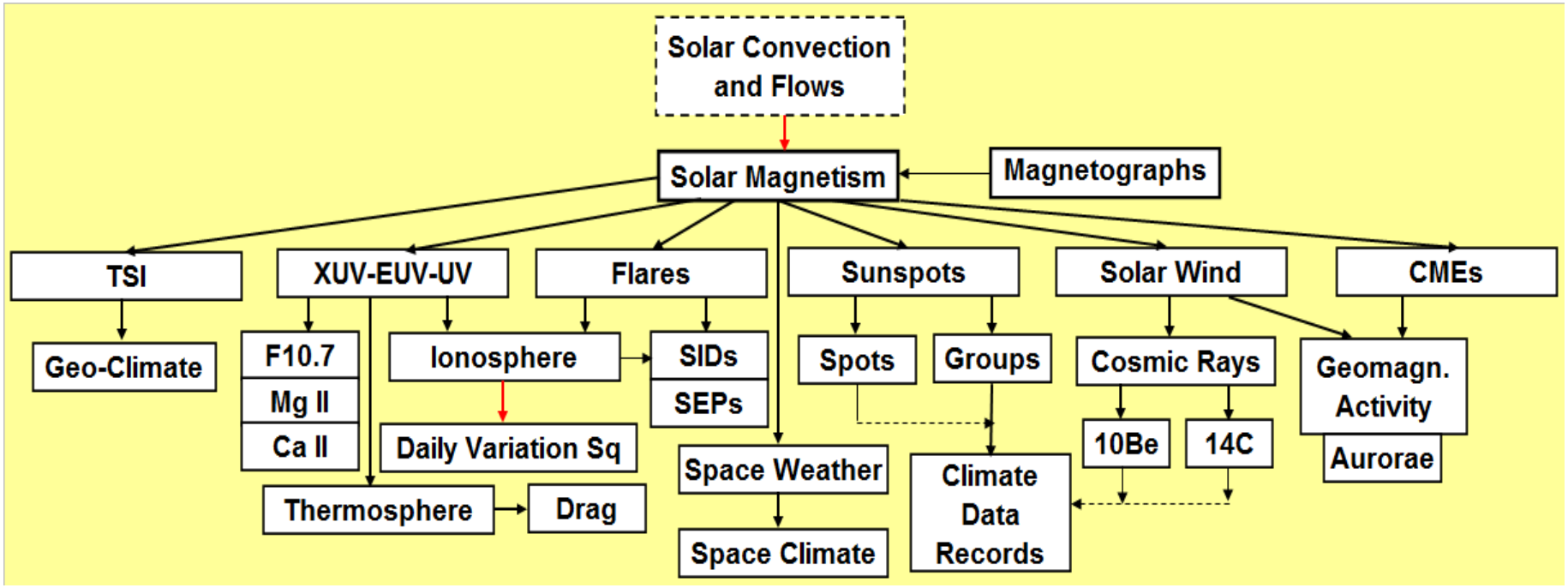
Reconstructions of Solar and Solar Wind Activity for Past Centuries

Leif Svalgaard
Stanford University, USA
with Ken Schatten
a.i.Solutions, USA

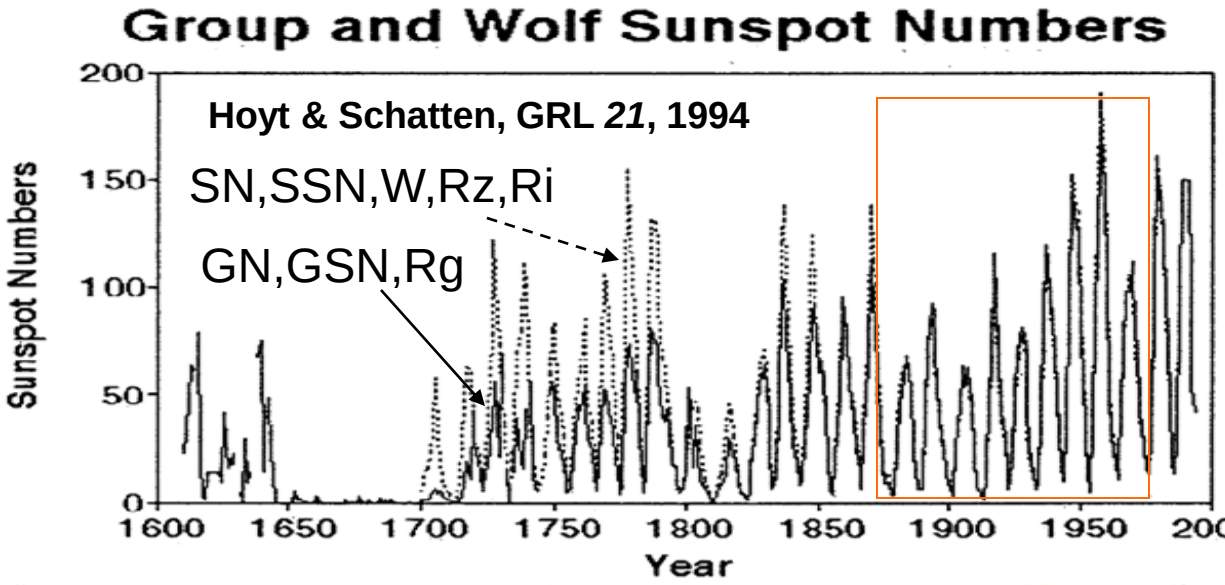
IAGA-2017, Cape Town, ZA
A35-1227, Sept. 1, 2017

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...

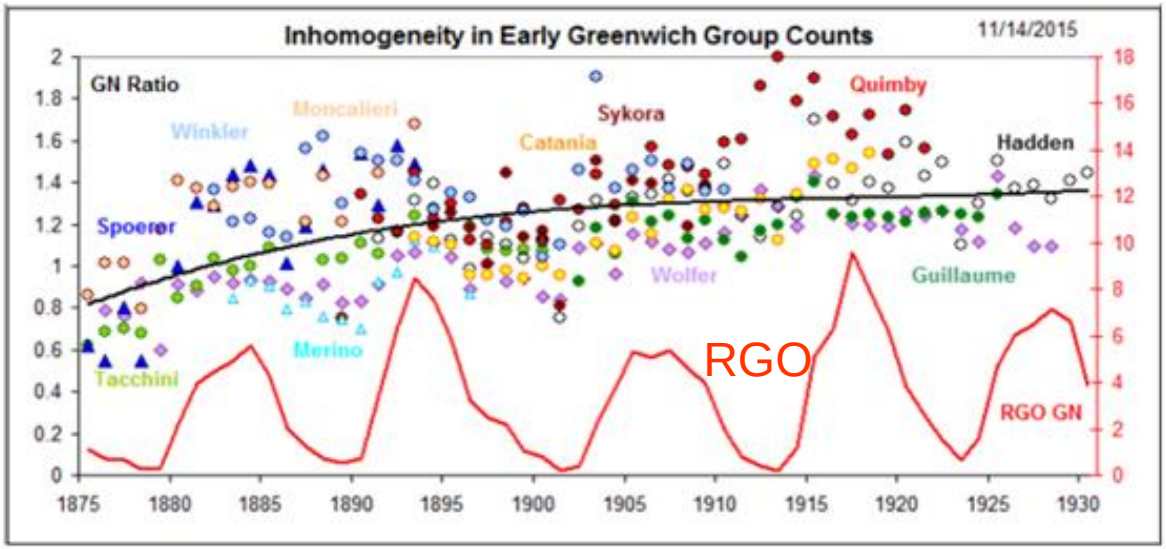
A Misfit: Two Very Different 'Sunspot Series'. Which One to Use?



