Prospects for the LWA-Swarm for Pulsars, Gravitational Waves, and Student Research

Timothy Dolch[1], A. Dulemba[1], S. Niedbalski[1], S. Smith[1], T. Creighton[2], L. P. Dartez[2], B. Cole[2], North American Nanohertz Observatory for Gravitational Waves (NANOGrav) and International Pulsar Timing Array (IPTA) Collaborations + many others

[1]*Hillsdale College, Hillsdale, MI, USA*

[2]*University of Texas, Rio Grande Valley*

1-Aug 2019

LWA Users Meeting, UNM

The NANOGrav Physics Frontiers Center

We have grown to about 120 students and scientists at ~40 institutions:

The NANOGrav Physics Frontiers Center

We have grown to about 120 students and scientists at ~40 institutions:

Since 2015, NANOGrav funded on a 5-year, $14.5M USD grant from the National Science Foundation after a highly competitive process. NANOGrav is recognized as a Physics Frontiers Center by the NSF Physics division. 6th year extension just granted.

The N... r

We have g... ions:

Astro2020 Science White Paper

Gravitational Waves, Extreme Astrophysics, and Fundamental Physics with Precision Pulsar Timing

Principal authors
James Cordes *(Cornell University)*, cordes@astro.cornell.edu
Maura McLaughlin *(West Virginia University)*, maura.mclaughlin@mail.wvu.edu

for the NANOGrav Collaboration
(The North American Nanohertz Observatory for Gravitational Waves)

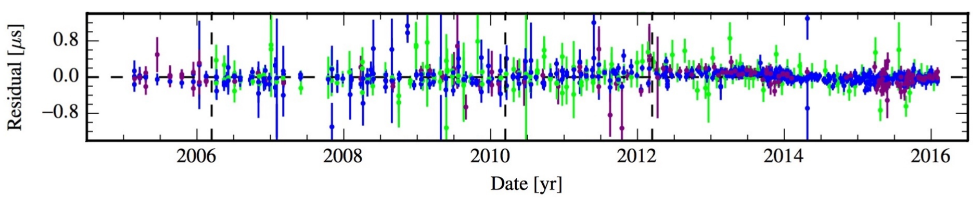


Figure 1: Over a decade of timing residuals from millisecond pulsar J1713+0747 with the Arecibo Observtory and Green Bank Telescope at 820 MHz (green), 1.4 GHz (blue), and 2.1 GHz (magenta) [1]. The RMS residual is 116 ns, demonstrating the remarkable stability of millisecond pulsars over long timespans.

This is one of five core white papers written by members of the NANOGrav Collaboration.

Supermassive Black-hole Demographics & Environments with Pulsar Timing Arrays, S. Taylor et al.
Fundamental Physics with Radio Millisecond Pulsars, E. Fonseca et al.
Physics Beyond the Standard Model with Pulsar Timing Arrays, X. Siemens et al.
Multi-messenger Astrophysics with Pulsar Timing Arrays, L. Kelley et al.

Other Related Science Whitepapers

Gravitational-Wave Astronomy in the 2020s and Beyond: A view across the gravitational wave spectrum, the Gravitational Waves International Committee
The Virtues of Time and Cadence for Pulsars and Fast Tra...
Twelve Decades: Probing the ISM from kiloparsec to sub-AU s...

Thematic Areas: ☐ Planetary Systems ☐ Sta...
☐ Formation and Evolution of Compact Objects ☑ Cosmolog...
☐ Stars and Stellar Evolution ☐ Resolved Stellar Population...
☐ Galaxy Evolution ☑ Multi-Messenger Ast...

10 NANOGrav Astro2020 white papers Submitted!

NANOGrav = North American Nanohertz Observatory for Gravitational Waves

NANOGrav

The Green Bank Telescope and the Arecibo Observatory

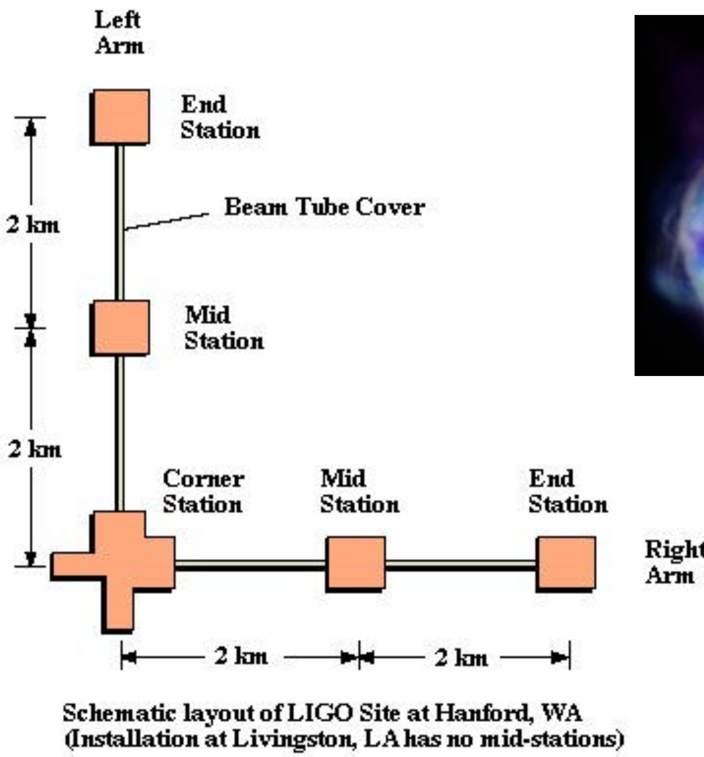
Our measurements are made every 3 weeks (with 7 best pulsars observed weekly), ~30min/pulsar on 76 millisecond pulsars, with the two most sensitive radio telescopes in the world:

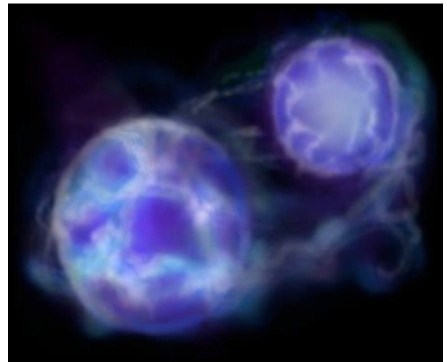
Arecibo Observatory (AO), PR
World's second largest single-dish radio telescope

Green Bank Telescope (GBT), WV
World's largest steerable single-dish radio telescope

