DLITE—An Inexpensive, Deployable Interferometer for Solar Radio Burst Observations

George Carson[1], Jason Kooi[2], Joseph Helmboldt[2], Blerta Markowski[2], David Bonanno[2], and Brian Hicks[2]
Affiliations: [1]Dickinson College, [2]U.S. Naval Research Laboratory

Sharing is encouraged

1) Radio Bursts

Solar radio bursts are periods when the Sun radiates a higher than normal level of radio waves. They range from just above background levels to orders of magnitude more and can sometimes be associated with large scale events such as solar flares and coronal mass ejections (CMEs). The radio frequency emitted depends on the emission mechanism and the properties of the plasma it originates from. Many radio bursts (e.g. Type I, II, III) are a consequence of plasma emission and therefore emit at the plasma frequency, given by:

$$f_p = \sqrt{\frac{e^2 n_e}{\pi m_e}} \approx 0.009\sqrt{n_e}\ \mathrm{MHz}$$

Other radio bursts (e.g. Type IV) radiate at the gyrofrequency

$$f_B = \frac{eB}{2\pi m_e c} \approx 2.8B\ \mathrm{MHz}$$

where n_e is electron density, e is the charge of an electron, B is the magnetic field strength, m_e is the mass of an electron, and c is the speed of light. In the

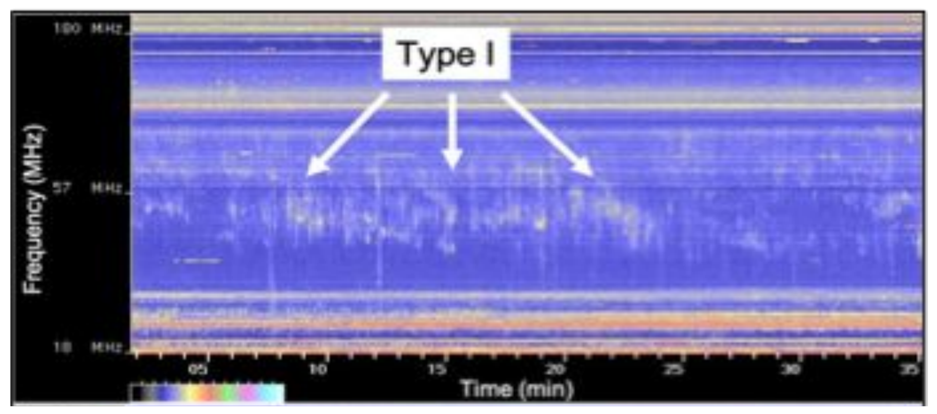

Figure 1: Examples of a Type I burst shown in a radiospectrograph. Taken from https://en.wikipedia.org/wiki/Solar_radio_emission

Sun's corona, where the magnetic field strength and plasma density decreases rapidly as a function of heliocentric distance, low-frequency thermal bremsstrahlung and plasma emission are the main forms of emission. Most types of solar radio bursts are caused by plasma emission, which occurs when a disturbed plasma's electrons are displaced relative to the ions and then are pulled back by the Coulomb force, causing them to oscillate.

