

Pulsar and FRB Science at GBO (And the Impact of RFI)

Ryan Lynch

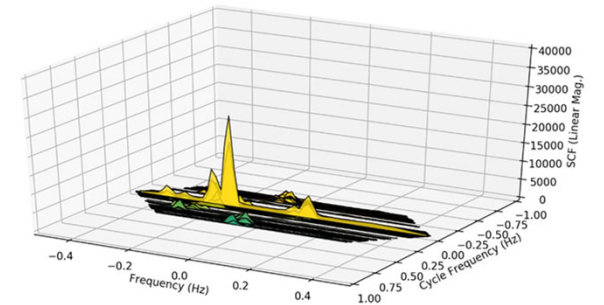
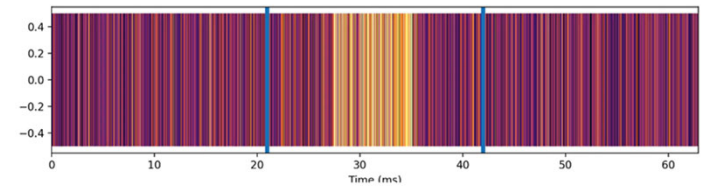
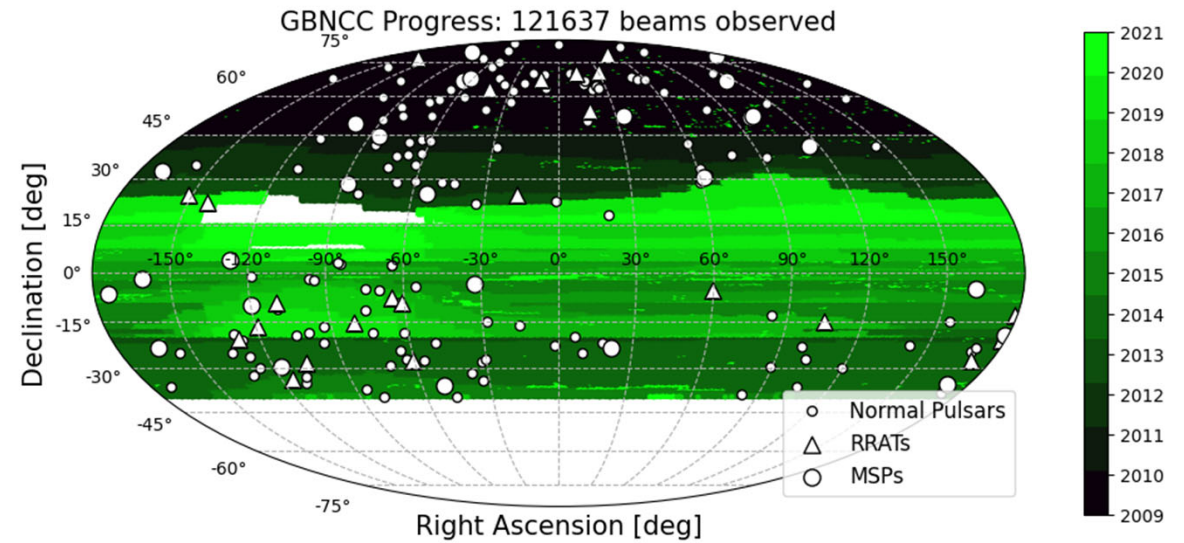
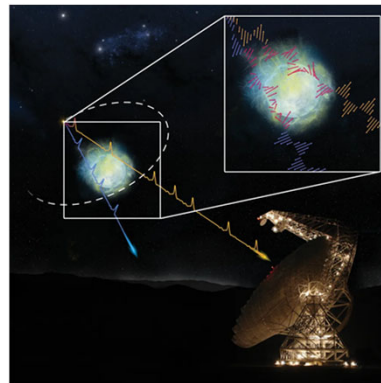
Staff Scientist

Green Bank Observatory

NAAS CORF Meeting
21 Nov 2024



About Me



Pulsar Basics

- Pulsars are **extreme** objects
- $1.4 - 2.0 M_{\text{Sun}}$ ($\sim 500,000 M_{\text{earth}}$)
- Radius ~ 10 km
- Supranuclear densities
- Magnetic fields $10^8 - 10^{14}$ Gauss ($B_{\text{Earth}} \sim 0.5$ Gauss)
- Frequently found in binary systems, usually with other compact objects, sometimes highly relativistic

