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## Solar Radio Bursts –Deployable Low-band Ionosphere and Transients Experiment (DLITE) Arrays

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## Solar Radio Bursts –Deployable Low-band Ionosphere and Transients Experiment (DLITE) Arrays

### Abstract

Solar radio bursts, phenomenon that often accompany CME, solar flares and other solar events, can be detected on earth and used in the prediction of solar weather that affects earth systems in several ways. As part of the NREIP Program supporting the Naval Research Laboratory, Remote Sensing Division, approximately ten interns participated in the analysis of data collected by DLITE and WAVES radio data. Data from DLITE is often used as a complement to data from WAVES due to differences in frequency range and resolution. The analysis helps to correlate the DLITE data with the data collected from other sources. This is important because using data from solar weather to predict effects on earth will help mitigate the potential problems that solar weather can cause for earth-based systems such as power grids, GPS systems and electronic communication.

RUNNING HEAD: SOLAR RADIO BURSTS

Solar Radio Bursts —Deployable Low-band Ionosphere and Transients Experiment (DLITE)  
Arrays

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Jason Kooi, Mentor

Macalester College Physics Capstone

## SOLAR RADIO BURSTS

## Abstract

Solar radio bursts, phenomenon that often accompany CME, solar flares and other solar events, can be detected on earth and used in the prediction of solar weather that affects earth systems in several ways. As part of the NREIP Program supporting the Naval Research Laboratory, Remote Sensing Division, approximately ten interns participated in the analysis of data collected by DLITE and WAVES radio data. Data from DLITE is often used as a complement to data from WAVES due to differences in frequency range and resolution. The analysis helps to correlate the DLITE data with the data collected from other sources. This is important because using data from solar weather to predict effects on earth will help mitigate the potential problems that solar weather can cause for earth-based systems such as power grids, GPS systems and electronic communication.

## Introduction/Background

This project was done in conjunction with an internship with the Naval Research Enterprise Internship Program (NREIP). NREIP places college and university students in Department of Navy (DoN) laboratories where they take part in real Naval research for ten weeks during the summer or as a remote internship in the fall.

NREIP gives academically talented college students, graduating seniors, and graduate students pursuing STEM careers the opportunity to learn about Naval research and technology while receiving first-class mentorship from top scientists and engineers.

NREIP is a competitive program with over 800 placements in 47 laboratories around the country in which many participants go on to careers within the DoN. Interns are selected based upon academic achievement, personal statements, recommendations, and career and research interests.

The US Naval Research Laboratory (NRL) is one of the largest scientific institutions within the US government. NRL provides the advanced scientific capabilities required to bolster our country's position of global naval leadership. Here, in an environment where the nation's best scientists and engineers are inspired to pursue their passion, everyone is focused on research that yields immediate and long-range applications in the defense of the United States. As corporate research laboratory of the Navy, NRL conducts a broadly based multidisciplinary program of scientific research in advanced technological development, techniques, systems, and related operational procedures.

Out of the nearly 50 labs at NRL, I was selected for an internship at the Remote Sensing Division, working with Mr. Jason Kooi, Research Physicist, on the DLITE project. Mr. Kooi is Research Physicist at the U.S. Naval Research Laboratory working in the Radio Astrophysics and Sensing Section (Code 7213). He uses radioastronomical remote-sensing techniques to

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determine the plasma structure of the Sun's corona, coronal mass ejections, and the Earth's ionosphere/plasmasphere.

The Remote Sensing Division conducts a program of basic and applied research aimed at the development of new concepts for sensors and imaging systems for objects and targets on Earth, in the near-Earth environment, and in deep space. The research, both theoretical and experimental, deals with discovering and understanding the basic physical principles and mechanisms that give rise to target and background emission and to absorption and emission by the intervening medium. The accomplishment of this research requires the development of sensor systems technology. This development effort includes active and passive sensor systems to be used for the study and analysis of the physical characteristics of phenomena that give rise to naturally occurring background radiation, such as that caused by Earth's atmosphere and oceans, as well as human-made or induced phenomena, such as ship/submarine hydrodynamic effects. The research includes theory, laboratory, and field experiments leading to ground-based, airborne, and space-based systems for use in such areas as environmental remote sensing (including improved meteorological support systems for the operational Navy), astrometry, astrophysics, surveillance, and nonacoustic antisubmarine warfare. Special emphasis is given to developing space-based platforms and exploiting existing space systems.

