Wave-like formation of hot arcades

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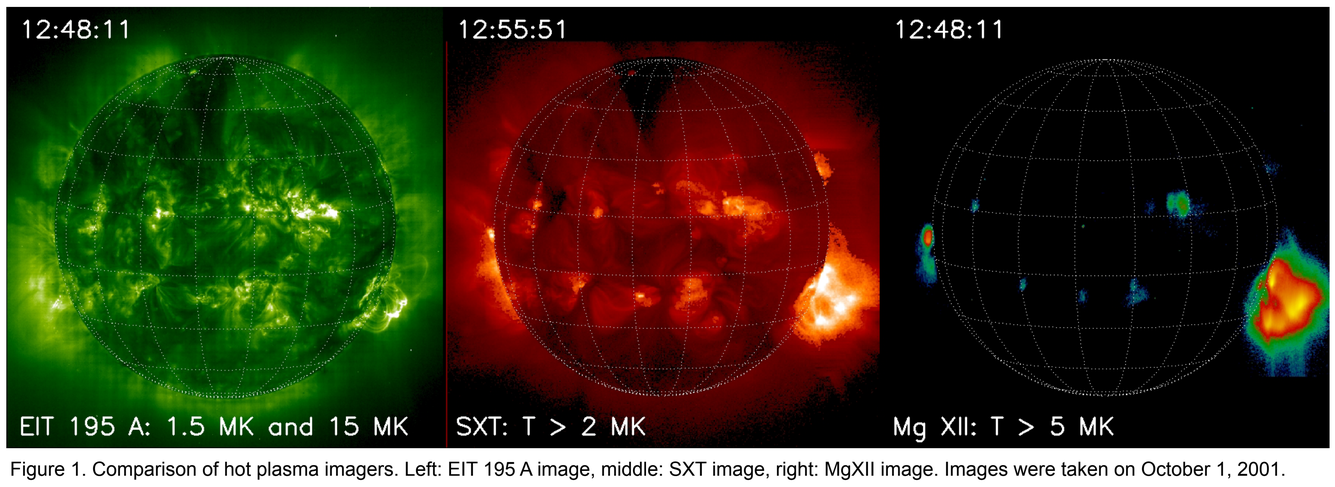

Figure 1. Comparison of hot plasma imagers. Left: EIT 195 A image, middle: SXT image, right: MgXII image. Images were taken on October 1, 2001.

1. Spectroheliograph Mg XII

The MgXII spectroheliograph (CORONAS-F satellite) built images of hot coronal plasma in the MgXII 8.42 A resonance line. Plasma emits this line at temperatures greater than 5 MK; therefore, the MgXII images contain only signal from hot plasma without any low temperature background. MgXII images differ from other telescopic images: there is neither a solar limb nor a quiet Sun background (see Figure 1). Typical structures on MgXII images range from 4 to 300 Mm in size and have a lifetime from several seconds up to several days. The MgXII spectroheliograph has two main advantages over `traditional' hot imagers:

1) all signal on the MgXII images is a hot plasma;
2) faint features can be seen, because cold background does not obscure them.