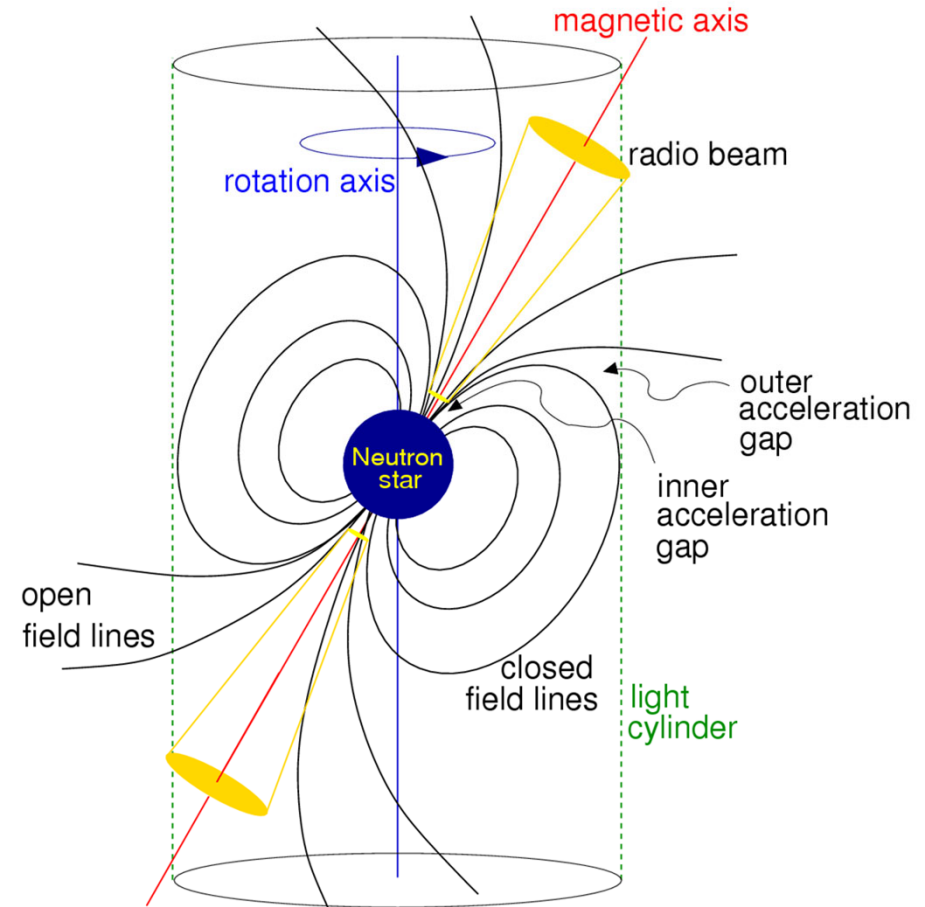


Image Credit: Lorimer & Kramer, Handbook of Pulsar Astronomy

Pulsar Basics

- ~3,400 pulsars known
 - ~10% are **millisecond pulsars**
 - ~100 transients (**RRATs**)
 - ~30 **magnetars** (5 radio)
- Pulsars are observed in radio, X-ray, γ -ray

