CHAPTER-6

SUMMARY AND FUTURE SCOPE

Here we summarize our results and also indicate the work to be done in future.

6.1 SUMMARY/CONCLUSIONS

In order to improve our current understanding about Prominence Eruptions, we have carried out study of Prominence Eruptions associated CMEs during the solar cycle 23.

The new observations from NORH and SOHO have improved our Knowledge and understanding of Prominence Eruptions and CMEs in many ways, with extended spatial and spectral coverage, as well as improved sensitivity and dynamic range over earlier radiographs and coronagraphs.

The findings of present study are summarized as under:

Prominences are caused by charged solar material being caught up by the strong magnetic field loops and lifted off of the surface. If the magnetic field is strong enough, it can pull the particles out of the pull of the sun’s gravity and create coronal mass ejections. It is well established that quite often prominence eruptions (PEs) are associated with coronal mass ejections (CMEs). There is a very close association between prominences and CMEs. The basic facts for understanding Prominence Eruptions in the context of microwave observation, and their relation with the coronal mass ejections and solar flares has been studied. A proper understanding of the prominences can be providing useful information about solar sources and, this study provides a diagnostic tool for studying the association rate between PEs and CMEs. Recent research has established that during the ascending phase of solar activity, large geomagnetic storms are correlated with the Earth passage of interplanetary CMEs (e.g., Gosling et al., 1991). As for the solar origin, magnetic clouds have been associated with the occurrence of CMEs at the Sun (klien and Burlaga, 1982; Wilson and Hildner, 1984) and with prominence eruptions (Wilson and Hildner, 1986; Rust, 1994; Bothmer and Schween, 1994). CMEs are strongly correlated with eruptive prominences (Gosling et al., 1974; Sheeley et al., 1983; Webb and Hundhausen, 1987), which are, turn in, and linked to geomagnetic storms (Joselyn and McIntosh, 1981; Wright and McNamara, 1983). The predicting of prominence associated with CMEs is important for preventing damage to instruments in space and at earth.

The eruption of limb prominence on 7 December 2001 associated with CMEs is investigated. The prominence reached a height of 3, 86,428 km. The maximum velocity observed was 87.5 km/sec. Finally, the energy and mass stored in the prominence of the associated CMEs is estimated.

Our observations show the well known three-part structure of CMEs (Illing and Hundhausen, 1896): a bright leading edge, a dark cavity, and a bright core (prominence). The spatial and temporal correlation between prominence eruption and initiation of CME is found to be good. Since there was no flare or radio burst associated with the eruption, our analysis supports the idea that neither radio bursts nor flares are necessary for CMEs production though generally they have good association with CMEs. A similar conclusion has been drawn for the CME of 5 December 1981 (Cane, Kahler and Sheeley, 1986; Kahler et al., 1986) and for CME of 6 January 1997 (Wu et al., 2002).

We have shown that the average kinetic energy of the CMEs is found to be 2.2×10^{30} erg, whereas the average kinetic energy stored in the prominence is about 1.69×10^{24} erg. These values suggest that CMEs moving faster than prominence. The mass of CMEs is 2.9×10^{15} gm and mass of prominence is 5.1×10^{10} gm that means the mass of CMEs is greater than PEs. Hence PEs is the inner core of CMEs.

In this thesis, the relationship of PEs associated CMEs by using a large data set for the period 2002-2008 covering solar cycle 23 have been investigated. NORH observed 165 prominences of all types, out of them 66% are found radial events (Eruptive prominences/EPs) while only 33% are transverse events (Active prominences/APs). When we compare the data with white- light CMEs data it is found that 41% Prominences are clearly associated with CMEs and 62% of

CMEs associated with EPs have cores, while only 46% APs have cores. We found that the average height and speed of radial events are larger than the transverse events and 99% of EPs reached at height $1.1R_o$ (solar radius). Our study of temporal and spatial behaviour of prominence and CMEs events shows that the PEs and CMEs seem to start nearly at the same time.

In chapter 5 we studied, some properties such as speed, apparent width, acceleration and latitudes, etc. of all types of Prominence Eruptions (PEs) and the associated Coronal Mass Ejections (CMEs) observed during the period of 1997-2006 covering the solar cycle 23.

