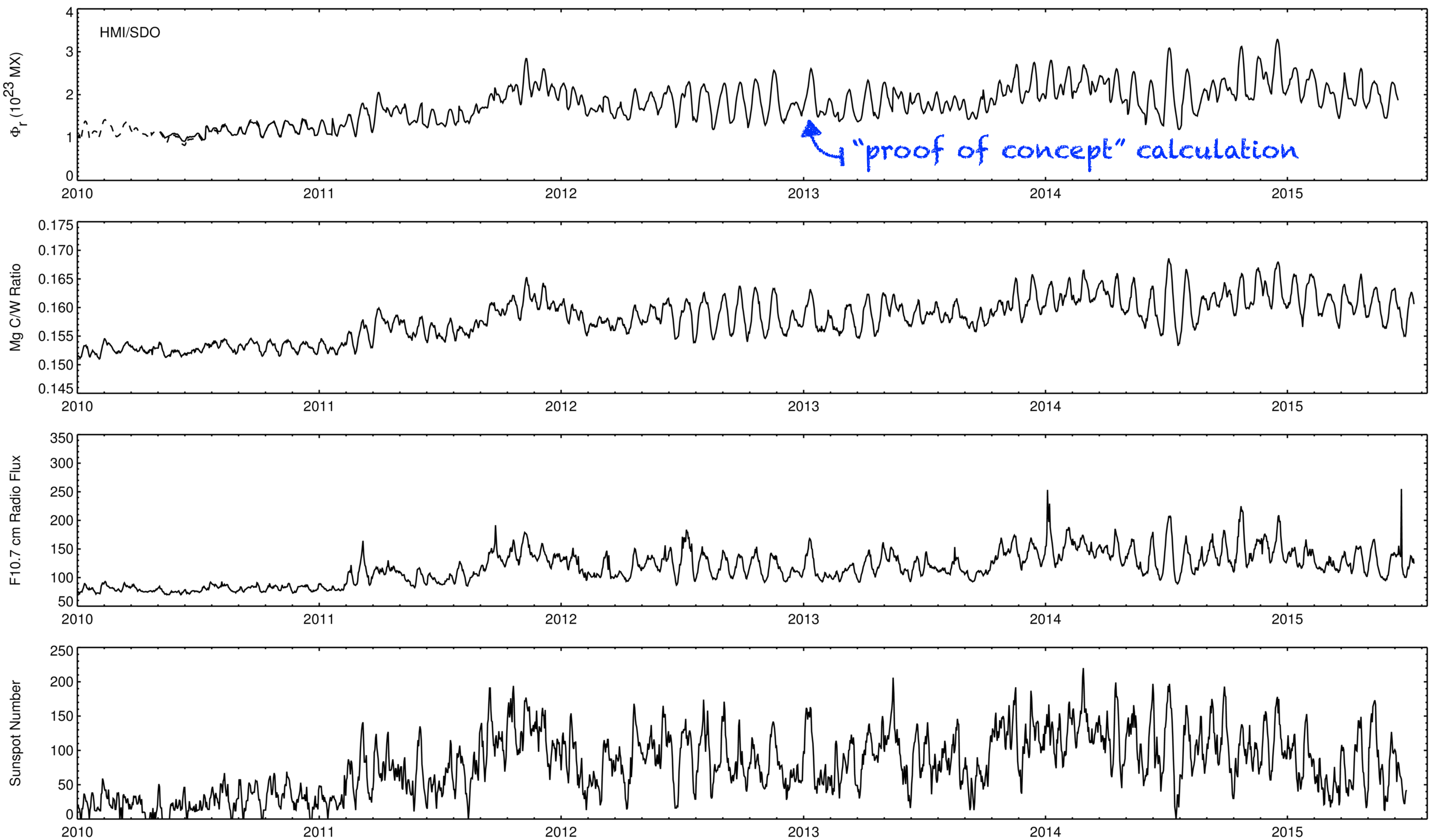


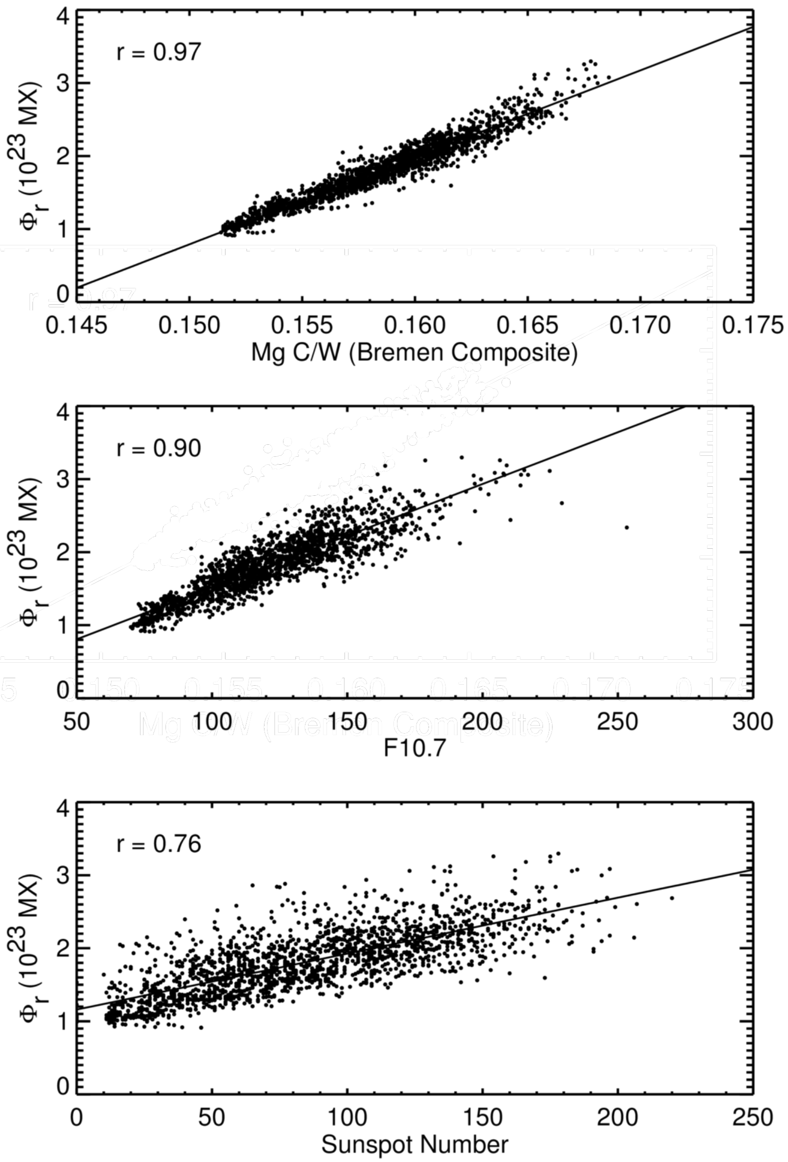

Example from EIT and MDI on SoHO

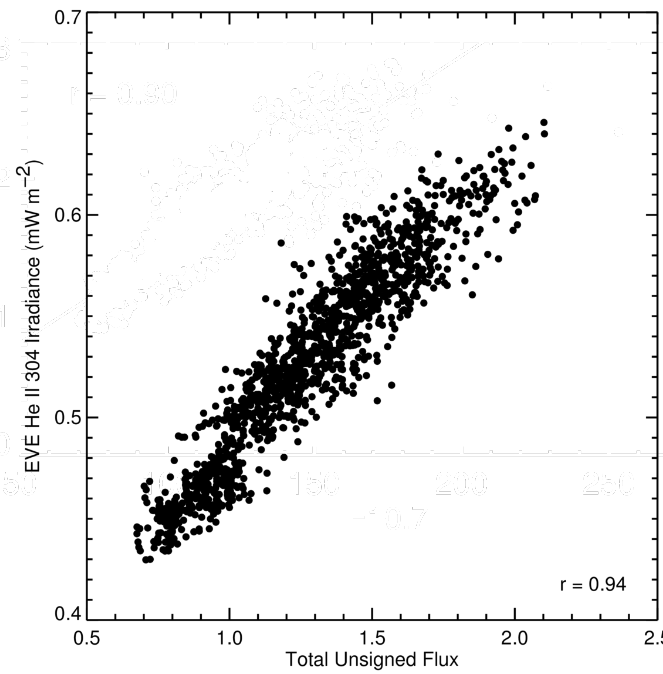

magnetic flux is hard to measure at the limb
Use projected Carrington Map instead
MDI 12–Aug–03 23:59:02
From Map 12–Aug–03 23:59:02