During the fall internship, I assisted in the evaluation of the Deployable Low-band Ionosphere and Transients Experiment (DLITE) arrays capability to detect solar radio bursts.

Prior to participating in the DLITE project, some basic understanding of solar phenomenon was useful. Observations of the sun certainly go back to when man first observed the sun at dawn. However, it was scientists in the 1850's who identified and documented the first observation of a sudden outburst of energy from the sun, what would come to be called solar flares. Studies grew and continued into the 1950's when the phenomenon of energy coming from the sun began to be called *solar wind*, and the resulting effects called *solar weather*. In January 1959, the first ever direct observations and measurements of strength of the solar wind were made by the Soviet satellite Luna 1. (Solar wind, 2023)

The sun is the main source of space weather. Sudden bursts of plasma and magnetic field structures from the sun's atmosphere called coronal mass ejections together with sudden bursts of radiation, or solar flares, all cause space weather which results in effects on Earth. (FEMA, 2022)

A solar radio burst (SRB) is the intense solar radio emission related to a solar flare and one of the extreme space weather events. The term "space weather" refers to the variable conditions on the sun and in space that can influence the performance of technology we use on Earth, as well as the survivability of objects in space such as satellites and spacecraft. (Ndacyayisenga et al., 2021)

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Solar radio bursts are generally divided into five groups designated as type-I, -II, -III, -IV and -V. Most of them show fine structures, especially type-IV bursts: fibers, zebra patterns, spikes and pulsations. (Karlický, 2017) Table I from the Australian Space Weather Forecasting Center provides a detailed description of the features of SRB's.

TABLE I

<b>Solar Radio Burst Classifications</b>				
TYPE	CHARACTERISTICS	DURATION	FREQUENCY RANGE	ASSOCIATED PHENOMENA
I	Short, narrow-bandwidth bursts. Usually occur in large numbers with underlying continuum.	Single burst: ~ 1 second Storm: hours - days	80 – 200 MHz	Active regions, flares, eruptive prominences.
II	Slow frequency drift bursts. Usually accompanied by a (usually stronger intensity) second harmonic.	3- 30 minutes	Fundamental: 20 – 150 MHz	Flares, proton emission, magnetohydrodynamic shockwaves.
III	Fast frequency drift bursts. Can occur singularly, in groups, or storms (often with underlying continuum). Can be accompanied by a second harmonic	Single burst: 1 - 3 seconds Group: 1 -5 minutes Storm: minutes - hours	10 kHz – 1 GHz	Active regions, flares.
IV	Stationary Type IV: Broadband continuum with fine structure	Hours - days	20 MHz – 2 GHz	Flares, proton emission.
	Moving Type IV: Broadband, slow frequency drift, smooth continuum.	30 – 2 hours	20 – 400 MHz	Eruptive prominences, magnetohydrodynamic shockwaves.
V	Flare Continua: Broadband, smooth continuum.	3 – 45 minutes	25 – 200 MHz	Flares, proton emission.
	Smooth, short-lived continuum. Follows some type III bursts. Never occur in isolation.	1-3 minutes	10 - 200 MHz	Same as type III bursts.

NOTES: In nearly all cases, drifting bursts drift from high to low frequencies.  
The Frequency Range is the typical range in which the bursts appear – not their bandwidth.  
The sub-types of type IV are not universally agreed upon and are thus open to debate.

