Declining Solar Polar Fields and their Signatures in the Solar Wind: Implications to near Earth Space

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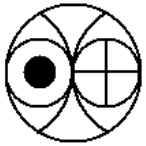

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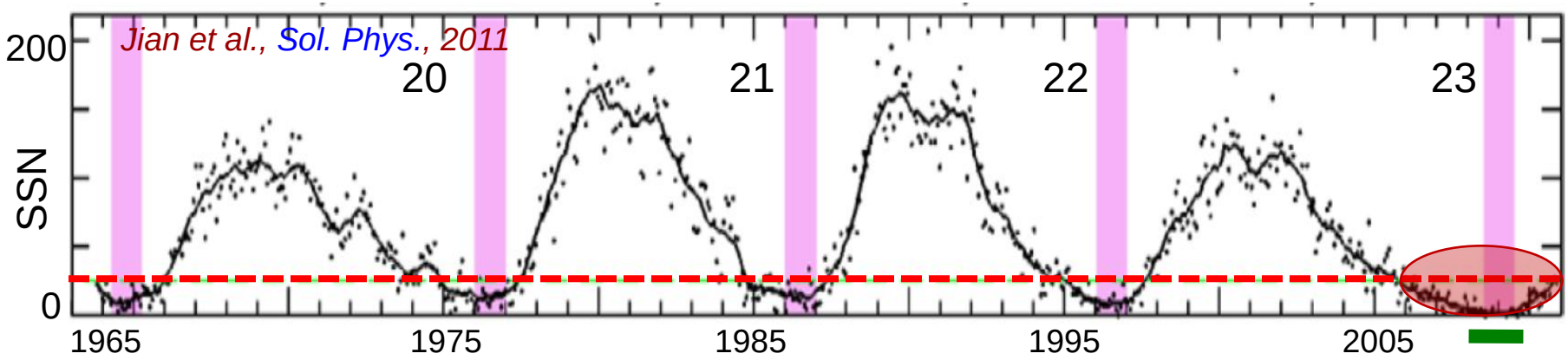
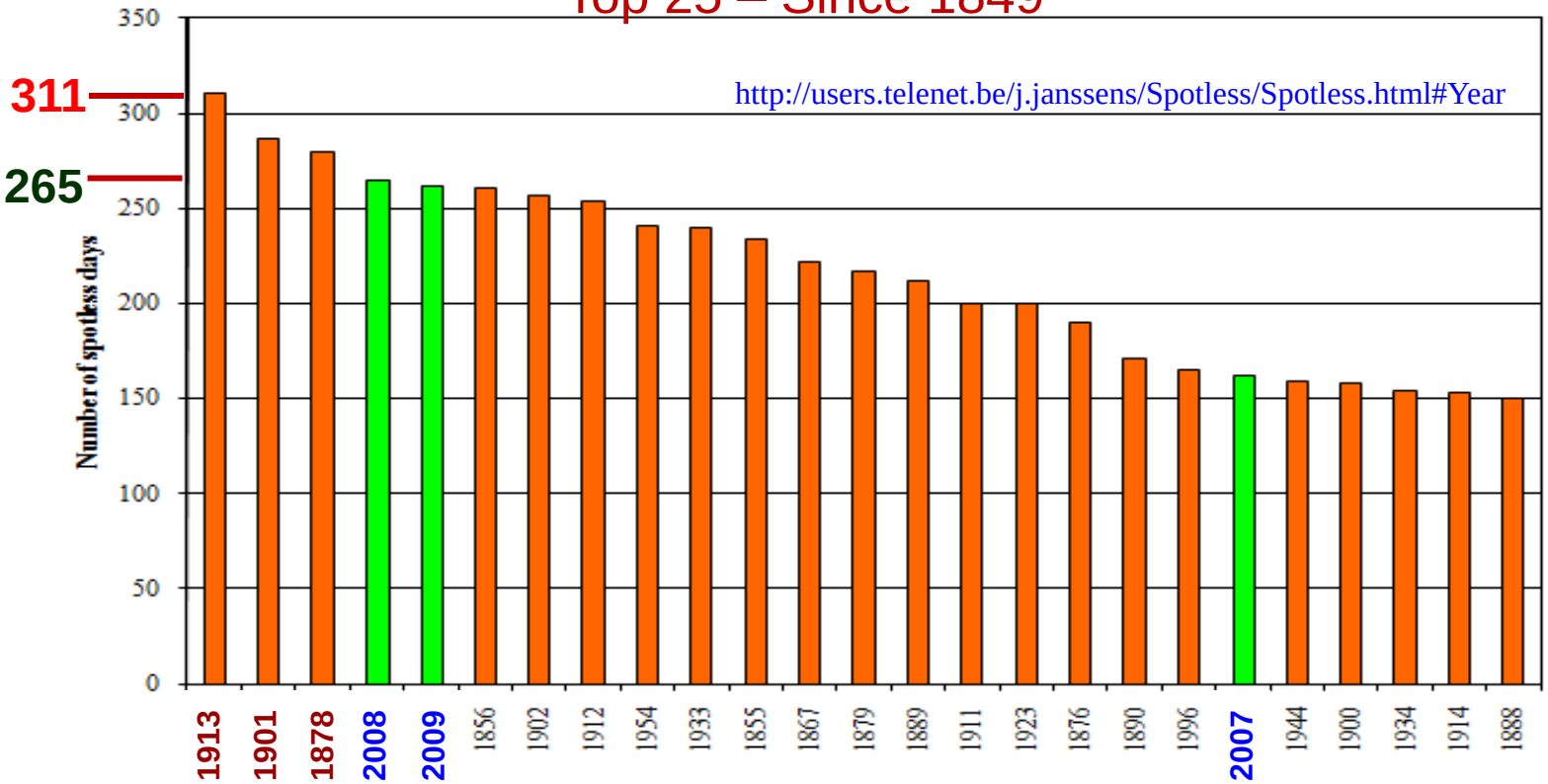
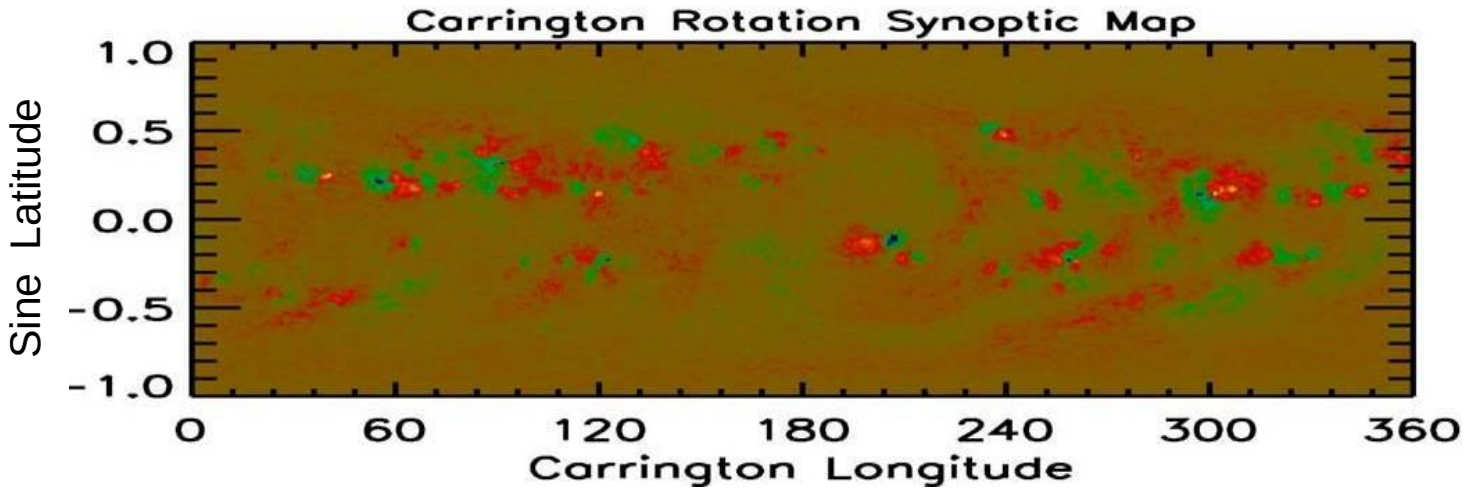
Unusual Solar Cycle 23



