# Succeeding D.Schove: 11-yr solar cycles during Common Era

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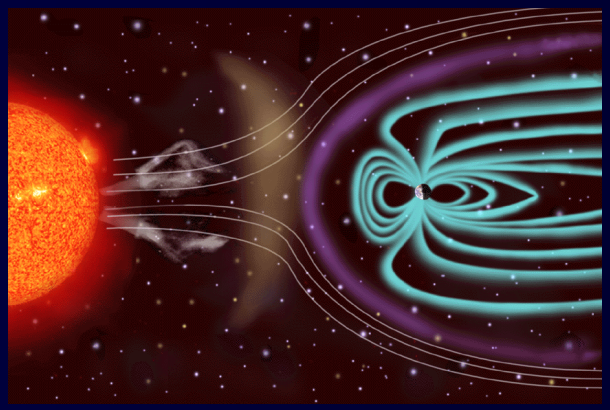
Space Weather and Space Climate – modern problems in framework of Solar-terrestrial relations.

Space Weather: short times, immediate impacts external cosmic factors on terrestrial processes.

Space Climate: Long-term tendencies of the Space Weather or Variations of long-term solar-terrestrial links

# Our Central Objective:

- To obtain the physically informative complex data on the dynamics of the solar magnetic field, geomagnetic field and interplanetary magnetic field over the long time scales.



## «**History of the Sun**» (The multi-scale description of solar activity behaviour on long times): **approach**

- Reconstructing the solar activity, geomagnetic parameters and the interplanetary magnetic field, we select successive in duration time scales, which naturally follow from capabilities of the available observational data. Altogether the four scales are selected: 100-150 years, 400 years, 1000-2000 years and >2000 years.

**«History of the Sun»** (The multi-scale description of solar activity behaviour on long times): **opportunities of reconstruction**

Time scales:

- 100-150 yrs – regular solar monitoring
- 400 yrs – non-regular, but *direct* observations
- 1000-2000 yrs – *non-direct* observations: proxies ($^{14}C$, aurorae, naked-eye sunspots)
- Overmillennial scale (Holocene) – $^{14}C$ ($^{10}Be$)

# Different proxies as a sources of information on Solar Activity variations:

- Information on the concentration of isotopes of 14C and 10Be (tree rings and polar ices), formed under the influence of the galactic cosmic rays which flux was modulated by a heliosphere (depending on the S.A. level CA) – *Stuiver, Usoskin, Bard, Beer…*. Its advantage is the wide length of time sets (about Holocene and more).
- Naked-Eye sunspots, fixed in chronicles. The basic source of such narrative data is the Chinese annals – *Wittman, Nagovitsyn, Vaquero…* -- reflecting changing celestial phenomena (including large sunspots appearing on the Sun) owing to features of the Chinese philosophy.
- The number of the auroras, fixed in chronicles, testifying on flare activity, and therefore on S.A. in the Past. If to separate only low-latitude auroras (less than 55° as offered Krzhivsky), this proxy is extensive archive of data on S.A. When activity level was high enough it allows to identify individual 11-year cycles (*Schove, Krivsky…*).

