AIP

Historical sunspot data – Part II

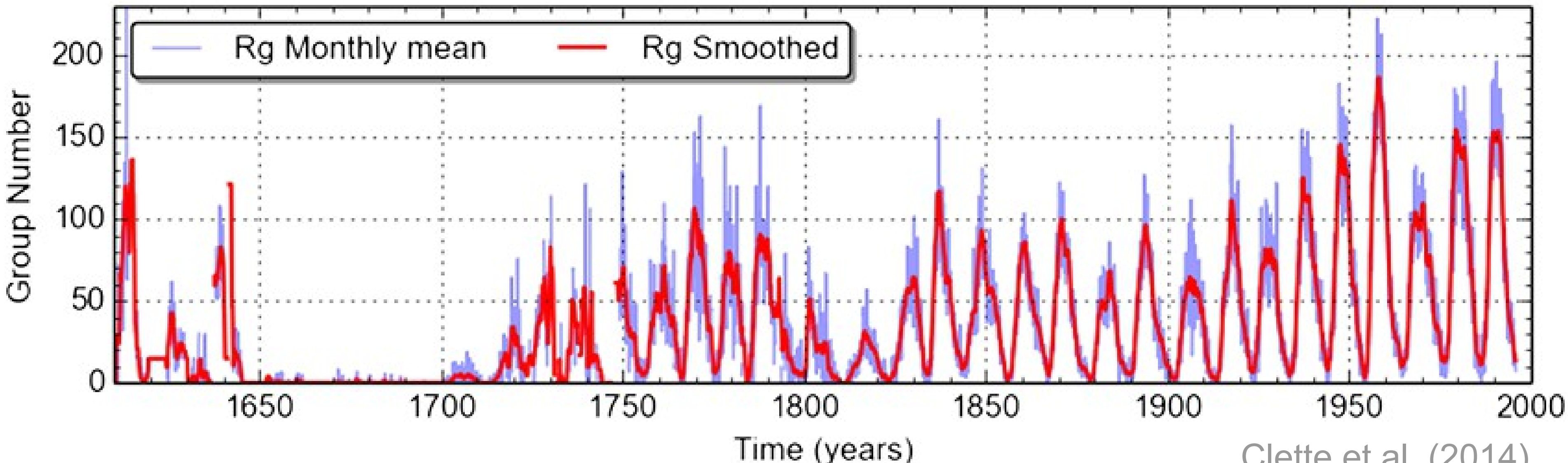
The Maunder minimum

- Period ~ 1650 – 1715 with almost no spots
- Period between 1661 – 1671 with *zero* spots
- How to evaluate this period?
  - Were telescopes good enough
  - Were enough observers watching the Sun?
  - Was society afraid of Sun being spotty?
  - Were there really years without any spot?

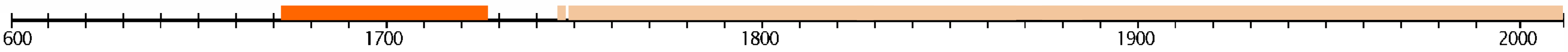
The group sunspot number (Rg or GSN)

- Data base by Hoyt & Schatten (1998)
- Number of sunspot *groups* as a robust measure

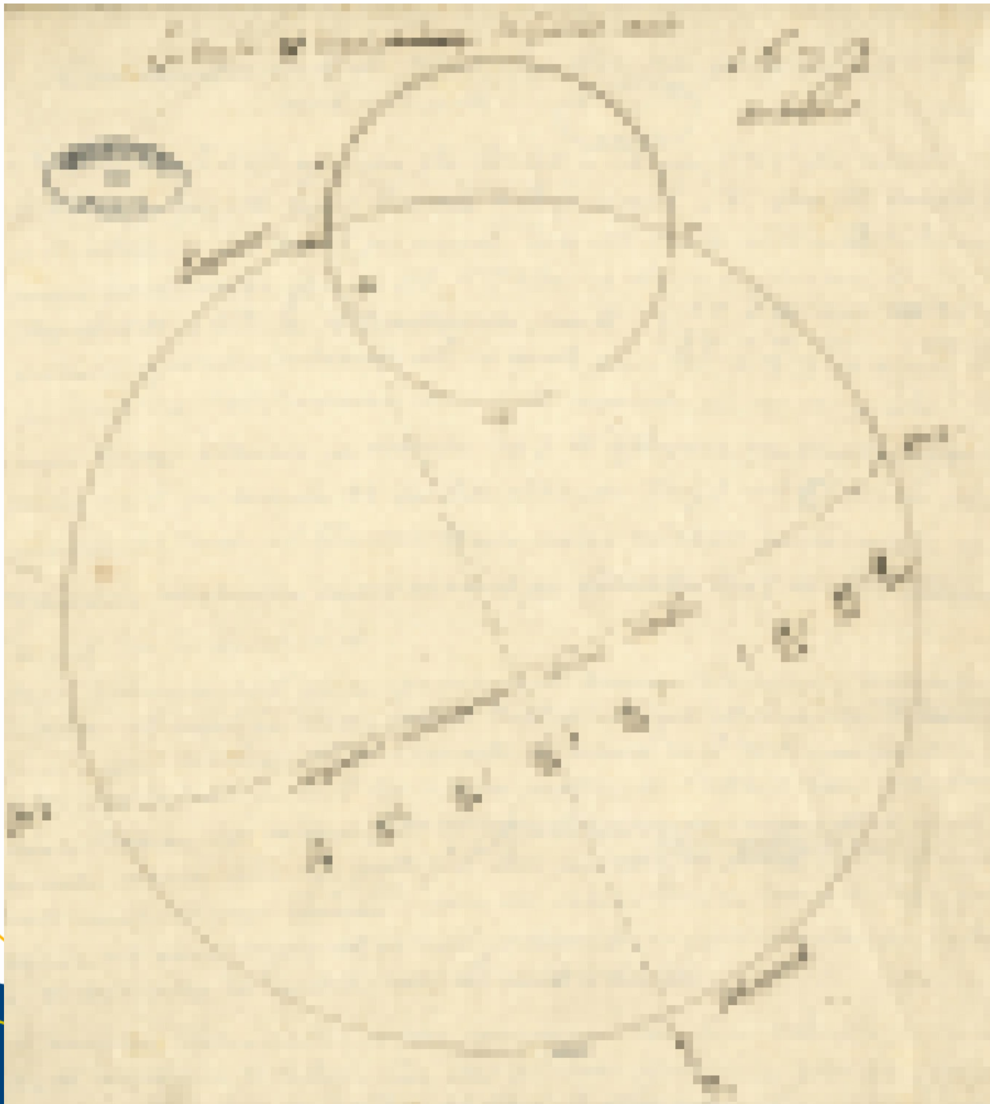
(times 12, in order to have smilar values as the sunspot number)

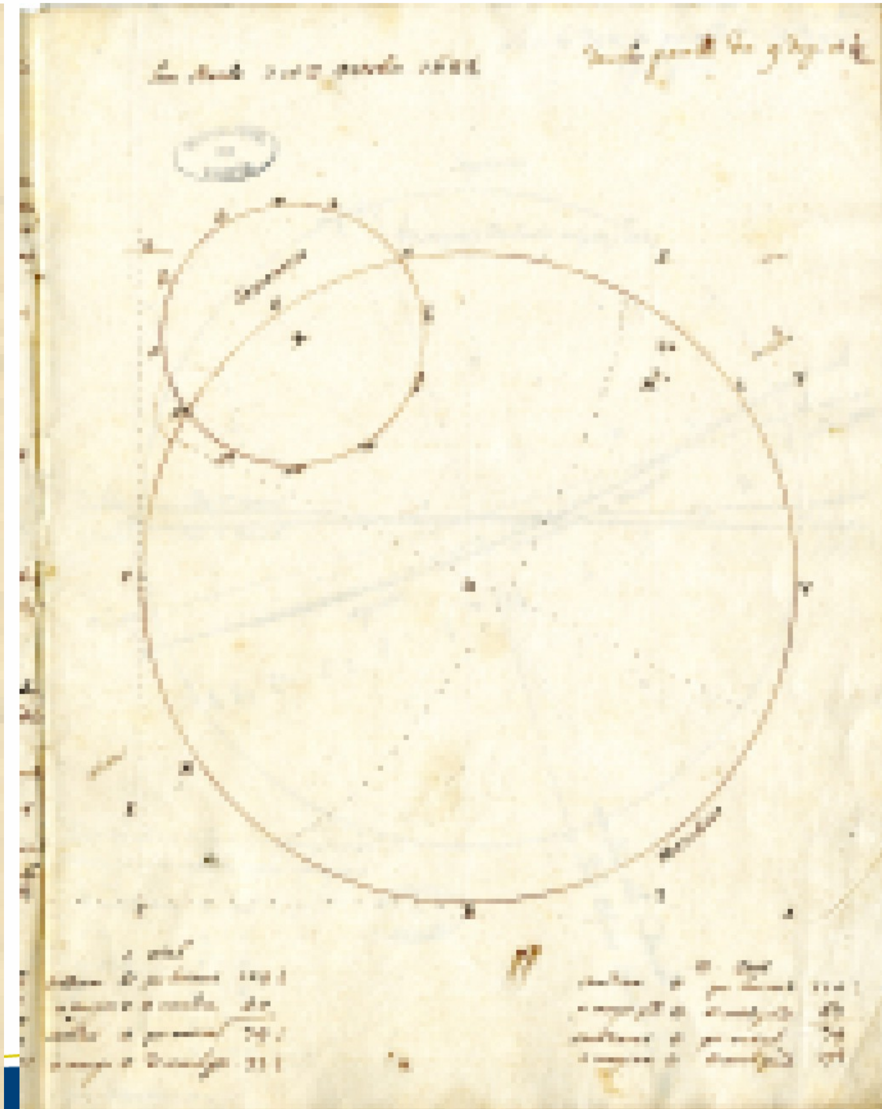


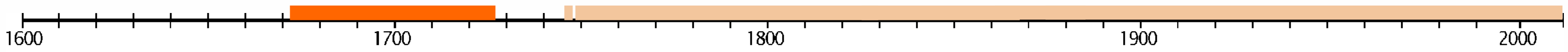
Clette et al. (2014)



