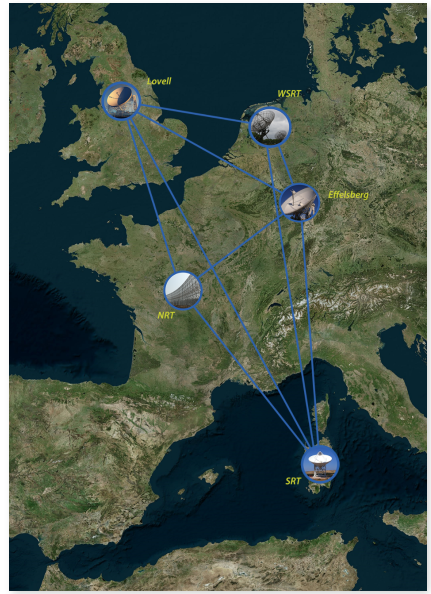


The Large European Array for Pulsars as a precursor to the SKA

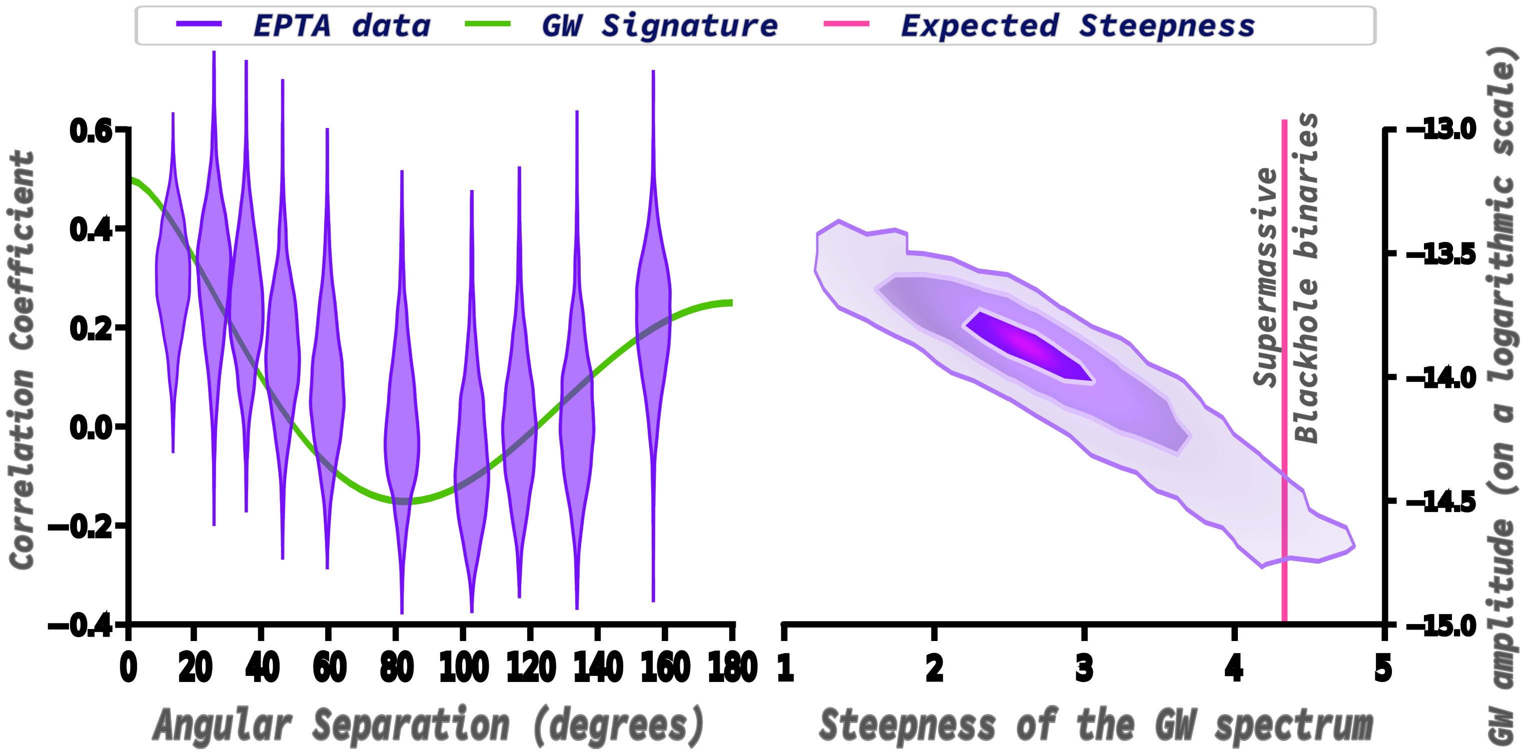
Delphine Perrodin
INAF – Osservatorio Astronomico di Cagliari

