Space Climate 5

Under the midnight Sun

15-19 June 2013

Oulu, Finland

Applied historical heliophysics: a review

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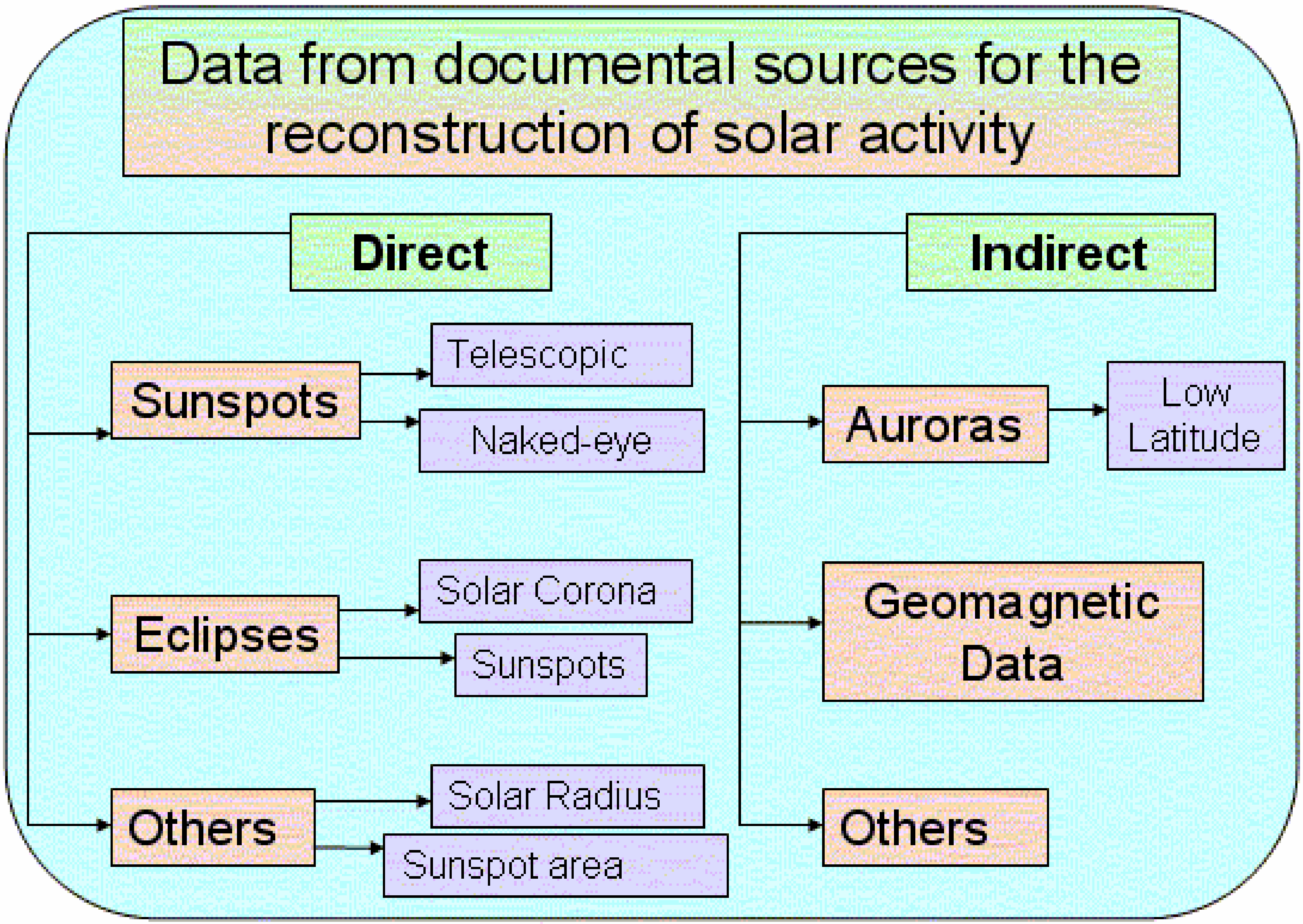

Data from documental sources for the reconstruction of solar activity
Direct
Indirect
Sunspots
Telescopic
Naked-eye
Eclipses
Solar Corona
Sunspots
Others
Solar Radius
Sunspot area
Auroras
Low Latitude
Geomagnetic Data
Others

SLOW SCIENCE

The world's longest-running experiments remind us that science is a marathon, not a sprint.

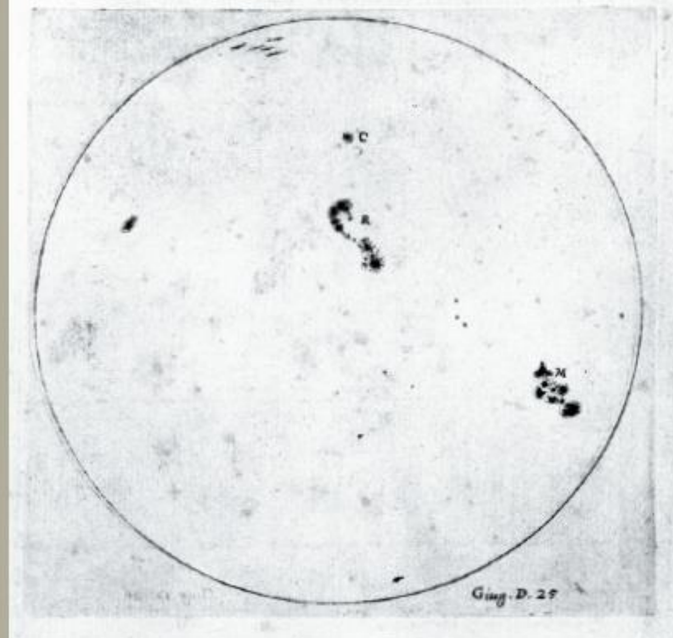
BY BRIAN OWENS

Although science is a long-term pursuit, research is often practised over short timescales: a discrete experiment or a self-contained project constrained by the length of a funding cycle. But some investigations cannot be rushed. To study human lifespans or the roiling of Earth's crust and the Sun's surface, for instance, requires decades and even centuries.

Here, *Nature* takes a look at five of science's longest-running projects, some of which have been amassing data continuously for centuries. Some generate hundreds of papers a year; one produces a single data point per decade.

Experiments operating at this pace are challenged by shifting research priorities and technologies, and their existence is regularly threatened by funding droughts and changes in stewardship. But they are bound together by the foresight of the scientists who started them and the patience and dedication of those who carry the torch. If persistence predicts a long and healthy life — as one 90-year study of human longevity has suggested — then the scientists featured here could set some records themselves.

➲ NATURE.COM
To hear a podcast about these experiments, visit: go.nature.com/jlada7



Galileo was drawing sunspots as early as 1613.

UNIVERSAL HISTORY ARCHIVE/UIG/BRIDGEMAN ART LIBR.

400 YEARS COUNTING SPOTS

Astronomers have been recording the appearance of sunspots ever since the telescope was invented more than 400 years ago; even Galileo recorded his observations. But early observers had no knowledge of what the dark patches on the Sun's surface were, or of the magnetic fields that created them. That began to change when, in 1848, the Swiss astronomer Rudolf Wolf began making systematic observations and developed a formula that is still used today to calculate the international sunspot number, also known as the Wolf number, which gives a measure of how solar activity is changing over time.

In 2011, Frédéric Clette became director of the Solar Influences Data Analysis Center, based at the Royal Observatory of Belgium in Uccle, which curates sunspot counts gleaned from photographs and hand drawings of the Sun's surface made by more than 500 observers since 1700.

The data are invaluable for predicting sunspot activity, says Leif Svalgaard, a solar physicist at Stanford University in California. The activity seems to wax and wane over the course of 11 years or so, and the streams of charged particles that the sunspots spray into space can affect satellites and electronics on Earth. The detailed records help researchers to understand why that cycle happens, and to refine predictions of particularly intense events. "The longer the time series is, the better we can check our theories," Svalgaard says. Around 200 papers a year cite sunspot data, in fields extending beyond solar physics to geomagnetism, atmospheric science and climate science.

But the enterprise runs largely on goodwill. Each month, the Belgian centre collates sunspot numbers from about 90 observers, two-thirds of them amateurs, who use small optical telescopes no more powerful than those available 200 years ago. And although it is a World Data

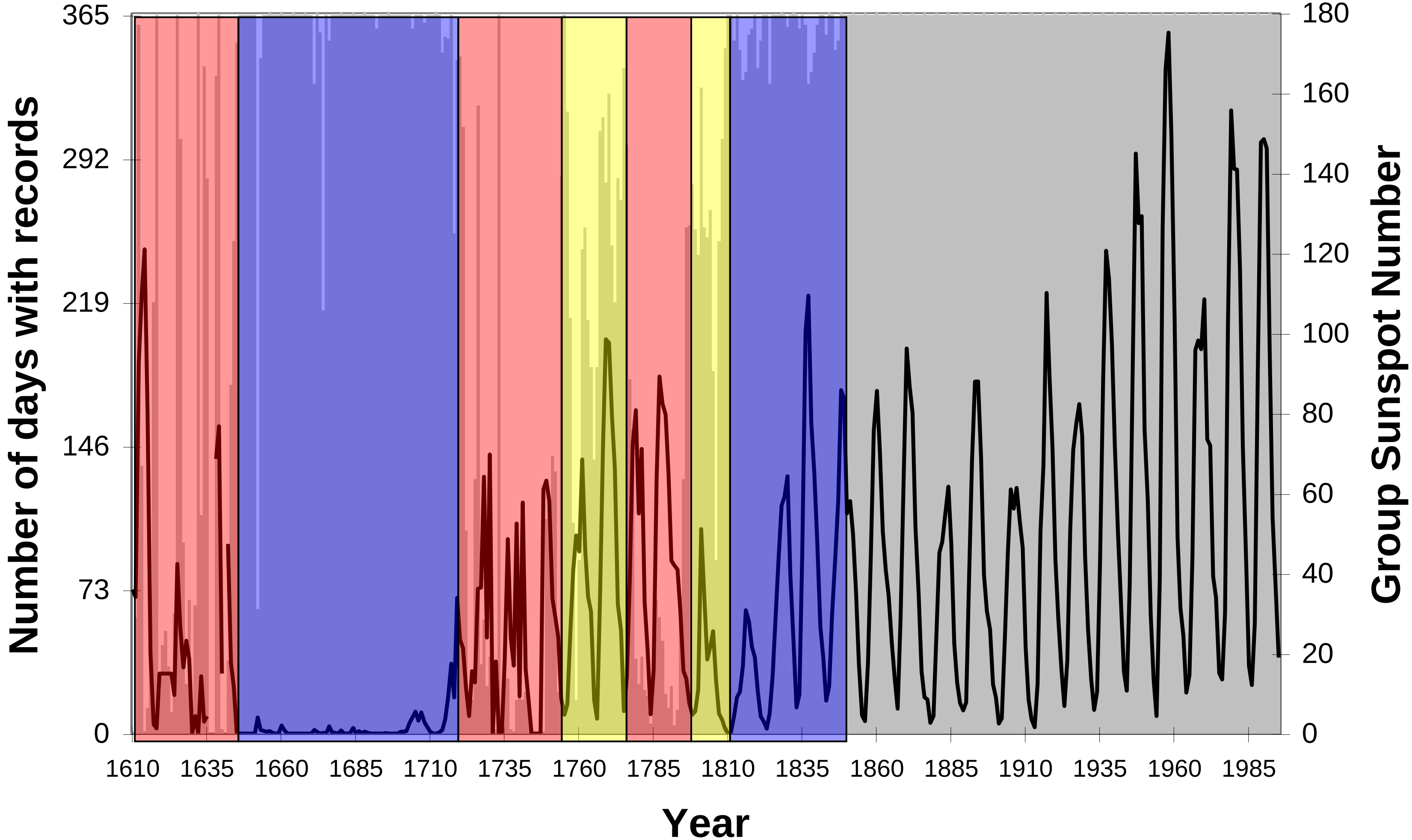
Outline

- Main changes in the Hoyt & Schatten Database
  - 17th century
  - 18th century
- Recovering old data
  - Great observers
  - Sunspot positions
  - Solar diameter
- Maunder Minimum
  - Reading original sources
  - Solar cycle signal?

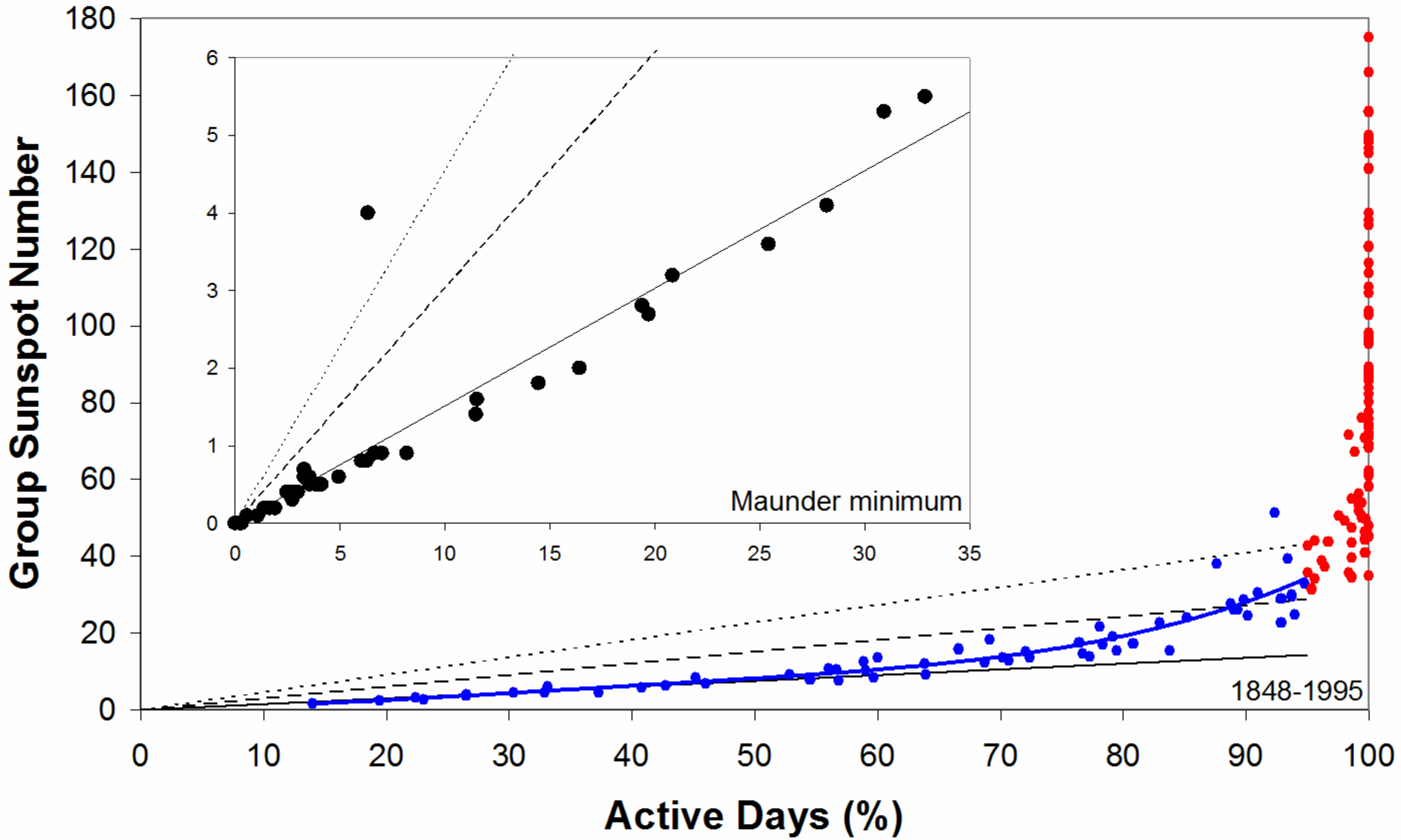
Main changes in the database compiled by Hoyt and Schatten

