Solar EUV Proxies:
Why would you want to use anything else?

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Outline

- **Solar EUV Spectra (min – max – flares)**
- **Solar EUV Proxies (SSN – F10 – MgII)**
- **Where do proxies work?**
- **Where do proxies fail?**

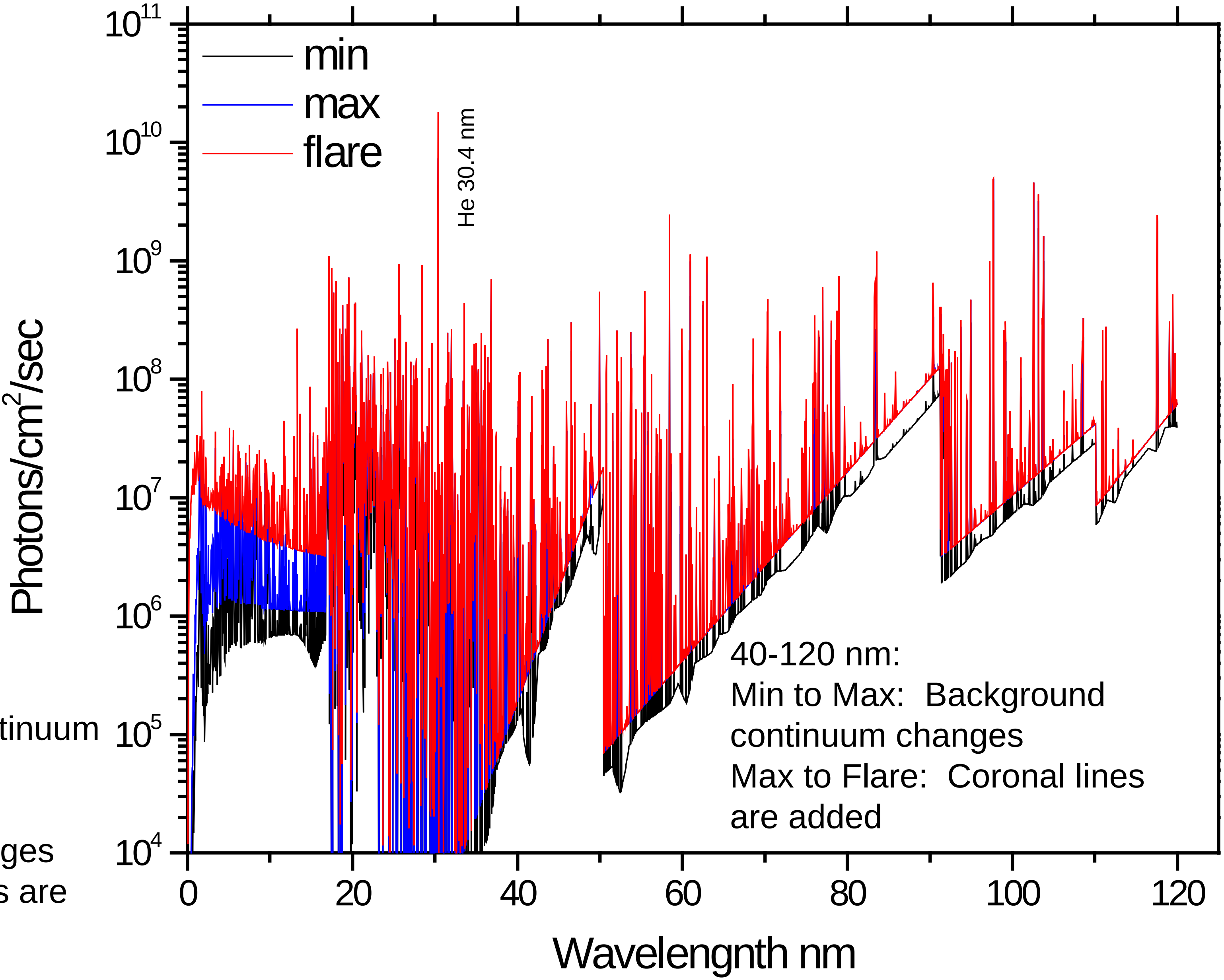
Solar EUV Irradiance

- Critical to the formation of the ionosphere
- Critical in heating the ionophsphere/thermosphere system

- Very difficult to observe over long time spans
  - Must be observed from space
  - Difficult to obtain sensor stability over many years
  - Often requires calibration rocket under flights to remove sensor degradation
- EUV irradiance is typically represented by proxies
  - F10.7 cm, Sunspot Number, MgII, etc….

Solar EUV Spectra

For solar min, solar max, and solar flares



0-40 nm:
Min to Max: Background continuum changes
Max to Flare: Continuum changes and coronal lines are added

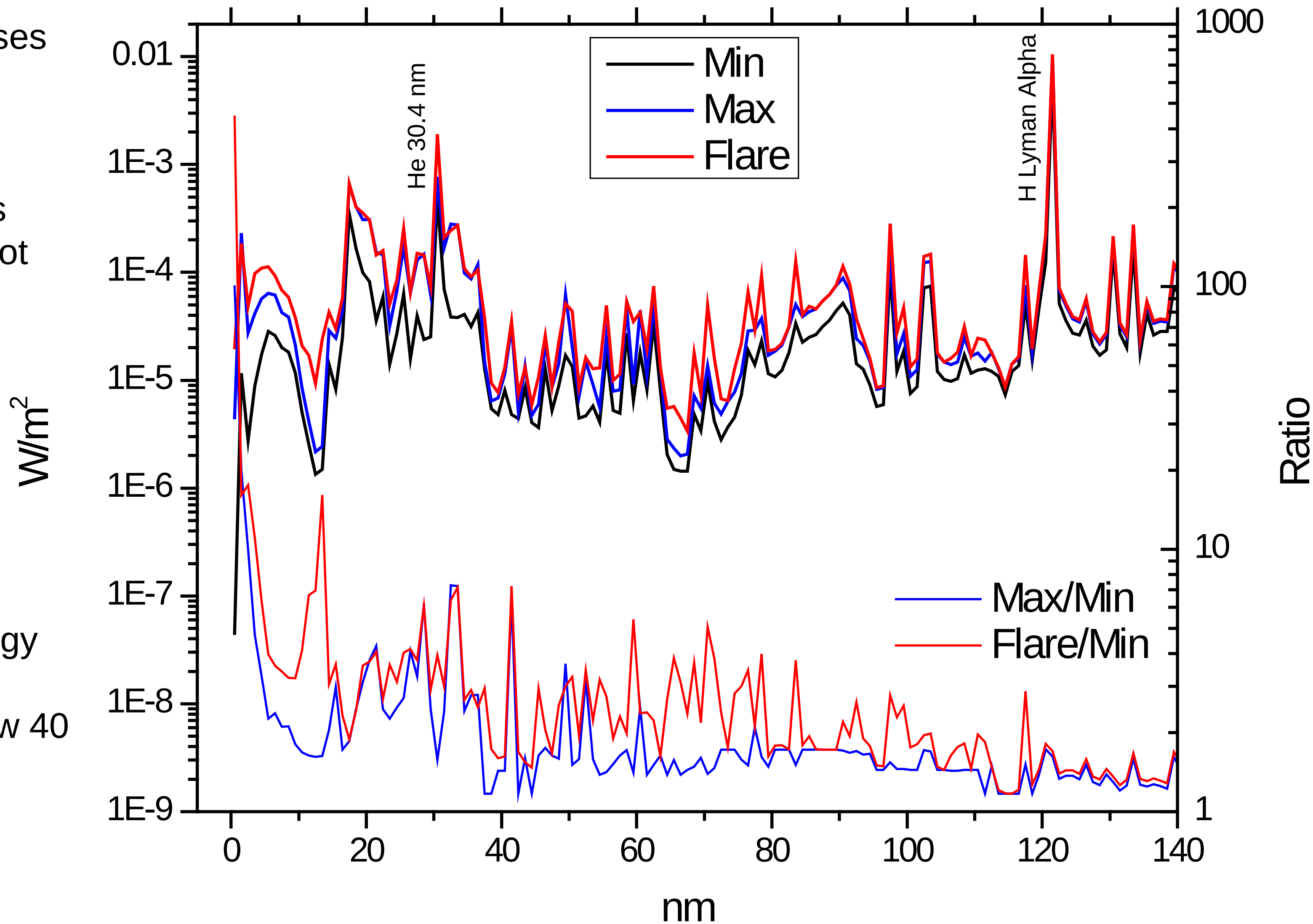
40-120 nm:
Min to Max: Background continuum changes
Max to Flare: Coronal lines are added

Changes in Solar EUV Spectra

Variability increases with decreasing wavelength

H Lyman alpha is bright but does not vary much

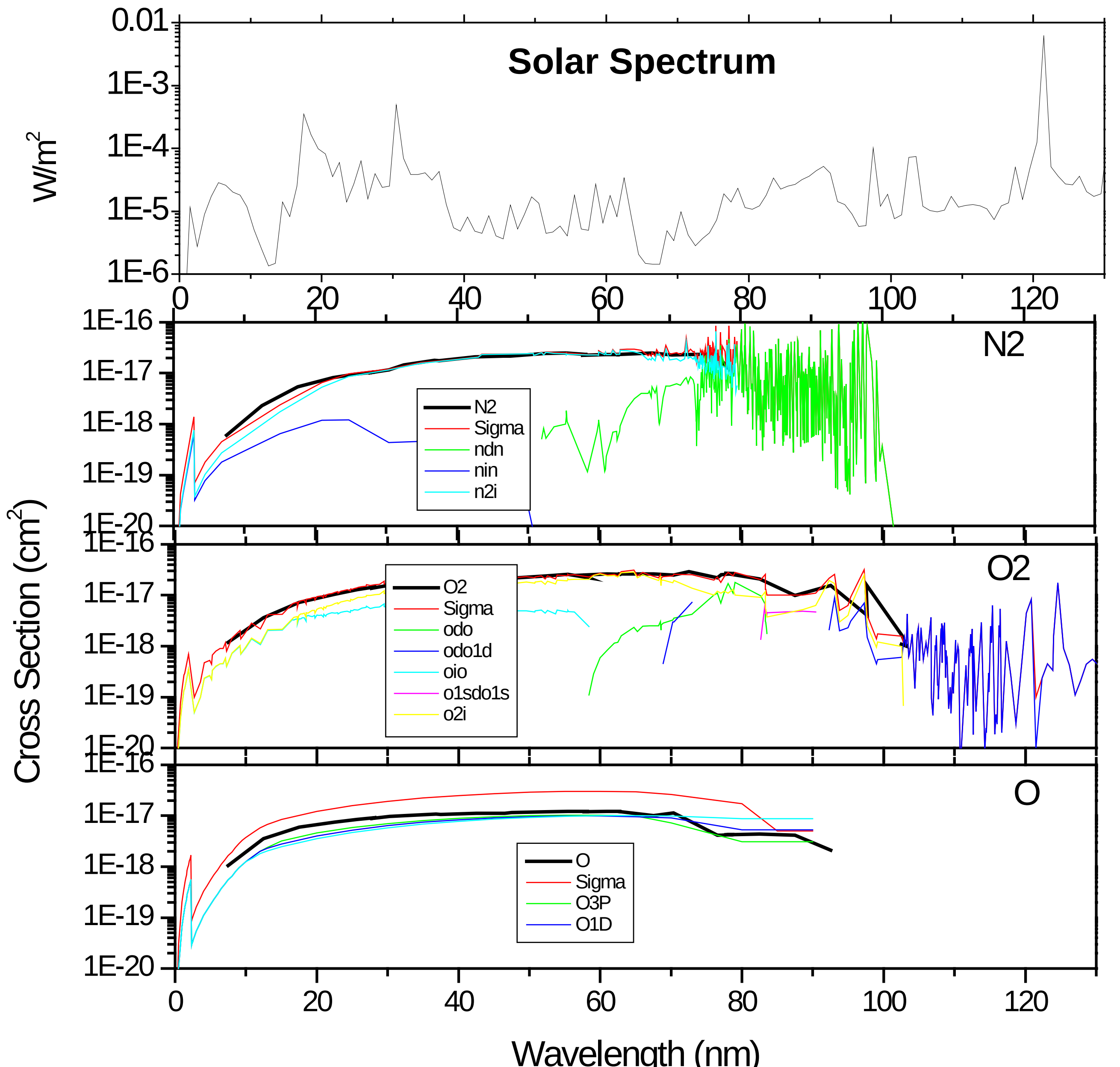
Much of the energy and much of the variability is below 40 nm

