Replicating 18th Century Sunspot Observations

WSO

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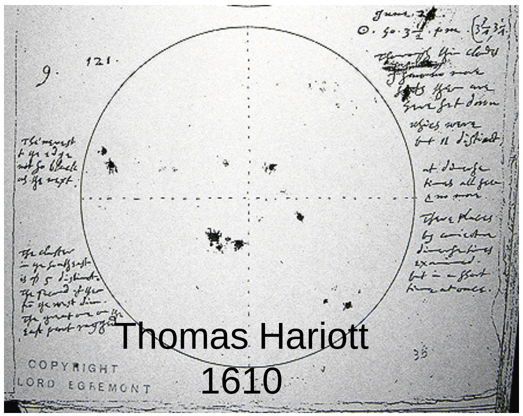
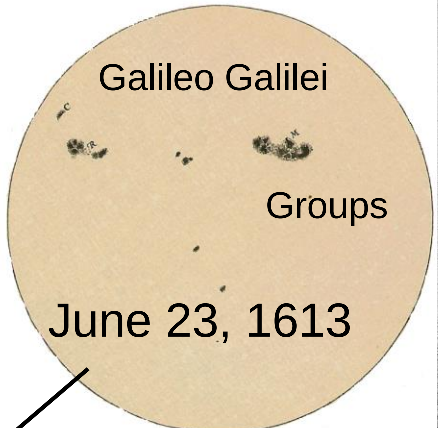
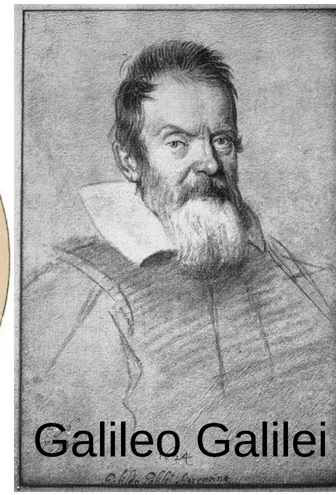
Seminar at Centro Interuniversitário de História das Ciências e da Tecnologia, Portugal: 27 May, 2021

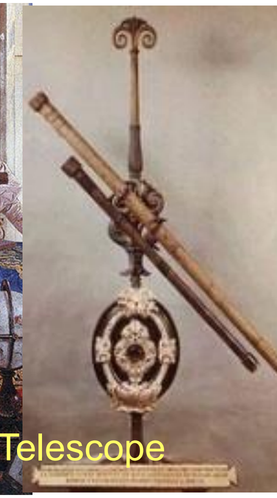
Centuries of Sunspot Observing

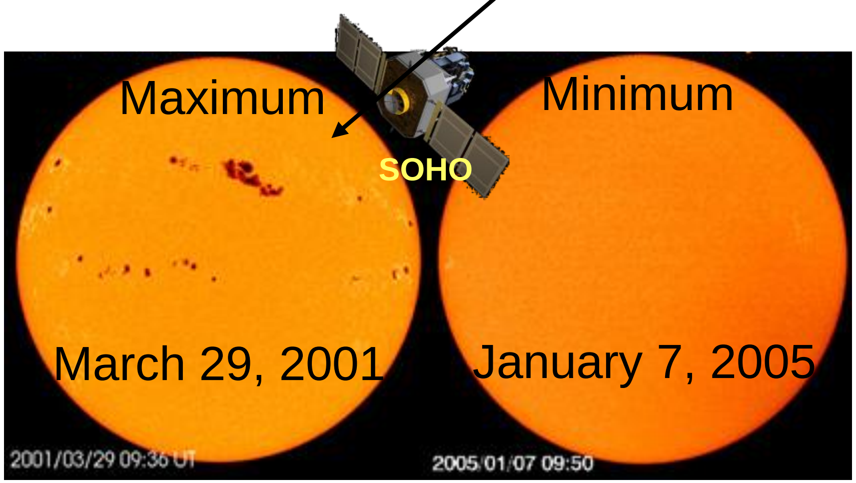
We have observed sunspots with telescopes for 400+ years



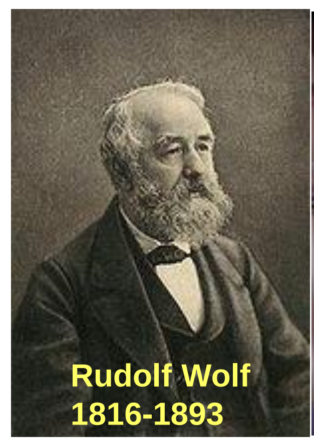








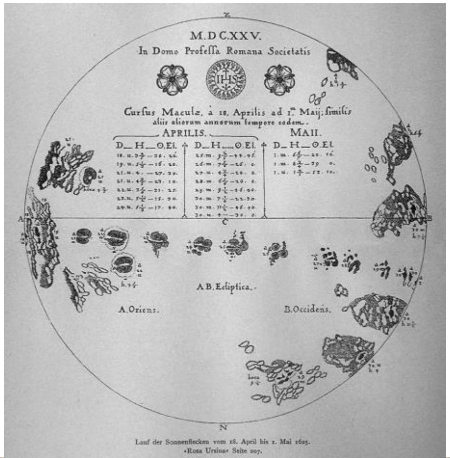
Sunspots observed by Spacecraft



'Compiler' of Sunspot Number

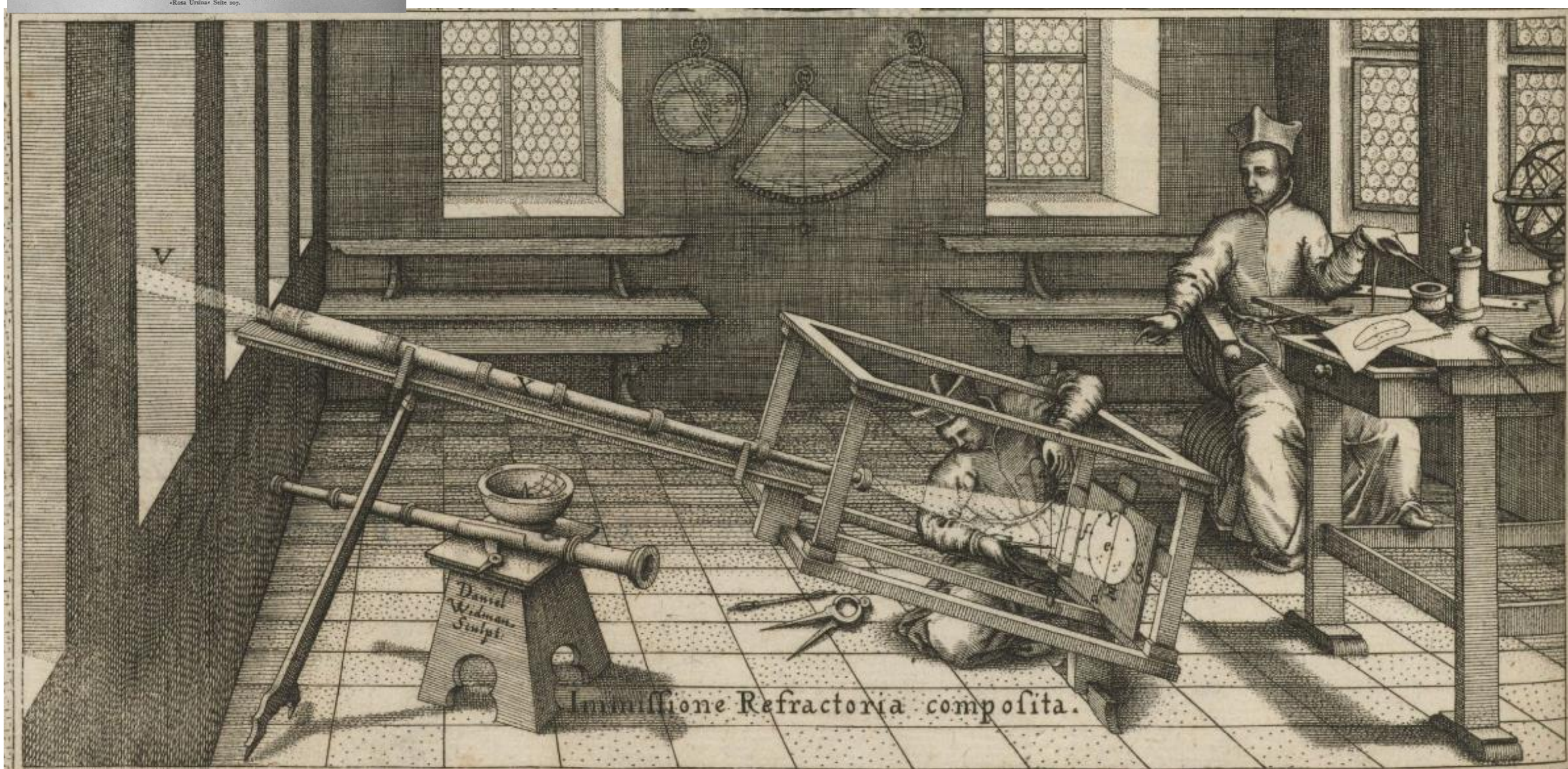
Still used today

The sunspot number is always determined using small telescopes

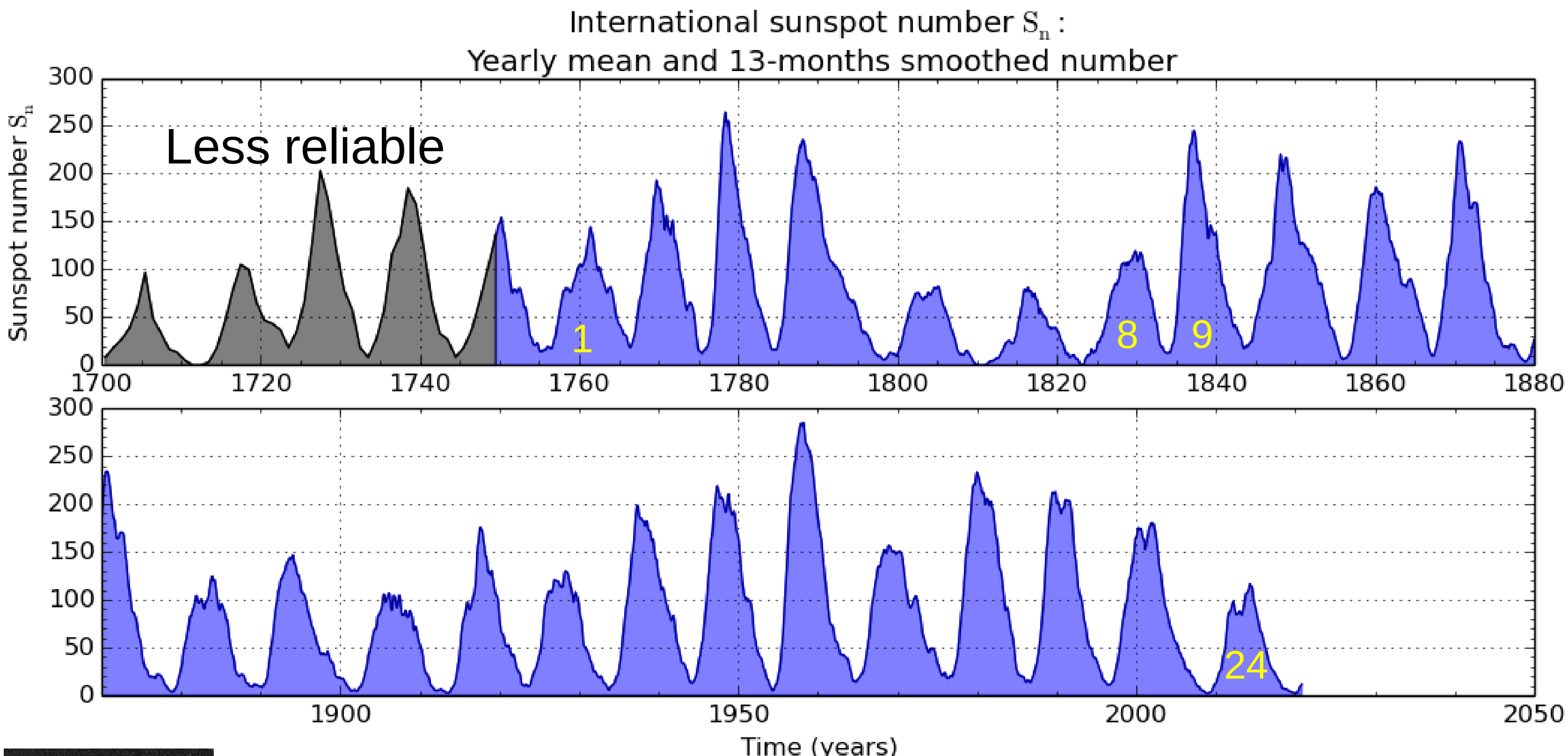


Christoph Scheiner
Rosa Ursina, Anno 1630

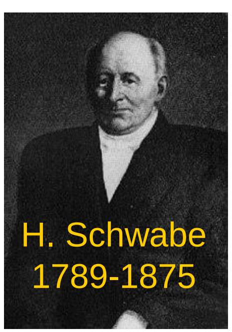
Helioscope: Projecting the Solar Image
(invented by one of Galileo's students)

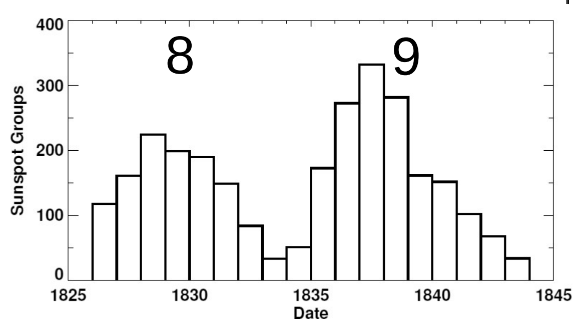


The Modern Sunspot Cycle Series



(http://sidc.be/silso) Royal Observatory of Belgium 2021 May 1





The cycle was discovered by Heinrich Schwabe in the 1840s

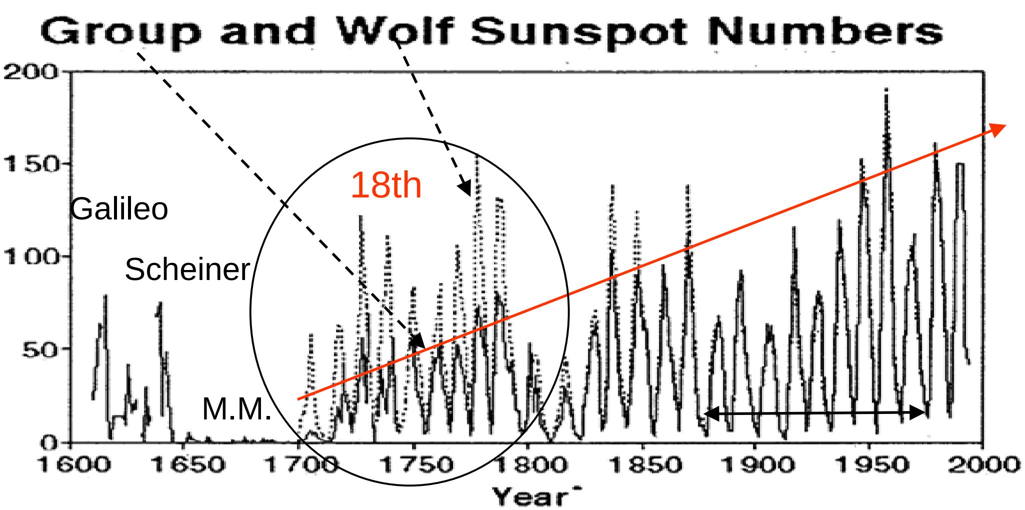
The Hoyt & Schatten Reconstruction

Hoyt, Douglas V.; Schatten, Kenneth H.; Nesme-Ribes, Elizabeth: The one hundredth year of Rudolf Wolf's death: **Do we have the correct reconstruction of solar activity?** *Geophysical Research Letters, Volume 21, Issue 18, p. 2067-2070, 1994*

