Automated Detection of Solar Radio Bursts Using a Statistical Method

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Abstract Radio bursts from the solar corona can provide clues to forecast space-weather hazards. After recent technology advancements, regular monitoring of radio bursts has increased and large observational datasets are produced. Hence, manual identification and classification of them is a challenging task. In this article, we describe an algorithm to automatically identify radio bursts from dynamic solar radio spectrograms using a novel statistical method. We use e-CALLISTO (Compound Astronomical Low Cost Low Frequency Instrument for Spectroscopy and Transportable Observatory) radio spectrometer data obtained at Gauribidanur Observatory near Bangalore in India during 2013–2014. We have studied the classifier performance using the receiver operating characteristics. Further, we analyze type III bursts observed in the year 2014 and find that 75% of the observed bursts were below 200 MHz. Our analysis shows that the positions of flare sites, which are associated with the type III bursts with upper frequency cutoff $\gtrsim 200$ MHz originate close to the solar disk center.

Keywords Corona, radio emission · Radio bursts · Instrumentation and data management

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1. Introduction

Radio bursts from the Sun play an important role in understanding the solar atmosphere, solar wind, and particularly coronal mass ejections. Many of these bursts provide clues to understand space weather. Radio bursts are observed over a wide range of frequencies (from few GHz to kHz) and they help to probe the solar atmosphere from chromospheric heights to 1 AU and beyond. Based on their morphology and frequency drift speeds (drift rates) in the dynamic spectrograms, they are classified into five primary types, viz. type I, type II, type III, type IV, and type V bursts (Wild, 1967). Type J and type U are the other complex bursts, which are often observed in the solar corona (Kundu, 1965; McLean and Labrum, 1985).

Technology advancements have enabled us to observe solar radio bursts with sophisticated telescopes both from ground and space. For example, some ground-based solar dedicated radio spectrographs are the: Radio Solar Telescope Network (RSTN) operated by the US airforce (Guidice et al., 1981), Gauribidanur Low frequency Solar Spectrograph (GLOSS) in India (Kishore et al., 2014), Hiraiso Radio Spectrograph (HiRAS) in Japan (Kondo et al., 1994), IZMIRAN in Russia (Gorgutsa et al., 2001), ARTEMIS IV in Greece (Caroubalos et al., 2001), and many others. Apart from these, there are more than 150 observing stations set up around the world to monitor the Sun, 24 hours a day. Presently about 52 of them regularly upload and make available data in a server at the University of Applied Sciences (FHNW) in Brugg, Windisch, Switzerland. The data processing is managed at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. All these stations jointly constitute the e-CALLISTO (Compound Astronomical Low Cost Low Frequency Instrument for Spectroscopy and Transportable Observatory) network2 (Benz et al., 2009; Sasikumar Raja et al., 2018). Space-based observations at ≲ 14 MHz are carried out using the Radio and Plasma Wave Investigation (WAVES) instrument onboard Wind (Bougeret et al., 1995) and the WAVES instrument onboard the Sun–Earth Connection Coronal and Heliospheric Investigation (STEREO) (Kaiser, 2005; Rucker et al., 2005). There are attempts to combine these space-based observations with ground-based observations also (see for example Hariharan et al., 2016). All these spectrometers produce large datasets. For instance, in the present work, we used data observed using the CALLISTO spectrometer located at Gauribidanur Observatory, India (Monstein, Ramesh, and Kathiravan, 2007) that recorded ≈ 13,000 files in two years. Therefore, manual identification of radio bursts is not possible, hence the present work.

In recent times, machine learning applications have been widely used in classification problems. It is well known that, if we want to apply them to classify various types of solar radio bursts, the machine needs to be “trained” and we need large sets of data for each type of burst. As mentioned previously, manual identification of bursts in a training dataset is an onerous task. We also know that the more training data, the better the performance of the classifier (or classification method). Hence, in this article, we present an algorithm to automatically identify the radio bursts using a statistical method. The developed algorithm can detect whether or not there is a radio burst present in the spectrogram. Our primary motivation is to use the database prepared using the algorithm described in the article and develop an automated classifier which would recognize various types of individual bursts. So far, there have been attempts to automatically identify specific type of bursts (Lobzin et al., 2009, 2010; Lobzin, Cairns, and Zaslavsky, 2014; Salmane et al., 2018; Zhang, Wang, and

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1 https://www.astro.gla.ac.uk/users/eduard/cesra/?page_id=187.
2 http://www.e-callisto.org/.
Ye, 2018). However, automatic recognition of all types of bursts was never reported in the literature to the best of our knowledge.