# Daily Magnetic Proxy $\quad \Phi_r = \sum B_r \cdot A$



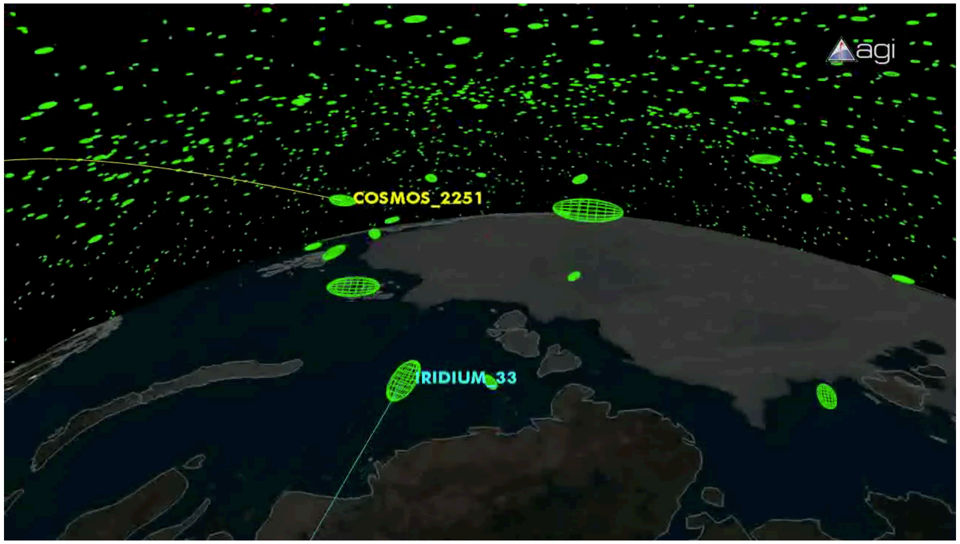
# Comparisons with Existing Proxies



# Forecasting Solar Activity: Autoregression

To predict collisions we need to forecast the solar irradiance




http://celestrak.com/SOCRATES/search.asp

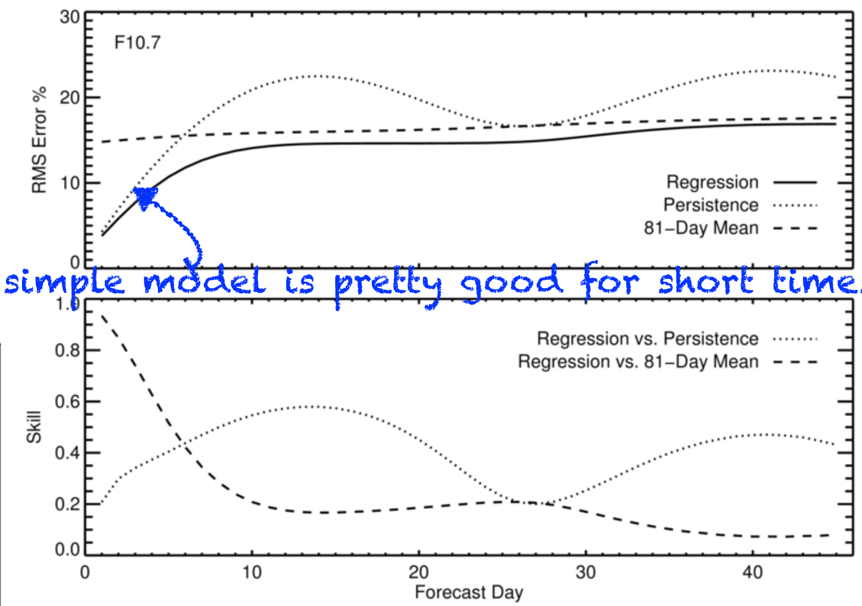
| Action | NORAD Catalog Number | Name | Days Since Epoch | Max Probability / Start (UTC) | Dilution Threshold (km) / TCA (UTC) | Min Range (km) / Stop (UTC) | Relative Velocity (km/sec) |
|---|---|---|---|---|---|---|---|
| Analysis | 29479 | HINODE (SOLAR-B) [+] | 3.469 | 8.402E-07 | 0.564 | 2.194 | 6.372 |
| | 31344 | FENGYUN 1C DEB [-] | 3.292 | 2015 Jul 14 23:52:10.773 | 2015 Jul 14 23:52:11.478 | 2015 Jul 14 23:52:12.183 | |
| Analysis | 29479 | HINODE (SOLAR-B) [+] | 5.939 | 5.993E-07 | 1.095 | 1.586 | 14.977 |
| | 40234 | COSMOS 2251 DEB [-] | 5.966 | 2015 Jul 17 11:08:56.004 | 2015 Jul 17 11:08:56.320 | 2015 Jul 17 11:08:56.637 | |
| Analysis | 29479 | HINODE (SOLAR-B) [+] | 6.135 | 1.977E-07 | [illegible] | [illegible] | 11.211 |
| | 38060 | COSMOS 2251 DEB [-] | 6.641 | 2015 Jul 17 15:51:55.010 | 2015 Jul 17 15:51:55.279 | 2015 Jul 17 15:51:55.548 | |
| Analysis | 29479 | HINODE (SOLAR-B) [+] | 1.629 | 1.919E-07 | 1.896 | 2.860 | 14.915 |
| | 37306 | COSMOS 2251 DEB [-] | 6.970 | 2015 Jul 13 03:43:00.228 | 2015 Jul 13 03:43:00.503 | 2015 Jul 13 03:43:00.778 | |
| Analysis | 29479 | HINODE (SOLAR-B) [+] | 2.228 | 8.836E-08 | 2.711 | 4.339 | 14.782 |
| | 30800 | FENGYUN 1C DEB [-] | 2.784 | 2015 Jul 13 18:05:14.140 | 2015 Jul 13 18:05:14.308 | 2015 Jul 13 18:05:14.476 | |

time between measurement and closest approach

Autoregression

$$X_t = \sum_{i=1}^{n} \varphi_i X_{t-i} + \epsilon_t$$

Autoregression Applied to F10.7



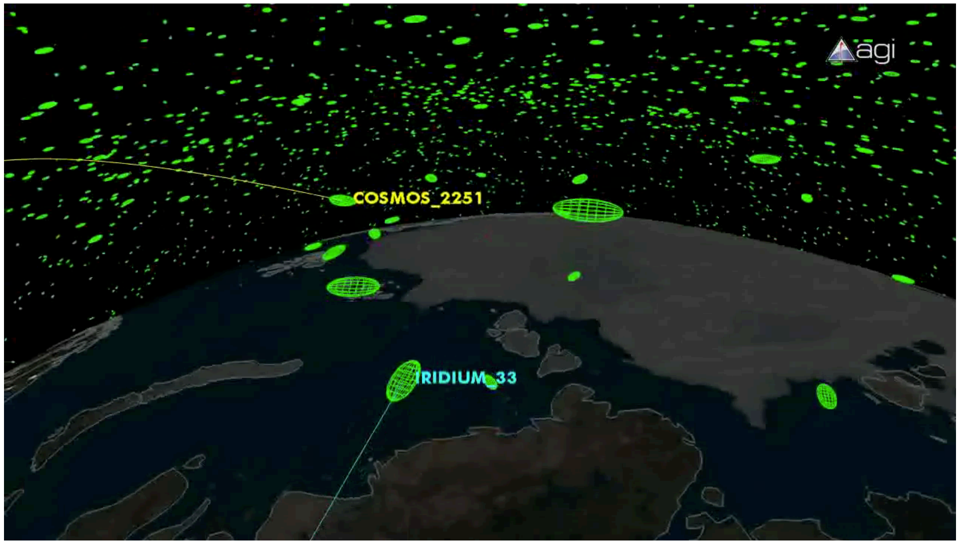

simple model is pretty good for short times

$$\text{Skill} = 1 - \frac{\text{MSE(model)}}{\text{MSE(reference)}}$$

Also See: Tobiska et al. 2008

# Forecasting Solar Activity: Autoregression

To predict collisions we need to <u>forecast</u> the solar irradiance

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| Analysis | 29479 | HINODE (SOLAR-B) [+] | 5.939 | 5.993E-07 | 1.095 | 1.586 | 14.977 |
| | 40234 | COSMOS 2251 DEB [-] | 5.966 | 2015 Jul 17 11:08:56.004 | 2015 Jul 17 11:08:56.320 | 2015 Jul 17 11:08:56.637 | |
| Analysis | 29479 | HINODE (SOLAR-B) [+] | 6.135 | 1.977E-07 | [illegible] | [illegible] | 11.211 |
| | 38060 | COSMOS 2251 DEB [-] | 6.641 | 2015 Jul 17 15:51:55.010 | 2015 Jul 17 15:51:55.279 | 2015 Jul 17 15:51:55.548 | |
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| | 37306 | COSMOS 2251 DEB [-] | 6.970 | 2015 Jul 13 03:43:00.228 | 2015 Jul 13 03:43:00.503 | 2015 Jul 13 03:43:00.778 | |
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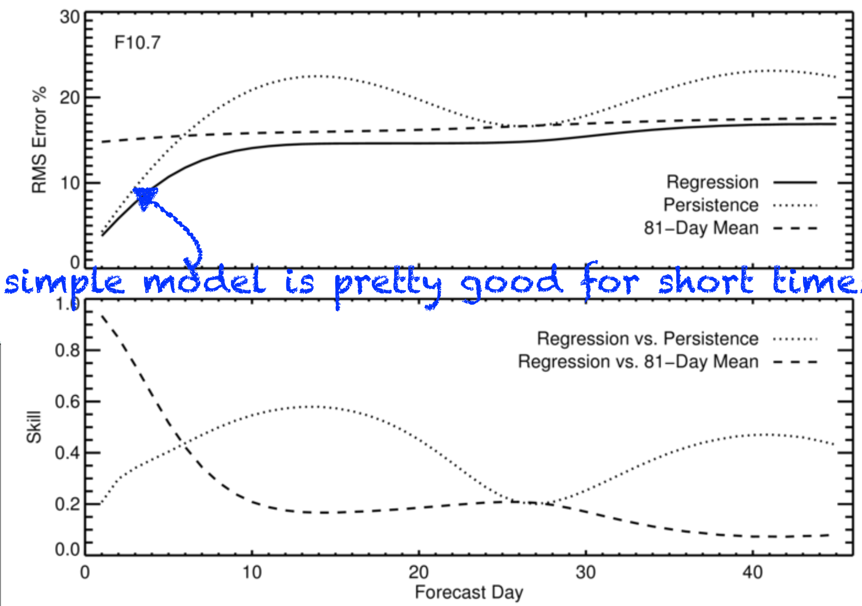
| | 30800 | FENGYUN 1C DEB [-] | 2.784 | 2015 Jul 13 18:05:14.140 | 2015 Jul 13 18:05:14.308 | 2015 Jul 13 18:05:14.476 | |

time between measurement and closest approach

Autoregression

$$X_t = \sum_{i=1}^{n} \varphi_i X_{t-i} + \epsilon_t$$

Autoregression Applied to F10.7




simple model is pretty good for short times

$$\text{Skill} = 1 - \frac{\text{MSE(model)}}{\text{MSE(reference)}}$$

Also See: Tobiska et al. 2008

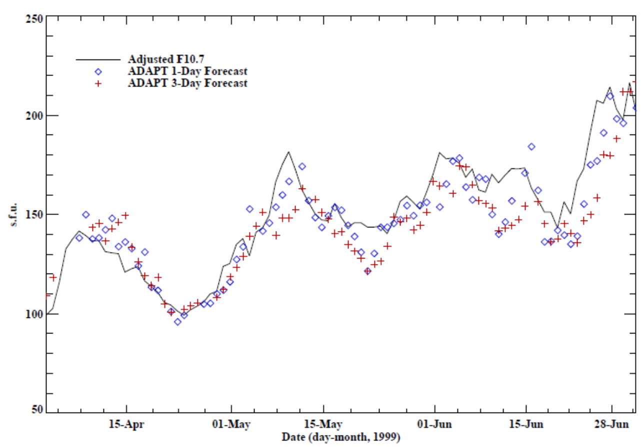
# Forecasting Solar Activity: Magnetic Flux Transport

