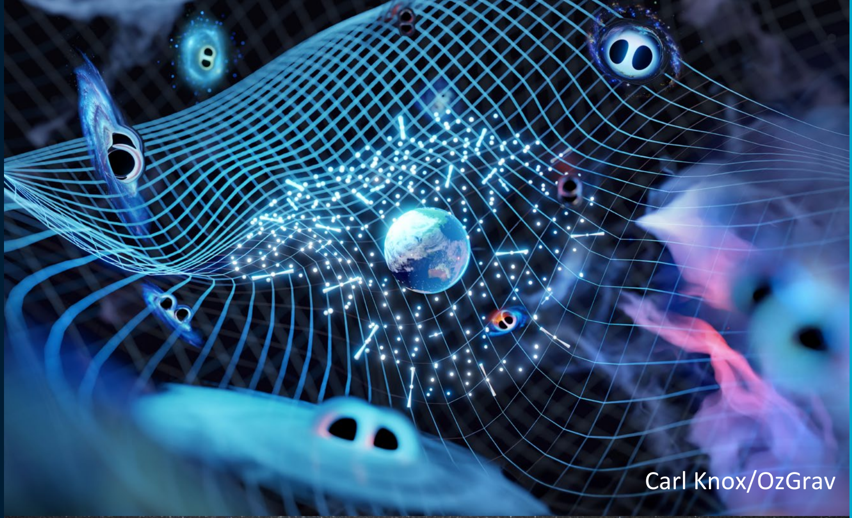
ATNF's role in the pulsar timing array landscape

ATNF Futures 2030

Andrew Zic
Bolton Research Scientist, ATNF, CSIRO

2026-02-19



Pulsar timing arrays

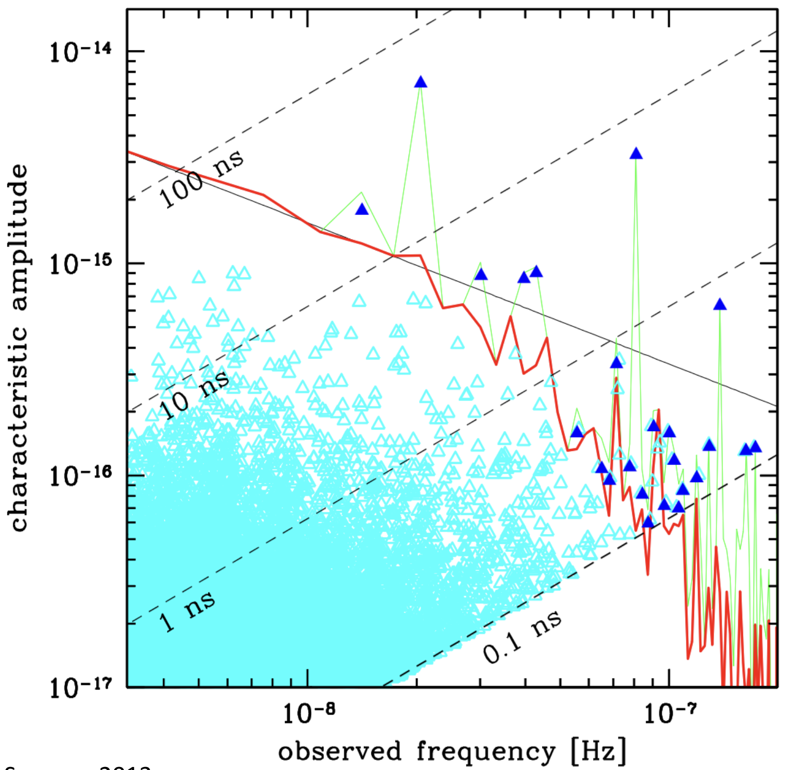
Primary aim: to detect *gravitational waves* at *ultra-low* frequencies (a few **nanohertz**)

A key science driver for the SKA.

A window into fundamental physics and astrophysics: cosmology, supermassive black hole evolution, dark matter, galaxy evolution, early Universe, and more

Ancillary science includes detailed studies of individual pulsars, studies of timescales and solar system ephemerides, the solar wind, and more.

Pulsar timing arrays and the Gravitational Wave Backgroun



Sesana+ 2013

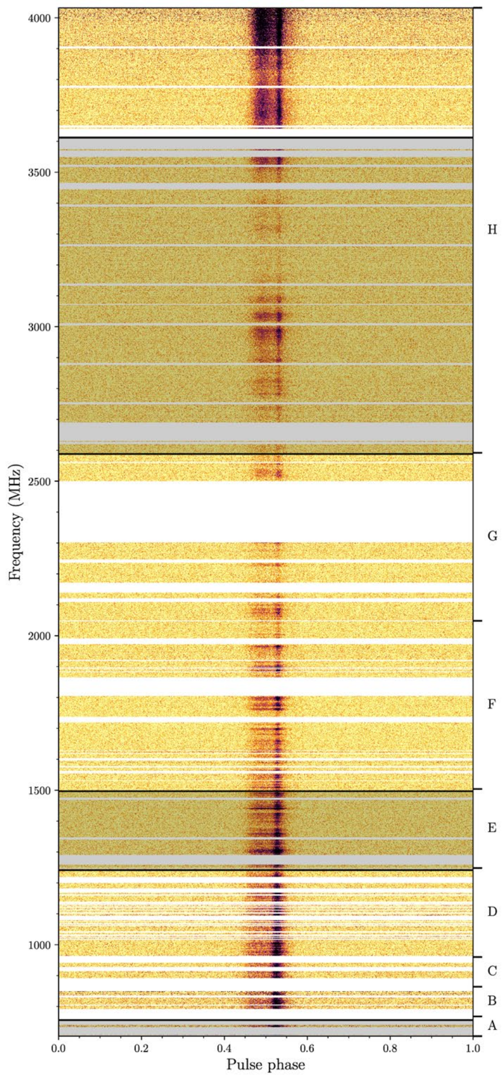
SMBH physics with pulsar timing arrays

Stochastic Gravitational-Wave Background (GWB): population-level SMBH astrophysics

