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# Studies on major Solar proton Events and Coronal Mass Ejection during 2000 to 2005

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***Abstract:***
*A study of major Solar proton events and Coronal Mass Ejection was carried out from 2000 to 2005 from online data obtained from NationalOceanicandAtmosphericAdministration's (NOAA's), Space Weather Prediction Center (SWPC) and the magnetic structure of the source region means activeregion was revealed in the SOHO/MDI magnetogram. Coronal Mass Ejection is mass of sun omitting during the Solar flare in the form large energy. From the study it was also observed that, 48.83% solar flares were of M- type, 33.72% solar flares were of X- type and 11.62%solar flare were of C-type.*

***Key Words:*** *Solar proton events, Coronal Mass Ejection, SOHO, NOAA's*

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## I. Introduction

Sun is a bright, massiveand luminous sphere of plasma heldtogether by gravity.It hassixlayers like core, the radiative zone,and the convective zone and then there is the visible surface known as the photosphere, thechromospheres,transition regionand finallytheoutermost layerofthecorona[1]. TheweatherontheSunismagneticinnature.Thenewmagneticfieldemergescontinuously into the atmosphere of the Sun. The collection of radiative, plasma and magnetic nature known as solar activity, which arises from these magnetic fields making theirtortuous way through the different layers of the solar atmosphere and into interplanetarymedium. The magnetic field is a tiny fraction of the outpouring ofenergy from the solar core and it produces diverse phenomena in the solar atmosphere.

An active region on the Sun has especially strong magnetic field.Sunspotsfrequentlyforminactiveregions.A solar flare is a sudden, rapid and intense burst of magnetic energy. The first imageof a solar flare was published by R. Carrington etal [2]. The first hard X-ray emissionfrom a flare was recorded by L. Peterson et al [3].Coronal mass ejections (CMEs) are large scale magneto plasma structure that eruptsfrom the Sun and propagate through the interplanetary medium.CMEs are very interesting from the point of view of plasma physics as well aspractical implications because of their space weather impact.It is found that the active regions could produce different number of flaresand CMEs. All solar flares erupt in initially closed magnetic fields and all CMEs erupt fromclosed-field regions on the Sun.The size of events has very large. CMEs areballoon-shaped bursts of solar wind rising above the solar corona, expanding as they climb. CMEsoccurfromclosedmagneticfieldregions, wheremagneticfreeenergy released during eruptions.

The source regionsof CMEs have been intensively studied [4,5]. It was found that the sigmoid structures aremore eruptive than the non-sigmoid regions [6,7].CMEs have to be powered by the magnetic free energy built up in active regions; the CMEspeed limit implies an upper bound to the maximum free energy extractable from the activeregions. The free energy in the magnetic fields needs to be estimated from the distribution ofcurrents in the active region corona [8]. The energy in the potential field depends on the sizeandmagneticfield strength oftheactiveregions [9,10].