Hoyt, Douglas V.; Schatten, Kenneth H.: Group Sunspot Numbers: a new solar activity reconstruction. *Sol. Phys. 179, 189–219, 1998*. [HS98 in what follows]

“In this paper, we construct a time series known as the Group Sunspot Number. […] The generation and preliminary analysis of the Group Sunspot Numbers allow us to make several conclusions: (1) **Solar activity before 1882 is lower than generally assumed** and consequently **solar activity in the last few decades is higher than it has been for several centuries.**” [Other researchers have claimed for more than ≈10,000 years]

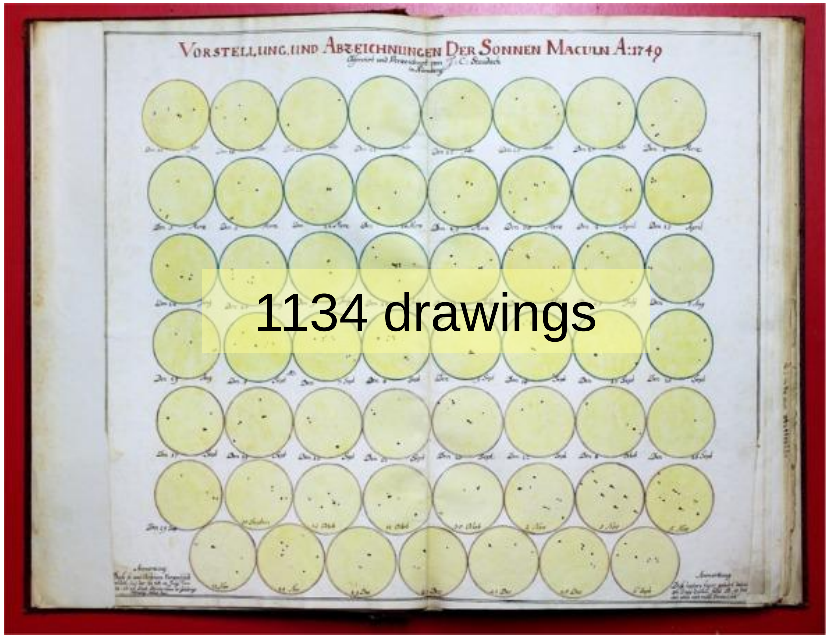
The Problem: Two Very Different ‘Sunspot Series’. Which One to Use?



Original Wolf Number: W_o = Groups + 1/10 Spots. (‘1/10 Spots’ was assumed to be a measure of the area of the group). $W = k\ 10\ W_o$

H&S GSN = 12 G where the ‘12’ was chosen to make the GSN = W for the interval 1874-1976

Our Knowledge of Sunspots in the 18th Century is Based on J.C. Staudach's Drawings 1749-1799



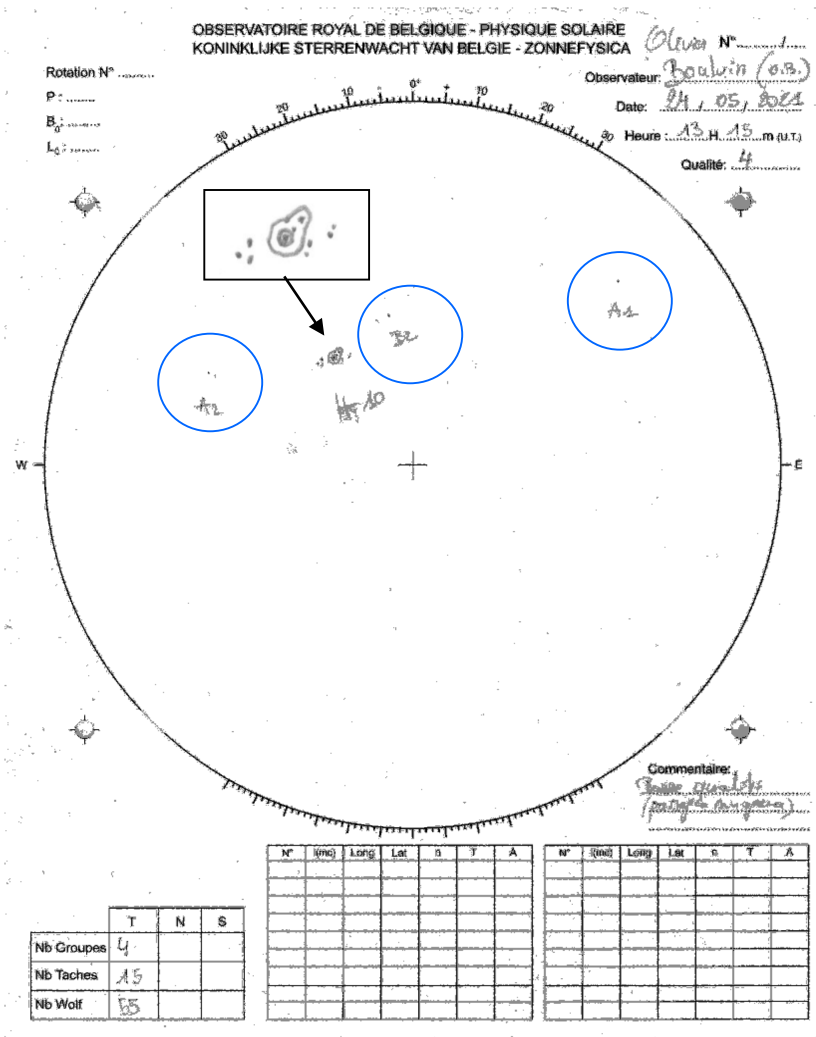
13th & 15th February 1760

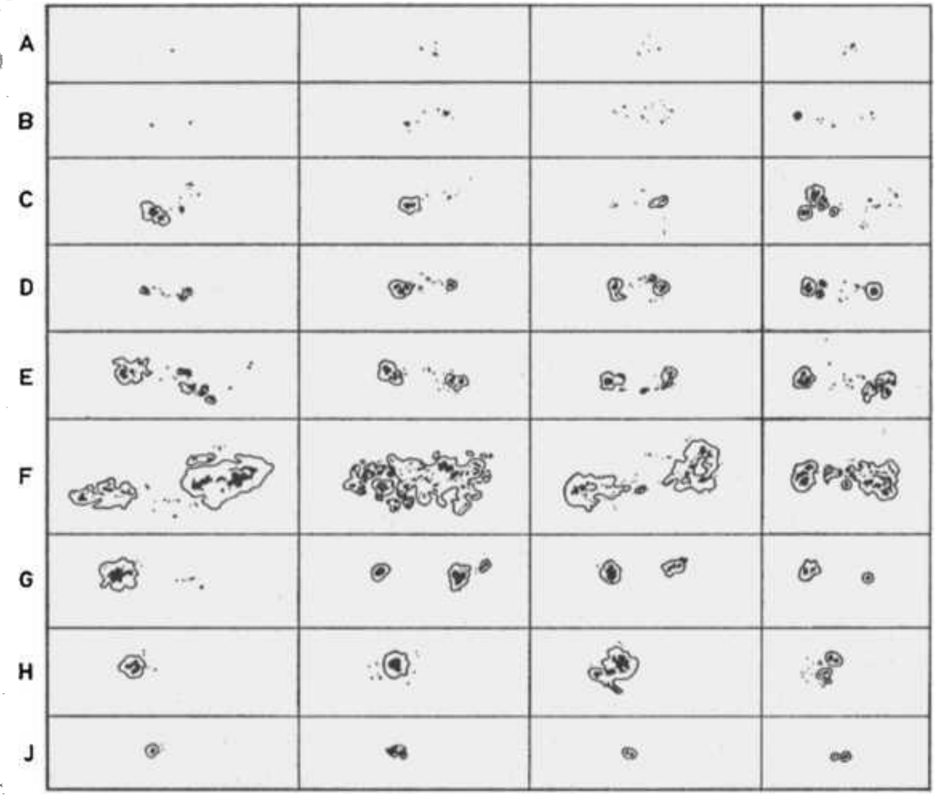
Achromatic telescopes were manufactured in the late 1750s. With such an (expensive) telescope, however, the distinction between umbra and penumbra should have been clear, and the Wilson effect (elongated spots near the limb) should have been visible. Both were not drawn by Staudach (using projection onto a sheet of paper). Arlt (2008; Arlt and Vaquero, 2020), who currently curates the Staudauch drawings, suggests that Staudach missed all the tiny A and B spot groups (according to the Waldmeier classification). Such groups make up 30-50% of all groups seen today.

Haase (1869) also reviewed the Staudach material and reports that a 4-foot telescope was used, but that it was not of particular good quality and especially seemed not to have been achromatic, because he quotes Staudach himself remarking on his observation of the Venus transit in 1761 that "for the size and color of the planet there was no sharp edge, instead it faded from the same black-brown color as the inner core to a still dark brown light red, changing into light blue, then into bright green and then to yellow".

So we assume that the telescope suffered from spherical (single lens) and chromatic aberration.

The Waldmeier Classification



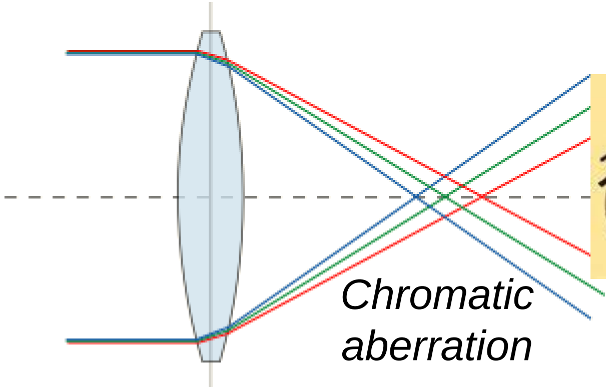


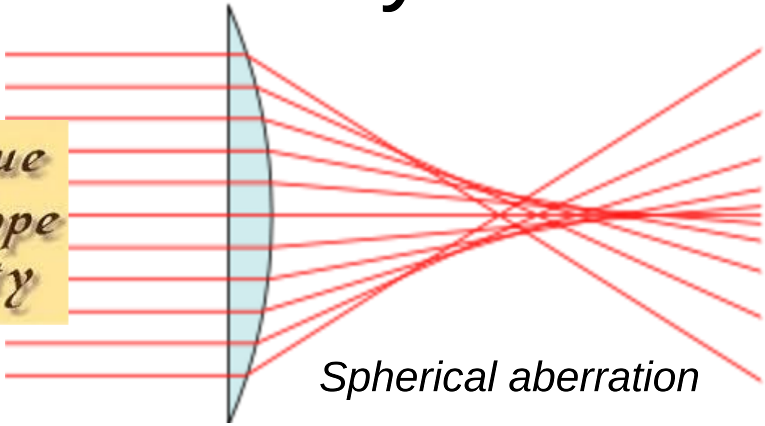
18th Century telescopes could not show the tiny A and B groups, nor the fine structure of large groups

The Project

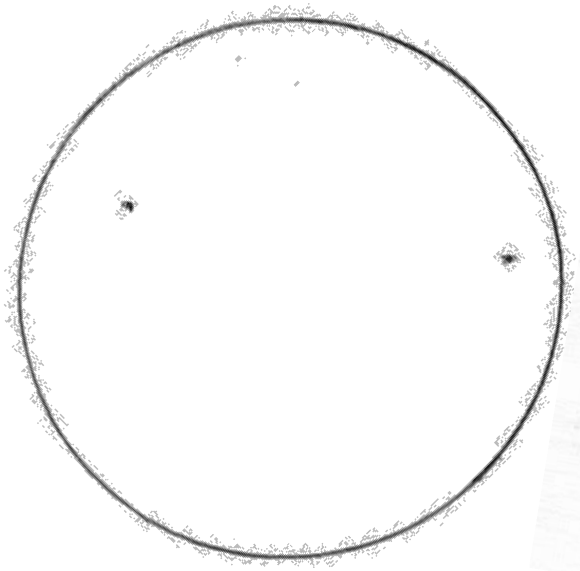
- Motivation: Is the apparent secular increase of solar activity real or an artifact?
- Find telescopes (from the 18th century or build replicas) with similar characteristics (flaws) as Staudach's
- Find people willing to observe, i.e. make drawings of what they see (high precision of positions not needed)
- Make systematic observations over some time (many months, years) perhaps at least one drawing per week, better daily
- If we can find several people, they can share the load (and also make it possible to assess the 'error bar')
- Scan the drawings and communicate them to me (leif@leif.org). Website: https://leif.org/research
- I'll process the drawings and produce a scientific paper with the observers as co-authors publishing the result
- Benefits: Exposure of ATS (Antique Telescope Society) and providing an important calibration point for the Sunspot Series (real science)
- First observation 14 January, 2016

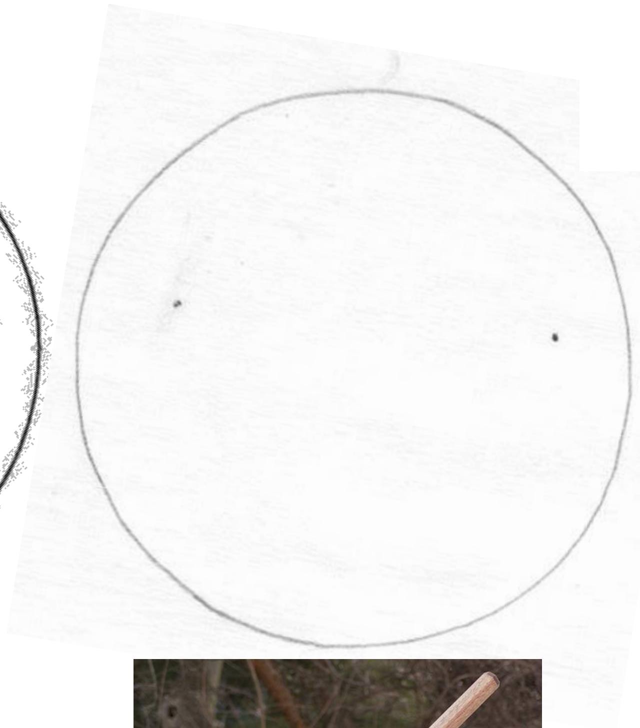
Construct Telescopes with the Same Flaws as Typical 18th Century Ones