End of Maunder minimum, ~1672-1727

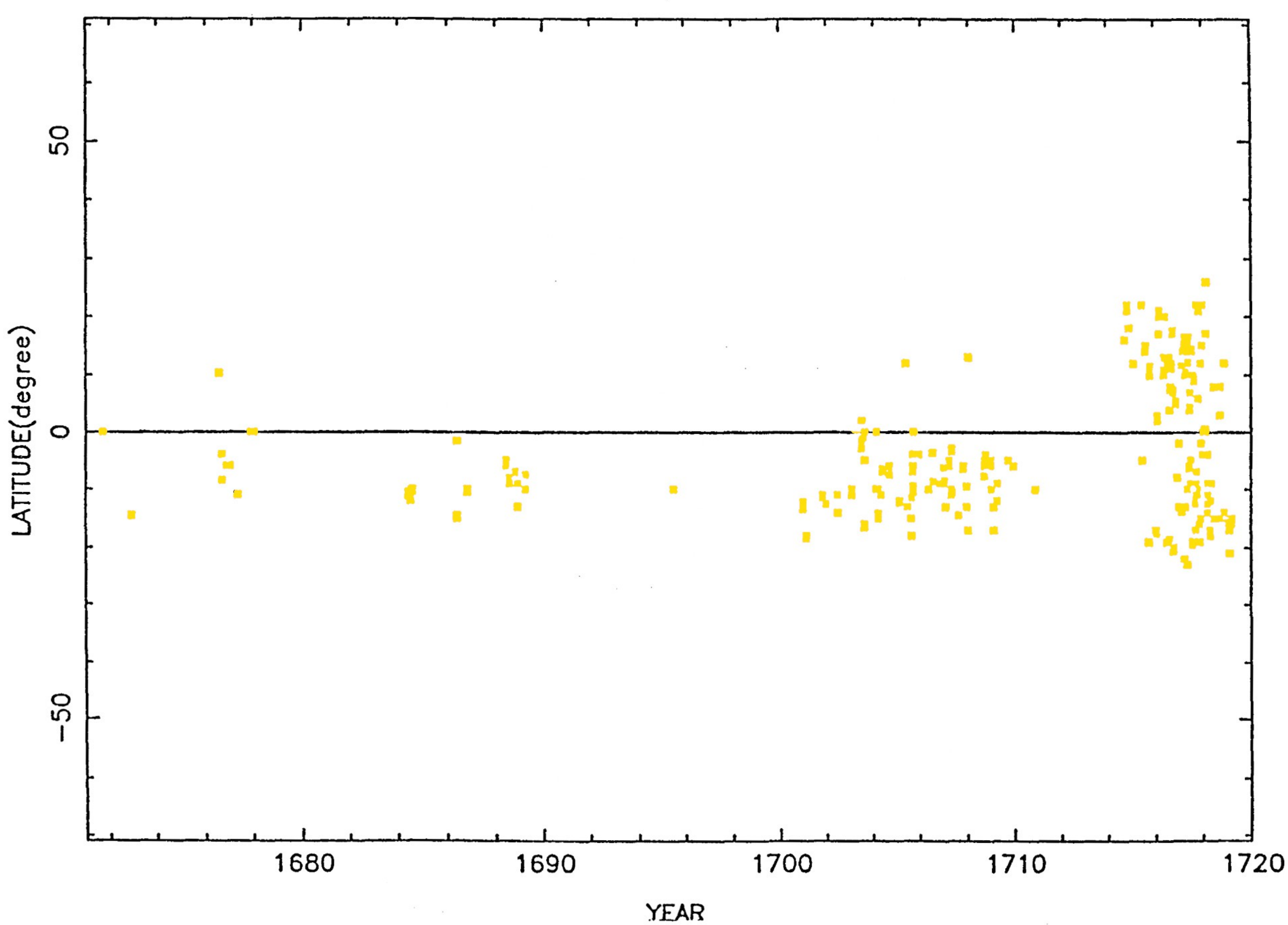


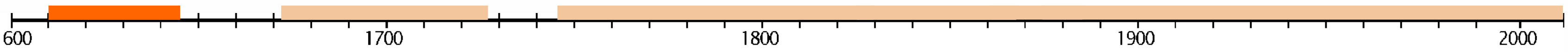




End of Maunder minimum

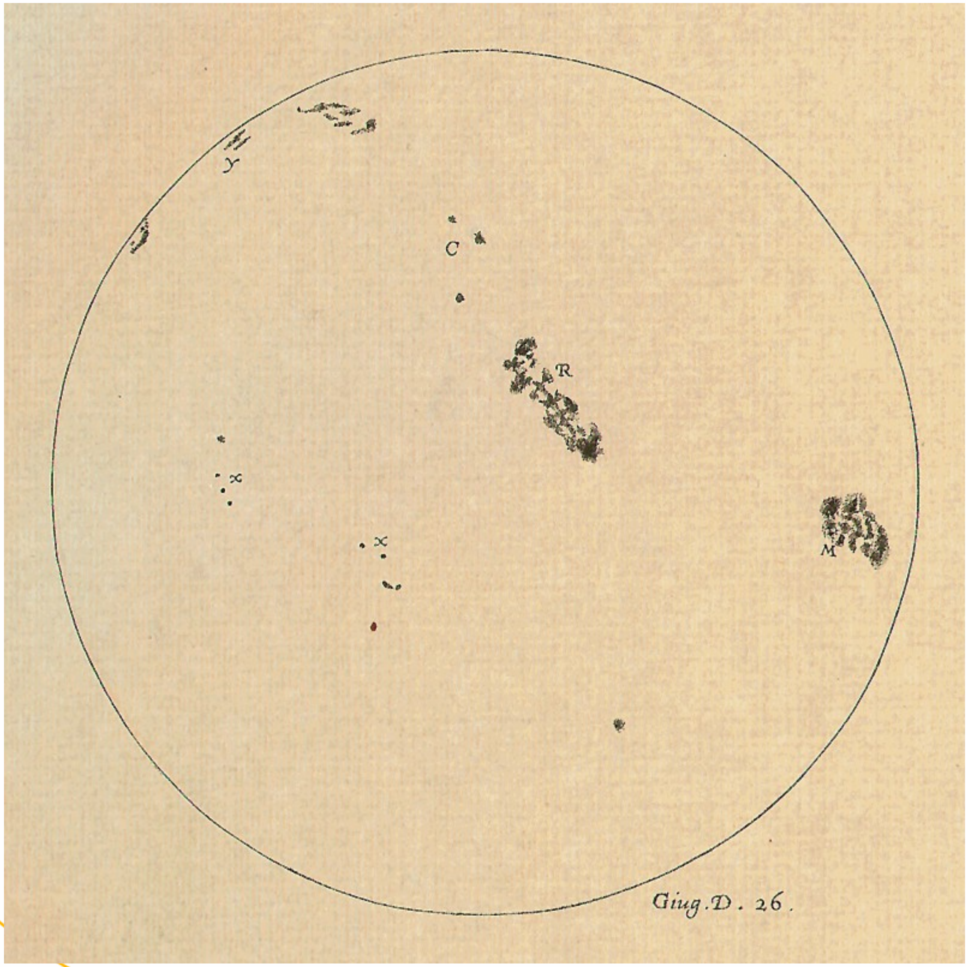
- Ribes & Nesme-Ribes (1993)



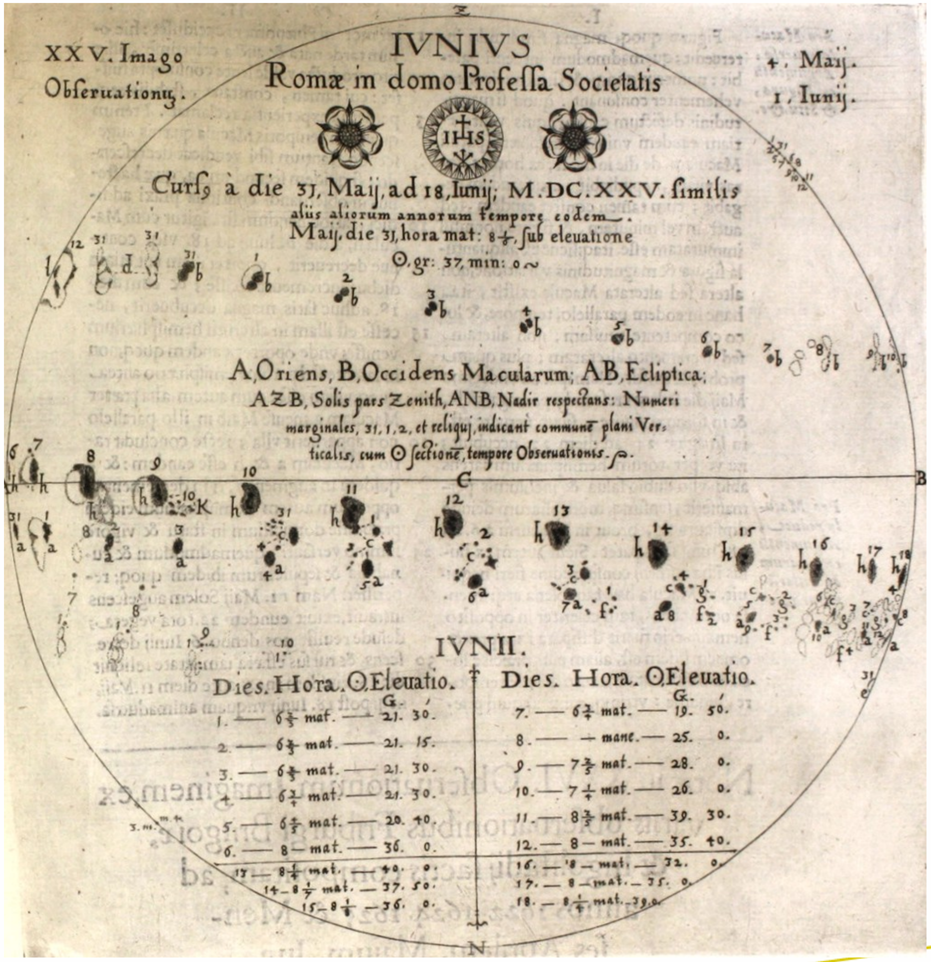


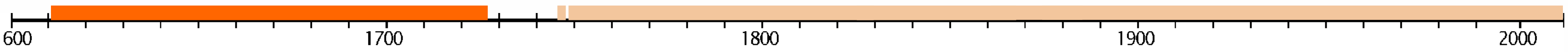
Telescopes good enough?

Galileo, 26. June 1612



Christoph Scheiner, June 1625





How deep was the Maunder minimum?

