Universal Heliophysical Processes
Proceedings IAU Symposium No. 257, 2008
N. Gopalswamy & D.F. Webb, eds.

doi:10.1017/S1743921309029482

Observations of radio spectra at 1–2.5 GHz associated with CME start time

José R. Cecatto[1]

[1] Astrophysics Division, INPE, P.O. Box 515
12227-010, São José dos Campos, Brasil
email: jrc@das.inpe.br

Abstract. We know Coronal Mass Ejections (CME) and flares are the most energetic phenomena happening on the Sun. Until now the information about origin and trigger mechanism of CMEs remains scarce. Also, there is unconclusive information about the association between them and flares although progress has been made in recent years. Multi-spectral observations suggested that the flare energy release occurs in regions from where the decimetric radio emission originates. In this case, investigations of the solar emission in this wavelength range can give us valuable information about these questions. During last solar maximum the Brazilian Solar Spectroscope (BSS) observed the solar radio spectrum (1–2.5 GHz) with high time (100–20 ms) and frequency (50–100 channels) resolutions on a daily (11–19 UT) basis. A survey during the period 1999–2002, shows that a significant fraction (20% −57 events) of CMEs recorded by LASCO has an association with the spectra of radio bursts recorded by BSS. Analysis of the radio spectrum associated to CME shows there is a dominance of continuum and/or pulsation and that the association becomes stronger when we consider the CME acceleration since its origin on the Sun. A statistics of this association between CME dynamics and the characteristics of decimetric radio bursts recorded by BSS is presented. Emphasis is given to observations of the association with CME start time.

Keywords. CME, radio, bursts

1. Introduction

CMEs are among the most energetic phenomena originated on the Sun. They carry enormous kinetic energies (10^{32}–10^{34} erg) out of the Sun due to the high mass ($\sim 10^{-15}$ solar masses) and velocities (hundreds to few thousand km/s). Also, they carry magnetic field in the form of bubbles which become unstable and buoyant, leaving the Sun and propagating out into the interplanetary space. Observed in white light they were first imaged with space-borne coronographs in the early 1970s (Tousey 1973; Gosling *et al.* 1974). Until now several aspects and a controversy in those investigations concerning the relationship between CMEs, solar flares and radio bursts remains. Some authors show that $\leqslant$ 40% of CME phenomena are associated with flares (Munro *et al.* 1979; Webb & Hundhaunsen 1987; St. Cyr & Webb 1991), while others concentrate on determining why part of the CME are related to flares and which are their common characteristics (Verneta 1997; Svestka 1995; Sheeley *et al.* 1983; Kahler 1994).

Some authors (Hudson *et al.* 2001) reported one case for which the CME occurred 15 minutes after the X-ray/radio emission. At decimetric waves a variant of the pulsation emission have been noticed at the initial phase of CME (Jun Fu, Q. *et al.* 2004). Also, Wang *et al.* (2005) investigated the radio spectra associated to quite strong CME during three days and found the spectra indicate association to type-II, type-III, type-IV, drifting pulsations and fine structures. Yet, fast drift structure and continuum from one radio burst have been found in association to CME by Pohjolainen (2008). However, investigations taking into account for a large sample of data are rare.

Taking this into consideration, this work represents a survey on data from ∼4 years period (1999-2002) searching for some association between CME phenomena and BSS bursts spectrum, within the BSS observational window 11–19 UT.

2. Instrumentation, observations and results

The BSS is a digital spectroscope operating daily from 11 to 19 UT since 1998, at INPE, São José dos Campos, Brasil. Jointly with its polar mounted 9 m diameter parabolic antenna, it operates in the frequency range (1-2.5 GHz) with high time (100, 50, 20 ms) and frequency (1–10 MHz) resolutions. Besides, within some limitations it allows us to select observing frequency range, frequency and time resolutions. The data is digitized and recorded in up to 200 frequency channels. Time minimum detectable flux is around 2-3 sfu, for several combinations of the observational parameters (Sawant *et al.* 2001; Fernandes 1997). Normally, BSS is operated using either 100 or 50 channels within the selected operational bandwidth.

LASCO comprises 3 coronographs which jointly imaged the solar corona since 1.1 until 30 Rs (C1: 1.1–3 Rs, C2: 2–6 Rs, C1: 3.7–30 Rs)(Brueckner *et al.* 1995). The LASCO (C2, C3) experiment recorded a total of 304 CME phenomena during the period of 1999-2002, 11–19 UT, corresponding to the BSS observing days.