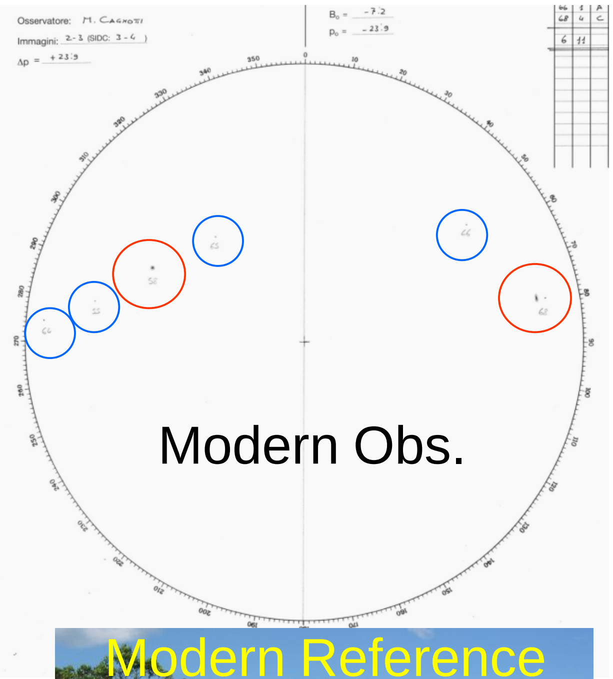


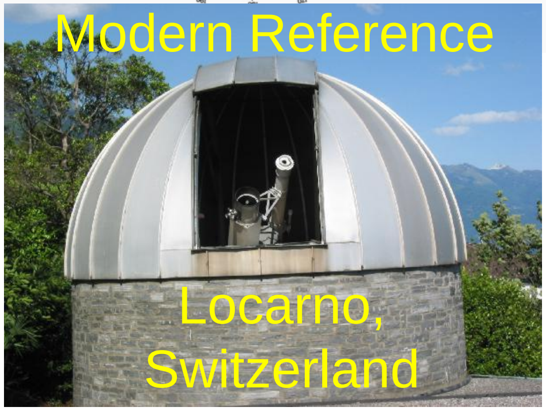


Sunspots 2016-03-11

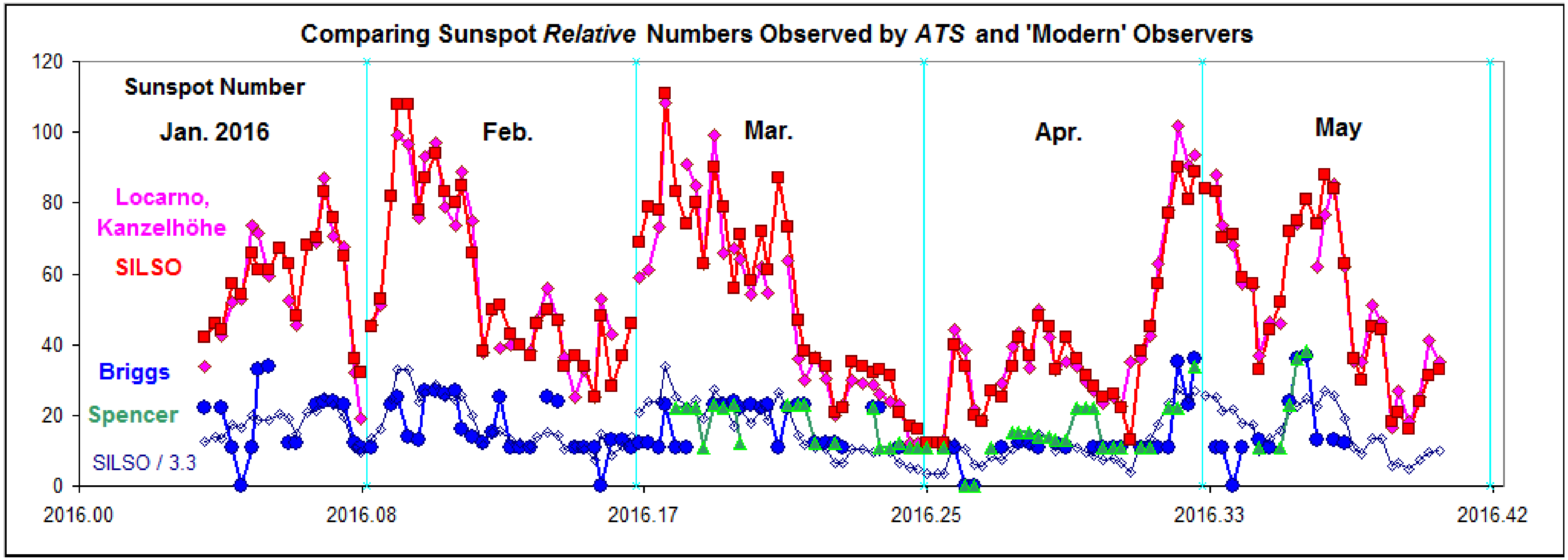


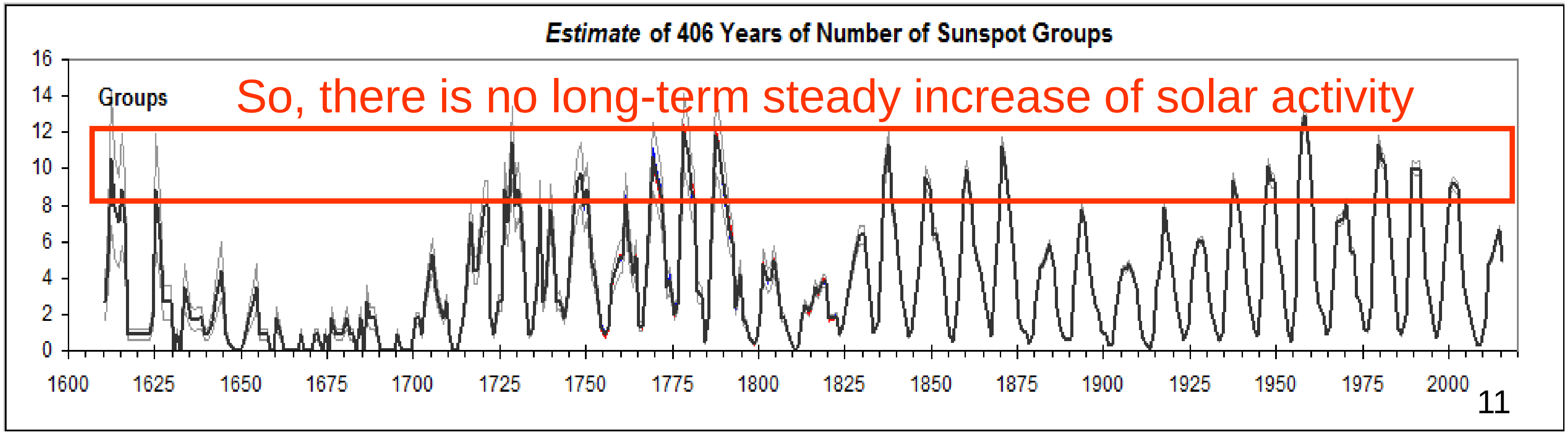




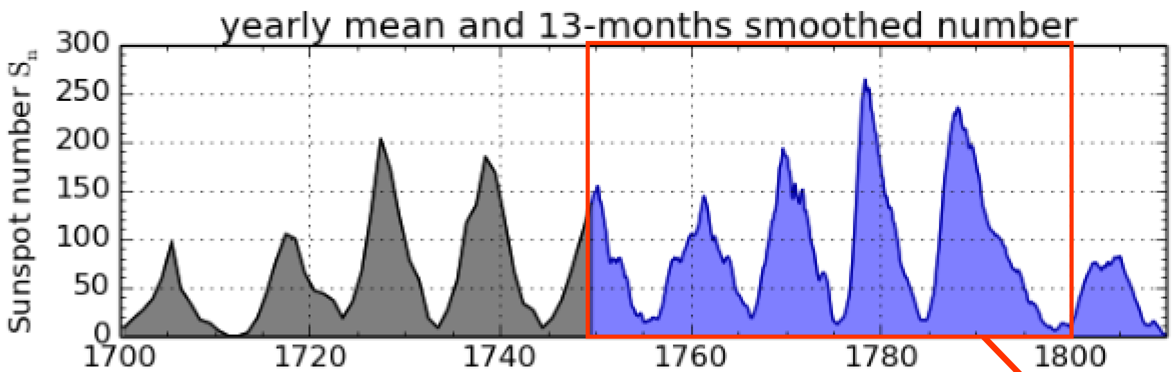


Modern Observers See Three Times as Many Spots as The Old Telescopes Show

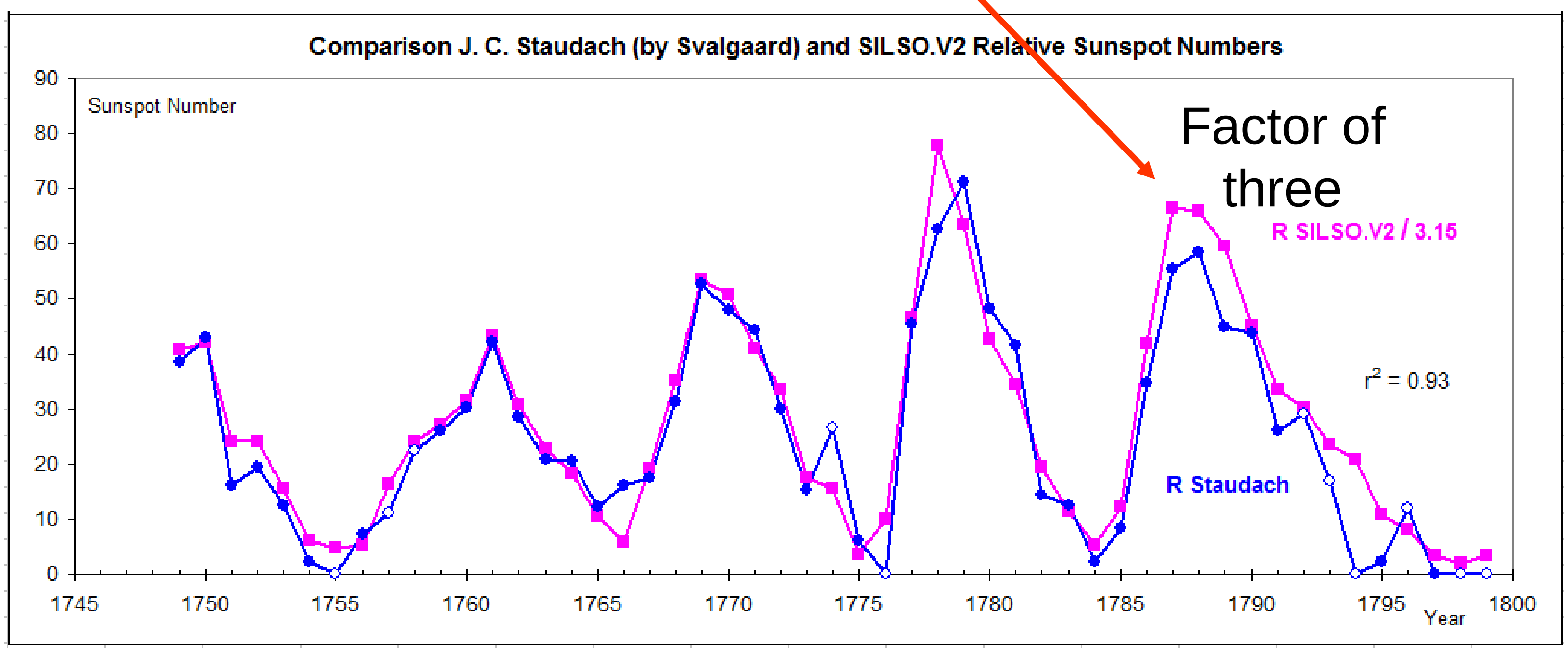




Our Project has Confirmed the ‘New Sunspot Number Series’



A recent revision (Clette et al. 2014) of the Sunspot Number is nicely validated by our observations

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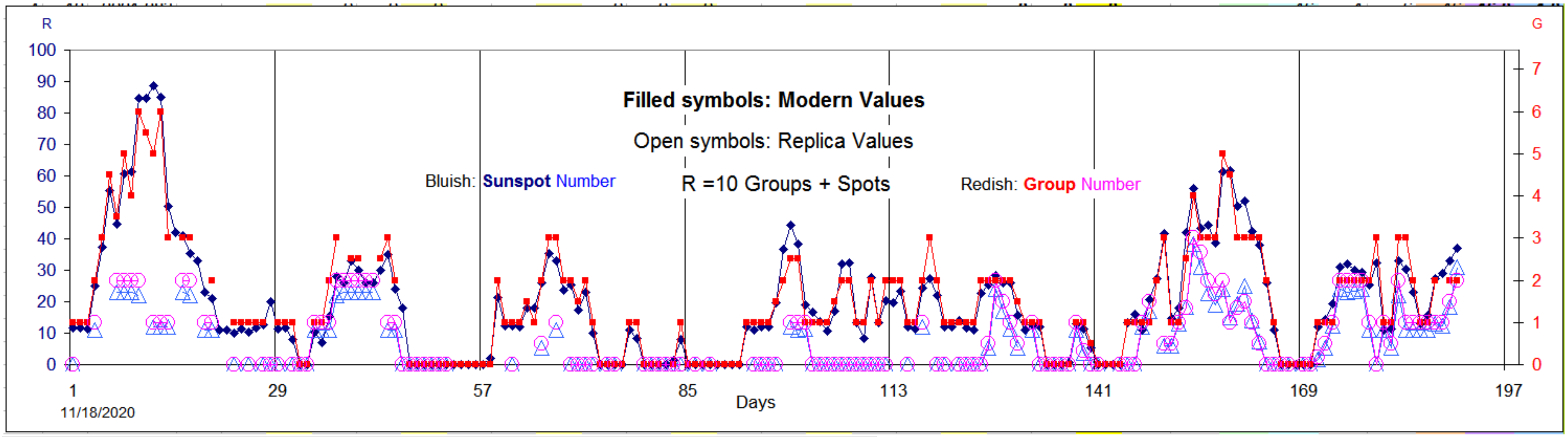
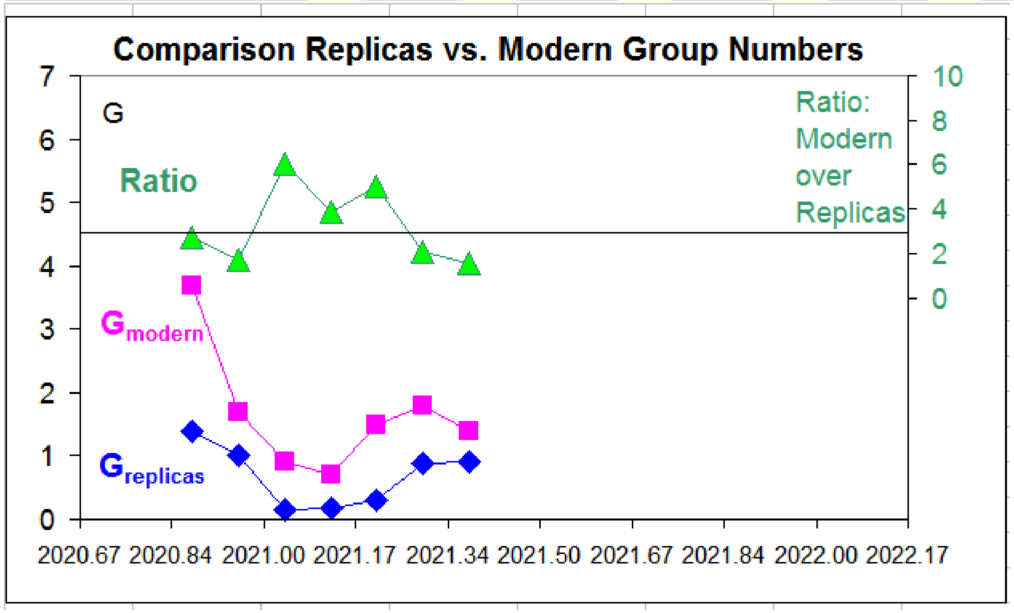
Nicolàs de Hilster,
Castricum, Nederland