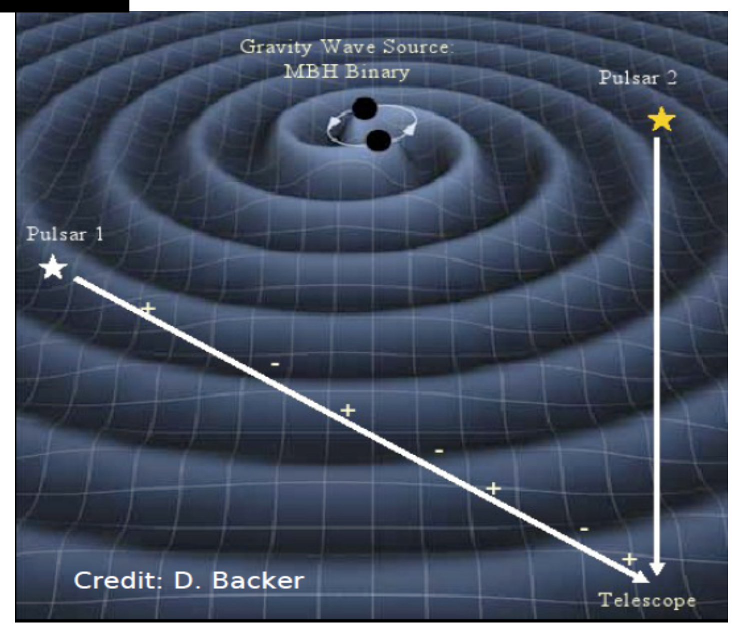
- The Very Large Array is also contributing to our data sets, and MOU with CHIME telescope recently signed
- Moore Foundation has recently funded development of an Ultra-Wideband Receiver for the GBT

Both LIGO and PTAs probe a ΔL on the scale of their respective "nuclei"

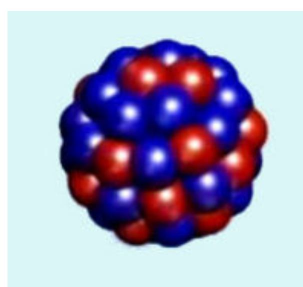




h = strain = $\Delta L/L = 10^{-15}$
PTA $\Delta L \sim 3$ km



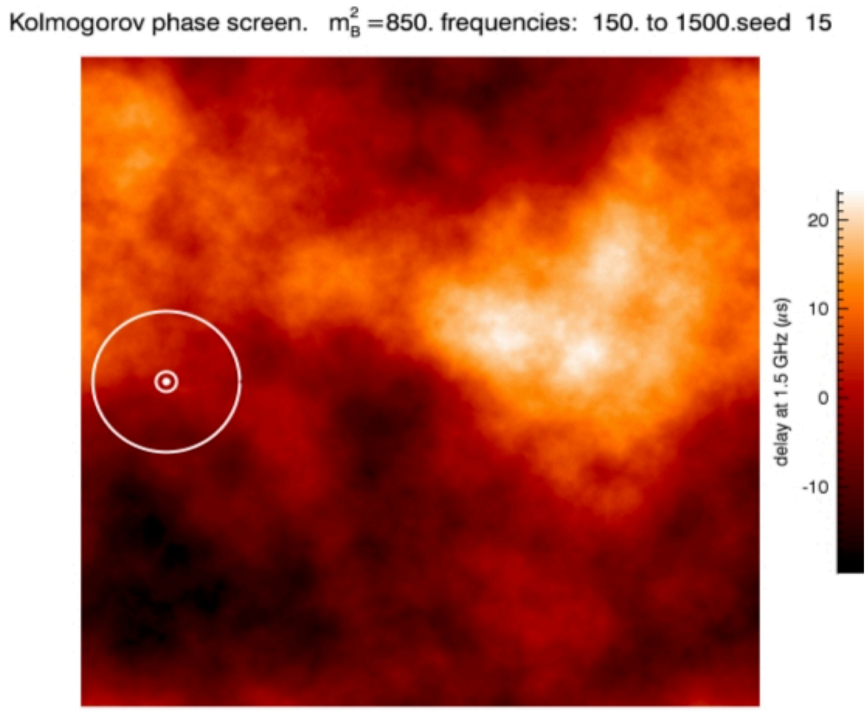
h = strain = $\Delta L/L = 10^{-21}$
LIGO $\Delta L \sim 10^{-19}$ m



The LWA Swarm

- Astro2020 White Paper: G. B. Taylor et al. (2019)
- LWA Mini-stations placed around continent: 864 antennas (LWA1+LWA-SV+LWA-OVRO) -> 1664 antennas
- Angular resolution: 0.5 arcsec
- The "Swarm" would consist of many mini-stations across continent with at least 48 LWA antennas/station – building off existing project sites and resources
- Pulsar astrophysics one of many science areas. Examples of benefits to pulsar timing arrays…
- <u>**For NANOGrav #1**</u>, an LWA-Swarm would be useful for line-of-sight characterization, including resolving scattering screens
- <u>**For NANOGrav #2**</u>, Possible pulsar discoveries could be made following up steep-spectrum point sources from imaging surveys from an LWA-Swarm
- <u>**For NANOGrav #3**</u>, resolution of dual AGN jets may be possible.

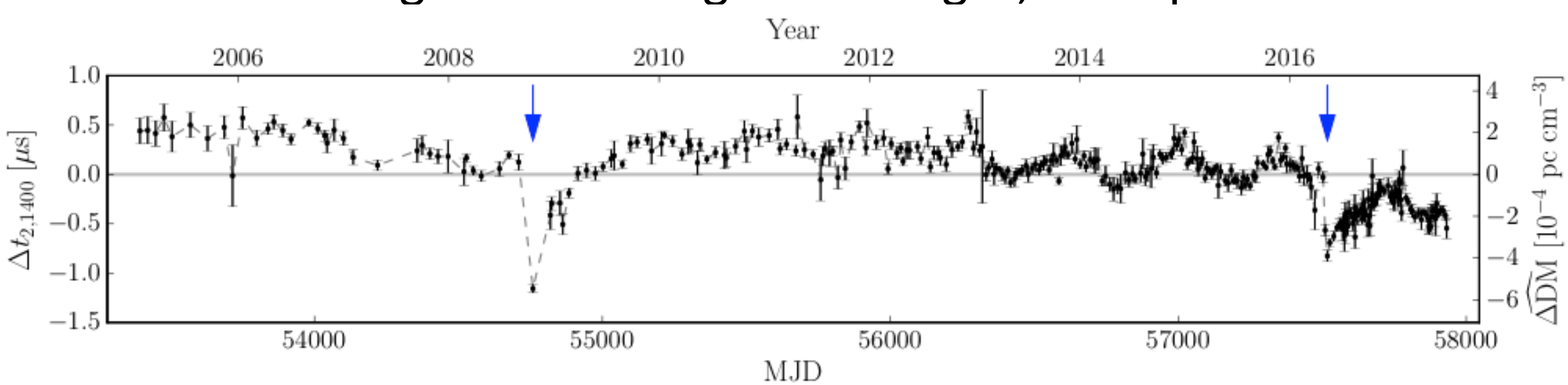
#1: Mitigating Pulsar Scattering for GW Detection



