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On the existence of solar variations in the 16th to 18th centuries

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RESUMEN

Una revisión de las mínimas de actividad solar y la relación entre la actividad auroral y geomagnética nos permiten establecer que la actividad mínima solar no es evidente en los datos disponibles.

PALABRAS CLAVE: Aurora, minimum de Maunder, actividad solar.

ABSTRACT

A review of solar activity minima and the relationship of the auroral and geomagnetic activities suggest that solar minima are not evident in the available data.

KEY WORDS: Aurora, Maunder minimum, solar activity.

INTRODUCTION

A number of papers have discussed the problem of solar variability (see Leon, Skumanich and White, 1992; Nesme-Ribes *et al*., 1993, Mendoza, 1996). Eddy (1976), based on the ideas of the English astronomer Maunder (see Schröder, 1984). He proposed that a long solar minimum occurred in the 17th century. The name “Maunder minimum” and other proposed minima such as the Spörer minimum (between 1460 and 1550) have been widely used in the literature.

Eddy proposed that the Maunder minimum occurred between 1645 and 1710. His assumption was supported by a small amount of data; however, later results in radio chemistry, archaeology and other fields seemed to support his idea.

The assumption of the Maunder minimum has been accepted (e.g. Kippenhahn 1992), and criticized (Gleisber, 1968; 1979; Landsberg, 1980). Legrand *et al.* (1993) and Schlamminger (1993) have shown that the minima are not supported by auroral data. The recently introduced Spörer minimum, which is supposed to have occurred between 1460 and 1550 (Kippenhahn, 1992; Suess, 1993) is not consistent with evidence that the solar cycle did function from the 16th to the 18th century and that there were continuously auroras in the middle latitude with the usual frequency of occurrence (Schöder, 1988).

Auroral activity

Data from different catalogues of auroras and from other sources (see Schröder, 1984, 1988, 1996) are summarized in Tables 1 and 2 (cf. Boue, 1856; Fritz, 1873; Krivsky, 1988; Landsberg, 1980; Legrand *et al*. 1993).

There is a fairly normal auroral activity for Central Europe during the alleged Spörer minimum as shown by Table 1. When interpreting such data, the present standards of observations cannot be used. In late Medieval times the existing scientific institutions were not interested in auroras. Such phenomena were assumed to possess some theological origin and were neither observed nor recorded as natural ones (Figure 1). Few records data from these centuries, but it is impossible to conclude that there were no auroras.

Even after the invention of printing there was no systematic solar and auroral research. Records remained sporadic. There are no data for some years, but it is possible that new data will be discovered in sources which have not yet been studied.

Eddy’s result seemed to be confirmed by the fact that GeV energy range of cosmic rays is coupled to solar activity. In this energy range, cosmic rays generate free neutrons in the atmosphere and influence the isotope composition. Therefore the fluctuations of the solar activity must be “fossilized” in the isotope composition (Suess, 1993).

Do solar “activity minima” exist?

Tables 1 and 2 cover a large historic time interval. There are years for which no auroras have been reported until now. Does this mean that there were no auroras in these years? By no means. As mentioned, the scientific and social conditions did not favour the compilation of complete statistics. On the contrary, the evidence of years with a high number of auroras (even if some events are questionable) suggest that the solar activity was normal, i.e. that the solar cycle with a period of about 11 years continued during these intervals (Figure 2).

Table 1

Auroras during the “Spörer Minimum” (1459-1550) from Middle European observations*

