A Synthesis of Solar Cycles 22-24

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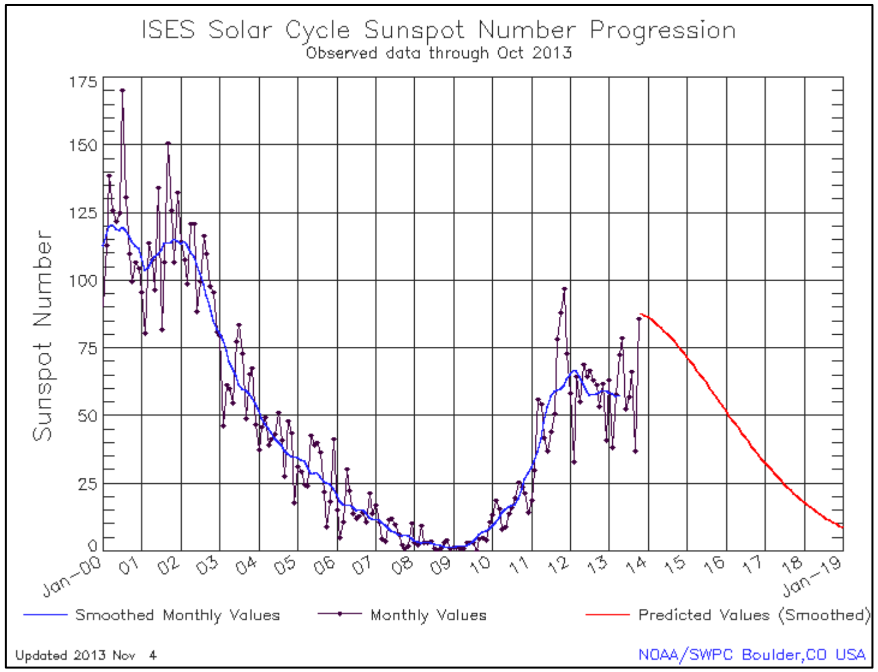
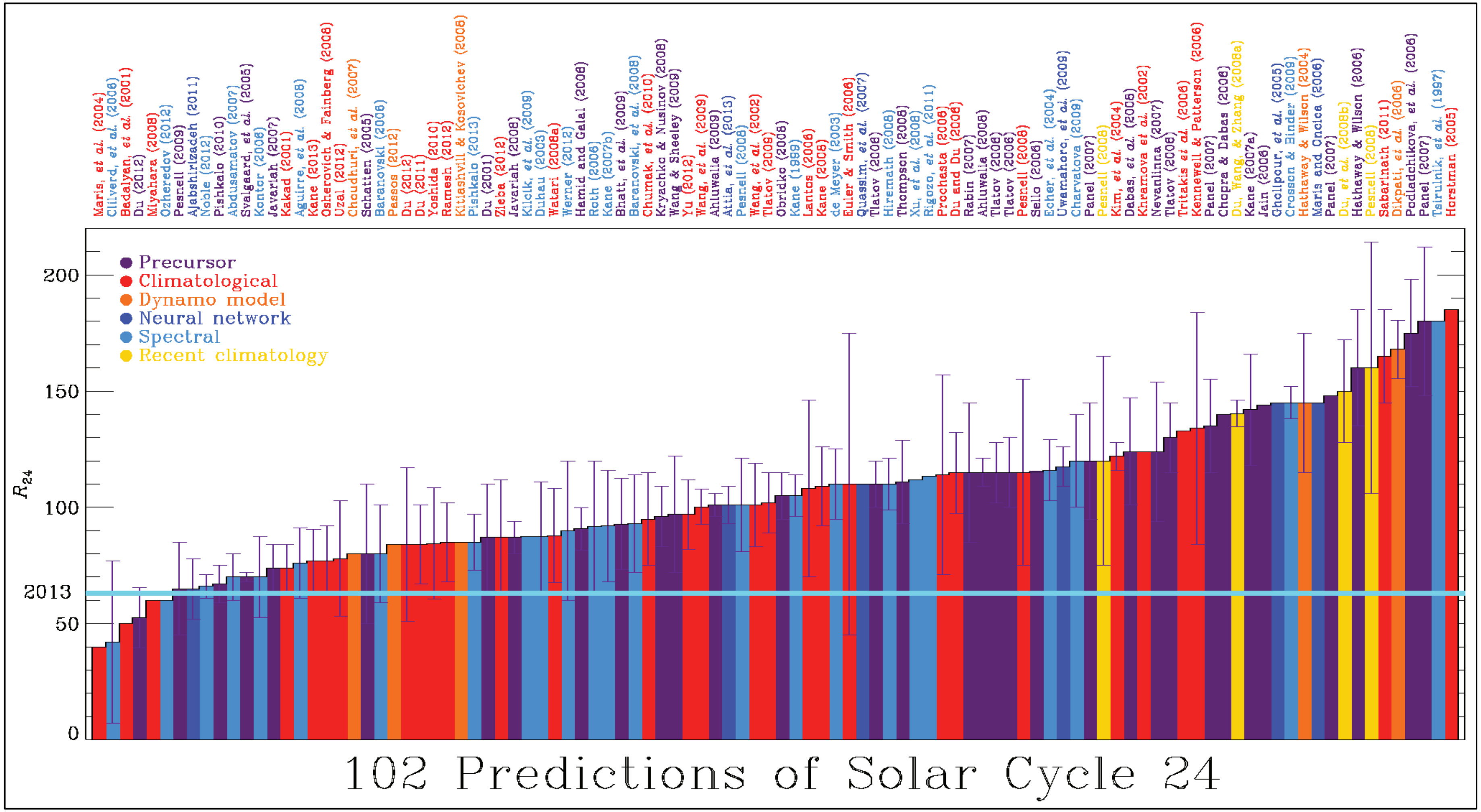
1.



Predictions



Pesnell, 2012

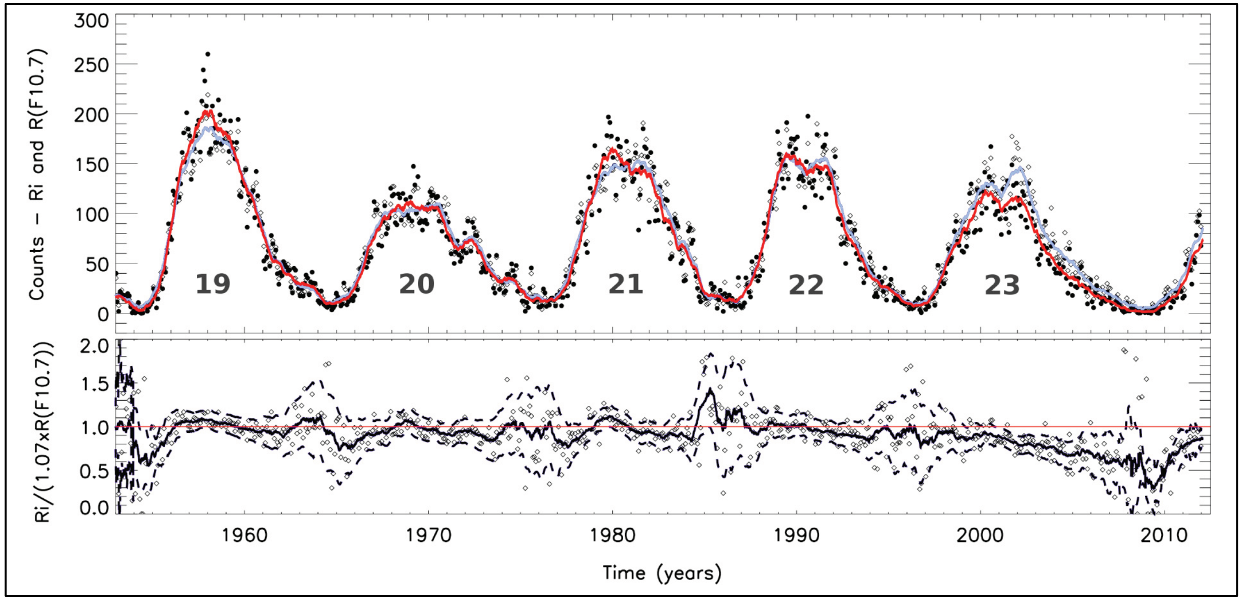
(Slightly revised) Thesis

Various measures of solar activity ("proxies") guide us to the behavior of the solar magnetic field. The proxies have limited precision and – and maybe less physical understanding - and conclusions are elusive.

