# The opposite evolution of spectral index of microwave and HXR emission in solar flare

*Jing Huang*[1]

[1]Key Laboratory of Solar Activity, National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China, huangj@bao.ac.cn

## Abstract

This paper presents an unusual phenomenon for the evolution of spectral index of non-thermal electrons related to HXR and microwave emission in a M1.5 class flare. It is found that the light curves of both microwave and HXR bursts has similar two rise-peak-decay phases. The spectral index deduced from HXR emission evolves as S-H-S pattern in each phase, while the spectral index relative to microwave emission presents S-H-H pattern in the first rise-peak-decay phase and H-S-H pattern in second one. Weak diffusion is proposed to explain the different evolution in the first rise-peak-decay phase. For the second period, microwave spectrum is softened, which imply one new process for pitch angle scattering occur. Strong diffusion of trapped electrons could be the available cause, which result in the decreasing number of trapped electrons. In additional, the change of magnetic structure of flare loop may shift the location of magnetic mirrors and the upward shifting of magnetic mirrors could reduce the number of microwave emission at 17 GHz and soften the microwave spectrum.

## 1. Introduction

The non-thermal electrons interact with the local plasma, magnetic field and waves and produce various bursts at different frequencies, such as radio bursts, hard X-ray bursts and gamma-ray bursts when they transport through the solar corona after acceleration. To study the phenomena of these bursts can help us to understand the temporal, spatial and spectral distribution of the non-thermal electrons during the transport process and the status of the magnetic field, local plasma and the waves. Hard X-ray emission is the most direct diagnostic of electron presence in the corona [1]. The most intense hard X-ray emissions are generally observed from the chromosphere at foot points of magnetic loops where the density is high enough to stop the electrons, which is interpreted in terms of thick-target bremsstrahlung. However, when the hard X-ray emission at foot points are blocked, extended hard X-ray sources are sometimes observed in the corona, which are produced by thin-target bremsstrahlung [2]. The electron energy spectrum or the spectral index of the power law distribution could be deduced from the photon spectrum in the thick-target case. Radio emissions related to the non-thermal electrons are produced by the incoherent mechanism like gyrosynchrotron emission and the coherent mechanism as plasma emission. Gyrosynchrotron emission is efficient in high magnetic fields, which is the dominant radio emission above sunspots [3]. From the observed radio dynamic spectrum, plasma emission usually occurs with short duration and narrow frequency band. Gyrosynchrotron emission is observed as a broadband spectrum from 1 GHz to 20 GHz, with the spectrum peak around 5-10 GHz [4]. The emission below the peak frequency is optical thick with the emitted wave being absorbed completely, while the emission above the peak frequency is optical thin, which could reflect directly the distribution of the non-thermal electrons.

Both the radio optical thin spectrum and the hard X-ray spectrum evolve as soft-hard-soft (SHS) pattern and soft-hard-hard (SHH) pattern in the rise-peak-decay phases [5-8]. The similarity between hard X-ray and radio emission profiles suggests that they are generated by a common population of electrons [9-10]. But their spectral evolutions are sometimes different. Ning [11] have analyzed the burst event on 2003 May 9 and found that the hard X-ray spectral index displays as a SHS pattern but the microwave emission has a SHH pattern, in which the thermal emission during the decay phase could play an important role on the microwave spectral hardening. Taking the thermal emission deduced from the GOES emission measure (EM) and temperature (T) as the template of the thermal emission around the 7 GHz, Huang and Yan analyzed the non-thermal radio spectral evolution by subtracting the thermal contribution [12]. They found that the hard X-ray emission has a SHS pattern but the radio emission still has a SHH pattern. They interpreted the different behaviors in the frame of the trap-plus-precipitation model of the kinetics of non-thermal electrons during solar flares. When the accelerated electrons are injected into the flare loops, the ones with the initial pitch angle less than the loss cone angle move freely along the flare loops (direct precipitation), whereas, the ones with the initial pitch angle larger than the loss cone are trapped between the two magnetic mirrors around the foot points. The trapped electrons are scattered into the loss cone by proper pitch angle scattering mechanisms or lose energy by