A fraction (20%) of those CMEs has the start time associated with various types of solar events within 5 minutes before the start up to 5 minutes after the end time of the bursts recorded by BSS. Since the CME acceleration - linear, quadratic approximations - is measured its onset time can be calculated. This information is available at CDAW-GSFC(NASA) website. Also, it has to be remarked that the minimum time interval between two consecutive LASCO images is 12 min. Table 1 shows the main characteristics as well as H-α and X-ray activity of all BSS events recorded in association with CME start times.

Two examples of BSS burst spectra recorded in association with CME start time are shown in Figure 1 (left, right). As can be clearly seen from Table 1, the dominant types of radio bursts associated to the CME are pulsations and continuum isolated as well as combined. In several cases the pulsations and continuum emissions are combined together, Figure 2 (left), or with other types of radio burst, e.g. fine structure, as can be seen in Figure 2 (right).

3. Discussions and conclusion

From the sample of all CMEs (∼ 300) observed within the BSS observational window during the period 1999-2002 about 20 % have estimated start time within an interval of 5 minutes before the start time and 5 minutes after the end of associated BSS bursts. Table 1 shows the BSS bursts characteristics as well as H-α and X-ray related flares. From all those 57 associated bursts about 20 % have no H-α flare associated and a little bit more no X-ray flare associated. About those X-ray associated fourteen are class C, twenty two M, and nine X flares. Only half of the cases not associated with H-α flares are simultaneously not associated with X-ray flares. Curiously, a look through the column of active region position (NOAA) shows that statistically the associated Northern hemisphere active regions were observed in about 2/3 of identified active regions while other 1/3 correspond to Southern identified active regions.

Also, a little less than half of CME recorded in association with decimetric radio burst emission is either Halo or Partial Halo CME. The velocity of CME associated ranged from 153 km/s to 2047 km/s with an average 715 km/s. There is a slight dominance of CMEs slower than the average.

Regarding the association between the CME estimated start time with the spectra of radio burst emission observed at decimetric wavelengths the following points need to be remarked. The limited frequency range (1–2.5 GHz) of radio observations. Second, BSS sensitivity does not permit to measure signals lower than 2–3 SFU. Finally, in some cases coronal inhomogeneities can cause absorption of radio waves at decimetric wavelengths. The combination of these factors could explain the relatively low percentage of association between the CME start time and radio bursts emission.

We showed that there is association between a fraction of burst spectra (1–2.5 GHz) recorded by BSS instrument with corresponding CMEs recorded by LASCO C2 and C3 coronographs, mainly concerning about CME start time. This association can give us

Table 1. Characteristics of BSS bursts and flares associated to the onset time of CME.

