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TRACE AND *RHESSI* OBSERVATIONS OF FAILED ERUPTION OF MAGNETIC FLUX ROPE AND OSCILLATING CORONAL LOOPS

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Abstract. We present the observations of the failed eruption of a magnetic flux rope recorded during an impulsive phase of a solar flare. We observed the restructuring of the magnetic field followed by the expansion of the magnetic flux rope. After an initial acceleration the expansion was stopped abruptly. We suggest that the main factor responsible for that is the magnetic tension of loops lying above expanding structure. Next, loops started to oscillate. Clearly seen global radial character of oscillating motion was observed and fitted with the damped sine function.

Key words: solar flares - filament eruption - hard X-rays - loop oscillations

1. Introduction

Solar flares, filament eruptions, CMEs and other processes observed in the solar corona are manifestations of the release of free energy contained in the solar magnetic field. Many observations and theoretical modeling of eruptions were made (Aschwanden 2005 and references within). In most cases observers and theorists analyse structures which erupt and move outward through the solar corona. However, it is possible that eruption can be stopped due to forces other than solar gravity. There are only few observations of such eruptions. Reported events were stopped due to forces within the flux rope (Vršnak 1990), reaching an upper equilibrium (Vrsnăk 2001), magnetic tension force and momentum exchange with the background plasma (Wang & Sheeley 2002), abrupt kink and stabilization of the erupting filament (Ji et al. 2003, Torok & Kliem 2005). Moreover, theoretical modeling made

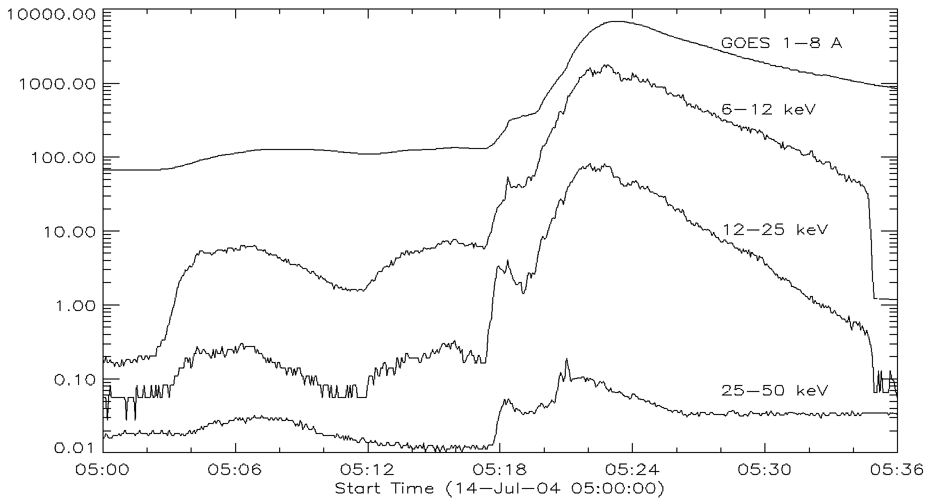

Figure 1: *GOES* and *RHESSI* lightcurves of the 14 July 2004 flare. Curves are shifted vertically for better presentation.

by Hirose et al. (2001) also shows that strong magnetic field existing above the erupting structure can stop the eruption.

Another type of motions which can be observed in the solar corona are loop oscillations. Various modes of oscillations are expected in loops (Edwin & Roberts 1983) and many observations were made (Aschwanden 2005 and references within). However, imaging observations of global kink oscillations have recently been made. There are several observations of horizontal oscillations (Aschwanden 2005) and only one observation of vertical oscillations (Wang & Solanki 2004).

Observations of the 14 July 2004 flare, presented in this paper, give us a complete view of the flare, accompanying eruption of flux tube and disturbances of system of loops lying above the expanding structure. Two very rare events met together in this case, i.e. failed eruption of magnetic flux rope and global, vertical oscillations of coronal loops.

2. Observations and Analysis

The analysed flare was observed near the west solar limb, its heliographic coordinates were N14W61. It was relatively strong event of M6.2 GOES class. In this paper we present observations obtained with the use of the *TRACE* and the *RHESSI* satellites. The *TRACE* made more than 90 images (of 1" spatial resolution) with the use of 171 Å filter. The temporal resolution of these observations varies from 8 s (impulsive phase and maximum of the flare) to 30 - 40 s (pre-flare activity and gradual phase).