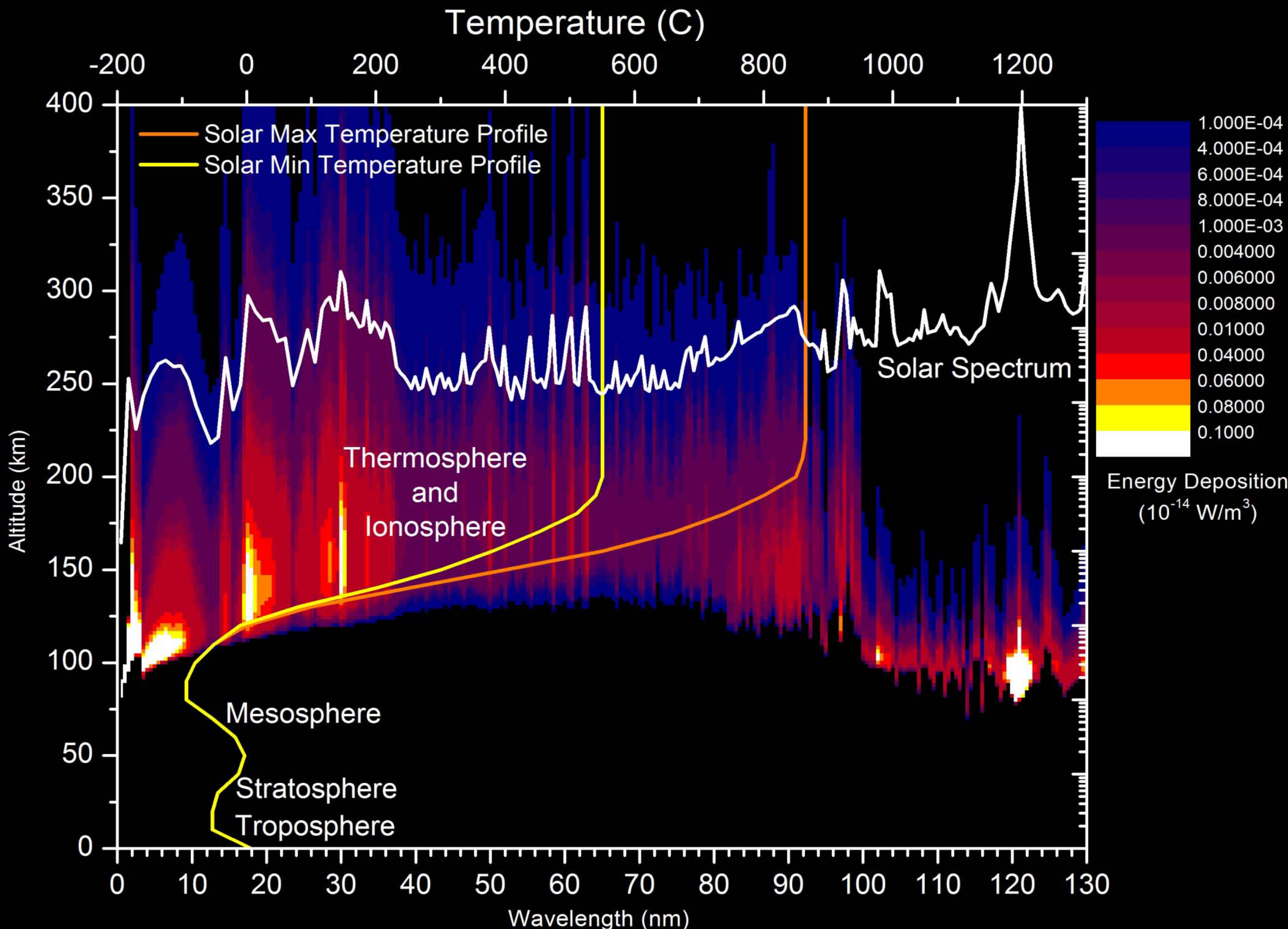


Solar Spectrum and Absorption Cross Sections

Solar EUV Photons collide with O, O2, and N2 in the thermosphere.

They heat and ionize the atmosphere





Solar spectrum (white) and where it is absorbed in the atmosphere (colors)

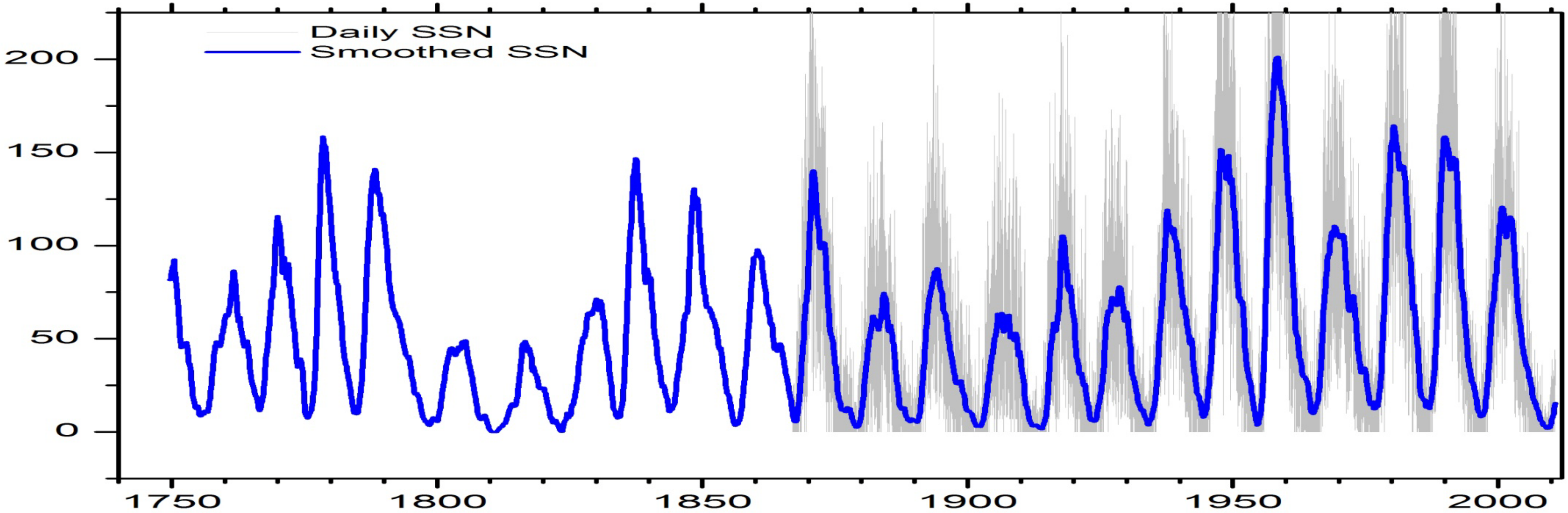
EUV Models

- Hinteregger (1970)
- Nusinov (1984)
- EUVAC (Richards, 1994)
- Solar2000 (Tobiska, 2000)
- FISM (Chamberlain, 2008)

Solar EUV Time Series

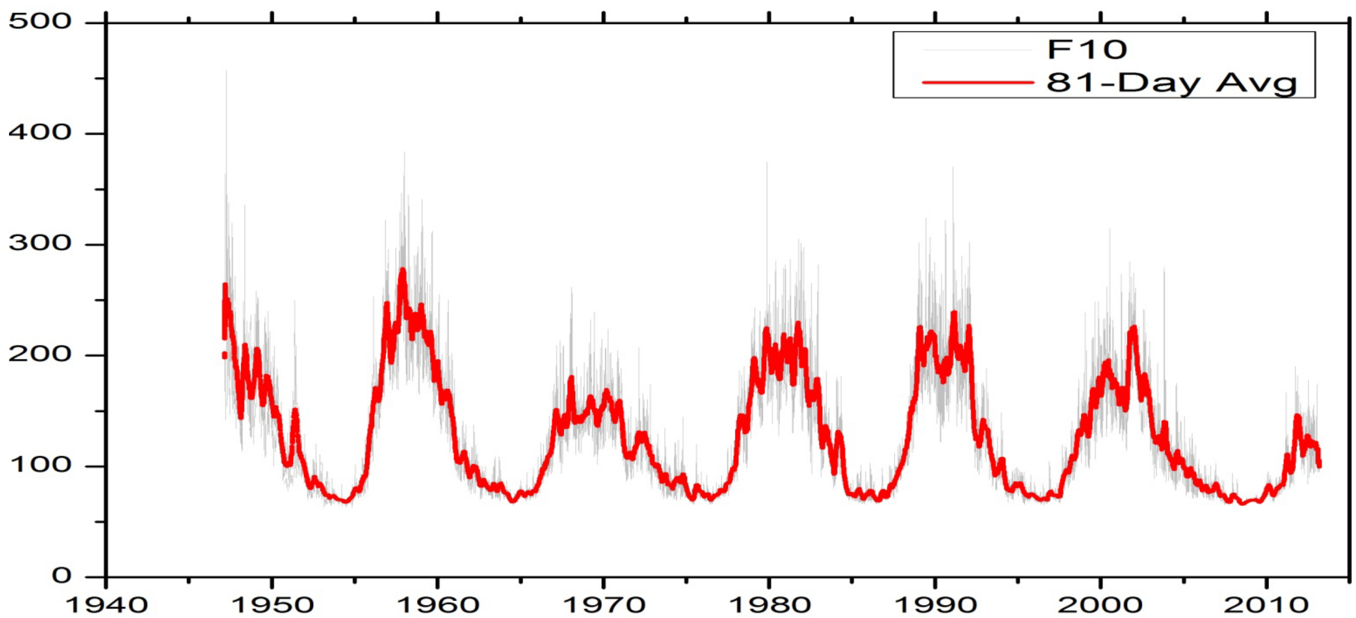
- **Very few exist over long time periods:**
  - **It is difficult to measure solar EUV irradiance**
  - **It is difficult to establish and maintain calibrations**
- **No continuous EUV measurements that span decades**
- **Proxies are required**
  - **Sunspot Number**
  - **F10.7**
  - **Mg II core-to-wing ratio**

