Observation of the Bastille day flare on 2000 July 14

Ting-Yun Cheng
Department of Physics, NTNU, Taiwan, Taipei

ABSTRACT

In 2011 UCAT Summer Student Program, it wants to use multi-wavelength to observe the sun and use the theory to investigate the phenomenon of the sun. On 14 Jul 2000, there was a large solar flare (X5.7) occurred, this event was known for its long and clear arcade. in the paper, using the magnetic reconnection theory and multi-wavelength observation such as HXR, radio, EUV and WL, etc to analyze the event. According to the image from TRACE and SOHO, it could know the ribbon and arcade's change; the magnetic field data from SOHO/MDI, it could know the magnetic change before and after the flare occurred; and the electric field analysis compare with HXR and radio change to verify what theory I use, magnetic reconnection.

I.Introduction

Solar flare is a great amount of release of magnetic energy which could be up to 6×10^{25} joules in tiny time, and meantime it would accelerate particles around the active region into chromospheres, then due to bumps between particles; it would emit electromagnetic wave such as HXR, radio and even microwave. And meantime, solar flare also would accelerate a part of particles out of the sun's surface along the magnetic line of force, called Corona Mass Ejection (CME), it also might form the strong solar wind to affect the earth. These parts of particles would fly to the earth, affecting seriously the earth's atmosphere, weather and people's usual life.

Solar flares are classified as A, B, C, M, and X according to the peak flux of SXR as measured on GOES spacecraft. The classes of M and X are large flare; and the classes of A, B and C are small flare. Large flare, as implied by the name, it emits more magnetic energy, and could make larger affect and danger to the earth.

So far, the sun's absolute structure is still a big mystery, and the reason why the particles could be accelerated to an extreme high speed during a tiny time at solar flare occur is also unsolved, yet there are many theories try to explain it.

Magnetic reconnection is the most potent theory to explain how particles could be accelerated to high energy during a really tiny time. In magnetic reconnection theory, the model of solar flare would form an arcade of magnetic line of force in corona, and meantime, the arcade where it connected with chromosphere was called footpoint, and lots of footpoints form a strip is called ribbon; therefore, it might have two ribbons formed when flare occurred. And according to the magnetic reconnection model, as the corresponding magnetic lines of force connect continuously and form the

arcade, the distance between ribbons would become wider and wider.

Why the magnetic reconnection could explain the problem of particles accelerating? According to Faraday's Law, the magnetic arcade which has changing magnetic flux would form an electric current called reconnection current sheet that is perpendicular to the arcade's plane. Have a current; it must have an electric field to force the electron. This theory considers the force to accelerate particles around the position where flare occurred is come from the reconnection electric field.

In paper, our main research was to analyze an X5.7 solar flare event which occurred at active region 09077, and on 14 July 2000, so-called Bastille Day. This event occurred at 10:03 UT, and energy release peaked at 10:24 UT, finally finished at around 11:00 UT. Due to it have a long, clear and beautiful arcade, it is much easier to analyze the event and see the ideal result, so I chose the event to analyze. Its arcade's length and width were about 180,000 km and 42,000 km, and it could be divided into two parts – western and eastern parts; the western half of the arcade almost aligned in the E-W direction, and the eastern half in the NE-SW direction. (Masuda et al., 2001).

In the paper, at first, I introduce the different view of solar flare on 14 Jul 2000 in different electromagnetic wave wavelength. Second, because the solar flare would emit a large amount of magnetic energy; therefore, I analyze the magnetic structure of Bastille Day flare, before, during and after the flare occurred. Finally, I calculate the electric field by the model of magnetic reconnection and compare it with the change of HXR and radio as time goes on. To observe whether the change of electric field could match the change of HXR or radio.

II.Observe the solar flare in different wavelength

2-1 Overview

When observing the sun in different wavelength, we just only see photosphere and the outside of photosphere of the sun, so-called the atmosphere of the sun. The atmosphere of the sun is including photosphere, chromosphere and corona, etc. And different wavelength of electromagnetic wave could display different structure or layer of the atmosphere of the sun. Generally, in solar observation, scientist use electromagnetic wave of HXR, SXR, EUV, H-α, white light and radio to see and research the structure, shape or evolution of ribbon, arcade or others, etc.

In this research, I used electromagnetic wave whose wavelength in 1600 A , 195 A and 171 A on TRACE, in 195 A on SOHO, in white light, and in radio to observe the active region 09077 which the Bastille Day solar flare occurred.

