Current-Injection Model for Loop Flares and Active Region Transient Loop Brightenings

Takehiro Miyagoshi, Tomohide Yabiku, Yutaka Uchida, Shigenobu Hirose

Department of Physics, Science University of Tokyo, Shinjyuku-ku, Tokyo 162-8601

Abstract

A magnetodynamic model for loop flares is given by considering the case where the energy input comes from below in the form of dynamic current injection, or the release of large amplitude torsional Alfven wave train along the magnetic loop. The initial dynamical behavior of loop flare obtained by the SXT/Yohkoh can be reproduced by the model.

Key words: Loop Flares - Active Region Transient Brightenings - Magnetohydrodynamics - 3-D Numerical Simulations - Torsional Alfven Wave Train - Magnetic Twist Packet

1. Introduction

Yohkoh has made it possible for us to look into the very interesting dynamical phase of flares by taking advantage of high resolution, high cadence, and large dynamic range observations by the SXT, together with those of the HXT. When flares are classified roughly into two types, the first is LDE type and the second is impulsive type. The former has a large spatial scale (about 5×10^4 to 2×10^5 km), and a time scale of several hours. In contrast, the latter has a small spatial scale (about $(5 \sim 20) \times 10^3$ km), and a time scale $10 \sim 30$ min. Loop flares are flares which have loop structure, occur in active regions, and are classified as impulsive flares. The energy released in loop flares is about $10^{30 \sim 31}$ erg. The motionless point-like feature in loop flares reported from previous satellites seem to correspond to the later phase loop-top source fading away quietly without any motion, after it is established in the still faint dynamical phase. And as phenomena which resemble loop flares, there are active region transient brightenings. We investigate these phenomena with a three-dimensional (3D) numerical simulation.

2. Yohkoh Observation

Fig. 1 is a Yohkoh SXT image which shows initial dynamical time development of the loop flare (Uchida et al.1998).

According to the observation in Fig. 1, the footpoints brighten first, and then the loop top brightens, and the brightening region stays there for a short while. It is also of extreme interest that the shape of the loop is distorted before the brightness maximum, and the loop restores a smooth loop shape as the bright region settles down at the top.

In active regions, brightenings of loop structures occur frequently. Fig. 2 is a Yohkoh SXT image which shows the time development of active region transient brightenings. Shimizu et al.(1992) found that in some cases of loop brightenings, mass which has already been heated is injected into the loop from one of the footpoints with a velocity of a few hundred km/s or larger. It is remarkable that the gas injected is *already heated*.

We present a physical description of these loop-brightening phenomena in active regions in the following. We think these two events (loop flares and transient brightenings) are closely related. One of the reasons for this is that they have the same time and spatial scale.

3. Model and Numerical Simulations Result

3.1. Model

To explain these phenomena, we specifically consider a mechanism for energy transport from the subphotospheric layers to the corona. We think the reason of extra heating of the corona is due to energy supplied from below. We regard the finite amplitude torsional Alfven wave train (TAWT) to be the most likely candidate for delivering

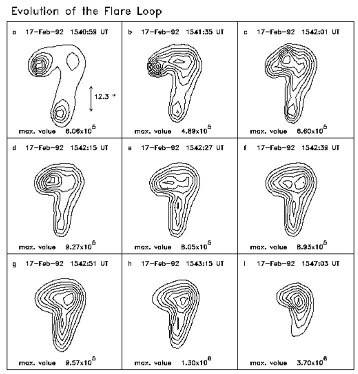

Fig. 1.. Initial Dynamical Development of a Loop Flare of Feb 17, 1992 (Uchida et al. 1998): Two footpoints brighten first, and the bright part is created at the loop top. During that time, movement of the bright point is seen. Then the shape of the loop is distorted.

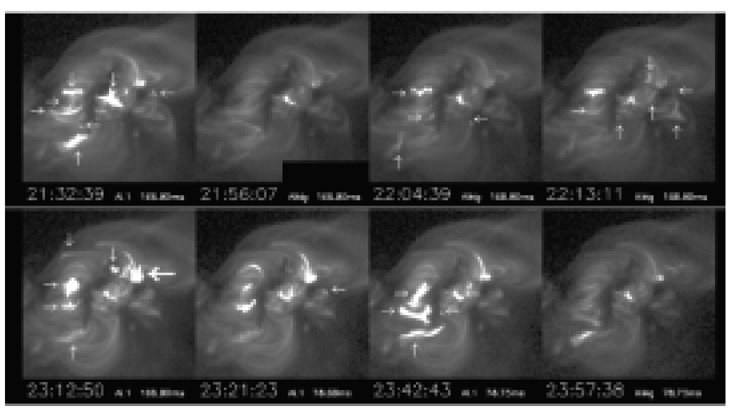

Fig. 2.. Active Region Transient Brightenings(Shimizu et al.1992). Time development of Transient Loop Brightenings in a typical active region.