Proxies for Solar EUV

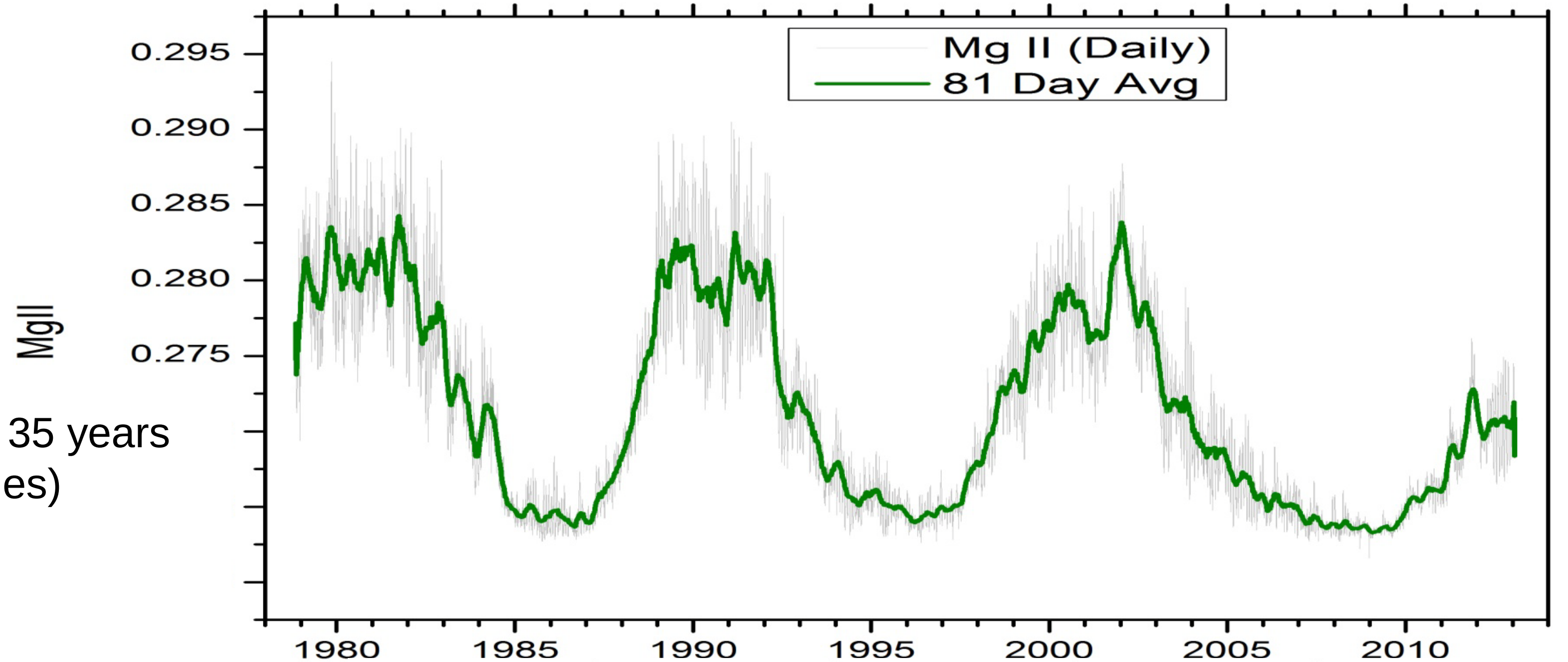


Sunspot Number provides the longest record

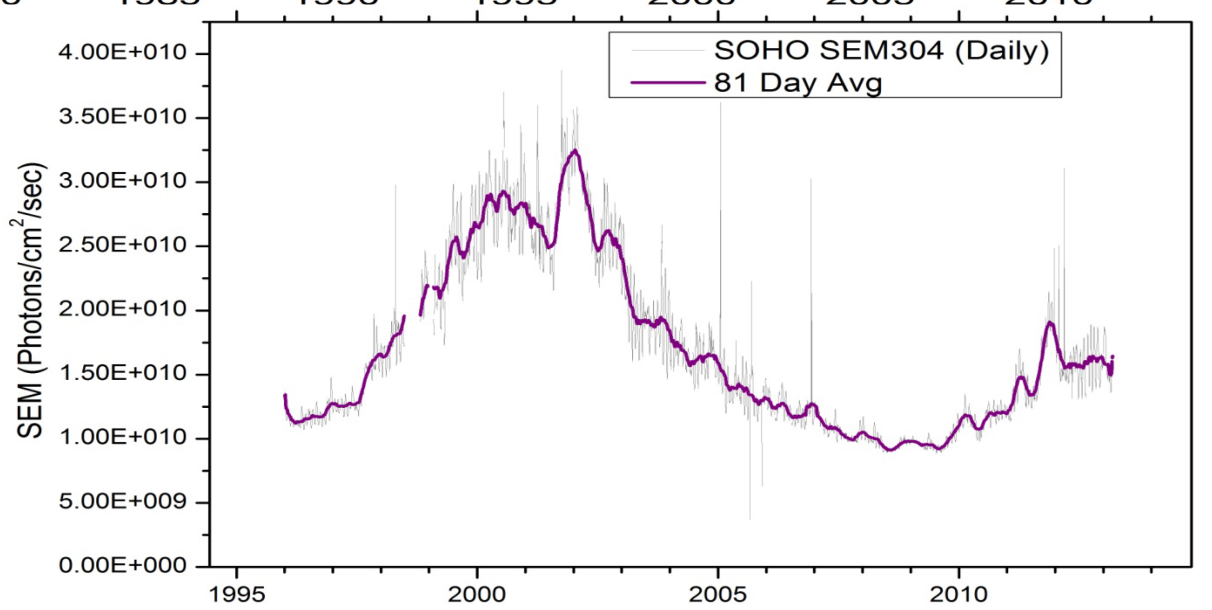
F10.7 provides a reasonably long record covering all of the modern era where ionospheric variability and space weather impacts are most important



Another Proxy and some Actual EUV



The MgII spans 35 years (three solar cycles)



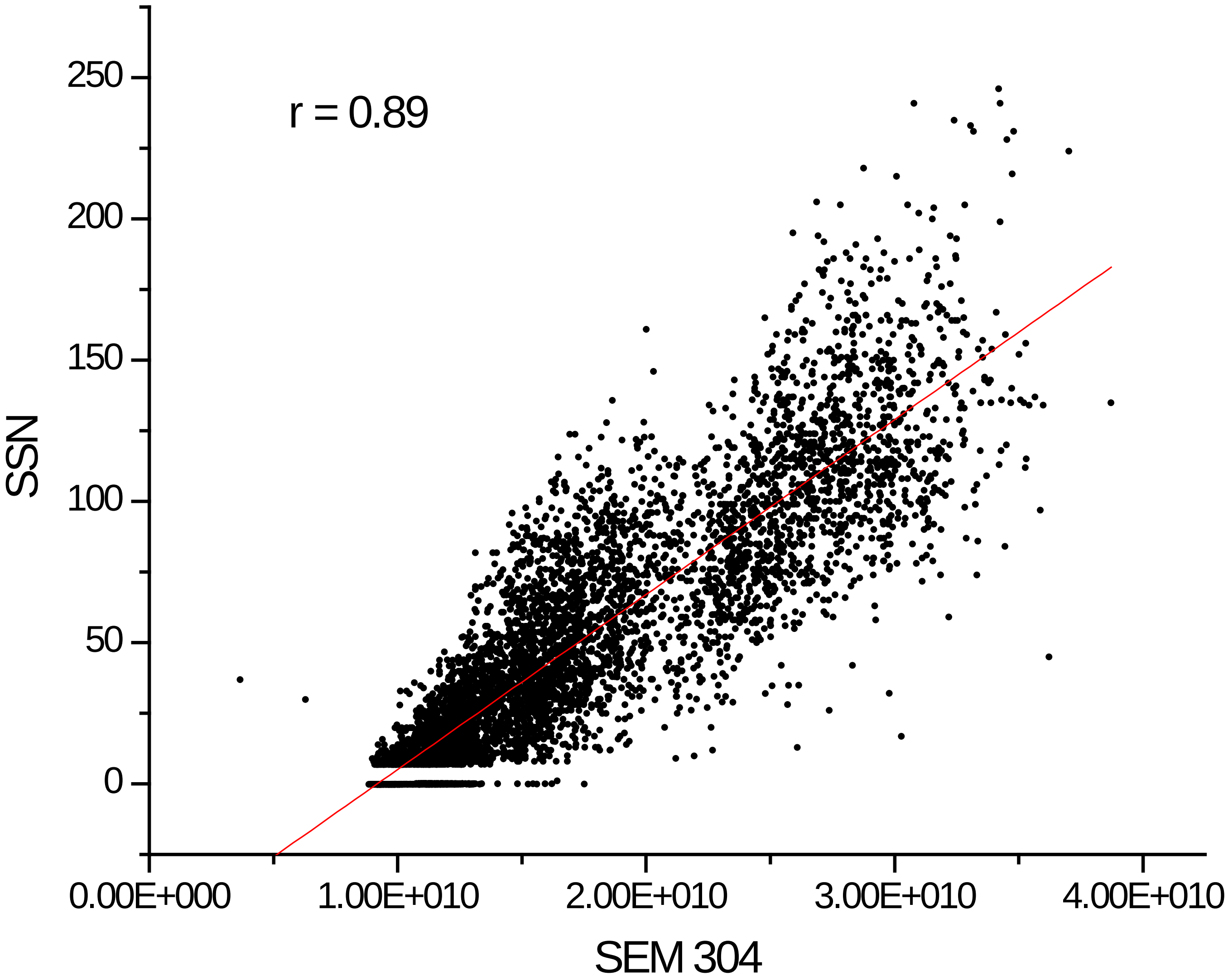
SOHO Solar EUV Monitor. The longest continuous solar EUV irradiance record. It measures two wavelength bands

1. 1-7 nm
2. 28 – 34 nm (He 304)

Sunspot vs SEM 304

Sunspot Number has been used as a proxy for solar EUV irradiance. But it can be off by as much as ±70%

Note that the SSN record goes to zero at solar minimum.

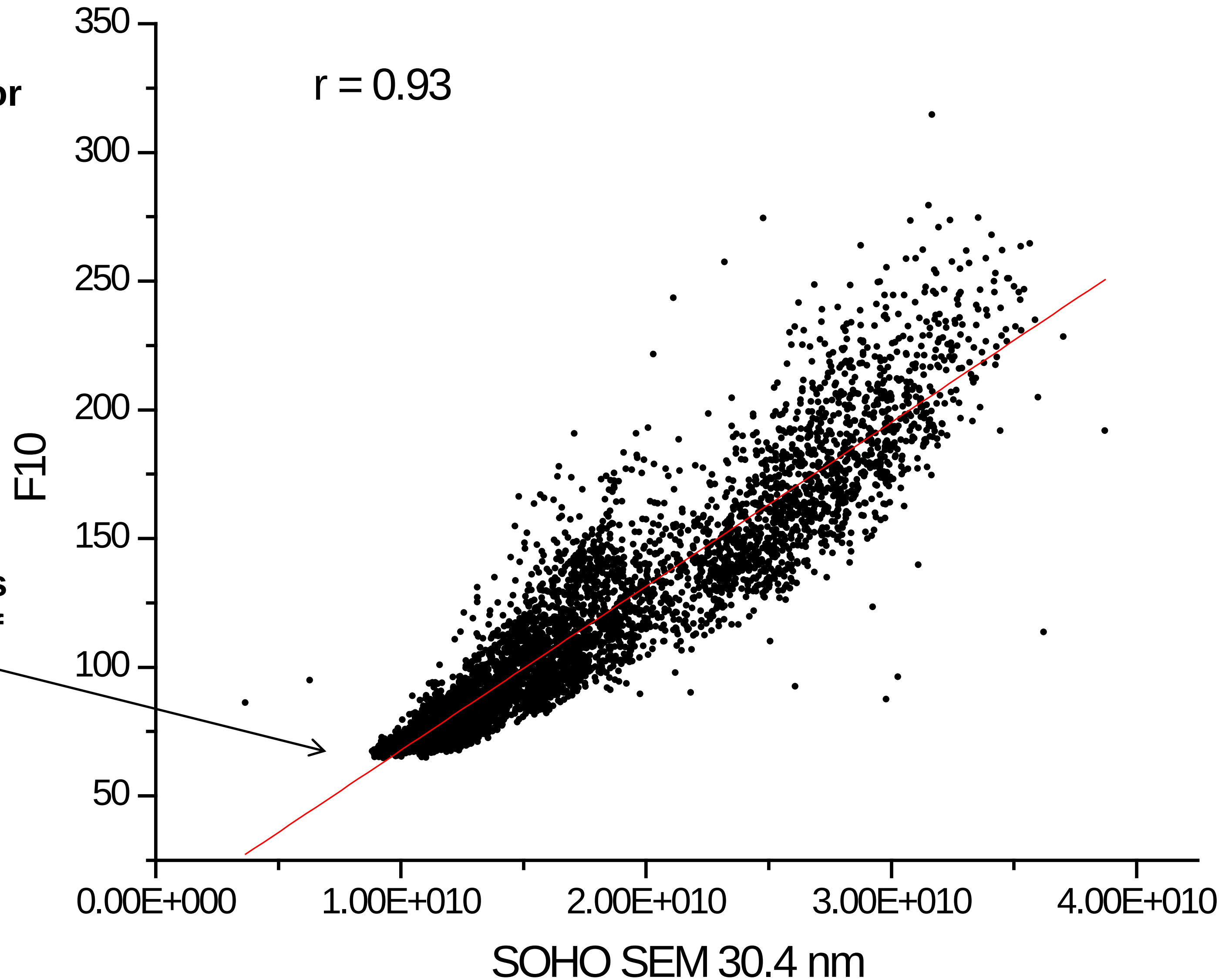


F10 vs SEM 304

F10 is a good proxy for solar EUV.

Note, this is just F10 and does not include any smoothed F10.