Date	BSS			LASCO		H-α					X-Ray		
	Begin (UT)	End (UT)	Type	Vel. (km/s)	Onset time(UT)	Loc.	AR	Begin (UT)	Max (UT)	End (UT)	Begin (UT)	End (UT)	Imp.
08/17/99	12:43	18:34	N, FS	776PH	12:44:28	N26E35	8668	B12:47	U12:50	14:05	12:32	13:57	C3
08/17/99	12:43	18:34	N, FS	962PH	15:16:28	N26E35	8668	15:05	15:22	16:34	14:28	17:54	C6
08/30/99	17:50	17:59	G, P	404	17:56:43	S21W58	8673	17:26	17:28	18:13	17:23	18:21	M4
11/27/99	12:09	12:22	G	641	12:14:13	S15W68	8771	12:08	12:12	13:19	12:05	12:16	X1
11/27/99	12:09	12:22	G	235	12:21:55	S15W68	8771	12:08	12:12	13:19	NF*		
04/18/00	14:55	15:01	DT	668	14:53:56	NF*					NF*		
05/02/00	14:43	14:49	CT, FS	1278	14:45:17	N22W68	8971	14:45	14:46	15:05	14:42	14:56	M3
05/19/00	13:12	13:18	IIIi,b	327	13:12:05			13:25	13:30	13:37	NF*		
05/22/00	13:24	13:41	CT	419	13:38:16	NF*					NF*		
06/06/00	15:01	17:17	Pre, CT	929	15:03:42	N20E18	9026	12:06	15:21	18:43	14:58	15:40	X2
06/06/00	15:01	17:17	Pre, CT	1119H	15:21:40	N20E18	9026	12:06	15:21	18:43	14:58	15:40	X2
06/07/00	15:37	15:43	IIIi,b	842H	15:35:42	N23E03	9026	15:04	15:46	18:51	15:34	16:06	X1
06/27/00	13:43	15:02	FB, FS	363	14:37:12	NF*					14:29	14:35	C2
07/04/00	14:58	14:59	DT	562	15:03:45	S22E31	9068	14:58	15:00	15:16	14:57	15:04	C2
07/04/00	15:18	15:18	FS SD	562	15:16:48	N17E49	9070	15:11	15:25	16:22	15:08	15:34	C3
07/06/00	12:26	12:37	CT, P	472	12:31:50	N18E25	9070	12:22	12:23	12:26	12:23	12:49	C4
07/11/00	12:31	12:31	DT	1078H	12:33:29	S18W42	9069	12:31	12:31	12:36	12:12	13:35	X1
07/31/00	15:55	15:55	P, PA	774	15:58:44	NF*					NF*		
09/15/00	14:31	14:37	P	481PH	14:33:13	N13E07	9165	14:31	14:38	15:06	14:29	14:44	M2
09/16/00	13:23	13:34	PA	1056	13:24:54	N14W08	9165	13:08	13:12	13:23	NF*		
11/24/00	14:53	15:20	CT, P	1245H	15:08:32	N22W07	9236	15:01	15:16	15:57	14:51	15:21	X2
04/05/01	16:53	17:21	CT	1390H	16:56:47	S24E50	9415	16:33	17:01	18:49	16:57	18:14	M5
04/06/01	17:18	17:19	P	648	17:20:24	S19E32	9415	17:24	17:30	18:18	17:11	17:50	C5
04/09/01	15:20	16:05	CT, P	1192H	15:32:02	S21W04	9415	15:24	15:34	17:03	15:20	16:00	M8
04/11/01	17:23	17:23	FS nb	1145	17:19:53	S21W27	9415	17:25	17:26	17:28	NF*		
04/25/01	13:42	13:45	FS, OS	856	13:46:51	N18W09	9433	13:44	13:45	14:20	13:39	13:59	M3
04/26/01	11:49	12:01	OS nb	1006H	11:51:38	NF*					11:26	13:19	M8
04/26/01	12:51	13:11	CT, FB, O	844	12:58:31	N17W31	9433	12:11	13:11	14:31	11:26	13:19	M8
06/04/01	15:12	15:14	IV	632	15:11:37	S19E52	9488	15:11	15:17	15:28	15:10	15:23	C1
06/13/01	11:35	11:42	CT, IV	576	11:36:19	S29E66	9502	11:35	11:39	12:18	11:22	11:51	M8
06/13/01	16:22	16:25	IV	276	16:25:57	N20W49	9489	16:21	16:28	16:39	16:20	16:35	C9
08/28/01	16:00	16:02	FS	478PH	16:02:42	N13E68	9601	16:01	16:09	16:14	15:56	16:26	M1
08/28/01	160227	160356	FS	478PH	16:02:42	N13E68	9601	16:01	16:09	16:14	15:56	16:26	M1
08/29/01	18:25	18:27	CT, P, RF	317	18:27:35	N18E58	9600	18:24	U18:39	19:29	18:19	18:50	C3
08/31/01	14:56	14:57	G	310H	14:52:52	N13E29	9601	15:29	15:31	15:52	NF*		
09/03/01	15:52	15:52	CT	196	15:51:07			15:45	17:16	17:37	15:45	17:37	M1
09/03/01	18:22	18:25	CT	1352PH	18:24:11			18:21	18:41	19:10	18:21	19:10	M2
09/11/01	14:17	14:17	DT	791H	14:17:13	N13E35	9615	14:16	14:39	15:30	14:00	15:08	C3
09/18/01	17:05	17:08	PA, SP, CT	376PH	17:00:14	S18E85	9628	17:06	17:06	17:13	17:02	17:09	M1
09/20/01	18:13	18:14	CT, EF	446PH	18:15:39	N09W11	9631	18:15	18:18	18:30	18:12	18:21	M1
09/28/01	14:02	14:08	IV	248	14:07:02	S17W47	9628	13:57	13:59	14:08	NF*		
10/01/01	14:42	14:42	IIIi, n	153	14:42:45	NF*					NF*		
10/19/01	16:22	17:06	P, CT, FB	901H	16:21:18	NF*					16:13	16:43	X2
10/22/01	14:50	15:09	IV	1336H	14:49:53	S21E18	9672	B14:25	15:12	16:02	14:27	15:31	M7
10/25/01	15:06	15:31	CT, LC	1092H	15:01:51	N09E26	9678	14:56	14:56	15:19	14:42	15:28	X1
10/26/01	14:30	14:37	CT, P	350	14:33:08	N07E16	9678	14:30	14:36	14:45	14:28	14:37	M2
11/28/01	16:33	16:35	IV	500H	16:33:37	N04E16	9715	16:32	16:36	16:52	16:26	16:41	M7
12/13/01	14:24	14:24	PA	864H	14:24:54	N16E09	9733	14:24	14:30	15:45	14:20	14:35	X6
04/04/02	15:27	15:27	FS nb	790	15:25:27			15:24	15:32	15:38	15:24	15:38	M6
04/13/02	12:07	12:33	IRF	599	12:07:02	S03E57	9907	12:12	12:13	12:22	12:08	12:20	C3
07/11/02	14:48	14:48	III nb	614	14:48:41	N21E58	10030	14:46	14:48	15:22	14:44	14:57	M6
07/19/02	16:16	16:20	CT	2047H	16:14:01	NF*					NF*		
07/24/02	15:43	15:51	IP	528	15:42:41	S13E49	10039	15:14	15:45	16:59	15:24	16:22	M1
08/28/02	16:40	16:51	OS	447	16:45:45	NF*					16:45	17:09	M1
08/30/02	14:37	14:48	OS	420	14:37:01	N08E75	10095	14:27	14:31	14:36	14:35	14:43	C8

