Another Maunder Minimum?

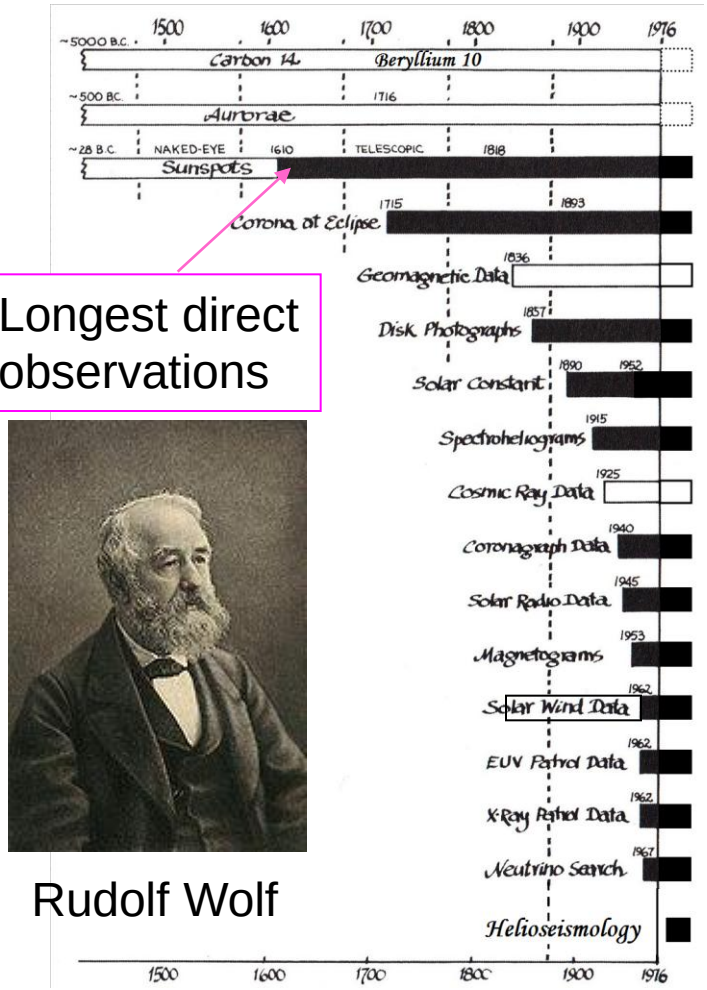
Leif Svalgaard

Stanford University

Nobeyama, 27 November, 2012

Indicators of Solar Activity

- Sunspot Number (and Area, Magnetic Flux)
- Solar Radiation (TSI, UV, …, F10.7)
- Cosmic Ray Modulation
- Solar Wind
- Geomagnetic Variations
- Aurorae
- Ionospheric Parameters
- Climate?
- More…



Longest direct observations

Rudolf Wolf

After Eddy, 1976

Solar Activity is *Magnetic* Activity

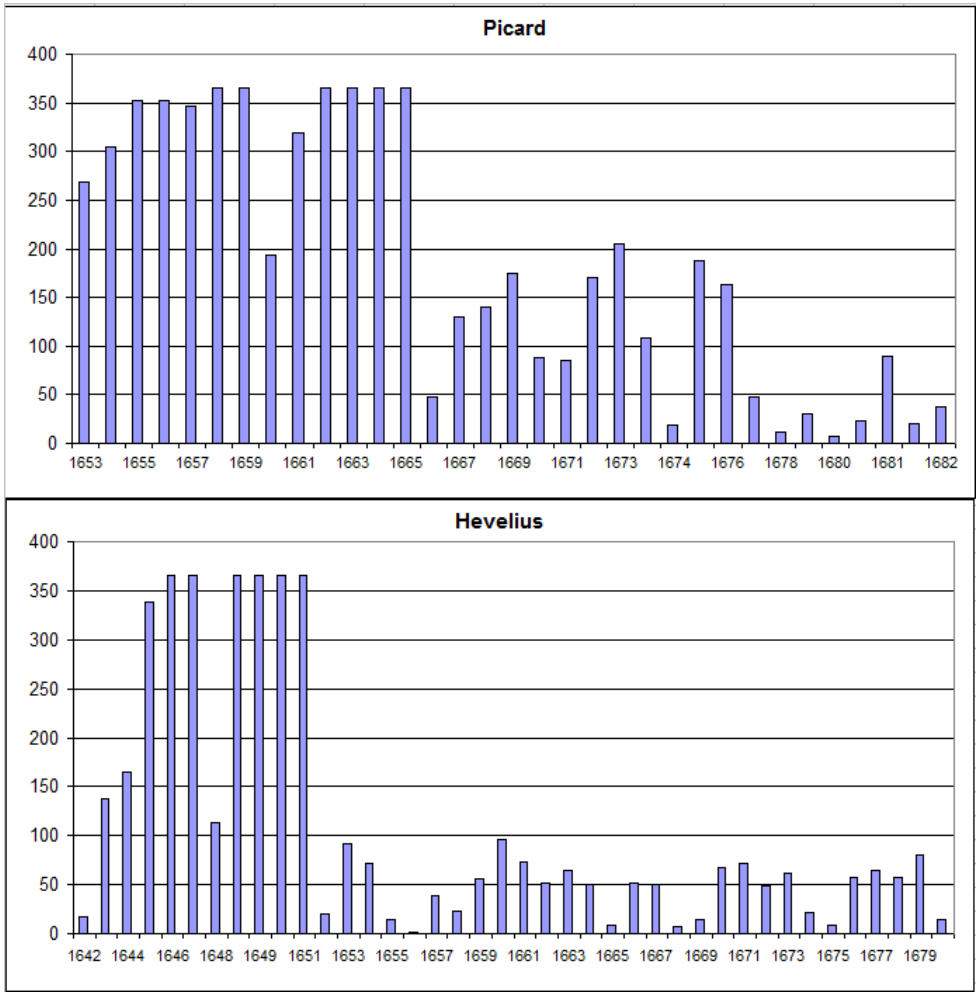
How Well was the Maunder Minimum Observed?

Hoyt &Schatten:

NUMBER OF SUNSPOT GROUPS FOR THE YEAR: 1658
AS OBSERVED BY: PICARD/KEILL, PARIS

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	-99	0	0	0	0	0	0	0	0	0	0
30	0	-99	0	0	0	0	0	0	0	0	0	0
31	0	-99	0	-99	0	-99	0	0	-99	0	-99	0
means:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

It is not credible that for many years there were not a single day without observations



Number of days per year with ‘observations’

More Realistic Assessment:

Unrealistic Coverage during MM:

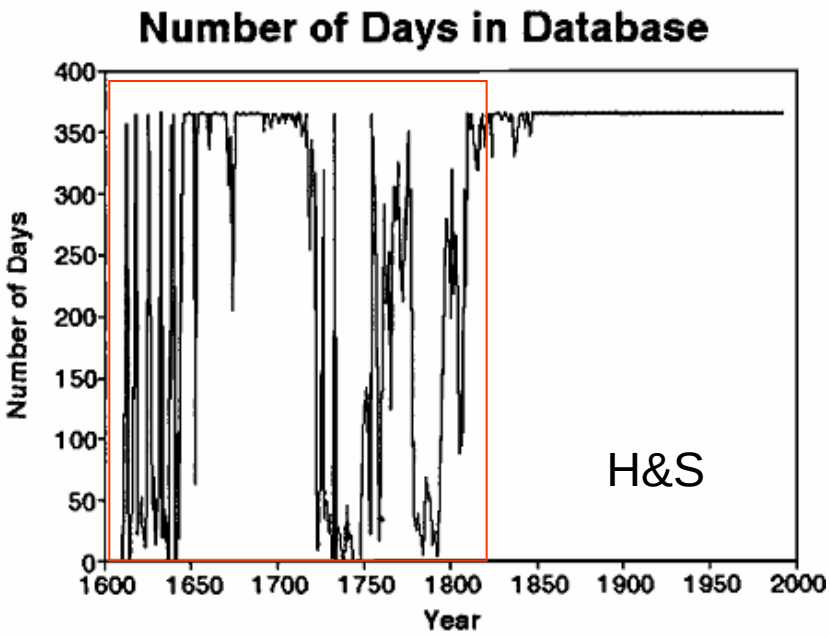
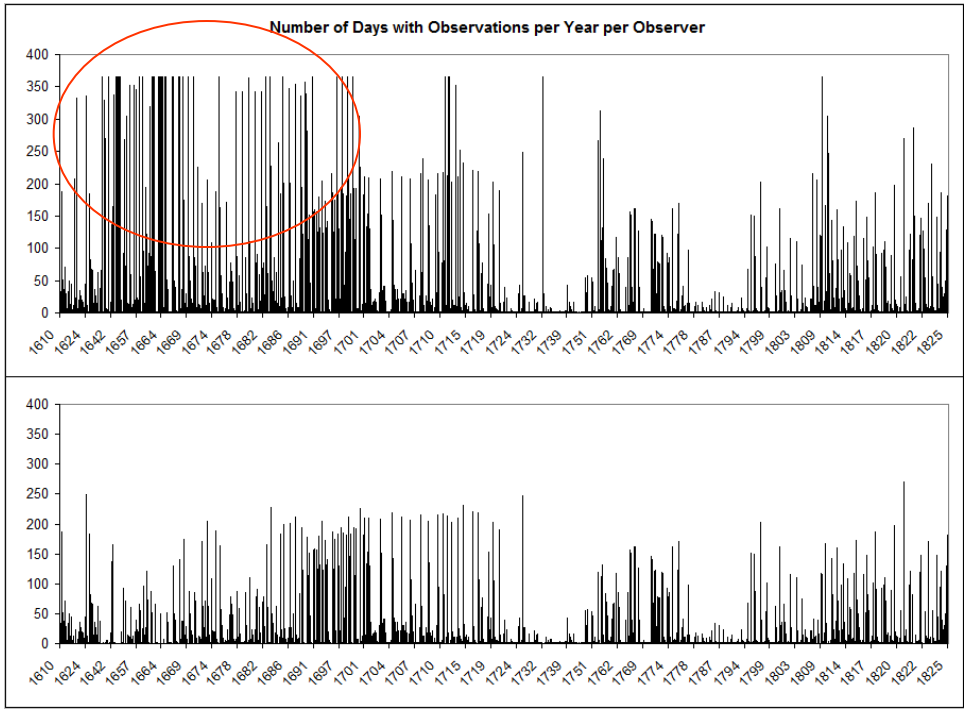


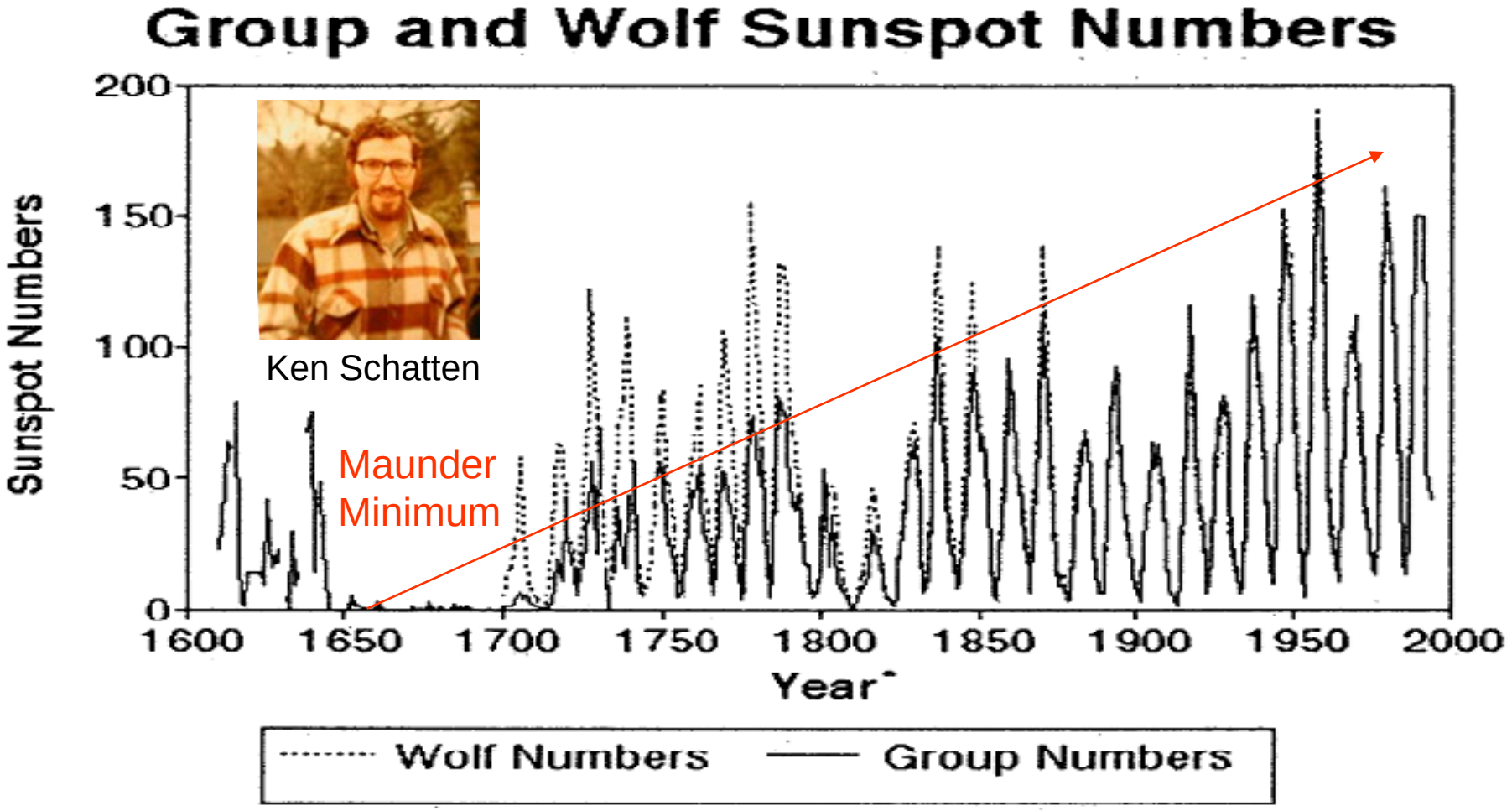
Figure 3. The number of days each year for we which have observations or interpolated values. If more than 5% of the days are observed in a year, a good yearly mean can usually be found. Most years meet this criteria. Note that the Sun was well observed during the Maunder Minimum.



1610 1700 1825

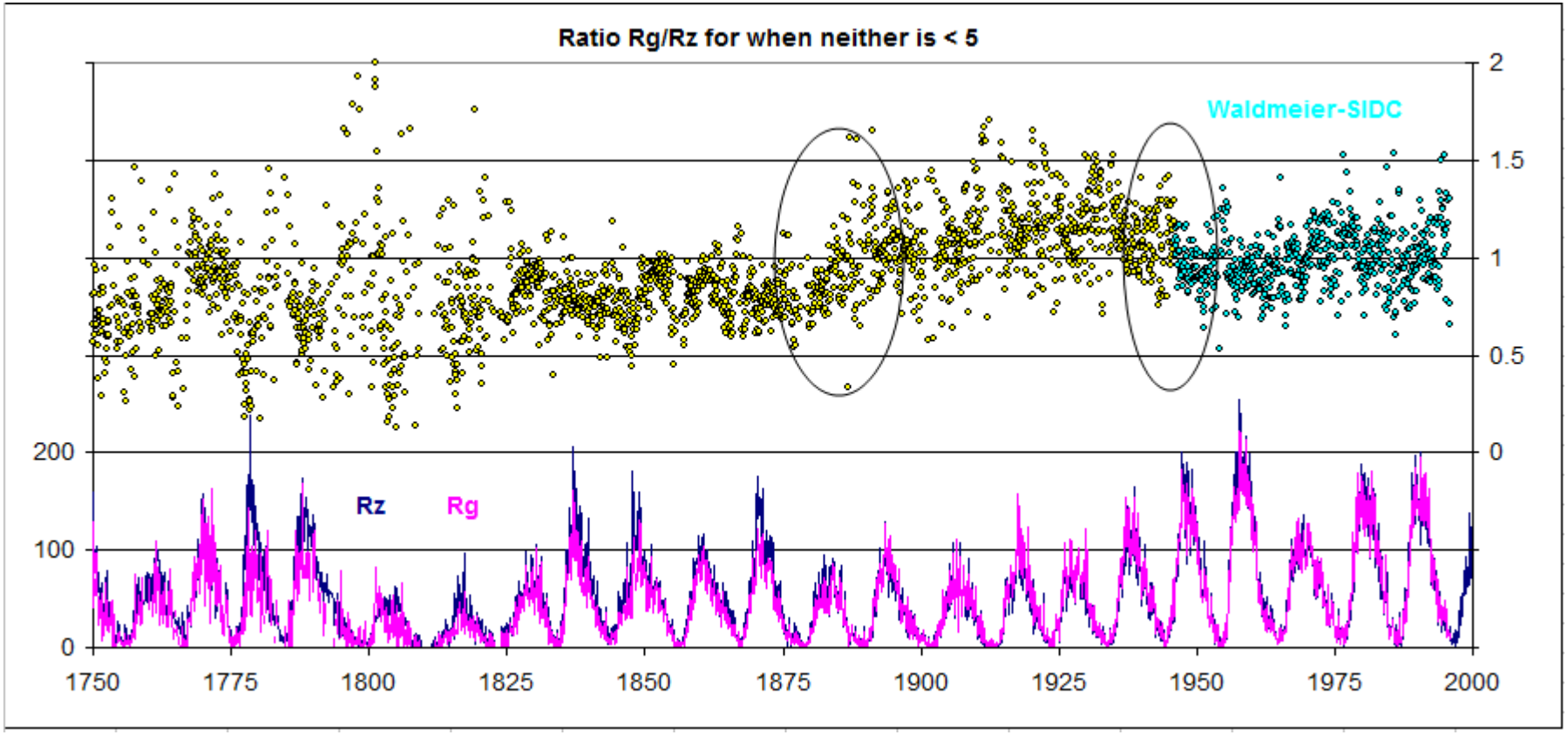
Even after eliminating the spurious years with 'no missing data' there are enough left to establish that the Maunder Minimum had very few visible sunspots and was not due to general lack of observations