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Radio bursts are identified by differences in duration, frequency, and pattern and when found are sometimes indicative of other solar phenomenon. The important thing to note is that while bursts are found in patterns, lengths of time, and frequency ranges, their appearance is usually not the same. Some are smaller or larger than others, some have slight imperfections in appearance, and some are at the lower or higher end of the frequency range. In the table where it says continuum, imagine large clusters of these bursts grouped together. This is a useful visualization for type I and type IV bursts although there are some deeper differences in structure that are outside the scope of this project. In the table, type II and Type III bursts are said to be accompanied by a second harmonic. In plain terms, this second harmonic is just another type of type II and type III burst, with the same pattern, located at a slightly different frequency. Imagine a picture of a logarithmic function and that is a rough estimate for the pattern of these two burst types (with type II and type III differing because one is more horizontal while the other is more vertical). Now imagine two horizontal or two vertical logarithmic functions graphed and those are the patterns usually found in data sets. Stationary

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vs Moving Type IV bursts usually differ in how they come to be (what phenomenon causes the burst). Type V bursts were not observed and therefore will also not be discussed.

The impact of solar weather on the earth (or space objects launched from earth) is what scientists such as the ones working at NRL are most interested in. When a Coronal Mass Ejection (CME) impacts the Earth's magnetosphere, it temporarily deforms the Earth's magnetic field, changing the direction of compass needles and inducing large electrical ground currents in earth itself; this is called a geomagnetic storm and it is a global phenomenon. (Ometola & Okeme, 2012) Evidence of this phenomenon results in the *Aurora Borealis* or Northern Lights. CME impacts can induce magnetic reconnection in Earth's magnetotail (the midnight side of the magnetosphere); this launches protons and electrons downward toward Earth's atmosphere, where they form the aurora. (Schroeder et al., 2021)

The increasing reliance of modern society on technologically advanced electronic systems has resulted in vulnerability to electromagnetic and particle influences from the sources external to the Earth. The inter-connected international power grids contain long-range electrical connections that are susceptible to the large-scale electric fields generated when the magnetosphere is compressed by disturbances in the solar wind, resulting in voltage and current overloads that can shut down power supplies to millions of people. Long-distance oil and gas pipelines, particularly at high latitudes, are similarly subjected to currents that cause damaging corrosion. Use of global positioning data from satellites is becoming widespread and many industries now depend on such data: air traffic is moving towards relying entirely on such technology. But the technology requires precise timing of radio signals passing through the Earth's ionosphere, where changing conditions caused by Space Weather effects can disrupt measurements. Cell phones rely on communications at microwave frequencies where the Sun can cause harmful interference during flares, disrupting service. Other ground-based radio communication methods require low-absorption paths through the atmosphere that can be destroyed when ionizing radiation from the Sun increases the charged particle densities in the lower ionosphere. With increased astronaut activity expected in coming years as NASA sends missions to the Moon and Mars, there is concern about the possibility of deadly radiation storms occurring during manned missions. There are frequent losses of satellites in low-Earth orbit due to increased drag from the atmosphere during periods of high solar activity when the upper atmosphere is heated by ionizing photon fluxes and expands outwards, while all satellites are susceptible to radiation damage in critical computing components that can result in complete loss of control. The commercial implications of Space Weather are now widely recognized, and insurance companies in particular are paying attention to its effects on their industry. For all of these reasons, the study of Space Weather has become an important practical task in addition to the intellectual value of understanding the physical processes involved. Since most of Space Weather's effects originate in the Sun's atmosphere, any diagnostics there can potentially be valuable. (White, 2007)

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## Methods/Experiment

There are a multitude of instruments being used to detect and identify SRB's and other solar phenomenon, both terrestrial and space-based. Table 2 provides a list of many of these. For the purposes of this project, I only looked at WAVES, SOHO LASCO and DLITE data, as discussed below.

TABLE 2
Solar Weather Instruments - (Source: <a href="https://secchirh.obspm.fr/spip.php?rubrique9">https://secchirh.obspm.fr/spip.php?rubrique9</a> )
Green Bank Solar Radio Burst Spectrometer (SRBS) Nancay Radio Heliograph WIND-WAVES: The Radio and Plasma Wave Investigation on the WIND Spacecraft SOLAR ORBITER Solar and Heliospheric Observatory (SOHO) mission's Large Angle and Spectrometric Coronagraph (LASCO) NRH Nancay Radioheliograph (NRH) ORFEES radio-spectrograph Nancay Decameter Array ARTEMIS IV Multichannel solar radiospectrograph Humain spectrograph Solar radio spectrometer of Yunnan Observatories Gauribidanur Low-frequency Solar Spectrograph (GLOSS) Culgoora spectrograph Learmonth spectrograph

