Radio Transients and Gravitational Waves: the LWA and LIGO Scientific Collaboration

John Simonetti
Virginia Tech

Bernadine Akukwe, LIU
Brandon Bear, VT
Sean Cutchin, NRL
Steve Ellingson, VT
Jonathan Gough, LIU
Jonah Kanner, Cal Tech
Michael Kavic, LIU
Leandro Quezada. LIU
Peter Shawhan, UMD
Jr-Wei Tsai, VT
Cregg Yancey, UMD

Outline

- Gravitational Waves (GWs) and the LIGO Scientific Collaboration (LSC)
- LSC and LWA transient work: Similarities
  - Sources of GWs and radio transients
  - NS-NS Mergers
- Benefits of Collaboration
- PSR B0950+08: Giant Pulses
- Future Plans

Gravitational Waves

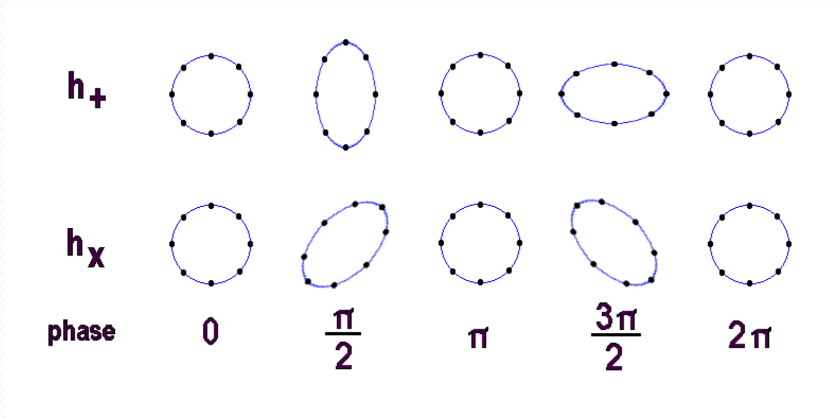
Consequence of General Relativity

Binary Pulsar B1913+16

Wanted: direct detection

Milestone in Physics!

New Astronomy!



Wm. Robert Johnston

Gravity is weak

Quadupolar distortions of the distribution of freely falling masses

Maximum fractional displacements ~ 10^{-21}

LSC and VIRGO

LIGO Hanford Observatory

LIGO Livingston Observatory

4000 m arms

distortions of
~ 10^{-18} m

All-sky
instruments

GEO near Hannover, Germany

VIRGO near Pisa, Italy

Similarities of LSC and LWA transient searches

LSC searching in frequency and time, for one-time transients

All-sky

Uninteresting, local signals can be present

Two separated instruments can be useful

Some directional information obtainable

Rates may be low, at first

LWA can be used to search in frequency and time, for one-time transients

Large beam(s), or All-sky

Uninteresting, local signals can be present (e.g., RFI)

Two separated instruments can be useful

Some directional information obtainable

Rates may be low, at first

Many Potential Sources in Common

- High energy astrophysical events
  - Compact object mergers
  - Gamma-ray bursts
  - Supernovae
  - Explosions of primordial black holes
  - Emission by cosmic strings
  - other exotic physical phenomena

- LSC: Mergers of NS-NS binaries

Benefits of a Collaborative Search

Three scenarios

Source strongly detected in GW → radio search benefits

Source strongly detected in radio → GW search benefits

Marginal detection in both → both searches benefit!