From Cordes, Shannon, Stinebring (2016)

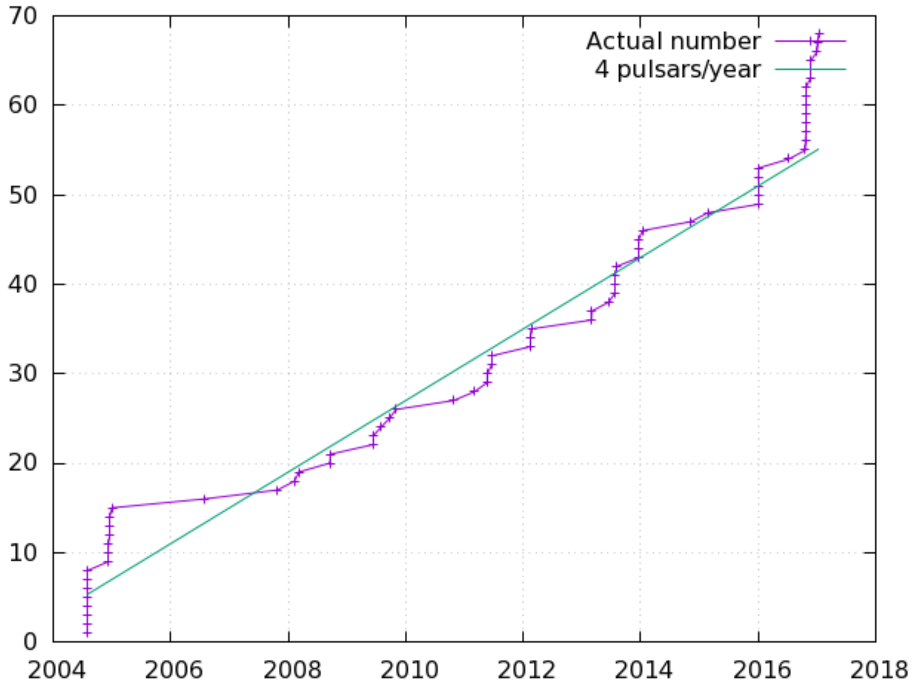
- In future, wide-bandwidth receivers, we may need to account for frequency-dependent dispersion measures (left)
- 6 NANOGrav pulsars currently detectable w/LWA (of 76, but 3 are in 13 most GW sensitive); more possible in future with cyclic spectroscopy
- as in Bansal et al. (2019) - want to understand scattering timescale vs. frequency for all NANOGrav pulsars as widely as possible

- Resolved pulsar scattering screens can also model or limit unusual scattering events along line-of-sight; example J1713+0747

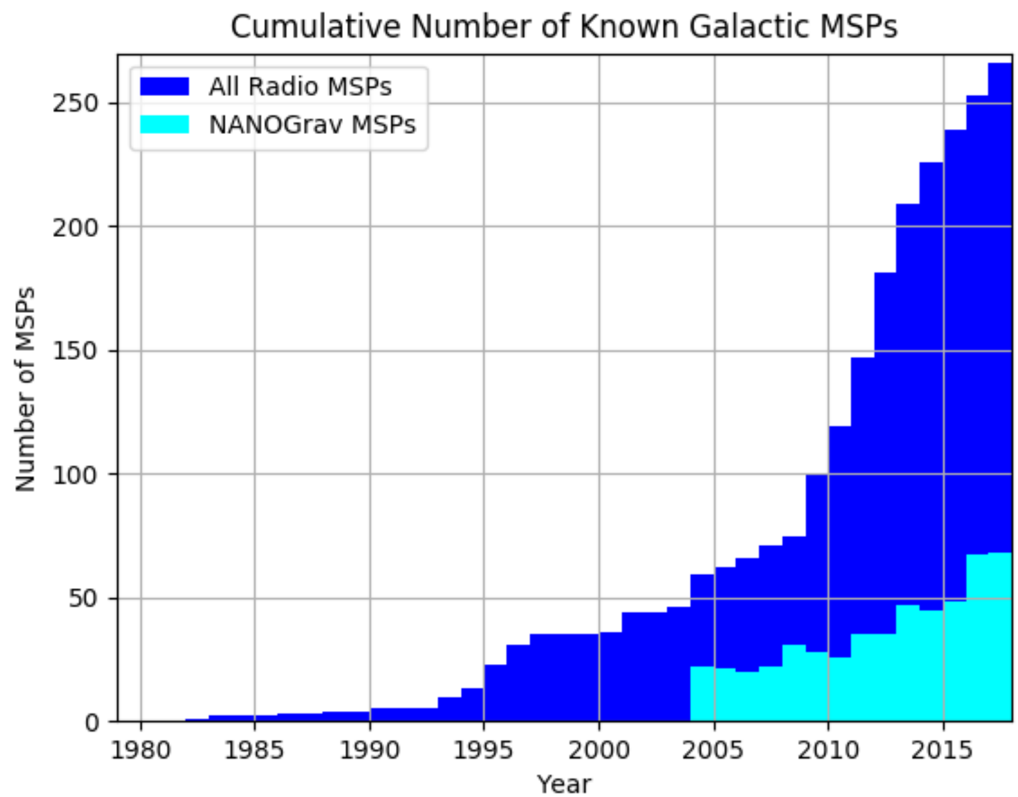


from Lam et al. (2018)

#2: Building a better GW detector by discovering more pulsars adding more lever arms