The WAVES investigation on the WIND spacecraft provides comprehensive coverage of radio and plasma wave phenomena in the frequency range from a fraction of a Hertz up to about 14 MHz for the electric field and 3 kHz for the magnetic field. This package permits several kind of measurements, all of which are essential to understanding the Earth's environment --the Geospace-- and its response to varying solar wind conditions. In situ measurements of different modes of plasma waves gives information on local processes and couplings in different regions and boundaries of the Geospace leading to plasma instabilities: magneto-acoustic waves, ion cyclotron waves, whistler waves, electron plasma oscillations, electron burst noise and other types of electrostatic or electromagnetic waves. (MacDowall, 2016)

The Deployable Low-band Ionosphere and Transient Experiment (DLITE) array is a low-cost, four-element interferometer created as an inexpensive alternative to larger, permanent interferometers (e.g. the VLA or LWA). Each of the four antennas is an LWA antenna operating in a 30–40 MHz band, but with good sensitivity (sky-noise dominated) in the 20–80 MHz range. DLITE arrays were specifically designed to probe the Earth's ionosphere, hence their narrow



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band centered on 35 MHz. They continuously monitor the brightest cosmic radio sources to characterize ionospheric structure and have been used to study km-scale irregularities at mid-latitudes and medium-scale Traveling Ionospheric Disturbances as well as mid-latitude ionospheric magnetic field fluctuations. (Carson et al., 2022)

During my internship with NRL, I was assigned an observation window from November 2 to November 30, 2020. My task was to study the WIND WAVES data for the month of November 2020 and determine if there were any significant solar events detected. From these observations, I was then given the DLITE data from the same time period. The task was to compare the data from days where significant information was available from both sets of data and to offer insight into the significance of the DLITE data as a tool to observe solar events that may effect the earth's magnetic field.

The data analysis was performed by visually inspecting the data output from the SWAVES database and the DLITE database and looking for evidence of significant solar activity that could impact earth. Figure 1. And Figure 2. Show samples of the data from November 24, 2020 from the DLITE and SWAVE databases.