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

interactions with the local plasma and move towards the foot points freely, which we call the secondly precipitation [3]. The hard X-ray emissions are produced by the direct and second precipitation electrons when they move towards the chromosphere. The radio emissions around 7 GHz are produced by the trapped ones and direct precipitation ones. Under the weak diffusion of the pitch angle scattering, the high energy electrons are easier to be trapped and the low energy electrons have shorter trapping time. Hence, the hardening spectrum of the radio spectrum should be caused by the effect trap of the high energy electrons. And the increasing number of the second precipitating electrons at lower energy softens the hard X-ray photon spectrum.

Hence, the analysis of radio and hard X-ray spectrum could reveal more details of the electron transport process. What is more, the gyrosynchrotron emission covers a broader band from about 2 GHz to 20 GHz, which means that the the resonant layers at different frequency spread at a wider space from the flare loop top to the foot points. The study of radio spectrum at broader frequency range could help us to understand the distribution of non-thermal electrons in a wider space. In this paper, we will compare and analyze the hard X-ray spectrum and radio spectrum between 9.4 GHz and study the spectral evolution of non-thermal electrons and the kinetic process during the burst event. Section 2 gives the data reduction and Section 3 presents the initial results of the selected event. The discussion and conclusions are presented in Section 4.

## 2. Data reduction

The Nobeyama Radio Polarimeters (NoRP) are observing the Sun with multiple frequencies at 1, 2, 3.75, 9.4, 17, 35 GHz, which facilitates the study on the radio spectrum of the gyrosynchrotron emission. The non-thermal radio flux spectrum is assumed of the frequency dependence power-law form with the spectral as A. The spectral index for non-thermal electrons emitting radio waves (B) is derived by the following relation: B=1.1(A+1.2) [13]. A forward-fitting method implemented with the OSPEX code from SSW is used to derive the index of the HXR spectrum from RHESSI (Reuven Ramaty High-Energy Solar Spectroscopic Imager) data. The integral time is 8 s. The thermal plus a single-power-law electron distribution model is applied to simulate the photon spectrum, where the thermal part is assumed to be an isothermal bremsstrahlung spectrum and the non-thermal part is simulated by the thick target model. The spectral Index of non-thermal electrons producing HXR emission (B) can be deduced from the photon spectral index (A) as: B=A-1.

## 3. Results

The M5.1 class SXR flare of the burst event on 23 April 2003 started at 00:39 UT, peaked at 01:06 UT and ended at 01:15 UT. The radio burst at 9 and 17 GHz peaks at 01:02:02 UT and the HXR emission at 30-70 keV peaked at 01:02:00 UT. The analysis of the burst event is shown in Fig. 1. The radio fluxes at 9 and 17 GHz, subtracting the thermal contribution, are plotted in Fig. 1(a).The HXR light curve at 30-70 keV is plotted in Fig. 1(b). It can be seen that both microwave and HXR emission had two peaks and they peaked almost at the same time. Two rise-peak-decay phases are cut as: (1) from 01:00:30 to 01:04:50 UT, (2) from 01:04:50 UT to 01:10:00 UT. The spectral index of HXR related electrons (+) and microwave related electrons (dot) are plotted in Fig. 1(c). The spectral index deduced from HXR emission evolves as S-H-S pattern corresponding to each rise-peak-decay phase of HXR flux. For the results from microwave bursts, the spectral index shows S-S-H pattern in the first rise-peak-decay phase and H-S-H pattern in the second phase. The evolution of spectral index deduced from HXR and microwave emission are opposite from each other. In additional, the value for HXR related electrons is larger than that for microwave emission.