- Mass function, merger rates, cosmic assembly history encoded in GW spectrum
- Deviations from power-law probe environmental effects and insights into finite source popula

Continuous-wave sources: astrophysics of resolved individual SMBH binaries

- EM-selected candidates (e.g., LSST…) enable targeted high-sensitivity GW searches, allowing confirmation or stringent limits on SMBH binary systems, multi-messenger Galaxy astrophysics
- Precision SMBH dynamics (e.g. spin-orbit coupling), orbital evolution and tests of weak-field GR
- Potential to search for high-redshift lensed sources



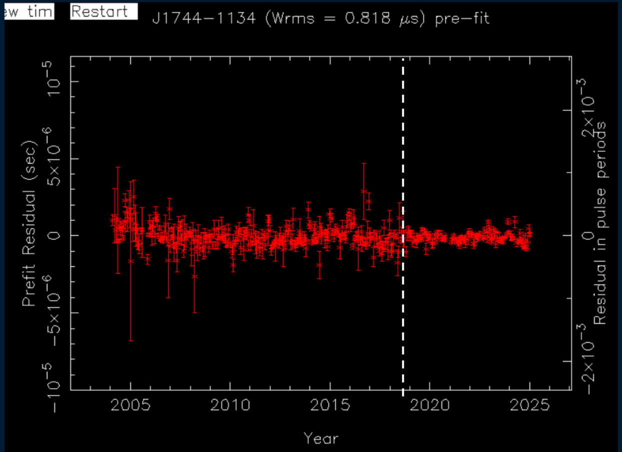
PPTA: enabled by ATNF technologies

The PPTA was the first pulsar timing array experiment to get off the ground in earnest, supported by Dick Manchester's 2003 Federation Fellowship

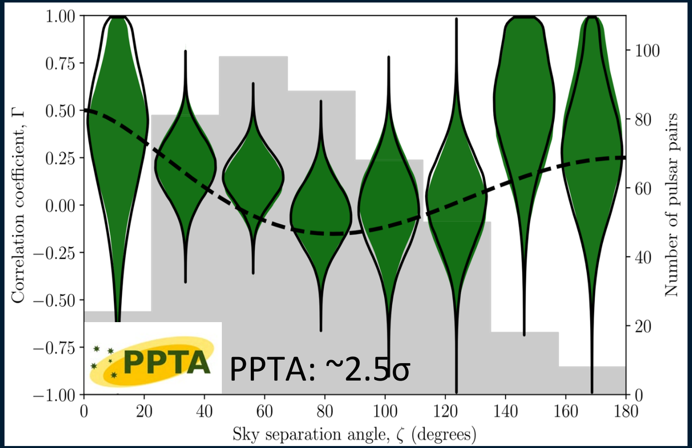
The development of the 10/50cm receiver was a crucial development

The PDFB (and CASPSR) backends continued to improve data quality throughout the 2000s-2010s

Since 2018, have observed using the Ultra-Wideband Low receiver:



Evidence for gravitational waves: the state of play



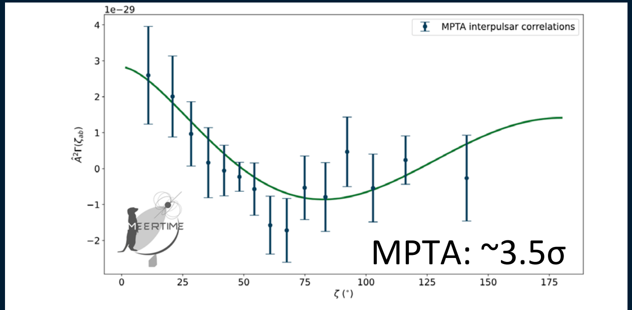
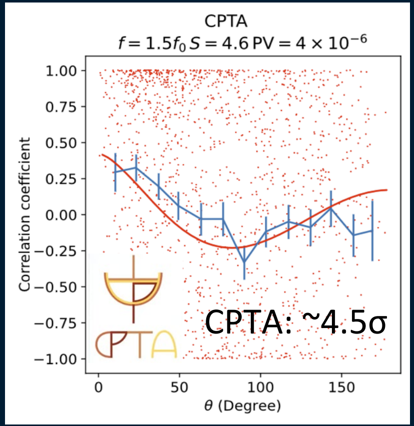
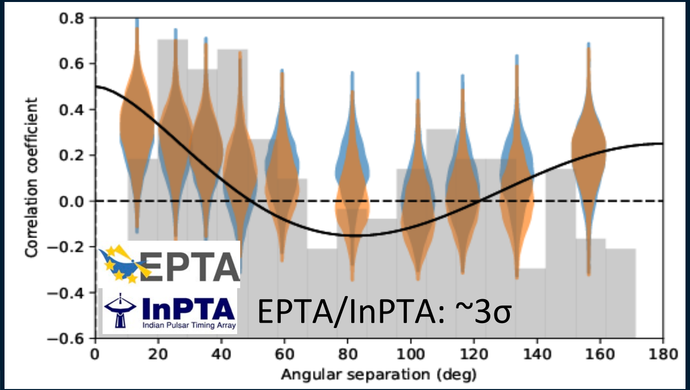
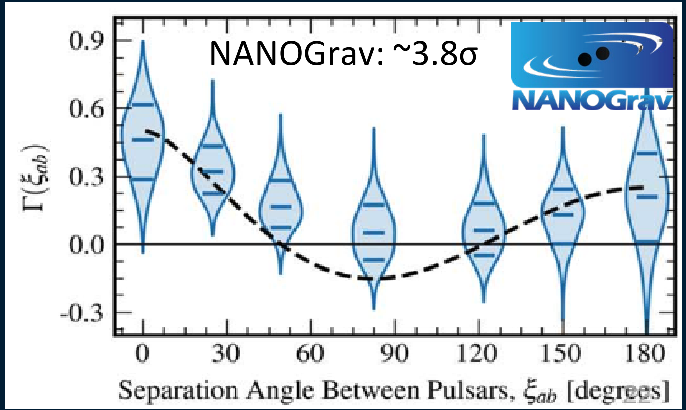


