

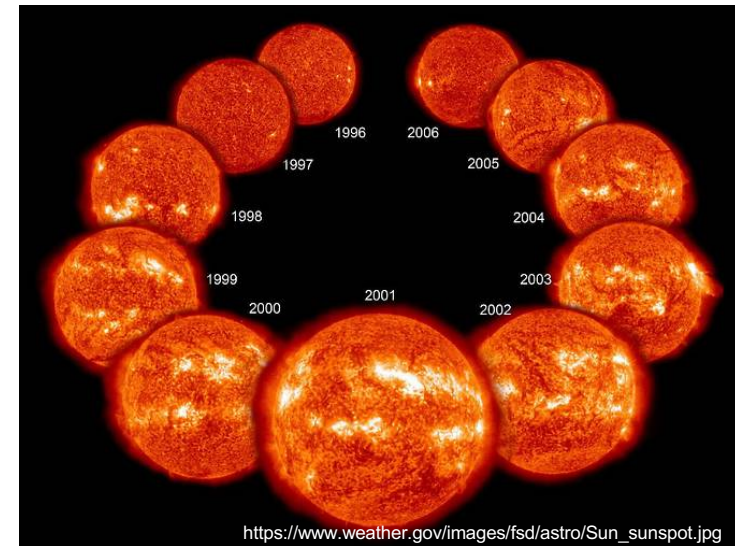
[https://d2r55xnwy6nx47.cloudfront.net/uploads/2018/07/SolarFull\\_SeonDoran\\_2880FullwidthLede-2880x1620.jpg](https://d2r55xnwy6nx47.cloudfront.net/uploads/2018/07/SolarFull_SeonDoran_2880FullwidthLede-2880x1620.jpg)

# Radiocarbon in tree-rings reveals the solar 11-yr cycle over the last millennium

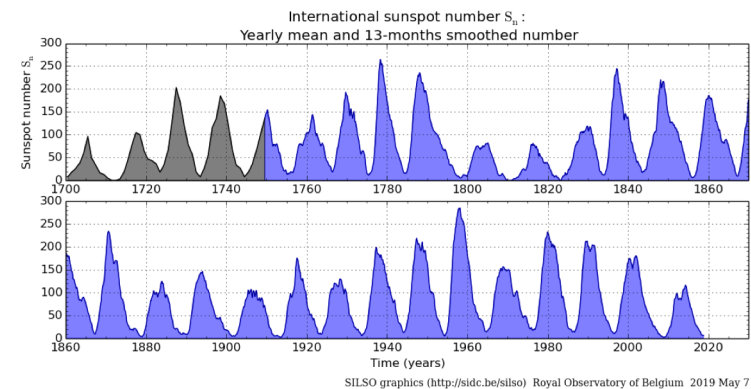
**Lukas Wacker, Nicolas Brehm**, Alex Bayliss, Marcus Christl, Hans-Arno Synal, Florian Adolphi, Jürg Beer, Bernd Kromer, Raimund Muscheler, Sami K. Solanki, Ilya Usoskin, Niels Bleicher, Silvia Bollhalder, Cathy Tyers

# 11-year cycles of the sun

- Sun goes through 11-year cycles (Schwabe cycles)
- Active sun → High sunspot number
- Passive sun → Low sunspot number