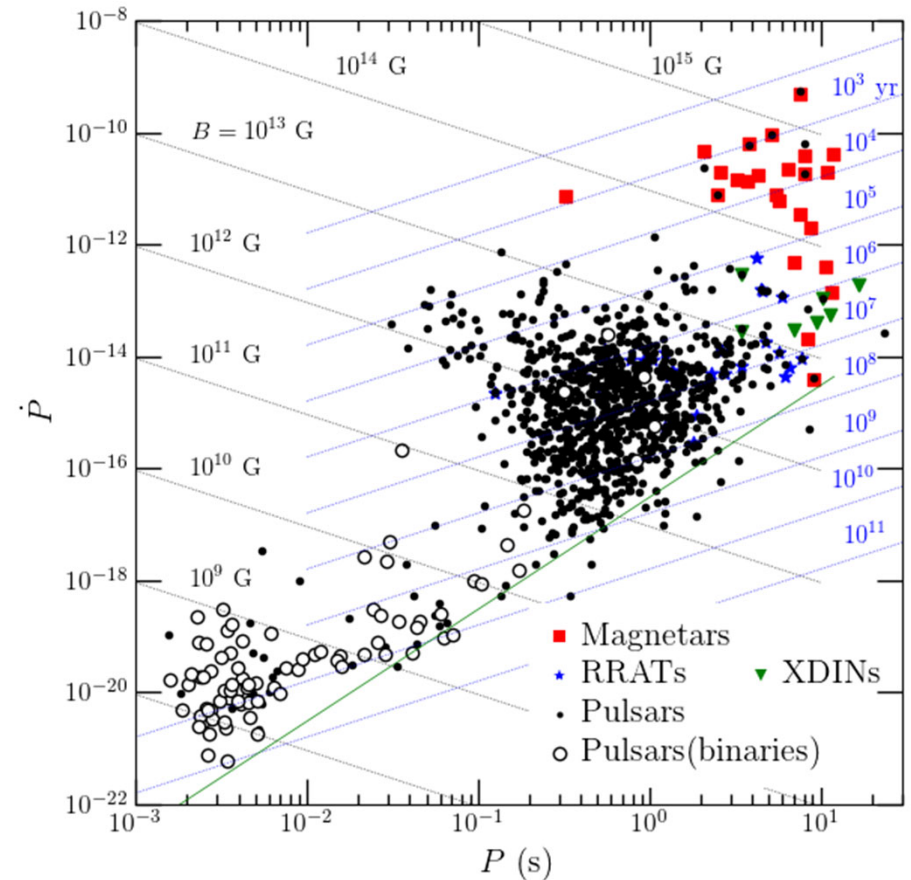


Image Credit: Andrew Steiner

Pulsars as Clocks

- Rotation is extremely stable and predictable

$$f = d\phi/dt, \text{ at some reference } t_0$$

$$\phi(t) = \phi_0 + f(t - t_0) + \frac{1}{2} df/dt (t - t_0)^2 + \dots$$

- Spin period can be measured to $\sim \delta/N_{\text{rot}}$

- At 2024-11-21 10:05 EST the frequency of PSR J0437-4715 is/was

$$.173.6879458121737 \pm$$

$$. 0.000000000000005 \text{ Hz}$$

Fast Radio Bursts

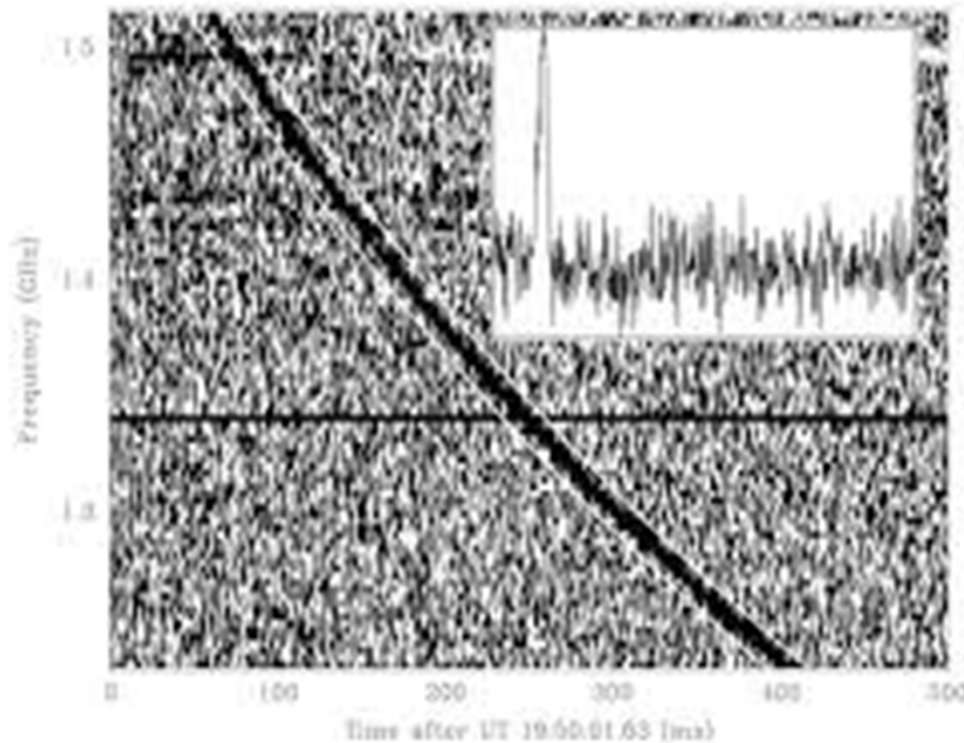


Image Credit: Lorimer et al., 2007, *Science*, 318, 777

- Extremely luminous, millisecond radio bursts of extragalactic origin
- Some repeat, most seem to not
- Can be highly polarized
- Energy and duration suggest the source(s) are magnetized, compact objects

The GBT: 25 Years as a Pulsar Discovery Engine

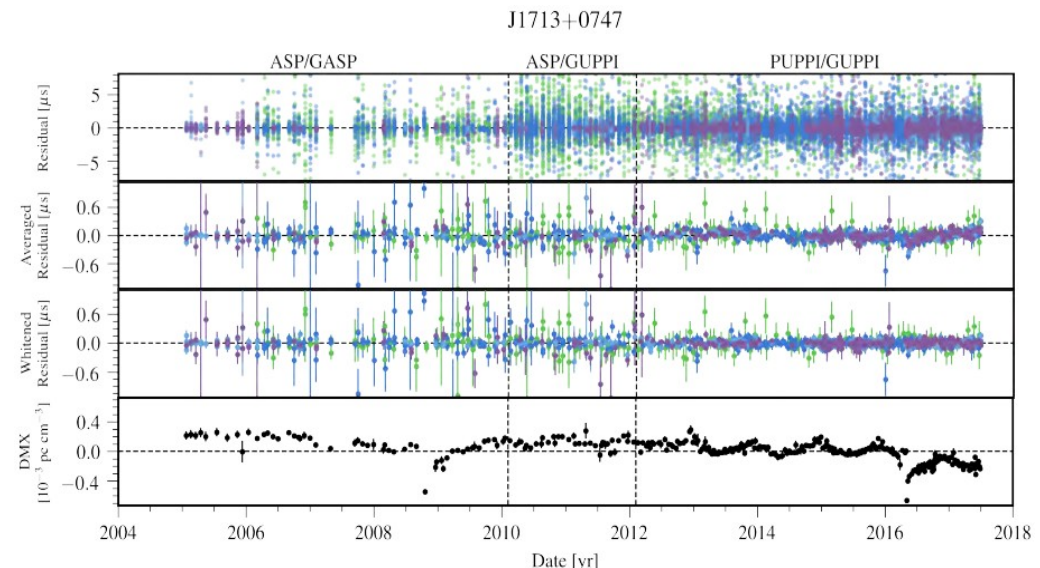
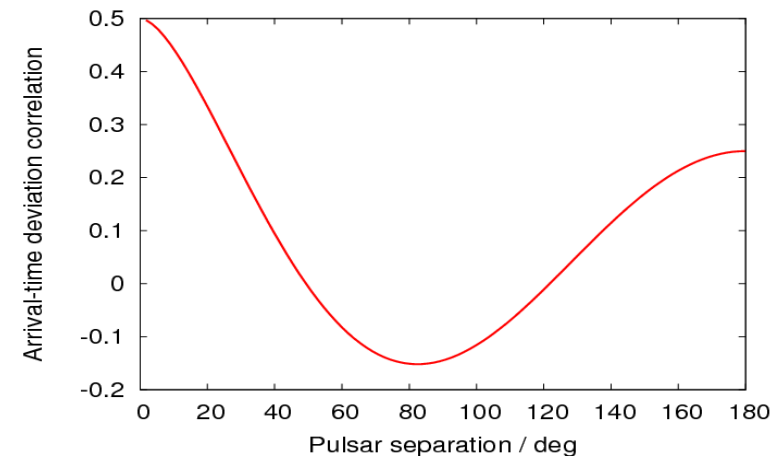


.The GBT is one of the world's best telescopes for studying pulsars because of...

- It's large collecting area
- Full sky coverage
- Suite of sensitive receivers
- Advanced digital backends
- RFI-quiet environment