SKA Italy, Catania, 30/11/2023

Outline

- Evidence for a background of GW in PTA data
- The European Pulsar Timing Array (EPTA)
- The Large European Array for Pulsars (LEAP)
- LEAP data combined with EPTA radio telescopes
- Other astrophysical implications

Evidence for a background of gravitational waves in Pulsar Timing Array data



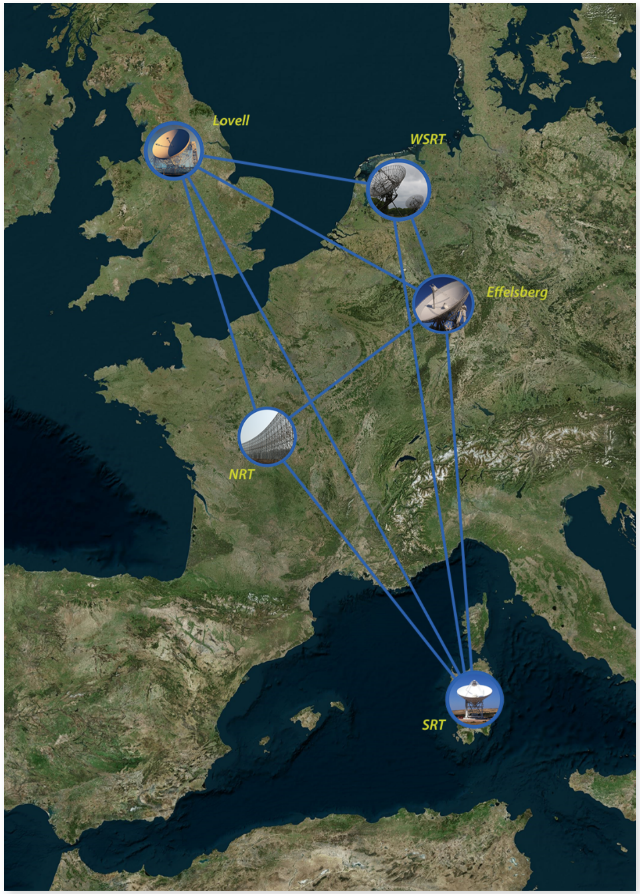
A higher significance is needed to confirm this result and to identify its origin
This can be achieved by improving the timing sensitivity of pulsar observations
Use LEAP to improve precision

European Pulsar Timing Array (EPTA)

- 100m Effelsberg Telescope (Germany)
- 94m–equivalent Nançay Radio Telescope (France)
- 94m–equivalent WSRT (Netherlands)
- 76m Lovell Telescope (UK)
- 64m Sardinia Radio Telescope (Italy)

The Large European Array for Pulsars (LEAP)

- LEAP is a project of the European Pulsar Timing Array (EPTA) collaboration which involves 5 European radio telescopes
- Was supported by ERC Advanced Grant (2M Euro, PI Kramer), 2009-2014
- Project continued with local funding at each institution
- Observations started in 2012
- The Sardinia Radio Telescope (SRT) joined LEAP in 2013 during its scientific validation phase