the energy. If a TAWT (equivalent to coaxially closed MHD current packet) is created and released from the subphotospheric layer into a magnetic loop, it causes a progressing pinching which drives the heated, higher density gas with the Alfvén velocity (case 1 in Fig. 3). This very likely explains the active region transient brightenings. Next, we consider here TAWTs input to both footpoints. We consider the second one may come into the same loop coincidentally while the first one is still progressing in it; it collides with the first one somewhere high in the loop. The sweeping pinch model in Uchida and Shibata(1988) treats this situation in a 2.5D simulation. The collision produces a very high temperature region (case 2 in Fig. 3). The probability for this occuring is the square of the transit time/mean interval of active region transient brightening in that loop. The injector can either be the twist packets generated at the feet of loops due to the convection below the photosphere, or be the small emerging magnetic loops supplying the twist to the loop considered through magnetic reconnection. We investigate these phenomena by 3D MHD numerical simulations.

3.2. Numerical Simulations

To investigate these processes in active regions on the Sun through numerical simulations, we use the system of ideal MHD equations, and use a Lax-Wendroff scheme. For the detailed initial and boundary conditions refer Uchida et al. (1999). We release "magnetic twist packet" from one footpoint (for transient brightenings case), or from both footpoints (for loop flare case). Fig. 3 is schematic picture of this model. Figs. 4 and 5 are the result of numerical simulations for transient brightenings case. Figs. 6 and 7 are for the loop flare case.

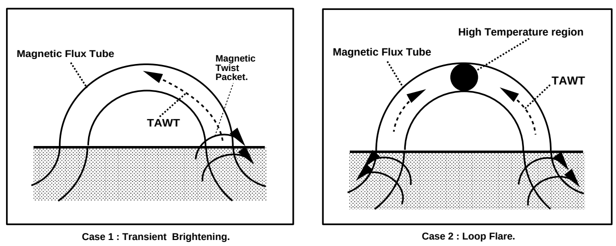

Fig. 3.. Models of transient brightenings and loop flares.

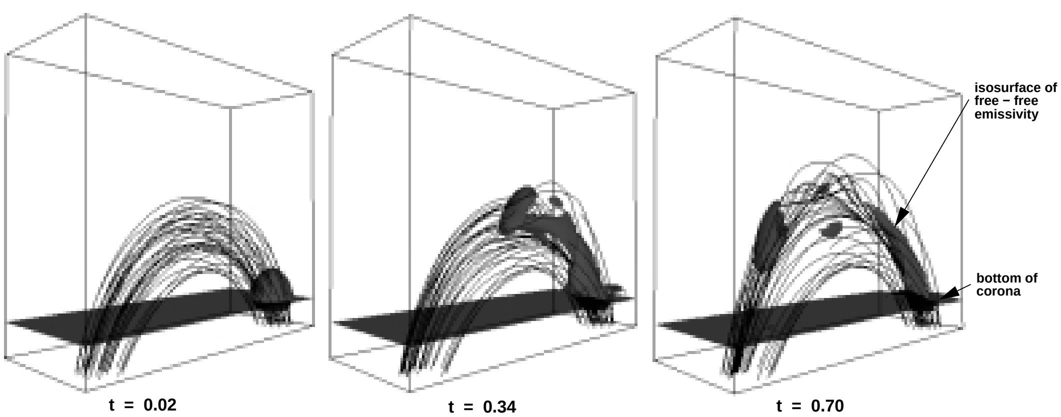

Fig. 4.. A Current Injection Model of Transient Brightenings with 3D MHD Simulation. The time development in the case of the injection of one TAWT into a loop. The line is magnetic field lines, and the iso-value surface is for $\rho^2 T^{1/2}$. The loop shape is distorted as time development, and high emission region travels along the loop.

From numerical simulation result, the following features are seen.

1. The loop is twisted with the torsional Alfven wave traveling.
2. High emission region moves from the footpoint to the top along the loop.

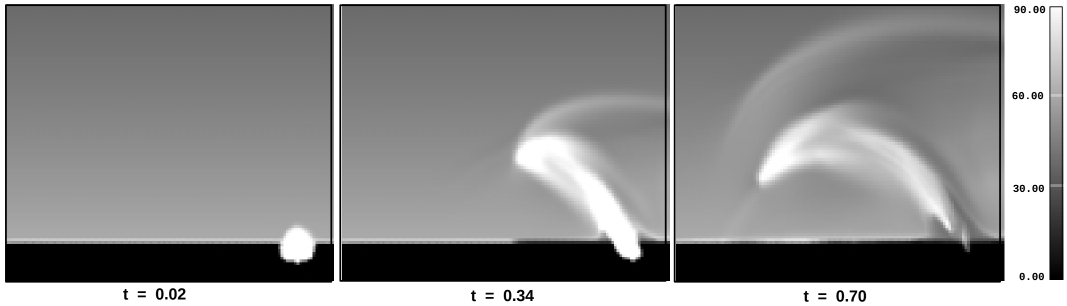

Fig. 5.. Color contour of Free-Free emissivity integrated along the line of sight. As time development, high emission region travels along the loop from one of the footpoints, and the gas injected is already heated from the beginning.