# of recently discovered pulsars added to NANOGrav: $\sim 4/yr$



$$(S/N)_{GW} \propto N_{pulsars}$$

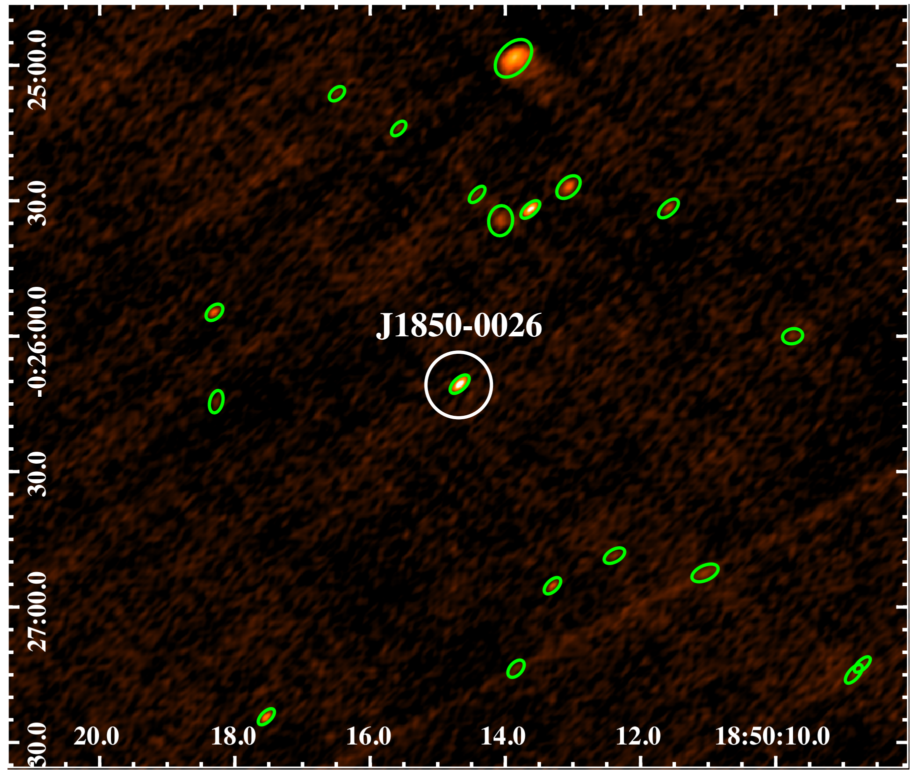
(Siemens et al 2013)

…discovering new pulsars is critical to discovering long-period GWs due to merging supermassive BH binaries.
Searching done at 342 MHz and 430 MHz.
Future: lower frequencies, imaging surveys

Courtesy S. Ransom, P. Demorest

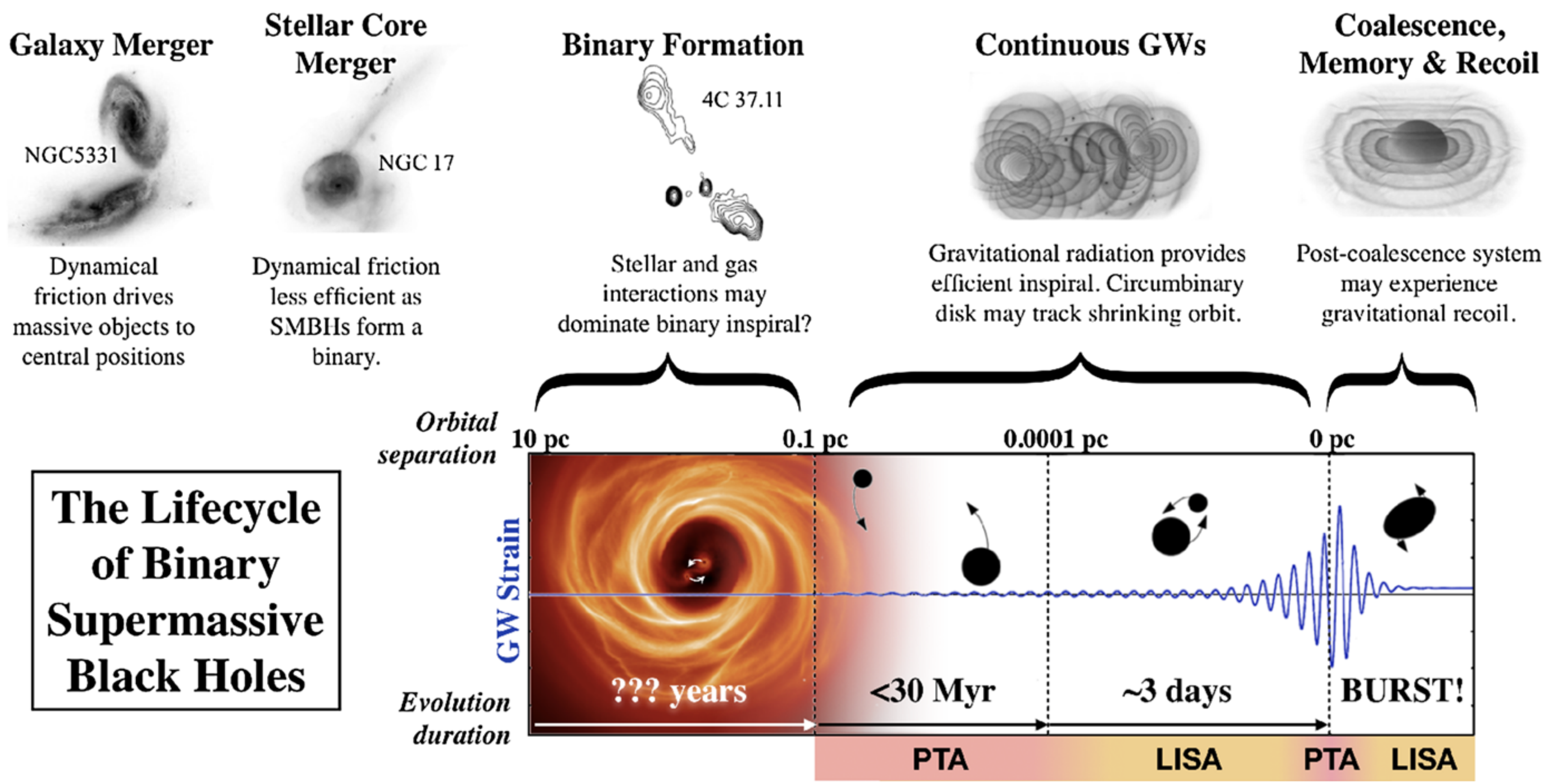
#2: Building a better GW detector by discovering more pulsars adding more lever arms

- Unidentified Fermi gamma ray sources have yielded new radio MSP discoveries; also possible for unidentified steep spectrum radio point sources in imaging data
- Searching project targets Very Large Array steep-spectrum point sources, searching for radio pulsations
- Pilot VLA survey data showed that the method can recover known sources; planned for VLASS
- Like Frail et al. (2016) with TGSS data
- an LWA-Swarm Sky Survey would likely yield pulsar discoveries; pulsation detection not necessary
- Possible issues: background, low-frequency turnover