17th century

18th century

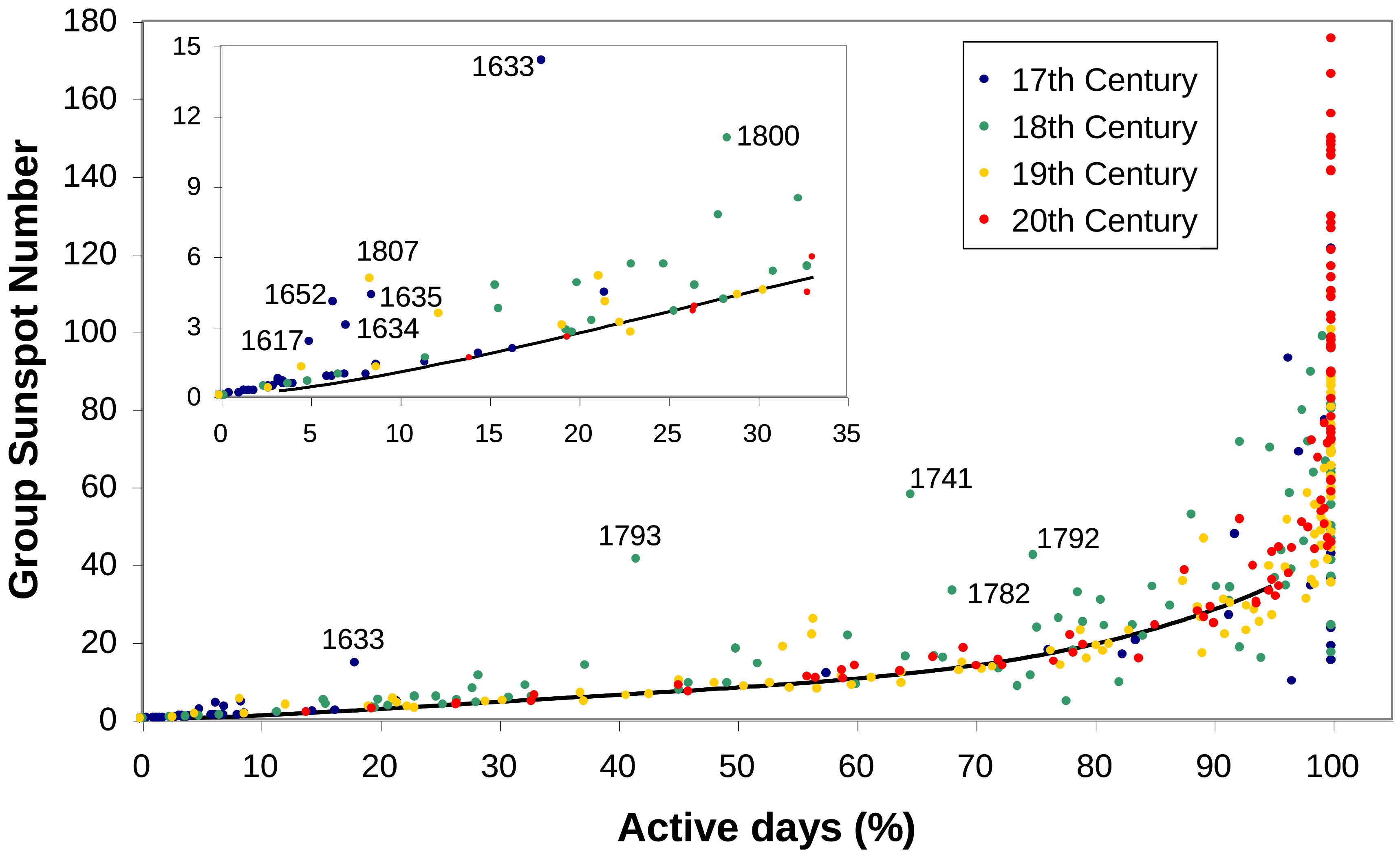


Vaquero (2007) *Adv. Spa. Res.* **40**, 929.



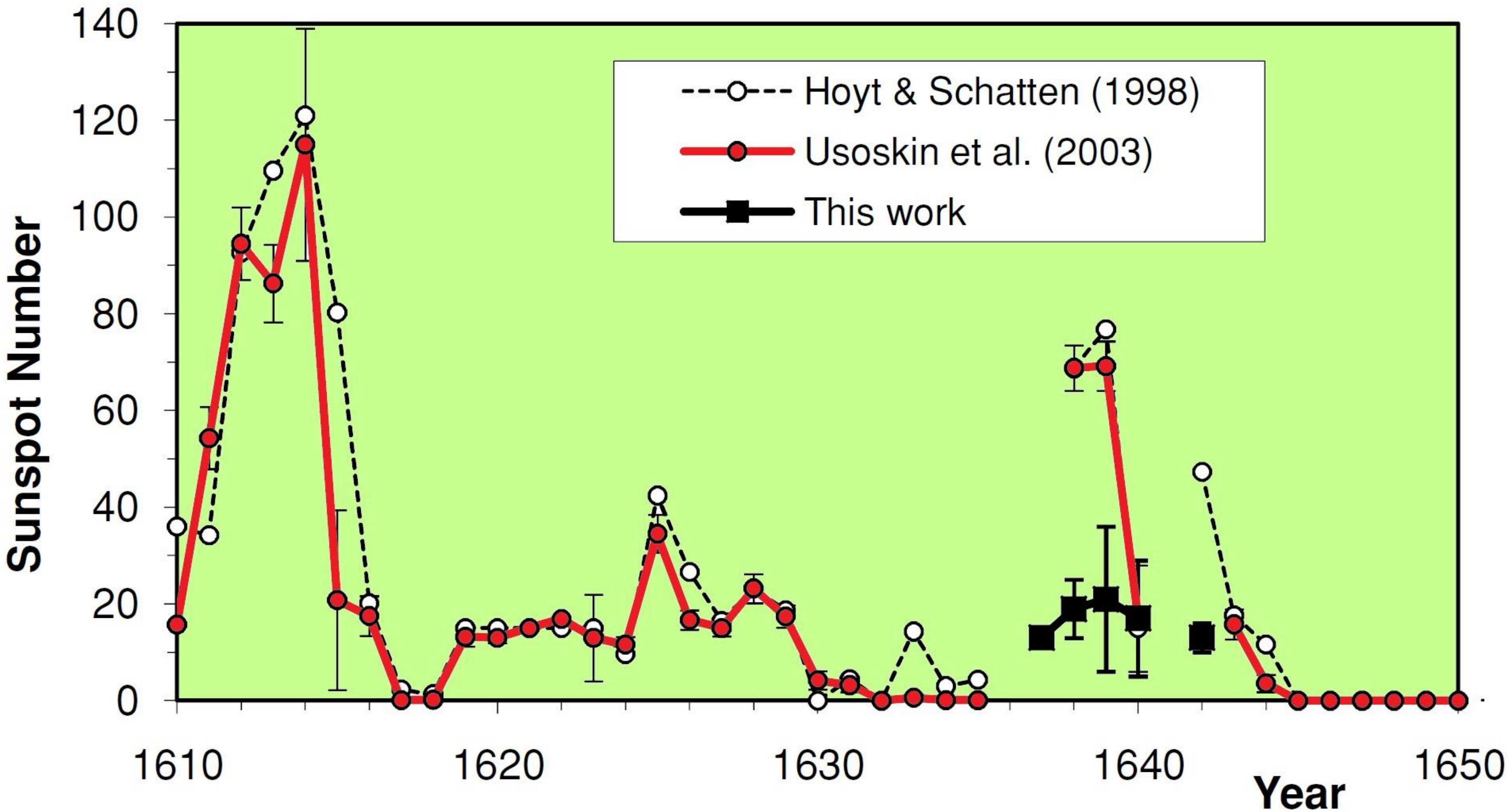
Vaquero et al. (2012) *Solar Phys.* **277**, 389

Relationship between GSN and AD for 1848–1995 from Hoyt & Schatten (1998). Polynomial fit (order 4) is shown for AD < 95% (blue line and points). Graphic inserted shows the same relationship during the Maunder minimum. Black lines represent the theoretical values for an average observer with 1 (continuous), 2 (dashed), and 3 (dotted) groups for each active day.

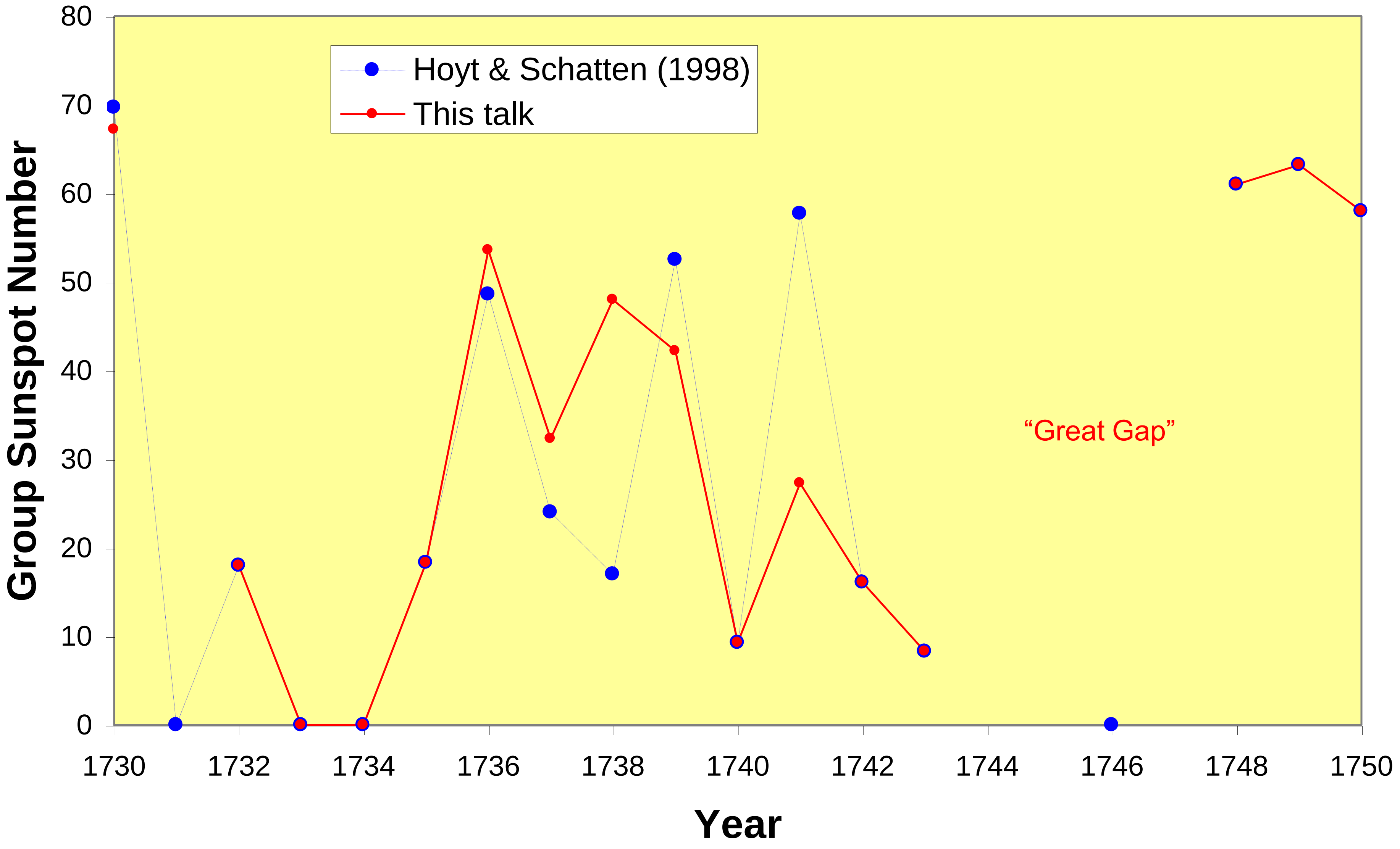


Vaquero et al. (2012) *Solar Phys.* **277**, 389

Relationship between GSN and AD for all available data from Hoyt & Schatten (1998). Black line is the polynomial fit of last Figure. The inset presents an enlarged version but restricted to values AD < 35%.



Vaquero et al. (2011) *ApJL* **731**, L24.

