# Contrasts of the Maunder Minimum and the Dalton Minimum: Archival Analyses

Hisashi Hayakawa
IAR/ISEE Nagoya Univ.
Sun Climate Symposium, Flagstaff,
18 Oct. 2023


名古屋大学
高等研究院

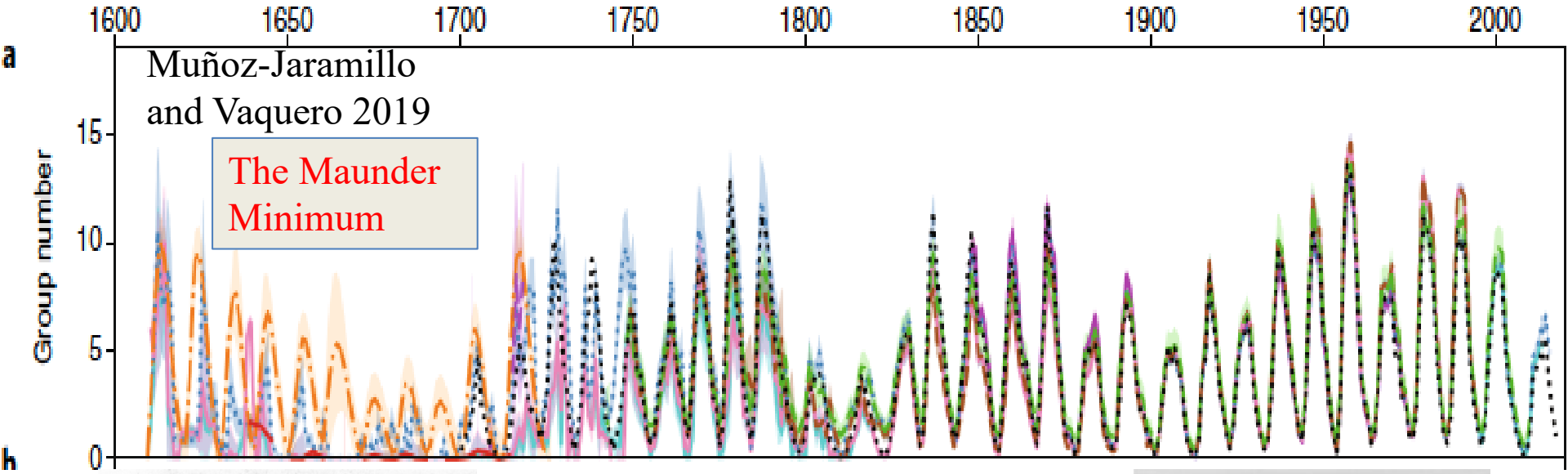
名古屋大学
NAGOYA UNIVERSITY

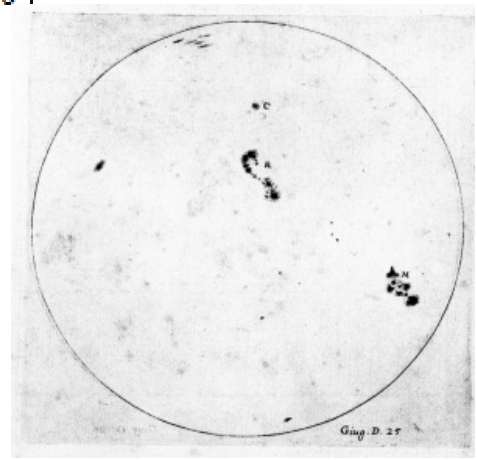
Science & Technology Facilities Council
Rutherford Appleton Laboratory


Scientific Committee on Solar-Terrestrial Physics


宇宙地球環境研究所
Institute for Space-Earth Environmental Research

# Conflicting Reconstructions of the solar activity: sunspot group number



Galilei in 1612
(Galilei 1613)

Solar activity is evaluated with sunspot group number

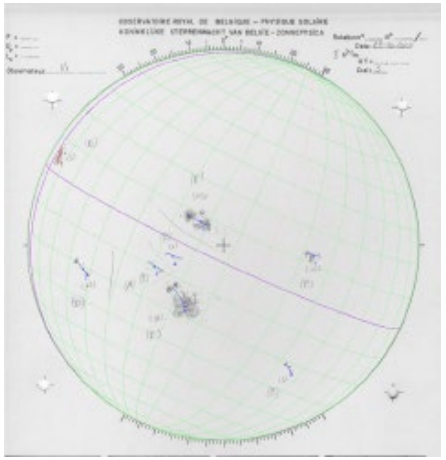
⇒ 1610 – present

⇒ More or less homogeneous reconstruction

⇒ More inconsistent before 1900

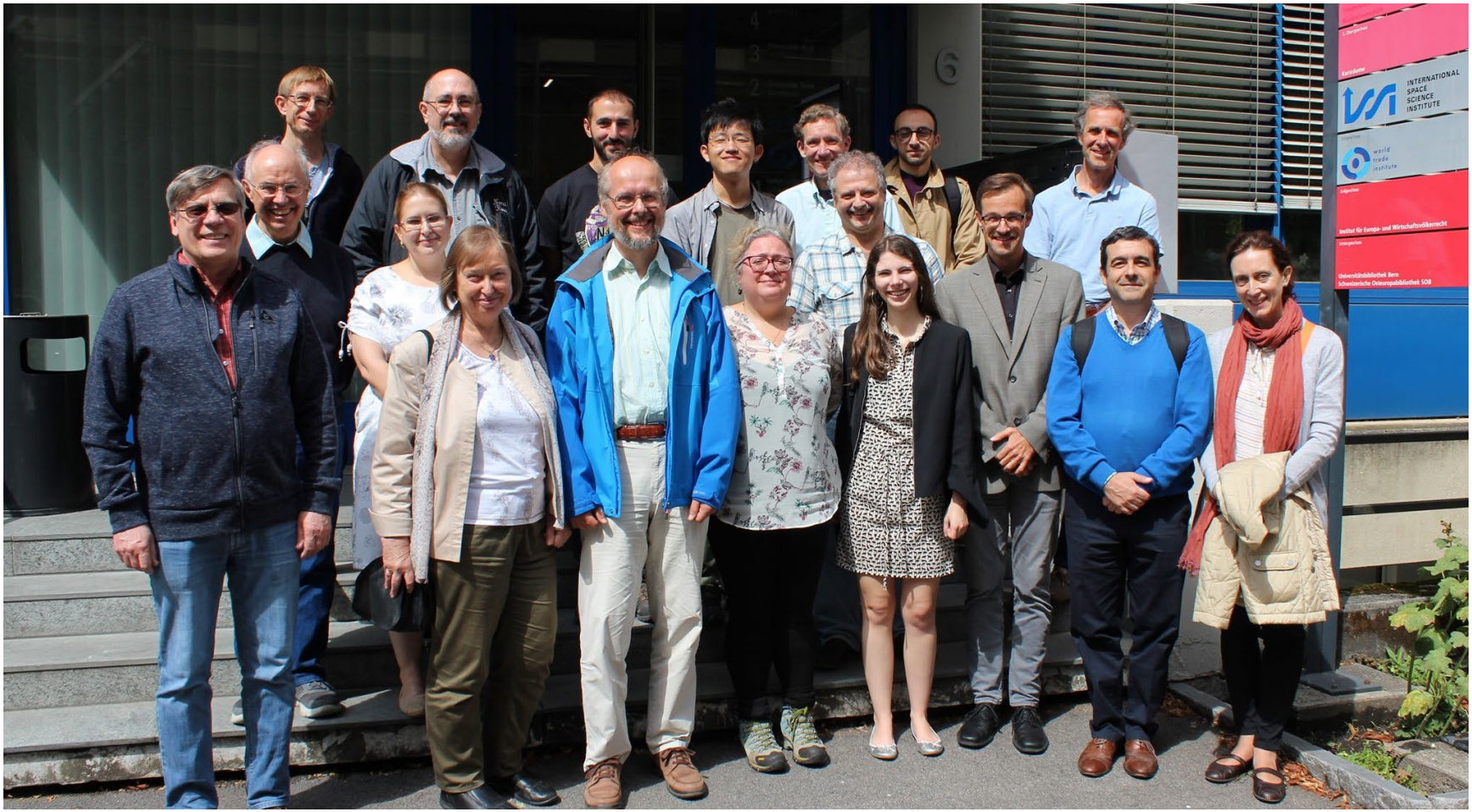
⇒ We need to look at the original records

⇒ What happened around the MM?



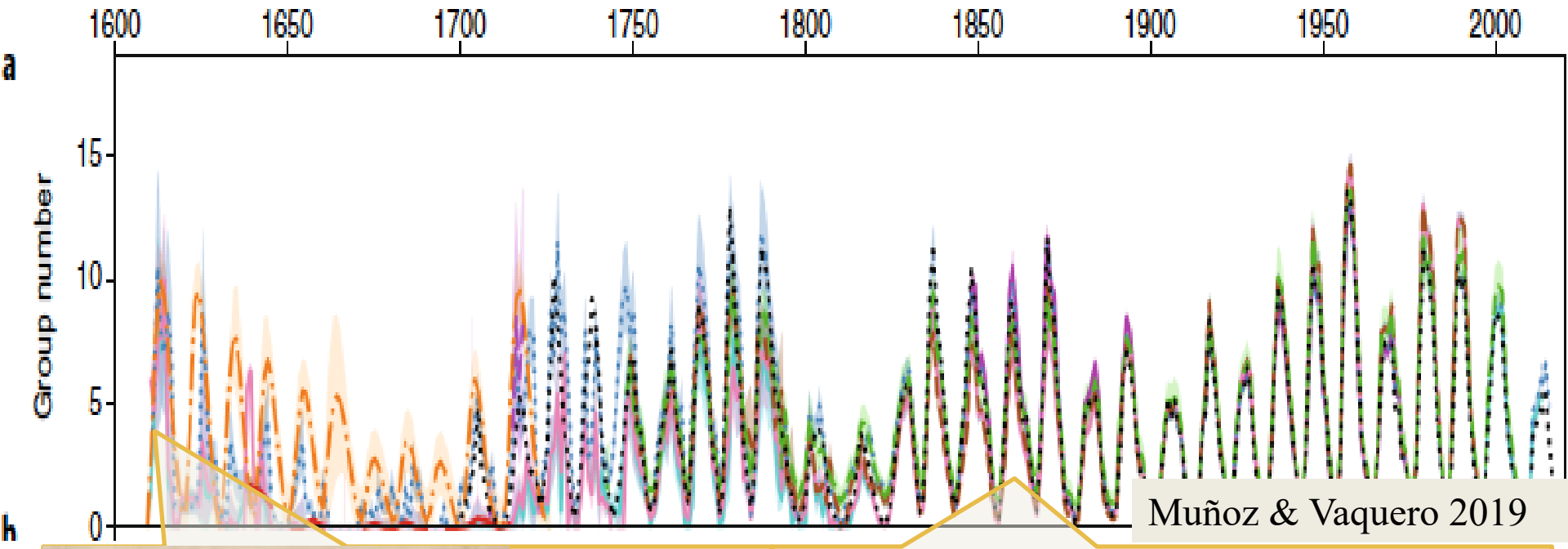
SILSO in 2003
(Clette et al., 2014)

# Ongoing International Collaborations for the Recalibration of the Sunspot Number

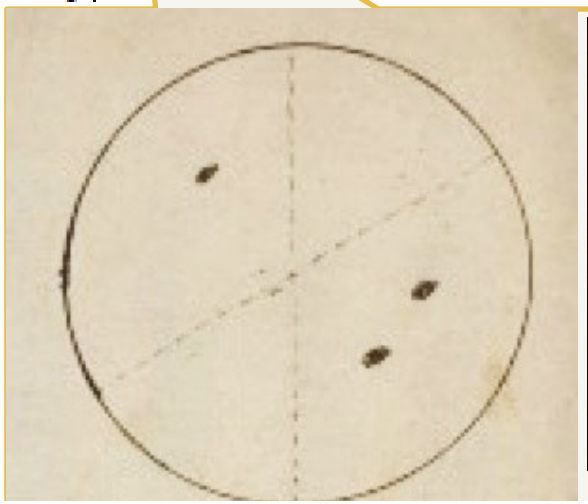


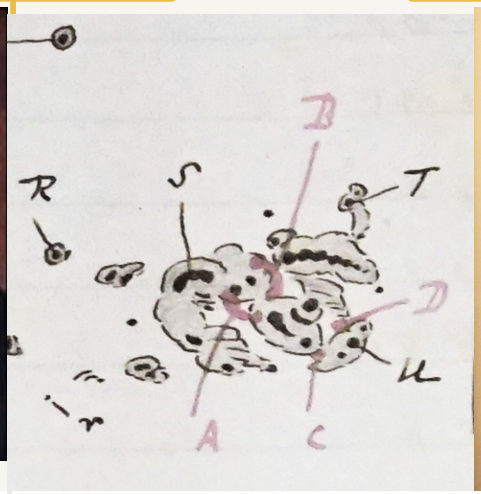

ISSI Sunspot Number Recalibration

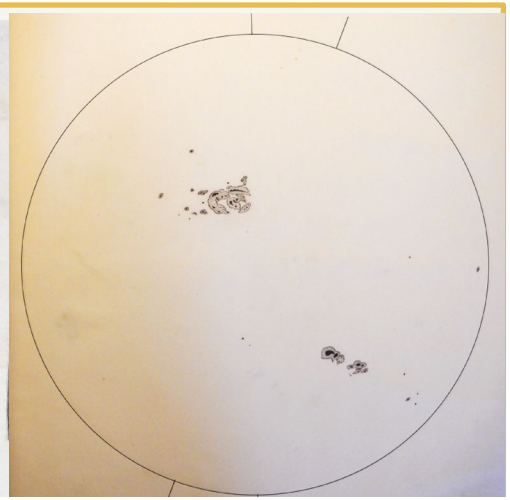
# History of Instrumental Solar Observations




Muñoz & Vaquero 2019



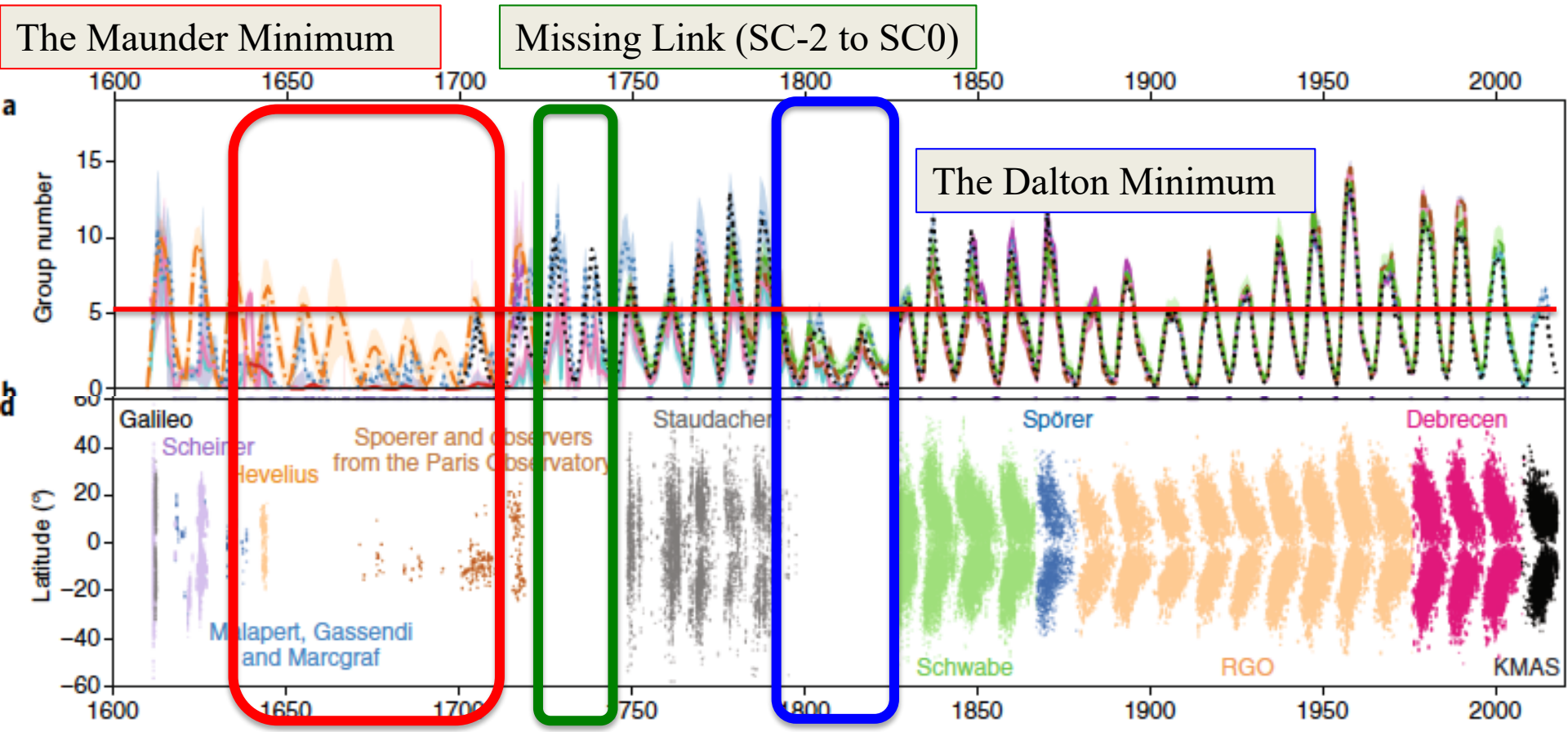


Thomas Harriot, 1610 Dec. 18 (Petworth HA)

Carrington event in 1859 (Hayakawa+2018)

# Conflicting reconstructions of the solar activity




Muñoz & Vaquero 2019

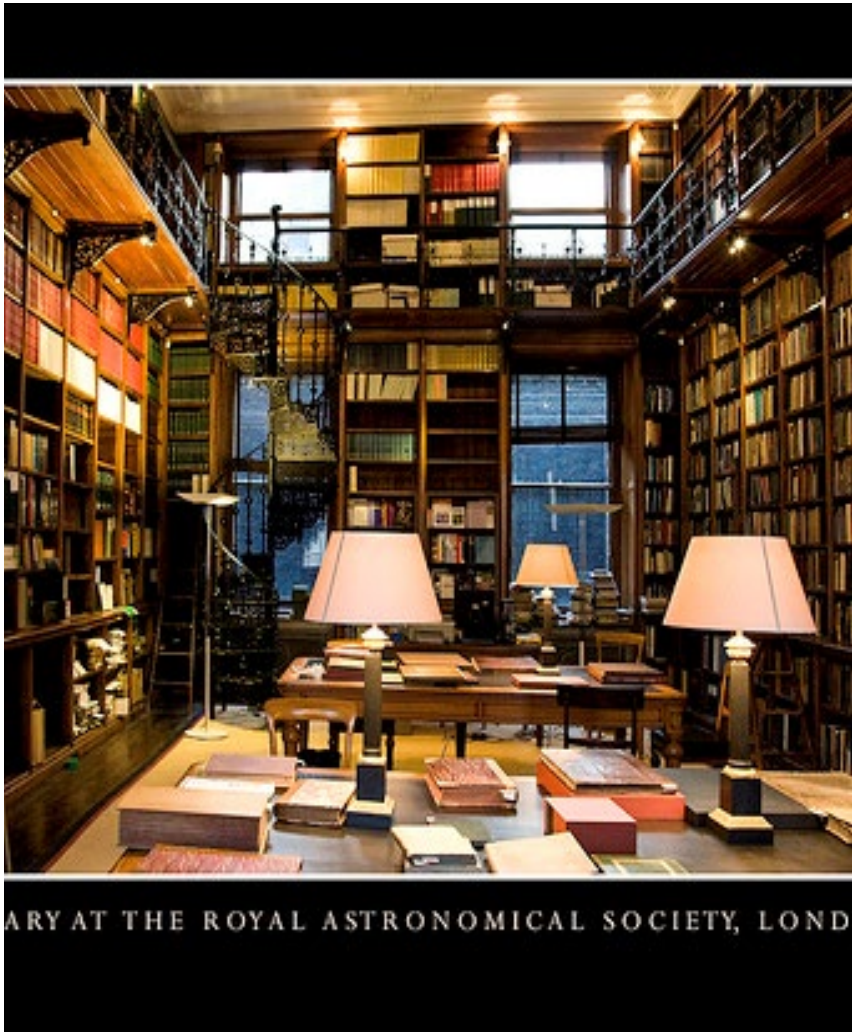
Even after Muñoz & Vaquero (2019), we have three problematic periods.

