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SOLAR AND AURORAL ACTIVITIES DURING THE SEVENTEENTH CENTURY

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The dark spots on the solar disk visible by eye and the aurorae, including some of them stretching down towards tropics, are the most visible manifestations of the solar activity. Since more than one century, we know that this activity follows a rather regular periodic cycle of eleven years, but with an intensity, measurable in spot number, which is sufficiently variable to speak of "small" or "large" solar cycles.

Actually we observe a series of large cycles, on the contrary at the end of the 17th century this activity was incomparably weak during several decades, at the epoch of the rise of the instrumental astronomy in Europe.

This period of weak intensity which has attracted the attention of the German astronomer Spoerer as early as 1890, is known by the name of "Maunder Minimum".

What are we knowing exactly about this epoch?

Were the tools used accurate enough?

Did the climate conditions, known to be cloudy, get the better of the astronomer's assiduity?

What can we bring from the analysis of more ancient data, dating from the beginning of the 17th century at the time of astronomical telescope invention?

This paper makes the state on all these historical questions and highlights the original documents at the light of more recent knowledge on the running of our star.

Keywords: auroral activity; history of geophysics; Maunder minimum; solar activity

The Spoerer minimum

"It is just one-third of a century since Prof. F W G Spoerer, the veteran observer of sunspots, published two important papers with regard to the "sunspot cyle", in which he drew attention to evidence pointing to a long continued "damping-down" of the solar activity which began in the middle of the seventeenth century. It fell to my duty to supply a short note on these two papers to the Council of the Royal Astronomical Society for their Annual Report for the year 1890, and four years later, I gave a fuller account of the first paper, in knowledge for August 1, 1894 (p. 173).

It appears to me that this discovery of Spoerer has not received as much attention as it deserves, and I would ask permission from the Association to summarise the main facts."

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It is in the previous terms that the astronomer E W Maunder began his paper "The prolonged minimum 1645–1715" published in 1922 by the "British Astronomical Association Journal" in which he gave a description of the sunspots and aurorae observed at this epoch, showing the reality of this weak solar activity period.

Then in 1976, Eddy published a new paper on this subject confirming the thesis of the prolonged minimum. Curiously he named his paper "The Maunder minimum", even this discovery belongs to Spoerer, according to the English astronomer.

After Eddy's paper, several textual criticisms were published especially by Gleissberg and Damboldt (1979), Kopeczky and Kuklin (1987), Landsberg (1980), Link (1978), Schröder (1979, 1988), Zhen-Tao (1982), some of them gave a clear indication that the solar activity, even weak during this period, has already followed the well known solar cycle variation. And, as a consequence, there was not a long minimum of sunspots. In particular, the frequency of aurora appearance during the 17th century was used for these studies.

But during these periods of stammering instrumental astronomy, the sunspot and aurora data were certainly not homogenous because there was no regular auroral watch. This fact does not allow their interpretation in terms of activity level.

In this study, all the observations available have been collected and discussed in order to determine their reliability and especially the exhaustivity. Then a detailed synthesis, made at the light of the recent progress made in the knowledge of the solar source of the geomagnetic activity (Legrand and Simon 1989, Simon and Legrand 1989), allows us to show the reality of the desorders which occurred in the "Solar machine running working", precisely during Louis XIV's reign ("Sun King").

The sunspot activity during the seventeenth century

The solar data available for this century of evolution of the astronomy of precision can be classified following these periods:

- the period of discovery of sunspot activity with the help of astronomical telescope (1610–1645)
- the period of "uncertainty" (1646–1670)
- the period of weak activity (1671–1710).

The period of discovery of sunspot activity and the astronomical telescope invention (1610–1645)

Historic

The use of telescope to see more clearly distant objects started in Italy between 1580 and 1586, and in the Netherlands in 1608 (Danjon and Couder 1935).

The first telescopes built at this epoch, with a convex lens and a concave ocular, were made by competent opticians or technicians. These tools were rare for a long time, as it was not easy to acquire a technology whose secrets were jealously kept. Nevertheless, this invention was too bright to be a long time in the sole hands of a few constructors. In a short time, this invention was known by many people and erudits were not the last one to be interested by it, in particular the famous Galileo from Florence.

It is through his Paris corresponding friend, Jacques Badouere that Galileo heard of this "Dutch lens", for the first time, in June 1609.

These tools had just appeared at merchants in the French capital (Danjon and Couder 1935). Pierre l'Estoile was stating these facts in his journal on Henri IV's reign for the year 1609: *"On April 30, Thursday, I went to an optician at pont Marchand and he showed to me and to several others a new type of glasses. These glasses consist of a one foot long tube with glasses at both ends which differ from each other; they are used to observe distant objects which can be seen else confusedly: you have to put the glasses near to one eye and to close the other; if you observe the object you want to see, it is much nearer and you see it very clearly so that you can identify him from a half mile: It was told me that these glasses were invented by an optician in Midelbourg in Zeland and he presented two of them last year to Prince Maurice with which distant objects could be seen very clearly, from three or four miles. This Prince sent them to the Council of the United Provinces which gave to the inventor as compensation three hundred écus with the condition that he should not tell anybody how to make similar ones."*

It is nearly sure that Galileo never had such a telescope in his hand, but, with the use of the refraction theory, he rapidly discovered the construction of the "approach lens".

After July 1609, he undertook the construction of a telescope by using a long pipe with two glasses at the extremities, one convex, the objective, the other concave, the ocular, and established that the observed objects were three times enlarged.

He built other telescopes: three of them are in the Museum of Science History at Florence, their characteristics are given in the following table:

diameter of the objective (cm)	effective diameter (cm)	focal distance (cm)	amplification power
5.1	2.6	132.7	14
3.7	1.6	92	20
3.8	objective partly destroyed	169	?

To obtain a better image definition, Galileo was stopping down the objectives. The resolution power of this lens was of 10 to 15″ with a field of view of approximative one half of the solar diameter.

With these tools Galileo discovered the Jovian satellites on January 7, 1610, the planets phase, the lunar mountains, the nebulas, the sunspots and the milky way stars. The telescope so described, was the sole operational during a long time. It had the inconvenience to have a narrow field of view.

Later Kepler showed in his "Dioptrique" published in 1611, that one can substitute the divergent ocular of the telescope by a convergent one; and, therefore he is the inventor of the astronomical telescope which was the first used by Father Scheiner, Jesuit at Ingolstadt.

If Galileo seems to be the first to observe the sunspot with a lens, it is Fabricius, young Dutch student in medicine, who was the first to publish a work named " Joh. Fabricii Physii de maculis in sole observatis et apparute earum cum sole conversione narratio, Wittenbergae, 1611 petit in 4° ". In this work of forty three pages, with dedicatory epistle, dated June 13, 1611, only eight pages concern sunspots.

Lalande (1778), translated all the Fabricius work on this subject as follows: *"Having invented the telescopes in Holland, one started to observe the Moon, then Jupiter and Saturnus and Galileo found there curious things: I myself have observed the Sun driven by the same curiosity, its borders seemed to me to have remarkable inequalities which have already been observed by my father David Fabricius as I learned from his letters he sent me during my study. I have observed (6 March, 1611) a black spot on the Sun with one side less dense and more pale, rather big as compared to the solar disk; at first I thought it is a cloud; but having observed it ten times with different glasses and calling my father to observe it, too we got sure that it is no cloud; as the Sun ascended more and more that we could not observe it any more, during more than two days the appearance of these objects changed: that is why I propose those who want to make similar observations, at first they should receive only a small part of the light to get accustomed the eye so that it could tolerate the light of the whole solar disk. We spent the rest of the day and the next night very impatiently and dreamt about what this spot could be: if it is on the Sun, I would see it again, if it is not on the Sun, its movement would make it for us invisible. Finally I have seen it again the next morning with great delight, but we have seen, too, that it changed its position a little bit what increased our incertitude: meanwhile we let the Sun's rays to come through a small hole into a black room on a white sheet of paper and we have seen this spot in the form of an elongated cloud; during the next three days, bad weather prevented us from observations. After this time, we have seen again the spot which proceeded obliquely toward West; we have seen another much smaller one at the border of the Sun which reached in a few days the centre; a third followed them, then the first one disappeared and the other followed it some days later. I wobbled between hope and fear not to see them again. Some ten days later, however, the first appeared to the East: I realized that it made a revolution and since the beginning of the year, I have been confirmed in this idea and I have showed them to other people who accepted them. Meanwhile I had a problem which prevented me from writing on them and which made me nearly repent the time which I spent with their observation: namely I found that the spots did not conserve the distance between them, their form and speed have changed, too, but my pleasure was the greater when I found the reason. Namely it is likely based on these observations that these spots are on the body of the Sun which is spheric and solid, therefore their movement is to be slower and smaller toward the borders: we invite enthusiasts of physical facts to profit from this sketch we presented them: they would surely suppose that the Sun rotates as said by Jordanus Bruno and recently by Kepler in his book on the movement of Mars as without it I don't know what we could do with these spots. I don't think that they are clouds; similarly I don't agree with those who put the comets into the Sun as emissaries which should return there soon: I prefer to keep silence than* *to guess; but I am tempted to consider this solar movement as the cause for other celestial movements following Aristotle who told in one of his poems "that the Sun is the father and author of movements"."*

The knowledge of the enthusiastic Fabricius on the sunspot must be certainly noted as a first step in this field. Galileo and Father Scheiner were able on many observations to give more precision to the nature and motions of these spots. Morever, both claimed the newness of the discovery.

Galileo in his "Discours sur la comète de 1618" in "Saggiatore o Trutinator" and in "Dialogues du systeme du monde" has always claimed that he was the first to see the sunspot in July-August 1616 and that Father Scheiner had began to observe them after he had seen Galileo's papers. This fact was refuted by Father Scheiner in his book "Rosa Ursina, 1630".

Whatever it might be, Galileo in his book "Istoria dimostragion interno alle macchine solari (Rome, 1613)", in which he presented for the first time the sunspots, showed that they are located on the solar surface, that sometimes there are a lot of spots and sometimes few or no spot, that the sun in its turning motion brings back them to our view, some of them last one or two days, others more than one solar rotation; they can merge or divide, they run on parallel circles; they never move more than thirty degrees from the equator.

Galileo also discussed the solar pole rotation, but he had not noticed the seven degree tilting of the solar equator to the ecliptic plan.

"*Since that time a set of detailed observations was just missing to the theory of the sunspots to confirm the rotation of the sun and to precise the location of its equator*" (Lalande 1778). This was done by Father Scheiner who published in "Rosa Ursina" the results of 2000 observations made during eighteen years.

