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Millimeter Observation of Solar Flares with Polarization

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Abstract. We present the investigation of two solar flares on February 17 and May 13, 2013, studied in radio from 5 to 405 GHz (RSTN, POEMAS, SST), and in X-rays up to 300 keV (FERMI and RHESSI). The objective of this work is to study the evolution and energy distribution of the population of accelerated electrons and the magnetic field configuration. For this we constructed and fit the radio spectrum by a gyro synchrotron model. The optically thin spectral indices from radio observations were compared to that of the hard X-rays, showing that the radio spectral index is harder than the latter by 2. These flares also presented 10-15 % circular polarized emission at 45 and 90 GHz that suggests that the sources are located at different legs of an asymmetric loop.

1. Introduction

Due to its great complexity, the study of a flare at many wavelengths is necessary to understand the physical processes involved. The radio spectra of flares provides important information about the characteristics of the flare source such as size, accelerated electron energy distribution and the loop magnetic field. The spectral index of the energy distribution of the accelerated electron population can shed light into the acceleration mechanisms of these electrons. Of fundamental importance are polarization measurements that besides testing the non-thermal character of the emission, also provide the intensity of magnetic field at the source and loop geometry (Kundu & Vlahos 1979). We analysed two solar flares detected at radio and X-ray wavelengths to characterise the electron energy distribution and the magnetic field configuration during flares.

2. Observations of two flares

Two solar flares that occurred on February 17 and May 13, 2013 were detected at several radio wavelengths, from 5 to 212 GHz. The millimetre observations were obtained by the telescopes POEMAS (POlarization Emission of Millimeter Activity at the Sun) that monitor the Sun at 45 and 90 GHz with circular polarization (Valio et al. 2013). Microwave emission were detected by the Sagamore Hill Observatory from the Radio Solar Telescope Network (RSTN, 1-15 GHz) with a temporal resolution of 1 second. High frequency emission, at 212 GHz, was observed by the Solar Submillimeter Telescope (SST) (Kaufmann et al. 1994). X-rays from the flares were also detected on February 17, 2013 with Fermi Gamma-Ray Space Telescope, while on May 13 the event was observed by RHESSI.

Figure 1 shows the time profiles at radio wavelengths of the February 17, 2013 (left panel). This event, classified by GOES as M1.9, occurred between 17:47:03 and 17:48:02 UT, in active region NOAA 11675 (N12E17). A time lag between the high-frequencies (45, 90 and 212 GHz) and the microwaves (4.99, 8.8 and 15.4 GHz) can be seen. The right frame of Figure 1 shows the hard X-rays from Fermi Gamma-Ray Space Telescope up to 300 KeV.

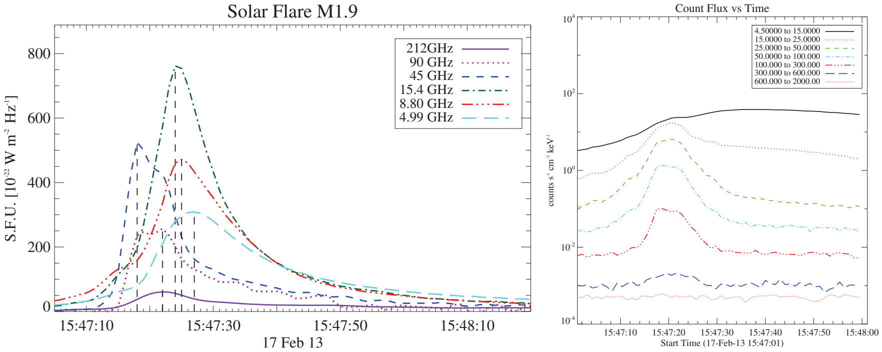

Figure 1. Time profiles at radio (left) and X-ray (right) wavelengths of the February 17, 2013, solar flare. The colored figure can be found in the electronic version.

The radio emission time profile of the May 13 event is shown in the left panel of Figure 2 between 15:48:06 and 16:16:03 UT, with the flux peaking at 16:05 UT. The GOES soft X-ray class of this event was X 2.8 and occurred at NOAA active region 11748 (N08L89). The radio time profiles for this event present multiple peaks. Hard X-rays from RHESSI for this flare are shown in the right panel of Figure 2.

3. Radio spectra and polarization

Combined radio data from 5 to 212 GHz (RSTN, POEMAS, SST) was used to build the spectra of both flares every 1 sec. These spectra were fit by the Ramaty (1969) model of gyrosynchroton radiation considering only the four varying parameters: magnetic field, source size, accelerated electron density and spectral index. The other parameters of the

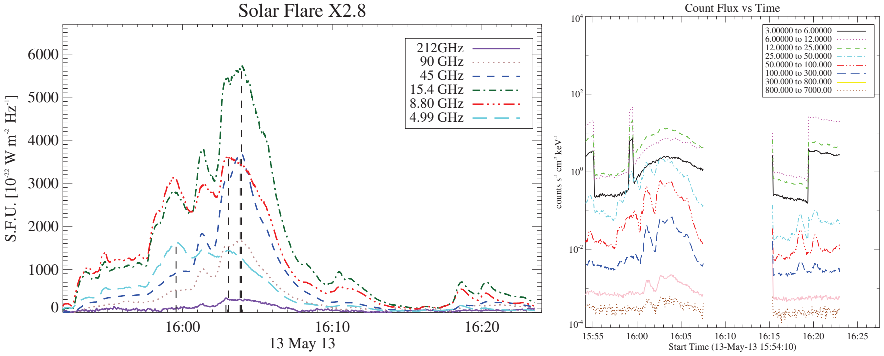

Figure 2. Time profiles at radio (left) and X-ray (right) wavelengths of the May 13, 2013, solar flare. The colored figure can be found in the electronic version.