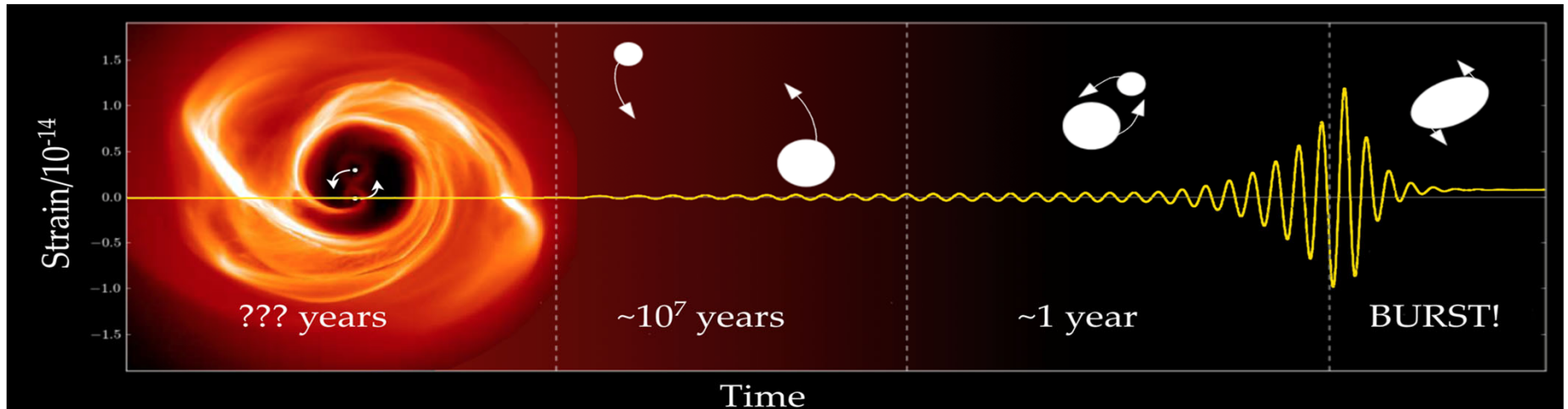
Pulsar Timing Arrays

- Gravitational waves cause spatially *correlated* delays between pulsars
 - General relativity predicts a **quadrupolar pattern**
 - Can distinguish other effects such as reference clock error (monopole) or local (Solar system) effects (dipolar)
- Requires regular, years-long monitoring of dozens of pulsars
 - Predict pulse times of arrival to 10s of ns over 10+ years



The nHz GW Universe

Image Credit: NANOGrav



- Galaxies merge, so should their supermassive BHs
- Gravitational radiation will take over as dominant mechanism of energy loss
- Orbital periods of few years correspond to nHz GW frequency

Observational Signatures

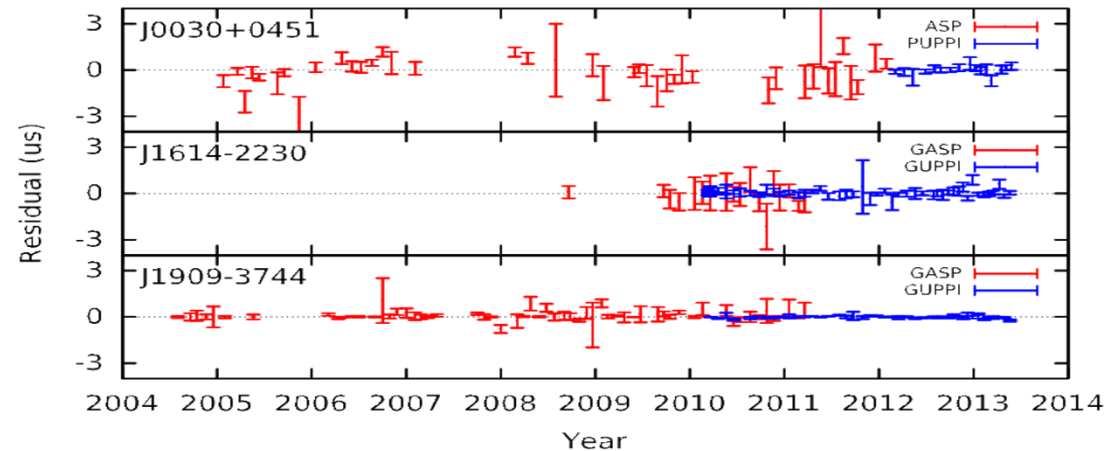
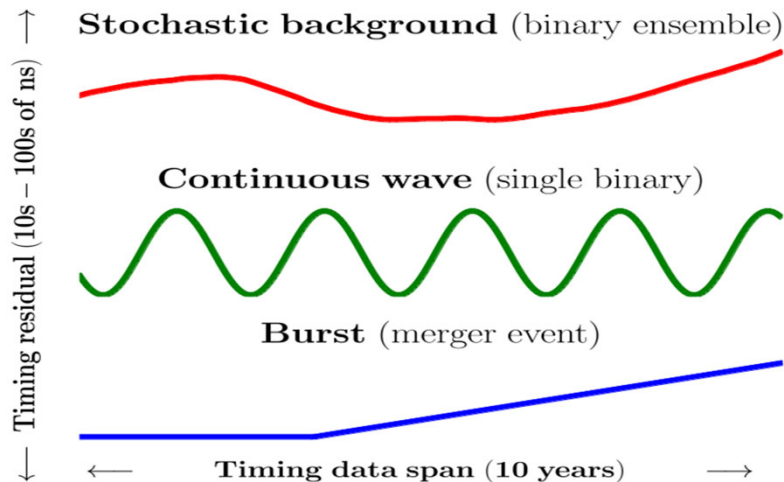
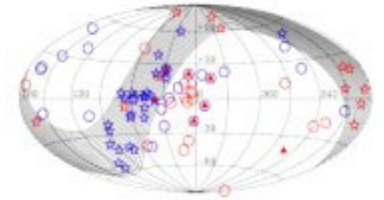


Image credit: NANOGrav

- Different source classes have different structure in residuals
- NANOGrav is currently timing over 76 MSPs many with sub- μ s RMS residuals

NANOGrav Observing Program



Green Bank Telescope

Main: 39 pulsars / dual Rx / every month (began 2004)

High cadence: 5 pulsars / dual Rx / every week (began 2015)



Arecibo Observatory

Main: 39 pulsars / dual Rx / every three weeks (began 2004)

High cadence: 5 pulsars / dual Rx / every week (began 2015)



Very Large Array

Experimental program: 7 pulsars / single or dual Rx



CHIME (w/ CHIME/Pulsar collaboration)

All NANOGrav pulsars at $\delta \geq 20^\circ$ / single Rx (400-800 MHz) / daily
(began late 2018)

First Detection of nHz GW Background

•NANOGrav announced strong evidence for a GW background in 2023

•15 years of data

•Most likely a background made up of GWs from many supermassive black hole binaries