Yashiro et al. [11] considered the productivity of CMEs and flaresfromtwoactiveregions.Theyfoundthattheactiveregionscouldproducedifferentnumberof flares and CMEs. All solar flares erupt in initially closed magnetic fields, and all coronalmass ejections (CMEs)erupt from closed-field regions of the Sun [12]. CMEs and all flares are magneticexplosions [13], Photospheric magnetic field configurations are the boundary conditions fordeterminingthecoronal magneticfieldwhichisdisruptedduringaCME.WilsonandHildner [14] found that about half of the magnetic clouds, considered to be signatures of CMEs at 1Å, The significance of CMEs are their magnetic effects on the corona as a hydromagneticatmosphere [15]. D. Webb et al. [16,17] found anumber of cases where interplanetary shocks, which are associated with CMEs and energeticparticleeventsarosefromisolatedEruptiveProminences(EPs). Althoughthebrighteststructures match well with H$\alpha$-emitting material lower in the corona, most of this materialbecomes nearly fully ionized as it moves outward [18]. It has become generally accepted inrecent years that the fast interplanetary manifestations of CMEs are the major solar drivers of space weather,includinglarge,non-recurrentgeomagneticstorms[19,20]andsolarenergeticparticleevents[21].CMEsaremostreadilyobservedwithwhite -lightcoronagraphs were only discovered with the advent of space-borne coronagraphs on OSO-7and Skylab [22]. It also studied and showed that CMEs are associated with flares and prominence eruptions[23]. This means CMEs originate wherever prominence flares occur. Flares occur inactive regions, which contain high magnetic field with or without sunspots. Active regionsconsistingofsunspotsofoppositepolarityseemtoproducethemostenergetic CMEs. Regionsonthesolarsurfacewherecoolprominencesaresuspendedinthecorona also contain closed magnetic field structures and they produce spectacular CMEs that carry theprominences out into the interplanetary (IP) medium. Even tiny bipoles observed as bright points in the X – ray containclosed field structure producing small jet like ejections [24] which are not counted asCMEs. Theassociation between CMEsand flaresnaturally suggeststhe CMEs are the dynamical response of the corona to the sudden input of energy liberated by a flare atthe coronal base [25]. The CME-flare phenomenon can be explained simply in terms of atwo-step process [26]CME opens up an initially closed coronalmagnetic field to eject mass previously trapped in the closed magnetic field. This is followedby the flare which results from the re-closing of the opened field by magnetic reconnection[27, 28]. The first step is an ideal MHD process, and the second step a dissipative MHDturbulenceprocess,atthebaseofthecorona,acrosswhichmass,energyandmagneticfluxdo pass continually into the corona during the course of a solar cycle, some of the initiallyclosed magnetic fields in the corona may open up to produce a CME [29]. The dynamicalbreakup of a pre-existing coronal structure is likely to be the result of a loss of equilibrium inthe course of slow quasi-steady evolution [30]. Breakout and tether cutting can often all bepresent in the eruption [31]. A combination of the magnetic breakout scenario and kinkinstabilitycould beresponsiblefortheeruption event presented by[32].The magnetic neutral lines were altered [33]. The CMEs originated from lowlatitude coronal holes [34], study shows that CMEs originate from closedmagnetic field regions on the Sun [35]. However, filaments near coronal holes seem to have aprobabilityforeruption[36].There exists a broadspectrum of CME sources ranging from large flares in complex active regions to eruptions ofisolated quiescent prominences. These events would then differ only by degree, and wouldnotbeseparateclasses assuggested by[37].

In this communication the data of solar proton even and major CMEs observed between the years 2000 and 2005 has been presented.

## II. Experimental Methods and DataCollection

To study the solar sources of CMEs, the data CMEs with major Solar Proton Events(SPEs) wasobtainedfromNationalOceanicandAtmosphericAdministration's (NOAA's) , Space Weather Prediction Center (SWPC)are presented inTable1. The solar proton flux data measuredby a seriesof Geostationary Operationalenvironmentalsatellites(GOES)such as GOES-8 measures proton flux for period 2000, 2001, 2002 where as GOES-11measures proton flux for period 2003, 2004and 2005. Daily integrated particle fluxes datawithprotonfluxofenergy>1MeV,>10MeV,>100MeV,solarx-rayflaredataandlocationof the CMEs etc with details of occurrence is available on web site www.swpc.noaa.gov.Details of solar activity for each event were accessed from same web. Progression of solaractivity along the types of flare, plots of X- ray data, five-minute averaged integratedprotonsdatameasuredbyGOES satellitesarealsoavailableon web.The Solar and Heliospheric Observatory (SOHO) moves around the Sun in step withtheEarth,byslowlyorbitingaroundtheFirstLagrangianPoint(L1). To study the morphological properties of CMEs a useful data and images of partial,halo, halo with SPEs and CMEs are collected fromthe SOHO spacecraft. Theemissions and locations of different solarflares like C, M and Xtype,themagneticstructureofthesourceregionisrevealedintheSOHO/MDI magnetogram.Large Angle and Spectrometric Coronagraph (LASCO) aboardSOHO, which actually consist of three coronagraphs: C1, C2 and C3 have been taken.

| **Sr. No.** | **CMEs** | | **CME Linearspeed** kms$^{-1}$ | **CME Location** | **NOAA ActiveRegion No.** | **SPEs** | | **ProtonfluxPfu@ >10 MeV** |
|---|---|---|---|---|---|---|---|---|
| | **Day** | **Max.time** | | | | **Day** | **Start.time** | |
| 1 | 14/7/2000 | 10:54 | 1674 | N22W07 | 9077 | 14/7/2000 | 10:45 | 24000 |
| 2 | 8/11/2000 | 23:06 | 1738 | N00-10W75-90 | 9212<br>9213<br>9218 | 8/11/2000 | 23:50 | 14800 |
| 3 | 24/9/2001 | 10:30 | 2402 | S16E23 | 9632 | 24/9/2001 | 12:15 | 12900 |
| 4 | 1/10/2001 | 5:54 | 1405 | S22W91 | 9628 | 1/10/2001 | 11:45 | 2360 |
| 5 | 4/11/2001 | 16:35 | 1810 | NO6W81 | 9684 | 4/11/2001 | 17:05 | 31700 |
| 6 | 22/11/2001 | 23:30 | 1437 | S15W34 | 9704 | 22/11/2001 | 23:20 | 18900 |
| 7 | 21/4/2002 | 1:27 | 749 | S14W08 | 9906 | 21/4/2002 | 02:25 | 2520 |
| 8 | 28/10/2003 | 10:54 | 1054 | S16E08 | 10486 | 28/10/2003 | 12:15 | 29500 |
| 9 | 25/7/2004 | 15:06 | 1333 | N08W33 | 10652 | 25/7/2004 | 18:55 | 2086 |
| 10 | 15/5/2005 | 22:06 | 2861 | N15W05 | 10720 | 16/01/2005 | 02:10 | 5040 |
| 11 | 13/05/2005 | 17:22 | 1689 | N12E11 | 10759 | 14/05/2005 | 0525 | 3140 |