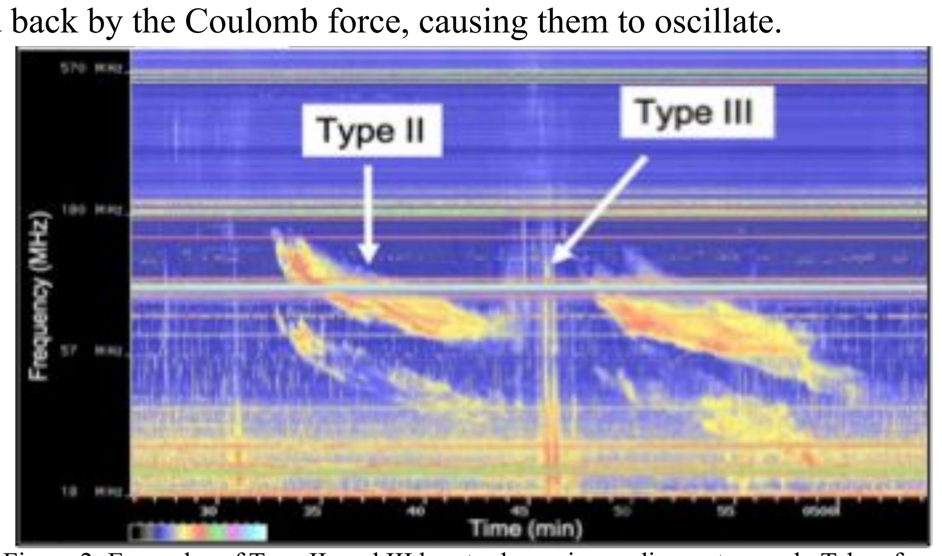

Figure 2: Examples of Type II, and III bursts shown in a radiospectrograph. Taken from https://en.wikipedia.org/wiki/Solar_radio_emission

Bursts are categorized into five main types. Type I are short, low frequency range bursts that tend to happen in larger noise storms. Type II are longer bursts that last a few minutes and slowly drift from high to low frequencies. These are typically linked to CMEs and result from a shock developed near the leading edge of the ejected plasma. Type III are short lived bursts that drift from high to low frequencies rapidly and are typically associated with solar flares. Type IV bursts are long lasting spikes of continuum emission following either Type II or Type I bursts. Type V are uncommon and are also continuum emission and may follow a Type III burst. Here, we mainly focus on Type II and Type IV bursts.

2) Importance

Tracking solar radio bursts aids understanding of various solar activity such as sunspots, solar flares, and CMES, which are closely related to or the cause of the bursts. Plasma density obtained from burst data can be used to discover the underlying processes that cause such events. Because bursts are caused by various different forms of emission, observing different types of these bursts aids in pinning down what types of emission are prevalent in the corona and during related activity. Our hope is to be able to continuously monitor these bursts through a global network of affordable DLITE detectors. The existence of a new detector will allow for observations which are quite complementary to other detectors, such as e-Callisto.

Abstract

Solar radio bursts (SRBs) are brief periods of enhanced radio emission from the Sun which contain information concerning the plasma where the emission originates; consequently, SRBs can provide critical information concerning space weather events such as coronal mass ejections (CMEs). A new network of four-element interferometers is being developed and used to monitor SRBs. These interferometers, called the Deployable Low-band Ionosphere and Transient Experiment (DLITE) arrays, operate in a 30-40 MHz band and were originally designed to probe the Earth's ionosphere using hih resolution measurements (1.024-s temporal resolution, 16.276-kHz frequency resolution). The DLITE network has recently been demonstrated to be a powerful tool for detailed observations of SRBs at these frequencies. We have used DLITE to detect long-duration Type II and Type IV SRBs. Each DLITE array provides a higher sensitivity (e.g. >10 dB) compared to single-receiver stations using the same antenna. We demonstrate DLITE's enhanced functionality by examining SRBs associated with a CME on May 11, 2022. The high resolution SRB data that DLITE provides can complement ground-based networks like e-Callisto or space-based observations, e.g., from Wind/WAVES. Future improvements could be made to DLITE arrays by utilizing the 20-80 MHz band and millisecond time-resolution possible by the antennas. This would expand DLITE's detection ability to shorter Type I and Type III SRBs and improve its ability to track long-duration bursts.

3) DLITE

Figure 3: Shows the locations of three operational DLITE arrays (blue), one planned array (red), and five proposed arrays (orange) around the world.