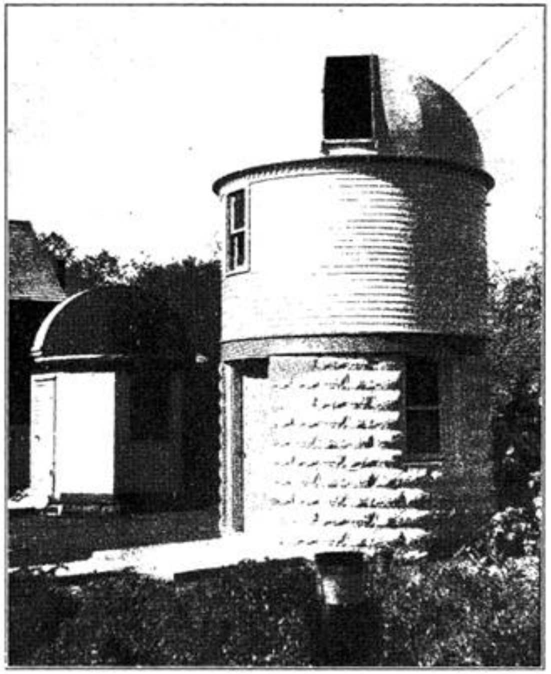


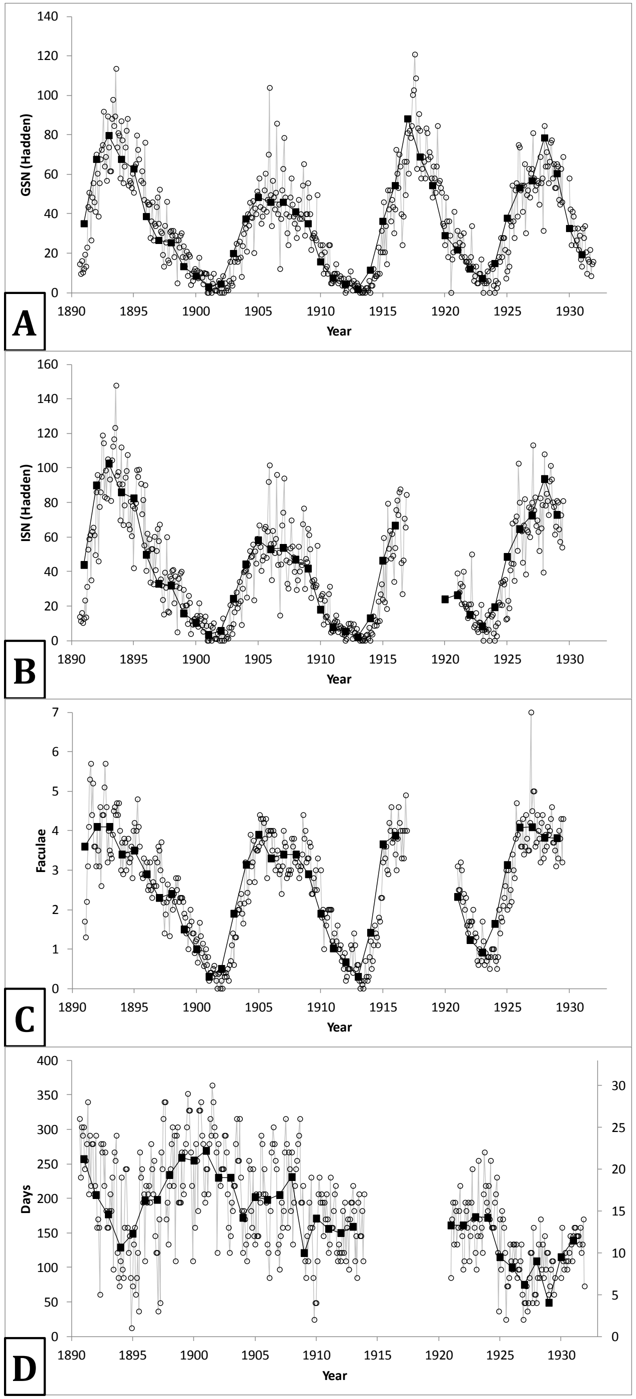
Vaquero & Trigo (2013), in progress

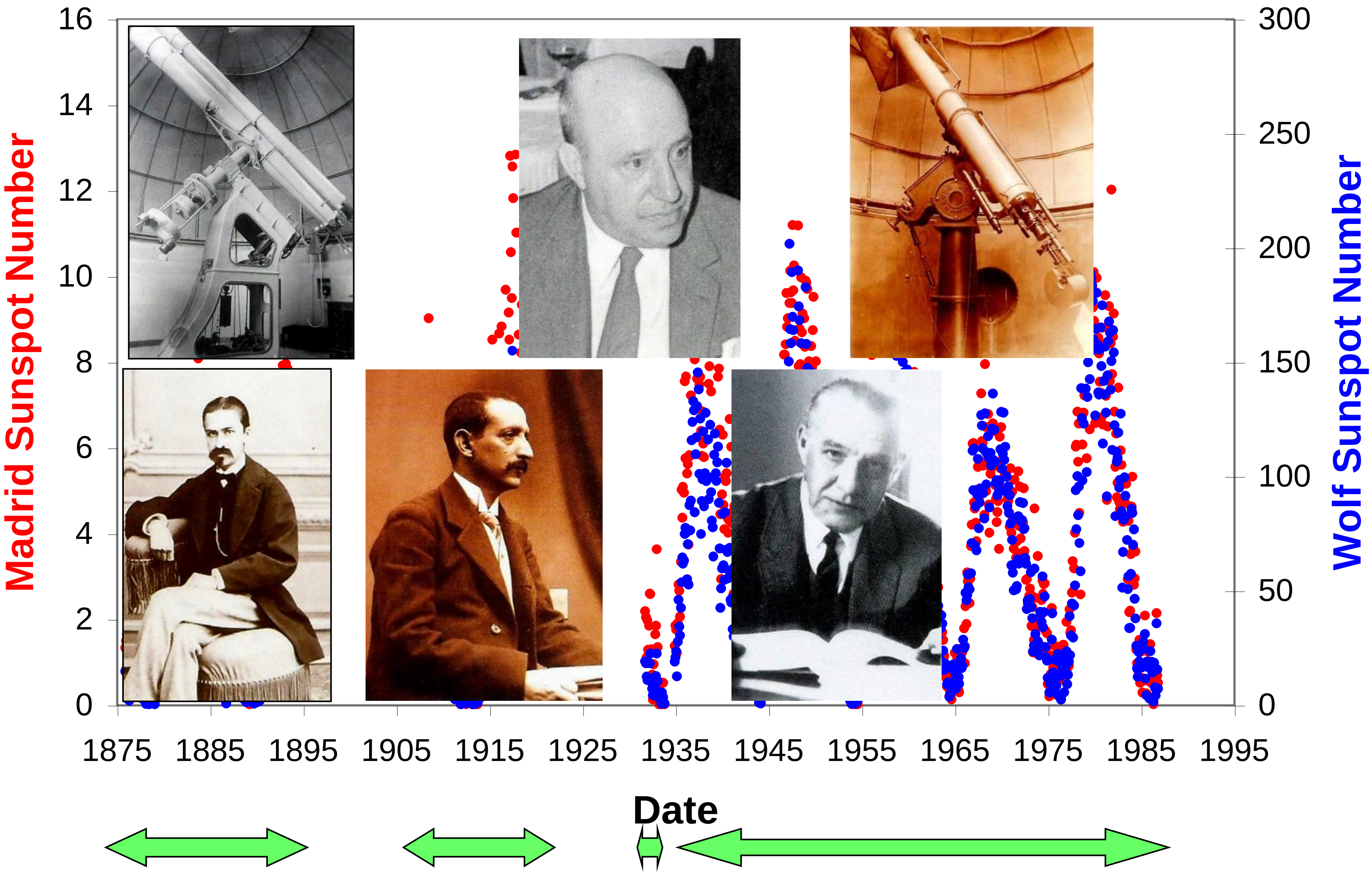
Important sunspot observers: the cases of D.E. Hadden (Alta, Iowa), Madrid Observatory, and Lisbon Observatory

Carrasco et al. (2013) *New Astronomy* **25**, 95
Pérez-Aparicio et al. (2013), in progress
(see posters)

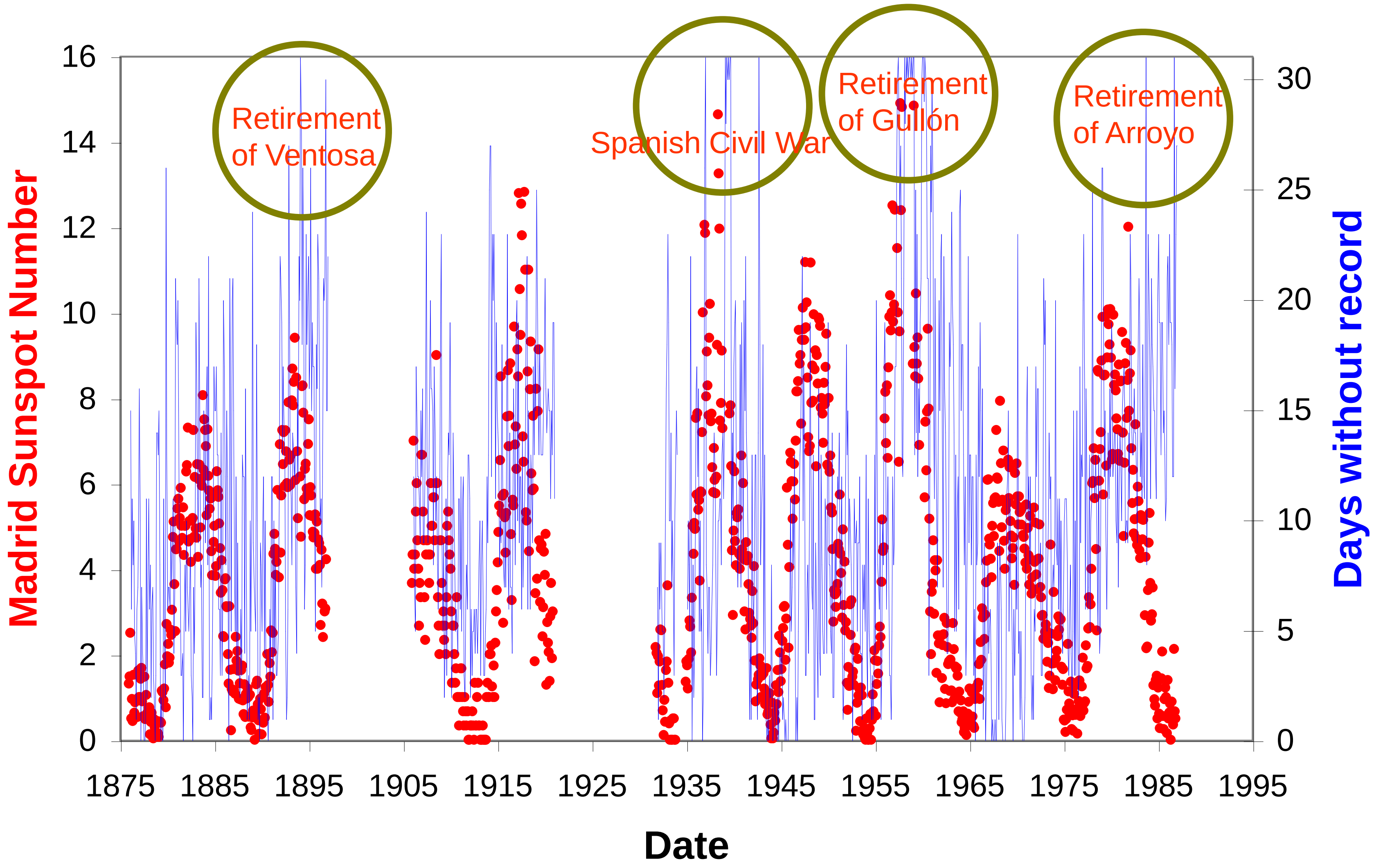
Vaquero et al. (2012) *The Observatory* **132**, 376

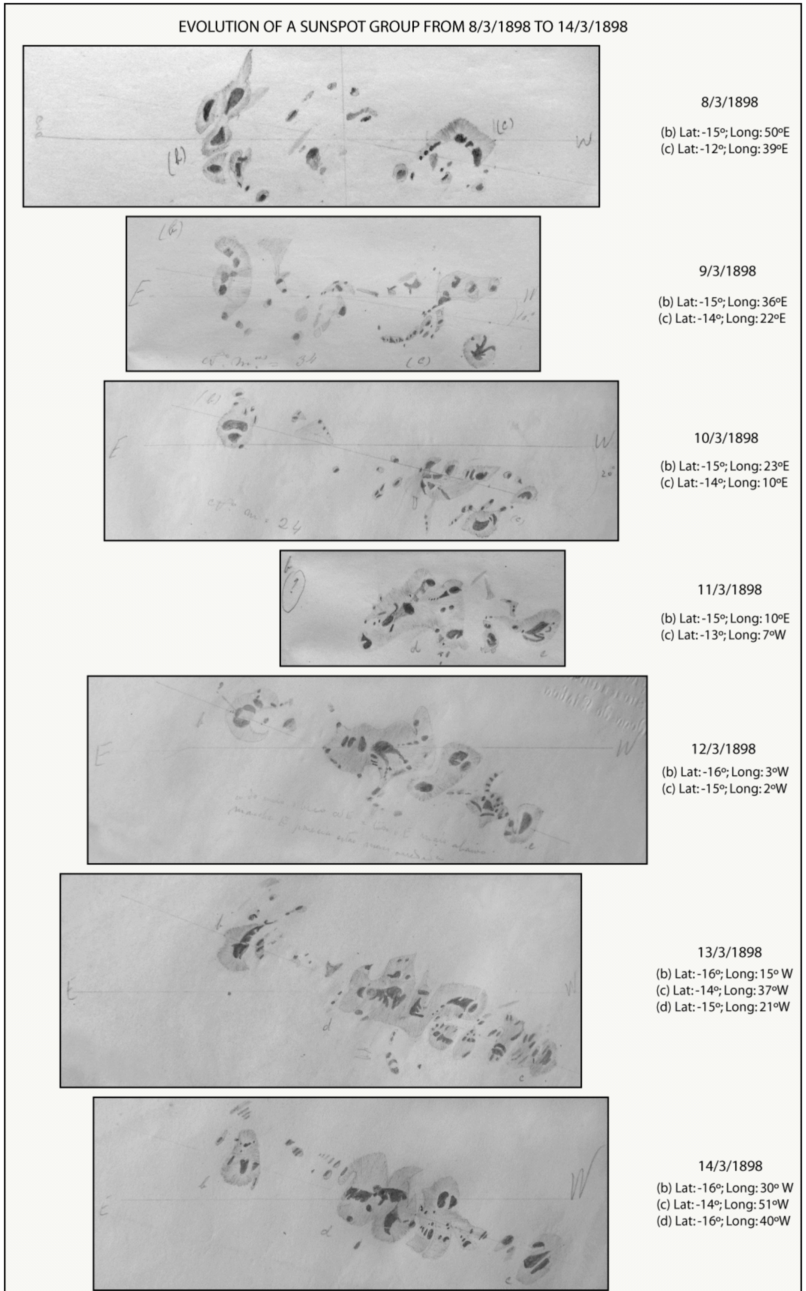



GSN (Hadden)
ISN (Hadden)
Faculae
Days
Year
A
B
C
D

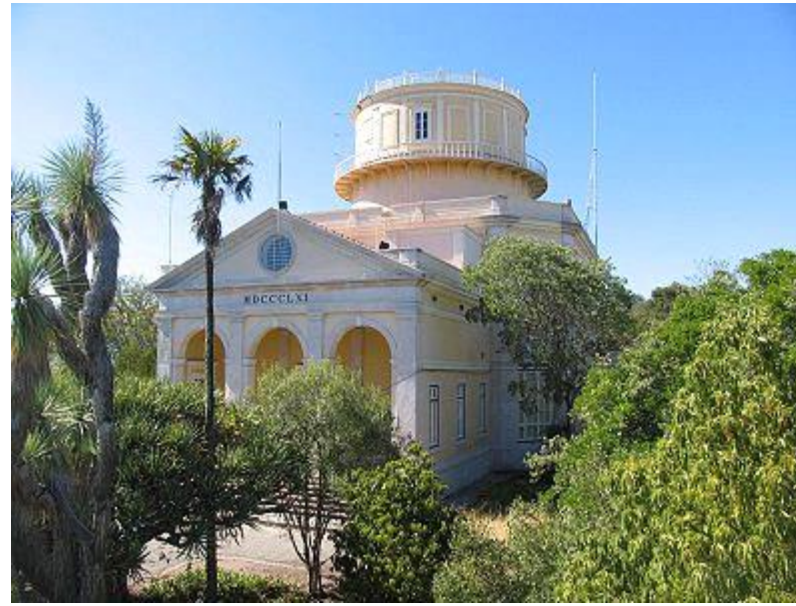


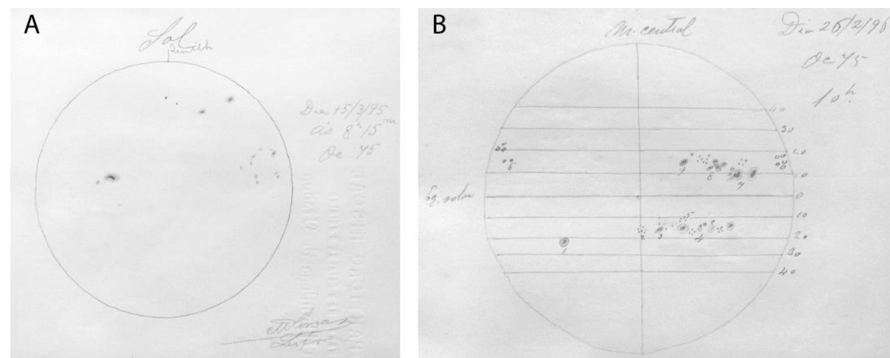
Madrid Sunspot Number
0
2
4
6
8
10
12
14
16
Wolf Sunspot Number
0
50
100
150
200
250
300
1875
1885
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
Date


Madrid Sunspot Number
Days without record
Date
Retirement of Ventosa
Spanish Civil War
Retirement of Gullón
Retirement of Arroyo
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
1875
1885
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995



Detailed drawings of sunspot group observed from 8 to 14 March 1898.