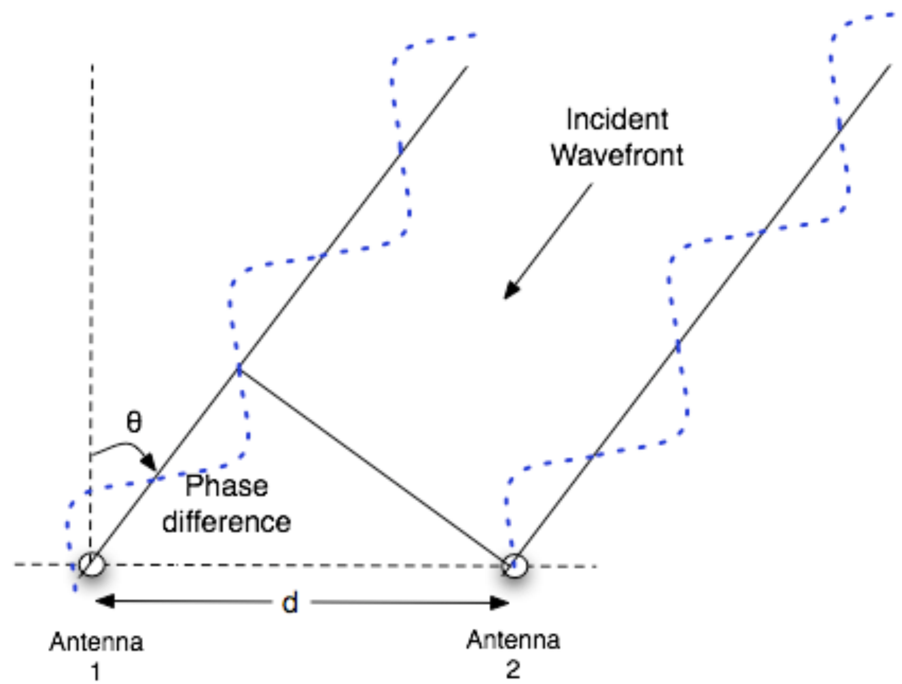
LEAP: the experimental design

- Simultaneous pulsar observations at all EPTA telescopes
- Monthly observing of ~ 22 millisecond pulsars from 2012 - today
- Coherently combine raw voltage (baseband) data from the five 100m-class European telescopes to form a tied array
- Sensitivity equivalent to a 194-m dish, similar to SKA Phase 1. Pathfinder for next generation of radio telescopes/SKA
- Comparable in aperture to the illuminated Arecibo dish, but able to cover – 30 < dec < 85 deg
- Sixth telescope of EPTA. Boost sensitivity at L-band.

LEAP: the experimental design

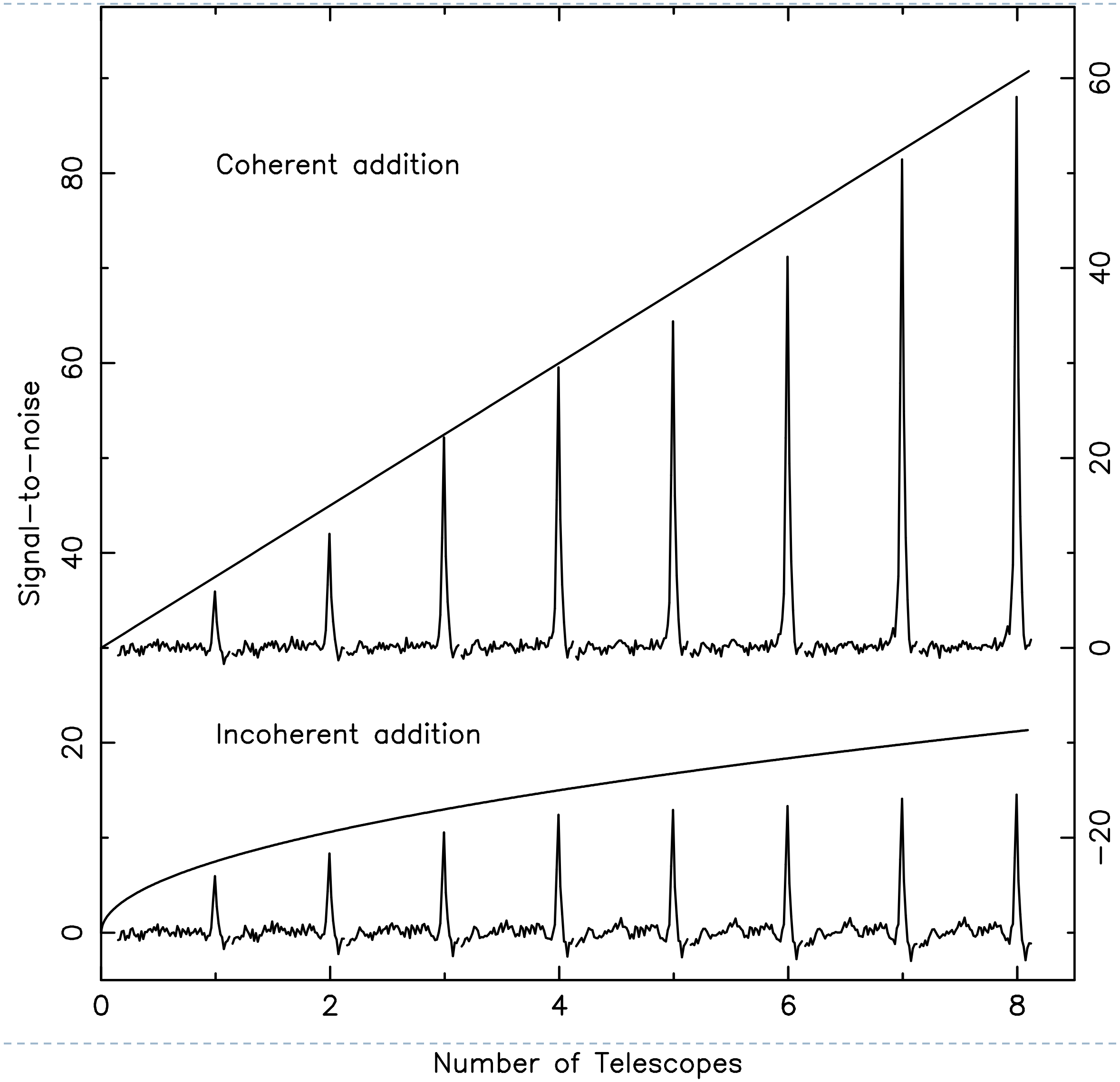
In a “tied array telescope”, signals from different telescopes are corrected for differences in time delay, then added in phase

