The Long Wavelength Array and the Radio Transient Sky

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Summary

The LWA and other low frequency, dipole-based, arrays in development (such as LOFAR and the MWA), will be powerful probes of the transient radio sky.

While we are confident of many exciting results based on the known classes of transients, as describe herein, it is likely that the most exciting discoveries will be those that are not anticipated. When a new wavelength regime is opened and instrumental capabilities are improved by orders of magnitude, as is the case for the LWA, the discovery space is such that it is very hard to anticipate what the most important scientific contributions will be.

Radio Transients

Transient emission—bursts, flares, and pulses on time scales of order one month or less—marks compact sources or the locations of explosive or dynamic events. As such, radio transient sources offer insight into a variety of fundamental physical and astrophysical questions including:

- The mechanisms of efficient particle acceleration;
- Possible physics beyond the Standard Model;
- The nature of strong field gravity;
- The nuclear equation of state;
- The cosmological star formation history;
- Detecting and probing the intervening medium; and
- The possibility of extraterrestrial civilizations.

(See Cordes, Lazio, & McLaughlin 2004)

In fact, relatively few radio transients are known and most that are were not found in blind radio searches, but rather by following up transients detected at other wavelengths (particularly X-ray). This paucity of radio transients can be attributed to two factors:

(1) Intrinsic: Many of the bright radio sources are from extended regions that can't vary rapidly (e.g. SNe, AGN radio lobes)

(2) Radio observations have historically been very insensitive to transients for a variety of reasons: imaging a very small field of view, not subdividing observations into time, not revisiting regions often, and confusion limits due to poor spatial resolution.

Known and Potential Classes of Transient Radio Sources

- Ultra high energy particles
- The Sun
- Planets
- Brown dwarfs
- Flare stars
- Pulsar giant pulses
- Transient (e.g. nulling) pulsars
- Rotating Radio Transients (RRATs)
- X-ray binaries
- Soft gamma-ray repeaters
- Maser flares
- AGN
- Radio supernovae
- Gamma-ray bursts
- Gravitational wave sources
- Annihilating black holes
- Extra-terrestrials

LWA Transient Capabilities and Technical Challenges

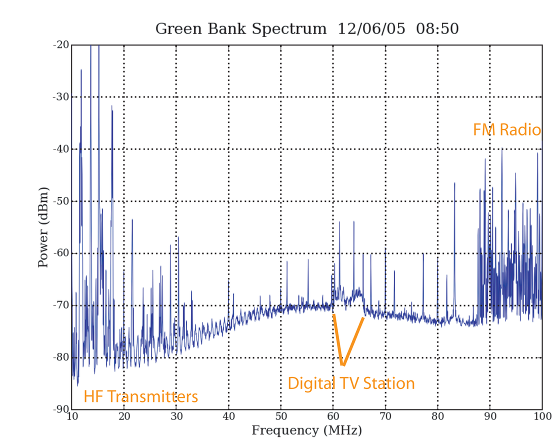
The LWA will be a fully electronically-steered dipole array with multibeaming capability (see summary table below). This design and the low observing frequencies employed present numerous advantages for transient science including:

- Large field of view for each beam
- Multiple beams allow monitoring of several directions at once
- Rapid repointing enables very quick sky surveys
- Low frequencies tend to select for steep spectrum sources such as coherent emitters which are nearly always highly variable
- The large field of view and planned calibration techniques allow observations to proceed uninterrupted by period visits to phase calibrators which disrupts the observations of conventional radio interferometers like the VLA.

Frequency range, bandwidth		20-80 MHz, 0.05-3.0 MHz
Total collecting area	@ 20 MHz	10^6 m^2
	@ 60 MHz	10^5 m^2
Angular resolution	@ 20 MHz	8"
	@ 60 MHz	**2"**
Pointing/frequency conversion ti me		< 1 ms
Sky coverage		< 60° zenith distance
Sensitivity ($\Delta\nu$=3 MHz, t=8 hr)	@ 20 MHz	~3 mJy
	@ 60 MHz	~1 mJy
Polarization		Full
Field of view	@ 20 MHz	~12°
	@ 60 MHz	~3°
Number of instantaneous baselines		1300
Time resolution		10 ms

Radio Frequency Interference

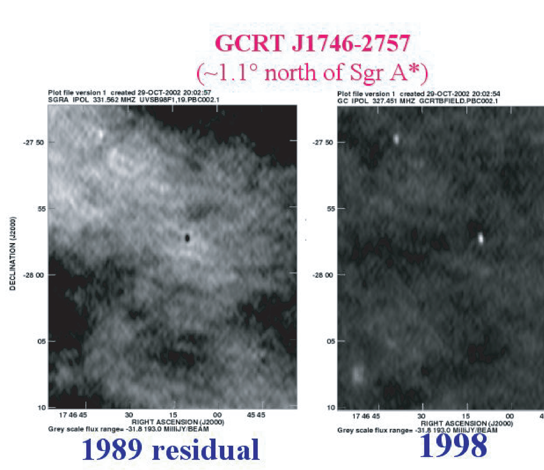
The low frequency band in which LWA plans to operate encompasses numerous very strong sources of interference (see figure at right). In order to address many of the transient science goals, the LWA must be able to operate robustly in the presence of these signals. This places significant requirements on the hardware design, for example the quantization dynamic range of the digital receiver, and early channelization of the signals to allow for RFI excision. In addition, automated techniques must be developed to support both pre- and post-correlation RFI removal.