2-2 Observation on TRACE

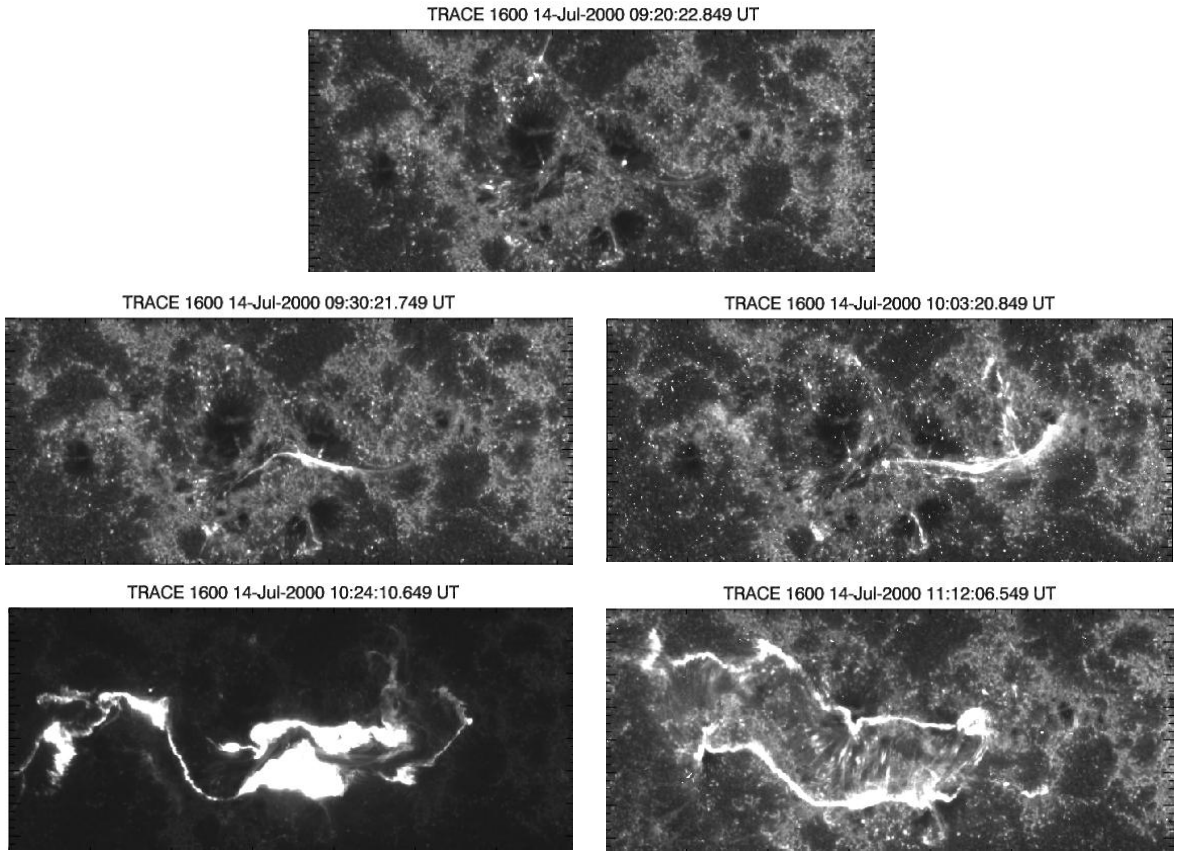

Figure 1. TRACE images before, during and after the flare. All images is at 1600 A. And all image's X axis' range is from -150 to 200 (arcsec) and Y axis' range is from 150 to 300 (arcsec).

In Figure 1, it could clearly see the ribbons of flare at 1600 A. At 09:20:22 UT, before the flare occurred, there was not any specially light part on image, yet it began showing a little white part at 09:30:21 UT, that was previous to the flare occurred. In the beginning of the flare at 10:03:20 UT, it showed branch of white strip on western part and revealed a Y sign on image, the white part was called ribbon. Then, the one which was in the N-S direction moved along the NW-SE direction until its direction became to the W-E direction like the over part of ribbon at 10:24:10 UT; and the other which was in the NW-SE direction, it moved to be parallel to the W-E direction like the underneath ribbon at 10:24:10 UT. After a while, it became two parallel ribbons and that there were arcs as if it contacted over ribbon with underneath ribbon at 11:12:06 UT, actually, we could see that it is truly an arcade structure and connected two ribbons in 195 A later.