Time delays are due to:
•Differences in geometry
•Observatory clocks
•Instruments (cable length)
•Atmospheric conditions

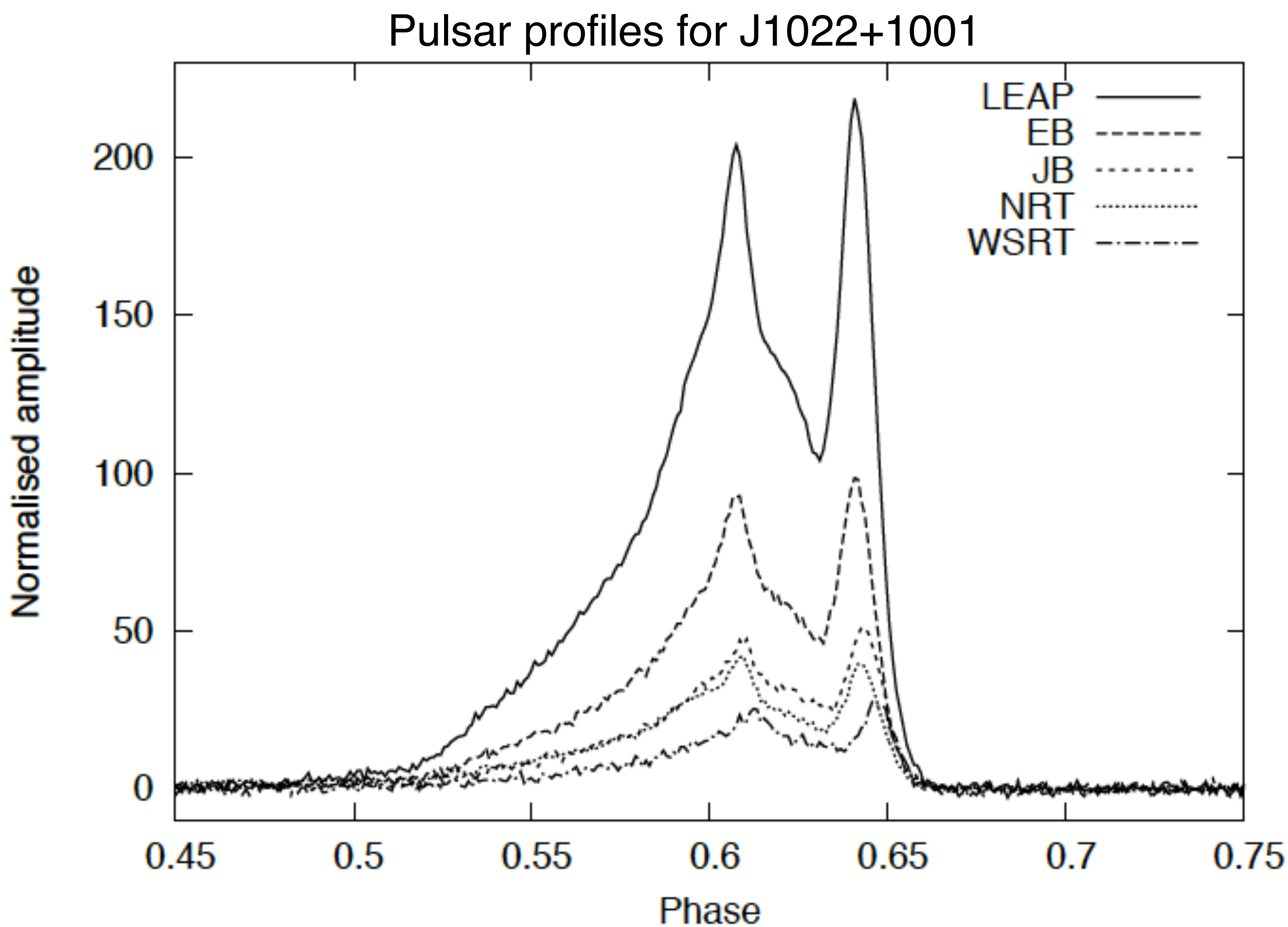


•Large aperture will improve TOA accuracy
•Ability to time weaker pulsars
•Calibration of instrumental delays between telescopes

