Pulsar Timing Arrays: Status and Techniques

George Hobbs

August 2012

CSIRO ASTRONOMY AND SPACE SCIENCE
www.csiro.au

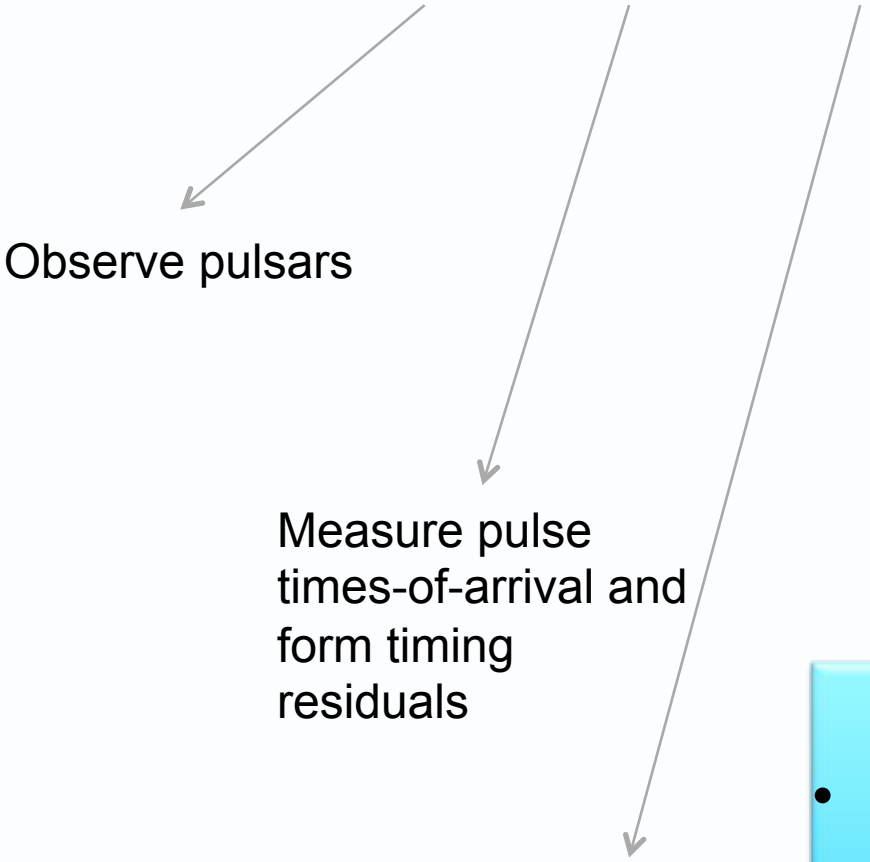
PPTA

CSIRO

Contents

1. What is a pulsar timing array?
2. What signals are in our data?
3. Some recent results

What is a pulsar timing array?



Traditional pulsar timing experiments

- Carry out observations of favourite pulsar
- Form timing residuals
- Get excited about resulting parameter fits or remnant signal left in the timing residuals

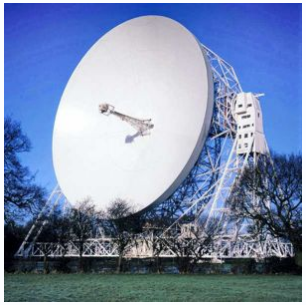
Pulsar Timing Arrays

- Observe large number of pulsars
- Search for signals in the residuals that are common between the different pulsars

What are the major goals of a Pulsar Timing Array?

1. Detect ultra-low frequency gravitational waves
2. Detect unknown objects in the Solar System
3. Develop a pulsar-based time scale

Existing timing array projects



NANOGrav

PPTA

EPTA

CSIRO

The international pulsar timing array project

EPTA

NANOGrav

PPTA

IPTA conference, Kiama 2012, Australia

IPTA Steering Committee

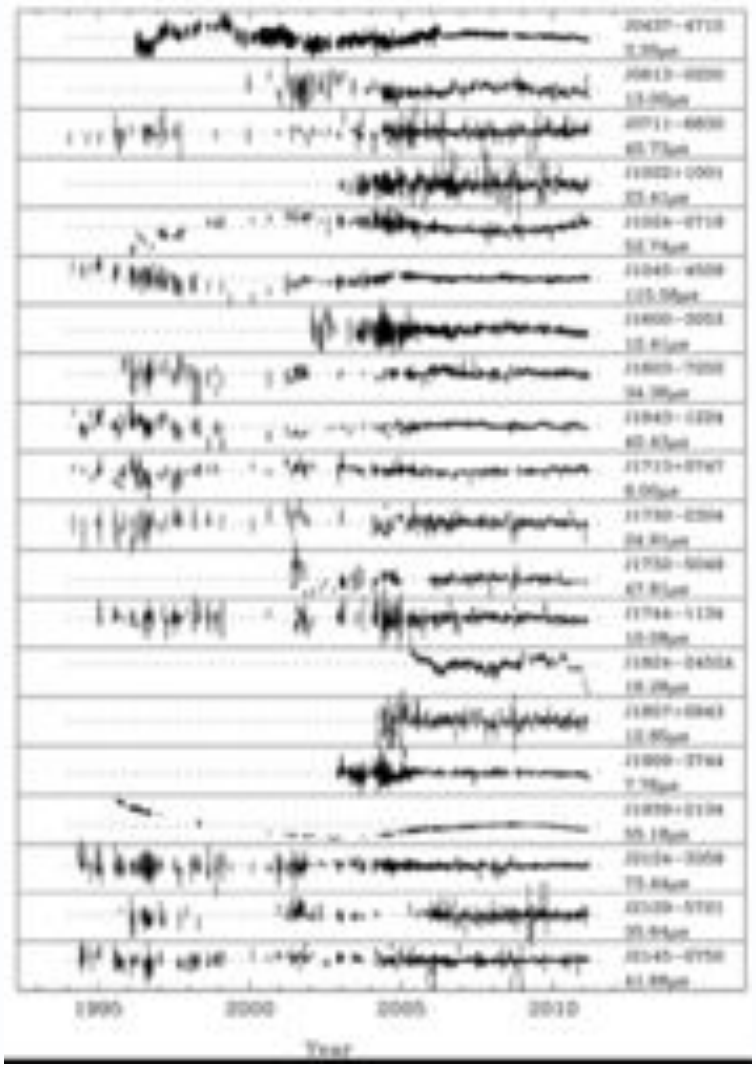
Richard Manchester (chair)
Willem van Straten

