Results of comparative analysis of the SEP events and the microwave bursts observed by 2-24 GHz and 4-8 GHz spectropolarimeters in 2010-2016

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Abstract.

We present a relationship analysis between the solar energetic particle (SEP) events and the microwave (MW) spectral observations of the solar bursts detected in 2010–2016. The information about the SEP events is taken from the Wind/EPACT catalog based on data in the period 1996÷2016. We use MW data from the archive of MW observations in the range 2÷24 GHz. Observations were made by spectropolarimeters of the SSRT observatory (Russia). We found that 40 events are present in both catalogs. We tested the relationships between the proton spectral index of SEP events and the peak frequency of the MW bursts and presence of circular polarization in MW emission of selected events. The results are finally discussed.

Introduction

Solar energetic particles (SEPs), i.e., temporal increases of charged particles flux in interplanetary (IP) space, together with their solar origins are keeping the interest of the Space Weather community during several dozen years [e.g. *Reames*, 2015]. There are several questions that have not been clarified yet. Where is the acceleration site of the particles, in the solar atmosphere during the flare or in the IP space on shock waves of coronal mass ejection (CME)? The comparison of solar event characteristics with the characteristics of the SEP events is one way to advance in solving these problems. The best tracers of acceleration processes are accelerated electrons. They move from the location of the primary energy release in two opposite directions and thus precipitate in two different conditions of plasma. The dense plasma provides generation of hard X-ray emission. The other part of electron flux occurs in conditions that are favorable for generating the gyrosynchrotron emission. It is assumed that the microwave (MW) emission at frequencies above 2 GHz is usually incoherent gyrosynchrotron emission from relativistic electrons. The flux maximum separates the MW spectrum into two parts. Accelerated electrons only generate the emission at frequencies above the peak frequency. The previous studies used 35 GHz frequency for testing of acceleration process during the flares produced the SEP events [e.g. *Grechnev, et al.,* 2017]. It is possible that this approach restricts the number of considered events that could result to a loss of important information as only the strongest flares can have flux at 35 GHz. The aim of this work is studying MW spectral signatures of the solar origins of SEP events with high proton flux in wide frequency region (2–24 GHz). We present the results of the first stage including the event selection and preliminary analysis.

Data

We used the microwave data of the 2–24 GHz Spectropolarimeter and 4–8 GHz Spectropolarimeter (BBMS) located in Radio Astrophysical Observatory of the Institute of Solar-Terrestrial Physics, Russia [*Zhdanov, et al.*, 2011]. The microwave data are the temporal profiles of the flux for right-hand circular polarization (RCP) and the left-hand of circular polarization (LCP) at 26 frequencies for the BBMS and at 16 frequencies for the 2–24 GHz Spectropolarimeter.