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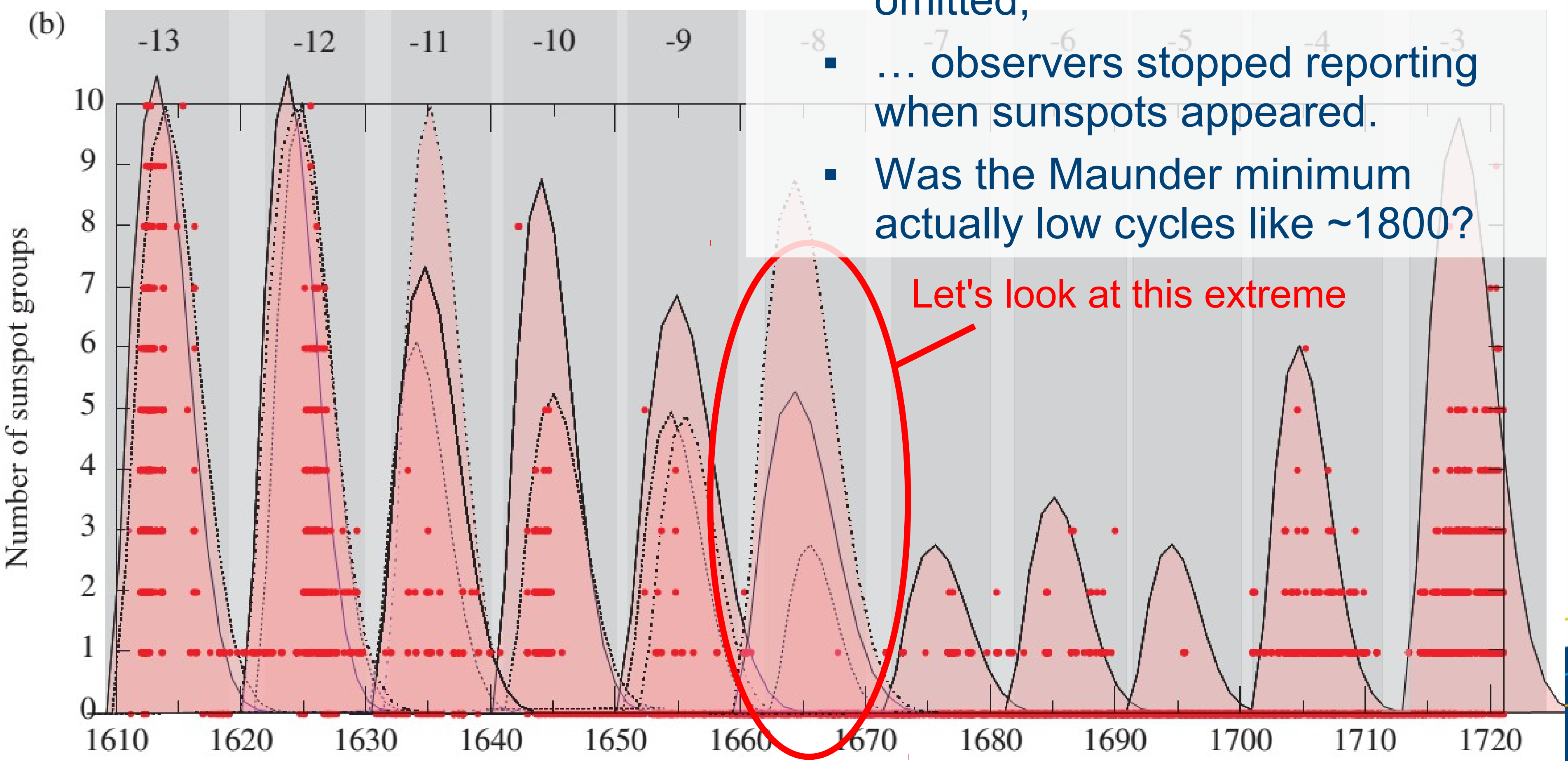
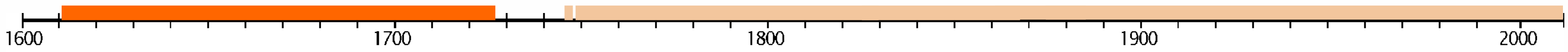
- Zolotova & Ponyavin (2015) raised questions whether …
  - … due to the world-view of the time, non-circular spots were omitted;
  - … observers stopped reporting when sunspots appeared.
  - Was the Maunder minimum actually low cycles like ~1800?



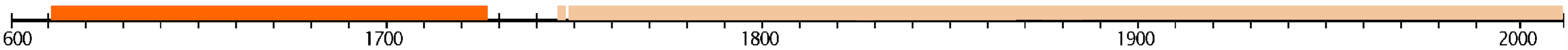


Problems of the record

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)



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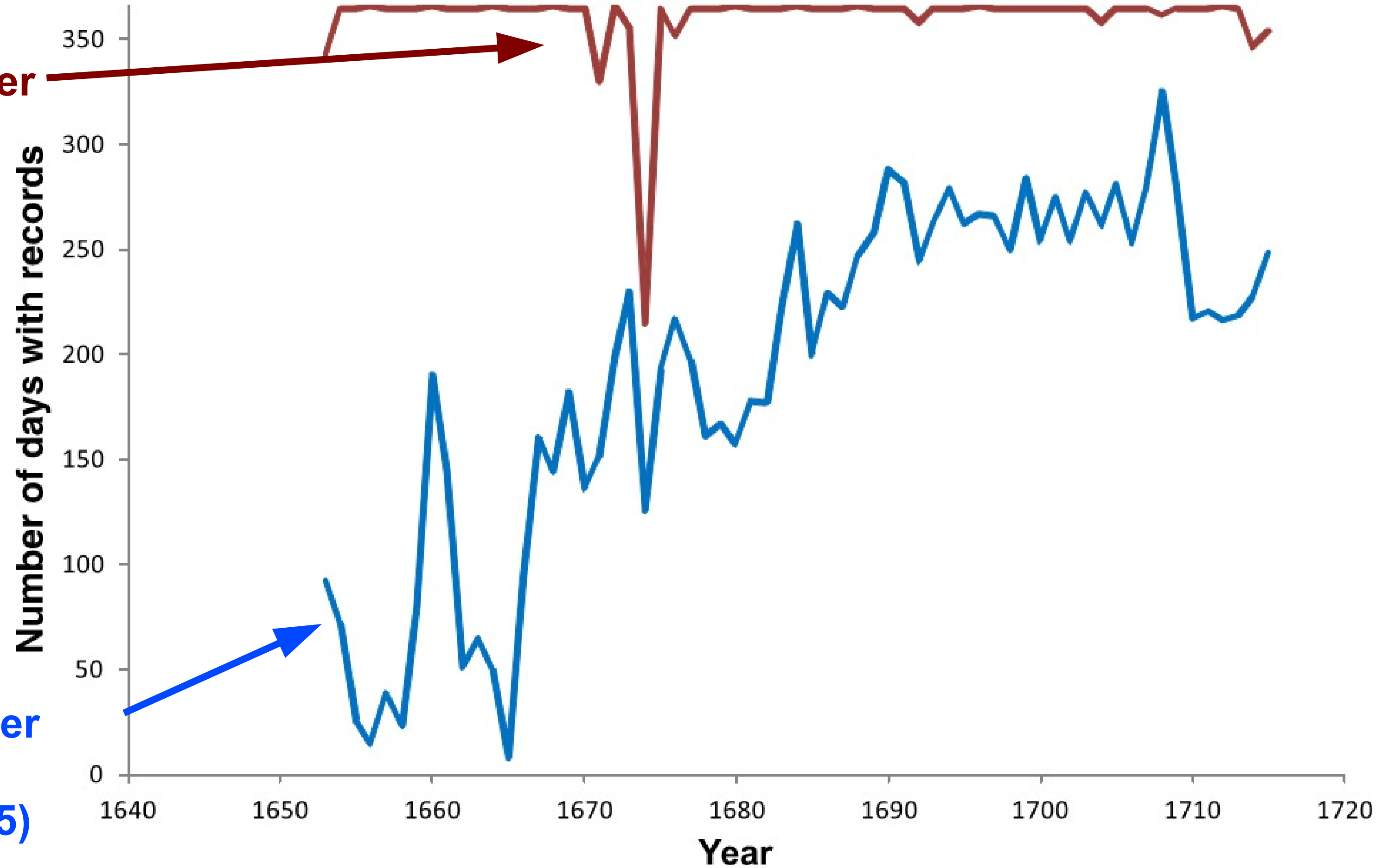
Deepest minimum: 1660-1671

- 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.)

How often did they observe?

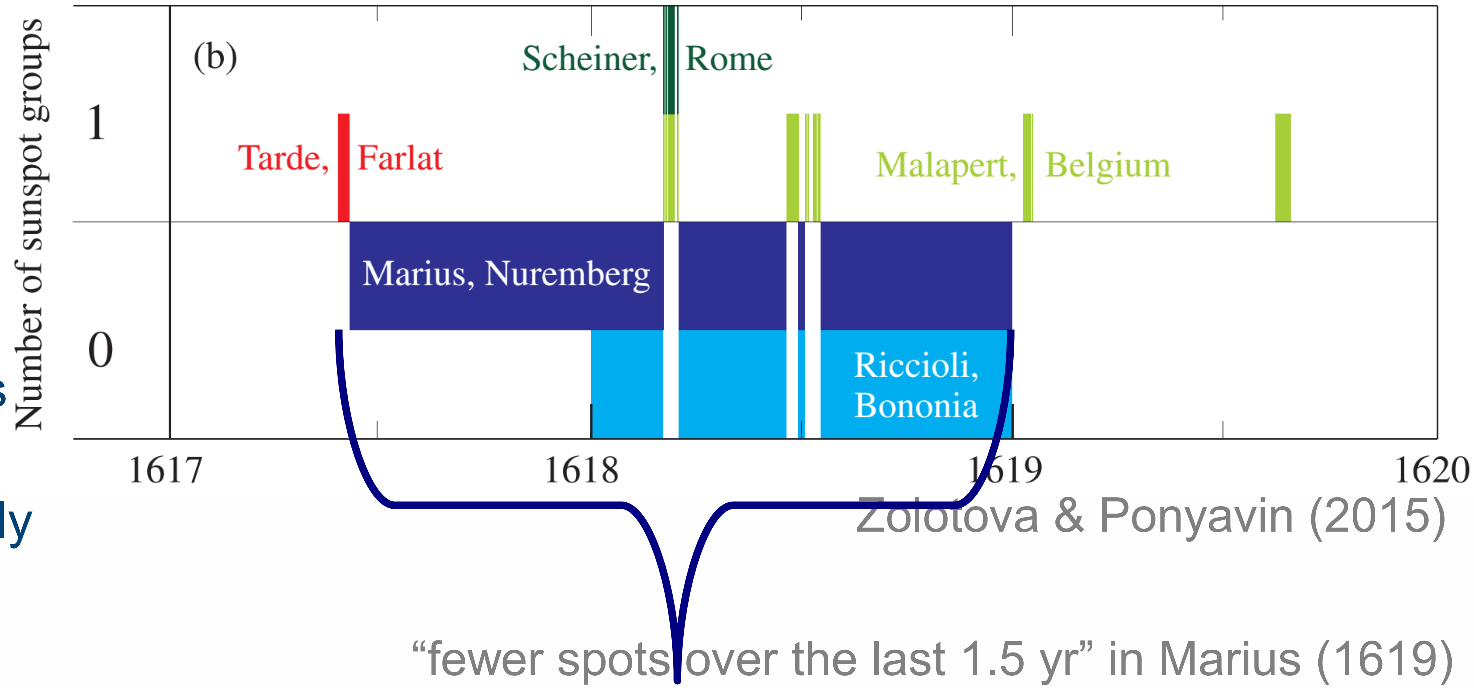


Observing days per year after Hoyt & Schatten (1998)

Observing days after Clette et al. (2014), Vaquero et al. (2015)

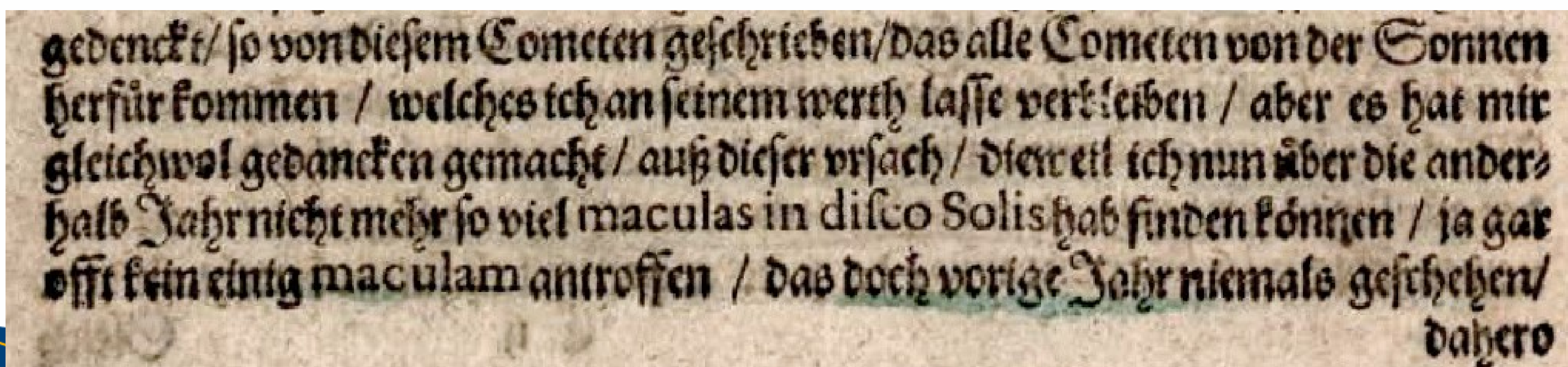
Spots omitted in verbal reports?

