ANALYSIS OF TYPE II AND TYPE III SOLAR RADIO BURSTS USING e-CALLISTO SYSTEM

JUDE VIJAYANGA WIJESEKERA

Faculty of Natural Sciences

Department of Physics

The Open University of Sri Lanka

A dissertation submitted in partial fulfilment of the requirements for the
Degree of Bachelor of Science
in Natural Sciences

Supervisor	Prof. Chandana Jayarathna
Second Supervisor	Mr. Janaka Adassuriya
Third Supervisor	Prof. V P S Perera

October, 2016

Created in Master PDF Editor

Declaration

I certify that this dissertation does not incorporate, without acknowledgement, any material previously submitted for a degree in any university and to the best of my knowledge and belief it does not contain any material previously published or written or oral communicated by other person except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, to be made available for photocopying and inter library loans and for the title and summary to be made available to outside organizations.

Signed:

Date:

25/11/2016

Created in Master PDF Editor

Acknowledgements

- My heartfelt gratitude to Open University of Sri Lanka and Arthur C Clark Institution for Modern Technologies for giving me this golden opportunity to engage in the project.
- I am sincerely thankful to Arthur C Clark Institution for Modern Technologies for giving me their solar radio burst antenna which helped me to successfully obtain the data.
- Every moment throughout this project, the enormous support given by my supervisors Mr. Janaka Adassuriya and Mr. Gayan Illeperuma was a great help for my progress. Without the extensive guidance of them, this project would not have become a reality.
- I am grateful to Prof. V.P.S Perera and Prof. K. P. S. Chandana Jayaratne for their valuable support throughout the project. Even though they had a busy schedule, they offered me their assistance and guidance whenever I needed.
- Most importantly, my sincere and deepest appreciation to my colleague, Meriesha Ruchini Fonseka for her guidance and constructive criticism which helped me to craft my project in a better way.
- I would also like to take this opportunity to praise my parents for their patience and understanding throughout the research.
- Last but not least, I am grateful to each and every one who has helped me to complete this project in the best way possible.

Created in Master PDF Editor

Abstract

There are several solar activities which are unpredictable events in the climate of the solar model. All solar activities are driven by the changes in the solar magnetic field. Solar flare is an intense burst of electromagnetic wave imminent due to the release of magnetic energy combination with sunspots. This has significant impacts on the Earth climate changes and therefore should study the details of such an important phenomenon. Type II and type III solar radio bursts were analyzed which detected by e-CALLISTO network system, a system operates in 67 locations around the world. Using CALLISTO network system, analysis of type II and type III solar radio bursts were carried out. For the comparison between type II and type III solar radio bursts, a set of five solar radio burst were taken from e-CALLISTO system. The five images of solar radio bursts could be analyzed in this research. Using those analyzed images variations of type II and type III could be retrieved Exponential decay types curve fitting could be seen in type II solar radio bursts and linear equation model could be indicated in type III solar radio bursts. Results of the drift rate graphs show the values of each chosen solar radio burst. High drift rates values can be seen in type III solar flares whereas low to medium drift rate values can be seen in type II solar flares. Drift rate values of each solar radio burst is ALMATY type II 2015-11-04: -1.4585 $MHz\ S^{-1}$, BIR type II 09-11-2015: -0.0989 $MHz\ S^{-1}$, ROSWELL-NM type II 16-04-2014- -1.07986 $MHz\ S^{-1}$, KRIM type III 07-12-2013: -3.062 $MHz\ S^{-1}$ and BLEN7M type III: -2.375 $MHz\ S^{-1}$. Consistent with the second part of research, proved chosen each solar radio burst obey the Newkirk model. Additionally, the selected solar radio bursts split into subtypes can be seen. These sub types do not provide any perfect difference between type II and type III because chosen solar radio burst does not show high variations. All the chosen solar radio bursts were located in solar radius of 0.9 - 1.3 range. The research results were that the electron density vs height graph always shows power equations in the form of f(x) = A $\times 10^{-bx}$.The calculation of the plasma velocity of each solar radio burst was the final part of the research. Low and medium velocities for type II, solar radio bursts and a high velocity for the type III solar radio burst

Created in Master PDF Editor

could be perceived. The CME was not associated with selected all type II solar radio bursts. Therefore velocity of chosen type II solar radio bursts indicates low velocities. The values are 233.2499 $Km\ S^{-1}$, 815.9522 $Km\ S^{-1}$ and 369.5425 $Km\ S^{-1}$. Thus 815.9522 $Km\ S^{-1}$ value was fraction higher than expected range. Velocity of chosen type III solar radio burst was 1443.058 $Km\ S^{-1}$

Created in Master PDF Editor

List of Tables

Created in Master PDF Editor

List of Figures

Created in Master PDF Editor

Created in Master PDF Editor

Table of Contents

Created in Master PDF Editor

Chapter 1

Introduction

Solar activity is one of the most important unpredictable events in the climate of solar model. Solar activities have significant impacts on the Earth climate changes and on the environment and therefore, should study the details of such an important phenomenon. Solar activities include solar flares, coronal mass ejections, high-speed solar wind, and solar energetic particles[1][2]. All solar activities are driven by the changes in solar magnetic field. Solar flare is an intense burst of electromagnetic wave coming from the release of magnetic energy combination with sunspots. It is the largest explosive event in our solar system. Solar flare can be observed by the photons it releases. They have a broad EM spectrum. All the solar activities consist of highly ionized charged accelerated particles. In this research, the scope is limited to finding the difference between the type II and type III solar flares, their properties and how they affect the space weather. There are many types of radio bursts emanate from the solar corona in a wide height range [3]. Only low radio frequency range is taken in to consideration for analysis. Properties of radio sources, emission and propagation of bursts are depend on the temperature, gas density and electromagnetic field. By analyzing the electromagnetic spectrum created by the solar flare, important details about corona can be found[4]. Solar radio bursts were the first phenomena identified in radio astronomy field.

Solar radio frequency range is 70 MHz to 2.2 GHz [5][6]. Most of radio burst can be identified in low frequency range such as below 200 MHz. Depending on the frequencies radio burst can be classified into five categories [1] [5][2].

- Type I burst (noise storm).
- Type II burst (slow drift rate).
- Type III burst (fast drift rate).

Created in Master PDF Editor

- Type IV burst.
- Type V burst.

The solar flare radio burst spectrum used by e-Calisto system.

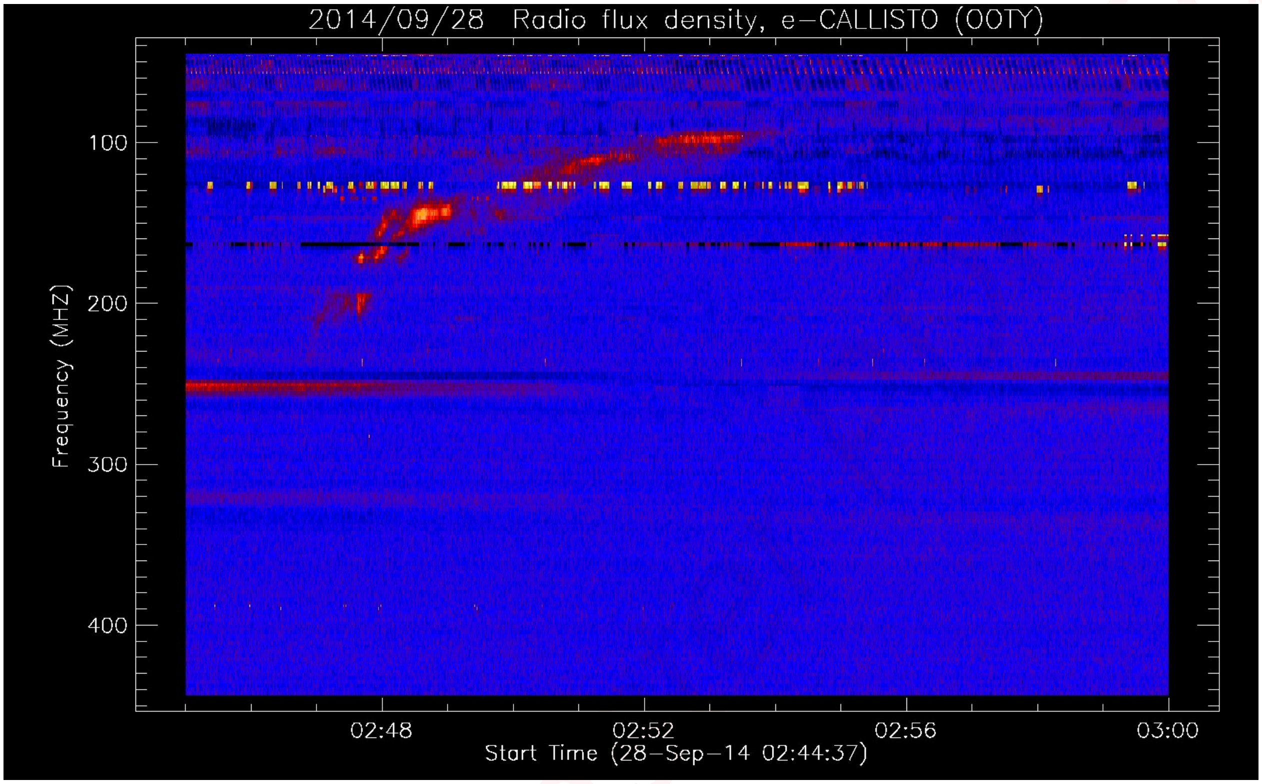


Figure 1.1: Type III solar radio burst extracted from e-callisto network.

Type II solar radio bursts are the most common radio burst and are slow frequency drift bursts. Most of the times they are accompanied by a second harmonic as well. Time duration of these types of bursts are between 3 min to 30 min. Frequency range between 20MHz 250 MHz[6][7][2][8]. There is a special characteristic in type II solar radio burst called "Herring bones" as illustrated in Figure 1.1.

The characteristic velocity of the solar disturbance which give rise to these slow burst may be deduced from their rate of change of frequency. This velocity is of the order of 1000 $Km\ S^{-1}$ and as it corresponds to that so-called "auroral corpuscular streams" it has long been held that the slow bursts are caused by the passage of the streams through the solar atmosphere [6]. Sometimes velocity of type II is above 200 $Km\ S^{-1}$ and sometime half of the speed of light. Type III solar radio burst is a fast drifting burst in frequency versus time and common phenomenon. Because the emission is at the plasma frequency (or its harmonic), the

Created in Master PDF Editor

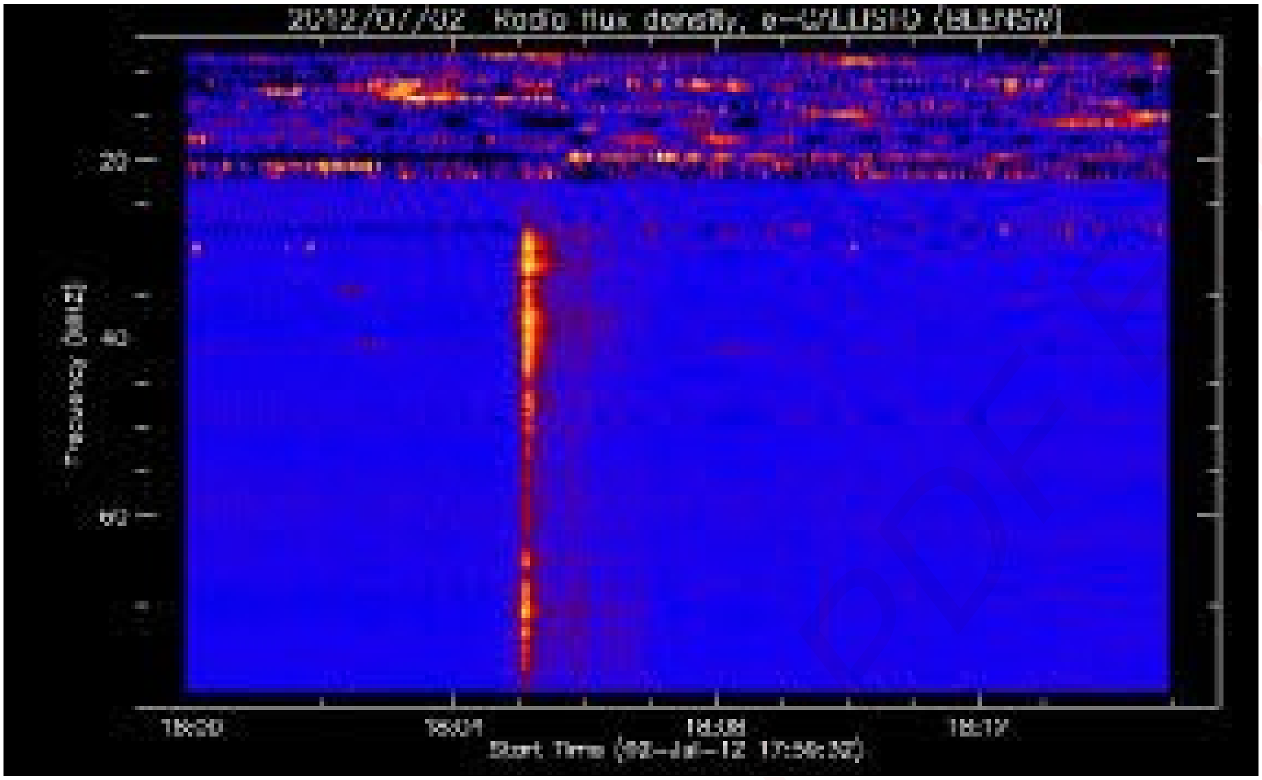


Figure 1.2: Type II solar radio burst extracted from e-callisto network.

drift in frequency with time can be directly converted into a drift from high to low ambient coronal density with time [9]. Time duration get few seconds. This type of solar radio burst commonly occurring in groups of 3 to 10 with total duration of less than 60 min [10]. Type III solar radio burst as shown in Figure 1.4.