In this article, Section 2 describes the observational details of the data used. In Section 3, a novel statistical method to automatically identify the radio bursts is explained. Section 4 describes the performance of the algorithm using the receiver operating characteristics and the analysis of all type III bursts observed in the year 2014. The summary, conclusions, and future work are discussed in Section 5.

2. Observations

The observations of e-CALLISTO spectrometers began in the year 2009. Since then, more than 150 stations were installed around the globe as previously mentioned. Most of the stations use the log-periodic dipole antenna (LPDA) as the primary receiving element (see, for example, Kishore et al., 2014; Sasikumar Raja et al., 2013a). The e-CALLISTO receiver is designed to operate over the bandwidth 45 – 870 MHz. But different e-CALLISTO stations operate over different user selected radio windows based on the local conditions. For this study, we use the data observed at Gauribidanur Observatory, located at longitude 77°27′07″ E, latitude 13°36′12″ N, and ≈ 694 meters above sea level (Ebenezer et al., 2007; Ramesh, 2011; Kishore et al., 2015). At Gauribidanur Observatory, spectral radio observations of the Sun with the e-CALLISTO are carried out everyday from 02:30 to 11:30 UT. The frequency range of operation is 45 – 450 MHz. The observed data, about 400 frequencies per sweep, are stored as FITS files. The time resolution of the instrument is 0.25 s at the rate of 200 channels per spectrum (i.e. 800 pixels/s). The integration time is 1 ms and the radiometric bandwidth is about 300 kHz. The overall dynamic range of the e-CALLISTO is > 50 dB.

Statistically, the number of radio bursts observed during solar maximum is larger (in comparison to solar minimum). Therefore, we select the years 2013 and 2014 (solar maximum of Solar Cycle 24) for this study. The detailed method and results are discussed in the subsequent sections.

3. Method

In order to classify the radio bursts, the basic observed parameters used from the dynamic spectrograms are area, slope, relative intensity, start and end time of the bursts, and the frequency range over which they were observed. We carefully inspect the above parameters to identify the radio bursts. The terrestrial radio frequency interferences (RFI) appear in general as continuous features in the dynamic spectra (for example FM, television, satellite signals, etc.); in some cases they appear as sharp pulses. By contrast, solar radio bursts drift as they propagate from high to low frequencies. We identify and eliminate the RFI making use of this key difference between RFI and radio bursts. The drift rate of the radio bursts can be measured using Equation 1. This is one of the main parameters which we use to identify solar radio bursts from the data. Figure 1 shows the spectrogram observed on 04 January 2013. Panel a shows the observed raw spectrogram (before processing). We calculate the median over time for every frequency channel and the resultant column matrix is subtracted from every column of the raw data corresponding to the spectrogram shown in panel a. After median filtering (background subtraction) most of the continuous local RFI are eliminated (see panel b). We repeat this process for the entire dataset observed in the
Figure 1 Various stages of processing the spectrogram observed at Gauribidanur Observatory on 04 January 2013 are shown. (a) Shows the raw spectrogram, (b) is the spectrogram after the background subtraction, (c) is the binary image of the spectrogram in (b), the region shown in red in (d) indicates the burst identified by the classifier discussed in the article.

year 2013 (Set-P). We find the standard deviation (i.e., \( \sigma \)) of the entire processed Set-P to be 0.6 dB. We select the \( 5\sigma = 3 \) dB as the initial cutoff to identify whether or not there is a solar radio burst present in the frame. To reduce complexity, we convert every processed image to a binary image, i.e., if the signal is greater than 3 dB we assigned the number one, else the number is zero. The binary image is shown in panel c. Using the binary images, contours of the images are traced using the “opencv” python library and the area \( A_c \) and coordinates of the contours are measured. In the e-CALLISTO spectrometers, channels with high RFI are avoided due to practical reasons. Therefore, in the cases where the radio bursts intercept the RFI band, our algorithm underestimates the area. For instance, at Gauribidanur Observatory, the FM band \( \approx 87 – 109 \) MHz was not used and therefore, the measured \( A_c \) was underestimated by a factor \( \approx 22 \times \) duration of the radio burst. However, this factor does not significantly impact our results.

