Pulsar Astrophysics with the LWA Swarm

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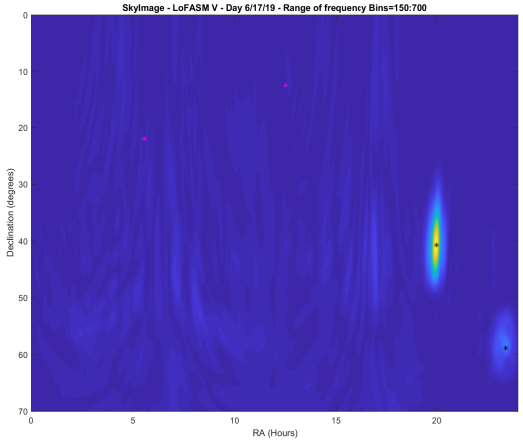
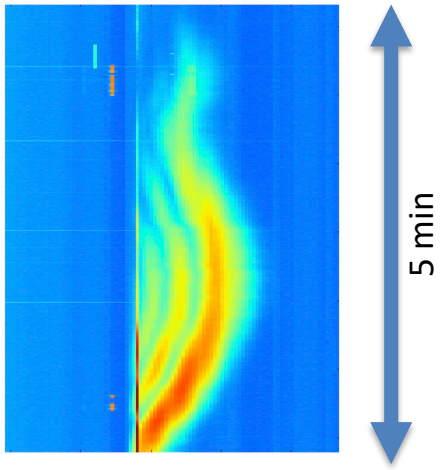
17-Aug 2021

LWA Users Meeting

LoFASM V: Hillsdale College

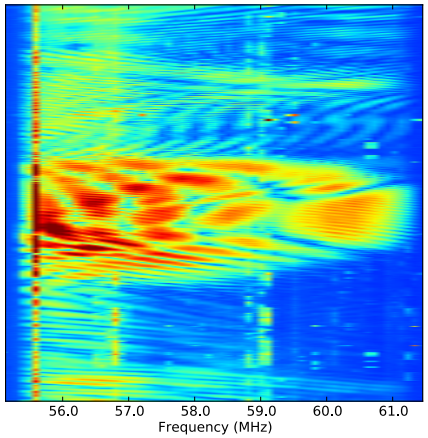
Hillsdale First Light + other results

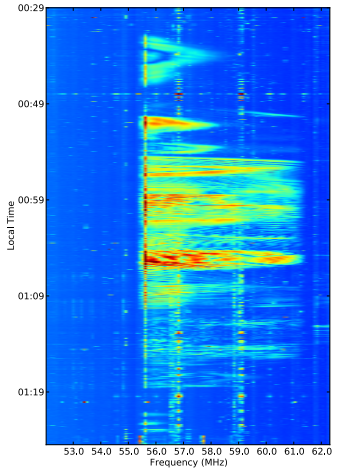




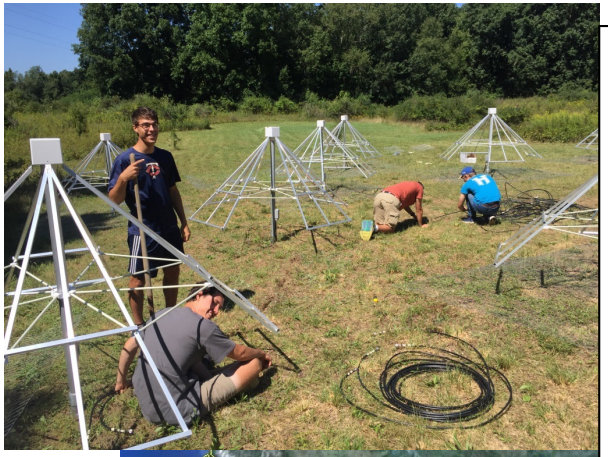
5 min

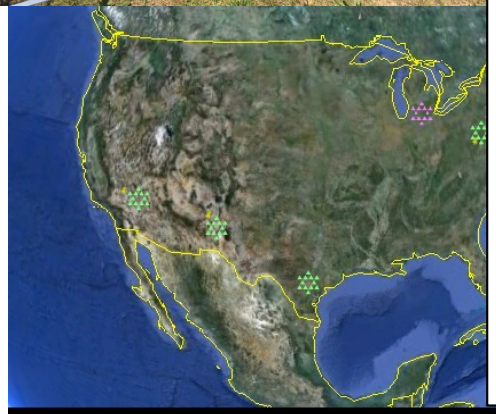
- (upper left) sky map with Cyg A + Cas A
- ~60 MHz events possibly of ionospheric origin (right, top and bottom; top is zoom-in of bottom) ~40min duration, likely digital TV signal interacting with ionosphere (Dolch et al. 2020, IEEExplore)
- (bottom left) ~5min event, possibly transmitted signal interacting with traveling ionospheric disturbance (TID)
- Some similarities to events reported in Koval et al. (2017), Koval et al. (2019)
- (right) Some ”teepee” structures similar to Fung et al. (2020) from Higgins RadioJove group