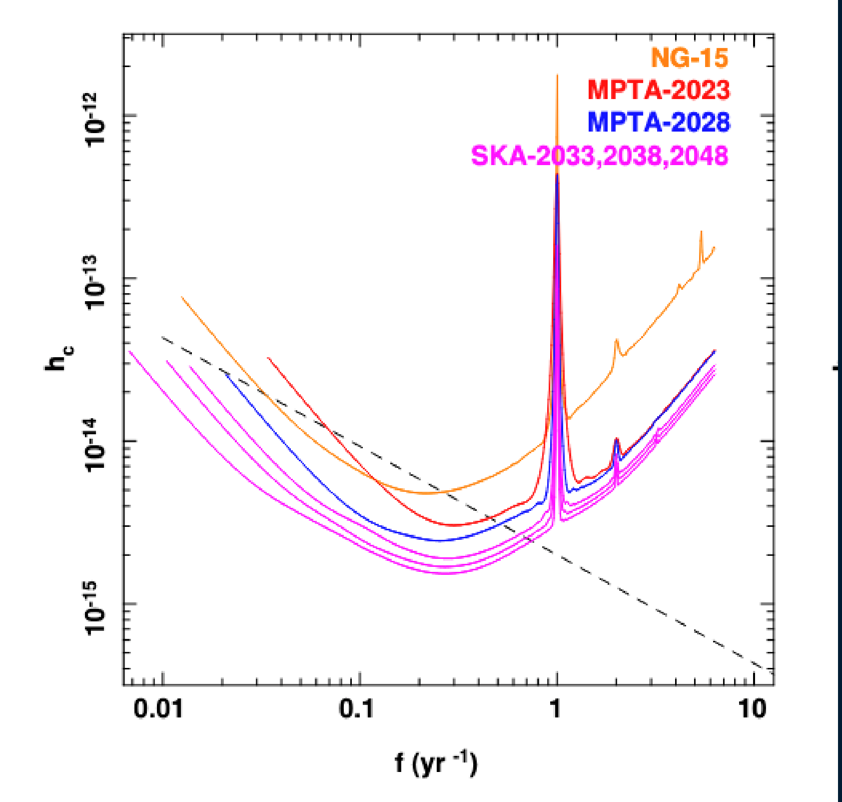
Figure 2. All-sky interpulsar correlations of the MPTA data set as a function of the angular separation between pairs of pulsars, displayed in 15 bins across the angular separation range. The $\hat{A}^2_{\mathrm{DATA}} = (5.65 \pm 1.2) \times 10^{-29}$ corresponds to a dimensionless GW amplitude of $7.5^{+0.8}_{-0.9} \times 10^{-15}$.