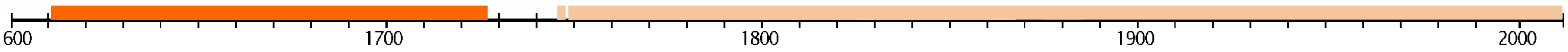
- Deliberately stopped reporting?
- No, since original reports have no dates.
- Gaps are purely technical



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 ander= halb Jahr nicht mehr ſo viel maculas in diſco Solis hab finden können / ja gar offt kein eintzig maculam antroffen / das doch vorige Jahr niemals geſchehen/ dahero



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Spots omitted in verbal reports?

- Riccioli (1653) in “Almagestum Novum”

V *Numerus* Macularum varius incertuſq. eſt; Aliquádo tamen 50. aliquando 33. diſtinctè numeratæ ſunt eodem tempore; ſed aliquando vna vel altera, & aliquando nulla; & tunc calidior ſicciorq. cæteris paribus tempeſtas extitit. Itaq. anno 1618. quo Trabs, & Cometes fulſit, nulla Macula obſeruata fuit, ait *Argolus* in Pandoſio Spherico cap.44. Sed neq. anno 1632. a die 12. aut 19. *Multitudo Macularũ.*

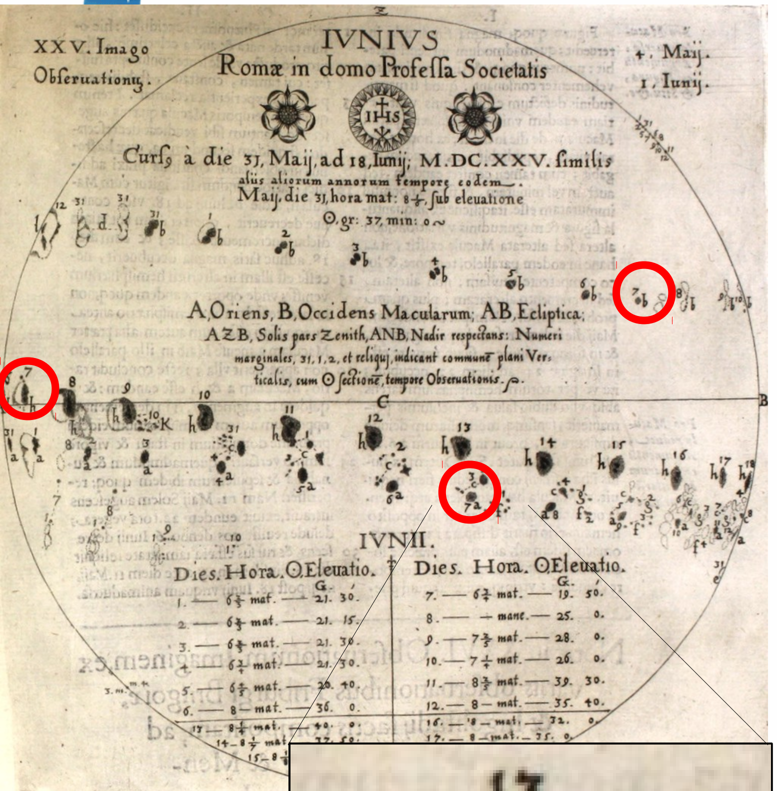
So in 1618 a tail and comet shone, but no spot was seen, says Argolus …

- Argolus (1644) in “Pandosium sphæricum”

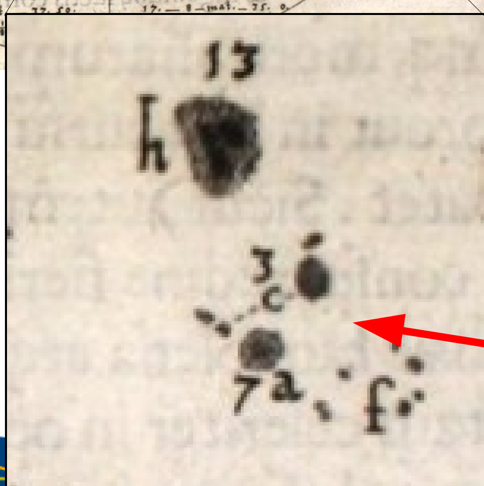
…, viginti, triginta, quinquaginta, innumerabiles.
Anno 1618. tempore quo Trabs, & Cometa affulſit nulla viſa eſt; Sic anno 1634. à 19. Iulij vſquè ad medium Septembris, vt nos Marzobi propè Vene-

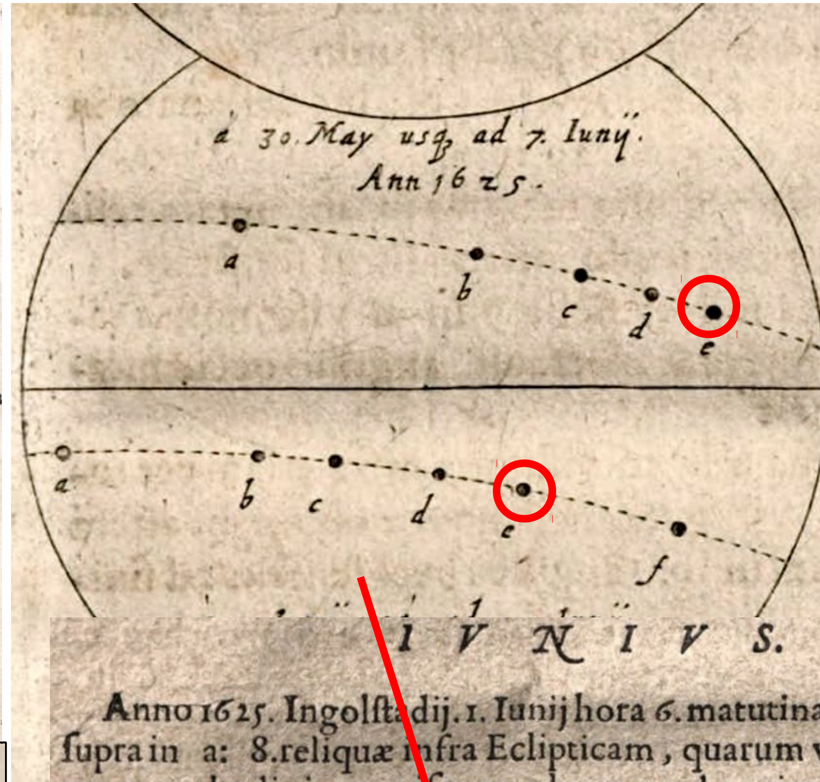
When in 1618 a tail and comet shone, zero [spots] were seen; so in 1634 from 19th Juli until mid-September, when we observed many times from near Venice.

Spots withheld?

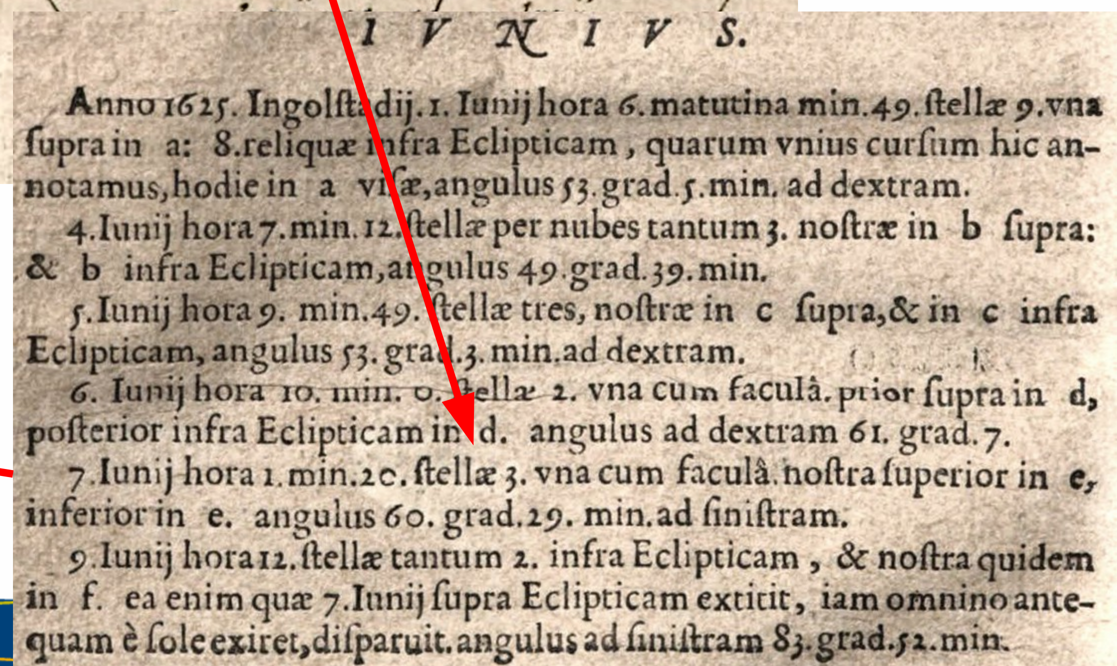


Scheiner, Juni 1625





Smogulecz & Schönberger, Juni 1625



I V N I V S.

Anno 1625. Ingolſtadij. 1. Iunij hora 6. matutina min. 49. ſtellæ 9. vna ſupra in a: 8. reliquæ infra Eclipticam, quarum vnius curſum hic annotamus, hodie in a viſæ, angulus 53. grad. 5. min. ad dextram.

4. Iunij hora 7. min. 12. ſtellæ per nubes tantum 3. noſtræ in b ſupra: & b infra Eclipticam, angulus 49. grad. 39. min.

5. Iunij hora 9. min. 49. ſtellæ tres, noſtræ in c ſupra, & in c infra Eclipticam, angulus 53. grad. 3. min. ad dextram.

6. Iunij hora 10. min. 0. ſtellæ 2. vna cum faculâ. prior ſupra in d, poſterior infra Eclipticam in d. angulus ad dextram 61. grad. 7.

