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On the statistical characteristics of radio-loud and radio-quiet halo coronal mass ejections and their associated flares during solar cycles 23 and 24

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HIGHLIGHTS

- RL-HCMEs follow solar cycle variation.
- Mean speed of RL and RQ front side HCMEs is 1370 km/s and 727 km/s, respectively.
- Average deceleration of front side HCME events is -13 m/s^2.
- RL CMEs associated solar flares are high energetic than RQ CMEs associated solar flares.
- Average duration of type II radio bursts those associated with HCMEs is 506 min.

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ABSTRACT

We have studied the characteristics of radio-loud (RL) and radio-quiet (RQ) front side halo coronal mass ejections (HCMEs) (angular width 360°) observed between the time period years 1996–2014. RL-HCMEs are associated with type II radio bursts, while RQ-HCMEs are not associated with type II radio bursts. CMEs near the Sun in the interplanetary medium associated with radio bursts also affect the magnetosphere. The type II radio burst data was observed by WIND/WAVES instrument and HCMEs were observed by LASCO/ SOHO instruments. In our study, we have examined the properties of RL-HCMEs and RQ-HCMEs and found that RL-HCMEs follow the solar cycle variation. Our study also shows that the 26% of slow speed HCMEs and 82% of fast speed HCMEs are RL. The average speed of RL-HCMEs and RQ-HCMEs are 1370 km/s and 727 km/s, respectively. Most of the RQ-HCMEs occur around the solar disc center while most of RL-HCMEs are uniformly distributed across the solar disc. The mean value of acceleration of RL-HCMEs is more than twice that of RQ-HCMEs and mean value of deceleration of RL- HCMEs is very small compare to RQ-HCMEs events. It is also found that RQ-HCMEs events are associated with C- and M-class of SXR flares, while RL-HCMEs events are associated with M and X-class of SXR flares, which indicates that the RQ-HCMEs are less energetic than the RL-HCMEs. We have also discussed the various results obtained in present investigation in view of recent scenario of solar physics.

1. Introduction

Coronal mass ejections (CMEs) are an eruption of magnetized plasma from the Sun into the interplanetary medium and they are among the main Heliospheric disturbances (Mittal and Narain, 2010). CMEs drive shocks through the heliosphere which accelerate electrons, leading to radio emission in ambient medium. A CME will produce an IP (inter-planetary) shock when the difference between its speed and the solar wind speed exceeds the Alfvén speed. These shocks accelerate electrons in the ambient medium to form type II radio burst in the energy range 0.2 – 10 keV. Such Type II radio bursts contain information about the shock and ambient medium in which the shock propagates (Bale et al., 1999; Mann and Klassen, 2005; Kahler et al., 2005, Gopalswamy et al., 2010). Type II radio burst formation may take place at any height in the inner and outer corona, but it is not necessary. A type II may take place if the speed of the shock driver exceeds the Alfvén speed in the corona. Cliver et al. (2004a, 2004b); shows that the CMEs were at a height of about 1.3R_S at the time of metric (m)

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type II onset. Gopalswamy et al. (2005) found that the average CME height at the time of the associated type II burst was $\sim 2R_S$, which was obtained by back-extrapolating the CME height-time plot from measurements made beyond $2.5R_S$ to the time of the type II burst but the extrapolation based on Large Angle and Spectrometric Coronagraph (LASCO) data is subject to large errors because CMEs accelerate from rest and speed changes rapidly in compare to constant speed. Using coronagraphic (COR1) observations, Gopalswamy et al. (2009) found that the CME height at the time of type II burst onset was $< 1.5R_S$ in many cases. Gopalswamy et al. (2013) find that the shock formation can occur at heights substantially below $1.5R_S$. In some cases, when the starting frequency of the type II burst was very low, the CME height at type II onset was close to $2R_S$. It shows that the shock can also form at larger heights. Zhang et al., (2001) shows that the CMEs are mainly accelerated below $3R_S$ where metric type II radio bursts are generated. The type II solar radio bursts and their properties in association with CMEs have been studied by solar physicist for more than half century (Kundu, 1965; Nelson and Melrose, 1985; Cane, 2000; Goplaswamy, 2008 and references therein, Sharma et al., 2008, 2012, 2015).

CMEs, flares and radio burst have been a major field of research in solar physics and space science for several decades. CMEs are believed to be the cause of many geo-effective activities such as geomagnetic storms (Mittal and Narain, 2010; Mittal and Verma, 2016). Front side halo CMEs (FH-CMEs) {the halo CME is the CME having latitudinal span equal to 360 degree (Howard et al., 1982) and when CMEs are erupting from the side of the Sun facing Earth i.e. directed towards the Earth known as front side CMEs}, are good potential candidates, which drive hazardous space weather in the form of intense solar energetic particle (SEP) events and severe geomagnetic storms. The SEP events and geomagnetic storms can directly affect the Earth's magnetosphere, however all front side halo CMEs are not geoeffective (Gopalswamy, 2004a, 2004b; Moon et al., 2005). CMEs at solar disk center, those accompanied by decametric-hectometric (DH) type II radio bursts are identified as sources of space-weather disturbances (Prakash et al., 2014). CMEs associated with type II radio bursts with metric and DH wavelengths are more energetic than most CMEs, which are associated with SEPs (Gopalswamy, 2003; Cliver et al., 2004a, 2004b).