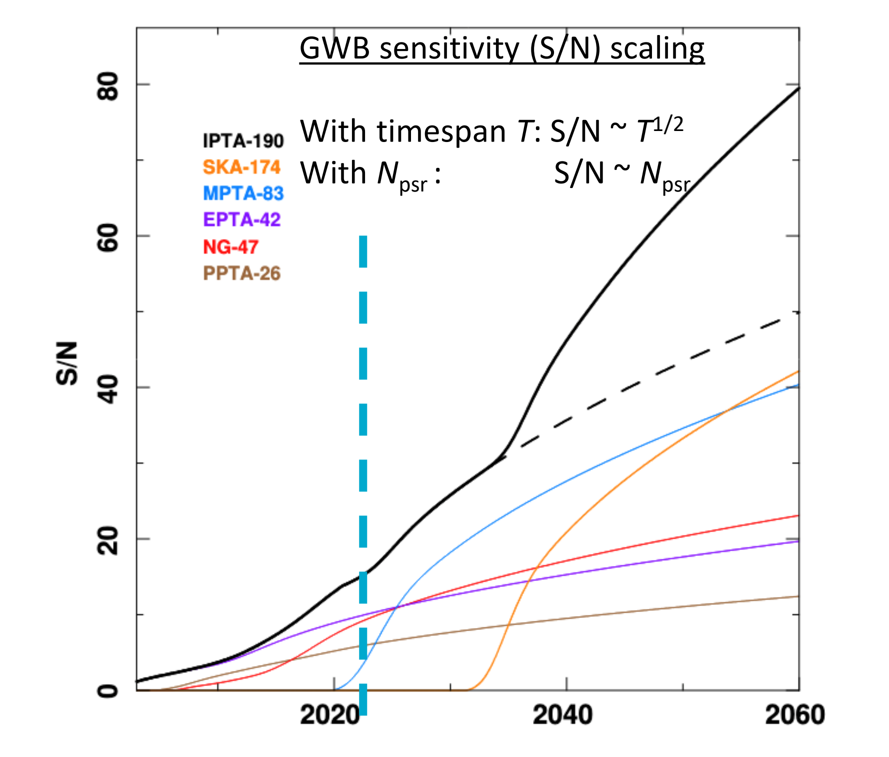






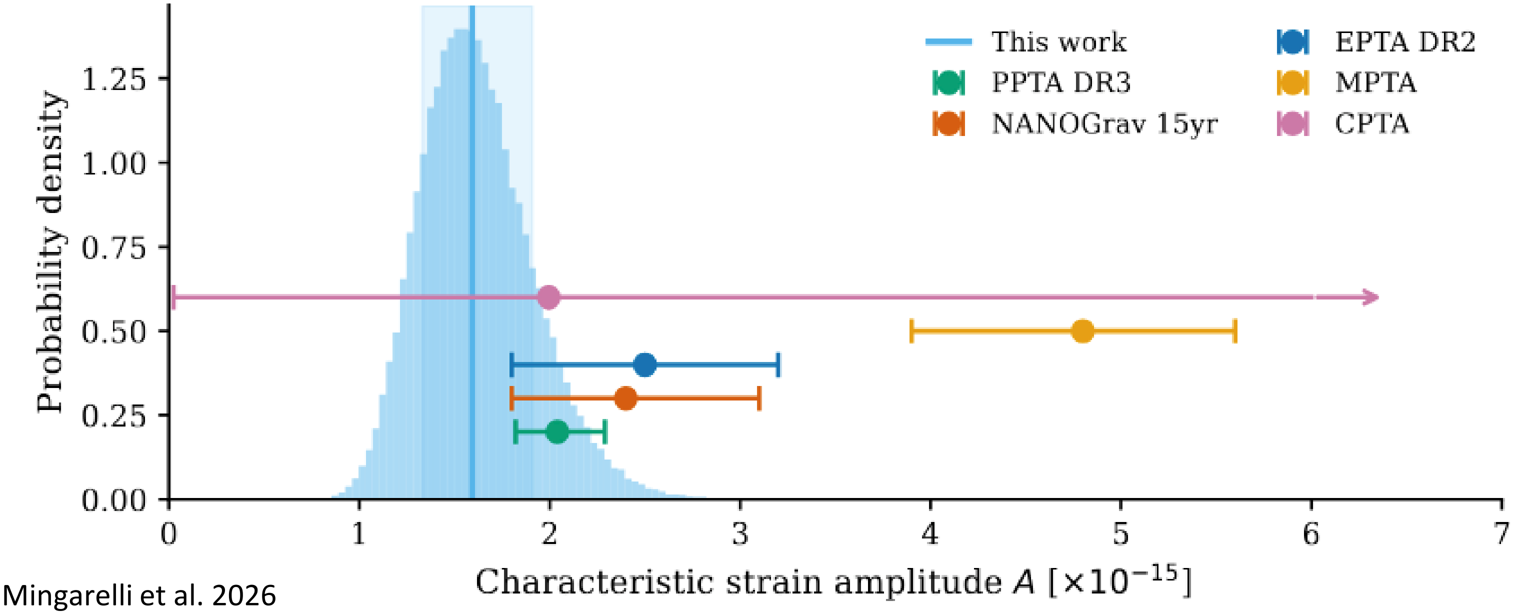
MeerKAT, the IPTA, and SKA-PTA will detect inter-pulsar correlations from the GW background





Shannon et al. 2025

… but the PPTA leads the world in measuring properties of the GWB

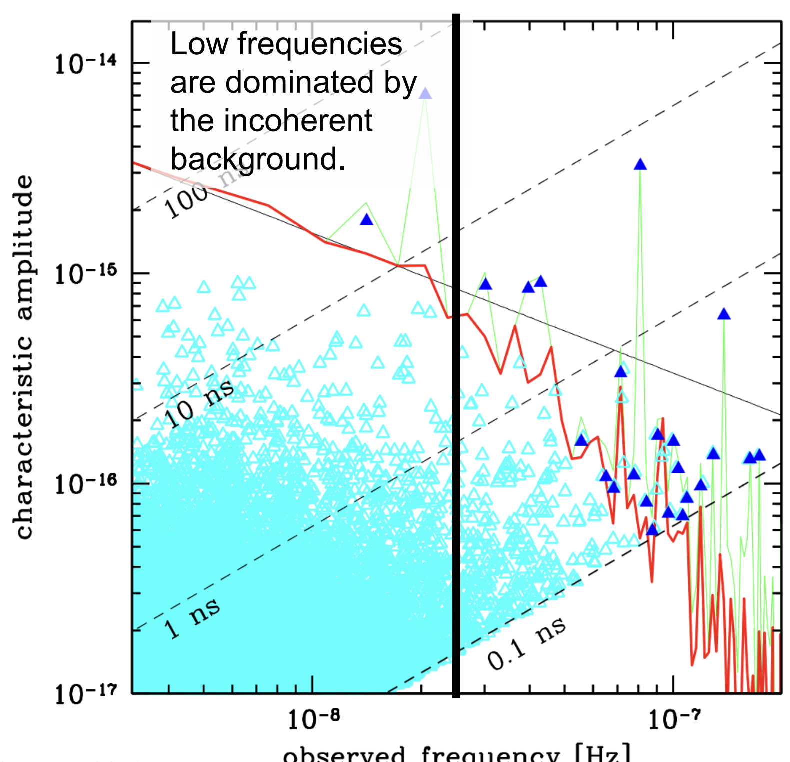


Mingarelli et al. 2026

PPTA places the strongest constraints on the astrophysical properties of the GWB

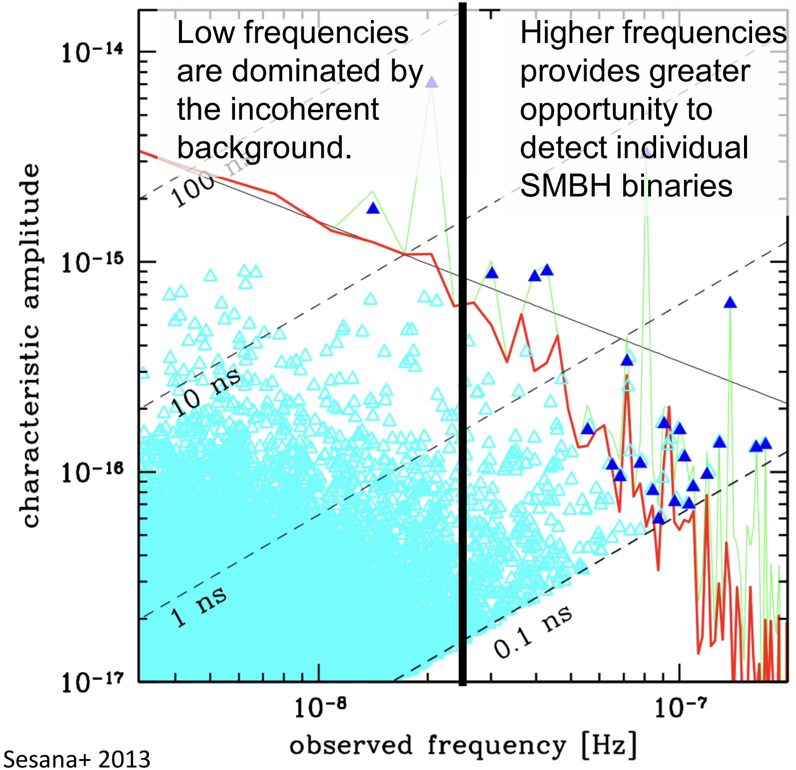
This is the legacy of having a world-leading radio-astronomy technology group over the long term.

