Contrib. Astron. Obs. Skalnaté Pleso **43**, 73 – 80, (2013)

The width of helmet streamers as inferred from ground-based eclipse observations

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Received: February 20, 2013; Accepted: July 29, 2013

Abstract. The white-light eclipse solar corona shows a plethora of structures of varying size and shape. A prominent type of them, very bright and far elongated of the solar limb, are the so-called helmet streamers, which connect regions of opposite magnetic polarity. We tried to derive their angular width from a series of eclipse observations. Our analysis shows that this width is, on average, around 32 degrees and seems not to depend on the cycle amplitude, its phase and/or its global magnetic activity. The traces of bright arcades, as located and observed at the bases of helmet streamers, were found to extend up to $0.70 R_{\odot}$.

Key words: Sun – helmet streamers – bright arcades

1. Introduction

The solar corona observed during total solar eclipses is endowed with a remarkable rich variety of structures, e. g. polar plumes, coronal cavities, helmet streamers, etc. Amongst them, helmet streamers are most conspicuous and usually long-lived features, brighter than the surrounding corona and extending far off the solar limb: from several to 20 $R_{\odot}$ as inferred from ground-based observations (Rušin et al., 2010), and even up to 32 $R_{\odot}$ as inferred from SOHO's data accessible at `http://sohowww.nascom.nasa.gov/data/realtime-images.html`. According to present knowledge, helmet streamers are located above quiescent prominences (or filaments when viewed against the solar disk) and represent quasi-static structures with closed magnetic loops which connect regions of opposite magnetic polarity. A typical helmet streamer exhibits a three-part structure: a high-density dome, a low-density cavity below the dome, and a quiescent prominence inside the cavity (Pneuman & Orrall, 1986). Distribution of helmet streamers varies within a solar cycle. During cycle minima, when the large-scale magnetic fields of the Sun have a pronounced dipole character, they are mostly located around the equator, whereas during cycle maxima they are seen around the whole solar limb. Helmet streamers are usually confined to the "streamer belt" in the mid latitudes, and, as shown by Bělík et al. (2004), their migration pattern during a cycle seems to follow that of prominences/active regions.

An importance of helmet streamers substantially increases with their intricate relation to the solar wind and interplanetary sector boundaries (Wang et al., 2007). Coronal streamers are assumed to be the source region of the solar wind. Sheeley et al. (1997) detected a continuous outflow of material in the streamer belt, as they were observing Thomson scattering from inhomogeneities in the solar wind. Wang et al. (1998, 2000) announced that helmet streamers have been observed to release "blobs" of coronal gas into the solar wind. These blobs are emitted from the tip of the streamer, with an occurrence rate of up to four blobs per day during quiet coronal conditions. Although a number of papers have been devoted to understand the origin and overall form of helmet streamers (e. g., Glukhov, 1997, Guo and Wu, 1998, Endeve et al., 2004, Wang et al., 2012), not much is known about their actual width. Here by the width of a helmet streamer we mean the angular distance between the visually-determined outer boundaries of the streamer's high-density dome at the level of the photosphere.

This short paper aims at finding a typical width (base) of helmet streamers based on the data acquired from ground-based observations of total solar eclipses. Our results may, for example, be of some relevance for theoretical modelings of helmet streamers, which have so far used this parameter as a free one.

2. Observations

Although helmet streamers can readily be identified on any properly processed picture of the eclipse corona, finding their width is a rather intricate task due to the following facts: a rather low contrast between individual streamers and a rather steep gradient of their brightness with the height above the solar surface; a varying alignment of the neutral line with respect to the line of sight; and an effect of superposition of thin and multifaceted streamers spread out alongside the neutral line, leading to a broader fan-shaped structure. However, a recently-invented method of image processing by Druckmüller (see Druckmüller et al., 2006, and/or Druckmüller, 2009, to be compared with Koutchmy et al., 1988) considerably facilitates this task. The observations employed for our analysis are mostly our own, covering the period from 1980 to 2012, complemented by several older high quality data found elsewhere. An older example of a couple of them is depicted in Figure 1 *top*, whilst Figure 1 *bottom* depicts a well-discernible streamer of the 2008 eclipse, based on the observations processed by the above-mentioned method. The results of our study are summarized in Table 1 and Figure 2.