Drawings of the full solar disc; A) 15 March 1895 B) 26 February 1895

Vaquero et al. (2012) *The Observatory* **132**, 376.

Recovering old data on sunspot positions

Nogales & Vaquero (2013), in preparation

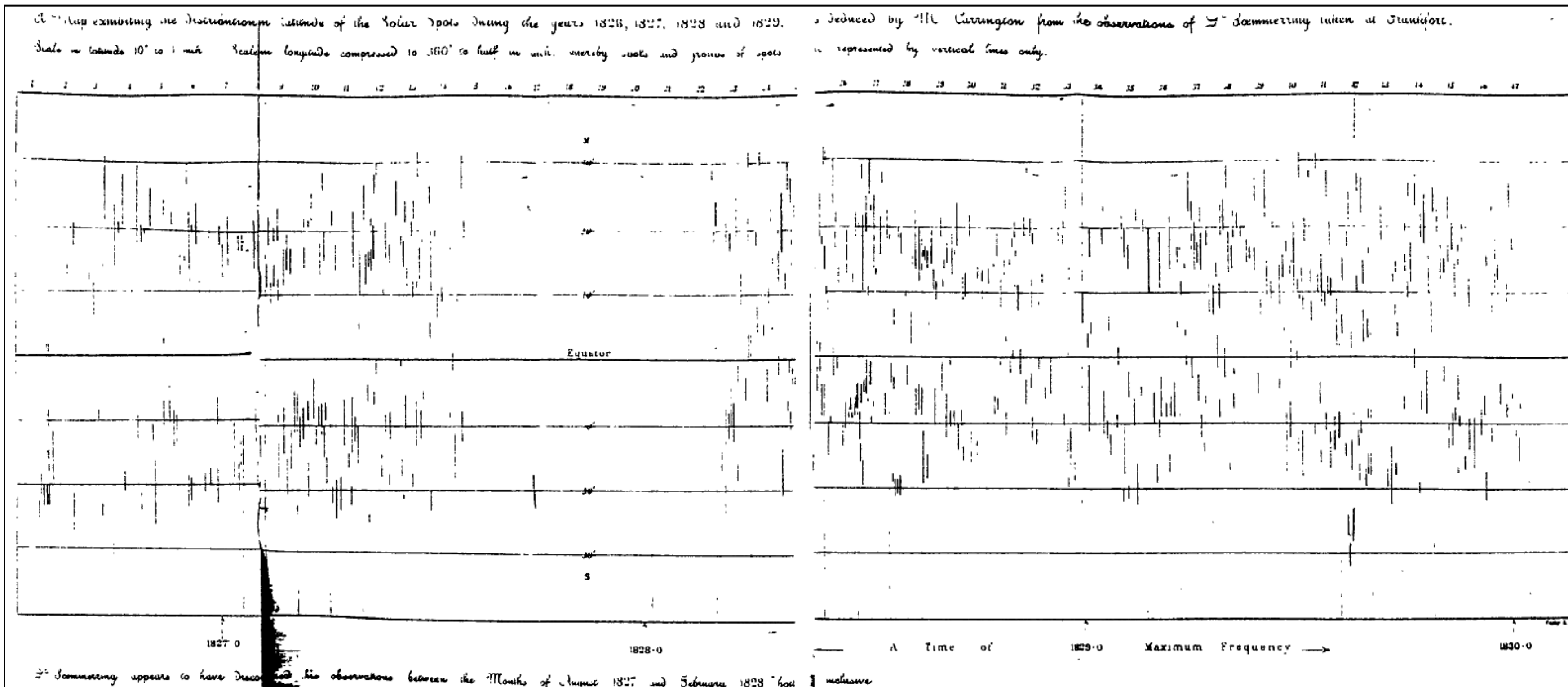
Casas & Vaquero (2013), *Solar Phys*., in press

Carrasco et al. (2013), in preparation

On Dr. Sœmmerring's Observations of the Solar Spots in the Years 1826, 1827, 1828, and 1829. By R. C. Carrington, Esq.

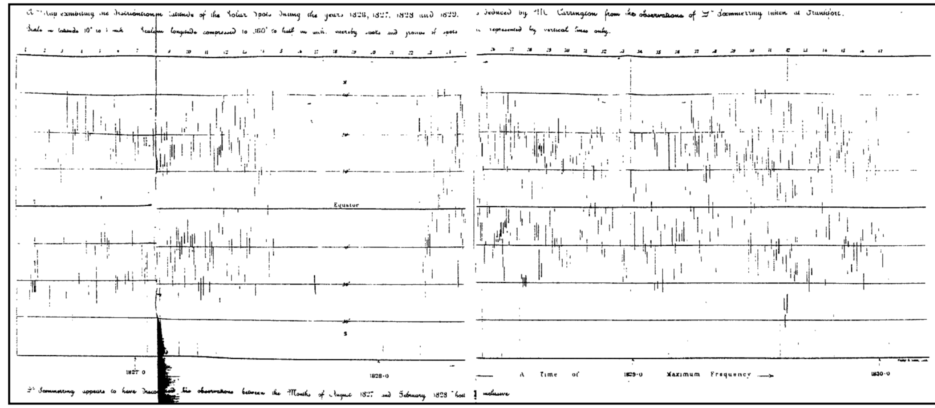
When I visited North Germany in the year 1856, one object which I had in view was to obtain personal information of the observations of the solar spots made by Dr. von Sœmmerring; as I thought it probable, from the account given of them by Professor Thilo, in a dissertation published in the year 1828, that records made by a man of Sœmmerring's eminence would exhibit a degree of accuracy which would repay the labour of reduction; and, when reduced, would put me in immediate possession of an ancient series which might enable me to obtain a more exact value of the time of rotation of the sun on its axis. I

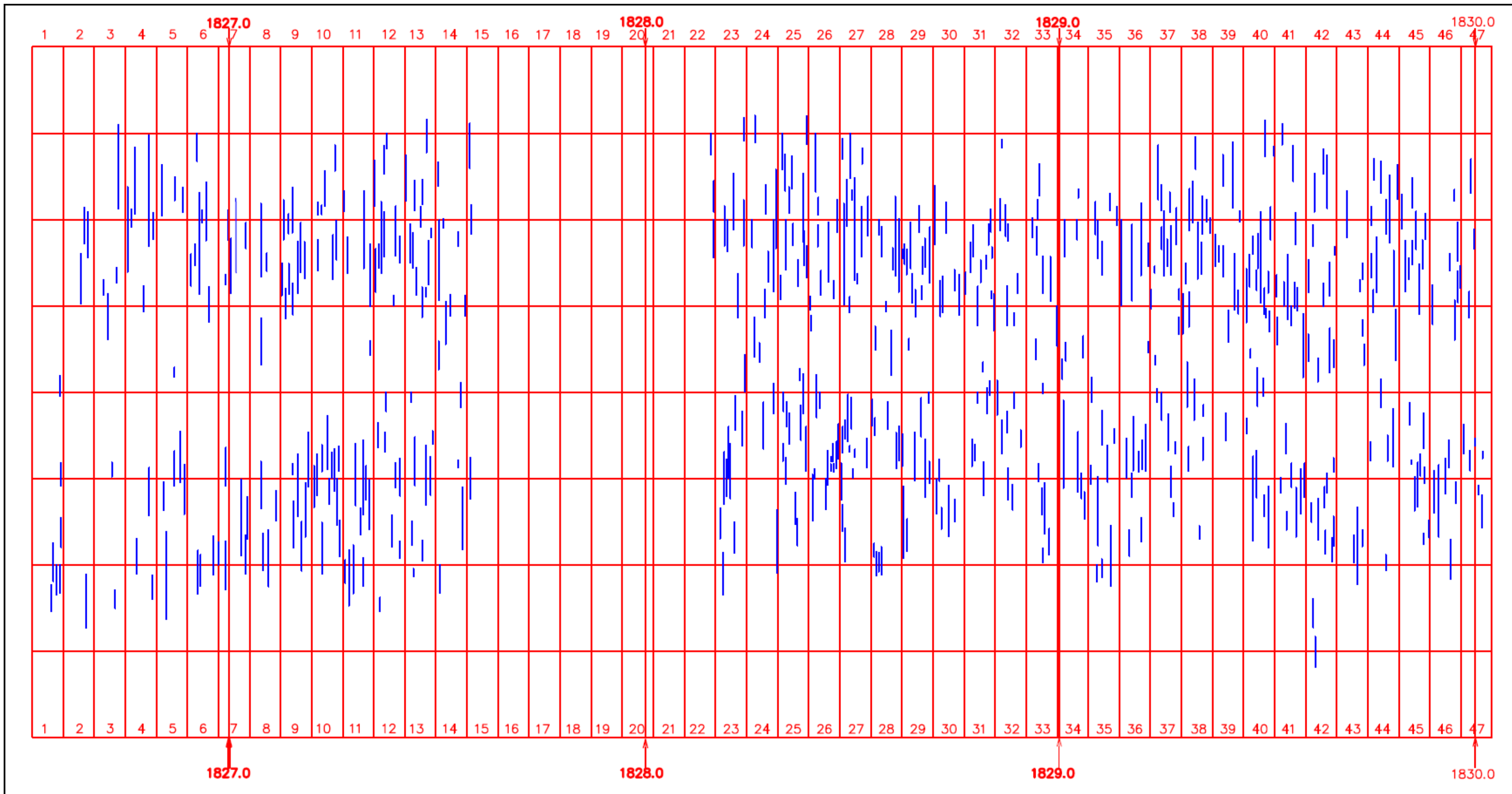
Carrington (1860)
MNRAS **20**, 71



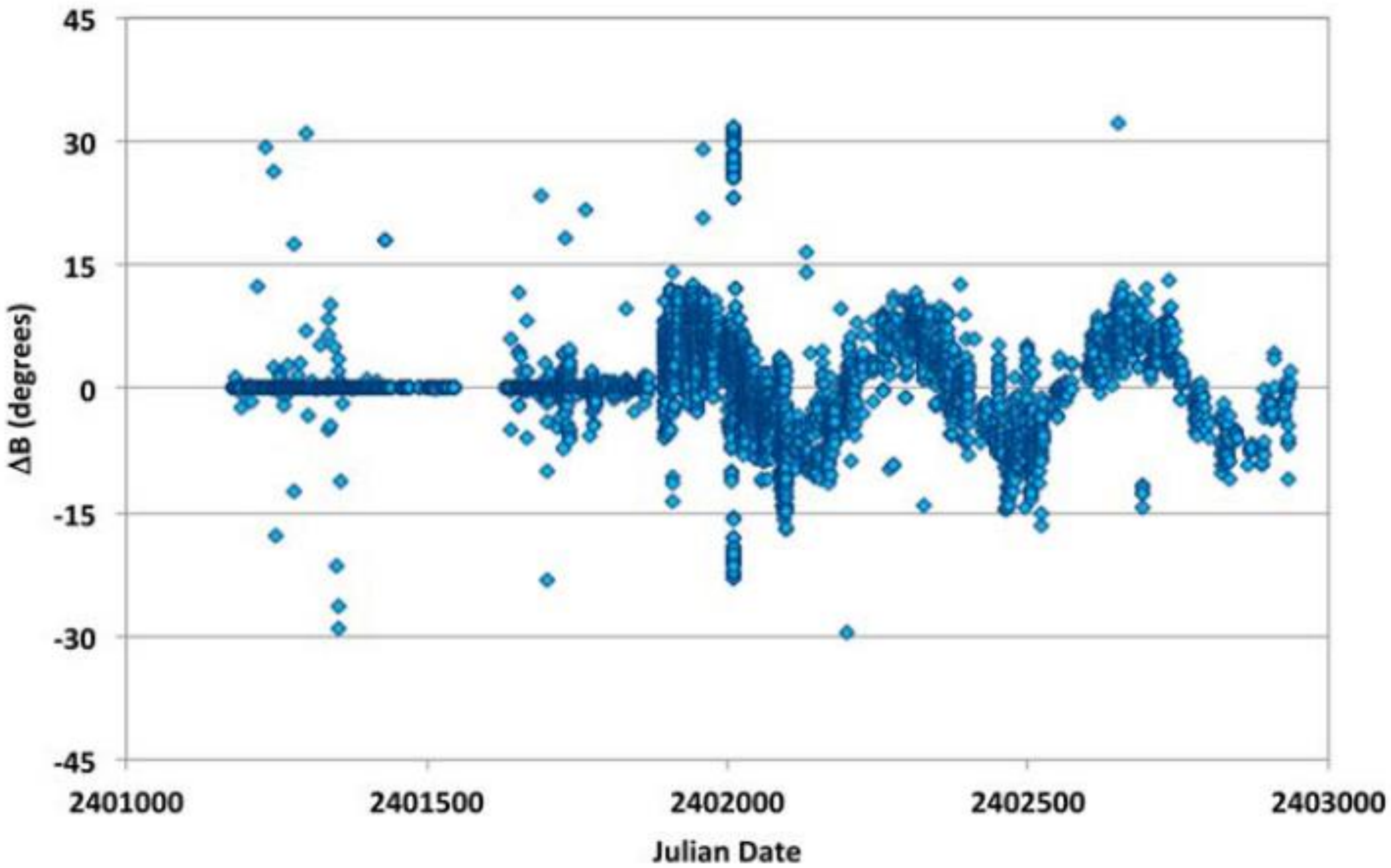
Nogales & Vaquero (2013),

in progress

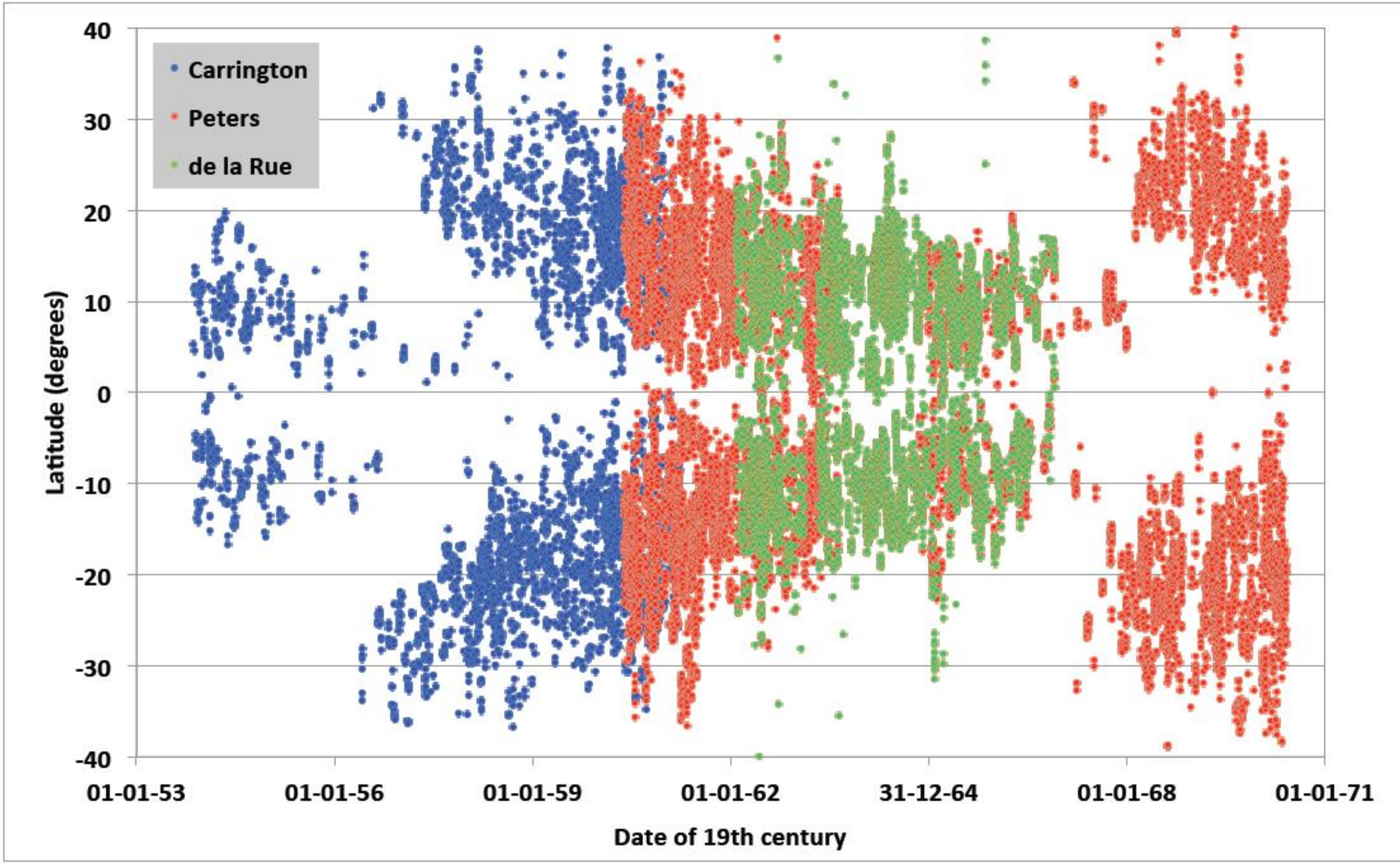




The sunspot catalogues of Carrington, Peters and de la Rue: quality control and readable-machine versions (Casas & Vaquero, 2013, *Solar Phys.*, in press)