Top 25 – Since 1849



Data Used

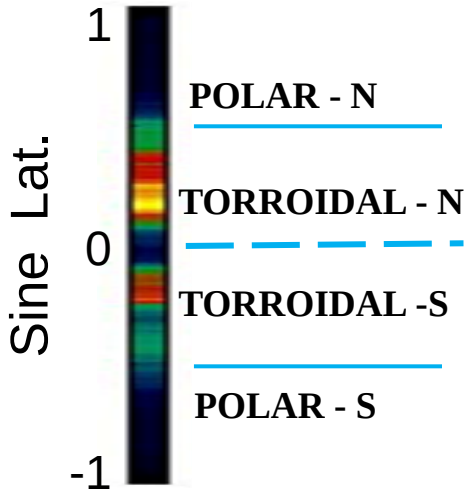


Longitude is averaged to produce a 1^{o} strip

Magnetic field is averaged for selected lat. bin

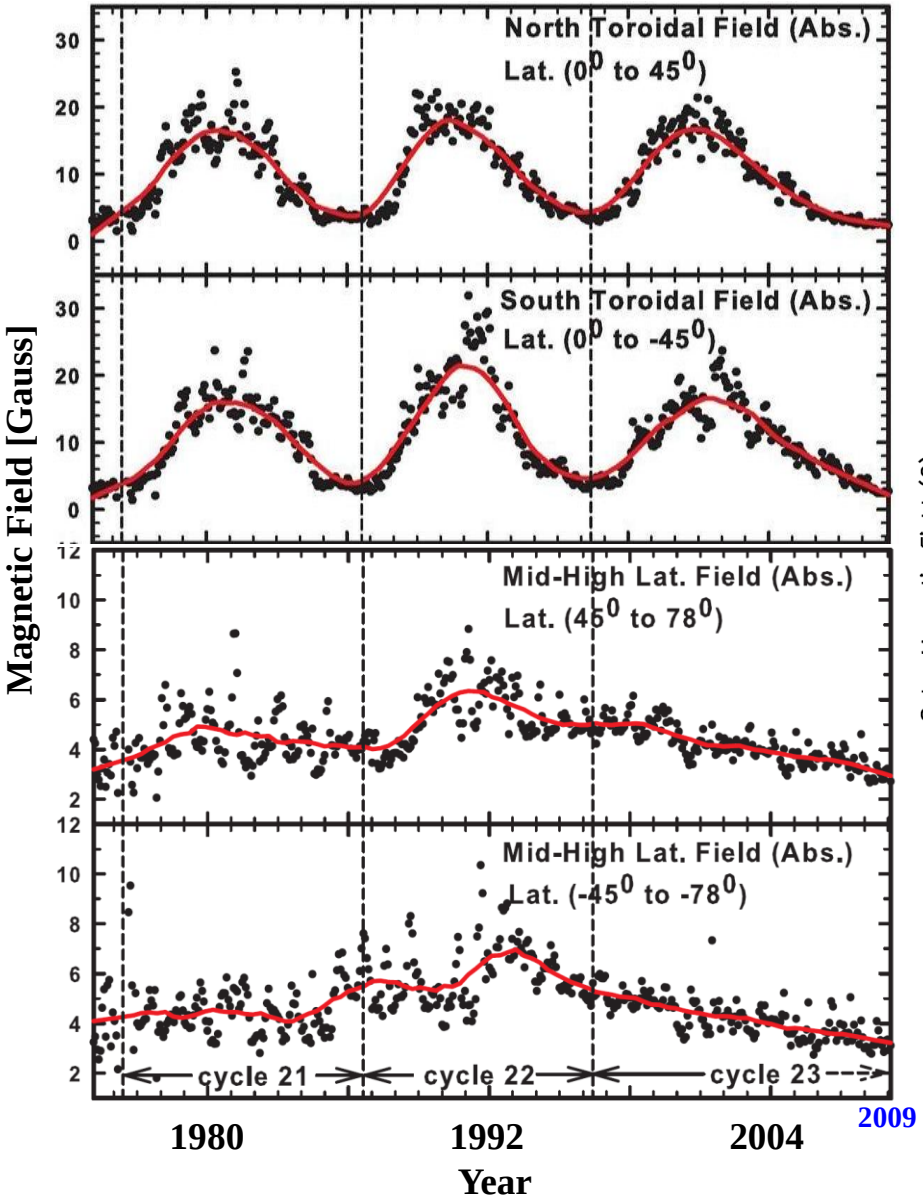
"TOROIDAL" FIELD (0-45 deg.)