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





Hillsdale Students

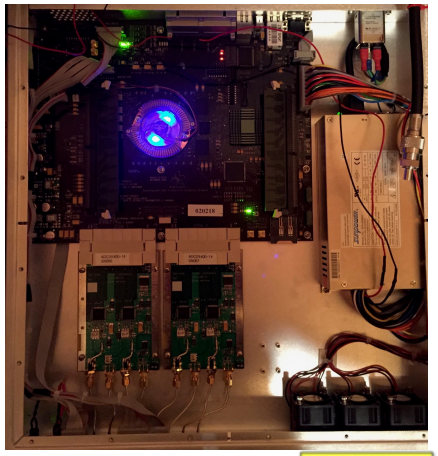
- Philip Andrews
- Nathaniel Birzer
- Sasahabaw Niedbalski
- Caleb Ramette
- Jay Rose
- Alex Dulemba
- Shane Smith
- Evan Anthopoulos
- Laurie Preston
- Stephen Mulchahey
- Joseph Harvey
- Konrad Ludwig

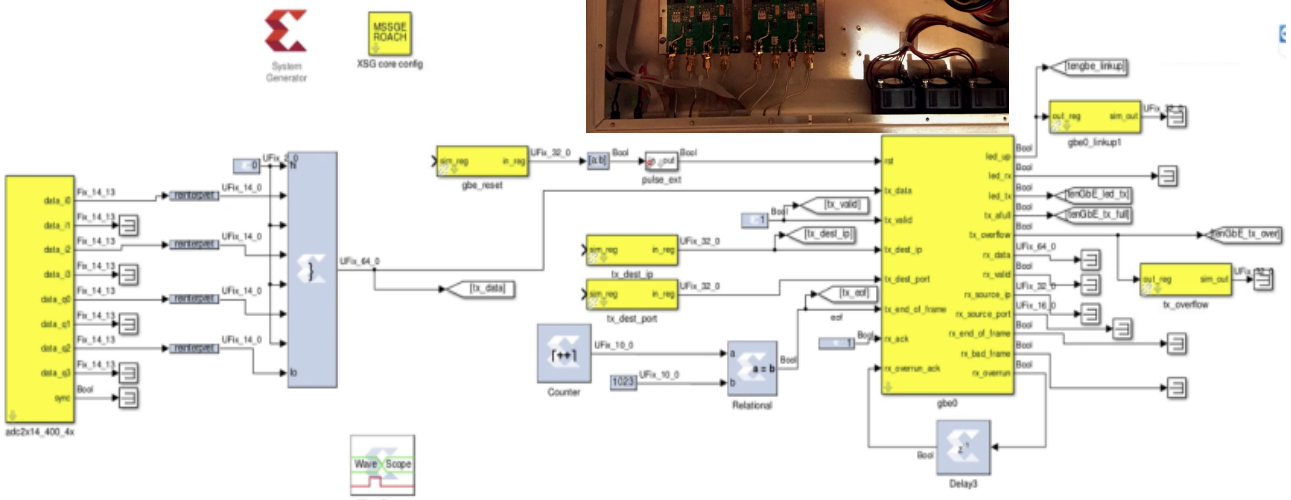
UTRGV Team

- Brent Cole
- Louis Dartez
- Teviet Creighton

Jay Rose (‘18) senior thesis: “Backend Electronics for a Radio Telescope”

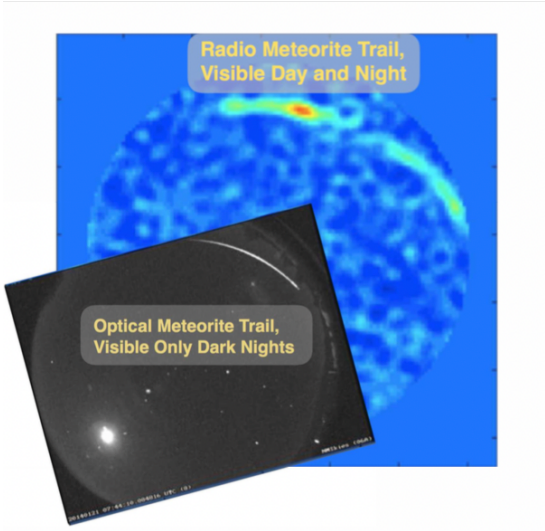
- Used MATLAB’s Simulink package to program the FPGA for the baseband (1TB/hr) mode of data taking:





The LWA Swarm

- Astro2020 White Paper: G. B. Taylor et al. (2019)
- Also 10—88 MHz, same LWA antennas
- Angular resolution: 0.5 arcsec
- The “Swarm” would consist of many mini-stations across continent with at least 64 LWA antennas/station – building off existing project sites and resources
- A LoFASM station could be a Swarm pathfinder, building off current infrastructure and local expertise and expanding
- Hillsdale College has joined as Swarm partner as MoU



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The Swarm Development Concept for the LWA