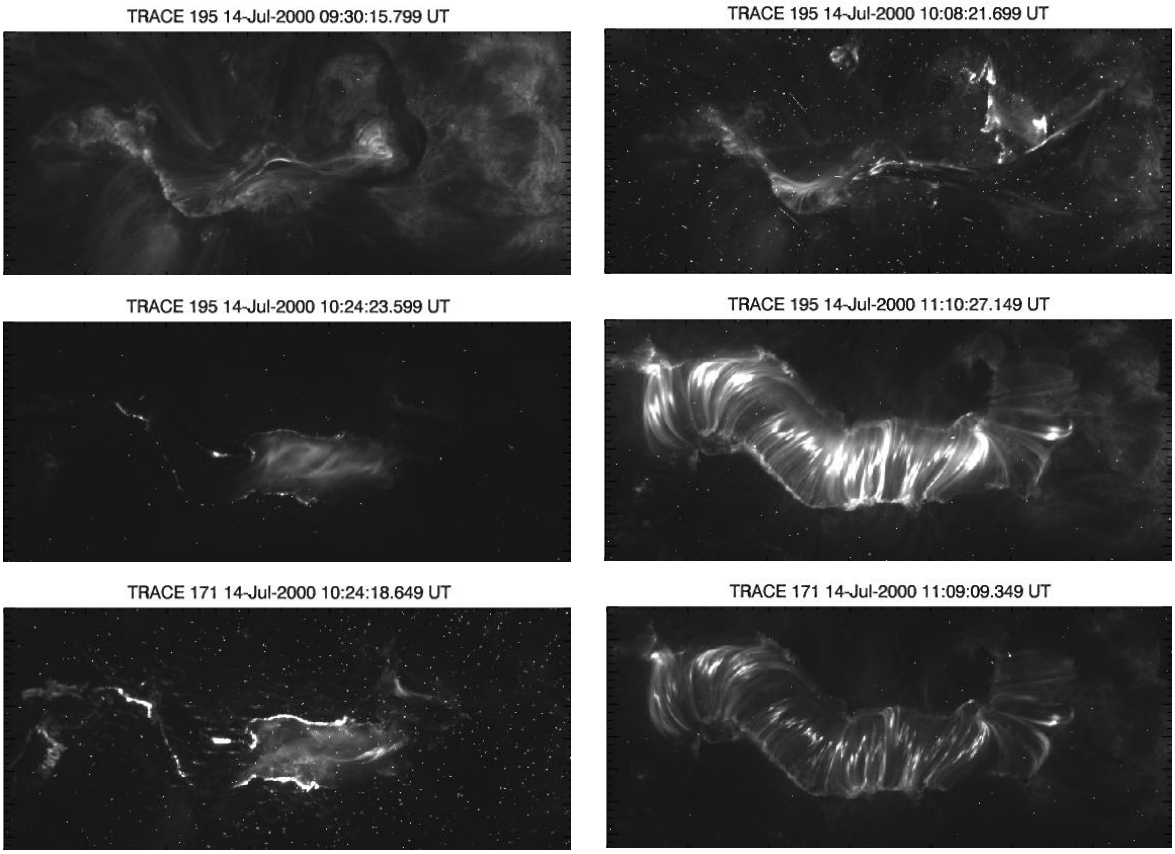

Figure 2. TRACE image before, during and after the flare. The images at 10:24:18 UT and at 11:09:09 UT are in 171 A, others are in 195 A. And all image's X axis' range is from -150 to 200 (arcsec) and Y axis' range is from 150 to 300 (arcsec).

In Figure 2, it could see the arcade of the flare at 195 A. Before the flare occurred, white part of image looked like more disordered. Along the flare broke up and time passed by, white part became ordered and ordered, finally, formed an arcade structure on image at 11:10:27 UT. And it could echo figure 1 image at 11:12:06 UT; meanwhile, the arcade and ribbons shown on images also could match the anticipation view of magnetic reconnection model.

The observation in 171 A likes the image in 195 A, also uses to observe arcade of flare, yet the arcade image in 195 A is much clearer than in 171 A. And the image in 195 A on SOHO, surely identical to the image in 195 A on TRACE; therefore, I also didn't put on the image in195 A on SOHO in the paper.

2-2 observation in white light

We could observe photosphere and some special structure such as sunspot, etc, of the sun in white light.

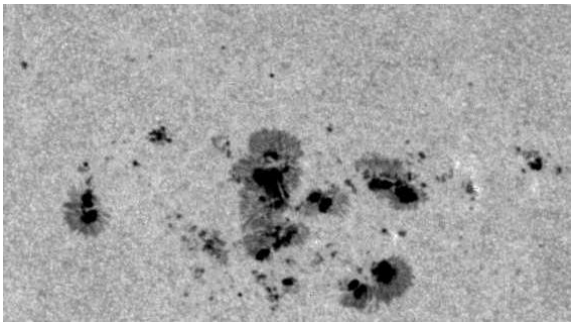

Figure 3. The image was at 10:09:33 UT in white light. The black parts of image were sunspot of the sun.

