High Precision Pulsar Timing at Nançay

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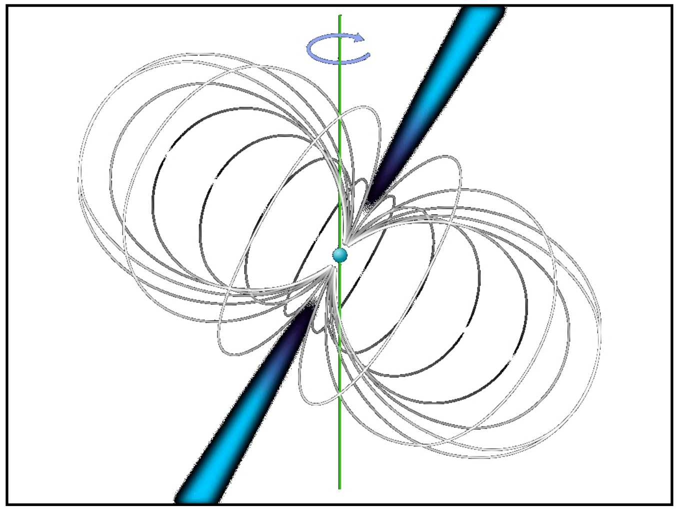
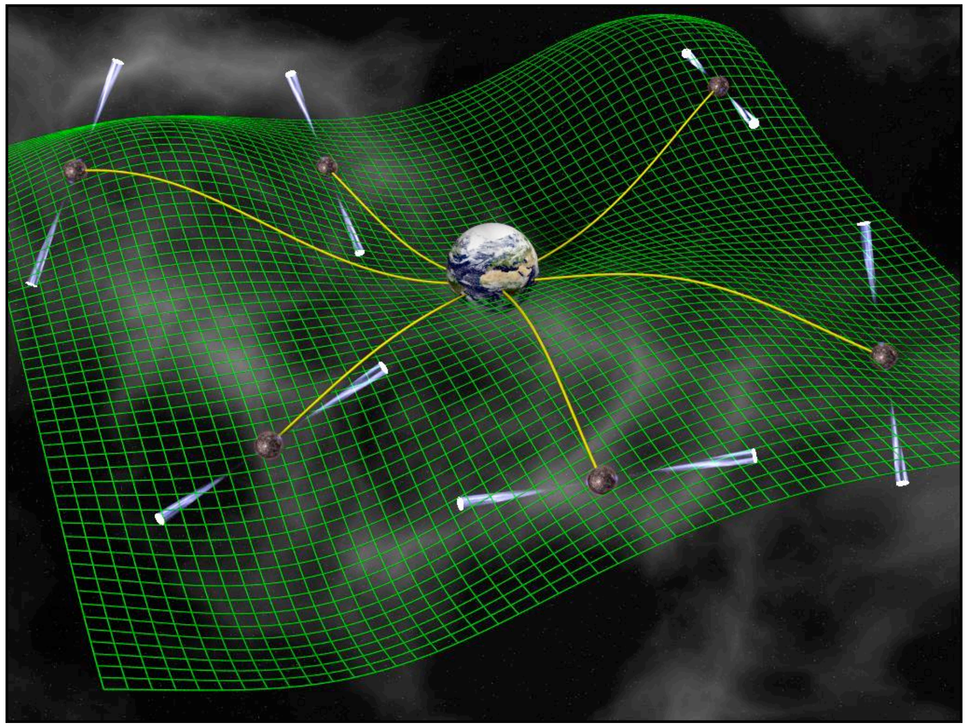
- Pulsars as high stable clocks

