A Statistical Study of Low-Frequency Solar Radio Type III Bursts

Aroori Mahender1 · K. Sasikumar Raja2 · R. Ramesh2 · Vemareddy Panditi2 · Christian Monstein3 · Yellaiah Ganji1

Received: 12 July 2020 / Accepted: 16 October 2020 / Published online: 9 November 2020
© Springer Nature B.V. 2020

Abstract We have studied low-frequency (45 – 410 MHz) type III solar radio bursts observed using the e-Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (e-CALLISTO) spectrometer located at Gauribidanur Radio Observatory, India, during 2013 – 2017. After inspecting 1531 type III bursts we found that 426 bursts were associated with flares, while the others might have been triggered by small scale features/weak energy events present in the solar corona. In this study, we have carried out a statistical analysis of various observational parameters like start time, lower- and upper-frequency cut-offs of type III bursts and their association with flares, variation of such parameters with flare parameters such as location, class, onset, and peak times. From this study, we found that most of the high frequency bursts (whose upper-frequency cut-off is > 350 MHz) originate from western longitudes. We interpret that this could be due to the fact that Parker spirals from these longitudes are directed towards the Earth and high frequency bursts are more directive. Further we report that the number of bursts that reach Earth from western longitudes is higher than from eastern longitudes.

✉ A. Mahender
mahenderastro@gmail.com
K. Sasikumar Raja
sasikumar.raja@iiap.res.in
R. Ramesh
ramesh@iiap.res.in
V. Panditi
vemareddy@iiap.res.in
C. Monstein
monstein@irsol.ch
Y. Ganji
gyh042000@yahoo.co.in

1 Department of Astronomy, Osmania University, Hyderabad, Telangana, 500 007, India
2 Indian Institute of Astrophysics, 2nd Block, Koramangala, Bangalore 560 034, India
3 Istituto Ricerche Solari Locarno (IRSOL), Via Patocchi - Prato Pernice, 6605 Locarno Monti, Switzerland
Keywords Corona, radio emission · Radio bursts, association with flares · Radio bursts, type III · Radio emission, active regions

1. Introduction

Among the various types of solar radio bursts classified by Wild (1950), type III bursts are the most intense, fast drifting and frequently observed ones. These bursts are observed ranging from the inner corona to 1 AU and sometimes even beyond. Type III bursts occur as isolated bursts (lasting from 1 to 3 s), groups that last 10 minutes, and as a storm lasting from 10 mins to a few tens of hours. Although their emission mechanism is still debated, their occurrence happens in two steps: (i) during a flare or magnetic reconnection event, where a huge amount of magnetic energy turns into kinetic energy that results in the acceleration of particles. Such particles generate plasma oscillations (also known as Langmuir waves) during their passage along open magnetic field lines in the solar corona and interplanetary medium (IPM), (ii) subsequent conversion of these oscillations into electromagnetic waves at the plasma frequency \( f_p \) called fundamental (F) and harmonic (H) at \( 2f_p \) (see for example Ginzburg and Zhelezniakov, 1958; Zheleznyakov and Zaitsev, 1970; Melrose, 1980; Ramesh et al., 2003, 2005; Reid and Ratcliffe, 2014; Kishore et al., 2015, 2017). The measured average frequency ratio of harmonic emission to fundamental emission is 1.8 (Stewart, 1974). It was also reported that F emissions are more directive than H emissions (Suzuki and Sheridan, 1982; Sasikumar Raja and Ramesh, 2013). The electron density \( (N_e) \) and hence plasma frequency \( (f_p \propto \sqrt{N_e}) \) decrease as we move radially outwards in the solar corona. Therefore, low-frequency observations correspond to outer layers in the corona and vice versa and hence, type III bursts always drift from high to low frequencies.