"*If Galileo is the first one to understand the nature and motion of sunspots, Father Scheiner is the one who had most observed them and best studied their motions*" (Lalande 1778). For this purpose he added to his telescope a projection mechanism and an equatorial mounting following the invention of his colleagues (Father Gruenberger).

The English mathematician and astronomer Thomas Harriot (1560–1621), also observed sunspots from December 8, 1610 to January 18, 1613. In his manuscripts found at the end of the 18th century in the Castle of the Sussex earldom, there were hundred drawings of the solar surface whose copies were sent to Wolf by Carrington in 1857. Harriot is the sole astronomer of this epoch who determined with accuracy the duration of the synodic solar rotation, the mean value of his measurements is 27.154 days for two years of observations (Shirley 1974).

Finally, still for the beginning of the 17th century, we must notice the solar observations of Trade, Canon of Sarlat made during five consecutive years from 1615 to 1620, for all periods, for which the sky conditions allowed it. For this religious clergyman, sunspots can only be small planets with trajectories near the sun, and he explained this as follow: *We begin to tell here something ...mainly as we have seen several Italians or Germans who having seen these phenomena have told and maintained (be any the respective merits of philosophy and astrology) that these are spots on the body of the Sun imposing so on the father of the light as if the* *eye of the world would be sick of ophtalmy. However, it must not be supposed that the Sun be such dishonest and injured, we started its protection by trying to show here that they are neither spots nor cavities, any signs of other defects, nor clouds flittering before the Sun: but they are planets which have orbits around the Sun and which we called the astres of Borbon, after the very Christian king of France, Louis de Borbon ... I have been confused and kept secret for three years without permitting it to see the light considering it to be a difficult and dangerous topic which could produce in the public something new ...*"

Some of these observations have been published in 1622, and particularly those obtained on August 25, 1615 for which he observed thirty sunspots on the solar disk.

The sole other sunspots observations made towards the middle of the 17th century were those made by the Polish astronomer Hevelius in Danzig from 1642 to 1644. The apparatus used by him is presented on Fig. 2. These observations were published in his book Selenographia, in 1647.

Results

From these first sun observations made with the telescope at the beginning of the 17th century, it is possible to estimate the sunspot activity level which was existing during this epoch.

Galileo in his book, published in 1613 presented several drawings of the solar disk with the number of observed sunspots during June and July 1612 (Fig. 1).

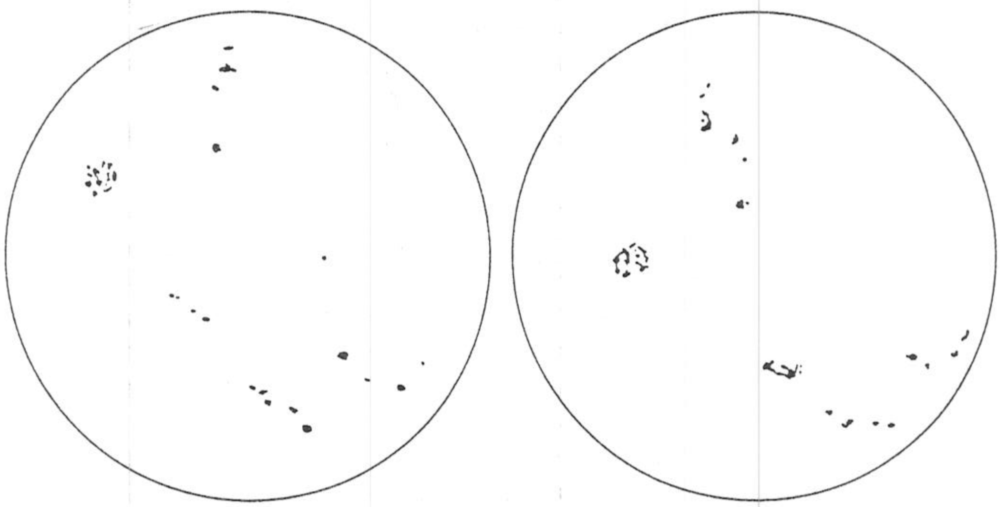

Fig. 1. Sunspot observed on July 5 (left) and July 6 1612 (right) by Galileo (Galileo 1613)

Sakurai (1980) has analysed these drawings and computed for each day of this period the relative Wolf number (R). He found daily values for R between 60 and 153. For thirty eight observational days, the R mean value is 99, this number corresponds to a relative high activity. This value is a minimum, if we take into account that some of the little spots must have escaped to Galileo. The analysis of the spot distribution (between +/ − 30° and +/ − 5°) as well as their structure indicate that Galileo made his observations during the solar cycle maximum.

In 1776, Lalande, in order to study precisely the duration of the solar rotation, analyzed again Father Scheiner's observations made between 1624 and 1627 and Hevelius's ones made from 1642 to 1644. So he could graphically estimate, by using the precise drawings made by these two astronomers (Fig. 2), the location of 176 sunspots and determine the date of their passage at the central meridian of the sun.

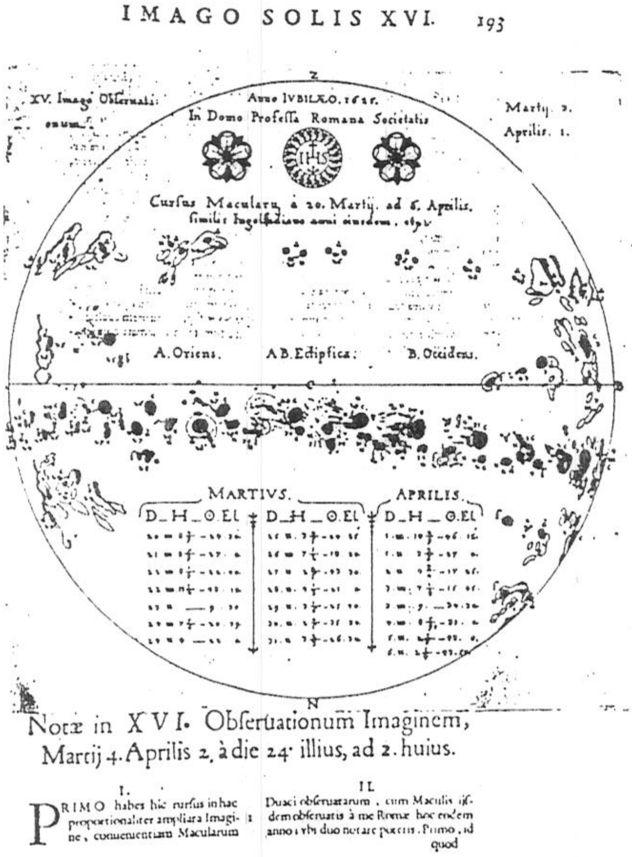

Fig. 2. Drawing of sunspot crossing from March 20 to April 6, by Father Scheiner (Rosa Ursina 1630)

Father Scheiner as Hevelius, have made mainly accurate drawings of the passage of the spot on the solar disk and rarely drawings of the solar disk aspect on a specific day. It is therefore difficult to estimate the Wolf number for these two periods.

For comparison with the sunspot activity which occurred at the end of the 17th century, we have computed the yearly mean value observed crossing spots. Between December 18, 1624 and November 28, 1627, Father Scheiner had observed 123 spot passages, *i.e.* 41 crossings for a year. The latitudinal distribution of these spots was between $+/-24°$ and $0°$. In Hevelius's book (1647), we found 49 spot passages between November 2, 1642 and October 9, 1649, *i.e.* 25 crossings for a year with a latitudinal distribution between $+/-18°$ and $0°$.

We actually know that the two distributions in latitude correspond to those found during the decreasing phase of the sunspot cycle.

By another way, we have looked if there were existing preferential solar longitudes for the spot appearance by computing for each of these 176 spot crossings the Carrington coordinates. Figure 11 shows the curve of the computed frequencies for the 10° classes of longitude. This curve have been smoothed by sliding average over three consecutive points.

One can remark two preferential areas, at the beginning (close to 45°) and at the end (close to 250°) of the Carrington rotation. This result has been also found by Trellis (1971) for the solar cycles 12 to 19. The too small number of data (3) for the analysed period prohibits to continue this kind of comparison but one can suppose that these preferential areas are permanent features.

The data analysis of this period 1610–1645 does not allow to present a homogeneous sunspot activity for all the observations made by the solar astronomy pioneers. On the other hand, one can conclude that the sunspot appearance was not a rare phenomenon and that activity would develop in the same fashion as for known solar cycles observed since 1850.

The period of "uncertainty" 1646–1670

For this period, it is difficult to found sunspot observations as the sun was not yet systematically observed by big observatories. It is necessary, as some authors recommended it (Eddy 1976), to conclude that the sunspot activity was very weak?

It is impossible to answer such a question without any previous knowledge on the frequency of sun observations, as we only dispose of two evidences:

- one from the French astronomer Picard who having seen a sunspot during August 1671 said: *"Since ten years I had not seen any of them in spite of efforts to look for them from time to time"*

- the other from Oldenburg, the Royal Society secretary, author of paper in Philosophical transaction, dated August 14, 1671. Oldenburg concerning the same sunspot, also seen by Cassini, noticed that no sunspot had been observed since the one seen with an excellent telescope by the English philosopher Boy, on April 27, 1660 at eight o'clock in the morning, in the presence of Hook.

If these two evidences plead in the favor of a weak solar activity, it is impossible to estimate sunspot activity. The few number of visible sunspots observed in China during this period (Zhen-Tao 1982), including some ambiguous events, do not change our conclusion.

The period of weak activity

Historic

It is the sole period of the 17th century where it is really possible to know the frequency of aurora appearance. Indeed, the construction of the Royal observatories, particularly those of Paris and Greenwich, shortly after the creation of academic assemblies (Sciences and Royal Society academies), contribute to the advance of astronomy and consequently to the development of systematic observations.

In 1669, in his program report before the Academy, Picard indicated: *"It would be necessary to continue with special attention the observations of the diameters of the Sun and of the Moon to discover some irregularities which occur mainly in the observations of the Sun, as during the last solstice e.g. the Sun appeared to be slightly greater than it used to be. And now it is smaller by 4 or 5 seconds as it didn't used to be for one year. There is no other way to detect the yearly path than to observe the diameter during a whole year and to deduce from it the distance of the Sun as being proportional with it, the path is very near to a circle but it can be distributed by small irregularities which can be found only by long series of observations. Such observations are to be made daily ..."*

In the same way, Cassini, in his recommendations to those who are working at the observatory, *i.e.* his students, noticed that: *"The Sun is to be observed each day at sunrise and sunset, to measure its apparent diameter, then to follow these observations after sunrise and before sunset till the corresponding heights."*

Piccard's observations, those of La Hire (who succeeded Picard, who died in 1682) and those of Cassini and his students are recorded in a series of registers kept in the Paris Observatory library. A copy of Cassini's observations, written during the 17th century, is also at the Institut de France library.