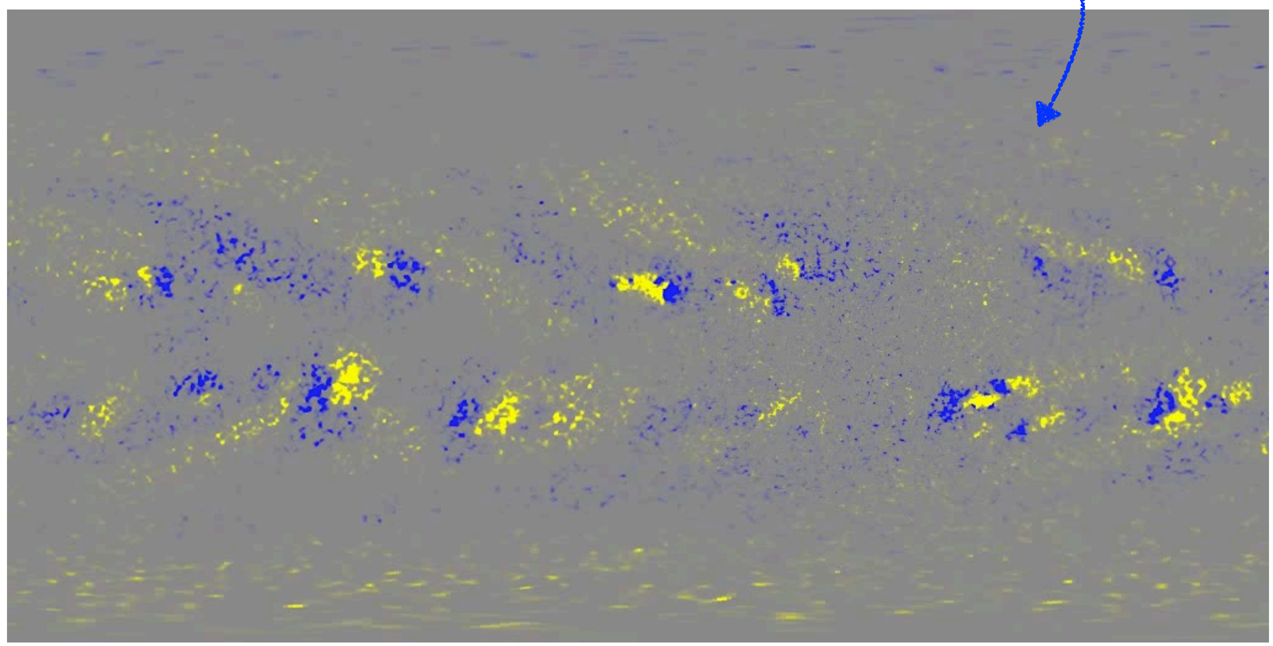
- Flux Transport Processes
  - differential rotation
  - super granular diffusion
  - meridional flow
  - flux emergence and cancelation

- Example References
  - Devore, Sheeley, Wang (1984)
  - Worden & Harvey (2000) ADAPT
  - Schrijver & DeRosa (2003) PFSS_VIEWER
  - Upton & Hathaway (2014a,b)

**Forecasting $F_{10.7}$ with solar magnetic flux transport modeling**

C. J. Henney,[1] W. A. Toussaint,[2] S. M. White,[1] and C. N. Arge[1]

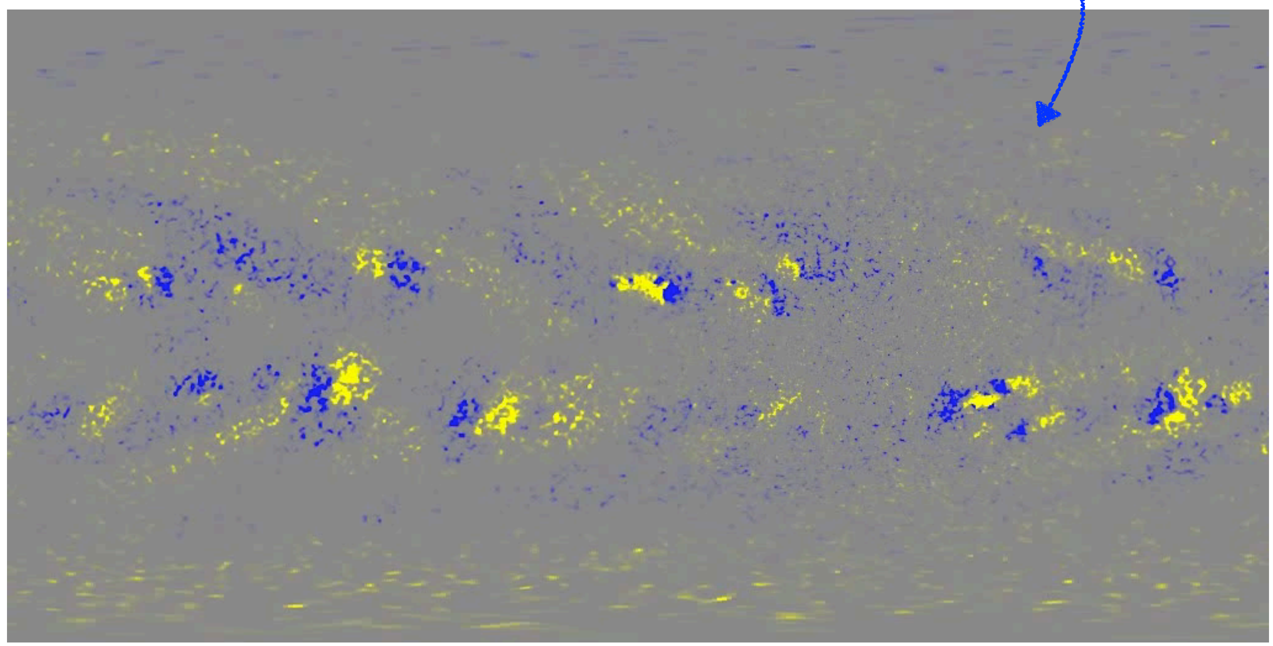


Upton & Hathaway Advective Transport Model

# Forecasting Solar Activity: Magnetic Flux Transport

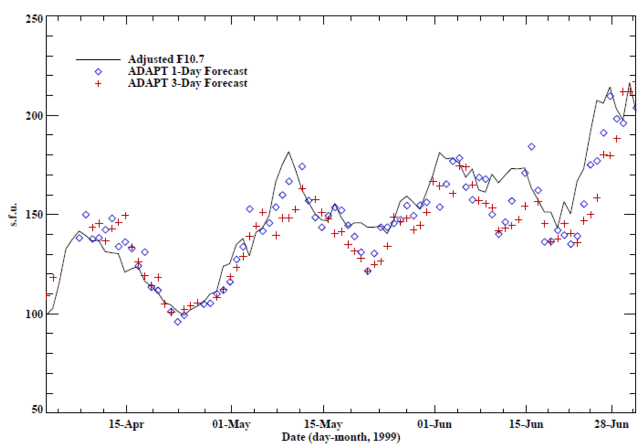
- Flux Transport Processes
  - differential rotation
  - super granular diffusion
  - meridional flow
  - flux emergence and cancelation
- Example References
  - Devore, Sheeley, Wang (1984)
  - Worden & Harvey (2000) ADAPT
  - Schrijver & DeRosa (2003) PFSS_VIEWER
  - Upton & Hathaway (2014a,b)



Upton & Hathaway Advective Transport Model

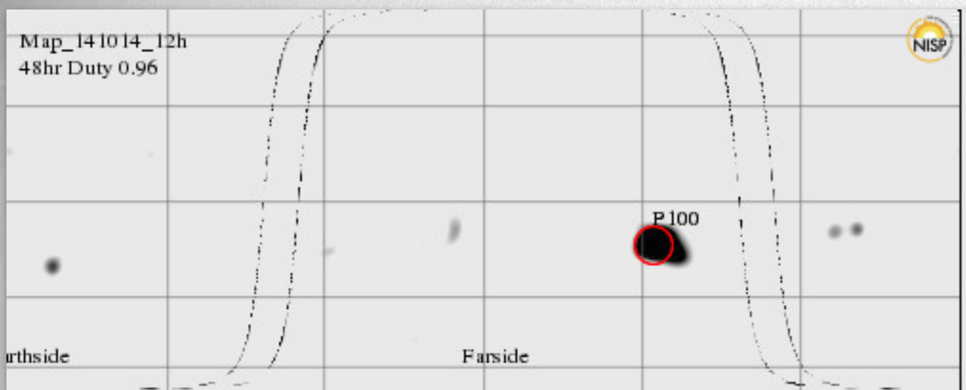
**Forecasting $F_{10.7}$ with solar magnetic flux transport modeling**