The image quotes from *ARTEMIS IV Radio Observations of the July 14, 2000 Large Solar Event, Caroubalos et al., (2010).*

Before the flare broke out, we found sunspot gather at the place where solar flare occurred. Due to discover of sunspot on the place, we could know that before the flare occurred, lots of magnetic line of force distribute over the region and magnetic field whether it was plus or negative should became much stronger and disordered. And about magnetic field of flare, we would talk detail in chapter 3 in paper.

2-3 Observation in radio

Radio is a kind of electromagnetic wave whose frequencies below those of visible light, about below 300GHz. And radio emission from solar flare can be detected from millimeter to kilometer wave-lengths. (Caroubalous et al. 2010)

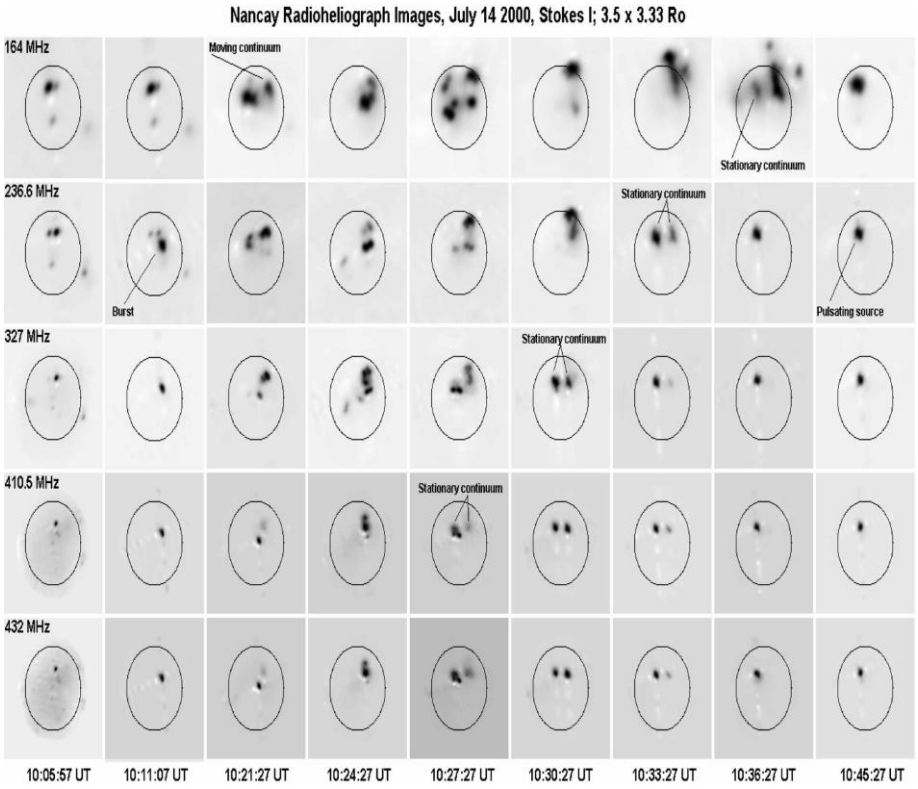

Figure 4. Images at five radio frequencies obtained with the Nancay Radioheliograph, illustrating the evolution of the event. Each image row corresponds to a particular frequency and each column to a particular time.

The image and description quotes from *ARTEMIS IV Radio Observations of the July 14, 2000 Large Solar Event, Caroubalos et al. (2010).*

Radio emission is produced by the accelerated particles bump on each other in chromospheres, like the produce of HXR and it could provide important diagnostics of acceleration processes in the corona. (Caroubalous et al. 2010)

III.Analysis of the magnetic field of solar flare on 14 Jul 2000

3-1 Magnetic field observation on SOHO/MDI

MDI, is the instrument of SOHO spacecraft, it could record magnetic field data of the sun. At 2D picture, it only shows the line of vision of the magnetic field direction. Because the event on 14 Jul 2000 occurred almost the center of the sun's plane, we could assume that the magnetic field data we get from program was real value of magnetic field.