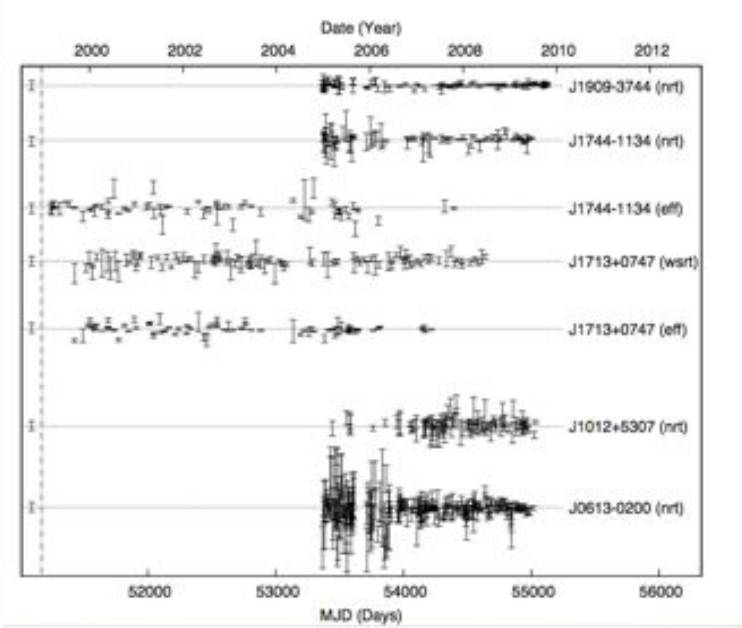
Ingrid Stairs
Scott Ransom
Andrea Lommen

Ben Stappers
Gilles Theureau

CSIRO

What do pulsar timing array data sets look like?



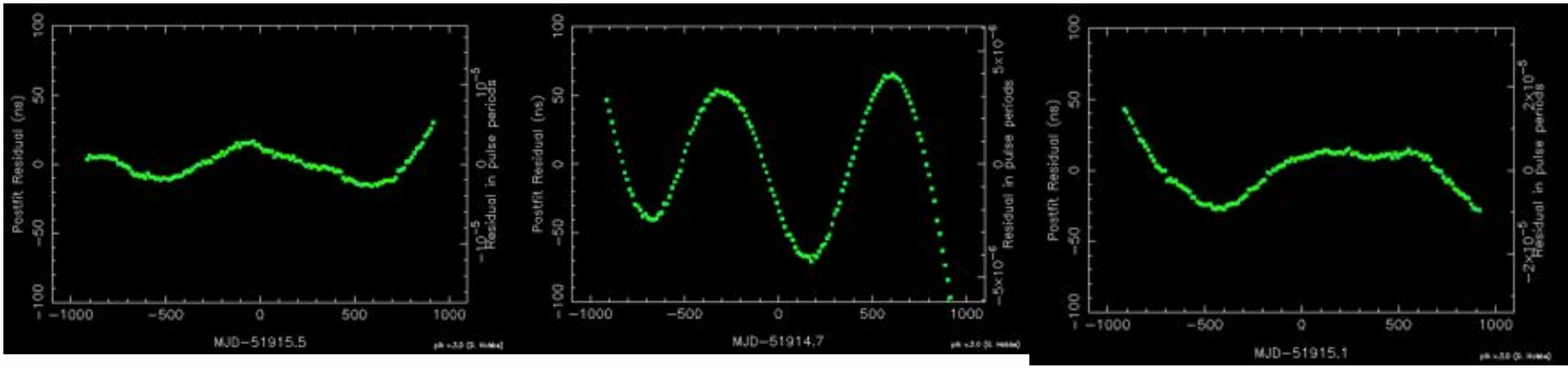


- 30+ pulsars in the IPTA (many in common between PTAs)
- Up to ~20yr data span (typically around 6yr)
- Observations approx 2-3 weeks

What signals are in the data? Gravitational waves

Simulated expected gravitational wave signal from coalescing supermassive binary black holes using results from the Millennium simulation (Ravi et al., submitted).