⇒ The Dalton Minimum in 1797-1827 – SGN△ BD×

⇒ The missing link in 1720-1748 – SGN△ BD×

⇒ The Maunder Minimum in 1645-1715 – SGN△ BD△

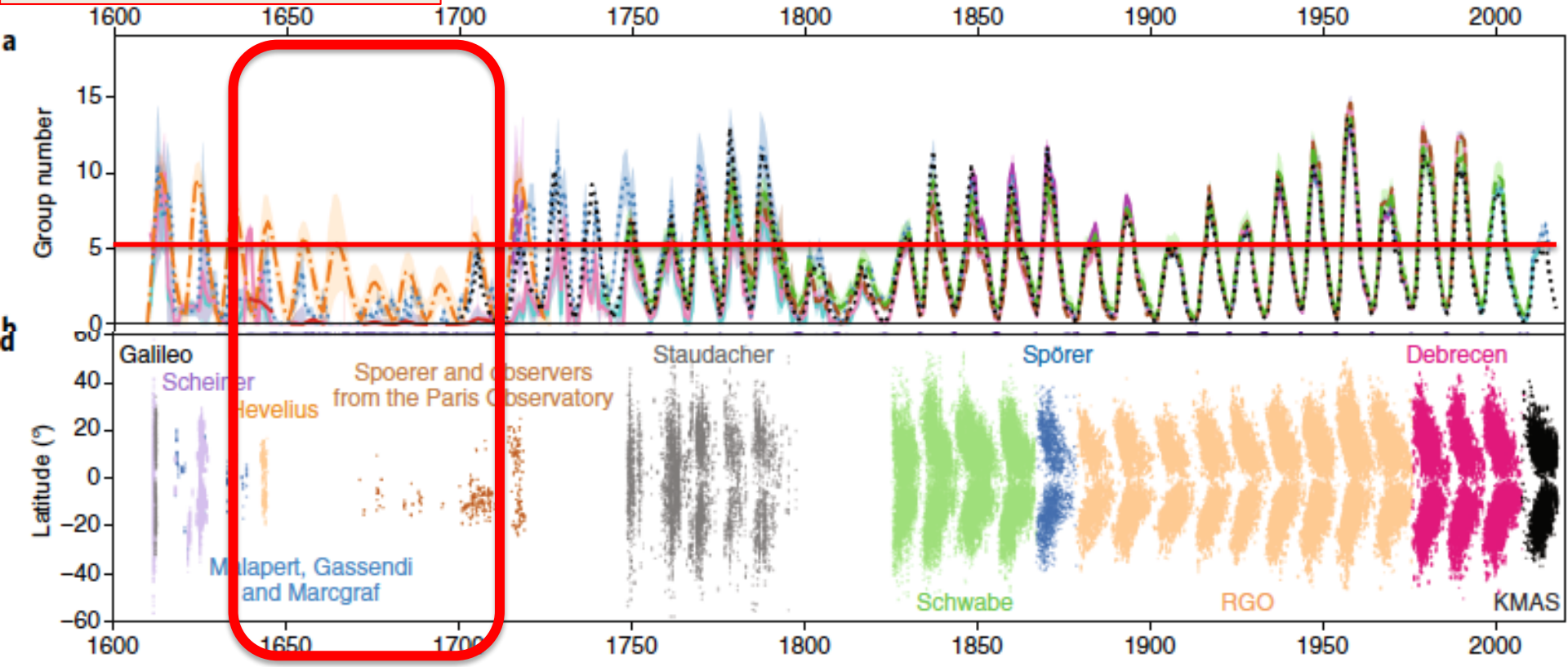
# What I am doing




RAS; Kremsmünster Observatory

# The Maunder Minimum

The Maunder Minimum

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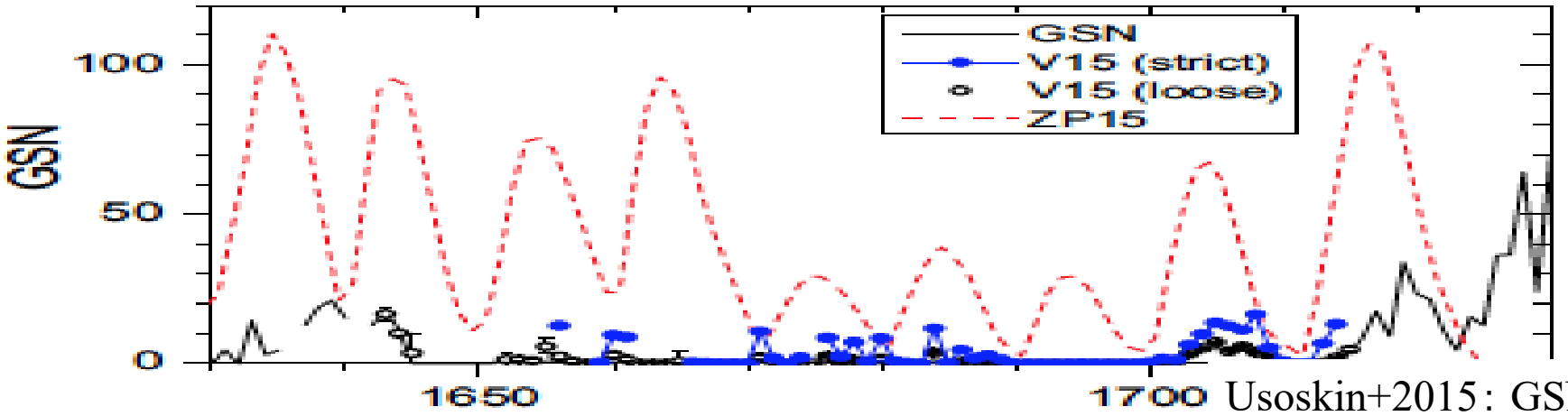
# Mystery of the Maunder Minimum

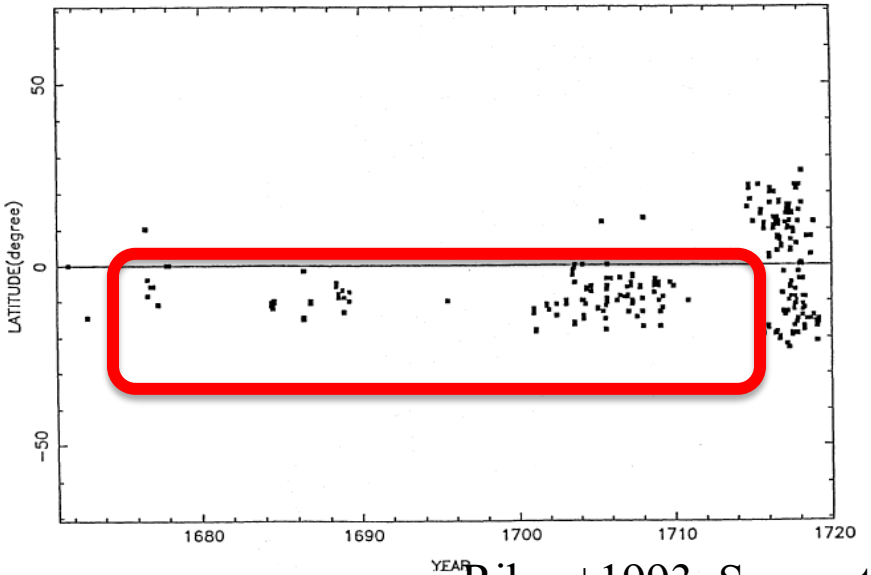



Usoskin+2015 : GSN

:: Some debates on group sunspot number (12.08G)

:: Suppressed solar cycles in the MM

:: Concentration of the reported sunspot positions in the southern solar hemisphere.



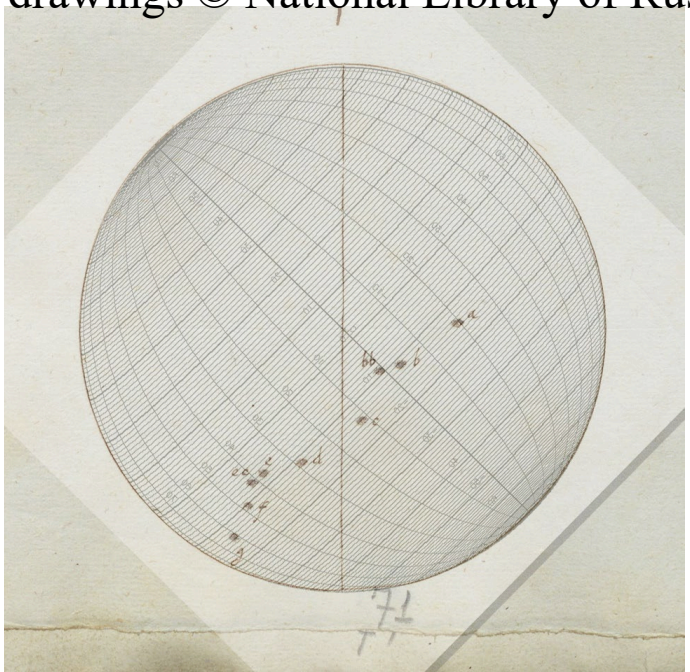

Ribes+1993 : Sunspot Positions

# The original manuscripts are in St. Petersburg

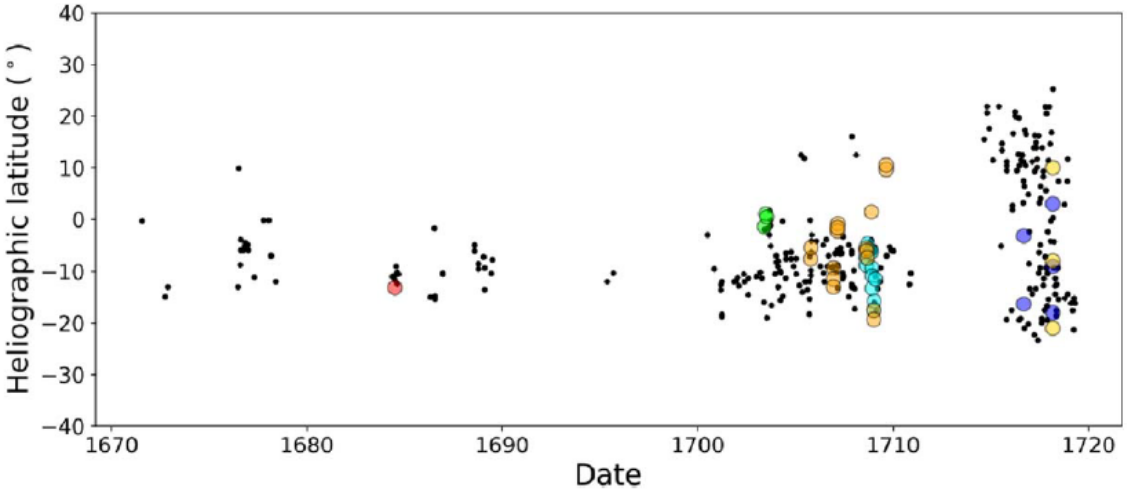


Eimmart Observatory © Stadtbibliothek im Bild. Nürnberg; One of Eimmart's Instruments © Rost 1718

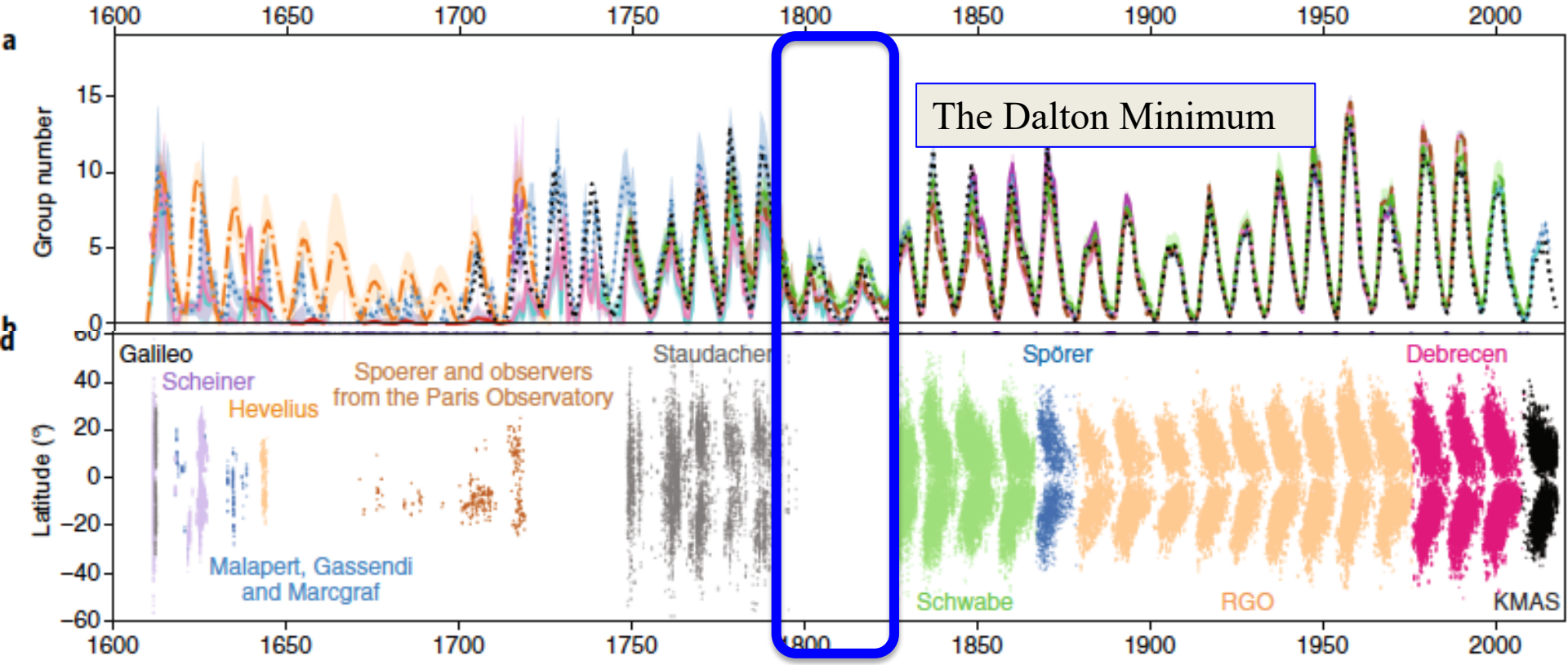
Analyses of the contemporaneous sunspot drawings © National Library of Russia



Output butterfly diagram with hemispheric asymmetry; © Hayakawa+2021b



# Conflicting reconstructions of the solar activity




© Muñoz & Vaquero 2019

Even after Muñoz & Vaquero (2019), we have three problematic periods.

⇒ The Dalton Minimum in 1797-1827 – SGN△ BD×

⇒ The missing link in 1720-1748 – SGN△ BD×

⇒ The Maunder Minimum in 1645-1715 – SGN△ BD△

# Some of them were not properly accessed: Douglas Hoyt's Letter (A07 03 20)

May 13, 1994

Dr. Fritz Steinegger
Stiftsarchiv
Klostergasse 7
A-06020 Innsbruck
Austria

Dear Dr. Steinegger,

Thank you for sending me the tables summarizing Prantner's sunspot observations. Unfortunately, the numbers you gave me appear in many instances to be the number of individual sunspots and not the number of sunspot groups. Each sunspot group consist of one or more sunspots which are close together. A common sunspot group has two nearby individual spots which may be accompanied by minor spots clustering about them. The sun has never been observed in modern times to have more than 25 groups, so when you report, for example, 32 groups on Sept. 13, 1816, it is probably really anywhere from 3 to 6 groups, with each group having 5 to 10 individual sunspots.

I am enclosing with this letter some tables I have already constructed of estimates of the number of sunspot groups based on other observers. Perhaps these could help you. It is too bad that copies of the sunspot drawings could not be made and sent to me. Nonetheless, I hope you have an opportunity to look at them again and can made a better determination of the number of sunspot groups. I look forward to hearing from you.

Sincerely,

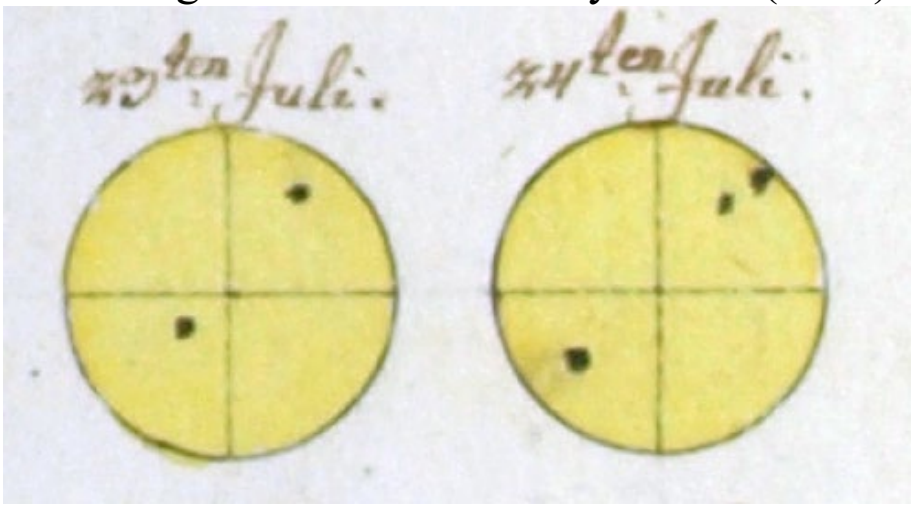
Douglas Hoyt

# Archival investigations for contemporary observations

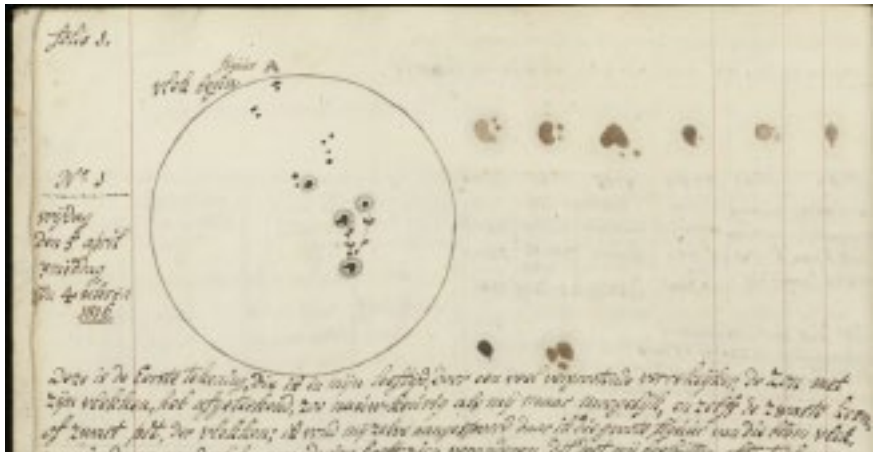
Kremsmünster Observatory and discussions therein

# Dalton Minimum: Tevel, Prantner, Derfflinger, and von Lindener

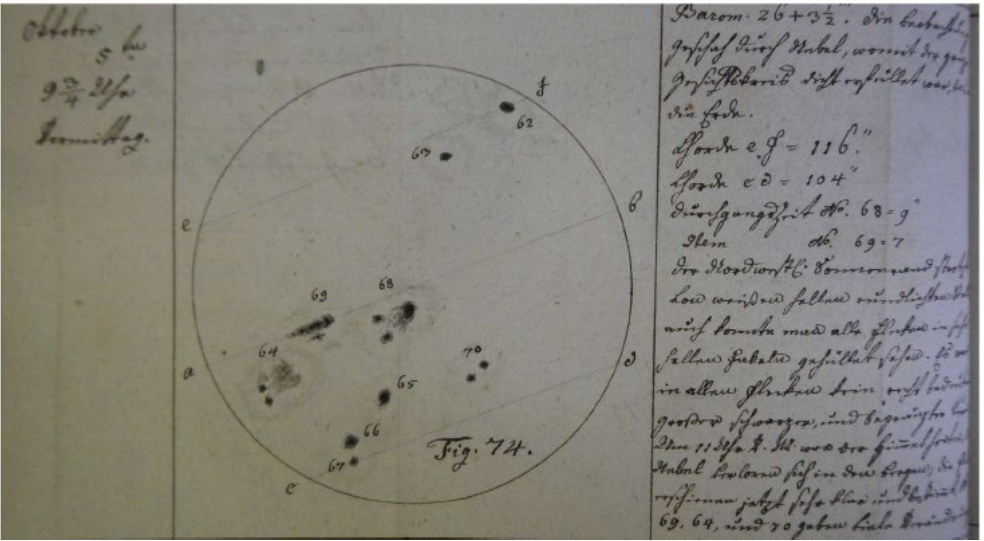
Derfflinger in 1802-1824: Hayakawa+(2020)



