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An Overview of LWA Science

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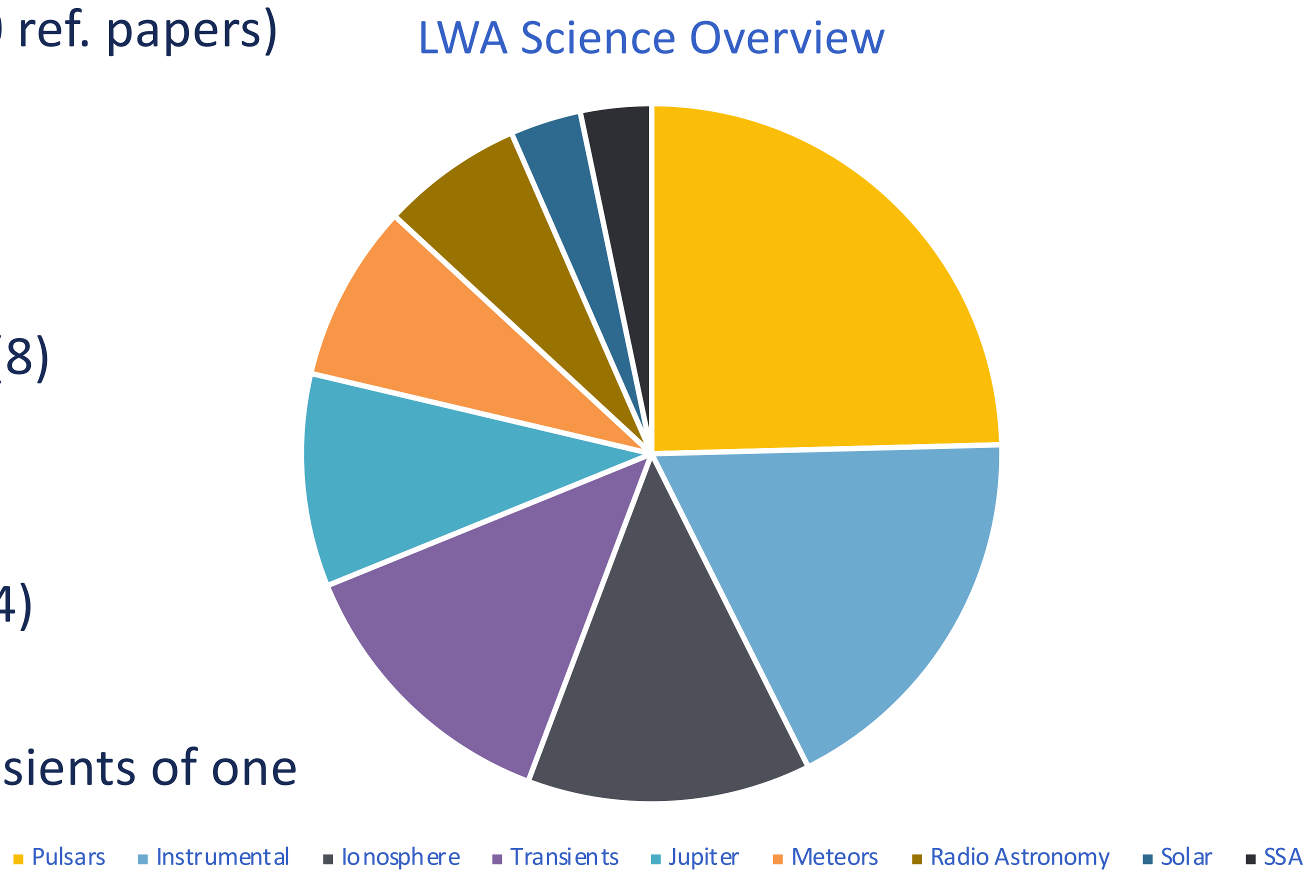
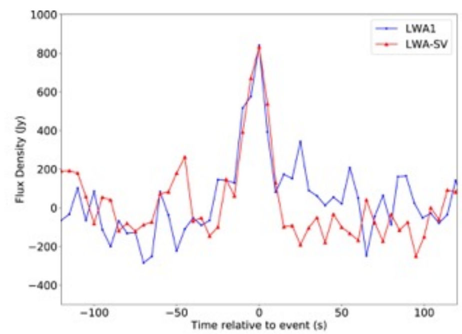
LWA Science Distribution

- Dominant themes (>60 ref. papers)
  - Pulsars (15)
  - Instrumental (11)
  - Ionosphere (8)
  - Cosmic Transients (8)
  - Jupiter (6)
  - Meteors (5)
  - Radio Astronomy (4)
  - Solar (2), SSA (2)
- Dominant Theme: Transients of one kind or another

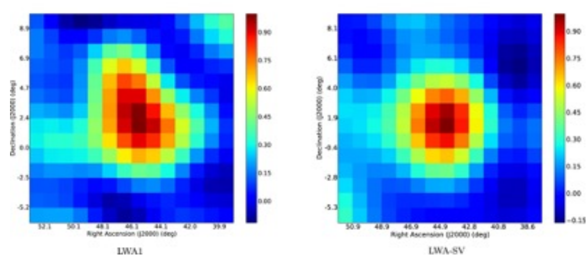


Blind Transient Searches: LWAT 171018!

- "Detection of a Low-frequency Cosmic Radio Transient Using Two LWA Stations"
  - Varghese, Obenberger, Dowell, Taylor 2019, ApJ, 874, 151
- Seen by both LWA1 and LWA-SV on 10-18-2017
  - 15-20 second duration
  - LWA1: 842 ± 116 Jy, LWA-SV: 830 ± 92 Jy
- Nature: Unidentified
  - Pan-STARRS optical SN on edge of position error circle (same day)
  - Would imply prompt, coherent emission



Stokes I light curves from LWA1 (blue) and LWA-SV (red).

