A Coincident Search for Fast Radio Transients and Gravitational Waves

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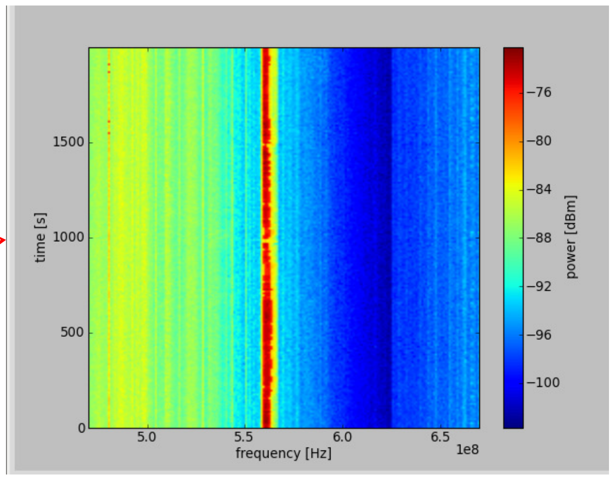
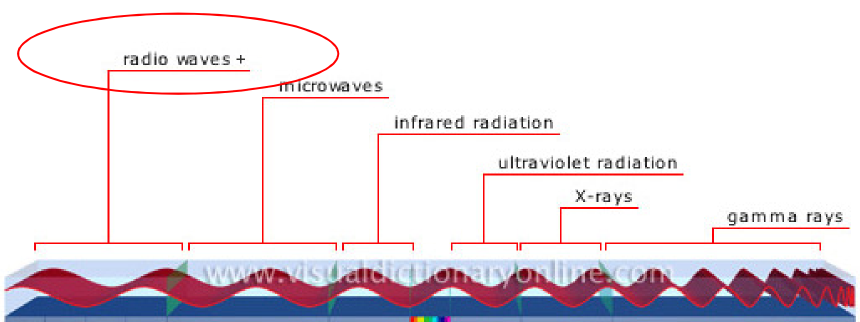
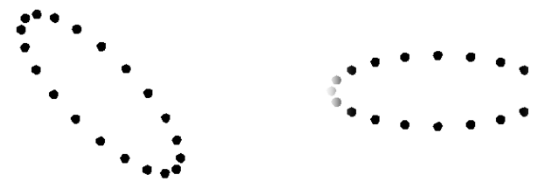
Multi–Messenger Astronomy

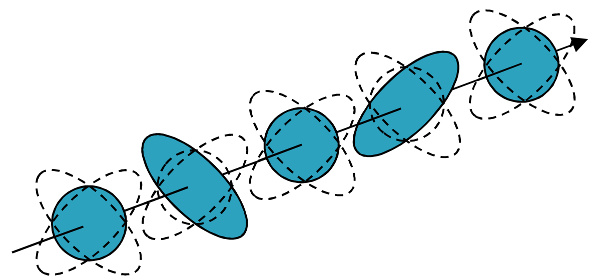
Low-frequency E/M Radiation

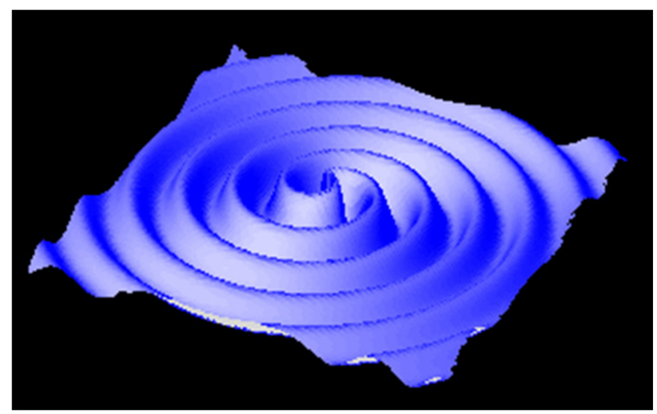




Gravitational Radiation



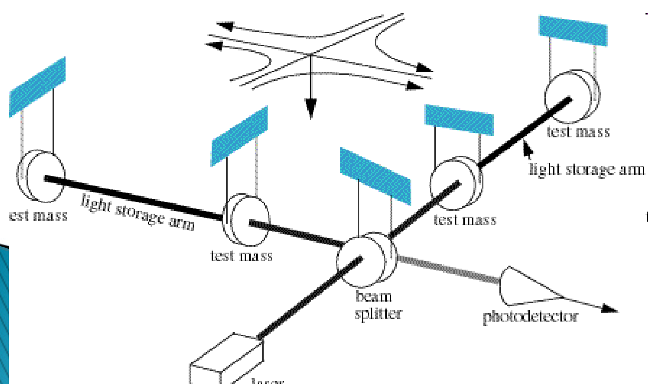




Motivations

- Reduced effective false alarm rate for correlated signals
- Multi-messenger observations give a more complete picture of common sources, even in the case of null detections!
- Recently observed fast radio burst (FRB) (Thorton et al. 2013)
- Wide field-of-view observations possible in both sets of instruments over shared section of the sky.
- Dispersive delay of low-frequency radio signals aids triggered observations.
- Common sources for GW and radio bursts.