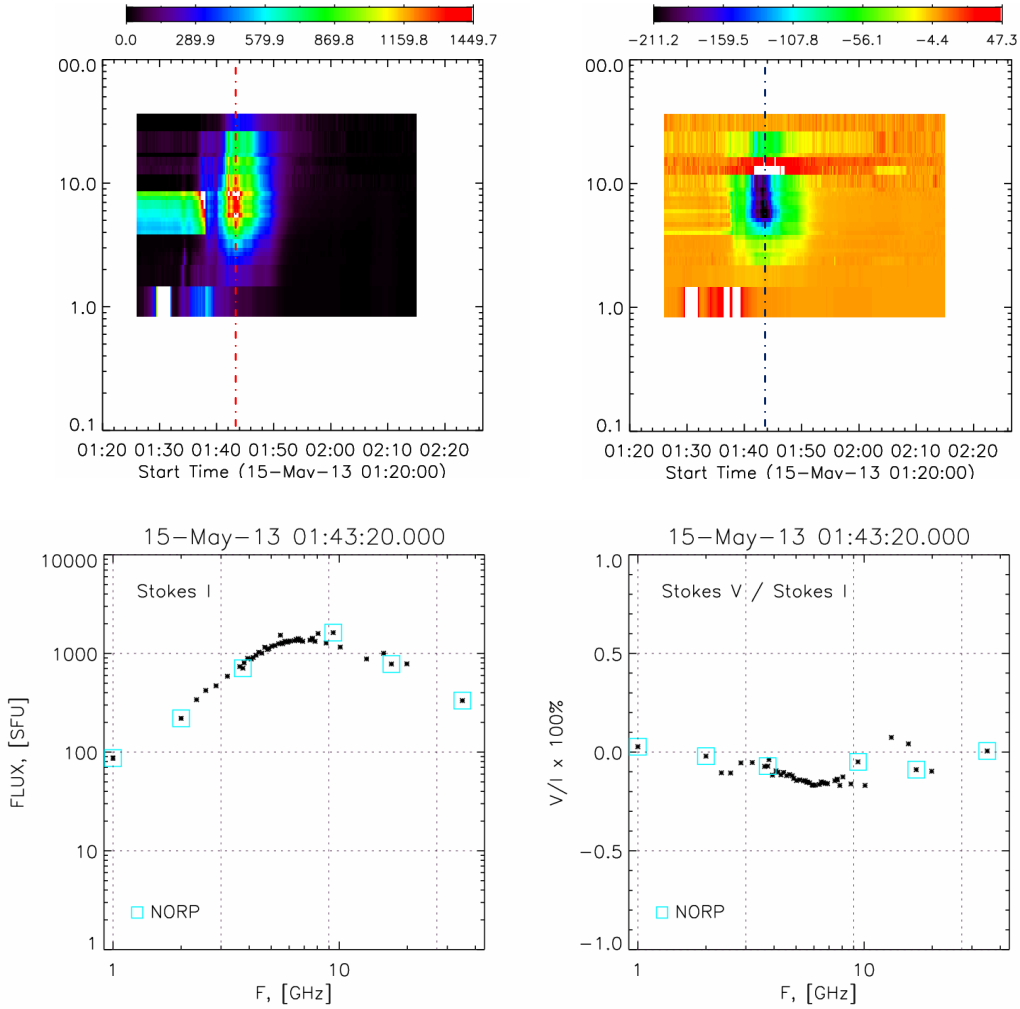

Fig. 1 Example of data processing for SOL2013-May-15 event: top row – dynamic spectra for both intensity (left plot) and the degree of polarization (right plot); bottom row – the spectrum at the time marked by the dash-dot lines for intensity (left plot) and the degree of polarization (right plot); the data points marked by squares denote data adopted from the Nobeyama Radio Polarimeters.

We used the catalog of SEP events detected by the Wind/EPACT instrument over the period 1996–2016 [*Miteva, et al.* 2018]. They are proton events. The catalog shows the times of SEP event onset, the peak times, the intensity of peak proton flux and the onset-to-peak proton fluences for proton fluxes detected in the two energy channels (above 25 and 50 MeV). Most of the events are associated with both solar flares and CME.

Results

We compared the data of the microwave burst catalog obtained by BBMS with the SEP event catalog obtained by Wind/EPACT. Microwave observations are available only from 2010, and it is limited by the local day time (00–10 UT). There are 172 SEP events that occurred from 2010 to 2016. Only 39 events from the 172 events took place between 0 and 10 UT that potentially could be observed by the spectropolarimeters. We carried out an analysis of these 39 events and found that 18 events are typical microwave bursts. Three events were related with very weak flares (B8.1, C1.2, C4.6) and 7 events had no microwave features. We did not reveal the solar flares for other 7 events. In the remaining 4 events, microwave observations finished earlier than 10 UT.