Outline

- *How have the recent cycles developed?*
- *How good are the proxies?*
- *What are the proxies proxies of?*

How have the recent cycles developed?



Clette-Lefevre 2012

- We see that a systematic change has occurred on solar-cycle time scales: there is a "relative diminution" of F10.7 (Svalgaard, Tapping) of some 20%.
- The uncertainty bands in the ratio are at 3σ (Clette & Lefevre)

What is different about Cycles 22-24?

- F10.7 began in 1947
- The space age began at the IGY, 1957

- Before this, our knowledge fades into the increasingly mythological past…

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What is different about Cycles 22-24?

- The 23/24 minimum was exceptional:
  - Prolongation
  - Penn-Livingston sunspots
  - TSI decrease
  - Cosmic-ray increase
  - F10.7 diminution
  - etc.
- But otherwise things seemed quite normal

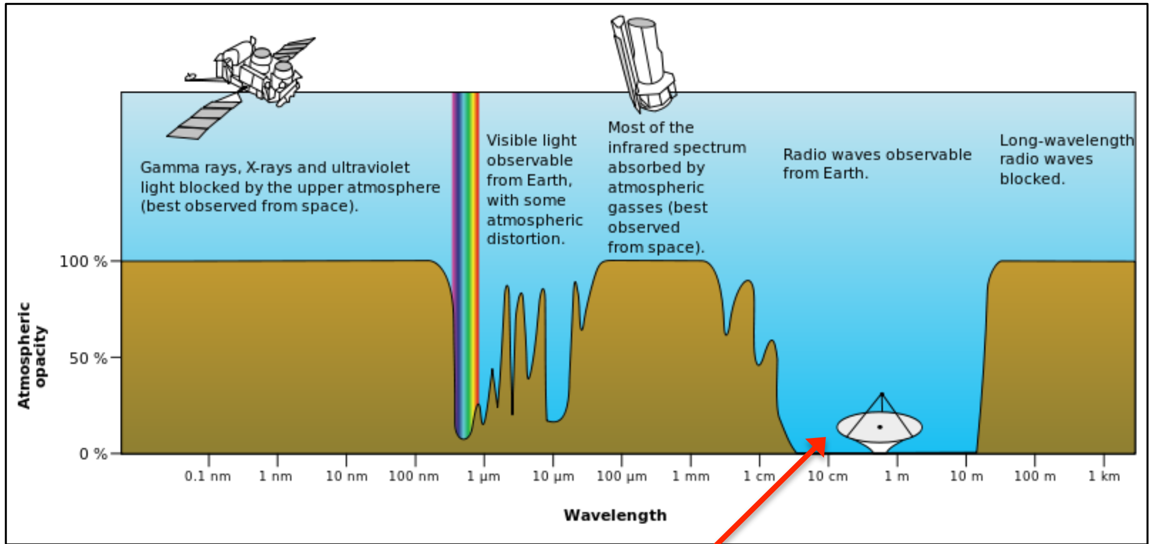
How do we understand the proxies?

- F10.7, SSN, Spot area, Ca K, K-index, GCR flux, Ap, flare index, TSI, Spectral Irradiance, open flux, …

- Each has a different and highly model-dependent relationship with the magnetic observables in the photosphere

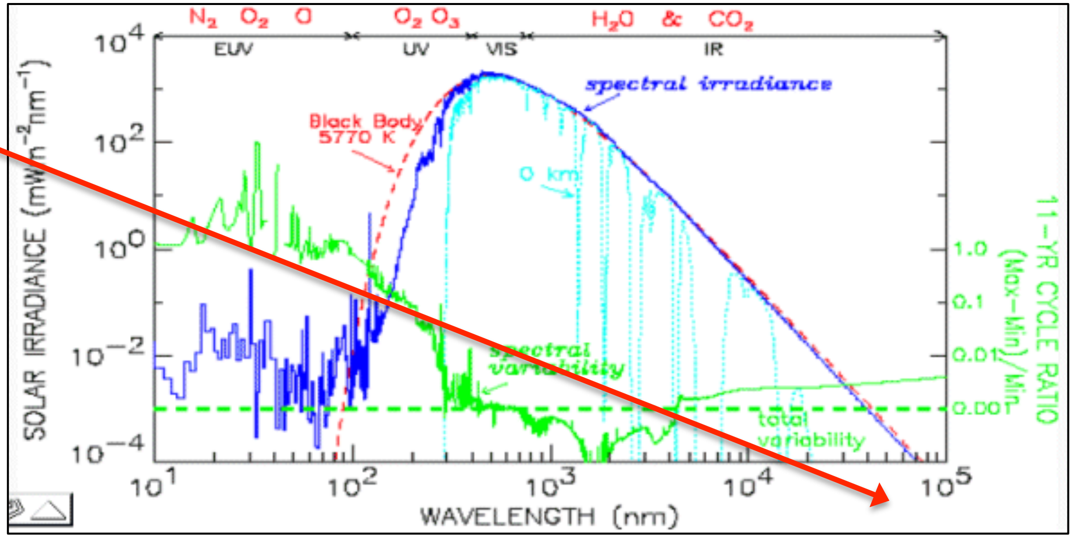
- None has any physically understood relationship with the field in the solar interior (the dynamo and/or relic field)

Why do F10.7 and space research matter, as regards proxy measures?