Difference between the latitude calculated by de la Rue and our study. A sinuosoidal behaviour is present from January 1^{st}, 1864 with a period of a year and an amplitude of 14.5 degrees.


Carrington
Peters
de la Rue
Latitude (degrees)
40
30
20
10
0
-10
-20
-30
-40
01-01-53
01-01-56
01-01-59
01-01-62
31-12-64
01-01-68
01-01-71
Date of 19th century

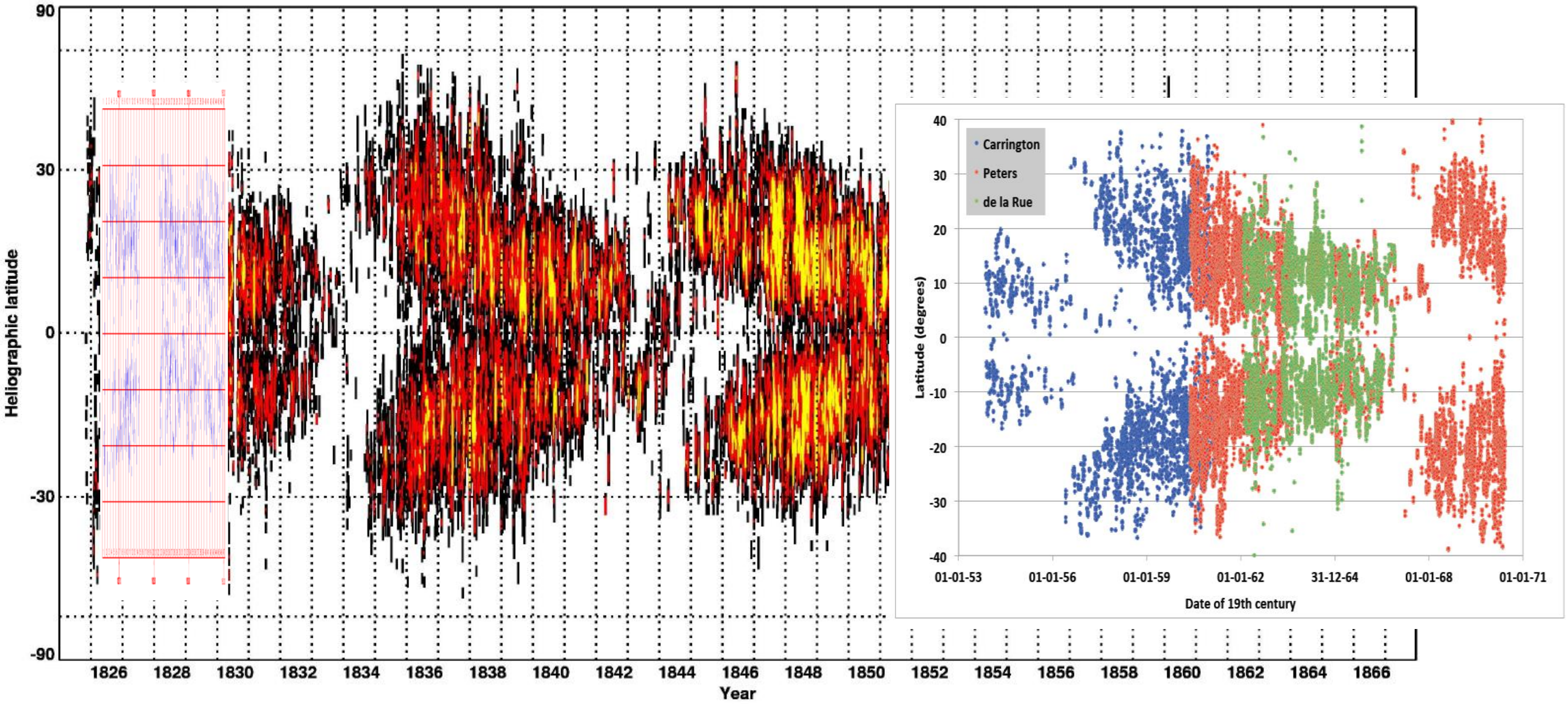
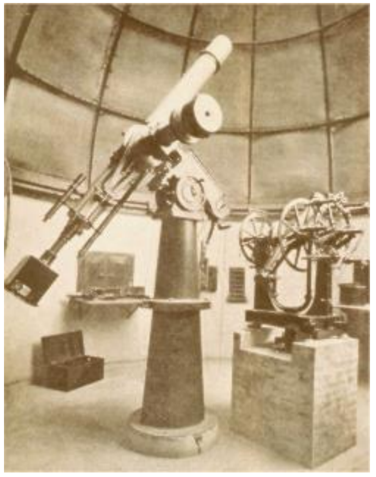
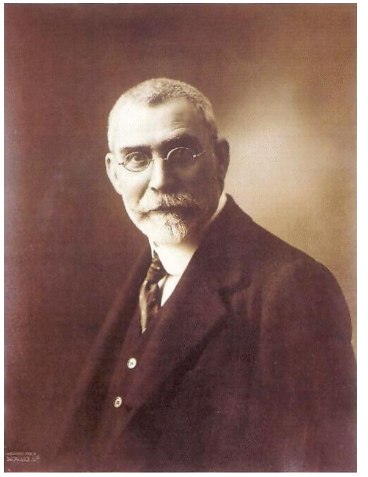


Figure 4. Butterfly diagram based on about 135,000 sunspot positions derived from Schwabe's observations of 1825–1867. A similar plotting style as used by Hathaway[2] is employed here.

Arlt et al. (2013), *MNRAS*

Astronomical Observatory of Universidad de Valencia (Spain)

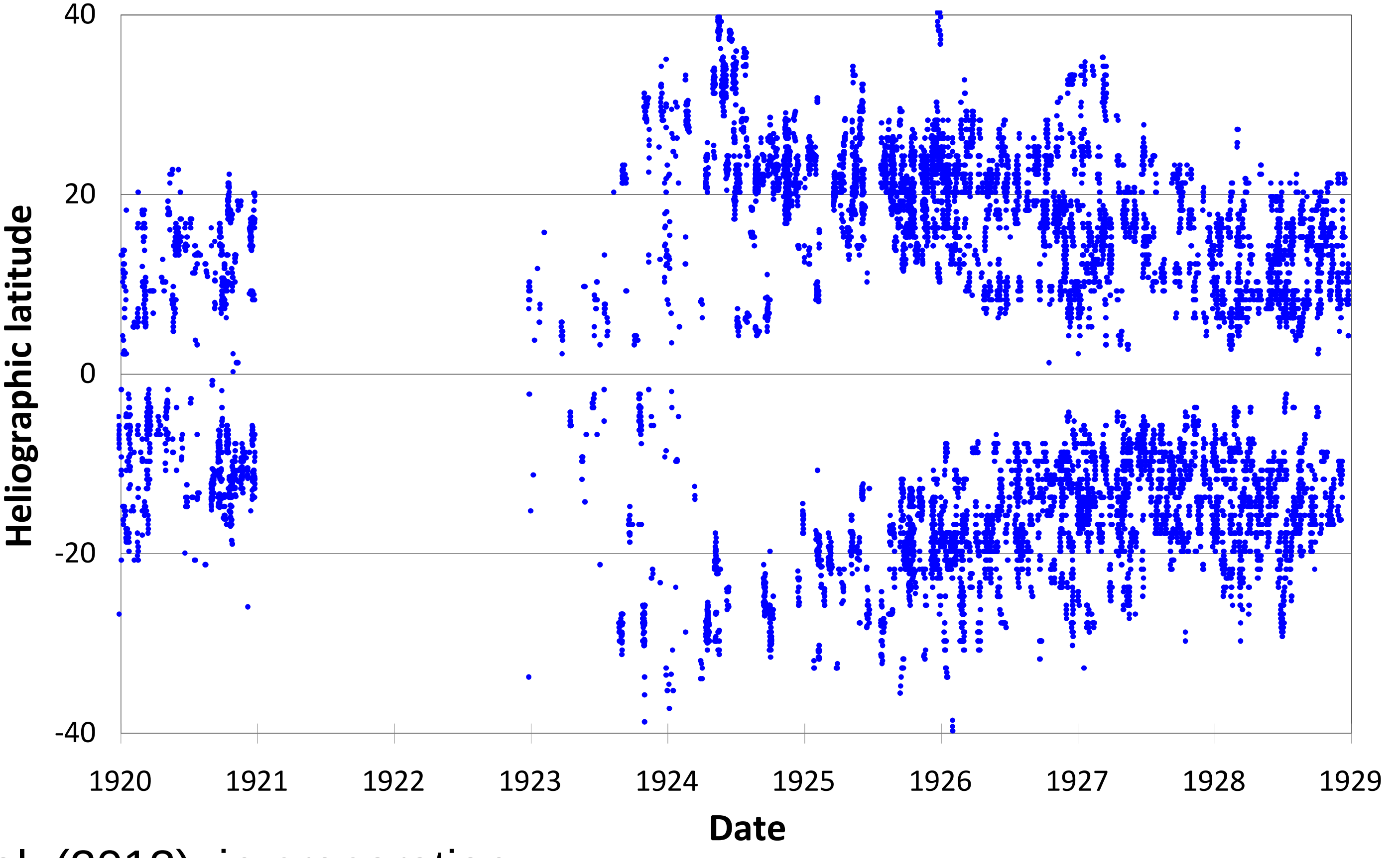




12921 spots

Coordinates

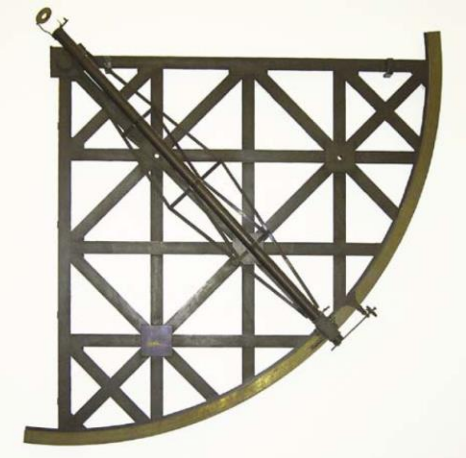
Areas



Carrasco et al. (2013), in preparation

Solar diameter in 18th century

Ruiz-Lorenzo et al. (2013), in preparation

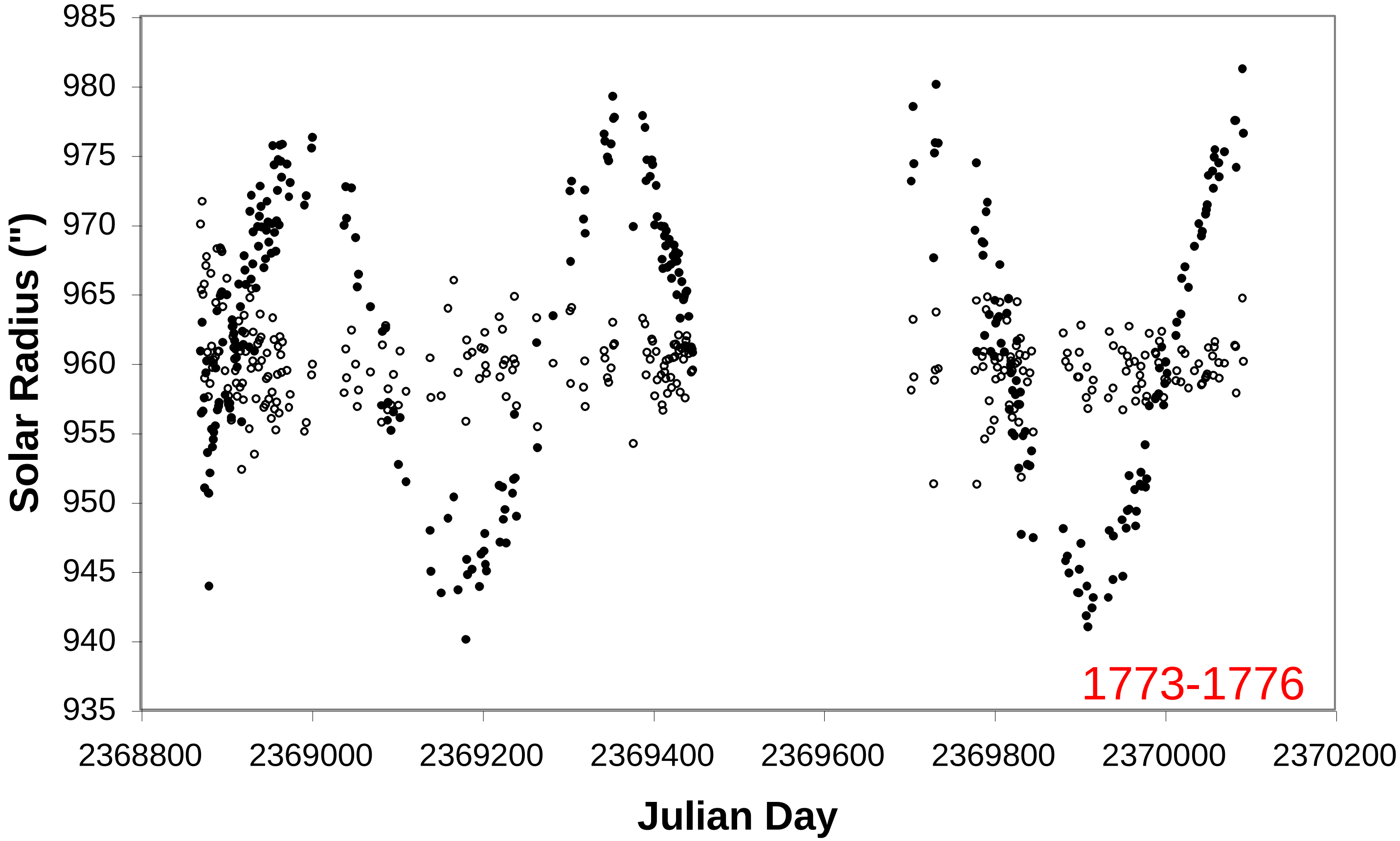


Mural quadrant by Bird (London)

Cadiz Observatory had the same instrument and methodology used by Tobias Mayer in Göttingen Observatory (Wittmann, 1980, 1998).