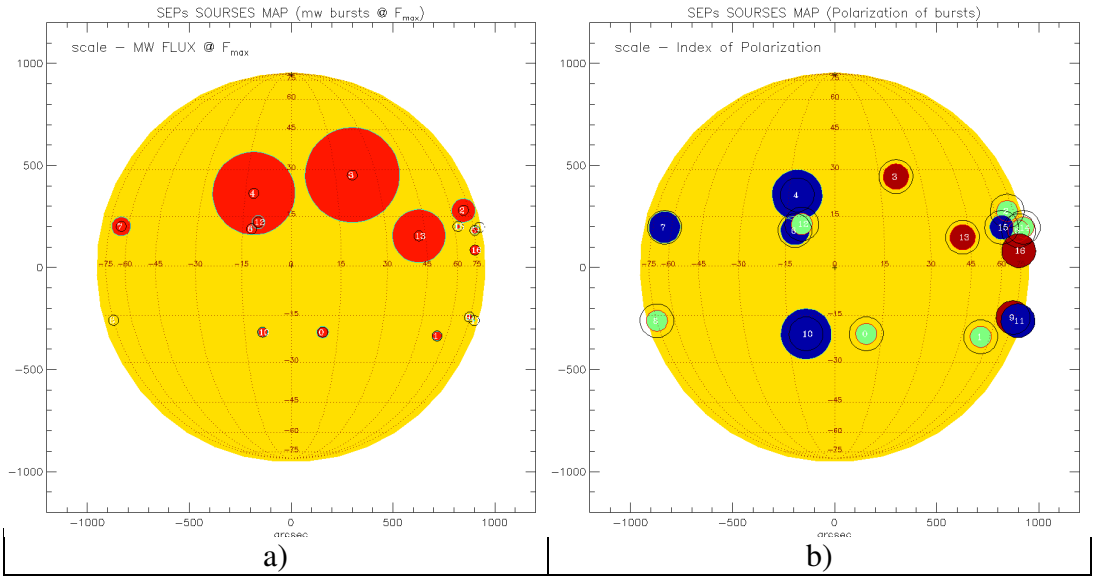

Fig. 2 SEP sources mapping; circles are positions of microwave bursts; sizes of circles depend on both strength of the microwave flux and values of the degree of polarization. a) microwave bursts; b) degree of polarization, blue color – LCP, red color – RCP, green color – no polarization

We focused further on the 18 events associated with microwave bursts. We processed the data, plotted the microwave spectrum and determined the following parameters for each event: the flux value at maximum; the frequency of spectral maximum; presence and sign of the polarization and the frequency of the maximum polarization value. Table 1 shows the obtained results.

Figure 1 shows the example of data processing for SOL2013-May-15 event. The top panel of the figure shows the dynamic spectra for both intensity (left plot) and the degree of polarization (right plot). The bottom panel shows the spectrum at the time marked by the dash-dot lines for intensity (left plot) and the degree of polarization (right plot). The squares denote the data of the Nobeyama Radio Polarimeters.

Figure 2 shows the location of radio sources on the solar disk according to the position of the solar origins in the SEP catalog. The left plot (a) shows the distribution of the strength of the microwave flux of the events. The right plot (b) shows the distribution of the values of the degree of polarization of the events. The circle color indicates the sign of polarization.

Summary

We carried out a selection and preliminary analysis of the microwave data for SEP events from the Wind/EPACT catalog. The studied events occurred from 0 to 10 UT in the years from 2010 to 2016. For information about microwave observations, we used data obtained by the 2–24 GHz spectropolarimeter and the 4–8 GHz spectropolarimeter.

We found that 39 events are present in both catalogs. But only 18 out of the 39 events were accompanied by typical MW bursts. The spatial distribution of MW bursts indicates to the more active northern hemisphere. The peak frequencies of the MW bursts vary within 2 GHz and 10 GHz. The circular polarization in MW emission was found in 10 events of the selected events. We did not reveal any dependence between the position of the solar origin of SEP event and the sign of circular polarization. The further analysis of the selected and processed data will allow getting new information about the properties of MW emission of SEP event origins.

Table 1. The characteristics of the 18 proton events associated with typical microwave bursts.

№	Date (yyyy-mm-dd)	Time (UT)	GOES class	$Flux_{max}$ (sfu)	F_{max} (GHz)	V/I (%)	F_{max} V (GHz)
1	2011-02-15	01:44	X2.2	1000	8	no	no
2	2011-06-07	06:16	M2.5	800	6.5	no	no
3	2011-08-09	07:48	X6.9	2000	10	no	no
4	2012-01-23	03:38	M8.7	8000	4	+10	4
5	2012-03-07	01:05	X1.3	7000	9.4	-30	3.7
6	2012-05-17	01:25	M5.1	600	5	no	no
7	2013-03-15	05:46	M1.1	120	1.5	-15	7.5
8	2013-05-15	01:25	X1.2	1600	7	-18	6.5
9	2013-06-21	02:30	M2.9	-	-	-	-
10	2013-11-02	04:40	C8.2	-	-	-	-
11	2014-02-20	07:26	M3.0	500	6	+20	6
12	2014-12-17	04:25	M8.7	800	7	-30	13
13	2015-06-18	00:33	M1.2	60	2	-20	2
14	2015-06-21	02:06	M2.6	1100	7.5	no	no
15	2015-06-25	08:02	M7.9	4500	9	+10	17
16	2016-03-16	06:34	C2.2	8	3.5	no	no
17	2016-04-18	00:14	M6.7	400	6	-8	9
18	2016-07-23	05:00	M7.6	850	2.5	+20	10

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