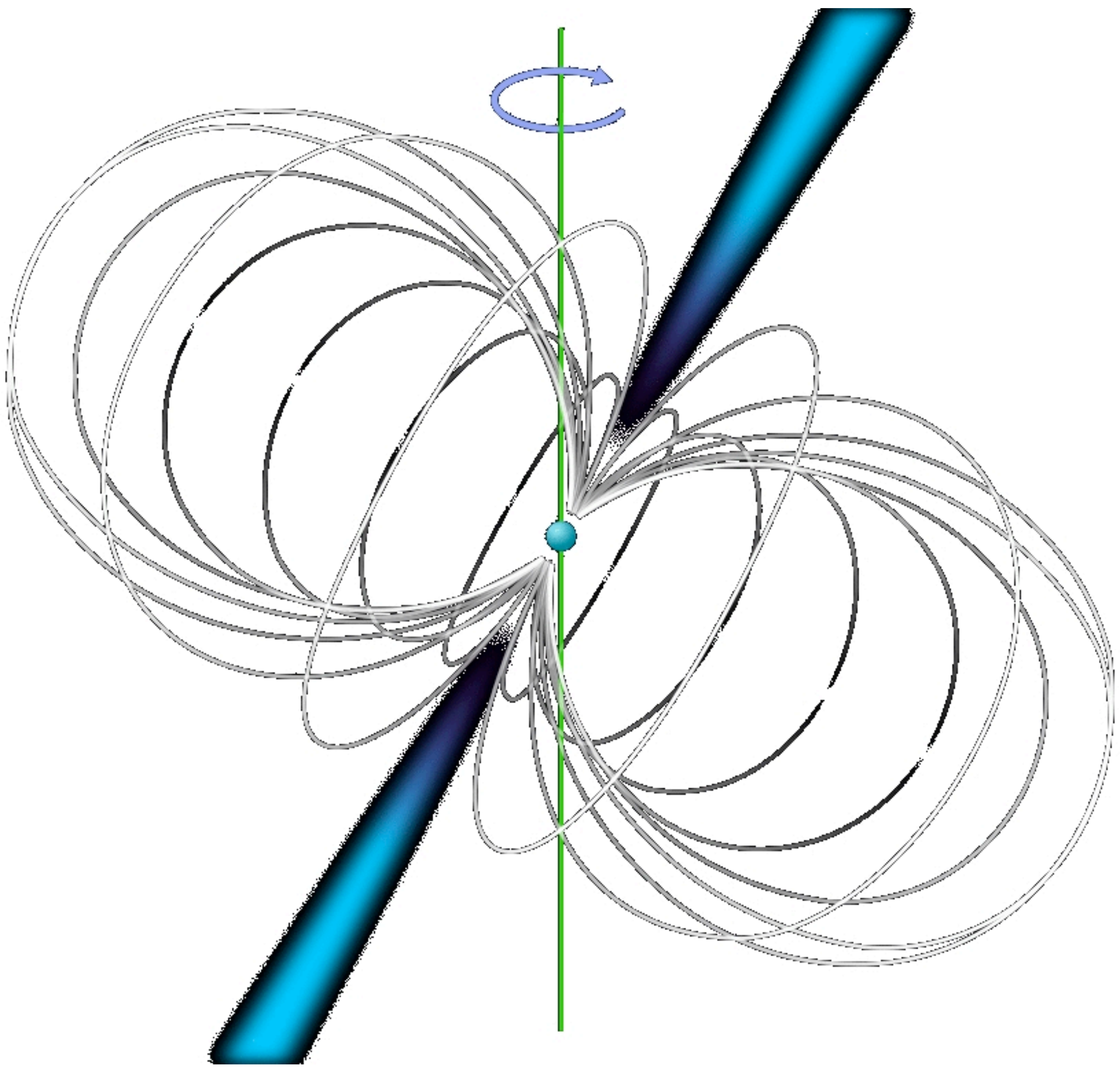


- The Nançay's Radiotelescope

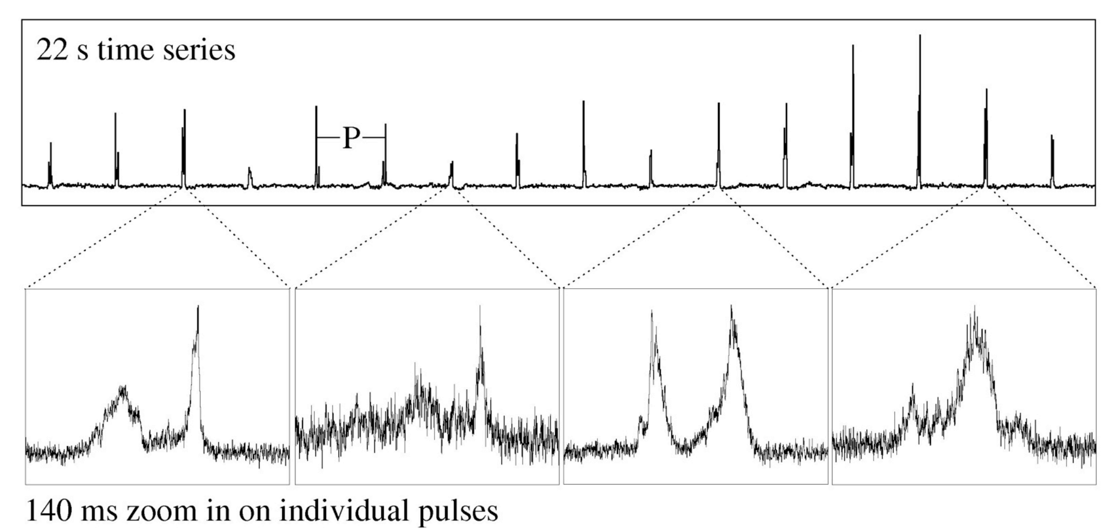
- Gravitational waves detection through Pulsar timing



Pulsars as high stable clocks

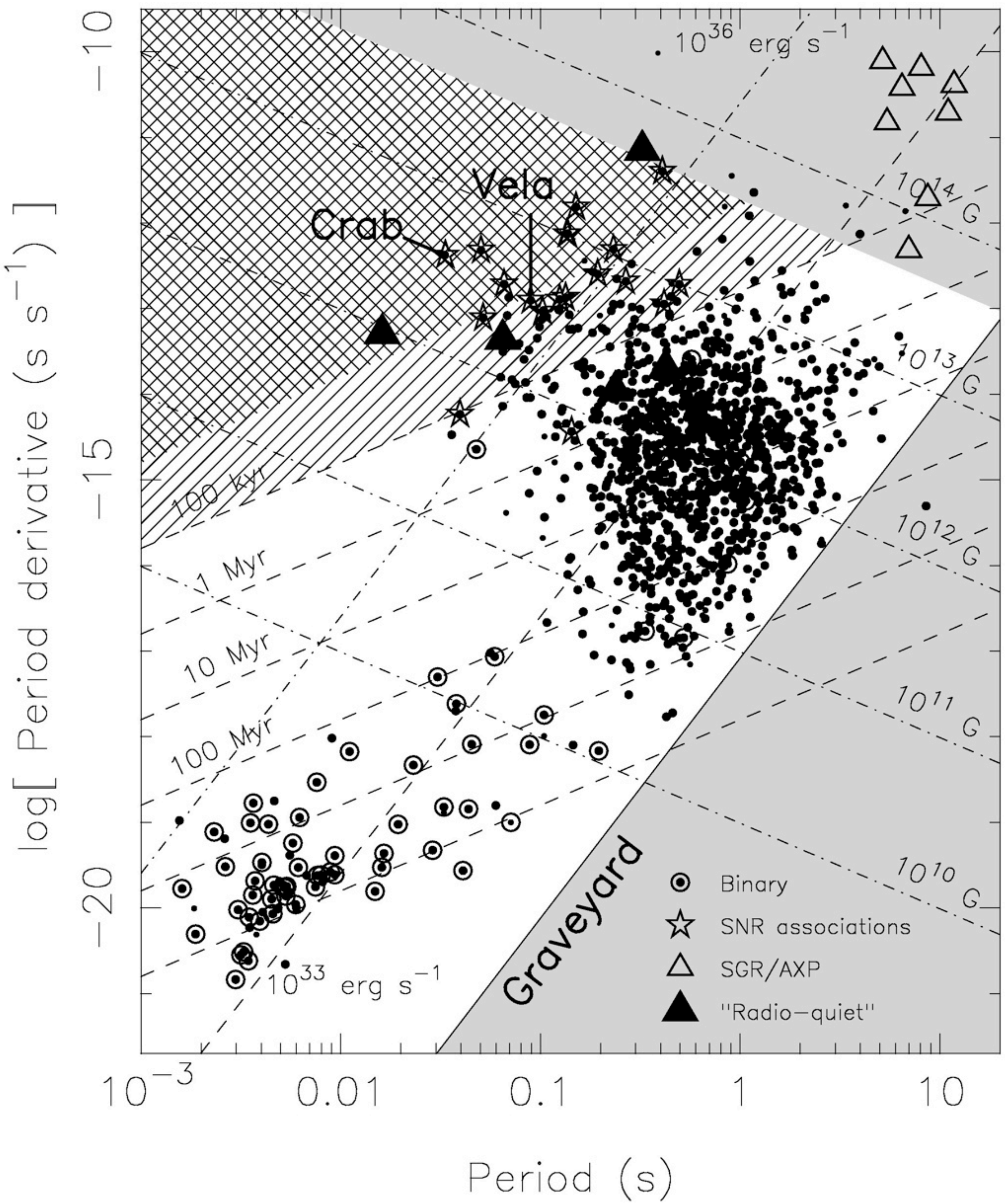


A pulsar is a highly magnetised neutron star, which emits two beams of radio waves along the magnetic axis.
As the star rotates, the radio beams sweep the sky (lighthouse effect) producing reception of periodic pulse on Earth.



Handbook of Pulsar Astronomy, D. Lorimer & M. Kramer 2005

Pulsars as high stable clocks



Handbook of Pulsar Astronomy, D. Lorimer & M. Kramer 2005

After its birth around 30ms,
the pulsar is rapidly slowing down
and stop emission after a few My.

