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Did the Sun's Prairie Ever Stop Burning?

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Abstract The presence of the red flash at total solar eclipses requires the existence of an extended chromosphere and therefore of a photospheric magnetic network that gives rise to spicules. We draw attention to the earliest historical reports of a red flash at the 1706 and 1715 eclipses, which therefore imply a substantial, widespread photospheric field during at least the last decade of the Maunder Minimum. Our finding is consistent with reports of a persistent photospheric field throughout the Maunder Minimum from analyses of ^{10}Be radioisotope evidence. We note, however, that the last decade may not be representative of conditions throughout the roughly 1645 – 1715 extent of that prolonged activity minimum.

Keywords Solar magnetism · Solar eclipses · Red flash · Maunder minimum

The rarity of sunspots between approximately 1645 and 1715, a period known as the Maunder Minimum of solar activity (Eddy, 1976), is of wide interest in studies of solar magnetism and of possible Sun – climate effects. The great reduction in the number of spots at this time implies an extended lull in solar magnetism, but it is unclear whether the magnetic field disappeared completely from the photosphere, or whether only the formation of the most intense fields into spots was suppressed. Persistence of a weakened 11-year cycle reported in ^{10}Be radioisotope data seems to argue for the latter scenario (Beer, Tobias, and Weiss, 1998). Here, we point out that historical observations of a prominent red flash at solar eclipses provide previously overlooked evidence for a significant level of solar magnetism, during at least the last decade of the Maunder Minimum.

The red flash, observed for almost ten seconds immediately before and after totality, is familiar to solar eclipse observers as a thin red arc on one side of the Moon's dark edge. It arises from the intense red hydrogen radiation of the chromosphere, which consists mainly

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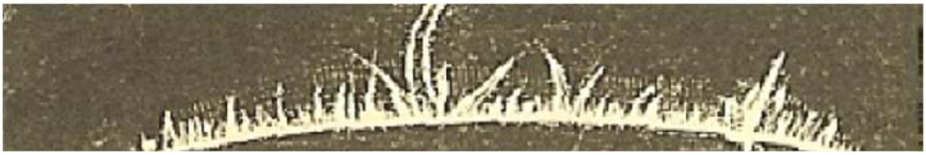

Figure 1 An early drawing of the "burning prairie" appearance of the Sun's limb made by C.A. Young, on 25 July 1872. All but the few longest individual radial structures are spicules.

of radially oriented spicules, extending 5 – 10 000 km above the photospheric limb (see, *e.g.,* Golub and Pasachoff, 2001). Drawings of these spicules by early observers (see Figure 1) led to the description of the chromosphere by the noted nineteenth-century Jesuit astronomer Angelo Secchi as a "burning prairie."

It is now well known (see, *e.g.,* the overview in Foukal, 2004) that the spicule jets move upward along magnetic field lines rooted in the photosphere outside of sunspots. Thus the observation of the red flash produced by the spicules requires the presence of widespread solar magnetic fields. Historical records of solar eclipse observations provide the first known report of the red flash, observed by Stannyan at Bern, Switzerland, during the eclipse of 1706 (Young, 1883). The second observation, at the 1715 eclipse in England, was made by, among others, Edmund Halley – the Astronomer Royal. These first observations of the red flash imply that a significant level of solar magnetism must have existed even when very few spots were observed, during the latter part of the Maunder Minimum.

This historical evidence may bear on reconstructions of total solar irradiance (TSI) variation and its possible forcing of climate over the past few centuries. It has been suggested, for example, that, during the Maunder Minimum, TSI may have decreased sufficiently to help account for the broad minimum in global temperature during the coldest part of the Little Ice Age (Lean, Beer, and Bradley, 1995). The mechanism suggested for this large TSI decrease is significant depletion of the bright magnetic regions in the photosphere that are associated with spicule foot points. To obtain a climatically significant TSI decrease, Lean, Beer, and Bradley proposed the disappearance not only of the bright network structures associated with spicule foot points but even of the faintest *inter-network* magnetic elements located within supergranule cell centers. The historical eclipse observations described here seem to require the presence of even the bright network structures, and thus of substantial solar photospheric magnetism during at least the last decade of the Maunder Minimum. Hence, the red-flash observations would argue against a climatologically important decrease in TSI during that period of time.

A more definitive conclusion is limited by the lack of a continuous daily record of sunspots during this early epoch of solar study (Hoyt and Schatten, 1996); such records would help determine whether the total eclipse of 1706 sampled typical conditions during the Maunder Minimum or a period of initial recovery from it. Although the presence or absence of spots on the face of the Sun is clear and unambiguous in sampled, daily accounts from the seventeenth and early eighteenth centuries, the more telling annual mean sunspot numbers (R_z) can be only poorly estimated from them. Eddy's (1976) estimates for 1706 and 1715 were $R_z = 15$ and 10: typical of years of minima of the 11-year cycle in the modern record. Earlier estimates by Waldmeier (1961) for the same years were somewhat higher: 29 and 27.

The presence or absence of a magnetically structured corona is, like the chromospheric network, another possible indicator of a more active Sun. Descriptions of the corona at times of total solar eclipses during the Maunder Minimum could answer this question, were they sufficiently detailed to allow the distinction between a structured, electron-scattered K-corona – linked to solar activity – and the ever-present glow of the dimmer and more symmetric F-corona, or zodiacal light. The F-corona, produced by the scattering of photospheric light by dust particles in the interplanetary medium, is dimmer than the K-corona near the limb. However, it is sufficiently brighter than the sky (see Golub and Pasachoff, 2001; Figure 5.13) to provide a coronal glow that would probably persist even if structured solar magnetic activity in the low corona were to vanish.

There are all too few eclipse accounts from this period, and all but one – the London eclipse of 1715, which is also the earliest known description of a structured corona – tell only of a dim symmetric glow surrounding the eclipsed Sun. The historical coronal descriptions thus add no additional information to what can be derived from observations of the red flash and spicules, cited here, at the eclipses of 1706 and 1715.

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