Original Wolf Number: W_o = Groups + 1/10 Spots

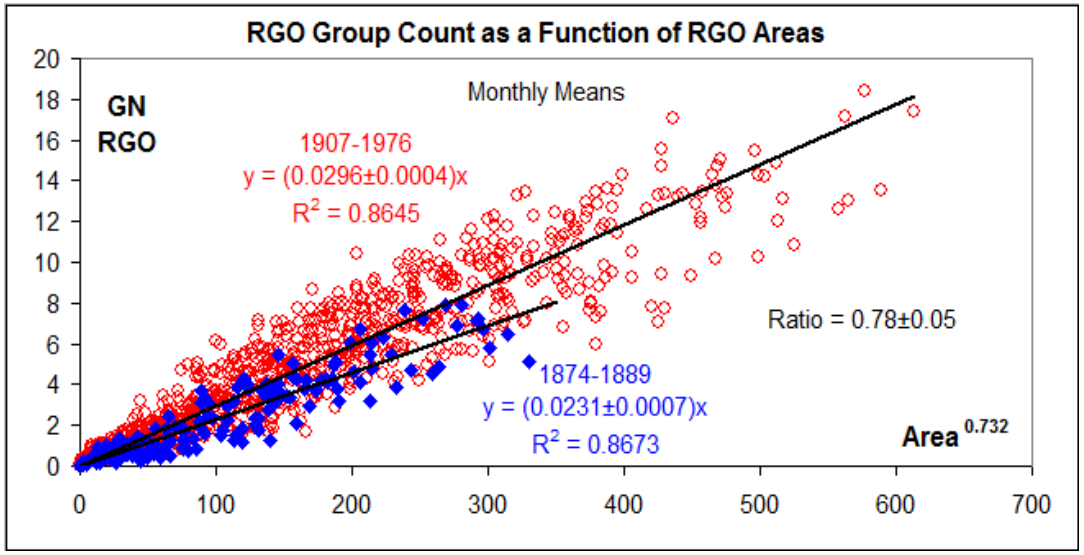
('1/10 Spots' was assumed to be a measure of the area of the group)

Later streamlined to W = k (10 G + S)



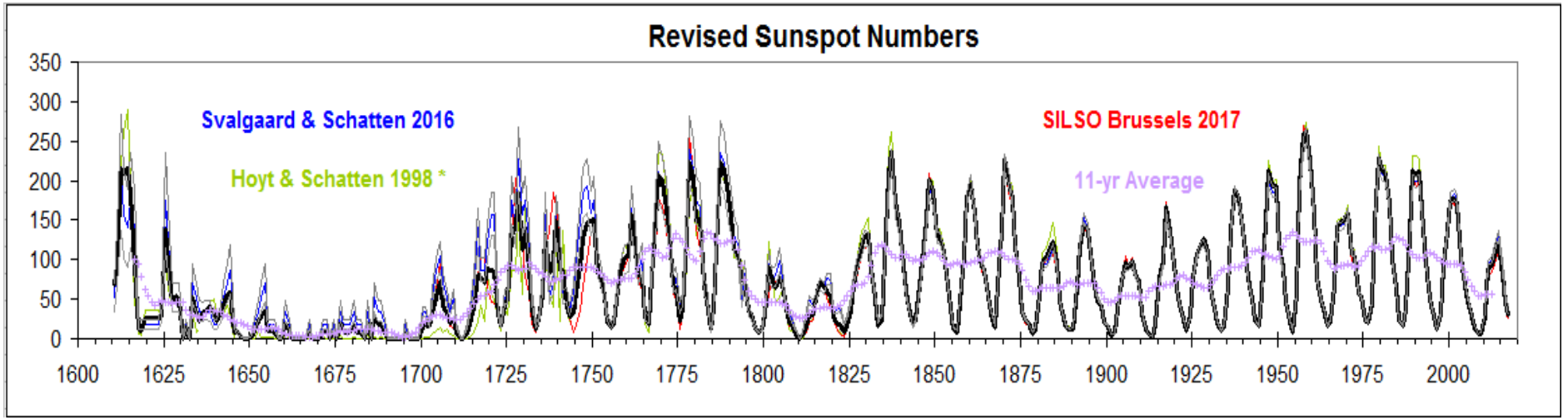
Hoyt & Schatten's [H&S] GSN = 12 * G where the '12' was chosen to make the GSN = W for the interval 1874-1976, so forcing an overall match with W for that.

The Revised Sunspot Numbers



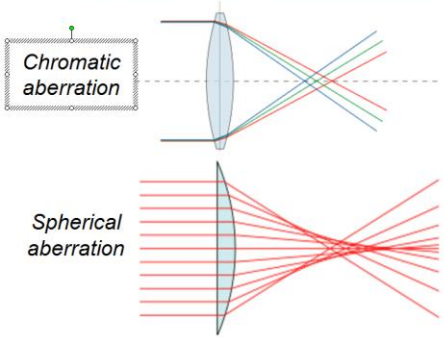
A Proposed Solution for Reconciliation:
The SSN Workshops

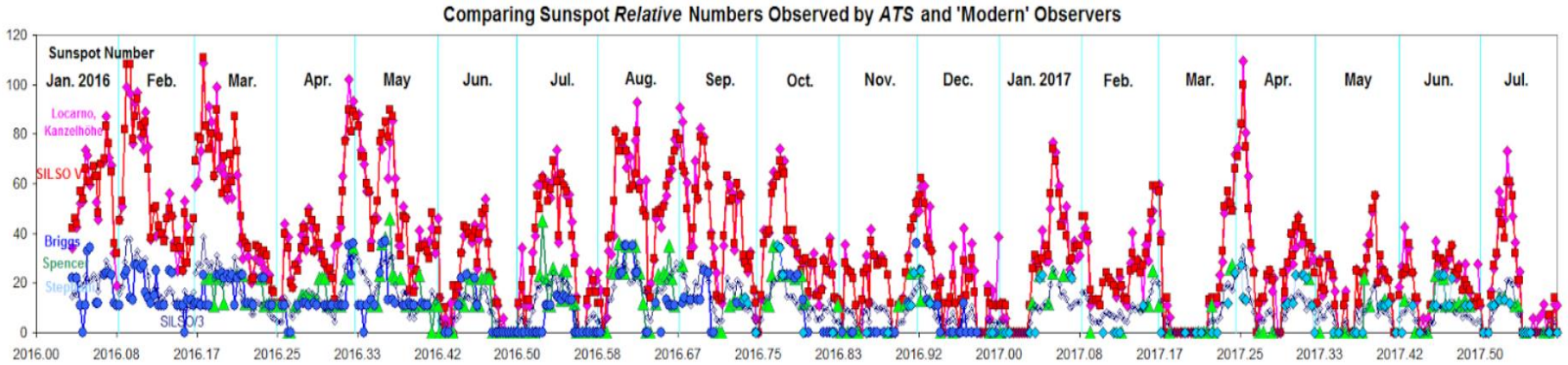
Goal: Community-vetted and agreed-upon solar activity series



Full Disclosure: There is still some holdouts preferring the obsolete H&S series

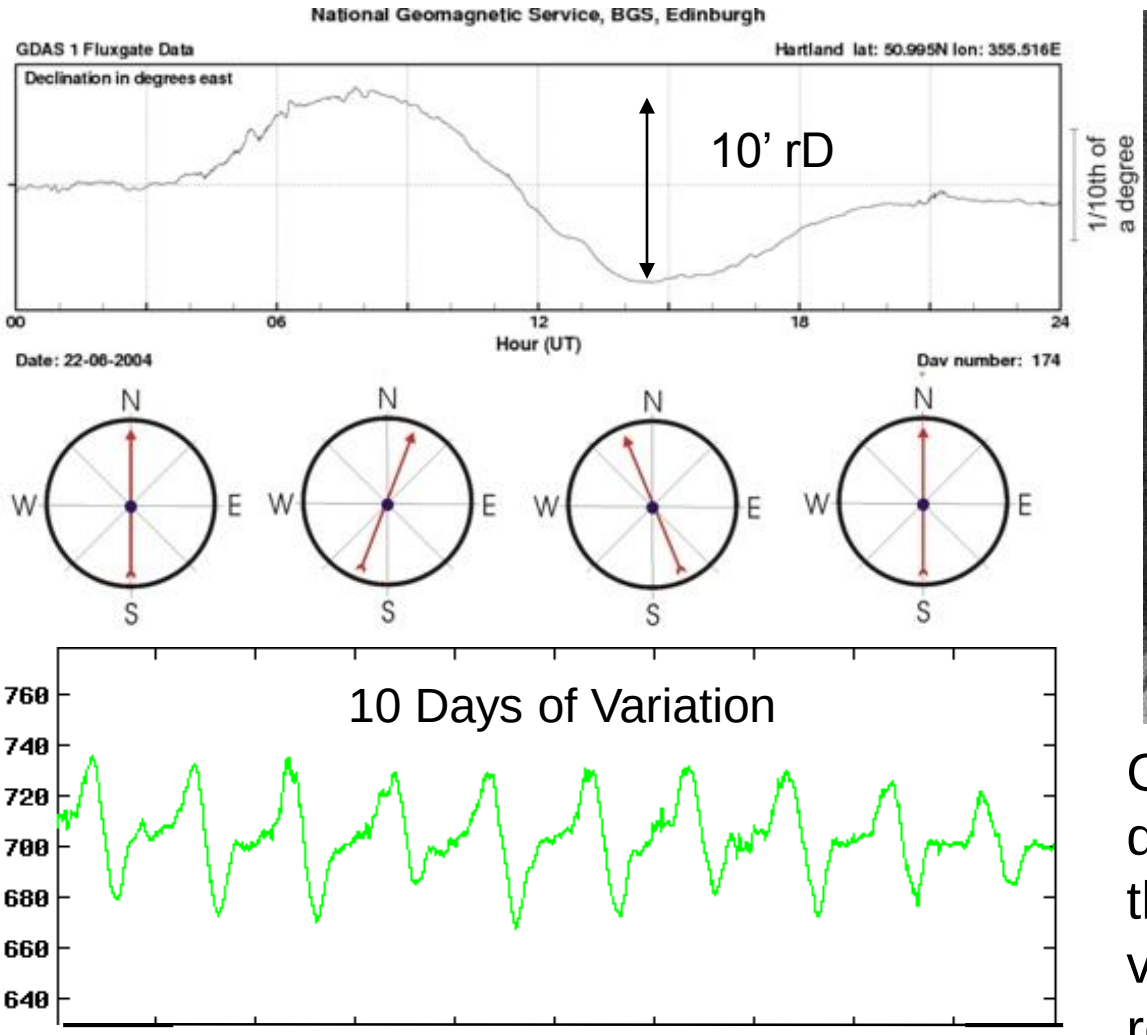
Checking the Calibration for the 18th Century: Build Replicas with the Same Optical Flaws