By knowing the coordinates, we calculate the slope \( v_d \), also called f–t range ratio) of the radio bursts using

\[
v_d = \frac{\Delta f}{\Delta t} = \frac{f_2 - f_1}{t_2 - t_1},
\]

where \( f_2 \) and \( f_1 \) are the maximum and minimum frequencies, respectively, \( t_2 \), and \( t_1 \) are the start and end times of the radio burst. As previously described, most of the RFI appears as horizontal and vertical lines. They are successfully eliminated by selecting the \( v_d \) in the range \( 0.81 \text{ MHz s}^{-1} < v_d < 162 \text{ MHz s}^{-1} \).
Figure 2  Variation of the probability ratio ($P_r$) with the ASI. The horizontal and vertical dash-dotted lines denote $P_r = 1.5$ and $ASI \approx 1312 \text{ MHz}^2$. The points in the gray shaded region with $P_r \gtrsim 1.5$ and $ASI \gtrsim 1312 \text{ MHz}^2$ indicate the presence of at least one radio burst in the spectrogram. There are no bursts present in the white region. $P_r = 0$ indicates that there were no images with at least one radio burst present in it for the corresponding ASI value.

We find that $A_c$ and $v_d$ alone are not sufficient to automatically identify the bursts. The area depends on the bandwidth and duration of the observed burst. At the same time, we find that the drift rate can mislead the algorithm for smaller $\Delta f$ and $\Delta t$. Therefore, we define a new parameter called the area slope index (ASI):

$$ASI = A_c \times v_d.$$  \hfill (2)

If the maximum ASI measured for each file is greater than a certain threshold, we conclude that there is at least one solar radio burst present in the image. If the ASI is less than the threshold, we conclude that no significant solar radio burst is present in the image.

In order to decide the ASI threshold, we manually separate the bursts observed in the year 2013 and named them as Set-B. We measure the probability of finding the number of bursts for a given ASI value ($P_B(ASI)$) for Set-B using

$$P_B(ASI) = \frac{N_B(ASI)}{N_{TB}},$$  \hfill (3)

where $N_B(ASI)$ and $N_{TB}$ are the number of bursts for a given ASI and the total number of bursts in Set-B, respectively.

Similarly, using the complete dataset observed in 2013 (Set-U, which includes the data with bursts and without bursts), we define another parameter,

$$P_U(ASI) = \frac{N_U(ASI)}{N_{TU}},$$  \hfill (4)

where $N_U(ASI)$ and $N_{TU}$ are the number of bursts for a given ASI and the total number of bursts in the Set-U, respectively.

The ratio between Equations 3 and 4 (which gives $P_r$, the probability ratio) for different ASI is calculated using

$$P_r(ASI) = \frac{P_B(ASI)}{P_U(ASI)}.$$  \hfill (5)

The probability ratio is then plotted as shown in Figure 2. From Figure 2, we find that $P_r = 1.5$ corresponds to an $ASI \approx 1312 \text{ MHz}^2$. As mentioned in the flowchart (Figure 3), if
Figure 3  The flow chart shows the algorithm to identify whether or not the input file has radio burst emission.

- Start
- Input image
- Subtract the background
- Convert to binary
- Find $A_c$, $v_d$ and compute maximum ASI
- Max. ASI > cutoff?
  - No
    - Output is not a burst
  - Yes
    - Output is a burst
    - Stop

The ASI is greater than the cutoff value of 1312 MHz$^2$, we conclude that the corresponding image has at least one solar radio burst. Otherwise, there is no burst present in the image. We use this method to identify all the solar radio bursts in the years 2013 and 2014. We note here that, for certain ASI values, there might be no images with radio bursts present – hence the value $P_t$ is zero as seen in Figure 2.