Unfortunately Two Data Series



Hoyt & Schatten, GRL *21*, 1994

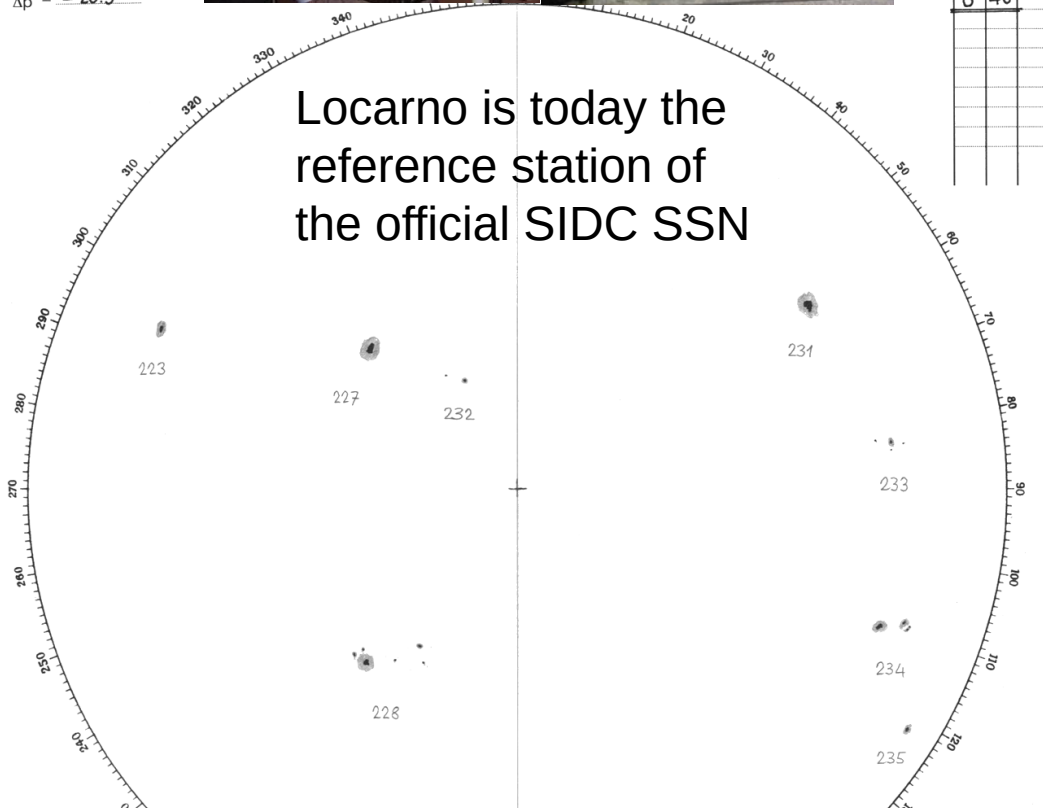
The Ratio Group/Zurich SSN has Two Significant Discontinuities



At ~1945 (after Max Waldmeier took over) and at ~1885

Effect of Weighting of Sunspots

g	f	t	B
223	3	J	+23
227	4	J	+23
228	13	D	-14
231	4	J	+23
232	4	C	+19
233	6	C	+9
234	9	D	-13
235	3	J	-27
8	46		



Locarno is today the reference station of the official SIDC SSN

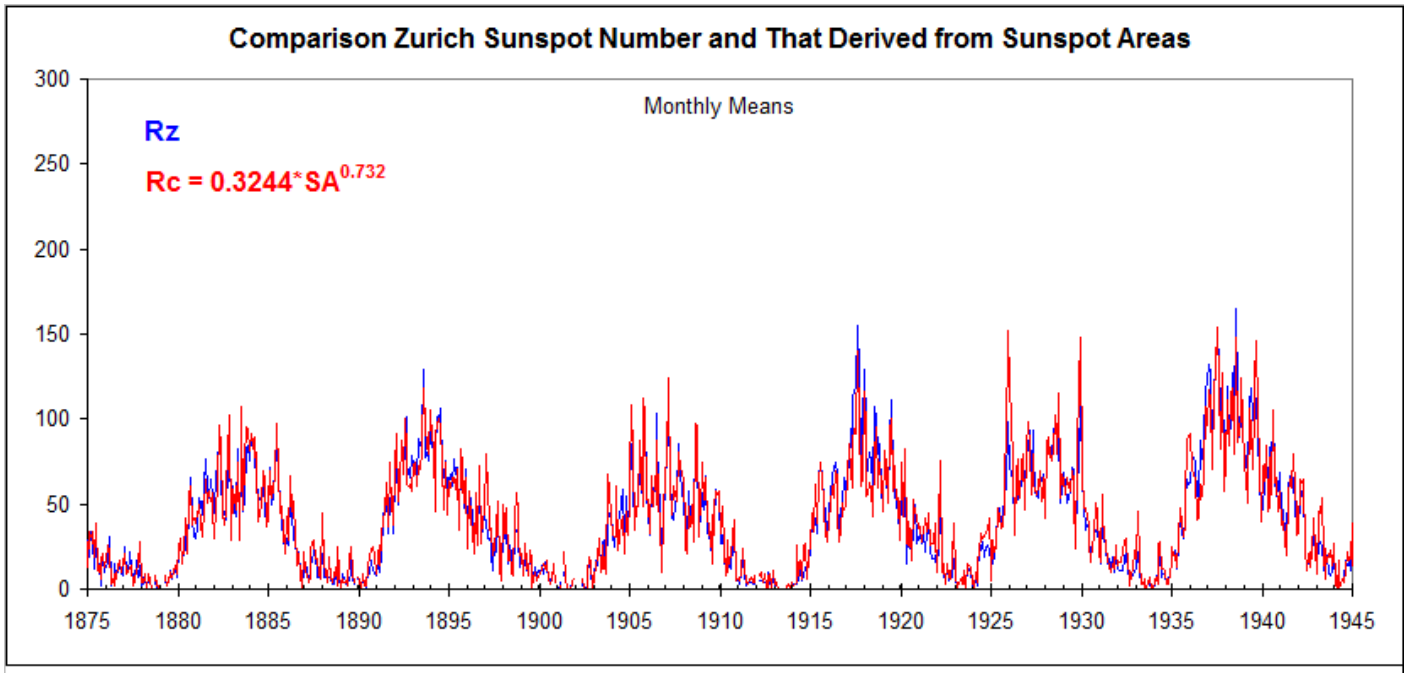
223	3	**1**
227	4	**1**
228	13	**6**
231	4	**1**
232	4	**2**
233	6	**4**
234	9	**4**
235	3	**1**
Unweighted count red		
8	46	**20**

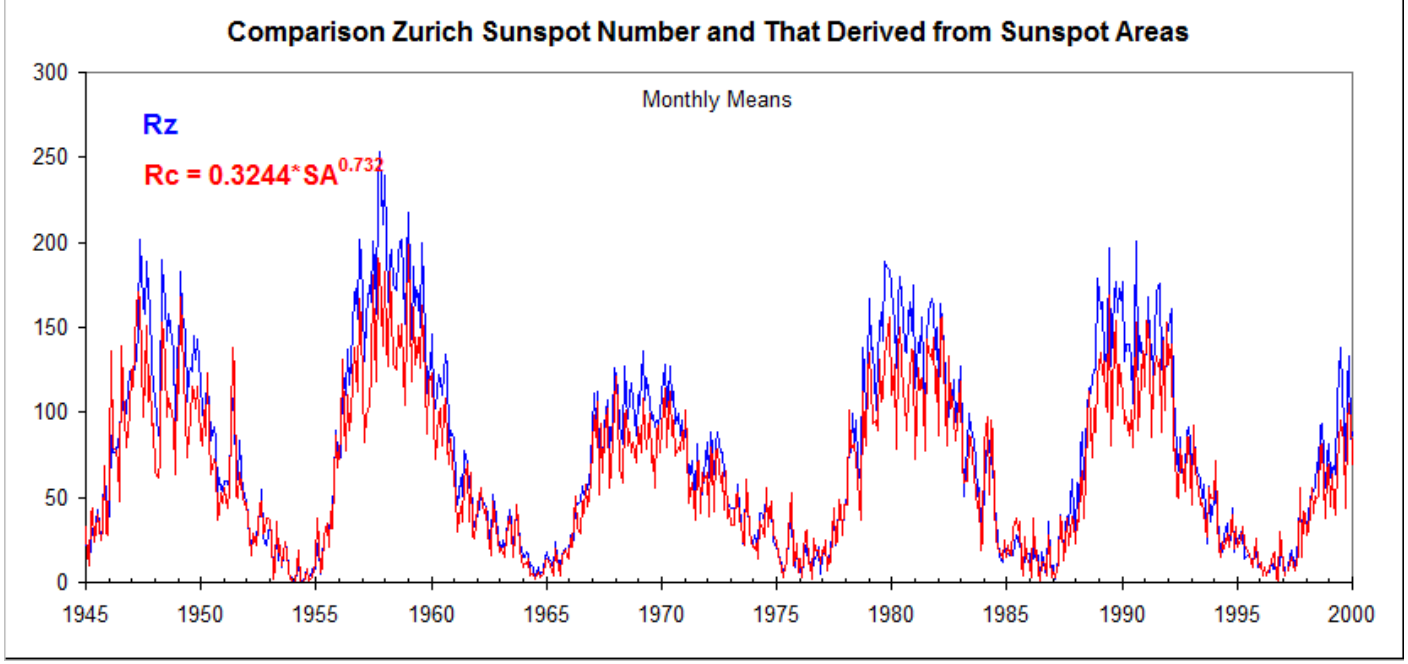
SSN = 10*G+S

126 **100**

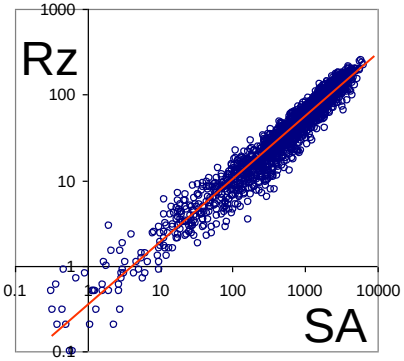
26% inflated

In the 1940s the observers in Zürich [and Locarno] began to Weight spots. The net result is a ~20% inflation of the official Zürich SSN since ~1945





Compared with Sunspot Area (obs)



Not linear relation, but a nice power law with slope 0.732. Use relation for pre-1945 to compute Rz from Area, and note that the observed Rz after 1945 is too high [by 21%]

What to do about all this?

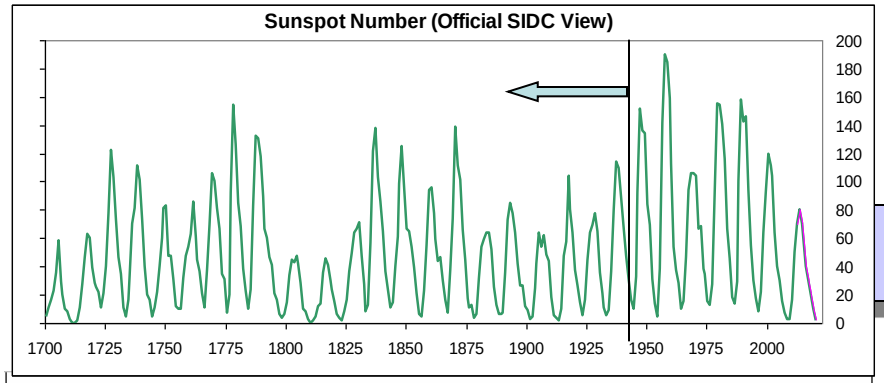
The implications of this re-assessment of the sunspot record are so wide-ranging that the SSN community has decided on a series of Workshops to solidify this.

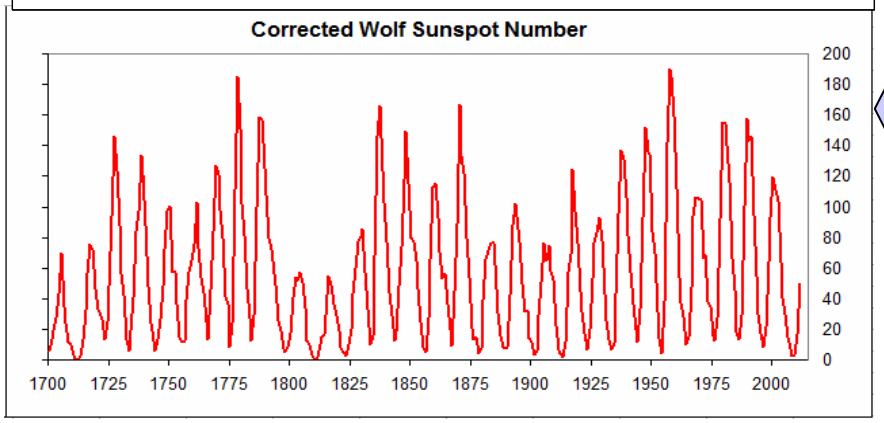
We have a Wiki giving details and presentations: http://ssnworkshop.wikia.com/wiki/Home

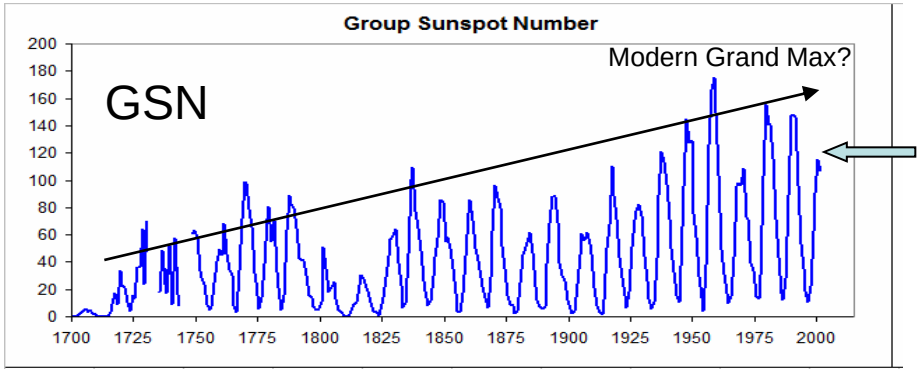
The goal is to arrive at a single, vetted series that we all agree on.

The SSN workshops are sponsored by the National Solar Observatory (NSO), the Royal Observatory of Belgium (ROB), and the Air Force Research Laboratory (AFRL).

Correcting for the 20% Inflation







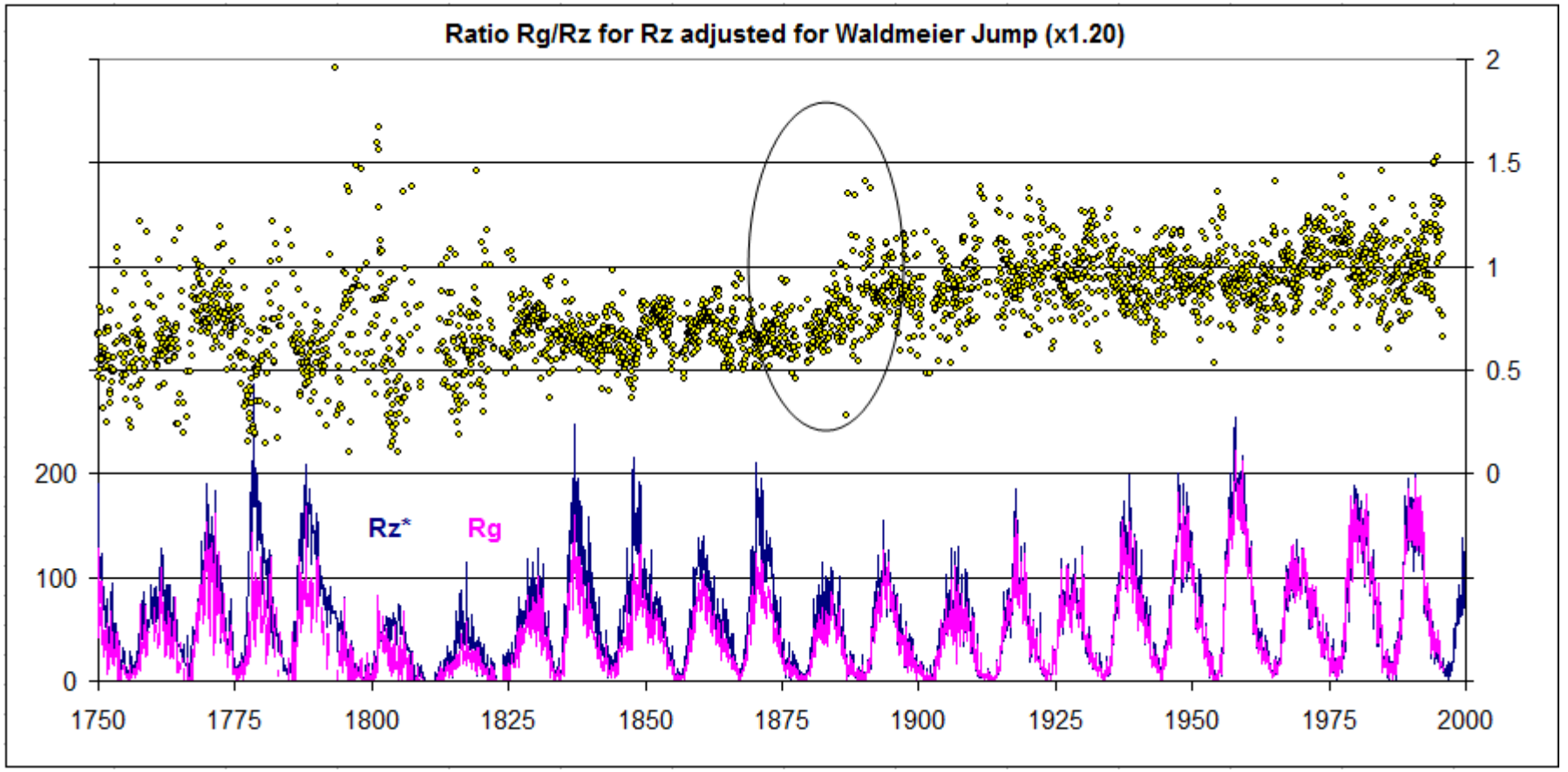
R*corr* = R*official* * 1.2 before ~1946

This issue is so important that the official agencies responsible for producing sunspot number series have instituted a series of now ongoing Workshops to, if at all possible, converge to an agreed upon, common, corrected series.