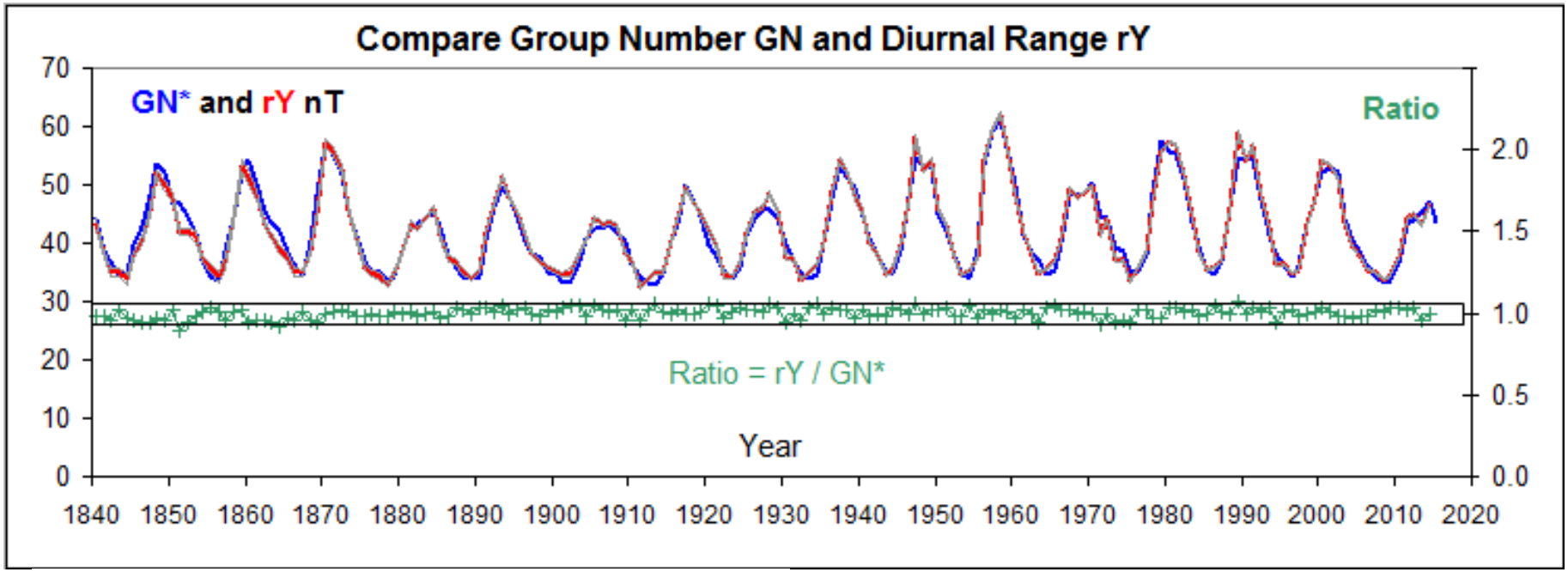
Modern observers see three times as many sunspots than our 18th century replicas

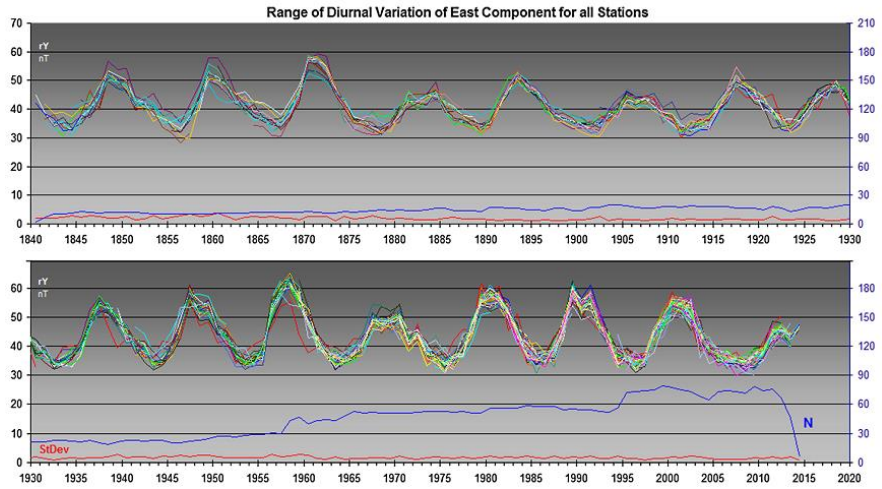
The Diurnal Variation of the Direction of the Magnetic Needle



George Graham [London] discovered [1722-1724] that the geomagnetic field varied during the day in a regular manner.

The Range (Amplitude) of the Daily Variation Matches that of the Revised Group Numbers

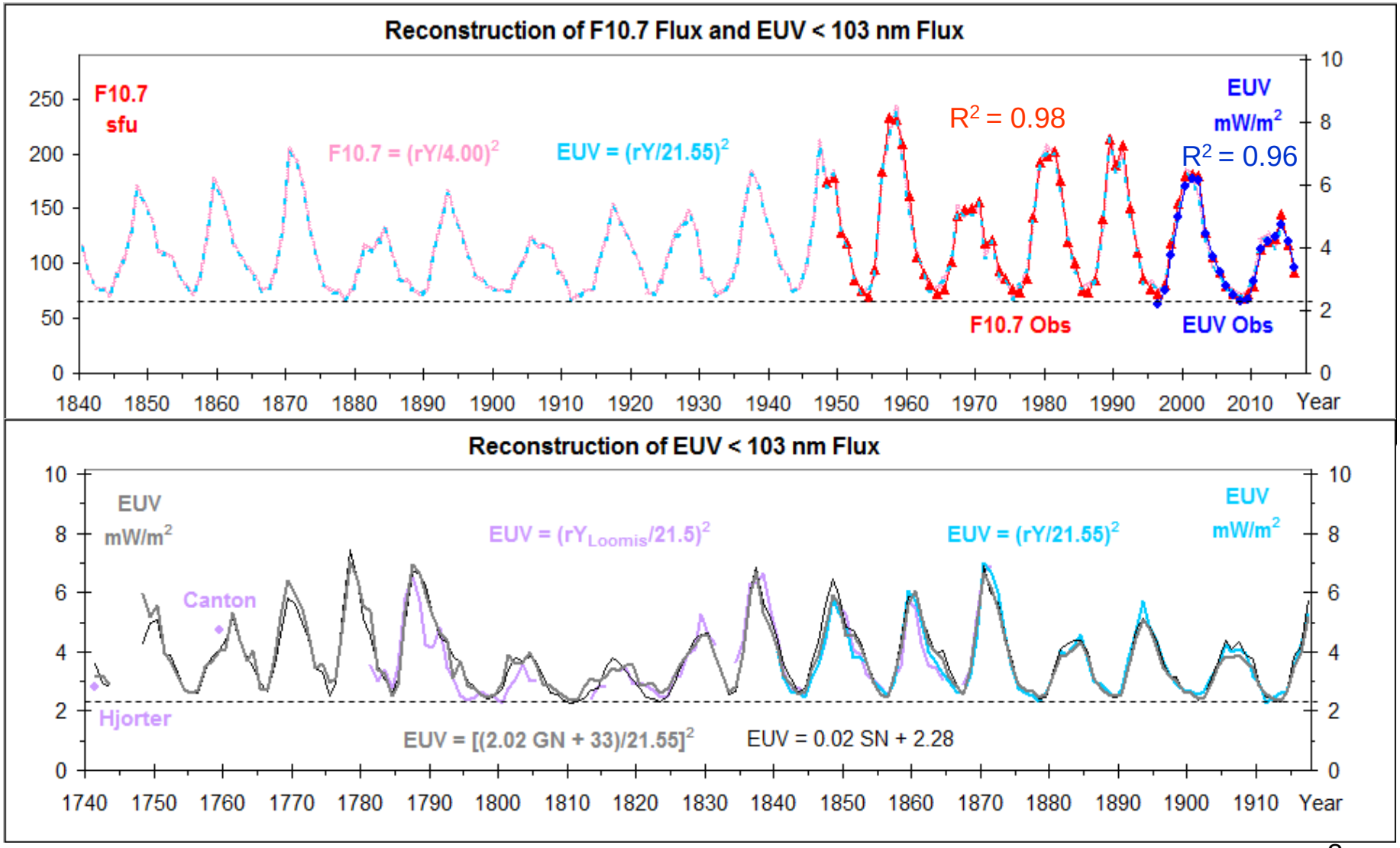




There is a good **linear** relationship between the Daily Range, rY, and the Group Number, GN, allowing us the scale GN to rY. The ratio rY/GN* [green] is unity throughout.