Radio emission from the quiet-Sun component remains relatively constant throughout the solar cycle. The slowly varying component varies with the solar cycle, but this is mostly observed at microwave frequencies. Due to sensitivity limitations neither the quiet Sun, nor the slowly varying components of radio emission can be observed using e-CALLISTO. The non-thermal radio bursts are easily observed with the e-CALLISTO, since they are comparatively stronger. Furthermore, although the occurrence rate of solar radio bursts varies with solar cycle, their characteristic properties (i.e. $v_d$, bandwidth, and duration of the radio burst) vary only minimally. Therefore the ASI cutoff (which depends on $v_d$, bandwidth, and
duration of the radio burst) remains unchanged throughout the solar cycle. The performance of the classifier is discussed in Section 4.

4. Results and Discussions

4.1. Performance of the Algorithm

We processed the raw data and identify the radio bursts using the method described in Section 3 and Figure 3. Using the receiver operating characteristics (ROC), we study the performance of the classifier (Fawcett, 2006). Herewith, we summarize the necessary terms for the sake of completeness. If the instance is positive and it is classified as positive then it is termed “true positive”. If the instance is negative and is classified as positive, then it is called “false positive”. By manually counting these parameters in the classified dataset (by the algorithm), we measure the true positive rate (tp rate or recall) using

\[
tp \text{ rate} = \frac{TP}{P},
\]

where TP and P are the positives correctly classified and the total number of positive instances.

We also measured the false positive rate (fp rate or false alarm rate) of the classifier using

\[
fp \text{ rate} = \frac{FP}{N},
\]

where FP and N are negatives incorrectly classified and the total negative number of instances.

By the tp rate and fp rate (see Equations 6 and 7), we calculate the recall and precision using

\[
\text{Recall} = \frac{TP}{P},
\]

\[
\text{Precision} = \frac{TP}{TP + FP}.
\]

Note that a high value of recall and precision indicate a small number of “false negatives” (i.e., where the instance is positive and classified as negative) and false positives, respectively. The calculated values of recall and precision for different ASI cutoffs are tabulated in Table 1. In the year 2013, for the significant ASI (i.e., 1312 MHz), the calculated recall and precision are 95.82% and 50%, respectively. The recall and precision for the dataset observed in 2014 (Set-Q, for the same ASI value) are 95.67% and 61.7%, respectively. The recall and precision for different ASI values are shown in Figure 4. The figure shows that the parameter recall is more or less consistent for both Set-P and Q. However, the precision shows a difference of 12% between Set-P and Q. We find that the improved precision in the year 2014 is due to the reduced RFI and the availability of the dataset.

4.2. Preliminary Analysis of Type III Bursts

We carry out a preliminary analysis of all the type III bursts detected during the year 2014 using the automatic detection method described in this article. We find a total of 238 type
Table 1  Variation of recall and precision of the Set-P and Set-Q for different area slope indices.

| No. | ASI (MHz²) | Set-P Recall | Set-P Precision | Set-Q Recall | Set-Q Precision |
|-----|------------|--------------|----------------|--------------|----------------|
| 1   | 1312       | 95.82        | 50.00          | 95.67        | 61.70          |
| 2   | 1394       | 93.59        | 51.85          | 93.75        | 63.40          |
| 3   | 1476       | 92.76        | 53.45          | 92.55        | 63.90          |
| 4   | 1558       | 92.20        | 55.26          | 90.87        | 66.08          |
| 5   | 1640       | 91.09        | 56.57          | 89.18        | 66.85          |
| 6   | 1722       | 91.09        | 56.97          | 87.74        | 67.72          |
| 7   | 1804       | 90.25        | 57.86          | 86.30        | 68.38          |

Figure 4  The ROC parameters, recall (left panel) and precision (right panel), are shown for different ASI. The red circles and blue triangles indicate the years 2013 (Set-P) and 2014 (Set-Q).

III bursts during our observing period (≈ 02:30 – 11:30 UT). Out of the above, 88 type III bursts were associated with GOES soft X-ray and/or Hα flares.3,4,5,6 Note that we define a type III burst to be flare associated if it occurred during the onset to end phase of the flare. The observational details of type III bursts and associated flares are provided in the Appendix (see Table 2). The remaining 150 type III bursts were not associated with any flare. These 150 bursts were probably due to weak energy releases in the solar atmosphere reported earlier in the literature (for example, Ramesh et al., 2010, 2013; Saint-Hilaire, Vilmer, and Kerdraon, 2013; Sasikumar Raja and Ramesh, 2013b; Mugundhan, Harihara, and Ramesh, 2017; James, Subramanian, and Kontar, 2017; James and Subramanian, 2018; Sharma, Oberoi, and Arjunwadkar, 2018).