CMEs which are associated with type II radio bursts in metric and DH wavelengths are characterized as radio-loud (RL), and on the contrary, when not associated with type II radio bursts in metric and DH wavelengths they are characterized as radio-quiet (RQ) (Sheeley et al., 1984). Gopalswamy et al., (2002) and Sharma et al, (2015) defined that CMEs which produce type II radio emission in DH wavelength is known as radio rich or radio loud CMEs. Gopalswamy, (2004a, 2004b) suggested that CME energy and Alfvén speed profile of the ambient medium are primarily responsible for the radio quietness of fast & wide CMEs but in their study Gopalswamy et al. (2008), suggested three characteristics for the radio-quietness of CMEs which are: (1) the lower kinetic energy with small speed and width within the fast and wide CME population, (2) smaller soft X-ray flare sizes, and (3) the eruption at large angles from the Sun – observer line. A slow CME can be radio loud while a fast CME can be radio quiet depending on the characteristic speed of the medium through which the CMEs propagate. CME energy and Alfvén speed are not in themselves responsible for radio quietness. They are simply factors which influence whether or not a CME will produce a shock and hence radio emission. The Alfvén speed of the corona will determine whether or not a CME may drive a shock and hence accelerate electrons to produce radio emission (Mann et al., 2003; Warmuth & Mann, 2005; Bemporad et al., 2014 and Zucca et al., 2014).

Gopalswamy et al. (2001) studied the characteristics of 101 CMEs those are associated with long wavelength type II radio burst for the period 1997–2000. They found that almost all of DH bursts are associated with wider and faster CMEs but 60% fast CMEs were not associated with DH type II bursts and a major fraction of fast CMEs decelerate. Properties of general population of CMEs compared to CMEs which are associated with metric, DH and m-to-km type II bursts for the period 1997–2004 were studied by Gopalswamy et al. (2005). They found that the average CME speeds were 487, 610, 1115, and 1490 km/s and average angular width for non halo CMEs were 56°, 85°, 139° and 171° and the average deceleration were −2, −3, −7, −11 m/s^2 for the general population, metric-associated, DH-associated, and m-to-km associated CMEs, respectively. They also show wider CMEs are generally more massive and CMEs associated with type II bursts are more energetic than average CMEs. This study was further substanciated by Gopalswamy et al., (2008) for RL and RQ CMEs that are fast & wide for the period 1996–2005 and they found that RL CMEs have speed 1438 km/s in comparison to 1117 km/s for RQ CMEs and Alfven speed in the low latitude outer corona can often exceeds 1000 km/s. They also found that 55% RQ CMEs and 25% RL CMEs are back-sided and RQ CMEs were not associated with SEPs.

Energetic storm particle (ESP) events associated with RQ shocks are also weaker than those associated with RL shocks. Hence, the study of RL and RQ CMEs helps to develop the better understanding of the physical mechanism behind the CME-shock association and other related phenomena such as e.g., particle acceleration, plasmoid eruptions, EUV waves etc. (Mann & Klassen, 2005; Mäkelä et al., 2009; Kozarev et al., 2011; Bain et al., 2012 and Carley et al., 2013). The shocks that generate metric type II radio bursts become sub-Alfvénic for some distance and then become strong enough to produce type II radio bursts at a later time in the DH or km wavelength domain (Mann et al., 2003; Gopalswamy et al., 2010). Hence we are interested in the study of DH and km type II burst associated front side halo coronal mass ejections (FH-CMEs).Here, we study type II burst associated front side halo CMEs and their association with solar flares, which has been analyzed by two different aspects (slow FH-CMEs and fast FH-CMEs). Prakash et al. (2009), investigated the relationship between m-type-II radio burst and DH-type-II radio burst for 38 events observed by Culgoora radio observatory and revealed that those DH-type-II radio burst are not continuation of m-type-II radio burst are well correlated with flares and CMEs in their energy release. Prakash et al. (2012) examined acceleration characteristics of 61 limb event CMEs when they had a signature in DH wavelengths i.e. RL CMEs that occurs in the period from 1997 to 2008 of Solar Cycle 23. In their study Prakash et al., (2014) found that RL CMEs produce more energetic geomagnetic storms than RQ CMEs.

Properties of flares and CMEs associated with metric and DH type II radio bursts have been studied by several authors (Lara et al., 2003, Gopalswamy et al., 2005, Prakash et al., 2009, Suresh and Shanmugaraju, 2015). Gopalswamy et al. (2001, 2012) show that CMEs associated with long-wavelength type II radio bursts like DH type radio bursts and large flares are decelerated in the field of view of the SOHO/LASCO (Brueckner et al., 1995). Lara et al. (2003) found that metric-CMEs were more energetic than general population of CMEs but less energetic than DH CMEs. Suresh and Shanmugaraju (2015) examined 552 fast RL and RQ CMEs and found that there is no considerable difference between accelerated and decelerated RL CMEs and RQ CMEs respectively, but there is significant difference observed in their properties such as their duration and energy intensity, when they are associated with flare.

The type II related shock waves associated with CMEs are important drivers of space weather physics and when interplanetary CMEs materials interact with the magnetosphere leads to trigger a geomagnetic storms (McAllister & Crooker 1997 and Cargill & Harra 2007). A type II radio burst gives the signature of shock initiation in the solar corona while type IV represents the material which