In this article, we have carried out a statistical study of 1531 type III bursts observed during 2013 – 2017. For this purpose, we have used data obtained with the Compact Astronomical Low-frequency Low-cost Instrument for Spectroscopy in Transportable Observatory (CALLISTO) spectrometer\(^1\) (Benz et al., 2009; Monstein, Ramesh, and Kathiravan, 2007; Zucca et al., 2012; Sasikumar Raja et al., 2018) located at Gauribidanur Radio Observatory (GRO; lat.: 13°36′12″ N and long.: 77°27′07″ E), which is 100 km north of Bangalore, India (Ramesh, 2011, 2014). An extensive statistical study of type III bursts has not been done so far because of the lack of data sets and due to the non-existence of the automated detection algorithms. In this work, we have made use of the catalog provided by Singh et al. (2019) that was produced using an automated algorithm. Earlier studies of type III bursts have been done by Saint-Hilaire, Vilmer, and Kerdraon (2013) using observations carried out with the Nançay Radioheliograph (Kerdraon and Delouis, 1997).

2. Observations

In this study, we have used data observed by the CALLISTO spectrometer that is located at Gauribidanur Radio Observatory (GRO). A single log-periodic dipole antenna that operates over 30 – 1100 MHz (voltage standing wave ratio, VSWR \( \leq 2 \)) with a gain of \( \approx 8 \) dB was used as a primary receiving element, which is then fed to an amplifier of 45 dB at the base of the antenna. The signal brought to the receiver room which is about 100 meters away using a coaxial cable and then connected to the receiver developed at ETH Zurich, Switzerland.

\(^1\)http://www.e-callisto.org/.
Figure 1 Dynamic spectra of type III burst observed on 7 September 2017 by CALLISTO spectrometer located at GRO. The median of every frequency channel is subtracted. The arrows refer to the start and end times (in UT) and lower and upper frequencies (in MHz) measured manually in this study. Note that at 88 – 108 MHz and around 170 MHz, band-stop filters have been used to avoid RFI from FM and TV stations.

Although the receiver can operate from 45 – 870 MHz, the CALLISTO spectrometer at GRO is configured to operate between 45 – 410 MHz in order to increase the frequency resolution, which is 62.5 kHz while radiometric bandwidth is ≈ 300 kHz. The CALLISTO spectrometer was set up in 2009 and since then it has been used to monitor transient emissions from the solar corona between 02:30 – 11:30 UT. The time resolution of the instrument is 0.25 s at a rate of 200 channels per spectrum. Note that the time difference between two consecutive spectral pixels is 1.25 ms (Benz et al., 2009; Monstein, Ramesh, and Kathiravan, 2007; Singh et al., 2019).

We have also used the catalog of type III bursts identified using an automated algorithm by Singh et al. (2019) during 2013 – 2017 (http://www.iiserpune.ac.in/~p.subramanian/Bursts.zip). For example, Figure 1 shows the dynamic spectrogram that was observed on 7 September 2017 using the CALLISTO spectrometer located at GRO. Note that the median of every frequency channel measured over a whole day was subtracted from the corresponding channel to avoid continuous radio frequency interference (RFI). While preparing the catalog, in order to mitigate type III burst-like RFIs, Singh et al. (2019) have eliminated the features and RFIs with drifting rates \( v_d = \frac{\Delta f}{\Delta t} \), where \( \Delta f \) and \( \Delta t \) are bandwidth and duration of the burst/feature in the dynamic spectrogram) that do not fall in the range 0.81 MHz s\(^{-1}\) < \( v_d \) < 162 MHz s\(^{-1}\). This filtering technique successfully eliminates the type III burst-like RFI without eliminating the type III bursts. In addition, we have measured the start and end times of the type III burst shown in Figure 1 which are 9:52:58 and 9:54:28 UT and the lower- and upper-frequency cutoffs which are 45 to > 410 MHz. Similarly, we have identified 1531 type III bursts and measured these parameters manually. Furthermore, we have studied the flare associated type III bursts by knowing the flare parameters like onset, peak and end times, class, associated active region, and location.\(^2\)\(^3\)\(^4\)\(^5\) For