Greg B. Taylor,[1] Jayce Dowell,[1] Ylva Pihlström,[1] Frank Schinzel,[2] Namir Kassim,[3] Gregg Hallinan,[4] Ian M. Hoffman,[5] Dave Besson,[6] Steven Prohira,[6] Andri M. Gretarsson,[7] Ramon D. Fobes,[7] Thomas J. Maccarone,[8] Timothy Dolch,[9] Judd D. Bowman,[10] Daniel C. Jacobs,[10] Fredrick A. Jenet,[11] Stan Kurtz,[12] Nithyanandan Thyagarajan,[13] Adam P. Beardsley,[10] Jack O. Burns,[14] Terry Bullett,[15] Michael Kavic,[16] and Peter Driessen[17]

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Keywords: instrumentation — radio — telescopes — education

Ground Based Project

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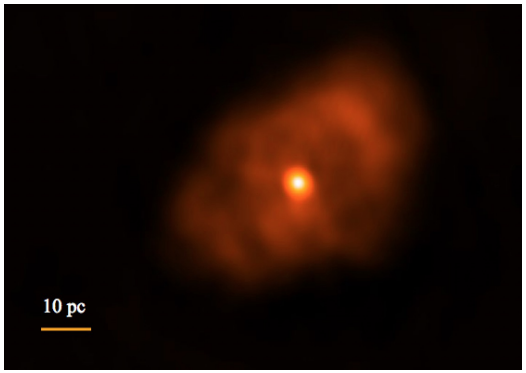
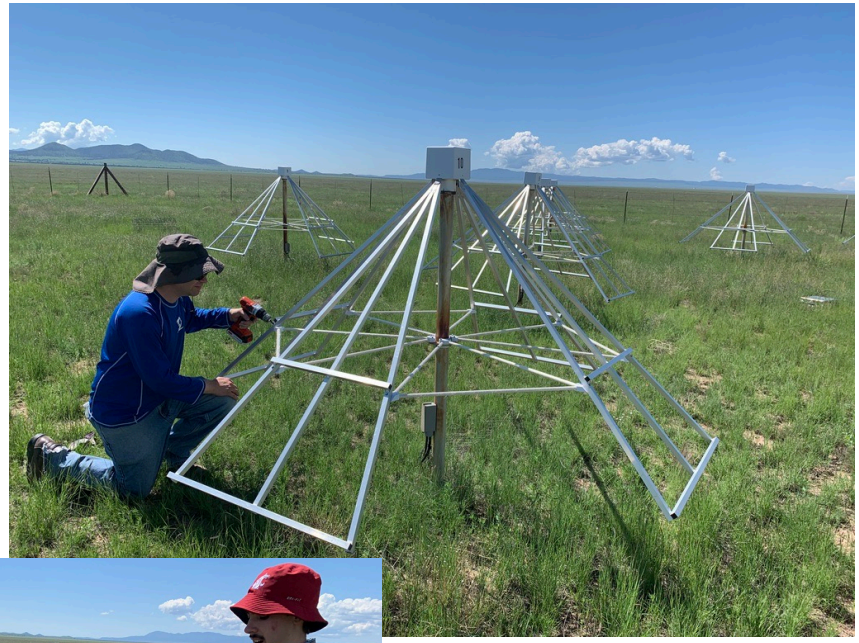
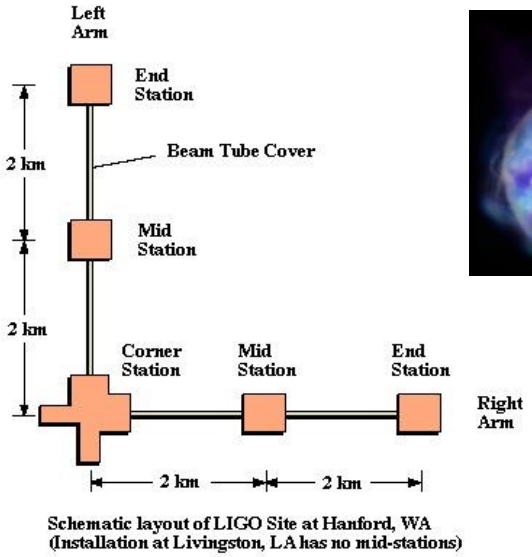
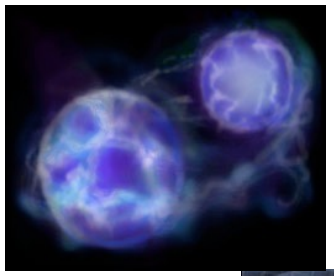




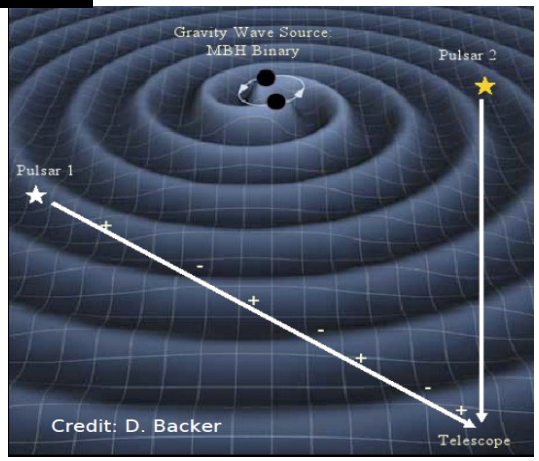
Both LIGO and PTAs probe a ΔL on the scale of their respective “nuclei”



Schematic layout of LIGO Site at Hanford, WA
(Installation at Livingston, LA has no mid-stations)



h = strain = ΔL/L = 10^{-15}
PTA ΔL ~ 3 km



h = strain = ΔL/L = 10^{-21}
LIGO ΔL ~ 10^{-19} m

Draft version September 11, 2020
Typeset using LaTeX **twocolumn** style in AASTeX63

NANOGrav Physics Frontiers Center recently renewed!