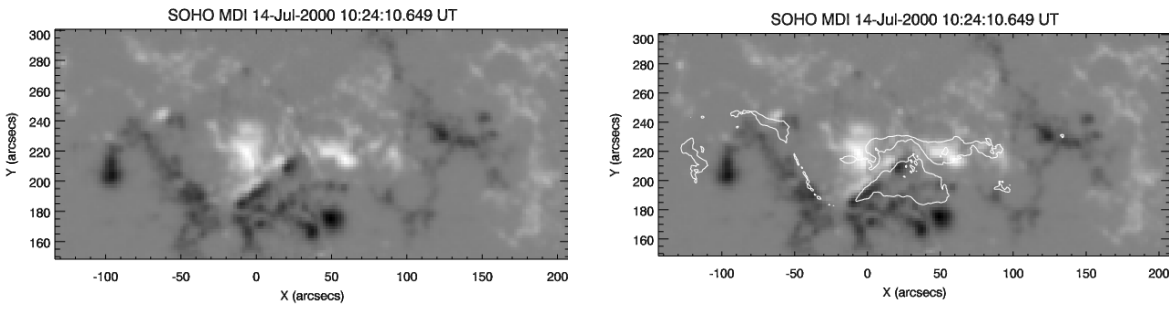

Figure 5. The two image's background are both the image of magnetic field on SOHO/MDI at 10:24:10 UT.
In left image, the black region shows the magnetic field into the plane; and white region shows the magnetic field outward.
In right image, white line draw the two ribbon's position at 10:24:10 UT.

In right image of figure 5, it could see the over ribbon's position was almost the place of white region on SOHO/MDI; and on the contrary, the underneath ribbon almost overlap the black region on SOHO/MDI. And in figure 1, the image at 11:12:06 UT showed the arcade structure of two ribbons, we could know the magnetic line of force was about out from the over ribbon and into the plane since the underneath ribbon.

3-2 Analysis of magnetic field

I use two way to analyze the magnetic field. First one, when solar flare occurred, it might have the change of flare ribbons' brightness, and the place where the flare break out must be specially light; therefore, using fixed brightness to draw different time's shape of ribbons on TRACE and get the magnetic field's data on SOHO/MDI. (figure 6)

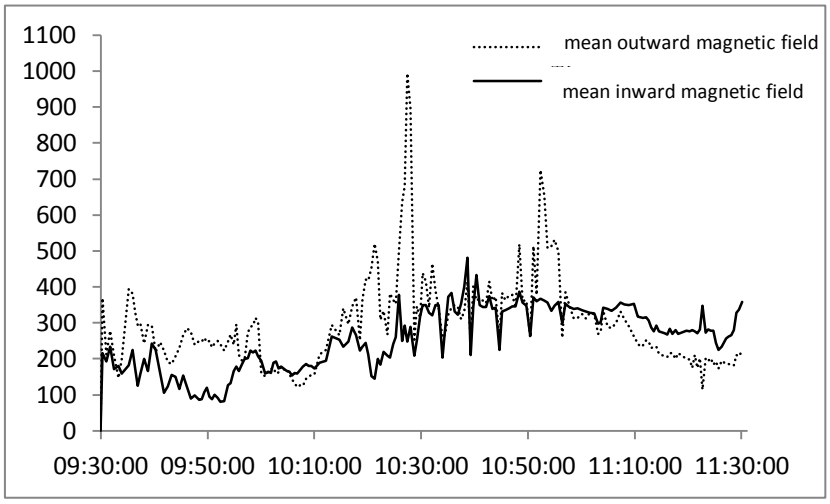

Figure 6. The x axis represents the changing time, and an interval of 20 minutes between the two neighbor times; the y axis represents the value of magnetic field and its unit is Gauss. (10000 Gauss = 1 Tesla)

In figure 6, it shows the outward average magnetic field, which is drawn by a dotted line, is more disordered and varies rapidly from about 10:10:00 UT to 11:00:00 UT. Although, the inward average magnetic field which is drawn by a solid line also varies apparently from about 10:10:00 UT to 11:00:00 UT, it doesn't vary rapidly like the plus one. Yet according to magnetic reconnection and the conservation of magnetic line of force, the outward parts should the same as the inward parts, so there are some answers for the problem, one is that because the magnetic line of force of flare might twist to everywhere and even extend far away to form the CME; therefore, it might not identical value between outward and inward in chose region.