Table 1. Observations performed in Observatory of Cádiz (Spain) in late 18th Century.

Period	Number of obs.	Solar Radius (")
Jun-Dec 1776	68	959.61±1.61
1773-1776	310	959.84±2.90
1788-1790	391	964.55±5.48
1776-1790	701	962.46±5.09



These observations are comparable to the ones done by Tobias Mayer at the same time, but the dispersion is higher.

The observations performed between June and December 1776 seem more reliable.

Maunder Minimum: consulting original sources

Vaquero et al. (2013), in preparation

JOHANNIS HEVELII

MACHINÆ COELESTIS

PARS POSTERIOR;

Rerum Uranicarum

OBSERVATIONES,

Tam Eclipsium Luminarium, quàm Occultationum Planetarum, & Fixarum,

Nec non

Altitudinum Meridianarum Solarium, Solstitiorum, & Æquinoctiorum;

Unà cum

Reliquorum Planetarum, Fixarumq; omnium hactenus cognitarum, Globisq; adscriptarum, æquè ac plurimarum hucusq; ignotarum

OBSERVATIS;

Pariter quoad

Distantias, Altitudines Meridianas, & Declinationes;

Additis

Innumeris aliis notatu dignissimis, atquè ad Astronomiam excolendam maximè spectantibus rebus,

Plurimorum annorum, summis vigiliis, indefessoque labore, ex ipso æthere haustas, permultisquè Iconibus, Auctoris manu, æri incisis, illustratas, & exornatas,

TRIBUS LIBRIS,

exhibens.

Cum Gratiâ & Privilegio Sac. Regiæ Majest. Polon.

GEDANI.

In ædibus AUCTORIS, ejusq; Typis, & Sumptibus

Imprimebat

SIMON REINIGER.

ANNO M DC LXXIX.

JOHANNIS HEVELII

IN

Partem Posteriorem

MACHINÆ COELESTIS

PRÆFATIO

AD

LECTOREM.

QUintus jam effluxit annus, cùm Partem Machinæ meæ Cœlestis Priorem, Organographiam videlicet, quâ Organa nostra universa, hactenus ad Observationes Cœlestes à me adhibita, graphicè delineata, atq; accuratè descripta, in lucem ediderim. Nunc verò cùm DEUS O. M. vitam porrò, sanitatem, otiumq; (pro quibus omnibus ex toto corde Ipsi & ago & habeo gratias) sub tantâ negotiorum, & molestiarum mole, clementissimè mihi concesserit, Tuis quoq;, mi Astrophile, (citiùs enim ob varia impedimenta, immensumq; laborem typis exscribi haud potuit,) Partem Machinæ

Quo anno Pars Prior Machinæ Cœlestis typis sit divulgata.

a

JOHANNIS HEVELII MACHINÆ COELESTIS

LIBER TERTIUS,

Rerum Uranicarum **OBSERVATIONES**, **GEDANI**,

Altitudines videlicet Solares, unà cum Solstitiis Æstivis & Brumalibus, tam Æquinoctiis Vernalibus, quàm Autumnalibus;

Nec non

Planetarum reliquorum omnium separatim, addito vero tempore ex Altitudinibus correcto,

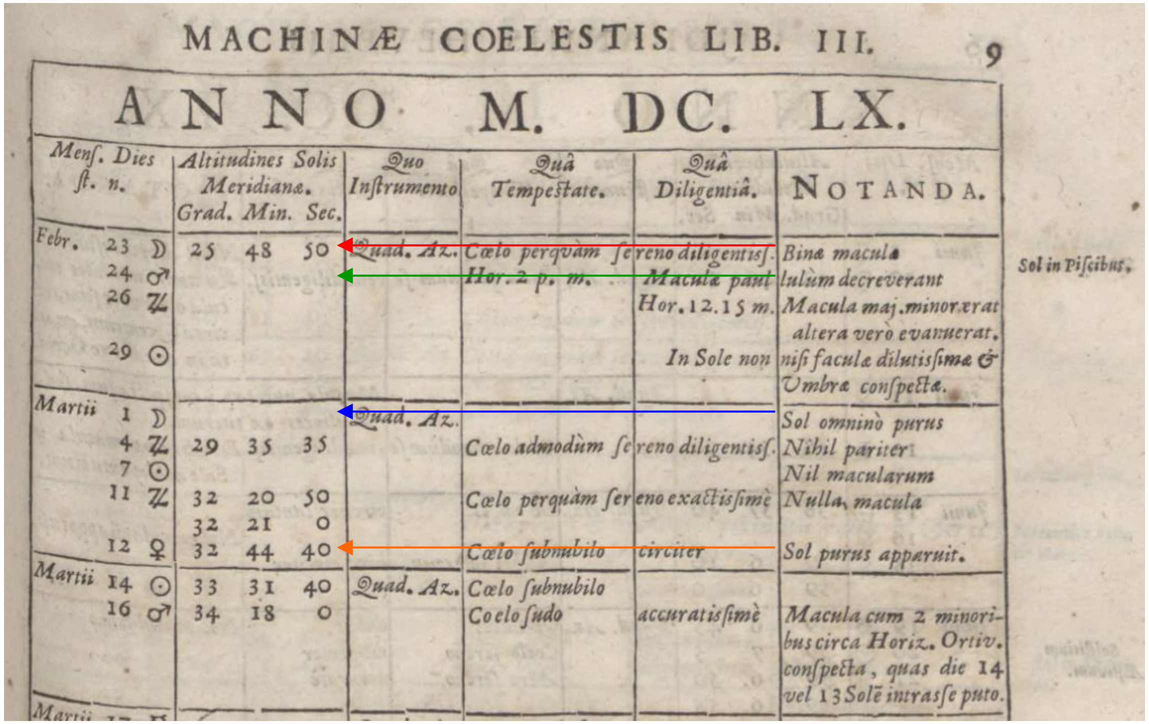
Plurimorum Annorum summis vigiliis, indefessoq; Labore, ex ipso Æthere, Majoribus Organis haustas, exhibens.

ANNO M. DC. LII.

Mens.	Dies	ſt. n.	Altitudines Solis Meridianæ. Grad.	Min.	Sec	Quo Instrumento	Quâ Tempestate.	Quâ Diligentiâ.	NOTANDA.	
Octobr.	12	♄	27	56	10	Quad. Az.	Cœlo sereno			Sol in Librâ.
	30	☿	21	35	0		Cœlo subnubila			
Novemb.	1	♀	20	56	20		Cœlo sereno			
	2	♄	20	37	40		Cœlo subnubilo	Vix satis dilig.		Sol in Scorpione.
Novemb.	4	☽	20	1	0	Quad. Az.	Cœlo nubilo			
	26	♂	14	32	20		Cœlo subnubilo			
	30	♀	13	51	45					Sol in Sagittario.
Decemb.	6	♀	13	3	30				Diam. ☉ obs. 34′ 0″	
Decemb.	7	♄	12	57	0	Quad. Az.	Cœlo perquam sereno			
	8	☉	12	51	0		Cœlo subnubilo			
	16	☽	12	18	7		Cœlo perquam sereno	diligentiss.	Diam. ☉ 34′ 30″	Diameter Solis.
	17	♂	12	16	15		Cœlo admodum sudo			
Decemb.	19	♃	12	13	30	Quad. Az.	Cœlo vix satis sereno			
	20	♀	12	12	45		Aëre sereno		Diam. ☉ 34′ 0″	
	21	♄	12	12	45		Aëre admodum sereno		Diam. ☉ 34 0	Solstitium Brumale in Capricorno.
	27	♀	12	22	40				Diam. ☉ 33 35	

ANNO M. DC. LIII.

	Mens.	Dies	ſt. n.	Altitudines Meridianæ Solis. Grad.	Min.	Sec.	Quo Instrumento	Quâ Tempestate.	Quâ Diligentiâ.	NOTANDA.
Sol in Capricorno.	Januar.	16	♃	14	51	20	Quad. Az.			Diameter Solis 34′ 0″
		19	☉	15	28	0		Cœlo admodùm sereno		
		25	♄	16	52	45				
	Februar.	5	☿	19	57	15				Macula exigua appar.
	Febr.	15	♄	23	13	30	Quad. Az.			
Sol in Piscibus.		24	☽	26	26	45				
		26	☿	27	12	10				
		27	♃	27	34	30		Cœlo subnubilo.		
	Martii	1	♄	28	19	20	Quad. Az.			Nil Macularum.
		9	☉	31	25	30		Cœlo perquàm ser	eno	Nil Macularum.
				31	25	25				
		10	☽	31	49	30				
				31	49	25				
	Martii	13	♃	32	56	50	Quad. Az.			
Æquinoctium Vernale.		20	♃	35	45	0		Ob intercurrentes	nubes dubia	
		23	☉	36	56	0				
				36	56	10				Mac. in quad. Or. Solis
	Martii	24	☽	37	19	30	Quad. Az.		dubia	Macula Solis
		25	♂	37	42	25				Bina macula in Sole
				37	42	30				
Sol in Ariete.	Martii	27	♃	38	29	0	Quad. Az.			Jam penitus disparuerat
		29	♄	39	16	15		Cœlo perquàm ser	eno	Nil Macularum
	Aprilis	4	♀	41	34	0				
		6	☉	42	20	0				Nil Macularum.
	Aprilis	8	♂	43	5	30	Quad. Az.			Nihil prorsus apparuit.
		11	♀	44	11	20				Nihil
		13	☉	44	55	0				Nihil
Sol in Tauro.		27	☉	49	59	30				
	Aprilis	28	☽	49	58	20	Quad. Az.			
		29	♂	50	17	0				
		30	☿	50	35	45				
	Maji	1	♃	50	53	40				
	Maji	3	♄	51	28	40	Quad. Az.			
		6	♂	52	19	45				
		9	♀	53	8	20		Cœlo subnubilo	dubia	
		10	♄	53	24	15				
Diameter Solis.	Maji	11	☉	53	39	0	Quad. Az.			Diamet. ☉ 32′ dilig.
		18	☉	55	20	45				
		19	☽	55	33	15			Diligenter.	Diamet. ☉ 32′
Sol in Geminis.		20	♂	55	46	0			Diam. ☉ 32′	Hucusq; nihil Macularum in Sole apparuit.
	Maji	25	☉	56	43	0	Quad. Az.	Cœlo sereno		
		29	♃	57	22	30		Nubes interpella	runt	
		31	♄	57	40	0		Cœlo sereno	diligentissimè	
	Junii	1	☉	57	47	0				Diameter ☉ 32′
Diameter Solis.	Junii	2	☽	57	55	45	Quad. Az.			Diameter ☉ 32′
		18	☿	59	6	0				Diameter ☉ 32′
		19	♃	59	6	35		Cœlo quidem subn	ubilo; satis tam	en accurate
		20	♀	Nihil observat.				Ob turbidum Cœ	lum	
Solstitium Æstivum.	Junii	21	♄	Nihil observat.			Azim. 2°	ob pluviam		Observarum
		22	☉	59	7	0		Momentum autem	ipsum Merid.	Altit. ob nubes haud ob-
		27	♀	59	0	20			Diam. ☉ 32′	Huc usque nihil in Sole
		28	♄	58	57	0		Cœlo sereno	Diligenter	apparuit, nisi unica exigua macula



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ANNO M. DC. LX.

Menſ.	Dies ſt. n.		Altitudines Solis Meridianæ. Grad.	Min.	Sec.	Quo Inſtrumento	Quâ Tempeſtate.	Quâ Diligentiâ.	NOTANDA.
Febr.	23	☽	25	48	50	Quad. Az.	Cœlo perqvàm ſe	reno diligentiſſ.	Binæ maculæ
	24	♂					Hor. 2 p. m.	Maculæ paul	lulùm decreverant
	26	♃						Hor. 12. 15 m.	Macula maj. minor erat altera verò evanuerat.
	29	☉						In Sole non	niſi faculæ dilutiſſimæ & Umbræ conſpectæ.
Martii	1	☽				Quad. Az.			Sol omninò purus
	4	♃	29	35	35		Cœlo admodùm ſe	reno diligentiſſ.	Nihil pariter
	7	☉							Nil macularum
	11	♃	32	20	50		Cœlo perquàm ſer	eno exactiſſimè	Nulla macula
			32	21	0				
	12	♀	32	44	40		Cœlo ſubnubilo	circiter	Sol purus apparuit.
Martii	14	☉	33	31	40	Quad. Az.	Cœlo ſubnubilo		
	16	♂	34	18	0		Coelo ſudo	accuratiſſimè	Macula cum 2 minoribus circa Horiz. Ortiv. conſpecta, quas die 14 vel 13 Solē intraſſe puto.

Sol in Piſcibus.

Sunspot record with measurement of solar meridian altitude

Sunspot record without measuring solar meridian altitude

No sunspot record with measurement of solar meridian altitude

No sunspot record without measuring solar meridian altitude

Be careful!!!

Sunspot records are not associated with measurement of solar meridian altitude!!!

Year	AD	NAD	AD%
1653	11	11	50.00
1654	3	1	75.00
1655	n.a.	n.a.	n.a.
1656	n.a.	n.a.	n.a.
1657	4	2	66.67
1658	0	2	0.00
1659	0	47	0.00
1660	28	30	48.28
1661	2	16	11.11
1662	n.a.	n.a.	n.a.
1663	0	7	0.00
1664	n.a.	n.a.	n.a.
1665	n.a.	n.a.	n.a.
1666	n.a.	n.a.	n.a.
1667	n.a.	n.a.	n.a.
1668	n.a.	n.a.	n.a.
1669	n.a.	n.a.	n.a.
1670	n.a.	n.a.	n.a.
1671	2	3	40.00
1672	n.a.	n.a.	n.a.
1673	n.a.	n.a.	n.a.
1674	n.a.	n.a.	n.a.
1675	0	2	0.00
Total:	50	121	29.24
1653-1663:	48	116	29.27
1659-1661:	30	93	24.39

AD%=24.39 (1659-1661)

GSN≈3

AD%=29.27 (1653-1663)

GSN≈4

The estimations of GSN from Hevelius' observations are 3-8 times higher than the values obtained by Hoyt and Schatten!!!

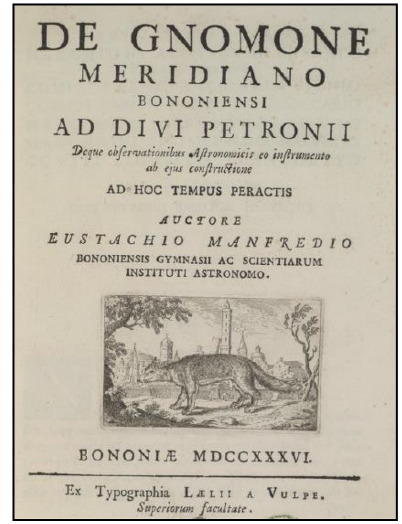
Year	H&S98
1653	0.9
1654	0.7
1655	0.5
1656	0.6
1657	0.2
1658	0
1659	0
1660	2
1661	0.8
1662	0
1663	0

GSN=0.9 (1659-1661)

GSN=0.5 (1653-1663)

Can we detect the solar cycle in the Hoyt & Schatten Database?

