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

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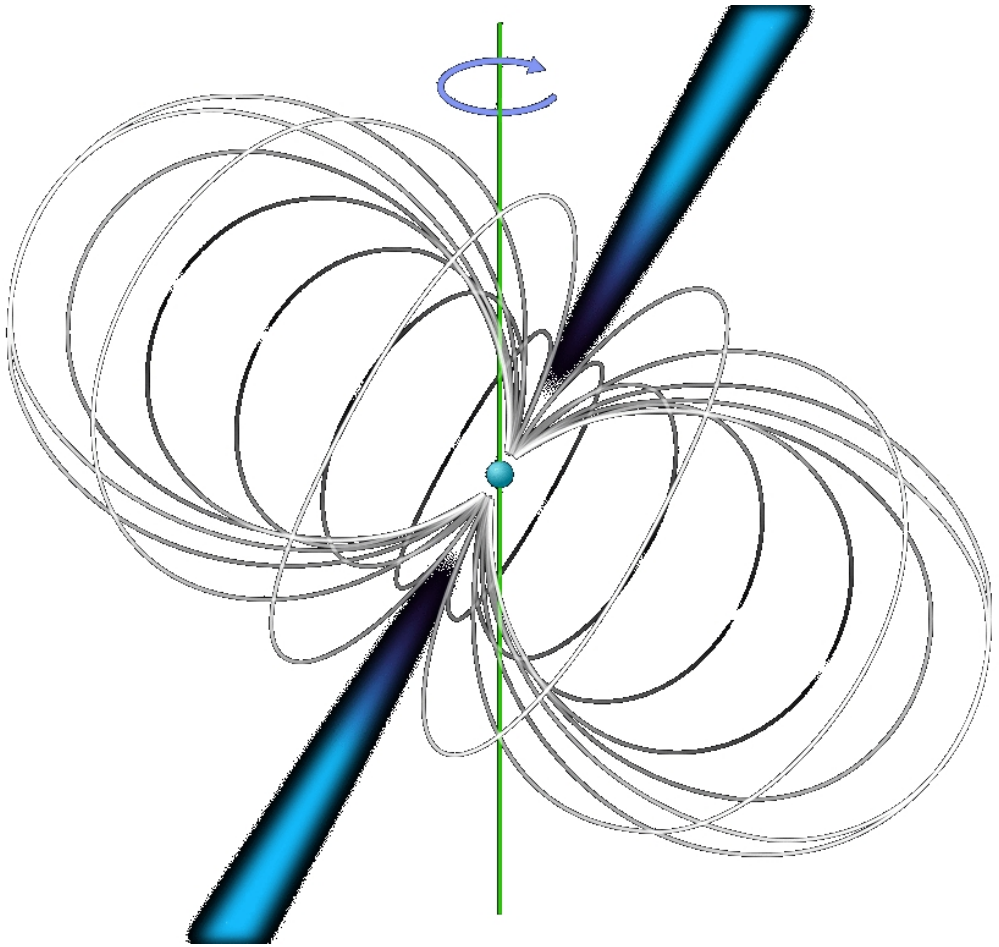
the 'EPTA' is a collaboration of the largest european radiotelescopes to search for a gravitational waves background using pulsar timing

