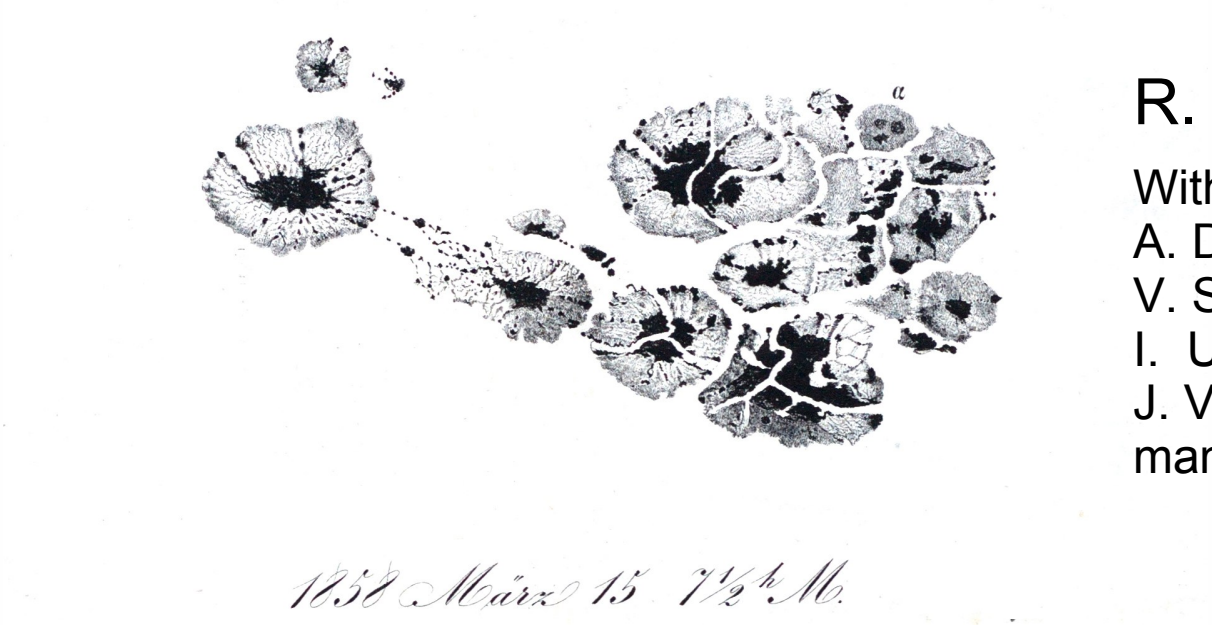
Sunspot observations in the past and the activity in the Maunder minimum



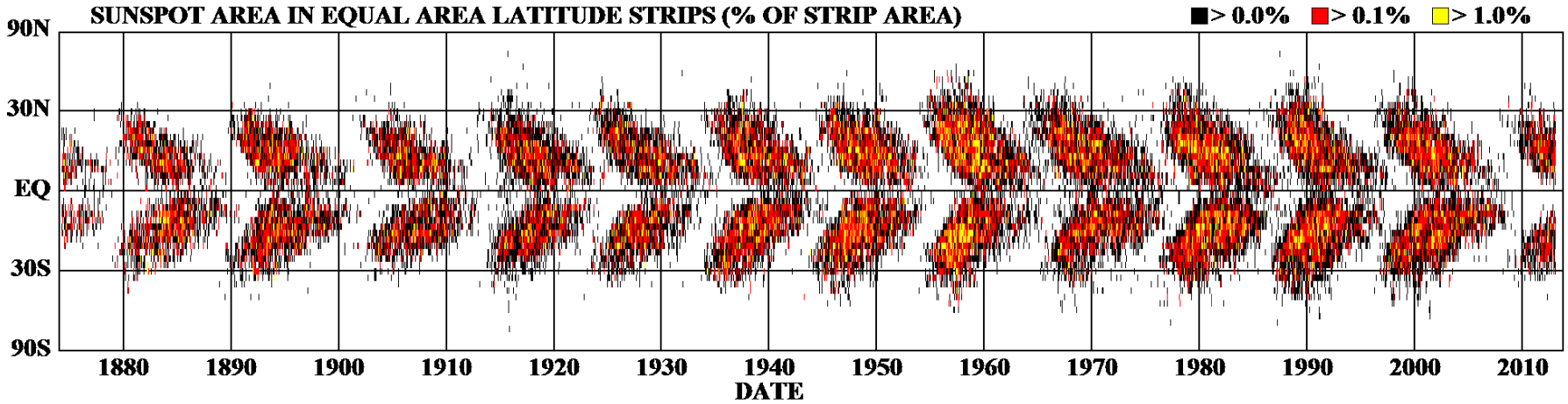
R. Arlt

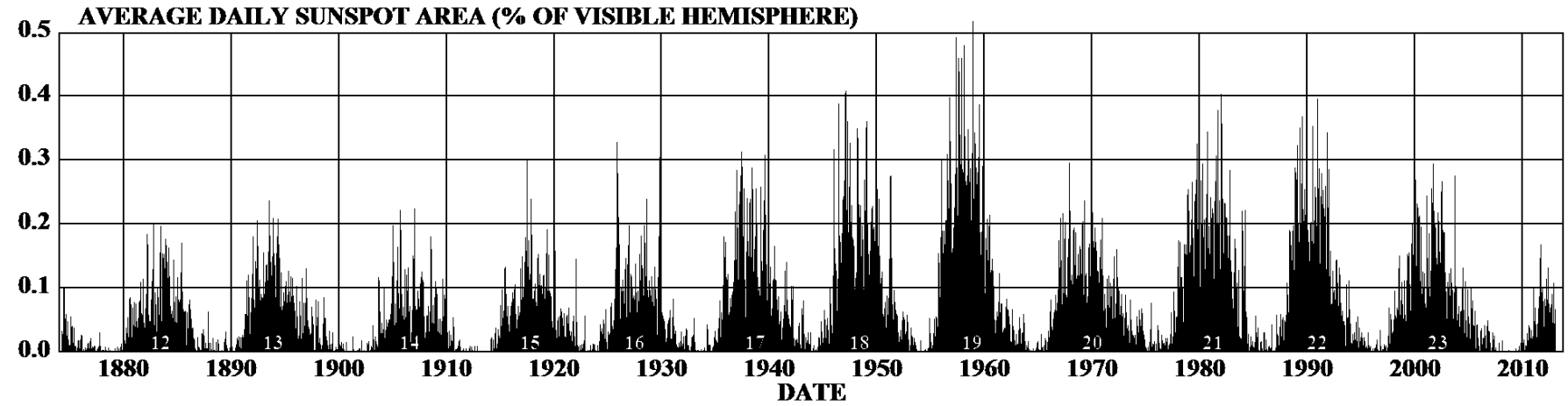
With contributions by
A. Diercke,
V. Senthamizh Pavai,
I. Usoskin,
J. Vaquero, and
many others who helped!

AIP

Solar cycle and butterfly diagram

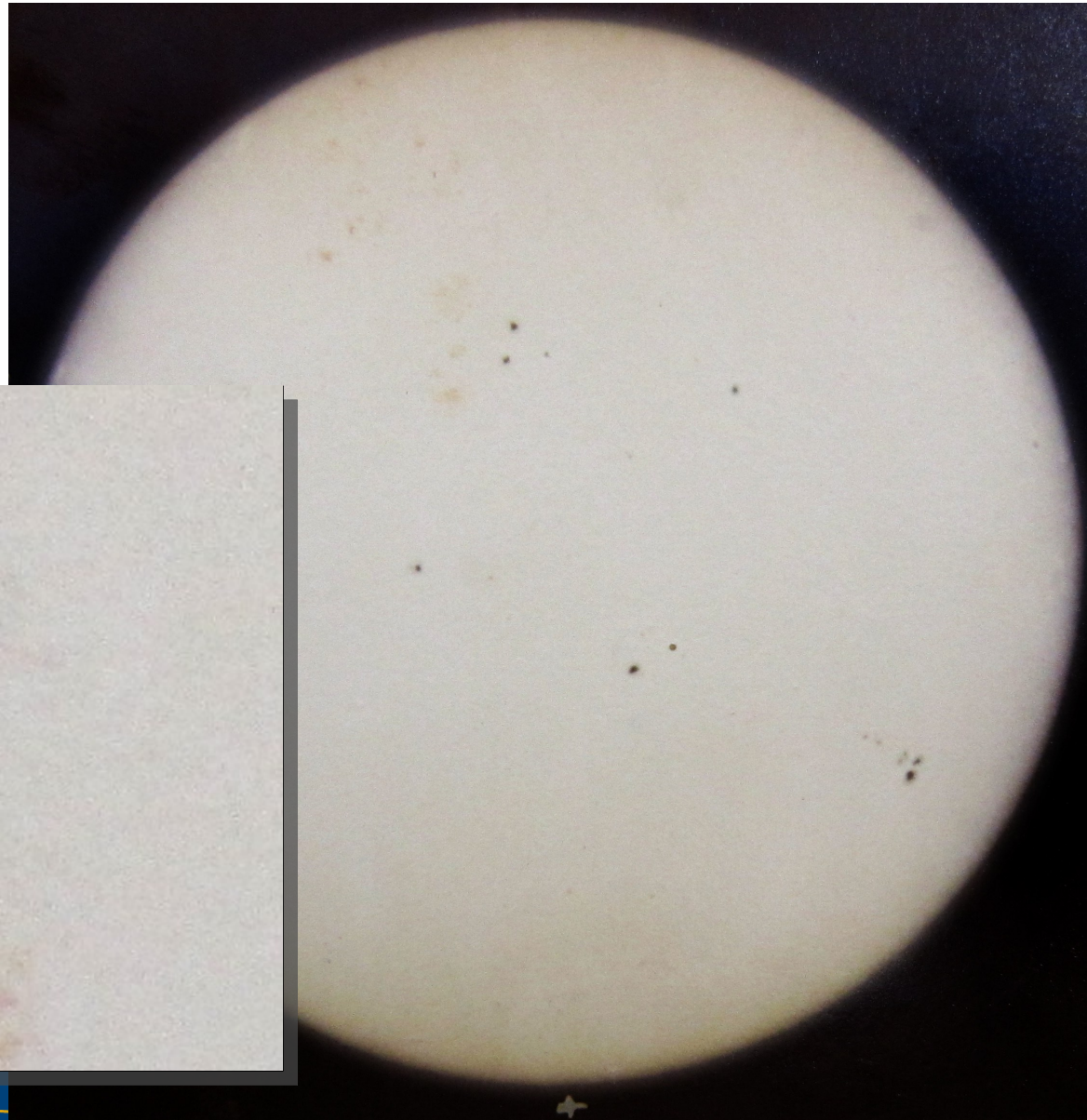
– has it always been like this?