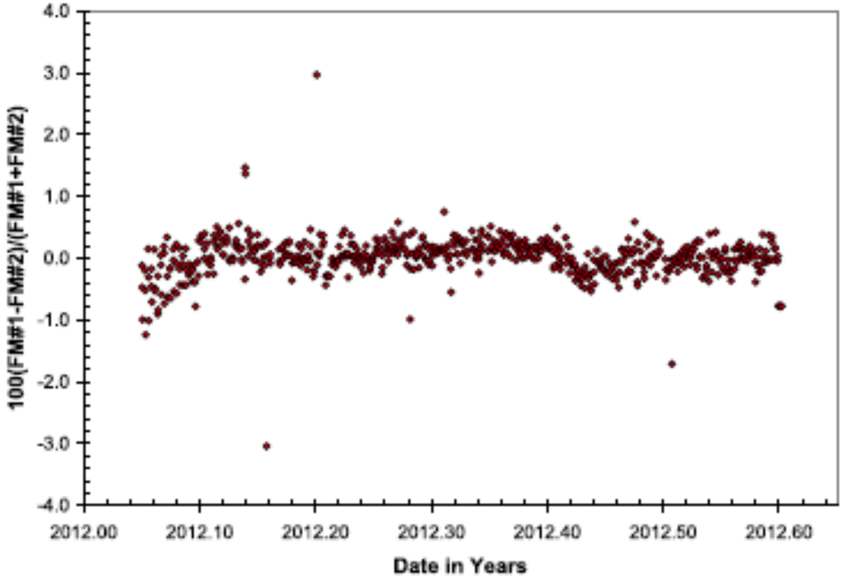


Covington

$f_L = 2.8\ B_{1000}$ GHz

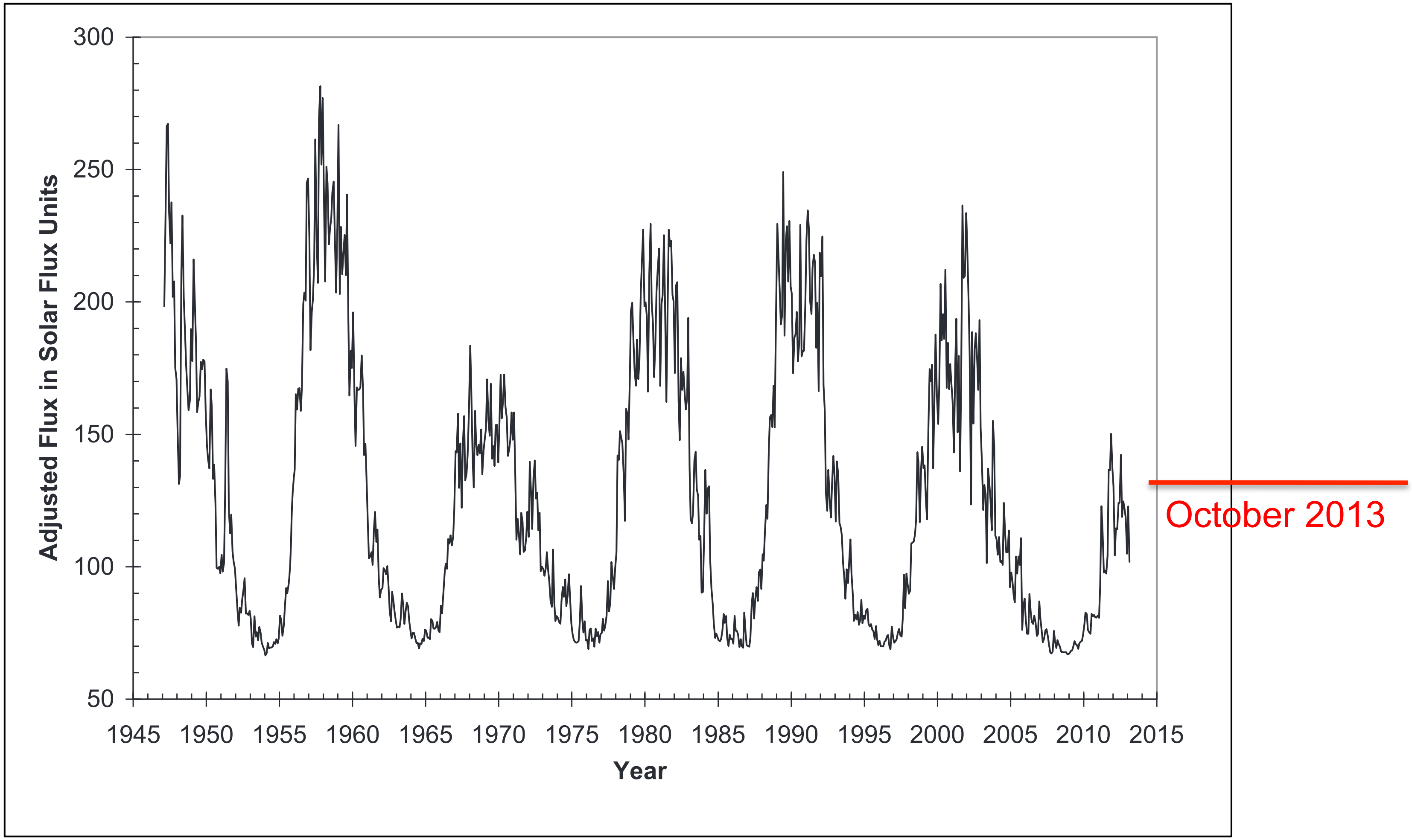


Calibrating F10.7



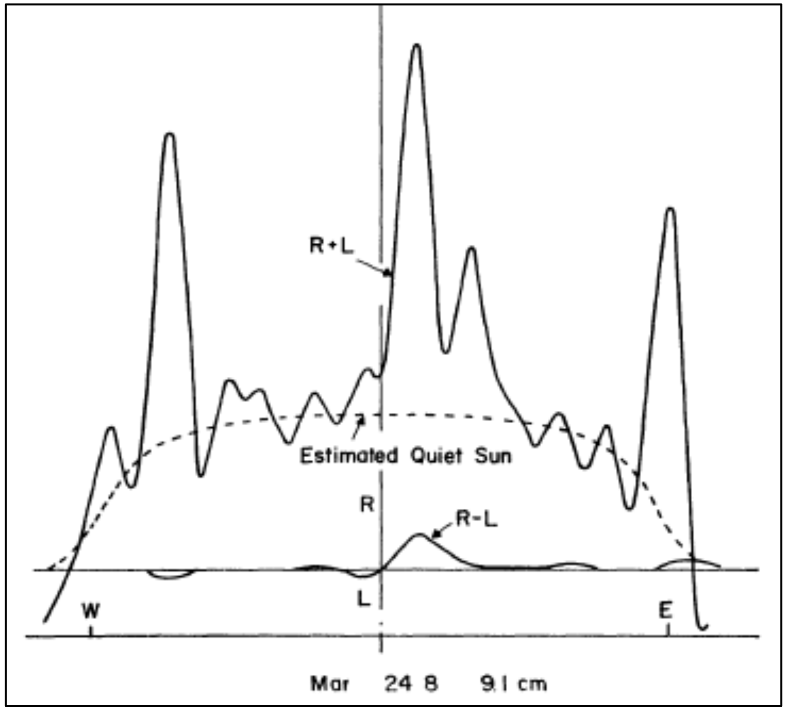
- *"The F10.7 values are deemed to be accurate to one solar flux unit or 1% of the flux value, whichever is the larger."* (K. Tapping, Space Weather 11, 394, 2013)
- The aperture of the calibration horn is only reported at the 1% level

The F10.7 results

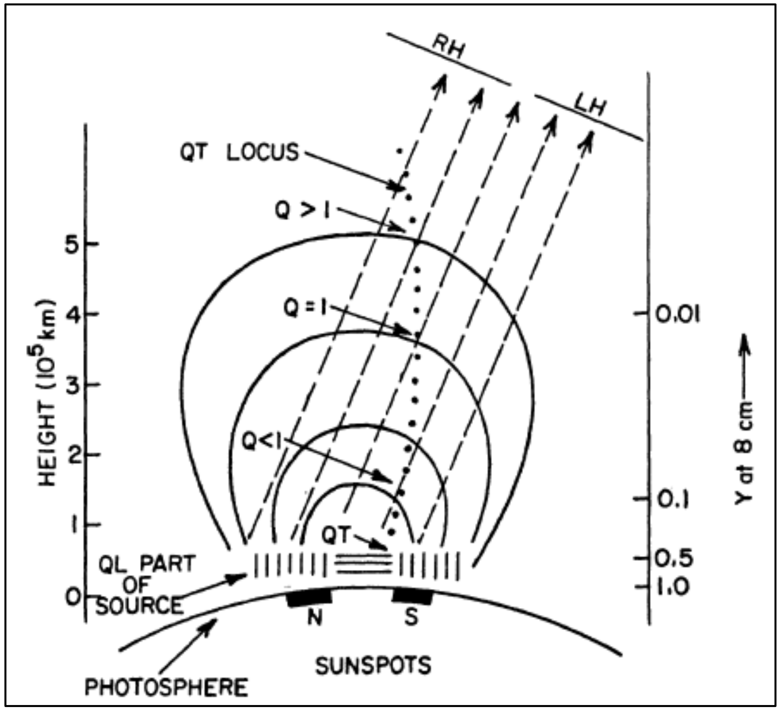


Tapping, 2013

F10.7 as a physical quantity



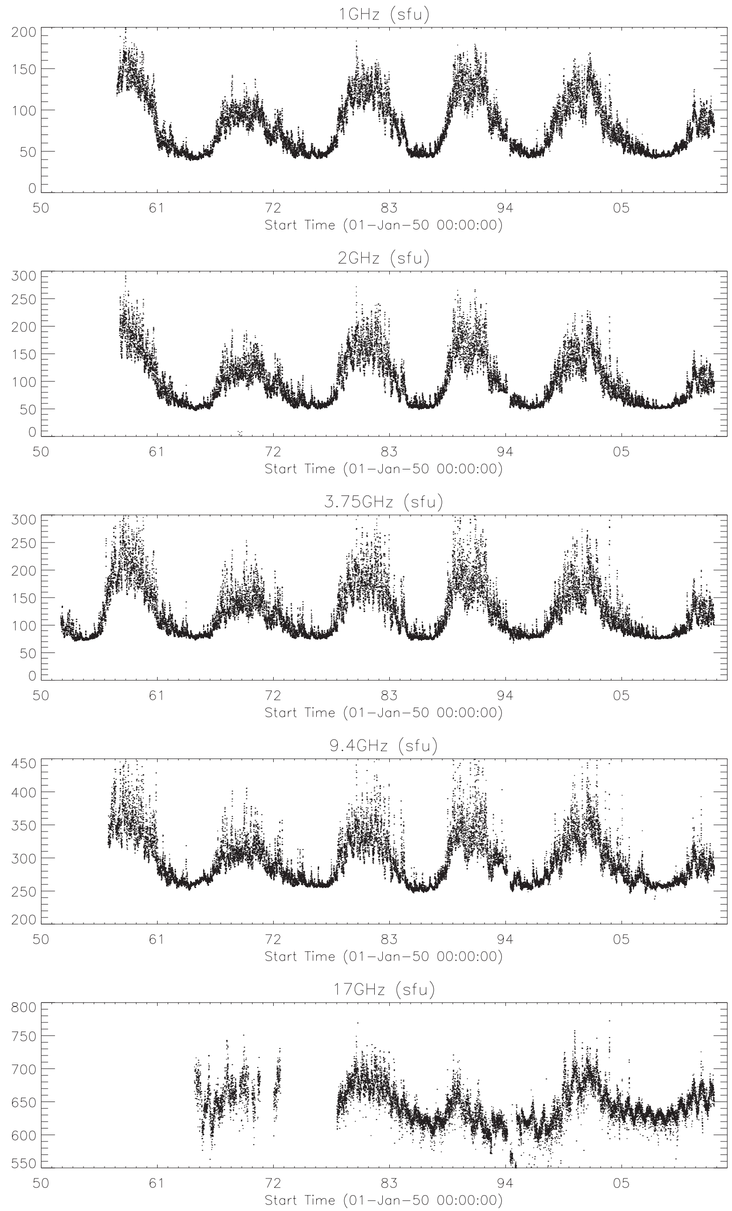
Quiet Sun and “S-components”



