European Pulsar Timing Array

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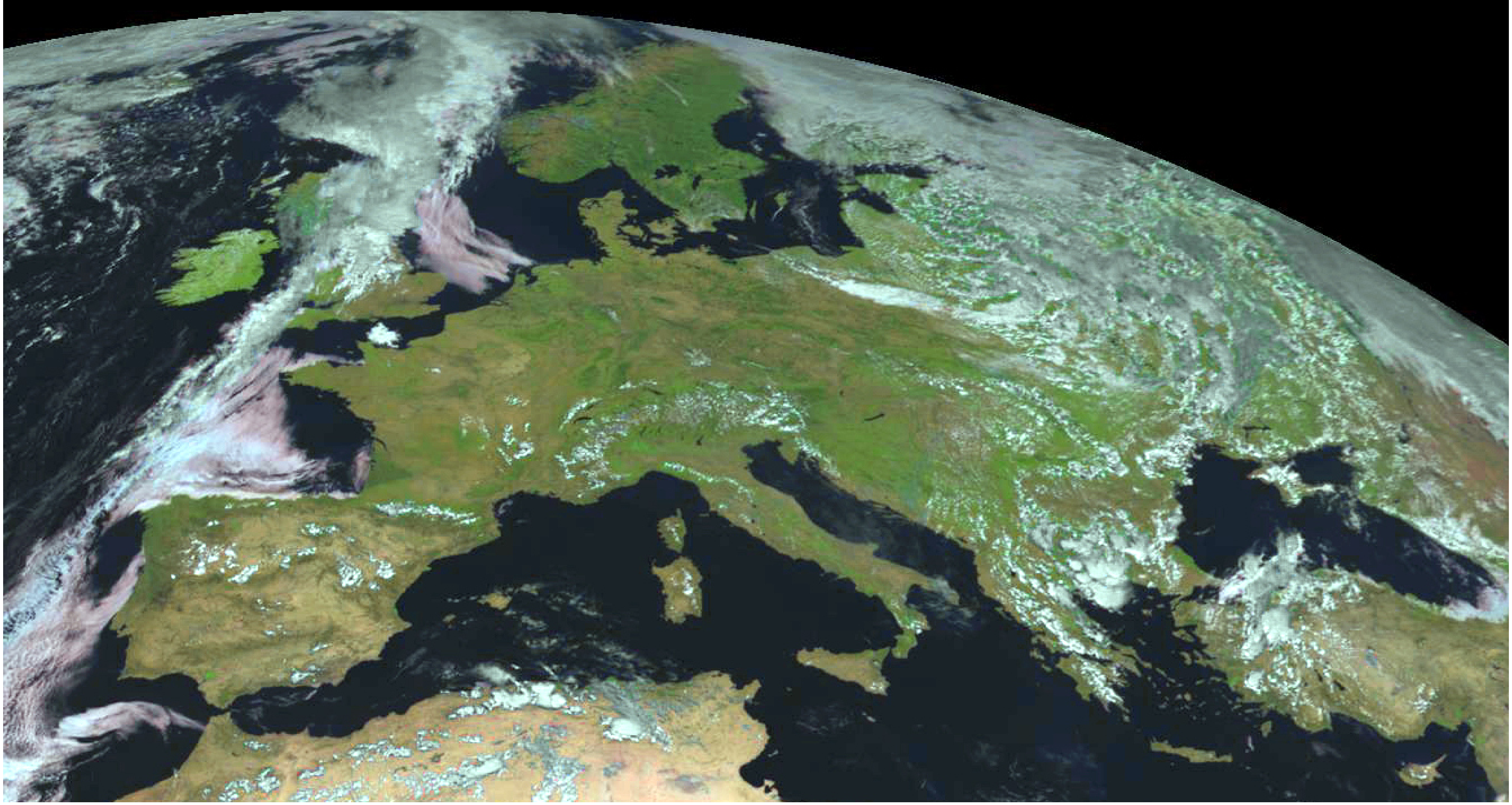
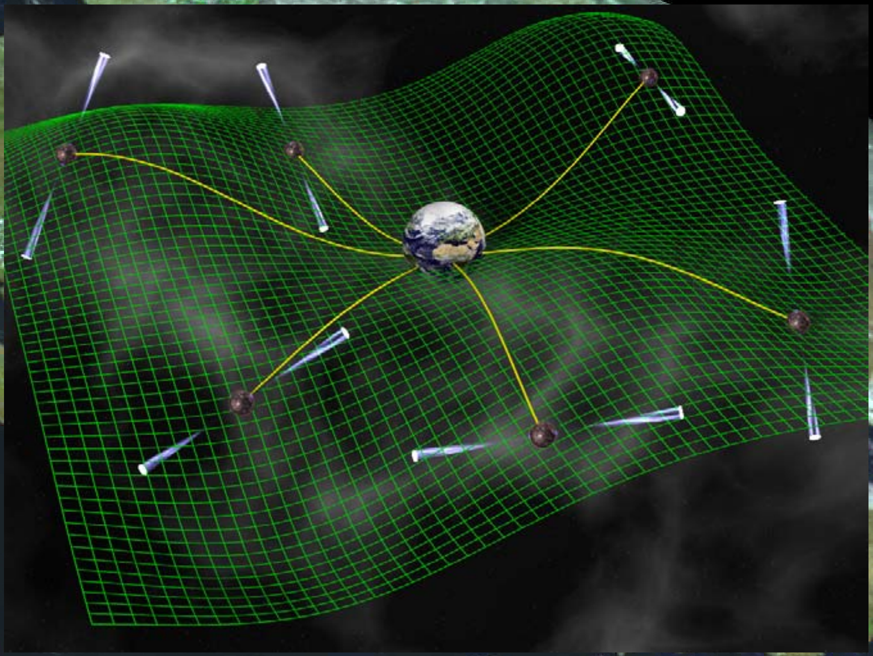


