Title: **Space Weather Study through Analysis of Solar Radio Bursts detected by a Single Station CALLISTO Spectrometer.**

Answers to the referee #1 comments

Firstly, we thank the referee for providing useful comments on our manuscript. Following the referee's comments, we have carefully gone through the manuscript and revised it. **For the sake of convenience, the newly added text in the manuscript is highlighted in boldface**. Herewith, we provide the answers and/or explanations to the referee's comments:

Comment #1

The paper is a summary of results of solar radio bursts analysis observed by the e-Compound Astronomical Low cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (e-CALLISTO), comprising the period Oct 2014 – Sept 2015, at the University of Rwanda, College of Education. Main motivation of this study is to use radio burst data to check their correlation with solar activities.

Response

We thank the referee for his/her suggestion. The objective is reformulated.

Comment #2

In Chapter 1 – "Introduction" a (too) short overview is presented on the morphologies of the various types of solar radio bursts, indicating the registration of 5 Type II bursts, 175 Type III bursts, and 22 Type IV bursts within the given period of observation. The data base of Type II and Type IV bursts is rather scarce, apparently owed to the limited sensitivity of the used antennas. At this point a more detailed description of the applied instruments (antennas and backend facilities) is strongly recommended.

Response

The introduction has been revised. The review of various types of solar radio bursts is limited and is beyond the scope of the current article. We have provided references for detailed literature and the introduction is as follows:

'*About eight decades ago, solar radio bursts (SRBs) were classified into five types based on their morphologies and drift rates (Wild, 1950). From the meter to decimeter range, characteristic burst signatures correspond to well-identified physical processes, such as shock waves (type II bursts, Nelson and Melrose (1985); Cairns et al. (2003); Ganse et al. (2012)), electron beams streaming along open magnetic field lines (type III bursts, Lin et al. (1981, 1986)), or electron populations trapped in eruptive flux ropes and post-flare loops (type IV bursts, Nindos et al. (2008)). Type II radio bursts are the bright radio emissions often associated with CMEs and characterized by a slow frequency drift rate (≤ -1 M Hz s -1) (McLean and Labrum, 1985; Nelson and Melrose, 1985). They are excited by magneto-hydrodynamics (MHD) shocks in the solar atmosphere (Nelson and Melrose, 1985; Cliver et al., 1999; Nindos et al., 2008, 2011; Vršnak and Cliver, 2008). MHD shocks are driven by both flares and CMEs in the solar atmosphere (Nindos et al., 2008). The type II radio emissions are generated at the fundamental and second harmonic of the local plasma frequency. The type III radio bursts are the intense, frequently observed, and fast drifting bursts from high to low frequencies in the dynamic spectra. These bursts usually come from active regions (Saint-Hilaire et al., 2013) and they are generated when solar flares send electron beams streaming into the heliosphere via plasma mechanism (Ginzburg and Zhelezniakov, 1958). Type III radio bursts typically appear as isolated bursts that last in 1–3 s, in groups that last in 10 minutes and as storms that last a few hours. The impulsive flares in X-ray and/or H α frequencies exhibit type III radio bursts at their ascending phases (Cane and Reames, 1988). The most detailed and most recent analysis of type III burst properties with their interpretations is given in the article by Reid and Ratcliffe (2014) and more generally on solar radio emission (e.g, Dulk (1985); McLean and Labrum (1985); Bastian (1990); Pick and Vilmer (2008); Gary et al. (2018)).*

On the other hand, type IV bursts are often accompanied by long-duration events observed at EUV or soft X-ray wavelengths and coronal mass ejections (CMEs). Type IV radio bursts are broadband continuum emissions at decimetric and metric wavelengths often associated with CMEs (Pick, 1986). These bursts can have either stationary or moving sources and various emission mechanisms (Bastian et al., 1998). Stationary type IV radio bursts (hereinafter referred to as type IVs) since their discovery, originate from plasma emission (Weiss, 1963; Benz and Tarnstrom, 1976; Salas-Matamoros and Klein, 2020). Type IVs prevail over the presence of non-thermal electrons in the solar corona for several hours in relationship with flare and the liftoff of a CME.'

The standard situation is that type III radio bursts are more intense and frequent emission from the Sun than type II and type IV bursts. The number of events reported herein has no relationship with brief introduction given. For example in Ndacyayisenga et al., 2021, we reported a total of 12971 type III radio bursts from Space Weather Prediction Centre (SWPC) occurred between 2010 and 2017, while in the same range, only 426 type II radio bursts have occurred.