Second one, according to the position of ribbon, I set a position range that x axis is from -150 to 200 (arcsec) and y axis is from 150 to 300 (arcsec) of the image on SOHO/MDI, then I get the magnetic field data which in the position range. (figure 7)

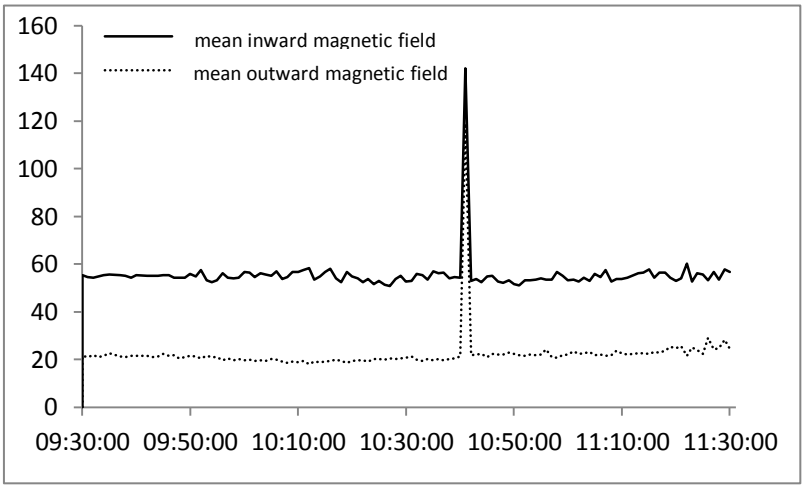

Figure 7. The x axis represents the changing time, and an interval of 20 minutes between the two neighbor times; the y axis represents the value of magnetic field and its unit is Gauss. (10000 Gauss = 1 Tesla).

And it is peaked at 10:41:01 UT.

IV.Analyze electric field of solar flare on 14 Jul 2000

4-1 Overview

According to magnetic reconnection theory and Faraday's Law of induction, the arcade which made by the magnetic line of force would form electric current, we called reconnection current sheet, that passes and is perpendicular to the plane of arcade. Due to forming current, so we know that the arcade definitely have an electric field. The electric field would accelerate particles around where the flare occurred in corona into chromosphere. For chromosphere has higher density of particle and

plasma than those in corona, as the accelerated particles fly into chromospheres, they have higher chance to collide with other particles. Plenty of particles collide with each other would emit a large amount of electromagnetic wave such as HXR and radio, etc.

According to magnetic reconnection, we know that the arcade obey conversion of magnetic flux; therefore, we could assume that the magnetic flux of corona is the same as the magnetic flux of photosphere. Apply one equation of Maxwell's equations – Faraday's Law to begin calculating:

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (1)$$

Then, integral left and right part:

$$\oint E \cdot dl = -\frac{\partial}{\partial t}\int B \cdot da \qquad (2)$$

$$\oint E \cdot dl = -\frac{\partial \phi}{\partial t} \qquad (3)$$

The sign of E represents the electric field of the solar flare; the sign of B represents the magnetic field of the solar flare; the sign of t represents the time; the sign of l represents the length of reconnection current sheet, yet in the calculation, I calculate the length of ribbon instead of reconnection current sheet; the sign of a represents the newly brighten areas; and the sign of ϕ represents the magnetic flux of ribbon. That is say, according to the Faraday's Law, by calculating the changing magnetic flux as time goes on, and divided by the length of reconnection current sheet, then we could get the value of electric field of the arcade.

And due to equations of motion:

$$m \cdot \frac{d\vec{v}}{dt} = q \cdot (\vec{E} + \frac{\vec{v}}{c} \times \vec{B}) \qquad (4)$$

Be multiplied by $\vec{v}$:

$$m\vec{v} \cdot \frac{d\vec{v}}{dt} = q\vec{v} \cdot \vec{E} \qquad (5)$$

$$\frac{d}{dt}(\frac{mv^2}{2}) = q\frac{d\vec{x}}{dt} \cdot \vec{E} \qquad (6)$$

$$\frac{d}{dt}(\frac{mv^2}{2}) = \frac{d}{dt}(q\vec{x} \cdot \vec{E}) \qquad (7)$$

$$\frac{d}{dt}(\frac{mv^2}{2} - q\vec{x}\cdot\vec{E}) = 0 \qquad (8)$$

According to equation (8), it could know that it is electric field to accelerate particles in corona into chromospheres; therefore, we could assume that the change of emission of electromagnetic wave is might echo the change of the electric field as time goes on.