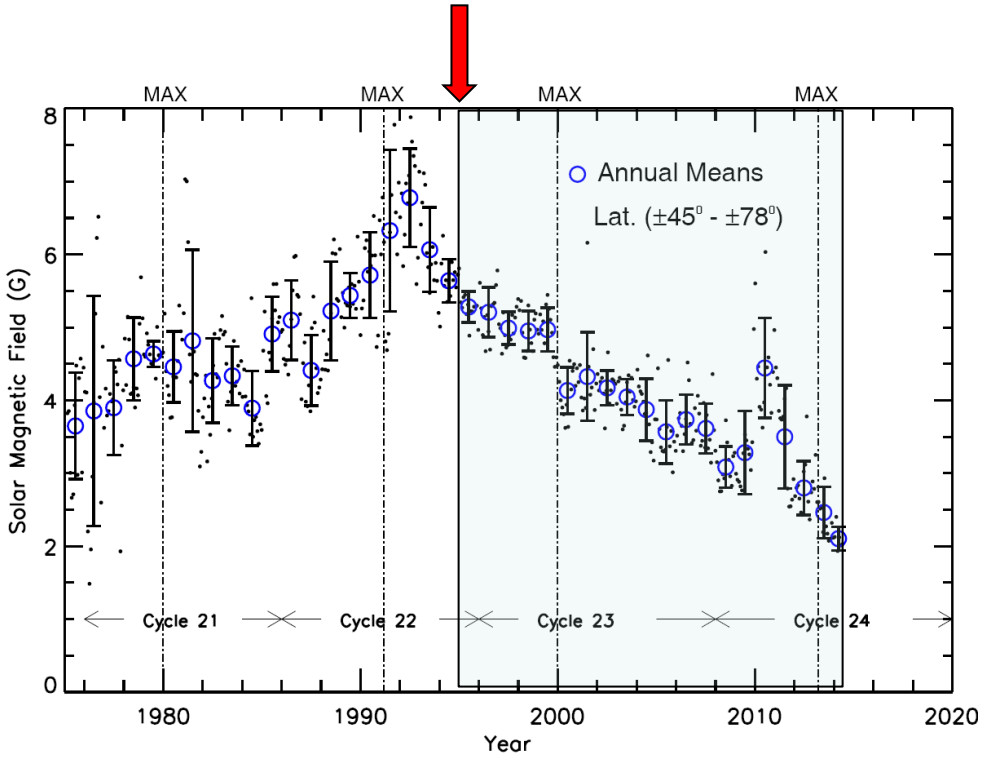
"POLAR" FIELD (45-78 deg.)



NSO/Kitt-Peak Data: February 1975 (1975.14) to July 2014 (2014.42), covering 526 Carrington Rotations between CR1625 and CR2151.

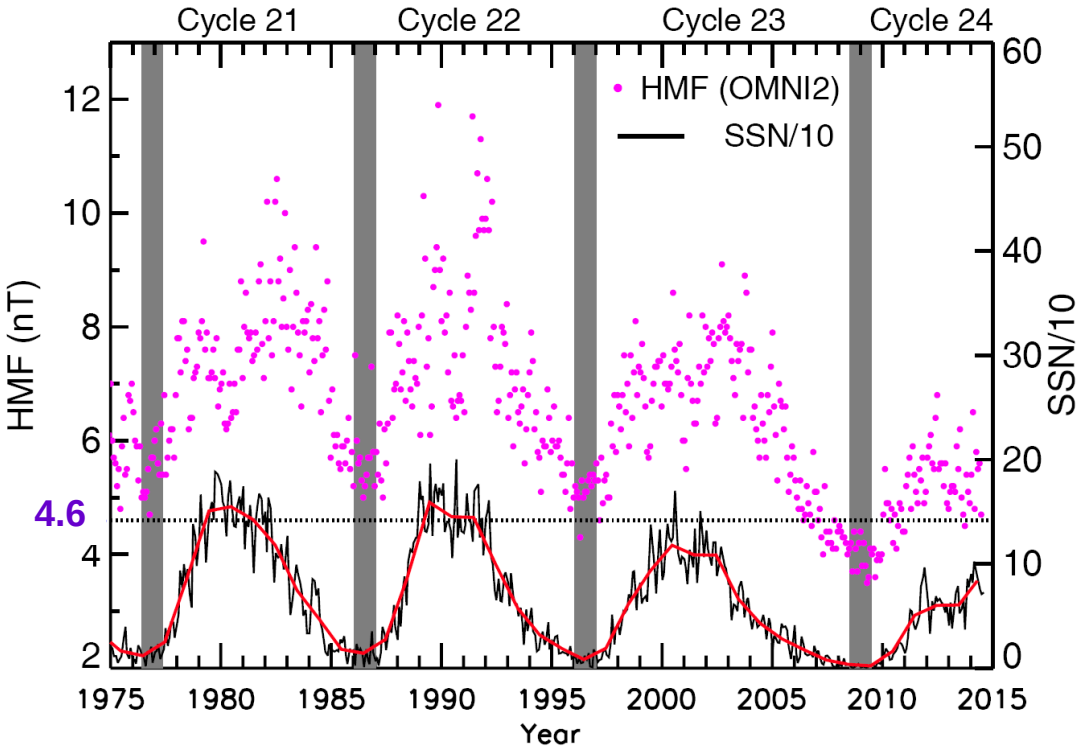
Photospheric Magnetic Fields





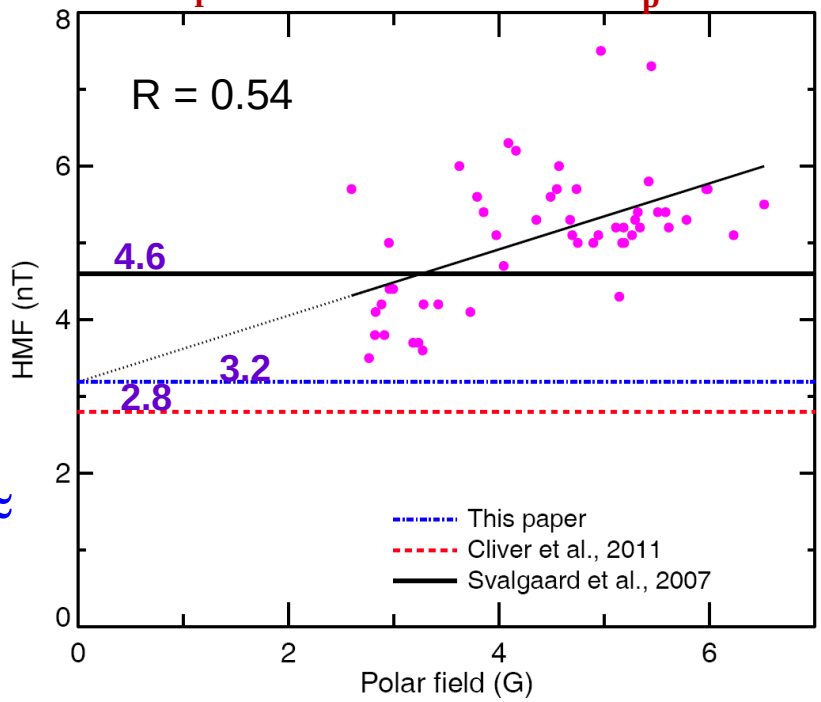
Janardhan et al., Sol. Phys., 2010

Heliospheric Magnetic Fields (HMF)