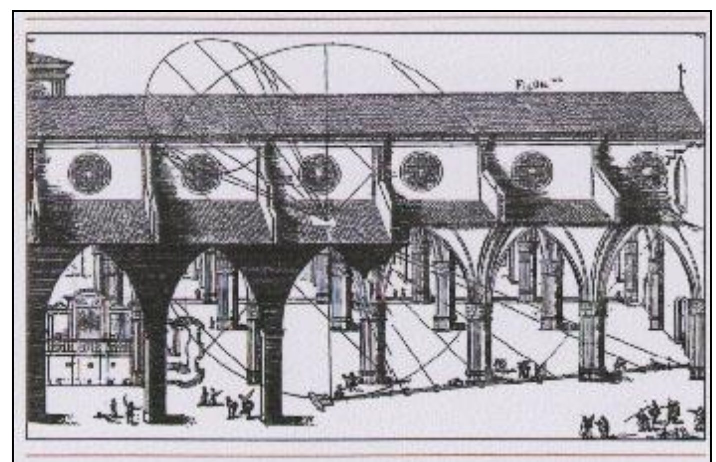
- Hoyt & Schatten Database is contaminated with “zero” values of SN derived from solar-astrometric observations (solar altitude, solar radius, …).
- As an example, we can cite the observations made with the great meridian lines (camera obscura).



DE GNOMONE
MERIDIANO
BONONIENSI
AD DIVI PETRONII
Deque observationibus Astronomicis eo instrumento
ab ejus constructione
AD HOC TEMPUS PERACTIS
AUCTORE
EUSTACHIO MANFREDIO
BONONIENSIS GYMNASII AC SCIENTIARUM
INSTITUTI ASTRONOMO.

BONONIÆ MDCCXXXVI.

Ex Typographia Lælii a Vulpe.
Superiorum facultate.



Can we detect the solar cycle in the Hoyt & Schatten Database?

I have designed a "new" database (extracted from HS98). The purpose is to use only reliable observations to pinpoint AD and NAD. I have only chosen (for each year) observers with recorded AD.

HS98

64 Observers

19358 days with records

402 Active days

→

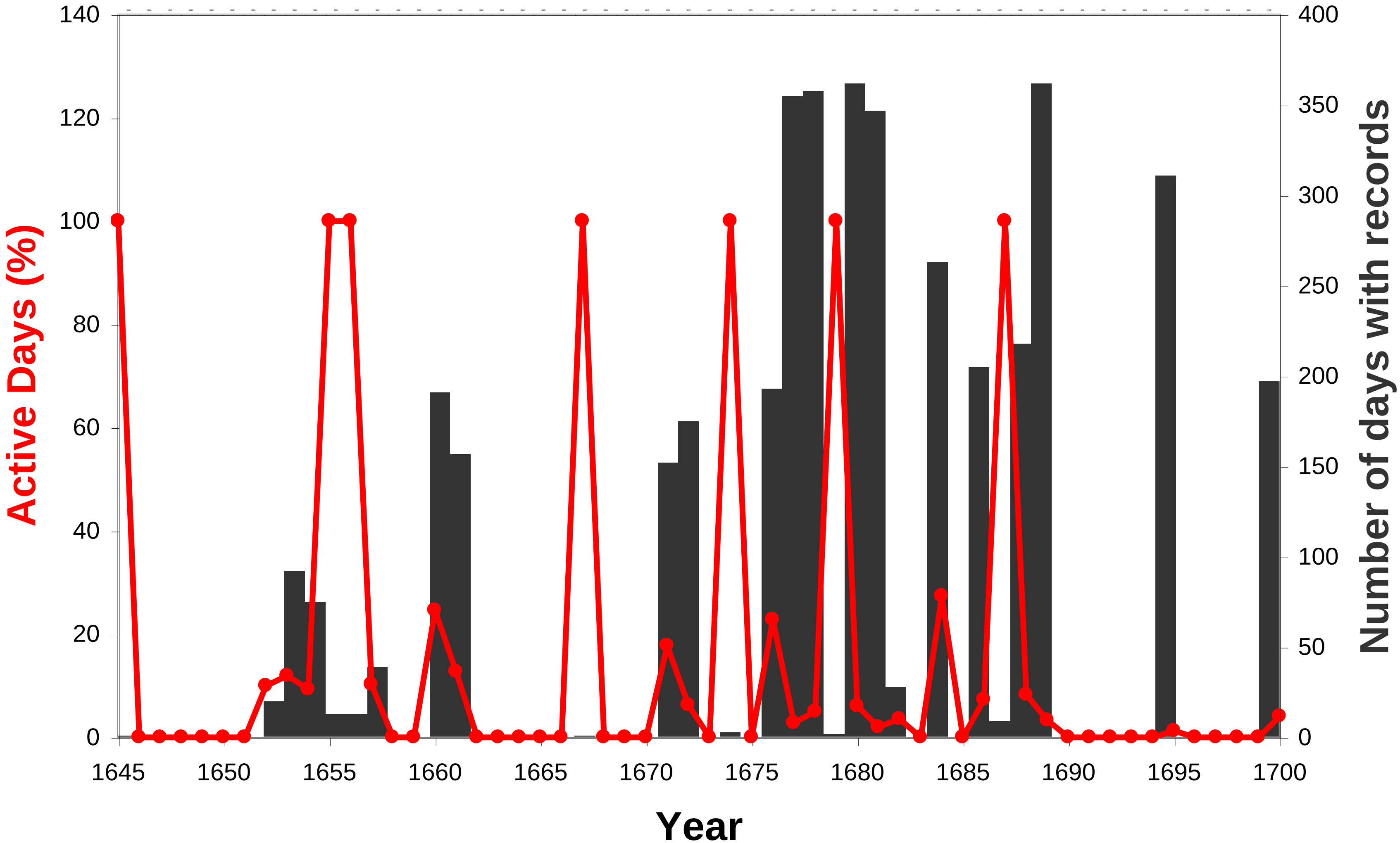
HS98 modified

36 Observers

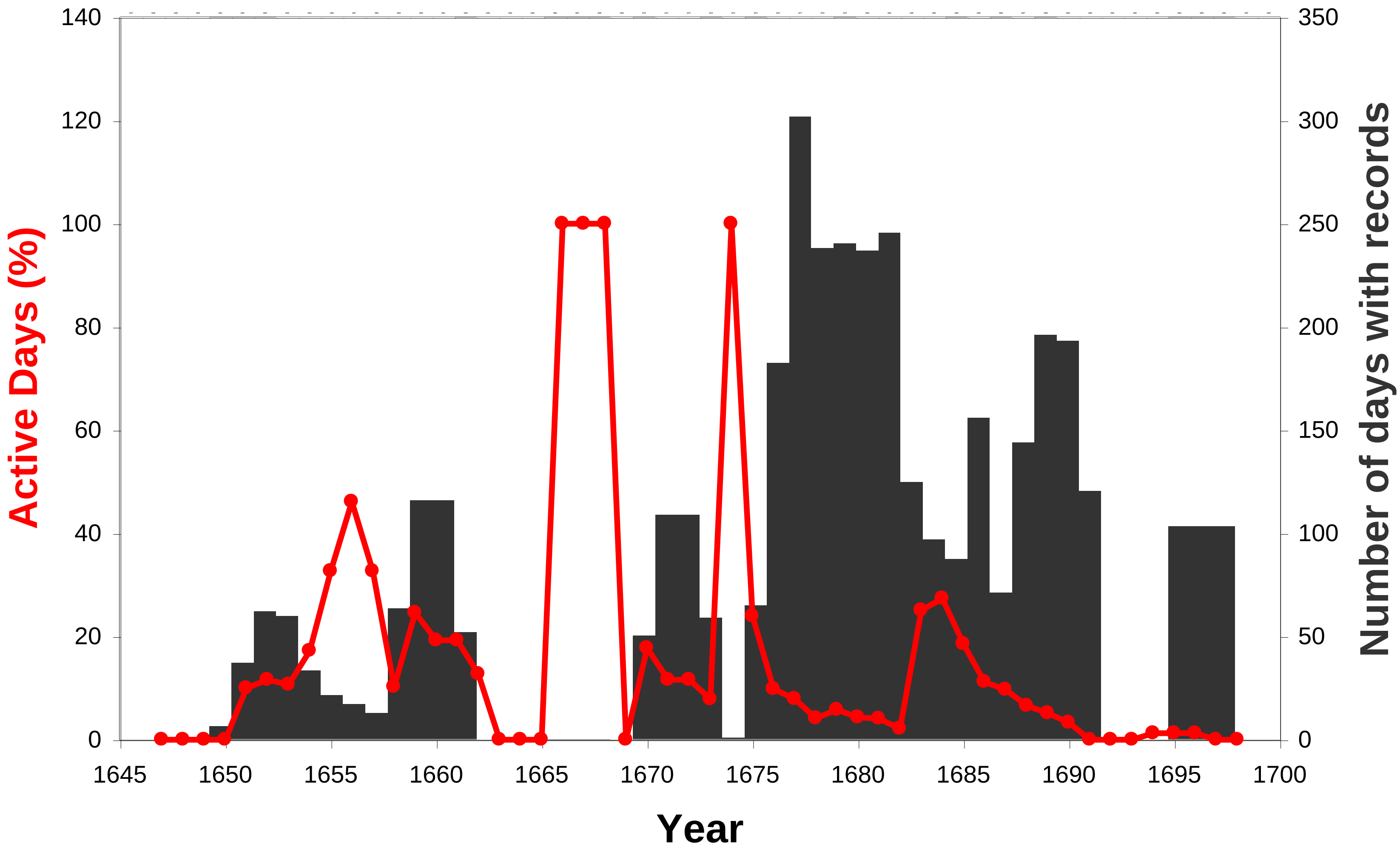
4141 days with records

402 Active days

Can we detect the solar cycle in the Hoyt & Schatten Database?

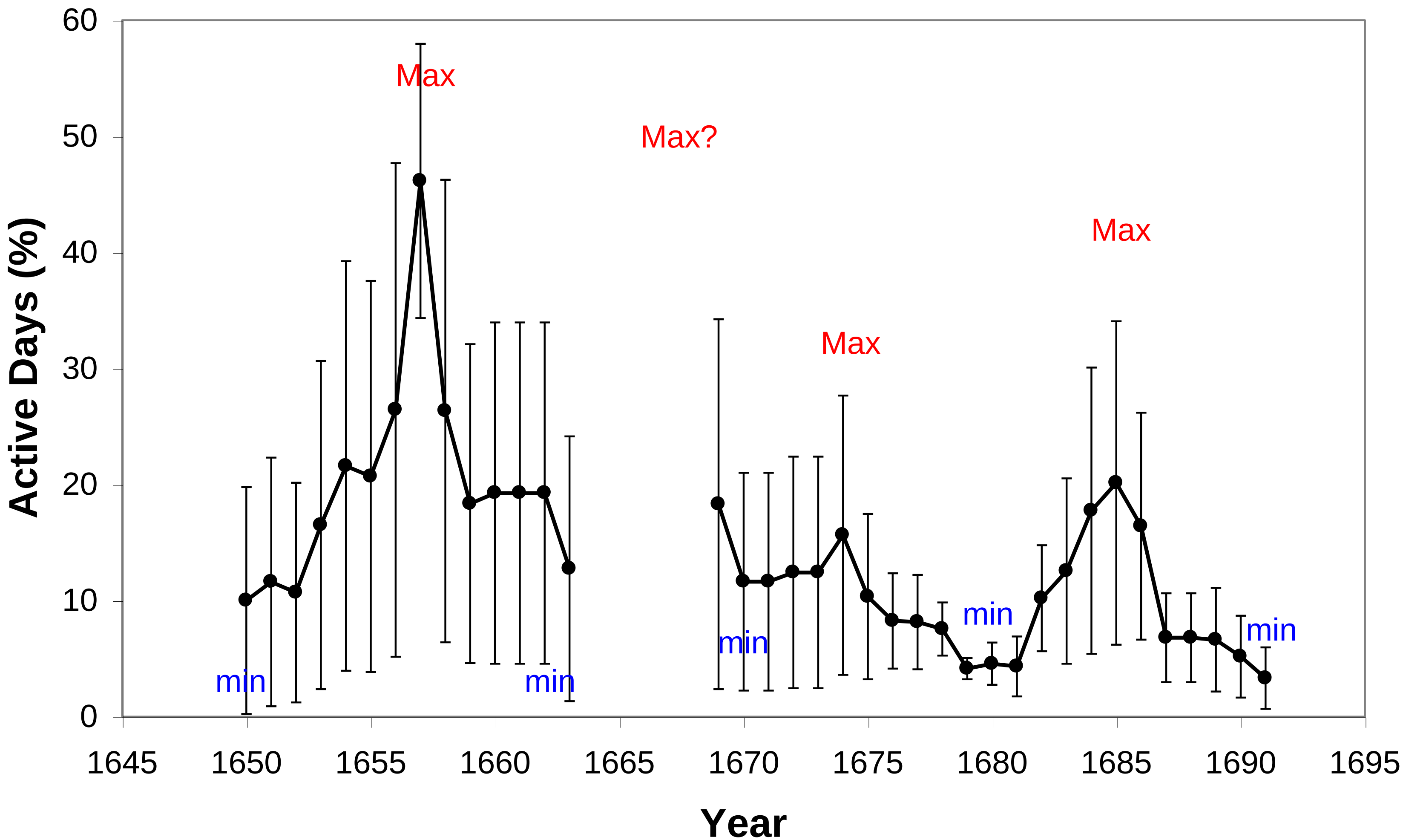


Can we detect the solar cycle in the Hoyt & Schatten Database?



Using a 3-year moving-average window.

Can we detect the solar cycle in the Hoyt & Schatten Database?



Using a 5-year moving-average window and assuming a hyper-geometrical probability distribution…

Some conclusions

- In the last few years, three major changes in H&S98 database have been proposed:
  - Onset of Maunder Minimum (Vaquero et al., 2011).
  - Solar Cycle -1 (Vaquero et al., 2007; Vaquero & Trigo, 2013)
  - Lost solar cycle (Usoskin et al., 2009; Zolotova & Ponyavin, 2011).

- There is interesting lost solar information that is preserved in archives and libraries. We need a "Sunspot/Solar Historical Archive".

- Maunder minimum was a period of very low sunspot numbers as Hoyt & Schatten stated. However, their values probably are understimated because they used astrometric observation records (including *camera obscura* records!). Most likely, the solar cycle is present in sunspot data.

Thank you very much!