Composite of 129 stations since 1840

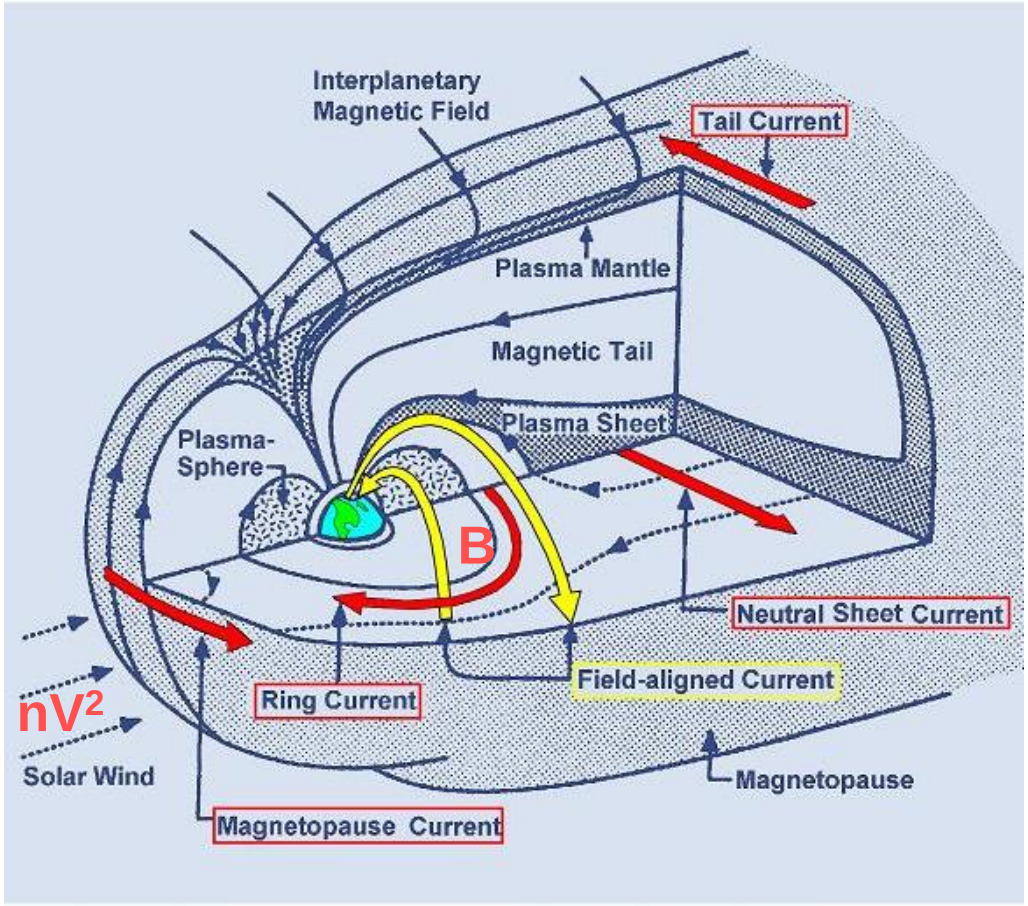
Reconstructions of EUV and F10.7

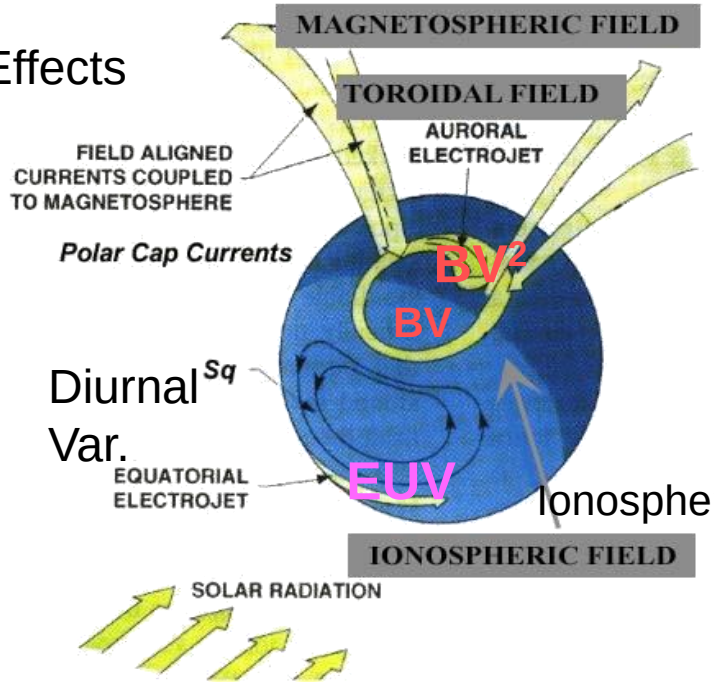


Note the constant basal level at *every* solar minimum

Electric Current Systems in Geospace

Different Current Systems ⇄ Different Magnetic Effects



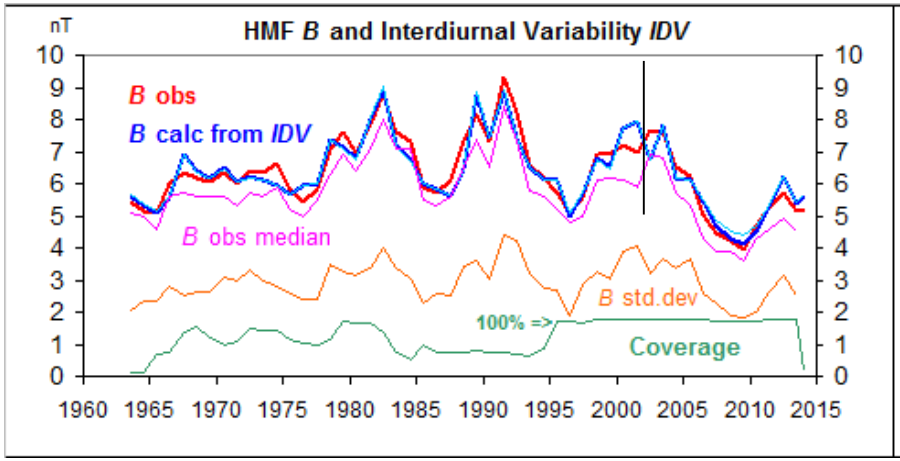


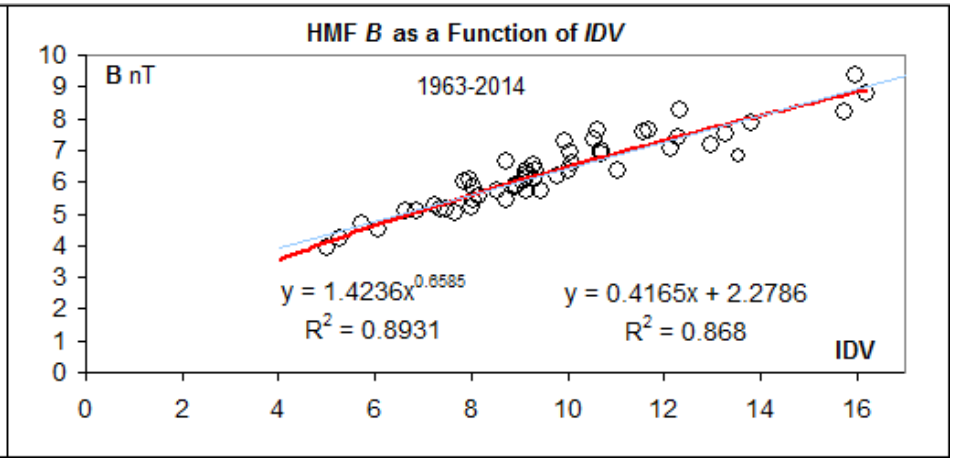
Oppositely charged particles trapped in the Van Allen Belts drift in opposite directions giving rise to a net westward ‘Ring Current’.