In Picard's and La Hire's registers, the meridian of the superior and inferior sun side, as well as the time of the passage of the oriental and occidental sides in the meridian plane are mentioned.

These observations made each time meteorologic conditions were appropriate, allowed to control the diurnal clock running, and to determine with precision the ecliptic parameters.

Several measurements were made on the sunspots which appeared on the solar disk. Since the beginning of Picard's program, the sun was the object of assiduous observation and the unusualness of sunspots was so noticed that each appearance was the object of a report at the Sciences Academy, or a note in the Journal des Savants.

After 1704, the increase of the sunspot activity was so important that the academy had published after that time only one annual report until 1716.

Besides, it is important to precise that sunspots observed from 1672 to 1704 appeared exclusively in the southern solar hemisphere and near the equator (rarely at a latitude greater than 10° south (Maraldi 1695)).

Later on September 27, 1707, when Cassini and Maraldi have observed a spot at the northern latitude of 10°, they noticed that they never remembered to have seen one spot in this hemisphere before this date, excepted for the event of April 1705 (Spoerer 1889, Maunder 1922).

In a same way, the existence of two distinct packs of sunspots on the solar disk was very scarce at this epoch, since, talking of the spot observed in October 1705, it rends in the history of Academy for this year: *"Since the observations by Father Scheiner some 80 years ago, one hadn't seen simultaneously two different groups of spots. We remarked in the History of 1700 how seldom this phenomenon had appeared, meanwhile it is the second time it has appeared within two years."*

It is necessary to say that the few number of observed spots during thirty years, and after 1702, the large number of spots, lead the astronomer of the beginning of the 18th century completely confused. We found the proof of that, in the history of Academy of 1713, where it is noticed: *"The time of the appearance of spots on the Sun is by no means regular. Ever since 1695 till 1700 one had not seen any of them. Afterwards, our Histories are full of them till 1710, when only one was observed and it seemed that they approximated their end. In 1711 and 1712, no spots were seen, and in 1713, only one in May ..."*

Results

The diagramms on Fig. 12 show the frequency of the daily sunspot observation on the solar disk (b). One can see that excepted for the time interval from 1677 to 1682, during which astronomers were on special mission for the king, few periods of thirteen days (duration of a spot crossing on the solar disk), are without any observations.

On the spot diagram (b), the Paris astronomers' data complete the European observations made by Kirch and his family (Landsberg 1980), Ettmüller, Liebknecht and Durham (Schröder 1990).

The analysis of this figure shows that few spots were appearing between 1671 and 1701, and that between 1690 and 1699, a single spot was seen on the sun in May 1695, the total number of days of spot observation by decade and the estimation of birth of crossing of spots on the solar disk can be summarized as follows:

years	days of observations	spot crossings/year
1671–1680	110	1.8
1681–1690	98	2.1
1691–1700	10	0.3
1701–1710	483	8.1

Compared to the values obtained by Father Scheiner (49 spot crossings/year) and Hevelius (25 spot crossings/year), the solar activity has been very weak at the end of the 17th century, particularly between 1691 and 1700.

Remarks on the Wolf number concerning the 17th century

In the empirical formula $R = K(10g + f)$ established by Wolf to determine the relative number of sunspots, the value of the K coefficient is a function of the apparatus used by the observer. Wolf has given a value of 1 for this coefficient for the telescope used by him which had an objective of 75 mm — diameter and a magnification of 64. For a more powerful tool, K is less than unit, it is greater in the opposite case. Wolf took also into account in the determination of K the regularity of the observer (Young 1883).

In these conditions, it appears to be difficult to use this formula as Wolf did it himself to compute the relative spot numbers before 1671 for the following reasons:

- the characteristics of the apparatus used at this epoch are not very well known and sometimes unknown
- one cannot know the annual days of sun observation before 1671, *i.e.* the assiduity of the observers which depends mainly on meteorological and also on personal factors.

The following table presents some relative annual numbers of sunspots computed by Wolf (Waldmeier 1961), compared to the spot crossings counted by Lalande (1776):

Year	R	Spot crossing	sun-observation days known
1625	41	88	?
1626	40	27	?
1627	22	7	?
1643	16	21	?
1644	15	26	?
1684	11	4	259
1642	6	2	?
1695	6	1	200

The examination of this table reveals the incoherency of these results in lack of any other complementary data which could well inform us on the value of the K coefficient given by Wolf.

For example there is a ratio of 7 between the R numbers for the year 1625 and the year 1695, while this ratio reaches 88 between the number of spot crossings.

It must be noticed that Sakurai's computations previously quoted for the determination of the sunspot activity of June and July 1612, seem to be more reliable as they are obtained from a data set of thirty eight days covering a period of two months. In this case, it is mainly the instrumental effect which can introduce uncertainty in the results.

Technical means and meteorological observation conditions at the end of the 17th century

The apparatus

The telescopes used at the beginning of the 17th century had a lack of performance due to the technical insufficiency of glassmakers and opticians, to which were added the natural aberration of the thin lens. Towards 1650 under the influence of Huygens, the astronomical optic performed evolution to a better quality.

Indeed, experiments had shown that one could improve the image from a telescope by increasing the focal distance of the objective: with constant diameter and enlargement, the sphericity aberration was reduced and simultaneously the angular diameter of the chromatic diffusion spot was diminished *"In a time when the efficiency of the objectives was so increased, the limits of the length of the telescope and of the discovery of the sky were not seen, and it was supposed that it would be possible to see animals on the moon"* (Auzout, cited by King 1979).

And that's why longer and longer telescopes were built, the focal distance of their objectives ($d = 24$ cm) could reach 68 m (Danjon and Couder 1935). These tools became very clumsy and difficult to handle. — With such an equipment Huygens discovered in 1655 a Saturnian satellite (Titan) and recognized the real structure of the ring of this planet, which had so intrigued Galileo. In 1664, Cassini observed, for the first time the shadow of the Joian satellites on the planet surface, in 1675 he perceived the distorsion of the Saturnian rings and between 1671 and 1684, he discovered four new satellites of the planet (Pingré 1901).

These different discoveries prove the quality of the tools used during the second part of the 17th century. To observe the sun, Picard and La Hire used a "quarter circle" and a wall quadrant including a telescope with a reticle whose focal distance was about five feet (1.60 m) (Bigourdan 1928). As Father Scheiner did, they probably used a thin plate colored glass to preserve eyes. In a same way, Cassini used a large quadrant having a telescope of 6 feet (1.95 m) focal distance, but he was sometime doing observations with more powerful tools in order to analyse the sunspot details or to see better small spots. Thus his observation note book includes some indications like:

— July 28, 1684: *"At 6 h according to the image received on the drum of the great telescope of 40 feet, may be due to the smallness and weakness of the image of the spot it could be influenced by the wind which moved the telescope, the spot was elongated six parts from the rim and passed at a distance of 31/2 (parts) from the centre."*

— July 29, 1684: *"the spot of the sun cannot be seen even by the telescope of 20 feet"*

— September 30, 1688: *"I observed two spots in the sun which did not appear neither in the morning, nor at noon."*

These particular observations refute Kopecky and Kuklin's remarks (1987). Kopecky and Kuklin state that long-lived visible sunspots were the sole observed, while the others were purely neglected.

This bright period of large tools, during which numerous discoveries have been made in astronomy-physics was followed by a long decline, because after Cassini's death, in 1722, the large telescope were forsaken on behalf of the quadrant.

"Fifty years later (1760), wrote Fabry, *the technique of these instruments was completely lost and the astronomers were unable to see several astres which had*

been discovered by Cassini; even the memory of these discoveries was nearly lost. The invention of the achromatic telescopes by Dollond (1758) in England did not modify this situation as the first instruments of this type being very perfect were too small to show what could be seen through the instruments of the 17th century: but these telescopes contained the germ of a progress which only brought his fruits much later. It is true that with the reflexion telescope which had been known for a long time but which were not used seriously, Herschel (1789) renewed the interrupted tradition of the great observers of the first years of the observatory (in Paris)." (Danjon and Couder 1935).

The solar observations did not escape this decline, as Lalande noticed at the beginning of his long memorandum on the subject in 1776: *"Since more then 60 years next to nothing has been made about the spots of the Sun about its rotation and about the situation of its equator and of its poles."*

It is obvious that the astronomical tools at the end of the 17th century were enough accurate so that the reliability of the sun observation could not be challanged and that the astronomers were observing with attention the evolution of the spot activity of the "star of the day".

The meteorological conditions

The 17th century, which had particularly variable meteorological conditions, corresponds partly to the period named "little ice-age" whose duration is mainly defined by the expansion of Alpine ice (see Appendix 1).

The cloudy covering during this epoch is sufficiently well known only by the forty years of meteorological records of Louis Morin (see Note 4 in Appendix 2). These records made at Paris, three times a day between 1675 and 1713, concerning temperature, pressure, direction of clouds and nebulosity (Legrand and Le Goff 1987) allow us to show the weak influence of climate on the sunspot observations, contrarily to the suppositions made by Kopecky and Kuklin (1987).

In his meteorological note book, Morin characterized the nebulosity by an index which was changing from 0, for a clear day, to 4 for a complete cloudy covered day.

For each day of solar observation at the Paris observatory, we know the indices for the cloudy covering. We have computed, for each class of the index, the mean percentage of the number of observation days as a function of the total number of days of the class from 1682 to 1709.

index 4: complete cloudy covering	8 % of observations for 44 days/year
index 3	34 % of observations for 55 days/year
indices 1 and 2	71 % of observations for 219 days/year
index 0: clear day	97 % of observations for 47 days/year

The general mean value for the whole set of 28 years is 61 %, it is comparable to the mean value obtained at Meudon for the years between 1930 and 1940 (Martres 1987).

Louis Morin's records show a clear increase of the cloudy covered days (with index 4) during the decade 1690–1699: 54 days/year with a maximum of 83 in

1692. The number of clear days remains constant. The increase of the number of cloudy covered days, induced by the frequent passage of frontal systems and the persistency of an anticyclone over the North sea (Legrand et al. 1990) had no repercussion on the number of sun observation.

One can conclude that during the last half part of the 17th century and until the end of the Sun King's reign, the sun was carefully observed, each time the weather allowed it. One can affirm that the cloudy cover of the coldest period of this epoch (1690–1700) is by no means the cause of the lack of observation of sunspots.