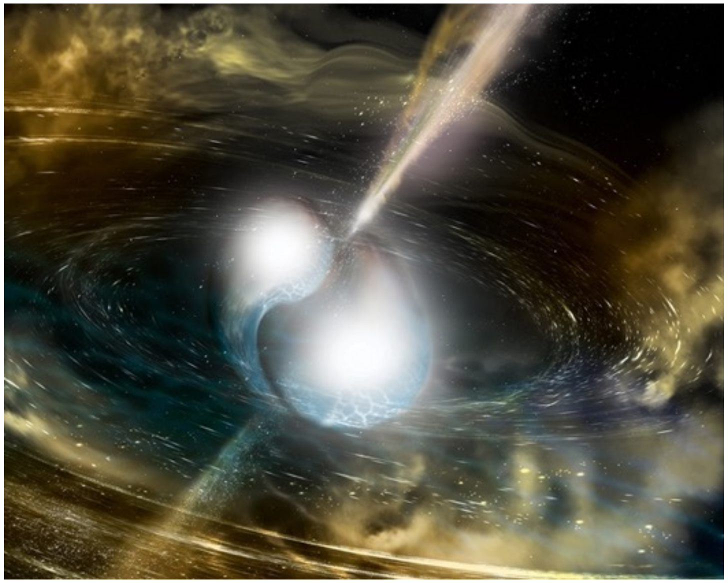


Subtracted image of the transient from each station.

Targeted Transient Searches: Radio Emission and the physics of compact object mergers (incoherent)

Incoherent synchrotron Emission

- Critical diagnostic of the blast wave ejecta energetics and merger environment
- Sub-GHz sensitivity to spectral peak (probing energetics and geometry) and SSA turnover (constrains ambient density)
- These quantities are difficult to measure at higher frequencies.



Artist's depiction of GW170817: 1st NS-NS merger observed across the electromagnetic spectrum, including radio (Hallinan et al. 2017, LWA limits in Abbott et al. 2017).

Targeted Transient Searches: Radio Emission and the physics of compact object mergers (coherent)

- **Coherent emission** predicted for BH+BH, BH+NS and NS+NS mergers
- Not detected yet but favors sub-GHz regime
- In analogy with FRBs, prompt, coherent emission provides a DM and an *independent distance measurement*
- "A first Search for Prompt Radio Emission from a Gravitational-wave Event"
  - Tom Callister, Marin Anderson, Gregg Hallinan et al. 2019, ApJ, 877, L39
- Targeting GC170104 (binary BH merger) detected by LIGO & Virgo (O2)
  - Searched 900 deg^2 region within ~1 hr
  - Upper limit: 2.5×10^{41} erg s^{-1} equivalent isotropic luminosity (27-84 MHz)
- Understood that binary BH merger is not the ideal candidate for EM counterpart
  - Learning experience to prep for O3 run and plans to target NS-NS mergers

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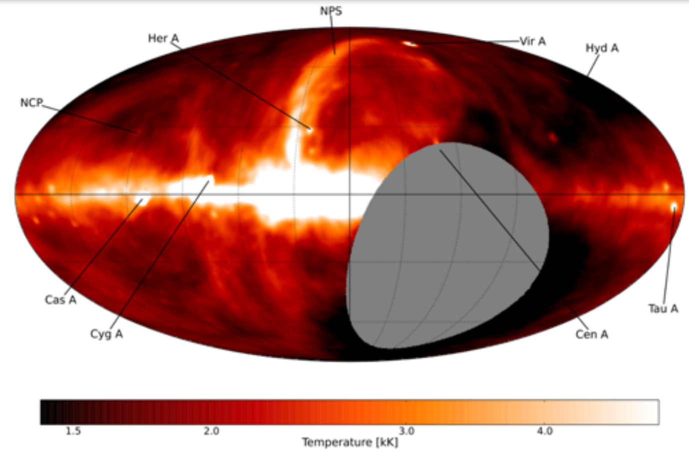
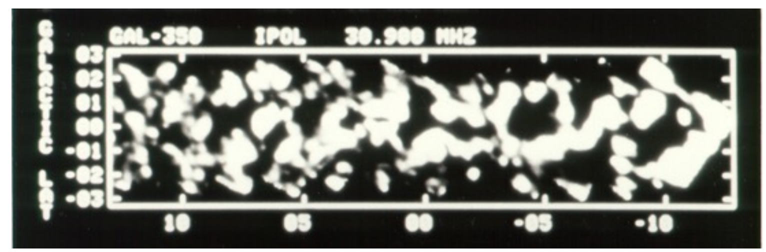
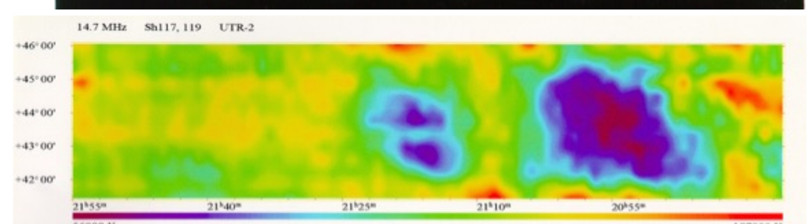
Mapping the Galactic Background

- The LWA1 Low Frequency Sky Survey (Dowell et al. 2017)
- Images across 9 frequencies from 35 to 80 MHz
  - Most systematic survey within this frequency range
- Better account of free-free absorption in the ISM – can't ignore it!
- Motivated in part to understand foreground emission for cosmic dark ages (z>10) and EOR (z>6) experiments