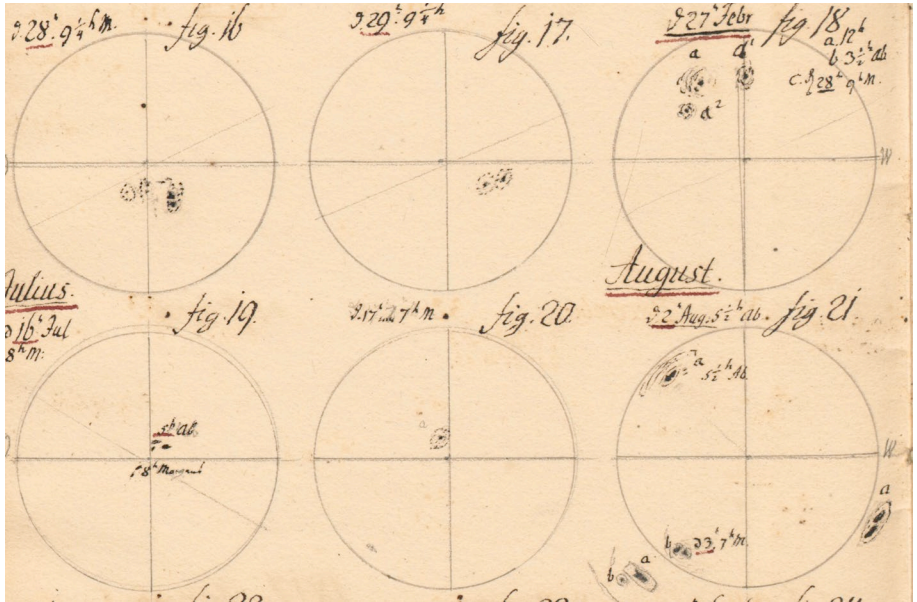

Tevel in 1816-1836: Carrasco (2022)



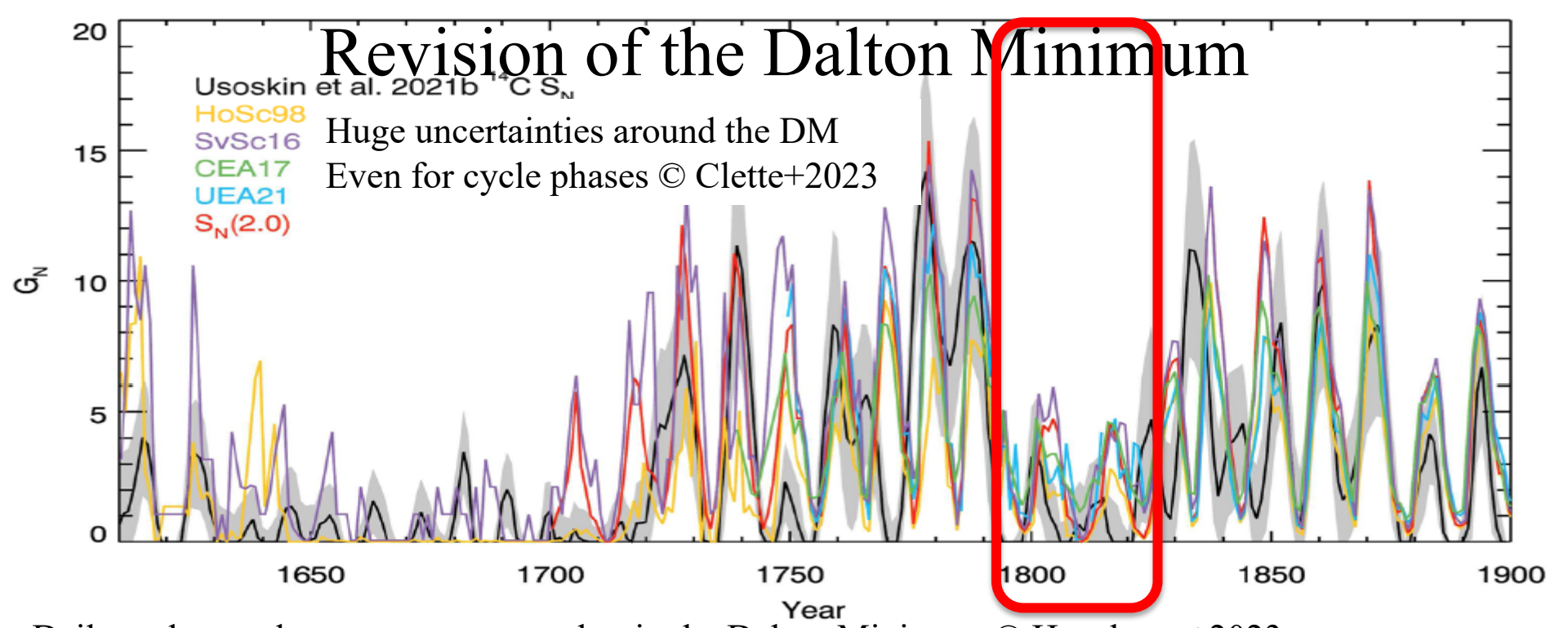
Prantner in 1804-1844: Hayakawa+ (2021)



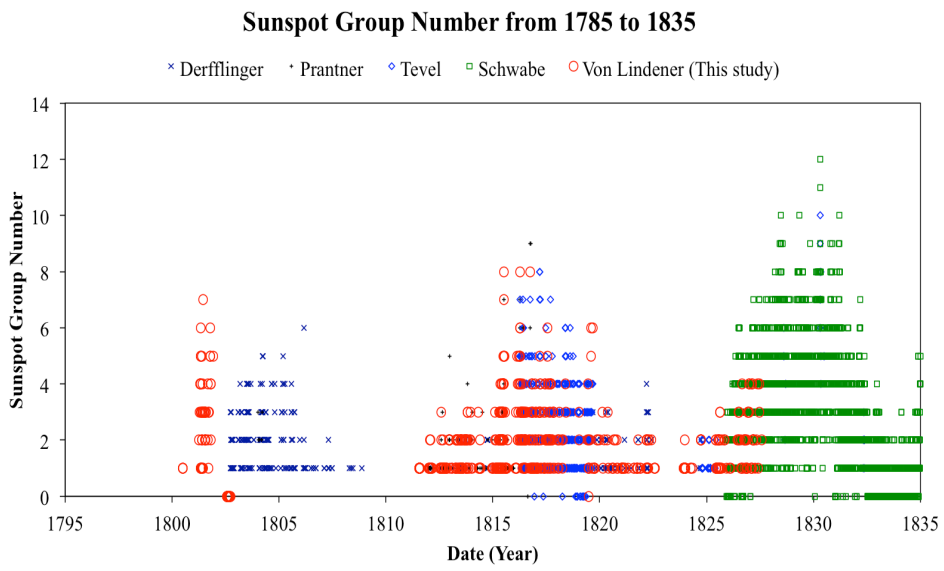

Von Lindener in 1800-1827: Hayakawa+ (2023)

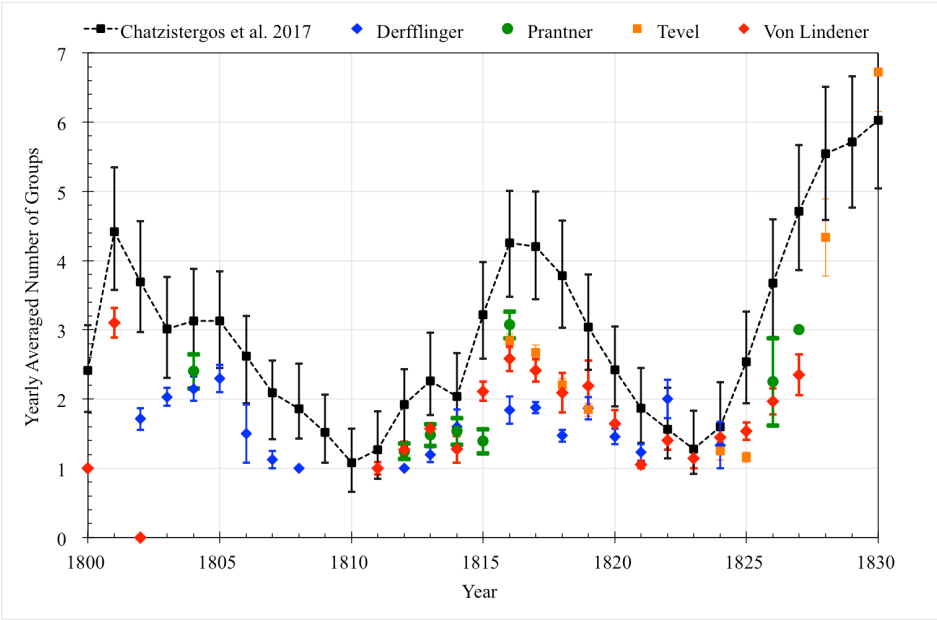


# Revision of the Dalton Minimum



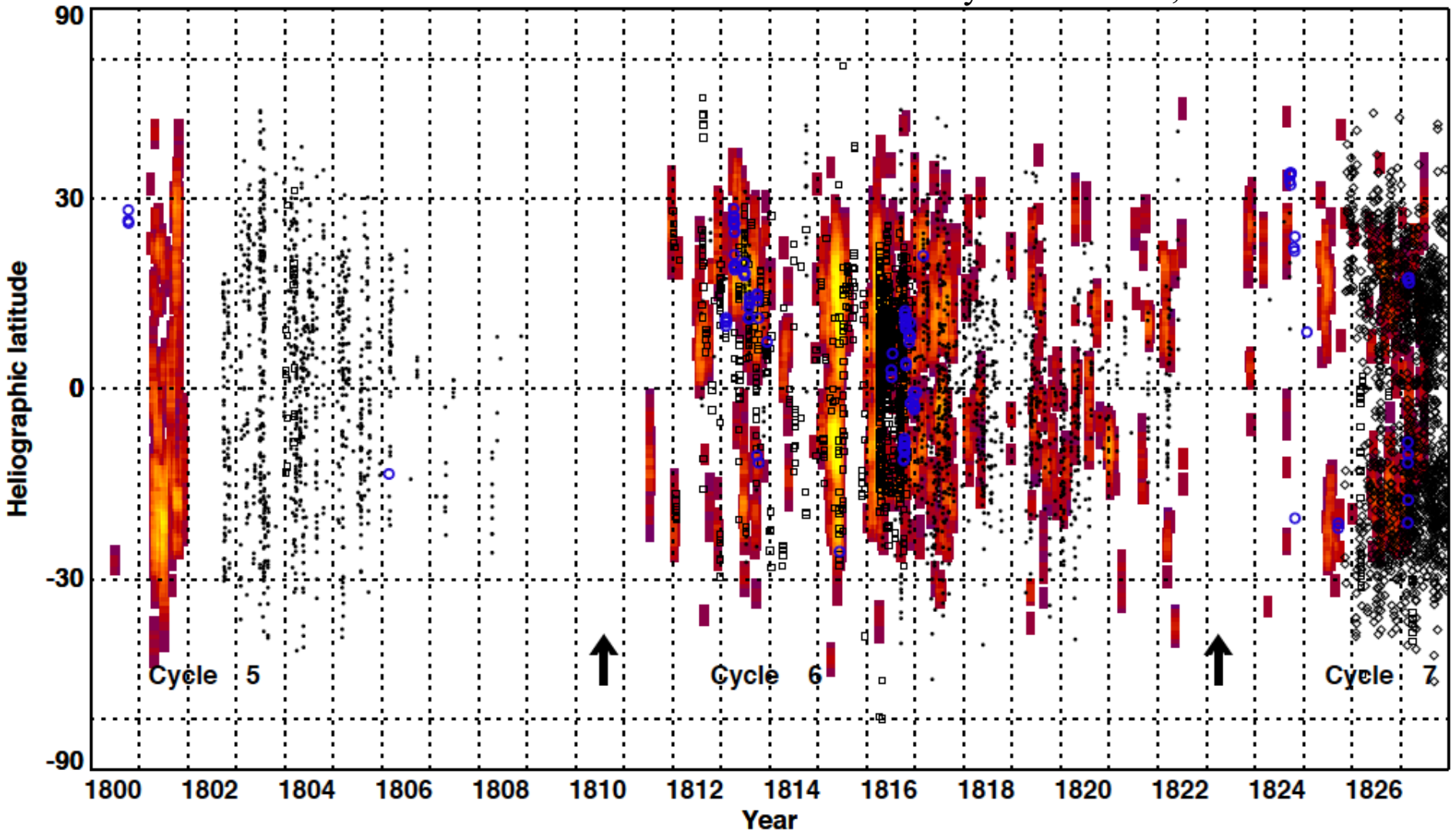

Daily and annual sunspot group number in the Dalton Minimum © Hayakawa+2023



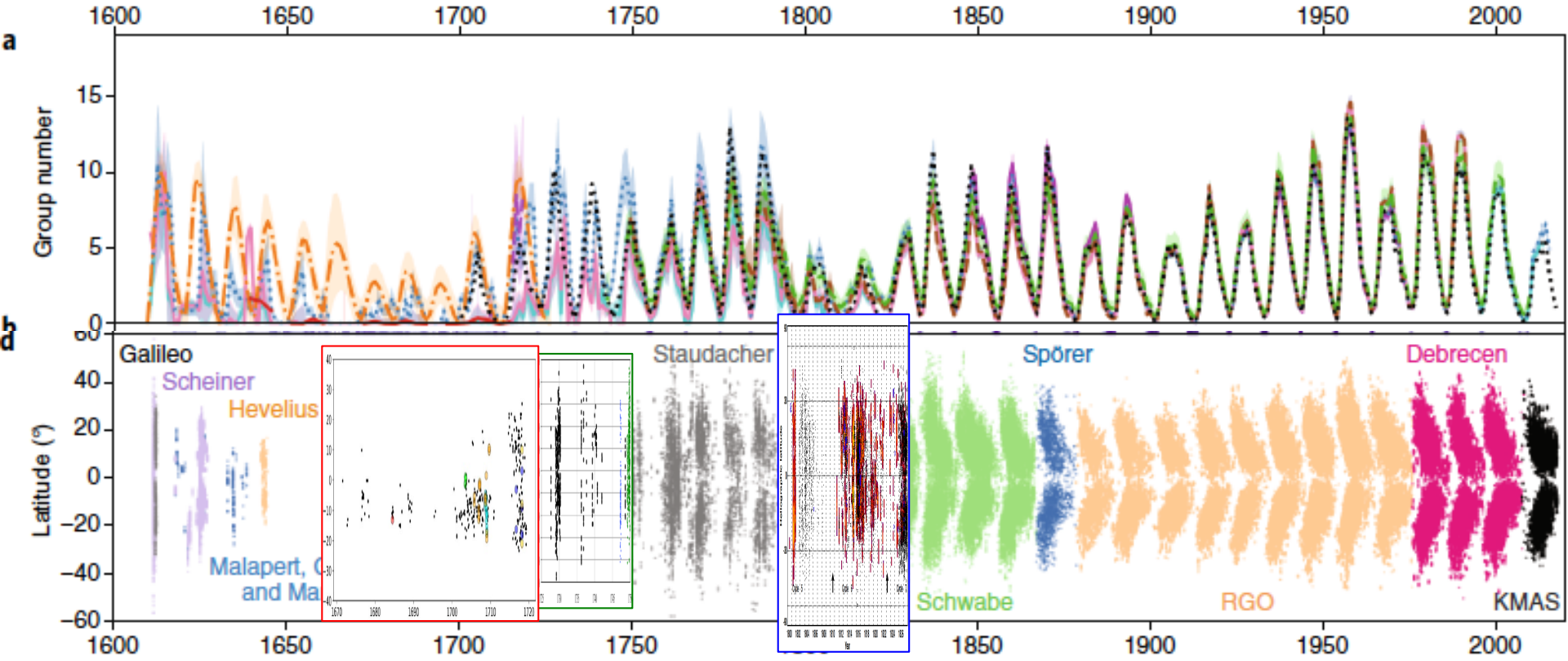
# Sunspot Posutions in the Dalton Minimum






Von Lindener's sunspot positions (Hayakawa *et al*., 2023) in comparison with those of Derfflinger (black dots: Hayakawa *et al*., 2020a), Prantner (black squares; Hayakawa *et al*., 2021a), Flaugergues (blue circles; Illarianov and Arlt, 2023), and Schwabe (black diamonds: Senthamizh Pavai *et al*., 2015).

# An almost continuous BD for 4 centuries!!




Muñoz & Vaquero 2019

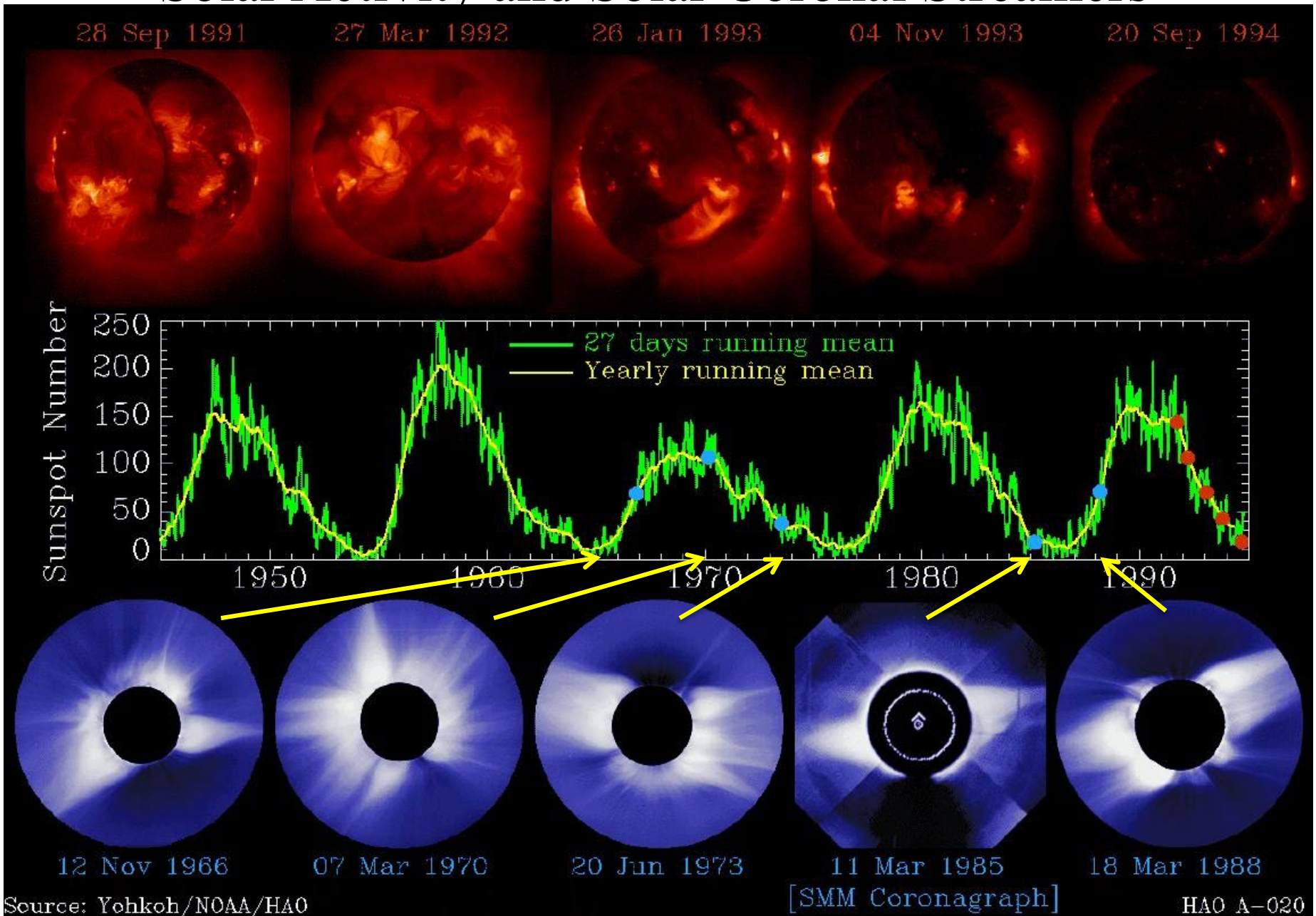
Even after Muñoz & Vaquero (2019), we have three problematic periods.