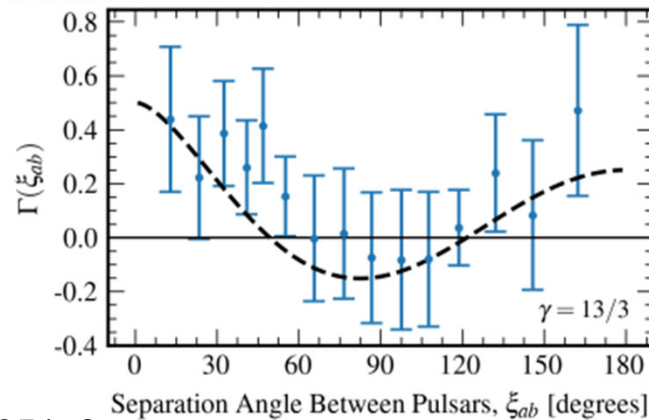


Image Credit: Agazie et al., 2023, ApJL, 951, 8

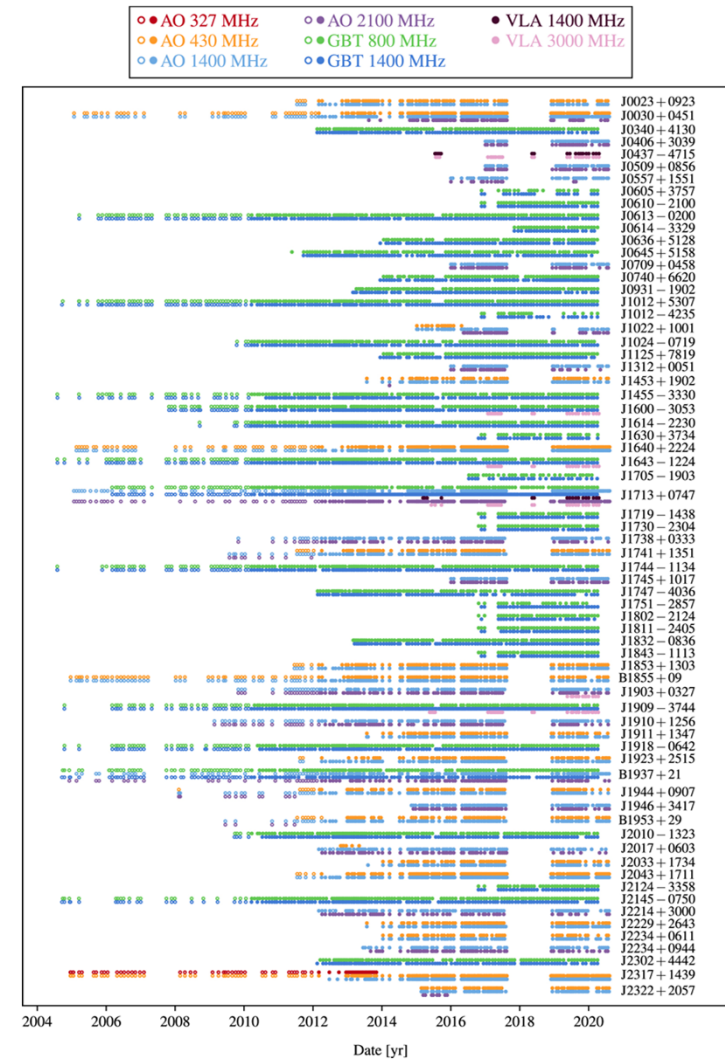
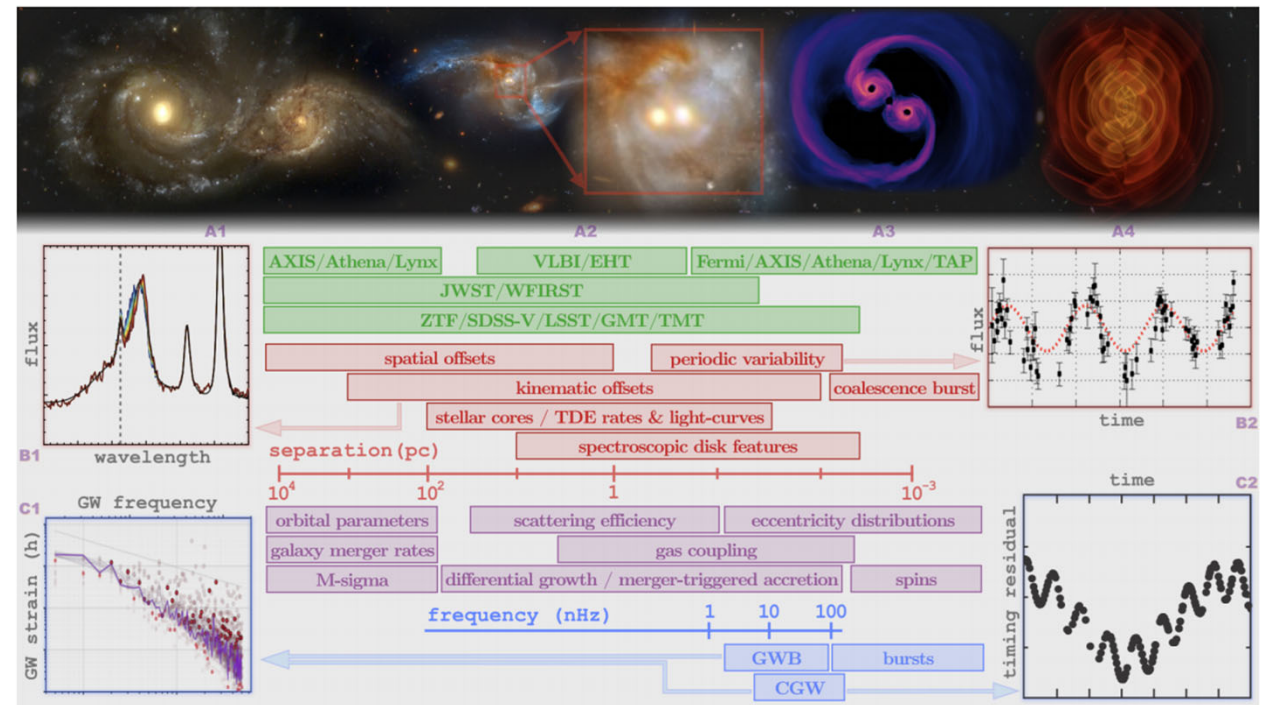


