High precision pulsar timing: Nançay and the European Pulsar Timing Array

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the 'EPTA' is a collaboration of the largest european radiotelescopes to search for a gravitational waves background using pulsar timing

Cagliari, I, 64m, A.Possenti
Effelsberg, G, 100m, M.Kramer
Jodrell Bank, UK, 76m, B.Stappers
Nançay, F, ~100m, I.Cognard
Westerbork, NL, ~100m, J.Hessels
A magnetized neutron star

As a lighthouse, two beams of radio waves, emitted along the magnetic axis, sweep the sky as the star rotates, yielding periodic pulses on Earth.
Ultra-stables clocks
Instrumentation
The Pulsar Timing Array

An outstanding stability
Numerous applications
Detection of a Gravitational Waves Background

A first very short life...

After a birth at \( \sim 30\)ms, the pulsar is rapidly slowing down and stops emission after few millions years.

... then eternity!

Those still present in a binary system speed-up by angular momentum transfer, and produce radio waves again, those are the recycled millisecond pulsars with an outstanding rotational stability!

Alpar et al., Nature 300, 728 (1982)
An extraordinary stability and a very high precision

Together with the exceptional stability of the fastest pulsars, the state-of-the-art coherent dedispersion instrumentations provide times of arrival (ToAs) of radio pulses characterized by a precision as good as $\sim 30$ns.

Numerous applications

- search for a Gravitational Waves Background
- tests of the different Gravitation theories
- propagation and turbulence in the interstellar medium
- stellar evolution
- globular clusters and gravitational potential of the Galaxy
- constrains on the Solar System ephemeris
- detection of extra-solar planets (3 with PSR B1257+12)
- physique of pulsar emission
- long term stability of terrestrial time scales
- precise link between celestial references (equatorial and ecliptic)
Detection of a Gravitational Waves Background

Many sources...
Supermassive black-hole binary systems
Cosmological background
  relic gravitational waves
  cosmic strings

Correlation...
Searching for a correlated noise, coming from the effect of the gravitational waves on Earth, on a set of stable pulsars well distributed on the sky.
→ Pulsar Timing Array (PTA : EPTA, PPTA, ... )
Ultra-stables clocks
Instrumentation
The Pulsar Timing Array
ISM limitations

Timing

Measuring a time of arrival
a large radiotelescope
a good clock,
and a special instrumentation
to remove the ISM dispersion

Analysis of a collection of measured times of arrival (ToAs)

→ Having a set of parameters (period, position, etc...),
→ computing 'calculated times of arrival',
→ fitting the parameters by minimization of the differences (called residuals)
  between 'measured ToAs' and 'calculated ToAs'
→ looking at the residuals to find unmodeled effects...
GPUs based coherent dedispersion at Nançay

**Diversion of GPUs**
Using high performance graphical card (GPU), 2 PCs / 4 GPUs easily dedisperse bw 128Mhz (512MB/s=4Gb/s) in real time
Sept 2010 : a 512MHz version is nearly ready

**An ultimate precision**
Timing uncertainty can be as good as 30ns for a few pulsars.

**A large scale program**
Around 50% of the Nançay telescope time
More than 200 pulsars monitored
More than 20000 observations since Nov 2004
Effects of the turbulent interstellar medium

in addition to the constant dispersive effect, variable multi-propagation →
mean pulse received on Earth is a mixture of differently delayed pulses
Can we try to correct for those variable delays?
Interstellar holography

**Impulse response**

A high SNR dynamic spectra, the calculation of the 'secondary spectrum', and the adjustment of thousands of coefficients describing the electric field provide the impulse response of the medium.

Here, multi-propagation delays up to 100 $\mu$s are observed, and the pulse has a mean delay $\sim 15\mu$s...

Walker et al., MNRAS 388, 1214 (2008)

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PSR B0834+06, Arecibo, 321MHz
Dynamical and secondary spectra: data, model and residuals
The ultra-stable pulsar PSR J1909-3744

Pulsar J1909-3744 ToAs residuals
(P = 2.95 ms, DM = 10.39 pc cm$^{-3}$, $P_b = 1.53$ d)
are characterized by an rms $\sim 110$ ns
A major contribution to the Pulsar Timing Array

Many and well done

over 20 stable pulsars
regularly timed at Nançay:
10 are better than 1μs,
5 better than 500ns...

for the EPTA

Nançay is a major contributor to the European Pulsar Timing Array

and... LEAP

Large European Array for Pulsars:
ERC funds to build
a 'virtual' 200m radiotelescope
by coherent addition
of the voltages recorded
at the five telescopes

<table>
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<th>Pulsar</th>
<th>$P$ (ms)</th>
<th>$P_b$ (days)</th>
<th>$T$ (years)</th>
<th>$N_{toa}$</th>
<th>$\sigma$ (μs)</th>
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Timing of ultra-stable pulsars

is a way to search for a Gravitational Waves Background...

With a large collecting area and with an excellent instrumentation, the Nançay radiotelescope is deeply involved in the European Pulsar Timing Array and then within the International PTA : EPTA + Parkes PTA + US NanoGrav