Livingston & Penn Data and Findings so Far (and some random reflections)

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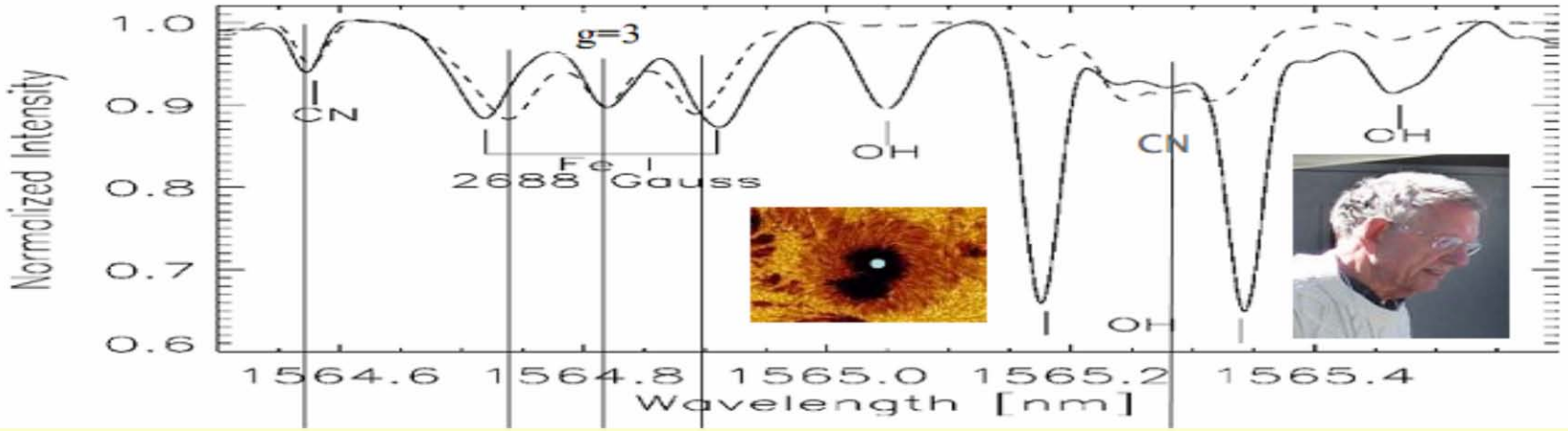
Stanford, July 2011

What is Livingston Measuring?

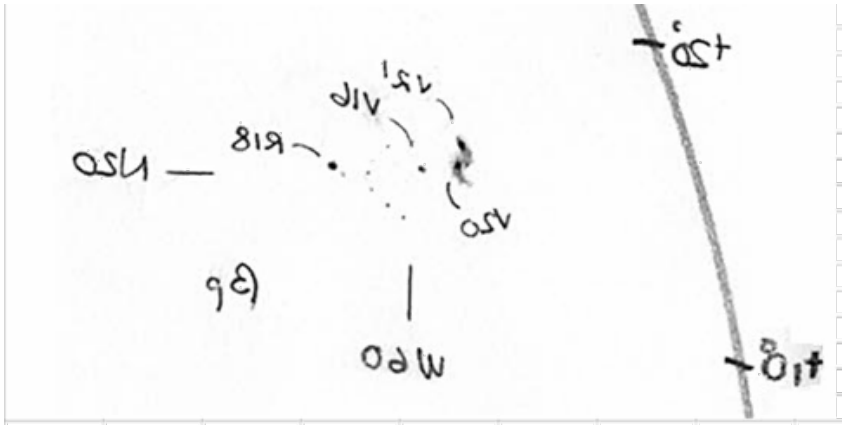
The Fe I line at 1564.8 nm has a very large and easily measured Zeeman splitting. The Hydroxyl radical OH is very temperature sensitive and the lines weaken severely at higher temperatures.



Courtesy Bill Livingston

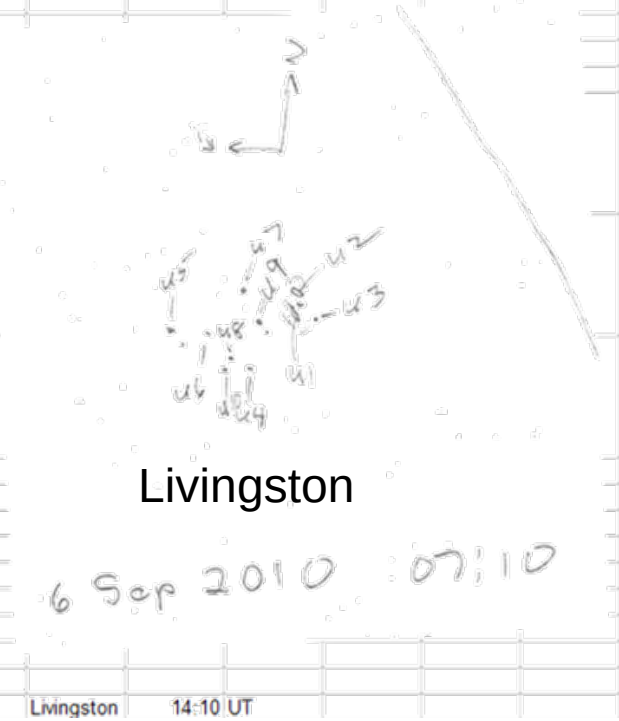
From 2001 to 2011 Livingston and Penn have measured field strength and brightness at the darkest position in umbrae of 1843 spots using the Zeeman splitting of the Fe 1564.8 nm line. Most observations are made in the morning [7h MST] when seeing is best. Livingston measures the absolute [true?] field strength averaged over his [small: 2.5″x2.5″] spectrograph aperture, and not the Line-of-Sight [LOS] field.