4-2 Analysis of electric field and emission of HXR and radio

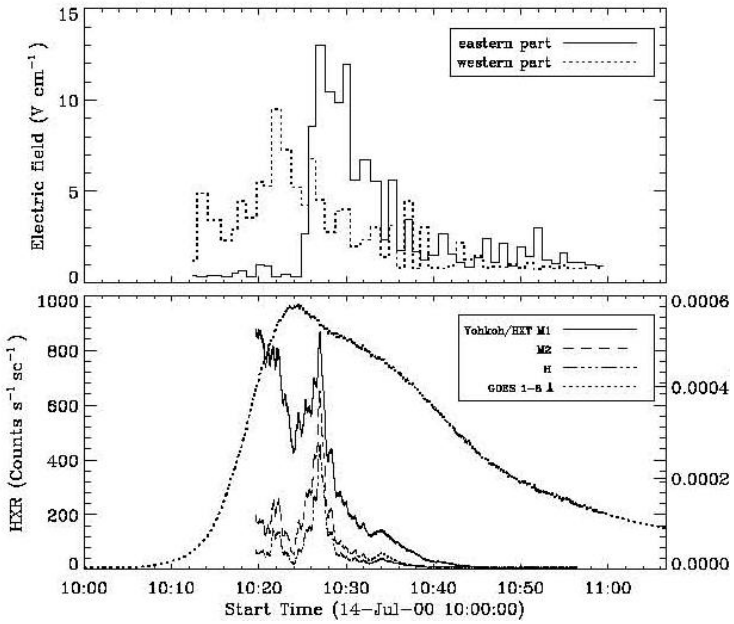

Figure 8. Reconnection electric field inferred from two parts of the X5.7 flare ribbons compared with hard X-ray and soft X-ray light curves. The three Yohkoh/HXT energy bands(M1, M2, H) cover the energy ranges 23–33, 33–53 and 53–93 keV, respectively.

The plot and description quotes from *The acceleration characteristics of solar energetic particles in the 2000 July 14 event, Li et al., (2007)*

In figure 8, it could see the change of electric field as time goes on approximately match the change of HXR and in figure 9, it also could see the change of electric field approximately match the change of different wavelength's radio emission.

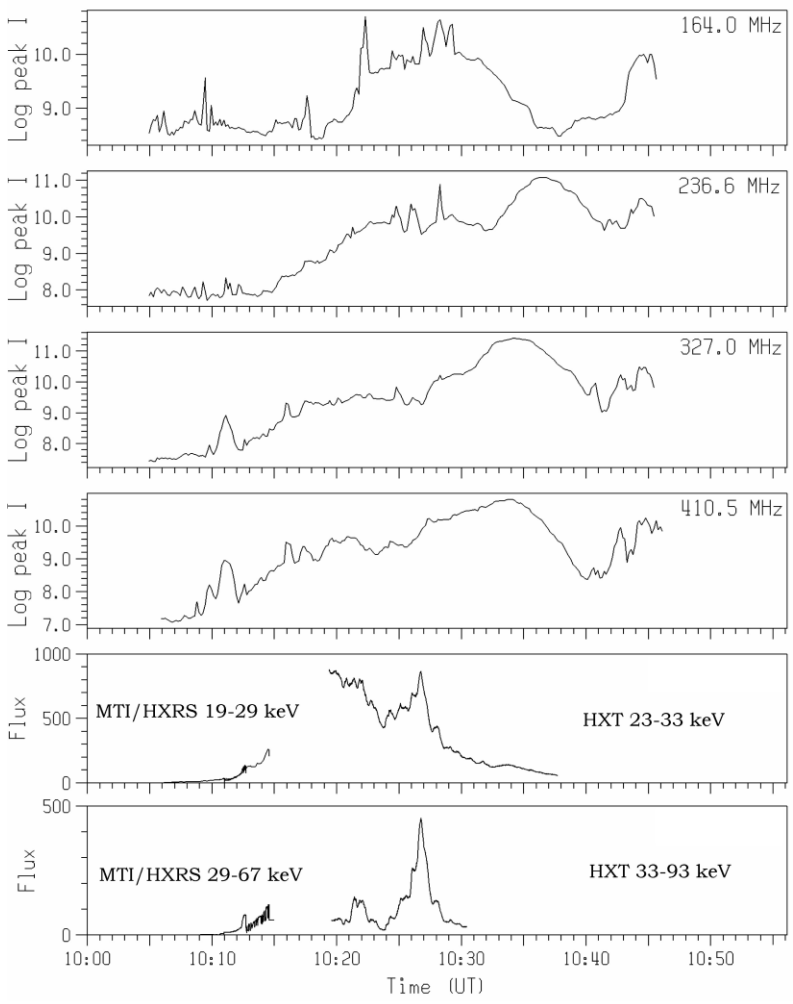

Figure 9. The dynamic spectrum of the event observed with the ARTEMIS-IV ASG receiver (upper two panels); the lower panel shows the time derivative of the flux, which helps to identify rapidly varying structures. Horizontal lines at the right of the spectrum mark the frequencies of the Nancay Radioheliograph channels. The four plots below the spectrum give the logarithm of the peak intensity (in K), measured by the NRH at four frequencies. The lower two panels show the hard X-ray flux observed with the Yohkoh SXT and the MTI HXRS instruments.