Pulsar timing arrays and the Gravitational Wave Backgroun



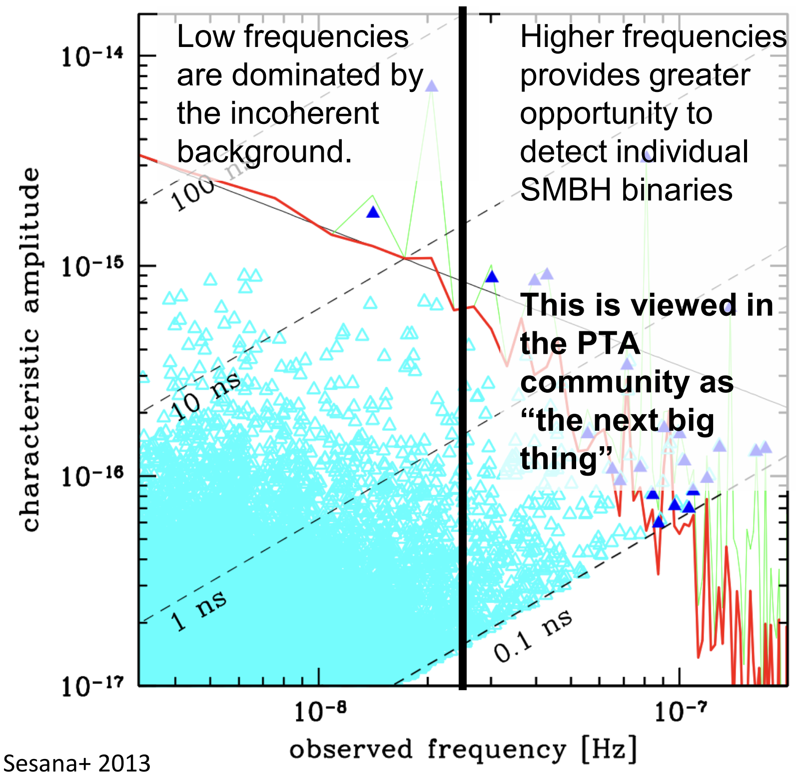
Sesana+ 2013

Pulsar timing arrays and the Gravitational Wave Backgroun



Sesana+ 2013

Pulsar timing arrays and the Gravitational Wave Backgroun



Sesana+ 2013

What’s on the table

Current status quo:

PPTA provides high-precision GW spectrum measurements,
Observing ~30 pulsars every ~2-3 weeks.

ASKAP PAF upgrade:

Status quo remains as such.

ASKAP++ (e.g. George’s flexible dish array):

Potential to extend PTA experiment (eg 30 --> 50 MSPs), but still can’t compete w/ SKA (174 MSPs) on sensitivity to correlations
PPTA still world leading for spectrum measurement

Large scale mid-frequency aperture array

Plug in a machine to form ~a few hundred simulataneous timing beams. Open new doors.

The Recipe: massive scale pulsar timing with an all-sky aperture array

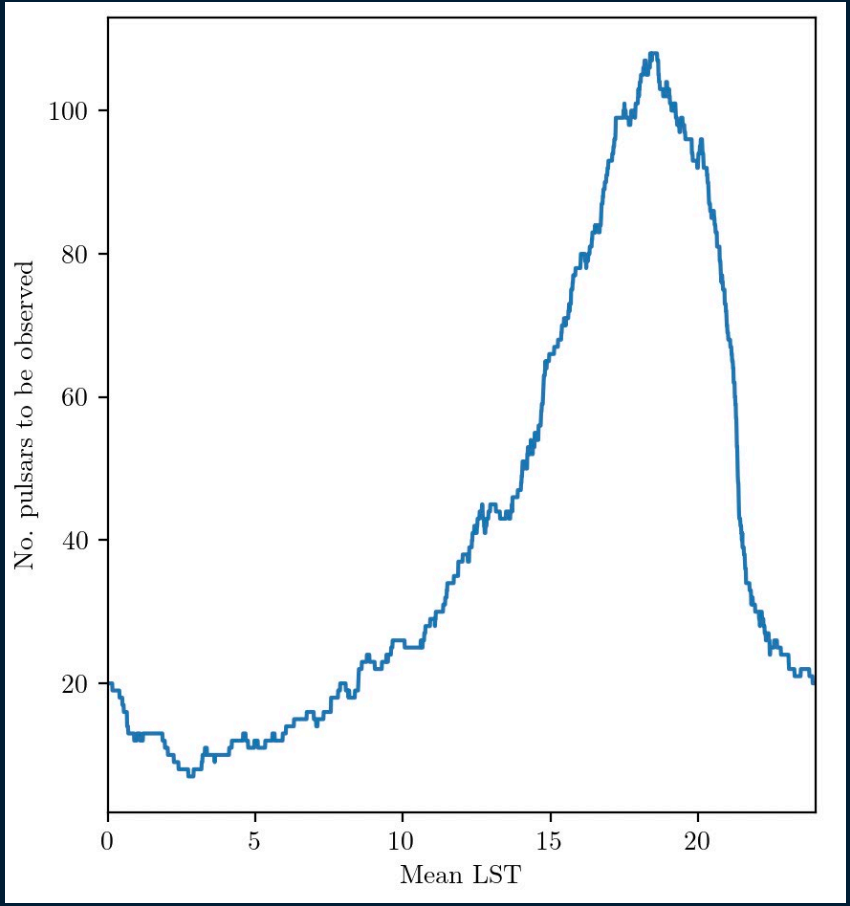
Ingredients

- Relatively high sensitivity (SEFD > ~100 Jy),
- A beamforming machine capable of forming >100 timing beams
- All-sky FoV