3 https://cdaw.gsfc.nasa.gov/CME_list/NOAA/org_events_text/.
4 https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/xrs/goes-xrs-report_2014.txt.
5 http://www.lmsal.com/solarsoft/ssw/last_events-2014/.
6 http://hec.helio-vo.eu/hec/hec_gui.php.
We also find that 75% of the type III bursts in our list were observed below 200 MHz (left panel of Figure 5). An inspection of the source region of the associated flares indicates a pattern. While the flare locations are uniformly distributed between 0° and 90° longitudes for bursts with upper frequency cutoff < 200 MHz, they are limited to 0° – 50° longitudes for bursts with upper frequency cutoff > 200 MHz (see right panel of Figure 5). This seems to indicate that bursts with higher starting frequencies are more directive. A detailed investigation of these results (using more data) will be reported elsewhere.

5. Summary and Conclusions

In this article, we have presented an automated method to detect solar radio bursts. Although this method does not classify the types of radio bursts, it is able to discriminate between dynamic spectra with and without solar radio bursts. Our algorithm can operate with all standard image formats and does not need FITS files. The method is tested on two years of e-CALLISTO data observed at Gauribidanur Observatory. Using this method, we have identified 1182 radio bursts from January 2013 – April 2018. The list of these bursts can be found at http://www.iiserpune.ac.in/~p.subramanian/Bursts.zip. Furthermore, we study all type III bursts observed in the year 2014 and found that 75% of the bursts observed were below 200 MHz. The source region of the associated flares was close to the disk center (i.e. heliographic longitudes 0° - 50°) for bursts with upper frequency cutoff > 200 MHz (Figure 5).

We have defined an area slope index (ASI) and found that the dynamic spectra images with $ASI \gtrsim 1312 \text{ MHz}^2$ have at least one solar radio burst. Using this ASI threshold, the recall for this method is over 95% and the precision is between 50 and 61.7%. The precision and recall for different ASI values are shown in Figure 4. The precision of the method can be improved (at the cost of poor recall by increasing the ASI cutoff) and vice versa. The precision can also be improved by comparing with the observations at other e-CALLISTO stations. One of the drawbacks of this method is that the weak radio bursts whose signal-to-noise ratio (SNR) is < 5$\sigma$ are insensitive to it. Better data (which allow for a lower SNR cutoff) can overcome this drawback.
A successful classifier with good performance can play a crucial role in understanding properties of solar radio bursts like drift rates, spectral indices, and emission mechanisms, which are in turn very useful in solving long-standing solar physics problems associated with coronal heating, propagation of coronal mass ejections, and other problems. For instance, it is well known that some kinds of radio bursts (such as type II and type IV) correlate with geomagnetic storms, auroras, and other space-weather effects.

Accordingly, we plan to develop an automated burst classifier (that can discriminate between different kinds of bursts) in the future. We know that more the number of training datasets, the better the performance of the classifier. However, this is a challenge because of the way the data is processed. Since e-CALLISTO stores one frame every 15 min and since observations are carried out for \( \approx 9 \) hours per day, it produces \( \approx 65,000 \) files in 5 years. Therefore, a 52 station e-CALLISTO network produces \( \approx 3.37 \) million files in 5 years. Each file size is \( \approx 700 \) kB. The file sizes are expected to be much higher for digital back end instrumentation based on field programmable gate arrays (FPGAs) and fast analog-to-digital converters (ADCs) (see, for example, Kumari et al., 2017; Mugundhan et al., 2018); hence, the necessity of a sophisticated algorithm to classify solar radio bursts. We want to remark here that there are other type of short duration (\(< 0.1 \) s) spike bursts (e.g. Tarnstrom and Philip, 1972) with a small area difficult to identify using the reported algorithm. In the future, we will attempt to develop an algorithm which can identify such bursts by cross-comparing the dynamic spectrograms observed by different observatories (which would help in mitigating local RFI). Such an algorithm cannot only identify spike bursts but also improve the efficiency of the scheme reported in this article.

