Chapter 5

Studying Transient Features through the Solar Corona by 406.7 MHz Radio Telescope

5.1 Introduction

A coronal mass ejection is a large eruption of coronal plasma and magnetic field rising above the solar corona. The corona is only about one-millionth of the brightness of the Sun. As a matter of fact its observation, outside eclipses, is quite difficult. Total solar eclipses are rare and also visible from very restricted areas of the Earth. The dynamic pattern of highly structured solar corona is produced owing to dense tube of solar plasma. The solar flare is one of the active phenomena in solar system wherein the magnetic energy is transformed into kinetic energy of the accelerated charged particle through magnetic reconnection [1-3]. The observation of white light corona is a complicated task since many kind of aberration, largely chromatic aberration may occur and so we need an aberration free instrument in which both spherical as well as chromatic aberration will not be present. But in practice, it is difficult to built a completely aberration free ideal instrument though spherical aberration may be diminished widely. From this consideration, if one use monochromatic beam (i.e. of particular wavelength) then this problem can be minimized. That is, in fact, the main reason for using monochromatic beam in our study. In addition, if we collect monochromatic narrowband radio emission of the corona by using monochromatic filters which allow the particular frequency of the spectrum, which we have chosen for recording, it becomes much simpler [4-6]. At the beginning of 1960's a small sized coronagraph suitable for amateurs was developed. Twenty five years later the study of the corona has taken on new life with the development radio methods [5, 6]. We have received radio signals from solar corona by using 406.7 MHz radio telescope in our observatory at Kalyani (22.98°N, 88.46°E). Some interesting results are presented in this chapter.
5.2 The Solar Variability

Solar activity changes on time-scales from hours to years. Solar variability essentially originates from the interior of the Sun. Broadly one can classify the two distinct types of emissions from the Sun as (i) continuous emission and (ii) solar cycle dependent emission. This is clearly categorized in Figure 5.1.

**Continuous Emission:**

Electromagnetic Radiation → Solar Constant → Climate, Structure of the Atmosphere

Solar Wind and Solar Magnetic Field → Structure of the Interplanetary Medium → Magnetosphere, Indirectly also Upper Atmosphere

**Solar- Cycle-Dependent Emission:**

Electromagnetic Radiation → Upper atmosphere

Coronal Mass Ejections → Magnetic Clouds and Interplanetary Shocks → Geomagnetic Activity, Upper Polar Atmosphere

Energetic Particles → Upper Polar Atmosphere

*Figure 5.1 Two distinct types of emissions from the Sun*

One very important aspect of solar variability is linked to solar magnetic fields generated below the convective zone in the interior. The evolution of magnetic fields is responsible for variety of manifestations such as the well-known coronal mass ejections and solar wind structures. Though the influences from the variation of the electromagnetic radiation have considered widely and largely available in literature [7-10], a changing solar wind and energetic particles have got less priority, perhaps due to its very complex scenario, which can also influence Earth either directly or indirectly through modulating the cosmic ray flux.
5.3 Extension of Solar Corona into Interplanetary Medium

The plasma corona region consists of completely ionized material containing mainly protons and electrons trapped by the overall magnetic field lines of the Sun. Figure 5.2 shows a schematic representation of the solar corona and its extension into the interplanetary medium.

The figure reveals the principal features involved in the process like the exceptionally large coronal streamers. Light arises from scattering of solar radiation by free electrons in the ionized gas. The shape of the corona depends on the distribution of the magnetic field lines. It is possible to study transient features due to large scale mass ejections through the corona.

![Schematic representations of the solar corona and its extensions into the interplanetary medium](image)

**Figure 5.2** Schematic representations of the solar corona and its extensions into the interplanetary medium [1]

5.4 Selection of Frequency

The frequency range involved in the solar corona region is presented in Figure 5.3. In this figure the ranges of frequencies connect to certain portions of the solar atmosphere. The selection of the
fixed frequency of 406.7 MHz of the receiver is evident as it can successfully provide our interest of reception of radio signal from the corona region of the Sun.