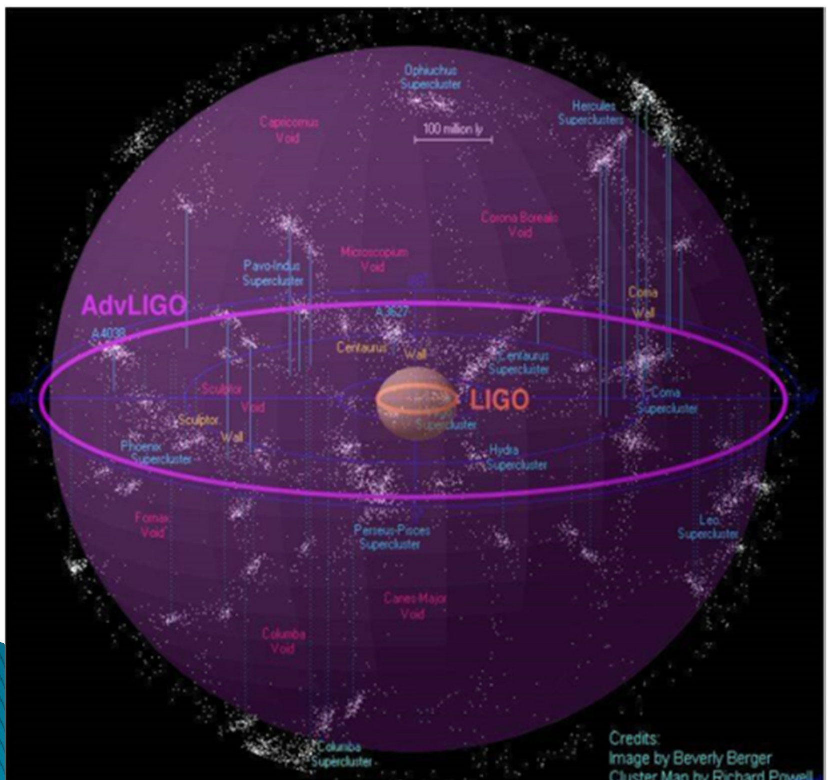
The Laser Interferometer Gravitational-Wave Observatory (LIGO)

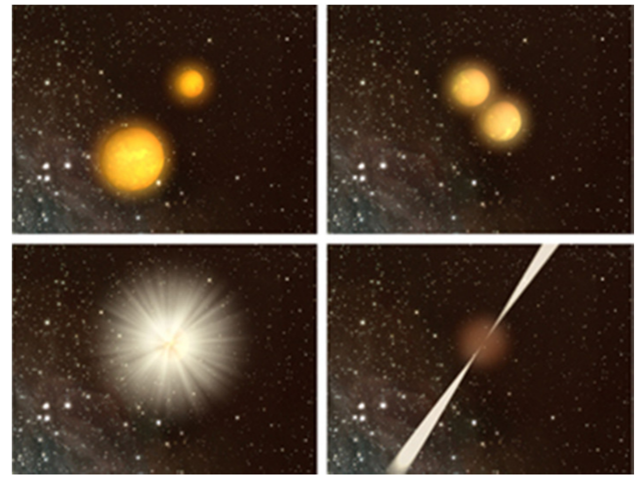


- Observatory dedicated to the direct detection of gravitational waves.
- 2 large laser interferometers located in Washington State and Louisiana
- LIGO is a truly all-sky instrument, seeing both above and below the horizon.
- Data is logged and searched for positive detections much like LWA data.
- Coordinates operations and data analysis with Virgo in Italy and GEO in Germany. Future detectors in Japan, India.

Coincident Emission from Compact Object Mergers

Neutron Star Binaries:
Initial LIGO: ~15 Mpc → rate ~1/50yrs
Advanced LIGO: ~ 200 Mpc
Realistic rate ~ 40/year !