During this period more than 14000 CMEs were observed by SOHO/LASCO, whereas NORH has found 376 prominence eruption events, out of them 195 prominences are associated with CMEs.

The average speed of prominences and associated CMEs are 51km/sec and 559km/sec, respectively. The average angular width is 32^o and 74^o, respectively. As expected the associated CMEs are relatively faster and wider than the prominences. About 6% of prominences show little acceleration, i.e. they move with constant speed, but about 53% of prominence decelerated i.e. their speed goes on decreasing as they move away from the Sun. The remaining 40% have positive acceleration, i.e. their speed goes on increasing. The distributions of PEs are biased towards deceleration. The associated CMEs show 4% little acceleration whereas 45% of CMEs are

decelerated. The remaining 49% have positive acceleration. The associated CMEs have a clear bias towards positive acceleration.
The present study is important as PEs associated CMEs may provide an excellent source of advanced warning of geoeffective solar eruptions.

It may be concluded that:

1. The average median speed and apparent width of prominence are 38km/sec and 32^o, respectively, whereas the respective quantities for associated CMEs are 526km/sec and 63^o ie., during 1997-2006, the median speed and median width are lower than the respective average values.

2. PEs and the associated CMEs show that there is no clear trend because speed varies year to year.

3. The variation of the annual average speed of PEs and the associated CMEs does not agree with solar cycle 23.

4. The apparent width distribution of prominence is biased towards lower widths and shows the solar cycle variation, whereas the associated CMEs has no clear bias and do not show solar cycle variation.

5. Around solar minimum the prominences tends to occur at lower latitudes which increase towards maximum. The associated CMEs also have similar behavior. The average latitudes of PEs and associated CMEs are well-correlated with the solar cycle.

6. During the period 1997-2006, the average latitude of PEs and associated CMEs are 32^{o} and 27^{o}, respectively. Prominences and the associated CMEs approximately have same latitudes, i.e. both occur roughly at the same position.

7. About 48% of all prominence come from the northern hemisphere and about 43% come from the southern hemisphere. Only 8% prominence comes from equatorial regions, whereas 44% of associated CMEs come from the northern hemisphere and about 47% come from the southern hemisphere. Only 9% CMEs come from equatorial regions.

8. The correlation coefficients for acceleration vs. speed of PEs and associated CMEs are -0.7 and -0.16, respectively i.e. they have reasonable correlation.

9. The variation in the number of prominence and associated CMEs are well- correlated with the solar cycle variation.

10. In our study only 32% R events and 10% T events are associated with CMEs during the period 2002-2008. Our result shows a poorer association as compared to the results of Gopalswamy (2003) and Gilbert (2000).

11. The average height of R and T events is $1.27R_o$ and $1.18R_o$, respectively. Gopalswamy (2003) found the average height of R and T events as $1.40R_o$ and $1.16R_o$ and Gilbert (2000) found the average height as $1.45R_o$ and $1.16R_o$, respectively. All these results agree with each other. Gilbert (2000) further concluded that 100% of EPs reached at least $1.1R_o$; which agree with our study where 99% of EPs attained a height of $1.1R_o$.

12. The average speed of R and T events is 43km/sec and 22km/sec, respectively, during the period 2002-2008. The average speed during (1996-2001) obtained from Gopalswamy (2003) is 64km/sec and 10km/sec, respectively which differs from the present values, significantly.

13. In our data the correlation coefficient for maximum height and the average speed is 0.2 whereas Gopalswamy (2003) have the value is 0.62. These results seem to contradict each other.

14. We find that the onsets of PEs and CMEs are nearly simultaneous; the two events are separated by within ~30 minutes to 1hour. There is no solar cycle dependence of the temporal relationship. This result may have important implications for the theories of CME initiation.

15. We have also studied the spatial relationship between PEs and corresponding CMEs. We define the spreading of the source locations of CMEs and PEs at all latitudes towards the solar maximum. There is a solar cycle dependence of the spatial relationship. During the solar minimum, the central position angle of the CMEs tends to cluster around the equator as compared to that of prominence.