The Deployable Low-band Ionosphere and Transient Experiment (DLITE) arrays are four-element interferometric radio telescopes that were created as a cheaper alternative to larger, stationary radio telescopes. They operate in the High Frequency (HF) and Very High Frequency (VHF) regimes, nominally in a 30-40 MHz band, but with good sensitivity (sky-noise dominated) in the 20-80 MHz range. Three DLITE arrays have been established, shown as blue circles in Figure 3: one located near Long Wavelength Array station 1 (LWA-1) in New Mexico (DLITE-NM), one located near Pomonkey, Maryland (DLITE-POM), and one located in Florida (DLITE-FL). There is another DLITE array currently being constructed in Texas that will be online in the near future (red circle) and several other locations have also been proposed (orange circles).

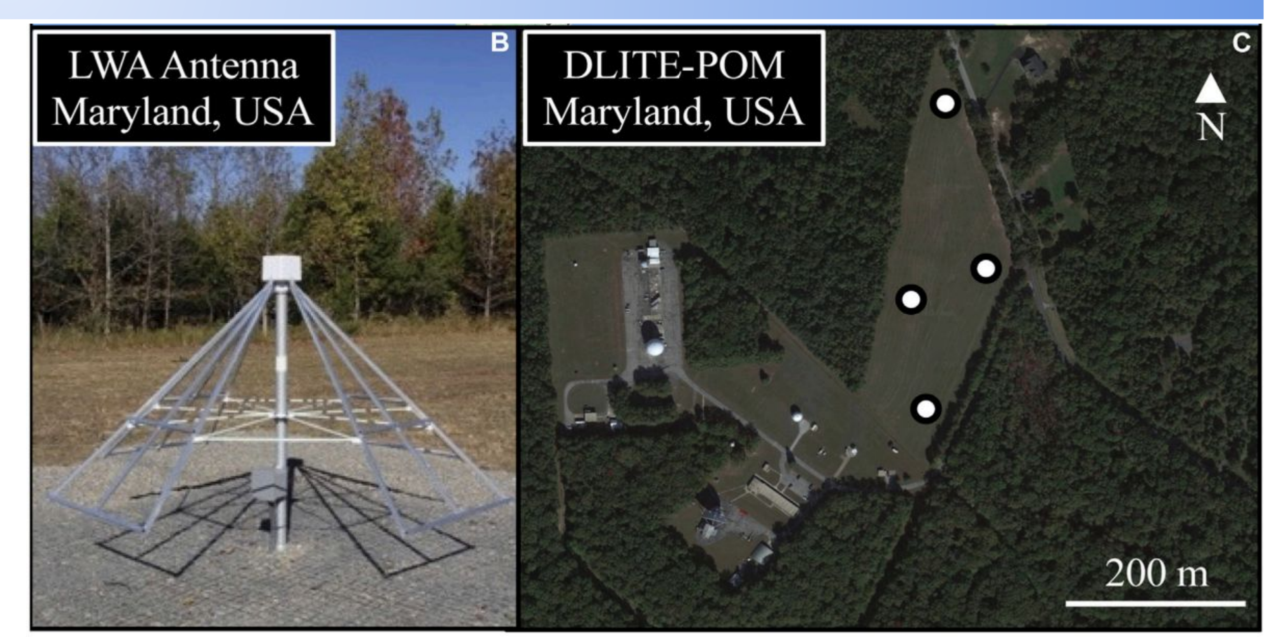

Figure 4: (Left) displays a Long Wavelength Array (LWA) antenna as it appears on-site at the DLITE-POM station in Maryland, United States. (Right) provides an overhead view of the DLITE-POM site with the four antenna positions given by the white points.

While DLITE stations principally operate as probes of ionospheric structures, they return high resolution data (1.024s temporal resolution, 16.276 kHz frequency resolution) allowing for sensitive measurements of solar radio bursts. Within DLITE's 30-40 MHz band, SRBs are the strongest source of radio emission in the sky. This band corresponds to emission located at heliocentric distances of 2–3 $R_\odot$, which are complementary to many other SRB detectors. Many ground-based SRB detectors operate near or well above these frequencies because the ionosphere limits their utility below DLITE frequencies. Many space-based SRB detectors (e.g. Wind/WAVES) operate near or below these frequencies because they are located well beyond Earth's ionosphere.