The NANOGrav 12.5-year Data Set: Search For An Isotropic Stochastic Gravitational-Wave Background

Zaven Arzoumanian,[1] Paul T. Baker,[2] Harsha Blumer,[3,4] Bence Bécsy,[5] Adam Brazier,[6] Paul R. Brook,[3,4] Sarah Burke-Spolaor,[3,4,7] Shami Chatterjee,[6] Siyuan Chen,[8,9,10] James M. Cordes,[6] Neil J. Cornish,[5] Fronefield Crawford,[11] H. Thankful Cromartie,[12] Megan E. DeCesar,[13,14,*] Paul B. Demorest,[15] Timothy Dolch,[16] Justin A. Ellis,[17] Elizabeth C. Ferrara,[18] William Fiore,[3,4] Emmanuel Fonseca,[19] Nathan Garv[illegible] S. Hazboun,[21,*] A. Miguel Hol[illegible] drew R. Kaiser,[3,4] David L. Kapla[illegible] ichael T. Lam,[26,27] T. Joseph W. L[illegible] in R. Madison,[3,4,*] Maura A[illegible] vid J. Nice,[13] Timothy T. Pennucc[illegible] nt J. Shapiro-Albert,[3,4] Xavier Siemens,[illegible] el R. Stinebring,[39] Kevin Stovall,[illegible] acob E. Turner,[3,4]

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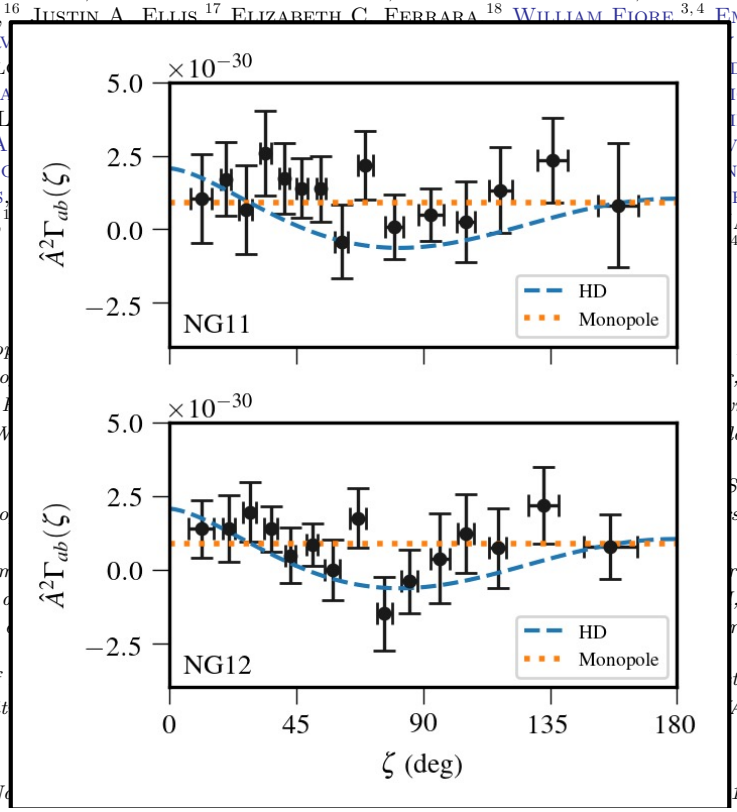
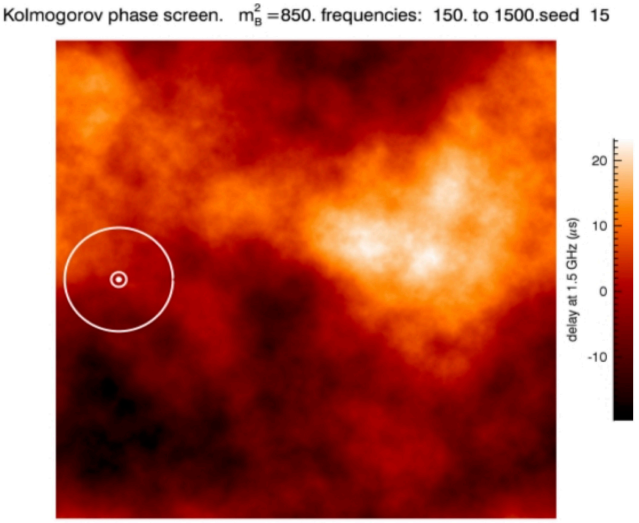