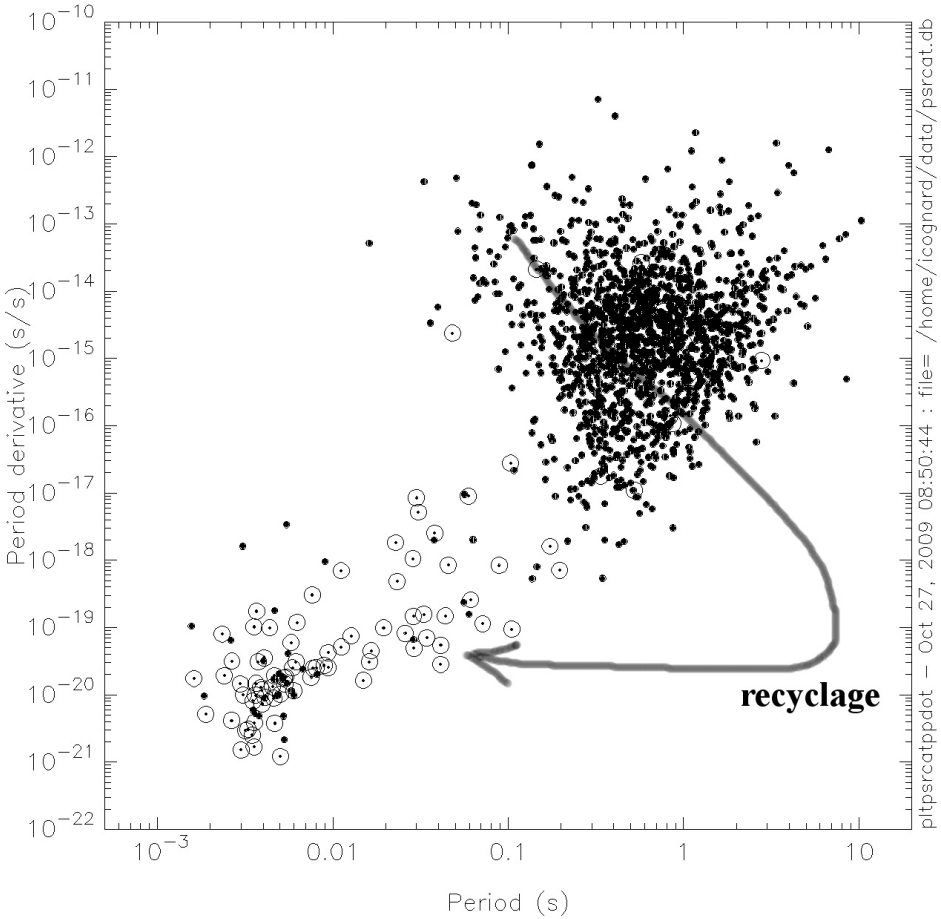
Cagliari, I, 64m, A.Possenti
Effelsberg, G, 100m, M.Kramer
Jodrell Bank, UK, 76m, B.Stappers
Nançay, F, ∼100m, I.Cognard
Westerbork, NL, ∼100m, J.Hessels

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.

An outstanding stability



Period - Period derivative diagram

A first very short life...

After a birth at ∼30ms,
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)

Numerous applications

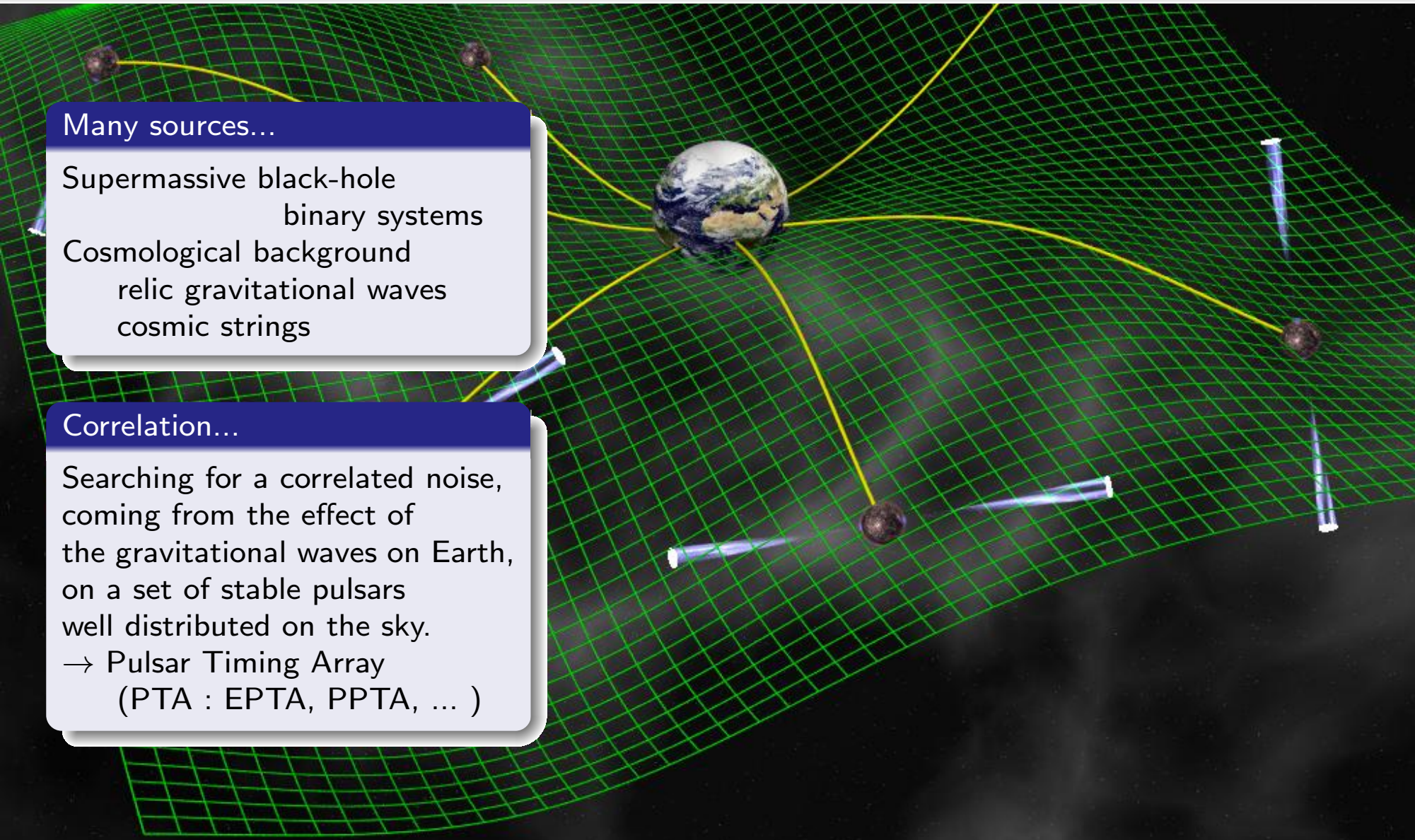
An extraordinary stability and a very high precision