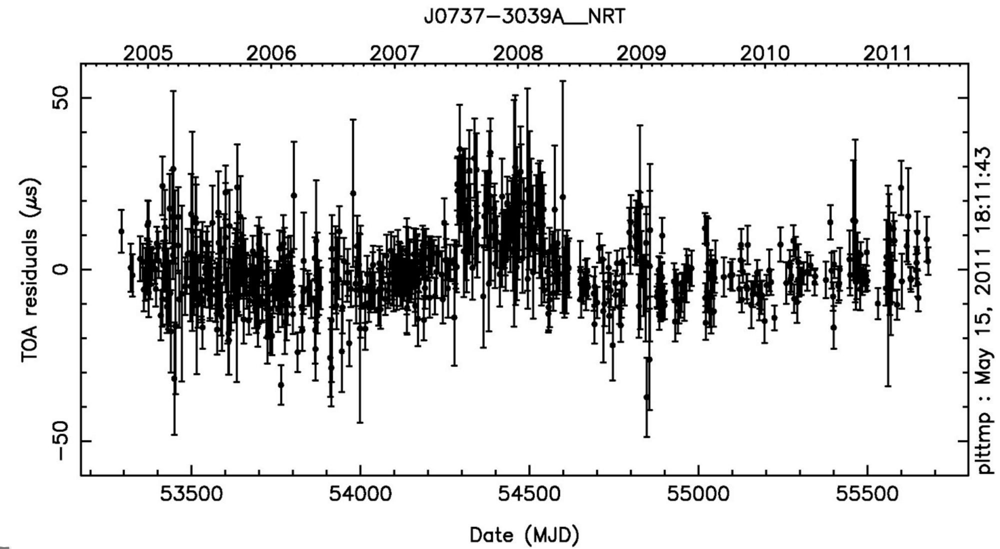
Some of them in binary system are
speed-up by angular momentum transfer
until a few milliseconds period.
These MSPs (millisecond pulsar) are highly
stables and can be use as clock.

Alpar et al., Nature 300, 728 (1982)

0.1% of change every 30 millions years !

Pulsars as high stable clocks

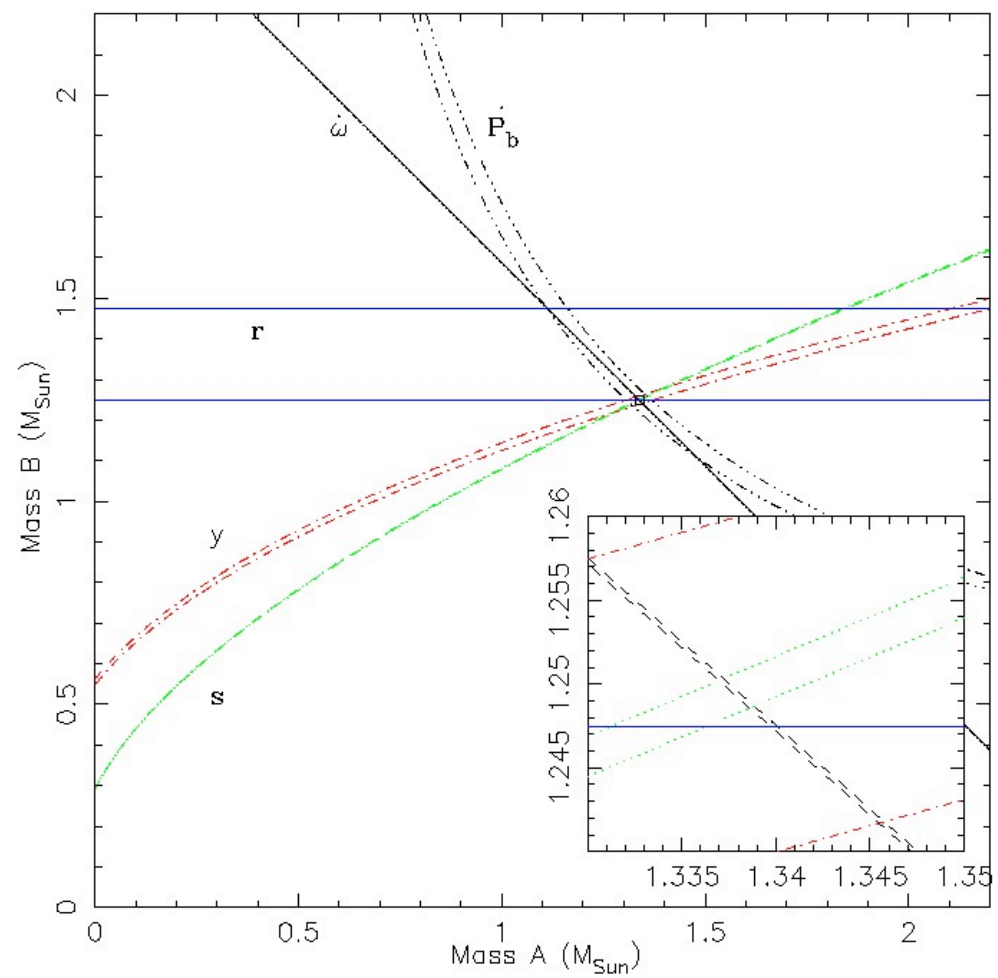
These MSPs stability with high precision instrumentation allow to provide extremly precise Time of Arrival (ToAs) mesurements with incertainties as low as ~30ns.



Many applications :
- Stellar evolution
- Globular or MW potential
- Constrains on SS ephemeris
- ISM
- long term stability of terrestrial time scales
- and ...

...Test theories of gravitation in high field situation :
Double pulsar J0737-3039 gives 5 post-Keplerian parameters agreement with GR at 0.05 %.

Kramer et al. Science 314, 97 (2006)



...A possible detection of gravitational waves...

The Nançay's Radiotelescope

Nançay's radio-telescope is a 94m equivalent dish which 50% of observation time dedicated to pulsar timing.

Observation in two band :
L-band (1.1-1.8 GHz)
S-band (1.7-3.5 GHz)

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

Over 20 pulsars regularly timed at Nançay:
10 with pecision under 1μs and 5 better than 500 ns.

The Nançay's radio-telescope is one the major contributor of the European Pulsar Timing Array (EPTA) and part of the LEAP project to build a '200m' equivalent telescope by adding coherently signal recorded at the five biggest european radio-telescopes.