C. J. Henney,[1] W. A. Toussaint,[2] S. M. White,[1] and C. N. Arge[1]

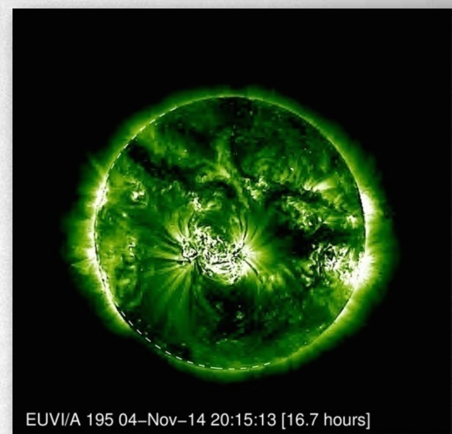


# Magnetic Flux Transport: Incorporating Far Side Information

## AR 12192



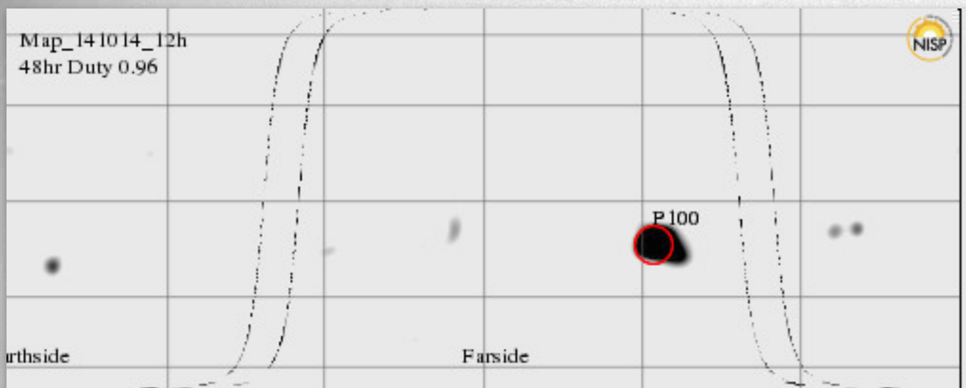

http://farside.nso.edu/




STEREO

# Magnetic Flux Transport: Incorporating Far Side Information

## AR 12192

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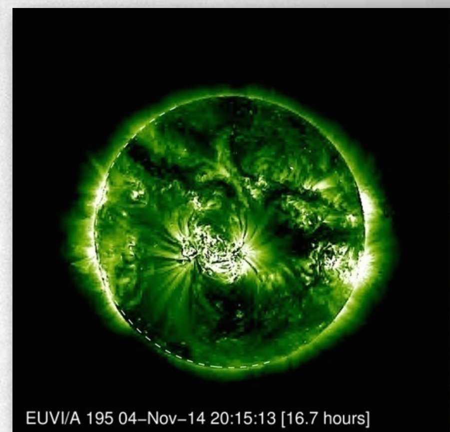
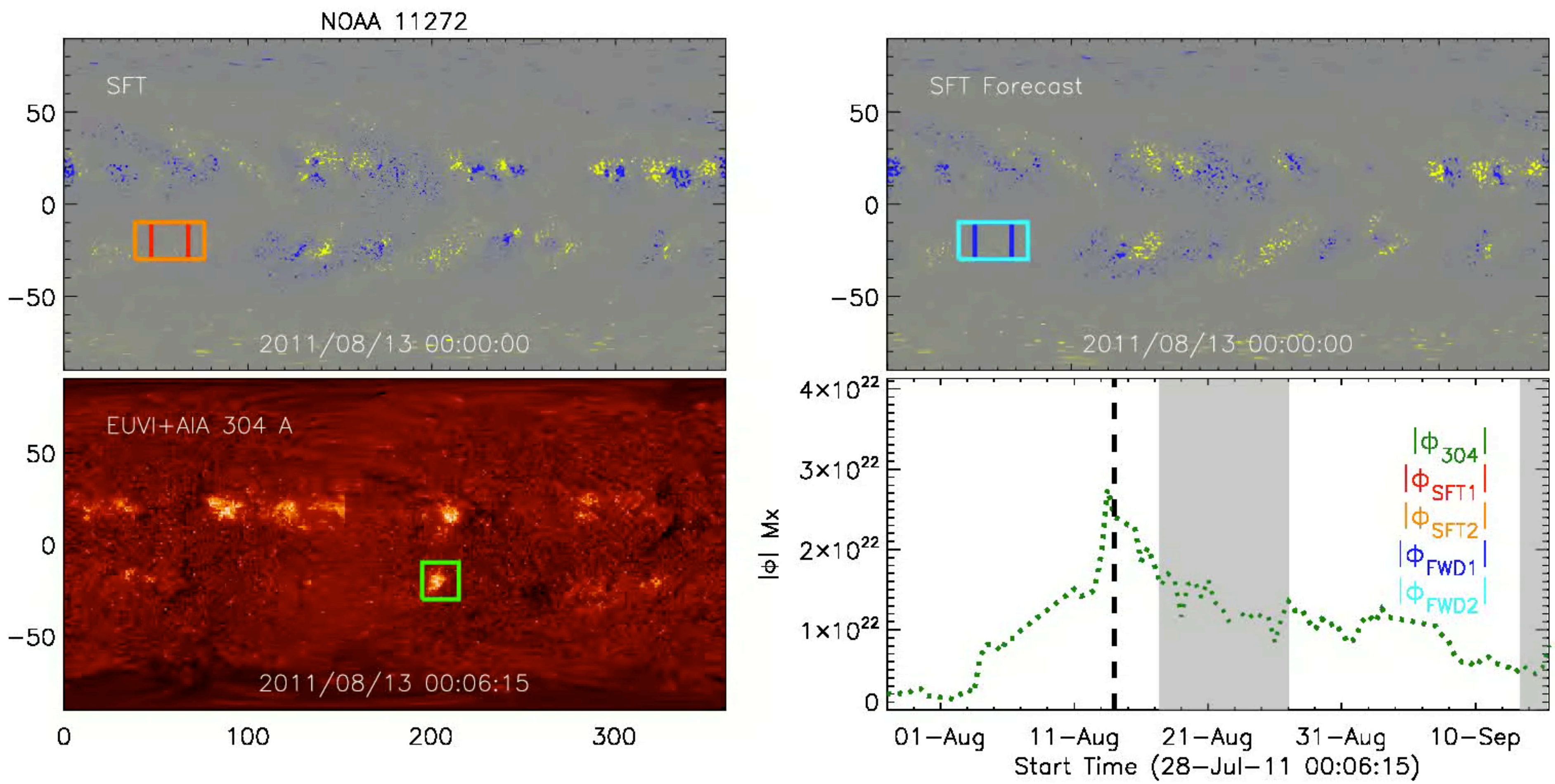


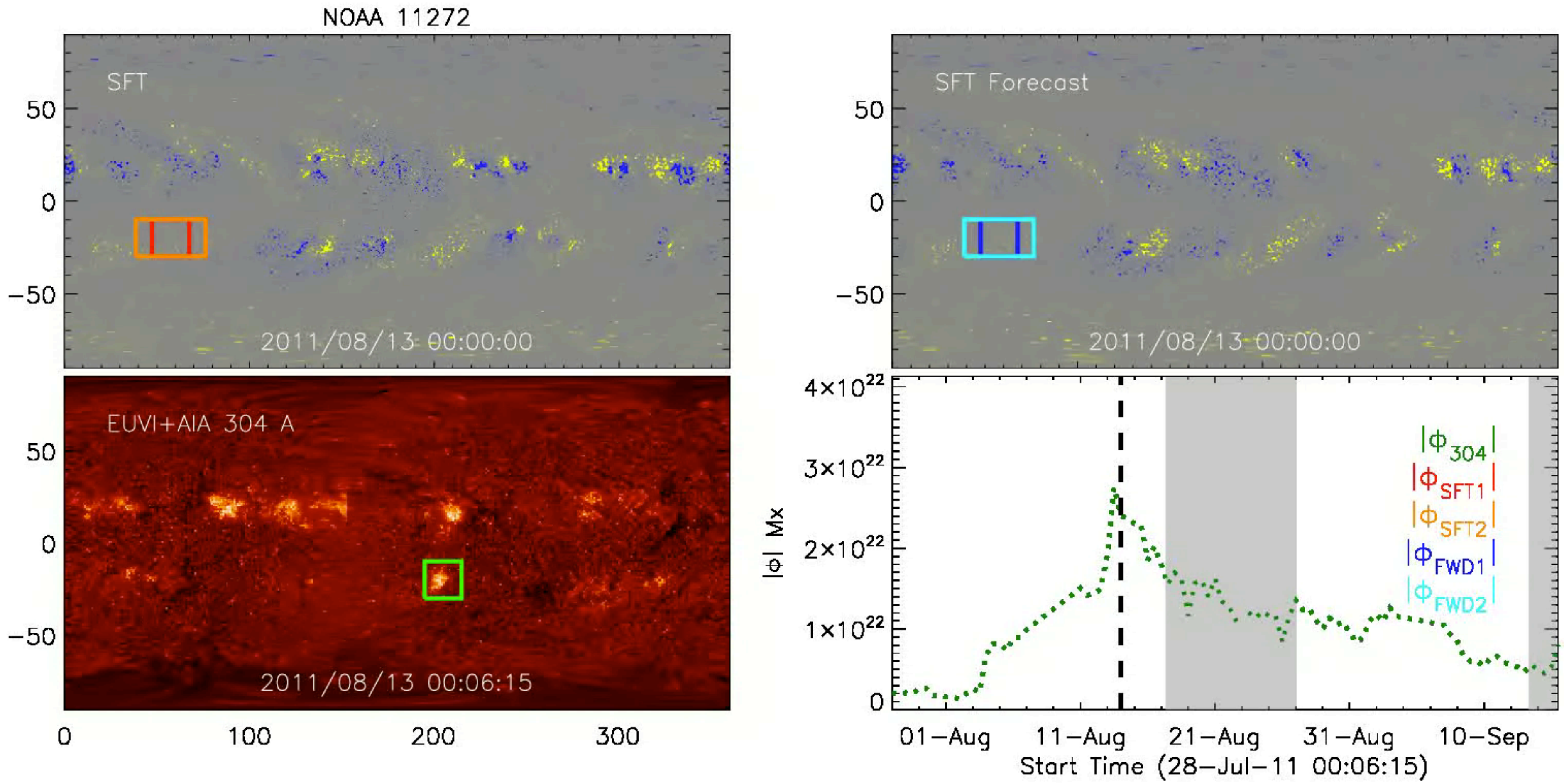

STEREO

# Magnetic Flux Transport: Incorporating Far Side Information




Ugarte-Urra, Upton, Warren, & Hathaway (2015, submitted)

# Magnetic Flux Transport: Incorporating Far Side Information

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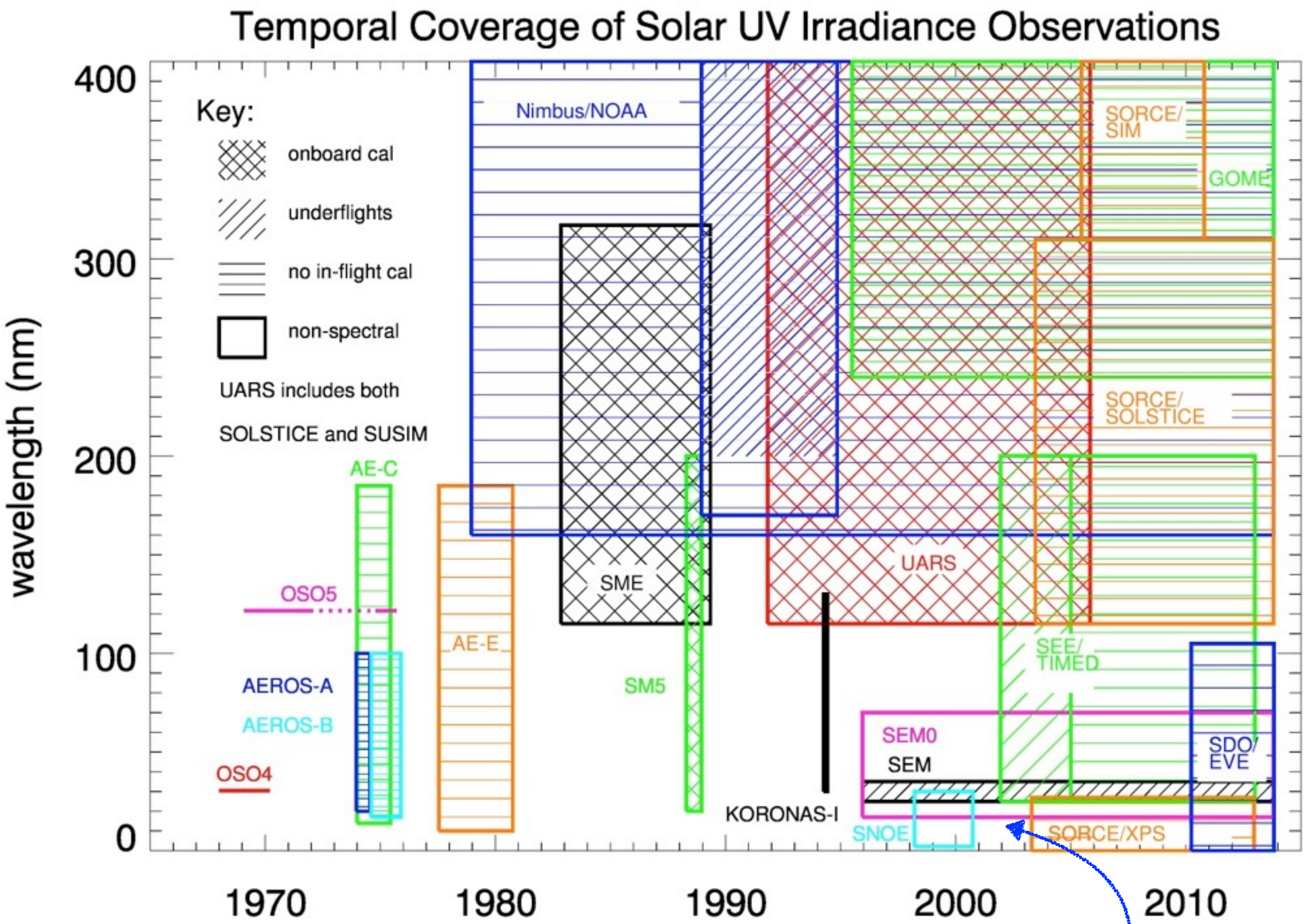