(Simultaneous) Drawings of Sunspot Group at Different Observatories



MWO 15:30

Locarno 8:00



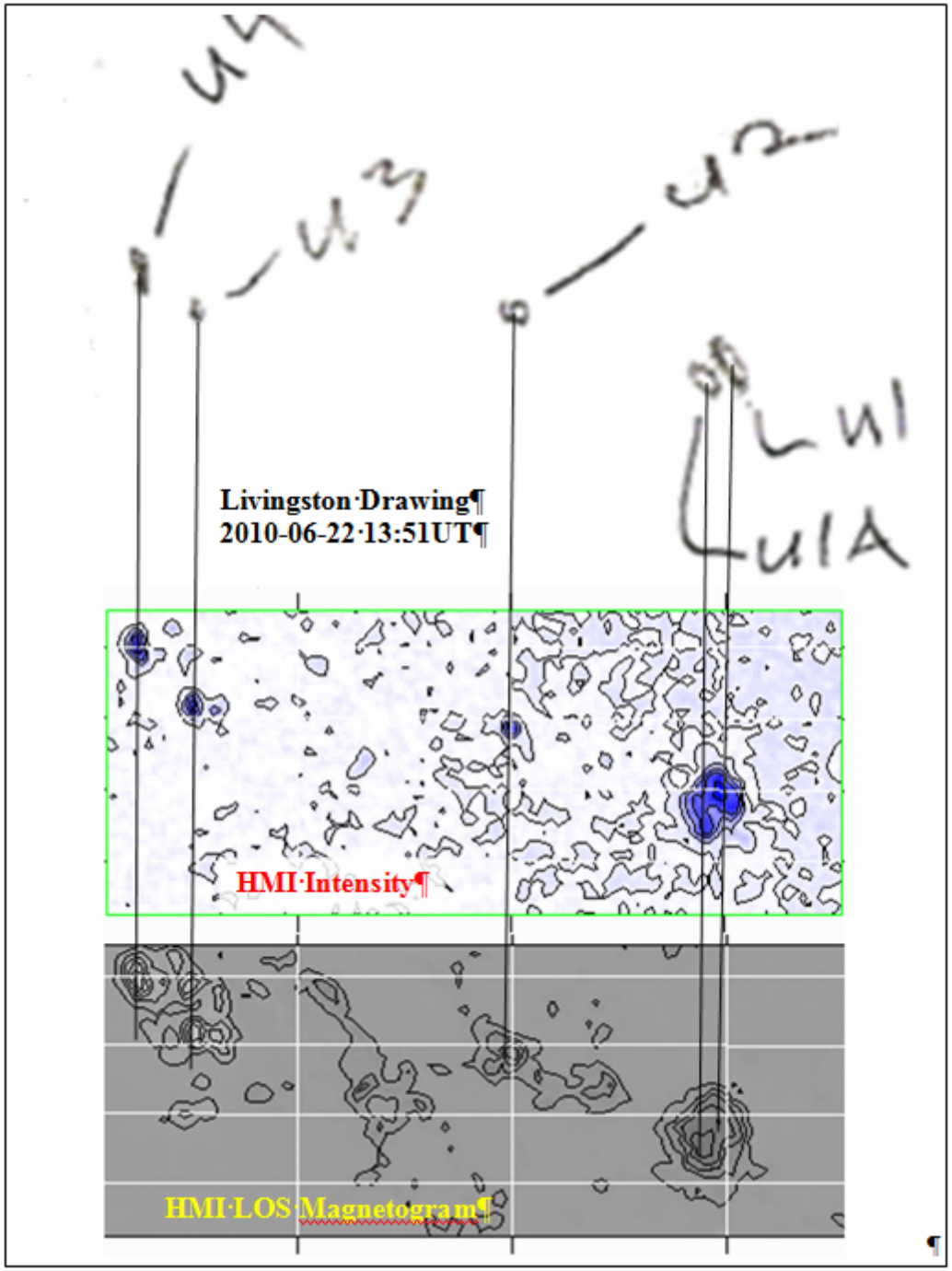
Livingston

6 Sep 2010 07:10

Livingston 14:10 UT

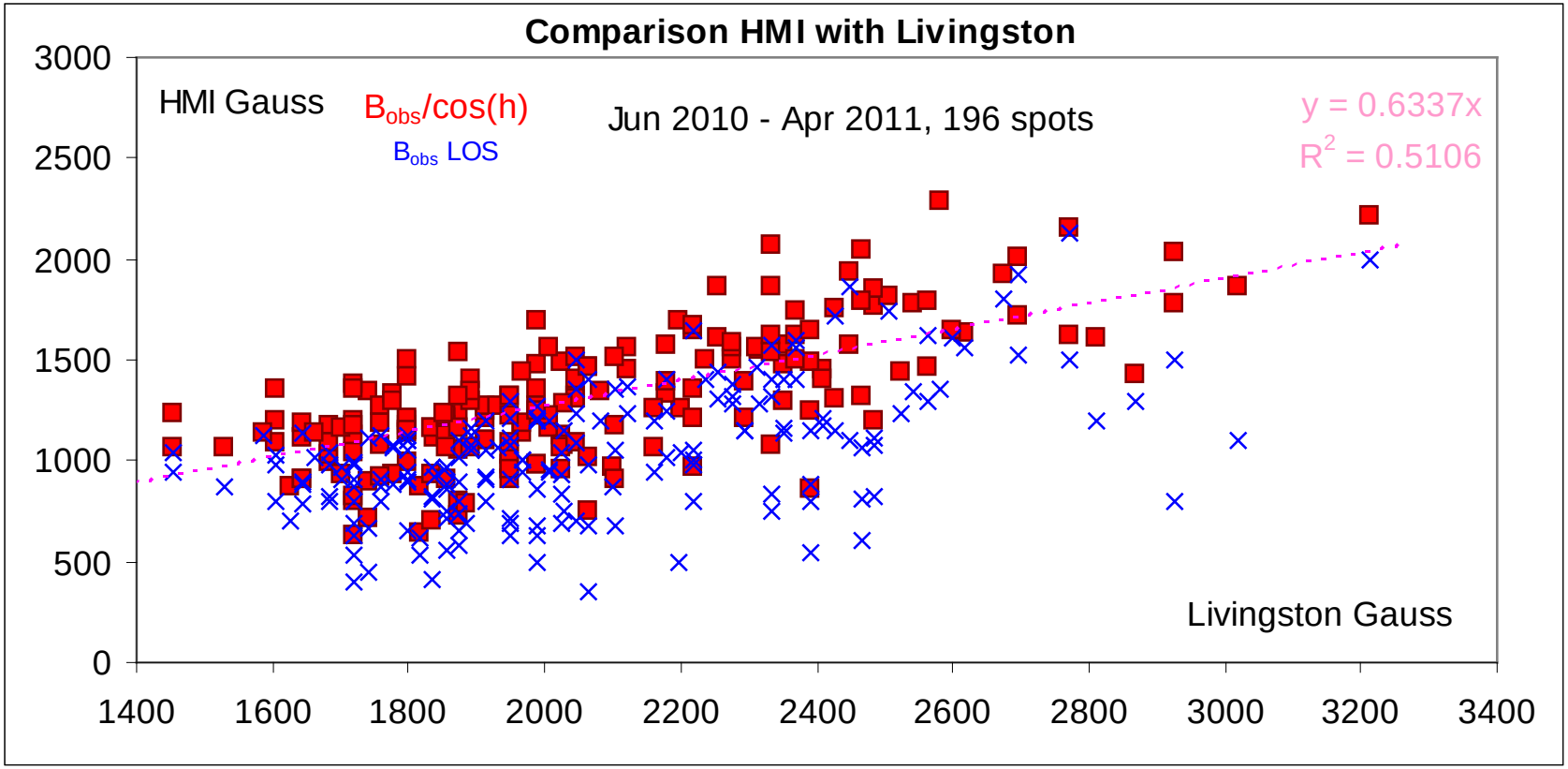
NSO	82 cm
MWO	42 cm
Locarno	25 cm

Livingston makes a ‘finding chart’ of the spots he observes directly from the projected image.



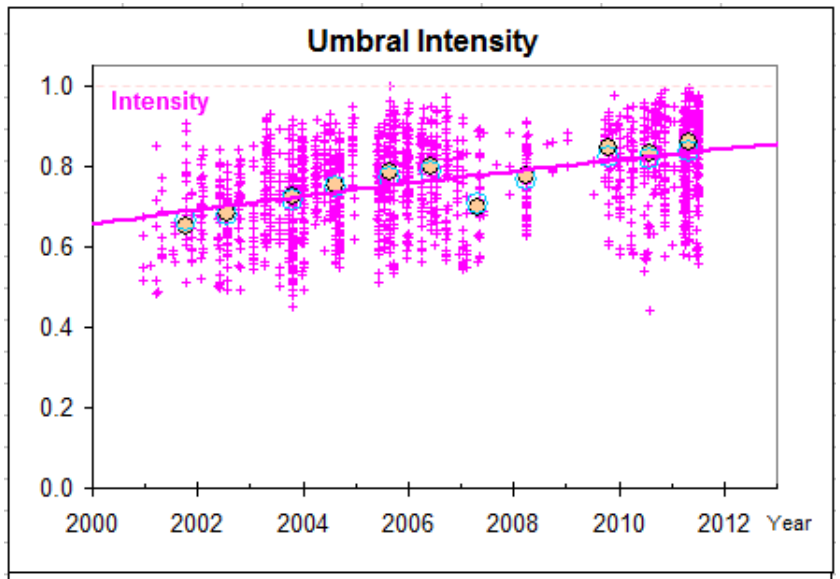
Using the Finding Chart we can identify the spots on HMI (and other) magnetograms

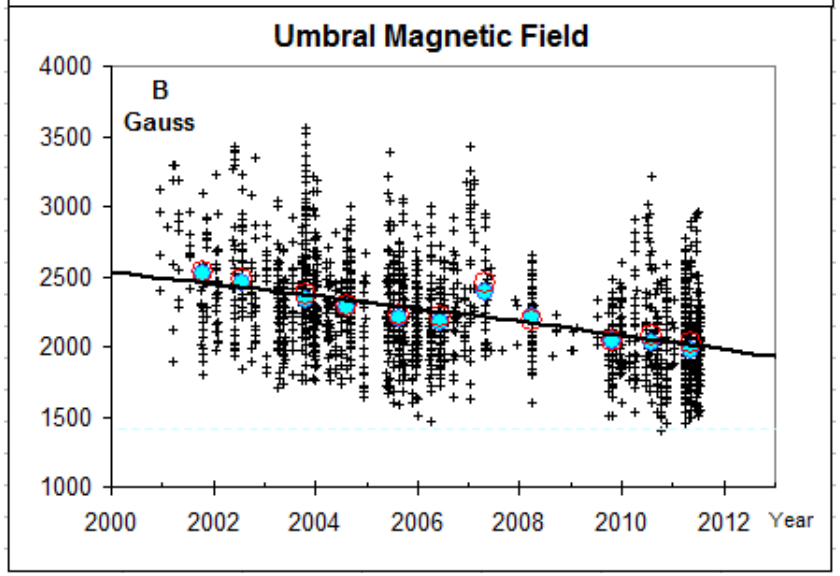
And compare the measured magnetic fields



HMI LOS fields [corrected for simple projection] is only 63% of Bill Livingston's. This is our problem, not his. SOLIS and HINODE (and our Vector fields) agree with Bill.

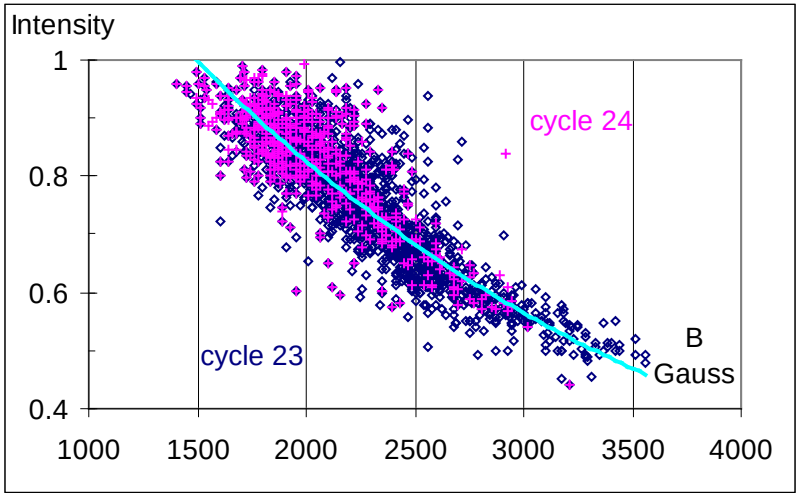
In spite of large scatter the magnetic field has decreased 500 G since 2001