\(^2\)https://cdaw.gsfc.nasa.gov/CME_list/NOAA/org_events_text/.
\(^3\)https://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/xrs/.
\(^4\)http://www.lmsal.com/solarsoft/ssw/last_events-2014/.
\(^5\)http://hec.helio-vo.eu/hec/hec_gui.php.
instance the type III burst shown in Figure 1 was triggered by an M1.4 class flare observed by the Geostationary Operational Environmental Satellites (GOES) as seen in Figure 2. The onset and end times of the flare were 09:49 and 09:58 UT with peak emission at 09:54 UT. Figure 3, left panel shows the observations of the Atmospheric Imaging Assembly (AIA: Lemen et al., 2012) on board the Solar Dynamics Observatory (SDO: Pesnell, Thompson, and Chamberlin, 2012) at 171 Å wavelength band and the right panel shows the observations of the Helioseismic and Magnetic Imager (HMI: Schou et al., 2012) on board SDO. The red colored boxes in both panels indicate the active region NOAA 12673 that triggered the type III burst (see Figure 1) and the flare (see Figure 2). The location of the flare was S07°W46° (see Figure 3).

Among the studied 1531 type III bursts we found that 426 of them were flare associated. By knowing the class and location of the flare, we have studied the way these parameters affect the lower- and upper-frequency cut-off of type III bursts.
3. Results and Discussions

After a careful manual inspection of the catalog of type III bursts listed at http://www.iiserpune.ac.in/~p.subramanian/Bursts.zip, we have identified 1531 intense and well separated type III bursts observed in the frequency range 45–410 MHz during 2013–2017. We have found that among them only 426 (28%) bursts are associated with the flares. The remaining 1105 type III bursts (72%) presumably originated due to small scale features present in the solar corona and they are signatures of weak energy releases reported earlier in the literature (Ramesh et al., 2010, 2013; James, Subramanian, and Kontar, 2017; James and Subramanian, 2018; Sharma, Oberoi, and Arjunwadkar, 2018; Mugundhan et al., 2016, 2018; Singh et al., 2019).

We have then identified the type III bursts that were actually observed during the onset–end times of the flares. Assuming that such bursts are associated with flaring processes, we have identified the flare class, location, and onset and end times; we have studied the way these parameters vary with the lower and upper frequency cut-offs of type III bursts. Firstly, we have plotted the heliographic longitudes and latitudes of the flares associated with the type III bursts as shown in Figure 4. We have found that most of them originated close to the equator (i.e. heliographic latitudes $\pm 23^\circ$) except for the three cases that occurred near the polar cap of the southern hemisphere.

Figure 5 shows the variation of the lower and upper frequency of type III bursts with heliographic longitude and latitude of the associated flares. Panel a shows the way the upper frequency of the bursts vary with the heliographic longitude of flares. Red and blue colors indicate the eastern and western heliographic longitudes. It is clearly seen that type III bursts with larger upper-frequency cut-off originate from western longitudes. We interpret this to be due to the following facts: (i) the Parker spirals from the western longitudes are directed towards the Earth, (ii) type III bursts have directivity, and (iii) they are more directive at high frequencies than at low ones. Panel b shows the variation of lower frequency cut-off with heliographic longitudes. It does not show any trend because of instrumental limitation (i.e. we cannot observe below 45 MHz). Panels c and d show the variation of upper and lower frequencies with heliographic latitudes, respectively, additionally they show that most of the flare associated type III bursts originate in the heliographic latitude range of $\pm 23^\circ$. This study also indicates that a few bursts are observed coming from southern polar cap regions. The red and blue color regions in panel c and d indicate the southern and northern latitudes, respectively.