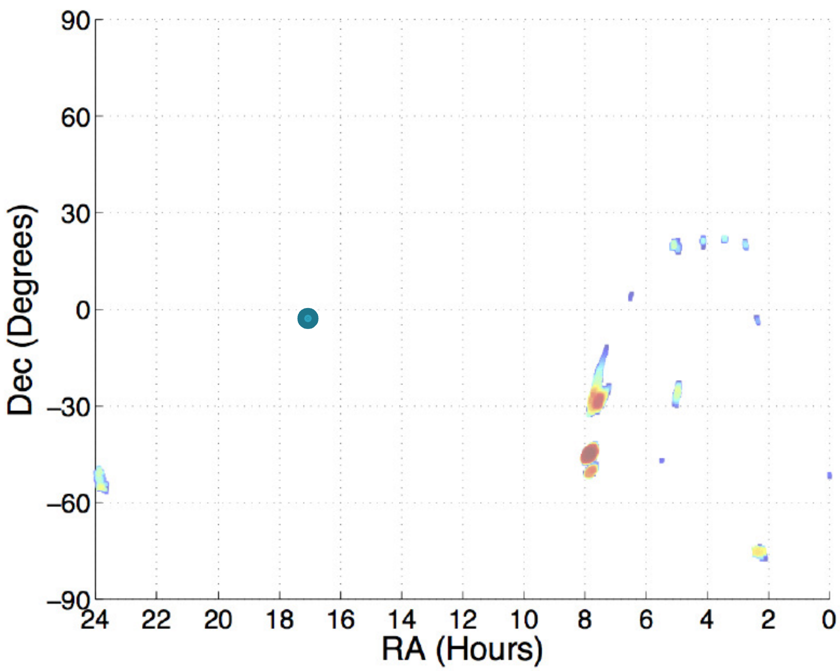
$$D_{Gpc} \sim \left[0.8 \cdot 10^{15\gamma} \, \dot{E}_{50}{}^{1+\gamma} \left(\frac{SNR}{10} \right)^{-1} \nu_{120}{}^{3/4} \, B_4{}^{1/2} \, N_{ant}{}^{1/2} \right]^{10/19}$$

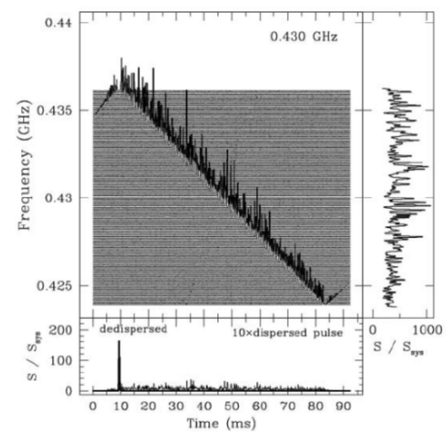
LWA-1 can detect these events out to ~1 Gpc.

M.S. Pshirkov, K.A. Postnov
Astrophys.Space Sci. 330 (2010)

Spatial & Temporal Search Windows

- Correlated signals can be found establishing a spatio-temporal search window for partner instruments. Observations can be triggered or simultaneous wide FOV searches.
- The LWA-1 station as a solitary instrument has 2 degree resolution at 80 MHz and 8 degree resolution at 20 MHz, at the zenith. LIGO produces probability sky-maps for candidate events.
- Using the measured dispersion of a transient radio signal we can calculate the approximate time the GW which does not dispersion should have arrive in the corresponding detector.