Image Credit: Agazie et al., 2023, ApJL, 951, 9

Multi-messenger Astronomy with nHz GWs

- Individual sources will allow for EM-follow-up in radio, IR, optical, X-ray
- Joint GW-EM study will elucidate BH growth, coupling to local gas, ecc. distribution, and spins
- New telescopes will be used to follow-up individual sources and identify



Kelley et al, 2018, Astro2020 WP #490

FRB Polarization Studies

- .1000s of FRBs are potentially visible over the full sky each day
- .Best approach to finding them is to maximize time on sky and field of view
 - The GBT has found FRBs, but this is not where its strength lies
 - Better to use instruments like CHIME
- .GBT is a powerful tool for following up FRBs
 - Higher frequency capabilities have been especially useful for studying polarization

FRB Polarization Studies

.GBT, Parkes, and FAST follow-up of FRB 20190520B show surprising evolution of Faraday rotation measure

- Like some other FRBs, RM can be extremely high
- But the RM is also changing dramatically and has even flipped in sign

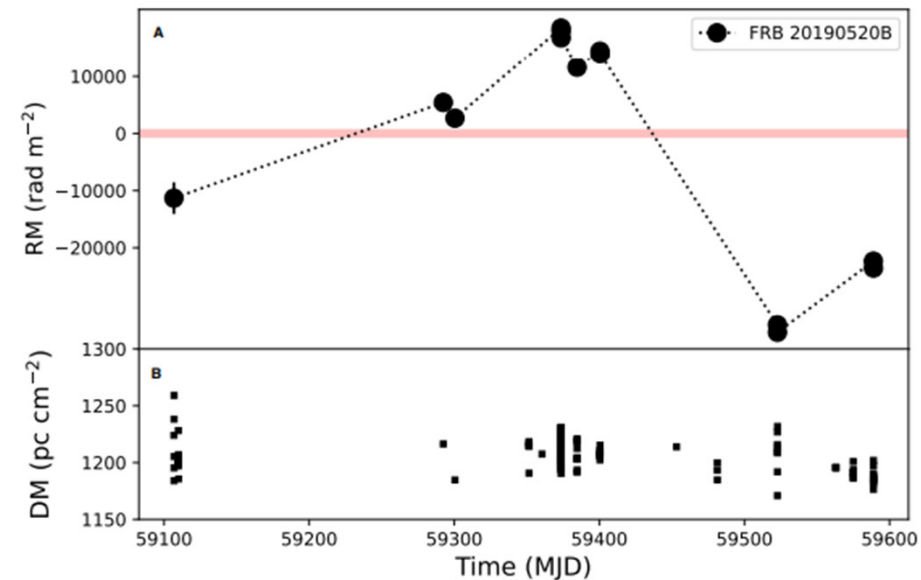


Image Credit: Thomas et al., 2023, *Science*, 380 599

FRB Polarization Studies

- Possible periodicity in RM changes may point to the FRB source being in orbit around a stellar companion
 - As FRB signal passes through different parts of stellar wind the RM changes