**Table 1:Data ofCMEswithmajorSPEs from 2000 to 2005.**

## III. Results and Discussion

### 3.1 SolarsourcesofCMEs

On 14th July 2000, the LASCO coronagraphs showed in Figure 1is a very fast halo coronal massejection in association with the radio bursts seenshortly at 10:30UTwith a proton flux of 24000 pfu. Thisflare is located at an angle of north $22^0$ and west $7^0$ the sources encompassed all the visiblerange in longitude and a huge span in latitude. CME are seen at10:54UTwhichismaximumat10:24UT.TheCMEsareseenafterthesolarflare.Thiseventisseen at distances upto2.7 solarradiifrom theSun center.CMEisshock-drivingasevidencedbythediffusefeaturesurrounding the brightCME. The CME are surrounding the occulting disc. The dimmingrepresents an evacuation of coronal material as part of the eruption process. The coronaldimming and the large-scale disturbance have become important signatures of CME eruption,often useful in connecting CMEs to their IP consequences [35, 36]. In the EUV differenceimage, one can see a compact flare on the disk surrounded by an EUV wave [37]. The solarsource is obtained by superposing a EUV difference image taken at 10:48 UT. The imagetakenat11:12UTissubtractedfromtheimagetakenat10:48UTtoseethechangetaken.place between the two frames. In the EUV difference image, one can see a compact flare onthe disk surrounded by a EUV wave. The magnetic structure of the source region, activeregion 9077 is revealed in the SOHO/MDI magnetogram taken just before the eruption. Twoother EUV images of the active region are also shown, which reveal the location of the flarerightatthecenteroftheactiveregion.Figure1also showsthesoftX-rayflarecurveobtainedby the Geostationary Operational Environmental Satellites (GOES). The flare which emits X-class(X5.0, means theX-rayfluxis $5.0X10^{-4}Wm^{-2}$).One can also use X-ray, microwave and H- alpha pictures to identify the source region.Each represents a slightly different manifestation of the eruption. It is difficult to identify thesolar sources of CMEs occurring behind the limb. If the sources are within a few tens ofdegrees behind the limb, one can still observe EUV disturbances above the limb with nosignatureon thedisk.