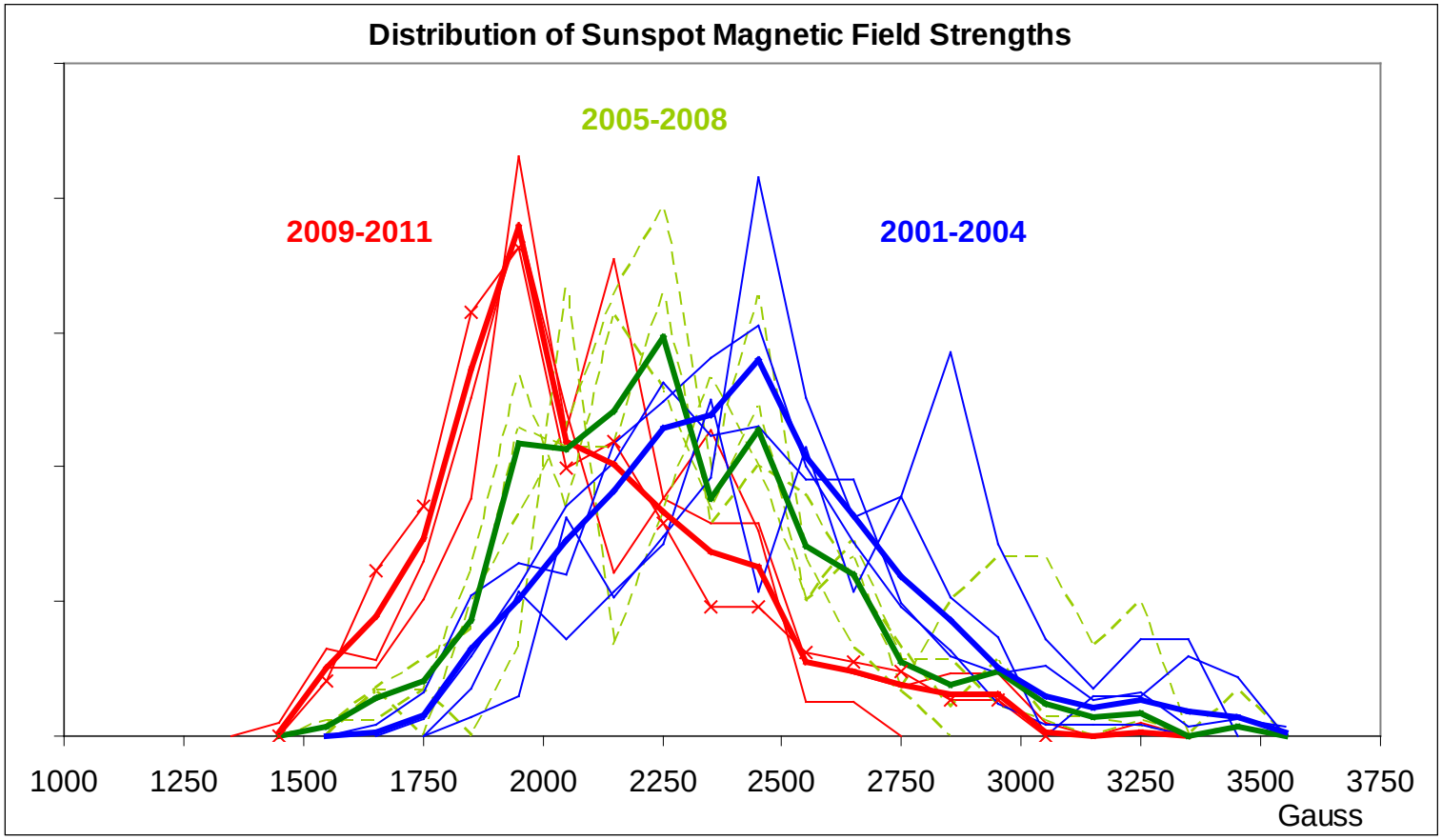


Livingston also measures the intensity of the umbra compared to the continuum and finds that [in the infrared] that for all spots he can see [i.e. intensity < 1] the field is greater than ~1450 G. Another 500 G to go...

Hence his statement that if [when?] the decline of the field continues, spots will effectively ‘disappear’ or at least be much less visible.

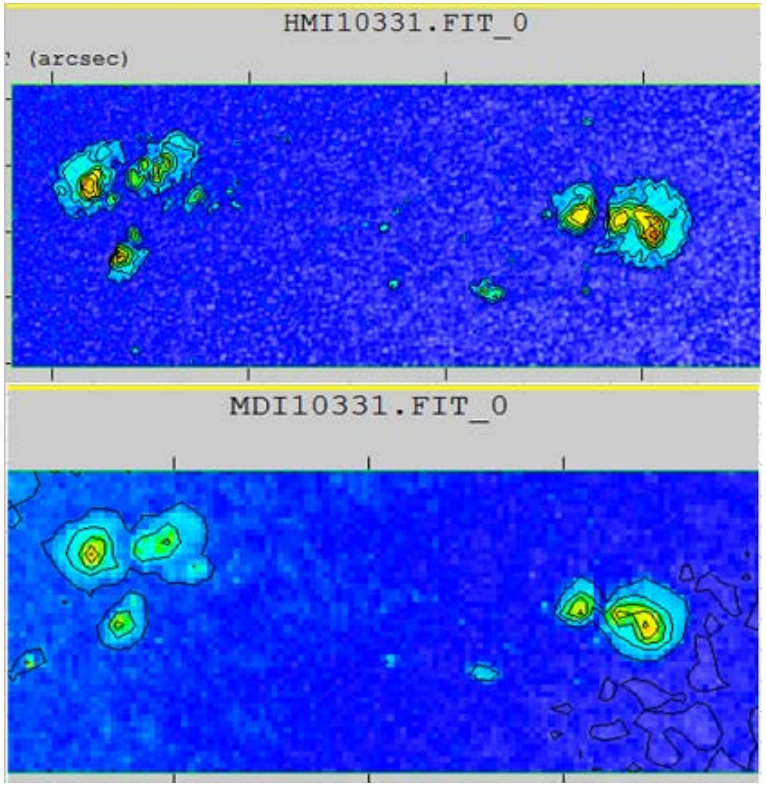


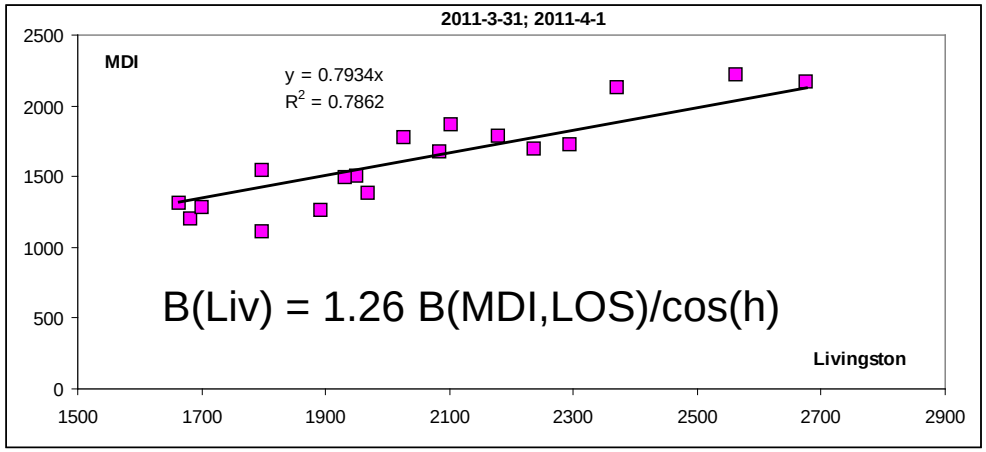
The Distribution of Field Strengths has Shifted with Time

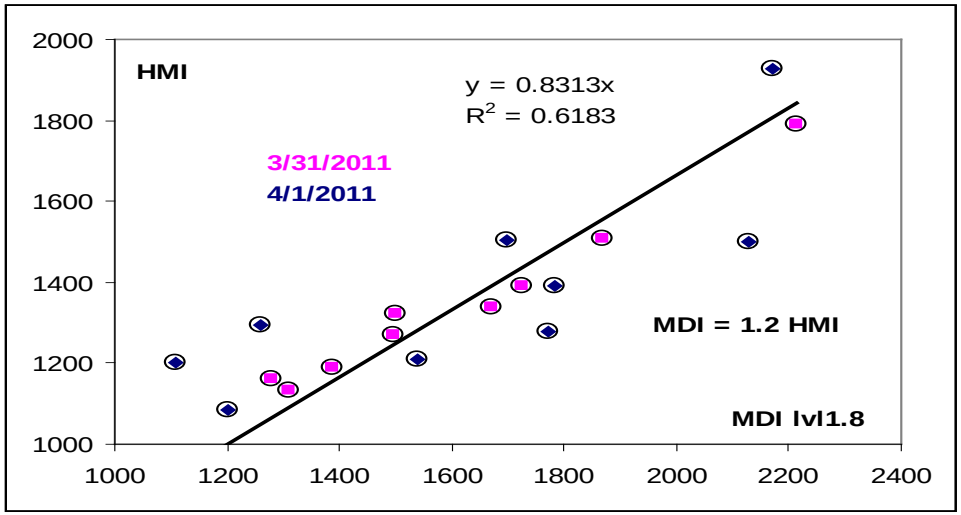


Is this just a sunspot cycle dependence?