CT - continuum, DT - Dots, FS NB - elementary flare narrow band, FS SD - elementary flare slow drift, FB - fiber, FS - fine structure, G - gradual, IP - intermediate pulsation, IV - intermediate variation, III IS - isolated type III, III NB - narrow band type III, IIIi, b - intermediate and broad band type III, LC - Lace-like, N - Noise, OS - Oscilations, PA - Patch, PRE - Pre-flare, P - Pulsations, RF - Rise and Fall, SP - Split, NF* - No Flare

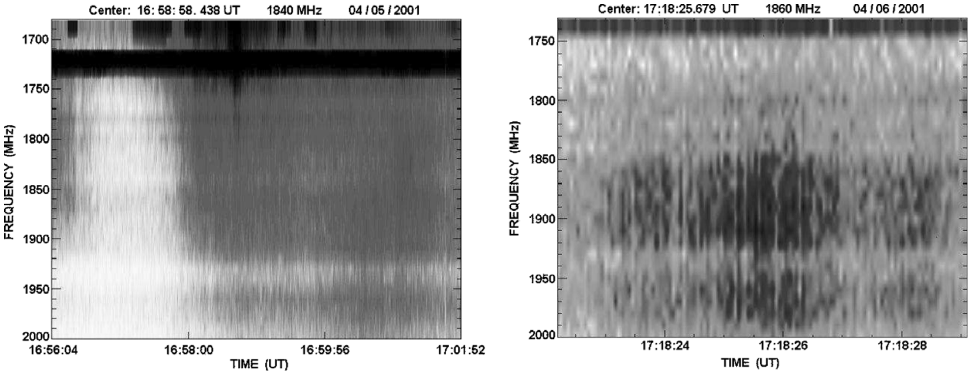

Figure 1. (Left) BSS burst dinamic spectrum associated to CME exhibiting a continuum radio burst emission observed on 04/05/2001 at 16:58 UT. (Right) Pulsation radio emission associated to CME observed on 04/06/2001 at 17:18 UT.

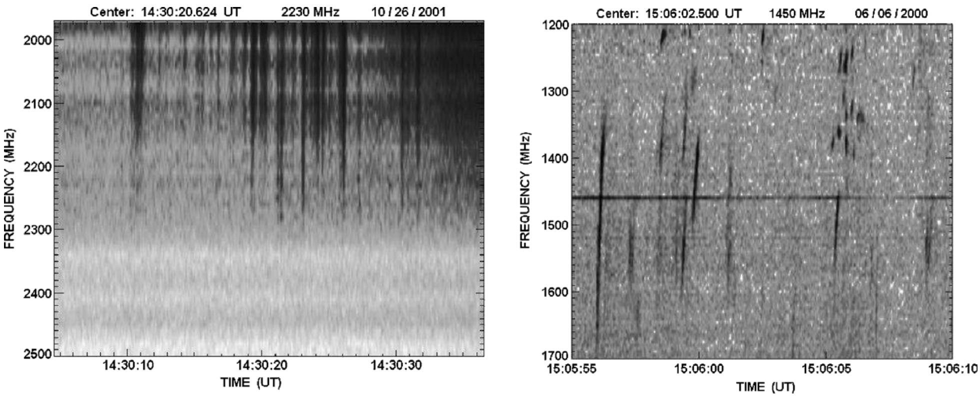

Figure 2. (Left) Dinamic spectrum of BSS bursts observed on 10/26/2001 at 14:30 UT associated to CME. It is clear in the beggining the pulsation emission and its superposition on continuum radio burst emission in the time evolution of the radio burst. (Right) Dinamic spectrum showing a combination of various kinds of radio emission observed by BSS on 06/06/2000 at about 15:06 UT and associated to CME.

