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Variations of Coronal Mass Ejections and Solar Proton Events (E >10 MEV)

Probhas Raychaudhuri
Department of Applied Mathematics
Calcutta University, Kolkata-700009, India
Presenter: Probhas Raychaudhuri (probhasprc@rediffmail.com), ind-raychaudhuri-P-abs2-sh14-oral

We study the preliminary list of coronal mass ejections (CMEs) events observed by SOHO / LASCO from the beginning of 1996 to the end of 2003 and find that the occurrence of average CME rate is 121.15 per month during June 1999 to June 2003 (sunspot maximum range) and that the occurrence of average CME rate is 41.24 per month during 1996 to May 1999 (sunspot minimum range). We find also that the average speed of CME during sunspot maximum range is 496 km / sec. whereas average speed of CME during sunspot minimum range is 338 km / sec. The CME speed is also correlated with sunspot number with less significant level than the average rate of CME occurrence. The average speed of CME is possibly related to the solar radius variation which may indicate that the perturbed nature of the solar core may be their common origin

We collect also the preliminary list of halo CME from SOHO / LASCO during 1996 to 2003 and find that occurrence rate of average halo CME during the sunspot minimum range is about 1.10 / month whereas during sunspot maximum range about 4.10 per month. We also find that the average speed of halo CME events is about 838 km / sec during sunspot minimum range whereas to maximum range is about 1000 km / sec.

We also study the preliminary list of solar proton events (E > 10 MeV) that are occurred almost during halo CME events and find that there are six events with high proton flux during the sunspot maximum range which are responsible for strong geo-magnetic storms. From the solar proton event we find five phases of solar proton events during the solar activity cycle.

We have also studied magnetic clouds (MC) data from the year 1996 to 2003 and found that they exhibit periods around 7 and 32 months.

1. Introduction

Coronal mass ejections (CME) from the solar corona are the most spectacular phenomena of solar activity and were first detected in the early 1970. After that solar physicists are tried to relate CME with other forms of solar activity e.g. sunspot, flares, filament eruption and radio emission etc. CMEs are the result of a large - scale rearrangement of solar magnetic field [1](Low 2001) and they are often observed as an eruption of twisted magnetic fields from the solar atmosphere[2] (Canfield et al. 1999).CMEs can occur at any time during the solar activity cycles but their occurrence rate increases with increasing solar activity and peaks around solar maximum . Fast CMEs are traveling faster than the ambient solar wind and they are responsible for triggering large nonrecurrent geomagnetic storms when they encounter the Earth's magnetosphere. The majority of large and major geomagnetic storms are governed by the encounter with both the interplanetary shock and CME that drives it. The geoeffectiveness of CMEs—i.e., their ability to disturb Earth's magnetosphere — is a function of their speed, the strength of the magnetic field and the presence of strong southward magnetic field component.

Within CMEs we have also halo CMEs. The difference between a CME and a halo CME is primarily a matter of perspective. CME is the name given to an ejection of large amount of matter from the sun's outer atmosphere. When one of these ejections is directed towards the Earth (or conversely directed away from the Earth) it looks like roughly circular halo surrounding the sun. The halo CMEs are those, which are more likely to impact the Earth those of which are right angles to Earth-Sun line.

Manifestation of CMEs are frequently observed in the solar wind near 1 AU and are called interplanetary coronal mass ejections (ICMEs). The term magnetic cloud (MC) is used to characterize an ICME having a specific configuration in which magnetic field strength is higher than average, the magnetic field direction rotates smoothly through a large angle and a low proton temperature. MCs have been studied intensively after their discovery, as they are important drivers of magnetic storms.

2. Data and analysis

(i) CMES

SOHO/LASCO routine recorded CMEs (http:// cdaw.gsfc.nasa.gov / CME_list) and more than 7500 CMEs are detected during 1996-2003 June. The catalog contains all the CMEs with primary characteristics e.g. linear speed, central position angle, and the angular width. We will use these characteristics to study the variations of CME within these periods. The period starts from the sunspot minimum to entire sunspot maximum range where the solar activity is high.. We find that the occurrence of average CME rate is 121.51 per month during June 1999 to June 2003 (sunspot maximum range) whereas the occurrence of average CME rate is 41.24 per month during January 1996 to May 1999 (sunspot minimum range), although during the year 1996 (when the average sunspot number is 8.6 per month) occurrence of average CME rate is 18.16 per month. The CME occurrence rate is also correlated with the sunspot numbers with high statistically significant level. The CME number is highest in the year 2002 but CME is higher in the year 2000 than the year 2001. We find also that the average speed of CME during sunspot maximum range is 496 km/sec. The CME speed is also correlated with the sunspot numbers with less significant level than the average rate of CME occurrence. There is an overall similarity between sunspot number and CME rates, but there are differences particularly from June 1999, which is actually the beginning of the sunspot maximum range. The CME rate peaks in September 2001 to October 2002, which is about 1.25 year from the sunspot maximum. Similarly the average speed of CME at the time of sunspot maximum range is 575 km/sec. whereas the average speed at the sunspot minimum range is around 266 km/sec. This means that the average speed of CMEs is increases from 1996 to June 2003. The maximum monthly average speed occurred at the time of April 2001 and is about 677.3 km/sec., which is about 5 months earlier than the second sunspot maximum.

