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On some statistical characteristics of radio-rich CMEs in the solar cycles 23 and 24

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Abstract In this paper we have presented the properties of radio-rich coronal mass ejections (CMEs), during the period 1997–2013. The CME event accompanied by the type II radio burst is referred to as radio-loud (RL), while the one lacking a type II burst is termed radio-quiet (RQ). These radio rich CMEs produce type II (1–14 MHz), i.e. decametric–hectometric or DH radio burst. It is found that the average width of all DH CMEs during the study period is 235° and 75% of the DH CMEs are halo CMEs in solar cycle 24. The DH CMEs linear speeds distribution is in the range 112–3387 km/s, with an average speed of 1043 km/s; the acceleration varies between 434 m/s^2 and −179 m/s^2. About 62% of the DH CMEs are decelerated. A CME associated with a type II burst and originating close to the center of the solar disk typically results in a shock at Earth in 2–3 days and hence can be used to predict shock arrival at Earth.

1. Introduction

Coronal mass ejections (CMEs) are the most energetic eruption in the solar system. Previous studies have established that many CMEs are associated with flares, and some of the physical properties of CMEs and flares are closely related; the flare, CME events which are associated with type II are said to be radio-loud, while the others without type II are named to be radio-quiet. Type II solar radio bursts have been studied by solar astronomers for more than 50 years. Wild and McReady (1950) first reported the observations of type II radio bursts from the dynamic spectra of solar radio bursts. The dynamic spectrum of a type II burst shows an emission band drifting from high to low frequency with a drift rate of < 0.5 MHz/s, (Subramanian and Ebenezer, 2006). There is a general consensus that the type II radio bursts are a signature of shock wave propagating away from the Sun (Uchida, 1960; Nelson and Melrose, 1985; Gopalswamy et al., 2005). It has been established that shocks driven by CMEs are responsible for interplanetary type II bursts observed at decametric–hectometric wavelength (Gopalswamy et al., 2001) and kilometric wavelengths (Cane et al., 1987). However, the drivers of shocks associated with the metric (or coronal) type II radio bursts are still controversial. CME-driven shocks as in IP type

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Table 1 Annual number, average speed, average width, median speed, median width and standard deviation of 471 DH CMEs.

Year	Number	Average width (°)	Median width (°)	Standard deviation of width	Average speed (km/s)	Median speed (km/s)	Standard deviation of speed
1997	10	199	118	132	590	428	372
1998	22	262	360	118	1038	1009	438
1999	17	251	360	123	1062	1025	568
2000	94	190	136	143	801	700	451
2001	56	234	271	134	1117	1008	588
2002	45	257	360	134	1211	1092	598
2003	34	225	226	128	1279	1101	583
2004	35	218	214	136	1067	925	594
2005	47	278	360	128	1295	1380	764
2006	12	161	67	148	853	829	554
2007	3	210	164	109	1106	995	185
2008	1	112	112	–	1103	1103	–
2009	–	–	–	–	–	–	–
2010	6	216	165	104	883	845	402
2011	37	275	360	111	1001	924	518
2012	43	300	360	106	1158	1138	509
2013	9	210	199	147	866	663	507

II bursts (Cliver et al., 1999; Gopalswamy et al., 2009; Cho et al., 2011) and flare blast waves (Vrsnak et al., 1995; Khan and Aurass, 2002; Magdalenic et al., 2008) are the two possibilities (Yashiro et al., 2014). DH and km type II radio bursts are recorded in the 1–14 MHz and 20 kHz – 1 MHz frequency ranges by RAD2 and RAD1 instruments respectively, constituting the Radio and Plasma Wave (WAVES) experiment (Bougeret et al., 1995) on board the wind spacecraft (Acuna et al., 1995).

In this paper we study the properties of DH-type II (1–14 MHz), i.e. radio-rich CME occurred during the period January 1997–May 2013 for the solar cycle 23 and 24. Earlier (Sharma et al., 2008; Gopalswamy et al., 2005) have investigated the properties of radio-rich CMEs during the period January 1997–November 2006, with 367 events, and found that these DH CMEs are relatively faster and wider than the normal CMEs. The DH type II bursts provide an opportunity to remotely observe the formation and propagation of shocks in the solar corona and in interplanetary (IP) spaces.