## 4. Discussion and Conclusion

Form HXR and microwave emission of an M1.5 class flare, the spectral index of non-thermal electrons related is analyzed. It is found an unusual phenomenon that the spectral index deduced from HXR emission evolved at an opposite pattern with that from microwave emission. Although the flux of HXR and microwave emission has similar light curve and both of them shows two individual peaks, the microwave emission presents a more smooth decay phase. This could be interpreted in the frame of trap-plus-precipitation mode of the energetic electrons in solar flares. The smooth decay may suggest the trap process for non-thermal electrons.

During the first rise-peak-decay phase, the hardening spectrum of microwave related electrons imply the accumulation of high energy electrons and the soften spectrum of HXR related electrons imply the decrease of high energy electrons. This means that the trapping time of high energy electron is longer than that at lower energy and weak diffusion of pitch angle scattering could be proposed to generate it, which is similar to the results of [12]. However,

during the second rise-peak-decay phase, the spectral index deduced from HXR and microwave evolves oppositely. HXR spectrum shows S-H-S pattern as the former, but microwave presents as H-S-H pattern. Different process for electron trap could take place to change the distribution non-thermal electrons. We focus on the period from 01:04:50 UT to 01:06:00 UT, when the microwave spectrum is softening. It could be produced by longer trapping time for low energy electrons and the strong diffusion of pitch angle scattering is the available mechanism. After 01:06:00 UT, it shows the same pattern as the first phase. In additional, the change of the structure of flare loop could make the magnetic mirror points shifted to upper or lower altitude. For this case, the magnetic mirror points may shifte upward and the trapped electrons are shifted upward correspondingly, which results in the decreasing number of electrons emitting at 17 GHz. And the spectrum deduced will be softened.

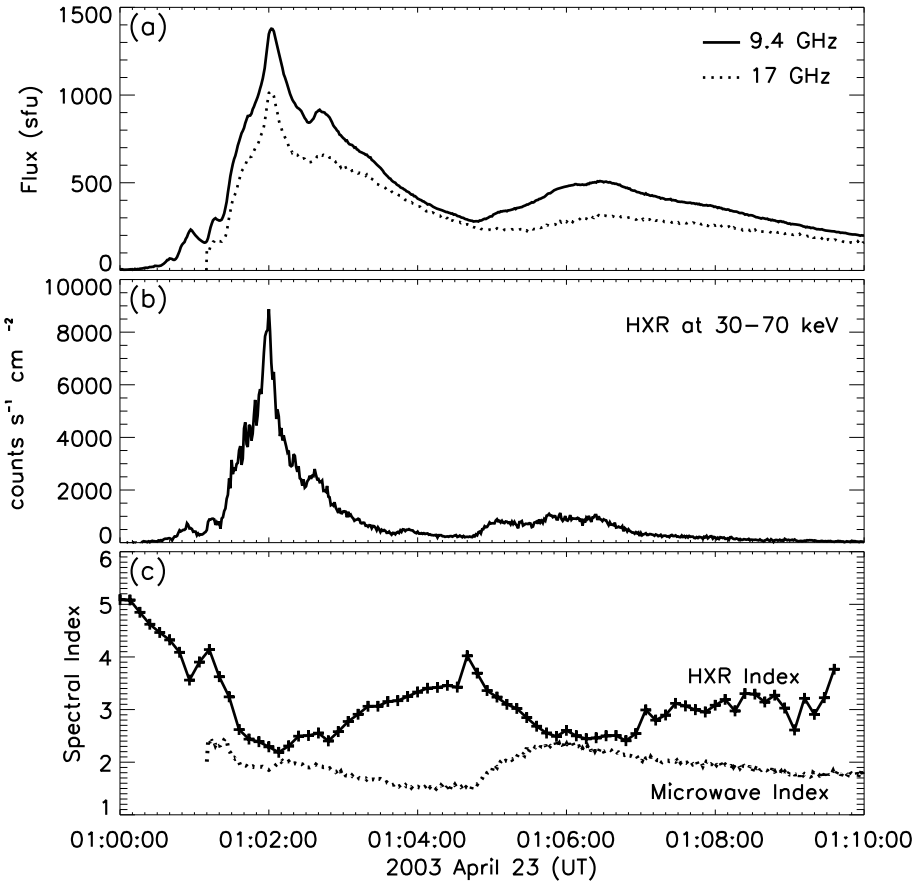


Fig. 1. The light curve at 9.4, 17 GHz (a), HXR at 30-70 keV (b) and the spectral index deduced (c).