European Pulsar Timing Array

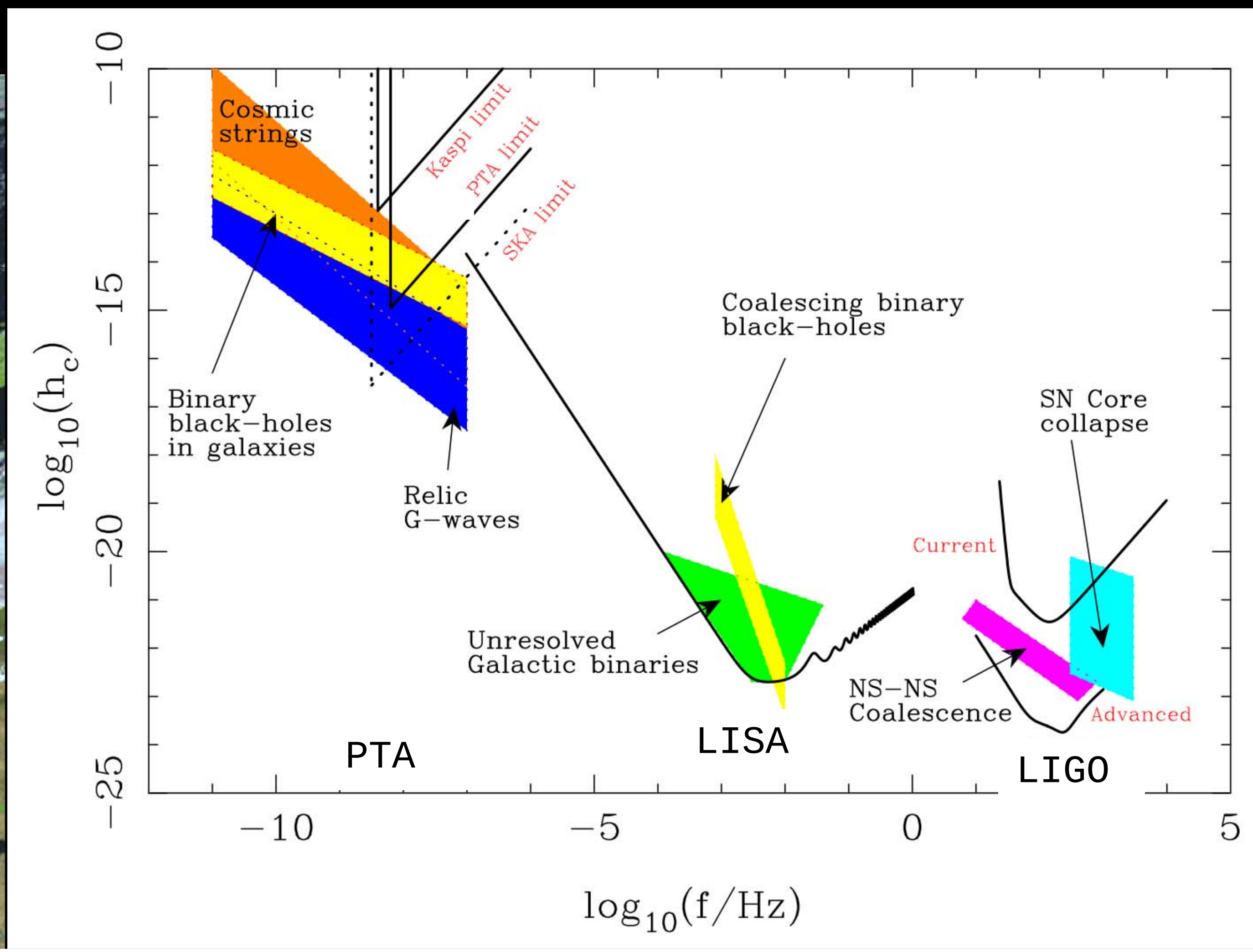
AIM: To combine past, present and future pulsar timing data from 5 large European telescopes to enable improved timing of millisecond pulsars in general, and in specific to use these millisecond pulsars as part of a pulsar timing array to detect gravitational waves.