We have studied the relationship between onset, peak, and end times of the flare and start time of the type III bursts. Figure 6, left panel, shows the burst start time minus the flare
Figure 5  Relationship between the upper and lower frequency of type III bursts with the heliographic longitude and latitude. Panel a shows the variation of the upper-frequency cut-off of radio bursts with the heliographic longitude and panel b shows the variation of the lower frequency cut-off with the heliographic longitude. Similarly, panel c shows the variation of the upper-frequency cut-off with heliographic latitude and panel d shows the variation of the lower frequency cut-off of type III bursts with heliographic latitude.

Figure 6  In the left panel the time difference between the start time of the burst and the flare onset time vs. the number of bursts is shown. In the right panel the time difference between the burst start time and the flare peak time vs. the number of bursts is shown.

onset time vs. number of bursts. It is evident that most of the bursts in this sample originate within 30 mins after the flare onset. The right panel shows the burst time minus the peak time of the flare vs. the number of bursts. It is evident from the plot that most of the type III bursts occurred close to the peak of the flare (approximately ±10 mins).

Figure 7, panel a shows the upper-frequency cut-off of radio bursts vs. the number of observed radio bursts. The blue and red color bars in panel a indicate the total number of bursts and flare associated bursts, respectively. It is evident from the plot that the total number of both bursts and both flare associated bursts when plotted against the frequency cut-off show
Figure 7  Relationship between the parameters derived using radio dynamic spectrograms, light-curves from the GOES X-ray profiles, and various instruments on board SDO. Panel (a) shows upper-frequency cut-off of radio bursts vs. number of bursts. Blue and red colors indicate the total number of bursts and flare associated bursts, respectively. Panel (b) shows the total number of bursts and flare associated type III bursts observed in different years. The green markers indicate the yearly averaged sunspot number. Panel (c) shows the total number of bursts observed in different heliographic longitudes. Blue and red colors indicate the eastern and western heliographic longitudes and panel (d) shows the flare class vs. the number of bursts. a power law. Panel b shows the total number of bursts (in blue) and flare associated bursts (in red) observed in different years. We found that the total number of bursts observed in different years weakly correlates with the yearly averaged sunspot number (green curve). Note that we have used the sunspot number\(^6\) provided by Clette et al. (2016). Panel c shows the variation of the number of flare associated type III bursts with the heliographic longitude. The blue and red histograms indicate the eastern and western longitudes, respectively. From this plot it is evident that the total number of flare associated bursts in the western longitudes is higher than that in the eastern one. As previously mentioned this could be due to the fact that type III bursts possess directivity and also Parker spirals originating in the western longitudes are directed towards the Earth. In the eastern longitudes it is possible that an equal number of bursts exist when compared to western longitudes; however, because of their directivity we could not observe part of them from the Earth. Panel d shows the flare class based on GOES X-ray flux vs. the number of flare associated bursts. In this study, out of 426 flare associated bursts, we have found that 239 (56%) are due to C-class flares, 136 (32%) are due to B-class ones, 136 (32%) are due to M-class flares, and one burst is due to an X-class one. We did not observe any A-class flare associated burst, presumably because the sensitivity of CALLISTO spectrometer is not sufficient. From the plot, it can be noticed that most of the type III bursts are triggered by C-class flares.

\(^6\)http://www.sidc.be/silso/datafiles.
4. Summary and Conclusions

We have studied 1531 type III bursts observed in the frequency range 45 – 410 MHz during 2013 – 2017. The observations were carried out using CALLISTO spectrometer located at the Gauribidanur Radio Observatory, India. We have performed a statistical study of the way the upper and lower frequency cut-offs vary with the onset, peak, and end times of flare associated type III bursts, the flare class, and location of the active region. Conclusions drawn from this study are given below:

i) Only 28 % of bursts are flare associated while the remaining ones may have originated from weak energy release events (like jets) present in the solar corona.

ii) Most of type III bursts in this sample are triggered by C-class flares.

