The sunspots and the auroral displays of the Maunder Minimum

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The period in years 1645-1715 (or 1717 what can be concluded from an earlier text by Maunder (1894) stays in opinion of a part of scientists as an example of very low level of solar activity in the past. A new findings of archival reports appear to confirm that the level of solar activity was in fact higher.

1 Introduction

In 1887 a long period of changed solar activity during the second part of 17th century was mentioned by Spörer, what was a few years later analyzed by Spörer (1889); Maunder (1890). The conclusion about a different course of the solar cycle was confirmed by Clerke (1894), who found similar disruption in case of the auroral displays on the base of de Mairan catalogue edited in 1733. The second issue of de Mairan (1754) work, that was also published before 1894, contains an additional data sets had prepared by others, with the total number of reports with auroral displays in the years 1645-1715 increased by about 100 days.

2 The missed sunspots

The Spörer catalogue, discussed later by Maunder (1922), does not contain descriptions of the sunspots observed in 1672 by N. Bion, that Casas et al. (2006) found on the pictures in an old book written by him. Also the sunspots discerned by Flamsteed (1725) in 1703, observations catalogued by Derham & Crabtrie (1711) and numerous phenomena that were visible in 1704 and observed by Stannyan & Hodgson (1704) are omitted in Spörer's data set. 33 sunspots that Stannyan saw during one day are presented on illustration in his paper. Also the numerous reports on sunspots had made by Hevelius (1679) in 1660 were not taken into account by Spörer, what was supposedly caused by limited spread of these descriptions in Europe.

An observers names of the Maunder Minimum era, collected by Hoyt & Schatten (1998), can be find in "De Gnomone" written by Manfredi (1736). This work contains a long list with results of measurements of the solar diameter, had made in the years 1655-1736 with notes about the air conditions during observations, that could distort the image of the Sun, without any mentions about visibility of the solar surface details. Among these reports can also be find an one day when sunspots were surely observed by Cassini in 1676 in Paris and more days of observations had made by de La Hire and Cassini since 1700 with sunspots missed by observers mentioned by Manfredi.

An example of missed sunspot was identified also by us in the course of observations made by unknown name (1684) observer in Paris and by Flamsteed (1684) in Greenwich, in May 1684. In 1695 other sunspot was not discerned by Flamsteed (1725) making the measurement of the solar diameter.

The observations had made by Hevelius in the years: 1642-1644, 1653-1654, 1657, 1659-1661, 1671 and 1684 were analyzed in detail by Rek (2013). A big part of the astrometric measurements had made by this astronomer was before interpreted as observations of the solar surface, however Eddy (1976) was able to distinguish one from another.

It is known, that the sunspots were not discerned during all the 1687 year by Cassini, who is mentioned by Maunder (1922) as very careful observer. But the set of a great phenomena, that had been visible since May to December of this year, was in modern times found by Landsberg (1980) in G. Kirch and J. A. Ihle diaries. Moreover, Manfredi is reported by Baiada & Merighi (1982) as observer of two sunspots in 1705, at the latitude almost 30N and about 35S. These phenomena were not discerned anywhere in the world and both were visible out of the latitude range (about 20 degrees) of all sunspots had registered in Paris Observatory in a course of astrometric observations during the Minimum (Ribes & Nesme-Ribes, 1993).

3 The auroral catalogues and periodicity

The catalogue of auroral displays had observed in the range of medium geographical latitudes, also during the Maunder Minimum, was edited in the modern times by F. Link in 1964. The next such data set was later published by Křivský & Pejml (1985). The records of all phenomena discerned anywhere were earlier collected by Wolf (1857), but the latitude range of these observations appears to be rather unknown. Majority of the data, contained in his catalogue, can be find in Boué (1856) paper, also without information about geographical coordinates.

A two years time delay between the sunspot maximum and the following interval of the highest geomagnetic storm activity, therefore also more frequent auroral displays produced by flares, appears to be a regular feature of the descending phase of 11-year cycle. The Wolf's records contain sixty days of an auroral displays, which had been reported in the years 1698-1699, but this auroral maximum is not connected with any historical reports about visibility of more numerous sunspots. Only one sunspot was discerned after 1690 but before November of 1700 year and was visible in May 1695 (Maunder, 1922).

The last 17th century auroral maximum established on the base of the catalogue by Wolf (1857) appears to be the highest during all the century. The previous was in 1687, the next in 1707 and the next rather in 1719, not later. These years are divided by intervals of variable length, but this divergence is similar as in case of sunspots, from 9 to 13 years. A part of these auroras was discerned in an other months than higher auroral activity could have been created by the polar coronal holes.