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

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 celestrial references (equatorial and ecliptic)

Detection of a Gravitational Waves Background



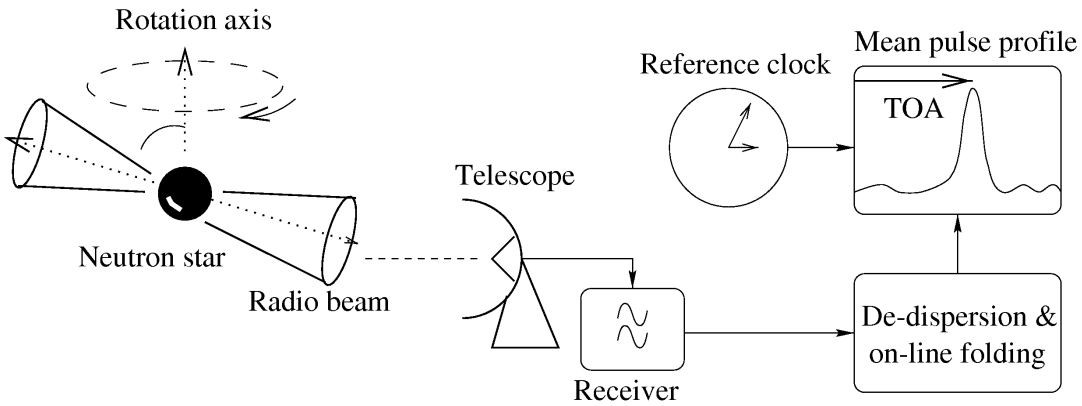
Many sources...

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, ...)