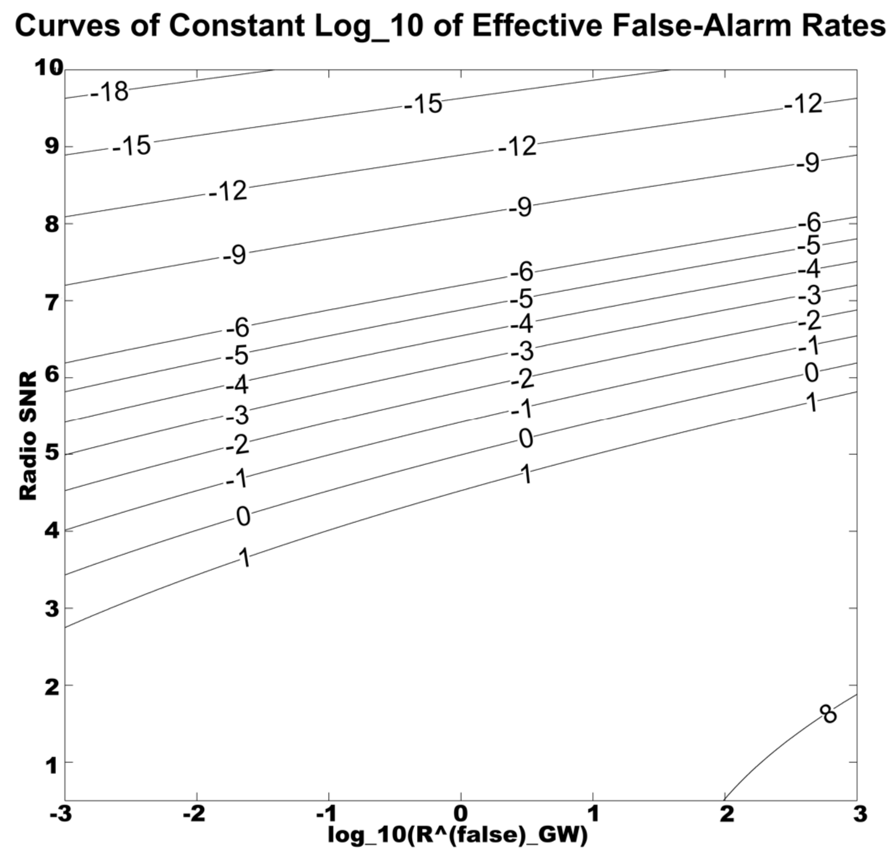
$$DM = \int n_e dl.$$

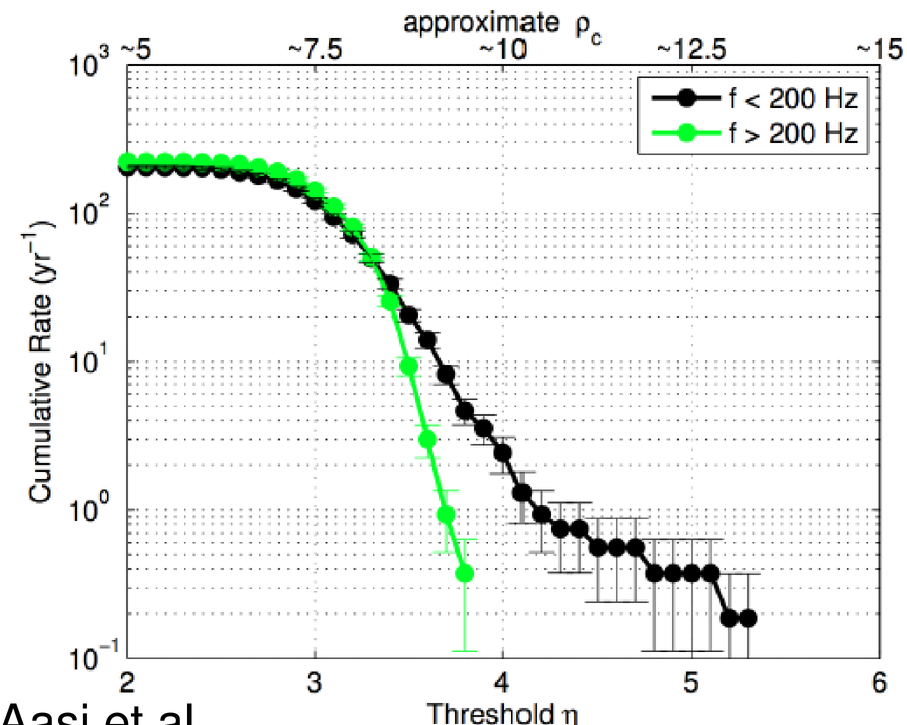
$$t_{Dispersion} = 4.2\, DM\, \nu_{GHz}^{-2}\, ms.$$

http://www.ligo.org

Reduced false alarm rate

- Requiring coincidence of a marginal GW candidate with a marginal radio burst may allow the effective false alarm rate to be decreased by a factor of ~10^4 .





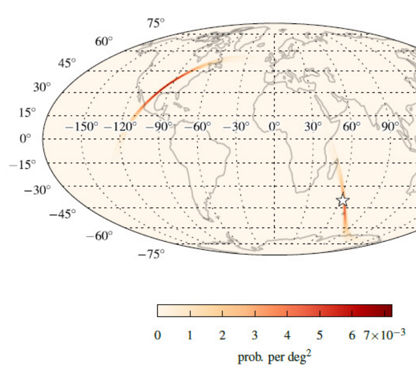
$$R_{\rm eff}^{\rm false} = R_{\rm GW}^{\rm false}\, S\, {\rm erfc}\left(\frac{\rm SNR}{\sqrt{2}}\right) t_{\rm w}$$

Aasi et al., arXiv:1304.0670

LV-EM Follow-up Program

Preliminary

	CBC	Burst
IVORN	ivo://gwnet/[GraceDBID]-[version]	
Who	LIGO Scientific Collaboration and Virgo	
WhereWhen	estimated geocentric arrival time	
What	gracedb ID	
	Version number of the alert	
	link to FITS skymap	
	link to gracedb event page	
	Chirp mass	Peak frequency
	Symmetric mass ratio	Duration
	Approx. max distance	Energy fluence at Earth
Why	Online search or externally triggered	
How	Name of the search that found the event	
	list of detectors contributing to the event	