CALLISTO system is which operates at Arthur C Clarke Institute is one of the solar radio spectrometers in the e-CALLISTO network. The CALLISTO spectrometer is a programmable heterodyne receiver built in the framework of IHY2007 and ISWI by former Radio and Plasma Physics Group at ETH Zurich, Switzerland [11]. The instruments observe automatically, its data is collected every day via internet and stored in a central database. There are many solar radio stations combine with the e-CALLISTO system. In Sri Lanka, the solar radio station was setup in Arthur C Clarke Institute for Modern Technologies. The data taken for this research is mainly taken from our national solar radio station, Ooty and Gauri station from India, Almaty station, BIR station, KRIM station and Roswell station.

Created in Master PDF Editor

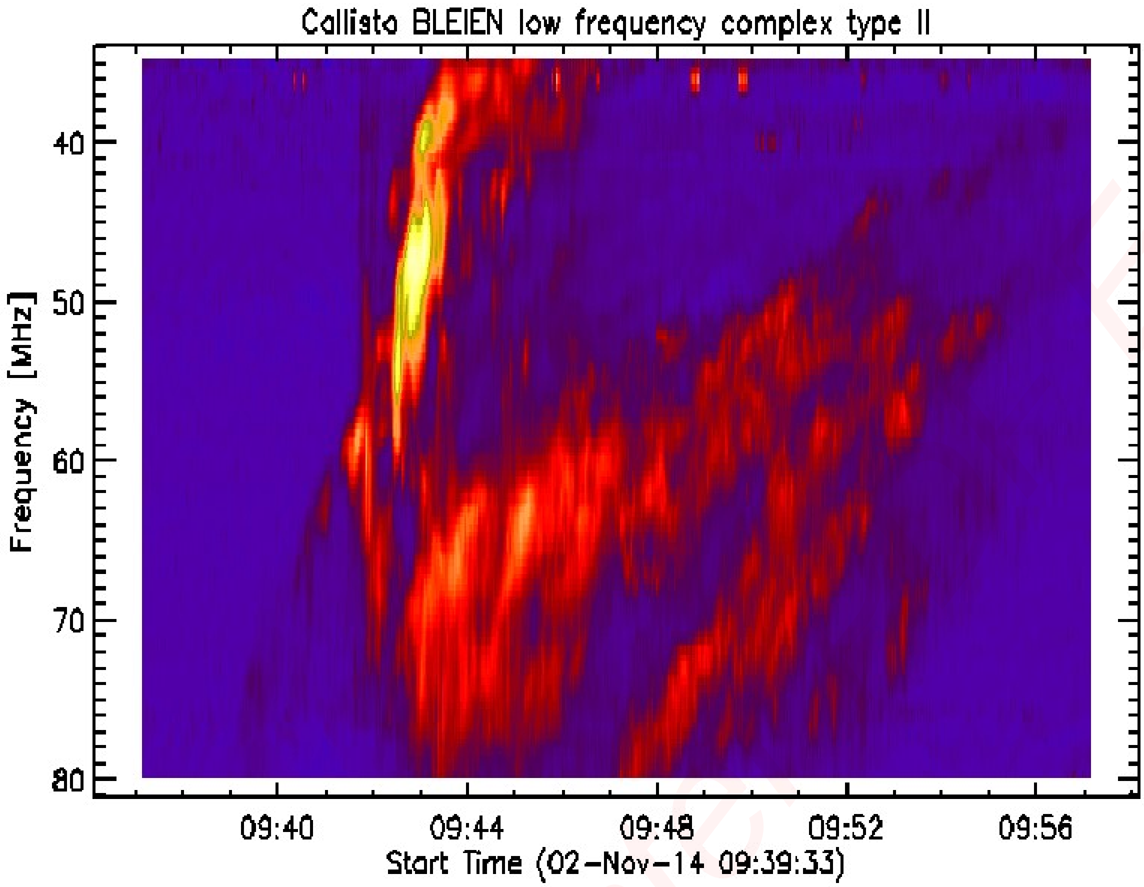


Figure 1.3: Type II solar radio flare with 'herring bones' extracted from Callisto BLEEN observatory.

1.1 Objective

In this research it is expected to analyze the type II and type III solar flares radio burst and their properties which include.

1. Plasma velocity or shock wave of solar flares.
2. Intensities of solar flares.
3. Drift rates of solar flares.
4. Electron densities.

The main objective of the research is the study of plasma velocity. Plasma velocity is the velocity of the solar flare been ejected from the solar atmosphere. Hence, the research invest-

Created in Master PDF Editor

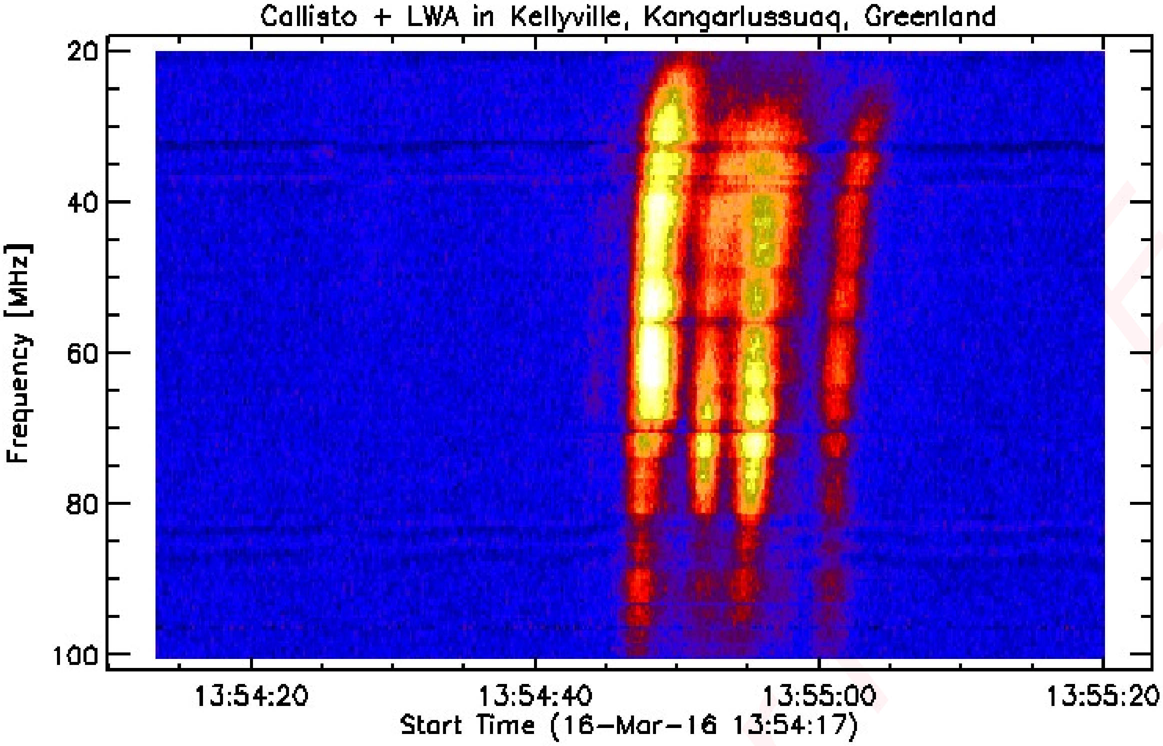


Figure 1.4: Group of type III burst. Observatory in Kellyville, Kangarlussuaq, Greenland 16 March 16 extracted from http://e-callisto.blogspot.com/.

igates how plasma velocities different from type II and type III. In addition, the relationship between the plasma velocities and space weather can be evaluated.

Created in Master PDF Editor

Chapter 2

Literature Review

2.1 e-CALLISTO system

e-CALLISTO system is the name given for the solar radio spectrometer network in the CALLISTO system. The CALLISTO spectrometer is a programmable heterodyne receiver built in the framework of IHY2007 and ISWI by former Radio and Plasma Physics Group at ETH Zurich, Switzerland Callisto stands for: Compound Astronomical Low cost Low frequency Instrument for Spectroscopy and Transportable Observatory. That system has more than 121 instruments in more than 67 locations with users from more than 129 countries. It has been established since 2002[11].

2.2 Earlier researches of solar radio bursts

There are many solar radio burst research projects and most of which are depend on e-CALLISTO system. This system provides various data from multiple servers. The articles "CORONAL MASS EJECTIONS AND SOLAR RADIO EMISSIONS" and "LARGE-SCALE SIMULATIONS OF SOLAR TYPE III RADIO BURSTS: FLUX DENSITY, DRIFT RATE, DURATION, AND BANDWIDTH" were used to check the validity of this research.

2.3 Coronal Density Model

Coronal density models could be used to find the electron density of solar radio bursts. Few basic electron density models for chromosphere, inner corona and outer corona of the sun were considered for admonitory purposes. This was because solar radio bursts are originated

Created in Master PDF Editor

near the solar chromosphere in different height levels. Some are close to the corona of the sun. Few coronal density models are given below.

- Global sun model[3]
- Newkirk model[3][12]
- Saito model[3]

The research used the Newkirk model to calculate the electron density of solar radio bursts. Though Newkirk model is a simple model, it is perfect for this research. By using this model can find the electron density of solar radio bursts in different heights. According to the model there is a relationship between electron density vs height and it is a power law distribution where height is calculated from solar radius. All the coronal density models have a common issue of perturbing electron density. Hence the assumption of "quiet sun" (no solar activities in the sun) was used. When the sun is "quiet", the value of electron distribution of corona is roughly constant[3][12]. Should there be any perturbing coronal density, the electron density value will change. The distribution of electron density is spherical symmetric but Newkirk model can use for non- spherical models as well[12]. Electron density of 'quiet sun' and perturbed sun are shown in Figure[1] 2.1.

Each solar heights have related electron density. Sometimes it will vary 10 times with original value due to perturbing activities[12][3]. Table [13] was helped to acquire comparison between research results and Newkirk model. Figure[2] 2.2. has summarize the average characteristics of solar radio events in the lifetime-height space to emphasize their time-space probing capabilities[3].

[1]Figure 2.1 adapted from MOTIONS IN THE SOLAR ATMOSPHERE book
[2]Figure 2.2 adapted from MOTIONS IN THE SOLAR ATMOSPHERE book

Created in Master PDF Editor

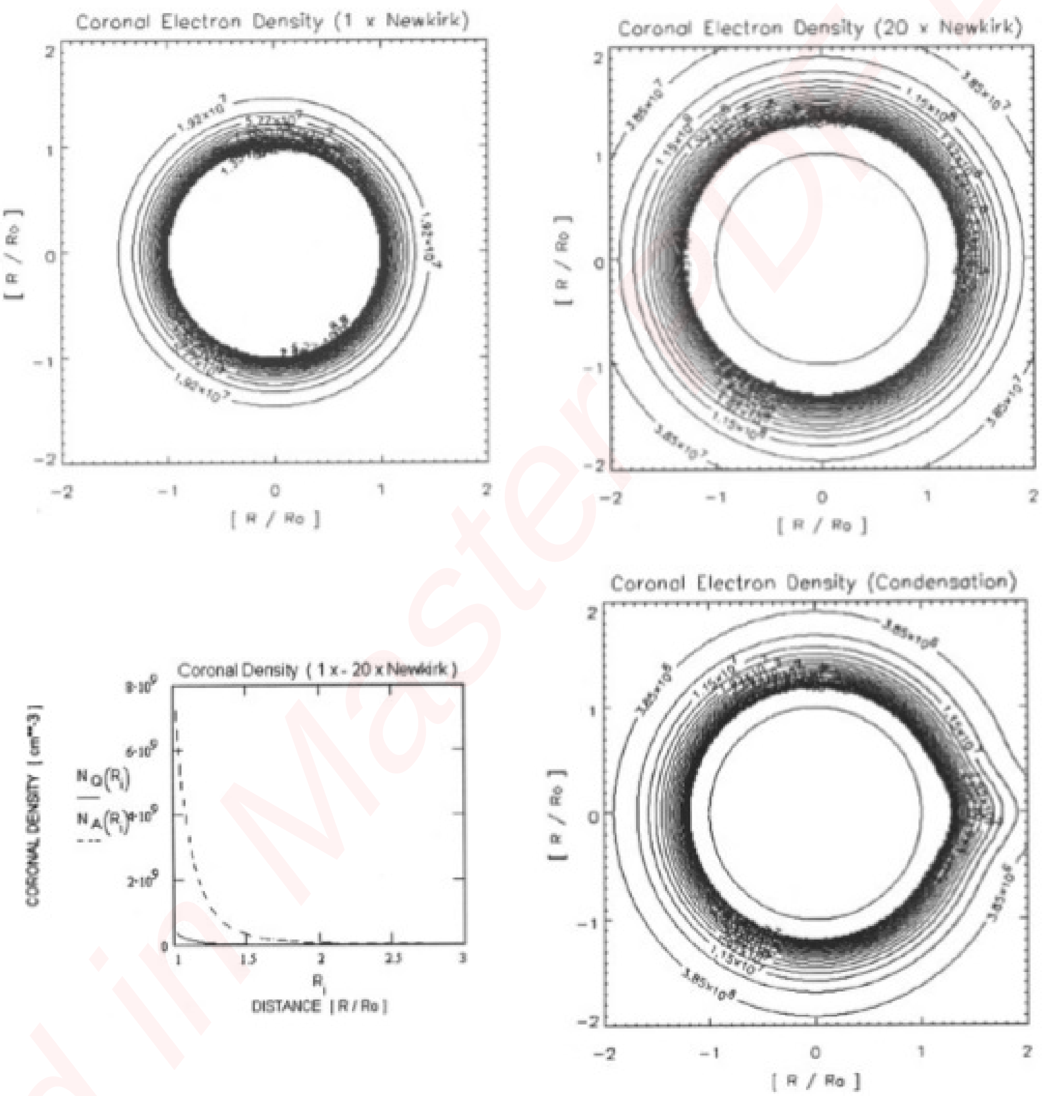


Figure 2.1: Newkirk (1961) coronal density model for the quiet and the perturbed corona.