The NANOGrav Physics Frontiers Center

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

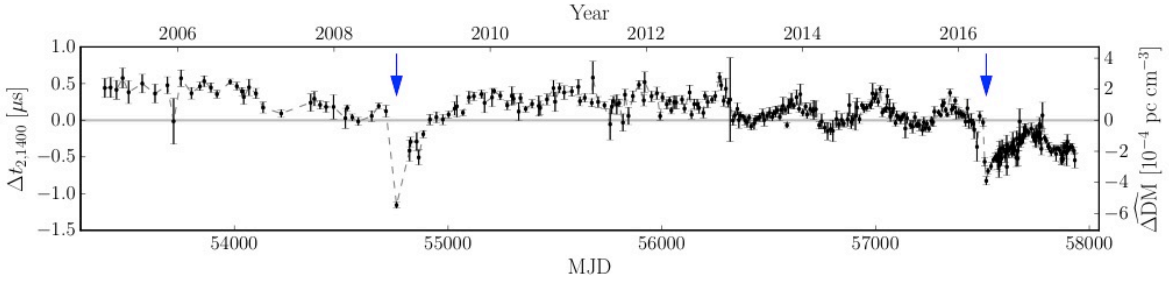
#1: Mitigating Pulsar Scattering for GW Detection



From Cordes, Shannon, Stinebring (2016)

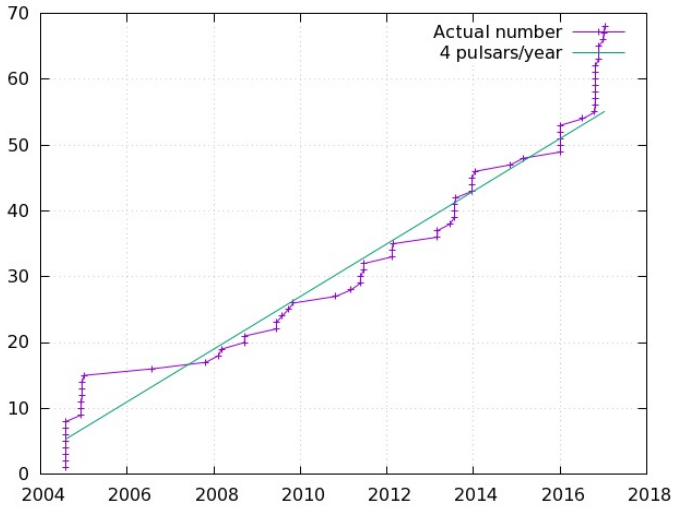
- In future, wide-bandwidth receivers, we may need to account for frequency-dependent dispersion measures (left)
- 6 NANOGrav pulsars currently detectable w/LWA (of 76, but 3 are in 13 most GW sensitive); more possible in future with cyclic spectroscopy
- as in Bansal et al. (2019) - want to understand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

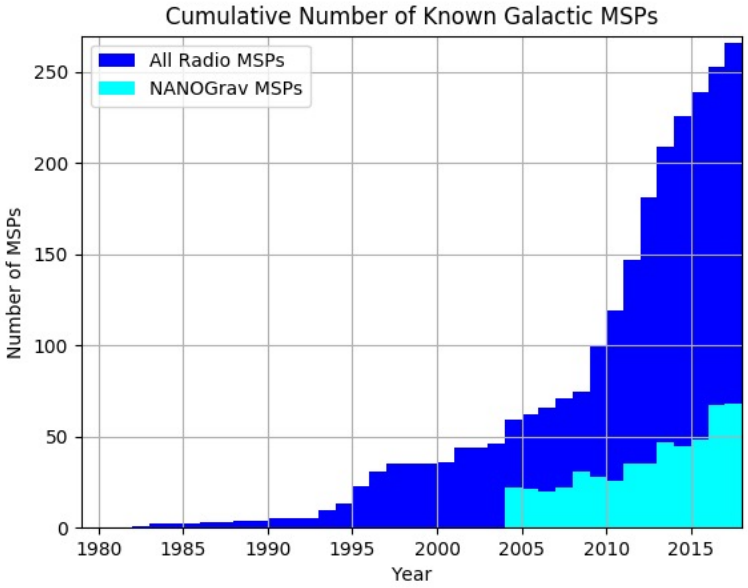


from Lam et al. (2018)