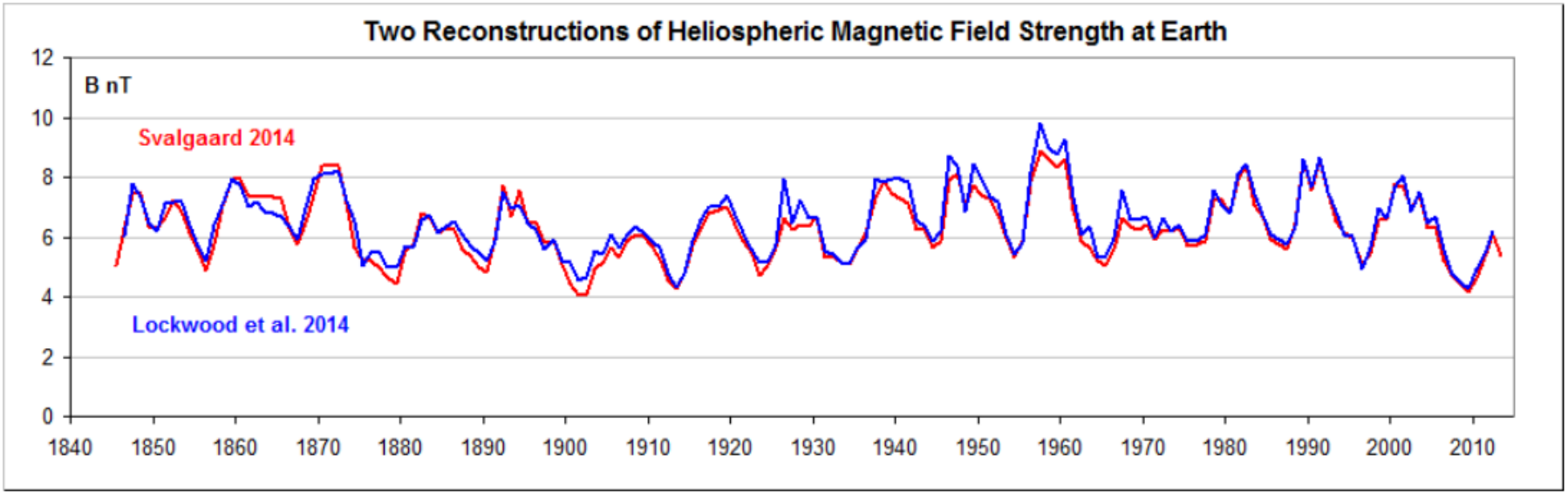
The IDV and Dst magnetic indices are good proxies for that current and thus for the magnetic field **B** in space