Complicated radiative transfer

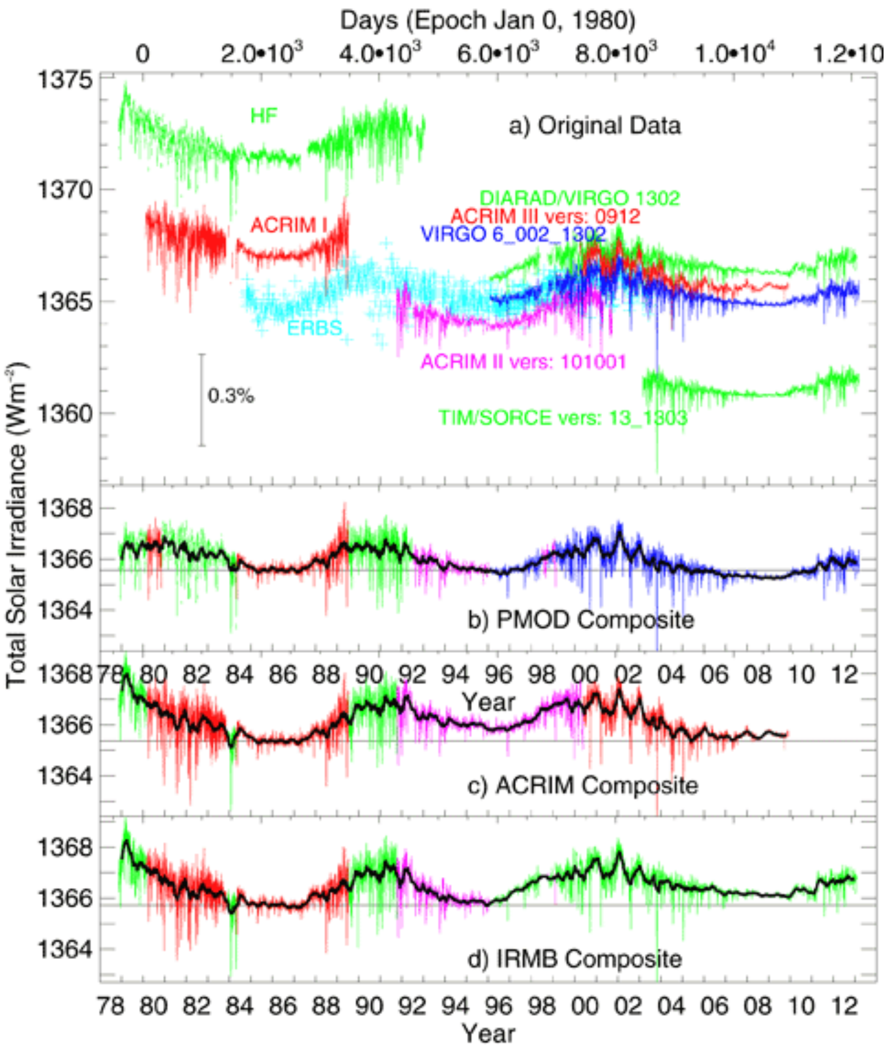
Kakinuma & Swarup (1962)

Multiple frequencies (Japan)



- The Japanese program began a few years after Covington
- Its leader, H. Tanaka, helped to put the calibrations on a firmer footing
- Its four (7) frequencies (1-9.4 GHz) span the S-component gyroresonance peak

Total Solar Irradiance

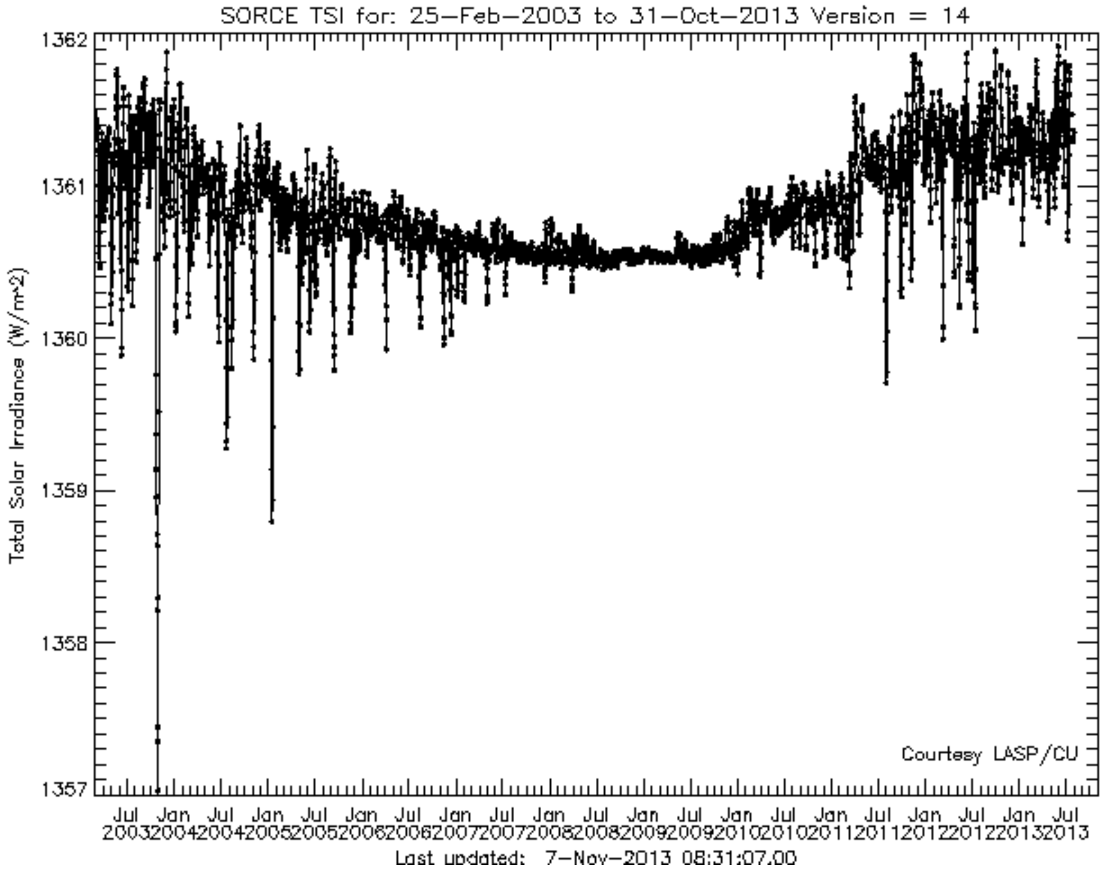


Courtesy PMOD, Davos Dorf

Notes:

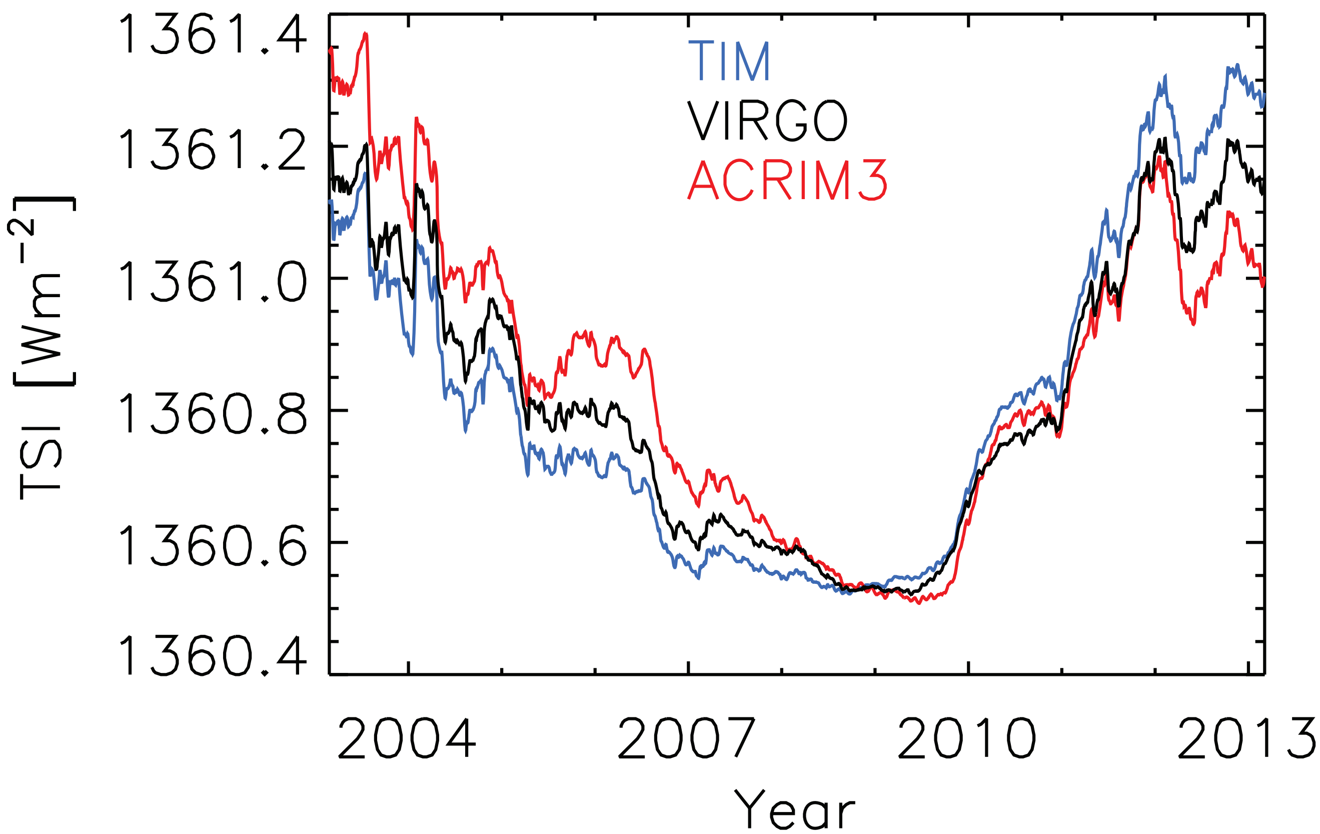
- The TSI is a basic and very precise proxy
- So far as we can tell, the low-frequency variations are entirely due to solar activity
- There is a difference of opinion about minimum-to-minimum variation
- The measurements are absolute, and only empirically calibrated between instruments
- SORCE, with the best TSI measures, is not taking data now

The SORCE/TIM Record



- Spots, faculae, and network contribute
- The “dips” differ systematically across 23/24
- The minimum is flat (convection dominates)
- Data residuals are expressed in ppm

Total Solar Irradiance



- Discrepancies of 0.04% per decade
- 1/KH time for convection zone 0.03%

TSI as a proxy

• TSI (and spectral irradiance) can be measured quite precisely, relative to other proxies

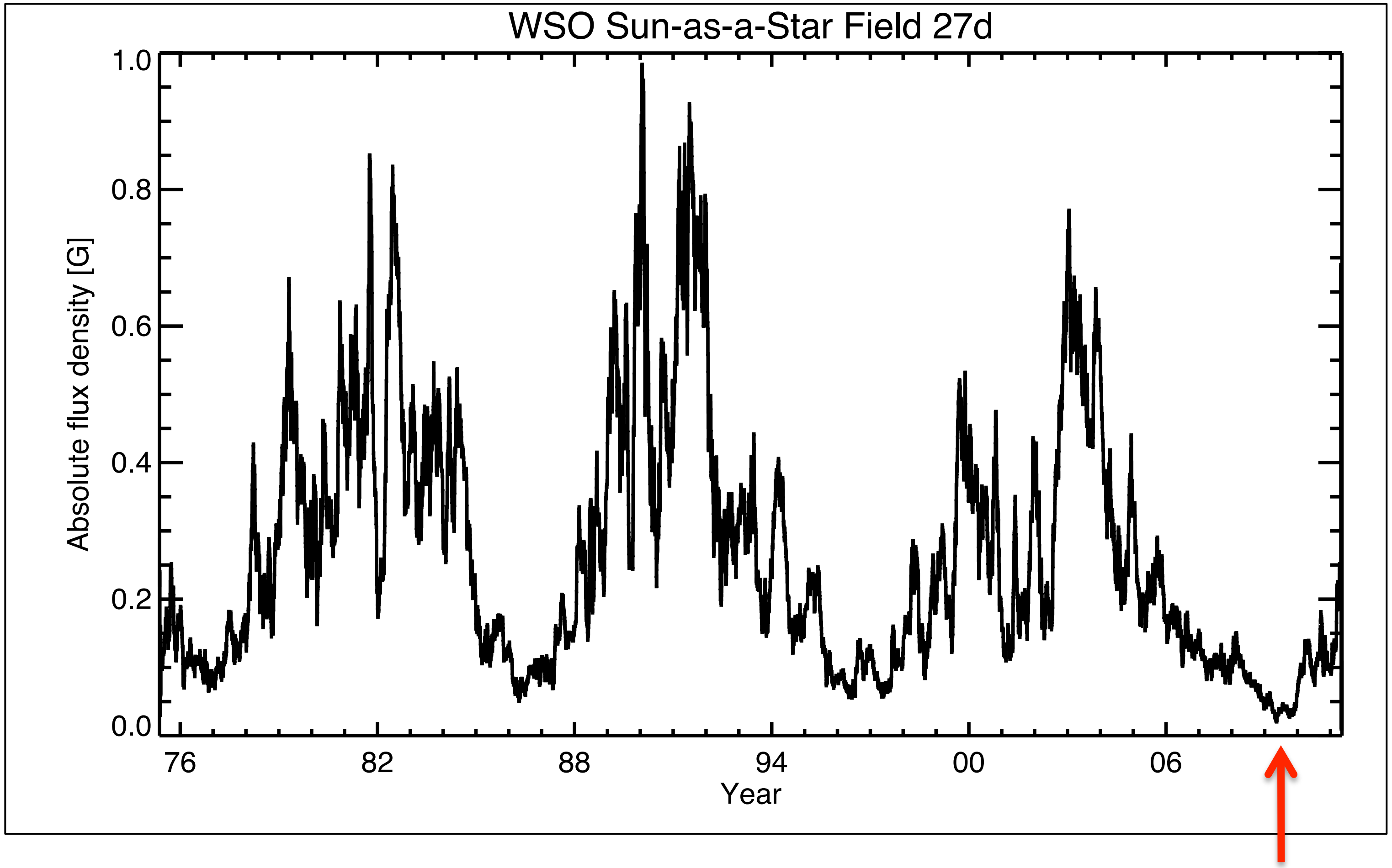
• TSI is related to B in a highly non-linear and model-dependent manner that is only understood empirically.
  - At solar maximum, faculae/network dominates
  - In other stars it's the opposite – the spots dominate

• Irradiance is not luminosity

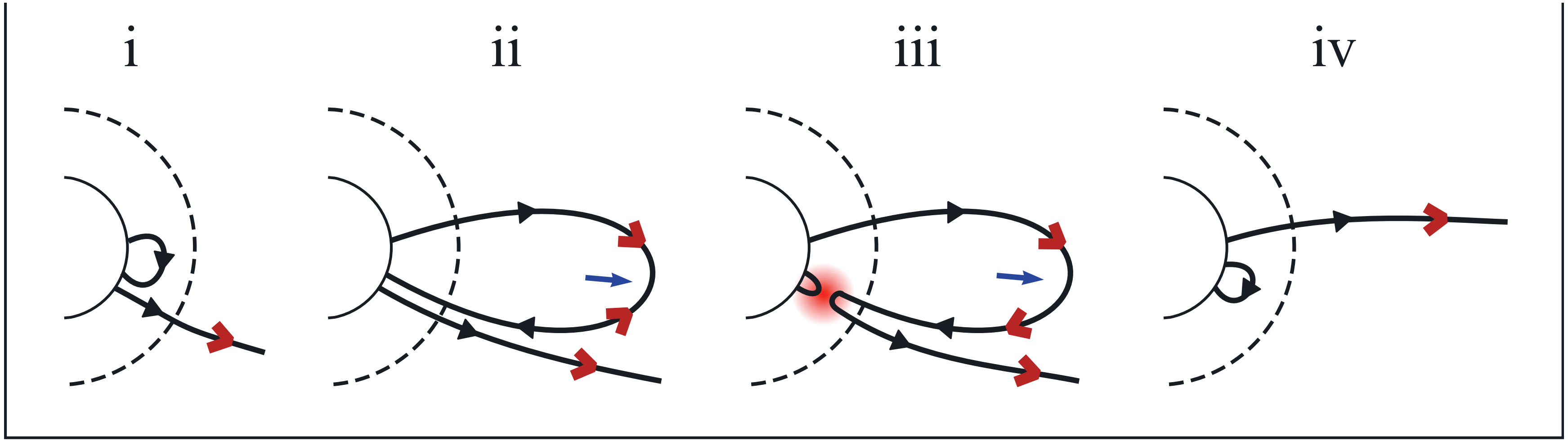
What are the proxies proxies of?