LSC false alarms are not Gaussian (there is a substantial tail)

GW searches benefit more from coincident radio detections

<u>Examples, for a coincidence window of 1 minute</u>

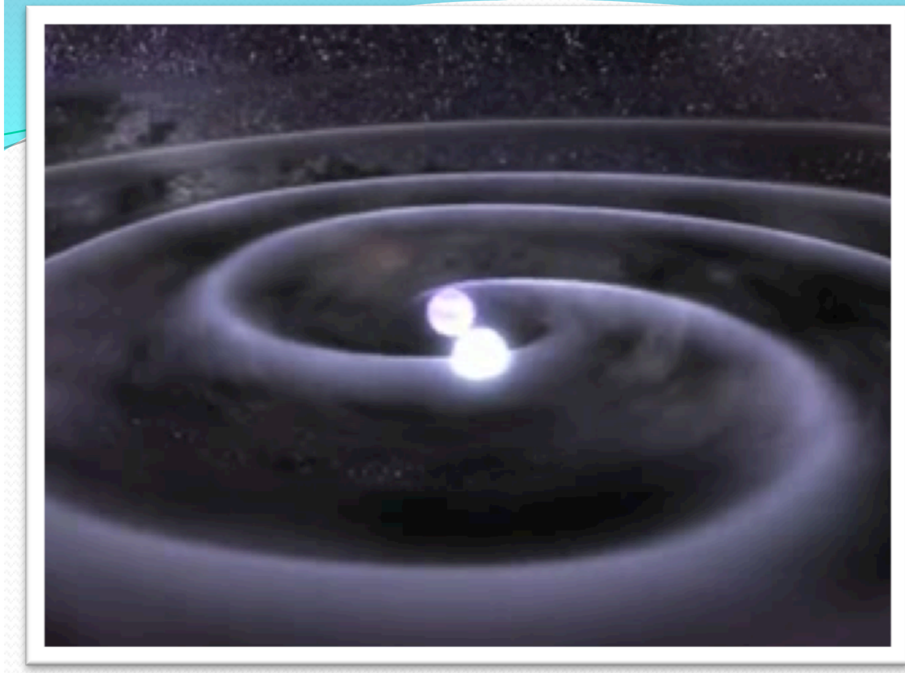
We can achieve a combined false-alarm rate of about 1 per century:

1) GW false-alarm rate of 10 y^{-1}

with coincident radio detections of SNR > 6

2) GW false-alarm rate 0.1 y^{-1}

with coincident radio detections of SNR > 5



NS-NS pair emits GWs, producing inspiral

A GW "chirp" signal is emitted with increasing frequency & amplitude, until merger, at which point a coalescence wave-form is emitted