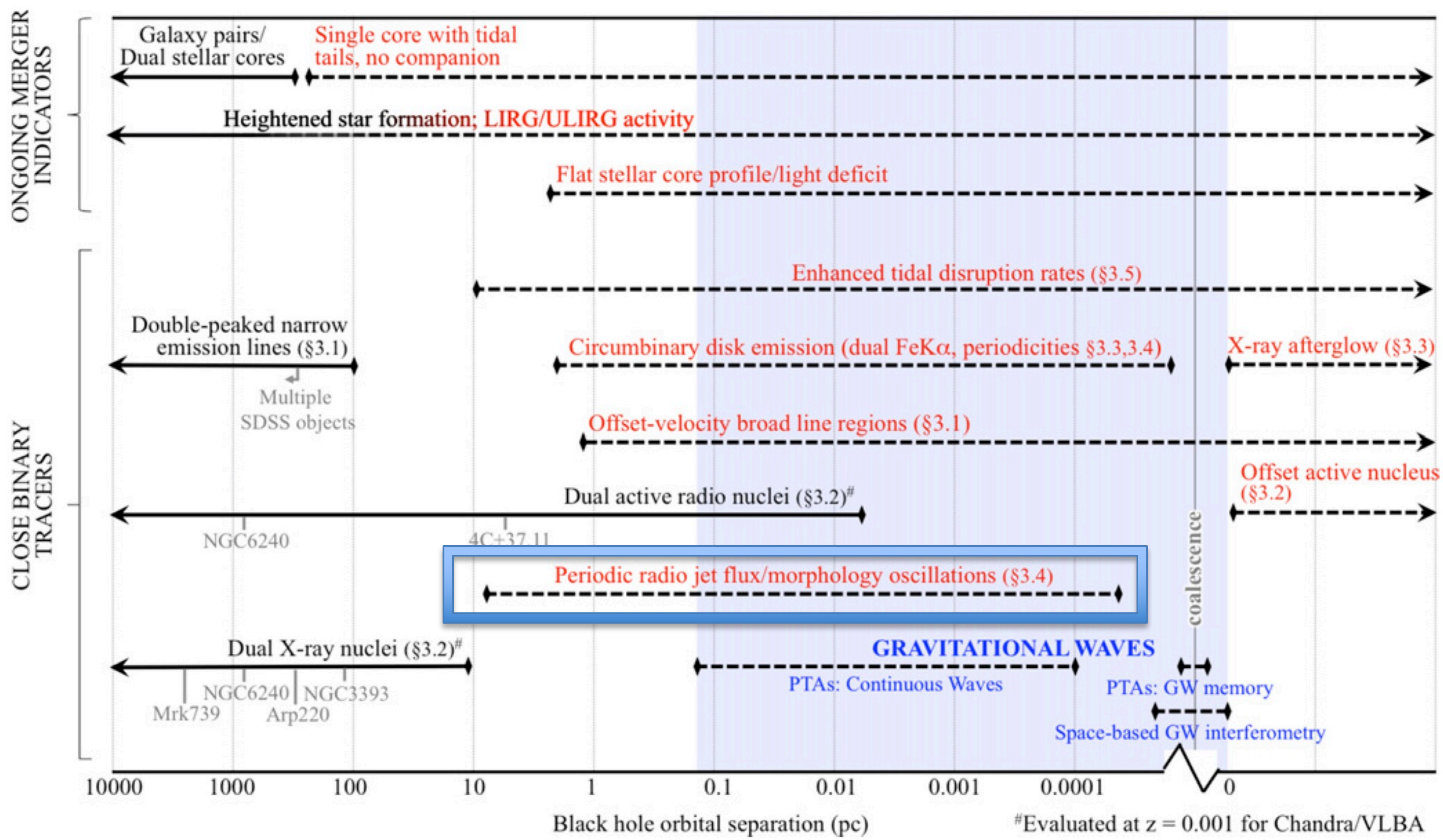
Courtesy Robert Wharton, MPIfR

#3: Imaging dual AGN structures corresponding to future GW detections with pulsar timing arrays



Burke-Spolaor et al., A&Arv (2019)

#3: Imaging dual AGN structures corresponding to future GW detections with pulsar timing arrays

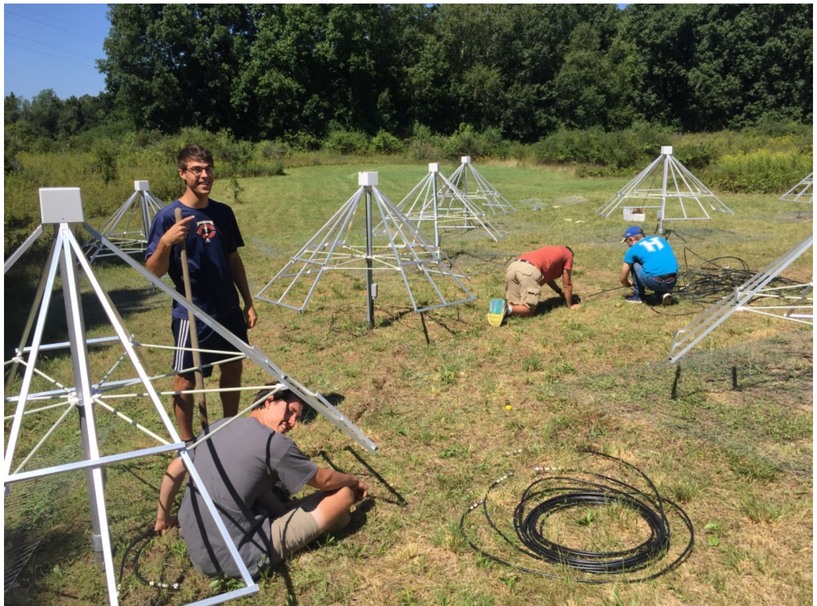


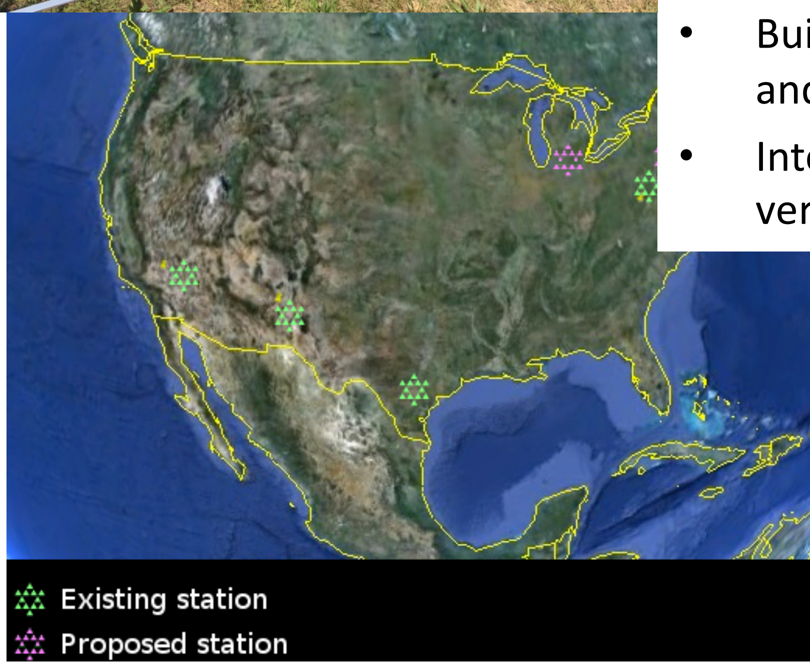
Burke-Spolaor et al., CQG (2013)