***Regarding the instrument**: CALLISTO instrument was designed in the framework of IHY2007 and the idea of providing a cheap instrument to support developing countries in solar radio astronomy. Total cost for such a telescope was decided to be in the order of US2000$ which every interested institute can afford. This financial constraint was only possible by selecting a cheap antenna (LPDA) with main beam gain of ~6 dB and a low cost frequency agile spectrometer as a back-end. Any high sensitive digital back-end with similar frequency range would cost in the order of 100 times more than a CALLISTO spectrometer. Given this low antenna gain, selected frequency range 45 MHz - 80 MHz, low noise amplifier with ~2 dB noise figure, 300 KHz radiometric spectrometer bandwidth and 1 ms integration leads to a system sensitivity during transit of the Sun in the order of 22 sfu to 66 sfu. Thus, such a low cost system can never see weak bursts, it can only detect strong bursts during Sun transit +/- 3 hours. A CALLISTO based radio telescope can never detect quiet Sun unless the antenna (LPDA) is replaced by a parabolic dish in the order of at least 5m diameter and an appropriate tracking system. Nevertheless a CALLISTO system allows one to step into solar radio astronomy and study dynamic radio spectra.*

Comment #3

Among the mentioned spaceborne and ground-based radio observatories (lines 34 – 39) reference should be given to renowned radio telescopes of Nancay (France) and Charkiv and Poltava (Ukraine), resp., which provide with their huge arrays excellent observations in the decameter range.

Response

We thank the referee for the suggestion. The recommended instruments have been added to the appropriate lists.

Comment #4

In Chapter 2 – ”Observation and methods'' a comparison and supplementary investigation of the e-CALLISTO results with observations of other stations would enable a better classification and judgement of the quality of the e-CALLISTO results obtained at the College of Education, University of Rwanda. Among other stations the use of the world-wide distributed e-CALLISTO network just offers this opportunity.

Response

The aim of the current study is to demonstrate the possibility of a single station to the contribution of the space weather studies using observations of solar radio bursts. To test the efficiency of the CALLISTO with any other spectrometers may shift the purpose of this paper.

Using the e-CALLISTO data, it is reported in Ndacyayisenga et al., 2021 that the e-CALLISTO observed 698 intense type III radio bursts among 12971 bursts from Space Weather Prediction Center (SWPC) within the range of 2010 - 2017. In the similar range only 426 type II radio bursts are on SWPC. Similar analysis by Umuhire et al.,2021 found that among 365 type II bursts, only 107 type II bursts could be detected by e-CALLISTO spectrometers.

Comment #4

In Chapter 3 – ”Results and discussions” the obtained radio data are listed in tables (including an online-link for the Type III burst data which however – checked on different days - is unavailable!) with the ”associated” solar phenomena (Table 1 and Table 3). In this respect the terms ”associated” and ”related” (line 72) need a clear definition. Table 2 is trivial and its content can be described in not more than two short sentences.

Response

We thank the referee for pointing out these issues. We have included in the text a correct link which is also given here:
http://www.e-callisto.org/GeneralDocuments/Type_III_radio_bursts_2014_2015_kigali.pdf
The term 'related' was removed and kept 'associated' which has a clear meaning in the context. However, table 2 was removed.

Comment #5

The solar radio burst observed on Aug 22, 2015, had a frequency stop at 45 MHz (according to Table 1) whereas in the text (line 82) 46 MHz are given.

Response

The difference between the two values arose from typing. The correct value is 45 MHz and we have corrected the text accordingly.

Comment#6

Figure 2c visualizes a CME image where the red line is considered as the CME shock height. This needs a clear physical justification.

Response

The CME shock height was taken as the radius of the circle fitted to the outermost part of the disturbance; the assumption is that the disturbance expands spherically above the solar surface. Hence the CME shock height is shown by the red line. More details on the method used can be found in Gopalswamy et al., 2013.

Comment # 7

Figure 3 shows running difference images with the last image taken at 10:04:05 UT, correctly cited in the figure legend, whereas in line 103 the time 10:05 UT is mentioned.

Response

We thank the referee for finding it out. The mistake is corrected.