We can now invert the Solar Wind – Magnetosphere relationships…

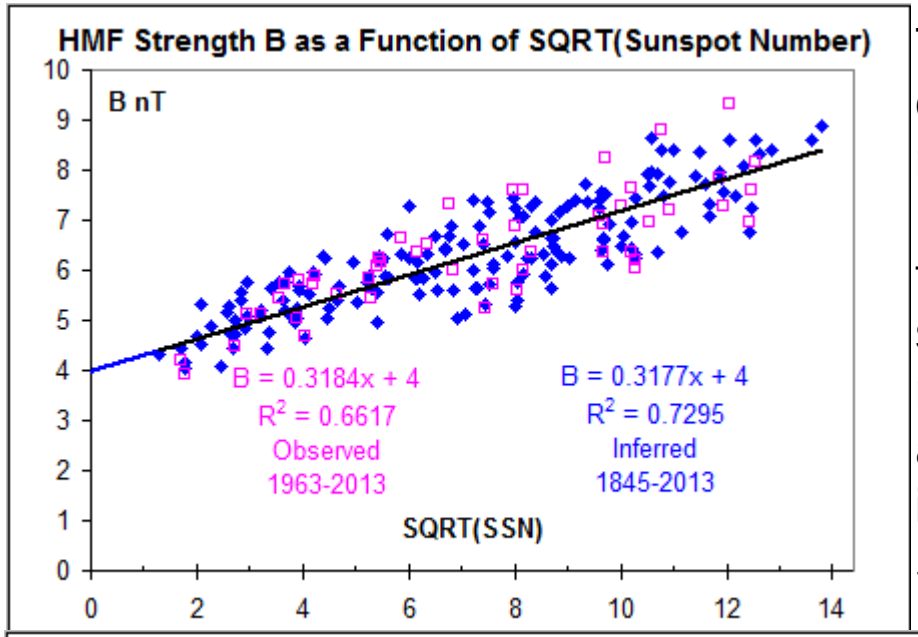
Relationship between HMF *B* and *IDV*



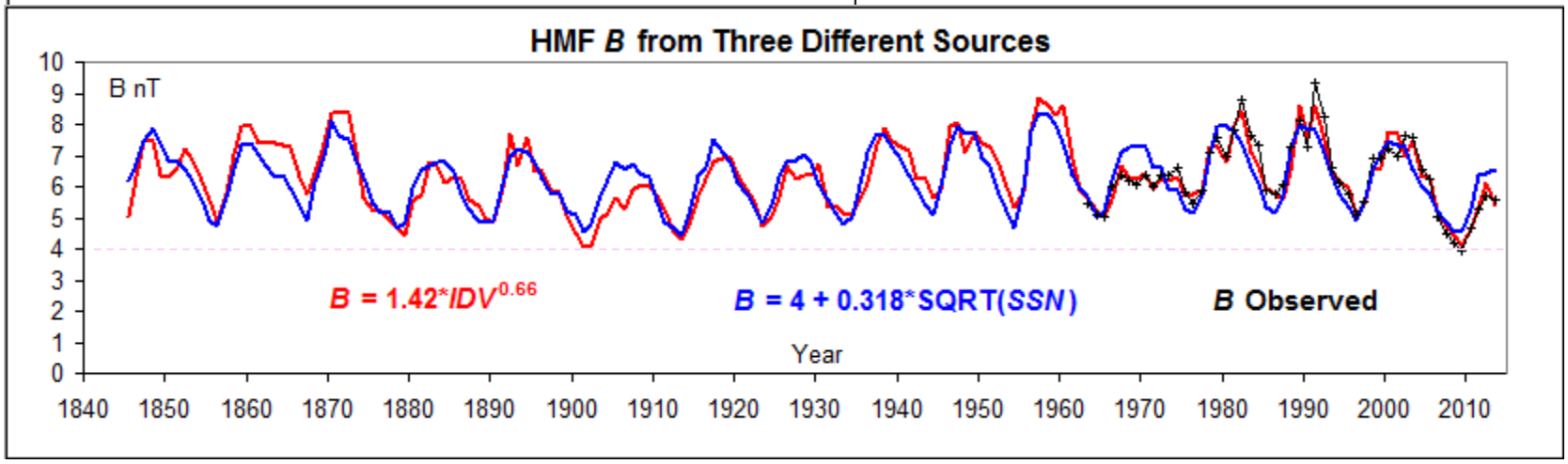




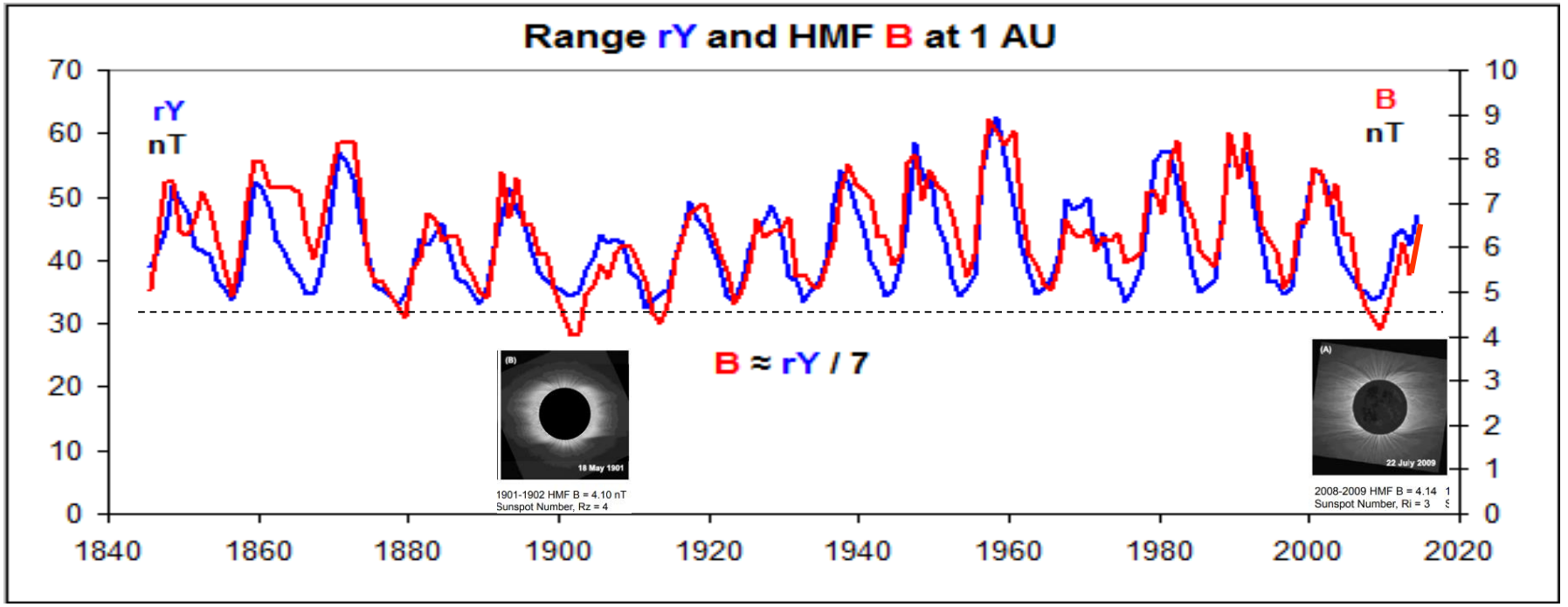
HMF *B* related to Sunspot Number



The main sources of the equatorial components of the Sun's large-scale magnetic field are large active regions. If these emerge at random longitudes, their net equatorial dipole moment will scale as the square root of their number. Thus their contribution to the average HMF strength will tend to increase as $SSN^{1/2}$ (see: Wang and Sheeley [2003]; Wang et al. [2005]).



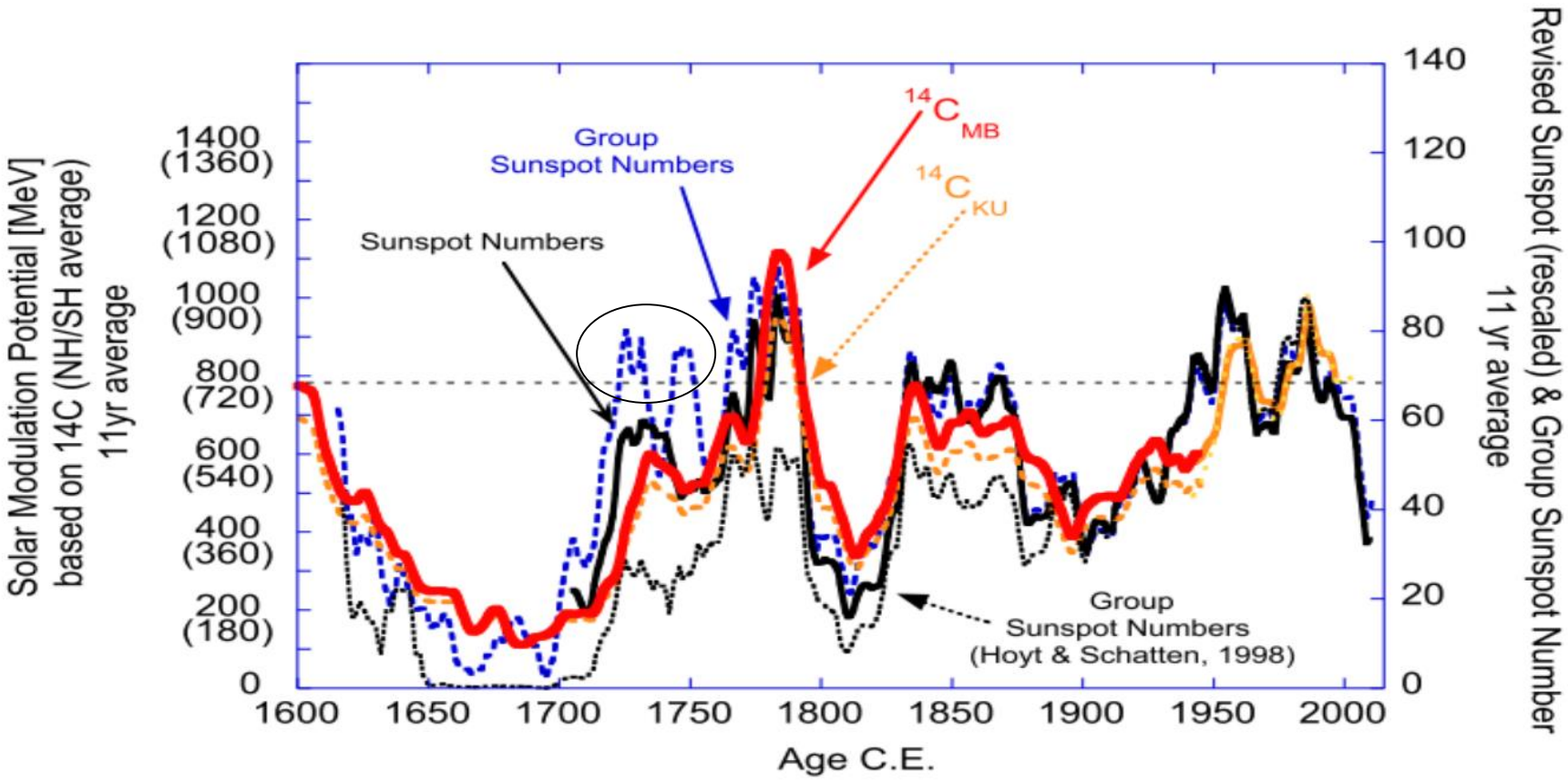
Network Field and Solar Wind Field



The magnetic field in the solar wind (the Heliosphere) ultimately arises from the magnetic field on the solar surface filtered through the corona, and one would expect an **approximate** relationship between the network field (EUV and rY) and the Heliospheric field, as observed.

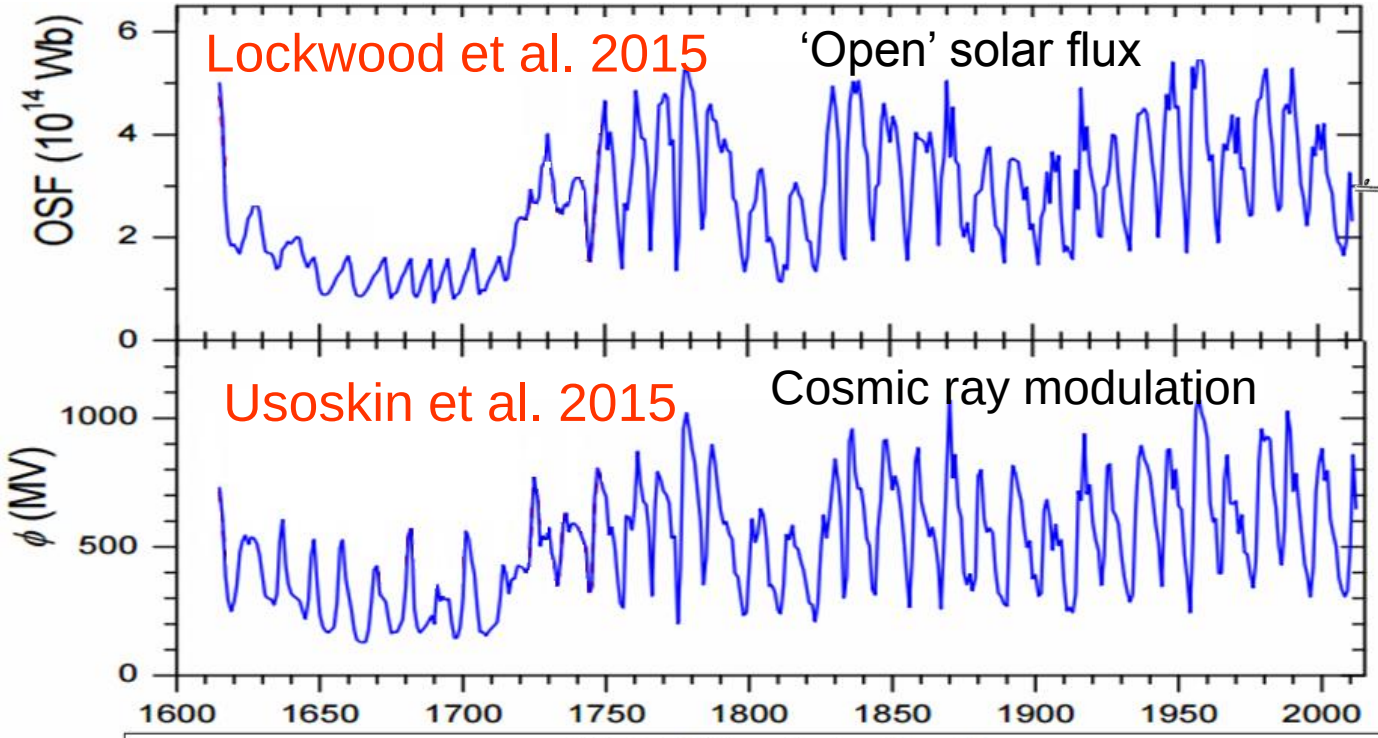
For both proxies we see that there is a constant ‘floor’ upon which the magnetic flux ‘rides’. I see no good reason that the same floor should not be present at all times, even during a Grand Minimum.