Gravitational Wave Spectrum

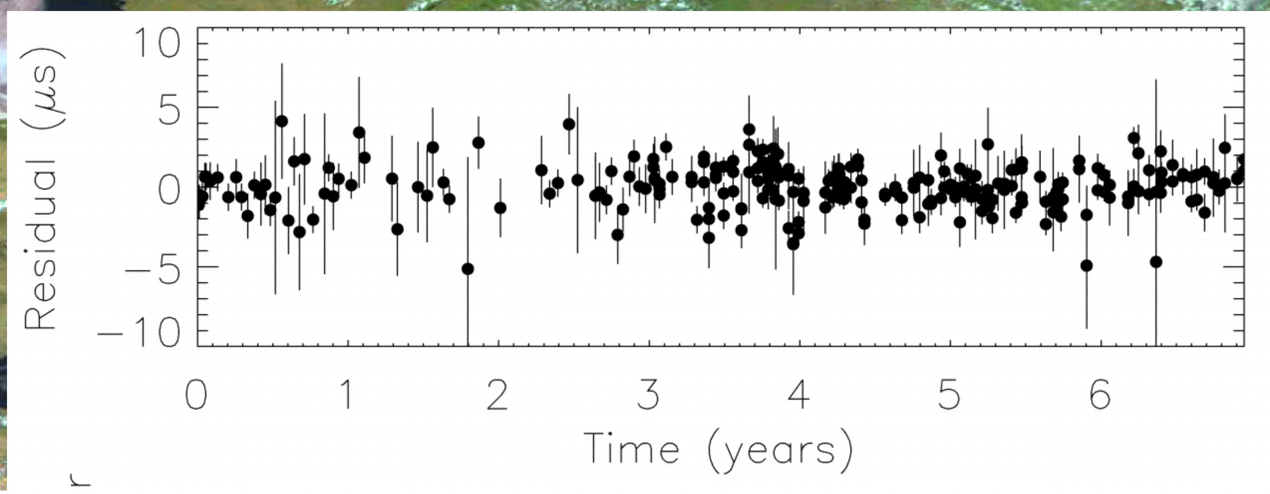
$$h_c(f) = A f^{\alpha}$$

$$\Omega_{gw}(f) = (2 \pi^2/3 H_0^2) f^2 h_c(f)^2$$



Detecting Gravitational Waves With Pulsars

- Observed pulse periods affected by presence of gravitational waves in Galaxy
- For stochastic GW background, effects at pulsar and Earth are uncorrelated
- With observations of one or two pulsars, can only put limit on strength of stochastic GW background, insufficient constraints!
- Best limits are obtained for GW frequencies ~ 1/T where T is length of data span
- Analysis of 8-year sequence of Arecibo observations of PSR B1855+09 gives $\Omega_g = \rho_{GW}/\rho_c < 10^{-7}$ (Kaspi et al. 1994, McHugh et al.1996)
- Extended 17-year data set gives better limit, but non-uniformity makes quantitative analysis difficult (Lommen 2001, Damour & Vilenkin 2004)



A Pulsar Timing Array

• With observations of many pulsars widely distributed on the sky can in principle ***detect*** a stochastic gravitational wave background resulting from binary BH systems in galaxies, relic radiation, etc

• Gravitational waves passing over the pulsars are uncorrelated

• Gravitational waves passing over Earth produce a correlated signal in the TOA residuals for all pulsars

• Requires observations of ~20 MSPs over 5 – 10 years; with at least some **down to 100 ns** could give the ***first*** direct detection of gravitational waves!