important information regarding CMEs origin and trigger mechanism, and also about the associated solar bursts. Further investigation and a deeper analysis of this sample of data as well as statistical analysis of additional data coming from other observatories in other radio bands are required to improve our understanding of the relationship between radio bursts, flares and CME occurrence. Mainly, the investigations have to search for some kind of radio signature associated to CME occurrence. Also, further analysis must be done on those CME phenomena not related to radio bursts and flares.

4. Acknowledgements

We are grateful to the Brazilian Financial Agencies CNPq for the financial support through the grant 475723/2004-0, and FAPESP through the grant 06/55883-0. We would also like to thank the SOHO team for maintaining the database and processing of LASCO and EIT data. SOHO is operated by ESA, CDAW(NASA) scientists whose dedication has made data available to the solar community. Our acknowledgements to the SEC team that maintains The Weekly report and forecast of Solar Geophysical Data. Thanks are also given to the referees for their helpful comments on the manuscript.

References

Brueckner, G. E., Howard, R. A., Koomen, M. J., Korendyke, C. M., Michels, *et al.* 1995, *Solar Phys.*, 162, 357

Fernandes, F. C. R. 1997, in: INPE-6396-TDI/612, , *Tese de Doutorado* (São José dos Campos), p. 178

Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., & Ross, C. L. 1974, *JGR*, 79, 4581

Hudson, H. S., Kosugi, T., Nitta, N. V., & Shimojo, M. 2001, *ApJ*, 561, L211

Jun Fu, Q., Yan, Y. H., Liu, Y. Y., Wang, M., & Wang S. J. 2004, *Chin. J. Astron.Astrophys.*, 4(2), 176

Kahler, S. W. 1994, *ApJ*, 428, 837

Munro, R. H., Gosling, J. T., Hildner, E., MacQueen, R. M., Poland, A. I., & Ross, C. L. 1979, *Solar Phys.*, 61, 201

Pohjolainen, S. 2008, *A&A*, 483, 297

Sawant, H. S., Subramanian, K. R., Faria, C., Fernandes, F. C. R., Sobral, J. H.A., & Cecatto, J. R., *et al.* 2001, *Solar Phys.*, 200, 167

Sheeley Jr., N. R. Howard, R. A., Koomen, M. J., & Michels, D. J. 1983, *ApJ*, 272, 349

St. Cyr, O. C. & Webb, D. F. 1991, *Solar Phys.*, 136, 379

Svestka, Z. 1995, *Private communication*

Tousey, R. 1973, in: Rycroft, M. J. & Kuncorn, S. K. (eds.) *The solar corona-Space Research XIII* (Berlin: Akademie-Verlag), p. 713

Verneta, A. I. 1997, *Solar Phys.*, 170, 357

Verneta, A. I. & Hundhausen, A. J. 1997, *Solar Phys.*, 108, 383

Wang, S. J., Yan, Y., Fu, Q., Liu, Y., & Chen, Z. 2005, in: Dere, K. P., Wang, J., & Yan, Y. (eds.) *Coronal and Stellar Mass Ejections* (Beijing), p. 139

Discussion

Melnikov: It is known that dm-continua and pulsations are quite common during solar flares. You say that these types frequently observed in association with CMEs. But possibly this is not a radio signature of CMEs only. Did you study the appearance of dm-continua and pulsations in events without CMEs?

Cecatto: I think there is some reason for a higher relative association between CME onset with continuum and pulsations radio bursts which has to be studied on a physical basis. I think it is not possible to say this is a signature of CME occurrence, yet. Improved statistics and interpretation on a physical basis is required to these observational results. The suggestion to compare with events without CME is welcome.

Nindos: How do you know that the radio emission comes from the CME and not from the flare?

Cecatto: I did not say "CME radio emission". These investigations are about the radio burst emission associated with the onset of CME on a statistical basis. Also: 1. There are 13 out of 61 cases which have no associated H-alpha flare; 2. I do not believe I can measure the radio emission of a CME with a 9-m-diameter antenna due to the lack of sensitivity.