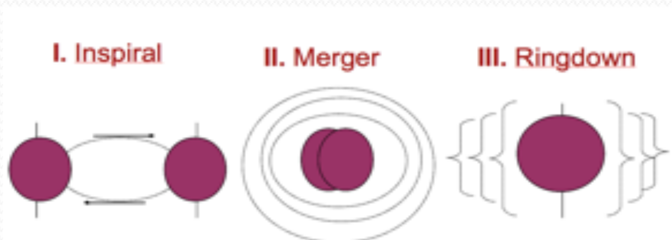
NS-NS mergers

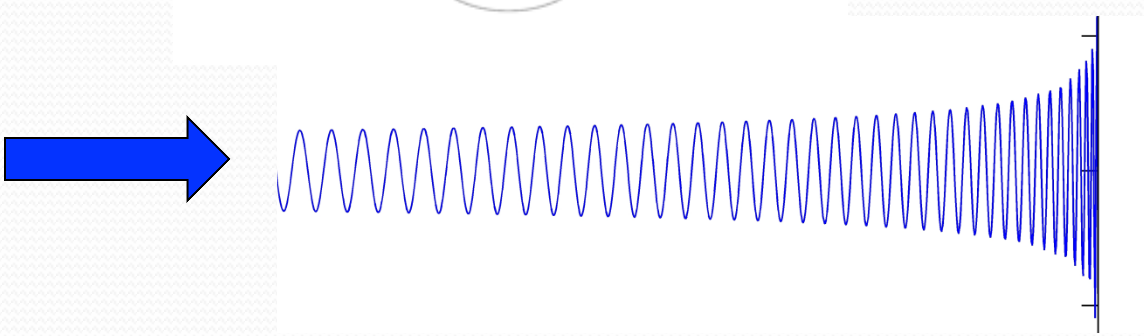
Initial LIGO

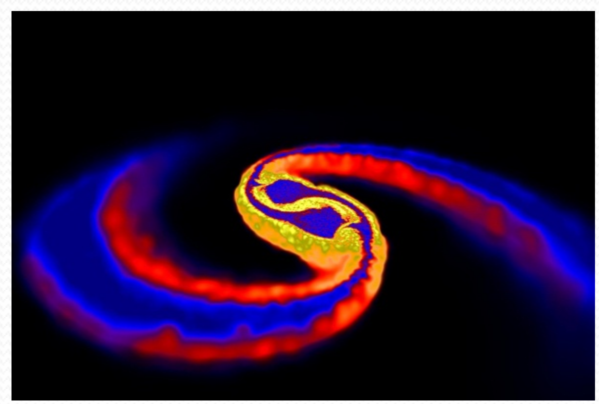
~15Mpc (~1/50 year)

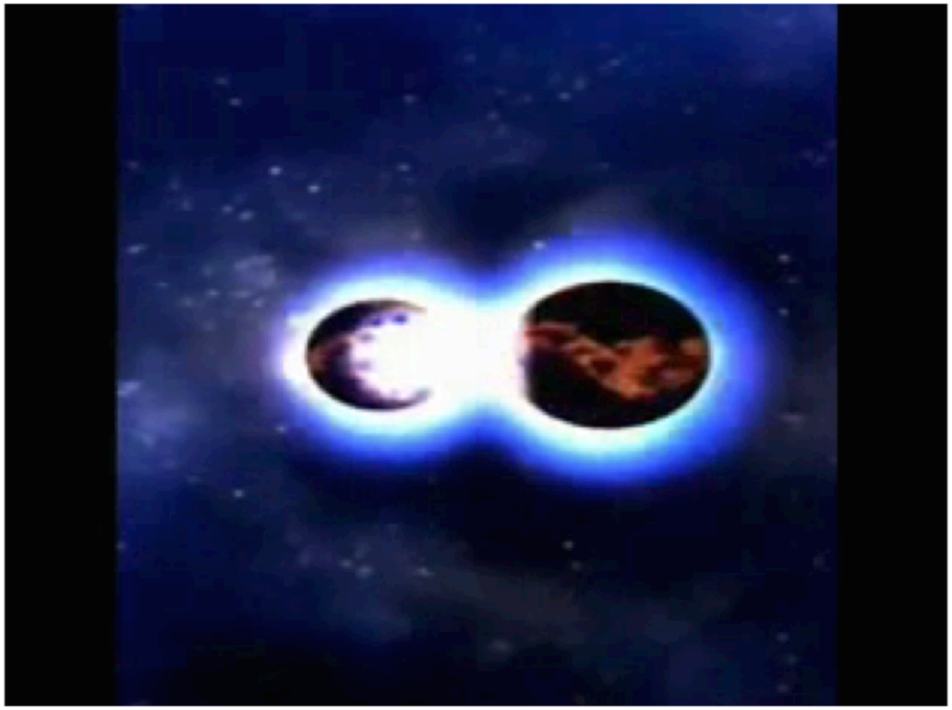
Advanced LIGO (2014-2015)

~200Mpc (40/year!)









M.S. Pshirkov, K.A. Postnov
Astrophys. Space Sci. 330, 13-18 (2010)

$$\dot{E} \sim \frac{\Omega^4 B^2 R^6}{c^3}. \sim 10^{50} \text{ erg s}^{-1}$$

10^{-5} of energy
released in radio pulse

$$F \sim 8000 \ \dot{E}_{50} D_{\rm Gpc}^{-2} \quad \text{Jy}$$

Rotational energy is converted into an increased magnetic field strength of the system, by nearly an order of magnitude, to B~10^{15} G