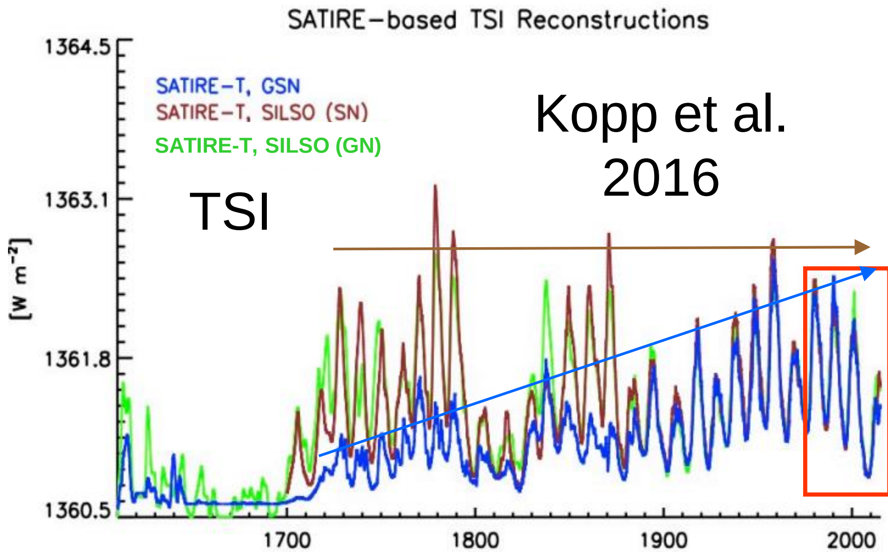
Results from Cycle 25

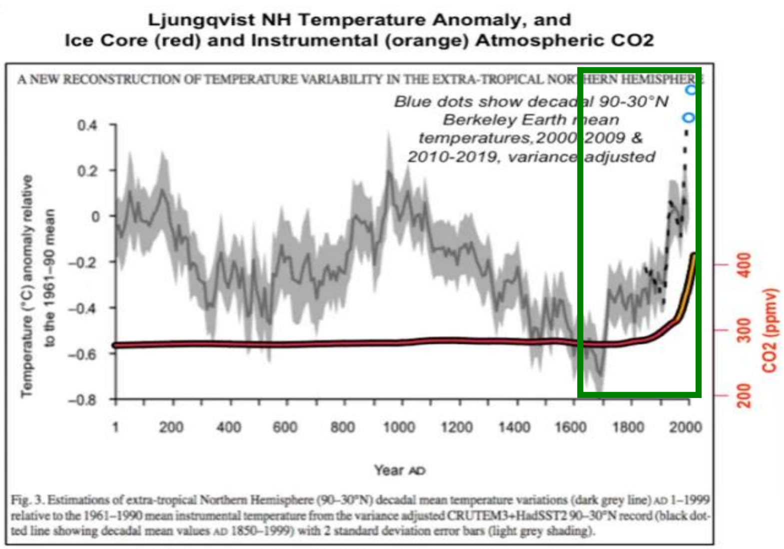




Continuing the observations (now with six observers) basically confirms the findings from Cycle 24.

It will be interesting to see what the result will be at the coming solar maximum (we have not yet observed at a maximum)





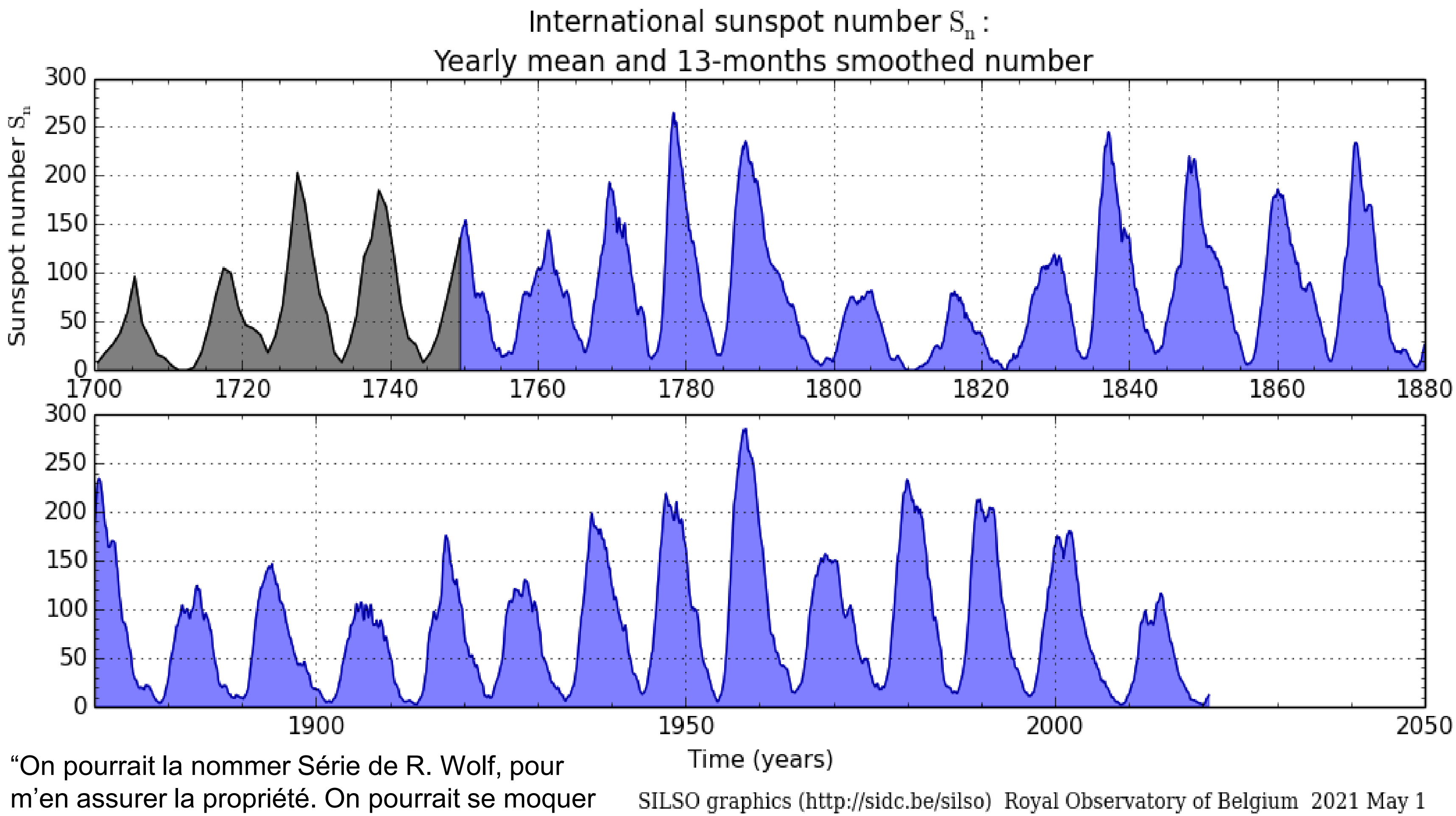
DATA:https://sci-hub.se/10.1111/j.1468-0459.2010.00399.x

The climate record does not follow the revised sunspot records nor the CO_2

Why Is This Important?

1. The Total Solar Irradiance (output of heat) in the past before satellite measurements is reconstructed from the sunspot numbers and is used as input to climate models
2. Predictions of future solar activity, damaging solar storms, and our general understanding of the sun rely on knowledge about its past behavior
3. Influence on Climate also rely on correct sunspot records

But how do we know that the Wolf Number is even correct?

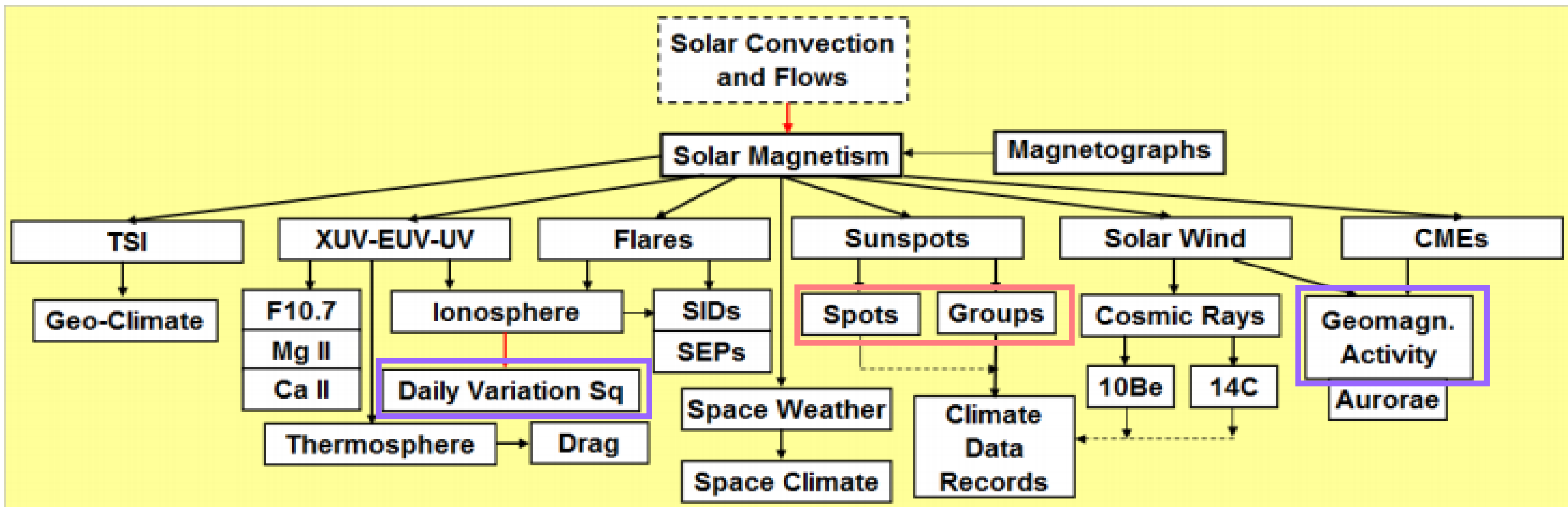


“On pourrait la nommer Série de R. Wolf, pour m’en assurer la propriété. On pourrait se moquer de cette prétention; mais puisqu’il existe des auteurs sans conscience on est forcé de défendre sa propriété”, Wolf (1877))

Because Wolf had discovered something truly marvelous

Sunspots are but one manifestation of the Complicated Physics of a ‘Great System’

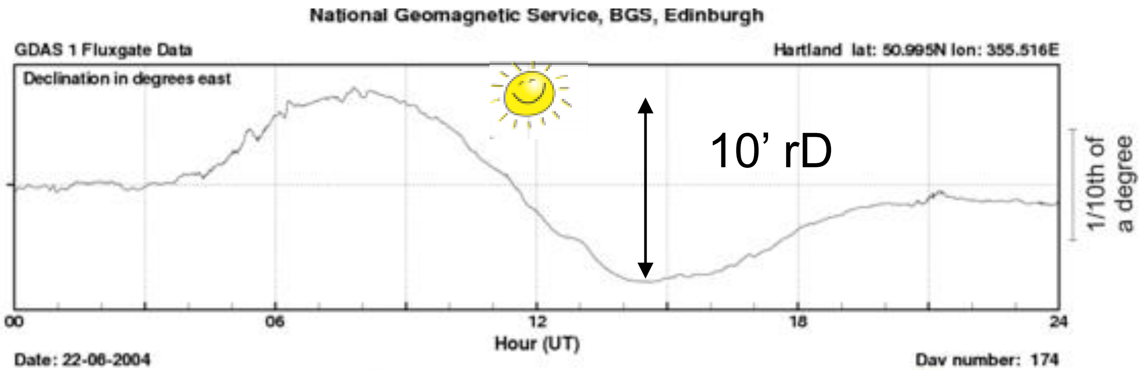
A Systems Approach: Everything Must Fit

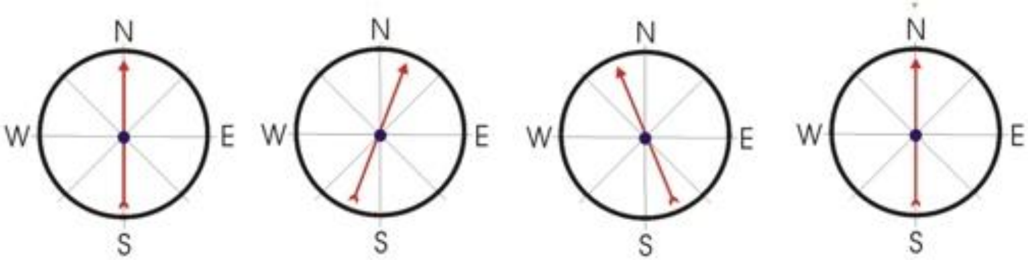


Faraday wrote to R. Wolf on 27th August, 1852: “I am greatly obliged and delighted by your kindness in speaking to me of your most remarkable enquiry, regarding the **relation existing between the condition of the Sun and the condition of the Earths magnetism**. The discovery of periods and the observation of their accordance in different parts of **the great system, of which we make a portion**, seem to be one of the most promising methods of touching the great subject of terrestrial magnetism...