(ii) HALO CMES

Now we study the preliminary list of halo CME events from SOHO/LASCO during January 1996 to June 2003 and find that the occurrence rate of average halo CME events during January 1996 to May1999 (sunspot minimum range) is about 1.10 per month whereas during June 1999 to June 2003(sunspot maximum range) is about 4.00 per month, during the year 1996 only two halo CMEs is occurred. We also find that the average speed of halo CME events during sunspot maximum range is 838 km/sec, whereas average speed of the halo CME events during sunspot maximum range is 1000 km/sec. Although during the year 1996 the average speed of halo CME events is 451 km/sec. We see from table 5 that number of halo CME increases from 1996 to 2001 and then decreases and the number of halo CME is maximum in the year 2001 after that number of halo CME decreases. In the 23rd solar cycle maximum solar activity occurred during June to September 2001 we call the time as 2nd sunspot maximum time. We also find that number of high speed (>1000 km/sec.) halo CME is highest during 2nd.sunspot maximum range (i.e., during 2001 and 2002). From the halo CME data we see that average halo CME speed increasing from 1996 to 1998 and then decreases from 1998 to 2000 and again increases from 2000 to 2003 and we expect that the average speed of halo CME will decrease after 2003.

(iii) SOLAR PROTON EVENTS (E> 10 MeV):

The solar energetic particles (SEP) i.e., mainly of solar proton events (E >10 MeV) were collected from NOAA website (http://www.lep.gsfc.nasa.gov/waves) of the associated CMEs with halo CMEs.
We find 78 solar proton events (E> 10 MeV), and about 43 of them are from halo CME data. We noticed that the maximum solar proton events occurred at the second sunspot maximum, which is occurred after 1½ sunspot maximum in the 23rd solar cycle. We find also that there are five phases exist for the solar proton (E> 10 MeV) events in the 23rd solar cycle. The first phase is at the sunspot minimum, 2nd phase is after two years from the sunspot minimum, 3rd.phase is at the time of sunspot maximum and 4th phase occurs just one and half year (usually it is about 2/3 years) after the sunspot maximum and 5th phase occurs 2/3 years before the sunspot minimum. We have found six solar proton events (E>10 MeV) within 1999 to 2003 with proton flux from 12900 to 31700 pfu and it is observed that they produced strong geomagnetic storms and all of them are very high-speed halo CME. It is shown by Yurchyshyn et al.[3] that very fast CMEs (Vp > 1000 km/sec.) are capable of causing extremely intensive geomagnetic storm when Dst index decreases below -300nT. We have found that there is a significant correlation between the speed of the CME and solar proton events (E> 10 MeV) data.

(iv) MAGNETIC CLOUDS:

We have studied also magnetic clouds (MC) data observed by the WIND and ACE satellites from the year 1996 to 2003 (http://lepmfi.gsfc.nasa.gov/mfi/mag_cloud_publ.html). We have found five phases also in MC data as in other solar activities. However, the peak of MC data is in the year 1997 after 1 year from sunspot minimum and then the next peak is in the year 2000 during sunspot maximum. We have also found periodicity in the MC data and the period is around 7.2 and 32 months.

3. Discussion

Kahler et al [4] have shown that all E > 10 MeV solar proton events (SPE) are associated with the occurrence of CMEs and CME-solar flares then appear responsible for Forbush decrease in cosmic rays. The result we have presented here i.e., the average occurrence rate of CME and average speed of CME is increasing from sunspot minimum to sunspot maximum may be related to the variations of solar diameter which is in phase with the sunspot cycle. We suggest that the variations of the solar core radius with the solar activity cycle and is supported by the time variations of solar neutrino flux data with the solar activity cycle [5] and also by the solar radius variations during the year from 1976 to 2002 from the Danjon Astrolabe [6]. Solar radius measurement at Rio de Janeiro 1997-2000 shows that the apparent solar radius would vary in phase with solar activity cycle. The agreement of the astrolabes of Antalya, Rio de Janeiro, is supported by recent results based on the different observational techniques that give also empirical evidence that the apparent solar radius would vary in phase with the solar cycle. In a three-year experiment (1996-1998) to detect solar radius fluctuations with the MDI on board SOHO, Emilio [7] found that the solar radius increases approximately in a linear way with the number of sunspots [8]. It appears that solar radius variation is due to the variation of solar core pulsation which in turn give rise to variation of the solar radius with the solar cycle and is mainly responsible for the variation of CMEs and its speed that is in phase with the solar activity cycle and although there may be lag of several months. We suggest that the above mentioned characteristics are interrelated and the common source of solar activity of the sun is the pulsating solar core.

Raychaudhuri [9, 10] has shown that CMEs are multiperiodic in nature. In fact the solar CMEs data from 1999 February 5 to 2003 February 10 studied by Lou et al.[11] and found that CMEs data exhibit periods around 358± 38, 272± 28 and 196± 13 days.

Again the periodicity around 2.5 years[12] in solar flares data, major SPE data (E> 10 MeV), CME data together with solar diameter and the neutrino flux variations indicating that perturbed nature of the solar core[13] may be the common origin of the above mentioned phenomena.

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