Greenwich photographs

- Visual sunspot drawings superior to photos

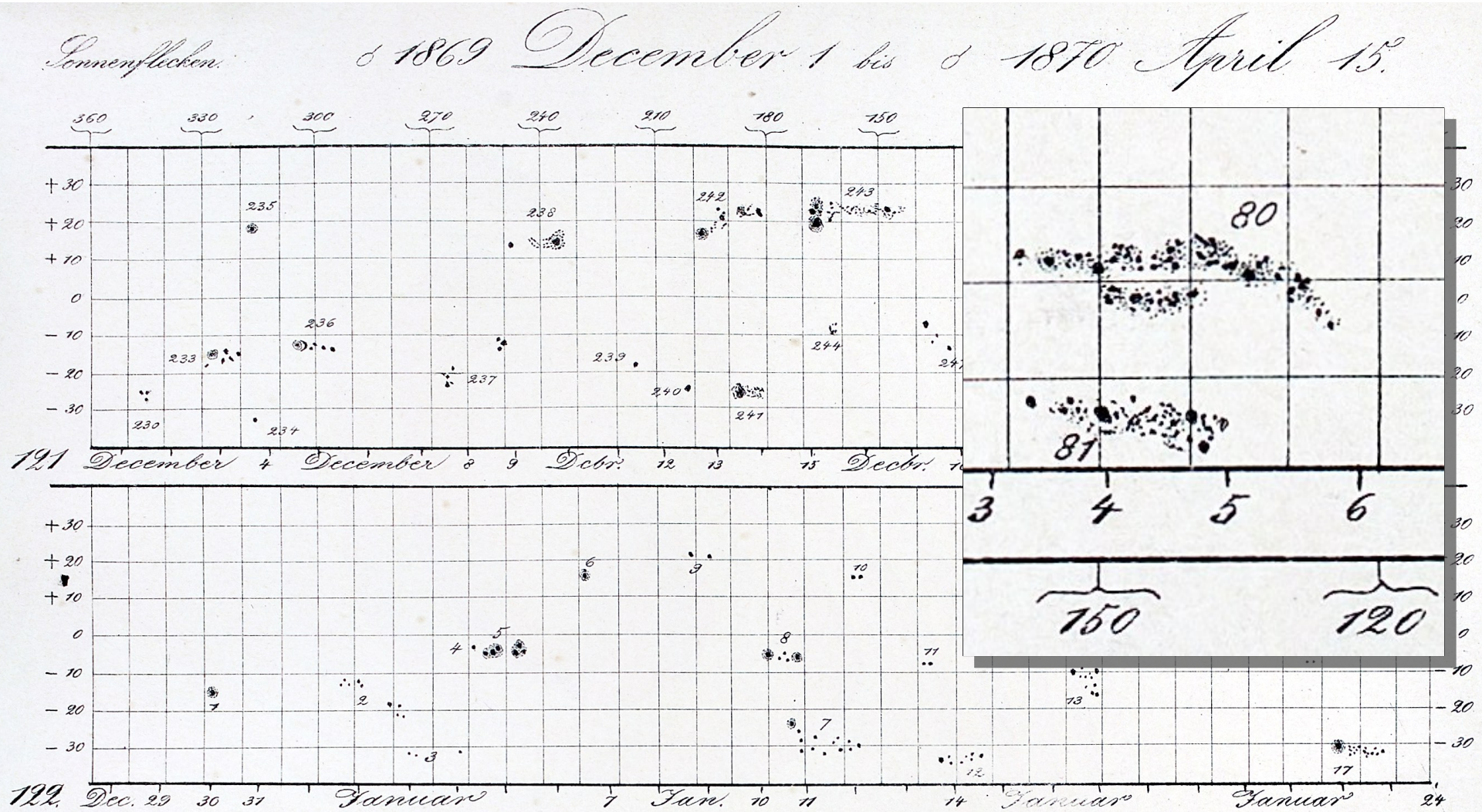


AIP

Spörer (1861-1894), Carrington (1853-1861)

- Groups drawn near passage of central meridian

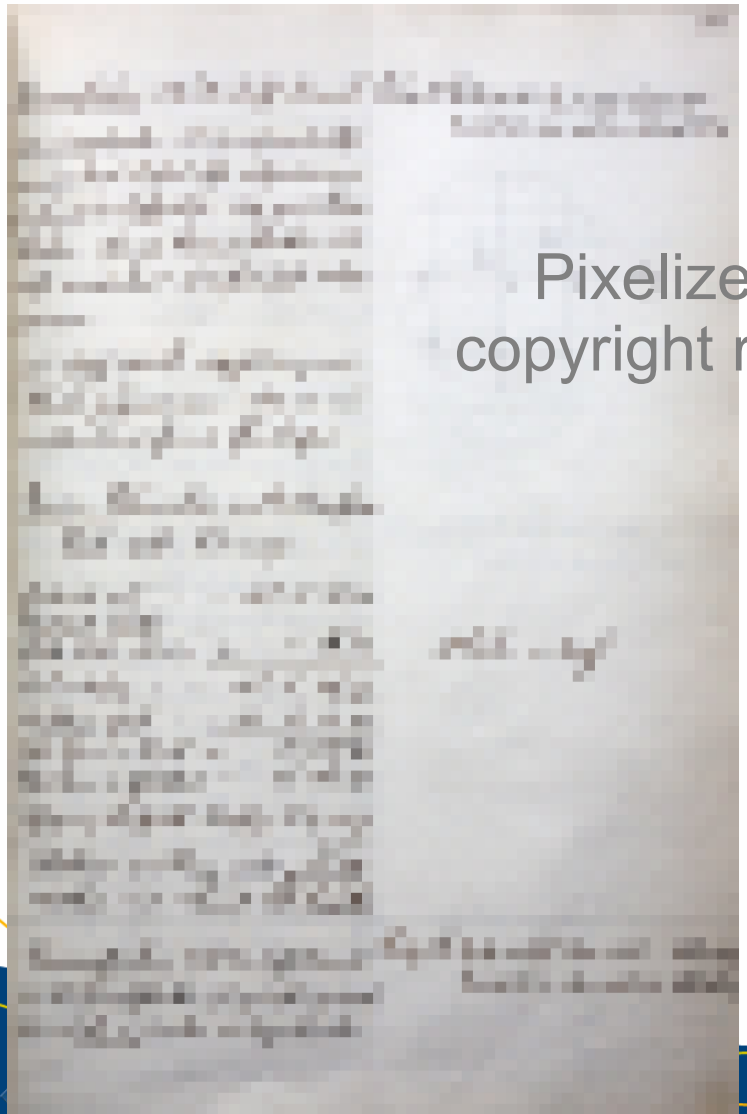
Diercke et al. (2015)