The inflation due to weighting is now an established and accepted fact

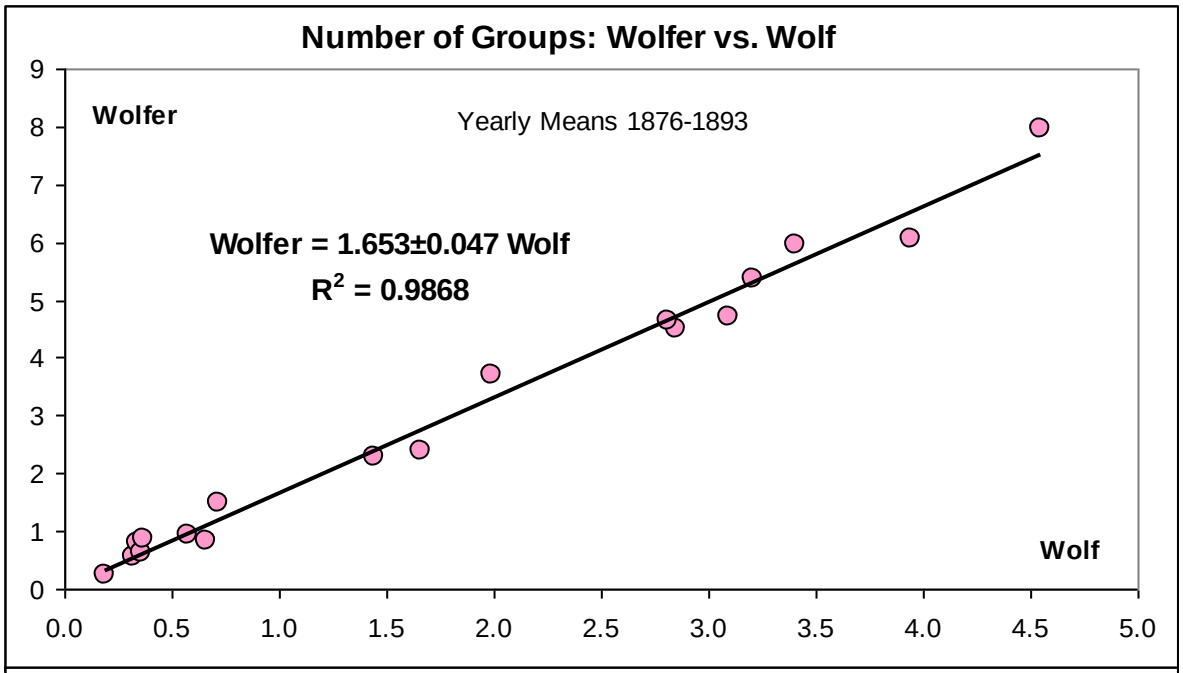
That the corrected sunspot number is so very different from the Group Sunspot Number is a problem for assessing past solar activity and for predicting future activity. This problem must be resolved.

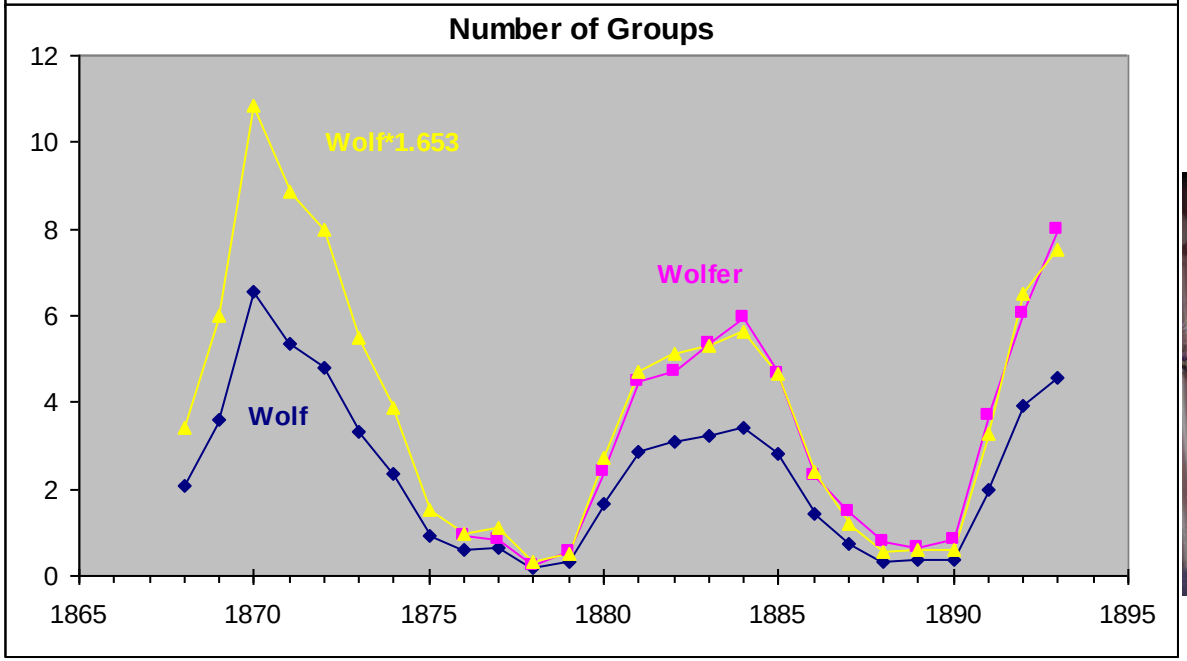
Removing the discontinuity in ~1945, by multiplying Rz before 1946 by 1.20, yields

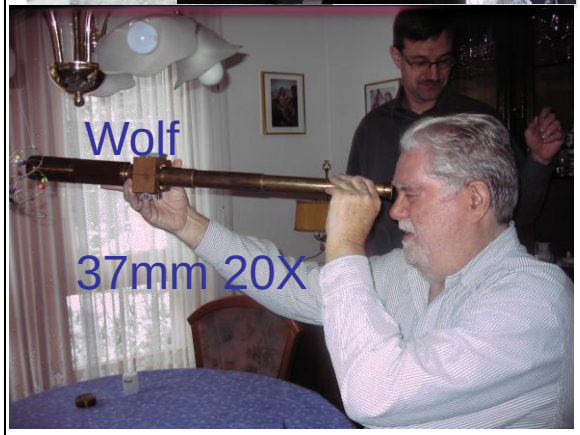


Leaving one significant discrepancy ~1885

Wolf-Wolfer Groups







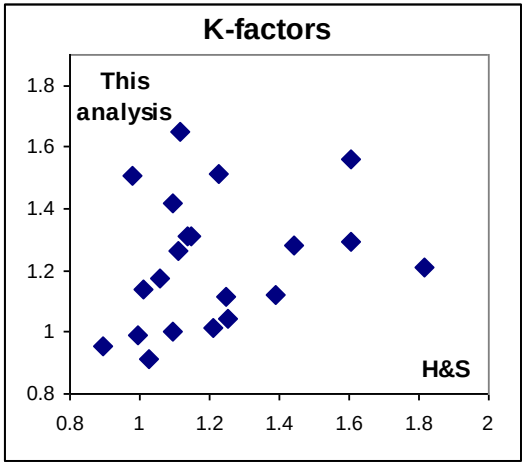
Why are these so different?

K-Factors

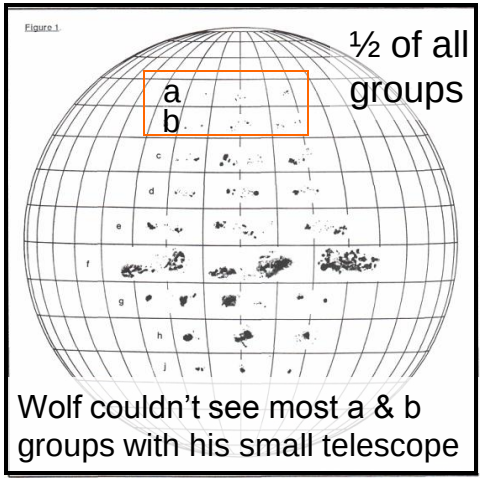
This is the main reason for the discrepancy

Observer	H&S RGO	to Wolfer	Begin	End
Wolfer, A., Zurich	1.094	1	1876	1928
Wolf, R., Zurich	1.117	1.6532	1876	1893
Schmidt, Athens	1.135	1.3129	1876	1883
Weber, Peckeloh	0.978	1.5103	1876	1883
Spoerer, G., Anclam	1.094	1.4163	1876	1893
Tacchini, Rome	1.059	1.1756	1876	1900
Moncalieri	1.227	1.5113	1876	1893
Leppig, Leibzig	1.111	1.2644	1876	1881
Bernaerts, G. L., England	1.027	0.9115	1876	1878
Dawson, W. M., Spiceland, Ind.	1.01	1.1405	1879	1890
Ricco, Palermo	0.896	0.9541	1880	1892
Winkler, Jena	1.148	1.3112	1882	1910
Merino, Madrid	0.997	0.9883	1883	1896
Konkoly, Ogylla	1.604	1.5608	1885	1905
Quimby, Philadelphia	1.44	1.2844	1889	1921
Catania	1.248	1.1132	1893	1918
Broger, M, Zurich	1.21	1.0163	1897	1928
Woinoff, Moscow	1.39	1.123	1898	1919
Guillaume, Lyon	1.251	1.042	1902	1925
Mt Holyoke College	1.603	1.2952	1907	1925

2% diff.



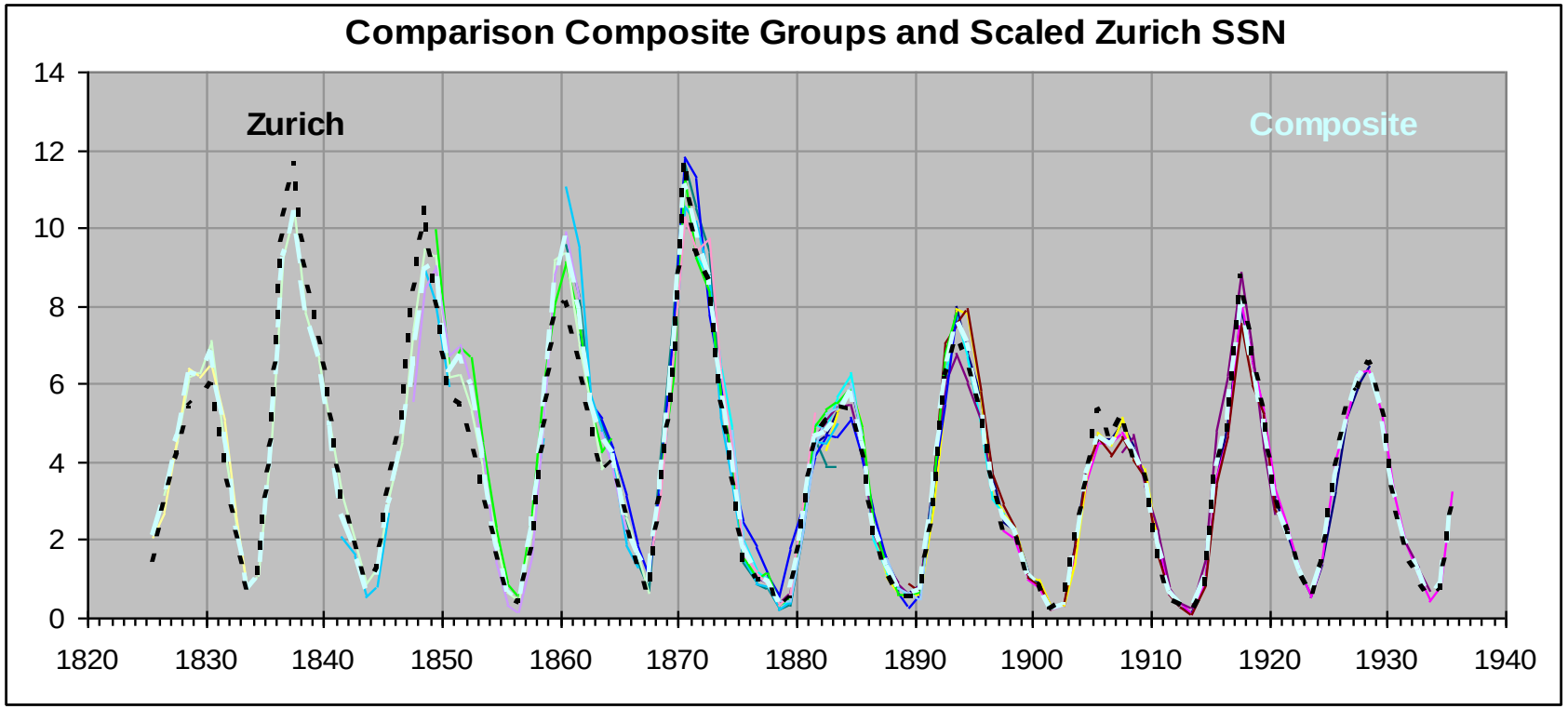
Zürich Classification:



A still unresolved question is how Hoyt & Schatten got the *K*-factors so wrong

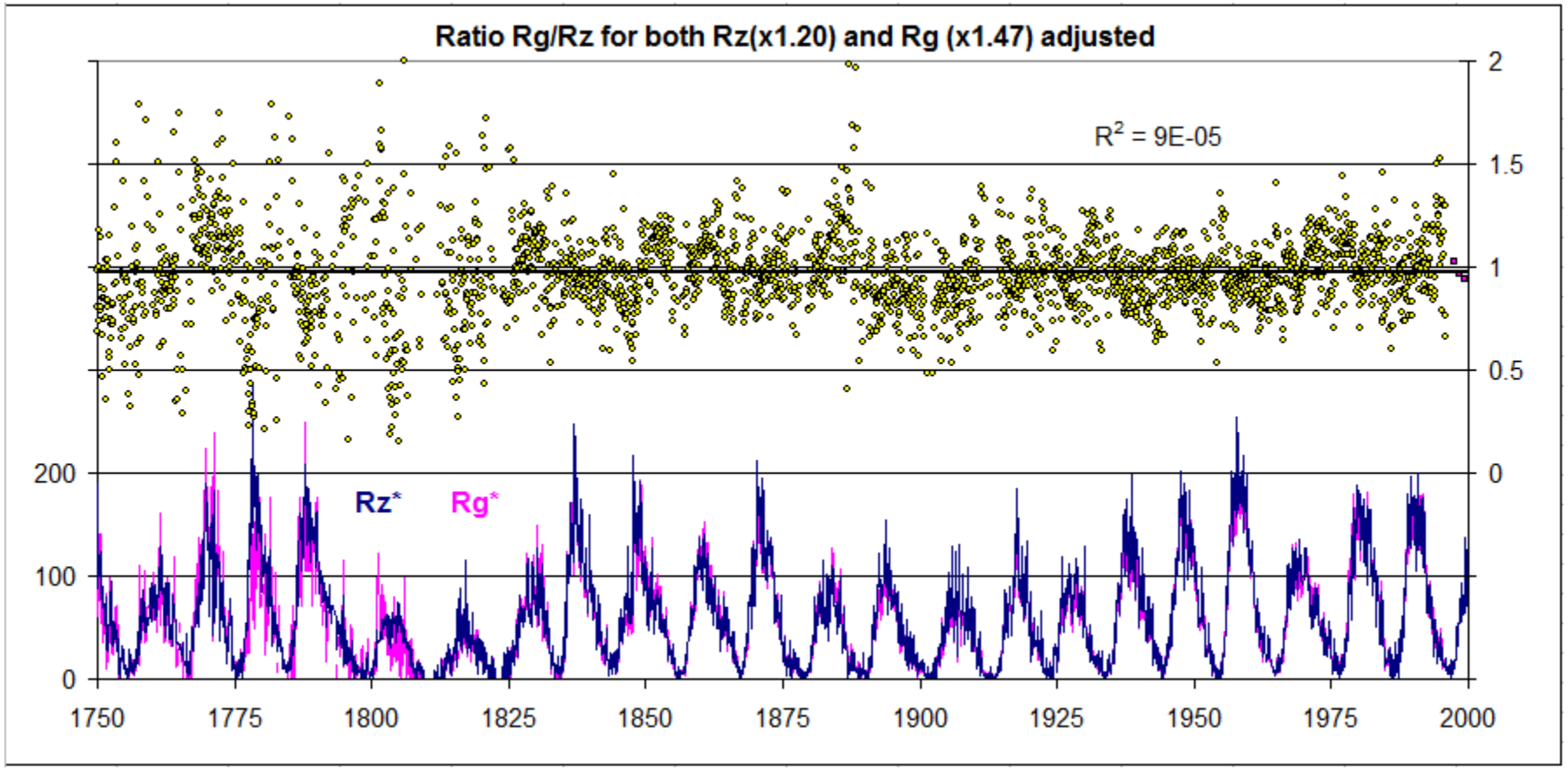
Constructing a Composite

Comparing 22 observers that overlap with each other one can construct a composite group number successively back to Schwabe and up to Brunner:



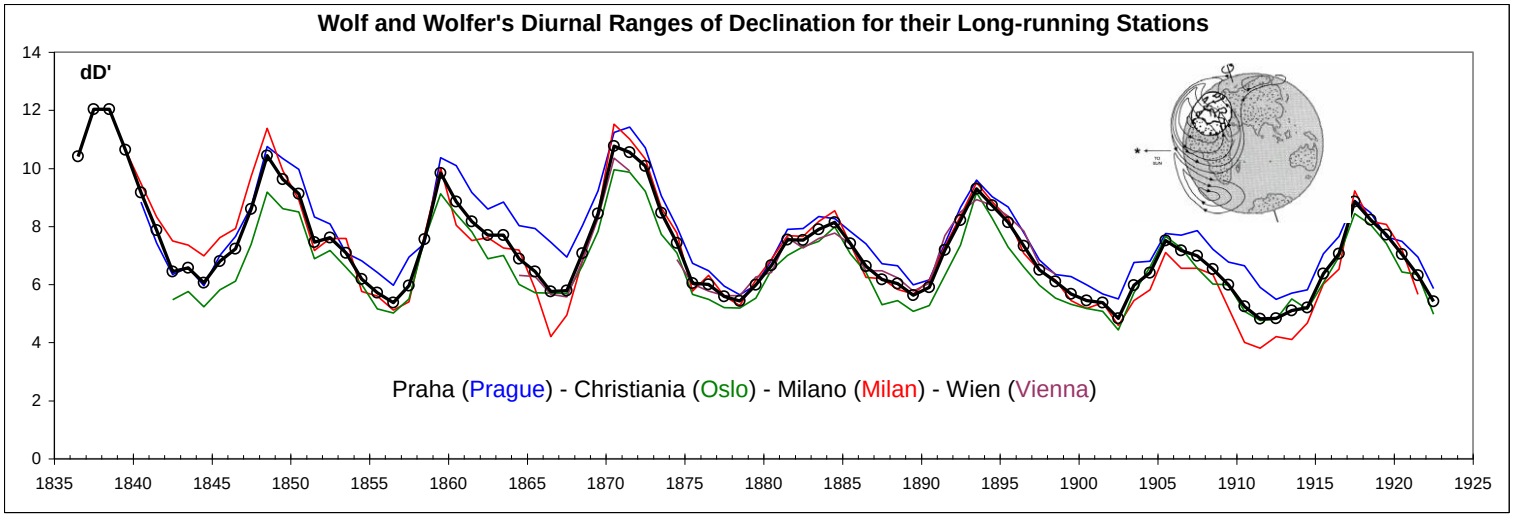
There is now no systematic difference between the Zürich SSN and a Group SSN reconstructed here by using correct *K*-factors relative to Wolfer.

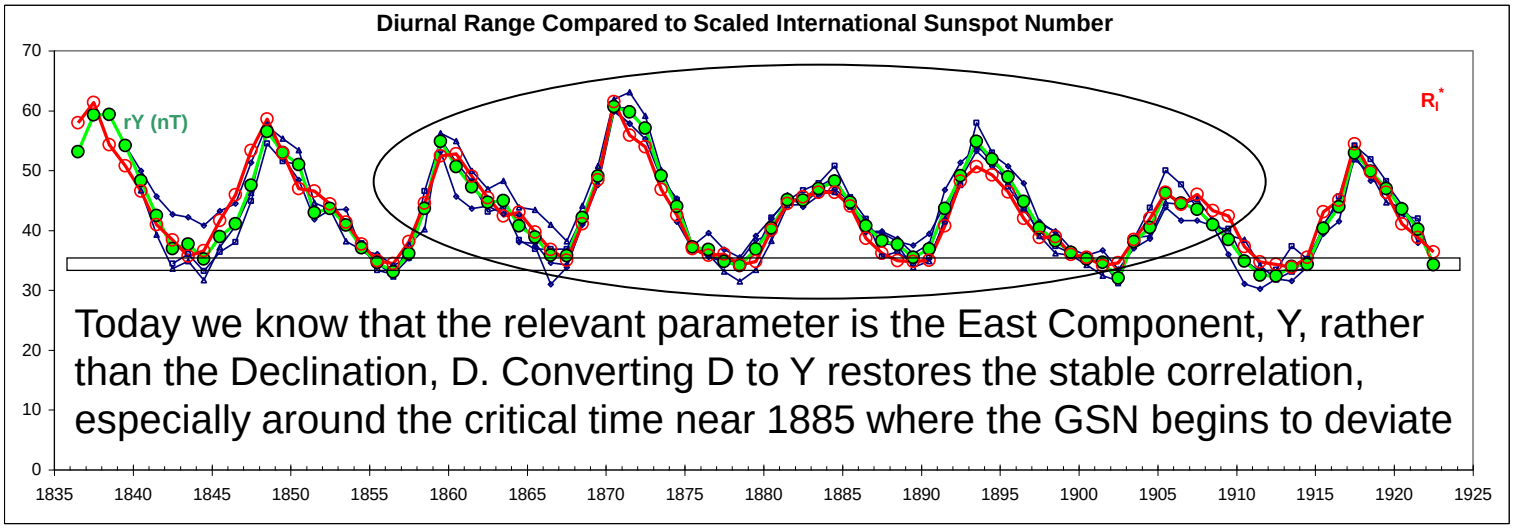
Removing the discontinuity in ~1885 by multiplying Rg by 1.47, yields



Only two adjustments remove most of the disagreement and *also the 'evidence' for a recent grand maximum (1945-1995)*

Wolf's Original Geomagnetic Data

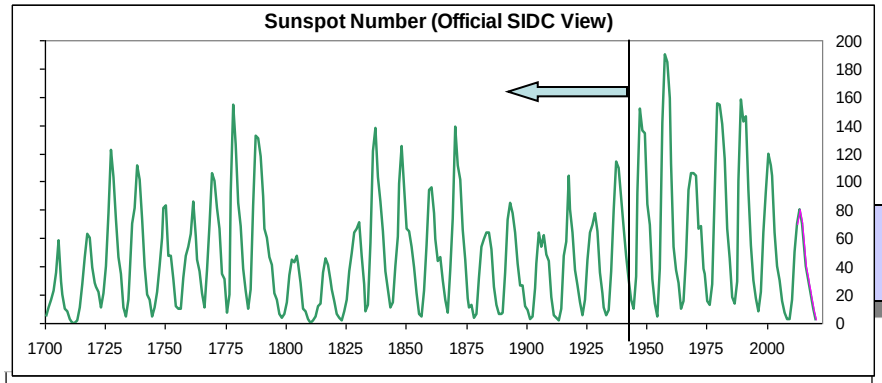


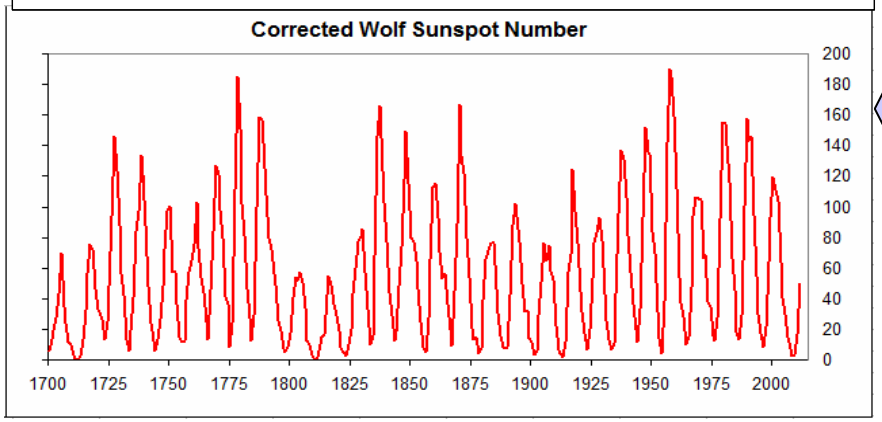


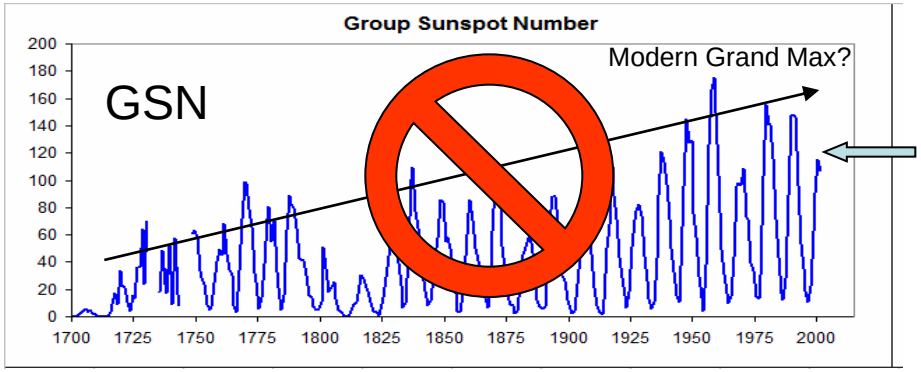
Wolf found a very strong correlation between his Wolf number and the daily range of the Declination.

Wolfer found the original correlation was not stable, but was drifting with time and gave up on it in 1923.

Correcting for the 20% Inflation







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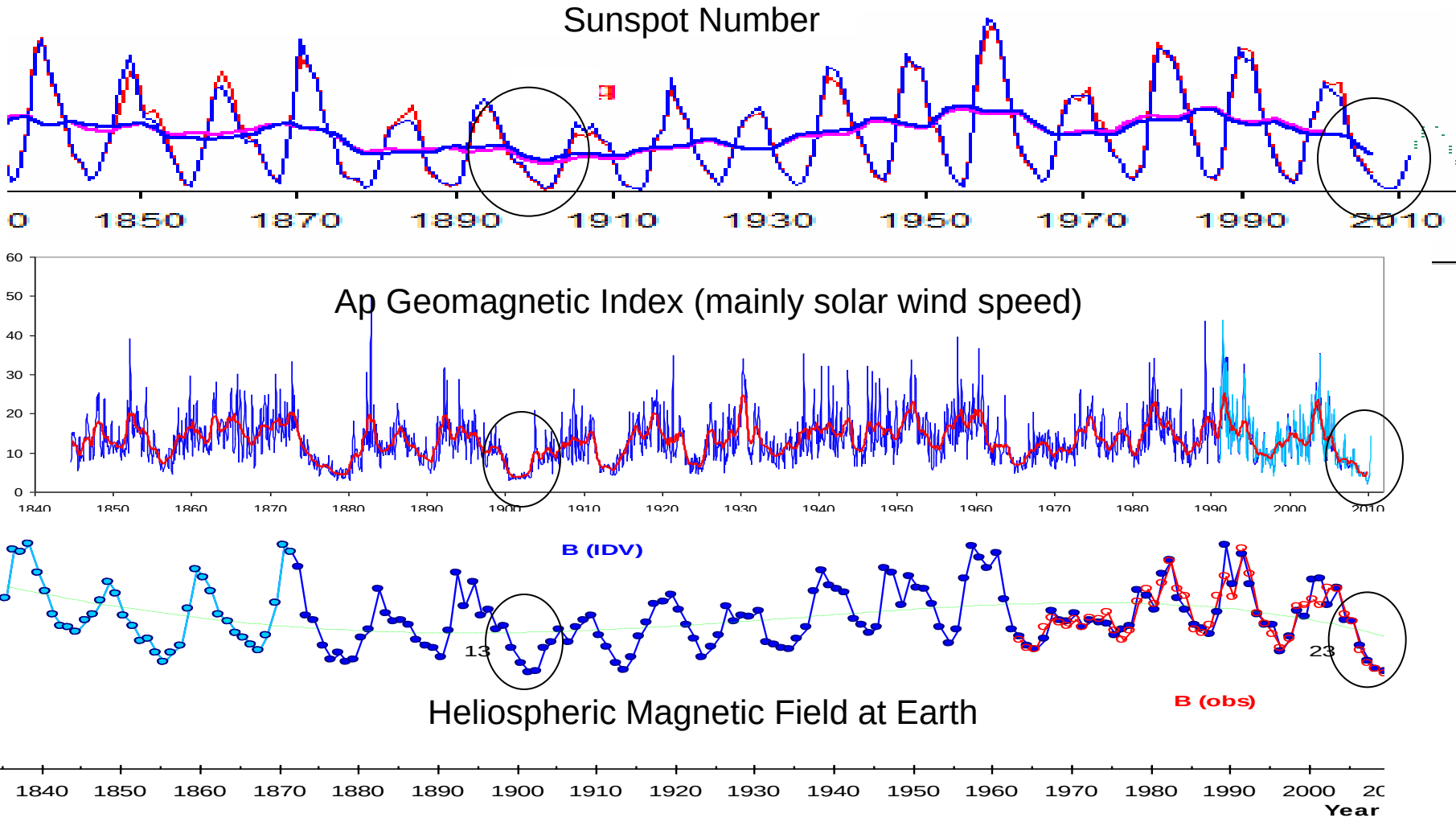
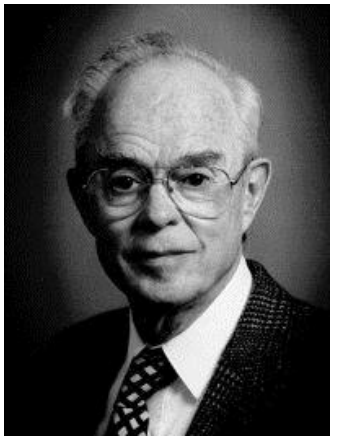
Solar Activity 1835-2011



Activity now is similar to what it was a century ago

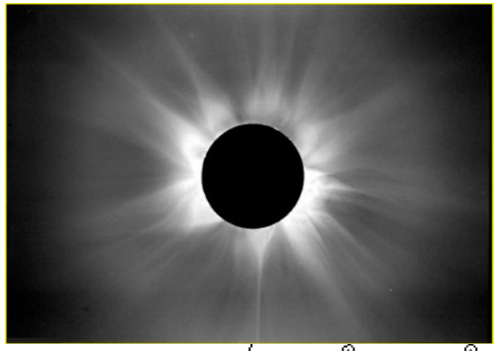
The Solar Wind

Ludwig Biermann
1951

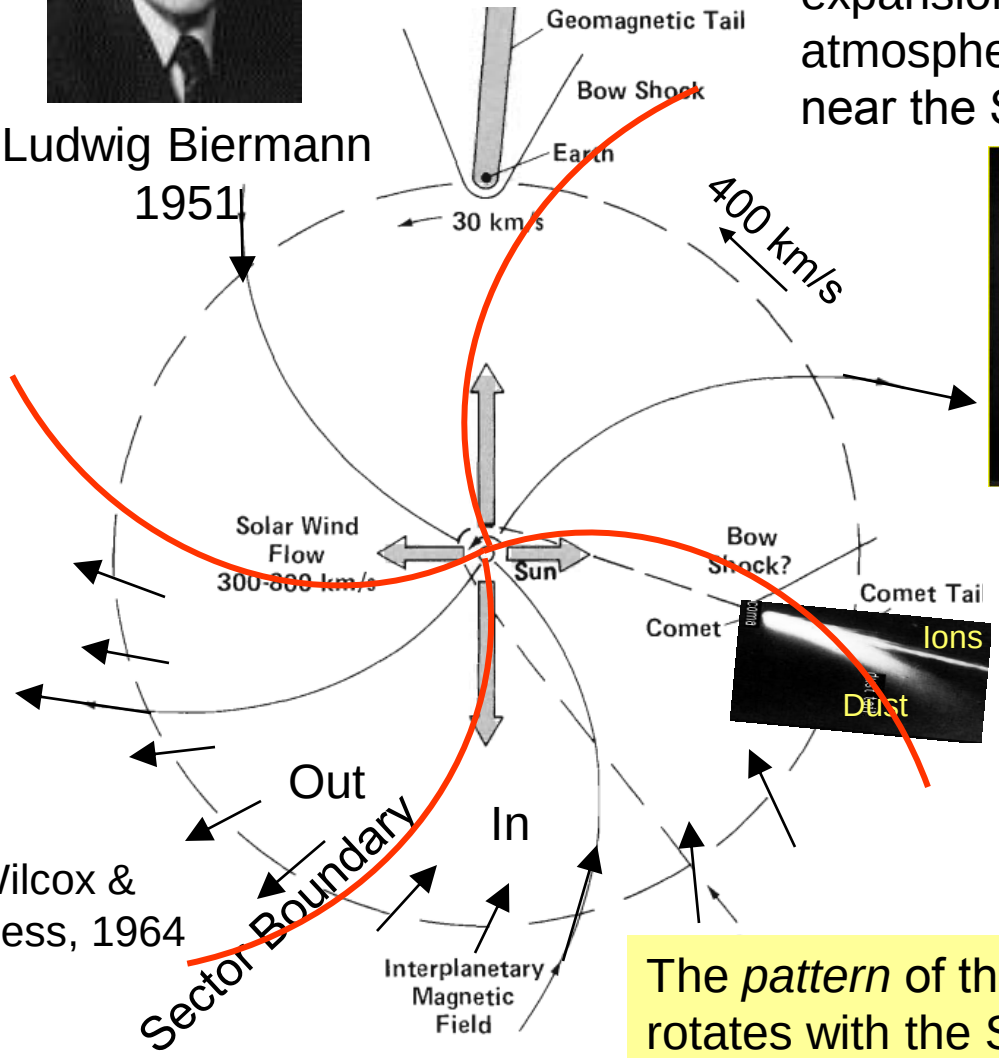


Gene Parker
1958

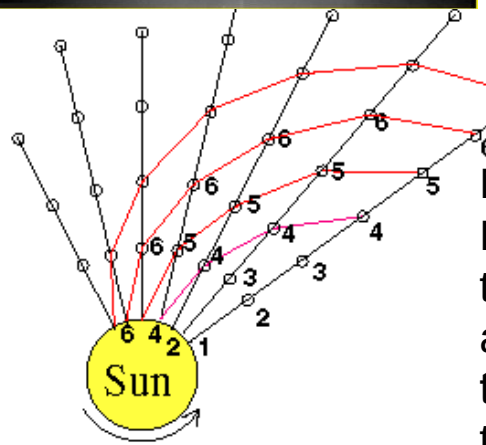
"Blows" all the time and is the expansion of the extremely hot atmosphere into space, visible near the Sun as the 'Corona':