#3: Imaging dual AGN structures corresponding to future GW detections with pulsar timing arrays

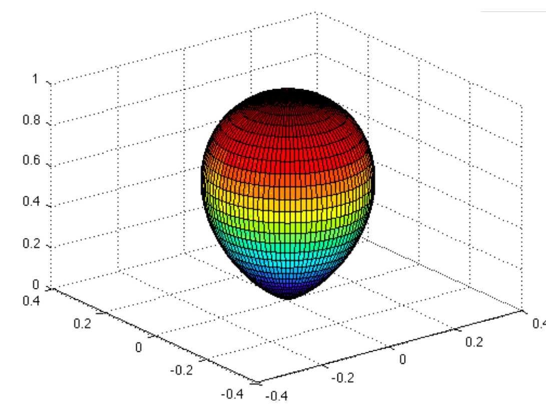
- Most likely GW source with PTAs is stochastic background of all ongoing mergers across cosmic time
- But… continuous-wave sources (e.g. individual supermassive black hole binaries) also likely to be detected by NANOGrav by 2030 (Mingarelli et al. 2017)
- Jet structures (sub-kpc structures) from dual AGN could be resolved with LWA Swarm - advantageous for diffuse synchrotron
- helical structures interesting for jet precession, etc. (Roos, Kaastra & Hummel 1993; Romero et al. 2000; Britzen et al. 2001; Lobanov & Roland 2005; Valtonen & Wiik 2012; Caproni, Abraham & Monteiro 2013; Kun et al. 2015)

An LWA-Swarm Pathfinder: The Low-Frequency All-sky Monitor



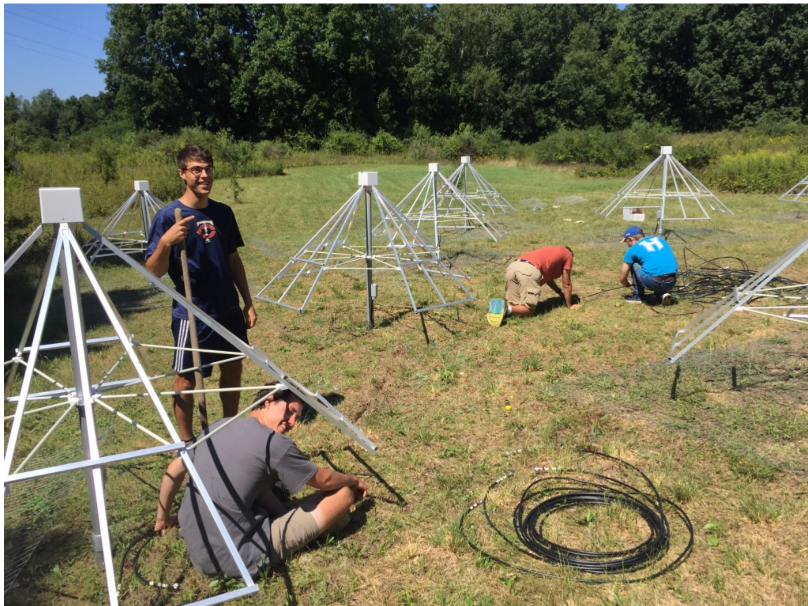


- Wide-beam sky monitor, each station with 12 LWA antennas + outrigger
- 10 – 88 MHz
- ~80 ms time resolution currently
- 4 previous stations (Port Mansfield TX, Socorro NM, Goldstone CA, Green Bank WV)
- **Expanded to new station: Hillsdale College, Michigan (Dolch): LoFASM V**
- Led by UTRGV (T. Creighton, L. Dartez, B. Cole)
- Built largely with student researchers, undergraduate and graduate
- Intended for daily monitoring of Sun, very rare and very bright transients

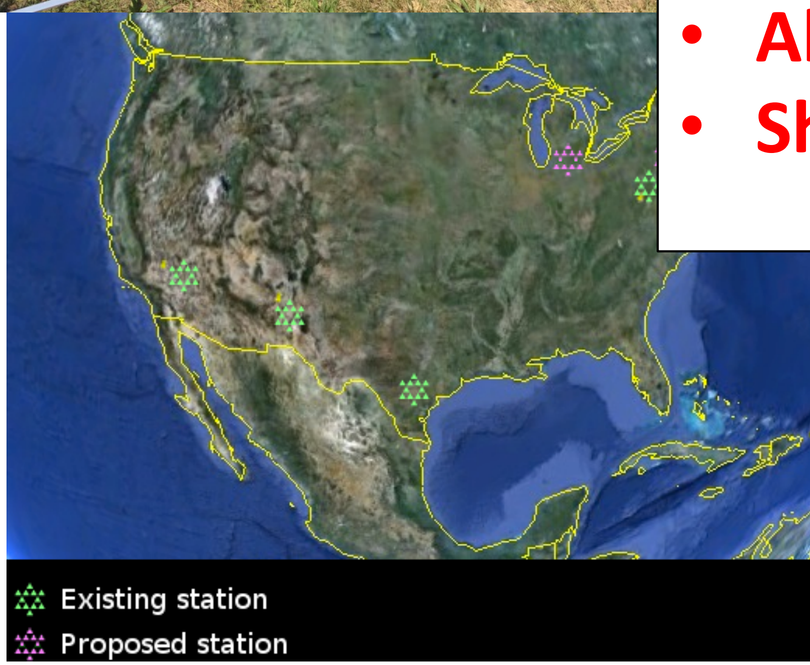


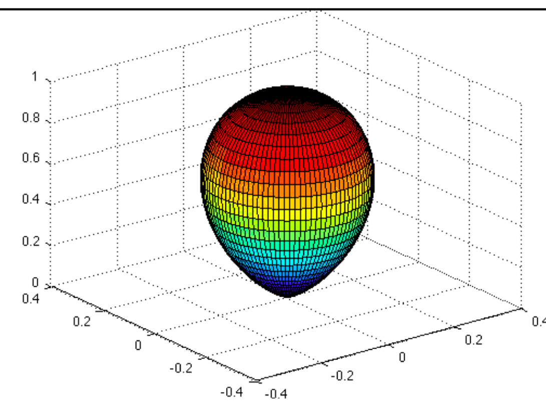
Dartez (2014)