2. Data and result

The data (such as speed, angular width, acceleration and occurrence rate of CMEs) in this study are selected through

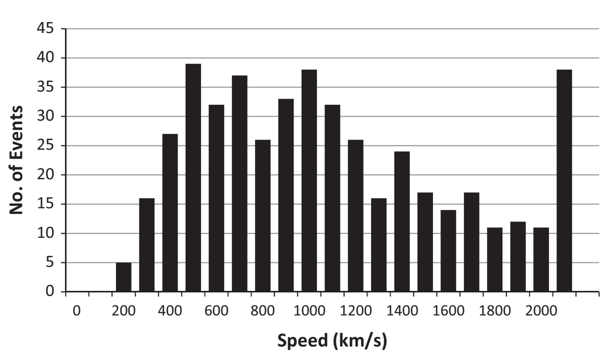

Figure 1 Histogram showing the speed distribution of 471 DH CMEs, during the period 1997–2013.

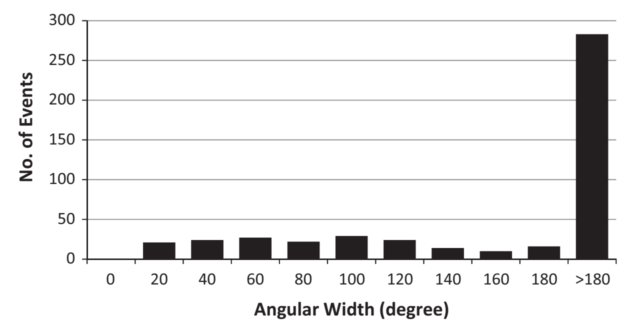

Figure 2 Histogram showing the angular width distribution of 471 DH CMEs during the period 1997–2013.

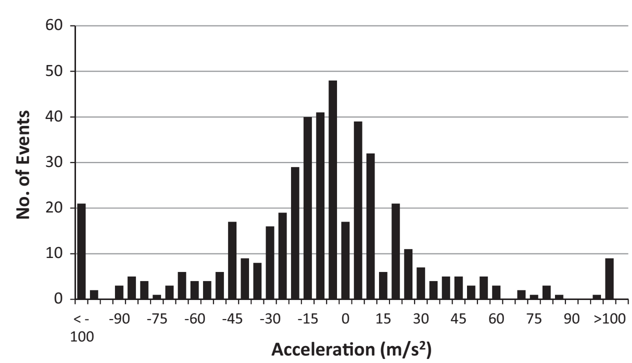

Figure 3 Histogram showing the acceleration distribution of 471 DH CMEs, during the period 1997–2013.

the on line Coordinated Data Analysis Workshop (CDAW, http://cdaw.gsfc.nasa.gov/CME_list) database for CMEs observed by the Large Angle and Spectrometric coronagraph (LASCCO) onboard SOHO (Bruckner et al., 1995). During the solar cycle 23 and 24 in total more than 23000 CMEs have been observed till now by this instrument. Type II radio bursts were observed by Wind/WAVES spacecraft, (Bougeret et al.,

1995) which is available on http://ssed.gsfc.nasa.gov/waves/burst. Since different observation use different density models for the calculation of the estimated shock speeds and different methods to determine the characteristics of the bursts, we have selected the events observed by Wind/WAVES spacecraft. A total of 638 events were observed by spacecraft from December 1994 to May 2013. Out of which 48 seem to be type IV radio bursts, and remaining 590 are type II burst. In our study we have considered 471 DH CMEs during the period 1997–2013, for the solar cycle 23 and 24. In solar cycle 24 (January 2009–June 2013) 95 events are taken.

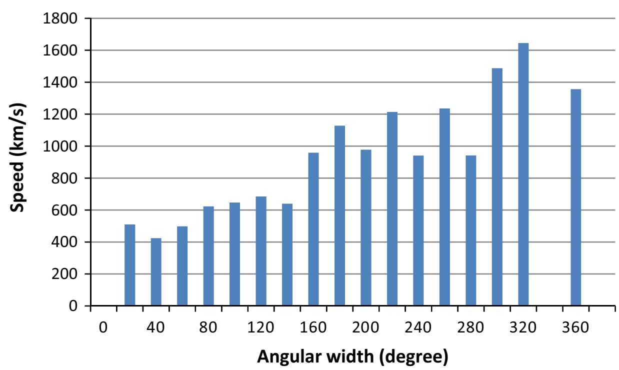

Figure 4 Histogram showing the distribution of angular width with the speed during the period 1997–2013.