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Appendix

Details of flare associated solar radio type III bursts mentioned in Section 4.2 are listed in Table 2.

Table 2  Flare associated type III bursts observed using Gauribidanur e-CALLISTO during 2014.

| No. | Date     | Type III bursts | Start time (UT) | Frequency (MHz) | Flares |
|-----|----------|----------------|----------------|----------------|--------|
|     |          |                | Start | Stop | Time (UT) | Class | Active region | Location |
| 1   | 20140101 | 7:25:14        | 47    | 143  | 07:21 | 07:29 | C | 11940 | S12W47 |
| 2   | 20140126 | 8:28:44        | 45    | 219  | 08:26 | 09:33 | C | 11967 | S14E85 |
| No. | Date       | Type III bursts | Flares |
|-----|------------|-----------------|--------|
|     |            | Start time (UT) | Frequency (MHz) | Time (UT) | Class | Active region | Location |
|     |            | Start | Stop | Onset | End | |
| 3   | 20140126   | 10:07:31 | 171  | 10:05 | 10:19 | C       | 11960   | S15W24  |
| 4   | 20140129   | 4:16:44  | 157  | 04:06 | 04:42 | C       | 11967   | S12E65  |
| 5   | 20140129   | 6:54:50  | 161  | 06:53 | 07:34 | C       | 11967   | S12E65  |
| 6   | 20140129   | 7:00:25  | 98   | 06:53 | 07:34 | C       | 11967   | S12E65  |
| 7   | 20140129   | 7:28:47  | 168  | 06:53 | 07:34 | C       | 11967   | S12E65  |
| 8   | 20140130   | 7:53:54  | 127  | 07:54 | 08:41 | M       | 11967   | S12E52  |
| 9   | 20140131   | 5:32:56  | 168  | 04:46 | 05:17 | C       | 11967   | S14E37  |
| 10  | 20140210   | 5:03:01  | 177  | 05:04 | 05:23 | C       | 11974   | S12E30  |
| 11  | 20140215   | 8:24:09  | 148  | 08:25 | 08:39 | C       | 11974   | S13W38  |
| 12  | 20140303   | 7:22:29  | 135  | 07:10 | 07:19 | C       | 11989   | N07W31  |
| 13  | 20140415   | 7:06:00  | 315  | 07:04 | 07:11 | C       | 12035   | S15E27  |
| 14  | 20140415   | 9:16:07  | 284  | 09:15 | 09:25 | C       | 12035   | S14E25  |
| 15  | 20140416   | 3:20:38  | 106  | 03:03 | 03:16 | C       | 12035   | S15E16  |
| 16  | 20140416   | 4:15:03  | 163  | 04:11 | 04:14 | C       | 12042   | N19E79  |
| 17  | 20140416   | 5:01:50  | 181  | 04:57 | 05:14 | C       | 12035   | S15E14  |
| 18  | 20140416   | 5:15:00  | 242  | 04:57 | 05:14 | C       | 12035   | S15E14  |
| 19  | 20140416   | 5:34:13  | 111  | 05:21 | 05:38 | C       | 12042   | N19E78  |
| 20  | 20140416   | 6:37:11  | 358  | 06:37 | 06:48 | C       | 12035   | S17E13  |
| 21  | 20140416   | 6:44:04  | 312  | 06:37 | 06:48 | C       | 12035   | S17E13  |
| 22  | 20140416   | 7:16:59  | 253  | 07:17 | 07:26 | C       | 12034   | N03W01  |
| 23  | 20140416   | 8:19:42  | 152  | 08:12 | 08:20 | C       | 12034   | N03W01  |
| 24  | 20140416   | 8:48:38  | 166  | 08:36 | 08:51 | C       | 12035   | N19E75  |
| 25  | 20140419   | 9:18:44  | 105  | 09:17 | 09:22 | C       | 2032    | N12W76  |
| 26  | 20140419   | 9:25:00  | 254  | 09:24 | 09:29 | C       | 2036    | S15W42  |
| 27  | 20140501   | 4:06:00  | 180  | 03:58 | 04:04 | B       | 12048   | N19W78  |
| 28  | 20140506   | 8:49:46  | 104  | 08:41 | 09:21 | M       | 12051   | S15W84  |
| 29  | 20140604   | 7:20:52  | 105  | 07:07 | 07:16 | B       | 12080   | S11E51  |
| 30  | 20140611   | 4:40:50  | 103  | 04:39 | 04:56 | C       | 12087   | S12E71  |
| 31  | 20140611   | 5:31:15  | 152  | 05:30 | 05:36 | M       | 12080   | S12W35  |
| 32  | 20140611   | 7:07:46  | 140  | 07:09 | 07:15 | C       | 12080   | S12W36  |
| 33  | 20140611   | 8:58:06  | 104  | 08:59 | 09:10 | X       | 12087   | S18E65  |
| 34  | 20140613   | 7:44:00  | 105  | 07:49 | 07:59 | M       | 12089   | N18W01  |
| 35  | 20140613   | 7:50:30  | 108  | 07:49 | 07:59 | M       | 12089   | N18W01  |
| 36  | 20140613   | 9:14:28  | 236  | 09:14 | 09:20 | C       | 12087   | S17E41  |
| 37  | 20140613   | 9:16:20  | 180  | 09:14 | 09:20 | C       | 12087   | S18E39  |
| 38  | 20140617   | 6:29:04  | 183  | 06:29 | 06:31 | B       | 12087   | S20W07  |
| 39  | 20140617   | 7:38:40  | 154  | 07:36 | 07:46 | B       | 12085   | S23W65  |
| 40  | 20140617   | 8:22:55  | 103  | 08:13 | 08:49 | C       | 12093   | S11E61  |
| 41  | 20140617   | 10:07:01 | 169  | 09:59 | 10:05 | B       | 12085   | S22W68  |
| No.  | Date          | Type III bursts | Flares                  |