Several features were observed during the flare. Between 05:00 UT and 05:18 UT two small brightenings were seen in X-ray range (Fig. 1). In this time interval we observed small loops (height about 10^4 km) with increasing brightness. Moreover, strong brightenings of footpoints were visible suggesting the energy release in these small structures. Impulsive phase of the flare started at 05:18 and lasted about 4 minutes. During the rise phase we observed dramatic change in the evolution of the analysed flare.

During the first HXR peak we observed strong brightenings in the *TRACE* images (Fig. 2, upper panels) and small magnetic structure of increasing height. Next, during the strongest HXR peak (05:21 UT), fast moving structure was observed. Its characteristic bulb-like shape can be seen in Fig. 2 (middle-left panel). This shape changed dramatically two minutes after the eruption started. The front of the eruption got broken (Fig.2, middle-right panel) and then we observed two side eruptions. The southern part of the eruption was faint and poor observed since the northern one was clearly visible in images (Fig. 2, bottom panels).

The system of high, regular in shape loops was observed above the flare and eruption (Fig. 2, upper panels). The height of the loops was constant until the braking of the front of the main eruption happened. The clear rising of these loops was then observed (Fig. 2, middle and bottom panels) suggesting that there had been an interaction between the eruption and the loops lying above.

The change of height of the high-lying loops was straightforwardly similar to the evolution of the eruption. It suggests that the interaction between the eruption and the high-lying loops existed. After the northern eruption developed, the force driving the movement of the high-lying loops diminished, next the loops moved back and finally the radial oscillations of the loops appeared.