1453	large aurora observed including in Switzerland
1460	13 January, observed down to Bohemia
1462	observed down to Poland, different shapes
1465	27 November, designated also as a comet
1478	observed down to Switzerland, striking
1494	at different locations in Europe
1499	May?, observed everywhere in Europe
1500	aurora observed, no details
1503	among others in Bavaria, the auroral crown developed
1511	aurora as clouds, no further data
1514	January, different shapes
1516	observed in Saxony, no data available
1517	among others in Saxony and in Poland, the heavens on fire
1518	no date, among others in Poland
1519	?
1520	among others observed in Austria, supposedly in September
1521	January ?, in Germany, strong aurora seen
1523	January, among others observed in Wittenberg and at different other localities. Description from Hungary
1524	at different places in Germany (weapons in the heaven)
1526	December
1527	11 October, then 11 August and 11 December-aurora everywhere in Germany, among others blood-red heavens and extreme radiation
1528	general descriptions
1529	11 January, strong aurora
1529	28 January, the heaven was open, striking forms
1529	seems to be a different aurora, but cannot be dated
1531	29 September, fiery heavens, supposedly observed in Portugal
1532	different European localities
1533	spread over all Germany
1534	June or July, among others seen in Schleswig-Holstein
1535	different localities
1536	25 December, spread over all of Germany (also September 19)
1537	February ?, a phenomenon which can be interpreted as aurora
1538	several auroras in Germany
1540	December, widely spread in Germany
1541	chasm (a name for certain forms of aurora), among others in Hungary?
1542	observed among others in Württemberg
1543	May, seen as South as in Baden
1544	May ?
1545	February, seen down to Poland
1545	7 April, strong aurora spotted by arches
1546	19 February, the heaven opened, coloured phenomenon, people saw two armies in a celestial battle
1547	July?, different description which can be interpreted as auroras
1548	17 November, a spread wide aurora
1549	April?
1549	30 September, there are several phenomena described that year which could be interpreted as auroras.
1550	several reports indicate auroras
1551	6 February, even at Lisbon, bloody rays and bundles in heaven, a striking phenomenon
1551	11 September ?
1551	1 October, big chasm (aurora), I. e. strong rays

(Auroras from different sources)

* The examples for the period of the Spörer Minimum may give an idea or the terminology used at that time.

According to cosmic electrodynamics, the solar magnetic field is the source of the corpuscular radiations which causes auroras. This radiation consists of electrically charged particles which propagate with a velocity up to 2000 km/s, and reach the Earth within one day. The particles of this solar corpuscular radiation extend the solar magnetic field to the vicinity of the Earth and increase the shielding effect of the geomagnetic field against cosmic radiation from space.

Cosmic radiation consists of positively charged nuclei, mainly protons, which propagate nearly at the speed of light. The particles cause nuclear reactions in the terrestrial atmosphere, which transform e.g. N^{14} to C^{14}. Plants incorporate C^{14} into their structure; thus the isotope composition of carbon in fossil wood reflects the intensity of cosmic radiation during the lifetime of a tree.

As a shielding effect of the geomagnetic field is less strong in the case of low solar activity than in the case of an active Sun, more charged particles of cosmic rays reach the Earth. Thus more C^{14} is produced and this could be detected from fossil wood. If the number of auroras and thus the corpuscular solar radiation were not correlated with the sunspot number, no correlation would exist with the amount of C^{14} in plants.

However, it is not generally true that solar activity always decreases the number of high energy particles in cosmic rays reaching the vicinity of the Earth. Sunspots are possible sources of high-energy corpuscular radiation, too. There are events of a strong increase of cosmic radiation following magnetic storms one day later. On the other hand, the magnetic fields of the Sun produce energetic rays at almost the velocity of light. This effect is opposed to the former and has been investigated by Heisenberg (1953; cf. also Smith, 1991). Kahler (1992) shows that solar protons do not reach the Earth exactly from sunspots but from flares and/or mass ejections, often rooted in the photosphere active regions and the associated sunspots.

Note that there is no theoretical basis for a secular or periodic variation of the amplitude of the solar cycle, including the 11-year cycle maxima. The 11-year cycle itself and

Fig. 1. Tipical figure of a Aurora observed in the 16th Century.