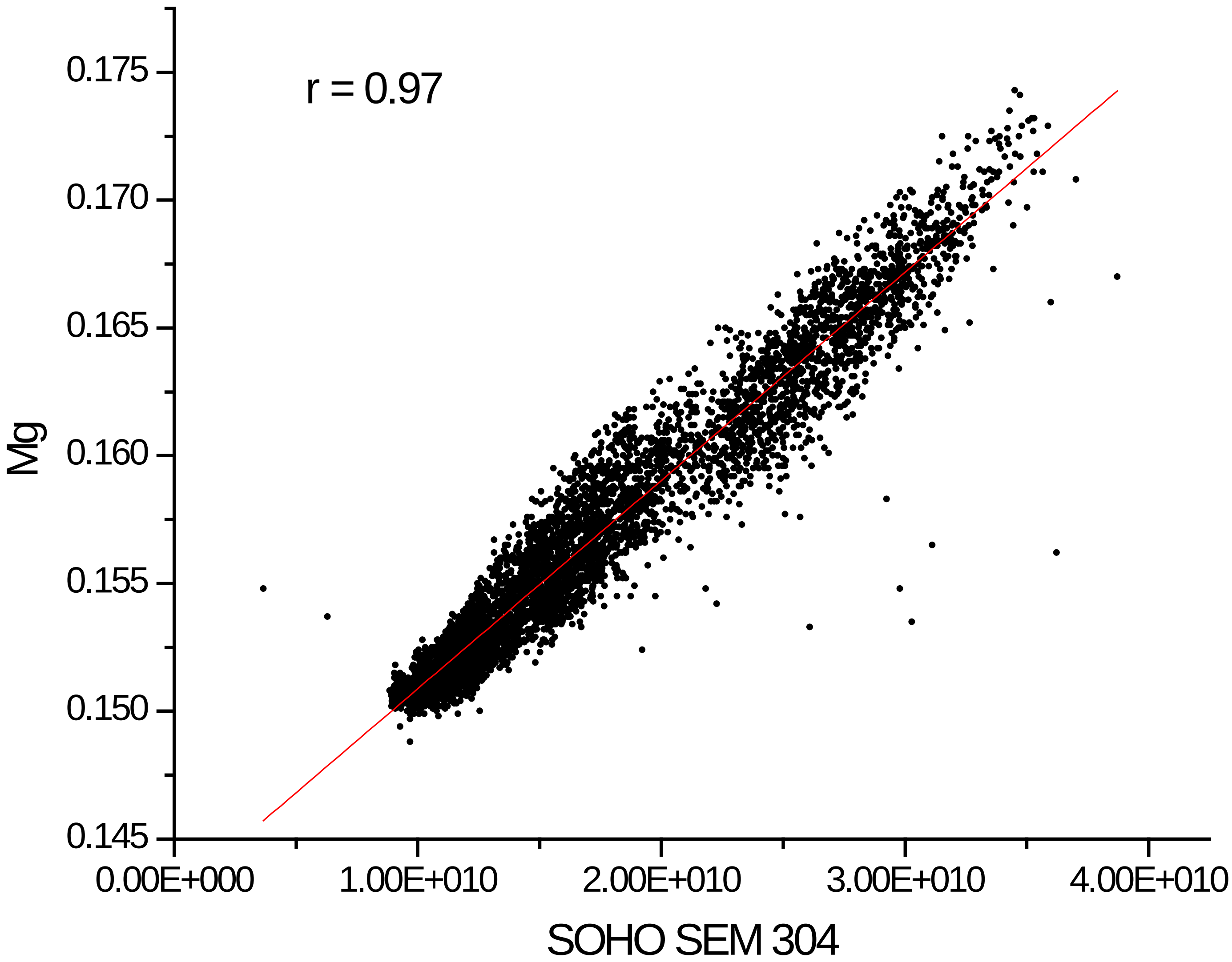
Note also that F10 has a tendency to level off near solar minimum



Mg II vs SEM 304

Mg II is a better proxy for solar EUV with a correlation of r = 0.97.

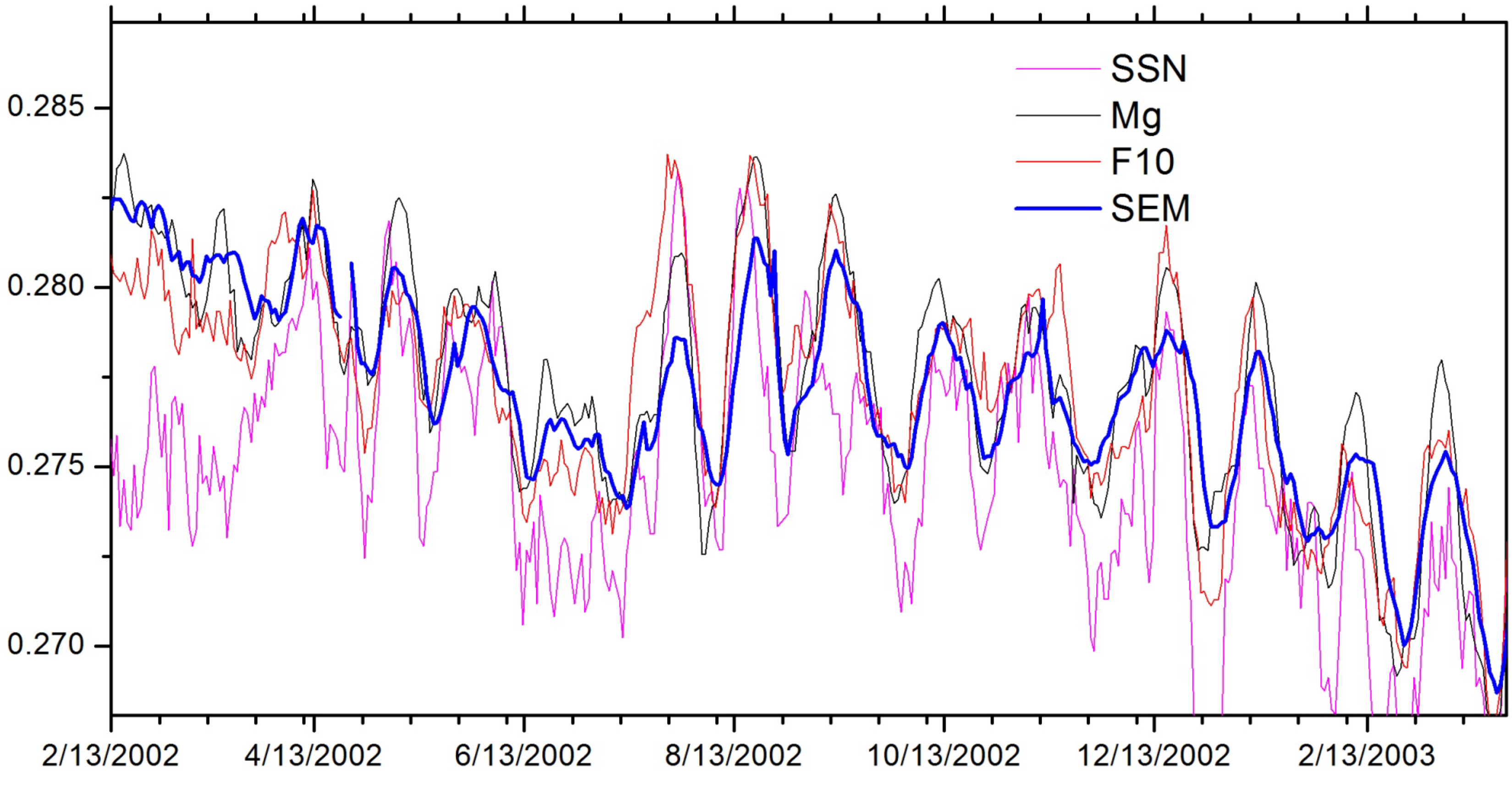
Note, this is just MgII and does not include any smoothed MgII.



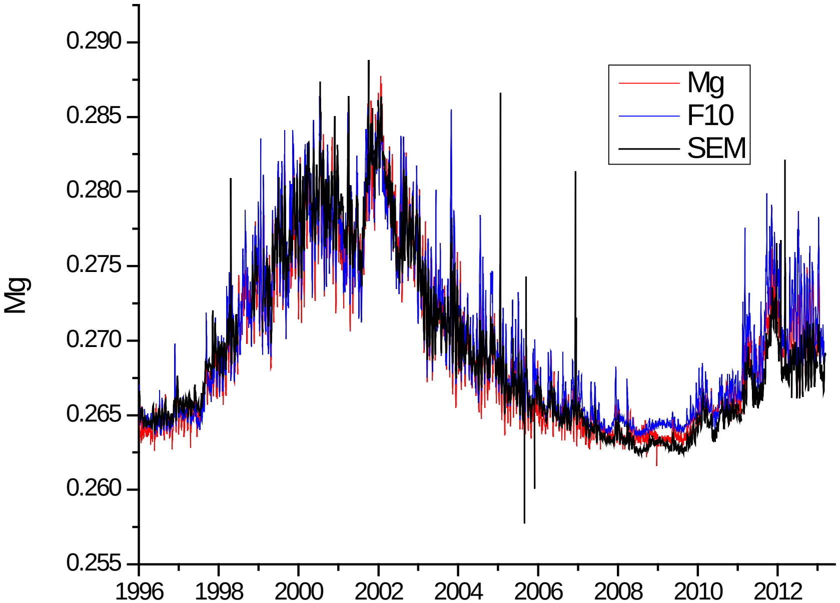
Proxies vs Actual EUV

SSN really should not be used as a proxy for solar EUV except for climatology studies.