Timing



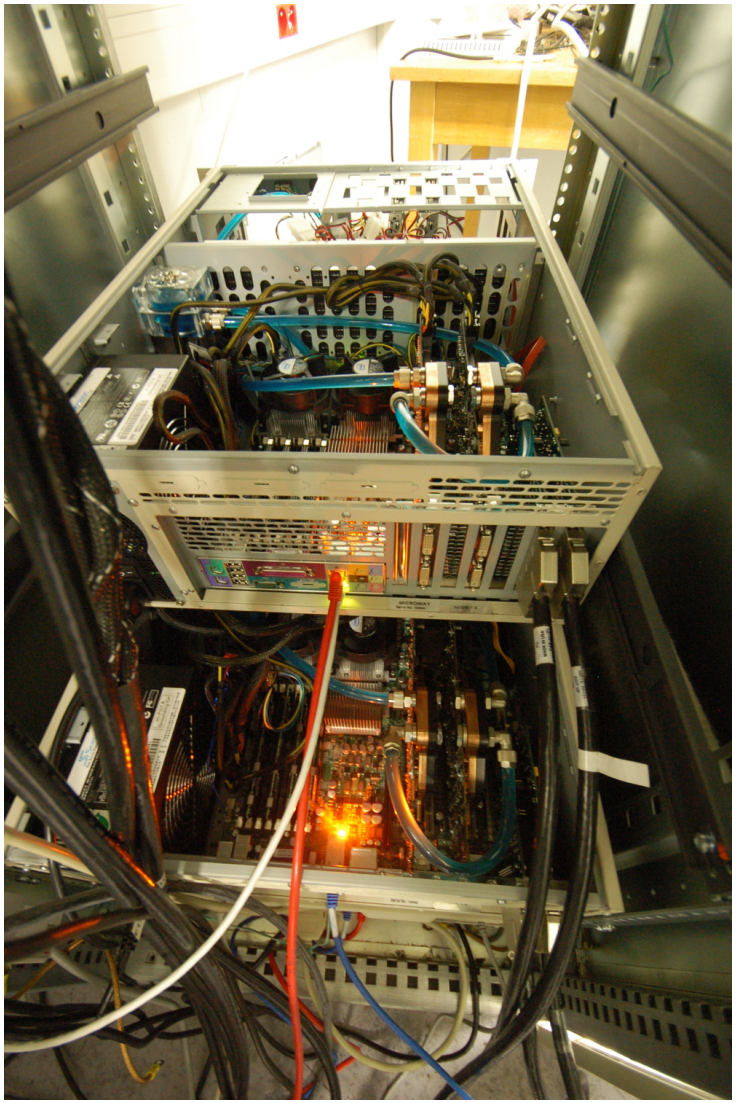
Measuring a time of arrival

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

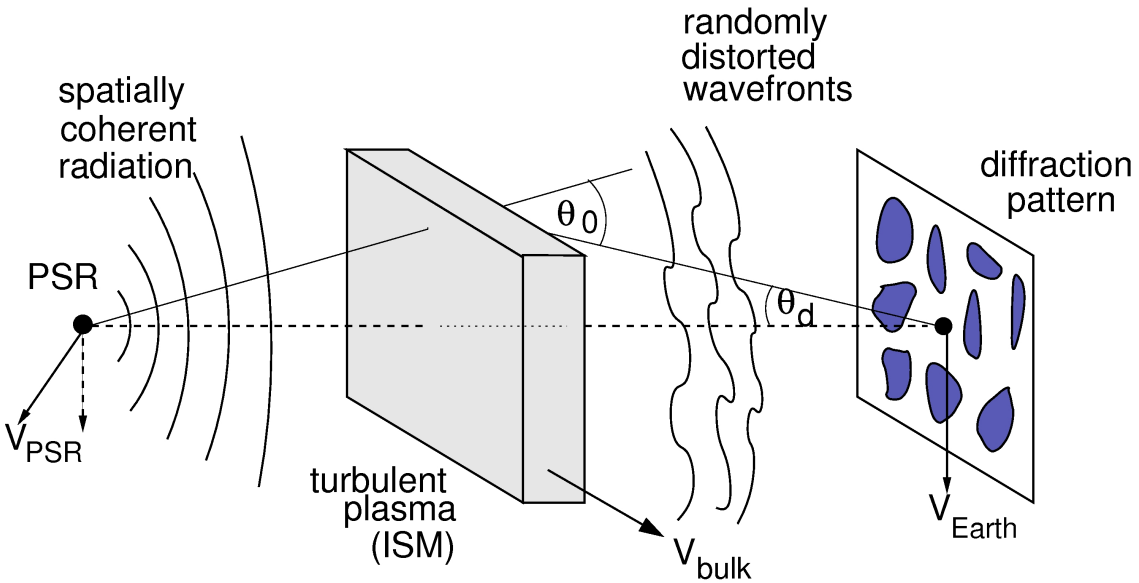
An ultimate precision

Timing uncertainty can be
as good as 30ns for a few pulsars.