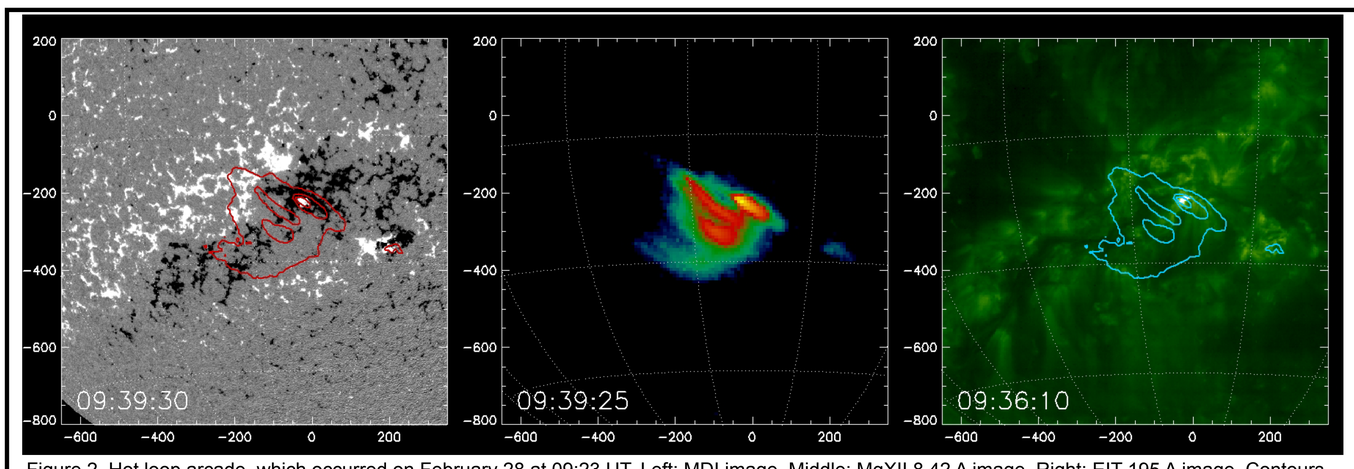

Figure 2. Hot loop arcade, which occurred on February 28 at 09:23 UT. Left: MDI image. Middle: MgXII 8.42 A image. Right: EIT 195 A image. Contours denote the MgXII signal. Coordinates are measured in arc seconds.

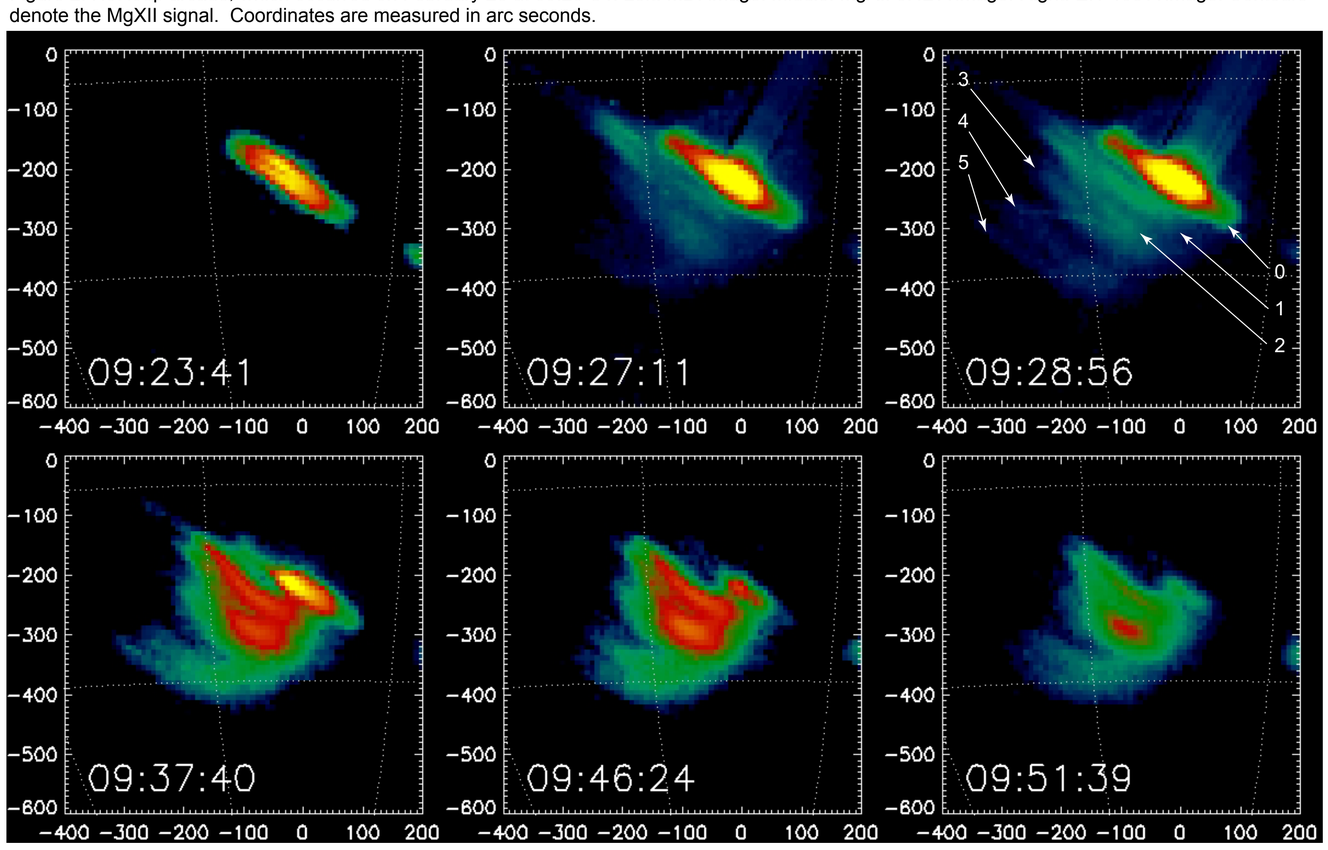

Figure 3. Hot arcade, which occurred on February 28 at 09:23 UT. 0) precursor; 1-5) loops of the arcade. Coordinates are measured in arc seconds.