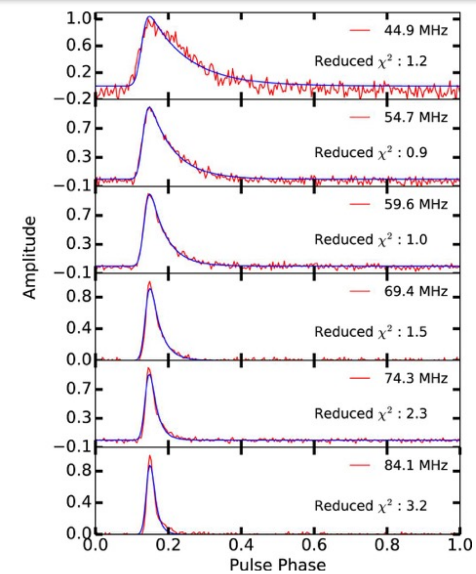


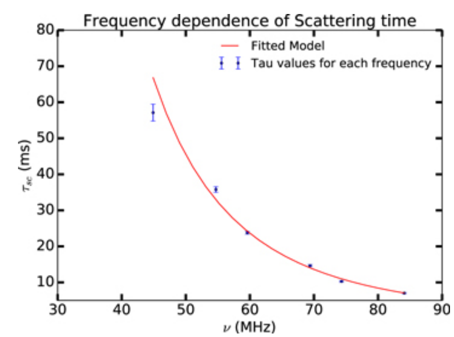




The Local ISM: Constraining turbulence with PSR Scattering

- Multi-year study of scattering time (τ_{sc}) spectral index (α) and DM variations for nearby PSRs (Karishma Bansal et al. 2019)
  - *First systematic evolution study of α*, with one PSR showing a variation anti-correlated with DM
- Tests assumptions of thin screen scattering models
  - Gaussian ($\tau_{sc} \propto \nu^{-4} * DM^2$) vs. Kolmogorov: ($\tau_{sc} \propto \nu^{-4.4} * DM^{2.2}$) - deviations from both for DM <50 pc
  - Better understanding of relation between PSR scattering and ISM structure
  - Could significantly increase the number of PSRs available for PTA GW studies

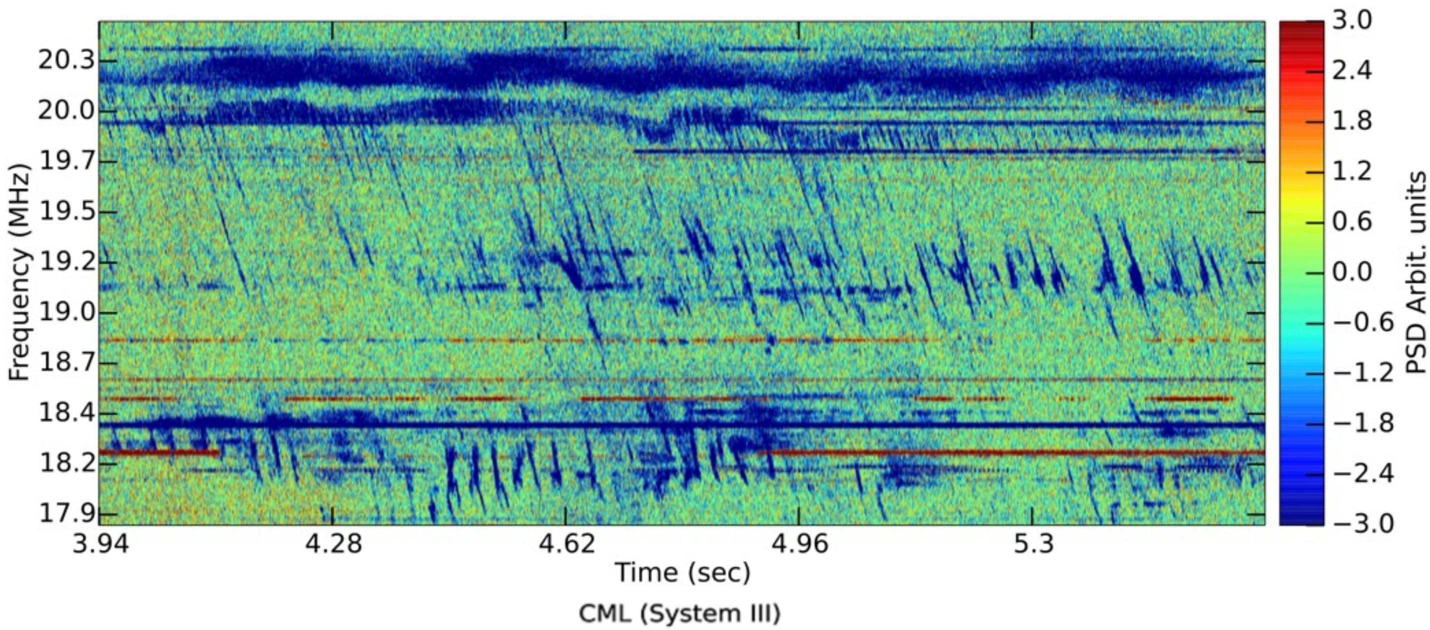




Extra-Solar Planets: Our Local Cool Analog to Hot Jupiters

LWA1 Jovian obs. refined burst start/end times, traced rare Io-D S bursts w/ drift rates.