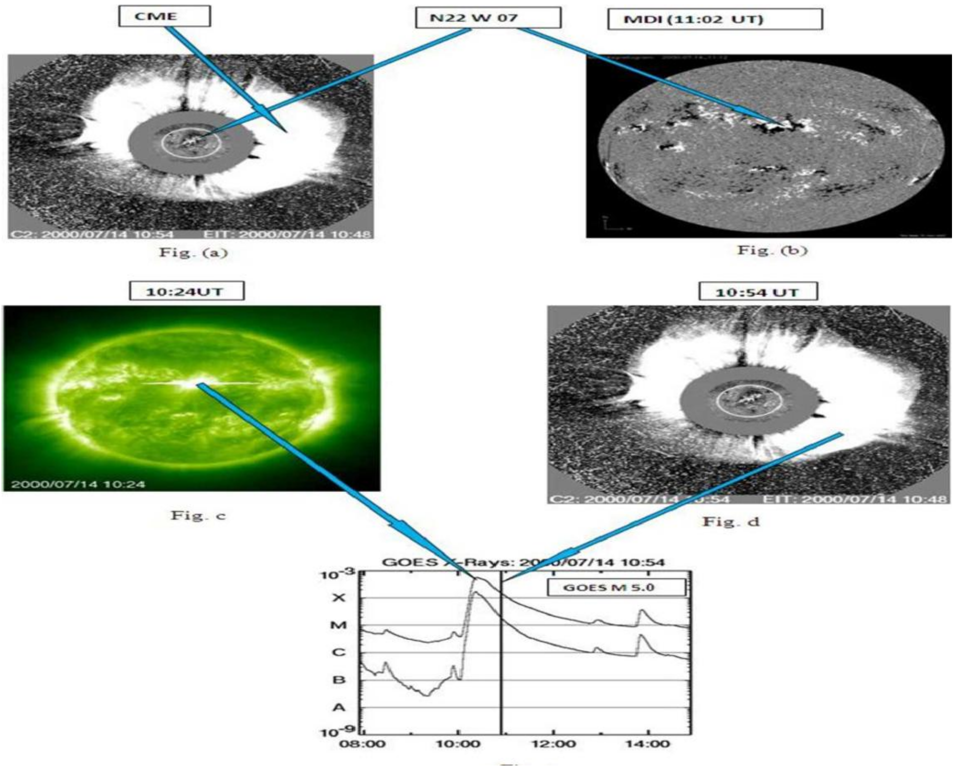

**Figure1:(a) The LASCOCME(b)Photosphericmagnetogram(c)EUVimageoftheSun**

**(d) TheLASCOCME(e)TheGOES soft X-raycurve.**

On 8th November 2000, the LASCO coronagraphs showed a very fast halo coronal massejection in association with solar flare seen at 23:50 UT. This is maximum on 9th November2000 at 16:00 UT observed by SOHO/LASCO.The flare showed a very complex event thatcan be regarded as global: which are emitted with a proton flux of 14800 pfu. This flare islocated at an angle of north $0^0$ -$10^0$ and west $75^0$ - $90^0$ the sources encompassed all the visiblerange in longitude and a huge span in latitude. At the same time the CME are seen at 23:06UT which is maximum at 23:28 UT. The CME appear before the solar flare which is shock-driving as evidenced by the diffuse feature surrounding the bright CME in the north - westquadrant.Thisevent isseen atdistances upto2.7solarradii fromtheSuncenter.The shock-driving CME erupted in the north - west quadrant.The solar source is obtained by subtracting image at 23:24 UT from the image at 23:00 UT tosee the change taken place between the two frames. The magnetic structure of the sourceregion was active region 9212, 9213, 9218 isrevealed in the SOHO/MDI magnetogramtaken just before the eruption. Two other EUV images of the active region are also shown,which reveal the location of the flare right at the center of the active region.

On 24th September 2001, the LASCO coronagraphs showed a very fast halo coronal massejection in association with solar flare seen at 12:15 UT. This is maximum on 25th September2001 at 22:35 UT observed by SOHO/LASCO.The solar flare showed a very complex event thatcanberegardedasglobal,whichareemittedwithaprotonfluxof12900pfu.Thisflare is located at an angle of south $16^0$ and east $23^0$ the sources encompassed all the visible rangein longitude and a huge span in latitude. At the same time the CME are seen at 10:30 UTwhich is maximum at 10:38 UT. The CME appears before the solar flare. This event is at distance up to 2.7 solarradii fromtheSun center. Thesourceregionof24thSeptember2001CMEat10:30UTobserved by SOHO/LASCO. The CME is erupted in the south - west quadrant. The solarsource is obtained by superposing a EUV difference image taken at 10:25 UT. The imagetaken at 11:00 UT is subtracted from the image taken at 10:25 UT to see the change takenplace between the two frames.

On1stOctober2001,theLASCOcoronagraphsshows acoronalmassejectioninassociation with solar flare seen at 11:45 UT. This flare showed a very complex event that can beregarded as global, which are emitted with a proton flux of 2360 pfu. This flare is located atan angle of south $22^0$ and west $91^0$ the sources encompassed all the visible range in longitudeand a huge span in latitude. At the same time the CME are seen at 05:30 UT and maximum at 05.55 UT.TheCMEappearsafterthesolarflare.Thiseventisseenatdistancesupto2.7solarradii from theSun center.Figure2illustratesthesourceregionofthe1stOctober2001CMEat05:54 UT observed by SOHO/LASCO. The CME is erupted in the south - east quadrant. The solarsource is obtained by superposing a

EUV difference image taken at 05:48 UT. The imagetaken at 06:00 UT is subtracted from the image taken at 05:48 UT to see the change takenplace between the two frames. The magnetic structure of the source region called active region9628 is revealed in the SOHO/MDI magnetogram taken just before the eruption. Two otherEUVimagesoftheactiveregionarealsoshown,whichrevealthelocationoftheflarerightat the center of the active region. Figure 2 also shows the soft X-ray flare curve obtained bythe Geostationary Operational Environmental Satellites (GOES). The flare which emits M -class(M 9.0, means theX-rayfluxis9.0X10$^{-5}$Wm$^{-2}$).