200ns



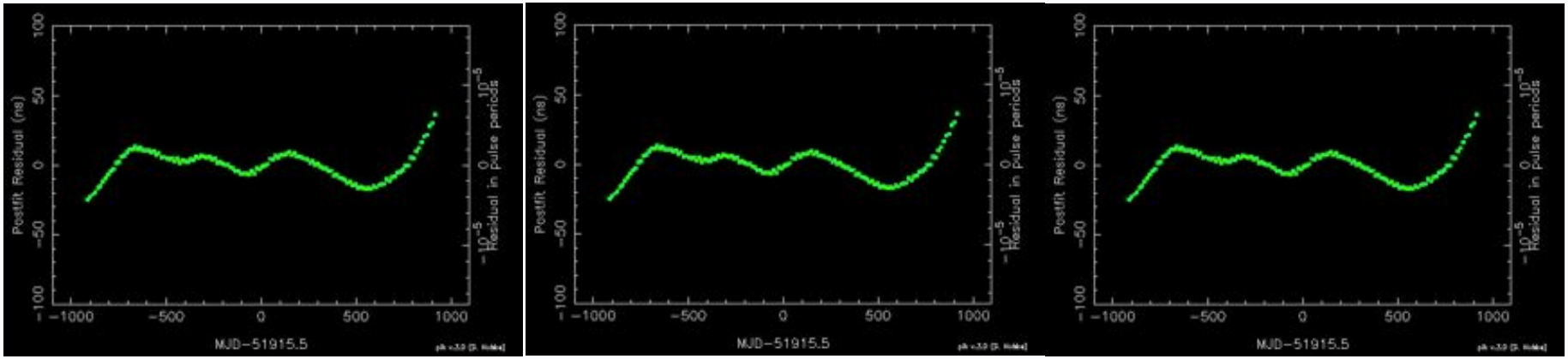
5 yr

Timing residuals will be partially correlated between different pulsars. Degree of correlation is a prediction of general relativity.

What signals are in the data? Errors in terrestrial time standards

Simulate pulsars using TT(BIPM2011), but process data using TT(TAI)

200ns



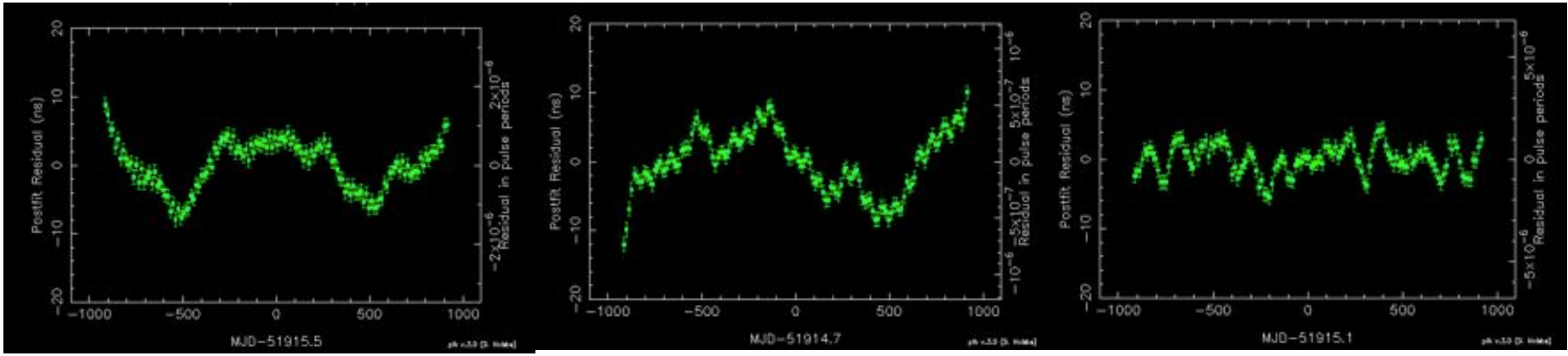
5 yr

Timing residuals will be identical.
(In the real case different data spans and fitting will mean that the resulting residuals will have a different form)

What signals are in the data? Errors in the Solar System ephemeris

Simulate pulsars using JPL Ephemeris DE421, but process data using DE414

200ns



5 yr

Timing residuals will depend on the pulsar's ecliptic latitude

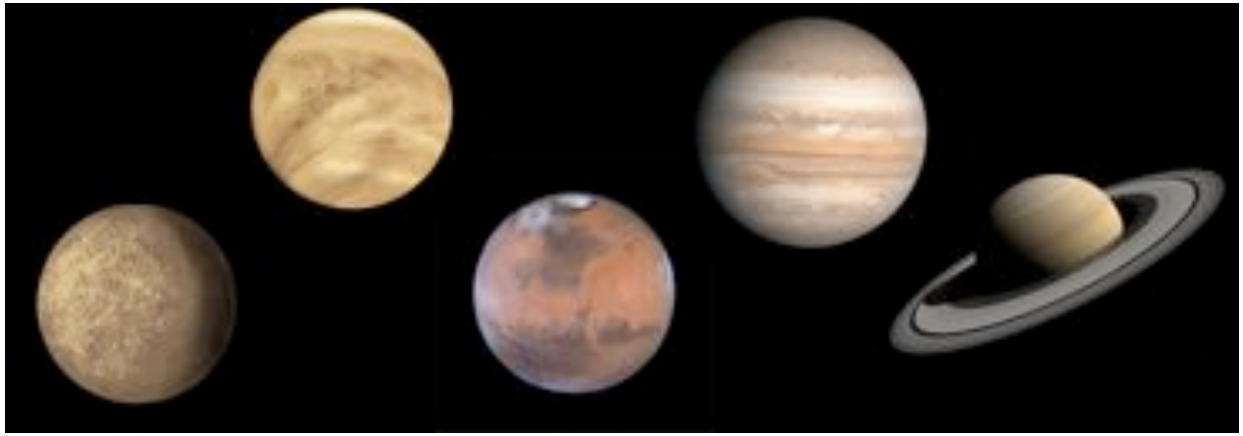
Recent results: Planetary mass determination (Champion et al. 2010, ApJ)