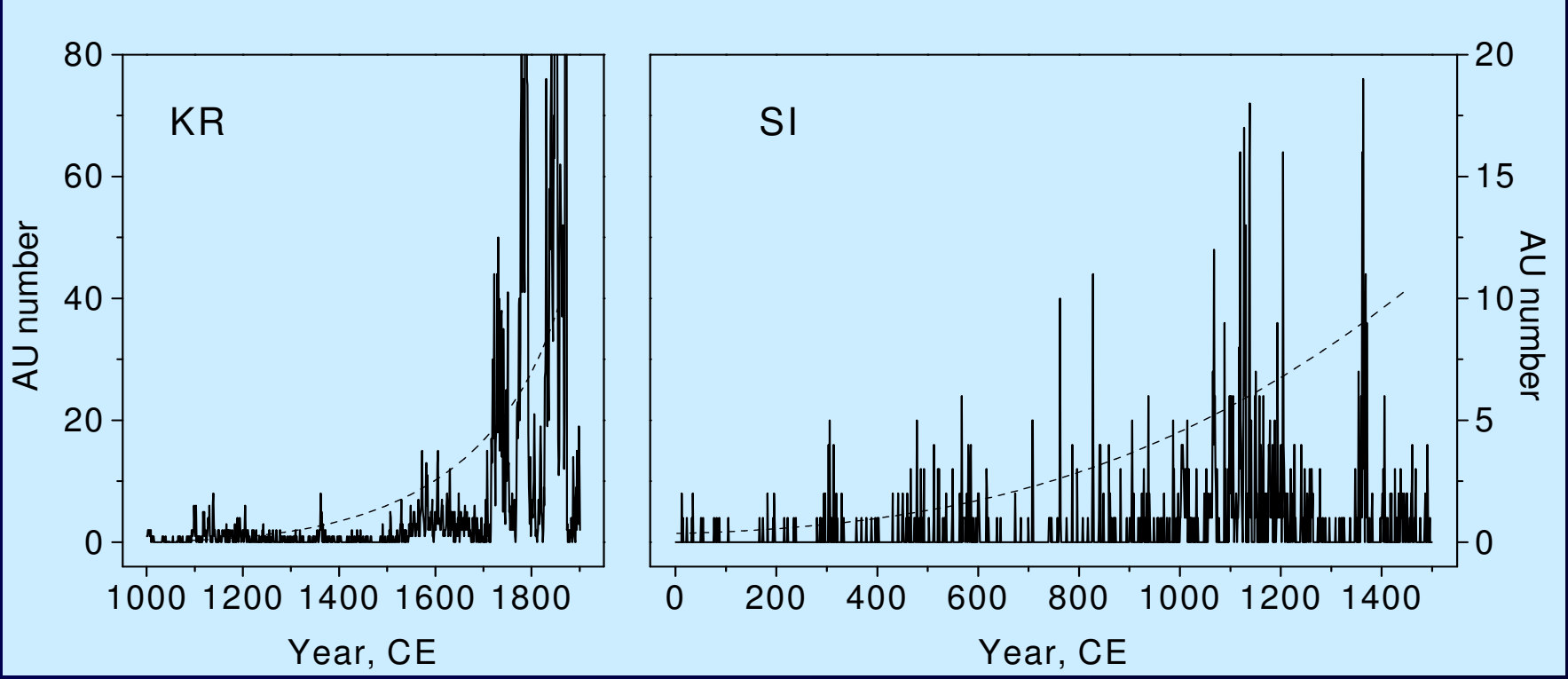
# Schove's Spectrum of Time Project

**D.Schove** has made an attempt to discover extrema of 11-year cycles in the Past, leaning on various proxies, mainly - on auroras. For the time of its study (1950 - 1960) were not catalogues of auroras detailed enough, and he accepted some hypothesis which further were exposed to criticism by some authors. As example, Schove assumed, both that durations of a cycle are no less than 8 years and no more than 16 years, as well as every century contains 9 cycles exactly.

# Objective of the study

The central aim of our work is verification of Schove's data on times of 11-year cycle extrema in the Past on the basis of modern catalogues of auroras by Krivsky (*KR)* and Silverman (*SI)* using the actual mathematical approaches based on the wavelet-analysis mainly.

# Yearly numbers of Auroras from catalogs by Krivsky (KR) and Silverman (SI)




**KR** ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/AURORAE/aurorae.dat.rev

**SI** http://nssdcftp.gsfc.nasa.gov/miscellanous/aurora/cat_ancient_auroral_obs_666bce_1951/pre15f.txt

# Problem of temporal (informational) trend

$$\left[\widehat{W}_{\psi}x\right](a,b)=\int_{-\infty}^{+\infty}x(t)\psi_{ab}^{*}dt=|a|^{-1/2}\int_{-\infty}^{+\infty}x(t)\psi^{*}\left(\frac{t-b}{a}\right)dt$$