LEAP: the experimental design

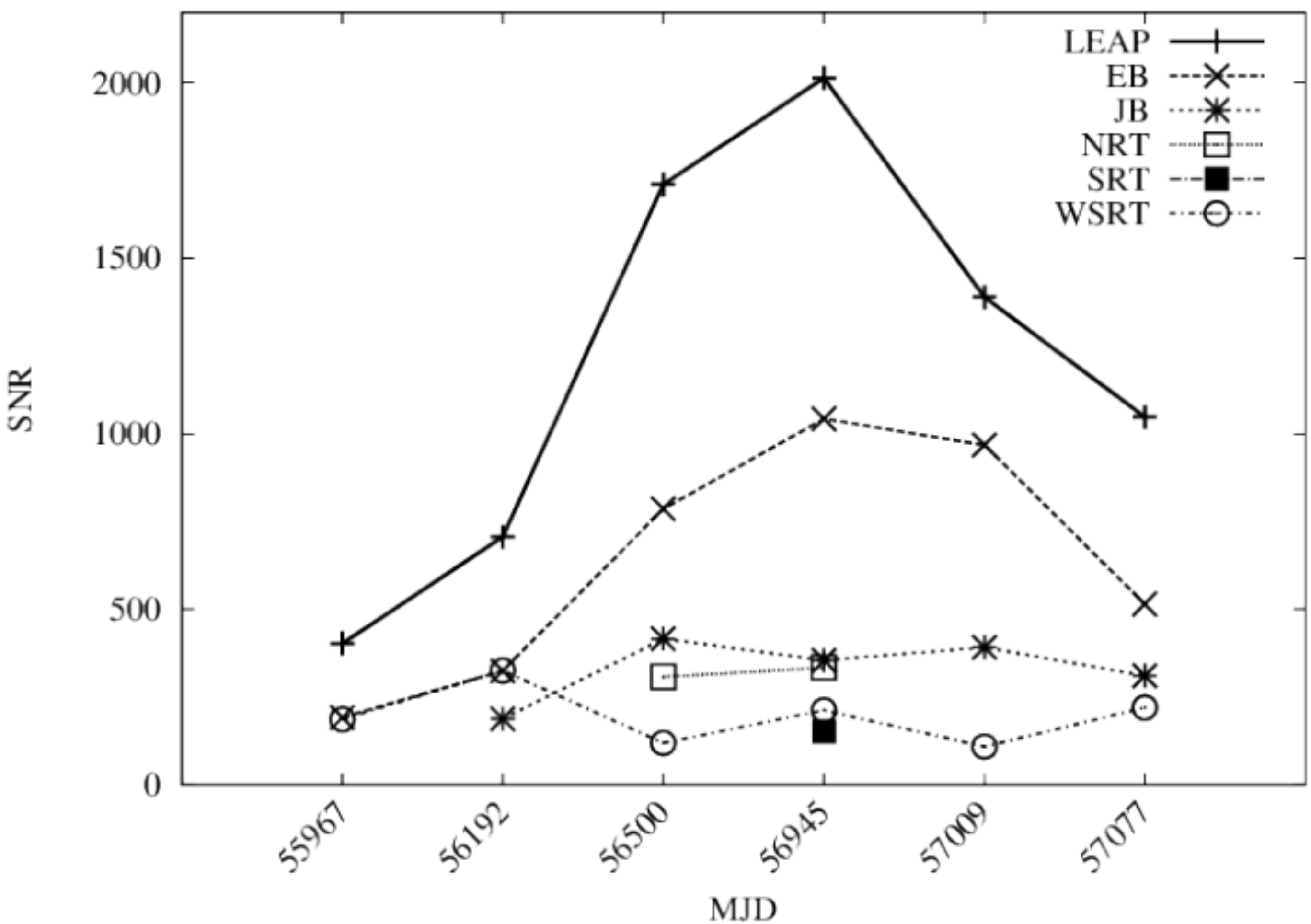


LEAP results: Coherence

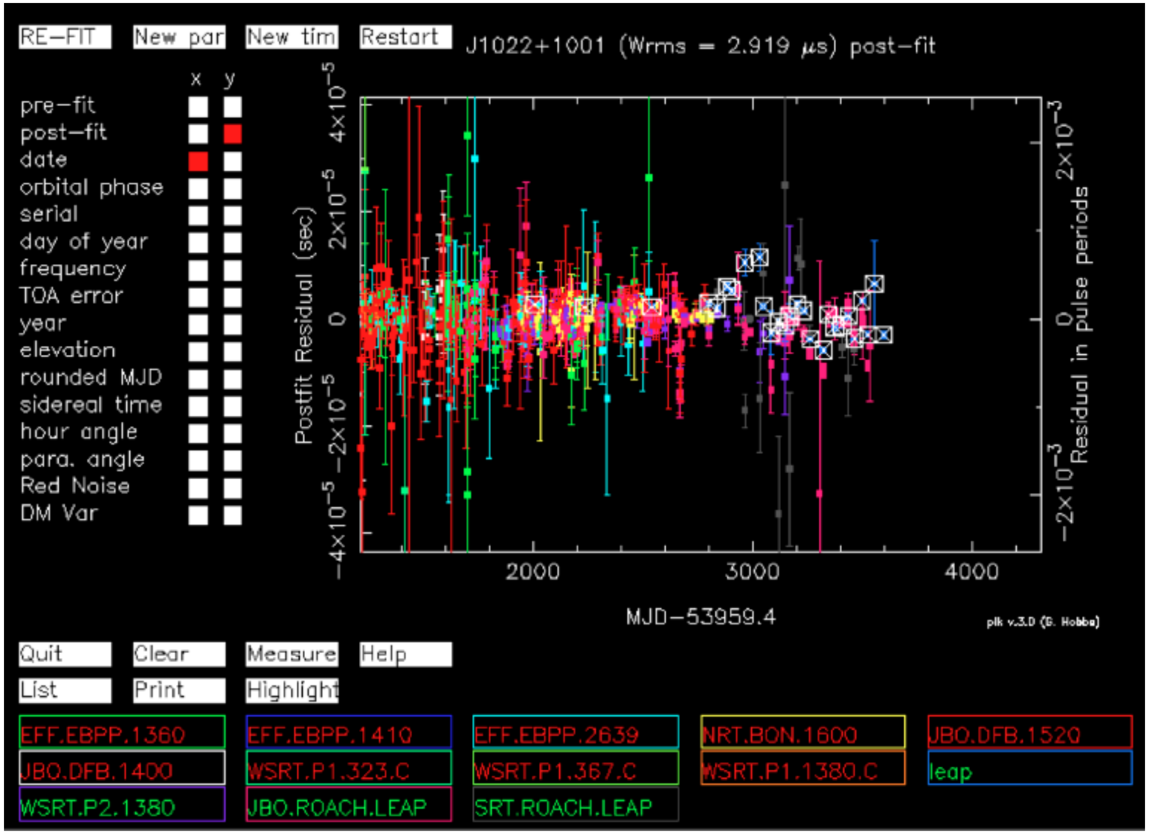


LEAP results: Coherence

Coherent addition of J1022+1001



EPTA data combination



Correlated LEAP data added to EPTA dataset for better timing precision

EPTA data added to other PTAs to form IPTA dataset

Tests of strong gravity in Double Neutron Star (DNS) systems

- LEAP coherent addition significantly increases S/N of pulsar observations, leading to lower residual rms and better constraints on pulsar model