7. Iunij hora 1. min. 20. ſtellæ 3. vna cum faculâ. noſtra ſuperior in e, inferior in e. angulus 60. grad. 29. min. ad ſiniſtram.

9. Iunij hora 12. ſtellæ tantum 2. infra Eclipticam, & noſtra quidem in f. ea enim quæ 7. Iunij ſupra Eclipticam extitit, iam omnino antequam è ſole exiret, diſparuit. angulus ad ſiniſtram 83. grad. 52. min.

1600 1700 1800 1900 2000

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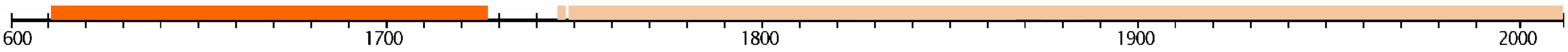
Hevelius' positional measurements

12 JOHANNIS HEVELII

ANNO M. DC. LXI.

	Menſ.	Dies ſt. n.		Altitudines Solis Meridianæ. Grad.	Min.	Sec.	Quo Inſtrumento	Quâ Tempeſtate.	Quâ Diligentiâ.	NOTANDA.
Sol in Geminis.	Maji	23	☽							Nil macularum
		25	☿	56	44	50	Quad. Az.	Cælo ſereno	diligentisſimè	
	Junii	3	♀	58	5	10				Nulla macula
		19	☉	59	6	40		Coelo perquàm ſu	do diligentisſ.	
Solſtitium Æſtivum.	Junii	21	♂	59	7	10	Quad. Az.	Coelo perquàm ſer	eno diligentisſ.	
		22	☿	59	6	20		Coelo admodùm ſe	reno diligentisſ.	?
		26	☉	59	1	30		Coelo admodùm ſe	reno diligentisſ.	
		30	♃	58	49	50		Coelo perquàm ſu	do diligentisſ.	
Sol in Cancro.	Julii	2	♄	58	41	15	Quad. Az.	Coelo admodùm ſe	reno diligentisſ.	
		3	☉	58	36	25		Coelo perquàm ſer	eno diligentisſ.	?
				58	36	30				
		8	♀	58	6	20		Coelo admodùm ſu	do diligentisſ.	
	Julii	15	♀	57	6	40	Quad. Az.	Cælo ſereno	diligentisſimè	
		17	☉	56	47	30		Cælo ſatis ſereno	diligentisſimè	?
		22	♀	55	51	30		Cælo admodùm ſu	do diligentisſ.	Nil macularum
Sol in Leone.		23	♄	55	38	40		Cælo ſatis ſereno	diligentisſimè	
	Auguſti	4	♃	52	46	30	Quad. Az.	ob nubes vix certa		
		9	♂	51	23	20		Cælo ſereno	diligentisſimè	?
		13	♄	50	11	46		Cælo ſubnubilo	dubia	
		16	♂	49	16	0		Ob Aërem turbid	um valdè dubia	

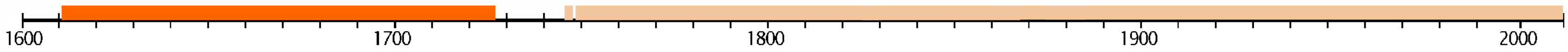


Interpretation error

- Many meridian observations misinterpreted
- Hevelius did not use a telescope at his quadrant → could not decide whether or not there were spots!

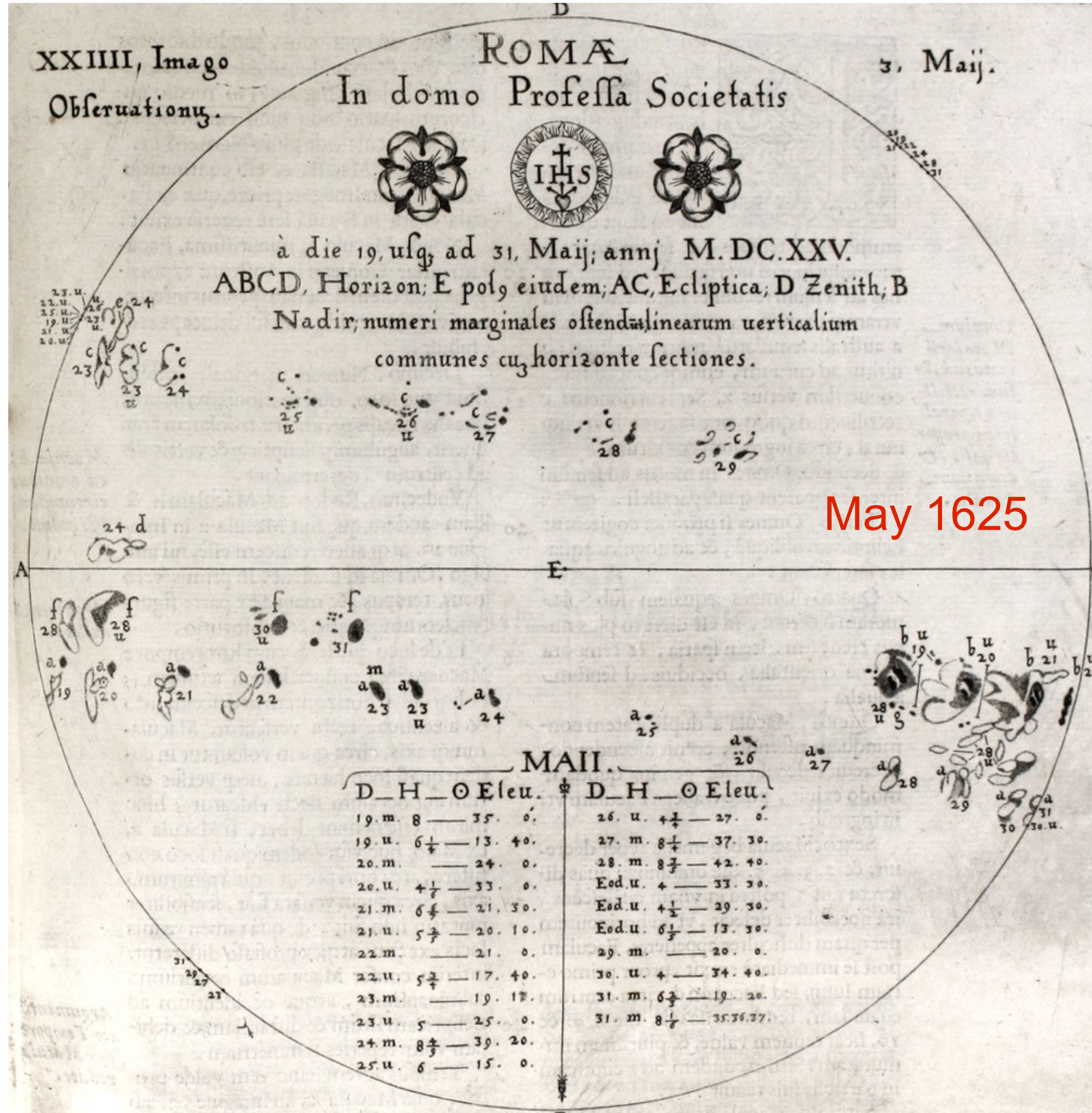
Hevelius (1673) Machina cœlestis

Crüger's großer Azimuthal-Quadrant, vollendet von Hevel 1644, nach Hevel's Machina coelestis.

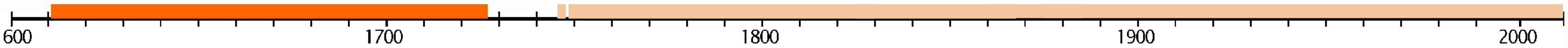


Non-circular spots not reported?

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

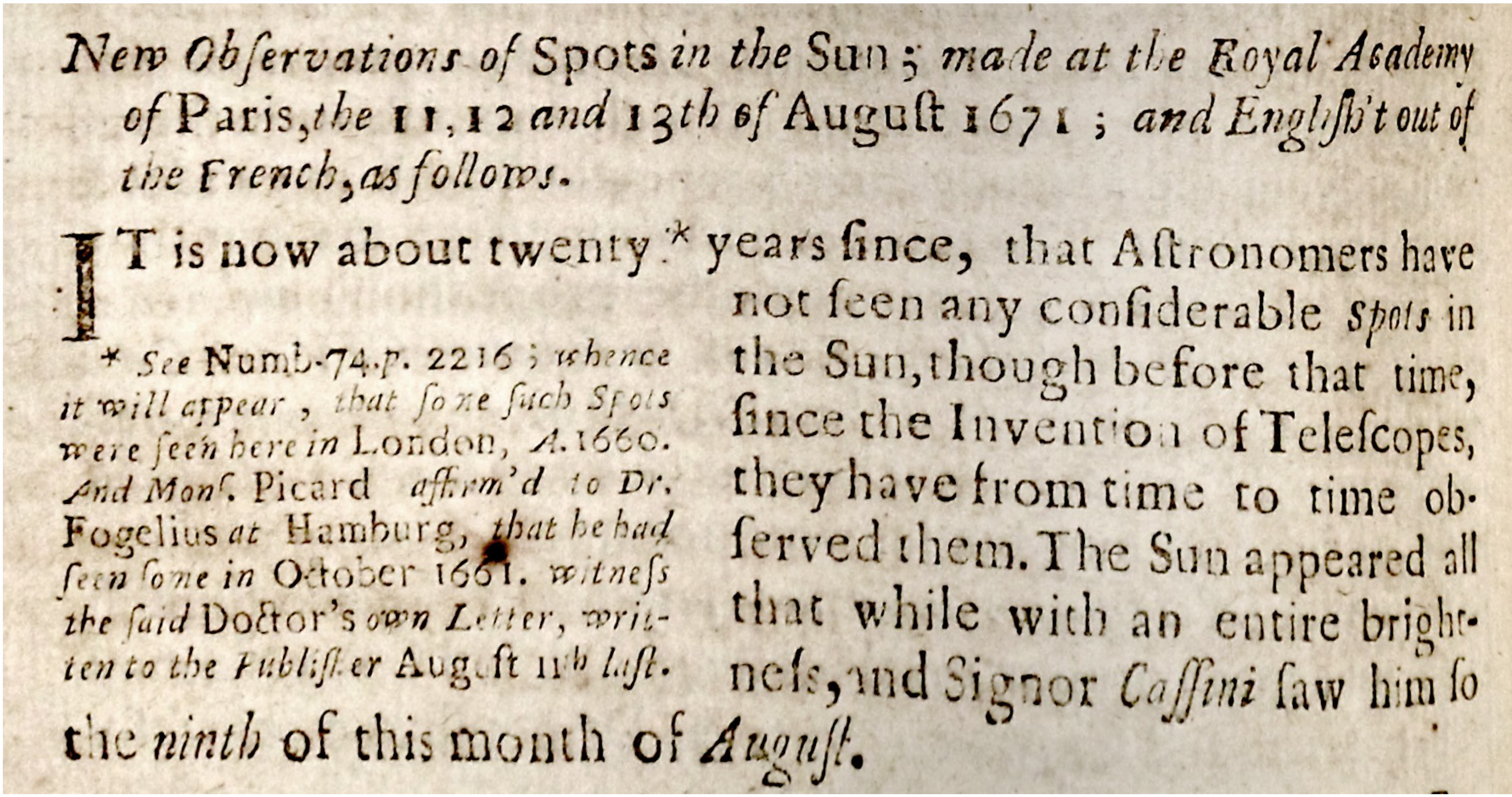


Scheiner (1630)