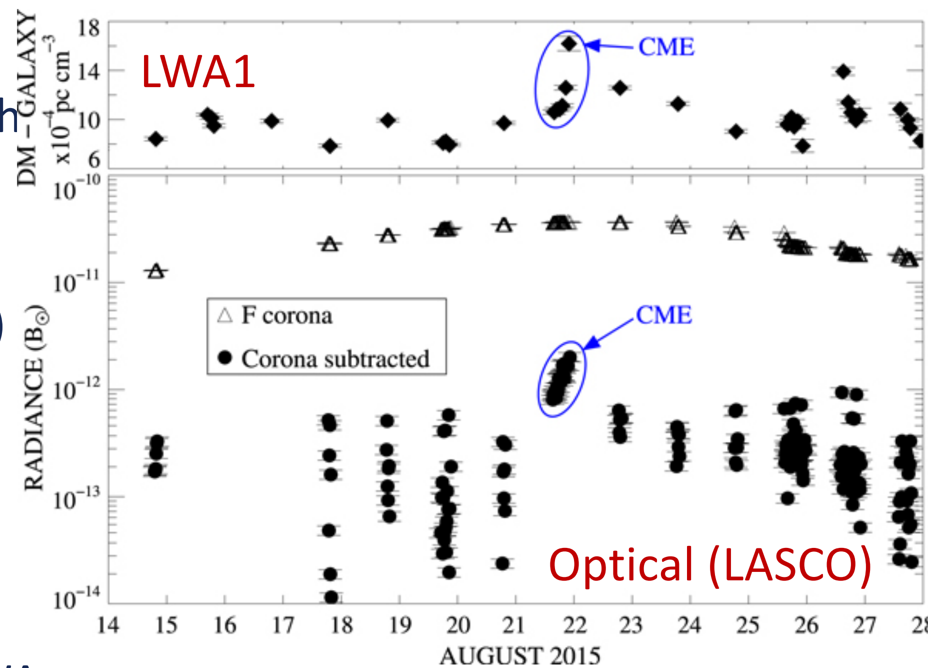
Stimulated studies of S-burst beaming, Io-D event properties & coordinated JUNO campaigns



Clarke et al. (2014), JGR, 826, 176

Coronal Mass Ejections
Magnetic Fields and Densities from Pulsar Scattering

- LWA1 observations of PSR B0950+08 (Howard et al. 2016)
  - DM enhancement during CME correlates with optical from LASCO - see the same CME!
- Measurements constrain CME density and B
  - Radio: N_e (from DM) and B (from FR α N_e * B)
  - Estimates of CME magnetic field and density
- Powerful demonstration!
- Kooi et al. expanding with greater sensitivity and using multiple LOS w/ L band VLA
  - Other efforts inc. LOFAR (M. Bisi et al.) & MWA (C. Lonsdale et al.)



The Impact of Surface Explosions on the Ionosphere

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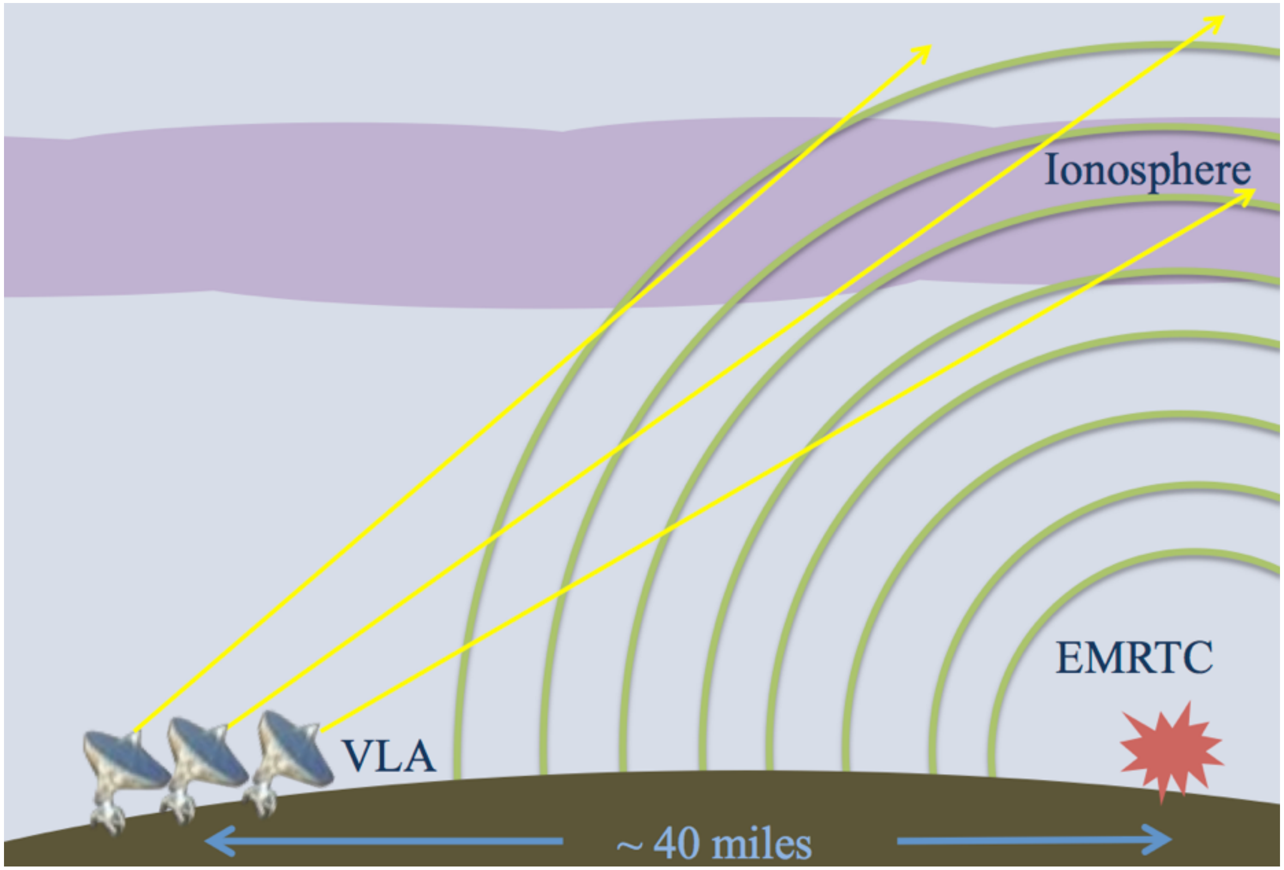
IONOSPHERIC APPLICATIONS

