Aurora borealis during the Maunder minimum

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SUMMARY
Observations of 404 occurrences of the aurora borealis recorded in Central Europe during the sixteenth and seventeenth centuries are compared with known phase relationships between auroral activity and sunspot cycles in modern times. A satisfactory coincidence of the aurora borealis with current sunspot cycles is found, both with respect to phase-dependent frequency and to the delayed maxima. The 118 occurrences during the ‘Maunder minimum’ of solar activity show the same degree of coincidence with the sunspot cycles of that period.

1 INTRODUCTION
In the mid-nineteenth century, the astronomer R. Wolf (1852) published the mean sunspot period of 11.11 yr, which is still accepted. Shortly afterwards, H. Fritz presented the first statistical proof of a parallelism between the frequency of auroral displays and of sunspots. Fritz’s (1864) discovery that the cycle of auroral activity lags considerably behind the sunspot cycle attracted less attention.

The phase shift of the cycles of auroral activity is due to the increase in solar wind storms during the declining phase of the sunspot cycle. As the sunspots decline, holes arise in the solar corona, so that growing regions of the Sun’s surface without sunspots, named M regions by Bartels (1932), can increase the emission of stormy solar winds. Shock waves generated in the process in the solar wind cause a compression of the geomagnetosphere and an increase in its field strength during their passage through it. The auroral activity is triggered when electrons of the solar wind collide with atoms and molecules of the ionosphere, and the kinetic energy of the solar wind particles is converted into electrical energy. Electrical power of the order of more than a million megawatts is generated. This auroral generator feeds the activity of the auroral lights, with the lagging maximum discovered by Fritz falling about 1.5 yr after the sunspot maximum of each cycle. The spectral analysis of the index of geomagnetic activity, $A_p$, and of the relative sunspot numbers by Fraser-Smith (1972) gave the exact time difference of this lag.

Historical sunspot cycles are determined from contemporary sources by means of dated observations of the aurora borealis, as well as of sunspots (Schove 1979). If there are only a limited, discontinuous number of reports of northern lights, then indisputable evidence of sunspot cycles cannot be provided in certain cases. For such cases, the discovery of an existing phase-dependent frequency of auroral activity could provide solid support for the assumption that these cycles are persistent. This paper examines, from this point of view, whether sufficient arguments for or against the existence of sunspot cycles during the period of the Maunder minimum can be found.

2 FREQUENCY
In the following, the frequency distribution of auroral displays is considered only over intervals corresponding to the sunspot cycles during the period from 1543 to 1712 CE according to Schove (1979). These are cycles numbered $-18$ to $-4$ in the usual Zurich numbering. The set of data used consists of observations of northern lights made mostly in what is now Austria, Czechoslovakia, Germany, Hungary, the Netherlands and Switzerland. Their annual rate is taken

![Figure 1. Frequency of aurorae borealis in Central Europe during the sunspot cycles $-18$ to $-4$, from 1543 to 1712 CE.](image-url)
from papers by Schröder (1979, 1988, 1990). For this period, a total of 404 occurrences of the aurora borealis are given, 118 of them during the ‘Maunder minimum’ of solar activity from 1645 to 1712 CE.

The average annual rate of aurora borealis activity in middle latitudes, between 45° and 55° north, which covers Central Europe, is given as five events (Schröder 1987). For the above-mentioned historical period, the count of 2.4 northern lights per year is relatively good, considering that a substantial 40 per cent of the period falls in the below-normal Maunder minimum. The bar chart of Fig. 1 shows the auroral frequency in the corresponding sunspot cycles. During the Maunder minimum, the number of northern lights observed remains low. It may, in fact, already have begun during cycle number −10, as the low figure for the latter would suggest.

3 FREQUENCY PHASES

Each sunspot cycle is bounded by a rising phase to the sunspot activity maximum, and a declining phase after this. Each phase has specific characteristics of sunspot and aurora borealis frequency. Thus Wittmann (1978) has shown that of the 90 large sunspots (area greater than $5.7 \times 10^9$ km²) occurring from 1874 to 1976, there were 9.3 per cent more in the rising phase than in the declining phase of the cycles involved. The frequency of the aurora borealis has an opposite characteristic: they are normally more frequent in the declining phase of a cycle. In Schove's (1979) statistics of auroral activity, an excess in this phase is found both for different regions and for different levels of sunspot maximum.

Northern lights over Central Europe, according to Schröder (1972), shown in Fig. 2 as bar chart A, display a pronounced excess in the declining phase of the cycles, in the equal portions of the phases of the superimposed cycles. The set of data comprises 376 aurorae observed in Germany from 1880 to 1964. This period falls in the Zurich sunspot cycles 12 to 19.

The set of data on historical occurrences of the aurora borealis from Fig. 1 is shown by the same method in bar chart B of Fig. 2. Although this is based on almost twice the number of superimposed sunspot cycles, only a broad, moderate clustering of auroral activity during the declining phase is found. This may be due to the small number of northern lights relative to the cycles, and the limited accuracy of the cycles in the sixteenth century.

However, bar charts A and B in Fig. 2 do show that, with the help of superimposed sunspot cycles, even small sets of data can indicate an existing phase-dependent frequency of the aurora borealis. This would make indirect proof of the persistence of the sunspot cycles possible.

4 THE MAUNDER MINIMUM

Exactly one hundred years ago, W. Maunder (1890) pointed out that there are remarkably few observations of auroral activity from the period of 1645 to 1715 CE, and that this might be due to a prolonged sunspot minimum. Based on this assumption, there have been several studies in the past decade attempting to explain such a 70-yr abnormal phase of solar activity, with an interruption of the sunspot cycles (Eddy 1975; Eddy, Gilman & Trotter 1976). But this interpretation of the Maunder minimum is not universally accepted among solar researchers. For example, Gleissberg (1977) is of the opinion that the minimum phase of an extra-long sunspot cycle (Henkel 1972) with sharply reduced sunspot activity might also have caused the Maunder minimum.

The superposition of cycles in bar charts A and B permits the amplification of the statistical trend of an existing phase-dependent frequency of a few aurorae of a cycle. Schove (1979) gives times for the phases of sunspot cycles −9 to −4, those falling within the Maunder minimum. For 118 occurrences during this period, their number varies from 29 down to 5 events during one of these cycles according to Schove. Bar chart C in Fig. 2 has correspondingly low values.

A comparison between bar charts A, B and C clearly shows the phase of decreasing sunspots to be the greater frequency phase of the aurora borealis. For the 6 cycles of the Maunder minimum we may conclude that the superimposition of cycles of northern lights during the Maunder minimum shows the lag discovered by H. Fritz, with a maximum during the decreasing phase of the sunspot cycles. It is therefore very probable that the sunspot cycles persisted during the Maunder minimum.

5 CONCLUSION

A statistical survey of historical sunspot cycles from the sixteenth and seventeenth centuries is based on over 400 reports of the aurora borealis from Central European sources. The known phase relationships between the sunspot and aurora borealis cycles serve as a comparison standard. The result of this study permits the conclusion that, in the
period studied, the cycles of sunspot frequency were accompanied by normal phases of aurora borealis frequency. Analogous results were obtained for the partial period of the Maunder minimum. The cycles during the Maunder minimum according to Schöne (1979) show a normal periodicity in their effects on the phase-dependent frequency of auroral activity in middle latitudes of Europe.

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REFERENCES