• A timing array can detect instabilities in terrestrial time standards – establish a ***pulsar timescale***

• Can improve knowledge of Solar system properties, e.g. masses and orbits of outer planets and asteroids

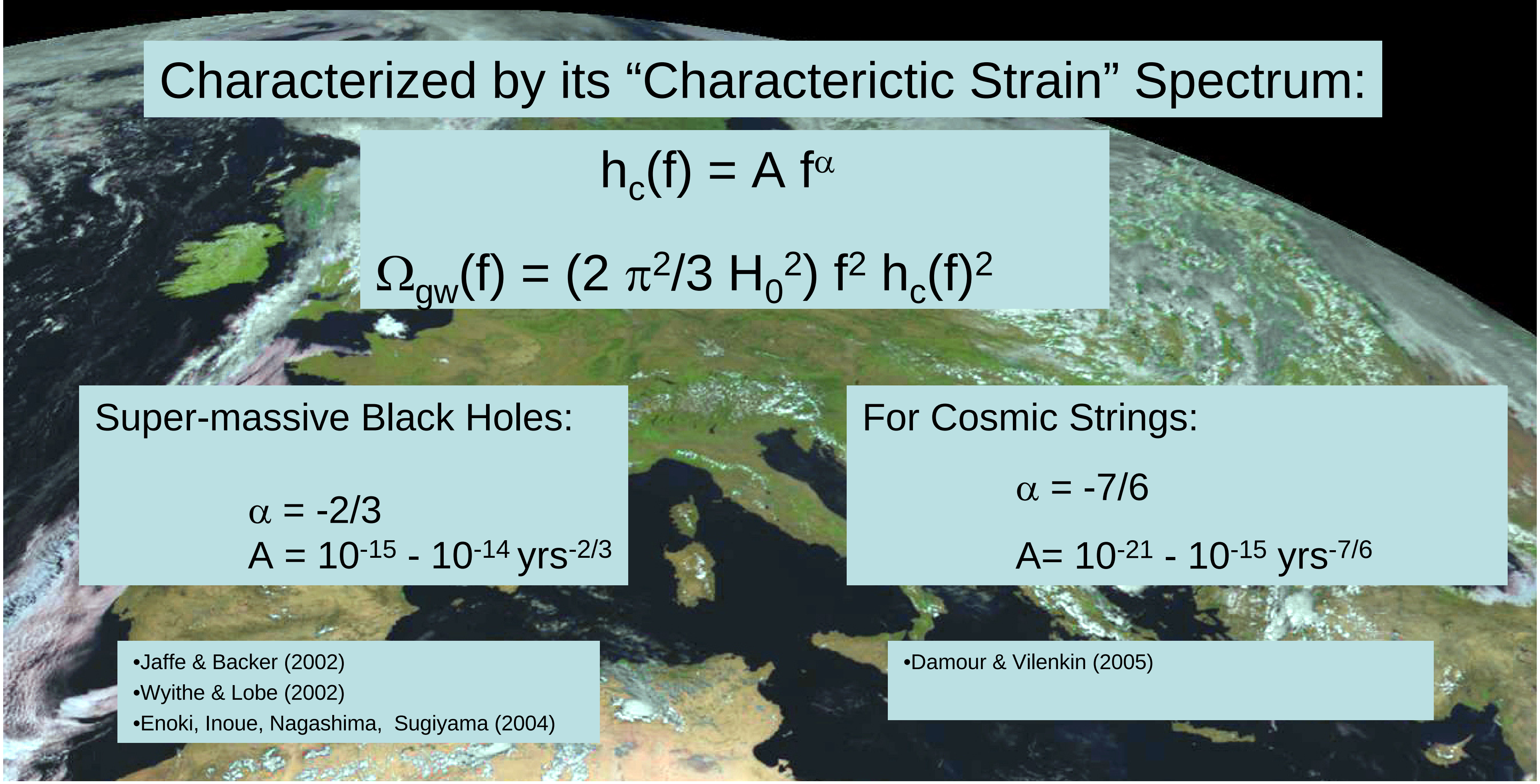
Idea first discussed by Foster & Backer (1990)

The Stochastic Background

$$R(t,\hat{k}) \;=\; -\int_0^t \sum_{s=0}^{N-1} \mathcal{H}(\hat{k},\hat{\eta}_s)^{ij}\left(h_{ij}(t_e,x_e,\hat{\eta}_s) - h_{ij}(t_e-d,x_p,\hat{\eta}_s)\right)dt_e$$

This is the same for all pulsars.