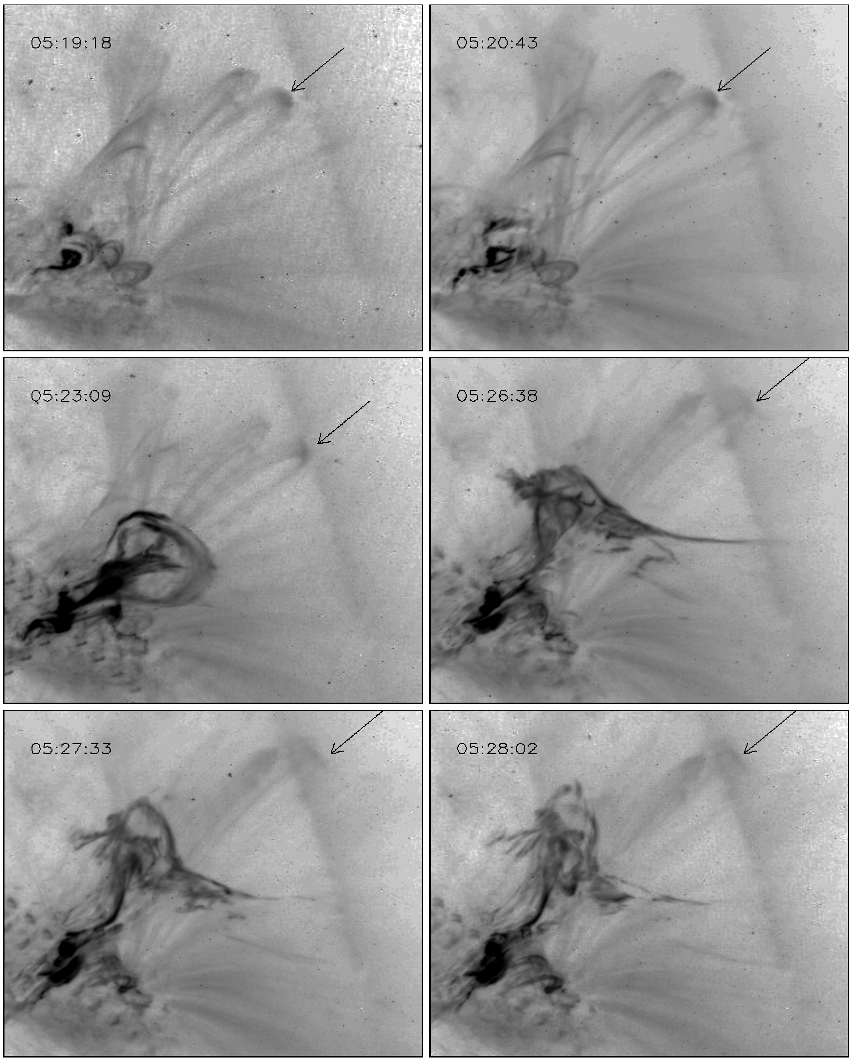

Figure 2: The images illustrating the evolution of the erupting structure. The system of loops lying above the eruption is marked with an arrow.

We calculated temporal evolution of the all moving features using the *TRACE* images. The main eruption height was obtained through measuring the distance between the eruption front and the location of the first

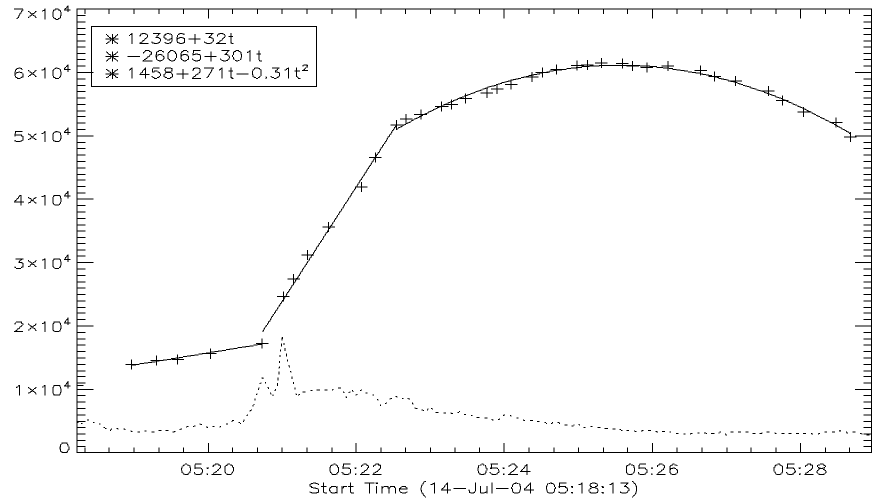

Figure 3: The evolution of the height of the eruption front with time. Parameters of the fitted functions are presented in the legend. The *RHESSI* lightcurve for 25-50 keV energy range is presented with dotted line.

brightened loop seen in the Fig. 2 (upper-left panel). There is a clear connection between this loop and the erupting structure (Fig. 2, middle-left panel). The height of the high-lying loops was measured as a distance of the centroid of the loop-top and the baseline connecting points where the loop was rooted. These points can be determined by careful inspection of images obtained before and after the flare when the system of loops was brightest.

3. Results

Figure 3 presents the evolution of the height of the main eruption. There are three different stages of evolution visible in the images. During the first stage we observed small (~10000 km) structure changing its height very slow. The movement could be described as uniform one with velocity of 30 km/s. Next, we observed two strong HXR pulses which correlated with the dramatic acceleration of the erupting structure. Obtained velocity raised by a factor of 10 and was equal to 300 km/s. Finally, abrupt braking of the eruption was observed. The estimated deceleration of the eruption was equal to 600 m/s^2. The value is almost twice the gravitational force on the solar surface thus there must exist, except for the gravitational force, additional force responsible for decelerating the eruption.

Careful analysis of the height curves obtained for the erupting front and for the high loops lying above shows that there is close similarity between them seen in time range 05:20-05:30 UT (Fig. 4). The high-lying loops started to rise one minute after the fast acceleration of the main eruption. Next, the height curves obtained for both features had almost the same shape. The distinctions between the evolution of the high-lying loops and the erupting front are the time shift between height curves which is about 1-2 minutes and, obviously the difference in absolute height.