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



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



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

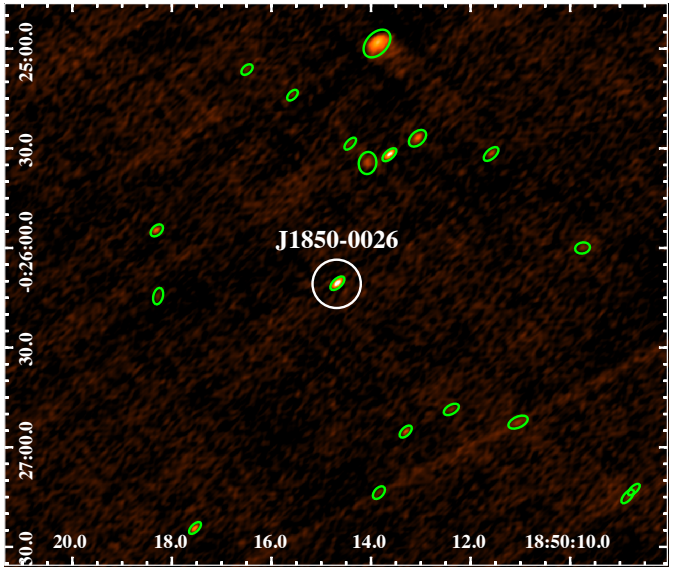
(Siemens et al 2013)

…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

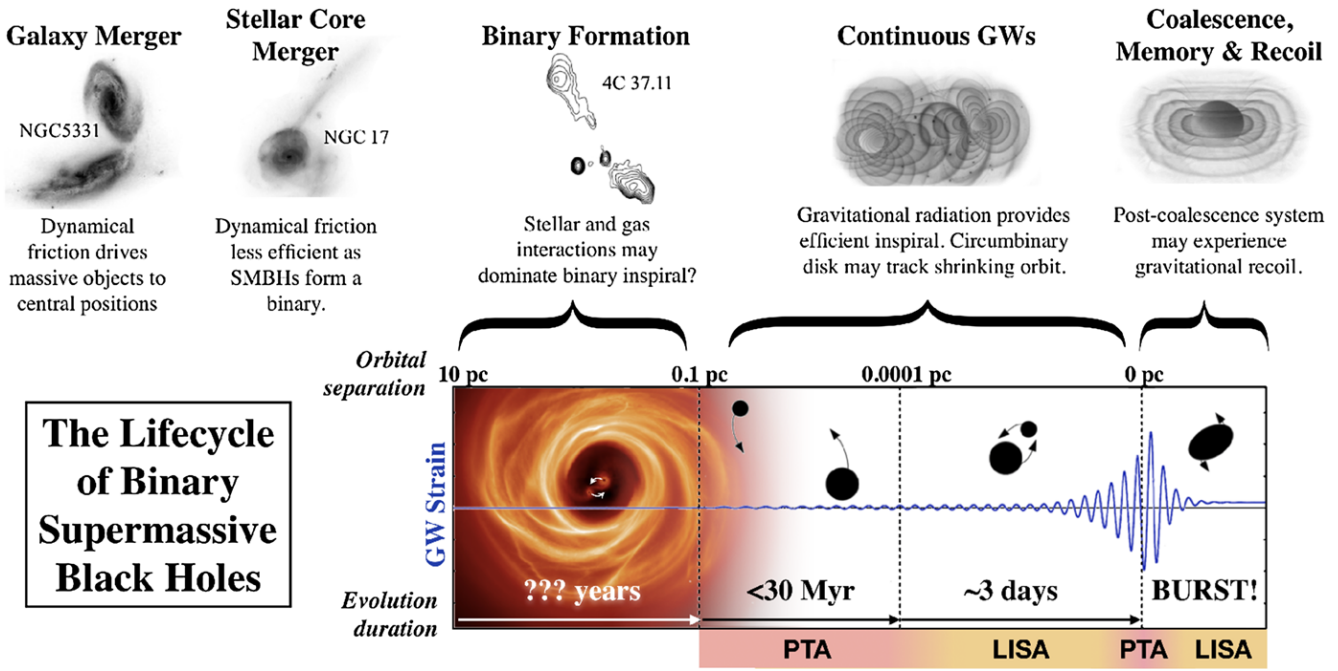
#2: Building a better GW detector by discovering more pulsars adding more lever arms