The auroral activity during the 17th century

The solar sources of the magnetospheric activity and the conditions of aurorae appearances

The solar sources

The analysis of the hundred and twenty years of geomagnetic data made by Legrand and Simon (1989, 1990) and Simon and Legrand (1989, 1990) shows that two solar sources of magnetospheric activity (*i.e.* auroral and ionospheric) are existing:

a) transient events associated to the sunspot cycle which generate shock waves

b) solar wind jet streams with a speed greater than 450 km/s.

The distribution of solar wind speed is determined by the intensity and the direction of the solar dipole whose cycle is related to the sunspot cycle, but with an opposite phase. Faster winds escape from the dipole poles and slower winds from the "neutral sheet" located at the equator of the dipole. Due to this fact the Earth is sweeped by speedy winds when the dipole reaches its maximum intensity and is a little tilted on the solar rotation axis, or when the dipole is turning during the maximum phase of sunspot cycle; this evolution is indicated on Fig. 3.

Nevertheless, for a weak amplitude of the solar cycle ($R_{\max}40$), at the maximum intensity of the dipole, the fast winds of polar origin never reach the earth and the "neutral sheet" is thick. During this phase, the geomagnetic and auroral activities are weak as the earth is swept by slow winds. The situation is not the same at the time of the dipole turning, *i.e.* during the multipolar phase, when relatively faster winds from a region contiguous to the neutral sheet can reach the Earth.

The conditions of aurora appearance at middle and low latitudes

To observe aurorae at middle and low latitudes, without any confusion, it is necessary that the boreal auroral oval extends towards the south of its mean position located around 66° geomagnetic latitude.

In general an aurora occurs in the altitude range from 100 to 400 km and the maximum intensity of the red line (6303 A°) is located around 300 km. Under the diagram of Fig. 13, the aurorae can be visible at 10° below the horizon at a distance

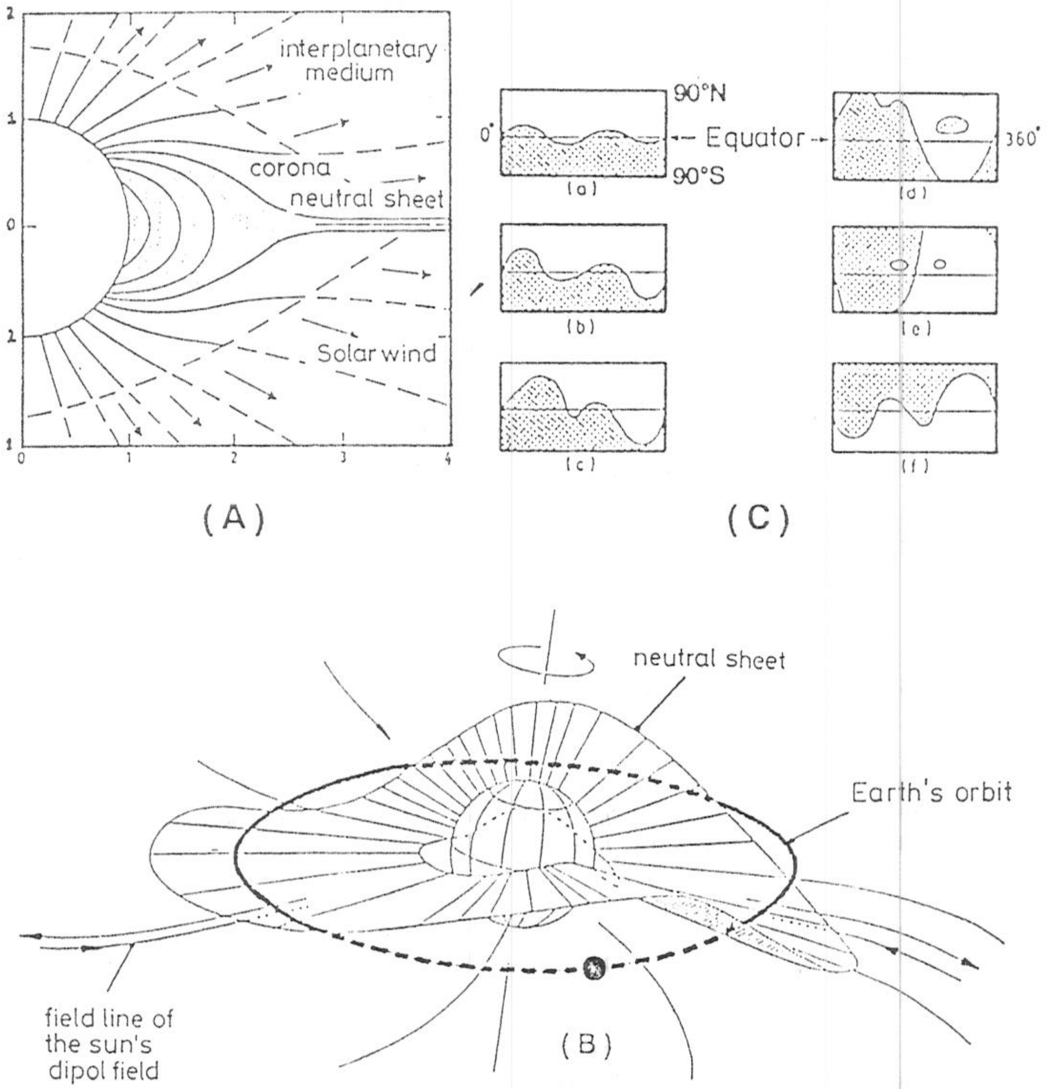

Fig. 3. "Structure and evolution of the solar dipole, the neutral sheet". (A) Theoretical model of the solar dipole field distorted by the solar wind flux: the discontinuous line schematizes the passage of the plasma from the solar crown to the interplanetary environment. The plasma trapped by the coronal field in the equatorial zone (grey surfaces) can only escape through the "neutral sheet" which is formed between the two magnetic sheets of opposed polarities. (B) Representation of the solar dipole "neutral sheet" at the level of the terrestrial orbit (T): in this diagram, the earth, during a solar rotation (2+3 days) crosses four times the "neutral sheet" source of the slow speed plasma. Between each of these crossings it is swept by solar wind of higher speed coming from the regions contiguous to the "neutral sheet". (C) Cycle of the solar dipole field established according to the photospheric data from 1963 to 1984; each rectangle corresponds to a different period of the eleven years solar cycle. The solar latitudes are in ordinate and the Carrington longitude in abscissae. The white and grey areas respectively correspond to North and South polarities. They are separated by a line showing "the neutral sheet" shape (a) and (b) show a phase during which the coronal field configuration is dominated by the solar dipole (c), (d) and (e) show the reversal stages of the "neutral sheet" occurring during the change of dipole polarity. The "neutral sheet" form is the signature of this multipolar phase. The "neutral sheet" goes up to high latitudes, and as a consequence fast wind sources are brought in the equatorial plane (f) what corresponds at the turn to a dipolar configuration but with opposite polarities

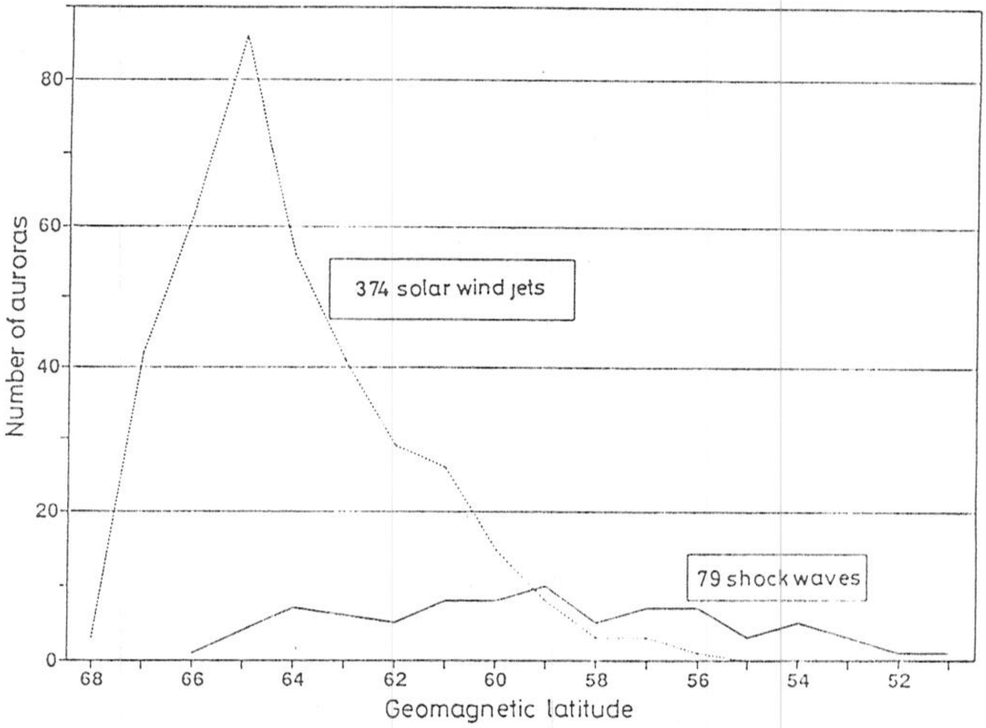

Fig. 4. Distribution of aurorae produced by solar wind jets and by shock waves from 1956 to 1965. These aurorae are observed at the zenith of British stations distributed from Calais to Faroe Island

of 1100 km, *i.e.* at a latitude 10° less than that where the phenomenon takes place. So, aurorae observed at the limit of the visibility at the geographic latitude of 50°, develop at a latitude of 60° (Legrand 1990).

Legrand and Simon (1988, 1989) studied the latitudinal distribution of 453 aurorae observed between 1956 and 1965 at the zenith of several British stations stretching from Calais to Faroe Island. Figure 4 shows the frequency of aurorae appearances as a function of geomagnetic latitude (F) according to their mechanism of generation: shock waves or solar wind jets.

This distribution has been derived from aurorae appeared during a particularly strong sunspot solar cycle (1956–1965). As Stringer and Belon (1967) showed that the location of the maximum of auroral activity does not change in the case of a much weaker sunspot activity, one can suppose that aurorae observed in the 17th century presented similar distribution.

It is necessary to know that the position of the geomagnetic pole can change during centuries, and that precisely in the 17th century, the location of the northern magnetic pole was 4° closer to Europe than is now (Champion 1980). One can also verify in Fig. 5 that aurorae produced by solar wind jets were more visible in occidental and central Europe. The geomagnetic latitudes were at this location 4° higher than now.