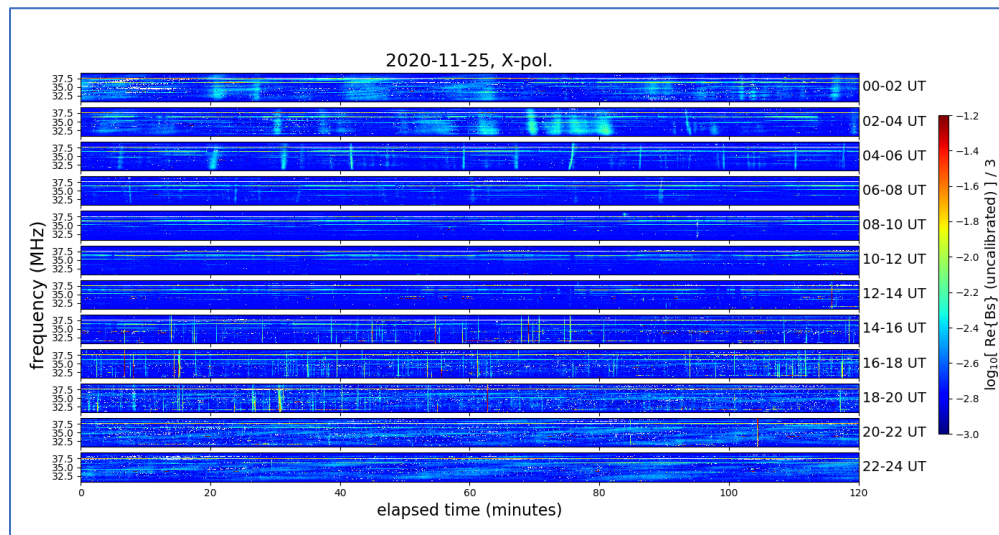


Figure 1. DLITE DATA FOR NOVEMBER 25, 2020-From Nasa.gov

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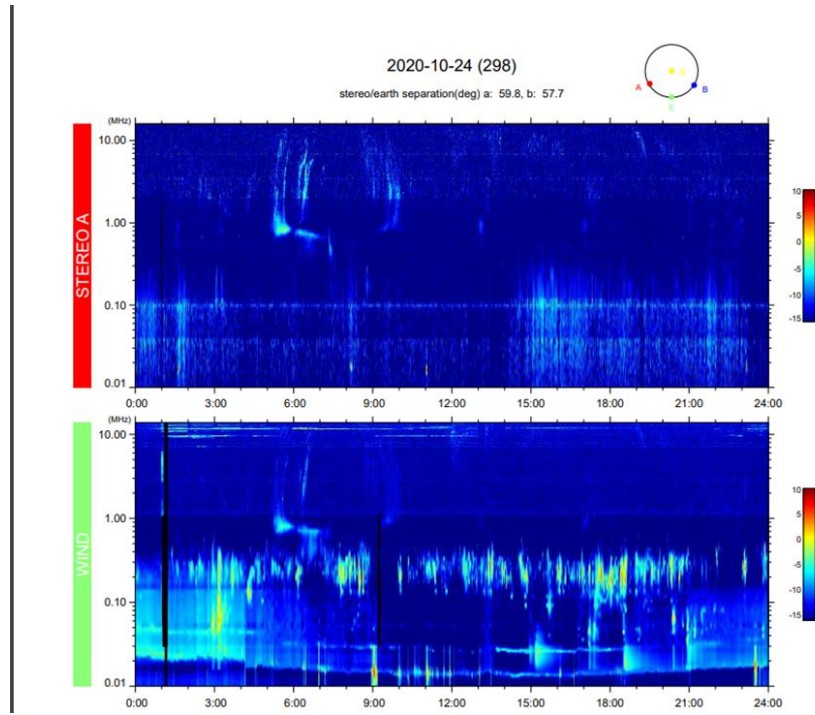


Figure 2. WAVES DATA-From Nasa.gov

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## RESULTS

Figure 3. is an example of a data set with type 2 and type 3 SRB's from the WAVES dataset.