A large scale program

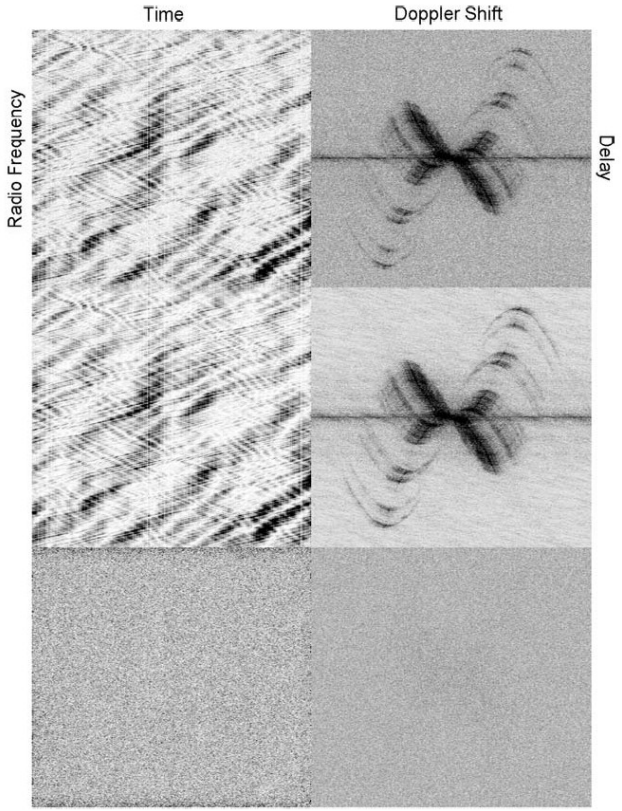
Around 50% of the Nançay telescope time
More than 200 pulsars monitored
More than 20000 observations since Nov 2004

Effects of the turbulent interstellar medium



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

Interstellar holography

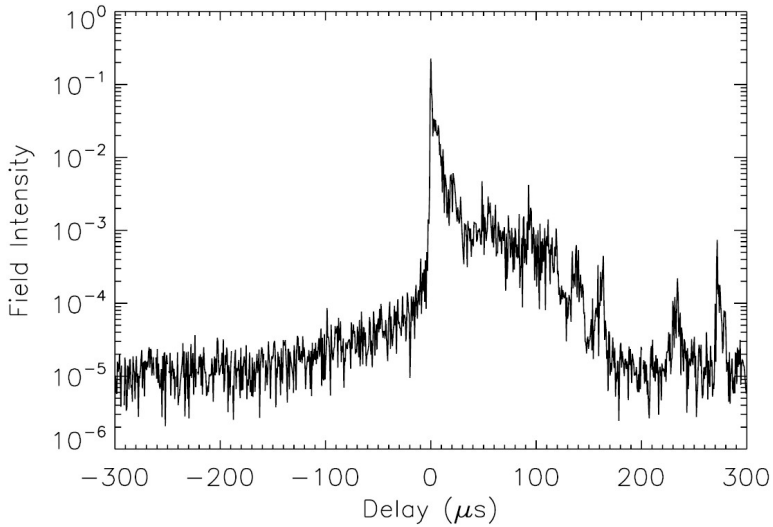


PSR B0834+06, Arecibo, 321MHz
Dynamical and secondary spectra :
data, model and residuals

Impulse response

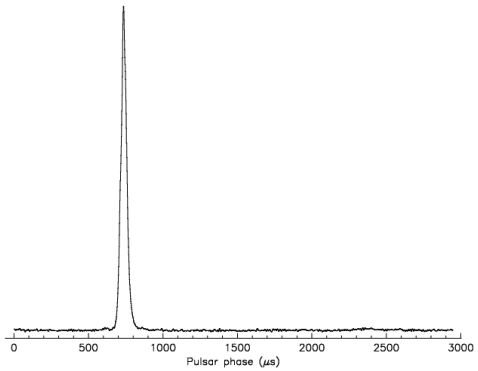
a high SNR dynamic spectra,
the calcul of the 'secondary spectrum',
and the adjustment of thousands of coefficients describing the electric field
provide the impulse response of the medium