Decelerating front was observed until 05:29 UT. After it disappeared the force driving the movement of the high-lying loops disappeared either. Thus, loops started to move back. They moved back and showed oscillations which were clearly visible in the *TRACE* images. The oscillating part of the movement is marked in Fig. 4 with vertical bars. These bars correspond to the loop-top measurements uncertainty. The oscillatory character of the movement is clearly visible. Observed changes of height were fitted with the use of damped sine function:

$$H(t) = A \sin\left(\frac{2\pi}{P}t + \phi\right) e^{-\frac{t}{\tau}} + H_0 \tag{1}$$

where A is the amplitude, P is the period, τ is the characteristic time of damping. For the parameters A, P and τ we obtained the values of 9490 km, 345 s and 499 s, respectively. There is one known observation of the global radial oscillations (Wang & Solanki 2004). The authors obtained different parameters i.e. lower value of period and longer damping time. However, they were able to observe oscillations for one and a half period only. Thus, the obtained damping time was calculated with large uncertainty. Theoretical modeling (Selwa et al. 2005) shows that the P/τ ratio for global radial oscillations should be near the value of 2. Authors assume that the only source of damping is energy leakage to the ambient plasma. Observations (Wang & Solanki 2004, this paper) show that this ratio is significantly less than the value of 1. This means the model predict too large damping of oscillations, i.e. we do not observe such fast energy dissipation. Thus, other damping mechanisms should be considered in theoretical modeling of radial

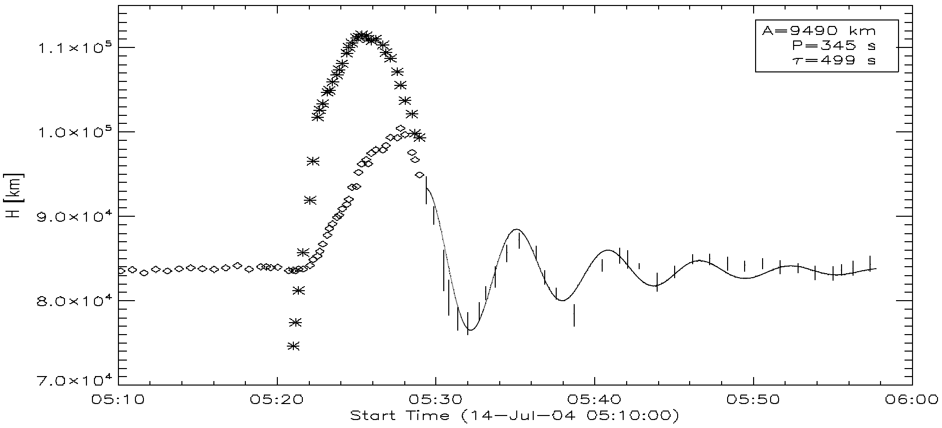

Figure 4: Damped sine function (line) fitted to measured height of tops of high-lying loops (vertical lines). The previous evolution of the loops is presented with diamonds. Moreover, the evolution of the main eruption front is marked with stars. The absolute values of the front height are not actual since were shifted vertically for better presentation.

oscillations, e.g. anomalous viscosity or resistivity, phase mixing (Ofman & Aschwanden 2002 and references therein).

The second important difference between the models and the observations is the height of oscillating loop before and after oscillating motion. Models show (Selwa et al. 2005) that after radial oscillations the loop have to be significantly higher. Wang & Solanki (2004) reported that the loop had the same height before and after oscillations. We observe the same effect (Fig. 4), the height of the loops after the oscillations is exactly the same as before the oscillations (8.4×10^4 km). This result suggest that there is no effect of 'stretching' the loop caused by the oscillations.

4. Conclusions

In this paper we showed the observation of the 14 July 2004 flare. In this event two very rare phenomena have met together, i.e. failed eruption and radially oscillating loops. The eruption was failed due to the magnetic tension of the loops lying above. The interaction between the eruption and the above lying loops was observed in two ways. First, the eruption changed its velocity and shape. The deceleration of the eruption was significantly larger than the gravitational force. The change of the shape seemed to 'trace' the above system of loops. Second, the height curves of failed eruption and high-lying system of loops have similar shapes. Moreover, side eruptions happened in two directions where high loops were not observed.

The global radial oscillations of loops were observed only once before (Wang & Solanki 2004). In this paper we report the second observation of this type. Significant differences between models and observations have been found. First, damping is not as strong as predicted by Selwa et al. (2005). Second, oscillating loops have exactly the same height before and after the oscillations.

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