Space weather study through analysis of solar radio bursts detected by a single-station CALLISTO spectrometer

T. Ndacyayisenga¹, A. C. Umuhire¹, J. Uwamahoro², C. Monstein³

¹University of Rwanda, College of Science and Technology, Kigali – Rwanda.
²University of Rwanda, College of Education, Rwamagana – Rwanda.
³Istituto Ricerche Solari (IRSOL), Università della Svizzera italiana (USI), Switzerland.
Outline

1. Solar Activity: connection with SRBs
2. Characteristics of SRBs
3. Detection of SRBs and Space weather connection
4. Statistical Analysis of SRBs by CALLISTO - Rwanda station
5. Space weather Connections
6. Summary of Results
Explosive solar phenomena: Solar flare & CMEs

Solar Activity: connection with SRBs

Characteristics of SRBs

Detection of SRBs and Space weather connection

Statistical Analysis of SRBs by CALLISTO - Rwanda station

Space weather Connections

Summary of Results
Solar radio bursts (SRBs) are Sun’s EM emissions in radio band often associated with solar flares and CMEs.

- SRBs originate from solar atmosphere (solar corona) mainly by plasma emission mechanism.
- They are signatures of solar activity.
- SRBs are common during the years of high solar activity.
Morphology of Solar Radio Bursts in time-frequency domain
Types of Solar radio bursts

- **Type I (storm burst):** short-lived emission with duration $\sim 1$ s and narrow band events.
- **Type II:** slow drift from high to low frequencies associated with fundamental-harmonic frequency structure.
- **Type III:** fast drift from high to low frequencies and often accompany the flash phase of large flares.
- **Type IV:** broadband continuum. broadband continua which may appear with type III and last 1 to 2 minutes.
- **Type II, III & IV bursts** are generated by non-thermal electrons accelerated during solar eruptions.
- The latter are relevant to space weather study.
Solar radio type II bursts

2015/08/22 Radio flux density, e-CALLISTO (RWANDA)

Frequency (MHz)

Start Time (22-Aug-15 06:44:41)

06:48 06:52 06:56 07:00
Estimation of CMEs Speed from type II bursts characteristics

- The drift rates $\frac{df}{dt}$ of type II SRBs are estimated using the relation

$$\frac{df}{dt} = \frac{f_2 - f_1}{t_2 - t_1}$$

- These frequencies will be estimated from the CALLISTO spectrum.
- The plasma frequency can be assumed to be

$$f_p \ [MHz] = 9 \times 10^{-3} \sqrt{n}$$
Estimation of CMEs Speed from type II bursts characteristics ...

- By differentiating equation (2) with respect to the radial distance \( r \), we get
  \[
  \frac{df_p}{dr} = \frac{f_p}{2n} \frac{dn}{dr}
  \]  
  \( (3) \)

- The plasma frequency is a function of both radial distance and time, so using the chain rule it can be written as
  \[
  \frac{df_p}{dt} = \frac{df_p}{dr} \cdot \frac{dr}{dt}
  \]  
  \( (4) \)

- Where \( \frac{dr}{dt} \) is the speed of CMEs.
Estimation of CMEs Speed from type II bursts characteristics...

- Then by substituting equation (3) into equation (4)

\[
\frac{df_p}{dt} = \frac{f_p}{2} \frac{dn}{dr} \frac{dr}{dt} = \frac{f_p}{2n} \frac{dn}{dr} \frac{dr}{dt}
\]  

(5)

- Knowing that \( \frac{dr}{dt} = v \), the above equation can be written as

\[
\frac{1}{f} \frac{df_p}{dt} = \frac{V}{2} \frac{1}{n} \frac{dn}{dr}
\]  

(6)

- The expression \( \frac{1}{n} \frac{dn}{dr} \) in equation (6) is known as the scale height, \( L_n^{-1} \).
Assume a density model of the form $n_0 r^{-\alpha}$ (Gopalswamy, 2009), the scale height becomes

$$L_n = \frac{-\alpha}{r}$$

Plug equation (7) into (6), we finally get

$$V = \frac{-2r}{\alpha} \frac{1}{f} \frac{df}{dt}$$
Instrumentation for SRBs Observations

**Ground-based observations**

- In decametre - metre wavelengths: Solar radio type II bursts, the Hiraiso Radio Spectrograph (HiRAS), IZMIRAN in Russia and many others.
- e-CALLISTO (e-callisto.org)

**Space-based observation**

- Space observation mostly in longer wavelength than metric wavelength (Decametric - Kilometric): WAVES on wind spacecraft and STEREO on board SOHO.
SRBs Spectra

Examples of type II and type III radio bursts observed by CALLISTO Rwanda.
Global Coverage of ground-based CALLISTO Spectrometers

Callisto Day/Night Map for 05 Dec 2022 11:50:05 (UTC). blue=no data, orange=data two days ago, red=current data

Number of active instruments today: 74
Observations of SRBs from Rwanda station

Fig. 1: The CALLISTO core team at University of Rwanda in front the fence with LPDA antenna. The new LNA at the top of the mast is connected with the LPDA by a very short coaxial cable to keep the noise temperature as low as possible. This LNA version is supplied with DC through the coax and by a Bias-Tee, so there is no extra cable required to provide dc-voltage. Contact person (right) is: Dr Jean Uwamahoro, University of Rwanda, College of Education (UR-CE) Deputy Director, African Center of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), P.O.BOX 55, RWAMAGANA - RWANDA Tel: +250784432839; +250782391748, E-mail: mahoroipacis(at)gmail.com