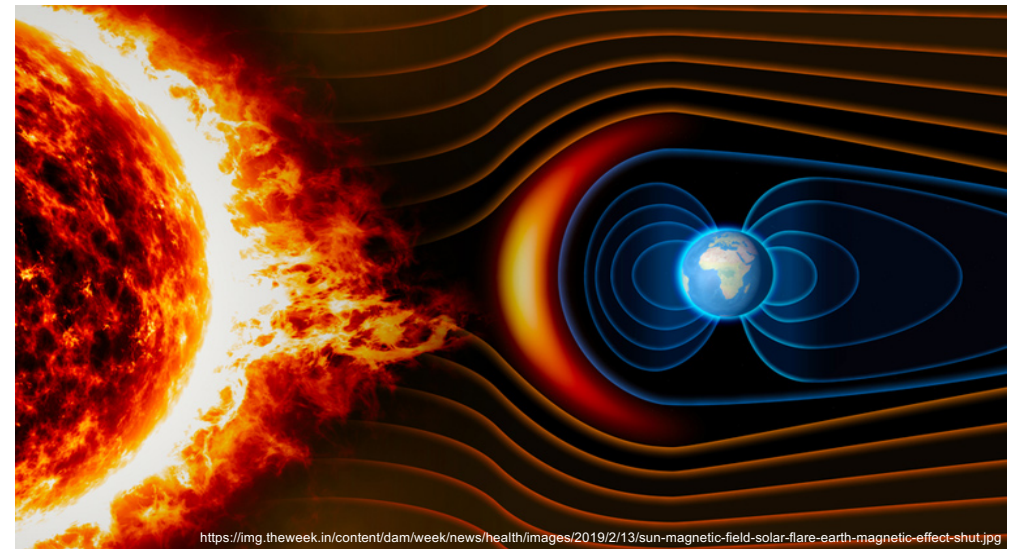


[https://www.weather.gov/images/fsd/astro/Sun\\_sunspot.jpg](https://www.weather.gov/images/fsd/astro/Sun_sunspot.jpg)



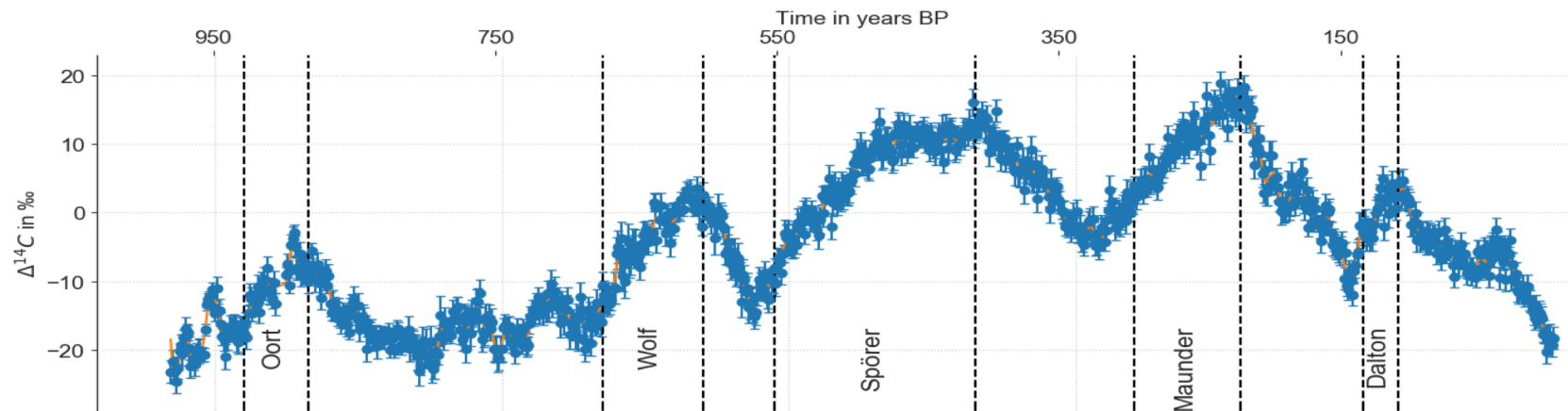
# Dependency of radiocarbon content

- 11-year cycles of the sun:  
**Active sun** → **more shielding** from comic rays  
**Passive sun** → **less shieling** from comic rays
- **Low shielding** → **high  $^{14}\text{C}$  production**  
(increase in atmospheric  $^{14}\text{C}$ )
- **More shielding** → **low  $^{14}\text{C}$  production**  
(decrease in atmospheric  $^{14}\text{C}$ )