- In DNS systems constrain

Post-Keplerian parameters:

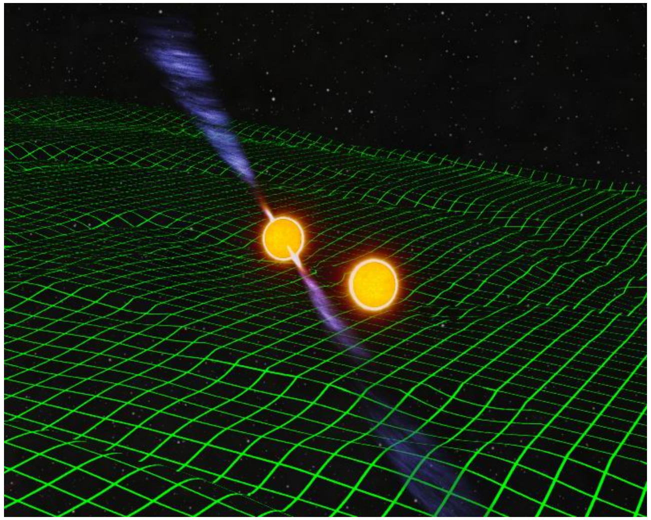
Rate of advance of periastron

Einstein delay

Shapiro delay

Orbital period decay

John Rowe



- Campaign of monthly monitoring of DNS sources during LEAP runs for strong gravity tests

Pulsar searches

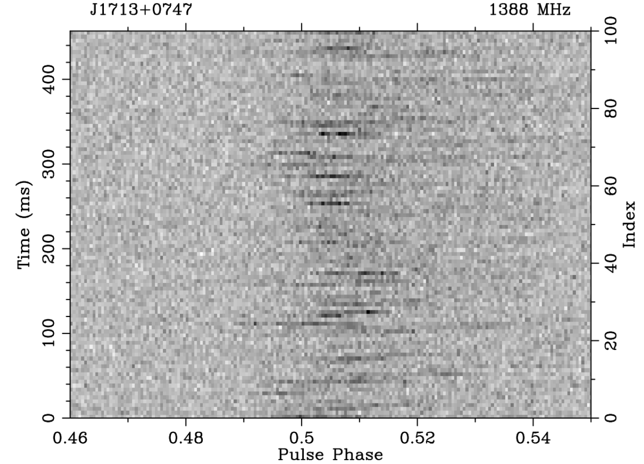
Wang et al : Search for pulsars in Globular Clusters GC M28
Focus on X-ray sources
Re-detection of known pulsars