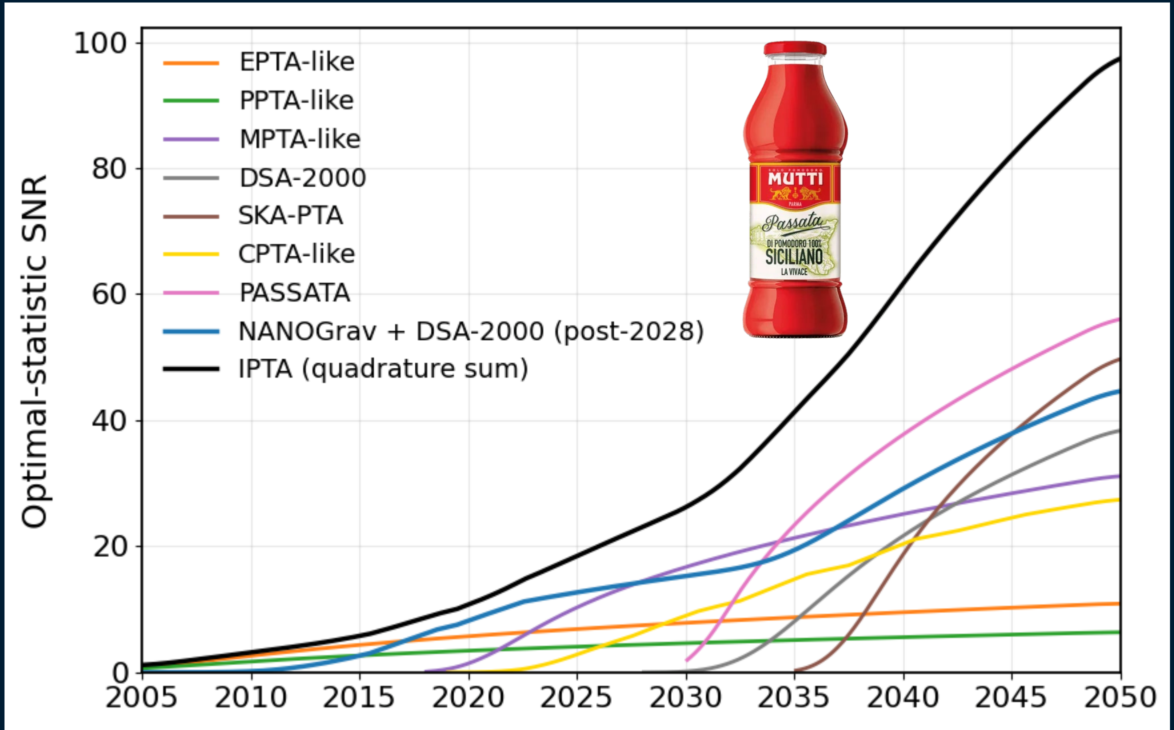
Method

- Integrate on every detectable millisecond pulsar rise-to-set, every day

An experiment of this scale is infeasible with anything less than all-sky FoV

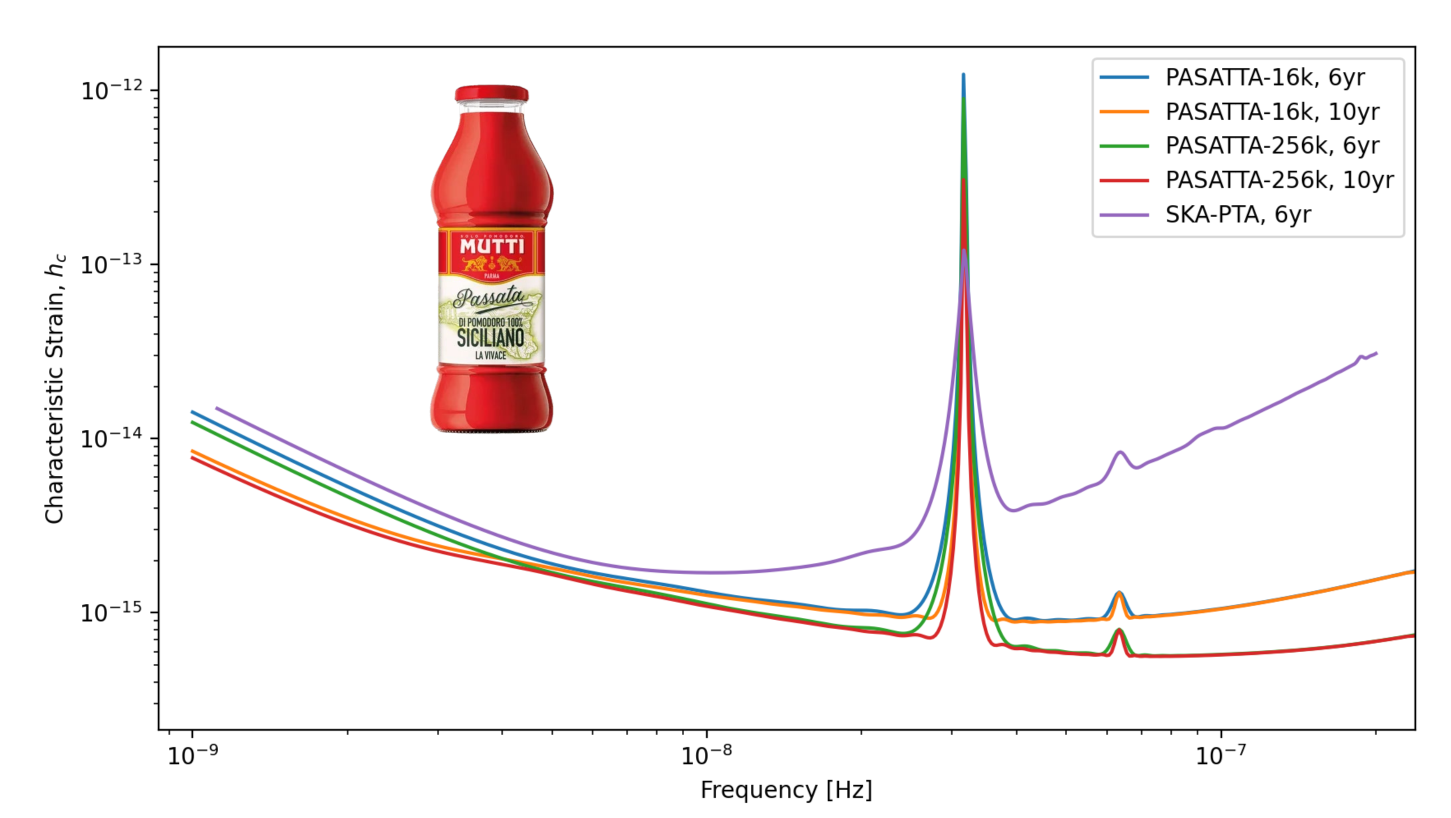


The Main Course: world-leading sensitivity to the GWB

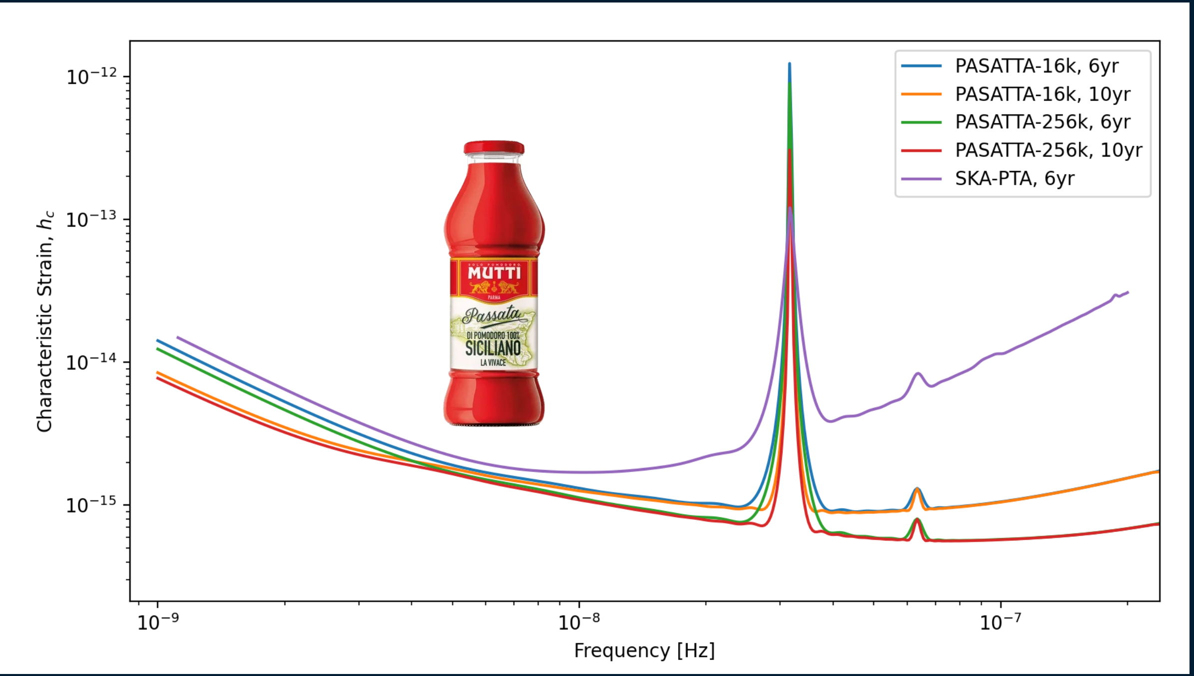


Credit: Matt Miles

The Main Course: 10x SKA sensitivity to high-frequency CWs



The Main Course: 10x SKA sensitivity to high-frequency CWs



Tasting notes

- Similar sensitivity to the SGWB as SKA-PTA
- Significant improvement for for single-source detection above 10 nHz
- Strong notes of ISM

Conclusions

The PPTA is world leading in our ability to measure the spectral properties of the GWB