- The “Sun-as-a-star” mean field
- The photospheric magnetic field
- The heliospheric open flux
- The plasma Poynting flux

Sun-as-a-star field



Heliospheric open field



Owens & Lockwood 2012

• The open flux must be eliminated by reconnection beneath the Alfvenic critical point. The concept of “interchange reconnection” as an explanation for variations suffers from the standard 2D misconception

• Heliospheric open flux is not a fundamental property of solar interior dynamics

What about the dynamo?

• It would be very nice to have a proxy-based tool that could complement helioseismology in understanding solar interior dynamics

• No predictive theory of the cycle exists, and likewise no adequate theory of surface flux concentration (hence no guidance for the proxies)

• Nevertheless, we learn a great deal qualitatively from the statistical properties of stellar magnetic fields

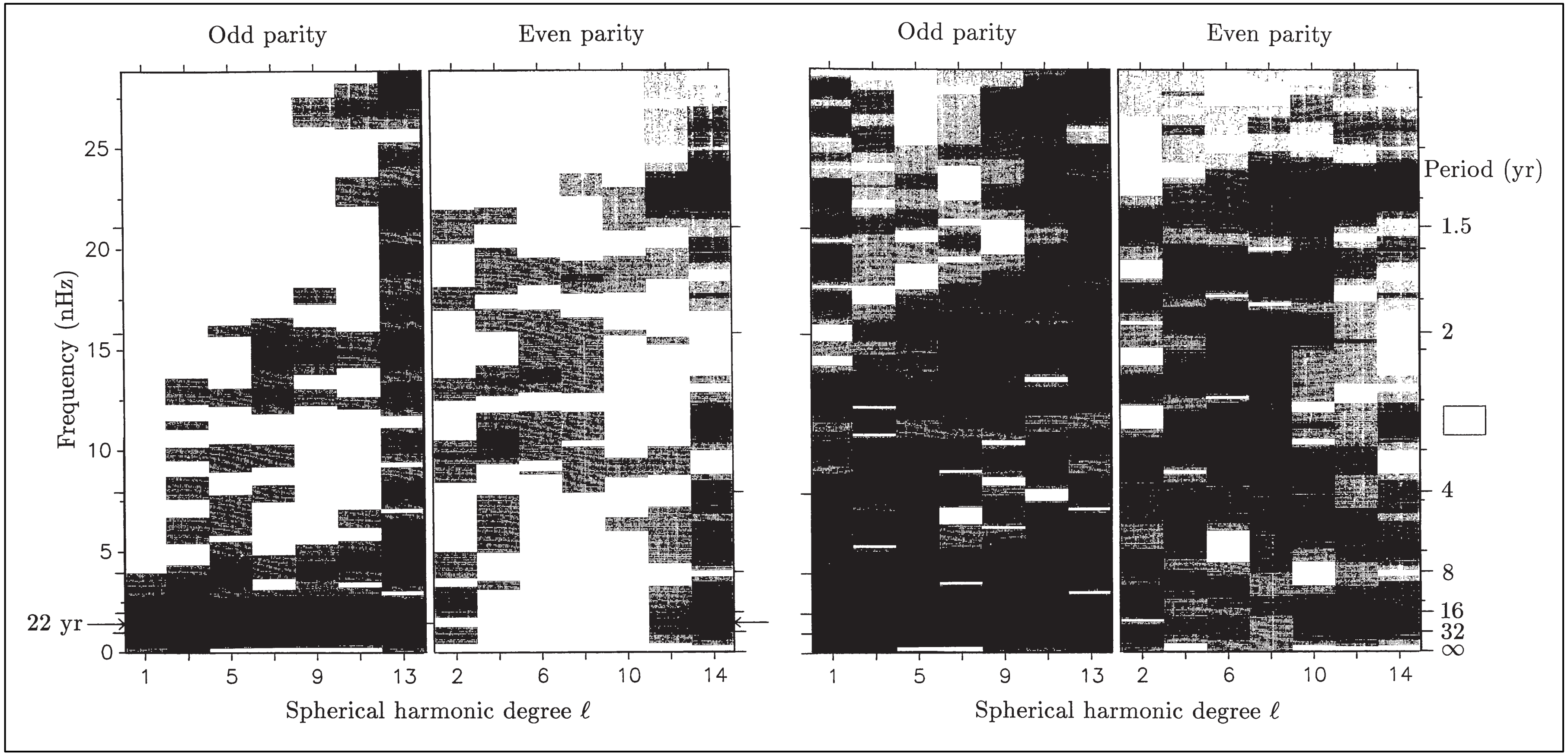
A magnetic “k-ω diagram”: Eigenstates of the dynamo?

• Stenflo’s concept of a magnetic “k-ω diagram” should be the route to a tool for the use of magnetic proxies to probe the solar interior

• Imaging data is much better for this purpose (it incorporates “k”) but doesn’t extend so far in time (1/ω)

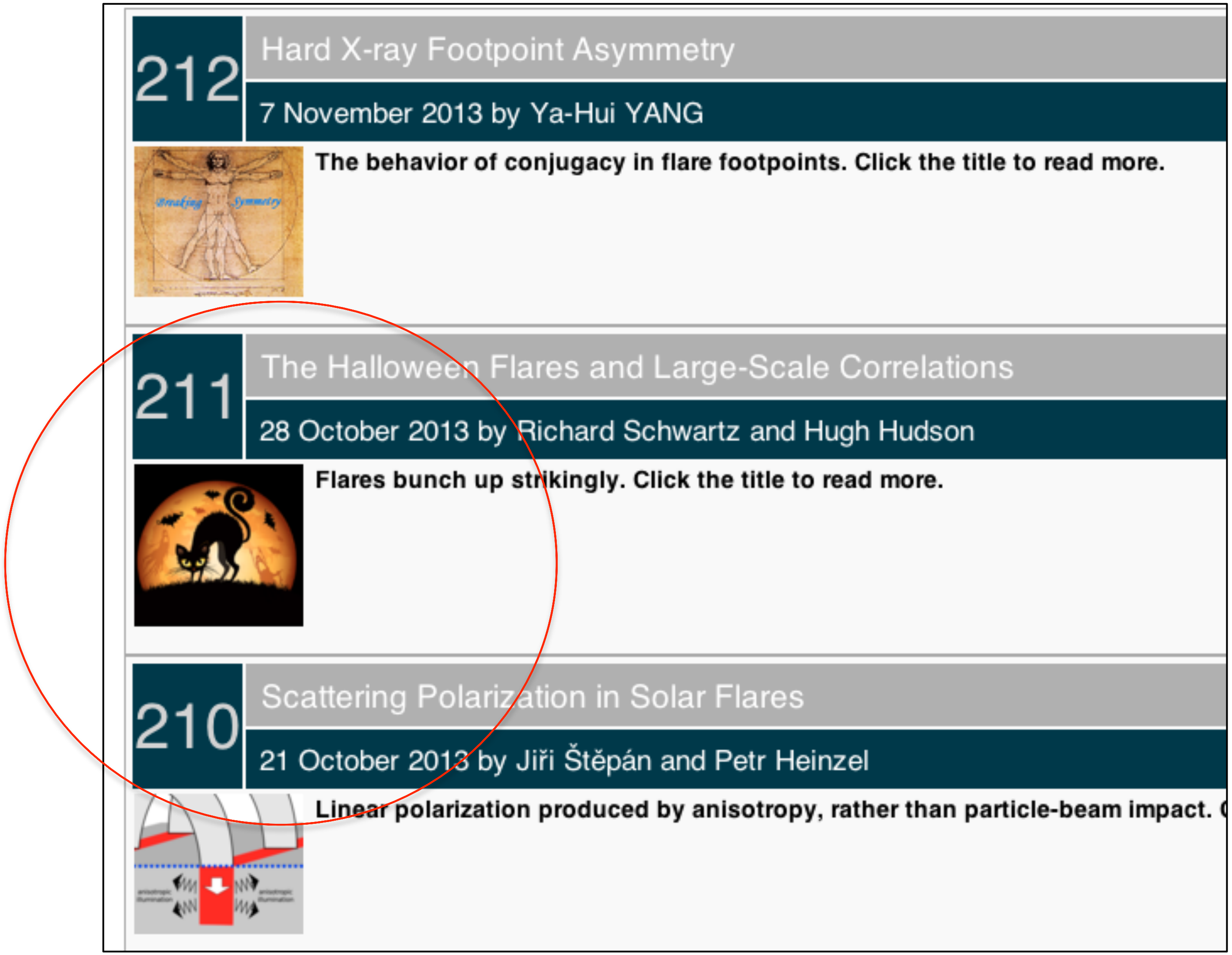
• See Stenflo & Güdel (1988) for a discussion