F10 and Mg tend to overestimate the magnitude of the solar rotation

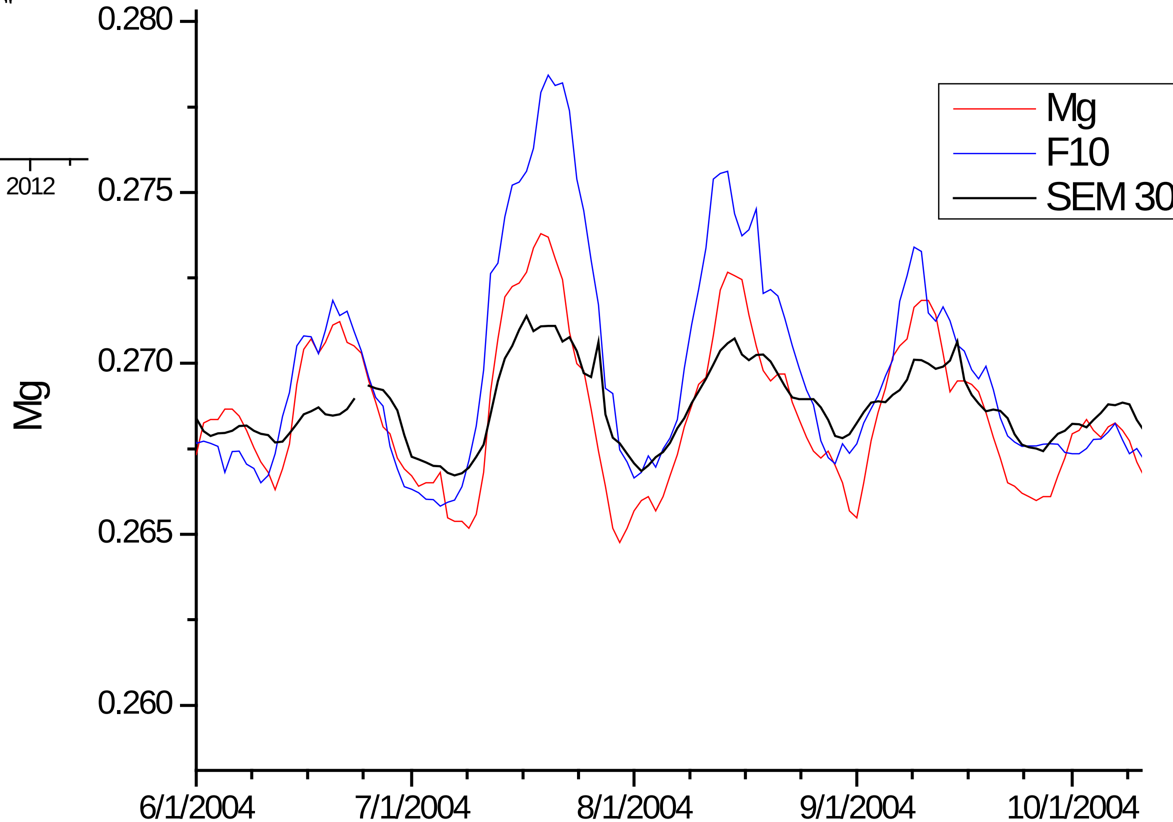


Proxies



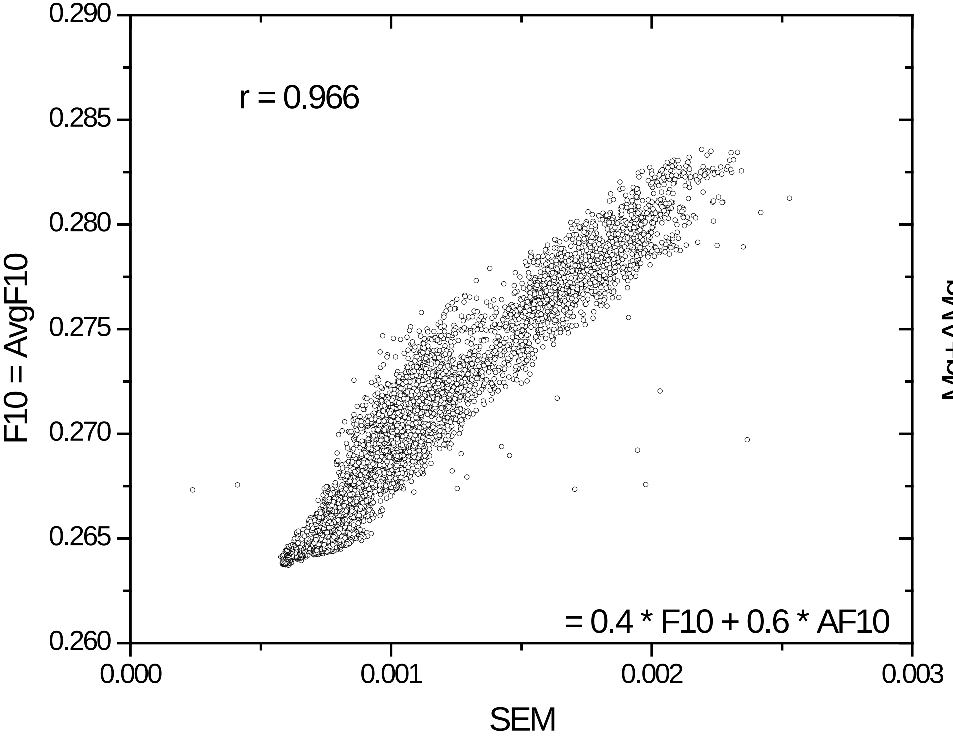
F10 and MgII capture the major features of the solar cycle…

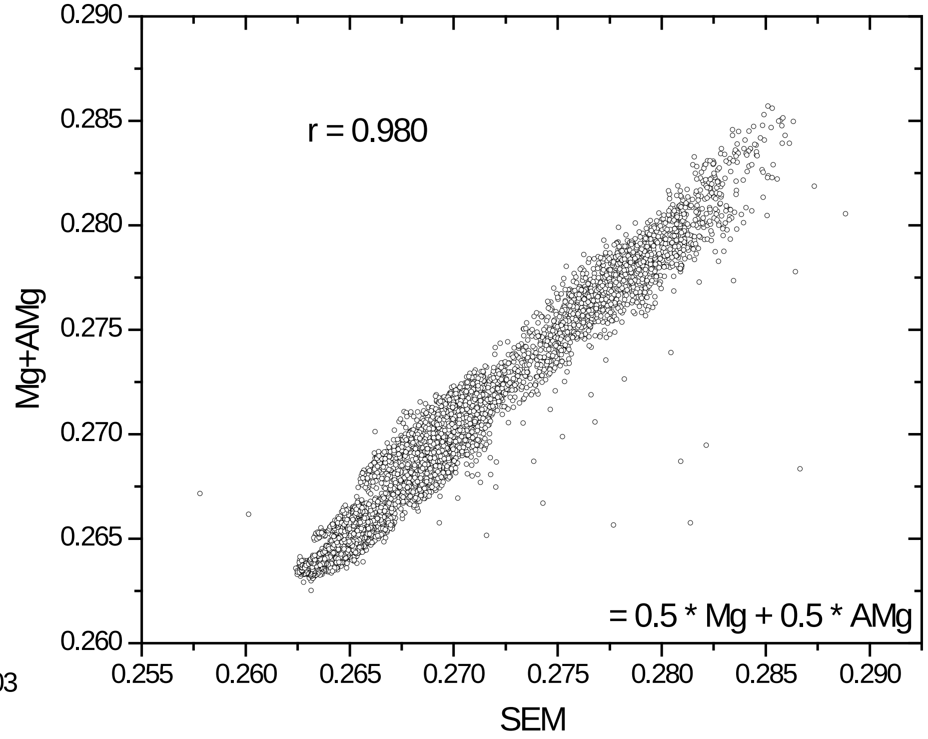
But over estimate the solar rotation amplitude



Mg and F10

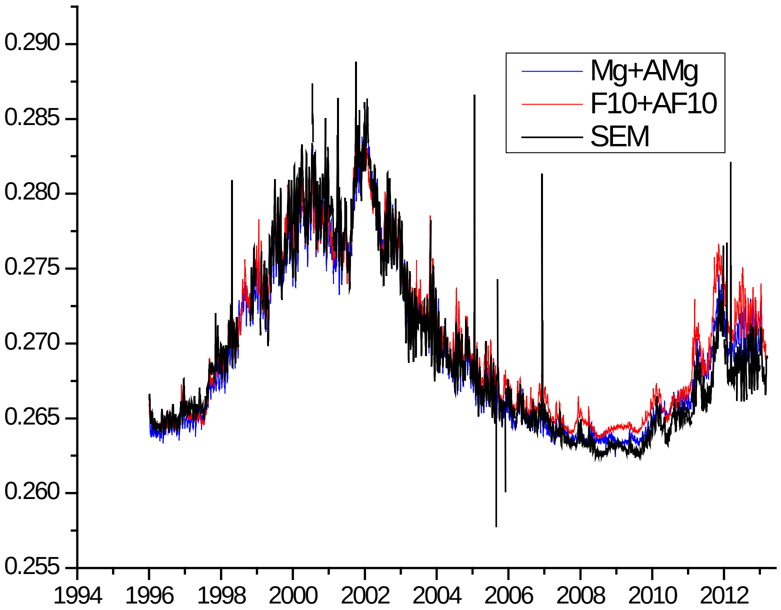
- **Combining the daily with an 81-day average helps to minimize the over-estimation**





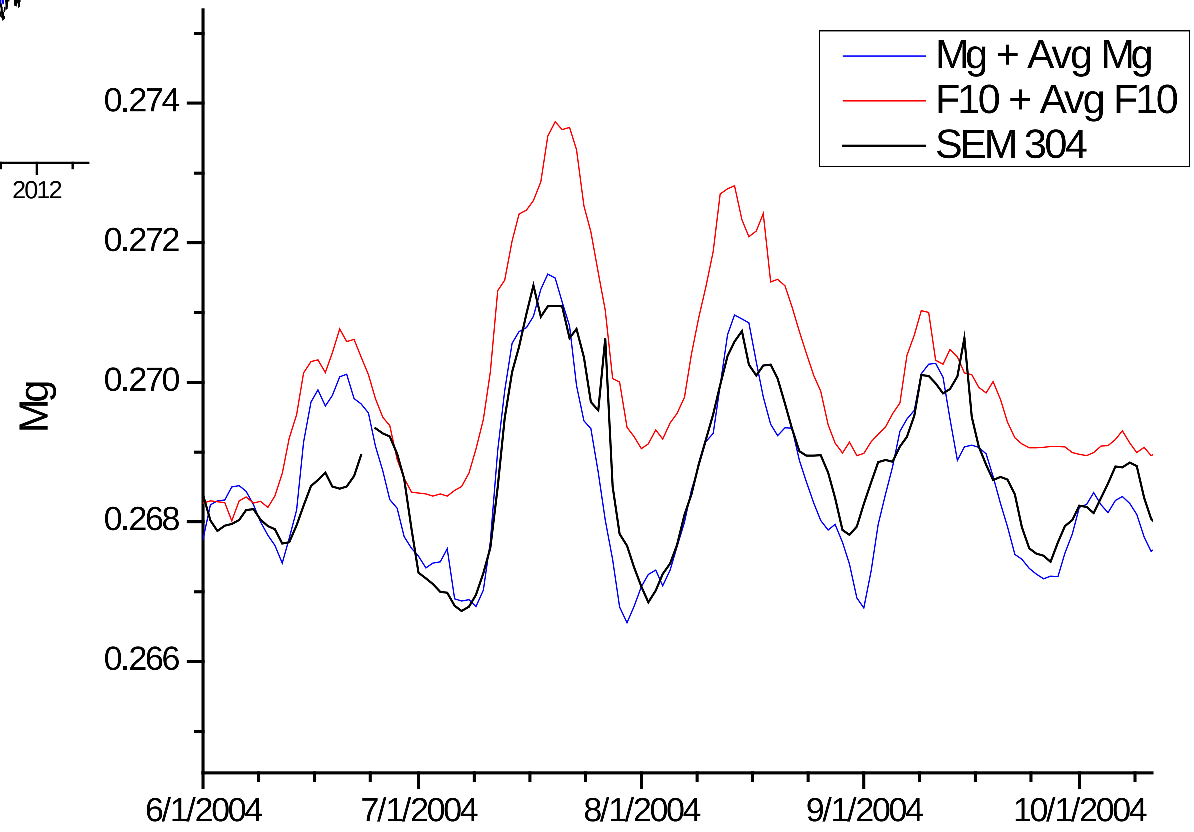
- **Serious Limitation: This formulation cannot be used for real-time applications**

Including Smoothed Values



Adding the 81-day smoothed component reduces the over-estimate of the solar modulation…

But now offsets become apparent.



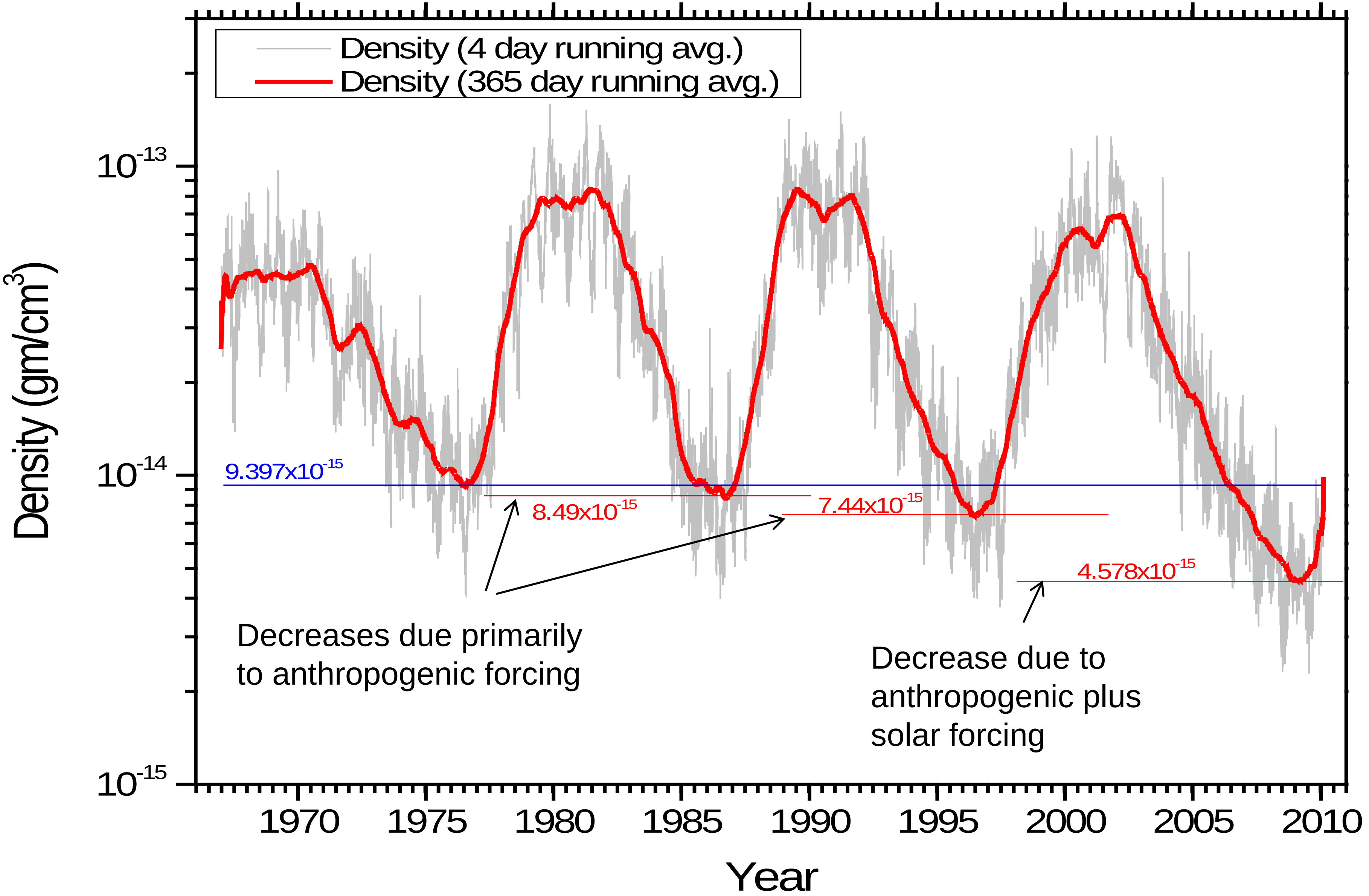
With these records, it is not possible to say which most accurately represents the true solar EUV irradiance.