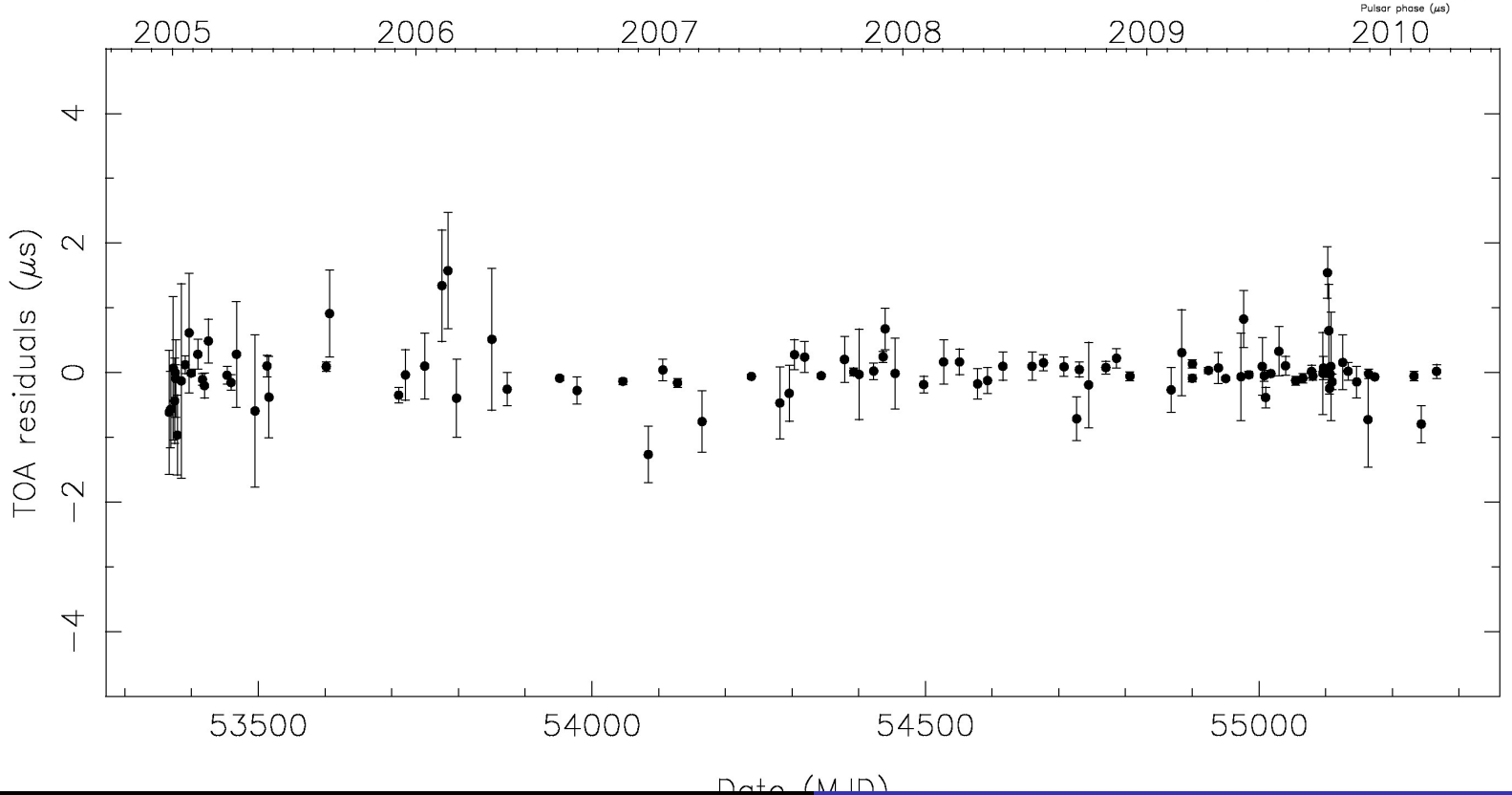
Here, multi-propagation delays up to 100 μs are observed
and the pulse has a mean delay $\sim$15μs...
Walker et al., MNRAS 388, 1214 (2008)



The ultra-stable pulsar PSR J1909-3744

Pulsar J1909-3744 ToAs residuals
(P=2.95ms, DM=10.39pc.cm^{-3}, P_b=1.53d)
are characterized by an rms ∼110ns