The huge and numerous sunspots reported during 1687 year since the end of May by G. Kirch, that were found in 20th century by Landsberg (1980), confirm higher level of solar activity during this year.

Silverman (1992) found four periodicities of the phenomena had observed during the Maunder Minimum in the data set based on the catalogue by Křivský & Pejml (1985) and equal to about 2,94, 3,5, 15 and 18,8 years. The omitted 11-year periodicity appears to be a part of the wing of 15-year cycle in the power spectrum derived by him, where 9-year periodicity is not evident at all.

At the beginning of 17th century de Mairan discovered that the auroral displays are more frequently observed in the months close to equinoxes. Using the data of the same catalogue we found the 11-year period in the years 1660-1671 when these

phenomena were only visible during the months close to spring equinox (Rek, 2010). This premise, connected with possible asymmetry of the surface of the solar polar holes during a particular period from one sunspot maximum to another (Prigancová & Bieleková, 1993), appears to confirm a persistence of 11-year cycle during this deep phase of the Maunder Minimum, also in the data set of Wolf (1857) catalogue.

The phenomena which were visible in following years of the Minimum in an other months than every year activity of the solar polar holes can be observed, allowed us to derive the diversity of auroral cycles length, that was typical as for the sunspot cycle.

4 Conclusions

The examples of sunspots omitted by observers of the Maunder Minimum allowed us to suppose, that the sunspots could have been more numerous during this period than it was reported. An astrometric measurements could be interpreted as the solar surface observations and in result the time-covering of the period higher than it really was.

A newly found archival reports about visibility of auroral displays during the same period can be useful for these research, as the phenomenon observed by Hevelius in 1659 (Rek, 2013). In 2011, we also found two other archival notes about sunspots in the letters written to Kirch and published by Kirch (2006); the letters with number 745, written on 26 September 1700, and 594. These phenomena could have been related with the high maximum of auroral displays, reported in catalogue by Wolf (1857).

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The Maunder Minimum, also known as the "prolonged sunspot minimum", is the name used for the period around 1645 to 1715 during which sunspots became exceedingly rare, as was then noted by solar observers. The term was introduced after John A. Eddy published a landmark 1976 paper in Science. Astronomers before Eddy had also named the period after the solar astronomers Annie Russell Maunder (1868â€“1947) and her husband, Edward Walter Maunder (1851â€“1928), who studied how sunspot latitudes changed with Maunder minimum, unexplained period of drastically reduced sunspot activity that occurred between 1645 and 1715. Sunspot activity waxes and wanes with roughly an 11-year cycle. In 1894 the English astronomer Edward Walter Maunder pointed out that very few sunspots had been observed between 1645 and. 2 Sunspot observation in the 17th century. 3 Indirect proxy data. 4 Consequences of the Maunder minimum. 5 Conclusions. Astronomy & Astrophysics.Â We also consider peculiar features of the Sun (very strong hemispheric asymmetry of sunspot location, unusual dierential rotation and the lack of the K-corona) that imply a special mode of solar activity during the Maunder minimum. Results. The level of solar activity during the Maunder minimum is reassessed on the basis of all available data sets. Conclusions. We conclude that solar activity was indeed at an exceptionally low level during the Maunder minimum. Although the exact level is still unclear, it was denitely below that during the Dalton minimum around 1800 and signicantly below that of The extremely low sunspot activity during the period of the Maunder minimum 1645â€“1715 was confirmed by group sunspot numbers, a new sunspot index constructed by Hoyt and Schatten (1998a,b). Neither sunspots nor auroral data time behavior indicate the presence of 11-year solar cycles as stated by Eddy (1976).Â Two-ribbon flares appear in plages with only very small or no sunspots. Some of these flares are geoactive. Most aurorae (90%), which were observed during the Maunder minimum, appeared in years when no spot was observed. Auroral events as a consequence of proton flares indicate that regions with enhanced magnetic field can occur on the Sun when these regions do not produce any sunspots. Discover the world's research. 19+ million members. Although the time of the Maunder minimum (1645â€“1715) is widely known as a period of extremely low solar activity, it is still being debated whether solar activity during that period might have been moderate or even higher than the current solar cycle #24. We have revisited all existing evidence and datasets, both direct and indirect, to assess the level of solar activity during the Maunder minimum. Methods.Â If sunspot ac-tivity was high during the MM, as proposed by the H-scenario, the Sun must have been displaying sunspots almost every day. However, this clearly contradicts the data, since the reported sunspot days, including those reported by active observers, cover only a small fraction of the year, even around the proposed cycle maxima (see Fig.