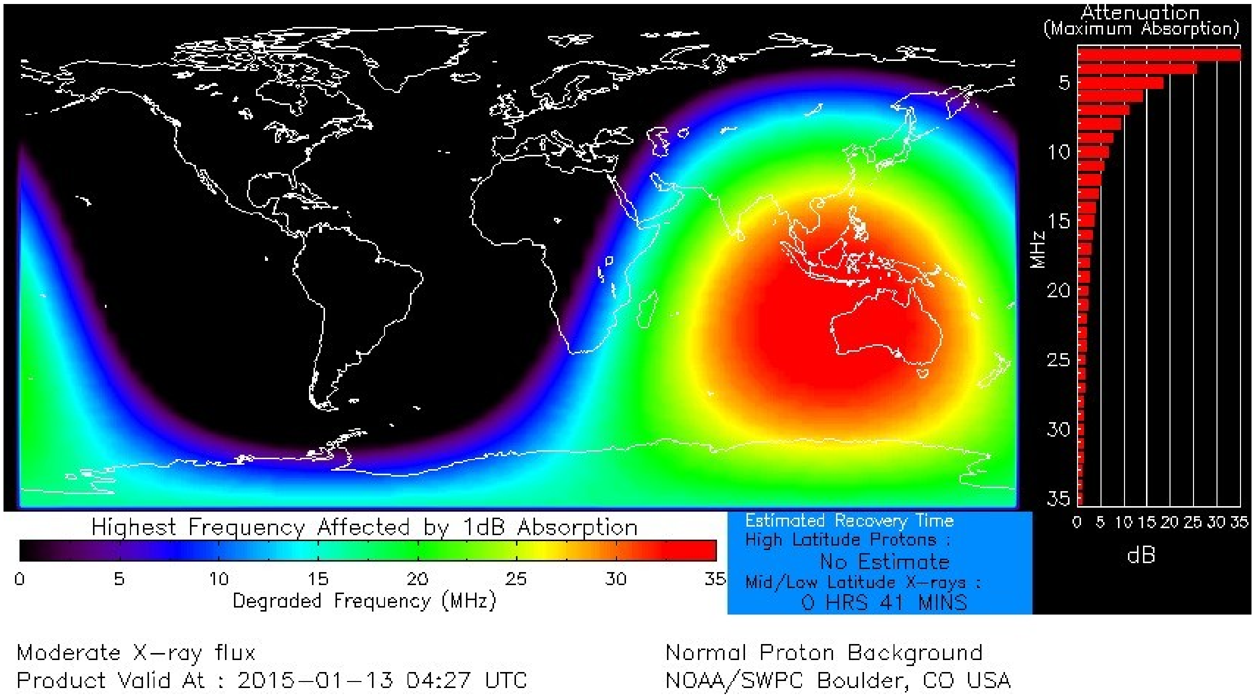
Comment # 8

As the title of the paper indicates (”Space Weather Study ...”) this branch of space physics comprises the varying conditions within the solar system, caused by the sun, including near-Earth conditions, e.g. in the magnetosphere and ionosphere. At least some examples of strong solar radio emission observed by e-CALLISTO and connected with solar plasma phenomena (flares, CMEs, shock waves) and their impact on Earth would clearly demonstrate the ”main motivation of this study” as mentioned above.

Response

The authors thank the referee for raising this issue. It is clear that this part was missed out which led to the title to be a bit irrelevant.

We have taken care of this section and included a discussion with supporting examples. In this regard: Using space weather website, it is seen that the flare associated with type II bursts given in Table 1 have given rise to an alert of incoming aurora phenomena in polar regions. Type IV bursts are attributed to electrons trapped in closed field lines in the post-flare arcades and have high degree association with solar energetic particle events (White, 2007). Thus they can be used as extreme solar radiation precursors. An example is an extreme UV radiation on 13 January 2015 from the flare which ionized Earth’s atmosphere and caused radio blackout in part of the Earth. This hazard happened while our instrument detected two type IV bursts on 12 January 2015 and one on the next day. Affected areas are shown on top of Figure 7.



The intense radio emissions shown in the above figure are associated with major impulsive increases with X-rays and EUV emission. Also energetic particles from the Sun arrive at the Earth within a few hours after the flare and result in a large enhancement of high proton levels which in turn cause shortwave radio blackouts in different parts of the Earth.

Comment#9

It should also be pointed out in what phase of the solar cycle the observations have been performed in order to evaluate the number, the kind and strength of radio bursts and their connection to solar phenomena.

Response

The observation was made within the solar cycle 24 in the range October 2014 - September 2015.