Created in Master PDF Editor

Table 2.1: Representative Coronal Electron Densities

$R(R_o)$	Ne cm^{-3}
1.02	4×10^8
1.1	1.4×10^8
1.2	7.0×10^7
1.3	3.7×10^7
1.4	2.3×10^7
1.6	1.0×10^7
2.0	2.8×10^6
2.5	9.0×10^5
3.0	4.0×10^5
4.0	1.2×10^5
6.0	3.1×10^4
8.0	1.3×10^4
10.0	9.8×10^3
15.0	2.5×10^3
20.0	1.3×10^3
30.0	4.6×10^2
50.0	1×10^2
100.0	2×10^1
215.0	2.5

Created in Master PDF Editor

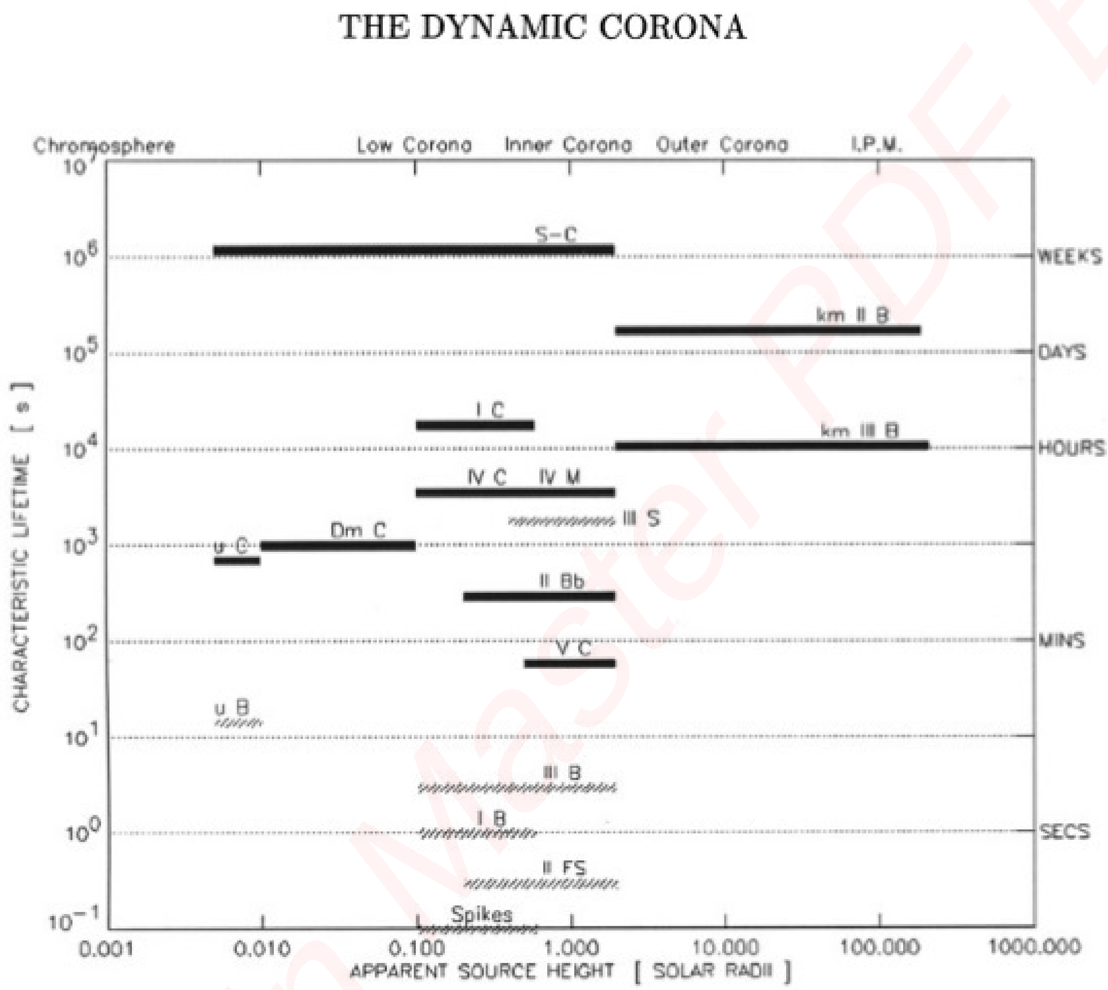


Figure 2.2: Solar radio events in the lifetime-height space: solid colour continuum emission, hatched pattern impulsive emission; S-C Slowly-Varying Component, I C Type I Continuum, I B Type I Bursts, II Bb Type II Burst Backbone, II FS Type II Burst Fine Structures, km II B Kilometric Type II Bursts, III B Type III Bursts, III S Type III Storm, km III B Kilometric Type III Bursts, IV C Type IV Continuum, IV M Moving Type IV, V C Type V Continuum, Dm C Decimetric Continuum, J.L C Microwave Continuum, J.L B Microwave.

Created in Master PDF Editor

Chapter 3

Methodology

In this research, few solar radio burst events were selected covering type II and III radio bursts using e- Callisto system which is used to calculate above objectives and get the comparison between type II and type III.

There were five major solar radio bursts images selected to ensure research and these are shown in Figures 3.1,3.2,3.3 and 3.4

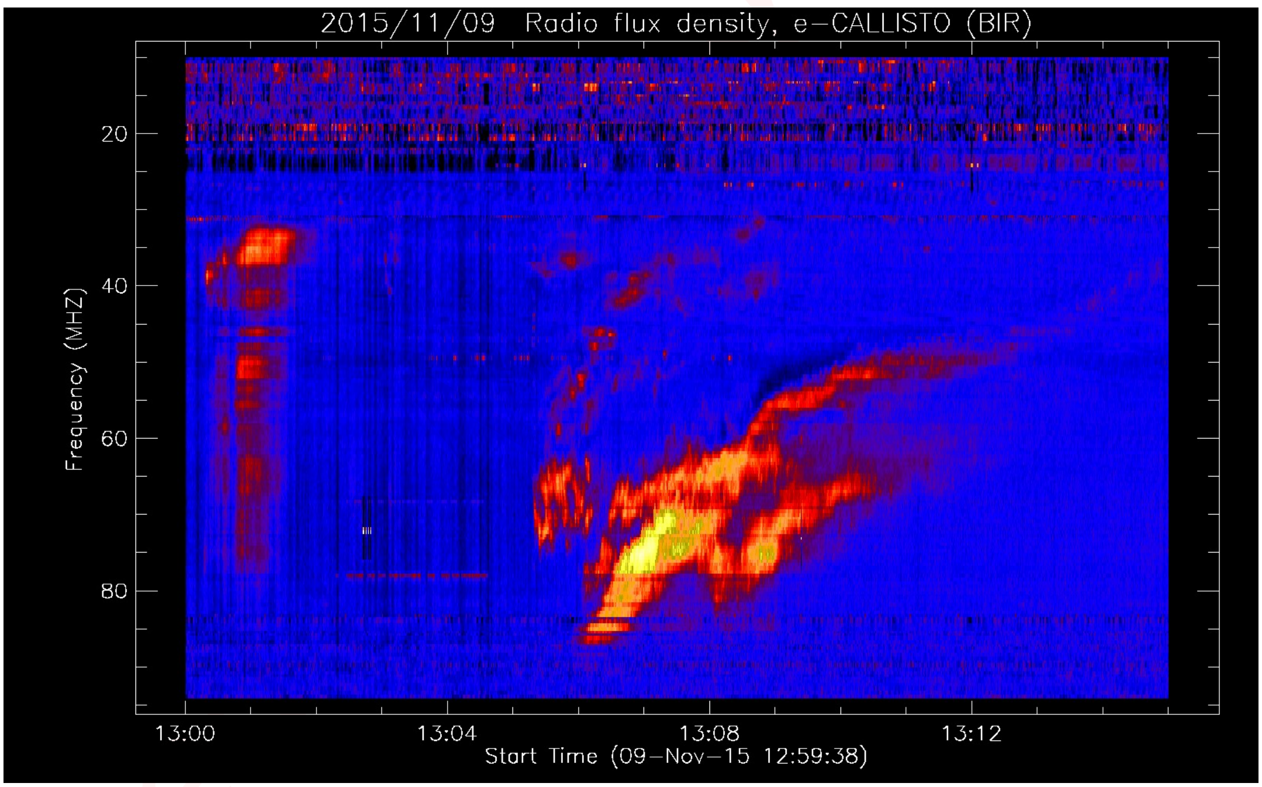


Figure 3.1: Type II solar radio burst extracted from BIR station 09-11-2015 time period between 13.04UT- 13.12U.

Created by PDF Editor

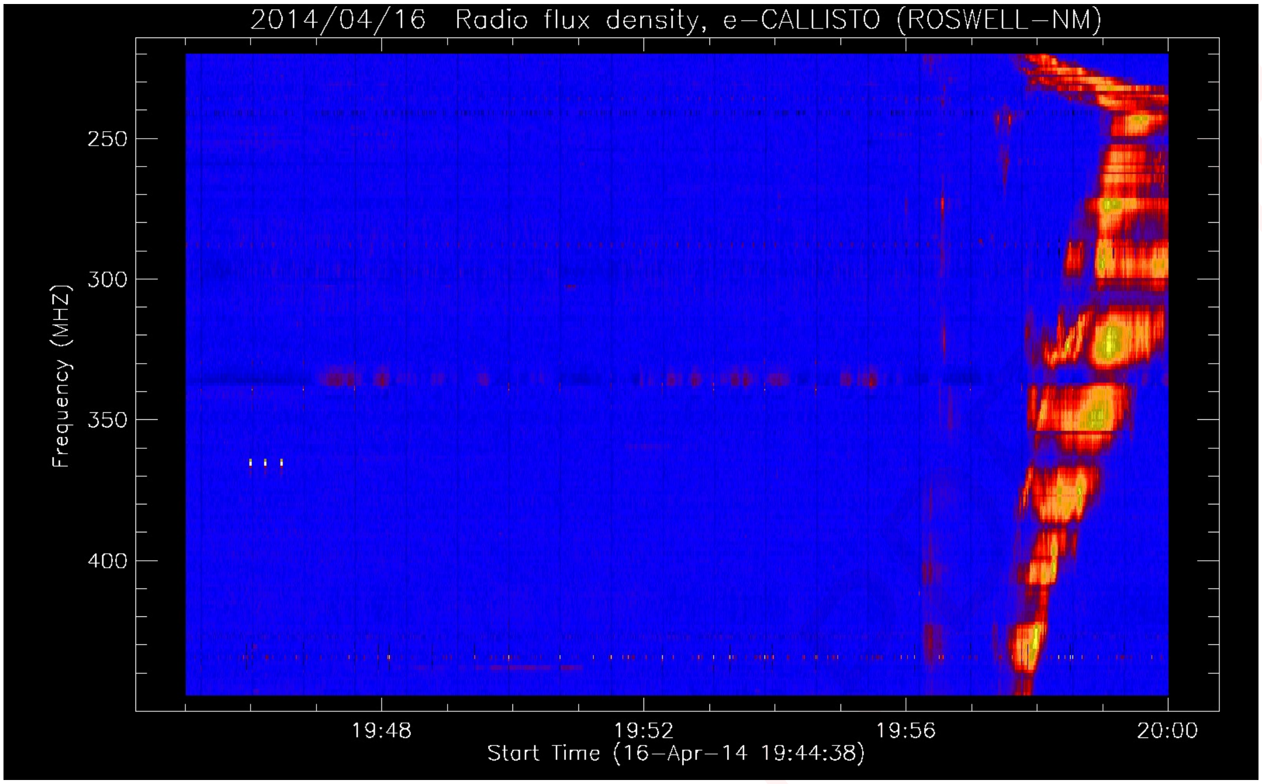


Figure 3.2: Type II solar radio burst extracted from ROSWELL station 16-04-2014 time period between 19.56UT- 20.00UT

3.1 Analysis of drift rates of solar radio bursts

Type II is slow drift from high to low frequency in dynamic radio spectra burst and also type III is fast drift rate. For us to distinguish, the frequency drift rate of a solar burst is a power law in the frequency of emission. Drift rate (df/dt) is a displacement of the peak in frequency per unit time. It can be determined by taking start time to end time and start frequency to end frequency of the solar burst type II and type III [9].