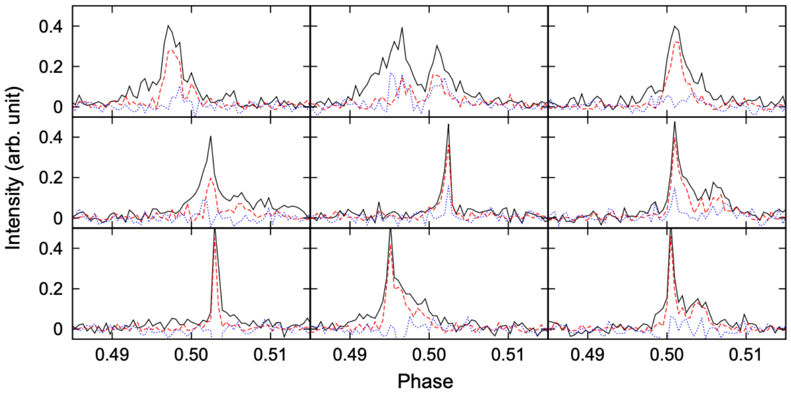
Single pulse studies

Liu et al (2016): Variability, polarimetry, and timing properties of single pulses from PSR J1713+0747 using the Large European Array for Pulsars

Single pulses preserve information about the pulsar radio emission and propagation in the pulsar magnetosphere, and understanding the behavior of their variability is essential for estimating the fundamental limit on the achievable pulsar timing precision.

- Find periodic intensity modulation that is phase-dependent
- 2 modes for drifting sub-pulses
- Brightest pulses are highly linearly-polarized



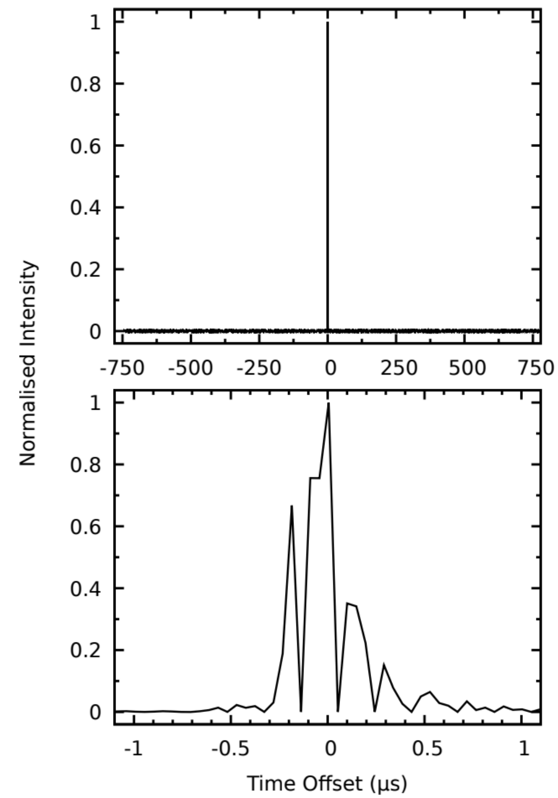


Giant pulses

McKee et al (2018) A detailed study of giant pulses from PSR B1937+21 using the Large European Array for Pulsar

Studied 4265 GPs in PSR B1937+21

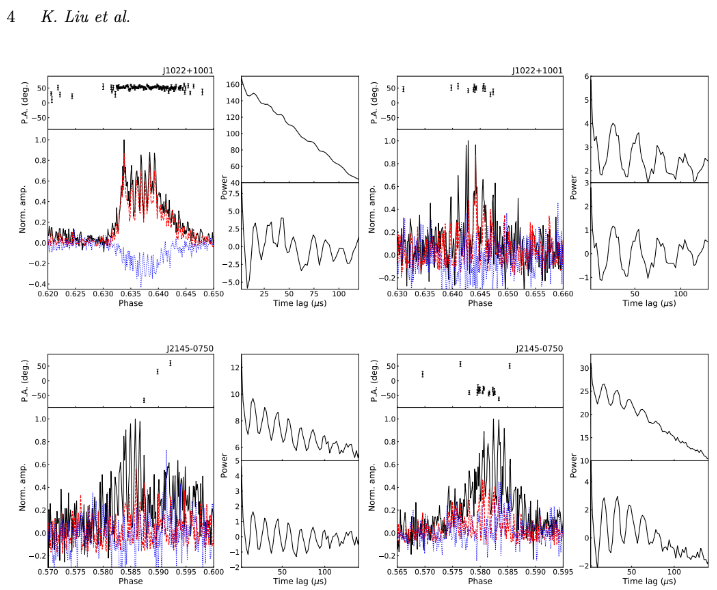
Giant pulses (GPs) are a rare phenomenon where occasional single pulses of flux densities orders of magnitude greater than the mean are emitted



Pulse micro-structure

Liu et al (2022) Detection of quasi-periodic micro-structure in three millisecond pulsars with the Large European Array for Pulsars

Some pulses show concentrated emission in sub-millisecond features, usually with a typical width and sometimes a quasi-periodicity



Detected quasi-periodic micro-structure in 3 MSPs (PSRs J1022+1001, J2145-0750 and J1744-1134)

