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PROPOSAL COVER SHEET

V6.0

Cycle 10 Call for Proposals: LWA1 Radio Observatory

Submit to: lwa@unm.edu by 11:59 MDT Nov. 1, 2021

Project title: **Studies of Solar Radio Bursts with LWA**

Project Summary (please do not write beyond this space):

This is a proposal to continue studies of solar radio bursts, focusing on coordination with perihelion passages of the Parker Solar Probe satellite. Major observing campaigns will be carried out in conjunction with these passages, occurring about every 3 months. Four perihelia occur in 2022, but we will primarily be interested in 3 perihelia where Probe approaches the Sun from the Earth side. Probe has in-situ radio and energetic particle detectors that can measure simultaneously radio bursts generated in the solar wind and the electrons that produce them. Electron beams ejected from the Sun via energy releases in the atmosphere produce radio emission by the plasma emission mechanism, and are visible as Type III bursts in radio observations. LWA's frequency range of 15-85 MHz samples the corona at heights of order 1-2 solar radii above the surface, while Probe can see radio emission at lower frequencies, and measure the radiating electrons directly in the solar wind when a beam intersects with the spacecraft. Thus the evolution of electron beams with height can be studied by the combination of Probe and LWA data.

Project Investigators:

	Name	Affiliation	Email
PI	[redacted]	[redacted]	[redacted]
Co-I			
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Co-I			
Co-I			

PI Contact Information

Mailing address: [redacted]

Phone number: [redacted]

Requested mode(s):	Backend(s) for each requested mode:			
■ LWA1 only	☐ DRX	☐ TBN	☐ TBW	■ DR-Spec
☐ LWA-SV only	☐ DRX	☐ TBN	☐ TBF	☐ DR-Spec
☐ LWA1+SV Interferometer	☐ DRX			

Observing Request Information (leave fields that do not apply to your setup empty):

LWA1 only time request:	hrs/beam:	120	nr of beams:	2
LWA-SV only time request:	hrs/beam:		nr of beams:	
LWA1+SV interferometer time request:	hrs:		–	–
Repeated observations: length of each block (hrs):	4			
frequency of blocks (or when):	2 per day for 4 consecutive days every 4 months			
Restrictions in observing time (time of day):	Daytime			
Restrictions in observing time (time of year):	Coordination with Solar Probe perihelion dates			

Special requirements (e.g. external trigger, outrigger dipole – describe use):

Solar tracking; flexible scheduling in case of solar activity.

Observational Details:

Please give center frequencies (ν_1, ν_2) and corresponding bandwidth (BW) for each source. If more pointing positions are required, please attach a separate sheet with all details.

Source 1		**Beam 1**		**Beam 2**		**Beam 3** (*LWA1 only*)		**TBN**	
Name	Sun	(MHz)		(MHz)		(MHz)		(MHz)	
RA (hh.h)	00:00	ν_1	24	ν_1	58	ν_1		ν_1	
Dec (dd.d)	00:00	BW	19.6	BW	19.6	BW		BW	
LST beg (hh.h)		ν_2	41	ν_2	75	ν_2		ν_2	
LST end (hh.h)		BW	19.6	BW	19.6	BW		BW	
Source 2		**Beam 1**		**Beam 2**		**Beam 3**		**TBN**	
Name		(MHz)		(MHz)		(MHz)		(MHz)	
RA (hh.h)		ν_1		ν_1		ν_1		ν_1	
Dec (dd.d)		BW		BW		BW		BW	
LST beg (hh.h)		ν_2		ν_2		ν_2		ν_2	
LST end (hh.h)		BW		BW		BW		BW	
Source 3		**Beam 1**		**Beam 2**		**Beam 3**		**TBN**	
Name		(MHz)		(MHz)		(MHz)		(MHz)	
RA (hh.h)		ν_1		ν_1		ν_1		ν_1	
Dec (dd.d)		BW		BW		BW		BW	
LST beg (hh.h)		ν_2		ν_2		ν_2		ν_2	
LST end (hh.h)		BW		BW		BW		BW	
Source 4		**Beam 1**		**Beam 2**		**Beam 3**		**TBN**	
Name		(MHz)		(MHz)		(MHz)		(MHz)	
RA (hh.h)		ν_1		ν_1		ν_1		ν_1	
Dec (dd.d)		BW		BW		BW		BW	
LST beg (hh.h)		ν_2		ν_2		ν_2		ν_2	
LST end (hh.h)		BW		BW		BW		BW	