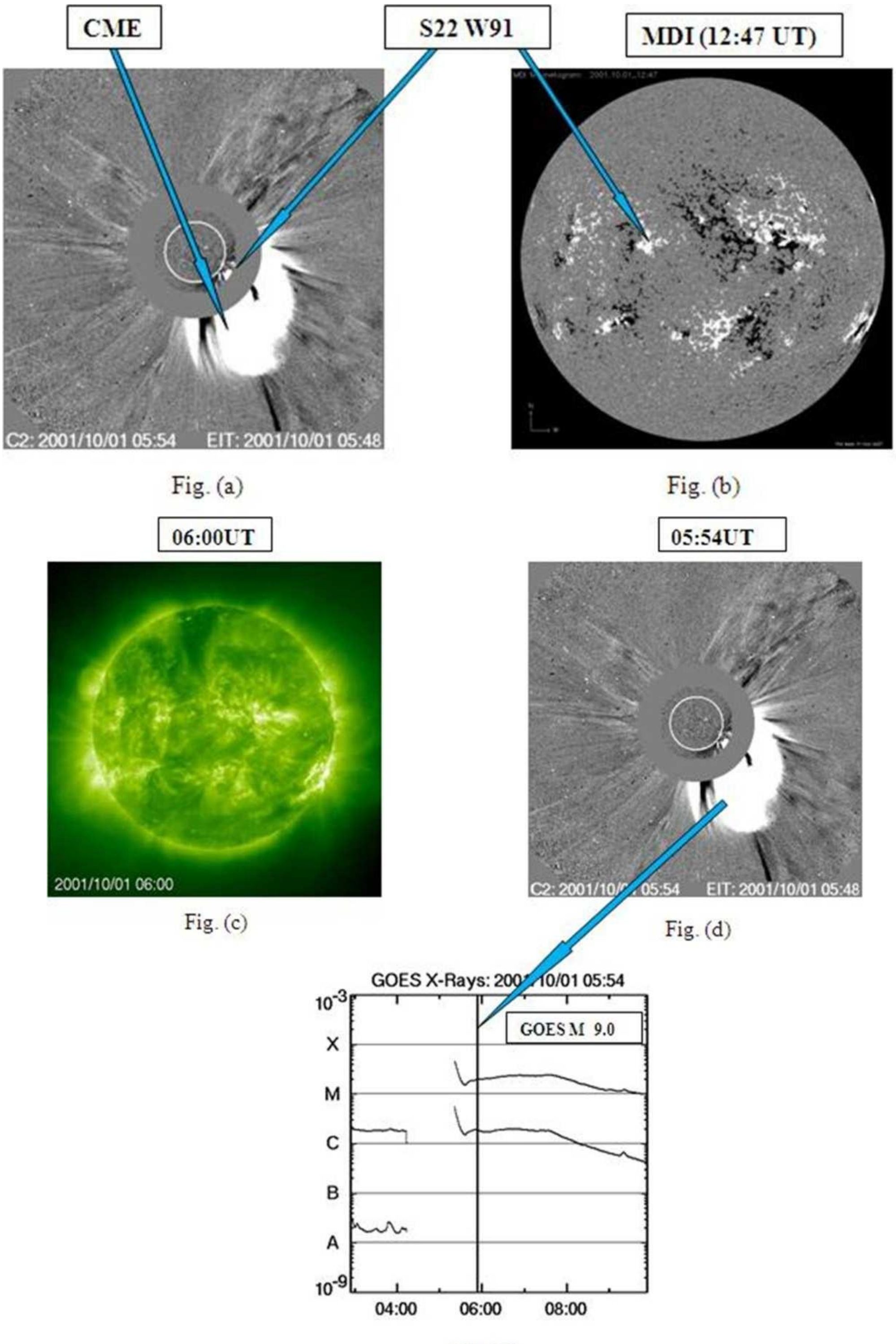

Fig. (a)

Fig. (b)

Fig. (c)

Fig. (d)

Fig. (e)

**Figure2.(a) The LASCOCME(b)Photosphericmagnetogram(c)EUVimageoftheSun**

**(e) TheLASCOCME(e)TheGOES softX-raycurve.**

Similarly on 4th November 2001, the LASCO coronagraphs showed a very fast halo coronal massejectioninassociationwithsolarflareseenat17:05UT.The flare showed a very complexevent that can be regarded as global: which are emitted with a proton flux of 31700 pfu. Thisflare is located at an angle of north $6^0$ and west $81^0$ the sources encompassed all the visiblerange in longitude and a huge span in latitude.