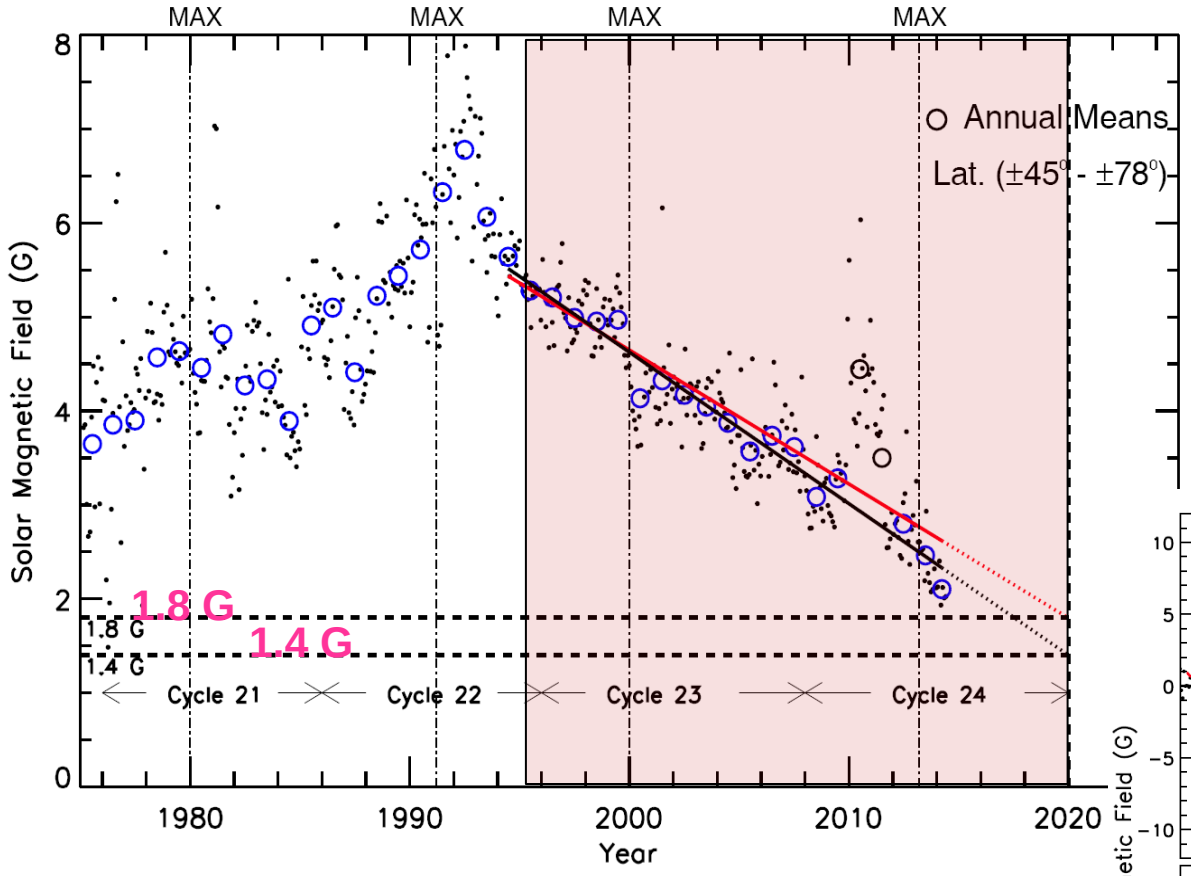
The floor of the HMF is the yearly average value to which it returns at each solar min. A floor of 4.6 nT was proposed by Svalgaard and Cliver [2007] using estimates of the HMF from 1872-2004.

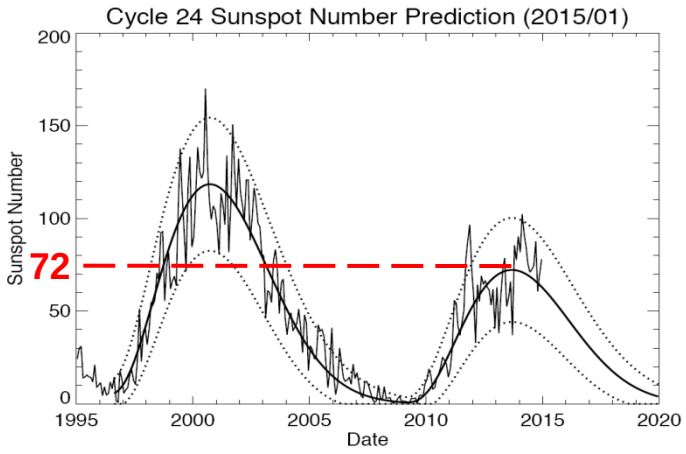
$B_r = 3.2 + 0.43 \times B_p$

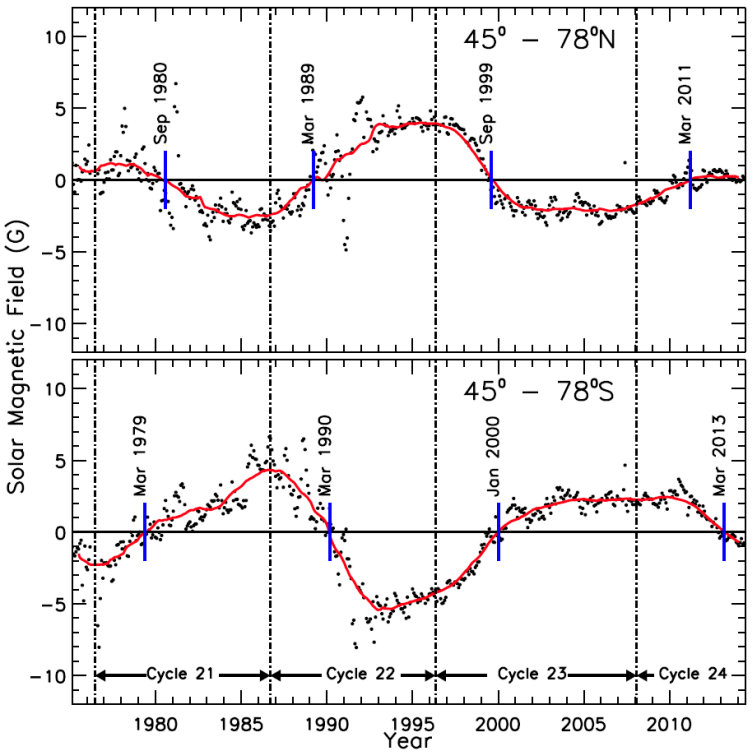


- ✓ **At 11-year minima, *B consists of* :**
  - ***i)*** ***a floor of ≈ 2.8 nT.***
  - ***ii)*** ***a* component due to solar polar fields that varies from ≈ 0 nT to ≈ 3 nT (Cliver and Ling, 2011).**
- ✓ **Polar fields provide the "seed" for the subsequent sunspot maximum.**

Declining Photospheric Fields (1975 – 2014)