4) Results

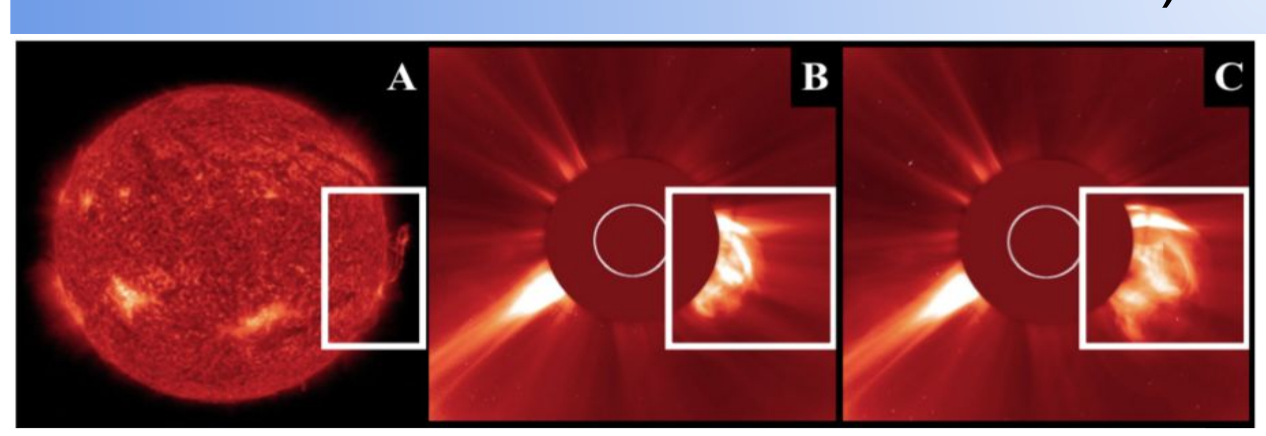

Figure 5: A series of high-resolution radio bursts associated with a CME seen by DLITE arrays on 2022 May 11. (A) SDO/AIA 304 ˚A image of the emerging CME at 18:45 UT. (B) and (C) SOHO/LASCO-C2 coronagraph images of the CME erupting at 19:00 UT and 19:12 UT, respectively.

DLITE arrays have detected 100s of SRBs since the Maryland and New Mexico stations came online in the fall of 2019 and they are quite good at detecting long duration SRBs, especially Type II and Type IV. Figure 5 and 6 shows a series of Type II and Type IV-moving SRBs coinciding with the eruption of a CME off the western limb on 2022 May 11. The CME erupted near 18:30 UT, accompanied by an M-class X-ray flare. Figure 5A shows a 304 Å image of the CME at 18:45 UT, shortly after eruption, taken with the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO). The SDO/AIA uses extreme ultraviolet emission to trace the flow of plasma along magnetic field lines. Figures 5B, C show the emergence of the CME into the range of 1.5–6.0 $R_\odot$ at 19:00 UT and 19:12 UT, respectively, in white-light coronagraph images from the C2 Large Angle and Spectrometric Coronagraph on board the Solar and Heliospheric Observatory (LASCO-C2). Figure 6 shows the bispectrum for the DLITE-NM station. Vertical black bars have been placed in Figure 6 to highlight the time of each event shown in Figures 5A−C. Both the fundamental and harmonic Type II bursts are present shortly after 18:36 UT, when the shock front enters the SOHO/LASCO-C2 field of view. This is then followed by a long-duration Type IV-moving burst. All three DLITE stations detected these bursts, however only the New Mexico data are shown here. There are small differences among the three