$$\hat{\psi}_{m}(k)=m(\mathrm{i}k)^{2}\exp\left(-\frac{k^{2}}{2}\right)$$

$$\psi_{jk}=2^{j/2}\psi(2^{j}t-k)$$

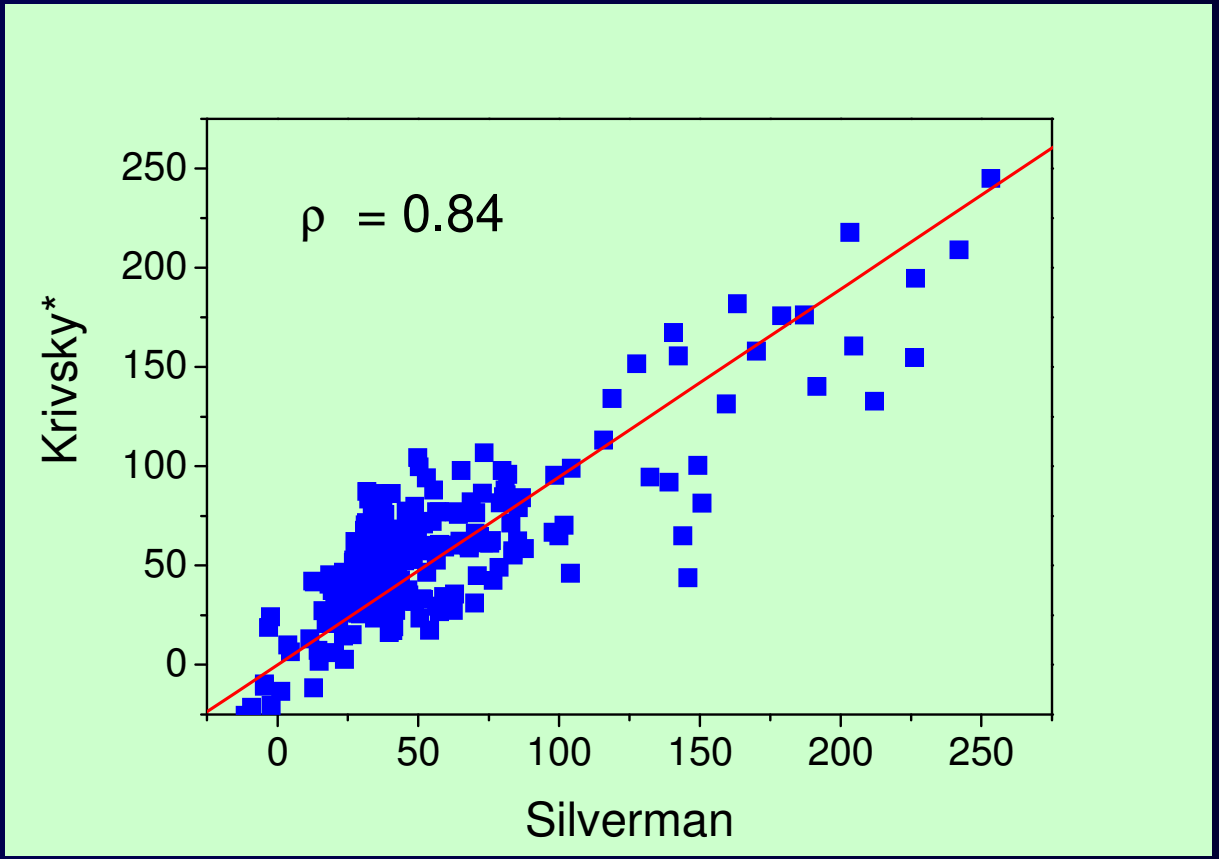
$$Y(\omega,t)=\widehat{W}^{-1}\left[\widehat{W}Y\right](2^{q},t),\ Y:KR,SR,WR$$

$$KR^{*}(\omega,t)=\frac{\sigma[WR(\omega,t)]}{\sigma[KR(\omega,t)]}KR(\omega,t)$$