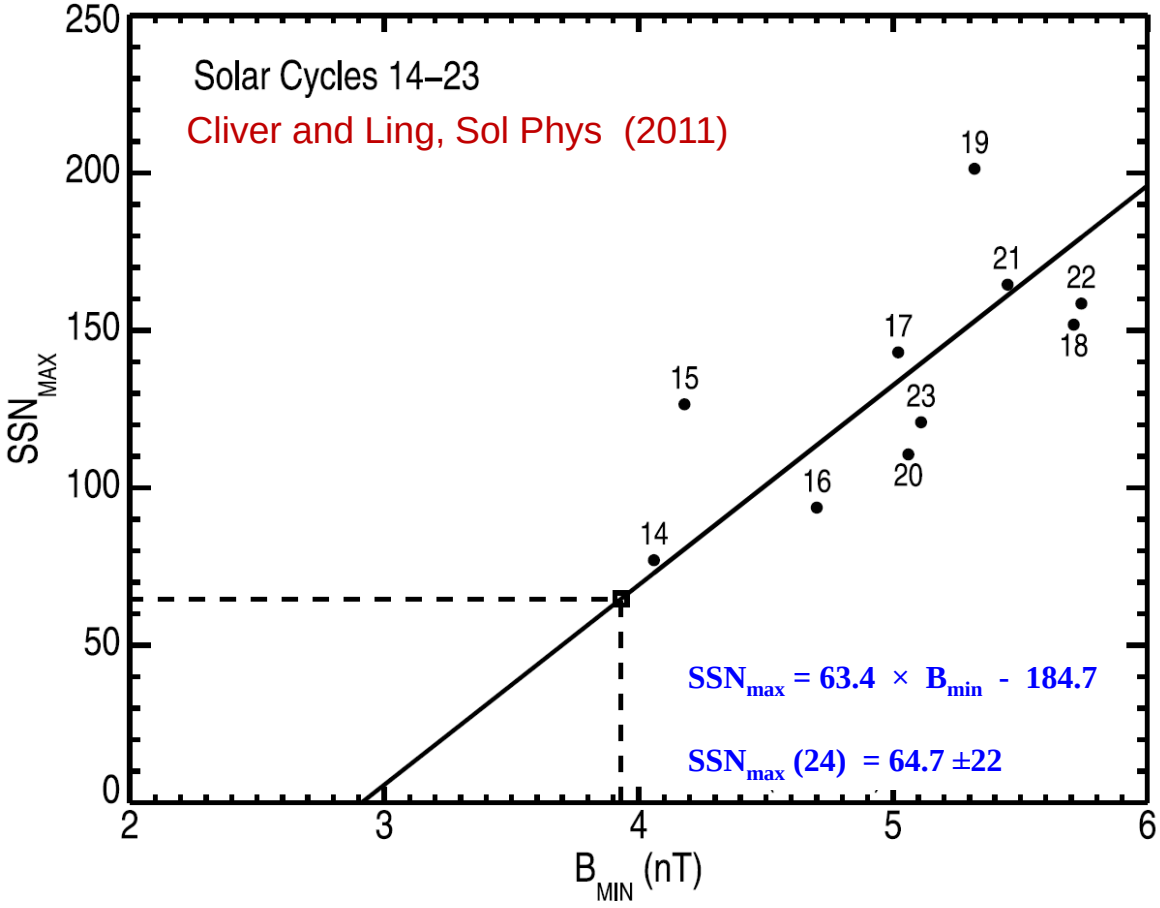






The linear relation between the Polar Field and the HMF ($\mathbf{B_r = 3.2 + 0.43 \times B_p}$) implies that the HMF ($B_r$) will lie between 3.8 nT and 4.0 nT by 2020.

Estimating the Strength of Cycle 25

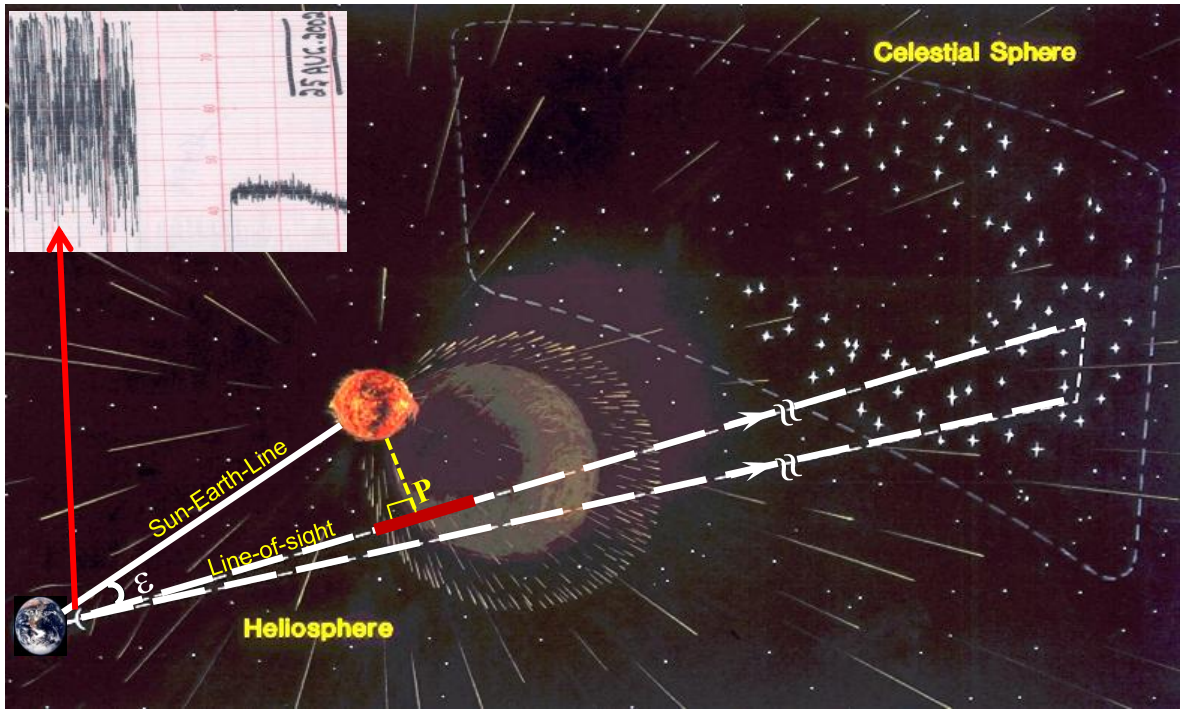


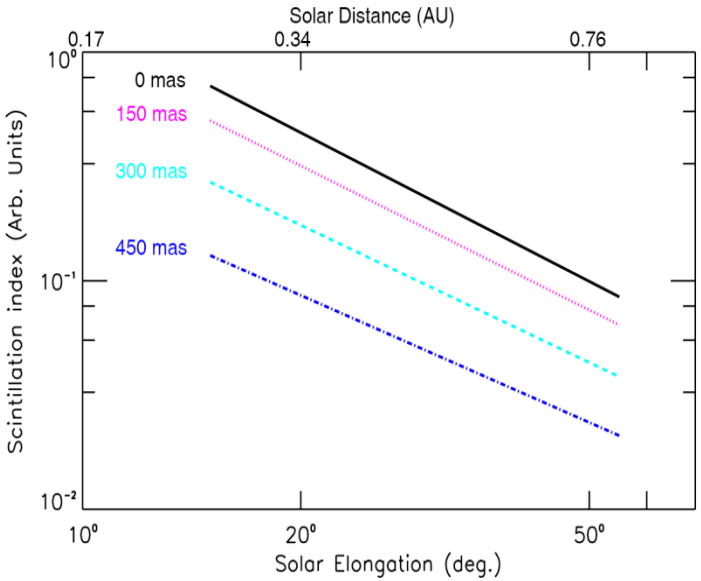
For Cycle 14-23, Cliver & Ling (2011) showed a precursor relationship between peak SSN and B_{MIN} at their preceding minima.