We can also compare with MDI to extend the time base

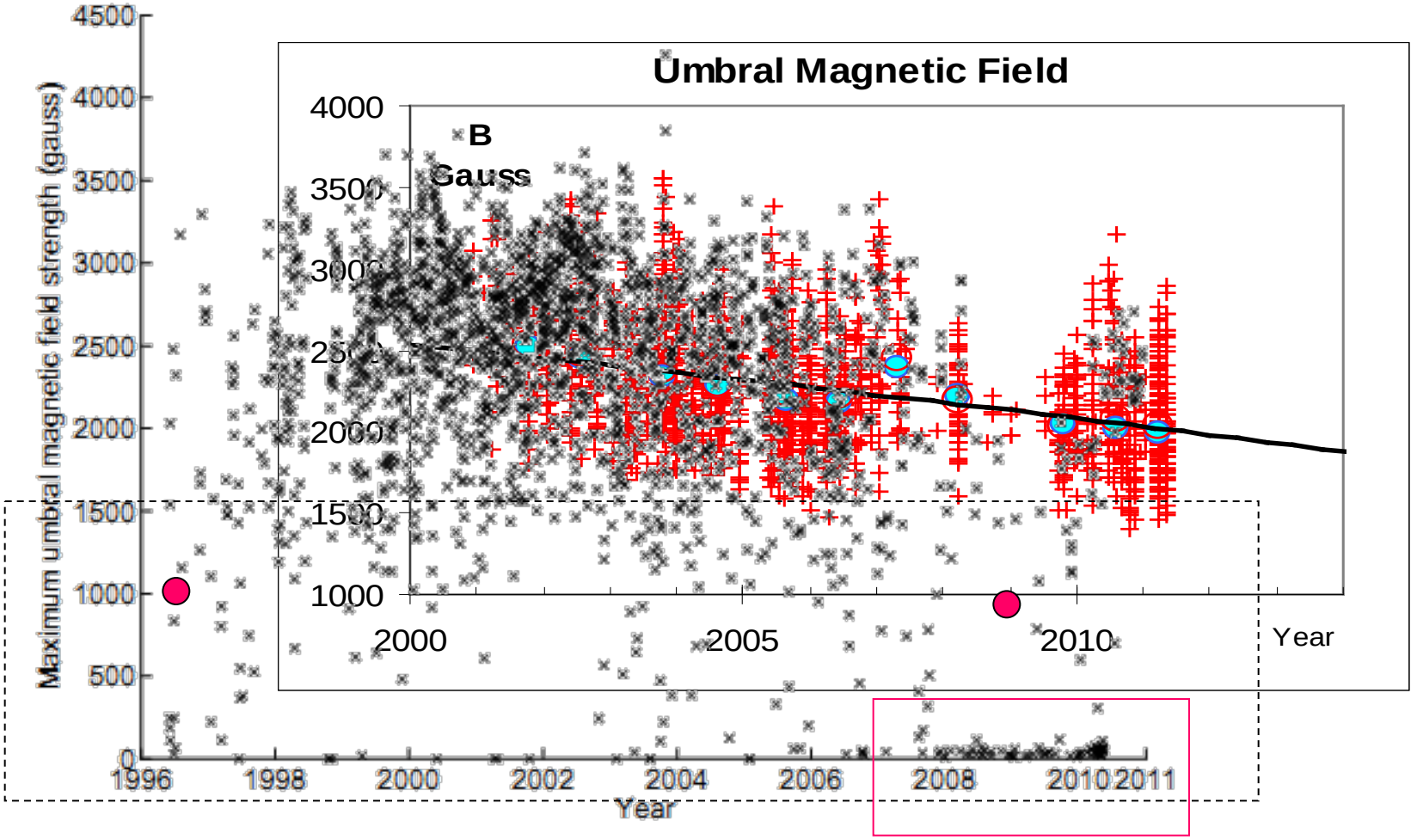






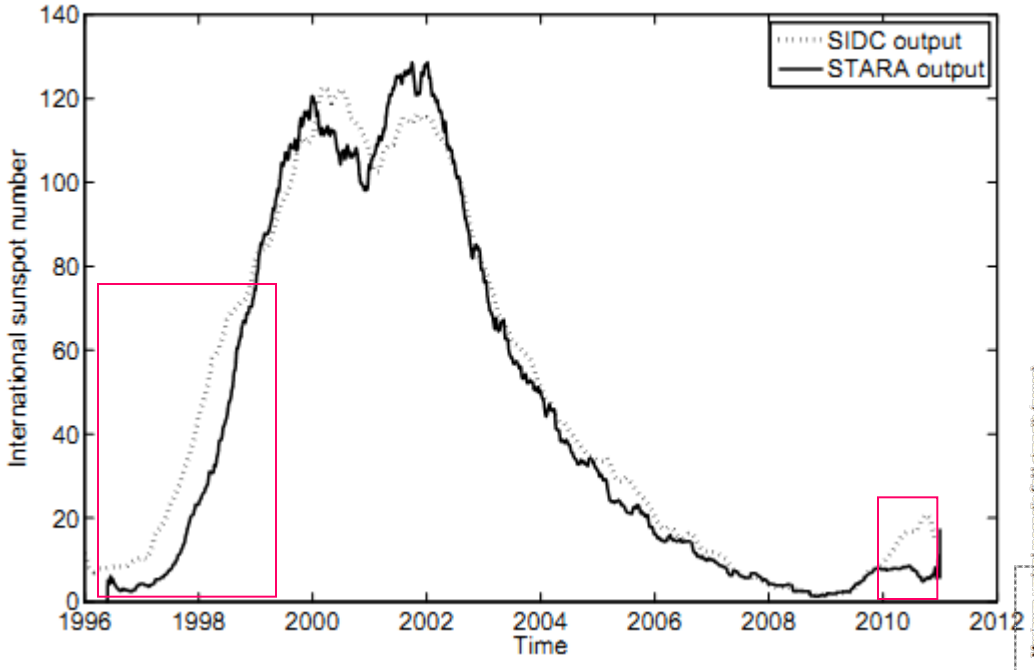
B(HMI) =1/(1.2*1.26)~ = 0.6614 B(Liv)

Some people have already done that (using automatic detection of sunspots)

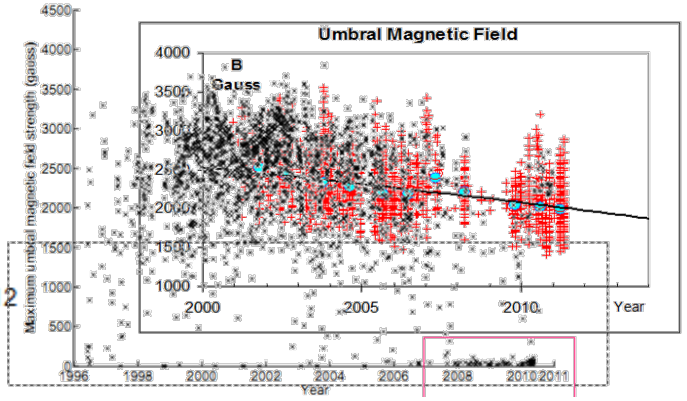


F. T. Watson, L. Fletcher, and S. Marshall, A&A 2011

It is not clear what they plot [LOS or corrected for projection, how?]



Their STARA algorithm does not seem to perform very well for small spots so the data in 1996-1997 and 2008-2010 is suspect



So, unfortunately, it is hard to draw any firm conclusion one way or the other. The next year or two will be crucial.

Livingston has some scattered measurements back to 1998, so one could look at those and compare

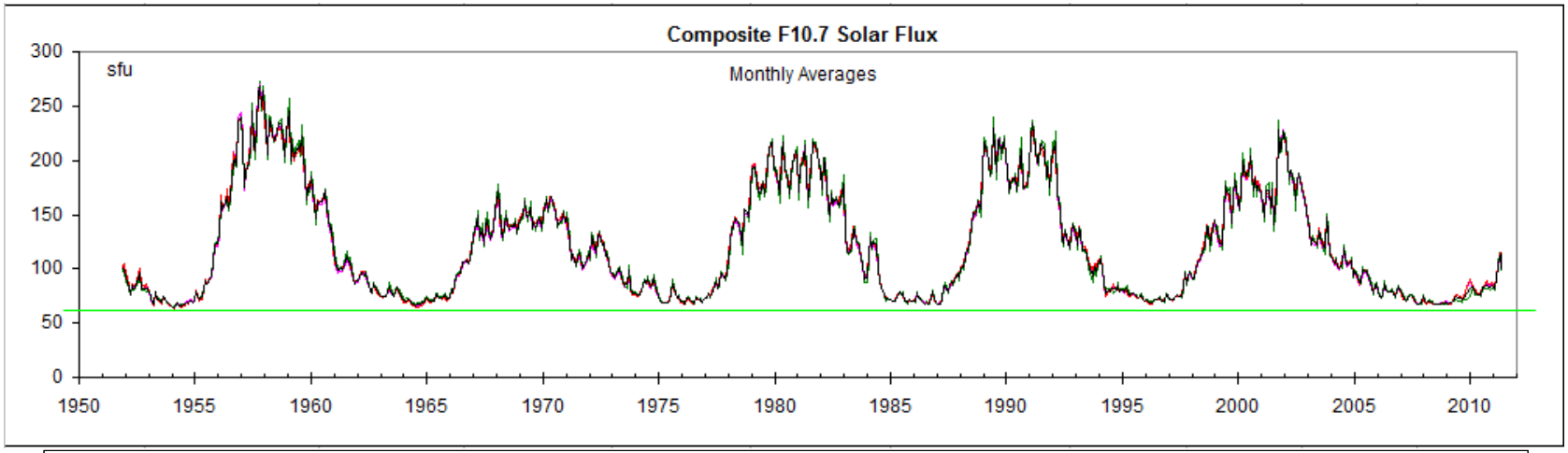
Livingston, Penn, and Svalgaard:

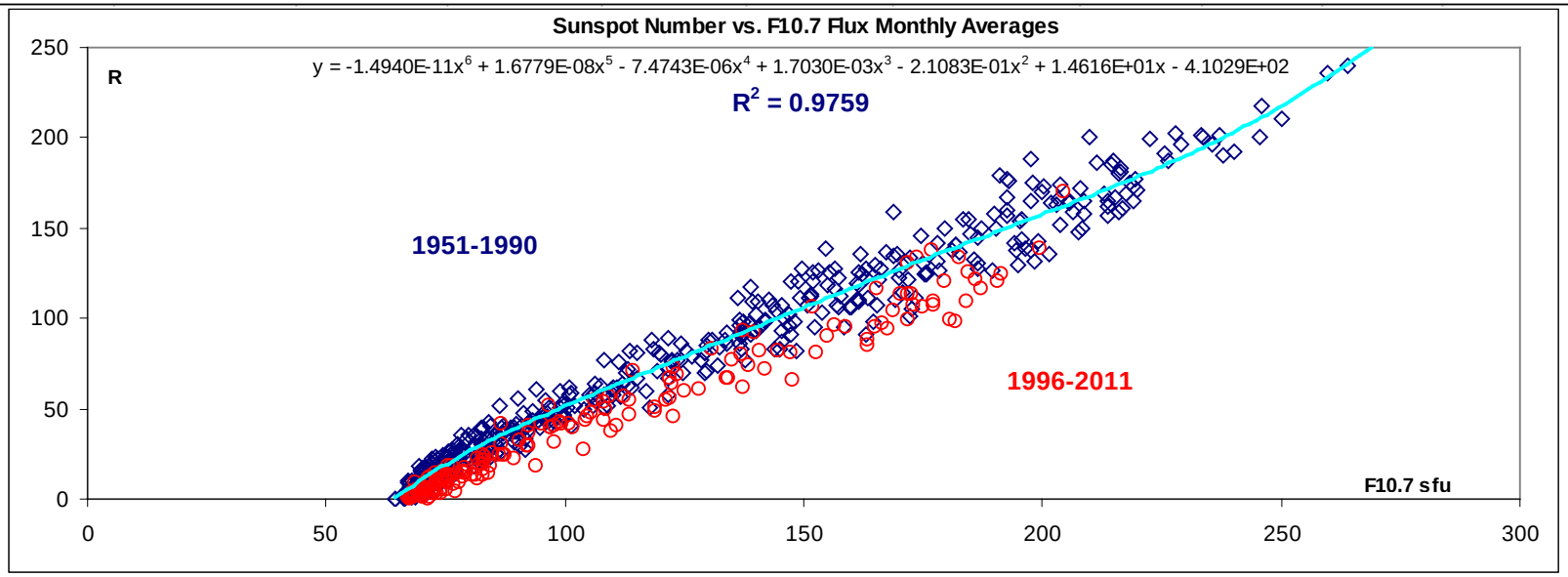
Extrapolating the behavior from the past 13 years into the next 13 years suggests the Sun may enter a new Grand Minimum.

If true, we shall learn a lot about ‘The Forgotten Sun’ that nobody alive today has ever seen, with obvious implications for the climate debate and environmental issues generally.

Are there other indications that this might happen?

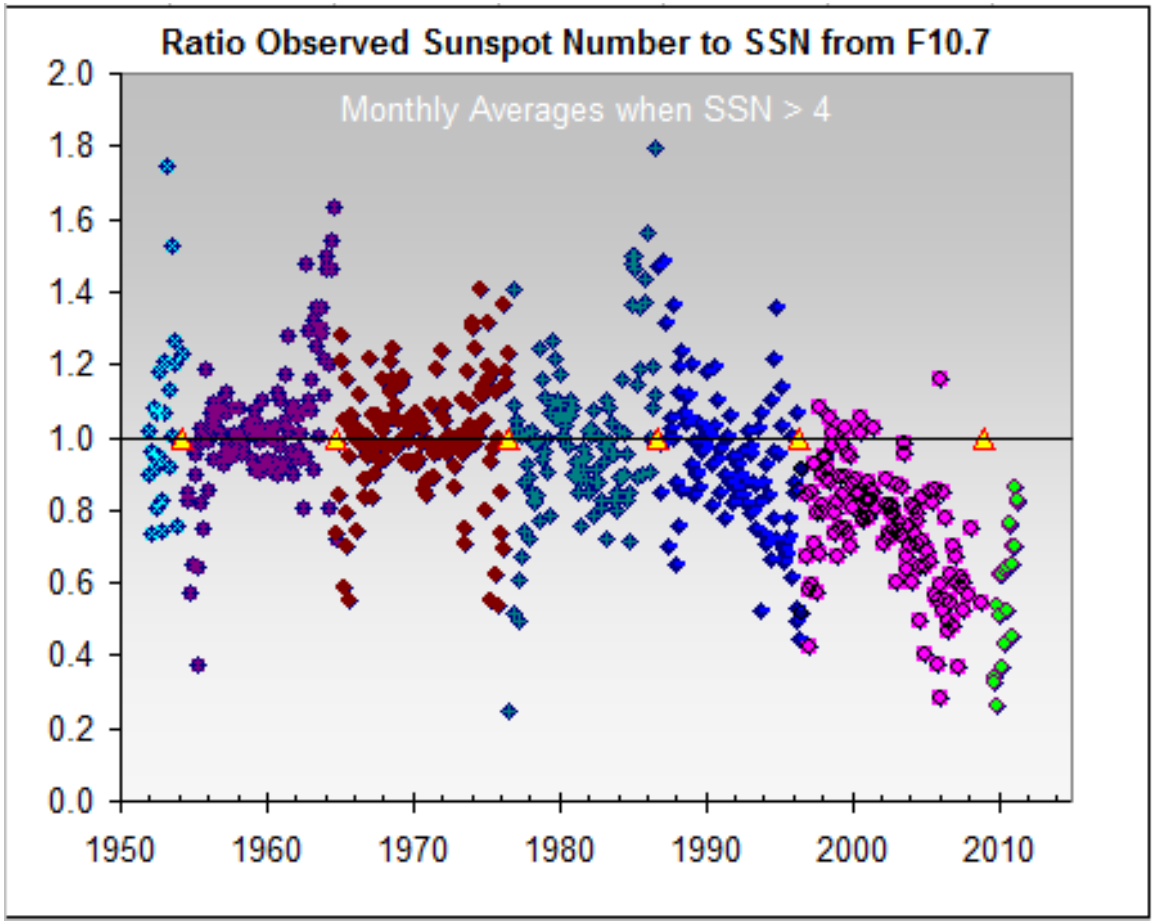
Other indications of fewer spots





Since ~1996 there have been fewer visible sunspots for a given F10.7 flux

The Observed Sunspot Number vs. that Calculated from the ‘old’ Relationship is too low Recently

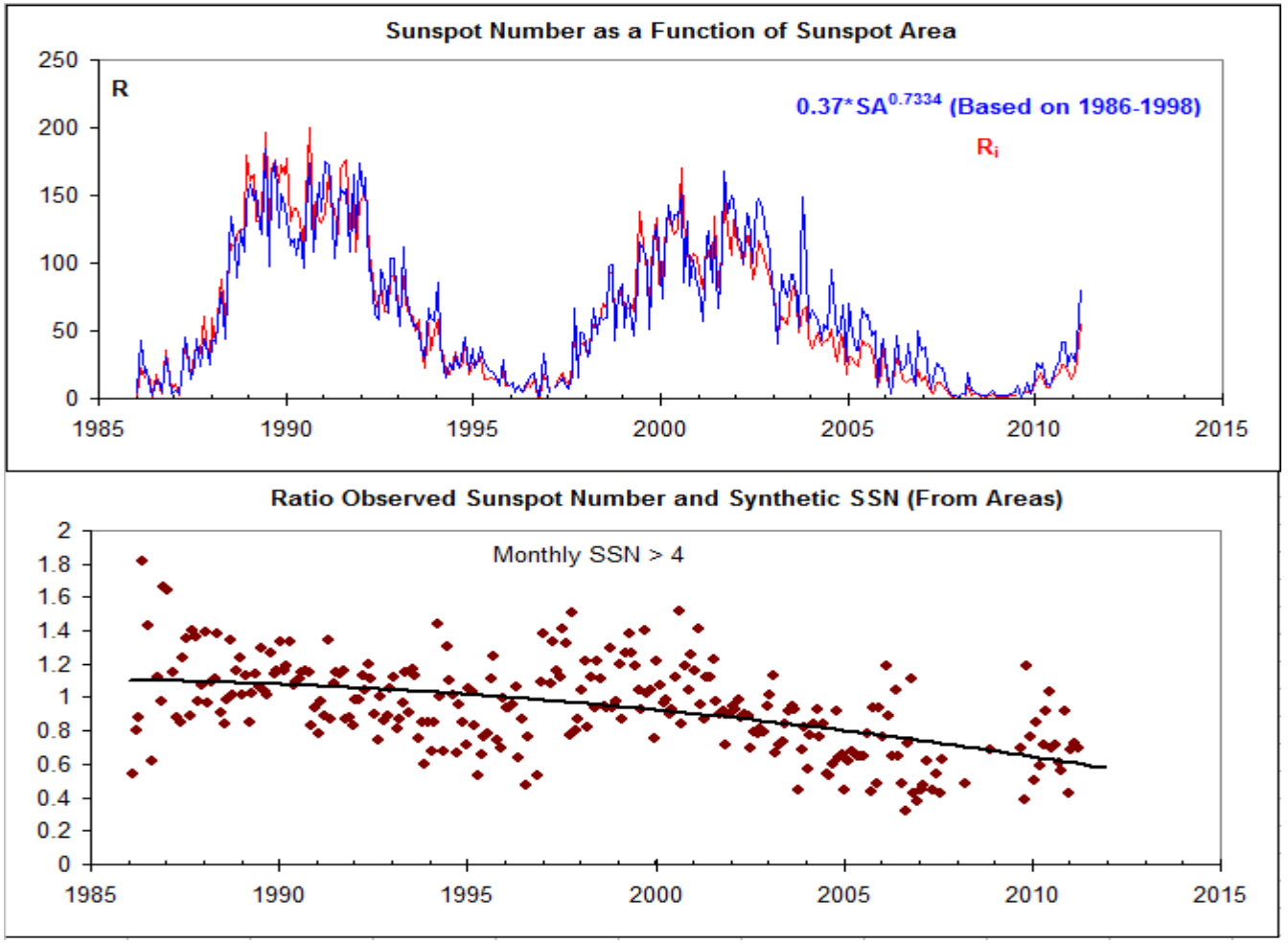


Since the Sunspot Number is dominated by the number of small spots, the loss of visibility of small spots might be a natural explanation.