This leads to a bright pulsar-like emission emitted as the binary pair mergers

Intrinsic radio pulse width ~ 10 ms

Include scattering:

$$f_\nu \sim 0.6 \ \dot{E}_{50} D_{\rm Gpc}^{-4} \nu_{120}^2 \quad \text{Jy}$$

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

Detection of Giant Pulses using LWA-1

Pulsar B0950+08 (J0953+0755)

DM = 2.9702 pc cm^{-3}

(galactic latitude = 43.7 degrees)

P = 253 ms

Giant Pulses observed by Singal and Vats (2012)

Rajkot radio telescope: 1024 dipoles, 5000 m^2

103 MHz, mean pulse ~ 3 Jy

~1% > 20 times mean pulse strength (~100/hour)

~0.01% > 100 times mean pulse strength (~1/hour)

LWA-1 observations

Five 6-hour observations, March-April 2012

- Two beams tracking PSR B0950+08
- Two tunings per beam (4 frequencies on PSR)
- Nighttime observations; pulsar transits during obs
- Analyzed 24 hours, 39 MHz; 16 MHz BW

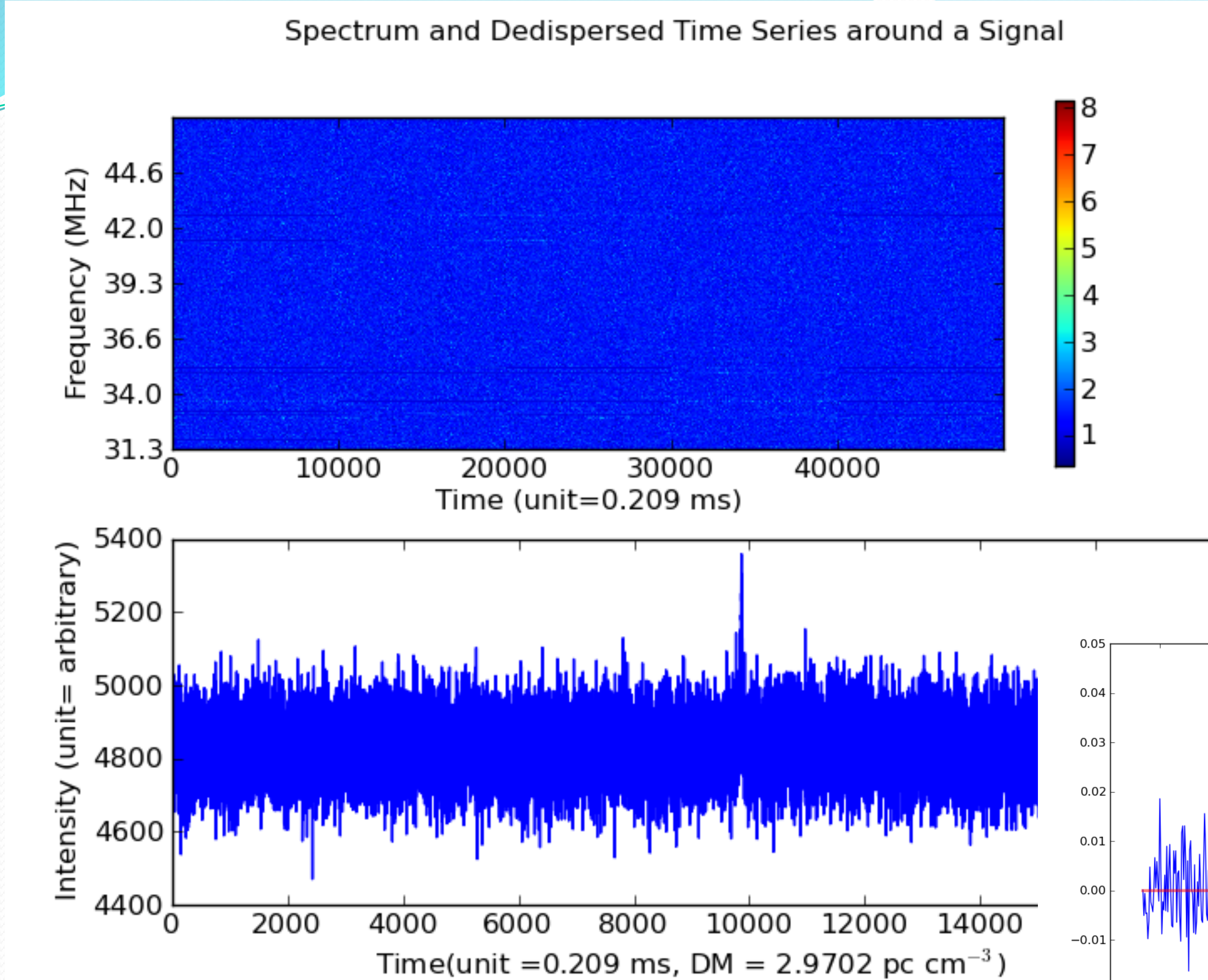
Data Reduction

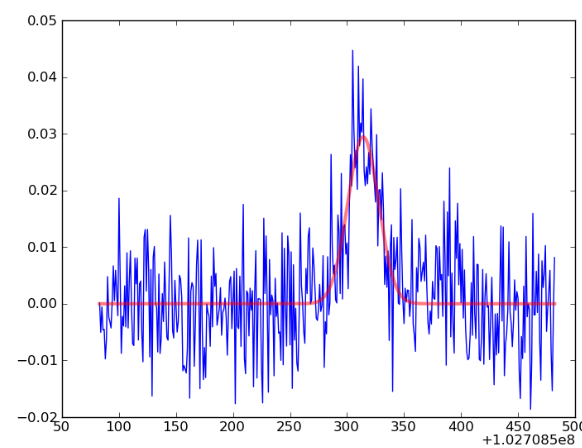
Data Analysis

- LWA Software Library
- Scripts written by Sean Cutchin
- Additional analysis by Jamie Tsai