This depends on the pulsar.



Characterized by its “Characterictic Strain” Spectrum:

$$h_c(f) = A\, f^{\alpha}$$

$$\Omega_{gw}(f) = (2\,\pi^2/3\,H_0^2)\, f^2\, h_c(f)^2$$

Super-massive Black Holes:

$\alpha = -2/3$

$A = 10^{-15} - 10^{-14}\ \mathrm{yrs}^{-2/3}$

For Cosmic Strings:

$\alpha = -7/6$

$A = 10^{-21} - 10^{-15}\ \mathrm{yrs}^{-7/6}$

- Jaffe & Backer (2002)
- Wyithe & Lobe (2002)
- Enoki, Inoue, Nagashima, Sugiyama (2004)

- Damour & Vilenkin (2005)

The Stochastic Background Current Status

Combined data from PSR B1937+21 and PSR B1855+09

It was assumed that $\Omega_{gw}(f)$ is constant (α=-1):

Kaspi et al (1994) report $h_c(f=1/yr) < 1.1\times 10^{-14}$

$$\Omega_{gw}h^2 < 6 \times 10^{-8} \text{ (95\% confidence)}$$

McHugh et al. (1996) report $h_c(f=1/yr) < 1.32\times 10^{-14}$

$$\Omega_{gw}h^2 < 9.3 \times 10^{-8}$$

Frequentist Analysis using Monte-Carlo simulations Yield

$$h_c(f=1/yr) < 1.5\times 10^{-14} \quad \Omega_{gw}h^2 < 1.2 \times 10^{-7}$$

Parkes PTA Current Status:

20 pulsars for 2 years, 5 currently have an RMS < 300 ns

Combining this data with the Kaspi et al data yields:

$\alpha = -2/3$: $A<1.3 \times 10^{-14}$ yrs$^{-2/3}$ $\Omega_{gw}(1/2 \text{ yrs})h^2 < 1.2\times 10^{-8}$

Present PTA Goal:

Timing 20 pulsars for 5 years, each RMS at 100 ns

$\alpha = -2/3$: $A<3.8 \times 10^{-16}$ yrs$^{-2/3}$ $\Omega_{gw}(1/5 \text{ yrs})h^2 < 2.6\times 10^{-11}$

European Pulsar Timing Array

A MOU was signed in August of 2005 in which the institutions below agreed to share their past and future pulsar timing data to form the EPTA.
Nançay joined this year

European Pulsar Timing Array

Advantages of combining multi-telescope data:

- Larger total number of TOAs
- Commensurate scheduling will allow for improved binary and yearly phase coverage
- A wide range of frequencies can be sampled and then compared in quasi-simultaneous sessions.
- Simultaneous same frequency observations can be used to check polarisation calibration and overall timing offsets.
- Telescope, Instrumentation, or Observatory clock based errors can be quickly identified and corrected. (e.g.

European Pulsar Timing Array

RESOURCES:

WSRT:
- ≡ 93m dish
- 8 years timing
- 110 - 2000 MHz
- up to 160 MHz
- PuMa II
- ~ 30 pulsars, 15 MSPs

Lovell:
- 76m dish
- 30 years timing
- 200 - 2000 MHz
- up to 100 MHz
- COBRA
- 100’s of pulsars
- 10’s MSPs

Effelsberg:
- 100m dish
- 9 years timing
- 800 - 10000 MHz
- up to 112 MHz
- ~ 40 pulsars, ~20 MSPs

Nançay:
- ≡ 94m dish
- >7 years
- 1400 MHz
- ~ 100 pulsars
- 15 MSPs

SRT:
- 64m dish
- 290 -- 7000 MHz
- up to 500 MHz

European Pulsar Timing Array

RESOURCES:

Telescope	Frequency (MHz)	Bandwidth (MHz)	T_{sys} (K)	Occurrence
Effelsberg	860	40	60	rarely
	1400	100	20–25	often
	2700	80	20–25	rarely
	4900	500	30	rarely
	8400	1200	30	rarely
Jodrell Bank	1400	100	25	often
	6000	500	25	eventually
Nancay	1000–3500	128	35	often
WSRT	328	60	120	often
	840	80	75	rarely
	1100–1800	160	27	often
	2300	160	30	rarely
	4900	160	30	rarely
Sardinia	300/1400	100/500	25	eventually
	6700	500	25	eventually