Deepest minimum: 1660-1671

Oldenburg (1671) Phil Trans



New Obſervations of Spots *in the* Sun; *made at the* Royal Academy *of* Paris, *the* 11, 12 *and* 13*th of* Auguſt 1671; *and Engliſh't out of the French, as follows.*

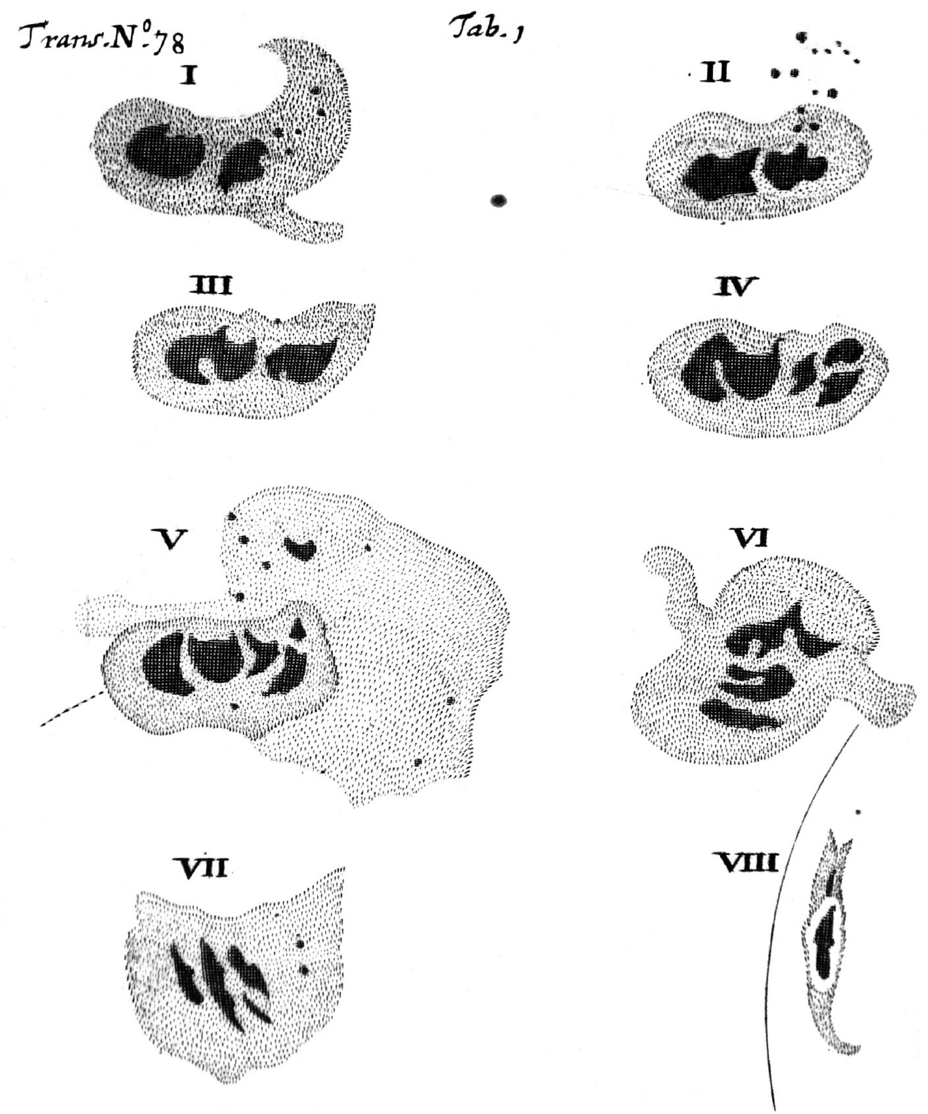
IT is now about twenty * years ſince, that Aſtronomers have not ſeen any conſiderable *ſpots* in the Sun, though before that time, ſince the Invention of Teleſcopes, they have from time to time obſerved them. The Sun appeared all that while with an entire brightneſs, and Signor *Caſſini* ſaw him ſo the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

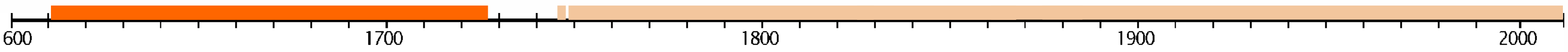
* *See* Numb. 74. *p.* 2216; *whence it will appear, that ſome ſuch Spots were ſeen here in* London, *A.* 1660. *And Monſ.* Picard *affirm'd to Dr.* Fogelius *at* Hamburg, *that he had ſeen ſome in* October 1661. *witneſs the ſaid* Doctor's *own Letter, written to the Publiſher* Auguſt 11*th laſt.*

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

Sunspots considered little planets?

- Drawings of sunspots were complex
- Perspective foreshortening near solar limb
- Visible in drawing by Galileo, Scheiner, Hevelius, Cassini, de la Hire, Derham
- Here: Cassini 1671 Aug 14-19 (Phil. Trans. No. 78)





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Sunspots considered little planets?

- Cassini about an observation in 1684 in the “Mémoires of the Academy in Paris” of 1730:
- This penumbra becomes typically rounder, when the spot approaches the centre, this is an indication for a flat penumbra, and that it looks slim only because it appears in an oblique manner, just as the surface of the Sun near the limb, **on which it (the penumbra) has to lie**.

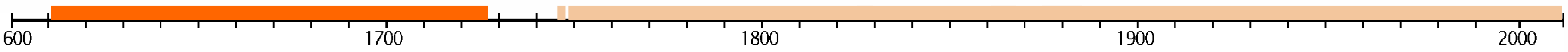
de Saturne auquel la Tache ſervoit de globe. Cette nébu-
loſité s'arrondit à meſure que la Tache approcha du cen-
tre, cela ne manque jamais d'arriver, & c'eſt une marque
que cette nébuloſité eſt platte, qu'elle ne paroît étroite
que parce qu'elle ſe préſente obliquement, comme la ſur-
face du Soleil vers le bord apparent, ſur laquelle elle doit
être couchée.

Sunspots considered little planets?

- William Crabtree writes in a letter to Gascoigne in 1640:

  I have often observed these Spots; yet from all my Observations cannot find one Argument to prove them other than fading Bodies. But that they are no Stars, but unconstant (in regard of their Generation) and irregular Excrescences arising out of, or proceeding from the Suns Body, many things seem to me to make it more than probable. Derham & Crabtrie (1711)

- Main reasons listed:
  - the shape ("they are seldom round, but of irregular Shapes"),
  - the color,
  - the shape of the spots near the limb,
  - the occasional vanishing in the middle of the disk.



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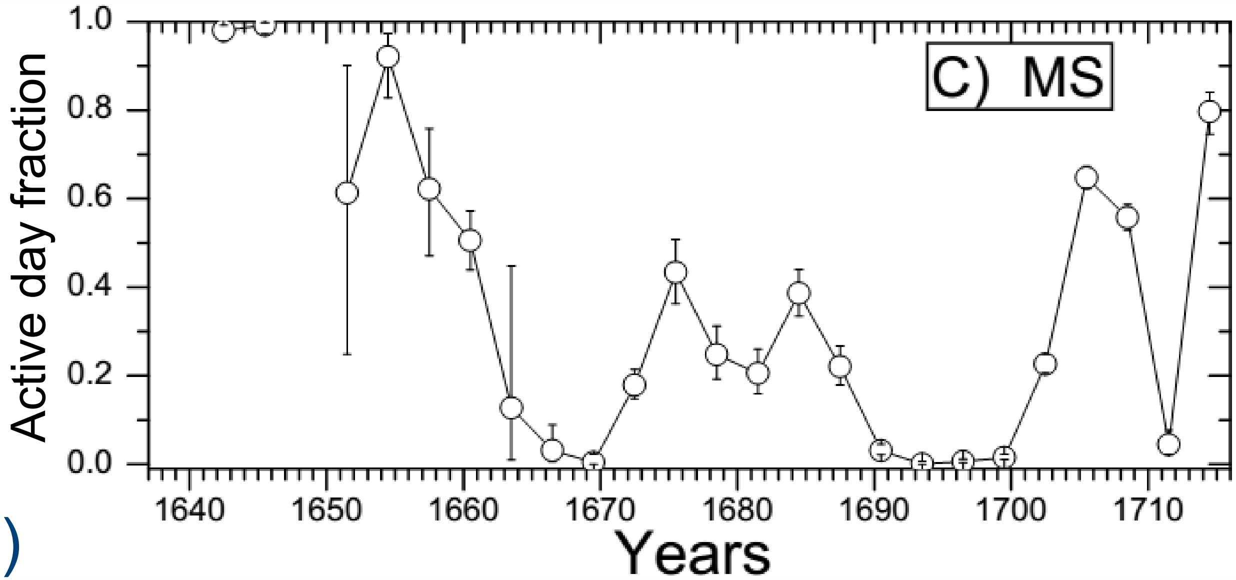
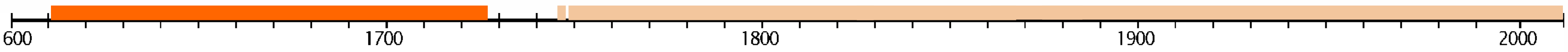
How was activity at best?

- Strict model:
  "Zero spots" only considered if at least 2 observers reported that.