The equation of drift rate of solar radio burst type II and III was defined in Equation 3.1 [9][10][13].

$$\frac{df}{dt} = \frac{f_e - f_s}{t_e - t_s} \tag{3.1}$$

f_s is a frequency of starting time, f_e is a frequency of ending time, t_e is an end time andt_s is a start time. MATLAB software could be used for analysis of drift rate graphs and few solar radio stations which belong to e-callisto network system were selected.

Created in Master PDF Editor

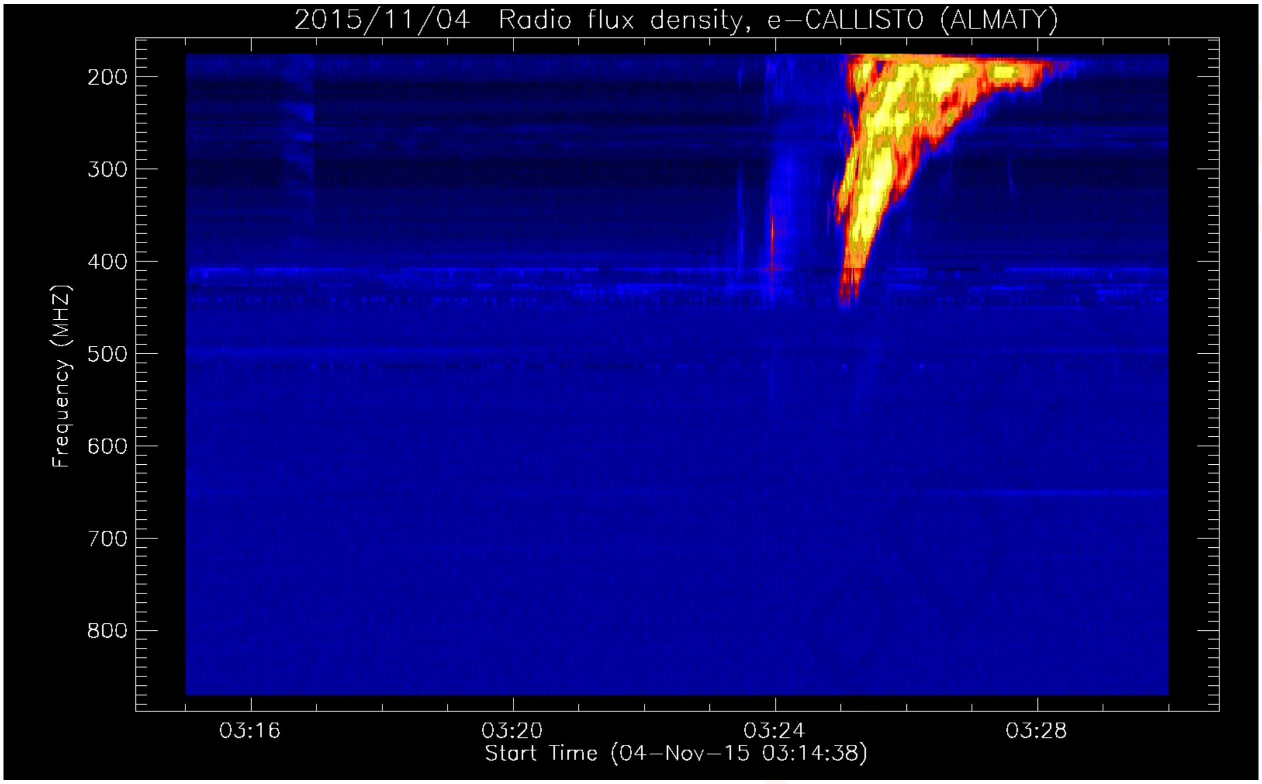


Figure 3.3: Type II solar radio burst extracted from ALMATY station 04-11-2015 time period between 03.24UT- 03.28UT.

Few solar radio burst flares from each type were taken for getting better comparison between type II and type III. Drift rate graphs of solar flares can be plotted by using frequency (which corresponding to highest intensity) with time. This method is used to get the best drift rate graph of solar radio burst flares. Each type of solar radio flares was extracted by using MATLAB software. A sample of extracting type II flares was shown in Figure 3.5 and 3.6.

There several noises could be realized in the images. These noises can be reduced by isolating the solar radio burst part, using the crop tool. This method was successful to reduce noise in certain levels but not for all. Edited solar flare image was shown in Figure 3.7.

Using cropped image, maximum intensity frequency corresponding to time can be calculated. Each maximum frequency points and each time were obtain. Subsequently feat those points, maximum frequency vs time graph was plotted to obtain the drift rate graph. The above method could be used for each solar flares which were selected. The actual frequency value of above-plotted graphs could not be acquired due to the extracted solar radio burst image showed only certain channel number in MATLAB software. The channel number was conver-

Created in Master PDF Editor

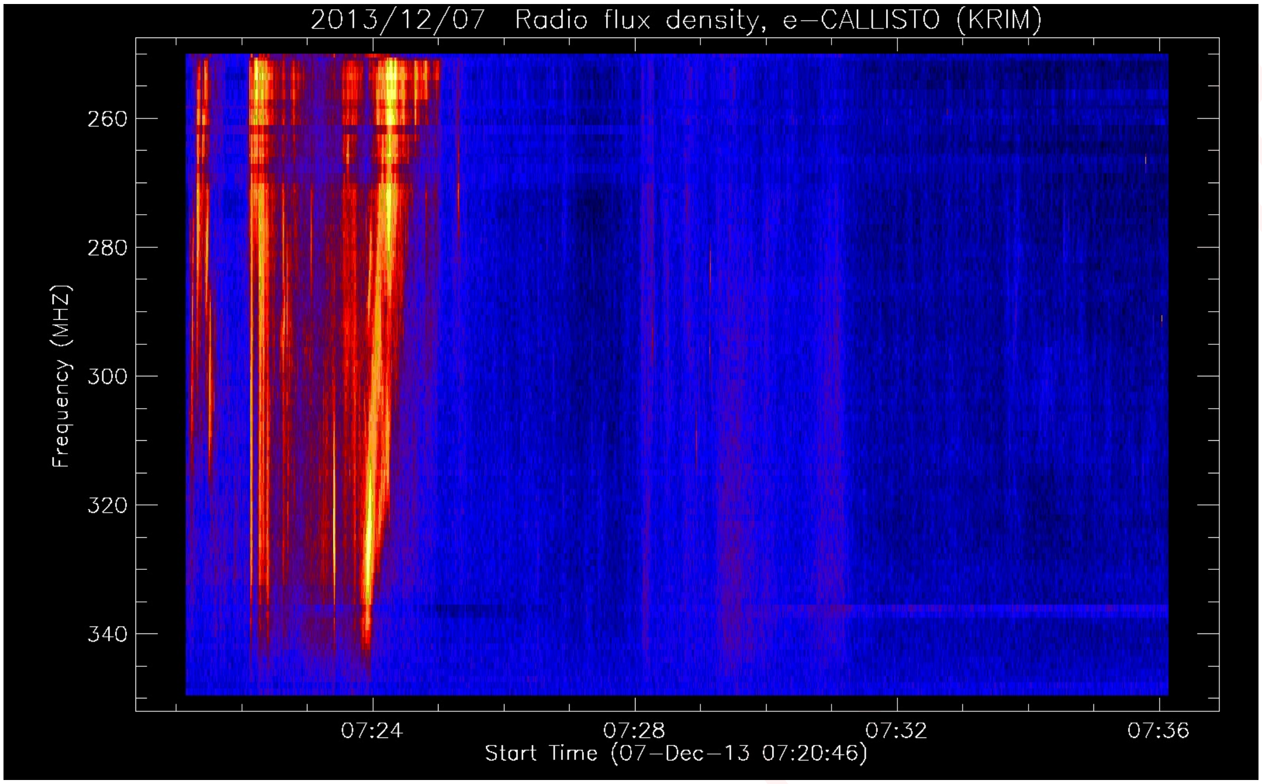


Figure 3.4: Type III solar radio burst extracted from KRIM station 07-12-2013 time period between 07.24UT- 07.25UT.

ted into the corresponding frequency value by using equations. Maximum frequency vs time graph could be plotted by using generated frequency value. However certain amount of noise was still present in the graph. That noise frequency needs to be eliminated to get the best distribution graph. The shape of distribution shape drift rate could not be retrieved under the noise frequency. That might possibly affect our final comparison. Noise frequency was eliminated by deleting the repeating same pattern frequencies in this research. This method was repeated to all other selected images. After recognizing the noise area of the images had eliminated the noise frequency. This was shown in Figure 3.8..

The frequency time graph from each image could be obtained by plotting those points. Equating these graphs can be identified, what is type II and what is type III. Model equations for each solar radio burst type could be initiated by using frequency vs time graph. The drift rate vs frequency graph was plotted after the frequency vs time graph. Though to find drift rate of each solar radio bursts, should differentiate each model equation separately. After obtaining those derivatives could see a variation of drift rates for each solar radio burst. Thus

Created in Master PDF Editor

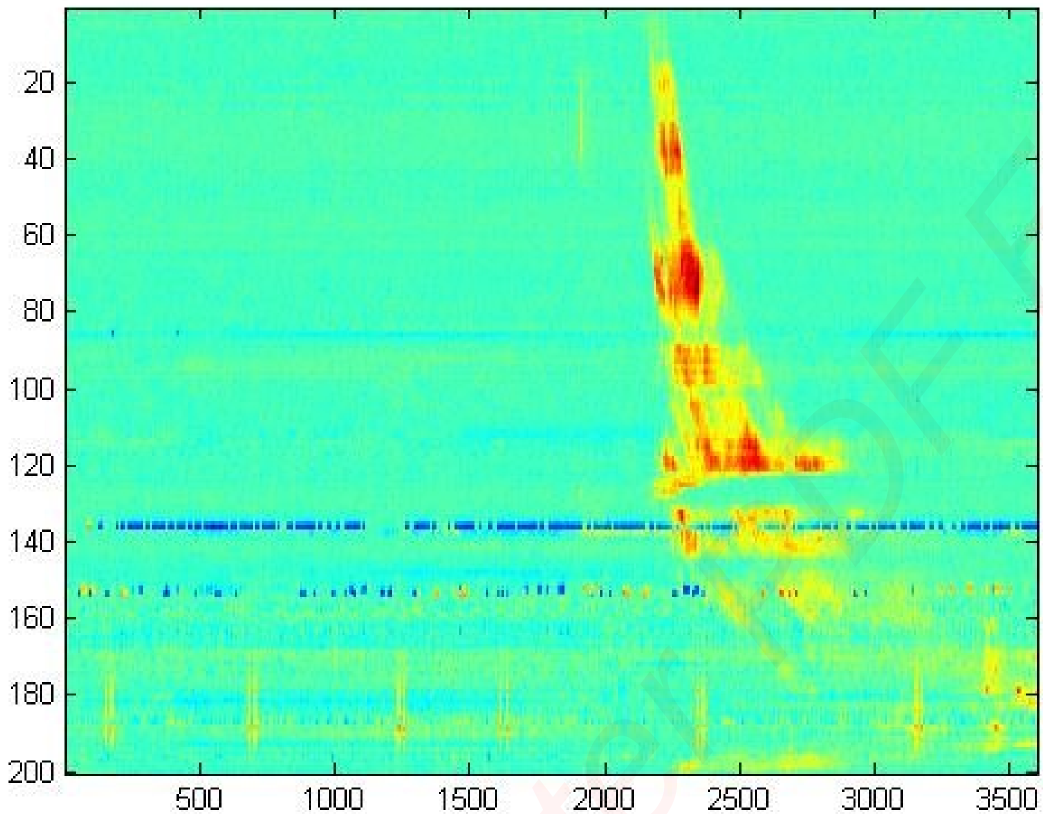


Figure 3.5: Type II solar flare occurred on 4th of November 2015. Detected by Ooty solar radio station India

by finding the mean value of these drift rates, could obtain an average value for the particular solar radio burst.