On 22nd November 2001, the LASCO coronagraphs showed a very fast halo coronal massejectioninassociationwithsolarflareseenat23:20UT.Thiswasmaximumon24thNovember 2001 at 05:55 UT observed by SOHO/LASCO. The flare showed a very complexevent that can be regarded as global: which are emitted with a proton flux of 18900 pfu. Thisflare is located at an angle of north $6^0$ and west $81^0$ the sources encompassed all the visiblerange in longitude and a huge span in latitude. At the same time the CME are seen at 23:30UT which is maximum at the same time. The CME appear after the solar flare. This event isseenat distances up to2.7 solarradii fromthesuncentre.Figure 3.6 illustrates the source region of the 22nd November 2001 CME at 23:30 UTobserved by SOHO/LASCO. The CME is surround the occulting disc and shock-driving asevidenced by the diffuse feature surrounding the bright CME. The solar source is obtained bysuperposing a EUV difference image taken at 22:12 UT. The image taken at 23:24 UT issubtracted from the image taken at 22:12 UT to see the change taken place between the twoframes. The magnetic structure of the source region i.e. active region 9704 is revealed in theSOHO/MDI magnetogram taken just before the eruption. Two other EUV images of theactive region are also shown, which reveal the location of the flare right at the center of theactive region. Figure 3.6 also shows the soft X-ray flare curve obtained by the GeostationaryOperationalEnvironmentalSatellites(GOES).TheflarewhichemitsM-class(M9.0,meanstheX-rayfluxis 9.0X$10^{-5}$W$m^{-2}$).

On 21st April 2002, the LASCO coronagraphs showed a very fast halo coronal massejection in association with solar flare seen at 02:25 UT. This was maximum at 23:20 UTobserved by SOHO/LASCO. The flare showed a very complex event that can be regarded asglobal: which are emitted with a proton flux of 2520 pfu. This flare is located at an angle ofsouth $14^0$ and west 80 the sources encompassed all the visible range in longitude and a hugespan in latitude. The flare which emits X - class(X1.0, means theX-rayfluxis 1.0X$10^{-4}$W$m^{-2}$).

On 28th October 2003, the LASCO coronagraphs showed a very fast halo coronal massejection in association with solar flare seen at 12:15 UT. The flare showed a very complex event thatcan be regarded as global: which are emitted with a proton flux of 29500 pfu. This flare islocated at an angle of south $16^0$ and east $8^0$ the sources encompassed all the visible range inlongitude and a huge span in latitude. The CME erupted in the south - west quadrant. The dimming representsan evacuation of coronal material as part of the eruption process. TheflarewhichemitsX-class(X17.0,meanstheX-rayfluxis 17.0X$10^{-4}$W$m^{-2}$).

On 25th July 2004, the LASCO coronagraphs showed a very fast halo coronal massejection in association with solar flare seen at 18:55 UT. The flare showed a very complex event thatcan be regarded as global, which are emitted with a proton flux of 2086 pfu. This flare islocated at an angle of north $8^0$ and west $33^0$ the sources encompassed all the visible range inlongitude and a huge span in latitude. At the same time the CME are seen and maximum at15:14 UT before solar flare. The CME is erupted in the south - east quadrant. The flare which emits M - class(M-1.0, means theX-rayfluxis 1.0 X$10^{-5}$W$m^{-2}$).

On16thJanuary2005,theLASCOcoronagraphsshowedaveryfasthalocoronalmass ejection in association with solar flare seen at 02:10 UTwith a proton flux of 5040 pfu. Thisflare is located at an angle of north $15^0$ and west $5^0$ the sources encompassed all the visiblerange in longitude and a huge span in latitude. The flare which emits X-class(X-2.0, means theX-rayfluxis 2.0 X$10^{-4}$W$m^{-2}$).

On 13th May 2005, theLASCO coronagraphs showed a solar protonevent with asolar flare is seen at 05:25UT. The flare showed a very complex event that can be regarded as global which are emitted with a proton flux of 3140 pfu. This flare is located at an angle ofNorth $12^0$ and East $11^0$ the sources encompassed all the visible range in longitude and a hugespan in latitude. Figure 3, illustrates the source region of the 13th May 2005 CME at 16:57 UTobserved by SOHO/LASCO. The CME was erupted in the south - west quadrant. The magnetic structure of the source region in active region3140 is revealed in the SOHO/MDI magnetogram taken just before the eruption. Two otherEUVimages,revealthelocationoftheflarerightat the center of the active region. Figure 3 also shows the soft X-ray flare curve obtainedbytheGeostationaryOperational EnvironmentalSatellites (GOES).