Figure 5.3 Solar Frequency Spectrums

5.5 Radio Signal Records

Two typical patterns of radio emissions originating from solar corona received at 406.7 MHz corresponding to two different dates are shown in Figure 5.4 (a) and 5.4 (b).
The figure exhibits that the voltages, when the two cases are taken into account, vary significantly from 0.16 volt [in Figure 5.4 (a)] to 0.37 volt [in Figure 5.4 (b)]. Similar prominent variations we have noted in many occasions.

Radio signals owing to solar corona received at different dates when analyzed have shown different characteristic patterns with a variation in the signal levels. In Figure 5.5 we have shown such characteristic differences for three different dates. These varying characteristics are not uncommon as the solar coronas are well classified into different types in shape depending on its point of origin. Out of the various type of corona, the ‘Helmet streamers’ are large cap-like coronal structures with long pointed peaks which usually overlie sunspots and active regions. They are formed by a network of magnetic loops that connect the sunspots in active regions. The closed magnetic field lines trap the electrically charged coronal gases for forming relatively dense structures. The pointed peaks are produced by the action of the solar wind blowing away from the Sun in the spaces between the streamers. The second category is the ‘polar plumes’ which are long thin streamers projecting outward from the Sun’s north and south poles and are associated with the “open” magnetic field lines at the Sun’s poles. These are formed by the action of the solar wind in similar way as the peaks on the helmet streamers. ‘Coronal loops’ are observed around sunspots and in active regions. These structures are related to the closed magnetic field lines that connect magnetic regions on the solar surface. ‘Coronal holes’ are regions where the corona is dark and are associated with “open” magnetic field lines. The high-
speed solar wind is known to originate in coronal holes. The ‘White-Light’ coronas, the ‘Emission Line’ corona, the ‘X-ray Corona’ are other important types with characteristic differences. The varying nature of enhancement in the received radio signal may presumably be associated with the type of corona responsible for producing the radio signal nature.

Figure 5.5 Varying characteristics of radio signal due to solar corona
5.6 Variations of Signal Strength during Solar Radio Bursts, Coronal and Surface Effects on the Sun

In course of our observation, we have simultaneously received radio signals originated from solar corona by using 406.7 MHz radio telescope and the solar flare emitted from the surface of the Sun by using log periodic dipole antenna (LPDA) in the frequency range 50 to 300 MHz at Kalyani, West Bengal, India, Besides this investigation, for studying the effect of radio signal propagation we have considered alternative search strategy for interstellar communication as well as propagation of radio signals during solar eclipse [11, 12] in our laboratory. It is purpose to examine the variation of signal strength at the two systems by using two separate antennas and the associated receiving system; one operated at a particular frequency and the other operated in a small frequency band. In general, there are five type of solar radio bursts, classified as type I, type II, type III, type IV and type V. But we have received type II and type III bursts only through our receiving system. Out of the two, the type II bursts are slow frequency drift bursts, usually accompanied by a stronger intensity and lies in the frequency range of 20 MHz to 150 MHz, Flares, proton emission, magneto hydrodynamic and shock waves are often associated with type II bursts. On the other hand, the type III radio bursts are fast frequency drift bursts and can occur in groups in the frequency range of 10 kHz to 1 GHz. In the study we have also determined the effect of various geomagnetic parameters at such times covering a period of four months August 2012 to November 2012.