3.2 Analysis of electron density and height of solar radio bursts

The major issue of this research was find the electron density on chromosphere in sun. The several solar chromosphere models can be used to find electron density. Newkirk model is one of the best models that can be used. Newkirk model could be used reversely for verdict each electron density and height of solar radio bursts. The frequency corresponds to electron densities should be found for calculating a height of each solar radio burst. The electron

Created in Master PDF Editor

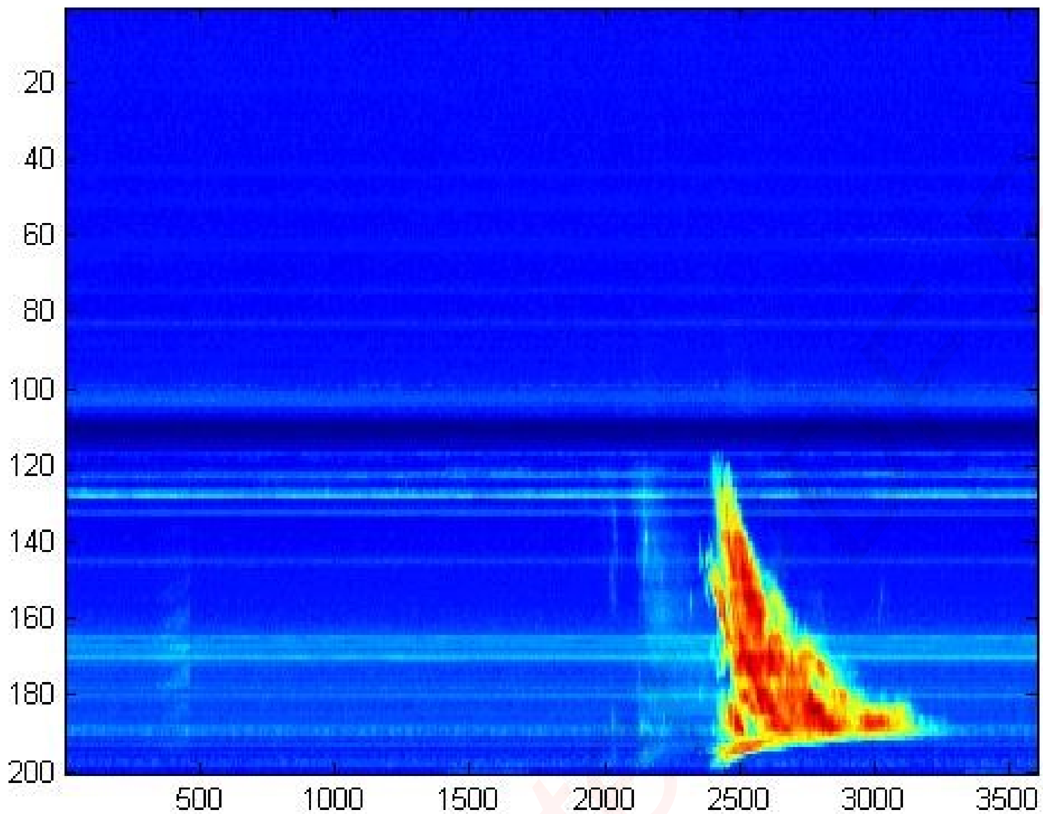


Figure 3.6: This is an edited type II solar flare using MATLAB. It occurred 4th of November 2015.

densities of each radio burst could be initiated by using Equation 3.2. The main frequency of plasma radiation F is proportional to electron density $\sqrt{Ne_r}$ [3][14][15][16].

$$F_{elec}= 8.973\times10^{-3}\sqrt{Ne_r} \tag{3.2}$$

Where F is a plasma frequency in MHz and $\sqrt{Ne_r}$ is the electron density in cm^{-3}.

A wide range of frequency was selected to get better distributions and it reduced error factor. The electron density vs plasma frequency graphs could be plotted by collaring the electron densities related to the plasma frequency. This research only got the highest intensity frequencies as mentioned earlier and by using same frequency value could find related electron

Created in Master PDF Editor

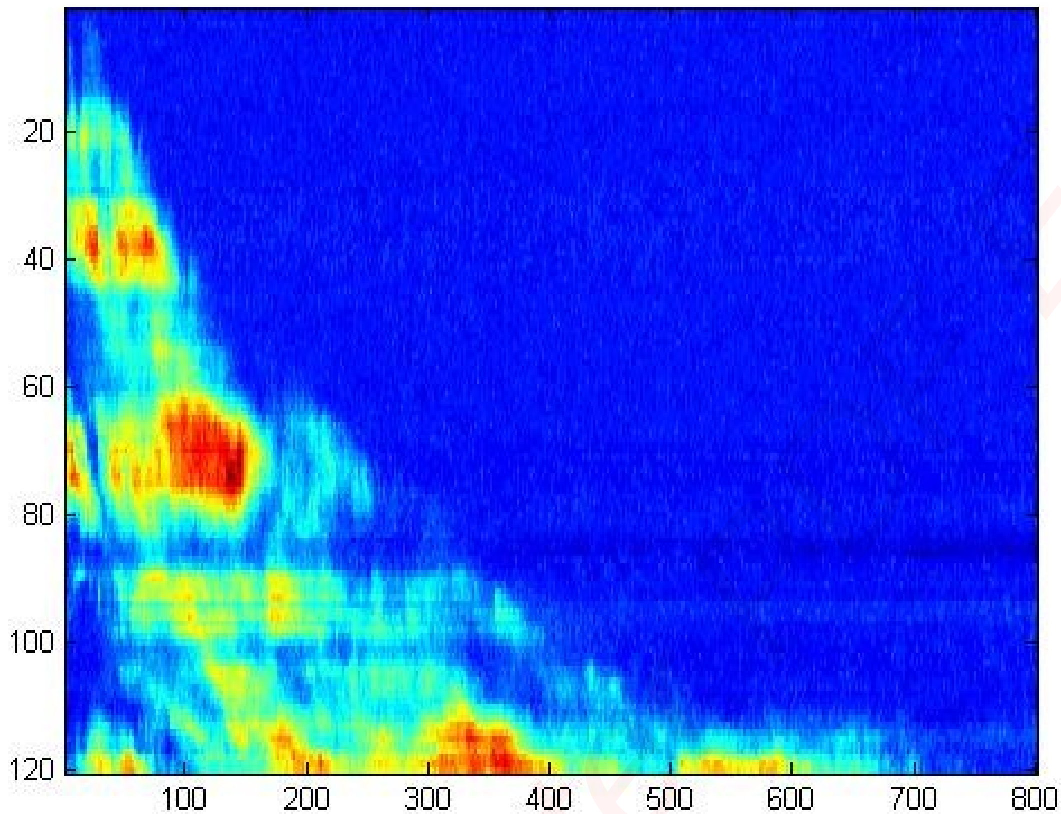


Figure 3.7: Cropped Ooty solar flare 4th November 2015.

densities and heights as well The height distribution of electron density could be found by using Newkirk model as well. Newkirk model equation is shown in Equation 3.3[12][3][15].

$$N_e = N_o \times 10^{\frac{4.32R_o}{R}} \tag{3.3}$$

Where $N_o = 4.2{\times}10^4\ cm^{-3}$. - Concentration, R_o - solar radius, R - distance from solar center to source of type burst.

The distribution graph of electron density vs height could be plotted after getting height values corresponding to electron densities. The above step was repeated for other chosen solar radio bursts. Thus, these graphs could be plotted in one main graph. This main graph should be shown the same pattern as with all the individual distribution graphs, obeying the Newkirk model.

Created in Master PDF Editor

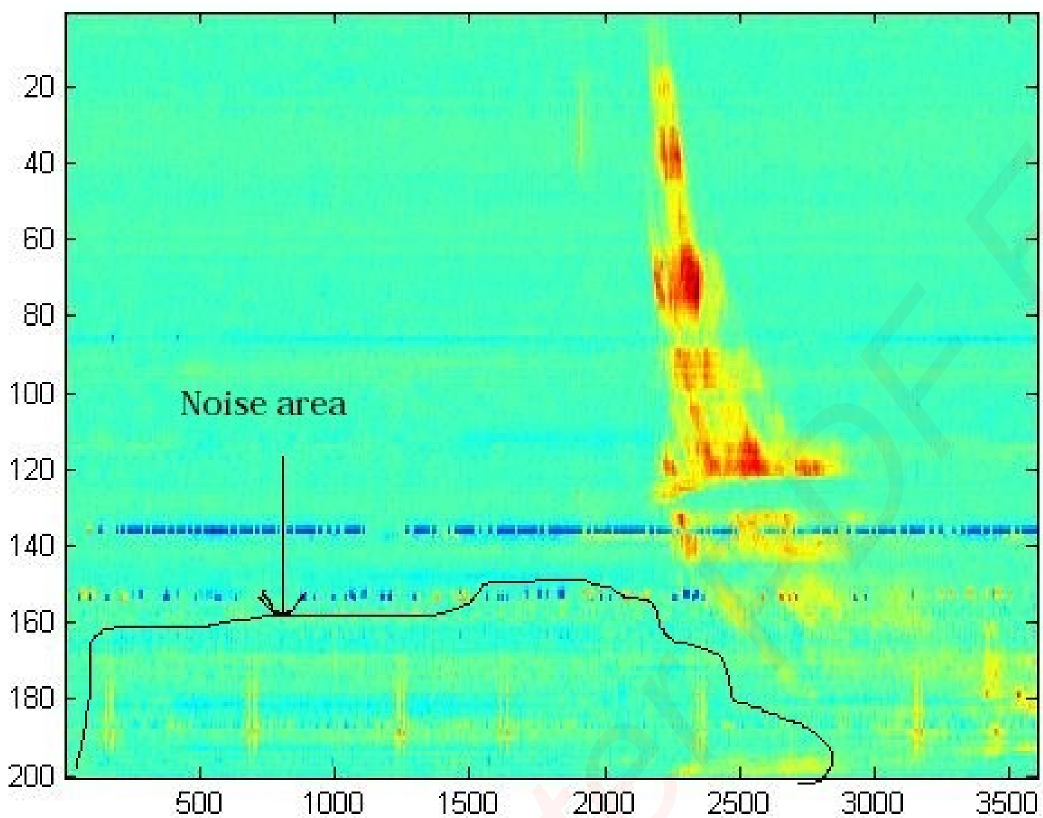


Figure 3.8: This solar radio burst extracted from Ooty station 04-11-2015.

3.3 Analysis of plasma velocity of solar radio bursts

Calculation of electron densities and ejection heights were used to calculate its plasma velocities. For this calculation following parameters need to be used as well.

1. Plasma frequencies of each solar radio bursts.
2. Change of Electron density with respect to height.
3. Drift rate value for each solar radio bursts.

Every solar radio burst made up of collections of charge particles. Each particle has its own frequency, electron density value and drift rate value. In this research, it was impossible to get all the particles. However taking the highest intensity values of each solar radio burst helped to get more accurate results.

Created in Master PDF Editor

Frequency vs time graphs as mentioned in above paragraphs was used to calculate the plasma frequency of each solar radio burst. Calculation of the change of electron density with respect to height was the next step and the electron density vs height graphs was used for it. The each value of the change of electron density with respect to height should be calculated by differentiating above mentioned graph. An example is given below.

Figure 3.9 shows the electron density vs height graph of type II solar radio burst taken from ROSWELL station. The equation of each particular graph could be found using regression analysis. The equation is given below.

$$F_{(x)}{=}8.616{\times}10^{8}x^{-10.6} \tag{3.4}$$

The change of electron density with respect to height could be found by differentiating the above equation. Values of rates of electron density respect to height are shown in annex 1. Calculate the drift rate, first needed to use the frequency vs time graph as mentioned earlier. The next step is to differentiate the graph. To obtain more accurate results, coordinate points were differentiated individually.

By using the above mentioned parameters (plasma frequency, electron density, drift rate, change of electron density with respect to height) to the equation 04, could successfully obtain the plasma velocities of the solar radio bursts [2][16].

$$v = \frac{2\frac{df}{dt}N}{f\frac{dn}{dr}} \tag{3.5}$$

Where;

v plasma velocity(km S^{-1}),

$\frac{df}{dt}$ - drift rate(MHz S^{-1})

N electron density (cm^{-3})

f plasma frequency (MHz)

$\frac{dn}{dr}$ change of electron density with respect to height ($cm^{3}\ R_o^{-1}$).

As an enrichment for both the reader and the writer, further effort was taken to clearly show the comparison between mean velocities of the type II and the type III solar radio

Created in Master PDF Editor

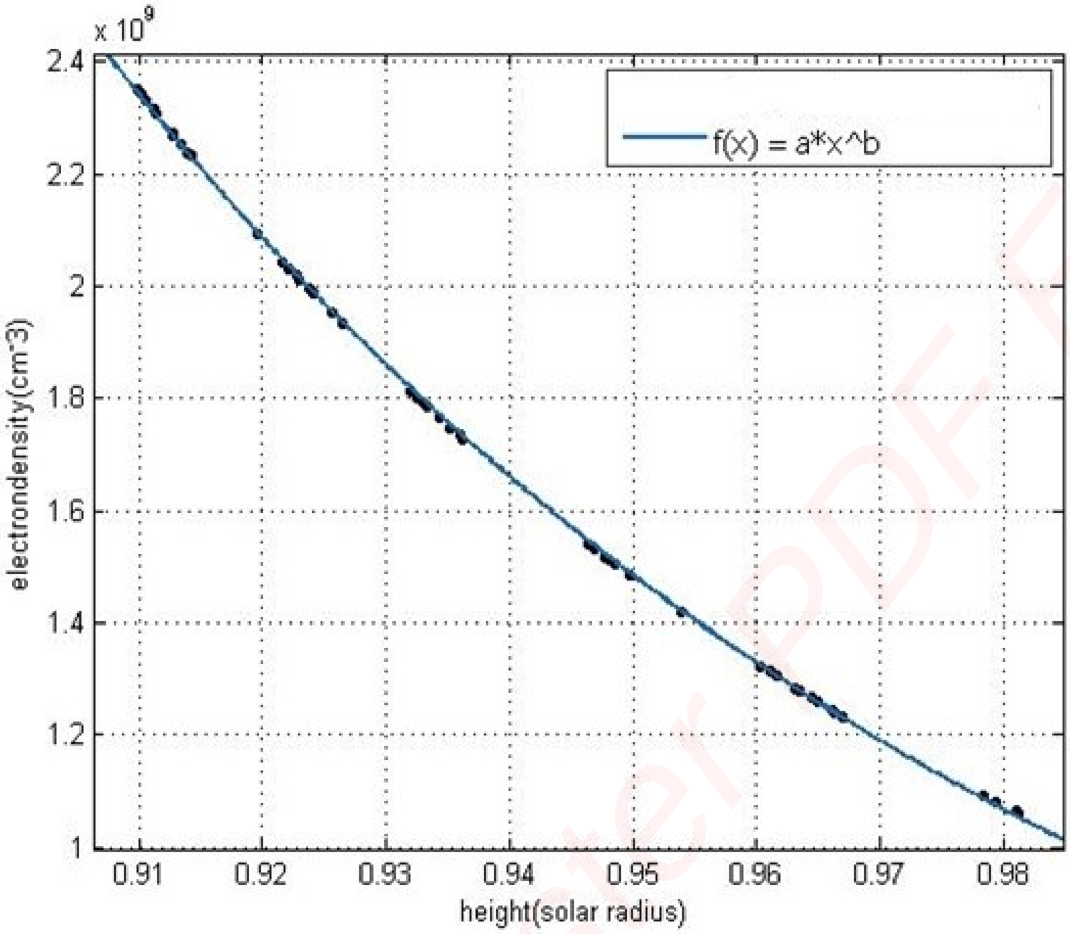


Figure 3.9: Electron density vs time graph of type II solar radio burst taken from ROSWELL station.

bursts. Therefore, has obtained a graph of mean velocity vs height. This then allows the clear clarification of the final conclusion.

