Historical eclipses and the recent solar minimum corona

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Abstract.

We have studied the corona as seen at the eclipses of 1878, 1900, 1901 and others. These eclipses occurred during extended sunspot minimum conditions. We compare these data with those of the recent solar minimum corona, using data from the eclipses of July 22 2009 and August 1 2008. An attempt to characterize the global solar magnetic fields is made. We speculate on the origin of the non-dipolar structure seen in the 2008 and 2009 eclipse images.

The SOHO-23 meeting was concerned with understanding if and why the sunspot minimum of 2008-2009 is indeed peculiar. We looked at historical eclipse data to see how the corona, seen during eclipse, has evolved in time since the advent of photography in the mid 1800s. Our goal is to place the 2008 minimum into the historical record by comparing the images obtained many decades ago to those obtained during the recent minimum by one of us (MD).

Since the photographic era began in the mid 1800s, over 100 total solar eclipses have occurred, a considerable fraction of which were photographed using telescopes of large focal length. In the late 1960s, Jack Eddy researched, copied and carefully documented many of the historical eclipse plates. He compiled data for 20 eclipses, those of 1869, 1878, 1889, 1893, 1898, 1900, 1901, 1905, 1908, 1918, 1922, 1923, 1925, 1932, 1937, 1952, 1962, 1963, 1965, 1966. The copied plates are now stored at the High Altitude Observatory in Boulder, Colorado. In the 1990s, Eddy’s collection was scanned commercially and the digital images have been archived at HAO.

Solar cycle 11 began in 1867 and as of January 2010 the recent minimum has passed, and cycle 24 has begun. Of the 12 minima which have occurred since 1869, digitized data in Eddy’s archive exist within 1 year of the minima for the eclipses of 1878, 1900, 1901, 1923, 1965. Digital eclipse data are available from other sources for the minima of 1986, 1996, and 2008. The following table lists circumstances for eclipses during the minima we have examined. The sunspot data are from the National Geophysical Data Center (NGDC). Cycle lengths were computed from minimum to minimum, using minima in the mean sunspot number from a 13-rotation triangular averaging.

On the basis of sunspot cycle lengths alone, we would have selected, in order, the years 1901, 1878, 1975 (11.6 yr) to compare the corona with that of 2008/2009. In terms of spotless days we would have selected 1913, 1901,
1878, 1954. From monthly sunspot numbers we would have selected 1878, 1954, 1944, 1889, 1922, 1932. There was no eclipse in 1913. Patterns in the sunspot behavior alone suggest that the eclipses of 1900, 1901 and 1878 occurred at phases in cycles which appear most similar to those of eclipses of the recent minimum. It would be helpful to include an analysis of data from the 1954 eclipse, often cited as a canonical minimum corona (e.g. Billings [1966]). Instead we show data for the 1995 eclipse in Figure 5.

Figure 1 shows the timings of the eclipses on Hathaway’s butterfly diagrams. The eclipse dates of 1878, 1900, 1901 seem to sample similar phases in their respective cycles as the 2008 and 2009 eclipses. We conclude that the 1878, 1900 and 1901 eclipse data are indeed appropriate datasets to compare with the recent minimum corona. Note that the 1995 eclipse occurs at a period when significant flux emergence is still occurring.

Table 1. Eclipse images examined

| Eclipse date | Location(s)          | SSN<sup>a</sup> | Spotless days<sup>a</sup> | Cycle length<sup>b</sup> (yr) |
|--------------|----------------------|------------------|--------------------------|------------------------------|
| 1878 Jul 29  | Wyoming, Colorado    | 3.4              | 280                      | 11.7                         |
| 1900 May 28  | Georgia              | 9.4              | 158                      | 11.6                         |
| 1901 May 18  | Sumatra              | 2.8              | 287                      | 11.6                         |
| 1923 Sept 10 | Mexico               | 5.8              | 199                      | 9.9                          |
| 1965 May 30  | Bellinghausen Island | 15.1             | 70                       | 10.3                         |
| 1995 Oct 24  | India                | 17.5             | 61                       | 10.0                         |
| 2008 Aug 01  | Russia               | 2.8              | 266                      | 12.6                         |
| 2009 Jul 22  | Marshall Islands     | 3.2              | 261                      | 12.6                         |

Notes: <sup>a</sup>These are sunspot numbers and spotless days for the year during which the eclipse occurred; <sup>b</sup>This is the length of the complete cycle before the date of the eclipse.

Historical eclipse photographic data are not of a uniform quality. Furthermore they suffer from limitations inherent in photographic techniques and, in a few cases, from damage and/or artifacts. Before 1907 plates were sensitive only to blue light (Wallace [1907]). Figure 2 shows one exposure from the 1878 eclipse.
obtained by Hall. In this case the dynamic range of the image is limited, and

which, as shown in the figure, are rotated and scaled to the solar orientation (N upwards, E left) and apparent angular size. The rotations are accurate to about 1 degree and have been done by eye only, and the scales are set to a fixed angular diameter for convenience.