Expansion is radially outwards



Wilcox & Ness, 1964

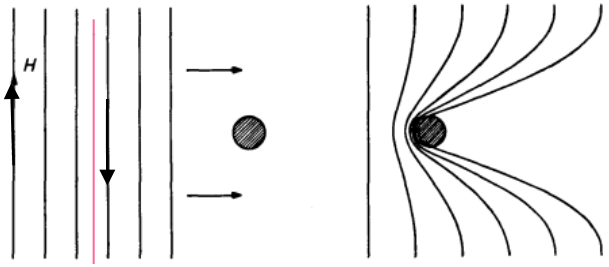


Magnetic Field Lines are tied to the expanding atmosphere and therefore 'rooted' in the Rotating Sun

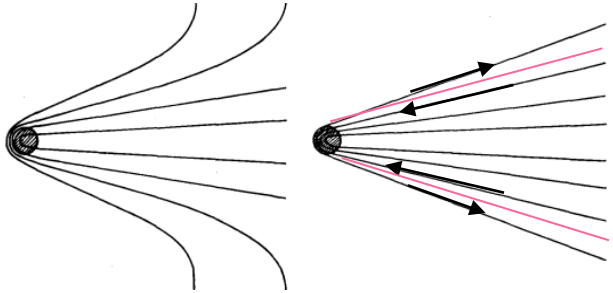
The *pattern* of the magnetic 'spiral' rotates with the Sun once in 25 days

Solar Wind Stealing a Comet Tail

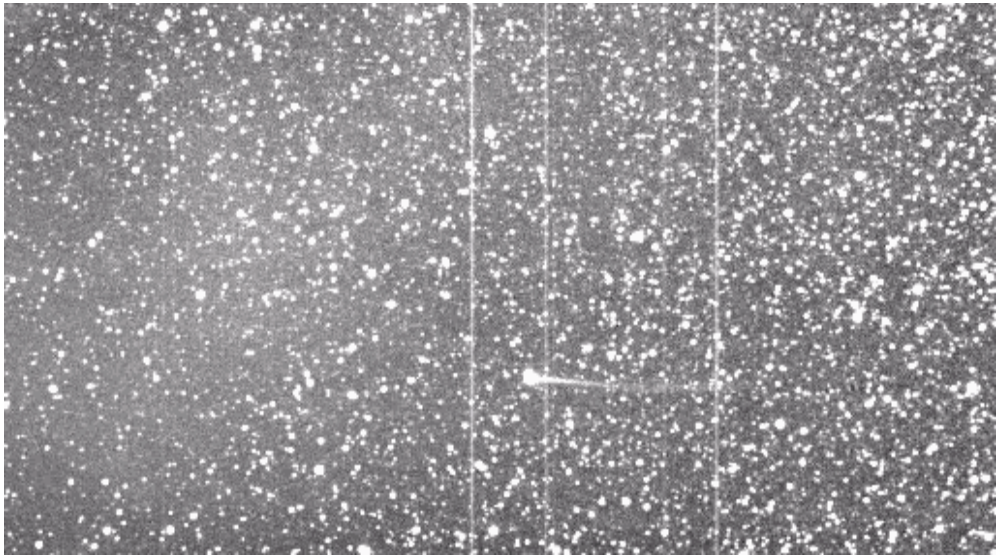
Sector Boundary



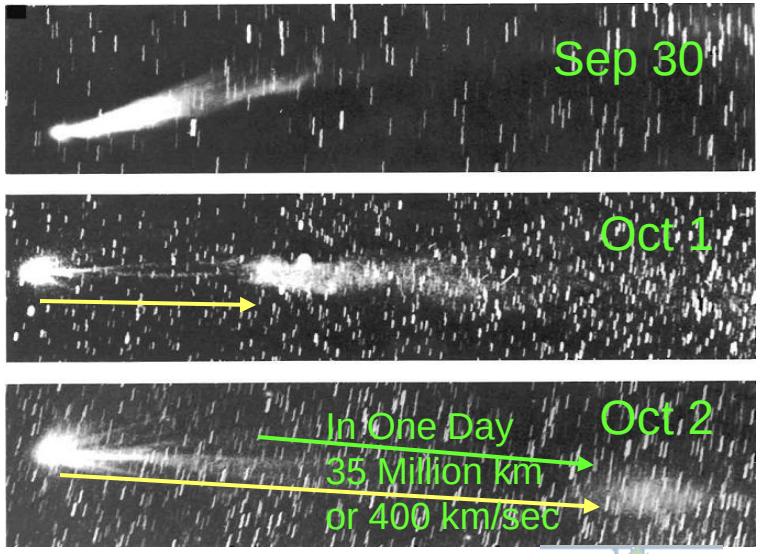
Reconnection



Fragile: Comet ion tail inside



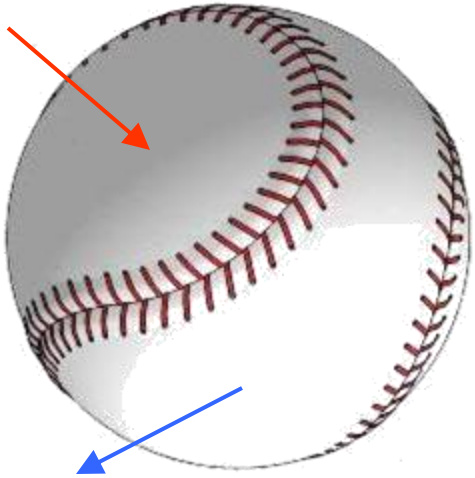
Comet Encke, 2007/04/20

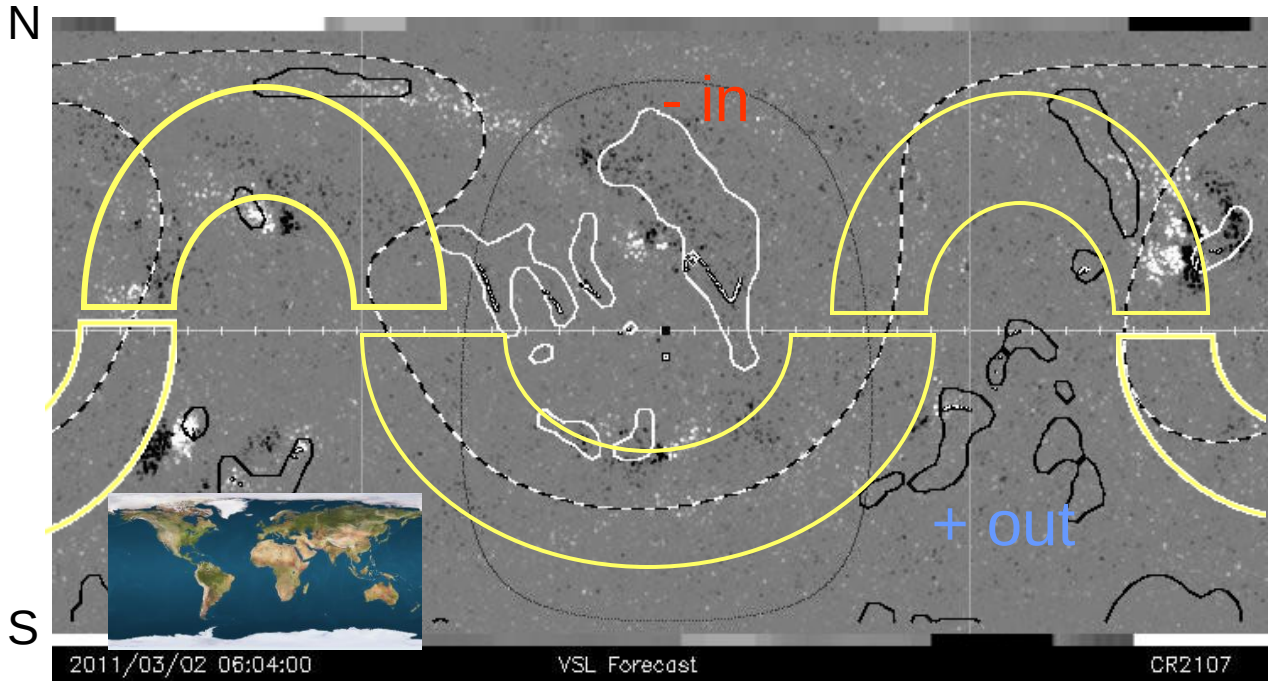


Comet Morehouse, 1908

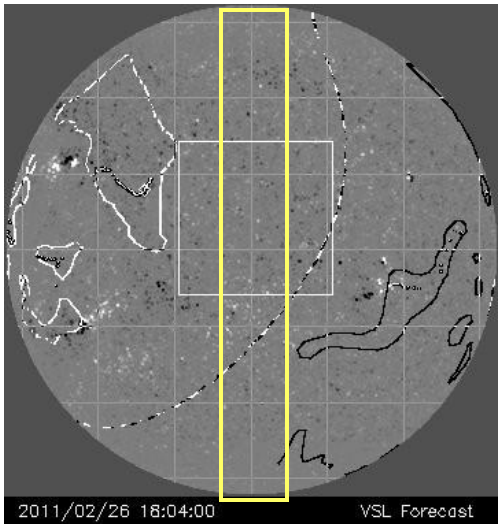
Sector Boundaries on the Sun

From the measured magnetic field we can calculate where the boundary between opposite polarities is. It winds its way across the surface looking like the seam of a baseball



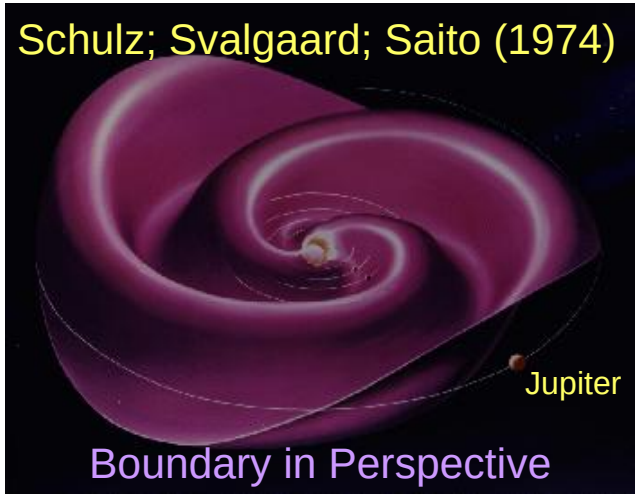


'Synoptic' map from 27 daily strips showing the whole Sun



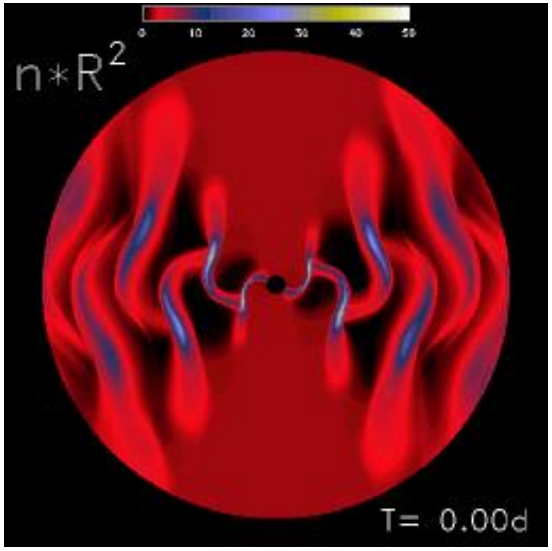
Disk Magnetogram

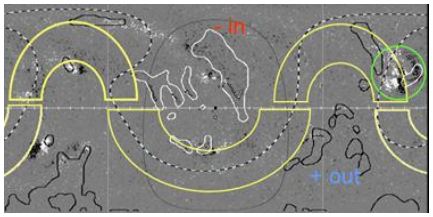
Returning to Solar Wind…



‘Vertical’ cut through the sweeping boundary:

← 50 AU →

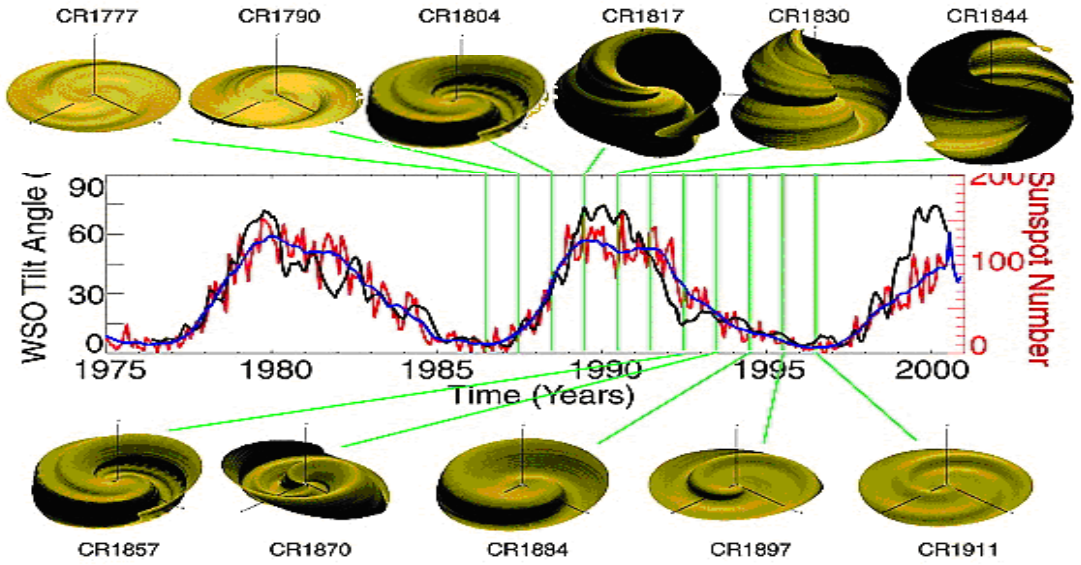


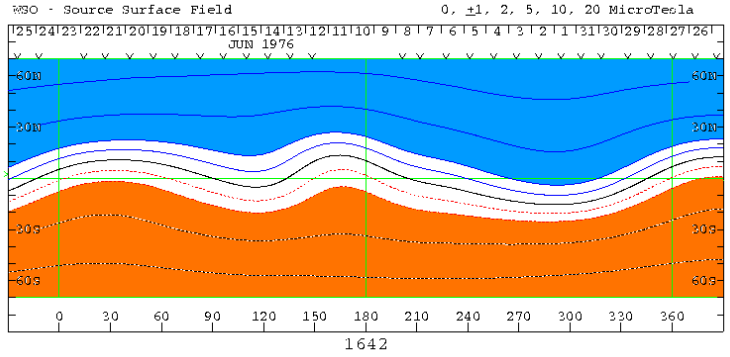


Sector boundary

The Boundary through the Cycle

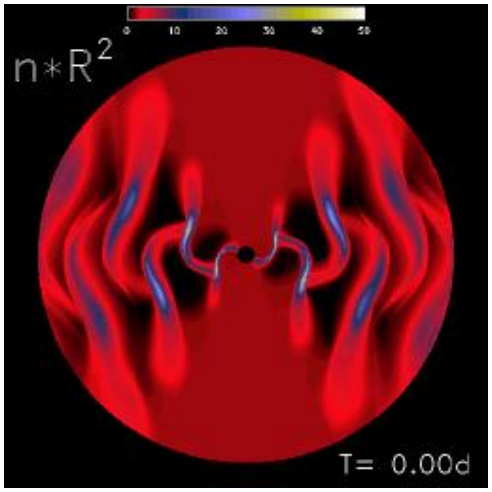
Near the sector boundary the solar wind is denser and slower. As the Sun rotates this builds up spiraling layers of denser plasma wrapping around the Sun many times:



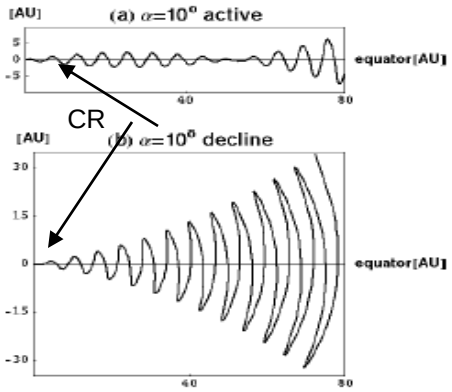


The ‘flapping’ sector boundary in time. Note the changing extent

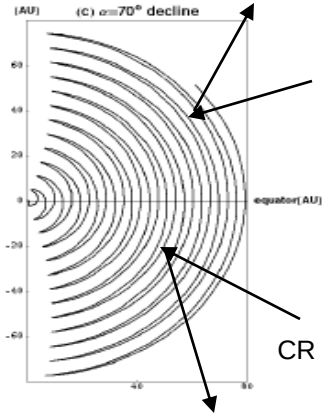
Cosmic Rays from the Milky Way Galaxy



Minimum

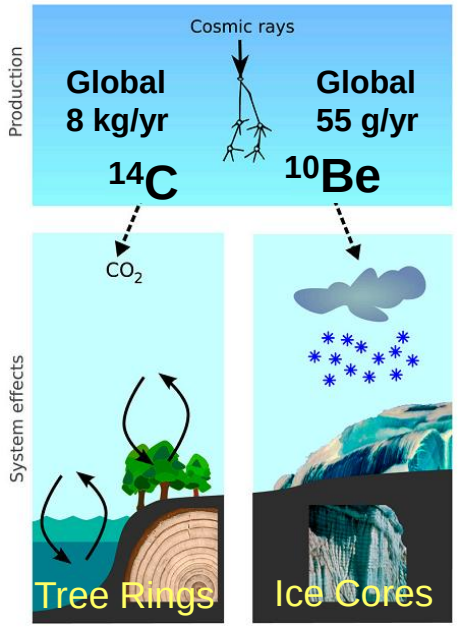


Maximum



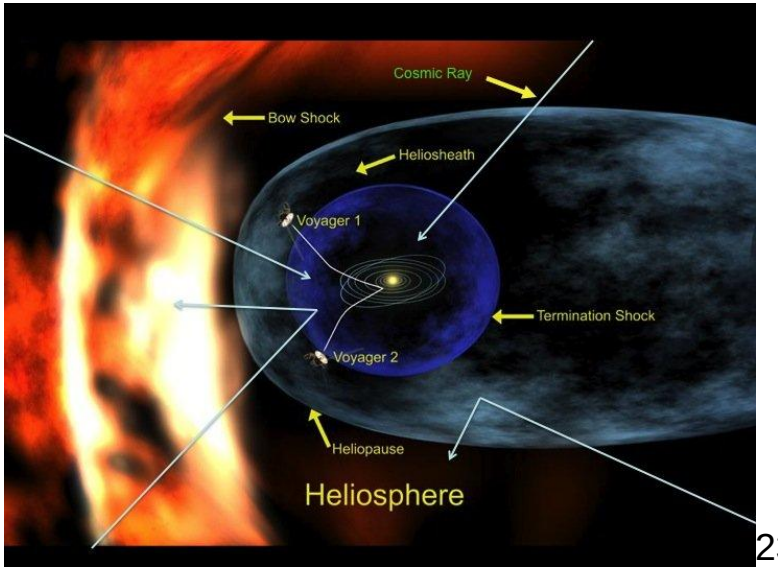
Cosmic Ray Modulation caused by solar cycle variation of current sheet extent and of solar storms

At maximum, more Cosmic Rays are deflected out of the solar system and do not reach the Earth:



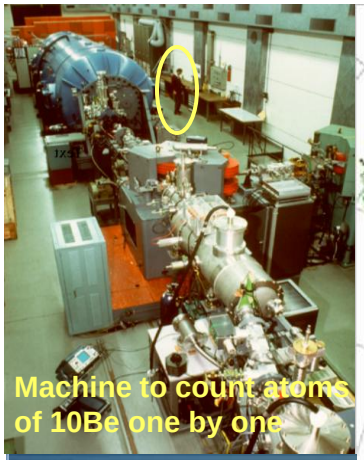
About 30 [secondary] cosmic rays fly through your body every second

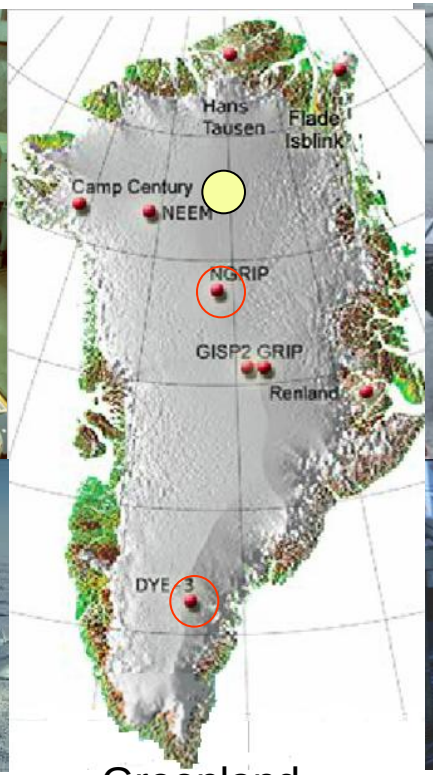
When hitting the atmosphere Cosmic Rays produce radioactive Carbon14 and Beryllium10 isotopes



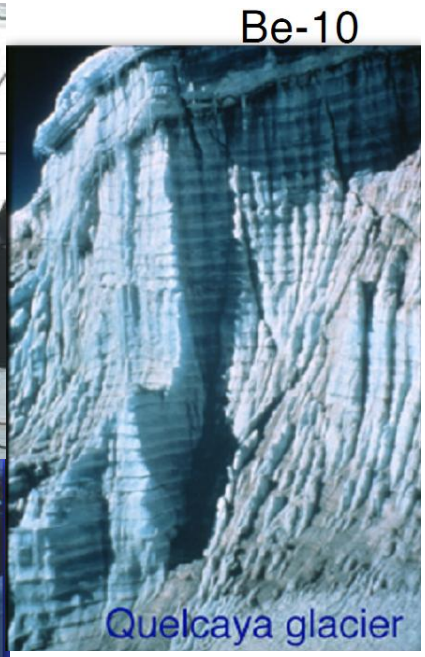
Drilling for Ice Cores

To measure the 10Be concentration and thus the Cosmic Rays thousands of years back in time

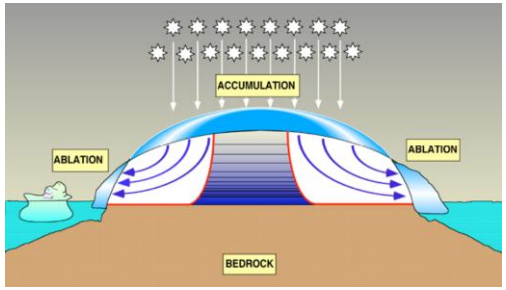


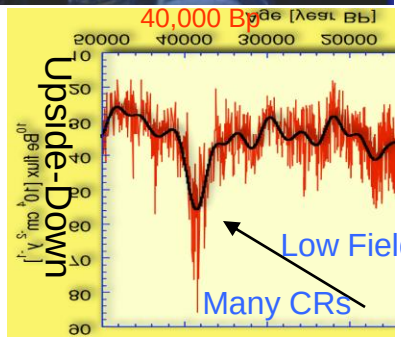


Greenland



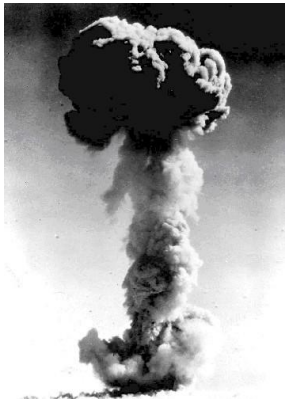
Annual Layers in the Ice





Cosmic Ray counts are also influenced by the Earth's magnetic field. We can correct for that.

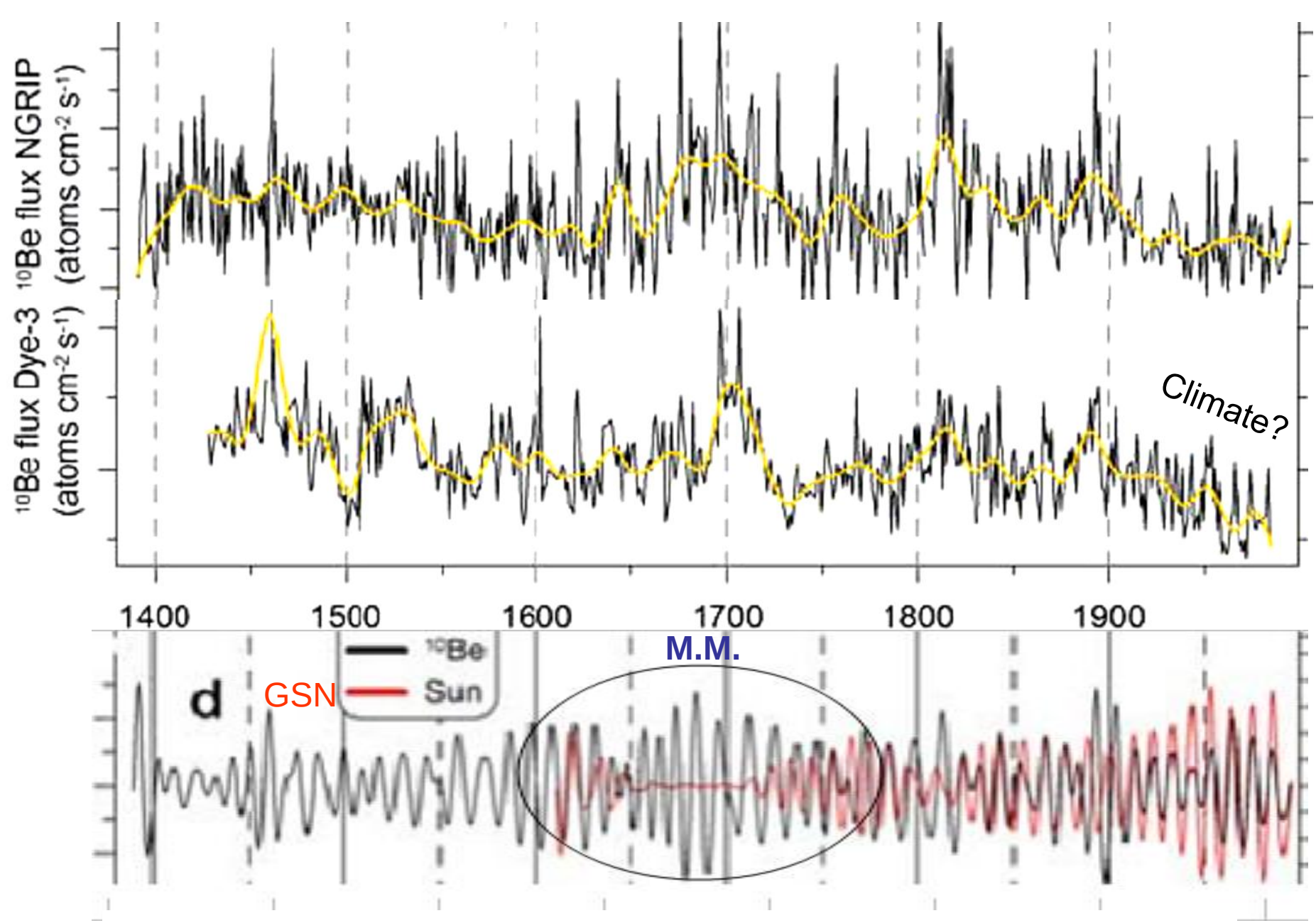
Getting to the Station on the Ice



Low seismic ‘noise’, good for detection of Atomic Bombs

But my job (in 1967) was to make magnetic observations…

Inge Lehman Station 77.92ºN 39.23ºW, 2400 m (7900 ft), 1966-1967



Cosmic Ray Proxy [Berggren et al.]

‘Burning Prairie’ => Magnetism

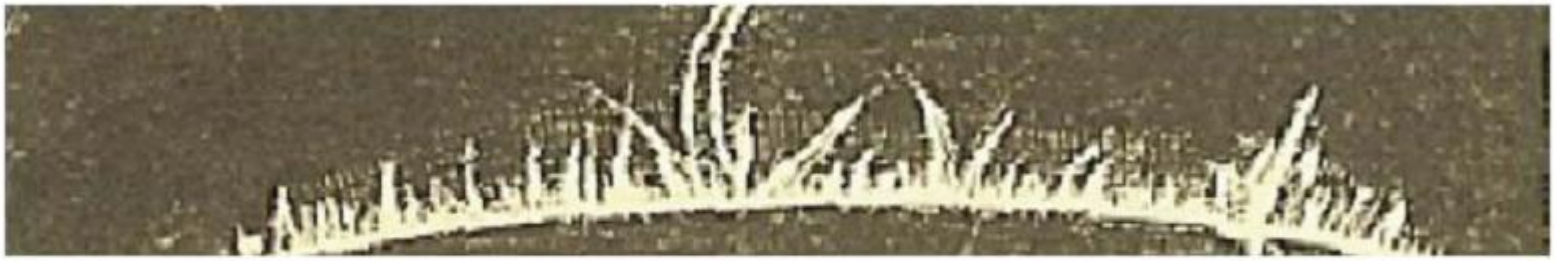


Figure 1 An early drawing of the “burning prairie” appearance of the Sun’s limb made by C.A. Young, on 25 July 1872. All but the few longest individual radial structures are spicules.

It is now well known (see, *e.g.,* the overview in Foukal, 2004) that the spicule jets move upward along magnetic field lines rooted in the photosphere outside of sunspots. Thus the observation of the red flash produced by the spicules requires the presence of widespread solar magnetic fields. Historical records of solar eclipse observations provide the first known report of the red flash, observed by Stannyan at Bern, Switzerland, during the eclipse of 1706 (Young, 1883). The second observation, at the 1715 eclipse in England, was made by, among others, Edmund Halley – the Astronomer Royal. These first observations of the red flash imply that a significant level of solar magnetism must have existed even when very few spots were observed, during the latter part of the Maunder Minimum.