2. Wave-like hot arcades

On February 28, 2002 spectroheliograph Mg XII observed four arcades, which formed in a wave-like manner. The arcades formed in the same active region (AR): above polarity inversion line (PIL) between two elongated regions of opposite polarities (AR NOAA 09847 and 09848, see Figure 2 left). On February 25, 2002, there was a flux emergence in the western part of the negative polarity region, and on March 1, 2002, it disappeared. This flux emergence caused 26 flares, after four of which hot loop arcades formed at 09:18, 14:13, and 22:28 UT on February 28, 2002, and at 00:40 UT on March 1, 2002 (see Figure 3). The evolution of all four arcades followed the same scenario:

1) On the MgXII images, a small hot source - we will call it “precursor" - appeared above the flux emergence region. At the same place and approximately same time, an HXR source appeared on the RHESSI images. For different flares, this phase lasted for 2-10 minutes.

2) Then, hot plasma filled other loops in a wave-like nature: loops that are closer to the precursor are filled earlier than the loops that are further. All four arcades formed in 5 minutes, which corresponded to wave speed of approximately 700 km/s.

3) The loops' intensity increased and reached maximum after 5-20 minutes. Maximum loop intensity was located in the apex above the PIL.

4) The loops' intensity gradually decreases over approximately 1 hour.

All four arcades had similar sizes: the loop length was 170 Mm, and the arcade length was 200 Mm (see Figure 2 center). The arcades consisted of 3-5 loops separated at ≈ 50 Mm. The brightness of the loops gradually decreased with distance from the precursor. Loop footpoints were rooted in the main regions of positive and negative polarities (see Figure 3).

On the EIT 195 Å images, the precursor looked like a loop with the size 20 Mm, but the arcade was invisible (see Figure 2 right). When the arcade cooled down and disappeared from the MgXII images, the brightest loop of the arcade appeared on the EIT 195 Å images.

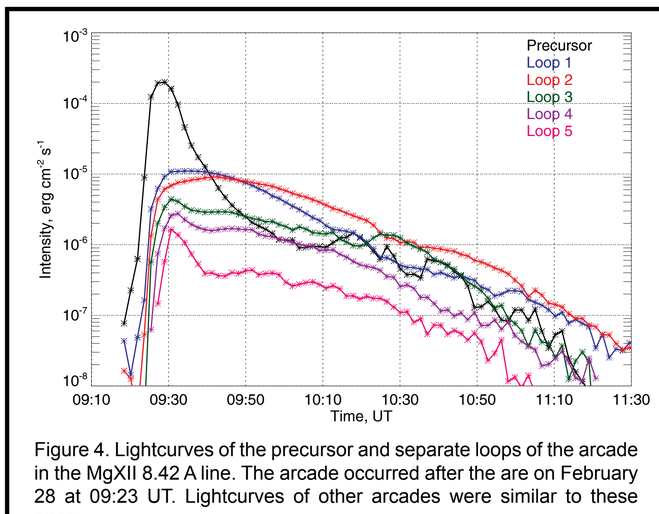

Figure 4. Lightcurves of the precursor and separate loops of the arcade in the MgXII 8.42 A line. The arcade occurred after the are on February 28 at 09:23 UT. Lightcurves of other arcades were similar to these ones.

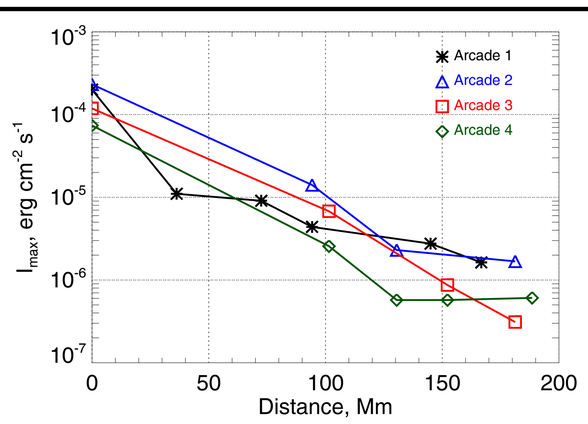

Figure 5. Dependence of the loops maximum intensity in the MgXII 8.42 A line on the distance from the precursor.