“Wer hätte noch vor wenigen Jahren an die Möglichkeit gedact, aus den Sonnenfleckenbeobachtungen ein terrestrisches Phänomen zu berechnen”

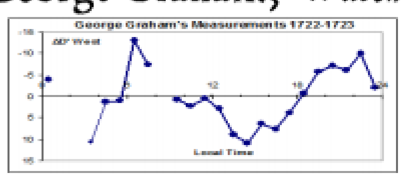
The Diurnal Variation of the Direction of the Magnetic Needle





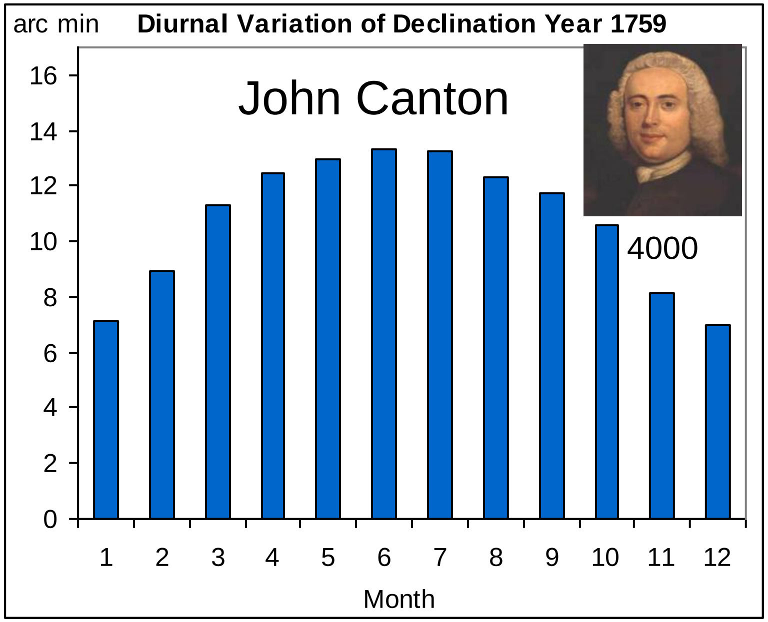
IV. *An Account of Observations made of the Variation of the Horizontal Needle at* London, *in the latter Part of the Year* 1722, *and beginning of* 1723. *By Mr.* George Graham, *Watch-maker, F. R. S.*

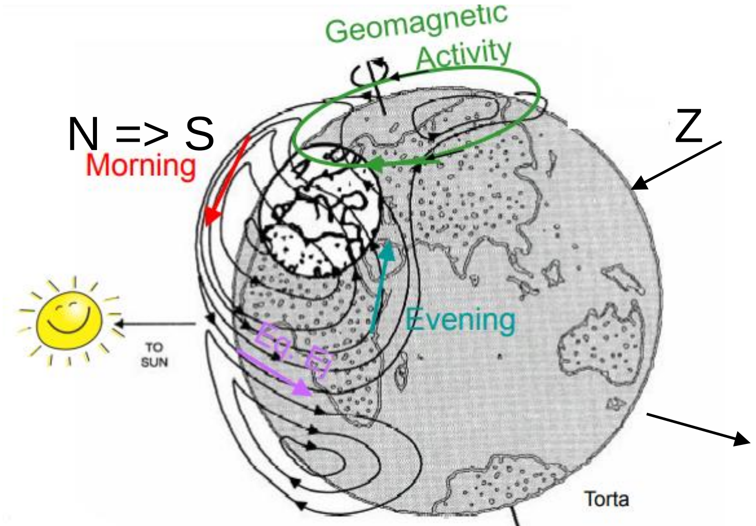
Made ~1000 observations



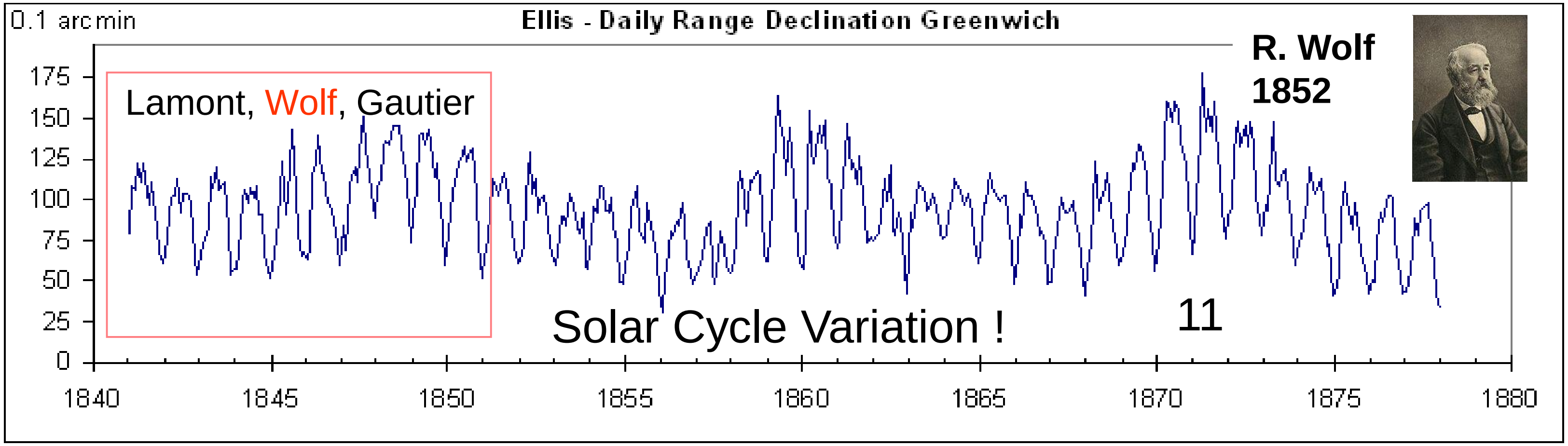
George Graham [London] discovered [1722] that the geomagnetic field varied during the day in a regular manner.

Zenith Angle Dependence Discovered

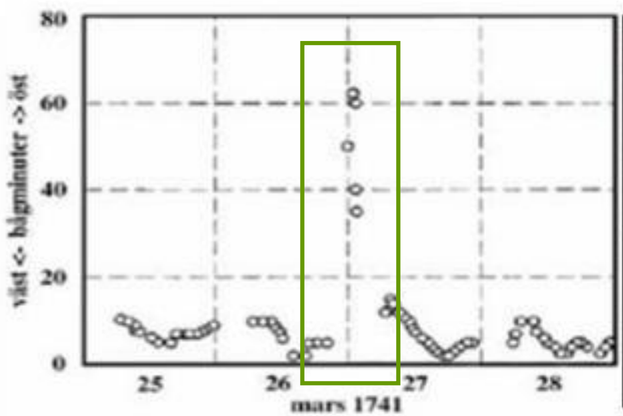


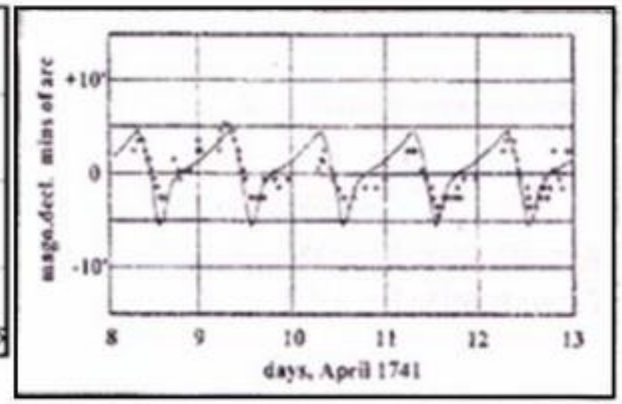


A current system in the ionosphere is created and maintained by solar EUV radiation



Observations in the 1740s





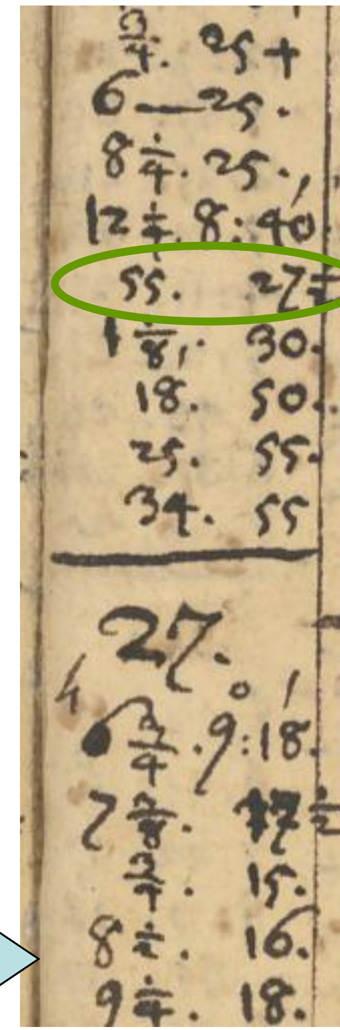
Right: Hjorter's measurements of the magnetic declination at Uppsala during April 8-12, 1741 (old style). The curve shows the average variation of the magnetic declination during April 1997 at nearby Lovö (Sweden).

Left: Variation during strong Northern Light on March 27th. Also observed by Graham in London, showing that the aurorae and magnetic field are connected on a large scale and not just local meteorological phenomena.

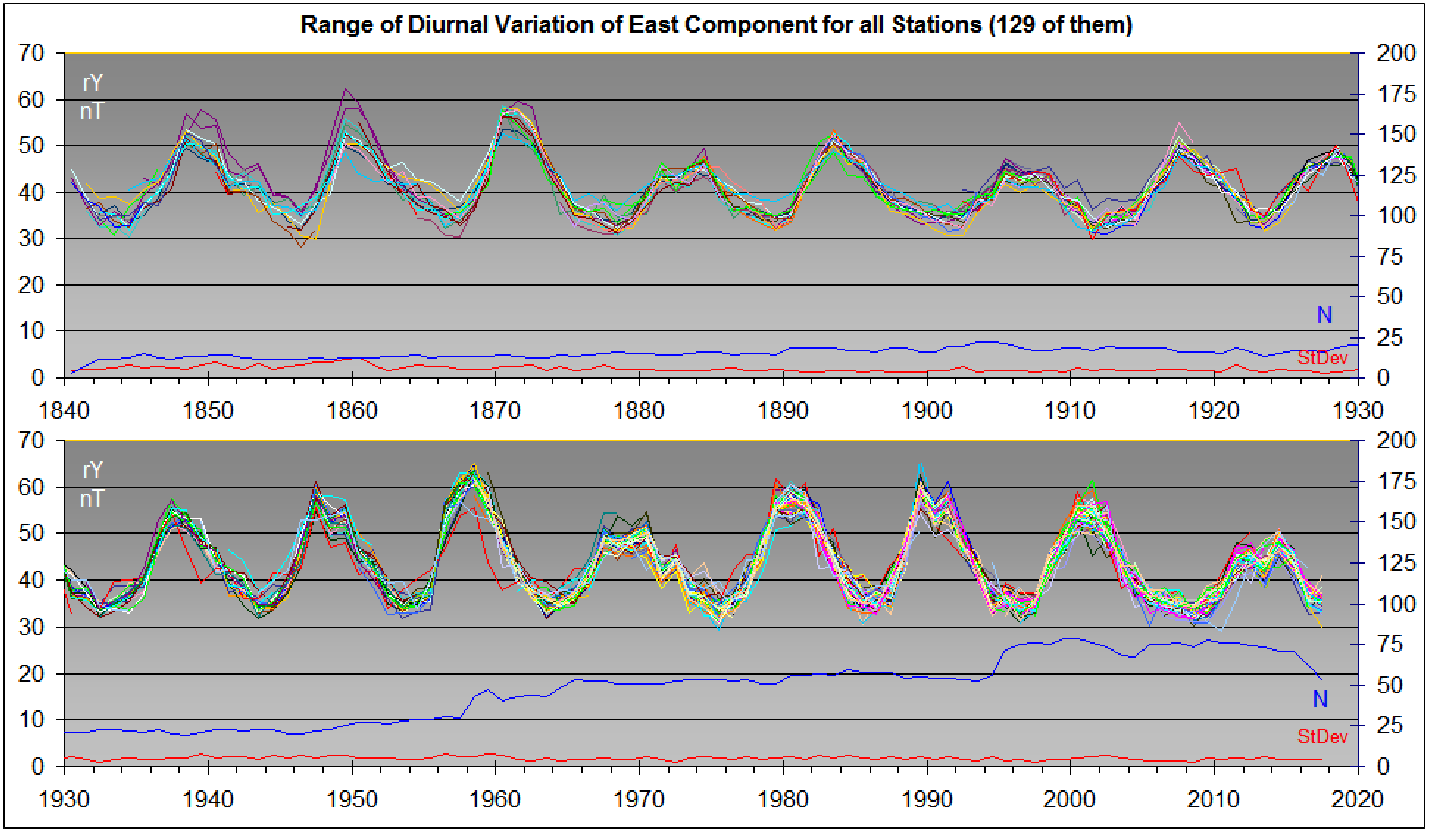
Note there are really two phenomena going on, regular daily variation and sporadic, large aurora-related excursions…

This is from Hjorter's original notebook for that day. Observations were made with an instrument (compass) made by Graham.

Olof Petrus Hjorter was married to Anders Celsius' sister and made more than 10,000 observations of the magnetic declination in the 1740s.



Normalized Observed Diurnal Ranges of the Geomagnetic East Component since 1840



We plot the yearly average range to remove the effect of changing solar zenith angle through the seasons. A slight normalization for latitude and underground conductivity has been performed. Data used comprise 48 million hourly values.

The Observational **Facts** are Not New

THE AMERICAN JOURNAL OF SCIENCE AND ARTS. Second Series

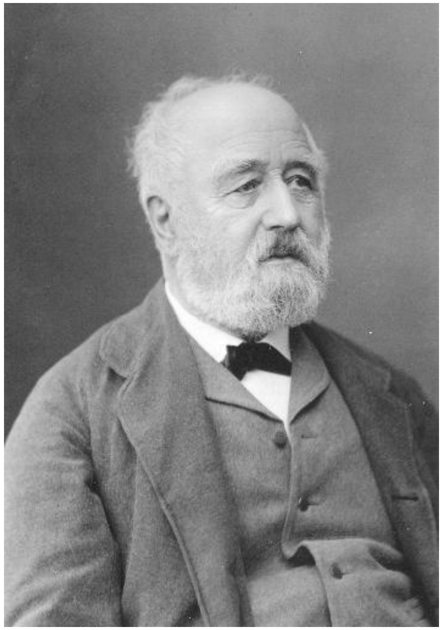
ART. XVI.-Comparison of the mean daily range of the Magnetic Declination, with the number of Auroras observed each year, and the extent of the black Spots on the surface of the Sun, by ELIAS LOOMIS, Professor of Natural Philosophy in Yale College. Vol. L, No.149. Sept.1870, pg 160.

This comparison seems to warrant the following propositions:

1. A diurnal inequality of the magnetic declination, amounting at Prague to about six minutes, is independent of the changes in the sun's surface from year to year.

2. The excess of the diurnal inequality above six minutes as observed at Prague, is almost exactly proportional to the amount of spotted surface upon the sun, and may therefore be inferred to be produced by this disturbance of the sun's surface, or both disturbances may be ascribed to a common cause.