5) Results

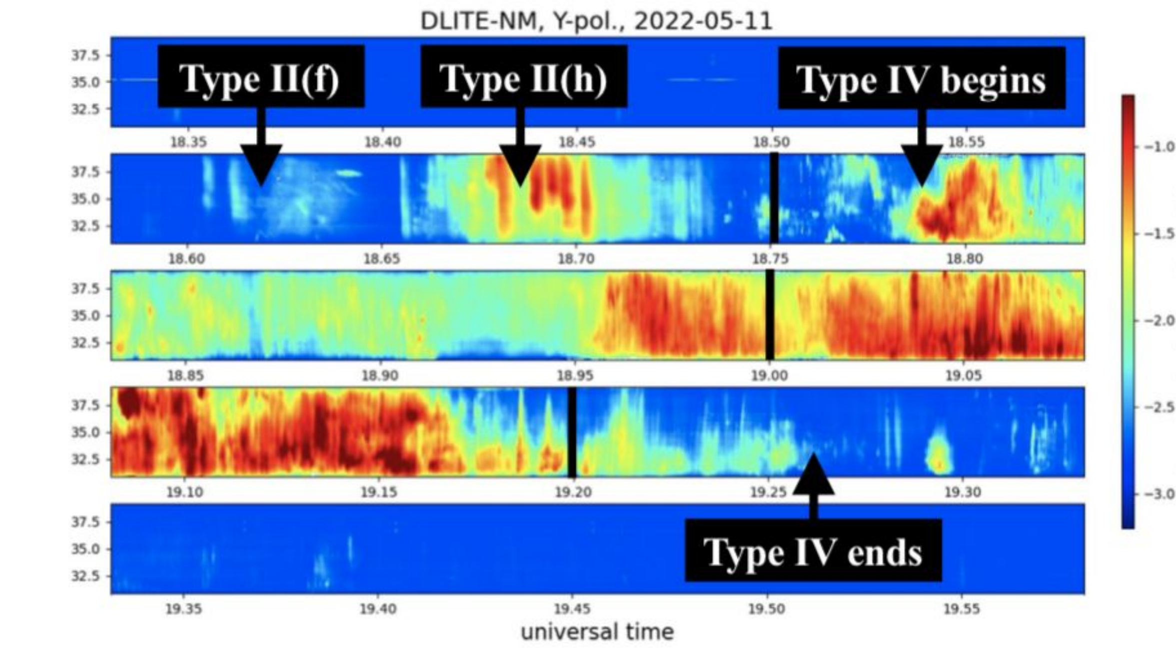

Figure 6: DLITE-NM detection of SRBs with black vertical bars corresponding to the times associated with figure 5 (A)–(C).

different bispectra, which may be due to geometric effects due to each detector's location. It may also be due to differing configurations of a non-point-like emission region or multiple emission regions. These radio bursts were also observed by e-Callisto stations. In the Figure 7, we have plotted a time series of the (uncalibrated) received power from the Arecibo e-Callisto spectrometer near the radio astronomy band at 34 MHz (in black) compared to the mean bispectrum from DLITE-NM at the same frequency (in red).