Characterizing in detail the response of the ionosphere to moderate-yield surface explosions

Introduction:

- GOAL: To use the VLA to observe ionospheric disturbances in the wake of explosion tests conducted at a nearby research facility (EMRTC; ~40 miles east).
- Exploratory study to examine in fine detail the impact of explosion-generated acoustic waves.
- Incorporates other sensors in the area (e.g., LWA1, infrasound and seismic sensors at Kirtland AFB, GPS).
- Complementary to GPS-based effort at NRL funded by DTRA.



Schematic (not to scale) of the experiments to observe the ionospheric impact of explosion-generated acoustic waves

The Impact of Surface Explosions on the Ionosphere

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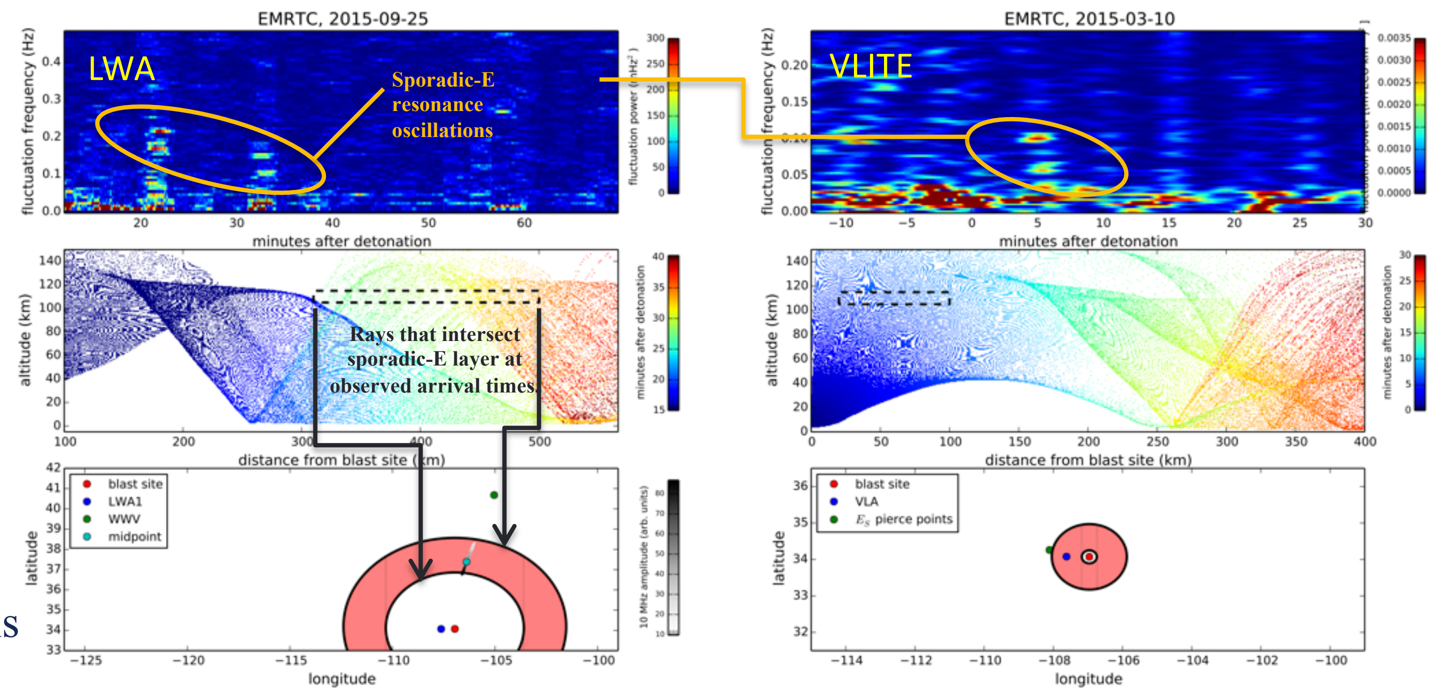
IONOSPHERIC APPLICATIONS

It worked!

- ✧New signature of IS induced oscillations in sporadic-E layers detecting events down to ~300 lbs.
- ✧Thanks to VLITE & passive bistatic HF radar, signature detected w/ VLA & LWA1 probing spatial & temporal density gradients, respectively.
- ✧IS propagation code confirms disturbance arrival times consistent w/ explosion
- ✧Under review @*Radio Science*.



Top: Spectrogram of fluctuations in (left) LWA1-measured 10-MHz WWV Doppler shift and (right) VLITE-measured TEC gradient.

Middle: Infrasound ray-tracing for date/time/location, color-coded by arrival time.

Bottom: Locations of sporadic-E pierce points and infrasound rays that intersect sporadic-E layer at observed arrival times.