Jeff Morrill NRL/NASA HQ

What do we do when there is limited spectral coverage?

# Computing Line Intensities

$$I_\lambda = n_u A_{ul} V$$

# Computing Line Intensities

intensity

transition rate

$$I_\lambda = n_u A_{ul} V$$

number density

volume

ionization fraction

$$I_\lambda = \frac{n_u}{n_{ion}} \frac{n_{ion}}{n_{el}} \frac{n_{el}}{n_H} \frac{n_H}{n_e} n_e A_{ul} V$$

level pop

elemental abund

emissivity

emission measure

$$I_\lambda = \epsilon_\lambda(T_e) n_e^2 V$$

$$I_\lambda = \int_{T_e} \epsilon_\lambda(T_e) n_e^2 \frac{dV}{dT_e} dT_e$$

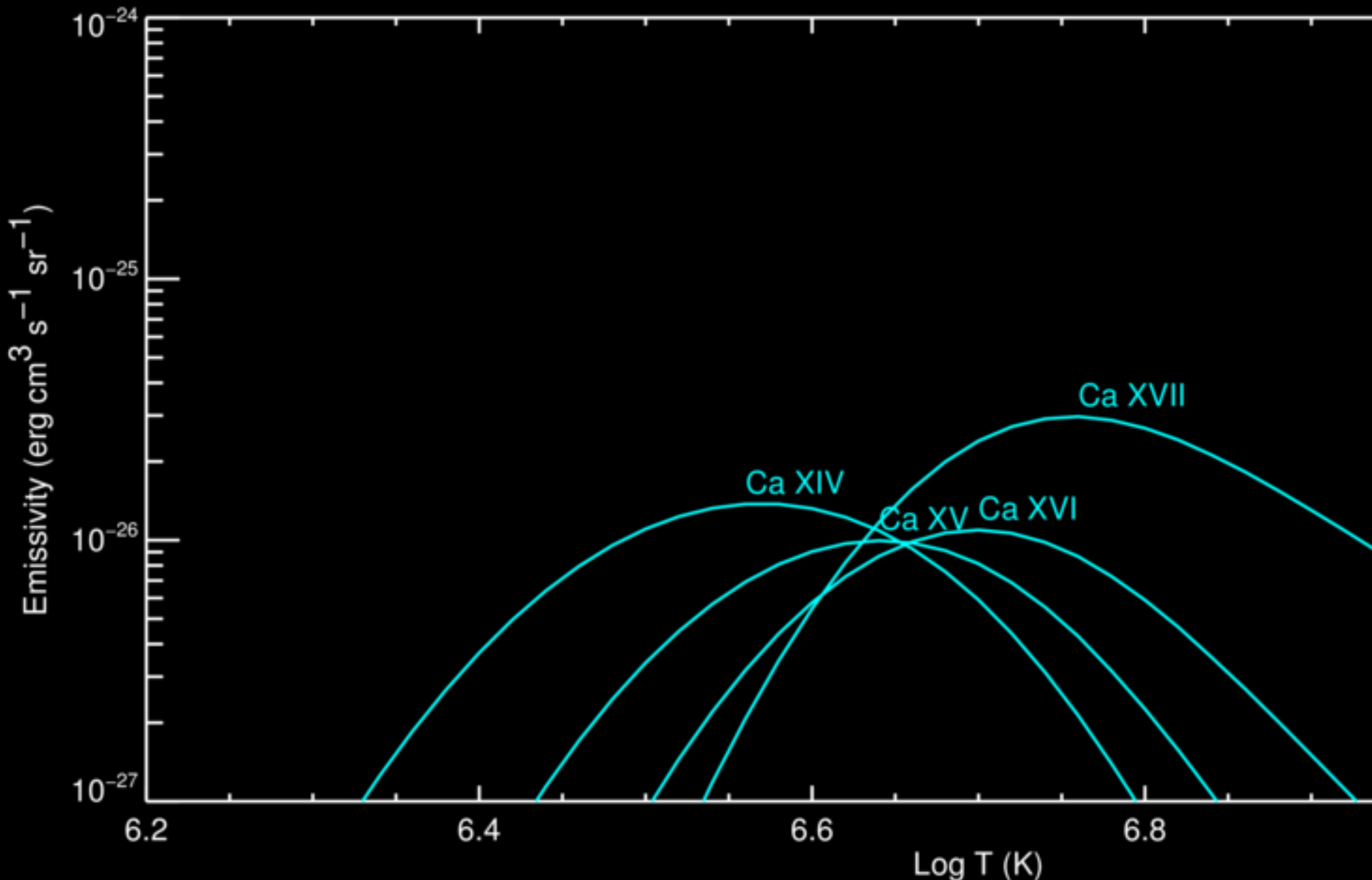
convert to an integral over temperature

need many lines

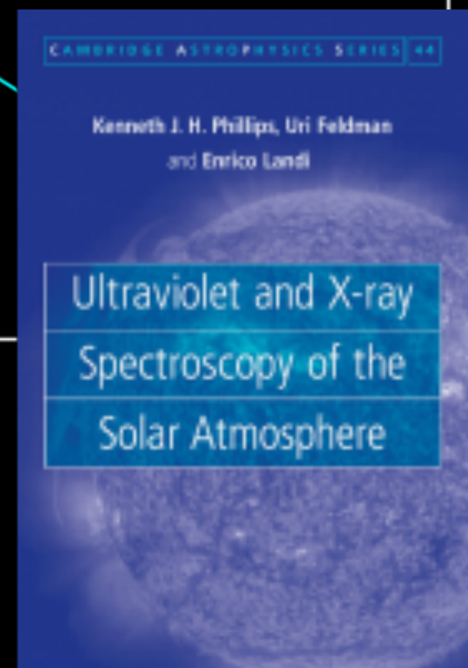
$$I_\lambda = \int_{T_e} \epsilon_\lambda(T_e) \xi(T_e) dT_e$$