3. Results and Conclusions

We have found that a typical width of helmet streamers lies within a rather narrow interval of 28–40 degrees, with the average amounting to 32 degrees. As our data — spanning cycles 17 to 24, except for cycle 18 (1944.2 – 1954.3) — roughly cover all phases of a solar cycle, save that around the cycle min-

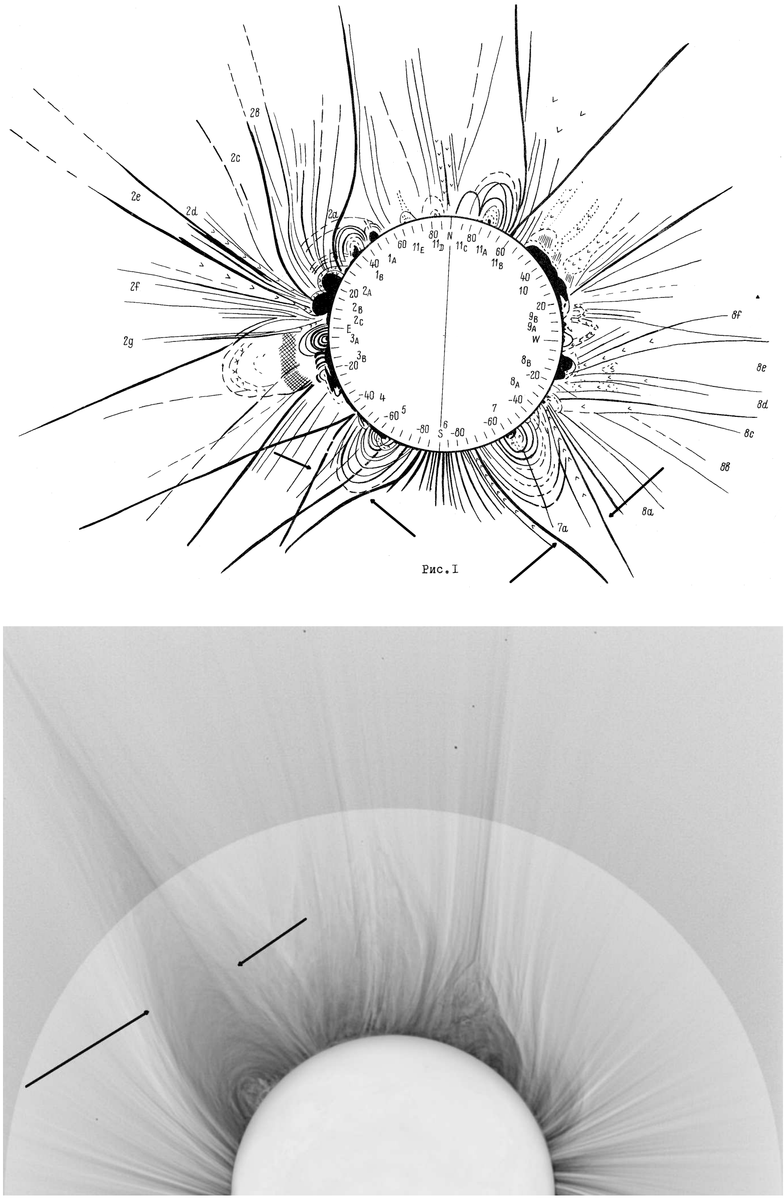

Figure 1. *Top*: – An illustration of the structure of the eclipse white-light corona of September 22, 1968 as observed by Vsekhsvjatsky et al. (1970; Figure 1), using a 10-meter (focal length) telescope. The helmet streamers selected for our study are denoted by arrows. *Bottom*: – An example of a well-developed helmet streamer (marked by arrows) as observed on August 1, 2008. The east is directed to the top, the south is left. (Courtesy by M. Druckmüller, P. Aniol and V. Rušin.)

Table 1. The characteristics of well-developed helmet streamers. Here PA stands for the positional angle, W represents the width of the helmet streamer and P denotes the cycle phase.

Date of observation	PA	W	P	Reference
July 19, 1936	304–339	35	0.26	Bronshtejn (1960)
October 2, 1959	125–157	32	0.51	Waldmeier (1978)
February 15, 1961	300–330	30	0.64	Vsekhsvjatsky & Ivanchuk (1961)
February 4, 1962	221–253	32	0.74	Saito and Hyder (1968)
July 20, 1963	300–333	33	0.87	Waldmeier (1963)
May 30, 1965	63–95	32	0.04	Waldmeier (1965)
September 22, 1968	198–238	40	0.33	Vsekhsvjatsky et al. (1970)
	137–171	34		
March 7, 1970	25–57	32	0.46	Waldmeier et al. (1970)
	174–206	32		
July 10, 1972	109-142	33	0.66	Kim and Nikolsky (1975)
	155-187	32		
June 30, 1973	281–311	30	0.74	Lilliequist (1977)
February 16, 1980	23–53	30	0.35	Rušin and Rybanský (1983)
	58–86	28		
	182–210	28		
July 31, 1981	205–235	30	0.49	Rušin and Rybanský (1984)
June 11, 1983	118–156	38	0.67	Rušin and Rybanský (1985)
August 11, 1999	320–352	32	0.22	yet unpublished
August 1, 2008	110–143	33	0.96	Rušin et al. (2010)
November 13, 2012	134–168	34	0.36	Shiota (2013)