Using our estimate of B_{min} (in 2020) of 3.8 nT the sunspot maximum in cycle 25 :

$$SSN_{max}\ (25) = 56 \pm 13$$

Interplanetary Scintillation (IPS)



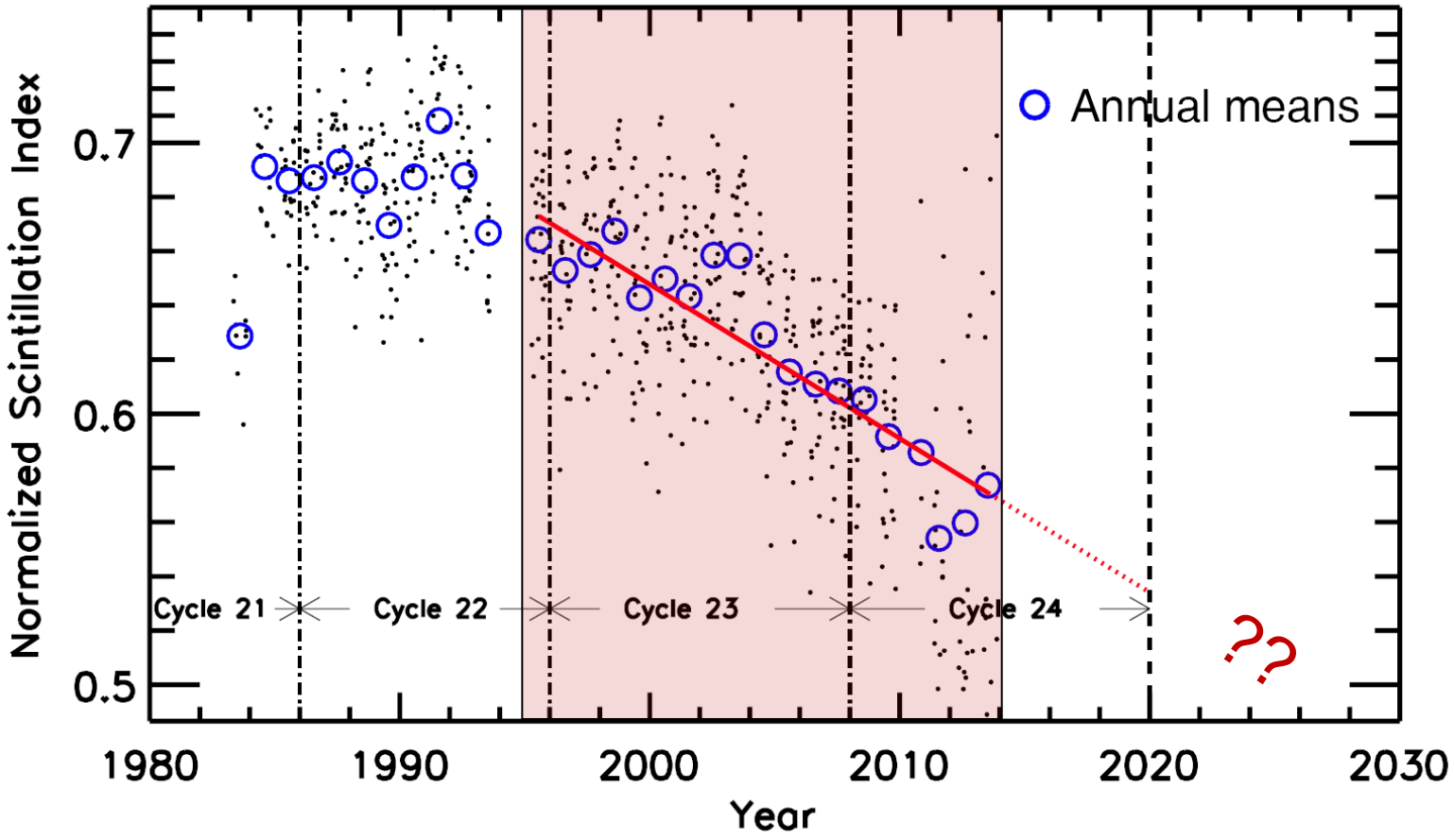


✓ IPS Obs. yield: $Scintillation\ Index\ (m) = \frac{\Delta S}{\langle S \rangle} = \sqrt{2}\,\phi_{rms}\ (weak\ scattering)$

$$\phi_{rms} = (2\pi)^{1/4}\,\lambda r_e\,(aL)^{1/2}\,\Delta N_{rms}$$

At 327 MHz: $12^o \le \varepsilon \le 55^o \equiv 0.2$ A.U. $\le r \le 0.8$ A.U.

Normalized Scintillation Index



Janardhan et al., GRL., 2011

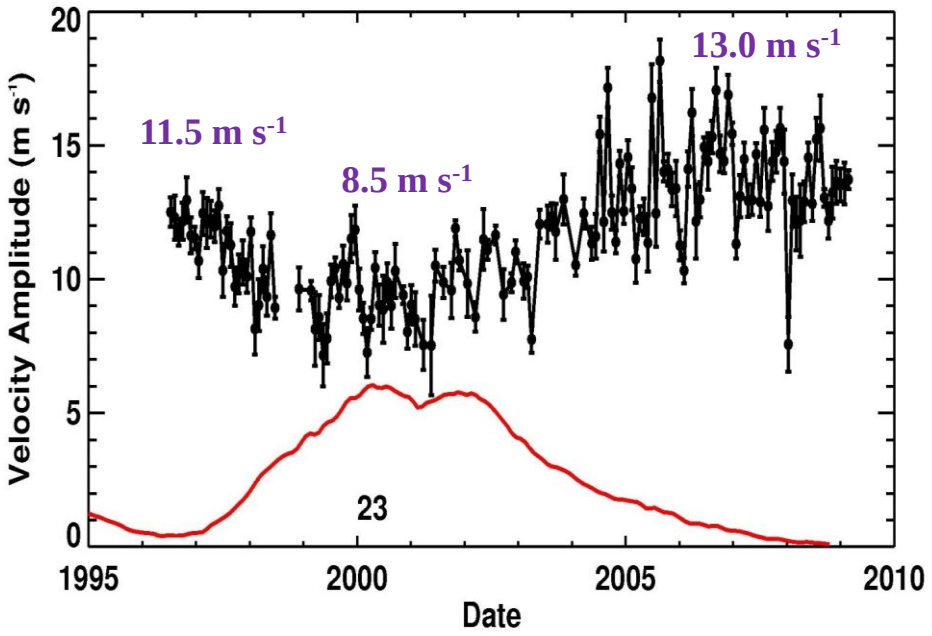
Modelling Grand Minima

Using records of ^{14}C in tree rings 27 grand minima have been detected in the last 11,400 years (Usoskin et al. 2007; Steinhilber et al. 2012).