inversion is noisy ⇒ regularize or smooth

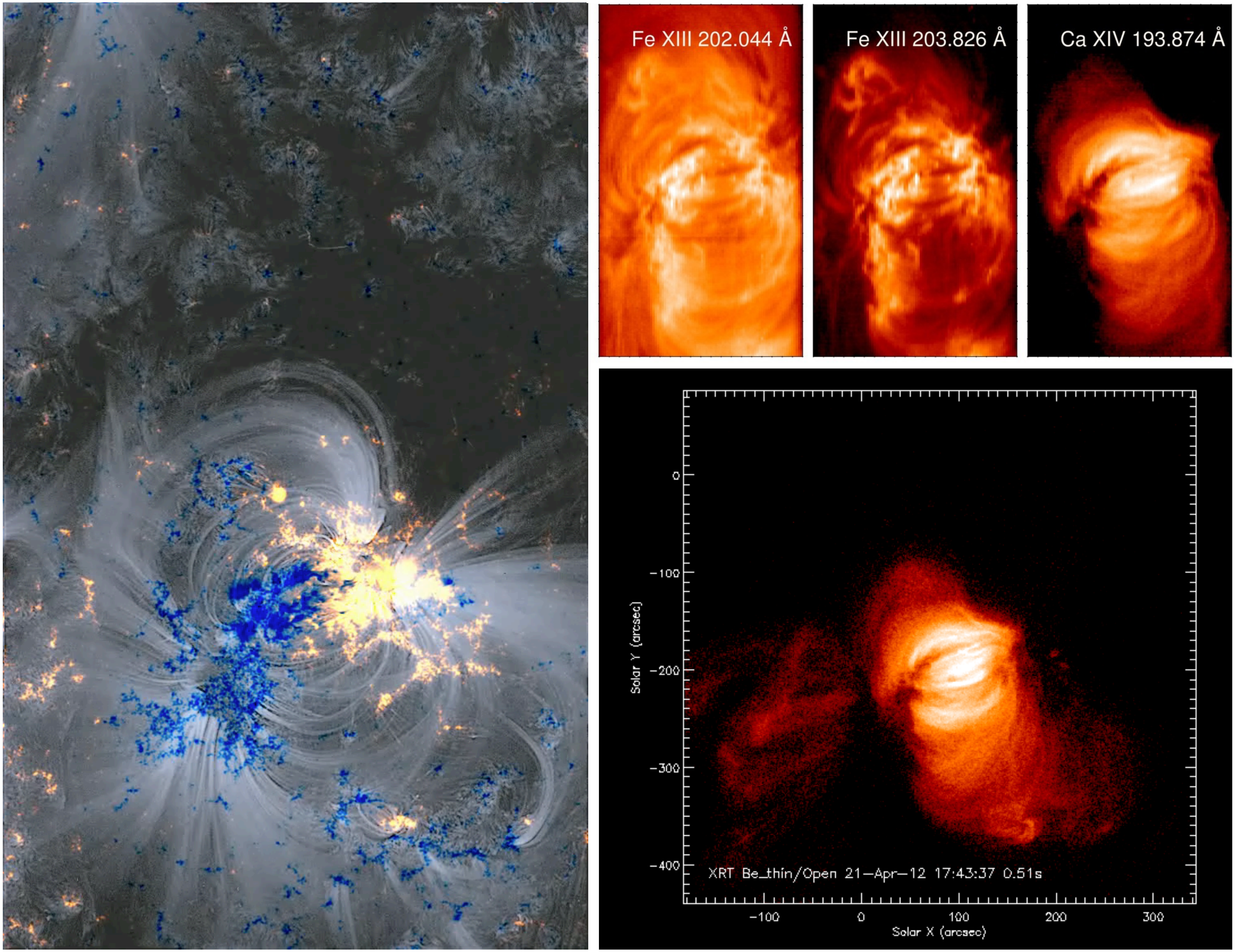
# Example Emissivities

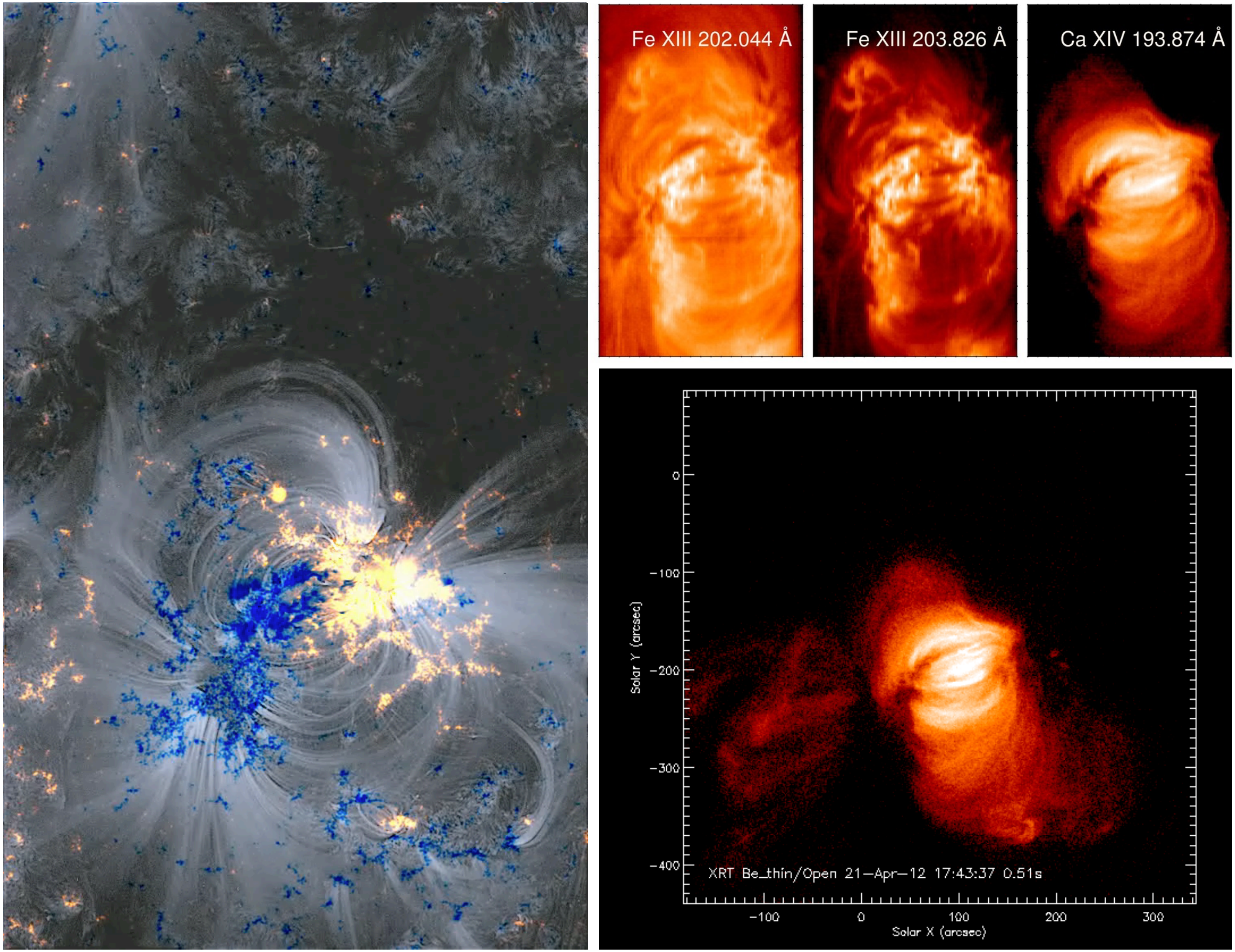



$$I_\lambda = \int_{T_e} \epsilon_\lambda(T_e)\xi(T_e)dT_e$$




Phillips, Feldman, and Landi


Fe XIII 202.044 Å
Fe XIII 203.826 Å
Ca XIV 193.874 Å
0
-100
-200
-300
-400
Solar Y (arcsec)
XRT Be_thin/Open 21-Apr-12 17:43:37 0.51s
-100
0
100
200
300
Solar X (arcsec)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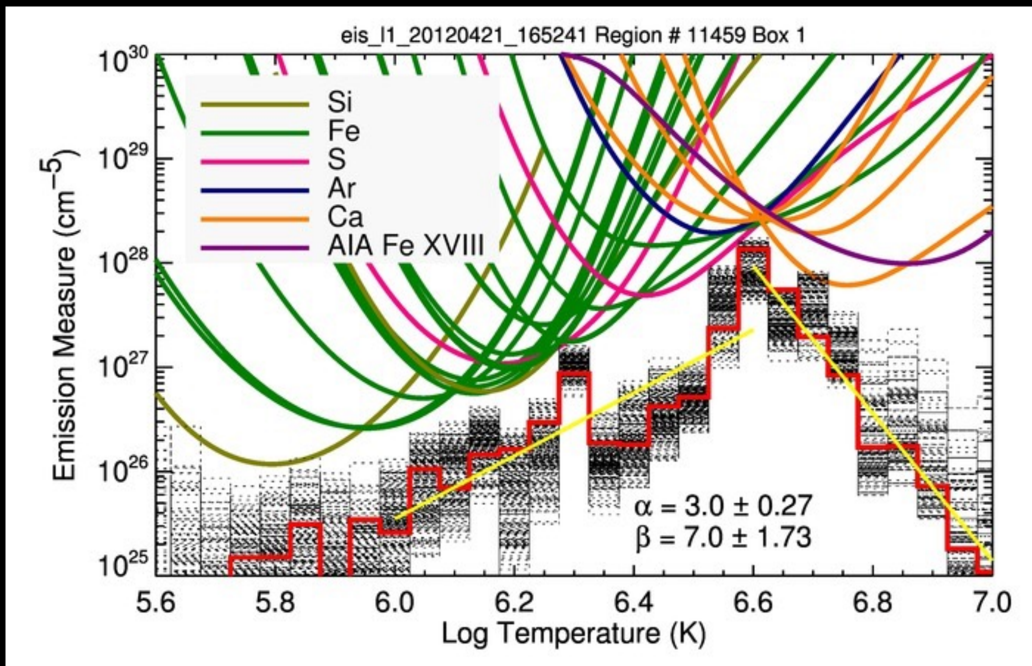
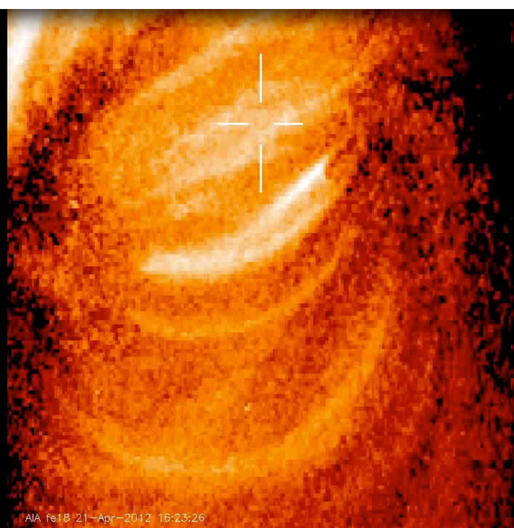
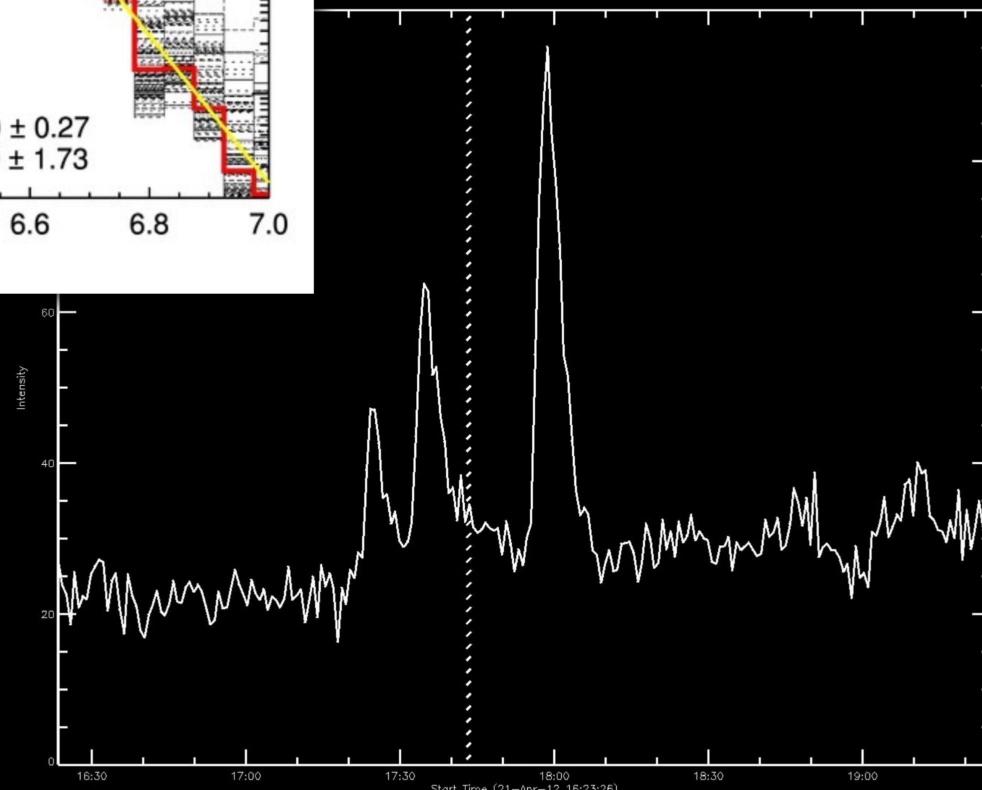
Solar Y (arcsec)
Solar X (arcsec)
0
–100
–200
–300
–400
–100
0
100
200
300

