CHAPTER 6

SUMMARY AND FUTURE PROSPECTS

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 radio emissions, we have carried out study of types of radio bursts during the solar cycle 23. The new observations from WIND/WAVES and SOHO have improved our knowledge and understanding of radio bursts and CMEs in many ways, with extended spatial and spectral coverage, as well as improved sensitivity and dynamic range over earlier radiographs and coronagrams.

The findings of present study are summarized as under:

Radio burst in the interplanetary medium (IP) are caused due to energetic electrons from the Sun. The basic facts for understanding type II, and IV bursts in the context of white light observation, and their relation with the coronal mass ejections and solar flares has been studied. Radio bursts can provide useful information about solar sources and, it can be interpreted that the burst were produced by electron beam accelerated in blast wave shocks and injected along open magnetic field lines.

The properties of the radio rich coronal mass ejections (CMEs) which produce type II (1-14 MHz) i.e. decametric · hectometric or DH radio burst have been studied (observed during 1997 · 2006). These DH
CMEs are relatively faster and wider than the normal CMEs. Majority (about 54 %) of DH CMEs decelerate, but about 21% show positive acceleration. The remaining 25% move with little acceleration. These special characteristics of radio rich CMEs could be used to identify the population of geoeffective CMEs, which are quite relevant to space weather.

The relationship between type IV bursts, CMEs and grouped solar flares during the period 1996-2007 have been investigated. The speeds of type IV bursts associated CMEs ranges from about 500 km/s to 2700 km/s but a majority of these CMEs have speeds in the range 1100-1500 km/s. The moving type IV bursts are only about 30%. The speeds of type II associated CMEs are only slightly greater than those of type IV bursts associated CMEs which implies that the type IV bursts move slightly behind the leading edge of the CMEs. The average ending frequency, which gives heliocentric distance of the type IV bursts, is 6 MHz, which differs from Gopalswamy (2004) by 25%. The occurrence of type IV bursts does not show appreciable correlation with solar cycle or the number of grouped solar flares, but it does show annual variation.

Two or more type II bursts, occasionally observed in close time sequence during solar eruptions, are said to be multiple type II bursts. The origin of the successive bursts has been interpreted in terms of CMEs and or flares. Detailed investigation of the relationship between CMEs and the bursts enable us to understand the nature of the multiple type II bursts. 42 multiple type II events observed during the period 1997-2007 for the complete solar cycle 23 recorded by WAVES/WIND instrument have been studied. The average speed of associated CMEs is 1311 km/s and 57
% of CMEs have their widths larger than $200^0$ or they are halo CMEs. The mean of starting and ending frequencies is 9.09 MHz and 1.82 MHz, respectively. The linear correlation factor is 0.052 which implies that starting and ending frequencies have no correlation.

WIND/WAVES observed 510 radio bursts of all types during the period 1996-2007 in the complete solar cycle 23. Out of which 43 seem to be type IV bursts, and 42 seem to be multiple type II bursts, and the rest are type II bursts. A total 12981 CME of all types were observed by LASCO/SOHO during the complete solar cycle 23. Out of these 737 (5.7%) are halo CMEs and 367 DH CMEs are considered during the study period.

It may be concluded that;

1. The average and median speed of the DH CMEs is found to be 1048 km/s, and 943 km/s respectively. The average and median speed of 220 DH type II bursts obtained by previous investigators for the data from 1997-2004 is 1115 km/s and 1068 km/s respectively.

2. The average speed of DH CMEs varies from about 580 km/s to about 1380 km/s during solar cycle 23.

3. The average and median width of DH CMEs is 98 degrees and 80 degrees respectively. The average and median width of 220 DH type II burst obtained by earlier scientist are $139^0$ and $130^0$ respectively, during the period 1997-2004.
4. Out of 367 DH CMEs, only 85 CMEs show little acceleration, a majority of CMEs are decelerated and remaining are accelerated. Previous study shows that about 24% of the events show very little acceleration. Events with deceleration constitute the largest fraction (45%). The remaining 31% show positive acceleration. The measured acceleration of the CMEs within coronagraph field of view depends on the relative contribution from the propelling and retarding forces. We infer that the coronal drag may play a significant role in deciding the propagation of CME in the IP medium.

5. The type IV burst associated CMEs of solar cycle 23 have speeds from 500 km/s to 2700 km/s but a majority of them have speeds in the range 1100-1500 km/s. The average speed of the 12 WAVES type IV bursts observed between 1997 – 2002, by Gopalswamy (2004) is 1184 km/s and found by us is 1354 km/s which is greater than obtained by previous investigators.

6. The occurrence of moving type IV bursts during cycle 23 is about 30% (13/43), which is much larger than that reported by Gerregly (1986).

7. The average ending frequency, giving heliocentric distance of the source of type IV bursts, is 6 MHz. The corresponding value reported by Gopalswamy (2004) is about 8 MHz, which is 25% less than previous investigators. The duration of type IV bursts at 14 MHz, found by earlier investigators is 120 minutes, and that obtained by us is 115 minutes.
8. The number of type IV events increase from 5 (in 1998) to 10 (in 2003) and decline after 2005 in the solar cycle 23.

9. The life time of multiple type II bursts varies from 1 to 1437 minutes, and the mean value is 272 minutes.

10. The mean of starting frequency is 9.09 MHz with a standard deviation of 5.62 MHz for them.

11. The end frequency varies from 1 to 10 MHz with most of its value lying around 1 MHz. The average end frequency is 1.82 MHz.

12. The band width varies from 0.08 to 13.96 MHz, and the average band width is 7.27 MHz.

13. The mean normalized drift rate is $3.23 \times 10^{-4}$ sec$^{-1}$

14. The linear correlation coefficient, $r = 0.034$ between starting frequency and normalized drift rate implies very poor correlation.

15. Only 7 of the type II MHD shocks originate in the CME front, the remaining correspond to CME flank.

6.2 FUTURE SCOPE

Since the observations of the first’s radio waves from the Milky Way by Jansky in 1932, our understanding about solar eruptive phenomena has increased manifold. It is the result of continuous monitoring of the Sun from the ground as well as from space. After over 80 years of study, radio bursts, and associated phenomena 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 phenomena 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. 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 scientists around the world have been able to develop the 2-D models of solar eruptions. Now we better understand the 2-D nature of these phenomenon and eruptions. The theoretical models about these eruptions are entering into the new era of 3-D modeling and advanced computational facilities are readily available to meet this challenge but the 3-D observations of the Sun are still a dream. For even better understanding of these eruptive phenomena we need even more sophisticated observations.

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

During the last decade the availability of high quality data from numerous space crafts such as WIND/WAVES, SOHO/LASCO, YOHKOH, ULYSSES, CACTus, SOXS, TRACE, ACE, GOES and RHESSI has deeply changed our picture of the processes occurring on the Sun. A fleet of new space crafts has been developed which are capable of making significant progress in our physical understanding about solar eruptive phenomena. The STEREO mission is designed to make 3-D 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 Radio bursts 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 radio bursts, 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 radio bursts and CMEs will play a major role in the international solar cycle studies programs. We would, like to emphasize that India is currently in very strong position to deliver front science related to solar physics and, therefore, should plan 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 II radio bursts are not associated with CMEs?
2. Still deeper study is required to know the different types of radio bursts, coronal mass ejections and their association with various types of flares viz. impulsive and gradual.
3. What kind of shocks form during a flare or CME?
4. To study about the relationship between multiple type II bursts and solar flares.
5. How well can we predict a geomagnetic storm on the basis of radio bursts and CMEs?