5.7 Results

Figure 5.6 shows some typical variations of solar bursts recorded by the two systems of observations corresponding to two specified frequencies, 406.7 MHz and 100 MHz. In the typical record we have chosen to reproduce the radio signal data of solar bursts at a fixed frequency of 100 MHz due to its prominent nature in the record. For the months of August and September prominent bursts as recorded by the two receivers are shown. The X-axes in the records represent the same time scale while the Y-axes indicate the amplitudes. It is interesting to note that the amplitude of the signals received at 406.7 MHz is much larger than that received at 100 MHz.
Figure 5.6 Some typical variations of solar bursts recorded at (a) 406.7 MHz, and (b) 100 MHz on August 06, 2012; the other two samples corresponding to the said two different frequencies for September 06, 2012 are marked by (c) and (d) respectively

5.7.1 Signal Strength Variations due to Solar Bursts

Some other records related to signal strength variations due to solar bursts have shown in Figure 5.7, which also exhibit identical behavior of the characteristic variation as pointed out in the typical variations of Figure 5.6. However, it is seen that for radio signals at 406.7 MHz there is a
more prominent variations in the level. These varying characteristics are not uncommon as the
solar flare itself produces variety of shapes with changing strengths depending on its positions.
During our observational period using LPDA, from August 2012 to November 2012, we noted
that for majority of the cases the maximum amplitude of the response lies in the frequency range
from 100 MHz to 110 MHz as indicated in some others records exhibited in Figure 5.7.

Figure 5.7 Some other records of solar bursts recorded at the two frequencies at different dates: (a) and
(b) for October 08, 2012, (c) and (d) for October 10, 2012, (e) and (f) for November 08, 2012, (g) and (h)
for November 14, 2012

There are five types of solar flare, classified as A-class (intensity <10\(^{-7}\) watt/m\(^2\)), B-class
(intensity 10\(^{-7}\) to 10\(^{-6}\) watt/m\(^2\)), C-class (intensity 10\(^{-6}\) to 10\(^{-5}\) watt/m\(^2\)), M-class (intensity 10\(^{-5}\) to
10\(^{-4}\) watt/m\(^2\)) and X-class (intensity ≥10\(^{-4}\) watt/m\(^2\)).
The solar flares we have received when compared with the NASA reported time exhibit a good time coincidence. The solar radio burst, associated with solar flares, we have received when compared with the NASA reported time exhibit a good time coincidence. It may be noted that the flares we have analyzed are mostly of M-type solar category. The signal strengths of the coronal effect (electromagnetic radiation from the solar corona, we call it coronal effect) at such times were very high compared to the surface effect (that radiation emitted from the sun, we call it surface effect) of the Sun due to the tremendous temperature of coronal area belonged to the outer most layer of the solar atmosphere. Actually, the temperature is the vital part of solar radiation and it controlled the radiation strength. According to Wien’s law the temperature increases with the decrease of wavelength of the radiation \( i.e. \) the temperature is increased with the increase of frequency of the radiation. So the energy of the radiation becomes high with the higher value of the frequency. This explains why the amplitude of these signals emitted from the corona is much higher compared to other recorded burst data. The signal level of surface effect of the sun lies on the ‘zero’ line while the peak activity varies in the amplitude range of 0.06 volts to 0.1 volt. On the other hand, in the case of first category related to solar corona, the signal level lies in between 7.0 to 7.2 volts. It is also noted that there are some time differences (There are small times differences between the peaks of the two signals receive by us through two receivers) occasionally between these two types of emissions.

<table>
<thead>
<tr>
<th>Date (Year 2012)</th>
<th>Time (IST)</th>
<th>Flare Type</th>
<th>Sunspot Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 06</td>
<td>10:08</td>
<td>M1.6</td>
<td>1542</td>
</tr>
<tr>
<td>September 06</td>
<td>9:43</td>
<td>M1.6</td>
<td>1560</td>
</tr>
<tr>
<td>October 08</td>
<td>16:47</td>
<td>M2.3</td>
<td>Un-numbered eastern limb</td>
</tr>
<tr>
<td>October 10</td>
<td>10:34</td>
<td>M1.0</td>
<td>Un-numbered eastern limb</td>
</tr>
<tr>
<td>November 08</td>
<td>7:53</td>
<td>M1.7</td>
<td>1611</td>
</tr>
<tr>
<td>November 14</td>
<td>9:34</td>
<td>M1.1</td>
<td>1613</td>
</tr>
</tbody>
</table>