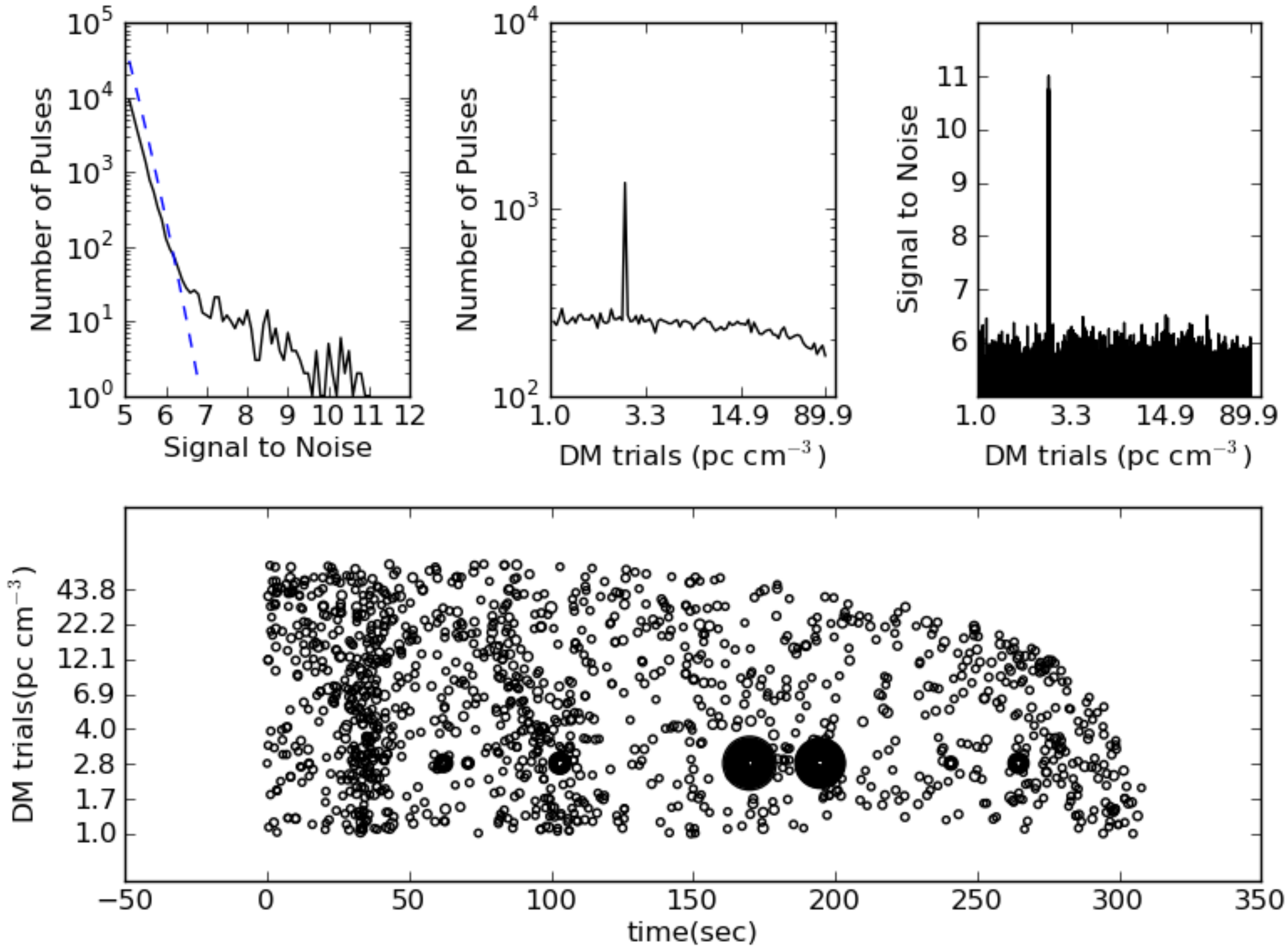
Clusters

- T-bird at VT: 24 cores
- Blueridge at VT: 1024 cores
- Arcturus at LIU: 24 cores
  - (initial processing of 44 hours other obs)





6 hours of observing time, 39 MHz, 16 MHz bandpass
Pulse is 15.8 sigma (strongest), pulse width is 10.9 ms, 306 Jy
Detected in one polarization