This is where much of the underlying astrophysics of nHz GWs can be extracted

Under the status quo, or with ASKAP upgrades, the PPTA will continue down this path.

An all-sky aperture array equipped with a beamformer capable of pulsar-timing beamforming has open up novel astrophysics inacessible with any other facility

Extra slides

The Parkes Pulsar Timing Array

- Major project on *Murriyang*, CSIRO's Parkes Radio Telescope, observing ~30 pulsars/fortnight in 36-hour sessions

- **Dedicated observing programme since 2004,** initiated by Dick Manchester's Federation Fellowship

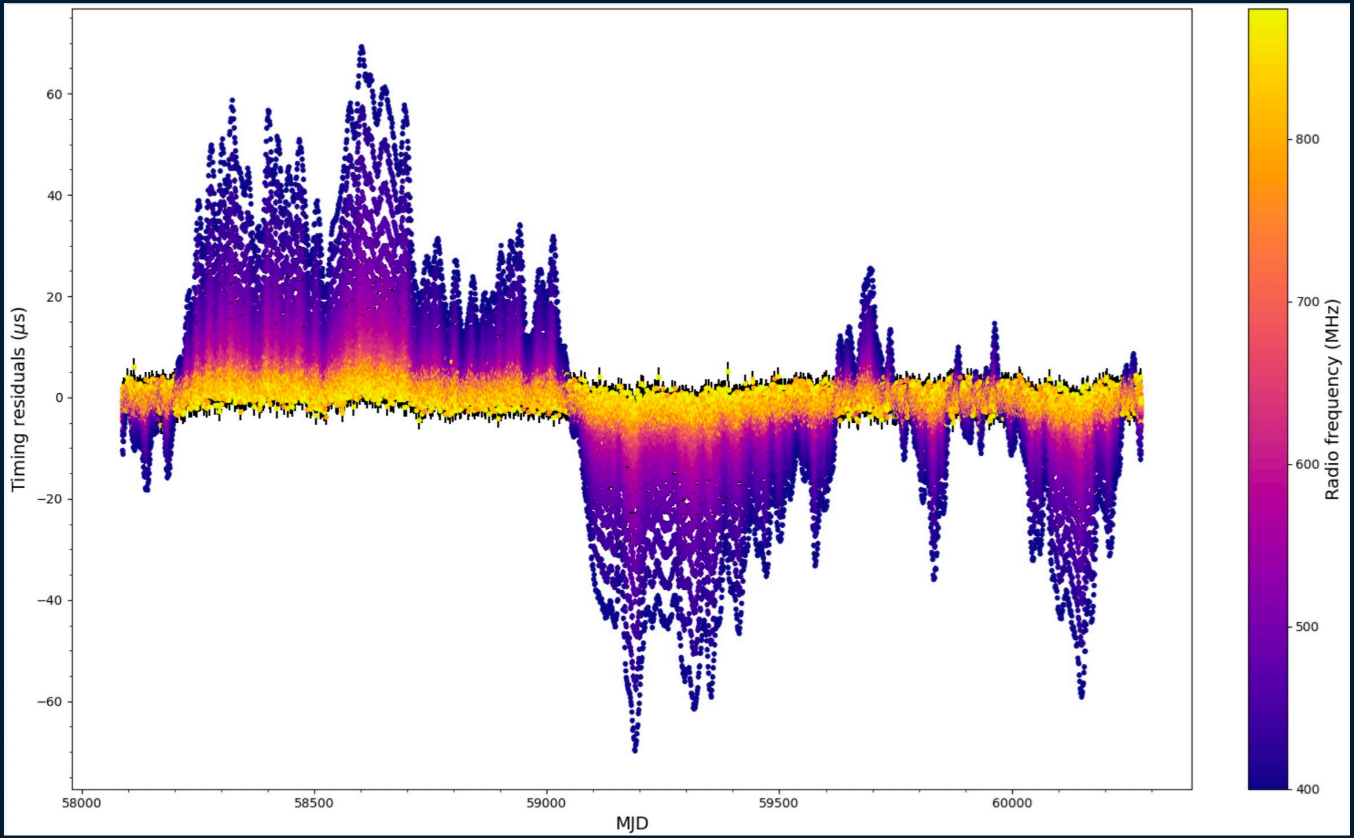
- ~40 active members in Australia, China, US, Poland, Germany, New Zealand, …