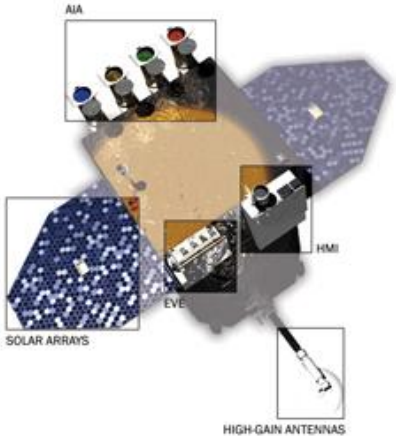
Foukal & Eddy, Solar Phys. 2007, *245*, 247-249

Birth of an Active Region

NOAA 11158, February, 2011

Solar Dynamics Observatory (SDO)

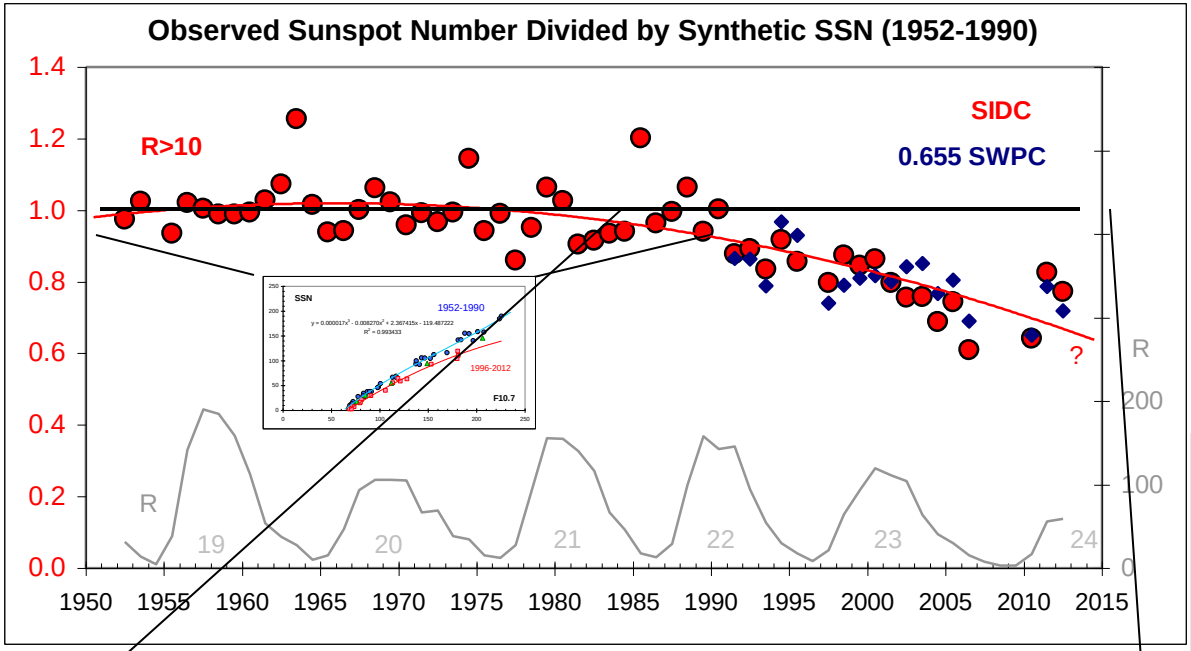
“All the Sun, All the Time”

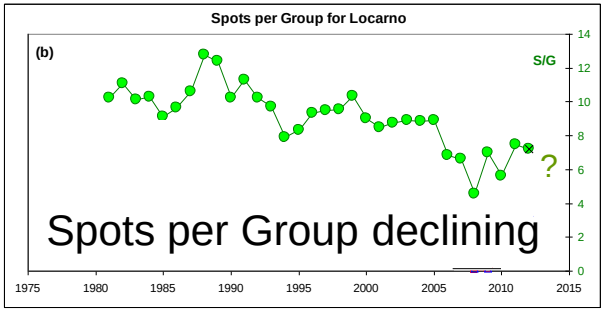


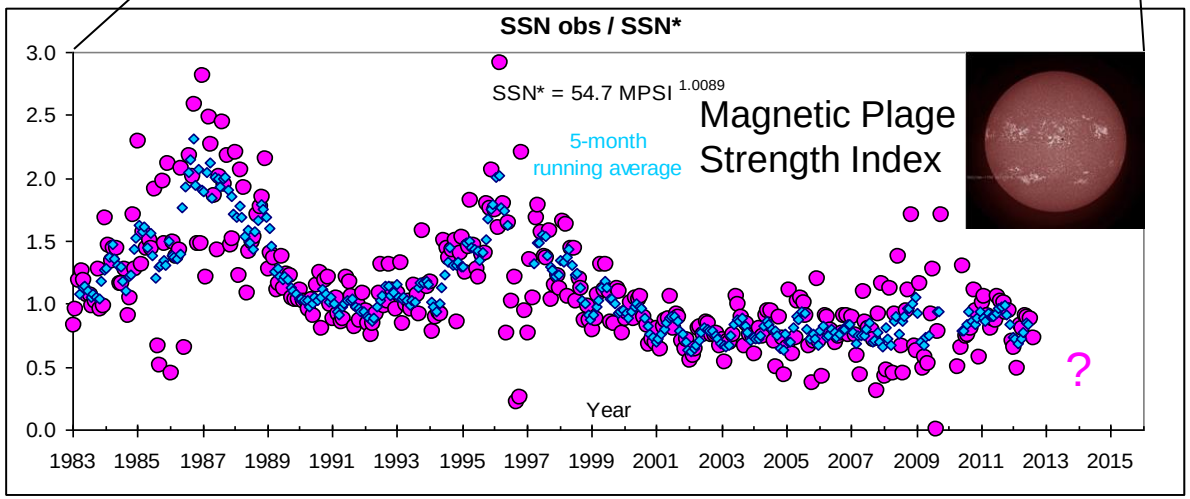
Visible Light

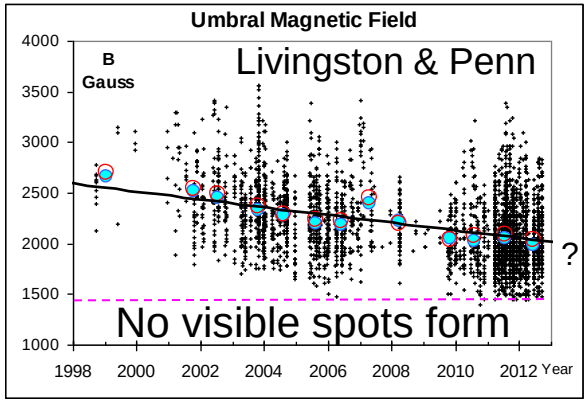
Sunspots grow by the accumulation of smaller spots and pores.

Something *is* happening with the Sun



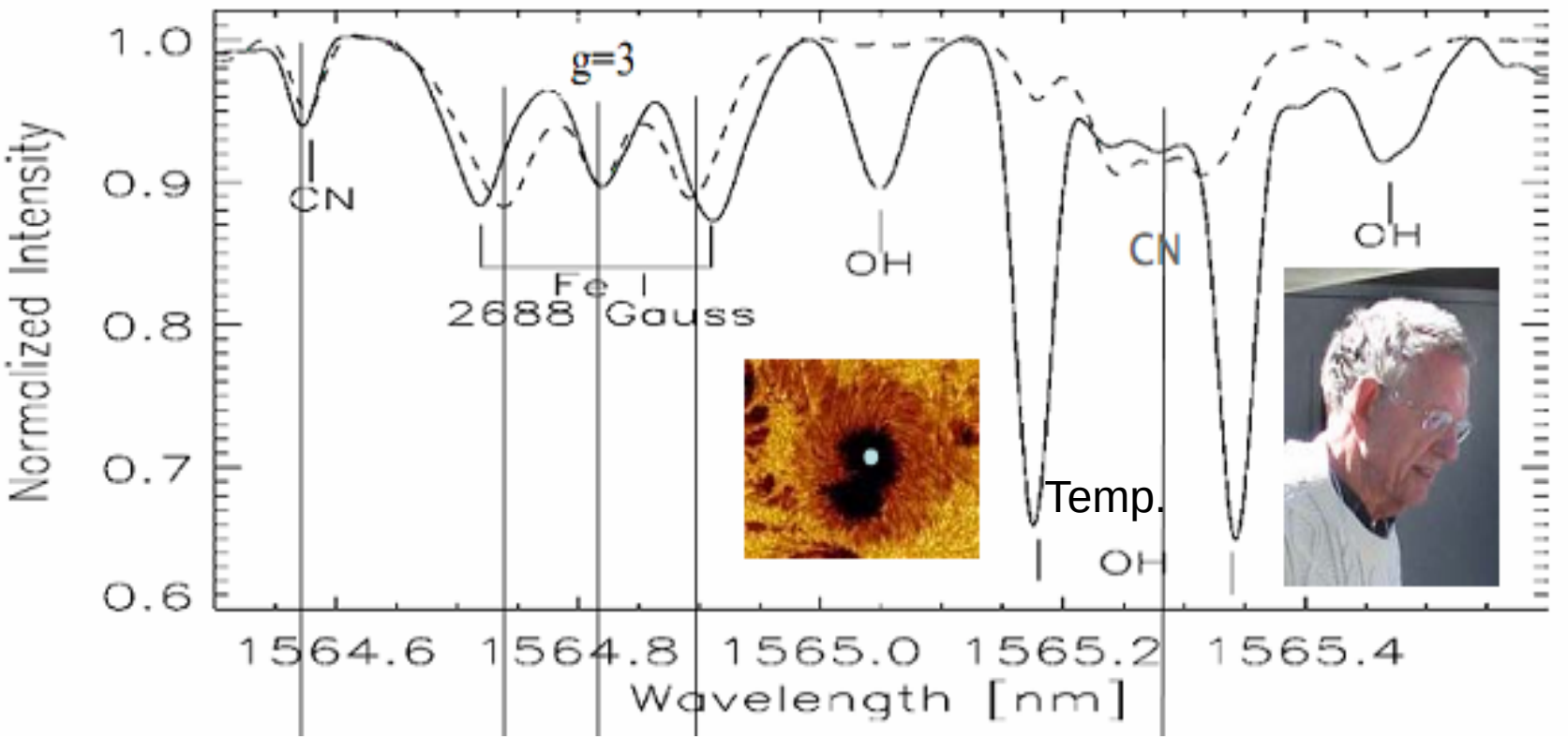






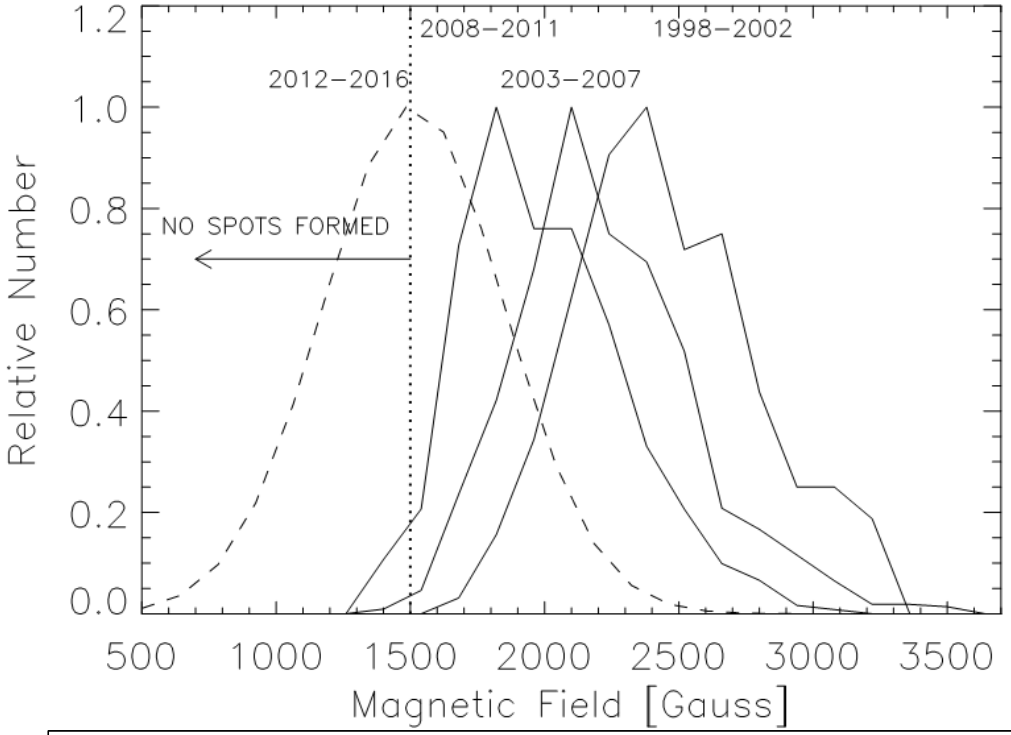
We don't know what causes this, but sunspots are becoming more difficult to see or not forming as they used to. There is speculation that this may be what a Maunder-type minimum looks like: magnetic fields still present [cosmic rays still modulated], but just not forming spots. If so, exciting times are ahead.

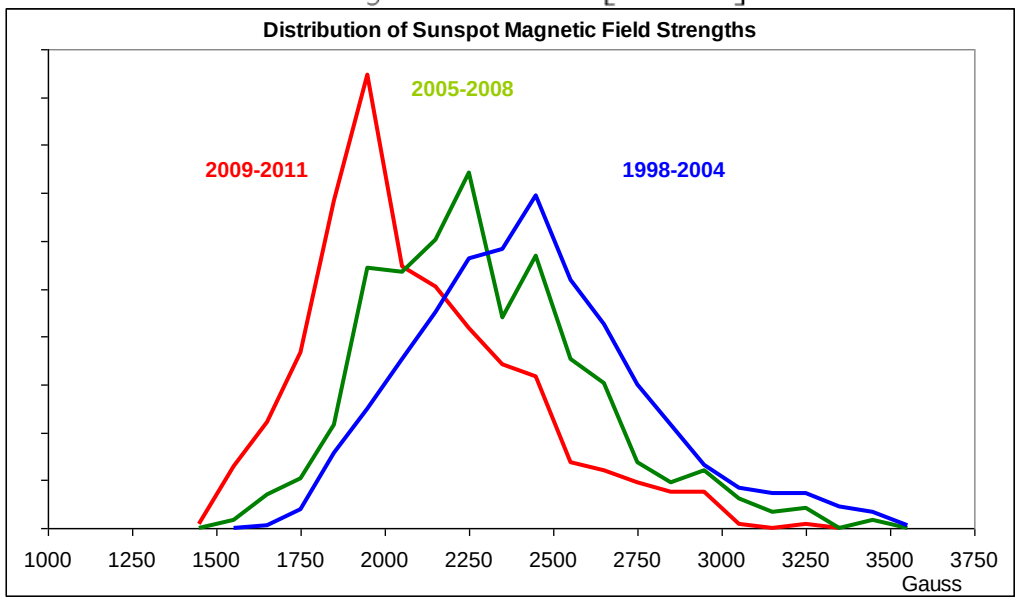
The Livingston & Penn Data



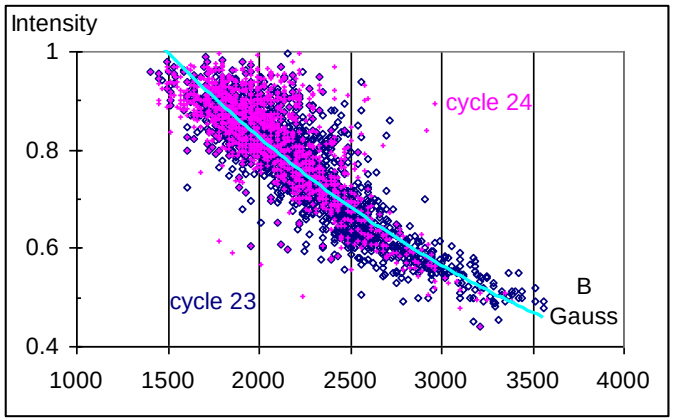
From 2001 to 2012 Livingston and Penn have measured field strength and brightness at the darkest position in umbrae of 1843 spots using the Zeeman splitting of the Fe 1564.8 nm line. Most observations are made in the morning [7h MST] when seeing is best. Livingston measures the absolute [**true**] field strength averaged over his [small: 2.5″x2.5″] spectrograph aperture, and not the Line-of-Sight [LOS] field.

Evolution of Distribution of Magnetic Field Strengths

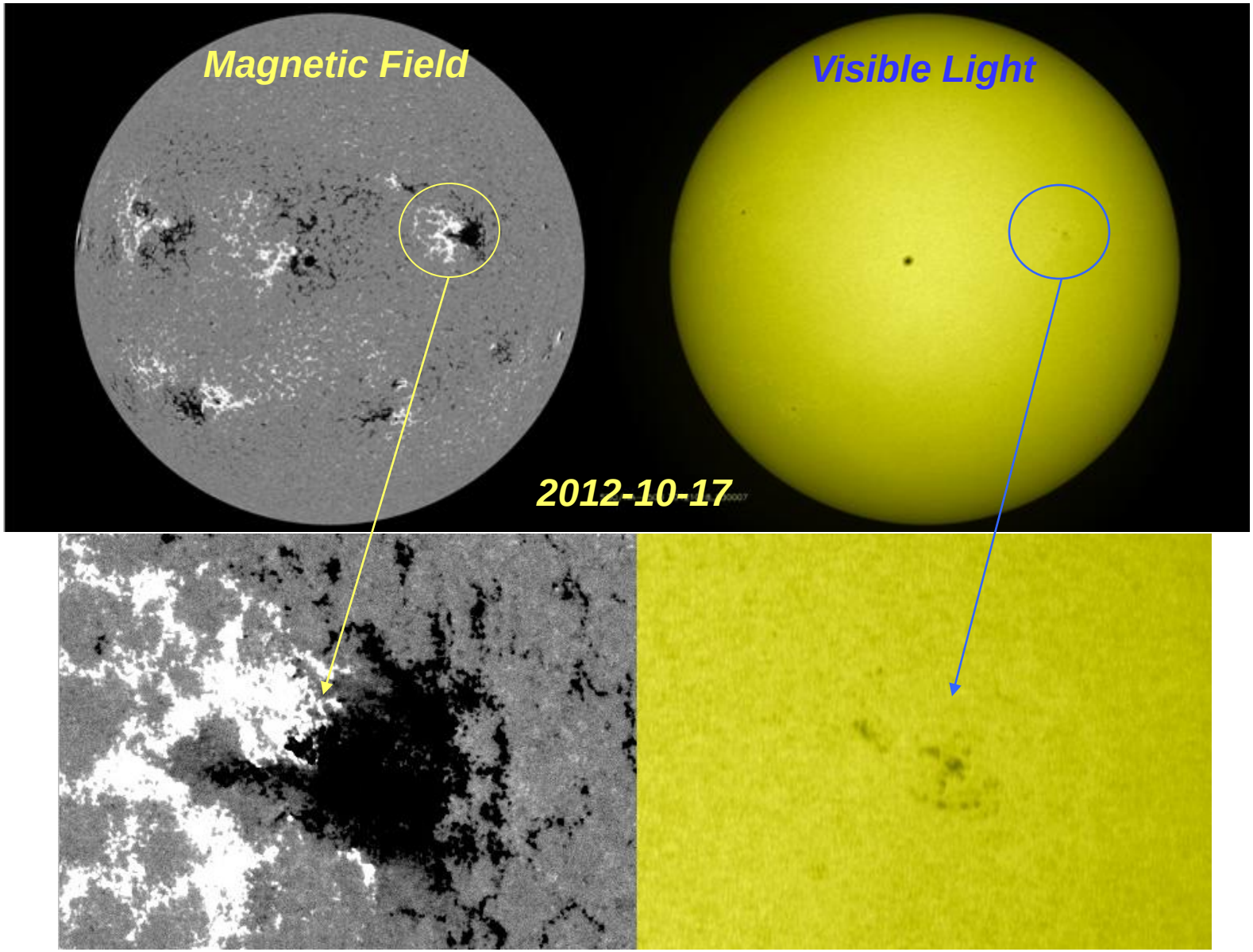




Sunspots form by assembly of smaller patches of magnetic flux. As more and more magnetic patches fall below 1500 G, fewer and fewer spots will form



