Inverted U-Burst Observed on 21 August 2017

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1. Introduction

Totality of the solar eclipse that occurred 21 August 2017 was observable in a narrow corridor across the United States from Oregon to South Carolina, and a partial eclipse was observable from almost everywhere else in North America. Because the Sun is nearing the minimum of its current solar cycle, we were expecting that radio observations would be of a quiet Sun with possible effects from the eclipse. It turned out that the Sun had two active regions, AR2671 and AR2672, visible from Earth at the time with AR2671 pointed almost directly at Earth (figure 1). We observed numerous Type III radio bursts throughout the day of the eclipse and a rare inverted U-burst (called, simply, *U-burst* here) during the eclipse. The radio activity was coincidental with but unrelated to the eclipse itself.

In this paper we describe observations of the U-burst that were recorded at four stations in the e-Callisto solar radio spectrometer network at 1741 UTC. This burst has both fundamental and harmonic characteristics. Space Weather Prediction Center (SWPC) did not record any radio sweeps at the time of the U-burst (table 1) but we know from experience that SWPC occasionally misses solar radio events.

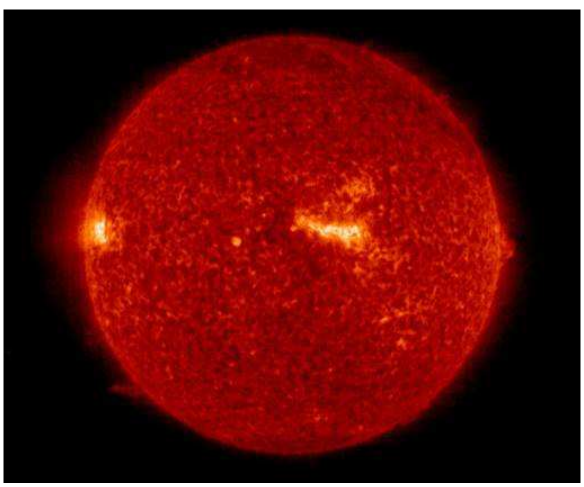

Figure 1 ~SOHO image of the Sun at 304 Å wavelength at 1319 UTC on 21 August roughly 3 h before the eclipse. It shows two active regions, AR2672 on left and AR2671 near the center. AR2671 was pointed almost directly at Earth – that is, near central meridian – during the eclipse. Source: https://sohowww.nascom.nasa.gov//data/REPROCESSING/Completed/2017/eit304/20170821/20170821_1319_eit304_512.jpg

Table 1 ~ Extract from SWPC solar events report from 21 August 2017 showing only the time period of the U-burst discussed in this paper. The U-burst occurred at 1741 UTC coincident with a reported weak X-ray event (XRA) that was detected by GOES13 (G13) spacecraft between 1739 and 1757. A few minutes later the Sagamore Hill station (SAG) in Massachusetts USA detected a weak radio burst at 410 MHz. Note that SWPC did not attribute these events to a specific active region, which normally is shown in the Reg column, probably because it was unknown. Source: ftp://ftp.swpc.noaa.gov/pub/indices/events/20170821events.txt

#Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
3370 +	1739	1757	1801	G13	5	XRA	1-8A	C3.0	1.8E-03	
3370 +	1754	1754	1754	SAG	G	RBR	410	110		

2. Inverted U-Bursts

A U-burst is a radio sweep-type burst whose frequency drift reverses direction (changes sign) over time. The burst typically starts at a higher frequency and sweeps to a lower frequency similar to a Type II (slow drift) or Type III (fast drift) but then reverses and sweeps back up to a higher frequency. A similar burst, called J-burst, stops before reversing.

The actual generation of the radio burst is thought to be a two-step process, first consisting of Langmuir wave production by an electron beam that has been accelerated to near-relativistic speeds (energies) by reconfiguration of the unstable magnetic field associated with a flare, and then followed by conversion of the waves to electromagnetic emissions. The dynamic spectra are produced as the beam moves from higher electron density areas in the upper corona outward to lower density areas. For U-bursts, the beam reverses direction as it is ducted between large-scale coronal magnetic field loops (magnetic arch) in the solar atmosphere (figure 2).