Created in Master PDF Editor

Chapter 4

Data Analysis

Five solar radio bursts were selected to analysis in this research. The names of the solar radio bursts were mentioned in above. Calculation of the drift rates of solar radio bursts were the first part of this research. According to that drift rates of each solar radio bursts were calculated. Furthermore the regression analysis was used to obtain better results. An example are shown in below.

4.1 Calculations of drift rates values

Details of Figure 4.1 shows the best relationship between frequency and time because correlation coefficient between model frequency and original is 0.94516. According to this value can predict this was a good model and a model equation also straight line type unlike other type II radio burst shown in above. This is a different between type II and type III. This straight line shows fast drift rate value compare to others.

Table 4.1: Data table of KRIM 07-12-2013 solar radio burst type III frequency vs time graph

Model equation	SSE	R-square	Adjusted R-square	RMSE	correlation coefficient
f(x)=3.062x+450.9	1.372×10^4	0.8933	0.8925	10.23	0.94516

According to the Figure 4.2 indicates the straight line parallel to frequency axis. This is perfect drift rate line belongs to type III KRIM solar radio burst. It always constant drift rate value. This constant drift rate value can be acquired by differentiating above frequency vs time model equation. Compared to other types solar radio bursts this was high drift rate value.

Created in Master PDF Editor

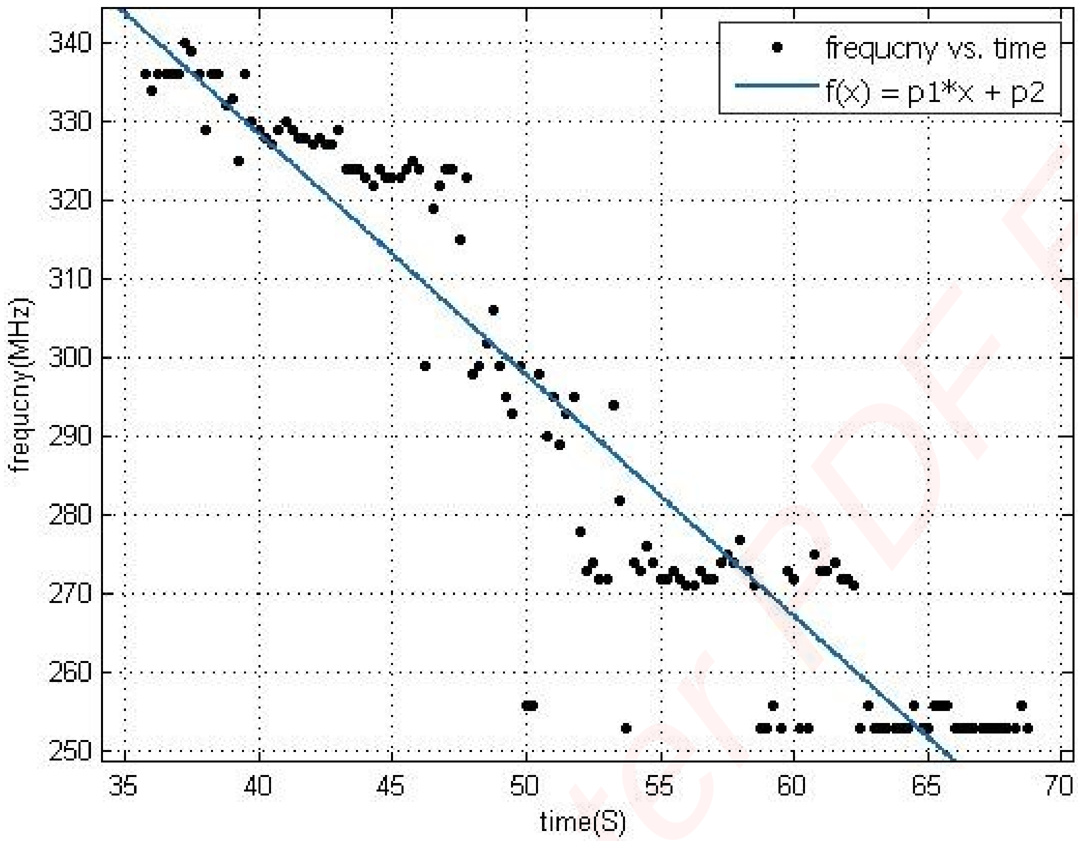


Figure 4.1: Type III solar frequency vs time graph extracted from flare KRIM 07-12-2013.

Drift rate of KRIM 07-12-2013 type II solar radio burst is -3.06 MHz S^{-1}

4.2 Calculations of electron density

Next part of this research was the calculation of electron density of solar radio bursts. According to many publications there, some solar radio burst could be ejected in a vast height range Most of type II and type III radio bursts were situated between solar radiuses 0.1 to solar radius 5[11]. The main problem of this research was how to calculate solar electron densities in different heights. There were so many Coronal Density models were there. Newkirk model was the one of the successive model choose by us. Electron density of solar radio burst related to height could be found by using the Newkirk model.

Created in Master PDF Editor

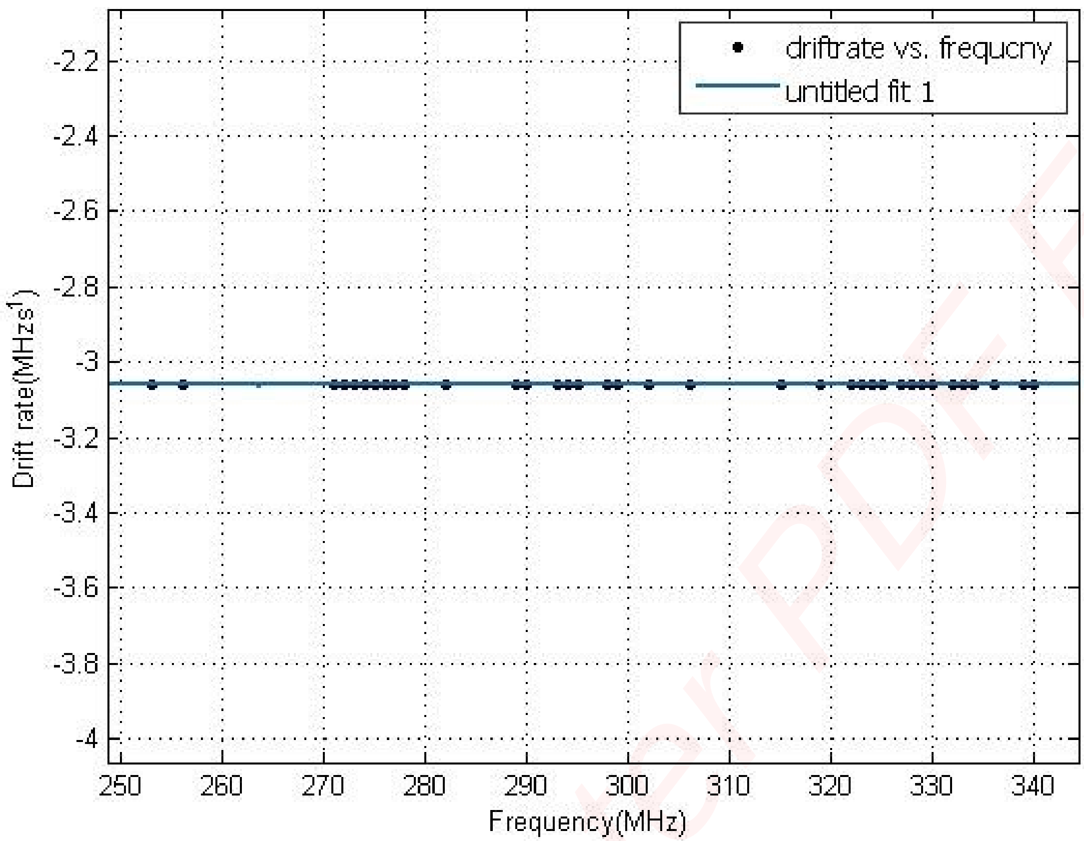


Figure 4.2: Type III solar drift rate vs frequency graph extracted from flare KRIM 07-12-2013.

4.2.1 Distributions of electron density vs plasma frequency graphs

There was five main electron density vs plasma frequency graphs are shown in figures. Each of graph has belonged to their solar radio burst type. Figure 4.3 shows the distribution of electron density vs frequency time. According to graph the fractional shape of solar radio burst could be seen and the reason for this can be obtained the noise.

4.2.2 Distribution of electron density vs height graphs

Calculation of electron density vs height, graphs were the another part of this research. Above mention five selected solar radio bursts were used to calculate this. This could be appropriated by using Newkirk model. One of the examples is shown in below.

Identical alignments were seen in graphs. That means all the electron density vs height

Created in Master PDF Editor

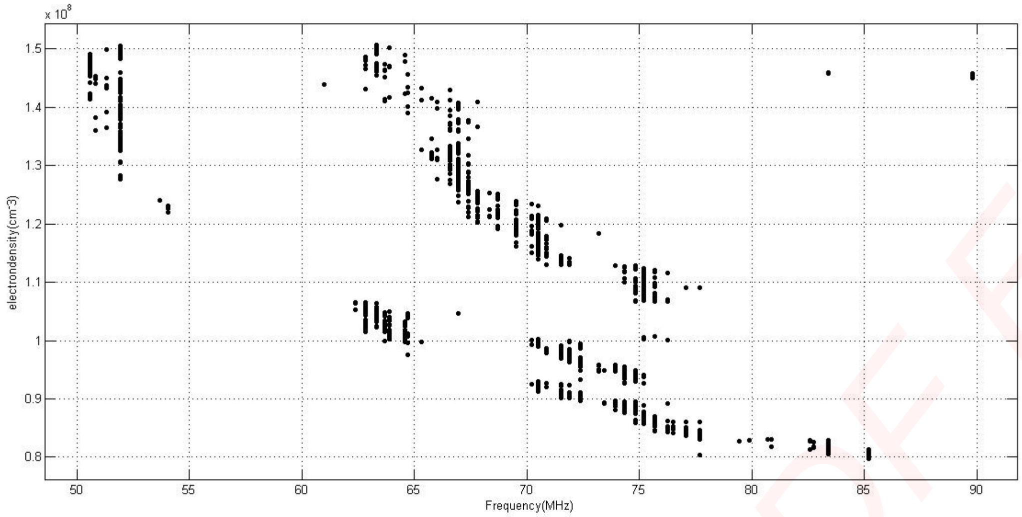


Figure 4.3: Type II solar radio burst electron density vs frequency graph taken from BIR station.

Table 4.2: Data table of BIR solar radio burst type II electron density vs height graph

Model equation	SSE	R-square	Adjusted R-square	RMSE
f(x) = $6.994 \times 10^8 \times x^{7.891}$	5.386×10^{13}	0.9999	0.9999	2.104×10^5

graphs obey the Newkirk model as well. Permitting to the chosen type II and type III solar radio bursts, the electron ejection height range between solar radiuses 0.9 to 1.3 could be seen. Summary of chosen type II and III solar radio bursts electron density vs height graph is shown in Figure 4.5.

Table 4.3: Data table of type III and II solar radio burst electron density vs height graph

Model equation	SSE	R-square	Adjusted R-square	RMSE
f(x) = $8.994 \times 10^8 \times x^{9.929}$	5.386×10^{13}	0.9989	0.9989	2.131×10^7

MOTIONS IN THE SOLAR ATMOSPHERE book has been used to analysis our data further[3]. According to that book, our chosen solar radio bursts types belongs to subparts. Each type II and type III solar radio burst divvied into subparts. There were shown on Table 4.4 [3], [12].

Comparing our analyzing heights value and above table value, chosen solar radio burst types belongs to type II Bb, type II FS, type II FS and type III B.