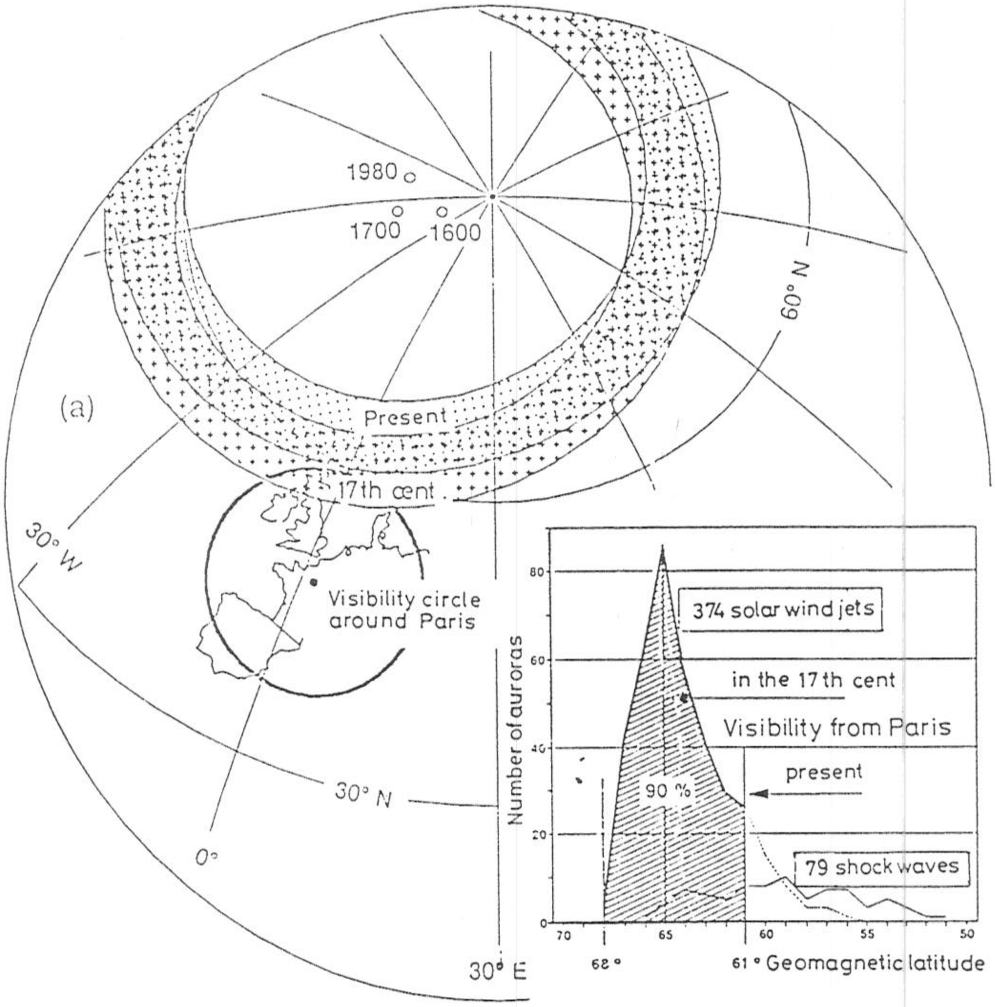

Fig. 5. Position of the auroral zone related to the solar wind jets, with regard to a station located at 50° latitude North during the 13th and 20th centuries

Aurorae observations during the 17th century

Since a very long time, large aurorae developing at middle and low latitudes were known. They have been described, especially in Europe and China where the civilization has early developed, by philosophers and erudits in chronicles which were published after invention of printing in the 15th century. The description always included fantastic expressions mixed to superstitious concepts as this phenomenon was considered by people of this epoch as an ominous sign which announced war, scarcity or other flail.

The first scientific description of an aurora was published by Conrad Gessner (1516–1563) after the aurora appearance on January 6, 1651. It contains details of the colour fluctuations, of brightness and of its structures: arcs, rays, diffuse spots, crowns.

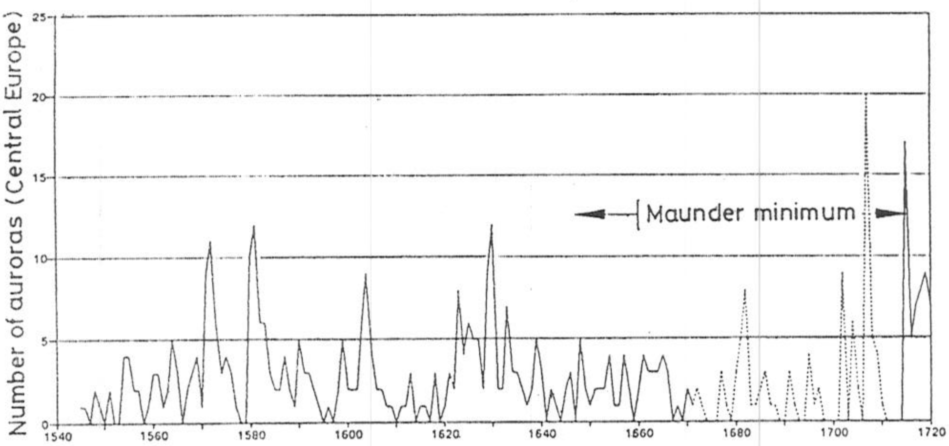

Fig. 6. Curves of annual frequency of aurora observations in Central Europe: the dotted part of the curve represents the period of the "Maunder minimum" during which the sunspot activity is known with greatest precision

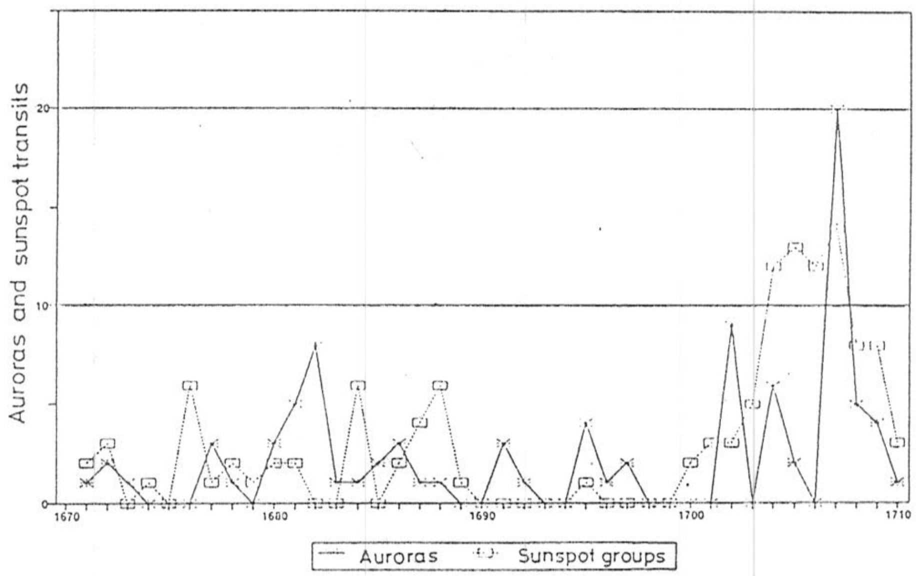

Fig. 7. Recapitulative curve of the auroral activity (total annual number) and of sunspot activity (total annual number of observations on 13 consecutive days) during forty years for which these two phenomena are precisely dated

During the 16th and 17th centuries, a substantial number of observations of this phenomenon has been reported in chronicles of this epoch. But wars, as the "Thirty years" war (1618–1648) or revolts brought their share of ruins in Central Europe and led to the distruction of precious documents. Successfully some works outlived, for example the journals of the astronomers David (1564–1616) and Johan (1587–1615) Fabricius and also of the Kirch family (between 1677 and 1774) contain a considerable number of auroral data among descriptions of the solar surface. More generally the ancient chronicles and the observation note books of erudits have been searched by several authors as: De Mairan, Frobesius, Schöning at the 18th century, Fritz at the 19th century, and Link, Keimatsu, Schröder among the more recent ones, to establish catalogs for which some data date back several centuries B.C. Some of these catalogs include not only the dates of aurorae appearances but also those of comets, meteors and atmospheric phenomena. The exploitation of these data request a considerable work as each description of these events must be examined carefully to identify the uncertainties.

Concerning Europe, the observations were generally made from countries located between 48° and 54° geographic latitudes: Germany, Austria, Spain, Hungary, Switzerland. Few auroral data are from England and Russia. The observation were generally irregular, but remarkable auroral events were always recorded except when the sky was completly cloudy.

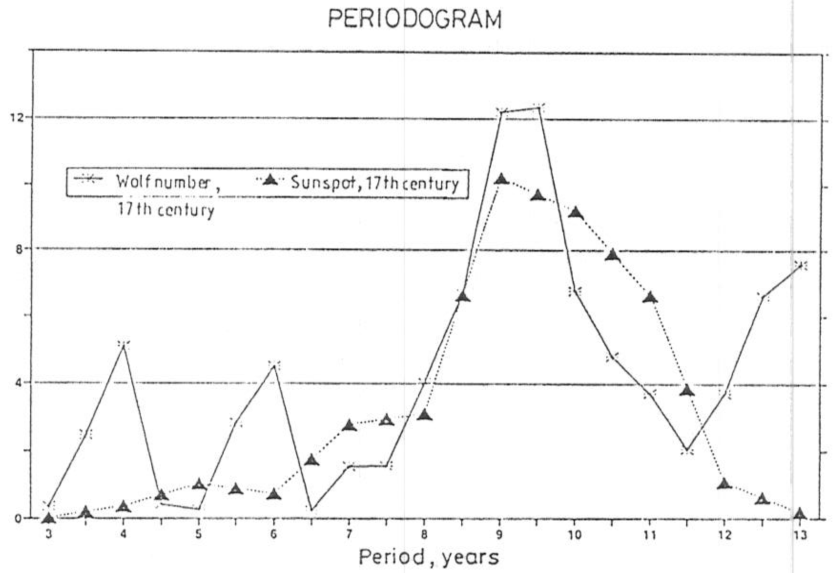

Fig. 8. Periodogram made with the series of spot crossings from the end of the 17th century (1671–1710, continuous line) and with the series of Wolf numbers during the 18th century (1744–1783, dashed line). The maximum occurs during a period of 9–10 years for these two series of same duration

Between 1550 and 1710, approximatively 430 aurorae visible from Europe have been recorded, 150 between 1645 and 1710, the period corresponding to the Maunder minimum.