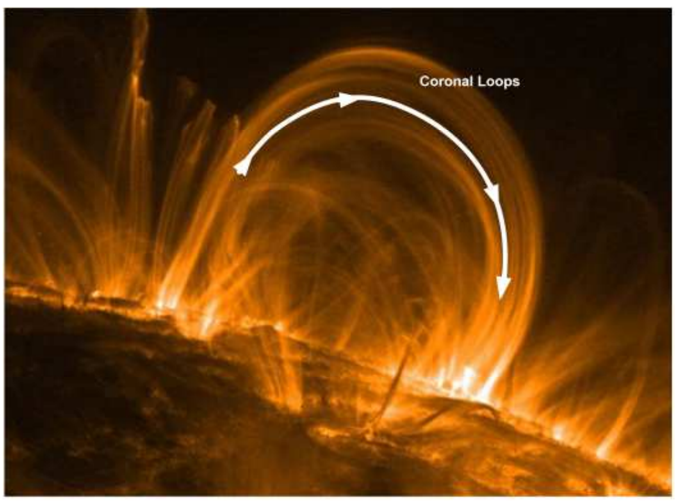

Figure 2 ~ Ducted propagation (white) of an electron beam along a coronal loop, which carries the beam from a higher electron density region up to a lower density and back down to a higher density. Underlying image source: https://www.nasa.gov/centers/goddard/news/topstory/2008/coronal_loops.html

U-bursts at lower frequencies (below approximately 100 MHz) often include a fundamental and second harmonic. If it exists the harmonic usually is in a ratio of 1.6 to 1.8:1 rather than the exact 2:1 ratio due to propagation effects in the solar atmosphere. The bursts may be weakly polarized with the polarization sometimes turning near the apex (lowest frequency) of the burst, but many bursts show no polarization. Our observations are described in section 3 following and the polarization aspects are described in section 4.

3. Observations

The U-burst was observed at four stations (table 2), which varied in west longitudes from 4° to 151° and north latitudes from 33° to 67°. None of the stations were along the path of totality; three were in North America and one in Europe. All stations produced Flexible Image Transport System (FITS) data files with 15 minute lengths consisting of 200 frequency channels and four observations per second (3600 x 200 pixels). These files were processed to produce the spectra below.

Table 2 ~ e-Callisto stations that observed the inverted U-burst on 21 August 2017.

Latitude (°)	**Longitude (°)**	**Elevation (m AMSL)**	**Frequency (MHz)**	**Polarization**	**Antenna**	**Figure**
Cohoe, Alaska USA						
60.37 N	151.32 W	22	45 ... 92	Circular	LWA	3, 4
Roswell, New Mexico USA						
33.44 N	104.52 W	1103	20 ... 92	LCP	LWA	5
Kangarlussuaq, Greenland						
66.98 N	50.94 W	149	10 ... 106	Circular	LWA	6
Glasgow, Scotland						
55.90 N	4.30 W	50	45 ... 81	Linear	LPDA	5

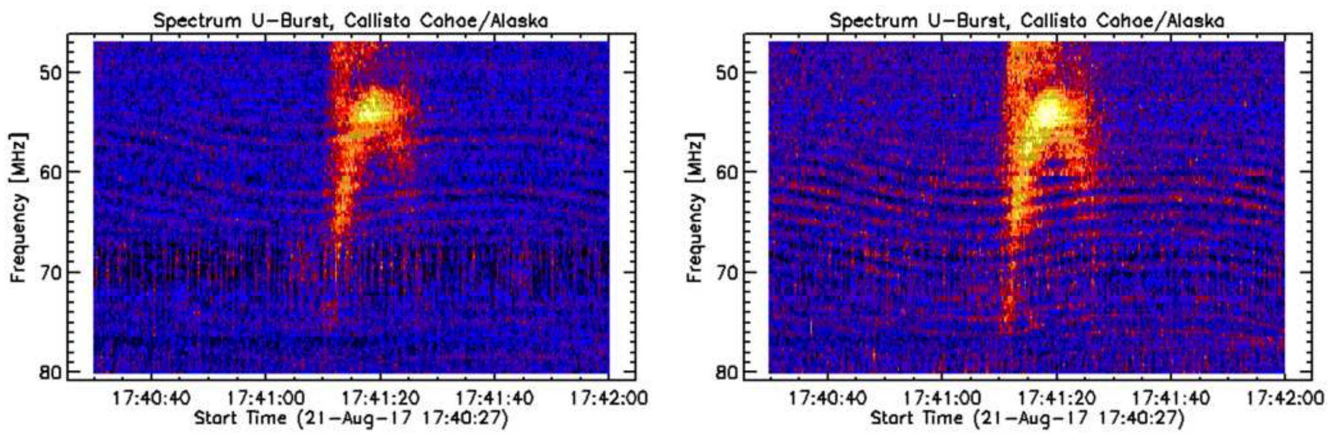

Figure 3 ~ Cohoe, Alaska USA: RHCP and LHCP circular polarizations, Bandwidth: 300 KHz, Integration: 1ms per pixel, LWA antenna. Comment: We see part of the fundamental excitation and 1st harmonic as complete structure. No RFI from nearby transmitters but some self-produced RFI, probably due to switched power supplies or other nearby electronic circuits