We have processed some of the data following Druckmüller et al. (2006); Druckmüller (2009). The processing has two major components- co-alignment and filtering. Co-alignment is done using a modified phase correlation method, based on Fourier transforms, enabling the translation, rotation, and scaling factors to be found for two images. Pairs of images with different exposure times and different brightness scales (including non-linear cases like the photographic records) are treated. Adaptive filters inspired by human vision are applied to sets of eclipse plates. The resulting co-added and filtered images approximate what is seen by the human eye during an eclipse, and have minimal artifacts. They represent considerable improvements over unsharp masking methods. In the case of the 1878 eclipse, the scanned data are of insufficient quality to apply these algorithms. In this particular case the sketches made by observers are better suited to examine the morphology of the corona (USNO 1880). But for other data the processing is effective. Figure 3 shows the results applied to the eclipse of 1901.

For comparison, we show in Figure 4 data obtained by one of us (MD) using CCD imaging techniques, and processed in the same manner, for the 2008 and 2009 eclipses. Note that only the morphology can really be compared between the

Figure 2. Left: One scanned negative plate for the eclipse of 1878. Note the limited dynamic range of the image. Right: Edge-enhanced version of the same image highlighting polar plume structure and some plate defects.
photographic and CCD data, owing to non-linearities inherent in photography, the filtering techniques, and the color tables chosen simply to highlight the coronal structures. We see that the morphology of the 2008/2009 corona is qualitatively similar to the corona in 1901. It is certainly not a “canonical solar minimum” corona consisting of a simple dipole with an equatorial current sheet—such a configuration is represented by the image shown in Figure 5. Instead we see that there are prominence cavities around the polar crown (see articles by Burkepile and Altrock in this volume).

Conclusions and speculations

It is sometimes believed that more information on the coronal morphology is contained in the 19th and early 20th century drawings of eclipses than in the photographic records. But we have shown that the historical eclipse plates, when digitized and carefully processed, can approach a quality which enables meaningful comparison with modern CCD images. We have shown that the recent solar minimum corona has a morphology very similar to eclipses from 1900 and 1901, and perhaps 1878, which is to be re-processed.

Qualitative differences seem to exist between a “classic” dipolar/current sheet minimum configuration (Figure 5) and the extended minima apparent in other figures. Eclipse data for extended minima show higher order multipolar structure, associated with high latitude prominence cavities. In coronagraph data much of the low-lying structure lies beneath the occultor. In the recent minimum, coronagraph data are dominated by two streamers either side of the equator (Burkepile, this volume), structure also manifested as a “warped” helio-
spheric current sheet, consistent with the prominence cavity structure evident in Figure 4.

We speculate on two different causes of these different properties. It is common to invoke the strength and area of the unipolar polar fields as a dominant influence on the coronal morphology. But this can occur mostly at heights $\gtrsim 0.5R_\odot$, say, when the excess magnetic pressure from strong polar fields pushes magnetic structures equator-ward, producing a classic dipole/current sheet corona (Figure 5). However, below $\sim 0.5R_\odot$, local magnetic sources tend to dominate the magnetic force balance. This is obviously more evident in eclipse data than in coronagraph data, simply because of the angular size of the occulter. We can apply arguments concerning the distribution of magnetic polarity on the Sun’s surface put forward by [Callebaut et al. (2007)]. While these authors discuss non-simultaneous polar field reversals, we draw attention to lower latitude regions. During extended minima, little flux emergence occurs at low latitudes, but emergence from the new cycle begins. Trans-equatorial coronal structures may then be relatively dim. At the same time meridional circulation continues to transport the footpoints of the previously emerged magnetic flux pole-ward. In time, less magnetic flux crosses the equator, as coronal magnetic connections are re-made at higher latitudes. The equatorial current sheet weakens, and the coronal images appear more multipolar, as seen in eclipse data for 2008, 2009 and 1901.

Perhaps the primary differences relate ultimately to the total magnetic field generated by the dynamo. If the total emerging magnetic flux in cycle 23 were less than that in cycle 22, it would take longer to reverse the polar fields, there would be more mixed polarity at the poles, and weaker fields near $1R_\odot$.

Figure 4. Left: Processed CCD image for the 2008 eclipse, obtained and processed by Druckmüller. Right: Similar data for the 2009 eclipse.
Figure 5. A 1995 eclipse image obtained by Rusin and processed by Druckmüller.

The HAO eclipse archive will be made publically available soon\footnote{http://mlso.hao.ucar.edu/mlso\_eclipses.html}. Readers are encouraged to contact HAO staff if they have data that might be added to this archive.

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