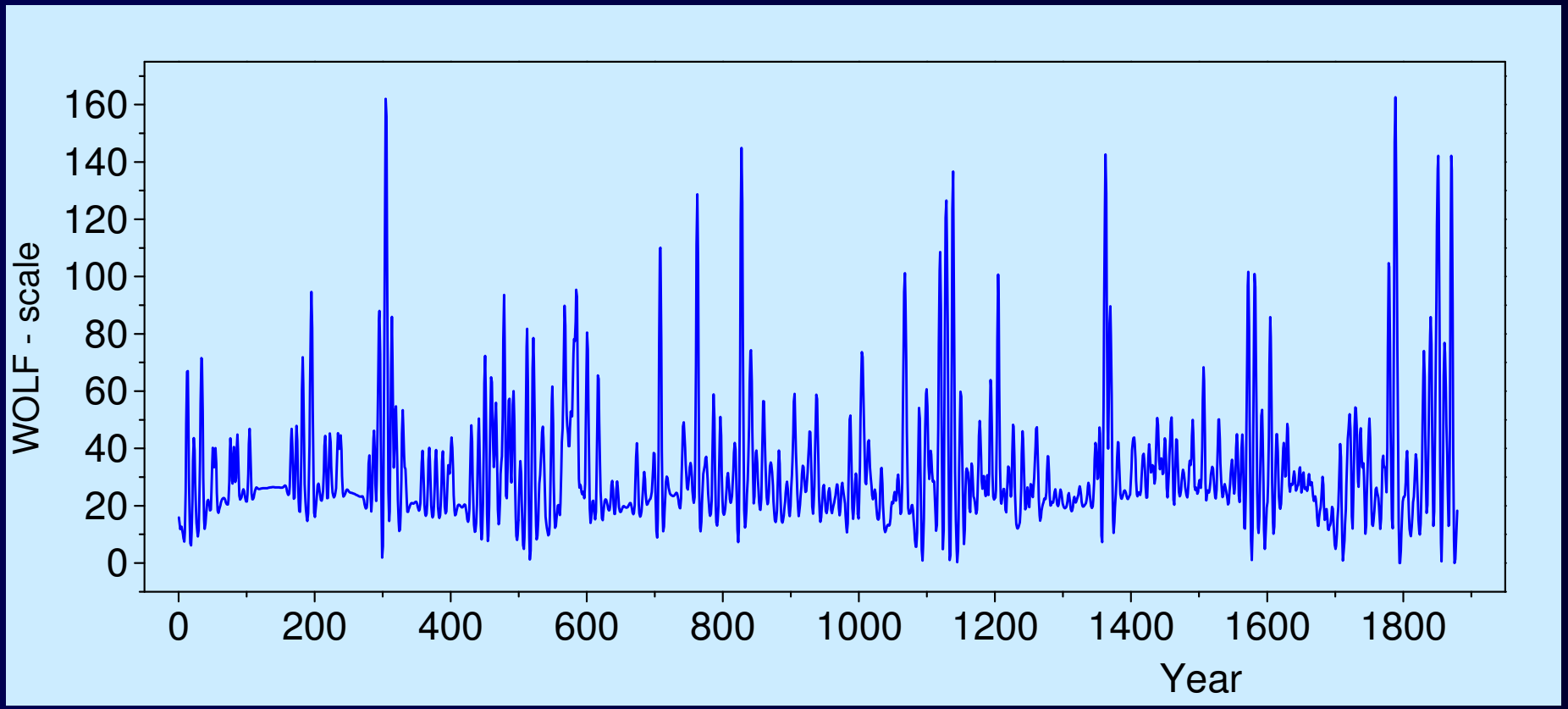
$$SI^{*}(\omega,t)=\frac{\sigma[WR(\omega,t)]}{\sigma[SI(\omega,t)]}SI(\omega,t)$$