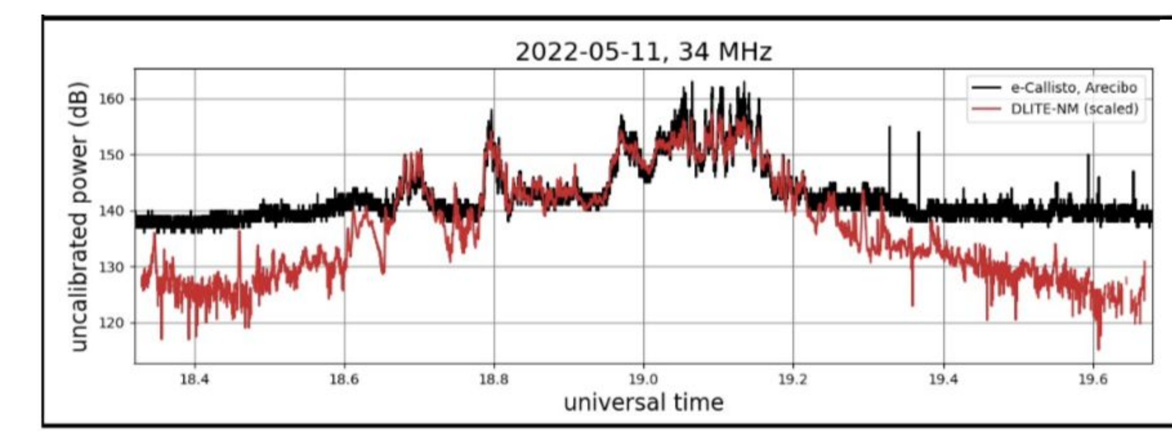

Figure 7: e-Callisto spectrometer at Arecibo Observatory (black) with a scaled version of the DLITE-NM bispectrum at the same frequency (red).

There are several features within the DLITE-NM time series not visible within the Arecibo curve, especially around 18:45 UT and after 19:12 UT. The equivalent noise floor from the DLITE-NM bispectrum is at least 10 dB below that of the Arecibo curve, though when using the equivalent of spectra from four antennas averaged incoherently, we would expect the noise floor to only be about 3 dB lower.

6) Discussion

The two primary advantages of ground-based SRB detectors such as CALLISTO spectrometers or DLITE arrays are that they are inexpensive to build and can be deployed virtually anywhere. The cost for parts of a DLITE array is ≈$45,000, making it an ideal candidate for hands-on learning at universities interested in implementing their own SRB detector. Another of DLITE's strengths is its multifunctionality. DLITE is designed for ionospheric observations, but has proven itself more than capable of observing SRBs and Jovian Bursts as well. DLITE also has strong potential as an educational tool for colleges and universities due to its inexpensive cost and scientific versatility. Countries that are developing new space programs, space weather centers, or radio astronomy programs should find value in DLITE for similar reasons.

Selected References

1. Benz, A. O., Monstein, C., and Meyer, H. (2005). Callisto A new concept for solar radio spectrometers. Sol. Phys. 226, 143–151. doi:10.1007/s11207-005- 5688-9
2. Brueckner, G. E., Howard, R. A., Koomen, M. J., Korendyke, C. M., Michels, D. J., Moses, J. D., et al. (1995). The large Angle spectroscopic coronagraph (LASCO). Sol. Phys. 162, 357–402. doi:10.1007/BF00733434
3. Carson G, Kooi JE, Helmboldt JF, Markowski BB, Bonanno DJ and Hicks BC (2022) DLITE—An inexpensive, deployable interferometer for solar radio burst observations. Front. Astron. Space Sci. 9:1026455. doi: 10.3389/fspas.2022.1026455
4. Domingo, V., Fleck, B., and Poland, A. I. (1995). The SOHO mission: An overview. Sol. Phys. 162, 1–37. doi:10.1007/BF00733425
5. Helmboldt, J. F., Markowski, B. B., Bonanno, D. J., Clarke, T. E., Dowell, J., Hicks, B. C., et al. (2021). The deployable low-band ionosphere and transient experiment. Radio Sci. 56, e07298. doi:10.1029/2021RS007298
6. Lemen, J. R., Title, A. M., Akin, D. J., Boerner, P. F., Chou, C., Drake, J. F., et al. (2012). The atmospheric imaging assembly (AIA) on the solar dynamics observatory (SDO). Sol. Phys. 275, 17–40. doi:10.1007/s11207- 011-9776-8
7. Pesnell, W. D., Thompson, B. J., and Chamberlin, P. C. (2012). The solar dynamics observatory (SDO). Sol. Phys. 275, 3–15. doi:10.1007/s11207-011- 9841-3

Basic research at the United States Naval Research Laboratory (NRL) is supported by 6.1 Base funding. Development and testing of the DLITE system were supported by the Defense Advanced Research Projects Agency (DARPA) Space Environment Exploitation (SEE) program. Student research was supported by the Naval Research Enterprise Internship Program (NREIP) under the Office of Naval Research (ONR) contract N00014-21-D-4002.