⇒ The Dalton Minimum => Derfflinger, Prantner, Tevel, and von Lindener

⇒ The missing link in 1720-1748 => Comprehensive analyses (Hayakawa+2022)

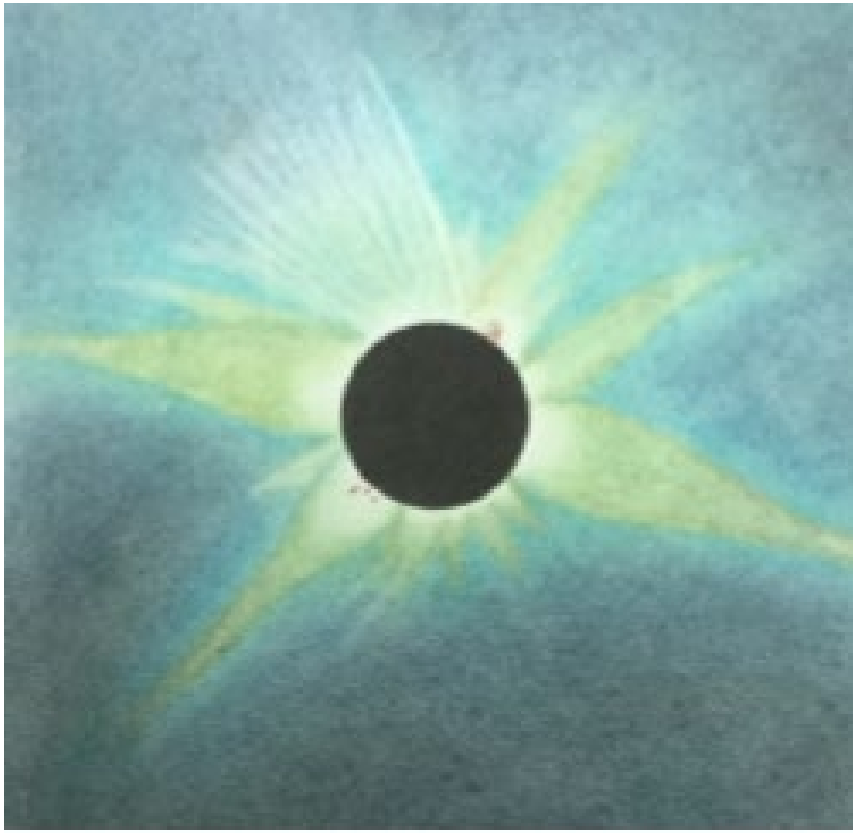
⇒ The Maunder Minimum in 1645-1715 => Hamburg & Eimmart

# Independent References:
# Solar Activity and Solar Coronal Streamers

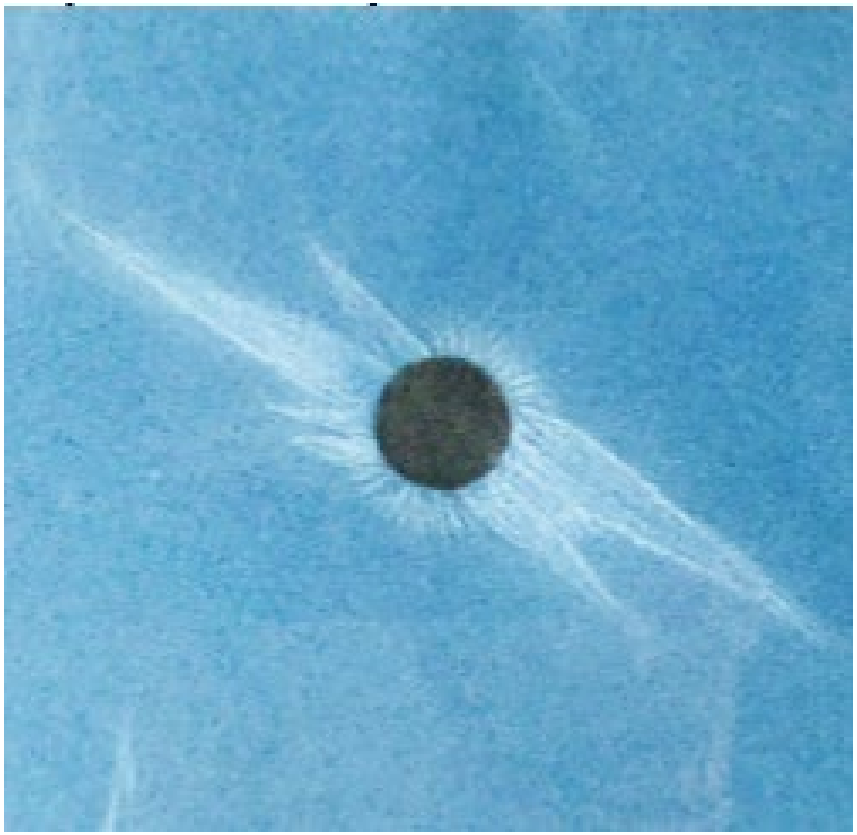


# Usual coronal structures

**Maximum-type corona (1991)**



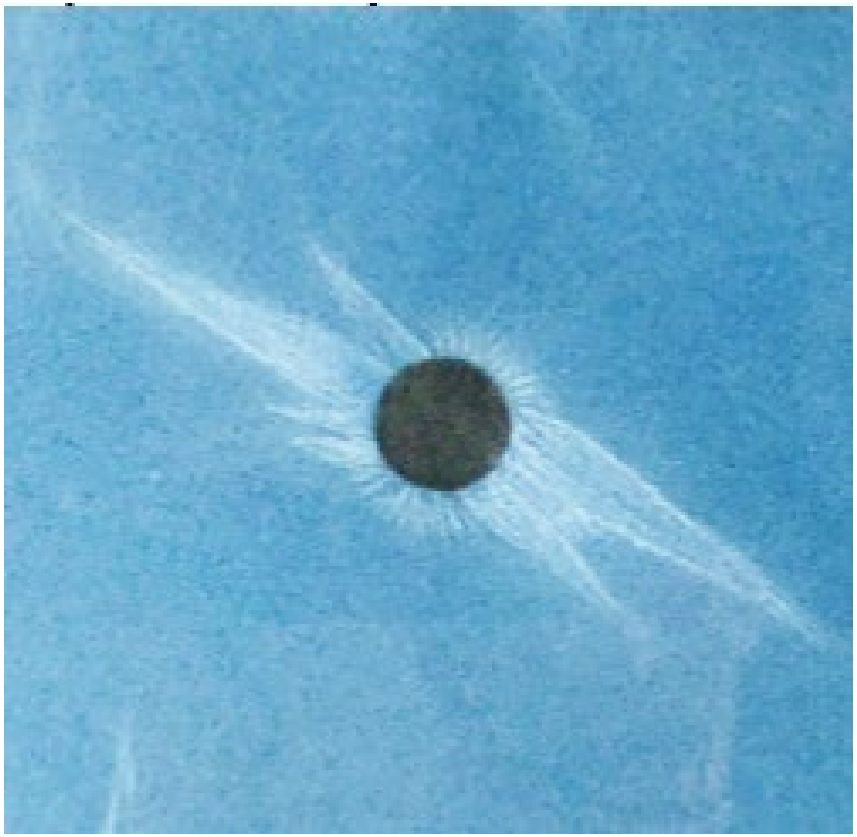
**Minimum-type corona (2009)**



© K. Fujimori (Hayakawa+2021), with naked-eye observations

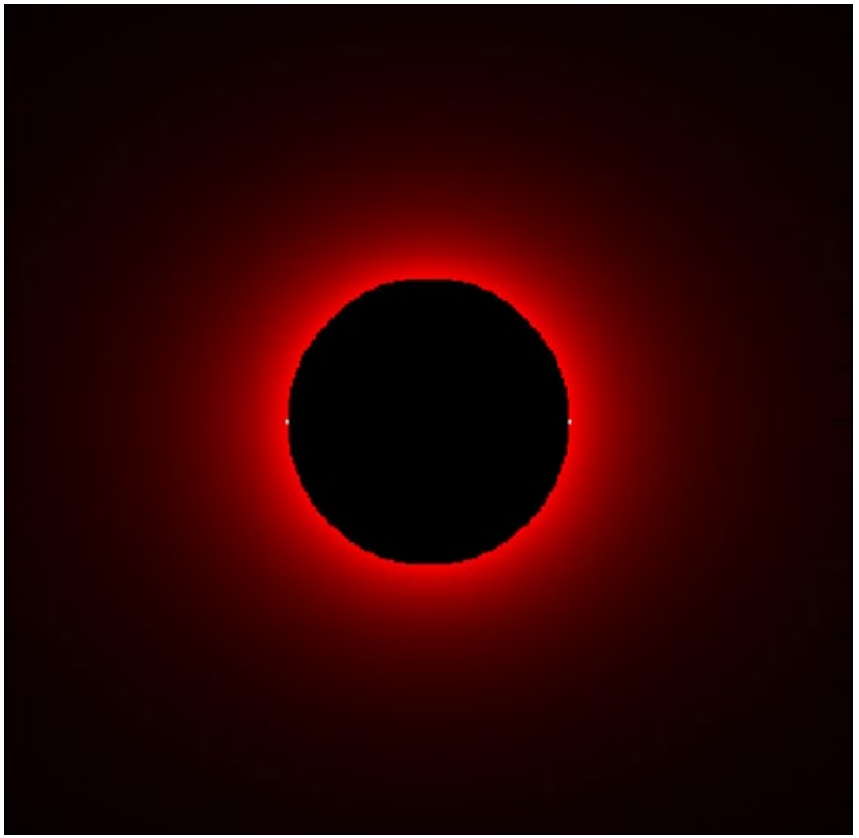
# Hypothesised coronal structure

**Normal Minimum**



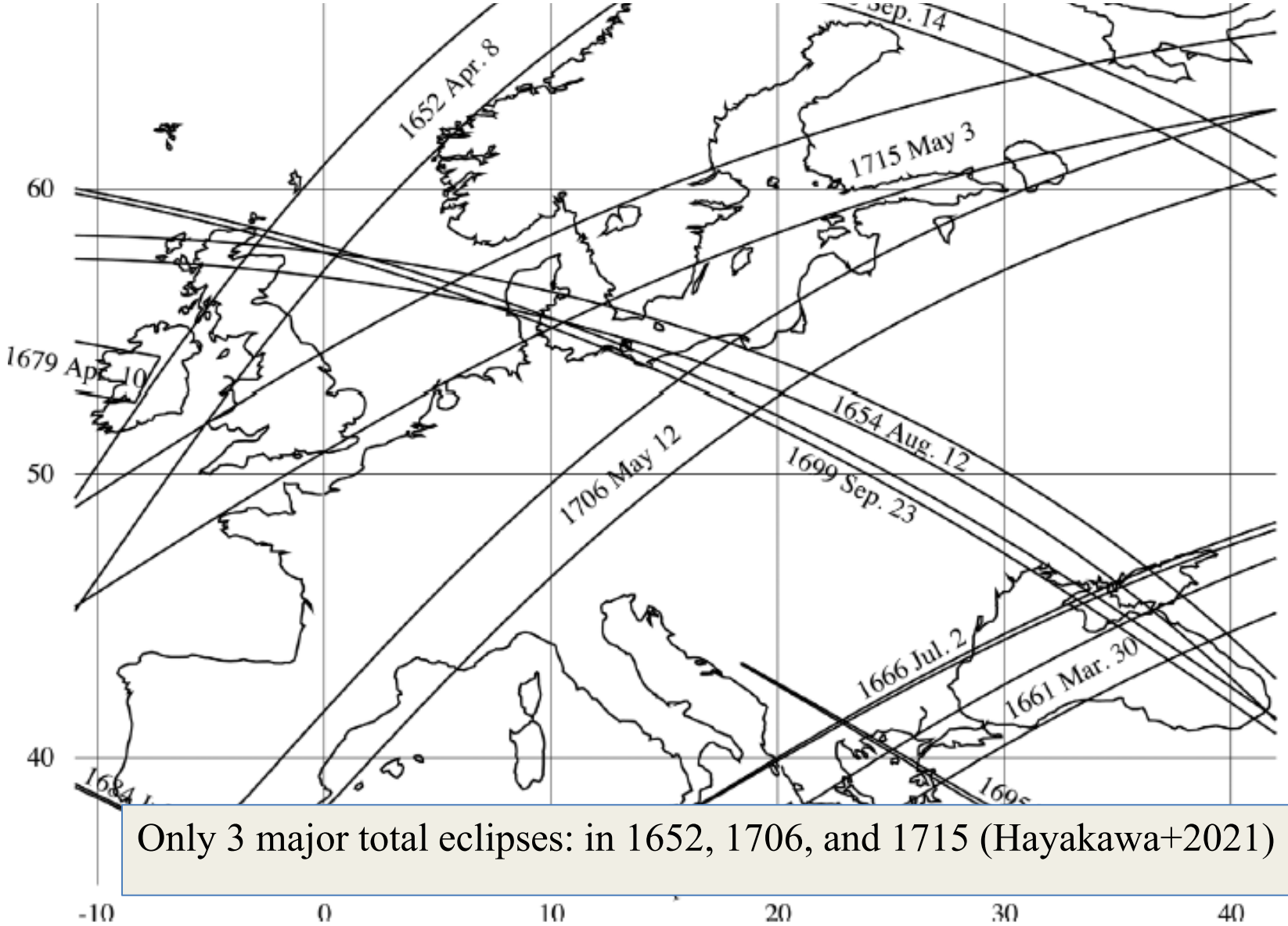
The 2009 eclipse © K. Fujimori

**Maunder Minimum (hypothesis)**



Riley+2015 => Any graphical evidence?

# Total solar eclipses in the MM




Only 3 major total eclipses: in 1652, 1706, and 1715 (Hayakawa+2021)

# Overview of the 1706 eclipse drawings

H. Hayakawa et al.: J. Space Weather Space Clim. 2021, **11**, 1

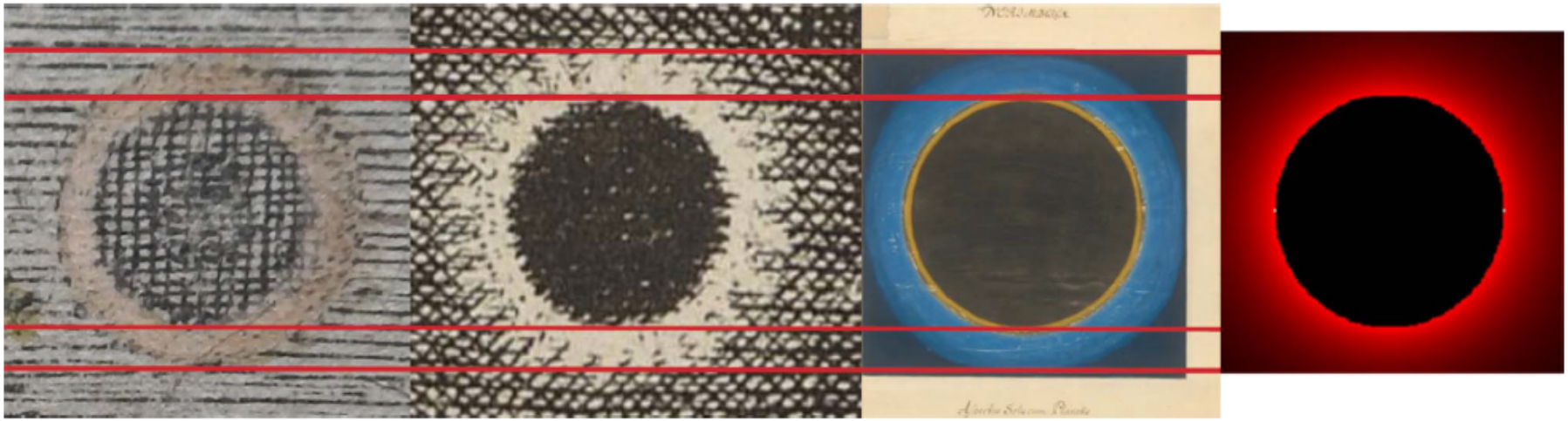


**Fig. 11.** [Left] Comparison of the coronal extent in each eclipse drawings: Johann Meyer (Fig. 7; CUL.MS.RGO 1/69, f. 256; Photograph by Hisashi Hayakawa, reproduced by permission of Syndics of ©Cambridge University Library), Johann Melchior Füssly (Fig. 8), and Maria Clara Eimmart (Fig. 9; MS SBB Kart A2398; with courtesy of ©Staatsbibliothek zu Berlin, Kartenabteilung). They show significantly good agreements in their extent; [right] Simulated corona during the MM adopted from Figure 6 of Riley et al. (2015). Note that this comparison takes the lunar disk in Mayer's depiction to be the cross-hatched area and not the irregular inner region that has the same cross hatching with additional dark marks. Being depictions of the eclipse over landscapes, only Meyer's and Füssly extend beyond the frame shown. The shading of the outer region using horizontal lines in Meyer's print extends throughout the sky over Zürich (except where he marks planets and one star) so there is no doubt that he is not depicting any brightness outside the uniform halo. Füssly's landscape does, on the other hand, contain a very faint enhancement on one side of the Sun that is shown in Figure 12.

Hayakawa+2021

# The 1715 eclipse drawings

H. Hayakawa et al.: J. Space Weather Space Clim. 2021, **11**, 1

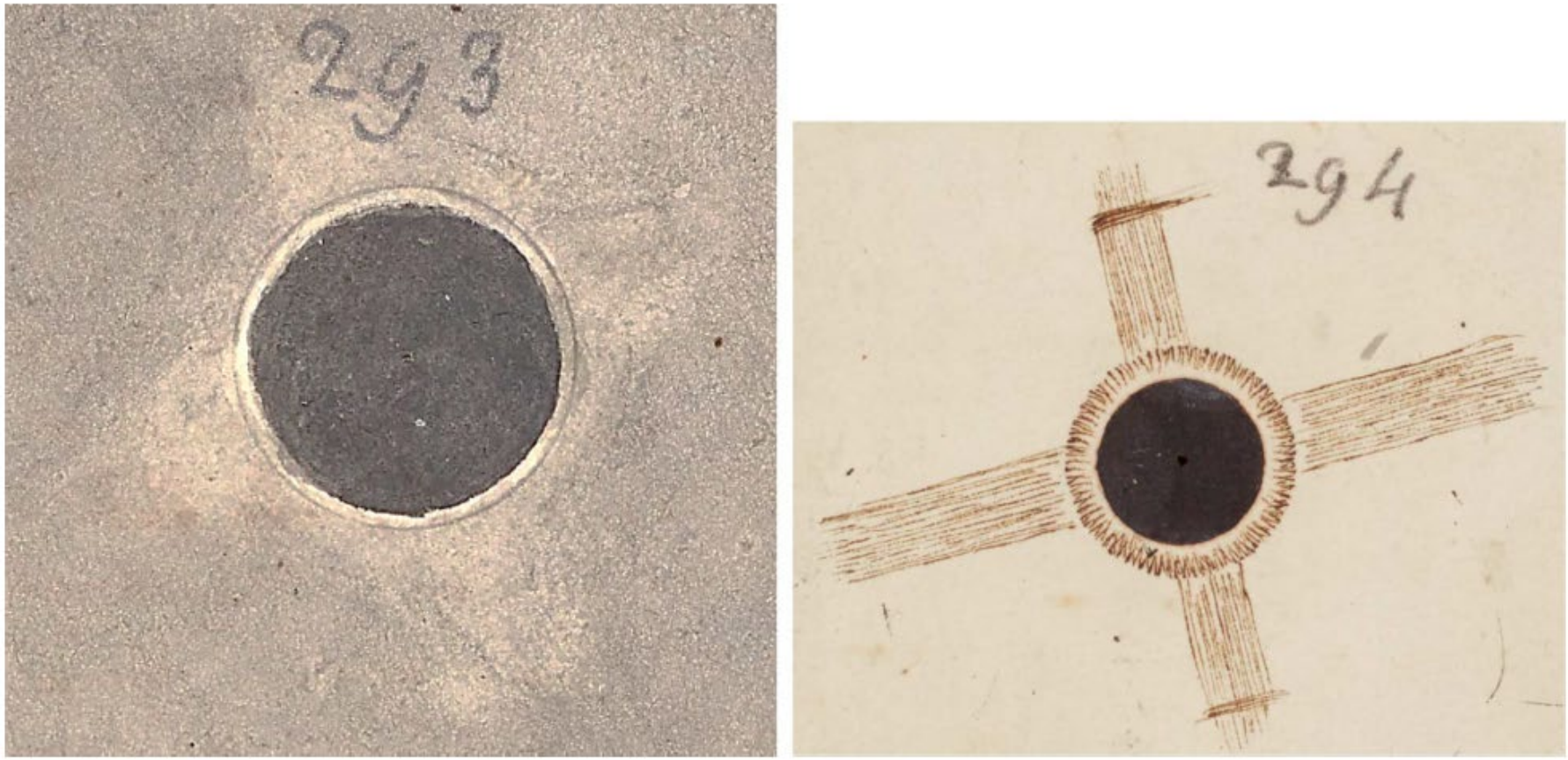
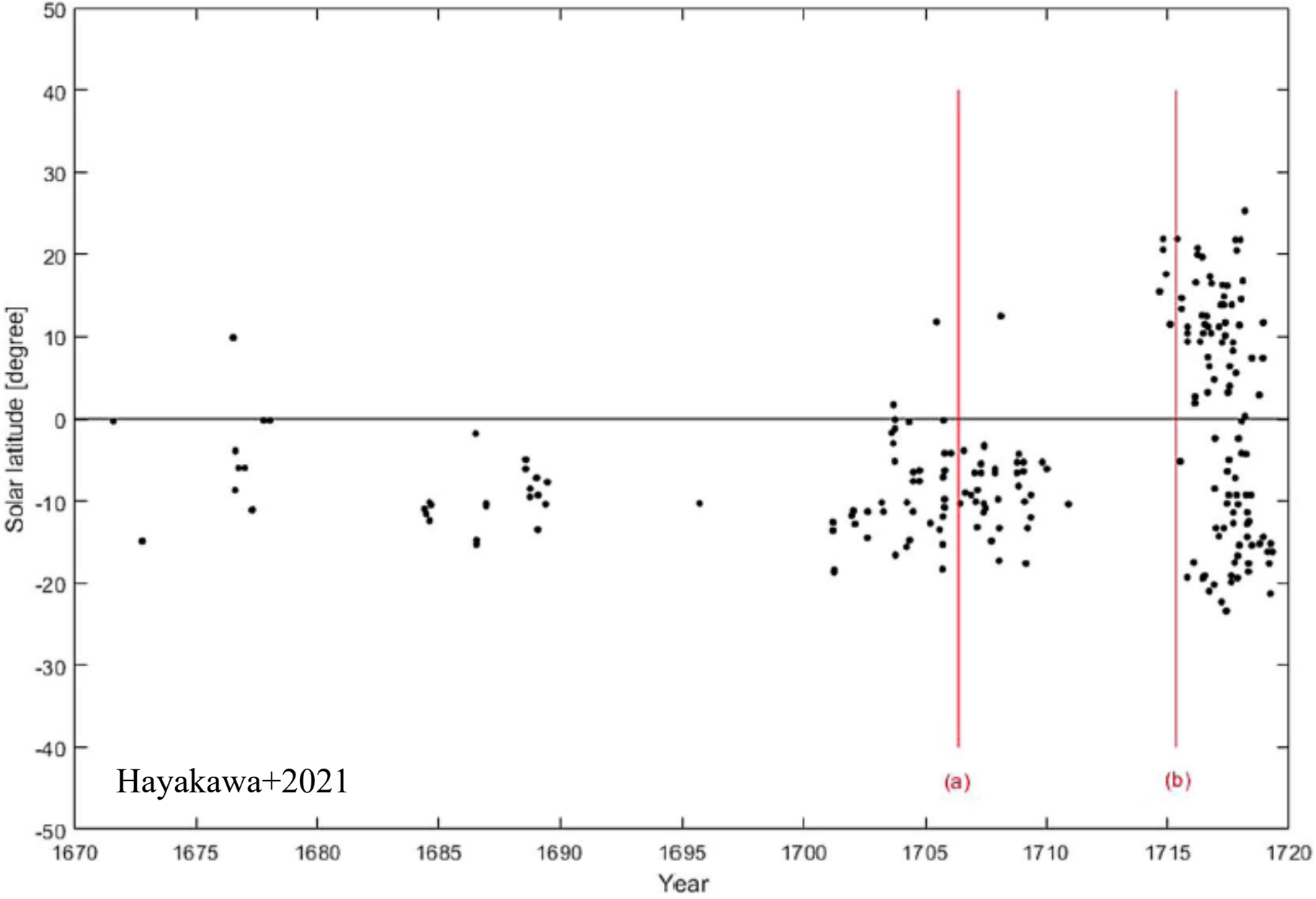