Long Term Trends

- **Which proxies (or measurements) capture the solar cycle variability?**

Drag Density at 400 km (Emmert)

(Note: Log plot to enhance differences and minimum)



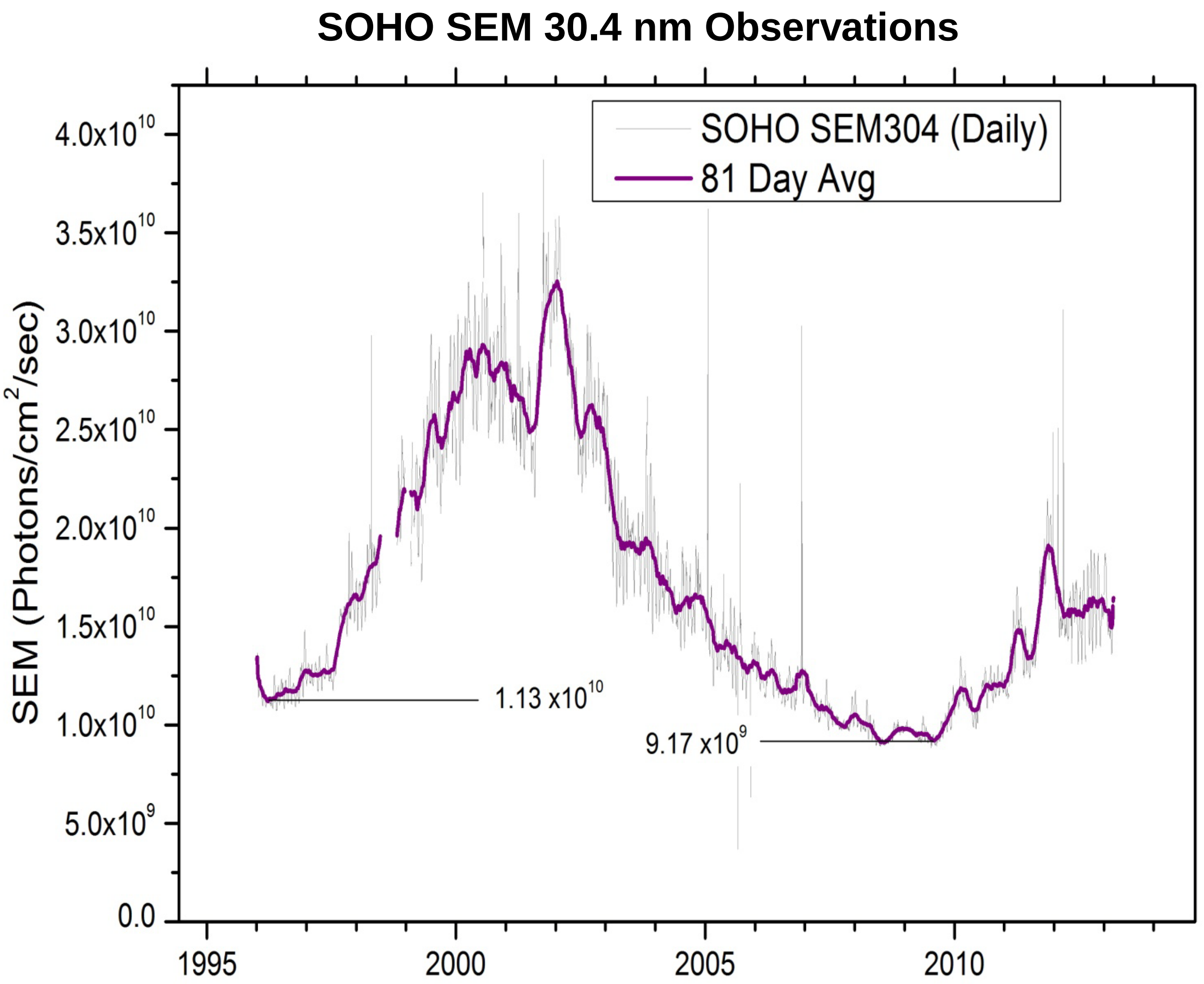
Observations of He 30.4 nm EUV

The Solar EUV Monitor (SEM) on SOHO has been measuring the 30.4 nm band (27-34 nm) since 1996.

Long term degradations and trends have been removed using periodic rocket under-flights.

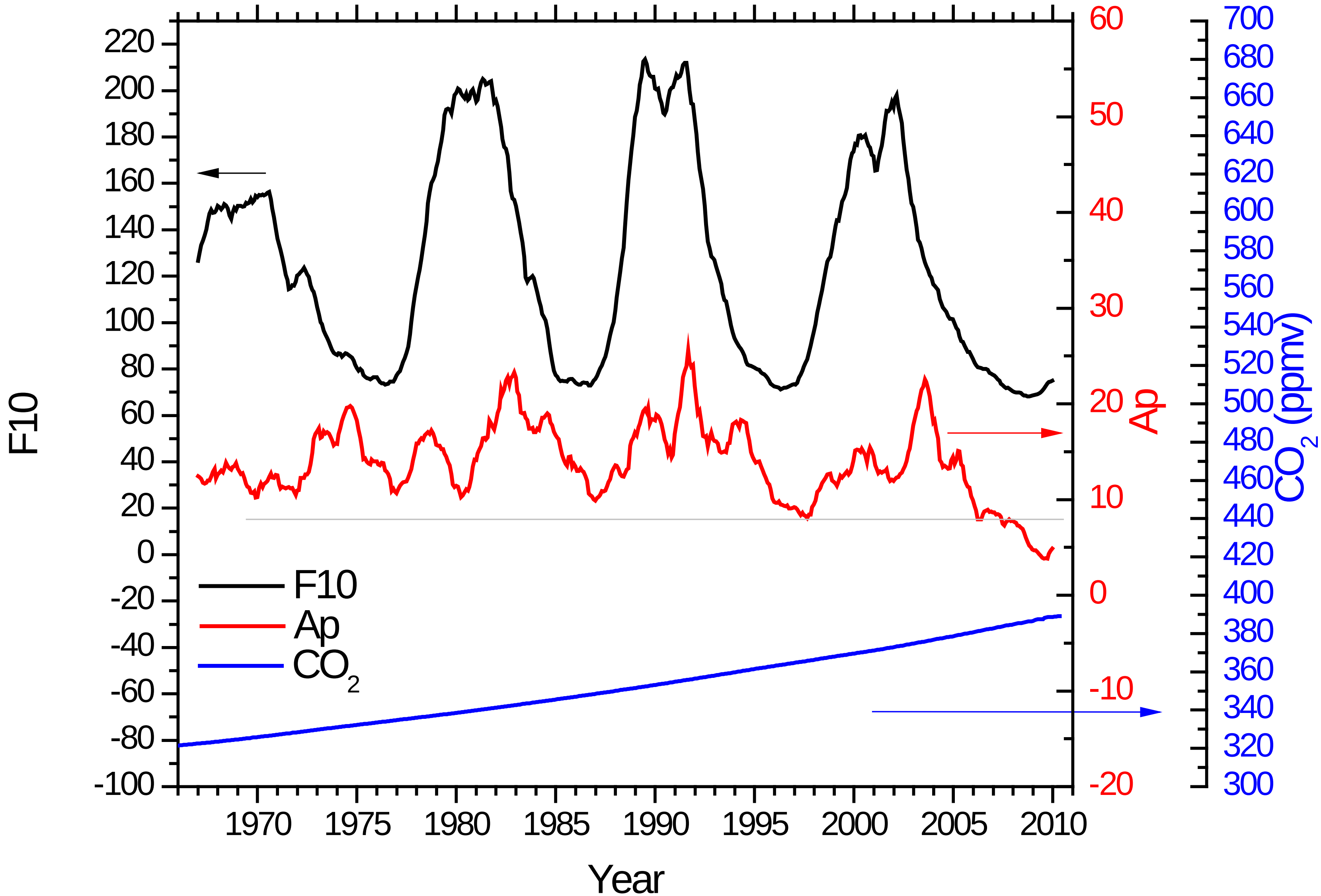
The data set shows a decrease of 18% in EUV irradiance during the most recent minimum compared to the previous minimum.

Is it real?

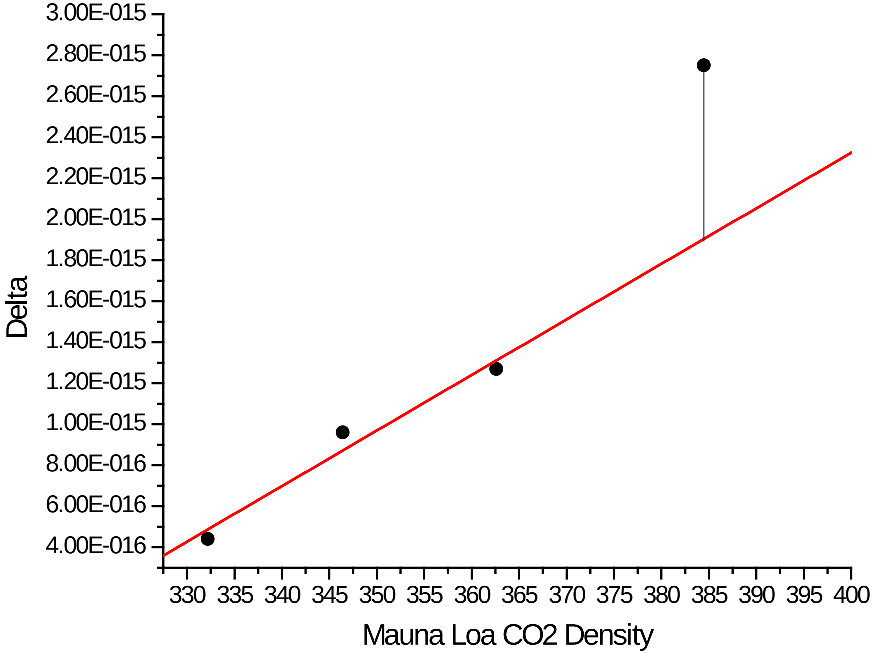


Thermospheric Drivers

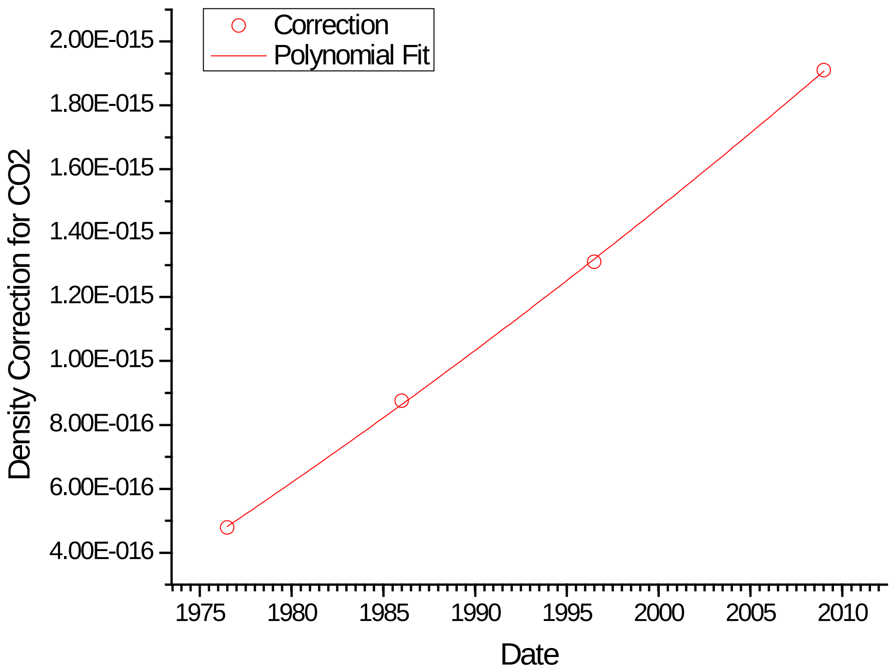
Solar EUV (F10), Geomagnetic Storms (Ap), Climate Change(CO_2)