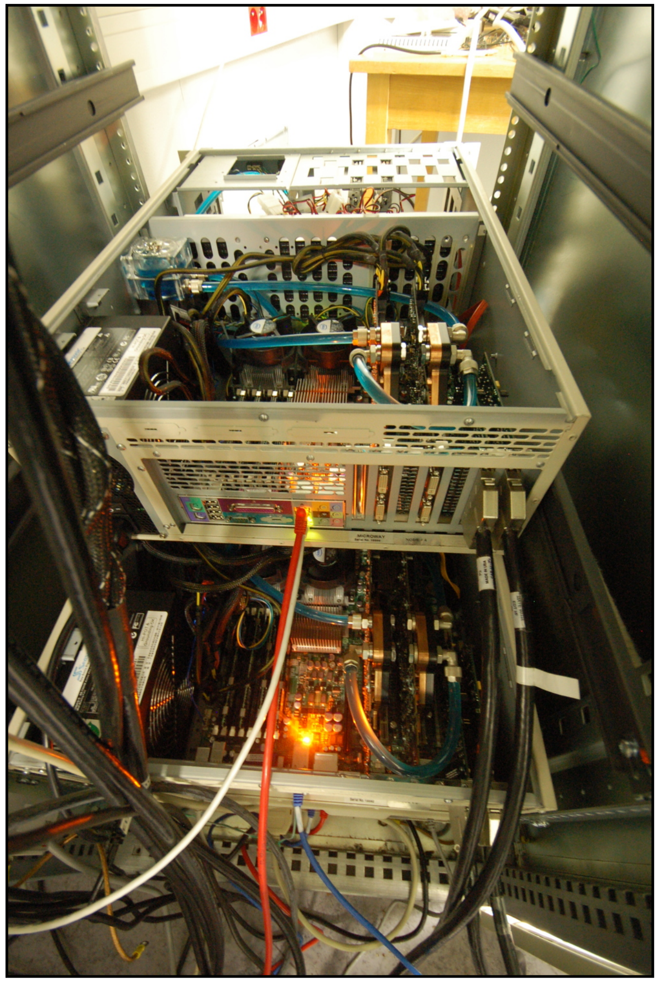
The Nançay's Radiotelescope

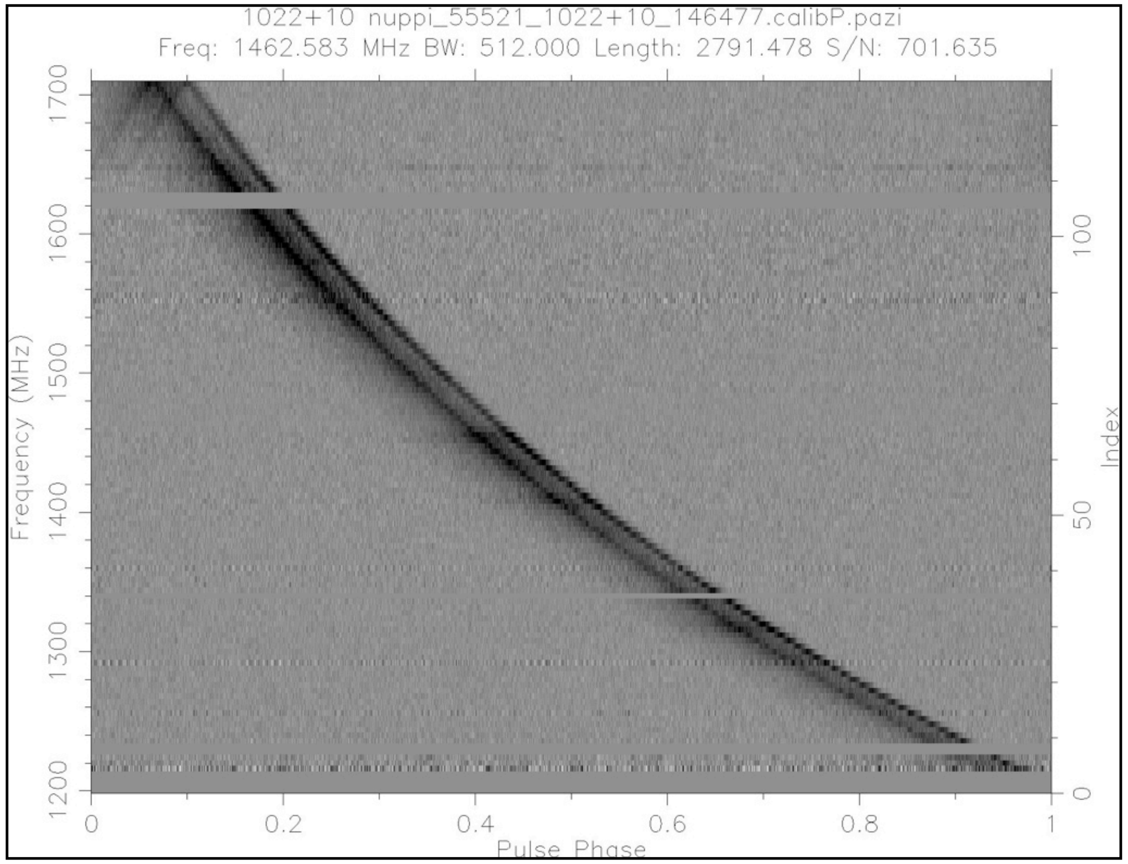
Instrumentation

Dedispersion instrumentation is needed to remove dispersion of the EM signal during its travel through the ISM: lower frequencies travel slower than higher one.

$$\Delta t = k \times \left(f_1^{-2} - f_2^{-2}\right) \times DM \qquad DM = \int_0^d n_e(l)dl$$