1. Use International Pulsar Timing Array data from Parkes, Effelsberg, Nancay and Arecibo.
2. A planetary mass error will lead to incorrect determination of the Solar System barycentre => correlated pulsar timing residuals
3. Can fit to multiple pulsars simultaneously to search for such a signal

CSIRO

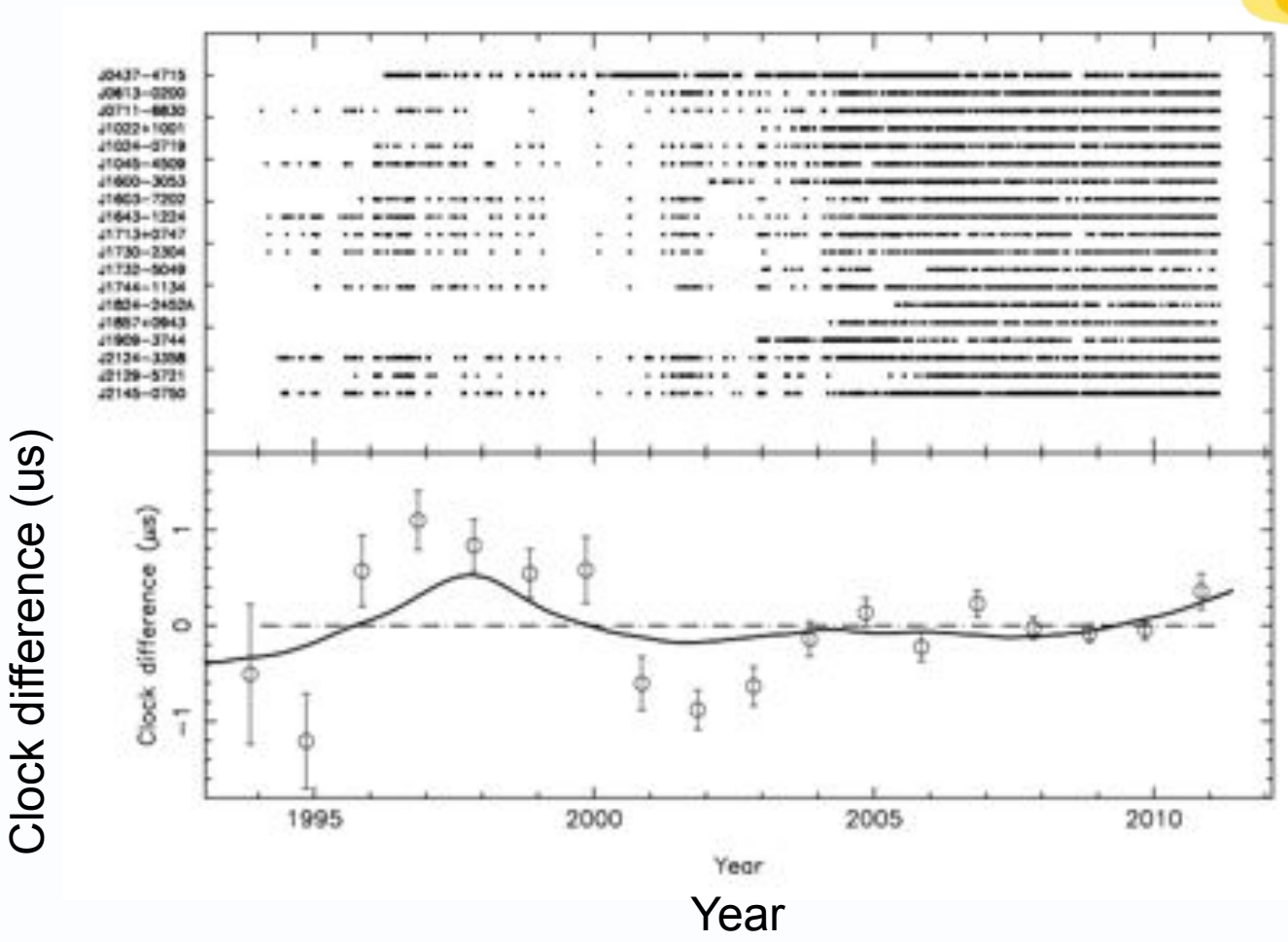
Measuring planetary masses

M_{Sun}	Best Published (Mo)	This work (Mo)
Mercury	$1.66013(7)\times10^{-7}$	$1.660(2)\times10^{-7}$
Venus	$2.4478686(4)\times10^{-6}$	$2.44782(10)\times10^{-6}$
Mars	$3.227151(9)\times10^{-7}$	$3.2277(8)\times10^{-7}$
Jupiter*	$9.54791915(11)\times10^{-4}$	$9.547916(4)\times10^{-4}$
Saturn	$2.85885670(8)\times10^{-4}$	$2.858858(14)\times10^{-4}$