Estimating the Anthropogenic Contribution



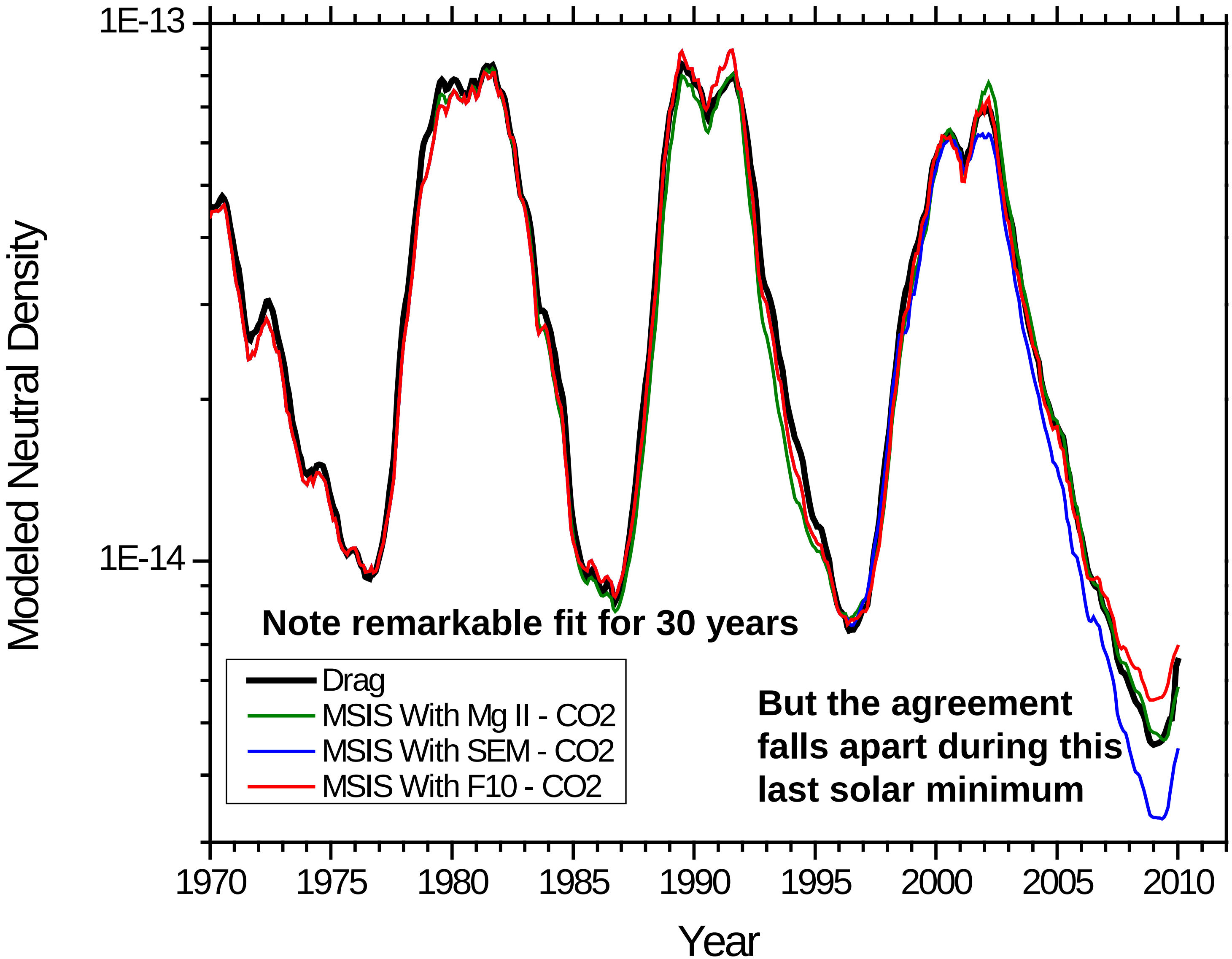
Density offset (delta) vs CO2 data. (fitting a line to only the first three minima)



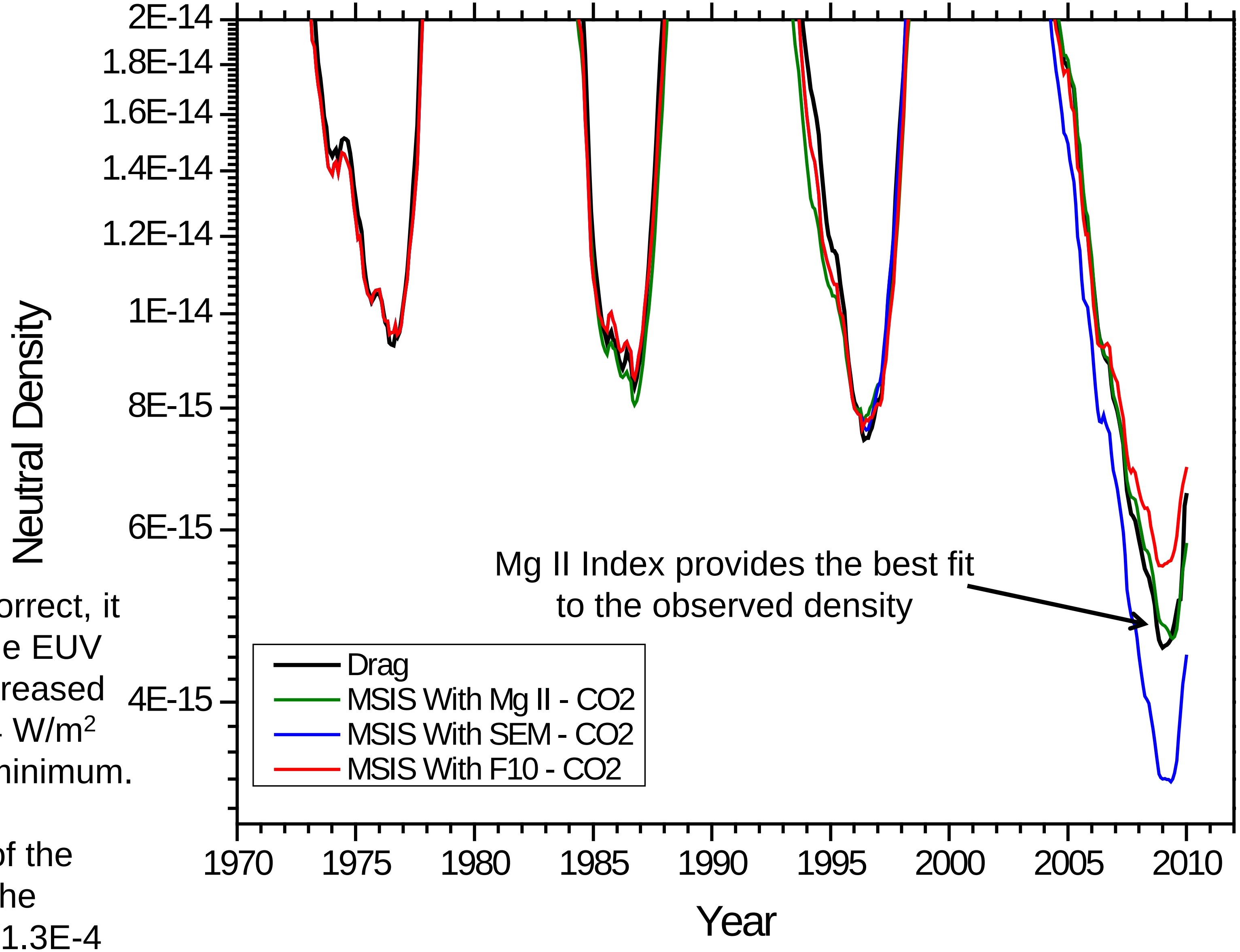
Extrapolating the correction to the full extent if the time series
Note: This is about twice the rate of Roble’s estimate

MSIS Results Using the Three Solar Inputs

(Corrected for anthropogenic trend)



MSIS Results Using the Three Solar Inputs

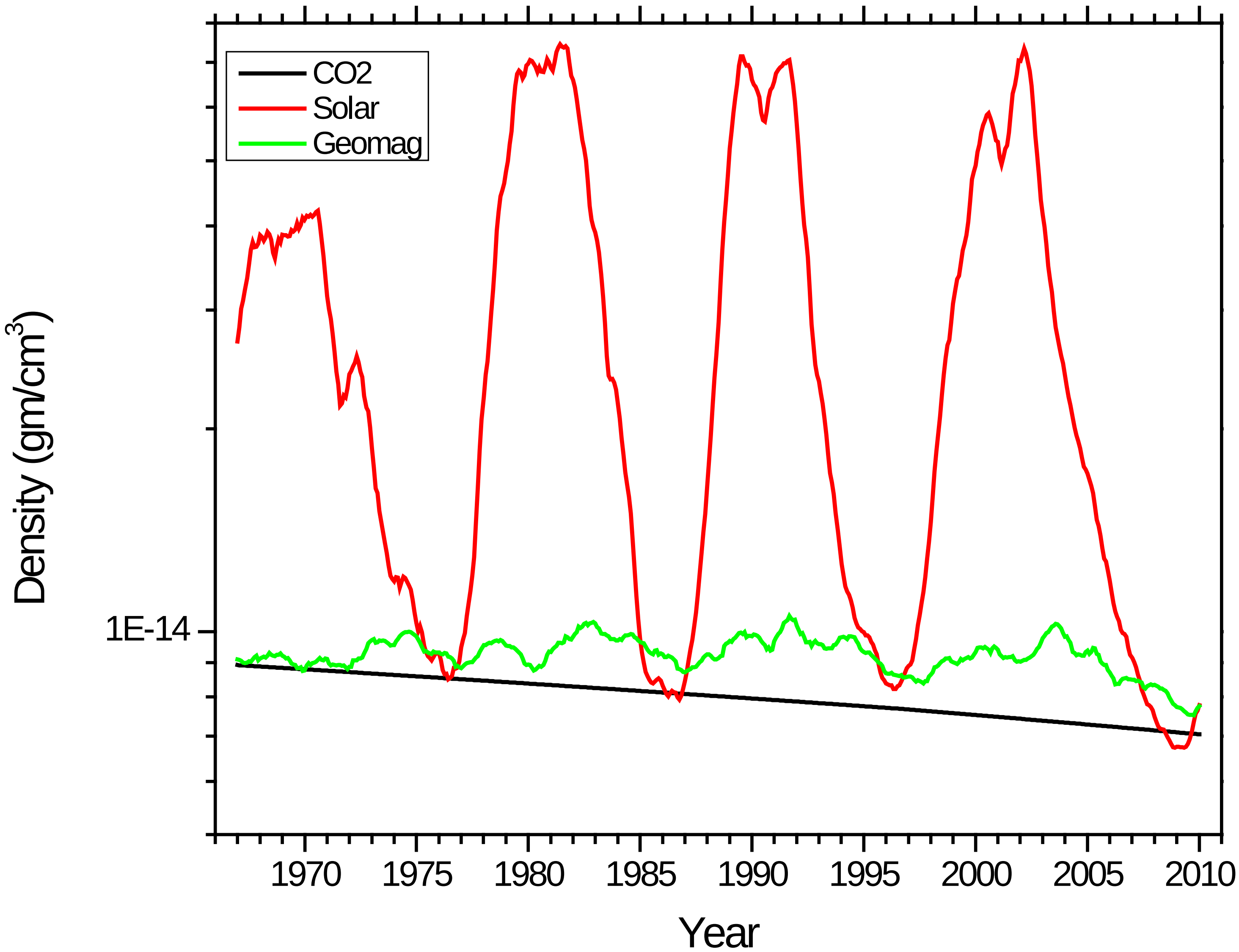


If this analysis is correct, it would imply that the EUV 304 irradiance decreased by 8.5% or 0.6E-4 W/m^2 from minimum to minimum.