16. The average height of PEs with CMEs (68) is $1.27R_o$ and without CMEs (97) is $1.22R_o$. This result is similar to the R and T events. Clearly the height of PEs associated with CMEs is larger than those without CMEs.

17. The average speed of PEs associated with CMEs is 46km/sec and that of PEs without CMEs is 31km/sec, during the period 2002-2008.

18. During the period 2002-2008, the same number of PEs and corresponding CMEs are ejected from close to the equator.

19. During the maximum of solar cycle 23, the PEs and corresponding CMEs latitudes exhibit two peaks, one in 2000 and another in 2002.

20. The number of such prominences and corresponding CMEs was larger in the southern hemisphere during the period 2002-2008.

6.2 FUTURE SCOPE

The real study of solar prominences began in 1868, when Janseen and Lockyer independently discovered a method of observing the prominence in full daylight. Previous to this time only brief glimpses of the objects had been obtained during total eclipse of the Sun (Frederick Slocum, 1912). It is the result of continuous monitoring of the sun from the ground as well as from space. After over the past one and 100 years of study, Prominences, and associated phenomenon are still a major scientific puzzle. During this thousand of research papers have been published and hundreds of scientists are involved in unfolding the mysteries surrounding these phenomenon and eruptions. With the beginning of the space era our understanding about the sun in general and about these enigmatic solar eruptions in particular has increased by leaps and bounds. There are certain issues which are still unresolved and need attention and future research. One such issue is the inter-relationship between flares, prominence eruptions and the CMEs. Apart from the inter-relationship, the individual aspects of these eruptive phenomena are too not very clear. We know that they are mainly caused by an explosive discharge of magnetic energy in the sun's atmosphere, the corona, but many fundamental questions like how the energy build up takes place in the corona, and by what mechanism the corona holds such a vast energy for a long time. In the recent past people around the world has been able to develop the 2D models of the solar eruptions. Now we better understand the 2D nature of these phenomenon and eruptions. The theoretical models about these eruptions are entering into the new era of 3D modelling and advanced computational facilities are readily available to meet this challenge but the 3D observations of the sun are still a dream. For even better understanding of these eruptive phenomenons we need even more sophisticated observations.

We need observations with better spatial and temporal resolution. We are also looking to have 3D images of the sun and solar corona.

Recently we have used the data from SOHO/LASCO satellites in conjunction with our ground based NORH data to understand the intricacies of solar eruptions.

During the last decade the availability of high quality data from numerous spacecrafts such as SOHO/LASCO, YOHKOH, CACTus, TRACE, GOES and RHESSI has deeply changed our picture of the processes occurring on the Sun. A fleet of new spacecrafts has been developed which are capable of making significant progress in our physical understanding about solar eruptive phenomenon. The STEREO mission is designed to make 3D measurements of the solar corona. The solar-B spacecraft will observe the sun with much higher spatial and temporal resolution. It will also make higher-resolution EUV spectra of the corona. We are looking forward to analyze the data sets from these promising space missions to gain further insight into these eruptive phenomena. We propose that there is ample future scope for continuing investigations on Prominence Eruptions and CMEs using multi wavelengths observations from the ground based and space borne instruments. However, simultaneously, we strongly feel for the great need of high resolution instruments for both ground and space-based programs. Finally, although we are beginning to obtain closeness between the data and various models of Prominence Eruptions, there is a need for continuous improvement in the models to reflect the vast amount of new data that is becoming available. It is clear that both observational and theoretical studies of Prominence Eruptions and CMEs will play a major role in the international solar cycle program. We would, like to emphasize that India is currently in very strong position to deliver front science related to solar physics and, therefore, should advanced instrumentations for both space and ground observations.

Nevertheless, with the currently available ground-based and space-born facilities we feel, the following questions/studies must be addressed:

1. Why some type Active and Eruptive prominences are not associated with CMEs?
2. Why some type Eruptive prominences is strongly associated with CMEs rather than Active prominences?
3. To study about the inter-relationship between Prominence Eruptions, CMEs and solar flares.
4. How well can we define the energy storage and release mechanisms between Prominence eruptions and CMEs?
5. How well can we predict a geomagnetic storm on the basis of prominence eruptions associated with CMEs?
6. How and why prominences are formed?