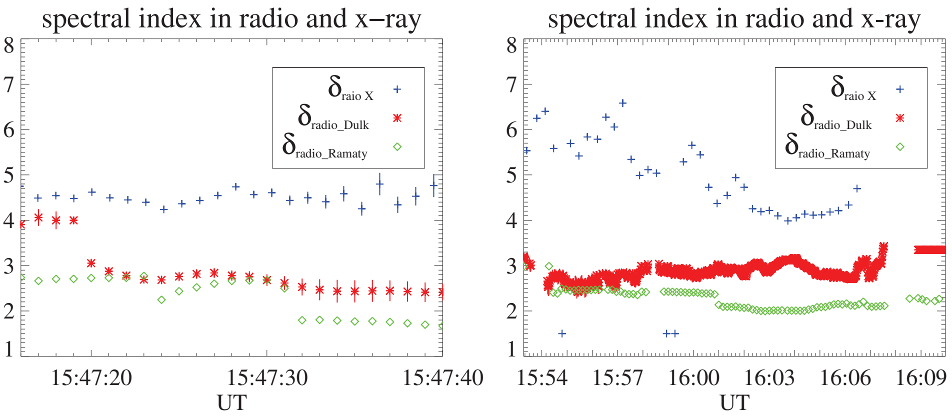

Figure 3. Radio spectral indices, δ_r obtained from Dulk (asterisks) and Ramaty (diamonds) models, and X-ray spectral index, δ_x (crosses) for both flares, 17 February (left panel) and May 13 (right panel), 2013. The colored figure can be found in the electronic version.

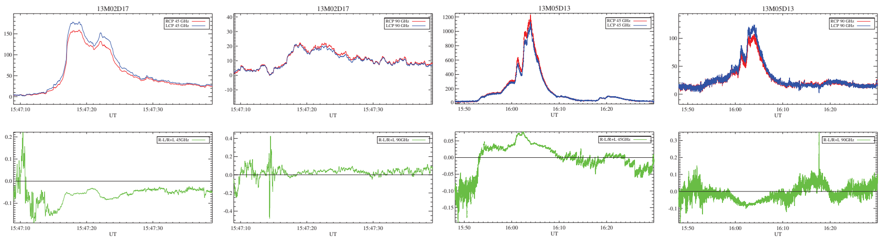

Figure 4. *Top:* brightness temperature for RCP emission (black/blue) and LCP (gray/red) at 45 and 90 GHz for both events. *Bottom* Degree of polarization for both events. The colored figures can be found in the electronic version.

model, such as source depth and line–of–sight angle were kept constant. The magnetic field for the emitting source was about 750 G and 950 G for the flares of February 17 and May 13, 2013, respectively.

The radio spectral index was also calculated by fitting the spectra with the equation of Hurford et al. (1989) that yields the optically thin index, α. Using the approximate equation given by Dulk (1985): $\delta_r = 1.11\alpha + 1.36$, we determined the spectral index δ_r. Both spectral indices obtained from the radio spectra were compared to that obtained from the hard X ray spectra fit by a power-law, where $\delta_x = \gamma + 1.5$. These indices are plotted on Figure 3, and as can be seen, the radio spectral index is harder than the hard X-rays by about 2 units. This result is in agreement with that reported by Silva et al. (2000).

The 45 and 90 GHz emission from the February 17 and May 13, 2013, flares were measured in RCP and LCP by POEMAS. Figure 4 shows the degree of polarization, $p = (R - L)/(R + L)$, for each event at both frequencies. The polarization reaches 10 to 15 %, and is the opposite at both frequencies. Also, the polarisation is reversed in both events.

4. Conclusions

Two flares were analysed in detail at radio and hard X-ray wavelengths. Their radio spectra were fit by gyrosynchrotron emission (Ramaty 1969) and the Hurford et al. (1989) approximation and the radio spectral index, δ_r was calculated. The hard X-rays were fit with thermal emission plus non-thermal emission from accelerated electrons with a power-law distribution, yielding the spectral index, δ_x. The spectral indices for the accelerated electron population emitting the radio and X-rays do not match, the radio index being approximately 2 units harder than that of the X-rays, similar to the result obtained by Silva et al. (2000). An explanation is that the radio emission is produced by higher energy electrons (White & Kundu 1992) than the X-rays, and that the common accelerated electron population has a power-law energy distribution that breaks up above 300 KeV.

Both flares presented circular polarization of about 10-15% at 45 and 90 GHz with the polarization having the opposite sign at each frequency, and also reversed for each event. An interpretation of such result can be that the emission at 45 and 90 GHz arise from sources on both sides of an asymmetric magnetic loop (Kundu & Vlahos 1979) with the 90 GHz source being located at the loop leg with a stronger magnetic field.

References

Dulk, G. A. 1985, ARA&A, 23, 169
Hurford, G. J., Stahli, M., & Gary, D. E. 1989, in Bulletin of the American Astronomical Society, vol. 21 of Bulletin of the American Astronomical Society, 836
Kaufmann, P., Parada, N. J., Magun, A., Rovira, M., Ghielmetti, H., & Levato, H. 1994, in Proceedings of Kofu Symposium, 323
Kundu, M. R., & Vlahos, L. 1979, ApJ, 232, 595
Ramaty, R. 1969, ApJ, 158, 753
Silva, A. V. R., Wang, H., & Gary, D. E. 2000, ApJ, 545, 1116
Valio, A., Kaufmann, P., Giménez de Castro, C. G., Raulin, J.-P., Fernandes, L. O. T., & Marun, A. 2013, Solar Phys., 283, 651
White, S. M., & Kundu, M. R. 1992, Solar Phys., 141, 347