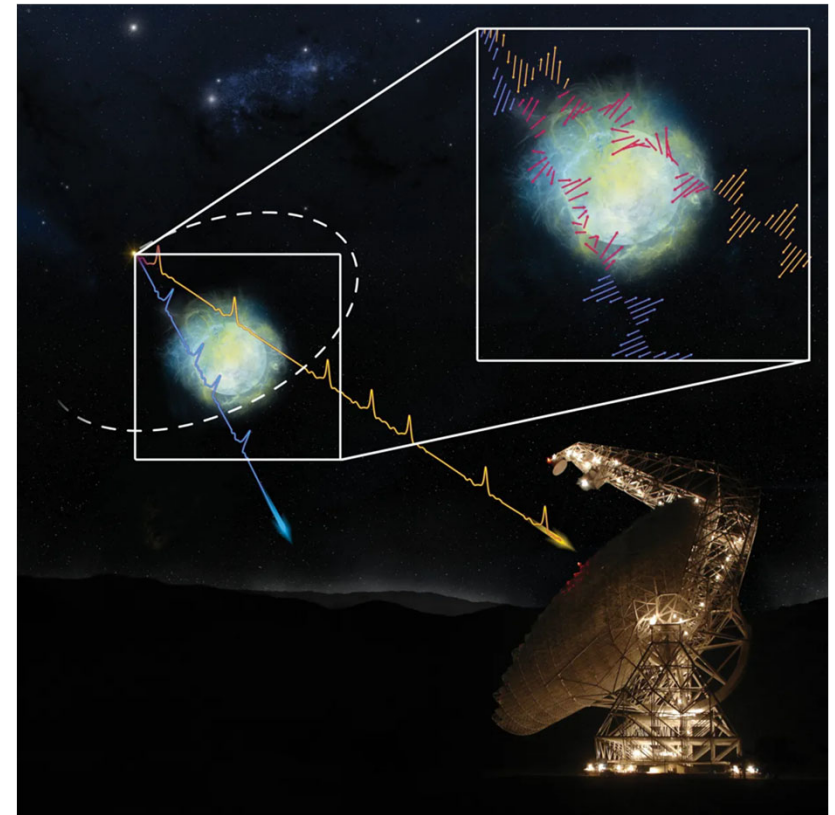
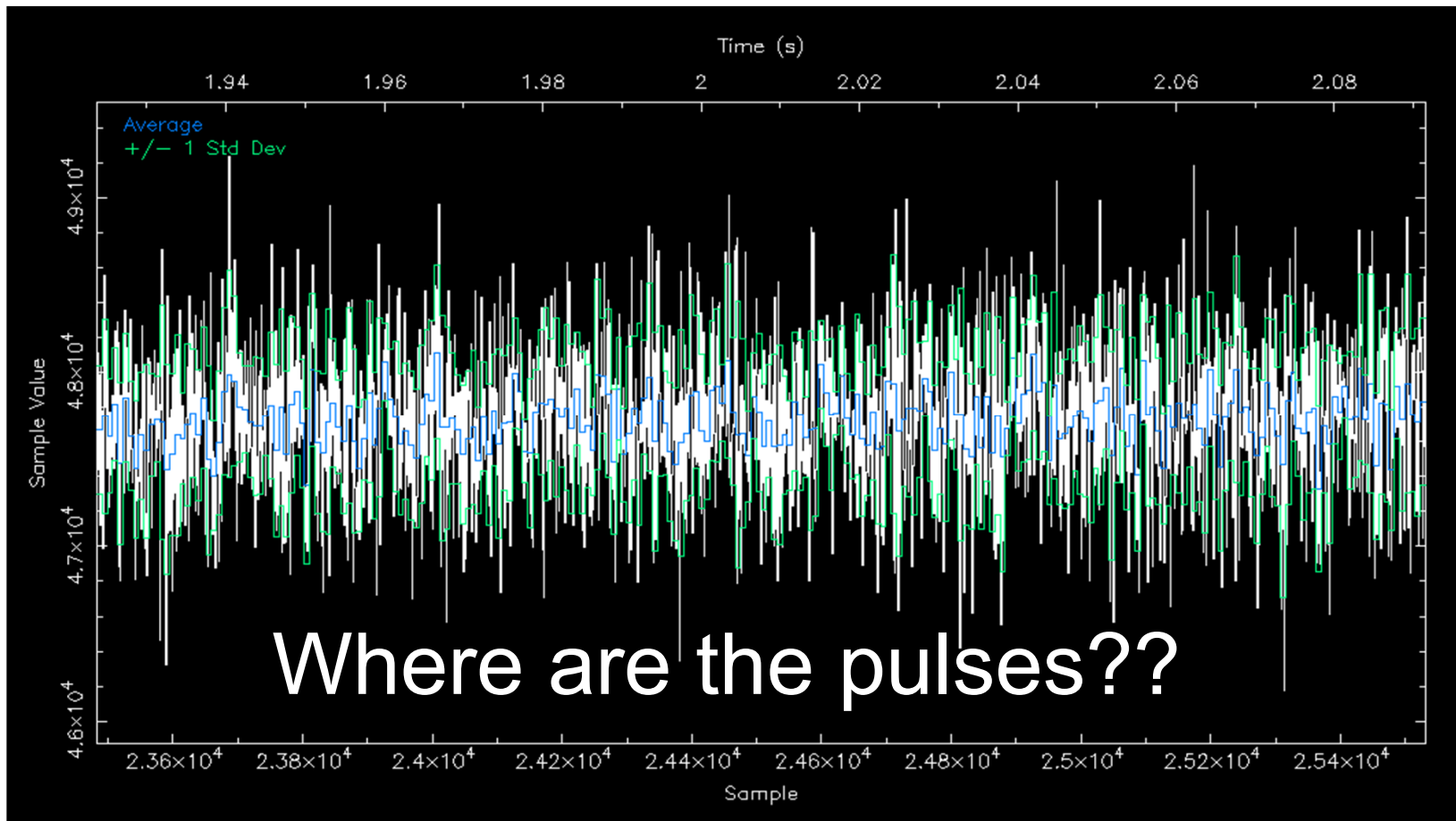


Image Credit: P. Vosteen (GBO/AUI/NSF)