Sample of RFI in the 10-100 MHz band, at a quiet site!

Imaging Issues

In order to realize the transient source capabilities of the LWA, several significant imaging issues need to be overcome:
(1) Wide-field imaging with high fidelity across the full field of view,
(2) Accurate subtraction of images from different epochs (and with different u-v coverage) for detection of transients,
(3) Imaging data sets split into different length segments optimized for different types of transients, and
(4) Advanced algorithms for automated detection of transients in large data sets (e.g. McGowan, Junor & Lazio 2005)



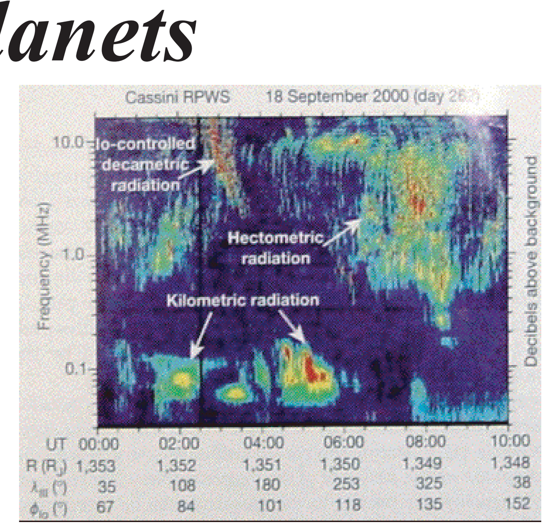
Example of image subtraction for transient detection.

Potential LWA Transient Science Highlights

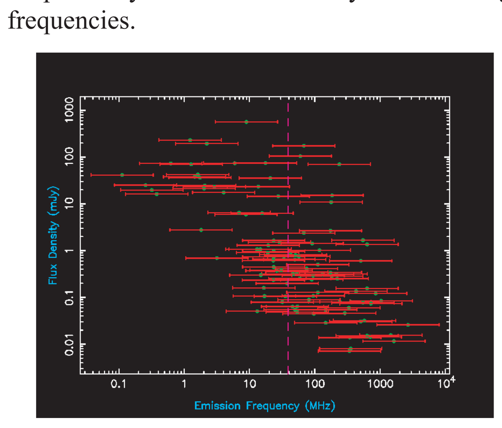
Extrasolar Planets

The Earth and the giant planets in our solar system generate planetary-scale magnetic fields. The polar regions of these "magnetic planets" produce intense radio emission from solar wind-powered currents. For the solar system planets, empirical scaling laws relate their magnetic field strengths and radio luminosities to their masses and distances from the Sun.

Extrapolating these relations to the known extrasolar planets suggests that the radio emission from some extrasolar planets may be detectable with the LWA. Detection of magnetically-powered emission from extrasolar planets provides information that will be difficult to obtain otherwise: The existence of a magnetic field constrains a planet's interior while modulation of the radio emission can yield its rotation rate and the possibility of satellites. More generally, magnetic fields may be important in helping a planet retain its atmosphere and affect its albedo. These latter effects are more important for terrestrial-mass planets rather than the known extrasolar planets. Making robust estimates of the strength of a terrestrial-mass planet's magnetic field (e.g., discovered by *Kepler* or *Terrestrial Planet Finder*) may be essential in assessing the planet's habitability.

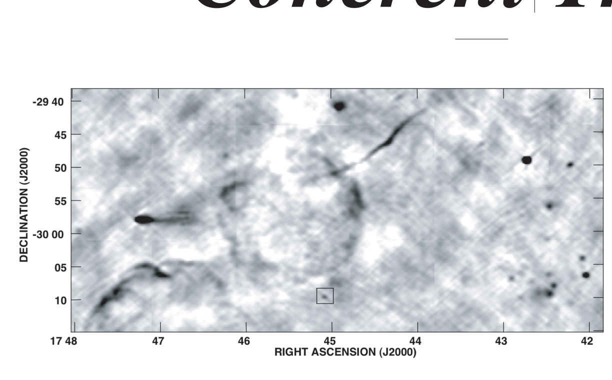


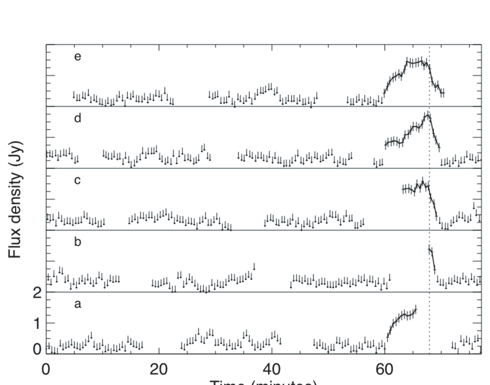
A dynamic spectrum of Jovian radio emission, illustrating its variability. While most of this emission is below the Earth's ionospheric cutoff, Jupiter's emission extends to 40 MHz, and extrasolar planetary radio emission may extend to higher frequencies.