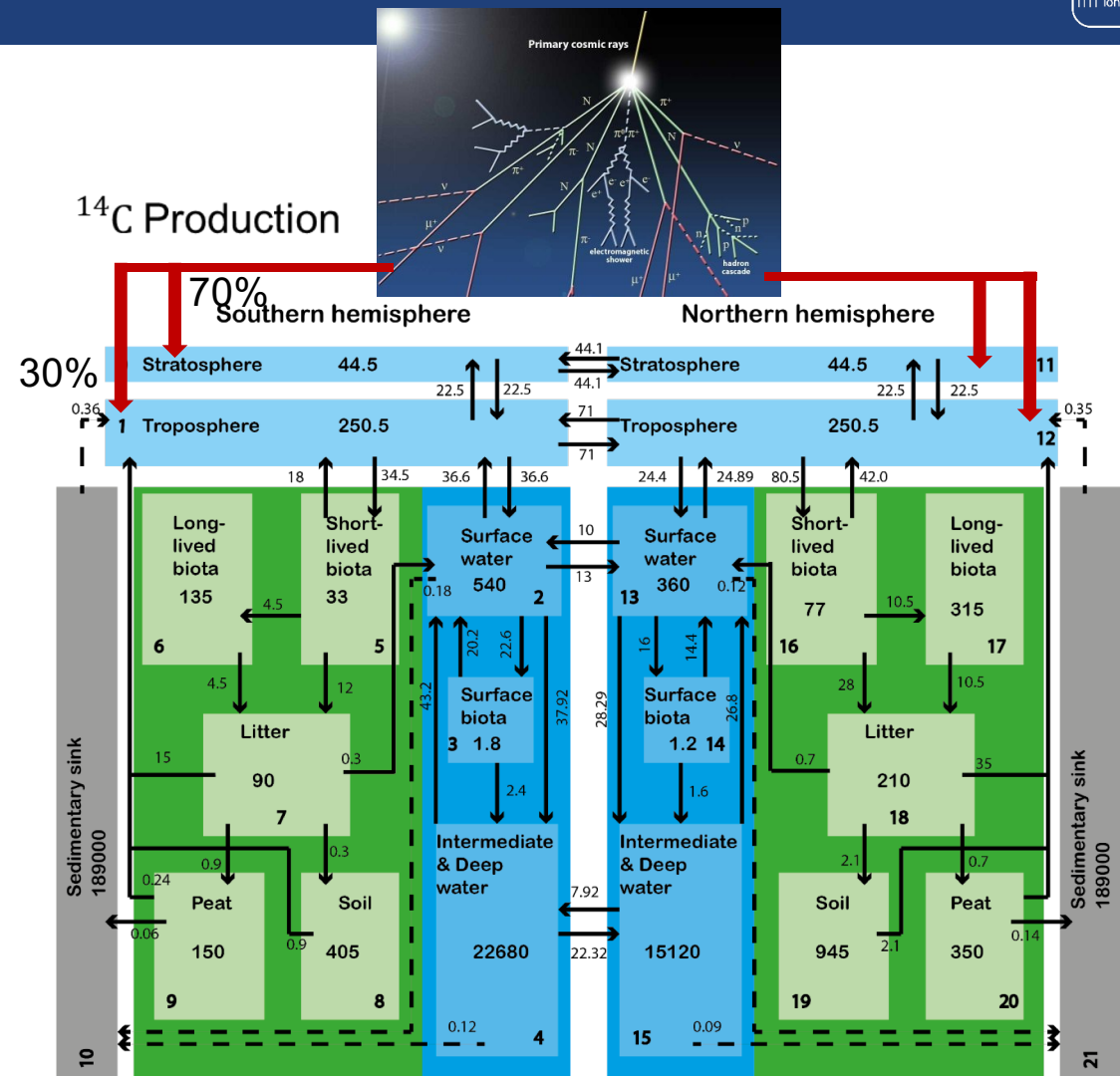
# Reconstructed annual atmospheric radiocarbon concentrations

- **1300 tree-ring samples** measured with **1.6‰** uncertainty
- Increases during grand solar minima (Oort, Wolf, Spörer, Maunder, Dalton)