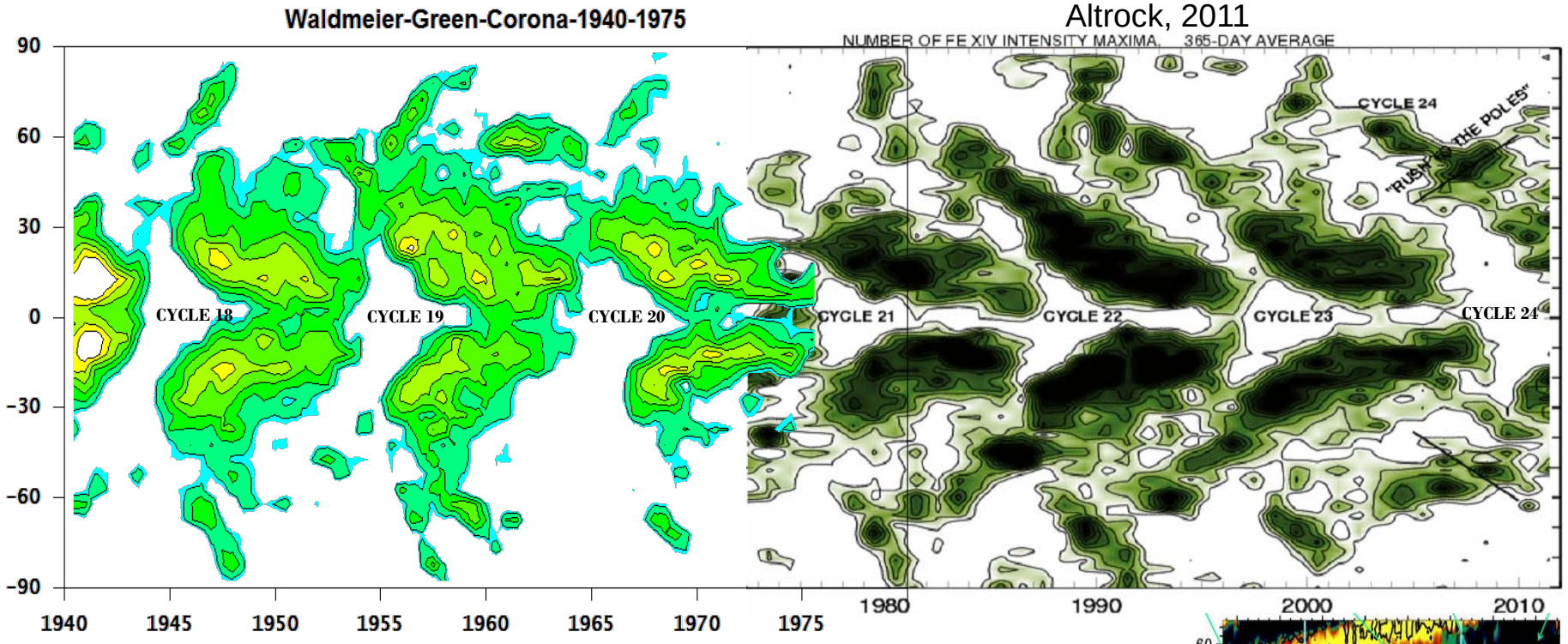
Was the Maunder Minimum just an example of an extreme L&P effect?

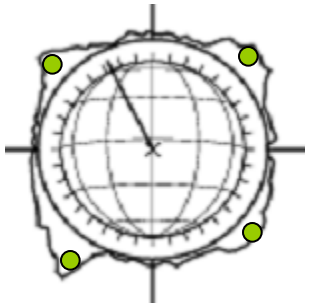
Is this happening again?

Similar effect seen in SSN compared to sunspot areas

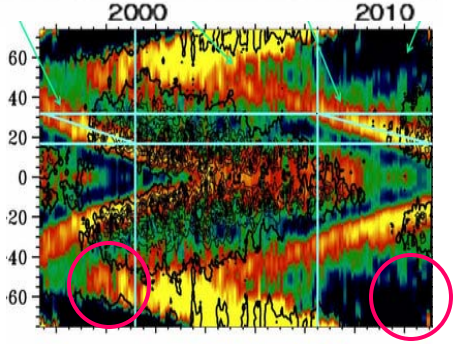


Where is the Extended Cycle?

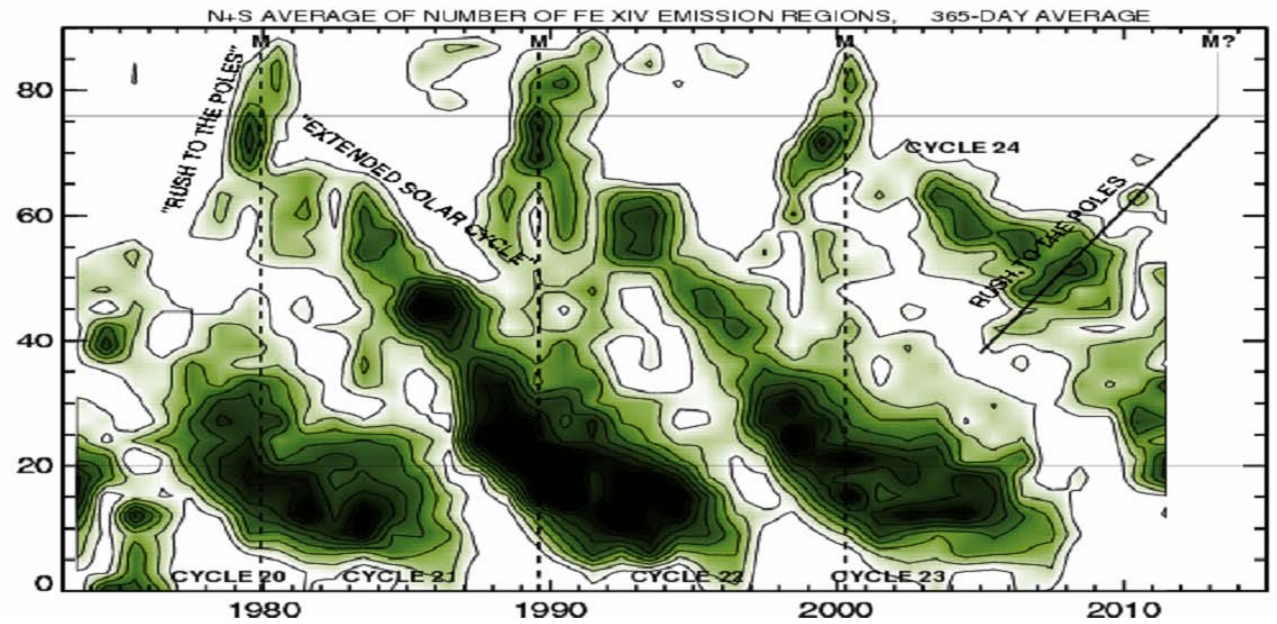




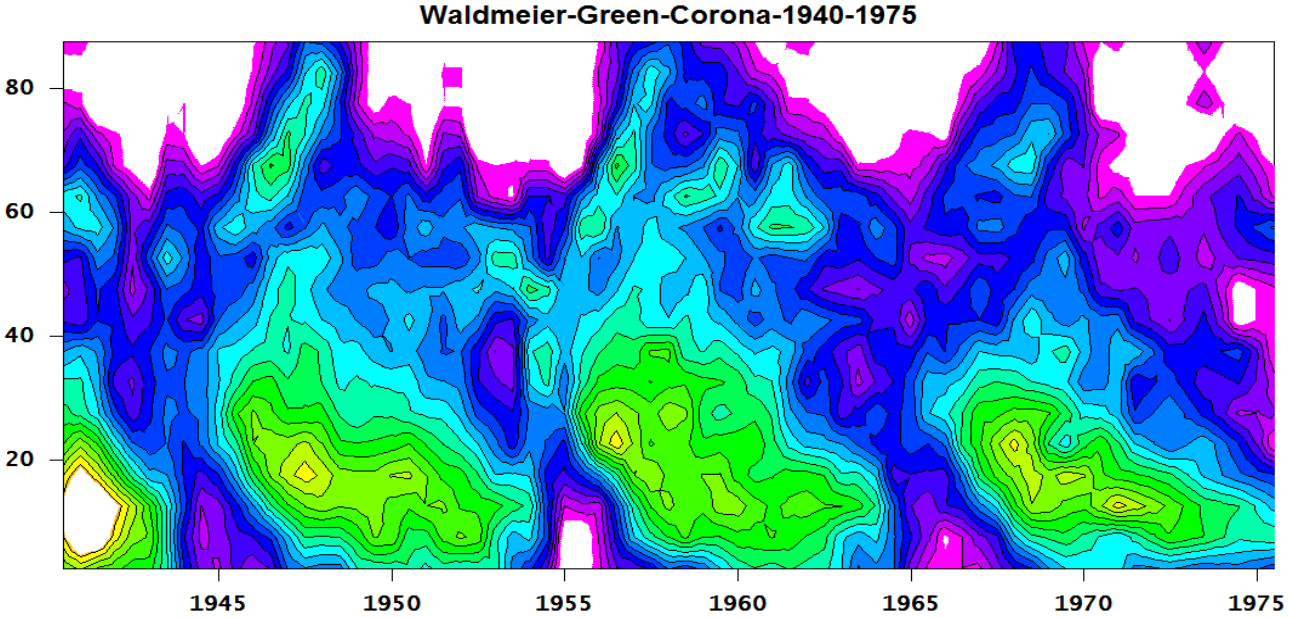
Measurements of the location of ‘peaks’ of Fe XIV coronal emission at 503 nm (the ‘Green Line Corona’) over 7 solar cycles. The plots show the probability of observing a ‘peak’ at a given latitude as a function of time.