A Magnetic "k-ω Diagram"



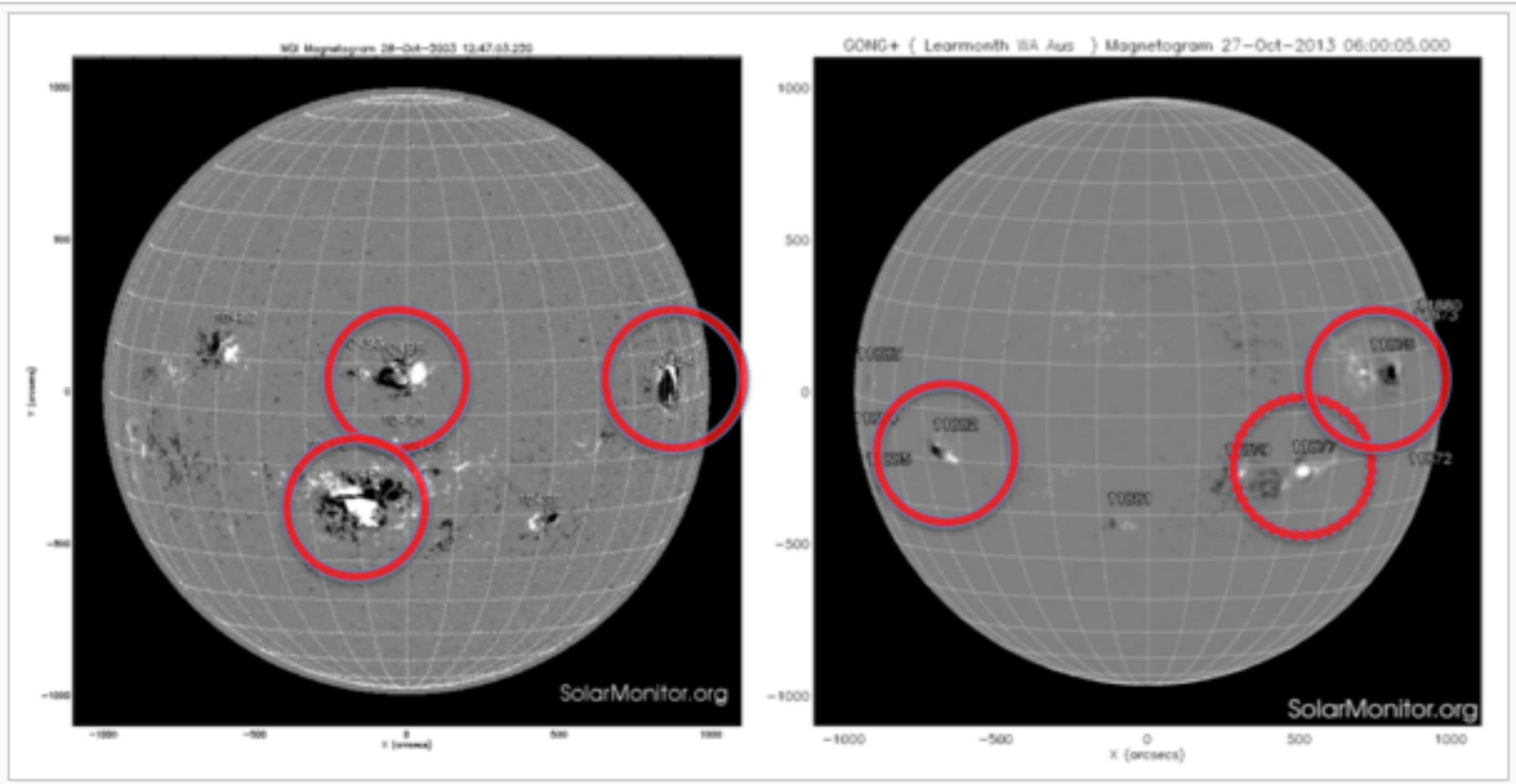
Stenflo & Güdel 1988

Flare occurrence as a proxy



http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/RHESSI_Science_Nuggets

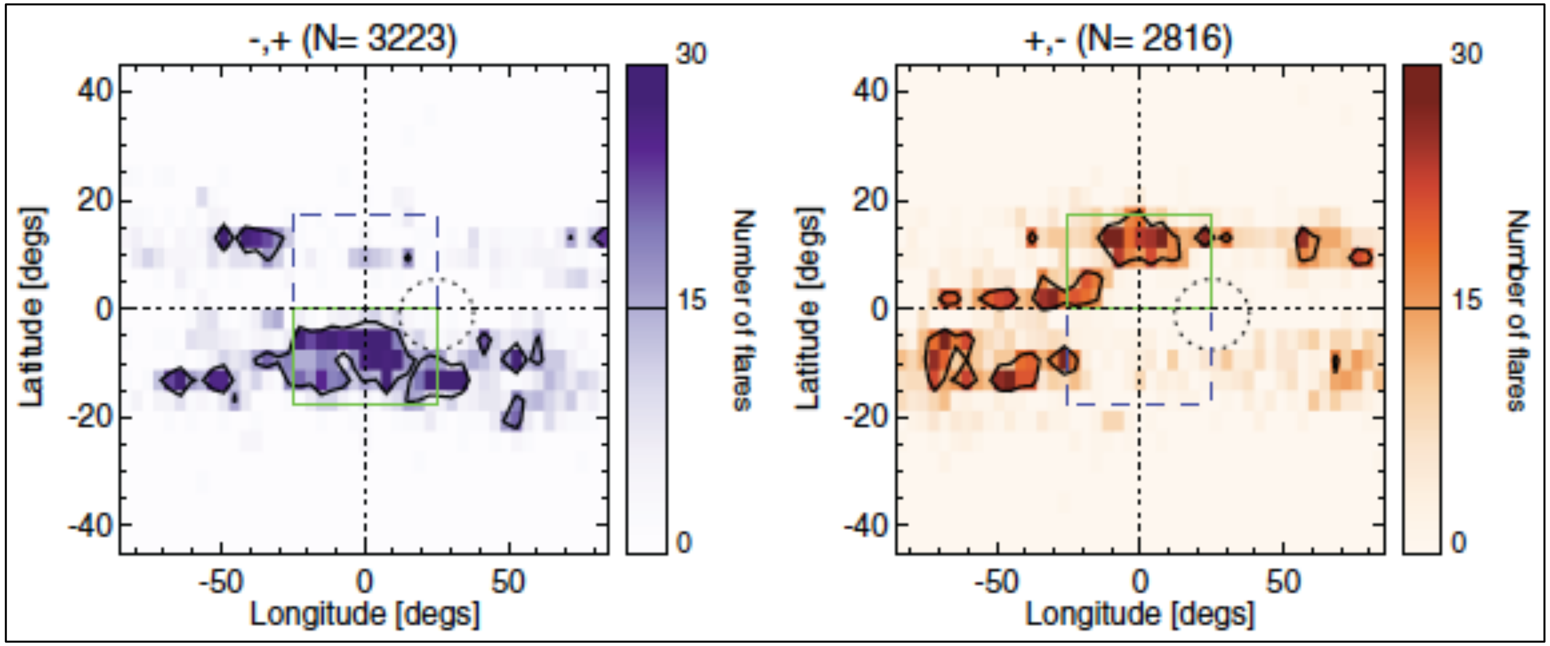
Flare occurrence as a proxy



October 2003 October 2013

http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/RHESSI_Science_Nuggets

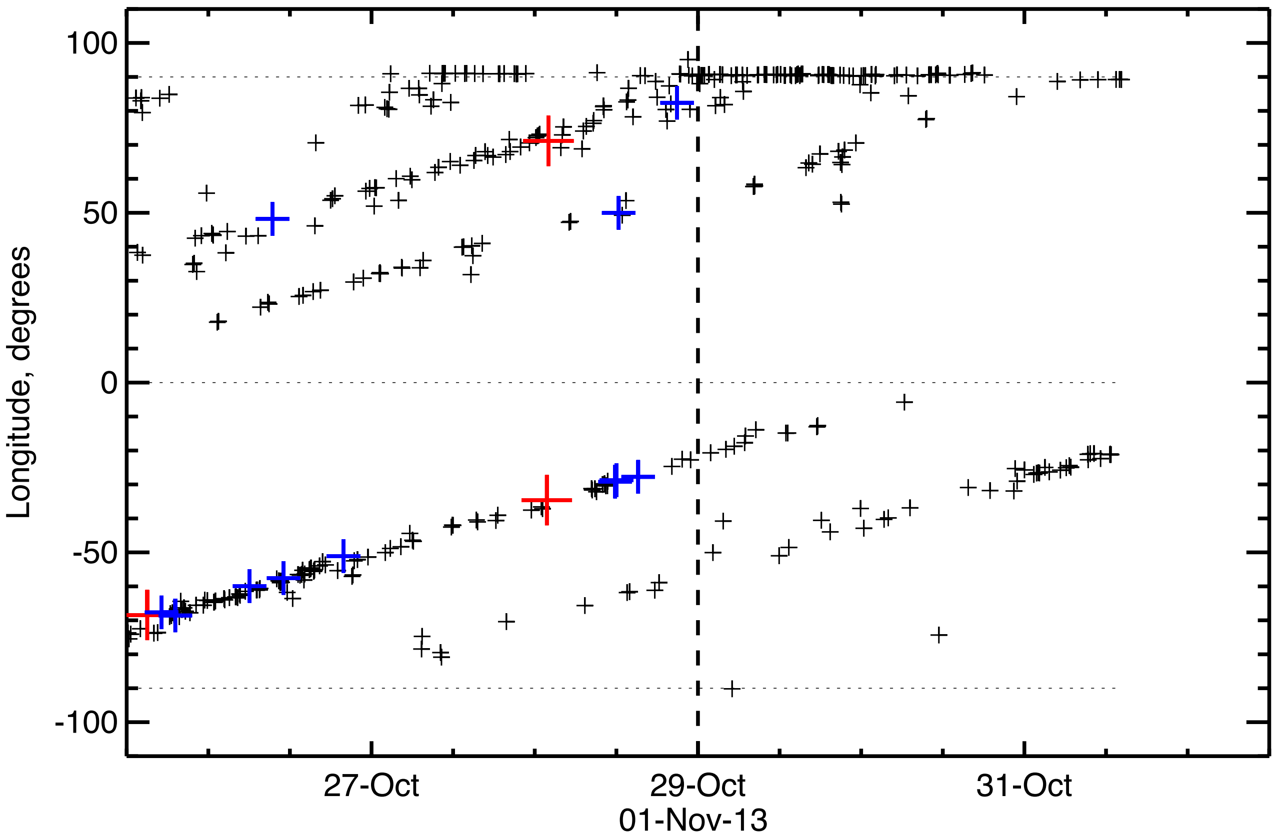
Flare occurrence as a proxy



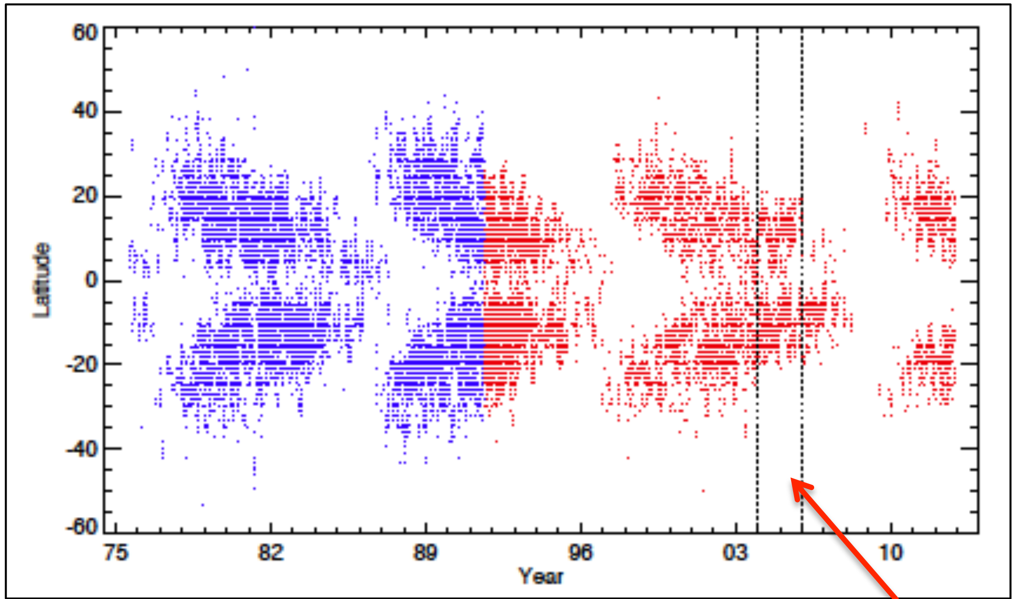
Svalgaard et al. 2011

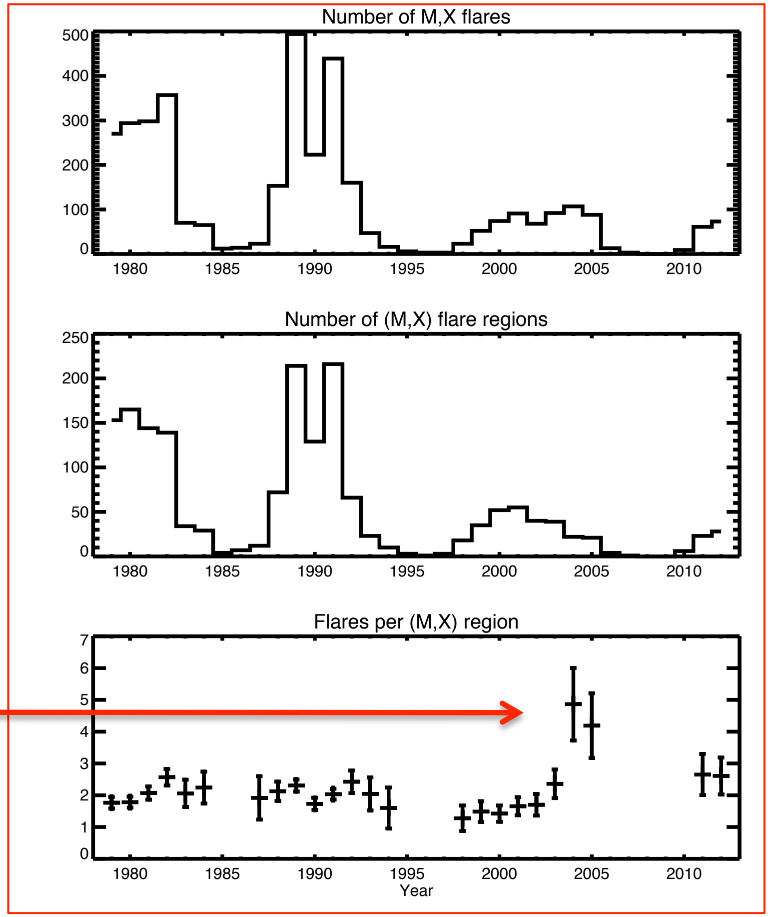
- RHESSI flares occur at “Hale Sector” boundaries
- It’s a striking effect; ask Leif to explain

Flare occurrence as a proxy: RHESSI flare longitudes



Flare occurrence as a proxy: Flare productivity





- M,X flare count per (M,X) region

Hudson et al., 2013

Flare occurrence as a proxy: The Poynting flux as an objective

- Active regions, and flares, appear where "magnetic flux emergence" happens

- In physics language, this means "where there are concentrations of plasma Poynting flux"

- Flares can precisely locate the result of the most intense of these concentrations

Conclusions

- Some of the proxies are quite precise
- All are related in complicated ways to the magnetic flux at the solar surface, and in no case do we have adequate physical understanding
- The space-age data can, in principle, characterize the magnetic k-ω diagram usefully
- The plasma Poynting flux may also be a useful target for the interpretation of proxy data