European Pulsar Timing Array

CURRENT TIMING PRECISION:

PULSAR	JBO	EFF	WSRT
B1937+21	140	0.8	0.6
J1713+0747	<10	0.5	0.5
J0034-0534	60		5
J0218+4232	50	28	16
J1012+5307	20	3	1.4

European Pulsar Timing Array

HARDWARE IMPROVEMENTS:

PuMa II:
- Up to 160 MHz Coherently Dedispersed all 4 Stokes
- 8 bit resolution
- Makes use of DMA cards
- Total data rate > 640 MB/s
- Both real time and Offline data reduction
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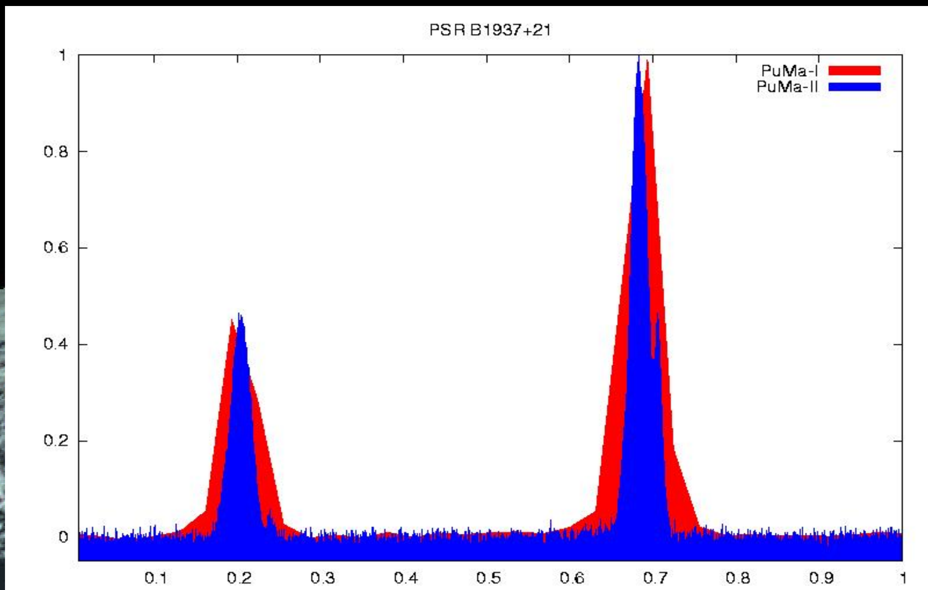
-
cl

COBRA:
- Up to 100 MHz Coherently Dedispersed all 4 Stokes
- 8 bit resolution
- Makes use of DMA cards
- Total data rate > 400 MB/s
- No data storage
- Processing done with

Both seen quite regular operation since Septem
Effelsberg & Nancay will have new instruments Su
Sardinia will have state of the art instrumenta

European Pulsar Timing Array

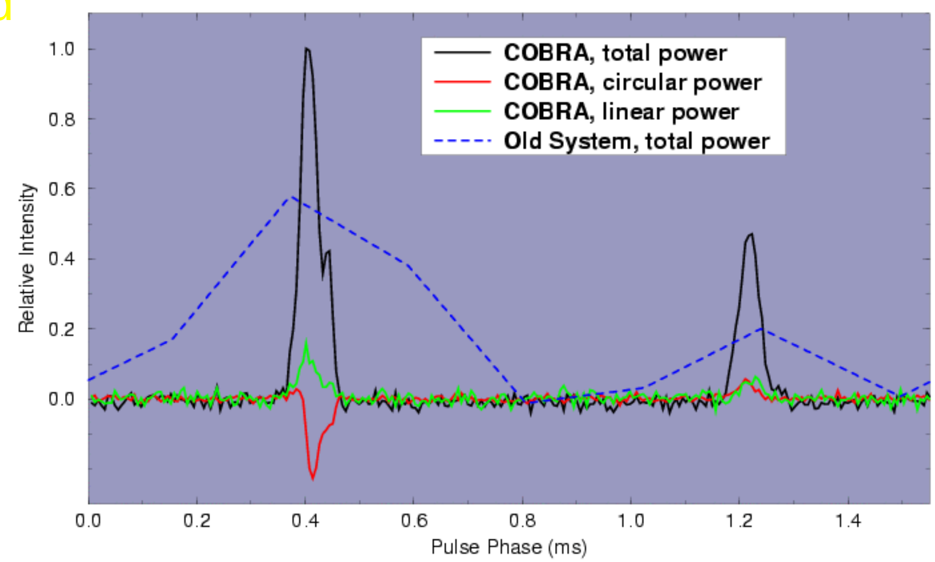
EXAMPLES FROM HARDWARE IMPROVEMENTS:



PULSAR	RMS (us)
0034-0534	1.1 (4)
0613-0200	0.9 (2)
1012+5307	0.6 (2)
1713+0747	0.3 (1.6)
1937+21	0.2 (3)

2 years of data PuMa II

PuMa II, 20 MHz, L-band



COBRA, 5 MHz, L-band

European Pulsar Timing Array

EXAMPLES OF CURRENT WORK:

Recent 3 telescope work is currently being writte
J1811-1736, J1518+4904 & J0218+4232 (PM).

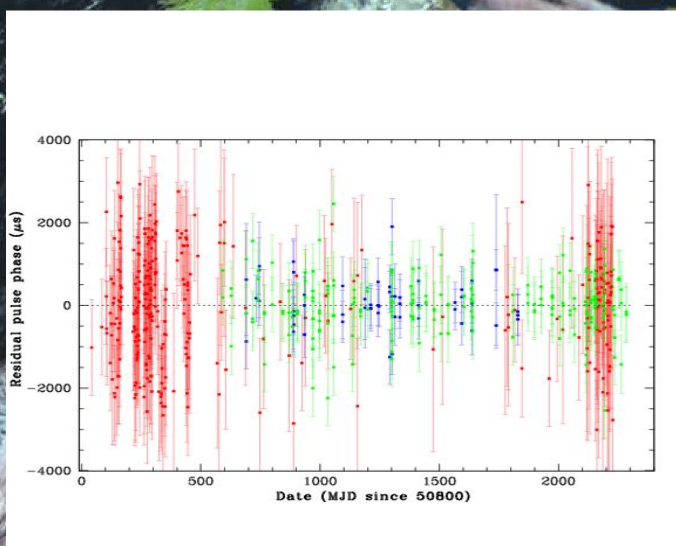
J1811-1736:

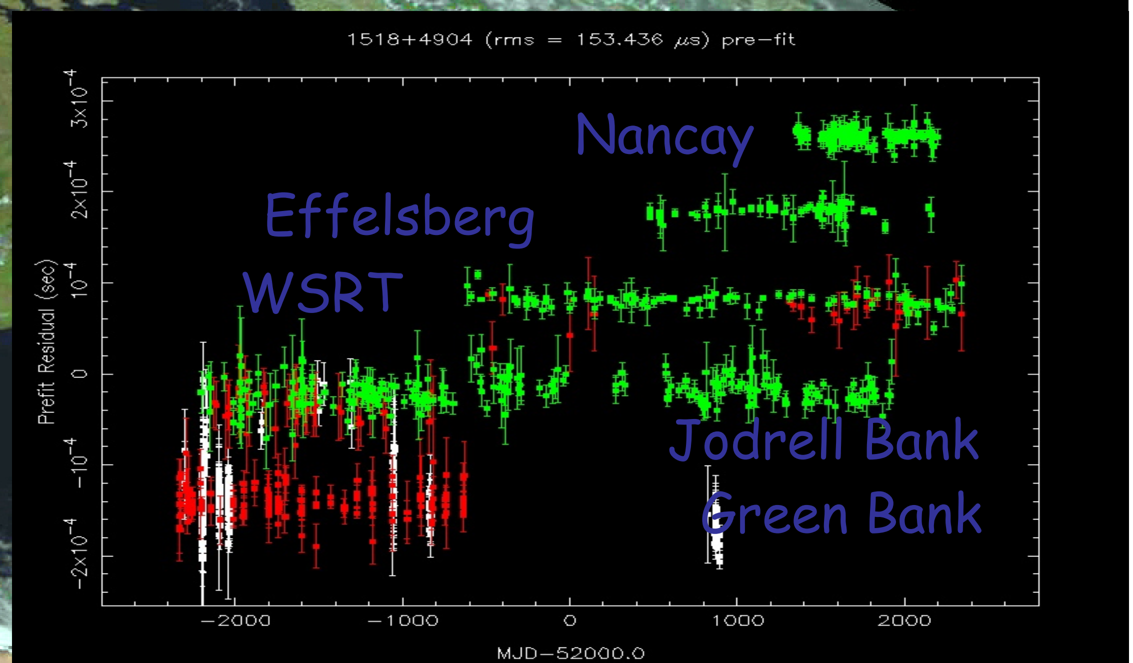
Improved Periastrion advance.