The plot and description quotes from *ARTEMIS IV Radio Observations of the July 14, 2000 Large Solar Event, Caroubalos et al., (2010).*

V.Conclusion

At first part, using different wavelength to observe the evolution of the ribbon and arcade. And second part, the analysis could make me know the magnetic field change before, during and after the solar flare occurred. Before the flare occurred, magnetic field is a little disordered, during the period, magnetic field become much

more disordered, and after the period, magnetic field become more ordered. At third part, the carve of electric field, HXR and radio all have a tendency to increase during the flare occurs, and before and after the flare break out, they are more lower value.

VI.Reference

- Caroubalos, C. , Alissandrakis, C. E. ,Hillaris, A. , Nindos, A. , Tsitsipis, P. , Moussas, X. ,Bougeret, J-L. , Bouratzis, K. , Dumas, G. ,Kanellakis, G. ,Kontogeorgos, A. ,Maroulis, D. ,Patavalis, N. ,Perche, C. ,Polygiannakis, J. and Preka-Papadema, P. (2010). ARTEMIS IV Radio Observations of the July 14, 2000 Large Solar Event. *Solar Physics.* DOI: 10.1007
- Caroubalos, C. , Tsitsipis, P. , Kontogeorgos, A. , Moussas, X. , Alissandrakis, C. E. , Hillaris, A. , Preka-Papadema, P. , Polygiannakis, J. , Bougeret, J.-L. , Dumas, G. , Kurt, V. , Vassiliou, C. , Perche, C. , Gazeas, K. , Kolovos, G. RADIO SIGNATURES OF MAGNETIC RESTRUCTURING DURING THE 2000 JULY 14 MAJOR SOLAR EVENT
- Eric Priest and Terry Forbes. (2000). MAGNETIC RECONNECTION, MHD Theory and Applications. Cambridge University
- Haimin Wang, Chang Liu, Yuanyong Deng, and Hongqi Zhang. (2005). REEVALUATION OF THE MAGNETIC STRUCTURE AND EVOLUTION ASSOCIATED WITH THE BASTILLE DAY FLARE ON 2000 JULY 14. *The Astrophysical Journal, 627:1031–1039.*
- Hongqi Zhang. (2002). Magnetic field, helicity and the 2000 July 14 flare in solar active region 9077. *Mon. Not. R. Astron. Soc. 332, 500–512.*
- Jiong Qiu, Chang Liu, Dale E. Gary, Gelu M. Nita, and Haimin Wang. (2004). HARD X-RAY AND MICROWAVE OBSERVATIONS OF MICROFLARES. *The Astrophysical Journal, 612:530–545.*
- Li, C., Tang, Y. H., Dai1, Y., Zong, W. G., and Fang, C. (2007). The acceleration characteristics of solar energetic particles in the 2000 July 14 event. *Astronomy &Astrophysics, 461, 1115-1119.* DOI: 10.1051/0004-6361:20065754
- Liu, Y. and Zhang, H. (2001). Relationship between magnetic _eld evolution and major flare event on July 14, 2000. *Astronomy &Astrophysics, 372, 1019-1029.* DOI: 10.1051/0004-6361:20010550
- Masuda, S. , Kosugi, T. , Hudson, H. S. (2001). A HARD X-RAY TWO- RIBBON FLARE OBSERBED WITH YOHKOH/HXT. *Solar Physics, 204, 57-69.*
- Parnell, C. E. (2000). Magnetic reconnection and some solar applications. *Phil. Trans. R. Soc. Lond. A, 358, 669-688.*
- Somov, B. V., Oreshina, I. V., and Kovalenko, I. A. (2008). Magnetic Reconnection, Electric Field, and Particle Acceleration in the July 14, 2000 Solar Flare. *Astronomy Letters, Vol. 34, No. 5, pp. 327 – 336.*
- SCHUNKER, H. and DONEA, A. -C. (2003). VARIATIONS OF THE MAGNETIC FIELDS IN LARGE SOLAR FLARES. *Space Science Reviews 107: 99–102.*