✓Fluctuations in meriodional circulation initiate grand minima (Karak and Choudhuri, 2013), with gradual changes giving rise to a gradual onset.

✓One or two solar cycles before grand minima onset, the cycle period becomes longer (since meridional circulation determines cycle period - Karak and Choudhuri, 2013).

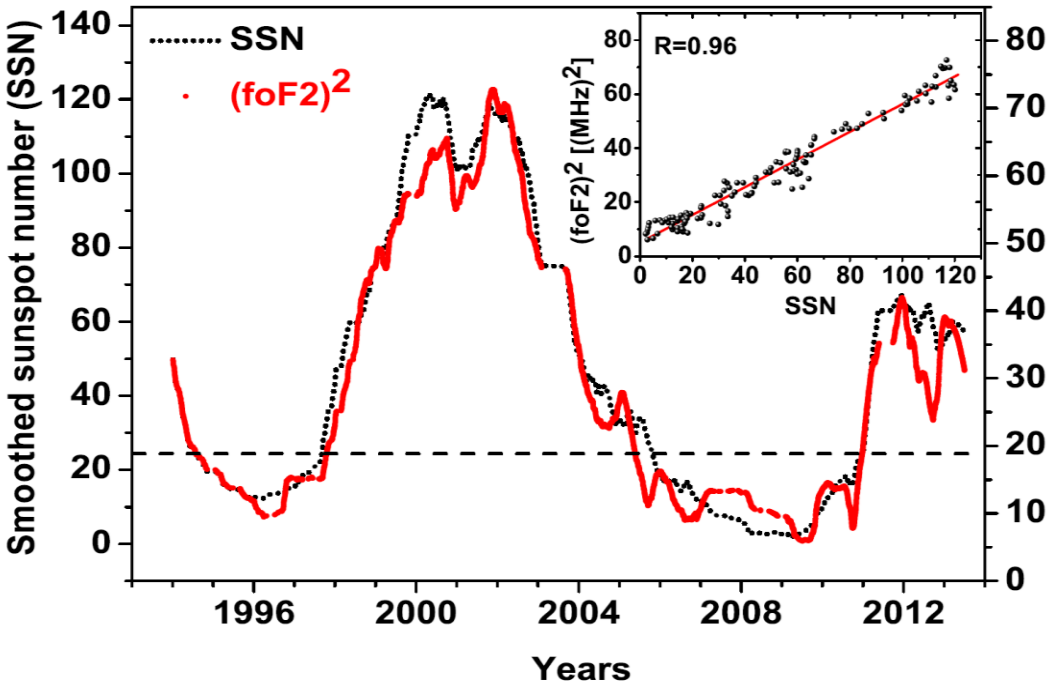
✓There is evidence of longer cycles before the start of the Maunder minimum and Spörer minimum (Miyahara et al., 2010).

