The Butterfly Diagram in the Eighteenth Century

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Abstract Digitized images of the drawings by J.C. Staudacher were used to determine sunspot positions for the period 1749–1796. From the entire set of drawings, 6285 sunspot positions were obtained for a total of 999 days. Various methods have been applied to find the orientation of the solar disk, which is not given for the vast majority of the drawings by Staudacher. Heliographic latitudes and longitudes in the Carrington rotation frame were determined. The resulting butterfly diagram shows a highly-populated Equator during the first two cycles (cycles 0 and 1 in the usual counting since 1749). An intermediate period is cycle 2, whereas cycles 3 and 4 show a typical butterfly shape. A tentative explanation may be the transient dominance of a quadrupolar magnetic field during the first two cycles.

Keywords Sun: sunspots - Sun: magnetic field

1. Introduction

Sunspots typically appear at heliographic latitudes between 10° and 40°. At the beginning of the solar cycle, latitudes tend to be relatively high, but the appearance locations of sunspots shift to low latitudes as the cycle goes on. A plot of the spot appearance latitudes versus time leads to the butterfly diagram (Maunder, 1904). The diagram is typically plotted starting in 1874 with the Greenwich drawings of the solar disk. The shape of the appearance latitude as a function of time has not significantly changed since. Regular updates of the butterfly diagram are provided by Hathaway in publications and on the Internet (see, e.g., Hathaway et al., 2003).

It is desirable to extend the butterfly diagram into the past. Especially after the Maunder minimum, the butterfly diagram may tell us about the characteristics of the solar dynamo when it was returning to normal after an activity lull with very few sunspots seen between 1645 and 1715.
There is a considerable set of drawings of the solar disk made by Johann Staudacher from 1749 to 1796. The total set of 848 drawings was digitized and described by Arlt (2008, hereafter Paper I). The drawings contain information about 1031 days in this period, with several days combined in one drawing, and notes about days when nothing was seen. (Note that the number has slightly increased since Paper I, because of additional notes taken into account.) For 999 of them, sunspots were plotted. Note that Wolf (1857) was aware of Staudacher drawings and counted the sunspots for his sunspot-number time series, which is still used today. But the positions have never been determined.

In this study, sunspot positions for 999 of the drawings by Staudacher and the first butterfly diagram obtained for the eighteenth century are presented. Section 2 evaluates the direction of the rotation in the drawings, which appeared to have changed during the observing period of 47 years. Section 3 deals with the various methods to derive the orientation of the solar Equator, and Section 4 describes the actual position measurements once the Equator is given. Section 5 shows the results of the coordinate determinations in the form of a butterfly diagram and discusses its features and limitations. Finally, Section 6 discusses possible implications for the theory of the solar dynamo.

2. Rotational Direction

Even though the rotation is obvious in many sequences of drawings over several days, there is still an ambiguity between a “normal” image and a mirrored, upside-down image. The two cases are geometrically distinct only by the inclination of the solar rotation axis to the ecliptic, which is far less obvious.

Although the rotational direction was from right to left – according to a mirrored, upright projection image – in all images until the end of 1760, spots appear to move from left to right starting in 1761. An obvious occasion is already the pair of observations of 20 and 24 February 1761. If the images were still projected, North must then be at the lower border. The observation of 25 May 1761 has indeed “Süd” (South) at the upper solar limb.

Did Staudacher stop using the mirrored image of the projection, or did he turn the images by 180°? The eclipse of 1753 is an upright but mirrored image, just as the sunspot drawings. The eclipse of 1769 is a mirrored image, turned by 180°, which is consistent with the upside-down sunspot drawings starting in 1761. The eclipse of 1791 does not show the direction of the motion of the Moon, but the geometry and the indications of the south pole and the north pole, which are assumed to point to the celestial ones, are consistent with a mirrored and rotated image, just as it was in 1769.

The assumption of rotated, but still mirrored, images is backed up by further annotations with compass directions, which are listed in Table 1. These are – together with the lunar motion in solar-eclipse drawings – all of the indications available, and it is assumed that all images are mirrored throughout the period of 1749 – 1796. Before any of the operations described in the following sections are performed, all images were mirrored. The change in orientation may mean that Staudacher used a Keplerian telescope until 1760 and a Gregorian starting in 1761, but this is speculation.

3. Position Angles of the Disks

There is no single way of fixing the orientation of the drawings. We have to rely on various methods with various uncertainties. An automatic method to obtain the sunspot positions