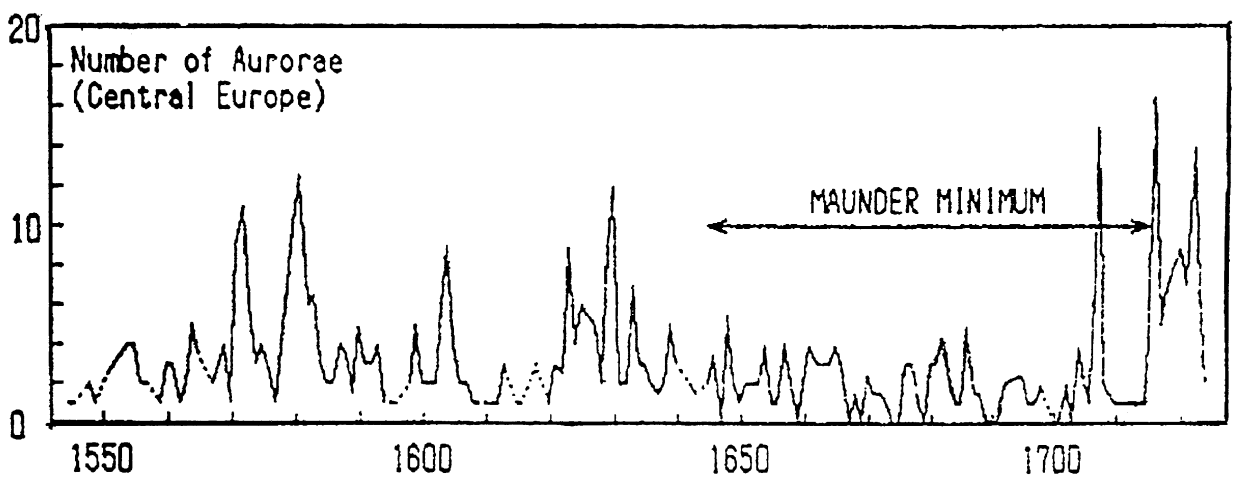

Fig. 2. Auroral frequency from 16th to 18th century from European data (middle latitudes).

related phenomena are fairly well explained by the dynamo models of magnetohydrodynamics. But these models are based on linear (or quasi-linear) approximations (Eulerian equations of ideal fluids, Maxwell-Lorents equations of electrodynamics) which cannot give any estimate about the absolute value of solar activity.

Thus the amplitude of the solar activity mus be assumed to remain constant as long as the physical parameters of the solar atmosphere do not change. The nature of such changes and their existence are unknown.

Thus the supposed variation of the solar activity in his-

Table 2

Number of auroras between 1545 and 1724 (Central Europe)

Year	Number	Year	Number	Year	Number	Year	Number
1545	1	1590	5	1635	3	1680	3(3?)
1546	1	1591	3	1636	2	1681	3
1547	-	1592	3	1637	1(2?)	1682	4(5?)
1548	2	1593	2(6?)	1638	2	1683	2(3?)
1549	1	1594	1	1639	5	1684	1
1550	+	1595	-	1640	3	1685	1
1551	2(3?)	1596	1?	1641	-	1686	5
1552	-	1597	-	1642	2	1687	1(2?)
1553	-	1598	2	1643	1(2?)	1688	1(2?)
1554	4	1599	5	1644	?	1689	0
1555	4	1600	2	1645	2	1690	?
1556	2	1601	2	1646	3(4)	1691	0
1557	2	1602	2	1647	0	1692	1(3)
1558	+	1603	6	1648	5(6?)	1693	?
1559	1	1604	9	1649	2	1694	?
1560	3	1605	4	1650	1	1695	2(3?)
1561	3	1606	2	1651	2	1696	1
1562	1	1607	2	1652	1(3?)	1697	1
1563	2	1608	1	1653	2	1698	(2?)
1564	5	1609	1	1654	4	1699	?
1565	3(4?)	1610	?	1655	1	1700	0
1566	-	1611	1	1656	1	1701	0
1567	2	1612	1	1657	4	1702	2
1568	3	1613	3	1658	2	1703	0
1569	4	1614	?	1659	0	1704	4
1570	1	1615	1	1660	2	1705	2
1571	9	1616	1	1661	4	1706	1?
1572	11	1617	-	1662	3	1707	15
1573	6	1618	3	1663	3	1708	2
1574	3	1619	?	1664	3	1709	1(2?)
1575	4	1620	1	1665	4	1710	1
1576	3	1621	3	1666	3	1711	?
1577	1	1622	2(3?)	1667	0	1712	?
1578	-	1623	8(10)	1668	1(2?)	1713	1
1579	-	1624	4	1669	0	1714	?
1580	10	1625	6	1670	2(3?)	1715	1
1581	12(13?)	1626	5(6?)	1671	1(2?)	1716	16(17?)
1582	6	1627	5	1672	1(2?)	1717	5
1583	6(7?)	1628	2	1673	1	1718	7
1584	3	1629	9	1674	0	1719	8
1585	2	1630	12	1675	0	1720	9
1586	2	1631	2	1676	3	1721	7
1587	4	1632	2	1677	3	1722	14
1588	2(5?)	1633	7	1678	1	1723	7
1589	1(2?)	1634	3	1679	0	1724	(2?)