19th century 'Inequality' = deviation from [i.e. 'not equal to'] the mean

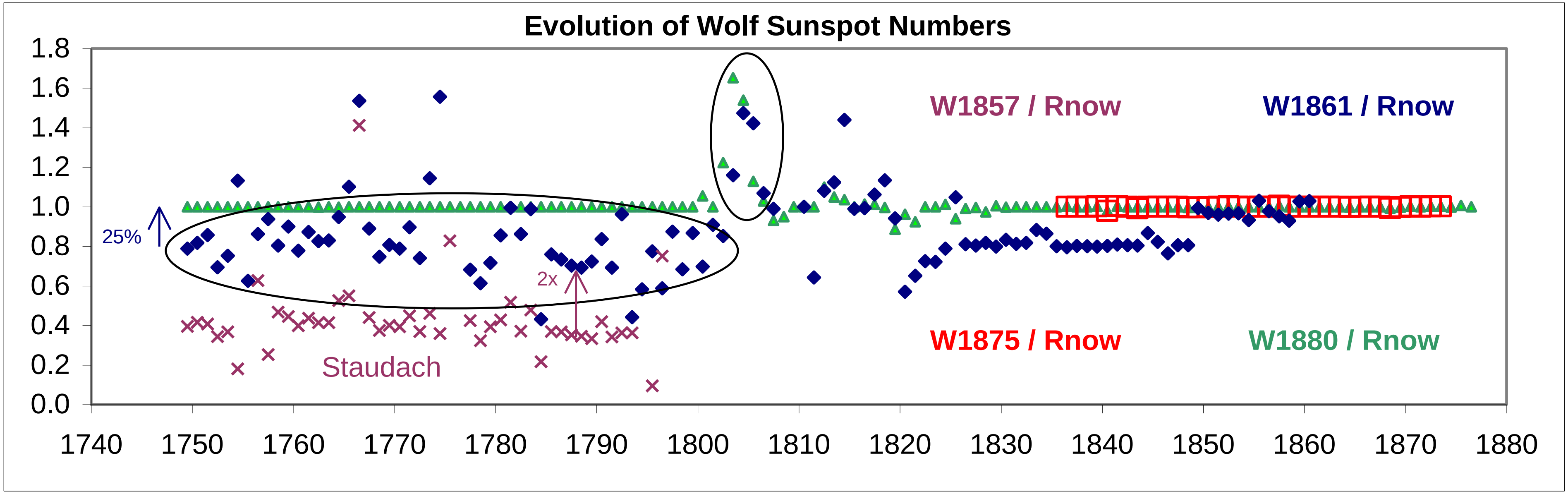


Rudolf Wolf

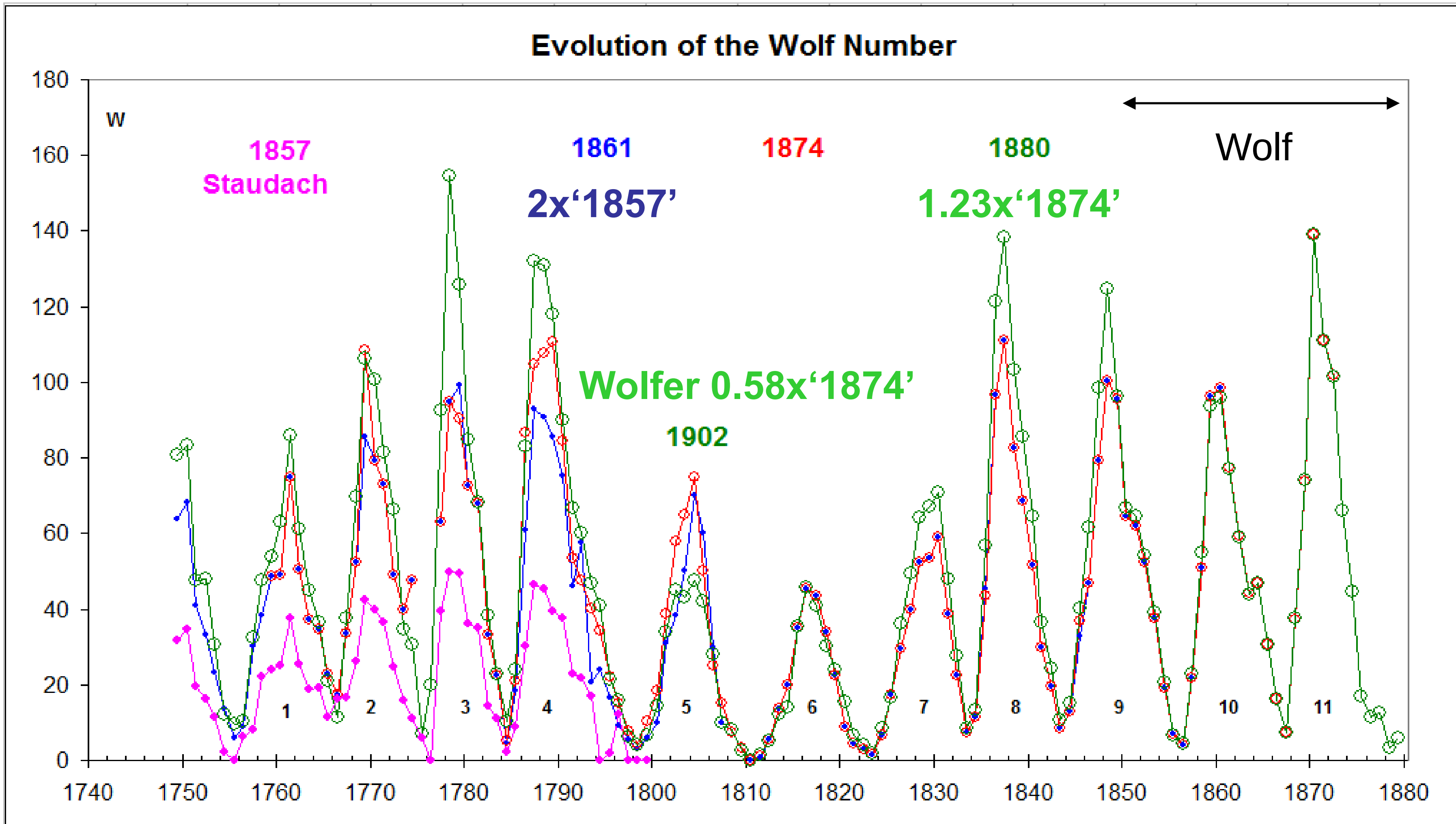
Wolf (1875) seemingly used the SSN-daily range relationship to check the SSN calibration for years before 1848

$$\boxed{rD = a + b\,R_z}$$

So, the sunspot series were already from its beginning a 'living' dataset, constantly being recalibrated as new data and/or insights became available



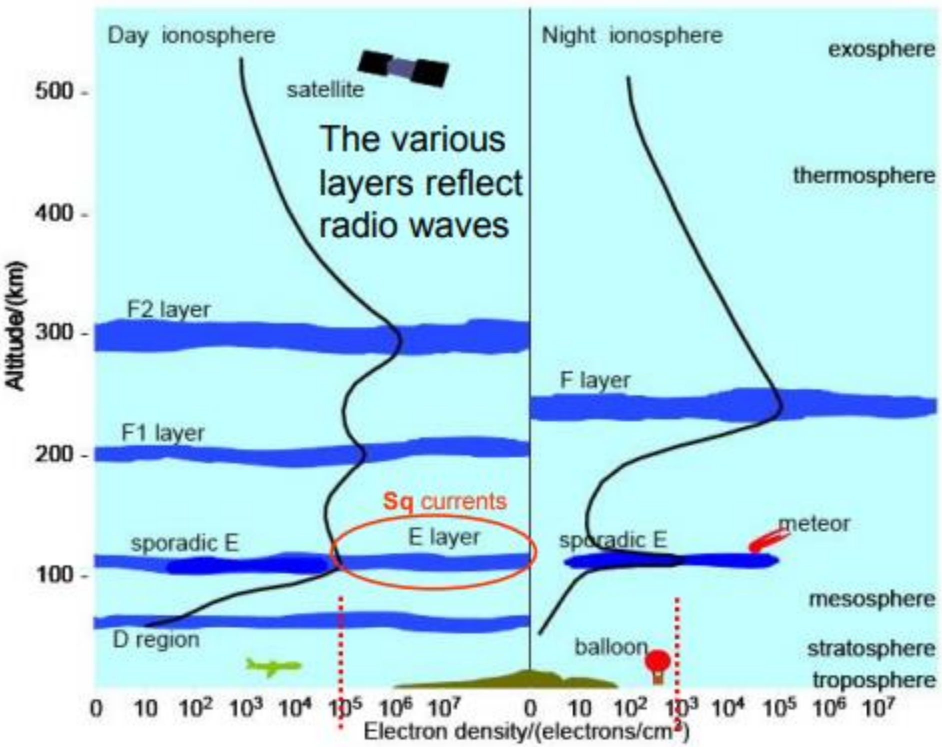
Major Adjustments to Wolf Number



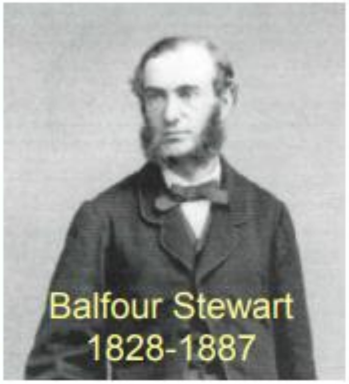
Wolf published several versions of his series over time, but did not modify his raw data

The Physics of the Daily Variation

Ionospheric Conducting Layers



Winds moving the charges across the magnetic field creates a dynamo current, whose magnetic effect we can observe at the surface as Graham discovered



1882, Encyclopedia Britannica, 9th Ed.:

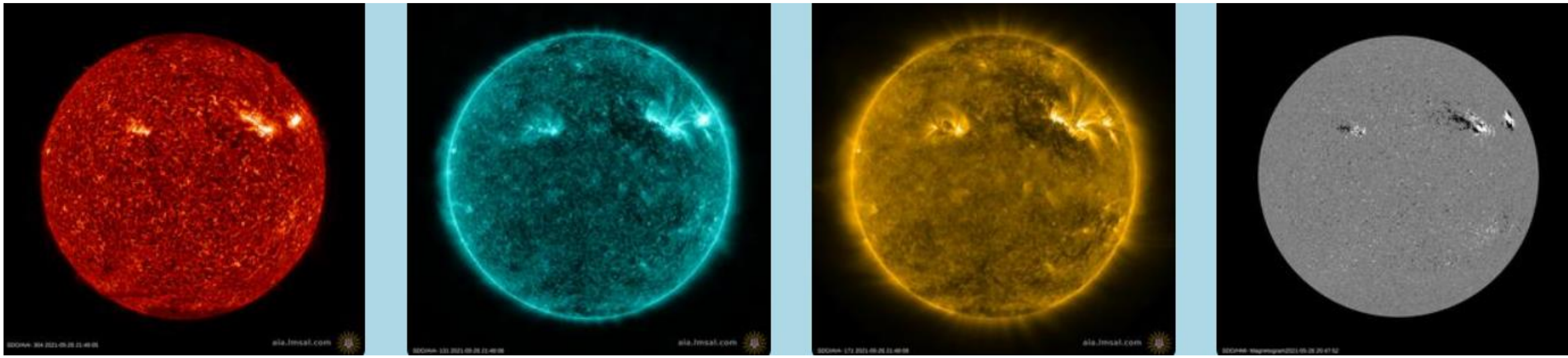
"there seems to be grounds for imagining that their **conductivity may be much greater than has hitherto been supposed**."

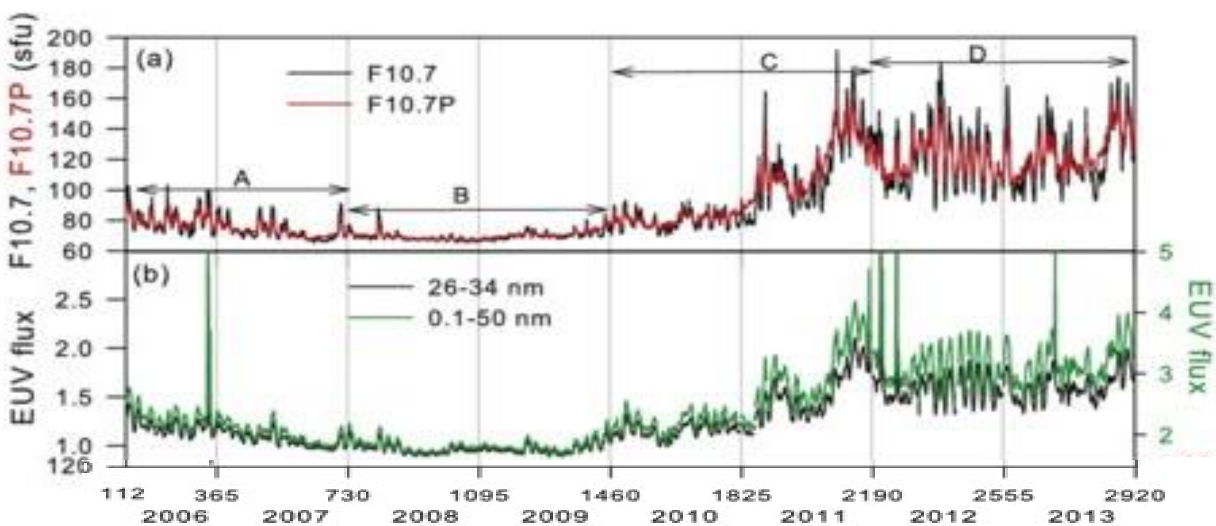
But why?

Dynamo

An effective dynamo process takes place in the dayside E-layer where the density, both of the neutral atmosphere and of the electrons are high enough.

Extreme Ultraviolet from the Sun





Measuring the Microwave Flux

The microwave flux at λ10.7 cm is a proxy for EUV

Electron Density due to EUV

< 102.7 nm

$$O_2 + h\nu \xrightarrow{J} O_2^+ + e^-$$

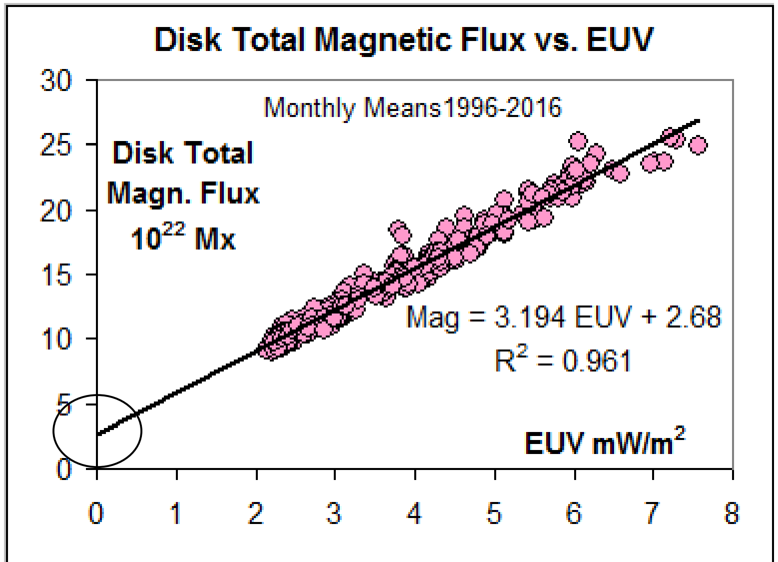
$$O_2^+ + e^- \xrightarrow{\alpha} O + O$$

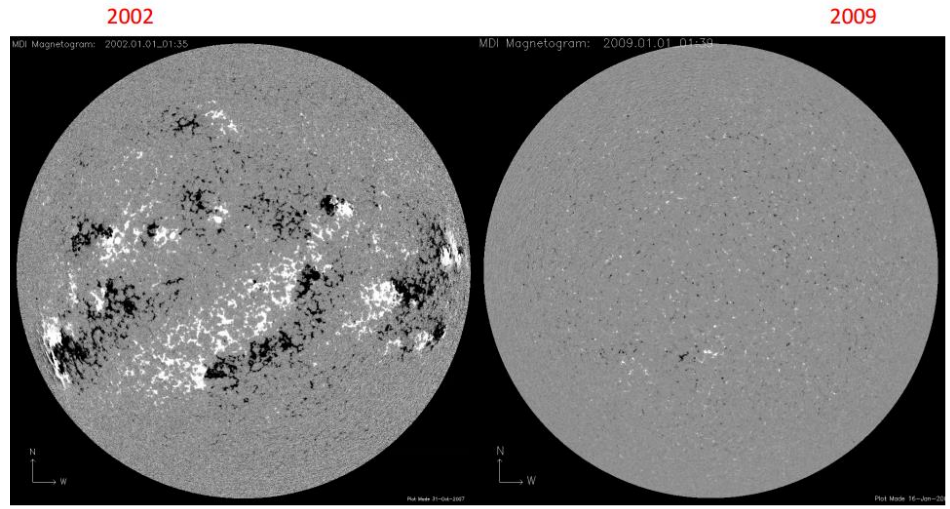
The conductivity at a given height is proportional to the electron number density N_e. In the dynamo region the ionospheric plasma is largely in photochemical equilibrium. The dominant plasma species is $O^+{}_2$, which is produced by photo ionization at a rate J (s^{-1}) and lost through recombination with electrons at a rate α (s^{-1}), producing the Airglow.