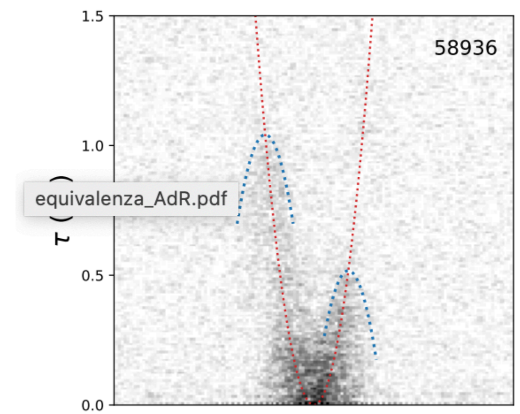
Links with FRBs

Interstellar delays

Main et al. (2020) Measuring Interstellar Delays of PSR J0613-0200 over 7 years, using the Large European Array for Pulsars

Mall et al, 2022 (Modelling annual scintillation arc variations in PSR J1643-1224 using the Large European Array for Pulsars

Scintillation: interference of the scattered paths of propagation leads to a variation of the intensity of the measured signal
Characteristic time and frequency scales of this variation depend on geometrical situation: proper motion of the source perpendicular to the line of sight



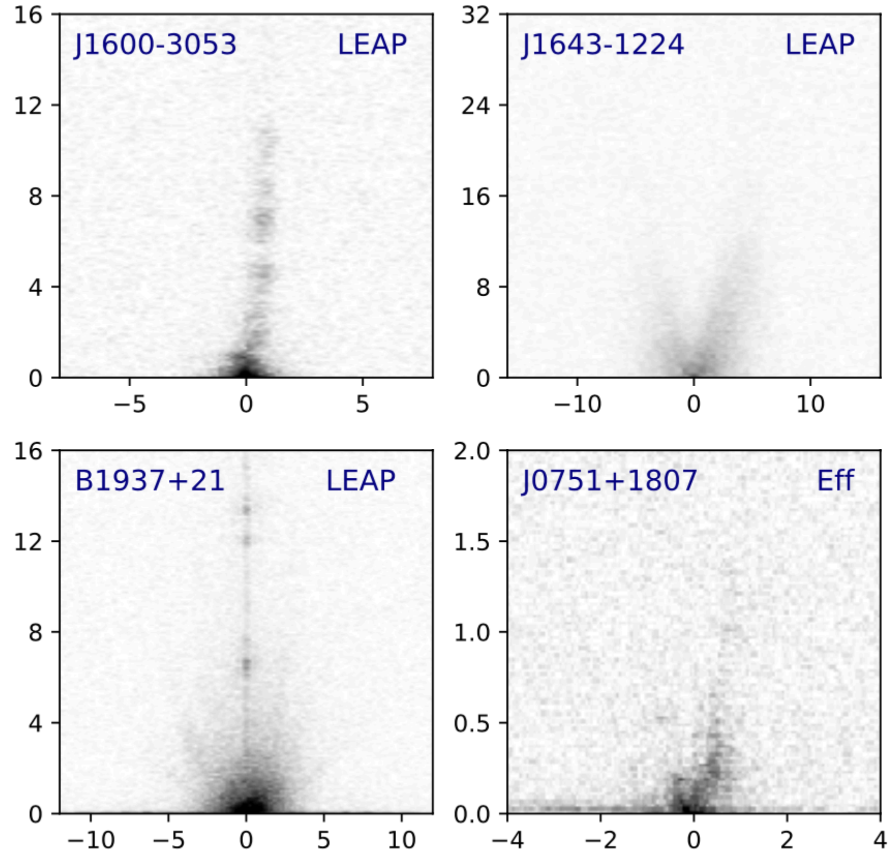
The "secondary spectrum" -- the 2D power spectrum of scintillation -- presents the scattered power as a function of time delay, and contains the relative velocities of the pulsar, observer, and scattering material. We detect a persistent parabolic scintillation arc, suggesting scattering is dominated by a thin, anisotropic region.

Interstellar delays

Main et al. 2022: Variable scintillation Arcs of Millisecond Pulsars observed with LEAP scintillation study of 12 MSPs

Scattering screen properties (compact vs. asymmetric scattering; multiple arcs)

Information about pulsar orbit (orbital inclination etc.)



Long-term scintillation studies such as this serve as a complementary tool to pulsar timing, to measure a source of correlated noise for pulsar timing arrays, solve pulsar orbits, and to understand the astrophysical origin of scattering screens

Conclusion

- LEAP is a tied array with a sensitivity equivalent to SKA-1
- Gives highly precise data useful for Pulsar Timing Arrays and GW detection
- Other applications (single pulses, giant pulses, micro-structure, interstellar delays etc.) useful to pulsar and PTA science
- Understand these effects better with SKA