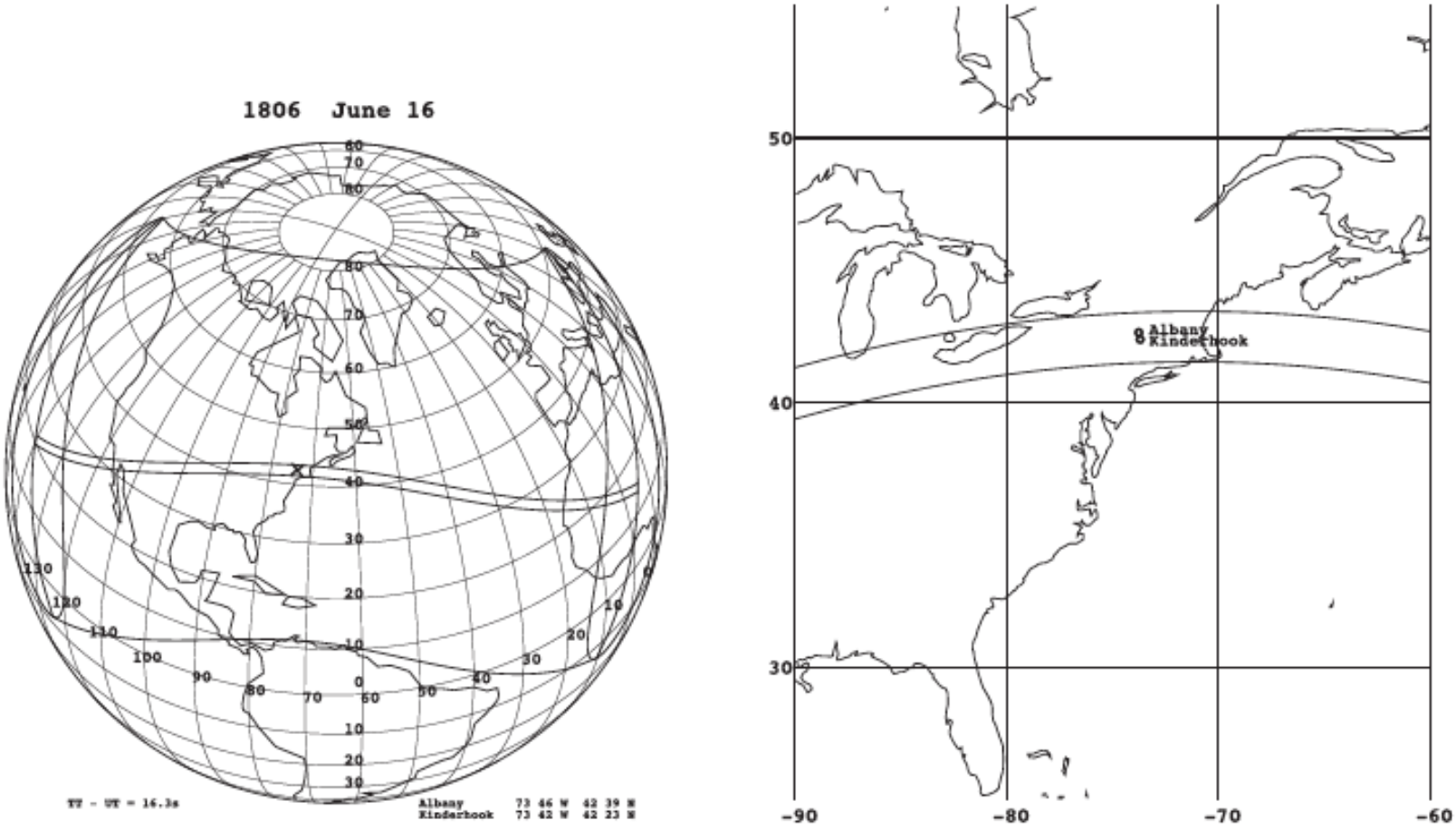

**Fig. 13.** Drawings of the total eclipse on 1715 May 3 in the correspondence Roger Cotes at Cambridge to Isaac Newton (Trinity College Cambridge, MS R.16.38b, ff. 293–294; courtesy of the Master and Fellows of Trinity College, Cambridge). The left panel shows another eclipse drawing "by a very ingenious Gentleman representing the appearance as seen by himself" and the right panel shows Cotes' own eclipse drawing (Edleston, 1850, pp. 183–184). Both of these drawings show cross-like coronal structure, although it was depicted very faintly in the left figure.

Hayakawa+2021; with cross-like streamers

# Context of the two total solar eclipses in 1706 & 1715



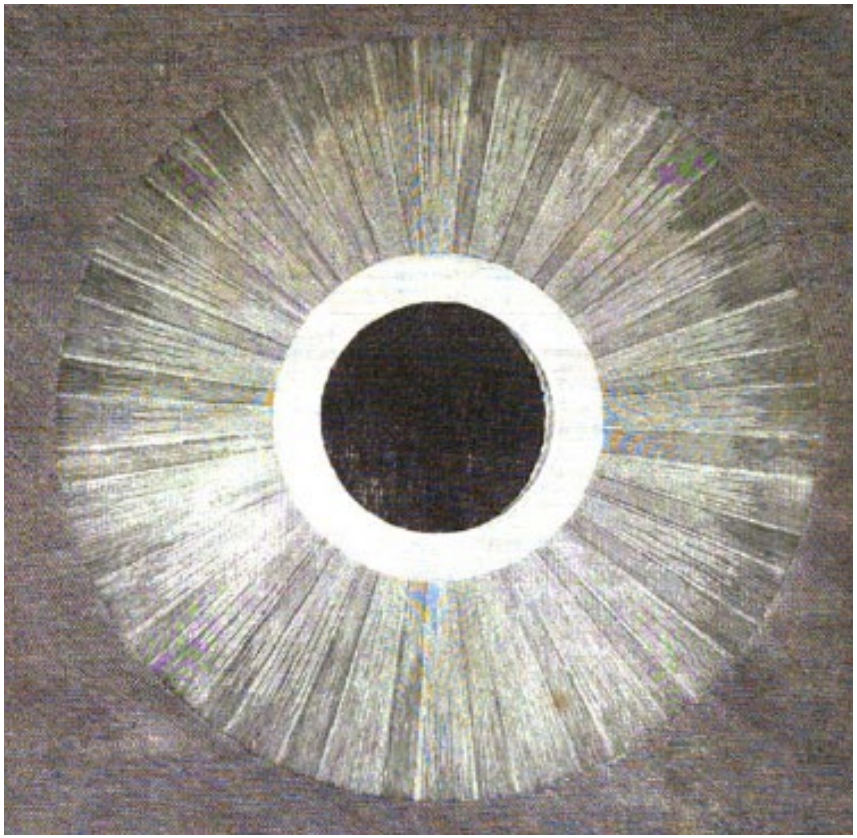
# Total Solar Eclipse on 1806 June 16



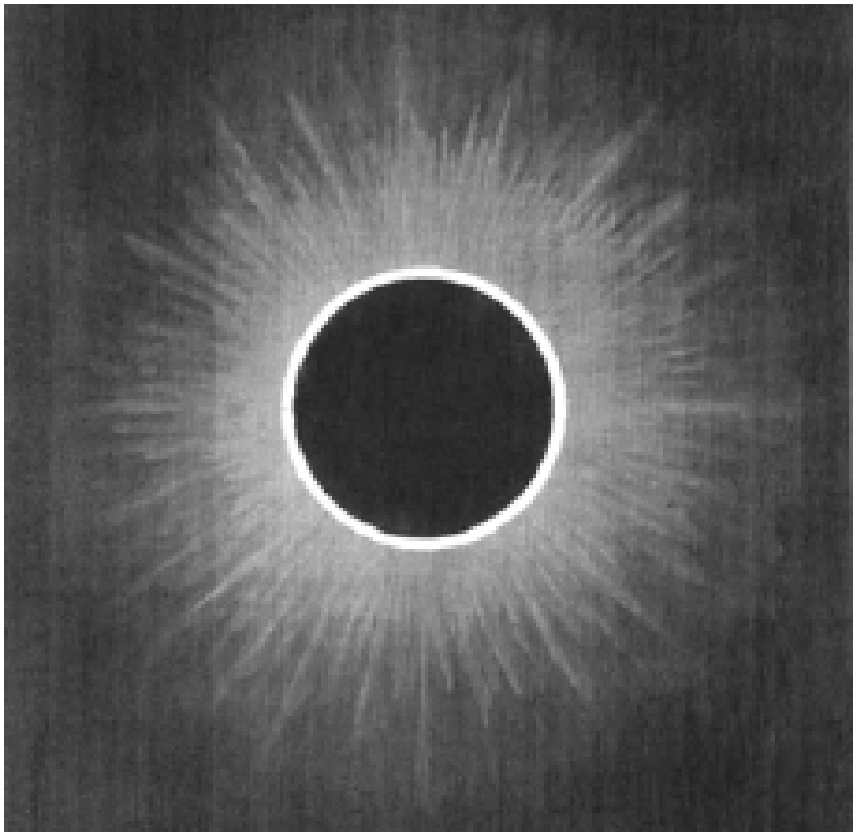

Hayakawa+2020b

# The eclipse drawings

**Ferrer at Kinderhook**

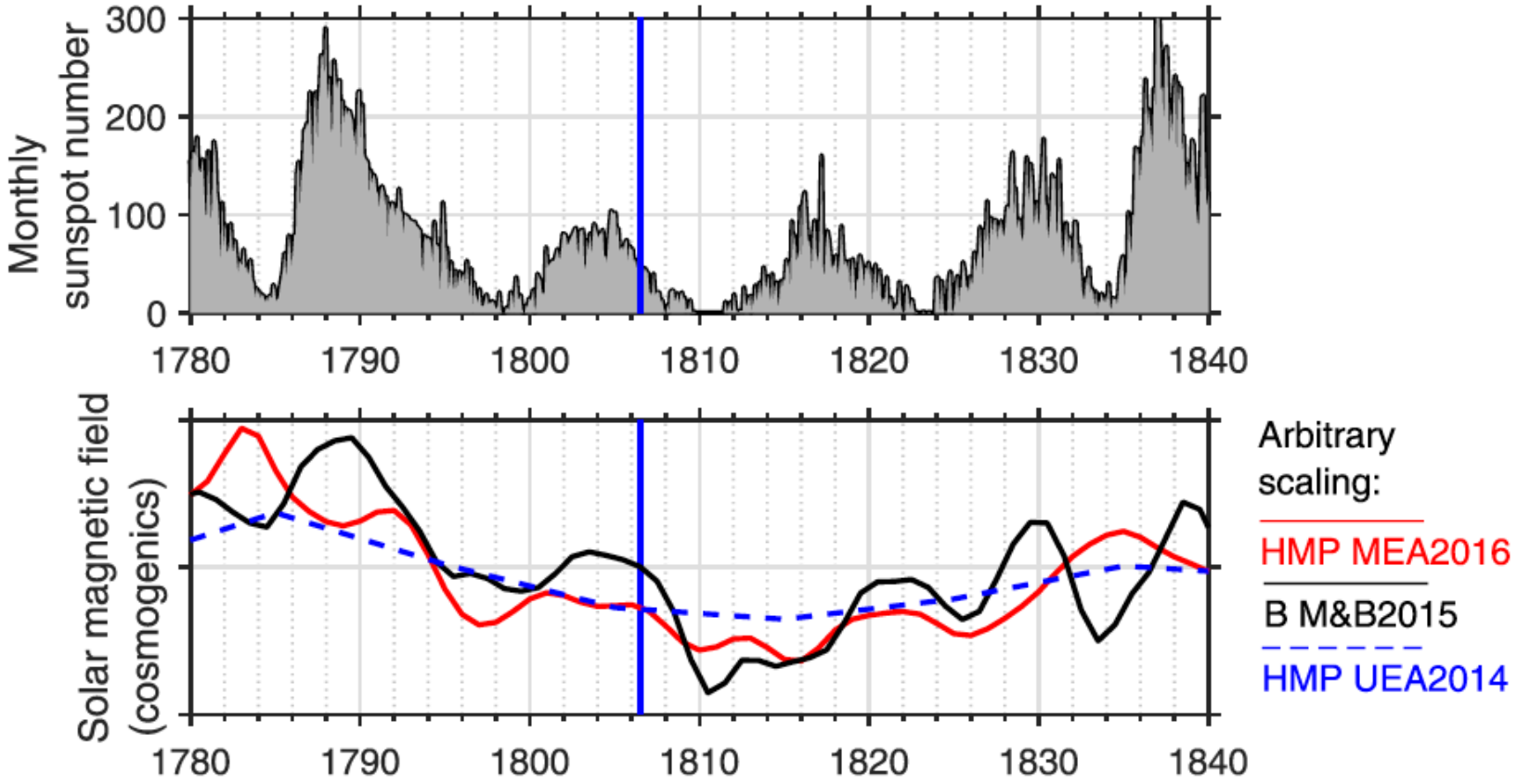


**Ames at Albany**



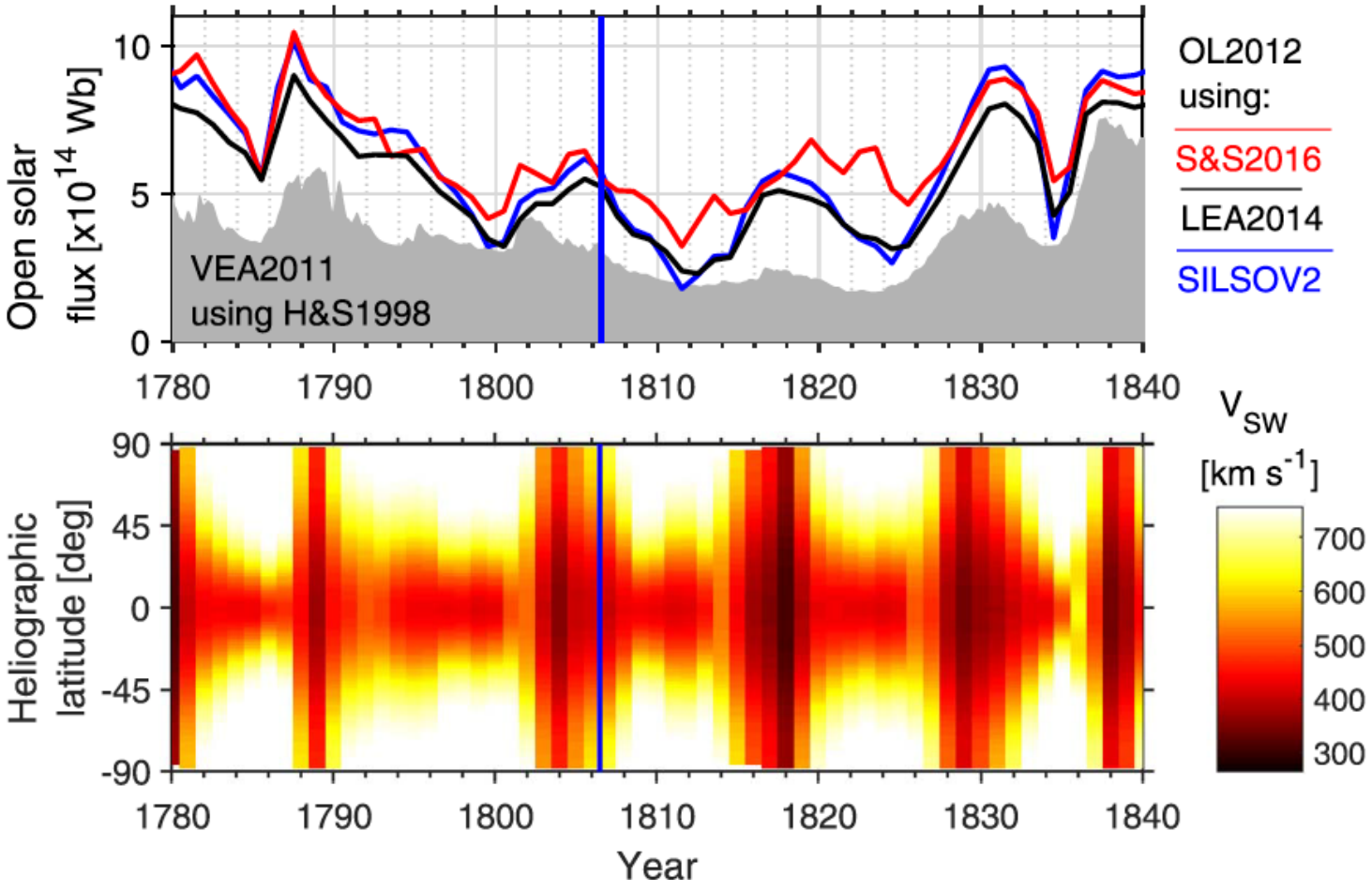
Hayakawa+2020b

# Context of the coronal drawing in 1806




Hayakawa+2020b;

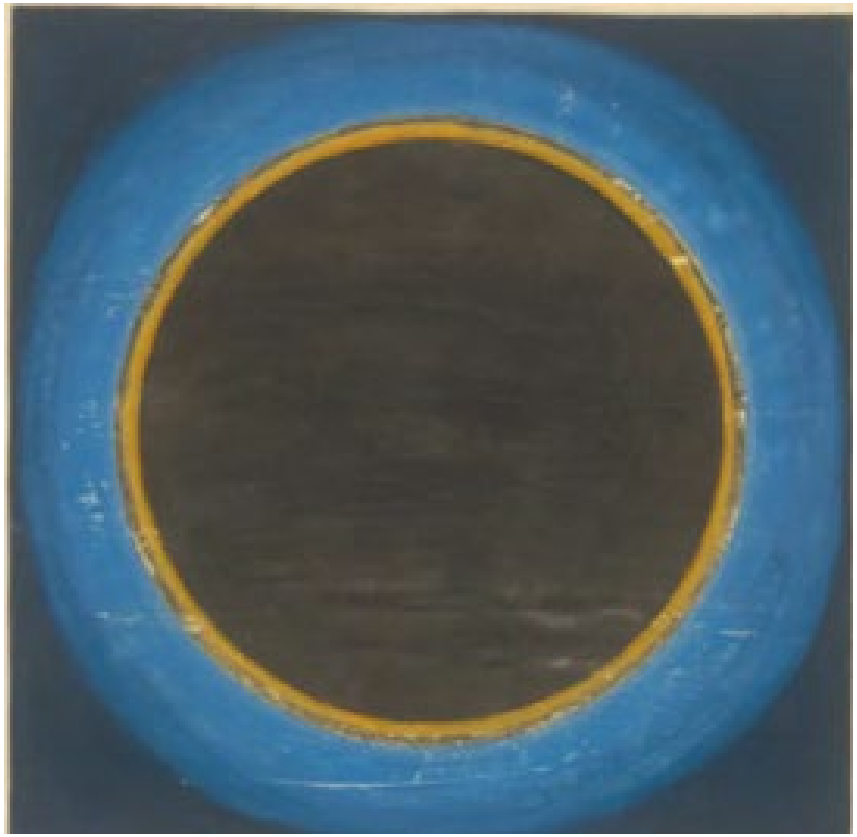
# Context of the coronal drawing in 1806