- Then active-day fraction (annual fraction of days with ≥1 spot) is 40%.
  (sort of "upper limit")

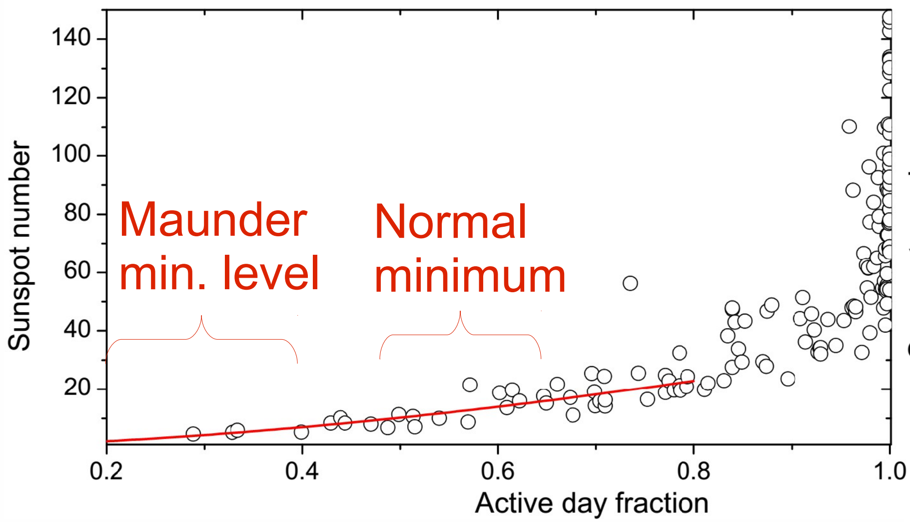


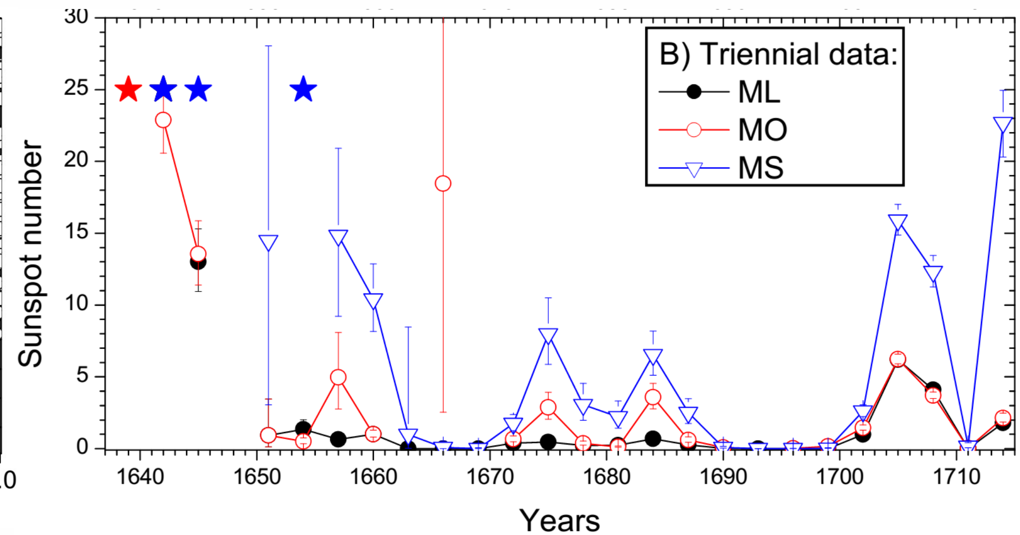
Vaquero et al. (2015)



Assessment of the activity level

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



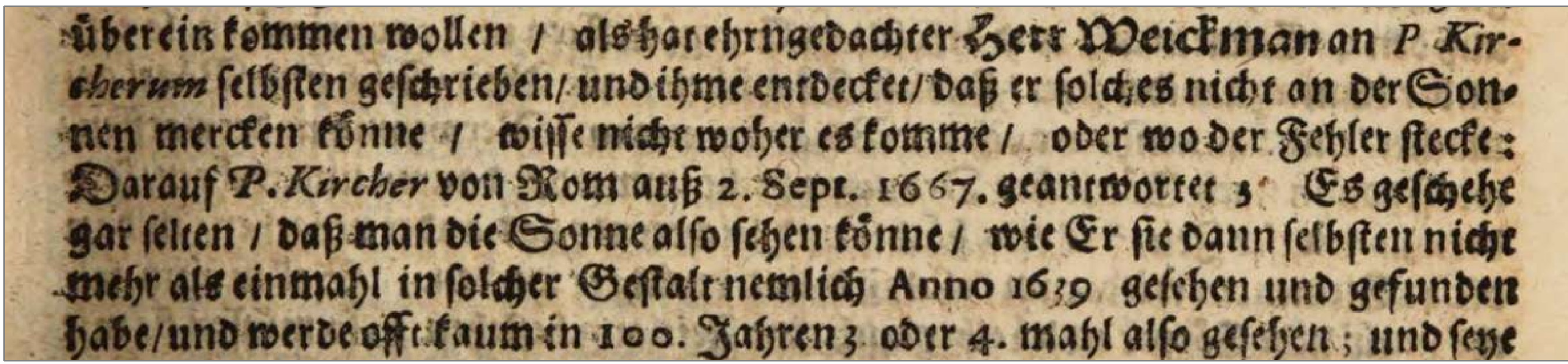


- Active day fraction is a function of sunspot number
- Active day fraction converted into sunspot number

Vaquero et al. (2015)

Deepest minimum: 1660-1671

- Just a single record in HS98 for 1667
- Original text:



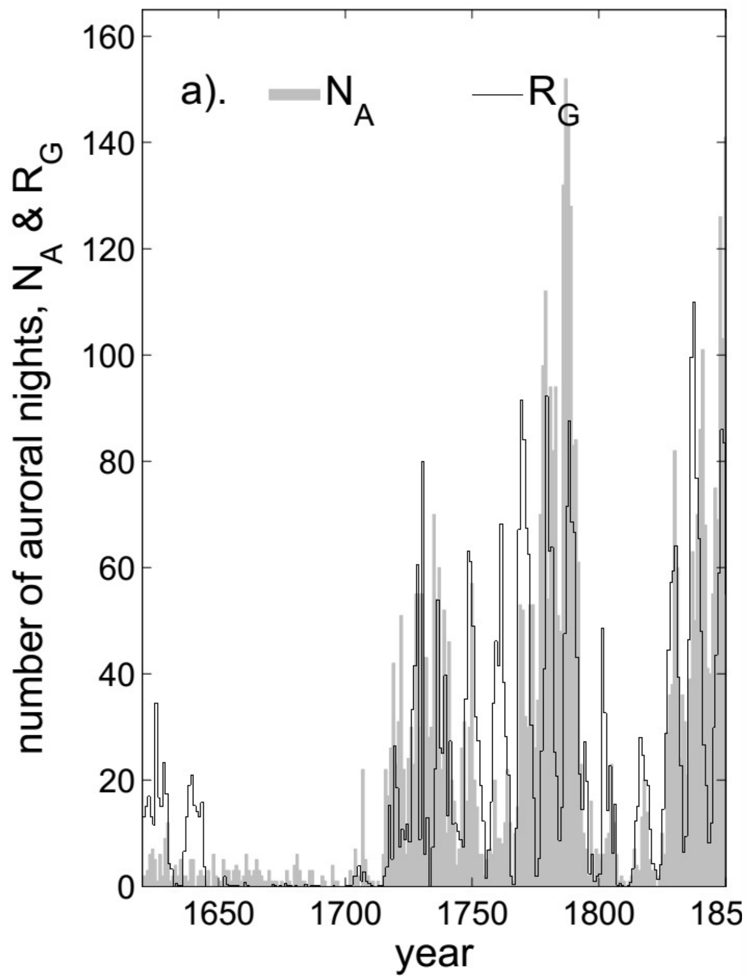
überein kommen wollen / als hat ehrngedachter Herr Weickman an *P. Kircherum* selbsten geschrieben/ und ihme entdecket/ daß er solches nicht an der Sonnen mercken könne / wisse nicht woher es komme / oder wo der Fehler stecke: Darauf *P. Kircher* von Rom auß 2. Sept. 1667. geantwortet : Es geschehe gar selten / daß man die Sonne also sehen könne / wie Er sie dann selbsten nicht mehr als einmahl in solcher Gestalt nemlich Anno 1639 gesehen und gefunden habe/ und werde offt kaum in 100. Jahren 3 oder 4. mahl also gesehen ; und seye

Frick (1681): Philosophisches und Theologisches Bedencken...

- No spot!

Aurorae

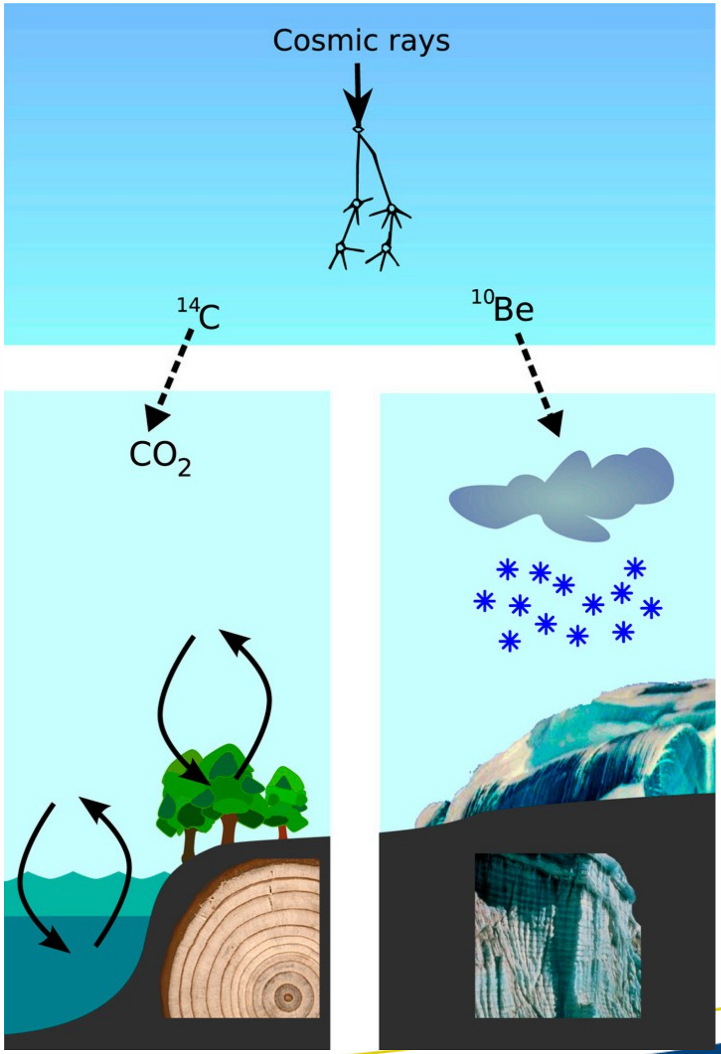
- Aurorae are consequence of solar activity
- Solar charged particles get trapped in Earth's magnetosphere and spiral towards the north/south poles along magnetic field lines
- Compilation of 41 aurora catalogues
- Only aurorae (boreales) south of 55°N:



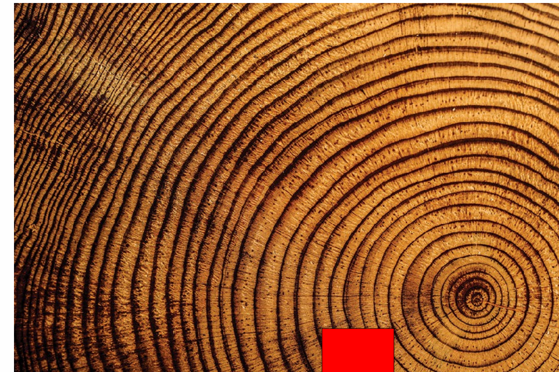
Usoskin et al. (2015)

Isotopes made by cosmic rays

- Energetic particles from the cosmos penetrate atmosphere
- Spallation into various elementary particles
- Neutrons converts $^{14}N + n \rightarrow$ unstable $^{14}C + p$
- Solar magnetic field shields planetary system from cosmic rays