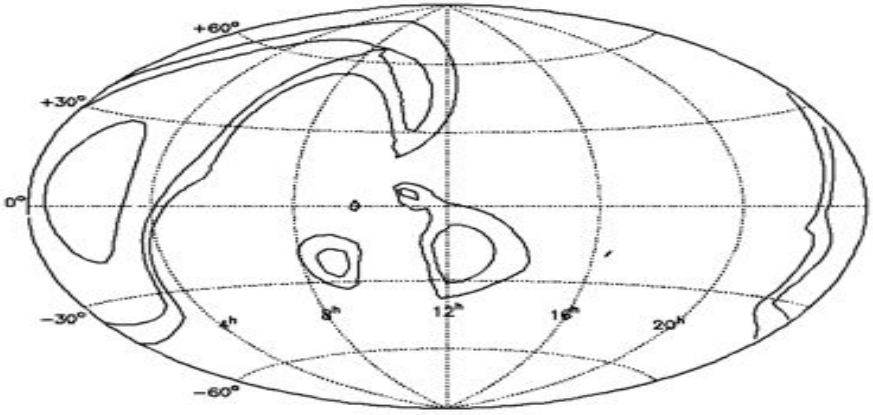
Developing a pulsar-based time standard

Hobbs et al. (accepted by MNRAS/arXiV 1208.3560)