To appreciate the homogeneity of the data collected during the 16th and 17th centuries, we have examined the seasonal variation of the reported aurorae which must follow the geomagnetic activity whose maxima appear at equinox and minima at solstices.

On Fig. 14 we have drawn this variation for the two distinct periods studied by Schröder:

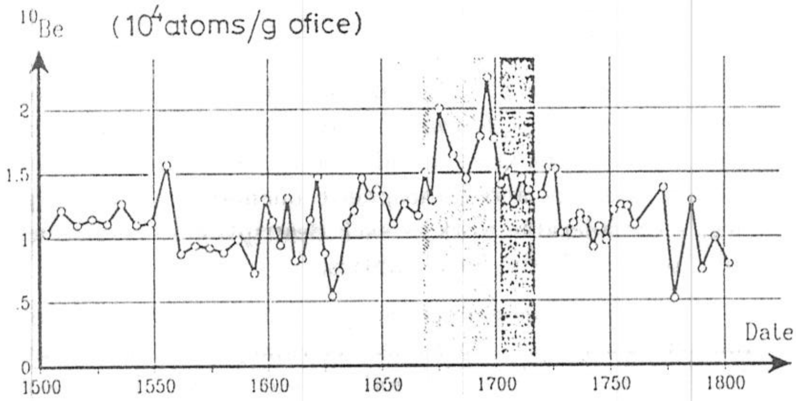

Fig. 9. Be10 concentration between 1500 and 1800 (Beer et al. 1983)

a) before the Maunder minimum, from 1545 and 1644 and

b) more recently from 1822 to 1956.

June and December minima clearly appear for the data set (b) while only the summer solstice minimum can be identified for the data set (a).

This summer minimum for the concerned latitudes, 48°N to 54°N, is mainly produced by the crepuscular effect due to the small height of the sun below the horizon. This summer minimum does not inform about the degree of homogeneity of ancient data. On the contrary, the absence of a winter solstice minimum and of pronounced equinox maxima, lead to the supposition that the available data are only an incomplete sample of the auroral activity.

The frequency of aurorae appearances between 1545 and 1728 presented on Fig. 6 (Schröder 1990) shows in spite of inhomogeneity of the data a deficit of aurorae between 1640 and 1702 characterized by the total absence of important maxima.

Periodicity of spots and aurorae appearances

The data set concerning the best documented sunspot activity period from 1671 to 1710, contains 91 days of aurorae observations and 561 days of sunspot observations; the low number of events representing a period somewhat shorter than four mean solar cycles yields uncertain the research of periodicity. Nevertheless we have computed the periodograms of the two series classified following half-yearly values. We have tested the stability of the periodograms by computations on the raw data, then corrected for the trend by second order regression, and then smoothed (or not) by a sliding mean over three ponts.

The two series are presented on Fig. 7 (annual values):

a) aurorae: attempts were unfruitful due to the instability of the results depending on the statistical data processing. Moreover, each updating of the data set added instability. This fact leads to confirm the inhomogeneity of the aurorae set previously noticed in the section on magnetospheric-solar activity.

b) the spots: For this data set, we have estimated the number of thirteen days periods (half solar rotation) for which a group of spots have been observed. By this mean we give the same importance to a spot observed during all the time of its passage on the solar disk as to an other spot which could not have benefit of the same time fo observation. The total number of groups is 123 with a half yearly maximum of 8. In this case the periodogram (see Fig. 8) is more stable and shows a maximum around 9 years. As a comparison we have plotted on the same figure the periodogram made with the Wolf numbers for a similarly 40 years period (1644–1683). With fifty more time data, the regularity is remarkable and we found in this case a series of four short cycles of 9 to 10 years.

One can conclude, prudently, that at the end of the 17th century, the weak sunspot activity appeared as several short cycles (9–10 years) for which it is impossible to precise the dates of maxima and that the auroral activity, as it is actually known, does not present any correlation with the sunspot activity.

The relation between the spot passages and the aurora appearances

Legrand et al. (1990) have studied the coincidence between the spot passages on the solar disk and the aurora appearances in Europe, in order to analyse the evolution of the solar activity during the 17th century and particularly during the period of weak sunspot activity (1671–1701).

One knows that a shock wave is generated when in an active region of the sun an important atmospheric eruption occurs associated to a jump in the X and radio radiations domains.

This wave reaches the Earth with a delay of fifty hours and produces a magnetospheric storm materialized by an aurora. This phenomenon is the more intense the eruption develops the nearer to the solar central meridian between 30°E and 30°W (Legrand 1990). The comparison of the spot crossing and the appearance of one or several aurorae in Europe between 50° and 55° latitudes, can therefore inform about the sunspot activity existing at this epoch on the solar disk.

Figure 15 shows that among the 44 aurorae observed between 1671 and 1701 originating from the catalogs of Link (1964), Schröder (1979) and Landsberg (1980) no one coincides with a spot passage. On the contrary during the period from 1702 to 1709, among the 47 observed aurorae, 28 coincide with a spot crossing: 12 aurorae present an exact coincidence and 16, an estimated one, if we are supposing that the observed sunspots are active during a half solar rotation (13 days). The following table resumes the whole set of sunspot and aurorae observations during the two periods: 1671–1701 and 1702–1710.

If the aurorae would appear at random, the probability of coincidence between one aurora (A: number of days with aurorae) and one spot (T: number of days with spots), Pr (AT/A), should be equal to the probability to observe one spot (Pr/T/N), N being the total number of days.

Period	1671–1701	1702–1710
Total number of days (N)	11315	3285
Days of sun observations (N1)	4098	1892
Days of spot observations	233	418
Estimated number of days with spots (T) (long-lived spot 13 days)	585	1014
Days of aurora observations (A)	44	47
Number of coincidences sunspot/aurora (AT) (including the propagation time)	0	28
Probability of sunspot activity Pr (T/N) population N, threshold = 95 %	4 to 6 %	28 to 32 %
Probability of coincidence Pr (AT/A) population A, threshold = 95 %	0 to 9 %	45 to 74 %

The computation of intervals with a probability of 95 % for T/N and AT/A (binomial law, Morice and Chartier 1954) shows that:

— between 1671 and 1701, there is no coincidence, therefore the hypotheses of independence between aurora and spot can be supported

— on the contrary, between 1702 and 1709, the probability of coincidence is significantly greater than the hazard and the hypothesis of a strong connection between spot crossing and an aurora appearance cannot be rejected, particularly after 1704.

It is also interesting to notice that the five aurorae of the year 1625, precisely dated (Link 1964), coincide with spot crossings observed by Father Scheiner. Knowing the date of these spot passages at the central meridian (Lalande 1778) and assuming a time for the shock wave transit of 48 hours, one can suppose that these five aurorae probably appear after chromospheric eruptions occurring between 0° and 30°W.

The absence of coincidence between spot crossing and aurora appearance from 1671 to 1701, leads to prove that only fast wind jets must exist during this period. This hypotheses in confimed by the analysis of the Be10 concentration of the polar ice (Beer et al. 1983).

The maximum of concentration appears between 1669 and 1700, this fact means that the intensity of the cosmical galactic radiation was large due to the absence of shock activity. Indeed, the shock activity induces a large very important modulation of the cosmic radiation compared to the modulation due to the high speed solar wind jets (Venkatesan et al. 1982, Legrand ans Simon 1985, 1989, Badrudinn et al. 1986).

The so-called "Maunder" minimum and the running of the solar machine

From the description of the sunspot activity and from the analysis previously presented we can remember the following facts:

a) during the period 1610–1645, the sunspot activity was relatively high and probably developed in cycles as those actually well known since their discovery by Schwabe in 1843. The curve of the Be10 concentration confirms it (Fig. 9) as well as the number of the eye-visible sunspots observed in China (Eddy 1983).

b) it is impossible to state anything for the period of "uncertainties" (1646–1670) due to the total absence of data on the number of days of sun observations. The comments of Picard and the paper published in Philosophical Transactions dated August 14, 1671 plead in favor of a very weak sunspot activity, but it is impossible to estimate it. On the other hand, the Be10 concentration for this period is similar to the Be10 concentration appeared from 1720 to 1730, which is relatively high.

c) all the spots which were observed between 1660 and 1704, were located in the southern hemisphere of the sun at a latitude close to the equator.

d) during the period 1671–1710, we have a data set which allows us to state that the sunspot activity was weak between 1671 and 1689 and almost inexistent betwen 1690 and 1700. Since 1702, active centres began again to appear on the solar disk.

e) between 1671 and 1710, a spectral analysis of the frequency of spot appearances seems to show the presence of a 9 year cycle as those for which the maximum occurred between 1769 and 1778.

f) We must recall that the speed of rotation of the sunspots between 1642 and 1710 presented variations (Ribes et al. 1987) and that the solar diameter seems to have a mean increase of 0.2 % with a periodic variation which also follows a 9 years cycle (Ribes et al. 1989).

All these results indicate that here was an anomaly in the running of the "solar machine" since a date which took place between 1646 and 1670, but it is impossible to precise it. This anomaly remained until 1702.

The auroral activity observed during this century cannot give any reliable information on the level of sunspot activity as the connection betwee these two phenomena, not very reliable, was turned off by aurorae due to solar wind jets. Indeed, at this time the position of the geomagnetic pole led to the visibility of such aurorae at Central-European latitudes.