iii) Most of the flare associated type III bursts originate from active regions with heliographic latitudes between ±23°. Note that this work was carried out during 2013 – 2017 (i.e. during Solar Cycle 24); it will be interesting to perform similar studies at different phases of the solar cycle and magnetic polarities.

iv) Bursts whose upper frequency is higher than 350 MHz originate from western longitudes. We interpret this to possibly be due to the fact that Parker spirals from western longitudes are directed towards the Earth and type III bursts have directivity. Also this work corroborates that high frequency type III bursts are more directive than low-frequency ones (Singh et al., 2019).

v) Most of type III bursts occurred within 30 minutes of the onset of the flare.

vi) It was observed that the most of type III bursts occurred during the peak time of the flare (within ±10 mins).

viii) The total number of bursts and flare associated bursts show a power law when plotted against the upper-frequency cut-off of the type III bursts.

ix) This study infers that the number of bursts observed from the western longitudes is larger than that from the eastern longitudes. Presumably, some of the bursts originating in the eastern longitudes do not reach Earth because of their high directivity.

Acknowledgements The sunspot number used in this article is credited to WDC-SILSO, Royal Observatory of Belgium, Brussels. This research used version 2.0.1 of the SunPy open source software package (The SunPy Community et al., 2020). We thank the data centre of the e-Callisto network which is hosted by the FHNW, Institute for Data Science, Switzerland. We thank the referee for his constructive suggestions on the manuscript.

Disclosure of Potential Conflicts of Interest The authors declare that there are no conflicts of interest.

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Benz, A.O., Monstein, C., Meyer, H., Manoharan, P.K., Ramesh, R., Altyntsev, A., Lara, A., Paez, J., Cho, K.-S.: 2009, A world-wide net of solar radio spectrometers: e-CALLISTO. Earth Moon Planets 104(1–4), 277. DOI. ADS.

Clette, F., Lefèvre, L., Cagnotti, M., Cortesi, S., Bulling, A.: 2016, The revised Brussels-Locarno sunspot number (1981 – 2015). Solar Phys. 291(9 – 10), 2733. DOI. ADS.

Ginzburg, V.L., Zhelezniakov, V.V.: 1958, On the possible mechanisms of sporadic solar radio emission (radiation in an isotropic plasma). Soviet Astron. 2, 653. ADS.
Suzuki, S., Sheridan, K.V.: 1982, On the fundamental and harmonic components of low-frequency Type III solar radio bursts. Proc. Astron. Soc. Aust. 4, 382. DOI. ADS.

The SunPy Community, Barnes, W.T., Bobra, M.G., Christe, S.D., Freij, N., Hayes, L.A., Ireland, J., Mumford, S., Perez-Suarez, D., Ryan, D.F., Shih, A.Y., Chanda, P., Glogowski, K., Hewett, R., Hughitt, V.K., Hill, A., Hiware, K., Inglis, A., Kirk, M.S.F., Konge, S., Mason, J.P., Maloney, S.A., Murray, S.A., Panda, A., Park, J., Pereira, T.M.D., Reardon, K., Savage, S., Sipőcz, B.M., Stansby, D., Jain, Y., Taylor, G., Yadav, T., Rajul, Dang, T.K.: 2020, The SunPy project: Open source development and status of the version 1.0 core package. Astrophys. J. 890, 68. DOI.

Wild, J.P.: 1950, Observations of the spectrum of high-intensity solar radiation at metre wavelengths. III. Isolated bursts. Aust. J. Sci. Res., Ser. A 3, 541. DOI. ADS.

Zheleznyakov, V.V., Zaitsev, V.V.: 1970, Contribution to the theory of type III solar radio bursts. I. Soviet Astron. 14, 47. ADS.

Zucca, P., Carley, E.P., McCauley, J., Gallagher, P.T., Monstein, C., McAteer, R.T.J.: 2012, Observations of low frequency solar radio bursts from the Rosse Solar-Terrestrial Observatory. Solar Phys. 280(2), 591. DOI. ADS.