Created in Master PDF Editor

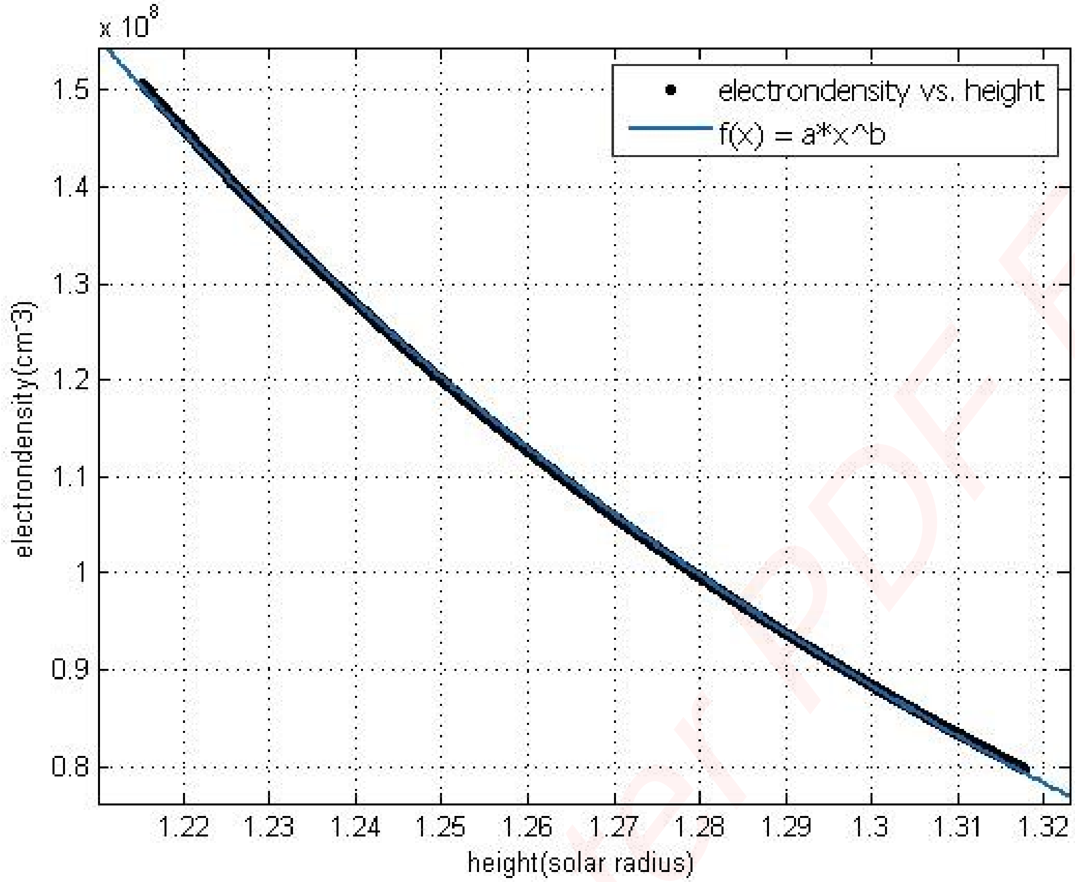


Figure 4.4: Type II solar radio burst electron density vs frequency graph taken from BIR station.

4.3 Calculations of velocity vs height graph

Calculation of the drift velocity of type II and type III solar radio bursts was the last step of this research and for this calculation had to use above data. Electron density rate per height, related electron density frequency and drift rates of each point of related solar radio burst types should be calculated for finding velocity.

Figure 4.6 shows the plasma velocity of type II solar radio burst extracted from the BIR station. There is a better linear distribution in this graph. Better correlation coefficient value shows the Table 4.5. This indicates our regression model fitted line is true.

Average velocity of BIR 09-11-2015 type II solar radio burst is 233.24 Km S^{-1}

Summary of above all velocity vs time graphs are shown in figure 4.7. According to that

Created in Master PDF Editor

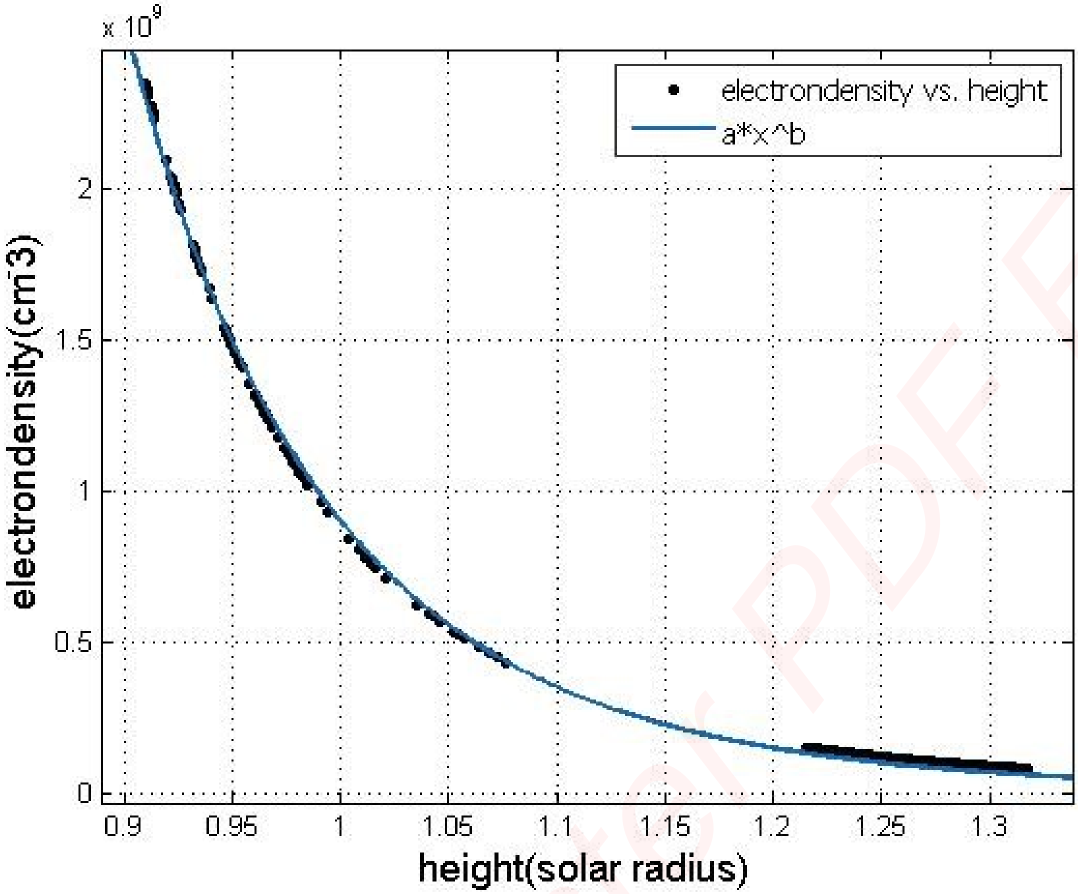


Figure 4.5: Type III and II solar radio burst electron density vs height graph.

graphs could see high velocity value associated with type III solar radio bursts and low range velocity values associated with type II solar radio bursts.

Created in Master PDF Editor

Table 4.4: Classification of solar radio bursts respect to height

Type II solar radio burst with height range(solar radius)	Type III solar radio burst with height range(solar radius)
Km II B / solar radius 2 to 200 II Bb/ solar radius 0.2 to 4 II FS /solar radius 0.4 to 4	Km III B /solar radius 2 to 200 III S / solar radius 0.5 to 4 III B / solar radius 0.1 to 4

Table 4.5: Data table of type III and II solar radio burst electron density vs height graph

Model equation	SSE	R-square	Adjusted R-square	RMSE	correlation coefficient
f(x)=$575.1x^2 - 1266x + 914.2$	0.00979	1	1	0.002837	0.996801

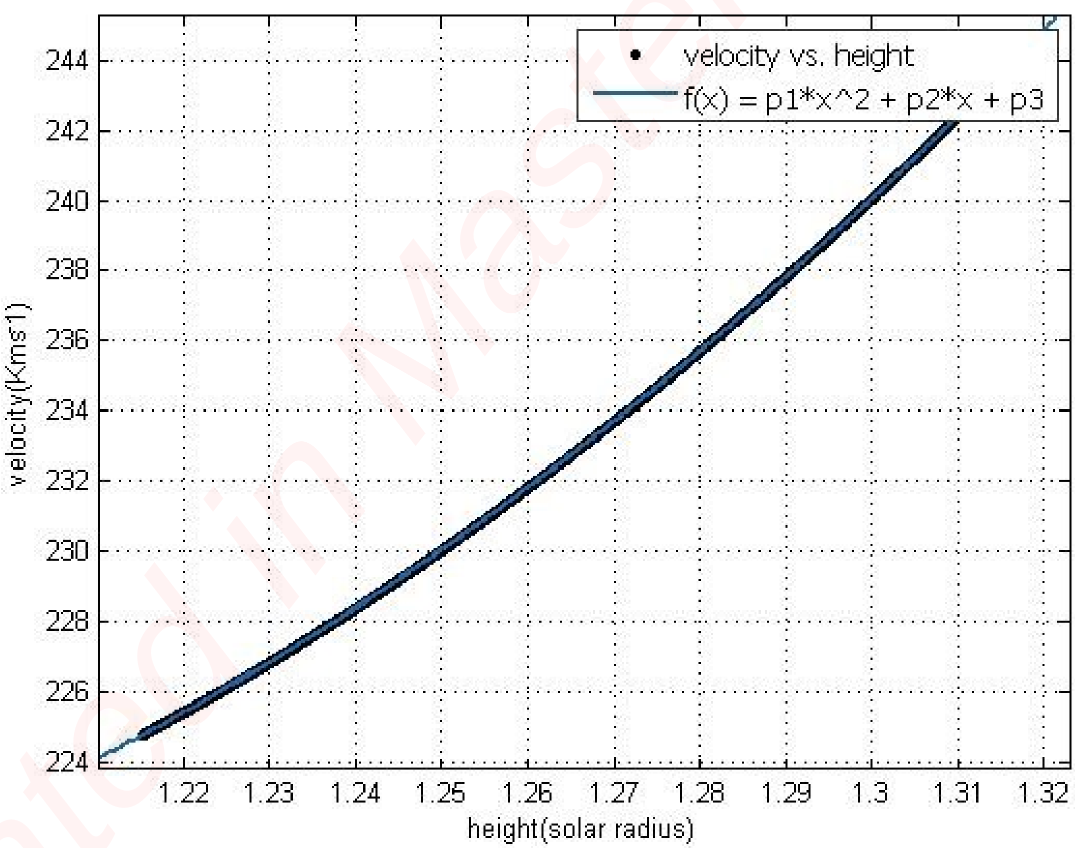


Figure 4.6: Type II solar radio burst velocity vs height graph taken from BIR station 09-11-2015.

Created in Master PDF Editor

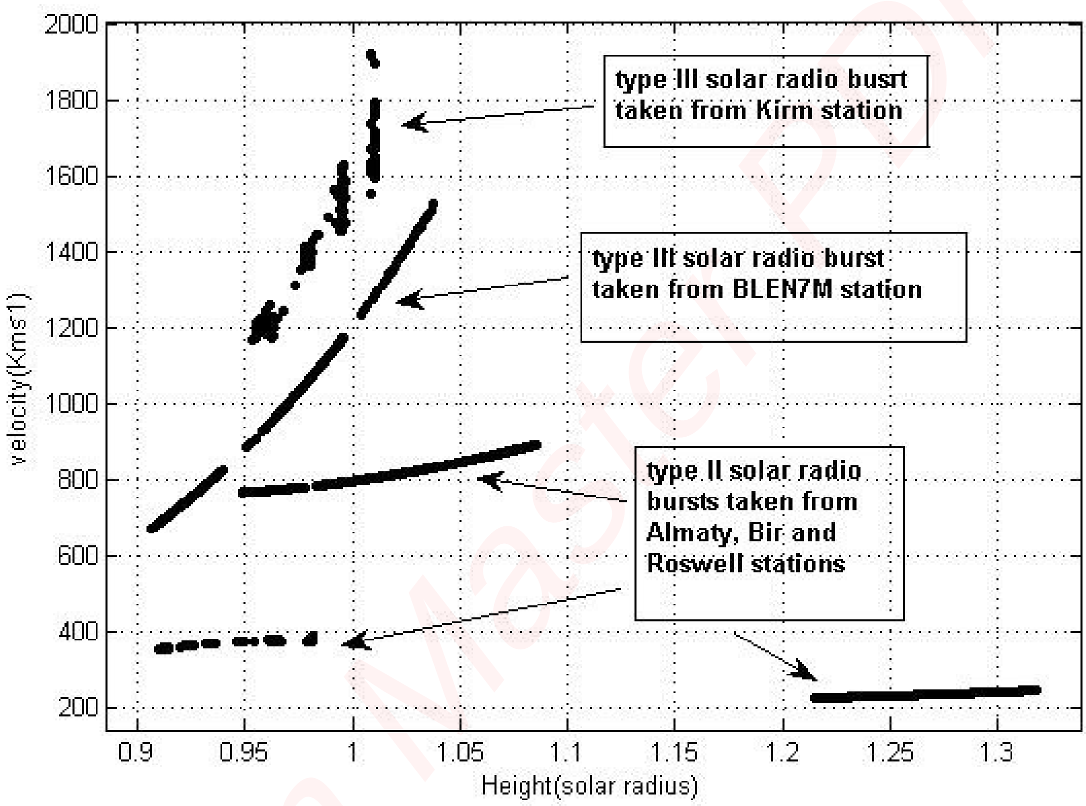


Figure 4.7: Type II and type III solar radio bursts velocity vs height graphs taken from chosen station.