|------|---------------|-----------------|-------------------------|
|      |               | Start time (UT) | Frequency (MHz) Time (UT) | Class | Active region | Location |
|      |               | Start Stop      | Start Stop Stop Onset End |       |              |          |
| 42   | 20140625      | 7:57:44         | 45 101                  | 07:53 08:26 | B  | 12096 | N09E42 |
| 43   | 20140628      | 7:35:57         | 45 173                  | 07:36 07:49 | C  | 12104 | S12E89 |
| 44   | 20140630      | 6:51:43         | 45 100                  | 06:52 07:10 | C  | 12100 | N09E20 |
| 45   | 20140630      | 7:04:16         | 45 104                  | 06:52 07:10 | C  | 12100 | N09E20 |
| 46   | 20140702      | 6:56:33         | 53 100                  | 06:41 06:49 | C  | 12106 | N15E45 |
| 47   | 20140702      | 7:39:07         | 53 153                  | 07:34 07:38 | C  | 12108 | S08E64 |
| 48   | 20140702      | 10:50:03        | 53 152                  | 10:26 10:58 | C  | 12102 | N15E28 |
| 49   | 20140708      | 2:31:09         | 54 98                   | 02:31 02:36 | C  | 12114 | S19E88 |
| 50   | 20140708      | 5:30:00         | 45 100                  | 05:31 05:39 | C  | 12113 | N09E60 |
| 51   | 20140709      | 4:37:42         | 51 176                  | 04:37 04:39 | C  | 12114 | S12E61 |
| 52   | 20140709      | 6:17:00         | 45 107                  | 05:29 06:12 | C  | 12113 | N11E48 |
| 53   | 20140723      | 7:28:02         | 45 228                  | 07:28 07:51 | B  | 12121 | N07E69 |
| 54   | 20140724      | 9:24:06         | 45 192                  | 09:10 09:17 | B  | 12121 | N08E56 |
| 55   | 20140725      | 6:58:50         | 45 280                  | 06:57 07:07 | C  | 12121 | N11E35 |
| 56   | 20140731      | 4:39:22         | 45 156                  | 04:39 05:09 | B  | 12127 | S05E30 |
| 57   | 20140810      | 6:41:42         | 45 138                  | 06:44 06:52 | B  | 12137 | S18W10 |
| 58   | 20140811      | 6:16:52         | 45 104                  | 06:21 06:27 | B  | 12137 | S17W24 |
| 59   | 20140811      | 10:07:26        | 45 208                  | 10:09 10:12 | B  | 12137 | S19W26 |
| 60   | 20140905      | 6:50:42         | 45 174                  | 06:16 07:18 | C  | 12152 | S13W45 |
| 61   | 20141003      | 3:04:36         | 45 179                  | 02:57 03:15 | C  | 12173 | S13W85 |
| 62   | 20141009      | 7:43:13         | 45 111                  | 07:35 07:51 | C  | 12182 | S18W46 |
| 63   | 20141011      | 4:12:09         | 45 104                  | 03:26 04:25 | B  | 12187 | S13E88 |
| 64   | 20141018      | 6:50:00         | 45 176                  | 06:43 06:48 | C  | 12192 | S13E72 |
| 65   | 20141021      | 4:05:18         | 45 177                  | 04:03 04:07 | B  | 12192 | S09E30 |
| 66   | 20141021      | 8:08:16         | 45 243                  | 08:08 08:12 | C  | 12192 | S09E31 |
| 67   | 20141024      | 3:55:45         | 45 107                  | 03:56 04:02 | C  | 12192 | S22W00 |
| 68   | 20141027      | 7:25:58         | 45 106                  | 07:11 07:20 | C  | 12192 | S18W48 |
| 69   | 20141031      | 9:21:06         | 45 280                  | 09:19 09:27 | C  | 12201 | S02E59 |
| 70   | 20141101      | 10:22:45        | 45 220                  | 10:20 10:30 | C  | 12201 | S05E47 |
| 71   | 20141102      | 3:06:28         | 45 184                  | 03:05 03:11 | B  | 12201 | S05E36 |
| 72   | 20141102      | 5:53:36         | 45 228                  | 05:41 05:50 | B  | 12201 | S05E34 |
| 73   | 20141103      | 3:47:59         | 45 360                  | 03:47 03:56 | C  | 12201 | S03E21 |
| 74   | 20141103      | 4:48:34         | 45 330                  | 04:50 04:56 | C  | 12201 | S03E18 |
| 75   | 20141103      | 7:04:00         | 45 253                  | 07:06 07:09 | B  | 12201 | S03E17 |
| 76   | 20141104      | 5:25:25         | 45 111                  | 05:19 05:40 | C  | 12205 | N16E84 |
| 77   | 20141108      | 4:54:31         | 45 108                  | 05:02 05:10 | C  | 12207 | S12E88 |
| 78   | 20141130      | 5:17:48         | 45 251                  | 04:52 05:38 | C  | 12222 | S18E31 |
| 79   | 20141130      | 8:42:58         | 45 404                  | 07:58 09:15 | B  | 12222 | S18E29 |
| 80   | 20141201      | 5:12:59         | 45 180                  | 05:11 05:22 | C  | 12217 | S16W25 |
Table 2 (Continued.)