## 5. Acknowledgments

The authors would like to thank the GOES, NoRP and RHESSI teams for providing observation data. This work is supported by NSFC Grant 11373039, 11273030, 11221063, 11103044, MOST Grant 2011CB811401, the National Major Scientific Equipment R&D Project ZDYZ2009-3, and the Grant P209/12/00103 (GA CR). This work was also supported by the Marie Curie PIRSES-GA-295272-RADIOSUN project.

## 6. References

1. S. Krucker, M. Battaglia, P. J. Cargill, L.Fletcher, H. S. Hudson, A. L. MacKinnon, S. Masuda, L. Sui, M. Tomczak, A. L. Veronig, L. Vlahos, S. M. White, "Hard X-ray emission from the solar corona", *Astron. Astrophys Rev.*, Vol.16, pp.155-208, 2008

2. W. Liu , V. Petrosian, B.R. Dennis, Y.W. Jiang, “Double coronal hard and soft x-ray source observed by rhessi: evidence for magnetic reconnection and particle acceleration in solar flares”, *ApJ*, Vol.676, pp.704-716, 2008

3. M.J. Aschwanden, “Physics of the Solar Corona”, Praxis Publishing Ltd., *Chichester and Springer*, Berlin, 2004

4. T.S. Bastian, A.O. Benz, D.E. Gary, “Radio emission from solar flares”, *Annu. Rev. Astron. Astrophys.*, Vol. 36, pp. 131-188, 1998

5. B.R. Dennis, “Solar hard X-ray bursts”, *Sol. Phys.*, Vol. 100, pp. 465-490, 1985

6. A.L. Kiplinger, “Comparative Studies of Hard X-Ray Spectral Evolution in Solar Flares with High-Energy Proton Events Observed at Earth”, *ApJ*, Vol. 453, pp. 973-986, 1995

7. S. M. White, S. Krucker, K. Shibasaki, T. Yokoyama, M. Shimojo, M. R Kundu, “Radio and Hard X-Ray Images of High-Energy Electrons in an X-Class Solar Flare”, *ApJ*, Vol. 595, pp. L111-114, 2003

8. P. C. Grigis and A. O. Benz, “The spectral evolution of impulsive solar X-ray flares”, *A&A*, Vol. 426, pp. 1093-1101, 2004

9. V.F. Melnikov, “Temporal Evolution of Solar Flare Microwave and Hard X-Ray Spectra: Evidence for Electron Spectral Dynamics-I.pdf”, *High Energy Sol. Phys.*, Vol. 206, pp. 371-376, 2000

10. V.F. Melnikov, “Temporal Evolution of Solar Flare Microwave and Hard X-Ray Spectra: Evidence for Electron Spectral Dynamics-II.pdf”, *High Energy Sol. Phys.*, Vol. 206, pp. 475-477, 2000

11. Z.J. Ning, “Different behaviors between microwave and hard x-ray spectral hardness in two solar flares”, *ApJ*, Vol. 671, pp. L197-2000

12. J. Huang and Y.H. Yan, “Analysis of kinetic process of energetic electron during a flare on 2004 december 1”, *ApJ*, Vol.705, pp. 1063, 1072, 2009

13. G.A. Dulk, “Radio emission from the sun and stars”, *Annu. Rev. Astron. Astrophys.*, Vol.23, pp.169-224