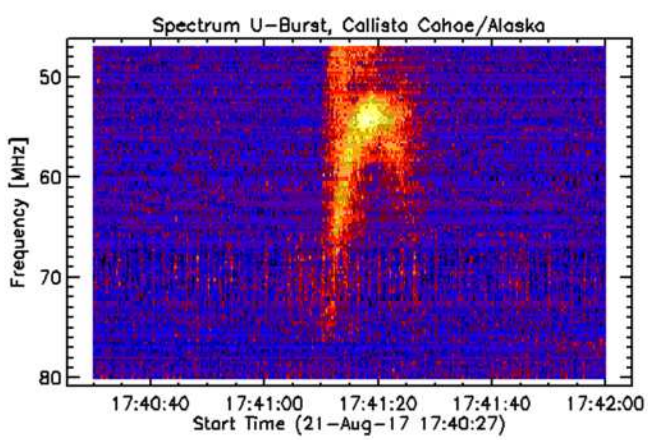

Figure 4 ~ Cohoe, Alaska USA: Combination LHCP + RHCP showing Improvement of signal by factor of 2 (=3 dB) and reduction of Gaussian noise by factor $\sqrt{2}$ (=1.5 dB). Comment: RFI is reduced because it is mostly not correlated. Combination with GLASGOW unfortunately is not possible due to different frequencies – although both stations use the same frequency range the individual frequencies are different.

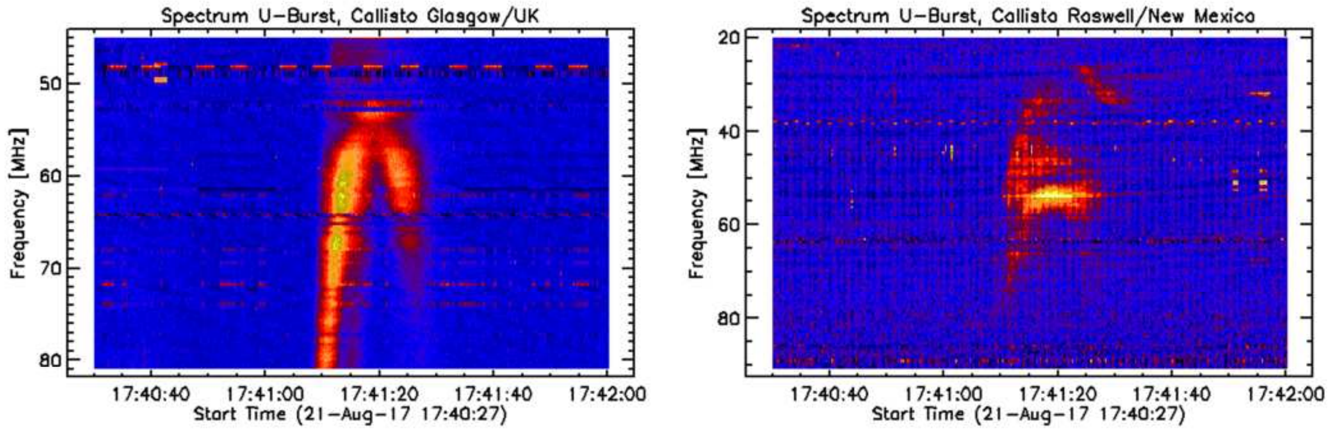

Figure 5 ~ Above left: Glasgow, Scotland: Left linear polarization, Bandwidth: 300 KHz, Integration: 1ms per pixel, log periodic dipole array antenna; Above right: Roswell, New Mexico USA: Left-hand circular polarization, Bandwidth: 300 KHz, Integration: 1ms per pixel, LWA antenna, Heterodyne up-converter between antenna and spectrometer. Comment: In left spectra we only see 1st harmonic > 55 MHz; in right spectra we see both fundamental and 1st harmonic. Both show RFI (horizontal structures from transmitters) and wavy structure from self-produced RFI, probably power supplies.