The Impact of Surface Explosions on the Ionosphere

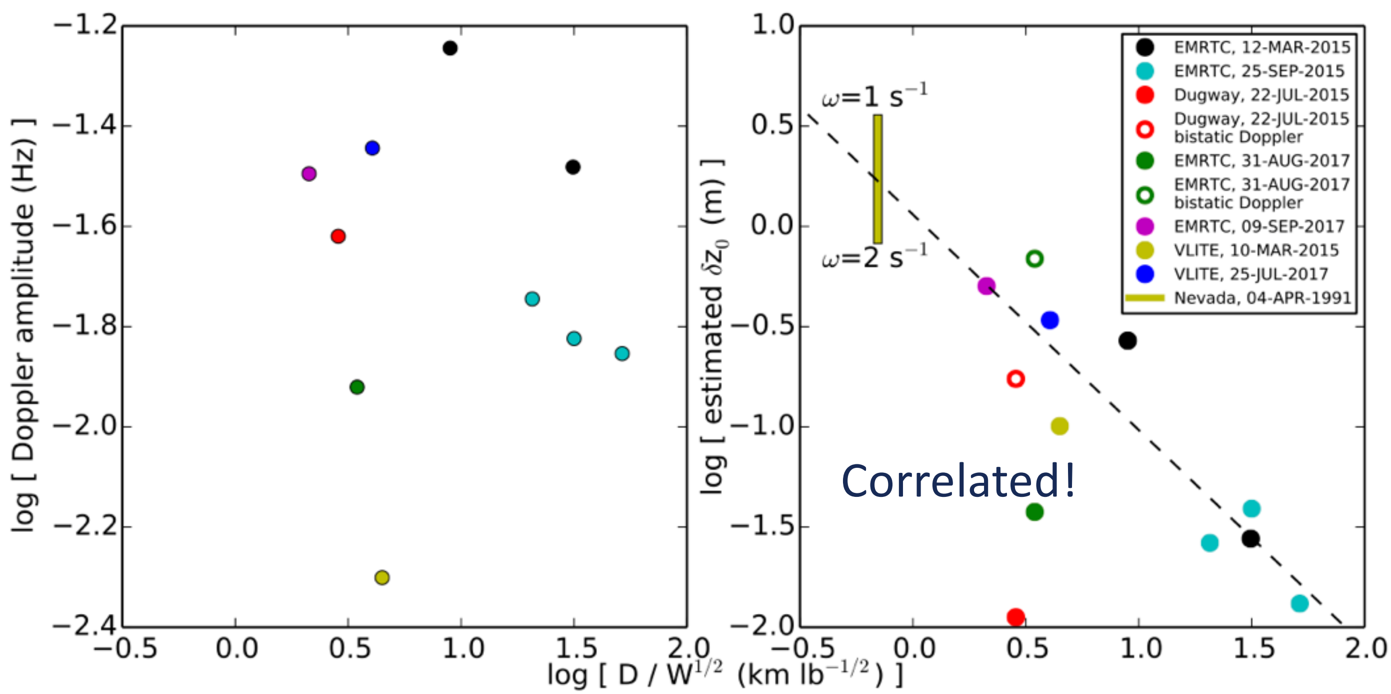
IONOSPHERIC APPLICATIONS

Can we calibrate the yield?

From Helmboldt et al. (2018; under review): Magnitude of Doppler fluctuations associated w/ surface explosions detected w/ LWA1/VLITE vs. yield-scaled range (left panel). VLITE spatial gradients converted to Doppler w/ c_s = 300 m s^{-1}. **When converted to displacement amplitudes (right panel), clear power-law relationship (slope ~1) similar to ground-based IS measurements.**

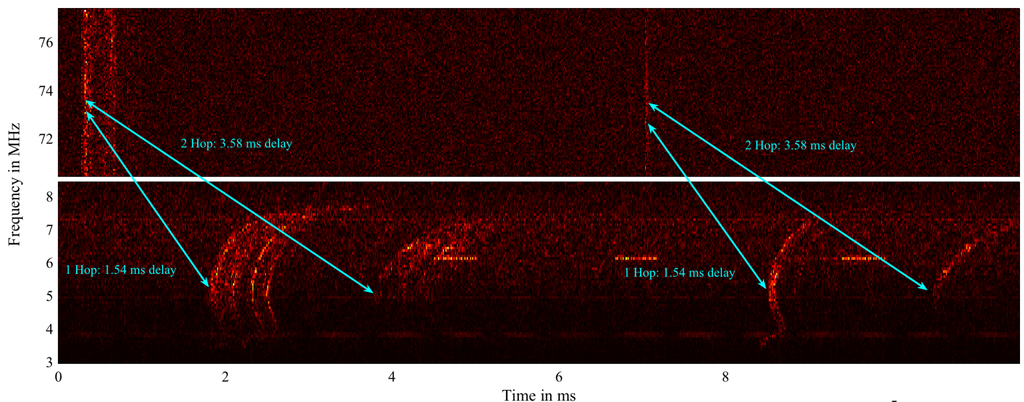
Doppler signature from explosion & natural E_S oscillations

Doppler signature with E region background filtered out.



Ionospheric Sounding with Lightning!