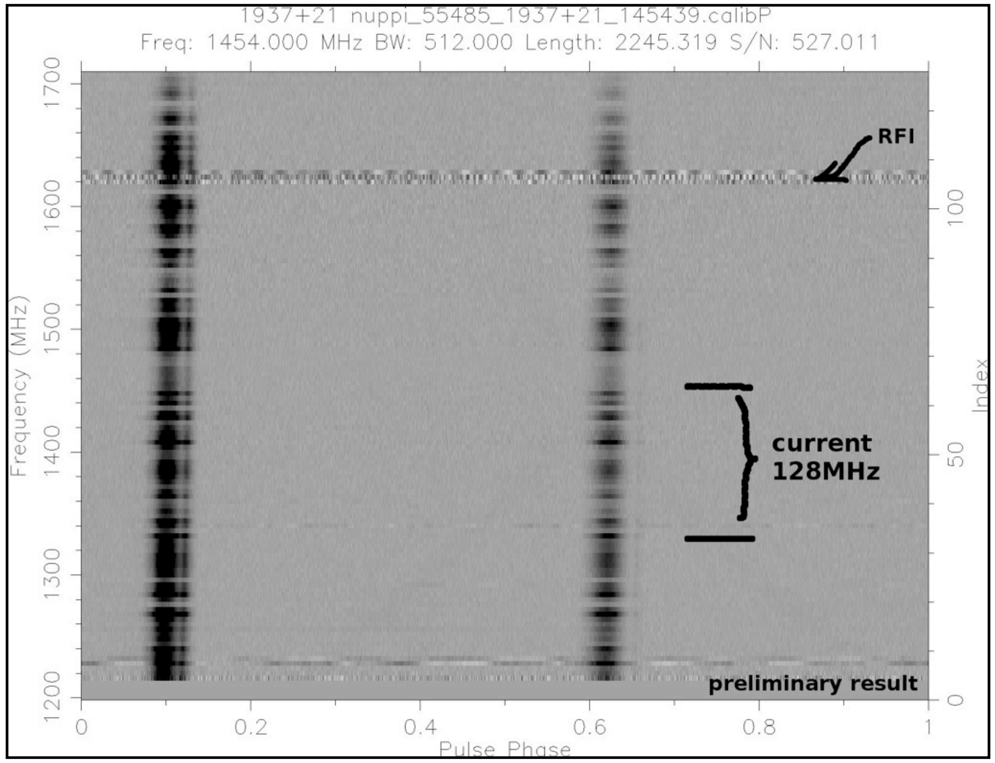
$$k = \frac{e^2}{2\pi m_e c}$$





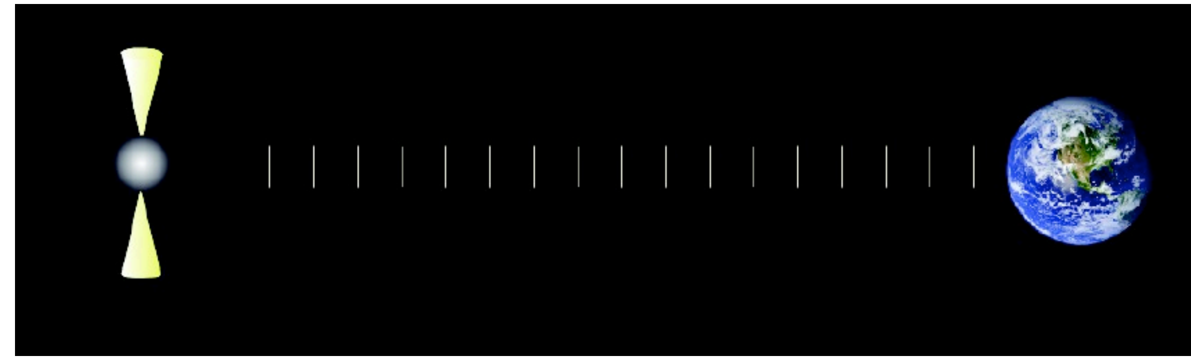
We use a GPUs based coherent dedispersion instrumentation : 2PCs/4GPUs dedisperse bw 128MHz (BON)

Which is about to be increased to bw 512MHz (BON512)

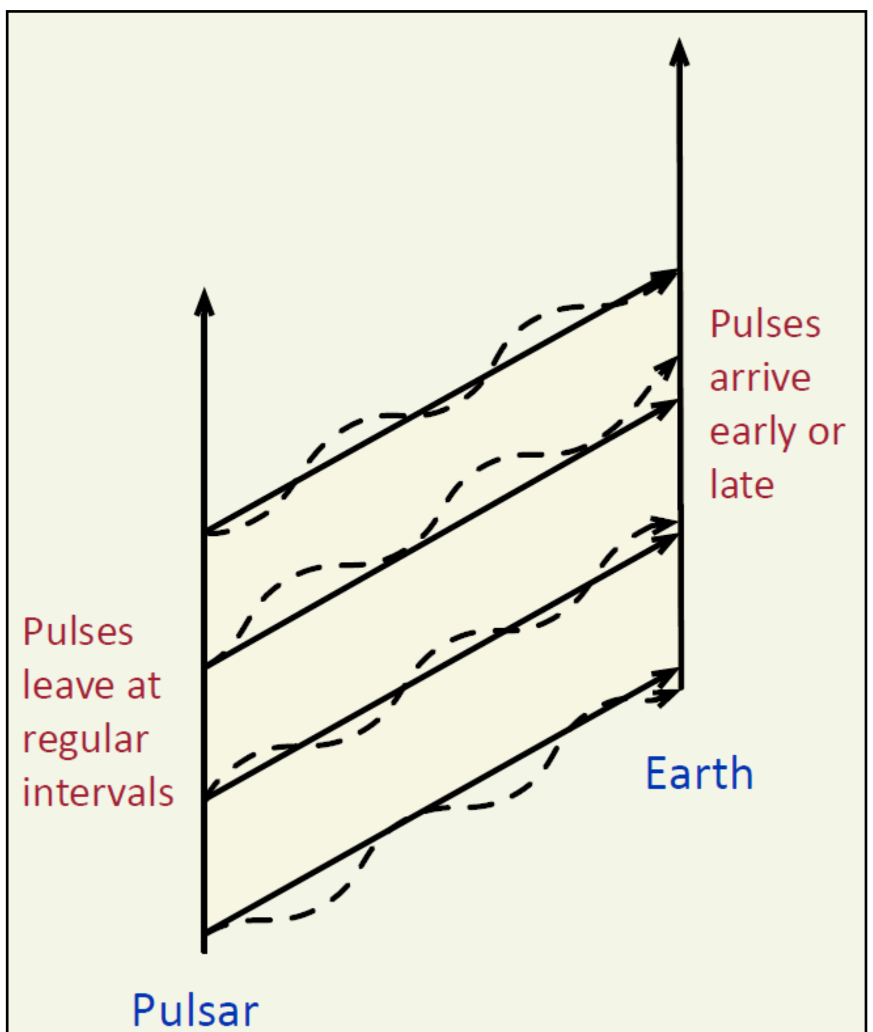


Gravitational waves detection through Pulsar timing

Consecutive pulses travel along null geodesics from pulsar to Earth.
Gravitational waves as metric perturbations cause delays on the pulse's arrival time.



S. Finn, IPTA conference, Leiden 2010



S. Finn, IPTA conference, Leiden 2010

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$$

Space-time interval

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

Flat metric

perturbation

Gravitational waves detection through Pulsar timing

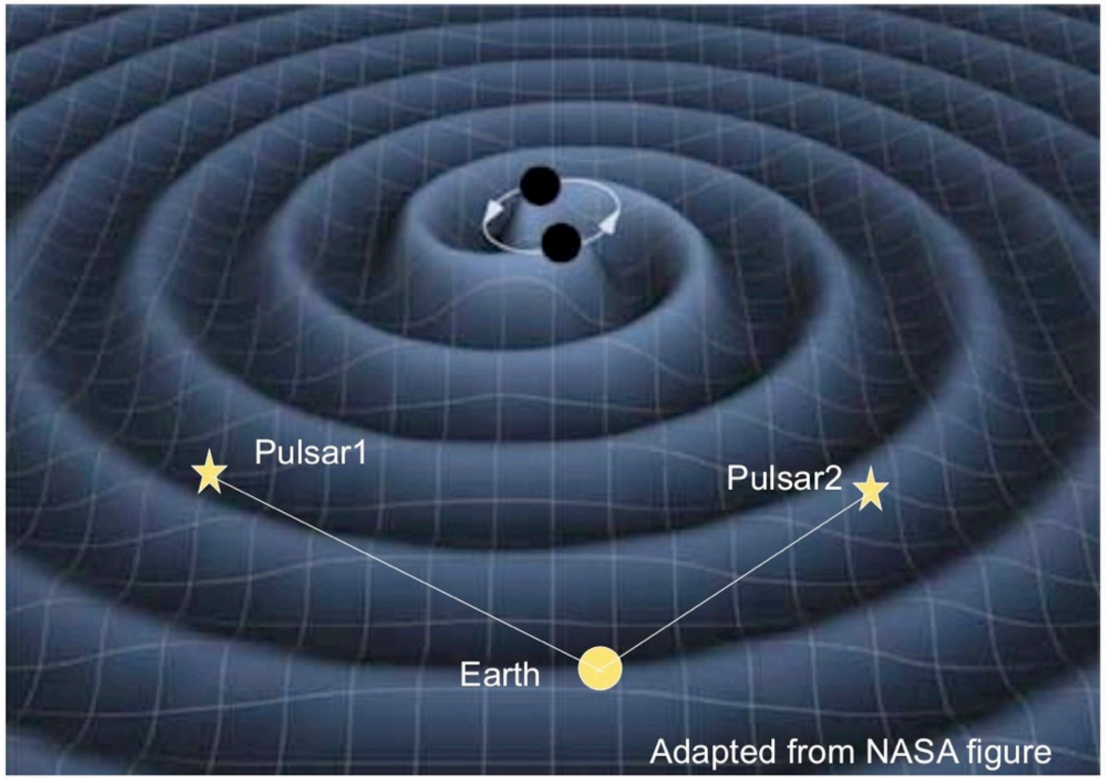
GWs background sources :
- Super Massive Black Holes Binaries (SMBHBs)
- Cosmic strings
- Cosmological Gravitational waves Background (CGB)