- 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



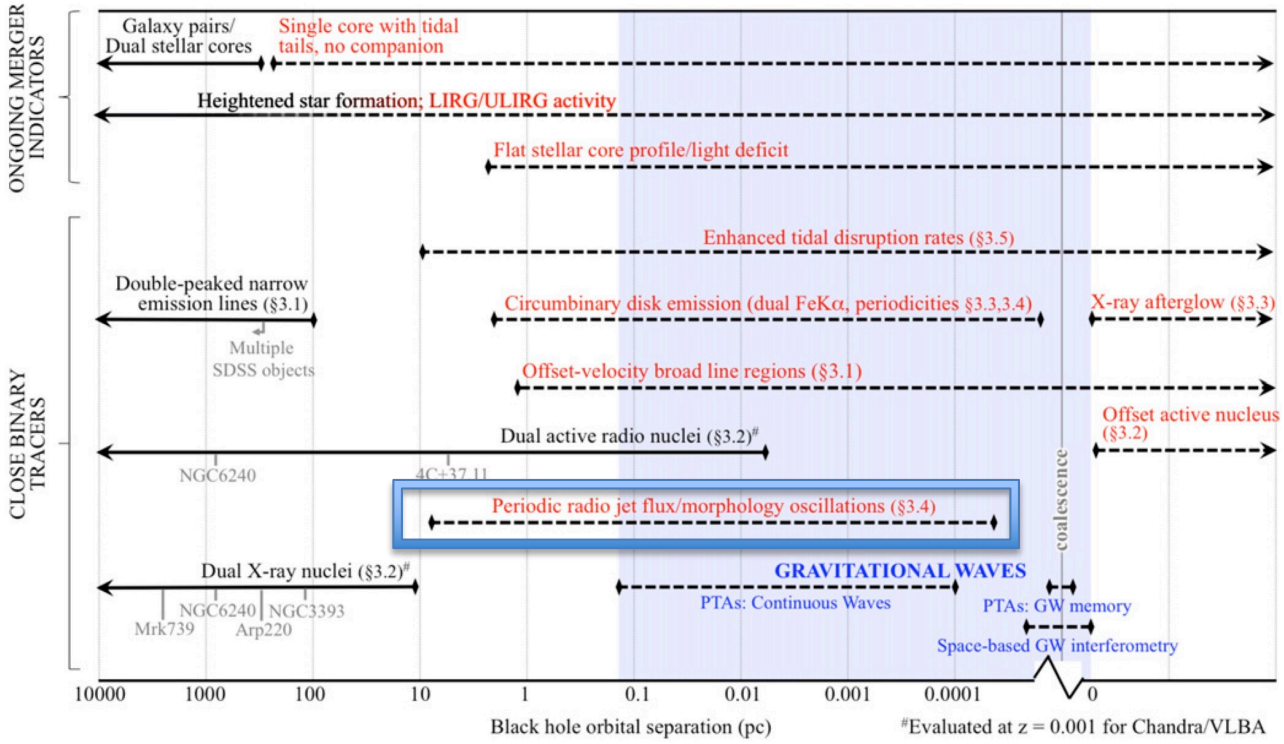
Courtesy Robert Wharton, MPIfR

#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

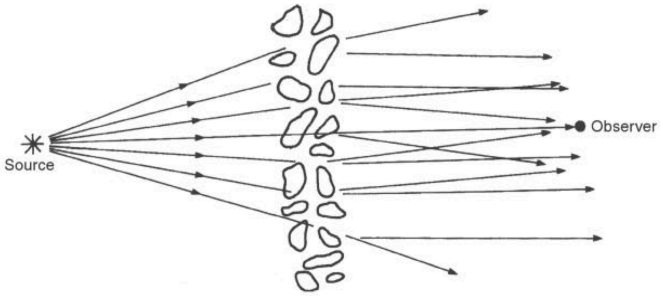


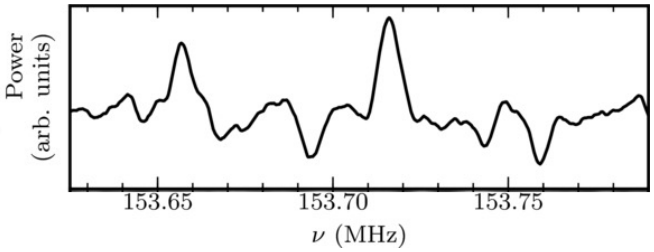
Burke-Spolaor et al., CQG (2013)

#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)

Inhomogenous ISM scatters and scintillates pulsar signals.

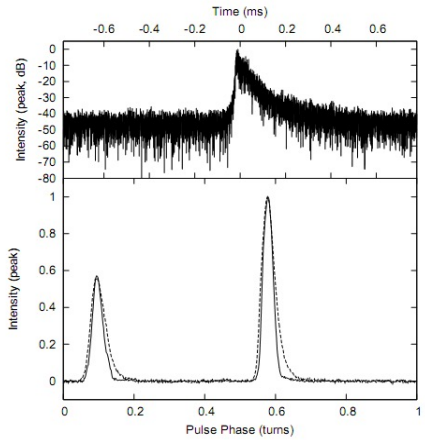




Archibald Hessels & Stinebring (2014)

Cyclic Spectroscopy…

- a signal processing technique useful for pulsed noise
- separates out the intrinsic pulsar signal from the effects of the interstellar medium (Walker, Demorest, Van Straten 2013; Palliyaguru 2015)
- E-field amplitude phase information required. Can be saved as cyclic spectrum to avoid bulky baseband data.