Studies of Solar Radio Bursts with LWA

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Radio observations in conjunction with Parker Solar Probe

The Sun is presently well into the rise phase of solar cycle 25. In fact, the first major flare of soft X-ray class X, together with the first official energetic proton event of the cycle, occurred 3 days prior to the LWA deadline. Thus we can expect significant flaring activity in 2022 as the new activity cycle ramps up further. Studies of solar activity will focus on coordinated observations with two major satellites now operating in the inner heliosphere: NASA's Parker Solar Probe (PSP) and ESA's Solar Orbiter (SO). One of the main goals of these missions is to study the solar wind and its evolution with distance from the Sun. This includes electron beams released by the Sun in impulsive events. These electron beams can produce bright radio emission that can be observed by LWA. Ground-based observations supporting these missions is a major activity that will continue to occupy the solar community over the next few years.

Probe has a highly elliptical orbit that will progressively approach closer and closer to the solar surface over the next few years using fly-by's of Venus to alter its orbit, eventually getting down to below 10 $R_\odot$. During 2022, the 4 Probe perihelia will each pass within 13.3 $R_\odot$ of the Sun. Probe only turns on all instrumentation during perhelia passages. This is because telemetry is not possible while Probe is close to the Sun, so data taken during perihelia are stored on-board and then telemetered back to Earth slowly during the aphelion phase of the orbit. Probe needs to hide all instruments behind a strong heat shield, since otherwise they would all melt, and thus it mostly takes in-situ data (solar wind particle data, electric and magnetic fields, and wind composition). A major scientific justification for Probe is the ability to sample the region close to the Sun where the solar wind accelerates and forms: better understanding of the solar wind is important both for astrophysical reasons, and for forecasting impacts to Earth. Thus Probe measures particle and turbulence properties in the low solar wind; over time, it will sample the full range of solar activity and wind conditions.

Solar Orbiter has an eventual closest approach to the Sun of 0.28 AU, but will also travel out of the ecliptic. It has in-situ instruments, but also imaging telescopes that Probe lacks. In particular, it has a hard X-ray imaging telescope (STIX; Krucker & multiple co-authors, 2020) that will observe accelerated electrons as they produce X-rays in the low atmosphere and thus is an excellent complement to radio data.

The Probe instrumentation is focussed on sampling solar wind properties and is not optimal for the study of higher-energy particles. This is where LWA can play a role: it is incredibly sensitive to nonthermal electrons in the solar atmosphere through the radio emission they produce. With two beams LWA1 can cover the full 15–85 MHz spectrum and thus observe solar radio bursts as they drift across this frequency range, which corresponds to heights of order 1 to 2 solar radii above the photosphere. Bursts at these heights are strong emitters via the "plasma emission" mechanism, which involves conversion of electrostatic Langmuir waves at the plasma frequency, $f_p = 9000\sqrt{n_e}$ (where n_e is the electron density), generated by unstable electron energy distributions, into escaping electromagnetic waves. In particular, electron beams propagating out into the solar wind produce so-called "Type III" radio bursts, which show up in dynamic spectra as short-duration features travelling rapidly from high to low frequency, since the frequency of plasma emission maps to electron density as $\sqrt{n}_e$.

With the proposed LWA observations, we seek to measure the radio emission from nonthermal electron beams that Probe will also measure (up to keV energies) in situ. We note that the LWA frequency range does not sample the same height range that Probe does: emission at 10 MHz and higher frequencies arises below 10 $R_\odot$. However, Probe carries radio instrumentation (FIELDS; Bale & 83 co-authors, 2016) that covers the range from 1-16 MHz appropriate for the height range that Probe will sample. Thus we hope to see radio bursts arising low in the solar atmosphere, where EUV instruments on SDO can see brightenings, propagating through LWA's height range, and then into Probe's path where both lower-frequency radio data and in-situ data can be measured. An important issue is how electron beams evolve with height as they propagate, and being able to trace the entire path out to where Probe can measure them in situ would allow us to investigate this question in detail.