**For each 312 yrs with shift 100 yrs**

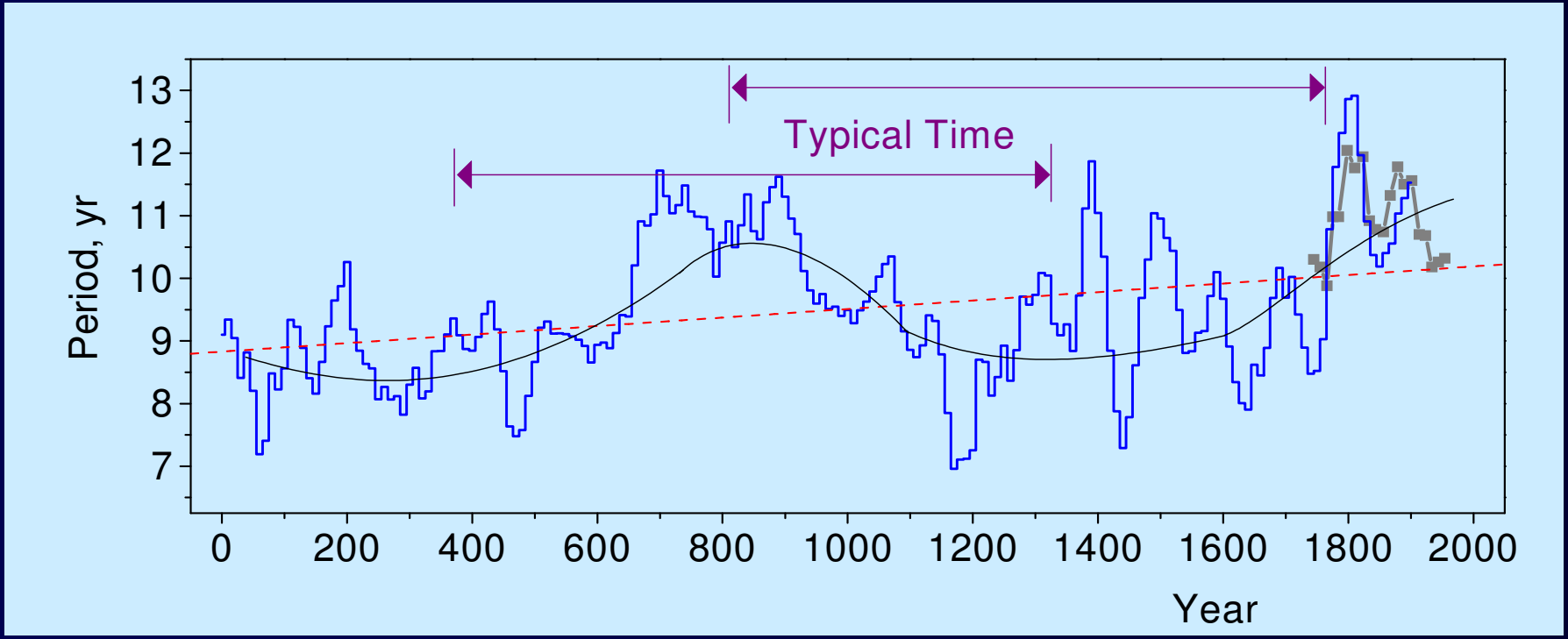
# Krivsky cat. vs Silverman cat. -> synthesis