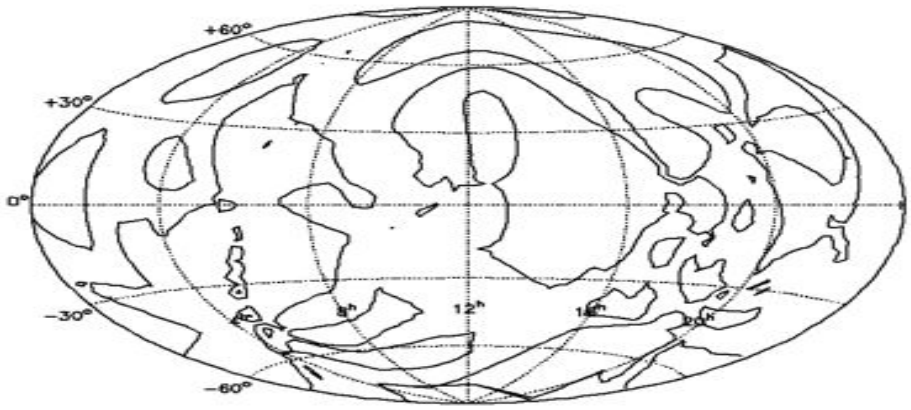


Sampling for different pulsars

Searching for single gravitational waves



Simulated data with strong source

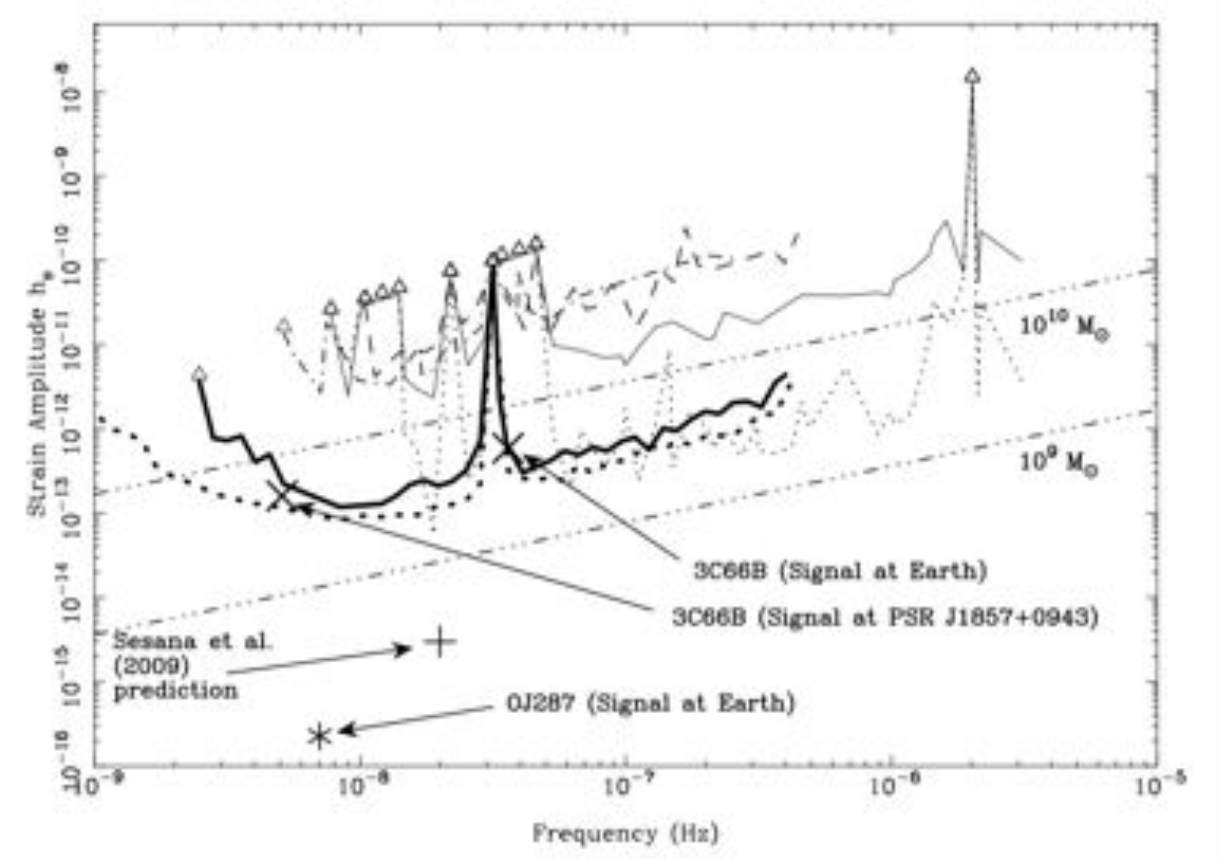


Search using PPTA data set

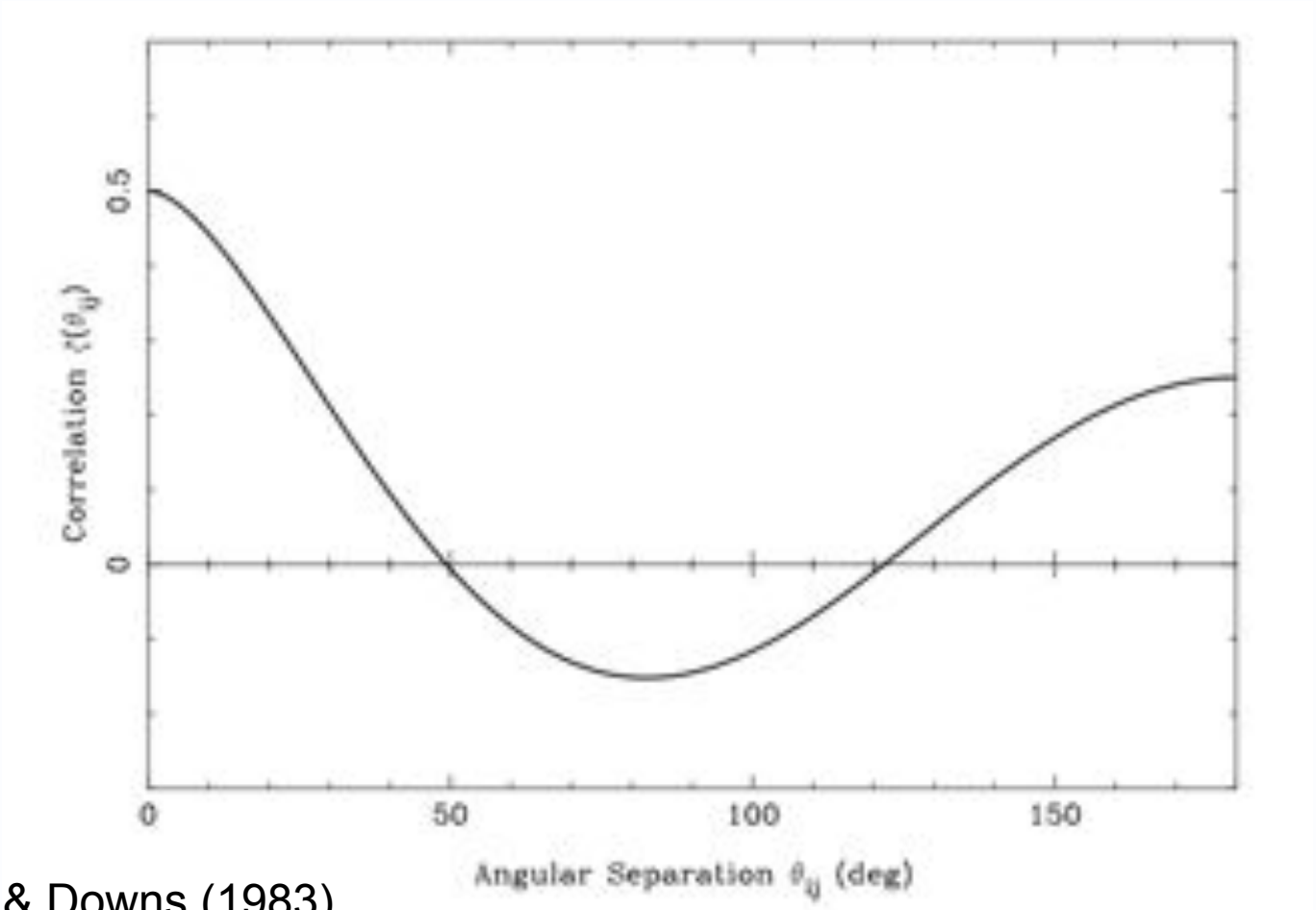
No gravitational waves detected

Limiting the existence of individual single gravitational wave sources

Yardley et al. (2010; MNRAS, 407, 669)