TO: Hill, 2011



Fold South unto North



The Extended Cycle [if any] is not very clear

Our ‘Understanding’ of the Extended Cycle

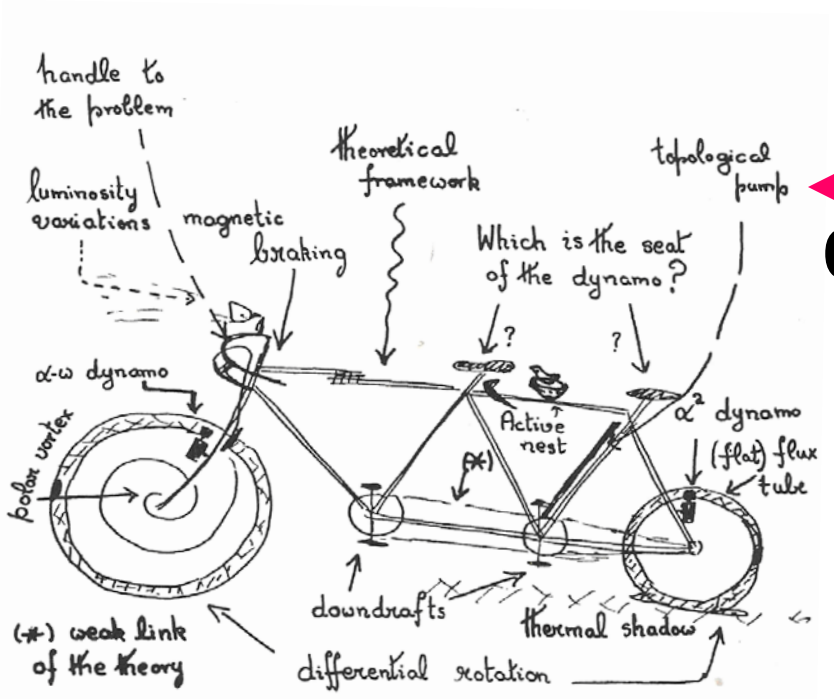
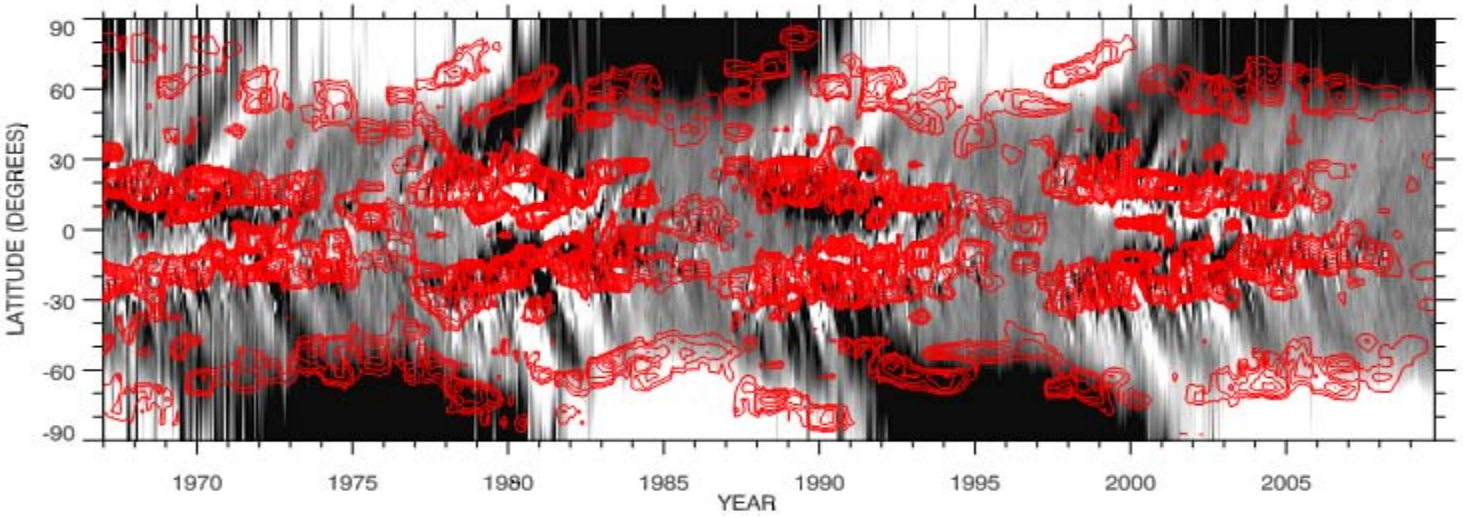


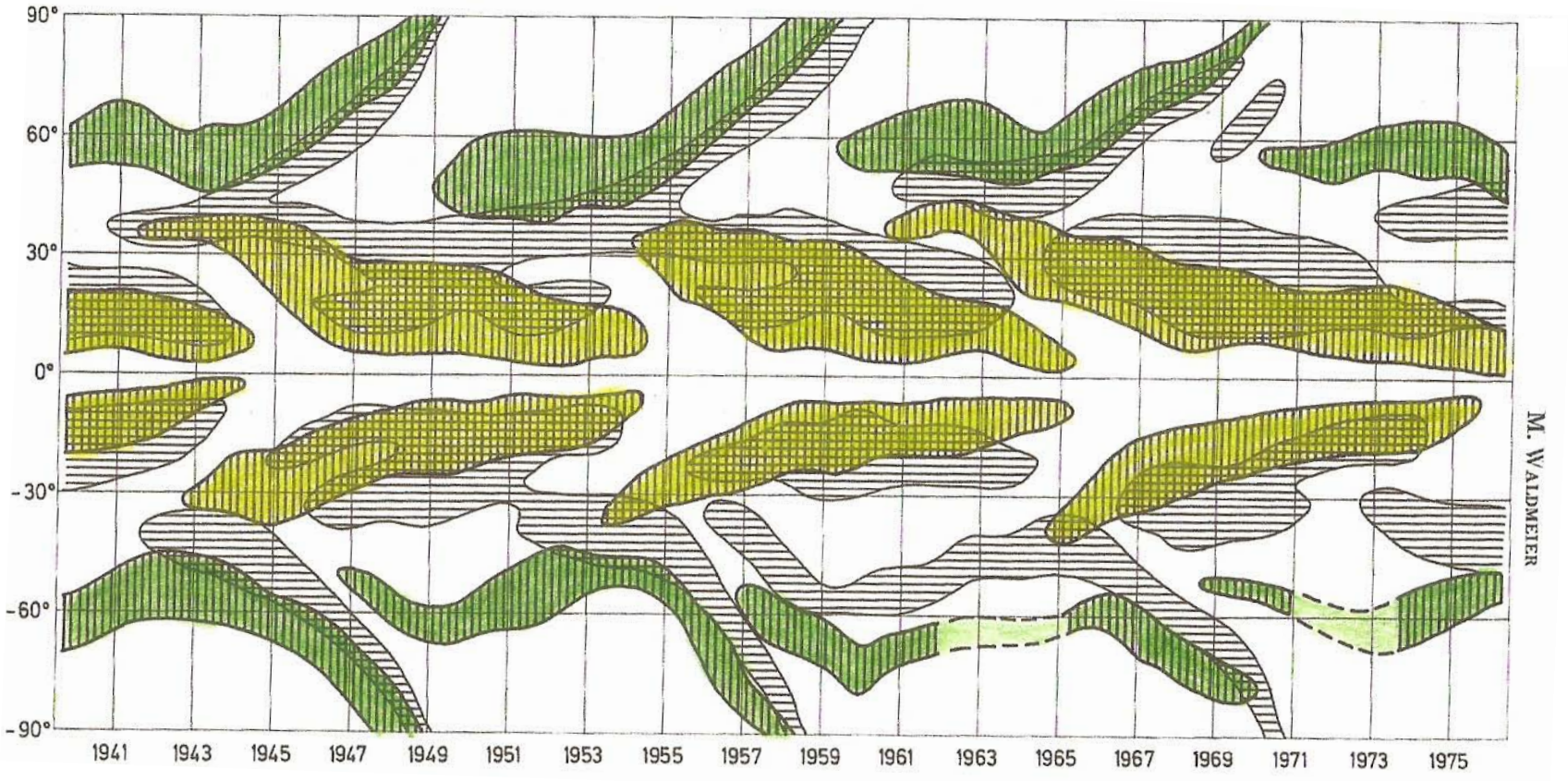
Fig. 8.8 A diagram of the *Xtended Cycle* constructed at a party held during the Sunspot meeting of the Solar Cycle Workshop in 1991. The author disclaims any responsibility but understands that Jean-Paul Zahn is liable for the drawing,

Robbrecht et al. ApJ, 2010:
“We conclude that the so-called extended cycle in coronal emission is a manifestation not of early new-cycle activity, but of poleward concentration of old-cycle trailing-polarity flux by meridional flow”