+ uncertain attribution

toric times is a purely empirical problem. Records and fossil data are relevant at very different levels. The records have the same problem as all primary sources from ancient times. Some studies lack a critical evaluation of the primary sources, and the conclusions drawn from incomplete secondary sources are not well supported. Fossil data (see Suess, 1993) depend on the existence of a quantitative connection with solar activity. Moreover, the synchronization of the data series (and perhaps of the historical records) is to be established.

The fundamental parameter of solar radiation, and thus of the global climate of the Earth, is the constant J. This constant depends on the average distance between the Earth and the Sun, and on the total radiative capacity of the Sun. The average Sun-Earth distance is the major axis of the Earth's orbit which is a constant of celestial mechanics (Laplace's law). The radiactive power of the Sun is determined by the energy production of nuclear fusion in the centre of the Sun, which is governed by the Helmholtz-Kelvin time scale. It needs about 25 million years to reach the surface of the Sun. In the present phase of the Sun's evolution this radiative power is constant over several hundred million years.

This has been recently confirmed by extraterrestrial measurements of the solar radiation (Fröhlich, 1987). There are, however, short-time fluctuations ΔJ (in the solar minimum range) by fractions a thousand part of the total value. Changes of a similar order of magnitude, $\Delta J/J \approx 10^{-3}$ are experienced within the 11-year solar cycle. The average value J_0 of the solar constant has remained constant for decades. The instantaneous value is given by the equation $J=J_0-\Delta J \sin(t/T)$, with T about 11 years.

The past changes of the global average temperature are "frozen" into the annual rings or varves of trees, sediments, glaciers and firns. Thus, temperature changes with a period of 11 years would reflect variations in solar activity as a fossil indicator. No climatic changes are, however, expected in the long run controlled from primary solar irradiation, as the period of the solar constant is 11 years (except for smaller variations with periods of N x 11 years).

It is important to note that the long-time constancy of the amplitudes is nor relevant to the long-time constancy of the solar constant. The solar constant of the quiet sun J is equal to the average value J_0 of J over the total activity period T. Without solar activity, $J=J_0$ would always hold and its value would be that of the extrema of a periodic activity (sunspot maximum and minimum). Thus the secular temperature radiation of the sun is independent of the solar activity.

At the present level of discussion it seems nevertheless that there is some solar activity and that it may have changed in the past, though we do not know the extent of such change. The possible change of solar activity seems to imply some ΔJ which might affect the Earth's temperature over decades, which is certainly relevant for human beings.

CONCLUSIONS

Is the Sun a variable star? Many recent publications on this point have questionable basis. If the 11 year cycle is considered, and the available auroral data are collected they may be used, similarly to the geomagnetic activity as an indicator of an active Sun. Another matter is the magnitude of this activity. This is an open question which needs more research on solar and auroral data.

In conclusion, the level of auroral occurrence during the Spörer and Maunder minimum was similar to modern levels from Central European data in the middle ages, mostly in Germany, Switzerland, Hungary and Austria. Furthermore, it seems possible that the aurorae occur with an approximate 11-year cycle. The problem is for determination of this solar cycle to find more data from European, mostly unpublished sources.

More geophysical and historical studies are required (Cf. Schröder, 1984; 1988; Wittmann, 1978).

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