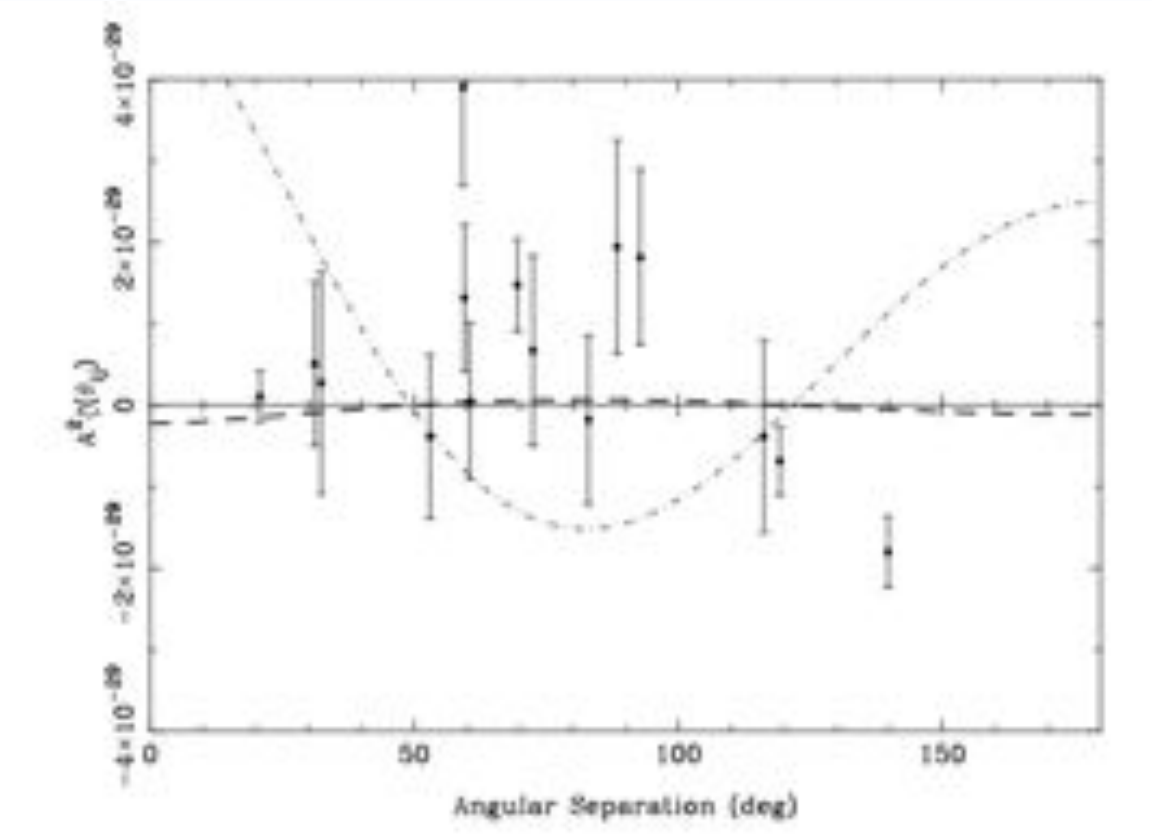


Searching for the stochastic gravitational wave background



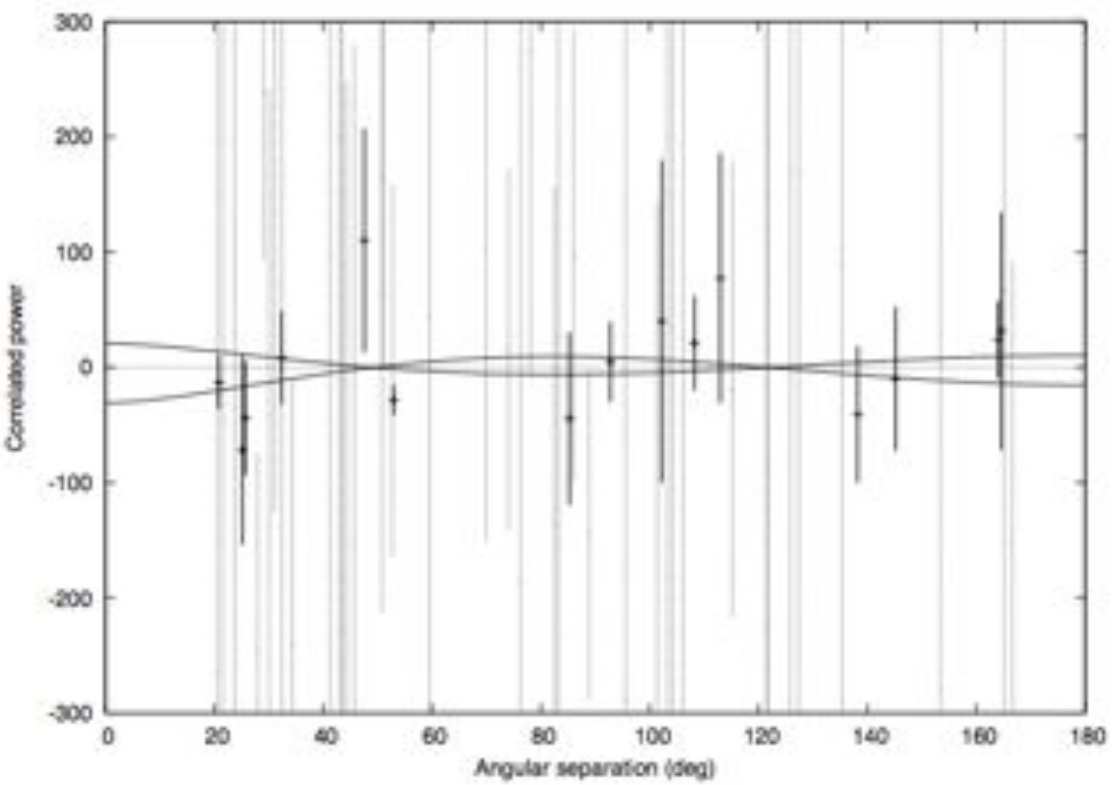
Hellings & Downs (1983)