Image: A. Zic

PPTA

What are the challenges to overcome?

The inter-stellar medium



What are the challenges

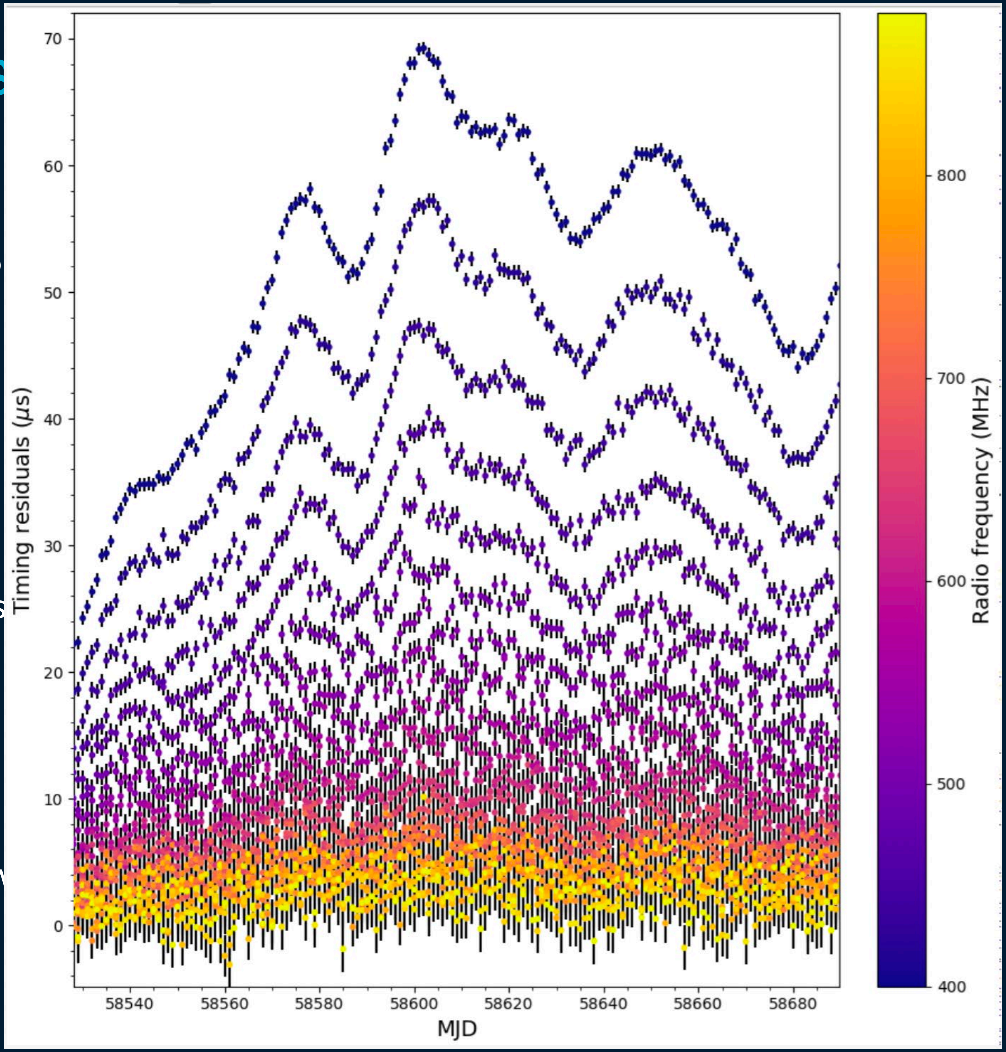
The inter-stellar medium
Induces variations to pulse times of arrival that vary (dispersion measure) or f^{-4} (scattering), and higher-o effects (e.g., decorrelation of chromatic delays)

Aperture array sensitivity scales as f^{-2},
pulsar flux densities typically scale as $f^{-1.4}$
– so low frequency ToAs are greatly upweighted

Is the challenge insurmountable?
Bandwidth and sensitivity will be the key ingredients solve this. I am optimistic.

Can we instead construct a sensitive L-band all-sky array?

A fully fledged simulation study is under way to answ these questions.



PPTA into the (pre)SKA era

The PPTA role has evolved in the era of MeerKAT, FAST, and the SKA

Timing precision on brightest pulsars which dominate constraints on GW power spectrum limited by pulsar-intrinsic systematics, not telescope sensitivity

We are providing the highest-precision measurements on the brightest pulsars