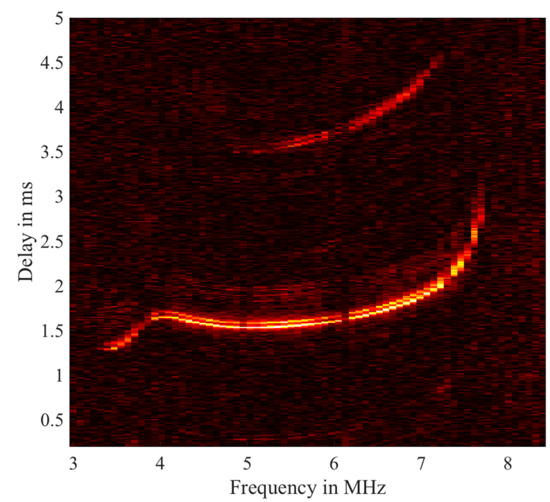
(Nature's natural broad-band transmitter)



69 – 79 MHz

3 – 8 MHz

– Observed lightning across wide frequency band, above and below maximum plasma frequency of ionosphere
– Correlate power time series from upper band with each channel of lower band to get high (summed) SNR ionogram
– Obenberger et al. 2018, Radio Sci, 53, 11



Developing smaller mobile rigs to take the show on the road.

The Radiation Pattern of Meteor Radio Afterglows: Are they isotropic?

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- Flux of the meteor afterglow from each station can be measured

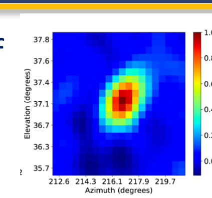
  F_1 -LWA 1 , F_{sv} - LWA-SV
- Triangulation gives the physical location of meteor
- Station locations are known >> distance

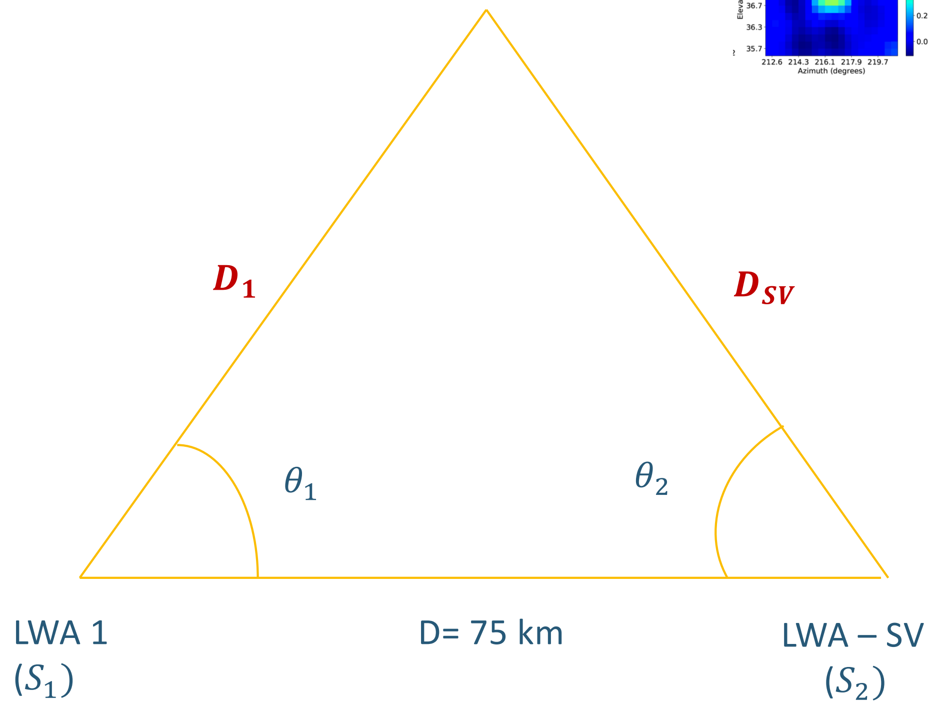
  D_1 -LWA 1 , D_{sv} - LWA-SV
- If isotropic:

$$L_1 = L_{SV}$$

$$F_1 {D_1}^2 = F_{SV} {D_{SV}}^2$$

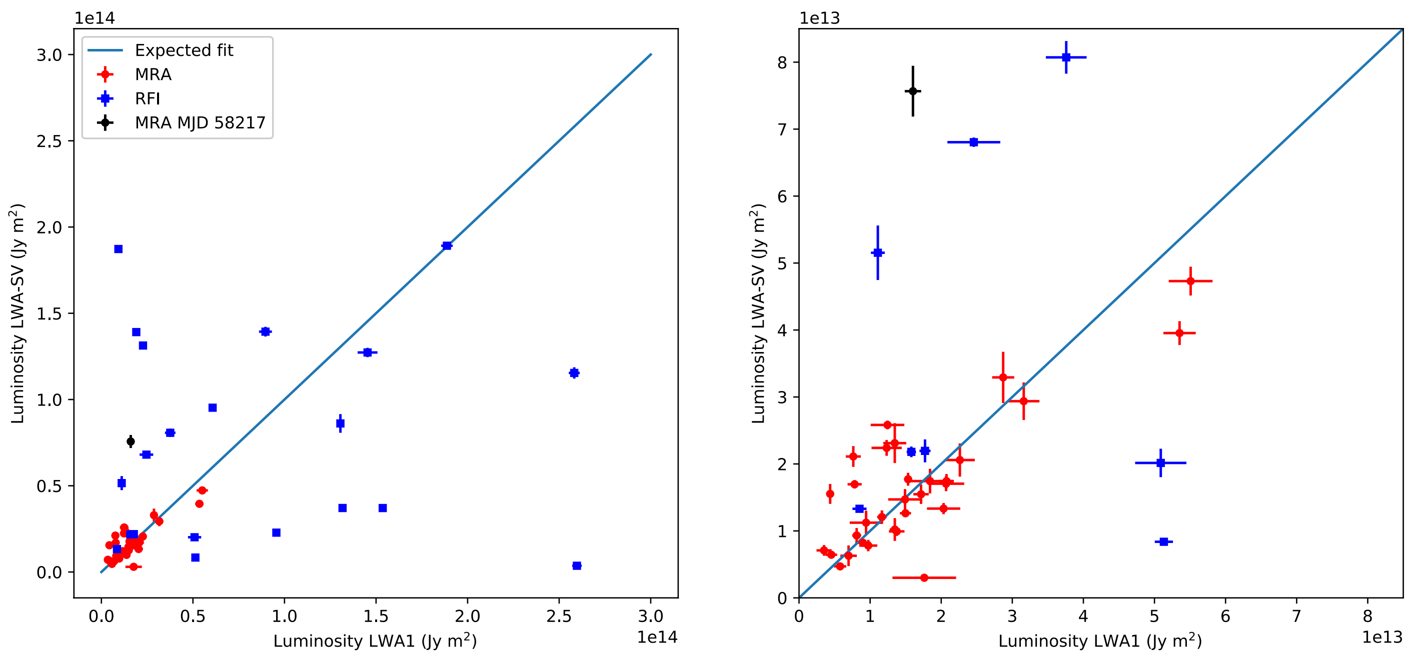
- Plotting this should give a straight line