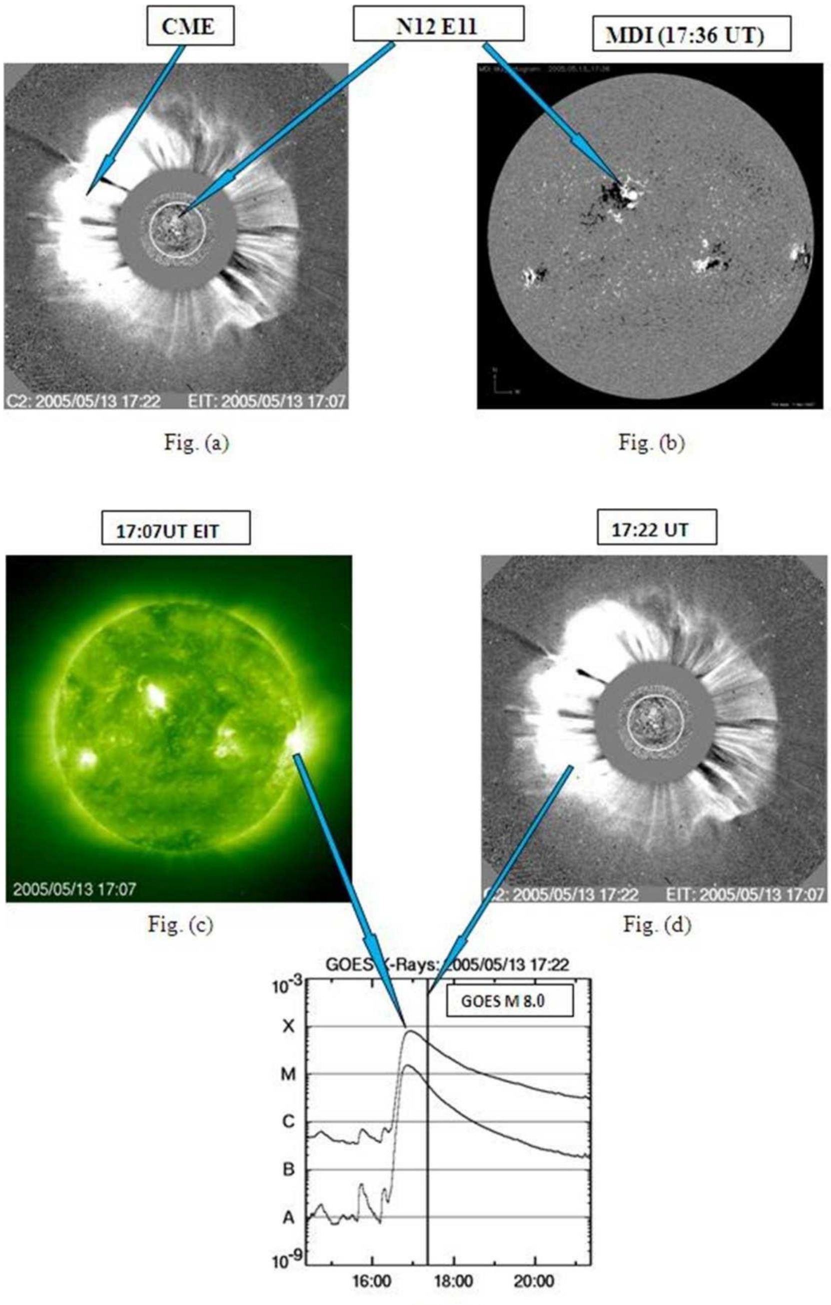

Fig. (a) Fig. (b)

Fig. (c) Fig. (d)

Fig. (e)

**Figure3.(a)TheLASCOCME(b)Photosphericmagnetogram(c)EUV imageoftheSun(d)TheLASCOCME(e)TheGOESsoft X-raycurve**.

### 3.2. LocationsofSolarSourcesofCMEswithmajorSPEs

CMEs originating from the disk center would be observed as MCs while those ejectedat larger central meridian distances would be observed as non-MCs [38]. Gopalswamy etal. [39] found that a large coronal hole was situated near the eruption region such that itdeflected the CME away from the Sun- Earth line, making the CMEs behave like limbCMEs. Halo CMEs that appear to surround the occulting disk were known before theSOHO era as occasional events.