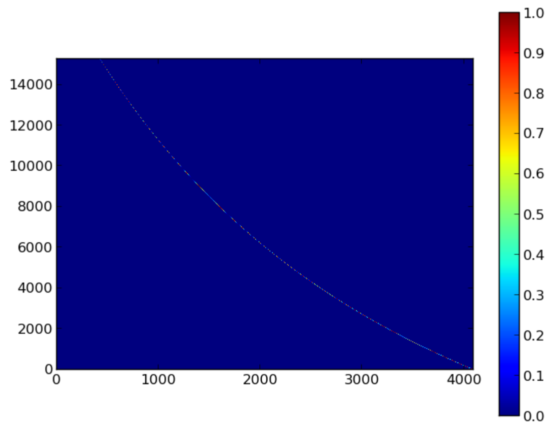
- Triggers for candidate events will be sent via GCN to all groups that have signed an MOU with the LSC.
- LWA-1 has joined the LV-EM follow up program and will received triggers following possible GW detections.
- Triggers will include event information and a probability sky map delivered as a fits file.
- The goal is to have the trigger deliver ~5 mins after the event.

Advanced LIGO Observing Schedule

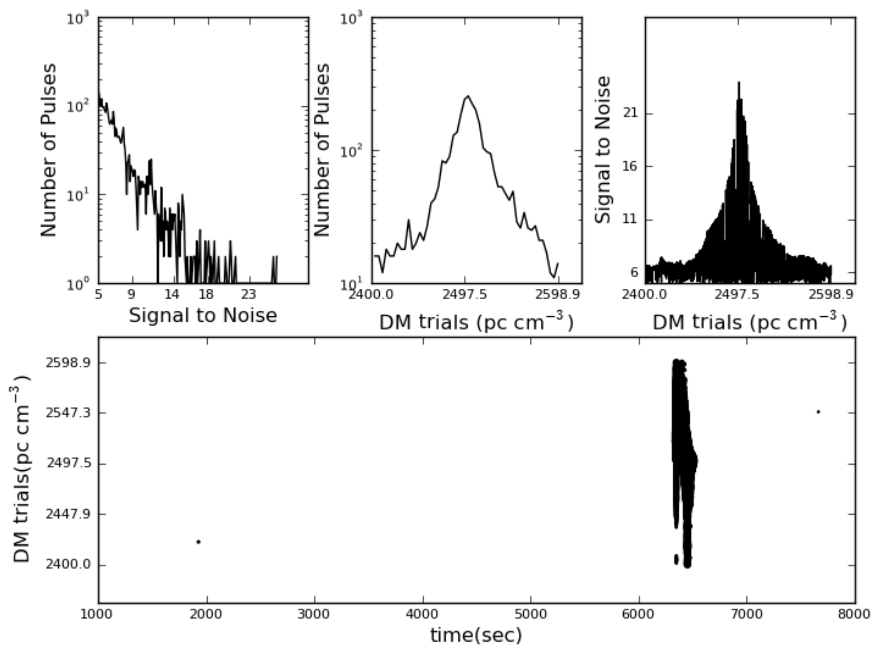
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc)		BNS Range (Mpc)		Number of BNS Detections	% BNS Localized within	
		LIGO	Virgo	LIGO	Virgo		$5\,\mathrm{deg}^2$	$20\,\mathrm{deg}^2$
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 70	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

Multi-messenger Survey with LIGO Scientific Collaboration

(LK001, LK002, LK003, LK003, LK004)