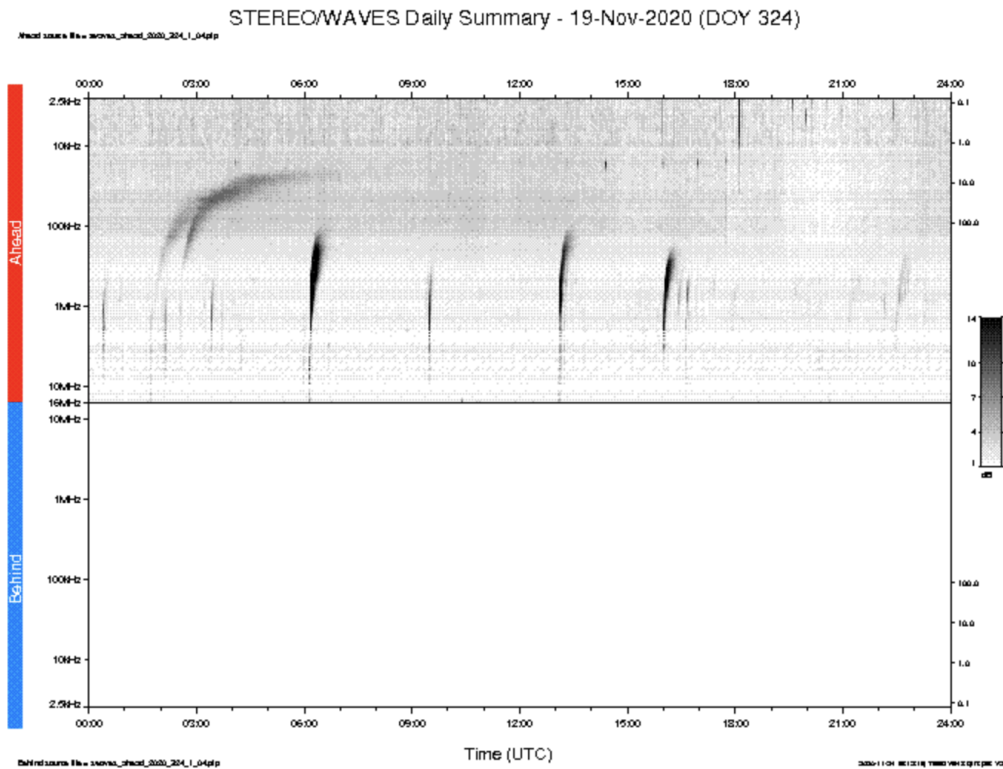


Figure 3. WAVES DATA from Nasa.gov

Type 1- (not illustrated) The best way to describe how they look is blurry vertical splotches with variation in size(width) that usually occur next to other type 1 bursts.

Type 2-shape is characterized by a logarithmic, horizontal sweeping motion. Each burst, fundamental or harmonic, usually has two lines that drift vertical and horizontal, each can help calculate the drift rate.

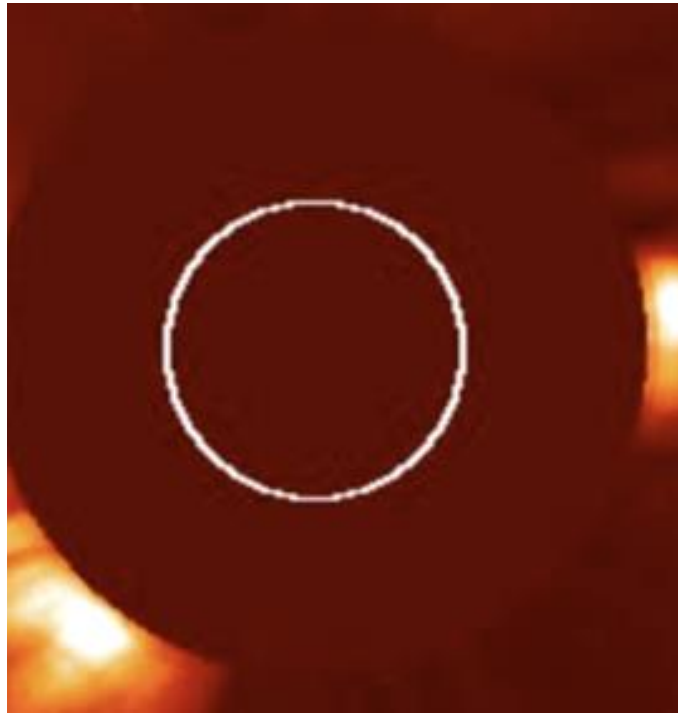
Type 3-similar in shape to type two's, logarithmic and horizontal sweeping, but angled a little more vertically and a little less horizontally. 2 types. Did not mention that for each burst there are two lines, but there may be unsure.

Type 4-cluster (not illustrated) that ends up looking somewhat rectangular or square.

In addition to the WAVES and DLITE data, I also compared information from the SOHO LASCO (Large Angle and Spectrometric Coronagraph) database. A successful entry on a day that could confirm some possible correlation between the bursts and and a CME. The SOHO LASCO

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Imagery would indicate partial or full halo, a CME headed towards the earth. Usually, as represented on image below (figure 4) taken from a SOHO LASCO video, the CME is represented by a clear circle quickly disseminating out from the center.

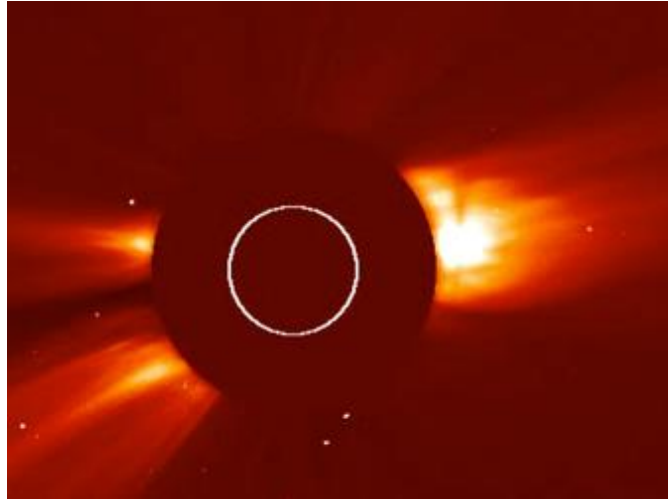


*Figure 4 SOHO LASCO IMAGE-From Nasa.gov*

CMEs can occur as non-halo's, not headed towards earth, and halo's, CMEs headed towards earth. The impact on the earth's magnetic field depends on the halo orientation.