On the other hand, the absence of correlation between sunspots and aurorae between 1671 and 1702 convinced us that the aurorae observed in Europe were only produced by solar wind jets and give information on the evolution of the solar

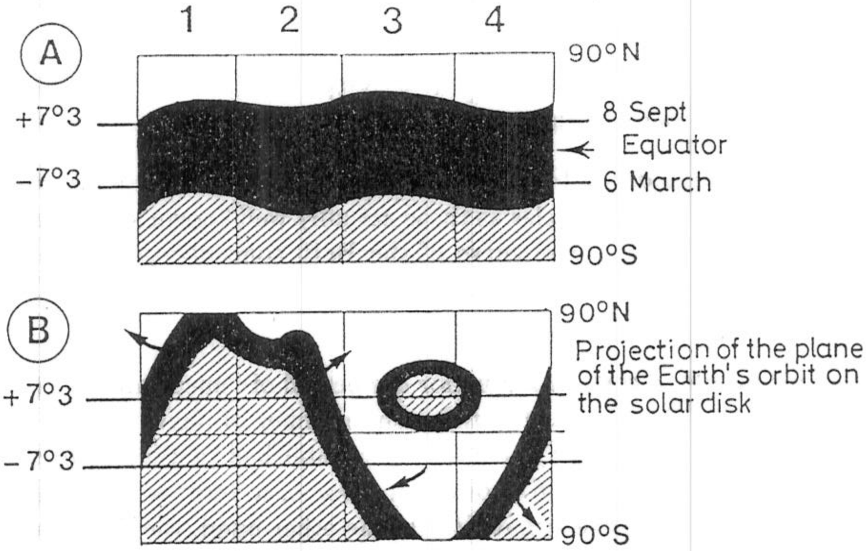

Fig. 10. Examples of the structure of the solar "neutral sheet" during the dipolar phase (A) and the multipolar phase (B). This example shows the extremum positions (March 6 and September 8) of the ecliptic plane with regard to the thick "neutral sheet"

magnetic fields: the toroidal component of the solar magnetic fields which represents the sunspot activity is closely related to the dipolar component which occurred 4 to 5 years earlier (Simon and Legrand 1989, Legrand and Simon 1990). One can conclude that the maximum of intensity of the dipolar field remained weak during the three solar cycles of the end of the 17th century. Therefore, the neutral sheet was thick (Fig. 10) and due to this fact the Earth was mainly sweeped by solar wind jets of low speed and not by fast jets originating from the poles as it is normally the case for this period of the solar cycle. The magnetic activity was probably very quiet and the auroral oval located at very high latitudes (around 74°) during several consecutive years for which no aurora was observed in Europe. This was the case from 1673 to 1676, from 1687 to 1690, and from 1698 to 1701.

It is at the time of the turning of the solar dipole polarity, *i.e.* during the phase of maximum of sunspots, and a little after that the Earth received solar wind jets of high speed coming from regions contiguous to the "neutral sheet"; at this period of the cycle this structure presents large undulations (Fig. 10). Probably these jets produced the aurorae observed at that time in Europe.

It seems perhaps audacious to propose such a scheme for the dipolar field evolution based only on the auroral data of middle latitudes (48° – 54°) which are available for this epoch. However the period of weak activity at the beginning of the 19th century, though it was a little more important than that occurring during the Sun King's epoch, allows us to maintain this hypothesis (see Appendix 2). As a matter of fact, between 1671 and 1700, three sunspot cycles with a periodicity probably near 9 years appeared successively. The structure of the spots which were only in the southern hemisphere, could only produce a very weak chromospheric activity.

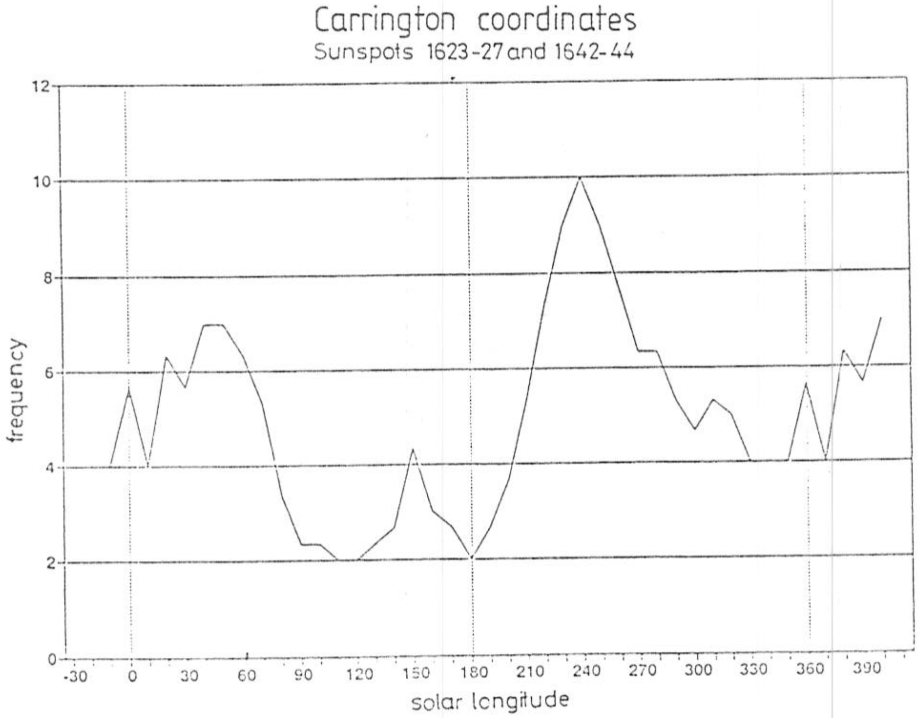

Fig. 11. Frequency of the spots as function of solar longitude in Carrington coordinates by Father Scheiner and Hevelius

After 1702, the spot activity, though weak, gave bright regions capable to emit shock waves and the "solar machine" took again progressively its normal rythm at the amazement of the astronomers of this epoch. The year 1701 underlined the end of this period of minimum of sunspot activity which ought to be named "Spoerer".

This period of low activity which lasted 30 years, perhaps 60 years, is the only one in the history of sun observations by telescope, and arises, precisely at the beginning of the development of the astronomy-physics. It is certain that this anomaly delayed the discovery of the spot cycle. So, even for the astronomers of the 17th century, working hard on numerous captivating studies (measure of the flattening of the earth at the poles, precise determination of the Sun-Earth distance, establishment of catalogs of stars, *etc.* ...) sunspots were a transitory phenomenon; their appearance does not have any rules, they were born and disappeared under the observer's eyes. These variations led the astronomers to confusion (Bailly 1782). "Don't stick to the spots, said Lalande to a young student, a phenomenon which has no law" (Deslandres 1906).

We know only of two other periods of weak sunspot activity, but with a cycle amplitude greater than the amplitude observed during the "Maunder minimum". One occurred from 1798 to 1823, and the other from 1878 to 1912. The astronomy was still limited to optical observations in the visible spectrum, and the variation of the earth magnetic field was the only one geophysical parameter recorded since 1847.

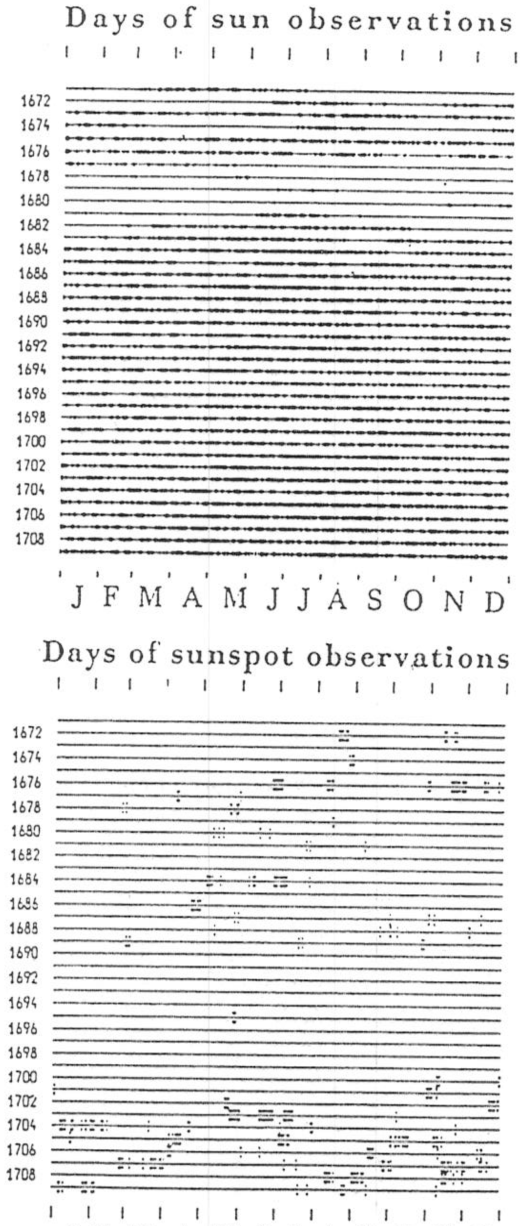

Fig. 12. Sun observations from 1671 to 1709: top, frequency of observation (the hollow dashes correspond to Cassini's observations); b) bottom, frequency of sunspots for all European observers together

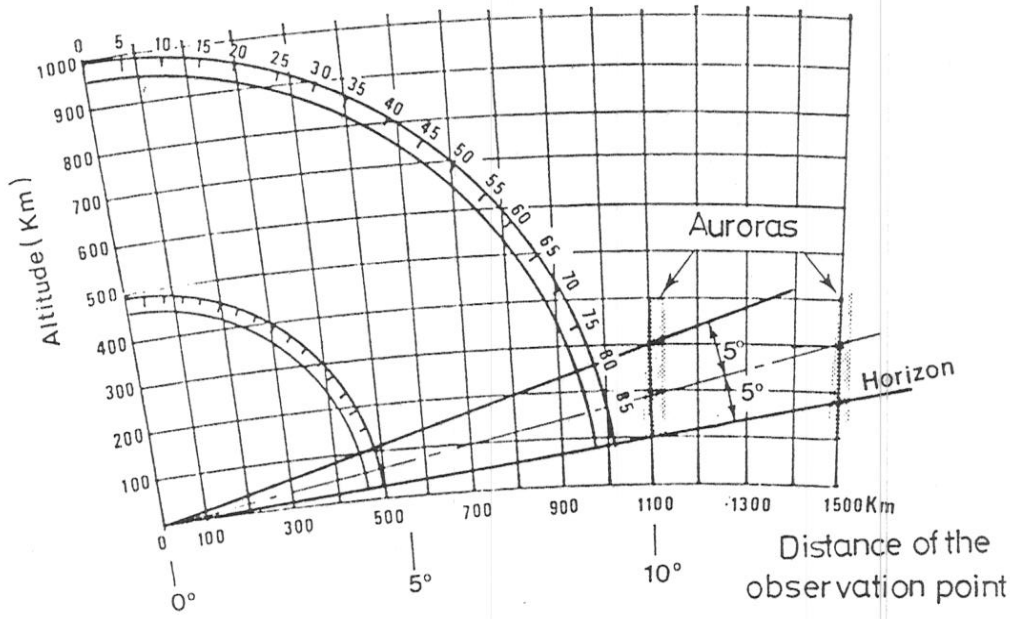

Fig. 13. Diagram of aurora visibility as function of the distance of appearance related to the station of observation