This is about half of the decrease seen in the SOHO SEM data (1.3E-4 W/m^2)

Relative Magnitude of the Density Changes

Modeled density changes for each input while holding the other two constant



Relative Contributions of the change from (1996 to 2009)

Solar 1.49E-15 = 48%

Geomag 1.03E-15 = 33%

Anthro 0.61E-15 = 19%

Comments on EUV Proxies

- **Sunspot Number**
  - **Captures the large scale features of solar variability**
  - **Provides the longest record**
  - **Does not capture day-to-day variations well**
- **F10.7 cm Flux**
  - **Extends back six solar cycles (to 1947)**
  - **Works for most time intervals (weeks to years)**
  - **May level off at solar minimum**
- **MgII core-to-wing Ratio**
  - **Extends back three solar cycles (1978)**
  - **Works over most time intervals (weeks to decades)**
  - **Captures long term variability including solar minimum**
- **The inclusion of an 81-day smoothed component precludes real-time applications**
- **None of the proxies allow for temporal resolution shorter than 1 day.**

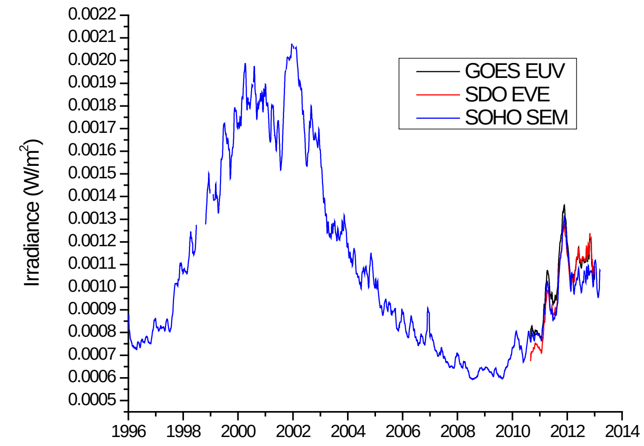
A New Era of Solar EUV Observations

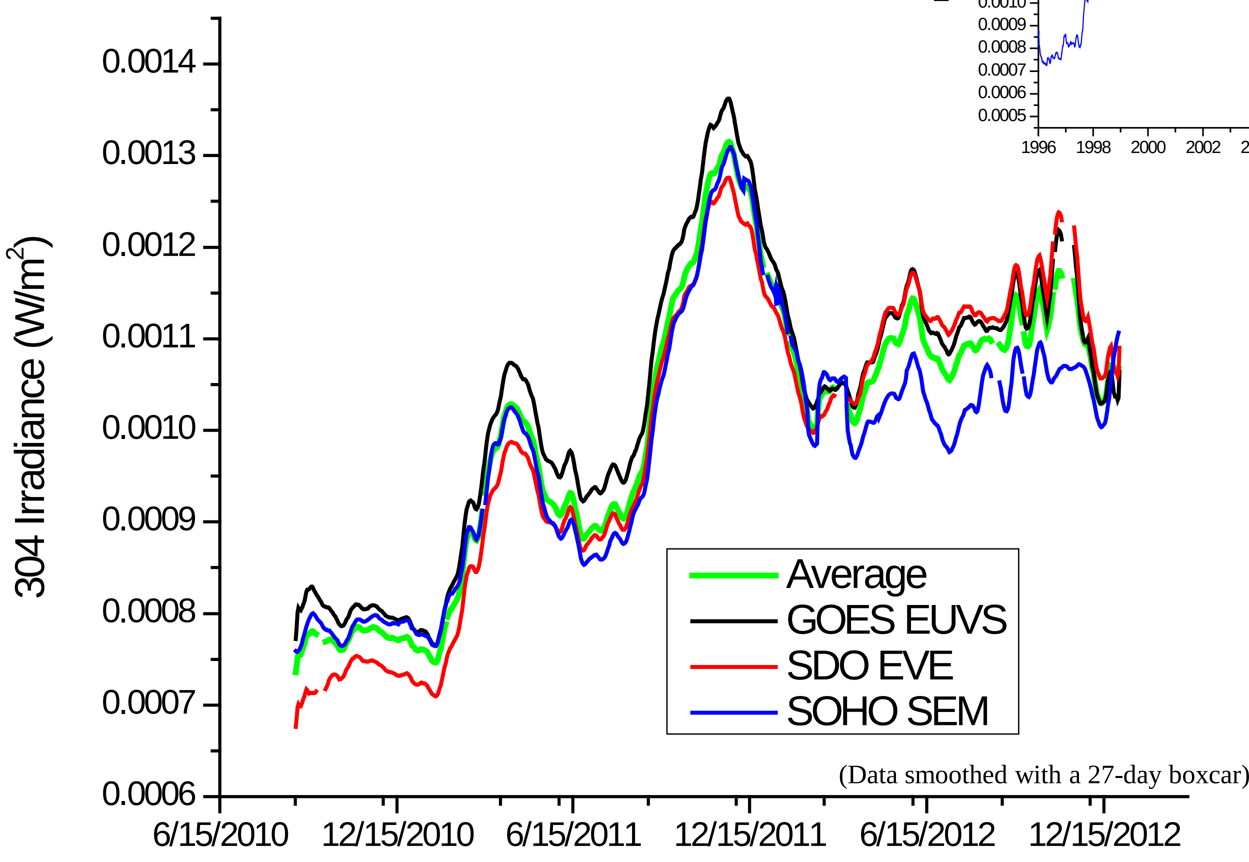
- **F10 and SSN (and MgII) have served well**
- **We can now make actual EUV measurements**
  - **Improved accuracy**
  - **Improved cadence and latency**
  - **Improved long-term stability!**
- **SOHO SEM (1997 – Present)**
- **TIMED SEE (2001 – Present)**
- **GOES EUVS (2009 – Present)**
- **SDO EVE (2010 – Present)**

- **Solar EUV irradiance models should be driven with actual EUV observations**

New EUV Observations at 30.4 nm

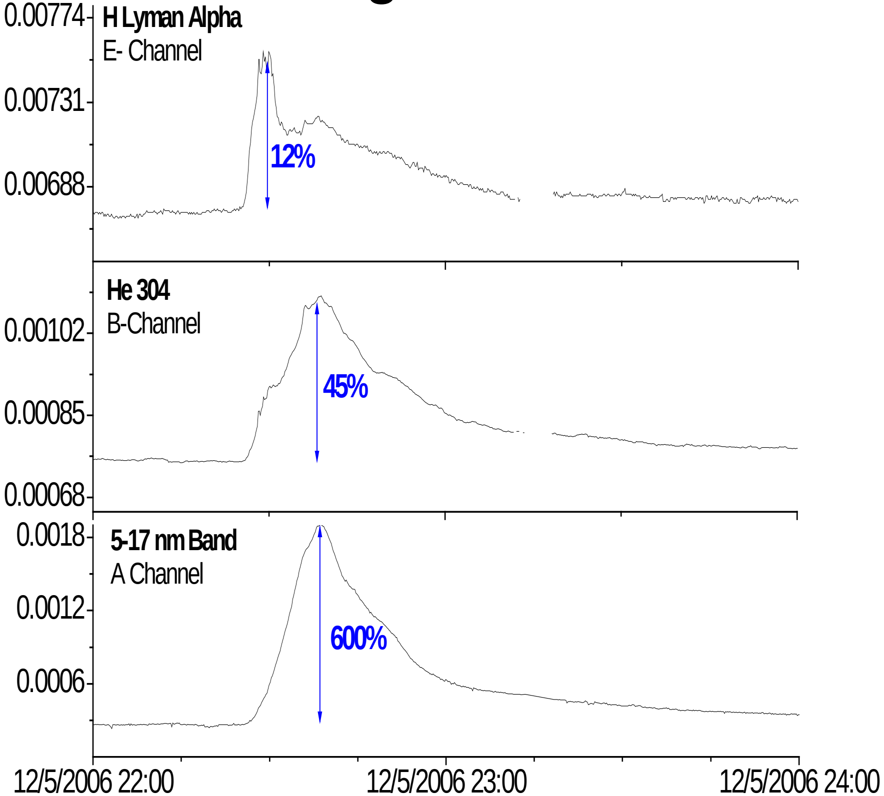
Multiple sensors are now observing 304



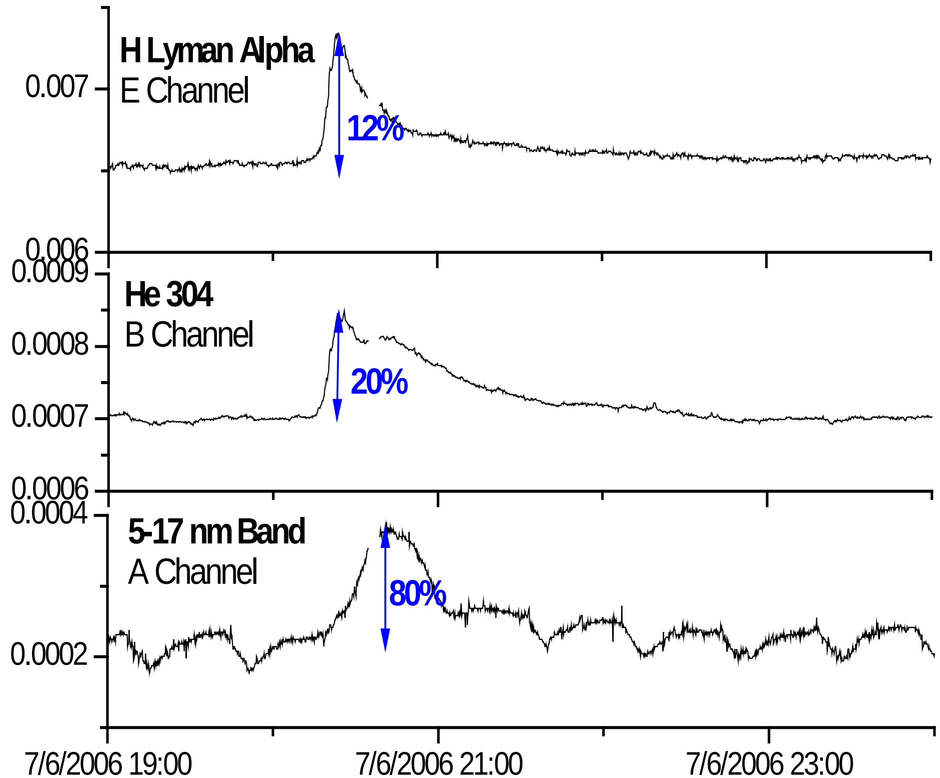


Solar Flares
Observed with GOES EUVS

Large X-Class Flare



Moderate M-Class Flare



Solar flares represent new complexities:

- **Emission ratios change from flare to flare**
- **Flare emissions rise and fall at different phases of the flare**

Summary

- **Sunspot Number should not be used as a proxy for solar EUV**
- **F10 + $F10_{81\text{-day-avg}}$ works well for most timeframes and applications**
- **MgII + $MgII_{81\text{-day-avg}}$ may work a little better for decadal studies**
- **It is time to start using actual EUV observations to drive models.**