Searching for the stochastic gravitational wave background



Yardley et al. MNRAS 414, 1777 (2011)

Searching for the stochastic gravitational wave background



Demorest et al., submitted to ApJ

Searching for a stochastic background of gravitational waves

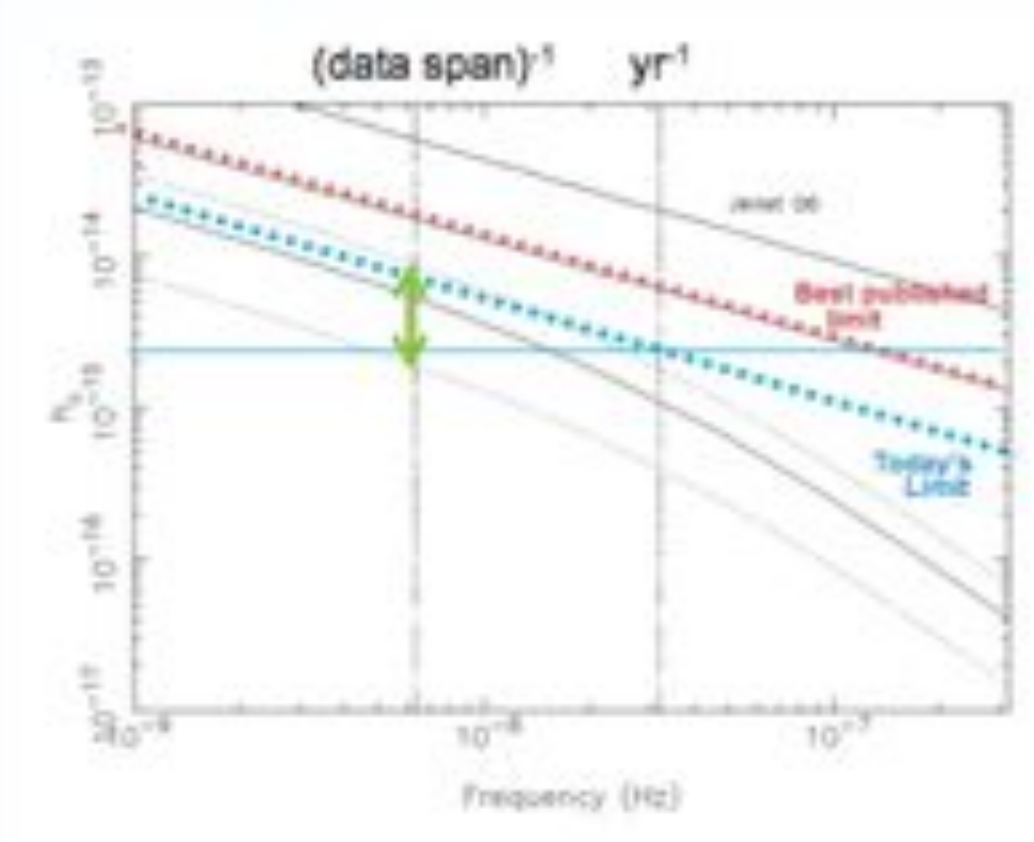
For stochastic background from supermassive binary black holes

Jenet et al. (2006):
$A < 11 \times 10^{-15}$

van Haasteren et al. (2011)
$A < 6 \times 10^{-15}$

Demorest et al. (2012)
$A < 7 \times 10^{-15}$

Shannon et al. (in prep.) …
A < ? (listen to Ryan's talk!)



When will we detect gravitational waves?

Keith et al. (in preparation)

Depends upon the how well can we predict the expected sources.
For supermassive binary black holes, we assume:
- Millennium simulation predictions
- No eccentricity
- …

Depends upon how stable the pulsars are
- No in-depth analysis of the timing noise for millisecond pulsars carried out

(predictions currently range from “now” to “within ~30 years”)

Will be advertising a 3-yr postdoc position with CSIRO in Australia to research this topic

Conclusions

- Three major pulsar timing array projects currently exist and together form the International Pulsar Timing Array
- Expect more groups (China/Russia/India) to join and improve our sensitivity
- Have three major goals (gravitational waves, clocks and the Solar System)
- Major advances have been made towards all our goals

- We have not detected gravitational waves yet!

Thank you

CSIRO Astronomy and Space Science
George Hobbs
Research Scientist

t +61 2 93724652
e george.hobbs@csiro.au
w www.atnf.csiro.au/people/ghobbs