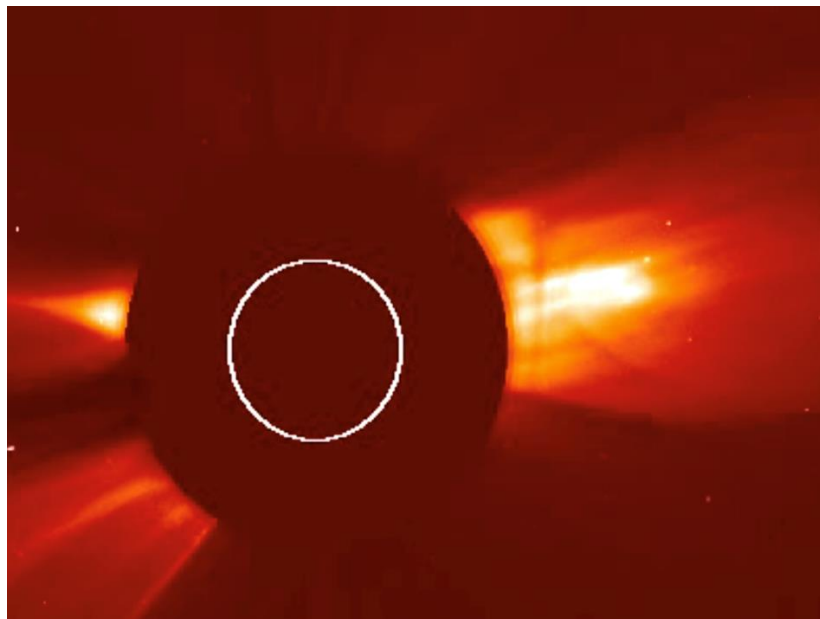
In the image below (Figure 5) SOHO LASCO shows a partial halo. On both sides of the circle for SOHO LASCO, plasma, or "streamers" as they are called can be seen drifting away from the circle (representing the sun).

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*Figure 5. SOHO LASCO Image showing plasma streamers-From Nasa.gov*

The image below (Figure 6) shows a yellow blob shooting (to the right of the sun) outward with two lines connecting it to the circle and that space between the two lines. This is possibly another indication of CMEs.



*Figure 6. Possible CME-From Nasa.gov*

The data I analyzed and submitted for the DLITE project are presented in Table 2, below.