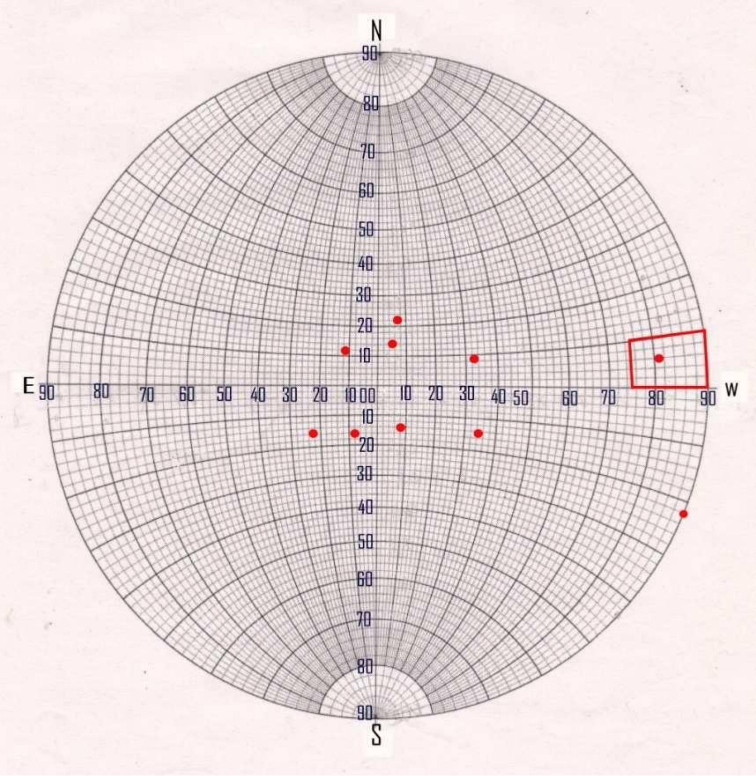

**Figure4: LocationsofsolarsourcesofHaloCMEsfromtheNOAAactiveregions.**

During the SOHO era, they became very prominentbecause of their ability to impact Earth and producing geomagnetic storms. Halo CMEsare generally more energetic than ordinary CMEs and high velocity > 1000 kms$^{-1}$. Whichmeans they can produce severe impact on Earth's magnetosphere. Their origin of haloCMEs are close to the disk center of the Sun shown in Fig. 3.12 ensures direct impact onthe magnetosphere, although their internal magnetic structure is crucial in causing storms.TheactiveregionswhichproduceCMEsare9077,(9212,9213,9218),9632,9628,9684, 9704, 9906, 10486, 10652, 10720, 10759. In some active regions the CMEs areejected in rapid succession so CMEs interact resulting in trajectory change [40]. The solarsourcesofCMEsthatproduceSPEsandCMEstowardsEarth,ontheotherhand,aregenerally in the western hemisphere because of the magnetic connectivity requirement.CMEs areveryinterestingfortheplasmaphysics.

From the study of solar sources, it seems that CMEs with SEPs are originates fromthe eastof west30$^{o}$ and within 30$^{o}$ the North to 20$^{o}$ the South hemisphere.According to Nat Gopalswamy [41], only about a third of the front side haloCMEs are originate within 30$^{o}$ of the disk center and this number is similar to thenumber of geoeffective CMEs. The source regions of the SPE effective CMEs aregenerallylocatedonthewesternhemisphere,althoughoccasionallytheydooriginate from the eastern hemisphere [42]. The geoeffective CMEs, on the otherhand, originate close to the disk center. The CMEs produced in these regions aremore geoeffective because solar protons originated from western side of the solardisc follows the Archimedean spiral pattern of interplanetary magnetic fields andspiral down into the Earth vicinity. However, the proton trajectories may not besimple spiral lines, because the arrival times are greater than the expected time.This arrival time delay is observed because of the Archimedean spiral curve,which is rotating with angular velocity less than $2.9 \times 10^{-6}$ rad s$^{-1}$ [43]. Thus halo CMEsthat appear to surround the occulting disk they have ability to impact Earth andproducinggeomagneticstorms.

## IV. Conclusions

The solar sources that produce CMEs with SEPs are generally situated in the east of west30$^{o}$ and within 30$^{o}$ the North to 20$^{o}$ the South hemisphere. Thus, halo CMEs that appear tosurroundtheoccultingdiskhaveabilitytoimpactEarthandproduce geomagneticstorms. 48.83% solar flares were of M- type, 33.72% solar flares were of X- type and 11.62%solar flare were of C-type. Some CMEs were observed before and after the onset time of theCME. The solar flare observed before or after launching of CMEs is a part of underlyingmagneticprocess and haveno correlation withonsettimeoftheCMEs.CMEs areveryinterestingfortheplasmaphysics.

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