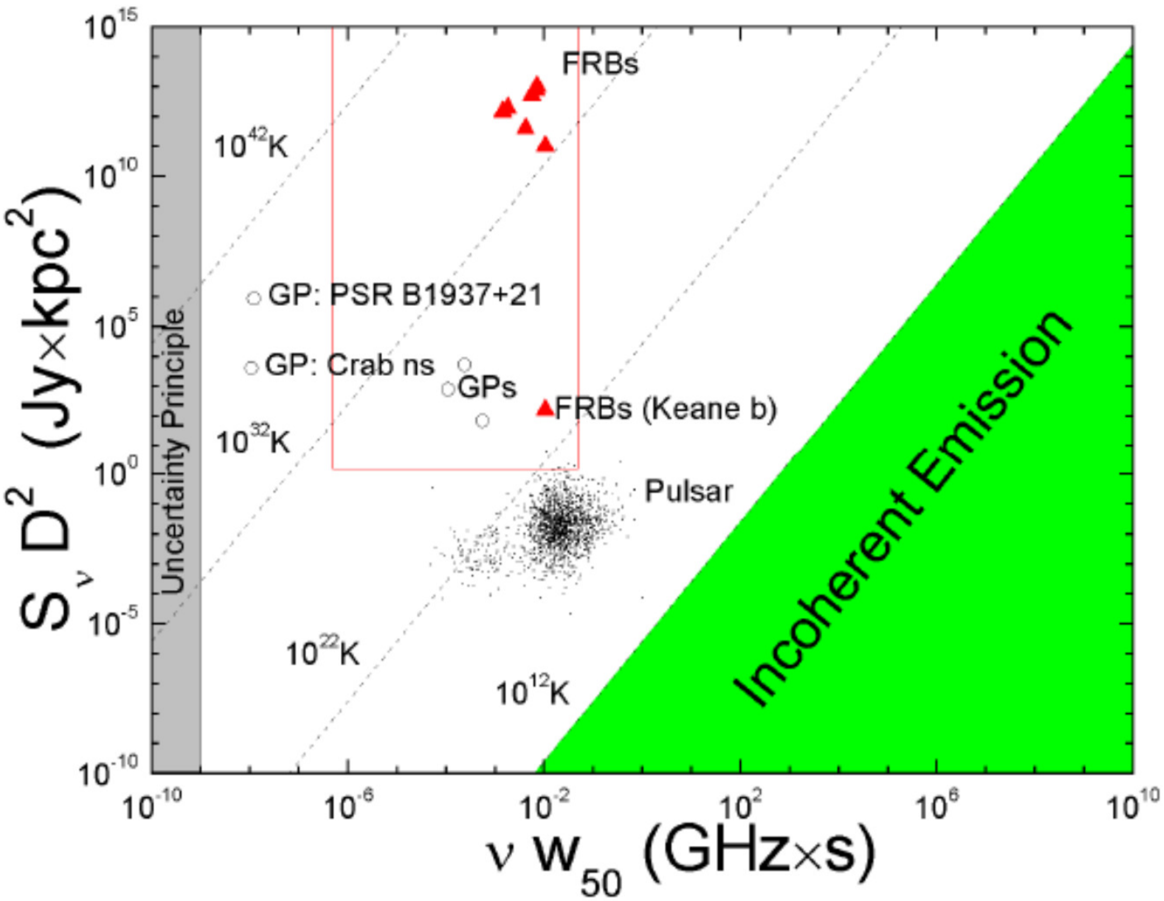


A simulated pulse injected into our data reduction pipeline.



- A dedicated software and computational infrastructure has been developed to look for fast radio transients in beam-formed data and then to search for correlated burst emission in LIGO data sets.
- This data pipeline has been tested with simulated dispersed signal injections and pulsar observations
- Observations were conducted with 2 beam pointings with 2 tunings each, 39.4 & 73.7 MHz, 19.8 & 59.0 MHz. Beams pointed near the zenith, M31, M81, M82 and Pulsar B0950+08 and Pulsar B0031-07.
- Coincident observation ongoing with GEO detector in anticipation of joint observations with Advanced LIGO. Joint analysis methods being developed.

Transient Phase Space



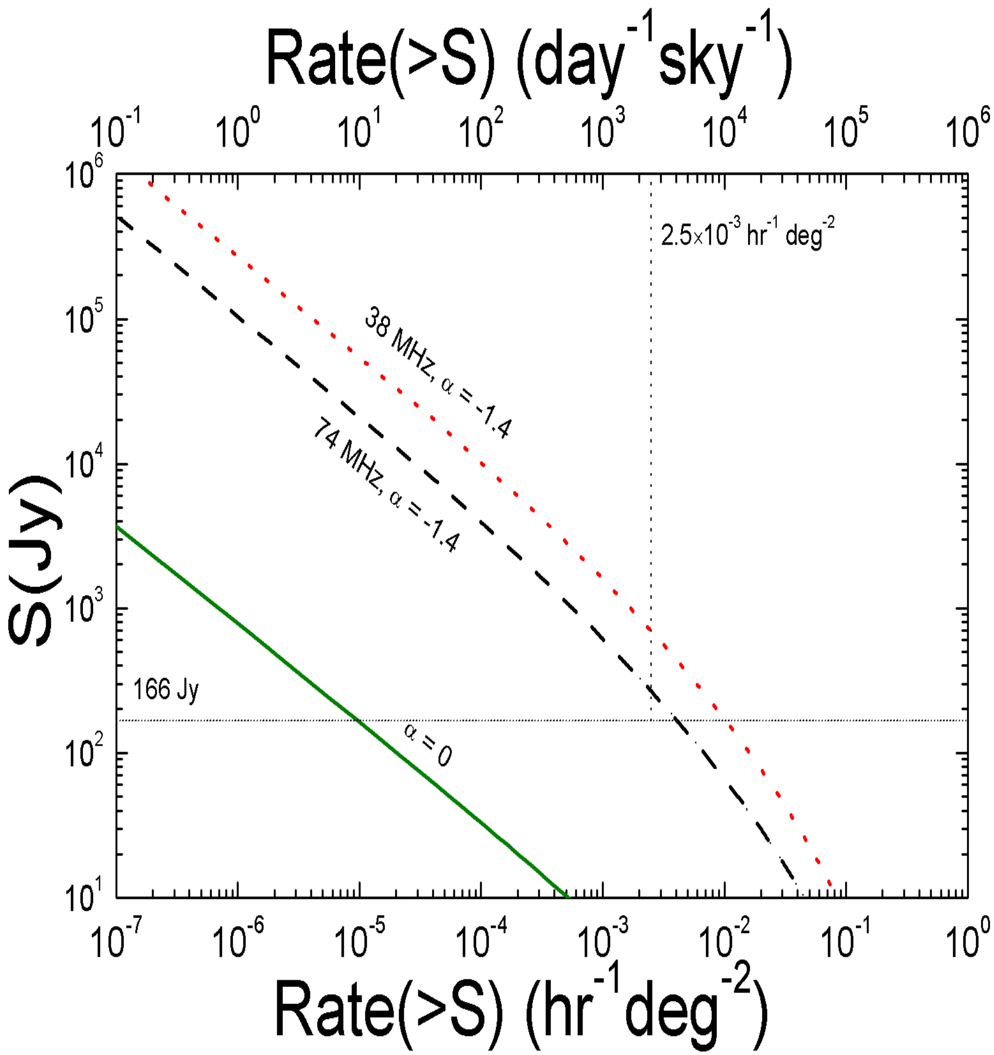
- The transient phase space can be explored by plotting pseudo-luminosity L = SD^2 v.s. νW^2, where S is the flux density, D is the distance to the source, ν is the emission frequency and W is the pulse FWHM.