AIP

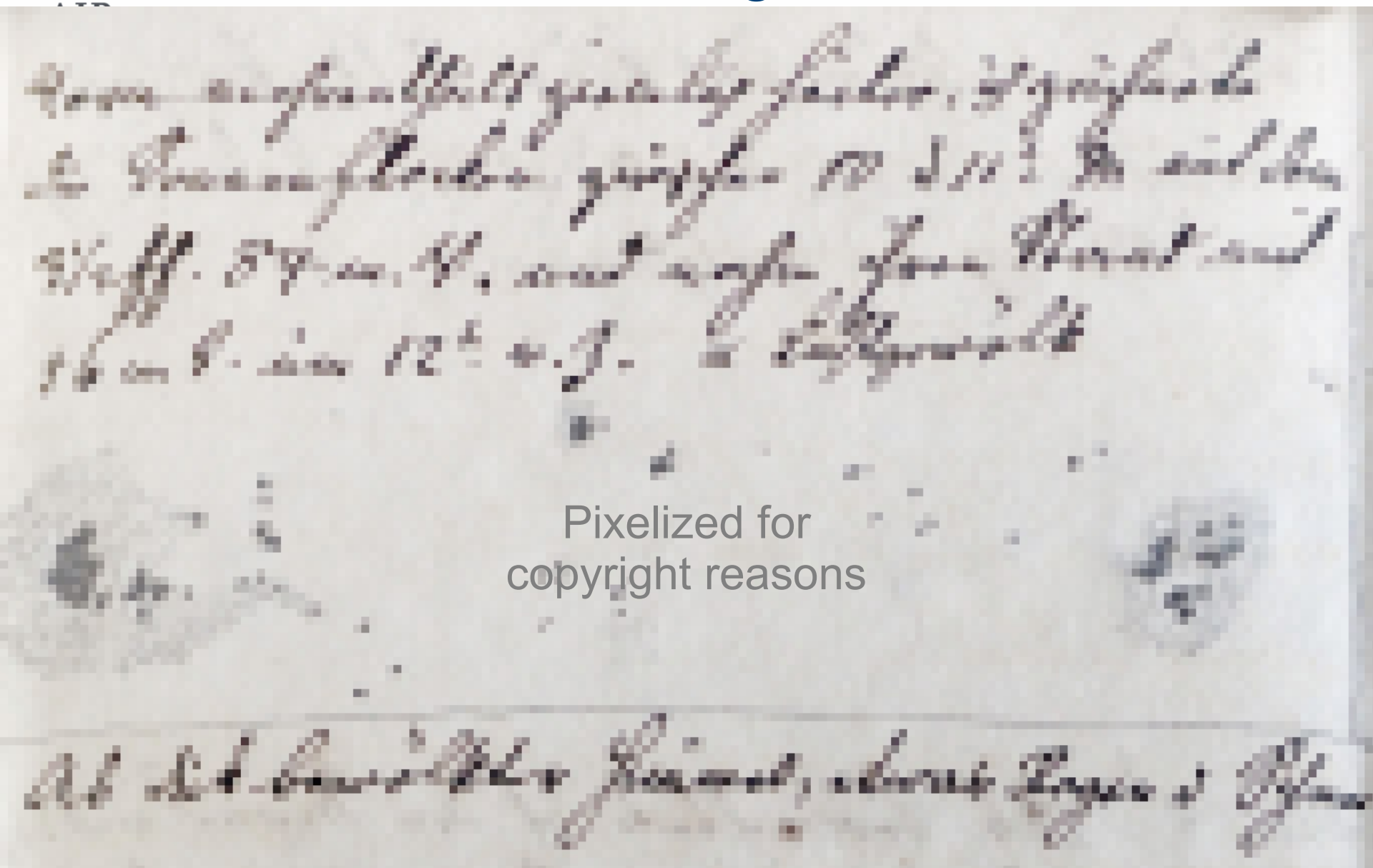
Samuel Heinrich Schwabe, 1825-1868

~8500 drawings



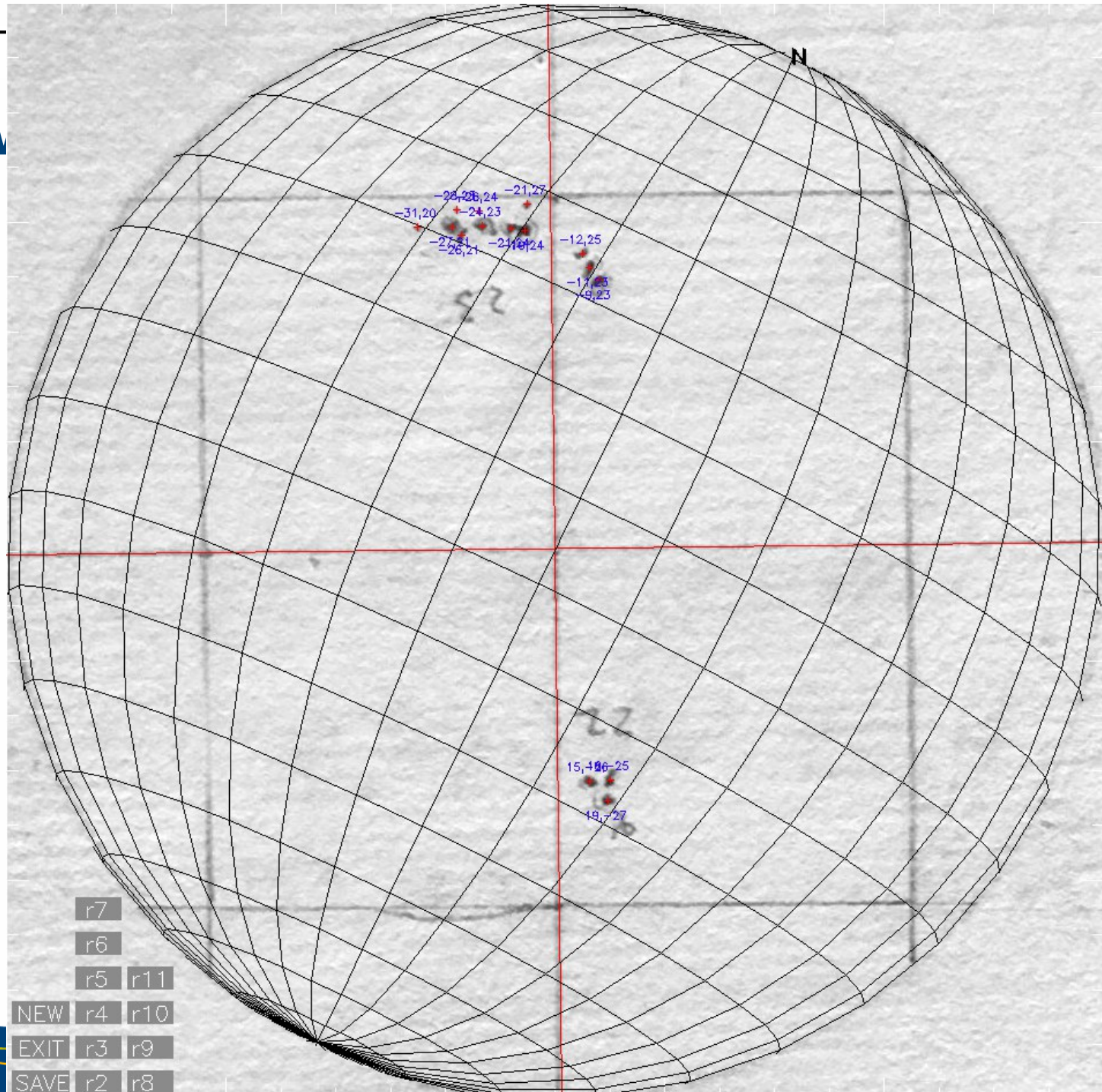
Pixelized for copyright reasons

Schwabe's drawings



Schw

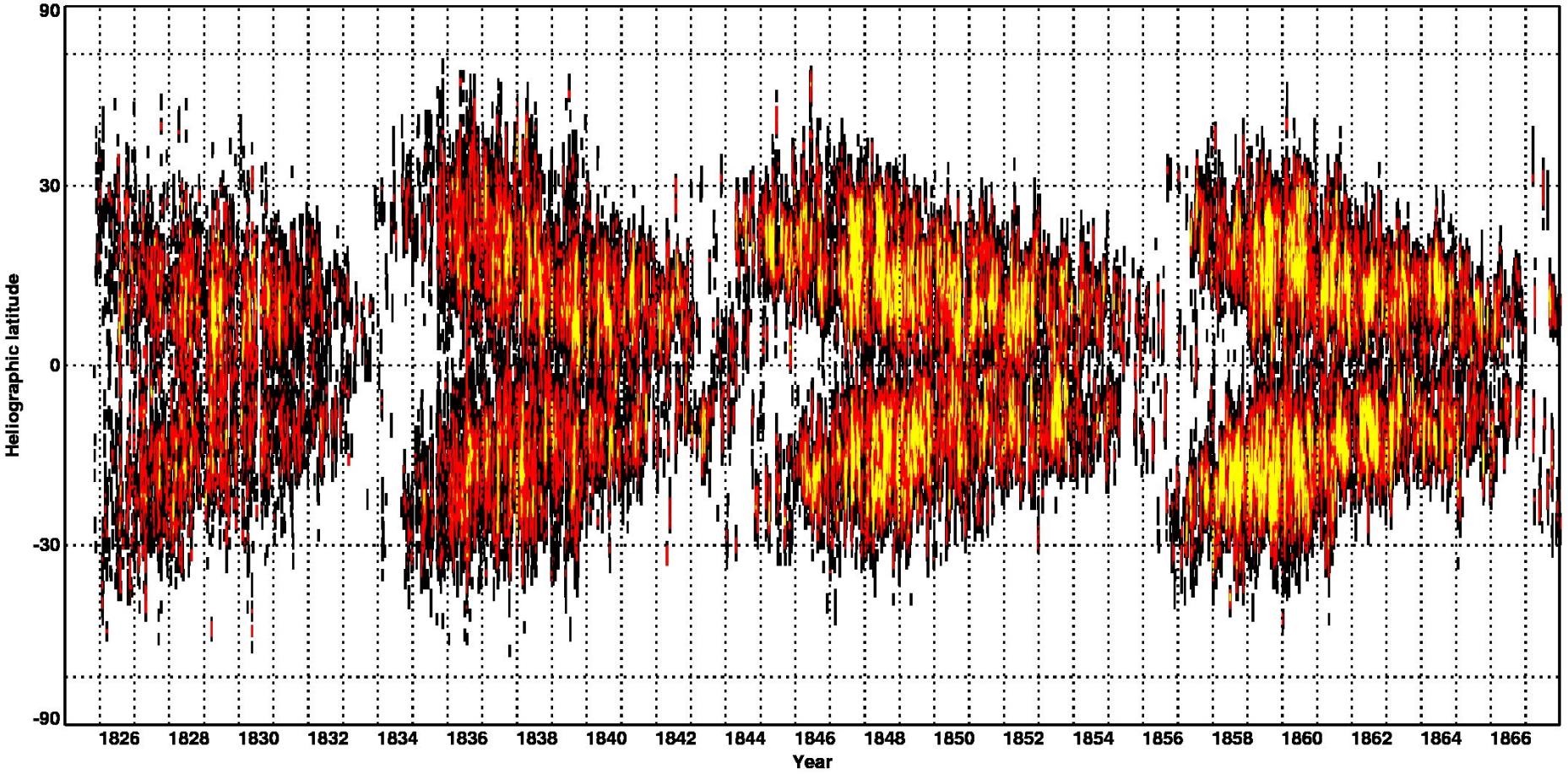
- Manual on-screen measure-ments
- 12 cursor-sizes for areas



AIP

Schwabe

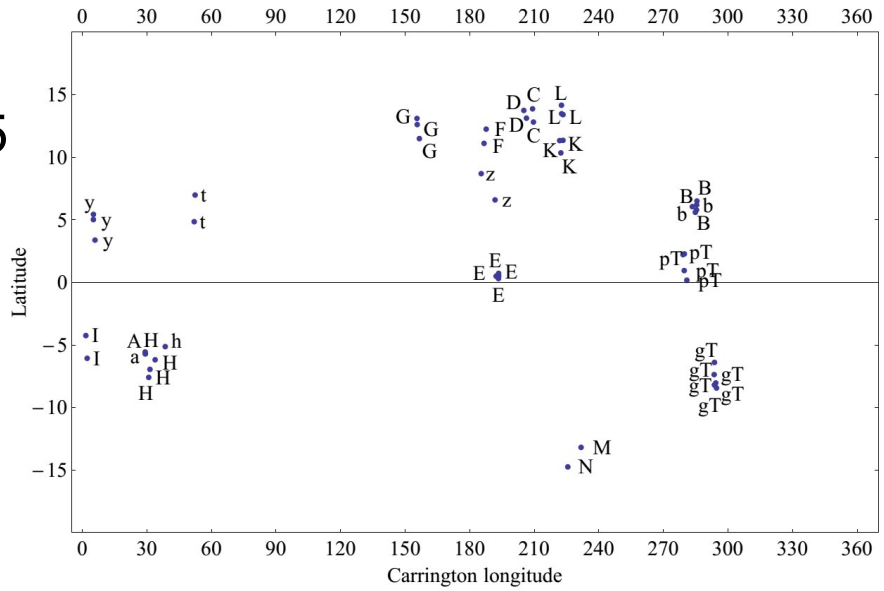
- 134,000 positions (Arlt et al. 2013), ~ 95,000 by Raisa Leussu, Oulu



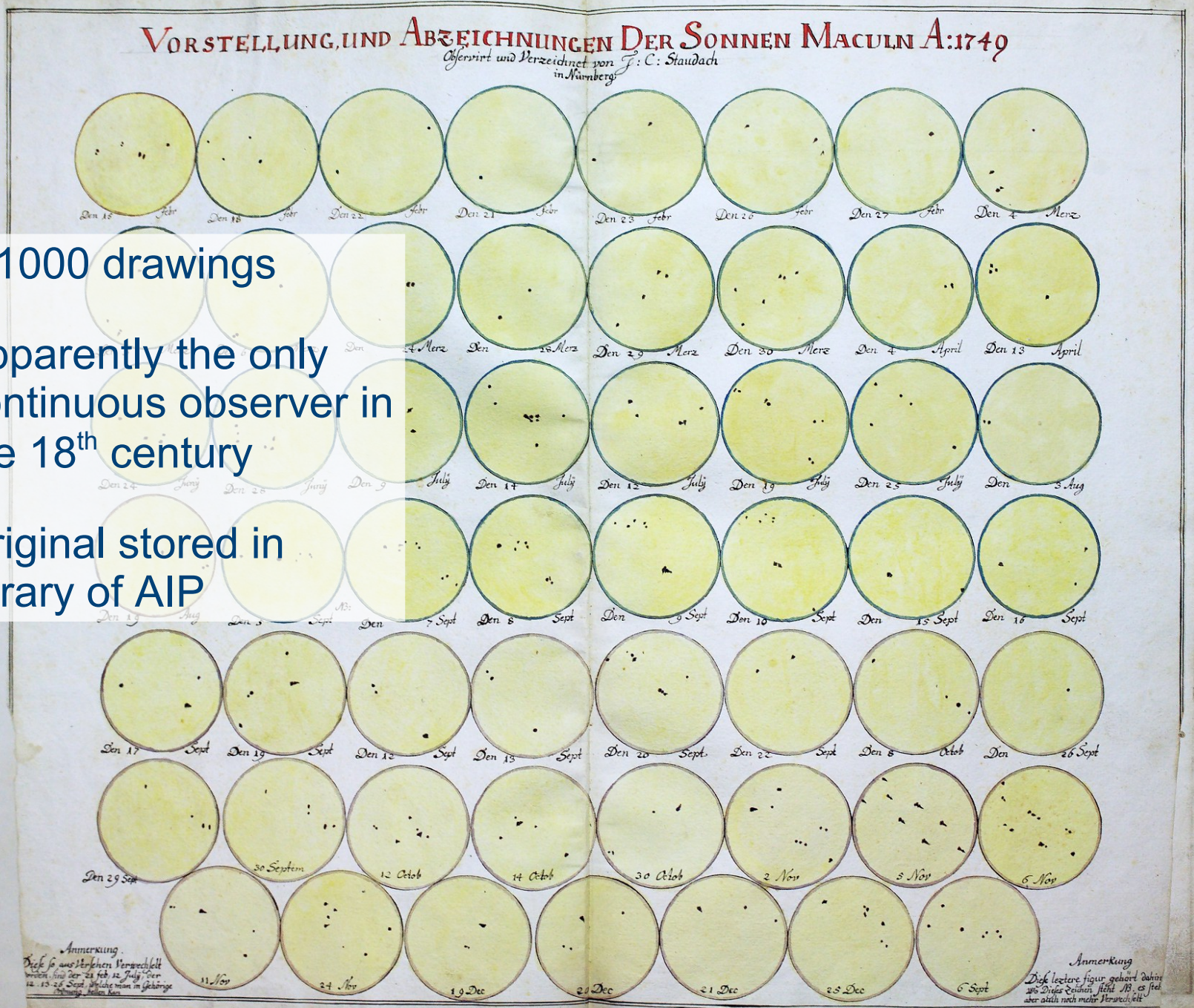
Honoré Flaugergues, ~1788-1830

- Several hundred sunspot observations
- Wolf's interpretation of *sunspot numbers* correct
- Today in archives of the Paris Observatory library
- Mostly contact times:

le bord du ⊙ al horaire	12 39 58
la grande tache a l'oblique	12 40 22.5
la petite tache a l'oblique	12 40 46
la grande tache al horaire	12 41 21
la petite tache al horaire	12 41 31
le bord du soleil al horaire	12 42 09
la petite tache al oblique	12 42 18
la grande tache al oblique	12 42 22



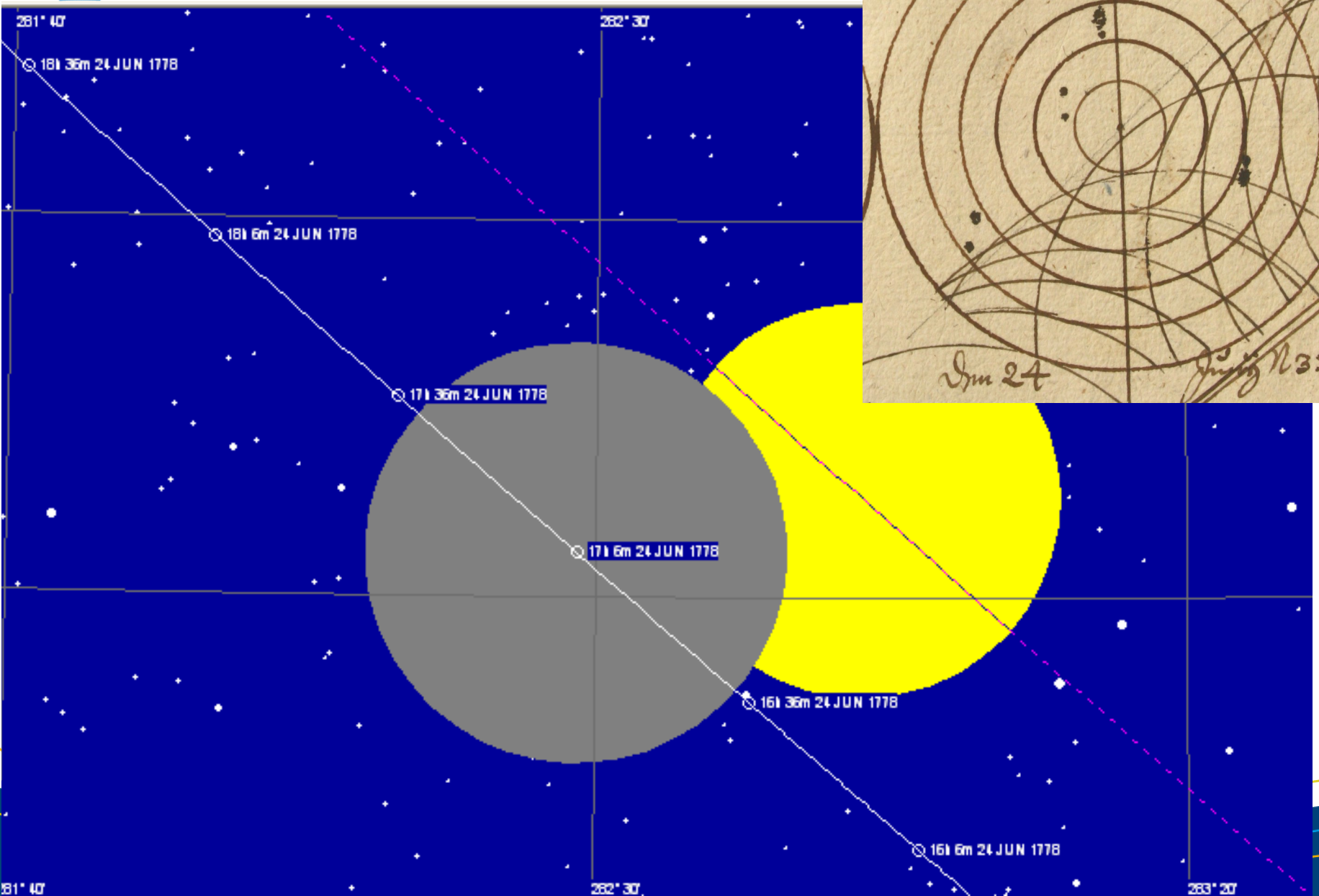
Graph by E. Illarionov



- > 1000 drawings
- Apparently the only continuous observer in the 18th century
- Original stored in library of AIP

1600 1700 1800

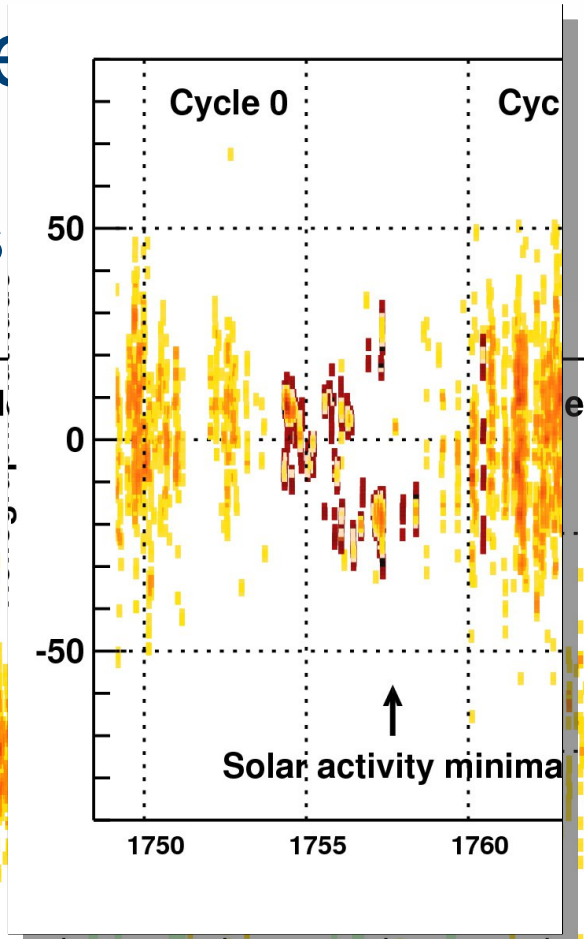
Staudacher: Jun 24, 1778

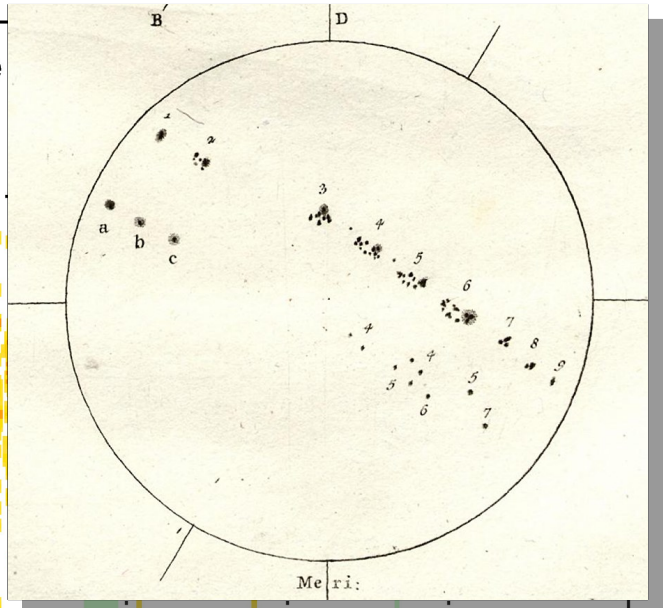


Staudache

- 6200 positions

Ludovico Zucconi
Cristo et al. (2011)