These delays are extremly small and act on both Earth and pulsar.

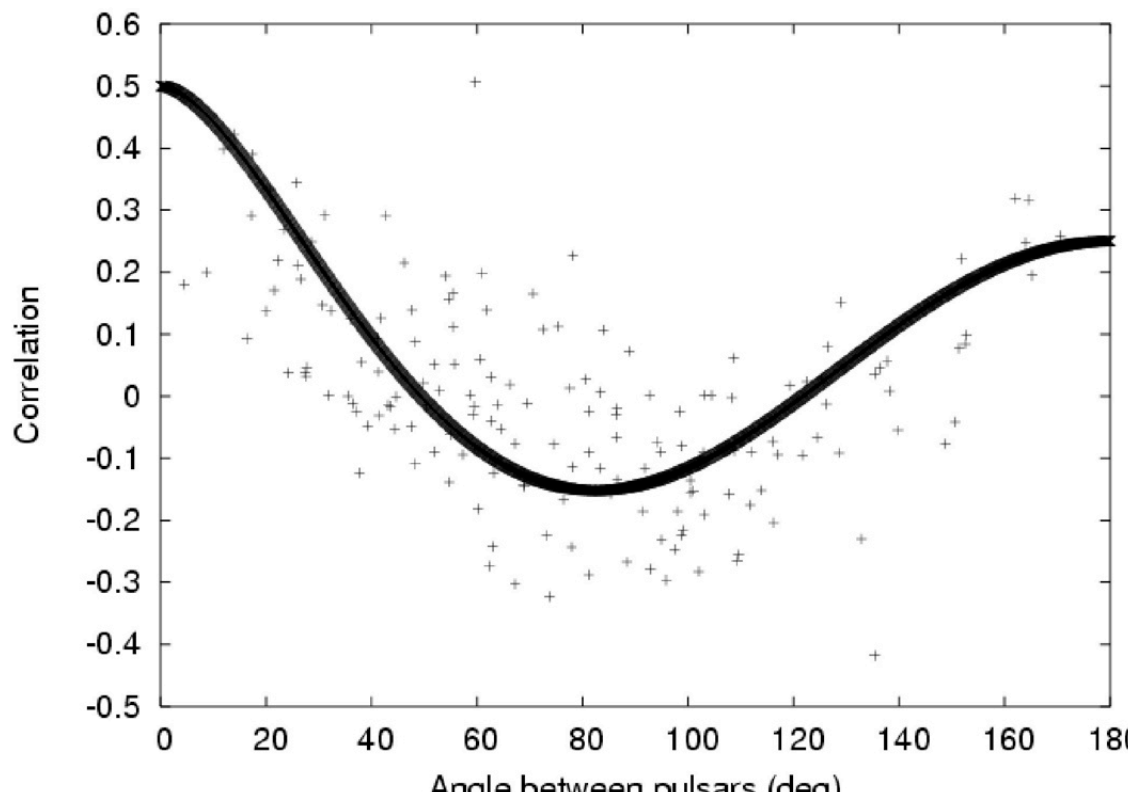
$$r(t) \simeq 26 \left(\frac{\mathcal{M}}{10^9 M_\odot}\right)^{5/3} \left(\frac{D}{100Mpc}\right)^{-1} \left(\frac{f}{5\times10^{-8}}\right)^{-1/3} ns$$

Vecchio, IPTA conference, Morgantown 2011

We are looking for a correlation between arrival times of multiple stable pulsars distributed on the sky as the effect of the gravitational perturbation in the Earth neighbourhood.