ima, and also entail different heliographic latitudes, this would indicate that the widths of helmet streamers are not very sensitive on the solar activity and variations of large-scale magnetic fields of the Sun; indeed, from the data acquired from the site `ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/INTERNATIONAL/maxmin/` one sees that these cycles differ pronouncedly from each other concerning the magnetic field strength as inferred from smoothed out Wolf's number, the latter ranging from the value of 201.3 (cycle 19) to that of 96.7 (current cycle; `http://www.solarham.net/averages.htm`), yet the phase variation of the widths (Figure 2) does not seem to mimic that. From Table 1 it also follows that the width is rather insensitive on the positional angle as well.

The above findings and claims, however, represent at this stage only a rough conjecture as our sample is rather meager and much more extended statistics has to be performed to confirm or falsify them. At first sight, this might not appear to be a big problem due to a relatively large number of helmet streamers

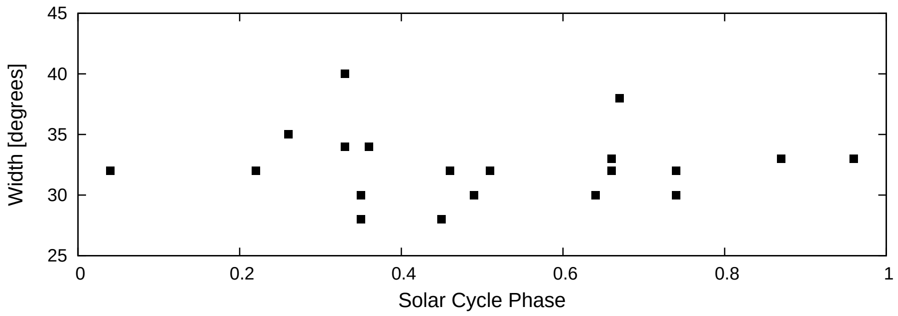

Figure 2. A distribution of the widths of helmet streamers with a cycle phase. The cycle minima correspond to 0 and 1, the maxima are located around 0.3. As already mentioned, we do not have at hand a sufficiently representative sample. This implies that since around the maxima the number of observed helmet streamers is biggest, also their widths can acquire various values. If the observed widths attain their biggest and smallest values around the maxima, the phase of the cycle thus plays no role.

visible during total eclipses and their dominant shape. The problem, however, is that to get a reasonable estimate of their widths, due to the facts listed above, a streamer must be seen "face-on," i. e. oriented in such a way that the line-of-sight is almost parallel to the neutral line, or the axis of the cavity it envelops. This rather stringent constraint is only met by a tiny fraction of streamers, since a prevailing position/orientation of a streamer is that depicted in Figure 3. Anyway, our analysis seems to point out the existence of a characteristic width of helmet streamers, which is certainly the parameter that should tell us something new about the generation of large-scale structure of magnetic fields well under the photosphere, maybe in a form of giant cells, that are responsible for the formation of helmet streamers and their generic shape. Pushing this even further, couldn't such a characteristic width be an indicator that the magnetic fields governing the shape and structure of a mature helmet streamer are rooted/anchored right at the boundary between the convective zone and the zone of radiative transfer (the so-called tachocline)? This seems to be a viable scenario as helmet sreamers could be connected with giant cells (giant structures of a cellular shape with the size of 30–40 degrees) as shown and extensively discussed by Plyusnina (1998, and references therein) using the background magnetic fields. Interestingly, the existence of a cellular-like structure of large-scale magnetic fields also stems from a recent work of Merzlyakov and Starkova (2012) based on the analysis of the K-corona emission polarization plane during three solar eclipses; they found two characteristic angular sizes of 61 ± 6 and 36 ± 2 degrees, the latter being very close to our finding.