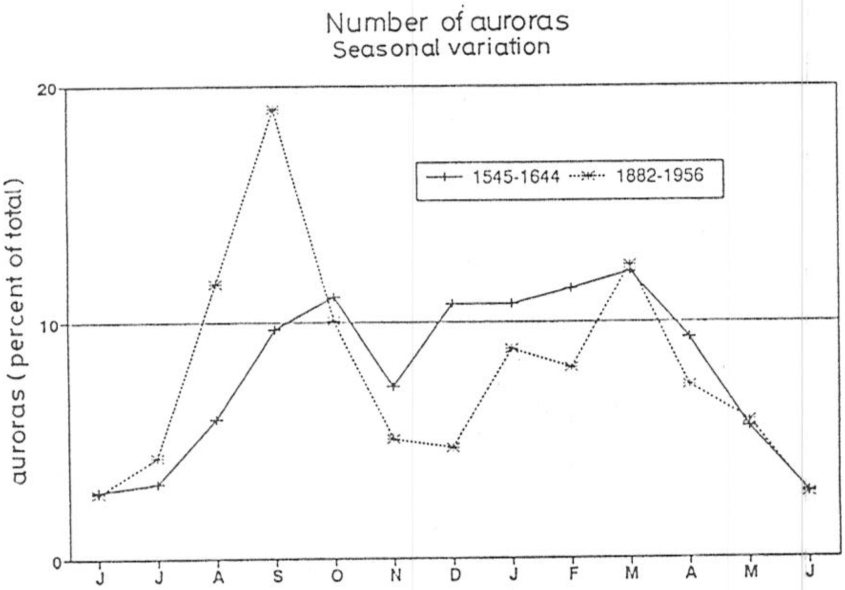

Fig. 14. Seasonal variation of aurorae from European observations between 1545–1644 and recently between 1882–1956

All the actual knowledge on the solar cycle and its consequences on the terrestrial environment were established since the International Geophysical Year and the advent of spatial era (1957), during the four last and large sunspot cycles (R_{max} between 106 and 190). For the elaboration of a reliable model of the running of the "solar machine", data are obviously missing on the development of small sunspot

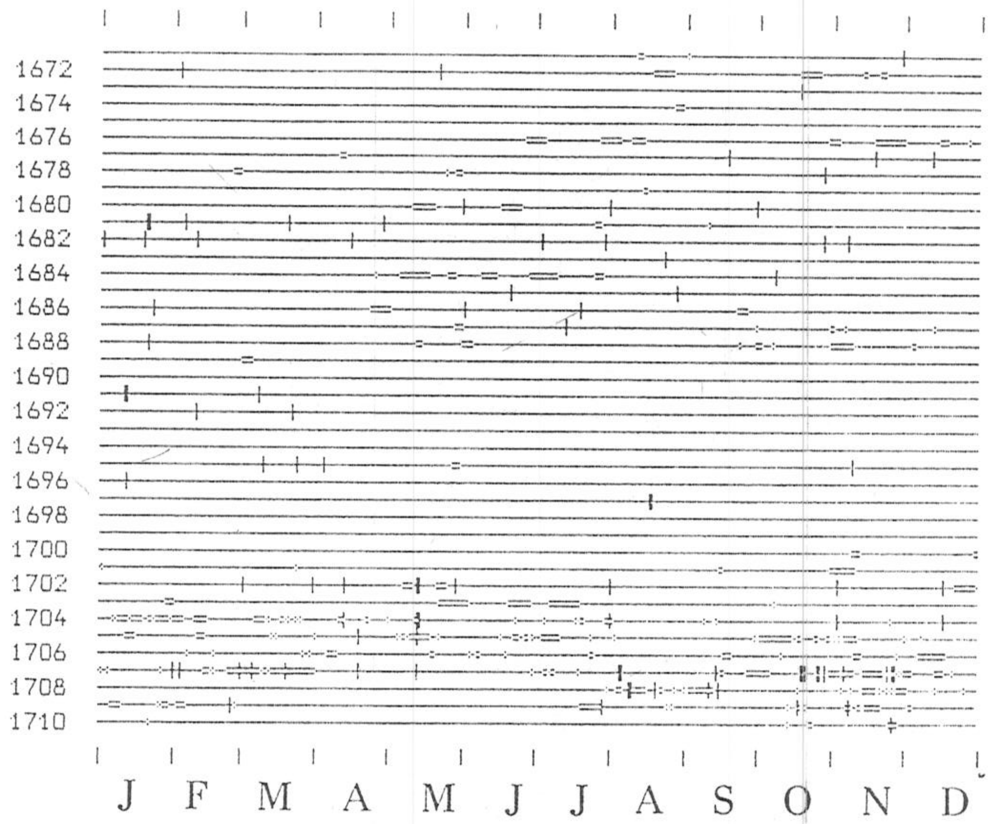

Fig. 15. Diagram representing the day when sunspots (small empty sign) and aurorae (fig. sign) were observed between 1671 and 1709

cycles. It is necessary to continue assiduous solar and geophysical observations, from the ground as well as from space, waiting the hypothetic return of a sun sine macula.

Appendix 1

The "Maunder minimum" and the climate variations during the 17th century

Several authors have established a relation between the minimum called "Maunder" and the "little ice-age" (Eddy 1976, Ribes et al. 1987) while other detailed studies on the climatic variations which occurred during the last five centuries made by Legrand (1979), Landsberg (1980) and Pfister (1980) do not reveal a permanent temperature reduction during this minimum from 1645 to 1715.

The ambiguity seems to result from the definition of the "little ice-age". This name is generally given to the cooling period which started around the middle of the 16th century and ended around 1700. It corresponds to the meteorological conditions: large temperature variations from one year to another and from one decade or several decades to the following. According to Lamb (1982), "it is reasonable" to consider the period from 1420, or even 1190, until 1850 or 1900, as part of the "little ice-age".

However that may be, the reconstitution of the climatic variations made by Legrand (1979) on the basis of the vintage dates in France and Switzerland and on hard winters which occurred in Occidental Europe shows that during the 16th and 17th centuries, the minimum of the "little ice-age" occurred between 1550 and 1630. It is during this period that "the historical maximum" of ice extension in Alps appeared (Le Roy Ladurie 1967, Pfister 1988). Another cooling, well pronounced, occurred between 1690 and 1700. It is confirmed by the temperature measurements made at Paris by Louis Morin (Legrand and Le Goff 1987). So, only this last brief and intense cooling occurs in the centre of the minimum named after Maunder. Besides, it coincides with the period of the weakest solar activity. But, it appears hazardeous to deduce a connection between the two phenomena since the maximum amplitude of the "little ice-age" took place during a period of relative sustained solar activity (Legrand et al. 1990).

Appendix 2

Comparison of the weak solar activity period of the end of the 17th century to the one of the beginning of the 19th century

The reconstitution of the spot cycles made by Wolf for the 17th century and the beginning of the 19th century, shows evidence of a weak activity period between 1798 and 1822 including two small cycles ($R_{\max} = 47.5$ in 1804; and $R_{\max} = 45.8$ in 1816) comparable to the cycle of 1703 ($R_{\max} = 53$).

During this period of a sunspot activity greater than the 17th century activity (1671–1700), the number of observed aurorae in Europe at a latitude equal or less than 55° (Fritz 1873), has been only 124 during 25 years, *i.e.* a mean value of 5 aurorae/year. This mean value is particularly weak in 1807 and 1813 since it is about 1 aurora/year. It is comparable to the auroral activity level from 1671 to 1700. Father Cotte (1808) had noticed this reduction:

On Fig. 24, we have plotted the curve of the frequency of aurora appearances at the geomagnetic latitude equal or less than 62°. This curve has been established by Legrand and Simon (1987), on the basis of homogeneous data. According to the previous remarks on the conditions of aurora observations, the maxima of this curve correspond to aurorae which were mainly produced by relatively high speed solar wind jets coming from the regions continuous to the "neutral sheet" and from polar coronal holes. The first ones sweep the Earth at the time of the solar dipole turning near the spot maximum (1804 and 1817) and the second ones when the dipole reaches its maximum intensity (1807 and 1820). The aurorae shown on a Bartels' diagram, present a clear 27 days recurrence during the years close to the maxima. This fact brings another confirmation concerning their origin.

The small number of aurorae which appeared in 1807 at the geomagnetic latitude 62° indicates that the maximum intensity of the dipolar field was weak announcing the development of the weak sunspot cycle 1816. The structure of such a field corresponded to a thick "neutral sheet" in which the Earth was during several consecutive years. Therefore, the magnetic activity remained very low from 1809 to 1815, and this leads to the quasi complete disappearance of aurorae at latitudes equal or lower to 55°.

On the contrary, in 1820, the auroral activity was high. It was corresponding to a more intense maximum of the dipolar field which announced the cycle of 1830 whose maximum reached 71 ($R_{\max} = 71$).

Notes

1. The "relative Wolf number" is an index of the sunspot activity introduced by Wolf in 1849. It can be computed by the expression $R = K(10g + f)$, where g is the number of spots groups and f of isolated spots, R the total number of spots, and K, a factor close to one, depending on the observer and his tool. This index which is globally proportional to the spotted surface of the solar disk is more significant than the simple number of spots.
2. To determine the location of spot appearance on the solar surface, Carrington defined the meridian of solar origin: it is the central meridian of the sun which pass by the ascendant node f the solar ecliptic equator on January 1st, 1854 at 12 UT. The sideral solar rotation period being 25.38 days, the synodic rotation is comprised between 22.20 and 27.33 days following the Earth position on its orbit. One can deduce the daily longitude of the central solar meridian.
3. The study made by Trellis concerns several ten thousand spot crossings during eight solar cycles.
4. Louis Morin (1635–1715) French physician, member of the Sciences Academy.

Активность солнца и полярного сияния в I7-ом веке

Ж П Легранд, М Ле ГоФФ, С Мазадие, В Шредер

Темные пятна на диске солнца, которые видны и невооруженным глазом, а также полярные сияния, которые иногда простираются до зоны экватора являются наиболее явными проявлениями активности солнца. Известно уже более I00 лет, что указанная активность имеет довольно правильные циклы с периодом в II лет, но по интенсивности этих циклов можно говорить о "малых" и "больших" циклах солнца.

В настоящее время целый ряд больших циклов следят друг за другом, но в конце I7-го века, во время возникновения инструментальной астрономии в Европе активность оказалась в течение десятилетий несравнимо слабее.

Этот период небольшой активности, который навлек на себя внимание германского астронома Шперера уже в I890 г., известен под названием "максимума Маундера".

Что мы знаем об этом периоде?

Были ли принятые приборы достаточно точными?

Могла ли настойчивость астрономов справиться с климатическими условиями, которые характеризовались повышенной облачностью?

Что мы можем узнать на основе данных, полученных еще в начале I7-го века, во время изобретения астрономической трубы?

Настоящий доклад занимается этими вопросами, и показывает оригинальные документы в свете настоящих сведений о нашей звезде.

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