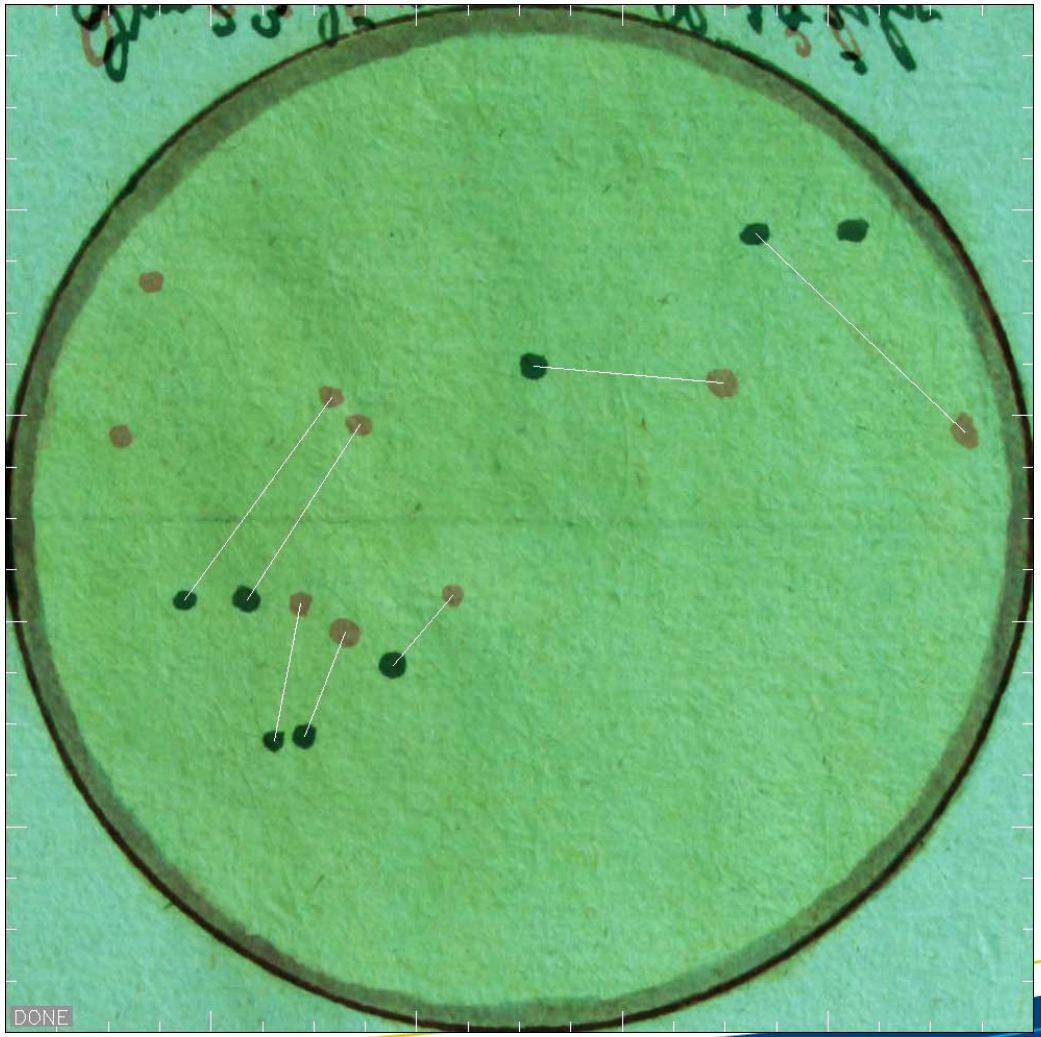




AIP

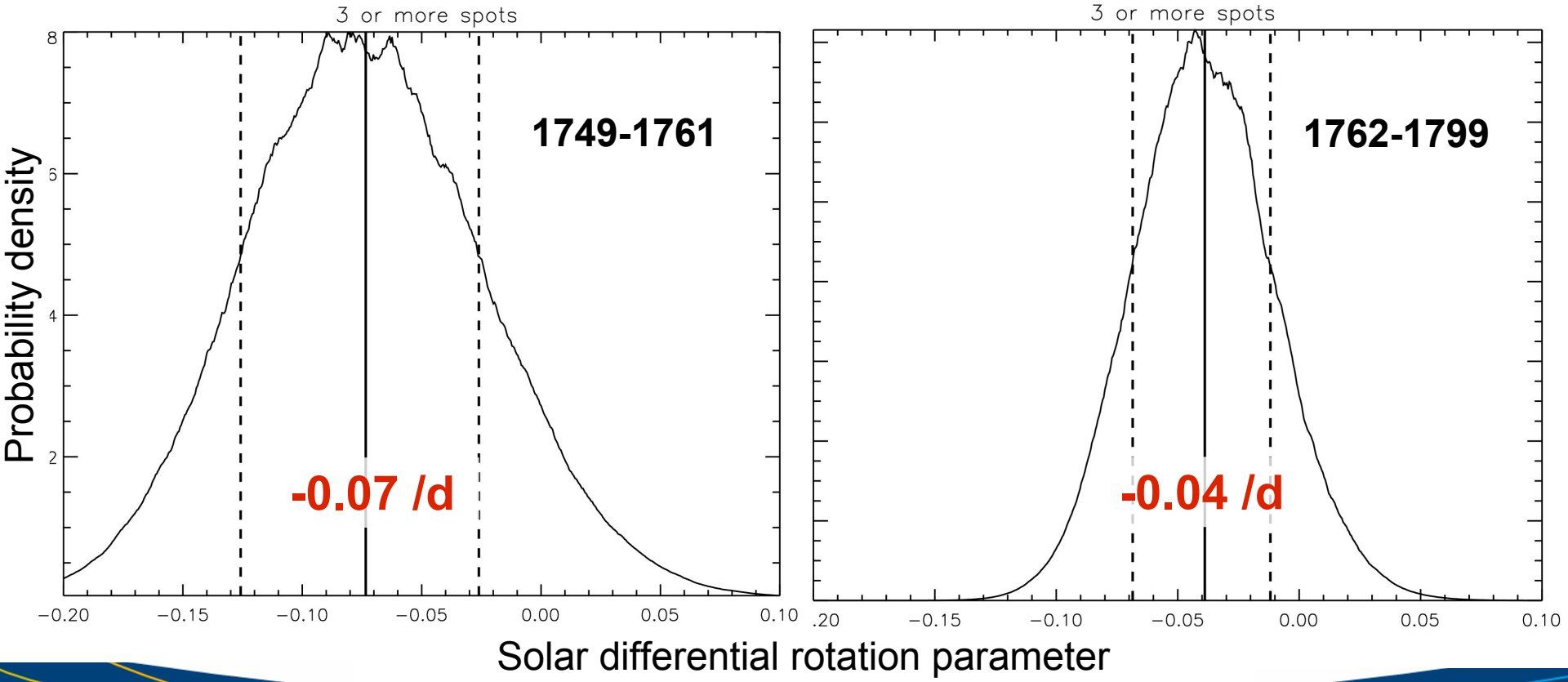
Staudacher – differential rotation

- Pairs of drawings
- Free parameters:
  - Sunspot positions
  - Differential rotation
  - Time offset
- Bayesian inference
  - → Full knowledge of error margins



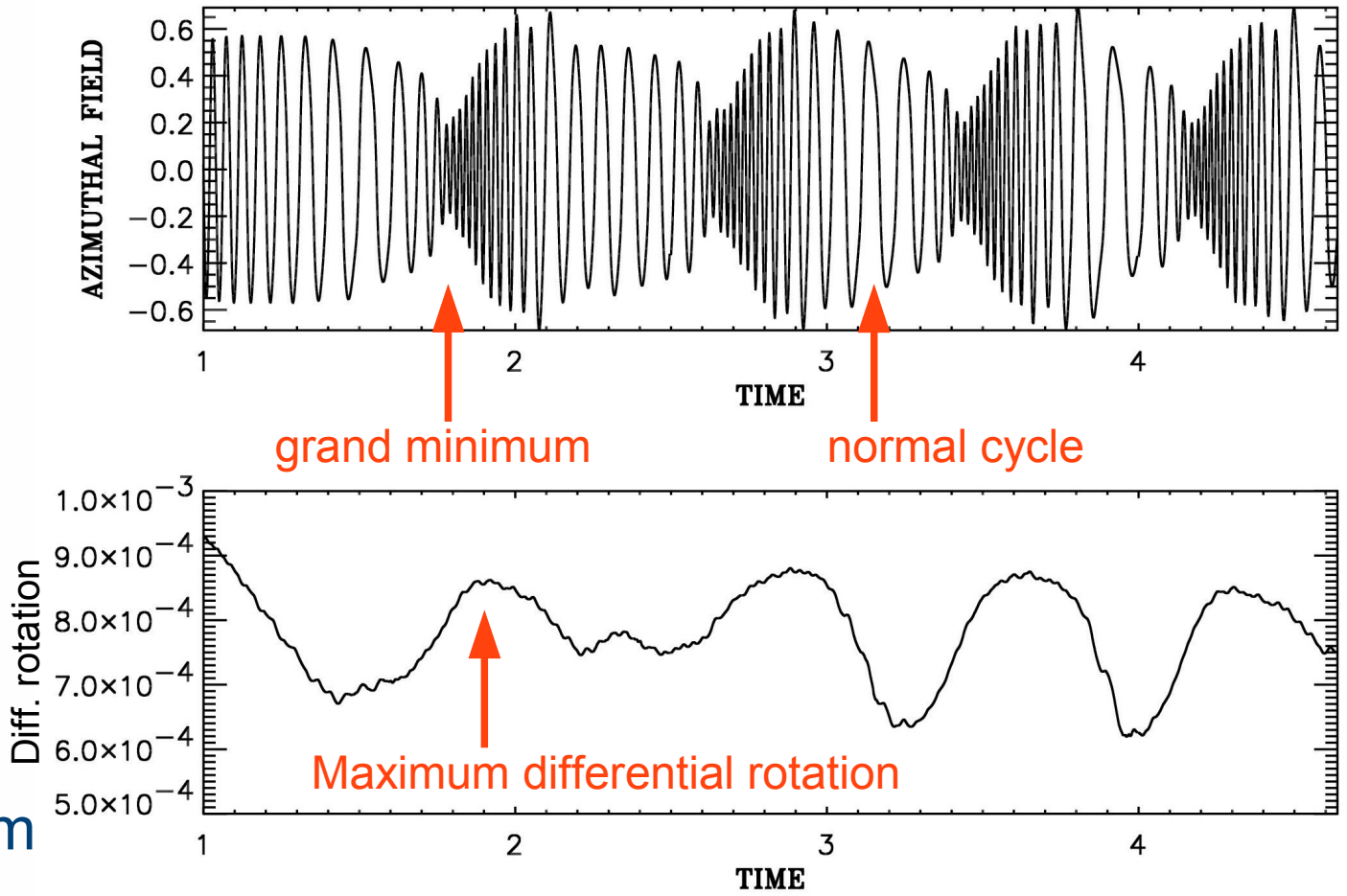
Staudacher – differential rotation

- Bayesian inference for ~250 observation pairs; Sun today: -0.05/d
  (Arlt & Fröhlich 2012)



Differential rotation in dynamo

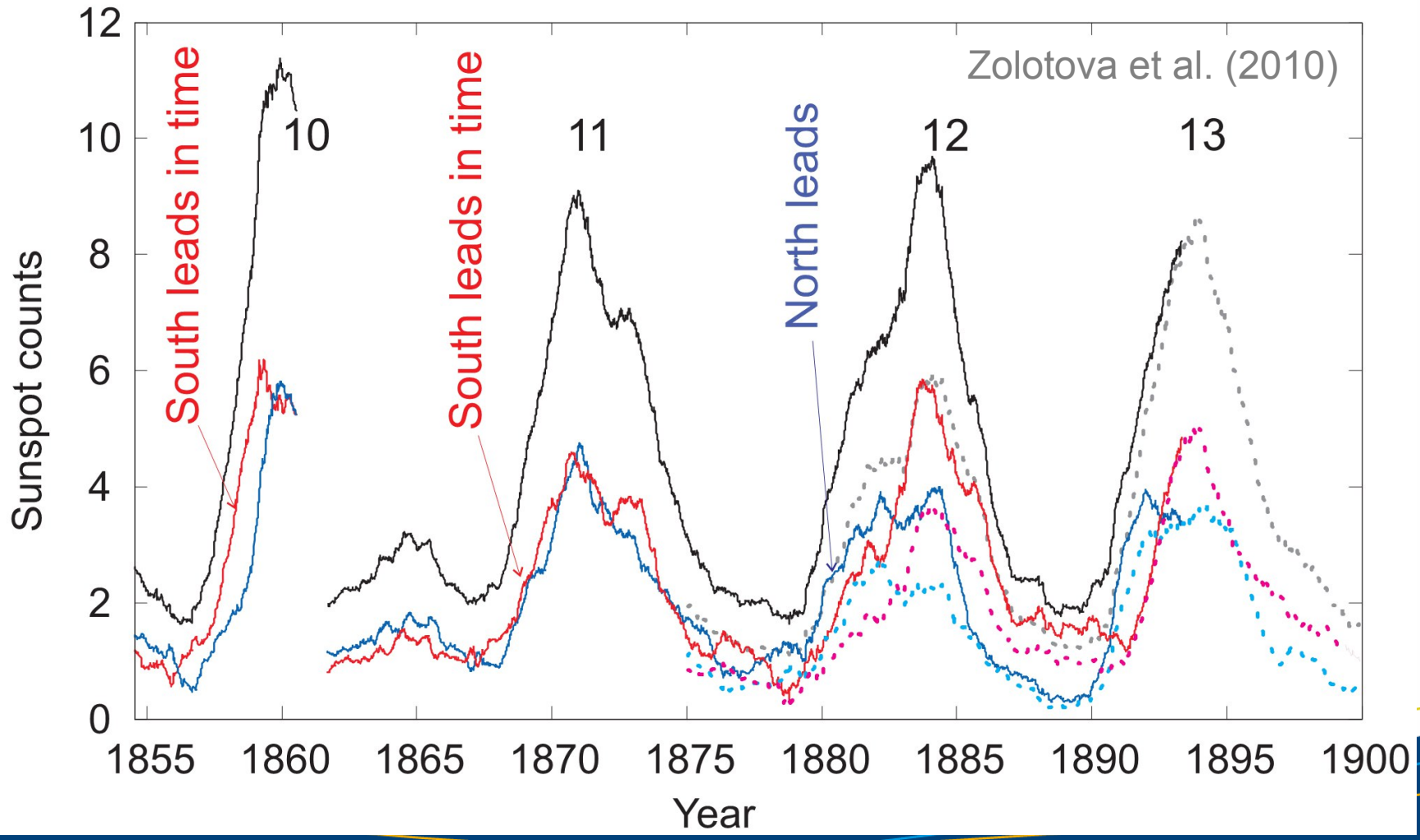
- Solve mean-field eq. for ***B*** *and* $\Omega(r,\theta)$
- Include back-reaction on generation of diff. rotation
- Get maximum diff. rot after grand minimum