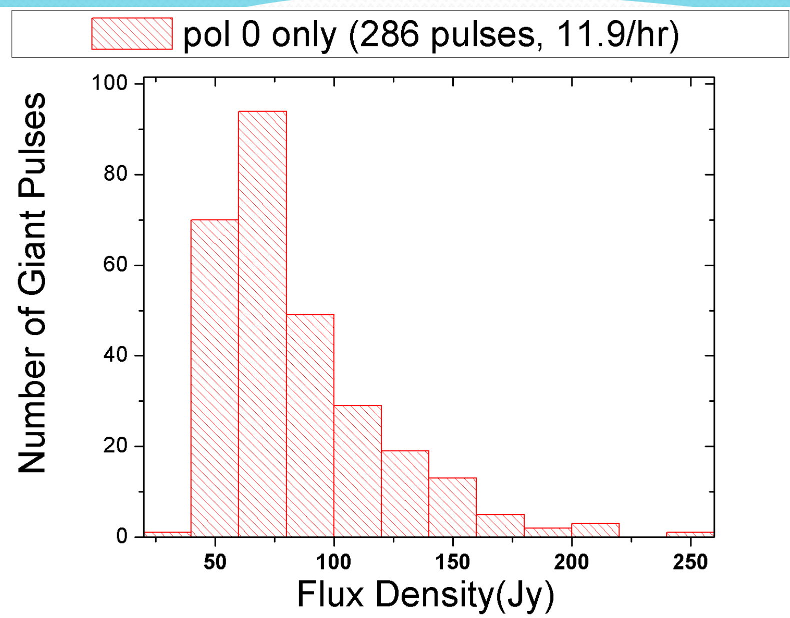


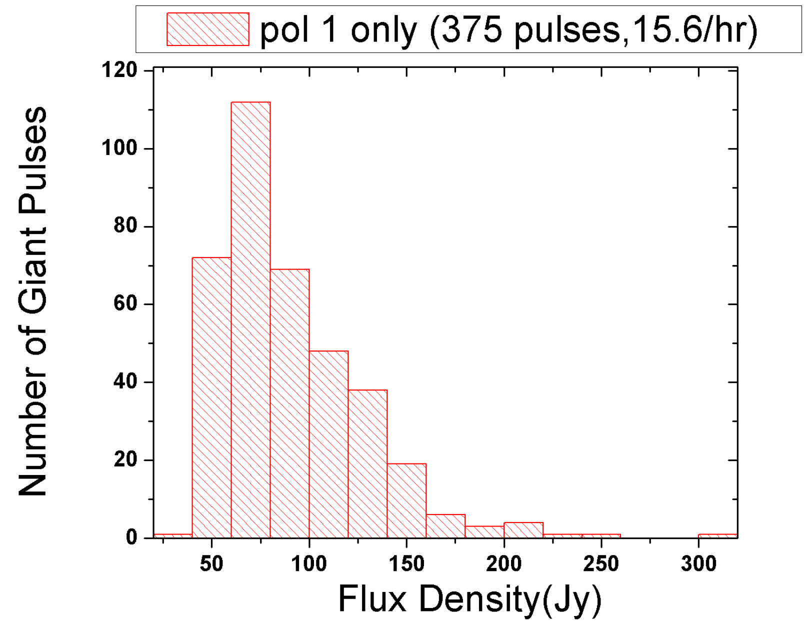
5 minutes of observed data, 38MHz

One polarization

15,000 DM trials (DM search from 1 to 90 pc cm^{-3})

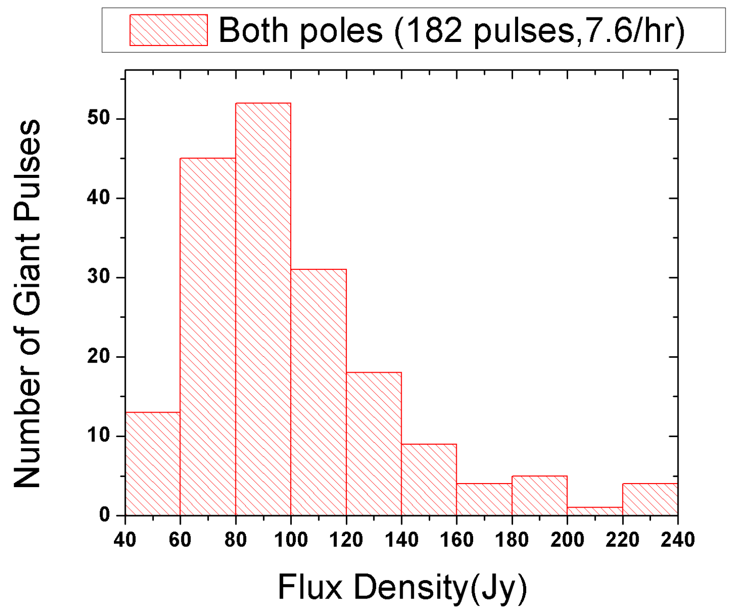
DM = 2.97 pc cm^{-3}





Pulses observed in 24 hours of data
> 5 sigma, pulse width between 4 ms and 40 ms

5 sigma ≈ 8 Jy
for a bandwidth of 16 MHz,
integration time of 1 second



Plans for the Future

Short range: Coincident observations with GEO (time already awarded)

Medium range: Develop/refine procedure,

Triggered observations?

Long range: Collaborative work with Advanced LIGO

Letter of Intent

MOU