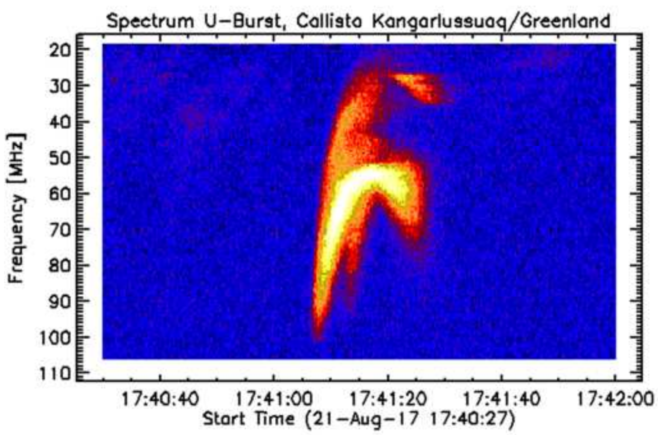

Figure 6 ~ Kangarlussuaq, Greenland: Circular polarization, Bandwidth: 80 KHz, Integration: 1ms per pixel, LWA antenna. Comment: We clearly see fundamental and 1st harmonic and no RFI at all.

4. Polarization Analysis

Burst polarization is derived from the difference between the received left and right circular polarizations (figure 7). Most scientists expect a change in polarization for the two different branches of the U-burst. However, due to so-called de-polarization of the burst while traveling through interplanetary space, polarization can get lost. At the Cohoe station, the only station for which both polarizations are available for the U-burst, polarization was completely lost and the burst was received unpolarized. The upper limit for maximum polarization error *pme* was calculated from

$$\boldsymbol{pme} = \mathbf{100\%}\ \mathbf{3}\boldsymbol{\sigma}\left[\frac{\boldsymbol{LHCP}-\boldsymbol{RHCP}}{\boldsymbol{LHCP}+\boldsymbol{RHCP}}\right] = \mathbf{1.4\%} \tag{1}$$

The expression inside the brackets stands for polarization, while 3 σ (σ = standard deviation) defines the maximum possible error in polarization *p*. LHCP stands for left-hand circular polarization and RHCP for righthand circular polarization. In case of the U-burst as received at Cohoe, the maximum error in polarization is in the order of ± 1.4%. Therefore, the U-burst disappears under the instrumental noise. This value was evaluated at 57.688 MHz for the first (leading) burst branch at 17:41:15 UT and at 17:41:20 UT for the second (lagging) branch.

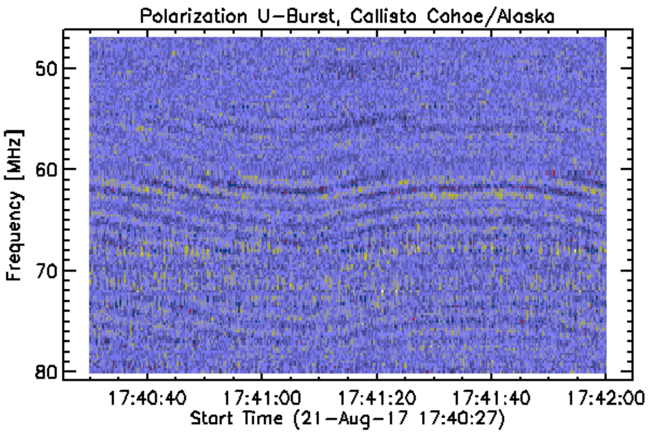

Figure 7 ~ Cohoe, Alaska USA: Difference LHCP – RHCP. We only see noise and some remaining RFI from nearby electronic circuitry. In this case, RFI was not completely compensated due to slightly different amplitudes and phases in the crossed-dipoles of the LWA antenna.

5. Discussion

Several Callisto stations in Europe and Asia could not observe the burst because the Sun was at too low elevation, near or even below the horizon. Other stations in South America could not observe the burst due to their frequency ranges which were far above the spectral range of the U-burst (INPE in Brazil and MEXART and UNAM in Mexico). We still hope to get more solar radio spectrometers operational on North America to provide cheap earth bound data to the scientists through the e-Callisto network.

The e-Callisto instrument network, politically supported by UN and NASA, has proved itself several times to be a cheap and simple system. In conjunction with e-Callisto, we hope to provide more and better data once the *Solar Orbiter* is in space (ESA}. While Solar Orbiter is observing the radio sun from dc to 20 MHz, Callisto could easily provide spectral data above the ionospheric cutoff frequency from 16 MHz up to 870 MHz or even higher by using heterodyne converters and appropriate antennas like the LWA antenna and log periodic dipole arrays (LPDA). Information about instrument concepts, hardware, software and data access may be found at the instrument website {Callisto}.

It was purely by chance that we observed a U-burst during the total solar eclipse over the United States. Some people believe that the U-burst has something to do with the eclipse, but from a scientific point of view this is simply speculation with no physical background. We hope to receive more U-type bursts for evaluation of the polarization – a topic that is still under discussion among the solar physicists.

6. References and Web Links

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{Callisto} http://www.e-callisto.org/

{ESA} http://www.esa.int/Our_Activities/Space_Science/Solar_Orbiter

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