The rate of change of the number of ions N_i, dN_i/dt and in the number of electrons N_e, dN_e/dt are given by $dN_i/dt = J \cos(\chi) - \alpha\, N_i\, N_e$ and $dN_e/dt = J \cos(\chi) - \alpha\, N_e\, N_i$. Because the Zenith angle χ changes slowly we have a quasi steady-state, in which there is no net electric charge, so $N_i = N_e = N$. In a steady-state $dN/dt = 0$, so the equations can be written $0 = J \cos(\chi) - \alpha N^2$, and so finally $N = \sqrt{(J\, \alpha^{-1} \cos(\chi))}$

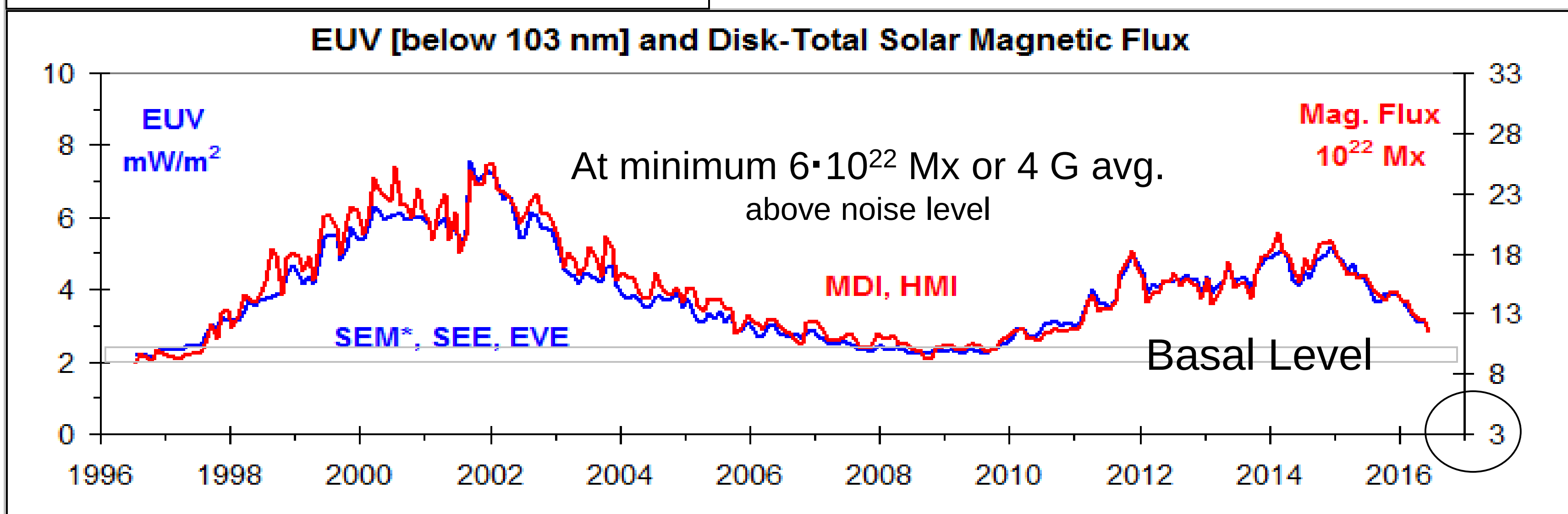
Since the conductivity, Σ, depends on the number of electrons N, we expect that Σ scales with the square root $\sqrt{(J)}$ of the overhead EUV flux with $\lambda < 102.7$ nm.

EUV Follows Total Unsigned Magnetic Flux



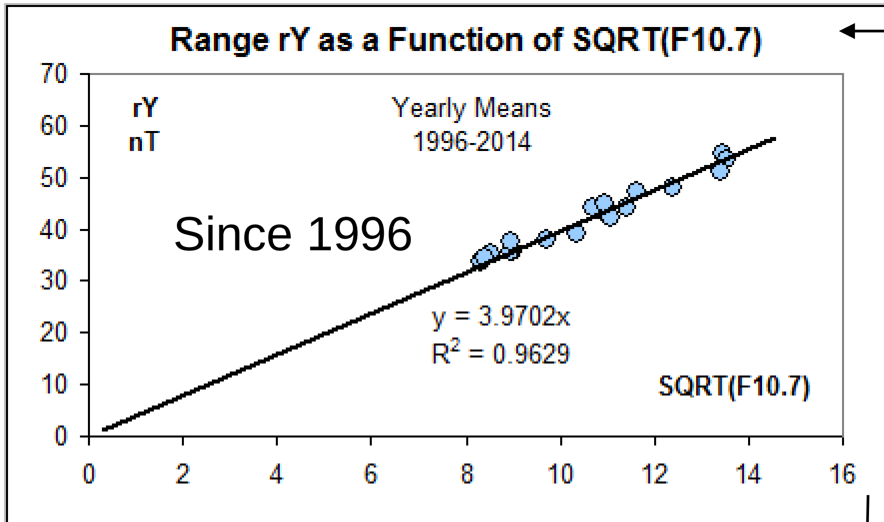


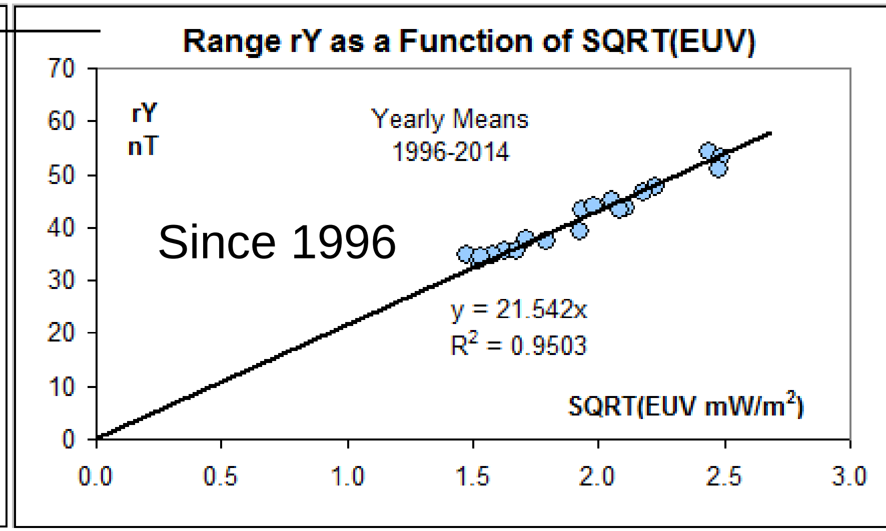
Offset interpreted as Noise Level ≈ 3·10^{22} Mx

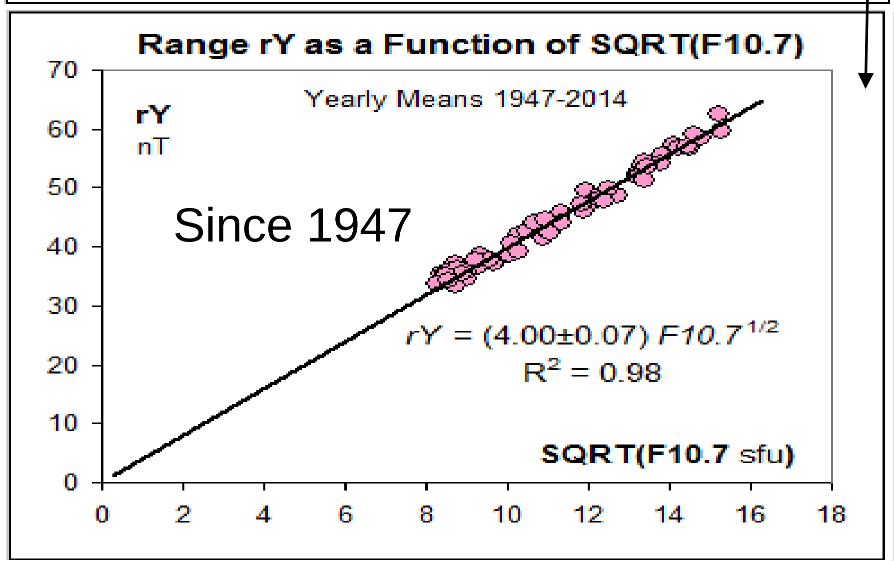


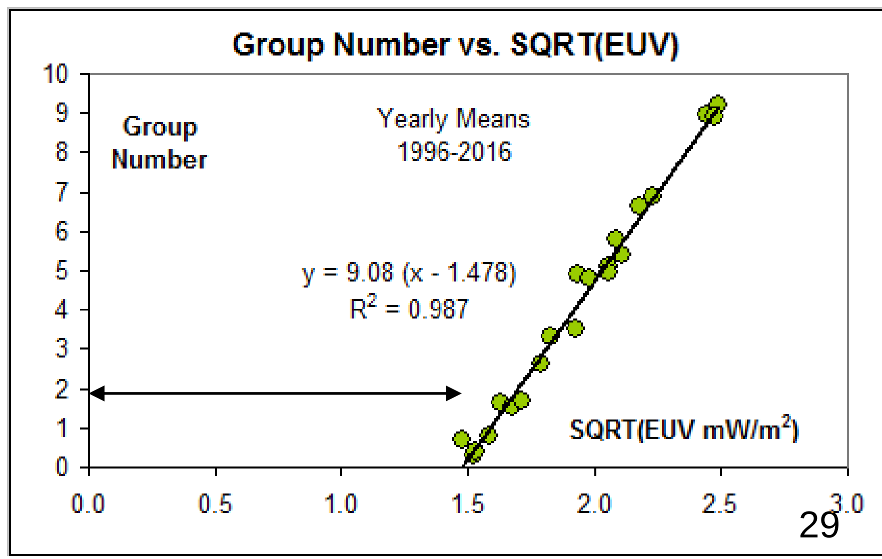
There is a 'basal' level at solar minima. Is this the case at every minimum?

Theory tells us that the conductivity [and thus rY] should vary as the square root of the EUV [and F10.7] flux, and so it does:

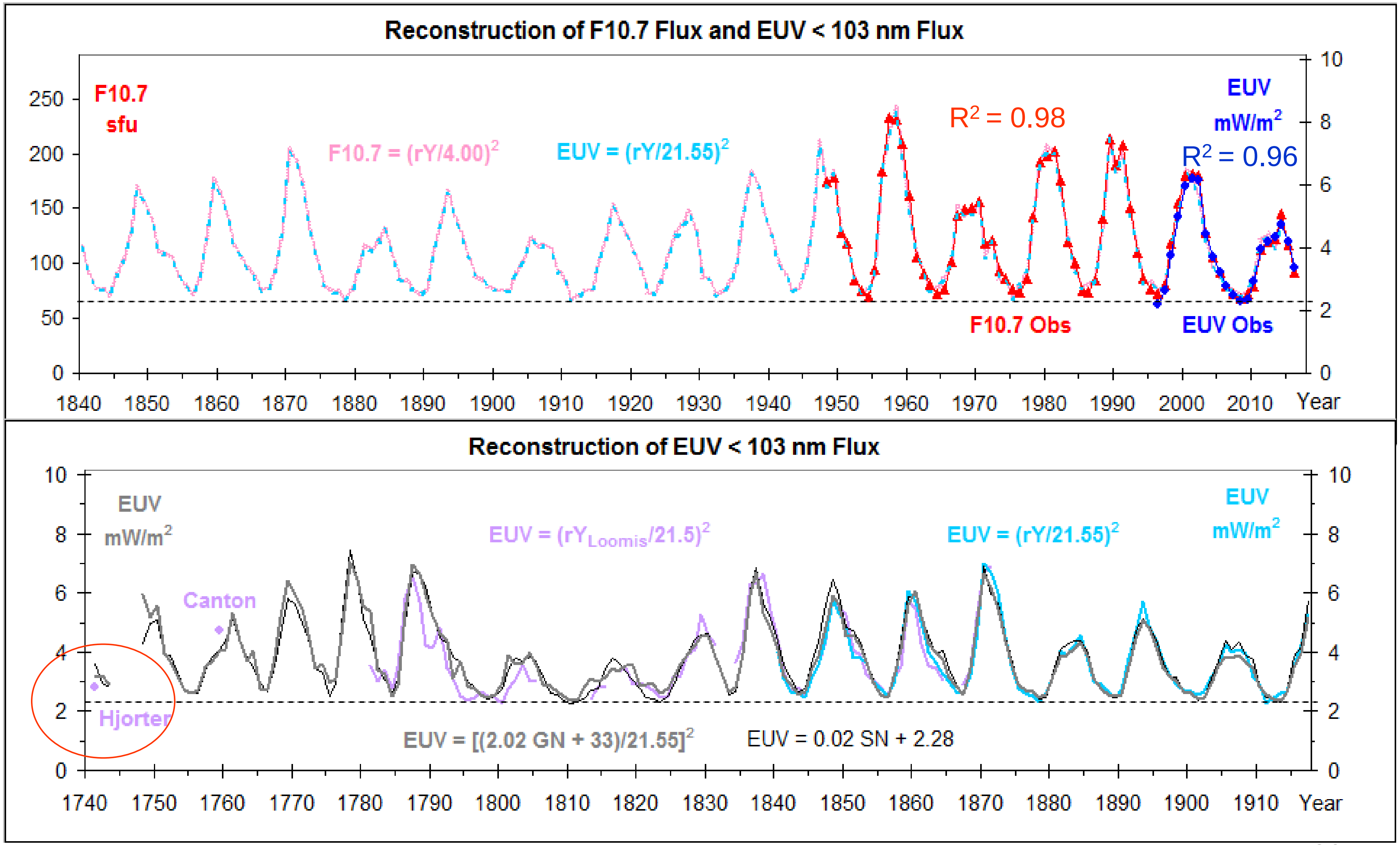


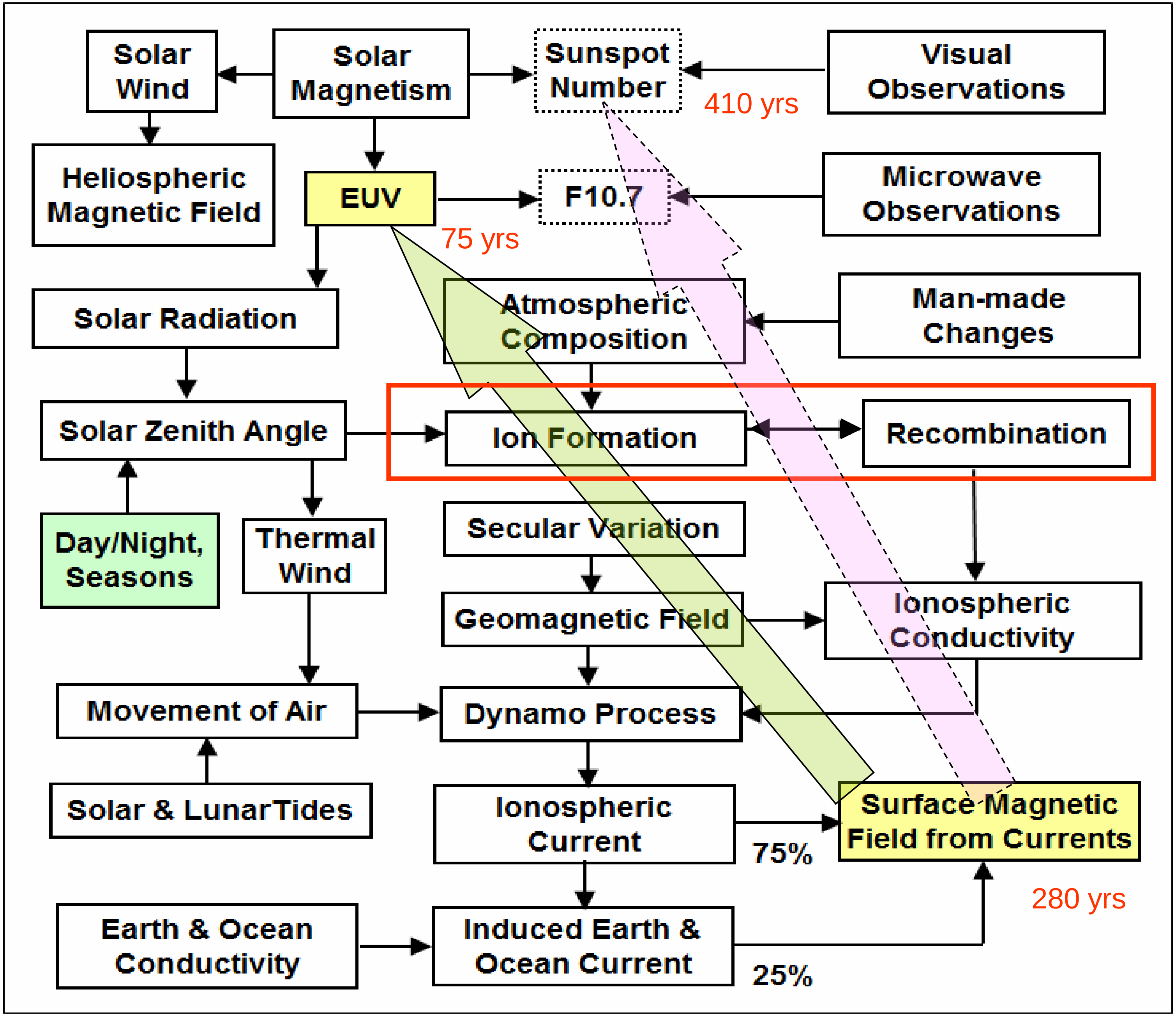






Reconstructions of EUV and F10.7



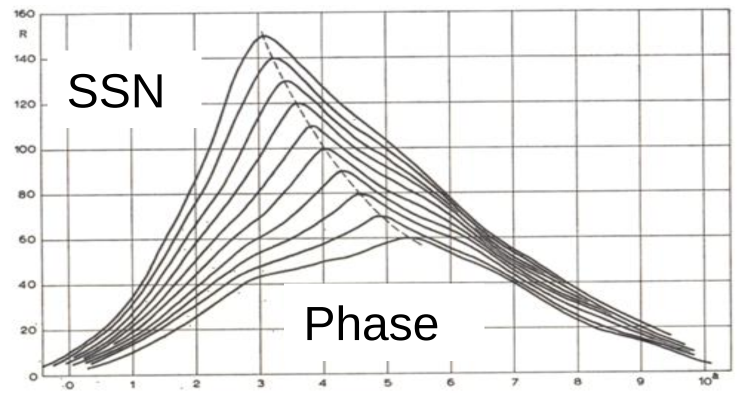


Determining EUV Flux from the magnetic effect of dynamo currents in the E-region of the ionosphere

The physics of the boxes is generally well-known

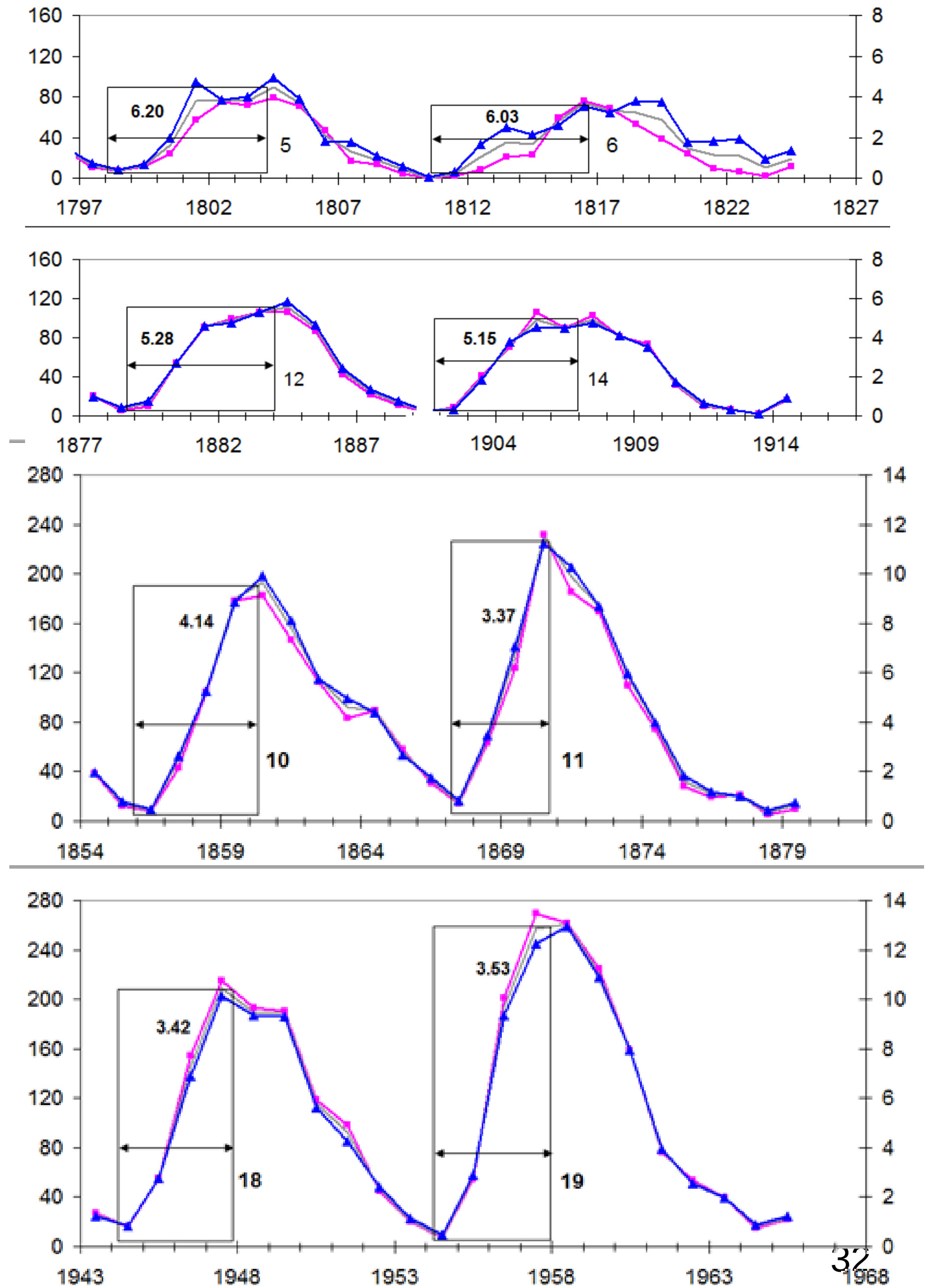
We can determine the EUV from the magnetic effects

The Waldmeier Effect

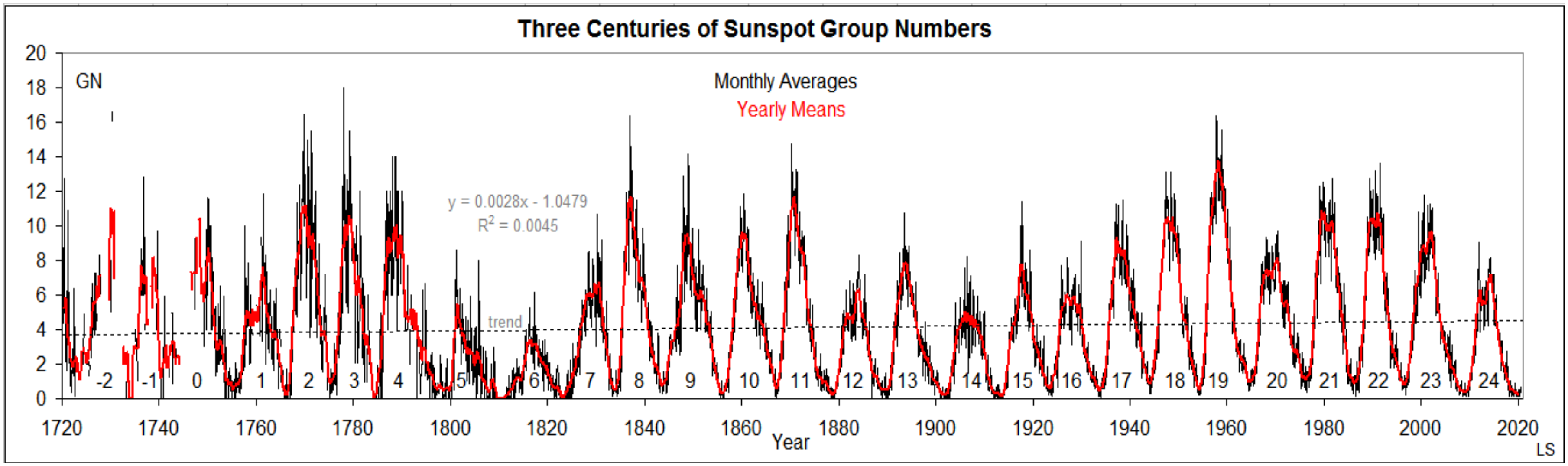


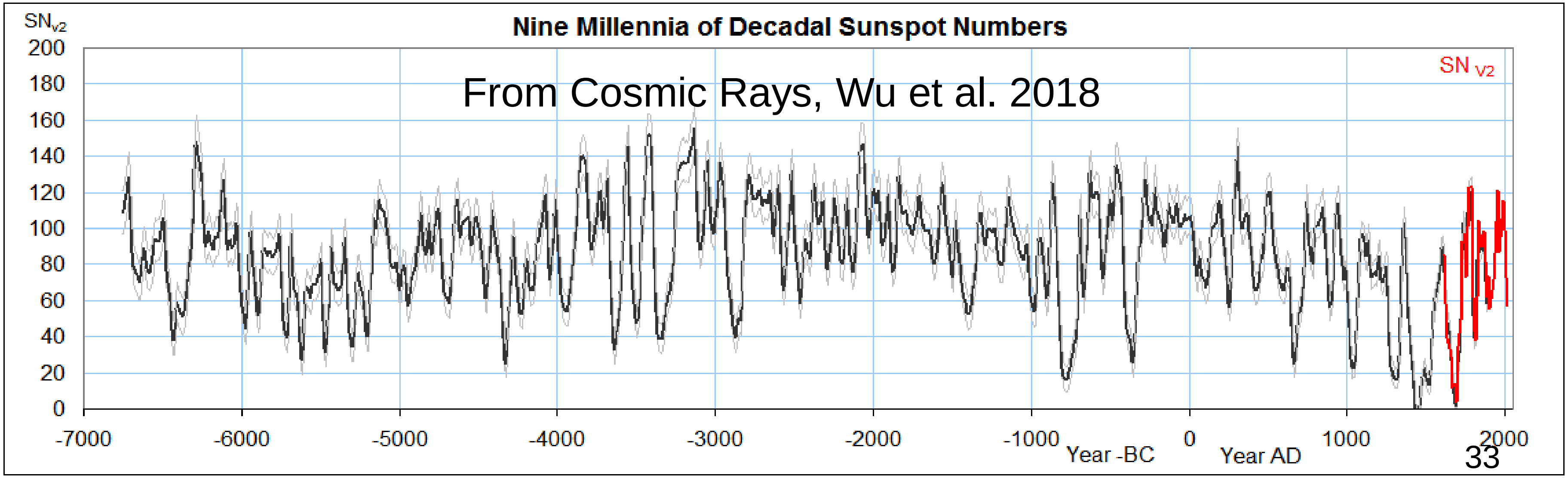
“There is a relationship between the rise time T (in years) from minimum to maximum and the maximum smoothed monthly sunspot number. The times of the extrema can be determined without knowledge of the reduction (or scale) factors. **Since this relationship also holds for the years from 1750 to 1848 we can be assured that the scale value of the relative sunspot number over the last more than 200 years has stayed constant** or has only been subject to insignificant variations.” Waldmeier (1978).

Later cycles have confirmed that the scale has stayed constant more than 270 years



Finally: The Big Picture





Conclusion

Observations with telescopes suffering from the same spherical and chromatic aberrations as we think Staudach’s ‘sky tube’ did, validate the factor of about three that we previously found was needed to normalize the 18th century amateur observations to the modern scale, and hence that there has been no steady increase of solar activity since 1700 AD

The modern sunspot record is validated against several proxies, such as the diurnal variation of the geomagnetic field and others; and is GOOD

So, we have now solved the problem of the difference between the H&S reconstruction and the sunspot number series: the 18th century amateur telescopes were simply not good enough

The end