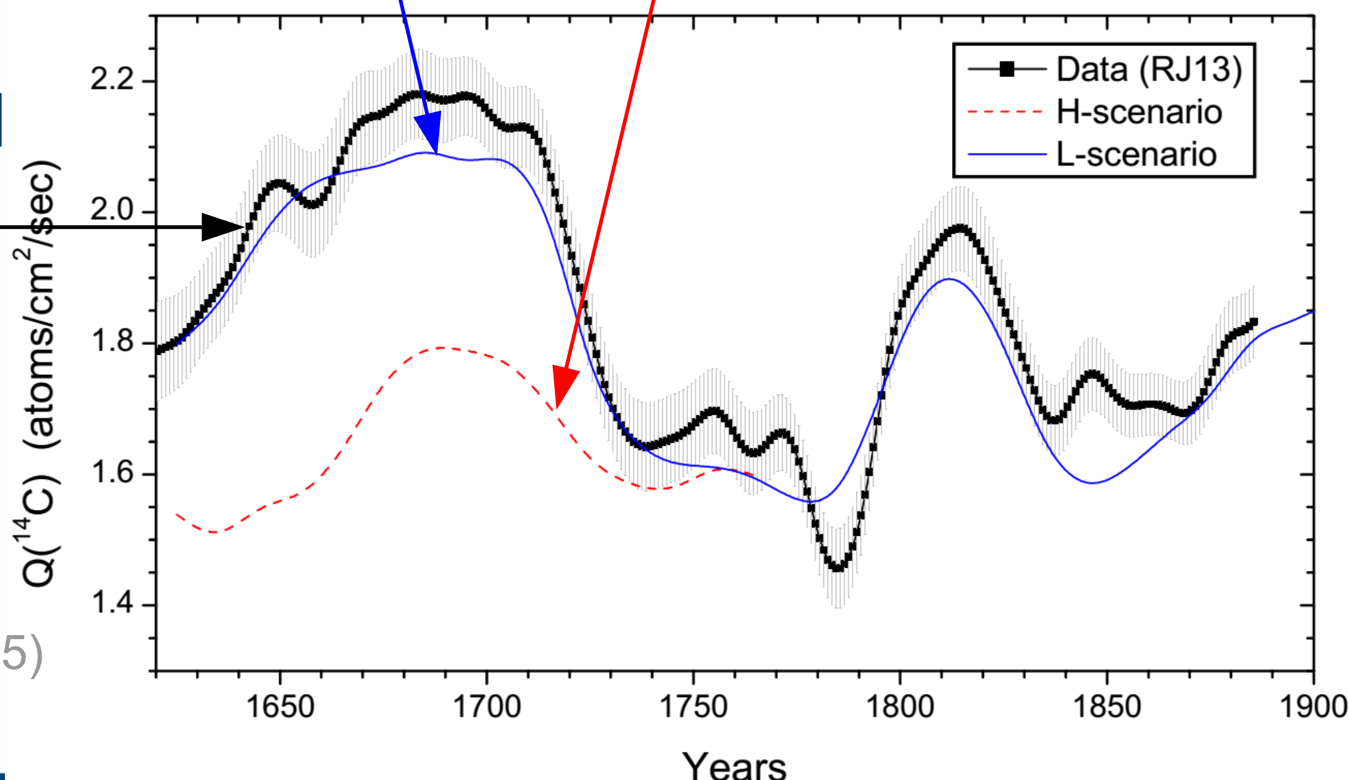
^{14}C as an (inverse) solar activity indicator



- Measure atmospheric ^{14}C, incorporated in dead trees
- ^{14}C content varies inversely with solar activity
- Reconstruction of solar activity possible for 10,000 years

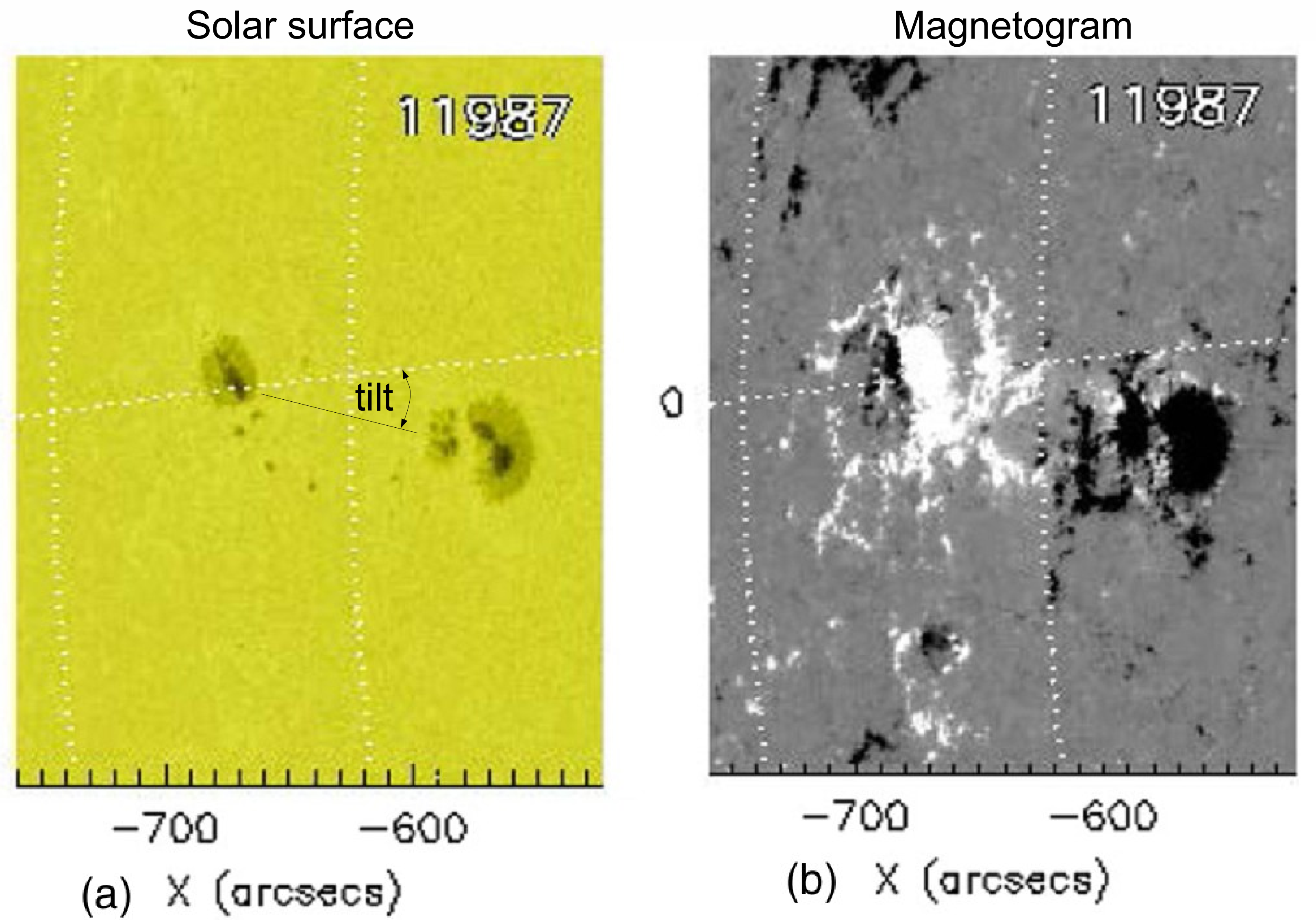
^{14}C as an (inverse) solar activity indicator

- Theoretical ^{14}C production for a
  - Maunder minimum with relatively **High** activity and
  - Maunder minimum with **Low** activity
- Comparison with observed data (■)



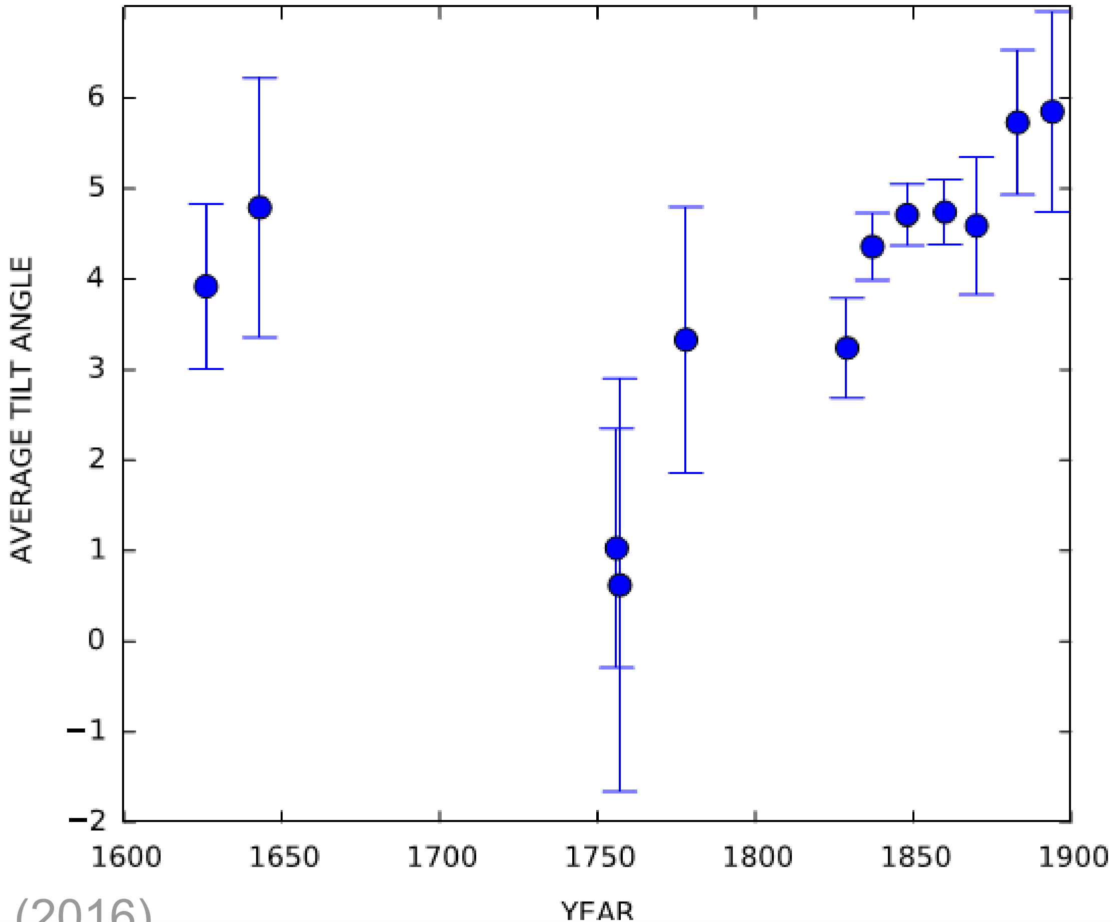
Usoskin et al. (2015)

Tilt angle of bipolar sunspot groups



Group tilt angles over time

- Tilt angles of bipolar groups
- Cycle averages typically 4°–6°
- Cycles 0 and 1 again peculiar (two independent observers)



After Senthamizh Pavai et al. (2016)

Summary

- 400-year series of sunspot positions possible
- There is much more information in historical observations than just sunspot number
  - variation of butterfly diagram – empiric relations to *B*
  - persistent active longitudes – nonaxisymm. dynamo
  - group tilt-angles – measure Babcock-Leighton effect
  - differential rotation variation – Lorentz force in dynamo
  - Spot decay – *B*-dependence of turbulent diffusivity
- Goals:
  - understanding the solar dynamo
  - reconstructing open flux and TSI (with MPS Göttingen)