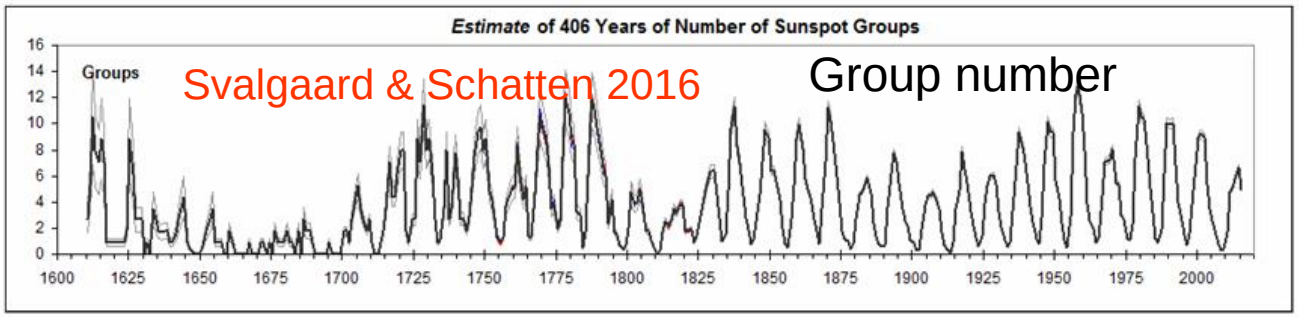
Cosmic Rays Proxies Agree with the New Sunspot Group Series



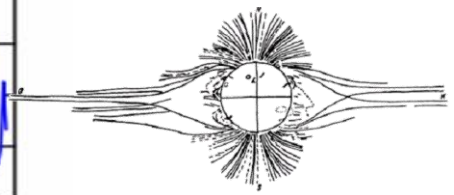
Muscheler et al. [2016]

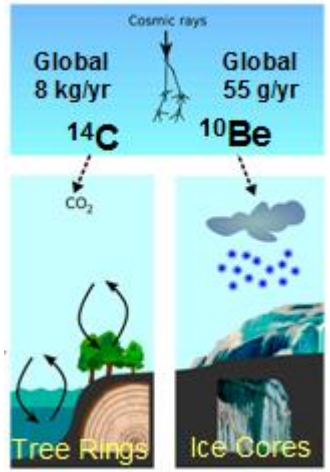
Revised Solar Activity Records (Progress!)





Solar Eclipse 1954

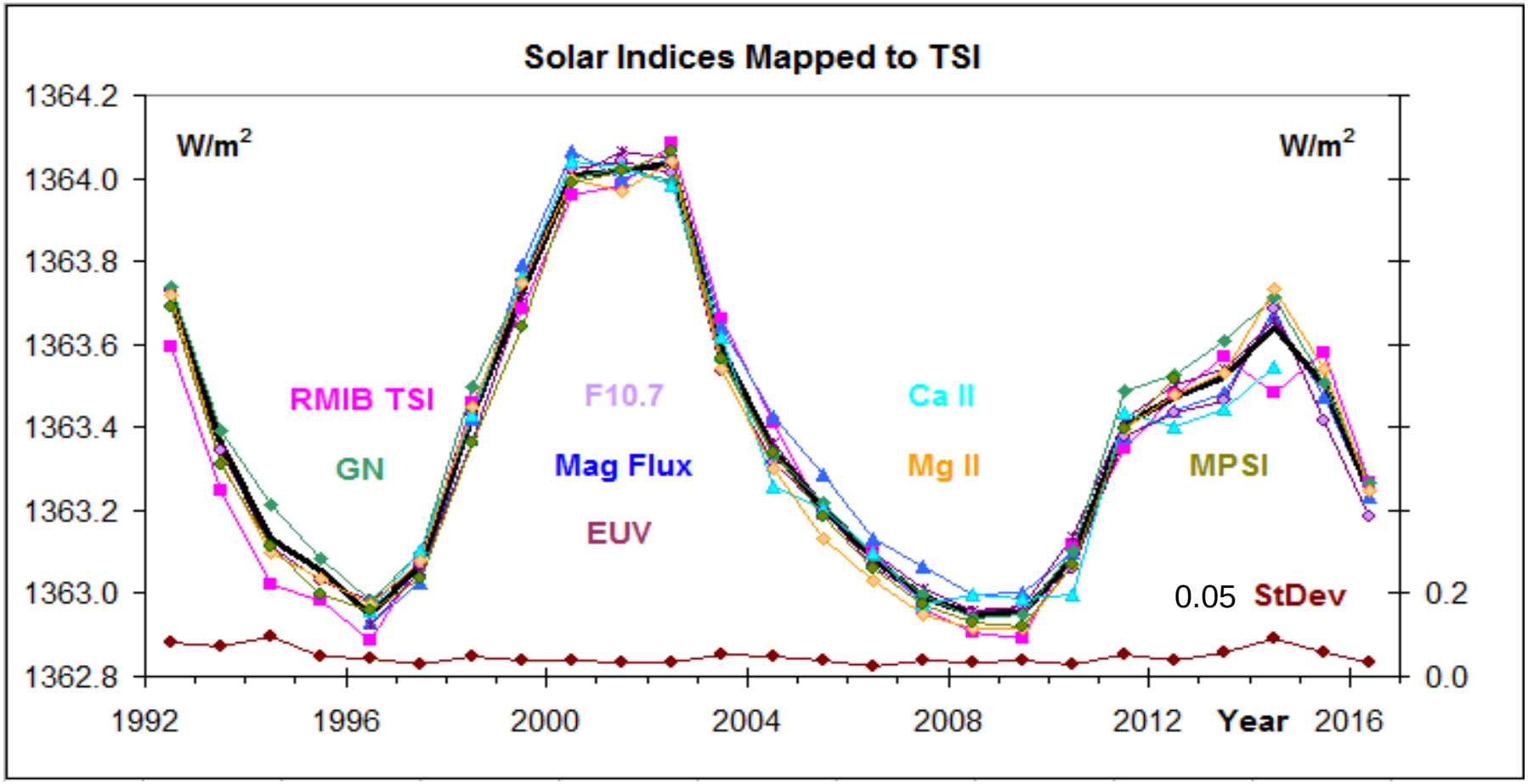




Very good agreement between different reconstructions.

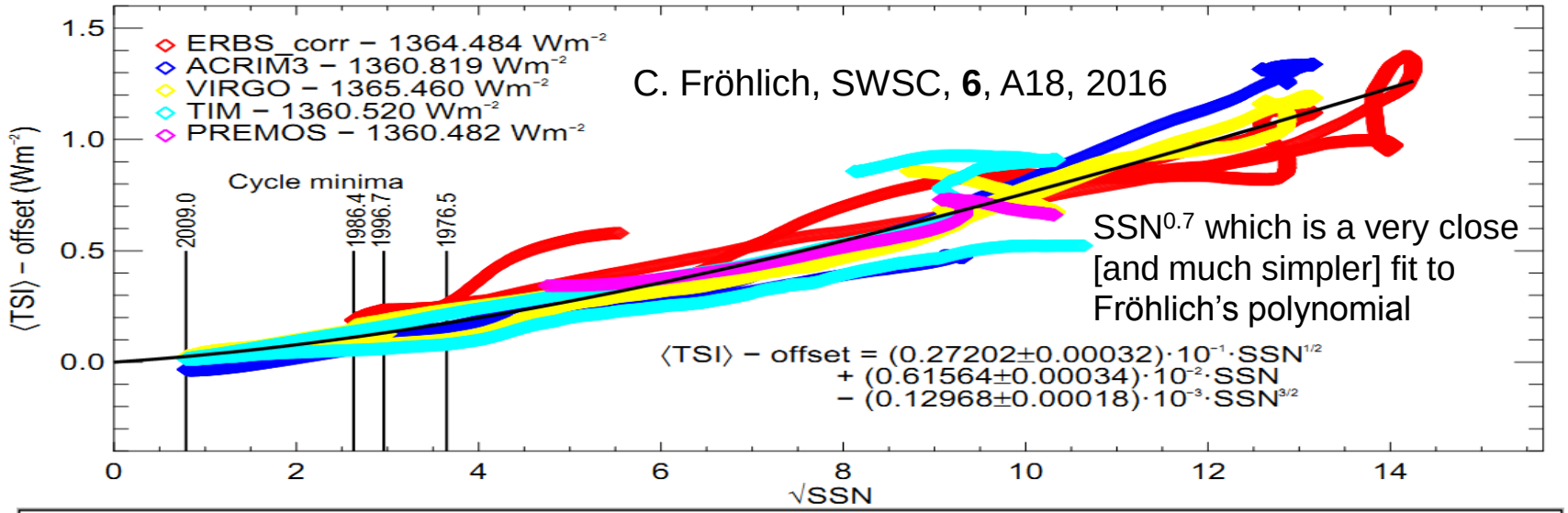
Full Disclosure: There is still a rear-guard debate about the early record