A. Lommen, IPTA conference, Leiden 2010

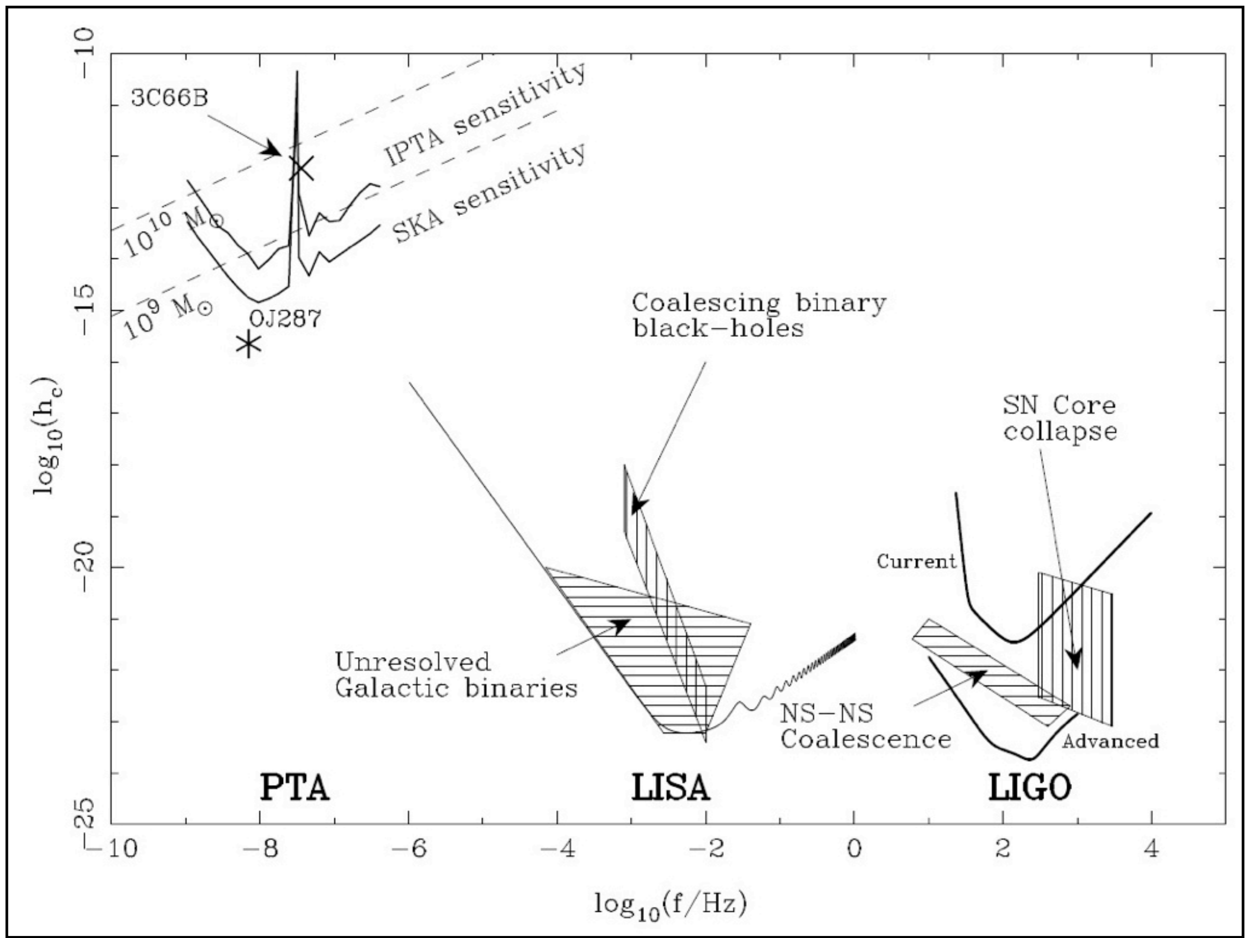


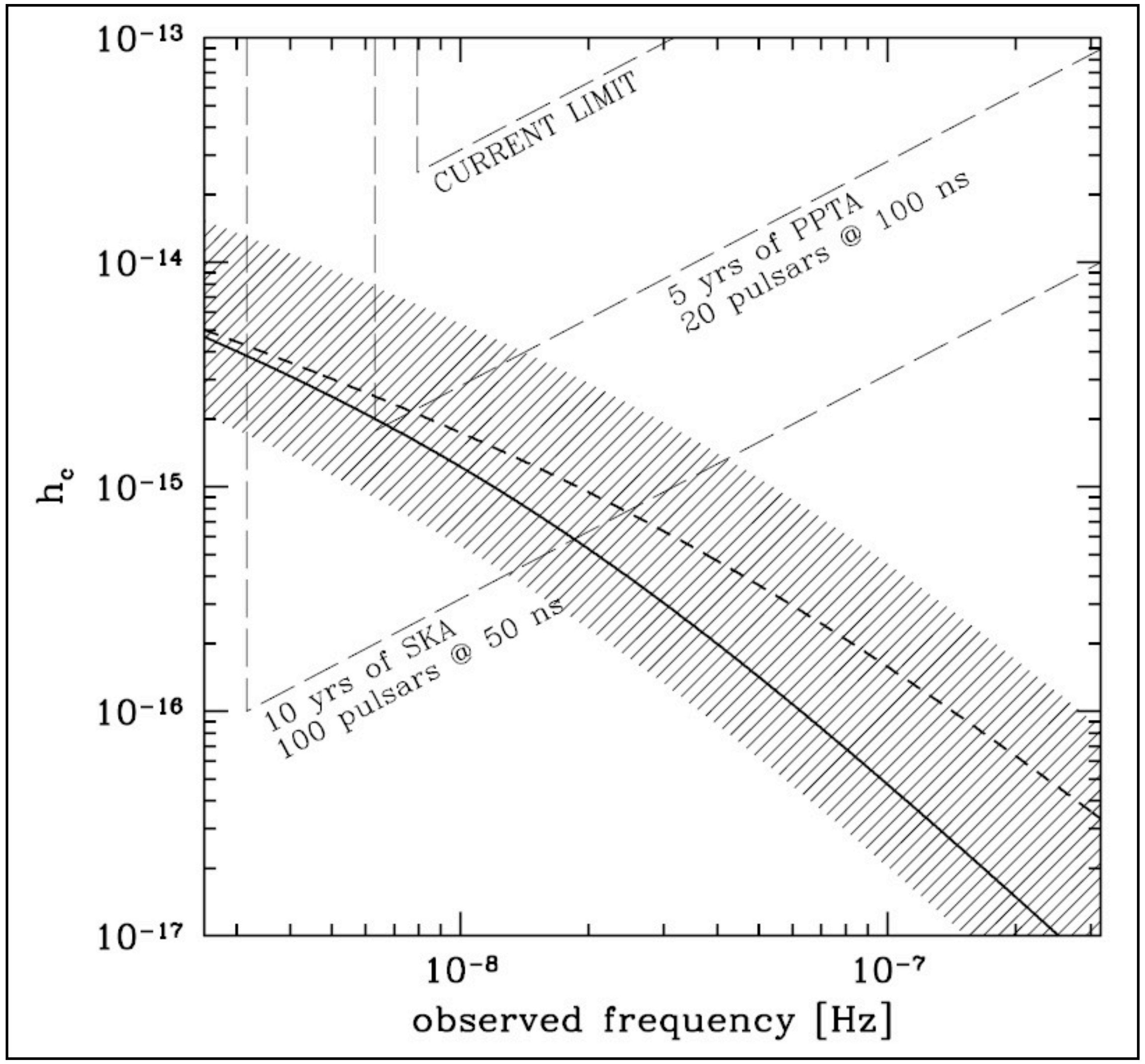
Hellings and Downs, ApJ 265, L39 (1983)

Gravitational waves detection through Pulsar timing

The expected SMBHBs background signal is caracterised by a correlated red noise in the ultra-low frequency range (nHz) with a power spectrum of the form :