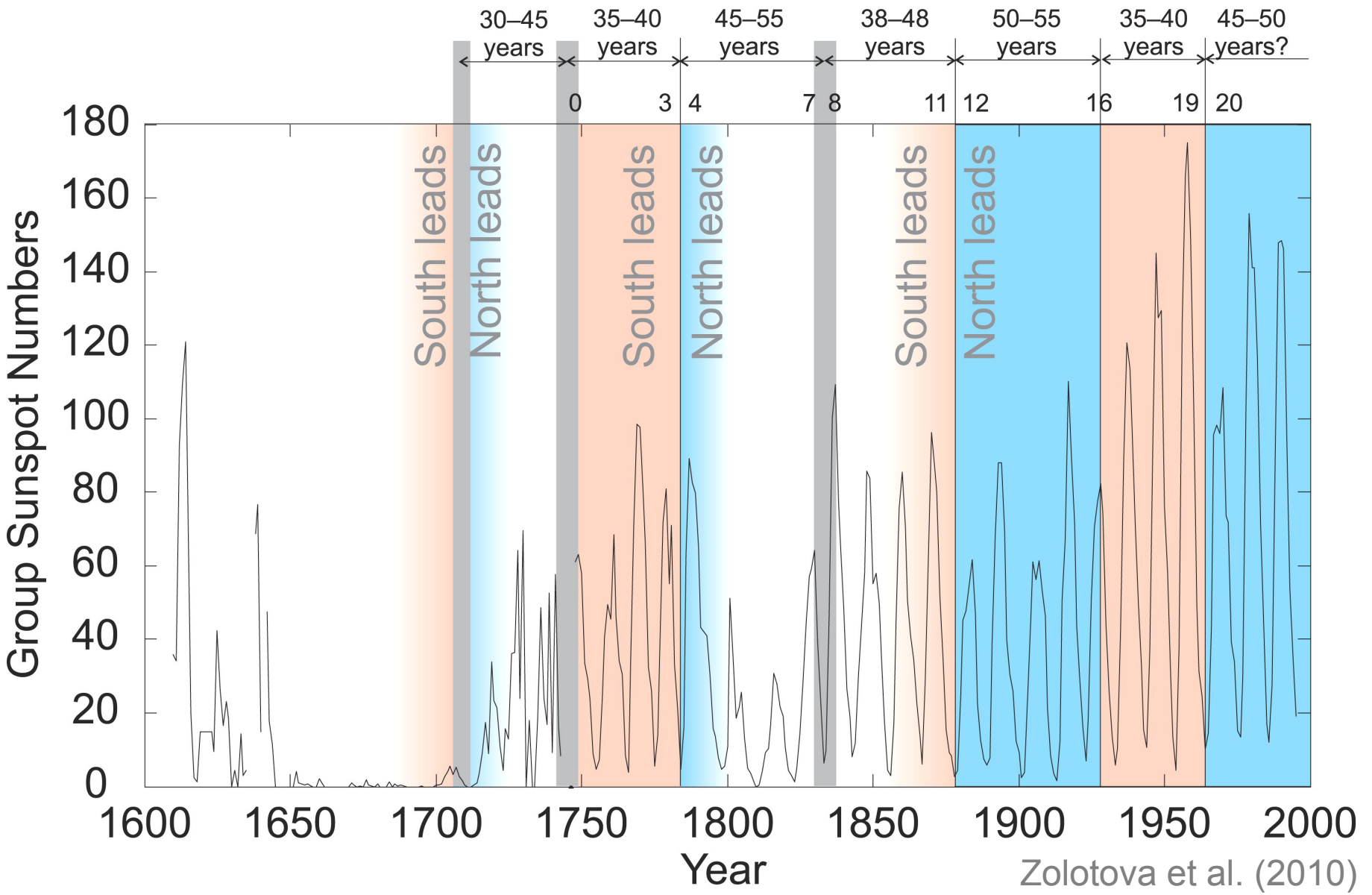
Küker, Arlt, Rüdiger (1999), but also Tobias (1997), Pipin (1999), Bushby (2006)

Hemispheric cycle phase

- Cycle of northern and southern hemisphere not in phase



Hemispheric coupling important for dynamo

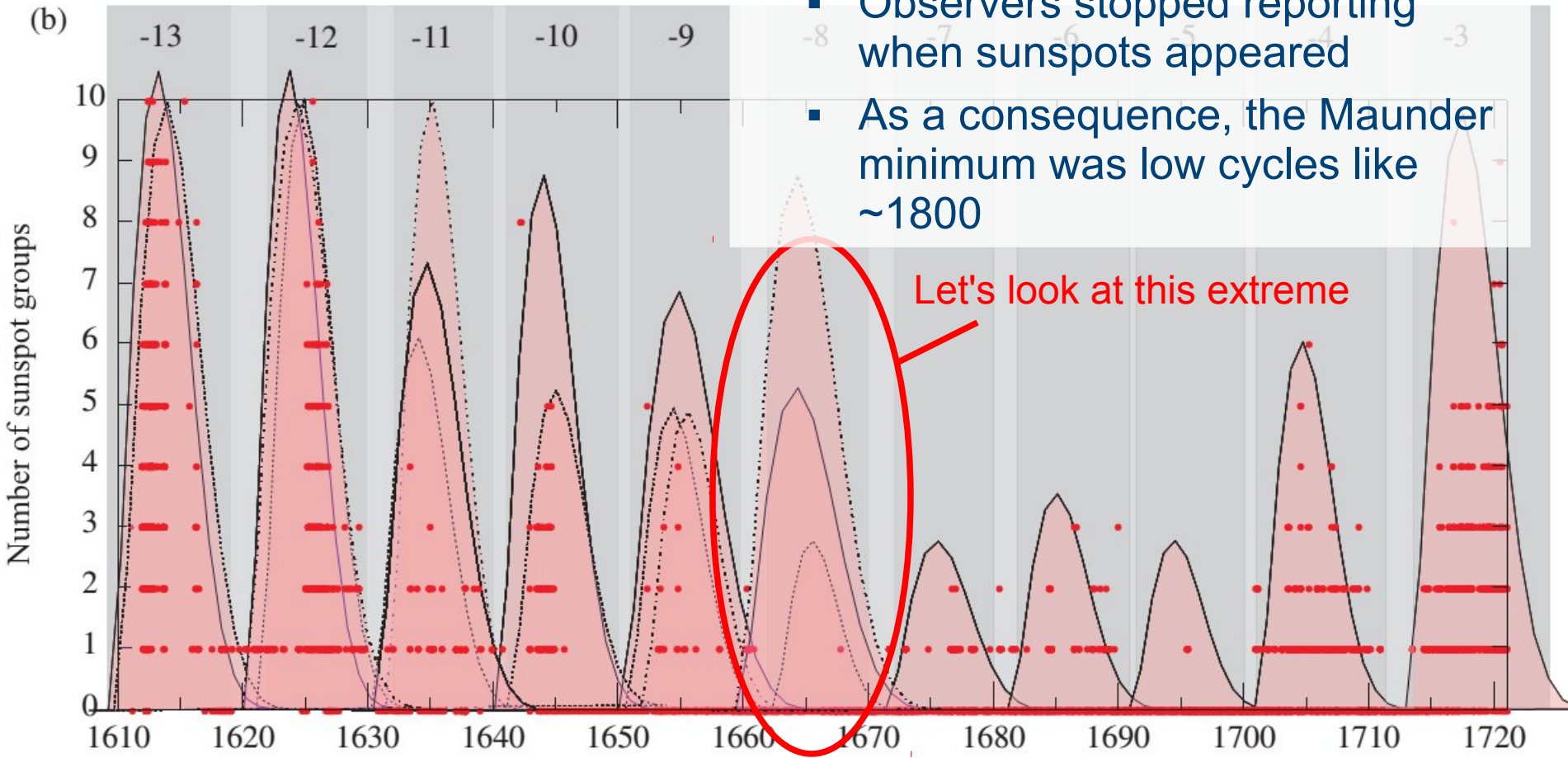


Zolotova et al. (2010)

AIP

The 17th century (incl. Maunder min.)