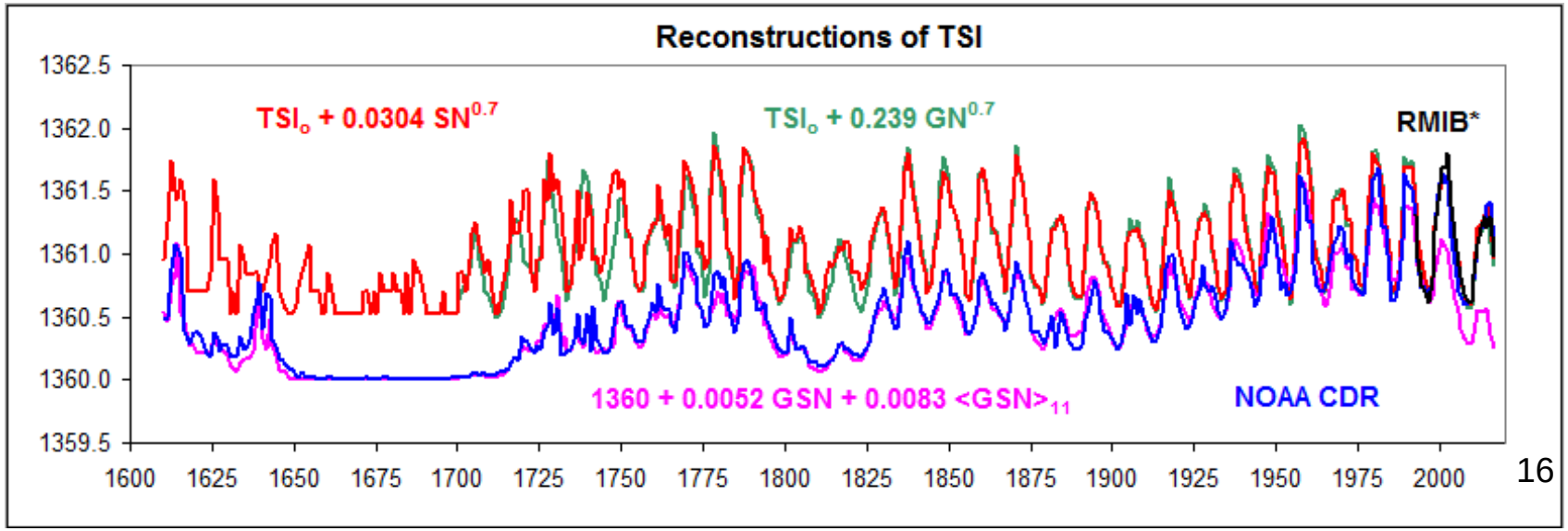
Solar Indices Mapped Linearly to TSI



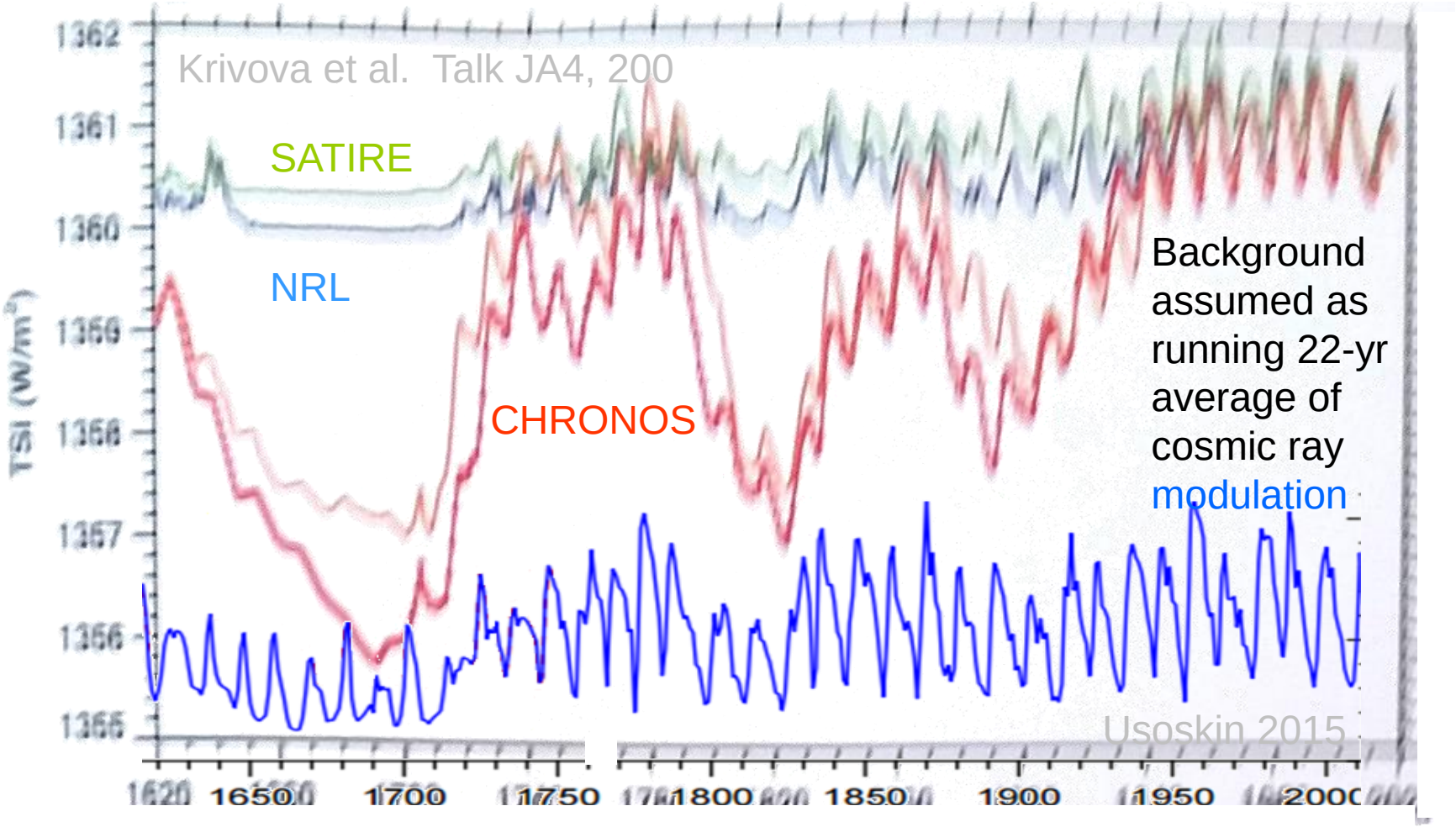
The TSI record is that by the Belgian Meteorological Institute [RMIB]

Claus Fröhlich Lined up TSIs as a Function of the Square Root of the Sunspot Number





We Began with a Misfit, and We End with an Extreme One



They have clearly much more work to do…

Abstract

The last decade of vigorous research have produced a remarkable consensus [as well as some dissent] about the long-term variation of solar and heliospheric parameters. Using geomagnetic observatory data from centuries past have resulted in reliable reconstructions of properties of the solar wind since at least the 1840s and of solar EUV well back into the 18th century. On the solar side, errors and inconsistencies of the sunspot number series have been identified and corrected leading to a revision of the fundamental datasets of solar activity. The geomagnetic-based and sunspot-related reconstructions of past solar activity support and complement each other forming a solid base for long-term research into the response of the terrestrial system in which we live and spurred renewed interest research of long-term variations, including rescue and digitization of historical data.