# Example DEM Calculation

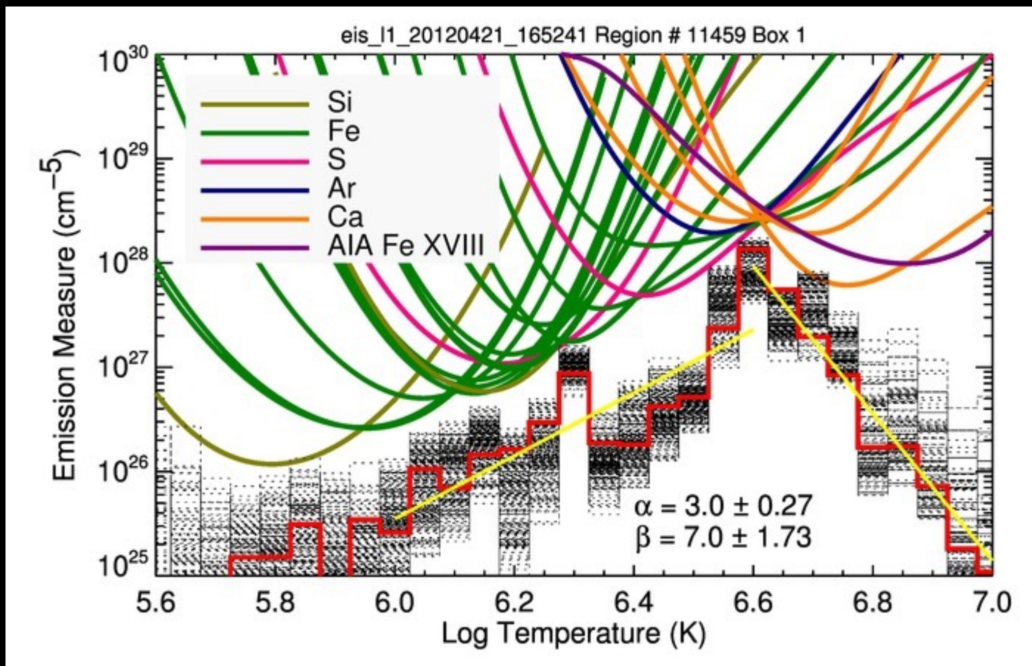



AIA Fe XVIII

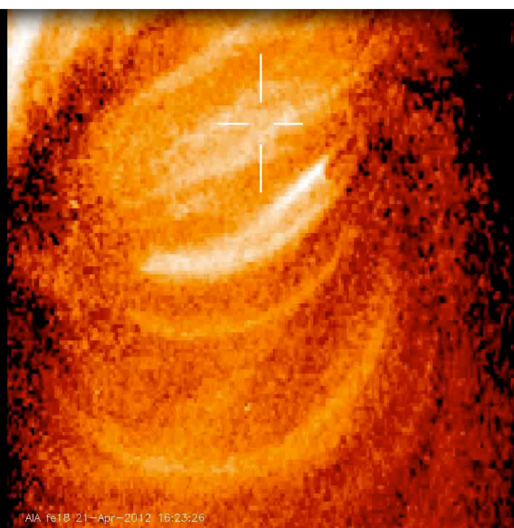


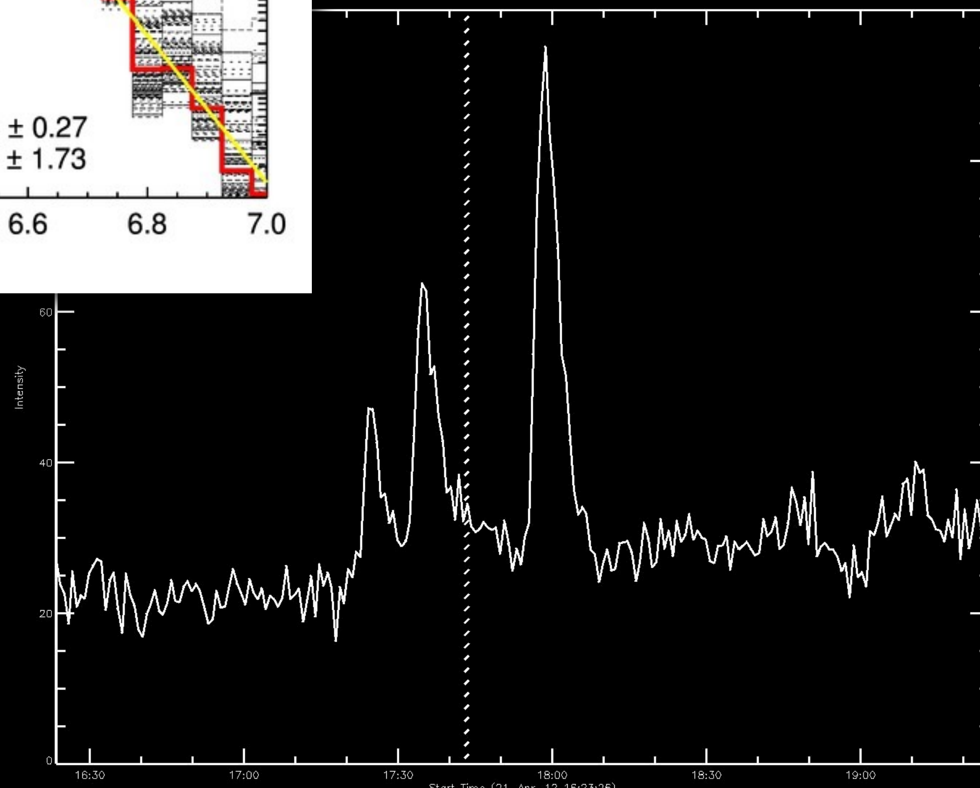



# Example DEM Calculation



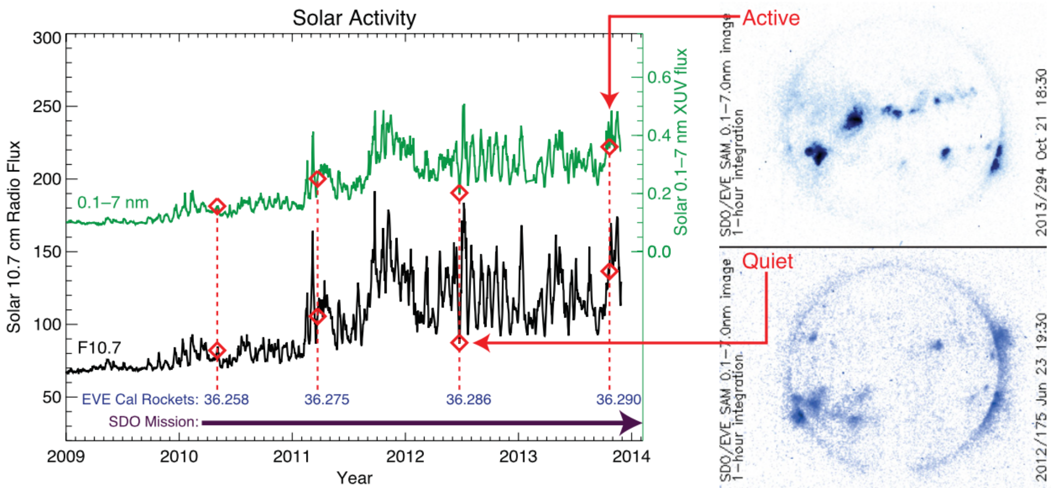

AIA Fe XVIII

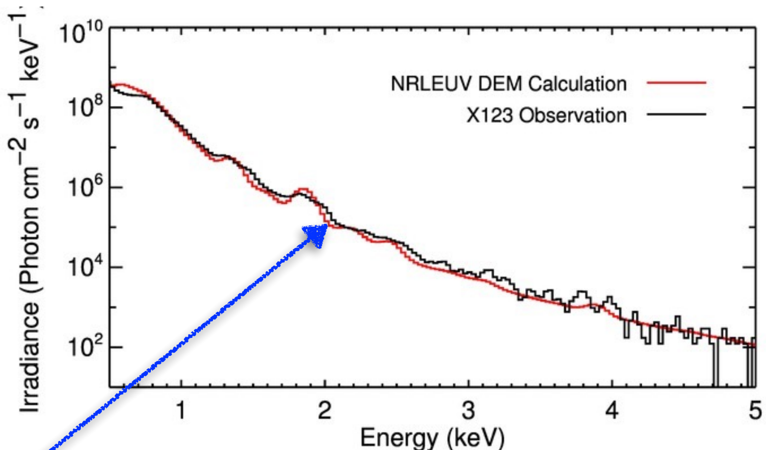


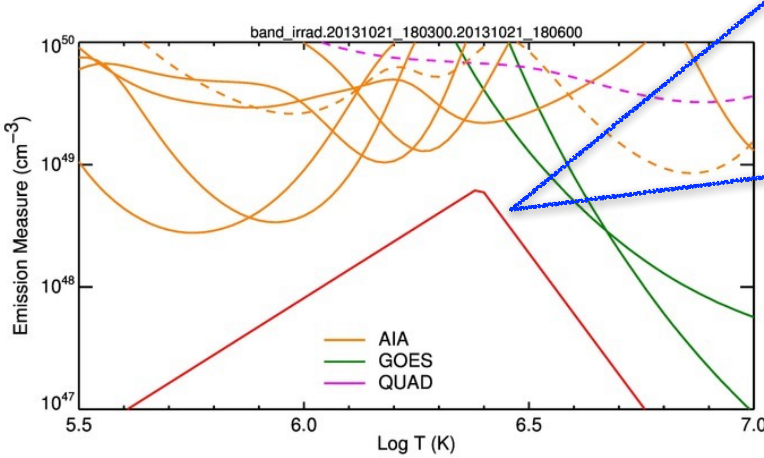



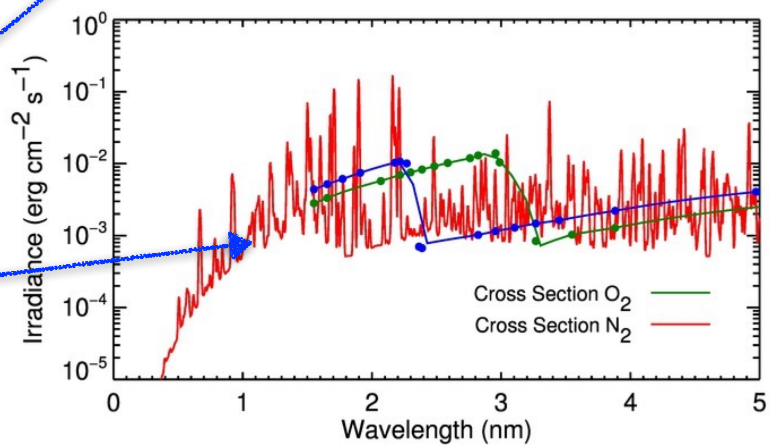
# Example SXR Irradiance Spectrum
# New Observations from X123