- Zolotova & Ponyavin (2015) claimed that
  - Due to the world-view of the time, non-circular spots were omitted
  - Observers stopped reporting when sunspots appeared
  - As a consequence, the Maunder minimum was low cycles like ~1800



Problems of the record

NUMBER OF SUNSPOT GROUPS FOR THE YEAR: 1663 AS OBSERVED BY: WEIGEL, E., JENA

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

Group sunspot number by Hoyt & Schatten (1998)

AIP

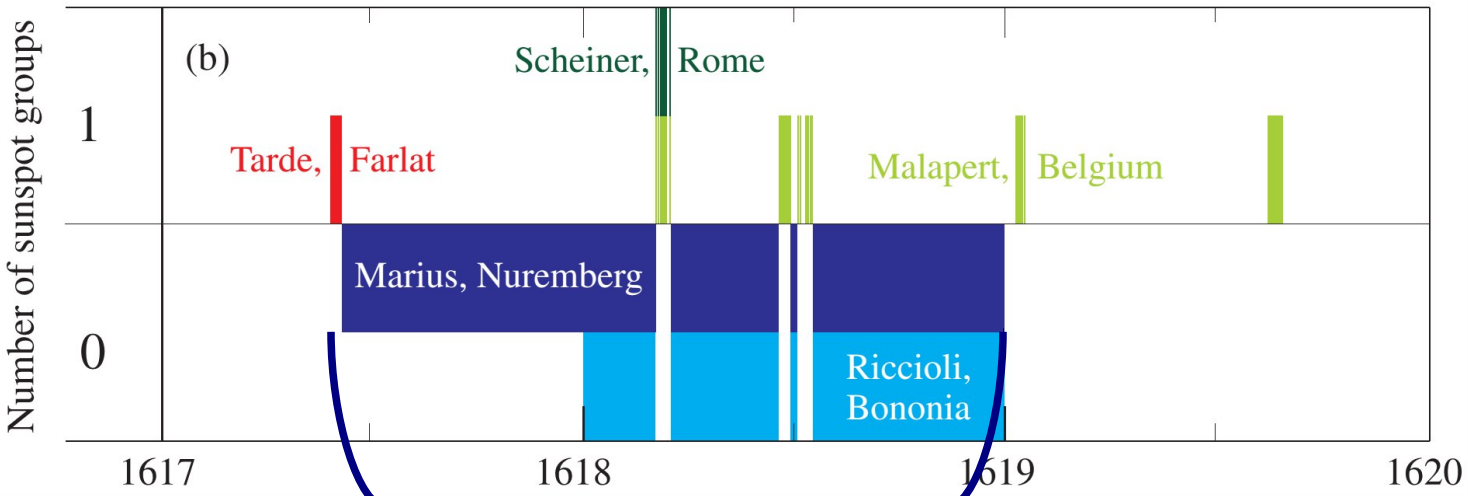
Deepest minimum: 1660-1671

- According to Spörer (1889), Weigel (Jena, Germany) reports in 1665:
- Many dilligent observers of the skies have wondered here that for such a long time no spots were noticeable on the Sun […] despite having tried in many ways, setting up large and small spotting scopes pointed to the Sun [...]

gefunden wurde, was von Zeitgenossen berichtet wird (W. 112). Weigel in Jena sagt 1665: Es haben sich anhero viel fleissige Himmelsbetrachter gewundert, dass so lange Zeit keine Flecken an der Sonne zu spüren gewesen. Und müssen wir allhier zu Jena bekennen, dass, ob wir es wohl auf allerhand Weise versuchet, grosse und kleine Perspectiven aufgestellet und nach der Sonne gerichtet, wir dennoch von dergleichen Erscheinungen eine geraume Zeit nichts befunden. (Vergl. auch W. 3.)

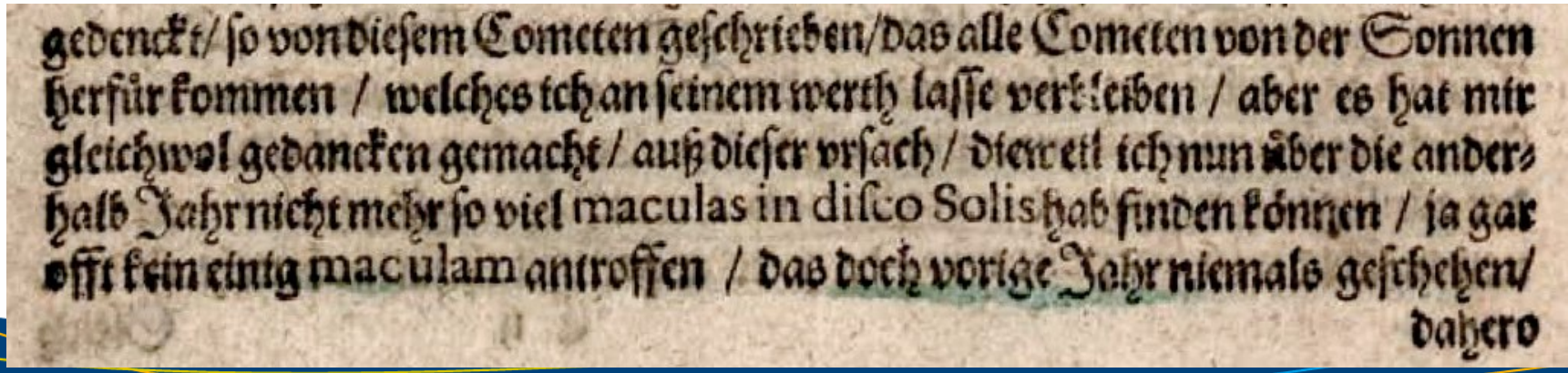
Spots omitted in verbal reports?

- Deliberately stopped reporting?
- No, since original reports have no dates.
- Gaps are purely technical



Zolotova & Ponyavin (2015)

"fewer spots over the last 1.5 yr" in Marius (1619)


gedenckt/ ſo von dieſem Cometen geſchrieben/das alle Cometen von der Sonnen herfür kommen / welches ich an ſeinem werth laſſe verbleiben / aber es hat mir gleichwol gedancken gemacht / auß dieſer vrſach / dieweil ich nun über die anderthalb Jahr nicht mehr ſo viel maculas in diſco Solis hab finden können / ja gar offt kein einig maculam antroffen / das doch vorige Jahr niemals geſchehen/ dahero

AIP

Deepest minimum: 1660-1671

New Observations of Spots *in the* Sun; *made at the Royal Academy of* Paris, *the* 11, 12 *and* 13*th of* August 1671; *and* Englisht *out of the* French, *as follows.*

IT is now about twenty * years since, that Astronomers have not seen any considerable *Spots* in the Sun, though before that time, since the Invention of Telescopes, they have from time to time observed them. The Sun appeared all that while with an entire brightness, and Signor *Cassini* saw him so the *ninth* of this month of *August*.

* *See* Numb. 74. *p.* 2216; *whence it will appear, that some such Spots were seen here in* London, *A.* 1660. *And Mons.* Picard *affirm'd to Dr.* Fogelius *at* Hamburg, *that he had seen some in* October 1661. *witness the said* Doctor's *own Letter, written to the Publisher* August 11*th last.*

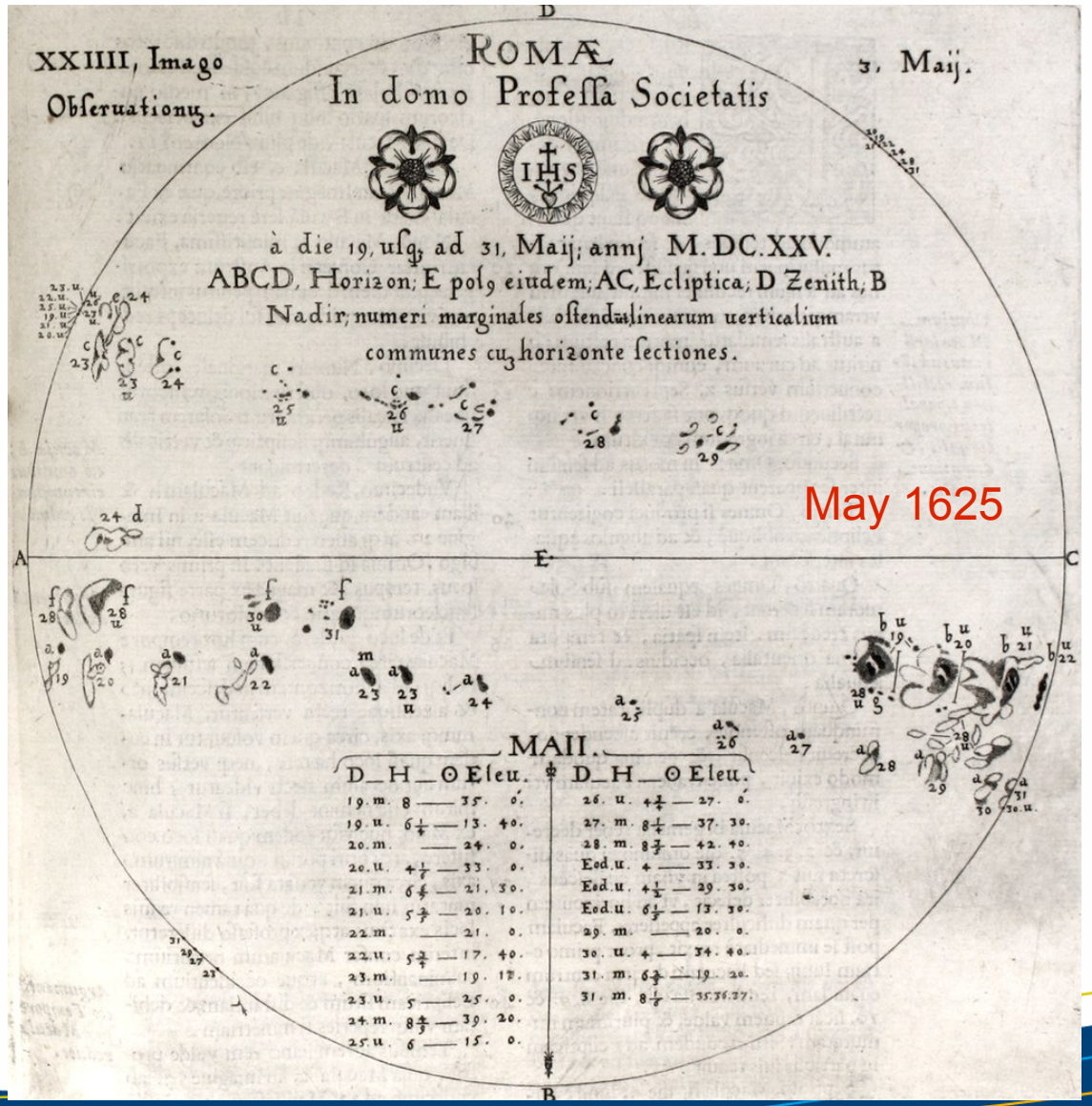
Oldenburg (1671) Phil Trans

- Spots described as oblong and curved – why reporting if non-circular spots “have been omitted all the time”?

AIP

Non-circular spots not reported?