At each perihelion passage there are large supporting campaigns involving essentially every telescope (ground- and space-based) capable of observing the Sun. Even in the absence of active regions, there can still be small eruptions in regions of evolving quiet-Sun magnetic fields that produce electron jets that can propagate into the solar wind. Studies of such brightenings are important for investigating the role they play in heating the solar atmosphere. The LWA observations are more sensitive to such weak radio bursts than most other ground-based instrumentation: since plasma emission is a coherent mechanism, it can produce quite strong emission from a small energy release. Sensitivity comparisons with FIELDS on PSP should prove interesting. Simultaneously the soft X-ray imaging telescope on the *Hinode* satellite will be looking for X-ray signatures. LWA data can play an important role in these campaigns by revealing when nonthermal electron beams are produced, and associating them with phenomena seen at other wavelengths. We may also request observations should any periods of major activity occur during 2022.

Recent LWA Solar Observations

Under LW011 we observed PSP perihelia 7, 8 and 9. During perihelion 8, significant activity was observed. Figure 2 shows the LWA dynamic spectrum for a bright isolated Type III burst on 2021 May 1, showing complex structure including discrete narrow-band striae (short horizontal structures) and long-lived broader-band emission.

Figure 2 shows a Type II burst observed 2 days later from an active region that had passed behind the solar limb as seen from Earth, so no flare was observed by Earth-orbiting satellites, but a coronal mass ejection was visible. Probe's line of sight was better placed for the likely flare location, so it is expected that the Probe radio instruments at least detected any radio emisison at lower frequencies. However, as noted earlier, one drawback of a mission that passes so close to the Sun is that telemetry is very limited during perihelia, so most Probe data are not telemetered back to Earth until it is passing back outwards to the orbit of Venus. For this reason, data release is highly delayed: specifically, the data from the FIELDS instrument for perihelion 8 are not yet available.

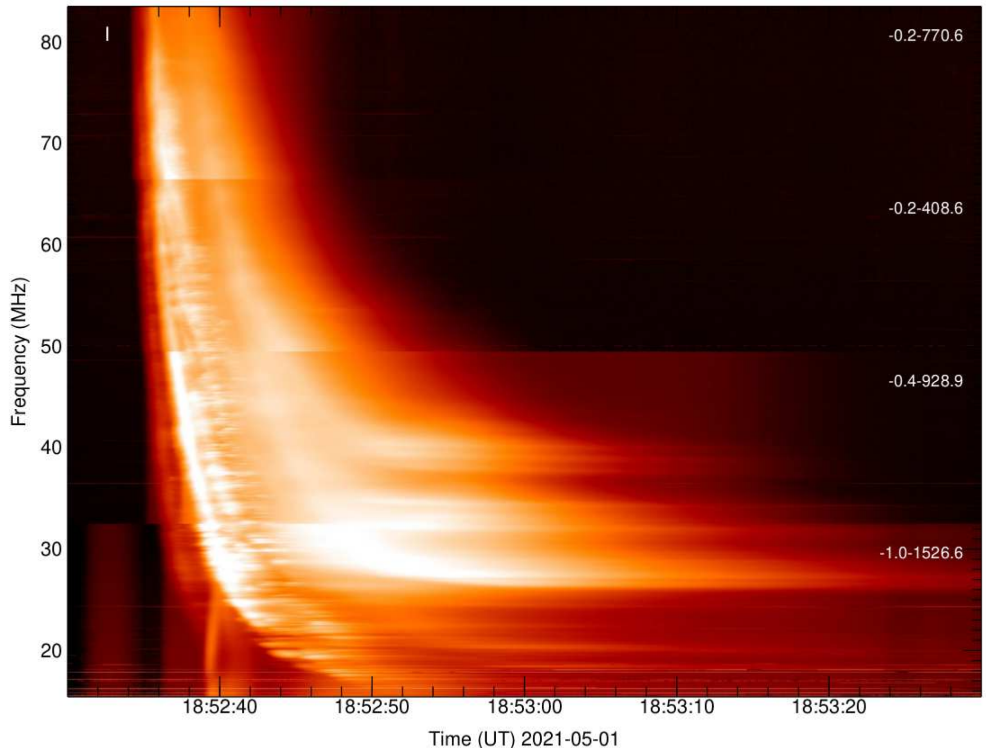

Figure 1: The LWA dynamic spectrum (two beams combined, upper panel = Stokes I) of a Type III burst observed on 2021 May 01 during perihelion passage #8 of PSP. The four sidebands are combined to provide continous frequency coverage. The data have been flux-calibrated against a strong source, and the numbers in each of the 4 frequency ranges represent the peak flux in sfu in that range. The discrete narrowband features seen early in the event are "striae" that are probaly at the fundamental plasma frequency f_p, while the smoother trailing traemission may be harmonic emission at $2f_p$.