An LWA-Swarm Pathfinder: The Low-Frequency All-sky Monitor



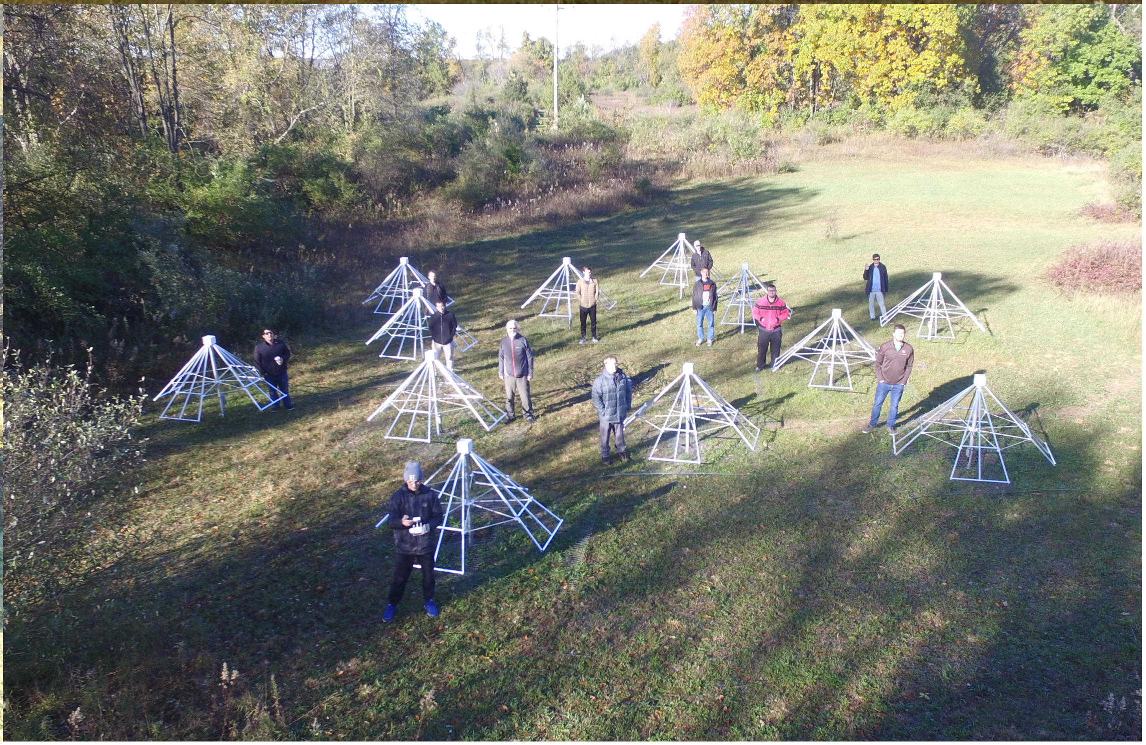
- Built and operated in 2018 - 2019 with 5 LAUREATES-funded summer research students **(HERE AT MEETING)**:
- **Philip Andrews**
- **Nathaniel Birzer**
- **Sasahabaw Niedbalski**
- **Caleb Ramette**
- **Jay Rose**
- **Alex Dulemba**
- **Shane Smith**



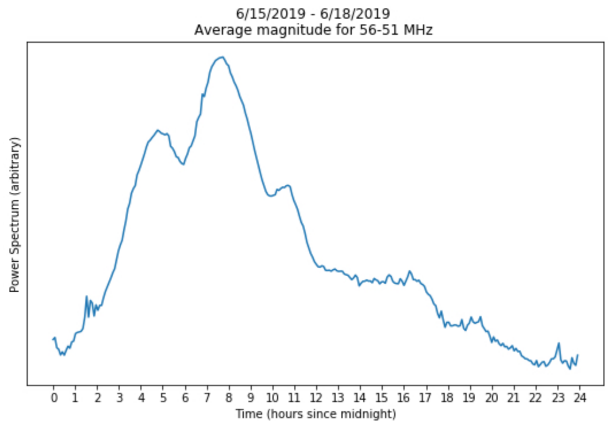


Dartez (2014)