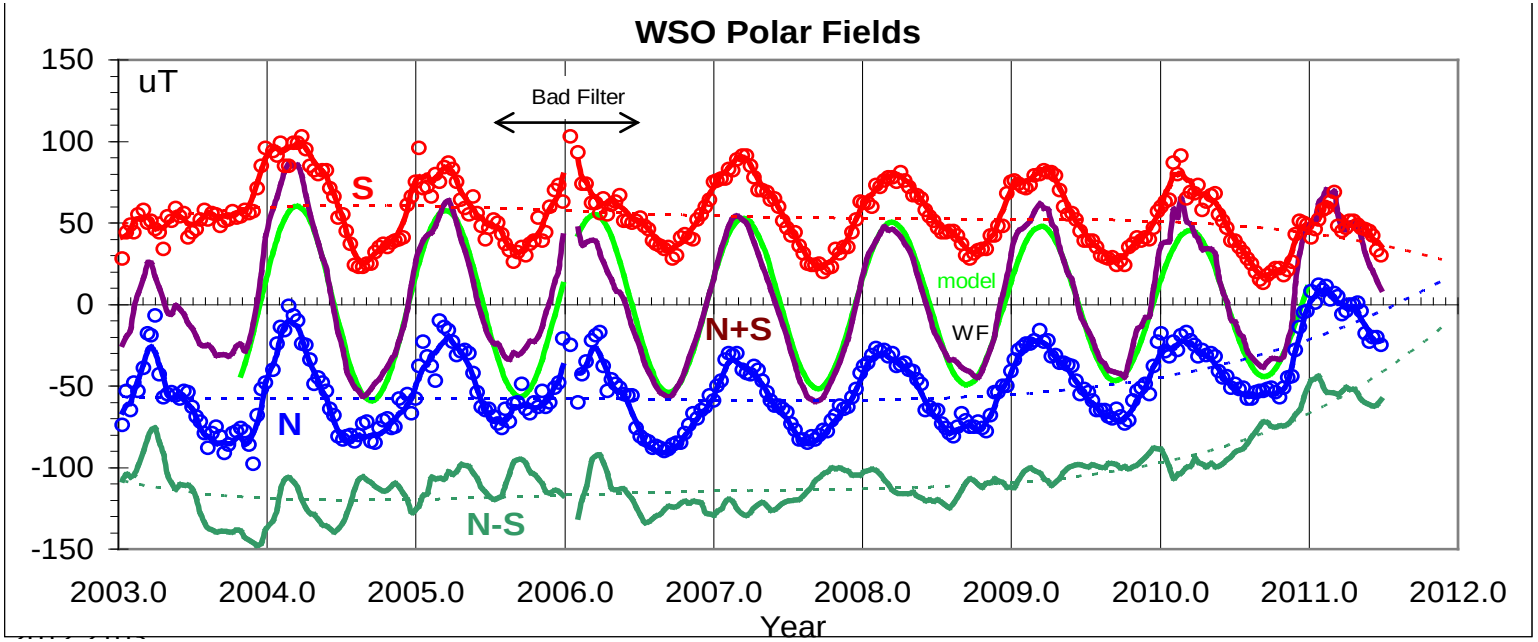
The red contours computed from PFSS coronal field (MWO)

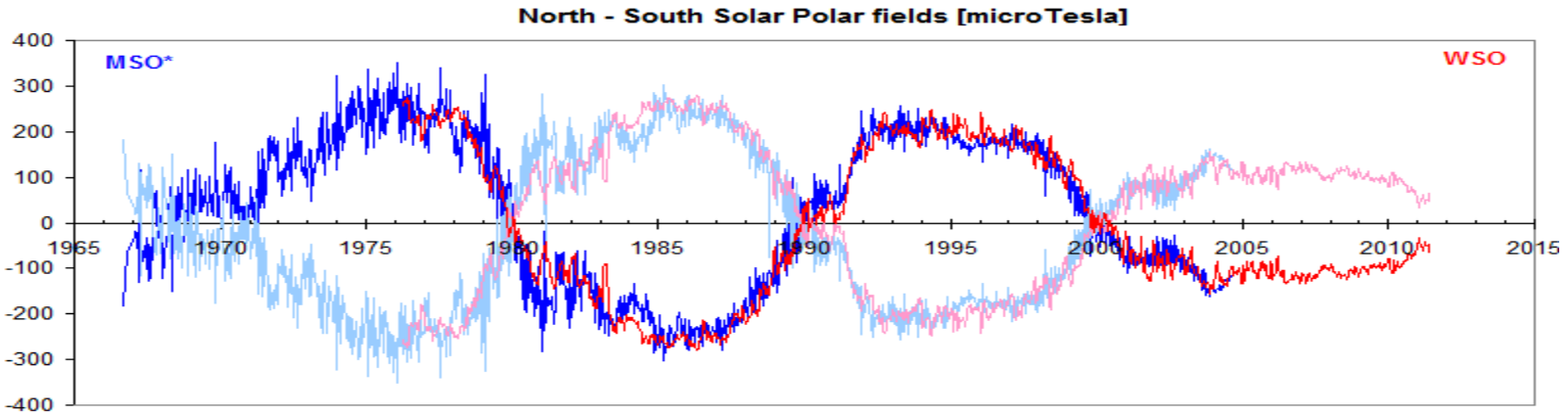
Waldmeier also Interpreted The Green Line Emission as Marking the Boundary of the Polar Cap, ‘Rushing to the Pole’ when the New Cycle Started



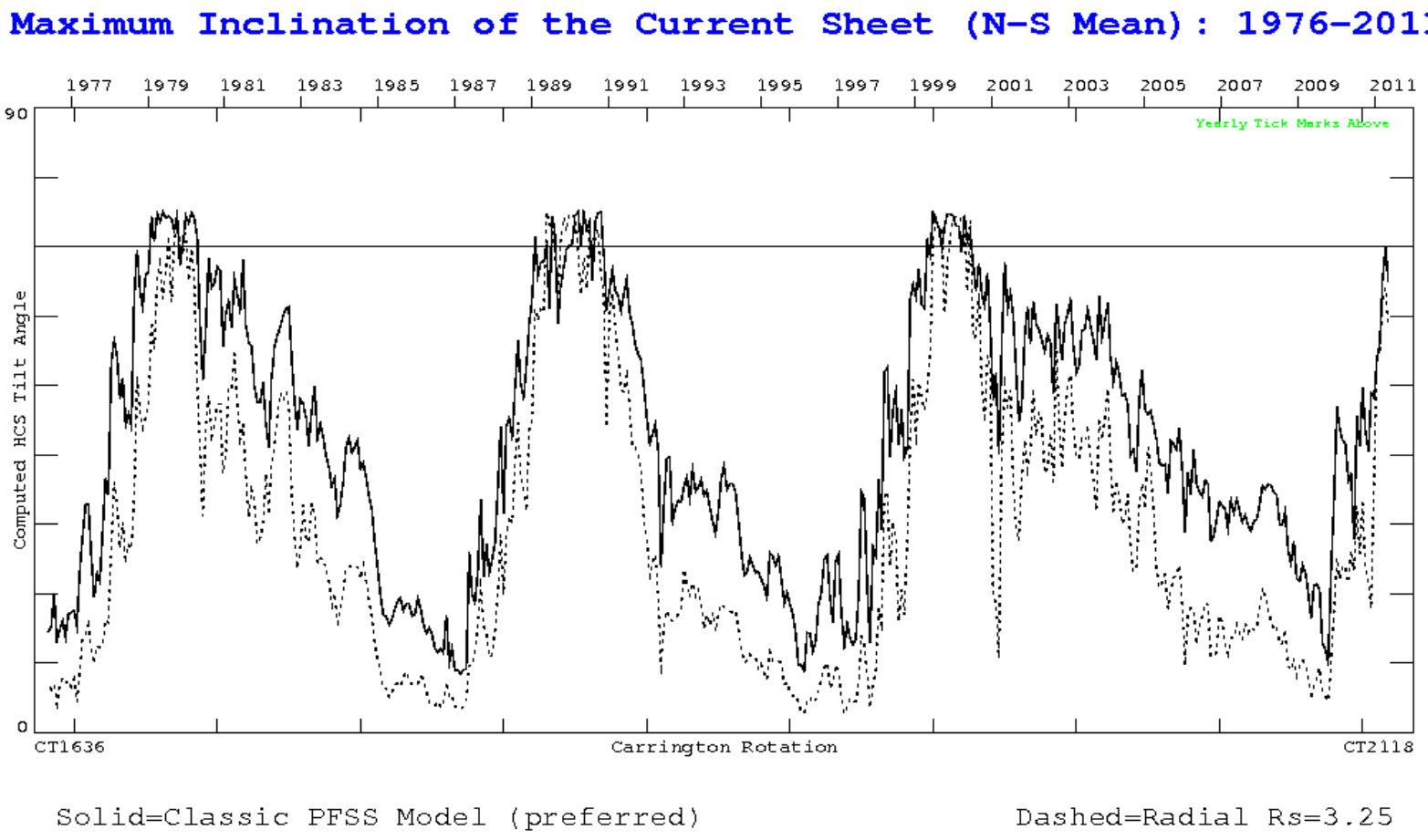
Solving the Enigma of the ‘Extended Cycle’ is a worthy Goal of SC24 Research

The Polar Fields are as Mysterious as Ever, perhaps Reversing Early





The HSC is Approaching Typical Solar ‘Maximum’ Inclinations



And We Have to Leave it at That, because there are More Questions than Answers (what a Wonderful Time)