$$h_c(f) = A\left(\frac{f}{f_0}\right)^{\alpha} \qquad \alpha = -2/3$$





Sesana & Vecchio, CQG 27, 084016, 2010

Parkes Limit : *Jenet et al, ApJ 653, 1571, 2006*

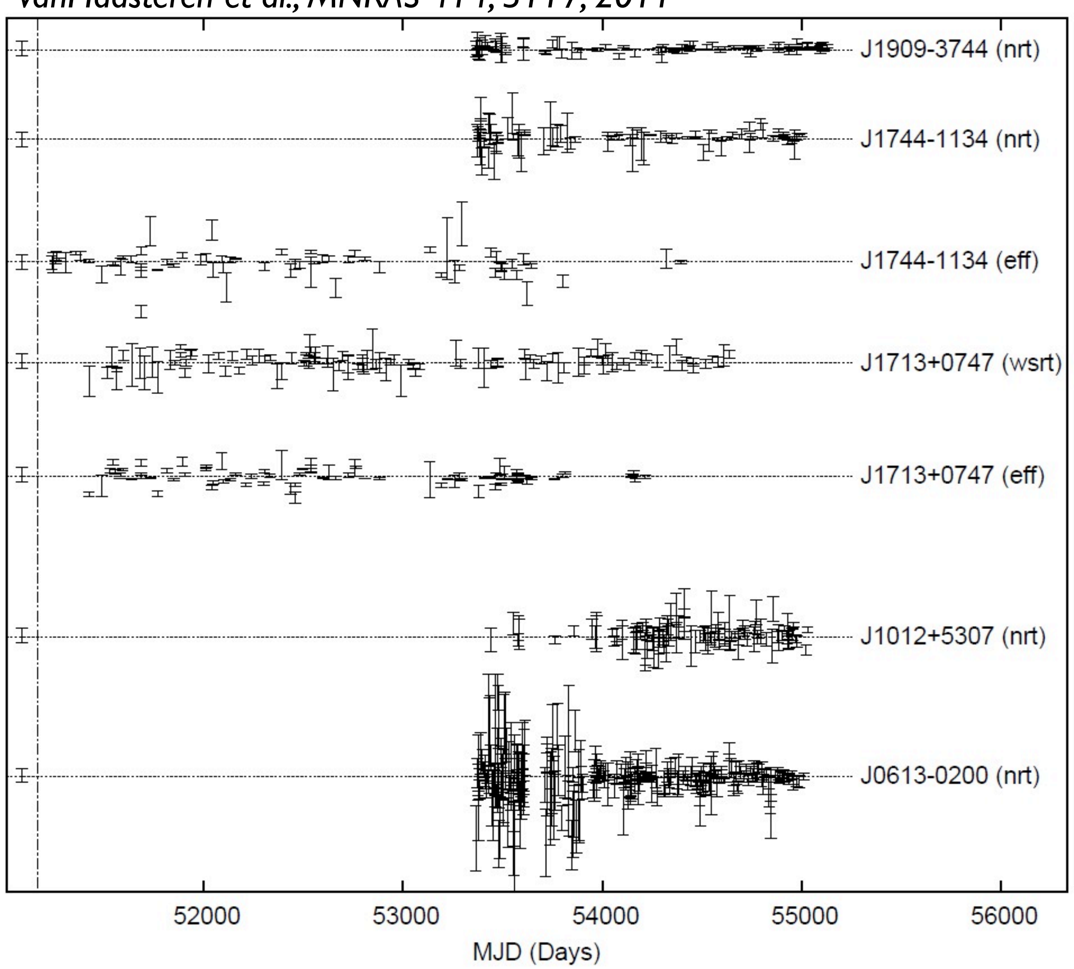
This ultra-low frequency is complementary with LIGO/VIRGO and LISA frequency band

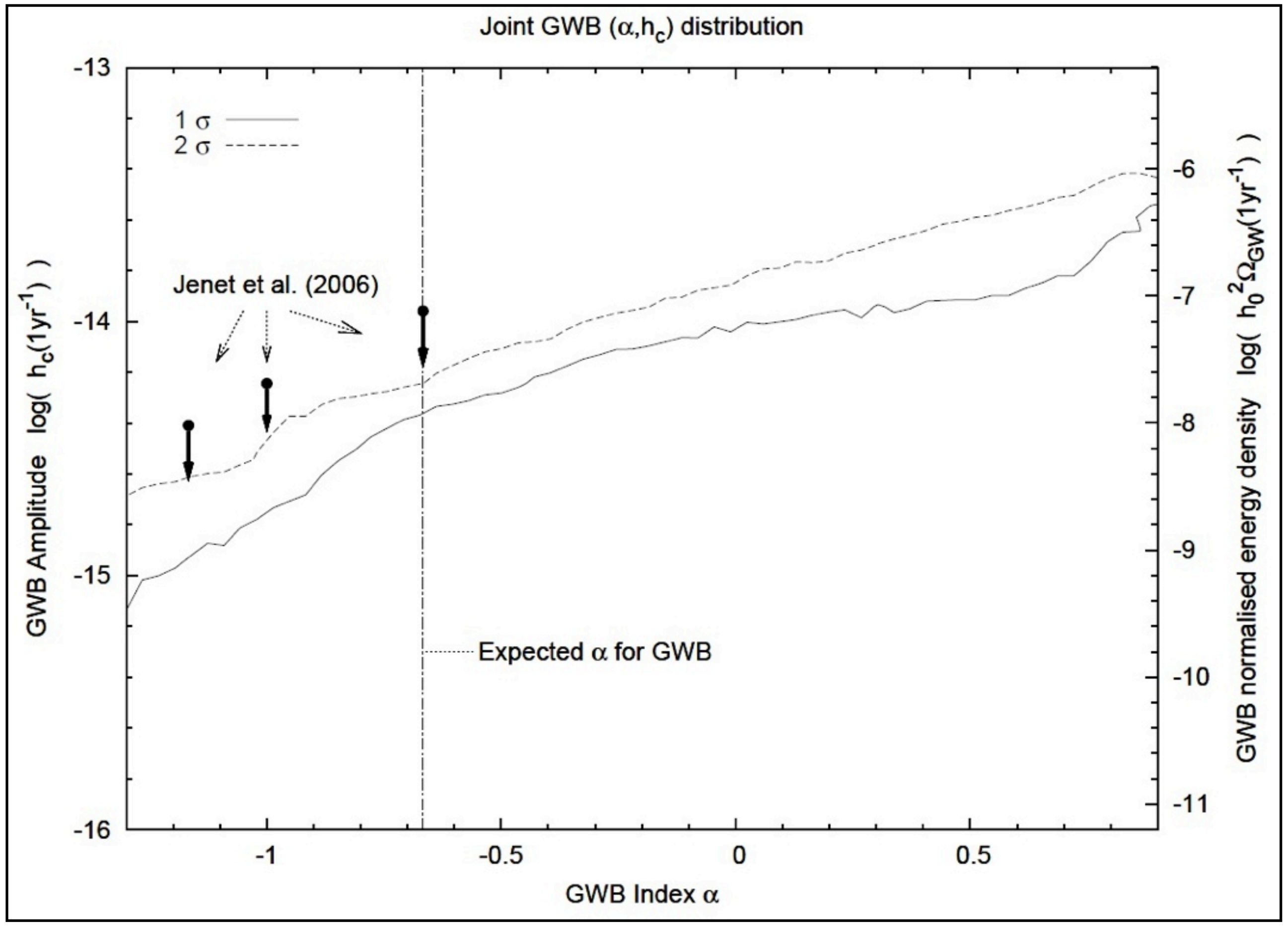
Gravitational waves detection through Pulsar timing

EPTA through a bayesian statistical analysis developped by R. vanHaasteren, using 5 of highest stable pulsar from european telescopes determined a 2 sigma upper limit on the GWB two times better than the one find from the PPTA by Jenet et al.

$$A < 6 \times 10^{-15}$$

vanHaasteren et al., MNRAS 414, 3117, 2011





vanHaasteren et al., MNRAS 414, 3117, 2011

With four of this seven data sets, Nançay is a the major contributor for this limit.

Only five different pulsar are been used for this limit. IPTA project to increase this limit concequently by adding more pulsars from different observatories.