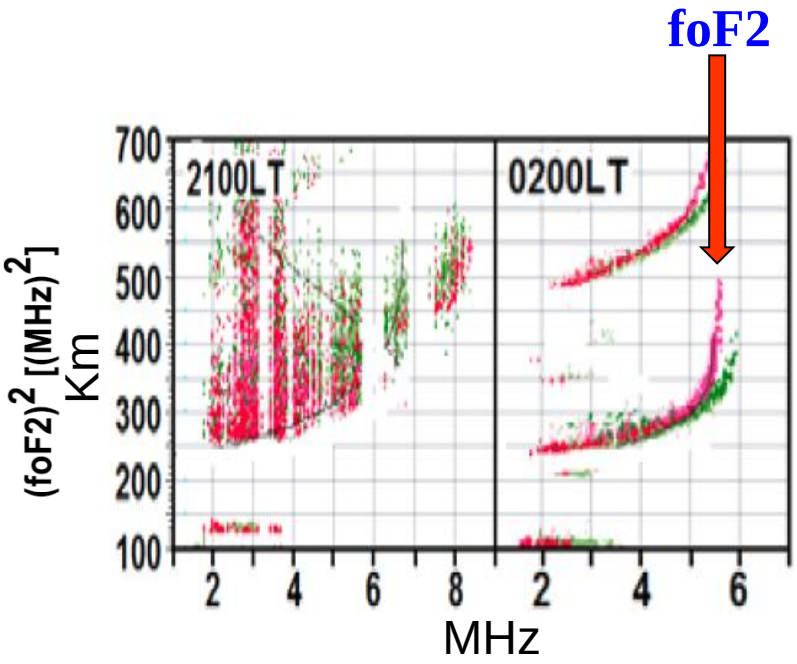


Hathaway & Rightmire, *Science*, 2010

The Terrestrial Connection

$N = 1.24 \times 10^4 \times [fo\ F2]^2$ electrons/cm^3



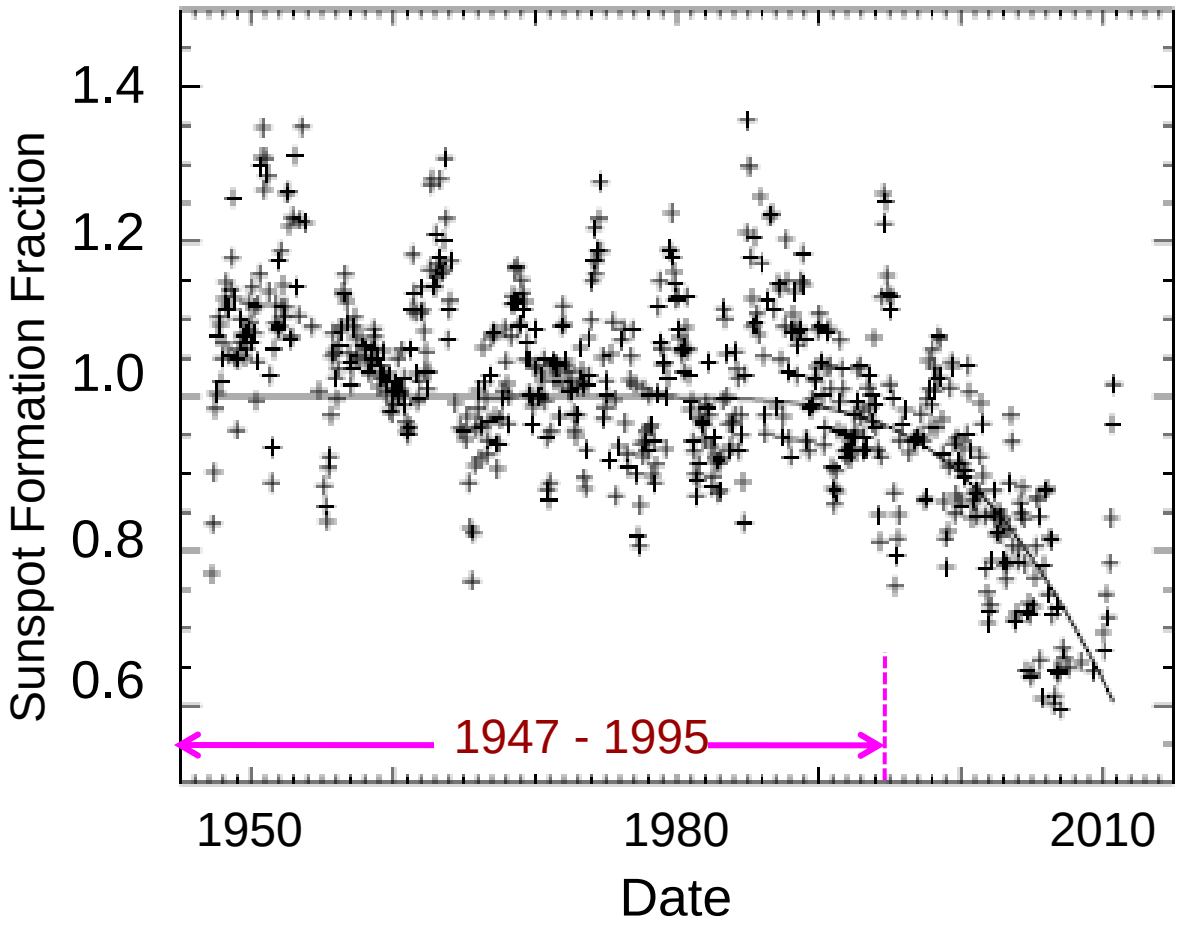


- ✓ **The F-region ionosphere is produced by solar EUV.**
- ✓ **A crucial ionospheric parameter is the critical frequency, in MHz, of the F-region (foF2), a quantity proportional to the root of the electron density at the height corresponding to that of maximum electron density.**
- ✓ **foF2 is a good proxy for SSN.**

Conclusions

- ✓ Solar photospheric fields and solar wind micro-turbulence levels have been steadily declining for the past 19 years and will continue to decline at least until 2020 . There is indication that we are probably headed towards a Maunder-like grand minimum beyond Cycle 25.
- ✓ Based on the correlation between the high-latitude magnetic field and the HMF at the solar minima, the HMF will decline to a value of 3.8 – 4.0 nT by 2020.
- ✓ SSN_{max} of Cycle 25 will be between **56 ±13**, making it only a little stronger than the cycle preceding the Maunder Minimum between 1645 and 1715.
- ✓ There is some indication that the ionospheric cut-off frequency had reduced significantly

Sunspot Formation Fraction



Sunspot formation fraction is the sunspot number divided by the sunspot number predicted from the 10.7 cm radio flux.

The value is 1.0 ± 0.11 from 1947 to 1995 followed by a statistically significant decline.

Predicts 50% fewer spots in cycle 24 than cycle 23 and almost no spots in cycle 25 !

Livingston, Penn & Svalgard, ApJ Lett. (2012)

Extreme Events ?

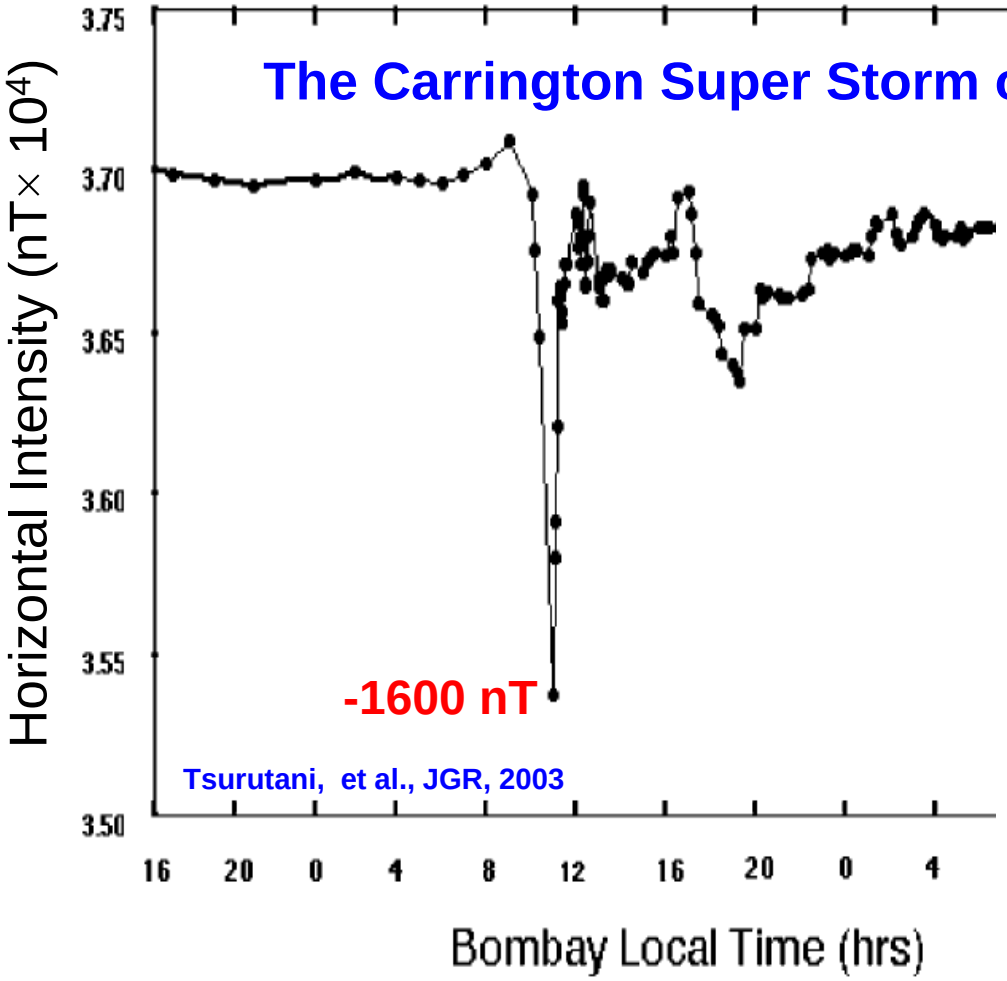


*Table 5: Top 10 Dst Storms**

Rank	Dst (nT)	Date
1	-589	03/14/1989
2.	**-465****	**11/20/2003**
3.	-429	07/15/1959
4.	-427	09/13/1957
5.	-426	02/11/1958
6.	**-401****	**10/30/2003**
7.	-387	03/31/2001
8.	-387	05/26/1967
9.	-354	11/09/1991
10.	-339	11/13/1960

✓ Three of the five largest solar energetic proton events and two of the eight strongest storms in the last 150 years occurred during relatively weak solar cycles 13 and 14.