It should also be stressed that although in the white light a fully-developed helmet streamer looks as a compact object, in reality it is a rather complex and

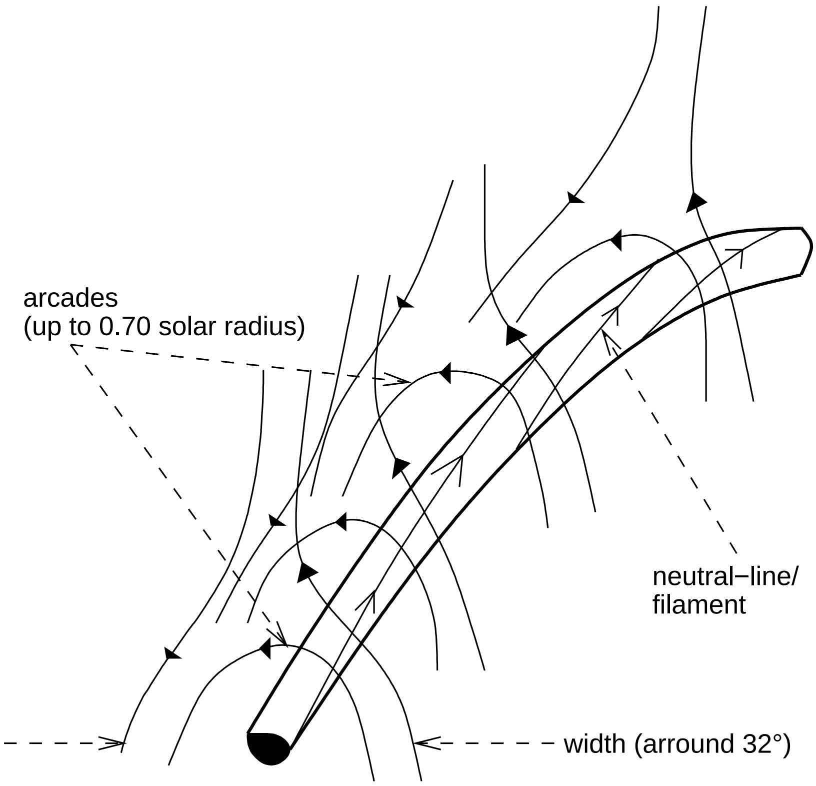

Figure 3. Illustration of a typical orientation (and magnetic field topology) of helmet streamers with respect to the line-of-sight.

highly dynamic ensemble of various structures, see, e. g. Guo and Wu (1998, and references therein), which are still difficult to model. Thus, for example, Morgan and Habbal (2007) proposed an empirical 3D model of the large-scale coronal structure — which contains an ensemble of high-density sheets as seen from SOHO at greater heights above the solar surface — based on the distribution of H_α filaments on the solar disk. Even though the agreement between their modeling and observational data is rather good, they stress that "the model does not closely replicate the internal or core structure of helmet streamer bases." A rather complicated structure of the bases is also pointed out by Berger et al. (2011), who have found that low density "bubbles" contain plasma at temperatures in the range $2.5 - 12 \times 10^5$K, which is 25–120 times hotter than the streamer's overlying prominence.

Finally, we shall briefly address the questions of the height of arcades characterizing a helmet streamer. Saito and Hyder (1968 and references therein) analyzed such arcades for 1962 eclipse observations and some older data and found an intriguing sequence 0.10, 0.18, 0.27, 0.36 (photometric) and/or 0.42 (visual estimate) $R_\odot$. For the September 22, 1968 corona, Vsekhsvjatsky et al. (1970) found the maximum height of 0.72 $R_\odot$, whereas in the case of the June 30, 1973 corona this height amounts to 0.75 $R_\odot$ (Vsekhsvjatsky et al., 1981). A brief inspection of our data yields the maximum height to be $0.70R_\odot$, with its well-identified (visual) average being 0.42 $R_\odot$. In this respect, it would be interesting to find out whether the observed maximal height of arcades is pronouncedly connected with the dynamics of helmet streamers as it is, for example, indicated by older observations of Schwenn et al. (1997), considered in more recent modeling of Endeve, Holzer and Leer (2004) and lately also discussed by Wang et al. (2012). It is obvious that to answer all these questions, and thereby get deeper insights into the very existence of helmet streamers, one needs not only new ground-based observations of the eclipse corona, in particular those with sufficiently high spatial resolution, but also improved numerical simulations of the behavior of coronal plasma, as recently emphasized by Antiochos et al. (2012). This all the more since a proper understanding of sharp gradients across the boundaries of helmet streamers is a key issue not only for the large scale structure of the corona, but also because they determine the coronal and solar wind structures and in which solar energetic particles are accelerated and propagate.

Acknowledgements. This work was partially supported by the VEGA project 2/0003/13 and NGS-3139-12 of the National Geographic Society. We are grateful to K. Shiota (Japan) for kindly providing us with one of his 2012 eclipse corona pictures. We also thank the anonymous referees for their constructive remarks and suggestions.

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