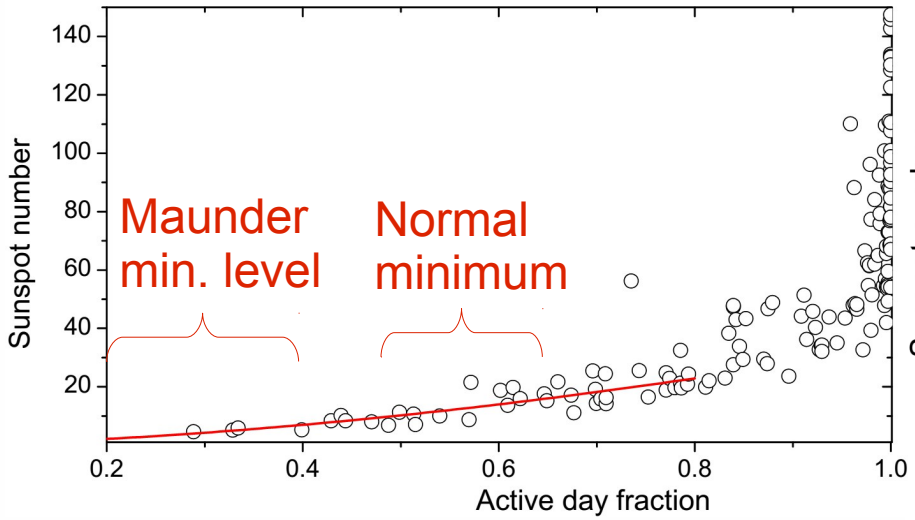
- Christoph Scheiner, 1611-1625
- Many non-circular spots + foreshortening
- Galileo, Hevelius, Cassini, de la Hire, Derham as well

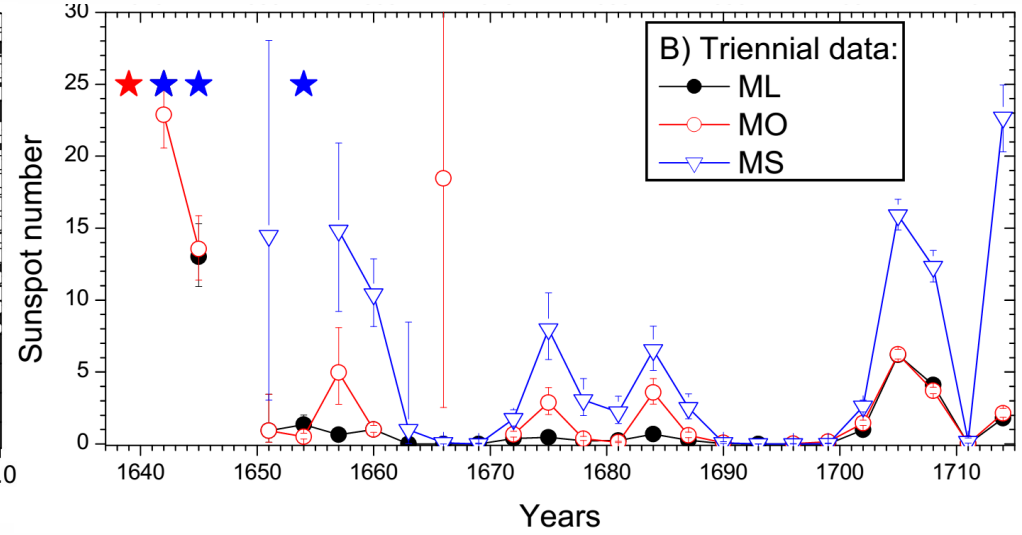


Scheiner (1630)

Assessment of the activity level

- Use fraction of active days; modern minima: >0.5
  Maunder minimum: <0.4





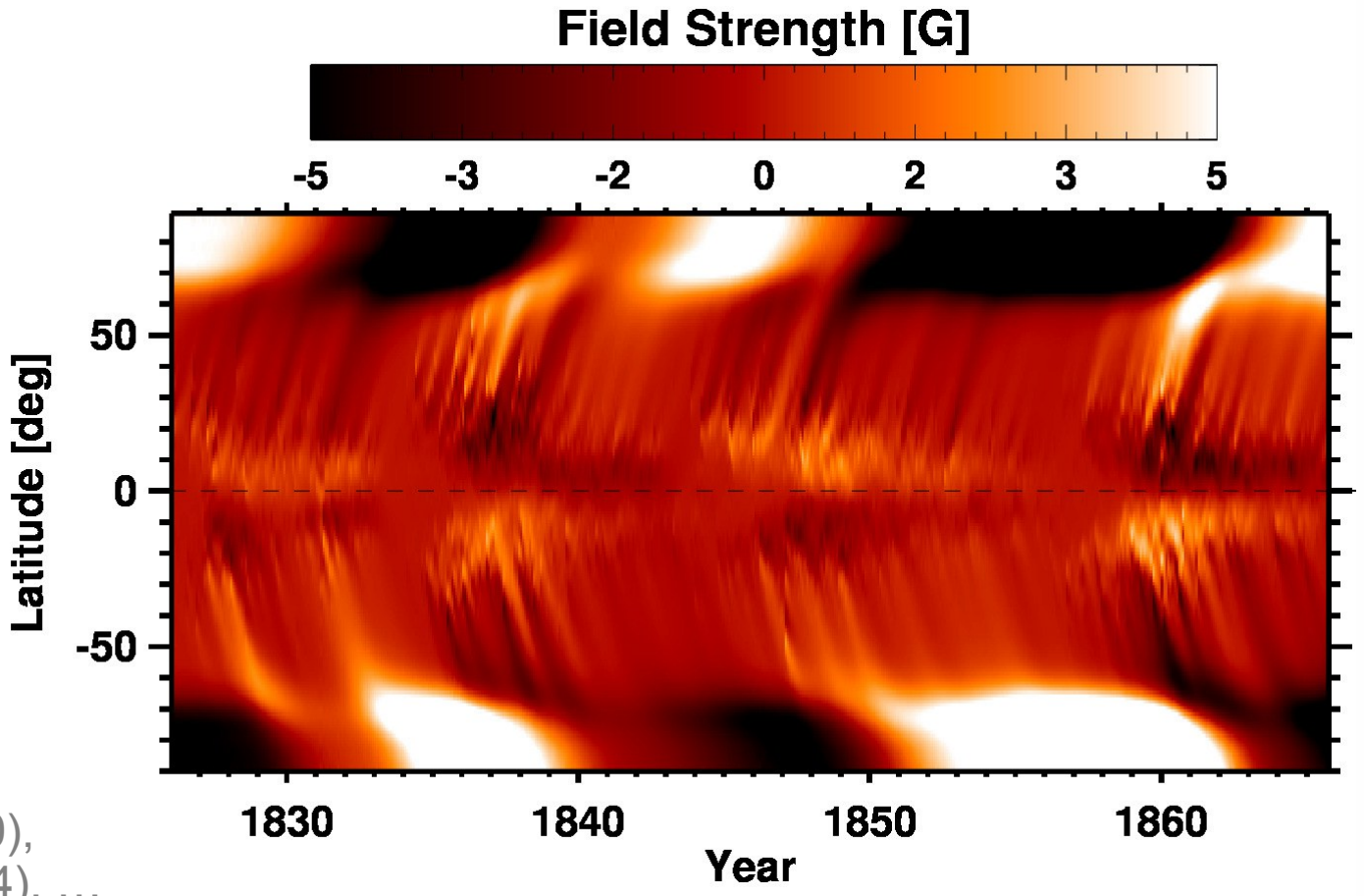
- Active day fraction is a function of sunspot number
- Active day fraction converted into sunspot number

Vaquero et al. (2015)

Surface flux transport

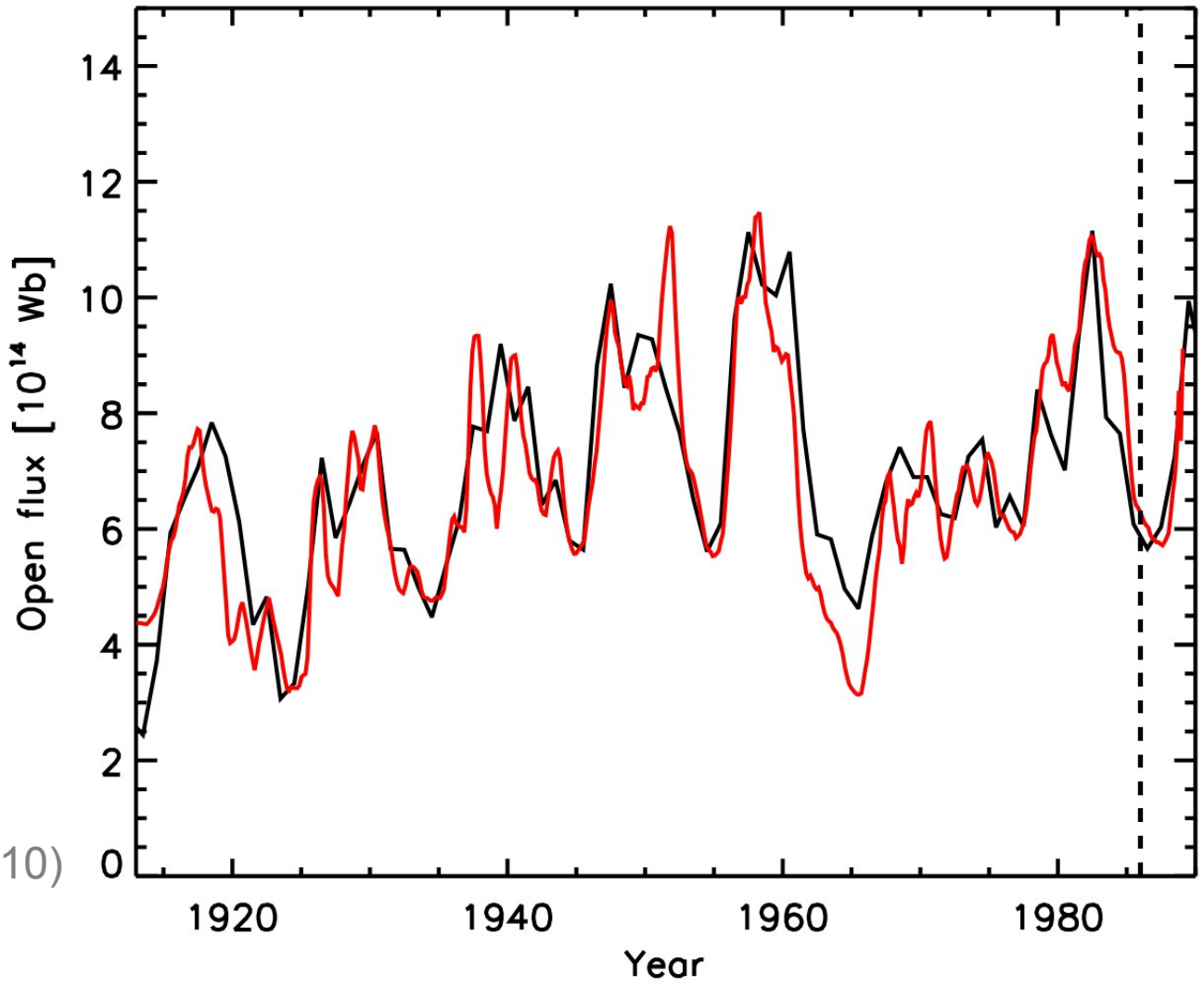
- MPS's surface flux transport model for determining the polar flux
- Meridional flow + magnetic diffusivity

For methods see Jiang et al. (2011), Cameron et al. (2010), Baumann et al. (2004), …



Open-flux reconstruction

- Black: aa-index
- Red: reconstructed



Cameron et al. (2010)

Summary

- 400-year series of sunspot positions possible
- There is a lot of information in historical observations
  - variation of butterfly diagram – empiric relations to *B*
  - persistent active longitudes – nonaxisymmetric dynamo
  - group tilt-angles – measure Babcock-Leighton effect
  - differential rotation – Lorentz force in dynamo
  - Spot decay – *B*-dependence of turbulent diffusivity
- Maunder minimum was a Grand minimum
- Goals:
  - understanding the solar dynamo
  - reconstructing polar flux, open flux, TSI (with MPS)