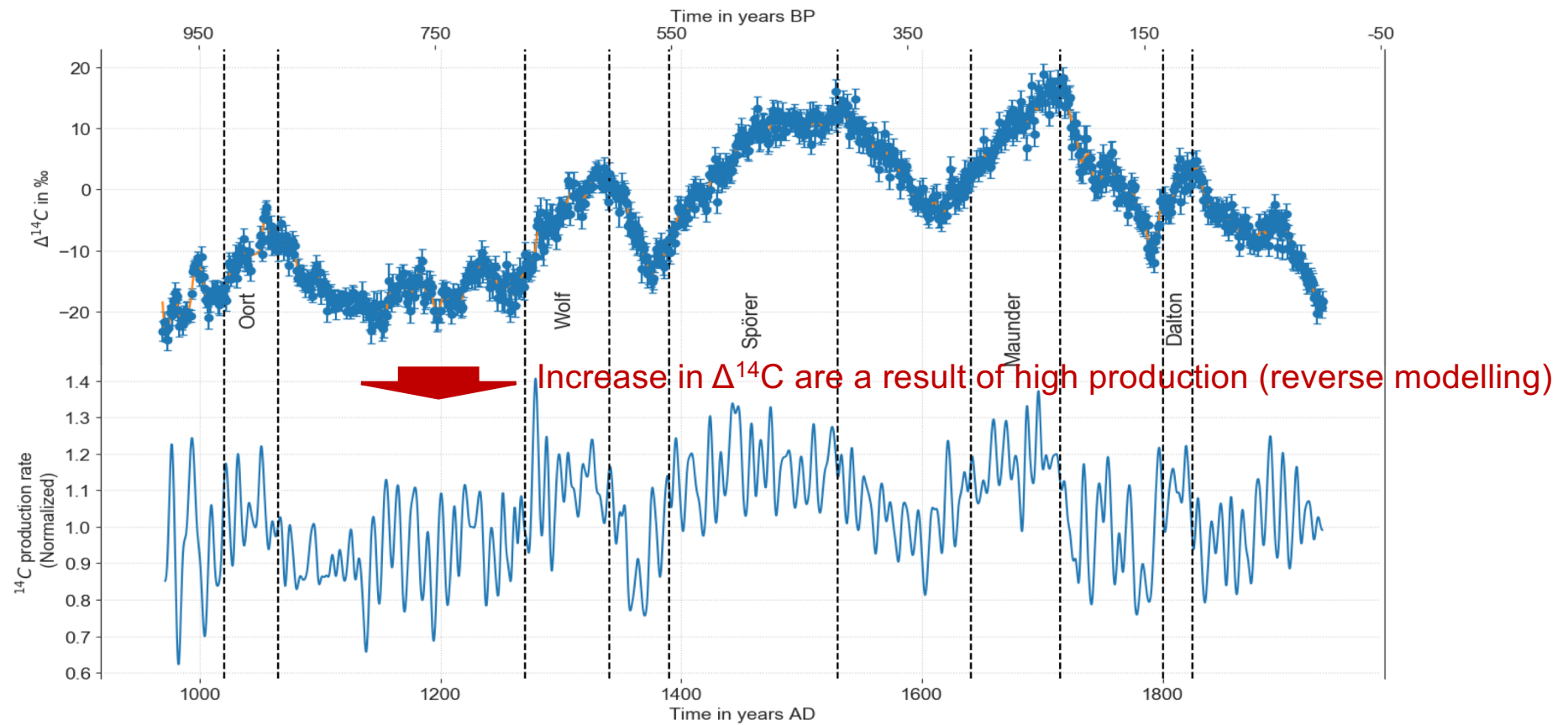


# Carbon cycle box model

- Trees record the  $^{14}\text{C}$  of the troposphere
- $^{14}\text{C}$  production can be obtained with a box model