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

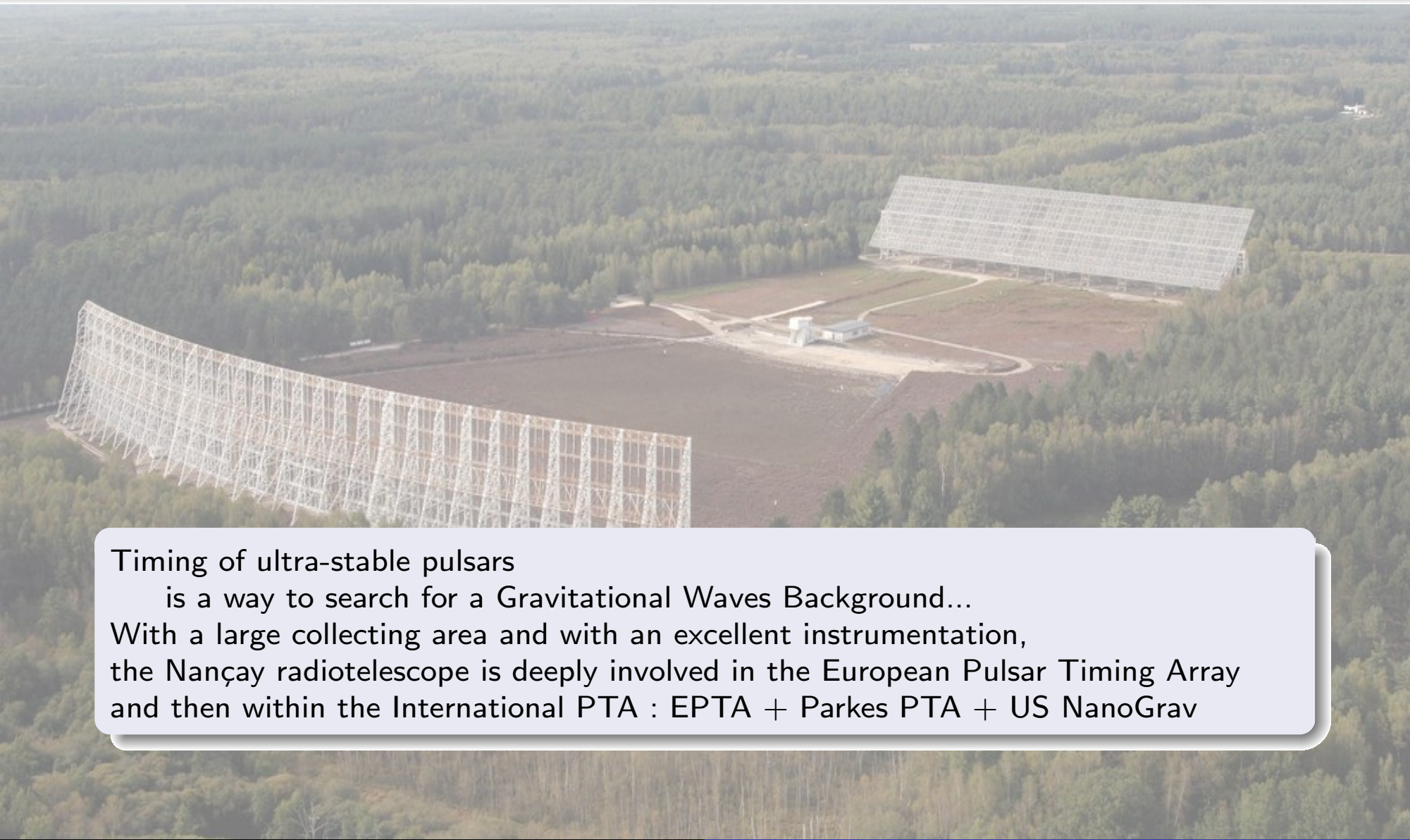
Nançay is a major contributor to the European Pulsar Timing Array

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

Pulsar	P (ms)	P_b (days)	T (years)	N_{toa}	σ (μs)
J0030+0451	4.87	–	4.6	402	1.84
J0613−0200	3.06	1.2	4.5	280	0.913
J0751+1807	3.48	0.26	4.5	158	1.73
J0900−3144	11.10	18.7	2.0	199	2.87
J1012+5397	5.25	0.6	4.3	107	0.771
J1022+1001	16.45	7.8	4.5	136	1.97
J1024−0719	5.16	–	3.6	128	1.23
J1455−3330	7.99	76.2	4.5	139	2.33
J1600−3053	3.60	14.3	2.8	211	0.495
J1643−1224	4.62	147	4.5	271	1.7
J1713+0747	4.57	67.8	4.5	260	**0.350**
J1730−2304	8.12	–	4.5	85	1.55
J1744−1134	4.07	–	4.5	87	**0.343**
J1751−2857	3.91	110.7	3.5	36	0.948
J1824−2452	3.05	–	4.5	313	2.63
J1857+0943	5.36	12.3	4.5	51	0.860
J1909−3744	2.95	1.53	5.2	103	**0.111**
J1910+1256	4.98	58.4	3.5	31	1.04
J1939+2134	1.55	–	4.5	277	0.483
J2145−0750	16.05	6.84	4.5	159	0.993
J2317+1439	3.44	2.46	4.8	163	2.64

Conclusion



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