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November	SWaves	WWaves	SOHO LASCO CME Catalog	SDO AIA	Solar Monitor Flares	DLITE MD	DLITE NM
6	type three burst (17:00)	type 3 burst (21:30-23:00)	11:48-Poor event; only three points: Only C2	moderate brightening detected	C1.1(17:40)- active site 12781 C1.8(15:13)- active site 12781	(-)	(-)
11	multiple type three bursts (3:40-6:00)	furry of type 3 bursts and noise storms throughout the entire day	12:48-poor event	two active sites-one moderate dimming, the other small eruption	(-)	17:40, 19:40, scattered points	19:40
13	type three burst (3:30)	a few smaller type three bursts followed by a large type three, potential type two(blurry) and noise storm (1:30-11:00)	18:00-Poor Event; Only C2	(-)	(-)	(-)	6:00-8:00
18	a few type three's and potential type two seen in the morning (before 12:00); 12:00-24:00 plethora of type three bursting in the higher frequencies)	notable noise storm(7:00-8:00); bursting with noise storm (12:00-14:30); multiple type three bursts (16:00-24:00)	00:12:06, 08:12:05, 11:12:06- Poor event	moderate amount of magnetic flux emitted near the end of the day	(-)		18:30 17:21:40
19	type 2 harmonic burst(about 2:00 and 3:00); type 3 bursts (6:00, 9:20, 13:00, 16:00, most notably); type 4 noise storm (9:40-11:20), most notably	potential type 2 harmonic burst(about 2:00 and 3:00); type 3 bursts (6:00, 9:20, 13:00, 16:00, most notably); type 4 noise storm (9:40-11:20), most notably	activity on both sides of the sun with a possible opening in the middle of the plasma that is being emitted (as talked about as an indicator of CMEs); 08:24:05 (Poor event)	small amount of magnetic flux emitted near start of morning	(-)	9:00-10:40, 16:00(maybe)	16:30(maybe)
24	large type three (1:00,16:00, 18:00, 19:30) smaller type three sprinkled throughout	larger type threes (1:00,16:00, 18:00, 19:30) large noise storm (4:00-10:00) with smaller type threes and potential type 2s	19:36:05- Partial halo	flux emitted from non active sites; large flux change on surface not near the non-active sites	C4.3(22:59)- active site 12785; C1.4(22:49)-- active site 12785	1:20, 18:00, scattered points	4:00-6:00
25	potential type two harmonic (1:00-2:00) noise storms and type threes throughout (major type threes 12:00, 17:00)	potential type two harmonic (1:00-2:00), moderate noise storm (5:00-7:00) heavy noise storm with bursts (10:00-20:00)	six instances of either poor or very poor events (01:36-14:24:05)	moderate brightening detected	C3.4(03:47)- active site 12786	3:00-4:00, (1:00)	(-)
26	moderate type three and noise storms all day	smaller type three bursts and noise storms all day	no halo, but in C2, two streamers can be seen emitting plasma in the shape of an upside down U with straight lines connecting the edge of the U to the edge of the sun, 21:12:10	moderate brightening detected	C1.0(15:35)- active site 12786 C3.8(12:42)- active site 12786 C1.8(06:52)- active site 12786	throughout (8:00-14:00 void)	throughout (8:00-14:00 void)
29	huge type three (13:00-16:00), smaller type threes before and after (1:00-20:00), noise storm in upper frequency (13:00-14:00)	same characteristics as s waves data except the addition of heavy noise storming (5:00-7:00) and (9:00-10:30)	17:12:05-Poor event, only C2	small eruption in the afternoon, some brightening	(-)	evidence for noise storm/large burst (13:00-13:20)	(-)

DISCUSSION

The Data table produced correlates some of the DLITE data and waves data to provide insight into the way different sensors and data analysis tools can be used to study the solar weather. The variety of sensors and data used to observe solar phenomenon has led to many opportunities to study and model the impacts of solar weather on the earth and humans and objects in space. The DLITE experiment is able to make a contribution to these efforts as a low cost sensor and as an educational tool to teach others about the properties of SRB's.

DLITE and SWAVES and other sensors are different because each sees a different part of the radio burst spectrum due to their positioning or around the earth and each picks up a slightly different piece of the sun. The creators of DLITE propose its value because d-lite different frequency pick up then s/w waves data with better sensitivity, less extra noise, and more accuracy.

CONCLUSION

CMEs can be predicted, but there is no absolute way to know when CMEs will occur. Scientists try to use data like this to come up with predictive models and use radio waves specifically because they come from solar flares which can be correlated with CMEs. There is no current way to block solar winds or solar flares. The frequency of radio bursts can help determine the location of the plasma emission and the strength of the magnetic flux leaving the sun. Using S/W waves, DLITE data on radio bursts, and SDO and SOHO LASCO observations, data we can look back and categorize solar phenomenon in hopes of furthering our understanding of the correlation between these things. With an increased knowledge of correlation, scientists, with

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the help of mathematicians should be able to create new hypothesizes and then test them theoretically. After they should be able to test the theories in real time using the gathered data. Continued work on gathering data is necessary, especially from new d-lite locations that may receive signals from different areas of the sky. After, resources should be allocated to theory and testing in both physics and statistics to make probabilistic models. In time, scientists should be able to better predict their occurrences and take protective measures.

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