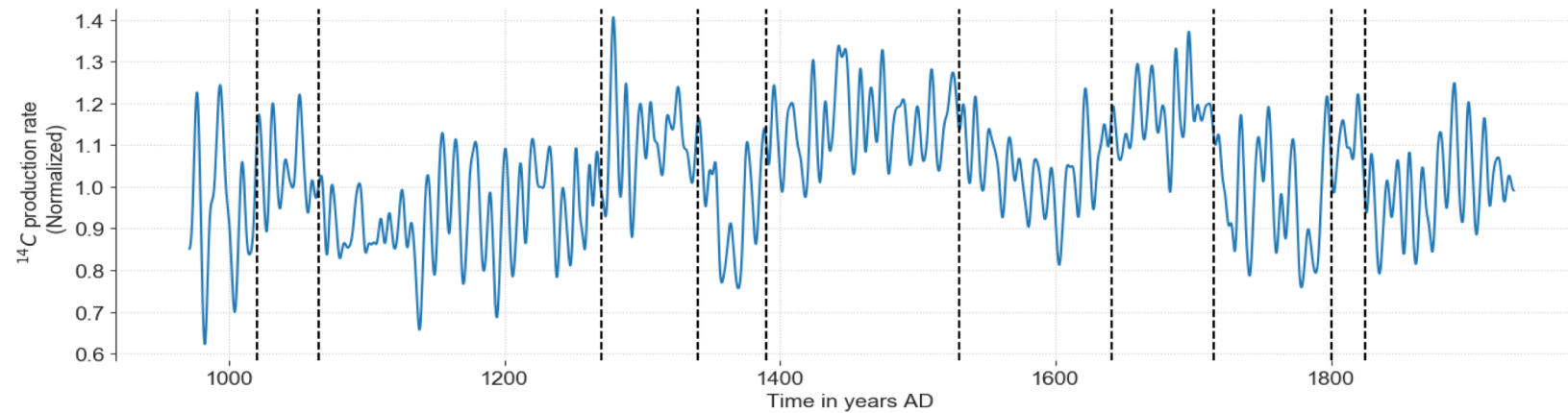


# Reconstruction of $^{14}\text{C}$ production rate

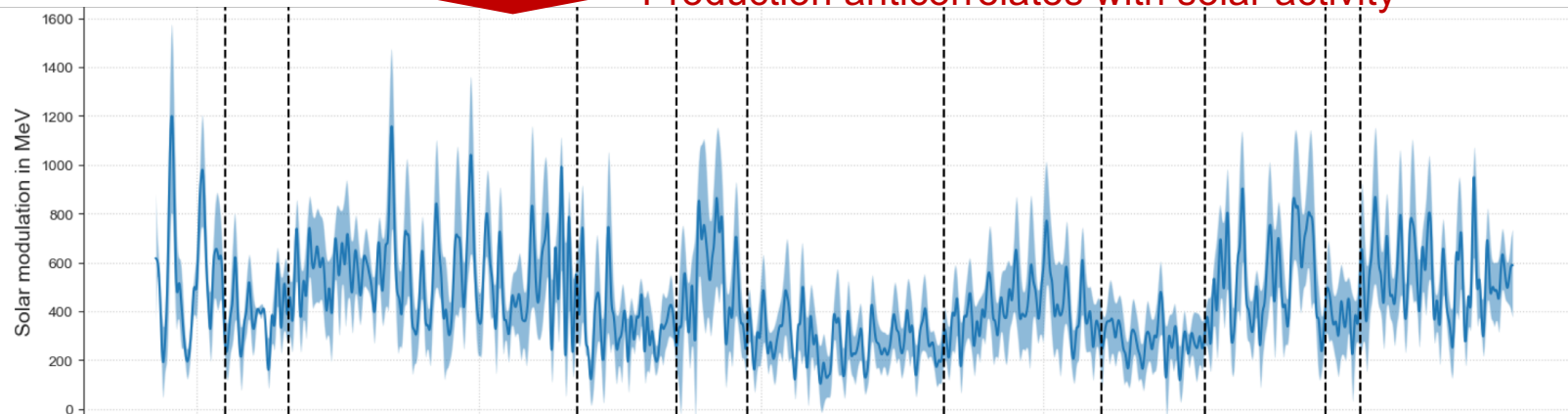




# From production to solar modulation

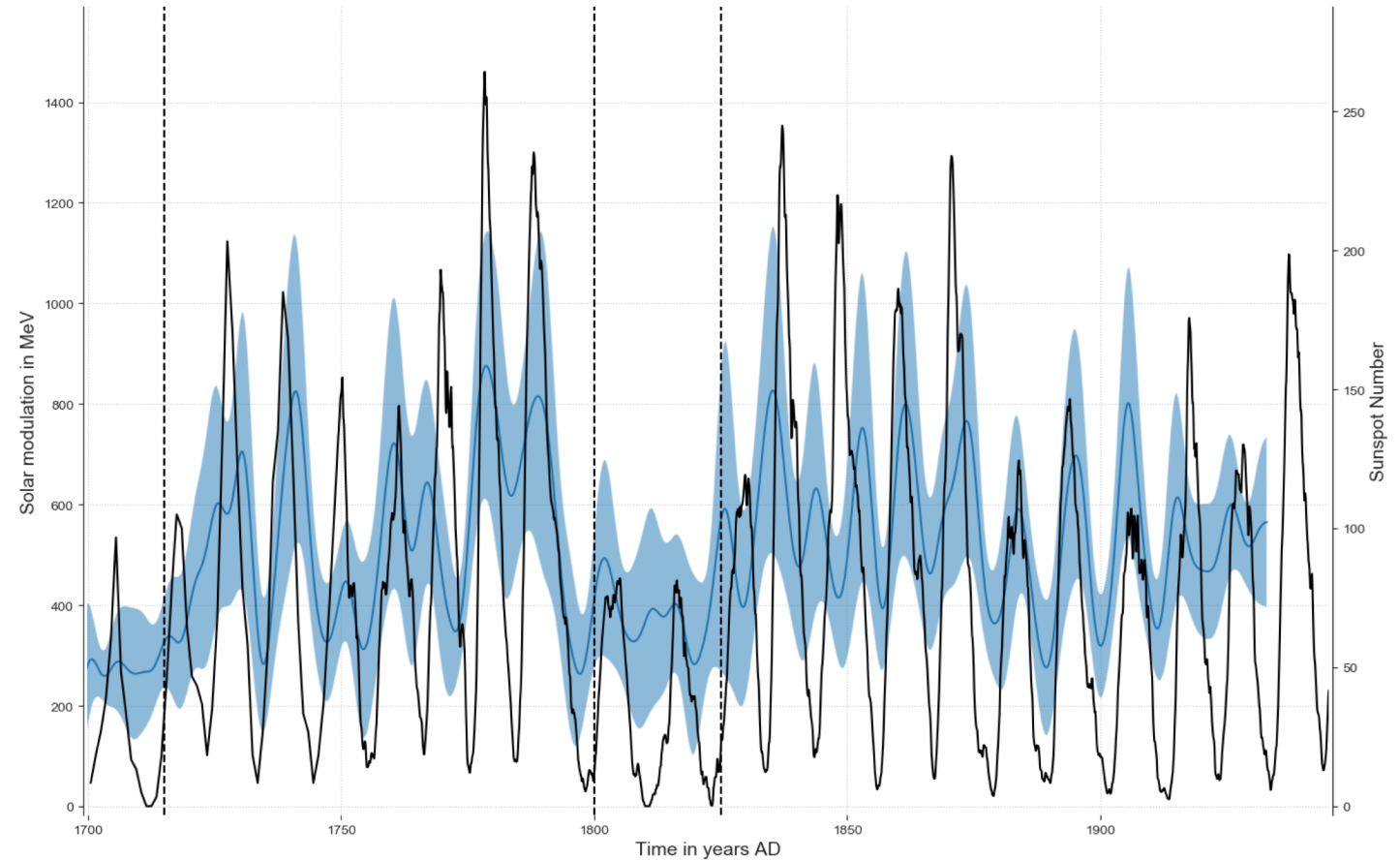


Production anticorrelates with solar activity



## Short term solar variability

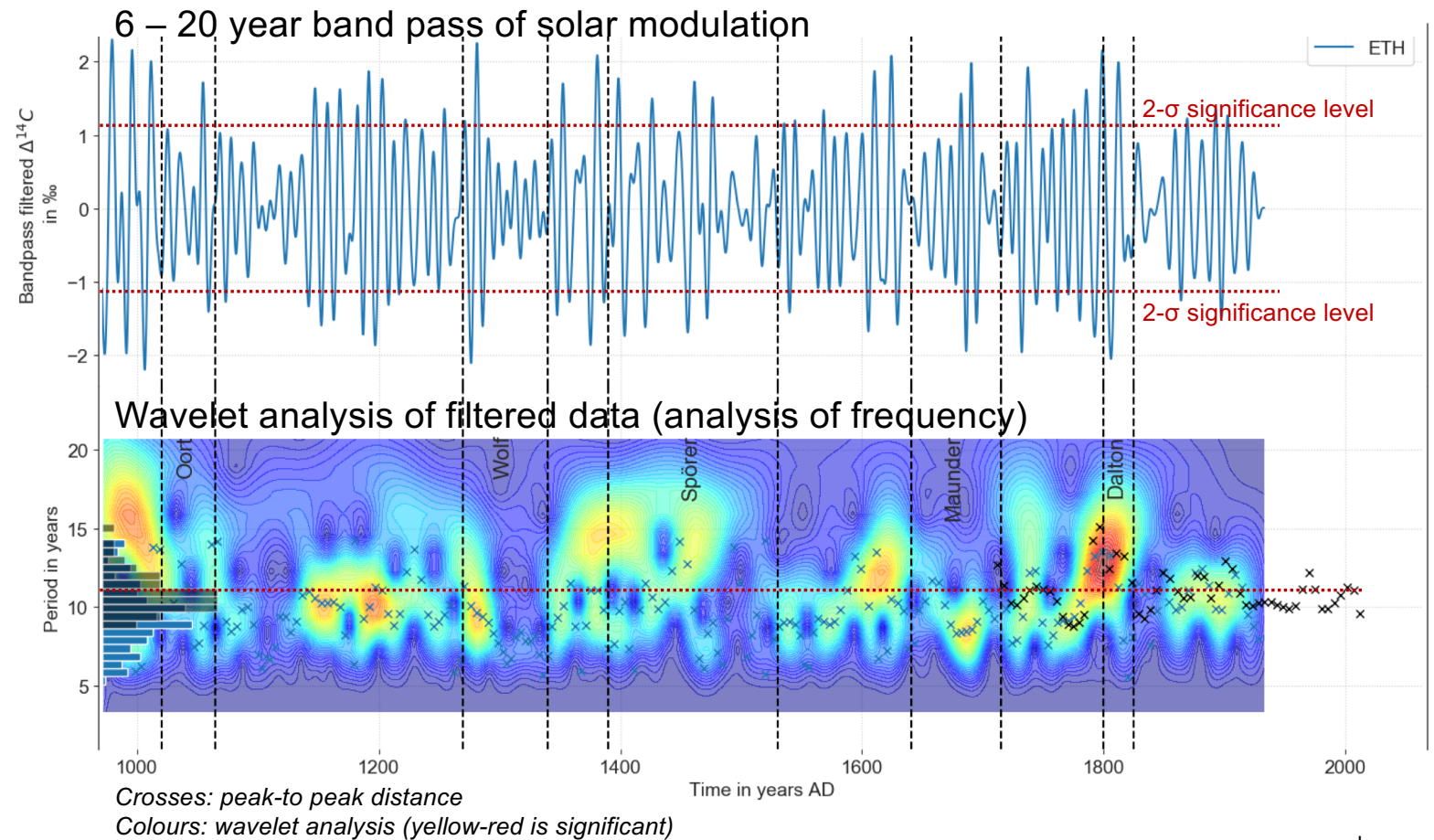
- General agreement of **solar modulation (blue)** from  $^{14}\text{C}$  with observed **sunspot numbers (black)**
- Correlates in **amplitude and phase**





# Band pass filtered analysis

- High-frequency solar modulation (from  $^{14}\text{C}$ ) extended **further back in time!**
- **11-year cycles still there...**
- ... but **not always** detected!  
Too low amplitudes!



## Summary

- For the first time we have **clear evidence for 11-year cycles** from proxy data (previous analyses on  $^{14}\text{C}$  were of too short length) prior to direct observations
- **Detection of cycles is not easy** – we estimate an average **amplitude of only 1‰** (previous estimations of 1.4‰ or more are clearly too high)
- The fine structure of the 11-year cycles is also very valuable for age determination of samples by **high-precision  $^{14}\text{C}$  wiggle-matching**

*... will be published soon with statistical analysis*