New types of the chromospheric anemone microflares: Case study

Yu. V. Dumin$^{1,2,*}$ and B. V. Somov$^{1,**}$

1 Sternberg Astronomical Institute (GAISH) of Lomonosov Moscow State University, Universitetskii prosp. 13, 119234, Moscow, Russia
2 Space Research Institute (IKI) of Russian Academy of Sciences, Profsoyuznaya str. 84/32, 117997, Moscow, Russia

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ABSTRACT

Context. The chromospheric anemone microflares (AMF) are an interesting kind of the transient solar phenomena where the emission regions have a multi-ribbon configuration, as distinct from the ordinary flares usually possessing only two ribbons. The previously reported AMFs had typically three or, less frequently, four ribbons; and it was shown in our recent Letter [Yu.V. Dumin & B.V. Somov, A&A, 623, L4 (2019)] that they can be reasonably described by the so-called GKSS model of magnetic field, involving four magnetic sources with various polarity and arrangement.

Aims. An interesting question is if one can see more complex types of AMF (containing the greater number of the emission ribbons), which might be produced by more elaborated magnetic configurations?

Methods. To answer this question, we performed a visual inspection of the large set of the emission patterns in the chromospheric line Ca\(\text{II}\) recorded by Hinode/SOT and confronted them with the respective magnetograms obtained by SDO/HMI.

Results. As follows from our analysis, it is really possible to identify the AMFs with much more complex spatial configurations as compared to the previously-known ones, e.g., involving five luminous ribbons with a nontrivial arrangement. They are produced by the effective magnetic sources (sunspots) of different polarity with intermittent arrangement in the cross-like configuration, but their number is greater than in the standard GKSS model.

Key words. Magnetic fields – Sun: flares – Sun: magnetic fields

The so-called anemone microflares (AMF) are the specific type of flaring phenomena in the solar atmosphere, which were discovered by Hinode satellite soon after beginning of its operation (Shibata et al. 2007). These flares are characterized by the unusual spatial configuration of the emission regions: as distinct from two ribbons in the large solar flares, the AMFs reported by now possessed three or, less frequently, four ribbons oriented at various angles with respect to each other (Nishizuka et al. 2011, Singh et al. 2011, 2012).

It was assumed in the first paper by Shibata et al. (2007) that the multiple emissive ribbons are formed due to the split magnetic tubes in the base of the solar atmosphere; see Fig. 3(D, E) in the above-cited article. Next, our recent paper (Dumin & Somov 2017) have shown that the entire variety of geometric configurations in the three- and four-ribbon AMFs can be reasonably described by the so-called GKSS model of magnetic field, suggested by Gorbachev et al. (1988) over three decades ago (for mathematical details, see also Brown & Priest (1999)), in brief, this model involves four magnetic sources (sunspots)—two positive and two negative—located in the same plane (photosphere). The global pattern of the magnetic-field lines is given by the “two-dome” structure, where four domains of different topological connectivity are bounded by the two superimposed domes (separatrices), which intersect each other along the separator (e.g., Fig. 4.2 in Somov 2013).

Then, assuming that the primary energy-release region is localized at the top of the separator (see Fig. 3 in Dumin & Somov (2017)), it can be shown that its projections along the magnetic-field lines onto the plane of chromosphere experience a complex transformation near the region of “topological instability” (Fig. 5 in the same paper); and the resulting pattern of the emissive ribbons closely resembles the entire variety of three- and four-ribbon AMFs reported previously in the literature (Shibata et al. 2007; Nishizuka et al. 2011, Singh et al. 2011, 2012). The above-mentioned topological instability is realized, roughly speaking, when three magnetic sources with intermittent polarity are situated approximately along the same line, while the fourth source is located aside from them (for more details, see Fig. 1 in Dumin & Somov 2017, and the corresponding discussion there).

A natural question arises: Is it possible to get more complex AMFs (namely, involving more than four ribbons) when a more sophisticated configuration of the magnetic sources is realized? (Unfortunately, as far as we know, such cases were not reported in the previous literature.) To answer this question, we performed a visual inspection of a large series of pictures of emission in Ca\(\text{II}\) line taken by the Solar Optical Telescope (SOT) onboard Hinode spacecraft (Kosugi et al. 2007, Tsuneta et al. 2008), which are stored now in the Hinode archive and confronted them with the corresponding magnetograms by the Hinode satellite.

\[\text{https://hinode.nao.ac.jp/en/for-researchers/qlmovies/top.html}\]
temporal sequence of emission in \textit{Ca} \textit{ii}

Fig. 1. Example of the five-ribbon flare in the solar chromosphere: a science teams). A sketch of the ribbon configuration is also plotted in (bottom panel, courtesy of NASA

lioseismic and Magnetic Imager (HMI) onboard \textit{SDO} satellite [Pesnell et al.2012], which are available at the Joint Science Operations Center (JSOC) web-site. Attention was paid, first of all, to the regions of the solar surface involving a complex configuration of sunspots with different polarity.

The above-mentioned analysis really enabled us to identify the AMFs with a larger number of the emissive ribbons as compared to the previously-known three- and four-ribbon flares. One of the most interesting examples is shown in Fig. 1: it was recorded on 16 February 2014 at about 05 UT. As is seen, the flare begins to develop at 05:04:43 UT with three or four ribbons (depending on their definition). Then, at 05:05:44 and 05:06:43 UT one can see a complex structure composed of five (or even six) ribbons. At last, starting from 05:08:44 UT the ribbons acquire a diffusive character and gradually disappear.

At the first glance, a semi-circular segment in the right-hand side of the structure looks like an arc extending into the upper layers of the atmosphere. However, one should keep in mind that this AMF occurred quite close to the west limb, while it looks bent to the center of the Sun (rather than outwards) in the picture plane. So, we should conclude that it is located most probably on the surface.

A lifetime of the entire structure is 2-3 minutes, which is comparable to (or even somewhat less than) the lifetimes of “ordinary” AMFs reported before (e.g., Fig. 2 in Shibata et al. 2007). On the other hand, a characteristic length of the entire structure in our case is about 20" (15 000 km), which is substantially greater than for ordinary three- and four-ribbon AMFs (3–7", or 2000–5000 km). Besides, while thickness of the ribbons in the ordinary AMFs is 0.2–0.4" (150–300 km), in our case they can be much thicker (up to 1–2", or 700–1500 km), but this depends on the particular ribbon.

To understand the structure of magnetic field responsible for this AMF, we superimposed a sketch of the emissive ribbons onto the magnetogram of the corresponding region (bottom panel in Fig. 1). As is seen, the flare is produced by four magnetic sources (positive, negative, negative, and positive) along the parallel and a few sources (mostly, positive) away from them, along the meridian. Such a configuration qualitatively reminds GKSS model of the magnetic field, successfully used for the description of three- and four-ribbon AMFs, but evidently involves a larger number of sources. A detailed topological analysis of such magnetic configurations is still to be done (for the recent reviews of topological models of solar magnetic fields, see Longcope 2005, Janvier 2017).

In summary, by analyzing the available archives of solar data, we have found new types of AMF, which are much more complex than the previously-known ones, and identified them with the magnetic-field structures responsible for their occurrence.

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\footnote{One of the theoretical models with a large number of magnetic sources was developed, e.g., by Inverarity & Priest (1999); but these sources had a very symmetric arrangement, which is hardly relevant for the case under consideration.}

\url{http://jsoc.stanford.edu/HMI/hmiimage.html}

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