Caspi, Woods, & Warren (2015)



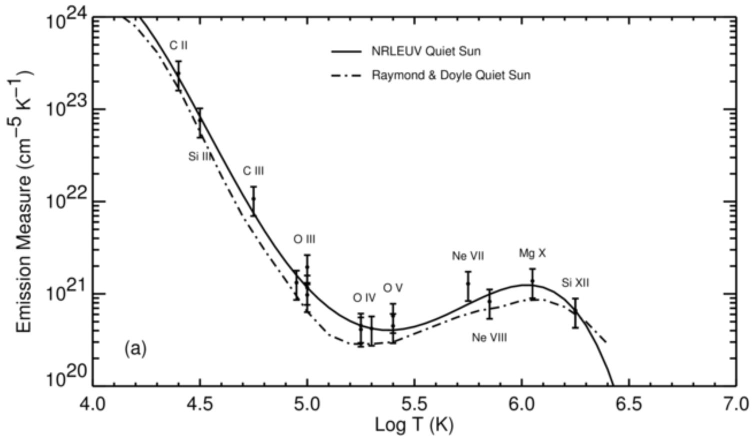



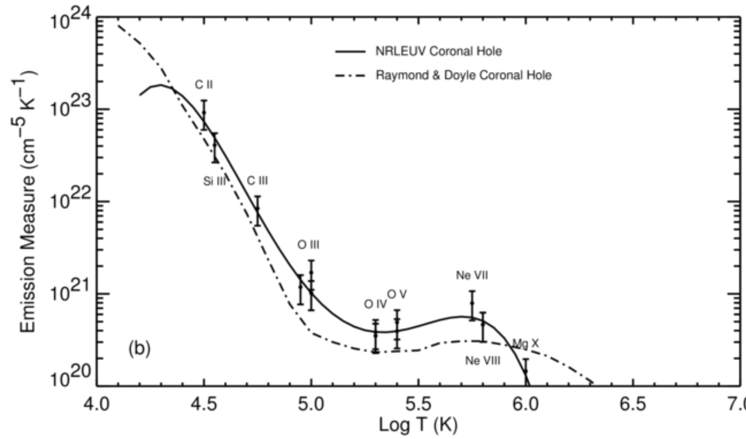



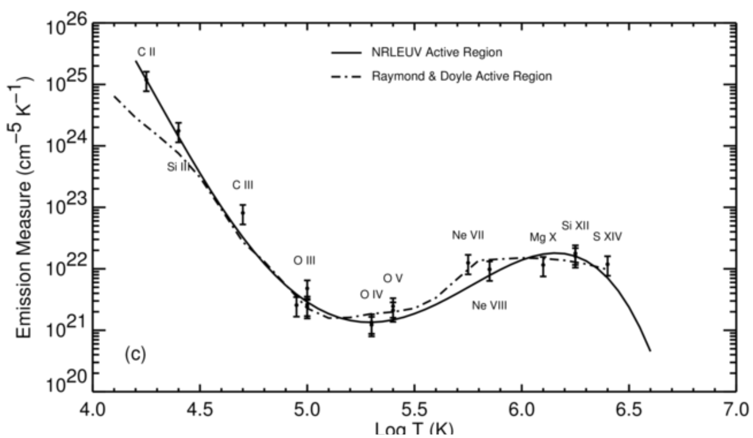

infer spectra from
emission measure model?

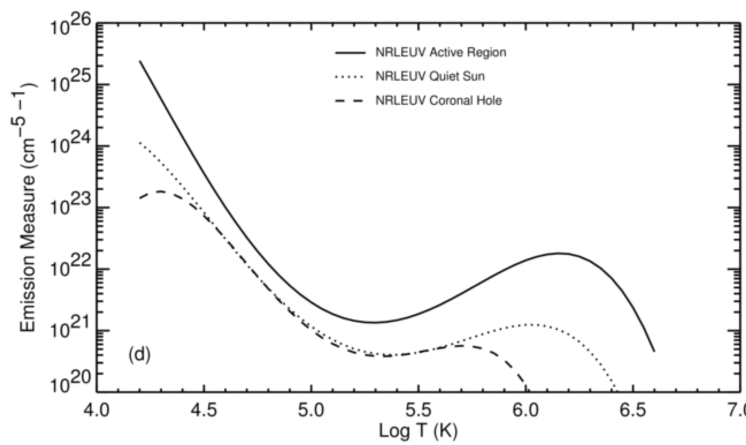
MinXSS: LASP CubeSat
X123 SXR Detector
2015 launch

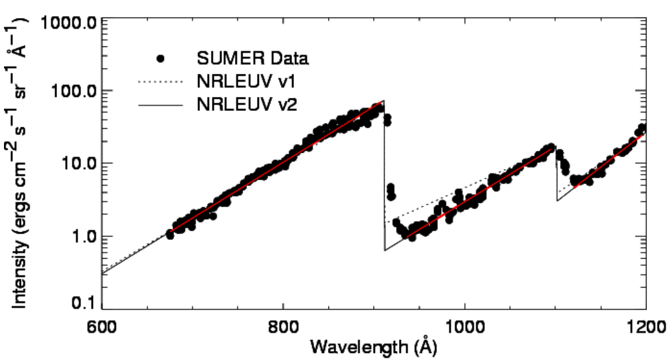
# Example Emission Measure Distributions



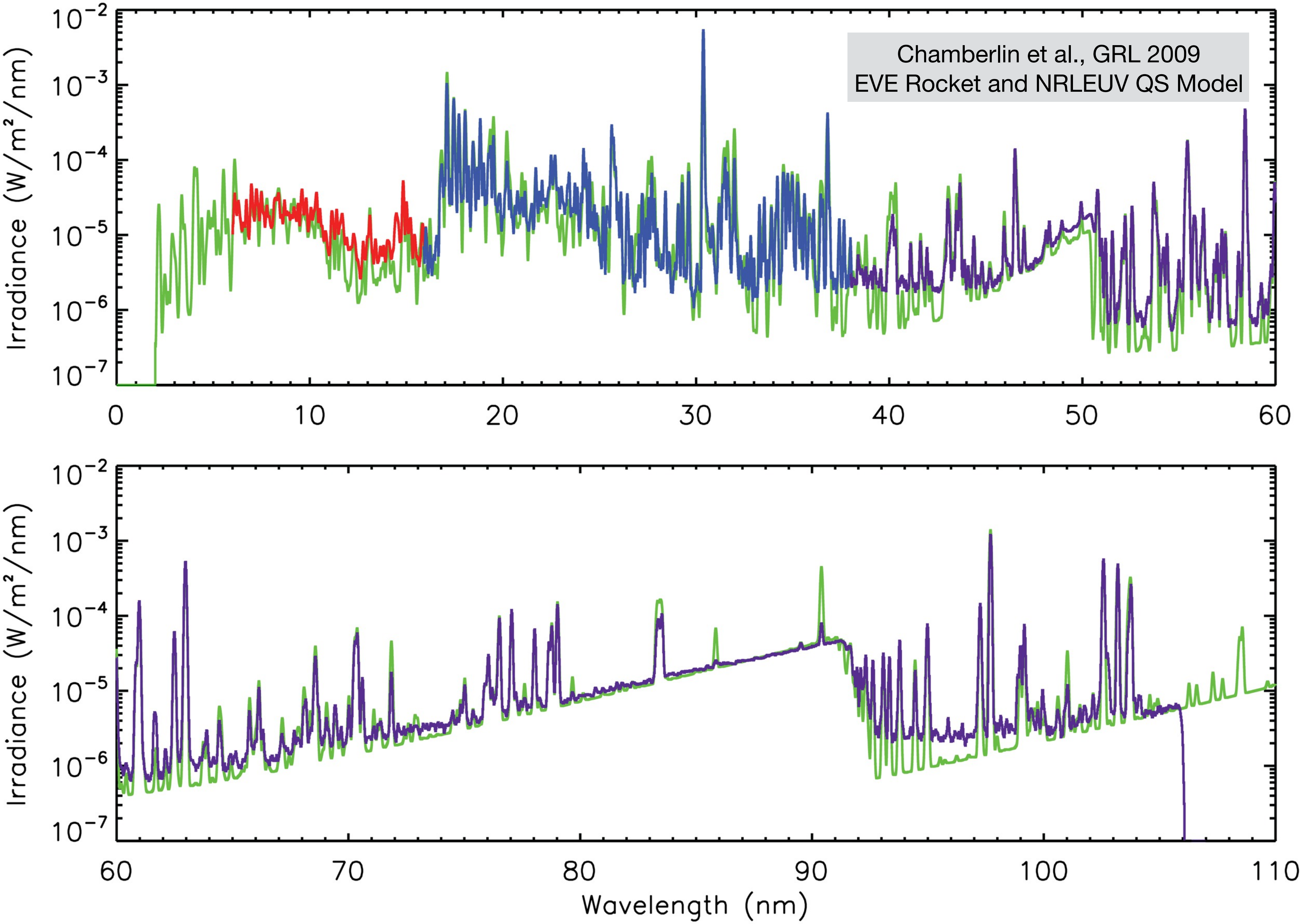



# EUV: 50-1200 Å



Chamberlin et al., GRL 2009
EVE Rocket and NRLEUV QS Model
Irradiance (W/m²/nm)
10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷
0 10 20 30 40 50 60
60 70 80 90 100 110
Wavelength (nm)

# Wrapping Up: What do I wish I knew when I was your age?

- Computation
  - IDL (for now) [“Modern IDL” Galloy]
  - python (for the future)
  - Java/C++/C (some compiled language)
  - Object oriented programming (even in IDL)
  - Version control (git or svn)
  - Algorithms
- Statistics
  - Bayesian inference
- How to write
  - “The Sense of Style” by Steven Pinker
- How to give a talk
  - “Presentation Zen” by Garr Reynolds
  - “Slide:ology” by Nancy Duarte
- Have mentors - three?
  - Someone senior
  - Someone your age
  - Someone younger
- Think about a day job
  - Soft money = proposals!
- Don’t be afraid