Fig. 2: CALLISTO core team in the CALLISTO laboratory during tests of the instrument.
The current analysis presents the trends of SRBs detected by the CALLISTO station in Rwanda and discusses their correlation with solar explosive phenomena which occurred during its first year of operation.
Data Coverage in Rwanda

- E-Callisto data: Rwanda station
- Images from the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory.
- Sample: 201 radio bursts comprising 4 type II radio bursts, 175 type III radio bursts and 22 type IV radio bursts.
Radio data used in this study were detected from October 2014 to September 2015 during SC 24.

Using quick plots provided by the e-CALLISTO network and by manual inspection, we made cross-checked to identify all radio bursts observed by the CALLISTO Rwanda.

Radio bursts are used as diagnostics of the level of solar activity (e.g., Salmane et al., 2018). We carefully examined their association with the solar transients.

White light coronagraph data from the LASCO C2 on board the SOHO and the SECCHI on board STEREO were analyzed.
Methodology

- The association of SRBs and CMEs was confirmed upon the time coincidence (a time window of ~ 1 h of CME from the onset of radio burst was considered).

- A burst is considered as being flare associated if it appears between its onset and end times.

- For some type III and type IV bursts, the AIA images on board SDO were used to indicate the possible launch sites.
A total of 201 radio bursts comprising 4 type II radio bursts, 175 type III radio bursts and 22 type IV radio bursts.

All type II radio bursts are associated with solar flares, and $\sim 37\%$ of the type III and $\sim 13\%$ of type IV radio bursts detected are flare associated.

The remaining non-flare associated type III radio bursts may be due to small-scale reconnection events present in the solar corona.

All type II radio bursts are associated with CMEs.

$\sim 44\%$ of type III radio bursts are accompanied by CMEs.

The majority ($\sim 82\%$) of type IV radio bursts are associated with CMEs.
Example of type II radio burst observed by Callisto Rwanda

**Image Explanation:**

- **Image (a):** Band split fundamental emission of type II burst.
- **Image (b):** Band split harmonic emission of type II burst.
- **Image (c):** GOES X-Rays: 2014/11/05 09:48, with M7.9.
- **Image (d):** CME.
A sample of SDA/AIA images using the 171 Å bandpass of the Sun on 3 November 2014
Observed Type IV emission and corresponding Magnetic loops in the solar corona
Maps with radio blackout on 13 January 2015 (top) and on 12 March 2015 (bottom)
Summary of Results

- In this study analyzed 201 SRBs detected by the CALLISTO spectrometer installed in Kigali, Rwanda.
- The obtained results show that, during its first year of operation, 4 type II, 175 type III and 22 type IV radio bursts were detected in the frequency range of 45–80.9 MHz.
- Analyzed data indicate that all detected type II radio bursts are flare associated; ~ 37% of observed type III bursts are triggered by impulsive flares.
- We found that the remaining non-flare-related type III bursts might have been triggered by small-scale features or weak energy events present in the solar corona according to the literature and with the help of AIA/SDO images in the 171 Å bandpass.
Summary

- All detected type II radio bursts are associated with CMEs, while only \( \sim 44\% \) of type III are found to be accompanied by CMEs.
- The majority (\( \sim 82\% \)) of detected type IV radio bursts are accompanied by CMEs.
- Findings from this study indicate the possibility and importance of detecting potential Geo-effective solar phenomena through analysis of SRBs.
- Use of low cost and ground-based instrumentation such as CALLISTO to analyze SRBs can be effective way to provide early warning of space weather hazards that can affect GNSS operation.
Publications

1. **Umuhire Ange Cynthia**, Gopalswamy N, **Uwamahoro J**, Akiyama S, Yashiro S, Mäkelä P. Properties of High-Frequency Type II Radio Bursts and Their Relation to the Associated Coronal Mass Ejections. *Solar Physics*. 2021 Jan;296(1):1-8. https://doi.org/10.1007/s11207-020-01743-8.

2. **Ndacyayisenga Theogene**, **Uwamahoro Jean**, Raja KS, Monstein C. A statistical study of solar radio Type III bursts and space weather implication. *Advances in Space Research*. 2021 Feb 15;67(4):1425-35. https://doi.org/10.1016/j.asr.2020.11.022.

3. **Ndacyayisenga Theogene**, **Ange Cynthia Umuhire**, **Jean Uwamahoro**, and Christian Monstein. "Space Weather Study through Analysis of Solar Radio Bursts detected by a Single Station CALLSTO Spectrometer." *Ann. Geophys.*, 39, 945–959, https://doi.org/10.5194/angeo-39-945-2021, 2021.

4. **Umuhire Ange Cynthia**, **Uwamahoro Jean**, Raja KS, Kumari A, Monstein C. Trends and characteristics of high-frequency type II bursts detected by CALLSTO spectrometers. *Advances in Space Research*. 2021 Oct 15;68(8):3464-77. https://doi.org/10.1016/j.asr.2021.06.029.
Thank you for your kind attention