- As radio frequencies are in the Rayleigh-Jeans regime we can draw lines of constant minimum brightness temperature. Plotted are pulsars (Hobbs et al. 2004), pulsar's giant radio pulses and FRBs, which we give only as a representative but not exhaustive list of sources. The boundary between coherent and incoherent emission is due to inverse Compton cooling (Redhead 1994).

- The solid red line represents the region of the parameter space to which the LWA1 is sensitive with SNR threshold > 10 and assuming the distance is at least 0.67 kpc and ns < W< 1s.

$$W^2 = \frac{1}{2\pi k}\frac{SD^2}{T}\frac{1}{\nu^2}$$

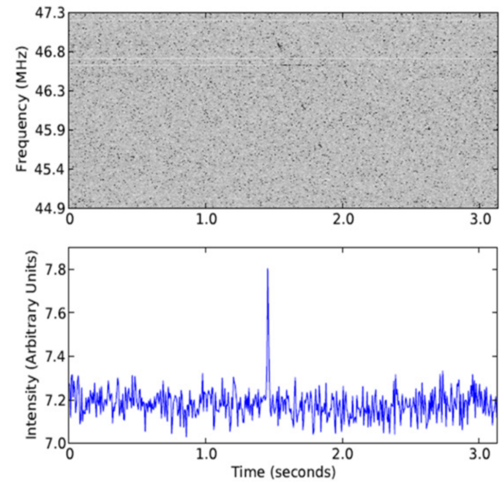
Event rate limits

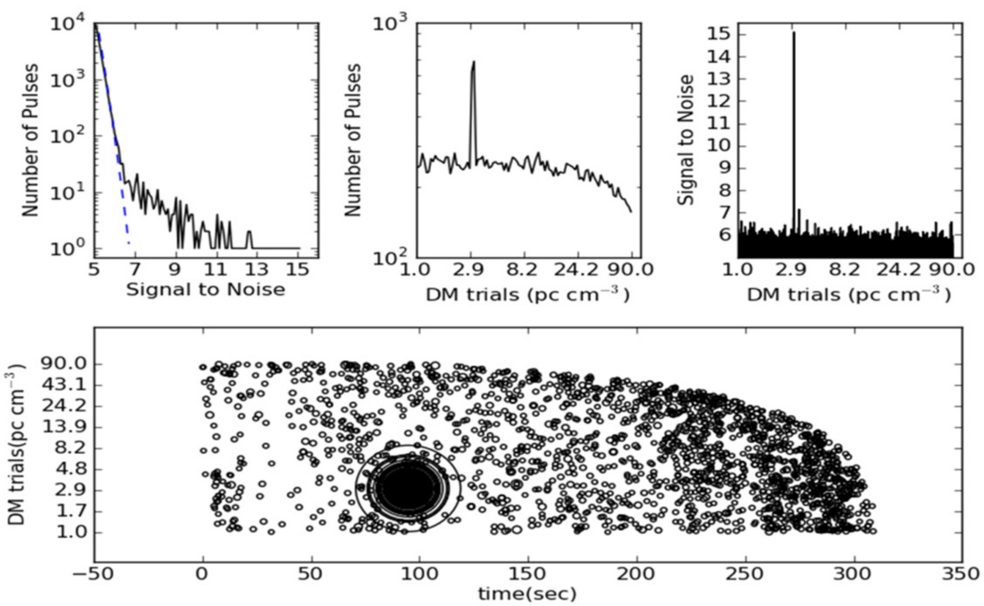


- An upper limit on the event rate for fast radio transients can be set using LWA1 observations.
- After 40 hours of observation no transient signals above SNR = 7 (or 166Jy if assuming averaged SEFD = 6k) were detected yielding a limit on the event rate <2.5x10^{-3}hr^{-1}deg^{-2}.
- Using data from FRB observations a model can be developed for an extragalactic source with luminosity = 8x10^{44}erg/s (Lorimer et. al. 2013) and the event surface density can be determined. We extrapolated this event rate under two scenarios-: spectral indices 0 and -1.4.