Created in Master PDF Editor

Chapter 5

Conclusions

Drift rates and frequency vs time graphs were obtained in the first part of the research. Variations of drift rates between type II and type III solar radio bursts can be observed from this. A difference between type II and type III was also observed by the distribution of solar radio bursts which were shown by the frequency vs time graphs. The research thoroughly and successfully analyzed the five images of solar radio bursts. Using those analyzed images variations of type II and type III could be retrieved. Details of frequency vs time graphs are shown in Table 5.1.

Table 5.1: Details of frequency vs time graphs

Solar radio burst type	Curve fitting type
Type II	Exponential fitting f(x) = A$\times e^{-bx}$
Type III	Linear fitting f(x)=-mx+c

According to Table 5.1, could see that the type II solar radio burst indicates some exponential curve fitting model and type III solar radio bursts indicates straight line curve fitting model. On following these data could find the drift rates of each solar radio burst types. Drift rate graphs tables are shown in Table 5.2.

Table 5.2: Details of chosen all drift rates

Solar radio burst type	Drift rates value(MHz S^{-1}
ALMATY TYPE II 2015-11-04	-1.458
BIR TYPE II 09-11-2015	-0.098
ROSWELL-NM TYPE II 16-04-2014	-1.079
BLEN7M TYPE III 10-06-2014	-2.375
KRIM TYPE III 07-12-2013	-3.062

Table 5.2 shows the drift rate graphs values of each chosen solar radio burst. High drift rates

Created in Master PDF Editor

values can be seen in type III solar flares whereas low to medium drift rate values can be seen in type II solar flares.

Fast drift rate values indicate the fast distribution type and this may range from few seconds to minutes. Slow drift rate values indicate the slow distribution type and this may takes quite a few minutes. Table 5.2 shows the main different between type II and type III solar radio bursts.

In the second part of this research, the electron density of solar radio bursts, ejection height and plasma frequency were calculated. Using Newkirk model could get the above mentioned parameters. According to the results of plasma frequencies and electron densities some distributions look like their original image forms. However, their height values depict different values. That meaning to say that each solar radio burst ejects different heights [[3], [12].Hence could see that the chosen solar radio bursts split into sub types. According to the "MOTIONS IN THE SOLAR ATMOSPHERE" [3]book, chosen solar radio burst types belong to type II Bb, type II FS and type III B [3].These sub types do not provide a perfect difference between type II and type III because chosen solar radio burst does not shows high variations. All the chosen solar radio bursts were located in solar radius of 0.9 - 1.3 range, but main point was that they always obey the Newkirk model graph. The comparison between MOTIONS IN THE SOLAR ATMOSPHERE book and the research results was that the electron density vs height graph always shows power equations in the form of f(x)=A$\times 10^{-bx}$.

Final part of this research is the calculation of plasma velocity of each solar radio burst. According to that could see low and medium velocities for type II solar radio bursts and a high velocity for the type III solar radio burst. This conclusion has further proved by the figure 30. When Coronal Mass Ejection (CME) was associated with type II solar radio bursts it helps to improve the velocity. In this research mean velocities of 233.24 Km S^{-1} , 815.95 Km S^{-1} and 369.54 Km S^{-1} for type II solar radio bursts and 1443.05 Km S^{-1} , 1205.058 Km S^{-1} for type III solar radio burst were obtained. According to "CORONAL MASS EJECTIONS AND SOLAR RADIO EMISSIONS" article, type II solar radio bursts could get the mean velocities less than 500 Km S^{-1} and if the CME was associated, they might get fast mean velocity values.

Created in Master PDF Editor

Solar radio burst type	Conclusion
Type II solar radio bursts	• Have got slow drift rate value . • According to the research type II solar radio bursts drift rates are 1.458 MHz S^{-1} , 0.098 MHz S^{-1} and 1.079 MHz S^{-1}. • Shows the same Newkirk model graphs fitting. • Low to medium range plasma velocities. According to the research type II solar radio bursts velocities are 233.24 Km S^{-1} , 815.95 Km S^{-1} and 369.54 Km S^{-1}.
Type III solar	• Have got fast drift rate value. According to the research type II solar radio bursts drift rates are -3.062 MHz S^{-1} and 2.375 MHz S^{-1}. • Shows the same Newkirk model graphs fitting same as type II. • Have high plasma velocity value according to the research values are 1443.05 Km S^{-1} and 1205.05 Km S^{-1}.

Created in Master PDF Editor

Chapter 6

Discussion

In this research, have considered the drift rate of each point for more accurate results. The drift rate was obtained by differentiating each point on the model fitted line of frequency vs time graph. Applying the parameters of the chosen solar flares to the Equation 1, drift rates were calculated. The calculated drift rates are approximately equals to the values obtained. This was done to check the validity of the research

Created in Master PDF Editor

Chapter 7

References

[1] National Aeronautics and Space Administration, "Solar Storm and Space Weather - Frequently Asked Questions," 2015. [Online]. Available: `http://www.nasa.gov/mission_pages/sunearth/spaceweather/index.html`

[2] R. Behlke, "Solar radio bursts and low frequency radio emissions from space," SE-755 91 Uppsala, Sweden, 2001.

[3] M. . Hanslmeier, A., Messerotti, Motions in the solar atmosphere, vol. 239, no. 9. SPRINGER- SCIENCE+BUSINESS MEDIA, B.Y., 1999.

[4] IPS AUSTRALIA, "Solar Radio Burst Classifications," pp. 1–4, 2009.

[5] Z. S. Hamidi, U. Ferwani, S. Ungku, and N. N. M. Shariff, "Theoretical Review of Solar Radio Burst III (SRBT III) Associated With of Solar Flare Phenomena," vol. 3, no. 2, pp. 20–23, 2013.

[6] C. Monstein, "Catalog of dynamic electromagnetic spectra," Physics, Astron. Electron. Work Bench, pp. 1–16, 2015.

[7] S. White, "Solar radio bursts and space weather," Asian J. Phys, vol. 16, pp. 189–207, 2007.

Created in Master PDF Editor

[8] H. A. S. Reid and H. Ratcliffe, "A review of solar type III radio bursts," Res. Astron. Astrophys., vol. 14, no. 7, pp. 773–804, 2014.

[9] M. I. Aguilar-Rodriguez, E., Gopalswamy, N., MacDowall, R., Yashiro, S., Kaiser, "A Study of the Drift Rate of Type II Radio Bursts at Different Wavelength," Proc. Sol. Wind 11 / SOHO 16, "Connecting Sun Heliosphere" Conf. (ESA SP-592), p. 65.1-65.4, 2005.

[10] N. H. Zainol, Z. S. Hamidi, N. N. M. Shariff, S. Arifin, and C. Monstein, "Investigation of Drift Rate of Solar Radio Burst Type II due to Coronal Mass Ejections Phenomenon," Int. Lett. Chem. Phys. Astron., vol. 48, no. i, pp. 146–154, 2015.

C. Monstein, "E-Callisto solar spectrometer." [Online]. Available: http://www.e-callisto.org/.

[12] G. A. Newkirk, "Structure of the solar corona," in Structure of the solar corona, vol. 53, no. 9, 1967, pp. 1689–1699.

[13] M. O. Ali, Z. S. Hamidi, N. N. M. Shariff, and C. Monstein, "An Analysis of the Electron Density and Drift Rate of Solar Burst Type III During 13 th of May 2015," World Sci. News, vol. 31, no. May 2015, pp. 1–11, 2016.

[14] H. Ratcliffe, E. P. Kontar, and H. A. S. Reid, "Large-scale simulations of solar type III radio bursts: flux density, drift rate, duration, and bandwidth," Astron. Astrophys., vol. 572, p. A111, 2014.

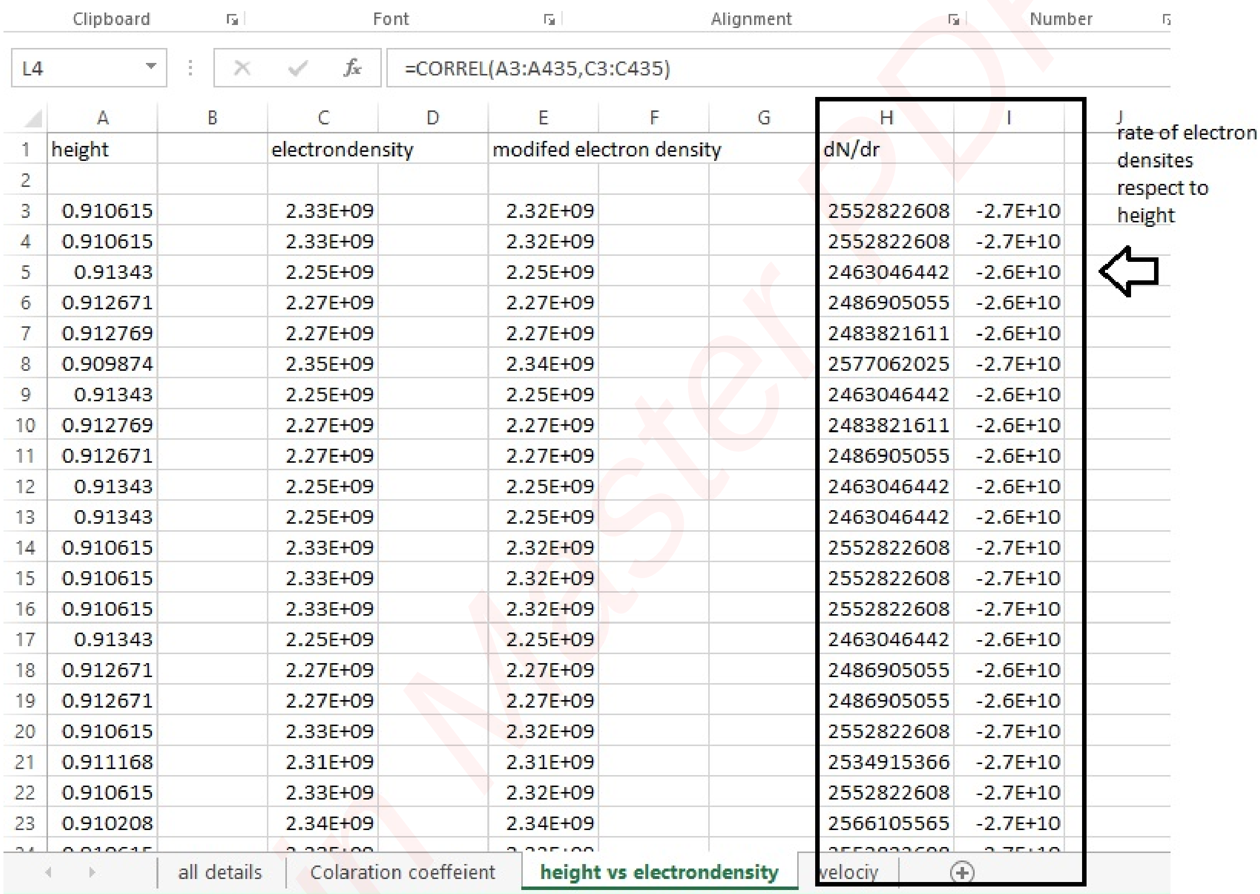
[15] T. Takakura, "Implications of Solar Radio Bursts for the Study of the Solar Corona," Space Sci. Rev., vol. 5, no. 1, pp. 80–108, 1965.

[16] N. Gopalswamy, "Coronal Mass Ejections and Solar Radio Emissions," Public Hist.

Created in Master PDF Editor

Chapter 8

Annex



	A	B	C	D	E	F	G	H	I
1	height		electrondensity		modifed electron density			dN/dr	
2									
3	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
4	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
5	0.91343		2.25E+09		2.25E+09			2463046442	-2.6E+10
6	0.912671		2.27E+09		2.27E+09			2486905055	-2.6E+10
7	0.912769		2.27E+09		2.27E+09			2483821611	-2.6E+10
8	0.909874		2.35E+09		2.34E+09			2577062025	-2.7E+10
9	0.91343		2.25E+09		2.25E+09			2463046442	-2.6E+10
10	0.912769		2.27E+09		2.27E+09			2483821611	-2.6E+10
11	0.912671		2.27E+09		2.27E+09			2486905055	-2.6E+10
12	0.91343		2.25E+09		2.25E+09			2463046442	-2.6E+10
13	0.91343		2.25E+09		2.25E+09			2463046442	-2.6E+10
14	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
15	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
16	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
17	0.91343		2.25E+09		2.25E+09			2463046442	-2.6E+10
18	0.912671		2.27E+09		2.27E+09			2486905055	-2.6E+10
19	0.912671		2.27E+09		2.27E+09			2486905055	-2.6E+10
20	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
21	0.911168		2.31E+09		2.31E+09			2534915366	-2.7E+10
22	0.910615		2.33E+09		2.32E+09			2552822608	-2.7E+10
23	0.910208		2.34E+09		2.34E+09			2566105565	-2.7E+10

Figure 8.1: rate of electron density respect to height values.

Created in Master PDF Editor