The predicted ``burst" flux densities for roughly 100 extrasolar planets vs. the characteristic emission frequencies (Lazio et al. 2004). The horizontal bars indicate the assumed ranges for the emission frequencies, allowing for statistical variations in planetary magnetic moments. The vertical dashed line indicates the Jovian cutoff frequency.

Coherent Transients





GCRT J1745–3009

GCRT J1745–3009 was discovered in a search for radio transients near the Galactic center using 330 MHz VLA observations (Hyman et al. 2005, 2006). In the initial analysis of the full dataset, it appeared only as a new 100 mJy source (above left). Upon imaging the data in 30-s intervals, the source was found to exhibit apparently regular 10-min. bursts that peaked at about 1.5 Jy! These bursts occurred every 77 min. during the 6 hr observation (above right). Other 330 MHz VLA observations, and deep 1.4 GHz observations, did not detect the source. A single burst was seen in a 330 MHz GMRT observation taken a year later.

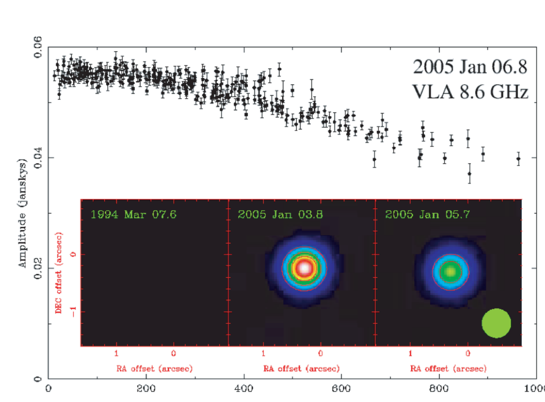
The time scales ($\tau \sim 2$ min.) and flux densities of the outbursts implies a brightness temperature > 10^{12} K if the source is at a distance > 70 pc. As this is greater than the maximum brightness temperature expected from an incoherent synchrotron emitter, GCRT J1745-3009 may well be the first example of a new class of coherently emitting radio transients.

The LWA will be a powerful tool for searching for coherent transients. It will be able to survey much larger regions of sky than has been possible with conventional pointed dish interferometers, and, as coherent emission processes tend to be very steep spectrum, the low frequency band may make them much easier to find.

SGR Giant Flares & GRBs

SGR Giant Flares

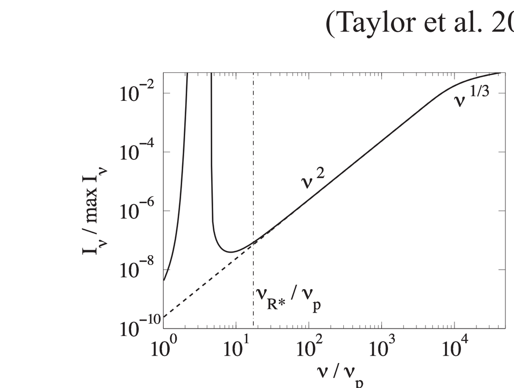
The 2004 December 27 giant flare from SGR1806–20 was detected as a steep spectrum ($\sim\nu^{-0.6}$ at *t*+7 days) fading radio source that reached flux densities of a few hundred mJy at 220 MHz. The LWA will allow detections of such flares at lower frequencies and at very early times (either in blind searches or triggered by satellite observations). The low-frequency spectrum constrains the electron energy spectrum and probes absorption at early times. SGR giant flares may be detectable in nearby galaxies and may explain some of the short/hard gamma-ray bursts.



(Taylor et al. 2005)

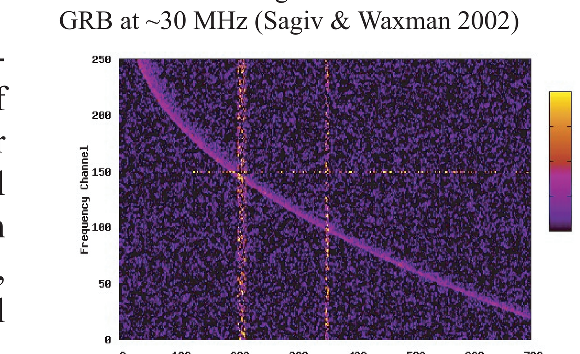
Gamma-ray Bursts

GRBs may produce prompt radio emission, peaking at low radio frequencies (right). If detected, such emission will be an important probe of the GRB environment and the intergalactic medium (Morales et al. 2005).



Predictions for strong coherent emission from a GRB at ~30 MHz (Sagiv & Waxman 2002)

The rapid pointing capability, broad frequency coverage, and spectral resolution of the LWA make it an excellent instrument for searching for prompt emission. Fine spectral resolution is required to correct for dispersion in the interstellar and intergalactic medium, which would otherwise smear the signal (below right).



The effect of interstellar dispersion on a prompt GRB signal.