Observations: PSR B0950+08

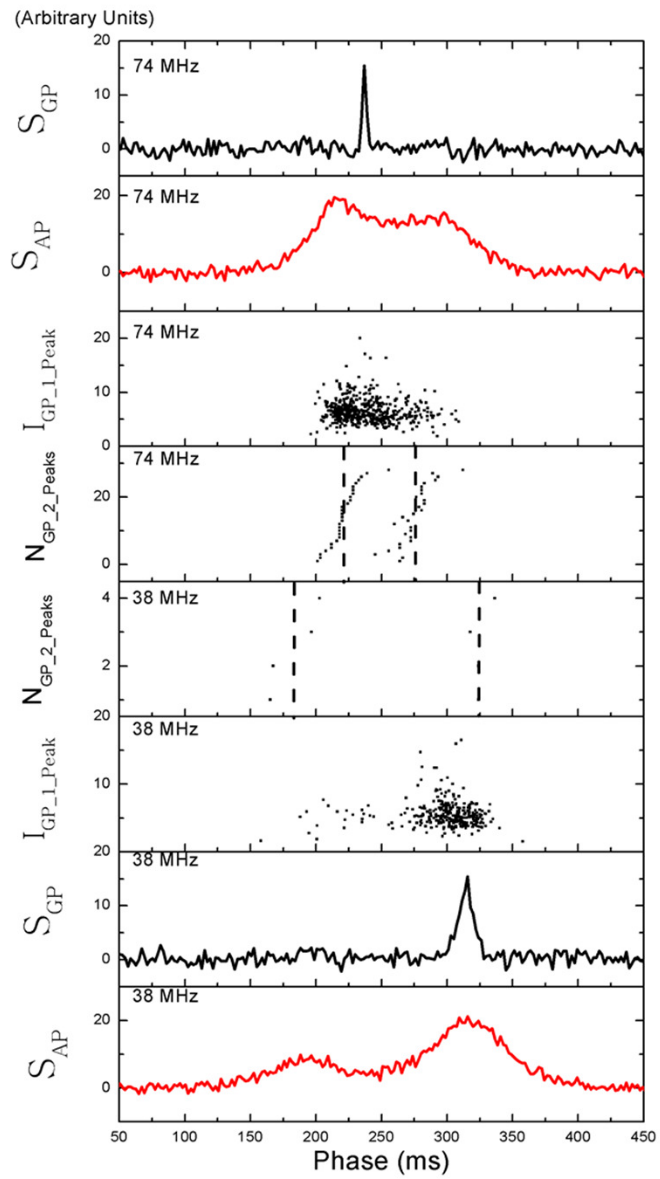
- Giant pulses were detected from PSR B0950+08 in 24 hours of observations made at 39.4 MHz, with a bandwidth of 16 MHz, using LWA1.
- 119 giant pulses from B0950+08 were observed (at its dispersion measure).
- These 119 pulses are 0.035% of the total number of pulse periods in the 24 hours of observations. The rate of giant pulses is about 5.0 per hour.





Observations: PSR B0031-07

- GPs from PSR B0031-07 were observed over a period of 12 hours.
- Shown here for 74MHz and 38 MHz are the averaged pulse profiles (red) and brightest giant pulse's phase position(black) followed by the phase position of the single peak giant pulses and the double peaks giant pulses. The dashed lines are the mean phase positions of peaks.
- The GP's phase positions are spread throughout the AP's phase. The GP's phase and strength clusters matches AP's. Among all data only 10% GPs are detected in both tuning in the same period after dedispersion.



Outlook

- Multi-messenger astronomy is a promising approach to pursue in searching for transient events.
- The LV-EM follow-up program will begin in 2015 allowing for triggering on potential GW detections.
- LWA-1 will receive triggers from the LV-EM program. For high DMs the delay should be sufficient to allow for follow-up observations.
- Searches for radio transient with LWA-1 are underway in coordination with GEO.
- GPs from PSR B0950+08 and PSR B0031-07 have been observed and limits are being set on radio transient event rates and FRBs properties at low frequency.
- With continued focus on this program LWA-1 will be well situated to search for radio transients and to fully participate in a multi-messenger search for sources of GWs.