Perhaps like this:

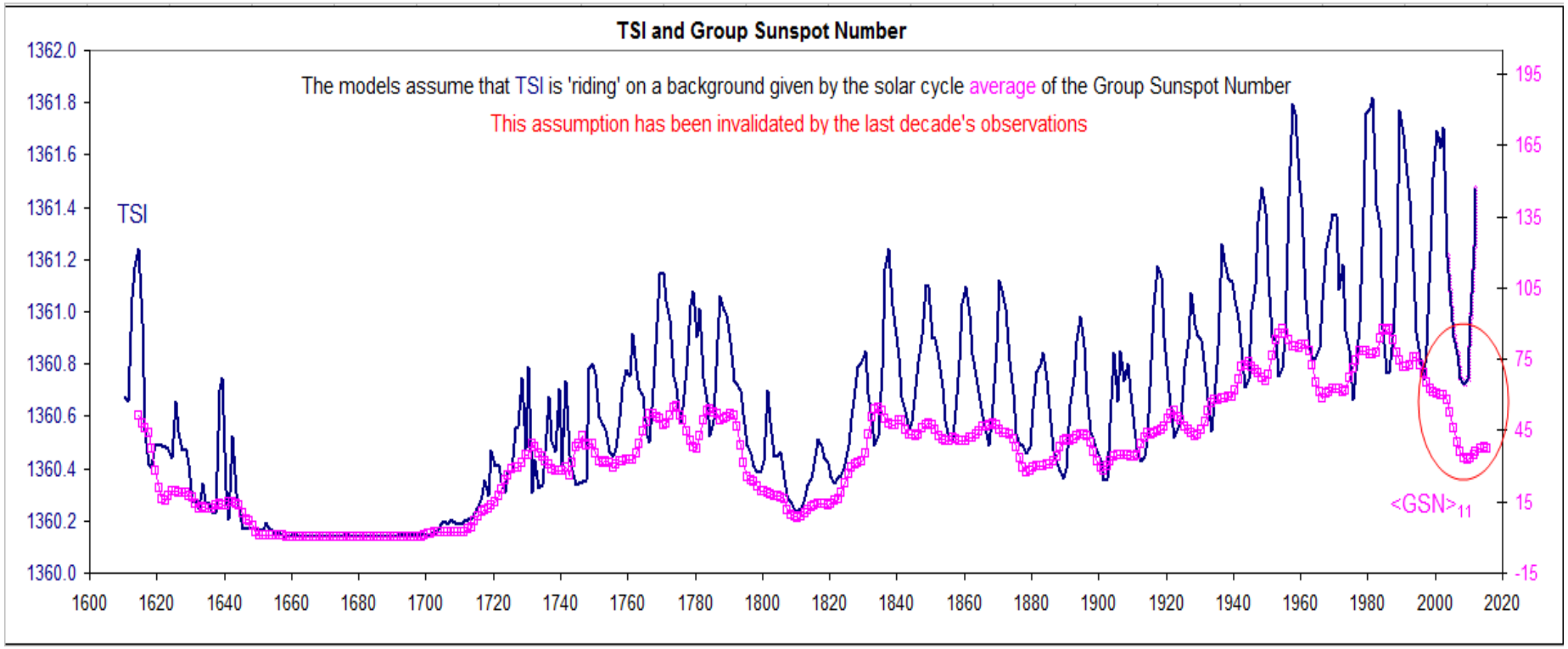


Working Hypothesis

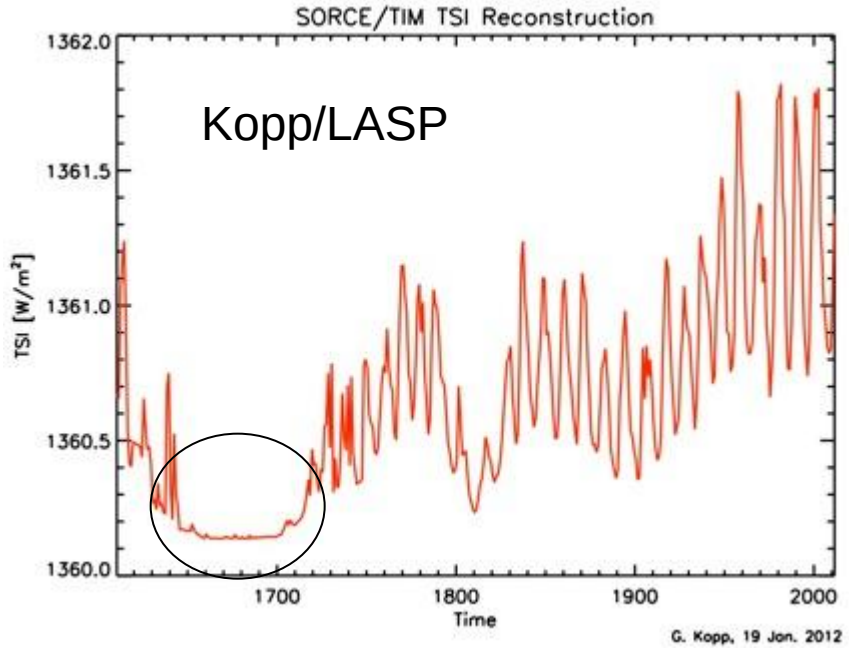
- The Maunder Minimum was not a deficit of magnetic flux, but
- A lessening of the efficiency of the process that compacts magnetic fields into visible spots
- This may now be happening again
- If so, there is new solar physics to be learned
- I'll end with something on TSI and climate

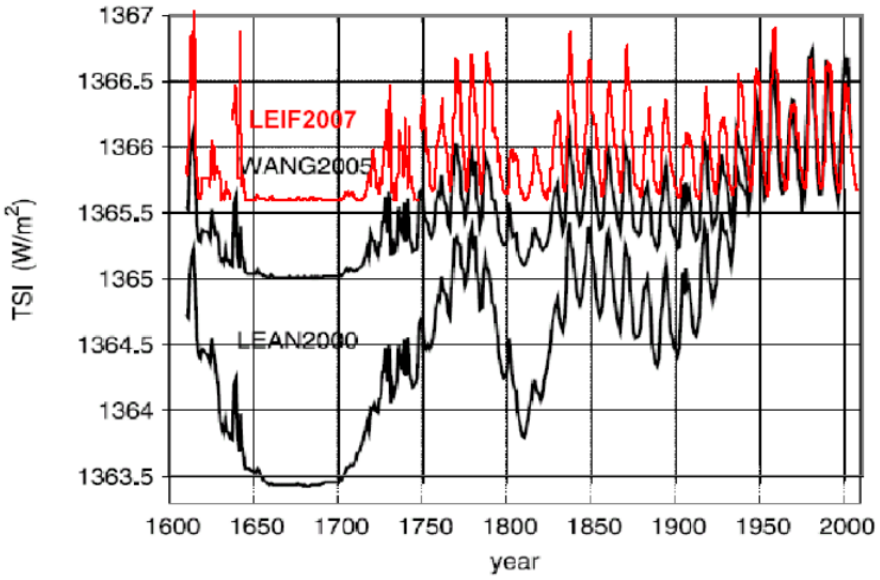
Removing the discrepancy between the Group Number and the Wolf Number removes the ‘background’ rise in reconstructed TSI

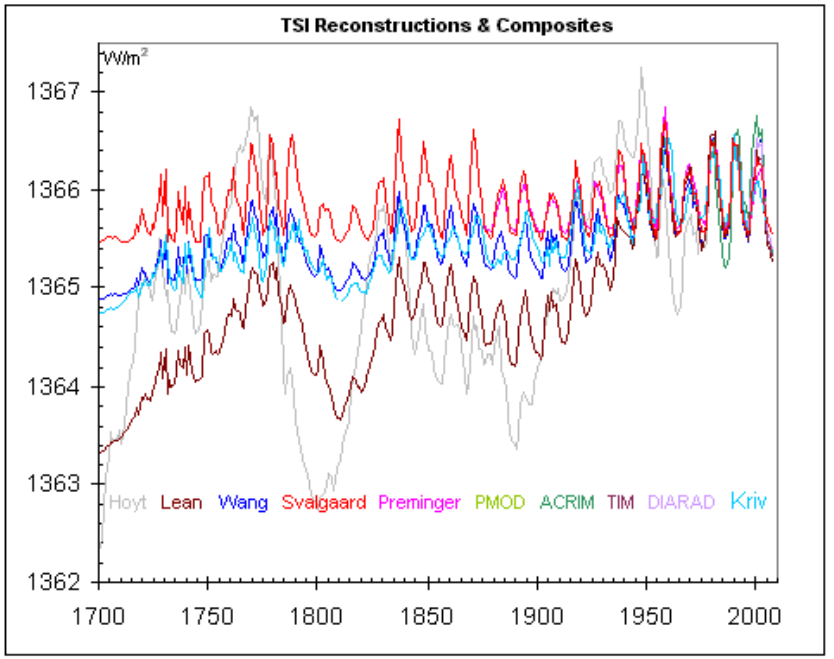
I expect a strong reaction against ‘fixing’ the GSN from people that ‘explain’ climate change as a secular rise of TSI and other related solar variables



Some More TSI Reconstructions

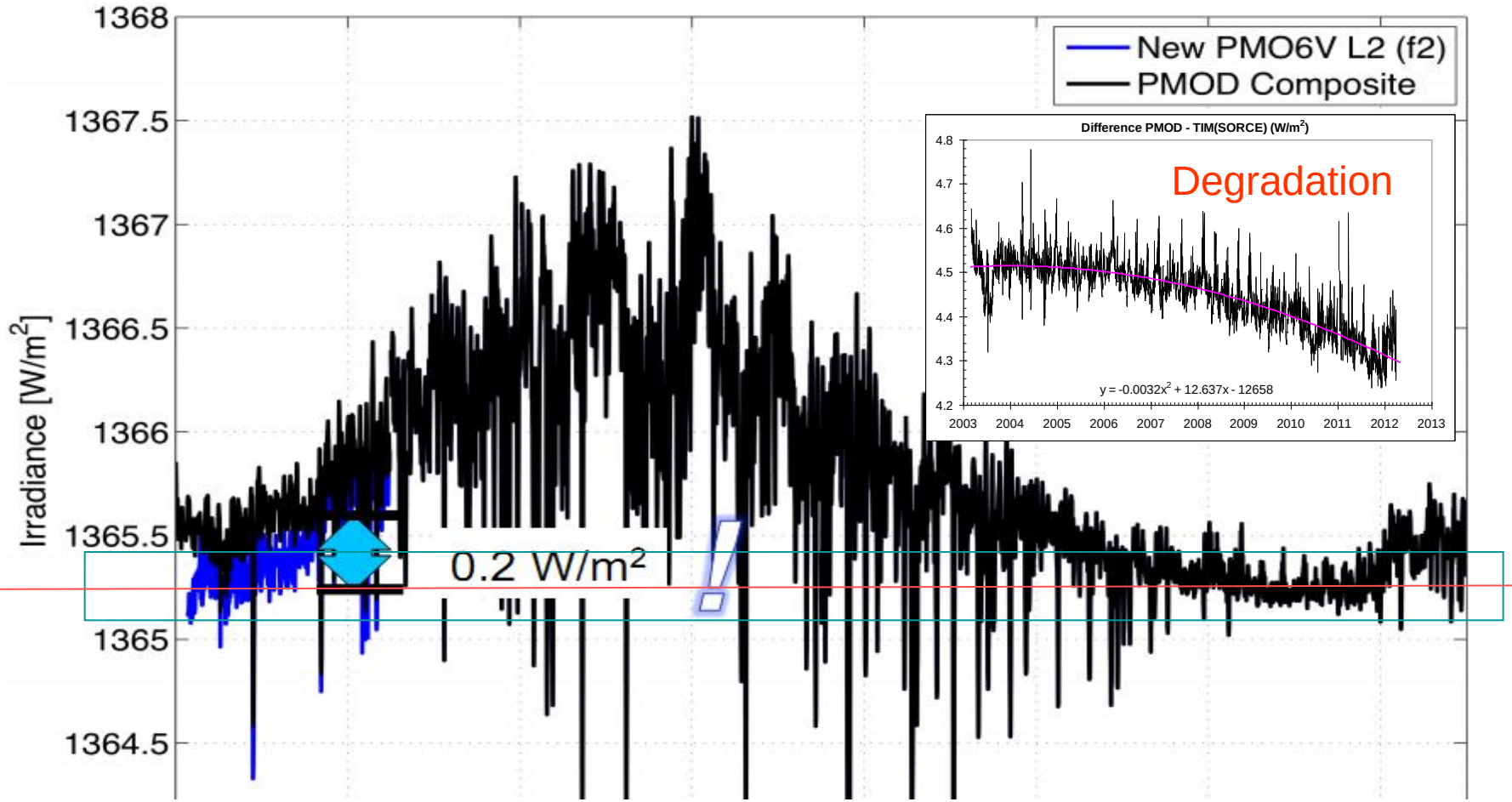






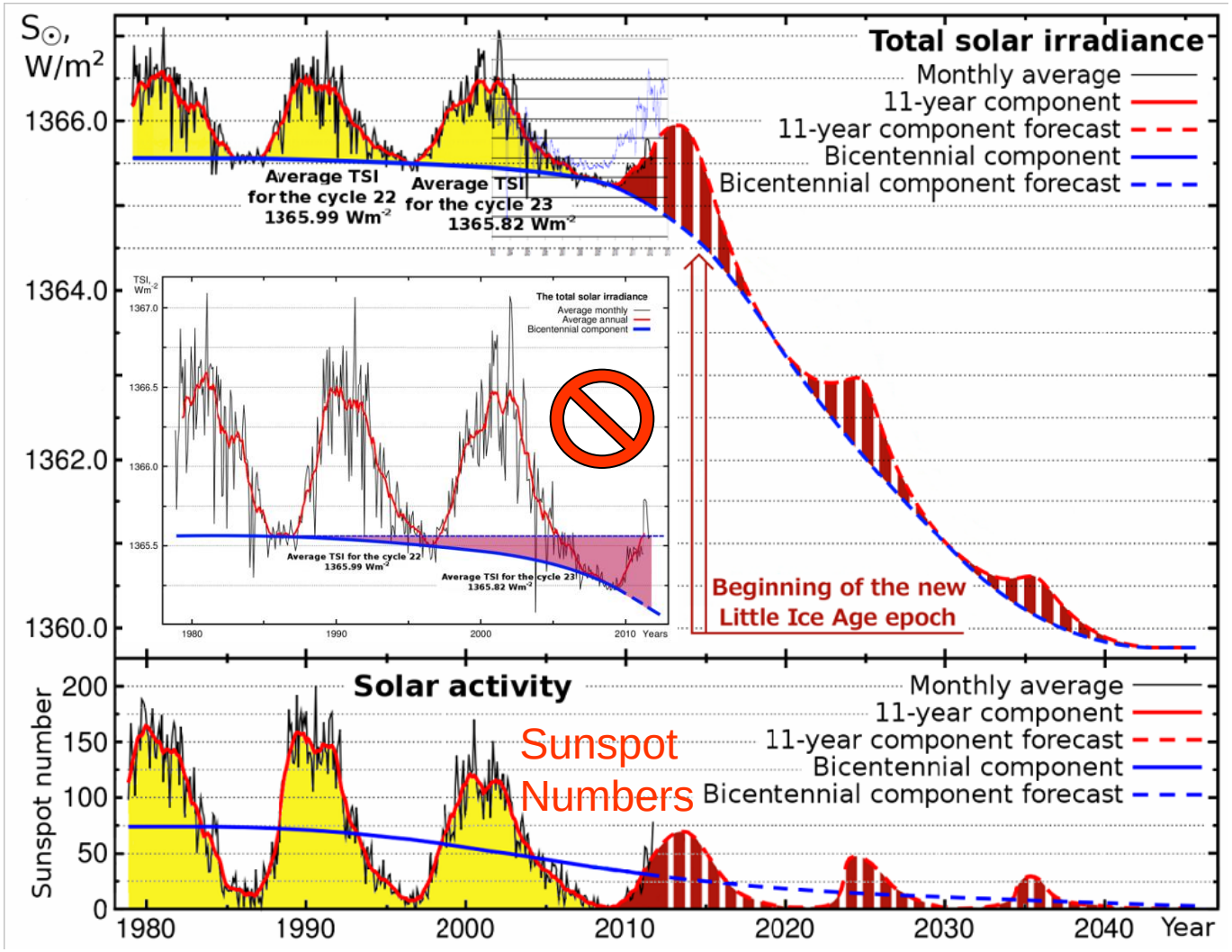
Crucial question: is there a slowly varying background? I think not.

TSI (PMOD) not lower at recent Solar minimum



Schmutz, 2011

Absurd Extrapolation



Based on a decline that did not take place

No Ice Age soon, but well in 20,000 years

The lower solar activity in sunspot numbers may well happen

The End