Comments, suggestions, etc.:

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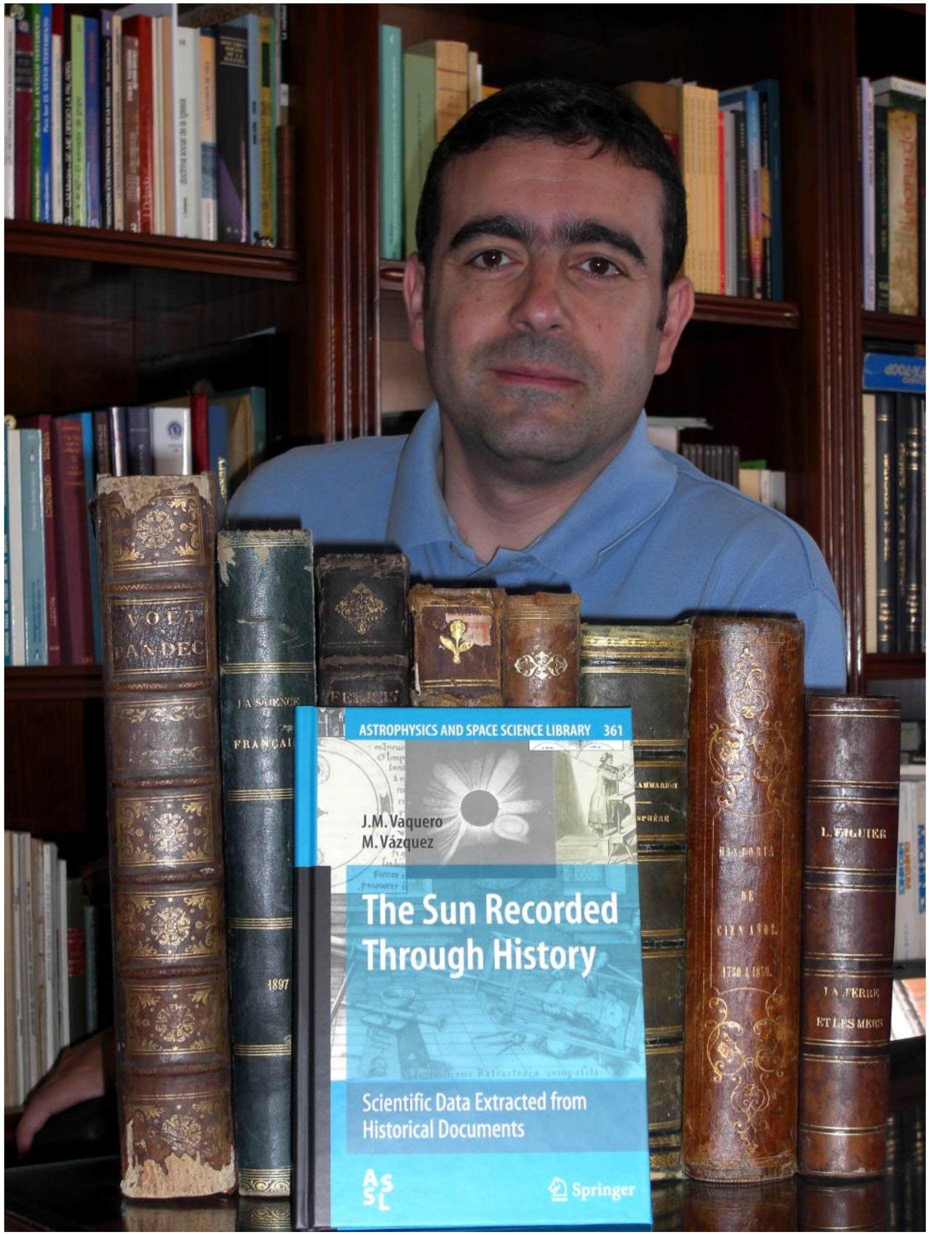
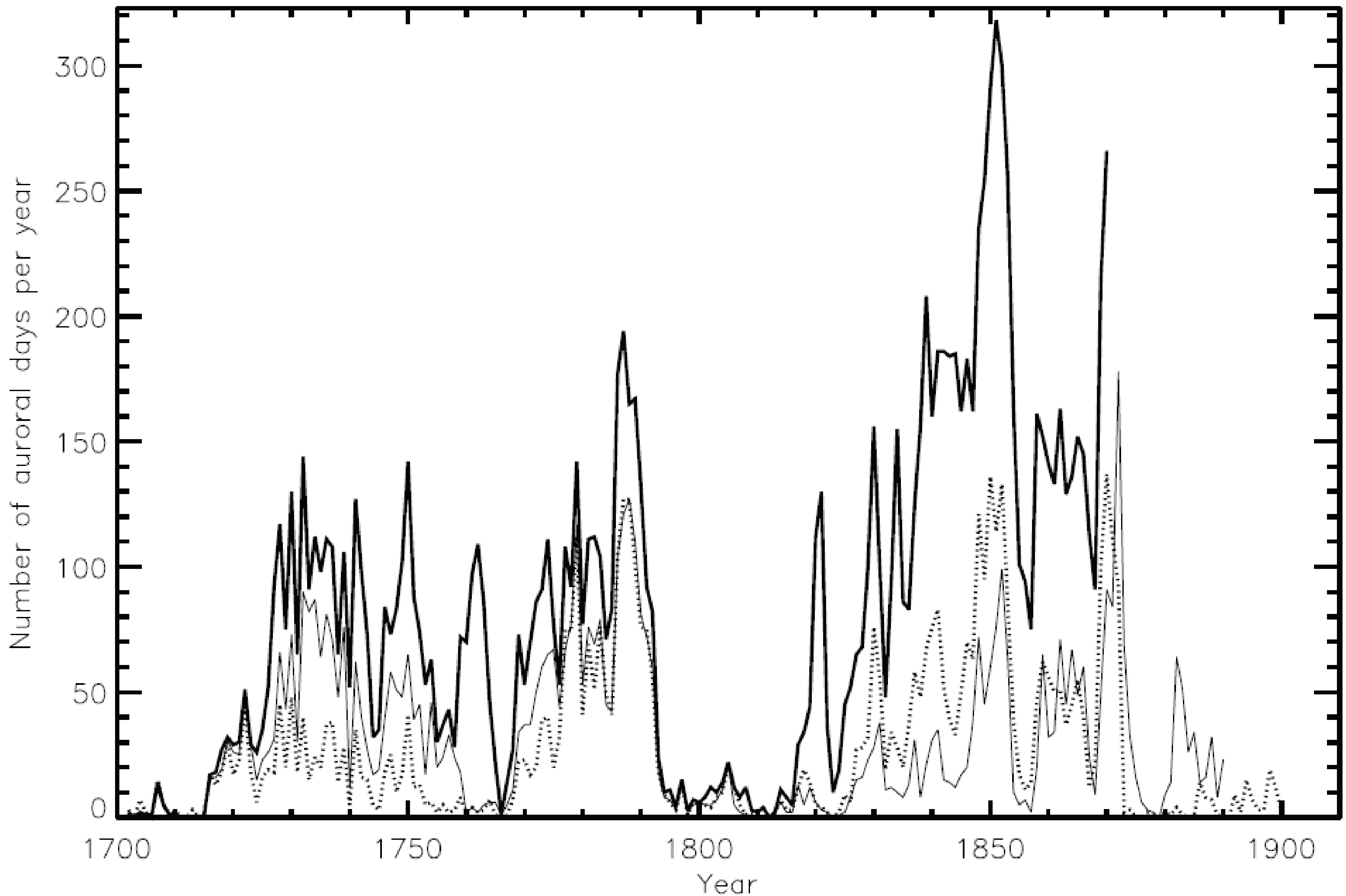
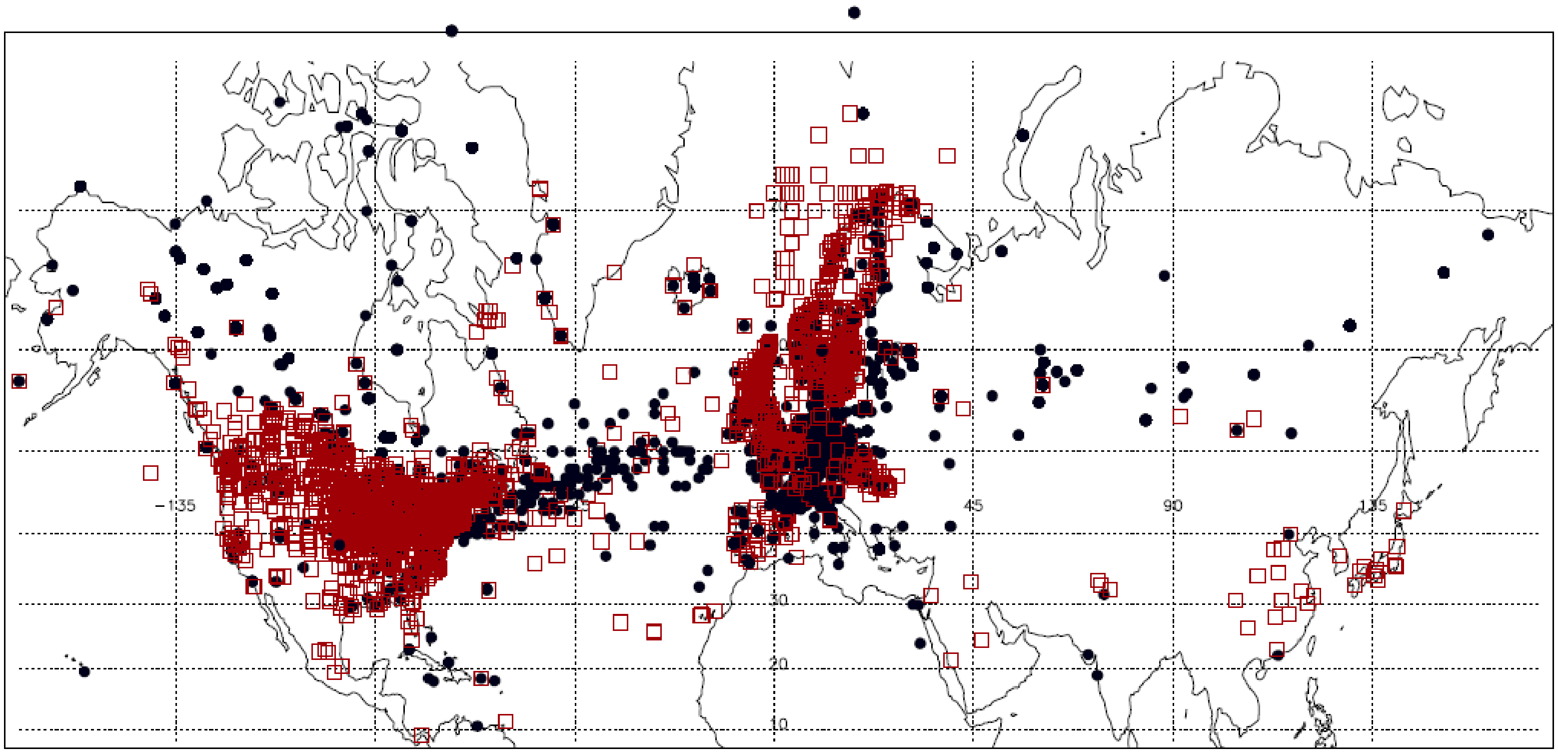


Long-term Spatial and Temporal Variations of Aurora Borealis Events in the Period 1700–1905

Vázquez, Vaquero & Gallego (2013), *Solar Phys*. (submitted)

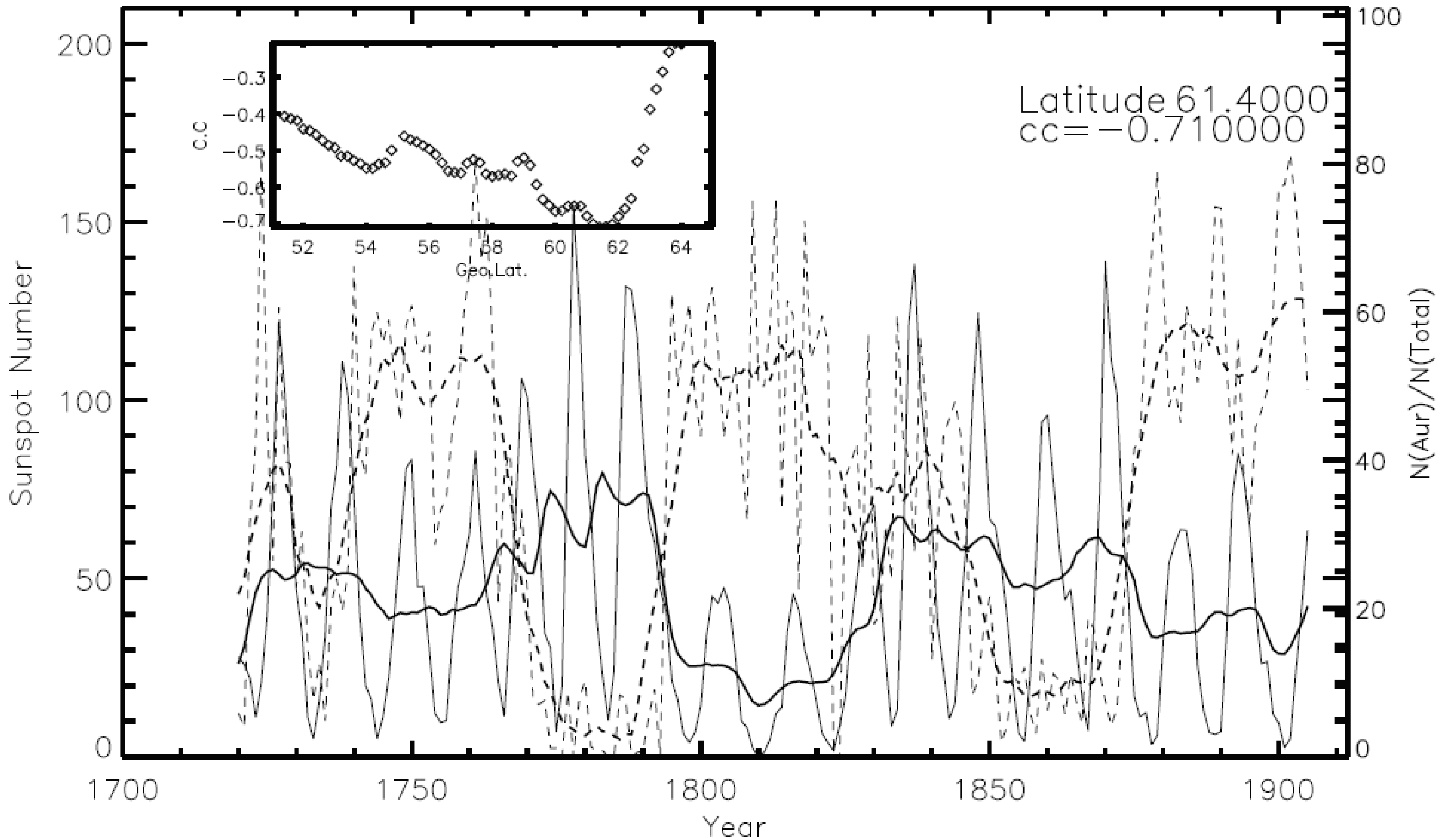


Yearly number of aurorae in the following catalogues: (dotted line) Krivský and Pejml (1988) updated by Krivský (1996), (thin solid line) Angot (1897), and (thick solid line) Fritz (1873). The first two catalogues are limited to zones further south than 55 degrees of geographic latitude.



Map showing the places where aurorae were visible at least once in the Northern Hemisphere during the studied period. (●) Fritz and Angot catalogues; (red squares) other catalogues and reports.

27 000 auroral events with more than 80 000 observations.



European and North African data: Correlation of the annual sunspot number with the fraction of auroral events above a critical geomagnetic latitude. The inset shows the variation of the correlation coefficient for different geomagnetic latitudes.