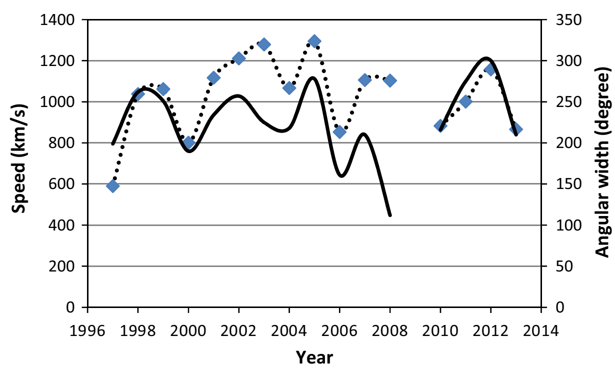

Figure 5 Annual variation of speed and angular width. Dotted line shows the speed distribution and angular width distribution is represented by solid line.

Table 1 gives the annual distribution of average width, average speed and their width median, speed median along with standard deviation. Fig. 1 gives the distribution of speed during the study period but Fig. 2 shows the distribution of width of events of the same period and the variation between them is given in Fig. 4. It is found that the most of the events have speed greater than 800 km/s and width greater than 200°. It is also noted from Fig. 4 that DH CMEs having more width have greater speeds.

Fig. 3 gives the distribution of acceleration, which shows that the most events are decelerated that is about 62%, but about 34% show positive acceleration and remaining move with little acceleration.

Fig. 5 gives the relation between the annual variations of angular width and speed. There is a remarkable change in the speed width relationship through the study period.

Fig. 6 shows the relation between the annual variation of number of events and mean sunspot numbers. The solar maximum of cycle 23 falls in the year 2000 whereas solar maximum of cycle 24 falls in year 2012. From the figure it is clear that from year 2007 to 2009 there is a deep solar minimum as discussed by several investigators. Due to this deep solar minimum there is no DH CME in year 2009 and only 03 DH CMEs occur in 2007 and only one event in 2008. There is a good annual variation between the events.

3. Discussion and conclusions

The release mechanism of magnetic energy in the corona is a core issue of the CME studies. The CMEs speeds are given by the numerical differentiation using interpolation of three lagrangian points. The uncertainties of the CME speed and acceleration come mainly from the uncertainty in height measurements (Song et al., 2013). The average speed of 471 DH CMEs is 1043 km/s and their median is 943 km/s. The DH CMEs linear speeds distribtution is in the range from 112 km/s up to 3387 km/s. The average width of 471 DH CMEs is 235° and their median is 360° for the solar cycle 23 and 24. In solar cycle 24 (January 2009–June 2013), we have considered 95 DH CMEs, out of which 59 are full halo CMEs (width = 360°), i.e. 62% of the DH CMEs are full halo CMEs, and 75% are halo CME (width > 180°). The CME of

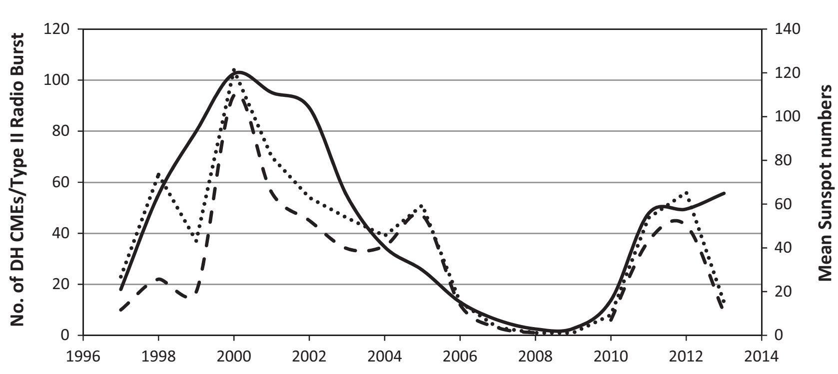

Figure 6 Annual variation of number of events and mean sunspot numbers. Solid line represents mean sunspot number; dashed line represents DH CMEs whereas dotted line represents type II events.

solar cycle 24 expand anomalously compared to those in cycle 23. This is supported by a larger fraction of halo CME (width > °) in solar cycle 24 CMEs. This anomalous expansion of CMEs can be attributed to the significant reduction in the observed total pressure (Magnetic + plasma) in the ambient medium into which the CMEs are ejected (Gopalswamy et al., 2014). The acceleration of the 471 DH CMEs during the study period varies from 434 m/s^2 to -179 m/s^2. Most of the events are found to be decelerated (i.e. 62%) and 34% move with positive acceleration. There is a good annual variation between the average widths and average speed, both the curve almost move parallel (c.f. fig. 5), there is break in the year 2009, which distinguish between solar cycle 23 and 24. It also shows a good yearly distribution of number of events with the mean sunspot numbers (c.f. Fig. 6). In the end we conclude that these DH CMEs are relatively faster and wider than the normal CMEs, (Gopalswamy et al., 2005; Sharma et al., 2008), which is relevant to space weather.

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