| No. | Date         | Type III bursts | Flares | Location |
|-----|--------------|-----------------|--------|----------|
|     |              | Start time      | Frequency (MHz) | Time (UT) | Class | Active region |
|     |              | (Start)         | (Stop) | Onset | End |     |          |
| (1) | (2)          | (3)             | (4)    | (5)   | (6) | (7) | (8) | (9) | (10) |
| 81  | 20141203     | 2:33:05         | 45     | 186   | 02:30 | 02:37 | C   | 12217 | S16W54 |
| 82  | 20141214     | 4:26:57         | 45     | 156   | 04:17 | 04:41 | C   | 12241 | S11E74 |
| 83  | 20141214     | 4:30:29         | 45     | 107   | 04:17 | 04:41 | C   | 12241 | S11E74 |
| 84  | 20141214     | 6:17:18         | 45     | 97    | 06:19 | 06:24 | C   | 12227 | S02W79 |
| 85  | 20141214     | 6:21:12         | 45     | 166   | 06:19 | 06:24 | C   | 12227 | S02W79 |
| 86  | 20141214     | 8:02:41         | 45     | 97    | 08:04 | 08:12 | C   | 12237 | S02E51 |
| 87  | 20141214     | 8:25:05         | 45     | 187   | 08:25 | 08:37 | C   | 12237 | S18E49 |
| 88  | 20141226     | 5:31:00         | 45     | 186   | 05:18 | 05:36 | C   | 12249 | S12W37 |

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