# De-trended Phase profile of 11-yr cycles over AD, based on Silverman and Krivsky catalogues

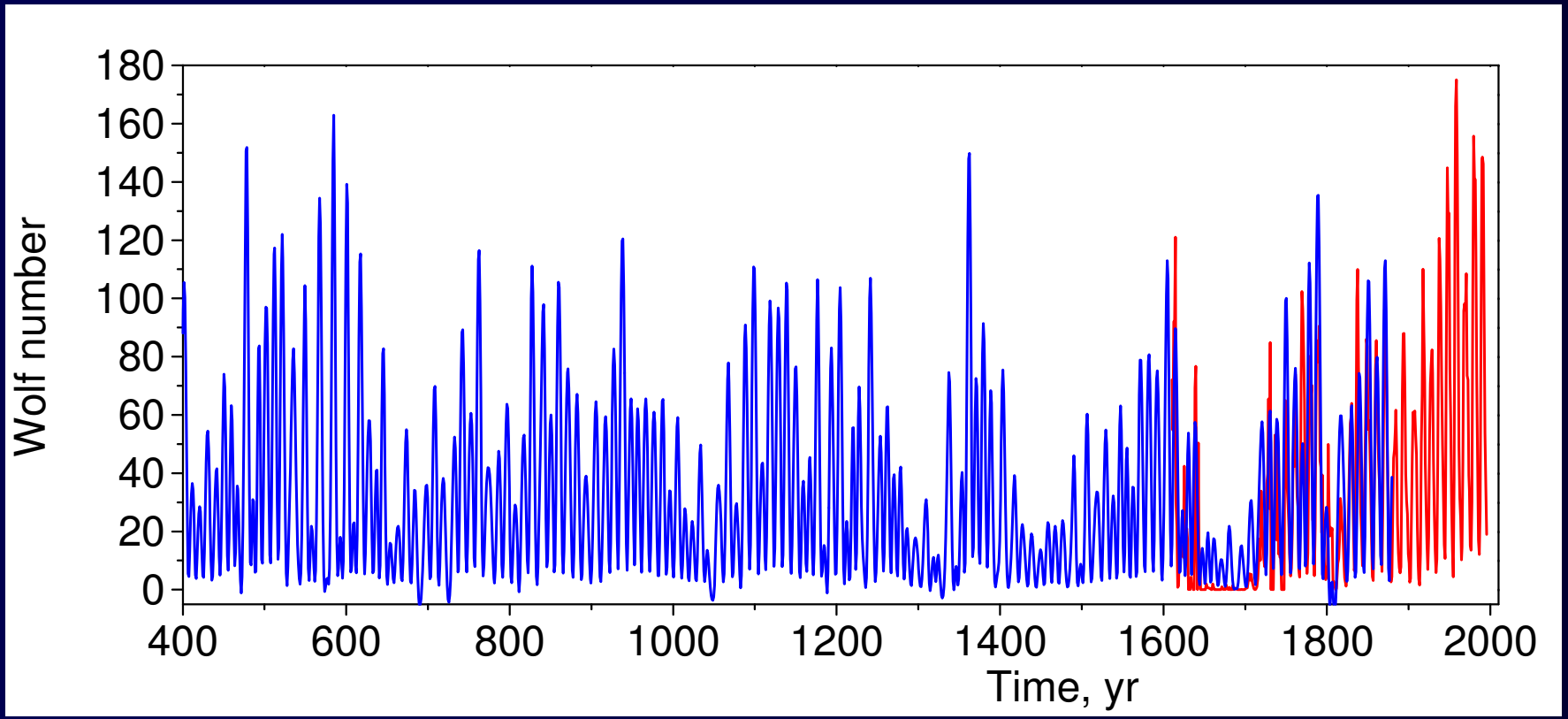


# Secular variations of 11-yr cycle lengths




**Cycles: ~100, ~200, ~1000 yrs**

# Synthetic reconstruction of the Wolf number yearly means: radiocarbon (amplitude) proxy by both Solanki&Usoskin (2004) and Volobuev&Nagovitsyn (2004) + (phase) aurora data of this study



# Results

I. Using both the Krivsky and the Silverman catalogues as well as wavelet transform approach, "phase profiles" of 11-yr cycles over A.D. are considered.

II. Over 0-1900 AD the moments of 11-yr cycle extrema are defined.

III. It is shown that 11-yr cycle lengths varied with ~ 1000-yr typical time as well as with time of Gleissberg and Suess cycles.

IV. New reconstruction of yearly means of Wolf number over 400-1900 AD is proposed.

**Thank you!**

**Photo** of polar aurora during the Maunder Minimum :)