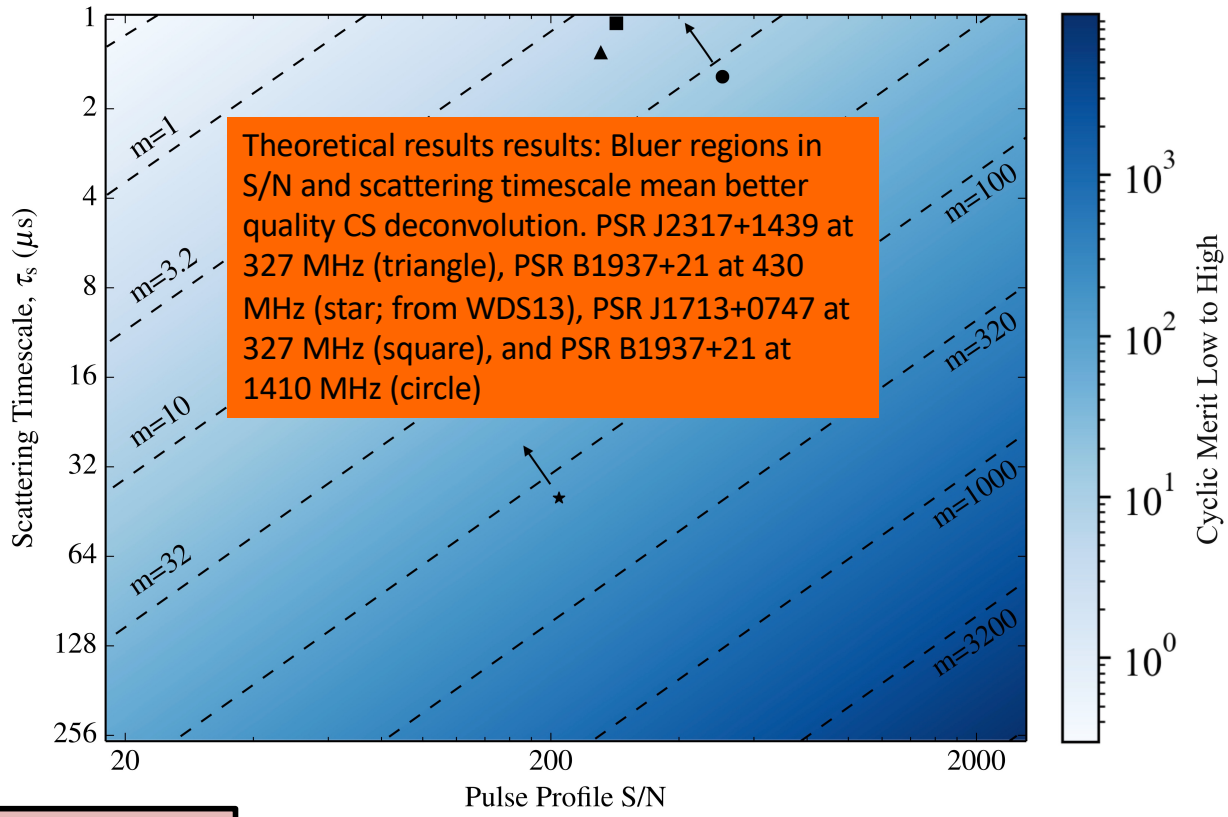


Demorest (2011)

h(t) is best-fit IRF (impulse response function) from ISM

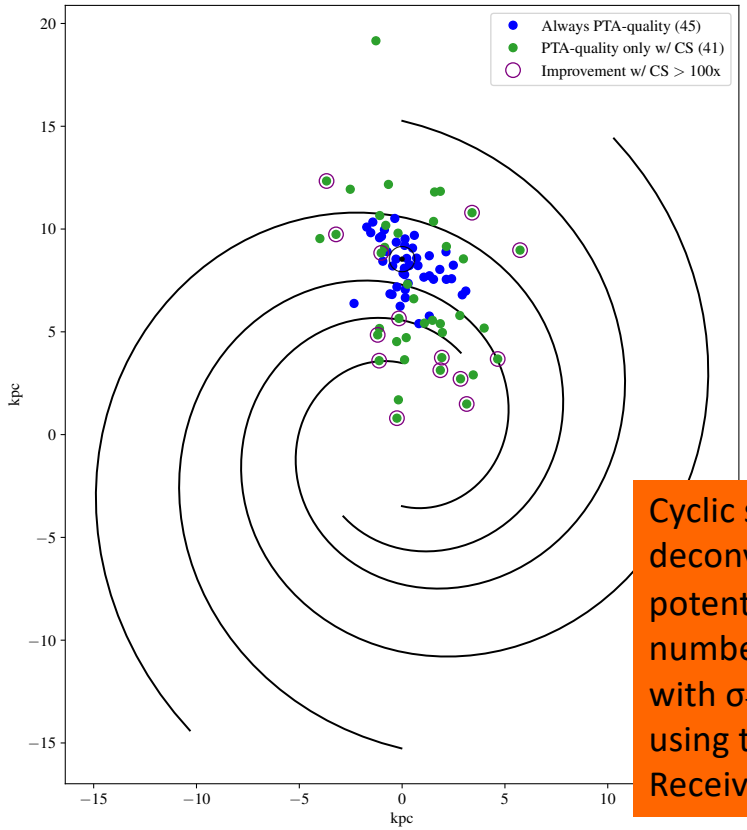
CS aims to deconvolve the ISM's IRF from original pulse profile

Diagnostic for CS deconvolution ability as function of pulse profile S/N and scattering timescale



Dolch et al. 2021, ApJ

Galactic Distribution of Simulated Pulsars



Cyclic spectroscopy deconvolution has the potential to double the number of PTA-quality MSPs with σ_{TOA} <1μs at the GBT using the Ultra-Wideband Receiver under construction.

Dolch et al. 2021, ApJ