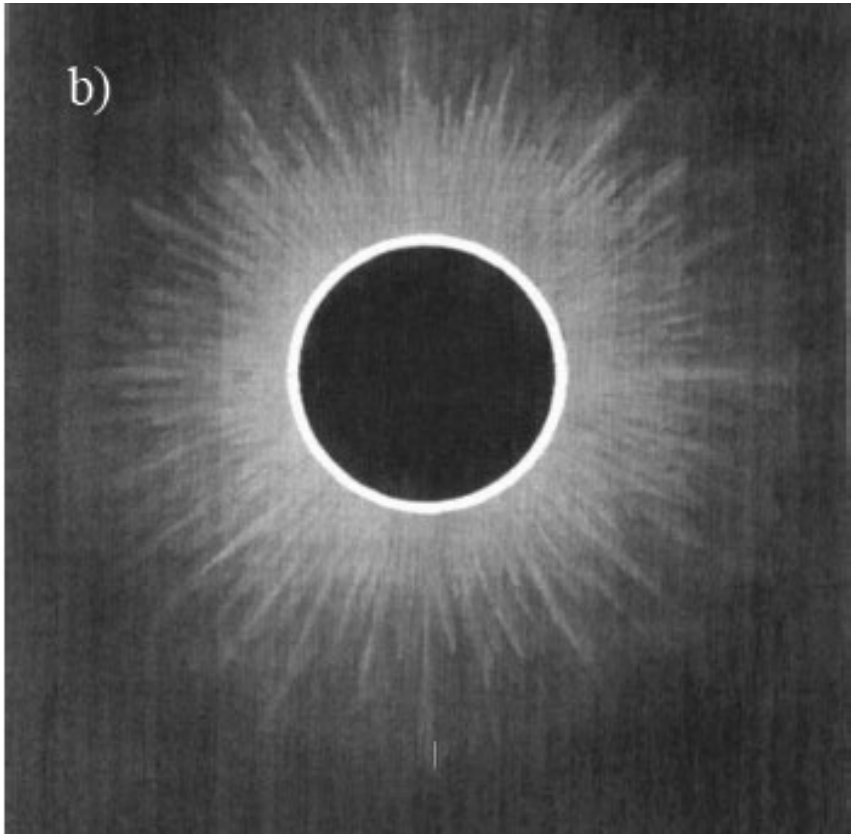

Hayakawa+2020b;

# Solar Coronal Structure

**Observed coronal structure in the Maunder Minimum**

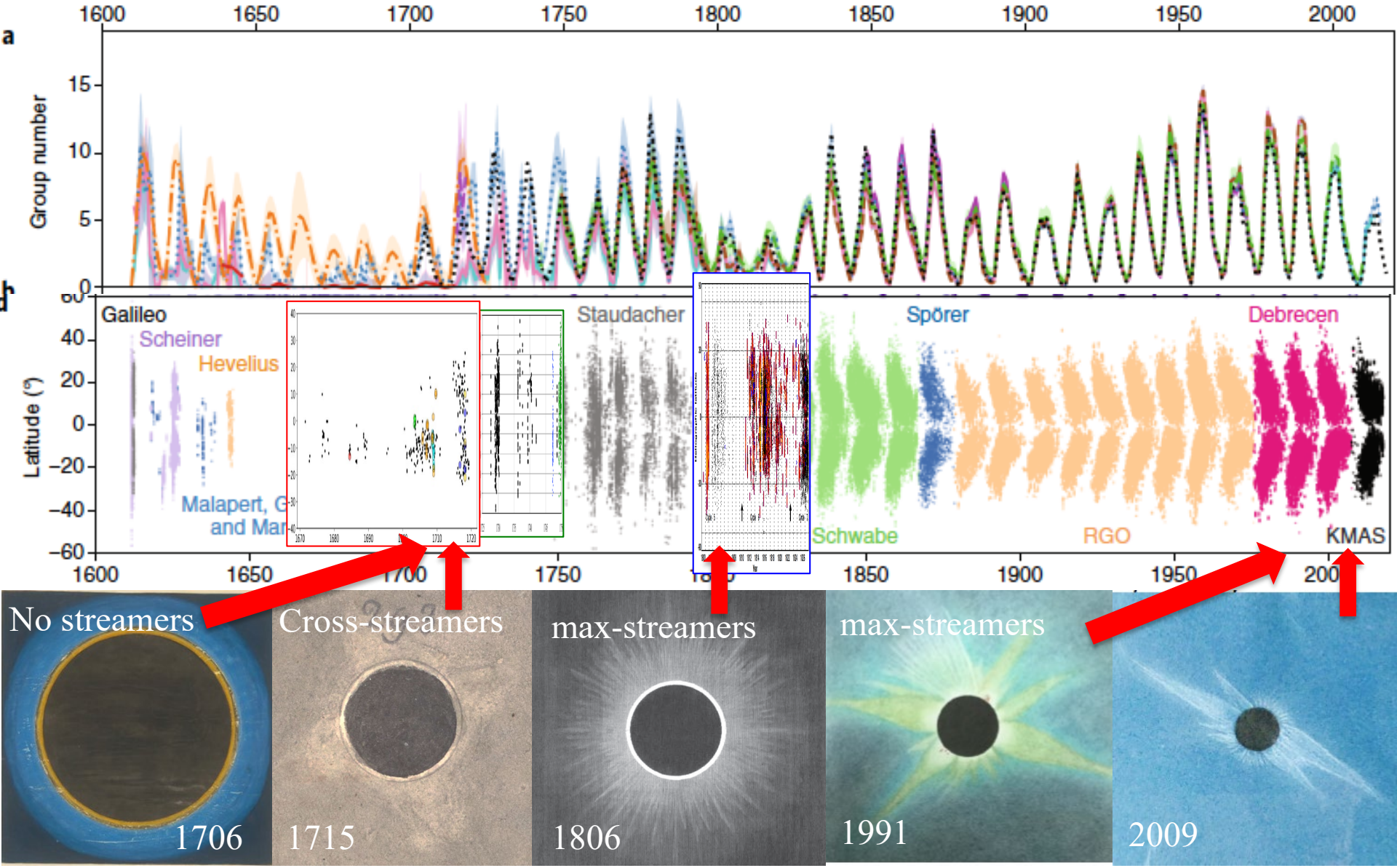


**Observed coronal structure in the Dalton Minimum (1806)**




Observed corona during the Maunder Minimum (Hayakawa+2021)
v.s. 1806 June 16 at Albany USA (Hayakawa+2020b)

# The Maunder Minimum was indeed unusual!

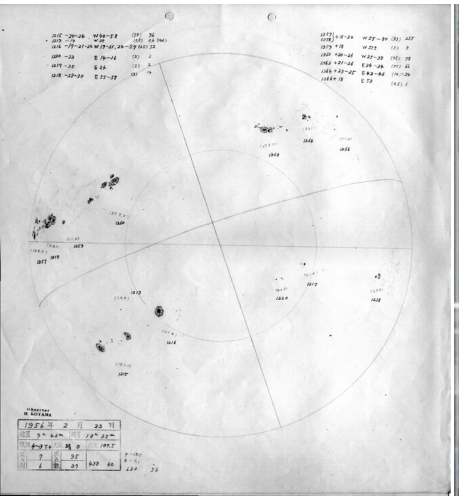


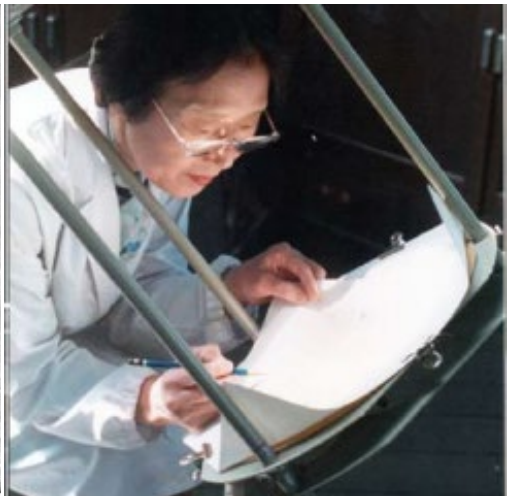
# The Maunder Minimum vs the Dalton Minimum

- The Maunder Minimum
  - The sunspot group number was at best 1-2 in the MM.
  - Most of the sunspots appeared in the southern hemisphere in the MM.
  - No significant coronal streamers
- The Dalton Minimum
  - During the DM, up to 9 sunspot groups are confirmed in Prantner's sunspot observations.
  - The sunspot are located in both solar hemispheres in the DM.
  - Significant coronal streamers are confirmed.
- The MM and the DM were significantly different from each other, probably because of the different solar dynamo activity.

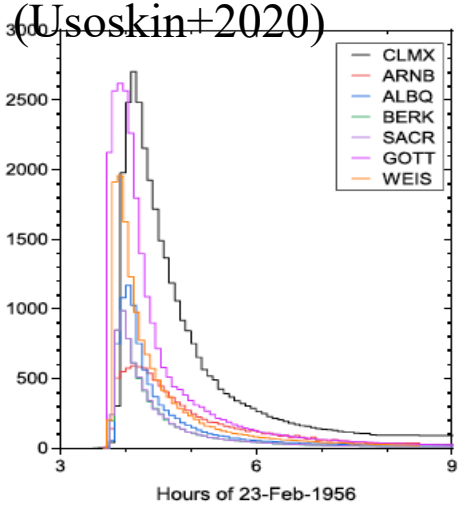
# Please let me know any historical data around you!

Sunspot drawings: （Hayakawa+2020a）

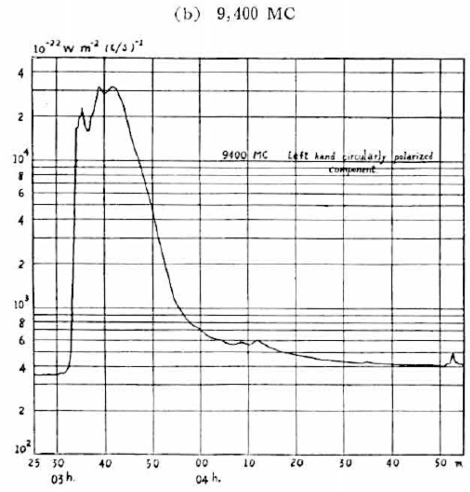


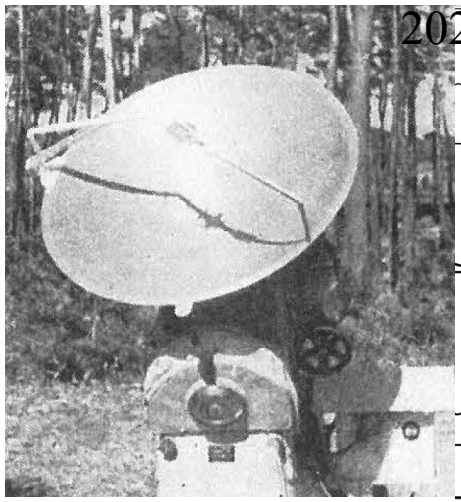


Cosmic ray observations => Neutron Monitor (Usoskin+2020)

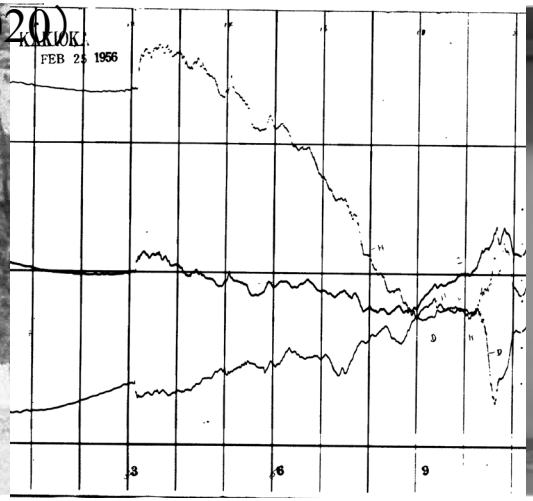


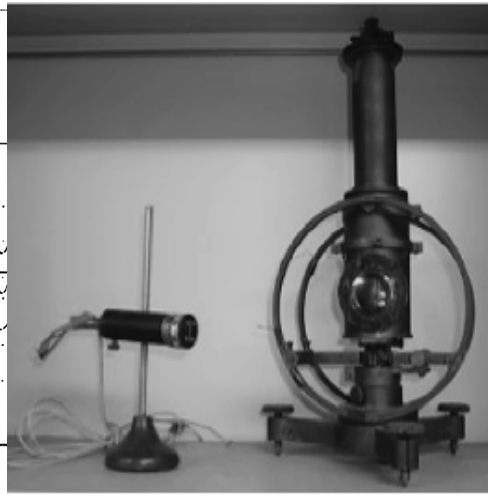

Solar radio observations（田中1956, 1957）



Geomagnetic observations （柿岡観測所+能勢2020）



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- Hayakawa+2020a, ApJ, 890, 98.
- Hayakawa+2020b, ApJ, 900, 114.
- Hayakawa+2021, JSWSC, 11, 1.
- Hayakawa+2021b, ApJ, 919, 1.
- Hayakawa+2022, ApJ, 941, 151
- Hayakawa+2023, JSWSC, DOI: 10.1051/swsc/2023023
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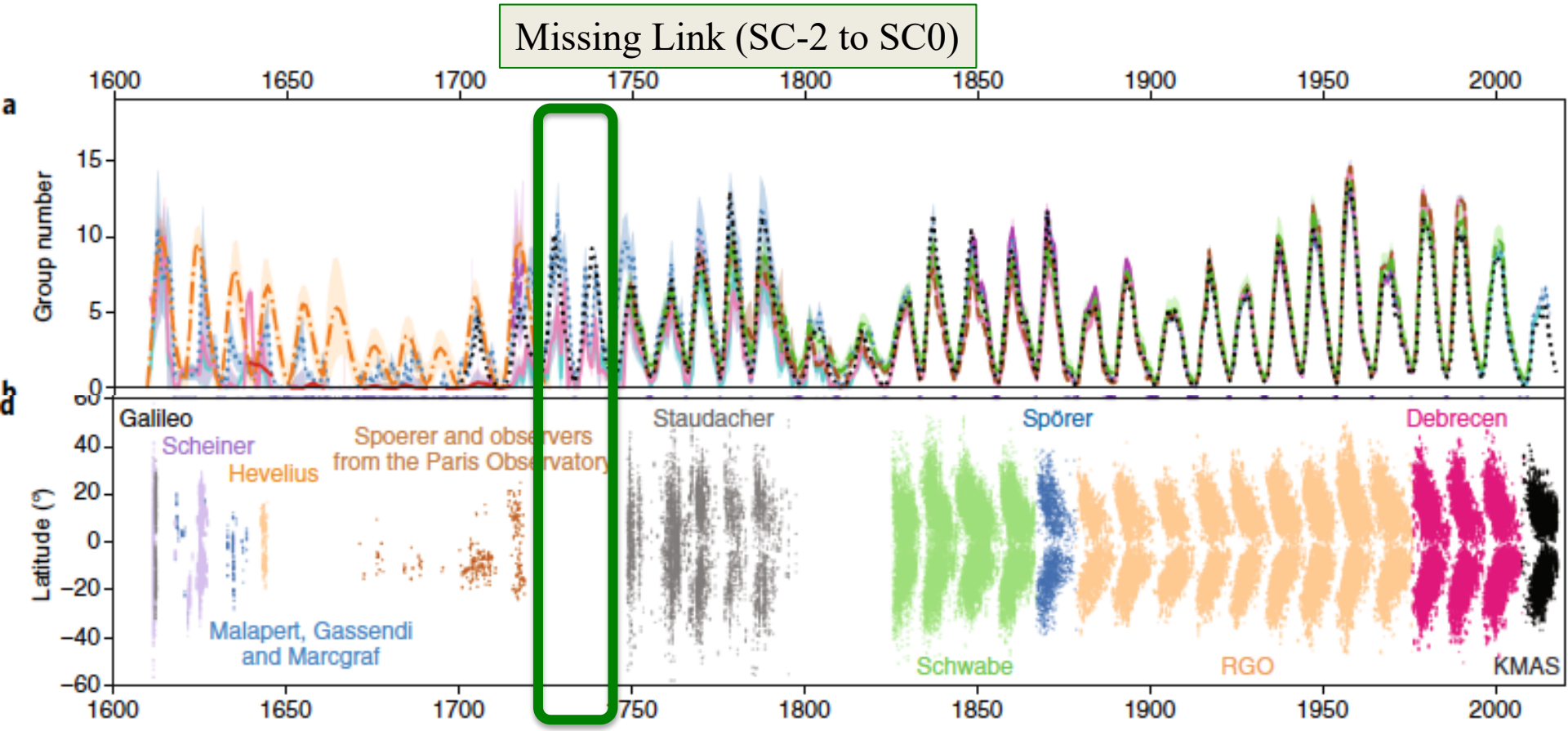
- Riley+2015, ApJ, 802, 105.
- Silverman & Hayakawa 2021, JSWSC, 11, 12.
- Usoskin+2015, A&A, 581, A95

# Conflicting reconstructions of the solar activity




Muñoz & Vaquero 2019

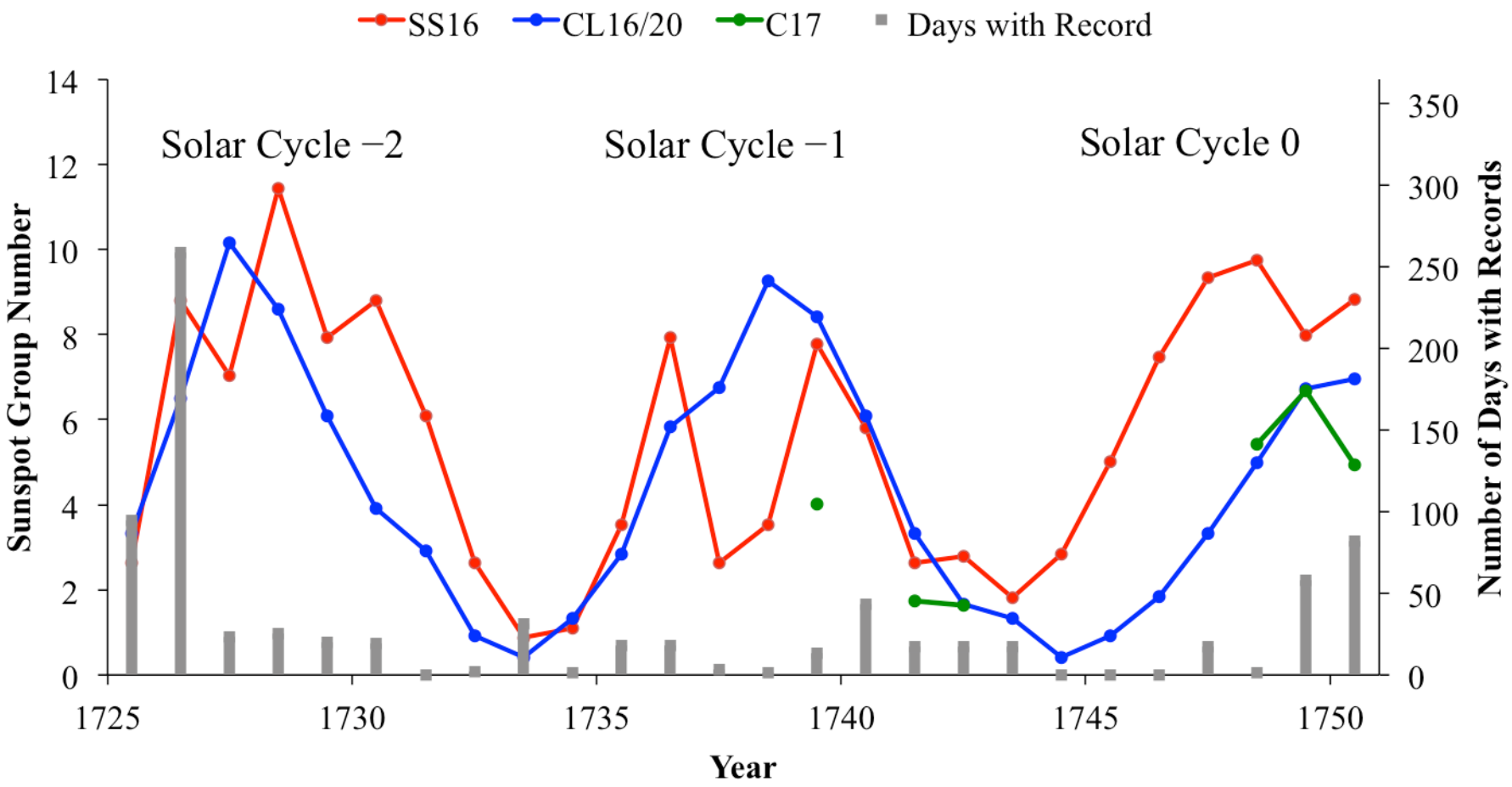
Even after Muñoz & Vaquero (2019), we have three problematic periods.