A list of solar flares related to Figure 5.6 and Figure 5.7 is presented in Table 5.1. The corresponding time (in IST) and the sunspot region have also shown.
5.8 Solar Wind Parameters

The solar wind is constituted by highly energetic charged particles. This is mainly composed of electrons and protons, released from the upper atmosphere of the Sun. The temperature and the speed of these particles are changed from time to time. These particles with huge amount of kinetic energy enable them to escape from the solar surface. Corona is the determining factor for the source of solar wind. The temperature of the corona being extremely high, the solar gravitational force cannot hold these particles. With a view to examine the contribution of the solar wind parameters, we have collected the solar wind data (Bartol Research Institute, http://umttof.umd.edu/pm/crn/) for the concerned period. In Figure 5.8 we have plotted the solar wind velocity (proton velocity), proton density, most probable velocity and their arrival direction for the four months. It is highly interesting to see from Figure 5.8 that both the solar wind velocity and proton density are increased in the dates of solar activity producing severe bursts. We have also noted that there are sudden disturbances in the arrival direction of solar wind particles. These increments are assumed to happen due to emitted solar flare from the outer surface of the sun.

Figure 5.8 The solar wind parameter in the month of August to November 2012: (a) corresponds to solar wind velocity, (b) proton density, (c) most probable velocity and (d) arrival direction of solar wind particles
The solar wind particles are coming from the sun. They are arrived to the earth atmosphere from north or from south. Here positive sign indicates they are coming from south while negative sign specify the incoming particles are coming from the north side.

5.9 Disturbance Storm Time Index

The disturbance storm time index (DST) is a geomagnetic index, which checks worldwide magnetic storm levels. Actually this DST index is a measure of geomagnetic activity used to find the severity of magnetic storms. It is based on the average value of the horizontal component of the Earth's magnetic field measured hourly at four near-equatorial geomagnetic observatories [13]. In the case of a classic magnetic storm, the DST exhibits a sudden rise, corresponding to the sudden commencement of the storm and then decreases sharply as the ring current intensifies. In our analysis, we have plotted the DST index in the month of August, September, October and November 2012. It should be noted that there have some sudden fall in the DST strength in August 06, September 06, October 08, October 10, November 08 and November 14, 2012. This happens due to the interaction of solar radiation with the magnetic field of the Earth. It appears from Figure 5.9 that the amplitude is dropped from the negative value of 32 nT on August 06, 2012 to the negative value of 110 nT on November 14, 2012.

![Figure 5.9 Disturbance time storm index in the month of August to November 2012](image-url)
5.9.1 Other Geomagnetic Indices

The K-index quantifies disturbances in the horizontal component of earth's magnetic field with an integer in the range 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval. The label 'K' comes from the German word 'Kennziffer' meaning 'characteristic digit.' The $A_p$ index is a measure of the general level of geomagnetic activity over the globe for a given day and is derived from measurements made at a number of stations worldwide of the variation of the geomagnetic field due to currents flowing in the earth's ionosphere and magnetosphere. $C$ index is a subjective daily character figure of geomagnetic activity for a single observatory for Earth and considered 0 – for very quite magnetic condition, 1 – for moderately disturb condition and 2 – for severely disturb condition. $C_p$ index is observed from sum of eight daily values of $c_p$ index range from 0 to 2.5 wherein 2.5 is taken as most disturbed. The $aa$-index is a simple global geomagnetic activity index and is derived from the $K$ indices and has units of nT.

It is seen from Figure 5.10 that the magnitudes of $K_p$, $C_p$, $A_p$ and $aa$ are increased between September 01, 2012 to September 09, 2012 showing peak value around September 06, 2012. Again a second peak is noticed during October 06, 2012 to October 12, 2012 when the received solar bursts become very prominent.