3. Lightcurves

We measured the lightcurves in the MgXII 8.42 Å line of the precursors and each loop of the arcades (see Figure 4). The maximum intensity of the precursor exceeded the maximum intensity of the brightest loop by one order of magnitude and by two orders of the intensity of the faintest loop.

The maximum intensity of the loops exponentially decreased with the distance from the precursor (see Figure 5). The intensity e-folding distance is 35 ± 5 Mm.

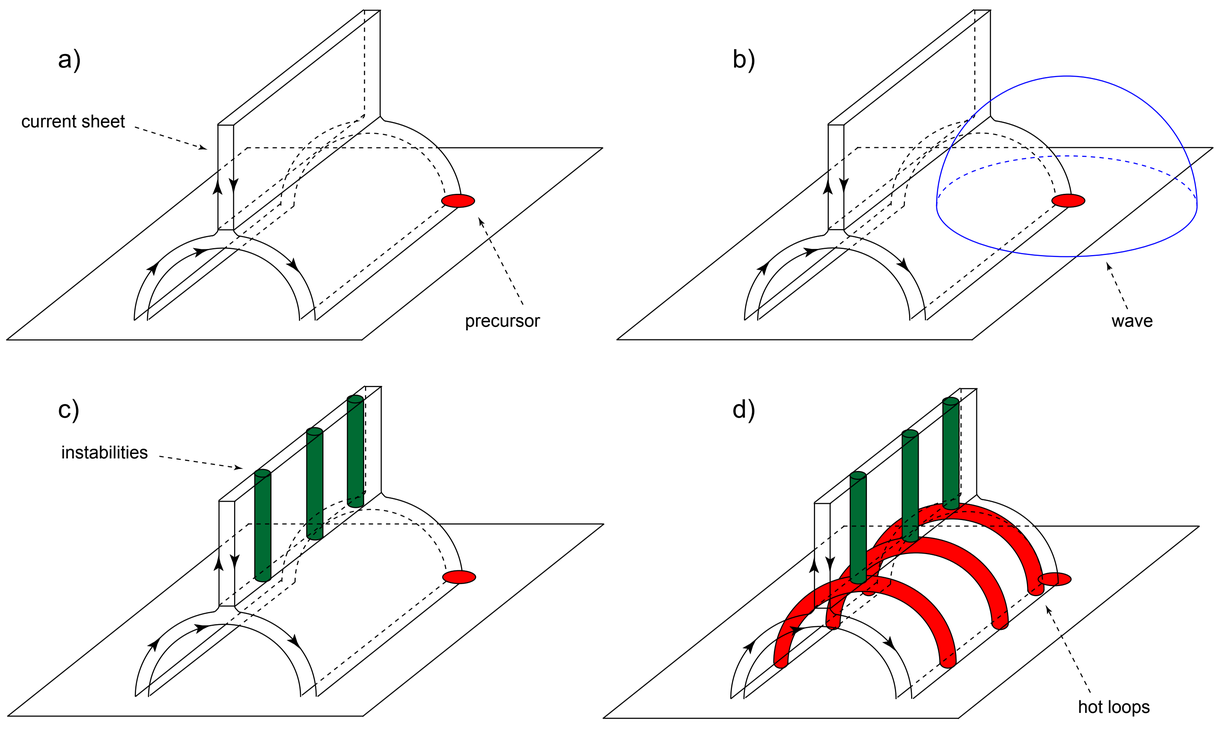

Figure 6. Schematic model of hot loop arcade formation.

4. Model

Some aspects of the observed arcades look unusual. First, it is the magnetic configuration, in which the events occurred. The precursor occurred above the flux emergence region in the quadrupolar magnetic configuration, suitable for flaring reconnection. It is clear that flux emergence caused the precursor reconnection. However, the arcade loops formed in a simple bipolar configuration, without changes in their magnetic field structure.

Second, the arcades formed in a wave-like manner, which hints that waves could play a role in the phenomena. Third, there is a cold space (distance) between hot loops. It is unclear, why some loops of the arcade are heated, and some are not. Neither wave-like formation, nor cold space, can be explained with the standard 2.5D flare model. We need an extension of the standard flare model into 3D, which will explain the observations.

To explain the observations, we propose that the current sheet existed above the loops apexes before the arcades ignited (see Figure 6). We think that the arcades evolution was the following:

1) The precursor occurred at the edge of the arcade (see Figure 6a).
2) The precursor launched an MHD wave, which propagated along the arcade (see Figure 6b).
3) The MHD wave caused instabilities in the current sheet (see Figure 6c).
4) The instabilities led to the heating of the underlying loops (see Figure 6d).