⇒ The Dalton Minimum in 1797-1827 – SGN△ BD×

⇒ The missing link in 1720-1748 – SGN△ BD×

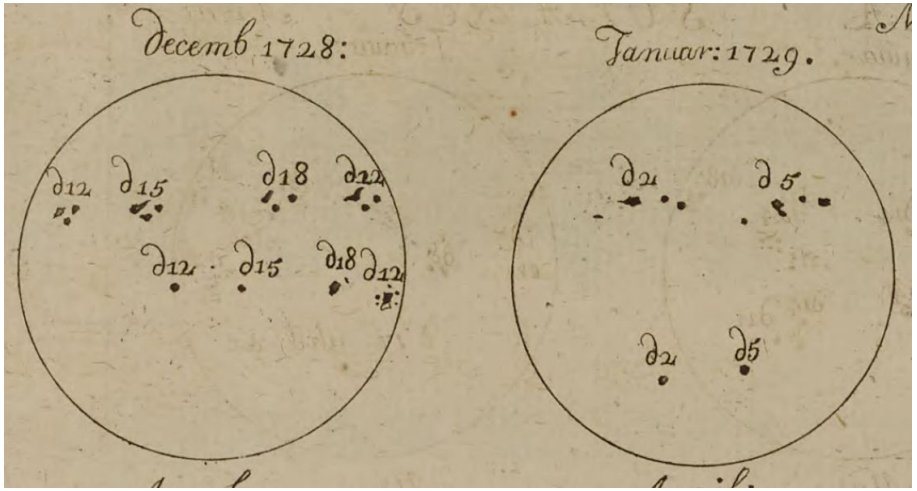
⇒ The Maunder Minimum in 1645-1715 – SGN△ BD△