Savin Varghese et al. submitted to JGR Space Physics

Yes!



MRAs follow an **isotropic radiation pattern**

RFIs are distinct from MRAs

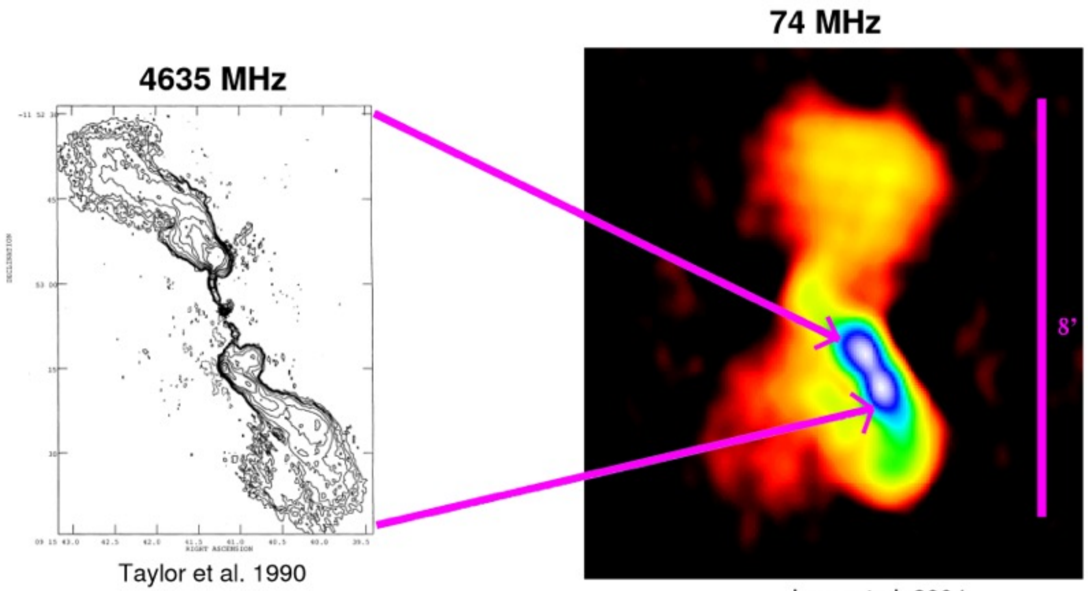
Projection effects causes variations from the fit

Savin Varghese et al. submitted to JGR Space Physics

Back to the Future with ELWA!!

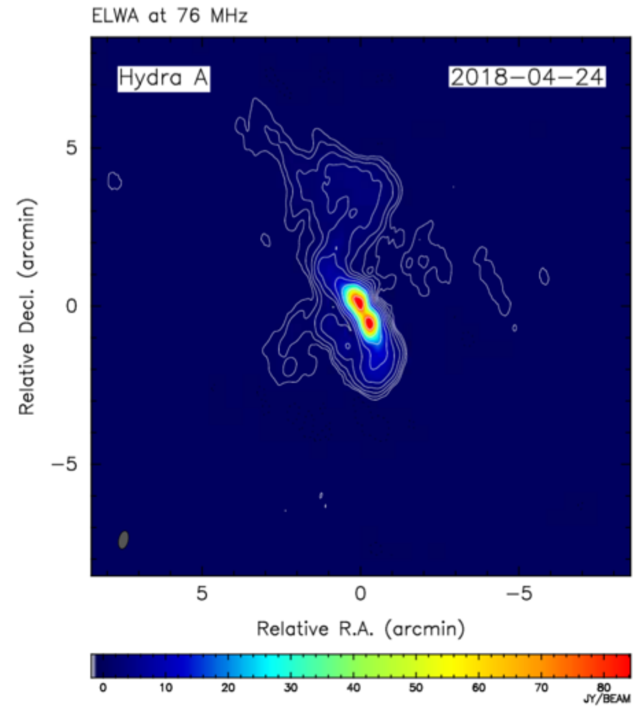
74 MHz legacy VLA imaging - PAST

ELWA imaging w VLA+LWA - NOW!



Taylor et al. 1990

Lane et al. 2004



Summary

- Remarkable science portfolio given limitations of current instrument
  - Most science currently reliant on time and spectral domain information
- Second station increasing value of LWA Observatory
  - Anti-coincidence used for possible first transient detection
  - New all-sky imaging capability being developed on LWA-SV
  - Access to lower frequencies useful for sponsored applications
- Rapidly Emerging LWA capabilities at OVRO starting to have a big impact
  - LWA OVRO taking off – science productivity impressive
- Bodes extremely well for SWARM concept
  - Imagine what we can do when we open our eyes to imaging!