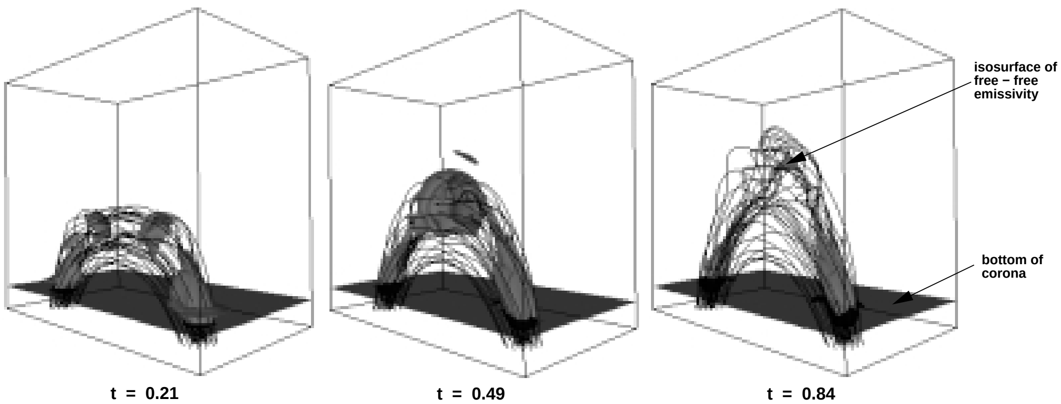

Fig. 6.. A Current Injection Model of Loop Flares with 3D MHD Simulation. The time development in the case of the injection of two TAWT into a loop. The shape of the loop is distorted. High emission region stays at the loop top for a short while.

3. The injected gas is already heated.
4. In Figs. 6 and 7, very high emission region is produced at the loop top.

We think (1) may correspond to the distorted loop of Yohkoh SXT's image. (2) may correspond to the initial dynamical phase of loop flares or active region transient brightenings. (3) may correspond to already heated gas which is often seen at active region transient brightenings of Yohkoh observation. (4) may correspond to the strong brightening of the loop top in loop flares.

4. Summary and Discussion

In these simulations, magnetic twist packet causes a progressing pinching which drives the heated higher density gas. When magnetic twist packet was released at the one footpoint of the loop, the high emission region travels along the loop (this may correspond to transient brightenings case). When two magnetic twist packets collide, higher emission region is created and the loop is strongly distorted (to the loop flare case). In previous models of loop flares, the most essential point of how the energy is provided to the top of the loop has *not* been discussed. Our standpoint is that the energy is provided from below a few tens of seconds before the superhot source (produced by the collision of hypersonic shock fronts in our model) appears, probably corresponding to the source found in the L-band/HXT image at the flare start.

References

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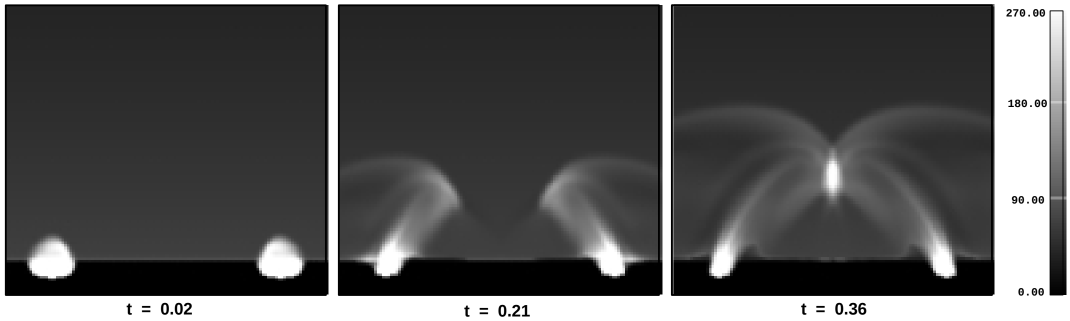

Fig. 7.. Color contour of free-free emissivity integrated along the line of sight. The footpoints brighten first, and when pinching gas travels along the loop before colliding at the loop top ,the emission value is low, and the loop top is shining strongly only after colliding each other.

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