J1518+4904

Proper Motion, improved Post-Keplerian

Perhaps lightest NS known!





European Pulsar Timing Array

CONCLUSIONS:

- The European Pulsar Timing Array will ultimately combine the pulsar timing data from 5 telescopes
- These data will be used to obtain better timing results for a large number of millisecond pulsars
- This Array of pulsars will be used to attempt to detect gravitational waves in the nHz regime.

- Current and Future improvements in pulsar hardware will greatly improve the pulsar timing accuracy and thus bring us closer to this goal.
- Collaboration with theorists in NL and

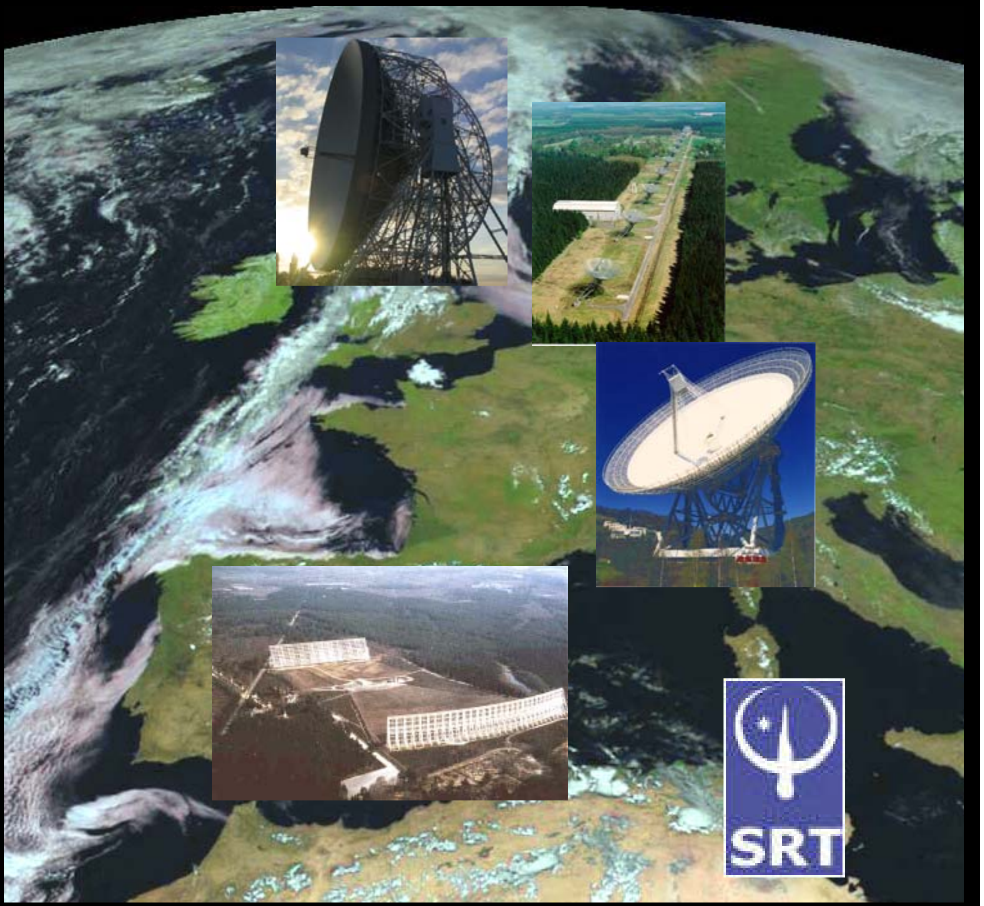
LEAP: Large European Array for Pulsars

To achieve even better sensitivity to GWs we are planing on combining all the telescopes coherently.

Gives a telescope with sensitivity equivalent to Arecibo.

And will be able to see much more of the sky.

Will test limits of sensitivity and pulse jitter.



Effective collecting area for pulsar work still more than ASKAP/ATA/meerKAT!

Also provides excellent tests of SKA like pulsar observing.

Already all these PSR groups are collaborating