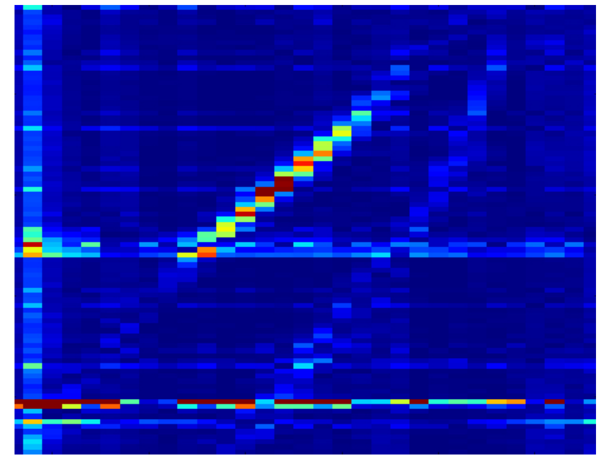
LoFASM V: Hillsdale College

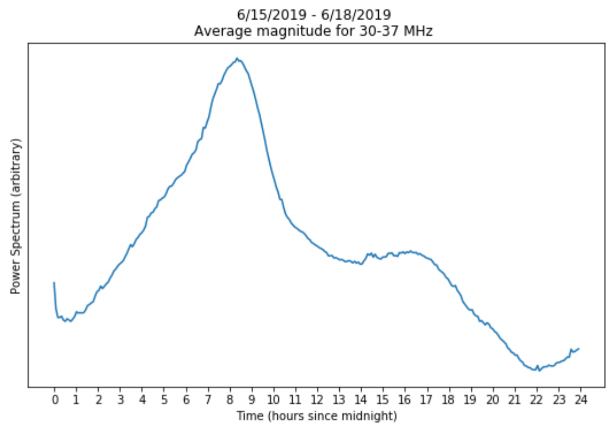


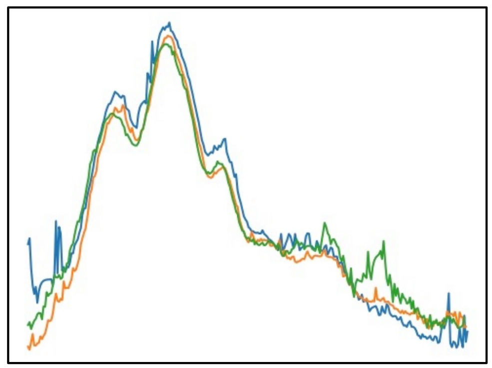
Hillsdale First Light + other results

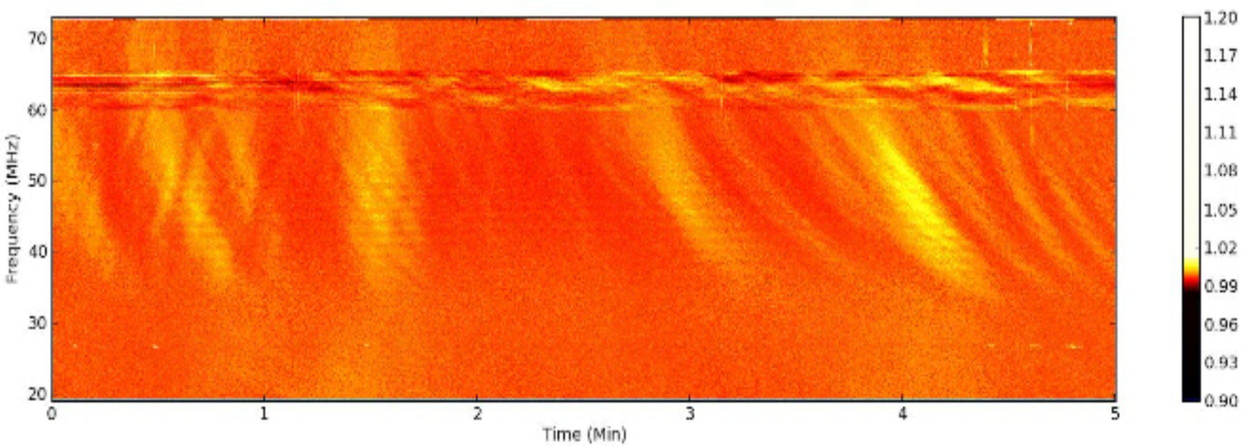


- LoFASM V (Hillsdale) Delay spectrum with Cyg A and Cas A using interferometry mode with outrigger (right)
- LoFASM V Galactic diurnal cycle (daily averaged left, individual days below)



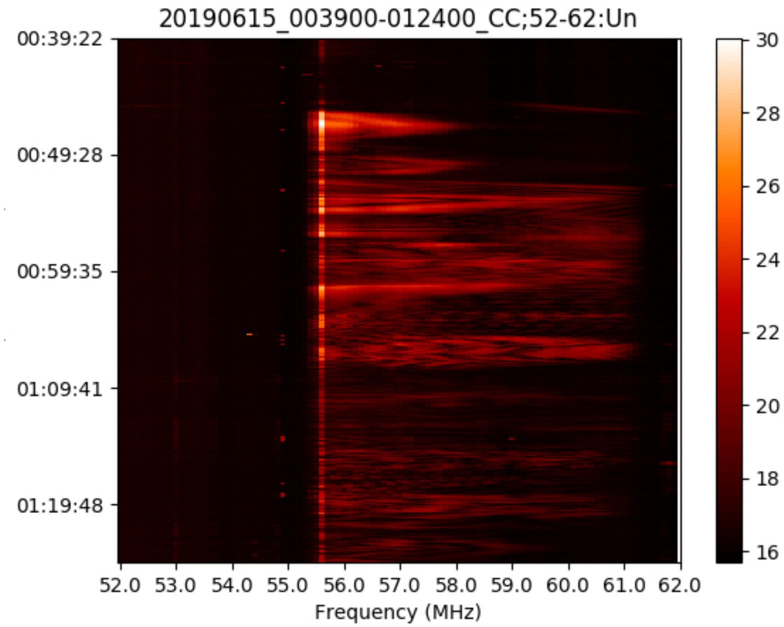


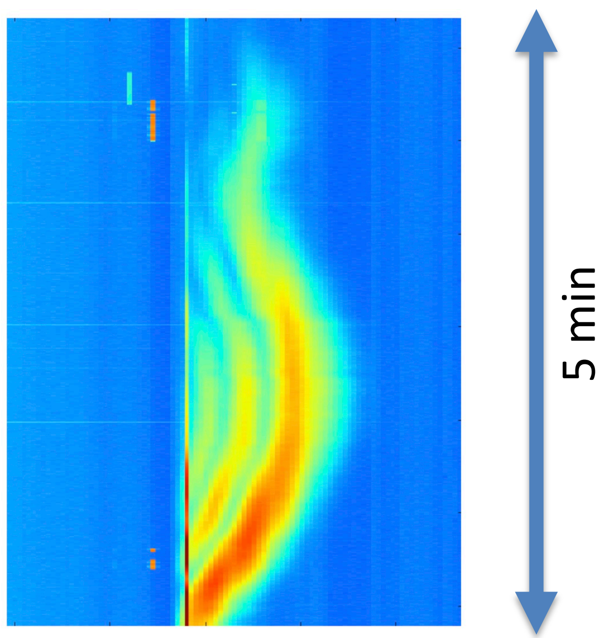




Broad, slightly-dispersed signals, likely solar in origin *(LoFASM IV, Goldstone CA; courtesy Andrew Danford, UTRGV)*

Hillsdale First Light + other results





- ~30s, ~20MHz radar sweeps
- ~60 MHz events possibly of ionospheric origin, occurring around 01:00 AM
- (above) ~30min duration, possibly digital TV signal interacting with magnetic instability
- (below) ~5min event, possibly transmitted signal interacting with traveling ionospheric disturbance
- 33GB spectra/day. Continued Hillsdale/UTRGV student involvement + local chapter of the Society of Amateur Radio Astronomers (SARA)
- Ongoing student project to apply scikit-learn machine learning code to identify events

Conclusions

- NANOGrav (the North American Nanohertz Observatory for Gravitational Waves) searching for long-period GWs from supermassive black hole binaries
- A pulsar timing array's GW sensitivity is proportional to the number of pulsars. Low-frequency telescopes good for ongoing pulsar discoveries, ISM characterization along pulsar lines-of-sight, maybe dual-AGN structures
- The Low-Frequency All-Sky Monitor at Hillsdale College a pathfinder for an LWA-Swarm telescope.
- Join the swarm.