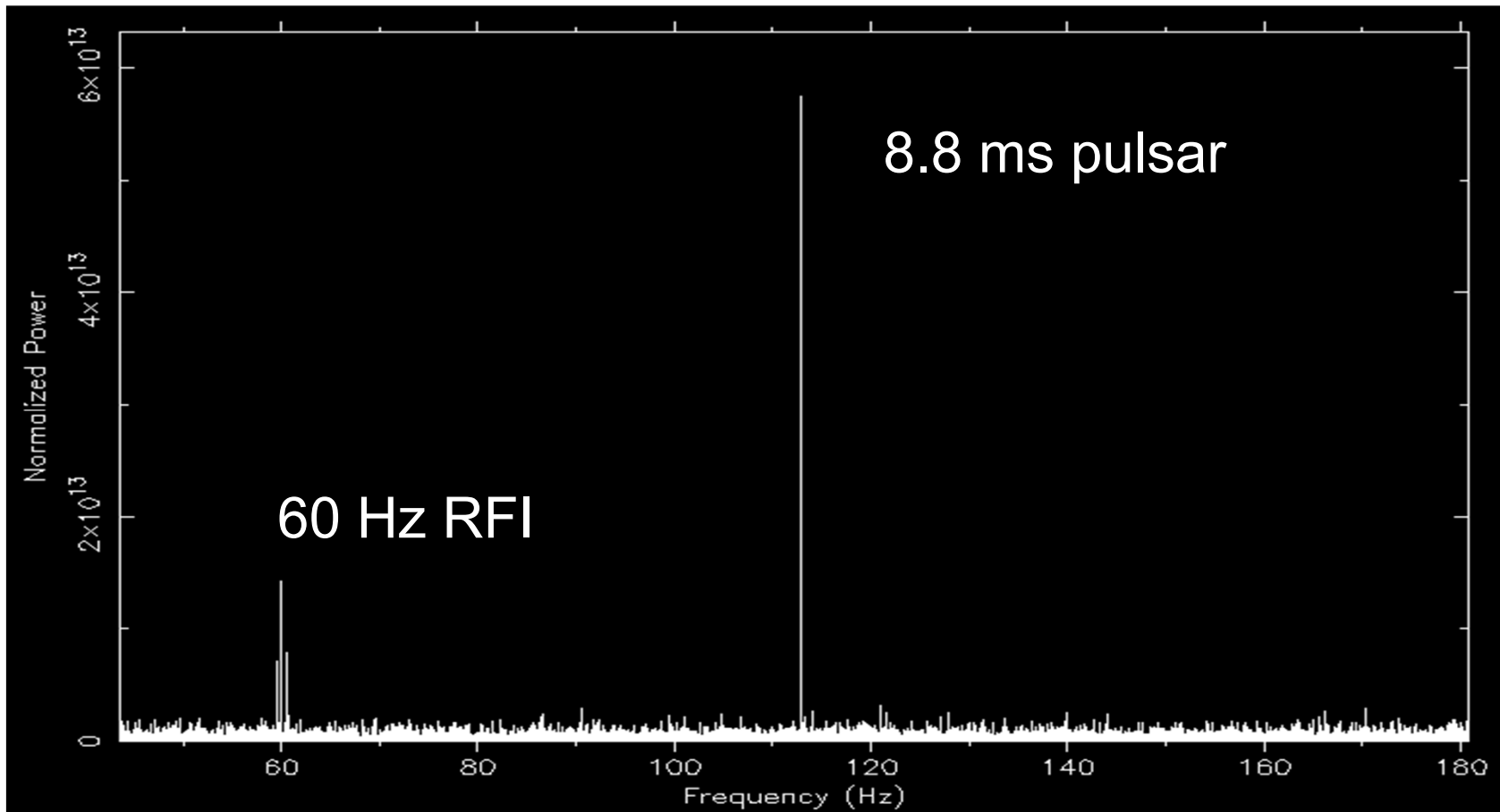
Impact of RFI

- Pulsars are broadband and brightest at frequencies $< \text{few GHz}$
 - We've been living with RFI for a long time
- RFI impacts two main pulsar observing modes differently
 - Pulsar timing: raises noise floor and can distort pulse profile
 - Pulsar searching: Pollutes Fourier power spectrum leading to many false positives

Impact of RFI



Impact of RFI



Impact of RFI

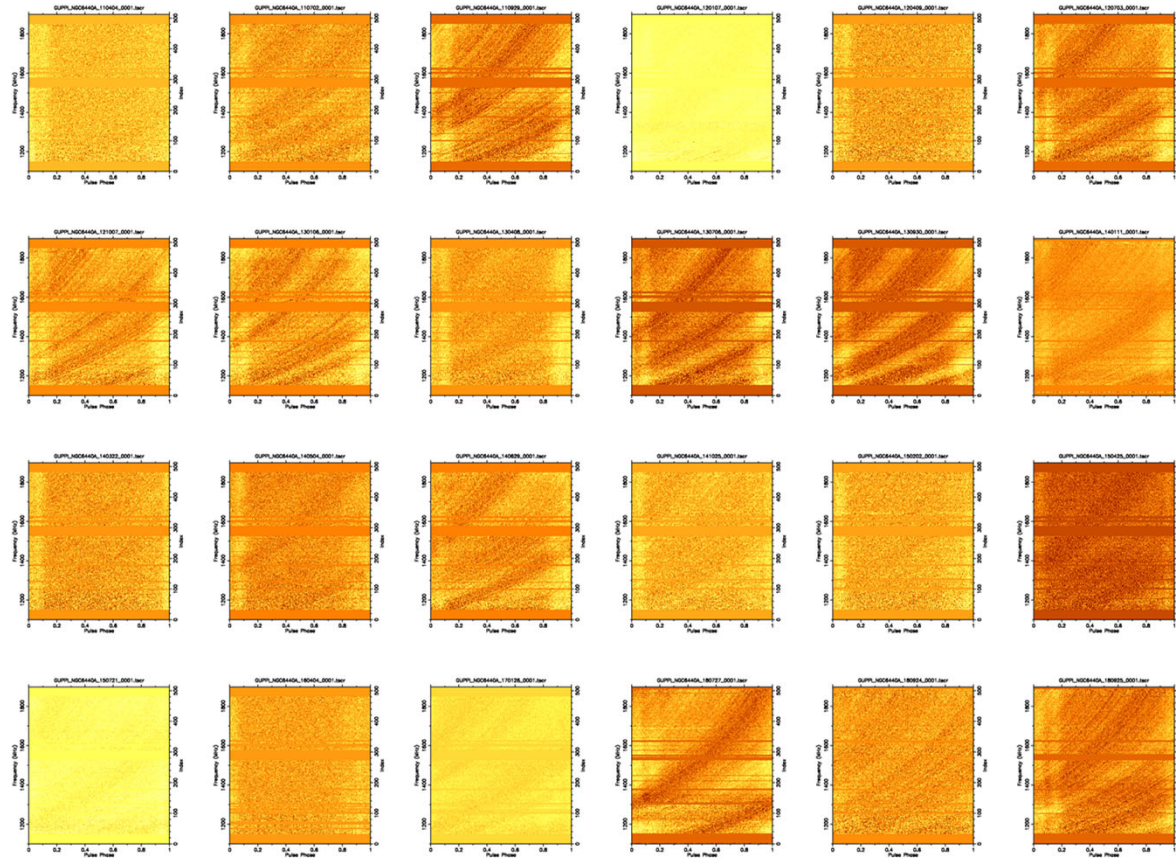


Image Credit: Scott Ransom

Impact of RFI

.Pulsar astronomers have developed good tools over the years to mitigate the most obvious sources of RFI

- Work well for narrow-band and periodic sources
- Broadband and persistent sources are still difficult to automatically mitigate

.The most common approach is to simply remove contaminated frequency channels from further analysis

- Loss of S/N

.Biggest concern is introducing non-linear response in receiver electronics and loss of more and more of the spectrum, especially

Summary

- Pulsars are fantastic tools for studying extreme physics and opening new frontiers in astronomy
- FRBs remain one of the most interesting astronomical mysteries and continue to surprise us
- The GBT is one of the world's best telescopes for high-precision studies of pulsars and FRBs
- RFI can severely limit our ability to find new pulsars and subtly bias pulsar timing data
- It's essential to protect what remains of the low-frequency radio spectrum