![Figure 5.10 The Solar Geomagnetic indices (Sum $K_p$, $C_p$, $aa$ and $A_p$) for the corresponding months](image-url)
5.10 Discussion

Observations of the solar corona in front of the solar disk have established a direct relationship between coronal features and solar wind. Regions of solar atmospheres known as coronal holes closely correspond to the high-speed component of the solar wind. The solar wind is able to generate significant heating of the lower thermosphere at high latitudes by direct particle precipitation and also by generating upper atmospheric ionization that may influence the global electric circuit. Due to coupling with the magnetosphere the solar wind drives ionospheric currents at high latitudes which in turn accelerate the neutral atmosphere. Some investigations [14, 15] have suggested a strong relationship between the electric field of the solar wind and a pressure phenomenon in the north Atlantic called as the North Atlantic Oscillation (NAO) [16].

A substantial portion of the climate variability in the Atlantic sector is highly related to the NAO with variations occurring on a wide range of scales. Some model studies [17, 18] indicate that the influence of geomagnetic activity on the stratosphere is comparable to that of ultraviolet flux variation between solar minimum and solar maximum. Bucha and Bucha [19] observed an intensification of both thermo-spheric and tropospheric flows associated with strong geomagnetic activity and suggested a mechanism where downward winds are generated in the polar cap of the thermosphere and penetrate to the stratosphere and troposphere [10, 20-22].

Early observations of the visible spectrum of the corona showed bright emission lines at wavelengths that did not correspond to any known materials. From this, astronomers were able to propose the existence of "coronium" as the principal gas in the corona. However, the true nature of the corona remained a mystery until it was determined that the coronal gases are super-heated to temperatures greater than 1,000,000°C. At these high temperatures the two dominant elements hydrogen and helium are completely stripped of their electrons. Even the minor elements like carbon, nitrogen, and oxygen are stripped down to bare nuclei. In fact, in this intense heat only the heavier trace elements like iron and calcium are able to retain a few of their electrons [16]. The emission from these highly ionized elements produces the spectral emission lines that were mysterious to early astronomers. It is by now possible to produce artificial eclipses in coronagraphs that cover the disk of the Sun and filter out everything except the emission due to these coronal ions. These coronagraphs produce images of the "emission line corona."
The fluctuations, which are usually independent for each forcing parameter, e.g., Forbush decreases, solar flares, ground level events, etc., provide a possible way for distinguishing between the different processes [24-28]. However, the solar processes being highly variable at time-scales of hours to days, the task of identifying a solar signal in the climate data can mask the solar effect and there may be a strong impact on the data analysis and subsequently to establish a possible solar terrestrial relationship.

The corona is basically a part of the solar flare (Coronal mass ejections are often related with other forms of solar activity, most notably solar flares, although a causal relationship has not been established). The temperature of the corona is so high that it may throw some charged particles as solar wind. These may build up the electric field that again accelerates the charged particles [29]. The relation of solar wind and coronal feature can be established by observing the solar corona in front of solar disk. Coronal holes closely communicate with high speed component of solar wind and these solar wind particles can interact with upper atmosphere and may influence the global electric circuit at high latitude [30]. The signal strengths of the coronal effect in our observed data were very high compared to the surface effect of the Sun. In fact, the signal level of surface effect of the Sun at the peak activity appears to vary in amplitude from 0.06 volts to 0.1 volt while those related to solar corona exhibit a change in between 7.0 to 7.2 volts. The solar wind also couples with magnetosphere and hence derives the ionosphere so that it again interacts with neutral atmosphere [14, 31]. These solar wind particles, i.e. the so called charged particles interacts with Earth’s magnetic field and influence the geomagnetic indices. Due to the active role of the charged particles, the geomagnetic indices are enhanced at the time of solar bursts when the DST index reduces rapidly.

References