Proposed observations and data management

For Probe studies we will request observations during daylight hours for several days (3 to 5) around each perihelion. Four PSP perihelia will occur in 2022, as the distance of closest approach continues to decrease: Feb 25 (11), Jun 01 (12), Sep 06 (13) and Dec 11 (14). Not all perihelia are suitable for comparison of LWA data with Probe data: in particular, during the September perihelion Probe is mostly on the back side of the Sun and less likely to sample electron beams from the visible hemisphere that LWA can see. The time request is an estimate for the coverage of the other three events where Probe has good coverage on the Earth's side of the Sun.

The observing mode we generally request is to use two DRS spectrometer beams with 19.6 MHz bandwidth per band on the Sun simultaneously, although we cannot rule out the need for full DRX data for some applications (e.g., if Type II bursts seem likely). A pair of beams can cover essentially the full LWA frequency range from 15-84 MHz. Type III bursts produced by electron beams often cross this entire frequency range (e.g., Fig. 1). We will observe a strong source at the beginning of each track for bandpass and flux calibration.

DRS files are generally small and are not an issue for transfer, data analysis and storage. Raw DRX mode produces large files and a large data volume, but we have already demonstrated the ability to handle this at AFRL with the existing LWA1 DRX data. Data storage will be handled at AFRL, and any DRX data transfer will be achieved by hand–carrying hard drives between AFRL and UNM, as has been done previously. We will comply with the LWA publication policy.

References

Bale, S. D. & 83 co-authors. 2016, Space Sci. Rev., 204, 49

Krucker, S. & multiple co-authors. 2020, Astron. Astrophys., 642, A15

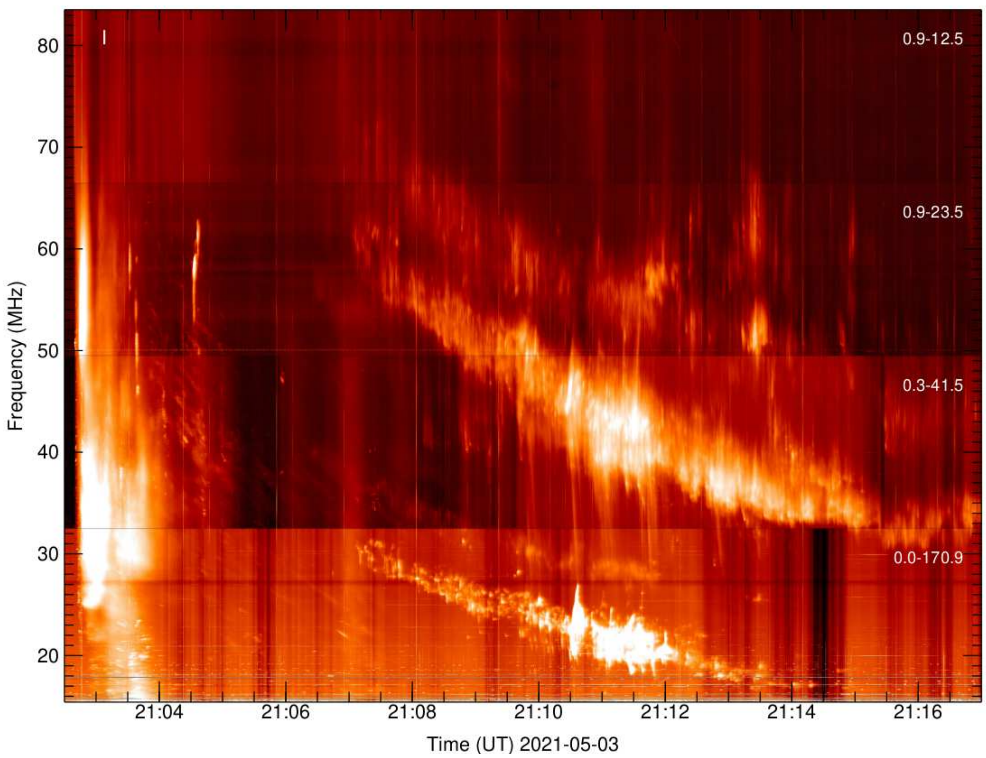

Figure 2: The LWA dynamic spectrum of a Type II burst observed on 2021 May 03 during perihelion passage #8 of PSP. This exhibits the classic Type II fundamental-harmonic band structure with each band being split. This event was from an active region that had passed behind the visible solar limb and thus no flare was observed from Earth.