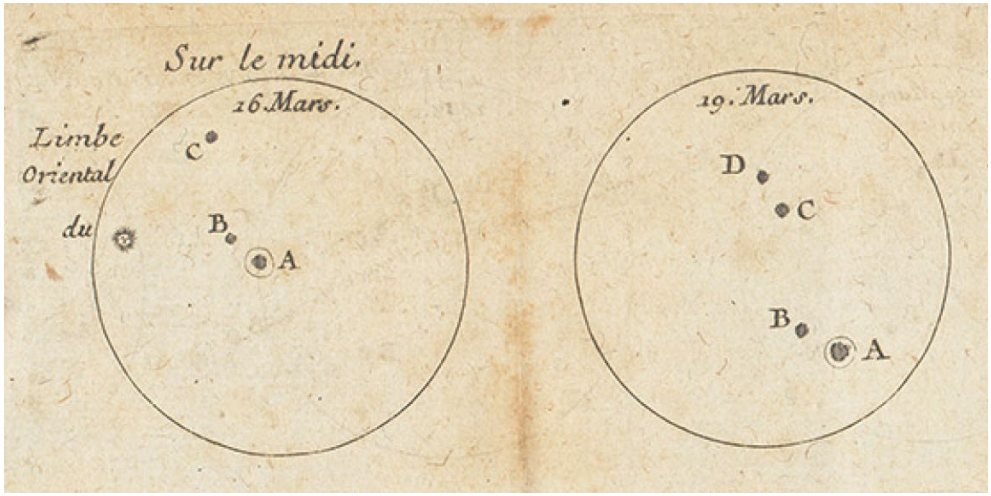
# Unfavorable data availability



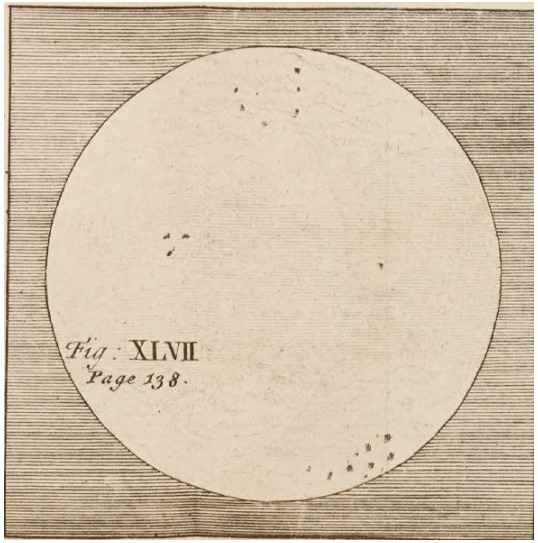

Plotted after Vaquero+2016, Svalgaard & Schatten 2016, and Clette & Lefevre 2016

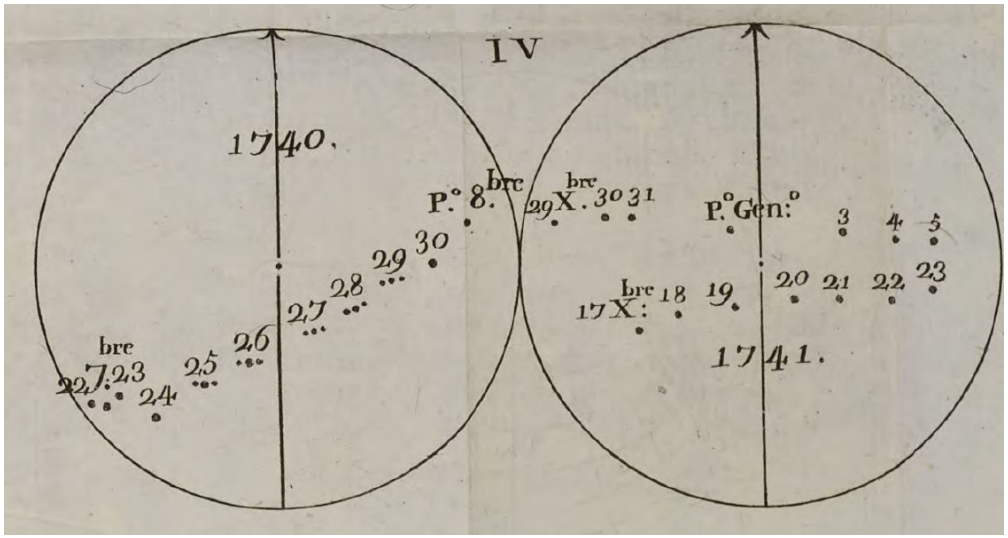
# New Data & Revisions



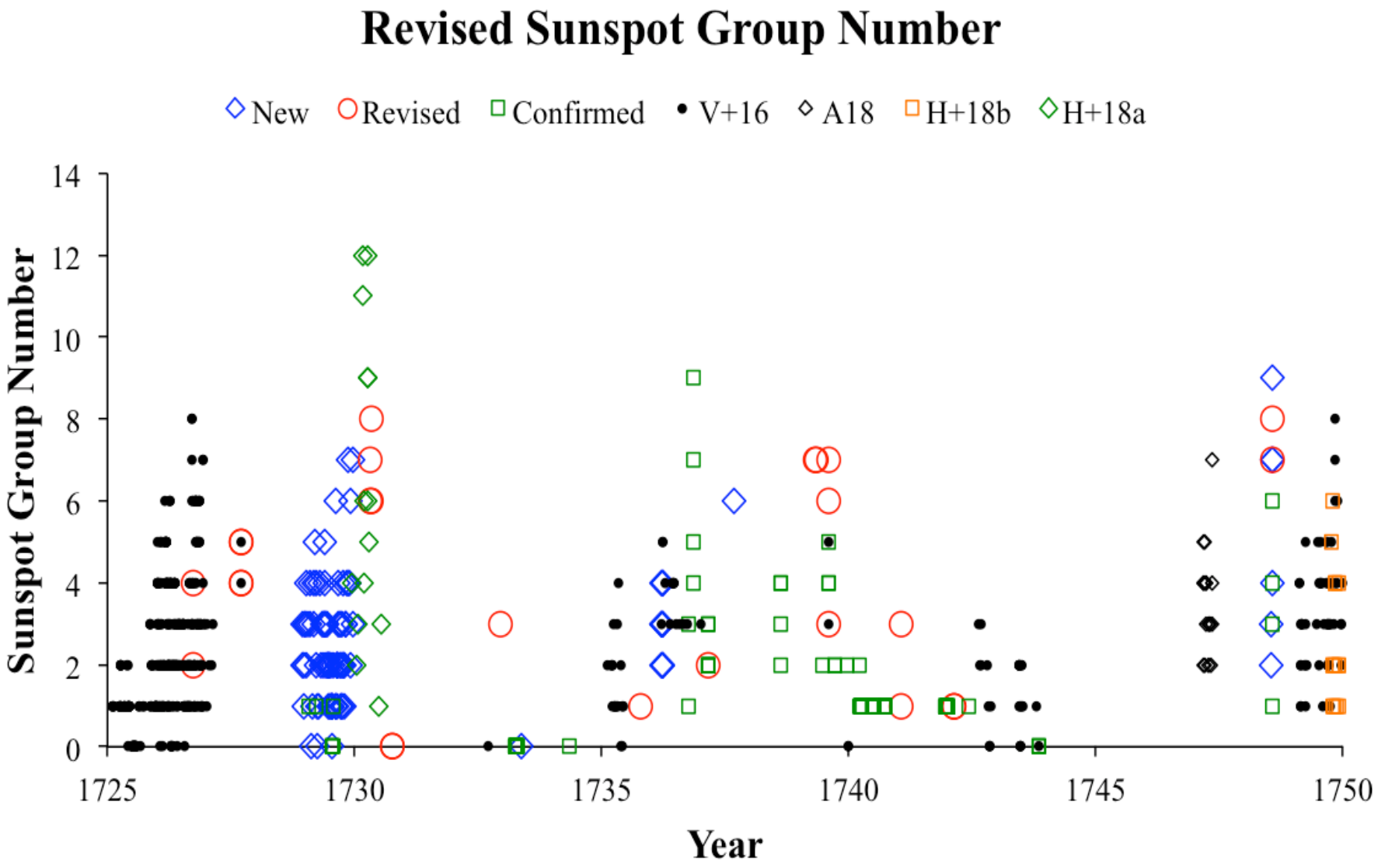




Van Coesfeld in 1729, Duclos in 1736 (BnF), Martin in 1737, and Muzano in 1741



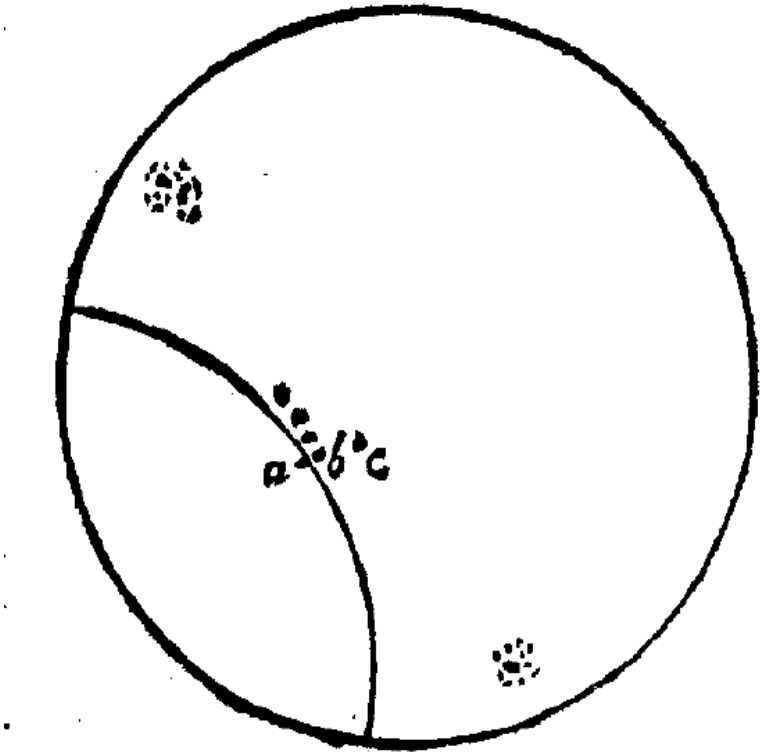



# Revised Sunspot Group Number

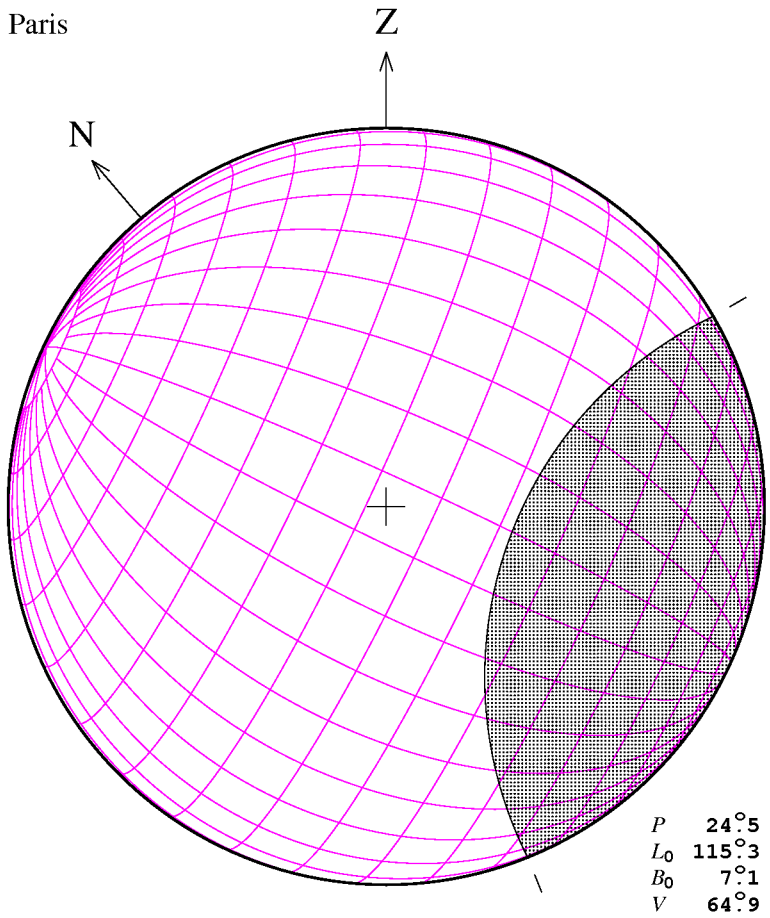


# Sunspot Positions

Cassini de Thury at Paris Observatory on 1727 Sep 15

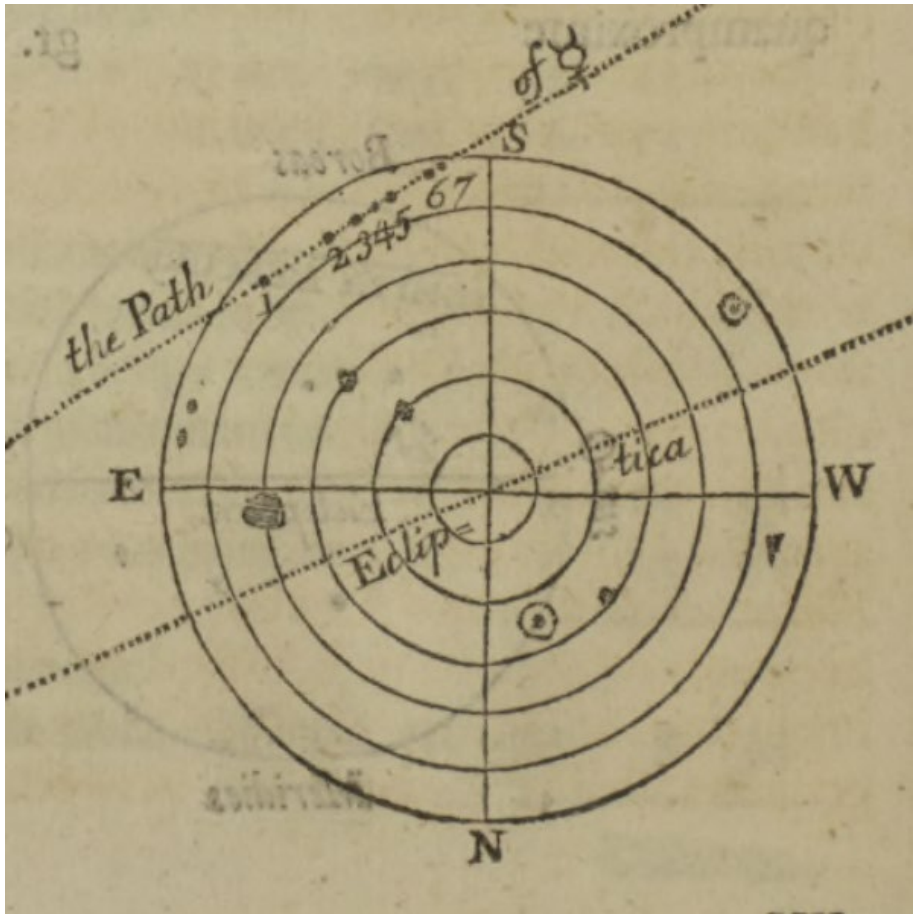



Cassini 1727

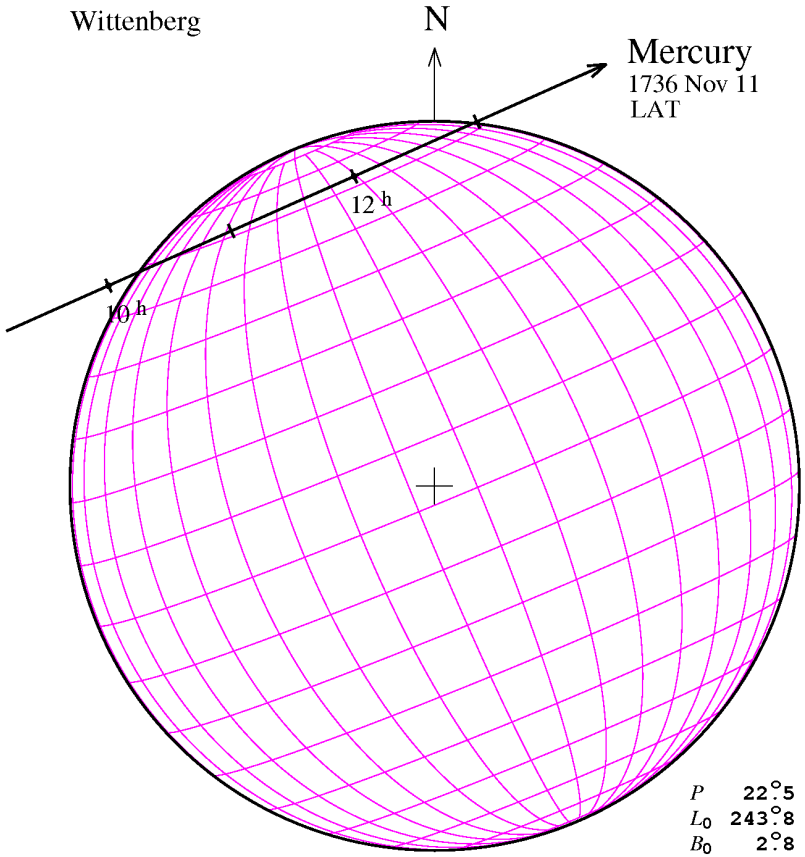


# Sunspot Positions

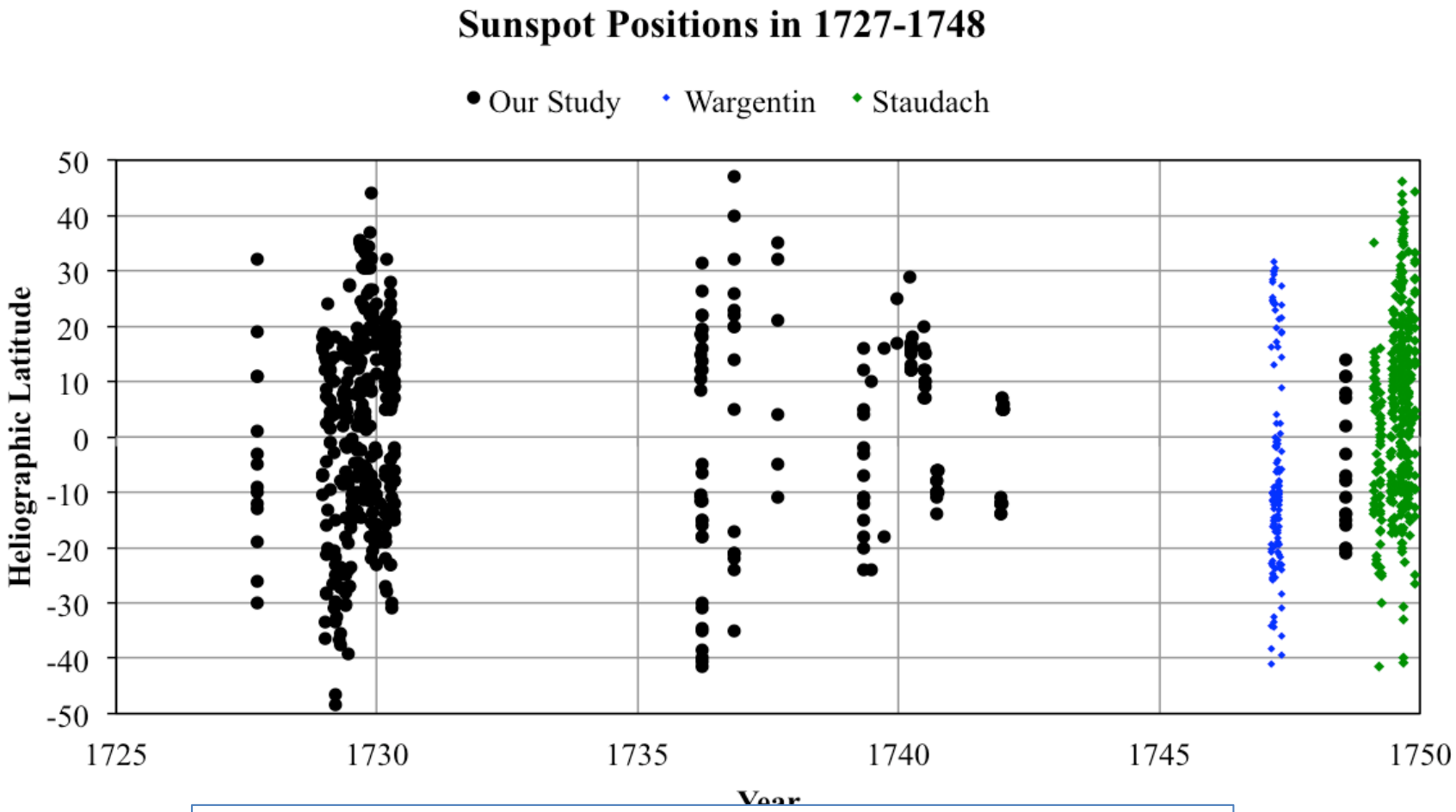
Weidler at Wittenberg on 1736 Nov 11




Weidler 1741

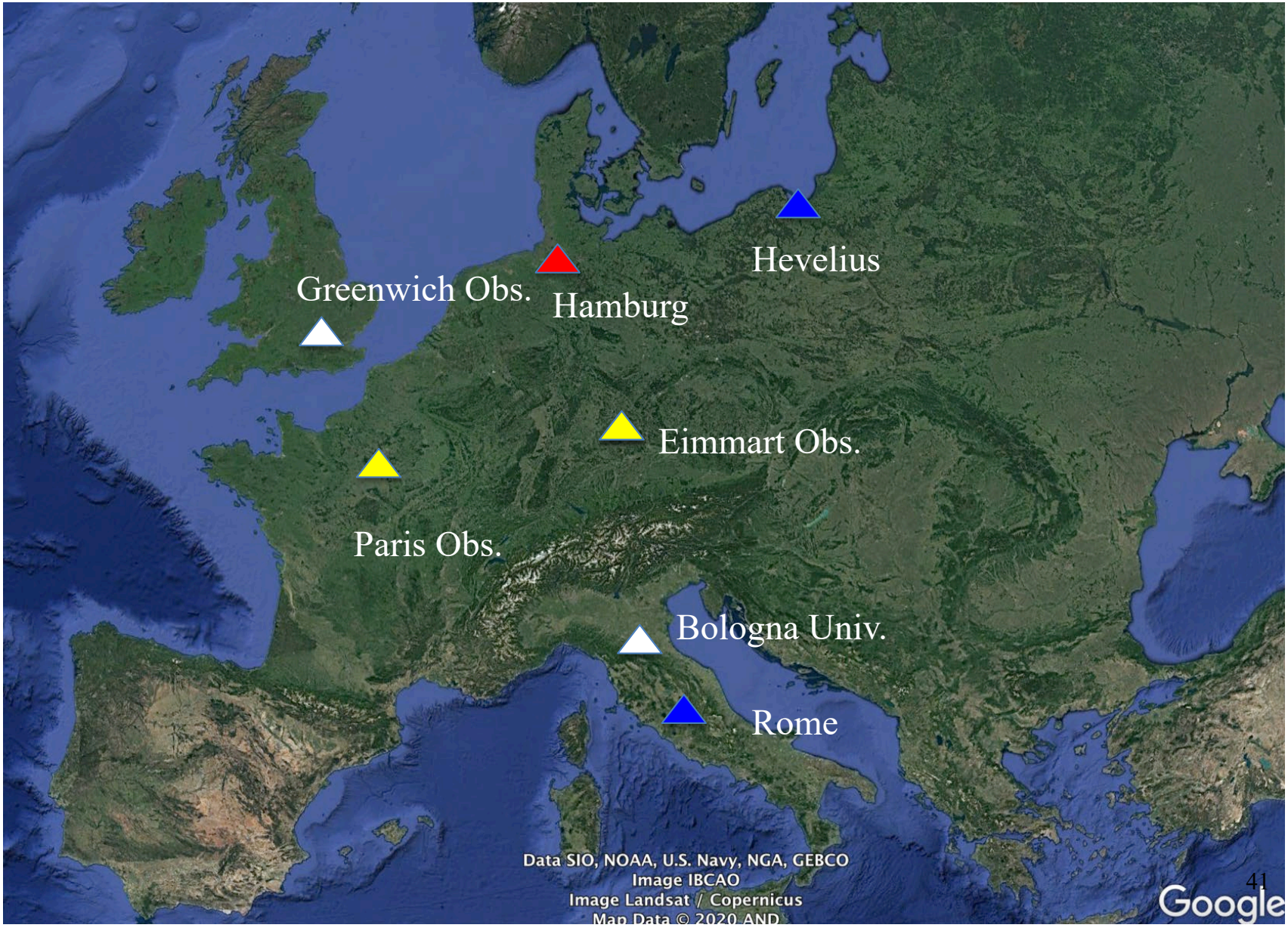


# Sunspot Positions



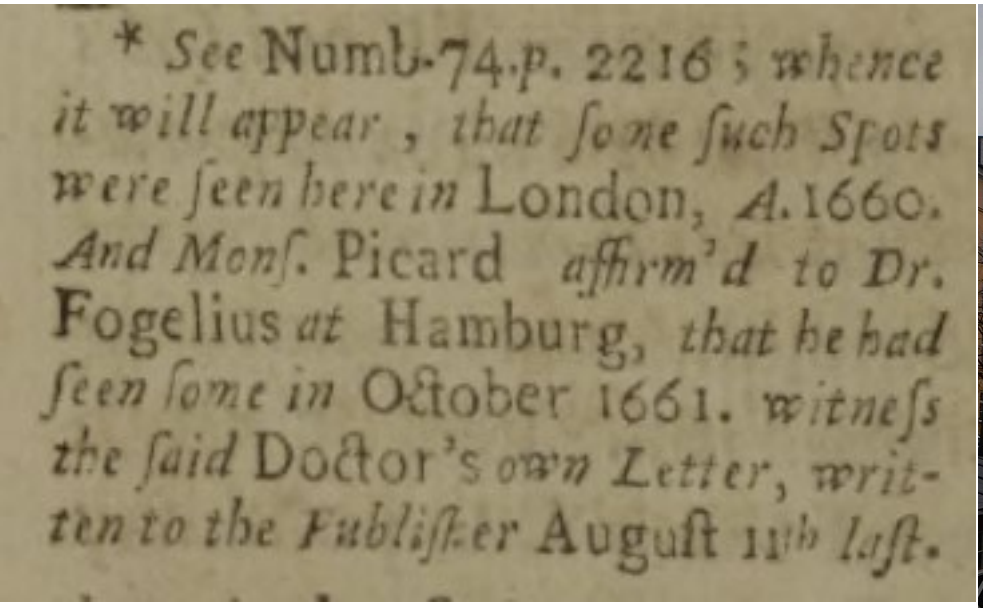

Normal sunspot migrations are visible!

# Fogelius & Siverus in 1661-1690



# Fogelius' spotless days

**Notes in Cassini (1671)**



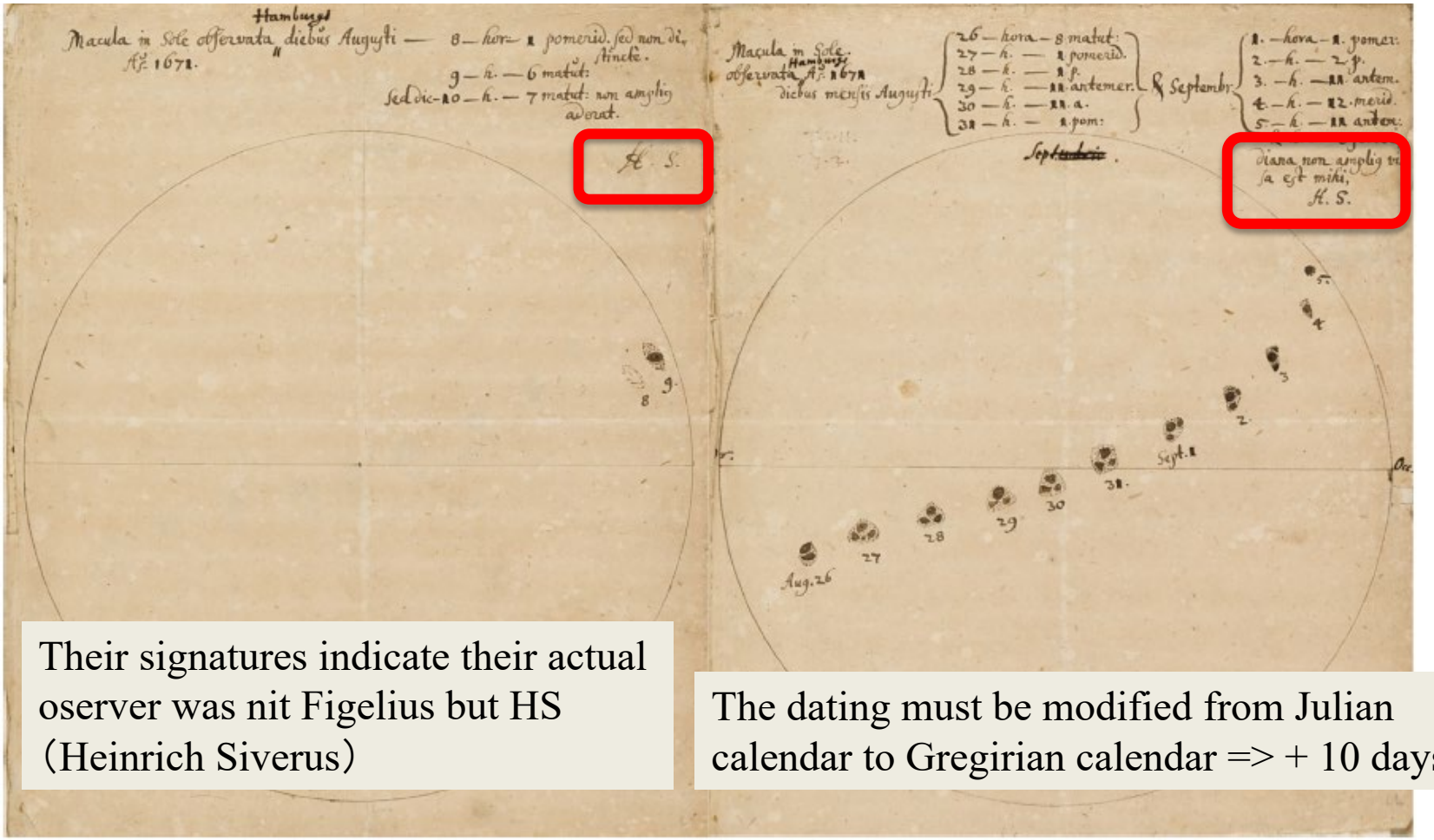
* See Numb. 74. p. 2216; whence it will appear, that ſome ſuch Spots were ſeen here in London, A. 1660. And Monſ. Picard affirm'd to Dr. Fogelius at Hamburg, that he had ſeen ſome in October 1661. witneſs the ſaid Doctor's own Letter, written to the Publiſher Auguſt 11th laſt.

In 1671 August, Fogelius reported the long dearth of sunspot visibility since 1660 Oct, whereas this is actually a hearsay from Picard (not continuous observation by Figelius)

**A good day to see sunspots!**

HH's photo at Copenhagen in Jan 2018
The solar disk is certainly not visible, because…

# Not Fogelius but Siverus




Their signatures indicate their actual oserver was nit Figelius but HS (Heinrich Siverus)

The dating must be modified from Julian calendar to Gregirian calendar => + 10 days

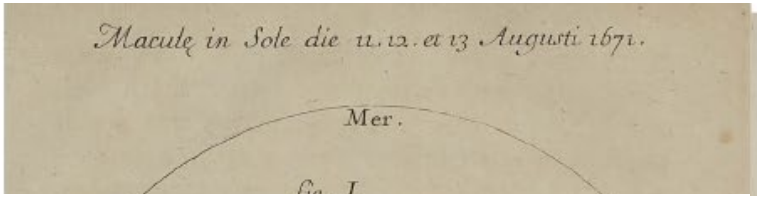
**Figure 1.** Heinrich Siverus' original sunspot drawings in Fogelius's correspondence dated on 1671 November 1 (MS RS EL/F1/34; ©The Royal Society).

# Revision of the observational dates

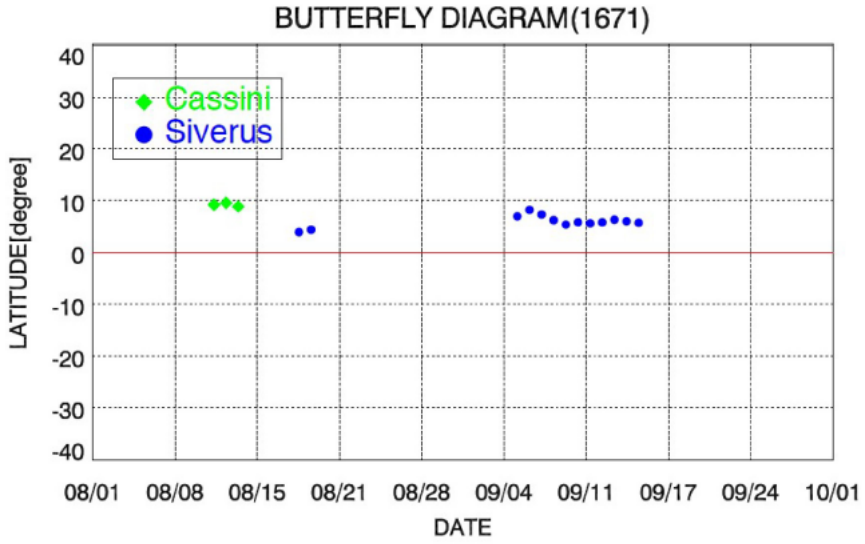
| Gregorian calendar | | | Group number | Reference | Observer |
|---|---|---|---|---|---|
| Year | Month | Date | | | |
| 1661 | 10 | 13 | 1 | MS EL/F1/33 | Picard |
| 1661 | 10 | 14 | 1 | MS EL/F1/33 | Picard |
| 1666 | 7 | 2 | 0* | MS CLP 8i/13a | Willoughby |
| 1671 | 8 | 13 | 1 | MS EL/F1/33 | Picard |
| 1671 | 8 | 17 | 1 | MS EL/F1/33 | Fogelius |
| 1671 | 8 | 18 | 1 | MS EL/F1/33 | Fogelius |
| 1671 | 8 | 18 | 1 | Fig. 1(a) | Siverus |
| 1671 | 8 | 19 | 1 | MS EL/F1/33 | Fogelius |
| 1671 | 8 | 19 | 1 | Fig. 1(a) | Siverus |
| 1671 | 8 | 20 | 0 | Fig. 1(a) | Siverus |
| 1671 | 9 | 5 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 6 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 7 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 8 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 9 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 9 | 1 | Hook (1671) | Hook |
| 1671 | 9 | 10 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 11 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 11 | 1 | Hook (1671) | Hook |
| 1671 | 9 | 12 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 13 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 14 | 1 | Fig. 1(b) | Siverus |
| 1671 | 9 | 15 | 1 | Fig. 1(b) | Siverus |
| 1676 | 8 | 8 | ≥1 | Hook (1677) | Hook |
| 1676 | 8 | 14 | ≥1 | Hook (1677) | Hook |
| 1676 | 8 | 17 | 0 | Hook (1677) | Hook |
| 1680 | 8 | 14 | ≥1 | Ettmüller (1693) | Siverus |
| 1680 | 8 | 16 | ≥1 | Ettmüller (1693) | Siverus |
| 1681 | 5 | 24 | ≥1 | Ettmüller (1693) | Siverus |
| 1681 | 6 | 25 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 7 | 29 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 7 | 30 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 7 | 31 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 8 | 1 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 11 | 6 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 11 | 7 | ≥1 | Ettmüller (1693) | Siverus |
| 1689 | 11 | 8 | ≥1 | Ettmüller (1693) | Siverus |

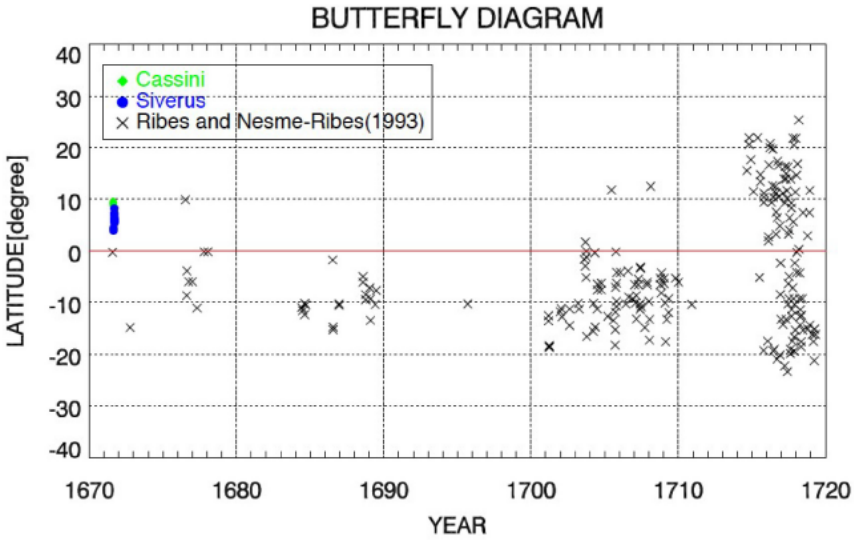
- Siverus
- 5400 d => 25 d
- Fogelius
- 3605 d => 3 d
- The existing database has been drastically revised.
- Sunspot group number is at best 1-2. This supports the suppressed solar activity during the MM.

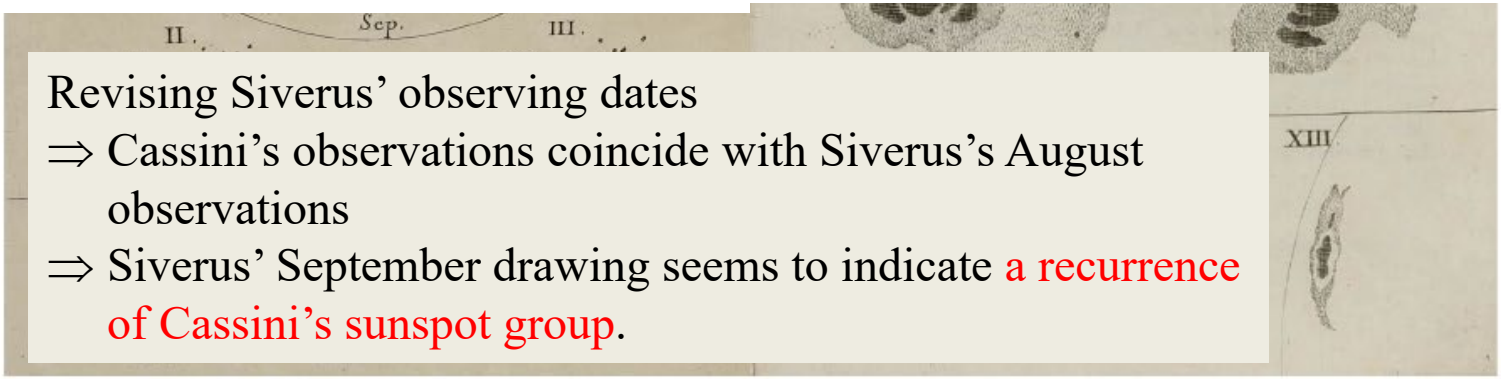
# Not two different group but one recurrent group








Revising Siverus' observing dates

⇒ Cassini's observations coincide with Siverus's August observations

⇒ Siverus' September drawing seems to indicate a recurrence of Cassini's sunspot group.

**Figure 3.** (a) Cassini's sunspot drawing with time sequence of a sunspot group in the whole-disc drawing during 1671 August 11–13 (I), with its enlargement on August 11 (II), 12 (III and IV), and 13 (V), adopted from Cassini (1671a); and (b) Cassini's enlarged sunspot drawings for the said group on 14 (I), 15 (II), 16 (III, IV, and V), 17 (VI), 18 (VII), and 1671 August 19 (VIII), adapted from Cassini (1671b).